
esa

## european space agency

The European Space Agency was formed out of, and took over the rights and obligations of, the two earlier European Space Organisations: the European Space Research Organisation (ESRO) and the European Organisation for the Development and Construction of Space Vehicle Launchers (ELDO). The Member States are Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Italy, Netherlands, Norway, Spain, Sweden, Switzerland and the United Kingdom. Canada is a Cooperating State.

In the words of the Convention: The purpose of the Agency shall be to provide for and to promote, for exclusively peaceful purposes, co-operation among European States in space research and technology and their space applications, with a view to their being used for scientific purposes and for operational space applications systems.

(a) by elaborating and implementing a long-term European space policy, by recommending space objectives to the Member States, and by concerting the policies of the Member States with respect to other national and international organisations and institutions;
(b) by elaborating and implementing activities and programmes in the space field;
(c) by co-ordinating the European space programme and national programmes, and by integrating the latter progressively and as completely as possible into the European space programme, in particular as regards the development of applications satellites;
(d) by elaborating and implementing the industrial policy appropriate to its programme and by recommending a coherent industrial policy to the Member States.

The Agency is directed by a Council composed of representatives of Member States. The Director General is the chief executive of the Agency and its legal representative.

The ESA HEADQUARTERS are in Paris.

The major establishments of ESA are:

THE EUROPEAN SPACE RESEARCH AND TECHNOLOGY CENTRE (ESTEC), Noordwijk, Netherlands.

THE EUROPEAN SPACE OPERATIONS CENTRE (ESOC), Darmstadt, Germany

ESRIN, Frascati, Italy.

Chairman of the Council: P.G. Winters

Director General: J.-M. Luton.

## agence spatiale européenne

*L'Agence Spatiale Européenne est issue des deux Organisations spatiales européennes qui l'ont précédée — l'Organisation européenne de recherches spatiales (CERS) et l'Organisation européenne pour la mise au point et la construction de lanceurs d'engins spatiaux (CECLES) — dont elle a repris les droits et obligations. Les Etats membres en sont: l'Allemagne, l'Autriche, la Belgique, le Danemark, l'Espagne, la Finlande, la France, l'Irlande, l'Italie, la Norvège, les Pays-Bas, le Royaume-Uni, la Suède et la Suisse. Le Canada bénéficie d'un statut d'Etat coopérant.*

*Selon les termes de la Convention: l'Agence a pour mission d'assurer et de développer, à des fins exclusivement pacifiques, la coopération entre Etats européens dans les domaines de la recherche et de la technologie spatiales et de leurs applications spatiales, en vue de leur utilisation à des fins scientifiques et pour des systèmes spatiaux opérationnels d'applications:*

*(a) en élaborant et en mettant en oeuvre une politique spatiale européenne à long terme, en recommandant aux Etats membres des objectifs en matière spatiale et en concertant les politiques des Etats membres à l'égard d'autres organisations et institutions nationales et internationales;*
*(b) en élaborant et en mettant en oeuvre des activités et des programmes dans le domaine spatial;*
*(c) en coordonnant le programme spatial européen et les programmes nationaux, et en intégrant ces derniers progressivement et aussi complètement que possible dans le programme spatial européen, notamment en ce qui concerne le développement de satellites d'applications;*
*(d) en élaborant et en mettant en oeuvre la politique industrielle appropriée à son programme et en recommandant aux Etats membres une politique industrielle cohérente.*

*L'Agence est dirigée par un Conseil, composé de représentants des Etats membres. Le Directeur général est le fonctionnaire exécutif supérieur de l'Agence et la représente dans tous ses actes.*

*Le SIEGE de l'Agence est à Paris.*

*Les principaux Etablissements de l'Agence sont:*

*LE CENTRE EUROPEEN DE RECHERCHE ET DE TECHNOLOGIE SPATIALES (ESTEC), Noordwijk, Pays-Bas.*

*LE CENTRE EUROPEEN D'OPERATIONS SPATIALES (ESOC), Darmstadt, Allemagne.*

*ESRIN, Frascati, Italie*

*Président du Conseil: P.G. Winters*

*Directeur général: J.-M. Luton.*

# esa bulletin

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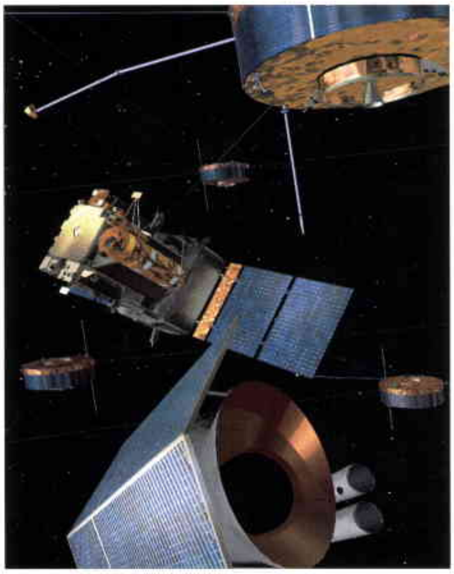

Cover: The ISO (bottom), SOHO (centre) and Cluster (top) spacecraft (this illustration and pages 120/121 courtesy of ISD Visulab)


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**european space agency**

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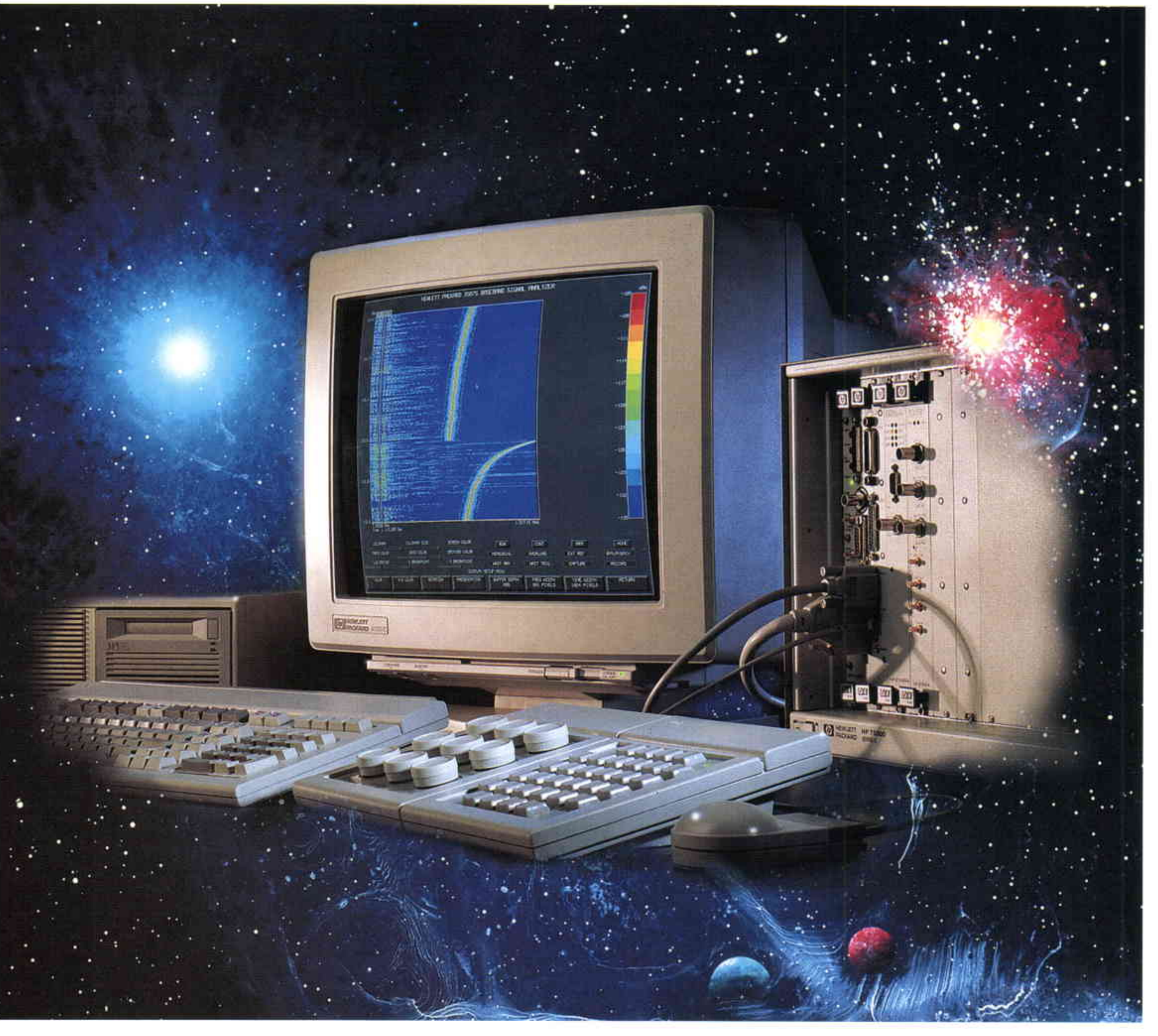

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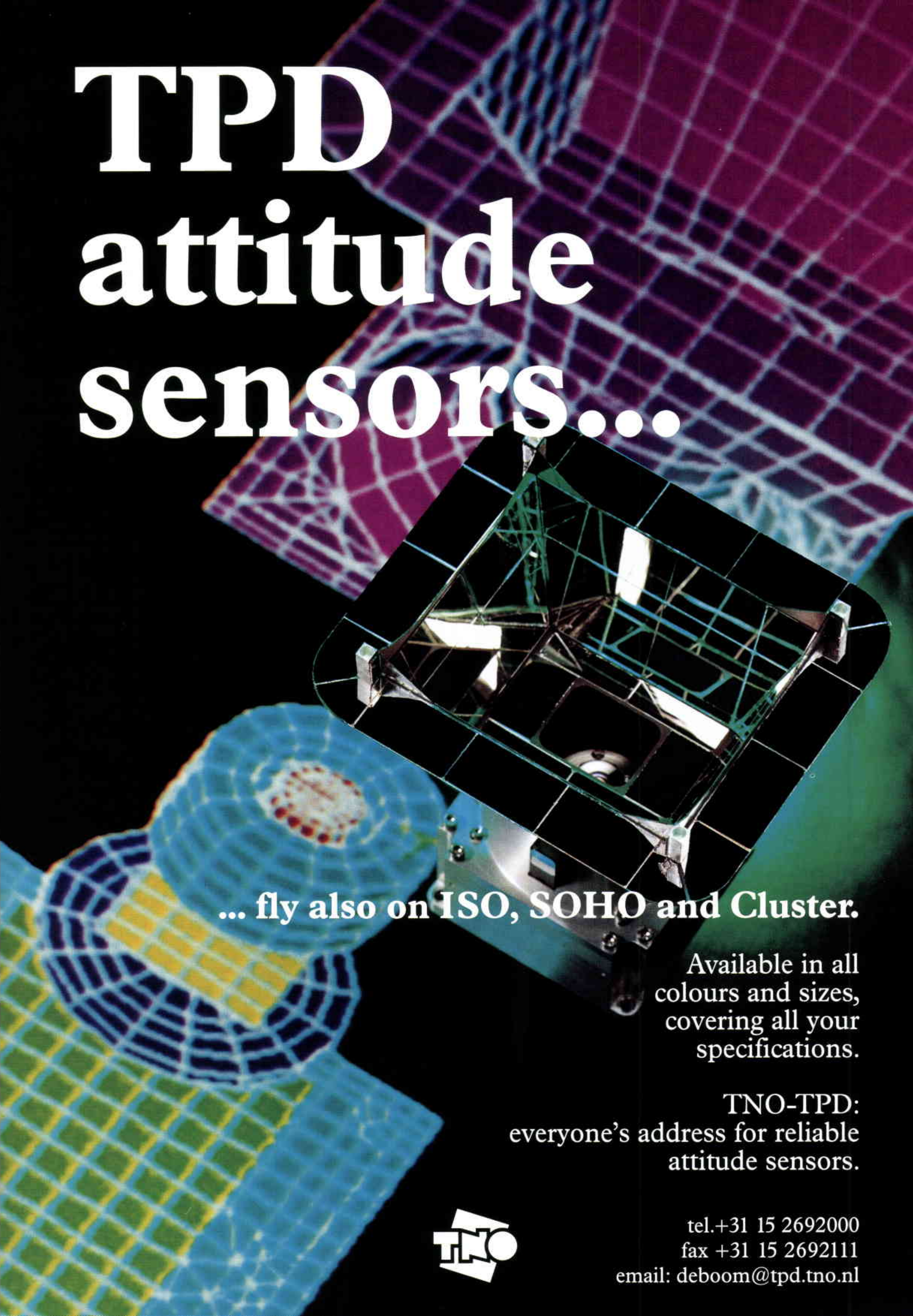
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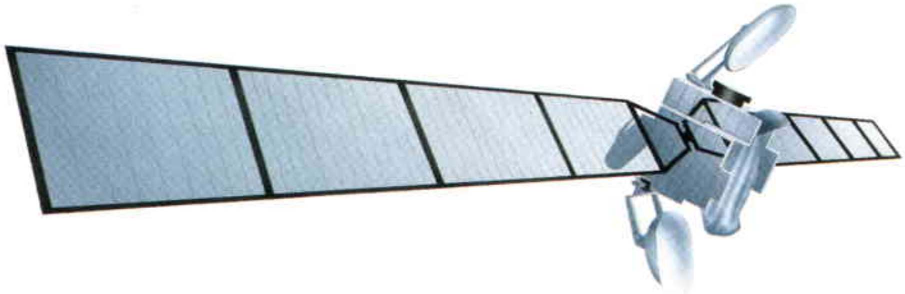


# European Endeavours in Space – A New Momentum

**J.-M. Luton**
Director General, ESA, Paris

**Jean-Marie Luton**

The ESA Council Meeting at Ministerial Level which took place in Toulouse on 18 – 20 October was of critical significance to the future of European space activities. This meeting, Chaired by Mr Yvan Ylieff, the Belgian Minister for Science Policy, was attended by Ministers and Senior Representatives of the Agency's fourteen Member States and Canada (a Cooperating State). Representatives of the Commission of the European Union, Eumetsat and Eutelsat were present as observers.

During their three days in Toulouse, the Ministers took far-reaching decisions – decisions that will shape the future of ESA's Programmes for decades to come – in five major areas:
- the Level of Resources for ESA's Mandatory Programme for the years 1996 – 2000
- Europe's participation in the International Space Station Programme
- the Ariane-5 Complementary Programmes
- ESA's Industrial Policy
- the introduction of the ECU as ESA's currency unit.

Particularly gratifying for the Agency was the strong will shown on the part of so many of the Ministers to overcome the prevailing barriers – both financial and political – and to reach an agreement that will allow Europe's space activities to continue to develop, with a renewed vigour and spirit of international cooperation and, within the remit of ESA.

Importantly, the decisions that the Ministers have taken in Toulouse relate not only to the programmes to be carried out until the end of this century, but also to programmes that will continue into the first decade of the next one. This means that ESA's horizon now stretches much further into the future with a greater degree of certainty than has been the case in recent years.

**The Mandatory Programme**
The Agency's Mandatory Programme, which covers both the Scientific Programme and the General Budget, was the subject of lengthy discussion, a unanimous vote by the Ministers being required to secure its approval.

Despite the strong support for the ESA Science Programme voiced by many of the Ministers present, who see it as both a fundamental and a highly successful element of the Agency's past and future activities, the necessary unanimity could not be achieved for the budget proposal that was initially tabled. In order to achieve unanimity, a compromise proposal had to be put to the vote.

The compromise reached was that the budget for Science will be frozen for the next five years, with no increase for inflation except in so far as it exceeds 3%. The Science budget will therefore be subject to annual review, with a more extensive review in mid-1998.

During the efforts to reach the final compromise, many Ministers expressed their concerns that the Horizon 2000 and Horizon 2000 Plus Programmes should continue to be supported to the maximum extent possible.

**The International Space Station**
Recognising the significant scientific, technological and political benefits that will accrue to Europe from participation in the Space Station Programme, the Ministers agreed to fund the ESA contribution to the project. They subscribed, with immediate effect, the Declaration covering the development of the Columbus Orbital Facility (COF), and the Automated Transfer Vehicle (ATV) to be lauched by Ariane-5 to service the Station. They also approved definition studies for a Crew Transport Vehicle (CTV) and preparation activities for Station utilisation. In addition, the exploitation programme, which will run from 2002 to 2013, was also very clearly defined. The Participating States were able – after some constructive horse-trading between several of the major contributors – to

enter into binding commitments, despite the fact that the programme will not start in earnest until 1999 or 2000 and some progress remains to be made on various aspects, with clear conditions having to be met in our relations with the Space Station partners.

The Ministers also endorsed the Microgravity Facilities for Columbus (MFC) Programme which, although not planned to start until 1997, has already been subscribed.

**Ariane-5**

On several occasions during their Toulouse meeting, the Ministers stressed the importance they attach to autonomous European access to space. Ariane-5 is a critical factor in this respect and the Ministers had little hesitation in subscribing with immediate effect the three Declarations that were presented to them, covering:

- the Ariane-5 Evolution Programme, designed to ensure the launcher's adaptation to evolving user requirements
- the Ariane-5 Infrastructure Programme, intended to put the launcher on an equal footing with its global competitors
- the Ariane-5 ARTA Programme, which will consolidate the launcher's reliability.

In addition, on the eve of the Ministerial Meeting, agreement was reached on funding to cover the latest contingencies in the Ariane-5 Development Programme.

**Industrial Policy**

The Ministers discussed ESA's Industrial Policy in some detail. In recent years there have been considerable imbalances in the industrial returns of several Member States, and that of Italy in particular. Consequently, the Ministers have invited me to review ESA's industrial procurement practices in order both to solve the return problems and at the same time generate greater competition. They have also initiated a Council Working Group composed of high-level representatives from the Member States, to improve the Agency's Industrial Policy. Based on the final report of this Group, I will be formulating a proposal for reform, to be put before the next Council at Ministerial Level.

**The ECU**

The Ministers decided that from 1 January 1997, the Agency will gradually move over to a financial system based on the ECU (European Currency Unit), which will become its only currency from 2000 onwards, both for the payment of the Member States' contributions and for ESA's industrial contracts and invoicing. This should prove a real step forward, providing much greater stability in the Agency's day-to-day financial operations. It should certainly alleviate many of the problems

**The Toulouse Ministerial Council Meeting in session**


**Ministers and Senior Representatives of the ESA Member States gathered outside Toulouse Civic Hall, venue for the 1995 Ministerial Conference.**

Front row (from left to right): G. Salvini (Italy), I. Taylor (United Kingdom), G.J. Wijers (The Netherlands), A. Breiby (Norway), F. Fillon (France), Y. Ylieff (Belgium), J. Rüttgers (Germany), J.M. Eguiagaray (Spain), J.-M. Luton (Director General, ESA)

Back row: K. Larsen (Denmark), P.G. Winters (Chairman of ESA Council at Delegate Level), S. Heckscher (Sweden), W.M. Evans (President, Canadian Space Agency), P. Rabbitte (Ireland), R. Kneucker (Austria), A. Kalliomäki (Finland), M. Parr (Norway) we have had with wide fluctuations in European currencies and their negative influences on industrial return. The problem of what in ESA jargon are known as 'retroactive adjustments' will hopefully disappear and no longer be a political issue.

**Directions for the future**

As far as the longer-term future of the Agency is concerned, the Ministers welcomed the report of the Long-Term Space Policy Committee (LSPC). This Committee was created by the ESA Council in June 1993 with the mandate to prepare a report on European space policy after the year 2000 for the Toulouse meeting. It was asked specifically to address the need for a strategic vision for European space policy, responding both to the challenges and threats facing humanity in the next century. In endorsing the LSPC's report, the Ministers also expressed the wish that such long-term strategic reflection on European space policy be continued.

As far as the nearer term future is concerned, my proposals to:

- build on the existing achievements of ESA's Earth-observation programme by proposing research and applications missions based on the Earth Explorer and Earth Watch concepts
- put forward specific programme proposals for new advanced telecommunications missions (such as a Global Navigation Satellite System) in conjunction with users
- draw up a proposal for a future Launcher Preparatory Programme to validate new technologies and concepts for a new generation of launchers, and
- pursue the concept of small missions, working together with the Member States, Industry and research organisations

were welcomed by the Council. I was also asked to intensify the dialogue with other space organisations in Europe, in particular the Commission of the European Union, to ensure greater synergy between our respective activities and thereby reinforce Europe's already strong position in worldwide space activities.

As you will have realised from the above, a great deal of decision-making was packed into the Toulouse Ministerial Meeting and, despite what amounted to more than slight differences between the positions of the various Member States on a number of issues prior to the meeting, an overall agreement has been achieved that has removed the indecision that has plagued the Agency in recent times.


**Minister Rüttgers of Germany talks live with ESA Astronaut Thomas Reiter aboard the Mir space station, from Toulouse. On the right is Minister Ylieff of Belgium, who chaired the Toulouse Meeting**

Much work on the various programmes that were agreed in Toulouse now lies before us if we are to make them a success. A clear message that emerged from the Executive's discussion with the Ministers is that they have confidence in ESA, but we in turn must strive to adapt as an organisation to today's political and financial realities. The Agency already has a Transformation Programme in place with the objective of adapting to the current economic difficulties affecting our Member States, including reducing both our internal and industrial costs.

All in all then, the 1995 Ministerial Conference has set ESA a bold new set of objectives and ambitions. It is now up to the Agency and its dedicated staff to prove to the Ministers that they were right in giving us a clear, revitalised and challenging mandate for the future.

**The Press Centre at the Ministerial Conference**

# Resolution concerning Decisions on Agency Programmes and Finances

**(adopted on 20 October 1995)**

The Council, meeting at Ministerial Level,

HAVING REGARD to the Resolution on the implementation of the European long-term space plan and programmes, adopted at Ministerial Level in Granada on 10 November 1992 (ESA/C-M/CIV/Res.1 (Final)),

HAVING REGARD to the Director General's Overview and Proposal on the Agency's Policy and Programmes (ESA/C-M(95)5),

HAVING REGARD to the Director General's report on the review of the Agency's internal operations (ESA/C(95)96),

HAVING REGARD to the work done in the Agency's delegate bodies to examine in detail the Director General's proposals on the programmes and activities calling for decisions at this meeting and to prepare the corresponding legal instruments, and CONSCIOUS of the urgency of those decisions for reinforcing the Agency's role and presence in worldwide space activities,

## CHAPTER I
## PROGRAMMES

### A. The International Space Station

WHEREAS the International Space Station programme is currently the greatest cooperative endeavour undertaken by spacefaring nations and CONSIDERING that such a programme is bound to set significant scientific and technical challenges,

HAVING REGARD to the letter addressed on 29 November 1993 by the IGA Coordinating Committee's Chairman to his US counterpart which outlined the specific European requests to be met during the IGA negotiation process and to the letter of 6 October 1995 of the NASA Administrator to the ESA Director General,

HAVING REGARD to the Act in Council of 15 February 1994 (ESA/C/CXI/Act-ISSP(Final)) and to the Resolution on Europe's participation in the International Space Station programme of 23 March 1995 (ESA/C/CXVII/Res.1(Final)),

HAVING REGARD to the report (ESA/C-M(95)8) on the amendments, formulated in the current negotiation process involving Russia, to the Agreement among the Government of the United States of America, Governments of Member States of the European Space Agency, the Government of Japan and the Government of Canada on Cooperation in the Detailed Design, Development, Operation and Utilisation of the Permanently Manned Civil Space Station (hereinafter the 'IGA'), signed on 29 September 1988 (ESA/C(95)89, rev.1), and to the Arrangement for the provisional application of the IGA, effective on the date of its signature on 29 September 1988,

HAVING REGARD to the report (ESA/C-M(95)8) on the amendments proposed to the Memorandum of Understanding between the United States National Aeronautics and Space Administration and the European Space Agency on Cooperation in the Detailed Design, Development, Operation and Utilisation of the Permanently Manned Space Station (hereinafter the 'MOU'), signed on 29 September 1988 (ESA/C(95)89, rev.1),

# Résolution relative aux décisions sur les programmes et les finances de l'Agence

**(adoptée le 20 octobre 1995)**

Le Conseil siégeant au niveau ministériel,

VU la Résolution sur la mise en oeuvre du Plan spatial européen à long terme et des programmes, adoptée au niveau ministériel à Grenade le 10 novembre 1992 (ESA/C-M/CIV/Rés.1 (Final)),

VU le document intitulé Revue d'ensemble et proposition du Directeur général relative à la politique et aux programmes de l'Agence (ESA/C M(95)5),

VU le rapport du Directeur général sur la revue du fonctionnement interne de l'Agence (ESA/C(95)96),

VU les travaux accomplis au sein des organes de l'Agence composés de délégués afin d'examiner dans le détail les propositions du Directeur général relatives aux programmes et activités devant faire l'objet de décisions lors de la présente réunion, et afin de préparer les instruments juridiques correspondants, et CONSCIENT du caractère urgent de ces décisions aux fins de consolider le rôle et la présence de l'Agence dans le domaine des activités spatiales à l'échelle mondiale,

## CHAPITRE PREMIER
## PROGRAMMES

### A. Station spatiale internationale

ATTENDU que le programme de Station spatiale internationale représente actuellement le plus grand projet de coopération entrepris par les puissances spatiales et CONSIDERANT que ce programme suscitera nécessairement des défis scientifiques et techniques considérables,

VU la lettre en date du 29 novembre 1993 adressée par le Président du Comité de coordination de l'IGA à son homologue américain, laquelle exposait les demandes spécifiques de l'Europe à satisfaire au cours du processus de négociation de l'IGA, et la lettre que l'Administrateur de la NASA a adressée au Directeur général de l'ESA le 6 octobre 1995,

VU l'Acte en Conseil du 15 février 1994 (ESA/C/CXI/Act-ISSP(Final)) et la Résolution sur la participation de l'Europe au programme de Station spatiale internationale du 23 mars 1995 (ESA/C/CXVII/Rés.1 (Final)),

VU le rapport (ESA/C-M(95)8) sur les amendements, formulés dans le cadre de l'actuel processus de négociation auquel participe la Russie, de l'Accord entre le gouvernement des Etats-Unis d'Amérique, les gouvernements d'Etats membres de l'Agence spatiale européenne, le gouvernement du Japon et le gouvernement du Canada relatif à la coopération en matière de conception détaillée, de développement, d'exploitation et d'utilisation de la Station spatiale civile habitée en permanence (ci-après dénommé 'IGA'), signé le 29 septembre 1988 (ESA/C(95)89, rév.1) et de l'Arrangement relatif à l'application provisoire de l'IGA ayant pris effet à la date de sa signature, le 29 septembre 1988,

VU le rapport (ESA/C-M(95)8) sur les amendements qu'il est proposé d'apporter au Mémorandum d'Accord entre l'Administration nationale de l'Aéronautique et de l'Espace des Etats-Unis et l'Agence spatiale européenne relatif à la coopération en matière de conception détaillée, de développement, d'exploitation et d'utilisation de la Station spatiale civile habitée en permanence (ci-après dénommé 'MOU'), signé le 29 septembre 1988 (ESA/C(95)89, rév.1),

### A.1. Subscription of programme Declarations

1. WELCOMES the subscription by the States participating in the development programme, of the Declaration on the European participation in the International Space Station and the entry into force on this day of this Declaration (ESA/PB-MS/XI/Dec.1 (Final)) in accordance with Chapter I.C of this Resolution, allocating for completion of the programme a financial envelope of 2651.2 million accounting units at mid-1995 economic conditions over the period 1996 – 2004.

2. NOTES that the European contribution to the International Space Station shall consist of the Columbus Orbital Facility (COF), a general-purpose pressurised laboratory, the provision of logistics services using Ariane-5 and the Automated Transfer Vehicle (ATV) and of orbital manoeuvring capabilities by the ATV, complemented by utilisation preparation activities with a view to multidisciplinary utilisation of the Space Station by the European Partner, and NOTES further that a decision by the end of 1997 will be taken by Member States concerned, on the basis of proposals to be presented in due time by the Director General, on the continuation of activities concerning the development of a crew transport vehicle.

3. WELCOMES the subscription, by the States participating in the programme, of the Declaration on Microgravity Facilities for Columbus (MFC) and the entry into force on this day of that Declaration (ESA/PB-MG/XLV/Dec.1 (Final)) in accordance with Chapter I.C of this Resolution, for the purpose of developing the facilities necessary to take advantage, during execution of the exploitation programme referred to in Section A.3 of this Chapter, of utilisation opportunities afforded to the European Partner, thus allocating for completion of the programme a financial envelope of 206.7 million accounting units at mid-1995 economic conditions over the period 1997 – 2003.

### A.2. Finalisation of the IGA and MOU negotiation process

1. APPRECIATES the progress made in the negotiation process by the International Partners, in particular as regards the inclusion of Russia in the International Space Station partnership and CONSIDERS that the amendments to the IGA and MOU already identified and the plan of action outlined in ESA/C-M(95)8 for the timely finalisation of the current negotiation process represent significant progress towards meeting the specific European demands, primarily those resulting from the adoption at Ministerial Level of ESA/C-M/CIV/Res. 1(Final), communicated to the other Partners at the outset of the negotiations and outlined in Section VII of ESA/PB-MS/XI/Dec.1(Final).

2. CONSIDERING that the Declaration on the European participation in the International Space Station development programme referred to above stipulates:
   'that the European Partner's share of the International Space Station annual common operations obligations shall:
   (a) not exceed 0.6 Ariane-5/ATV equivalent flight per year,
   (b) be fulfilled by means of Ariane-5/ATV and other European services, such as provision of personnel, in such a way that the objective of no exchange of funds will be achieved;'

   MANDATES the European Partner's spokesman and the Director General to negotiate the necessary amendments to the IGA and to the MOU between ESA and NASA respectively to provide the legal basis for the implementation of the above-mentioned stipulations.

3. EXPRESSES its support for finalisation of the current IGA and MOU negotiation process by 30 June 1996 at the latest; NOTES that Member States concerned intend to review the results of the negotiation, bearing in mind the terms of the Declarations on the programmes referred to in Section A.1, and in this connection INVITES the Director General, as soon as the negotiation process is finalised, to submit the draft amended MOU between NASA and ESA, and supporting documentation, to the Agency's competent bodies for completion of the examination and approval procedures, with a view to its signature on the same date as the amended IGA.

4. INVITES Member States which are signatories to the IGA, and others intending to join the European Partner States, to make appropriate arrangements for the concomitant signing of the legal instrument confirming the amendments to the IGA and the related Arrangement for the provisional implementation of the IGA,

**A.1 Souscription des Déclarations de programme**

1. SE FELICITE de la souscription par les Etats participant au programme de développement de la Déclaration relative à la participation de l'Europe à la Station spatiale internationale et de l'entrée en vigueur ce jour de ladite Déclaration (ESA/PB-MS/XI/Déc.1 (Final)), conformément au Chapitre I.C de la présente Résolution, cette Déclaration affectant à l'exécution de ce programme une enveloppe financière de 2651,2 millions d'unités de compte aux conditions économiques de la mi-1995 sur la période 1996 – 2004.

2. NOTE que la contribution de l'Europe à la Station spatiale internationale consiste dans l'élément orbital Columbus (COF), laboratoire pressurisé à usage général, dans la fourniture de services logistiques au moyen d'Ariane-5 et du véhicule de transfert automatique (ATV) et des capacités de manoeuvre en orbite de l'ATV, complétés par des activités de préparation en vue d'une utilisation multidisciplinaire de la Station spatiale par le Partenaire européen, et NOTE en outre que les Etats membres en cause prendront d'ici la fin de 1997, sur la base de propositions que le Directeur général devra présenter en temps opportun, une décision sur la poursuite des activités relatives au développement d'un véhicule de transport d'équipages.

3. SE FELICITE de la souscription par les Etats participant au programme de la Déclaration relative aux installations de recherche en microgravité pour Columbus (MFC) et de l'entrée en vigueur ce jour de ladite Déclaration (ESA/PB-MG/XLV/Déc.1 (Final)), conformément au Chapitre I.C de la présente Résolution, afin de réaliser les installations nécessaires pour tirer parti, pendant l'exécution du programme d'exploitation visé au point A.3 du présent Chapitre, des possibilités d'utilisation offertes au Partenaire européen, affectant ainsi à l'exécution de ce programme une enveloppe financière de 206,7 millions d'unités de compte aux conditions économiques de la mi-1995, sur la période 1997 – 2003.

**A.2 Clôture du processus de négociation de l'IGA et du MOU**

1. APPRECIE les progrès accomplis par les Partenaires internationaux dans le processus de négociation, en particulier en ce qui concerne l'intégration de la Russie dans le partenariat de la Station spatiale internationale, et CONSIDERE que les amendements de l'IGA et du MOU déjà définis et le plan d'action tracé dans le document ESA/C-M(95)8 en vue de la conduite à bonne fin en temps voulu du processus de négociation actuel, représentent un progrès significatif allant dans le sens de la satisfaction des demandes spécifiques de l'Europe, principalement celles qui résultent de l'adoption au niveau ministériel de la Résolution ESA/C-M/CIV/Rés.1 (Final), communiquées aux autres Partenaires au début des négociations et exposées au point VII de la Déclaration ESA/PBMS/XI/Déc.1 (Final).

2. CONSIDERANT que la Déclaration relative à la participation de l'Europe au programme de développement de la Station spatiale internationale visée ci-dessus énonce:

   'que la part des obligations annuelles liées à la conduite opérationnelle en commun de la Station spatiale incombant au Partenaire européen
   (a) n'excédera pas 0,6 équivalent de vol Ariane-5/ATV par an,
   (b) sera fournie au moyen d'Ariane-5/ATV et d'autres services européens, tels que la fourniture de personnel, de façon à ce que l'objectif du non échange de fonds soit atteint;'

   DONNE MANDAT au porte-parole du Partenaire européen et au Directeur général de négocier les amendements à apporter respectivement à l'IGA et au MOU entre l'ESA et la NASA pour constituer le fondement juridique de la mise en oeuvre des dispositions ci-dessus.

3. APPUIE l'intention de mener à terme le processus actuel de négociation de l'IGA et du MOU pour le 30 juin 1996 au plus tard; NOTE que les Etats membres en cause ont l'intention de passer en revue les résultats des négociations en gardant à l'esprit les termes des Déclarations relatives aux programmes visées au point A.1 et, dans ce contexte, INVITE le Directeur général, dès que le processus de négociation aura abouti, à soumettre le projet de MOU amendé entre l'ESA et la NASA et la documentation à l'appui aux organes compétents de l'Agence en vue des procédures d'examen et d'approbation, afin qu'il soit signé le même jour que l'IGA amendé.

4. INVITE les Etats membres signataires de l'IGA et ceux qui ont l'intention de se joindre aux Etats Partenaires européens à prendre les dispositions nécessaires pour la signature concomitante de l'instrument juridique confirmant les amendements apportés à l'IGA et à l'Arrangement correspondant relatif à la mise en oeuvre provisoire de l'IGA,

5. INVITES the Member States participating in the development programme referred to in Section A.1.1 of this Chapter which are not yet among the European Partner States to initiate the procedures required for becoming IGA signatory States so as to ensure proper legal cover at international level for activities conducted in the framework of the above-mentioned development programme.

**A.3. Exploitation programme**

1. WELCOMES AND SUPPORTS the agreement of the States participating in the development programme referred to in Section A.1.1 of this Chapter to set up and participate in a programme for the exploitation by the European Partner of the International Space Station implemented in successive phases from 2001 until the end of the Space Station's lifetime, planned for 2013, in accordance with the principles and mechanisms detailed in Section VII of ESA/PB-MS/XI/Dec. 1(Final).

2. INVITES Member States which have not subscribed the Declaration on the development programme referred to in Section A.1.1 of this Chapter to participate in the exploitation of the International Space Station by the European Partner.

3. ENCOURAGES the community of European users, together with Member States through their nationally-funded programmes, to make appropriate arrangements for the purpose of taking maximum advantage of the utilisation opportunities offered by the International Space Station; INVITES the States participating in existing and future programmes of the Agency to make where appropriate, the best use of the opportunities offered by the International Space Station and to take this opportunity into account in their planning, and INVITES further the Director General to regularly elaborate proposals for utilisation plans accordingly.

**B. Ariane-5 Complementary Programmes and European access to space**

HAVING REGARD to the successful commercial exploitation of the Ariane launcher and its resulting benefits for Europe and the trend of the international commercial market in launch services, in particular the advent of new operators and the heightened competition,

CONSIDERING that the European launch services industry must operate under conditions comparable to those of other spacefaring nations and that the needs of Agency Member States for launch services, in particular availability at the lowest possible cost, are best served by the widest possible marketing of the Ariane launchers throughout the world,

HAVING REGARD to the Resolution updating the Resolution on the CSG 1993 – 2000 for the period 1996 – 2000 (ESA/C/CXXI/Res.1 (Final)), complemented by the Resolution on the CSG fee (ESA/C/CXXI/Res.2 (Final)), both Resolutions adopted on 28 September 1995, and to the Resolution on the Ariane-5 complementary programmes (ESA/C/CXVII/Res.2 (Final)) adopted on 23 March 1995,

HAVING REGARD to the role that the Ariane-5 launcher in combination with the Automated Transfer Vehicle (ATV) is called upon to play in the International Space Station programme,

CONVINCED that suitable measures should be taken, in cooperation with Arianespace, to ensure the success of Ariane-5 exploitation, to maintain and consolidate Ariane-5's reliability, to reduce the production costs, to improve commercial competitiveness and to maintain the Ariane-5 infrastructure as a strategic European asset,

NOTING the importance of adapting the launcher to evolving user requirements, and NOTING the start-up of the Ariane-5 Evolution preparatory programme (ESA/PB-ARIANE/CXLV/Dec.1(Final) rev.1.),

NOTING the agreement under the form of an exchange of letters between the Agency and Arianespace confirming Arianespace's acceptance of the new Ariane launch pricing policy (ESA/PB-ARIANE(95)66) and the commitment made by Arianespace and the European launcher industry to contribute to the transition from Ariane-4 to Ariane-5,

5. INVITE les Etats membres participant au programme de développement visé au point A.1.1 du présent Chapitre et qui ne sont pas encore au nombre des Etats Partenaires européens à engager les procédures nécessaires afin de devenir des Etats signataires de l'IGA pour faire en sorte que les activités conduites dans le cadre du programme de développement susmentionné bénéficient d'une couverture juridique adéquate au niveau international.

**A.3 Programme d'exploitation**

1. ACCUEILLE FAVORABLEMENT ET APPUIE l'accord des Etats participant au programme de développement visé au point A.1.1 du présent Chapitre qui conviennent de mettre sur pied et de prendre part à un programme d'exploitation de la Station spatiale internationale par le Partenaire européen, mis en oeuvre par phases successives à partir de 2001 et jusqu'à la fin de la durée de vie de la Station spatiale, prévue pour 2013, conformément aux principes et mécanismes dont le détail est énoncé au point VII de la Déclaration ESA/PB-MS/XI/Déc.1(Final).

2. INVITE les Etats membres qui n'ont pas souscrit la Déclaration relative au programme de développement visée au point A.1.1 du présent Chapitre à participer à l'exploitation de la Station spatiale internationale par le Partenaire européen.

3. ENCOURAGE la communauté des utilisateurs européens, ainsi que les Etats membres par l'intermédiaire des programmes qu'ils financent au niveau national, à prendre des dispositions appropriées pour tirer le meilleur parti des possibilités d'utilisation offertes par la Station spatiale internationale; INVITE les Etats participant aux programmes de l'Agence en cours et à venir à faire le cas échéant le meilleur usage possible des occasions offertes par la Station spatiale internationale, à prendre en compte dans leurs plans les possibilités qu'elle offre et INVITE en outre le Directeur général à élaborer périodiquement des propositions correspondantes de plans d'utilisation.

**B. Programmes Ariane-5 complémentaires et accès de l'Europe à l'espace**

VU le succès de l'exploitation commerciale du lanceur Ariane et les avantages qui en résultent pour l'Europe ainsi que l'évolution du marché commercial international des services de lancement et notamment l'arrivée de nouveaux exploitants et le renforcement de la concurrence,

CONSIDERANT que l'industrie européenne des services de lancement doit travailler dans des conditions comparables à celles des autres puissances spatiales et que les besoins des Etats membres de l'Agence en matière de services de lancement, et notamment la disponibilité de ces derniers au moindre coût possible, sont satisfaits au mieux par la commercialisation la plus large possible des lanceurs Ariane à travers le monde,

VU la Résolution actualisant la Résolution relative au CSG 1993 – 2000 pour la période 1996 – 2000 (ESA/C/CXXI/Rés.1 (Final)), complétée par la Résolution relative à la redevance CSG (ESA/C/CXXI/Rés.2 (Final); toutes deux adoptées le 28 septembre 1995, et la Résolution relative aux programmes Ariane-5 complémentaires (ESA/C/CXVII/Rés.2 (Final)) adoptée le 23 mars 1995,

VU le rôle que le lanceur Ariane-5 est appelé à jouer dans le cadre du programme de Station spatiale internationale, en association avec le véhicule de transfert automatique (ATV),

CONVAINCU que des mesures appropriées devraient être prises, en coopération avec Arianespace, pour assurer le succès de l'exploitation d'Ariane-5, maintenir et consolider la fiabilité d'Ariane-5, en réduire les coûts de production, améliorer sa compétitivité commerciale et maintenir l'Infrastructure Ariane-5, comme atout stratégique de l'Europe,

PRENANT NOTE de l'importance d'adapter le lanceur à l'évolution des besoins des utilisateurs et PRENANT NOTE du démarrage du programme préparatoire Ariane-5 Evolution (ESA/PB-ARIANE/CXLV/Déc.1(Final) rév.1),

PRENANT NOTE de l'accord sous forme d'un échange de lettres entre l'Agence et Arianespace qui confirme qu'Arianespace accepte la nouvelle politique de prix des lancements Ariane (ESA/PB-ARIANE(95)66) et l'engagement pris par Arianespace et l'industrie européenne des lanceurs de contribuer au passage d'Ariane-4 à Ariane-5,

1. REAFFIRMS that European autonomous access to space constitutes a strategic asset bringing political and economic benefits for Europe, and STRESSES that development of the European launcher capability is an integral part of a coherent overall European space policy.

2. UNDERLINES the need for international arrangements to ensure fair conditions in the launcher market.

3. (a) WELCOMES the above-mentioned agreement with Arianespace as endorsed by the Participants in the Declaration on the Ariane launcher production, concerning in particular a new pricing policy for the Ariane launcher;

   (b) TAKING into account the international environment in the commercial launcher sector, CONSIDERS that this agreement with Arianespace constitutes an important step towards ensuring that Member States take full advantage of the Ariane launchers and their facilities across the range of their national and international space-related activities, and ENCOURAGES Member States to make appropriate arrangements for the purpose of granting preference to the utilisation of the Ariane launcher according to the terms of the Declaration on the Ariane launcher production and of Chapter V of the Resolution No. 1 adopted at Granada in November 1992.

4. WELCOMES the subscription by the States participating in the Ariane-5 complementary programmes, and the entry into force on this day, of the following programme Declarations in accordance with Chapter I.C of this Resolution:
   - the Additional Declaration on the Ariane-5 Evolution programme (ESA/PB-ARIANE/CLIV/Dec.1 (Final)), with a financial envelope for completion of the programme of 1026.2 million accounting units at mid-1995 economic conditions for the period 1996 – 2003;
   - the Additional Declaration on the Ariane-5 Infrastructure programme (ESA/PB-ARIANE/CLIV/Dec.2 (Final)), with a financial envelope of 335.7 million accounting units at mid-1995 economic conditions for the period 1996 – 2000;
   - the Additional Declaration on the Ariane-5 ARTA programme (ESA/PB-ARIANE/CLIV /Dec.3 (Final)) with a financial envelope of 351.5 million accounting units at mid-1995 economic conditions for the period 1996 – 2000.

### C. Entry into force of the Declarations

NOTES that the participating States concerned have agreed to the simultaneousness of the entry into force of the Declaration on the European participation in the International Space Station development programme, the Declaration on the MFC programme, and the three Declarations on the Ariane-5 complementary programmes referred to in this Chapter, subject to receipt of confirmation of contributions pending.

## CHAPTER II
## LEVEL OF RESOURCES FOR MANDATORY ACTIVITIES 1996 – 2000

HAVING REGARD to Articles V.1(a) and XI.5(a)(ii) and (iii) of the Convention,

RECALLING the Resolution on the level of resources for the mandatory activities covering the period 1991 – 1995 (ESA/C/XCIII/Res.3 (Final)) adopted on 13 December 1990,

NOTING that it was not possible to vote as required by the Convention (article XI.5.a.iii), before the end of the current five year period the new level of resources for the period 1994 – 1998 and that due to this fact the next five-year period of the level of resources has now to cover the period 1996 – 2000,

HAVING REGARD to the Resolution on the scale of contributions for mandatory activities for the years 1994 – 1996 (ESA/C/CXI/Res.2(Final)) adopted on 16 December 1993,

HAVING REGARD to the Director General's proposal for the level of resources for the mandatory activities covering the period 1996 – 2000 (ESA/C-M(95)6),

1. REAFFIRME que l'accès autonome de l'Europe à l'espace constitue un atout stratégique en raison des avantages politiques et économiques qui en résultent pour l'Europe et SOULIGNE que le développement des moyens européens en matière de lanceurs est partie intégrante d'une politique spatiale globale cohérente de l'Europe.

2. SOULIGNE la nécessité d'arrangements internationaux de nature à garantir des conditions équitables sur le marché des lanceurs.

3. (a) ACCUEILLE FAVORABLEMENT l'accord avec Arianespace mentionné ci-dessus et entériné par les participants à la Déclaration relative à la phase de production des lanceurs Ariane; en particulier en ce qui concerne une nouvelle politique de prix pour le lanceur Ariane;

   (b) TENANT COMPTE de la situation internationale dans le domaine des lanceurs commerciaux, CONSIDERE que cet accord avec Arianespace constitue un grand pas en avant de nature à garantir que les Etats membres tirent pleinement parti des lanceurs Ariane et des installations correspondantes pour toutes leurs activités nationales et internationales en liaison avec l'espace et ENCOURAGE les Etats membres à prendre les dispositions appropriées aux fins d'accorder la préférence à l'utilisation du lanceur Ariane conformément aux dispositions de la Déclaration relative à la phase de production des lanceurs Ariane et au Chapitre V de la Résolution n° 1 adoptée à Grenade en novembre 1992.

4. ACCUEILLE FAVORABLEMENT la souscription par les Etats participant aux programmes Ariane-5 complémentaires et l'entrée en vigueur ce jour des Déclarations de programme ci-après, conformément au Chapitre I.C de la présente Résolution:
   - la Déclaration additionnelle relative au programme Ariane-5 Evolution (ESA/PB-ARIANE/CLIV/Déc.1 (Final)), avec pour l'exécution du programme une enveloppe financière de 1026,2 millions d'unités de compte aux conditions économiques de la mi-1995 pour la période 1996 – 2003;
   - la Déclaration additionnelle relative au programme Infrastructure Ariane-5 (ESA/PB-ARIANE/CLIV/Déc.2 (Final)), avec une enveloppe financière de 335,7 millions d'unités de compte aux conditions économiques de la mi-1995 pour la période 1996 – 2000;
   - la Déclaration additionnelle relative au programme ARTA Ariane-5 (ESA/PB-ARIANE/CLIV/Déc.3 (Final)) avec une enveloppe financière de 351,5 millions d'unités de compte aux conditions économiques de la mi-1995 pour la période 1996 – 2000.

**C. Entrée en vigueur des Déclarations**

NOTE que les Etats participants en cause sont convenus de l'entrée en vigueur simultanée de la Déclaration relative à la participation de l'Europe au programme de développement de la Station spatiale internationale, de la Déclaration relative au programme MFC et des trois Déclarations relatives aux programmes complémentaires Ariane-5 visées au présent Chapitre, sous réserve de la notification de la confirmation des contributions en suspens.

## CHAPITRE II
## NIVEAU DE RESSOURCES 1996 – 2000
## POUR LES ACTIVITES OBLIGATOIRES

VU les Articles V.1(a) et XI(a)(ii) et (iii) de la Convention,

RAPPELANT la Résolution relative au niveau de ressources couvrant la période 1991 – 1995 pour les activités obligatoires (ESA/C/XCIII/Rés.3 (Final)) adoptée le 13 décembre 1990,

NOTANT qu'il n'a pas été possible de voter avant la fin de la période de 5 ans en cours comme le demande la Convention (article XI.5.a.iii) le nouveau niveau de ressources couvrant la période 1994 – 1998 et que de ce fait la prochaine période de 5 ans du niveau de ressources doit maintenant couvrir la période 1996 - 2000,

VU la Résolution relative au barème des contributions aux activités obligatoires pour les années 1994 – 1996 (ESA/C/CXI/Rés.2 (Final)) adoptée le 16 décembre 1993,

VU la proposition du Directeur général relative au niveau de ressources couvrant la période 1996 – 2000 pour les activités obligatoires (ESA/C M(95)6),

1. AGREES that the Level of Resources for mandatory activities for the years 1996 – 2000 will include the Scientific Programme, the General Budget, as well as the costs for the part of the Transformation Programme related to mandatory activities, which are necessary from 1996 to 1999 to achieve the savings planned in the Science Programme and in the General Budget;

2. DECIDES by unanimous vote to put at the disposal of the Agency for the General Budget, the Scientific Programme and the relevant Transformation Programme for the period 1996 – 2000, the amount of 2553.2 million accounting units at mid-1995 economic conditions, consisting of 804.2 million accounting units for the General Budget, 1735 million accounting units for the Scientific Programme and 14 million accounting units for the part of the Transformation Programme related to mandatory activities (an amount of 65 million accounting units being foreseen as other income, the remaining part being contributions); as an indication, an annual breakdown is given below.

(Amounts in MAU,at mid-1995 economic conditions)

| YEARS | 1996 | 1997 | 1998 | 1999 | 2000 | TOTAL |
|---|---|---|---|---|---|---|
| SCIENTIFIC PROGRAMME | 347.0 | 347.0 | 347.0 | 347.0 | 347.0 | 1735 |
| GENERAL BUDGET | 166.5 | 162.5 | 158.4 | 158.4 | 158.4 | 804.2 |
| TRANSFORMATION PROGRAMME | 1.6 | 4.4 | 6.0 | 2.0 | | 14.0 |

3. DECIDES furthermore that:

   (a) the Scientific Programme will not be subject to economic updating for price and conversion rate variations for the years 1997 and 1998 as long as the yearly variation for this Programme does not exceed 3% per annum;

   (b) if the 3% level is exceeded in either year, the difference between that level and the actual percentage increase will give rise to an equivalent updating of the Scientific Programme;

4. NOTES the determination of the Director General to implement efficiency improvement measures with the aim to reduce both internal and industrial costs of the activities of the Scientific Programme and INVITES the Director General to report to Council in June 1998 on the effects of these measures as well as on the consequences of the introduction of the ECU and the new charging policy referred to in paragraph 6 hereafter.

   INVITES the Director General to take full account of these consequences when making his proposal for the level of resources for the years 1999 – 2003.

5. UNDERLINES the Member States' determination to vote unanimously in 1998 the Level of Resources for the period 1999 – 2003 and as a consequence, DECIDES that if no new level of resources is adopted in 1998, the provisions in paragraph 3(a) and (b) above shall continue to apply in 1999 and 2000, until a new level of resources is adopted, and the amounts in the table above shall form the basis for the adoption of the relevant budgets. If the budgets proposed for those years are above the levels contained in the table above after application of the provisions of paragraph 3(b) above, they shall be adopted by a unanimous vote.

6. UNDERLINES the need to define and to implement a new charging policy taking into account, in particular, the interests of the Scientific Programme and to achieve its entry into force by 1 January 1997, thus ensuring continuity with the special measures adopted for the Scientific Programme by the Council on 13 December 1990 (ESA/C/XCIII/Res.3 (Final)) and on 17 September 1991 (ESA/C/XCV/Res. 2 (Final)), it being understood that these special measures would be extended by one year, should the entry into force of the new charging policy be postponed to 1 January 1998.

1. CONVIENT de ce que le niveau de ressources couvrant les années 1996 – 2000 pour les activités obligatoires englobera le programme scientifique, le budget général ainsi que les coûts de la partie du programme de transformation se rapportant aux activités obligatoires, nécessaires de 1996 à 1999 pour réaliser les économies projetées sur le programme scientifique et le budget général;

2. DECIDE à l'unanimité de mettre à la disposition de l'Agence pour le budget général, le programme scientifique et la part correspondante du programme de transformation, pendant la période 1996 – 2000, un montant de 2553,2 millions d'unités de compte aux conditions économiques de la mi-1995, se répartissant en 804,2 millions d'unités de compte pour le Budget général, 1735 millions d'unités de compte pour le programme scientifique et 14 millions d'unités de compte pour la partie du programme de transformation se rapportant aux activités obligatoires (un montant de 65 millions d'unités de compte étant prévu sous forme d'autres recettes et le reste sous forme de contributions); une ventilation par exercice est donnée ci-dessous à titre indicatif.

(Montants en MUC, conditions économiques de la mi-1995)

| Exercices | 1996 | 1997 | 1998 | 1999 | 2000 | TOTAL |
|---|---|---|---|---|---|---|
| Programme scientifique | 347,0 | 347,0 | 347,0 | 347,0 | 347,0 | 1735 |
| Budget général | 166,5 | 162,5 | 158,4 | 158,4 | 158,4 | 804,2 |
| Programme de Transformation | 1,6 | 4,4 | 6,0 | 2,0 | | 14,0 |

3. DECIDE en outre que:
   (a) le programme scientifique ne fera pas l'objet d'une actualisation économique pour variations des prix et des taux de conversion pendant les années 1997 et 1998, tant que la variation annuelle ne dépasse pas pour ce programme 3% l'an;

   (b) si le niveau de 3% est dépassé l'une quelconque de ces années, la différence entre ce niveau et l'augmentation réelle en pourcentage donnera lieu à une actualisation équivalente du programme scientifique.

4. PREND ACTE de la détermination du Directeur général à mettre en oeuvre des mesures d'amélioration de l'efficacité ayant pour objet de réduire les coûts et internes et industriels des activités du programme scientifique, et INVITE le Directeur général à faire rapport au Conseil en juin 1998 sur les effets de ces mesures ainsi que sur les conséquences du passage à l'ECU et de la mise en place de la nouvelle politique d'imputation présentée au point 6 ci-après.

   INVITE le Directeur général à tenir pleinement compte de ces conséquences lorsqu'il soumettra sa proposition de niveau de ressources pour les années 1999 – 2003.

5. SOULIGNE la détermination des Etats membres à voter à l'unanimité en 1998 le niveau de ressources pour la période 1999 – 2003 et, en conséquence, DECIDE que, si aucun niveau de ressources nouveau n'est adopté en 1998, les dispositions des paragraphes 3 (a) et (b) ci-dessus continueront de s'appliquer en 1999 et en 2000 jusqu'à ce qu'un nouveau niveau de ressources soit adopté, et que les montants figurant au tableau ci-dessus serviront de base à l'adoption des budgets correspondants. Si les budgets proposés pour lesdites années sont supérieurs aux niveaux figurant dans le tableau ci-dessus après application des dispositions du paragraphe 3 (b) ci-dessus, ils devront être adoptés à l'unanimité.

6. SOULIGNE la nécessité de définir et de mettre en oeuvre une nouvelle politique d'imputation prenant en particulier en compte les intérêts du programme scientifique et de parvenir à la faire entrer en vigueur pour le 1er janvier 1997, ce qui assurera une continuité avec les mesures spéciales adoptées par le Conseil pour le programme scientifique le 13 décembre 1990 (ESA/C/XCIII/Rés.3 (Final)) et le 17 septembre 1991 (ESA/C/XCV/Rés.2 (Final)), étant entendu que ces mesures spéciales pourraient être prolongées d'un an si l'entrée en vigueur de la nouvelle politique d'imputation était reportée au 1er janvier 1998.

7. AGREES to set up a Working Group of Council composed of financial experts, preferably using the competent delegate body, with the task of reviewing, within the applicable provisions of the Convention, the Agency's system of calculating the scale of contributions for the funding of mandatory activities with a view to submit a report and INVITES the Director General, on the basis of this report, to formulate a proposal to Council at Ministerial Level for approval and implementation of the relevant decisions as from 1 January 1997.

## CHAPTER III
## INDUSTRIAL POLICY MATTERS

RECALLING the objectives of the Agency's industrial policy as set out in Article VII of the Convention, namely to meet the requirements of the European space programme in a cost-effective manner, to improve the worldwide competitiveness of European industry, to ensure that all Member States participate in an equitable manner in implementing the European space programme, and to exploit the advantages of free competitive bidding except where this would be incompatible with other defined objectives of industrial policy.

### A. Correction of overall industrial return imbalances

RECALLING the decision taken by Council, meeting at Ministerial Level in Granada in November 1992, to fix at 0.96 the lower limit for the cumulative return coefficient referred to in Article IV.6. of Annex V to the Convention, below which special measures have to be taken at the end of 1996 on the basis of Article V.1 of Annex V to the Convention,

HAVING REGARD to the industrial return coefficient situation at the end of June 1995, as reported in document ESA/C(95)65, rev.1 and TAKING INTO ACCOUNT the continuous unsatisfactory situation of the industrial return of Italy,

1. CONSIDERS favourably the Director General's proposal to take corrective actions in anticipation to the formal review and TAKES NOTE of the actions already taken by the Director General under approved programmes.

2. APPRECIATES the effort already made by Participating States to introduce, in the Declarations of programmes referred to in Chapter I of this Resolution specific measures for correcting overall industrial return imbalances and ENCOURAGES other Member States with an overall return coefficient above 1 as at 30 June 1995 to complement these initiatives before end 1996 in order to alleviate current imbalances and facilitate the formal review to take place at the end of 1996.

3. INVITES the Director General to monitor the results of the above measures and, taking into account these results, to propose complementary measures under programmes already approved, or to be approved by the end of 1996, for the purpose of reducing residual imbalances.

### B. Improvement of procurement procedures

STRESSING the importance of procurement procedures to the cost-effectiveness of the Agency's programmes and to European industry's competitiveness,

INVITES the Director General, within the provisions of Article VII and Annex V of the Convention and the Agency's Contract Regulations

(a) to significantly increase the number of competitive tenders,

(b) to significantly reduce the volume of cost reimbursement contracts by placing, whenever practical, fixed price contracts, making increased use of financial incentives and penalties for contractors as a means of sharing the risk between ESA and industry,

(c) to convert those cost reimbursement contracts which are necessary to fixed price contracts as soon as possible in order to limit the exposure of ESA to cost overruns.

7. CONVIENT d'établir un Groupe de travail du Conseil composé d'experts financiers, en faisant de préférence appel à l'organe compétent, composé de délégués, groupe chargé de revoir, dans le cadre des dispositions pertinentes de la Convention, le système de calcul du barème des contributions utilisé par l'Agence pour financer les activités obligatoires et de faire rapport, et INVITE le Directeur général, sur la base de ce rapport, à formuler une proposition au Conseil au niveau ministériel en vue de l'approbation et de la mise en oeuvre des décisions pertinentes à compter du 1er janvier 1997.

## CHAPITRE III
## QUESTIONS DE POLITIQUE INDUSTRIELLE

RAPPELANT les objectifs de la politique industrielle de l'Agence tels qu'ils sont énoncés à l'Article VII de la Convention, à savoir répondre aux besoins du programme spatial européen d'une manière économiquement efficiente, améliorer la compétitivité de l'industrie européenne dans le monde, garantir que tous les Etats membres participent de façon équitable à la mise en oeuvre du programme spatial européen et bénéficier des avantages de l'appel à la concurrence, sauf lorsque cela serait incompatible avec d'autres objectifs précis de politique industrielle,

### A. Correction des déséquilibres du retour industriel global

RAPPELANT la décision prise par le Conseil siégeant au niveau ministériel à Grenade en novembre 1992 de fixer à 0,96 la limite inférieure du coefficient de retour cumulé visé à l'Article IV.6 de l'Annexe V de la Convention, en deçà de laquelle des mesures spéciales doivent être prises fin 1996 en application de l'Article V.1 de l'Annexe V de la Convention,

VU la situation des coefficients de retour industriel à fin juin 1995 telle qu'elle est exposée dans le document ESA/C(95)65, rév.1, et COMPTE TENU de la situation du retour industriel de l'Italie qui continue d'être non satisfaisante,

1. CONSIDERE favorablement la proposition du Directeur général de prendre des mesures correctrices par anticipation de l'examen formel et PREND NOTE des actions déjà engagées par le Directeur général dans le cadre des programmes approuvés.

2. APPRECIE l'effort déjà accompli par les Etats participants pour insérer dans les Déclarations de programme visées au Chapitre premier de la présente Résolution des mesures spécifiques afin de corriger les déséquilibres du retour industriel global, et ENCOURAGE d'autres Etats membres dont le coefficient de retour global est supérieur à l'unité à la date du 30 juin 1995 à prendre avant fin 1996 des initiatives complémentaires afin d'atténuer les déséquilibres actuels et de faciliter l'examen formel qui doit avoir lieu fin 1996.

3. INVITE le Directeur général à suivre les résultats des mesures ci-dessus et, compte tenu de ces résultats, à proposer dans le cadre des programmes déjà approuvés ou à approuver d'ici la fin de 1996, des mesures complémentaires ayant pour objet de réduire les déséquilibres qui subsistent.

### B. Amélioration des procédures d'approvisionnement

SOULIGNANT l'importance des procédures d'approvisionnement pour le rapport coût/efficacité des programmes de l'Agence et pour la compétitivité de l'industrie européenne,

INVITE le Directeur général, en application des dispositions de l'Article VII et de l'Annexe V de la Convention et du Règlement des contrats de l'Agence,

(a) à augmenter sensiblement le nombre des appels d'offres concurrentiels;

(b) à réduire sensiblement le volume des contrats à remboursement des frais en concluant, chaque fois que les circonstances s'y prêtent, des contrats à prix forfaitaire faisant davantage appel à des systèmes de pénalités et d'intéressement financiers des contractants, en tant que moyen de partager les risques entre l'Agence et l'industrie;

(c) à convertir dès que possible en contrats à prix forfaitaire les contrats qu'il a été nécessaire de passer en remboursement des frais, afin de limiter pour l'Agence le risque d'être exposée à des dépassements de coûts.

**C. Review of the Agency's industrial policy**

CONSIDERING the reflections and proposals of the Member States, the Agency, the European Commission and industry with regard to strengthening the competitiveness of European industry, and TAKING INTO ACCOUNT changes in the economic and industrial environment,

UNDERSTANDING that industrial policy is crucial for the future of ESA and requires a positive commitment from all Member States to formulate common positions,

1. DECIDES to set up a Council Working Group composed of high-level representatives from Member States with the task of reviewing the Agency's industrial policy.

2. INVITES the Council at delegate level to elaborate and approve the terms of reference of such a Working Group by 1 January 1996 which should comprise, among other tasks:

   (a) assessing the industrial environment and its potential evolution;

   (b) examining current industrial policy's rules and procedures;

   (c) examining the reasons behind the industrial return structural surplus and deficit situations;

   (d) proposing adaptations of the Agency's industrial policy, including if necessary amendments to Annex V of the Convention;

3. INVITES the Director General, on the basis of the report of the Council Working Group, to formulate a proposal t to t Council at Ministerial Level for approval and implementation of the relevant decisions as from 1 January 1997.

## CHAPTER IV
## REFORM OF FINANCIAL SYSTEM — INTRODUCTION OF THE ECU

RECALLING that ESA/C-M/CIV/Res.1 (Final) adopted at Ministerial Level in Granada had created the framework for embarking on the reform of the Agency's financial system, taking due account of the principles of neutrality and non-transfer of funds between Member States,

RECALLING the work performed by the Council Working Group on the Reform of the Financial System of the Agency,

HAVING REGARD to the Resolution ESA/C/CXXI/Res. 3 (Final) adopted on 11 October 1995, on the technical modalities for the implementation of the Reform of the Financial System,

DECIDES to reform the Agency's financial system as of 1 January 1997 so as to allow for the introduction of a single payment unit in the form of the ECU as defined in ESA/C(95)100, rev. 3, and REPLACES to this end Article V of Annex II to the Convention with the following text, with effect from 1 January 1997:

### Article V

1. The budgets of the Agency shall be expressed in ECU as currently defined by the European Union's competent bodies and subsequently in the European payment unit which may replace it as soon as it is set into force by these bodies.

2. Each Member State shall pay its contribution in ECU and in the subsequent replacement for it as referred to in paragraph 1 above.

**C. Révision de la politique industrielle de l'Agence**

CONSIDERANT les réflexions et les propositions des Etats membres, de l'Agence, de la Commission européenne et de l'industrie, en ce qui concerne le renforcement de la compétitivité de l'industrie européenne et PRENANT EN COMPTE l'évolution du contexte économique et industriel,

CONSCIENT que la politique industrielle est capitale pour l'avenir de l'Agence et exige que tous les Etats membres s'engagent positivement à formuler des positions communes,

1. DECIDE d'établir un groupe de travail du Conseil composé de représentants de haut niveau des Etats membres, chargé de revoir la politique industrielle de l'Agence.

2. INVITE le Conseil au niveau des délégués à élaborer le mandat de ce groupe de travail et à l'approuver d'ici le 1er janvier 1996, mandat qui devrait notamment consister:

   (a) à évaluer le contexte industriel et son évolution potentielle;

   (b) à examiner les règles et procédures de politique industrielle en vigueur;

   (c) à examiner les raisons qui motivent les situations de surplus et de déficit structuraux du retour industriel;

   (d) à proposer des adaptations de la politique industrielle de l'Agence, y compris le cas échéant des amendements de l'Annexe V de la Convention.

   3. INVITE le Directeur général, sur la base du rapport du groupe de travail du Conseil, à formuler une proposition au Conseil au niveau ministériel en vue de l'approbation et de la mise en oeuvre des décisions pertinentes à compter du 1er janvier 1997.

## CHAPITRE IV
## REFORME DU SYSTEME FINANCIER – PASSAGE A L'ECU

RAPPELANT que la Résolution ESA/C-M/CIV/Rés.1 (final), adoptée au niveau ministériel à Grenade, a créé le cadre nécessaire pour entreprendre la réforme du système financier de l'Agence, compte dûment tenu des principes de neutralité et de non transfert de fonds entre Etats membres,

RAPPELANT les travaux accomplis par le Groupe de travail du Conseil sur la réforme du système financier de l'Agence,

VU la Résolution sur les modalités techniques de mise en oeuvre de la réforme du système financier ESA/C/CXXI/Rés.3 (Final), adoptée le 11 octobre 1995,

DECIDE de réformer le système financier de l'Agence à compter du 1er janvier 1997 de façon à permettre la mise en place d'une unité de paiement unique, l'ECU, comme cela est exposé dans le document ESA/C(95)100, rév.3, et REMPLACE à cette fin l'Article V de l'Annexe II de la Convention par le texte ci-après, avec effet au 1er janvier 1997:

### Article V

1. Les budgets de l'Agence sont exprimés en ECU tel que le définissent actuellement les organes compétents de l'Union européenne et ultérieurement dans l'unité de paiement européenne qui pourra le remplacer, dès que lesdits organes lui auront donné force légale.

2. Chaque Etat membre paie ses contributions en ECU et dans l'unité qui le remplacera ultérieurement comme il est dit au point 1 ci-dessus.

# Resolution on Directions for the Agency's Policy and Future Programmes

**(adopted on 20 October 1995)**

The Council, meeting at Ministerial Level,

HAVING REGARD to the Resolutions of Granada on 10 November 1992 (ESA/C-M/CIV/Res. 1(final)) on the implementation of the European long-term space plan and programmes, ESA/C-M/CIV/Res.2 (final) on international cooperation, and ESA/C-M/CIV/Res.3 (final) on space cooperation with the Russian Federation,

HAVING REGARD to the Director General's Overview and Proposal on the Agency's Policy and Programmes (ESA/C-M(95)5),

WELCOMING the arrival of Finland on 1 January 1995 as the fourteenth Member State of the Agency,

RECALLING the mission of the Agency as defined in Article II of the Convention,

NOTING the achievements obtained by the Agency in various fields, in particular, Science, Launchers, Earth Observation, Telecommunications and Microgravity,

## CHAPTER I
## OBJECTIVES AND PRIORITIES

STRESSING the strategic, economic, technological and social aspects of space activities,

RECOGNISING with satisfaction that the efforts of Member States through the Agency have resulted in placing Europe at the forefront of space research and technology and their applications, and NOTING that these efforts have also led to the building up of competitive sectors within the industry and successful operators of space systems,

NOTING the role of space activities and programmes as a contributing element to the continuing process of European integration,

NOTING the evolution in the world-wide political and economical environment leading on the one hand to increased possibilities for international cooperation and on the other hand to greater competition between space service providers,

1. (a) APPRECIATES the work performed by the Long-term Space Policy Committee as reflected in its report (ESA/C-M(95)4); TAKES NOTE of its contents and vision for future space activities, and EXPRESSES THE WISH that the Committee continue its work so as to give Member States a framework for long-term strategic thinking on European space policy;

   (b) INVITES the Director General to prepare an evaluation and discussion process within the relevant bodies of the Agency as input for its future planning.

2. STRESSES that in order to prepare Europe for the challenges and opportunities of the next century, the main objectives of the Agency are to be focused on:

   (a) providing the means of making use of the unique environment of space for scientific research and the development of applications;

   (b) promoting research and development of advanced space technologies, new space applications and suitable methods of carrying out space activities and ensuring the transfer of application activities to appropriate entities for operational and commercial exploitation;

# Résolution sur les orientations de la politique et des programmes futurs de l'Agence

**(adoptée le 20 octobre 1995)**

Le Conseil, siégeant au niveau ministériel,

VU les Résolutions adoptées à Grenade le 10 novembre 1992 sur la mise en oeuvre du plan spatial européen à long terme et des programmes (ESA/C M/CIV/Rés.1 (final)), sur la coopération internationale (ESA/C-M/CIV/Rés.2 (final)) et sur la coopération spatiale avec la Fédération de Russie (ESA/C-M/CIV/Rés.3 (final)),

VU la revue d'ensemble et la proposition du Directeur général sur la politique et les programmes de l'Agence (ESA/C-M(95)5),

SE FELICITANT de l'adhésion de la Finlande en tant que quatorzième Etat membre de l'Agence à compter du 1er janvier 1995,

RAPPELANT la mission de l'Agence telle qu'elle est définie à l'Article II de la Convention,

PRENANT NOTE des résultats obtenus par l'Agence dans différents domaines, en particulier dans ceux de la science, des lanceurs, de l'observation de la Terre, des télécommunications et de la recherche en microgravité,

**CHAPITRE PREMIER**
**OBJECTIFS ET PRIORITES**

SOULIGNANT les aspects stratégiques, économiques, techniques et sociaux des activités spatiales,

RECONNAISSANT avec satisfaction que les efforts consentis par les Etats membres par l'intermédiaire de l'Agence ont eu pour effet de placer l'Europe à l'avant-garde de la recherche et de la technologie spatiales et de leurs applications, et NOTANT que ces efforts se sont également traduits par la mise sur pied, dans l'industrie, de secteurs compétitifs et par des succès chez les exploitants de systèmes spatiaux,

NOTANT que les activités et programmes spatiaux contribuent au processus permanent d'intégration de l'Europe,

PRENANT NOTE de l'évolution de la situation politique et économique à l'échelle mondiale, qui conduit d'une part à renforcer les possibilités de coopération internationale et d'autre part à accroître la concurrence entre les fournisseurs de services spatiaux,

1. (a) SE FELICITE des travaux du Comité de la politique spatiale dans le long terme faisant l'objet du rapport (ESA/C-M(95)4); PREND NOTE de son contenu et de la vision qu'il donne des activités spatiales de demain, et SOUHAITE que le Comité poursuive ses travaux de manière à permettre aux Etats membres de disposer d'un cadre de réflexion stratégique à long terme sur la politique spatiale européenne;

   (b) INVITE le Directeur général à engager, au sein des organes compétents de l'Agence, une évaluation et un débat dont les résultats seront pris en compte dans la planification des activités futures.

2. SOULIGNE que pour préparer l'Europe aux défis et aux chances qui se présenteront à elle au siècle prochain, l'Agence doit axer ses efforts sur les principaux objectifs suivants:

   (a) fournir les moyens d'utiliser l'environnement sans équivalent qu'est l'espace pour la recherche scientifique et le développement d'applications;

   (b) promouvoir la recherche et le développement de technologies spatiales de pointe, d'applications spatiales nouvelles et de méthodes adaptées à la conduite des activités spatiales, et faire en sorte que les activités d'applications soient transférées à des entités compétentes en vue de leur exploitation opérationnelle et commerciale;

(c) enhancing Europe's capability to access space at the lowest costs for users and ensuring the most efficient exploitation of Ariane as a competitive European launch asset;

(d) furthering the participation of Europe in international space infrastructure programmes and their exploitation with elements and services able to assert the European identity and to prepare technologies for longer term exploration and exploitation endeavours;

(e) ensuring that the programmes of the Agency contribute to promoting the world-wide competitiveness of European industry.

## CHAPTER II
## PROGRAMMES

HAVING REGARD to the Resolution concerning Decisions on Agency Programmes and Finances (ESA/C/CXXII/Res.1) adopted on 20 October 1995,

HAVING REGARD to the constraints on the resources which Member States can contribute to the Agency's Programmes,

WELCOMES the Director General's Overview and Proposal on the Agency's Policy and Programmes (ESA/C-M(95)5) as the framework for the following directions:

**1. Scientific Programme**

(a) WELCOMES and ENDORSES the continuation of the Horizon 2000 Programme and its evolution into the Horizon 2000 Plus Programme in accordance with the decisions on the Level of Resources;

(b) INVITES the Director General to initiate the preparatory activities leading to Horizon 2000 Plus in accordance with his Proposal mentioned above.

**2. Earth Observation**

(a) WELCOMES the progress towards a European policy for Earth Observation from space being achieved by the Agency in cooperation with the European Commission, Eumetsat and Member States, as an important step towards identifying and meeting the needs of users and APPROVES in principle the concept described in the Director General's Proposal of two distinct themes:
- the study of planet Earth for scientific research purposes (Earth Explorer) corresponding to needs expressed by the relevant scientific and other user communities, and the development of relevant technologies;
- pre-operational and operational activities corresponding to needs expressed by user organisations and conducted in cooperation with these organisations (Earth Watch).

(b) INVITES the Director General to develop proposals for implementing the Earth Explorer objectives in close consultation with the user communities;

(c) INVITES the Director General to continue the Agency's concerted efforts with Eumetsat, the European Commission and other relevant European entities to define further activities having operational objectives together with their respective roles and responsibilities, and to encourage the progressive transfer of responsibilities from the Agency to operational entities, and INVITES the Director General to bring forward appropriate proposals.

**3. Telecommunications**

(a) RECOGNISES the benefits of having set up the Agency's Programme of Advanced Research in Telecommunications System (ARTES); WELCOMES and ENDORSES the objective to promote, in conjunction with user entities and industry, new fields of applications such as navigation, mobile communications and multimedia information, and to contribute to the reinforcement of the competitiveness of the European telecommunications industry;

(c) renforcer les capacités européennes d'accès à l'espace au coût le plus bas possible pour les utilisateurs et obtenir l'exploitation la plus efficace possible d'Ariane, comme atout compétitif de l'Europe sur le marché des lancements;

(d) favoriser la participation de l'Europe à des programmes internationaux d'infrastructure spatiale et à leur exploitation en fournissant des éléments et des services permettant d'affirmer l'identité de l'Europe et de préparer des technologies adaptées à des activités d'exploration et d'exploitation à plus long terme;

(e) faire en sorte que les programmes de l'Agence contribuent à promouvoir la compétitivité de l'industrie européenne sur la scène mondiale.

**CHAPITRE II**
**PROGRAMMES**

VU la Résolution relative aux décisions sur les programmes et les finances de l'Agence (ESA/C/CXXII/Rés. 1), adoptée le 20 octobre 1995,

VU les contraintes pesant sur les ressources que les Etats membres peuvent mettre à la disposition des programmes de l'Agence,

ACCUEILLE FAVORABLEMENT la revue d'ensemble et la proposition du Directeur général sur la politique et les programmes de l'Agence (ESA/C-M(95)5), comme cadre aux orientations ci-après:

**1. Programme scientifique**

(a) ACCUEILLE FAVORABLEMENT et FAIT SIENNES la poursuite du programme Horizon 2000 et son évolution vers le programme Horizon 2000 Plus, en accord avec les décisions sur le niveau de ressources;

(b) INVITE le Directeur général à engager, conformément à sa proposition mentionnée ci-dessus, les activités préparatoires conduisant au programme Horizon 2000 Plus.

**2. Observation de la Terre**

(a) SE FELICITE des progrès actuellement accomplis par l'Agence en coopération avec la Commission européenne, Eumetsat et les Etats membres, dans la mise en place d'une politique européenne d'observation de la Terre à partir de l'espace, ces progrès contribuant pour une part importante à recenser les besoins des utilisateurs et à y répondre, et APPROUVE dans son principe le concept des deux thèmes distincts suivants exposé dans la proposition du Directeur général:
- missions d'étude de la planète Terre à des fins de recherche scientifique (Earth Explorer), en réponse aux besoins exprimés par les chercheurs de ce domaine et par d'autres communautés d'utilisateurs compétentes, et développement de technologies appropriées;
- missions préopérationnelles et opérationnelles répondant aux besoins exprimés par des organisations utilisatrices et conduites en coopération avec ces organisations (Earth Watch).

(b) INVITE le Directeur général à élaborer, en concertation étroite avec les communautés d'utilisateurs, des propositions de mise en oeuvre des objectifs Earth Explorer;

(c) INVITE le Directeur général à poursuivre les efforts entrepris par l'Agence en concertation avec Eumetsat, la Commission européenne et d'autres entités européennes compétentes, en vue de définir à la fois d'autres activités à vocation opérationnelle et les rôles et responsabilités de chacun en la matière et à encourager le transfert progressif des responsabilités de l'Agence à des entités opérationnelles, et INVITE le Directeur général à présenter des propositions appropriées.

**3. Télécommunications**

(a) RECONNAIT les avantages découlant de la mise en place à l'Agence du Programme de recherche de pointe sur les systèmes de télécommunications (ARTES); ACCUEILLE FAVORABLEMENT et FAIT SIEN l'objectif consistant à promouvoir, en liaison avec des entités utilisatrices et l'industrie, de nouveaux domaines d'application comme la navigation, les télécommunications avec les mobiles et les systèmes d'information multimédia, et à contribuer au renforcement de la compétitivité de l'industrie européenne des télécommunications;

(b) INVITES the Director General to make specific programme proposals for new advanced telecommunications applications in conjunction with the users and in close consultation with the Commission of the European Union, for example for a European contribution to the Global Navigation Satellite System (GNSS) and to the future Global Information Infrastructure (GII);

(c) INVITES the Director General to propose cooperation schemes, in particular with users, operators and industry in order to meet the objectives mentioned above, taking into account the organisational efforts made by the European space telecommunications sector as a whole;

(d) INVITES the States Participating in the DRTM Programme to review the mission requirements in consultation with the potential users and to adjust the planning accordingly.

**4. Microgravity**

STRESSES the need for the continuation of a microgravity research programme and WELCOMES the EMIR-2 programme which will ensure the extension of basic and applied research in physical sciences and life sciences using, in particular sounding rockets, retrievable carriers and the International Space Station capabilities, and INVITES all Member States to subscribe the EMIR 2 Declaration (ESA/PB-MG/XLIV/Dec.1(Final)).

**5. Future Launchers**

NOTING that the use and commercial exploitation of space would be stimulated and new avenues for space exploration opened if launch costs could be significantly reduced,

NOTING that adaptation of Ariane to evolving market requirements is one of the main factors to its success,

NOTING the large amount of enabling technology to be developed and demonstrated before the start of the development of a new generation of launch vehicles can be envisaged in Europe,

(a) STRESSES the need to maintain in Europe a competitive launcher capability in the long term which ensures an affordable independent European access to space, and the importance to prepare for a future launcher;

(b) INVITES the Director General to elaborate in due time a proposal on a future launcher preparatory programme to validate new technologies and technical concepts at system and sub-system level, so as to prepare for development of further Ariane-5 improvements and of a new generation of launchers.

**6. Manned space flights**

(a) RECOGNISES the unique potential offered by the International Space Station in the areas of scientific research, technology and applications,

(b) STRESSING the interest for Europe to participate in the manned spaceflight effort, INVITES the Director General to enhance the experience gained in this field by the Agency, its Member States and industry and to reflect on new opportunities in this field, including flight opportunities for Agency astronauts.

**7. Exploration**

NOTING the contents of the report of the Long-term Space Policy Committee with regard to the long-term interest of an international exploration programme,

(a) APPRECIATES, in particular, the concept of a four-stepped international lunar programme, as described in ESA/C-M(95)5.

(b) TAKES NOTE of the Director General's intention to elaborate and make proposals on the European contribution to precursor missions for the first step of such a programme.

(b) INVITE le Directeur général à élaborer, en liaison avec les utilisateurs et en concertation étroite avec la Commission de l'Union européenne, des propositions de programmes portant spécifiquement sur de nouvelles applications de pointe dans le domaine des télécommunications, par exemple pour une contribution européenne au système mondial de navigation par satellite (GNSS) et à la future Infrastructure mondiale de l'information (GII);

(c) INVITE le Directeur général à proposer des projets à mener en coopération, en particulier avec des utilisateurs, des exploitants et l'industrie, afin d'atteindre les objectifs précités en prenant en compte les efforts d'organisation du secteur européen des télécommunications spatiales dans son ensemble;

(d) INVITE les Etats participant au programme DRTM à réexaminer les impératifs de la mission en concertation avec ses utilisateurs potentiels et à adapter sa planification en conséquence.

**4. Recherche en microgravité**

SOULIGNE la nécessité de poursuivre un programme de recherche en microgravité et ACCUEILLE FAVORABLEMENT le programme EMIR-2, qui assurera la continuation des recherches fondamentales et appliquées en sciences physiques et en sciences de la vie en utilisant en particulier des fusées-sondes, des moyens d'emport récupérables et les moyens de la Station spatiale internationale, et INVITE tous les Etats membres à souscrire la Déclaration relative au programme EMIR-2 (ESA/PB-MG/XLIV/Déc.1 (final)).

**5. Lanceurs futurs**

NOTANT qu'une diminution sensible des coûts de lancement aurait pour effet de stimuler l'utilisation et l'exploitation commerciale de l'espace et d'ouvrir de nouvelles voies à l'exploration spatiale,

NOTANT que l'adaptation d'Ariane à l'évolution des besoins du marché est l'un des principaux facteurs de son succès,

PRENANT NOTE de la masse de technologies habilitantes à mettre au point et à démontrer avant que l'Europe puisse envisager de s'engager dans le développement d'une nouvelle génération de lanceurs,

(a) SOULIGNE la nécessité de maintenir en Europe une capacité de lancement compétitive à long terme qui garantisse à l'Europe, pour un coût raisonnable, un accès indépendant à l'espace, et SOULIGNE combien il est important de préparer la réalisation d'un lanceur futur;

(b) INVITE le Directeur général à élaborer en temps opportun une proposition de programme préparatoire relatif à un lanceur futur, ce programme ayant pour objet de valider des technologies et des concepts techniques nouveaux au plan des systèmes et sous-systèmes, de façon à préparer le développement de nouvelles améliorations d'Ariane-5 et d'une nouvelle génération de lanceurs.

**6. Vols spatiaux habités**

(a) RECONNAIT les possibilités sans équivalent offertes par la Station spatiale internationale dans les domaines de la recherche scientifique, de la technologie et des applications,

(b) SOULIGNANT l'intérêt qu'a l'Europe de participer aux vols spatiaux habités, INVITE le Directeur général à renforcer l'expérience acquise dans ce domaine par l'Agence, ses Etats membres et l'industrie et à réfléchir à de nouveaux projets en la matière, notamment à des occasions de vol pour les astronautes de l'Agence.

**7. Exploration**

PRENANT NOTE du contenu du rapport du Comité sur la politique spatiale dans le long terme eu égard à l'intérêt scientifique à long terme d'un programme d'exploration international,

(a) SE FELICITE en particulier du concept d'un programme international relatif à la Lune en quatre étapes, tel qu'il est décrit dans le document ESA/CM(95)5,

(b) PREND NOTE de l'intention du Directeur général d'élaborer et de présenter des propositions sur la contribution de l'Europe à des missions précurseurs pour la première étape d'un tel programme.

## 8. Technology

HAVING REGARD to the benefits of the various Agency's technology programmes (such as TRP, GSTP and ARTES) in the success of the Agency's scientific and application programmes and in the competitiveness of industry, and to the need to refocus and reinforce the relevant efforts in view of the future challenges;

INVITES the Director General to propose a coherent plan of Research and Technology consistent with the challenging objectives of future Agency programmes, customer needs in emerging commercial applications and new markets, in conjunction with Member States and industry.

## 9. New Missions

(a) Small missions opportunities

WELCOMES the initiative taken by the Director General to study ways to stimulate European industry to provide competitive opportunities for small missions and INVITES the Director General to work with Member States, industry and research organisations towards small missions implementation.

(b) Management of natural and technical risks

CONVINCED of the contribution of space techniques to the management of natural and technical risks,

WELCOMES the initiative of the Director General to perform support activities in close cooperation with the Council of Europe, the European Union and national entities from Member States or non-Member States and INVITES the Director General to make proposals to Member States for such support activities on the basis of the results of the ongoing studies.

# CHAPTER III
# THE AGENCY AND ITS ENVIRONMENT
# (Internal functioning and external relations)

RECOGNISING the achievements in the overall efficiency of the Agency, and CONSIDERING the need for further improvement, with the aim of preparing to meet new and increasing challenges within the prevailing public funding constraints,

CONSIDERING that this improvement in efficiency can best be achieved by adapting the Agency's operations, intensifying synergy and complementarity of the Agency's activities with those of national and other European Organisations, and taking advantage of the benefits of international cooperation,

NOTING the progress made in defining and setting up cooperative endeavours with European organisations such as Eumetsat and the European Commission and with space-faring countries such as Canada, the United States, Russia and Japan,

NOTING that the Agency has already concluded Cooperation Agreements with Poland, Hungary, Rumania and Greece and that Portugal and the Czech Republic have expressed great interest in establishing a cooperation according to Article XIV.1 of the Convention,

## 1. The internal functioning of the Agency

HAVING REGARD to the various reviews on the internal functioning, and to the Director General's Report on the Agency's internal operations (ESA/C(95)96),

(a) WELCOMES and SUPPORTS the adaptation already identified by the Director General to the internal structure and functioning of the Agency and INVITES him to pursue his effort within the next 3 years, in order to provide the most efficient framework for implementing the activities and programmes entrusted to the Agency;

**8. Technologie**

VU l'incidence positive des différents programmes technologiques de l'Agence (TRP, GSTP et ARTES, par exemple) sur les programmes de science et d'application de l'Agence et sur la compétitivité de l'industrie, et VU la nécessité de redéfinir et de renforcer les activités correspondantes en vue des défis à venir;

INVITE le Directeur général à proposer, en concertation avec les Etats membres et l'industrie, un plan cohérent de recherche et de technologie qui soit adapté aux objectifs ambitieux des programmes futurs de l'Agence ainsi qu'aux besoins des clients dans le domaine des applications commerciales et des nouveaux marchés qui se font jour.

**9. Nouvelles missions**

(a) Occasions de petites missions

SE FELICITE que le Directeur général ait pris l'initiative d'étudier les moyens d'encourager l'industrie européenne à offrir des occasions compétitives de petites missions, et INVITE le Directeur général à collaborer avec les Etats membres, l'industrie et les organismes de recherche en vue de mettre en oeuvre de petites missions.

(b) Gestion des catastrophes naturelles et des risques techniques

CONVAINCU que les techniques spatiales peuvent apporter une contribution à la gestion des catastrophes naturelles et des risques techniques,

SE FELICITE que le Directeur général ait pris l'initiative de conduire des activités de soutien en collaboration étroite avec le Conseil de l'Europe, l'Union européenne et les entités nationales des Etats membres ou non membres, et INVITE le Directeur général à soumettre aux Etats membres des propositions relatives à ce type d'activité, élaborées sur la base des résultats des études en cours.

## CHAPITRE III
## L'AGENCE ET SON ENVIRONNEMENT
## (fonctionnement interne et relations extérieures)

RECONNAISSANT l'efficacité d'ensemble à laquelle l'Agence est parvenue et CONSIDERANT la nécessité de poursuivre ces améliorations en vue de préparer l'Agence à relever, malgré les contraintes pesant actuellement sur les finances publiques, des défis nouveaux et sans cesse plus complexes,

CONSIDERANT que le meilleur moyen de parvenir à ce gain d'efficacité consiste à revoir le mode de fonctionnement de l'Agence, à obtenir une meilleure synergie et complémentarité des activités de l'Agence et de celles des agences nationales et autres entités européennes, et à tirer parti des avantages de la coopération internationale,

PRENANT NOTE des progrès accomplis dans la définition et la mise en place d'activités en coopération avec des organisations européennes comme Eumetsat et la Commission européenne ainsi qu'avec des puissances spatiales comme le Canada, les Etats-Unis, la Russie et le Japon;

NOTANT que l'Agence a déjà conclu des accords de coopération avec la Pologne, la Hongrie, la Roumanie et la Grèce, et que le Portugal et la République tchèque ont manifesté un vif intérêt pour l'établissement d'une coopération en vertu de l'Article XIV.1 de la Convention,

**1. Fonctionnement interne de l'Agence**

VU les différents passages en revue du fonctionnement interne de l'Agence et le rapport établi à ce sujet par le Directeur général (ESA/C(95)96),

(a) ACCUEILLE FAVORABLEMENT et APPUIE les modifications de structure et de fonctionnement qui ont déjà été définies par le Directeur général et INVITE celui-ci à poursuivre son effort dans les trois années à venir en vue d'instituer le cadre le plus propice à la mise en oeuvre des activités et des programmes confiés à l'Agence;

(b) WELCOMES the Director General's proposal to conduct a Transformation Programme having as objective to:
- bring the Agency's resources into line with the requirements of the programmes and activities entrusted to it;
- improve the efficiency in the management and in the cost control of these resources to the benefit of better achieving the Agency's mission;
- improve the Agency's interaction with industry especially in its procurement methods;
- implement a unique cost control system for all Agency activities based on an up-to-date cost accounting system.

(c) NOTES the estimation provided in the Director General's Proposal on the so far identified cost-savings and on the cost for executing the Transformation Programme;

(d) NOTES that the savings stemming from the increase in efficiency obtained through the Transformation Programme will, in case of the optional programmes, be used first to offset the relevant cost of the Transformation Programme and then be credited to the programme in question; and NOTES further that, for mandatory activities, foreseen savings and associated cost are included in the Level of Resources 1996 – 2000.

(e) INVITES the Director General to keep the Council informed every six months on the implementation of the above transformation programme, and to submit in the light of the experience gained additional proposals for further improvement in efficiency and cost-savings.

**2. Cooperation with other organisations in Europe**

(a) WELCOMES the cooperation under way on meteorology and climatology between the Agency and Eumetsat, between the Agency and the European Commission in the fields of navigation and observation of the Earth and its environment, as well as between the Agency and Eutelsat in the field of telecommunications;

(b) INVITES the Director General to work with other organisations in Europe at national and European level, in particular the European Commission, taking into account their respective roles, to ensure the synergy and complementarity of their respective activities, in particular in science, Earth observation, telecommunications, microgravity and technology in a coherent European space policy and to reinforce the position of Europe in the world-wide space activities.

**3. Cooperation with other space-faring nations**

(a) WELCOMES the results of the mid-term review of the cooperation Agreement with Canada and APPRECIATES the benefits of such a long-standing cooperation; and APPRECIATES as well cooperation with Canada in the context of the International Space Station;

(b) WELCOMES the efforts undertaken by the Director General to deepen the long-standing cooperation with the United States, to carry out joint activities with Russia and to lay the basis for closer cooperation with Japan, in particular in the frame of the International Space Station and of the Scientific Programme;

(c) INVITES the Director General to pursue his endeavours of strengthening the ties with the Agency's partners, in particular in global environmental systems and in future exploration programmes.

**4. Cooperation with Developing Countries**

NOTING the Resolution ESA/C/CXVI/Res.1(Final) adopted on 22 February 1995 and the lines of action specified in it,

(a) WELCOMES the actions taken by the Director General to make international and national organisations and entities with responsibilities for development aid aware of the potential contributions offered by the space technology and applications for Developing Countries;

(b) INVITES the Director General to pursue within the provisions of the above-mentioned Resolution, activities aiming at demonstrating the capabilities of European space technology, in particular as they relate to meeting the developing countries' needs.

(b) SE FELICITE de la proposition du Directeur général de mener un programme de transformation ayant pour objectif:
- d'adapter les ressources de l'Agence aux besoins des programmes et activités qui lui sont confiés;
- d'améliorer l'efficacité de la gestion de ces ressources afin que l'Agence puisse mieux accomplir sa mission;
- d'améliorer l'interaction entre l'Agence et l'industrie, notamment en ce qui concerne les méthodes d'approvisionnement;
- de mettre en application, pour toutes les activités de l'Agence, un système de contrôle unique des coûts fondé sur un système moderne de comptabilité analytique.

(c) PREND NOTE des estimations figurant dans la proposition du Directeur général au sujet des économies définies à ce jour et du coût d'exécution du programme de transformation;

(d) NOTE que les économies résultant du gain d'efficacité obtenu grâce au programme de transformation seront d'abord utilisées, dans le cas des programmes facultatifs, pour compenser le coût correspondant du programme de transformation, puis créditées au programme facultatif en question; et NOTE en outre que pour les activités obligatoires, les économies escomptées et les coûts correspondants sont inclus dans le niveau de ressources de la période 1996 – 2000;

(e) INVITE le Directeur général à informer le Conseil tous les 6 mois de la mise en oeuvre du programme de transformation précité et à présenter, à la lumière de l'expérience acquise, de nouvelles propositions de nature à réaliser un gain d'efficacité et des économies supplémentaires.

**2. Coopération avec d'autres organisations en Europe**

(a) SE FELICITE des activités actuellement menées en coopération entre l'Agence et Eumetsat dans les domaines de la météorologie et de la climatologie, entre l'Agence et la Commission européenne dans les domaines de la navigation et de l'observation de la Terre et de son environnement, ainsi qu'entre l'Agence et l'organisation Eutelsat dans le domaine des télécommunications;

(b) INVITE le Directeur général à collaborer au niveau national et européen avec d'autres organisations en Europe, en particulier avec la Commission européenne, en tenant compte de leurs rôles respectifs, à assurer la synergie et la complémentarité de leurs activités respectives, en particulier dans les domaines de la science, de l'observation de la Terre, des télécommunications, de la recherche en microgravité et de la technologie, dans le cadre d'une politique spatiale européenne cohérente, et à renforcer la position de l'Europe dans les activités spatiales mondiales;

**3. Coopération avec d'autres puissances spatiales**

(a) ACCUEILLE AVEC SATISFACTION les résultats de la revue à mi-parcours de l'Accord de coopération conclu avec le Canada, et SE FELICITE des avantages découlant de cette coopération de longue date; APPRECIE également la coopération avec le Canada dans le contexte de la Station spatiale internationale;

(b) SE FELICITE des efforts entrepris par le Directeur général pour renforcer la coopération de longue date avec les Etats-Unis, mener des activités communes avec la Russie et jeter les bases d'une coopération plus étroite avec le Japon, en particulier dans le cadre de la Station spatiale internationale et du Programme scientifique;

(c) INVITE le Directeur général à poursuivre ses efforts en vue de nouer des liens plus étroits avec les partenaires de l'Agence, en ce qui concerne notamment les systèmes d'observation de l'environnement à l'échelle de la planète et les futurs programmes d'exploration.

**4. Coopération avec les pays en développement**

PRENANT ACTE de la Résolution ESA/C/CXVI/Rés.1 (final), adoptée le 22 février 1995, et des lignes de conduite qui y sont exposées,

(a) SE FELICITE des mesures prises par le Directeur général pour sensibiliser les organisations et entités d'aide au développement, tant nationales qu'internationales, à l'intérêt que peuvent présenter la technologie et les applications spatiales pour les pays en développement;

(b) INVITE le Directeur général à poursuivre, dans le cadre des dispositions de la Résolution précitée, des activités visant à démontrer les capacités de la technologie spatiale européenne, notamment si ces capacités répondent aux besoins des pays en développement.

# Final Declaration of the Council Meeting at Ministerial Level

1. At the invitation of the French Government, the Council of the European Space Agency met at Ministerial Level in Toulouse on 18, 19 and 20 October 1995. It elected as Chairman, Mr Yvan Ylieff, the Belgian Minister for Science Policy.

2. The meeting was attended by the Ministers and high-level officials representing the Agency's fourteen Member States and Canada (Cooperating State). The Commission of the European Union, Eumetsat and Eutelsat attended as observers.

3. In his general presentation of the objectives to be achieved at the meeting, the Director General underlined the Agency's successes such as the Euromir missions, Ariane-4 launches and the Scientific Programme.

4. The Council welcomed the report made by the Long-term Space Policy Committee, under the Chairmanship of Mr P. Creola (CH), expressed its satisfaction with the perspectives for Europe's future space effort and asked the Committee to continue its reflections on long-term European space policy.

5. After hearing the Director General's overview and proposal on the Agency's Policy and Programmes, Ministers stressed that, despite the financial difficulties the Member States were facing, they had come to Toulouse in order to ensure that Council gave the essential programme commitments required to provide the Agency with a strong and stable framework, thus reinforcing the solidarity among Member States and Europe's leading position in worldwide space activities.

   Ministers emphasised that the achievement of this objective required full financial coverage of the programmes and an improvement in the efficient running of the Agency.

6. The Ministers recognised the excellent quality of the Agency's Scientific Programme, which has put Europe at the forefront of spacefaring nations.

   In this context, Ministers stressed their readiness to do their utmost to grant the Agency a level of resources sufficient to maintain the quality of the Scientific Programme, notwithstanding the financial difficulties facing the Member States.

7. Council took the following decisions:
   - adoption of the Level of Resources at a constant level for the period 1996 – 2000,
   - introduction of the ECU as the Agency's currency.

   Council set up a Working Group to review, within the applicable provisions of the Convention, the Agency's system for calculating contributions to the mandatory programme.

8. On industrial policy, the Ministers demonstrated solidarity with a view to settling industrial policy issues. They noted with satisfaction the efforts already made by certain Member States and encouraged complementary initiatives in order to achieve a satisfactory return for all Member States.

   Ministers underlined the need to improve the effectiveness of relations between the Agency and industry through enhanced procurement procedures. The Council decided to set up a Council Working Group with a remit to review the Agency's industrial policy. The Working Group's findings should be the basis for a proposal to be made by the Director General at a Council session at the end of 1996.

9. With regard to programmes, the Ministers decided in favour of Europe's participation in the development and exploitation of the International Space Station, thereby expressing the firm resolve of Europe to be a Partner in the most significant cooperative project in the field of science and technology undertaken so far.

# Déclaration finale de la session du Conseil au niveau ministériel

1. A l'invitation du gouvernement français, le Conseil de l'Agence spatiale européenne s'est réuni au niveau ministériel à Toulouse les 18, 19 et 20 octobre 1995. Il a élu à sa tête M. Yvan Ylieff, Ministre belge de la politique scientifique.

2. Les ministres et hauts fonctionnaires représentant les quatorze Etats membres de l'Agence ainsi que le Canada (Etat coopérant) ont participé à cette réunion. La Commission de l'Union européenne, Eumetsat et Eutelsat y ont assisté en qualité d'observateurs.

3. Dans sa présentation générale des objectifs assignés à cette conférence, le Directeur général a mis l'accent sur les succès de l'Agence, notamment les missions Euromir, les lancements Ariane-4 et le programme scientifique.

4. Le Conseil a accueilli favorablement le rapport présenté par le Comité de la politique spatiale dans le long terme, placé sous la présidence de M. P. Creola (CH), a marqué sa satisfaction au vu des perspectives du futur effort spatial de l'Europe et a invité le Comité à poursuivre ses réflexions sur la politique spatiale européenne dans le long terme.

5. Après avoir entendu la revue d'ensemble et la proposition du Directeur général sur la politique et les programmes de l'Agence, les ministres ont souligné que, malgré les difficultés financières auxquelles les Etats membres doivent faire face, ils étaient venus à Toulouse pour faire en sorte que le Conseil prenne des engagements de programmes essentiels pour donner à l'Agence un cadre solide et stable, renforçant ainsi la solidarité entre les Etats membres et la position en flèche de l'Europe dans les activités spatiales mondiales.

   Les ministres ont insisté sur le fait que pour atteindre cet objectif, il fallait que les programmes aient une couverture financière complète et que le fonctionnement de l'Agence soit amélioré.

6. Les ministres ont reconnu l'excellente qualité du programme scientifique de l'Agence qui a placé l'Europe à l'avant-garde des puissances spatiales.

   Dans ce contexte, les ministres ont souligné qu'ils étaient prêts à faire tout leur possible pour donner à l'Agence un niveau de ressources suffisant pour maintenir la qualité du programme scientifique, malgré les difficultés financières que connaissent les Etats membres.

7. Le Conseil a pris les décisions suivantes:
   — adoption du niveau de ressources à niveau constant pour la période 1996-2000,
   — adoption de l'ECU comme monnaie de l'Agence.

   Le Conseil a établi un groupe de travail chargé de revoir, dans les limites des dispositions pertinentes de la Convention, le système utilisé par l'Agence pour calculer les contributions au programme obligatoire.

8. En matière de politique industrielle, les ministres ont fait montre de solidarité pour résoudre les questions en suspens. Ils ont noté avec satisfaction les efforts déjà accomplis par certains Etats membres et ont encouragé le lancement d'initiatives complémentaires qui permettent de parvenir à un retour satisfaisant pour tous les Etats membres.

   Les ministres ont souligné qu'il était nécessaire de renforcer l'efficacité des relations entre l'Agence et l'industrie en améliorant les procédures d'approvisionnement. Le Conseil a décidé d'établir un groupe de travail ayant pour mandat de revoir la politique industrielle de l'Agence. Les conclusions de ce groupe de travail devraient servir de base à une proposition que le Directeur général devra soumettre à une session du Conseil fin 1996.

9. En ce qui concerne les programmes, les ministres se sont prononcés en faveur d'une participation de l'Europe au développement et à l'exploitation de la Station spatiale internationale, marquant ainsi la ferme résolution de l'Europe à être partenaire du projet en coopération le plus important entrepris à ce jour dans le domaine de la science et de la technologie.

At the same time, they instructed the European Partner's spokesman and the Director General to pursue their efforts in the negotiation of amendments to the IGA and the MOU between ESA and NASA in order to meet the European requests concerning offsetting, with Ariane-5/ATV flights and other services, the European share of common operations costs, which are to be contained within an agreed ceiling.

10. The Ministers stressed the importance they attach to European autonomous access to space by adopting the Ariane-5 complementary programmes (Ariane-5 Evolution, Ariane-5 Infrastructure, and Ariane-5 ARTA).

11. The Ministers furthermore endorsed the directions proposed by the Director General to prepare the future activities and programmes of the Agency. In particular, they stressed the importance of the decisions still to be taken on telecommunications and Earth observation.

12. The Ministers incorporated the above decisions and directions by adopting two Resolutions and subscribing five programme Declarations.

13. The Ministers underlined the very positive results achieved at the Council meeting and their immediate effect, which will give the Agency a solid basis for the execution of its programmes and activities.

14. To conclude, the Ministers thanked the French Government for its hospitality and the city of Toulouse for the excellent atmosphere it had helped to create.

Dans le même temps, ils ont chargé le porte-parole du Partenaire européen et le Directeur général de poursuivre avec détermination la négociation des amendements de l'IGA et du MOU entre l'ESA et la NASA afin qu'il soit fait droit aux demandes de l'Europe concernant la compensation, sous forme de vols Ariane-5/ATV et d'autres services, de la part européenne des coûts communs d'exploitation, lesquels devront être limités à un plafond arrêté en commun.

10. Les ministres ont souligné l'importance qu'ils attachent à l'accès autonome de l'Europe à l'espace en adoptant les programmes complémentaires Ariane-5 (Ariane-5 Evolution, Infrastructure Ariane-5 et ARTA Ariane-5).

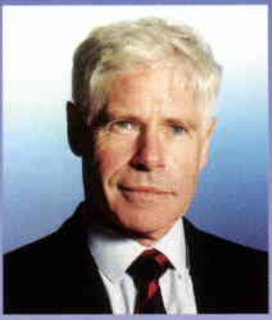
11. Les ministres ont en outre entériné les orientations proposées par le Directeur général pour préparer les activités et programmes futurs de l'Agence. Ils ont en particulier souligné l'importance des décisions qui restent à prendre en matière de télécommunications et d'observation de la Terre.

12. Les ministres ont donné corps aux décisions et orientations ci-dessus en adoptant deux Résolutions et en souscrivant cinq Déclarations de programme.

13. Les ministres ont souligné les résultats très positifs de la session du Conseil qui auront pour effet immédiat de donner à l'Agence une base solide pour la conduite de ses programmes et de ses activités.

14. En conclusion, les ministres ont remercié le Gouvernement français de son hospitalité et la ville de Toulouse pour la remarquable atmosphère qu'elle a contribué à créer.

# Three Launches, Six Spacecraft, Much New Science



From now until next spring should prove to be an exciting period for ESA's Scientific Programme: ESA is preparing to launch an unprecedented six scientific satellites on three missions in six months. Each mission will be ground-breaking in its own right: one mission will investigate the infrared sources deep in outer space, another will study the Sun and its characteristics, and the third will explore the magnetosphere around the planet Earth.

The Infrared Space Observatory, or ISO, will lead the trio into space. It will be launched on an Ariane-4 rocket early in the morning of 17 November (Central European Time) from ESA's launch site in Kourou, French Guiana. It will be followed a few days later by the Solar and Heliospheric Observatory, or SOHO, which will be launched by an Atlas IIAS rocket from Cape Canaveral, USA. Finally, in April 1996, four Cluster probes will be carried into space on the inaugural flight of Ariane-5.

Many scientists both in Europe and around the world have been patiently awaiting these missions: the state-of-the-art instrumentation onboard the satellites will gather information that will help to answer some of the long-standing scientific questions — What is 'dark matter'? How are stars 'born'? How do changes on the Sun, sunspots for example, affect the climate on Earth?

These missions also demonstrate the high technical standards of ESA and European space industry, which strived to develop what had not been built before: four spacecraft flying in a 'cluster' or tetrahedron, for example, or a spacecraft that must be kept cool, at absolute zero, at all times. The missions are also a tribute to successful international cooperation: two were developed in conjunction with other international space agencies, NASA and Japan's Institute of Space and Astronautical Sciences (ISAS) and all involve the participation of institutes around the world.

**Cool astronomy by infrared**

The infrared region of the wavelength spectrum is of great scientific interest. Many astronomical sources are surrounded by clouds of dust and gas that act as an interstellar 'fog', obscuring the astronomical objects and making it very difficult to observe them with visible light. Owing to its longer wavelength, infrared radiation can pierce through this fog and bring astronomers information about the conditions inside.

ISO will be the world's first true astronomical observatory in space operating at infrared wavelengths — and the only one for the next ten years. It will be used to observe all classes of astronomical objects, ranging from planets and comets in our own Solar System right out to the most distant galaxies.

**Making sense of the Sun**

The SOHO spacecraft will station itself 1.5 million kilometres from the Sun, on the Sun-ward side of the Earth, where the gravity of the Earth and the Sun are in balance. From that vantage point, it will study the processes that heat the outer atmosphere of the Sun to millions of degrees and propel the continuous stream of plasma known as the 'solar wind'. SOHO will also sample the solar wind as it blows towards the Earth, where it influences our planet's environment.

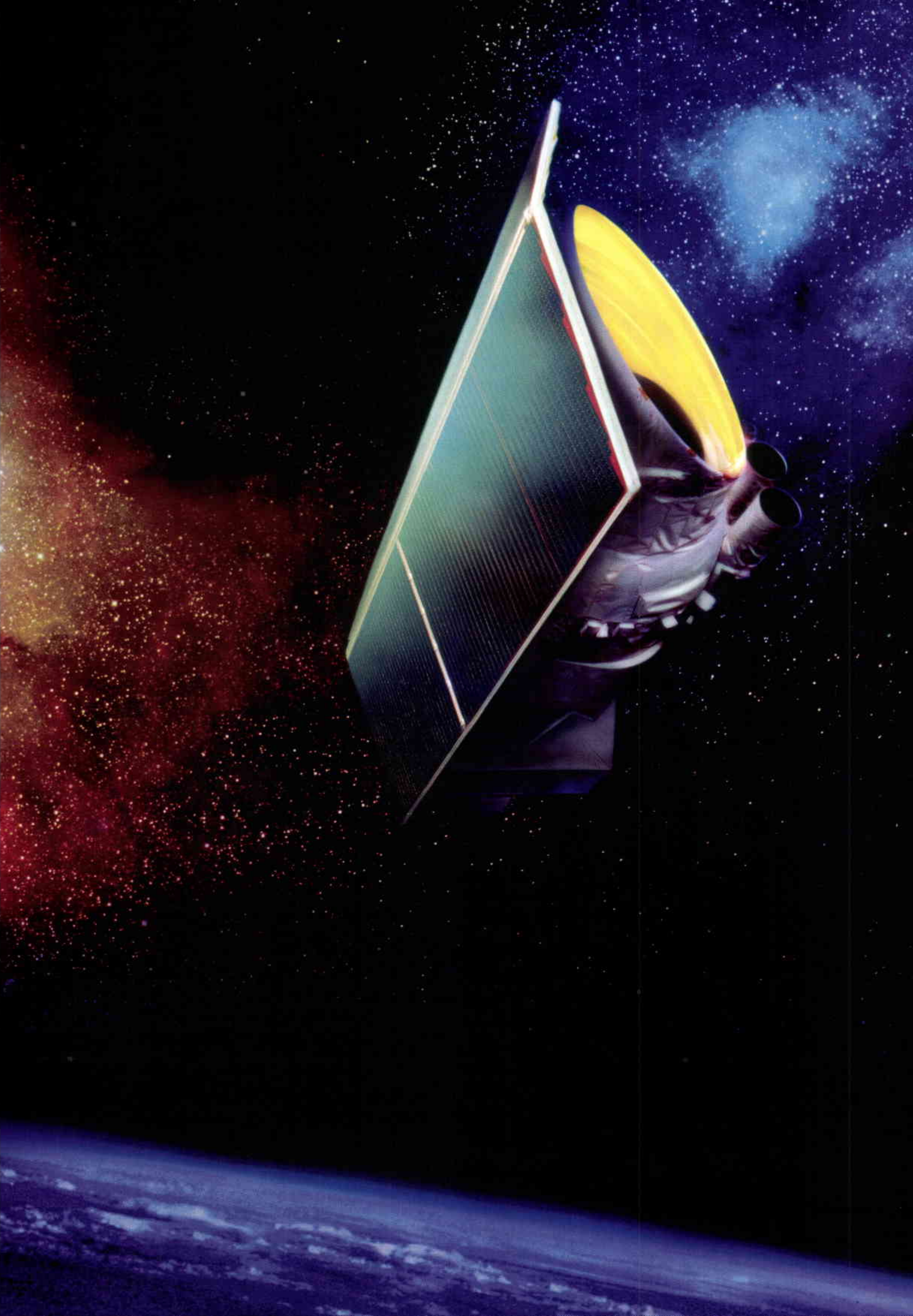
**The Earth's battle with the solar wind**

Earlier missions to explore the Earth's magnetosphere have shown how dramatic the interaction can be between near-Earth space and the solar wind. An incredible range of phenomena have been observed — the shorting out of satellite components in orbit, power surges in long transmission lines, and disturbances in short-wave radio broadcasting, to name a few.

The Cluster spacecraft will address, in unprecedented detail, the structure of electromagnetic fields and the distribution of particles in the solar wind and the Earth's magnetic field. To do so, Cluster will have four identical satellites flying in a kind of pyramid formation — another first — to investigate the phenomena in three dimensions.

Each of these exciting missions is described in detail in the rest of this special science issue of the Bulletin.

**R. Bonnet**
Director of ESA's Scientific Programmes



# The ISO Mission — A Scientific Overview

**M.F. Kessler, A. Heske, L. Metcalfe & A. Salama**
ISO Science Operations, Astrophysics Division, Villafranca, Spain

**The Infrared Space Observatory (ISO) satellite will be the world's first true astronomical observatory in space operating at infrared wavelengths. Astronomers will be able to choose specific targets in the sky and point ISO towards them for up to ten hours at a time to make observations with versatile instruments of unprecedented sensitivity. During its lifetime of 18 months, ISO will be used to observe all classes of astronomical objects ranging from planets and comets in our own solar system, right out to the most distant galaxies.**

## Why infrared observations?

In the years since observational astronomy finally escaped from its confinement to the narrow visible range of the electromagnetic spectrum accessible from the ground, it has become clear that a full understanding of the properties and physics of astronomical sources can only be obtained by studying them across the widest possible frequency range. A good example is a nova. The behaviour, at visible wavelengths, of a star suddenly brightening dramatically over a period of only hours or days and then fading slowly over hundreds of days has been known for centuries. However, it was only with the advent of X-ray, ultraviolet and infrared observations that the true nature of such a nova outburst, and the underlying physics, began to be understood.

The infrared region of the spectrum is of great scientific interest, not only because it is here that cool objects (10 – 1000 K) radiate the bulk of their energy, but also because of its rich variety of diagnostic atomic, ionic, molecular and solid-state spectral features. Measurements at these wavelengths permit determination of many physical parameters of astronomical sources, such as energy balance, temperatures, abundances, densities and velocities.

Infrared astronomy and the study of dust are inextricably linked. Dust particles, ranging in size from a few hundred Angstroms to tens of microns, are a very common phenomenon throughout the Universe. This dust absorbs visible and ultraviolet light and re-radiates it in the infrared. It is estimated that dust in the interstellar medium accounts for approximately one third of the total luminosity of our Galaxy.

Detailed photometric and spectroscopic study of this emission by ISO will give astronomers a much clearer understanding of the energy balance of the Galaxy and of the composition of the dust (large molecules, carbon grains, silicate grains, etc.) in different parts of it.

Many astronomical sources are surrounded by clouds of dust and gas. These clouds act as an interstellar 'fog', obscuring the astronomical objects and making it very difficult to observe them with visible light. Owing to its longer wavelength, infrared radiation can pierce these dusty regions and bring astronomers information about the conditions inside. As an example, the centre of our Galaxy is hidden from optical telescopes by thick veils of dust. However, a clear view can be obtained even at a relatively short infrared wavelength of 2 microns and the Galactic Centre can, therefore, be best studied at infrared wavelengths. Figure 1 shows how the Galactic Centre appeared to an earlier infrared survey satellite, IRAS.

## Why in space?

The scientific potential of infrared astronomy has been amply demonstrated by observations made from both ground-based telescopes and those on high-flying aircraft and balloons. However, Figure 2 shows the two main limitations to these observations. Firstly, the Earth's atmosphere is totally opaque at many wavelengths, absorbing all the incoming radiation and thus preventing the astronomer from viewing the celestial object. Work from ground-based telescopes is only possible through a number of narrow spectral 'windows'. Even at altitudes of 30 to 40 km, which are typical for balloon-borne telescopes, the atmosphere is not totally transparent.

Note: This article is an update of an article that originally appeared in ESA Bulletin No. 67 (August 1991).

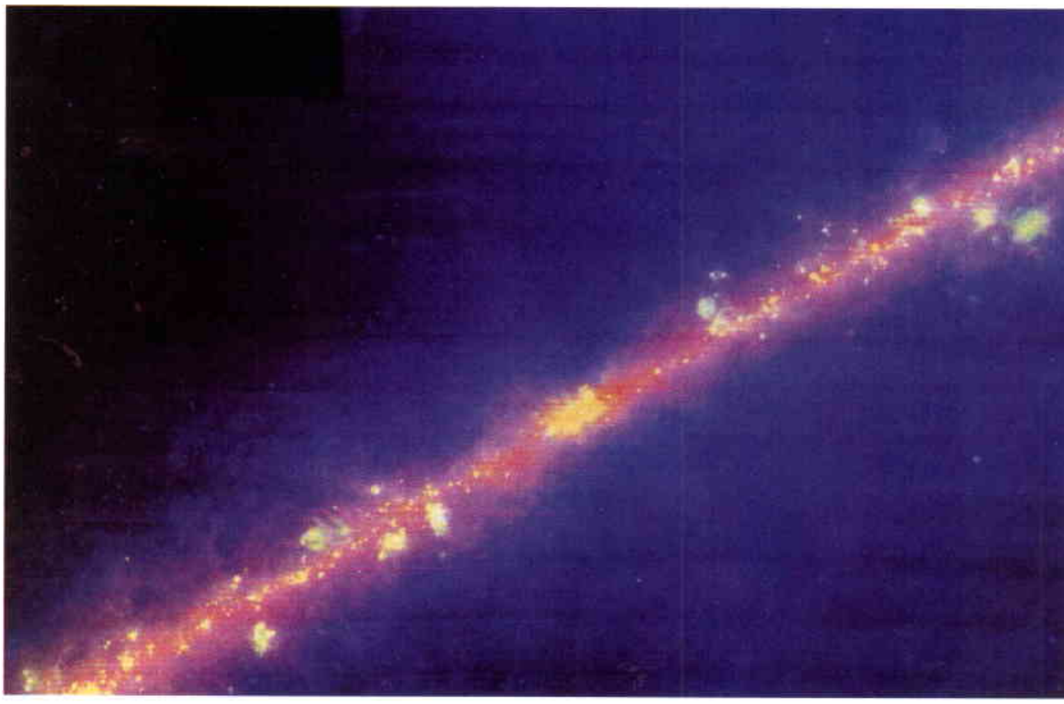


**Figure 1. IRAS view of the centre of the Milky Way. This is a composite image made from data taken at three wavelengths and presented in false colour. The yellow and green knots and blobs scattered along the band are giant clouds of interstellar gas and dust (called HII regions) heated by nearby stars. Some are warmed by newly-formed stars in the surrounding cloud, and some are heated by nearby massive, hot, blue stars that are tens of thousands of times brighter than our Sun. The red areas represent regions dominated by cold gas and dust. The large yellow bulge near the middle is the centre of our Galaxy. (Courtesy of NASA/JPL)**

The second problem is that the telescope and atmosphere are warm and emit infrared radiation themselves. Astronomical sources a million times fainter must be found against this undesired 'background' (really foreground) emission. This severely limits the sensitivity of ground-based observations.

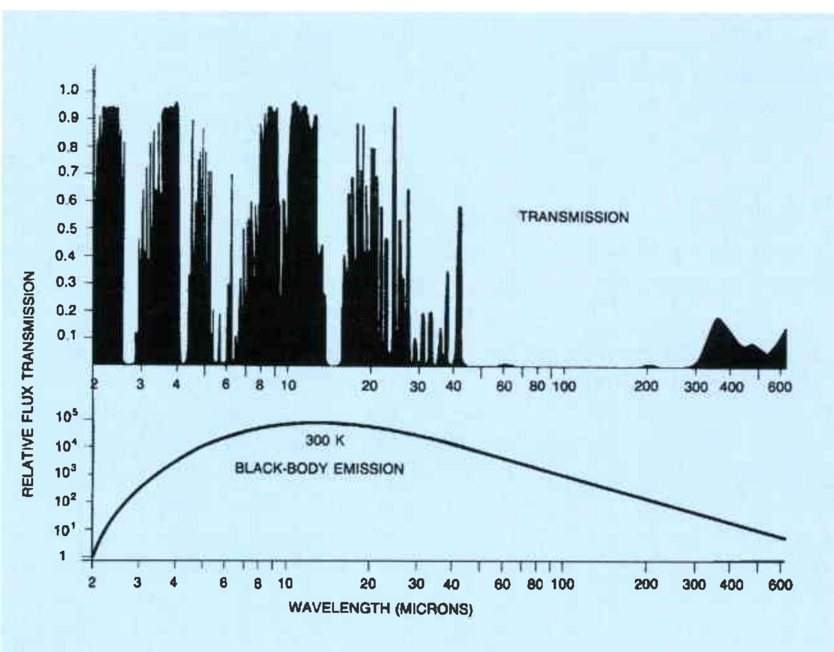



**Figure 2.**
**Upper panel:**
**Transmission of the terrestrial atmosphere as a function of wavelength. Note that, from the ground, observations are only possible through some 'windows', shown in black.**

**Lower panel:**
**Relative flux from a 300 K black body as a function of wavelength, showing that the thermal emission from the warm (approx. 300 K) telescope optics and atmosphere peaks around the 10-micron wavelength. This emission hampers observations and is at a maximum where the Earth's atmosphere is relatively transparent.**

Thus, for maximum sensitivity and wavelength coverage, it is necessary to cool the telescope and its instruments and to operate them in space. The first major step in this direction was taken with the highly successful Infrared Astronomical Satellite (IRAS), which surveyed nearly all the sky in four broad photometric infrared bands. Among the results of the IRAS mission (US/NL/UK) is a catalogue of over 250 000 sources. ISO will build on the results of IRAS by making detailed observations of selected sources. Compared to IRAS, ISO will have a longer operational lifetime, wider wavelength coverage, better angular resolution, more sophisticated instruments and, through a combination of detector improvements and longer integration times, a sensitivity gain of up to several orders of magnitude.

## ISO as an observatory

ISO is a true astronomical observatory. It has a highly versatile and sensitive set of scientific instruments, capable of undertaking a wide range of scientific tasks. Time on this observing facility is available to all European, Japanese and US astronomers. The overall ISO system includes not only the scientific instruments and the spacecraft in orbit, but also its control centre on the ground.

Four instruments make up the ISO scientific payload: an imaging photopolarimeter (ISOPHOT), a camera (ISOCAM) with polarimetric capabilities, a short-wavelength spectrometer (SWS), and a long-wavelength spectrometer (LWS). These instruments were built by international consortia of scientific institutes for delivery to ESA. The technical aspects of the instruments are discussed in 'The ISO Scientific Instruments — Technical Highlights' in this issue; their main features are summarised in Table 1, while an overview of their scientific capabilities is given in Figures 3 and 4. In summary, observers are provided with a range of photometric, polarimetric, spectroscopic and imaging capabilities across the entire ISO wavelength range. These unique instruments will reach out to new frontiers, probing fainter sources with higher spectral and spatial resolution than ever before at these wavelengths inaccessible from the ground.

In order to prevent the sensitivity of the scientific instruments from being degraded by their own thermal emission and that from the telescope, all parts of ISO 'seen' by the infrared instruments must be cooled to only a few degrees above absolute zero (−273°C). Thus, the ISO satellite is, essentially, a huge Thermos flask designed to provide the extremely low temperatures necessary. ISO consists of a cryostat containing, at launch, over 2000 litres of liquid helium, and a cryogenically cooled telescope with an aperture of 60 cm. The telescope can be pointed anywhere on the sky to an accuracy of a few seconds of arc for a period of up to 10 h. The in-orbit lifetime of the satellite is limited by evaporation of the liquid-helium cooling fluid, but will be at least 18 months. The spacecraft is described in more detail in another article in this issue, 'The ISO Spacecraft', and the cryogenic system was presented by Davidson et al in ESA Bulletin No. 57.

An Ariane-4 launcher will place ISO into a highly eccentric orbit with an apogee of 70 600 km, a perigee of 1000 km and a period

*Table 1. Main features of ISO's scientific instruments*

| Instrument (Principal Investigator) | Main function | Wavelength (μm) |
|---|---|---|
| ISOCAM (C. Cesarsky, CEN-Saclay, F) | Camera and polarimetry | 2.5 – 17 |
| ISOPHOT (D. Lemke, MPI für Astronomie Heidelberg, D) | Imaging photo-polarimeter | 2.5 – 240 |
| SWS (Th. de Graauw, Lab for Space Research, Groningen, NL) | Short-wavelength spectrometer | 2.4 – 45 |
| LWS (P. Clegg, Queen Mary & West Field College, London) | Long-wavelength spectrometer | 43 – 198 |

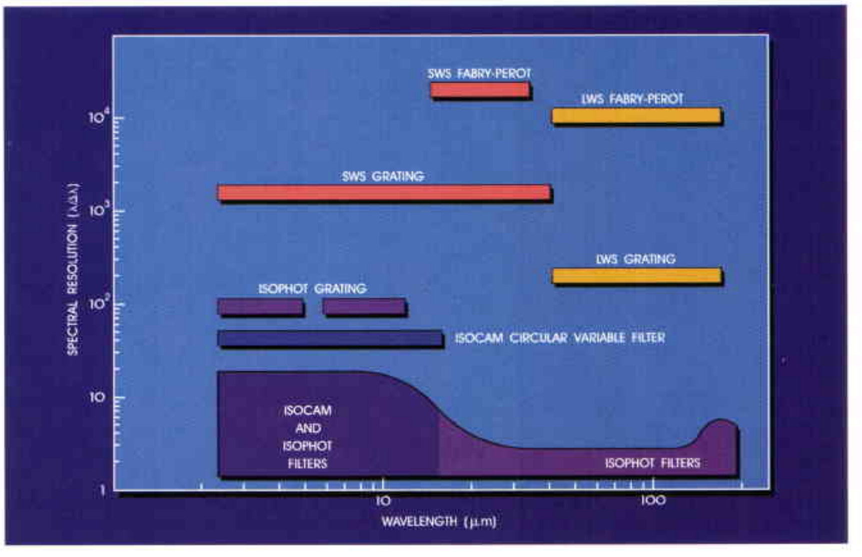



**Figure 3. Spectroscopic and photometric capabilities of the ISO scientific instruments.**

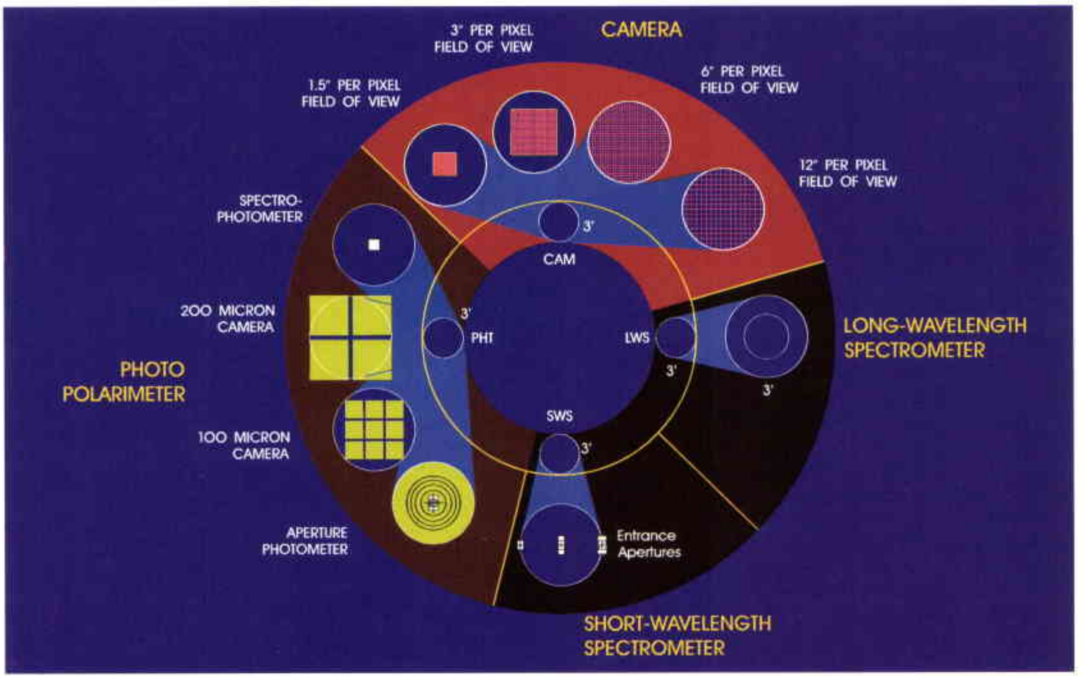



**Figure 4. Imaging capabilities of the ISO scientific instruments. Each of the four instruments receives a circular 3 arcmin field of view (drawn to scale in the central part of the figure). The outer ring shows, in expanded scale, more details of the detector fields of view as projected onto the sky.**

of 24 h. In this orbit, ISO will spend about 16 h per day outside the Earth's radiation belts. The infrared detectors in the scientific instruments are made from small pieces of silicon and germanium. If the energetic particles in the radiation belts (mainly electron and protons) hit these detectors, they release a large number of electrons, which prevents the ISO instruments from operating at full sensitivity.

The ISO operations will be carried out by a team of scientists and engineers located at ESA's satellite tracking station in Villafranca, Spain. However, to achieve continuous communications with ISO during all its scientifically-useful observing time, a second ground station is needed. It is at Goldstone, USA, and is provided for ISO as an international collaboration with NASA and ISAS. Since ISO's in-orbit lifetime is strictly limited by the evaporation of its liquid helium, the efficiency of the operations is even more important than usual.

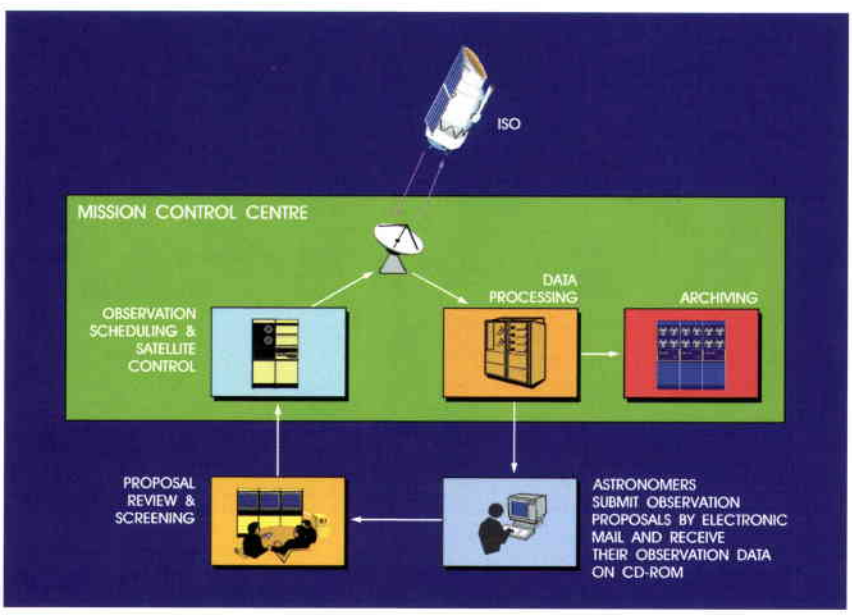



**Figure 5. An overview of the activities involved in planning, executing and analysing an ISO observation.**

ISO will be used to make observations of specific objects in the sky that have been selected by individual astronomers via a process of proposal submission and approval. (This process is described in more detail in 'Using ISO' in this issue.) The detailed observing schedule will be planned on an orbit-by-orbit basis a few days in advance. During scientific operations, ISO will always be in real-time contact with the ground Control Centre. However, real-time modifications to the scientific observing programme will be minimised in order to maximise overall efficiency.

The downlinked data will be quality-checked upon receipt. They will then be subjected to sophisticated pre-processing before being sent on CD-ROM to the commissioning astronomer's institute for scientific analysis and interpretation. The results will also be placed in an archive for later use by the astronomical community.

Figure 5 gives a pictorial representation of the ISO operations.

## Selected science highlights

ISO offers high sensitivity and sophisticated observing facilities for a difficult spectral region, and its scientific programme touches upon virtually every field of astronomy, ranging from solar system studies to cosmology. Some of the possible scientific highlights are summarised here.

### Solar system

*Planets and their satellites*

Like the Earth, most planets have atmospheres, composed mainly of molecules of various gases. ISO will be used to investigate the chemical composition and the physical nature of the atmospheres of the giant planets, together with Titan and Mars. A detailed inventory of the species present will be established, allowing for a better understanding of the planets' chemistry.

Titan is the only satellite in the solar system to possess a thick atmosphere. It is thought to be similar to the atmosphere originally possessed by the Earth. Studies of Titan's atmosphere are expected to lead to a better understanding of how the Earth's atmosphere evolved. Detailed studies of Mars's surface temperature and emissivity properties, their temporal variations and their relation with atmospheric dynamics (e.g. dust storms) will also be possible with ISO.

*Comets*

Comets are believed to retain, in the form of ice and trapped dust, the original content of the primordial solar nebula, from which our solar system condensed. Therefore, their study provides a unique probe into the history of our solar system and its relation to the interstellar medium. With ISO, it will be possible to detect comets at large heliocentric distances (5 AU), to study the onset of activity (emission of gas and dust) when a comet approaches the Sun, in particular to study the activity, evolution and composition of the coma. Cometary dust and nucleus have a low temperature and albedo, and are thus best detectable in the infrared. The spectral, spatial and sensitivity capabilities of ISO will allow a thorough comparison of the general interplanetary dust with the properties of dust close to its probable sources, comets (cometary trails) and asteroids (asteroidal bands) (Fig. 6).

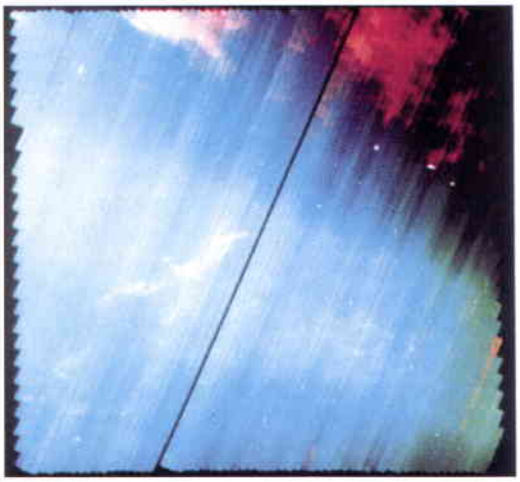


Figure 6. An IRAS image (wavelength 60 microns) of the ecliptic plane, showing the central asteroid dust band, consisting of asteroid collision debris (wide band cutting across centre of picture). (Courtesy of M. Sykes, Univ. of Arizona)

### Interstellar medium

The space between the stars is not empty (Fig. 7). It is a very active and violent space, containing objects such as gaseous nebulae, supernova remnants, dark molecular clouds, dust, and high-velocity winds from young stars. The material of the interstellar medium has an extremely wide variety of temperatures and densities.

*Cirrus*

IRAS revealed a new component of the interstellar medium — extended, fuzzy clouds which often have filamentary structures. These clouds range in angular size from tens of degrees down to a few arc minutes (the limiting spatial resolution of IRAS) and, because of their appearance, they have been named 'infrared cirrus'. ISO will explore the nature and composition of these puzzling clouds.

*Star-forming regions*

The processes by which stars form are not yet well understood. Much of the action is hidden by dust and more infrared observations are needed. Under the right conditions, some dense parts of molecular clouds can start to collapse upon themselves. Initially, these so-called 'protostars' radiate by virtue of the gravitational energy of the in-falling material and remain cold compared to the Sun. Eventually, their temperature rises sufficiently for nuclear reactions to start. When the 'burning' of hydrogen to form helium is underway, the protostar has become a star.

Stars are formed with a wide range of initial masses; a well-known example of a region of massive star formation is in the constellation Orion (Fig. 8). Among the many open questions on star formation to be addressed by ISO observations are: What triggers the collapse process? Does the accretion always involve a disk? What determines the relative numbers of large and small stars in the resulting cluster? What is the role of the high-velocity (several hundred km/s) mass outflows that are seen from young stars? and What are the properties of the embedded young stellar objects?

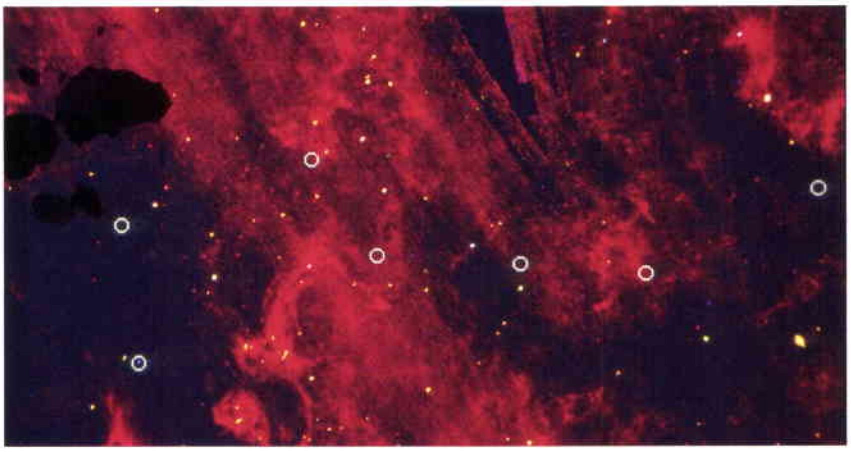


Figure 7. An infrared view from IRAS of the well-known Ursa Major (Great Bear or Plough constellation). The familiar stars, which can be seen with the naked eye, have been circled for recognition. Note the gas and dust between and around the stars radiating at infrared wavelengths. (Courtesy of NASA/JPL)

*Chemical factory*

The interstellar medium, containing atoms like hydrogen, oxygen and carbon and molecules like carbon monoxide or water vapour, acts as a chemical factory. Atoms and molecules can collide and they can absorb radiation from nearby stars. By these two processes, other larger molecules may be formed. The physical conditions in interstellar space under which the formation of molecules takes place are extremely difficult to simulate in the laboratory. The ISO spectrometers will reveal the chemical processes in molecular clouds or thick envelopes around young stars.

Figure 8. IRAS false-colour map of the sky around the constellation Orion. Well-known regions of star formation are apparent, such as the Orion Molecular Cloud (large feature dominating lower right of picture), located in and surrounding the sword of Orion. The large ring in the upper right of the image is a shell of gas swept up by the expanding gases around a young star. The bright region left of centre is the Rossette Nebula in Monceros. (Courtesy of NASA/JPL)

### Stars and stellar physics

Stars are dense gaseous spheres which, for most of their lives, burn or, strictly speaking, fuse hydrogen to form helium in their interior, like the Sun. As stars get older, other nuclear reactions start and, eventually, the star's life ends in a way that depends on its mass. Stars have been extensively observed at many wavelengths, but much important information

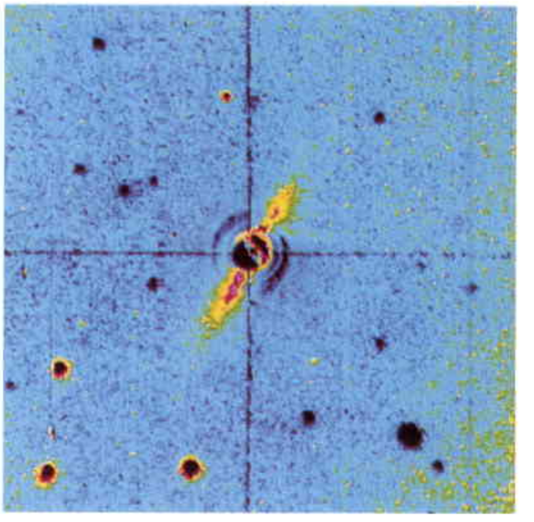


Figure 9. Dust around a star. The image of Beta Pictoris, with the star itself masked, shows the presence of a disk (seen edge-on) of dust similar to that from which the Earth and other planets supposedly formed, in the vicinity of the newborn Sun. The disk was discovered by IRAS. (Courtesy of B. Smith, Arizona, and R. Terrile, JPL)

on their structure and their evolution can only be extracted from infrared observations.

*Vega-type stars*

The nearby star Vega, or Alpha Lyrae, is the fifth brightest star at visible wavelengths and is still in its hydrogen-burning phase. It had been extensively observed at many wavelengths and its properties were thought to be well understood. It was, thus, a great surprise when infrared observations by IRAS showed brighter-than-expected emission at many wavelengths longer than 25 microns. These data indicate the presence of a disk of cool (around 85 K) material in orbit around the star. This disk may well represent an early stage in the condensation of a planetary system.

A number of other stars also have similar 'infrared excesses'. In one of these cases, Beta Pictoris, observations in the visible have actually revealed a thin disk of gas and dust around the star (Fig. 9).

Imaging, photometry and spectroscopy between 3 and 240 microns of these stars will also give us a deeper insight into the formation processes of our solar system. ISO will also be used to investigate how widespread the phenomenon of matter in orbit around these types of stars is.

*Stellar evolution*

Stars contain enough hydrogen for the fusion to last for a long time, but not forever. The rate at which a star consumes its fuel depends on its mass; the more massive a star, the quicker it evolves. After around five to ten billion years, stars like our Sun evolve to become so-called 'red giants', i.e. very large cool stars. More massive stars, such as those with around 40 times the mass of the Sun, race towards the red-giant phase in only a few million years. During this giant phase, the stars lose a significant amount of their mass via outflows and winds from their atmospheres. A circumstellar envelope is thus built up and sometimes these envelopes are so massive that the stars can no longer be seen in the optical. At the end of this phase, stars can evolve into planetary nebulae (Fig. 10), small hot stars, called white dwarfs, surrounded by their expelled material, which is ionised by the ultraviolet radiation from the stars themselves.

Figure 10. The Helix Nebula. An optical picture of a Planetary Nebula about 1 degree in diameter. (Courtesy of Hale Observatories)

With ISO, it will be possible to study those stars that are deeply embedded in their circumstellar envelopes. These are at the very end of the phase as a giant, and one open question is how the star evolves during the very short transition phase from a red giant to a planetary nebula and a white dwarf. During the phase of mass loss, the star returns its matter — now processed to include heavy elements — to the interstellar medium. This enriched interstellar medium is the source material for the next generation of stars, and its chemical composition is therefore of great interest. This will be deduced from measurements by the ISO spectrometers of the atomic and molecular spectra of planetary nebulae.

A massive star that fails to lose enough mass during its evolution is, then, doomed to end its life in a huge explosion, a supernova, such as that seen in our companion Galaxy, the Large Magellanic Cloud in 1987 (Fig. 11). This explosive event also returns the material from a dying star to the reservoir from which new stars may form. ISO will study the 'leftovers' (called 'supernova remnants') of such events, which are the source of very heavy elements, like iron.

## Extragalactic astronomy

Other galaxies, far distant from our own Milky Way Galaxy, have always attracted much observational attention. They have a variety of morphologies, many having spiral arms, interstellar matter and a core region or nucleus,

**Figure 11. Two colour photos showing the sudden appearance of the bright supernova 1987A (above the main body of the galaxy). The left-hand picture was taken before the supernova exploded and the right-hand one afterwards. (Courtesy of ESO)**

thus reflecting the structure of the Milky Way. Study of these galaxies gives a 'bird's eye view' of processes occurring in the Galaxy, but difficult for us to see. Many galaxies are so far away from the Earth, and their light takes so long to reach us, that observing them is like looking back in time, thereby allowing an examination of the evolution of the Universe. The infrared properties of galaxies are extremely diverse; for example, far-infrared luminosities have been found that span a range of seven orders of magnitude.

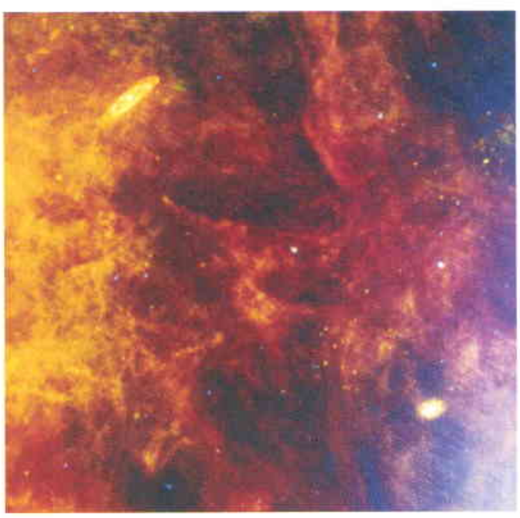


**Figure 12. A 'wide-angle' view of part of the infrared sky showing the galaxies M31 (Andromeda nebula, top left) and M33 (lower right) on a background of varying infrared emission (Courtesy of NASA/JPL)**

There are many questions in extragalactic astronomy needing answers: What are the mechanisms that trigger and maintain the formation of stars in galaxies? Why are some galaxies producing large numbers of new stars in hugely energetic bursts? What is the energy source at the centres of the most luminous galaxies making them orders of magnitude more energetic than their quieter neighbours? These questions are central to understanding the processes by which galaxies evolved from their original formation to give us the Universe we see today. In order to answer these questions, it is necessary to discover the physical conditions prevailing in the diverse and often exotic sources that populate the Universe.

Using ISO, astronomers will seek to understand the properties of star-forming regions in nearby, normal galaxies (Fig. 12) by studying, spectroscopically and photometrically, the properties and spatial distribution of the dust produced there, the kinds of organic compounds that form in the interstellar medium, the energetics of the gas, and the mass distribution of stars produced there.

The results of these studies will be compared with observations of the same entities in radically different environments such as the nuclei of active galaxies, completely obscured by dust absorption at visible wavelengths, or at the heart of colliding galaxy systems, powerfully luminous at far-infrared wavelengths. With these observations it may be determined whether some galaxies with extremely luminous nuclei ('active' galaxies) are, in fact, the final stage in the development of galaxy mergers. In this scenario, two galaxies collide, precipitating a huge burst of star formation throughout their interstellar material. This would give rise to a far-infrared, ultra-luminous galaxy which finally decays to become an active galaxy with a massive black hole at its nucleus: a Seyfert galaxy or a quasar.

Since ISO's instruments can see emission from cold (a few Kelvin to a few hundred Kelvin) dark matter (i.e. material not luminous in the visible), it may detect the elusive population of low-mass stars thought to condense out of the streams of gas that flow from intergalactic space onto many of the large elliptical galaxies at the centres of galaxy clusters. These 'cooling flows' of gas, inferred from X-ray observations, produce no corresponding population of stars detectable at visible wavelengths.

## Cosmology

ISO can address a number of questions of great cosmological significance. A particularly vital question concerns the total mass in the Universe. If this is greater than a certain amount, then gravitational force will eventually stop the expansion of the Universe and make it collapse into itself again. If the Universe is less massive than this 'closure' mass, it will go on expanding forever. The density of directly detected matter (self-luminous, light-reflecting, or light-obstructing) currently accounted for in the Universe is at most about 20% of the closure density. However, mass could be hidden in dark forms, invisible at optical wavelengths, but radiating in the infrared region.

One possibility is that some of this missing mass is hidden in the form of objects called brown dwarfs (Fig. 13). These are 'failed' stars, i.e. bodies formed out of the interstellar material, but which were not massive enough to support nuclear burning in their cores. It has been suggested that such objects might constitute the unseen halos of galaxies, postulated in order to account for the detailed orbits of material around galaxy nuclei. It is hoped that the camera (ISOCAM) and the photopolarimeter (ISOPHOT) will be able to unambiguously detect, and confirm the existence of, such objects for the first time.

It is planned that ISOCAM and ISOPHOT will both perform very long observations intended to detect sources out to high red-shifts. The relative proportions of blue galaxies, merging galaxies, active galaxies and more typical galaxies found in such deep-source counts is an indicator of the mechanisms through which galaxies originally formed. Did they form at about the same time in a single great burst, or have they formed by a process of hierarchical merging of galaxies, so that they grow, and mergers become less common, as time goes on?

**Figure 13. Artist's impression of a brown dwarf, silhouetted against the backdrop of the immensely rich star fields of the Milky Way. A brown dwarf is an object that started to collapse to become a star but was not massive enough to be able to initiate nuclear reactions. (Courtesy of NASA)**

### Chronology of the ISO Mission

| | |
|---|---|
| March 1979 | Proposal to ESA for ISO |
| 1979 | Assessment Study |
| 1980 | Pre-Phase-A Study |
| 1981 – 1982 | Phase-A Study |
| March 1983 | Selection of ISO for inclusion in ESA's Scientific Programme |
| June 1985 | Selection of scientific instruments |
| Dec. 1986 | Start of Phase-B (Definition) |
| March 1988 | Start of Phase-C/D (Main Development) |
| April 1994 | Release of 'Call for Observing Proposals' |
| November 1995 | Launch |

## Conclusion

During its lifetime, ISO will offer astronomers a unique opportunity to study the Universe at the relatively unexplored infrared wavelengths. ISO's legacy to the future will be the database of its observational results, which will be used by astronomers long after the in-orbit mission has been completed. The science of ISO will build not just upon the results of the IRAS mission, but also on those from ground-based optical, infrared, submillimetre and radio telescopes. Observations with ISO will have a significant impact on all areas of astronomy. However, the most exciting aspect of the mission is that it is a voyage into largely uncharted waters, and no-one knows what will really be discovered. Hopefully, nature has a few surprises in store for us once again!


## Acknowledgements

The scientific highlights described in this article are based, in large part, on the work of the Principal Investigators of the ISO instruments (Catherine Cesarsky for ISOCAM; Peter Clegg for LWS; Thijs de Graauw for SWS; and Dietrich Lemke for ISOPHOT) and their teams of astronomers, in defining their guaranteed-time observational programmes for the mission.

# The ISO Spacecraft

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**ESA's Infrared Space Observatory (ISO) consists of two modules: the Payload module, which includes the telescope and the scientific instruments, and the Service Module, which houses the instruments' electronics, the hydrazine propellant tank and all other classical spacecraft subsystems. To ensure that the telescope is kept near absolute zero and thus is the least disturbed by the effects of the infrared emissions from other elements of the system, the telescope is enclosed in a helium-cooled cryostat. The cryostat in turn is shaded by a Sun-shield to protect it from the heat of the direct Sun. The shield has a covering of solar cells that provide the electrical power needed for the mission.**

## Introduction

The ISO spacecraft, shown in Figure 1, was conceived as two largely independent modules: the Payload Module (PLM) and the Service Module (SVM). The PLM is essentially a large liquid-helium cryostat, which contains the telescope, with four scientific instruments mounted behind the primary mirror and cooled to a temperature near absolute zero. (The various scientific instruments are described in another article, 'The ISO Scientific Instruments', in this issue.) The SVM houses the warm electronics of the scientific instruments, the hydrazine propellant tank, and all the other classical spacecraft subsystems. The Sun shield, with its covering of solar cells, always faces the Sun to provide electrical power whilst at the same time protecting the PLM from direct insolation.

The ISO spacecraft will be placed in a 1000 km × 70 600 km elliptical orbit (24 h period) by an Ariane-4 launcher in November 1995. This particular orbit will ensure that most observations can be made during the 16 h per orbit when the satellite is travelling outside the Earth's radiation belts. The spacecraft will be tracked from a main ground station, at which the ISO ground segment will be housed, in Villafranca, Spain, and from a secondary ground station in Goldstone, USA.

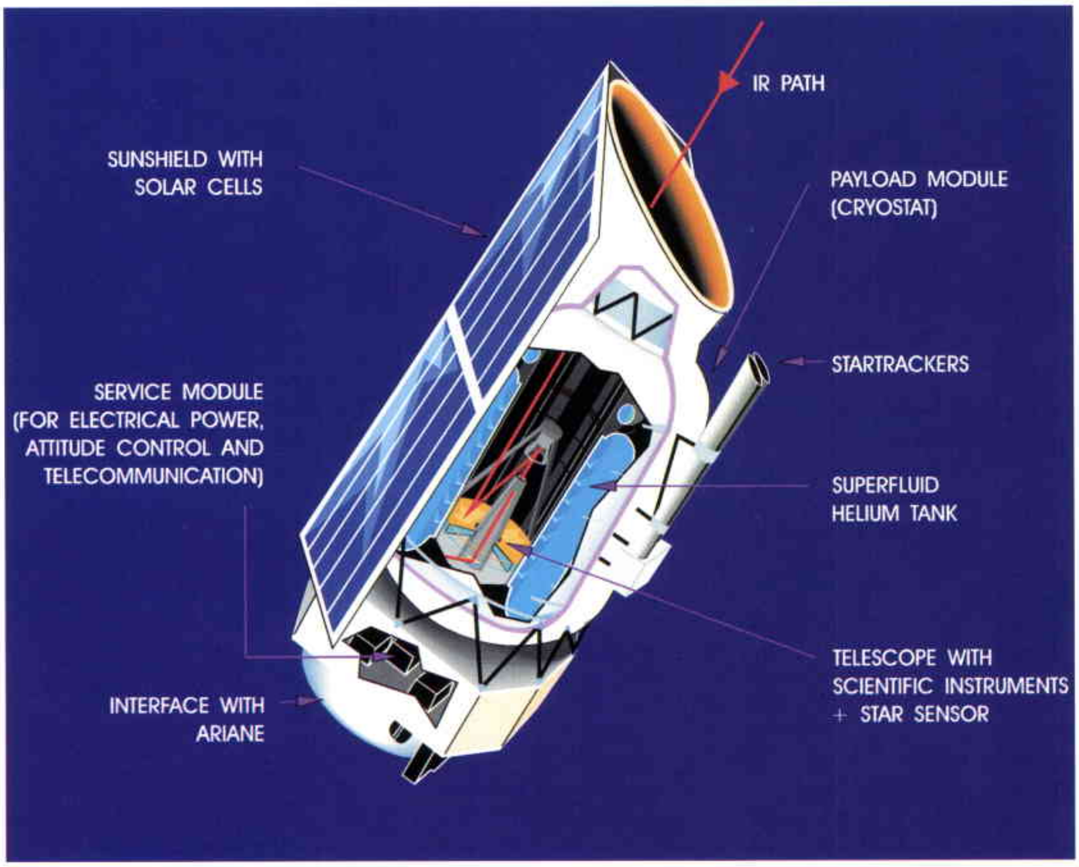



**Figure 1. Overall configuration of the Infrared Space Observatory (ISO)**

Note: This article is an update of an article that originally appeared in ESA Bulletin 67 (August 1991).

*Table 1. Temperature requirements*

| Component | Temperature, K | Temperature stability, deg |
|---|---|---|
| Detectors interface | $1.7<T<1.9$ | ±0.05 in 1000 s |
| Optical Support Structure/ Focal-Plane Unit interface | $2.4<T<3.4$ | ±0.10 in 1000 s |
| Primary mirror | <3.2 | ±0.10 in 1000 s |
| Secondary mirror | <4 | |
| Lower baffle | <5 | |
| Upper baffle | <7.5 | |

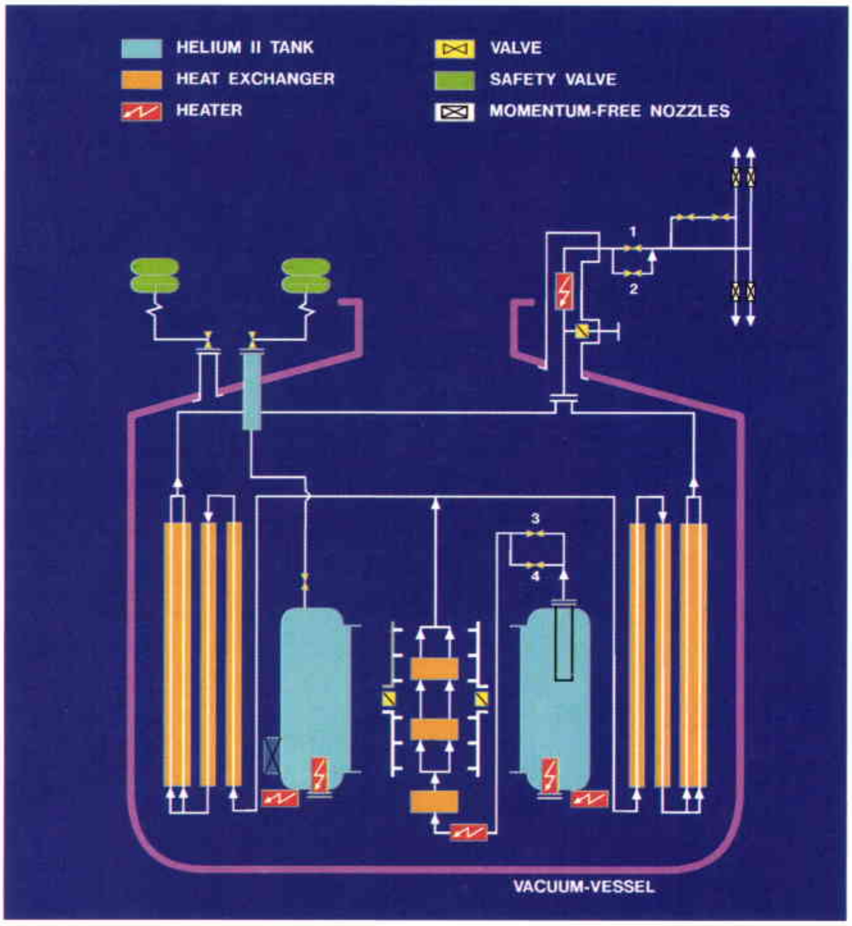
## Mission requirements and system description

### Observations of infrared celestial sources

The primary objective of ISO is to make observations of celestial objects at infrared wavelengths between 2.5 and 200 microns. It is therefore essential that all radiation-gathering equipment, the telescope and scientific detectors, be protected from the disturbing effects of infrared emissions from various elements of the system itself.

All objects emit radiation as a function of their absolute temperature $T$. The total energy emitted is proportional to $T^4$, and the wavelength at which the radiation's spectral density is at a maximum is inversely proportional to $T$. The first requisite for ISO, therefore, is to provide a telescope, including baffles, that is kept very cold. The focal-plane units (FPUs) of the scientific instruments and the infrared detectors inside those units must also be maintained at temperatures close to absolute zero. The detailed requirements are summarised in Table 1.

**Figure 2. Helium flow diagram for ISO when in orbit**




The solution adopted for ISO is to enclose the telescope in a cryostat. The main element is a toroidal tank containing 2286 litres of superfluid helium (HeII) at a temperature of 1.8 K. The tank is insulated from external heat inputs by three vapour-cooled radiation shields (VCS) equipped with multi-layer insulation (MLI). The tank, radiation shields and telescope are suspended from the cryo vacuum vessel (CVV) by low-conductivity straps. Boiling helium from the tank provides cooling to the optical support structure (OSS), the focal-plane units and telescope mirrors mounted on the OSS, the optical baffles and, when flowing through the radiation shields to the exhaust nozzles, intercepts incoming heat from the outside environment. Some of the scientific detectors are directly cooled by copper straps connected to the helium tank. A heat shield connected to the OSS encloses all four focal-plane units and provides a light-tight environment.

The pressure inside the HeII tank is 17 mbar, the equilibrium boiling point at a temperature of 1.8 K. This pressure is maintained in orbit by the impedance of the vent line, and on the ground prior to launch by continuous pumping of the tank exhaust. The gaseous-helium exit is located at the highest point of the tank, allowing separation by gravity of the liquid and gas phases during ground operations. Once in orbit, one of the remarkable properties of superfluid helium is exploited, the so-called 'thermodynamic fountain effect', by which a simple porous plug functions as a phase separator, keeping the liquid phase in the tank while allowing the gaseous helium to flow through the vent line.

A flow diagram for the ISO cryostat is shown in Figure 2.

To protect the cryostat from external heat inputs and in particular from direct solar illumination, a Sun shield shades the cryo vacuum vessel. This shield is composed of two flat plates (Fig. 1), the outer faces of which carry the solar cells that provide the electrical power needed for the mission.

During ground operations, the vacuum in the cryo vacuum vessel is maintained by a cryo cover, which is also insulated with radiation shields and multi-layer insulation. It is held in place by a clamp band, which will be released in orbit to jettison the cover after satellite outgassing, approximately 15 days after lift-off, at which point the scientific observation programme will commence.

The cryostat is designed for a minimum operational lifetime of 18 months (calculated nominal lifetime of 20 months).

### Optical requirements

Two main sets of optical requirements are imposed on the ISO spacecraft. Firstly, there are the light-gathering requirements, which can be summarised as follows:

| | |
|---|---|
| Entrance-pupil diameter: | 600 mm |
| Focal length: | 9000 mm |
| Unvignetted field of view: | 20 arcmin |
| Instrument unvignetted field of view: | 3 arcmin |
| Wavelength range: | 2.5 – 200 microns |
| Image quality: | diffraction limit at 5 microns |

These requirements are met with a Ritchey-Chrétien Cassegrain telescope configuration, as this is the best solution for an astronomical telescope that must cover a wide spectral range in combination with a limited field of view. This configuration is free from either coma or spherical aberration.

The ISO telescope has a primary mirror with an overall diameter of 640 mm (Fig. 3), a secondary mirror with a diameter of 87.6 mm, and a four-faced pyramidal mirror that distributes the light collected to the four focal-plane units. The pyramidal mirror has a central hole that allows some of the light to impinge on a quadrant star sensor (QSS). This will allow measurement of the alignment offset between the telescope and the spacecraft's attitude-control sensors.

The lightweight mirrors are made of fused silica and are gold-coated to give them good reflection characteristics in the infrared. The primary mirror is circumferentially mounted onto the optical support structure via three fixation devices, each consisting of an invar pad fixed to the mirror and crossing blades that provide the required degrees of freedom. The secondary mirror is mounted on a tripod. Both mirrors are cooled by copper straps connecting their rear faces to the helium-cooled optical support structure.

The second set of requirements relates to the stringent control of stray light emanating from bright infrared sources outside the telescope's field of view, for which the following viewing constraints have been defined:

- The direction to the Sun must be kept in the plane of symmetry of the Sun shield, and the solar aspect angle must be between 60° and 120° from the telescope axis.
- The directions of the Earth, Moon and Jupiter must be outside cones of 77°, 24° and 5° half angle from the telescope axis, respectively.

**Figure 3. The primary mirror of the ISO telescope**

With these viewing constraints, the total stray light falling on the instruments must be less than 10% of the diffuse zodiacal background. This requirement is fulfilled by means of the main baffle with sharp-edged vanes surrounding the telescope, Cassegrain baffles around the secondary mirror and the central hole of the primary, and a gold-coated truncated-cone Sun shade that reflects direct illumination from the Earth back to space (Fig. 4).


**Figure 4. The ISO Sun shade**

Moreover, with the temperature distribution described in the previous section, the infrared self-emission of all optical elements gives a noise background that is also less than 10% of the zodiacal background, at wavelengths from 5 to 200 microns.

### Pointing requirements

ISO will be operated in a similar manner to a ground-based observatory, and therefore the spacecraft has to be able to manoeuvre smoothly from one celestial source to the next, and then maintain accurate pointing on that target. The spacecraft must also be capable of pointing at any region of the sky that satisfies the stray-light constraints described above. The slew speed between sights is set at 7°/min in order to optimise observation time, and the duration of each observation can range from a few seconds to up to 10 h, depending on the type of source.

During a scientific measurement, the following telescope optical-axis pointing accuracy is required:

Absolute pointing error: 11.7 arcsec
Absolute pointing drift: 2.8 arcsec/h
Relative pointing error: 2.8 arcsec

These pointing requirements must be satisfied by the spacecraft's Attitude and Orbit Control Subsystem (AOCS), in combination with careful spacecraft structural design, to avoid thermo-elastic deformation between the telescope's optical axis and the attitude sensors. Three operational pointing modes have been defined:

- Fine-pointing mode on a single point source
- Raster pointing mode, where the telescope axis is slewed through a rectangular pattern of pointings (up to 32 × 32 pointings)
- Calibration mode, in which any misalignment between the telescope and the spacecraft's attitude sensors is measured.

For the high-accuracy pointing modes, the attitude errors are measured with gyroscopes, a star tracker and fine Sun sensors. In the calibration mode (activated nominally once per orbit), the quadrant star sensor replaces the star tracker. The performances of the various sensors are summarised in Table 2.

A state-reconstructor in the AOCS computer produces minimum-variance estimates for the attitude, angular velocity and disturbance acceleration. This state-reconstructor also serves as a sensor-data smoothing filter.

The control torques for high-performance slews and pointing modes are provided by a reaction-control wheel system, giving a maximum torque of 0.2 Nm, with a total of 126 torque levels, and a maximum angular-momentum storage capability of some 18 Nms. A so-called 'dual control law' is used together with a velocity controller that limits angular velocities to 8 deg/min. The 'dual control law' consists of a nonlinear time-optimal subcontroller and a linear state feedback subcontroller. For large errors during slewing, the time-optimal control prevails, whereas for fine pointing, the linear law predominates.

A schematic of the AOCS is shown in Figure 5. The modes of operation include, besides the pointing modes, other functions related to safety, satellite autonomy, and health checking of the subsystem elements, some of which are addressed below.

An important factor in achieving the requisite pointing accuracy for the ISO spacecraft is the limiting of the drift between the optical axis of the telescope and that of the star tracker. Such drift can be induced by transient thermo-elastic deformation of structural elements linking the two optical axes. Consequently, the star-tracker support structure has been mounted on the cryostat's outer wall, rather than on the Service Module. This alone does not prevent local deformation due to temperature gradients in the cryo vacuum vessel from degrading pointing performance. It is also necessary to maintain a stable and uniform temperature distribution in these two structures.

This temperature stability is achieved by covering the cryo vacuum vessel with multi-layer insulation, even at the expense of a penalty in the lifetime of the satellite. In addition, the star-tracker sensors (two for redundancy) are enclosed within a thermal housing, with heaters, which should provide a constant sensor temperature and, even more importantly, maintain a constant temperature gradient between the mounting feet of the operational star tracker (better than 0.1°C over one orbit, except for 2 h around perigee). The specially stiffened fixing of the housing to the cryo vacuum vessel ensures that the thermal conductance between the two is less than 3 mW/°C.

*Table 2. Performance figures for the various ISO sensors*

| | |
|---|---|
| **Star tracker** | |
| Field of view: | 4 × 3° |
| Sensitivity: | Visual magnitude from +2 to +8 |
| Bias error: | 2 arcsec (0.5 arcsec in centre of field of view) |
| Tracking speed: | 5 arcsec/s |
| **Gyroscope** | |
| Random drift: | 3.6 arcsec/h |
| Gyro noise: | 0.2 arcsec at 2 Hz |
| Maximum rate: | 1 deg/s |
| **Fine Sun sensor** | |
| Field of view per slit: | 62 x 1° |
| Accuracy: | 3 arcmin (1 arcmin in centre of field of view) |
| Noise equivalent angle: | 2 arcsec |

### Autonomy safeguards

A further top-level requirement stems from the type of orbit that the ISO spacecraft will be in. The highly elliptical 1000 km × 70 600 km orbit makes spacecraft tracking and control impossible during perigee passage.

It is also imperative that the ISO spacecraft should be able to survive a possible failure of

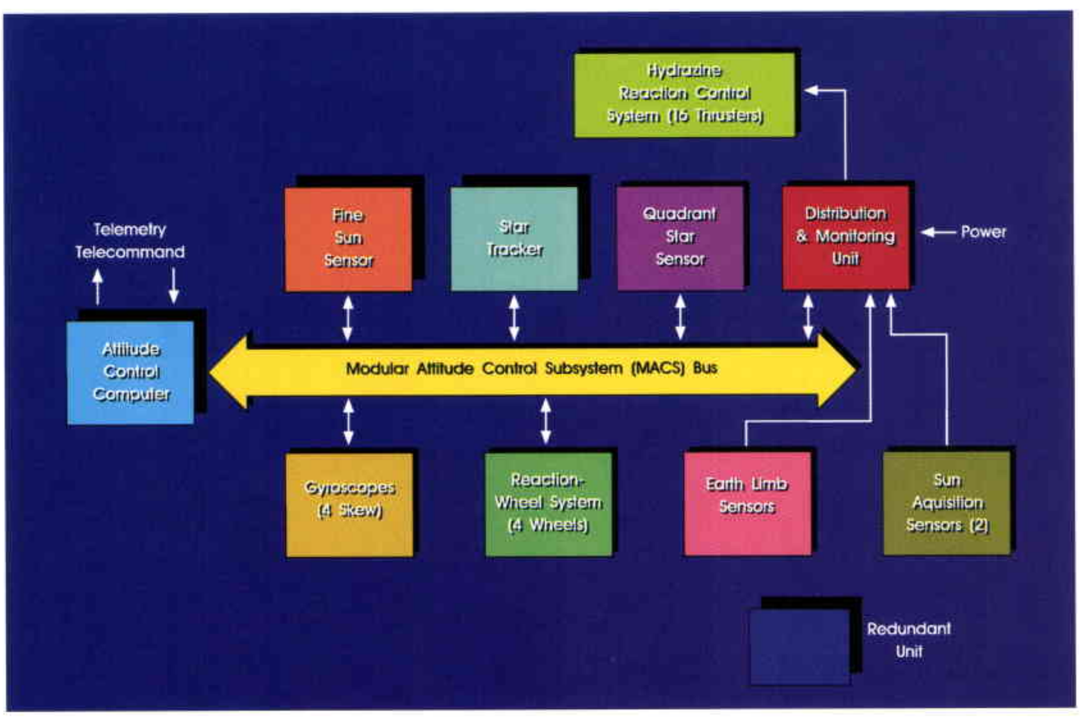



**Figure 5. Schematic of ISO's Attitude and Orbit Control Subsystem (AOCS)**

the ground stations. The system must therefore ensure that the satellite is safe and that its cryogenic helium is not wasted during any such event. Moreover, even small heat inputs to the optical elements during perigee passages could disturb the telescope's thermal equilibrium.

To meet these mission safety requirements, the launch window selected ensures that there is always a region of the sky to which the spacecraft can point without violating the stray-light constraints (the Sun and the Earth; the Moon and Jupiter do not affect the thermal equilibrium). Autonomous functions onboard the satellite would prevent violation of the constraints for at least three orbits in the event that ground control is lost.

Several souces could trigger these autonomous functions:

- Ground command, if the Control Centre is aware of an imminent station shutdown
- Detection by the AOCS of a violation of any of the pointing constraints
- Detection by the onboard data-handling system of a longer than normal break in ground transmission to the satellite (period programmable by the Control Centre).

Two main functions are active during the period of autonomy:

- Firstly, the cryostat must be protected against catastrophic heat inputs. The OBDH system will therefore switch-off all electrical units that could dissipate power inside the cryostat, i.e. the four scientific instruments and the cryo electronics unit (used to measure temperatures, pressures and amount of helium in the tank). The AOCS will initiate the first level of attitude safeguard, called the Programmable Pointing Mode (PPM), in which the spacecraft will follow a pre-programmed path on the sky that avoids violation of Sun and Earth constraints. The PPM ensures that the spacecraft's attitude is maintained with sufficient accuracy for observations to be resumed without need for further calibration.
- The second function safeguards the thermal environment of units outside the cryostat. The OBDH will scan the temperatures on the spacecraft and switch on and off the relevant heaters, located on or near critical elements such as the hydrazine tank and pipework, the reaction wheels and the fine Sun sensor.

### Electromagnetic compatibility

The very weak output signals from the scientific detectors have to be protected from electronic noise, whether conducted or radiated, originating from other elements of the satellite. A stringent spacecraft design requirement, verified by testing at unit, subsystem and satellite levels, ensures full electromagnetic compatibility (EMC) between the onboard instruments and other subsystems.

An important element in this clean EMC design is the spacecraft's power subsystem. It is based on a sequential switching shunt regulator, which provides very good efficiency and reliability as well as a low output impedance and constant bus ripple under all load conditions.

A further requirement is that the spacecraft's external surfaces must not become electrically charged and no electrostatic discharges should take place. Special care has therefore

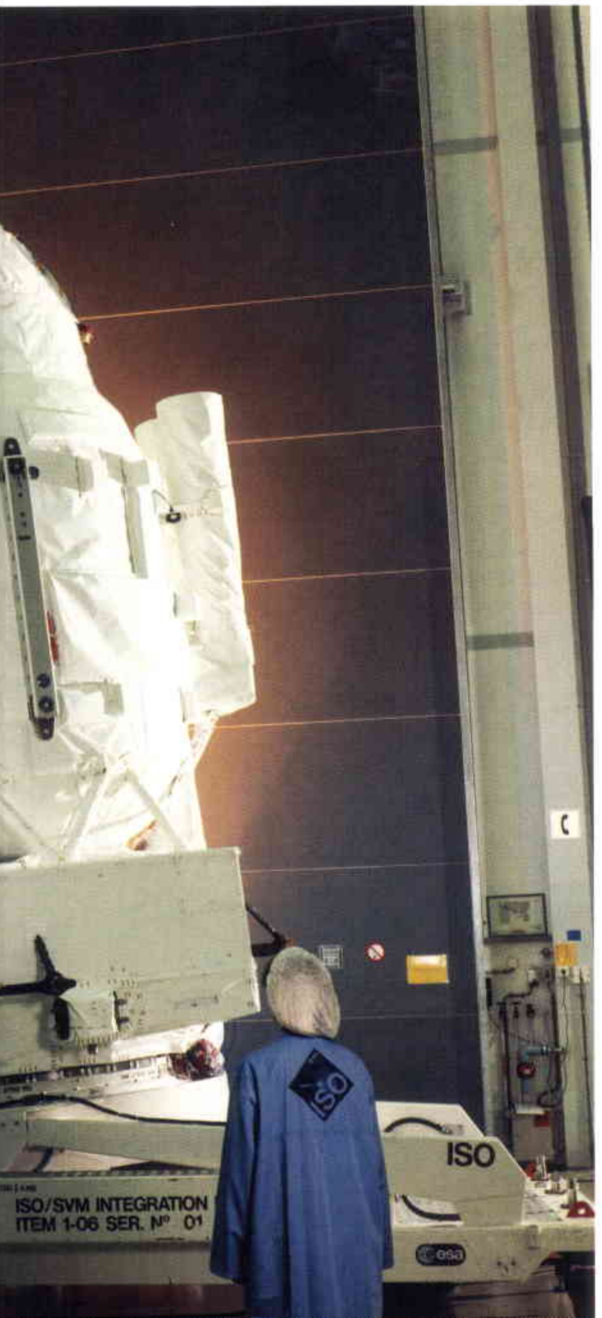

**Figure 6. ISO Payload Module undergoing testing at DASA, Ottobrun**

been taken in the design of the thermal-control hardware, which could be susceptible to charging, by making the outside surfaces conductive and grounding all elements to the structure.

Another developmental challenge lay in designing the optical coatings for the baffling system, which have to preclude any electrostatic charging close to the focal-plane units and provide a high absorptivity in the far-infrared. A special conductive black paint has been produced for this purpose.

### Data collection and transmission

ISO is a real-time mission. The operating principle involves having a single scientific instrument, selected as a function of the type of observation in hand, active at any given moment. An exception to this philosophy is the ISOCAM instrument, which could be active in parallel at low bit rate to provide images of the celestial source under study.




For this reason, four different data formats — one per instrument — can be selected. Each of these formats also includes all of the satellite housekeeping information, the largest part of which is devoted to the AOCS parameters needed for accurate spacecraft attitude reconstitution.

The nominal data rate is 32 768 bits/s, 23 424 bits of which are allocated to the prime instrument. Communications with the ground are via a transponder working at S-band.

## Other special features of ISO

### Heat balance of the Payload Module

As noted above, heat inputs to the helium tank have been minimised by enclosing it with vapour-cooled shields that intercept ambient heat before it can reach the cryogenics. Another important source of heat is the Service Module, the average temperature of which will be 20°C when the Payload Module's outer wall is at −150°C.

To avoid such a temperature gradient causing a net conductive heat transfer to the vessel, the interface between the two Modules consists of 16 tubular glass-fibre struts with very low thermal conductivity. They are filled with Ecofoam resin to prevent radiative heat transfer from taking place inside the tubes. The development programme for these struts has included extensive mechanical and thermal validation testing.

### Direct liquid-content measurement

An important factor for the planning of ISO's scientific operations is accurate knowledge of the amount of superfluid helium (HeII) remaining in the tank. The ability to make this measurement under microgravity conditions is a novel development for ISO, which relies on the near-infinite thermal conductivity of the superfluid helium. A calibrated heat pulse is introduced into the tank, which increases the temperature of the helium by an amount directly proportional to the mass remaining.

### Launch operations

An important aspect of the Payload Module is the cryogenic operations required prior to launch. The superfluid-helium tank will be topped off when the satellite is already mounted on the launcher, by removing the Ariane fairing (a non-standard operation). The tank will then be closed to minimise helium loss and to avoid having to pump. To maintain the insulation performance after this operation, a second reservoir containing 60 litres of normal liquid helium (HeI) will be used to cool the radiation shields. This HeI tank, which can be accessed through windows in the Ariane fairing, will be completely depleted prior to lift-off.

During the launcher's flight, commands issued by Ariane's electronics will operate a set of cryogenic valves that will open the helium vent line to space, and also the main helium tank and its porous-plug phase separator. Initially, the vented helium mass flow rate will be about 20 mg/s, rising to a peak of about 27 mg/s and then falling until, after about 20 days in orbit, it will be about 5 mg/s, the in-orbit equilibrium point.

To cope with this range of flow rates, the system is equipped with two sets of nozzles. Initially, both will be open to accommodate the high mass flow rate: as the rate falls and the temperatures decrease, the larger nozzles will be valved off, leaving only the smaller set open.

**Development plan**

The development plan for ISO was based on two independent development and integration activities for the PLM and the SVM. A system integration phase followed, during which the two modules were mated and the system tests (mechanical, acoustic, electromagnetic compatibility, functional and thermal tests) were carried out.

The development of the PLM was a challenging task, involving more laboratory experimental effort than a classical qualification procedure, and requiring inventive solutions to unforeseen problems. The operation of the cryostat was demonstrated on a qualification model, first at room temperature and later in a vacuum chamber that simulated the in-orbit environment. The tests revealed that some elements of the external vent line had too great a pressure drop. Also, the filling port, together with the helium subsystem, indicated that there was a possibility of thermo-acoustic oscillations due to unwanted heat transport. The mechanical tests of the model showed that the main helium tank was not rigid enough. (Later, a non-negligible interaction between the compressible liquid helium and the structure was also found.)

The telescope underwent its own qualification programme, and a special facility was developed at the Centre Spatial de Liège in Belgium to test it optically at cryogenic temperatures. The tests demonstrated the correct behaviour of the optics in terms of both image quality and alignment of the mirrors with respect to the scientific instrument focal plane units. The same facility was used to test the flight model of the telescope, using tests similar to those for the qualification model.

After rectification of the problems encountered during the qualification programme, and a re-development of the cryogenic helium valves to improve the leak characteristics, the PLM flight model was built. After completing extensive testing, it was delivered in June 1995 for system integration.

The SVM was first qualified thermally and mechanically on a structure/thermal model. In parallel, the spacecraft's electrical subsystem was developed and qualified at unit/subsystem level. The more challenging unit was the star tracker, with its stringent requirements. However, it represents today the state of the art for that type of sensor. Also, the gyroscopic units used by the AOCS were given special attention, and problems encountered on other satellite programmes were resolved. The final integration of the SVM flight model was finished at the end of 1993.

The system-level integration and test phase started upon the arrival of the PLM at ESTEC (Noordwijk, The Netherlands). It was mated with the SVM. The system was functional-tested successfully and the electromagnetic compatibility was established. Afterward, the satellite underwent a series of mechanical/dynamic tests at proto-flight level to verify its behaviour and compatibility with the launcher, the Ariane 44P.

The final environmental tests were the thermal balance/thermal vacuum tests at ESTEC's Large Space Simulator (LSS). These tests confirmed the correct functioning of the cryostat, in particular the transient phase after launch, and the lifetime of ISO, and the adequacy of the SVM thermal control. The final settings of the active thermal control of the star tracker were established based on the data gathered during these tests.

The final activities prior to shipment were dedicated to proving the compatibility with the control centre in Villafranca and to developing the operational procedures. The satellite was then shipped to the launch site (CSG) in Kourou, French Guyana, in June 1995.

The ISO satellite was functionally tested upon arrival at CSG and, at the end of July, was declared ready for flight. Final preparations — refilling the Helium tank and filling the propulsion tank with hydrazine — will now follow as the countdown for the launch in November 1995 nears.

# The ISO Scientific Instruments — Technical Highlights

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**The payload of ESA's Infrared Space Observatory (ISO) consists of four scientific instruments: a camera (ISOCAM), an imaging photo-polarimeter (ISOPHOT), a long-wavelength spectrometer (LWS), and a short-wavelength spectrometer (SWS). Each of these instruments was built by an international consortium of scientific institutes using national funding. ESA was responsible for their subsequent integration into the ISO spacecraft and will carry out the in-orbit operations.**

## Introduction

ESA's Infrared Space Observatory (ISO) is an astronomical satellite that will provide astronomers with an unique facility of unprecedented sensitivity for detailed exploration of the Universe. Operating at wavelengths from 2.5 to 200 microns, it will be able to study objects in the solar system right out to the most distant extra-galactic sources.

The ISO satellite consists essentially of a large cryostat, the payload module, containing about 2300 litres of superfluid helium to maintain the Ritchey-Chrétien telescope, the scientific instruments, and the optical baffles at temperatures between 2 K and 8 K.

The telescope has a 60-cm diameter primary mirror, and is diffraction-limited at a wavelength of 5 microns. A pointing accuracy of a few arcseconds is provided by a three-axis stabilisation system consisting of reaction wheels, gyros and optical sensors.

The cold focal-plane units (FPUs) of the scientific instruments are mounted behind the telescope's primary mirror. They are connected to 'warm' instrument electronics boxes on the spacecraft platform. The main characteristics of the four instruments are summarised in Table 1.

## Infrared technology

### Detectors

The ISO instruments use photo-conductors made from indium-antimonide (InSb), silicon (Si) and germanium (Ge). The last two are doped with various materials to achieve particular sensitivities in different wavelength ranges of interest. To extend the long-wavelength coverage of the gallium-doped germanium detector, the detector crystal is 'stressed' by applying mechanical pressure using a clamp. Infrared radiation falling on the detector produces a proportional photo-electric current, which is integrated as the output signal.

For correct operation, the detectors have to be kept at well-defined stable temperatures (ranging from 1.8 to 10 K for different materials). The detectors for the longer wavelengths (Ge) require the lowest operating temperatures.

Detectors are configured either as single elements (up to 1 × 1 × 1 mm in size), linear arrays (max. 64 pixels), or two-dimensional arrays (max. 32 × 32 pixels), and are directly connected to the pre-amplifiers and multiplexers within the FPUs.

### Optical elements

Mirrors are needed in the FPUs to fold the optical paths (flat mirrors) and for focussing purposes (curved mirrors). Aluminium substrates are diamond-machined and the surfaces coated with gold. Lenses made from silicon, germanium and zinc-selenide (ZnSe) are used for focussing and changing the field of view (FOV) at shorter wavelengths (up to 15 microns).

Filters are used to select specific wavelength bands for each detector. Materials like germanium, silicon, calcium-fluoride, sapphire, and quartz are used as carrier substrates for multilayer interference filters.

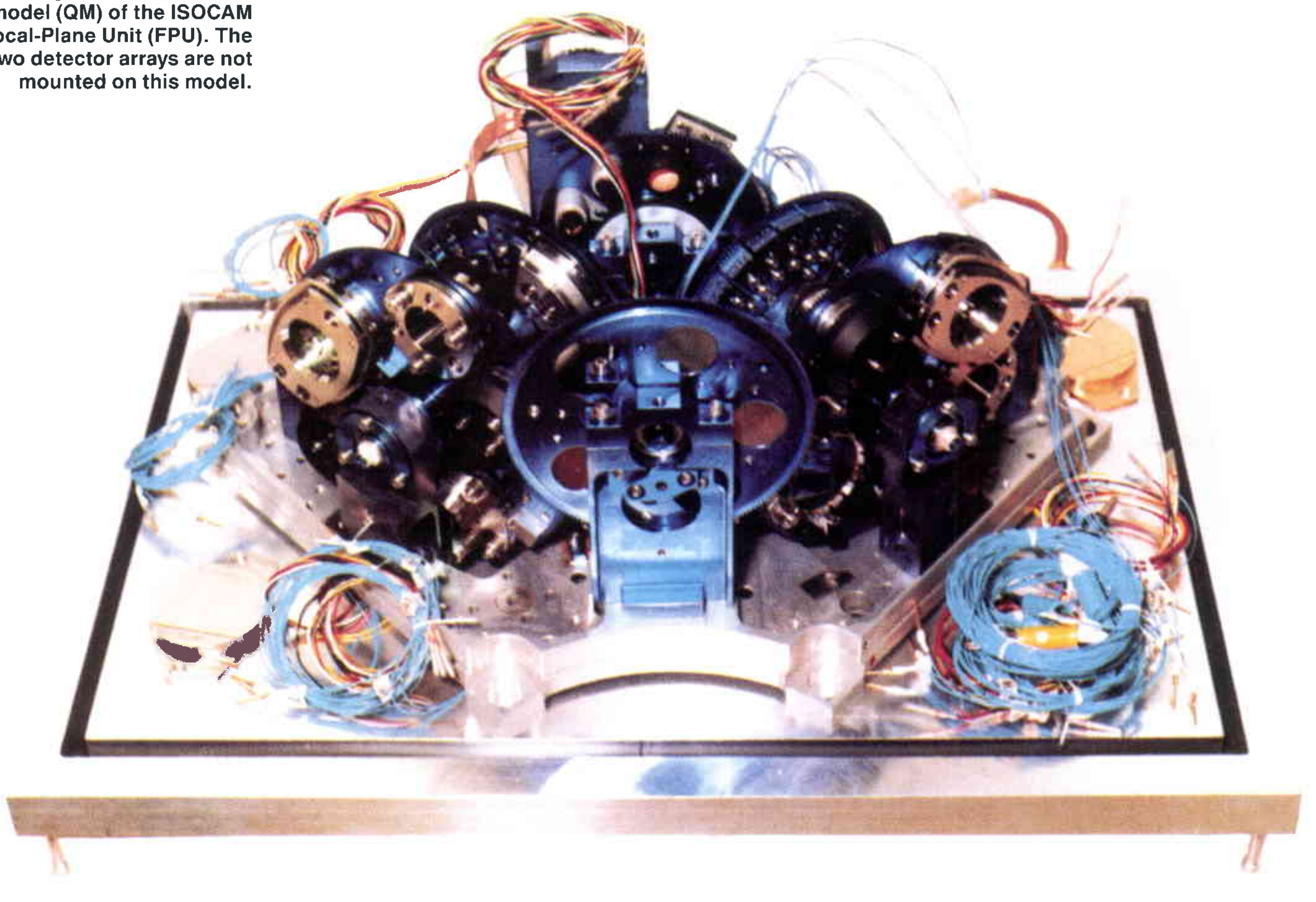
The dichroic beam splitters, which combine the functions of beam separation and filtering, are made from crystals such as sapphire, strontium-fluoride or lithium-fluoride. For longer wavelengths, multilayer metal-mesh assemblies are used.

Note: This article is an update of an article that originally appeared in ESA Bulletin No. 61 (February 1990).

*Table 1. Main characteristics of ISO's scientific instruments*

| Instrument (Principal Investigator) | Main function | Wavelength (µm) | Spectral resolution | Spatial resolution | Outline description |
|---|---|---|---|---|---|
| ISOCAM (C. Cesarsky, CEN-Saclay, F) | Camera and polarimetry | 2.5–17 | Broad-band narrow-band, and circular variable filters | Pixel FOVs of 1.5, 3, 6 and 12 arcsec | Two channels each with a 32 x 32 element detector array |
| ISOPHOT (D. Lemke, MPI für Astronomie, Heidelberg, D) | Imaging photo-polarimeter | 2.5–240 | Broad-band & narrow-band filters<br>Near-IR grating spectrometer with R ~ 90 | Variable from diffraction-limited to wide beam | Three subsystems:<br>(i) Multi-band, multi-aperture photo-polarimeter (3–120 µm)<br>(ii) Far-infrared camera: (40-130 µm, 3 x 3 pixels) (90-240 µm, 2 x 2 pixels)<br>(iii) Spectrophotometer (2.5–12 µm) |
| SWS (Th. de Graauw, Lab. for Space Research, Groningen, NL) | Short-wavelength spectrometer | 2.4–45 | 1000—3000 across wavelength range & 23000–35000 from 12–44 µm | 14 x 20 to 20 x 44 arcsec, depending on wavelength | Two gratings and two Fabry-Pérot interferometers |
| LWS (P. Clegg, Queen Mary & West Field College, London) | Long-wavelength spectrometer | 43–198 | ≈ 200 and $10^4$ across wavelength range | 1.65 arcmin | Grating and two Fabry-Pérot interferometers |

**Figure 1. Qualification model (QM) of the ISOCAM Focal-Plane Unit (FPU). The two detector arrays are not mounted on this model.**



Polarisers allow different orientations of the electromagnetic field vectors of the infrared radiation to be distinguished.

Diffraction gratings (ruled on aluminium blanks, 8 to 100 lines/mm) disperse the wavelengths for spectroscopy, for which Fabry-Pérot etalons provide a very high resolution. Within an etalon, a resonant cavity between two partly reflecting, partly transmitting mirrors (metal meshes) is created. Only the 'resonant' wavelengths are transmitted. Tuning is performed by changing the distance between the metal meshes.

**The Infrared Camera (ISOCAM)**

The ISOCAM consists of two similar optical channels which operate in two spectral regions with two different arrays of infrared detectors, each with 32 × 32 elements (Fig. 1).

In the short-wave (SW) optical channel, an InSb array operates in the 2.5 – 5.5 micron wavelength range. In the long-wave (LW) channel, a Si:Ga array covers the 4 – 17 micron band.

Opto-mechanical design

A schematic of the camera layout is shown in Figure 2. Upon entering the camera, the optical beam, deflected by a pyramidal mirror, first encounters the 'entrance wheel'. In addition to clear apertures, this wheel also carries a set of three polarising grids spaced at angles of 120°. These grids allow polarisation measurements to be made in either channel.

Next, the beam encounters the 'selection wheel', which allows one of the two optical channels to be chosen by means of two Fabry mirrors. This wheel is also used for the in-orbit calibration of the detectors.

On the following two 'filter wheels', one for the long-wave and the other for the short-wave section, a total of 26 filters are mounted. These filters, including three Circular Variable Filters (CVFs), define the infrared spectral range of the observations.

Finally, in each channel, a so-called 'lens wheel', positioned in front of the array, carries four lenses with different magnification factors for matching the fixed pixel size of the detectors to the desired pixel field of view (PFOV) on the sky or, in other words, the size of the window through which the detector will observe the sky. Choices of 1.5, 3, 6 and 12 arcsec per pixel are possible.

Each wheel, made from titanium, is driven by a superconductive stepper motor (which eradicates Joule losses) in order to limit heat dissipation inside the unit and thereby minimise temperature fluctuations. Vespel, a composite polymeric material, has been chosen for the motor pinion, both for its good elastic properties and satisfactory mechanical behaviour at low temperatures, and for its low coefficient of friction.

**The Infrared Photo-polarimeter (ISOPHOT)**

The ISOPHOT instrument (Fig. 3) is a photo-polarimeter designed to work in the infrared spectral band, between 2.5 and 240 microns. The 144 detector elements used in the instrument are divided into four arrays

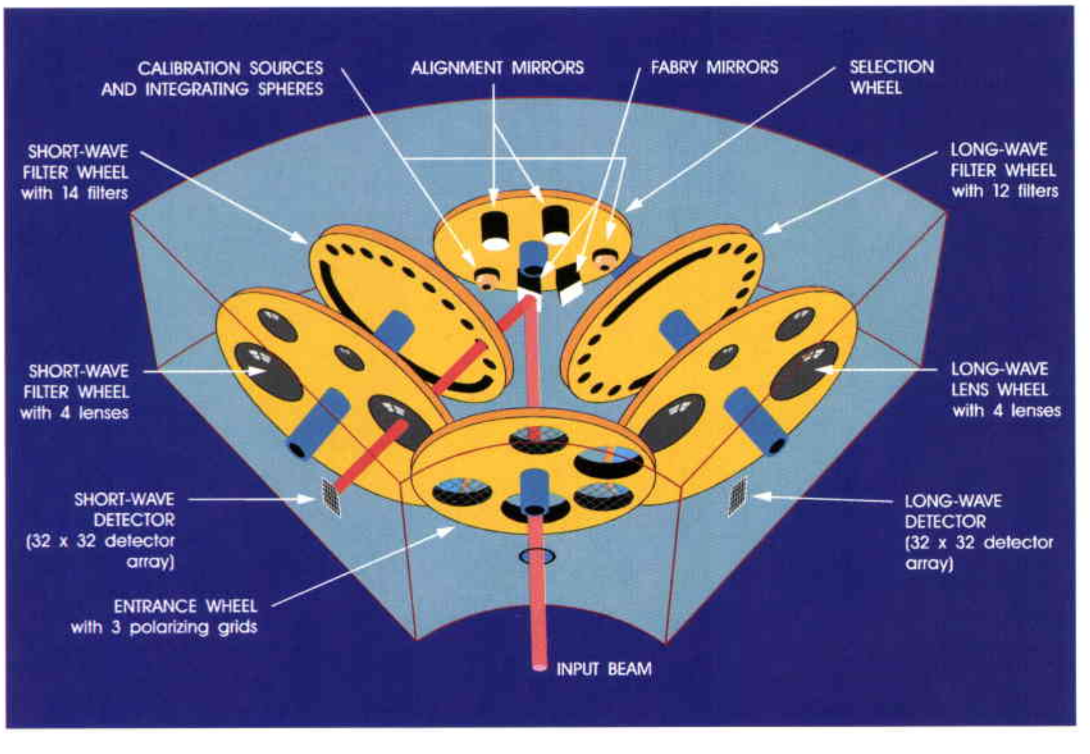



**Figure 2. Schematic of the ISOCAM instrument's opto-mechanical design**

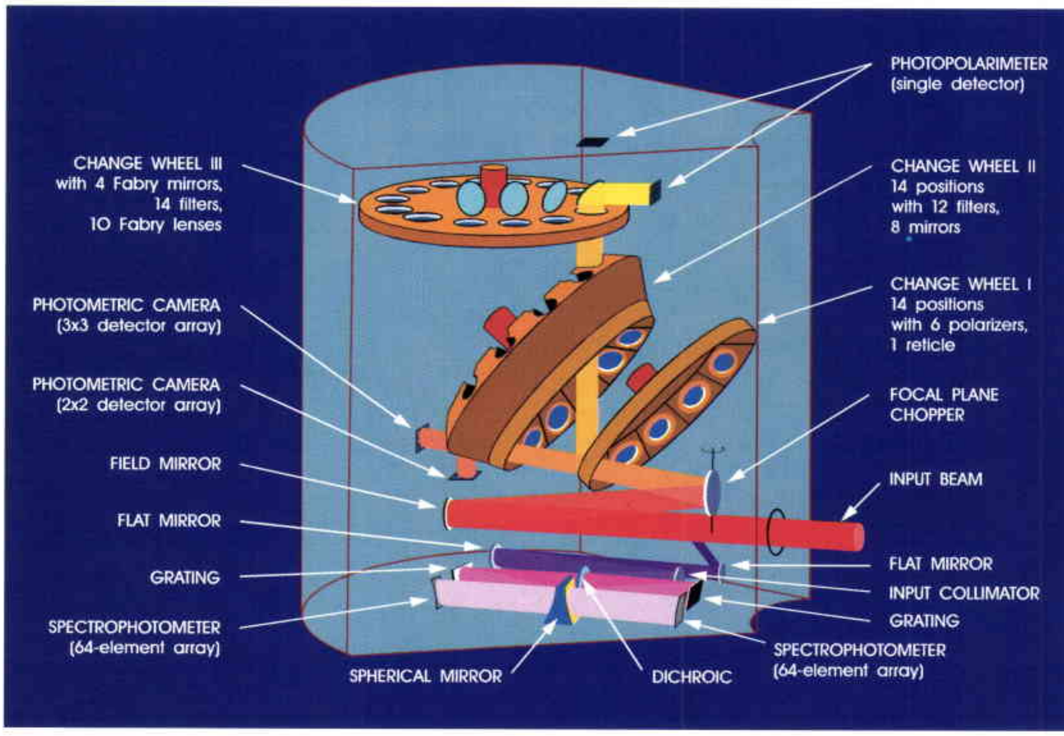



**Figure 3. Schematic of the ISOPHOT instrument's opto-mechanical design**

and three single detectors, mounted in three different subsystems. These subsystems, each of which is employed in a different photometry mode, are:

— ISOPHOT-P, a multi-band, multi-aperture photo-polarimeter, working in the 3 – 120 micron range
— ISOPHOT-C, a photometric camera for the range 50 – 200 microns
— ISOPHOT-S, a spectrophotometer with two gratings for the 2.5 – 12 micron range.

### Opto-mechanical design

By suitable use of three filter wheels, the three subsystems can be operated in different modes, selected from a very large choice of wavelength/aperture combinations. When ISOPHOT-P is selected, through wheels 2 and 3, 14 bandpass filters, with apertures ranging from 5 to 180 arcsec, can be used in combination with the two single detectors (Si:Ga and Ge:Ga) mounted on it.

In ISOPHOT-C, two two-dimensional arrays (3 × 3 Ge:Ga and stressed 2 × 2 Ge:Ga) are each used in combination with nine bandpass filters and three polarisers.

Finally, with ISOPHOT-S selected, by means of wheel 1, the 128 detector elements, divided into two 64-element Si:Ga arrays can be used as spectro-photometers, giving a spectral resolution of about 100.

Directly behind the entrance aperture, before the radiation is deflected into one of the three subsystems, the beam encounters the 'focal-plane chopper', which can be used for:

— differential measurements between two adjacent sky positions
— DC measurement of the sky
— absolute modulation between the sky and the internal calibration sources
— step scanning to provide high resolution with bright sources.

Driven by a magnetic coil, the tilting mirror of the chopper allows a beam throw ranging from 5 to 360 arcsec at a frequency of between 1/256 Hz and 16 Hz. A position sensor of the field-plate type enables the drive to generate any travel/time cycle within the limits specified above.

## The Short-Wave Spectrometer (SWS)

The SWS is a grating spectrometer designed to cover the 2.4 to 45 micron band, with a spectral resolution* of between 1000 and 2000; this can be raised to between 23 000 and 35 000 in the 12 – 44 micron range.

A variety of detectors have been chosen to cover the short-wave band, ranging from InSb (2.4 – 4.0 microns) to Si:Ga (4.0 – 13 microns), from Si:As (12 – 29 microns) to Ge:Be (28 – 45 microns), and for the Fabry-Pérots, Si:P (12 – 26 microns) to Ge:Be (26 – 44 microns). The detectors consist of four 12-element arrays and two detector pairs for the Fabry-Pérots.

### Opto-mechanical design

The instrument consists of two parallel

*The 'spectral resolution' is the capability to distinguish different monochromatic components.

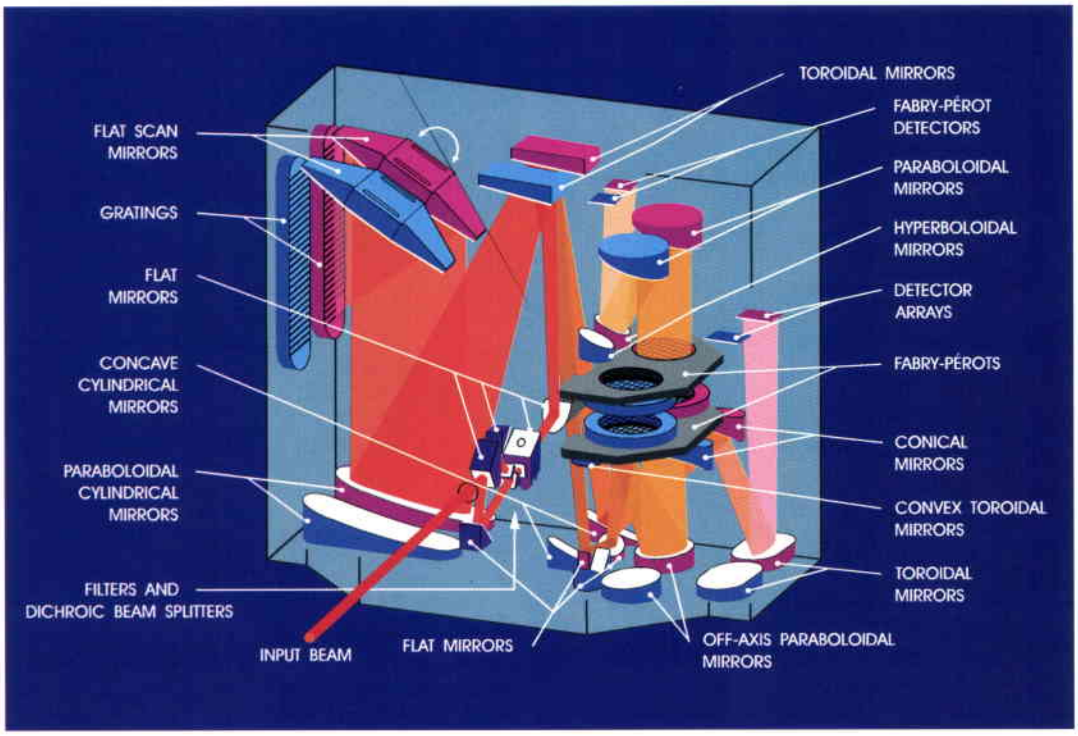



**Figure 4. Schematic of the SWS instrument's opto-mechanical design**

sections, which work in two infrared sub-bands at 2.4 – 13 and 12 – 45 microns (Fig. 4).

An optical input unit contains three different entrance apertures, which are used for different sub-bands. The aperture can be selected by means of shutter blades, repointing the telescope when necessary. Dichroic beamsplitters and transmission filters behind the shutter system define six different sub-bands, necessary to separate the different spectral orders of the gratings. The beamsplitters provide three transmission paths into the 2.4 – 13 micron section and three reflection paths into the 12 – 45 micron section.

Using collimating optics (two independent sets of toroidal and paraboloidal cylindrical mirrors), the beams are focussed onto two diffraction gratings, which disperse the radiation. Each grating has its own scanning mirror, allowing use of two sub-bands at the same time.

After reflection from the grating, each sub-band almost retraces its path before it is finally refocussed on the detector blocks by means of re-imaging optics. Further filtering is applied in the detector blocks.

Tunable Fabry-Pérot etalons allow a resolving power between 23 000 and 35 000 to be achieved in the 12 – 44 micron range by suitably deflecting the beam coming from one of the two gratings.

The grating drive employs a linear motor and has two flexural pivot hinges. The yoke, which carries the flat scanning mirror, is pushed by a coil in the field of a permanent samarium-cobalt magnet, against the counterforce of the flexural pivots. The full range of rotation is 12°, with a position reproducibility of 3 arcsec. The power consumption of this unit is less than 1 mW.

**The Long-Wave Spectrometer (LWS)**

The LWS is a grating spectrometer that operates in the infrared band between 43 and 196.8 microns in the grating mode and 47 to 196.8 microns in Fabry-Pérot mode. The resolving powers vary between 150 and 350 in grating mode and between 7000 and 10 000 in Fabry-Pérot mode. Three types of photoconductive detectors will be used:

— one Ge:Be detector, to cover the 45 – 55 micron region
— five Ge:Ga detectors, to cover the 55 – 110 micron region
— four stressed Ge:Ga detectors for the 110 – 180 micron region.

Although the three types of detectors are mounted in a single array, the stressed and unstressed detectors operate at different temperatures and are only weakly thermally coupled.

**Opto-mechanical design**

The LWS has three main subsystems (Fig. 5):

— input/collimating optics, which contains seven mirrors
— two Fabry-Pérot etalon assemblies (FP), mounted on an FP exchange wheel controlled by a cryo stepper motor

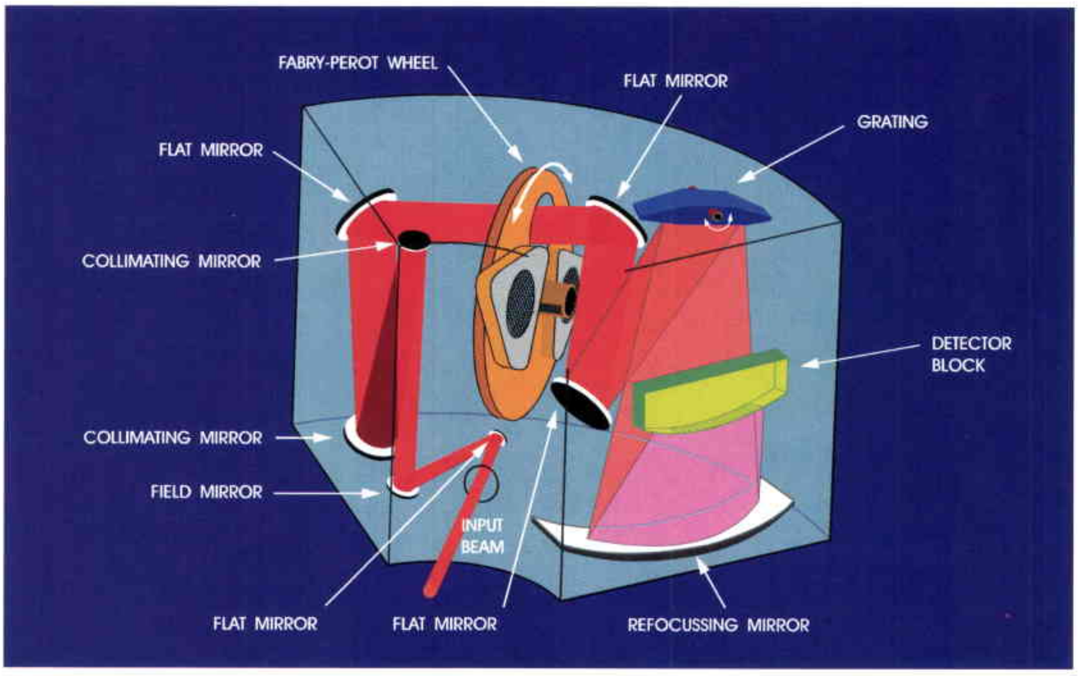



**Figure 5. Schematic of the optical components of the LWS**

— a diffraction grating, mounted with its own scanning structure, as in the SWS, and completed by refocussing optics and the detector array.

After having been deflected by the first five mirrors, which define the field of view and produce a parallel beam, the radiation passes through the FP exchange wheel. In addition to the two FP etalons, the latter also carries a clear aperture.

In the low-resolution mode (neither of the two Fabry-Pérot etalons selected), the beam illuminates the diffraction grating directly, via mirrors M5 and M6. The grating disperses the radiation, which the refocussing mirror M8 then brings to a focus at the ten-detector assembly. A resolving power of about 200 is achieved by this approach.

The high-resolving mode (up to 10 000) is activated when the FP wheel is rotated and one of the two etalons is selected. The short-wavelength FP is optimised for wavelengths from 47 to 110 microns; the long-wavelength FP covers the range 110 – 197 microns.

Each of the two FPs (Fig. 6) consists of three triangular-shaped plates carrying three electromagnet assemblies, which move the meshes of the etalons against the force of three leaf springs.

**Instrument electronics**

The instrument electronics can be divided into:
— detector read-out and amplification
— analogue signal conditioning
— digital processing
— power supply
— spacecraft interfaces.

With the exception of the detector read-out, which is part of the focal-plane unit (FPU) and is mounted inside the cryostat, the remainder of the electronics are mounted either on the spacecraft's equipment platform or on the cryostat itself (ISOCAM preamplifier).

Detector readout and amplification

Single-element detectors (LWS, SWS and ISOPHOT) are read-out by means of integrating amplifiers, located close to the detector itself, on the support structure. The detector signals, which are generally in the microvolt range, are amplified and bandwidth-limited before being converted to digital form (12-bit analogue-to-digital converter).

Analogue signal conditioning

This involves various tasks, such as:
— generation of detector bias voltages
— temperature sensor conditioning
— heater control
— calibration source control
— mechanism control.

Bias voltages are variable within a certain range and can be commanded to achieve optimum detector performance. Voltages are as high as 100 V and need extremely good filtering as any noise would directly feed into the detector amplifier and thereby cause serious degradation.

As detector performance is temperature-dependent, this temperature must either be known exactly or controlled within narrow limits. For this purpose, the FPUs contain a variety of temperature sensors capable of measuring in the range up to 10 K.

Various motor types are used to rotate/move the FPU mechanisms such as the filter wheels and the grating. All of these motors have been carefully selected for minimum power dissipation.

Mechanisms are monitored using position encoders. The CAM instrument, for example, uses magneto-resistors for wheel origin and step counting. Hall sensors are used to determine the positions of the three PHT ratchet wheels. Servo loops are used for the gratings and etalons in the spectrometers.

### Digital processing

All instruments will be completely controlled by one of two redundant 16-bit microprocessor assemblies.

Each assembly consists of a processor, memories and spacecraft interfaces. Address, data and control busses are generally separated, but each assembly can interface to any part of the analogue electronics.

In summary, the assemblies will:

- accept, interpret and execute commands
- output formatted scientific and housekeeping data (approx. 25 kbit/s)
- control mechanisms
- control calibration sources
- control and read-out the analogue electronics
- control detector temperature.

Operational software is stored in read-only memory and can be called automatically or by ground command. Some of the operational software is loaded in RAM.

### Power supply

All instruments use redundant converters to generate secondary voltages from the 28 V spacecraft bus.

### Spacecraft interfaces

Instrument sensitivities dictate the use of opto-couplers and pulse transformers as digital interface circuits in order to separate the various grounding points. For analogue signals, differential stages are used.

A total mass of 90.5 kg is allocated to the instruments (36.1 kg to the FPUs). The total instrument power is 80 W, but only 10 mW are allowed to be dissipated per FPU for thermal reasons.

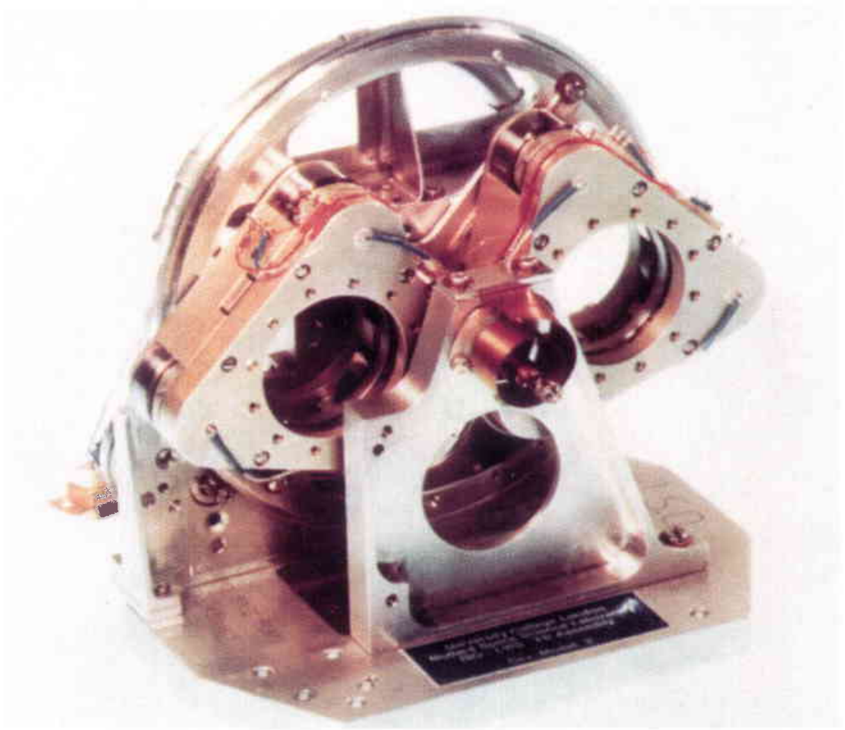


**Figure 6. The two Fabry-Pérot etalons of the LWS mounted on the exchange wheel**

A more unusual 'resource' on ISO is the limited cross-section of the cryo-harness which connects the FPUs with the warm electronics. Stainless-steel and brass in two wire gauges have been selected, to minimise the heat loss along the harness.

With an average cryo-harness length of 5 m, this leads to typical operational resistance values of 500 ohm for stainless steel. Brass wires are only used where the higher wire resistance would lead to impractical voltages and/or high dissipative losses in the harness.

### Conclusion

The scientific instruments that make up the ISO spacecraft's scientific payload constitute a complete, complementary and versatile package for infrared astronomy.

Having completed the design and development phase, the qualification models of the instruments were delivered to ESA for integration into a suitable cryostat and subsequently underwent a test and verification programme. Upon delivery of the flight models, those models were integrated into the ISO satellite. After the completion of the full test programme, ISO is now awaiting launch.

### Acknowledgement

The authors wish to acknowledge the efforts of the ISO Principal Investigators (noted in Table 1) responsible for the four instruments making up the ISO spacecraft's scientific payload, and their groups, on whose work this article was based.

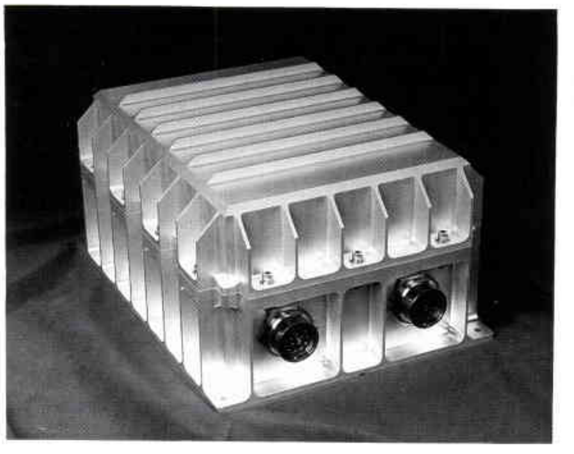
AMP TEK ®

# SPACEFLIGHT DATA RECORDER

# FDR-8000

**Product Spotlight**

| | |
|---|---|
| Model: | FDR-8500C |
| Capacity: | 5 Gigabytes (uncompressed) |
| | 10 Gigabytes (2:1 compression) |
| | 250 Gigabytes (50:1 compression) |
| Date Rate: | 10 Mbit/s per channel (burst) |
| | 4 to 12 Mbit/s total (sustained) |
| Weight: | 16 lbs (7.3 kg) |
| Power: | 18 Watts @ 28VDC |
| Size: | 11.8" x 9" x 6" |
| | (300mm x 229mm x 152mm) |
| Interface: | RS-422 |



FDR-8000 series recorders are flight-proven, high performance data storage units built for operation within the Space Shuttle bay, on the aft flight deck, and aboard space platforms. Designed with 8mm helical scan technology, the FDR-8000 line provides economical mass data storage. These recorders' unique characteristics make them equally useful in avionics and satellite applications.

## Capacity

The newest member of the FDR-8000 family is the FDR-8500C. The capacity of the FDR-8500C is 5 Gigabytes of uncompressed data. Hardware compression is typically 2:1, yielding 10 Gigabytes of storage space. Depending on data content, compression rates of 50:1 are attainable. Peak data rates are 10 Mbit/s per channel into a 4 Mbit buffer. Multiple input models are available. Total sustained data rates from combined channels are from 4 Mbit/s to 12 Mbit/s depending on compression efficiency. The error rate is less than one in $10^{13}$ bits read.

## Mechanical

The FDR-8000 enclosure is a sealed box purged with nitrogen. The inert gas provides an air cushion around the recording head and protects the tape from common corrosive gases during long term storage. Internal heaters activate below +10°C. During initialization, recording is disabled until heaters can stabilize the internal environment above 0°C. Shock and vibration isolation allow the tape transport assembly to surpass Shuttle launch and landing requirements.

The recorder's footprint measures 11.8" x 9" (300mm x 229mm), with a height of 6" (152mm). The mounting hole pattern is on 70mm centers for easy interfacing with ESA cold plates and Hitchhiker pallets. Total weight is 16 lbs (7.3 kg).

## Electrical

Power dissipation is 18 Watts at 28V. Each recorder contains its own DC/DC power converter. An internal controller supports serial data transfer, file structures, error recovery, and regulation of the recorder's operating environment.

## Interface

Communication with the FDR-8000 is provided via RS-422 compatible channels. The command channel is asynchronous at 1200 baud. The data channel is synchronous from DC to 10 MHz.

Let Amptek provide the solution to your high-capacity data storage needs.

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# The ISO Programme

**J. Steinz & A. Linssen**
ISO Project, ESA Directorate of the Scientific Programme, ESTEC, Noordwijk, The Netherlands

**ISO, the Infrared Space Observatory, will provide astronomer's with an unprecedented opportunity — and the only one for the next 10 years — to make scientific observations of weak infrared radiation sources. The development of the Observatory proved to be a challenging task: there was little available experience with the advanced technologies required for such a new infrared-astronomy mission. The scientific instruments were developed by groups of scientific institutes and industry under national funding. The satellite was developed, manufactured, integrated and tested by an industrial consortium made up of 32 companies, mostly from Europe. ESA is performing the flight operations. The USA and Japan are also contributing to the mission in return for observation time.**

### Introduction

ISO, the Infrared Space Observatory, is a general purpose telescope facility to be used by the scientific community. It will provide infrared astronomers with an unprecedented opportunity — the only one in the world for at least the next decade — to make scientific observations of a wide variety of weak infrared radiation sources. The first major opportunity for European scientists was using IRAS, the Dutch-British-American Infrared Astronomical Satellite, which flew in 1983. The next possibility using a European satellite after ISO (in 1995) will be with ESA's FIRST (Far Infrared and submillimetre Space Telescope), which is proposed for launch in 2006.

ISO was conceived in the early 1970s. The Phase A study was completed in 1982 and in March 1983, ESA's Science Programme Committee (SPC) approved ISO as a project of ESA's Science Programme. The design and development phase of the project started in late 1986. The satellite has now been successfully tested and is waiting in Kourou, French Guyana, to be launched in early November of this year. The satellite will be operated from ESA's Villafranca ground station near Madrid, Spain. A second ground station, at Goldstone, California, will be used to relay telecommands and to receive telemetry from the satellite for several hours each day.

An overview of the organisation of the project, the satellite procurement approach and development programme follow.

### International cooperation

Both the USA and Japan had expressed great interest in using ISO. As a result, ESA made a special agreement with NASA, and Japan's Institute of Space and Astronautical Sciences (ISAS): NASA is providing the second ground station and ISAS is supporting the flight operations; in return, NASA and ISAS will each be allotted a half hour per day of ISO's time for use by their scientists.

### Project organisation

The overall project organisation is shown in Figure 1. Central to this organisation is the ESA Project Team which is located at ESA's European Research and Technology Centre, ESTEC, in Noordwijk, The Netherlands. This project team, part of the ESA Directorate of the Scientific Programme, is responsible for the management of the development, launch and in-orbit commissioning of the satellite. The ESA Space Science Department assumes responsibility during the subsequent routine operations phase of the mission, with the spacecraft operations being delegated to ESOC.

The main groups involved in the development of the project are described below.

### Principal Investigator groups

ISO has four Principal Investigators (PIs), one for each of the scientific instruments. The scientific instruments were developed under national funding, with each Principal Investigator being responsible for his or her own scientific instrument. Each instrument was developed by a group involving many institutes and industries. Over 45 organisations in total were involved. Figure 2 lists these organisations by country and instrument name.

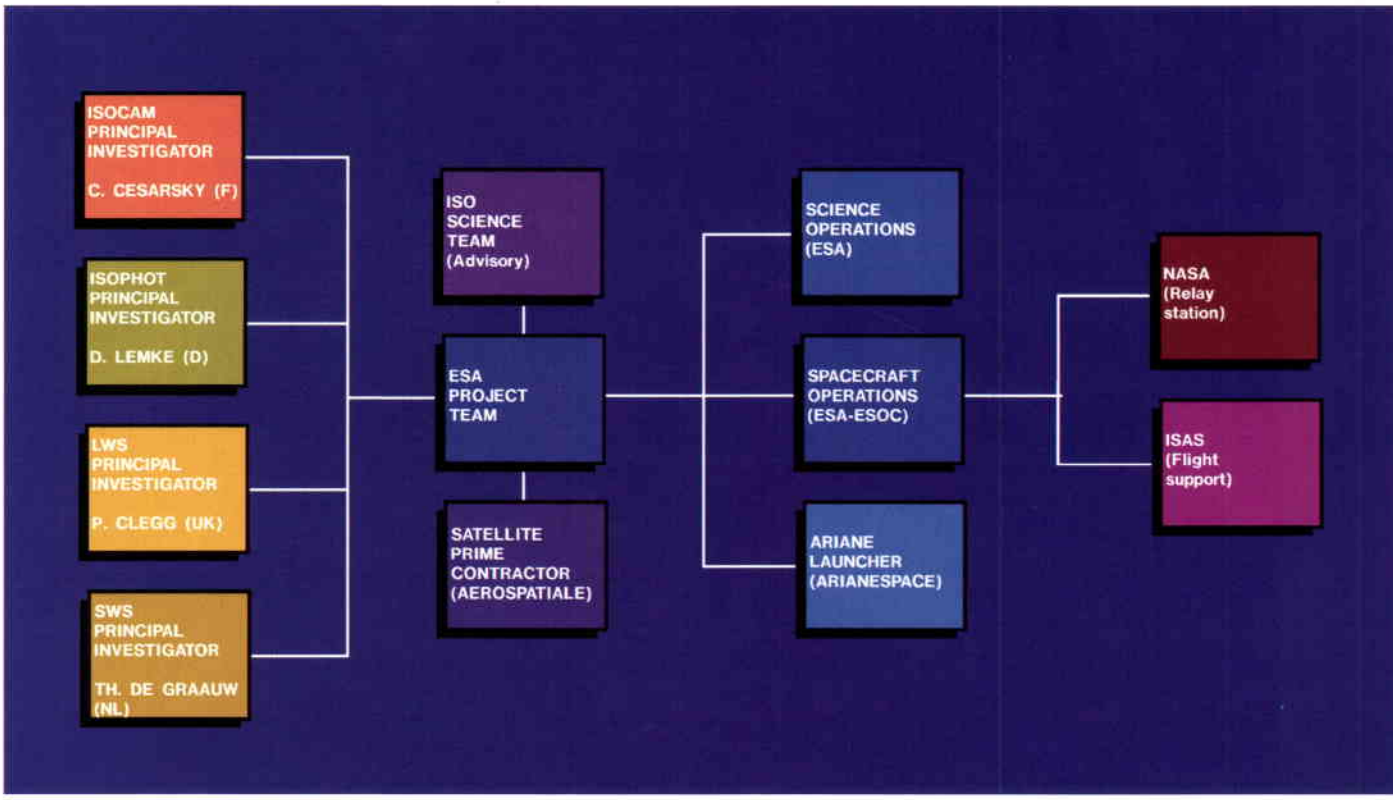



**Figure 1. ISO project organisation**

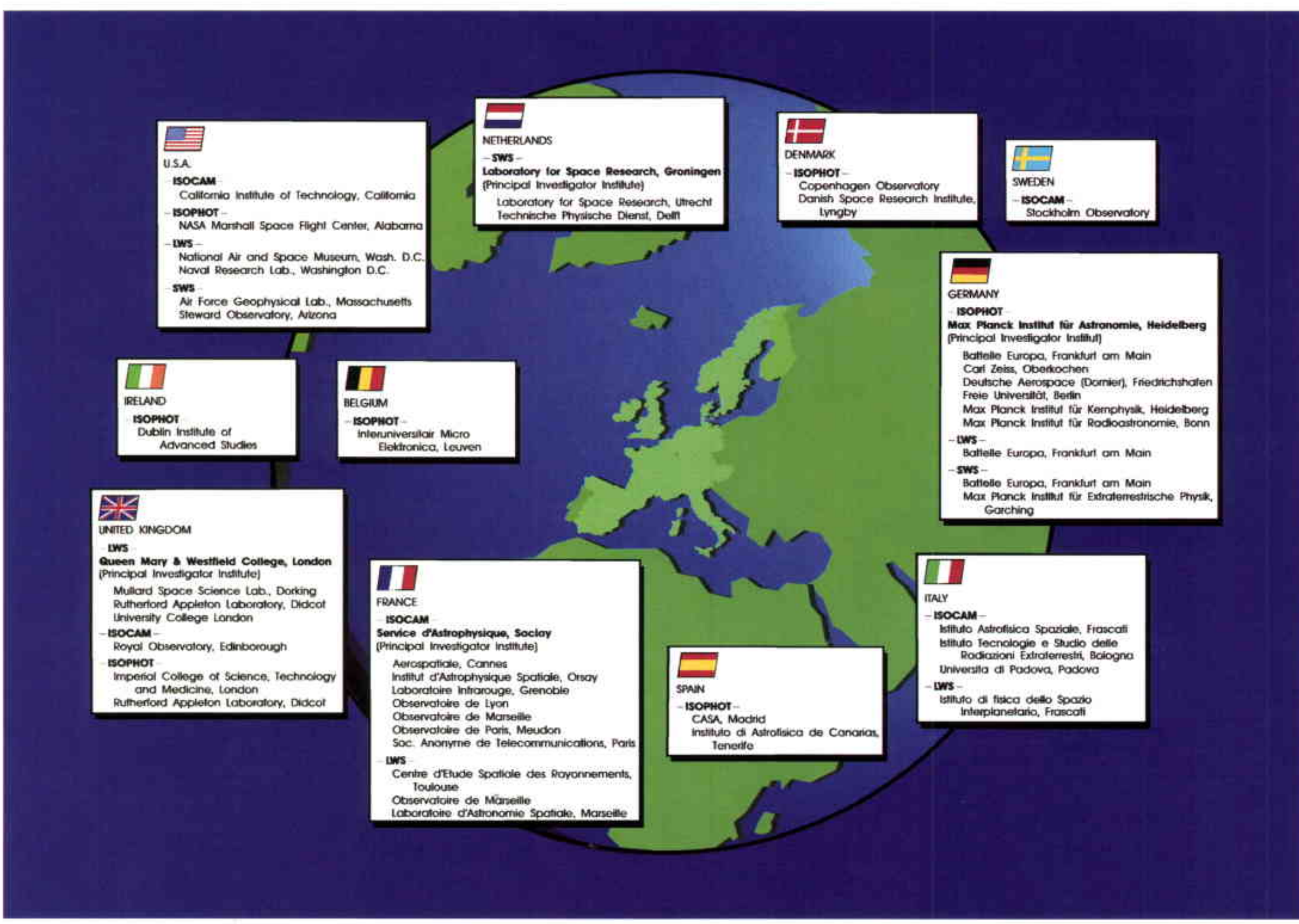



**Figure 2. Principal Investigator (PI) organisations by country and instrument**

The PIs are responsible to the ESA Project for the delivery of their scientific instruments for integration and testing with the satellite. In return for the effort of developing the instrument, the PIs are guaranteed the use of ISO for about one-third of its total operations time in orbit. The PIs plan this guaranteed time in great detail and share it with their many Co-Investigators and Scientific Associates, about 100 astronomers in total. The remaining two-thirds of ISO's operations time is open to the scientific community, i.e. any scientist in Europe, the USA or Japan, through the submission of observing proposals (see the following article, 'Using ISO').

## Science Team

The ISO Science Team (IST) is an advisory group appointed by ESA's Director of the Scientific Programme to advise ESA on all scientific aspects of the mission. The IST consists of the ESA Project Scientist, the four PIs, five Mission Scientists providing independent advice, and a representative from the ESA Project Team and both ISAS and NASA. The IST has followed the development of the project and has met quarterly to address the important scientific issues that have arisen during the development phase.

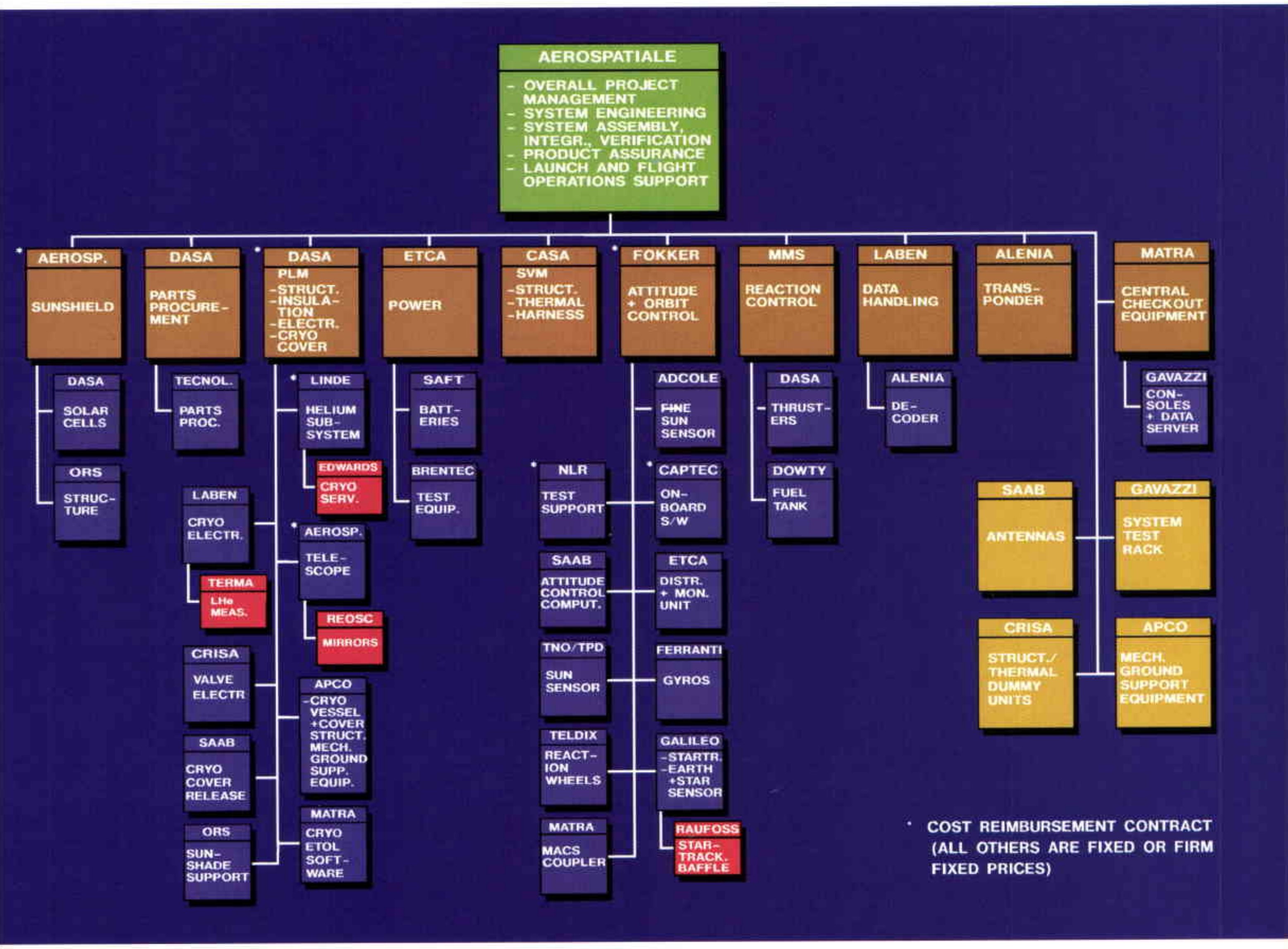
## Satellite Prime Contractor

The Satellite Prime Contractor, Aerospatiale (F), was responsible for the design and development of the satellite and for the integration and testing of the scientific instruments with the satellite. The industrial organisation required to design and develop the hardware required to build and test the satellite consisted of 32 companies. The structure and each participant's contribution are shown in Figures 3 and 4.

## Launcher authority

Arianespace is providing the launch vehicle and all associated launch services. The interfaces and operations with ISO, however, are unusually complex because of ISO's need for frequent liquid helium cryogenic servicing until shortly before launch. Arianespace has had to make special provisions to cope with the

**Figure 3. Structure of the industrial consortium that developed, manufactured, integrated and tested the ISO satellite**



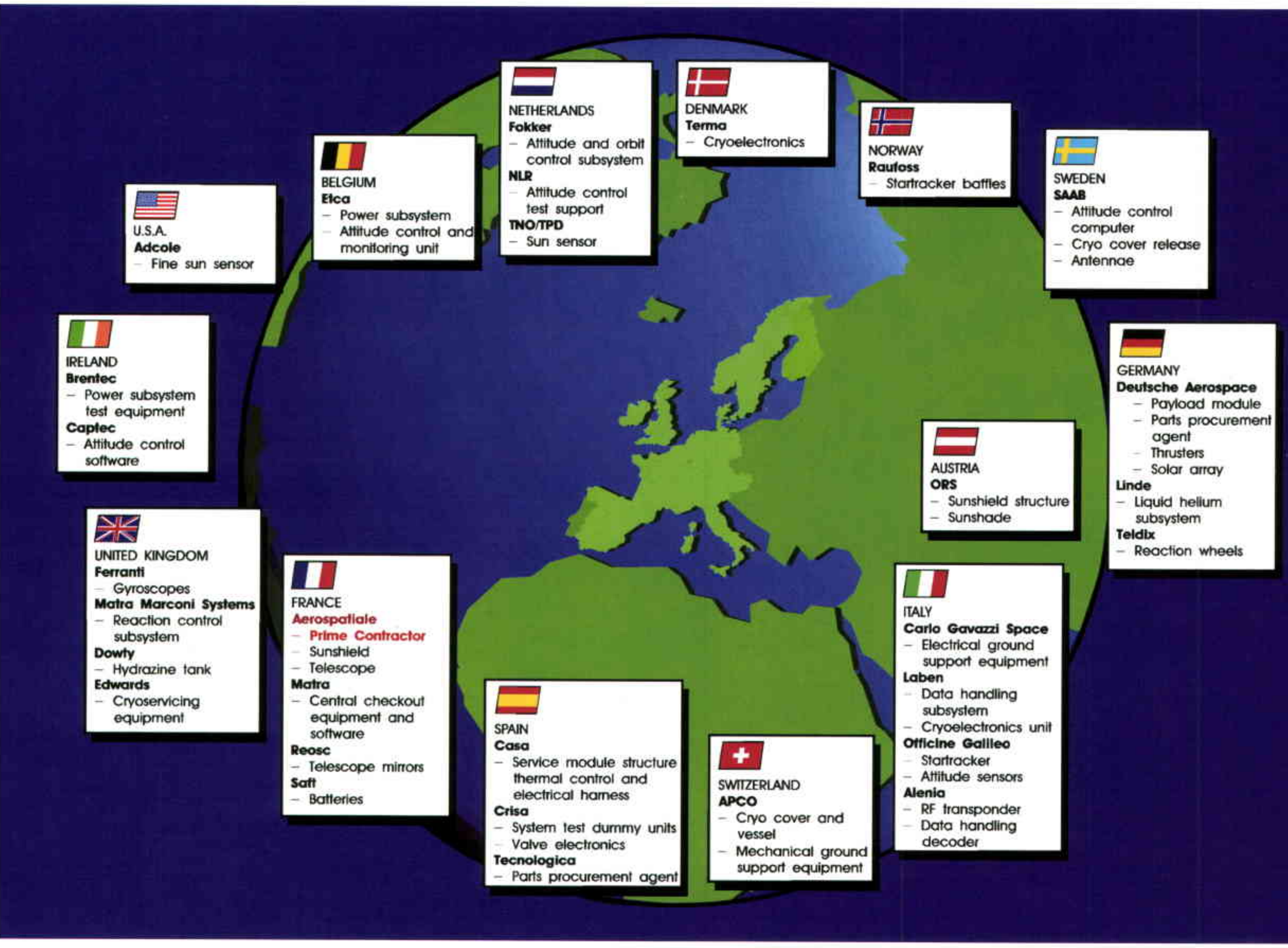



**Figure 4. Industrial contractors by country and contribution**

more complicated and longer duration launch campaign and combined operations with the launch vehicle.

### Science and spacecraft operations

The ESA Space Science Department is responsible for the science operations, i.e. the in-flight operations of the scientific instruments. It developed the necessary software at ESTEC. This software development was a difficult and challenging undertaking, mainly because of the high degree of automation required to perform scientific observations. It is further complicated by the many constraints to be respected to ensure the safety of the satellite even if control from the ground is lost.

ESA's space operations centre, ESOC in Darmstadt, Germany, is responsible for the ground segment and for operating the spacecraft. ESOC will control the satellite from its operations control centre at Darmstadt during the Launch and Early Orbit Phase, i.e. the first four days after launch. After this critical phase of the flight, the satellite and its scientific instruments will be controlled from the ISO Control Centre at Villafranca, Spain, where both the science operations and spacecraft operations teams are co-located.

ESOC is also coordinating its operations with NASA-JPL, which is providing the second ground station for ISO at Goldstone, and with ISAS in Japan, which is providing support for ISO's flight operations.

## Satellite development

### Procurement

A number of specific features of ISO had to be taken into account to establish the industrial policy regarding the satellite development. In particular, there was little experience available anywhere in the world with respect to infrared astronomy. Only one major mission, IRAS, had been flown. The expertise available in the field of space cryogenics and the assembly, integration and verification of large super-fluid-helium cryostats, was also very limited. Only two companies in Europe had relevant experience: Aerospatiale (formerly SNIAS) which had developed a laboratory model liquid-helium cryogenic facility, and Daimler-Benz Aerospace (formerly MBB) which had manufactured a development model of a German infrared laboratory (GIRL).

It was decided that the Phase B design should be carried out by one prime contractor who would lead several subcontractors. (Competitive parallel studies was not considered a realistic option because of various constraints, such as the need for confidentiality, that impede progress and creativity.) ESA's Industrial Policy Committee (IPC) approved, in April 1984, the proposal to enter into direct negotiation with Aerospatiale which would lead a consortium of companies that would include Daimler-Benz (formerly MBB) and Linde AG (D). It was also decided that critical technology items such as cryostat components and telescope mirrors would be developed in parallel to the Phase B design activities.

In November 1986, the IPC approved the placing of the Phase B contract and work started in industry in early December 1986. By the end of Phase B, 15 companies were involved in the work. Following the successful completion of Phase B, the Phase C/D contract was placed with Aerospatiale and work started at the end of March 1988. The industrial consortium was extended to include a number of companies that had been selected through competitions that Aerospatiale as Prime Contractor conducted in an effort to meet the overall geographical distribution and cost targets for Phase B and C/D. Competitions were conducted for the following items:

— Parts procurement agent
— On-board data handling subsystem
— Optical subsystem
— Star tracker
— Central checkout equipment
— Service module payload module and system mechanical ground support equipment.

At a later stage during Phase C/D, more competitions were held for the cryo-electronics unit and the data handling decoder. As a result, the final industrial consortium for ISO comprised 32 companies, with one prime contract and 44 sub-contracts. The final structure of the industrial consortium that developed, manufactured, integrated and tested the ISO satellite is depicted in Figures 3 and 4.

The total price for the Phase C/D is made up of cost-reimbursement prices associated with a cost-incentive scheme, and firm-fixed or fixed prices with variation. The percentage of the price consigned to a cost reimbursement is higher than in a typical scientific spacecraft mission, i.e. about 70%. This is due to the very advanced technology of the payload module and the greater-than-usual development risk. Also, the demanding mission requirements, such as those of the attitude and orbit control subsystem, imply a high technical risk and therefore also dictate a cost-reimbursement arrangement.

**Development plan**

The ISO satellite (in particular the cryogenic cooling system) and its scientific instruments (e.g. the detectors) employ very advanced technologies and therefore demand an extensive development plan. The plan, however, must be sufficiently flexible to cope with unexpected problems. (The development plan is described in another article, 'The ISO Spacecraft', in this issue.) The main technical challenges encountered were with the scientific instruments, the telescope, the cryogenic subsystem and cryostat, the attitude control subsystem and the star tracker. The difficulties have all been successfully overcome.

The project schedule is shown in Figure 5. The overall development at system level was ultimately accomplished using two models:

— A Development Model (DM):

The Service Module was essentially a structural/thermal model with dummy mass units. The Payload Module (cryostat) was built in full flight configuration. Nearly all development problems were resolved using this model.

— A Protoflight Model (PFM):

All of the DM's shortcomings were corrected on the PFM and the PFM was then subjected to qualification tests. This approach was extremely successful: the final PFM test sequence did not reveal any new major problems. Clearly, all the major problems had been identified and resolved on the DM.

All units were required to be delivered in two models, a flight model and a flight spare (which is generally a refurbished qualification model). The availability of flight spare units contributed greatly to the success of the programme: small problems could be easily resolved by simply exchanging units and thus avoiding any major delays. The scientific instruments also

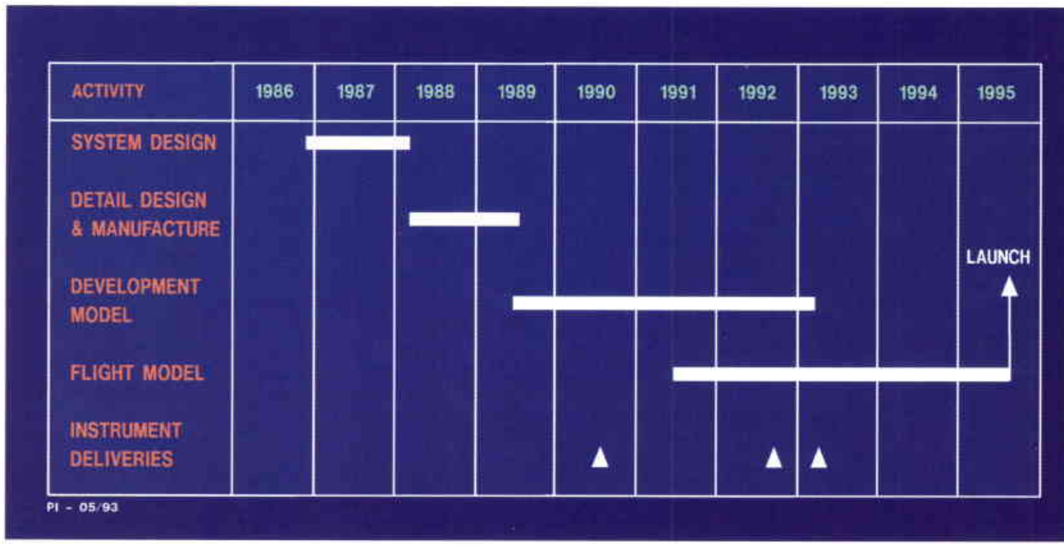



**Figure 5. ISO project schedule**

benefitted because the flight model and flight spare could be alternately improved in parallel to the satellite development.

## Projected costs

The total project costs, based on the expected lifetime of 18 months, are predicted to be 713 MAU based on 1994 economic conditions.

## Outlook

The satellite qualification and acceptance test programme and all tests with the ground segment have been successfully completed. The satellite and all its associated support equipment were transported by ship to the launch range in Kourou, French Guiana, in June 1995. The satellite was fully tested again in Kourou and is now waiting to be installed on the Ariane launch vehicle to be launched in early November 1995.



# Using ISO

**M.F. Kessler**
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**In keeping with ISO's role as an observatory, the majority of its observing time will be available to the astronomical community. The traditional route of Calls for Observing Proposals, followed by peer review, is being used. There has been one Call prior to launch and a single Supplemental Call is foreseen post-launch.**

**The expected high sensitivity of the ISO instruments will lead to observations of relatively short duration, typically tens of minutes to a few hours. This, in turn, means that many thousands of observations using the four highly sophisticated instruments with multiple operating modes will be carried out in ISO's limited lifetime of 18 months. Thus, as many as possible of the processes, from proposal submission to sending specific commands to the satellite to carry out a particular observation, have been automated. In addition, all details of the desired observations have to be specified by the observer in advance of the observation being executed to allow the complex observing programmes to be established.**

## Orbit and sky coverage

ISO will be operated in a highly-elliptical orbit with a perigee height of 1000 km, an apogee height of 70 600 km and a period of just under 24 hours. The lower parts of this orbit lie within the Earth's Van Allen belts, regions of trapped electrons and protons. When the satellite is inside these belts, the majority of ISO's detectors are scientifically unusable due to effects caused by radiation impacts. ISO will spend roughly 16 hours per day outside the radiation belts and during this time all its detectors may be operated at maximum sensitivity.

There is no data storage available on board ISO and only very limited storage for telecommands. Therefore, for scientific use, ISO needs two ground stations to provide continuous contact. One of these stations, co-located with the ISO Control Centre at Villafranca, Spain, is provided by ESA. The second one, at Goldstone, USA, acts as a relay between ISO and its Control Centre for telemetry and telecommands for part of each day.

For thermal and power reasons for the spacecraft and also to prevent celestial stray light reaching the instruments and degrading their performance, there are a number of very stringent constraints on the allowed pointing directions for ISO. These constraints are shown in Figure 1. Note that Jupiter is normally kept more than 7 degrees away from the optical axis but can be pointed at, if it is the target of the observation. These constraints mean that, at any moment, ISO only has a limited area of sky available for observations (averaging approximately 12% and ranging from about 8% to 20%).

The 'available' part of the sky changes with time as ISO's orbit precesses and as the Earth plus ISO moves around the Sun. However, during the 18-month in-orbit lifetime, approximately 12 – 15% of the sky (depending on the exact launch date) will not emerge from behind the various constraints, particularly that due to the Earth. Thus, this area will never be observable by ISO. The precise location of this 'hole' depends on the exact date and time of launch. For other reasons, the launch date is constrained to two different periods of the year. For a launch in the spring period, the hole will be in the region of the galactic centre and for an autumn launch, it will be in the Orion region.

These sky accessibility constraints and the need to keep open the possibility of launching in either season meant that, during the satellite development, it has effectively been necessary to plan two different observing programmes in parallel. This has been achieved by having two different lists of astronomical targets for each research programme.

## Observing time

In keeping with ISO's role as an observatory, the majority of its observing time will be distributed to the general astronomical community in ESA Member States, the USA and Japan via two competitive 'Calls for Observing Proposals', one pre-launch and the other post-launch. Based on pre-launch estimates of efficiency, a total of about 3600 hours of 'Open Time' will be available during the mission. Since it is believed that ISO will make new and unexpected discoveries and, in

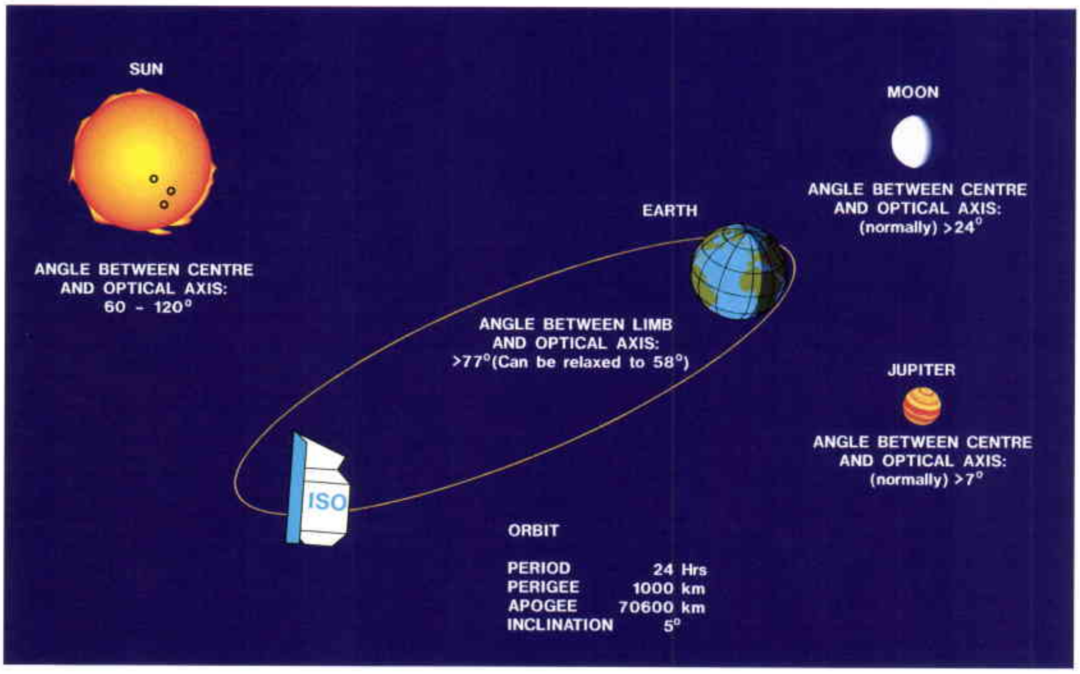



Figure 1. The ISO orbit, showing the observing constraints imposed by the Sun, the Earth, the Moon and Jupiter (not to scale)

many cases, will be the only facility capable of follow-on investigations of these discoveries for many years, an additional 250 hours of observing time, called 'Discretionary Time', will be made available for 'observations that could not have been foreseen at the time of proposal selection'. This mechanism introduces a suitable degree of flexibility into the ISO observing programme.

The remaining time, amounting to about 2800 hours of 'Guaranteed Time', is reserved for those scientists involved in building and operating the facility. They are: the four Principal Investigator teams that built ISO's scientific instruments; the group of five Mission Scientists who advise ESA on ISO; ISAS and NASA who, via collaborative agreements with ESA, provide the second ground station and its associated resources; and the astronomers in the ISO Science Operations Team who are responsible for the scientific operations of ISO and who support the community in using ISO.

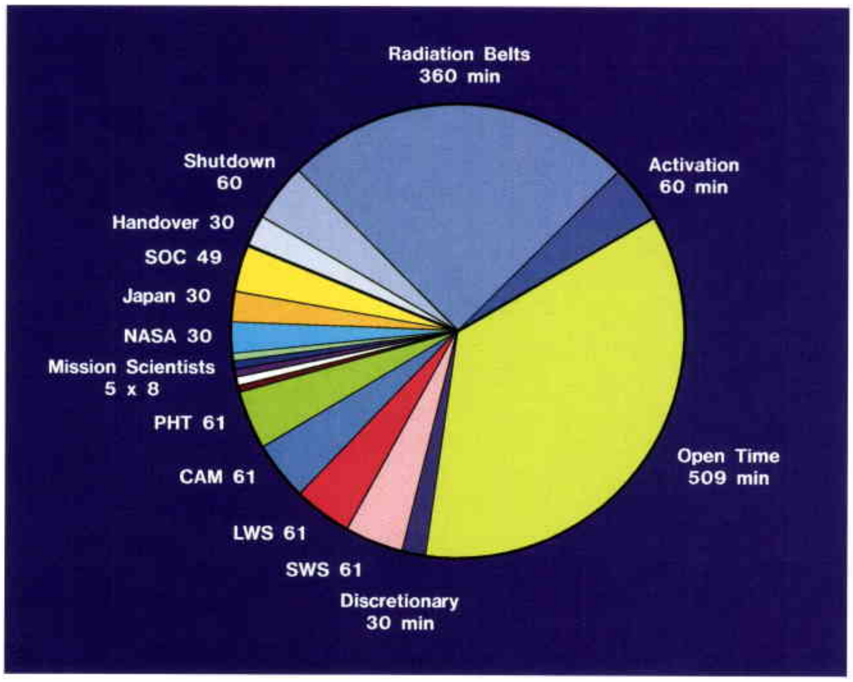



Figure 2. The average daily distribution (in minutes) of ISO time during the routine phase. ISO spends about 16 out of each 24 hours outside the radiation belts; this time is available for science observations.

Following ISO's launch, there will be a period of about three weeks during which the satellite will be commissioned. Then, there will be a performance verification phase of nearly eight weeks during which the core instrument calibrations will be carried out and the in-orbit performance of ISO and its instruments established. Thereafter, ISO will enter into its routine operations phase, which will last at least 16 months. Figure 2 shows the average daily distribution of observing time between all parties in this routine phase.

## Preparation of observing programmes

Observing programmes for both the Open and Guaranteed Time were prepared in two phases. During Phase 1, potential observers worked at their own institutes to establish the scientific rationale for their programmes and to specify the desired observations, including instrument and mode, filter or wavelength, and total time required. During Phase 2, the successful proposers visited one of two support centres to enter full details of the observations into the Science Operations Centre's Mission Database.

Preparation of the Guaranteed Time programme started more than five years ago and has involved at least 150 astronomers. In order to take maximimum scientific advantage of ISO's limited lifetime, the holders of the guaranteed time have worked together to achieve the maximum possible degree of coherence among the 139 individual research projects. As part of the coordination process, two major workshops, each attended by over 100 scientists, were also organised. The ISO Science Team oversaw the final preparations and worked continuously to ensure the required coordination. The complete programme was prioritised into three bands and presented to the Observing Time Allocation Committee (OTAC), composed of external scientists, for their endorsement in February 1994. The whole guaranteed time programme was then published, not only to inform the community of which observations were 'reserved' for the guaranteed-time holders but also to serve as a set of 'worked examples' thus permitting the general astronomy community to submit complementary and feasible observing proposals for the Open Time available.

The Open Time programme was then defined. The pre-launch Call for Observing Proposals was issued in April 1994, and was distributed to close to 2500 astronomers worldwide. In addition to the guaranteed-time summary, the 10-volume Call contained Observer's Manuals for the instruments and the satellite. The Science Operations Centre (SOC) also made 'hot-off-the-press' information available via electronic computer networks (ftp). Proposers had to use a special software tool, the ISO Remote Proposal Submission System, on their own computers to prepare observing proposals. They then submitted their proposals, via the network, to the SOC by August 1994 for processing and review.

A total of 1000 Phase-1 proposals was received. Approximately one third of these proposals were for stellar/circumstellar topics, another third for extragalactic studies and one quarter addressed the interstellar medium. The rest were split roughly equally between solar-system and cosmological subjects. In total, about four times more time was requested than will be available. The SOC assessed the technical aspects of each proposal, often through interaction with the proposer, and sent the assessments to the OTAC.

The OTAC was organised into seven panels, each one addressing a different scientific area. The OTAC ranked the proposals by scientific merit, often considering the details of individual observations. It was recommended to enter observations totalling 3000 hours of time (leaving some to be allocated by the post-launch 'Supplemental Call') into the Mission Database in two priority classes. Additionally, another lower priority 3000 hours of observations were identified for entry in order to help the Mission Planning system to maximise scientific usage of ISO.

In Phase 2 of the programming process, Guaranteed Time observers and the successful Open Time proposers were requested to enter their data into the Mission Database. They were invited to visit either the Proposal Data Entry Centre (PDEC) at ESTEC in Noordwijk, The Netherlands (mainly European and Japanese observers), or the equivalent centre at IPAC in Pasadena, USA (mainly US observers). Both centres provided visitors with a range of software support tools (astronomical and technical), and ISO experts were continuously on hand to provide assistance in optimising the observing programmes. Details of the observations, such as instrument and sub-instrument, source coordinates, filters, wavelength ranges, expected fluxes, and desired signal-to-noise ratio, were entered into the Mission Database using the Proposal Generation Aids (PGA) software. PGA checked the input parameters for validity at the time of entry and then calculated how much time would be needed for each observation. Another system, Proposal Handling, made further checks to ensure that only valid and feasible observations were passed on to the Mission Planning software. The interaction with observers proved to be extremely useful in helping the SOC staff to gain a better understanding of the various programmes.

PDEC and IPAC were open from December 1994 until the end of July 1995. During that time, full details of over 32 000 observations arising from about 800 proposals were entered. At PDEC, there was a total of 540 visitors and for part of the time, the centre was operating at its maximum capacity of 30 visitors in parallel. Figures 3 to 5 give some statistical information from the Database, when most of the observations had been entered.

After the end of the in-orbit performance verification phase, it may well be necessary to modify the observing programme in light of the achieved performance. Depending on the volume and complexity of the changes, either these will be done by the SOC staff (in close contact with the observer) or the PDEC will be re-opened so that observers may update their own programmes directly. Another possibility under consideration is remote log-in to PDEC by observers.

It is planned to issue a Supplemental Call for Observing Proposals some time in the second quarter of 1996; a procedure similar to that used for the pre-launch Call will be followed.

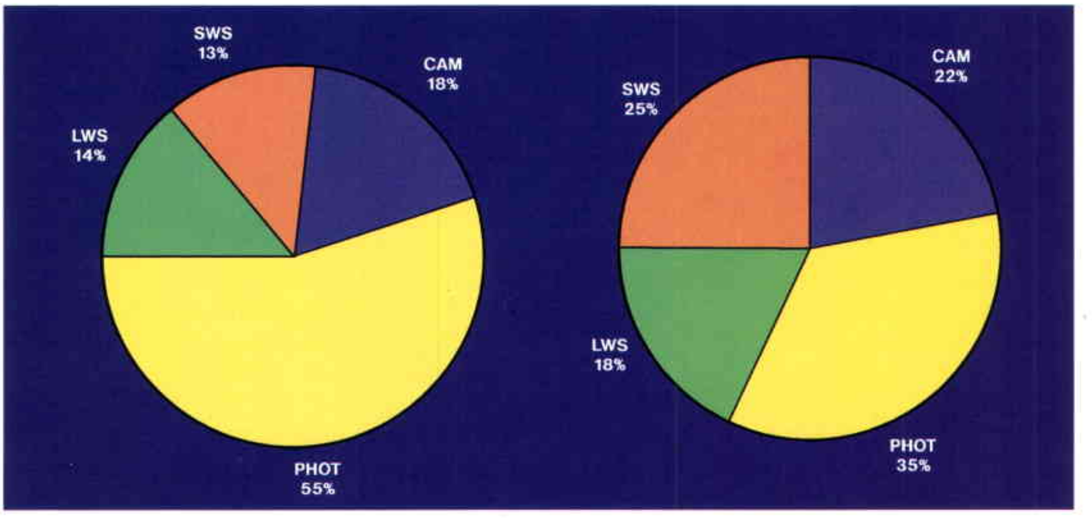



**Figure 3. ISO instrument usage by number of observations (on left) and by time (on right)**

## Observing modes

The standard observing mode for the spacecraft will be three-axis-stabilised pointing at a selected target for a period of up to 10 hours with an accuracy of a few seconds of arc. In addition to this single pointing, the satellite has an on-board capability to point sequentially at a user-specified rectangular grid of positions on the sky. This is known as 'raster pointing' and enables mapping of a larger area of the sky.

There are several ways of scheduling observations using the scientific mission planning system, MPP1 (Mission Planning Phase 1). The system treats each observation as a separate, schedulable element. If there is a scientific reason why two or more observations should be carried out contiguously in time, the observer may 'concatenate' them and force MPP1 to treat then as one observation. This facility has been used quite extensively, with about 50% of the observations being in concatenated chains.

It is also possible to request that an observation is carried out at a specific 'fixed' time. This is to permit, for example, observations of variable or periodic phenomena at specific times or co-ordinated observations with other facilities. However, it may not always be possible to carry out such observations due to the sky-coverage constraints. Also, such observations restrict the efficiency of the scheduling process; thus, the use of this facility will be restricted to absolutely essential cases. Currently, about 2000 observations are flagged as fixed time.

Another method of scheduling is using linked observations. A linked observation is composed of an initial exploratory or test observation that determines whether, and in what form, a more in-depth science observation (main) should subsequently be performed. This facility exists for cases where the source properties are so poorly known that there is a significant risk of wasting ISO time with the wrong instrument settings. Because of the extra demands it places on ground

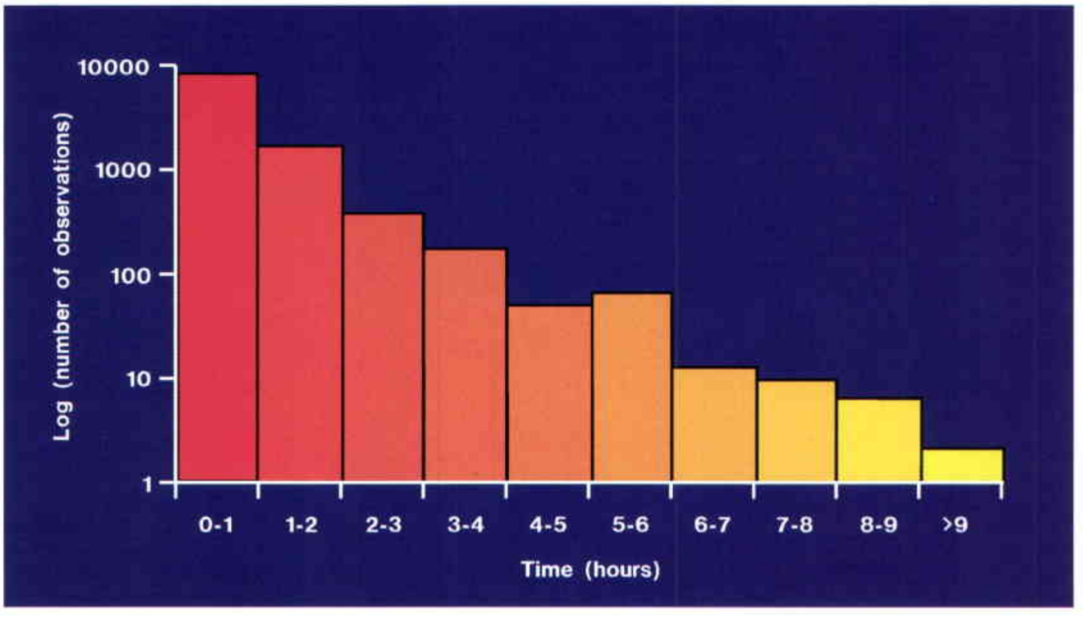



**Figure 4. Distribution of number of observations against time (note the logarithmic scale)**

segment resources, a strong scientific justification is necessary for all linked observations.

Each of the four instruments on the spacecraft has many possible operating modes. To simplify the user interface, so-called Astronomical Observation Templates (AOT) have been defined for the astronomically-useful modes of the instrument. Each AOT is designed to carry out a specific type of astronomical observation. The LWS instrument has four such observing modes, SWS four, ISOCAM four, and ISOPHOT eleven. The AOT acts as an interface between the instrument and the observer. It allows users to specify their observation in terms familiar to them; the software (the AOT logic or AOTL) then generates directly and automatically the necessary spacecraft and instrument commands to be sent to the satellite.

The duration of an observation is calculated by determining exactly how the instrument will execute that set of measurements. To achieve this, the AOTL software needs not only the parameters filled in by the observer but also various tables of instrument and calibration parameters and logic on how to command the instrument. The use of tables simplifies the process of updating the system as knowledge of the calibration of an instrument, for example, changes. The Proposal Generation Aids software, used by the observer, calculates observing times using the AOTL.

### Operations overview

The limited lifetime of ISO, the severe sky-coverage constraints, the complexity of the scientific instruments, together with the necessity to make many short observations, dictate that a pre-scheduling operation must be carried out in order to maximise the time spent acquiring useful astronomical data. The staff at the SOC will schedule the different observations within a proposal so as to optimise the overall usage of the facility.

Once in orbit, ISO will be operated from ESA's Villafranca Satellite Tracking Station, which is also the European home of the IUE observatory. Two ISO teams are co-located there: one is responsible for the operations of the spacecraft and the other, the Science Operations Team, is responsible for all aspects of the scientific operations ranging from the issue of the 'Calls for Observing Proposals', through the scheduling and use of the scientific instruments, to the pipeline data processing in which the data products for distribution to the observers are generated. A simplified overview of the SOC's activities is given in Figure 6.

The main purpose of the scientific mission planning system MPP1 is to construct, for each ISO orbit, the sequence of astronomical observations that are to be carried out. It has to make a trade-off between maximising the overall observational efficiency and performing those observations with the highest scientific priority. The main inputs to MPP1 are information on sky visibility and the observations, including priorities, contained in the Mission Database. The efficiency of the schedules is increased when MPP1 works from a database containing more observations than can be made in the available time. Its main outputs are (a) a file, named the Planned Observations File (POF), that contains the time-ordered list of scheduled observations, with an exact time at which every group of commands must be sent to the instruments

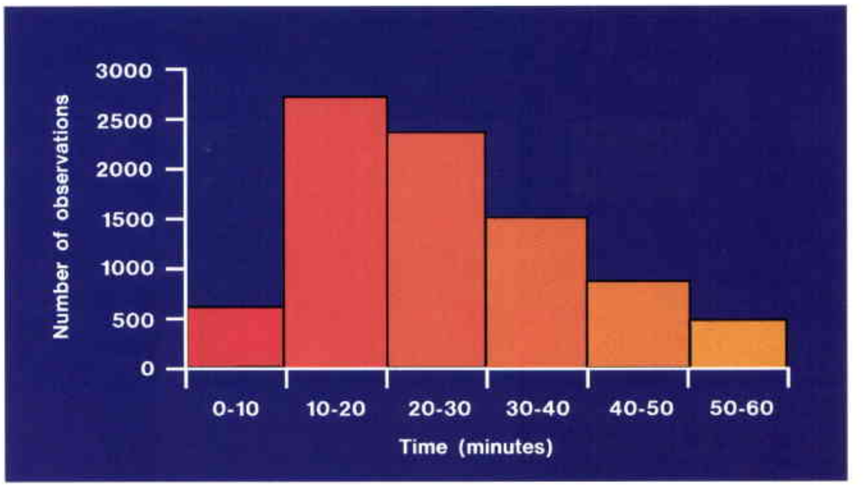



**Figure 5. Expansion of Figure 4 showing the distribution of number of observations against time for observations less than one hour. (Note that the scale is now linear).**

and/or the spacecraft, and (b) a second file, named the Instrument Command Sequence File (ICSF), that gives the details of the groups of instrument commands called up in the POF. These two output files are passed on to the Spacecraft Control Centre at least three days in advance for further processing, leading to the production of a Central Command Schedule containing all necessary spacecraft and instrument commands.

The observations will be carried out under the supervision of SOC staff in a 'service observing' mode. Observers are not expected to be present for their observations. The commands in the Central Command Schedule will be sent automatically to the satellite at the specified times. Overall safety of the spacecraft and instruments is the responsibility of the Spacecraft Control Centre. The SOC will monitor some aspects of the instrument performance and scientific data in real time.

The calibration and processing of ISO data will be a major task. ISO is a complex instrument with over 20 operating modes and a data

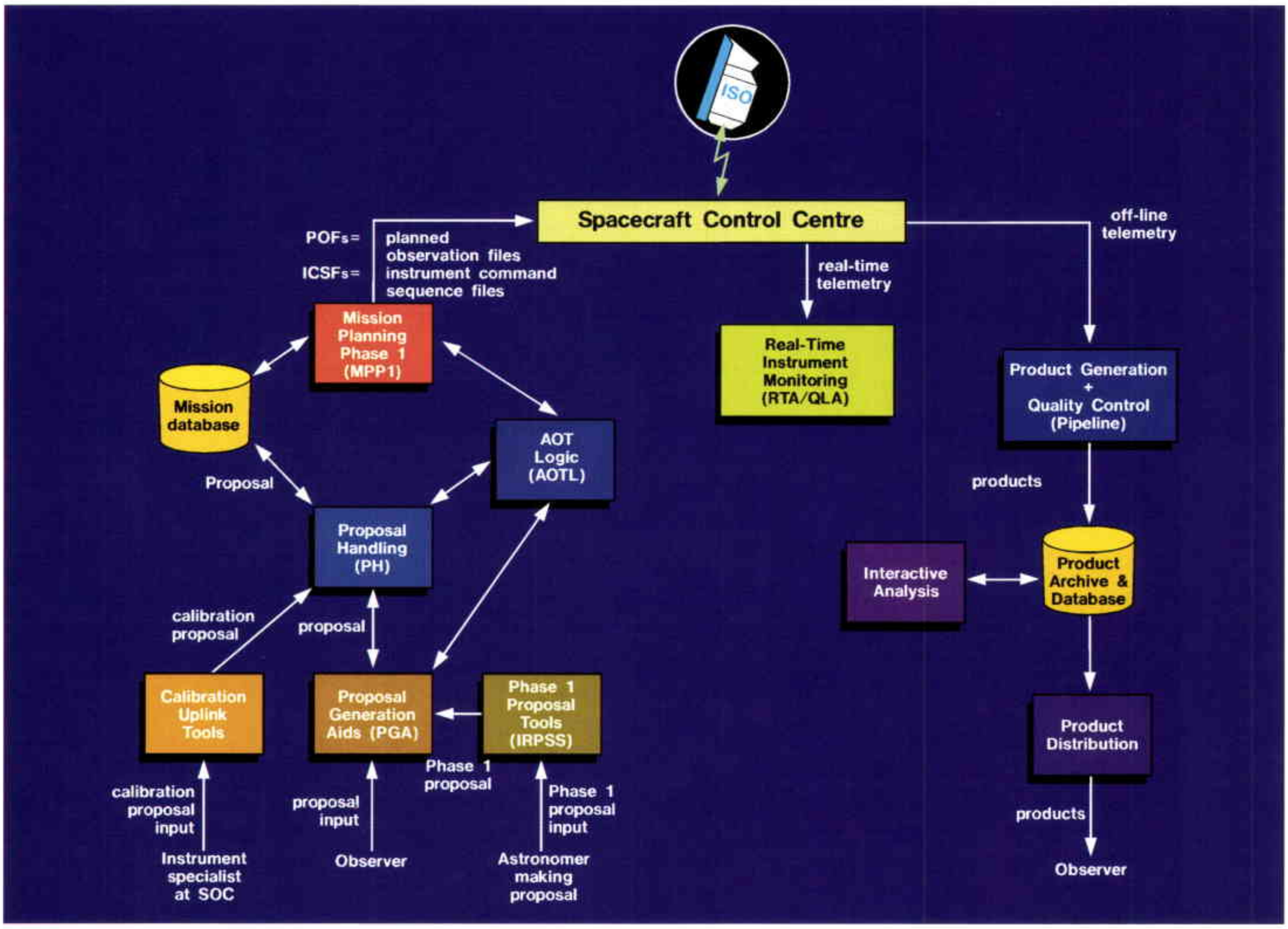



**Figure 6. Simplified overview of the SOC's activities**

volume of about 1 Gb per day. Infrared detectors with such a high sensitivity are intrinsically not well behaved, showing various non-linearities and memory effects, and having time-dependent calibrations. In addition, operating conditions in space are very different to those in the laboratory, for example, the effects of impacts from cosmic rays must be considered. The knowledge of how to calibrate and reduce the data will increase during the mission and the associated software will have to evolve strongly from the launch system. Changes in calibration impact all areas of science operations from the planning of the observations through the real-time data assessment to the off-line pipeline processing. Thus, each of these systems has been designed to allow changes to be made as easily as possible.

The off-line data processing can be thought of as a 'pipeline processing' system plus an 'interactive analysis' facility. However, the two are not separate systems and have many common features. The interactive analysis system will be mainly used for characterisation and calibration analysis of the instruments; and for working out how to upgrade the pipeline processing. The pipeline processing will produce a standard set of products from each observation. The observers are responsible for the scientific analysis and interpretation of their data. Thus, the goal of the pipeline processing is to provide observers with data in a form with which they can work without an unnecessarily deep knowledge of the specifics of the ISO instruments. Per observation, all observers will receive:

— Edited Raw Data: This is a very low level data product, essentially reformatted telemetry consisting of raw (or minimally-processed) instrument data.
— Standard Processed Data: This is the data product from which it is expected that the majority of observers will work. Its derivation involves certain calibrations and the removal of instrument-specific peculiarities. The intention is to make standard processed data a self-contained product, screening general observers away from the more esoteric raw data while still offering them flexibility in data analysis at their home institutes.
— Auto Analysis Results: This product is some specific extracted scientific results from the data to give an indication of what will be found when the observers make their own detailed analyses.

**Entering observation data into the Mission Database at the PDEC**

These data products will be supplied on CD-ROM in FITS format, and it is planned to dispatch them to the observers within one to two weeks of the observation.

All products distributed will also be stored in the ISO archive. The Principal Investigator for an observation has exclusive rights to the data for one year, starting from the time at which an adequate calibration is available. At the end of this proprietary period, the data enters the public domain and can be used for archive research by the scientific community.

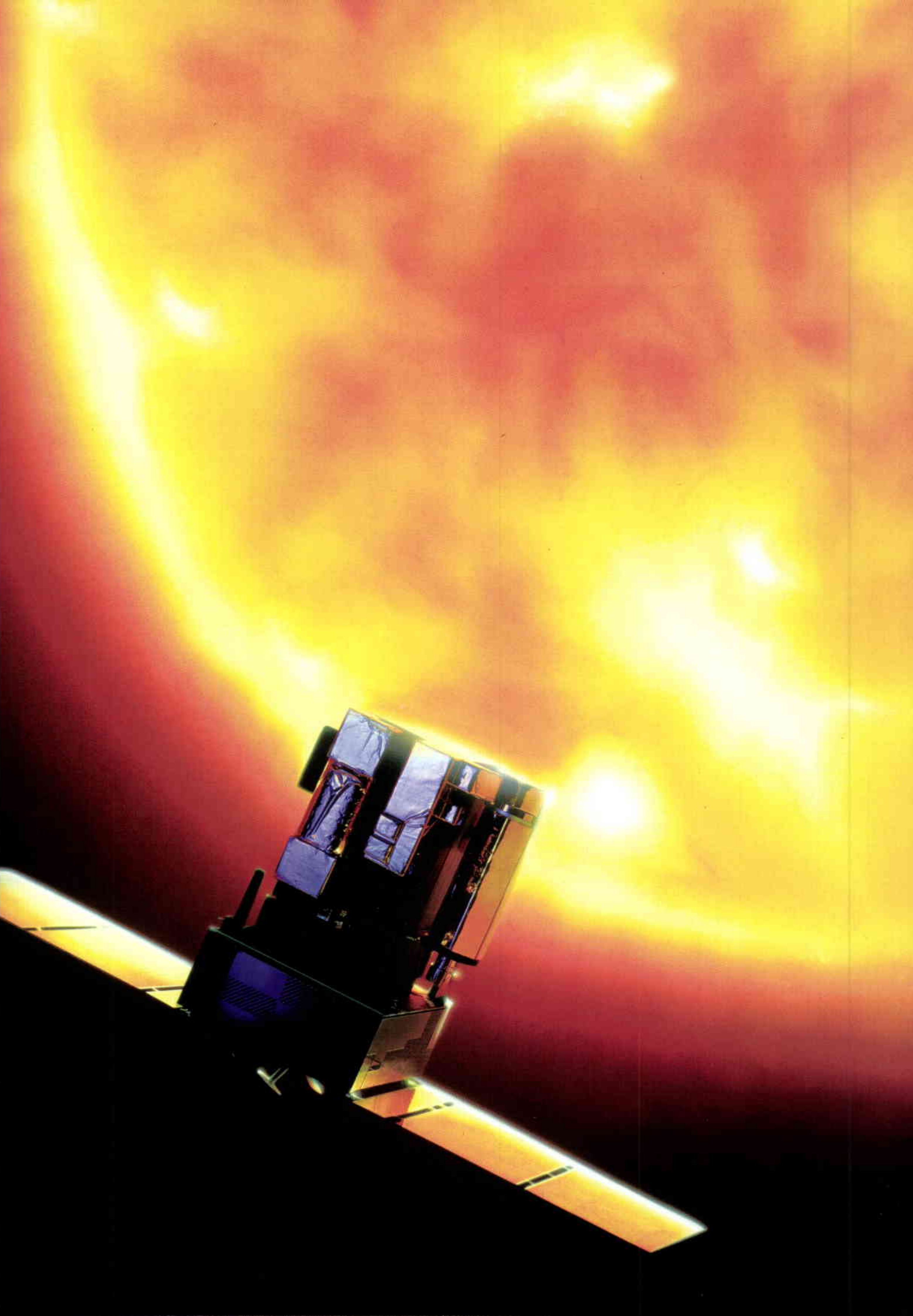
Since it is expected that the understanding of the behaviour and performance of the instruments will improve as the mission progresses and the associated data reduction and processing will evolve greatly, the data archive will be somewhat inhomogeneous by the end of ISO's in-orbit operations. During a post-operations phase of several years, the entire data set will have to be systematically reprocessed using the best available knowledge of instrument calibrations and data reduction techniques.

**Summary and conclusion**

ISO will be operated in a service observing mode with each orbit's observations being planned in detail and finalised at least three days in advance. SOC staff will supervise both the conduct of the observations and the quality of the data products, which will be sent to the observer on CD-ROM in FITS format within one to two weeks of the observation being carried out. After a one-year proprietary period, the data enter the public domain for archive observations. After the end of the in-orbit operations, the entire data set of ISO will be re-processed in a homogeneous manner.

The observing programmes of ISO, in both the Guaranteed and Open Time, have been established in a two-phase process. Full details of over 32 000 observations have been entered into ISO's Mission Database, have been carefully checked for validity and feasibility, and are ready for execution.

The world-wide user community now awaits eagerly ISO's launch and the first data from its unique instrument complement.



# The SOHO Project: An International Challenge

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## Introduction

By the end of this year, the SOHO mission will start yielding the technical and scientific rewards that it was conceived for more than ten years ago. At this point, shortly before the launch, it is perhaps useful to briefly recount the events that have seen the goals and concepts laid down in the early eighties transformed into a complex satellite weighing about two tons and fulfilling the ambitions of twelve groups of scientists working in three solar-science disciplines.

Articles in previous ESA Bulletins have dealt with various aspects of SOHO and its development (e.g. No. 71 in August 1992, and No. 82 in May 1995), and the accompanying SOHO articles in this issue describe the most important elements and features of the mission in more detail. We will focus here on management aspects and, in particular, the multiple roles of the Project Team in the evolving life and needs of an international cooperation such as SOHO, which embodies several facets that are unique in the history of the European Space Agency.

## The mission's beginnings

The widely differing missions of the SOHO and Cluster spacecraft have one goal in common: to understand the physical structures and processes in the plasma that makes up the solar-terrestrial system, i.e. the Sun, the solar wind and the terrestrial magnetosphere. Both SOHO and Cluster were proposed — initially in competition — in November 1982. Given their common aim, to be pursued in different contexts and by different methods, both missions were subsequently included as a Cornerstone called the Solar-Terrestrial Science Programme (STSP), in ESA's Horizon 2000 Programme. This long-term scientific programme was approved by ESA Council, meeting at Ministerial Level, in early 1985. ESA's Science Programme Committee (SPC) then selected STSP in November 1985 as the first Cornerstone to be implemented. At that time, the SOHO mission had undergone assessment and Phase-A studies, the latter with two competitive concepts for the spacecraft bus developed by British Aerospace, Bristol (UK) and Matra Espace, Toulouse (F) (now both part of Matra Marconi Space).

SOHO's complex multi-disciplinary payload, which included novel experiments in the then still relatively young solar discipline of helioseismology, was being conceptually developed in parallel. This parallel development provided the correct foundation and interfaces for the industrial studies and the further contractual steps that the Agency would need to take vis-a-vis industry.

The eventual outcome of all of the foregoing activities was an ESA Solar Terrestrial Science Programme, or STSP, which however exceeded the European budget allocated to it at the time of selection. The STSP Programme Manager and the SOHO and Cluster Project Managers therefore initiated a dialogue with NASA on the possibility of their contributing in terms of the scientific payload, the onboard equipment or other mission elements (launcher, operations, etc.). Certain cooperative elements were identified as early as 1986 and potential US industrial suppliers were visited by NASA and ESA representatives. This activity led to an inter-agency Memorandum of Understanding (MOU) defining the framework and principles of the proposed cooperation between ESA and NASA. This was followed by a lower-level Programme Plan laying out the details of the MOU's implementation (deliverables, schedules, management guidelines, etc.).

This agreement with NASA, together with the descoping and rationalisation of several aspects of the mission and its payload, brought SOHO and Cluster within the allowable financial envelope. This in turn cleared the way for the industrial tendering phase. In the meantime, the overall STSP payload had been selected in March 1988, also after extensive discussion and descoping under the aegis of two scientific committees led by Profs. H. Balsiger and D. Southwood. All of the elements were then in place to initiate a joint Invitation-to-Tender (ITT) to European industry.

## The mission takes shape

After the issue of the STSP Invitation-to-Tender to industry, the two separate Project Teams for SOHO and Cluster were built up. These teams were each faced with a complex array of specific interfaces, coupled with the triple constraints of simultaneously containing cost, risk and schedule: i.e. maximum use of competitive procurement as the principal means of reducing initial costs; geographical industrial return balanced on an STSP-wide basis; and implementation of joint SOHO/Cluster developments and procurements wherever possible.

These three industrial-policy precepts were also applied in the selection of the industrial subcontractor teams for SOHO and Cluster.

The submission of the industrial Phase-B proposal was followed by an extensive evaluation by senior ESA management of all cost and schedule, management and contract, product assurance, technical, and test-facility aspects. Phase-B then began in December 1989.

The selection of the industrial teams at lower levels was pursued through a series of proposal and evaluation cycles, with the close involvement of the two ESA Project Teams and their Prime Contractors. The result was a good matching of the final industrial organisation with the mandatory geographical return, with limited fragmentation of tasks and interfaces vis-a-vis what would have resulted from the application of geographical-return considerations to the two projects (SOHO and Cluster) separately.

## The building of the satellite

### The industrial interface

A novel feature of the SOHO programme has been the multiplicity of its interfaces across several widely geographically separated organisations (Fig. 1). The first, and financially most relevant interface for the SOHO Project Team has been that with the industrial grouping led by Matra Marconi Space (France), which has developed, built and tested the SOHO spacecraft during the main development phase (Phase-C/D). In this domain, the contractual relationship between ESA and the Prime Contractor has differed little from previous scientific projects. A 'cost-plus' contract with a target cost and a 'neutral zone' was defined at the start of Phase-C/D and updated as the project evolved, with a series of Change Review Boards.

Overall progress and the resolution of the inevitable technical problems along the way have been closely monitored both by the Project Team and our colleagues from ESTEC's Technical Directorate, in a classical 'shadow engineering' role.

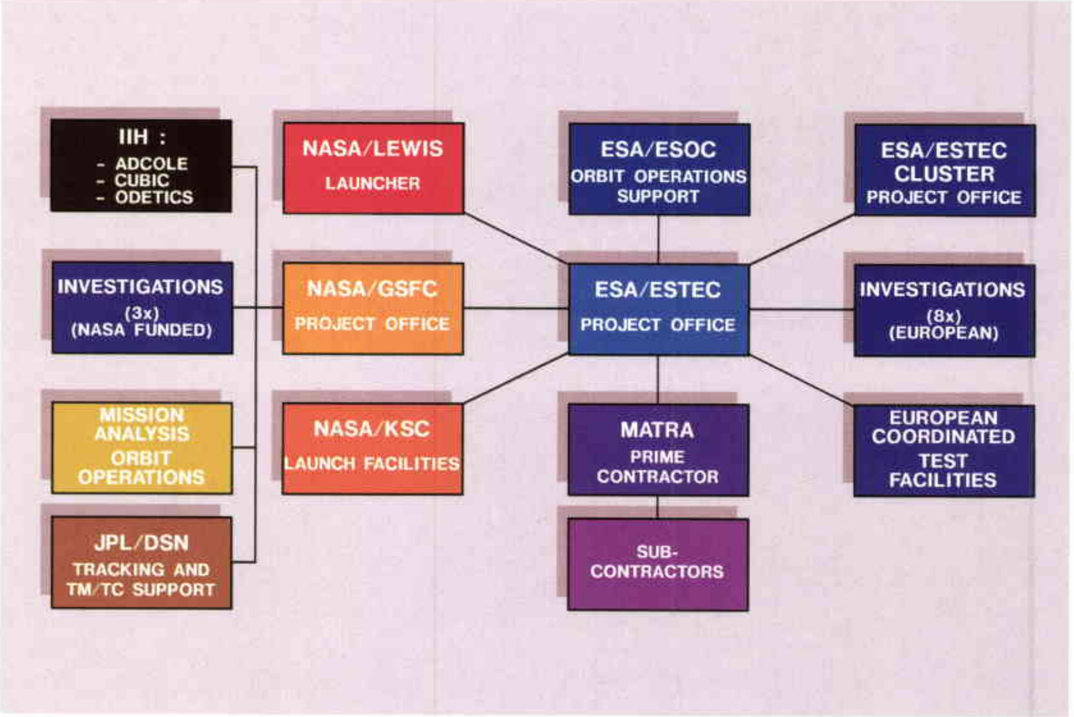



**Figure 1. The SOHO mission elements**

On several occasions, commercial-confidentiality claims were invoked and the SOHO team had to strive to balance those constraints with sound follow-up and evidence of technical acceptability, finding ad-hoc solutions agreeable to all parties involved.

SOHO's test campaigns were conducted using the 'coordinated European test facilities', requiring interfacing with the IABG, Ottobrunn (D) and Intespace, Toulouse (F) facilities for the structural-model and flight-model test campaigns, respectively. In this phase, the Project Team received dedicated resident support from ESTEC's Test Division.

The most demanding interfacing effort, however, was undoubtedly that between ESA and the Prime Contractor in order to cope with the large and complex payload that was finally selected for SOHO. The high number of separate experiment units – 32 in all – unavoidably brought delays in the definition of exact interfaces between the instruments and the spacecraft bus. A formal control over variations and changes to the Experiment Interface Document was established at the outset. Each Experiment Team request was evaluated by the relevant Project Team experts and, if found valid, passed to the Prime Contractor for comment before a final ESA decision on implementation.

One area in particular where some difficult decisions had to be made at certain stages was the management of the experiment mass budgets. Thanks to the early introduction of formal control procedures, the original payload allocation of 610 kg needed to be increased by just 40 kg by the time that the final flight models of the experiments were delivered.

Another area of difficulty in terms of experiment-interface management was the difference in standards between US experiment Electrical Models (EM) and the European equivalents. The generally lower electrical fidelity of the US models resulted in an EM test campaign somewhat lacking in EMC representativeness, and also led to a mismatch in the completion of development of these units. This had repercussions, particularly in the case of the UVCS instrument, on the evolution of the flight-model test programme.

Another element that required a considerable coordination effort was the handover of the structural and thermal mathematical models from the twelve Experiment Teams to the industrial team. As Agency deliverables, all of these models had to be checked by ESTEC specialists for consistency and compatibility.

The primary preoccupation of the ESA Project Team throughout these efforts was to provide for the maximum of scientific results from the mission whilst keeping costs and schedule under strict control. A good example in this respect is the work done on minimising the effects on short-term spacecraft pointing of moving parts of the spacecraft (reaction wheels, tape recorder) or experiments (mechanism actuation), the so-called 'jitter'. This was addressed by a Pointing Review Board, periodically attended by experimenters, industry experts and the ESA Project Team; during these meetings the results of analyses (initially) were discussed and further steps proposed. This open approach led to improved balancing of SOHO's reaction wheels, to a series of tests on specific experiments and, finally, to an end-to-end test on the flight model in January 1995. The result is a common consensus that all possible measures have been taken to make the jitter as low as is technically feasible within the cost and schedule constraints on the project, and compliant with the scientific objectives.

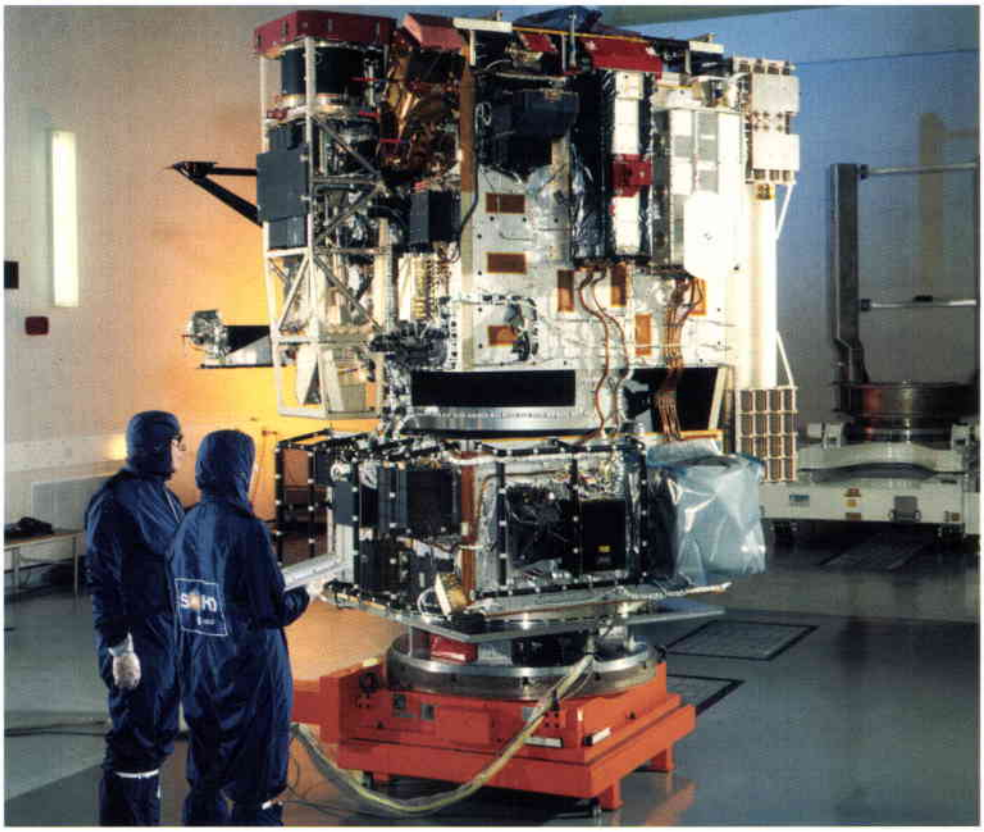


**Figure 2. The SOHO spacecraft, photographed at Matra Marconi Space in Portsmouth (UK)**

### The NASA interface

Another element of the SOHO programme which has called for substantial managerial effort has been the relationship with NASA. As in other cooperative programmes between the two agencies, no exchange of funds was foreseen and decisions affecting both parties had to be taken by consensus. Nevertheless, SOHO is the first such cooperative programme in which overall mission responsibility rests with ESA. This in turn has meant that the Project Team has had to interface with three separate NASA centres:

- Lewis Research Center (LeRC), for the interfaces to the launch vehicle, supplied by General Dynamics (now Lockheed-Martin)
- Kennedy Space Center (KSC) for the pre-launch ground operations, and
- Goddard Spaceflight Center (GSFC), which has supplied the three US-led experiments and hardware items, and provides operational support ranging from flight dynamics to the interfaces with the Deep Space Network, and the feeding of information to the Flight Operations Team (FOT). This NASA-led team of contractors will operate the spacecraft from GSFC, in close liaison with the Experimenter Teams, who will operate their experiments in so-called 'quasi-real-time' command mode.

The first two interfaces, with LeRC and KSC, have followed the normal evolution of such relationships, based on progressively more detailed requirement and interface documents. The Launch Vehicle Interface Control Document, for example, passed through several drafts before its publication as a formally configured document. The spacecraft mechanical qualification tests, the separation shock test and the final matching and mating with the SOHO-specific launch adapter, all of which were conducted in Europe, were typical examples of the excellent co-operation with LeRC and Lockheed-Martin, whose representatives were present to witness key launch-vehicle/payload compatibility tests.

The services offered by NASA at KSC were also agreed through a series of Ground Operation Working Group meetings, at which all contributing parties from Europe and the USA were present. These resulted in an ESA-produced Launch Operations Plan and Launch-Site Support Plan detailing the complex allocation of tasks between the US Air Force (supplier of the launch pad), the contributing elements of the KSC system, and the NASA industrial contractors.

Finally, the multiple GSFC interfaces absorbed a considerable amount of time, particularly at management level, for the SOHO Project Team. The three US experiments are in fact among the largest and most complex of the whole SOHO complement and their progress was therefore closely followed in the Quarterly ESA/NASA Management Meetings that have taken place during Phase-C/D.

Another novel interfacing aspect has stemmed from the fact that ESA is in charge of a mission for which the operations support is provided by a team and a facility not under its full direct control. This has required specific and continuing attention, particularly in terms of the transfer of knowledge of the spacecraft systems from the Prime Contractor and ESA to the Flight Operations Team, constituted by NASA contractors from Allied Signal.

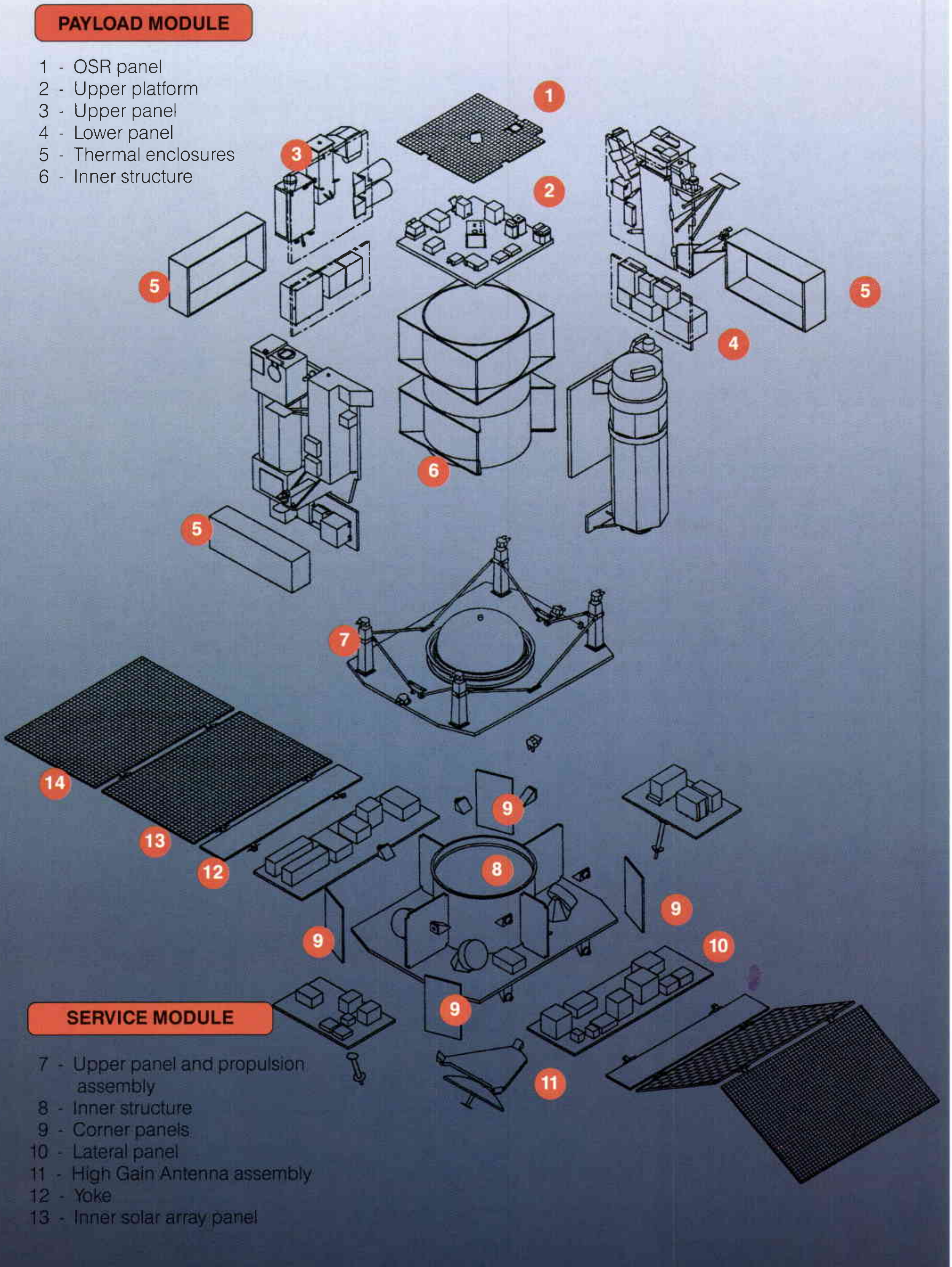
Mission and Science Operations Working Groups, meeting several times per year, have been the typical forum in which these exchanges have taken place. The main formal vehicle for such exchanges has been the Spacecraft Users Manual issued by Matra Marconi Space, which documents all necessary technical aspects of the spacecraft and includes those experiment procedures under the direct control of the Flight Operations team.

The critical cycle of familiarisation of the US team with a spacecraft and its experiments sitting on the other side of the Atlantic, six time zones away, has been accomplished through a series of three carefully planned ground-segment compatibility tests, each lasting one to two weeks. A fourth and final test involving GSFC and KSC was conducted during the launch campaign. During these tests, the spacecraft and its payload has been commanded from GSFC by the same teams that will operate it in space, using the same ground hardware and software procedures. In this case also, the ESA Project Team has been the coordinating element between industry and the NASA infrastructure and Flight Operations Team.

**Acknowledgement**

The fact that a set of interfaces so complex has been handled so successfully on a true partnership basis is to the credit of both agencies and also to the flexibility constantly shown by the industrial partners in accommodating the ever-changing situation when building and launching a spacecraft of the size and complexity of SOHO.

Figure 1. The SOHO spacecraft, showing the Payload Module (PLM) and Service Module (SVM) elements



# The SOHO Spacecraft

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## The spacecraft

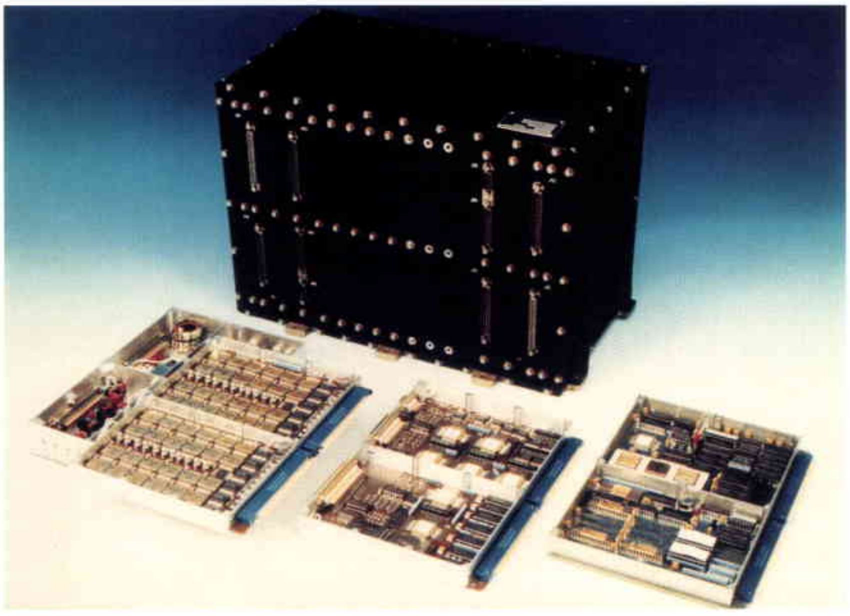
The SOHO spacecraft consists of two major elements (Fig. 1), the Service Module (SVM) and the Payload Module (PLM).

The Service Module is a box-shaped structure made of aluminium honeycomb panels attached to a corrugated aluminium cylinder by four shear webs. The four lateral panels carry the data-handling, communication, attitude and orbit control, and power subsystems. The box's upper floor houses the propulsion subsystem, tank and thruster masts. The high-gain antenna is mated into the aft part of the central cylinder.

The Payload Module provides an optical bench for the experiments and is composed of four upper lateral panels and a top panel connected to a central cylinder by a number of shear webs. The bottom section, consisting of three lower lateral panels connected to the central cylindrical tube by a number of shear webs and floors, houses the PLM electronics.

SOHO's nominal operational lifetime is 29 months, including the four months of the transfer phase and one month of in-orbit commissioning. It carries sufficient onboard propellant for six years of operation. The main spacecraft performance parameters are given in Table 1.

Figure 2. The CDMU's solid-state memory



## Thermal architecture

The PLM's thermal-control subsystem maintains all equipment mounted on the PLM structure within acceptable temperature limits and provides a stable thermal environment to meet all pointing requirements. Temperature control for both the PLM and SVM is provided with dedicated adjustable heaters. Substitution heaters replace the heat inputs of the experiments at times when the latter are switched off.

Critical spacecraft elements are temperature-stabilised by adjusting the heaters to compensate for seasonal variations and ageing. The temperature of the front sunshield assembly, for example, will be maintained to within $\pm 1°C$ for two months.

The PLM/SVM interface will be maintained at $20°C \pm 2.5°C$ in order to limit any deformation of the PLM structure.

## Data handling

The heart of this subsystem is a Central Data Management Unit (CDMU) responsible for:

- data acquisition and transmission to the ground
- decoding and distribution of commands to all users
- data storage (by either tape recorder or solid-state recorder; Fig. 2) during non-visibility of SOHO from the ground
- onboard processing.

The packet telemetry is used in conjunction with convolutional and Reed-Solomon encoding.

Three remote terminal units under the supervision of the CDMU provide the necessary interfaces to the users. Universal time (UTC) is generated on board by an ultrastable oscillator, and distributed to the experimenters.

Automatic failure detection and reconfiguration is provided and vital spacecraft parameters are retained in a special 'context memory'.

**Attitude and orbit control**
The Attitude and Orbit Control Subsystem's (AOCS) overall task is to provide the SOHO spacecraft with the requisite pointing performance during the various spacecraft activities as the mission evolves from SOHO's separation from the Centaur upper stage until and throughout its mission as an operational space solar observatory in a halo orbit around the L1 Lagrangian point, 1.5 million kilometres from Earth, for up to six years.

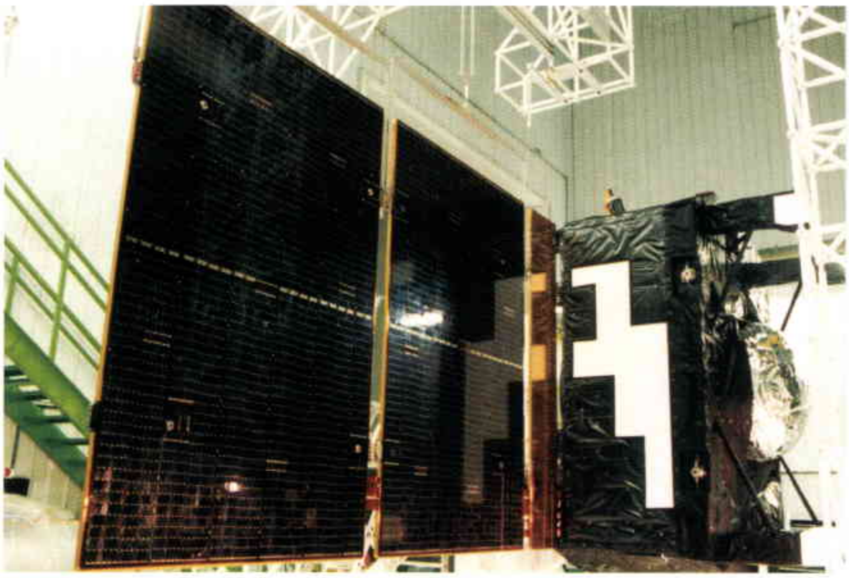


Figure 3. Deployment testing of SOHO's solar arrays, at Intespace in Toulouse (F)

Immediately after SOHO's separation from the Centaur upper stage, the AOCS will cancel the angular rates imparted by the separation and will coarsely align the spacecraft towards the Sun using hydrazine thruster and Sun-acquisition sensors arranged in a configuration giving omni-directional coverage. The control algorithms reside in the memory of an onboard microprocessor that processes the sensor data and issues commands to the thrusters.

SOHO's solar panels (Fig. 3) will subsequently be deployed with the AOCS in stand-by configuration. After full solar-panel deployment has been achieved, the AOCS will again coarsely point the spacecraft at the Sun and perform the transition to fine Sun pointing and roll-angle control using a fine-pointing Sun sensor (Fig. 4), a star tracker and three reaction wheels. It is in this configuration that the payload instruments will make their scientific observations, when the spacecraft's pointing towards the Sun is stabilised to within a few tenths of an arcsecond under quiescent conditions, i.e. when no spacecraft or experiment mechanism is being operated, or within about one arcsecond when some mechanisms are active to, for example, realign the spacecraft's high-gain antenna or to adjust an experiment's line of sight.

**Power**
The power subsystem provides regulation, protection and distribution of 1500 W of solar-array power, supported by two 20 Ah nickel-cadmium batteries. The main spacecraft power bus is regulated to 28 V ± 1% with a three-domain regulation of solar-array shunt mode, battery discharge and battery charge mode. All power lines to users are protected by latching-current limiters.

Decentralised undervoltage protection is provided in each Latching Current Limiter (LCL), which provides automatic switch-off if the input voltage falls below 23.5 V + 1V. In the event of a main-bus undervoltage, the system automatically enters a safe mode by switching off all LCLs until the main bus recovers. In addition, foldback current limiters are provided for some essential loads, as well as regulated battery power for the Kevlar cable cutters.

All electrical power subsystem functions are redundant, including connector redundancy all the way from the solar-array and battery inputs to the power distribution outputs.

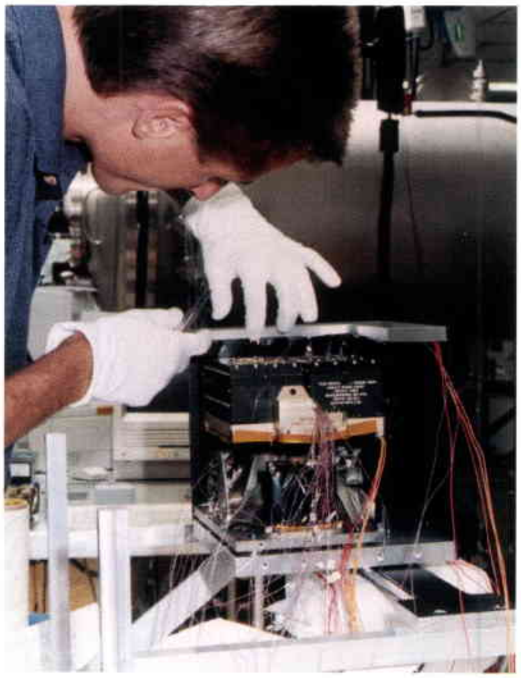
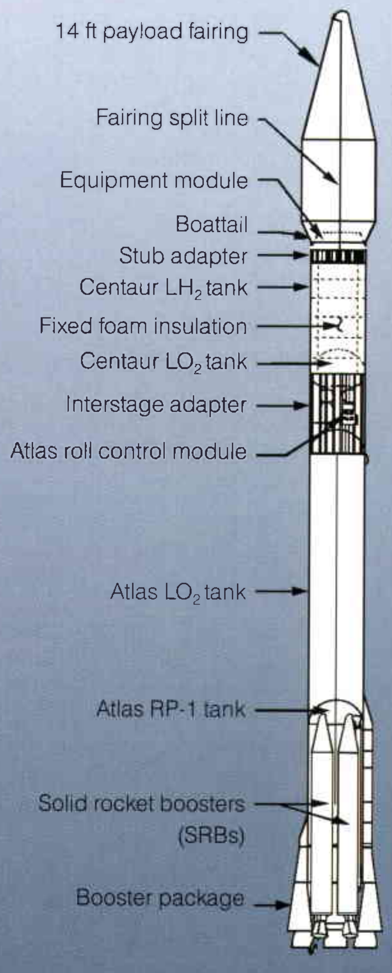


Figure 4. One of the AOCS fine-pointing Sun sensors

*Table 1. SOHO facts and figures*

| | |
|---|---|
| Mission Lifetime | 2 years (consumables for 6 years) |
| **Mass Budget** | |
| Launch mass | 1866 kg |
| Payload mass | 655 kg |
| Onboard propellant | 252 kg |
| Overall dimensions | 2.9 × 2.5 × 3.89 m |
| Payload-Module Dimensions (undeployed solar array) | 2.9 × 2.5 × 2.67 m |
| **Orbit** | |
| Halo at L1 libration point | 1.5 million km from Earth |
| Amplitude x in ecliptic, Earth – Sun | 200 000 kkm |
| Amplitude y in ecliptic | 650 000 km |
| Amplitude z out-of-ecliptic | 120 000 km |
| Orbital period | 6 months |
| **Attitude and Orbit Control** | |
| Pointing: short term | 1"/15 min |
| medium term | 10"/6 months |
| long term | 8' |
| Roll: short term | 32"/min, 90"/15 min |
| long term | 18' to 30' |
| Momentum storage capability | 17 weeks |
| Reaction wheels | 4 |
| Gyroscopes | 3 |
| Fine-pointing Sun sensors | 2 redundant |
| Star trackers | 2 redundant |
| Thrusters | 2 sets of 8 |
| Sun acquisition sensors | 3 internally redundant |
| **Data Handling** | |
| Bit rates | 1.19, 54.6, 214.25 bit/s |
| Command rate | 2 kbit/s |
| Clock stability | $\pm 6 \times 10^{-9}$ |
| Acquisition channel | 992 |
| Command channel | 660 |
| Storage | |
| Tape recorder | 1 gigabit |
| Solid-state recorder | 2 gigabit |
| Central Data Management Unit (CDMU) | redundant |
| Three remote terminal units | redundant |

| | |
|---|---|
| **Power Subsystem** | |
| Solar array (end-of-life) | 50 A min at 28 V |
| Cell type | 2 Ω cm BSR |
| Silicon-cell efficiency (begin-of-life) | 13.2% |
| Rigid panels | 4 (2 + 2) |
| Wing dimensions | 3.66 × 2.3 m |
| Power margin end-of-life | 10% |
| Main bus | 28 V ± 1% |
| Three-domain regulation | |
| Main-bus impedance (shunt BCR – BDR) | 22 mΩ/45 mΩ |
| Minimum user voltage | 26 V |
| Batteries | 2 |
| Type | 20 Ah/32-cell NiCd |
| Energy at 90% DOD | 900 Wh |
| Margin | 152% |
| Latching-current limiters | 4 × 56 (in four PDUs) |
| Foldback limiters | 4 + 4 |
| Cutter drivers | 12 + 12 |
| Keep-alive lines | 12 + 12 |
| Battery Discharge Regulator (BDR) modules | 4 |
| Current | 14.6 A max each |
| Efficiency | 92% (typical) |
| Battery Charge Regulator (BCR) modules | 2 |
| Charge rate | C/20 |
| Charge rate Trickle | C/220 |
| Efficiency | 77% (typical) |
| **Communications** | |
| Downlink frequency | 2245 MHz |
| Uplink frequency | 2067.27 MHz |
| Output power | 10 W |
| High-gain-antenna gain | 22.7 dbi |
| Low-gain-antenna gain | – 31 dbi |
| Polarisation | circular, right and left |
| Bit error rate | 99.999% of source packet delivery |
| Ranging performance | ± 5 cm |
| Link margin | greater than 3 dB |
| **Software** | |
| Data handling | |
| — memory size | RAM 64 kwords<br>PROM 40 kwords |
| — memory margin | 22% RAM<br>12% PROM |
| — context memory | RAM 8 kbyte |
| Attitude control | |
| — memory size | RAM 64 kwords<br>PROM 32 kwords |
| — memory margin | 60% RAM<br>41% PROM |




### The SOHO Launch Scenario

SOHO will be launched on a NASA-provided Atlas IIAS vehicle, composed of a Centaur IIA upper stage, mounted on top of a one and a half stage Atlas IIAS booster. Solid-propulsion thrust augmentation for the Atlas IIAS will be provided by four Thiocol Castor IVA boosters.

The SOHO mission uses a standard ascent profile in which the booster engines, sustainer engine and the first solid-rocket booster pair provide the thrust for lift-off. During the initial vertical rise, the vehicle rolls to the flight azimuth.

After the first pair of solid-rocket boosters burns out, the second pair is ignited and the first pair is jettisoned. The second pair continues until burnout and is also jettisoned. The ascent continues until booster-engine cut off (BECO).

Atlas flight then continues in the sustainer phase until propellant depletion. The payload fairing is jettisoned in the guidance steering phase.

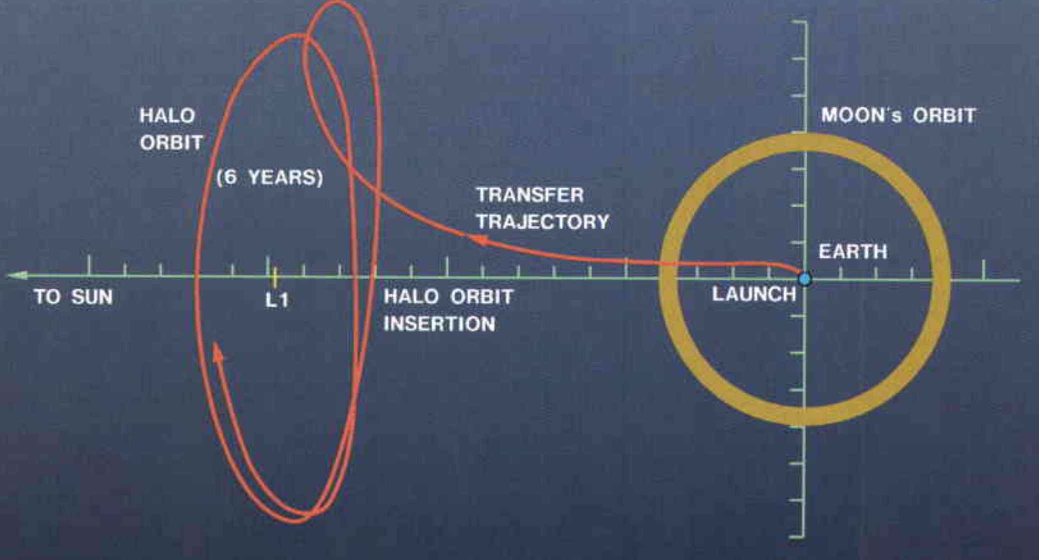
After sustainer engine cut-off (SECO), the Centaur stage separates and ignites in a first burn, the longer of the two Centaur burns needed to inject the vehicle into a parking orbit. During the first Centaur burn, the instantaneous impact-point trace progresses across the Atlantic Ocean and crosses the equatorial region of the African Continent.

After the Centaur first burn main-engine cut off (MECO 1), the Centaur and spacecraft composite enters a coast period. The parking-orbit coast duration varies as a function of the launch date throughout the year.

At an onboard-computer-calculated start time, the Centaur engines are re-ignited (MES-2) and the vehicle is guided into the desired transfer orbit.

Following shutdown of the second burn (MECO 2), the Centaur rolls for a 30 min coast prior to separation. For spacecraft separation, its +Z-axis must be located in the plane containing the spacecraft, Sun and Earth centres, such that the spacecraft's −Z-axis points towards the Earth.

During the subsequent four-month transfer phase, two mid-course manoeuvres using the onboard propulsion subsystem are expected to be needed for the correction of any injection errors and final tuning of the transfer trajectory.



### Telecommunications
The SOHO spacecraft will be tracked with the 26 m antenna of NASA's Deep-Space Network. The links between the spacecraft and ground will be provided by an S-band RF system, with duplicated receivers and transmitters. RF coverage is provided by a pointable high-gain antenna and two low-gain antennas, to ensure the full coverage.

### Antenna pointing
SOHO's High-Gain Antenna (HGA) assembly is composed of a 0.8 m-diameter antenna and associated mechanisms (Fig. 5). During launch, the HGA is rigidly attached to the spacecraft and is released only after spacecraft separation. The halo orbit requires that the HGA be capable of pointing in all directions within a ±32° cone.

### Software
The data-handling central onboard software (written in ADA) resides in a 16-bit computer (MAS 281) that uses the 1750A MIL Standard Instruction Set and contains a set of programs controlling the data handling. The central onboard software will play a pivotal role in performing a variety of functions, including telecommand and telemetry management and numerous application programme tasks. It manages and distributes the onboard time, performs the thermal monitoring and thermal control of the satellite, manages the antenna pointing and monitoring, handles the inter-instrument data exchange, performs various other monitoring functions, and executes the initial Sun-acquisition sequence.

The attitude and orbit control software resides in a similar 16-bit computer and obtains outputs from the spacecraft's attitude sensors in order to provide commands to the attitude-control actuators, after processing the digitally implemented control algorithms. In addition, it organises the data for telemetry communication and processes the telecommands.

### Modes of operation
At lift-off, the spacecraft will be powered by the batteries, the data handling will be powered, and the Service Module will be thermally controlled. Both gyroscopes will be on and their temperatures controlled.

After SOHO's separation from the launcher, the spacecraft's attitude-control and communications subsystems will be activated. The low-gain antenna will be used for communication with the NASA Deep-Space Network (DSN). The initial Sun acquisition will be performed.

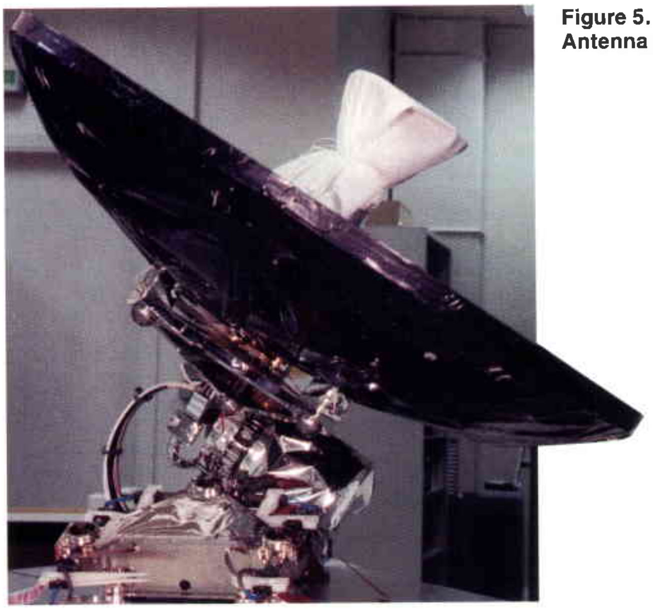


**Figure 5. The High-Gain Antenna (HGA) assembly**

After solar-array deployment, the data-handling subsystems will re-initialise the attitude control subsystem. The roll attitude acquired by the Centaur prior to separation will be maintained. The transfer-orbit correction manoeuvres, halo-orbit station-keeping manoeuvres, and momentum-wheel off-loading will be initiated as necessary.

The routine operating scenario during the halo-orbit phase will be as follows:
- 8 h during which real-time communication is foreseen with the ground system
- three periods of 3.73 h during which no communication with the ground is foreseen and onboard recording is performed
- three periods of 1.6 h with real-time communication during which the previously recorded data will be dumped to ground.

SOHO will be in continuous contact with the DSN for helioseismology data return for a period of two months per year.

### NASA's involvement
As their contribution to this ESA/NASA collaborative mission, NASA is supplying:
- the Atlas launch
- the mission operations
- various hardware elements such as the fine-pointing Sun sensors, the RF high-power amplifiers, and the onboard tape recorders.

### Acknowledgment
The author would like to acknowledge the contributions made by the following spacecraft team members: J. Candé, G. Coupé, P. Rumler, P. Strada and F. Teston.

# The SOHO Payload and Its Testing

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## Introduction

The Solar and Heliospheric Observatory (SOHO) forms part of the Solar-Terrestrial Science Programme (STSP), a collaborative effort between ESA and NASA. The STSP is the first 'Cornerstone' of ESA's long-term programme 'Space Science: Horizon 2000'.

The principal scientific objectives of the SOHO mission are: (a) to achieve a better understanding of the structure and dynamics of the solar interior using helioseismology techniques, and (b) to gain greater insight into the physical processes that form and heat the Sun's corona, maintain it and give rise to acceleration of its particles into the solar wind.

To achieve these goals, SOHO carries a payload consisting of twelve complementary instruments. It is an 1850 kg, three-axis-stabilised spacecraft, powered by solar panels delivering 1150 W. The payload itself weighs about 650 kg and will have a power consumption of 500 W once in orbit. It will produce a continuous science data stream of 40 kbit/s, which will increase by 160 kbit/s whenever the Solar Oscillations Imaging (SOI) instrument is operated in its high-rate mode.

SOHO will be launched by an Atlas-IIAS vehicle and will subsequently be placed into a halo orbit around the Sun – Earth L1 Lagrangian point, where it will be pointed continuously at the Sun's centre with an accuracy of 10 arcsec. The pointing stability will be better than 1 arcsec over 15 min intervals. Planning, coordination and operation of both the spacecraft and the scientific payload will be conducted from the Experiment Operations Facility (EOF) at NASA's Goddard Space Flight Center (GSFC), and the telemetry data will be received by NASA's Deep-Space Network (DSN).

SOHO's set of instruments had to be developed, and their design performances verified by analysis and test, taking into account strict cost and schedule constraints, without, however, compromising the mission objectives. This article describes the corresponding programme leading up to flight-qualification of the experiments and their performance validation within the overall spacecraft system environment.

*Table 1. The SOHO mission*

| | |
|---|---|
| Mission objectives | Investigation of the Sun from its interior out to and including the solar wind |
| Mission shares | ESA: spacecraft plus nine experiments supplied by Member States.<br>NASA: Launcher, ground segment and three experiments. |
| Launch | November 1995 |
| Mission lifetime | ≥2 years (onboard consumables for up to 6 years) |

## History

The Solar and Heliospheric Observatory (SOHO) mission was first proposed in November 1982 as a comprehensive, high-resolution spectroscopic investigation of the upper solar atmosphere, in response to one of the ESA Scientific Programme's regular Calls for Mission Proposals.

A Phase-A feasibility study followed, from July 1984 to October 1985. The Science Study Team responsible for the study was composed of both European and US scientists, supported by ESA and NASA. Meeting on 6 – 7 February 1986, ESA's Science Programme Committee (SPC) approved the Solar-Terrestrial Science Programme (STSP) as the first 'Cornerstone' mission of the Agency's long-term 'Space Science: Horizon 2000' programme and a mission to be implemented in collaboration with NASA. The STSP is composed of two missions SOHO and Cluster, the latter consisting of four identical spacecraft to study turbulence and small-scale plasma structures in the magnetosphere in three dimensions (described elsewhere in this issue).

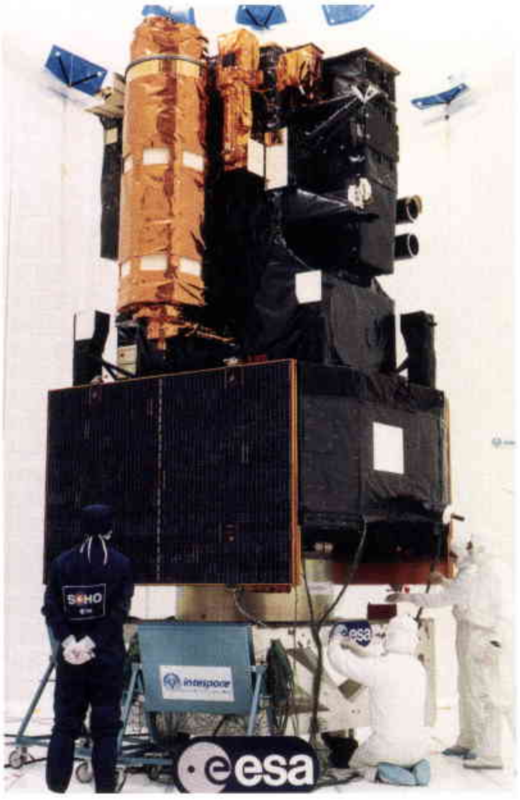


**Figure 1. The SOHO spacecraft in launch configuration prior to acoustic testing at Intespace in Toulouse (F)**

SOHO, together with Cluster and the Geotail, Wind and Polar spacecraft, constitute the International Solar-Terrestrial Physics (ISTP) Programme, a cooperative scientific satellite project involving ESA, ISAS (Japan) and NASA. The ISTP is aimed at gaining improved understanding of the physics of solar-terrestrial relations by coordinated, simultaneous investigations of the Sun – Earth space environment over an extended period of time.

A joint ESA/NASA Announcement of Opportunity for the STSP missions was issued on 1 March 1987, calling for 'Proposals for Investigations'. The proposals received were evaluated on the grounds of their scientific and technical merits, and the payloads were selected following the recommendations of the joint ESA/NASA advisory bodies. ESA and NASA subsequently announced the composition of the SOHO and Cluster payloads in March 1988. The SOHO Science Working Team (SWT), composed of all of the Principal Investigators (PIs), met for the first time from 27 to 30 June 1988.

A consortium of European industries, led by Matra of France as the Prime Contractor, started the industrial definition phase (Phase-B) on 1 December 1989. The main industrial development phase (Phase-C/D) started 14 months later, in early 1991. The Structural Model (SM) programme was completed in 1993, and the Engineering Model (EM) programme in early 1994. The first Flight Model (FM) instruments were delivered in December 1993. The Assembly, Integration, and Validation (AIV) activities for the flight-model spacecraft have taken place in 1994 and the first half of 1995. The SOHO spacecraft was shipped from Toulouse (F) to Kennedy Space Center at Cape Canaveral, ready for the launch campaign, on 1 August 1995.

Figure 1 shows the SOHO satellite in launch configuration prior to acoustic testing at Intespace in Toulouse. Figure 2 shows the SOHO Payload Module (PLM) during integration at Matra Marconi in Toulouse. Figure 3 shows the positions of the twelve payload instruments schematically.

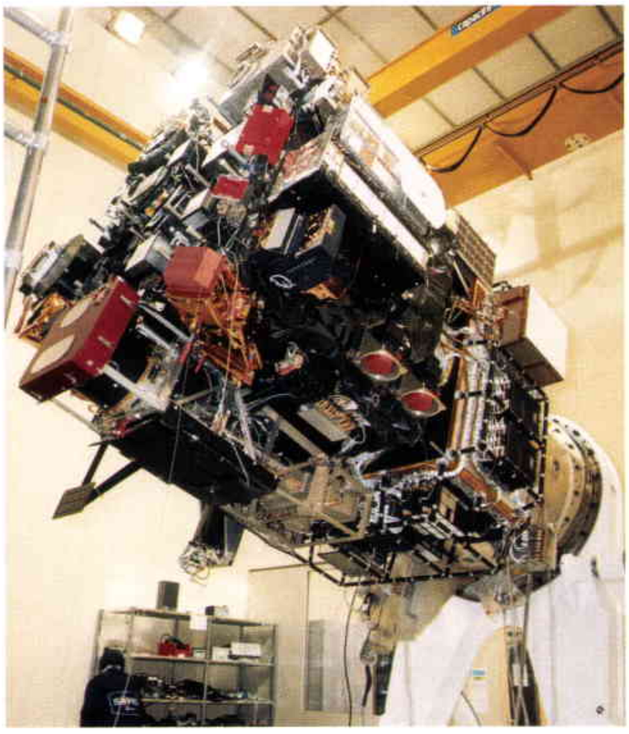


**Figure 2. The SOHO payload module, without thermal blankets, after integration and testing at Matra Marconi Space in Toulouse (F)**

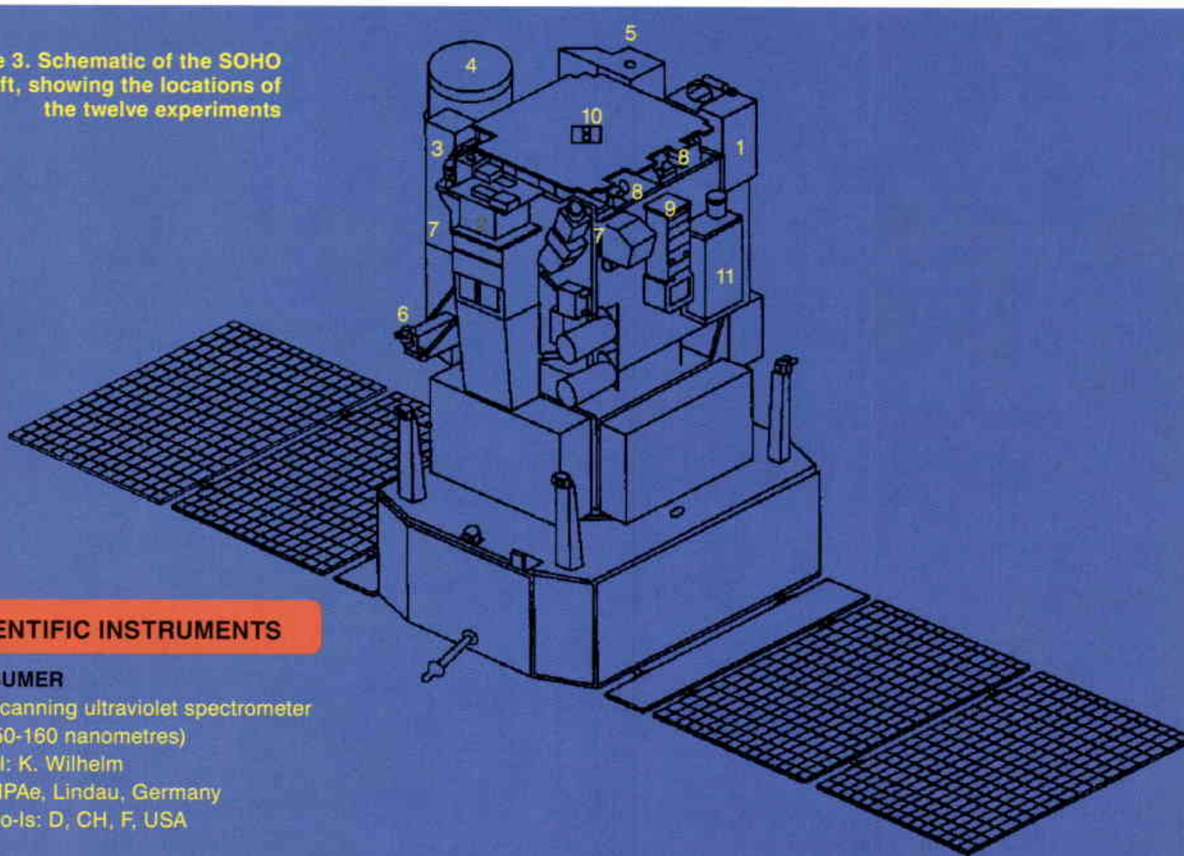
**Science objectives and payload**

The SOHO mission's three principal scientific objectives are:

(i) study of the solar interior, using helioseismology techniques,
(ii) study of the heating mechanisms of the solar corona, and
(iii) investigation of the solar wind and its acceleration processes.

The spacecraft's scientific payload consists of a set of state-of-the-art instruments, developed and furnished by twelve international Principal Investigator (PI) consortia, involving 39 institutes from fifteen countries: Belgium, Denmark, Finland, France, Germany, Ireland, Italy, Japan, Netherlands, Norway,

Figure 3. Schematic of the SOHO spacecraft, showing the locations of the twelve experiments




## SCIENTIFIC INSTRUMENTS

**1 SUMER**
Scanning ultraviolet spectrometer
(50-160 nanometres)
PI: K. Wilhelm
MPAe, Lindau, Germany
Co-Is: D, CH, F, USA

**2 CDS**
Extreme ultraviolet spectrometer
(15-79 nanometres)
PI: R.A. Harrison
DRAL, Chilton, UK
Co-Is: UK, CH, D, I, N, USA

**3 EIT**
Extreme ultraviolet imaging telescope
(17-30 nanometres)
PI: J.P. Delaboudinière
IAS, Orsay, France
Co-Is: F, B, USA

**4 UVCS**
Ultraviolet coronograph spectrometer
(50-130 nanometres)
PI: J.L. Kohl
SAO, Cambridge, USA
Co-Is: USA, CH, D, I

**5 LASCO**
Large-angle coronograph for visible light
PI: G.E. Brueckner
NRL, Washington DC, USA
Co-Is: USA, D, F, UK

**6 SWAN**
Whole-sky Lyman alpha mapper
PI: J.L. Bertaux
CNRS, Verrières le Buisson, France
Co-Is: F, SF, USA

**7 CELIAS**
Solar wind composition and extreme UV flux
PI: D. Hovestadt
MPE, Garching, Germany
Co-Is: D, CH, Russia, USA

**8 COSTEP**
Energetic particles (low range)
PI: H. Kunow
University of Kiel, Germany
Co-Is: D, E, ESA, F, IRE, J, USA

**8 ERNE**
Energetic particles (high range)
PI: J. Torsti
University of Turku, Finland
Co-Is: SF, UK

**9 GOLF**
Global low-degree velocity oscillations
PI: A. Gabriel
IAS, Orsay, France
Co-Is: F, CH, D, DK, E, ESA, NL, UK, USA

**10 VIRGO**
Solar irradiance and luminosity oscillations
PI: C. Fröhlich
PMOD, Davos, Switzerland
Co-Is: CH, B, E, ESA, F, N

**11 SOI**
Oscillations by Michelsen Doppler Imaging (MDI)
PI: P.H. Scherrer
CSSA, Stanford University, USA
Co-Is: USA, DK, UK

PI = Principal Investigator
Co-Is = Countries of Co-Investigators

Russia, Spain, Switzerland, the United Kingdom, and the United States. Nine of the consortia have been led by European PIs and three by US PIs.

The experiments aboard SOHO can be divided into three main groups, according to their respective areas of research: helioseismology instruments, solar-corona instruments, and solar-wind 'in-situ' instruments (Table 2).

### The helioseismology instruments

There are three helioseismology experiments, designed to provide high-precision measurements of solar oscillations, which are difficult, or even impossible, to obtain from the ground.

GOLF (Global Oscillations at Low Frequencies) will use a very stable sodium-vapour resonance scattering spectrometer to observe low-degree oscillation modes ($l \leq 3$) of the global solar velocity field with a sensitivity of better than 1 mm/s over the complete frequency range from 0.1 μHz to 6 MHz (periods from 3 min to 100 days). It will also measure the long-term variations in the global average of the line-of-sight magnetic field with a precision of 1 mG.

VIRGO (Variability of solar IRradiance and Gravity Oscillations) will perform high-sensitivity observations of *p*- and – if detectable – *g*-mode solar-intensity oscillations with a three-channel Sun-photometer measuring the spectral irradiance at 402, 500 and 862 nm, and with the 12-resolution-element Luminosity Oscillations Imager (LOI) ($l \leq 7$). The relative accuracy of these data will be better than 1 ppm (for a 10 s integration time). VIRGO will also measure the solar constant with an absolute accuracy of better than 0.15% using two different types of absolute radiometers (PMO6 and CROM).

Both GOLF and VIRGO lay particular emphasis on the very-low-frequency domain of low-order *p*- and *g*-modes, which penetrate deep into the solar core. They are difficult to observe from the Earth because of noise effects introduced by the Earth's diurnal rotation and the transparency and seeing fluctuations caused by the Earth's atmosphere.

The Solar Oscillations Imager (SOI) focusses on the intermediate to very high degree *p*-modes. By sampling the Ni 676.8 nm line with a wide-field tunable Michelson interferometer, SOI will provide high-precision solar images (1024 × 1024 pixels) of the line-of-sight velocity, line intensity, continuum intensity, longitudinal magnetic-field components, and limb position. It can be operated in a full-disk mode (2″-equivalent pixel size) to resolve modes in the range $3 \leq l \leq 1500$, or in a high-resolution mode (0.65″ pixel size) to resolve modes as high as $l = 4500$. The high-resolution field-of-view is roughly 650″ square and will be centred about 160″ north of the Sun's equator on the central meridian.

SOI will run four different observing programs. The 'structure program' will provide a continuous 5 kbit/s data stream of various spatial and temporal averages of the full-disk velocity and intensity images. It will be running at all times. The 'dynamics program' will operate for 60 consecutive days each year with continuous high-rate telemetry (+160 kbit/s). A full-disk velocity image and either a full-disk intensity image or a high-resolution velocity image will be transmitted every minute. The 'campaign program' will be conducted for 8 consecutive hours each day when the high-rate telemetry is available. This is a very flexible operating mode for performing a variety of more narrowly focussed scientific investigations (e.g. studies of meso- and super-granulation, active-region seismology, etc.). Finally, the 'magnetic-field programme' will provide several real-time magnetograms per day for planning purposes and correlative studies.

The three helioseismology instruments complement each other in several respects. While MDI will measure oscillations over the full range of degrees up to $l = 4500$, GOLF and VIRGO are expected to provide greater stability for the measurement of low-degree oscillations. GOLF and MDI will measure oscillations of the line-of-sight *velocity*, while VIRGO will measure *intensity* oscillations (both radiance and irradiance). GOLF and VIRGO complement each other because, given the difficulty that one can expect in identifying gravity modes, it may well prove essential to have two different approaches (velocity oscillations from GOLF and intensity oscillations from VIRGO) to achieve a convincing result.

### The coronal instruments

The remote sensing of the solar atmosphere will be carried out with a set of telescopes and spectrometers that will produce the data necessary to study the dynamic phenomena that take place in and above the chromosphere. The plasma will be studied by making spectroscopic measurements and high-resolution images at different levels of the solar atmosphere. Plasma diagnostics obtained with these instruments will provide temperature, density and velocity measurements of the material in the outer solar atmosphere.

*Table 2. The SOHO scientific instruments*

| Investigation | Measurement | Technique | Bit rate (kbit/s) |
|---|---|---|---|
| **HELIOSEISMOLOGY** | | | |
| GOLF | Global Sun velocity oscillations ($l = 0 - 3$) | Na-vapour resonant scattering cell, Doppler shift and circular polarisation | 0.160 |
| VIRGO | Low-degree ($l = 0 - 7$) irradiance oscillations and solar constant | Global Sun and low-resolution (12 pixels) imaging, active cavity radiometers | 0.1 |
| MDI/SOI | Velocity oscillations, harmonic degree up to 4500 | Fourier tachometer, angular resolution: 1.5 and 4″ | 5 (+160) |
| **SOLAR-ATMOSPHERE REMOTE SENSING** | | | |
| SUMER | Plasma-flow characteristics (T, density, velocity) chrom. through corona | Normal-incidence spectrometer, 50 – 160 nm, spectral res. 20 000 – 40 000, angular res. 1.5″ | 10.5 (or 21) |
| CDS | Temperature and density: transition region and corona | Normal- and grazing-incidence spectrometers, 15 – 80 nm, spectral res. 1000 – 10 000, angular res. ≈3″ | 12 (or 22.5) |
| EIT | Evolution of chromospheric and coronal structures | Images (1024 × 1024 pixels in 42′ × 42′) in the lines of He I, Fe IX, Fe XII and Fe XV | 1 (or 26.2) |
| UVCS | Electron and ion temperatures, densities, velocities in corona (1.3 – 10 $R_\odot$) | Profiles and/or intensities of several EUV lines between 1.3 and 10 $R_\odot$ | 5 |
| LASCO | Structures evolution, mass, momentum and energy transp. in corona (1.1 – 30 $R_\odot$) | One internal and two externally occulted coronagraphs Spectrometer for 1.1 – 3 $R_\odot$ | 4.2 (or 26.2) |
| SWAN | Solar-wind mass flux anisotropies and its temporal variations | Scanning telescopes with hydrogen absorption cell for Ly-α light | 0.2 |
| **SOLAR WIND 'IN SITU'** | | | |
| CELIAS | Energy distribution and composition (mass, charge, charge state) (0 – 1000 keV/e) | Electrostatic deflection, time-of-flight measurements, solid-state detectors | 1.5 |
| COSTEP | Energy distribution of ions (p, He) 0.04 – 53 MeV/n and electrons 0.04 – 5 MeV | Solid-state and plastic scintillator detector telescopes | 0.3 |
| ERNE | Energy distribution and isotopic composition of ions (p - Ni) 1.4 – 540 MeV/n and electrons 5 – 60 MeV | Solid-state and scintillator crystal detector telescopes | 0.7 |

In the past, the coronal observations with the best spatial and spectral resolution have covered only limited spectral ranges and were obtained from rockets, i.e. on a *snapshot* basis. SOHO will provide what is now desperately needed: an extended and concerted investigation of the physical structures, the dynamics and evolution of the transition region and corona on a *synoptic* basis. In addition, given its ability to make both (*remote-sensing*) coronal and (*in-situ*) interplanetary measurements, SOHO will help to establish the nature of the relationship between conditions in the regions where the solar wind originates and the observed properties at 1 AU distance, in particular the elusive acceleration.

SUMER (Solar Ultraviolet Measurements of Emitted Radiation) is an ultraviolet (UV) telescope equipped with a normal-incidence spectrometer. It will study plasma flows, temperatures, densities, and wave motions in the upper chromosphere, transition region and lower corona with high spatial (1.5″) and temporal (typically 10 s) resolution, by measuring line profiles and intensities of UV lines from 500 to 1600 Å The spectral coverage varies between 20 and 44 Å with a spectral resolving power of $\lambda/\Delta\lambda = 18\,800 - 40\,000$. It should be possible with SUMER to measure velocity fields in the transition region and corona down to 1 km/s.

At shorter wavelengths of 150 to 800 Å, CDS (Coronal Diagnostic Spectrometer), a Walter II grazing-incidence telescope equipped with both a normal-incidence and a grazing-incidence spectrometer, will measure the absolute and relative intensities of selected EUV lines to determine the temperatures and densities of various coronal structures. The telescope's spatial resolution is about 3″, and its spectral resolution varies between 2000 and 10 000.

EIT (Extreme-ultraviolet Imaging Telescope) will obtain full-Sun, high-resolution EUV images in four emission lines (Fe IX 171 Å, Fe XII 195 Å, Fe XV 284 Å, and He II 304 Å) corresponding to four different temperature regimes. It will thus provide the morphological context for the spectral observations to be made by SUMER and CDS. The wavelength separation is achieved by multilayer reflecting coatings deposited on the four quadrants of the telescope mirrors, and a rotatable mask to select the quadrant illuminated by the Sun. A 1024 × 1024 CCD camera with an effective pixel size of 2.6″ is used as the detector.

UVCS (Ultra-Violet Coronagraph Spectrometer) is an occulted telescope equipped with high-resolution spectrometers to perform spectroscopic observations of the solar corona out to 10 solar radii, in order to locate and characterise the coronal source regions of the solar wind, to identify and understand the dominant physical processes that accelerate it, and to understand how the coronal plasma is heated. One of the gratings is optimised for line profile measurements of Ly-$\alpha$, another for line intensity measurements in the range 944 – 1070 Å.

LASCO (Large Angle and Spectrometric COronagraph) is a triple coronagraph with nested, concentric annular fields of view with progressively larger included angles. The fields of view of the three coronagraphs C1, C2 and C3 are 1.1 – 3, 1.5 – 6 and 3 – 30 solar radii, respectively. All three coronagraphs will use 1024 × 1024 CCD cameras as detectors. C1 will not only be the first spaceborne 'mirror coronagraph', but also the first spaceborne coronagraph with its own spectroscopic capabilities. It is equipped with a Fabry-Perot interferometer to perform spectroscopic measurements with a spectral resolution of ≈700 mÅ in the lines Fe XIV 5303 Å, Fe X 6374 Å, Ca XV 5964 Å, $NaD_2$, and H$\alpha$.

SWAN (Solar Wind ANisotropies) will measure the latitude distribution of the solar-wind mass flux from solar equator to solar pole by mapping the emissivity of the interplanetary Ly-$\alpha$ light.

**The solar-wind 'in-situ' instruments**
These will measure the composition of the solar wind and energetic particles 'in-situ' to determine the elemental and isotopic abundances, the ionic charge states and velocity distributions of ions originating in the solar atmosphere. The energy ranges covered will allow the ion acceleration and fractionation processes to be studied under the various conditions that cause their acceleration from the 'slow' solar wind through solar flares.

CELIAS (Charge, ELement and Isotope Analysis System) consists of three mass- and charge-discriminating sensors based on the time-of-flight technique, making use of electrostatic deflection, post-acceleration and residual-energy measurements. It will measure the mass, ionic charge and energy of the low- and high-speed solar wind, of suprathermal ions, and of low-energy flare particles. It also carries the SEM (Solar Extreme-ultraviolet Monitor), a very stable photodiode spectrometer which will continuously measure the full-disk solar flux in the HeII 304 Å line as well as the absolute integral flux between 170 and 700 Å.

In order to study the energy-release and particle-acceleration processes in the solar atmosphere, as well as particle propagation in the interplanetary medium, COSTEP (COmprehensive Supra-Thermal and Energetic Particle analyser) will measure the energy spectra of electrons (up to 5 MeV), protons and He nuclei (up to 53 MeV/nuc).

ERNE (Energetic and Relativistic Nuclei and Electron experiment), having the same scientific objectives as COSTEP, will measure the energy spectra of elements in the range $Z = 1 - 30$ (up to 540 MeV/nuc), abundance ratios of isotopes, as well as the anisotropy of the particle flux.

In summary, the coronal remote-sensing and the in-situ experiments on board SOHO will provide a comprehensive data set with which to study the solar wind from its source at the Sun and out through the heliosphere. The solar imagers and spectrographs will allow study of the morphology, magnetic structure, and heating and particle-acceleration processes occurring at the Sun. At the same time, it will be possible with the particle experiments to make direct measurements of the particle composition and energy spectrum in the solar wind.

## The AIV programme

The assembly, integration and verification (AIV) programme consisted of validating the spacecraft system performances by means of a set of tests and analytical methods (Fig. 4). This SOHO baseline AIV programme served as the foundation for the full qualification of the spacecraft system design, using two development models: the Structural and Engineering Model (SM + EM) and one Flight Model (FM).

### The model philosophy

To minimise risk, the development models were of flight-build standard, but in order to constrain costs were not equipped with hi-rel parts.

These models were employed in the qualification and acceptance programme process as follows:

- The Structural Model (SM) was first used to perform a separate design validation of the Payload and Service Module structures, followed by a mechanical qualification at spacecraft level.
- The Engineering Model (EM) was dedicated to the electrical verifications at system level and to the validation of all electrical test equipment and test methods, including full EMC testing procedures.
- The Flight Model (FM), which was fully flight representative, was submitted to all of the functional, performance, electrical and environmental tests necessary to demonstrate the final design's ability to fulfil the mission requirements, and compliance with the quality requirements.

### System design verification by analysis

The analyses performed at system level were defined to support the validation of the design performance and the test/environmental level predictions in the following areas:

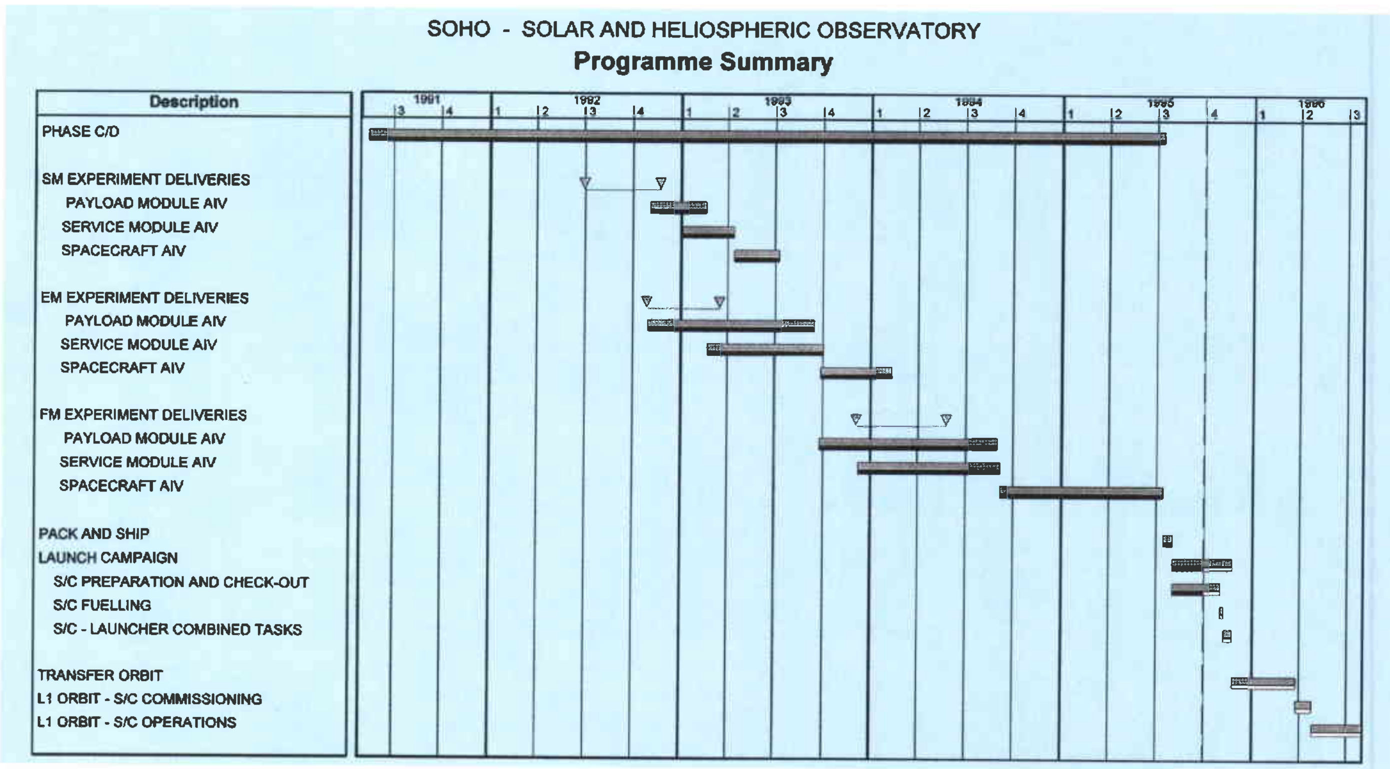



**Figure 4. The baseline Assembly, Integration and Verification (AIV) programme for SOHO**

- spacecraft dynamic analysis in launch and in-orbit configurations
- spacecraft thermal analysis
- spacecraft thermo-elastic analysis
- spacecraft microvibration assessment.

In support of these system tasks, the Principal Investigators produced a set of detailed structural and thermal models according to well-defined specifications provided by the Project Team.

### System design verification by testing

The system test programme leading to the full qualification of the spacecraft and payload designs is summarised in Table 3.

### The payload development plan

In order to fulfil the test objectives defined by the system programme, the experiments had to be developed and produced according to a model-compliant philosophy and build standard summarised in Table 4.

Due to both the diversity and complexity of the SOHO instruments and the firm budget limitations, two different development-path options were proposed to the Principal Investigators:

Option (a):
To produce a dedicated experiment qualification model, built to flight standards

*Table 3. The SOHO model and test-parameter philosophy*

| MODEL<br>TEST/ELEMENT | SM<br>PLM | SM<br>SVM | SM<br>S/C | EM<br>PLM | EM<br>SVM | EM<br>S/C | FM<br>PLM | FM<br>SVM | FM<br>S/C |
|---|---|---|---|---|---|---|---|---|---|
| PHYSICAL PROPERTIES | X | X | X | X | X | X | X | X | X |
| Mass | | | | | | | | | |
| Moment of Inertia/ | | | X | | | | X | | X |
| Centre of gravity | | | | | | | | | |
| Balancing | | | X | | | | X | | X |
| MECHANICAL | | | | | | | | | |
| Static | X | X | | | | | | | |
| Modal survey | X | X | | | | | | | |
| Sine | | | X | | | | | | X |
| Acoustic | | | X | | | | | | X |
| Separ. shock | | | | | | X | | | |
| Deployment | | | | | | X | | | (X)X |
| Manual release | | | | | | X | | | X |
| Leak test | | | | | | | | X | X |
| Launcher IF fit-check | | | | | | X | | | X |
| ALIGNMENT | X | X | X | | | | | | |
| Rehearsal | | | | | | | | | |
| Performance | | | | | | | X | | X |
| THERMAL | | | | | | | | | X |
| Thermal balance/Thermal vacuum/Solar simulation | | | | | | | | | |
| ELECTRICAL | | | | | | | | | |
| EMC/C | | | | | | X | (d) | | (X)X |
| EMC/R | | | | | | X | | | X |
| Autocompatibility | | | | | | X | | | (X) |
| ESD | | | | | | X | | | |
| Functional | | | | X | X | X | X | X | (X)X |
| Performance | | | | X | X | X | X | X | (X)X |
| COMPATIBILITY | | | | | | | | | |
| Onboard software | | | | | X | X | | X | X |
| Ground segment | | | | | | | | X | X |

(X) During thermal-balance/Thermal-vacuum test (d) Delta test if necessary

*Table 4. The SOHO experiment development options*

| | Model | Unit test | Spacecraft system test | Achieved |
|---|---|---|---|---|
| **Concept (a)** | QM | Qualification | Not delivered or flight spare | Design qualification |
| | SM | Physical properties | Mechanical verification | Spacecraft structure qualification |
| | EM | Electrical EMC verification | Electrical EMC verification | Spacecraft electrical EMC qualification |
| | FM | Flight acceptance | System protoflight | Spacecraft system qualification/acceptance |
| **Concept (b)** | SM | Mechanical development/ pre-qualification | Mechanical verification | Spacecraft structure qualification |
| | EM | Electrical/EMC development pre-qualification | Electrical EMC verification | Spacecraft electrical EMC verification |
| | PFM | Protoflight qualification | System protoflight | Spacecraft system qualification/acceptance |

and tested at qualification level and duration. This option was preferred since it would provide early confidence in the flight units to undertake a successful and less stressful acceptance-test programme.

Option (b):
To split the units' qualification among separate models (SM, EM, PFM) by subjecting them to specific and complementary mechanical, electrical and thermal tests.
This option required the flight-modell units to be subjected to protoflight testing, with completion of their qualification as part of the overall spacecraft system testing.

The resulting test matrix covered the following disciplines:
- Electrical functional verification, including electrical interfacing, functional checks and electromagnetic performance verification.
- Structural and mechanical verification by analysis and by testing, including quasi-static, sine, random and acoustic load checks validating the experiment structural analytical models also.
  Mechanisms were considered as structural elements as far as strength and stiffness tests were concerned. Their design was verified along similar lines to those applicable to other structures. The life test was a mandatory requirement for all mechanisms, applying a factor 4 to the pedicted service lifetime.
- Thermal verification by analysis was required, using (i) a detailed thermal mathematical model (up to 300 modes) of the experiment units to verify accurately compliance of the thermal performances with the thermal predictions, and (ii) a simplified thermal model derived from the above to analyse the spacecraft interface and compatibility performances.
- Thermal verification by testing (thermal-vacuum & thermal-balance) was required to: (i) demonstrate the ability of the units to operate nominally under vacuum and temperature conditions more severe than the maximum and minimum temperatures predicted during the mission phases; and (ii) correlate the experiment thermal analytical models and evaluate the thermal design under both steady-state and transient conditions.

Based on the excellent results obtained during the system test campaign, the test and analytical programme described above can be deemed to have been adequate and very successful.

The experiment design verification and qualification process was generally achieved within the cost and schedule envelopes defined and without compromising the system performances or disclosing design weaknesses at a late stage which could have endangered programme continuity.

Adequate design margins were also confirmed, further enhancing confidence in the ability of the SOHO payload to meet the scientific objectives laid down for this demanding mission to the Sun.

# The Cleanliness Aspects of the SOHO Satellite

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As with all satellites, extreme care had to be taken to limit the effects of both particulate and molecular contamination on SOHO's instruments. An additional complication in SOHO's case was that the twelve instruments were supplied by separate institutes as 'free issue' to ESA and its Contractors, making the cleanliness responsibilities rather diffuse. Some of the sensors are relatively insensitive to contamination, but some would be seriously affected by particles settling on optical surfaces and others by condensible molecular deposits. Some sensors have cold detectors for optimum noise reduction and so would be highly sensitive to organic contamination.

The range of wavelengths of interest with SOHO extends from 11 to 950 nm, with signal levels of up to 'one Sun'. In SOHO's nominal Sun-staring mode of operation, any organic material deposited on cold windows or mirrors would stand a high chance of photo-polymerisation, which would adversely affect their transmission or reflectance.

The first precautionary step taken by the Project was to obtain 'cleanliness budgets' from each of the Experimenters and to consolidate these as an overall budget for the spacecraft. For this it was necessary to calculate the potential impacts on each instrument of contamination emanating from all of the instruments and the spacecraft hardware, both during ground integration and test activities (including contributions from clean rooms, environmental test facilities and launch preparations) and during flight.

One main design solution for the instruments was to incorporate continuous gaseous nitrogen purging at low rates for the critical sensor volumes. This led to an onboard distribution system fed from a 'purge cart' during the ground testing, and via a special connector to the launcher until lift-off. The quasi-sealed nature of the instrument sensor boxes, isolation of optics from electronics, and the use of the gas purging virtually precluded the risk of the sensor optics and detectors being contaminated from external sources.

To comply with the overall cleanliness budget, it was decided to space-condition (vacuum-bake) certain hardware. This included the Payload Module structure, harness, Multi-Layer Insulation (MLI) and the Optical Surface Reflector (OSR) panels (due to 2 $m^2$ of OSRs being mounted very close to the aperture plane of most instruments and the use of silicone adhesives for OSR fixation). The instrument providers were required to space-condition their MLI and external harnesses, but not their internal hardware, although those with critical cleanliness requirements did choose to bake much of this.

The more critical sensor boxes were assembled under high-quality clean-room conditions (class 100 clean benches or class 1000 rooms; see accompanying panel), but it is impractical to integrate and especially test spacecraft of SOHO's size in such conditions. Most of the spacecraft integration was done in clean rooms of class 10000 or better, partly under class 100 downdraft clean units. Such a unit was used at Intespace in Toulouse (F) in preparing for the environmental tests, and was supplemented by the use of a low outgassing plastic cover suspended from a crane for acoustic and vibration test exposures, and for final preparation for entry into the thermal-vacuum chamber. Instrument doors were only opened under clean conditions.

Additional precautions were taken for the thermal-vacuum testing. The chamber was baked at 100°C prior to the test, using Quartz Crystal Monitors (QCMs) to measure the outgassing rates and to help identify the main materials deposited. The pumpdown was partly conducted with instrument purging and the shroud temperatures, Sun (simulated) intensity and OSR panel onboard heating were coordinated in pumpdown and recovery with

## Clean Rooms

Dust particles are ever present; just look across a narrow beam of sunlight in your house and you will see hundreds, dancing in the convection currents. These are still present in the 'clean rooms' in which spacecraft are tested, but in much lower concentrations. The quality of the air in these rooms is specified in terms of the number of particles of 0.5 microns or larger occurring per cubic foot (class 100 has about 3.5 particles per litre of air). The fact that you see particles dancing means that many are large but of such low density that they do not settle. Clean rooms therefore use a relatively high laminar air flow to entrain and sweep such particles into filters.

For spacecraft, the number of particles falling onto and remaining on critical surfaces is much more important than the number per unit volume. Hence sensors that allow this 'fallout' to be counted have been used on SOHO. Fallout is promoted by turbulence (even caused by the spacecraft itself) in otherwise laminar air flow, and by the presence of particle generators (such as people!) situated upstream of sensitive hardware. People working in clean rooms therefore need to follow strict disciplines and to wear appropriate clothing (releasing very little 'lint'). For class-100 clean rooms, full 'bunny suits' are needed, with just the eyes exposed. Class 1000 is compatible with faces being exposed (but beards covered), while class 100 000 allows clean coats and overshoes.

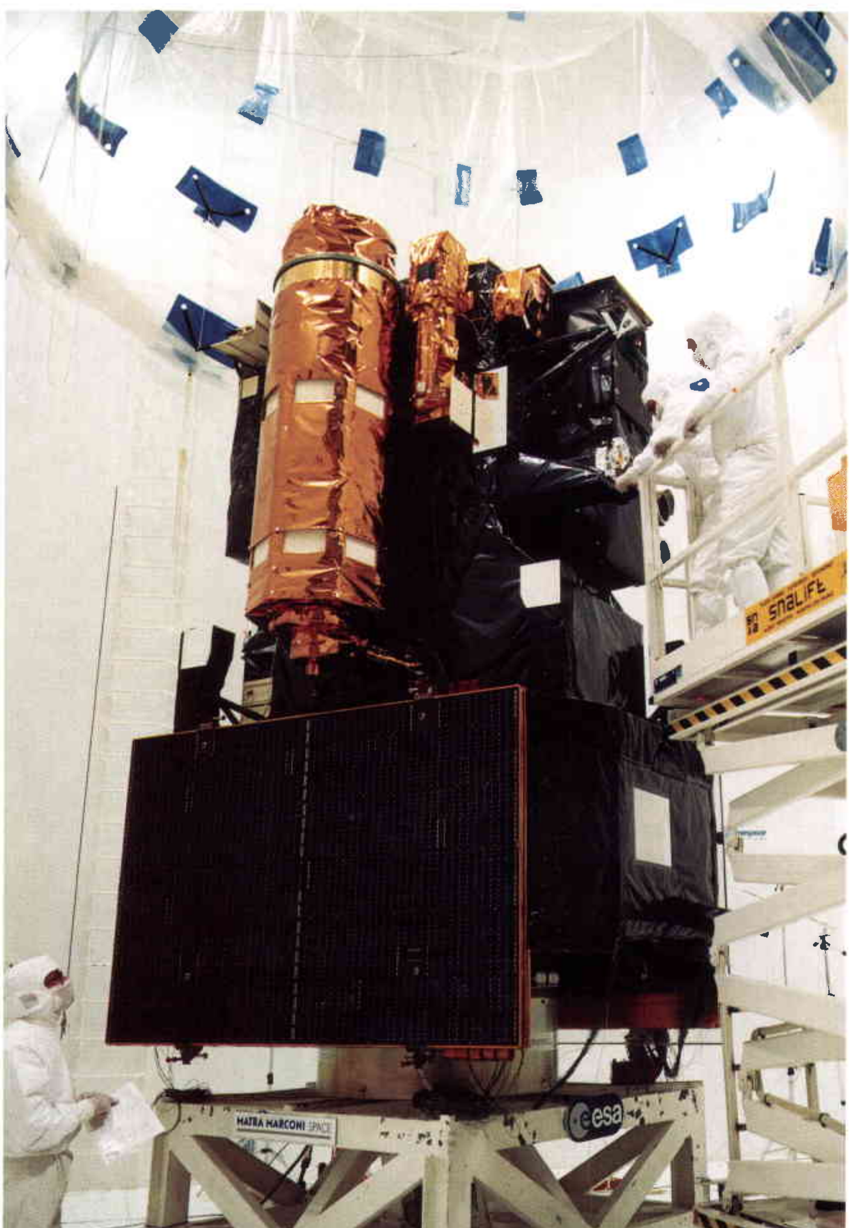

**Figure 1. SOHO being prepared for acoustic testing, with the anti-particle protective bag partly deployed over the spacecraft**

the objective of keeping the OSR panel and the front surfaces of the sensors warmer than the shrouds at all times. For most of the test duration, the shrouds were at very low temperatures (e.g. −190°C), so that spacecraft contamination was only likely to occur during recovery; this was modified from the usual sequence by ensuring that the shroud temperatures did not exceed −75°C until the pressure was greater than 1 millibar, with the objective of limiting migration of contaminants deposited on the shrouds at −180°C to the spacecraft's exterior during this phase. This extended the test by 12 hours but, as expected, subsequent witness-plate examination showed negligible deposits on the OSR panel and other external surfaces. Instrument doors were closed during pumpdown and recovery and so the internal optics are very unlikely to have been contaminated by the chamber or spacecraft outgassing.

Many of the planned launch-preparation activities (about to start at the time of writing) will take place in a clean-air tent in a room already offering better than class-10000 particulate control. During fuelling and other work necessarily conducted outside this tent, an overhead cover will protect the spacecraft from falling – i.e. relatively dense – particles, and the fairing will be cleaned to an equivalent standard. For the final 18 calendar days until launch, SOHO will be under the Atlas launcher's fairing, which will be conditioned with class-5000 air, and the instrument purge will be maintained throughout. A few sensors will be exposed to this environment, the 'red-tag covers' having been removed at encapsulation. These units have been

## Organic Cleanliness

If you buy a new car, look at the light scattered by the 'fogged' interior surface of its windscreen in low-angle winter sunshine. This fogging results from a heavy deposit of plasticisers, emitted by the car's new carpets and seat covers, etc. This is the plastic age, and spacecraft too use many different plastics, many of which contain volatile materials to provide added flexibility, discharge static, and serve as lubricants in sheet or roll form.

Volatility is increased in vacuum, and as temperature increases significant quantities of such organics can form a local cloud around a spacecraft. If a critical surface such as a lens, mirror or detector happens to be colder than the emitter, then it is possible for the volatile components to condense onto that surface and cause filtered obscuration, light scattering and loss of detector performance.

Other organic contaminants that may be present include unreacted potting agents, solvents, oils from lubricants and from human skin, and silicones used as parting agents. Sunlight falling on organically contaminated surfaces can cause chemical reactions, often stabilising and darkening them to form a brown tarry substance and destroying the critical optical properties required by experimenters.

Deposition rates in vacuum can be measured using Quartz Crystal Monitors (QCMs), especially if the crystal temperature can be cooled below that likely to apply to sensitive surfaces. As a rule of thumb, a temperature difference of 60°C corresponds to two orders of magnitude difference in acquisition rates, so that a test lasting 100 h can indicate the effect of a year's space exposure. For those materials found to have high contaminant potential, vacuum-baking can remove the majority of the more loosely bound molecules before integration into critical assemblies.

Apart from QCMs, so-called 'witness plates' may be used to accumulate organics in clean rooms, and infrared spectroscopy can be used to quantify, and possibly identify the nature of the deposits and hence pinpoint the sources.

determined by the Principal Investigators to be insensitive to the expected deposits.

In the first days after launch, instrument doors may be 'cracked' open to speed outgassing without admitting sunlight, but full opening is not recommended during the first month, to minimise the risks of in-flight contamination before reaching halo orbit four months after lift-off.

In the light of all of the above precautions, it is believed that the risk of any instruments being contaminated from either the spacecraft or the other instruments is extremely low, and that SOHO should not experience the rapid degradation seen on many previous Sun-staring missions.

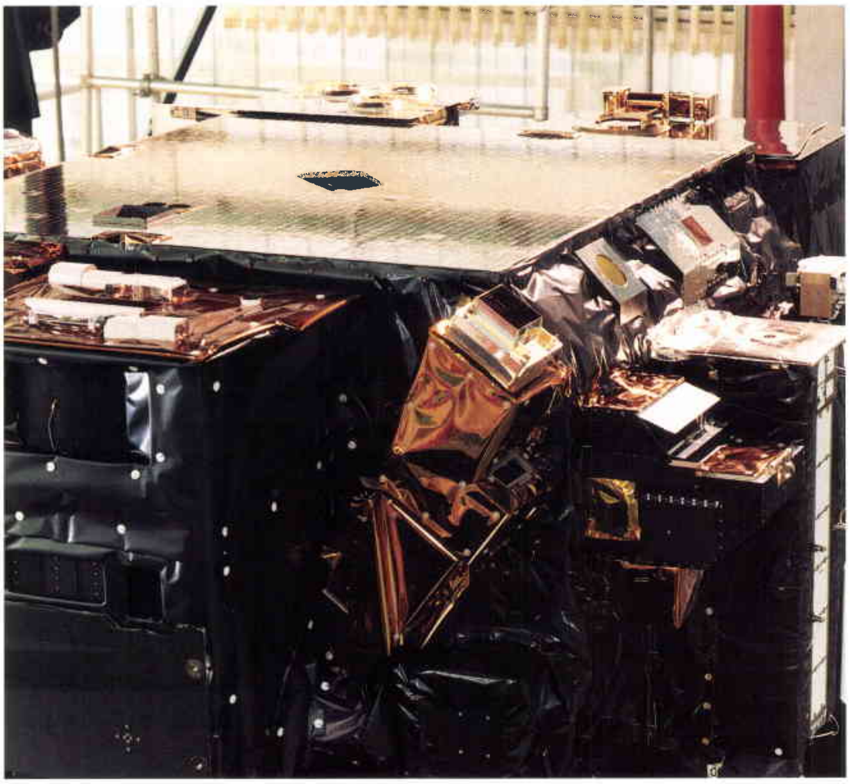

**Figure 2. View of the upper face of the SOHO Payload Module prior to thermal-balance/thermal-vacuum testing, showing mainly particle sensors on the right and the OSRs of the Sun shield pierced by the apertures for the Sun sensors**

# The SOHO Ground Segment and Operations

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**Mission overview**
The primary purpose of the SOHO mission is to investigate the Sun by focusing upon its solar wind, seismology, and coronal dynamics. Using SOHO's complement of twelve scientific instruments, particular emphasis will be placed upon:

- probing the interior structure of the Sun
- characterising the strong and weak magnetic-field regions in the Sun's chromosphere and corona
- Investigating the outflow of solar plasma and detailing the origin of the solar wind.

These scientific investigations will be conducted with the SOHO spacecraft operating in a halo orbit about the L1 Lagrangian point while maintaining a fixed, three-axis stabilised Sun-pointing attitude.

**Operations overview**
The SOHO Ground Data System (GDS) has been designed and implemented to accommodate the following key operational features:

- *Mission Phases Supported*
  Launch and Early Orbit Phase
  Transfer Trajectory Phase
  Halo Orbit Phase.

- *Mission Modes Supported*
  Nominal Support
  Critical Support
  Normal Science (12 h/day for 10 months)
  Continuous Science (24 h/day for 2 months).

- *Planning and Scheduling*

- *Spacecraft Commanding*
  Immediate Commands
  Time-Tag Commands
  Near-Real-Time Commands

- *Telemetry Data Collection*
  Real-time
  Playback
  Spacecraft Transition Modes

- *Telemetry Data Processing and Distribution.*

**The SOHO Ground Data System (GDS)**
The primary responsibility of the SOHO GDS is to support the SOHO mission flight operations from launch through end-of-mission in the following functional areas:

a. Space/Ground Interface: provides telecommunications support with the spacecraft.
b. Data Transport: provides communications support throughout the entire SOHO GDS.
c. Command and Control: provides mission operations, flight dynamics, and spacecraft commanding support.
d. Data Capture, Processing, and Distribution: provides scientific data support and distribution.
e. Test and Training: provides GDS performance verification and operator training.

The principal elements of the ground system are illustrated in Figure 1 and discussed in the following paragraphs.

The ISTP Programme will provide a Flight Operations Team (FOT) to conduct and coordinate the Control Centre operations. The FOT will be responsible for:
- health and safety of the instruments
- evaluation of spacecraft performance
- coordination of ground-station scheduling
- commanding of the spacecraft
- monitoring of scientific operations.

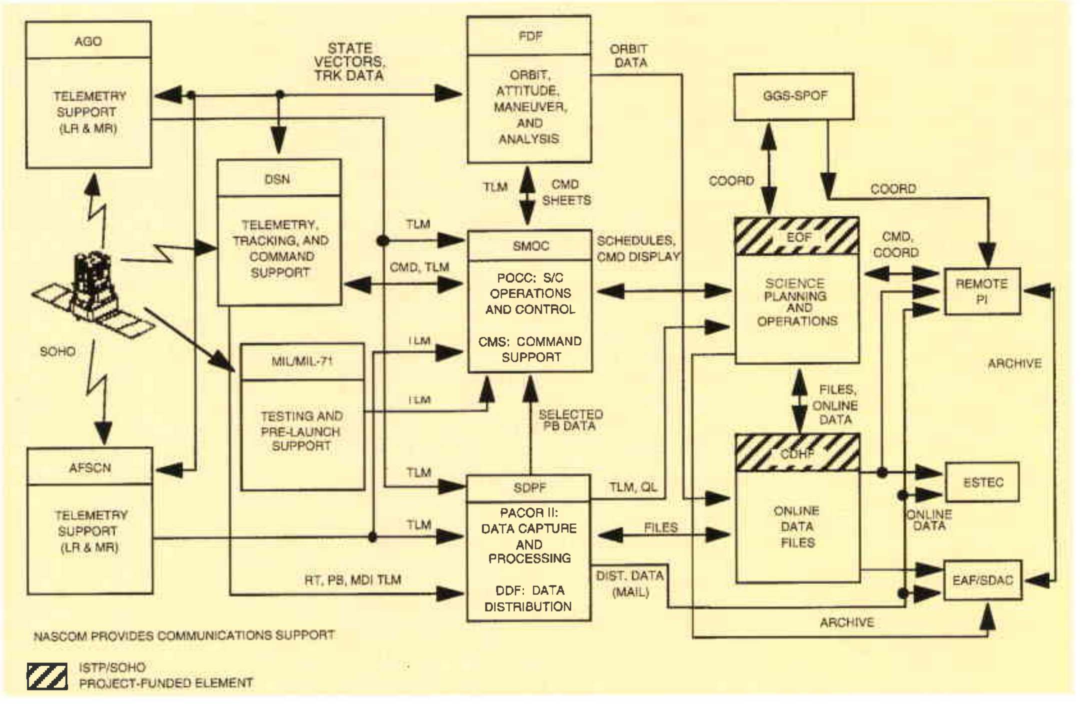



**Figure 1. The SOHO Ground Data System (GDS)**

## The GDS elements

*Jet Propulsion Laboratory (JPL)/Deep-Space Network (DSN)*

The DSN will provide primary SOHO telemetry, command, and tracking support during routine science operations (10 months per year) and continuous science operations (2 months per year continuous contact). The DSN will support SOHO operations utilising existing ground-station facilities at Madrid (E), Canberra (Aus) and Goldstone (Calif., USA). JPL (located in Pasadena, Calif.) will provide DSN interface coordination, central communications, scheduling, and facilities management. Figure 2 gives an overview of the DSN, JPL and GSFC interfaces.

The JPL/DSN will support the SOHO spacecraft telemetry data in both real-time and tape-recorder-playback modes. JPL/DSN telemetry processing is limited to convolutional coding removal, error correction, packaging, time-tagging, and transmission to other elements in the SOHO GDS.

Radiometric tracking data will typically be collected simultaneously with telemetry data and forwarded to the Flight Dynamics Facility in real time.

JPL/DSN will support command operations in throughput mode. Commands will be received from the Payload Operations Control Center

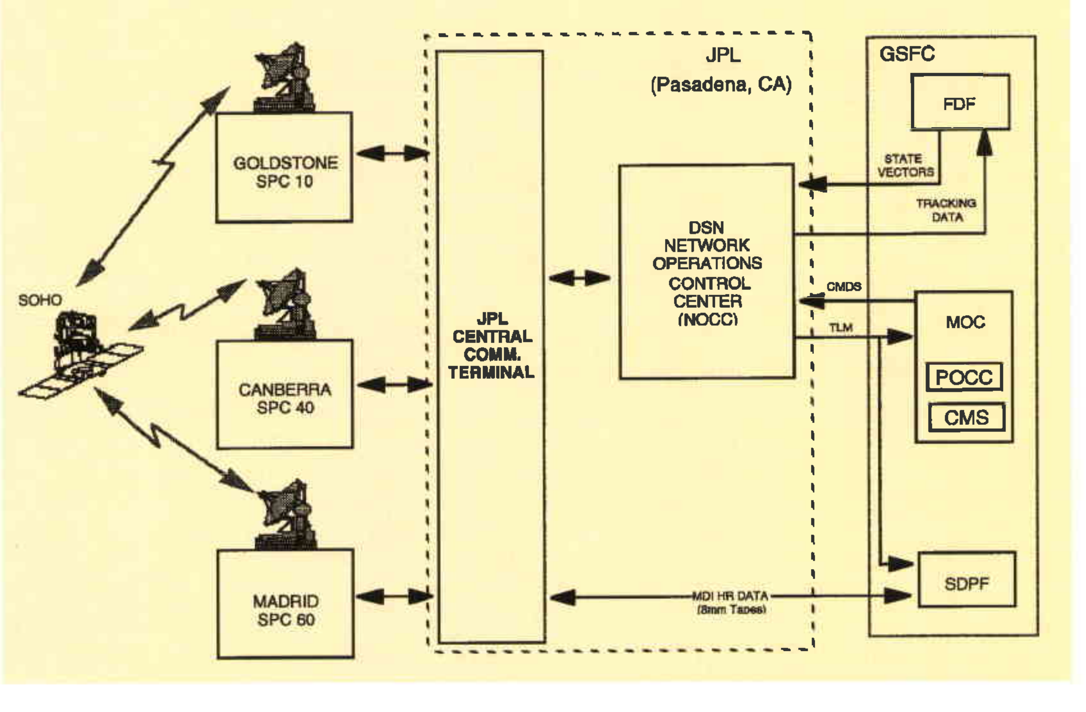



**Figure 2. The NASA/JPL Deep-Space Network (DSN) interfacing for SOHO**

(POCC), de-blocked, processed and uplinked to the SOHO spacecraft at 2 kbit/s.

Telemetry-only backup will be provided by the following networks in the event of DSN coverage gaps:
- the Santiago Ground Station (AGO)
- the Air Force Satellite Control Network (AFSCN).

Telemetry will be received by the ground station, decoded, and forwarded to GSFC via Nascom. Backup network support will only be required in the early orbit phase of the mission, during critical support periods.

*NASA communications (Nascom)*
Nascom institutional and mission-specific resources will provide communications support for the SOHO mission from pre-launch testing until the end-of-mission. Nascom is a global telecommunications system that provides real-time operational communications support. Through its primary switching and control center located at GSFC, Nascom provides centralised management for all its communications links. Figure 3 provides a Nascom configuration overview for SOHO.

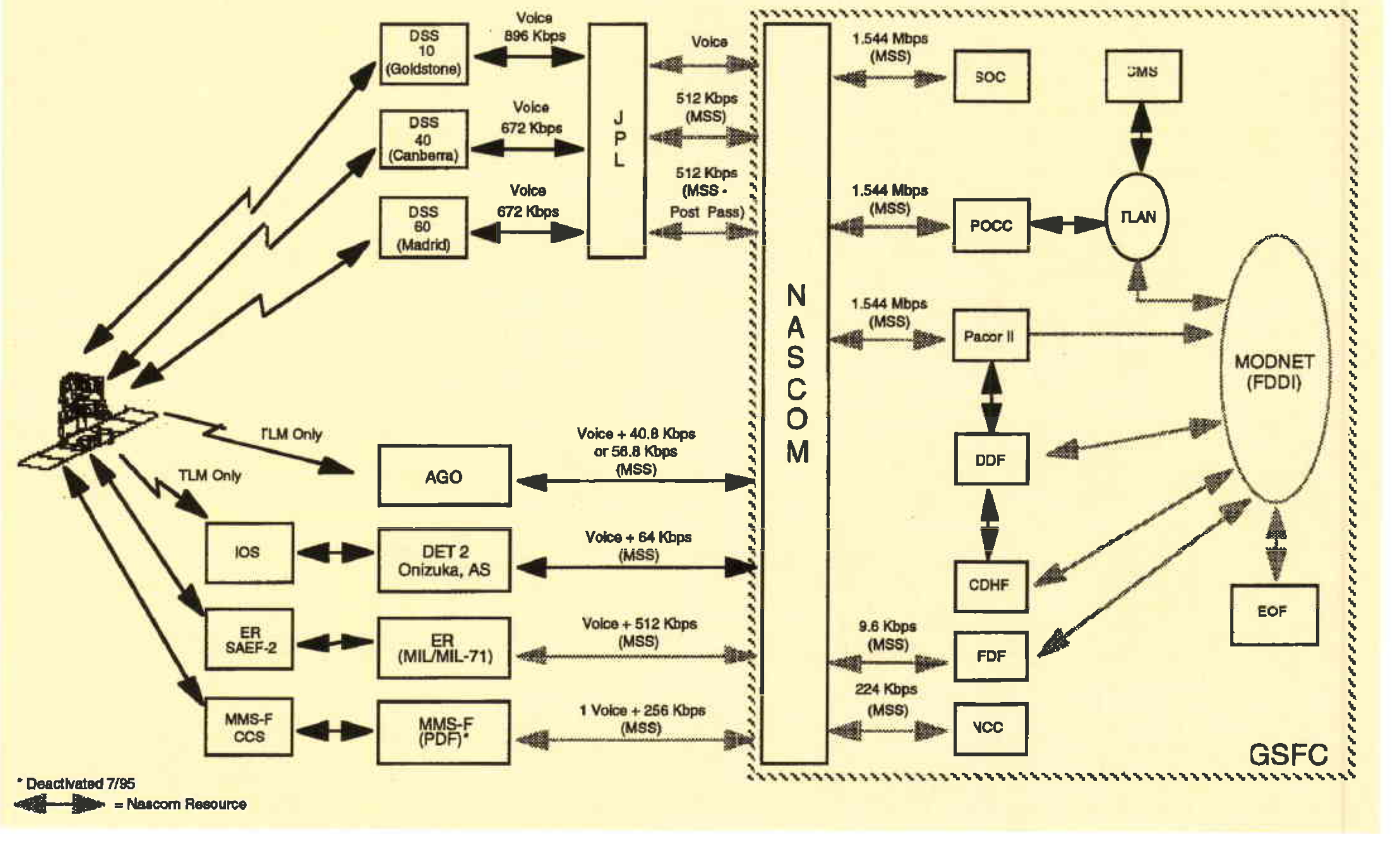
*Payload Operations Control Center (POCC)*
The POCC will be the focal point for all SOHO GDS operations. Continuously manned (24 h/day, 7 days/week) and operated by the FOT, the POCC will provide the capability to command and monitor the SOHO spacecraft and all its instruments. The POCC will have sole control over all commanding modes, including near-real-time commanding of the instruments from the Experiment Operations Facility (EOF).

The POCC consists of mission-specific hardware and software which provides a central data collection and control facility for operations, planning, monitoring, and commanding of the spacecraft. The POCC provides the following fundamental SOHO support capabilities for all mission phases:
- processing of real-time and tape-recorder-playback telemetry, including Reed-Solomon decoding
- decommutation of telemetry parameters
- redundant processing strings (no single-point failures in the hardware design)
- off-line processing and analysis
- uplinking of spacecraft and instrument commands
- database generation, management, and configuration control.

The POCC equipment is physically located in two main areas at GSFC (Building 3):
- the SOHO Mission Operations Room (MOR)
- the SOHO Mission Analysis Room (MAR).

The baseline architecture of the SOHO POCC is shown in Figure 4.

**Figure 3. The Nascom configuration for SOHO**



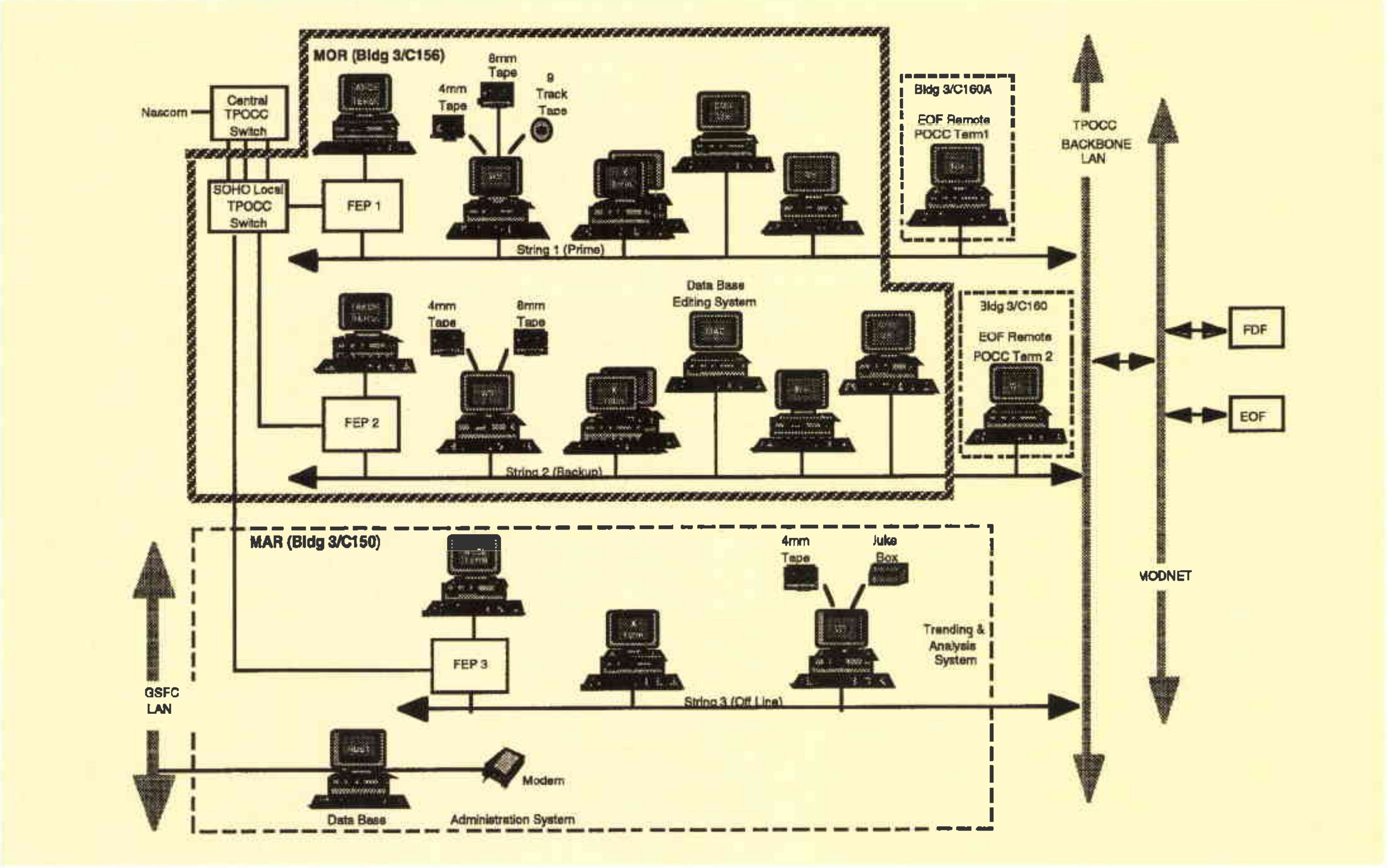



**Figure 4. Baseline architecture of the SOHO Payload Operations Control Center (POCC)**

*Command Management System (CMS)*
The CMS is co-located with the POCC and is also manned and operated by the FOT. The CMS will provide the functions necessary for constructing spacecraft and instrument command groups (real-time commands) and loads (software and stored commands). The CMS will also support near-real-time commanding of the instruments, and will serve as the focal point for reporting and exchanging status on the near-real-time commanding link.

The primary function of the CMS is the generation of planned sequences of spacecraft commands (command loads) to be transmitted to the spacecraft. The CMS helps ensure the safe operation of the spacecraft by checking that the command loads are free from known operational constraint violations or conflicts. The CMS also provides the following fundamental SOHO support capabilities for all mission phases:
- uplink scheduling
- timeline and pass plan generation
- load validation and constraint checking
- near-real-time commanding link between the EOF and POCC
- spacecraft memory management.

*Experiment Operations Facility (EOF)*
The SOHO EOF will provide for the day-to-day coordination and execution of SOHO instrument observation programmes. The EOF will also serve as the principal data-processing centre for certain solar experiments. Through work stations in the EOF, investigators will be able to command their instruments in near-real-time mode, via an interface with the CMS and POCC, without FOT intervention.

*Flight Dynamics Facility (FDF)*
The FDF will provide all orbit support required for the SOHO mission, including mission analysis, orbit determination, attitude validation, and manoeuvre planning and implementation. The primary functions of the FDF are:
- Mission Analysis
  - studies optimal trajectories and orbits from the early phases of a mission
  - determines launch dates, windows, and targeting information.

- Orbit Determination
  - provides regular definitive and predictive orbit determination, state vectors for ground networks, station coverage, event files and other planning aids for operations using radiometric tracking data supplied by the DSN.

- Attitude Determination
  - calculates attitude of spacecraft and verifies onboard-computed attitude using available telemetry.

– Manoeuvre Support
  - supports orbit and attitude manoeuvres, including orbit adjustment notification, burn command inputs, Doppler tracking during burns, and manoeuvre verification.

– Momentum Management Support
  - tracks and adjusts onboard momentum via thruster or other torque manoeuvres
  - provides command request sheets for these manoeuvres.

Definitive attitude will be computed onboard SOHO and down-linked within the telemetry. During spacecraft contacts, FDF will provide attitude support involving the real-time processing of attitude-sensor telemetry data, provided via the POCC, and displaying the results for FOT inspection.

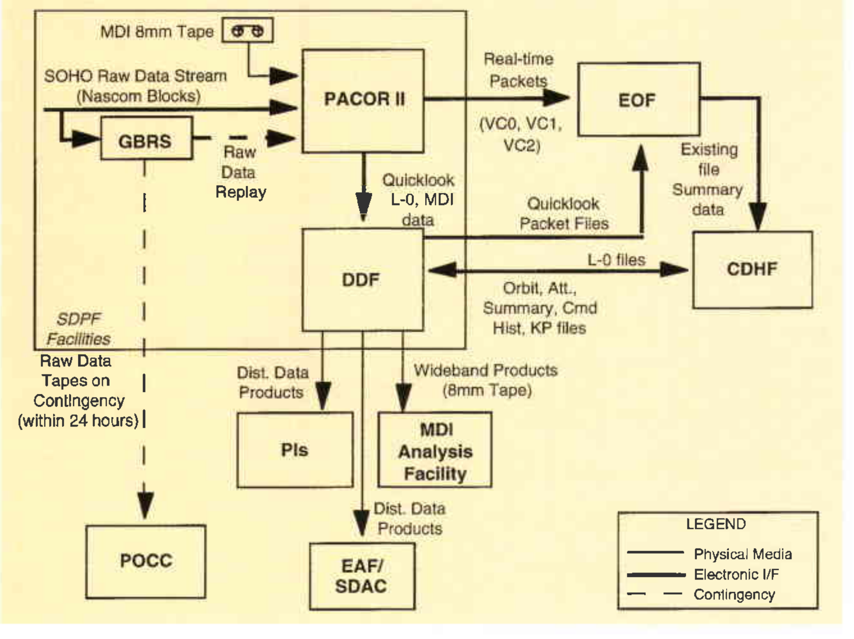



**Figure 5. The Sensor Data Processing Facility (SDPF) interfacing for SOHO**

During critical manoeuvre periods the FDF will provide real-time Doppler analysis and display support. This support compares actual Doppler data computed from real-time radiometric tracking data with predicted values created when the manoeuvre was planned. Results will be displayed in real-time for manoeuvre execution support.

*Sensor Data Processing Facility (SDPF)*
The SDPF comprises the following systems and their corresponding functions:

– Generic Block Recording System (GBRS)
  - records all incoming Nascom blocks of data.

– Packet Processor (Pacor)
  - performs RS decoding
  - processes telemetry to the packet level
  - creates Level-0 and quick-look data sets.

– Data Distribution Facility (DDF)
  - organises data according to destination requirements
  - distributes data products.

These facilities provide the functions necessary for data capture, intermediate data processing, and the creation, compilation, and mailing of distributed data. Figure 5 gives an overview of the SDPF interfaces and products.

*Central Data Handling Facility (CDHF)*
The CDHF will provide instrument-specific data-reduction support together with the capability for online access to the data. For the SOHO mission, the CDHF will receive orbit and, in the event of a spacecraft contingency, attitude data from the FDF on a weekly basis. Nominally, the CDHF will reformat onboard-computed definitive attitude and generate user reports for distribution upon request.

The CDHF will also receive daily command history files, summary data, a time-anomaly file, and a data-accountability log from the EOF. The command history and orbit/attitude data will be maintained on line for electronic access by the users, and transferred to the DDF to be included with other distributed data.

*SOHO Simulator*
A dynamic SOHO spacecraft simulator has been developed to support the verification of the GDS elements, interfaces, and flight databases. The Simulator has also been utilised successfully to support FOT training, science simulations, and emulate spacecraft anomalies.

**Orbit description**
SOHO will be injected into a halo orbit around the L1 Sun – Earth libration point, about 1.5 x $10^6$ km sunward from the Earth – Moon barycentre, following a four-month transfer trajectory. The halo orbit will have a period of 178 days and has been chosen because:
– it provides a smooth Sun-spacecraft velocity change throughout the orbit, appropriate for helioseismology
– it is permanently outside of the magnetosphere, which is appropriate for the 'in-situ' sampling of the solar wind and particles
– it allows continuous observation of the Sun, which is appropriate for all of the investigations.

The Sun-spacecraft velocity along the Sun line will be measured to better than 0.5 cm/s.

**Operations impacts**
The orbit and distance involved in the halo orbit presents some operational challenges. There

will be a 5 s (approx.) light time delay in communications each way to SOHO, which makes it difficult to perform command verification and still allow a high rate of commanding. Special ground software is required to allow 'pipelining' of commands, whereby up to ten may be sent before the first is verified, without losing track of the command sequence. This is made necessary by the high rate of real-time science commanding and large amount of real-time contact required for the mission.

**Mission phases**

The operational mission is divided into three main phases:
- the Launch and Early Orbit Phase (LEOP)
- the Transfer Trajectory Phase (TTP), and
- the Halo Orbit Phase (HOP).

Launch and Early Orbit Phase (LEOP)

This phase starts at lift-off, includes the coasting period in parking orbit, and ends with the injection of the spacecraft into the transfer trajectory (Main Engine Cut-off 1: MECO1). It is divided into two subphases: the Ascent Subphase and the Parking-Orbit Subphase, as shown in Figure 6.

a. *Ascent Subphase (lift-off until injection into parking orbit)*

SOHO will be launched by the Atlas-IIAS using a Centaur upper stage, from Kennedy Space Center. The first burn of the Centaur will inject the SOHO/Centaur composite into a near-circular parking orbit.

b. *Parking-Orbit Subphase (injection into parking orbit until injection into transfer trajectory)*

This subphase begins at SOHO/Centaur insertion into parking orbit and finishes at the SOHO/Centaur injection into transfer trajectory.

The parking orbit is nearly circular, at 150 – 200 km altitude and inclined at 28.5°. The orbital period is 90 min.

The eclipse duration is approximately 37.5 min, but the cumulative time in eclipse can be a maximum of 58 min in the case of a long coast (10 min eclipse duration in parking plus 10 min eclipse after injection into transfer). Depending on the launch date, the SOHO/Centaur may remain for between a minimum of 10 min and a maximum of 100 min in the parking orbit.

During the LEOP phase, the SOHO/Centaur composite will be oriented with its X-axis towards the south ecliptic, with a roll rate of about 0.2 rpm. This attitude will be achieved and maintained by the Centaur upper stage. The latter will start the thermal roll soon enough after insertion into parking orbit and sufficiently late before transfer trajectory insertion for the spacecraft to be exposed to sunlight (from launcher payload fairing jettison until injection into transfer) for less than 8 min.

No communication with the ground is foreseen during this phase.

Transfer Trajectory Phase (TTP)

The TTP starts with the injection of the spacecraft into transfer orbit (MEC02) and ends with the injection into the halo orbit. It lasts about 4 months and, although science operations should be possible and will likely occur, priority will given to the health and status of the spacecraft bus in this phase. The maximum duration for the first Acquisition of Signal (AOS) after injection into transfer trajectory is 35 min. Housekeeping and science telemetry, telecommand, and ranging links will be established during this phase.

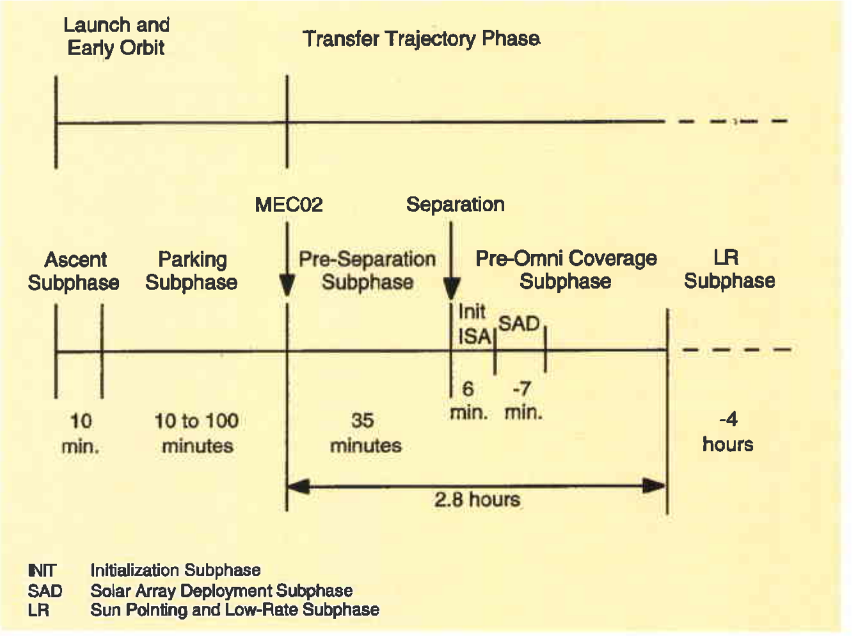



**Figure 6. The SOHO early-orbit phases**

After the first three days of continuous contact, the normal operations contact sequence will begin. The communication scenario is based on three daily passes of 1.6 h each and one 8 h pass, as during the normal halo-orbit phase. This leaves the remaining 11.2 h of the day without contact during three periods of about 3.73 h typically (if divided evenly). However, for critical operations (initial Sun acquisition, solar-array deployment up to 12 h after transfer trajectory insertion, and orbit-correction manoeuvres), the ground segment will be available continuously for critical support.

The TTP is divided in the following four subphases (Fig. 6):

a. PRE-SEP Subphase: This lasts about 35 min from Transfer Trajectory Insertion (TTI), or MECO2, until separation from the Centaur upper stage.

b. PRE-OP Subphase: This begins at separation and ends when the anti-Sun line/spacecraft/Earth angle is less than 33°. It should last about 3 h.

c. LR Subphase: Redundant low-gain antennas are both available for the low data rate only.

d. HR Subphase: About 7 h after separation, the high-gain antenna should be deployed, providing both uplink reception and medium- or high-rate telemetry downlinking for the remainder of the TTP (and mission).

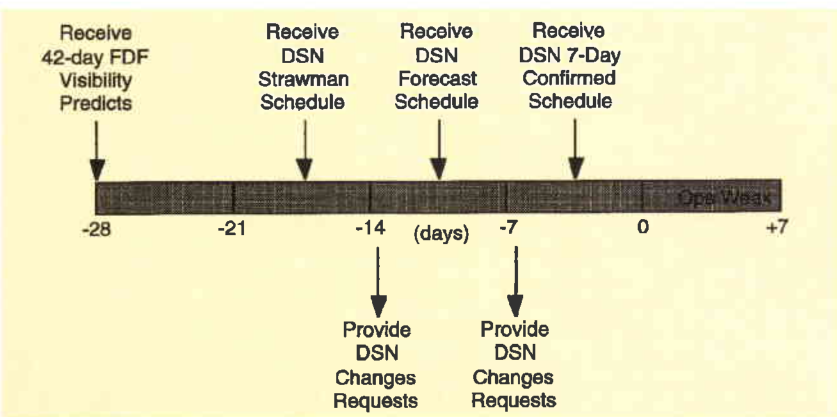



**Figure 7. The SOHO mission planning and scheduling timeline**

## Halo-Orbit Phase

The Halo-Orbit Phase (HOP) starts at the spacecraft's injection into the halo orbit. The subphases of the HOP are:

a. Commissioning Subphase: This phase starts with injection into the halo orbit and ends after successful check-out and commissioning for all on-board instruments. It may last up to one month. Part of the commissioning may already have been performed previously, during the TTP.

b. Mission Operations Subphase: This starts after commissioning and includes all scientific and routine operations necessary to undertake the desired experiment activities. After insertion into the halo orbit, a first station-keeping manoeuvre will be performed. Every 8 weeks, an orbit maintenance manoeuvre will be conducted. Momentum-wheel off-loading will be coupled with orbit correction manoeuvres. During this phase, the satellite will be three-axis-stabilised in a Sun-pointing attitude. In the case of safe-mode activation, it maintains this Sun-pointing attitude but to a lower accuracy.

Three daily passes of 1.6 h and one 8 h pass are baselined for SOHO support during 10 months per year, the remaining 2 months having 24 h/day support. The onboard data recorder provides data storage during all non-contact periods. These contacts are sufficient for complete recorder-play-back data capture and to meet all telemetry, ranging and command requirements. During the operational phase, any combination of the ranging, telemetry, and telecommanding links will nominally be available.

## Flight operations

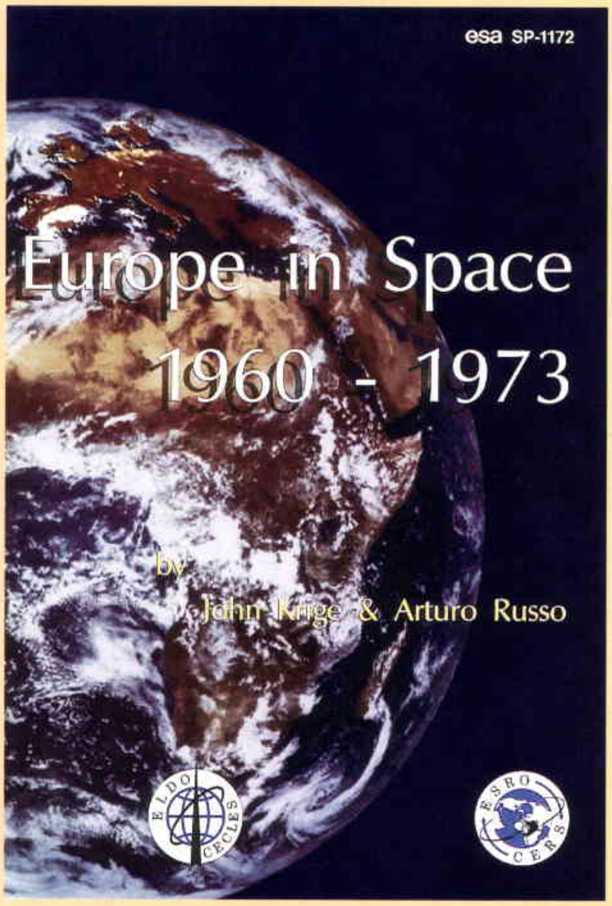
SOHO possesses many unique features, such as the near-real-time commanding from the Experiment Operations Facility, an extensive number of telemetry and command parameters, and an innovative spacecraft design. Managing all of these features presents a special challenge to the Flight Operations Team. A combination of online and offline activities will be used for the complete study of the spacecraft's performance.

The health of the spacecraft will be continually assessed by monitoring the appropriate telemetry during real-time contacts. This monitoring will be performed using telemetry processing, various software tools, and online expert systems. Offline data processing will also be performed to monitor selected parameters in detail and watch for more subtle changes and trends in performance and behaviour.

## Mission planning and scheduling

The SOHO Command Management System (CMS) will receive inputs for planning and scheduling from four major sources – the FDF, DSN, EOF and the Project Team – and from one minor source, the FSM. FDF will provide orbit and attitude products, manoeuvre-related data and predicted-event products. The DSN will provide four phases of schedules: Strawman, Forecast, Confirmed, and Changed Confirmed (Fig. 7). Due to this schedule process, the Mission Planner may work on four future weeks simultaneously. The EOF provides throughput-mode commands, delayed instrument command groups, large instrument table loads and science-activity plans. The science-activity plan will be merged with the FOT activity plan so that all mission goals are met. The Project will provide inputs for FOT-controlled events. The FSM will supply memory loads for the main on-board processor.

Only when all of the above inputs have been received, digested and verified – and all of the inevitable conflicts have been resolved – will the SOHO Activity Plan be finalised!




## EUROPE IN SPACE 1960 – 1973

*by John Krige & Arturo Russo*

This is the first part of a two-volume history covering Europe's cooperative space efforts, which traces their beginnings from the late 1950s and the subsequent developments of a European space programme from that time up to the early 1970s. It recounts the efforts of the fledgling space community that launched ESRO (the European Space Research Organisation) and ELDO (the European Launcher Development Organisation), with much government support, and shows how those two organisations gradually evolved, and how the foundation was laid for a single European Space Agency.

Drawing on the ESA documentation in the Historical Archives of the European Community at the European University Institute in Florence, and the many interviews with key players involved in the build-up of the European space programme, John Krige and Arturo Russo provide a lively picture of the complex and at times dramatic process of Europe's slow, but determined, efforts in establishing a cooperative space programme.

'This volume provides an important contribution to our understanding of the development of science and technology in postwar Europe. It should thus be of interest not only to those who were directly involved in Europe's fascinating venture into space, the space scientists, and those concerned with the organisation and implementation of the space projects in government and industry, but also to the general public who watched, and simply by virtue of their support became participants in, one of the most remarkable successes of European integration.

I hope that the reader will get a feel for what drove the pioneers in their efforts to set up a European space programme and their enthusiasm for that cause, and will read this fascinating story with a similar sense of attachment and participation as I have read it and look forward to the second volume of the study.'

*Reimar Lüst*
*Chairman of the Advisory Committee to the ESA History Study*

***Europe in Space 1960-1973, ESA SP-1172***

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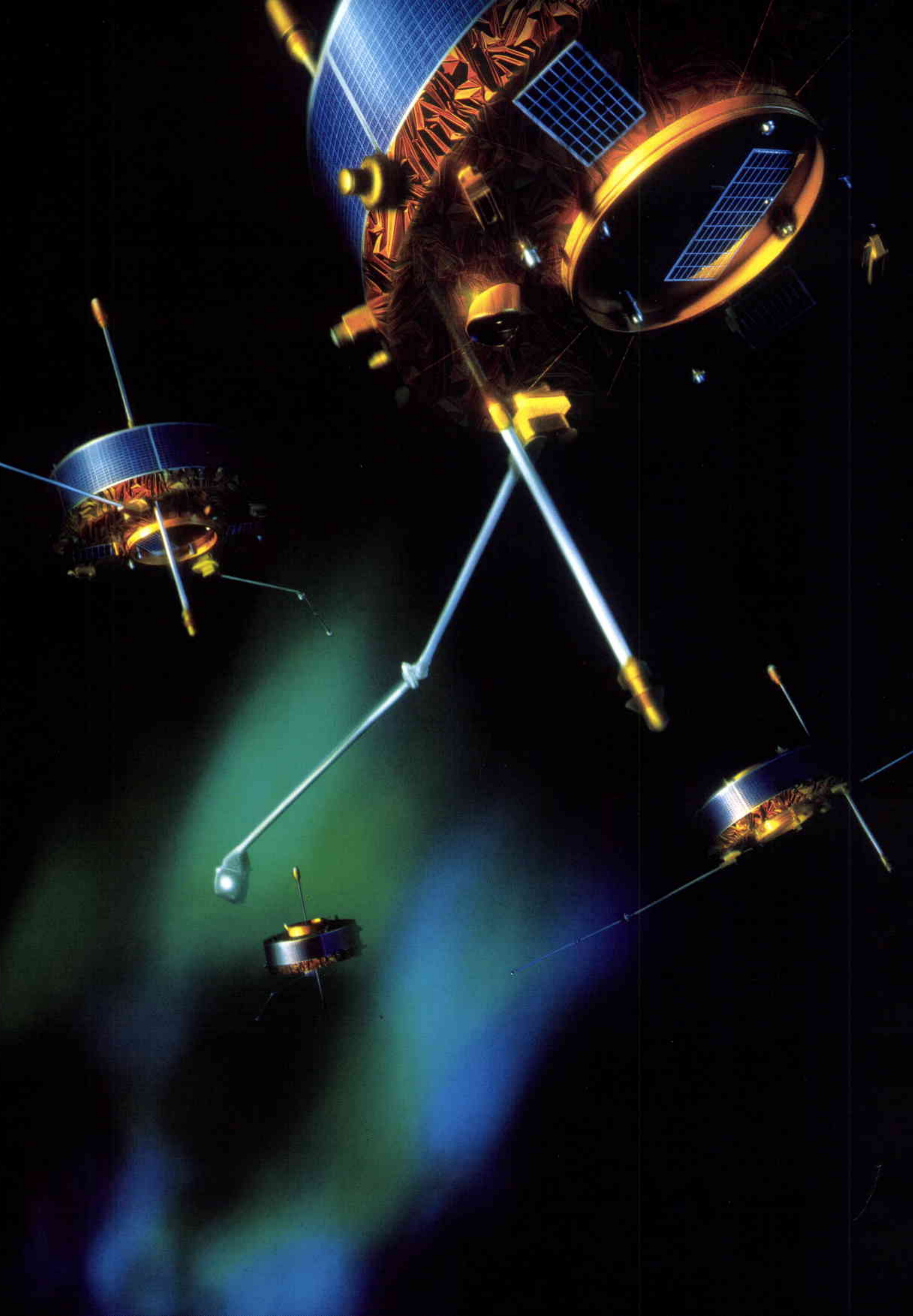

# The Cluster Mission – ESA's Space Fleet to the Magnetosphere

**J. Credland**
Cluster Project Division, ESA Directorate for Scientific Programmes,
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During the first half of 1996, the Agency will launch a unique flotilla of spacecraft to study the interaction between Sun and Earth in unprecedented detail.

The Cluster mission was first proposed to the Agency in late 1982 and has since evolved into a complex four-spacecraft mission to carry out three-dimensional measurements of the magnetosphere, covering both large- and small-scale phenomena in the sunward and tail regions.

The series of firsts achieved by the mission is impressive, this being:
- the first time that four identical spacecraft have been launched on a single launch vehicle
- the first time that ESA has built spacecraft in true series production and operated them as a single group
- the first time that European scientific institutes have produced a series of up to five instruments with full intercalibration, and
- the first launch of the Agency's new heavy launch vehicle Ariane-5.

## The mission concept

The Cluster mission was first proposed in November 1982 in response to an ESA Call for Proposals for the next series of scientific missions. Originally, there was an idea from a group of French scientists to make a detailed study of the Earth's magnetic-tail region in the equatorial plane. This idea was transformed for the proposal into a polar-orbiting mission to study the 'cusp' regions of the magnetosphere.

The assessment study ran from February to August 1983 and was followed by a design study (so-called Phase-A) during 1984/85, which was presented to the scientific community in late 1985. One proposal at that point was for a four-spacecraft mission consisting of a mother spacecraft weighing 270 kg and carrying 46 kg of scientific payload, and three daughter spacecraft each of 217 kg and carrying 26 kg of scientific payload. These four spacecraft were intended to be launched into a polar orbit of 4 x 22 $R_E$ (Earth radii).

During the period of mission selection, the SOHO mission had also been studied at Phase-A level, and both missions were originally intended to be an international collaboration with NASA. In the meantime, the Science Programme Committee had approved the Agency's long-term programme 'Space Science: Horizon 2000', and in February 1986 the combined Cluster and SOHO missions were selected as the first 'Cornerstone' of that Horizon 2000 plan, together constituting the Solar Terrestrial Physics (STP) mission.

The mission was initially approved by ESA's Science Programme Committee (SPC) as a European-only mission, but once detailed definition of the STP mission was pursued it became obvious that the costs could not be accommodated within the 400 MAU baseline figure allocated to Horizon 2000 Cornerstones. Thereafter, further collaboration with NASA was rigorously pursued.

As a part of the cost-reduction exercise, two ESA committees of external scientists then embarked on a process of scientific descoping, and with international cooperation from NASA the cost estimates for the STP mission were reduced to 484 MAU, a figure finally accepted by the SPC as a target cost for the mission. This figure, escalated to current prices and adjusted for changes in the overhead rates, remains the cost envelope for the two missions and has been contained in all the subsequent years of mission evolution.

At one stage, as part of the collaborative effort with NASA, a proposal was made to use the first Cluster spacecraft in place of the planned NASA Equator spacecraft, and to launch this first spacecraft on a NASA launch vehicle into

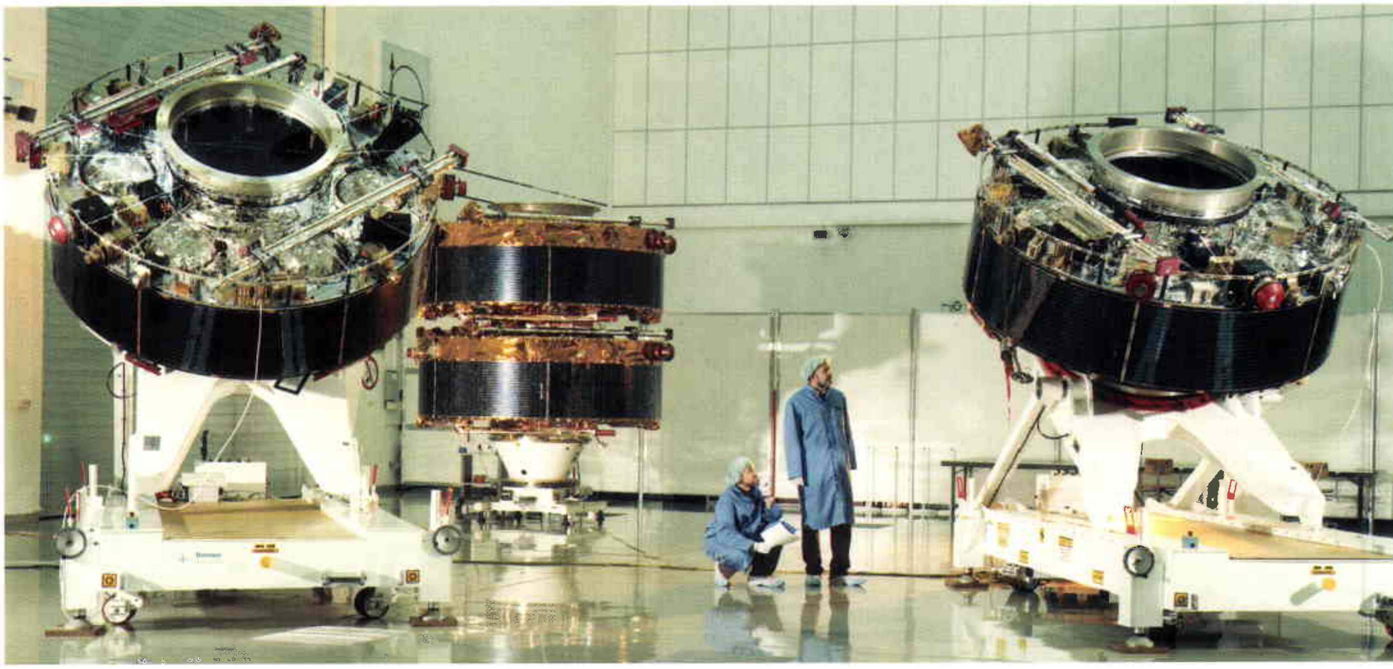

Figure 1. The four Cluster flight-model spacecraft together for the first time in the cleanroom at IABG, Ottobrunn (D). Two spacecraft are shown complete with thermal hardware and stacked in launch configuration, whilst the other two are 'open' with the payload platform visible

an equatorial orbit for an initial one-year mission. The remaining three Cluster spacecraft would then have been launched by ESA into their polar orbit, to be joined by the first 'equatorial' spacecraft to form the cluster of four. This concept was subsequently abandoned due to the expected degradation of payload units after the first year in equatorial orbit. The difficulties of intercalibration of the four spacecraft's scientific instruments after the launch of the other three were thought to be insurmountable.

The final baseline mission, renamed the Solar-Terrestrial Science Programme (STSP), consisted of a two-thirds/one-third cooperative endeavour between ESA and NASA, which occurs principally on SOHO with its NASA-supplied launch vehicle and full spacecraft and science operations, from Goddard Space Flight Centre. Cluster, on the other hand, was able to benefit from a special concession within the framework of the Ariane-5 Apex development programme, eventually securing a launch on the first test firing of Ariane-5 (V501).

### The current mission

The Cluster mission is an *in-situ* investigation of the Earth's magnetosphere using four identical spacecraft simultaneously (Fig. 1). It will permit the accurate determination of three-dimensional and time-varying phenomena and will make it possible to distinguish between spatial and temporal variations.

The four Cluster spacecraft will be placed in nearly identical, highly eccentric polar orbits, with a nominal apogee of 19.6 $R_E$ and a perigee of 4 $R_E$ (Fig. 2). This nominal orbit is

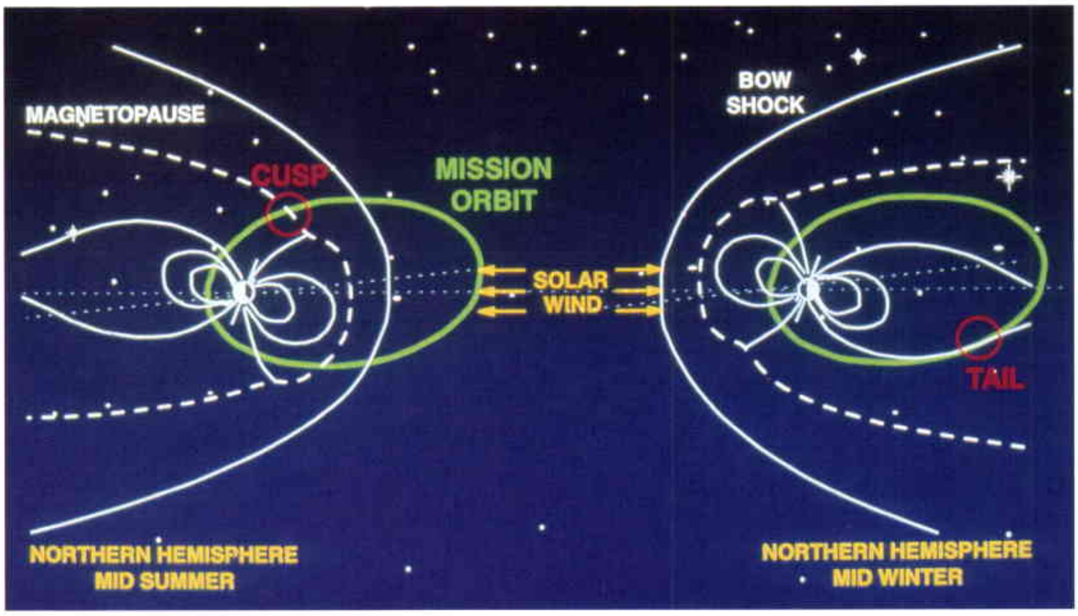


Figure 2. The Cluster operational orbit. This highly elliptical polar orbit of 4 x 19.6 $R_E$ is essentially inertially fixed, so that in the course of a year the apogee moves from the tail region into the solar-wind region, thereby allowing all areas of the magnetosphere to be addressed

essentially inertially fixed, so that in the course of the two-year mission it will enable a detailed examination to be made of all significant regions of the magnetosphere. The plane of this orbit bisects the geomagnetic tail at apogee during the northern-hemisphere winter, and passes through the northern cusp region of the magnetosphere six months later. The operational orbit finally selected for each spacecraft will depend upon the actual launch and orbit-transfer scenario.

The orbit for each spacecraft will be selected so that each is located at a vertex of a pre-determined tetrahedron (Fig. 3) when crossing the regions of interest within the magnetosphere. The relative separations within this constellation of spacecraft will be adjusted during the mission to correspond with the spatial scales of the structures to be studied, and will vary from a few hundred kilometres to a few Earth radii. The separation manoeuvres will be performed at intervals of approximately six months, synchronised with normal orbit-maintenance manoeuvres.

In the programme baseline, all four spacecraft will be injected into Geostationary Transfer Orbit (GTO) on a single Ariane-5 launch vehicle. The spacecraft will then be transferred one by one to their mission orbits through a series of spacecraft propulsive manoeuvres (Fig. 4).

In orbit, the spacecraft will be spin-stabilised at all times. Their attitudes will be selected to ensure a solar-aspect angle of approximately 90°, which optimises the performance of the spacecraft's solar-power generator and thermal-control subsystem throughout the mission. This attitude will be maintained during manoeuvres in the operational phase of the mission, but it will be necessary to reorient the spacecraft temporarily during the orbit-transfer phase in order to permit specific manoeuvres to be carried out. Eclipses will occur during all phases of the mission. Their durations will depend on the final launch date, transfer scenario and mission orbit. Current mission plans suggest that the longest eclipses will last approximately 240 min.

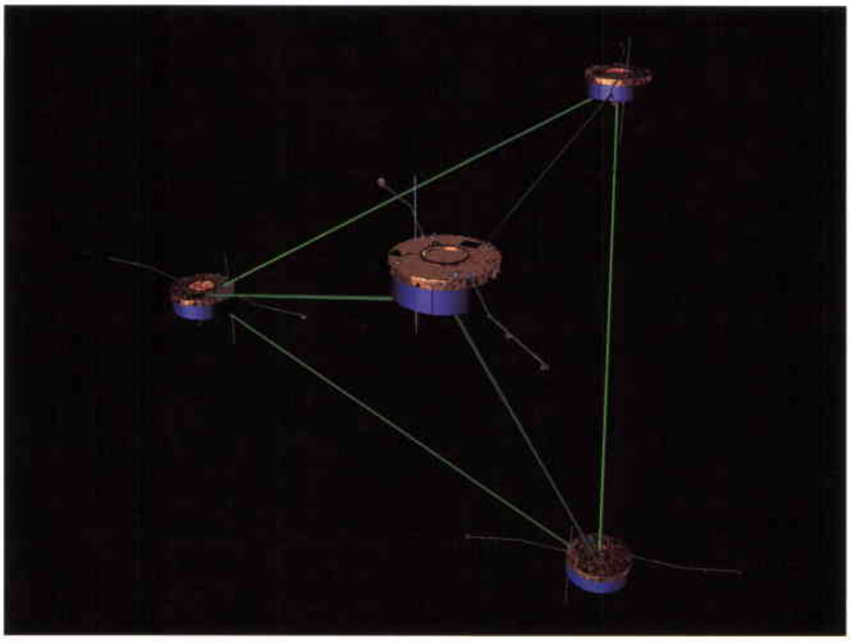

**Figure 3. The tetrahedral formation in orbit. The four Cluster spacecraft are placed in slightly different orbits, which ensures that at a specific point in space they form the vertices of a tetrahedron. This will allow true three-dimensional measurements to be made in the regions of primary scientific interest**

## The scientific payload

The Cluster payload experiments gave rise to some fundamental spacecraft design requirements. In particular, the mission demands that the spacecraft have a very high degree of electromagnetic cleanliness to avoid disturbing the local plasma field or otherwise interfering with the sensor measurements. The particle experiments all require unobstructed fields of view and a high level of chemical cleanliness to preserve the sensitivity of their micro-channel plate detectors.

In order to measure the undisturbed local DC magnetic field to the required sensitivity, the DC magnetometer (FGM) sensors had to be mounted away from the main body of the spacecraft, on a deployable rigid boom. The AC magnetometer (STAFF) experiment is sensitive to AC magnetic fields, and also had to be mounted in a position remote from the spacecraft body, on a second rigid boom.

The total mass of each Cluster payload is 72 kg. It produces data at different rates, depending on its operating mode. In its nominal mode, it will deliver data at the moderate rate of 17 kbit/s, but at certain locations within the orbit it will be operated in a 'burst mode' with the significantly higher data rate of 105 kbit/s. In addition, the Wide Band Data (WBD) experiment produces data at the very high rate of some 220 kbit/s, but this experiment will only be


**Figure 4. The orbit-manoeuvre scenario. The spacecraft will be injected into a standard GTO orbit by Ariane-5. The change in orbit from equatorial will be accomplished by a series of intermediate manoeuvres**

operational for approximately 30 min during each orbital revolution. The power required by the payload is specified as 47 W and is nominally constant.

## The ground segment

The European Space Operations Centre (ESOC) in Darmstadt (D) will be responsible for the Cluster Operations Control Centre. It will control the four spacecraft in their mission orbits via ESA's Odenwald and Redu ground stations (Fig. 5). Additional ESA ground stations will be used during the mission's Launch and Early Orbit Phase (LEOP).

A ground station belonging to NASA's Deep-Space Network (DSN) will support the mission during certain specific scientific operations, when data from the WBD experiment is being transmitted at high bit rate. Further NASA/DSN support will be used to back-up the ESA network, including ranging, telemetry acquisition and telecommand back-up functions during the critical transfer-orbit phase.

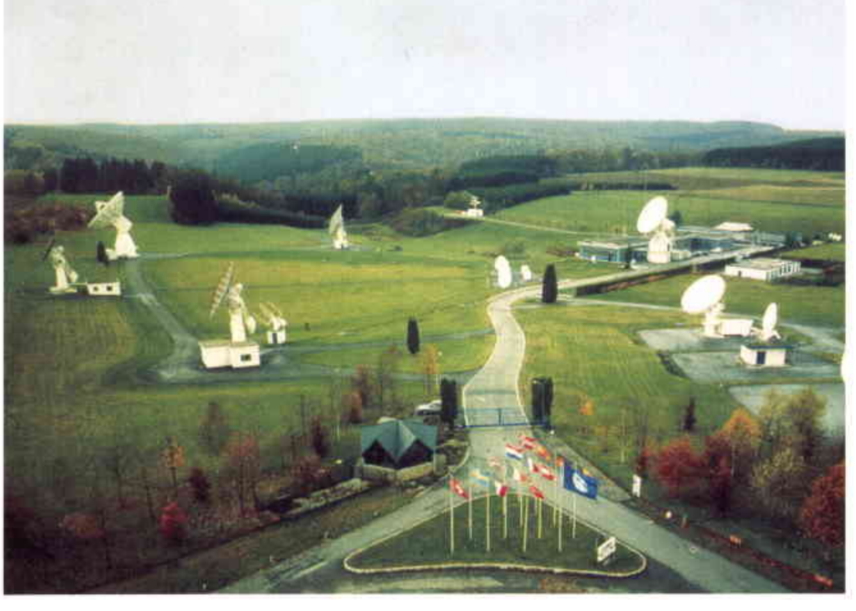

**Figure 5. ESA's Redu (B) ground-station complex has been equipped with a new 15 m antenna (on extreme left of photo) and associated equipment to support Cluster operations in S-band**

Orbit determination for all mission phases will also be performed by ESOC. The Cluster mission requires that the relative separations of the four satellites be determined to within 1% or 10 km, whichever is the smaller. This will be achieved by determining the orbit of each spacecraft individually from the ground.

Simultaneous acquisition of two or more spacecraft from one ground station is not planned. However, the OCC is able to monitor and control two spacecraft simultaneously by using two ground stations. All communications with the spacecraft will be in S-band, and the up- and down-links of each individual satellite will be assigned different frequencies.

## Mission operations

The mission is divided into several distinct phases, each with specific operational objectives. One special feature of this mission is that the four spacecraft will be controlled in a time-sharing mode, presenting the OCC with an unusually complex task. This will be particularly true during the early mission phases, when many critical operations will have to be performed under strict time constraints. The spacecraft design therefore includes a high degree of autonomy and a flexible on-board software concept in order to facilitate the meeting of these operational requirements.

In the Launch and Early Orbit Phase (LEOP), following injection into Geostationary Transfer Orbit (GTO) by Ariane, ground contact will be established with all four spacecraft at the earliest possible opportunity. This will permit a quick-look status verification of essential parameters, which will be followed by less time-critical checkout and orbit-determination activities.

The Transfer-Orbit Phase (TOP) is characterised by a number of large orbit-profile and inclination-change manoeuvres, to target the spacecraft into the desired mission orbits. The spacecraft attitude will be temporarily adjusted for each of these manoeuvres to align the single main engine with the desired thrust direction. Throughout the TOP, the four spacecraft will be treated as two pairs, and injected with approximately 40 h between spacecraft pairs.

Once in mission orbit, a Commissioning and Verification Phase (CVP) will commence, which will be devoted mainly to payload operations. These include the deployment of the two rigid radial booms, followed by the deployment of the flexible wire booms, the experiment check-out, and the calibration activities.

During the main Mission Operations Phase (MOP), the primary objective is to maximise the scientific data return from the payload. The areas of scientific interest within the orbit will vary seasonally, and do not generally coincide with real-time ground contacts. To accommodate these, in the nominal operating mode the scientific data will be stored on on-board solid-state recorders, which will then play them back, together with the real-time telemetry, during subsequent ground-contact periods.

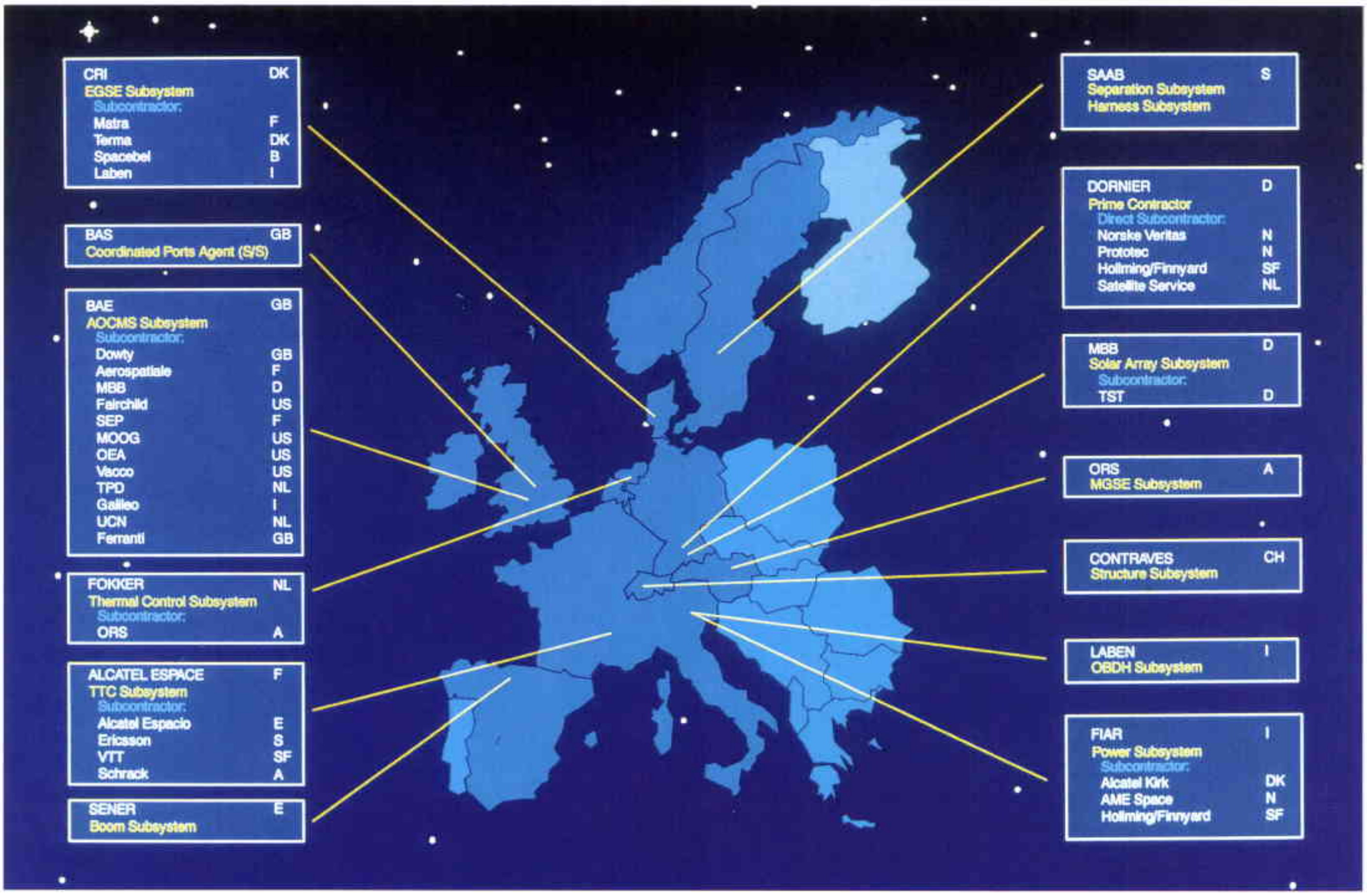


**Figure 6. The Cluster industrial structure**

### The industrial team

The Invitation to Tender for the Cluster mission was issued by the Agency in mid-1988. Following a phase of industrial competition, the Prime Contractorship was awarded to Dornier in Summer 1989.

Phase-B, the design phase, then commenced in October 1989 with a core team of contractors already selected with the Dornier proposal. The full industrial team (Fig. 6) was built up during this phase, with lower-tier subcontractors being selected on a technical-competence and price basis to achieve the requisite geographical distribution targets set for the project.

The achievement of those geographical-return targets was made easier by an agreement with the ESA Industrial Policy Committee (IPC) that the targets could be met for the STSP Cornerstone as a whole, rather than at individual project (SOHO and Cluster) level. Several pieces of equipment (power-distribution units and transponders) were in fact procured as common items between the two projects as a pragmatic way of achieving the required targets.

The main Cluster development programme (Phase-C/D) commenced in April 1991 with delivery of the four spacecraft to the Agency in April 1995 as a target. In reality, despite a number of critical setbacks during the programme, delivery by Dornier was completed in July 1995, still on schedule for the originally foreseen 1 December 1995 launch date.

The system-level environmental test programme was conducted entirely at IABG in Ottobrunn (D) and lasted for two years. During this period, all four Cluster spacecraft successfully underwent sine-vibration, acoustic noise, thermal-balance/vacuum and DC-magnetic testing, in the most extensive test programme of this nature ever undertaken for any ESA project.

The Cluster launch campaign started in late August to meet a by then declared, slightly delayed launch date of 17 January 1996 for Ariane-5's first flight (V501). A natural break point occurs in the programme during November, at the completion of all electrical checks and prior to spacecraft fuelling. At the time of writing (end-September), the launch campaign is expected to be suspended at this break point, pending declaration of a new firm launch date for V501, which is currently expected to take place in late Spring/early Summer 1996.

# The Cluster Spacecraft: A Unique Production Line

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The Cluster mission is a 'first' for the Agency in that it requires the delivery of four identical spacecraft for simultaneous launch on a single vehicle. This series production of spacecraft to meet a unique launch opportunity has never previously been attempted and has represented a major challenge for all involved: the Agency, Industry and the Experimenters.

Long before the start of the Cluster design phase (Phase-B) activities in October 1989, a launch date towards the end of 1995 had been fixed. This limited the time available for development, manufacture and testing of the four spacecraft to that which other satellite projects normally need to deliver only one flight model. Consequently, the logistics for Cluster hardware and software production and verification were crucial, leading to such requirements as modular design at system level, allowing parallel pre-integration and late exchange of the PROMs in the Central Data Management Units (CDMUs)

**Constraints on spacecraft design**

The Cluster mission is designed to investigate the Earth's magnetosphere from nearly identical, higly elliptical polar orbits using identical instruments on four spacecraft simultaneously. A prerequisite to achieve this is maximum similarity of the various spacecraft functions on the four flight models. Reproducibility of the Cluster hardware at all levels has therefore been of major importance.

During the operational mission phase, the four satellites will fly in a tetrahedral configuration when crossing the magnetospheric regions of interest (Fig. 1). The predefined separation distances between the satellites will be regularly adjusted for different periods of the two-year mission. Each spacecraft therefore has to carry sufficient propellant for all of these manoeuvres.

The mission orbits selected impose eclipse durations of up to 4 h and this has been a major design driver for the whole spacecraft

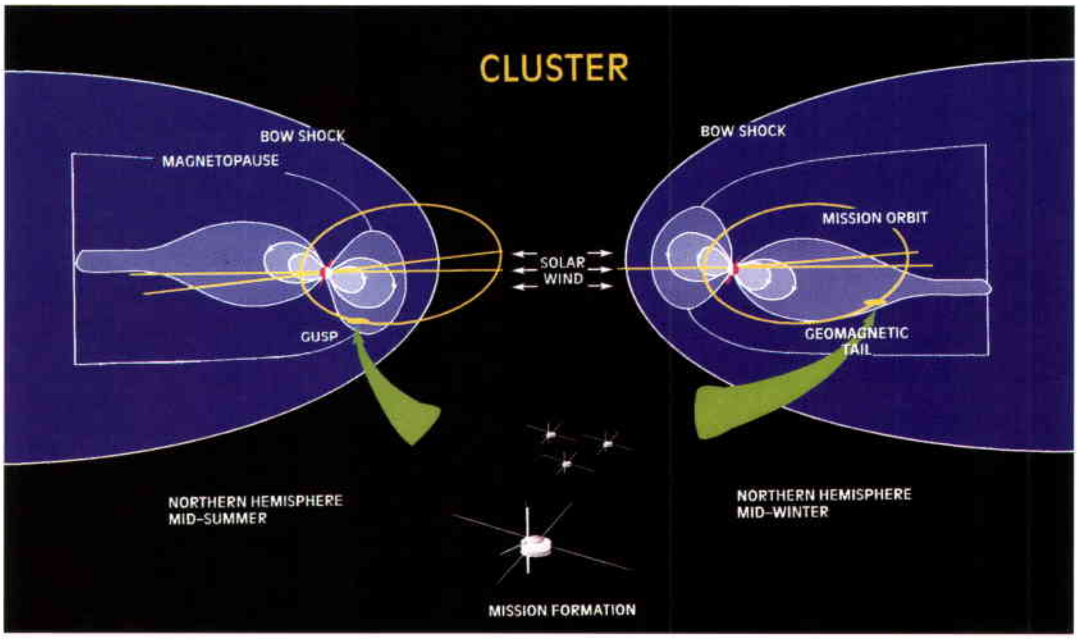



**Figure 1. The Cluster operational orbits**

system, and for the thermal-control, power and structural subsystems in particular. Another important design requirement originating from the scientific payload is the need for a high degree of spacecraft electromagnetic cleanliness, such that they do not disturb the local plasma fields or otherwise interfere with the sensor measurements. All of the particle experiments require unobstructed fields of view and chemical cleanliness to preserve the sensitivity of their micro-channel plate detectors. Very high magnetic cleanliness of the spacecraft is also required, to allow measurements to be made of the local DC and AC magnetic fields. In addition, these sensors (FGM and STAFF) require mounting in a position remote from the spacecraft's main body.

Globally speaking, each spacecraft has to accommodate 72 kg of payload, provide 47 W of power to the payload, and support the recording and transmission of the scientific data at rates ranging from 17 to 220 kbit/s.

All four Cluster spacecraft will be launched on a single Ariane-5 vehicle, the first qualification flight of which will deliver them into the Geostationary Transfer Orbit (GTO). The four spacecraft will be accommodated in two pairs within the two launcher payload compartments (Fig. 2). This requires that each of the lower spacecraft must have a dedicated separation system on top to carry the upper spacecraft of the pair.

Because the development of Cluster and of Ariane-5 have been proceeding in parallel, specific and sometimes severe requirements were imposed on Cluster to cover uncertainties in the launcher development programme. For example, conservative loads were specified for sine, random and acoustic vibration testing. Nevertheless, very late in the Cluster development programme – in fact after acceptance of the Cluster hardware – unusually high predicted shock loads originating from launcher separations were identified by Ariane, necessitating additional, unforeseen verification activities at unit and system level for Cluster.

A further constraint resulting from the fact that it will be the first Ariane-5 launch is that launch must occur within a daily 2 h launch window during Kourou daylight time.

Since the four spacecraft will be injected into GTO rather than their mission operational orbits, each will have to perform a complex series of orbit transfer manoeuvres (Fig. 3), requiring large quantities of propellant. To make this transfer scenario manageable from the operational point of view, a strategy for handling the spacecraft as two pairs during the early mission phases has been adopted, leaving one pair twice as long as the other in GTO. The design of onboard equipment, including the solar arrays, has had to take the associated increased radiation damage into account. Operability requirements in general have played a major role during Cluster's development, to facilitate safe parallel operation of the four spacecraft by ESA's European Space Operations Centre (ESOC) in Darmstadt (D).

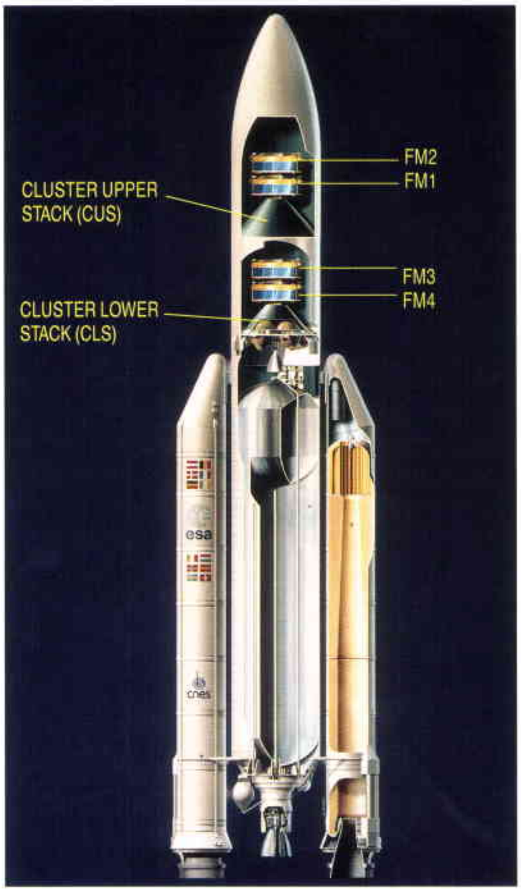



Figure 2. The Cluster launch configuration aboard Ariane-5

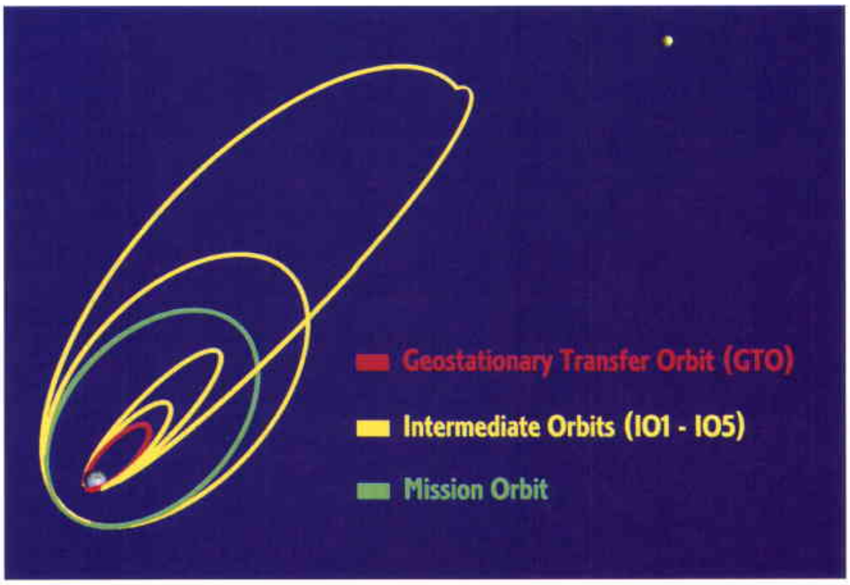
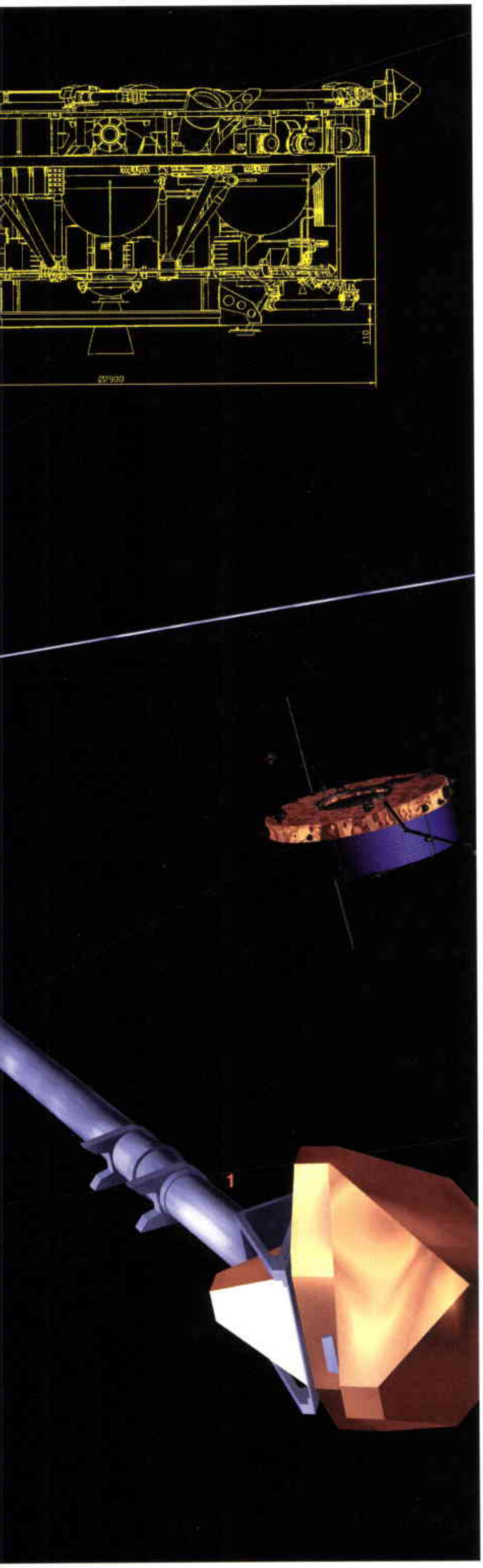



Figure 3. The Cluster transfer strategy from GTO


**Figure 4. Flight configuration of the Cluster spacecraft and a cutaway section**



Another challenge in this context was presented by the normal ESA practice regarding the geographical distribution of work across industry in the ESA Member States. In Cluster's case, the Prime Contractor, Dornier (D), has had to coordinate the activities of 36 contractors for flight hardware and software alone.

### The resulting spacecraft design

In orbit, the four spacecraft will be spin-stabilised at all times, normally at around 15 rpm. The in-orbit spacecraft configuration is characterised by four 50 m experiment wire booms, two 5 m experiment radial booms and two axial telecommunications antenna booms (Fig. 4).

The spacecraft's cylindrical design is driven by the body-mounted solar array and also optimises the fields of view available to the experiments, which are accommodated around the rim of the main equipment platform on the upper side of the spacecraft. The height of the spacecraft body has been minimised to make optimal use of the fairing volume offered by the launch vehicle.

The compact spacecraft primary structure provides mass-efficient load paths to its mechanical interfaces. It consists of the central

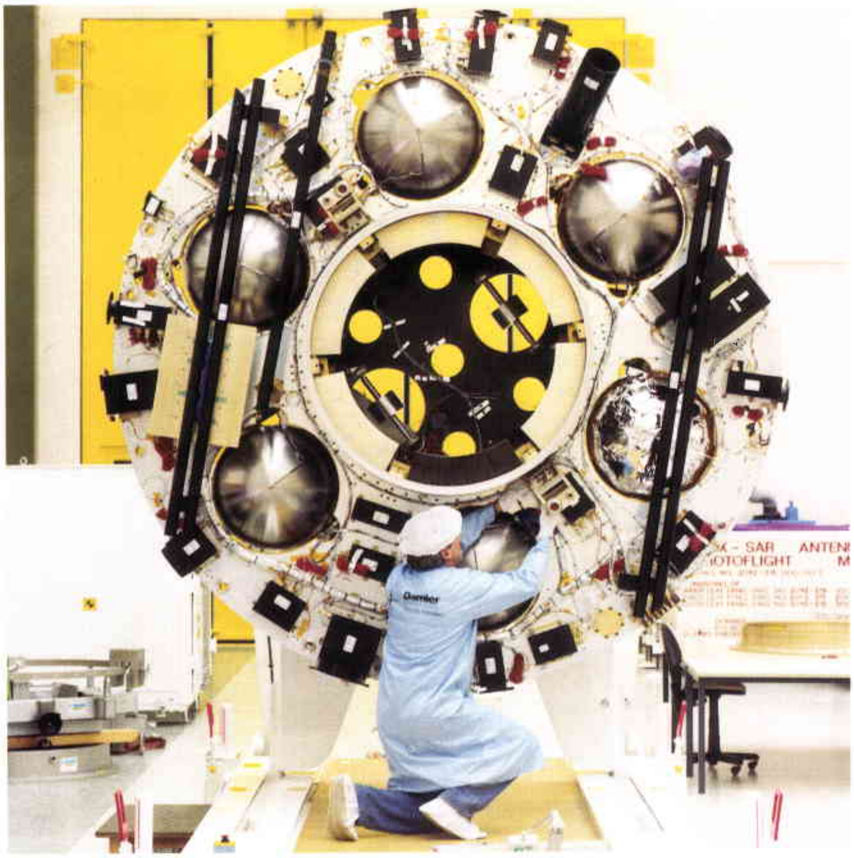


**Figure 5. The Cluster Structural Model spacecraft during integration. The six propellant tanks, booms, main platform and central cylinder are visible, together with the harness and mass dummies of the various units**

cylinder, the main equipment platform, a tank support structure, a platform internal to the central cylinder and a Reaction Control Subsystem (RCS) support ring (Fig. 5). The central cylinder is fabricated as a CFRP-skinned aluminium honeycomb sandwich, and the Main Equipment Platform (MEP) as an aluminium-skinned honeycomb panel reinforced by an outer aluminium ring. The MEP is supported by symmetrically arranged CFRP struts connected to the central cylinder. Overall, each spacecraft body is 2.9 m in diameter and 1.3 m high.

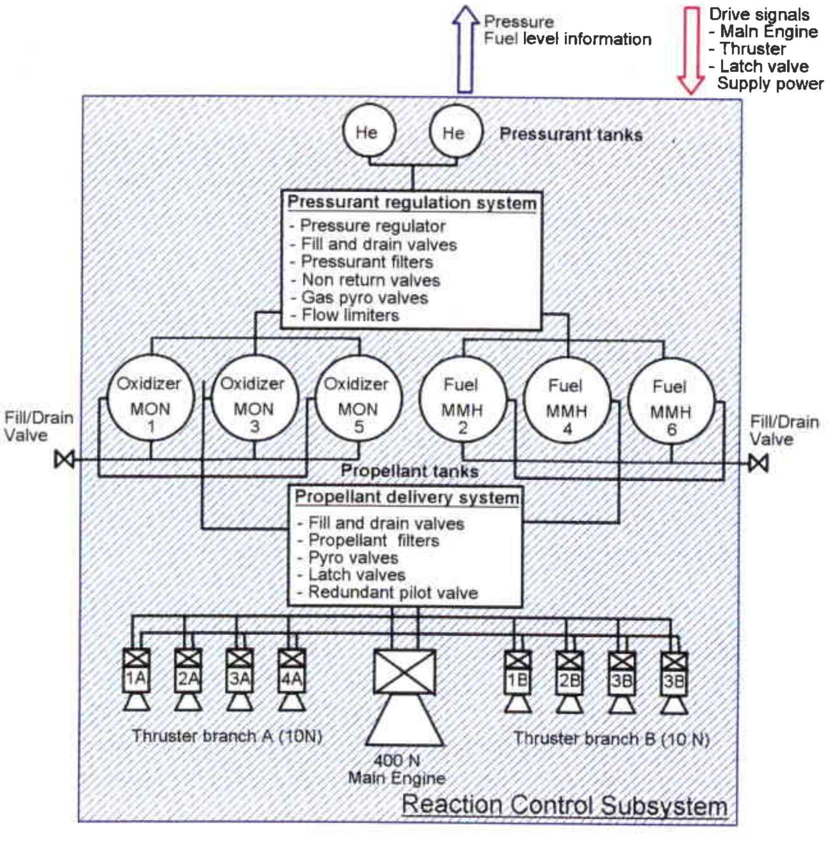



**Figure 6. The Reaction Control Subsystem (RCS)**

The overall design allows for parallel integration of all equipment with the Main Equipment Platform on one side, and the central cylinder with the RCS components on the other. This feature proved essential in maintaining the imposed schedule.

Six cylindrical titanium propellant tanks with hemispherical ends are each mounted to the central cylinder via four CFRP struts and a boss. The propellant carried in these tanks will constitute more than half of each spacecraft's launch mass of around 1180 kg.

Six curved solar-array panels together form the outer cylindrical shape of the spacecraft body and are attached to the Main Equipment Platform. This platform provides the mounting area for most of the spacecraft units, the payload units being accommodated on the upper surface and the subsystem units, in general, on the lower surface. The five batteries and their associated regulator units needed to provide energy to the spacecraft during the 4 h eclipses in mission orbit are mounted directly on the central cylinder.

At their lower ends, the solar-array panels support a ring accommodating many of the RCS components, including four radial 10 N thrusters. Four axial 10 N thrusters are mounted on studs on the upper and lower faces of the spacecraft. All thruster positions were carefully chosen to minimise the chances of contamination reaching the sensitive experiments.

Because the solar-array panels will experience extremely low temperatures during the eclipses, special care has had to be taken in designing their attachments to the structure and the thermal insulation of their inner faces, in order to minimise the onboard heating requirements in eclipse.

The inner equipment panel inside the central cylinder supports the single main engine, two high-pressure tanks and associated propellant-management hardware.

The RCS (Fig. 6) is configured as a conventional bi-propellant system, based on a single 400 N main engine and eight 10 N thrusters. It is arranged in two redundant branches (with the exception of the main engine), each of which is capable of performing a complex mission profile. Electrical cross-coupling permits the operation of either of the two branches from either redundant half of the Attitude Determination and Control Electronics (ADCE). The propellant is stored in six tanks pressurised by helium stored in two smaller spherical tanks. Pressure-regulation and propellant-delivery systems manage the pressurant and propellant conditioning and distribution functions. During launch, the pressurant, fuel, oxidiser and the manifold will be isolated from each other by pyrotechnically operated valves, to comply with launch-vehicle safety requirements. After each manoeuvre, the main engine and thrusters will also be isolated by additional latching valves, thereby increasing reliability by eliminating potential leak paths.

Two rigid, double-hinged radial booms on the upper surface of the Main Equipment Platform carry payload sensors. These booms are stowed for launch, as are the four payload wire booms and the two rigid, single-hinged antenna booms carrying the S-band antennas. The rigid booms consist of CFRP tubes with

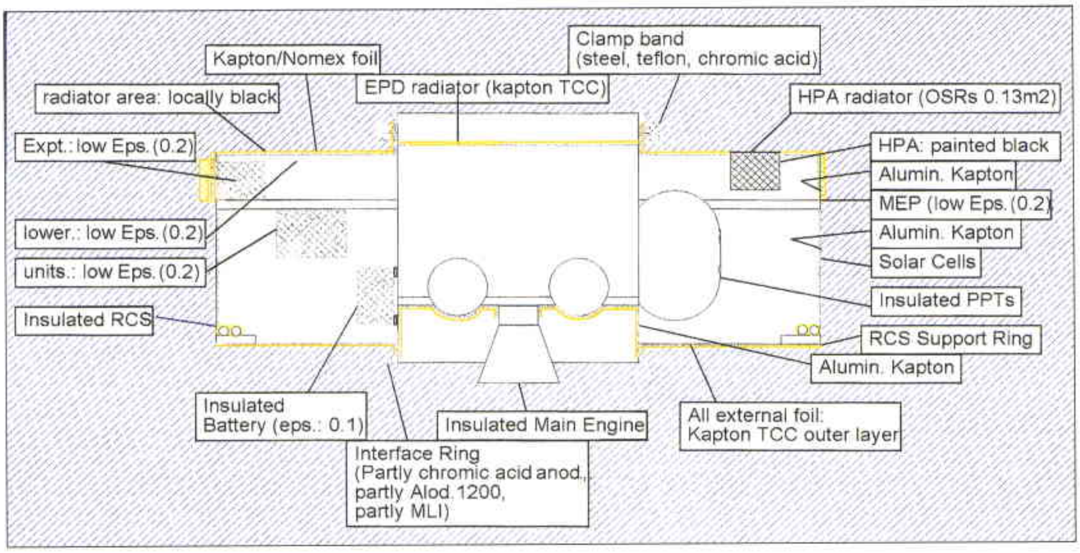



**Figure 7. The Cluster thermal-control concept**

titanium-alloy end fittings and deployment mechanisms. The radial booms will be deployed mainly by the centrifugal force developed by the spinning spacecraft, while the antenna booms are driven by redundant springs.

The passive thermal control of the Cluster spacecraft is based on a low-emissivity concept, insulating the spacecraft from the exterior environment to the extent needed to survive the 4 h eclipses in mission orbit, whilst still allowing the internally generated heat to be rejected (Fig. 7). The thermal closeout is provided by three types of hardware: low-emissivity double foil shields on the upper and lower surfaces of the spacecraft; MLI on the top and bottom of the central cylinder, below the RCS ring and around the upper part of the satellite, enclosing the experiments; and thermal insulation of the inner sides of the solar-array panels and on the 400 N main engine. An Optical Surface Reflector (OSR) radiator is integrated into the top surface to allow for the high dissipation of the RF power amplifiers. An External Power Dumper (EPD) radiator located in the upper thermal shield within the central cylinder dissipates excess power generated by the solar arrays. Heaters are used to keep equipment within specified temperature ranges throughout all mission phases, including eclipses. Temperature control is achieved by a combination of thermostats with thermistor surveillance and thermistor-guided software control.

The thermal design has been optimised for the almost constant solar-aspect-angle range (92°<SAA<96°) that will apply throughout the nominal mission phase. During the orbit transfer manoeuvres, however, the spacecraft may experience a much wider SAA range (65°<SAA<115°). The heat-rejection concept that has been selected therefore permits the satellite to dissipate heat through either the upper or the lower thermal shield. With these precautions, Cluster can safely withstand the complete range of solar aspect angles that will be encountered.

A heated-environment concept has been chosen for the lower spacecraft compartment, comprising RCS equipment, batteries and battery regulators. The complexity and duration of the assembly and integration activities were greatly reduced by this approach compared to a solution with insulated components, but it requires somewhat more heater power during eclipses.

All external surfaces, including the solar cells, blankets, double foils and radiator have been finished with an electrically conductive Indium Tin Oxide (ITO) coating to comply with the EMC requirements imposed by the experiments.

The central cylinder carries aluminium interface rings at both its upper and lower ends. The lower ring is compatible with the Ariane 1194 mm diameter adaptor and separation mechanism. The upper ring simulates the interface offered by the adaptor and is equipped with a separation mechanism. This allows two spacecraft to be stacked on top of one another, whilst themselves still remaining identical to the maximum extent possible.

Electrically, the spacecraft is configured in four major functional areas (Fig. 8): a power-supply subsystem including a pyrotechnics unit, an onboard data-handling subsystem, an attitude and orbit control and measurement subsystem, and a telecommunications subsystem. Dedicated, physically separated and carefully shielded harnesses interconnect the various subsystem and payload units. The payload includes a separate experiment interconnection harness.

Spacecraft power demands will be met by the body-mounted solar array and five non-magnetic silver/cadmium batteries. The batteries will power the spacecraft during eclipses and supplement the solar-array output during periods of peak power demand. Full payload operation will be supported throughout the entire mission orbit phase, except during eclipses. A block diagram of the Power Subsystem is shown in Figure 9.

The solar arrays consist of 2 Ohm cm Back-Surface-Reflection (BSR) cells, arranged in self-compensating formations to minimise the generation of DC magnetic fields. A conductive coating on the cell cover glass minimises the build-up of differential charge potentials.

Spacecraft power is conditioned and distributed via a voltage-regulated bus and redundant current-limiting switches. Where required, permanent 'keep alive' lines are provided to payload and subsystem units. Full protection against short-circuit or overload is provided by limiting the maximum current in any supply line. Excess solar-array output power is automatically routed to Internal Power Dumpers or shunted by commandable switching to an External Power Dumper. The power bus operates on a linear shunt regulation approach, rendering the main bus voltage extremely 'clean' during payload measurement periods. This significantly reduces any potential electromagnetic disturbances due to the power subsystem.

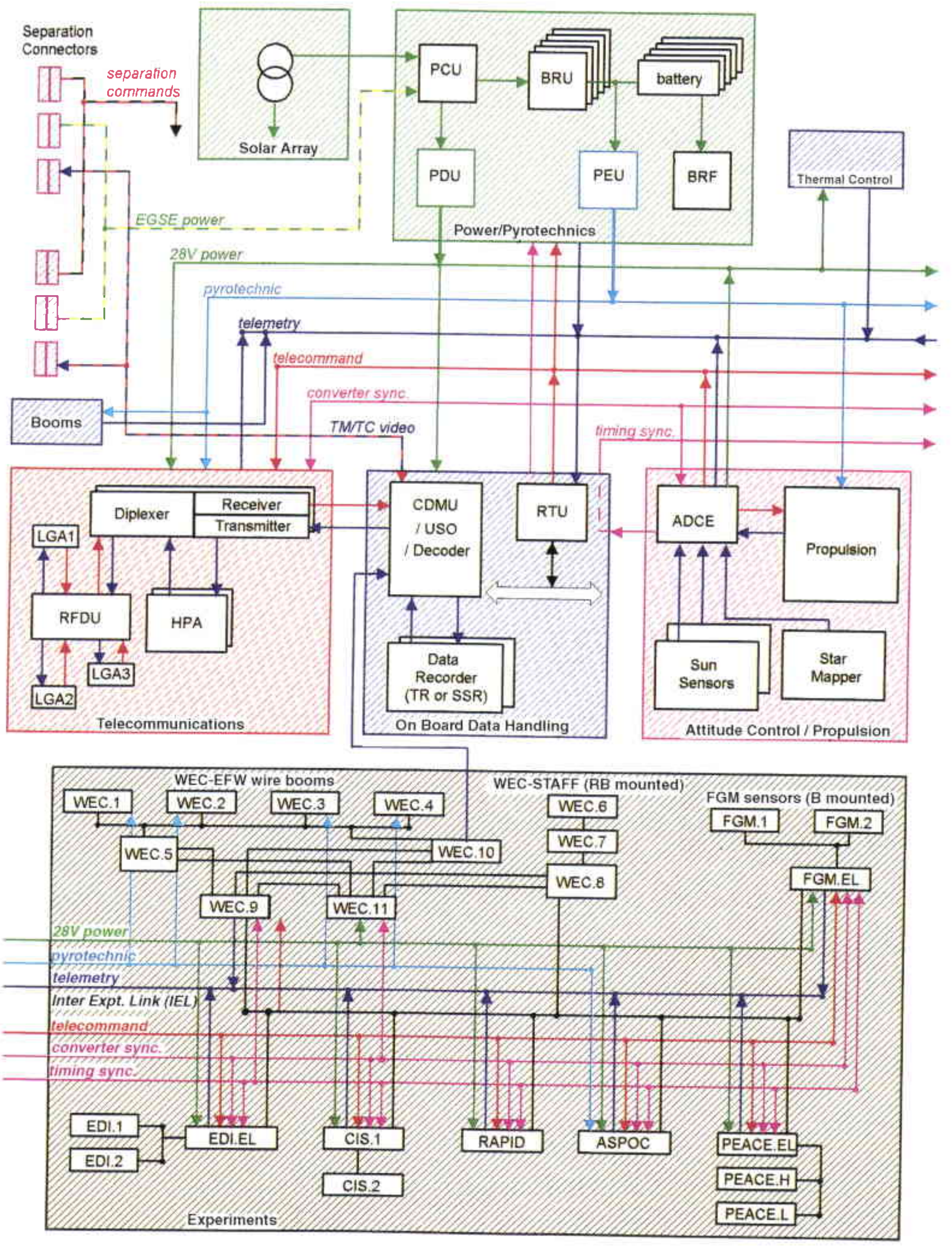



**Figure 8. The Cluster electrical system**

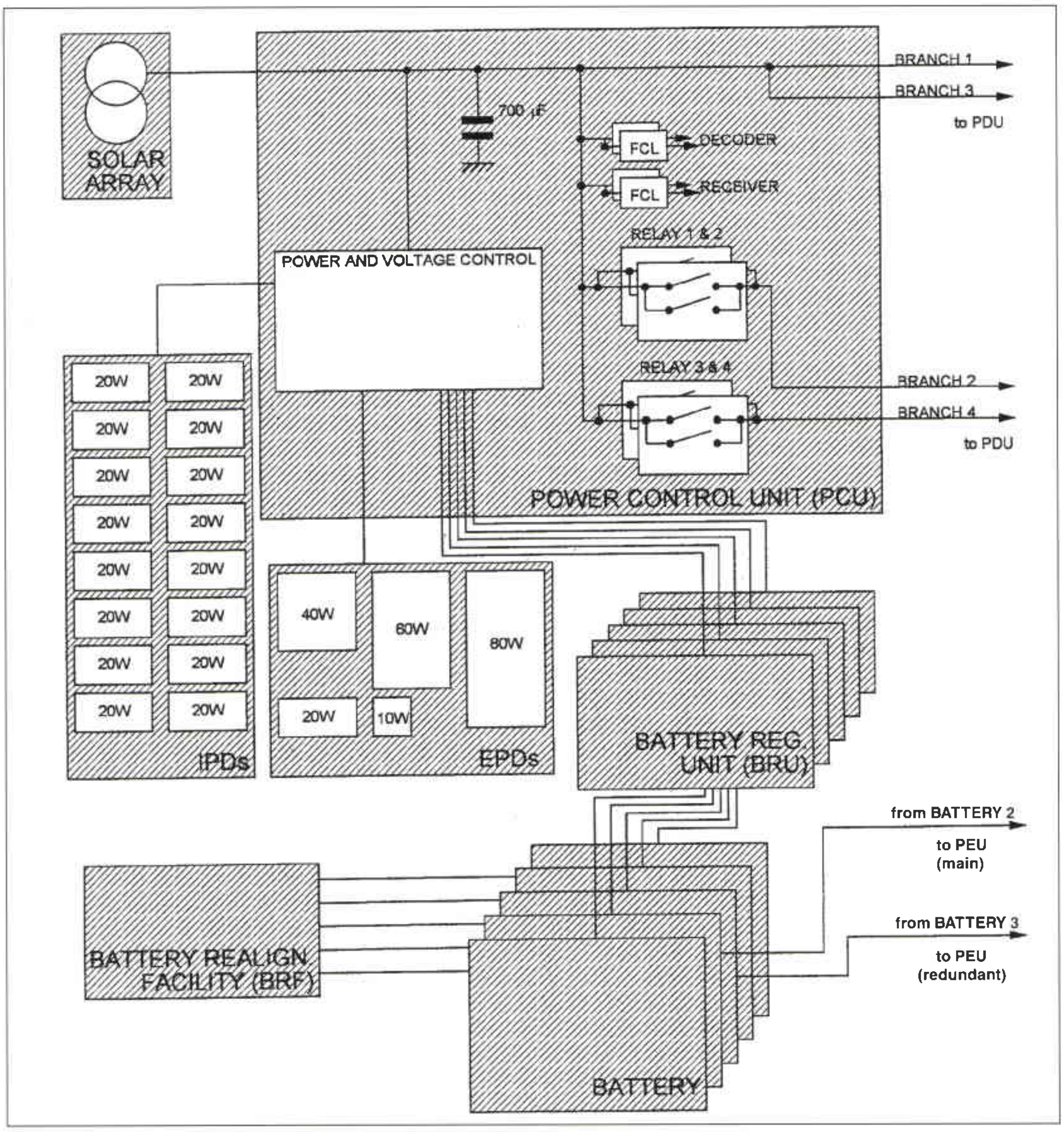



**Figure 9. The Cluster power subsystem**

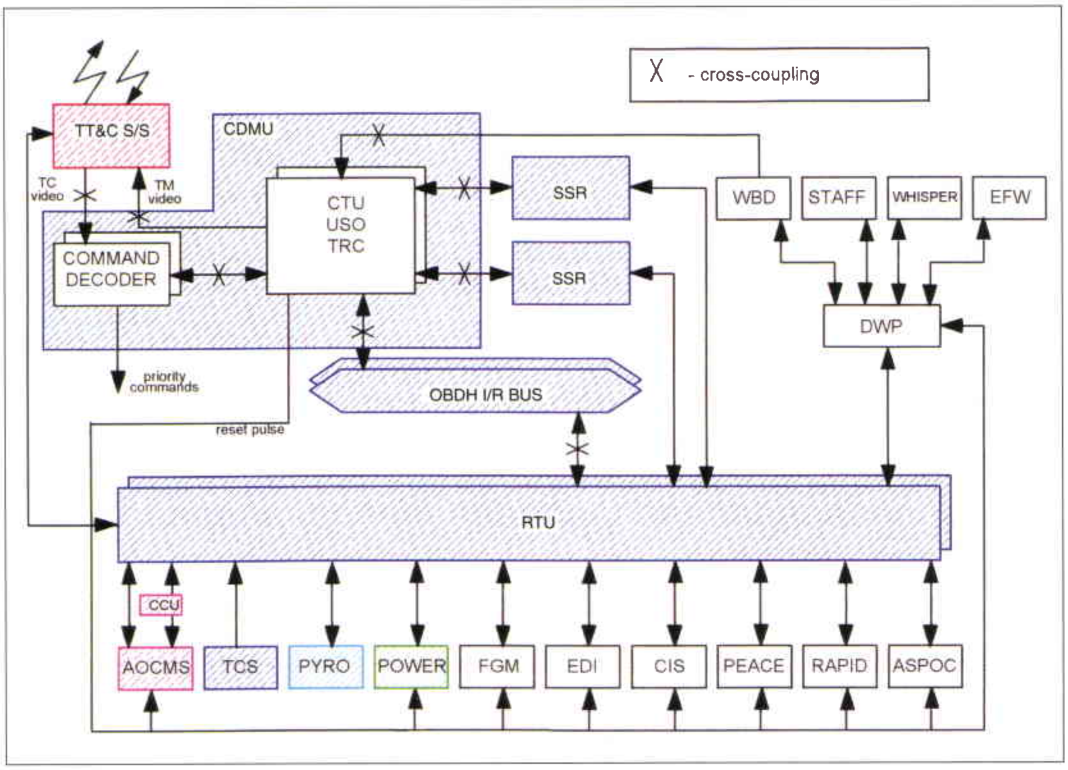



**Figure 10. The Cluster onboard data-handling subsystem**

The Onboard Data Handling (OBDH) subsystem, which will perform the primary spacecraft control functions, is based on an ESA standard approach (Fig. 10). It consists of a Central Data Management Unit (CDMU), a Remote Terminal Unit (RTU), and two Solid-State Recorders (SSRs). The CDMU and RTU are internally redundant; each SSR provides memory for about 2.2 Gbit of data at beginning of life.

The OBDH decodes and distributes commands, received by the telecommunication subsystem at a command bit rate of 2 kbit/s, and acquires and encodes telemetry from payload and subsystem units. This telemetry is delivered either to the telecommunications subsystem for real-time transmission to ground, and/or to the SSRs for later transmission. Dedicated high-data-rate interfaces are provided to the Wide Band Data (WBD) experiment and the SSRs. Stored data will be played back at a much higher rate than real-time data, in order to reduce the duration of the downlink during the limited ground-station visibility periods. WBD telemetry will only be transmitted in real-time.

Telemetry-stream bit rates are fixed at about 2 kbit/s for housekeeping telemetry, 22 kbit/s for nominal science telemetry, 131 kbit/s for burst science-data/recorder playback, and 262 kbit/s for WBD transmission/recorder playback.

The OBDH will also provide timing and synchronisation signals to payload and subsystem units, as well as AOCMS data to the payload. It will perform a surveillance function using onboard software to provide the autonomy required because of the extended non-visibility periods.

Maintenance of the orbit and attitude of the spacecraft will be performed by the Attitude and Orbit Control and Measurement Subsystem (AOCMS; Fig. 11). Spacecraft attitude and spin data are provided by an internally redundant star mapper and an internally redundant X-beam Sun sensor. The reconstitution of attitude data, such as inertial attitude, spin rate and spin phase, will be performed on the ground. This information is essential for the interpretation of the payload science data. The necessary accuracies for these attitude data are comfortably met by the subsystem.

Orbit and attitude maintenance will be performed by using control thrusters, both semi-radial and axial, together with the main engine, which will be used to perform the large orbital change manoeuvres required to reach the polar mission orbit from GTO.

Communications with the spacecraft will be established through the Telecommunications Subsystem (Fig. 12), which includes uplink and downlink capabilities to support the telecommand, telemetry and tracking functions. It will interface with the ESA Ground Segment and the NASA Deep-Space Network at S-band frequencies (uplink 2025 – 2110 MHz; downlink 2200 – 2290 MHz).

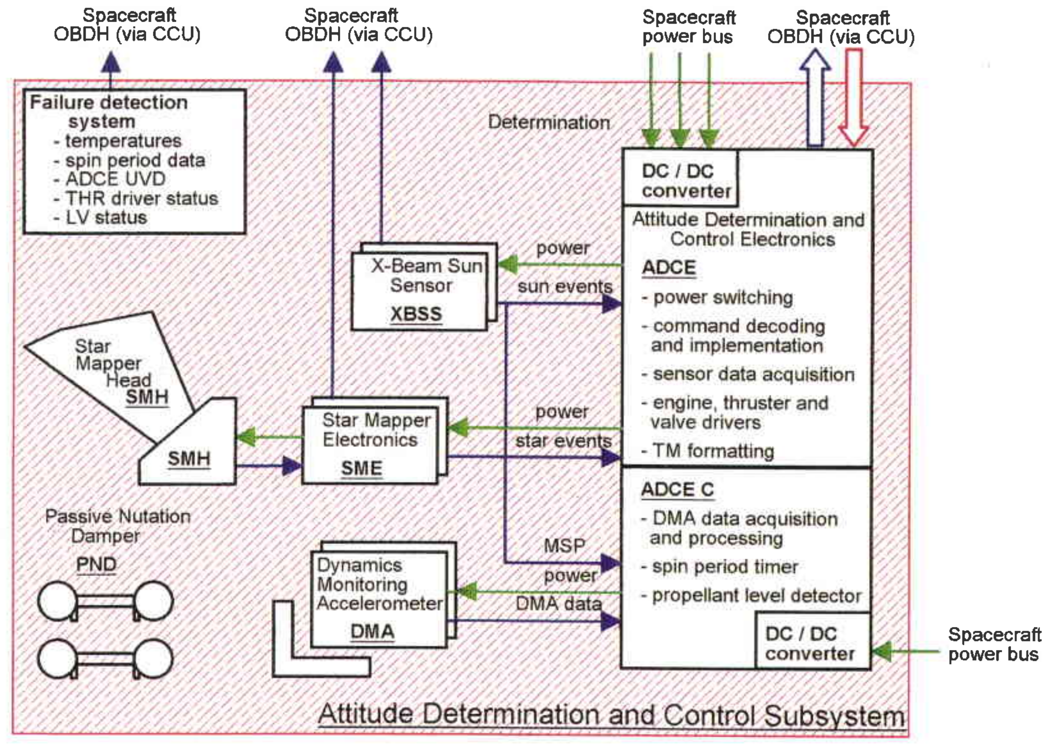



**Figure 11. The Cluster attitude determination and control subsystem**

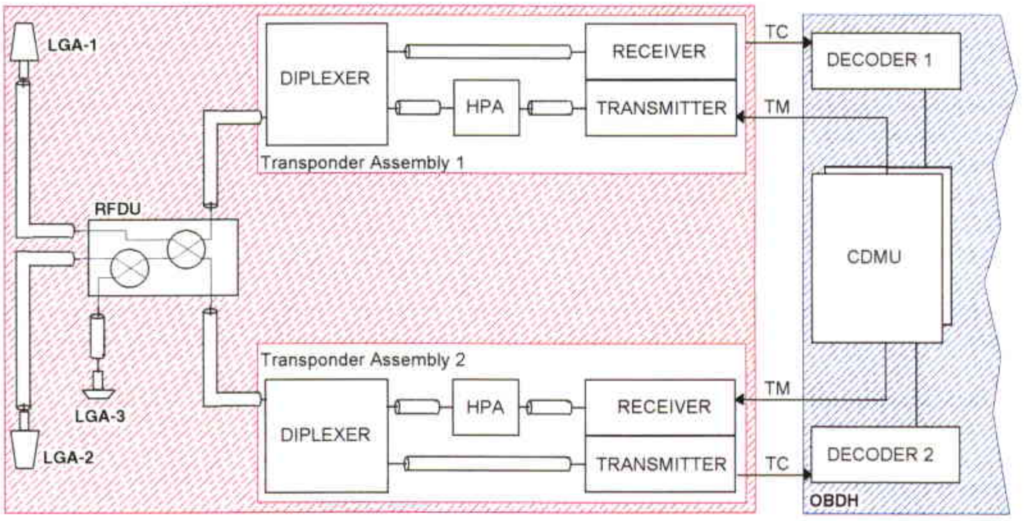



**Figure 12. The Cluster telecommunications subsystem**

The subsystem includes three low-gain antennas, a redundant set of transponders (including a NASA-supplied 10 W RF amplifier), an RF distribution unit, and associated RF harnesses. Two low-gain antennas are mounted on deployable booms attached to the upper and lower faces of the spacecraft. They will ensure full spherical coverage for uplinking and hemispherical coverage for downlinking. A third antenna mounted on the lower side of the spacecraft will be used until the in-orbit deployment of the lower antenna boom.

**The Cluster production line**

The four Cluster spacecraft have constituted a low-volume, process-oriented production run of a custom design. Rather like custom-built homes designed by architects and built by contractors to customer's specifications, they are characterised by their uniqueness and the need for both high quality and on-time delivery. This combination of characteristics demands considerable flexibility in the production process in order to be able to cope with unforeseen difficulties and yet still achieve the original design goals.

Whilst such characteristics also apply to other spacecraft programmes, the situation with Cluster differed considerably in that four flight models had to be produced within the time normally allowed for one. Although Cluster was of course not a series production in the full commercial sense, at system level it stands somewhere between the 'one-off' product of other scientific projects and the 'mass production' in the telecommunications satellite sector, for example of satellites for mobile services.

The picture changes completely when looking at the unit and component levels: the hardware of the four flight spacecraft alone is comprised of a total of about 360 units, 16 rigid booms (without the 16 wire booms), 36 propellant tanks, 8 pressure tanks, 32 thrusters, 320 m of RCS pipework, almost 17 km of harness, 1440 connectors and more than 57 000 electrical contacts. Here, Cluster is indeed much closer to a series production product.

A mix of strategies originating from the two extremes of a 'one-off' and a series production were therefore employed in the Cluster programme. 'Standardised' or 'off-the-shelf' items are typically used in mass production because they represent readily available identical units at reasonable cost. Such items have therefore been used in many areas on Cluster; e.g. RCS equipment, silver-cadmium batteries, battery regulator units, sensors, booms, tape recorders and pressure tanks. Because such items are considered 'flight-proven' and usually have a long history of successful application in space, both development time and risk can be reduced by using them.

The designs of some 'existing items' like booms and battery regulator units had to be slightly changed to cope with Cluster's specific requirements, which required the initiation of a full new space-qualification process. In other cases such as the pressure tanks, waivers against the Cluster requirements were granted after careful evaluation of the item's acceptability.

Parallel work flows are a typical mass-production technique for reducing overall production time. For Cluster, the modular design at system level allowed the parallel integration of the RCS system with the central

*Table 1. Launch masses of the four Cluster spacecraft*

| | FM1 | FM2 | FM3 | FM4 | ALL 4 | |
|---|---|---|---|---|---|---|
| **Total Spacecraft Dry Mass** | **531.21** | **517.90** | **519.80** | **532.50** | **2101.41** | |
| Maximum Allowed Dry Mass | 550.0 | 550.0 | 550.0 | 550.0 | | |
| Maximum Propellant (650 kg + 1.4 kg in pipework) | 651.4 | 651.4 | 651.4 | 651.4 | | |
| **Total Spacecraft Launch Mass** | **1182.6** | **1169.3** | **1171.2** | **1183.9** | **4707.0** | |
| | | | | Ariane -5 limit | **4800.0** | |
| | | | | Margin | **93.0** | 1.9% |

cylinder, and the various equipment items with the Main Equipment Platform. Mating of these two modules was performed after their pre-integration. Without this approach, the overall schedule could not have been met.

Parallel testing at unit and system level also became necessary to meet the overall schedule. This situation was not ideal in that the first system-level tests had to be performed in parallel with the production of the next spacecraft model's units. Compromises between requirements and actual performances and between unit/subsystem and system verification became necessary, tending sometimes to increase the risk. Further on, this situation resulted in extremely high workloads for longer periods than usual for those involved simultaneously in the unit, subsystem and system activities.

The system-level testing periods were extremely long, embracing static load testing of the Structural Model/Spacecraft Mass Dummy (SM/SMD) stack, electrical testing on the Engineering Model (EM), two sine/random/ acoustic vibration campaigns on the SM/SMD stack (before and after an SM failure), two sine/acoustic vibration campaigns for Flight Model stacks, and four thermal-balance/thermal-vacuum tests. Most of these tests were performed at IABG in Munich (D) between March 1992 and March 1995, except for the period from mid- to end-1993 during which the EM tests took place at the Prime Contractor's site. The electrical system-level tests ran almost continuously on the various flight models.

While this situation presented logistic difficulties, the positive effect was that the various specialists worked with high efficiency because they could move almost immediately from one spacecraft to the next. A pronounced learning-curve effect due to repeated integration and testing activities also became visible at all levels, helping to achieve the prescribed overall schedule.

The flexibility during the production process that resulted from the production-line approach because more than one model per unit was available for much of the time, provided more possibilities for work-arounds in the event of a failed unit. Under normal circumstances only one flight spare model is available (if at all).

The high motivation of all personnel involved in the activities was another prerequisite for success, allowing the timely solution of many unforeseen difficulties and problems. This included, for example, three-shift working at the Prime Contractor for an extended period during the early electrical-testing campaigns, to compensate for unit delivery delays of up to six months.

The timely availability of hardware and software was of the utmost importance to achieve the prescribed delivery date for the Cluster flight models. Problems with long-lead-time items and some specific items like CMOS devices, hybrids, specific heaters, double foils for the thermal top and bottom shields, etc. had to be resolved. Sometimes only limited quantities of particular parts or materials were available because of production stops in industry.

Traceability of the hardware and software has been another important element in Cluster's four-model programme. Each unit model has its own performance characteristics and its own calibration curves for the conversion of telemetry data into meaningful physical measurements, with slight nuances occurring from one model to another. It was therefore important to keep track of which model of a given unit was finally integrated to which spacecraft and in which position, not only for the ground testing, but even more so for later in-orbit operations. Databases containing this information are therefore being continuously updated until launch.

Identical functioning of the four Cluster spacecraft is extremely important, as noted earlier. This goal was achieved at unit level by

*Table 2. Achievable delta-V for actual spacecraft dry mass*

| | $I_{sp}$ (sec) | Dry Mass $M_{dry}$ (kg) | Launch Mass $M_{wet}$ (kg) | Delta-V 650 kg (m/s) | Delta-V 640 kg (m/s) | Delta-V required* (m/s) |
|---|---|---|---|---|---|---|
| FM1 | 303.5 | 531.2 | 1182.6 | 2382.8 | 2327.3 | 2300.0 |
| FM2 | 303.3 | 517.9 | 1169.3 | 2423.1 | 2366.2 | 2300.0 |
| FM3 | 302.6 | 519.8 | 1171.2 | 2411.4 | 2354.8 | 2300.0 |
| FM4 | 302.5 | 532.5 | 1183.9 | 2371.0 | 2315.8 | 2300.0 |

* $\Delta V = g.I_{sp}.\ln(m_{wet}/m_{dry})$

applying common specification limits for all models of any given unit. Proof of specification compliance, and hence of 'identicality' between models, was provided by the individual unit acceptance tests.

Identical functionality at system level could be checked via system-parameter measurements on each of the Cluster flight models. Only a very small scatter was found between the four spacecraft models in terms of mass, power, thermal, alignment, pointing, DC magnetic-field performance, RF link, etc., as evident from Tables 1 to 3.

*Table 3. Cluster pointing performance*

| | Calculated | Requirement |
|---|---|---|
| Ground Processing | 0.060 | |
| Spacecraft Wobble | 0.060 | |
| Structure Distortions | 0.100 | |
| Star Mapper | 0.197 | |
| **Attitude Reconstruction Accuracy (Worst case)** | **0.24** | **0.25** |
| Minimum Precession Increment | 0.050 | |
| Attitude Reconstruction Accuracy | 0.240 | |
| **Attitude Pointing Accuracy** | **0.29** | **0.50** |
| Sun Sensor Misalignment | 0.023 | |
| Spin Phase Error | 0.028 | |
| Experiment Misalignment | 0.070 | |
| Wobble Effect | 0.013 | |
| Residual Nutation Effect | 0.011 | |
| Attitude Uncertainty Effect | 0.020 | |
| Ground Processing | 0.060 | |
| Structure Distortion Effect | 0.010 | |
| Other Effects | 0.050 | |
| **Experiment Spin Phase Accuracy** | **0.11** | **0.20** |

### Conclusion

All four Cluster spacecraft flight models have been successfully built and verified as meeting ESA's stringent requirements. By taking maximum advantage of the production-line approach, and a number of specific design, production, integration and work-around strategies, and due to the dedication of all those involved, all four flight models have been completed in the time normally required for the production of a single flight-model spacecraft: 6 years from the start of Phase-B to launch, and just 4.5 years from the start of Phase-C/D to launch. As a consequence, the Cluster project has achieved a very low specific cost in terms of 'MAU per kg in orbit', making them probably the most efficiently developed ESA satellites to date. Moreover, all four are ready for launch at a date that was fixed seven years ago!

### Acknowledgement

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# The Cluster Payload – A Unique Engineering Challenge

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Cluster's payload is an advanced set of experiments to measure electric and magnetic fields, plasmas and energetic particles. They have been designed primarily to study the small-scale structure of the Earth's magnetosphere. In addition to the very sophisticated measurement techniques that have been incorporated, the engineering challenges of manufacturing the state-of-the-art instruments and accommodating them successfully on board the spacecraft have been immense. The unique opportunity to build,integrate and test four identical sets of eleven instruments has also created problems not only of a technical, but also of a management nature, with a complexity of interfaces and logistics never previously experienced in an ESA scientific programme.

## The overall payload complement

Each of the four Cluster spacecraft is equipped with the same state-of-the-art electrical and magnetic instruments and particle detectors. Table 1 lists all of the experiments (with their acronyms), the basic technical parameters of the instruments, and the names of the respective Principal Investigators.

Accurate measurement of the cold plasma population of the magnetospere demands that the electrostatic potential of the spacecraft be very low with respect to the ambient plasma. Cluster is the first mission that will be equipped with an ion emitter to routinely control this potential (ASPOC).

Cluster is equipped with a suite of five instruments – EFW, STAFF, WHISPER, WBD and DWP – to measure the electric fields and waves around each spacecraft. They have been combined together to make up the so-called 'Wave Experiment Consortium', which not only saves resources by using the same elements – sensors, data-handling unit and power supplies – but also enhances the scientific output.

The EFW instrument has been specifically designed for the investigation of fast time- and space-varying electric fields, but it will also cover the DC to low-frequency range, by using two pairs of thin, multiconductor wire booms per spacecraft. These booms deploy to a tip-to-tip distance of 100 m and on the end of each is a spherical sensor.

STAFF is a three-axis search-coil magnetometer which will measure the magnetic components of electromagnetic fluctuations in a frequency range up to 4 kHz. To put it beyond the influence of the spacecraft, the STAFF instrument is mounted on a 5 m rigid radial boom which will be deployed in orbit.

The relaxation sounder WHISPER is an intermittent transmitter/receiver instrument that can also be operated in a passive (receive-only) mode. The transmitter emits a short pulse to stimulate plasma resonances, thereby allowing the measurement of plasma density under widely varying plasma conditions. For both its transmit and receive modes, it will use the long wire booms of the EFW instrument.

The objective of the Wide-Band Data receiver system (WBD) is to provide high-resolution electric-field waveforms in order to analyse the highly structured and complex waves that occur in the Earth's magnetosphere.

The Digital Wave Processing (DWP) system contains a wave/particle correlator to correlate the time series of counts in the electron and ion analysers or the cross-correlation function between particle counts and wave measurements.

*Table 1. Investigations to be performed on Cluster*

| Instrument | Principal Investigator | Measurement | Technique |
|---|---|---|---|
| Fluxgate Magnetometer (FGM) | A. Balogh, Imperial College, London, UK | **B**, wave form DC to ~10 Hz; resolution ⩾6 pT | Two three-axis fluxgate sensors on 5 m boom |
| Spatio-Temporal Analysis of Field Fluctuations (STAFF)* | N. Cornilleau-Wehrlin, Centre de Recherche en Physique de l'Environnement Terrestre et Planetaire, Paris, F | **B**, wave form up to 10 Hz, compressed data up to 4 kHz. Cross-correlator for $\langle \mathbf{E}, \mathbf{B} \rangle$ | Three-axis search-coil sensor on 5 m boom |
| Electric Fields and Waves (EFW)* | G. Gustafsson, Swedish Institute of Space Physics, Uppsala, S | **E**, wave form up to 10 Hz, compressed data up to 100 kHz, sensitivity <50 nV/m $(Hz)^{1/2}$ | Double probes, two pairs wire booms, each 100 m tip-to-tip |
| Waves of High Frequency and Sounder for Probing of Density by Relaxation (WHISPER) | P.M.E. Décréau, Laboratoire de Physique et Chimie de l'Environnement, Orléans, F | Active: Total electron density<br><br>Passive: Natural plasma waves up to 400 kHz | Sounding, using parts of EFW wire booms<br>Filter banks |
| Wide Band Data (WBD)* | D.A. Gurnett, Univ. of Iowa, USA | Transmission of E-field wave form up to ~100 kHz, variable centre frequency | Using sensors of EFW |
| Digital Wave Processor (DWP)* | L.J.C. Woolliscroft, Univ. of Sheffield, UK | Data compaction & compression, event selection, particle/wave correlation, control of WHISPER. | CMOS multiprocessor unit |
| Electron Drift Instrument (EDI) | G. Paschmann, MPI für Extraterrestrische Physik, Garching, FRG | **E**, (0.1 – 10 mV/m, <100 Hz), ∇**B**, \|**B**\| (5 – 1000 nT), emission and tracking of two electron beams | Two emitter/detector assemblies, each with 2π field of view (FOV) |
| Cluster Ion Spectrometry (CIS) | H. Rème, Centre d'Etude Spatial des Rayonnement, Toulouse, F | CODIF: Composition and Distribution Functions Analyser, 0 – 40 keV/q | Symmetric hemispherical analyser with RPA and TOF, 2 π × 8° FOV, split geometric factor |
| | | HIA: Hot Ion Analyser for high time resolution (e.g. solar wind), 3 eV/q – 40 keV/q | Symmetric quadrispherical analyser, 2 π × 8° FOV with high resolution (⩾2.8°). |
| Plasma Electron and Current Analyser (PEACE) | A.D. Johnstone, Mullard Space Science Laboratory, Holmbury St. Mary, UK | LEEA: Low-Energy Electron Analyser, 0 – 100 eV | Spherical electrostatic analyser, π × 3.8° radial FOV. |
| | | HEEA: High-Energy Electron Analyser, 0.1 – 30 keV. | Toroidal electrostatic analyser, 2π × 4.6° FOV |
| Research with Adaptive Particle Imaging Detectors (RAPID) | B. Wilken, MPI für Aeronomie, Lindau/Harz, FRG | IIMS: Imaging Ion Mass Spectrometer, ion distribution and species, energy 2 – 1500 keV/nuc. | Position-sensitive solid-state detectors with TOF section. |
| | | IES: Imaging Electron Spectrometer, distribution of energetic electrons, energy 20 – 400 keV | Position-sensitive solid-state detector |
| Active Spacecraft Potential Control (ASPOC) | W. Riedler, Institut für Weltraumforschung, Graz, A | Spacecraft potential control, emission current of order 20 μA, indium ions | Field-ionisation, liquid-metal ion emitter |

* Members of the Wave Consortium

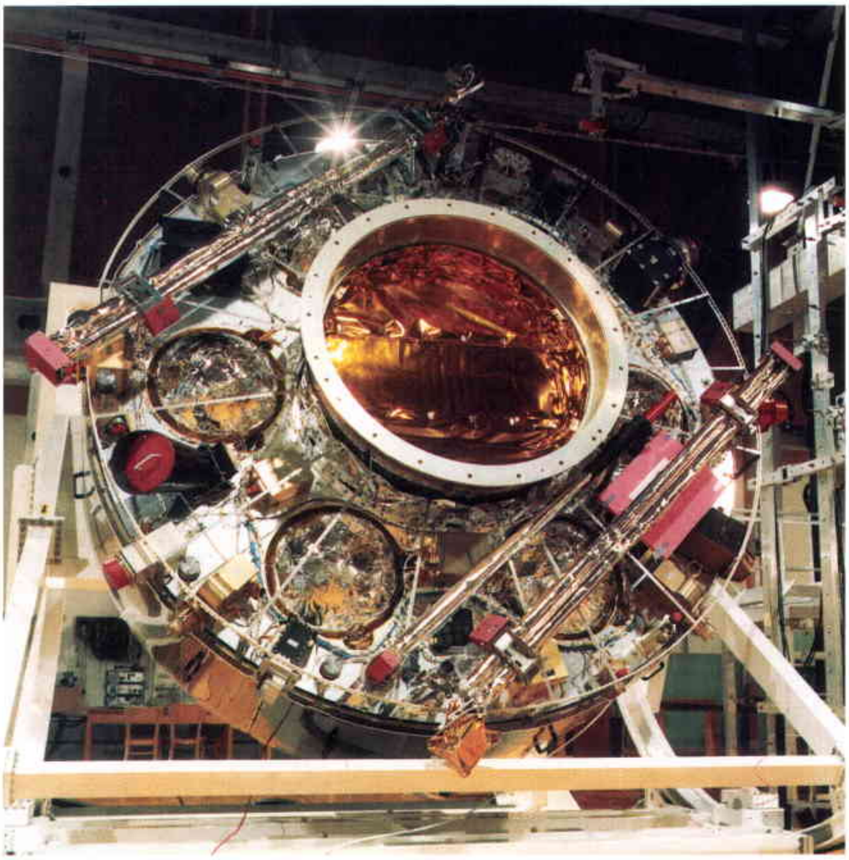

**Figure 1. Top view of a Cluster spacecraft, showing experiment accommodation around the periphery and on the stowed radial booms**

The Flux Gate Magnetometer (FGM) will perform important investigations by exploiting Cluster's four-point measurement capabilities in space. The resulting abilities to infer from true measurements in space the current density vectors, wave propagation characteristics and field discontinuities will represent 'firsts' in space plasma physics. The DC Magnetometer consists of two sensors mounted on a similar symmetric boom to that of STAFF, at distances of 3.5 m and 5 m from the spacecraft's body.

Cluster also carries another instrument to measure electric fields, namely EDI. The EDI instrument is based on the emission and subsequent detection of tracer electrons to derive the ambient electric field. It is a highly complex instrument, final calibration of which will only be possible in the true magnetospheric environment of space.

*Table 2. Major payload requirements on the Cluster spacecraft*

| | |
|---|---|
| Number of units per spacecraft | ~24 |
| Total mass of payload | ⩽72 kg |
| Total power available for payload (end-of-life) | ⩽47 W |
| Residual magnetism of spacecraft at magnetic sensors | ⩽0.25 nT |
| Stability of residual magnetic field | ⩽0.1 nT |
| Spacecraft skin potential: point-to-point | ⩽1 V |
| Accommodation of 100 m tip-to-tip wire booms | |
| High EMC cleanliness | |
| High cleanliness requirements for AIV programme and thruster positions | |

The plasma package, i.e. CIS and PEACE, is designed for the three-dimensional measurement of the distribution functions of both electrons and major ion species. CIS, the plasma ion spectrometer, employs two sensors to obtain the full three-dimensional ion distribution of the major species with high time resolution, and the mass-per-charge plasma composition. PEACE will perform the plasma electron measurements using two separate sensors covering the very cold electrons (LEAA) and the medium and higher energies (HEAA), respectively. PEACE will provide the three-dimensional electron distribution with high time resolution.

The final instrument aboard the spacecraft is RAPID, which consists of two spectrometers each containing position-sensitive solid-state detectors providing high angular and temporal resolution.

**The payload's demands on the spacecraft**

Installation of the payload has involved accommodating a total of 24 units on each of the four spacecraft. More than half of these units require unobstructed fields of view in space, something that has been difficult to accommodate given the presence of the many other experiments and the deployable rigid and the ultra-long wire booms (Table 2).

In addition, the detectors are highly sensitive to contamination, which could have occurred on the ground during the very long integration and test programme or could come from the thrusters and main engine of the spacecraft itself after launch. The first problem was solved by imposing a rigorous cleanliness programme during the integration and test phases, and only integrating the flight sensors at the last possible moment. In designing the spacecraft, the thrusters and main engine have been kept as far away as possible from the sensitive instruments, which are mounted around Cluster's upper periphery. The thrusters and main engine are thus on the opposite side of the spacecraft.

At the beginning of the programme, the payload was allocated 72 kg of mass and 47 W of power in the system budgets. The optimisation efforts to keep within these allocations have been extremely demanding. Cluster's various operating modes and the areas of operation within the elliptic orbit mean that the payload has a requirement for data rates varying between 17 and 220 kbit/s, whilst the overall volume of data to be handled per orbit can be as high as 2 Gbytes.

One of the major technical requirements on both the payload and the spacecraft has been to maintain electromagnetic cleanliness (EMC), as electric-wave and magnetic-field measurements are both adversely affected by spacecraft residual values. This resulted in a unique EMC programme for Cluster, and the mounting of the AC and DC magnetometers (STAFF and FGM) on rigid booms.

The planned detection of cold electrons by PEACE has called for a very careful design to eliminate the possibility of spurious effects being introduced by photo-electrons, which it is known will be abundant near the spacecraft's skin. The elimination of voltage potential variations over the surface has meant that the outer skin of the spacecraft must be as conductive as possible.

**Making the four payloads the same**

The Cluster mission's goal is to probe the Earth's plasma environment using four identical sets of eleven instruments on four identical spacecraft operating in closely coordinated orbits. This unique requirement imposes more stringent constraints on the accuracy of the individual instrument measurements than in a normal single-spacecraft mission.

The major error sources had to be quantified for each instrument and major efforts were required to reduce such errors by careful design, stringent control of materials and manufacturing processes, and extensive pre-flight (and later in-flight) calibration of the individual instruments, as well as careful intercomparison of different measurements from the different instruments.

For the particle detectors – CIS, PEACE and RAPID – proper sensor calibration is especially important. It is also known that some of the long-term drifts in such instruments, mainly involving the micro-channel plates are difficult to correct entirely.

PEACE is a good example of how differences between the instruments on the four spacecraft were assessed during the development programme. It is necessary to maintain comparability between the analysers on the four flight spacecraft to within 1%, including the in-flight intercalibration.

The PEACE analyser consists of two concentric hemispherical shells between which the electrons are deflected. In order to maintain the 1% goal, the concentricity of the hemispheres had to be maintained to better than 40 microns. When tested, the initial design (Fig. 2a) was found to have a value of 150 microns. Even by improving the manufacturing tolerances to state-of-the-art values using specialist facilities, it could only be reduced to 80 microns. A major redesign was therefore undertaken both to increase the rigidity of the hemispheres and to connect them by a shorter load path using materials with similar coefficients of expansion (thereby reducing the effects of minor temperature differences between detectors). By these means, and by using a Kapton instead of a ceramic anode and changing the mechanical design (Fig. 2b), the tolerances could be reduced to 37 microns even using the normal flight-standard manufacturing tolerances.

For the wave experiments, the question of similarity on the four spacecraft was not a central issue. The stability of the oscillators is far

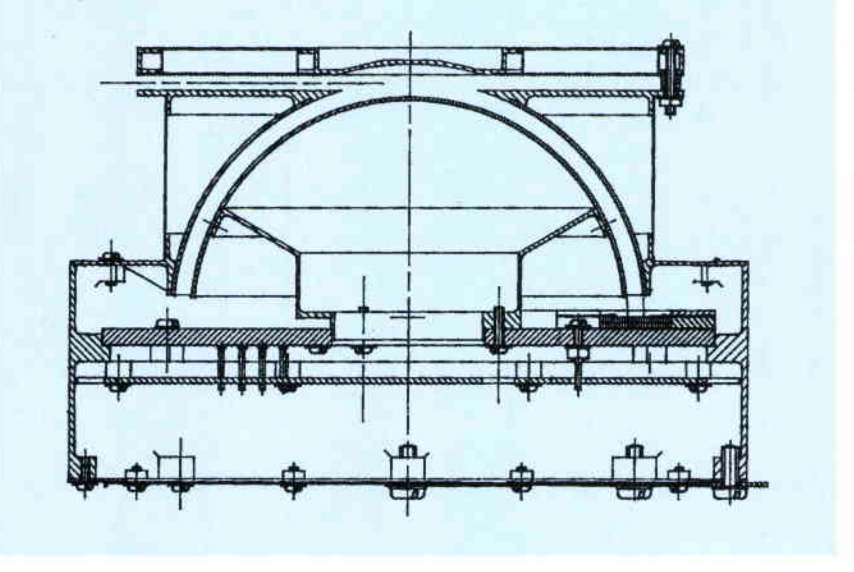

**Figure 2a. The original mounting of the PEACE hemispheres**

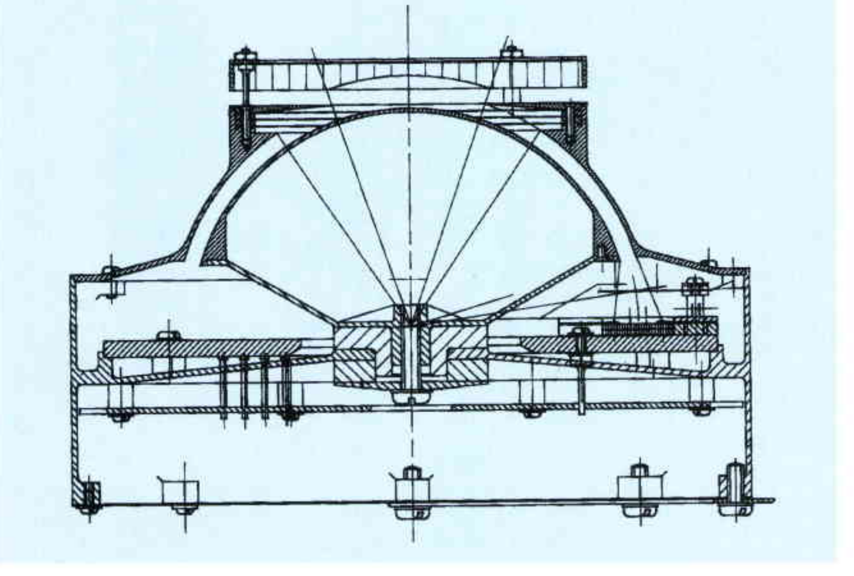

**Figure 2b. The final mounting of the PEACE hemisperes**

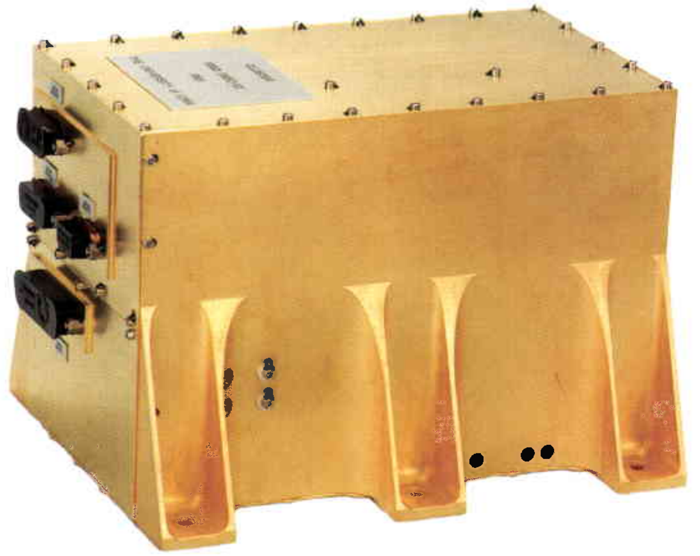

**Figure 3. The WBD experiment's outer structure, weight-optimised by the extensive use of magnesium**

better than the required frequency resolution, which is mainly dictated by telemetry constraints. In order to ensure correspondence between measurements on the four spacecraft, the relative timing between the measurements on each spacecraft is very important, which has meant that operational constraints have had to be rigorously defined.

FGM requires an overall single instrument accuracy of 0.1%. This has been demonstrated to be possible, and can also be checked in orbit using a four-point intercalibration technique (Div **B** must always be zero).

### Optimisation of resources

Payload resources were tight from the outset, with the baseline 72 kg/47 W/17 kbit/s being oversubscribed already at the proposal stage. A de-scoping and rationalisation exercise had to take place immediately, which resulted in the formation of the 'Wave Consortium' and the provision of the power-supply and data-handling functions via boxes common to all five of those experiments.

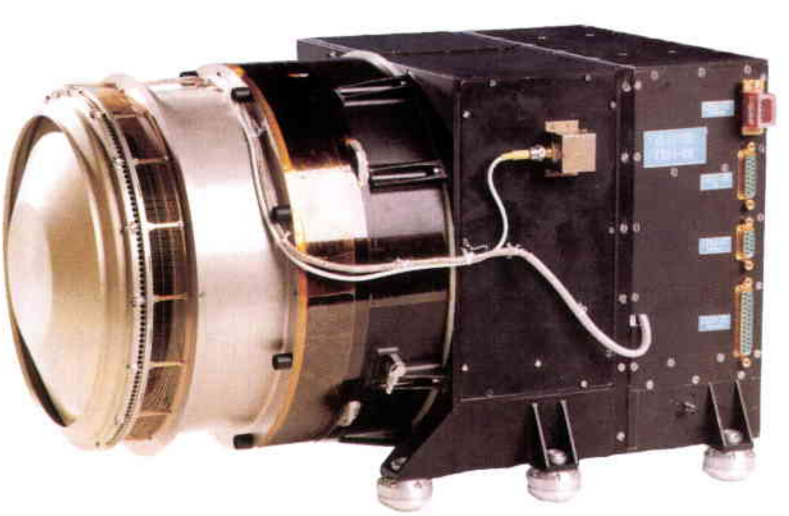

**Figure 4. CIS 1 sensor integrated on its anti-vibration mounts**

During the development phase, the payload mass again began to grow and every additional gramme had to be accounted for. Very thin walled structures were developed for some electronic boxes (e.g. FGM) and some instruments switched to using magnesium as their primary structural material (e.g. WBD; Fig. 3).

Power for driving the sophisticated instruments and their computers was also critical from an early stage. Various operating modes were therefore developed for each instrument to conserve power by, for example, running the processors at different speeds during the two-year mission. The data rates have also been optimised by defining different operational modes and time-sharing between the individual instruments.

The payloads to be launched on the flight spacecraft are still (just!) within their allocated resources, thanks to the continual attention that has been paid to the problem by both the Experimenters and the ESA Project Team.

### Surviving the launch and in-orbit environments

Before making any scientific measurements, Cluster's instruments will have to survive the launch-induced vibrations. Once in orbit, they must work in an environment varying between cold deep space and hot sunlight, and also endure a constant shower of strong radiation.

The Cluster launch vibration environment has been assumed to be slightly harsher than usual, to take into account the inherent uncertainties due to it being the first Ariane-5 launch. This has had design repercussions for some instrument units. The CIS experiment, for example, contains very thin carbon foils (density of order 3 $\mu g/cm^2$). It was very soon realised that these would have problems surviving the vibration environment and so the experiment was mounted on rubber anti-vibration mounts. During testing, however, these foils still broke due to the high induced displacements causing the foil to hit the surrounding structure. A design modification and further testing has ensured that CIS will survive the launch (Fig. 4).

The in-orbit thermal environment, varying from hot sunlight to long cold eclipses with a minimum of heater power provided by the spacecraft, has presented a severe challenge for all protruding sensors. These need an environment close to room temperature for their sensitive components like the micro-channel plates when operating, and not colder than a freezer when non-operational.

A few sensors required further design optimisation after the spacecraft thermal-balance test. In particular, their coatings and thermal blanket interfaces had to be changed. Figure 5 shows the complex way in which the thermal blankets are now 'hand-tailored' around the protruding instruments.

The harsh in-orbit radiation environment of typically 20 krad that Cluster must endure has required the use of radiation-hardened or shielded components. Special circuitry to survive the latch-up that could be caused by particle intrusion has also been necessary, especially for the CMOS technologies.

**The electromagnetic-cleanliness problem**

The instruments aboard each new generation of scientific satellite endeavour to exploit the latest sensor and electronic technology to achieve the highest possible sensitivity and resolution. For a plasma mission like Cluster, this ideally means that the spacecraft itself should be 'invisible', with no apparent interaction with the space environment.

Reality is rather different; the spacecraft does become charged under the cyclic influence of sunlight and shadow. In addition, certain of the spacecraft's subsystems contain relays and valves, which generate DC or slowly-varying magnetic fields. It has an electrical support system for power and data-handling, which also constitutes a source of electromagnetic interference. Last but not least, the scientific payload itself may generate signals that could influence the performance of other instruments on board. Most of these phenomena are either impossible to simulate, or the levels involved are orders of magnitude too small to be measured on the ground.

How then can a suitable spacecraft and its payload be built and tested to the satisfaction of the scientific community? Well, the process begins with a careful selection of design concepts and materials, which are then translated into an electromagnetic design and test specification. The necessary electrostatic cleanliness is achieved by using a conductive coating on the spacecraft's external surfaces, including the solar arrays. Thermal insulation blankets and foils are coated with indium tin oxide and, along with all other external parts, locally grounded to the spacecraft structure to avoid the build-up of electrostatic potential. DC magnetic cleanliness imposes the selection of non-magnetic materials wherever possible. In

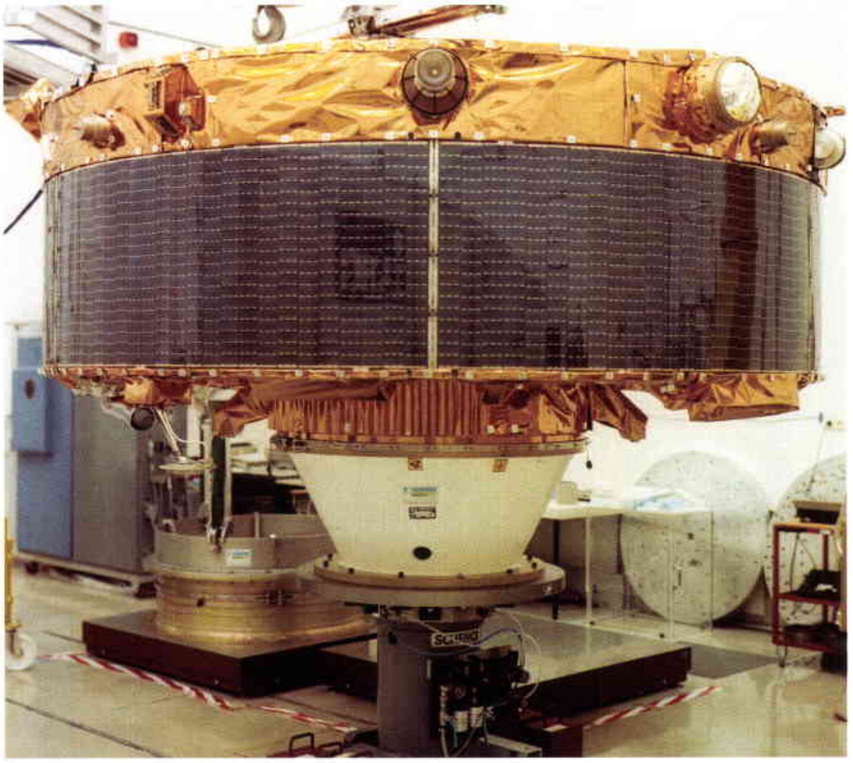

**Figure 5. Tailoring of the thermal blankets around the protruding experiments**

addition, the magnetic sensors are mounted on deployable booms, as far as possible from the spacecraft body.

Electromagnetic interference is usually controlled by the synchronisation of clock signals onboard the spacecraft. This, together with an optimised electrical harness configuration and grounding scheme, ensures minimum disturbance of the frequency bands being observed by the scientific instruments.

However, when these design optimisations came to be translated into hardware for Cluster, some of the above concepts could not be realised: either the ideal technology could not support the original purpose of a certain element or instrument, or it was not available within the given constraints of mass, power or schedule. An EMC Review Board was therefore established, made up of scientists from each particular area of Cluster plasma science, from Industry and from ESA, to analyse the problems and to agree on acceptable solutions.

The verification phase involved various EMC analyses and tests – not only state-of-the-art conductivity and susceptibility tests, but also dedicated experiment tests for the particularly sensitive WEC and PEACE instruments. After several iterations and optimisation of the grounding schemes of these experiments and the spacecraft interface, these two experiment teams were able to confirm a satifactorily low noise environment on the spacecraft. Radiated emission and susceptibility testing at IABG in Munich (Fig. 6) with the EFW wire booms

**Figure 6. Radiated emission and susceptibility testing of Cluster at IABG in Munich (D)**

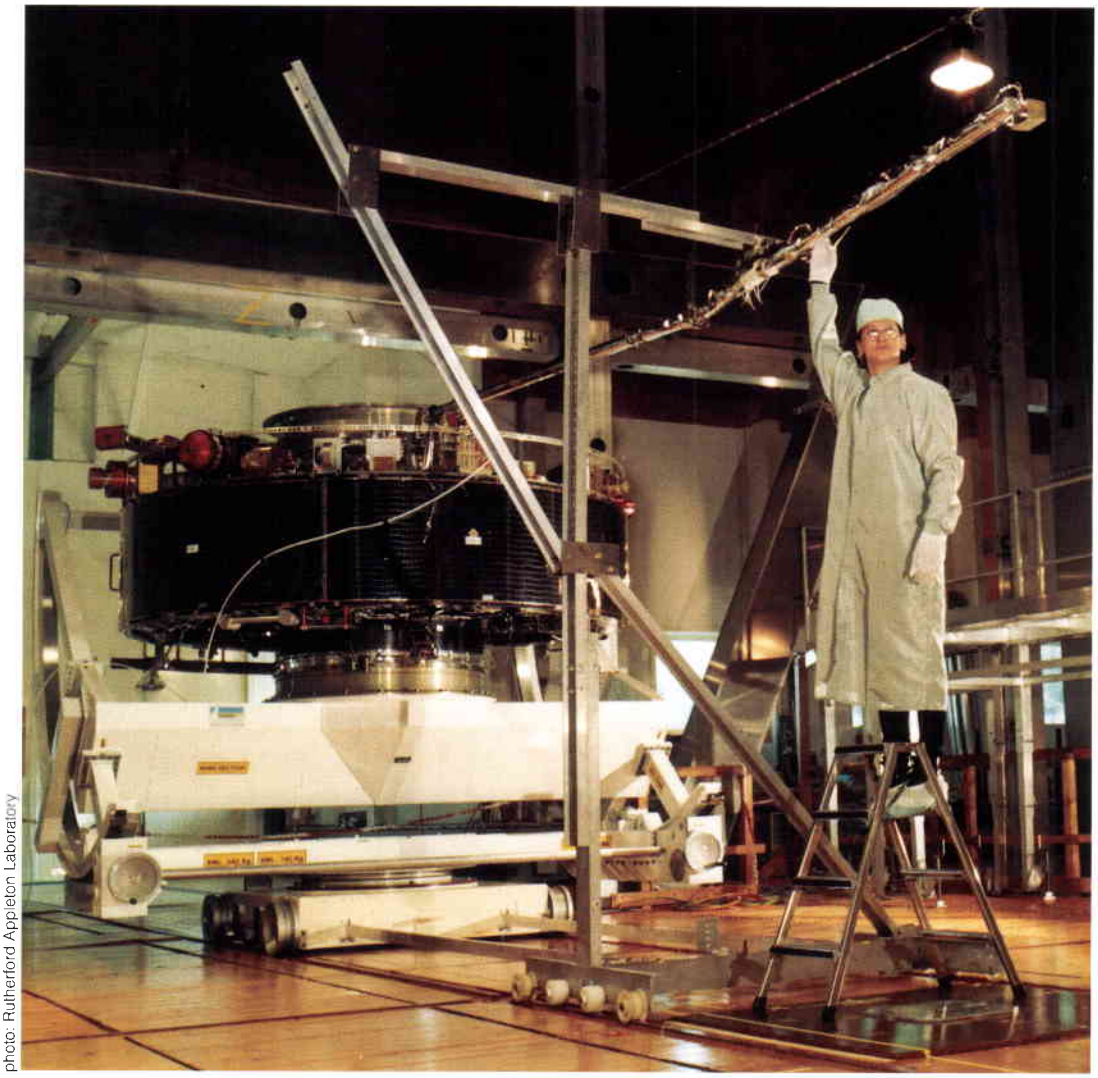

photo: Rutherford Appleton Laboratory

partially deployed finally confirmed that the Cluster spacecraft generates levels very close to the instruments' own background noise.

In summary, the way to EMC cleanliness was not straightforward, but the close cooperation of all parties involved in addressing the problem has resulted in Cluster being the most electromagnetically clean spacecraft that ESA has launched.

### Seven PC's on each spacecraft

A feature of modern-day instrumentation and the result of the great advances in micro-technology is the fact that each experiment has almost as much onboard computational capability as the spacecraft's own on-board computer (CDMU). In fact, the Cluster payload has the processing capability of almost seven personal computers (PCs), the Wave Consortium being served by one processing unit (DWP).

This onboard computational power not only provides the interfaces with the spacecraft bus in terms of telemetry and telecommand handling, but also the interface with the various experiment units. It also performs a certain amount of onboard scientific processing, which reduces the data rates needed to the ground.

The DWP (Fig. 7), perhaps the most performant computer, consists of three T222 transputers, each with 32 kbytes of external RAM (internal memory disabled to provide increased radiation tolerance) and 32 kbytes of PROM. The DWP's design permits the transputers to be operated at input clock frequencies of 2.5 or 5 MHz, the slower rate requiring less power.

The DWP performs two major software-driven tasks. The first is particle correlation, with a novel diagnostic technique based on forming auto-correlation functions of the time series of particle-detector counts as a function of energy and pitch angle. Secondly, it performs data compression in order to cope optimally with the restrictions on the available telemetry bandwidth. Various data-compression methods are implemented within the DWP to remove any redundant information from the data stream.

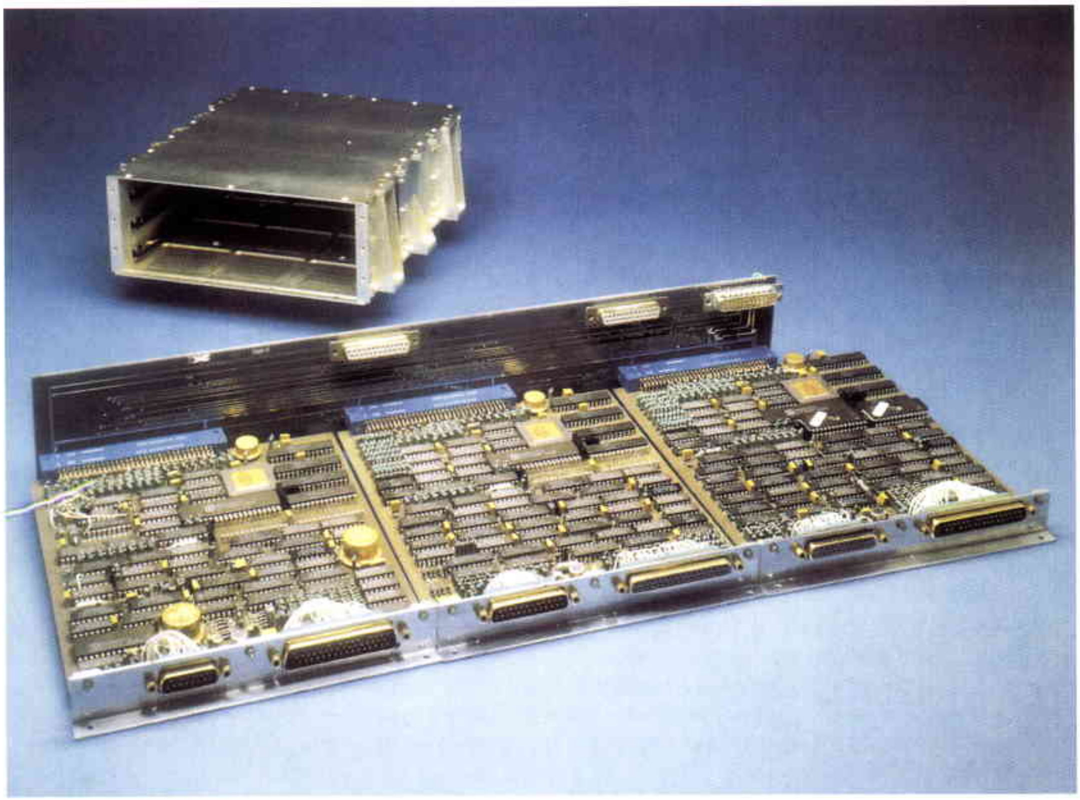

**Figure 7. The three printed-circuit boards of the DWP, including the three T222 transputers**

## Experiment management

Management of the Cluster experiments has provided some unique challenges for the spacecraft payload groups. To begin with, getting together the best payload suite in Europe to satisfy the mission requirements meant the involvement of 11 Principal Investigators (PIs) and interfacing with the 250 main investigators who will study the Cluster data. This is not a unique scenario in terms of ESA missions, but it did mean that rationalisation of the instrument groups was required early in the programme. One result of this was the setting up of the Wave Consortium, mentioned earlier.

The next major problem was that, because the integration, testing and preparation for launch of the four flight spacecraft would take over two years, engineering breadboards were required very early in the programme compared to the launch date. The experimenter groups performed this difficult task in a very satisfactory way for the hardware, but the software for ground testing and on-board processing always lagged behind.

For a nominal one-off spacecraft, once the flight hardware has been built and tested at the home institute, the payload team is available to assist the Project with the system-level Assembly, Integration and Verification (AIV) programme. In Cluster's case, once the first flight instruments had been delivered another four (including flight spare) were needed. In addition, system-level testing had to be performed simultaneously on up to three flight spacecraft (e.g. functional testing, EMC, and thermal vacuum), all of which required payload support. The short-term schedule for such system testing was also varying on a day-to-day basis. The logistical problems for the payload groups have therefore been immense and a successful outcome hinged on the trust built up between the Project and the payload groups in the early days of the programme, and on the flexibility shown by both sides. This has been supplemented by technological advances such as the remote links established to both the integration and test sites (Dornier and IABG), which gave the payload teams remote access to their test data from their home institutes.

## Conclusion

The engineering challenges faced with the Cluster payload have been some of the most demanding of any spacecraft hitherto launched. They have been faced by the instrument group and the Cluster Project together, in order not only to launch the most sophisticated instrument set possible but also to launch four identical sets. Their combined efforts over the past eight years will ensure that ESA's 'space fleet to the magnetosphere' will provide the scientific community with a wealth of unique data on that region of space around the Earth known as the magnetosphere and its interaction with the constant stream of particles known as the solar wind, emitted by our mother star, the Sun.

# Collection and Dissemination of Cluster Data

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### The Cluster Science Data System (CSDS) concept

Cluster is a very challenging mission in terms of data collection and dissemination. Each of the four Cluster spacecraft has 11 instruments on board and thus the information system must be capable of distributing data gathered by 44 instruments. Moreover, the scientific community interested in the Cluster data is very large and spread all over the world. In order to disseminate such a complex amount of scientific data to such a large community, the Cluster Science Data System (CSDS) has been established.

The CSDS (Fig. 1) is based on National Data Centres that have been established near the Principal Investigators' sites. Each Data Centre processes the raw instrument data from a specific set of experiments into data products and makes it available to the other Data Centres via the network. Each Centre is responsible for the nearby PI's set of experiments.

The National Data Centres set up to be directly involved in the CSDS are the following:

- The Austrian Cluster Data Centre (ACDC), responsible for the ASPOC experiment
- The French Cluster Data Centre (CFC), responsible for the CIS, STAFF and WHISPER experiments
- The German Cluster Data Centre (GCDC), responsible for the RAPID and EDI experiments
- The Scandinavian Data Centre (SDC), responsible for the EFW experiment
- The UK Cluster Data Centre (UKDC), responsible for the FGM, PEACE and DWP experiments
- The Hungarian Data Centre (HDC), which is not associated with one experiment but will support all of them.

Moreover, two other data centres will also participate in CSDS via directly-involved National Data Centres:

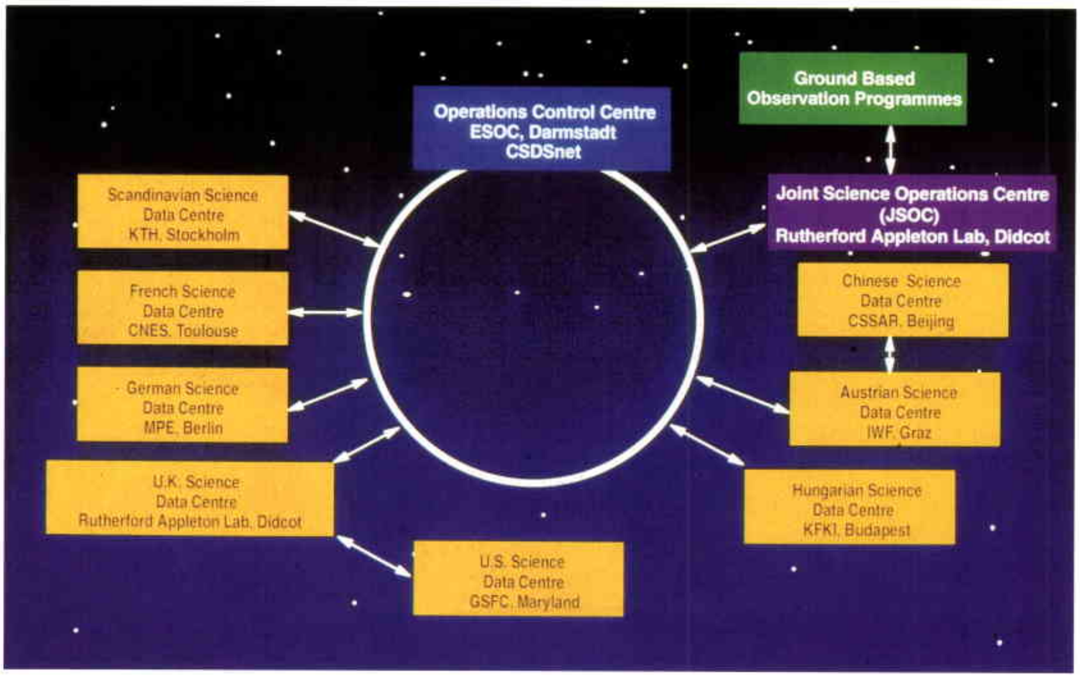


**Figure 1. The Cluster Science Data System (CSDS) and its components**

— The US Cluster Data Centre (USDC), responsible for the WBD experiment and linked to the UKDC
— The Chinese Cluster Data Centre (CNDC), which will receive data from the ACDC.

The other components of the overall CSDS configuration are:

— the CSDSnet, the network infrastructure provided by ESA that will permit data and information exchange within the CSDS
— the Cluster user interface, an infrastructure also provided by ESA that will allow the National Data Centres to ingest the data products, and the users to browse through, retrieve and manipulate scientific data
— the Operations Control Centre at ESOC (in Darmstadt, Germany), which is responsible for mission planning, data disposition and bulk distribution of raw data
— the Joint Science Operations Centre (JSOC), which will support the project scientists and will provide the scientific community with access to science planning.

**Data dissemination**
The Cluster mission will produce several types of data; the CSDS will not handle all of them. It will not handle directly the raw instrument data nor the high-resolution data.

The raw data will be distributed on a set of CD-ROMs to each participating institute (about 80 worldwide) on a weekly basis. Each CD-ROM will contain one day's entire payload data and the ancillary data. In this way, each member of the Cluster scientific community will have available the entire mission data.

The high-resolution data will be handled by the PIs only (in some cases using the facilities of their National Data Centre). The PIs will also respond to requests for the data from the user community. The CSDS infrastructure will probably be used to route the requests for high-resolution data.

The CSDS, however, will handle the following types of data:

— The scientific data products (Table 1)
— The ancillary data, obtained or derived on the ground, to give information such as orbit position and spacecraft attitude
— The housekeeping data from the spacecraft (used to monitor the health and status of the instruments).

The instruments will also measure the most important space physics and geophysical parameters, sometimes using more than one instrument technique. This provides a certain degree of redundancy and increases confidence in the data produced.

Not all the Data Centres will offer the same services. Some will offer nearly all products on-line (e.g. the French and the British data centres), while others may only keep a certain amount of data on-line. A request for data that is not on-line will require the retrieval of the data from an off-line storage medium.

One also has to remember that the user community interested in the Cluster payload data served by CSDS is very large and is not limited to the National Data Centres. At the moment, at least 250 investigators around the world are expected to be interested. CSDS has therefore been designed to cater to a large community of users with varying levels of familiarity with data manipulation. This has created the need to have both a convenient user interface and a solid and reliable network infrastructure. Unfortunately the existence of such a large community and the fact that National Data Centres are funded at national level and not by ESA, has also added some further complexity to the system design. It has in fact been necessary to develop the user

*Table 1. CSDS's basic scientific data products*

| Product | Nature | Typical Use |
|---|---|---|
| Summary Parameter Data Base (SPDB) | 54 scientific parameters at 1 min resolution. Data from one spacecraft only. | Unrestricted access. Used to select events for detailed analysis, detection of boundary crossings. |
| Summary Data Plots (SDP) | Postscript plots of SPDB parameters. Plot resolution: 6 h/20 cm. | As above. |
| Prime Parameter Data Base (PPDB) | 48 scientific parameters at 4 s resolution. Data from all four satellites, including ancillary data. | Restricted access (Cluster community only). Used in support of scientific analysis. |

interface to be compatible with both the Open VMS and the Unix operating systems. However, a Cluster-specific standard for data exchange, based on the Common Data Format (CDF), was established.

### JSOC

Considering the complexity of the Cluster scientific operations, with 11 instruments per spacecraft, a Joint Scientific Operations Centre (JSOC) has been established to ensure adequate planning and smooth execution of the scientific operations.

The JSOC's main task is to support the Project Scientists, and their Science Working Team (SWT), in the conducting of an efficient mission operation by coordinating the requests of the scientific community with the Operations Control Centre at ESOC. All PIs submit their observation requests to the JSOC. The Project Scientists then consolidate them and establish a mission plan, in collaboration with other space missions. The JSOC then ensures the implementation, testing and operations of tools for instrument commanding (e.g. spacecraft separation strategy).

The JSOC is not intended to take over some PI tasks nor to interfere with the responsibilities of the Operations Control Centre. The JSOC is needed because the task of coordinating all the entities specifying commands to the 44 instruments is simply too big to be left to the Project Scientist in his coordination role between the SWT and the Operations Control Centre.

As part of the operations support activities, the JSOC generates and distributes:

— Payload command sets
— Payload operational status information
— Orbit information.

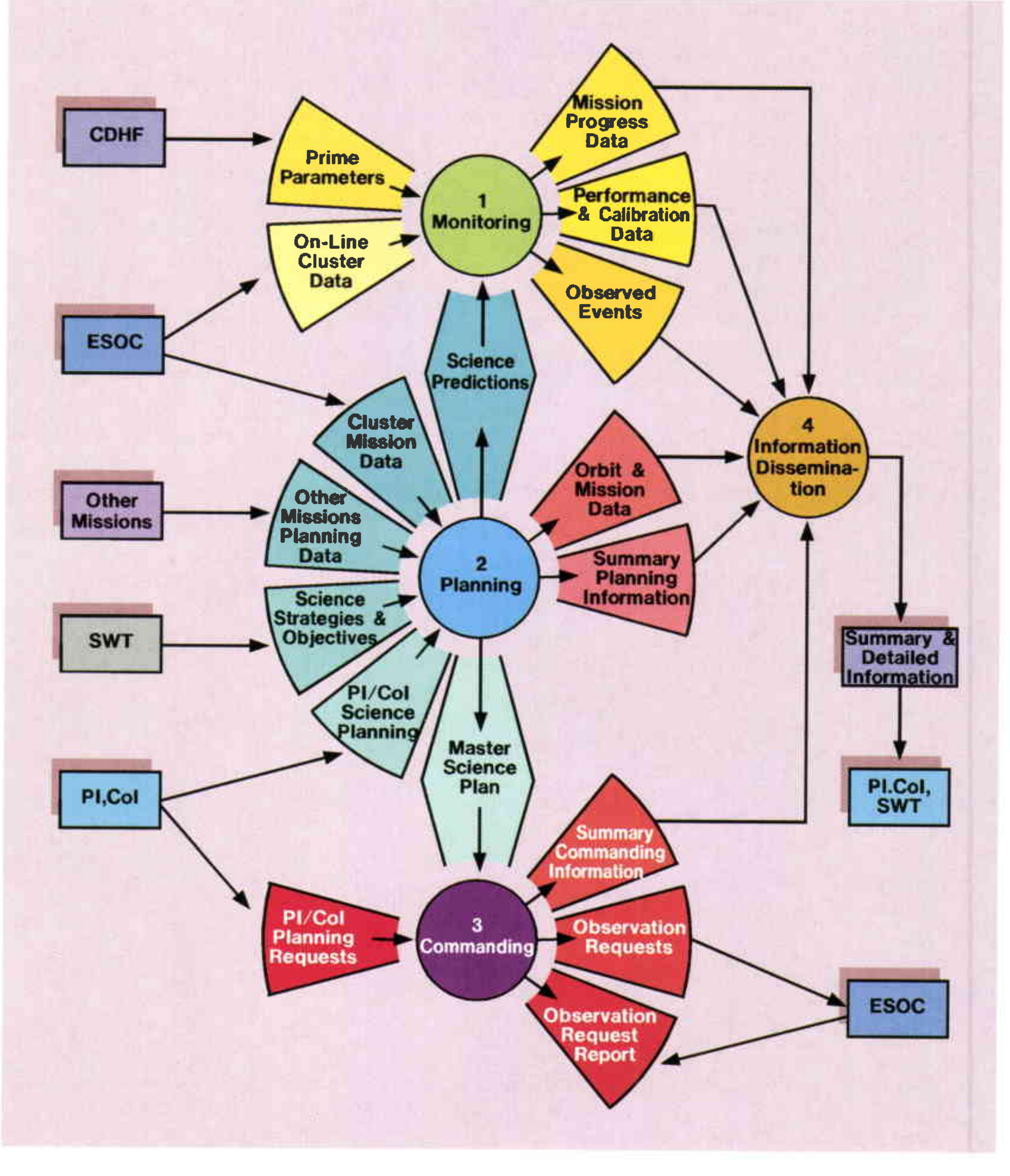


Figure 2. The functions of the Joint Scientific Operations Centre (JSOC) and its interaction with the other CSDS and Cluster Mission entities

The JSOC is located at the Rutherford Appleton Laboratory (UK), where the UK Cluster Data Centre also resides.

In terms of overall design, the JSOC functionalities can be grouped into the following four sub-systems:

1. The Monitoring sub-system, which monitors the progress of the mission as a whole, executes specific monitoring software on behalf of PIs and produces the Cluster event catalogue.

2. The Planning sub-system, which provides information concerning the Cluster and other missions, and supports the SWT and the PIs in planning observations with their instrument.

3. The Commanding sub-system, which implements the high-level science planning determined by the SWT, iterates these plans with the PIs and interfaces with ESOC.

4. The Information Dissemination sub-system, which provides the PIs, the SWT and the wider community with relevant planning, commanding and monitoring information.

Figure 2 shows the flow between the four sub-systems and the JSOC's interaction with the other CSDS and Cluster Mission entities.

**The CSDS user interface**
The CSDS user interface provides the interface with the National Data Centres to allow ingestion of their data products into the data bases and make these products available to the other Data Centres. It also permits the scientific users to interact with the system. The overall system architecture is shown in Figure 3.

With the user interface, the Data Centres can:
— Register scientific users, assign them data access rights and check these rights when they access the data
— Load and update data catalogues
— Validate, archive, update and distribute Summary and Prime Parameters Data (SPD and PPD)
— Maintain a log of user traffic
— Exchange data among Data Centres and fetch data from remote Data Centres upon user request.

The scientific users can:
— Browse through the data catalogues and identify the location/availability of data of interest by instrument, time interval, data quality flag and other parameters
— Read, extract, display and manipulate data from National SPDBs and PPDBs
— Order, read, display and manipulate data from the remote PPDBs and SPDBs.

Given the different configurations existing at the various National Data Centres, two versions of the CSDS user interface have been developed, one running on Solaris and the other on Open VMS.

In order to minimise costs and development time, it was decided to develop the CSDS user interface based on software available at ESRIN, ESA's establishment in Frascati, Italy, from the ESIS pilot phase. Under the overall responsibility of the Cluster Project, ESRIN has tailored the existing software to the specific Cluster requirements. Moreover, ESRIN is responsible for the delivery, installation and maintenance of the product.

Contributions on how to increase the functionalities of the CSDS user interface were solicited from the scientific community. This led to the participation of the Swedish Institute for Space Physics (IRF-U) in Uppsala, Sweden; the Rutherford and Appleton Laboratory (RAL), UK; and the Queen Mary and Westfield College, UK. The Swedish Institute for Space Physics, most notably, contributed a modification that renders the existing ISDAT software particularly suitable to coping with Cluster's specific requirements with respect to scientific data and data file manipulation.

**The Operations Control Centre (OCC)**
ESOC plays two roles with respect to CSDS: it hosts the Operations Control Centre (OCC), and provides the network infrastructure or CSDSnet.

The OCC is part of the Cluster Ground Segment and has the following main functions:
— To plan and schedule the mission from an overall point of view, i.e. both spacecraft and payload, considering the JSOC's requests as a result of its role of coordination
— To control the mission
— To provide support services such as orbit/attitude and spin-rate prediction.

In this way, the ESOC OCC is part of the CSDS both as recipient of the requests coming from JSOC and as distributor of data coming from the spacecraft.

**The network infrastructure (CSDSnet)**
The CSDSnet interconnects the CSDS National Data Centres, the JSOC and various ESA establishments (ESTEC, ESOC and ESRIN). In

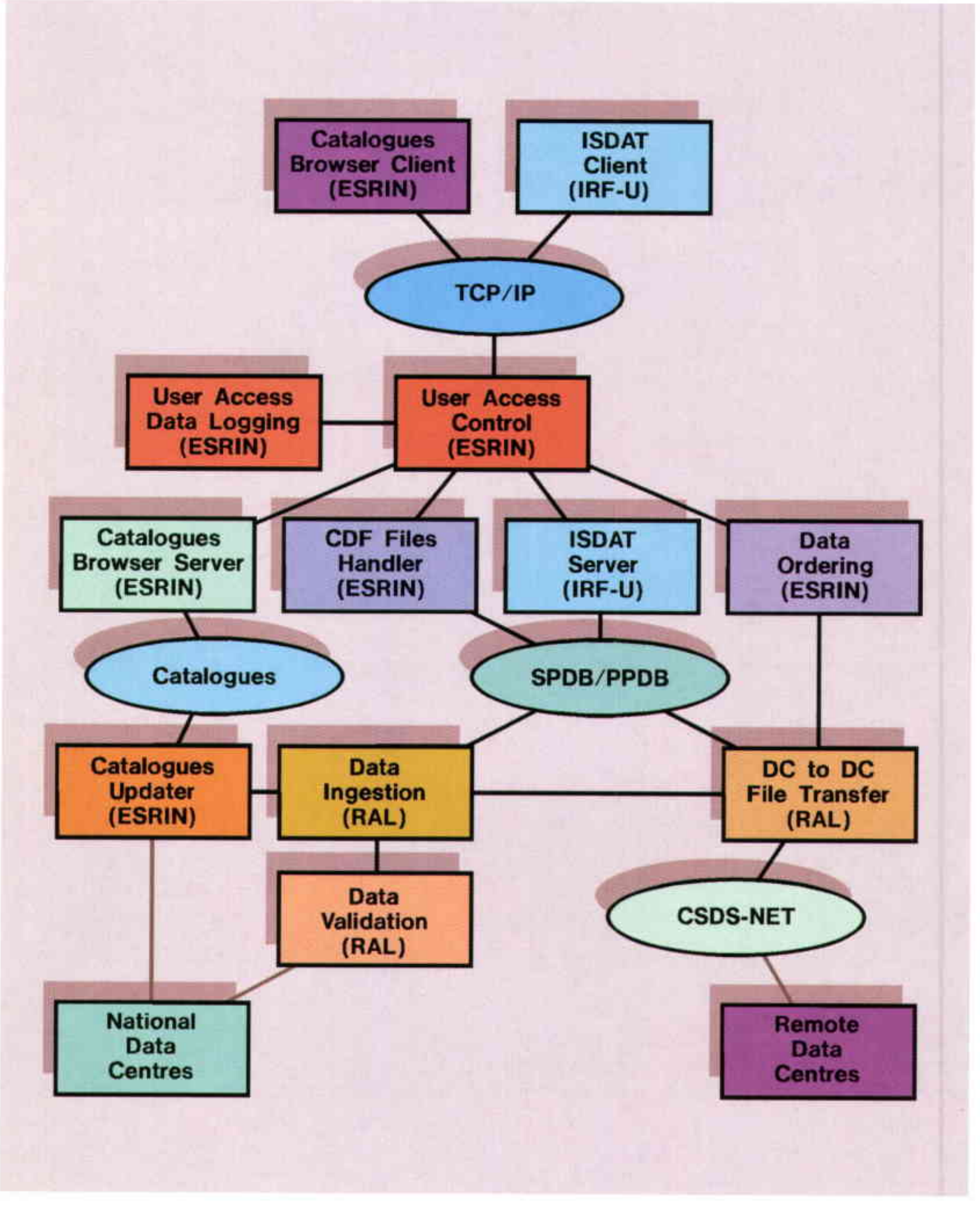


**Figure 3. Overall system architecture of the CSDS user interface. Each organisation's contribution is also indicated.**

principle, CSDSnet is based on the existing ESA infrastructure implemented as a self-contained logical system from an addressing, routing and security point of view. This is necessary to ensure the dedicated, Cluster-specific nature of CSDSnet.

The main services of the communication network are:

- Retrieval of quick-look raw science, house-keeping and auxiliary data residing at ESOC
- Exchange of processed science data between individual data centres
- Access to test data obtained during the spacecraft integration and test programme
- Submission of command request files from individual data centres to JSOC and the combined payload command request files from JSOC to ESOC.

As mentioned earlier, in order to reduce network loading, all raw data products, except quick-look data, will be exchanged on CD-ROM rather than via the network.

The CSDSnet has been designed to provide a logical interconnection between Local Area Networks (LANs) across a Wide Area Network (WAN) infrastructure. The end-user systems are hosts at the CSDS Data Centres, which are attached to Ethernet LAN segments at their local institute. They gain end-to-end access to their remote peers across Internet work routers, which connect the LANs to the common WAN. The logical connectivity thus supported on the CSDSnet is shown in Figure 4.

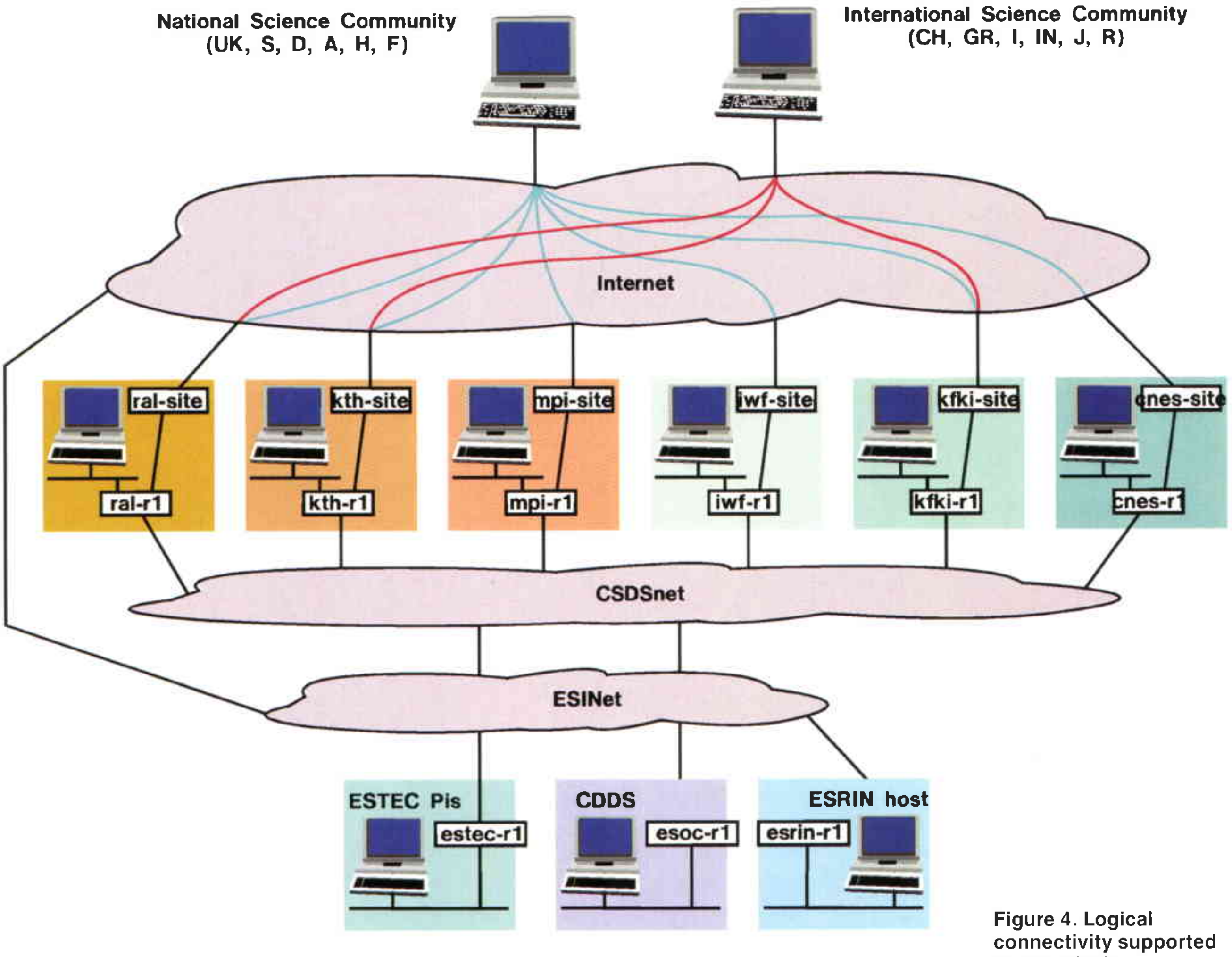


Figure 4. Logical connectivity supported by the CSDSnet

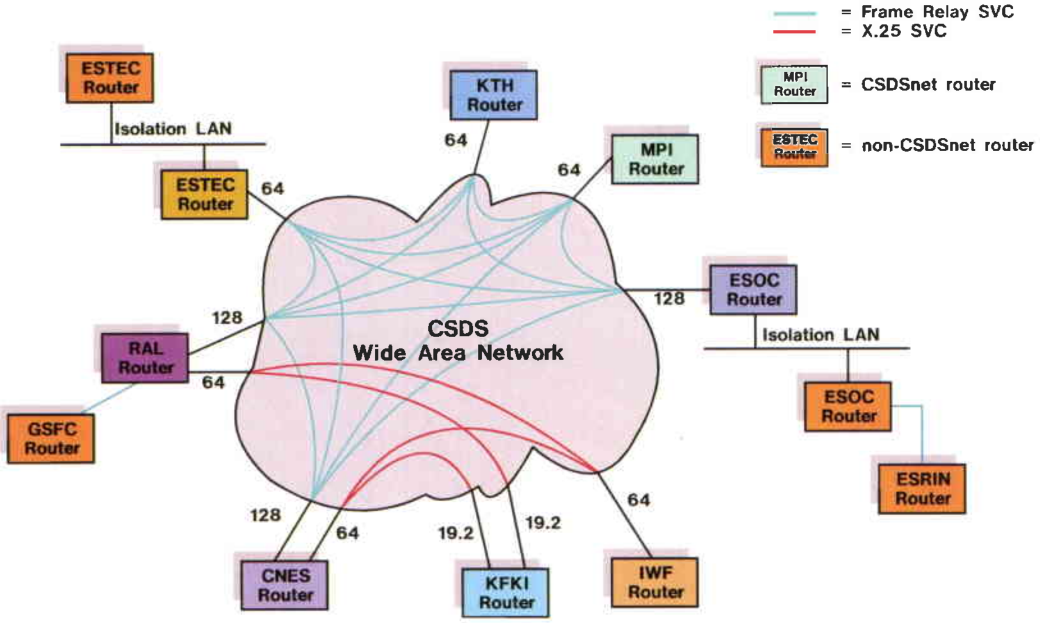


Figure 5. CSDS Wide Area Network (WAN) configuration

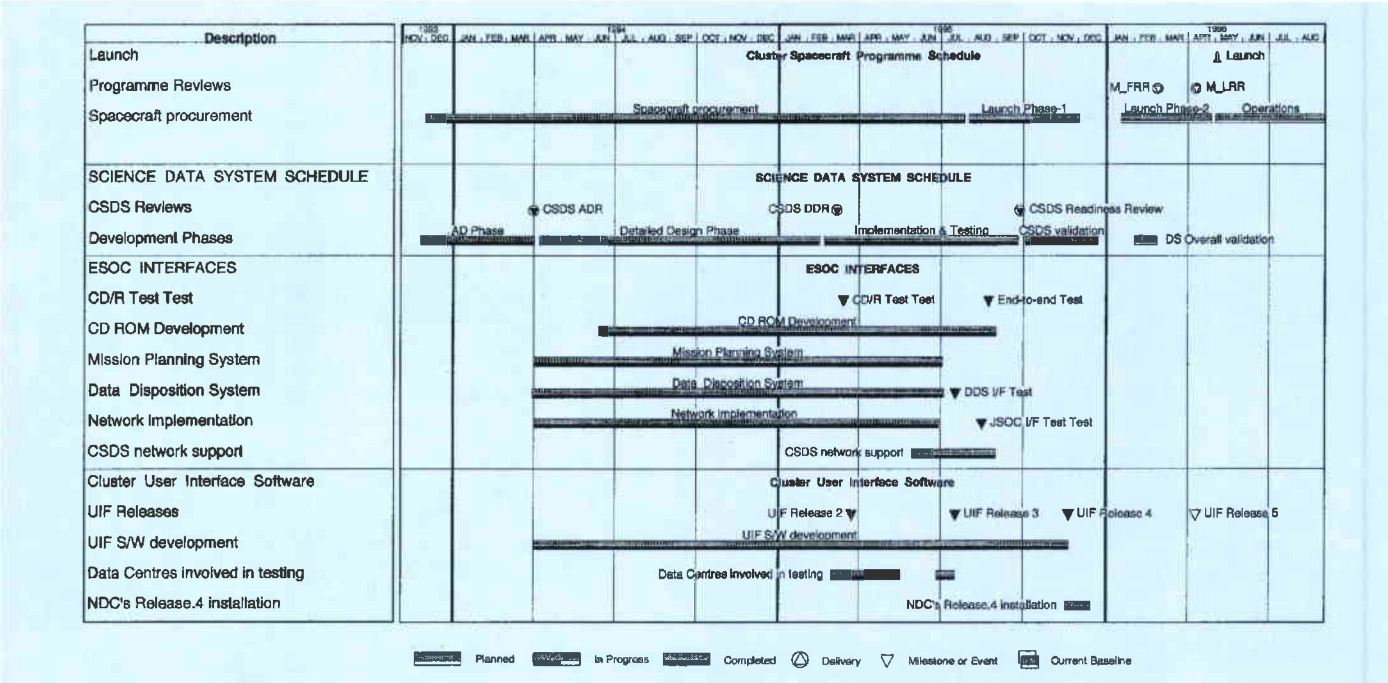


**Figure 6. Master schedule for CSDS development**

The implementation and operation of the hosts and local network is the users' responsibility. The CSDSnet protocol is TCP/IP.

The infrastructure on which the CSDS-WAN is implemented has been contracted out both in terms of supply and of operations. Its configuration is shown in Figure 5.

## The CSDS schedule

The preparation phase for the CSDS started in 1989, at the first meeting of the SWT. The system was then actually developed in the timeframe 1993 – 1995 to be ready for the original Cluster launch (the launch is now scheduled for the late spring of 1996). The overall CSDS development schedule had to be compatible with the overall Cluster schedule.

Based on the current launch date, the mission-level Mission Launch Readiness Review (M-LRR) is planned to be undertaken in late February 1996. The Mission Flight Readiness Review (M-FRR) was performed in September. The CSDS development schedule is summarised in Figure 6.

In that Figure, all the National Data Centres and JSOC are included in the so-called 'Science Data System Schedule' which has already achieved the following major milestones:
— The Architectural Design Review (ADR) in March 1994
— The Detailed Design Review (DDR) in March 1995
— The Readiness Review in September 1995.

The schedule foresees also a period for CSDS validation up to the Mission Launch Readiness Review. Work on the other two main elements in the schedule, the ESOC interfaces and the CSDS user interface, started in 1994 but in time to meet the mission-level milestones.

In particular, the user interface schedule was designed in such a way as to have multiple releases to the National Data Centres, which allowed the Data Centres to learn the system in stages while they participated in the debugging process. The Centres then accepted Release 3 of the user interface, in July 1995. Enhancements that the users had, in the meanwhile, suggested to include in the design baseline, will be incorporated in Release 4.

# The Cluster Mission Operations

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## Introduction

The Cluster mission is scheduled to be launched on the first Ariane-5 flight, which will put the four identical spin-stabilised satellites into Geostationary Transfer Orbit. Mission operations, for the baseline duration of 2.5 years, will be carried out from ESOC, in Darmstadt (D).

The ground-segment design and mission operations concepts for the Cluster mission have been defined according to the basic mission requirements, to allow the transfer of the four spacecraft from the initial Geostationary Transfer Orbit (GTO) achieved at separation from the launcher, into the final highly elliptical polar mission orbits. These orbits are such that, in the areas of scientific interest along the orbital paths, the four spacecraft will form a tetrahedral configuration with pre-defined separation distances. These distances will be changed every six months during the mission.

From the mission-operations point of view, the most critical phase of the mission will occur immediately after separation from the Ariane-5 launcher when, within a few minutes, all four spacecraft will be released and time-critical configuration activities have to be commanded from the ground within a few hours. During the routine phases of the mission, the challenge for the Cluster ground segment will be that of supporting and coordinating the simultaneous operations of the four spacecraft with careful utilisation of the available space- and ground-segment resources.

## The ground segment

The Cluster ground segment (Fig. 1) consists of a ground stations and communications network, an Operations Control Centre (OCC), a dedicated communications network for data distribution to the scientific community, and the Cluster Science Data System.

The Ground Station Network (Fig. 2) interfaces to the spacecraft via S-band antennas, which support all telemetry, telecommand and tracking activities. In the initial phases of the mission, from launch until all four spacecraft have reached their science operations orbits, five ESA ground stations – Redu, Odenwald, Kourou, Perth and Malindi – will be used to maximise the ground contact during critical activities. In addition during those phases, NASA's two Deep Space Network (DSN) stations, at Goldstone (USA) and Canberra (Aus), will be available. In particular, their 26 m and 34 m-diameter antennas will provide support during the periods when one or more spacecraft are cruising in a transfer orbit at large distances from the Earth (up to 60 Earth radii). The 15 m antennas of the ESA stations are not sufficient for tracking the weak telemetry signals coming from the Cluster spacecraft at such distances.

The routine science operations phase will be supported by two dedicated ESA ground stations, at Redu in Belgium and in the Odenwald in Germany. These stations will be unmanned and remotely controlled from the main computers located in the OCC at ESOC. The DSN stations will be used once per orbit during this routine phase to receive high-speed dumps of science telemetry from the Wide Band Data instrument on each of the four spacecraft.

The OCC will provide the necessary mission control functions for both the spacecraft and payload, commensurate with satellite safety, the scientific requirements, and the overall system resources. It will also conduct all activities relating to mission planning and scheduling of the overall system – ground segment, spacecraft and payload – taking into account the requests received from the Principal Investigators, as well as all system constraints and capabilities.

The core of the OCC facilities is the Cluster Mission Control System (CMCS), which will support all of the mission-control tasks, including: real-time/near-real-time data-processing tasks essential for controlling the mission; acquisition and interim storage of raw scientific data, to be accessible together with raw housekeeping and auxiliary data to the scientists at remote locations, as well as distribution of all data on a hard data medium; payload command request handling and the planning and scheduling of satellite operations.

The Mission Control System is supplemented by the Flight Dynamics System (FDS), which will handle all activities related to orbit and attitude determination and control, and by a number of auxiliary hardware and software tools.

Science Data Centres will be able to recover the data collected during the previous 10 days of the mission. The same computer system will generate, on a daily basis, CD-ROMs on which all scientific, housekeeping and auxiliary data are to be stored and distributed to the users.

**Mission operations**

The Cluster mission can be broadly divided into three phases:

- the Launch and Early Orbit Phase/Transfer Orbit Phase (LEOP/TOP), covering the activities from launch and first acquisition of the four spacecraft until the final manoeuvre into the desired mission orbits;

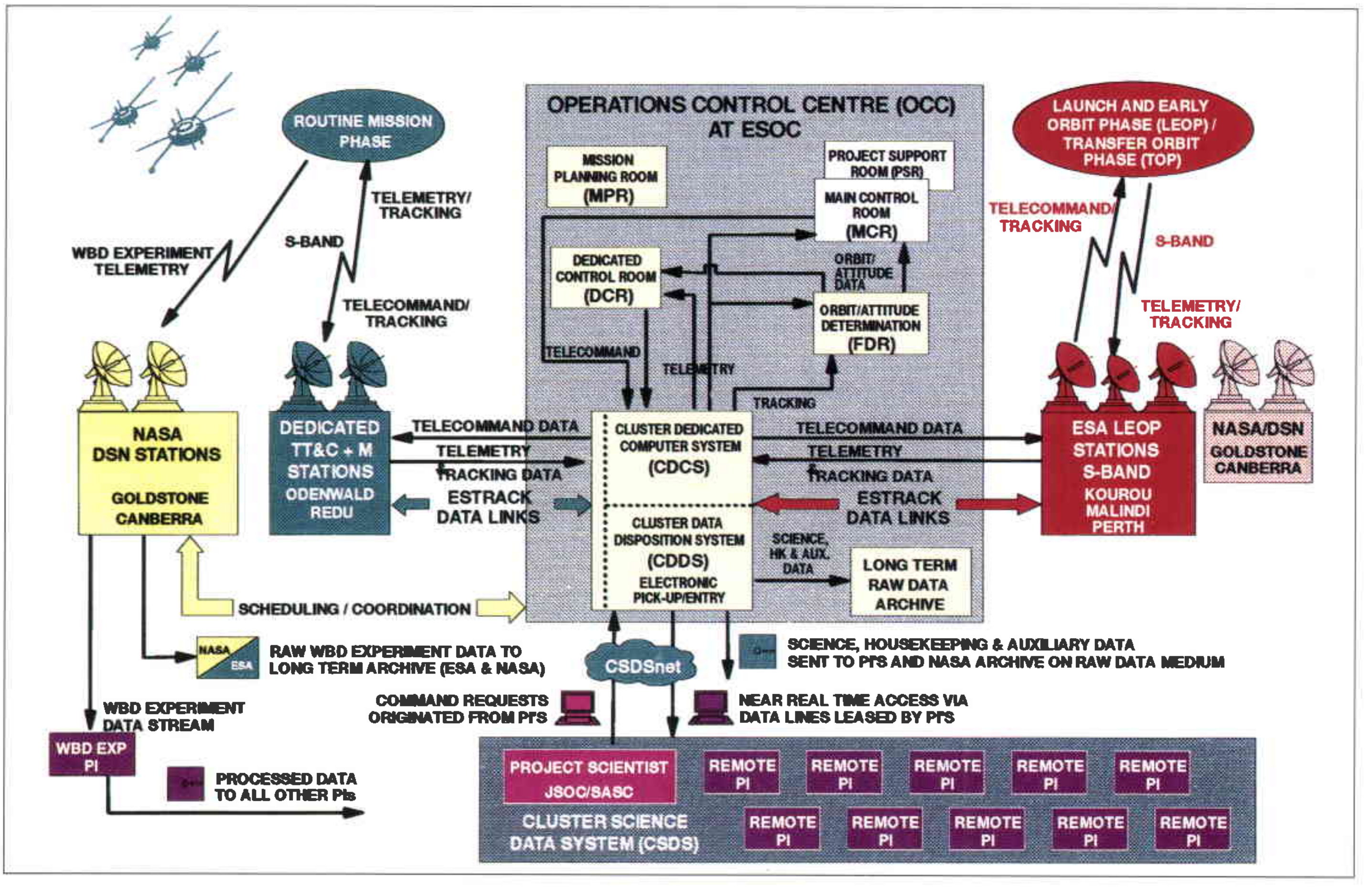



**Figure 1. Overview of the Cluster ground segment**

All detailed requests for science payload operations during the routine phase of the mission will be collected by the Joint Science Operations Centre (JSOC), which forms part of the Cluster Science Data System and is located at the premises of the Rutherford Appleton Laboratories in the United Kingdom. The JSOC will transmit to ESOC, over a dedicated data network, the payload operations requests necessary to support the weekly mission planning activities at the OCC.

The science data are to be processed separately at the OCC and temporarily stored in a dedicated Data Disposition System, from which all Principal Investigators and authorised

- the Commissioning and Verification Phase (CVP), during which the initial payload activation, spacecraft subsystems and payload commissioning will be carried out
- the Mission Operations Phase (MOP), consisting of all routine operations in support of payload activities and scientific data acquisition, the nominal duration of the science mission being two years.

**Launch and transfer to mission orbit**

All four Cluster spacecraft will be launched on a single Ariane-5 launcher, which will inject them into GTO approximately half an hour after lift-off, in a timed sequence lasting just a few minutes. The first acquisition is planned to be over the Malindi (Kenya) ground station, followed by the Perth (Australia) station about 15 minutes later. Within about one hour of launch, all four spacecraft will have been acquired for the first time from either Malindi or Perth, allowing the OCC to perform a quick status check and the first spacecraft configuration activities.

For the first ten hours of the mission, only two ESA ground stations will be in contact with the spacecraft, which means that a maximum of two spacecraft will be in ground contact at any given time. During this period, the critical initialisation of the reaction control subsystem and the first spin-up manoeuvre from 5 to 15 rpm will be carried out on all four spacecraft. For the rest of the phase, which nominally lasts about three weeks, five ESA stations – Kourou, Odenwald and Redu in addition to Malindi and Perth – and the two Deep Space Network (DSN) stations at Goldstone and Canberra will be dedicated to tracking the Cluster fleet.

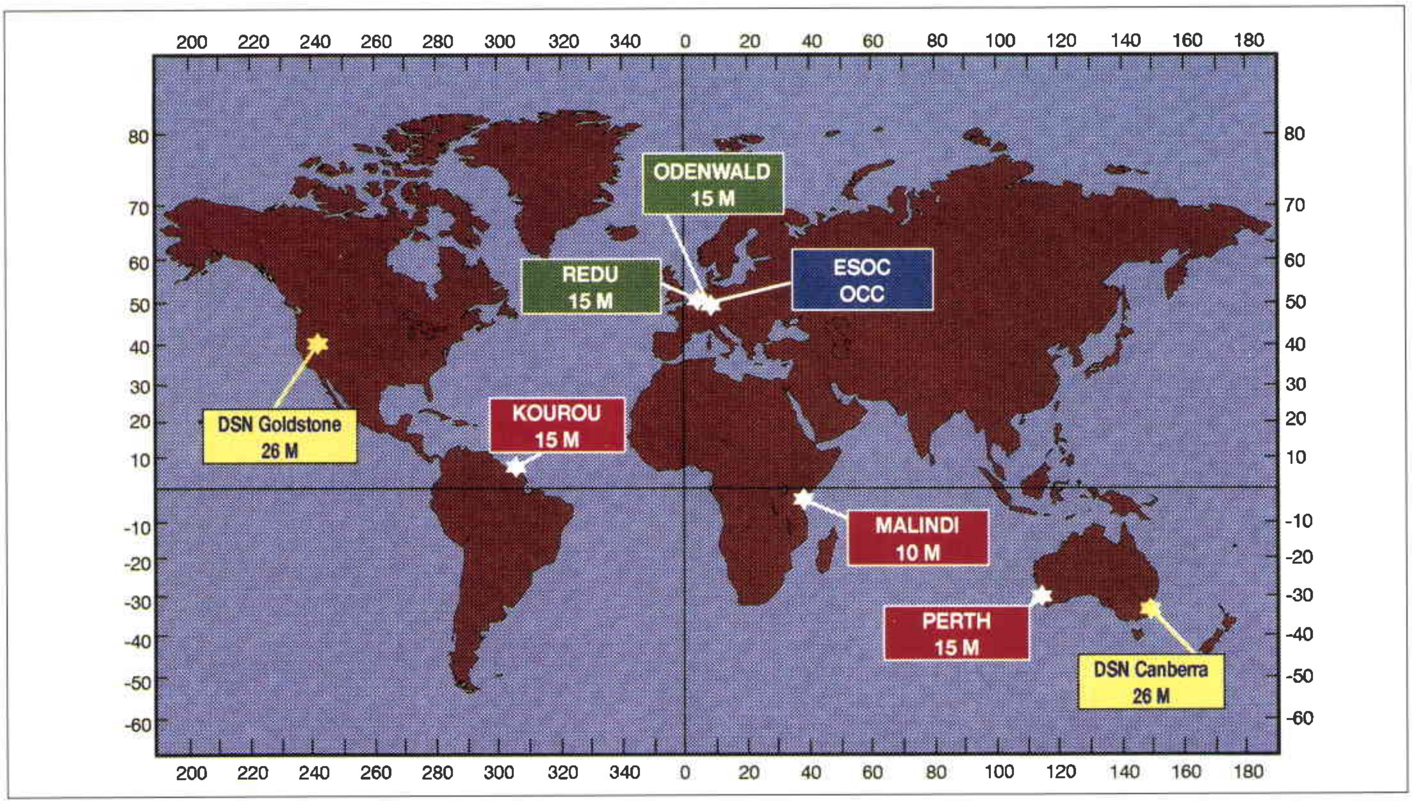
After the collection of the tracking measurements from the ground stations and acquisition of the desired spacecraft attitudes, a sequence of manoeuvres will be initiated to reach the pre-defined, highly elliptical (28 000 km perigee, 125 000 km apogee) orbits with an inclination of close to 90° and the line of apsides close to the equatorial plane. The spacecraft will be manoeuvred in pairs to minimise operational complication, particularly in case of contingencies. The nominal transfer scenario foresees six orbit manoeuvres for each spacecraft. A number of attitude and spin-correction manoeuvres will also be carried out during this phase. Most of the activities will be performed in real-time contact with one of the ground stations, although for some orbit manoeuvres ground coverage cannot be guaranteed.

### Spacecraft and payload commissioning

The first activities carried out on all four spacecraft once they have reached the science mission orbit will be the deployment of the second RF antenna, located on the bottom of the spacecraft, and the deployment of the two rigid radial booms and the four 50 m-long wire booms which carry some of the instrument sensors. These are very critical activities for the dynamics of the spacecraft, involving precise attitude and spin-rate changes performed under ground control. The wire-boom deployments will be carried out in successive steps, lasting about two weeks for each spacecraft, including long periods of science measurements from the sensors on the tops of the booms. Payload-instrument commissioning will start immediately after the completion of the rigid-boom deployment activities, and will continue throughout the following 8 to 10 weeks.

Ground coverage during the commissioning phase will be ensured by the Redu and Odenwald ground stations; the DSN ground stations used during the previous mission phases will also be available, but only for a few

**Figure 2. The Cluster ground-station network**




hours per orbit. Spacecraft and payload operations will typically be conducted in real time. Experts and scientists for all payload instruments will support the commissioning activities from the OCC during the entire phase. They will be located with their ground-support equipment in a dedicated area of the OCC and linked to the operations control rooms via voice and data links.

### Routine mission operations

Routine mission operations are based on the use of a single control centre in conjunction with two dedicated ESA ground stations (Redu and Odenwald). All payload operations will be pre-planned and executed according to an agreed plan, which is generated and modified in a periodic mission planning exercise. Real-time operations with the spacecraft will normally be limited to the acquisition of telemetry data recorded during the long non-coverage periods and dumped to the ground station during the real-time contacts, and the uplinking to the on-board memory of time-tagged commands for the execution of all pre-planned spacecraft and payload operations.

With the four spacecraft in the nominal operations orbit, the ground coverage is about 50% of the total orbital period of about 57 hours, divided into a long-visibility period (pass) of up to 20 hours and one or two short passes of a few hours each every orbit. Typically, one station will track one spacecraft for half of the available geometrical visibility time, and a second spacecraft for the rest of the pass. The second ground station will be similarly assigned to the second pair of spacecraft, resulting in an average ground coverage for each spacecraft of about 25% of the mission time.

The baseline approach for science operations is to activate the payload instruments and acquire science data only in specific areas of the orbit, when the most interesting regions of the magnetosphere are crossed. If the spacecraft is in real-time contact with the ground upon entering one of the regions of scientific interest, then the science data are to be directly downlinked to the station; otherwise all data are to be stored in one of two on-board recorders (each with a capacity of 2.25 Gbit).

In addition to the above, the Wide Band Data (WBD) instrument will be transmitting data for short periods each orbit to a DSN ground station, the only constraints being availability of the DSN station and non-simultaneity of coverage from an ESA station.

During the science mission phase, it is planned to vary the distance between the four spacecraft once every six months, to allow scientific investigation of the plasma structures over different scales. This will be done by means of a series of orbit manoeuvres conducted over a period of several weeks.

### Mission planning

All routine mission operations will be performed in accordance with an integrated space- and ground-segment schedule produced via a periodic planning exercise, which can be broadly divided into a long-term baseline planning cycle and a short-term detailed planning cycle.

The long-term planning is based on a planning period of 6 months, generally the period in which the spacecraft separation distances remain unchanged. This activity involves the Project Scientist and all Principal Investigators, who define the areas of scientific interest and the related desired data acquisition modes for each orbit in the planning period. The plan is then analysed by ESOC for feasibility from the


**Figure 3. The ESOC Main Control Room, configured for the Cluster mission**

point of view of spacecraft and ground-segment resources availability and operability. The finalised version of the baseline plan is then passed to the Joint Science Operations Centre (JSOC) to form the basis for the detailed short-term planning cycles.

The short-term planning works on planning periods of three orbits (about 1 week) starting eight weeks before the start of each planning period, when JSOC submits electronically to ESOC a complete set of operations requests for the payloads of all four spacecraft. At ESOC this request is analysed via software mission-planning tools, which check the correctness of the request and its feasibility in terms of available spacecraft resources (power and data storage) and ground-segment resources (data storage and link capacity between the station and the OCC). The results of this activity are then reported back to JSOC.

Further iterations of the request for science operations related to a specific planning period are allowed until the week before the start of the planning period. At this point all requests are frozen and the final implementation cycle begins at ESOC. Only minor change requests involving operations which have no impact on space- or ground-resource utilisation are allowed in this phase.

The final implementation of the science operations works on a cycle of nominally three days, in which the finalised plan is translated into time-tagged operations schedules for the four spacecraft and the two ground stations. The schedules are then released to the relevant control computers. Shortly before the beginning of a visibility period, the ground-station operations schedule is activated and the station operations are performed completely automatically. The time-tagged operations schedule is then uplinked to each spacecraft during the visibility period; in general, a period of 48 hours into the future will be covered by each uplink of time-tagged commands to guarantee continuity to the science operations.

## Mission product distribution

At the OCC, science data and house-keeping data contained in the telemetry streams, regularly dumped from the on-board recorders or received in real-time at every ground contact, will be time-stamped and stored as raw data. Further processing of science data and verification of the correct functioning of the experiments will then be performed by the Principal Investigators, who can access the most recently acquired data in quasi-real-time over an electronic network via the Data Disposition System, or receive all data about three weeks later on the CD-ROMs which are to be produced and distributed on a regular basis. A long-term archive of all mission data will be kept at ESOC for a period 10 years after the end of the mission.

## Conclusions

For ESOC, the Cluster mission presents the unique challenge of the simultaneous launch and control of four identical scientific satellites. In order to achieve this a very modern design approach has been adopted for the ground segment, based on distributed architectures and local and wide-area networks for data processing and distribution. The operations concept, based on a single mission control team, remotely controlled unmanned ground stations, and the concentration of real-time operations responsibilities into two control positions, has allowed costs to be reduced to a level within the envelope of a traditional single-spacecraft mission.

# RENDEZVOUS WITH THE NEW MILLENNIUM

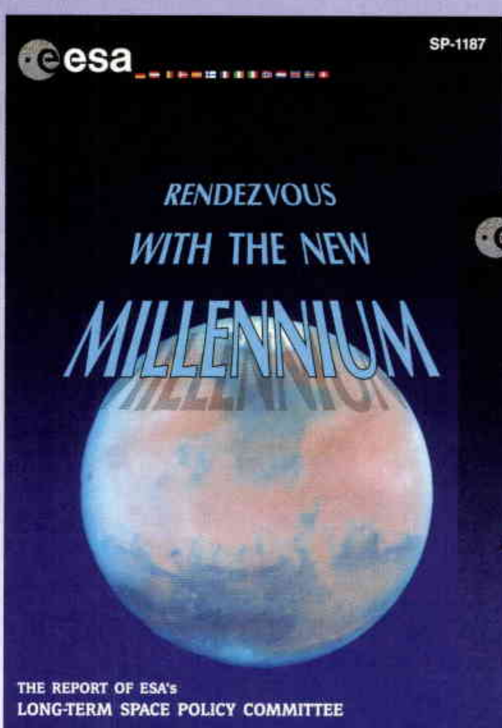
## The Report of ESA's Long-Term Space Policy Committee

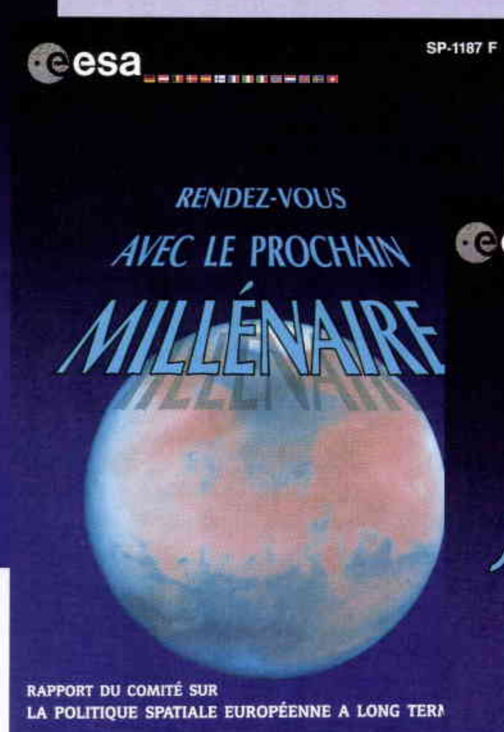
With 30 years of space activities behind us, we can now look forward to the next millennium on far more solid ground than the early pioneers ... At present, most space activities go from study phase to launch in about 10 years. The near-future is therefore already accounted for, and the major options for the next 20 years are also known. But what about the decades beyond that, and how will the world change over the next 50 years?

To identify a strategic vision for European space activities in the next century — one that will respond both to the challenges and threats facing humanity in the future — the ESA Council created a Long-Term Space Policy Committee (LSPC) in June 1993. The Commitee's task was to prepare a report on European space policy after the year 2000.

The LSPC chose to take a 50-year perspective in order to go beyond the mere extrapolation of current trends while still keeping in mind the present technological and financial constraints. The Committee analysed in depth the themes that it deemed to be of importance and collected the thoughts of recognised experts in relevant domains.

Its work has culminated in this report, *Rendezvous with the New Millennium*, which was presented to the ESA Council Meeting at Ministerial Level in Toulouse in October. The Ministers welcomed and endorsed the report: they expressed their satisfaction with the perspectives taken and have invited the Committee to continue to reflect on the long-term space policy for Europe.





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# Programmes under Development and Operations
# Programmes en cours de réalisation et d'exploitation

## In Orbit / En orbite

| | PROJECT | COMMENTS |
|---|---|---|
| SCIENCE PROG. | IUE | |
| | SPACE TELESCOPE | LAUNCHED APRIL 1990 |
| | ULYSSES | LAUNCHED OCTOBER 1990 |
| APPLICATIONS PROGRAMME | MARECS - A | EXTENDED LIFETIME |
| | MARECS - B2 | LEASED TO INMARSAT |
| | METEOSAT-4 (MOP-1) | LIFETIME 5 YEARS |
| | METEOSAT-5 (MOP-2) | LAUNCHED MARCH 1991 |
| | METEOSAT-6 (MOP-3) | LIFETIME 5 YEARS |
| | ERS - 1 | EXTENDED LIFETIME |
| | ERS - 2 | LAUNCHED APRIL 1995 |
| | ECS - 1 | LAUNCHED JUNE 1983 |
| | ECS - 4 | LAUNCHED SEPT. 1987 |
| | ECS - 5 | LAUNCHED JULY 1988 |

## Under Development / En cours de réalisation

| | PROJECT | COMMENTS |
|---|---|---|
| SCIENTIFIC PROGRAMME | SOLAR TERRESTRIAL SCIENCE PROG. (STSP) (SOHO, CLUSTER) | LAUNCHES NOV 1995/APR. 1996 |
| | ISO | LAUNCH NOV. 1995 |
| | HUYGENS | TITAN DESCENT SEPT. 2004 |
| | XMM | LAUNCH END 1999 |
| | INTEGRAL | LAUNCH APRIL 2001 |
| | ROSETTA | LAUNCH JAN. 2003 |
| COMM. PROG. | DATA-RELAY SATELLITE (DRS) | |
| | ARTEMIS | LAUNCH 1997 |
| EARTH OBSERV. PROGRAMME | EARTH OBS. PREPAR. PROG. (EOPP) | |
| | ENVISAT 1/ POLAR PLATFORM | LAUNCH MID-1999 |
| | METOP-1 PREP. PROG. | |
| | METEOSAT TRANSITION PROG. (MTP-1) | LAUNCH MID-1997 |
| | MSG-1 | LAUNCH JUNE 2000 |
| MANNED SPACE PROGRAMME | COLUMBUS (COF) | LAUNCH NOV. 2002 |
| | ATV | LAUNCH MARCH 2002 |
| | ERA | LAUNCH FEB. 1999 |
| | DMS (R) | LAUNCH APRIL 1998 |
| | ARD | LAUNCH MAY 1996 (AR. 502) |
| | MICROGRAVITY (IML-2, EM 94, EM 95, USML-2, MM-03, LMS, MM-05, MM-06, SLS-4) | |
| | EUROMIR 94/95 | |
| LAUNCH. PROG. | ARIANE-5 | |
| | ARIANE-5 EVOLUTION | FIRST LAUNCH END 2002 |

DEFINITION PHASE — MAIN DEVELOPMENT PHASE — ▲ LAUNCH/READY FOR LAUNCH

OPERATIONS — ADDITIONAL LIFE POSSIBLE — ▼ RETRIEVAL

## Soho

*En juin et juillet, le satellite a été soumis au dernier contrôle fonctionnel au niveau système à Toulouse (F) après que certains de ses composants eurent été remis en pleine conformité avec les normes de vol (répéteur et enregistreur à état solide).*

*La série programmée de revues des éléments de la mission a été organisée parallèlement: la revue d'avancement du lanceur et du secteur sol a eu lieu les 29 et 30 juin au Centre spatial Kennedy (KSC) et a été suivie, le 11 juillet, par la revue des opérations en vol au Centre spatial Goddard (GSFC). Ces différentes revues ont confirmé la validité d'ensemble des divers composants de la mission et ont mis en lumière certaines mesures à prendre et certains points à examiner.*

*La revue d'aptitude au vol de la mission, organisée à l'ESTEC (NL) en juillet, a été l'occasion de rassembler tous les résultats des autres revues et de mettre l'accent sur quelques points critiques relatifs au satellite. Des analyses complémentaires conduites sur l'ensemble des modèles de vol des roues à réaction du satellite avaient mis en évidence la nécessité d'améliorer leur processus d'assemblage afin de garantir la durée de vie requise pour Soho. En outre, un essai de mis à feu des propulseurs avait révélé la formation anormale d'un 'bouchon de vapeur' dans certaines conditions extrêmes. La revue avant expédition, organisée le 27 juillet, a entériné l'ensemble des plans établis pour résoudre ces deux points critiques.*

*Le satellite et ses équipements ont été expédiés directement par avion au Centre spatial Kennedy depuis Toulouse le 1er août. Quelques heures après l'arrivée du satellite et son entreposage dans l'installation SAEF 2 qui lui est affectée, le cyclone Erin a frappé la région, nécessitant l'évacuation de l'ensemble de la base.*

*Après ces débuts mouvementés, les activités programmées au KSC se sont déroulées sans aucun problème, avec la préparation et l'exécution du dernier essai fonctionnel au niveau système, ainsi que du dernier essai de compatibilité du secteur sol, au cours duquel l'équipe responsable des opérations en vol a été chargée de commander directement le satellite à partir du GSFC au moyen d'une liaison RF.*

*Dans l'intervalle, la remise à neuf des roues à réaction a progressé à un rythme extrêmement soutenu et quelques modifications mineures ont été expérimentées sur le sous-système de commande d'orientation et de correction d'orbite (AOCS). Celles-ci permettront d'utiliser les propulseurs en dehors des régimes critiques.*

*Le lanceur Atlas IIAS chargé de mettre Soho en orbite (vol AC-121) est arrivé au KSC le 15 septembre et a été placé sur le pas de tir 36B le 29 septembre.*

### Expériences

*Au début de la campagne de lancement, plusieurs expérimentateurs ont installé leurs instruments en configuration de vol après déverminage final et réparation.*

*Une troisième simulation de la conduite des expériences a également eu lieu au GSFC et a conduit à mieux affiner les interactions avec le secteur sol et le processus de collecte des données scientifiques.*

## ISO

*Le satellite ISO et tous les équipements associés ont été transportés par voie maritime, en juin, vers le centre de lancement de Kourou en Guyane française. Depuis lors, les sous-systèmes et instruments scientifiques du satellite, soumis à des essais approfondis, se sont tous avérés en parfait état de fonctionnement. C'est maintenant au tour d'ISO d'être monté sur le lanceur Ariane-44P. La campagne de lancement redémarrera début octobre, dans la perspective d'un lancement début novembre.*

*La préparation des opérations en vol à l'ESOC et au Centre de contrôle en vol de Villafranca près de Madrid (Espagne) est également en phase finale. Au cours des deux derniers mois précédant le lancement, l'essentiel des activités est axé sur l'entraînement et sur l'exécution de simulations ayant pour objet d'établir l'aptitude au vol.*

*La communauté scientifique attend avec impatience les premiers résultats des observations d'ISO.*

## Huygens

*Le modèle structure/thermique/pyro-technique (STPM) de la sonde Huygens a été livré au Jet Propulsion Laboratory (JPL) en juillet pour être ensuite intégré dans le modèle de structure de l'orbiteur Cassini, appelé modèle de développement (DTM). Le STPM restera assemblé au DTM jusqu'à fin 1995, un certain nombre d'essais étant réalisés au cours de cette période. On a déjà procédé à des essais de recherche des modes propres, qui n'ont révélé aucun résultat surprenant.*

*Le programme d'essais du modèle d'identification (EM) de la sonde a été mené à bien le 15 août. Ce modèle se trouve actuellement dans les locaux de DASA qui est responsable de l'ensemble des activités d'assemblage, d'intégration et de vérification (AIV) de la sonde. Il sera ensuite livré au JPL en avril 1996.*

*Les activités AIV relatives au modèle de vol de la sonde ont débuté le 7 août lors de la réception par DASA des sous-systèmes de vol structure interne et câblage d'alimentation. Le sous-système de vol régulation de puissance a également été livré et est en cours d'intégration mécanique et électrique dans la sonde. La livraison et l'intégration des sous-systèmes de vol se poursuivront pendant encore deux mois.*

*La revue critique de conception au niveau système est bien entamée. Le dossier de la revue a été remis à tous les participants et des comités de revue ont tenu des réunions préliminaires. La commission proprement dite de revue critique de conception se réunira à l'ESTEC le 12 octobre.*

## Integral

*Dans le cadre de la Phase B industrielle, le maître d'oeuvre, Alenia (I), a avancé dans les travaux de conception préliminaire du véhicule spatial.*

*Une configuration accueillant les quatre instruments sur le module de charge utile et permettant une ré-utilisation maximale de la conception du module de servitude XMM a été retenue comme base de référence. Les caractéristiques fondamentales de la conception des instruments ont également été arrêtées, un*

# Soho

In June and July the spacecraft was subjected to the last System Functional Check in Toulouse (F), after some of its units had been brought back to full flight standard (transponder and solid-state recorder).

In parallel, the planned set of reviews of the mission elements took place: the Launcher and Ground-Segment Status Review on 29/30 June at Kennedy Space Center (KSC), followed on 11 July by the Flight Operations Review at Goddard Space Flight Center (GSFC). All of these reviews confirmed the general good health of the relevant components of the mission and identified further actions and areas for attention.

The Mission Flight-Readiness Review held at ESTEC (NL) in July drew together all of the results of the other reviews and highlighted a few problem areas on the spacecraft. Further investigations on all spacecraft flight-model reaction wheels had revealed that their assembly process needed to be improved in order to guarantee the lifetime needed for Soho. In addition, a thruster firing check had shown an anomalous 'vapour lock' behaviour under certain extreme conditions. The Pre-shipment Review on 27 July endorsed all plans to resolve these two problem areas.

The spacecraft and its equipment were airfreighted direct to Kennedy Space Center in Florida from Toulouse on 1 August. A few hours after the spacecraft's arrival and its storage in the assigned SAEF-2 facility, hurricane Erin struck the area, forcing an evacuation of the whole range.

After such an eventful start, the planned activities at KSC have run very smoothly, with the preparation of the last System Functional Test and its execution, and the last Ground Segment Compatibility Test with the Flight Operations Team commanding the spacecraft directly via an RF link from GSFC.

Meanwhile, the refurbishment of the reaction wheels has progressed at maximum speed and some minor modifications to the Attitude and Orbit Control (AOCS) subsystem have been identified and tested. These modifications will allow the thrusters to be used outside the critical regimes.

The Atlas IIAS that will launch Soho (AC-121) arrived at KSC on 15 September and was erected on Pad 36B on 29 September.

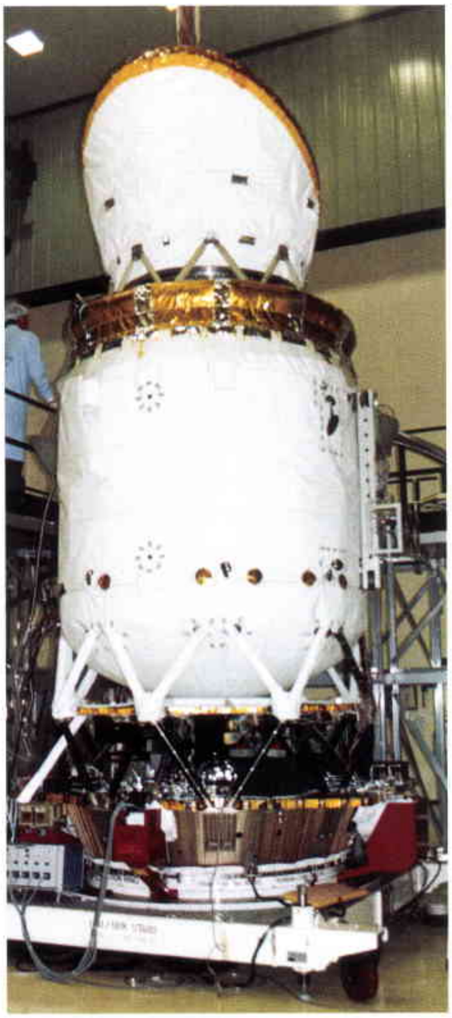
### Experiments

At the start of the launch campaign, several experimenters have installed their flight-unit instruments, which had been undergoing final debugging and repair.

A third simulation of experiment operations has also taken place at GSFC, resulting in further refinement of the interactions with the ground segment and the scientific data gathering process.

# ISO

The ISO satellite and all associated equipment was transported in June by sea to the launch site at Kourou in French Guiana. The satellite subsystems and scientific instruments have since all been thoroughly tested and found to be in perfect order. ISO is now waiting its turn to be mated with the Ariane-44P launcher. The launch campaign will restart in early October, with a view to a launch early in November.



Preparations for the flight operations by ESOC and the flight control centre at Villafranca, near Madrid, Spain, are also in their final stages. Most efforts in the last two months before launch are geared to training, and performing simulations to prove flight-readiness.

The scientific community is eagerly awaiting the first results from ISO's first look into space.

# Huygens

The Structural Thermal Pyro Model (STPM) of the Huygens Probe was delivered to Jet Propulsion Laboratory (JPL) in July and has subsequently been integrated with the Cassini Orbiter's mechanical model, known as the Development Test Model (DTM). The STPM will remain with the DTM until late 1995, during which time a number of tests will be performed. A modal survey has already been conducted and has not shown any surprising results.

The Probe Engineering Model (EM) test programme was successfully completed on 15 August. The EM is now being stored at DASA, which is responsible for all Probe Assembly, Integration and Verification (AIV) activities. It will subsequently be delivered to JPL in April 1996.

Probe Flight Model AIV activities began on 7 August, when DASA received the flight internal structure and harness subsystems. The flight power-control subsystem has also been delivered and is now being integrated mechanically and electrically into the Probe. Delivery and integration of the flight subsystems will continue for another two months.

The system-level Critical Design Review is well underway. The review data package

*ISO prêt au lancement sur la base de Kourou en Guyane française*

The ISO spacecraft being readied for launch, in Kourou, French Guiana *certain nombre d'options devront cependant faire l'objet d'arbitrages supplémentaires. Des mesures spécifiques en appui du développement de la charge utile ont été mises en route par l'équipe projet, notamment en ce qui concerne l'utilisation d'unités électroniques de conception commune pour le traitement des données des instruments, l'approvisionnement des pièces ainsi que des essais dans des installations coordonnées.*

*Le projet d'arrangement entre l'ESA et la RKA relatif à la fourniture d'un lanceur Proton en échange de temps d'observation scientifique est examiné par les autorités russes.*

# Rosetta

*Les activités se sont poursuivies en ce qui concerne la définition de la mission et du système, conjointement avec les deux groupements industriels qui fournissent une assistance technique à l'Agence. Les options de lancement de réserve incluses à l'origine dans les options de mission ont été écartées et la mission de référence vise désormais la comète Wirtanen, en tirant deux fois parti de l'effet de fronde de la Terre et une fois de celui de Mars. Le choix des astéroïdes à visiter au cours de la phase de croisière fait également l'objet d'un réexamen dans le cadre d'une optimisation complémentaire du scénario de la mission.*

*L'avis d'offre de participation relatif à la charge utile scientifique a reçu en août des réponses émanant d'une communauté scientifique à large spectre d'activités. Les efforts actuels en matière de conception système s'articulent autour de la mise en place de la charge utile. Le processus de sélection de la charge utile de l'orbiteur sera achevé à la fin de l'année, ce qui permettra de faire une recommandation au Comité du programme scientifique de l'Agence en février 1996.*

*Parallèlement, le processus de sélection est en cours pour les deux ensembles d'étude scientifique de la surface (SSP) qui constitueront la charge utile scientifique des modules d'atterrissage. Ce processus de sélection sera achevé au cours de l'automne et les deux propositions, avec la charge utile recommandée, sont attendues pour le 1er décembre. On procédera ensuite à la vérification de la compatibilité des interfaces des deux SSP, qui feront partie intégrante de la recommandation globale relative à la sélection de la charge utile de Rosetta.*

*Une réunion s'est tenue récemment entre les deux groupes en charge des SSP, l'équipe projet et l'ESOC pour discuter des concepts de navigation à proximité de la comète et de largage des modules d'atterrissage, ces deux questions pouvant influer sur la conception système de l'orbiteur. Sur le principe, il a été convenu d'utiliser pour les modules d'atterrissage les mêmes mécanismes de largage depuis l'orbiteur et les mêmes systèmes de télécommunications avec celui-ci, ce qui simplifie considérablement les tâches au niveau de la conception système.*

# ERS

### ERS-2

*Après la mise sous tension de sa charge utile, ERS-2 est entré dans sa phase de recette, au cours de laquelle les caractéristiques de fonctionnement en orbite de la charge utile et de la plate-forme ont été analysées et les instruments du satellite ont été étalonnés et validés.*

*La campagne d'investigations sur le diffusiomètre a été prolongée afin d'obtenir une meilleure caractérisation du problème apparu lors de la mise sous tension. En conséquence, la recette de cet instrument n'a pas encore été prononcée.*

*Les caractéristiques de fonctionnement des instruments d'ERS-2 sont très bonnes et comparables à celles d'ERS-1; tous les paramètres sont dans les limites des spécifications et leur évolution s'inscrit largement en-deçà des seuils fixés.*

*Les activités d'étalonnage et de validation des instruments SAR, RA et MWR ont été menées à bien en septembre, ce qui confirme que ces instruments sont en mesure d'assurer leur mission nominale. La qualité des produits obtenus est la même que pour ERS-1, ce qui facilite à la fois l'exploitation actuelle en tandem et une transition en douceur entre les deux satellites à une date ultérieure.*

*La recette des instruments GOME, ATSR-2 et PRARE de conception nouvelle ou améliorée a été achevée en octobre, les produits obtenus étant de très haut niveau. Ces instruments fonctionnent désormais normalement et les données scientifiques, dont on commence le traitement au sol, devraient être mises à la disposition des utilisateurs à partir du début 1996.*

*Au cours de la phase de recette d'ERS-2, ERS-1 a servi de satellite opérationnel nominal. Il s'est avéré qu'il présente toujours de très bonnes caractéristiques de fonctionnement, de sorte qu'il continuera à assurer le soutien du scénario de mission nominal jusqu'à ce que le problème constaté sur le diffusiomètre d'ERS-2 ait été entièrement résolu.*

*L'exploitation en tandem a déjà commencé avec l'acquisition systématique des flux de données par toutes les stations disponibles.*

*Le secteur sol d'ERS-2 a également passé avec succès ses essais de recette et est opérationnel depuis le mois d'octobre.*

# EOPP

### Programmes futurs

*Au cours de la période considérée, les efforts ont porté principalement sur l'établissement d'un mécanisme et de procédures susceptibles d'être utilisés pour sélectionner les missions d'exploration de la Terre et sur la définition, en parallèle, d'une formule de référence technique pour les neuf missions possibles qui ont été recensées.*

*La proposition relative à la prolongation de l'EOPP de 1996 à 2001 a été révisée à la suite de son examen par les délégations.*

### Campagnes

*Tandis que l'analyse des données des campagnes EMAE et ELITE se poursuit, des préparatifs sont en cours pour deux autres campagnes: INDREX (expérience radar indonésienne) et Chimie de l'atmosphère.*

# Envisat-1/Plate-forme polaire

### Plate-forme polaire

*La plupart des unités ou sous-systèmes du modèle d'identification du module de charge utile sont actuellement soumis aux derniers essais ou ont été livrés en vue de leur intégration au niveau du module. Les unités du modèle de vol du module de* has been delivered to all participants and Review Panels have held preliminary meetings. The formal Critical Design Review Board will be held at ESTEC on 12 October.

## Integral

Within the framework of the industrial Phase-B, the Prime Contractor, Alenia (I), has been progressing with the design concept for the spacecraft.

A configuration that accommodates the four instruments on the Payload Module and allows maximum re-use of the XMM Service Module design has been base-lined. Core features of the instrument design have also been settled, but a number of options will need further trade-offs. Special measures to support the payload development have been initiated by the Project, including the use of instrument data-processing electronic units of common design, parts procurement, and testing in coordinated facilities.

The Draft Arrangement between ESA and RKA concerning the provision of a Proton launcher in return for scientific observation time is under review by the Russian authorities.

## Rosetta

Work has continued on mission and system definition in conjunction with the two industrial groups providing technical assistance to the Agency. The back-up launch options originally included in the mission options have been eliminated and the mission is now baselined for Comet Wirtanen, with a Mars and two Earth gravity assist manoeuvres. The choice of asteroid targets to be visited during the cruise phase is also being revised as the mission scenario is further optimised.

Responses to the Announcement of Opportunity for the scientific payload were received in August from a wide-ranging science community. The current system-design effort is geared towards accommodation of the payload. The selection process for the Orbiter's payload will be completed by the end of the year, in time for a recommendation to be made to the ESA Science Programme Committee in February 1996.

In parallel with the Orbiter payload selection process, the two Surface Science Package (SSP) groups are also going through the same process for the scientific payload for the Landers. This selection process will be completed during the autumn and the two proposals, complete with a recommended payload, are due on 1 December. The two SSPs will then be checked for interface compatibility and included as a part of the overall Rosetta payload selection recommendation.

A meeting was recently held between the two SSP groups, the Project and ESOC to discuss the near-comet navigation and Lander-release philosophies, both of which can have an influence the Orbiter's system design. In principle, it has been agreed to use common Lander-release mechanisms and Lander – Orbiter communications systems, which greatly simplifies the system-design tasks.

## ERS

### ERS-2

Since payload switch-on, ERS-2 has been undergoing its commissioning phase, during which the in-orbit performances of the payload and platform have been analysed and the satellite's instruments have been calibrated and validated.

The Scatterometer investigation campaign has been extended in order to achieve a better characterisation of the problem detected at switch-on. As a consequence, the commissioning of this instrument is still pending.

The performances of ERS-2's instruments are very good and comparable to those of ERS-1; all parameters are within specification and their evolution well within the established thresholds.

The calibration and validation activities for the SAR, RA and MWR instruments were successfully completed in September, confirming these instruments as able to ensure their nominal mission. The quality of the products obtained is the same as for ERS-1, facilitating both the current tandem operations and a smooth transition between satellites at a later date.

The commissioning of the new/enhanced GOME, ATSR-2 and PRARE instruments was completed in October, with product results of a very high level. These instruments are now operating normally and the scientific data is starting to be processed on the ground and is expected to be available to users from the beginning of 1996.

During the ERS-2 Commissioning Phase, ERS-1 has served as the nominal operational satellite, showing still very good performances, and it will continue to support the nominal mission scenario until the Scatterometer problem on ERS-2 can be fully resolved.

The tandem operations have already started with the systematic acquisition of the data streams from all available stations.

The ERS-2 Ground Segment has also been commissioned and is operational from October onwards.

## EOPP

### Future programmes

The major effort during the reporting period has been to elaborate an acceptable mechanism and procedure for the eventual selection of Earth Explorer missions and, in parallel, to identify a technical baseline for the nine possible missions identified.

The proposed further extension of EOPP from 1996 to 2001 has been discussed with the Delegations and subsequently revised.

### Campaigns

While analysis of the EMAE and ELITE campaign data continues, preparations are in hand for two more campaigns: INDREX (Indonesian Radar Experiment), and Atmospheric Chemistry.

## Envisat-1/Polar Platform

### Polar Platform

Most of the Payload Module engineering-model units or subsystems are undergoing final testing or have been delivered for integration at module level. The flight-model units of the Service Module (except for the Solar-Array Drive Mechanism and the Dual Mode S-Band Transponder) have also been delivered.

*servitude ont également été livrées (à l'exception du mécanisme d'entraînement du réseau solaire et du répéteur mode double en bande S).*

*L'intégration du modèle d'identification du compartiment des équipements de charge utile a débuté et l'intégration du module de servitude du prototype de vol va bientôt commencer. La structure du porte-charge utile du prototype de vol est achevée et subit actuellement des essais statiques de qualification chez CASA en Espagne. Les dernières négociations avec le maître d'oeuvre (Matra Marconi Space, B) ont été menées à bien et, le 24 juillet, l'ESA a signé le contrat relatif à la phase principale de réalisation (phase C/D).*

### Charge utile d'Envisat-1

*La négociation des contrats industriels au sein du consortium Envisat est bien avancée et devrait être achevée à la fin de l'année.*

*L'effort principal porte désormais sur la consolidation du calendrier du programme et, sur le plan technique, les activités avancent dans la perspective du programme d'essais des unités du modèle d'identification.*

*Des revues critiques de conception au niveau des unités sont prévues pour le dernier trimestre 1995. La masse prévisionnelle totale de la charge utile continue d'être un sujet de préoccupation et fait l'objet d'une attention soutenue.*

## Métop

*Dans l'attente de la confirmation des recommandations formulées à la réunion de Venise du Groupe de travail du Conseil d'Eumetsat en ce qui concerne la composition de la charge utile de Métop, une phase de transition a été lancée en avril pour que les travaux puissent démarrer sur les points critiques du concept Métop. Les travaux correspondants ont été exécutés par le maître d'oeuvre Matra Marconi Space (F), associé à DASA (D), Matra Marconi Space (B) et Alenia (I).*

*Après confirmation de la charge utile, les activités principales de phase B ont été lancée en juillet 1995 et devraient durer un an.*

*La conception du satellite Métop a quelque peu évolué par rapport à celle qui avait été retenue à l'issue de la phase A avec l'adjonction de certains éléments supplémentaires de charge utile et la présentation d'une proposition de concept novateur de lancement double, dont la faisabilité est en cours d'examen. Selon ce scénario, Métop partagerait un lancement sur Ariane-5 avec un autre satellite, comme Spot-5, qui exige également une orbite héliosynchrone, mais dont les impératifs diffèrent en matière d'heure locale. Parmi les différentes questions à l'étude figure l'aptitude d'Ariane à accomplir le décalage d'heure locale correspondant.*

*Actuellement, les études de conception ont débouché sur une configuration compatible avec toute une gamme d'occasions de vol. Parmi les autres questions étudiées figurent l'évaluation détaillée des matériaux structurels, l'architecture du système de commande et de contrôle et la compatibilité avec les nouvelles normes de télémesure et de télécommande. La revue préliminaire de conception de Métop est prévue en décembre, date à laquelle on connaîtra suffisamment bien le cahier des charges des équipements pour procéder à la sélection des sous-traitants chargés des autres activités de phase B restant à engager.*


The qualification model of the Polar Platform solar array during a recent deployment test at Fokker (NL)

*Le modèle de qualification du réseau solaire de la Plate-forme polaire au cours d'un essai de déploiement récent chez Fokker (NL).*

Integration of the Payload Equipment Bay engineering model has started, and integration of the proto-flight Service Module will commence soon. The structure of the proto-flight payload carrier has been completed and is undergoing qualification static testing at CASA in Spain. Final negotiations with the Prime Contractor Matra Marconi Space (B) have been satisfactorily completed, and ESA signed the main development phase (Phase-C/D) contract on 24 July.

### Envisat-1 payload

The negotiation of the industrial contracts with the Envisat Consortium is well advanced and is expected to be finalised by the end of the year.

A major effort is now being focussed on the consolidation of the programme schedule, while on the technical side work is progressing towards the engineering-model unit test programme.

Critical design reviews at unit level are planned in the last quarter of 1995. The predicted overall payload mass is still a cause for concern and is being closely monitored.

## Metop

Pending confirmation of the recommendations made at the Venice meeting of the Eumetsat Council Task Force regarding the composition of the Metop payload, a bridging phase was initiated in April to allow work to start on critical areas of Metop's design. This bridging-phase work has been performed by Prime Contractor Matra Marconi Space (F) with support from the Co-contractors DASA (D), Matra Marconi Space (B) and Alenia (I).

Following confirmation of the payload, the main Phase-B activities were initiated in July 1995, with a planned duration of one year.

The Metop spacecraft design has evolved somewhat compared with the Phase-A design through the addition of some further payload elements and by a proposed innovative dual-launch concept, the feasibility of which is currently being studied. In this scenario, Metop would share an Ariane-5 launch with a partner, such as Spot-5, which also requires a Sun-synchronous orbit, but with different local hour requirements. Among other issues being studied is Ariane's ability to accomplish the associated local-hour shift.

Currently, the design has progressed to the point where a configuration that is compatible with a range of launch opportunities has been developed. Other topics investigated have included a detailed assessment of structural materials, command and control architecture and compatibility with new telemetry and telecommand standards. The Preliminary Design Review for Metop is foreseen for December, at which point the requirements on equipment will be known to the extent necessary for the selection of subcontractors for the remainder of Phase-B to be commenced.

Meetings of the Potential Participants in the main development phase (Phase-C/D) have taken place throughout this study phase and will continue. ESA and Eumetsat have prepared a joint Programme Proposal for the development of Metop-1 and -2, and the elements of Metop-3 which can be defined today, as well as the requisite ground infrastructure and the overall EPS programme.

A joint meeting of the Eumetsat Council and the Earth Observation Programme Board is foreseen in October to discuss the Metop Programme.

## Meteosat

The operational service is presently being provided by Meteosat-5, with Meteosat-4 and, recently, Meteosat-6 on standby.

Software has been developed and tested by ESOC to compensate for the anomalous behaviour of the Water Vapour and Infrared channels of Meteosat-6, and the commissioning of the spacecraft was declared complete at the end of July. The spacecraft has since been handed over to Eumetsat.

The launch date for the remaining spacecraft being built for Eumetsat by ESA under the Meteosat Transitional Programme has been rescheduled to June 1997. All subsystems except the radiometer and the apogee boost motor have already been delivered to the Prime Contractor, Aerospatiale (F).

### Meteosat Second Generation (MSG)

At its June meeting, the Agency's Industrial Policy Committee (IPC) approved the industrial Phase-C/D Contract Proposal and a kick-off meeting took place at the Prime Contractor, Aerospatiale, in Cannes (F) in July.

A proposal for the procurement of further spacecraft models, MSG-2 and MSG-3, was submitted to Eumetsat in September.

The MSG System Baseline Design Review is planned for October.

## Manned Space Programme

### Columbus Orbital Facility (COF)

The review of the industrial data package for the COF System Requirements and Configuration Review (SRCR) was successfully completed in mid-June with the participation of the NASA ISSA Programme Office. The Prime Contractor was briefed on the latest adaptations of the Executive's Programme proposal, particularly the funding and schedule aspects.

At the Space Station Control Board (SSCB) held in Houston in early June, an updated Assembly Sequence was baselined. Apart from a shift in the launch date for the COF, only detailed refinements not affecting ESA were introduced into the sequence. The launch dates for the Russian Service Module (DMS-R), the Russian Science Power Platform (ERA) and the first flight of the MPLM (ECLS) remained unchanged.

An ESA/NASA Joint Programme Review, co-chaired by the NASA and ESA ISSA Programme Managers took place at ESTEC at the end of June.

### COF enhancements

The Ground Software Reference Facility (GSRF) activities have been proceeding as planned. All hardware for the GSRF has been assembled, and software integration started at the end of August. The overall development effort is on schedule for final completion in December 1995.

### Early Delivery Items

The Columbus Mission Database (MDB) activities have been proceeding as planned with one incremental delivery to NASA/JSC performed in the reporting period; the final delivery is on schedule for December 1995.

Des réunions des participants potentiels à la phase principale de développement (phase C/D) ont été organisées tout au long de cette phase d'étude et se poursuivront. L'ESA et Eumetsat ont préparé une proposition commune de programme portant sur le développement de Métop-1 et 2 et des éléments de Métop-3 qui peuvent être définis aujourd'hui, ainsi que sur l'infrastructure sol nécessaire et sur l'ensemble du programme EPS.

Une réunion conjointe du Conseil d'Eumetsat et du Conseil directeur du programme d'observation de la Terre est prévue en octobre pour examiner le programme Métop.

## Météosat

Le service opérationnel est actuellement assuré par Météosat-5 avec l'aide de Météosat-4 et, depuis peu, celle de Météosat-6 en réserve.

Un logiciel a été mis au point et expérimenté par l'ESOC pour compenser l'anomalie des canaux vapeur d'eau et infrarouge de Météosat-6 et la recette du satellite a été prononcée définitivement fin juillet. Le satellite a été depuis lors transféré à Eumetsat.

La date de lancement du satellite restant, que l'ESA construit actuellement pour le compte d'Eumetsat au titre du programme Météosat de transition, a été reportée à juin 1997. Tous les sous-systèmes, à l'exception du radiomètre et du moteur d'apogée, ont déjà été livrés au maître d'oeuvre, Aérospatiale (F).

### Météosat de deuxième génération (MSG)

A sa réunion de juin, le Comité de la politique industrielle de l'Agence (IPC) a approuvé la proposition de contrat industriel de phase C/D et une réunion de lancement a eu lieu en juillet chez le maître d'oeuvre, Aérospatiale, à Cannes (F).

Une proposition relative à l'approvisionnement d'autres modèles de satellite, MSG-2 et MSG-3, a été soumise à Eumetsat en septembre.

La revue de conception de référence du système MSG est prévue en octobre.

## Programmes spatiaux habités

### Elément orbital Columbus (COF)

L'examen du dossier industriel pour la revue de la configuration et des impératifs du système (SRCR) du COF a été mené à bien à la mi-juin, avec la participation du Bureau de programme ISSA de la NASA. Le maître d'oeuvre a été informé des dernières adaptations apportées à la proposition de programme de l'Exécutif, notamment en matière de financement et de calendrier.

Lors de la réunion de la Commission de contrôle de la Station spatiale (SSCB) qui s'est tenue au début de juin à Houston, une séquence d'assemblage mise à jour a été inscrite dans la base de référence. A l'exception d'un glissement de la date de lancement du COF, seuls des perfectionnements de détail n'affectant pas l'ESA ont été introduits dans cette séquence. Les dates de lancement restent inchangées pour le module de servitude russe (DMS-R), la plate-forme scientifique et d'énergie russe (ERA) et le premier vol du mini-module logistique pressurisé ou MPLM (ECLS).

Une revue de programme commune ESA/NASA, co-présidée par les responsables du programme ISSA de la NASA et de l'ESA, a eu lieu à l'ESTEC à la fin juin.

### Installations complémentaires du COF

Les activités relatives au banc de référence de développement au sol de logiciels (GSRF) ont avancé comme prévu. Tous les équipements destinés au GSRF ont été assemblés et l'intégration du logiciel a démarré à la fin août. L'ensemble du travail de développement respecte le calendrier qui prévoit l'achèvement complet des activités en décembre 1995.

### Eléments à livrer à court terme

Les activités relatives à la base de données mission (MDB) Columbus se sont déroulées conformément aux prévisions, avec exécution d'une livraison au JSC de la NASA durant la période de référence; la dernière livraison va avoir lieu conformément au calendrier en décembre 1995.

Dans le contexte des éléments à livrer à court terme pour l'équipement de soutien de laboratoire et à la suite de l'autorisation d'engager les activités de phase B relatives au congélateur −80 degrés, plusieurs réunions se sont tenues à la NASA avec pour objectif principal la mise au point définitive des interfaces avec le MPLM et un accord sur la documentation officielle de contrôle des interfaces.

Les activités relatives à la boîte à gants pour la recherche en microgravité ont essentiellement porté sur la préparation de la maquette et de la documentation nécessaires à la revue préliminaire par l'équipage, ainsi que sur la préparation du dossier de données en matière de sécurité.

Deux consortiums industriels ont envoyé des propositions au sujet de la conception (phase B) d'Hexapod. La négociation d'un contrat a été menée à bien et l'ESA a donné en juillet le feu vert complet pour les activités de phase B.

### Système principal de gestion des données pour le module de servitude (DMS-R)

Un ensemble actualisé d'impératifs système applicables au DMS-R a été défini et a reçu l'approbation de l'ESA et de l'industrie russe en juillet, avec la pleine participation de l'industrie européenne et de la NASA. Une réponse satisfaisante a été apportée dans le cadre de la conception de référence actuelle au sujet des modifications portant sur les impératifs de fonctionnement, introduites par l'industrie russe pour la capacité de traitement du bus.

### Bras télémanipulateur européen (ERA)

Parallèlement à la négociation contractuelle en cours, les activités ERA se poursuivent aux niveaux système et sous-systèmes. Un certain nombre de spécifications et de normes clés au niveau système ont été définitivement arrêtées et ont reçu l'accord complet du maître d'oeuvre. Les préparatifs des essais de boucle asservie à un degré de liberté sont en cours dans l'industrie, les premiers essais devant démarrer très prochainement.

### Véhicule de transfert automatique (ATV)

Les activités de phase B relatives à l'ATV se sont poursuivies comme prévu; leurs résultats viendront à l'appui de la proposition de programme actualisée relative à la phase de développement de l'ATV. La revue des impératifs système de l'ATV a débuté début septembre afin de geler la base de référence des phases B1 et C/D.

In the context of the Laboratory Support Equipment early-delivery items, following authorisation of the Phase-B activities for the −80 deg freezer several meetings were held at NASA with the main objective of finalising the interfaces with the MPLM and agreeing upon the official Interface Control Documentation.

Activities concerning the Microgravity Glovebox have focused mainly on the preparation of the mock-up and documentation needed for the Preliminary Crew Review, and preparation of the Safety Data Package.

Proposals for the design (Phase-B) of the Hexapod were received from two industrial consortia. A contract was successfully concluded and the full go-ahead for Phase-B activities was given by ESA in July.

**Core Data Management System for the Service Module (DMS-R)**
An updated set of system requirements for DMS-R has been established and was approved by ESA and Russian industry in July, with the full participation of European Industry and NASA. Performance requirements changes introduced by Russian industry on bus throughput performance have been resolved satisfactorily within the present baseline design.

**European Robotic Arm (ERA)**
In parallel with the ongoing contract negotiation, work on the ERA is continuing at system and subsystem level. A number of key system-level specifications and standards have been finalised and fully agreed with the Prime Contractor. Preparations for 'one degree of freedom' servo-loop testing are in progress in industry, with initial tests due to start in the near future.

**Automated Transfer Vehicle (ATV)**
The ATV Phase-B work continued as planned and its results will support the updated programme proposal for the ATV development phase. The ATV System Requirements Review started in early September in order to freeze the baseline for Phases B1 and C/D.

**Atmospherlc Reentry Demonstrator (ARD)**
A splash-down test with an ARD mock-up from low altitude has been successfully completed and the data obtained are under evaluation. A drop test conducted in August with an ARD mock-up from a balloon at an altitude of 30 km failed due to a balloon malfunction. This test, designed to verify the drag and landing behaviour of the capsule cannot be repeated until March 1996 at the earliest. Several work-around options are under investigation, but the overall ARD schedule is compatible with the new launch date for the second Ariane-5 flight.

**Crew-Return Vehicle/Crew Transportation Vehicle (CRV/CTV)**
Two parallel and complementary Phase-A studies for the CRV/CTV were started as planned in July. Provisions have been made to redirect these studies depending on decisions taken at the ESA Council Meeting at Ministerial Level in October.

**Astronaut activities**
A contract has been finalised with the Russian astronaut centre at Star City for the training and certification of the two ESA On-Board Engineers as Return Vehicle Commanders in 1996. They will be the first non-Russian astronauts to receive this certification.

A plan for the running of ESA ground-based facilities in Russia (at ZPK and in ZUP) after the completion of the Euromir-95 mission has been established. This will ensure the reinforcement of the relationships with Star City.

One Training Engineer from the European Astronaut Centre will be temporarily assigned to the NASA Training Division at Johnson Space Center in Houston, for a period of two years. In the meantime, he will provide training support to ESA astronaut Pedro Duque, who is Alternate Payload Specialist for the LMS-1 Mission in 1996.

## Microgravity

The proposal for the continuation of the European Microgravity Research Programme (EMIR-1) has been approved by the Microgravity Programme Board. The Declaration for this continuation, to be known as the EMIR-2 Programme, was opened for subscription on 1 August and will be closed on 31 December 1995.

The proposal for Microgravity Multi-User Facilities on the Space Station, known as the MFC Programme, has been finalised and will be submitted to Delegations as part of the preparatory documentation for the ESA Council Meeting at Ministerial Level, to be held in Toulouse in mid-October.

The Euromir 95 mission began on 3 September with the launch of the ESA astronaut Thomas Reiter on board a Soyuz capsule. The mission, which will last for 4.5 months, includes physiological and materials-science experiments, as well as some radiation measurement studies. A total of twenty-five microgravity experiments will be flown, weighing a total of 350 kg at launch. With the exception of some minor deviations, the mission is proceeding very well and valuable experiment data have already been acquired.

The next Spacelab flight carrying a ESA microgravity payload will be the USML-2 mission, scheduled for launch at the end of September. It will carry the Advanced Glove Box, to used for both fluid-physics and materials-science experiments, and two units of the Advanced Protein Crystallisation Facility (APCF), with which 15 protein-crystallisation experiments will be conducted.

A flight of the largest available sounding rocket yielding 14 min of free-fall conditions is planned in November. This 'Maxus' rocket, which will reach an altitude of approximately 800 km, will carry five fluid-physics and three biological experiments.

Preparations for microgravity experiments to be flown in 1996 are also proceeding well. The flights foreseen are: two flights of Biorack on the Shuttle-to-Mir mission (March and December); the flight of a diffusion experiment on the Space Shuttle (January); participation in the LMS Spacelab mission (June) and in the Russian retrievable unmanned-carrier Foton 11 mission (autumn). In addition, ESA microgravity experiments will be flown on the Swedish 'Maser' and German 'Texus' sounding rockets.

### Démonstrateur de rentrée atmosphérique (ARD)

*Un essai d'amerrissage à basse altitude avec une maquette de l'ARD a été mené à bien; les données obtenues sont en cours d'évaluation. Un essai de largage réalisé en août avec une maquette de l'ARD à une altitude de 30 km à partir d'un aérostat a échoué en raison d'un mauvais fonctionnement de celui-ci. Cet essai, conçu pour vérifier le comportement de la capsule pendant le freinage aérodynamique et l'atterrissage, ne peut être répété avant mars 1996 au plus tôt. Plusieurs options de remplacement sont examinées, mais le calendrier global de l'ARD est compatible avec la nouvelle date de lancement du deuxième tir d'Ariane-5.*

### Véhicule de sauvetage des équipages/Véhicule de transport d'équipages (CRV/CTV)

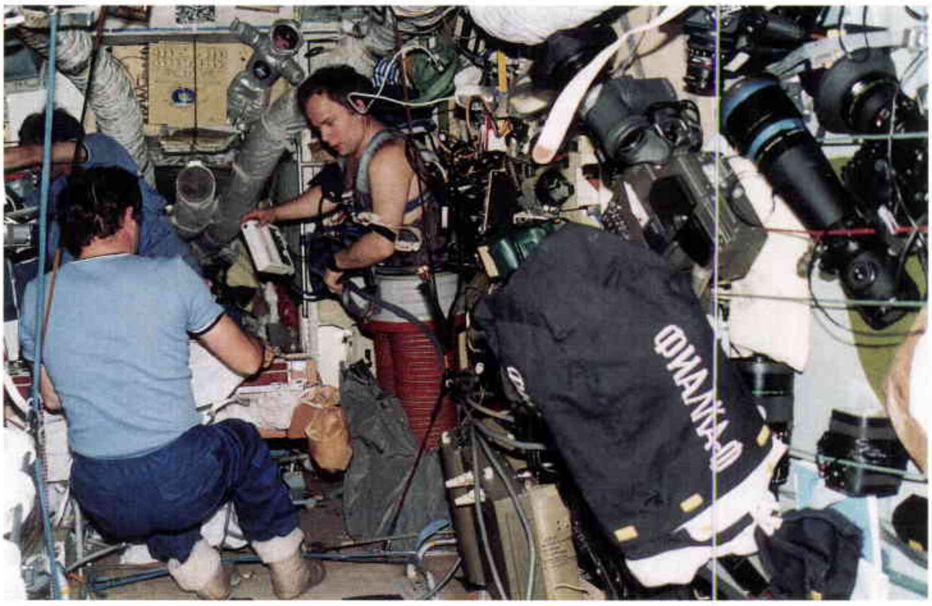
*Deux études de phase A parallèles et complémentaires relatives au CRV/CTV ont démarré en juillet comme prévu. Des dispositions ont été prises pour réorienter ces études en fonction des décisions de la session du Conseil de l'ESA réuni au niveau ministériel en octobre.*

### Activités des astronautes

*Un contrat a été définitivement arrêté avec le Centre russe de formation des astronautes de la Cité des Etoiles en ce qui concerne l'entraînement et la qualification des deux ingénieurs de bord de l'ESA comme commandants du véhicule de retour en 1996. Ils seront ainsi les premiers astronautes non russes à recevoir cette qualification.*

*Un plan relatif au fonctionnement des installations au sol de l'ESA en Russie (à la Cité des Etoiles et au Centre de contrôle en vol) après l'achèvement de la mission Euromir-95 a été mis au point. Ceci permettra de renforcer les relations avec la Cité des Etoiles.*

*Un ingénieur formateur du Centre des astronautes européens sera temporairement affecté à la Training Division de la NASA au Johnson Space Center de Houston, pour une durée de deux années. Entre-temps, il participera à l'entraînement de l'astronaute de l'ESA Pedro Duque, spécialiste de réserve pour la charge utile de la mission LMS-1 en 1996.*



Cosmonauts at work during the Euromir 95 mission (photo: Thomas Reiter, ESA astronaut)

*Les cosmonautes au travail pendant la mission Euromir 95 (photo: Thomas Reiter, astronaute ESA)*

## Microgravité

*La proposition de poursuite du Programme européen de recherche en microgravité (EMIR-1) a été approuvée par le Conseil directeur du programme. La Déclaration relative à la poursuite de ce programme, appelée EMIR-2, a été ouverte à la souscription le 1er août avec une date de clôture fixée au 31 décembre 1995.*

*La proposition relative aux installations à utilisateurs multiples de recherche en microgravité à bord de la Station spatiale, le programme MFC, a été définitivement mise au point et sera soumise aux délégations dans le cadre de la documentation préparatoire de la session du Conseil de l'ESA au niveau ministériel qui doit se tenir à la mi-octobre à Toulouse.*

*La mission Euromir 95 a débuté le 3 septembre avec le départ de l'astronaute de l'ESA, Thomas Reiter, à bord d'une capsule Soyouz. Cette mission, d'une durée de 4,5 mois, comporte des expériences de physiologie et de sciences des matériaux ainsi que certaines études se rapportant à la mesure des rayonnements. Vingt-cinq expériences au total seront embarquées, représentant en tout une masse de 350 kg au lancement. Malgré quelques écarts mineurs par rapport à ce qui avait été prévu, la mission se déroule de manière très satisfaisante et les expériences ont déjà débouché sur des résultats intéressants.*

*La prochaine mission Spacelab emportant une charge utile de microgravité de l'ESA sera la mission USML-2, dont le lancement est prévu à la fin de septembre. Elle emportera un modèle perfectionné de la boîte à gants qui servira à la fois aux expériences de physique des fluides et de sciences de matériaux, ainsi que deux exemplaires de l'installation de cristallisation de protéines de pointe (APCF) qui permettront de réaliser 15 expériences de cristallisation de protéines.*

*En novembre, il est prévu de procéder au lancement de la plus grosse fusée-sonde disponible, qui offre 14 minutes de chute libre. Cette fusée 'Maxus', qui atteindra une altitude d'environ 800 km, emportera cinq expériences de physique des fluides et trois expériences de biologie.*

*Les préparatifs des expériences de microgravité à embarquer en 1996 avancent également comme il convient. Les vols prévus sont les suivants: deux emports du Biorack sur des missions de la Navette vers Mir (mars et décembre); l'emport d'une expérience sur la diffusion à bord de la Navette spatiale (janvier); une participation à la mission Spacelab LMS (juin) et à la mission du porte-instruments automatique récupérable russe Photon 11 (automne). En outre, des expériences de microgravité de l'ESA seront embarquées sur les fusées-sondes 'Maser' de la Suède et 'Texus' de l'Allemagne.*

# In Brief

## Twenty Years of ESA Convention

The Convention establishing the European Space Agency was approved by a Conference of Plenipotentiaries held in Paris on 30 May 1975. The new entity — ESA — thus came into being from the merging of two existing organisations: the European Space Research Organisation (ESRO) and the European Organisation for the Development and Construction of Space Vehicle Launchers (ELDO). On 31 May 1975, the ESA Convention was signed by representatives of 11 European governments.

It was to celebrate this 20th anniversary — and also to prepare for the forthcoming Meeting of the ESA Council at Ministerial Level in Toulouse — that ESA's Executive organised an International Symposium in Munich, Germany, from 4 to 6 September. Hosted on the first day by the European Patent Office (EPO) and on the next two days by the Deutsches Museum, the Symposium gathered some one hundred participants representing different facets of the European space community, ranging from political decision-makers to scientists of international repute and major industrialists. The meeting offered a rare occasion for those pioneers of the European space ventures of the early 1960s to meet with their successors of the late 1990s. Two generations of personalities on the European space scene could thus exchange views on their past experiences and new ideas for getting ESA ready for the next century.


The main issues addressed during the Symposium were:

- The present situation of the European space effort
- Why was a European Space Agency born in the period 1970 – 75?
- The scientific harvest
- Space as a business — The Industry
- The European Space Agency in the wider, global context.

The final Round Table discussions were prefaced by a keynote address on the Long-Term Space Policy Committee (LSPC) report, titled '*Rendezvous with the New Millennium*', which triggered a lively and fruitful debate on the question: 'After 20 years of successes and some failures..., what next?'

Many interesting ideas were exchanged during the debate, of which the following are but a sample:

- ESA has been very successful with its mandatory Scientific Programme. This programme should be protected.
- ESA could do more with its Earth Observation Programme by making it mandatory as well.
- Ambitious missions should be prepared for the future (return to the Moon, for example).
- ESA's tremendous experience in organisation and management is well recognised, but it must be made more widely known.
- There is a need for clarification of roles between ESA and other European entities, such as the European Union.

# Opening Session at the European Patent Office

Edmund Stoiber, Minister-President of Bavaria


From left to right: Harry C. Holloway (Director of Life and Microgravity Sciences, NASA), Kerstin Fredga (Director General of the Swedish National Space Board), Jan-Baldem Mennicken (Director General of DARA), Silvano Casini (Administrator, ASI), and François Fillon (French Minister of Postal and Information Technologies)

Ludwig Baumgarten (left), Ministerial Director, German Federal Ministry for Education and Research


Yvan Ylieff (right), Belgian Minister for Scientific Policy

— The European spirit of the pioneers should be revived.
— Some aspects of the ESA Convention could be updated (e.g. the 'fair-return' rule).
— The future is not something that just happens — we make it happen.

The Proceedings containing all of the papers presented at the Symposium are in preparation (ESA SP-387) and will be available at the end of November from ESA Publications Division.

## Reception in the Kaisersaal of the Munich Residenz

From left to right: George van Reeth (former ESA Director of Administration), Sir Hermann Bondi (former ESRO Director General) and Peter Creola (Swiss Adviser for European Space Cooperation)

David Southwood (Chairman, ESA Science Programme Committee) on left, and Gerhard Haerendel (Director, Max Planck Institute, Garching)

Left to right: The Reception's host, Otto Wiesheu (Bavarian Minister for the Economy, Transportation and Technology), with Karl-Egon Reuter (Head of ESA Cabinet and Chairman of the Symposium Organising Committee) and Jean-Marie Luton (ESA Director General)

# Leaders of Space Agencies From Around the World Meet

The Space Agency Forum (SAF), a group of heads of 35 space agencies and representatives from international space organisations, met in Oslo, Norway, in October to discuss space issues of common interest.

This meeting, the group's third, was held in conjunction with the 46th Congress of the International Astronautical Federation (IAF). It was organised and chaired by ESA. The first two meetings of SAF were hosted by the Italian Space Agency (ASI) in April 1993 and by the Canadian Space Agency (CSA) in November 1993.

A total of 56 participants representing 26 countries attended the Oslo meeting. Bulgaria, Indonesia and Korea were represented at the forum for the first time. The International Space University and the Brazilian Space Agency (AEB) were admitted as new members.

### SAF's role in the future

The debate during the meeting centred on the rationale for SAF and its role in the future. It was agreed that:

- SAF should continue as a useful and valuable forum for the exchange of information and views.
- SAF should mainly be an informal gathering of the space agency heads, which would allow them to discuss freely current issues and challenges of future space activities. Their meeting would be followed by a more open meeting, where other members and observers would be invited to discuss specific topics such as small satellite missions or disaster warning and mitigation.
- SAF meetings will continue to be held in conjunction with the annual IAF Congress. That is because of the cost involved and because it is not realistic to expect that space agency heads would be able to meet twice per year, once for the IAF Congress and once for SAF. Many representatives stressed, however, that SAF should maintain its autonomy.

The organisational aspects related to SAF meetings, such as responsibility for the secretariat, could not be settled definitively. It was felt, however, that some linkage between the host organisation responsible for the IAF Congress and the agency managing the SAF secretariat would be beneficial. That issue will have to be refined in further consultations.

### Space education

The delegates welcomed the basic concept of a SAF Award that would recognise a person or organisation's distinguished contribution to heightening the public's awareness of space activities or to space education. Japan's Science and Technology Agency (STA), the initiator of the idea, was asked to consider assuming the secretariat for the award. Recognising SAF's role in space education, the delegates also decided to revive the Focus Group on Space Education, for which CNES has offered to take the lead.

### Reports from other organisations

Various space-related organisations reported on their activities. The Inter-Agency Consultative Group (IACG) for space science, which groups together ESA, Russia's IKI, ISAS, and NASA, gave an overview of its activities. The IACG was established in 1981 to coordinate the various missions to comet Halley in 1986. Since then, the theme for cooperation has been 'Solar-Terrestrial Science'.

The Committee on Earth Observation Satellites (CEOS) reported on some of its achievements, including the CEOS Yearbook, published in July, which describes all spaceborne Earth-observation missions and their applications. The International Academy of Astronautics (IAA) also announced the completion of a multilingual dictionary, containing 2500 terms in 14 languages, which will also be available on CD-ROM in six months.

### Next meeting

The participants will meet again for SAF 4 during the 1996 IAF Congress which will be held in Beijing.


*Some of the SAF 3 participants. From left to right: K.-U. Schrogl and J.-B. Mennicken (DARA), M.H. Farrow (Australian Space Office), and G. Thomas and D. Leadbeater (British National Space Centre).*

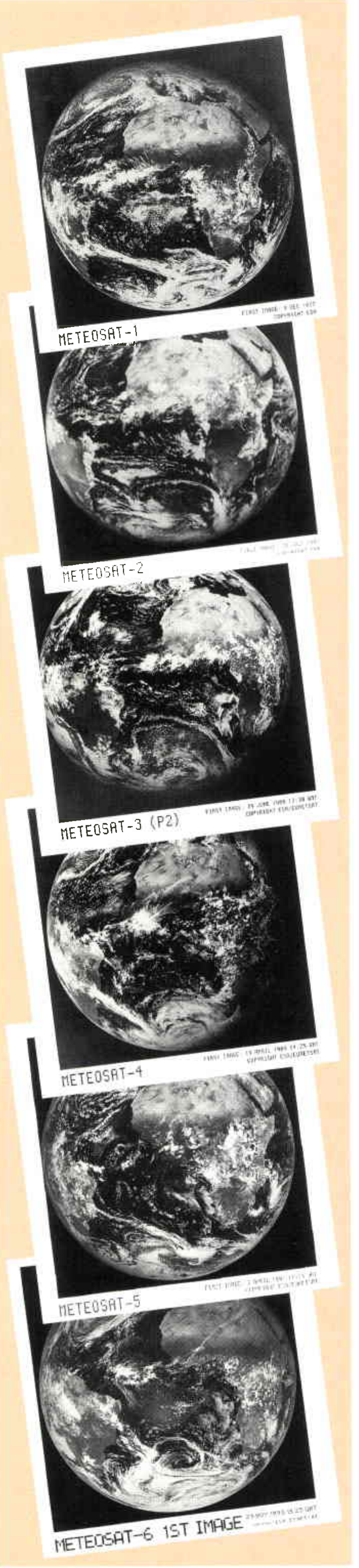
## Météosat est mort! Vive Météosat!

Depuis bientôt deux décennies, les téléspectateurs européens ont l'habitude de voir tous les soirs, sur leur écran de télévision, les images Météosat qui leur annoncent le temps qu'il fera demain. Or le programme Météosat opérationnel de l'Agence spatiale européenne va s'achever ces jours-ci.

Qu'adviendra-t-il ensuite? Serons-nous désormais privés de nos bulletins météo quotidiens?

Qu'on se rassure! Le 30 novembre 1995 verra certes la fin du programme Météosat operationel tel qu'il avait été défini au sein de l'Agence, mais l'exploitation des deux satellites restants se poursuivra, par les soins de l'organisation Eumetsat. Et, tel le phénix, ce programme Météosat, à peine disparu, renaît déjà de ses cendres sous la forme des programmes de transition et de 'seconde génération' qui permettront à la météorologie spatiale européenne d'entrer de plain-pied dans le troisième millénaire.

A l'occasion de la clôture officielle du programme Météosat opérationnel de l'ESA, il convient de rappeler succinctement les principales étapes d'un programme qu'on peut qualifier d'exemplaire et qui, en 18 années de bons et loyaux services, a fourni à l'Europe et au monde — à raison d'un jeu de trois images (infrarouge, visible et vapeur d'eau) toutes les demi-heures — pas loin d'un million d'images du disque terrestre ...




*The first image taken by each satellite in the series, Meteosat-1 through -6*

### Meteosat Programme Milestones

- 1968 — First European Studies on Space Meteorology

**Pre-Operational Programme**

- Dec. 1971 — Adoption by ESRO Council of the Meteosat Pre-operational Programme, with 8 participating countries: B, DK, F, D, I, S, CH, GB.
- 1975 — Memorandum on Meteosat Operations signed by ESA and participating countries (further extended from 1980 to Nov. 1983)
- 23 Nov. 1977 — Launch of Meteosat-1 (de-activated in Oct. 84).
- 19 June 1981 — Launch of Meteosat-2 (de-activated in Dec. 91)
- May 1983 — Creation of Eumetsat, responsible for European space meteorology systems
- 15 June 1988 — Launch of P2 (Meteosat-3, de-activated in Nov. 95)

**Meteosat Operational Programme (MOP)**

- March 1983 — Approval of MOP
- 6 March 1989 — Launch of MOP-1 (Meteosat-4, de-activated in Nov. 95)
- 2 March 1991 — Launch of MOP-2 (Meteosat-5, expected end-of-life in 1997)*
- 20 Nov. 1993 — Launch MOP-3 (Meteosat-6, expected end-of-life in 2001)*
- 30 Nov. 1995 — Formal closing of the MOP

* Eumetsat to take over the exploitation of MOP-2 and MOP-3.

**Meteosat Transition Programme (MTP)**

- Mid-1997 — Launch of MTP (Meteosat-7)

**Meteosat Second Generation (MSG)**

- June 1994 — Programme approved
- 2000 — First launch

## Ariane-5 Launch Schedule Revised

Following a number of disruptions and taking into account the outstanding qualification tests, the schedule leading up to the first flight of Ariane-5, the new Ariane launcher, has been modified: the start of the launch campaign is now planned for early February 1996, with the first demonstration flight (called 501) expected to take place in late April and the 502 flight in September.

The launcher's main cryotechnic system has been undergoing testing in Kourou, French Guiana, for the past year. The tests were to have been completed in the third quarter of 1995 with the qualification of the sub-assembly. Although there have been many positive results, it has not been possible to achieve some of the objectives set and a number of malfunctions have disrupted the tests, mainly as a result of problems encountered with the operation of the ground facilities.

Another incident on 1 September affected the actuator system of the Vulcain cryotechnic engine. An investigation showed that the fault lies in the high-pressure oil distribution system, which was subject to a 'water-hammer effect'. Measures were taken to reinforce the circuit. Repair work on the Vulcain has been completed. Leaks identified in liquid hydrogen and hydrogen pipes on the cryotechnic stage have also been repaired.

An overall verification test without firing was successfully carried out in October to validate the repairs made to the stage and to verify the proper operation of the ground facilities and associated software. That test was followed by a long-duration firing test of the main cryotechnic stage. The test was flawless; the firing duration was 613 seconds.

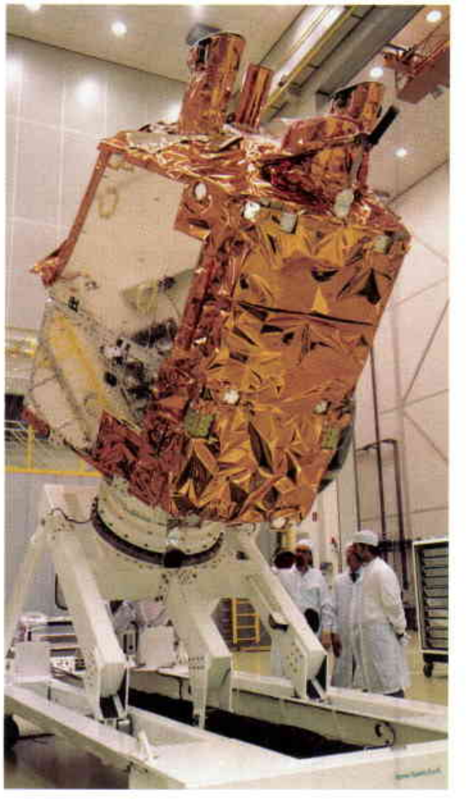
Four further firing tests, leading to the formal qualification of the main cryotechnic stage, are planned. The next one, a night test, is scheduled for 7 November.

## SAX Undergoes Final Tests

The protoflight unit of SAX, the X-ray Astronomy Satellite being built for the Italian space agency ASI arrived at ESTEC's Test Centre in Noordwijk, The Netherlands, in August. It is undergoing its final series of tests before shipment to Cape Canaveral. It is planned to be launched on an Atlas Centaur launcher in April 1996.

The scientific spacecraft will study galactic and extragalactic X-ray sources. It will act as a bridge between the second generation of X-ray satellites, which includes ESA's earlier Exosat, and the third-generation, which includes NASA's Advanced X-ray Astrophysics Facility (AXAF) and ESA's X-ray Multi-Mirror (XMM) missions. SAX has a minimum lifetime of 26 months, but it is expected to be active for two years longer.

This Italian satellite is being developed by ASI in collaboration with NIVR, the Dutch Agency for Aerospace Programmes. The main contractor is Alenia Spazio.



*The protoflight model of SAX, the Italian space agency ASI's X-ray Astronomy Satellite, undergoing final testing in ESTEC's Test Centre, in The Netherlands*

## ISU Students Look at Polar Regions & the Year 2020

The International Space University (ISU) held its eighth summer session this past summer at the Royal Institute of Technology in Stockholm, Sweden. A total of 106 students from 27 countries participated in the intensive 10-week programme. Each year, ESA sponsors a group of young professionals or graduate students to attend. This year, the group included three ESA staff members: Cessi Blacker and Maria Del Mar Lopez from ESTEC, and Johann Oberlechner from ESA headquarters.

### The curriculum

The ISU summer sessions provide participants with a broader knowledge of all aspects of space activity. Lecture topics range from science and engineering to medical, legal and humanitarian issues.

The curriculum has three components: core lectures, which give all students a common base of knowledge of space policies, activities and technologies; specialised lectures, which provide current information on major research issues in a participant's field of study; and design projects, which provide participants with the opportunity to exercise the skills and knowledge acquired at ISU.

### The design projects

Through the design projects, the students gain a better understanding of the complex combination of technical and non-technical issues that influence space activities, particularly when international cooperation is involved. Another aim is to stimulate the space community's interest in the chosen fields. That has been achieved in the past: several previous design projects are now at various stages of implementation.

This year, two design projects were undertaken: 'Vision 2020' and 'Earth's Polar Regions'.

Participants in the 'Vision 2020' project produced a vision of world space activities in the year 2020. A different 'planning' technique was used: the desired future was first defined and then, working backwards in time, the sequence of events needed to reach this future was established. The study looked at four main areas: quality of life, access to space, global cooperation and human expansion into the solar system. The vision that developed focussed strongly on the benefits of space activities to humanity, and may indicate that the new generation of space professionals brings a different outlook to the field of space.

The 'Earth's Polar Regions' project focussed on the observation, protection and use of these important but less used parts of the planet. Solutions to improve measurements of ozone, ice thickness, phytoplankton, and solar-terrestrial interactions ('space weather') using satellites and other space technology were proposed. The potential for shipping in the Northern Sea Route was investigated, and the establishment of an Antarctic observatory was recommended.

**Other activities**
Events outside the scheduled curriculum form an integral part of the ISU experience. The Swedish hosts arranged a field trip to Kiruna, above the Polar Circle, to visit the many Swedish centres for space activities that are located there, including the Esrange launch facilities, the Satellitbild centre for remote sensing, the Swedish Institute for Space Physics, and the ESA ground station facilities.

**Upcoming ISU activities**
ISU will hold its first symposium on 5 – 7 February 1996 in Strasbourg. The theme will be 'Space of Service to Humanity: Preserving Earth and Improving Life'. Successful space programmes that contribute to satisfying one or more basic human needs will be examined. The meeting is co-sponsored by the Committee on Earth Observation Satellites (CEOS), the IEEE, and the United Nations Office for Outer Space Affairs.

The next ISU summer session will be held in Vienna during the summer of 1996.

For more information on ISU activities, contact:
International Space University
Parc d'Innovation
Boulevard Gonthier d'Andernach
67400 Illkirch
France

Tel: (31) 88.65.54.30

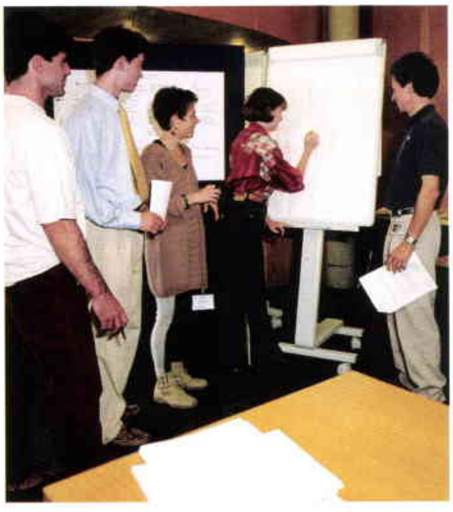
*Participants in this summer's ISU session in Stockholm*

## Students 'Plan' Mission to the Moon

Thirty undergraduate students from all over Europe gathered recently at a workshop organised by Euroavia, the European Association of Aerospace Students, and ESA's ESTEC. During the intensive 2½-week meeting, the students undertook a feasibility study for a fictional lunar satellite.

'Working together on an international level requires tolerance and mutual understanding', stated Euroavia's Aron Lentsch, 'those are skills that can be learned — especially as a student'.

This was thus the purpose of the workshop. It reflects Euroavia's major objective: to look beyond corporate and national interests and provide a forum for international exchange and educational opportunities that cannot be found at universities.



Although the technical solution proposed at the end of the workshop was interesting, the students' approach to the project was also notable — the students successfully put into practice some aspects of a new and promising organisational concept known as the 'virtual company'. Using this method, a team of system engineers from different organisations is assembled for a limited period to define a project. Each engineer represents a separate interest and is supported by specialists at their home site through electronic means — computer networks, telephone and fax. The students also each represented a specific system and were able to draw upon the knowledge and experience of ESTEC staff, members of the European space industry and former workshop participants.

**Eleven countries represented**
The workshop participants had been selected through a competition based on an essay that each one had submitted on the space-related topic of their choice. The judges were representatives from industry, universities and ESTEC. The participants came from 11 countries including many European countries as well as Hungary, Romania and Israel.

*Students at work during the recent Euroavia workshop*

**A satellite to support the LEDA mission**
The students were given their task, to prepare a mission proposal for a small satellite that would support the LEDA (Lunar European Demonstration Approach) mission, ESA's study of a lunar mission to the South Pole of the Moon in the 2001 – 2002 timeframe (described in ESA Bulletin No. 82, May 1995). The satellite should render the LEDA mission more beneficial and reliable, with the only additional cost being that of a small satellite mission. The satellite should have two functions: to assist in finding a suitable landing site for LEDA before the LEDA launch, and to provide a communications-relay function that the LEDA rover could use when it is out of sight of the ground stations and of the rover.

Given that task, the students were then left to structure themselves and their time as they wished in order to complete the work. They found the cooperation offered by the space professionals particularly beneficial, and the process of making trade-offs between the sub-systems of the satellite to achieve the common aims of the mission, difficult but educational.

**Fourth Euroavia workshop organised**
This is the fourth such workshop that Euroavia has organised. It was co-sponsored by ESA and the Commission of the European Union, with contributions from aerospace companies.

Euroavia was founded in the late 1950s and today includes 22 local groups, with a total of about 1000 members spread over many European countries. It is involved in a number of educational and cultural activities and publishes a quarterly newsletter, Euroavia News.
For more information about Euroavia, contact:

Aron Lentsch (Euroavia)
E-mail: alentsch@ecx.tuwien.ac.at

Dieter Kassing (ESA/ESTEC)
E-mail: dkassing@estec.esa.nl

## EuroMir Mission Extended

ESA astronaut, Thomas Reiter, soon to become the non-Russian astronaut to have spent the longest time in space (135 days), will be staying even longer. ESA and RSC Energia have agreed to prolong the EuroMir 95 mission, which is currently underway with the ESA astronaut on board, by 45 days. Reiter will now return on 29 February 1996. The extension will allow RSC Energia to make full use of the six-month lifetime of its transport vehicle, the Soyuz TM, rather than sending it after 4.5 months as the EuroMir mission called for, while ESA will be able to carry out additional scientific research. Thomas Reiter and one of his fellow Russian astronauts, will also make a second spacewalk during the mission extension.

The mission extension had been discussed with the crew before the launch. The astronauts reacted positively when they received the confirmation.

The crew is now preparing to receive house guests: the five-man crew of the Space Shuttle Atlantis is due to dock with Mir in mid-November. It will be the first contact that the Mir crew has had with others since they bade farewell to the previous Mir crew on 11 September.

The two crews will work together for three days. This will be a preview of the new space station era: for the first time, American, Canadian (one of the Atlantis crew members is a Canadian), European and Russian astronauts will be working together aboard the same spacecraft. They represent the partners which, along with Japan, are building the International Space Station.

The main goal of the Shuttle docking is to attach a special adapter for docking with Mir's Kristall module, which will be used by all visiting Shuttles in the future. The astronauts will also be bringing fresh food for the Mir crew — including steak, vegetables and even ice cream — and will be returning to Earth with 20 kilos of EuroMir experiment results.

RSC Energia has agreed to provide an additional 'upload' of consumables that are required to allow ESA's scientific programme to continue during the mission extension. They will be carried aboard a Progress M cargo vehicle scheduled to be launched in mid-December.

## First ESA Astronaut Walk in Space

"Greetings from 400 km above the Earth ... The view is magnificent ...."

Those were the words of ESA astronaut Thomas Reiter as he began his first Extra Vehicular Activity (EVA) or 'spacewalk' on 20 October. Although it is not a first for Europe, it was the first EVA made by an ESA astronaut (a French astronaut took the first European spacewalk outside Mir in 1988).

During the six-hour session, Thomas Reiter and Russian cosmonaut Sergei Avdeev successfully installed experiments in the European Science Exposure Facility, the astrophysics and space environment payload mounted on the exterior of the Spektr module, and changed cartridges on a nearby Russian experiment.

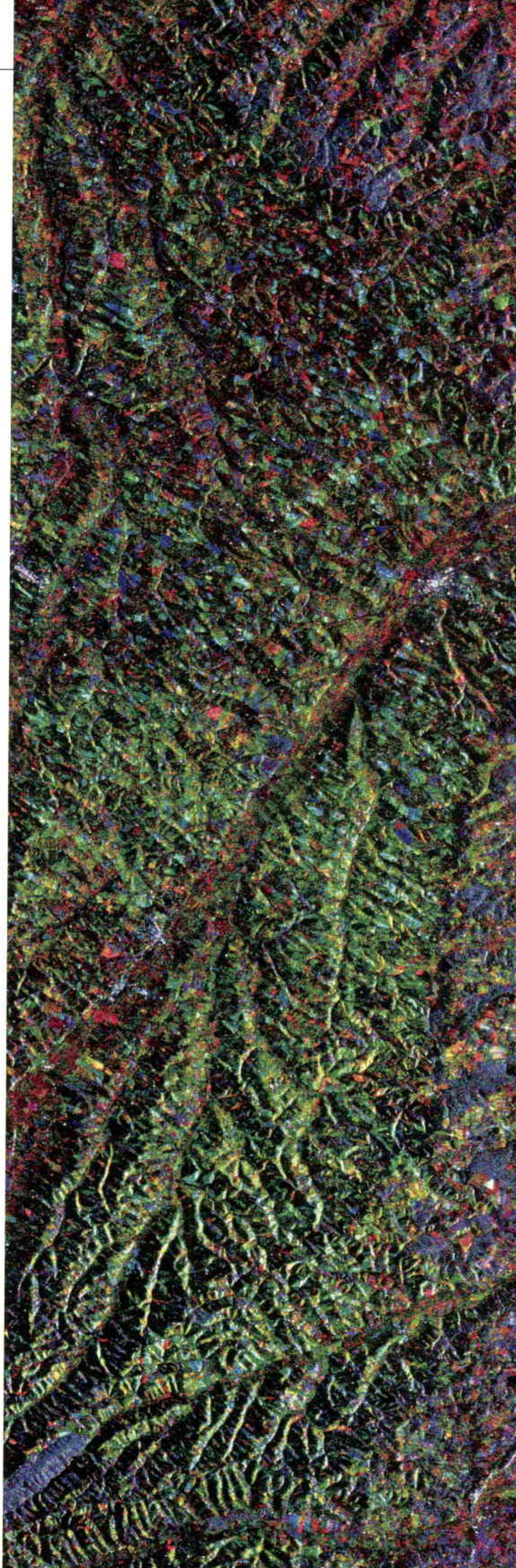
A second EVA is now scheduled for the beginning of February.

*The EuroMir crew going onboard. Thomas Reiter is second from bottom*

# Focus Earth

## Toulouse and Its Surroundings

**J. Lichtenegger & G. Calabresi**
*ERS Data Utilisation Section, ESRIN, Frascati, Italy*



This multi-temporal Synthetic Aperture Radar (SAR) image of Toulouse, in southwest France, is a composite of three separate ERS images:

- an ERS-1 image taken on 15 January 1993, displayed in red
- an ERS-1 image taken on 28 May 1995, displayed in blue, and
- an ERS-2 image taken on 7 August 1995, displayed in green.

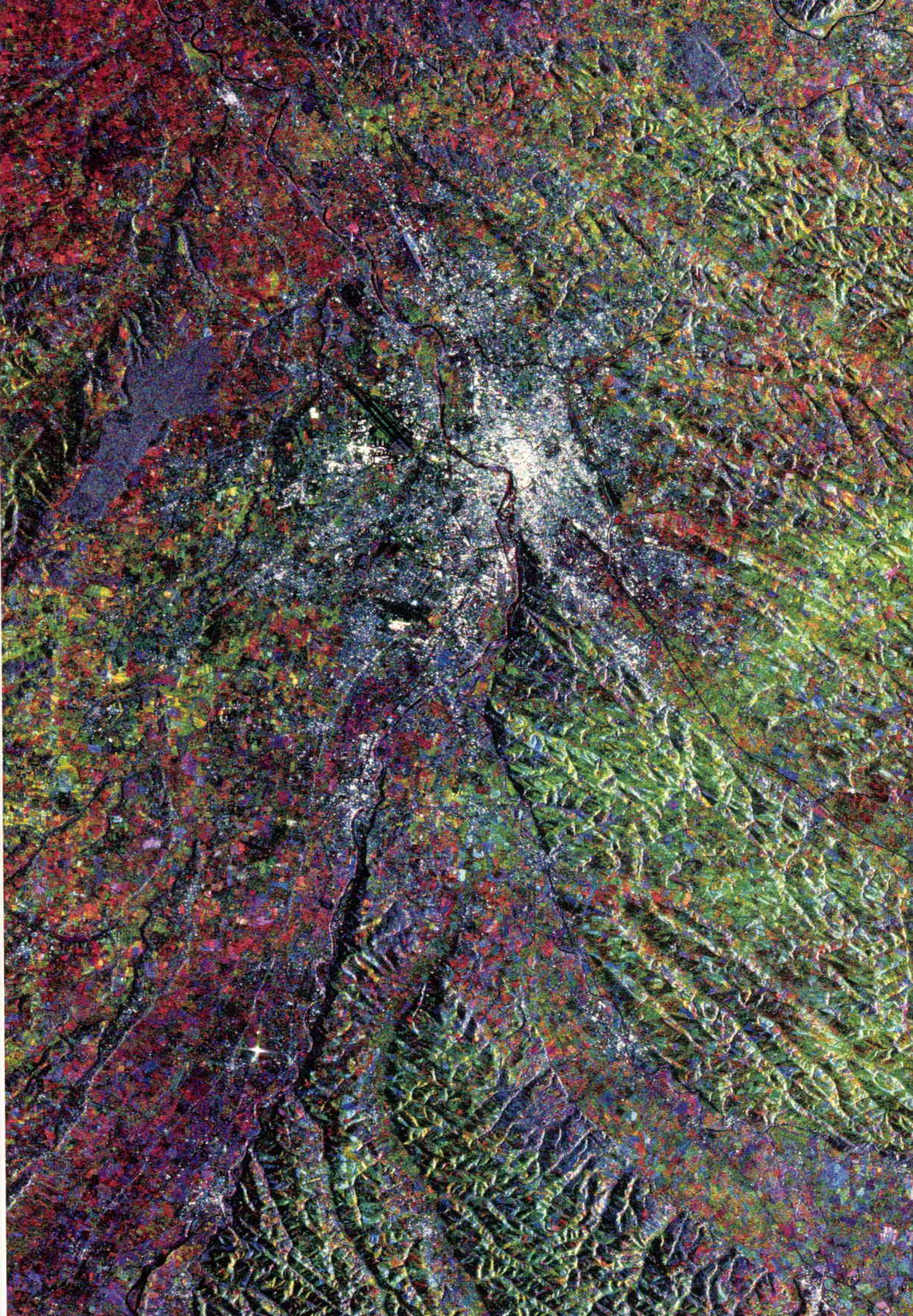
The scene covers an area of 70 km by 70 km. Near its centre is an agglomeration of bright spots, increasing in density towards the centre; they are representative of the city of Toulouse's degree of urbanisation.

ERS SAR imagery has proved to be very useful also for geomorphological mapping, with morphology being far better delineated than in images derived from traditional vertically observing optical sensors. The courses of the large valleys, which indicate a gentle gradient with meandering rivers, are clearly apparent. Surprisingly, the valley fringes are often marked by subtle but quite visible bright lines. They indicate some 5 – 20 m high steps in an otherwise flat landscape. To the west of the Garonne River, up to three such parallel bright lines can be observed, which mark the limits of alluvial terraces belonging to old, no longer active fluvial plains.

The landscape between the main valleys is gently undulating, rarely exceeding 400 m in elevation. Man-made structures – mainly buildings – appear as bright points, forming bright patches in the case of villages and towns. Industrial complexes in and around Toulouse itself are identified by larger bright spots, e.g. just south of the city centre, along the northern access and the 'Ateliers Aéronautiques', just south of the main Toulouse-Blagnac airport.

To the west of Toulouse, the forest of Bouconne appears in darker grey. The bright spot near the top centre is Grenade, whilst in the Save Valley, west of Toulouse, the town of L'Isle Jourdain is visible.

The colours in the image reflect changes in the structure (vegetation, etc.) or humidity of the ground. The uniform green aspect throughout can be explained by a day of rainy weather preceding the data acquisition of 7 August 1995. Wet vegetation and soil cause a higher return signal than on the other dates. The reddish colour is contributed by the January acquisition. Since the valleys are more affected by higher backscatter, it might be interesting to study the occurrence of local frost. The light blue (cyan) fields indicate a densely grown crop on both the May and August 1995 imaging dates, such as sunflowers, corn and another late crop.



# Publications

The documents listed here have been issued since the last publications announcement in the ESA Bulletin. Requests for copies should be made in accordance with the Table and Order Form at the back of this issue.

## ESA Special Publications

**Proceedings of the 12th ESA Symposium on European Rocket and Balloon Programmes and Related Research**
29 May – 1 June 1995, Lillehammer, Norway
*(Ed. B. Kaldeich-Schürmann)*
ESA SP-370, 100 DFL

**Proceedings of the AIAA/ESA Workshop on International Cooperation in Satellite Communications**
27 – 29 March 1995, ESTEC, Noordwijk, The Netherlands
*(Ed. W. Brandon & C. Mattok)*
ESA SP-372, 80 DFL

**Proceedings of the Sixth European Space Mechanisms & Tribology Symposium**
4 – 6 October 1995, Zurich, Switzerland
*(Ed. B. Burke)*
ESA SP-374, 100 DFL

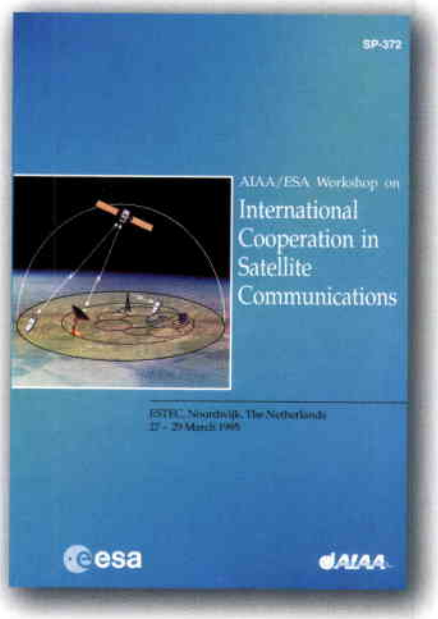
**Proceedings of the Fourth SOHO Workshop — Helioseismology (Vol. 1 & 2)**
2 – 6 April 1995, Pacific Grove, California, USA
*(Ed. B. Battrick)*
ESA SP-376, 100 DFL for two volumes

**Proceedings of the Future Possibilities for Astrometry in Space Workshop**
19 – 21 June 1995, Cambridge, UK
*(Ed. T.-D. Guyenne)*
ESA SP-379, 80 DFL

**SAR Ocean Feature Catalogue**
*J.A. Johannessen et al (Ed. W.R. Burke)*
SP-1174, 50 DFL

**Global Ozone Monitoring Experiment (GOME) User Manual**
*(Ed. F. Bednarz)*
SP-1182, 60 DFL

**Satellite Radar in Agriculture — Experience with ERS-1**
*(Ed. T.-D. Guyenne)*
SP-1185, 70 DFL




**Rendezvous with the New Millennium — The Report of ESA's Long-Term Space Policy Committee**
(available in English, French and German)
*(Ed. B. Battrick)*
ESA SP-1187, 35 DFL

**IUE – ULDA Access Guide No. 6: International Ultraviolet Explorer — Uniform Low Dispersion Archive, Supernovae**
*E. Cappellaro, M. Turatto & J. Fernley*
*(Ed. W.R. Burke)*
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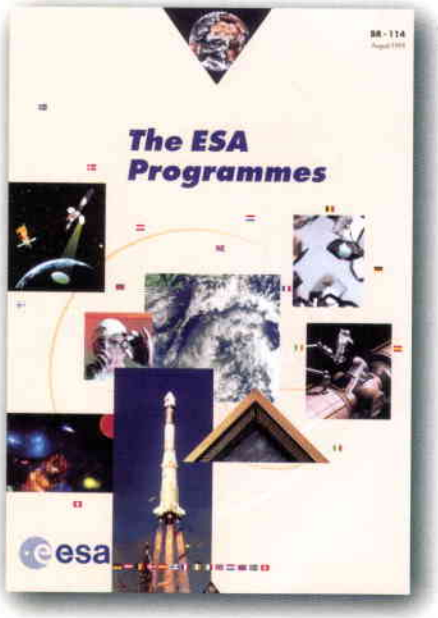



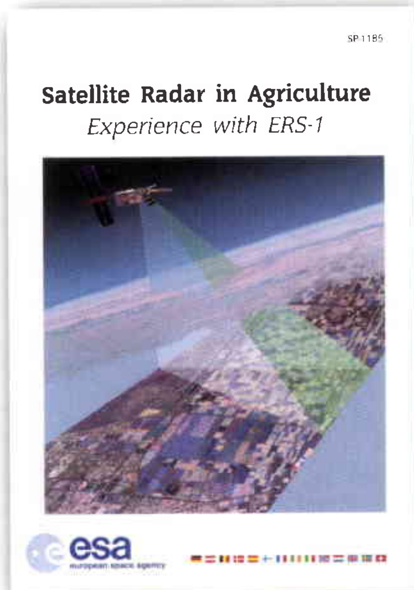


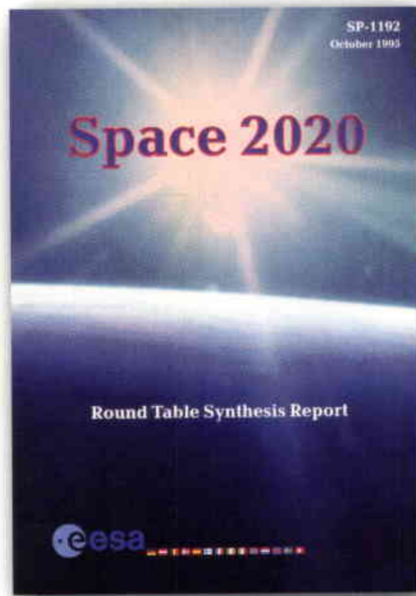


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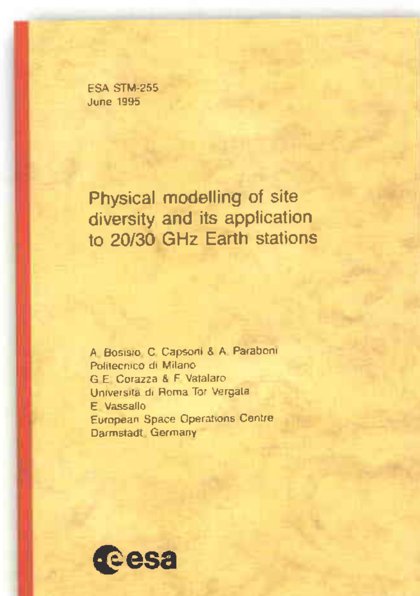

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