esa bulletin
number 107 - august 2001

European Space Agency
Agence spatiale européenne

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, the Netherlands, Norway, Portugal, 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:

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

ESRIN, Frascati, Italy.

Chairman of the Council: A. Bensoussan

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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 Portugal, le Royaumi-Uni, la Suède et la Suisse. Le Canada bénéficie d'un statut d'Etat coopérant.

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(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.

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ESRIN, Frascati, Italy

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Directeur général: A. Rodotà

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Editorial/Circulation Office
ESA Publications Division
ESTEC, PO Box 299, Noordwijk
2200 AG The Netherlands
Tel.: (31) 71.5653400

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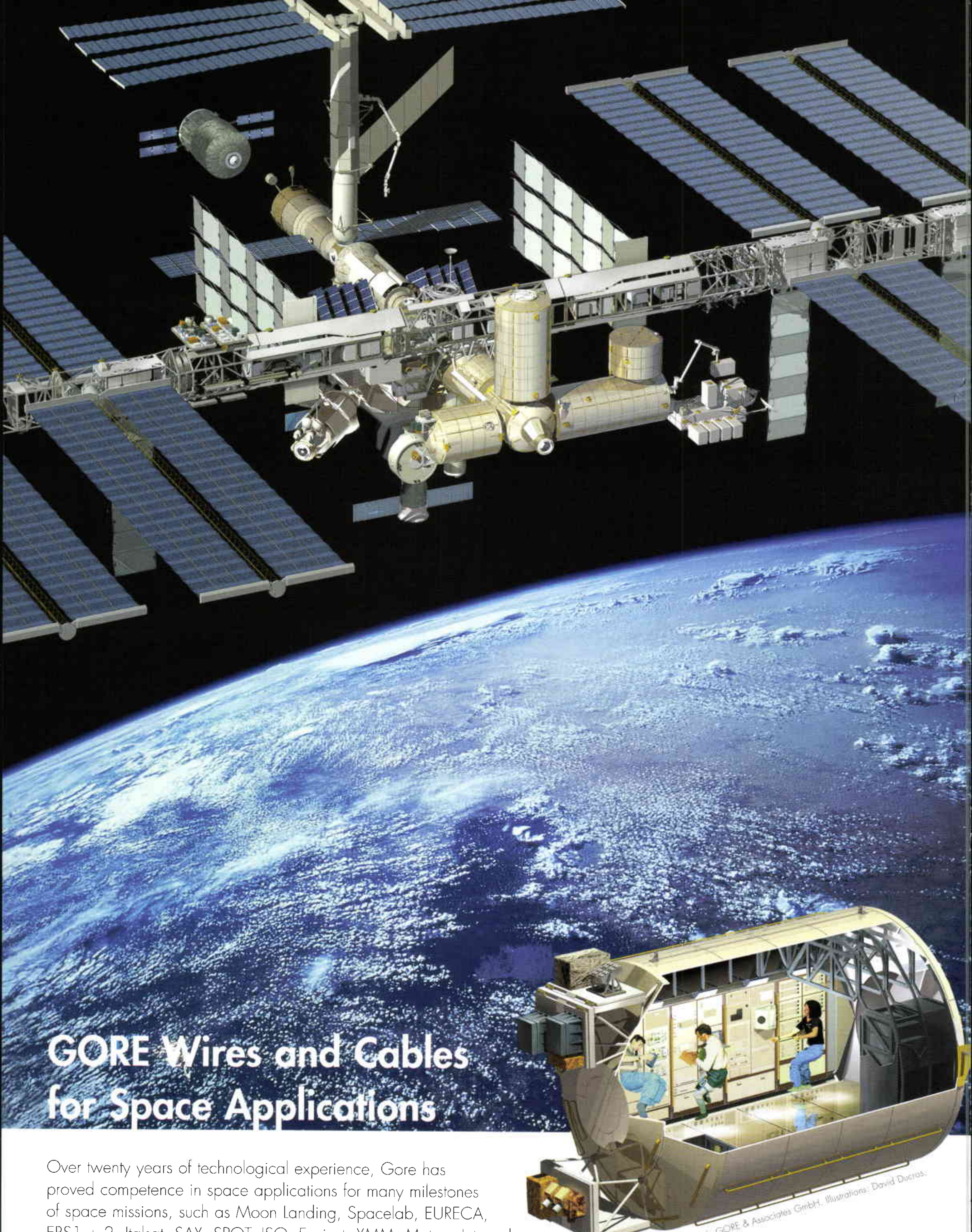
Printed in the Netherlands ISSN 0376-4265

European Space Agency
Agence spatiale européenne



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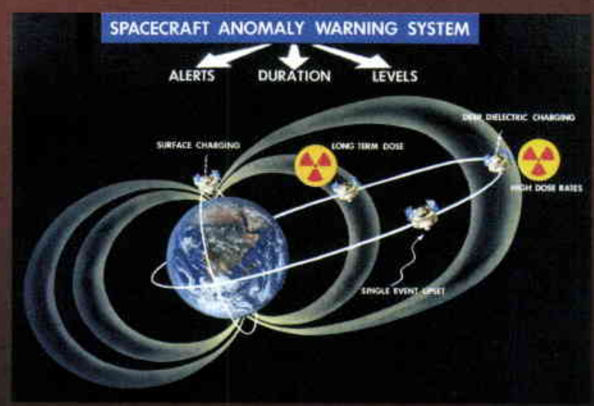

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Figure 1. Launch of the first ISS element (Zarya) by Proton on 20 November 1998.

Figure 2. Launch of the second ISS element (Unity) by the Space Shuttle on 4 December 1998. (NASA)

Figure 3. Launch of the first crew of three astronauts (Expedition-1) by Soyuz on 31 October 2000.

Figure 4. Umberto Guidoni: the first ESA astronaut aboard the ISS, in April 2001. (NASA)

Figure 5. Appearance of the ISS by the end of June 2001. (NASA)

The International Space Station is Real !

J. Feustel-Büechl
ESA Director of Manned Spaceflight and Microgravity,
ESTEC, Noordwijk, The Netherlands

It has taken a huge effort to bring the International Space Station (ISS) programme together. Many years of ups and downs, changes in partnerships, redesigns and other impacts have influenced the programme. But, finally, with the signature of the Intergovernmental Agreement on 29 January 1998 by 15 countries and the associated Memoranda of Understanding on the same day by the five Partner space agencies, the legal foundations were established. This article describes the achievements so far, and ESA's plans for the future.

ISS assembly status and outlook

The International Space Station (ISS) has made enormous progress in the past year (Figs. 1-5) and is a reality in orbit. Despite the challenges faced by such a global programme, it is now providing operational experience and – first and foremost – it is permitting the permanent crew of three astronauts to perform its first experiments in orbit. We have taken the first real step in ISS operations and utilisation.

As of end-July 2001, 18 launches have been performed (Table 1). The Expedition-1 first Station crew boarded in November 2000, opening the door even at this early stage to operations and the first experiments.

Table 1. ISS launches performed up to mid-July 2001.

Flight Nr.	Launch/Return Date	Element/Task	Vehicle
1: 1A/R	20 Nov 98	Zarya (FGB)	Proton
2: 2A	4/15 Dec 98	Unity (Node-1)	Shuttle STS-88
3: 2A1	27 May/3 Jun 98	Logistics	Shuttle STS-96
4: 2A.2A	19/29 May 00	Logistics/ Reboost	Shuttle STS-101
5: 1R	12 Jul 00	Zvezda (Service Module)	Proton
6: 1P	6 Aug 00	Logistics (Progress-M1)	Soyuz
7: 2A.2B	8/20 Sept 00	Logistics (Outfitting)	Shuttle STS-106
8: 3A	11/24 Oct 00	Z1 Truss	Shuttle STS-92
9: 2R	31 Oct 00/21 Mar 01	Expedition-1 Crew/Rescue	Soyuz
10: 2P	16 Nov 00	Logistics (Progress-M1)	Soyuz
11: 4A	30 Nov/11 Dec 00	P6 Truss/solar arrays	Shuttle STS-97
12: 5A	7/20 Feb 00	Destiny (US Lab)	Shuttle STS-98
13: 3P	26 Feb 01	Logistics (Progress-M)	Soyuz
14: 5A.1	8/21 Mar 01	Expedition-2 Crew/1st MPLM	Shuttle STS-102
15: 4P	12 Apr 01	Logistics (Progress-M1)	Soyuz
16: 6A	19 Apr/1 May 01	2nd MPLM/Canadarm2	Shuttle STS-100
17: 2S	28 Apr/Oct 01	Taxi Flight	Soyuz
18: 7A	12/25 Jul 01	Quest Airlock	Shuttle STS-104

Table 2. ISS launches planned to end-2001.

Flight Nr.	Planned Launch	Element/Task	Vehicle
19: 5P	Jul 01	Logistics (Progress-M)	Soyuz
20: 7A.1	mid-Aug 01	3rd MPLM/Logistics	Shuttle STS-105
21: 4R	Aug 01	Docking Compartment	Proton
22: 6P	Sep 01	Logistics (Progress-M1)	Soyuz
23: 3S	Oct 01	Taxi Flight	Soyuz
24: UF1	Nov 01	Expedition-3 Crew/4th MPLM	Shuttle STS-108
25: 7P	Dec 01	Logistics (Progress-M1)	Soyuz

The assembly steps planned for the rest of this year (Table 2) will considerably enhance the Station. Further outfitting of the laboratories already in orbit will allow a wider utilisation of the ISS to begin. The overall assembly schedule of more than 50 launches is expected to be completed around 2005. At that stage, the Station will have a mass of about 450 t, an overall size of 120 m by 75 m and an operational crew of 6 to 7 astronauts (Fig. 6).

The ESA contributions to the orbital complex

Ten European countries (Germany, France, Italy, Belgium, Denmark, The Netherlands, Norway, Sweden, Spain and Switzerland) contribute through ESA as a Partner Agency to the development and exploitation of the ISS. The European contribution (Fig. 7) amounts to about 3.5 billion Euros and corresponds to 8.3% in utilisation rights of the western part of the Station. Europe's contribution centres around two core elements: the Columbus laboratory (including its outfitting) and the Automated Transfer Vehicle (ATV).

While Columbus (Fig. 8) is our principal contribution to the ISS in-orbit configuration, the ATV (Fig. 9) launched by Ariane-5 will be used to service the Station during its operational phase. ESA is also making a considerable number of smaller, but still important contributions, including Nodes-2 and -3, the Cupola, the Data Management System of the Russian Segment, the European Robotic Arm (ERA), the early-delivery items (Material Science Glovebox, Hexapod, MELFI Minus

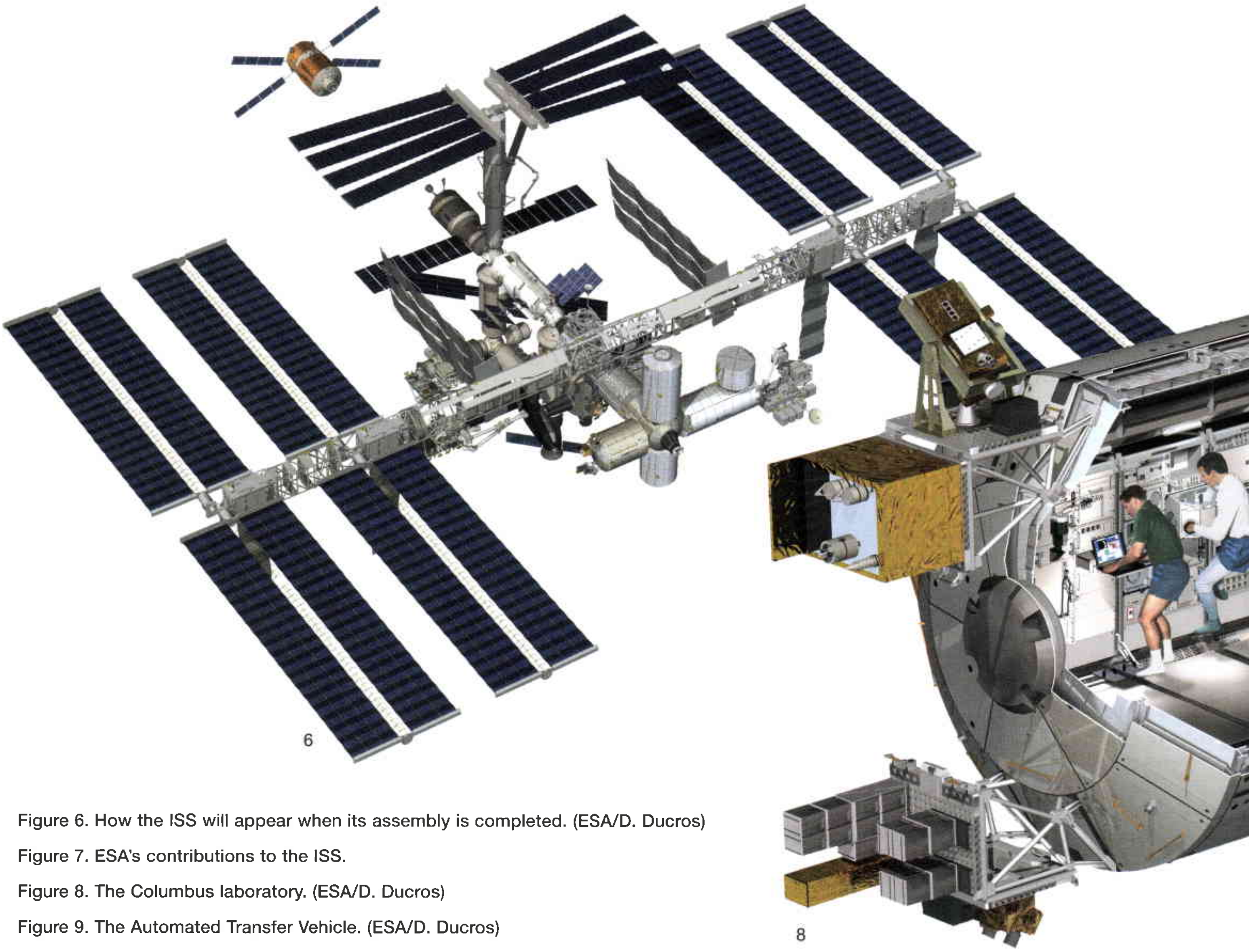

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Figure 6. How the ISS will appear when its assembly is completed. (ESA/D. Ducros)

Figure 7. ESA's contributions to the ISS.

Figure 8. The Columbus laboratory. (ESA/D. Ducros)

Figure 9. The Automated Transfer Vehicle. (ESA/D. Ducros)

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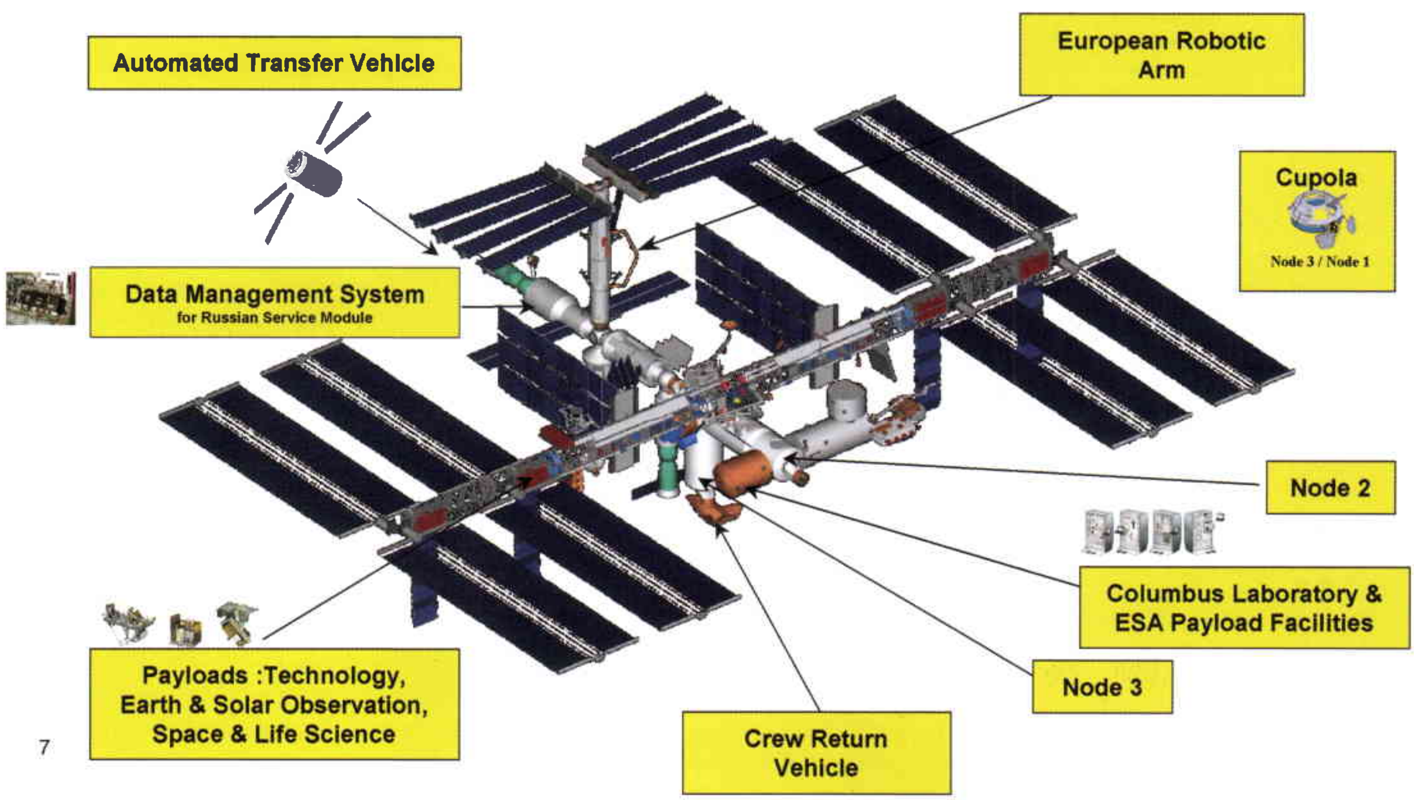

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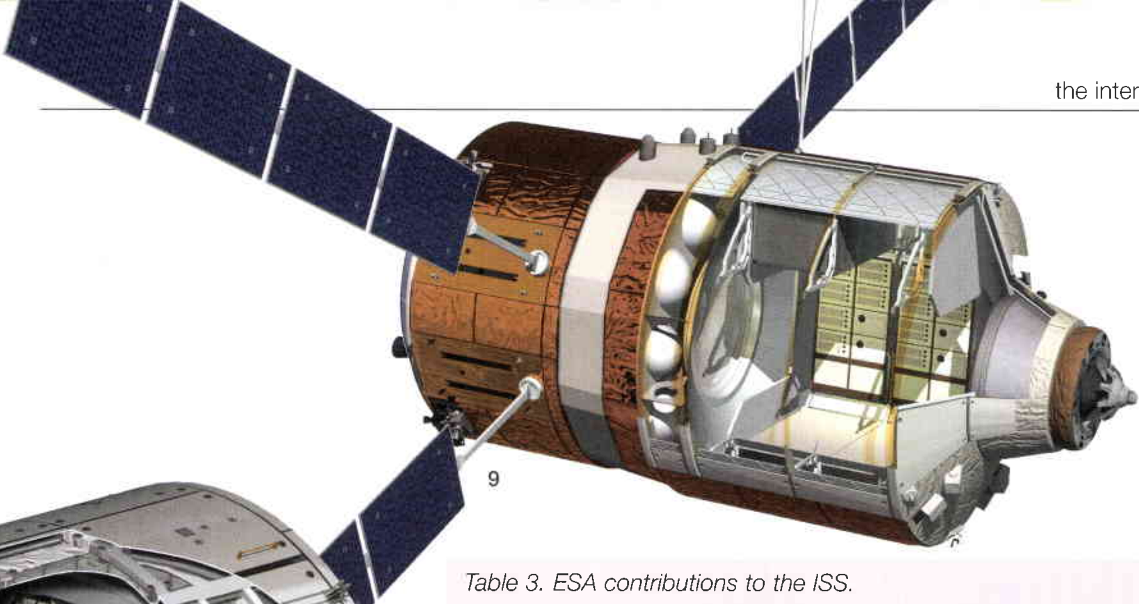

Eighty-degree Freezer), the Cryo-Freezer and Crew Refrigerator Freezer and participation in the Crew Return Vehicle (CRV) and its X-38 orbital test vehicle. Many of these additional contributions are barter items, aimed at achieving either early utilisation or other goods and services received from our partners as compensation on a no-exchange-of-funds basis. Together (Table 3; Figs. 10–20), these deliveries give Europe an important role – about 40% of all launches to the Station involve European-developed hardware.

Status of the ESA contributions

Some of the European deliveries, such as the Data Management System (DMS-R) of the Russian Segment or the Mission Data Base, have already been completed and delivered and are operational in orbit or on the ground. Most of the other European contributions are in an advanced state, and some are close to delivery. Columbus and ATV both recently passed important design steps. Columbus successfully completed its Critical Design Review (CDR) in January

Table 3. ESA contributions to the ISS.

Element / Task	Application	Delivery / Launch Date
Columbus module	Module for life and physical sciences experiments and commercial application, with external accommodation for astronomy, Earth observation and technology	Delivery to Kennedy Space Center: Mar 2004 Launch : Oct 2004/1E
Automated Transfer Vehicle	Logistics vehicle, for upload of payloads, system spares, fuel and fluids to ISS. Capability for ISS orbit reboost. Launched on Ariane-5, ATV will automatically rendezvous and dock with the Russian Segment. Performs destructive reentry with ISS waste products	Delivery to Kourou: May 2004 First launch: Sep 2004
Columbus Control Centre	Operation of Columbus module, acquisition and distribution of data	End-2003
ATV Control Centre	Operation of ATV	Aug 2003
ERA	Support assembly and external maintenance tasks on Russian Segment	2005/2006 (TBC)
DMS-R	Guidance, navigation and control of Russian Segment	12 Jul 2000
Nodes-2 & -3	Interconnecting modules with 6 docking ports (4 radial, 2 axial) and 8 equipment/stowage/system racks	Node-2: Feb 2004 Node-3: Jul 2005
Cupola	Observation module for crew viewing of ISS robotic arm, visiting vehicles and Earth observations. Houses ISS Robotic Work Station, to control Canadarm2	Jan 2005/2006
MPLM/ECLS	Pressure, temperature, humidity and ventilation control of the three ASI MPLM logistics modules	All hardware delivered by 2000, Launch: first two MPLMs 2001
ARD exploitation	Evaluation of the flight data of the Atmospheric Reentry Demonstrator (ARD) vehicle	Launched on Ariane-503 21 Oct 1998
ART/X-38	European elements of X-38 prototype of the ISS Crew Return Vehicle, covering several mechanical items (including hot structures, landing gear, etc) aerodynamics, parafoil GNC, etc	Hardware delivery 2002 Launch: orbital flight scheduled in spring 2003
Crew Return Vehicle	Fleet of 3-4 lifeboat / rescue vehicles for the 7-man ISS crew in the event of crew illness or Station emergency evacuation	First operational CRV 2006/7
Mission Data Base	Central engineering and operations data base	
Cryo-Freezer	Biolab sample storage	2005 / UF-6
Crew Refrigerator Freezer	Food transfer and storage	2004/on each MPLM in 2005
MELFI	Biolab sample storage	2004 / UF-3
Microgravity Science Glovebox	Small experiments	2002 / UF-2
Hexapod	Instrument pointing	2005 / UF-4
Biolab	Biotechnology experiments	2004 / 1E
Fluid Science Laboratory	Fluid dynamics experiments	2004 / 1E
European Physiology Modules	Human medical research	2004 / 1E
Material Science Laboratory	Material processing	2002 / UF-3
European Modular Cultivation System	Botanical experiments	2004 / UF-3
Protein Crystallisation Diagnostics Facility	Quick turnaround experiments	2004 / 1E

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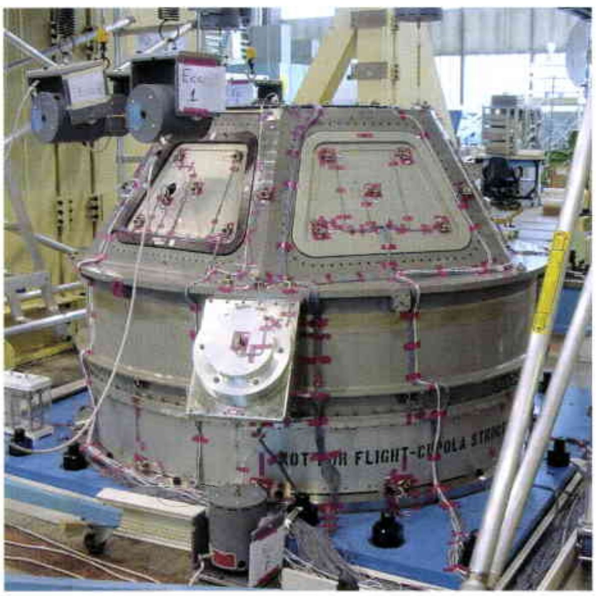

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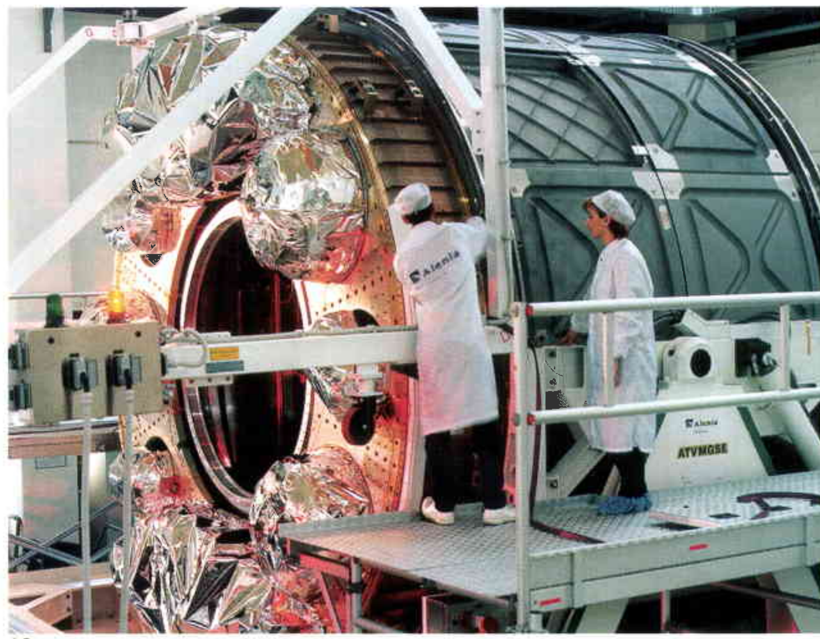

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Figure 10. The Columbus flight unit awaits final integration.

Figure 11. The completed Node-2 structure at Alenia Spazio, Turin.

Figure 12. The Cupola structural test article during the modal survey test, July 2001. (Alenia)

Figure 13. The ATV structural-thermal model at Alenia Spazio, Turin.

Figure 14. The X-38 V201 spacecraft during final assembly at the NASA Johnson Space Center.

Figure 15. The Biolab Engineering Model, June 2001, at Astrium (F).

Figure 16. The European Robotic Arm being prepared for testing in the Large Space Simulator at ESTEC.

Figure 17. Engineering Model of the Fluid Science Laboratory, June 2001 at Alenia (I).

Figure 18. Fault-tolerant computer of the DMS-R data management system at Astrium (D).

Figure 19. The Brayton Cycle assembly of the Minus Eighty-degree Freezer (MELFI) at Astrium (F).

Figure 20. ESA astronaut Paolo Nespoli evaluating the Materials Science Laboratory at NASA Marshall Space Flight Center, August 2000

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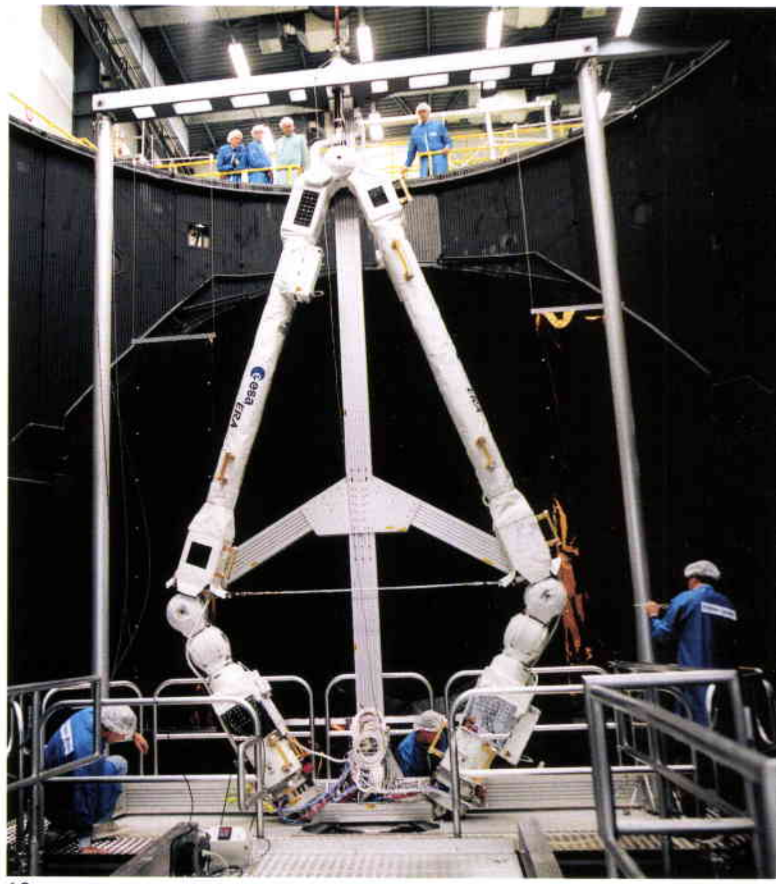

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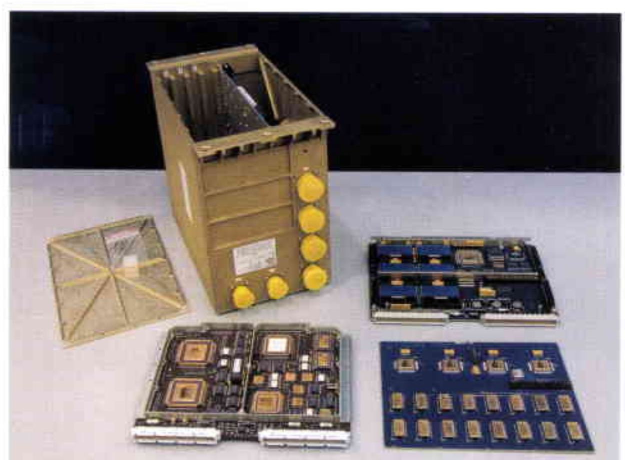

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Table 4. Mid-2001 status of ESA contributions to the ISS.

Element/Task	Status
Columbus module	– Critical Design Review and Safety Review II completed – Equipment and subsystem qualification about 80% completed – System qualification testing underway – Flight software development and integration about 80% complete – Flight unit mechanical assembly 85% complete, for delivery to prime contractor in Sep 2001
Automated Transfer Vehicle	– Preliminary Design Review completed – Equipment qualification testing initiated – System mechanical qualification model manufacturing nearing completion. Delivery to ESTEC for thermal vacuum, acoustic and vibration tests summer 2001
Columbus Control Centre	– System Requirement Review (SRR) completed; Phase-C/D Request for Quotation (RFQ) released
ATV Control Centre	– SRR successfully completed; RFQ for Phase-C/D about to be released
DMS-R	– Operating in orbit for 1 year with no anomalies; additional spares procured by Russia, long-term engineering support in negotiations
ERA	– Qualification / Acceptance Review planned for spring 2002. All deliveries to Russia on hold, pending resolution of SPP launch
Nodes-2 & -3	– Structural qualification completed – System-level modal survey test planned for Aug 2001 – Node-2 CDR completed – Node-2 Flight Unit integration and test to start after modal survey test – Node-3 Flight Unit manufacture ongoing – Node-3 CDR planned for May 2002
Cupola	– Structural verification nearing completion at system and equipment level – Manufacture of flight unit hardware initiated – System CDR planned for Jul-Sep 2001
MPLM/ECLS	– Project complete; two MPLMs already flown to the ISS
ARD exploitation	– Project/task complete, final report issued
ART/X-38	– About 90% of the hardware delivered – Aerodynamic (wind tunnel and computational fluid dynamic analyses conducted); continues until X-38 orbital flight in 2003 – System and subsystem engineering support on site at NASA Johnson Space Center continuing
Crew Return Vehicle	– Early tasks initiated in 1999 – Overall ESA participation in discussion with NASA – could be between 11% and up to 33% of total programme – Detailed planning awaits resolution of NASA programme decisions, expected early 2002.
Mission Data Base	– System in routine product support phase: all European industry activities paid by NASA under direct contract
Cryo-Freezer	– Phase-C/D kick-off imminent
Crew Refrigerator Freezer	– PDR in progress
MELFI	– Flight Unit integration ongoing
Glovebox	– Flight Unit delivery imminent
Hexapod	– CDR completed in 2000
Biolab	– Engineering Model integration completed, CDR completed
Fluid Science Laboratory	– Engineering Model integration ongoing, CDR completed
European Physiology Modules	– PDR completed in 2000
Material Science Laboratory	– Engineering Model integration ongoing, CDR completed
European Modular Cultivation System	– Engineering Model testing started
Protein Crystallisation Diagnostics Facility	– PDR completed
European Drawer Rack	– PDR in 2001, Phase-C/D ongoing

2001, opening the way to the final integration and system-testing of this important laboratory. ATV completed its Preliminary Design Review (PDR) in December 2000, allowing the development programme to continue at full speed towards the CDR in 2003 and the first (semi-operational) flight in September 2004.

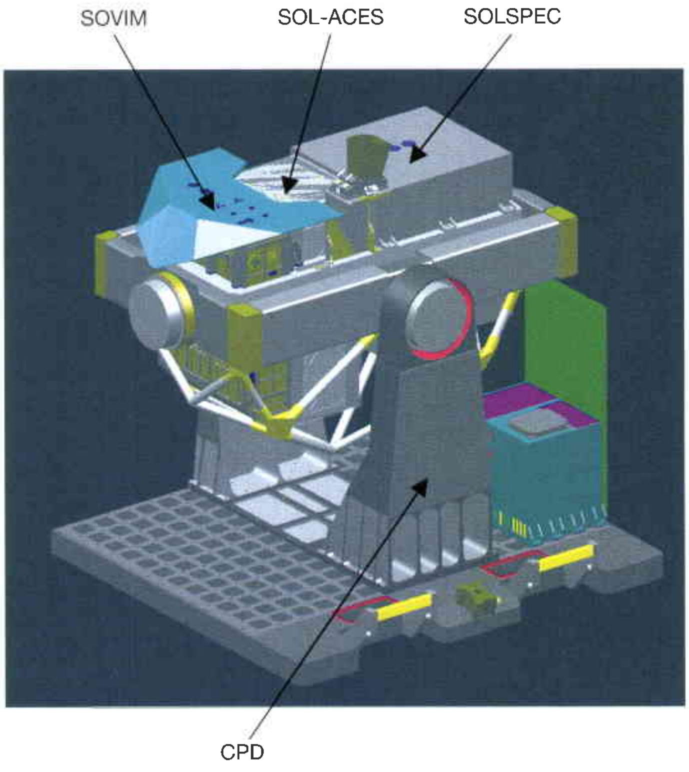
Table 4 gives the status of an overview of all our contributions.

ESA preparations for ISS utilisation
The crucial element of Europe's utilisation approach is the Columbus laboratory, with its internal and external facilities offering utilisation in almost all areas of space research and applications. Following the positive decision by the Ministerial Council meeting in 1995 in Toulouse to participate in the ISS programme, the utilisation plan has been systematically prepared. A considerable number of proposals have been received and peer-reviewed, and many have been accepted in the various disciplines. Indeed, part of the first European experiment is already in orbit: the Global Transmission Services (GTS; Fig. 21) demonstration will be able to synchronise watches worldwide and could provide protection against car and credit card theft.

The Station's external locations are suited to a variety of experiments in space science, technology and Earth observation. Europe will have access to several of these locations, including the external payload facilities of the Columbus laboratory. Two space science proposals have already been selected: SOLAR (Fig. 22) will measure solar spectral irradiance; EXPORT (Fig. 23) consists of a biological ultraviolet-exposure experiment and an instrument to measure the polarisation of diffuse millimetric radiation from the sky. SOLAR and EXPORT both employ the specially developed Coarse Pointing Device.

Two new proposals emerged from the 1999 Announcement of Opportunity (AO) for Flexi-missions from ESA's Science Programme. LOBSTER is an all-sky monitor in the soft X-ray band, and the Extreme Universe Space Observatory (EUSO) would explore ultra-high-energy cosmic rays and neutrinos. Both projects have recently successfully completed their accommodation studies and preparations are being made for the next phase. For the

Figure 21. The Global Transmission Services (GTS) system will broadcast data and high-accuracy time signals.



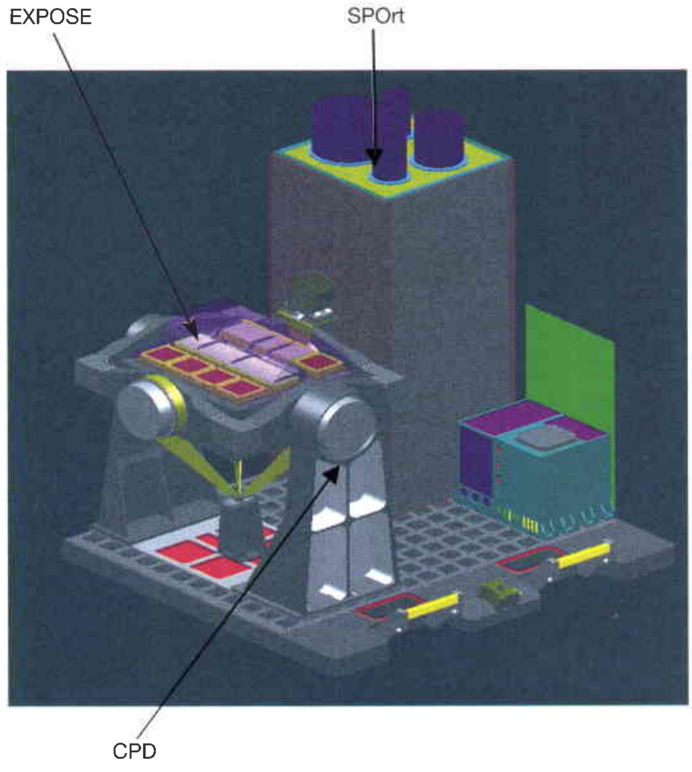


Figure 22. The SOLAR observatory (left).

Figure 23. The EXPORT payload (right).

long-term, the Directorates of Science and Manned Spaceflight and Microgravity are jointly studying the XEUS mission. XEUS is a next-generation X-ray telescope whose huge dimensions can only be realised by assembly in space. The ISS is an ideal platform for the in-orbit assembly and launch of such large objects.

The European Technology Exposure Facility (EuTEF; Fig. 24) provides flexible accommodation for technology experiments. Experiments range from investigating the influence of the harsh space environment on critical materials and components, to full functional tests of (electronic) subsystems. The Atomic Clock Ensemble in Space (ACES; Fig. 25) will test a new generation of microgravity clock and perform experiments in fundamental physics.

In Earth observation, a proposal has been approved for an instrument designed for identifying and monitoring forest and other fires from space. Several other proposals are expected as a result of the recent AO for Earth Explorer Opportunity missions.

Research continuity in life and physical sciences

The main disciplines using the internal volume of the Columbus laboratory and the ISS in general are life sciences and physical sciences. Here, more than 200 proposals have already been approved, directly involving almost 600 scientists and almost 125 European companies. In order to offer continuity in flight opportunities, facilities and support to this impressive user community, a new programme proposal will be submitted to the Ministerial Council in November. ELIPS (European programme for Life and Physical sciences and applications in Space) is an envelope programme, with the first phase covering 2002–2006, that will provide the required stability throughout the Station's lifetime.

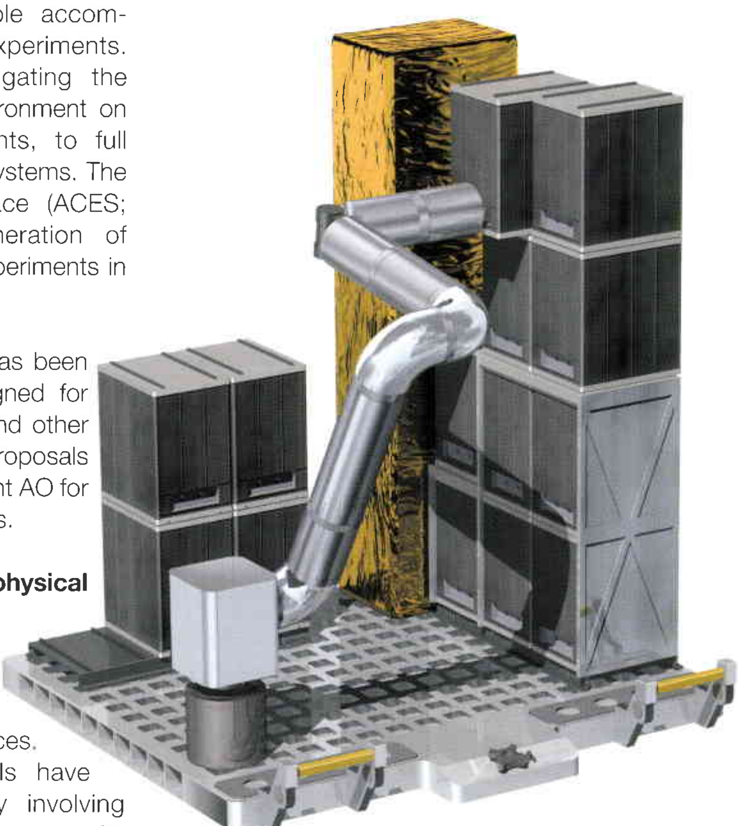


Figure 24. The European Technology Experiment Facility (EuTEF) for technology experiments aboard Columbus. (ESA/D. Ducros)

Figure 25. The Atomic Clock Ensemble in Space (ACES) experiment platform.

The contents of ELIPS will be defined from inputs received from the scientific and industrial user community. Four objectives have been defined, which will be reached by performing research on fourteen Research Cornerstones covering all of the relevant disciplines.

The first objective is *Exploring Nature*. This covers fundamental research in the life and physical sciences, as well as developing the scientific knowledge base for preparing future human planetary exploration missions. Fundamental research in space is considered to be the essential starting point and has by now gained considerable interest in the mother disciplines. Human planetary exploration is expected to be the great endeavour of this new century and many urgent questions need to be addressed.

The next objective is *Improving Health*. Experiments with astronauts as test subjects are already yielding valuable information on diseases occurring on Earth, in particular related to ageing and disabilities. Specific topics are studies on osteoporosis, cardiovascular problems and balance disorders. A large number of teams, incorporating scientists, physicians, hospitals and medical companies, are increasing their understanding, developing state-of-the-art diagnostics and evaluating new drugs and countermeasure techniques.

Research in space is also valuable for *Innovating Technologies and Processes*, the third objective. In areas such as biotechnology and in the more traditional environments like metallurgical or (petro) chemical industries, experiments under weightlessness can yield important data to improve the efficiency of processes such as drug design, steel casting and oil recovery. In some cases, completely new materials are envisaged, such as artificial cartilage and metallic foams.

Finally, the last objective selected is *Caring for the Environment*. In creating advanced Life Support Systems, techniques are developed for water purification and waste treatment that are immediately applicable on Earth. A system to purify air by biodegradation developed for space is already in use in several industrial plants. Another important field of study is combustion. The classical experiment of burning a candle in space demonstrates the influence of gravity on the combustion process. Now, not only scientists but also designers of powerplants and car engines are teaming up to use the results of space research for improving the efficiency or reducing the environmental loads of their products.

For several years, in addition to supporting basic research activities, ESA has been vigorously promoting applied research with a final goal of commercial utilisation. All the participating states are focusing on a good balance of basic research and applications. To this end, ESA has launched a group of individual application projects in life and physical sciences to bring scientists and user industries together to define such activities. These Microgravity Application Programmes (MAPs) have generated considerable interest between their research and industry partners. So far, 44 projects with a volume of 45 million Euro have been defined (Table 5), of which industry is financing a considerable part.

The Erasmus User Information Centre

In order to provide general support and to familiarise the user community with the possibilities offered aboard the ISS, ESA in June 1999 opened the Erasmus ISS User Information Centre (Fig. 26) in ESTEC. This Centre houses a number of hardware and software installations for potential users to learn about ISS utilisation.

In order to introduce potential users to the technical and operational environment of the Columbus experiment facilities, the Centre has built a full-scale model of the module, featuring one segment of the interior and one end-cone with the external payload-accommodation platforms. The model can be linked to a virtual Mission Control Centre and a User Home Base to demonstrate the interaction of the experimenter on the ground with the onboard crew and the mission control and user-support infrastructure.

Table 5. MAP projects.

Discipline	Application Area	Research Topics	Expected Outcome	Number of Projects	Number of Industries
Life Sciences	Health	Osteoporosis Cardiovascular problems Muscle atrophy Balance disorders Revalidation	Miniaturised diagnostics Drug tests New treatments Countermeasures Exercise machines	12	34
	Biotechnology	Bioreactors Microencapsulation Gene technologies	Artificial tissues Controlled drug release Improved harvest	7	20
Physical Sciences	Environment	Closed ecological systems Combustion research	More efficient powerplants Reduced engine emissions New waste treatment technologies	7	18
	(Petro) chemistry	Properties of crude oil Mass exchange through interfaces Liquid transport	Improved oil recovery Optimised chemical processes	9	16
	(New) materials	Metal foams Magnetic fluids Properties of liquid metals Crystallisation of semiconductors	Lighter car elements New heatpipes Improved metal casting New electro-optic devices	9	28

Figure 26. The Erasmus User Centre at ESTEC. (Inset) The Columbus mock-up in the User Centre

The Centre has a direct television link via cable with the NASA Johnson Space Center in Houston. This link has been used during the Shuttle assembly and resupply missions to the Station to allow ESA staff and guests to follow the progress of the missions in real-time. Daily mission summaries given by the staff of the User Information Centre complement these live transmissions. It is planned to use this capability in the future to channel first-hand information to the European media on ISS missions and the involvement of Europe in the utilisation of the Station. Since June 2001, the Centre has been able to record its 3D virtual-reality simulation of the ISS on magnetic tape and even to transmit the 3D pictures via direct TV satellite.

The Erasmus User Information Centre was intensely involved in preparing and conducting the first global user conference, *ISS Forum 2001*, in June in Berlin. The *Forum* also saw the Centre present, for the first time, its products and services to the public. The key product, which was introduced at the *Forum*, was the *ISS European Users Guide**. It describes the Station and the services available to European users. The guide is a configuration-controlled document and constitutes the reference source of validated information on the Station in Europe.

The Centre also presented at the *Forum* its customer-oriented Fact Sheets that summarise the ISS and its utilisation in a collection of four-page leaflets.

The *ISS European Users Guide* and the Fact Sheets are the main source of information for the more than 500 pages that the Centre will place on the world wide web for potential Station users. The Internet presence of the Directorate of Manned Spaceflight and Microgravity has been restructured and re-engineered profoundly over the last few months. The more public-relations-oriented information for the general public and the media are provided on the new ESA Web Portal at *<http://www.esa.int/export/esaHS>* while the more technical information dealing with utilisation and research is accessible through a dedicated server at *<http://www.spaceflight.esa.int/users>*. The first utilisation and research pages were recently uploaded for the new cycle of Announcements of Research Opportunities on the ISS and other microgravity and ground facilities. Several hundreds of new Internet pages will be created over the coming months. Interested users can already have a sneak preview of the amount of information that will be available by downloading the structure of the new site at *<http://www.spaceflight.esa.int/users/structure.cfm>*.

**<http://www.spaceflight.esa.int/users/downloads/userguides/ISS_European_Users_Guide.pdf>*

Visiting the International Space Station - My Mission Diary

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Having been fortunate enough to be the first European Astronaut to visit and live aboard the International Space Station, I would like to share with you my personal diary of this very special trip. Space Shuttle 'Endeavour', with an international crew of seven, lifted off from Kennedy Space Center in Florida on 19 April for an 11-day mission, which included the delivery of the European-developed 'Raffaello' logistics module to the Station and the attachment of the Station's new 17-metre Canadian Robotic Arm. We returned to Earth, with a landing at Edwards Air Force Base in California, on 1 May. Raffaello had been packed for its outward journey with 10 tons of new Station equipment, including six experiment racks and two storage racks for the US 'Destiny' module, as well as supplies for the astronauts and other equipment for future construction and maintenance work. One of my main tasks during the mission was to oversee the safe unloading of all of the experiments and equipment into the Space Station. I was relieved that the whole exercise went so smoothly and very proud to have been the first astronaut to represent Europe on the International Space Station.

Tuesday 17 April 2001

The launch of our STS-100 Space Shuttle mission is rapidly approaching. The crew arrived here at Kennedy Space Center in Florida yesterday. Meanwhile, preparations are continuing at Launch Pad 39A for Thursday's lift-off.

Thursday 19 April 2001

Commander Kent Rominger, Pilot Jeff Ashby and Mission Specialists Chris Hadfield of the Canadian Space Agency, John Phillips, Scott Parazynski, Yuri Lonchakov of Rosaviakosmos, and myself representing ESA, blasted off in the Space Shuttle 'Endeavour' at 18:41 GMT when the International Space Station (ISS) was over the southern Indian Ocean. Less than nine minutes after launch, Endeavour reached its preliminary orbit and we began to configure systems for in-orbit operations.

Lift-off of Space Shuttle 'Endeavour' (STS-100) from KSC on 19 April

Friday 20 April
Space Shuttle 'Endeavour' is on its way to the Station. STS-100 will be the ninth Space Shuttle mission to continue the ISS assembly sequence. Endeavour and our seven-member crew are delivering a new-generation robot arm and the Multi-purpose Pressurised Logistics Module (MPLM), known as 'Raffaello', to the Station. We are scheduled to dock with it on Saturday 21 April at 13:36 GMT.

Today the Shuttle crew checked out the spacesuits and the Orbiter's robotic arm, while the installation of the centreline camera and extension of Endeavour's Orbital Docking System ring was going on in preparation for the rendezvous. Another rendezvous engine burn is scheduled shortly before we finish today's activities.

Umberto Guidoni at work (above and facing page) on the International Space Station

Saturday 21 April
Endeavour successfully docked with the International Space Station at 13:59 GMT (15:59 Central European Time), at an altitude of around 400 km above the Southern Pacific, southeast of New Zealand.

The Shuttle approached the Station from behind and below. Commander Kent Rominger and Pilot Jeff Ashby, assisted by the rest of the crew, flew the Shuttle to a point about 200 metres directly below the Space Station. From there, with the cargo bay pointed towards the Station, we flew a quarter circle arc to a point about 100 metres ahead of the Station, and then began a slow approach to the docking port at the forward end of Destiny. When at distance of about 10 metres, Rominger verified good alignment with the Station's docking target, before resuming the approach at a speed of about one metre every 30 seconds until docking.

Our crew has transferred supplies into the Station's docking port in preparation for Sunday's space walk by Mission Specialists Chris Hadfield and Scott Parazynski. This will be the first of two scheduled space walks to install and activate the Station's new Canadian-built high-tech Robotic Arm 'Canadarm2'.

The Expedition-Two crew of Russian Commander Yuri Usachev and astronauts Jim Voss and Susan Helms have already been aboard the Station for more than a month and are keen to welcome us. But although we are already docked with the Station, due to cabin pressure differences we will not meet face-to-face until Monday, after the first space walk.

Sunday 22 April
Chris Hadfield and Scott Parazynski began the mission's first space walk at 11:45 GMT (13:45 CET). The main objectives of the space walk are the installation of Canadarm2 and an ultra-high frequency (UHF) antenna on the ISS. John Phillips is the EVA 'choreographer', while Pilot Jeff Ashby and I will be operating the Shuttle's robotic arm to install the new arm on the outside of the Station's Destiny laboratory.

Before the start of the space walk, Jeff and I manoeuvred the Shuttle arm to lift the Spacelab Pallet (SLP) containing the Canadarm2, also known as the Space Station Remote Manipulator System, out of Endeavour's payload bay. Then we attached the SLP to the Station's US Laboratory Module Destiny. During their space walk, Hadfield and Parazynski were able to connect cables to give the arm power and allow it to accept computer commands from the US Lab. They unbolted the arm from the pallet, then unfolded its two booms and tightened bolts to make them rigid. The space walkers also installed the UHF antenna on Destiny. Parazynski and Hadfield spent a total of 7 hours and 10 minutes working outside the Station. On completion of the EVA, Endeavour's cabin pressure was increased to match that of the Station. Finally, the hatches between the Shuttle and Station will be opened early on Monday morning.

Monday 23 April
At 11:25 CET (9:25 GMT) today, the Expedition-Two crew welcomed us aboard the International Space Station. We had a busy day

with the opening of the hatch linking the two spacecraft, the first movements of the new Canadarm2, and the unberthing of Raffaello and its installation on Node 1.

Scott and myself began to use Endeavour's robotic arm to lift the Raffaello Multi-purpose Pressurised Logistics Module out of the payload bay and attach it to the International Space Station's 'Unity' Module. The manoeuvre was completely nominal and the Italian module was 'bolted' with sixteen motorised bolts to the Unity Node, thereby becoming an integral part of the Station.

Tomorrow, the Expedition-Two crew will begin to transfer food, supplies, equipment and two experiment racks from Raffaello to the Station for installation in Destiny.

Tuesday 24 April

The unloading of Raffaello's 3 tons of supplies and the science racks for the Space Station went pretty smooth.

In preparation, the vestibule between Unity and Raffaello had been pressurised and I activated the MPLM. The first of the MPLM's Environmental Control and Life Support Systems (ECLSS) – developed by ASI for ESA – was activated, namely the air temperature sensor. Today, before the hatch was opened, we took a sample of Raffaello's air and analysed it to confirm no cabin-air contamination. At that point the Inter-Module Ventilation valve was opened and the cabin fan activated to provide a comfortable environment for the crew during their operations. The Positive Pressure Relief valves will be de-activated, since the ISS controls air pressure during open-hatch operations.

Yesterday had been a busy day for all of us aboard the ISS. Our two crews had performed over 10 hours of joint operations before the hatches were closed again in preparation for today's space walk.

The new 11.3 m long Canadarm2 robot arm took its first step, 'walking off' a pallet mounted at the top of the Destiny Laboratory to grab onto an electrical grapple fixture on Destiny capable of providing data, power and telemetry to the dexterous appendage. With Expedition-Two Flight Engineer Susan Helms sending commands from a workstation inside Destiny, the arm began to move off the pallet at 11:13 GMT. Three hours later, after an extensive checkout of all of its joints, the arm affixed itself to the Destiny grapple point, where it will remain overnight in preparation for its first active moving of a payload – the pallet on which it was launched.

Commander Kent Rominger and Pilot Ashby also fired the Shuttle's jets to raise the Space Station's altitude by 4 km. Two more re-boosts are planned on Wednesday and Thursday to put the Station at the correct altitude for the arrival of a Russian-commanded 'taxi' crew next week, delivering a fresh Soyuz return vehicle to the complex.

Mission Specialists Scott Parazynski and Chris Hadfield began today's EVA at 13:06 GMT (15:06 CET). Thanks to Leonardo's ECLSS system, they worked in shirtsleeve comfort, but for the time being they had to remain on their own. Although Endeavour is still firmly docked with the Station and I supervised the unloading by radio link, the Shuttle is operating at a lower air pressure than the ISS and the hatch between the two was sealed.

The pressure differential is necessary because of the EVA to install new Station equipment. Lower air pressure aboard the Shuttle makes the business of suiting up and unsuiting quicker and wastes less of the on-board oxygen supplies. The reduction in pressure makes no difference to the crew's breathing: as overall pressure falls, the proportion of oxygen is increased. Low air pressure is even more important for space-walking astronauts. 'Normal' air pressure would make their spacesuits hopelessly stiff and unmanageable. However, once Endeavour's EVAs have been completed, the Shuttle will match pressures with the Station and the two crews will be able to share the same space again.

The first order of business for the space walkers was to connect power, computer and video cables to the Power and Data Grapple Fixture on the side of the Station's Destiny laboratory. They also removed an antenna on Unity that is no longer needed. Cables on the pallet that carried the new robot arm to the Station were disconnected. Once those cables were removed, the Canadarm2 received power and communicated with the Station's Robotics Work Station inside Destiny.

Near the end of the 7-hour space walk, Helms commanded the Station's new robotic arm to pick up the 3000-pound pallet that delivered it to space. She then manoeuvred the pallet through various positions to test the arm with a load. Helms finished today's tests by manoeuvring the pallet over Endeavour's payload bay, where it will remain parked overnight still attached to the robotic arm.

MPLM attached to the International Space Station's 'Unity' Module

Wednesday 25 April
Six days after launch, our Shuttle mission STS-100 continues to go according to plan. While robotic-arm operations are underway by Expedition-Two crew members Susan Helms and Jim Voss aboard the Station, my Shuttle crew members and I continue the task of unpacking the Raffaello high-tech 'moving van'. It was a big day for me with the transfer of the powered experiments from the Shuttle's mid-deck to the US Lab.

Today, I woke up to the sound of 'Con te Partiro' ('With You I Will Go'), sung by Italian opera singer Andrea Bocelli. I felt moved when Steve MacLean called from the Mission Control Center and started to talk in Italian.

The crew continued to transfer equipment from Raffaello to the ISS. Endeavour's schedule allows for a maximum of three EVAs. But yesterday's intense activity – astronauts Chris Hadfield and Scott Parazynski were at work for almost 8 hours – went so well that the third EVA will probably be unnecessary. Pressures were equalised some time yesterday and the Shuttle crew helped Usachev, Voss and Helms with the unloading and restowing of Raffaello's contents. Today, the Canadarm will 'pass' the SLP pallet to the Shuttle's own robotic arm.

'Pallet' is actually quite a misleading term. The device has nothing in common with the wooden pack-and-stack units used by forklift trucks on Earth. It is a sophisticated payload carrier, and one with a long history. Back in the 1980s, when ESA built the pressurised modules for the Spacelab programme, it also built the unpressurised payload carriers without which the manned modules would be useless.

The two Spacelabs have long since been retired. But the un-pressurised modules, the humble pallets, are still at work on the ISS. Raffaello and the other MPLMs are often described as 'space moving vans'. If so, then the pallets are the 'pick-up trucks' – both robust and long lasting.

Thursday 26 April
As Shuttle Mission STS-100 comes to an end – Endeavour will undock from the ISS on 28 April – there has been no let-up for us.

The Raffaello logistics module has now been almost completely unloaded, and all of us have been busy installing the new equipment and scientific experiments on the Station. We would have been even busier if work schedules had not been affected by an annoying computer problem.

The trouble showed up in the early hours yesterday, as we slept after a hard day's work. ISS flight controllers on the ground reported that the Station's Command and Control Computer Number 1 was no longer responding to their inputs. The ISS has three of these 'CC' computers, so the controllers spent much of the night assigning CC-1's functions to the two backups. But they too seemed to be affected by the same software glitch and for a time the Station's communications had to be routed through the docked Shuttle's systems. Controllers have been rebooting and restarting the computers in an attempt to clear the fault. Although the problem is neither life-threatening nor safety-critical, it is certainly an irritation.

One consequence was the postponement of a scheduled manoeuvre with the newly fitted robotic arm. The arm was carried to the Station on the European-built Spacelab pallet during Tuesday's EVA. After installing the arm, we had left the pallet 'parked' beside the Station. We had planned to use the arm yesterday to lift the pallet back into Endeavour's cargo bay. With luck, the job should be accomplished today. It will be the most complicated operation so far performed by Canadarm2, but a task still easily within the capabilities of the world's most sophisticated robotic handling device.

Unlike its predecessors – the original Canadarm is the robot lifter fitted in the cargo bay of each Space Shuttle – the 17-metre Canadarm2 has no permanent anchoring point. The European Robotic Arm that will later serve the Russian Zvezda module is similarly dexterous. Each end is equipped with a Latching End Effector that can take hold on the Station while the other end deals with the job in hand. Canadarm2 can actually flip itself around the Station, moving from anchor point to anchor point.

Friday 27 April
We, the seven Shuttle astronauts and three ISS crew members, began our day in excellent health, but with a deepening sense of frustration. Continuing computer problems have stalled some important mission activities, and Endeavour's undocking, originally scheduled for tomorrow, has been postponed for one or two days, pending Russian concurrence.

After a series of re-boots, controllers had managed to get one of the Station's systems up and running. But with no working backup available, mission tasks planned for Wednesday and Thursday have had to be postponed. The problem seems to lie in the complex software in the Destiny computers. While experts on the ground check out thousands of lines of code, flight controllers are planning a tricky re-synchronisation procedure later today that should bring their recalcitrant machines back on line.

Fortunately, the ESA-provided Data-Management System (DMS-R) in the Russian Service Module 'Zvezda' – the software that actually 'flies' the Station and looks after most routine functions – is working smoothly, so we are in no danger. Since Endeavour has more than enough power and supplies to remain in orbit for as long as necessary, the two-day extension poses no problems for our Shuttle crew.

The delay in Endeavour's departure has a knock-on effect on the launch of a Russian Soyuz craft planned for Saturday 28 April, since the ISS cannot at present accommodate a Soyuz and a Shuttle at the same time. The Soyuz mission is what ISS people call a 'taxi flight'. One Soyuz craft is always docked to the Station to serve as a 'lifeboat' in case of an emergency, but the spacecraft's systems and propellant stores deteriorate with time, so every six months a replacement is launched. Its crew pass a few days with the ISS crew, then return in the Soyuz that has reached its 'best-before' date and leave their own spacecraft behind as the new lifeboat.

Saturday's Soyuz launch was an interesting space premiere. The three-seater spacecraft needs only two cosmonauts to operate it. The world's first space tourist, American millionaire Dennis Tito, occupied the third seat. The ISS partners had agreed to Tito's trip, albeit with some misgivings. Could it turn out that the world's first space tourist runs into the world's first space charter-flight cancellation?

Saturday 28 April
8:56 am CET: the crews of the ISS and the Shuttle are enjoying a well-earned night's rest after a hectic day that saw the resolution of most of the mission's problems. And I can sleep as sound as any – the Raffaello logistics module, my special charge, is safely back in the Shuttle's cargo bay.

In space and on the ground, astronauts and flight controllers wrestled with the computer problems. They got one of the backup computers working, but the other two remained intractable. Controllers were reluctant to attempt to undock Raffaello with only one computer working, since any glitch would have left the arm attached to the SLP in an awkward configuration, and in the way of the trajectory that the Shuttle arm is supposed to follow to cradle the MPLM in the cargo bay. But one of the payload computers loaded with the command and control software beamed from the ground was pressed into service as a backup, and Raffaello was successfully undocked at about 8.30 pm CET yesterday.

The module had already been deactivated and packed with 800 kg of material to be returned to Earth – work that could be accomplished without computer assistance. Endeavour also fired her motors to boost the Station's altitude by about 4 kilometres: the Shuttle's own computers could handle this manoeuvre.

Controllers sent new software to the stalled prime command computer last night. With support from this reprogrammed computer, they hope to use the Station's robotic arm today to move its loading pallet into the Shuttle's cargo bay. The flawed prime computer will also be part of Endeavour's return cargo, slated for disassembly and analysis: everyone wants to find out just what went wrong.

After his flight, Umberto Guidoni (far right), his fellow STS-100 crew members and ESA Director General Antonio Rodotà (centre) meet Romano Prodi, President of the European Commission

Yesterday's good work has reduced the possible two-day delay in Endeavour's departure to just one day. Meanwhile, the Russian Soyuz 'taxi flight' to the Station has been launched on schedule, at 8.37 a.m. CET. As things stand, the crew will have to endure at least an extra full day in orbit in the cramped Soyuz craft: it cannot dock with the ISS before Endeavour has left.

Sunday 29 April
Our two crews are very near to bringing our troubled mission to a successful conclusion. We hope to have three computers running this morning, which will allow Endeavour to undock and begin her journey home at around 7 pm CET, just one day later than planned. If all goes well, Endeavour will be clear of the Station before the arrival of the Russian Soyuz.

We are not wasting our additional time in space. Those not engaged in solving the computer problem are working with the ISS team to repair the Station's exercise treadmill. Its walking surface had worn out. So when Endeavour leaves, it will be 'back to the treadmill' for Station Commander Yury Usachev and astronauts James Voss and Susan Helms.

Monday 30 April - Mission accomplished!
My six shipmates and I waved goodbye to the International Space Station from aboard the Shuttle Endeavour at 18:34 CET yesterday. Endeavour undocked almost 27 hours later than originally planned.

Springs in the docking port pushed the loaded Shuttle gently away from the Station. Then, before igniting her main motor for orbital separation, the Shuttle flew slowly around the station at a distance of around 150 metres while Mission Specialist Yuri Lonchakov took pictures with an IMAX camera. The separation burn took place at 19.28 CET, and Endeavour is now hundreds of kilometres from the ISS.

Landing is scheduled at the Kennedy Space Center at 14.03 CET tomorrow.

Tuesday 1 May - Homeward bound!
We spent our last hours in space cleaning up, and stowing away equipment no longer needed for the mission. It is a routine chore, but not as easy as it sounds. In the weightlessness of orbit, everyday objects from pens and clipboards to breakfast crumbs, have a surprising ability to find their way into the most awkward places. That's why space farers soon learn to be tidy, and why crews aboard the ultra-high-technology Shuttle make sure they have plenty of low-technology adhesive tape to stop things getting lost in the first place!

The de-orbit burn is an hour away and we get the 'GO' from Mission Control in Houston to put on our space suits and get ready for re-entry. The weather is bad in Florida and we are targeting Edwards Air Force Base in California. Our wives are waiting for us in Florida and they will be disappointed – but we are going to meet them tomorrow!

The ISS Education Programme for Students: A New Outreach Initiative

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Today's students are tomorrow's work force, and thus students should participate in the global space programme so that they will feel motivated to follow space careers, work in the space domain, and create a generation that is literate in science and educated in space matters. This will lead to a continuously regenerated workforce that will profit from the injection of new ideas and initiatives.

Introduction

Getting students involved in today's space programmes is important not only for the space industry in terms of providing a talented work force for the future, but also for the public in general who are the voters and potential political supporters of European space exploration. In addition, present statistics show an overall decline in the numbers of science and technology students. For these reasons, ESA has committed, with a unanimous decision at the Manned Space Programme Board, to allocate 1% of the European utilisation resources on the International Space Station (ISS) to the youth.

Although, as the main tool for future research in microgravity, the ISS will only be routinely available to European researchers from 2005, there are already several possibilities for valuable education programmes for research in this domain. They include simulations in the

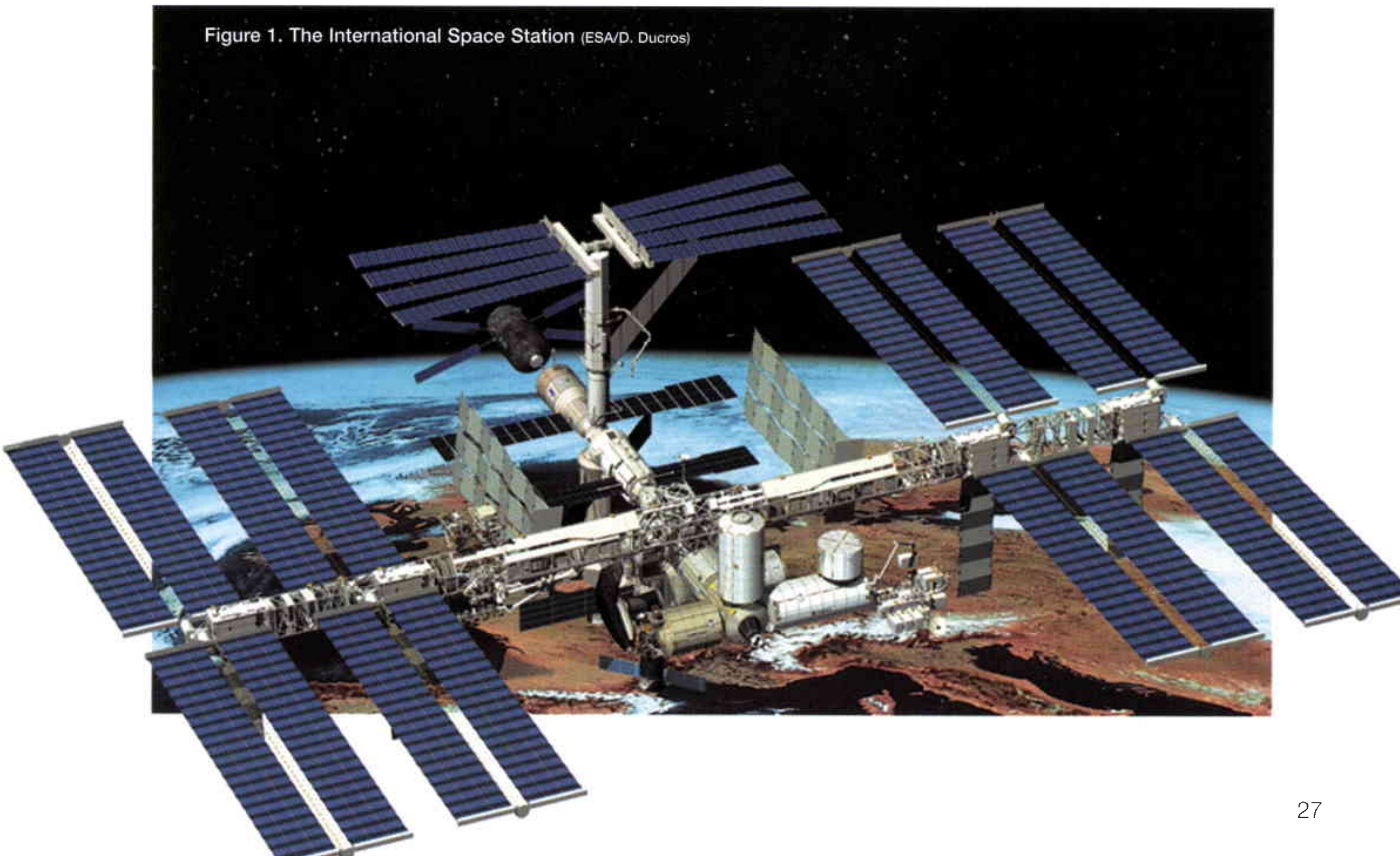

Figure 1. The International Space Station (ESA/D. Ducros)

Columbus module mock-up in the Space Station User Centre at ESTEC, student places on ESA parabolic-flight campaigns, and other opportunities such as those provided by the Russian Foton spacecraft. It is within this framework that ESA's Education Programme for Research on the International Space Station has been defined.

Objectives and scope of the Programme

The Education Programme for Research on the ISS has two distinct but linked objectives: to create opportunities for students to take part in microgravity research on a continuing basis, and to reach as many students and young people as possible during the process. The Programme addresses European students between 8 and 27 years of age. It makes use of the ground facilities and services provided as part of the European investment in the ISS, as well as of a portion of the accommodation and operational resources – 1% per year, equivalent to 13 kg of experiments annually – provided by the European Columbus laboratory.

The Education Programme is the result of a collaboration between ESA's Directorate of Manned Spaceflight and Microgravity and its Office for Education, who have together initiated the 'Pyramid to Space' programme. The latter is designed to dovetail with the Agency's existing outreach activities as a complementary and inter-linked entity. The activities proposed within it will work together with and respect existing policies and initiatives in order to create a continuous, flexible outreach programme.

The programme can be represented as a pyramid structure whereby the activities initially address tens of thousands of students, a few of whom are eventually awarded access to the ISS experimentation facilities. The numbers of young people targeted for involvement in each activity are indicated on the right-hand side of the pyramid.

In order to stimulate young people to get involved not only in the research but also in the outreach activities, the concept of 'Space Miles' has been created: by conducting outreach for ESA activities, students earn 'space miles'. Enough 'space miles' enable them to take part in space-related activities organised by the Agency, which can allow them to move up one level in the pyramid. For those with enough 'space miles', near the top of the pyramid, there might even be future employment opportunities with the Agency.

Figure 2. The Columbus module on the ISS

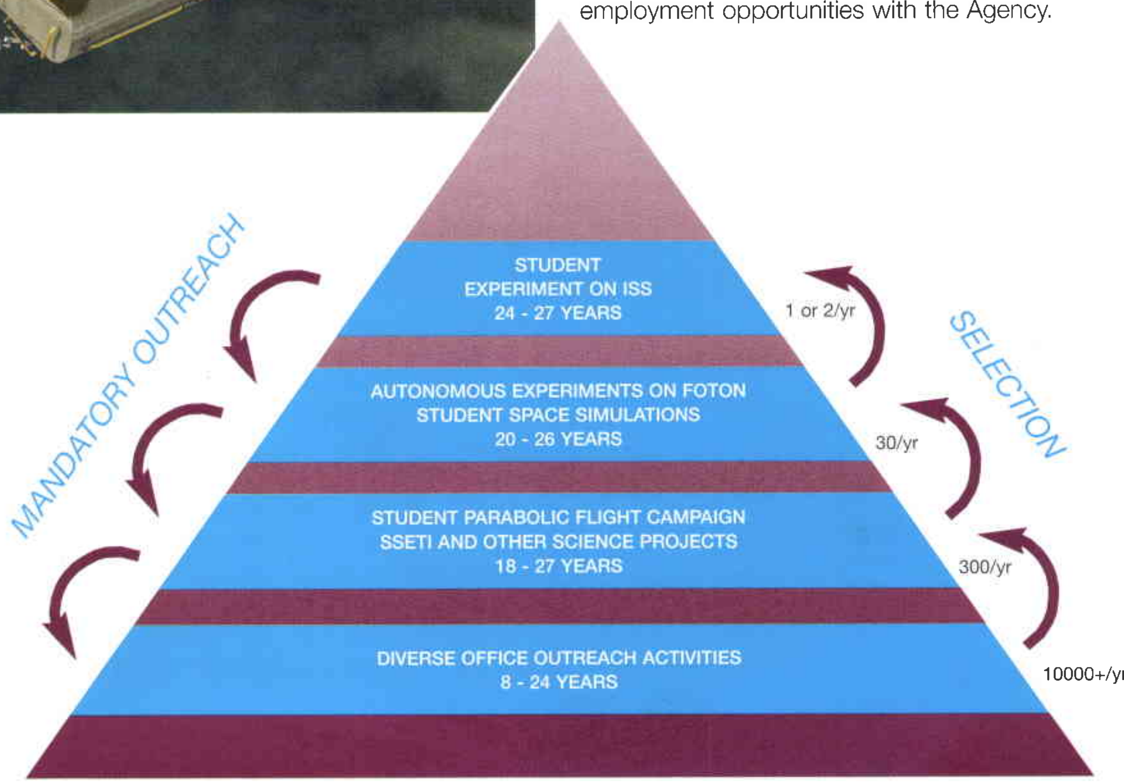

Figure 3. The 'Pyramid to Space'

The different activities in the Programme

Basic outreach

Basic outreach activities are aimed at involving a significant number of young Europeans and at increasing their literacy in science and technology in general, and in the space domain in particular. Examples are space games – both Internet-based ones and those sold in shops – teachers' programmes, congresses like the IAF and initiatives such as SSETI (Student Space Exploration and Technology Initiative), in which a large number of European students design a satellite using distributed development techniques.

Figure 4. Participants in the fourth ESA Student Parabolic-Flight Campaign, Bordeaux, July 2001 (ESA/Anneke van der Geest)

Student parabolic-flight campaign

The second layer in the 'Pyramid to Space' is the student parabolic flight campaign. This campaign takes place on an annual basis, with around 120 students and 30 microgravity experiments being flown during each campaign. The selection criteria take into account the originality of the idea, the technical complexity of the experiment, the demonstration of zero gravity, and the outreach activities conducted by the team. The latter can include video and web-site creation, television and newspaper coverage, and presentations to participating schools and universities. The students' outreach proposals will increase their 'space mileage' and be weighted in the selection procedure. From the student campaign, one or two of the best experiments will then be selected to be flown on an ESA professional parabolic-flight campaign.

Simulations in the Space Station User Centre

Student simulations will be a part of the User Centre's wider familiarisation and training sessions, which are aimed at both committed and potential ISS users. Facilities that are currently available and suitable for student simulations in the Columbus mock-up are:

- the Microgravity Glove Box
- the Drawer Racks, containing the Protein Crystal Growth Experiment, the Microgravity Applications Furnace, and the Electrophoretic Orientation Experiment.

The first student simulation activities are due to take place in 2001 with the arrival of seven

Figure 5. The Columbus module mock-up at ESTEC in Noordwijk (NL)

students from the 12th European Union's Young Scientist competition. They are the winners of the special award presented by ESA's Director of Manned Spaceflight and Microgravity at a Ceremony in Amsterdam in September 2000.

Student experiments on professional parabolic-flight campaigns

The presence of student experiments on professional parabolic flights is important because it represents the acceptance and recognition of their research by the scientific community. The distinct classification difference between the student and professional flights will give them the feeling that they have progressed and 'moved up the pyramid'. An average of one student experiment will be flown per professional parabolic flight. It also represents a vital test of ISS experiment suitability and is therefore positioned just before the ISS payload in the student 'Pyramid to Space' (Fig. 3). The selection criteria take into account the originality of the idea, the technical complexity of the experiment, the degree of scientific interest, and the practicality of actually performing the experiment during the student parabolic-flight campaign.

Experiments on the ISS

The ultimate reward for students offered by the 'Pyramid to Space' programme is to have their payload flown on the ISS. The students selected must have successfully completed the preceding 'steps' involving other microgravity research activities and also have carried out sufficient outreach activities along the way. They will therefore be those individuals who are the most motivated, who propose the most exciting and scientifically valuable experiments, and who have involved the most people through their outreach efforts.

From the start of utilisation activities in the Columbus laboratory (currently scheduled for 2005), approximately 13 kg of student experiments will be sent up each year to the ISS and accommodated in the European Columbus module or on the Columbus external attachment points. The experiments will then be carried out by the ISS crew members and the results or samples sent back to Earth.

One of the major problems with student experiments on ISS are the long turn-around times for typical ISS experiments. In order to reduce access time, and hence the cost, students could follow a 'piggyback' approach, fitting their experiment into any spare hardware/allocation space available.

The facilities available in the Columbus module and their respective launch dates are as follows:

Biolab	2004
Fluid Science Laboratory (FSL)	2004
Material Science Laboratory (MSL)	TBD
European Drawer Rack (EDR)	2004
External Attachment Points	2004

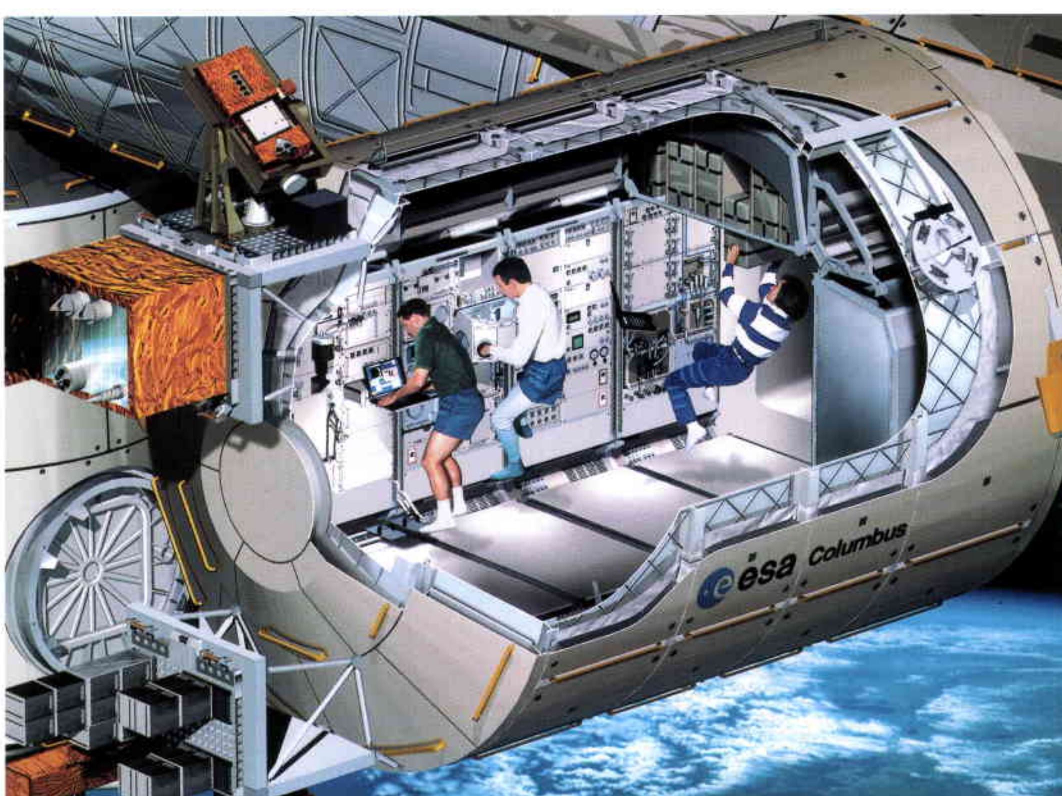

Figure 6. The interior of ESA's Columbus module (ESA/D. Ducros)

Biolab

The Biolab is designed for the study of small invertebrates, micro-organisms, cell cultures, etc.

Experiment costs	~ 50 kEuro (hardware only)
Turn-around time	2 years
Size limitation	60 x 60 x 100 mm^3 (the container)
Average weight per container	1.5 kg

Biolab is suitable for student experiments. It has been suggested that the student experiments should weigh less than 5 kg to minimise the number of containers needed, and hence also costs.

Biolab facility (ESA/D. Ducros)

European Modular Cultivation System (EMCS)

The EMCS is designed for early usage of the ISS before the other biological facilities such as Biolab become available. It will be located in an Express rack in the US Laboratory. Although it is provided as part of a barter agreement with the United States, European access is also possible. Its principal use will be for botanical experiments, but it will also be possible to accommodate experiments involving small invertebrates.

Experiment costs	< 50 kEuro (hardware only)
Turn-around time	Several years
Size limitation	60 x 60 x 160 mm^3 (the container)

Although the EMCS will fly for the first time only in 2003, experiment-proposal and peer reviews have already been taking place for two years. As a result, it is already fully booked for its first two years of operation, making its early use for student experiments highly unlikely.

Fluid Science Laboratory (FSL)

Experiment costs	2 – 4 MEuro
Turn-around time	3 years
Size limitation	400 x 270 x 280 mm^3 (the container)

Although theoretically the FSL is suitable, in practice it would be difficult to accommodate student/educative experiments, as there is only one large experiment container, which by its uniqueness and sheer size implies large, complex and hence expensive experiments and a very long waiting list of users. Any proposed sharing of the container would probably not be popular with those scientists. Therefore, the suggestion is to use the European Drawer Rack for student fluid-science payloads.

Fluid Science Laboratory (ESA/D. Ducros)

Material Science Laboratory (MSL)

Experiment costs	50 – 100 kEuro
Turn-around time	3 years
Size limitations	20–30 mm, 120 mm and 250 mm

As for the FSL, the MSL is considered theoretically suitable for educative use and student experiments. In particular, several past student material-science parabolic-flight experiments would be suitable for the MSL, as well as some of the combustion experiments.

Each experiment cartridge is estimated to weigh between 1 and 2 kg, and the weight of experiments that can be conducted per year in the MSL is predicted to be between 10 and 50 kg. The 13 kg currently proposed for one student experiment therefore appears to be far too ambitious and the suggestion is therefore to use the European Drawer Rack, or TEMPUS, for student material-science experimentation.

European Drawer Rack
(ESA/D. Ducros)

European Drawer Rack (EDR)

The EDR provides four Mid-Deck Lockers (MDLs) and four Standard European Drawers (SED). The main differences between the two are that the lockers are powered during transport and the drawers are not, and the drawers are slightly bigger.

Experiment costs	Depends on instrumentation
Turn-around time	6 months
Size limitations	44 x 25.3 x 56.6 cm^3 (MDLs)
	59 x 40 x 30.5 cm^3 (EDRs)

The EDR is considered suitable for student experiments because it is dedicated to smaller payloads with a quick return and delivery of mission products, estimated at around six months. In addition, it is recognised as the most flexible experiment carrier on board the Columbus laboratory, which would indeed seem to favour its use for student payloads. On the negative side, the EDRs are empty and would require all instrumentation to be added, which could greatly increase costs, depending on the experiment chosen.

Selection

The selection process will follow a two-step approach, with one step dedicated to satisfying the mandatory outreach requirement, and the other to evaluation of the proposed experiment itself. The outreach selection will consider motivation, excitement and the number of people involved, whereas the experiment itself will be scrutinised by the Directorate of Manned Spaceflight and Microgravity for scientific value, viability, feasibility and suitability for possible accommodation both in the parabolic-flight (zero-g) aircraft and on the ISS.

Schedule

Today it is expected that the first student payloads will be flown on the ISS in 2005, with the overall schedule being along the following lines:

November 2002	AO for student parabolic flight
July 2003	Student flight campaign
October 2003/May 04	Professional parabolic flight
Summer 2004	Simulations at ESTEC
Early 2004	AO Student ISS payloads
Late 2005	ISS payload flown

This would mean that the whole process, from student parabolic flight to ISS payload, could take less than three years, which is a suitable timeline for students.

The ISS Education Foundation

In order to provide comprehensive support to the Education Programme outlined above, in addition to the effort and funds invested by ESA, a foundation is being promoted called the 'ISS Education Foundation'. This foundation will be supported by industry, academia and governmental organisations, which will provide financial as well as 'in kind' contributions (e.g. technical expertise, access to facilities). The foundation will also include high-profile individuals (Honorary Members), who will make in-kind contributions to selected Education Programme activities that the Foundation is supporting (such as the awarding of prizes, etc.).

Conclusion

The ISS Education Programme is a comprehensive outreach/education initiative born through the combined efforts and collaboration of ESA's Manned Spaceflight and Microgravity and its Administration Directorates. The unanimous support for the initiative from the ESA Delegations is a concrete sign that European decision makers are very aware of the importance of education in today's society, particularly for the space sector. The long-term success of the initiative depends not only on the ESA commitment, but also on the support of those entities – industrial, academic and governmental – that will match ESA's effort and join the ISS Foundation.

A New Marketplace in Space: The International Space Station

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Commercialising the European segment of the International Space Station means creating conditions that attract private entities willing to do business in the near-Earth environment. The commercialisation of the Station is based on the assumption that there is a market for low-orbiting manned infrastructures. This market is driven by customer demand and covers a wide range of applications, encompassing commercially applied research, technology development and innovative activities linked with the image of space. The commercialisation process touches upon virtually all of the facets of ESA's day-to-day business: the evaluation and selection of projects, the legal environment, the exploitation of human and technical resources, and the corporate image. This article discusses the potential markets for the Station, the potential customers, why they might want to be in space and what they need from the Agency in order to get there. It also outlines ESA's strategy for making the Space Station a new marketplace in space.

The objectives of commercialisation

The overall motivation for the commercialisation of the International Space Station (ISS) is to foster the economic development and exploitation of space. Commercialisation of the ISS will contribute to the creation of value for the business and research communities that choose to access it, by sending commercial payloads to and conducting innovative activities on this world-class facility in space.

That value in turn translates into technologies, products and processes for applications on Earth as well as in space, generating prosperity and increasing European industry's competitive advantage. For Europe in particular, the primary objectives of ISS commercialisation are to:

- make full use of the European investment in ISS by stimulating applied and commercial research in space and exploiting and supporting innovative uses of the Station, thereby involving both space and non-space industry in space research and in improving products and processes on Earth and in space
- encourage investment by the private sector for future improvements and enhancements of the ISS, which will attract new users by providing new services
- reduce the need for ESA funding for ISS operations and servicing-type activities by charging the market rate for ISS utilisation in order to free ESA resources for research and development
- keep pace with the other ISS partners, who are moving aggressively towards ISS commercialisation
- generate revenue by using the ISS image, as well as the space and ground infrastructure, for projects in the fields of education, sponsorship, advertising and entertainment
- improve the public's perception of and interest in space and space science by communicating the benefits of space-based research to a wider community in the context of promoting commercial ISS utilisation.

The ISS business case

The International Space Station provides a unique environment in that it combines the virtual absence of gravity (microgravity) with the continuous presence of humans. Such an environment allows physical processes to be observed in an experimental context without the 'distortion' that is generated here on Earth by our planet's gravity or atmosphere.

In fluid physics, for instance, the absence of gravity enables one to study the complex interactions of many different phenomena in fluid phases. The environment of a space laboratory, where sedimentation and buoyancy-induced flows are virtually eliminated, allows one to study fluid phenomena that are otherwise dominated or even completely masked by these effects. The thermo-physical properties measured under such conditions have extreme levels of accuracy, which is critical for developing new materials such as commercially attractive alloys.

In tissue and cell engineering also, experimental data gathered under microgravity conditions or in microgravity simulation studies indicate a change in cell function that is related to the

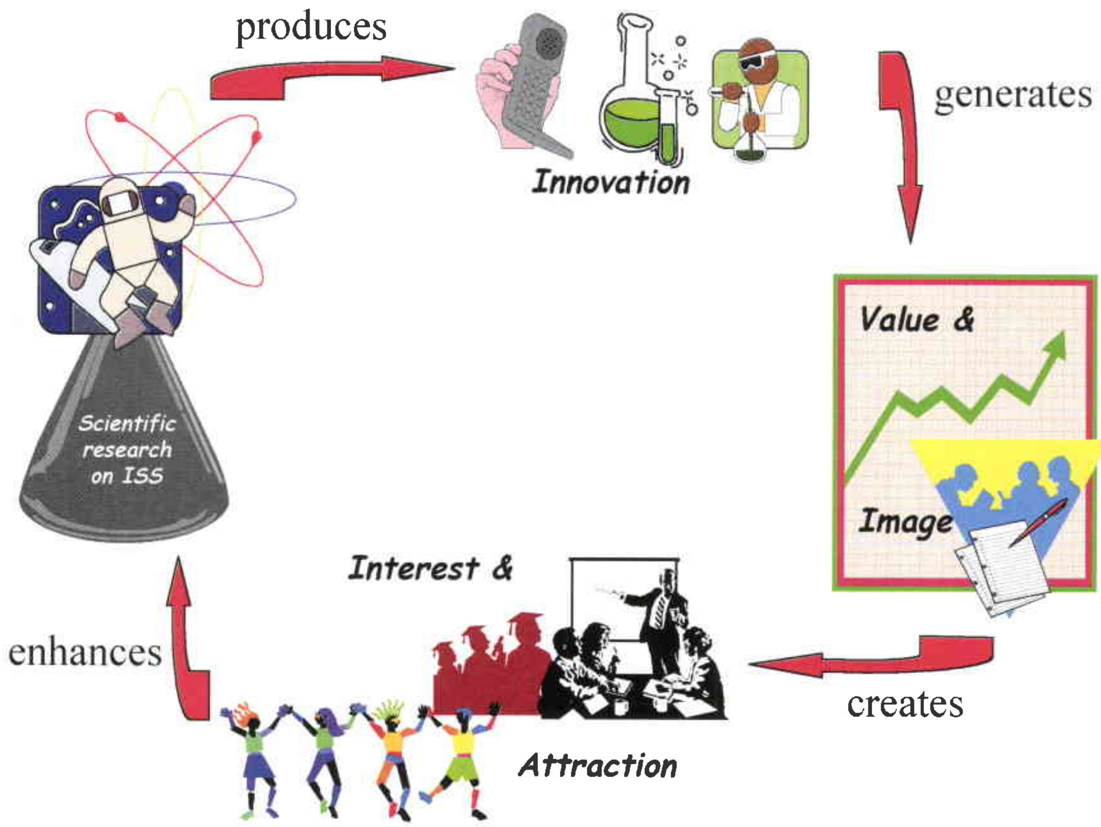


Figure 1. The commercialisation cycle

gravity level. The microgravity environment therefore provides new ways of isolating the various mechanisms inherent in the evolution of tissue structure. This knowledge can then be used, for example, for the production on the ground of improved artificial organs for medical purposes and for the design of bioreactors mimicking organo-typical conditions.

Moving clockwise in Figure 1 from the R&D, we see therefore that the generation of knowledge and processes in space can contribute to innovation on Earth, which generates added value for companies and a better image for the Station, which in turn serves to attract the attention of more potential customers – both commercial and academic – and further enhances its commercial utilisation by European customers.

Market research: identifying markets and customers

Where does one start in order to identify potential customers and attract them to the Station? In initiating its ISS commercialisation activities in 1999, ESA asked three companies specialised in market research and technology development to perform independent studies of the market for, and the customers who could be attracted to, the Station. These studies identified a broad spectrum of potential markets (Fig. 2), ranging from R&D for new product and processes in weightlessness, to the novel utilisation of the attractiveness of the human presence in space for commercial communication in terms of sponsorship, product placement and advertising. The studies also showed, however, that the markets for the ISS are latent ones that need promotion and nurturing. The three major market segments identified are:

(i) Research and Development
There is industrial market potential in the R&D area that is already being tapped through the

Figure 2. Promising market segments

Commercial Utilisation Development Areas

Research Field	**Relevant Applications**
Health	Pharmaceuticals, medical instrumentation
Biotechnology	Pharmaceuticals, biomedical products
New Materials	Aerospace, automotive, consumer goods, medical instrumentation
Process Improvements	Metals, electronics
Fluid Physics	Food, oil
Combustion	Fuel, automotive, aerospace

Publicity/Sponsorship	**Entertainment/Edutainment**
Product Placement	**Merchandising**

ESA Microgravity Application Programme (MAP), in which European non-space industry has been participating since 1995. This industrial participation is equivalent to almost one third of the total cost of the initial phase. Areas with commercial potential and interest for metal producers and refiners, car and aero-engine developers, energy producers, food and cosmetics companies, oil companies, pharmaceutical companies, medical instrumentation companies and others are:

- Innovative materials, products and processes (e.g. improved knowledge of the thermo-physical properties of metals, advanced foams, emulsions, high-quality crystals, high-performance alloys).
- Combustion processes (e.g. a better understanding of these processes leads to potential reductions in fuel consumption and pollution).
- Biotechnology and biomedical research with bioreactors.
- Research into osteoporosis.
- Tissue and cell engineering.
- Improved techniques for crew-health monitoring.

Such potential commercial applications need nurturing with pathfinder projects in order to foster their eventual growth into commercial processes and products.

(ii) Non-conventional activities
Advertising: Advertising offers short-term potential for revenue generation, but due consideration has to be given to the building-up of the ISS's image as an outpost for humanity devoted to advanced scientific and technological research.

Education: The possibility exists to broadcast lessons in real time on such subjects as physics, chemistry, biology and geography direct to schools from the Space Station. Although TV networks could pay for such ventures, it is unlikely that they will be big revenue producers. The main interest in this area is related more to image creation than to the generation of revenue.

Entertainment: Multimedia companies have already expressed strong interest in making films on the ISS, in using the ISS for broadcasting news, and in creating web-site links with real-time images involving crew members.

Sponsorship: Present indications are that the most promising market segment here is that of patronage or sponsorship of research by global companies that could benefit through association with a particular field, particularly research that benefits mankind, e.g. health- or environment-related.

Dedicated commercial flights: If there is sufficient demand, special flights to the ISS carrying commercial customers may be considered. These spaceflight participants would primarily be professionals in particular fields, such as industrial researchers, teachers, journalists, etc. In addition, there could be the possibility to involve private individuals, fully trained and willing to pay the associated costs to experience human spaceflight.

(iii) Commercial infrastructure and services
With its numerous laboratories and external mounting sites, the ISS offers excellent opportunities for introducing new infrastructures and services on a commercial basis targeted at special-interest groups or the general public. Typical examples might be the provision of a precise time signal from the Station for watch synchronisation, or the tracking/location of items like cars and transported goods.

The studies conducted for ESA have also indicated that:

- The potential markets have different development cycles. The R&D market is a medium- to long-term market, which needs nurturing as regards knowledge diffusion and financial support. The innovative markets have much shorter time scales, as current events in terms of space tourism and advertising show, but they can also be of a boom-and-bust nature, quickly disappearing if the public's interest wanes.
- All potential markets call for an improvement in the ISS's current image. Despite its size, complexity and attractiveness, the project has yet to receive the appropriate level of recognition vis-à-vis the scope that it offers for applied research or appropriate appreciation by the general public.
- The potential customers tend to be either large companies with significant research and marketing budgets (e.g. oil, pharmaceuticals) or 'niche' companies working in very specialised technological fields (medical equipment, mathematical modelling).
- Finally, before these customers will invest in the Space Station, there is a need to provide a business-friendly environment where access to the Station is based on a reliable schedule, confidentiality is guaranteed, and intellectual property rights are protected.

Commercial projects in space
The results of the studies that ESA commissioned have also provided the basis for creating contacts with potential customers. The

current development of the Microgravity Application Programme and the issue of a Call for Interest to the private sector in mid-2000 have allowed a set of initial projects with commercial potential in several markets to be created. These projects have different levels of maturity and times-to-market, depending on the degree of complexity of the activities involved (Fig. 3). They are essentially 'pathfinders' because their objective is to demonstrate that there is an actual demand for commerce on the ISS, and to explore the compatibility of the existing rules and procedures at ESA and the International Partners with future business needs.

The R&D-type projects originating from the MAP are currently in a pre-commercial stage, but several of them, especially those in the health, biotechnology and natural-resource exploration sectors, already look very promising for later commercialisation. The projects in the innovative-activities sector have shorter schedules, provide income, but offer a limited

Figure 3. Examples of commercial projects

Project	Market benefit	Industrial benefit	ESA contribution	Return to ESA	Countries involved
Research and Development					
Improvement of oil recovery and treatment of toxic liquid spillage	Availability of predictive models of liquid diffusion	Petro-chemical industry competitiveness and environmental protection	Sustain operational activities in the initial phase of the pathfinder project	Royalties from Intellectual Property Rights	Italy, France, the Netherlands, Norway and United Kingdom
Development of bioreactors technologies for tissue organisation / cell-matrix interaction	New bioreactor technologies allowing for commercial tissue formation, remodelling and repair	Bio-mechanical and bio-technology industry innovation	Sustain operational activities in the initial phase of the pathfinder project	Royalties from Intellectual Property Rights, products and processes	Switzerland, France, Germany
Development of treatments and monitoring equipment for osteoporosis and metabolism	Development of treatment and monitoring technologies	Pharmaceuticals and medical equipment industry innovation	Sustain operational activities in the initial phase of the pathfinder project	Royalties from Intellectual Property Rights, products and processes	France, Italy, Germany, Switzerland, the Netherlands, Finland, Canada
Physical-fitness equipment development	Development of specific exercise equipment	Medical equipment industry and leisure, sport industry	Sustain operational activities in the initial phase of the pathfinder project	Royalties from Intellectual Property Rights, products and processes	Sweden, France, Italy, United Kingdom, Germany
Non-conventional activities					
Sponsorship – Quality of life in the 21st century	Association with outstanding research on ISS	Image promotion for European corporations	Market research, Sponsorship package development	Funds for additional research and astronaut flights	All
Product placement	Association with space and ISS	Product demonstration, validation and promotion	N/A	Funds for additional research and astronauts flights	All
Commercial infrastructure and services					
ISS camera for commercial imaging	Urban mapping Crop control Harvest insurance	Government, local authorities Agriculture sector Insurance	Sustain operational activities in the initial phase of the pathfinder project	Payments of operational costs plus fee	All
GTS – Global Transmission Services	Provision of time synchronisation and asset location services	Watch, automotive, transportation industries	Sustain operational activities in the initial phase of the pathfinder project	Payments of operational costs plus fee	All

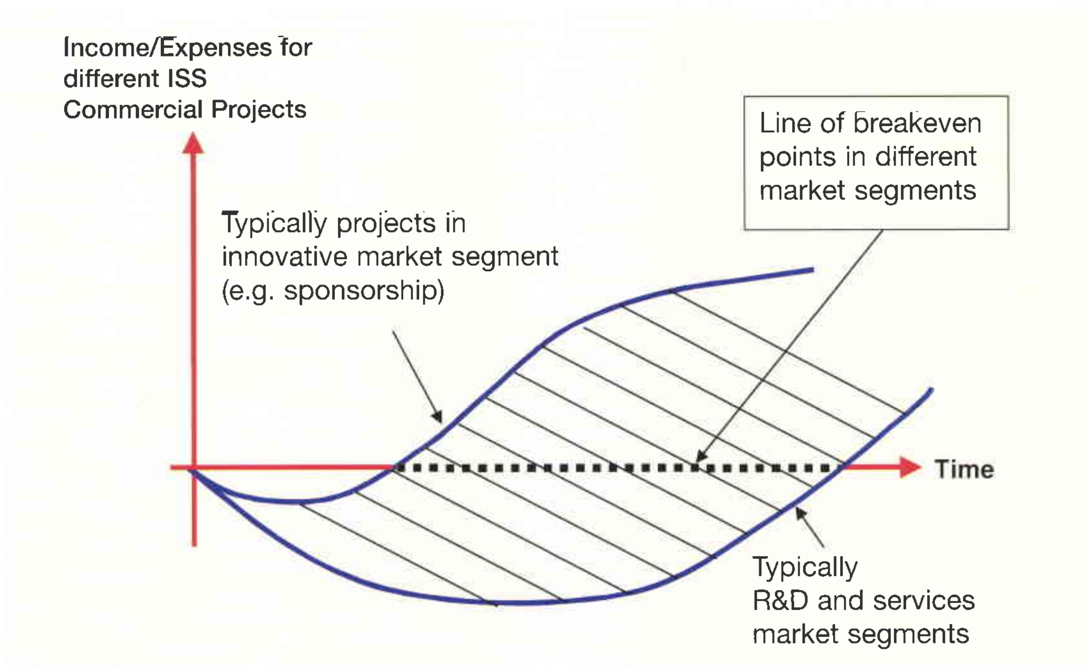


Figure 4. Income/expense model for ISS commercialisation

time window of opportunity. Together, however, they provide the commercial marketing effort for the ISS with an early start and cover the entire life cycle of the European ISS elements. Figure 4 shows the investment and return cycles for these projects; the R&D and services projects typically involve a longer and more intensive investment phase (initial part of the curve in the negative quadrant), before a balance is achieved between the expenses incurred and the income received (breakeven point).

This promising start has prompted ESA to offer further opportunities for commercial projects on a more permanent basis and the new 'Open Call for Commercial Proposals' can be found at: www.esa.int/spaceflight/isscommercialisation.

The legal framework

Attracting customers to the Space Station requires a set of commercial conditions to be put in place that provides for easy, reliable and confidential access. Figure 5 highlights the different conditions sought by commercial

Access Categories	Institutional Access	Commercial Access
Utilisation objective	Maximise scientific return Promote industrial research and development	Maximise economic return on investment
Type of Activities	Fundamental and applied research or pre-competitive technological development	Any, as long as compatible with ISS image
User Rights	Exclusive access to experimental results for one year; thereafter public access to data	Time-, market- or geographically-limited exclusivity rights Exclusive intellectual property rights
Origin	Academia, research institutes and industries from those ESA Member States[1] which contribute to ISS Exploitation	Any user from ISS Partner States [2], who pays the full price for ISS resources and services
Evaluation	By peer or merit review	By image review By business plan review in case of deferred payments
Priority	According to scientific and/or application value	According to 'first come first served' principle
Funding Source	ISS services and resources are provided to users through the contributions of the ESA Member States to the ISS Exploitation.	Users to purchase ISS services and resources from ESA or Business Developer(s).

Figure 5. Access categories

[1] ESA Member States are Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Italy, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and United Kingdom. States, that are underlined contribute currently to ISS Exploitation. In case of co-operative research proposals, users from non-contributing States and non-ESA Member States can also be granted access to ISS under certain conditions.

[2] ISS Partner States are all ESA Member States, United States, Russia, Canada, Japan. Users from other States may be granted access to ISS subject to approval by all Partner States.

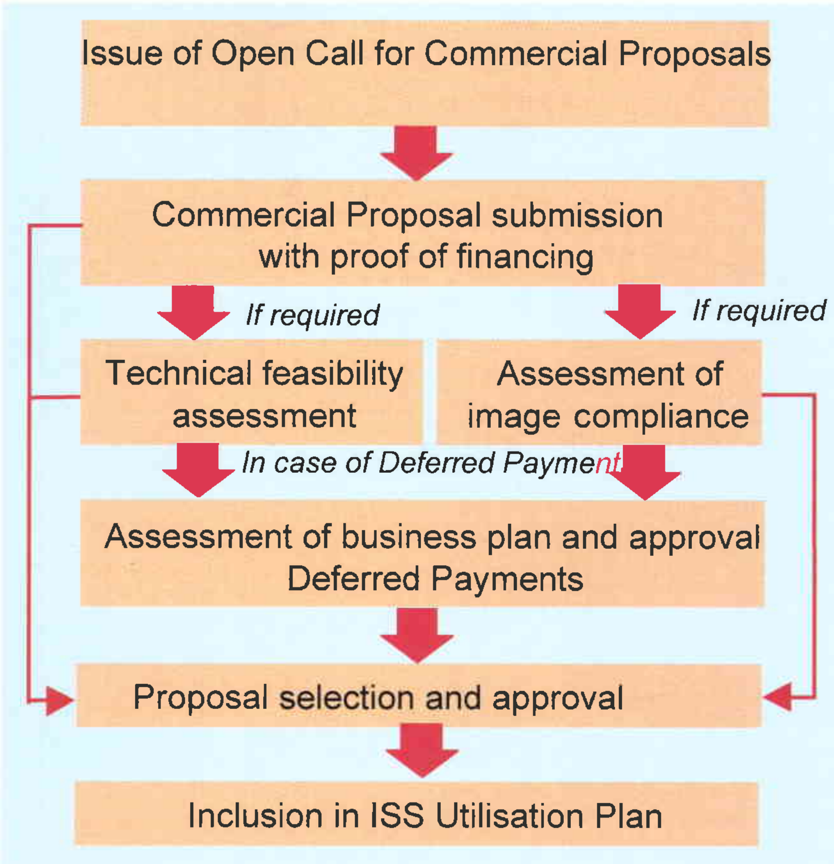


Figure 6. Commercial access route

customers compared with the traditional institutional access rights provided to programmes fully financed by the ESA Member States. Some of the major issues relating to the legal framework are highlighted below.

Evaluation and selection of commercial proposals
ESA is proposing a Commercial Access approach to potential customers, who are encouraged to respond to the Open Call for Commercial Proposals (Fig. 6). Within this process, private entities presenting commercial projects will have to provide a minimum set of information of a technical and financial nature. If financial support from ESA is requested, the proposal will have to be supplemented with a complete Business Plan.

The evaluation process will be based on three main elements:
- *Technical Feasibility Assessment*: If the proposal requires a payload to be transported to the ISS, the technical feasibility and safety aspects will need to be assessed. ESA has to certify that payloads meet safety requirements and plans.
- *Compliance with the ISS Image*: ESA wishes to protect the image of the ISS and will therefore assess the impact of any commercial proposal on the image of the Station and that of the participating space agencies.
- *Proof of Financing*: The customer must supply proof of their ability to finance the utilisation project, underwritten where necessary by financial institutions.

Fully self-financed commercial proposals, which are both technically feasible and are compliant with the ISS's image, will be selected by ESA on a 'first-come, first-served basis'.

Schedule
Reliability of the schedule for flights to and from the Space Station is of the utmost importance for commercial customers. However, the time needed from the selection of a business proposal to the actual launch of a payload to the International Space Station is payload-specific. For simple payloads, this period will typically be one year, and somewhat shorter in the case of a re-flight. For passive payloads (e.g. no power or communication interfaces required), the time to flight can be as short as three months. What ESA can offer to

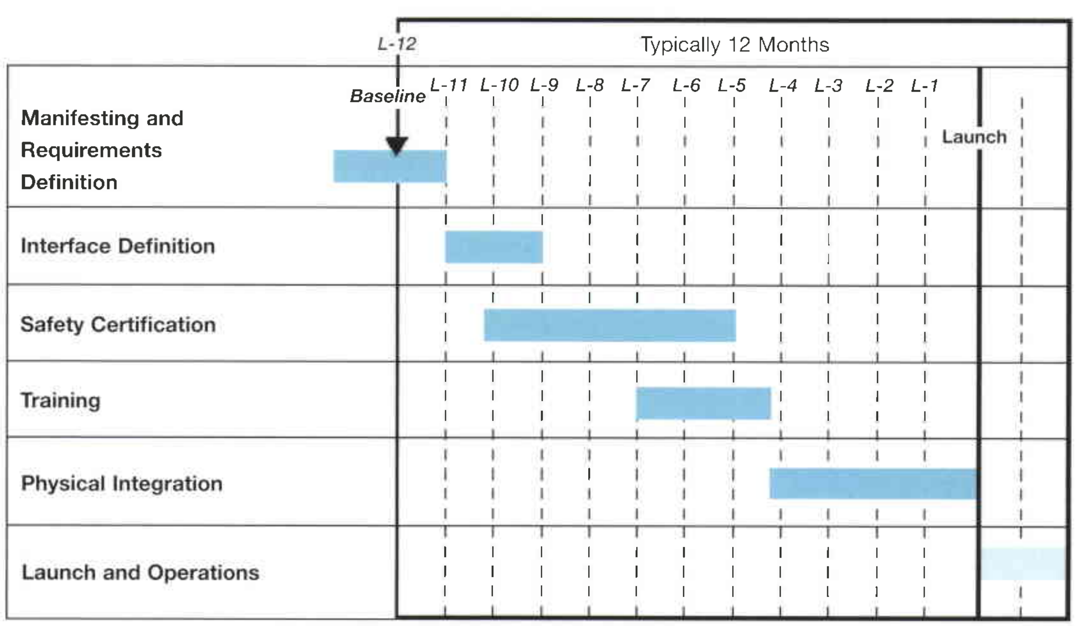


Figure 7. Access schedule

customers is, in any case, a standard set of activities for physically accessing the Station. Figure 7 shows the activities involved in preparing a simple payload for launch and their average duration. For media and commercial communications-related projects, the schedule may be much shorter, if no payload needs to be physically transported to the Station.

Intellectual property
ESA is currently in the process of reviewing its overall approach to intellectual property and defining the specific framework for ISS commercialisation in this respect. The principles envisaged in the commercialisation context are focussing on two main hypotheses:
- In cases where exploitation and project costs would be fully funded by the commercial customer, the intellectual property rights would remain with the customer.
- In cases where ESA would provide a non-reimbursable contribution, the intellectual property rights would be shared with the customer in relation to such funding, such sharing being negotiated on a case-by-case basis.

These principles remain to be confirmed within the overall ESA Intellectual Property Rights (IPR) policy, and to be elaborated in detail for implementation in the ISS commercialisation context. It is envisaged that the negotiation of IPRs will be a function of the funding being contributed by the respective customer and by ESA for each specific project.

Confidentiality
The Inter-Governmental Agreement (IGA) between the ISS Partners provides for confidentiality rules for the exchange of data within the ISS cooperation. In implementing the services carried out on behalf of customers, ESA will take all reasonable measures within this environment to provide conditions that protect customers' interests to the greatest extent possible. A minimum of information for safety certification will always have to be provided. Safeguards of confidentiality for proprietary data are also foreseen by the IGA in this respect. The IGA foresees the possibility of placing adequate markings on documents, software and equipment, to indicate the existence of proprietary information.

Product	Quantity	Price*
Accommodation:		
EDR locker, inclusive of standard services	1 locker for 3 months inclusive of: - 3 crew hours - 100 kWh	830 kEuro
EDR drawer, inclusive of standard services	1 drawer for 3 months inclusive of: - 4 crew hours - 130 kWh	1050 kEuro
Research Facility:		
ESA MFC facility or external facility	1 facility per day** including: - 15 crew minutes - 8.5 kWh	70 kEuro
Basic payload support	1 kg payload	10 kEuro
Communication Services:		
Data Rate	1 min of TDRSS link	100 USD***
Transportation Services:		
Pressurised up/downmass	1 kg (each way, passive cargo)	22 kUSD
Unpressurised up/downmass	1 kg (each way, passive cargo)	26.5 kUSD
Additional Resources and Services		On demand
Media and Commercial Communication		On demand

Note: specific customers' requirements will be agreed on a case-by-case basis

* Prices are applicable for customers from States contributing to ISS exploitation. Prices for customers from other States will be agreed on a case-by-case basis.
** Several customers may share the usage of one facility, thus reducing the individual cost.
*** Prices in US dollars refer to services provided via NASA and are subject to NASA pricing provisions.

Figure 8. Price list

Prices
ESA has established a transparent pricing structure for customers wishing to exploit the European portion of the ISS commercially. This pricing policy constitutes a reference for the agreement of commercial transactions with ESA. It will be updated periodically depending on prevailing market conditions and developments.

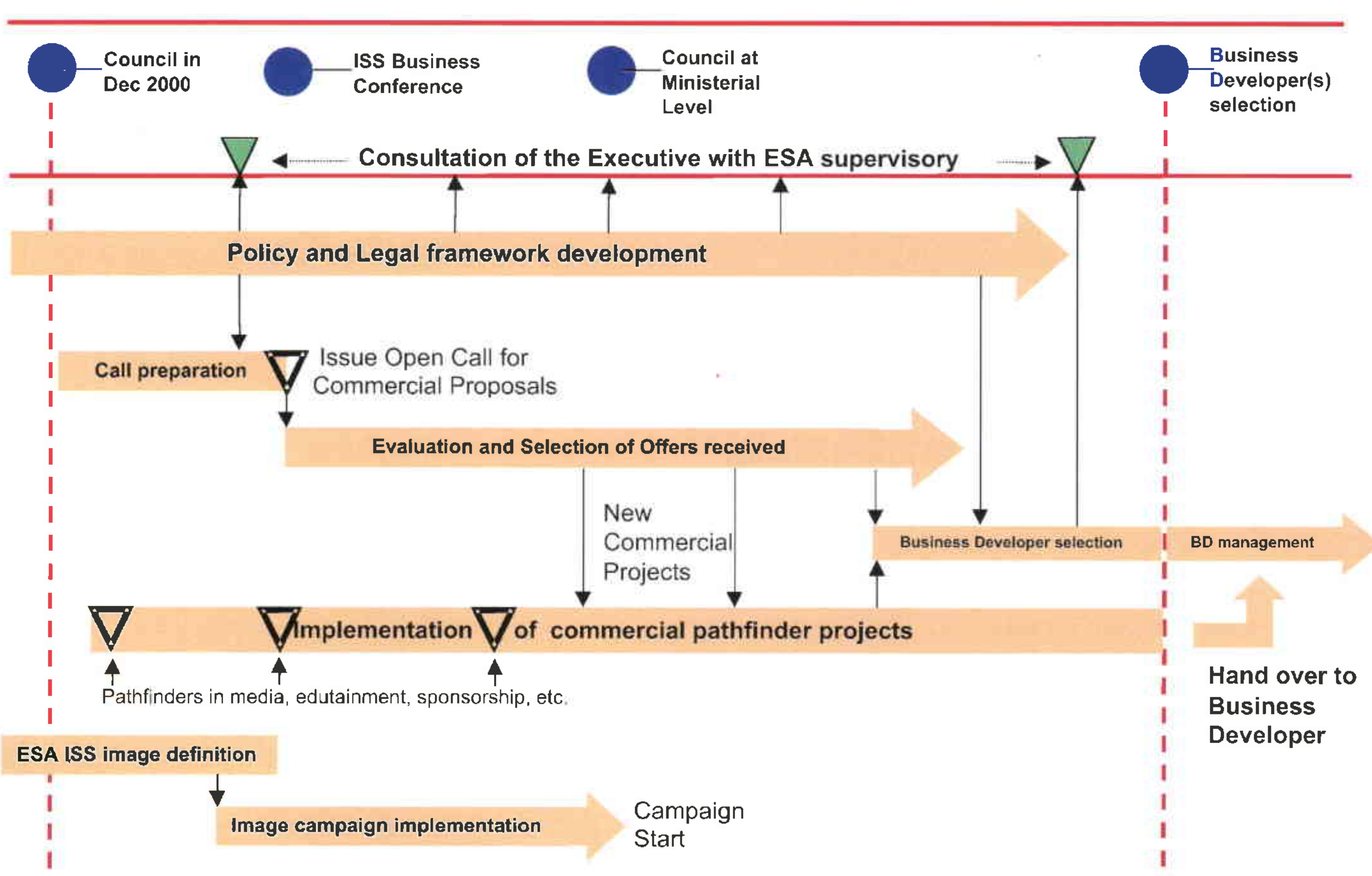
The prices quoted have been tailored to the basic facilities and services that ESA will have available on the ISS, mainly within the Columbus laboratory. They include the use of drawers and lockers by customers wishing to provide a complete payload experiment, and of the Microgravity Facilities – Biolab, European Physiology Modules, Fluid-Science Laboratory and Material-Science Laboratory – for experiments with standard samples. The prices shown in Figure 8 are valid for 2001.

Promoting the ISS's image
Awareness of the International Space Station needs to be increased within the market segments being targeted. But what are the messages about the ISS that should be spread? What makes the ISS commercially attractive for research and communication purposes? An ISS image concept has been defined by ESA focussing on:
- the great achievement of putting this first-class research facility into space – the human achievement, the technology development and the global co-operation that have made the ISS a reality; the scale of the project, and the size of ISS itself are unique
- the ISS is real – it is already up there, the largest outpost in space to be permanently inhabited
- the ISS is relevant – it has potential benefits for both companies and individuals.

The communication plan has a phased approach with short-, medium- and long-term objectives, emphasising respectively: general awareness of the ISS, its potential exploitation benefits for European industry, maintenance of interest in the ISS, and the consolidation of brand values. The target audiences will primarily be the general public, the business community and the scientific community. The communication media will consist of the specialised press, specialised advertising, seminars, scientific/educational material, direct promotion, edutainment programmes, web sites and sponsorship events.

In parallel, the market-analysis effort will be maintained to monitor market evolution, to adapt the promotion strategies, and to respond to customers' demands with the development of adequate services for the major commercial ISS market segments.

Figure 9. ISS commercialisation strategy



Milestones and activities not to time scale

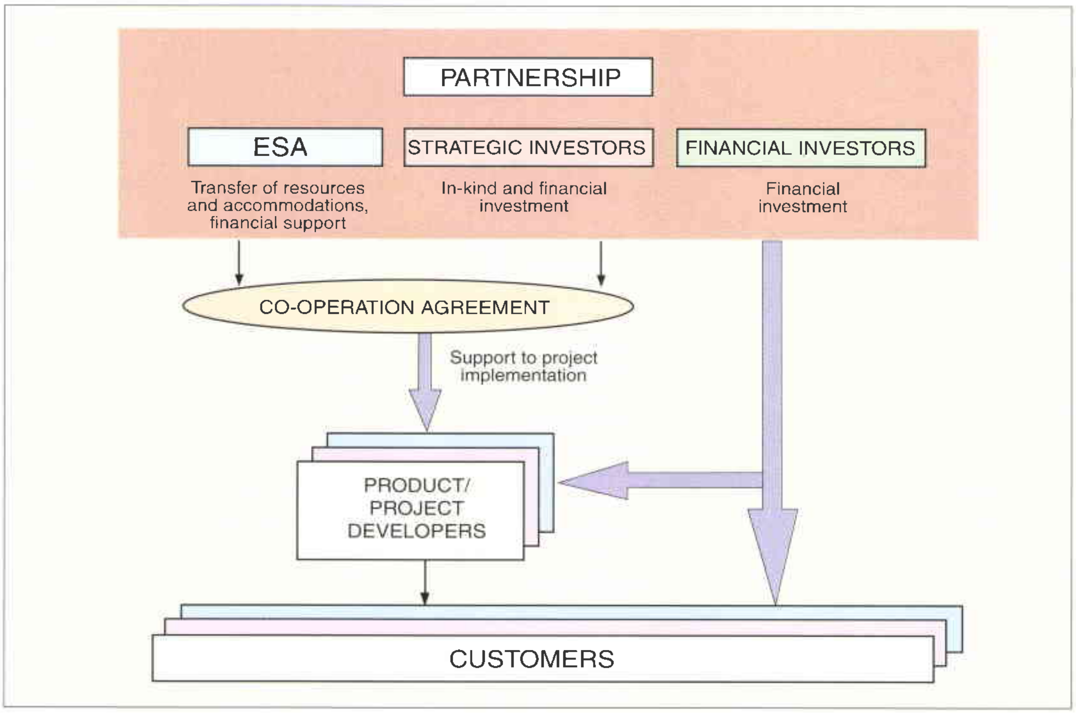


Figure 10. Public-Private Partnership model

The development and maintenance of an adequate ISS image will be safeguarded by the definition of criteria with which commercial activities will have to comply. The Agency is developing a Charter containing image compliance criteria, encompassing such aspects as the peaceful uses of the ISS, the legality of activities, coherence with agreements with the International Partners, etc.

The strategic approach

ESA's overall strategy in approaching Space Station commercialisation is founded on the activities described above and is summarised in Figure 9. The concerted actions of easing the legal environment, attracting customers and implementing pathfinder projects have the strategic objective of enabling the growth of one or more 'Business Developers' willing to assume overall responsibility for developing the European market for the ISS. In this scenario, ESA would make available the resources and facilities and the Business Developer would select the commercial projects to be implemented. This collaboration could take the form of a Private-Public Partnership (Fig.10) whereby ESA and strategic investors like the space industry, and with institutional investors such as financial entities, form an alliance to nurture the market and select and support the first commercial businesses to venture into space.

Conclusion

The potential market associated with the commercial utilisation of the International Space Station encompasses a wide set of segments ranging from pure R&D to highly innovative commercial activities. ISS commercialisation is therefore a process that is strongly market driven, which demands that the Agency review its conventional way of doing business in order to make the customer the focus of attention. The ESA strategy therefore responds to the needs that have been expressed by the market in striving towards full utilisation of the Space Station's capabilities, carefully matching the needs of business with the wishes and objectives of the Agency's Member States. To support such a strategy, a period of market nurturing and the involvement of European Business Developers is necessary. Such support has to cover technical, human and financial means, possibly being implemented within the framework of an alliance between the Agency and private entities willing to co-invest in this process.

By harnessing all of this knowledge and expertise – political, commercial and industrial – Europe will have an excellent chance of playing a competitive role in the emergence of the International Space Station as a new market place in space.

Acknowledgement

The author wishes to thank P. Graziano, B. Hufenbach, V. Kayser and G. Peters for their contributions to the ISS commercialisation effort, without which this article could not have been written.

Feedback

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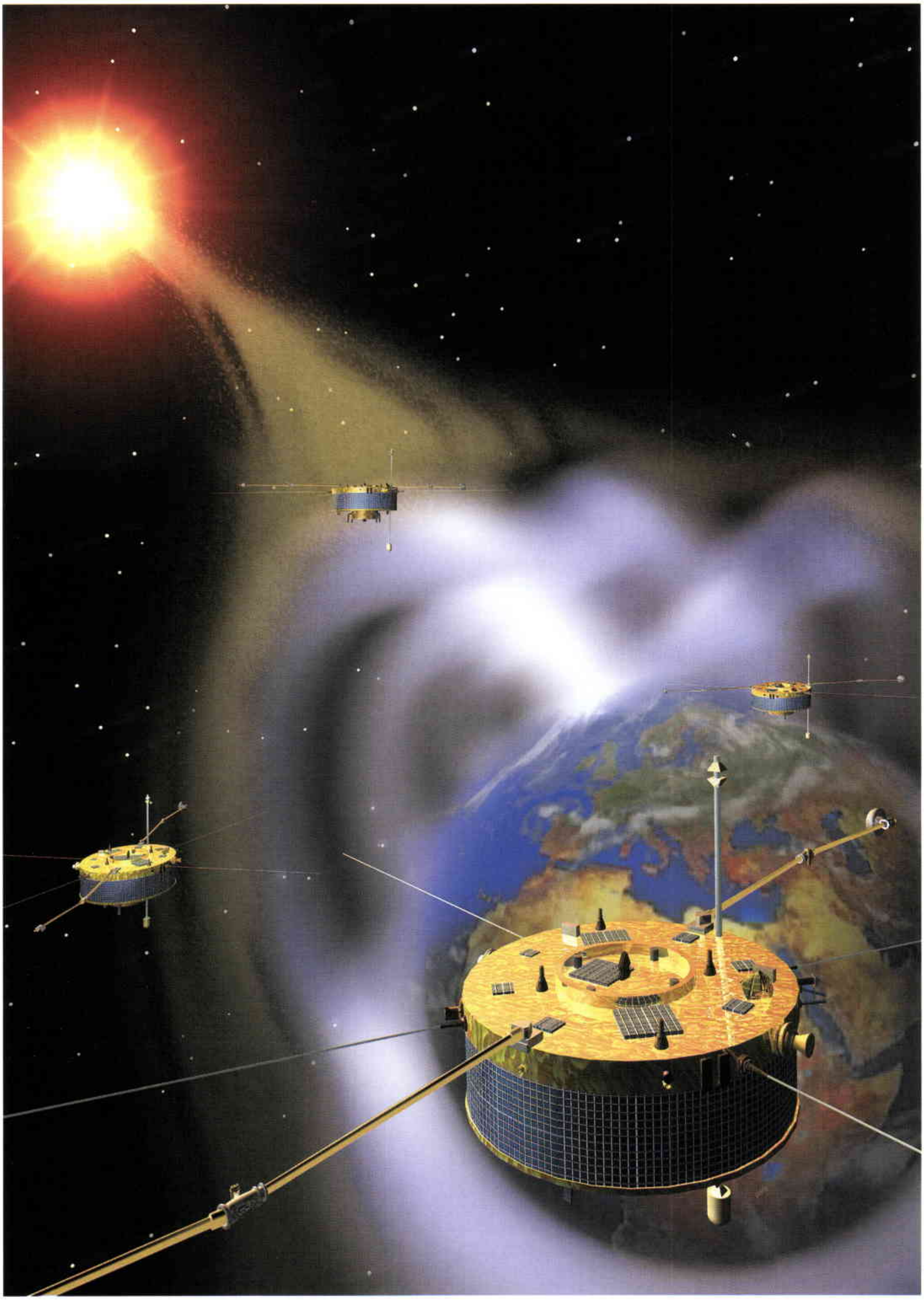

Rumba, Salsa, Samba and Tango in the Magnetosphere
- The Cluster Quartet's First Year in Space

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The four Cluster spacecraft were successfully launched in pairs by two Russian Soyuz rockets on 16 July and 9 August 2000. On 14 August, the second pair joined the first pair in highly eccentric polar orbits, with an apogee of 19.6 Earth radii and a perigee of 4 Earth radii. The very accurate orbital injection and low fuel consumption mean that spacecraft operations could continue for at least two more years after the nominal two-year mission.

This is the first time that the Earth's magnetic field and its environment have been explored by a small constellation of four identical spacecraft. Preliminary results show that, as predicted, with four spacecraft we can obtain a detailed three-dimensional view of the Sun-Earth connection processes taking place at the interface between the solar wind and the Earth's magnetic field.

Introduction
Cluster is one of the two missions – the other being the Solar and Heliospheric Observatory (SOHO) – constituting the Solar Terrestrial Science Programme (STSP), the first 'Cornerstone' of ESA's Horizon 2000 Programme. The Cluster mission was first proposed in November 1982 in response to an ESA Call for Proposals for the next series of scientific missions.

After the Ariane-5 launcher failure on 4 June 1996 and the destruction of the four original Cluster spacecraft, the Cluster scientists convinced the ESA Science Programme Committee (SPC) that it was essential for the European scientific community to rebuild the mission. This was agreed by the SPC in April 1997. In the meantime, SOHO, launched in December 1995, had begun to make some very exciting discoveries about the Sun and its environment. Now, with the successful launch of the rebuilt Cluster satellites, the STSP Cornerstone is complete and it is possible to combine these two missions in order to study the full chain of processes from the Sun's interior to the Earth.

Launch and commissioning phase
When the first Soyuz blasted off from the Baikonur Cosmodrome on 16 July 2000, we knew that Cluster was well on the way to recovery from the previous launch setback. However, it was not until the second launch on 9 August 2000 and the proper injection of the second pair of spacecraft into orbit that we knew that the Cluster mission was truly back on track (Fig. 1). In fact, the experimenters said that they knew they had an ideal mission only after switching on their last instruments on the fourth spacecraft.

After the two launches, a quite lengthy verification phase for all spacecraft subsystems and the payload of 44 instruments (Table 1) started. The 16 solid booms, eight for the magnetometers and eight for communications, were successfully deployed. A few days later, the spacecraft had to survive the first long eclipses, with up to 4 h of darkness, which they did with very good performances from the onboard batteries.

Then started the verification phase for the 11 sets of instruments. This phase was complicated by the fact that, to perform their measurements, some instruments had to deploy very long wire antennas. These 44 m antennas altered the spin rate of the spacecraft, which was incompatible with the particle instruments that needed a fixed spin rate. Altogether, more than 1100 individual tasks were performed on the instruments. At the end of this phase, in early December, a two-week 'interference campaign' was conducted to test how much the instruments influenced each other. After successfully testing all the instruments, the nominal operations phase began on 1 February 2001. Some of the results that are presented below were obtained during the commissioning and verification phase.

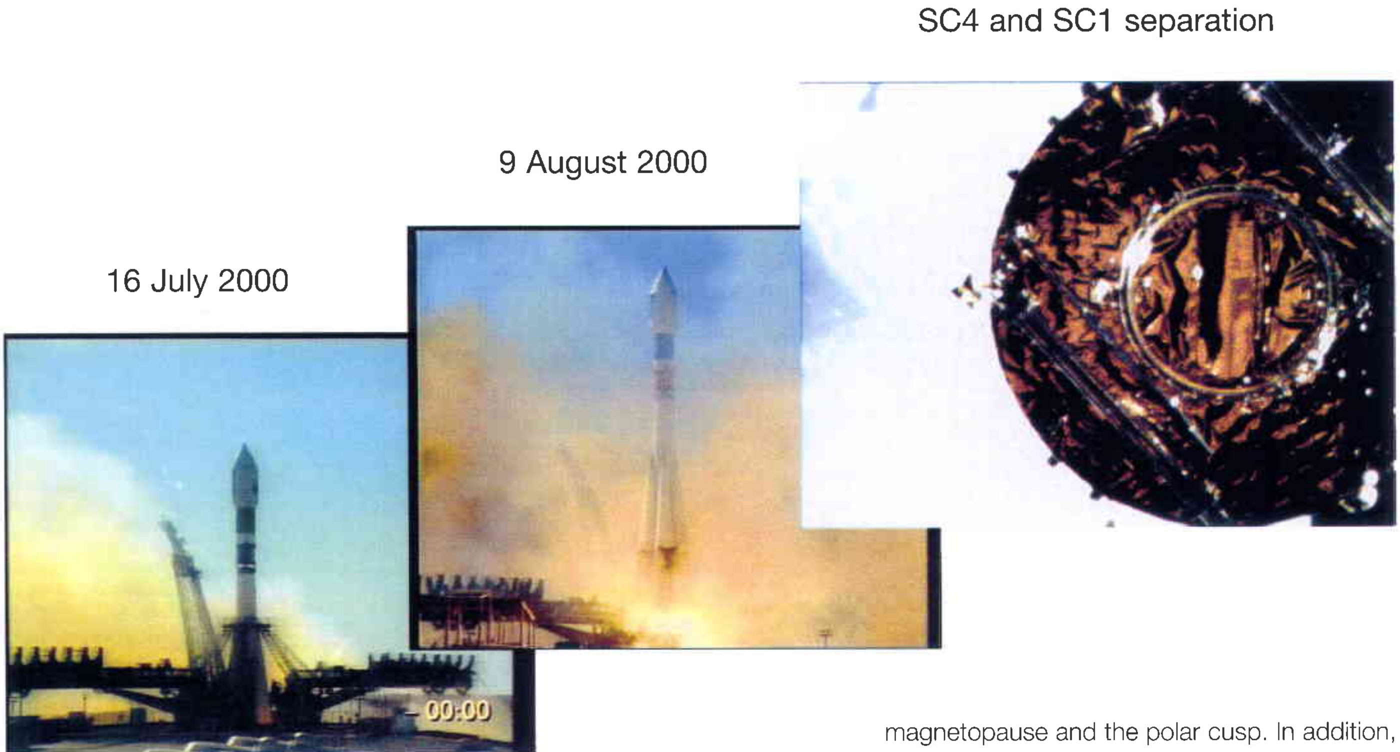


Figure 1. The two launches of the Cluster spacecraft on two Soyuz-Fregat rockets, on 16 July and 9 August 2000. An onboard camera took 27 pictures when Rumba-SC1 separated from Tango-SC4. Tango is shown in the upper-right corner. The Earth can be seen in the background

The Earth's magnetosphere is a very large volume of space extending about 65 000 km in the Sun's direction, and more than two million km in the opposite direction. The Earth's magnetic field dominates this space. Without the continuous flow of plasma (electrically charged particles) from the Sun, the Earth's magnetic field would be a dipole with a symmetric magnetic field around the polar axis. Instead, the solar wind compresses the magnetosphere on the front side and shapes it into a long tail in the anti-sunward direction (Fig. 2). During the first months of operations, the spacecraft orbits allowed Cluster to visit key regions of the magnetosphere – the bow shock, the magnetopause and the polar cusp. In addition, unique data were obtained during a strong solar storm that occurred in November 2000.

The bow shock

The bow shock is the surface that forms in front of the Earth's magnetosphere when the supersonic solar wind slams into it at a speed of about 400 km/s (around 1.5 million km/h). This is similar to the shock wave (or sonic boom) when a plane flies faster than the speed of sound in the atmosphere. The bow shock slows down the solar wind and deflects it around the magnetosphere. In the process, the particles – electron and ions – are heated and the strength of the magnetic field is increased. Intense electromagnetic waves are also produced at the shock.

Figure 3 shows the electric waves detected by the WHISPER instrument during two crossings of the bow shock by the four Cluster spacecraft. On the plot, which covers a period of 40 minutes, the wave frequency is shown as a function of time. The power of the waves is plotted in false colours: red/brown for the most intense and blue for the less intense.

The bow shock is characterised by an intense wave-emission enhancement below 20 kHz that is observed around 08:25 and 08:35 UT. The crossings do not occur at the same time for all spacecraft due to their different positions, which were about 600 km from each other at that time. The right panel of Figure 3 shows the spacecraft configuration at the first crossing, when they were located on the right flank of the bow shock. A closer view of the spacecraft configuration is shown in the middle-right and bottom-right panels.

Table 1. The 11 instruments on each of the four Cluster spacecraft

Instrument	Principal Investigator
ASPOC (Spacecraft potential control)	K. Torkar (IWF, A)
CIS (Ion composition)	H. Rème (CESR, F)
EDI (Plasma drift velocity)	G. Paschmann (MPE, D)
FGM (Magnetometer)	A. Balogh (IC, UK)
PEACE (Electrons)	A. Fazakerley (MSSL, UK)
RAPID (High-energy electrons and ions)	P. Daly (MPAe, D)
DWP * (Wave processor)	H. Alleyne (Sheffield, UK)
EFW * (Electric field and waves)	M. André (IRFU, S)
STAFF * (Magnetic and electric fluctuations)	N. Cornilleau (CETP, F)
WBD * (Electric field and wave forms)	D. Gurnett (IOWA, USA)
WHISPER * (Electron density and waves)	P. Décréau (LPCE, F)

** Wave Experiment Consortium (WEC)*

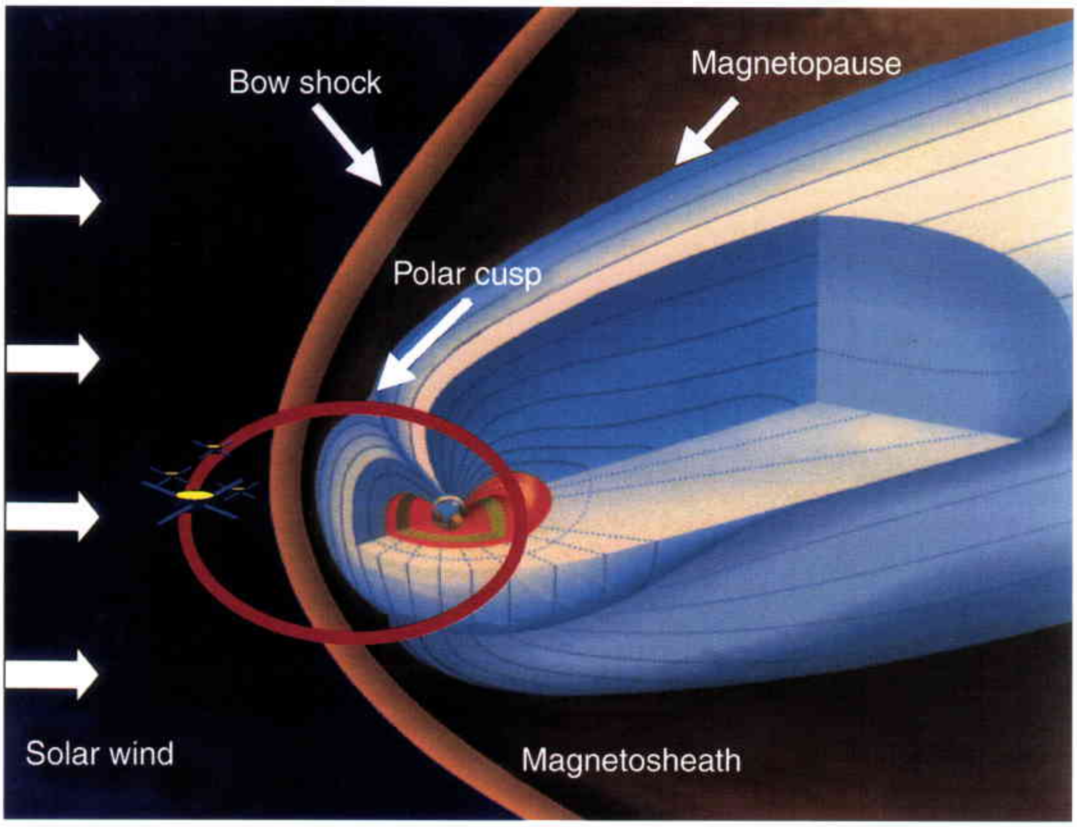
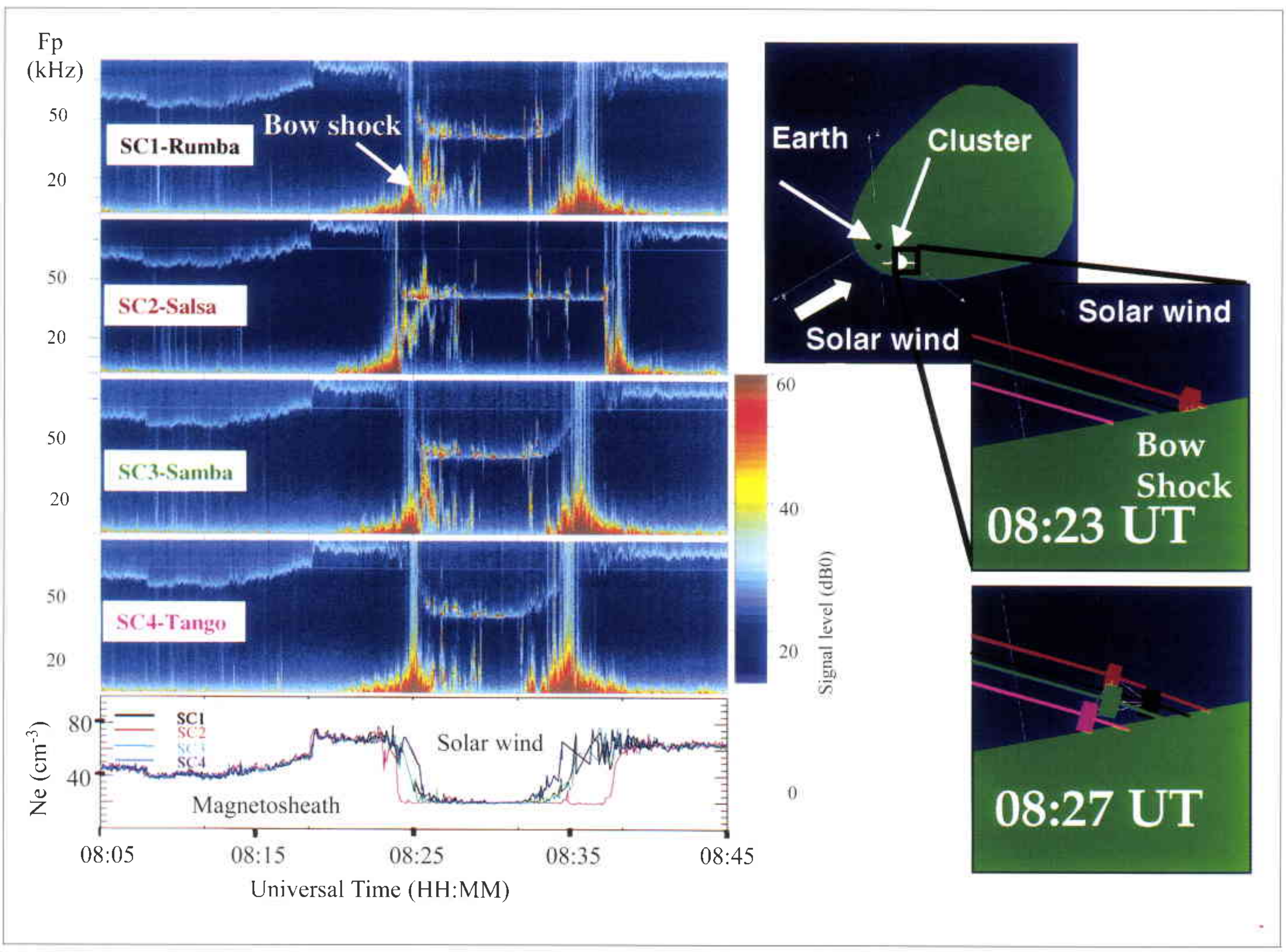


Figure 2. The Cluster orbit and the regions crossed during the first phase of the mission

Figure 3. Bow-shock crossings by each of the four Cluster spacecraft on 22 December 2000. The left panels show the frequency/time spectrograms of the electric waves observed by the WHISPER instrument. Between about 08:25 and 08:35 UT, the spacecraft were in the solar wind. The diagrams on the right show the Cluster configuration during the bow-shock crossing, in an overall view (upper panel) and two enlarged views at 08:23 UT (middle panel) and 08:27 UT (bottom panel). The spacecraft and their trajectories are colour-coded: spacecraft 1 (Rumba-SC1) is shown in black, Salsa-SC2 in red, Samba-SC3 in green, and Tango-SC4 in magenta. Data courtesy of WHISPER Principal Investigator, P. Décréau (LPCE, France)



Since the bow shock usually moves faster than the spacecraft, the latter can be considered immobile with the bow shock is moving through the group. This motion is due to an increase in the pressure of the solar wind (acting like a piston) on the magnetosphere, which pushes the bow shock closer to the Earth. It is clear from the figure that spacecraft 2 crossed the bow shock first, and then the other spacecraft followed. A few minutes later, around 08:35 UT, the pressure decreased again and the bow shock crossed the spacecraft in the opposite direction.

The second crossing was a little different because the wave emission appears slightly broader and stronger. Emission of electric waves at the plasma frequency is seen on the spectrograms as a light blue line. From this emission, the absolute electron density of the plasma can be deduced (shown in the lower panel).

At first, the satellites were flying through the magnetosheath (Fig. 2), which is characterised by a high particle density of between 40 and 70 cm^{-3}. After the crossing of the bow shock, the density in the solar wind decreased to around 20 cm^{-3}. An interesting difference between spacecraft 2 and the other spacecraft is observed before the spacecraft again crossed the bow shock at around 08:35 UT. Spacecraft 1, 3 and 4 observed a gradual increase in density from 20 to 70 cm^{-3}, which took about 3 to 4 min, while on spacecraft 2 this increase was very sharp, taking less than 1 min. This is an interesting observation, which shows that the bow shock can have different properties on quite short spatial scales, typically less than 600 km. Further studies will be conducted to understand the small-scale structures of the bow shock.

Figure 4 is another example of a bow-shock crossing. Here the magnitude of the magnetic field is plotted as a function of time for the four spacecraft. In the supersonic solar wind (upstream of the bow shock), the magnetic field is low, around 10 nT in this example, and high in the decelerated solar wind or magnetosheath (downstream of the bow shock), at around 30 nT. The bow shock was first hovering very close to spacecraft 2, from 06:50 to 07:03 UT, as seen in the multiple drops in its magnetic-field data, then moved sunward of all four spacecraft from 07:03 to 07:12 UT. Later, from 07:12 to 07:19 UT, it stayed between spacecraft 2 and the other three spacecraft. The crossing of the bow shock by the four satellites gives, for the first time, a direct measurement of the bow-shock speed - between 5 and 6 km/s.

The magnetopause

Inside the bow shock is the magnetopause, the external boundary of the Earth's magnetic field. The magnetopause is characterised by a discontinuity of the magnetic field, a sudden change in particle distribution function and large emissions of electromagnetic waves. In the following example, the magnetic field and the wave data will be used to study its geometry.

The top panel in Figure 5 shows the north-south component (B_z) of the magnetic field and

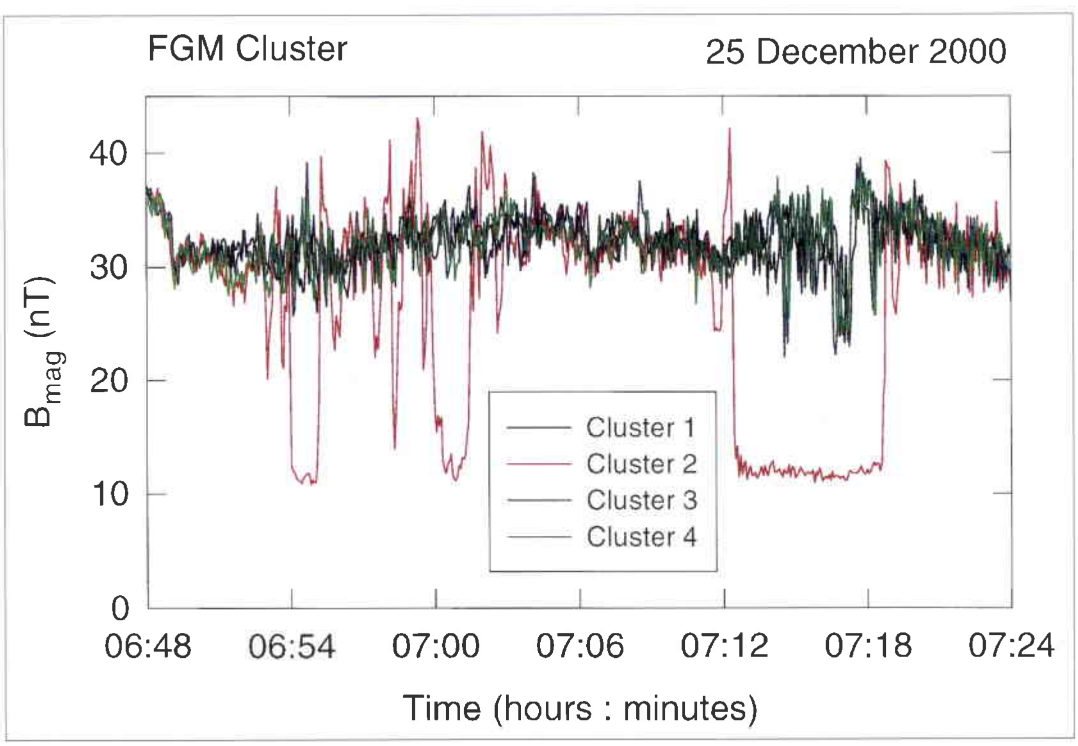


Figure 4. Multiple bow-shock crossing by Salsa-SC2 on 25 December 2000. The magnitude of the magnetic field from the FGM instrument is plotted as a function of time. A high value means that the spacecraft are in the magnetosheath, and a low value means that they are in the solar wind. The frequent drops in the magnetic field on Salsa-SC2 indicate the bow-shock crossings. Data courtesy of FGM Principal Investigator, A. Balogh (Imperial College London, UK)

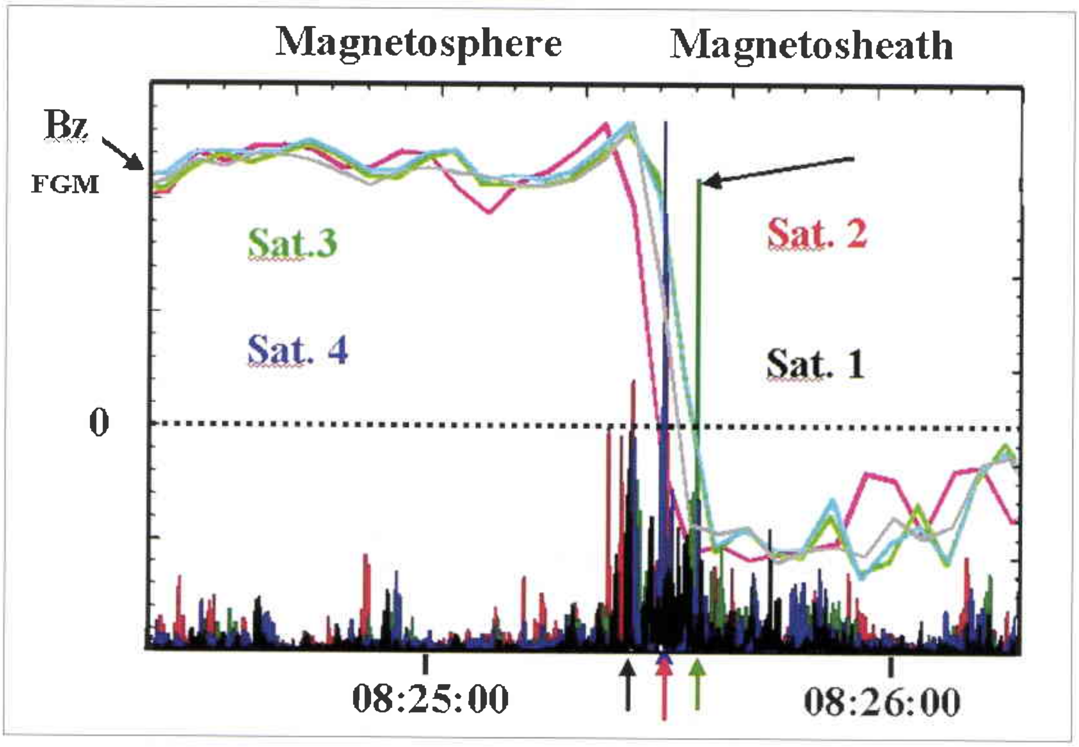
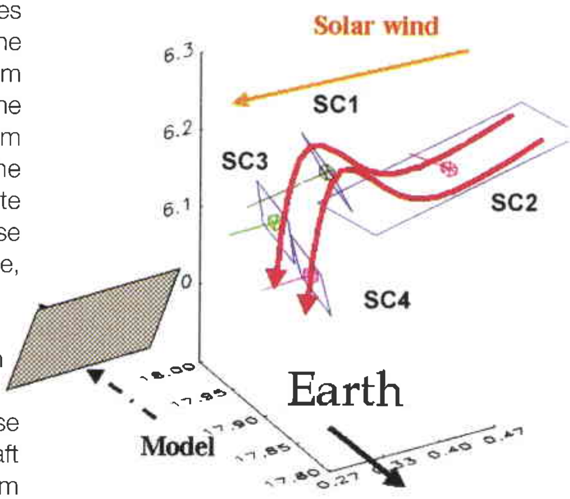


Figure 5. Magnetopause crossing by the four spacecraft on 10 December 2000. The B_z component of the magnetic field is plotted as a function of time (high value means inside the magnetosphere, and low value means outside). In addition, the integrated wave power from the STAFF instrument is plotted as a function of time. The maximum in the wave power (marked at the bottom by an arrow) indicates the magnetopause crossing. The diagram at the bottom shows the magnetopause surface and its normal plane detected by the four spacecraft. A wave passing by the spacecraft is shown in red.
Data courtesy of STAFF Principal Investigator, N. Cornilleau-Wehrlin (CETP, France), and FGM Principal Investigator, A. Balogh (Imperial College London, UK)

the total emission power of the magnetic waves generated around the magnetopause. The magnetopause is defined by the maximum power of the waves corresponding to the change in sign of B_z. The arrows at the bottom of the plot show the exact time of the magnetopause crossing. It is interesting to note that spacecraft 1 crossed the magnetopause first, then spacecraft 2 and 4 at the same time, and finally spacecraft 3.

Using a minimum-variance analysis, which means looking for a system where the variations in B are minimal, the magnetopause plane can be defined for each spacecraft crossing. The result is shown in the bottom panel of Figure 5. The individual spacecraft positions as well as the magnetopause plane are shown. It is clear that spacecraft 1, 3 and 4 detected the magnetopause in approximately the same plane, while spacecraft 2 detected it in an almost perpendicular plane. This observation cannot be explained by a usual planar magnetopause surface, but instead by a wave propagating along the magnetopause. The speed of this wave has been estimated at around 70 km/s. A simulation of this wave is shown in Figure 6. It is clear from this example that all four spacecraft are needed to measure the three-dimensional properties of the magnetopause. With two or three spacecraft, we could have missed the wave.



The polar cusp

The polar cusp is the 'window' above the northern and southern polar regions where the particles from the solar wind can penetrate directly into the magnetosphere (Fig. 7, top panel). Given their location at the outer boundary of the magnetosphere, the polar cusps react rapidly to changes that occur in the solar wind. For instance, when the solar wind changes from a north- to a south-pointing magnetic field, the cusp moves to lower latitudinal positions. On the other hand, when the solar-wind magnetic field changes to an azimuthal direction, the polar cusp moves longitudinally. The motion of the cusp is, therefore, a key element in the Sun–Earth interaction.

Until now, the polar cusp had only been observed by single spacecraft, so its motion could only be deduced indirectly from statistical analysis by combining many crossings. With Cluster, four spacecraft are visiting this region for the first time, allowing the speed of the polar cusp to be measured directly.

Figure 6. Simulation of a wave on the magnetopause's surface passing by the spacecraft. The wave is seen from the top in the top panel and from the side at two successive times in the middle and bottom panels. Simulation by Medialab, Leiden, NL

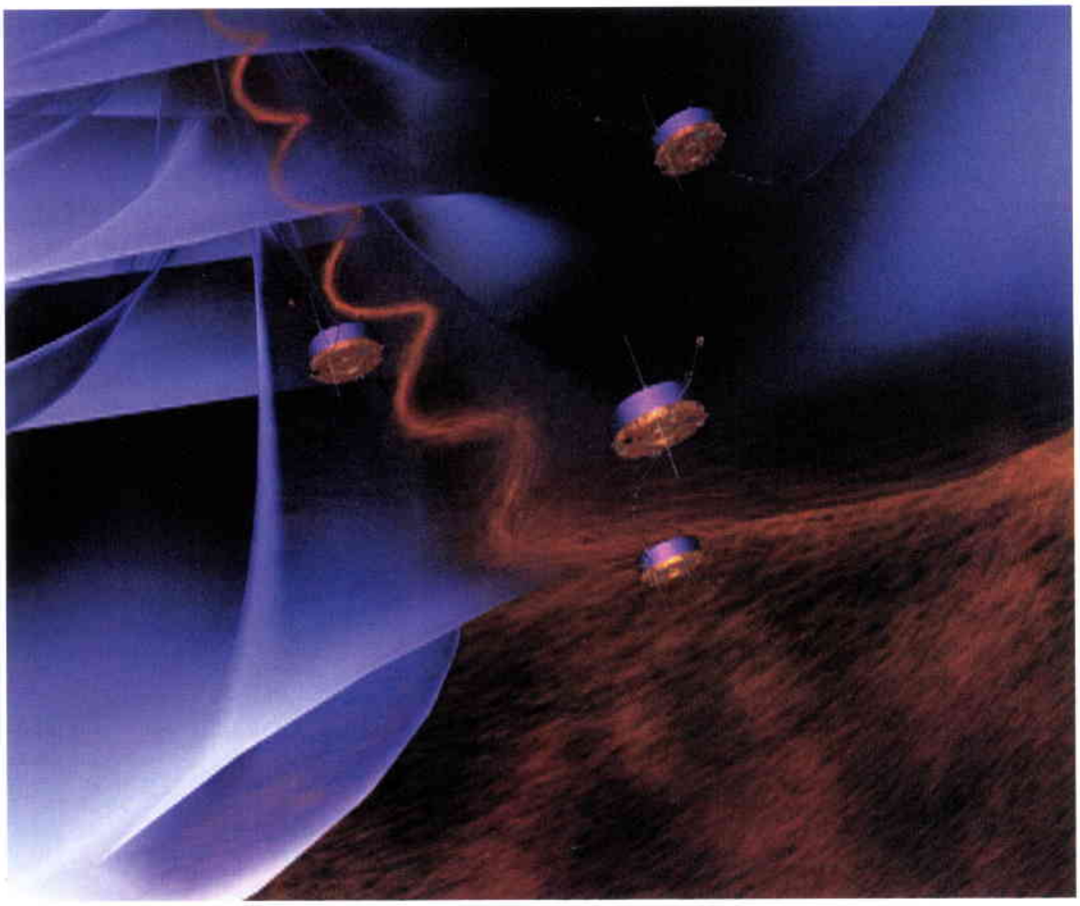
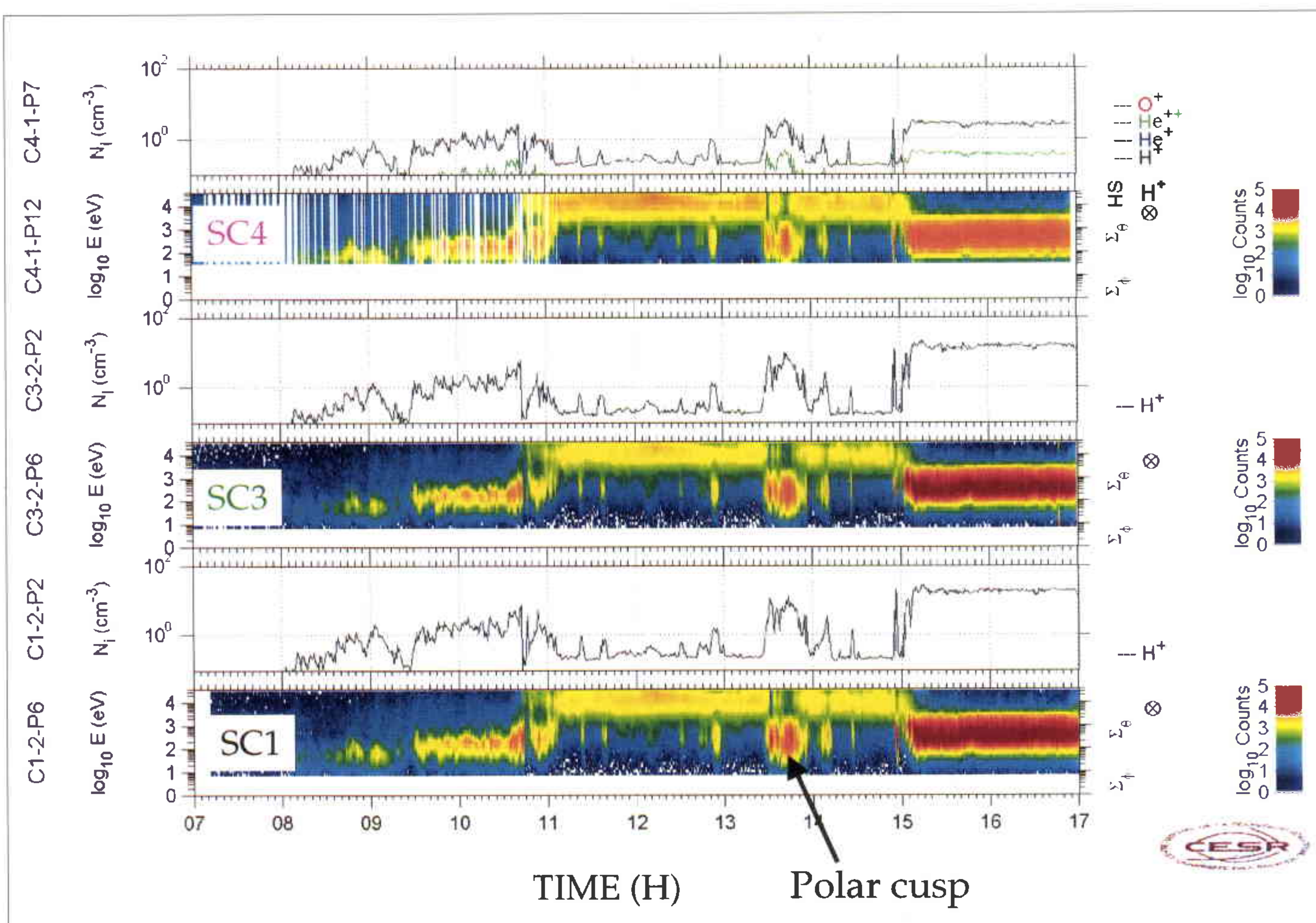


Figure 7. Cusp crossing on 14 January 2001. Top panel: sketch of the polar cusp with the four spacecraft. Bottom panel: energy/time spectrograms of ions from Rumba-SC1, Samba-SC3 and Tango-SC4. The total ion density is also plotted in the panel above each spectrogram.
Data courtesy of CIS Principal Investigator H. Rème and Co-Investigator J.P. Bosqued (CESR, France)



The bottom panel in Figure 7 shows the data from the ion detectors on spacecraft 1, 3 and 4 in the cusp region. The spacecraft were moving from above the pole at around 09:00 UT to the magnetosheath after 15:00 UT (Fig. 2). In between these two regions, the spacecraft crossed the polar cusp for about 30 minutes at around 13:30 UT. A few other shorter crossings of the polar cusp are also visible before and after that time.

The polar cusp is characterised by ions, mainly H^+ and He^{++} of solar origin, with energies between 100 eV and a few keV. On the large time scale shown in this figure, all spacecraft show the same data. However, as we will see below, clear differences are visible if we look at more detailed data. The top panel in Figure 7 sketches the spacecraft entering the polar cusp. Two spacecraft are in the cusp, one is at the border, and the fourth one is still outside. The precise timing of the crossing by each spacecraft and the spacecraft position will give the speed of the cusp.

This crossing on 14 January 2001 was supported by ground-based data sets, as the Eiscat and Superdarn radars were just below the spacecraft and providing additional information on the cusp region (Fig. 8). In fact, just before the cusp crossing by Cluster, the radar detected a change in ionospheric convection, which was an indication that the cusp was moving towards the east (bottom-right panel). This motion is sketched in Figure 9.

The left panel is a view from the Sun and shows the motion of the cusp towards the Cluster position (blue dot). The right panel shows the electron data for one of these cusp crossings by the four spacecraft. The entry of the spacecraft into the cusp is marked by a red arrow and the exit by a white arrow. It is clear that the entry and exit do not occur at the same time for each spacecraft. Using the time of the crossing and the position of the spacecraft, we can estimate that the polar cusp was moving at between 10 and 30 km/s. This is the first time that the speed of the cusp has been measured directly.

Solar storm in November 2000

With the Sun now at maximum activity in its 11-year cycle, numerous powerful solar storms are expected to occur. On 8 November 2000, the fourth biggest storm since 1976 was detected by SOHO. A huge cloud of plasma, in the form of a Coronal Mass Ejection (CME), was directed towards the Earth (Fig. 10). About 8 min later, the WHISPER instrument on Cluster detected the first consequence of the storm – an intense

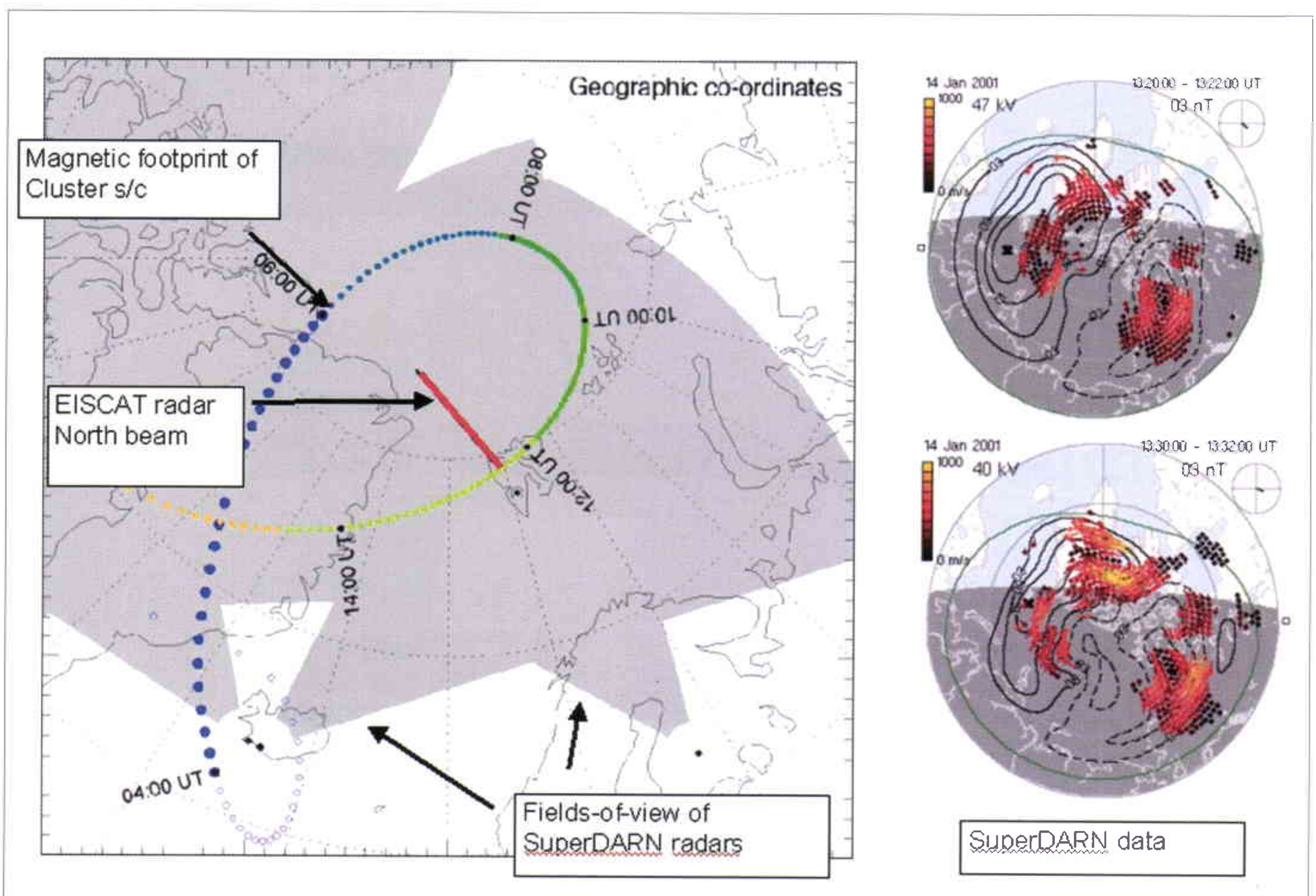


Figure 8. Ground-based radar observations on 14 January 2001. The left panel shows the projection of the Cluster trajectory over the northern polar cap. The fields of view of the Eiscat (red) and Superdarn (grey) radars are indicated. The right panels show the plasma convection pattern recorded by Superdarn at 13:20 UT (top) and at 13:30 UT (bottom). An enhancement of the flow towards the east is detected at 13:30 (yellow bright spot in the centre of the figure). Data courtesy of H. Opgenoorth (Uppsala, Sweden), M. Lockwood (RAL, UK) and R. Greenwald (APL, USA).

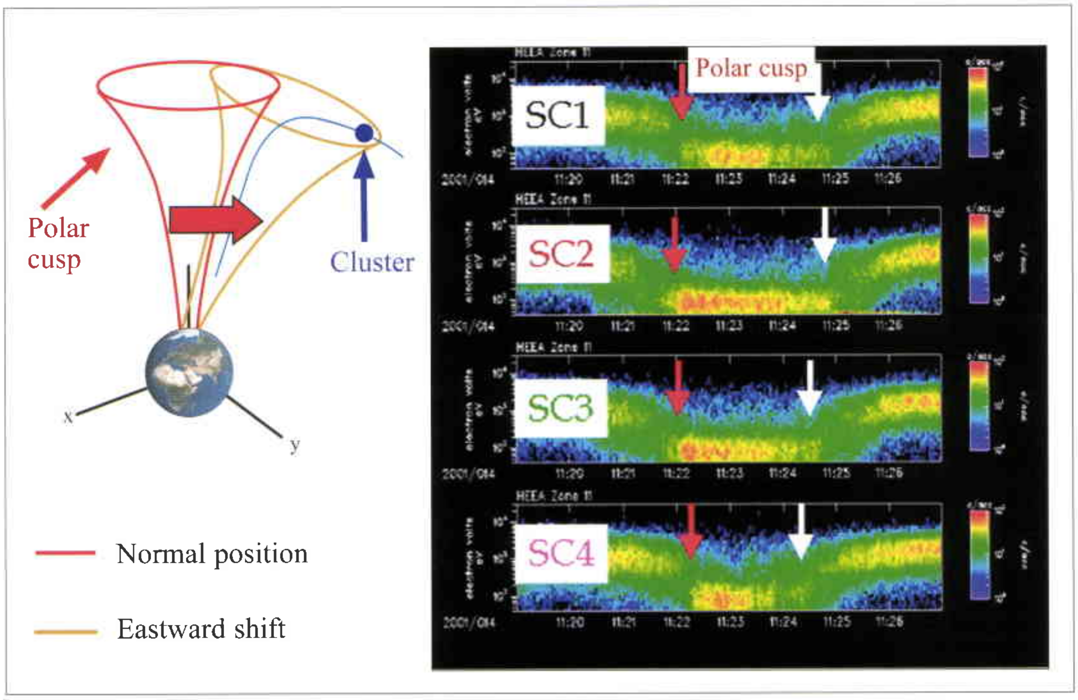
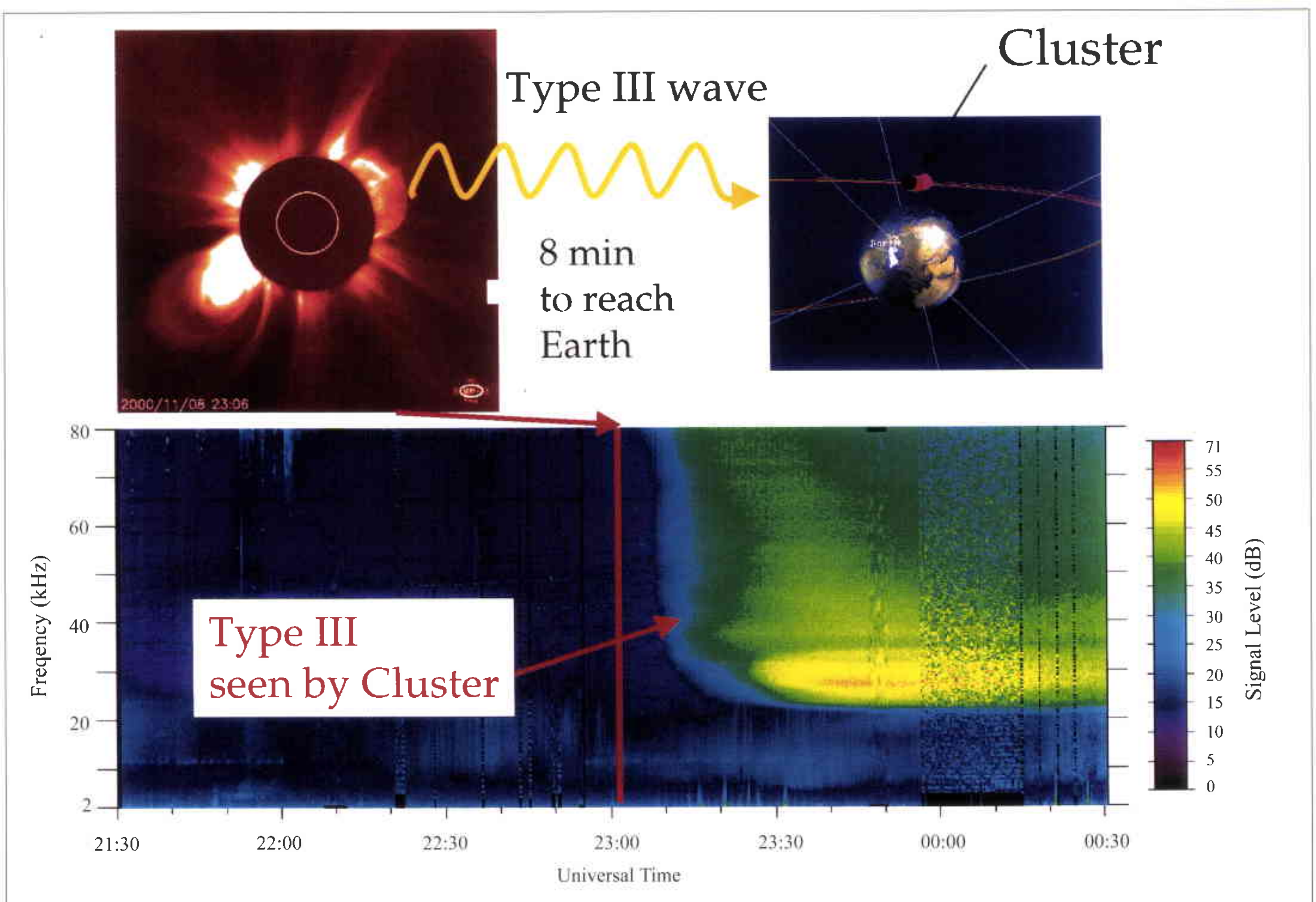


Figure 9. Detailed data obtained during the cusp crossing on 14 January 2001. The left panel sketches the motion of the cusp towards Cluster, which enabled the spacecraft to enter the cusp unexpectedly. The right panels show the energy/time spectrograms of the electron population observed by the four spacecraft. The red arrows indicate when the spacecraft entered the cusp, and the white arrows when they left the cusp.
Data courtesy of PEACE Principal Investigator, A. Fazakerley (MSSL, UK)

Figure 10. Solar storm on 8 - 10 November 2000. The SOHO image taken on 8 November is shown in the upper left panel. The position of Cluster is shown in the upper-right diagram. The frequency/time spectrograms showing the electric field wave measurements are shown at the bottom. The large band emission (from 20 to more than 80 kHz) is observed on Samba-SC3 about 8 min after the storm started on the Sun.
Data courtesy of WHISPER Principal Investigator, P. Décréau (LPCE, France)

radio emission from 20 kHz to above 80 kHz. Then, about 20 min later, the first energetic protons accelerated during the storm arrived at the Earth (Fig. 11). Their flux was 100 000 times higher than during quiet conditions.

These particles penetrate spacecraft and instruments and may damage vital components. In fact, single-event upsets, due to bit flips in the solid-state memory, were detected on-board Cluster about 100 times more often than under normal conditions. The last manifestation of the storm, which occurred about 1 day later, was the arrival of the CME. This acted as a piston on the magnetosphere and reduced its size by half.



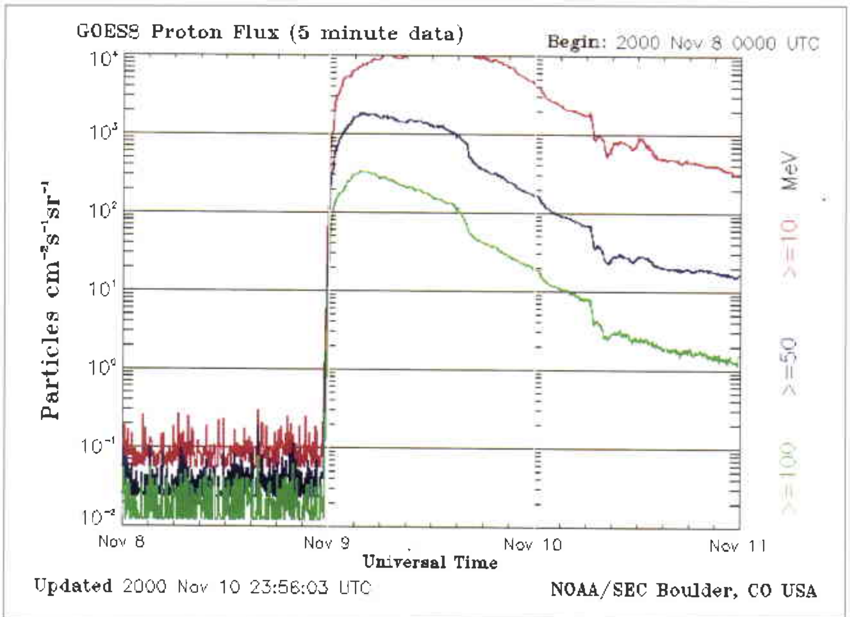


Figure 11. Protons produced during the solar storm on 8 November 2000. The flux is plotted for different proton energies, from above 10 MeV to above 100 MeV. The protons were still reaching the Earth, although with decreasing fluxes, several days later. Data courtesy of NOAA/SEC Boulder, USA

When we received the early warning from SOHO that the storm was coming, we decided to record data for about one day on each Cluster spacecraft. Although not all instruments were operating at that time due to on-going commissioning activities, the FGM magnetometer was switched on and so it was able to detect Cluster's first excursion outside the magnetosphere.

Figure 12 shows the magnetohydrodynamic (MHD) model that simulates the magnetosphere's status during the storm. This model reproduces the global interaction of the solar wind with the magnetosphere. All key physical parameters - magnetic field, density and temperature - are calculated in three dimensions using solar-wind data measured by the Wind spacecraft upstream of the bow shock. In the top panel, the magnetosphere is shown in dark blue, while to the left the magnetosheath is shown in green/yellow, and further to the left the solar wind is in light blue.

Due to the increased pressure coming from the solar wind at 07:00 UT, the colours of the above regions changed slightly, the solar wind becoming light yellow and the magnetosheath becoming red. Before the arrival of the cloud, at 05:48 UT, the magnetosphere was normal (top panel) and Cluster was located inside it. After the CME's arrival (bottom panel), the magnetosphere was compressed to about half of its normal size, and Cluster passed outside it and into the solar wind for many hours. This was about 10 days earlier than expected by the mission team.

Figure 13 shows the magnetometer data from one excursion outside the magnetosphere

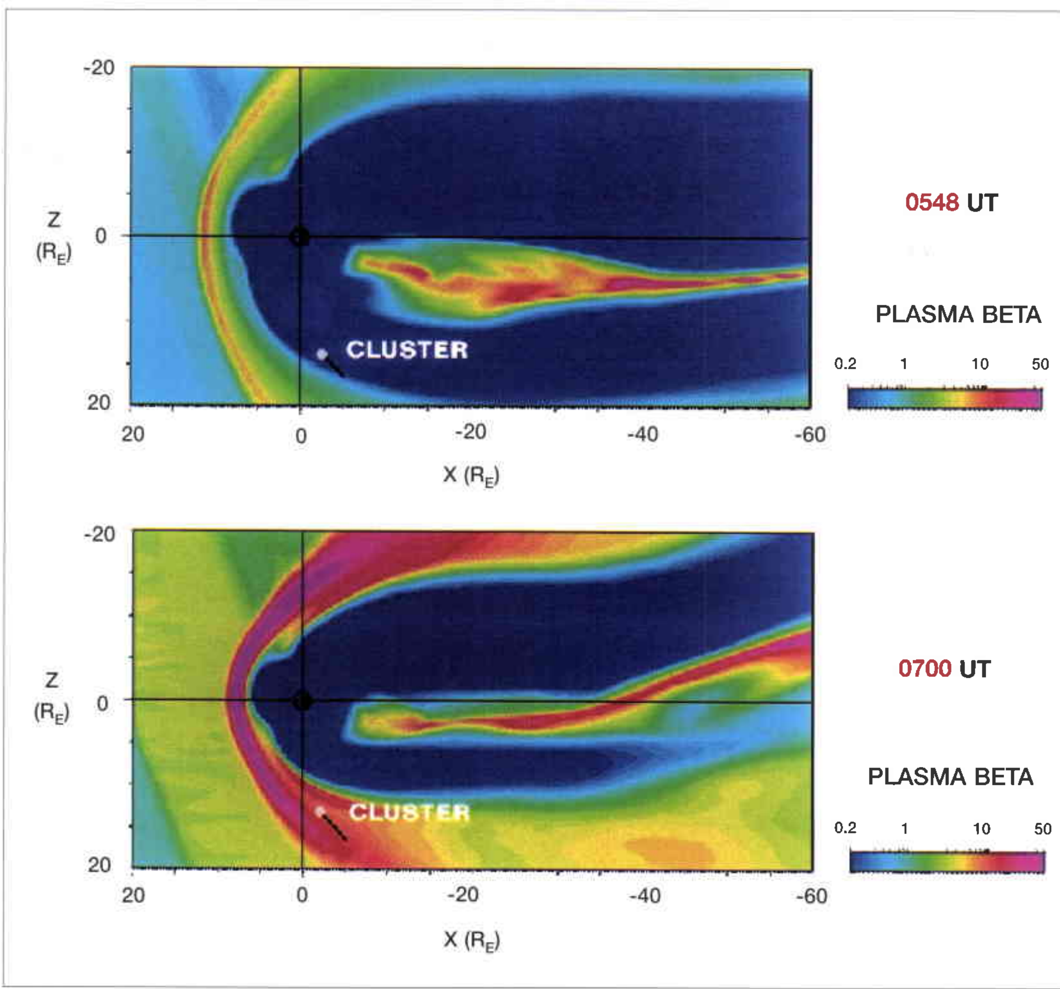


Figure 12. Magnetohydrodynamic (MHD) model of the magnetosphere on 10 November 2000. The top panel shows the magnetosphere before the arrival of the CME at 05:48 UT, and the bottom panel after the arrival of the CME at 07:00 UT. Data courtesy of J. Berchem (UCLA/IGPP, USA)

during the storm. Each spacecraft successively crossed the magnetopause, in agreement with the model shown on the right. The order of the crossing, starting at 06:02 UT, was first spacecraft 2 (Salsa-SC2), then Tango-SC4, then Samba-SC3, and finally Rumba-SC1. A few minutes later, starting at 06:03:30, Rumba-SC1, Samba-SC3, Tango-SC4 and Salsa-SC2 re-entered the magnetosphere in succession. The speed of the spacecraft was relatively slow compared to the motion of the magnetopause, so it should be seen as if the magnetopause was going back and forth through the spacecraft. The order of exit and entry is reversed, indicating that the magnetopause kept the same orientation during its motion.

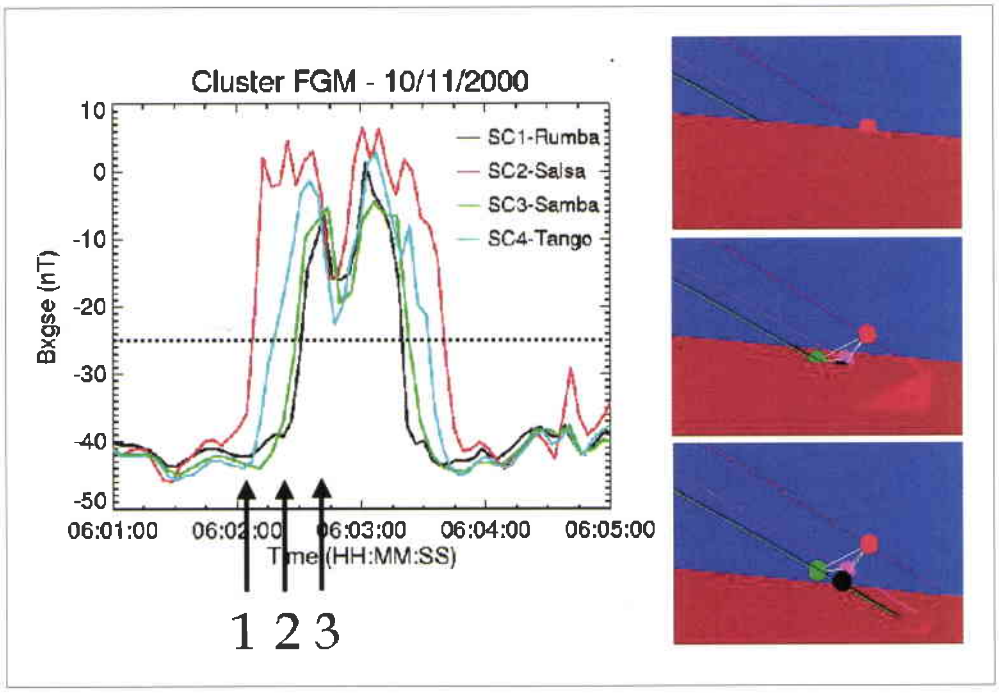


Figure 13. Magnetopause crossing during the solar storm on 10 November 2000. The left diagram shows the magnetic-field component B_x as a function of time as recorded on the four Cluster spacecraft: Rumba-SC1 in black, Salsa-SC2 in red, Samba-SC3 in green and Tango-SC4 in blue. B_x is negative inside the magnetosphere and positive outside it. The three right-hand diagrams show the configuration of the four spacecraft as they crossed the magnetopause in succession.
Data courtesy of FGM Principal Investigator, A. Balogh (Imperial College London, UK).

Conclusion

During just the first few months of operations, the Cluster spacecraft have fully demonstrated their ability to provide substantial advances in magnetospheric physics. For the first time, structures in the magnetosphere have been studied in three dimensions, which will bring new knowledge of the processes taking place during the interaction between the Sun and Earth.

The bow shock was captured between the four spacecraft, enabling its geometry and speed to be determined for the first time. Waves on the magnetopause were also directly observed for the first time and further studies of these should bring new insights into magnetic reconnection processes. The polar cusp, a moving window on the solar wind, was observed by the four spacecraft and its speed was measured for the first time. More data have been obtained in these regions and will allow scientists around the world to perform systematic studies of the physical processes involved.

Another main target of the Cluster mission is the magnetotail, where magnetic reconnection, current disruptions and particle acceleration are taking place. During the next few months, Cluster will look for the first time at the spatial variation of these processes, casting new light on the geomagnetic substorms that are responsible for the intense auroras on the night side of the Earth.

Acknowledgements

The authors thank R.M. Bonnet who made the rebirth of Cluster possible, J. Credland for his strong support of the mission, R. Schmidt without whom the mission would not have been a success, and K.P. Wenzel who supported both the mission and the rebuilding of the Cluster instruments. Special acknowledgements go to J. Ellwood, A. Gianolio and their team who made the Cluster-II project and the Soyuz launch a reality; and to G. Lehn and R. Nord and their team, who built the Cluster spacecraft with such care. D. Machi and M. Goldstein from NASA are specially acknowledged for their constant support throughout the Cluster project. Special thanks also go to the Principal Investigator teams who manufactured the Cluster instruments with jewel-like precision: H. Alleyne, A. Balogh, N. Cornilleau-Wehrlin, P. Daly, P. Décréau, A. Fazakerley, D. Gurnett, G. Gustafsson, H. Rème, W. Riedler, B. Wilken, L. Ahlen, C. Aoustin, C. Carr, P. Carter, B. de la Porte, W. Guttler, R. Huff, P.-A. Linqvist, A. Meyer, J. Quinn, H.-C. Seran, K. Torkar, H. Vaith and K. Yearby. We also thank M. Warhaut and S. Matussi and their team for their dedication in building the ground segment and now in operating the four spacecraft, and T. Dimbylow and M. Hapgood and their team, who are co-ordinating the science operations and always looking at maximising the scientific return. Finally, special thanks go to the Cluster Science Data System Working Group members, who were very inventive in building a simple and efficient tool for distributing the Cluster data to all interested scientists around the World.

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The Life Cycle of XMM-Newton's 'Targets of Opportunity'

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Introduction

The XMM-Newton (X-ray Multi-mirror Mission) observatory is the second Cornerstone of ESA's Horizons 2000 Scientific Programme. It offers astronomers simultaneous:
- high-throughput non-dispersive spectroscopic imaging
- medium-resolution dispersive spectroscopy
- optical-ultraviolet (UV) imaging and timing from a co-aligned telescope (the Optical Monitor, or OM instrument).

The term 'Target of Opportunity' (ToO) is used in astronomy to identify unpredictable events whose study is of the highest scientific interest. For XMM-Newton a ToO is an astronomical event observable by its instruments, which cannot be predicted and scheduled on the time scale of one year, yet is scientifically significant enough to justify the interruption of the ongoing observing programme. Here we discuss the kinds of objects that are suitable for observation as ToOs with XMM-Newton, their scientific interest, and how they are incorporated into the overall observing schedule in terms of target selection and mission planning. What has been done so far and the preliminary results for a few ToO examples are then presented.

The three European Photon Imaging Cameras (EPICs) provide a large effective area over the energy range from 0.1 to 15 keV. Each of the two modules of the Reflection Grating Spectrometer (RGS) covers the energy range from 0.35 to 2.5 keV. Thus, XMM-Newton provides a unique opportunity for a wide variety of sensitive X-ray observations accompanied by simultaneous optical/UV measurements.

For XMM-Newton, ToO types of interest are Gamma-Ray Bursts (GRBs), supernovae, classical novae, X-ray transient binary stellar systems and X-ray transient Active Galactic Nuclei (AGN). 'Hot topics' in astrophysics, for example newly detected objects that are of high scientific interest, can be awarded discretionary time by the Project Scientist. Some of the scientific issues relating to potential ToO targets are:

- GRBs are extremely energetic events whose nature is still far from being understood. Current models claim either the coalescence of a binary system of compact objects (such as black holes, neutron stars and white dwarfs), or the collapse of a massive star (hypernova). Observational evidence discriminating against the various models should come with measurements of X-ray emission lines. X-ray lines would also provide an estimate of their distance and a diagnostic tool for both the nature of the central engine and its environment, thereby probing the early Universe.
- The X-ray emission from supernova explosions comes from the interaction of the shock wave with the interstellar matter. XMM-Newton observations of supernovae shortly after the expansion should provide spectra to test the models for the different types, and light curves to monitor the interaction between the shock wave and the interstellar matter.
- Classical novae are stellar systems formed by a white dwarf and a giant star, where the mass transfer from the giant to the dwarf generates nuclear explosions in the hydrogen-shell-burning white dwarf. They emit X-rays during outbursts via three different mechanisms: (a) luminous super-soft X-rays by the shell, (b) thermal X-rays (0.5 to 20keV) from shocks in the wind or the interaction between the ejecta and the circumstellar material, and (c) hard X-ray emission due to Compton degradation of radioactive decay, which was predicted but never detected. XMM-Newton observations can be used to understand the properties of the shocked nova shell and the composition of the hard X-ray emission, to detect the supersoft component and to test the theoretical model predictions.
- AGN is a term that refers to very energetic phenomena that occur in the cores of certain galaxies. They are suspected of containing super-massive black holes surrounded by accreting material moving so fast that it

becomes sufficiently hot to produce X-rays. XMM-Newton observations of AGN in either outburst or extremely low state would allow constraining of the physical characteristics of the central engine. Moreover, they will provide tools to separate the emission from the different components (such as the inner relativistic accreting gas or the outer cold material that reprocesses the primary radiation) and to understand the accretion events that trigger an outburst (such as tidal disruption of nearby objects). They could also provide tools to discriminate between the outburst of the AGN itself and the circumnuclear starbursts observed in many AGN.

The routine XMM-Newton mission planning

XMM-Newton as an observatory

XMM-Newton activities are prepared long in advance, with the process starting more than eighteen months before the actual observations are performed. At that time, the ESA Director of Science makes a public call for observing-time proposals and astronomers from all over the world can respond by submitting proposals for observations of carefully selected objects before the specified deadline. All of the proposals are technically evaluated and are then sent to the Observing Time Allocation Committee (OTAC) for independent peer review of their scientific merits. The OTAC selects the proposals, and the observations within a proposal, that should be performed, and assigns them a priority. In addition to this 'Open Time' programme, routine calibration observations are necessary to understand the responses of the instruments.

Based on the OTAC recommendations, it is the task and the responsibility of the Science Operations Centre (SOC), located at ESA's Vilspa facility near Madrid, to ensure that all are 'visited' for the approved time in the safest and most efficient way. Being efficient means minimising idle periods and the time spent making manoeuvres. There are some additional items specific to XMM-Newton:

- Whenever possible, the six on-board instruments should operate in parallel (even if this was not requested).
- The exposures for all instruments should start and end at the same time.
- It may be that for safety reasons some instruments have to remain closed.

Scheduling constraints

The orbit of the XMM-Newton observatory (Fig. 1) is the basis of every planning activity. It is highly elongated, from ca. 7000 km altitude at perigee to 114 000 km at apogee, and it takes almost 48 hours to complete one revolution around the Earth. In the lowest part of the orbit, the platform passes across the Earth's radiation belts, consisting of high-energy atomic particles that extend for about 40 000 km from the Earth. The radiation environment there is so intense that all of the instruments need to remain inactive, and if possible closed, since otherwise they would be seriously damaged. The spacecraft can, however, start manoeuvring to the next target shortly after its perigee passage and it is usually ready to start an observation as soon as the observing conditions for some of the instruments are fulfilled. At an altitude of 46 000 km (about 4 h after perigee passage), the RGS and OM instruments are ready for scientific exposures. Currently, the EPIC instruments are only exposed to the sky after the spacecraft has reached an altitude of about 60 000 km (7 h after perigee). Similarly, at the end of the revolution all the instruments are put into a safe configuration at 46 000 km altitude. This means that during every 48 h orbit, about 37 h are available for uninterrupted observations with the EPIC cameras and about 3 more hours with the RGS and OM detectors.

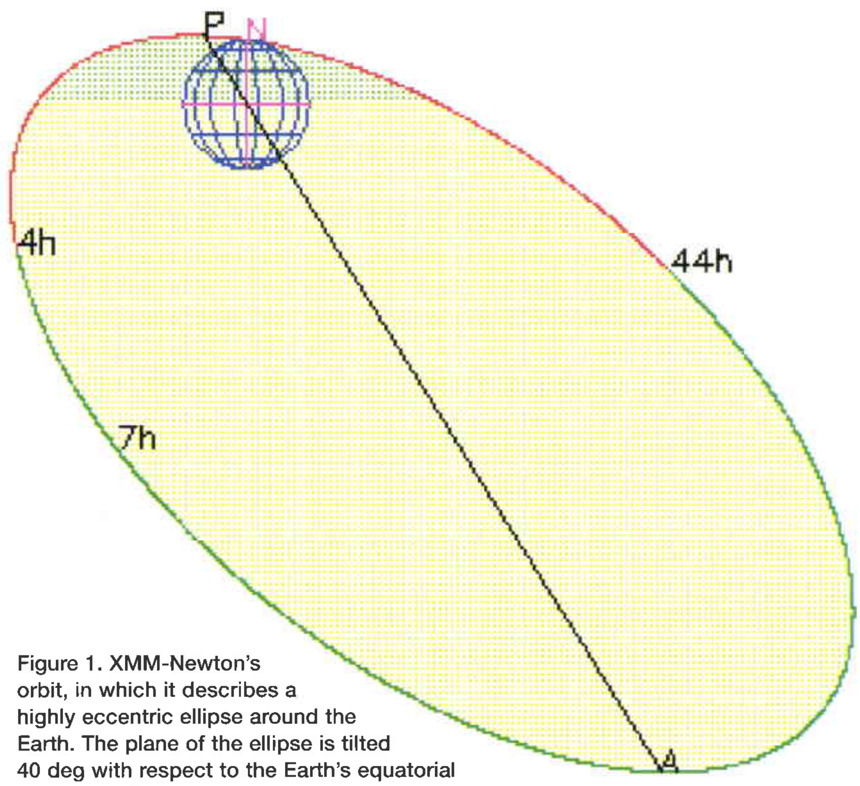


Figure 1. XMM-Newton's orbit, in which it describes a highly eccentric ellipse around the Earth. The plane of the ellipse is tilted 40 deg with respect to the Earth's equatorial plane. The fraction of the orbit that is above the Earth's equatorial plane (i.e. pointing to the North) is shadowed. At its maximum distance, or apogee (point A), the spacecraft reaches an altitude of 114 000 km before returning to its point of closest approach, namely 7000 km at perigee (point P). The duration of one orbit (its period) is very close to 48 h. The figure shows in red the fraction of the orbit that lies within the Earth's radiation belts. The green line shows the part of the orbit that is available for science. The time at which the EPIC observations can start (7 h after perigee passage) is also shown. With the spacecraft moving much faster at perigee than at apogee, this orbit offers the astronomers the possibility of long uninterrupted observations of close to 140 ks

There are more severe restrictions on the observations. The most important ones are related to the pointing constraints and are driven by either the instrument avoidance angles of bright objects, or the spacecraft requirements on the alignment with respect to the Sun, to ensure sufficient energy supply. The spacecraft solar aspect angle is limited to the 70 – 110 deg range. The angles with the Earth's limb and the Moon have to be larger than 47 and 22 deg, respectively. Major planets and Solar System objects have to be avoided for OM observations. In practice, only 34% of the sky is visible to XMM-Newton during a given orbital revolution, and even less at a given time within the revolution. The position of the Sun relative to the stars as seen by XMM-Newton changes during the year (in the same way as it changes for us on Earth!) and most of the sky can be visited for a few weeks only. Figure 2 shows, as an example, the sky that was visible during revolution number 221 (21-22 February 2001). In particular, the Earth's position in the XMM-Newton sky changes during the revolution, following the satellite path along its orbit. Therefore some visible objects

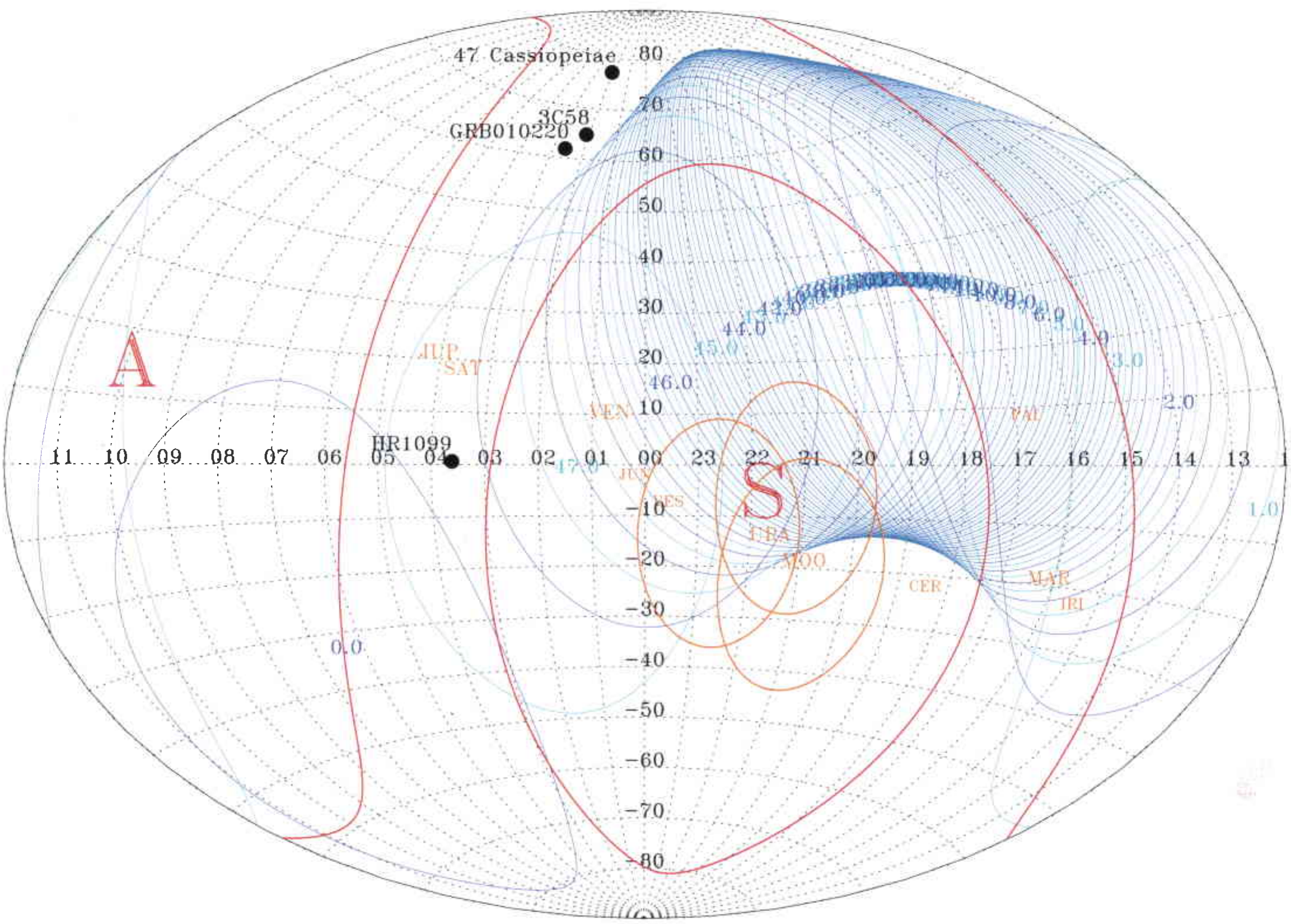


Figure 2. The projection of the sky as seen by XMM-Newton for revolution 221 (21-22 February 2001). The equatorial coordinates are shown in the centre (right ascension in hours goes horizontally, declination in degrees vertically) The Sun, Earth and Moon avoidance regions are shown in red, blue and orange, respectively. The Sun position is marked with an 'S'", the anti-Sun with an 'A'. Different Earth positions are shown and appear as deformed ellipses; the numbers close to the centres of these ellipses indicate elapsed time since the start of the revolution. Though these numbers cannot be read in part of the figure, they are used as an indication of the path followed by the Earth. The concentration of numbers at the top-right of the figure shows where the Earth is at XMM-Newton apogee, when the satellite is moving more slowly. It is also when the Earth's size projected on the sky is smaller, although this is not clearly seen here because of the projection effects. Only three different Moon positions (at the start, middle and end of the revolution) are shown. For this particular revolution, the Moon does not impose additional visibility constraints because it happens to be located in the Sun-avoidance region. However, a few days later when it is a bit higher and to the left (i.e. further to the North/West), it lies just inside the visibility window band. It should be noted that the Moon avoidance angle is larger for the Optical Monitor (OM). The positions of some major planets and asteroids are also indicated in orange. They should be avoided for observations with the OM. This is a revolution that was quickly re-planned to allow a ToO observation. The positions of the scheduled targets and the one that was removed from the schedule are shown. Note that it is just by chance that GRB010220 is very close to the second target in the schedule, 3C 58

are far enough from the Earth, while some others are only visible either at the start or end of the revolution.

Additional constraints are driven by scientific considerations. Examples of this are systems of two stars that should be observed at a given phase of their orbits; also multi-wavelength studies of variable objects that need co-ordination with other satellites or ground-based observatories; or variability monitoring projects that require a specific time lag between consecutive observations within the programme. Approved targets that, because of these different constraints, have short visibility periods are called 'critical targets'. Special care is needed to get all critical targets in the planning within their visibility windows.

Long- and short-term planning

The planning of XMM-Newton observations starts with the identification of all 'critical' objects and the time slots when they can be observed. The optimal date (usually the first possible) for each critical target is then 'reserved' in a long-term plan. The rest of the available time is filled with objects that are close to the critical ones, considering the assigned priorities. An observing plan is made public 3 months in advance, with half of the time left free. The detailed plan is prepared 3 to 4 weeks in advance. The SOC mission-planning group is responsible for the optimisation of the XMM-Newton scientific activities and creates a timeline, which is then passed to the Flight Dynamics group at ESOC in Darmstadt (D). Flight Dynamics checks that all the constraints are considered and introduces additional information for the manoeuvres. The final timeline (the actual telecommands and their execution dates and times) is generated at the Mission Operations Centre (MOC), which is also located at ESOC. The operations team at the SOC takes care of any additional manual commanding that is needed, though this is kept to a minimum to involve almost no significant manual routine intervention. It is therefore a team task that involves most of the groups at the SOC and MOC. The teams work in a close collaboration, which is one of the keys to the success of the entire project. As soon as one revolution is scheduled, the scientists that requested the scheduled observations are informed by electronic mail, and the scheduling details are made public via the XMM-Newton web site at Vilspa. The whole process can take 1 or 2 days for each revolution.

At this point, the nominal planning is complete and no changes would be introduced unless an unforeseen eventuality arises. A ToO alert is, by definition, one such eventuality.

Reception and scheduling of a ToO alert

The scientific value of many ToO observations increases significantly with decreasing reaction time. For example, a delay of 2 h in a GRB observation implies a 10% decrease in the expected flux. The procedure must therefore ensure the shortest possible reaction time for such observations after the request is received.

ToO alerts reach the SOC via the GCN (GRB Coordinates Network) circulars, or through the XMM-Newton SOC web site at Vilspa (which allows every astronomer to propose a ToO observation). Every incoming ToO alert is immediately checked by the SOC instrument operator on shift. There are three pre-defined selection criteria:

- Does the object require immediate reaction, like for example GRBs?
- Is the target visible for XMM-Newton during the current orbit?
- Are the target coordinates sufficiently accurate to allow an observation, i.e. would the target definitely be within the field of view?

If these three questions can be answered positively, then the SOC scientist on call is informed. He or she evaluates in detail the feasibility of the proposed observations (e.g. the earliest time at which the new target could be reached), the impact on the ongoing revolution (e.g. which observation(s) must be substituted), and the scientific expectations (e.g. expected flux and spectra). Based on this evaluation, the Project Scientist, who is always on call, decides whether 'to go' or 'not to go'. If he decides to go, the instrument and spacecraft operators are informed and one expert from the Flight Dynamics group is called at the MOC. The goal is to start the slew to the ToO within 4 h of the alert being received. The whole scheduling process described in the previous section, which under normal conditions requires from one to two and a half days, has to be done in 2 to 3 h.

This can only be achieved because all of those involved work as a team. Many tasks that are performed sequentially during routine scheduling are now done in parallel, or are pre-planned in advance. At the MOC, the flight dynamics are evaluated based on the new coordinates and the approximate starting time of the additional slews. The instrument operators carefully check the possibilities for interrupting ongoing observations and the time needed to swap timelines. The SOC scientist acts as mission planner. The observation of the ToO, i.e. instruments and modes, is prepared. Wherever possible observation templates, which have been prepared in advance, are used. The schedule for the current revolution is opened (without interrupting the ongoing satellite activities). One or more targets are removed from it and the ToO observation is fitted into the available slot. However, during all of this excitement, the security of the spacecraft and its instruments has absolute priority. A schedule generated in 2 to 3 h is not expected to be as optimised as a normally generated one. In this respect, ToOs are expensive, but the expected scientific results certainly justify paying the price.

After reception of the schedule generated at the SOC, the MOC generates the new version of the timeline. Half an hour before the time chosen for swapping the new timeline for the old one, the latter is interrupted and the spacecraft and instrument operators complete the ongoing observation manually. Immediately after the timeline swap, the spacecraft starts the slew to the position for the ToO. As a backup, the Flight Dynamics group and the spacecraft operators are ready to manually command the slew, which allows some flexibility in the procedure.


The XMM spacecraft

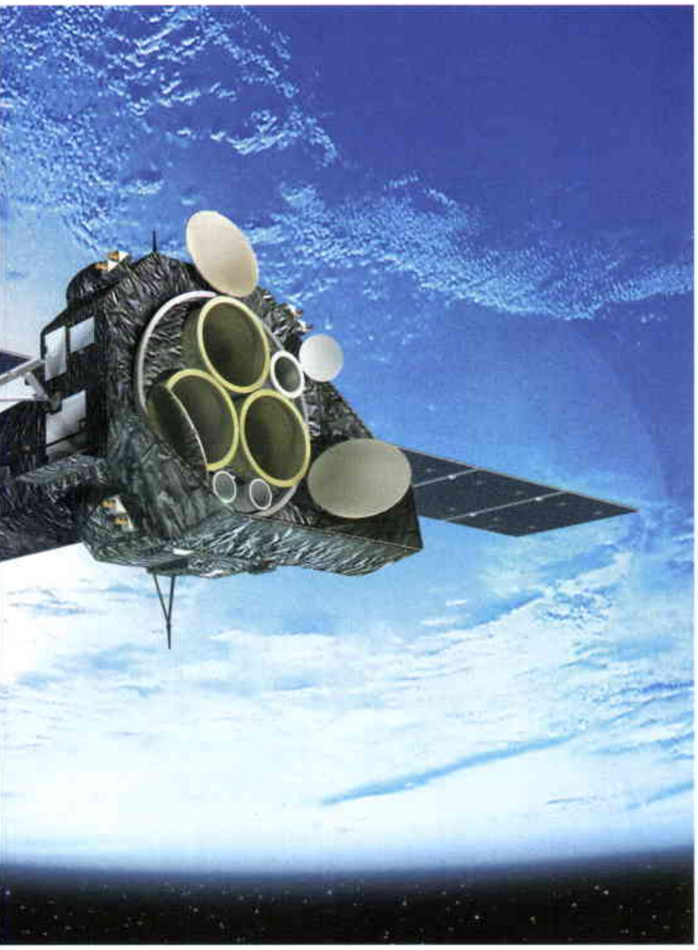
Once the slew has been completed and the ToO observation starts, more and more scientists arrive in the operations room. The excitement there increases with each extra minute of accumulated observing time. Do we see the target? Is it well centred in the field of view? Do we see emission lines? Is the target bright enough to get a spectrum in the RGS detectors? These are the questions that pervade the room and lead into the scientific analysis described below.

Example: scheduling GRB010220

An example of a revolution during which one of the two GRBs observed so far with XMM-Newton was targetted is illustrated in Figure 2. The figure shows a projection of the sky for XMM-Newton revolution 221, which started on 21 February 2001 at 6:38 (UT). The original plan for this orbit was to first spend 56 ks on 47 Cassiopeae, then 33 ks on 3C 58, and finally 47 ks on HR 1099. 47 Cassiopeae is an active cool star (a 'solar analogue'), but about 1000 times more luminous in X-rays than the Sun because of the presence of a close companion. 3C 58 is a point-like source at the centre of a supernova remnant, and almost certainly the youngest neutron star ever observed. HR 1099 is another cool star, much brighter in X-rays than 47 Cassiopeae, which is used to calibrate the RGS wavelength scale.

On 21 February at 4:30 (UT), an alert was sent by the X-ray BeppoSax satellite team. A GRB (GRB010220) had been detected on 20 February at 22:51 (UT) and it was visible with XMM-Newton, but the coordinates were only preliminary. A subsequent communication with the refined position reached the Vilspa SOC on the same date at 6:08 (UT). The error box was sufficiently small to fullfil the pre-selection criteria. Therefore, the ToO alert was triggered, the SOC scientist was called, and the Project Scientist approved the GRB observation. At this time, revolution 221 was just starting and so the EPIC cameras could observe about 7 h later (13:38 UT). The goal was therefore to be on target by 13:38 (UT). The requested exposure time was of the order of 40 ks. This was about the EPIC exposure time in the first observation scheduled in the original timeline, which by chance was close to the GRB position. The obvious way to re-plan the revolution was therefore to replace 47 Cassiopeae by GRB010220, leaving the two remaining observations unchanged.

Following the ToO implementation procedure described above, a new timeline was generated. In this case, the manoeuvre to the GRB was manually performed before the timeline swap. The observation was successful and X-ray emission from the GRB, though



already very weak, was detected. The results are outlined below.

Results of some ToO observations

The first XMM-Newton ToO observation was made as early as March 2000, during revolution 44. However, it was just after the end of the 'Commissioning Phase', and there was still some lack of knowledge of the instruments' performance. In addition, the target proved to be weaker than expected.

The next object in the XMM-Newton ToO list was a newly discovered high-redshift quasar, which was awarded discretionary time by the Project Scientist. The results are outlined below. It was followed by observations of a nova detected in the Large Magellanic Cloud (Nova LMC 2000). This nova was discovered on 12 July 2000 and first observed with XMM-Newton on 25 July. It is one example of a 'slow-reaction-time' ToO. Follow-up observations of the nova were requested to monitor its different phases. The third observation was performed on 29 March 2001 and analysis of the data received is still in progress. The first GRB observed with XMM-Newton was GRB001025, on 27 October 2000 at 0h (UT); though weak, X-rays were detected and an International Astronomical Union circular was published with the precise position as measured from the EPIC images. Another GRB and two binary systems have subsequently been observed. More details are given below.

X-ray binary systems

Quite recently, two binary systems have been observed as 'slow-reaction-time' ToO targets. Many X-ray binaries are transient. They are bright only occasionally (once every few months to tens of years) and briefly (between days and months) in comparison to the quiescent state. Such ToO observations enable the study of a wide dynamic range of luminosity states. In the X-ray-faint state, the optical emission is less affected by X-ray irradiation and the companion can be most easily studied, particularly if it is lighter than a few solar masses and intrinsically faint. The cause for the quiescent X-ray emission is not completely understood. Is there a different kind of less energetic accretion present, or does the emission relate more directly to the compact object? In the X-ray-bright state, the high-energy radiation enables detailed study of the compact object and its immediate neighbourhood. Because of the sensitivity of XMM-Newton's instruments, the platform is well-suited for studies at both ends of the flux scale if the X-ray binary is in our Galaxy. At low fluxes, the quiescent emission is easily detected. At high fluxes, X-rays may potentially reveal details about the chemical composition, density and morphology of the accreting matter, and relativistic effects close to the compact object may be detected. Transients in outburst necessarily have to be observed as ToOs, because the outburst times cannot be predicted.

SAX J1711.6-3808 is a new X-ray transient discovered on 8 February 2001 by the BeppoSax satellite and observed by XMM-Newton on 2 March. GRS 1758-258 is a well-known, very bright, black-hole-candidate, micro-quasar in the centre of our Galaxy. Although it is classified as a non-transient system, it suddenly moved into an extremely dim state between 21 and 27 February 2001, as detected by the RossiXTE satellite, providing a unique opportunity to study the low-state X-ray emission. It was observed by XMM-Newton on 22 March. Figures 3 and 4 show the EPIC and RGS images of this bright source; analysis of the observations is still in progress. GRS 1758-258 was observed previously with XMM-Newton, on 19 September 2000. At that time, its spectrum displayed the typical signature of an accretion disc around a black hole and the

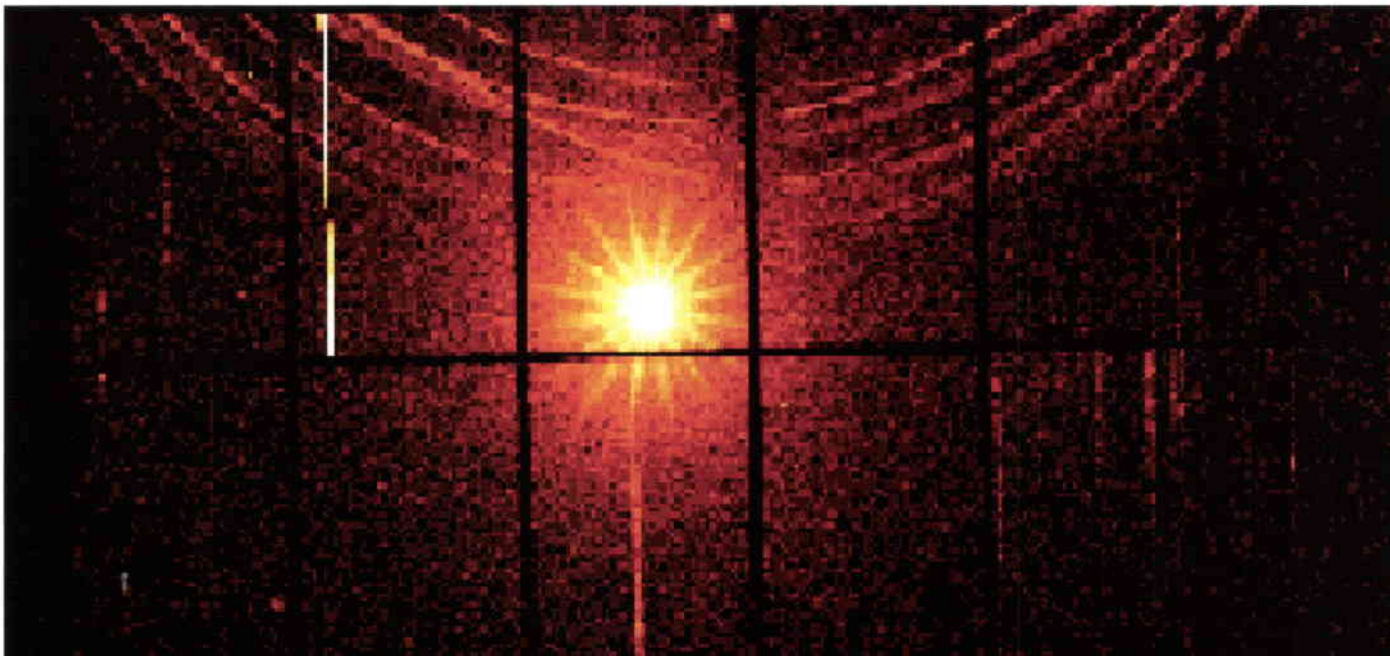


Figure 3. EPIC p-n image of GRS 1758-258. The sharp arcs that appear in the upper part of the image are caused by single mirror reflections of photons, possibly from GX 5-1, which is outside EPIC's field of view

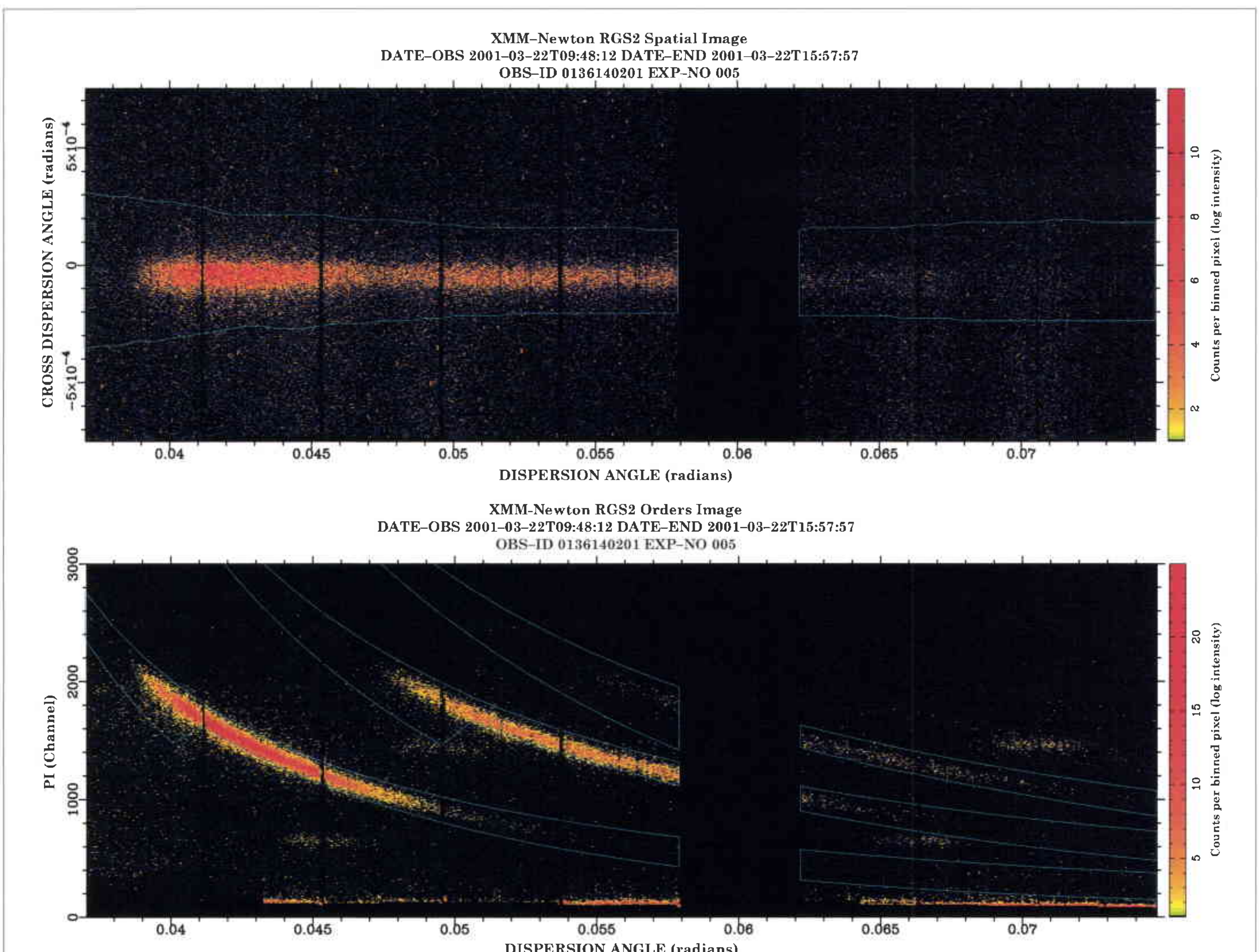


Figure 4. RGS data for GRS 1758-258. The dispersion axis runs horizontally, with shorter wavelengths (higher energies) to the left. The top panel shows the image of the dispersed light on the detector (the spatial, or cross-dispersion direction is along the vertical axis). The bottom panel shows the CCD's intrinsic energy on the ordinates, used to separate photons reflected, in first and second order, from the gratings. The lack of photons at long wavelengths is the result of the high absorption that the GRS 1758-258 photons suffer on their way to the Earth from the centre of the Galaxy

first indications of a transition state (more details are given in the ESA Science web pages). The comparison of the source spectrum in two different states promises even more valuable results.

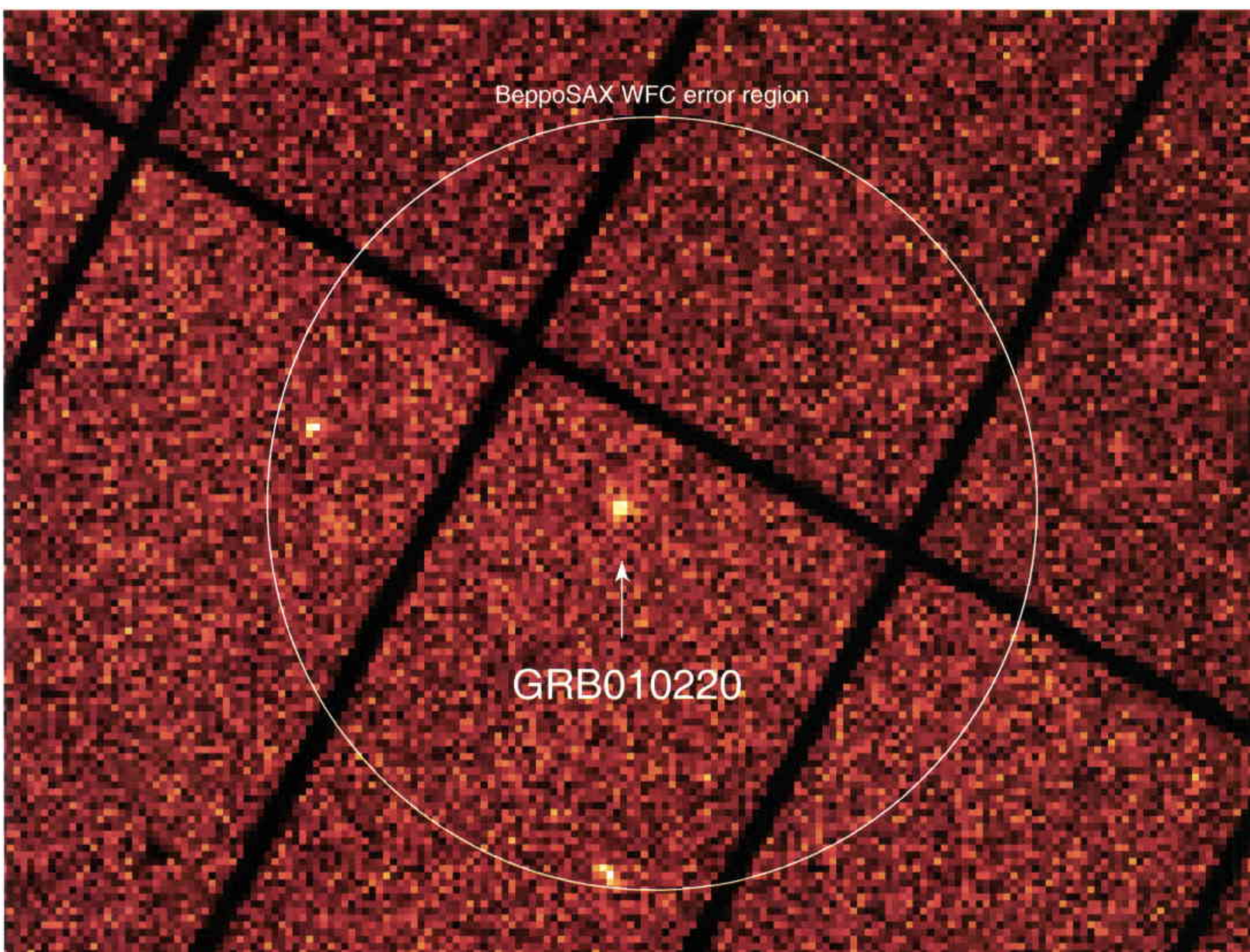
A high-redshift quasar

The most distant known celestial object at the time of observation, the quasar SDSJ1024-0125, was observed by XMM-Newton on 28 May 2000. Discovered in the Sloan Digital Survey, SDSJ1044-0125 has a redshift of z = 5.80, which corresponds to an age of only one million years after the Big Bang. The XMM-Newton observation yielded a statistically significant detection in the EPIC p-n camera in about 32 ks of exposure time. As exciting as the discovery of X-ray sparkles from the farthest reaches of the Universe was for the scientist team, it was also a source of puzzlement. If SDSSJ10.24-0125 would have an optical to X-ray luminosity ratio similar to objects of the same class, the X-ray flux should have been about two orders of magnitude higher. A possible explanation for this unexpected X-ray faintness is significant X-ray absorption. Intriguingly enough, that would fit with the idea that ancient quasars are preferably embedded in dusty environments, possibly due to regions of intense nuclear star formation, which are cleared up during subsequent phases of the quasar evolution. Alternatively, SDSSJ1024-0125 could represent an early stage of the quasar evolution, when the potential well required to produce their immense output energy was still in the process of being formed. The XMM-Newton observation was unable to discriminate between these competing scenarios. Nonetheless, it underlines the ability of the spacecraft's scientific payload to investigate these remote phenomena at the origin of the baryonic age in our Universe.

Gamma-ray bursts

Research in the field of GRBs has undergone an impressive acceleration in recent years. In parallel with the advances in our understanding of these huge explosions in the far Universe, new areas of investigation are being opened by the incoming data. The unprecedented capabilities of XMM-Newton will prove crucial in addressing some of the most important issues in the field. After the distance-scale determination, the study of afterglows of GRBs

Figure 5. EPIC p-n image of the field of GRB010220, the position of which is well within the BeppoSax error region



has allowed a fairly good understanding to be achieved of the radiation mechanisms in terms of a fireball model. There is evidence that at least some GRBs are the result of the explosion of a massive progenitor in a star-forming region. The latter scenario is supported by the discovery of iron lines and edges in the X-ray spectrum of five GRBs. The data are still sparse, and we still have to understand whether those lines are a common feature of GRBs, and whether we are missing them in other events because of a lack of sensitivity or because they fade away shortly after the burst. This is an area in which XMM-Newton's combination of high throughput, high spectral resolution and rapid reaction time can hardly be surpassed by other experiments, provided that a moderately bright afterglow is observed.

So far, XMM-Newton has observed two GRBs (GRB001025, GRB010220), finding a candidate afterglow in both cases, but one too dim for significant search into iron features. Nonetheless, the case of GRB010220 is of particular interest for another feature: the time decay connecting the early X-ray emission, observed by BeppoSax, with the Newton-XMM data point, taken 15 h after the GRB, is very steep – actually one of the steepest ever observed. Such behaviour is usually connected with either a collimated fireball or with an expansion in a very dense medium, typical for example of star-forming regions. Figure 5 shows an EPIC p-n image of this GRB.

Both old and new mysteries wait to be unveiled, and the key observation leading to their solution can be just around the corner. What is the origin of GHOSTs (GRB Hiding Optical Source Transient) or dark GRBs, i.e. events without optical afterglows (but with X-ray afterglows)? If GRBs are indeed associated with massive progenitors and therefore lie in regions of star formation, it is likely that in a large fraction of events the optical emission is heavily absorbed by dust. However, we cannot exclude the possibility that these events are GRBs at $z > 5$, such that optical photons are absorbed by the Lyα forest. BeppoSax has also revealed the existence of another new class of events, the so-called 'X-ray flashes', or 'X-ray-rich GRBs'. In these events, the bulk of the energy is not produced in gamma-rays, but in X-rays. An extremely intriguing possibility is that these phenomena occur in very distant galaxies ($z > 10$). Finally, very little is known about short GRBs, i.e. events lasting less than 1 s, since no counterpart has been so far identified. It is speculated that they may be produced by mergers of two neutron stars, which should result in very short bursts. No counterpart/afterglow has so far been identified at any wavelength for the last two classes of object. Here, the high sensitivity and rapid reaction time of XMM-Newton can be decisive in solving these mysteries.

Acknowledgement
The contributions of Dr. Luigi Piro and Dr. Jean in 't Zand to this article and the useful comments provided by B. Montesinos are gratefully acknowledged.

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Risk Management in ESA's Scientific Directorate: A Case Study

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A practical example of the implementation of Risk Management within ESA's Science Directorate is presented, both with a view to further promoting the use of this valuable programme-management tool, and also as a catalyst to promote the exchange of experience and know-how in this domain. A summary of a Risk Management Policy for the Directorate's Scientific Projects Department is provided here, followed by a brief description of a 'real-life' systematic risk assessment and the results achieved.

Introduction

In the European space environment, Risk Management (Fig. 1) has evolved to the point of being the subject of an ECSS (European Cooperation for Space Standardization) Management Standard in April 2000. Compared to other Risk Management standards (e.g. those of governmental organisations in the United States or Australia), the ECSS standard (ECSS-M-00-03A) used by the European space community represents a state-of-the-art approach. It is comprehensive, provides a common understanding of the subject, and also serves as a contribution to the establishment of an international ISO standard on Risk Management in Space Projects.

Definition of Risk Management implementation requirements

Risk Management is considered to be an important asset in the Scientific Projects Department, which therefore has its own Risk Management Policy. This Policy serves as a guide for the quantification of individual and overall risks, also promoting a common understanding of the subject within the Department. The aim is to appraise the Department's activities as a system in terms of technical, social and managerial factors, to provide clarity and visibility of the risks that influence the achievement of its overall objectives, as well as those of each of the scientific projects, to assess and quantify these risks, and to put the necessary solutions in place.

Goals and resource constraints

The Scientific Projects Department is charged with the implementation of the Horizons 2000 Programme, which involves a broad spectrum of current and future scientific missions. Each of these missions has its own objectives, resources, and constraints, based on the

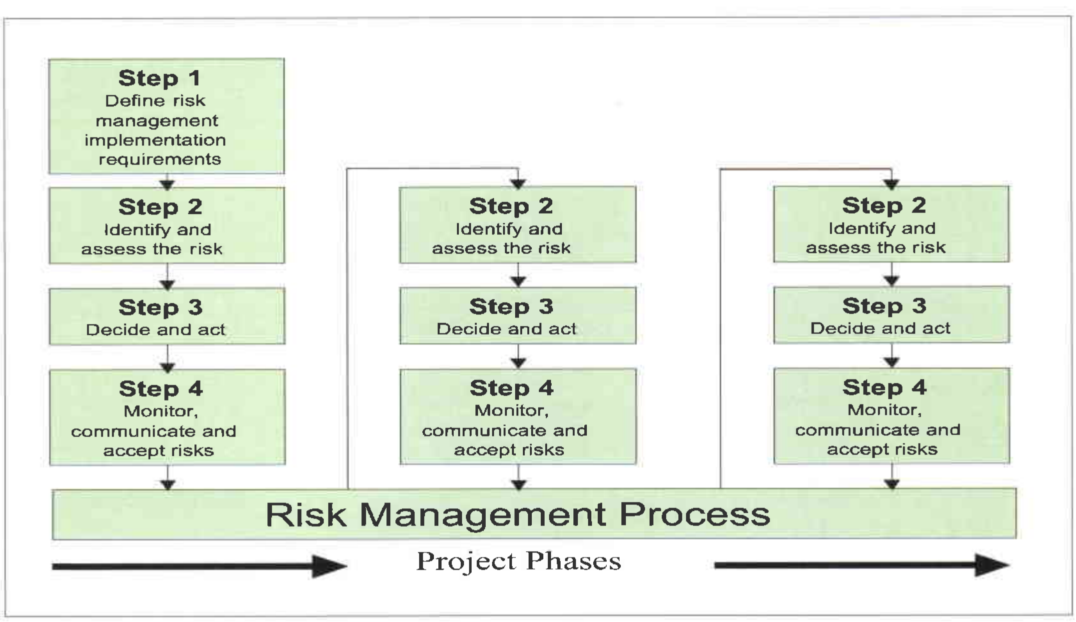


Figure 1. The Risk Management process

recommendations of the European space-science community and the decisions of ESA's Science Programme Committee (SPC). The Scientific Projects Department is responsible for designing, building and launching the scientific spacecraft and commissioning them for operation by ESA's European Space Operations Centre (ESOC). The ESA Space Science Department then operates the scientific instruments and realises the eventual scientific return.

The Scientific Project Department's resources or domains that may be affected by risk are:
- technical
- schedule
- cost
- science value.

The 'science value' domain addresses issues that can have an impact on the expected scientific return from a mission. The reason for introducing this domain is that, although a spacecraft may be delivered on time, within the planned cost envelope, and also delivers the required technical performance, there may still be inherent risks that can cause a loss of scientific return.

Strategy and approach

The role of the Risk Management Strategy is to proactively address risks before they become problems involving serious cost, schedule, technical-performance or science-value impacts. This strategy is considered an integral part of the Department's management approach in the implementation of Horizons 2000. The potential risks therefore have to be well-understood in order to evaluate the decision options and identify the appropriate actions as early as possible, to mitigate in particular all risks designated as category 3C and above (see below).

The Project must use a structured assessment approach to identify and analyse those items that are critical to meeting the project objectives. The risk mitigation options developed need to be monitored for their effectiveness. Careful identification of the resources required is crucial for the successful implementation of the risk treatment options chosen. Once approved, the chosen options need to be incorporated into the Department's overall planning and reporting. Furthermore, the risk-assessment process needs to be continuously updated using the latest risk-management tools available.

An updated risk assessment is mandatory prior to a project-milestone review (preferably conducted with external expertise). As new information becomes available, the project should conduct additional reviews if necessary to ascertain if new risks exist. The goal is to be continuously looking to the future for emerging risk items that may severely impact the programme.

Ranking risks

The procedural approach for ranking risk objectives is as follows:
1. Understand the system (technical, non-technical) and the environment of the project.
2. Identify as many risk items as possible by employing the most effective methods.
3. Analyse all identified risks in order to fully understand them.
4. Assess the impact of the identified risk items on the objectives.
5. Accept the risk if possible.
6. Risks that are not acceptable are to be avoided, mitigated or transferred in the most effective way, but will still need elaborating to ascertain their possible implications.

Identified risks should be quantified in terms of likelihood of occurrence and severity of consequence using Tables 1 and 2. The likelihood of occurrence is normalised on a scale of A to E, and the severity of consequence on a scale of 1 to 5.

Table 1. Likelihood-of-occurrence scoring scheme for the Scientific Projects Department

Score	Likelihood	Likelihood of occurrence
E	High	Near certainty
D	Medium/High	Highly likely
C	Medium	Likely
B	Low/medium	Unlikely
A	Low	Remote

A Risk Index is usually a combination of the likelihood of occurrence and the severity of the consequences for a given risk item. For the Scientific Projects Department, risk ratings of low, medium or high are to be assigned, based on the Risk Index Scheme criteria shown in Table 3. The highest possible Risk Index will therefore be 5E, and the lowest 1A.

Action criteria

The purpose of Risk Management is to identify what actions should be taken, and when. Experience shows that it is mandatory for all identified risk items in the 3C-5C-3C-3E quadrant to be analysed and responded to with proposals for risk treatment actions. For the remaining risk items, there should be an alert issued regarding a possible increase in the Risk Index.

Table 2. Severity of consequence – scoring scheme for the Scientific Projects Department

Score	Severity	Severity of consequence with impact on			
		cost	schedule	technical	science value**
5	High	Cost increase beyond the CaC and therefore approval at level of SPC	Impact on the planned launch date of a mission or a key milestone	Unacceptable impact such that the mission is in danger or that projects are also affected.	Impact that leads to more than 30 % science loss
4	medium / high	More than 80 % but less than 100% of the financial contingency is impacted	No direct impact on the planned launch date. However more than 50 % of the schedule margin is affected. Major slip in key milestone or critical path impacted.	Acceptable*. However no remaining margin	Impact that leads to more than 20 % science loss
3	medium	More than 50 % but less than 80% of the financial contingency is impacted	Minor slip in key milestone. No direct impact on the planned launch date. However up to 50 % of the schedule margin is affected.	Acceptable with significant reduction in margin	Impact that leads to more than 10 % science loss
2	low / medium	More than 20 % but less than 50% of the financial contingency is impacted	No direct impact on the planned launch. However up to 25 % of the schedule margin is affected.	Acceptable with some reduction in margin	Impact that leads to more than 5 % science loss
1	low	Up to 20 % of the financial contingency is impacted Items of previous higher level after mitigation having a residual impact that is not negligible. Negligible risk items with a potential of increase or being triggered negatively by other risk items	Items of previous higher level after mitigation having a residual impact that is not negligible. Negligible risk items with a potential of increase or being triggered negatively by other risk items	Items of previous higher level after mitigation having a residual impact that is not negligible. Negligible risk items with a potential of increase or being triggered negatively by other risk items	Items of previous higher level after mitigation having a residual impact that is not negligible. Negligible risk items with a potential of increase or being triggered negatively by other risk items

* Acceptability in the technical domain is considered if the identified risk item is not mission critical
** For reasons of simplification a rule of thumb for the measurement of science loss should be calculated linearly e.g. if a spacecraft has ten instruments, then the loss of one instrument would be 10%.

Table 3. The Risk Index scheme

Severity — Risk Index: Severity & Likelihood

Severity	A	B	C	D	E
5	5A	5B	5C	5D	5E
4	4A	4B	4C	4D	4E
3	3A	3B	3C	3D	3E
2	2A	2B	2C	2D	2E
1	1A	1B	1C	1D	1E

Likelihood

Red — Yellow — Green

The aim is not to accept every risk blindly, but only with a full understanding of the scale of the risk and why acceptance is justifiable. Ideally, all risk items should have reached a level of justifiable acceptance at the end of a project. It is the Project Manager's responsibility to decide on final risk acceptance. Where a risk cannot be accepted, appropriate action – risk avoidance, mitigation or transfer (see below) – is needed to achieve the necessary countermeasure(s) as effectively as possible. Within the lifecycle of the Project, individual items with a (currently) high Risk Index may be put on hold with respect to their acceptability, but only if it is clear that treatment may take place at a later stage without loss of effectiveness, or that alleviation may occur automatically over time because the item is triggered by other circumstances. However, a justification for not taking action, based on an analysis of the particular issue, is again needed.

The Project Manager acts as the integrator of the Risk Management activities across all of the project domains concerned, taking responsibility for reporting the results to Departmental management.

Deciding and acting

In evaluating the various options available, the following possibilities can be taken into account:

- *Avoiding the risk,* by deciding either not to proceed with the activity that involves an unacceptable risk, or choosing an alternative more acceptable or a less risky course of action that still meets the objectives. Reducing requirements as a risk-avoidance technique will be used only as a last resort, and then only with the participation of the Head of the Scientific Projects Department.
- *Mitigating the risk,* by reducing its likelihood of occurrence or the severity of its conse-

quences, or both. There is usually a trade-off to be made between the magnitude of the risk and the resources needed to reduce that risk to an acceptable level.
- *Transferring the risk,* in full or in part, to another party. Risk transfer may not reduce the magnitude of the risk, but in most cases merely reallocates the associated costs to different parties. In transferring risk to other parties, one must also consider the implications for one's own environment.

The results of such evaluations and the choices of risk-treatment options should always be documented and monitored to clearly establish whether the magnitude of the risk for the item in question has been reduced to an acceptable level.

Communication is an important consideration at each step in the Risk Management process. Effective internal and external communication is important to ensure that all parties directly involved in the Project, or who have a vested interest, understand the basis on which the decisions are being made and why particular actions are required. The different stakeholders' perceptions of risk can vary, due to differences in their assumptions, concepts, needs, issues and concerns.

An example of risk identification and assessment

What follows is a brief description of a risk identification and assessment performed for the main development phases (Phase-C/D) of the current scientific projects, and the consolidation of the results at Scientific Project Department level.

Methodology

Within the ESA Scientific Programme, a degree of technical risk due to technology advancement and the uniqueness of every mission is normal. This favours the use of a qualitative risk-assessment method, which not only looks for quantifiable schedule and financial impacts, but also pinpoints the exact cause and consequences of each risk item identified in terms of system understanding and lessons learnt.

The methodology used to identify the risk items was that of interviewing of the project's key staff. This approach was regarded as the most suitable, despite being more time-consuming than structured brainstorming techniques (e.g. the meta-plan technique). It also circumvents negative group-dynamic situations in which project team members tend to be less vocal than on a one-to-one basis. The initial interviews were conducted by an ESA staff member not belonging to the project team, but who was sufficiently familiar with the Agency's projects and environment. One underlying principle of Risk Management is that the project should be able to identify and assess its risks internally. When the interviewer does not belong to the project, there is always the chance that the project team might be reluctant to expose any shortcomings. The question of using an external person should therefore be treated very carefully, with due respect for the project team's feelings and wishes. One possibility is to have the outsider conduct only the initial risk identification exercise, leaving the recurring tasks to someone within the project itself.

To help in identifying the risk items, a checklist has been established for use as an interviewing guide (Fig. 2). This list, covering the spacecraft, payload and programmatic domains, has been developed in close collaboration with experienced Directorate staff and supporting parties, in order to be as comprehensive as possible. The spacecraft domain covers issues concerning the service module on which the scientific instruments (making up the payload) are mounted, the payload domain covers the scientific instruments themselves, while the programmatic domain deals with the typical managerial issues, such as project phasing, team motivation, records of contractors, financial and contractual items, etc.

A: Spacecraft oriented

A.1) Aspects of Technology Readiness
- a.) Technology Advancement
- b.) Technology Development

A.2) Systems Engineering and Integration aspects
- a.) Design maturity (system-subsystem-unit)
- b.) Internal interfaces
- c.) External interfaces
- d.) Complexity total system
- e.) Complexity required tools

A.3) Producibility aspects
- a.) Manufacturing requirements / manufacturing technology

A.4) Procurement aspects
- a.) Supplier availability

A.5) Software aspects
- a.) Software architecture (at all levels)
- b.) Software verification / validation
- c.) Interdependence of the various software (SW/SW interfaces)

A.6) Assembly Integration and Test aspects
- a.) Assembly & integration process, chronology requirements
- b.) Test procedures, customer requirements
- c.) Test facilities availability

C: Programmatic oriented

C.1) Administrative aspects
- a.) Procedures / Regulations

C.2) Financial aspects
- a.) Cost planning / estimation
- b.) Industrial return
- c.) Incentive / Penalty schemes
- d.) Economic constraints
- e.) Contingencies

C.3) Human resources aspects
- a.) Hard skills
- b.) Soft skills
- c.) Motivation team
- d.) Team expertise

C.4) Project planning aspects
- a.) Phasing continuity
- b.) Quality of schedule reporting
- c.) Schedule trend
- d.) Schedule versus launch gate

C.5) Contractual aspects
- a.) Past performance of Contractor
- b.) Relationship Contractor / ESA
- c.) Relationship Prime / subcontractors
- d.) Contract as is

Figure 2. The risk-identification checklist

The data collected was collated in a Risk Register, as shown in Figure 3. For later categorisation, the source of the risk had also to be identified or isolated. The consequences of the identified risks were then quantified in terms of likelihood of occurrence and severity of consequence (cost, schedule, technical or scientific return), in consultation with the Project

Project: Example	Organisation: D/SCI	Source: **IT / Software**	Date: 27. September 2000
Interviewer: SCI MM Jörg Schroeter		Controlled by:	Issue: 1.0
Interviewed: RM		Supported by:	

RISK SCENARIO and MAGNITUDE

No. **1** | Risk scenario title: **The chosen Software needs adaptations**

Cause and consequence:

Due to the chosen software (an off the shelf product) the aim was to save time and expenditure. However it seems adapatations to the software are necessary to meet the mission requirements. This causes additional time for design and verification of two months and a current cost increase of 1 Meuro which can not be managed within the approved allocations. The item lies on the critical path and therefore the launch date is in danger.

Severity (S)	Likelihood (L)	Risk Index	RED (*)	YELLOW (*)	GREEN (*)	Risk Domain (**)
Low 1, 2, Medium 3, 4, High 5	Low A, B, Medium C, D, High E	4B		X		S, C

RISK DECISION and ACTION

Accept Risk ☐ | Reduce Risk

Risk reduction measures: | Verification means: | Expected risk reduction (severity, likelihood, risk index):

Action: *A scrutiny team will be set up to analyze the situation*

Status: *Results expected by end of October, thereafter decision how to continue*

Agreed by Project Management:

Risk Rank: **1**

Name: | Signature: | Date:

Notes

(*) Mark box as appropriate for the value of "R" (risk index), according to the criteria defined in the risk management policy

(**) Indicate risk domain, e.g. technical, cost or schedule

Figure 3. The Risk Register

Project: **Example**			Organisation: D/SCI					Date: 01 November 2000 Issue: 1.0
Rank	**No.**	**Risk scenario title**	**Red (*)**	**Yellow (*)**	**Green (*)**	**Risk Domain (**)**		**Action / status / comment**
1	23	Payload, late delivery of instrument 1	5E			S, SV		- Submission of small support contracts / expertise where possible - Increase of the work time by working in long work shifts - Submission of human resources from the Prime to the instruments test team - Acceptance of small losses in science performances - Delivery of the instrument in two parts
2	19	Payload, instrument 2 current unit 1 will not perform well	4D			C		- As a backup unit can be procured otherwise, however schedule impact
3	20	Payload, late delivery of instrument 1	4D			S, C		- Submission of small contract / expertise where possible - Increase of the working time to shift working - Submission of support to the Prime test team - Reviews for rescheduling the test programme performed - Simulator for the payload mounted
4	7	AIT, Test chronology is highly sequential		3D		S, SV		- Payload reviews, rescheduling after payload delivery - New container for transportation of complete spacecraft - Improvement of test facilities
5	27	Managerial, Human resources, key people leave		3C		T, S, C		- Plan has been discussed how to keep key people until end of project
6	31	Product assurance, Exchange of Shotky diodes		3C		T, S		- The consequences and possible workarounds are assessed - On spacecraft an exchange of the diodes will be performed
7	22	Payload 2, potential detector failure on satellite		4B		S, SV		- There is a full spare availability, however failure means schedule impact of three months
8	12	AIT, Testing, insufficiencies might occur		3B		T, S, C		- Shaker approval by pre-testing it with high masses.
9	15	Operations, Science operations organization not yet fully sufficient		3B		SV		- Additional team to be set in place and streamline organization
10	4	Launcher, potential launch postponement		2C		S, C		- Negotiations with the launcher provider have been taken up

Figure 4. Ranked risk log

Manager and consistent with the established Risk Management Policy. Identified treatment actions, and their status, were to be assigned as appropriate.

It must be stressed that this risk-assessment approach cannot be claimed to be truly objective. It provides a systematic and consolidated impression of how a project team sees its efforts within the boundaries of set constraints. This, however, provides a starting point and a basis for decision-making.

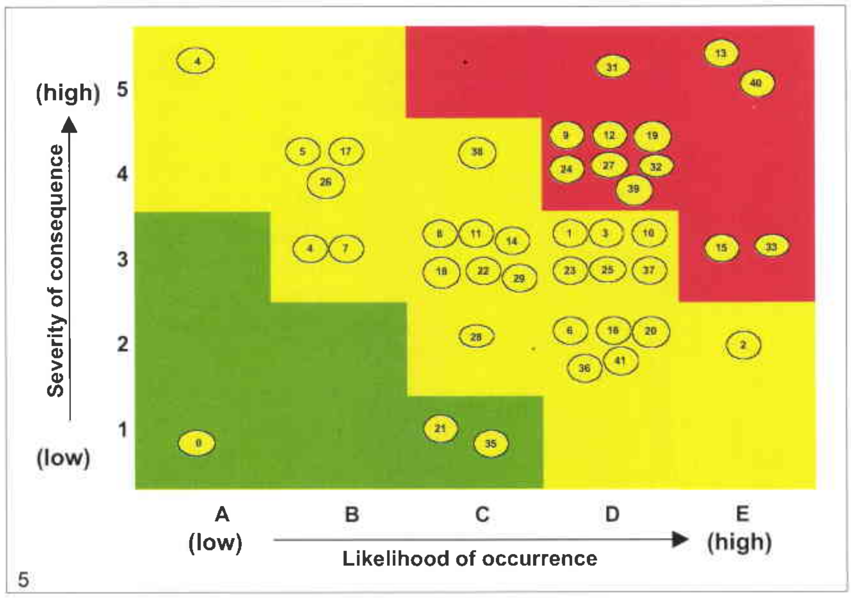
The next step, after having identified the risks items, was to consolidate the results across the project. During the interviews, it was apparent that different team members quantified identified risk items differently in terms of likelihood of occurrence and severity of consequence. This is why in the final consolidation, the Project Manager, who is ultimately accountable for the project's success or failure, was given the last word. During the consolidation procedure, the perceived criticality of a risk item could change, but at the same time this served as a motivation for the Project Manager to investigate carefully the different opinions within his team.

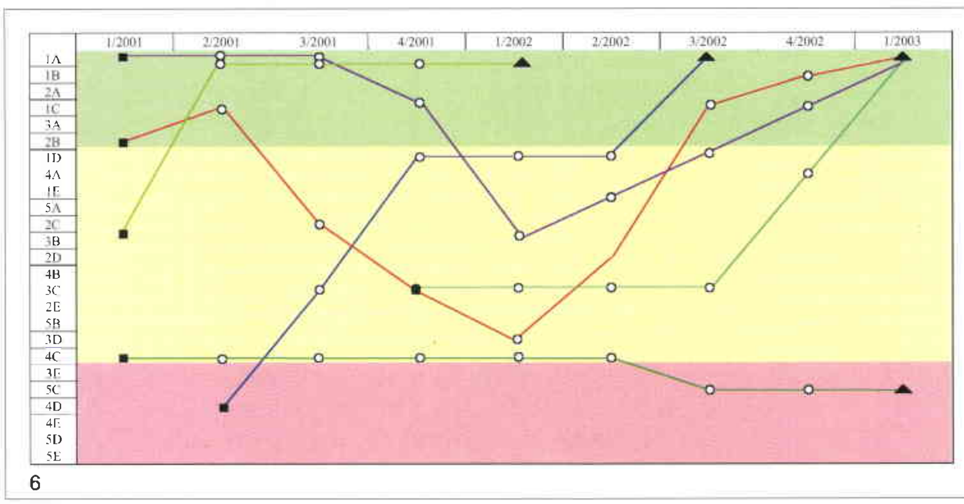
After consolidation, a ranking of the risks with respect to their risk indexes (i.e. the combination of likelihood and severity) within the project took place (Fig. 4). This gave an overview of the items with the greatest potential impact on the project's objectives solely by their criticality. Other ranking criteria could also be used, such as importance of action or cost of mitigation, etc.

Finally, to obtain a qualitative assessment of the overall risk exposure within a project, all identified risk items were displayed in a so-called 'Risk Portfolio' (Fig. 5), providing a basis for risk trend analysis and reporting for senior management.

For the continuation of the risk-mitigation process within the project, i.e. monitoring of identified risk items, the chart shown in Figure 6 was used to track risk evolution over time. Each line refers to a single risk item; the first appearance of a risk item is indicated by a square, and the acceptance of that risk by a triangle.

Consolidation of results
For the projects in question, a consolidation at Department level was conducted to evaluate the overall risk exposure. Firstly, a categorisation in terms of the different sources of risk was made based on the highest degree of commonality:
- Payload: payload-related issues such as delivery, software aspects, management aspects, etc.
- Managerial: all issues belonging to the management domain, such as ESA internal administration, contractual, procedural, human resources aspects, etc.





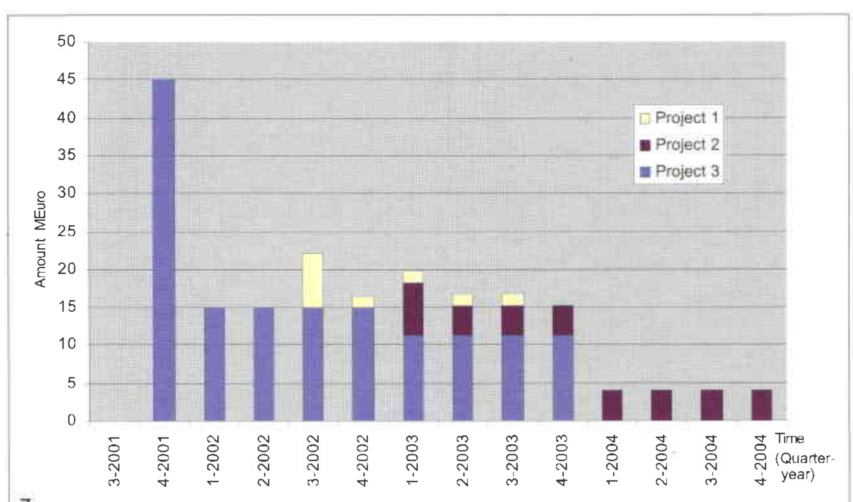


Figure 5. Risk index scheme/portfolio

Figure 6. Risk evolution chart

Figure 7. Financial exposure

- AIT: all issues related to spacecraft assembly and integration.
- Subsystem: issues related to the spacecraft's subsystems, whether a whole subsystem or individual units or parts of subsystems.
- Suppliers: issues related to the suppliers for a spacecraft, from the level of Prime Contractor down to lower-level subcontractors.
- Operations: issues related to ground, flight and science operations.
- Launcher.
- Product Assurance.
- IT/Software: all issues related to spacecraft software.

In consolidating the financial implications of risks in a project, a distinction has to be made between cost impacts covered by the project's approved financial envelope, and those going beyond that envelope, which must be sanctioned by the Agency's Science Programme Committee (SPC). For the projects treated, the financial impact was analysed and quantified in terms of likelihood and time of occurrence, as well as the actual amount involved. In addition, a basis for satisfactorily quantifying the implications of project exposure to risks affecting the scientific value of and scientific return from a mission still needs to be established.

In consolidating the analysis of schedule risk exposure at Department level, the implications for all projects within the Science Programme have to be assessed due to the constraints imposed by particular launch windows and by contracted launch vehicles and launch dates. The implications for ground-support planning and network availability for the different missions also have to be considered, including the finite adaptation times needed between successive launches. The implications of such schedule risks are illustrated in Figure 8.

In addition to giving an indication of the qualitative risk situation at Department level, consolidating the risk portfolios of all projects provides a unique overview that enhances cross-fertilisation and communication between projects. It should be borne in mind, however, that the aim is not to make direct comparisons between individual projects, given that the scientific goals and hence the levels of inherent and acceptable risk can vary greatly from one project to another.

In consolidating the distributed risk items from the various sources, a basis for management at senior level can be created, as illustrated in Figure 9.

Conclusion

From the project risk assessments conducted to date, it has been found that technical issues are the major source of the risk items identified. Software development for spacecraft is an area of particular concern, involving high risk and sometimes being mission-critical, with potential for loss of the spacecraft in the worst-case scenario. In some cases the software used was said to be too complex, leading to software development schedule risks, impacting the mission validation activities, and therefore increasing uncertainty – the outcome being forced acceptance of risk without sufficient understanding of the consequences.

The greatest number of risk items identified were in the payload domain, with some being mission-critical. They were not only purely technical, due to the use of new and developing technologies, but some were also due to financial constraints, resulting in the payload-providing institutes and manufacturers having funding, and in some cases human-resource, problems. The payload domain is a

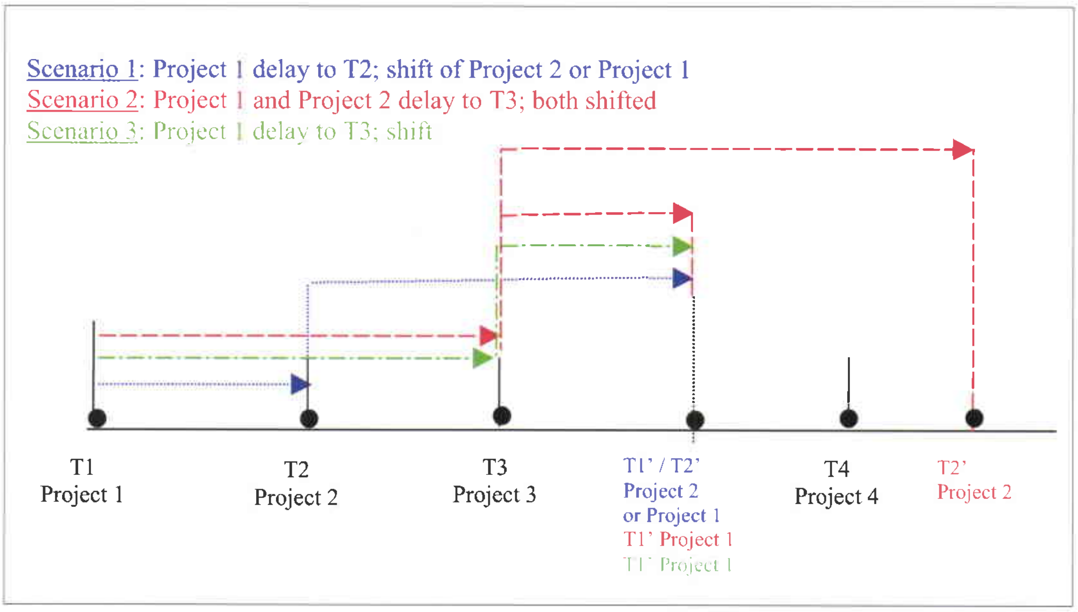


Figure 8. Schedule risk exposure

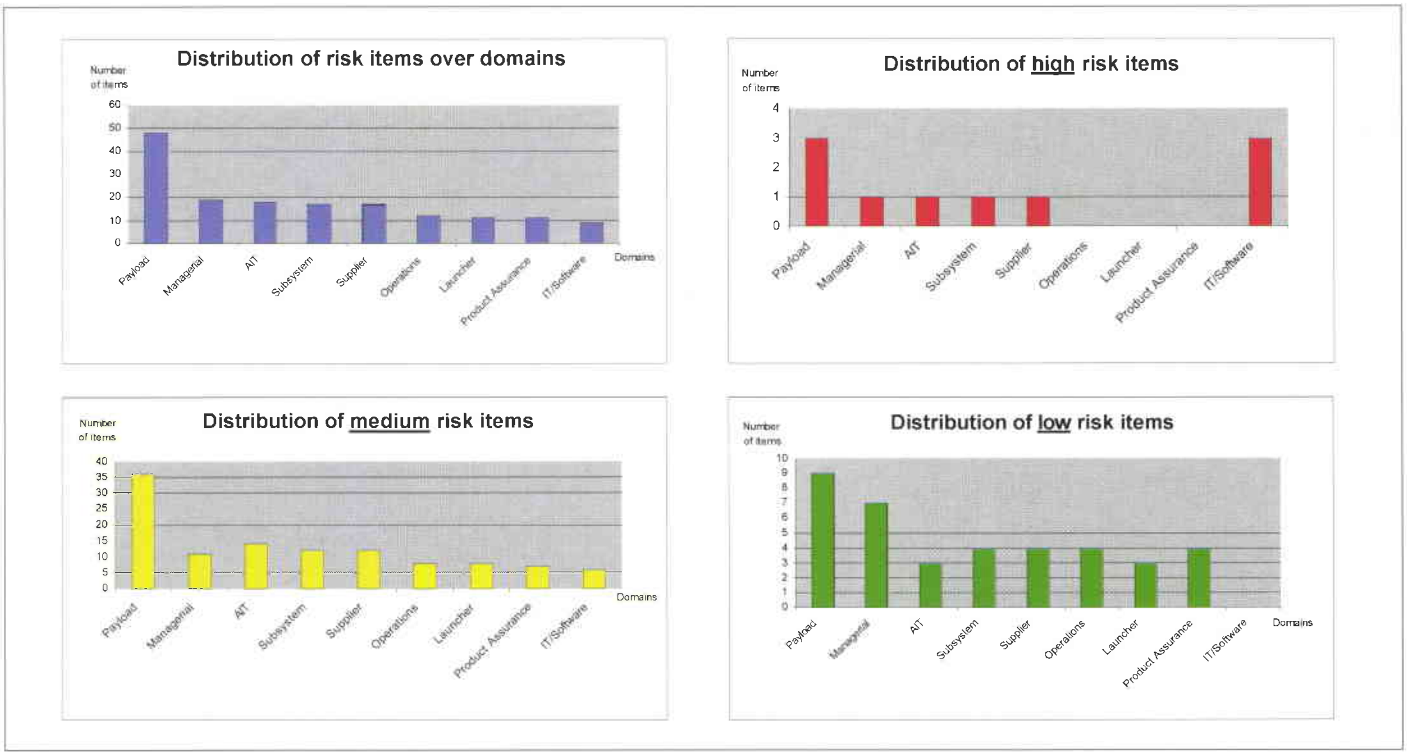


Figure 9. Distribution of risk items over domains

particular concern because responsibility for the design and delivery of the instruments generally does not reside with ESA. The instruments themselves are tending to become more and more complex, taking on the characteristics of small projects within the overall mission, and therefore requiring appropriate project management. There is a growing recognition of a creeping transfer of risk to these external parties, with ESA losing the possibility of risk control. Yet these payload-associated risks can potentially still impact the overall mission, as well as ESA, directly.

One issue that has not been taken into account during the assessments described here is simulation of the results being gathered. A variety of mathematical/statistical methods are available, but these mainly consider issues of insurable risk, i.e. they attempt to establish the amount of financial contingency needed to cover the perceived risks with a certain level of confidence. A first prerequisite for this approach to be valid is that the risk items in question can actually be mitigated by financial means. Secondly, the simulated events or scenarios need to be independent of and decoupled from each other in order to allow statistical simulation. This is rarely the case for scientific missions, where it seems that a different approach is needed. In addition, the casual use of numerical simulations might give the illusion that the results thus achieved enjoy a precision that is often completely unrealistic. A qualitative method like the one followed so far does not create this illusion, while at the same time can account for variables that cannot be quantified in a non-controversial way.

Thus, one proposal for scientific missions could be to create an 'expert system', achieved partly by establishing through specialised interviews the rules of thumb that successful managers instinctively apply, and partly by simulating a project as a cybernetic system with a set of linked variables with feedback loops. With such a model, the effects of various possible risk scenarios or decision options could be simulated, but the complexity and cost of defining such a system would have to be traded-off against the gains achieved in mitigating risk.

Having performed the initial structured risk-assessment exercise described in this article, an increased awareness within the Agency of the merits of Risk Management can be observed. Recognition of the practical usefulness of Risk Management is spreading slowly but surely, and the cultural change needed for it to be widely accepted as a valuable management tool is hopefully evolving.

Acknowledgements
The author would like to thank the Project Managers and the Project-Control, System-Engineering, Payload, AIV, Product-Assurance and Ground-Segment Managers of the Integral, Rosetta, Mars-Express and Smart-1 missions and all other contributors to this article. esa

Further reading:

Space Project Management: Policies and Practices, ECSS-M-00A.
Space Project Management: Risk Management, ECSS-M-00-03A.

These Standards are available from ESA Publications Division.

Determining Tropospheric Concentrations of Trace Gases from Space

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It is now possible to determine the concentrations of atmospheric constituents in the troposphere from satellite data, a development that heralds a new era in tropospheric chemistry. Some of the methods for retrieving tropospheric trace gases are described here, together with some of the latest results obtained from ESA Earth Observation (EO) measurements. The likely consequences for environmental monitoring and policy are outlined, as is the new Troposat project, the aim of which is to exploit these results, together with the requirements for future instrumentation, to build on the present situation.

Background

The new observations of the tropospheric distributions of trace gases such as NO_2 (nitrogen dioxide), SO_2 (sulphur dioxide), HCHO (formaldehyde), BrO (bromine monoxide) and O_3 (ozone), retrieved from GOME (Global Ozone Monitoring Experiment) measurements, herald the opening of a new era for tropospheric chemistry and remote sensing. Both the treatment of the data presently available, and that of the data from the missions planned for the near future, will add a new and much-needed dimension to this challenging field of research.

The study of the complex chemical interactions between the trace constituents of the atmosphere, many of which are pollutants, is not only of considerable scientific interest, but is also of importance both economically and politically. Primary pollutants, such as the nitrogen oxides (NO_x) and volatile organic compounds (VOC), are emitted during energy production, as a result of agricultural activities, and above all by vehicles such as cars and aircraft. Many of these primary pollutants are transformed in the atmosphere to secondary pollutants, such as ozone or formaldehyde, via sequences involving literally hundreds of compounds and thousands of reactions. These pollutants are transported within the atmosphere to regions that can be far from the sources, and there give rise to profound ecological damage and change. Many of the pollutants are damaging to human health and natural ecosystems.

The environmental concerns have been reflected in the Protocols to the Geneva Convention on the Long Range Transport of Pollutants, which now attempt to control emissions of SO_2, NO_x, VOC and ozone for the whole of the European Continent, and also in the Directives and Air Quality Initiatives promulgated by the European Commission, as well as in the numerous national air-pollution measures. However, experience, particularly in the USA, has shown that in order to be successful, these measures must be based on sound science, and thus on a thorough understanding of tropospheric chemistry and meteorology.

The chemistry of air pollution has been studied intensively since the first discovery, more than fifty years ago, of photochemical smog in the Los Angeles Basin, and since the realisation in the nineteen sixties and seventies in Europe that pollutants could be transformed and transported for hundreds of kilometres, often across national borders. The results of this work are encompassed within Chemical-Transport Models (CTMs), which attempt to combine the complex chemistry with the equally complex meteorology on global, regional and local scales. Until now, attempts to validate these three-dimensional models have been confined to comparisons with longer-term measurements of some species at sparsely scattered ground stations, and short-term intensive field measurement campaigns within a small area. Such validation exercises can only provide limited tests for the models. What is required are reliable and regular measurements over large areas and at a variety of heights throughout the troposphere. Satellite measurements can provide such data and fill this gap.

These new data offer the possibility of studying concentration distributions on global and regional scales, and at locations and levels in the troposphere that were only accessible to occasional individual observations in the past, and so can be expected to lead to a significant enhancement of our capability for investigating the chemistry and physics of the troposphere. Satellite observations, appropriately combined with modelling, will in turn help those responsible for environmental-policy development to monitor the outcome of legislative initiatives to control the quantities of pollutants in the troposphere.

Also, the reliability and frequency of space observations will be of great help in determining the longer-term changes that are taking place in the troposphere. There are many series of long-term measurements made at ground stations, but some of these are susceptible to local influences and changes and to issues concerning the continuity and accuracy of calibration and, as in model validation, they only sample a tiny local part of the atmosphere. Space-based observations, properly validated with ground truth and data assimilation, can provide the requisite long-term monitoring, as envisaged in the context of the Kyoto Protocol.

Satellites measuring tropospheric parameters

Table 1 shows the satellite instruments that have yielded or will yield data on the concentrations of chemical species in the atmosphere. Most were originally intended to obtain stratospheric data, but it has proved possible to retrieve tropospheric data as well. Some of the earliest retrievals were made by J. Fishman from NASA working with the TOMS data for ozone. Similarly, the observation of sulphur dioxide (SO_2) from volcanic eruptions using TOMS data by A. Krueger and colleagues, and the work of J. Herman, P.K. Bhartia and his NASA colleagues on absorbing tropospheric aerosol, has been of considerable importance.

The limb sounding of the upper troposphere for chemical constituents has also proved successful, but prior to the launch of the GOME instrument on ESA's ERS-2 remote-sensing satellite the observation of species in the lower troposphere had proved elusive. Using GOME data, a number of European groups, notably those led by U. Platt in Heidelberg (D), J. Burrows in Bremen (D), H. Kelder at KNMI (NL), P. Simon at the Belgian Institute for Space Aeronomy, B. Kerridge at Rutherford Appleton Laboratory (UK), and A. Goede at the Space Research Organisation of The Netherlands (SRON), have now obtained important results giving concentrations in the troposphere for ozone, NO_2, SO_2, BrO and HCHO.

The GOME instrument

For the last ten years, ESA's ERS Programme has been providing Earth-observation measurements to the international user community. The programme has stimulated the development of scientific, public-utility and commercial applications in a variety of disciplines to monitor the Earth's environment. The GOME measurements provide significant contributions to tropospheric-chemistry research.

The GOME instrument, originally proposed under the name 'SCIA-mini', is a smaller scale, de-scoped version of the then-proposed instrument SCIAMACHY (Scanning Imaging Absorption Spectrometer for Atmospheric CartograpHY). GOME was launched on ERS-2 in April 1995, which flies on a low-Earth Sun-synchronous orbit with a descending node and an equator-crossing time of 10.30 AM local time, approximately 800 km above the Earth. GOME observes the extra-terrestrial solar irradiance and upwellling earthshine radiance, which is comprised of the light reflected from the Sun-lit surface and clouds together with that scattered back from the atmosphere in the 240-790 nm spectral region.

The GOME instrument is a double monochromator, with the light entering being split into four separate spectral bands. In each of these four bands, the light is dispersed by a diffraction grating and focused onto monolithic silicon linear detector array comprising 1024 individual detector pixels. GOME, a forerunner of future European atmospheric satellite instruments, provides the possibility due to its nadir-viewing geometry and broad wavelength

Table 1. Satellite instruments, their coverages and the species measured*

Name	Target Species	Satellite Platform	Orbit
ATMOS: Atmospheric Trace Molecule Spectroscopy	O_3, NO_x, N_2O_5 ClO NO_2, HCl, HF, CH_4, CFCs, etc. (upper troposphere)	Space Shuttle Spacelab-3 (1985), ATLAS-1,2 and 3 (1992,1993,1994)	Inclined
ATSR: Along-Track Scanning Radiometer	Aerosols, clouds, sea surface temperature	ESA ERS-1and ERS-2 (1991-present)	Polar, Sun Sync.
AVHRR: Advanced Very-High-Resolution Radiometer (4/5 chan.)	Smoke, fire, clouds aerosols, vegetation	Tiros-N, NOAA-6 to 13 (1978-present)	
BUV: Backscatter Ultraviolet Ozone Experiment	O_3 (profiles)	Nimbus-4 (1970-1974)	Polar
GOME: Global Ozone Monitoring Experiment	O_3, NO_2, H_2O BrO, OClO, SO_2, HCHO, clouds, aerosol	ESA ERS-2 (1995-present), MetOp-1 – MetOp-3 (2005/6 2010/11, 2015/16)	Polar, Sun Sync.
GOMOS: Global Ozone Monitoring by Occultation of Stars	O_3, NO_2, upper troposphere	ESAEnvisat (2001)	Polar, Sun Sync.
IASI: Imaging Atmospheric Sounding Instrument	O_3, CO, CH_4, N_2O, SO_2	MetOp-1 (2005/6)	Polar, Sun Sync.
IMG: Interferometric Monitor for Greenhouse Gases	O_3, N_2O, H_2O, CH_4, CO and CO_2	ADEOS (1996-97) ADEOS-II (2001)	Polar, Sun Sync.
MERIS: Medium-Resolution Imaging Spectrometer for Passive Atmospheric Sounding	H_2O, clouds and aerosol	ESA Envisat (2001)	Polar, Sun Sync.
MIPAS: Michelson Inferometer for Passive Atmospheric Sounding	O_3, NO_x, N_2O_5 $ClONO_2$, CH_4, CFCs, etc.; temperature (upper troposphere)	ESA Envisat (2001)	Polar, Sun Sync.
MOPITT: Measurement of Pollution in the Troposphere	Total column of CO; CH_4 + CO profiles	NASA AM-1 (1999)	
ODUS: Ozone Dynamics Ultraviolet Spectrometer	SO_2, NO_2, BrO, OClO	GCOM-A1 Prog. Japan (2005)	Inclined
OMI: Ozone Monitoring Instrument	O_3, SO_2, NO_2,	NASA-EOS-CHEM (2004)	Polar, Sun Sync.
POLDER: Polarization and Directionality of the Earth's Radiance	Polarization, aerosols, clouds	ADEOS-1 (1996-97)	Polar, Sun Sync.
SAGE-I and -II: Stratospheric Aerosol and Gas Experiment	O_3, NO_2, (H_2O), aerosols (upper troposphere)	NASA Atmospheric Explorer Mission (1979-81), Earth Radiation Budget Sat. (1984 – present)	Inclined
SAGE-III: Stratospheric Aerosol and Gas Experiment	O_3, OClO, BrO, NO_2, NO_3 aerosols	Meteor-3M (2001); International Space Station (2003?)	Inclined
SBUV: Solar Backscatter Ultraviolet Ozone Experiment	O_3 profiles	Nimbus-7 (1979-90)	Polar
SCIAMACHY: Scanning Imaging Absorption Spectrometer for Atmospheric Cartography	O_2, O_3, O_4, NO, NO_2, N_2O, BrO, OClO H_2CO, H_2O, SO_2, HCHO, CO, CO_2, CH_4, clouds, aerosols, p, T, col. and profiles	ESA Envisat (2001)	Polar, Sun Sync
TES: Tropospheric Emission Spectrometer	Various incl. HNO_3, O_3, NO, H_2O (col. and profiles)	NASA EOS-CHEM (2004)	
TOMS: Total Ozone Monitoring Spectrometer	O_3	Nimbus-7 (1979-92) ADEOS (1996-97) Earth Probe (1996-) Meteor (1992-94)	Polar

* This list is not intended to be complete, but merely to illustrate the currently available instrumentation.

coverage to measure a range of atmospheric constituents both in the stratosphere and in the troposphere.

ESA GOME products are generated operationally at the German Processing and Archiving Facility (D-PAF) at DLR and comprise: calibrated earthshine radiances and the extraterrestrial solar irradiance (Level-1 product), total columns of ozone and nitrogen dioxide and cloud information (Level-2 product).

Retrieval of tropospheric concentrations from satellite (GOME) data
The GOME Level-1 data were intended to be exploited by the technique of Differential Optical Absorption Spectroscopy (DOAS). DOAS, as applied to satellite observation, first determines the effective atmospheric absorption for up-welling radiation for a selected spectral window. The relatively narrow-band spectral features of gases are then separated from broad-band gas and aerosol absorption, spectral reflectance (albedo) spectral features and gaseous and particle scattering by the subtraction of a polynomial.

The problem then is to obtain vertical column densities for the various spectroscopically absorbing species and, ideally, the detailed profiles of their vertical concentrations from these raw data. The problem is increased when, as is the case with ozone, the preponderance of the optical absorption is due to ozone in the stratosphere.

Appropriate fitting techniques allow the slant column amount (simply speaking, the column along the line-of-site of the satellite instrument) of the gases having suitable spectroscopic features in a given spectral window to be retrieved. This is converted into a total column amount by means of an Air Mass Factor (AMF). The AMF depends on a variety of factors, including the shape of the profile and the penetration of light through the atmosphere. The use of the standard DOAS approach is restricted to spectral windows where the AMF is constant and the penetration depth of light in the atmosphere is independent of wavelength. In the simplest case, the AMF is a geometrical factor. However, absorption of light by gases and scattering by air and aerosol results in the AMF often being dependent on the profile shape. More sophisticated DOAS approaches deal with this problem of retrieving the vertical column amount of a trace constituent by the fitting of several spectral windows at a variety of wavelengths.

Retrieval of the tropospheric contribution to the column densities of trace gases from nadir viewing presents a particular challenge since, in order to separate the total column into its components, additional information is required. The GOME data have been treated in a variety of ways by a number of European research groups to obtain tropospheric information.

One approach is to use our knowledge of the different temporal and horizontal scales of constituents in the stratosphere and troposphere. Thus the tropospheric sources of NO_2 are often local to polluted regions and those where it is produced by lightning. In comparison, the sources of stratospheric NO_2, the photolysis of nitrous oxide (N_2O) and the downward flux from the mesosphere are global. In addition, the transport in the stratosphere is appreciably greater than in the troposphere, so that a longitudinal homogeneity of the NO_2 stratospheric column is to be expected. Thus, comparison of, say, polluted regions with clean remote regions at the same longitude will give the tropospheric column of NO_2. This technique, known as the Tropospheric Excess Method (TEM), yields the tropospheric-excess slant-column absorption of NO_2, which has then to be converted into a tropospheric vertical column by the generation of an appropriate differential AMF and knowledge of the tropospheric vertical column in the remote region.

Another method for the retrieval of tropospheric NO_2 is a combined assimilation retrieval approach, which takes into account the stratospheric background, the sensitivity to the vertical profile, clouds and the surface albedo. This approach is applied to GOME measurements within the ongoing EU project GOA (GOME assimilated and validated ozone and NO_2 fields for scientific users and for model validation).

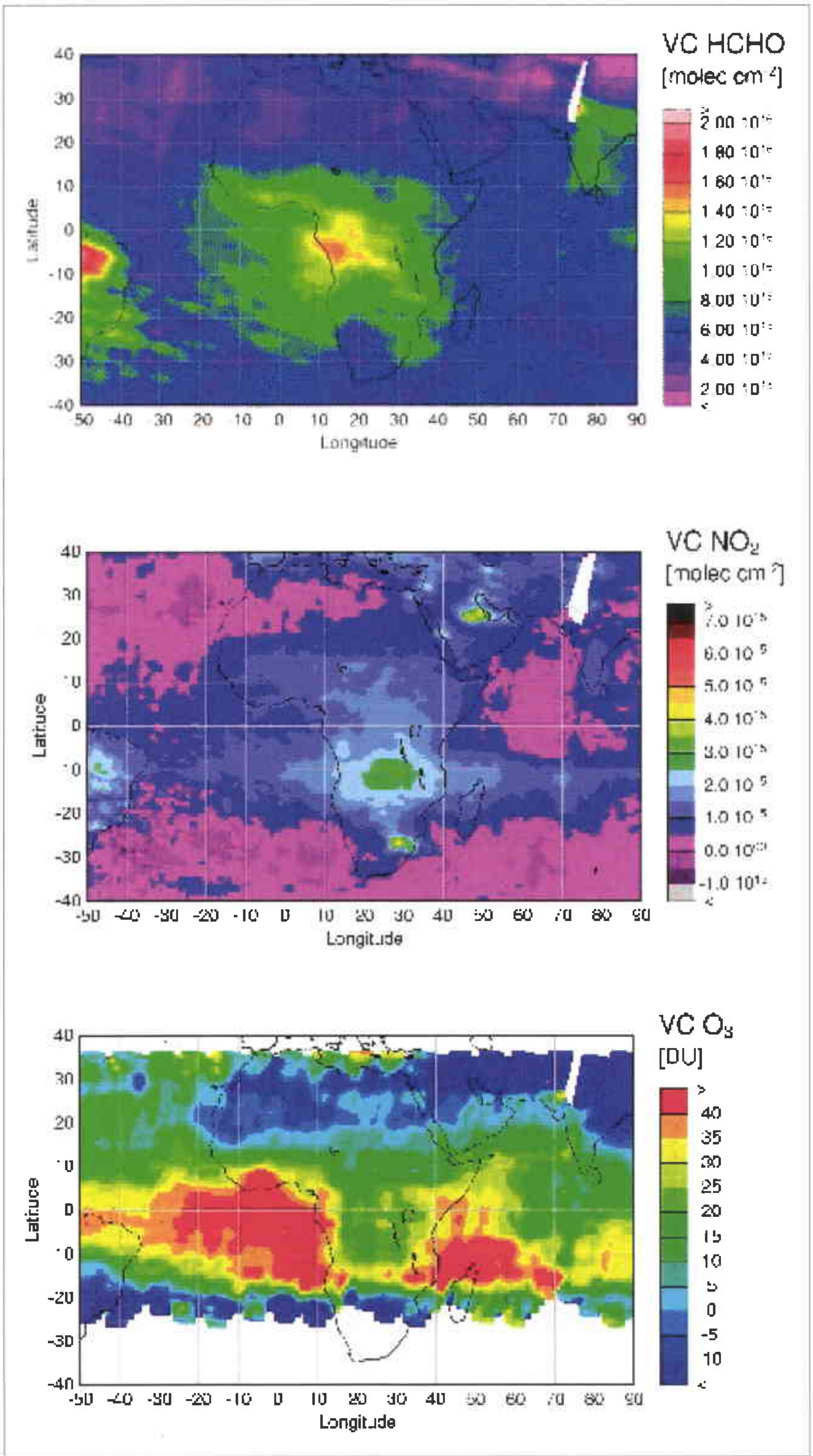
An alternative, vertical column (VC) approach for retrieving tropospheric information is to use measurements 'on-cloud' and 'off-cloud' to determine the amount below the cloud. The different albedos and the resulting photolysis field above the cloud introduce complications.

For the trace gases only having spectral features in a restricted wavelength region, such as BrO, HCHO and SO_2, the TEM and VC retrievals provide a very good means of determining tropospheric information from GOME.

The first BrO column products were successfully retrieved from GOME nadir earthshine spectra by groups at the University of Bremen, the University of Heidelberg, SAO, DLR and BISA. DOAS fitting algorithms for BrO slant-column retrieval, as well as the AMF calculations needed for conversion to vertical columns, are still optimised taking into account bromine photochemistry where necessary. Big tropospheric plumes of BrO have been monitored by using GOME measurements during Arctic/Antarctic springtime (Fig. 3).

Ozone profile information is being retrieved from GOME data by several different European institutes: RAL in the United Kingdom, KNMI and SRON in the Netherlands, and the University of Bremen and ZSW in Germany.

Figures 1 a-c. Tropospheric HCHO, NO_2 and O_3 retrieved from GOME observations in September 1997 (image courtesy of University of Bremen)



Different back-scattering layers of ozone (mainly in the 265 to 307 nm wavelength range – the Hartley bands) and the temperature dependence of the measurements (mainly from 323 to 335 nm – the Huggins bands) are used to retrieve ozone-profile information and determine the stratospheric and tropospheric contributions to the vertical column. A variety of computational algorithms have been devised, including one using neural networks, to take account of the variations due to ground albedo, the presence of clouds, the variation with temperature and stray-light effects. It is now possible to obtain GOME ozone profiles on a regular basis. Much of this work is supported by ESA through the ERS Announcement of Opportunity scheme and the Data User Programme.

Clearly, obtaining profile information for tropospheric species is not an easy task, and much work has to be done on each data set for each chemical entity. However, the coming of SCIAMACHY with its simultaneous limb and nadir measurements will facilitate the use of direct methods and allow the verification of what has been achieved so far. In addition, it is hoped that by combining observations made under different conditions (nadir and limb viewing, for example) with different techniques and suitable models, it will be possible, ultimately, to obtain tropospheric profiles on a routine basis, rather than on the case-by-case basis applicable for most species at the moment.

Some recent results

In this section, results for a number of tropospheric species are presented in order to illustrate the scientific topics that can be addressed with satellite data.

Biomass burning in tropical regions

Figure 1 shows results obtained for formaldehyde (HCHO), nitrogen dioxide (NO_2) and ozone (O_3) over Africa and India and Western Brazil. The large amounts of HCHO and NO_2 over Africa and Western Brazil can be attributed to biomass burning, which is an important part of agricultural practice in the tropical savannah. The peak of the NO_2 plume is probably above the biomass burning in the Congo and Eastern Africa, but a persistent pollution of high NO_2 is observed over the industrial region of South Africa and the oil-producing states of the Persian Gulf.

The Congo Basin is a centre of much storm activity, itself a significant source of NO_2 from lightning, also providing convective pumping of pollution into the free troposphere. It is interesting to note that the maximum amount of

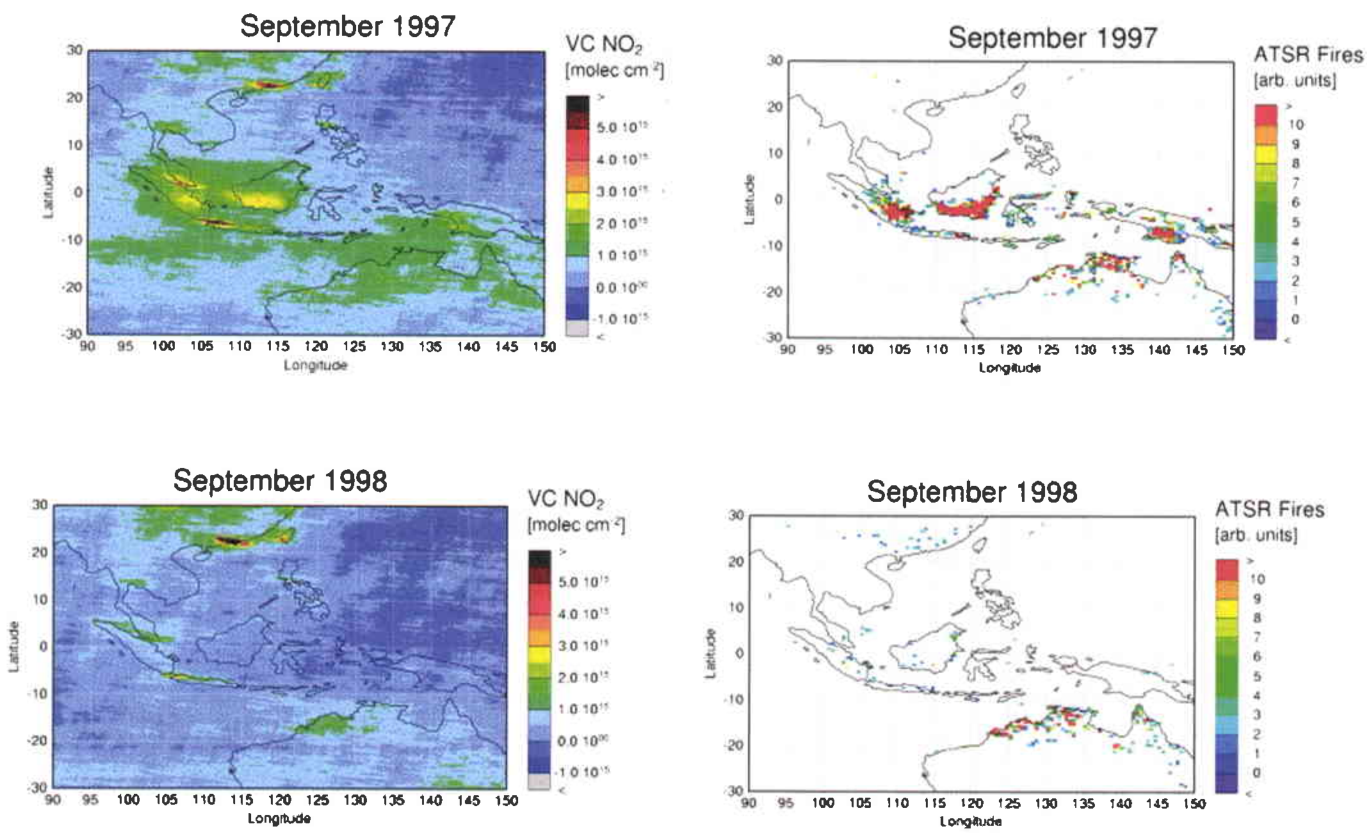


Figure 2. Synergistic use of retrievals of NO_2 and fire from simultaneous GOME and ATSR images. Note that both fires and the Asian cities are substantial sources of NO_2 (image courtesy of University of Bremen)

HCHO and a significant amount of NO_2 is above a region of convective uplift. Above East Africa, the NO_2 plume appears to be pumped into the upper troposphere, and then to travel westwards towards Australia. Additional NO_2 may result from pollution and biomass burning on the island of Madagascar, as well as convective uplifting and lightning.

Figure 1c shows the tropospheric O_3 vertical column estimated from GOME measurements. The large signal above the Atlantic Ocean was first observed in TOMS data in earlier years. Ozone is a product of the complex photo-oxidation of hydrocarbons catalysed by NO_2, while HCHO is a byproduct of this process. The NO_2 produced by biomass burning, other pollution and, to some extent, by lightning, results in enormous O_3 plumes off the east and west coasts of Africa.

Fires and pollution in Southeast Asia
Figure 2 shows how results from two satellites can complement each other. The ATSR results show the extensive fires that occurred in Southeast Asia in 1997, and to a much lesser extent in 1998. The GOME results show the resulting plumes of NO_2, which are closely correlated with and presumably result from the combustion processes. The NO_2 resulting from the industrial pollution in Southern China and Taiwan can be discerned in the 1998 results.

Tropospheric bromine monoxide (BrO)
One of the curiosities of the tropospheric ozone distribution is the almost complete disappearance of ozone in the atmospheric boundary layer around the fringes of the Arctic. This was first discovered in the early nineties in results from several ground stations. The explanation was far from clear for some time, until an anti-correlation with the chemical compound bromine monoxide (BrO) was found.

The presence of BrO around the whole of both the Arctic and Antarctic Oceans in their respective spring seasons is shown in Figure 3, produced using GOME measurements. The source of the BrO is not clear, but is presumed to be released from sea salt or biogenic organo-bromine species.

Global ozone
Figure 4 (lower part) shows the global-ozone distributions from 1995 to 1998, derived from GOME data. The upper part of Figure 4 shows model results for the same period. The major features are reproduced, but there are many differences in the detail. Such comparisons will serve to improve the models used both for the ozone and for extracting the data.

The quality of data available from GOME is nicely illustrated by the ozone hole in Figure 5.

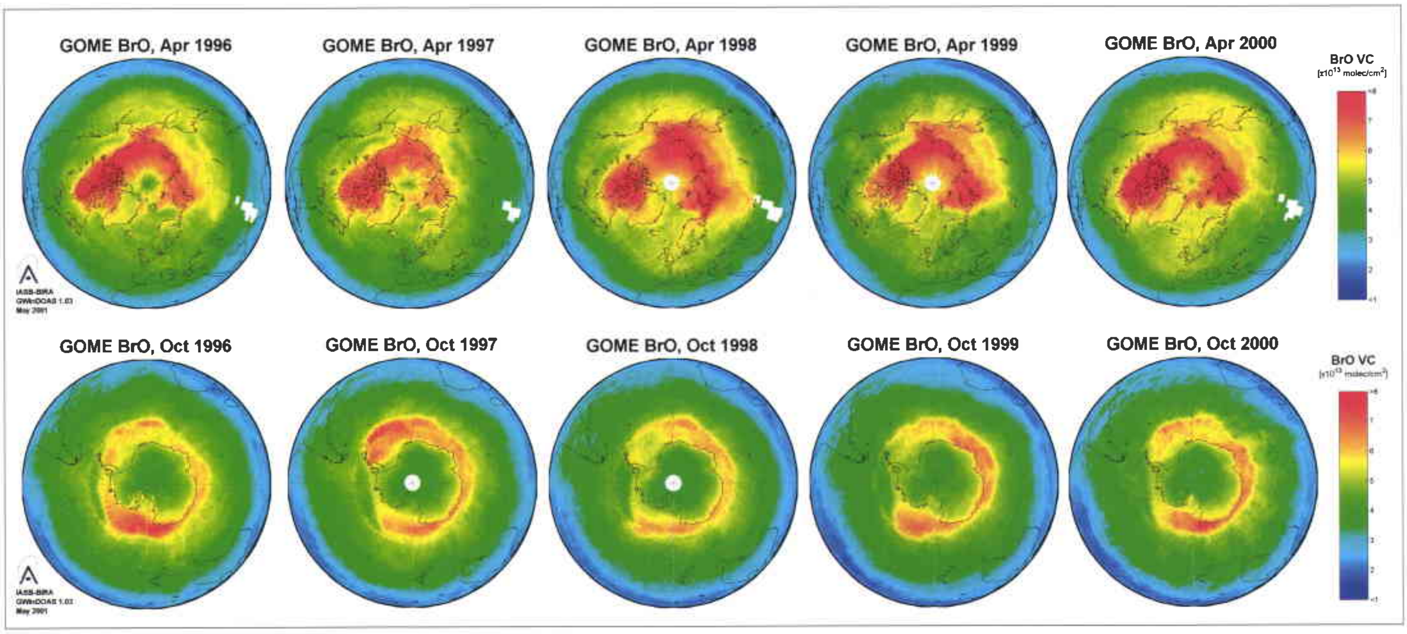


Figure 3. Observations of the large tropospheric clouds of BrO formed above sea ice at high latitudes around the Arctic (top row) and Antarctic (bottom row) oceans in spring each year (image courtesy of Belgian Institute for Space Aeronomy)

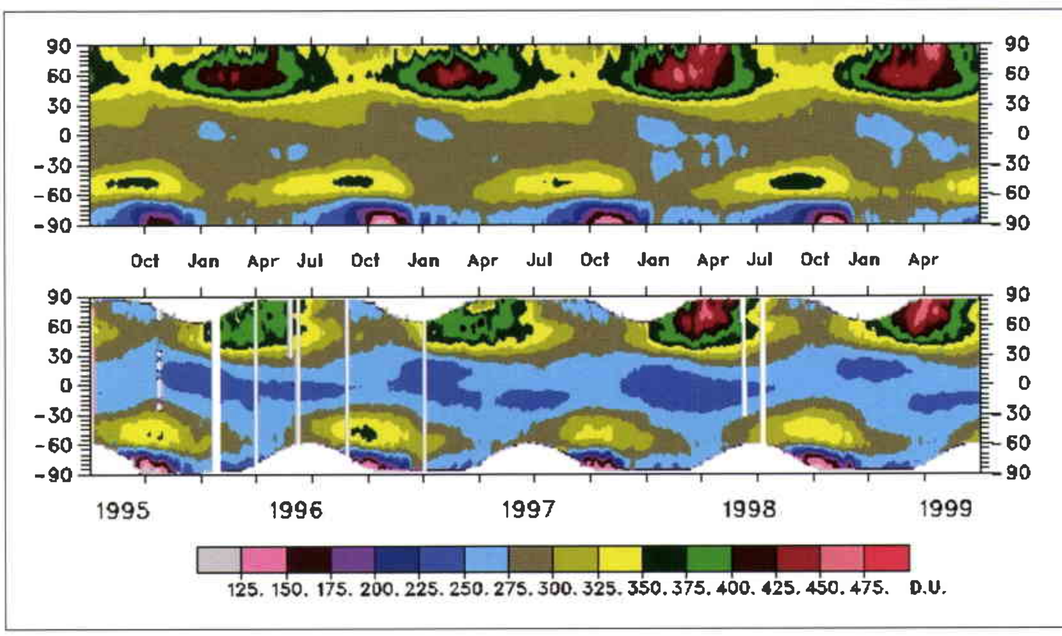


Figure 4. Global ozone, 1995 to 1997. The lower part of the figure shows four years of observations of the total ozone column with GOME (1 July 1995 to 30 June 1999). The upper part shows four individual years of a multi-year simulation with a chemistry-climate model (image courtesy of DLR)

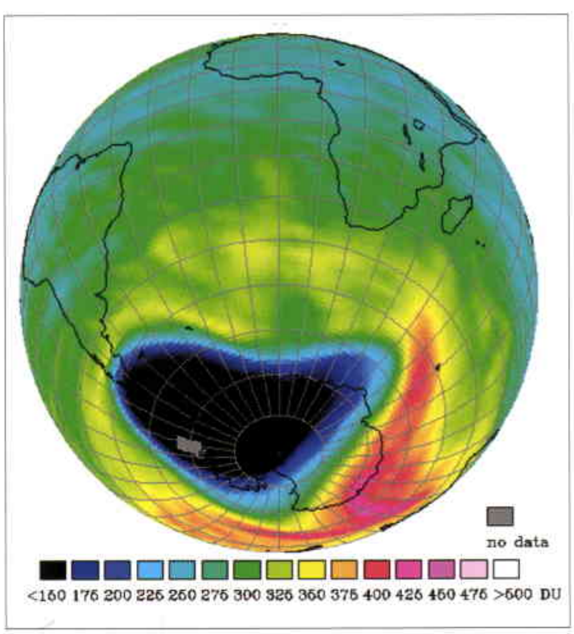


Figure 5. The Antarctic ozone hole during 2000, mapped from GOME data (image courtesy of KNMI)

Consequences for European environmental policy development

The availability of satellite data for the troposphere will assist those responsible for environmental-policy development in Europe both in monitoring on a regional scale and in the validation of the models used for different scenarios and to check compliance. As already mentioned, the development of legislation to control pollutants must be based on sound science encapsulated in reliable chemical-transport models. The expected contribution from satellite-derived tropospheric data will be invaluable in the thorough validation of these models. In addition, there is a requirement on the authorities to monitor pollutant concentrations on a regional scale, in order to verify compliance with the control measures.

A nice example of the possibilities offered by satellite-derived data is provided by Figure 6, which shows the seasonal variation in NO_2 concentrations over Europe during 2000. The high concentrations generally seen over Northwestern Europe and in the Po Valley confirm the model results and projections obtained by D. Simpson from EMEP (The Co-operative Programme for Monitoring and Evaluation of the Long-Range Transmission of Air Pollutants in Europe). These are just the regions where the NO_2 concentrations are high enough to titrate out much of the ozone formed in the boundary layer, and furthermore are regions where a substantial reduction in NO_2 may actually lead to an increase in photochemically produced ozone.

As part of the Troposat project, mentioned below, a feasibility study has been started to check whether the Envisat data products derived from SCIAMACHY and MIPAS (Michelson Interferometer for Passive Atmospheric Sounding) can be used as a part of an air-quality management system. As a test, GOME products have been used to assess the possibility of detecting signatures of regional-scale pollution. A detailed concept of how to use the Envisat data will be prepared. Also, in another Troposat investigation, satellite measurements are being used to trace the histories of individual air parcels, with the aim of identifying pollutant sources.

The Kyoto Agreement requires the long-term monitoring of the troposphere to try to identify changes due to man's activities. SCIAMACHY and MIPAS will offer a first opportunity to investigate the accuracy required for the space-based monitoring of greenhouse gases targeted by the Kyoto Protocol for emission control.

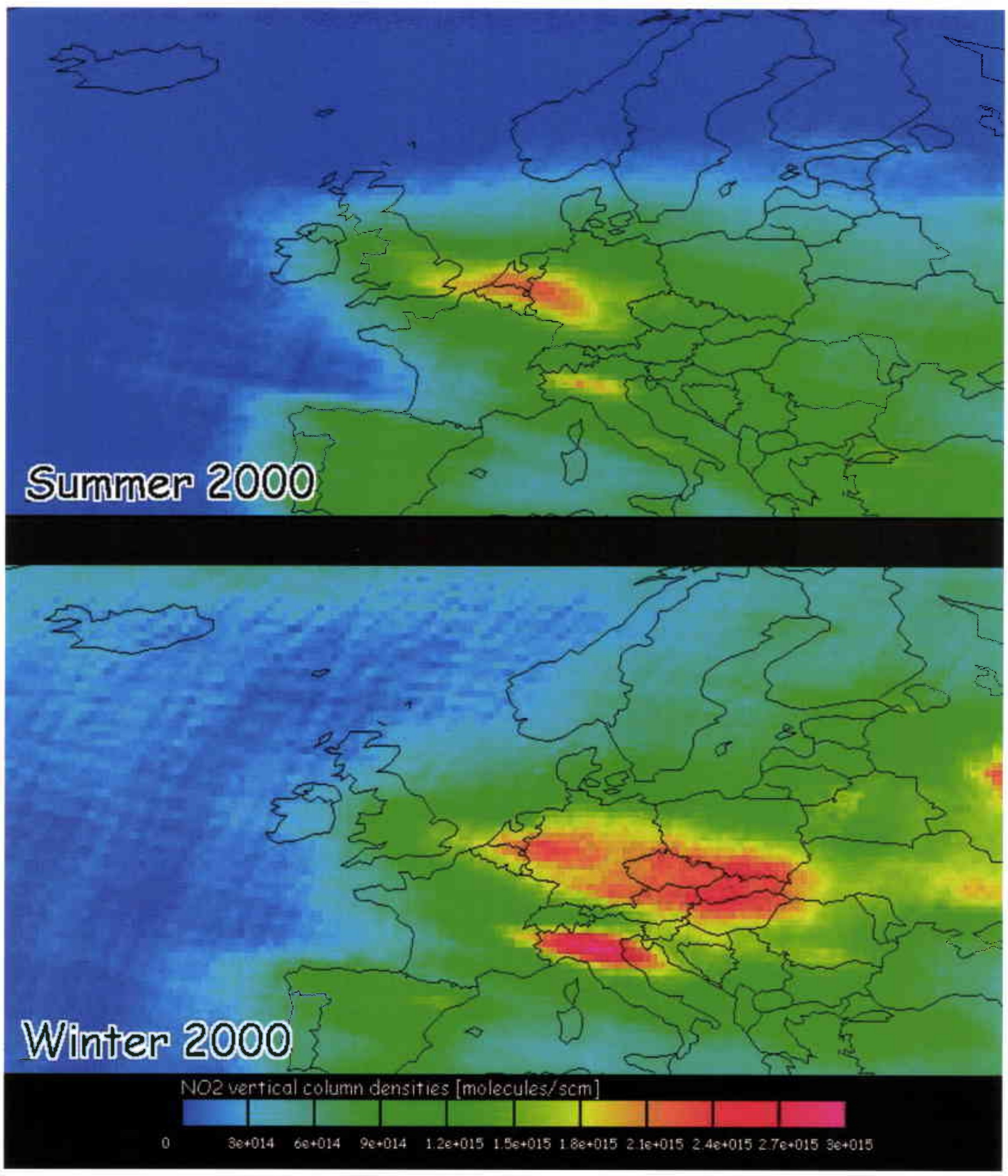


Figure 6. Seasonal variation in tropospheric NO_2 vertical column over Europe derived from GOME measurements (image courtesy of University of Heidelberg)

Clearly satellites, once they have been launched and the instrumentation and data production validated, offer a reliable and long-term way of achieving this goal on both global and regional scales. It is to be expected that, once the difficulties of retrieval and validation have been overcome, satellite-derived data for the troposphere will contribute appreciably to the required monitoring.

Troposat: a new project to obtain and study tropospheric data

To encourage the use of tropospheric satellite data within the tropospheric-chemistry community, a new subproject known as Troposat has been approved for inclusion in Eurotrak-2, the European Commission's Eureka project studying the transport and chemical transformation of trace substances in the troposphere over Europe.

The formal aim with Troposat is to determine two- and three-dimensional distributions and time series for trace gases and other parameters in the troposphere, and thereby facilitate future research and environmental monitoring on regional and global scales. The project is intended to act as a bridge between the satellite and the atmospheric-chemical communities, and to demonstrate the possibilities offered by satellite measurements for model validation on regional scales, for monitoring pollutants, and determining distributions and budgets. Studies will be carried out of pollutants on continental and regional scales, and the possibility of using remote sensing for Kyoto Monitoring will be investigated.

The work of Troposat is divided between four task groups:

1. The development of algorithms for the retrieval of tropospheric species and parameters

The extraction of tropospheric information from the raw data is still something of an art, the degree of difficulty of which depends on the particular chemical species being studied. Much development will be required before the procedures can become routine. Work is in progress on the effects of cloud shielding, wavelength and albedo effects, temperature effects, and the best combination of limb and nadir measurements to obtain the requisite profiles.

2. The use of satellite data for understanding atmospheric processes

The main objective is to demonstrate how satellite data can be combined with model results and data from terrestrial measurements to improve our qualitative and quantitative interpretation and understanding of dynamic and chemical processes in the troposphere. Satellite data are ideally suited to supply initialisation, boundary conditions, and test data for chemical-transport models on regional scales and coupled global chemistry-climate models. Activities include case studies comparing data with the results from chemical-transport models, validation of chemistry-climate models, and the comparison and interpretation of the results from modelling that combines ground-based and aircraft measurements with satellite data.

3. The synergistic use of different instrumentation and platforms for tropospheric measurements

It is now recognised that to obtain an accurate on-going picture of the state of the troposphere, a combination of modelling, ground-based measurements, field activities and satellite data will be required. Current activities include: the combination of satellite data sets to explore large-scale NO_x sources to assess the contributions from lightning and biomass burning; using satellite-derived data together with the regular aircraft measurements of water vapour and ozone made within the Mozaic programme, to explore the processes governing the global-ozone and water-vapour budgets; and exploring the possibility of including space-derived measurements as an operational part of a national air-pollution monitoring network.

4. The development of validation strategies for tropospheric satellite data products

The tropospheric data presently available are still tentative in that they have not yet been subjected to extensive validation procedures. The aim of this group is to devise and test procedures for the validation of tropospheric satellite data products. The activities foreseen include validation of data from Envisat instruments, improvement of strategies for validation, the identification of data sets from ground-based measurements suitable for the validation of satellite-derived tropospheric data, and the use of data assimilation and other modelling techniques in validation.

In addition, Troposat will undertake two other underpinning activities:

Specification of the requirements for future satellite instruments for tropospheric work

The initial experience of the group in obtaining and using tropospheric data has already indicated a need for new and improved satellite instrumentation to obtain more and better data for the troposphere. The group will draw on this experience to contribute to proposals for instrumentation for future missions.

Development of appropriate data-assimilation techniques for satellite measurements
A number of Principal Investigators are exploring the use of data assimilation in which satellite measurements and modelling results are compared, to the mutual benefit of both. In the future, one can imagine a modelling system running continuously, but being frequently updated with near-real-time satellite measurements to provide a continuous picture of the atmosphere.

Some forty research groups in ten countries began work in 2000 and will continue until the formal end of Eurotrac-2 in 2003. However, there is so much to do and so many possibilities that it is fully expected to continue the Troposat project beyond this date. As with all Eureka projects, the Principal Investigators must find their own funds from their national funding agencies or from international sources such as the European Union.

The future
The launch of Envisat, carrying three atmospheric instruments, is eagerly awaited. SCIAMACHY will extend the capability of GOME in two ways: by measuring in limb- (towards the horizon) and nadir-viewing geometries, and by recording the back-scattered and reflected light simultaneously from 220 to 2380 nm. SCIAMACHY will also measure solar and lunar occultation. Two limb-sounding instruments, GOMOS (Global Ozone Monitoring by Occultation of Stars) and MIPAS, will measure trace gases in the atmosphere using complementary techniques. As already indicated, the combination of nadir- and limb-sounding should facilitate the production of reliable tropospheric data for a number of trace chemical species and air pollutants.

With the development of data-assimilation techniques for satellite-derived data, one would hope that, in the not too distant future, a combined modelling/satellite data /ground-based data approach will yield a continuous picture of the chemical troposphere on both global and regional scales.

The data provided by low-Earth-orbit (LEO) satellites should be supplemented with data from geostationary platforms, which offer the possibility of making daily time-resolved studies. A future scenario, involving two proposed ESA missions, GEOSCIA and ACECHEM, would provide reliable vertical-profile information within the troposphere by the combination of stationary measurements with limb and nadir soundings.

Thus the future looks bright, with satellite data revolutionising the observation of trace substances and pollutants in the troposphere, and not only making an appreciable contribution to our understanding of the complex processes involved, but also playing an essential role in monitoring and establishing an environmental policy for the troposphere.

Acknowledgements
We wish to thank our colleagues and friends throughout the scientific community for their support and encouragement and, where indicated, for providing some of the images used in this article. We also wish to thank the Troposat Principal Investigators for their help in starting the project and Pauline Midgley and Markus Reuther of the Eurotrac-2 International Scientific Secretariat for their encouragement and support in the formulation of Troposat and in its further development.

The work would not have been possible without the data products and support, both for much of our work and for the co-ordination of Troposat, from ESA's ESRIN establishment. The Troposat Principal Investigators are supported by many national agencies throughout Europe and by the Framework programmes of the European Union.

Further information
Additional information can be found at the following Web addresses:

The Troposat project:
www.iup.uni-heidelberg.de/luftchem/troposat

ESA AO scheme: projects.esa-ao.org

The 'Space and Major Disasters' International Charter

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Considering on the one hand the increasing number of major disasters, and on the other the interest shown by Civil Protection Authorities in space techniques, ESA and the French national space agency CNES announced their intention to set a co-ordinated means of access to space facilities and tools, at the UNISPACE III Conference in Vienna in July 1999. The International Charter on 'Space and Major Disasters' was subsequently signed on 20 June 2000 by both Agencies, followed by the Canadian Space Agency (CSA) on 20 October 2000.

This far-reaching humanitarian initiative provides a worldwide, consistent framework for accessing data from a variety of sources. It is mainly oriented towards helping the emergency and rescue authorities during a crisis. The Charter is open for signature to all space agencies and operators, and a number of other agencies have already announced their intention to join, including NOAA (USA), ISRO (India), CONAE (Argentina) and NASDA (Japan).

The 'Space and Major Disasters' Charter has been in operation since 1 November 2000. Civil Protection Agencies may place their requests for assistance via a dedicated 24-hour telephone line. A specialised engineer analyses the situation together with the requestor and proposes an action plan, which includes emergency re-tasking of the satellites operated by the Charter's signatories. A project manager ensures that the necessary data are acquired and their timely delivery to the requestor or designated agent. During its first six months of operation, the Charter was invoked eight times.

After the earthquake that struck San Salvador on 13 February 2001, only 3 days were needed to re-task the Spot-4 satellite, to acquire the data and to prepare damage-assessment maps, just in time for the French Civil Protection rescue squad, which was arriving on a medical-assistance mission. As a by-product, the Salvadorian Geographical Survey requested and was given the maps in order to update its 25-year-old reference set.

The Charter was also invoked during the Saône River flood, one of the many that affected France earlier this year. Twelve hours after the acquisition of an ERS-2 image, a preliminary map of the flooded area covering 100 km of the Saône watercourse was provided to the relief co-ordination centre in Lyon. The images in Figure 1 show how a mix of two radar images (before and during the flood) allows accurate detection of the flooded areas. The map in the middle clearly shows the flooded area in blue, with the normal riverbed in dark blue; the right-hand map highlights areas affected by the flood and allows urban or agricultural usage to be identified. These maps represent a synthetic

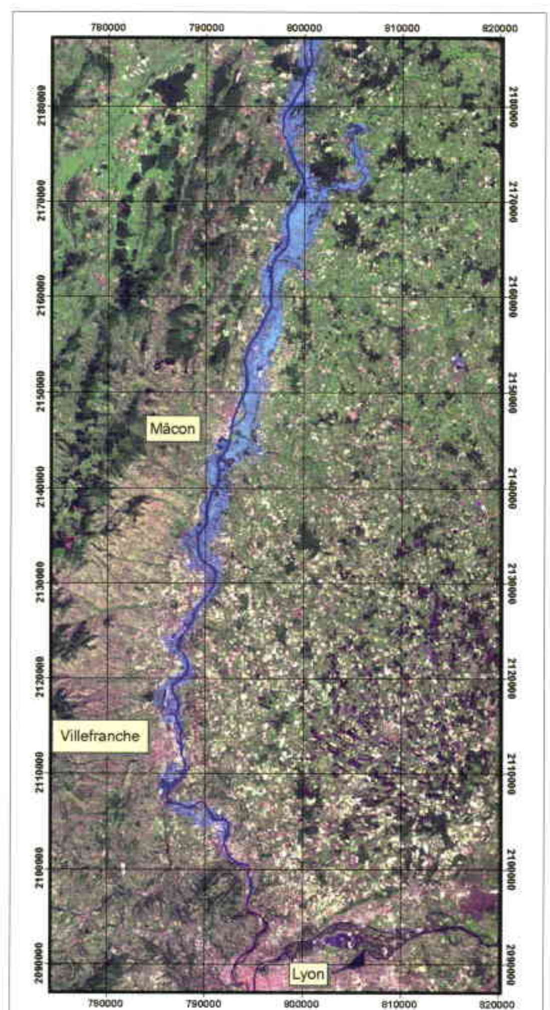

Figure 1. (a) A map of the Saône flood north of Lyon. Flooded areas are shown in light blue, the normal river course in dark blue. The map is obtained from a fusion of optical and radar data. Landscape in pseudo-natural colours. Extended Lambert II projection, scale in km

snapshot and will serve as reference data for this flood event in a decision support system. They will also be used as input to regulatory flood-prevention plans. These maps were obtained from a fusion of optical and radar images from the Spot and ERS-2 satellites.

The two examples above demonstrate the value of this co-operative endeavour. Nowadays, what limits the operational use of Earth Observation satellites during a natural disaster is more the number of satellites available for that purpose, rather than the technology itself.

The Charter has created a great deal of interest in Civil Protection and Humanitarian Emergency circles. It is being recognised as an efficient framework at international level, setting new standards and serving as a reference.

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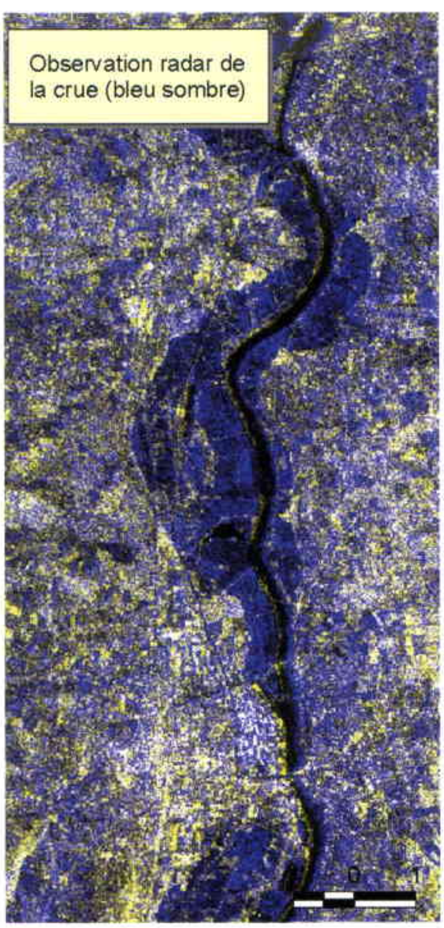

(b) The flood extent detected by a combination of two ERS SAR images appears in blue, near Villefranche-sur-Saône.

(c) The flood extent laid over a space map derived from SPOT imagery The flooded areas are shaded in light blue

(d) This map reveals the nature of the flooded areas (urban/agriculture), while non-flooded areas are dimmed. Extended Lambert II projection, scale in km

Towards an Enlarged Partnership – ESA's Relations with the Czech Republic, Hungary, Poland and Romania

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In October 1999, ESA organised a two-day Workshop in Budapest together with the Hungarian Space Office, with a view to analysing existing relations between ESA and its partners in Central and Eastern Europe, namely the Czech Republic, Hungary, Poland and Romania. The Workshop's main objectives were to discuss the results of the existing cooperation and to present ESA's new programmes and activities, as well as its administrative procedures and regulations. The space authorities from the four countries also presented their own space programmes and plans.

Background

The Budapest Workshop was well timed. ESA had first established relations with these countries in the early nineties when they approached the Agency asking to collaborate in its space programmes. This led in due time to the signing of framework Agreements with Hungary, Romania, Poland and the Czech Republic. These relations then evolved through joint co-operation projects, leading eventually to the participation of both the Czech Republic and Hungary in the PRODEX optional programme. Now, almost ten years later, it was felt necessary to analyse the current situation and to identify ways in which relations could evolve, and to discuss possible means for establishing closer links. Some of the countries involved expressed – formally or informally – their interest in acceding to the ESA Convention.

The Czech and Hungarian participations in the PRODEX programme have so far been a very positive experience. However PRODEX, being an optional programme with a limited scope, did not involve participation in any of the other ESA programmes and activities, a fundamental consideration in terms of the strengthening of links with ESA, especially with regard to possible future accession to the ESA Convention.

At the meeting in Budapest, ESA introduced the different mechanisms defined in the ESA Convention (Article XIV) in order to establish co-operating links with non-member States. Three types of co-operation are foreseen in this Article: Co-operation Agreements, participation in ESA Optional Programmes, and Associate Membership Agreements. These three types of cooperation have in fact been the paths followed by several States that have acceded to the ESA Convention since its initial entry into force. Austria, Norway and Finland, for example, were first linked with ESA by a general Cooperation Agreement, participated in ESA Optional Programmes, and were then granted Associate Member State status, before becoming full Member States. The only exception has been Portugal, which acceded to the ESA Convention after first having had a general Co-operation Agreement and a specific Agreement on Portugal's participation in the ARTES Optional Programme. Actual accession to the ESA Convention is dealt with under a separate article, namely Article XXII.

After the introduction to the different forms of co-operation under Article XIV and the presentations by ESA and by the four countries of their respective present and future plans and programmes in the space field, two aspects emerged at the workshop:

- *Interest and potential synergy existed between ESA programmes and the future plans in the space field of its four European partners.* The Director General of the Hungarian Ministry for Foreign Affairs introduced the Hungarian Research and Development Programme, which should provide more opportunities for Hungarian scientists. This recent increase in awareness of space programmes can be explained by the important brain drain among scientists in the former Central and Eastern European countries that has developed into a very serious issue. The Director General of Foreign Affairs explained that the Hungarian wish to seek closer relations with ESA should be seen in light of this new policy.

- *The path of cooperation proposed by ESA to these States in order to become, in the near or long term, an ESA Member State, did not suit their needs or current financial capacities.* The main difficulty for these States in following the usual path of cooperation with a view to acceding to the ESA Convention emanates from the step from a general Cooperation Agreement to an Associate Membership Agreement. In particular, the conclusion of an Associate Membership Agreement was not considered suitable because it required financial participation by the States concerned in ESA's General Budget (at a rate of 50% of what they would pay as a full Member State), which implied too steep a budgetary increase with respect to their current financial and industrial capacities. Therefore for these States, which had already signed a Co-operation Agreement with ESA and which wanted to reinforce their own space programmes through reinforced co-operation with ESA, the signing of an Associate Membership Agreement was seen as too broad. They explained that an intermediate step would greatly enhance the potential for cooperation and would facilitate the development of cooperation projects with ESA, with a view to facilitating their progressive integration into the Agency's programmes and activities.

In formulating his conclusions to the Budapest workshop, the ESA Director of Strategy and Technical Assessment proposed to convey these important messages to the ESA Member States.

The Council Working Group on the enlargement of the Agency

Following the Budapest Workshop, a report was presented to the ESA Council on its outcome, which also contained some proposals regarding the creation of a new concept that would allow our four European partners to participate more in ESA's programmes and activities. Member States were reminded in particular that official reflection on the Agency's enlargement had last taken place in 1985, when the Council had set up guidelines regarding this matter. Given the geopolitical changes since 1985, Council, during its December meeting in 1999, decided to set up an ad-hoc Council Working Group that would look into the Agency's enlargement.

The mandate of the Working Group was to:

- Identify the various stages leading to such enlargement in the mutual interests of the Member States and the States that want to accede to the Convention.
- Propose guidelines for the establishment of progressively closer ties with the Agency.
- Establish criteria for the admissibility of applications to accede to the Agency's Convention, and to identify the action required to enable the States concerned to meet those criteria.
- Define the specific status of a 'State in Transition' with a view to enabling States that may wish to accede to the Agency's Convention to prepare to do so by participating in Agency activities relevant to the scientific and industrial capabilities that they wish to develop.

The Working Group met twice and produced a report that was adopted by Council in June 2000. This report contained several recommendations, the most important being that *'the Agency establishes a specific framework for facilitating the participation of European non-Member States in ESA programmes'.* This has led to the creation of the new concept of a 'European Co-operating State'.

The new concept of a European Co-operating State (ECS)

Council also decided on several criteria as regards the eligibility of States wanting to assume ECS status. These must be European, and must have signed a framework Agreement with ESA. Council agreed that the Czech Republic, Hungary, Poland and Romania were directly eligible for the new ECS status.

Based on this report, a new model Agreement for ECSs was proposed, allowing for the indirect participation by an ECS in all ESA programmes and activities. This ECS model Agreement was discussed in the relevant Council subordinate bodies before being adopted by Council itself on 21/22 March 2001. As a result, ESA's Director General has been authorised to use this model in negotiations with Cooperating States that, in the near or longer term, want to become full Members of ESA.

To attain ECS status, the candidate State must first negotiate and then conclude an ECS Agreement with the Agency. This is then a bilateral engagement between the ECS and ESA whereby the State is allowed, subject to the fulfilment of certain conditions, to participate in ESA programmes and activities. These activities are defined in a five-year work Plan for European Cooperating States (PECS) to be jointly agreed by ESA and the ECS concerned. The Agency shall execute the PECS in conformity with its rules and procedures. A dedicated Committee composed exclusively of ECS representatives ('the PECS Committee') is set-up to monitor and control the execution of the PECS. One main difference between the previous general Cooperation Agreements and an ECS Agreement is that a minimum financial contribution of 1 MEuro per year is required from each ECS.

In conclusion, it is interesting to note that, with a limited financial contribution, the new Agreement provides the ECS with the possibility of taking part in ESA programmes through the PECS without actually becoming a participant in the ESA programme concerned as originally foreseen in Article XIV.2 of the ESA Convention. The purpose of this new form of cooperation is first of all to strengthen the links between the ECS and the Agency in order to facilitate its future possible membership of ESA. However, there is no obligation to accede to the ESA Convention, but the objective is clearly to associate the ECS to ESA programmes and activities and to prepare in the most efficient manner for this possible future accession. It is envisaged that PECS participation will not only strengthen the ECS's national institutional capacity, but also assist in the development of its national space industry. Another objective is to develop cooperation between the scientific and applications user communities in the ECS and in the Agency's Member States, and to ensure coherence between Member-State and ECS space activities, for example by avoiding unnecessary duplication.

The ECS Agreement will, upon its entry into force, replace the other Agreements concluded with ESA and will have a duration of five years. Thereafter, depending of the results achieved within this period of cooperation, three possibilities can be envisaged: the ECS can continue to cooperate with ESA under an ECS Agreement, the ECS can apply for Associate Membership, or the ECS can apply directly to become a Member State. The advantages of this new concept are that it provides a permanent structure, and links between the ECS and ESA permitting the development of relations through participation in Agency programmes. Not only the strictly programmatic side is involved, but also participation in new ESA initiatives like the SME (Small and Medium-sized Enterprise) and Outreach activities. This consolidation of joint activities via an ECS Agreement will hopefully ensure that the eventual step to becoming an ESA Associate or full Member State should not be too large.

The next steps

To support the International Affairs Department in the implementation of this new policy, a 'PECS Manager' has been nominated who will be responsible for the day-to-day relations with the ECS, especially as regards the content of the PECS. ESA will now present the new concept in detail to the four European partners, before proceeding with the negotiation of an ECS Agreement with each interested applicant. However, to ensure that this new concept would be broadly acceptable to those four States, ESA had already informed them of the basic underlying ideas prior to its adoption by Council, to check that it would be acceptable to them.

ESA will also organise a special workshop in Paris in September 2001 to which representatives of the four European partners will be invited. The objective will be to present in greater detail the different possibilities existing through this newly created status and to understand the different views and possible concerns of our partners in order to proceed, on a bilateral basis, with the negotiation of an ECS Agreement with each of them.

The return for the Agency and the ESA Member States lies in stimulating relations with interested European countries, expanding the overall European scientific and industrial base, and enriching ESA as a research and development organisation.

ESA's Financial and Invoicing System (EFIS)

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The putting into operation of the ESA Financial and Invoicing System (EFIS) marks an important step for the Agency because it introduces a modern tool for end-to-end financial process and contractual management, both in ESA and in Industry. With the introduction of EFIS, which exploits the efficiency of Web-based technology, ESA brings two important aspects of its day-to-day business much closer together:

- **the external relations with Space Industry, which becomes seamlessly connected to ESA across all of the financial processes relating to contracts and payments**
- **the internal relations between project management and financial management where, thanks to EFIS, the technical progress achieved by projects can be translated immediately into financial planning.**

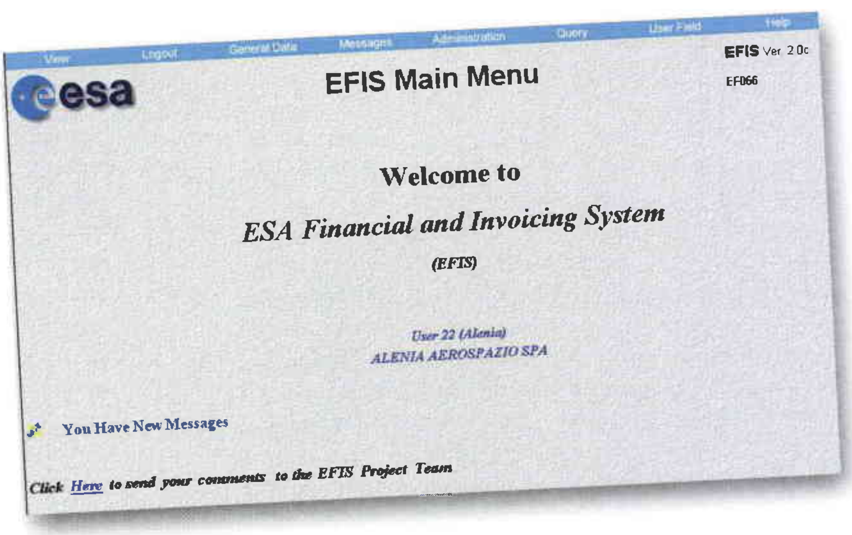
EFIS history

Over the past several years, ESA been developing and implementing electronic solutions for the management of its financial business, especially in its relationships with industry. Constant progress has been achieved by exploiting new electronic tools as the technology has advanced. In the area of electronic invoicing, the Agency started a pioneering project in 1987 whereby Industry could send invoices directly to the Agency using a commercial network. This evolved through development of the Agency's own system, and in 1991 a further major evolution took place when it was agreed with Industry that the Agency's Electronic Invoicing System (ETIS) would also be used by sub-contractors involved in the Agency's development contracts. By the use of routing tables per contract, sub-contractors' invoices could be put into higher tier contractors' electronic mailboxes simultaneously. Furthermore, there was then full visibility of the status and progress of those sub-contractor invoices. The great advantage over the circulation of paper invoices was immediately apparent, reducing the approval time in Industry by, in many cases, months. The system was further refined and made even more user-friendly, especially to smaller companies, by the introduction in 1999 of Web-transmitted ETIS invoicing.

In parallel with the purely invoicing side of the business, financial-management systems for project control have also been evolving, notably FCS, the Financial Control System created for the electronic handling of all contractual and financial data for the Agency's larger Programmes, particularly in the context of the Manned Space Programme and Earth Observation, but also used for smaller projects, such as in the Microgravity area. FCS was also designed to receive invoice and payment data from ETIS, although the two systems were essentially different products. In the late 1990s it was decided that, given the stability of the two systems, the next logical evolution was the complete integration of the FCS and ETIS systems to create EFIS, which would:

- be a pan-European tool for Industry and the Agency for all ESA contract/financial planning and invoice management, being easy to utilise from the largest development contract down to the simplest small contract and purchase order
- provide the basis for all planning, principally milestone payment planning, and invoice status information, and thus for payments and treasury predictions
- replace reliance upon paper transmission and reduce the residual paper requirements to negligible proportions.

Development work on EFIS began early in 1999, the contractor being Datamat Ingegneria dei Sistemi of Italy, under the technical direction of ESA's Informatics Department. The functional management was entrusted to ESA's Finance Department, with full support from a team of experts representing the Agency's Programme and Support Directorates, and Astrium representing European Space Industry. The team has overseen the satisfactory development of the user and system requirements, and the necessary intensive testing activities.



Version V.1 of EFIS was delivered last summer and, following successful testing, the first formal invoice was transmitted by Industry to ESA in September 2000. Migration of existing contracts from ETIS to EFIS for invoicing purposes has proceeded steadily, being completed in May 2001. Development and testing of Version V.2, incorporating the FCS part of the new system, has been completed and migration of existing contracts from FCS to EFIS has commenced in mid-2001 with the GOME and MetOp projects.

EFIS – an integrated E-business tool

For projects, EFIS is an integrated E-business tool for the administration of all financially relevant processes and data during the full life-cycle of an ESA obligation, and provides appropriate levels of visibility and access privileges for all parties concerned, e.g. ESA, prime contractors, subcontractors and suppliers. It is used by project managers/controllers and contracts officers both in ESA and in Industry to support and maintain all of the financial aspects of the contractual administration, focusing especially on:

- use of a common and consistent methodology and best practice for the financial administration of ESA obligations throughout the entire industrial consortium through the definition of common business processes
- establishment and maintenance of the financial part of the contractual baseline over the full life cycle of a contract
- handling of the complete invoicing and payment administration
- establishment and maintenance of a common data repository for all parties involved in the financial business processes, including querying, reporting and archiving capabilities.

EFIS covers and supports electronically the following key methodology aspects and business processes:

- the preparation and maintenance of the industrial contract structure, reflecting the hierarchy of industrial contracts related to each ESA obligation; the hierarchy information is used to identify the scope of visibility and access privileges of each supplier inside each obligation, and facilitates a unique numbering and coding system
- the setting-up and maintenance of the contract price data, including the associated relevant information like price types, contract subject, subsystems and geographical-return information; this information is stored in EFIS at the level of Milestone Payment Plans (MPPs)
- the preparation and maintenance of MPPs and Development Cost Plans (DCPs), both in terms of financial information and schedule-related aspects, i.e. milestone amounts and milestone dates
- the planning and control of progress achievement and incurred expenditures through the electronic creation and approval of Payment Milestone Achievement Certificates (PMACs), thereby providing the basis for financial forecasting
- the complete cycle of invoice creation and approval throughout the industrial consortium, including the payment process via the interface to the ESA accounting system, AWARDS; this provides visibility of the invoice status information at all contractual levels and at the earliest possible point in the process
- recording and tracing all financial impacts of the contractual change process, thus providing consistent and up-to-date financial status information, including traceability of the contractual baseline and history

- flexible configuration and setting-up of application functionality, e.g. using PMAC, allowing the distribution of responsibilities and user roles in electronic form; this facilitates the sharing of financial administration between ESA and Industry in accordance with the needs and requirements of individual projects, and enables Industry to assign obligation, contract and invoice administration roles to the various parties concerned, i.e. prime, higher tier, and sub-contractors, thereby eliminating the need for independent databases.

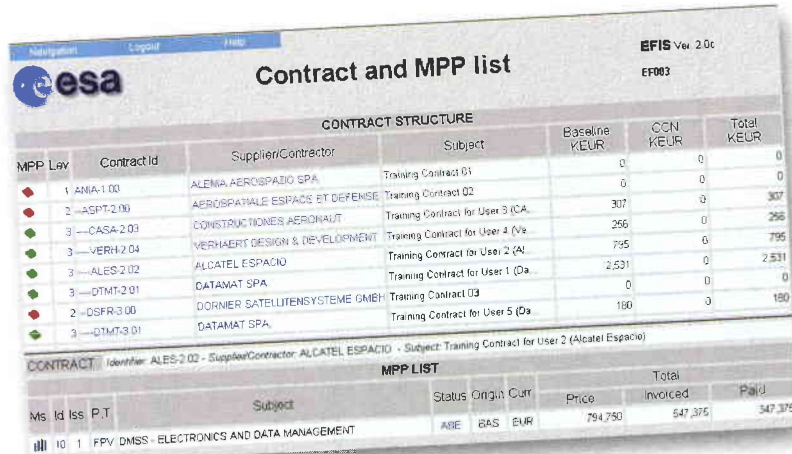
EFIS – benefits and synergies

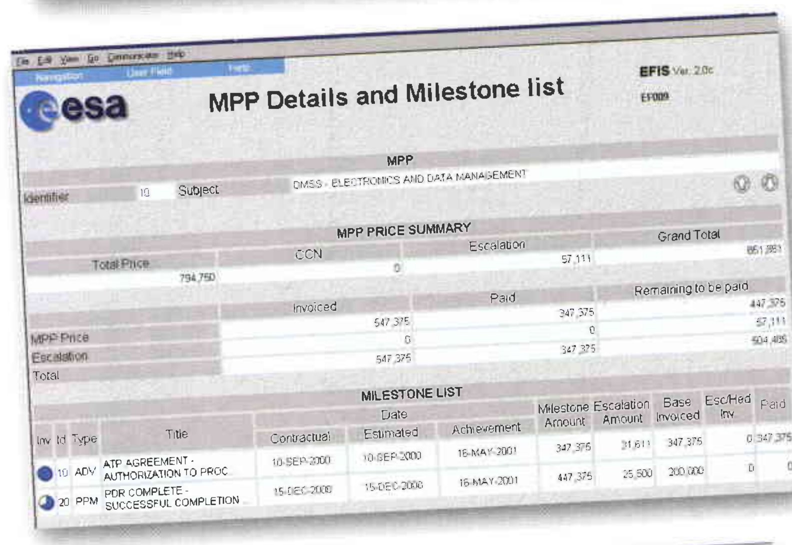
By using EFIS, an integrated financial administration tool for *all* ESA obligations, there are many benefits and synergies for the users in the contractual and financial administration disciplines in ESA and in Industry:

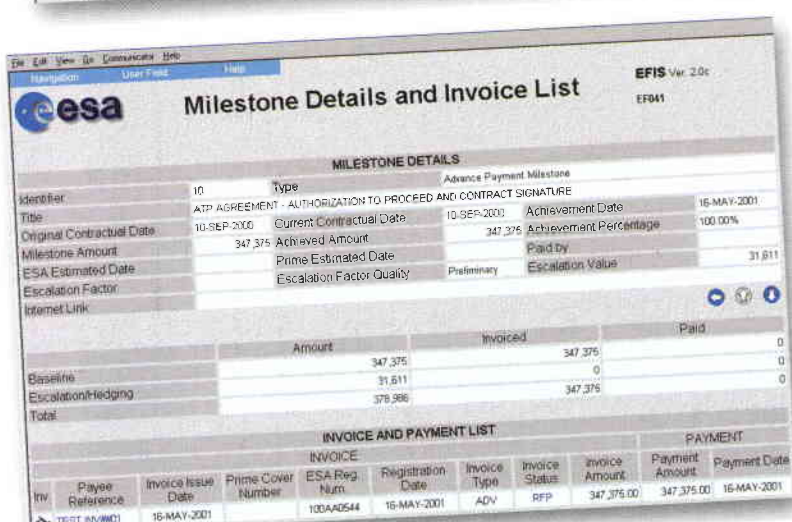
- The use of a common methodology and a common data repository for all parties involved in the financial administration of contracts avoids significantly the duplication of effort both in ESA and Industry, improves the data coherency and data quality, and thus increases the efficiency of the financial administration.
- EFIS covers the entire financial data life cycle of an ESA obligation, from the Authorisation to Proceed (ATP) until the contract close-out, including the recording of all financial impacts of contract changes, in a single integrated application.
- EFIS provides an automatic and systematic linking of the invoicing and payment process and the related information to the contractual data set, such as milestones, escalation, contract change notices and riders, etc., thus linking the financial information to project information. This not only eliminates queries and possible rejections, but also speeds up the processing with commensurate cash-flow improvements, both in predictability and actual performance for ESA and Industry, the former providing essential support for the Agency's Budget Management System.
- EFIS provides an instant and common view for all parties involved of financial and contractual status, including the related history and planning.

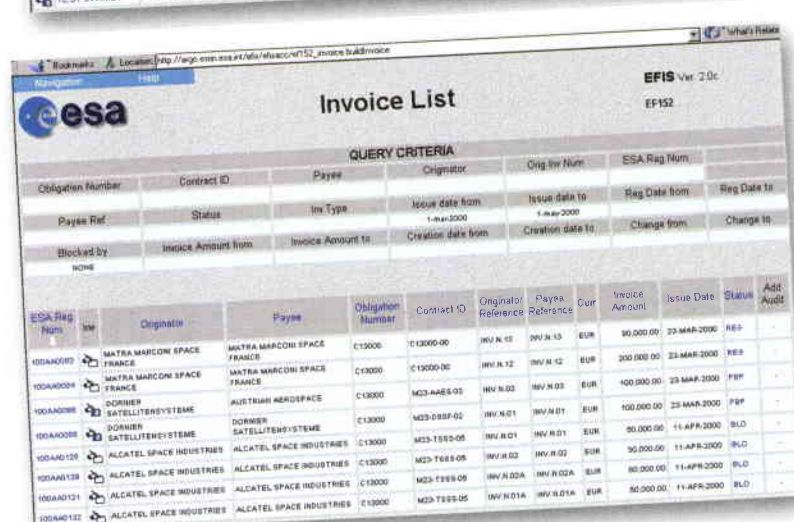
EFIS as part of the ESA MIS architecture

The 'heart' of the EFIS system is a major component of the ESA MIS (Management Information System) architecture (Fig. 1). It is one of the satellite systems of the Financial Ledger, interfacing with the AWARDS components (namely with Payables) and being the natural gateway to external systems used by ESA and Industry.









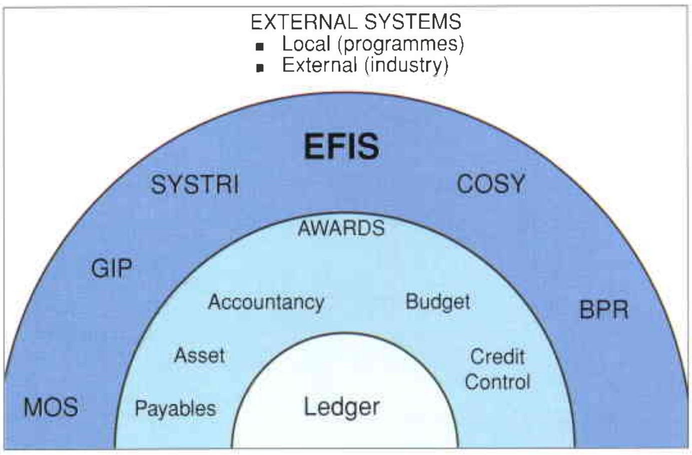


Figure 1. EFIS, a core component of the ESA Management Information System

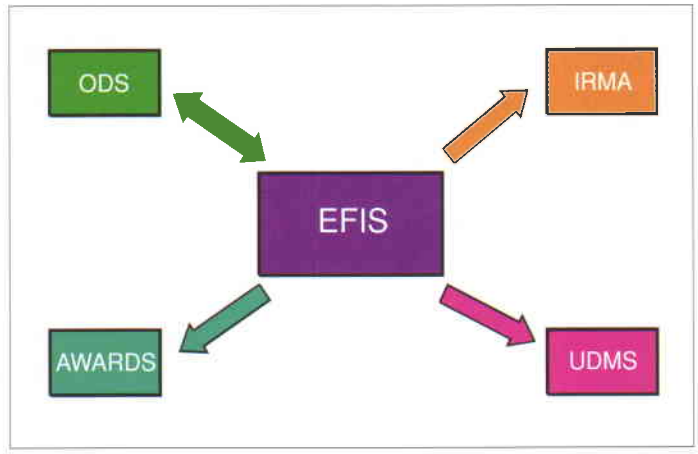
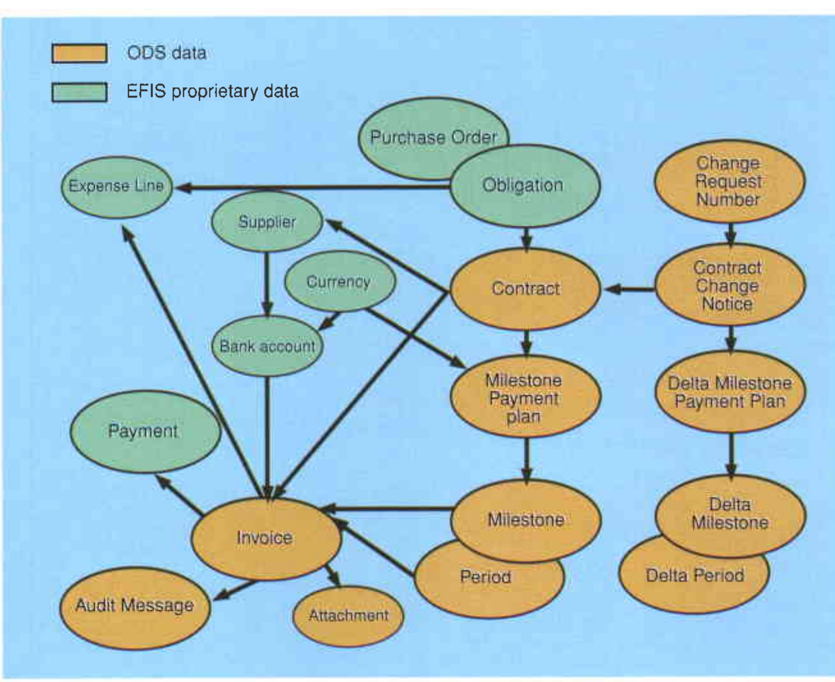


Figure 2. EFIS at the centre of ODS, IRMA, UDMS and AWARDS

EFIS has several connections with the other MIS components, namely (Fig. 2):

- ODS (the Operating Data Store), which is the source system for ESA corporate data (Fig. 3): obligations, suppliers, bank accounts, country/currency codes, budget-line codes; all of these data are automatically imported into EFIS on a daily basis.
- AWARDS, which is the ESA financial system where payments are authorised; invoices entered in EFIS are sent to AWARDS as soon as they become registered on a daily basis.
- UDMS (the User Data Management System), which is a system for user definition and authentication; it is used by EFIS and by most of ESA MIS applications (e.g. ETIS, COSY, EMITS); users already logged-in to an ESA application through UDMS can reach EFIS without performing a new log-in.
- IRMA, which is a system used to access ESA corporate data through a Web interface: ESA users, starting from ODS data imported into EFIS (e.g. budget-line codes), are allowed to follow hyperlinks (URLs) to the IRMA system (e.g. budget-line details).

Figure 3. The ODS tree



The architecture of EFIS system is based on the most modern technologies; it is a Web application accessible on the ESA Intranet for ESA users and via the public Internet for users in Industry. The central database (and the application) is built with Oracle and is located at ESRIN.

The high-level EFIS system architecture is outlined in Figure 4. At this level of detail, we can distinguish the following components or groups of components:

EFIS Web Client
The EFIS Web Client module provides access to financial and invoicing functions for users who wish to access EFIS services via the Web. It is based on a standard Web browser (i.e. Netscape or Internet Explorer) and the EFIS Web application is completely hosted on the central server site.

EFIS Java Client
The EFIS Java Client module allows users accessing EFIS from an Intranet connection to browse, enter and modify EFIS data using a Java-based application, providing more flexible and more user friendly access to the information.

EFIS Web Servers
The EFIS Web Servers are located outside the ESA firewall for Industry users and inside the firewall for fast access inside ESA. They are standard Oracle Application Servers (OASs), responsible for handling connections between the clients and the central database using the HTTP protocol.

Query, Reporting and Data Analysis Module
This module is built using a commercial off-the-shelf (COTS) package, configured specifically for EFIS needs, in order to cover the query, reporting and data-analysis areas. The COTS package used (also as the corporate tool) is WebIntelligence/Business Objects; this product is the leading query, reporting, and analysis

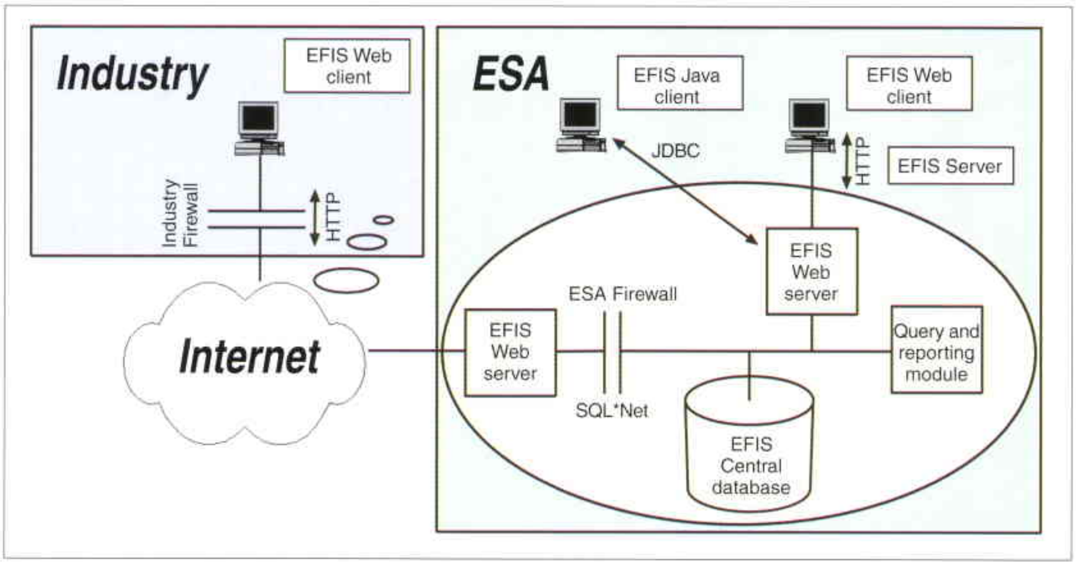


Figure 4. The EFIS high-level system architecture

solution for the Web. In particular, WebIntelligence enables users to access, analyse, and share corporate data using a simple browser as their interface, whilst still maintaining tight security in terms of data access. This module is used to produce printouts, to generate interactive reports in which users can 'drill-down' from aggregated amounts to individual elements, to generate ad-hoc queries, and to produce graphical charts that also include drill-down capabilities.

EFIS Central Database
The EFIS central site, which is the core of the system, is an Oracle 8i database that stores all the EFIS data (and related constraints to ensure data integrity and consistency) and procedures that include the implementation of the business logic behind the database transactions. These procedures dynamically generate the HTML pages and provide them to the EFIS Application Server.

EFIS security
EFIS contains delicate commercial/financial data, which is therefore protected and accessible only to authorised persons. Any user requiring access to EFIS has to have a log-in password provided by the ESA help desk. The authentication mechanism is the same as for other ESA applications (i.e. DODIS, EMITS, COSY), allowing authorised users to have only one log-in account for several systems. Once logged in, data visibility is governed by a strict view/modify access-right policy, according to the different roles assigned to each authenticated user. A data-ownership check is made every time a query, insert or update command is submitted to the system.

Security is further enhanced by locating the database server holding the sensitive data inside the ESA firewall. External users (Industry) access the data via the Internet through a dedicated front-end that is outside the ESA firewall and contains only the Oracle Application Server component and not the data. The Secure Socket Layer (SSL) protocol will shortly be installed in this server to facilitate encrypted data traffic.

Financial transactions related to the payment of invoices are not executed in EFIS, but in the totally separate ESA accounting system (AWARDS) and then only by authorised ESA Finance Department staff. Similarly the master database for bank accounts is not held in EFIS and changes can only be made in AWARDS first, and when accompanied by written/signed authorisation from the appropriate supplier.

EFIS – a tool for the present and the future
EFIS is now operational, with invoices being routinely transmitted. All remaining ETIS contracts are migrated to EFIS. The first full migration of the technical, FCS, part has begun and EFIS is well on the way to being the pan-European tool so desired by the Agency and Industry, through whose joint collaboration this very ambitious project has been realised. The next phases involve consolidation and expansion, extending the economic and efficiency benefits to all contractual parties, no matter how large or small, be they Prime Contractors, Small and Medium-sized Enterprises (SMEs) or simply purchase-order contractors. For ESA in particular, this tool offers the possibility to redesign in a more efficient way the processes related to the physical handling and approval of the financial part of contracts and of the invoices. It is reasonable, therefore, to look further ahead to a common and efficient tool for all, providing an entirely linked electronic contractual/financial planning, processing, approving, paying and archiving future!

Cryogenics in Space
- A review of the missions and technologies

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Since the first liquefaction of ^4He and the discovery of superconductivity by H. Kamerlingh-Onnes (1908 and 1911), cryogenics and its applications have come a long way. The continuous improvement of cryogenic equipment has made it easier and easier to achieve temperatures well below the liquefaction point of nitrogen (77 K), either by means of cryogens (liquid gases such as Xe, H_2, O_2, N_2, ^4He and ^3He) or by means of mechanical coolers. Cryogenic devices, such as sensors and cold electronics, have taken advantage of the progress made in materials science, thereby offering a reliable and effective solution to otherwise unsolvable problems.

In the last 15 years, several spacecraft have employed cryogenic equipment, mostly in the context of astrophysics missions, targeting the electromagnetic radiation emitted by celestial objects over a wavelength range that it is difficult to cover from the ground. Such missions include IRAS (Infrared Astronomical Satellite, launched in 1983), COBE (Cosmic Background Explorer, launched in 1989) and ISO (Infrared Space Observatory, launched in 1995). Several new missions are currently in preparation, including Herschel/Planck, SIRTF and the Next-Generation Space Telescope (NGST). In the higher temperature range, between 100 and 10 K, many missions are already operational or under development. They include military reconnaissance satellites (such as Helios), Earth-observation satellites (Spot) and meteorological spacecraft (MSG, Meteosat Second Generation), with infrared detectors operating at about 85 K.

Applications of cryogenics in space
The development, in-orbit commissioning, and operation of cryogenic instrumentation in space raises the level of mission complexity, risk and associated cost. Any application must then be justified on the basis of its specific return. In the case of scientific missions, the cryogenic detectors and related payloads are the only candidates for the accomplishment of the mission objectives, offering unmatched performance and unique advantages. In the case of other applications, such as telecommunications, the advantages offered by superconducting devices need to be evaluated against their development and operating costs, and compared with alternative technologies.

Cryogenic detectors for space applications
Cryogenic photon detectors offer two main advantages over conventional sensors:
- their much higher sensitivity (expressed by the Noise Equivalent Power or NEP, i.e. the amount of incident power required to achieve a signal-to-noise ratio equal to unity)
- the better energy resolution (expressed in terms of resolving power, i.e. the ratio $E/\Delta E = \lambda/\Delta\lambda$, with ΔE representing the full width at half maximum of the detector response to a monochromatic excitation of energy E).

Cryogenic detectors have driven the utilisation of cryogenics in space, determining the requirements in terms of operating temperature, temperature stability and architecture of the payload system. This trend is now well-established across the electromagnetic spectrum. Figure 1 provides a summary of the different detectors, including operating photon energy and temperature range. Table 1 provides an overview of other characteristics of the detectors, including typical power dissipations, array sizes and operating temperatures.

Applications involving the lower energy end of the electromagnetic spectrum (i.e. sub-millimetre wave and infrared) are the ones that benefit most from the utilisation of cryogenic detectors. Dramatic developments have recently taken place in infrared detector technology, driven mainly by the vast investments made by the US Department of Defense during the 1980s. Such developments embrace a very large spectral range, from the Near-IR (NIR, λ = 1 μm) to the Far-IR (FIR, λ = 200 μm), and have focused on low-background, high-sensitivity

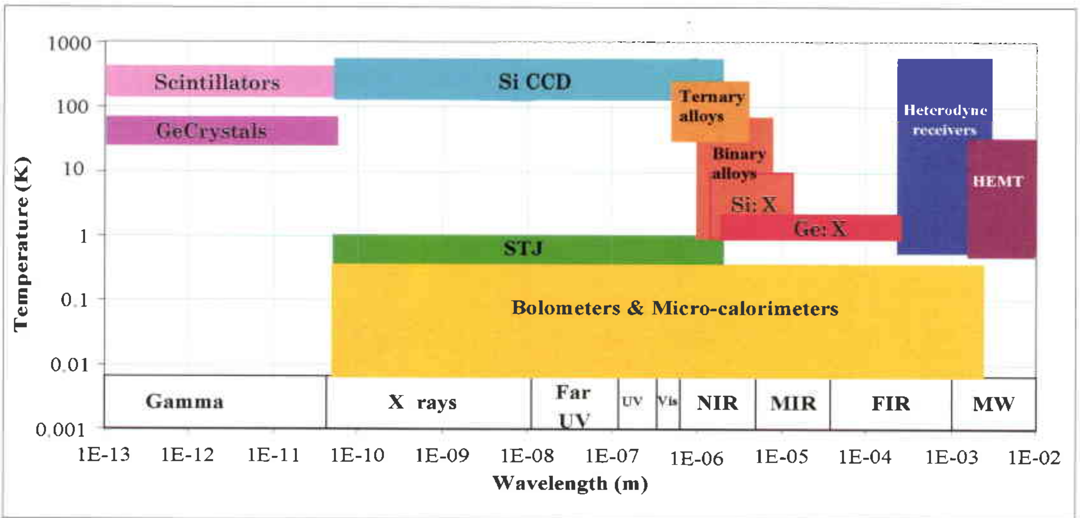

Figure 1. Overview of photon detectors and related operating temperatures. Note the extended sensitivity range of the cryogenic detectors, such as STJs and bolometers

Table 1. Main characteristics of photon detectors and SQUIDs

Detector type (pixel and array)	Temperature range (K)		Dissipation range (W)		Detector size		
	Min.	Max.	Min.	Max.	Pixel (µm)	Array (n x n)	Wavelength
Ge crystal	50	100	0	0	10 000	<10	Gamma
CCD	150-200	300	0.1	20	10-30	10^6	X-ray / Vis
STJs	0.01	1	10^{-9}	10^{-6}	20-50	$<10^3$	X-ray–UV-Vis-NIR
µ-Calorimeters	0.05	0.3	10^{-12}	10^{-11}	100	<100	X-ray
TESs	0.05	0.3	10^{-11}	10^{-9}	100	<100	X-ray-UV-Vis-NIR
Photo-conductors-NIR	30	100	0.01	0.02	30-50	10^6	NIR
Photo-conductors-MIR	2	20	0.01	0.02	50-100	$<10^4$	MIR
Photo-conductors-FIR	1	2	0.001	0.003	50-100	$<10^3$	FIR
Sub-mm bolometers	0.1	0.3	10^{-9}	10^{-8}	100-500	$<10^2$	Sub-mm
SQUIDs (LTS)	1	4	10^{-12}	10^{-11}	na	na	Read-out/accelerometer

and large-format arrays. IRAS used a total of 62 detector elements, while since 1995 large-format arrays for IR astronomy have been available with total pixel counts in excess of 10^6.

Astronomical observations in the far-infrared investigate objects that are colder than those observed in the visible or in the near-infrared, as blackbody radiation in the 30 – 300 µm wavelength range (emitted by bodies at temperatures ranging from 100 to 10 K). An example of such cold objects is the interstellar dust in our galaxy (at 20 – 30 K), as detected by IRAS in 1983, which both confirmed the existence of interstellar dust and detected its thermal emission. Photo-conductors represent the main detection technique use throughout the IR range. At low temperatures and low photon fluxes, the conductivity of these semi-conducting materials is influenced by the absorbed IR photons, which can ionise impurities and free charge carriers. Such photoconductors are typically operated at T < 3 K. In the case of Isophot, a broad-band photometer flown onboard ISO, Ge:Ga detectors were combined with low-noise CMOS integrating preamplifiers and multiplexers operating at 2 K to achieve a NEP of order 10^{-18} W/Hz$^{1/2}$.

Bolometers have also been used to detect sub-millimetre photons. Neutron-Transmutation-Doped (NTD) Ge detectors are well-established and operate at temperatures between 300 and 100 mK, with NEPs of order 10^{-17} W/Hz$^{1/2}$. Such devices will be used onboard ESA's Planck spacecraft.

In the sub-millimetre-wavelength range, heterodyne receivers provide very high sensitivities up to frequencies as high as 500 GHz. Several laboratories have shown that receivers based on Superconductor-Isolator-Superconductor (SIS) devices (such as Nb-based Superconducting Tunnel Junctions) offer better performance than the conventional Schottky-diode-based systems. Operating temperatures are of order 2 K. At frequencies η > 500 GHz, the so-called Hot-Electron Bolometers (HEBs) compete with SIS and Schottky diodes for the next generation of heterodyne receivers (e.g. on ESA's Planck and Herschel missions). In such devices, the incoming radiation excites the electron population, thus determining changes in the resistance of the device, according to a non-linear behaviour, used for mixing the signal voltage with the local oscillator voltage. Operating temperatures range from 70 K (2 deg, InSb HEBs) to 0.3 K (NIS HEBs).

In the NIR (at wavelengths between 1 and 5 μm), other photo-conductors are used, mainly PtSi, HgCdTe and InSb. Over the last decade, the introduction of two-dimensional InSb arrays has drastically changed the field of IR astronomy, with a 1 k x 1 k pixel array based on hybrid technology. These detectors have operating temperatures ranging between 77 and 35 K and have already been used onboard the Hubble Space Telescope.

A new generation of photon detectors is represented by Superconducting Tunnel Junctions (STJs) and Transition Edge Detectors (TESs), both photon-counting in the visible and NIR, with intrinsic spectroscopic capability.

Table 2. Summary of cryogenic space programmes (Space Science)

Mission	Application	Type/Class	Launch year	Cryogenic system
IRAS (NASA,NIVR,SERC)	Science / IR	Satellite (surveyor)	1983	^{4}He cryostat
COBE (NASA)	Science / IR	Satellite (surveyor)	1989	^{4}He cryostat
ISO (ESA)	Science / IR	Satellite (observat.)	1995	^{4}He cryostat
SFU (ISAS/NASDA/MITI)	Science / IR	Instrument (IRST)	1995	^{4}He cryostat + ^{3}He SC
MSX (BMDO,US)	MP/UV to FIR	Satellite (observat.)	1996	sH_2 cryostat
HST (NASA)	Science / NIR	Instrument (Nicmos)	1997	sN_2 cryostat
WIRE (NASA)	Science / IR	Satellite (surveyor)	1999	Dual, sH_2 cryostat
STEP (ESA)	Science / FP	Satellite		^{4}He cryostat
Astro-E (ISAS, NASA)	Science / X	Satellite (observat.)	2000	sNe + ^{4}He cryost.+ADR
INTEGRAL (ESA)	Sci. / Gamma	Instrument (observ.)	2001	Stirling cooler
SIRTF (NASA)	Science / IR	Satellite (observat.)	2002	^{4}He cryostat
Submillimetron (ASC)	Sci. / Sub mm	ISS telescope	> 2004	^{4}He cryost. + ^{3}He SC
XEUS (ESA)	Science / X	Instrument (observ.)	2005	Stirling cool. + ADR
Herschel (ESA)	Science / IR	Satellite (observat.)	2007	^{4}He cryost. + ^{3}He SC
Planck (ESA)	Science / FIR	Satellite (surveyor)	2007	H_2 & ^{4}He JT + DR
NGST (NASA)	Science / NIR	Satellite (observat.)	2008	Passive rad. + cooler
Constellation-X (NASA)	Science / X	Satellite (observat.)	2008-10	Astro-E like / coolers
ARISE (NASA)	Sci. / Radio	Satellite (VLBI)	2008	Cryo-cooler + H_2 JT
DARWIN (ESA)	Science / IR	Satellite (VLBI)	>2009	Cryo-cooler + H_2 JT
TPF (NASA)	Science / IR	Satellite (VLBI)	2010	Passive rad. + cooler.
Rosetta (ESA)	Sci. / Comet	Instrument (probe)	2003	Stirling cooler

FP = Fundamental Physics
MP = Multipurpose mission (defence + science)

Table 3. Summary of cryogenic space programmes (Applications / Technology).

Mission	Application	Type/Class:	Launch year	Cryogenic system
Meteosat 1-7 (ESA/EUM.)	Meteo.	P/L	1977-97	Passive radiator
ERS (ESA)-1/2	Earth Observat.	P/L (ATSR)	1991/1995	Stirling cooler
CRISTA (DARA, D)	Earth Observat.	P/L (STS-66/85)	1994/97	^{4}He cryostat
MSG-1/2(ESA/EUMETSAT)	Meteo.	P/L (Seviri)	2000/2002	Passive radiator
ENVISAT 1 (ESA)	Earth Observat.	P/L (MIPAS/AASTR)	2001	Stirling cooler
Metop (ESA/EUM./NOAA)	Meteo.	P/L (IASI)	2001	Passive radiator
MSG-2 (ESA/EUMETSAT)	Meteo.	P/L (Seviri)	2002	Passive radiator
USMP/LPE (NASA)	Technology	P/L (STS-52)	1992	^{4}He cryostat
SHOOT (NASA)	Technology	P/L (STS-57)	1993	^{4}He cryostat
HTSSE I-II (NRL/USAF)	Technology	P/L (ARGOS)	1993-1999	Stirling cooler
STRV-1B (DRA)	Technology	Mini-satellite	1994	Mechanical cooler
IN-STEP/CSE (NASA)	Technology	P/L (STS-63)	1995	Mechanical cooler
BETSCE (NASA)	Technology	P/L (STS-77)	1996	H_2 Stirling+JT+ Sorpt.
MIDAS (NASA)	Technology	P/L (STS79/MIR)	1996	Mechanical cooler
CheX (NASA)	Techn./MS	P/L (STS-87)	1997	^{4}He cryostat
ISS / Bosch (ESA)	Techn./TLC	P/L (ISS)	> 2005	Mechanical cooler
LTMPF (NASA)	Techn./MS	P/L (ISS)	2003	^{4}He cryostat
FACET (NASA/JPL)	Technology	P/L (STS)	< 2003	sCO_2+sNe cryostat
UARS (NASA)	Atmosphere	P/L (CLAES/ISAMS)	1991	sNe cryostat/ Stirling
Landsat 7 (NASA)	Earth Observat.	P/L (MISR)	1999	Passive radiator
Terra (NASA)	Earth Observat.	P/L (MODIS)	1999	Stirling cooler.
Aqua (NASA)	Earth Observat.	P/L (CERES)	2000	Stirling-PTR + passive
Aura (NASA)	Earth Observat.	P/L (HIRDLS)	2002	Stirling-PTR + passive

P/L = Payload/instrument onboard a satellite / STS / ISS
MS = Materials Science
STS = Space Shuttle flight
TLC = Telecommunications

STJs have operating temperatures ranging between 0.5 and 0.1 K, depending on the superconductors used (typically Nb, Al, Ta), responsivities of order 10^4 e^-/eV, resolving powers of order 10 at λ = 500 nm and maximum count rates of order 10^4 events/s. TESs operate at about 0.1 K, also have very conspicuous responsivities, comparable energy resolutions and a maximum count rates of order 10^3 events/s. Both STJs and TESs can operate over a large photon energy range, with very interesting performances in the UV and X-ray regions. The key benefits of such devices are the much higher detection efficiency (close to 100%), the photon counting and intrinsic spectroscopic capability, and the good imaging resolution (with individual pixels of order 20 µm). In the case of STJs, an energy resolution of 15 eV at 6 keV has been demonstrated, while TESs have achieved even better results (a few eV's at 6 keV).

In-flight T [K]	Lifetime	Orbit	Status
3	290 dd	Near Polar	Post-ops.
1.4 - 1.6	305 dd	Near-Earth	Post-ops.
1.8	840 dd	HEO	Post-ops.
0.3	30 dd	LEO	Post-ops.
< 8	600 dd	LEO	Post-ops
60	700 dd	LEO	Post-ops.
< 7.5	120 dd	LEO	Postops/loss
1.8	180 dd	LEO	Not approved
0.065	730 dd	LEO	Loss
85	2-5 yr	HEO	Development
1.4	2.5 yr	Earth trailing	Development
0.1-0.3	tbd	LEO	Study
0.05 – 0.3	> 10 yr	LEO	Study
0.3 & 1.74.	5 yr	Sun-Earth L2	Development
0.1 & 20	460	Sun-Earth L2	Development
4 – 40	5-10 yr	Sun-Earth L2	Study
0.05	3-5 yr	Sun-Earth L2	Study
20	tbd	HEO	Study
4	tbd	L2 / Earth trailing	Study
30	5 yr	L2 / Earth trailing	Study
80	10 yr	Heliocentric	Development

In-flight T [K]	Lifetime	Orbit	Status
90		GEO	Post-ops./ops.
80	2 yr	LEO	Operations.
2.5-12	10 dd	LEO	Post-ops.
75-85	7 yr	GEO	Development
80	5 yr	LEO - Polar	Development
100	5 yr	Sun-synchr.	Development
75-85	7 yr	GEO	Development
2.2	> 6 dd	LEO	Post-ops.
< 2.2	> 6 dd	LEO	Post-ops.
70-80	3 yr	Sun-synchr.	Loss / ops.
80	3 yr	GTO	Post-ops.
65	8 dd	LEO	Post-ops.
10	< 1 dd	LEO	Post-ops.
80	> 8 dd	LEO	
1.6	> 6 dd	LEO	Post-ops.
77	> 1 yr	LEO	Development
1.6	180 dd	LEO	Development
19	> 6 dd	LEO	Development
16/80	1.5 yr	Near-circular	Post ops.
90	5 yr	Sun-synchr	Operations
80	5 yr	Sun-synchr.	Operations
60-85	6 yr	Sun-synchr.	Development
65	5 yr	Sun-synchr.	Development

Fundamental physics and planetary sciences can also benefit from the utilisation of cryogenic detectors. One example are SQUID (Superconducting Quantum Interference Devices) based gravity gradiometers, to be used for low-altitude Earth and planetary missions. In addition to mapping the intensity of the gravitational forces, these sensors can be used to verify the well-known 'Equivalence Principle', which postulates the coincidence of gravitational and inertial mass. This issue is being addressed in the feasibility studies of several different space missions, including STEP (ESA) and LISA (NASA). SQUID-based accelerometers are the only ones capable of achieving the required accuracy. So far, SQUID devices based on low-temperature superconductors are favoured, with operating temperatures around 4 K. SQUIDs based on high-temperature superconductors (HTS) are also being investigated, in view of their ability to operate at about 77 K.

Scientific missions: a review

Scientific missions dominate the present scenario for cryogenics applications in space due to the advantages offered by cryogenic detectors over conventional sensors. This short review is organised in chronological order, starting with IRAS, the first 'cryogenic mission', which flew in 1983. Mission in the operations (or post-operations) phase, missions presently under development, and missions under study are grouped in different sections. Tables 2 and 3 provide a summary of all non-military space missions that involve cryogenics.

- Missions in operation/ post-operation

IRAS (Infrared Astronomy Satellite) was the first scientific satellite based on cryogenic instrumentation. Launched in January 1983 as a joint project by the United States, the United Kingdom and the Netherlands, its mission was to map the entire sky at IR wavelengths, from 8 to 120 μm. The satellite was equipped with a 0.6 m telescope cooled with liquid helium to about 4 K. The focal-plane assembly was located at the Cassegrain focus, at about 3 K. It contained the survey detectors (based on 62 photo-conductive elements made from four different materials), a low-resolution spectrometer and a chopped photometric channel.

COBE (Cosmic Background Explorer) was developed by NASA's Goddard Space Flight Center to measure the cosmic background radiation. This satellite was launched in November 1989 and operated for about 10 months in survey mode. It carried three instruments: a FIR Absolute Spectrometer (FIRAS), a Differential Microwave Radiometer (DMR) and the Diffuse IR Background Experiment (DIRBE), operating at wavelengths between 1.25 and 240 μm. FIRAS and DIRBE operated at 1.6 K, cooled by a 650 litre, superfluid helium cryostat.

ISO (Infrared Space Observatory) was developed by ESA and operated at wavelengths from 2.5 to 240 μm between November 1995 and May 1998, in a highly elliptical orbit. This satellite (Fig. 2) was based on a cryostat containing about 2200 litres of superfluid helium and on a 0.6 m-diameter telescope, feeding four instruments (an infrared camera, a photometer and two spectrometers) working in different wavelength ranges. The four instruments made use of different photo-conductors based on InSb, Si and Ge and operating between 1.8 and 10 K.

Figure 2. The ISO (Infrared Space Observatory) spacecraft, fully integrated and ready for transport to the launch facilities. The solar panels shield the satellite from direct Sun illumination. The cryostat is fixed to the Service Module via the struts visible in the lower part of the picture

- Missions under development

Several spacecraft presently under development will make use of cryogenic instrumentation (Tables 2 and 3).

Planck is the third medium-size mission (M3) in ESA's Horizon 2000 scientific plan. Its main objective is to map the temperature anisotropies of the Cosmic Microwave Background (CMB) over the whole sky, with a sensitivity ($\Delta T/T$) of $2x10^{-6}$ and an angular resolution of 10 arcmin. Such goals require bolometers operating at 0.1 K, HEMT at 20 K and a low-emissivity, cooled telescope (60 K). The cryogenic system proposed for Planck is based on pre-cooling to 60 K by passive radiators, cooling to 20 K with a H_2 Joule-Thomson Cooler (adsorption compressors), cooling to 4 K with a He Joule-Thomson cooler (mechanical compressors), and final cooling to 0.1 K with an open-loop Dilution Refrigerator. The nominal mission lifetime is 15 months.

Herschel (formerly known as FIRST – Far-Infrared and Submillimetre Telescope) is the fourth Cornerstone mission of Horizon 2000. It is dedicated to astronomical observations in the far-infrared and sub-millimetre wavelength range, from 85 to 600 μm. Herschel is a multi-user observatory, based on a superfluid helium dewar at 1.65 K and on a ^3He sorption cooler delivering a base temperature of 0.3 K. The scientific goals will be achieved with three instruments operating between 0.3 and 2 K. Herschel is presently scheduled for launch in 2007 and its He dewar is designed for a mission lifetime of 3.5 year. Due to the commonality in technologies, science objectives and final orbit (around the second Lagrangian point of the Sun-Earth system), ESA has decided to develop Herschel and Planck together, and to launch them with a single Ariane-5 flight. Detailed engineering assessments are in progress.

SIRTF (Space Infrared Telescope Facility) is the fourth member of NASA's family of 'Great Observatories'. It is designed to perform imaging and spectroscopy in a large wavelength range, from 3 (NIR) to 180 (FIR) μm via a 0.85 m-diameter, helium-cooled telescope. The detectors' temperature is 1.4 K, while the cryogenic system is optimised (passive radiation and efficient use of helium gas enthalpy) to make use of only 360 litre of superfluid He, for a minimum lifetime of 2.5 years. SIRTF is currently in the development phase and is scheduled for launch in May 2002. Thanks to a number of trade-offs, it has been possible to drastically reduce the mission costs by selecting a solar orbit and limiting the satellite mass to about 900 kg.

Finally, among the missions under development, we would like to mention Integral (International Gamma-Ray Astrophysics Laboratory) as an example of utilisation of space-qualified Stirling cryo-coolers. Integral is a medium-size ESA science mission dedicated to spectroscopy and imaging between 15 keV and 10 MeV. The spectro-meter on the spacecraft is based on about 30 kg of germanium detectors maintained at a temperature of 85 K. The satellite is scheduled for launch in 2001.

- Missions under study

NGST (Next-Generation Space Telescope) is considered the successor of the Hubble Space Telescope. The programme calls for a 6 to 8 m-diameter, passively cooled telescope to minimise thermal self-emission and enable observations to be made in the NIR and Medium-IR (MIR) from 1 to 30 μm. The scientific objectives for NGST are the study of galaxies, stars and planet formation and the study of the chemical and geometrical evolution of the Universe. The so-called 'NGST Yardstick Mission' (a mission design developed by NASA, academia and industry since starting in 1996) baselines a deployable 8 metre telescope, passively cooled below 50 K. The science instruments are an NIR camera, an NIR low-resolution spectrograph and a MIR camera-spectrograph combination. The first two instruments operate at 30 K (passive radiator cooling), the third one makes use of either an active cooler or solid H_2 to achieve a base temperature of about 8 K. ESA is also involved in the NGST project with a financial participation of some 15%. The telescope should be launched in 2008.

XEUS (X-ray Evolving Universe Spectroscopy mission) is the potential follow-on mission to the ESA XMM Cornerstone (launched at the end of 1999). The mission aims to place a permanent X-ray telescope in orbit by exploiting the facilities available on the International Space Station (ISS) and by ensuring significant growth and evolution potential. The main features of the proposed observatory are the very large telescope aperture and the utilisation of cryogenic detectors in two narrow-field imaging spectrometers (respectively TESs and STJs). The cryogenic design would be based on Stirling mechanical coolers, combined with ADR systems in order to extend the mission lifetime beyond what is achievable with consumable cryogens.

Darwin (Infrared Space Interferometry Mission) is a Cornerstone candidate in the ESA 'Horizon 2000 Plus' science plan. Its goal is to detect terrestrial planets in orbit around other stars and to allow high-resolution imaging in the medium infrared, between 5 and 30 μm. Interferometry would be carried out over a 50 – 500 m baseline, including six free-flying 1.5 m telescopes. Both the telescopes and the focal-plane detectors would be cooled to about 20 – 30 K. A similar mission is being studied in the USA, namely the Terrestrial Planet Finder.

Earth Observation and Meteorology satellites
The field of Earth observation (i.e. the remote sensing of our planet from space for civilian purposes) has grown considerably in importance over the last 10 – 15 years. Several missions have been developed with the objective of monitoring the Earth's natural environment and studying natural phenomena related to the planet's water cycle. Cryogenics are required because of the use of detectors capable of imaging the Earth's surface in the near- and medium-infrared (typically operating around or just below 100 K). Due to the low-altitude orbits of these satellites, the large thermal flux emitted by the Earth often precludes the utilisation of purely passive thermal control, obliging us to make use of mechanical coolers.

ESA's Earth Observation Programme is based on a number of missions for the monitoring of our planet's atmosphere, oceans and land. The ERS-1 and ERS-2 satellites (ESA Remote Sensing Satellites) were developed to provide information on the Earth and its environment and were launched in 1992 and 1995, respectively. The IR Along-Track Scanning Radiometers (ATSRs) embarked on ERS-1 and ERS-2 were equipped with Stirling-cycle coolers (from Oxford University) to maintain the focal-plane assembly at about 100 K.

The Meteosat Second Generation (MSG) continues the legacy of the previous Meteosat missions, with greatly improved performance. Three satellites (MSG-1 to 3) are being procured by ESA on behalf of Eumetsat to guarantee uninterrupted coverage from 2000 to 2012. Onboard MSG-1, two instruments have focal-plane assemblies operating at low temperatures – the Spinning Enhanced Visible and InfraRed Imager (SEVIRI) and the Geostationary Earth Radiation Budget (GERB) radiometer – and both are cooled by passive radiators to operate at about 80 K.

Envisat-1 is a large multidisciplinary mission, dedicated to study of the Earth and its atmosphere with both science and application objectives. Three instruments onboard this spacecraft (due for launch in autumn 2001) require cryogenic temperatures in order to operate, namely MIPAS, AATSR and SCIAMACHY. MIPAS is a Fourier-transform spectrometer operating in the 4 to 16 μm wavelength range and using photo-conductive and photo-voltaic HgCdTe detectors. The optics and detector assembly are cooled to 70 K by a pair of Stirling-cycle coolers. The AATSR is an IR-visible radiometer whose focal-plane assembly is cooled to 80 K by another pair of Stirling coolers. Finally, SCIAMACHY is an imaging spectrometer operating between 0.2 and 2.4 μm; it uses silicon and InGaAs detectors passively cooled to temperatures ranging between 235 and 130 K.

ESA, Eumetsat, CNES and NOAA are co-operating in the development of MetOp (Meteorological Operational), a new generation of weather satellites. MetOp will continue part of the ERS mission, complement the results provided by Envisat and support scientific investigations as well as weather forecasts. MetOp, presently undergoing development, will carry similar instruments to Envisat, with similar cryogenic requirements.

Technology-validation missions

A number of cryogenic space missions have been dedicated to the validation of specific technological issues (see Table 3). This is the case for payloads flown on research satellites and on the Space Shuttle, or to be flown on the International Space Station (ISS).

Others

- Telecommunications

The recent progress in High-Temperature Superconductors (HTS) has opened new perspectives for the fabrication of radio-frequency (RF) super-conducting devices, such as filters, delay lines, resonators and antennas. These devices provide the capability to improve the performance of telecommunications satellites, which needs to be traded off against the increased system complexity by implementing a cryogenic system onboard the spacecraft.

- Sample storage

The long-term storage of biological samples requires cryogenic temperatures. On the ground, this is achieved by using liquid nitrogen. For the ISS, ESA is developing a cryogenic freezer (Cryosystem) for the cooling down to and long-term storage of biological samples at –180°C. The cooling system consists of mechanical coolers.

In addition, cryogenic applications in the near future may include:
- zero-loss storage of cryogenic propulsion fuels for long-term missions (e.g. a Mars mission)
- liquefaction of propellant produced on the Moon or Mars
- use of low-temperature electronics with increased performance
- energy storage using superconductive devices (similar systems are already under development for ground applications).

Cryogenics and spacecraft engineering

The following paragraphs provide a summary of the engineering issues associated with cryogenics in space.

Architecture of cryogenic spacecraft

A spacecraft is usually composed of a Service Module (service bus) and a Payload Module (Fig. 3). The Payload Module carries one or more instruments that process signals coming from the Earth (e.g. for Earth observation, meteorological or telecommunications applications) or from space (e.g. for astronomy). The instruments can either have their own optics, or share a common unit (e.g. main telescope). The presence of cryogenic installations has a strong impact on the architecture of a spacecraft or of an instrument, the key factors coming into play being as follows:

- A cooler needs to be used (i.e. cryogens, radiators, mechanical coolers). The cooler must have a heat lift compatible with the satellite's size and the available power resources.
- The low-temperature equipment must be properly supported, insulated from the room-temperature satellite bus, and protected from solar and/or Earth radiation. The lower the operating temperature, the higher the demands on the thermal insulation.
- The cold parts have to be accessed (e.g. optical access to the detectors, signal wires, temperature sensors and heaters) and wiring needs to be routed between the cold payload and the satellite bus for further processing (analogue/digital conversion, data handling) before transmission to Earth via telemetry.
- Cryogenic ancillary equipment needs to be used to operate the cryogenic payload (e.g. heat links, heat switches, filters, thermometry).
- System testability (instrument performances and payload cooling system) is likely to have an impact on the payload architecture.
- The complete system must survive the vibrations induced by the launcher: this requirement has a strong impact on both the cooler and instrument designs (e.g. a compromise is required between the large support cross-section required for the launch, and the thermal-insulation requirements).
- The cooler has to operate in zero gravity for several years.
- The payload needs to be built with materials compatible with both the space and cryogenic environments.
- The lifetime (or MTBF, mean time between failures) of the equipment should be compatible with and preferably exceed the mission duration.

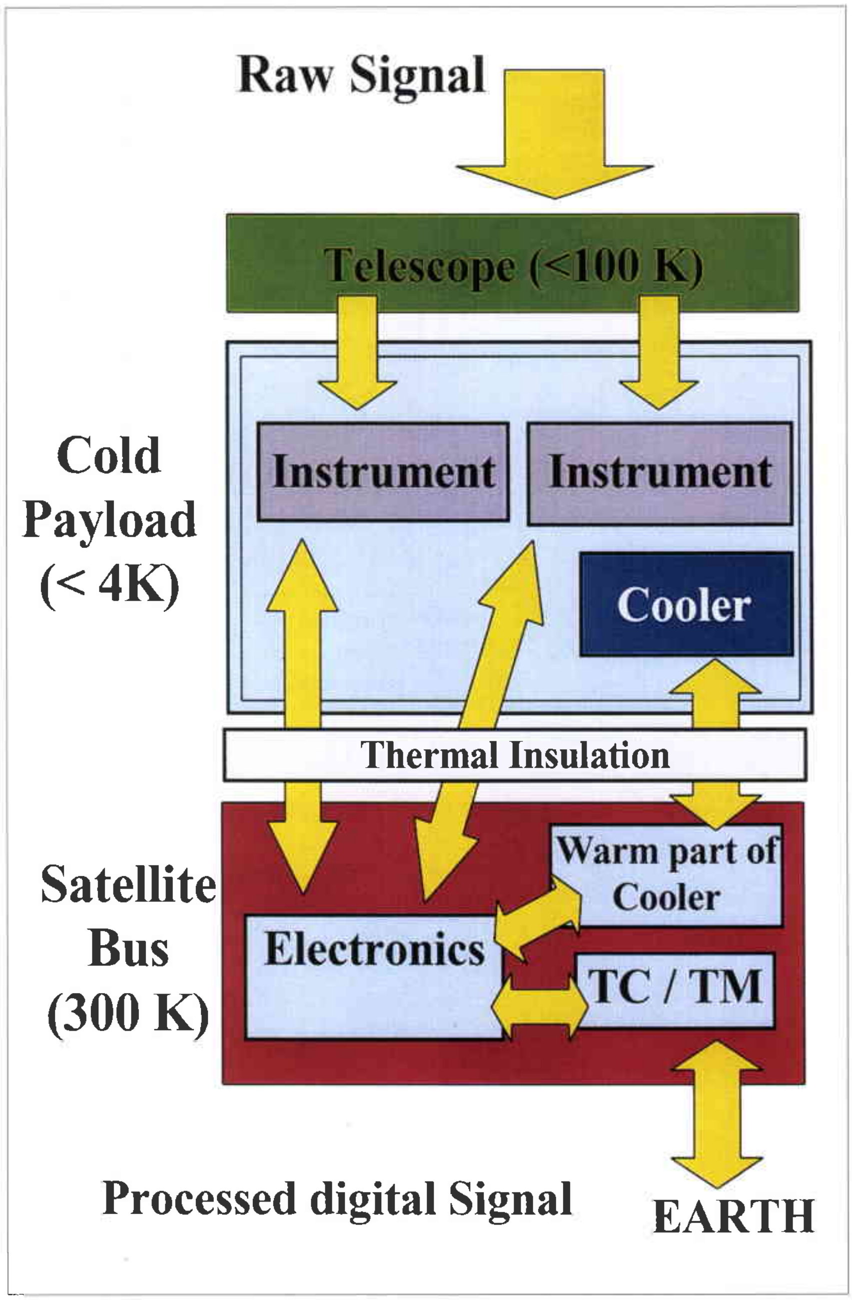

Figure 3. Typical architecture of a cryogenic satellite for space science. Three main sections can be identified: the telescope (cooled below 100 K), the Payload Module with focal-plane detectors maintained below 4 K, and the Service Module, maintained at room temperature

Space coolers

- Principle of cooling systems for space

Coolers provide a cold heat sink, by removing the heat in the cold area and dissipating it in the warm area. In the case of a satellite isolated in space, the energy will be finally radiated to space. The cooling process is well described by elementary thermodynamics: either the energy is directly radiated to space (via radiators), or some work has to be performed to pump it from a cold to a warm level where it can be more easily radiated away.

Such a heat-pumping operation can be achieved using an open- or closed-cycle configuration. The open cycle corresponds to the use of stored cryogens, where the work is performed on the ground before the mission by a liquefier. The cold heat sink is provided by the evaporation of liquid or solid cryogens. In this case there is no energy to radiate, but gas is released. The lifetime of the system is thus governed by the heat losses and by the mass of cryogen that can be flown.

The closed cycle relies on the use of mechanical coolers, where the work is done continuously during operations (Fig. 4). Existing space coolers can provide about 1 W of cooling power in the temperature range 50 – 100 K (Stirling coolers, pulse tubes), about 100 mW in the range 15 – 20K (double-stage Stirling), or a few mW at 4 K (Joule-Thomson). Very-low-temperature coolers (e.g. ^{3}He cryo-sorption refrigerators, dilution, ADR) rely on the pre-cooling systems mentioned above to achieve even lower temperatures (typically between 100 mK and 1 K).

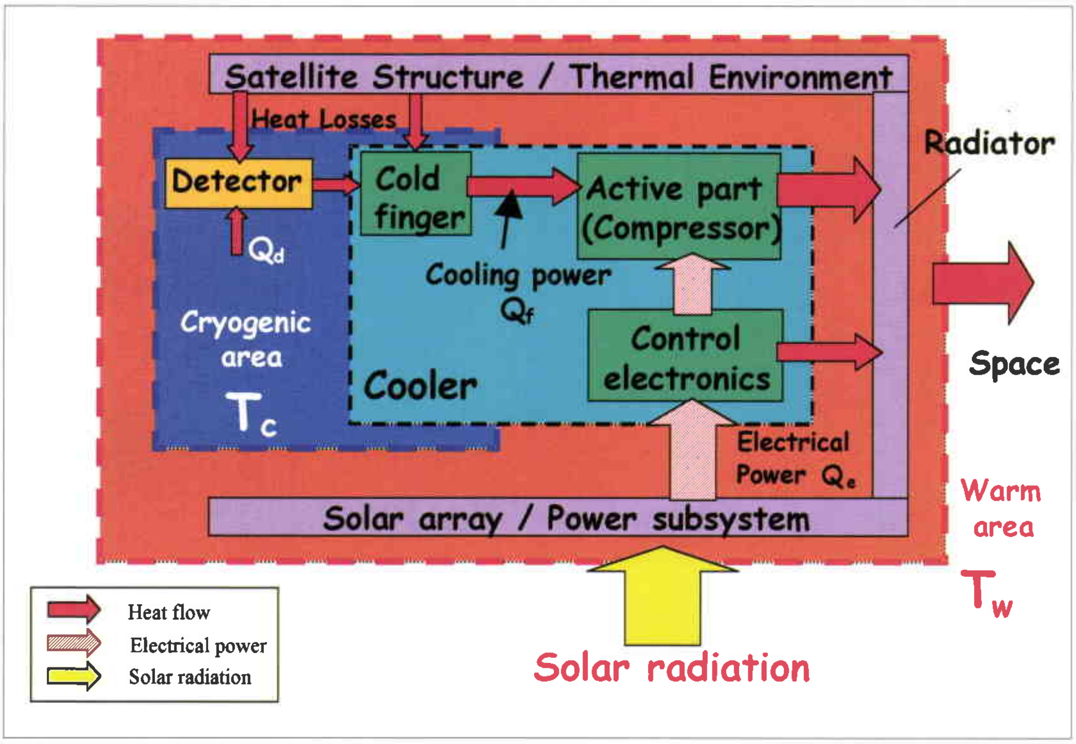

Figure 4. Schematic of a space cooler. Its cold end is interfaced to the focal plane (detectors), while its active part and control units are linked to the satellite structure and ultimately to the radiators. The heat load is minimised by thermally isolating the cryogenic area from the rest of the system

In all cases, some electronics is required to monitor the temperature, maintain it constant, or drive the cooler mechanisms. For higher temperature systems (T > 50 K), a single stage can be sufficient. For lower temperature systems, multiple-stage coolers or a chain of various types of coolers have to be used.

- Types of cooler

Radiators are the most efficient, simplest and more reliable space coolers. They are based on the fact that all objects emit infrared radiation in proportion to their surface area S, emissivity ε, and the fourth power of their temperature T, and on the fact that the deep-space environment is very cold (black body at T_0 = 2.73 K). The net cooling power is thus:

$$Q_{rad} = \sigma\, S\, F\, \varepsilon\, (T^4 - T_0^4) \approx \sigma\, S\, F\, \varepsilon\, T^4$$

where σ is Stefan's constant and F≈1 is the shape factor. Radiators are efficient above 100 K, but have limited performances at low temperatures (where the parasitic loads through the insulation increase) and also have size-related limitations (it is usually difficult to mount more than a few m^2 on a spacecraft). Figure 5 shows the actual performance of satellite radiators against the theoretical heat-rejection capabilities. Another limitation of

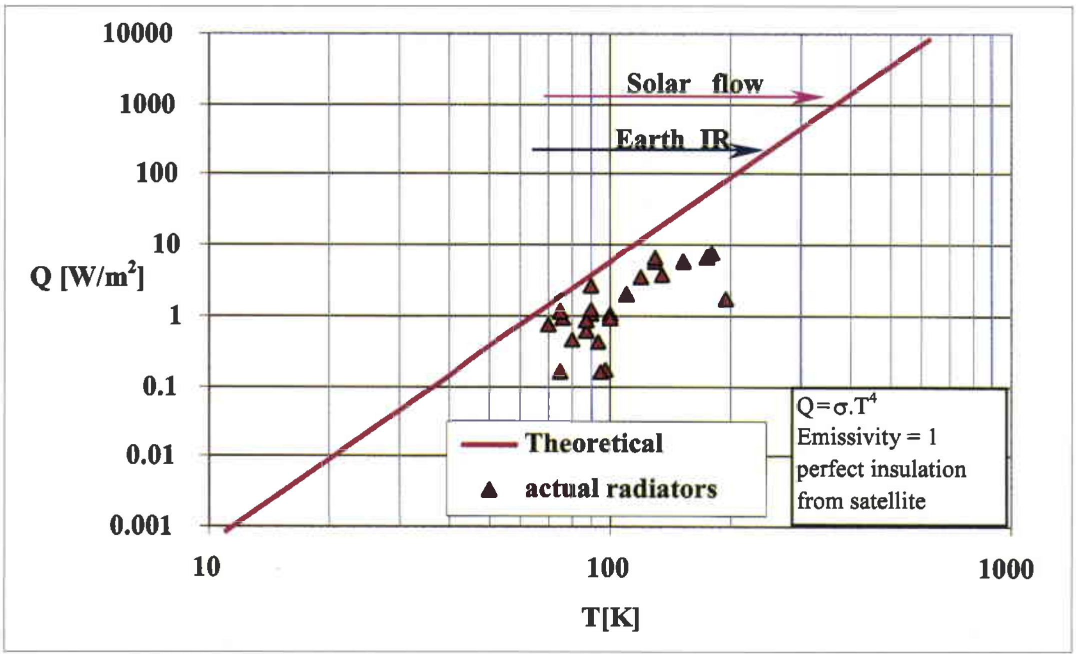

Figure 5. Radiator heat lifts as a function of temperature and area. Actual radiators deviate from theoretical expectations due to the actual emissivities of their surfaces. In practice it is difficult to run a passive radiator at T< 60 K, even in orbits far away from Earth

radiators is their orientation: they need to be shaded from solar radiation (1.4 kW/m^2), and from the Earth's infrared and albedo radiation (about 300 W/m^2 for the Earth), and to look towards deep space in order to radiate efficiently. This is a severe limitation that can be managed only by constraining the spacecraft's attitude and manoeuvring, together with careful baffle and shield design to reject the unwanted radiation. In addition, it is often necessary to have multiple-stage radiators, thereby increasing their complexity.

There is therefore a lower limit to the temperature and cooling power that can be achieved with radiators. For low Earth orbits (e.g. Earth-observation satellites), the temperature limit is about 100 K, with a cooling power lower than 1 W/m^2. For geostationary orbits (at 36 000 km, e.g. telecommunication satellites), the temperature limit can be reduced to 75 – 90 K. For far-away orbits (e.g. Lagrangian points), the Earth radiation constraint vanishes, and the radiator architecture becomes simpler, with lower temperatures and better performances. In the case of Planck, it is expected to have a cooling power of about 2 W and a temperature of about 50 K; in the case of NGST or Darwin it is estimated to have a cooling power of 200 mW at about 35 K.

A stored-cryogen cooler is composed of a cryogen tank, a vacuum vessel (isolating the cryogen tank before and during launch), filling and venting lines, heat shields/multi-layer insulation, and some interface or volume for instrument accommodation. In the absence of gravity, the fluid needs to be maintained inside the tank by a phase separator (based on capillary forces, or the fountain effect for superfluid helium). For ground dewars, the cryostat neck is normally used as a filling and venting line in addition to supporting the inner cryogen tank. Due to the dynamic loads present during the launch, space dewars are not compatible with this architecture. A separate venting line is used to use the gas enthalpy efficiently to cool the shields, and to release the gas without applying momentum to the spacecraft. In space, it is also possible to cool the whole vacuum vessel by radiation to space and by the venting line (as opposed to on the ground, where the tank must be at room temperature to avoid condensation). The ISO vacuum vessel, once in space, was at 110 K; the Herschel vessel is expected to be at 77 K, and that of SIRTF at 5 K. In addition, the bath equilibrium pressure is not 1 bar as on the ground, but it is vented to the vacuum of space. This allows a pump on the cryogen bath and the use of solid cryogens, which require no phase separator. The proper design of the exhaust nozzle allows tuning of the base temperature (vapour pressure) of the cryogen bath by adjusting the pressure drop. The volume of cryogen to be carried depends on the mission's duration and on the heat input. The choice of the cryogen depends on the base temperature required. The cryogens available do not provide a continuum of temperatures, but rather discrete values in different ranges. The most widely used are superfluid or supercritical helium, solid H_2 and solid Ne. An overview of the choices made for different missions is presented in Table 4. For low-temperature systems, to optimise the cryogen mass it is more interesting to use a bi-cryogen system, such as N_2 and He, or H_2 and He.

Table 4. Cryostat/cryogen choices for a number of spacecraft

Mission	Cryogen
IRAS, COBE, ISO, Herschel, SIRTF	Superfluid ^{4}He
IBSS, STEP	Supercritical ^{4}He
WIRE	Solid H_2
XRS on ASTRO-E	Solid Ne
NICMOS	Solid N_2

In a mechanical (or active) cooler, mechanical work produced by moving parts is transformed into refrigerating power. There are many ways to classify active coolers. The most widely used is to distinguish between regenerative cycles (Stirling, pulse tube, Gifford coolers) and recuperative cycles (Joule-Thomson or Brayton coolers). The regenerative coolers are based on a pressure wave generated by a compressor (usually mechanical), and a cold finger, using a mobile (Stirling, Gifford) or a fixed (Pulse Tube) regenerator. The heat is extracted at the cold end when the gas expands, and rejected at the warm end when the gas is compressed. The recuperative cycles use the enthalpy difference between high- and low-pressure gas. The Brayton-cycle coolers use a cold turbine to expand the gas, whereas the Joule-Thomson coolers use the expansion through an orifice, and the properties of real gas to get the cooling effect. Being irreversible, the Joule-Thomson cooler (normally coupled to Stirling units) is less efficient than the Brayton type, but is simpler.

The main difference between ground and space coolers lies in the lifetime required. A lifetime of 5 years is a typical requirement for most space applications, which means that friction between moving parts must be minimised. This has led to the development and qualification of coolers based on the 'Oxford compressors': this compressor uses a linear drive, while the leak tightness of the compressed volume is guaranteed by a tight clearance seal (about 10 μm). A diaphragm spring is then used to maintain an alignment compatible with such a small gap, whilst still allowing the axial motion of the piston. Life tests as long as 8 years have been performed with this system and many such coolers are currently flying in space.

Another important limitation for space coolers is the electrical power demanded. A typical power allocation for a cryo-cooler is between 50 and 200 W. Most mechanical coolers (typically based on the Stirling cycle) have an efficiency of order 2 – 5% of the ideal Carnot cycle, implying a cooling power of a few mW at 4.2 K with an input power of about 100 W. Figure 6 provides a summary of the Coefficients Of Performance (COPs) of different active coolers as a function of temperature, in the form of the ratio between cooling power and absorbed electrical power. The COP is compared to the efficiency of the ideal Carnot cycle.

Mass also represents a critical parameter in the evaluation of space coolers, typically being limited to 100 – 150 kg. In addition, coolers should not generate vibrations degrading the performance of the sensitive detectors that they are supposed to cool down. Vibrating forces are generated as reaction to moving masses within the cooler, and such forces may cause elastic deformation of the instrument structure, either affecting its alignment or causing electrical interference in the form of micro-phonic pick-up.

To date most of the mechanical coolers proposed for space applications are based on the Stirling cycle or on the Joule-Thompson expansion, but more recently Pulse Tube Refrigerators (PTRs) have been proposed as an interesting alternative, due to their lack of moving parts and the reduced vibration level. Most of the development effort is concentrated on improving the efficiency of such coolers. A small PTR developed by Lockeed-Martin in collaboration with NIST (USA) has been flown onboard the Space Shuttle (mission STS-90), delivering 50 mW at 100 K, with an input power of order 10 W (COP = 0.005). TRW (USA) has also delivered several PTR units, including a system used in the AIRS instrument, to be flown onboard the Aqua (formerly EOS-PM) mission, with a cooling power of 1.75 W at 55 K (Table 3).

Finally, we should mention that a closed-cycle, hydrogen sorption cooler is being developed by JPL (USA), with the potential to offer a vibration-free alternative to mechanical coolers for the 50 – 20 K temperature range; such an approach is presently baselined for ESA's Planck mission.

- Very-low-temperature coolers (T < 1K).
In many scientific satellite applications it is

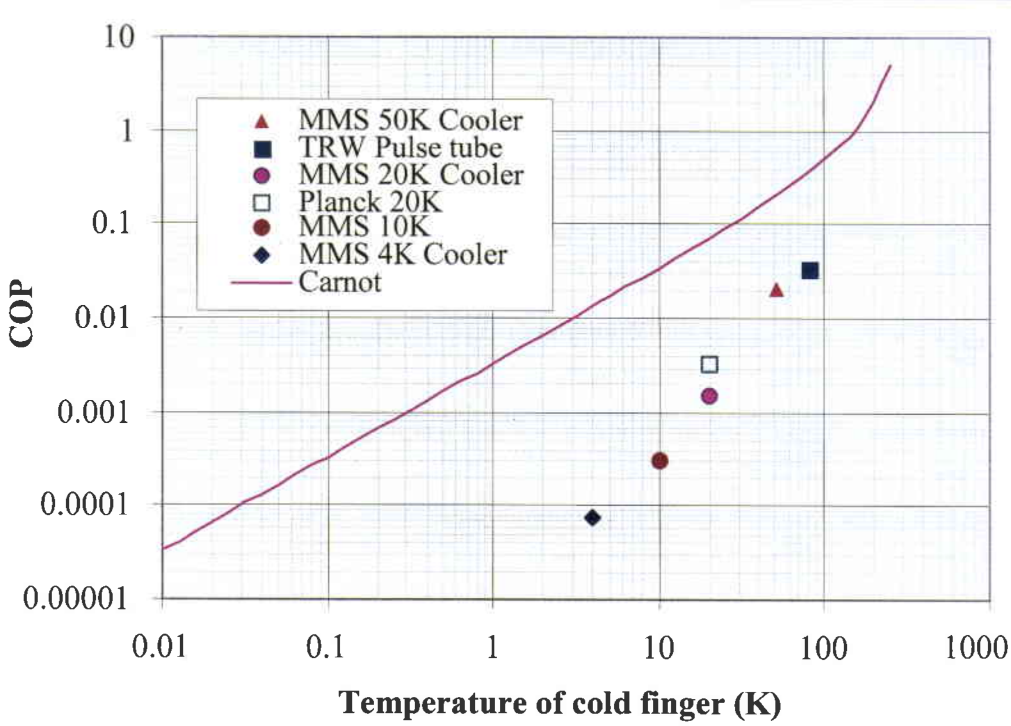

Figure 6. Coefficients Of Performance (COPs) of different coolers. The solid line represents the efficiency expected from an ideal Carnot cycle. The typical efficiency achieved at 10 to 20 K is of order 0.001

necessary to achieve even lower temperatures, well below 1 K. Such a temperature range can be achieved by using closed-cycle ^3He sorption coolers (down to 250 mK), by Dilution Refrigerators (50 mK) and by Adiabatic Demagnetisation Refrigerators (50 mK).

He sorption coolers offer interesting performances, due to the simplicity of their operation, the lack of moving parts, and the possibility to work in a closed cycle configuration with an efficient duty cycle (^3He condensation phase vs. hold time at base temperature). Their typical cooling power is of the order 10 µW at 300 mK. Sorption coolers have already been flown on balloons (Boomerang, Maxima, Archeops), on sounding rockets and on the SFU satellite (IRST - Infrared Space Telescope instrument). Sorption coolers will be used for the SPIRE and PACS instruments onboard Herschel (Table 2).

Dilution Refrigerators, based on the quantum-mechanical properties of ^3He – ^4He mixtures, are routinely used on Earth to achieve temperatures below 100 mK, with cooling powers exceeding 100 µW. This technique is now being adapted for space applications and it is planned to be flown on Planck (cooling power of order 0.1 µW). The absence of gravity and running the conventional mixture circulation in space are the main challenges of such a development. The proposed approach avoids the use of circulation pumps by working in open-loop mode, thus requiring a very large amount of gas mixture and offering a lifetime limited by the gas reservoirs. Alternative techniques may combine the capillary liquid confinement with a closed-loop system based on cryo-sorption pumps.

Adiabatic Demagnetisation Refrigerators have already been used on sounding rockets and scientific satellites (Astro-E). They produce base temperatures of 50 – 100 mK by reducing the entropy associated with the electronic spins of the atoms of paramagnetic salts. Forcing the electronic spins to align in a single direction via a magnetic field of a few Tesla reduces the entropy. Cooling powers of about 10 µW are achieved. ADRs offer very low base temperatures with simple operation and good duty cycle efficiency. The main challenges presented are the need for large magnetic fields (implying large currents and potential EMI issues) and for high-performance and high-reliability thermal switches. The use of an ADR system is baselined by ESA for the future XEUS mission (Table 3).

Solid-state coolers, analogous to Peltier elements but operating below 1 K, are also being investigated. They are based on metal-insulator-superconductors, which provide cooling of the lattice by relying on phonon-electron coupling and removing the hottest electrons present in the normal metal electrode of the device. Cooling of membranes from 0.3 K to 0.1 K has already been achieved. Such coolers are being developed with the aim of building self-cooling detectors (bolometers or STJs) with simpler pre-coolers (e.g. ^3He sorption coolers).

Thermal insulation and ancillary equipment

- Insulation technology for space

The goal of thermal insulation is to limit the heat loads on the cold stage to a level compatible with the cooler's heat lift. Given the limited COP of space coolers, minimisation of the heat load is crucial to meeting the mission requirements. In space, conductive and radiative coupling represent the loss mechanisms to be reduced by thermally insulating the cold stages, which includes the use of low conductive supports, Multi-Layer Insulation (MLI) and shielding (e.g. V-groove shields).

- Ancillary cryogenic equipment for space

Cryogenic ancillary equipment plays a critical role during ground testing and must be adapted and qualified for space utilisation. The key items required onboard spacecraft are: high-thermal-conductivity links; heat switches; high-heat-capacitance devices; space-qualified temperature sensors; pressure, level and flow meters; cold filters/windows; cryo-mechanisms (e.g. choppers, filter wheels, grating devices); special paints and coatings; cryogenic cables and wiring.

Key technologies

Present situation and future needs

On the basis of the needs highlighted in the preceding sections, a number of critical technologies have been identified. The main issues involved and the envisaged development needs are outlined below.

Passive Radiators (in the 100 to 40 K range) play a major role on scientific satellites, thereby reducing the requirements imposed on active cooling systems. They need to guarantee high emissivity at low temperature (see role played by micro-cavities), while the related thermal isolation technology requires improvements. Design as well as testing tools are required.

Active Cooling Systems (between 100 and 50 K) are slowly moving from the pioneering phase of technology demonstrators to a mature commercial phase. Owing to the lack of a large customer base, the existing space-qualified coolers are very expensive (order of a million Euro) and quite heavy. In addition they remain a major source of vibration and their efficiency needs to be improved.

20 K coolers also have an important role to play as pre-cooling stages within more articulated and lower-base-temperature cryogenic systems. The Stirling-cycle-based coolers are not easily accommodated onboard spacecraft, while Joule-Thompson coolers are less efficient but more flexible, allowing the use of radiative pre-cooling. Modularity and cooling-power scalability are also important qualities to be pursued. Cryo-sorption-based systems represent an attractive alternative to be explored.

2 to 4 K coolers should provide larger cooling power (> 50 mW) in view of supporting lower temperature stages. Absence of (or low) vibration levels is also required in applications involving very-low-temperature coolers, sensitive detectors and high-accuracy spacecraft pointing and/or positioning (e.g. astrophysical observatory).

Very Low Temperature (VLT) coolers ($T < 1$ K) are becoming more and more important to space missions due to the use of very sensitive cryogenic detectors. A large effort is required to develop closed-loop, space-qualified coolers (such as ADR, DR, Sorption Coolers) providing sub-Kelvin temperatures and offering reliable performances and long lifetimes.

Miniaturisation also represents an important trend, since it should allow the reduction of heat losses, power consumption and sensitivity to vibrations. New activities are aimed at verifying the possibility of using micro-machining technologies to develop both active and solid-state miniature coolers.

Finally, ancillary equipment and devices should not be neglected. These include: high-conductivity thermal busses (e.g. heat pipes) and connections; low-thermal-conductivity and orbital disconnect supports; heat switches (important also for VLT coolers); cryo-mechanics; temperature-stabilisation devices and low-temperature measurement techniques.

Technology road-map

In Table 5 we have summarised the key areas to be explored in the future to produce significant advances in the field of cryogenics for space applications. The content of the table reflects what has been discussed in the previous sections, with the addition of considerations on the development time-scale and on the temperature range involved with each specific technology. The overall time scale considered is limited to the next 10 – 20 years.

ESA, within its Technology Research Programme, its General Support Technology Programme and certain specific projects, is active in most of the areas indicated in the table. Potential advantages are offered by improved co-operation between ESA and other institutions of the European Union (e.g. in the field of materials science, such as advanced composites).

The smallness of the market for cryogenics for space applications (e.g. qualified mechanical coolers) has meant high costs and has drastically reduced the number of suppliers. To improve the situation, it is necessary to promote the maximum possible compatibility between space and ground products, thus widening the potential market base. To this end, future development activities should include the space qualification of cryogenic systems largely based on or derived from Commercial Off-The-Shelf (COTS) units, originally developed for ground-based applications.

Conclusions

The field of cryogenics has made remarkable progress over the last 15 years, moving from laboratory prototypes to commercial applications in several areas. Such progress, coupled with the advanced performance offered by cryogenic and superconducting devices, has triggered a virtuous cycle of ever-growing initiatives and new applications.

Reliability and simplicity of operation have made it possible to use cryogenics in space, albeit at the price of additional complexity and higher cost. Continuous improvements have resulted in longer lifetimes and reduced risk, with a number of design solutions, from cryostat- to mechanical-cooler-based systems, capable of covering a large range of instrument base-temperature requirements.

The use of cryogenically cooled devices on spacecraft, such as photon detectors, has brought unprecedented results, especially in the field of space science. Over the last 10 to 15 years, several missions have demonstrated that these devices can outperform any competing technology.

An emerging trend is the development of complete cryogenic payloads, in which the use of cryogenic devices is extended to both the front-end electronics (e.g. low-noise amplifiers

Table 5. Technology road-map for cryogenics in space

Area	Critical technologies	Time (yr)	T (K)
Coolers	High-efficiency, low-T passive radiators	>5	<60
	Improved-efficiency, large-size dewars	>5	<4
	Low-vibration, high-COP Stirling coolers	>10	<10
	High-COP, space-qualified PTR	>10	4-80
	Space-qualified compressors based on turbines	>10	<10
	High-COP, miniaturised active coolers	>15	<50
VLT	Optimisation of space-qualified ADR	>5	<0.1
	Development of closed-loop DR	>10	<0.1
	Space qualification of sorption coolers.	>2	<0.5
	Solid state coolers based on NIS devices.	>10	<0.3
Thermal Insulation	Orbital disconnect supports.	>5	<10
	Very low emissivity coatings.	>2	<50
	Improved V-groove shields.	>2	<100
Ancillary Equipment	Cryogenic heat pipes for Space.	>5	<10
	Cryogenic heat switches for Space.	>10	<10
	IR absorbing paints.	>10	<10
	Space thermometry/in-flight calibration.	>10	<4
	Pressure / level / flow meters.	>5	<4
	Cryo-mechanisms (e.g. filter wheels).	>5	<10
	Cryo-optics, large area cooled mirrors.	>5	<50
	Cryogenic wiring for low amplitude signals.	>5	<10
	High heat capacitance devices.	>2	<10
	Testing facilities (e.g. vibrating table at low T).	>2	<10
Materials	High Temperature Superconductors films/wires.	>5	>80
	Low Temperature Superconductors devices.	>5	<10
	Advanced composite materials for cryogenics.	>10	300-1

and input multiplexers) and back-end electronics (e.g. output multiplexers and superconducting digital electronics), in addition to the more traditional detectors and optics applications. The development of cryogenic payloads for space calls for a system approach, involving the complete spacecraft design from the outset of the project. Clear examples are set by several space-science observatories that are built around their cryogenic tanks, or by the crucial role played by spacecraft geometry and by mission control in the case of passively cooled instruments.

Several technologies need to be improved to extend the application of cryogenics in space, including active mechanical coolers, thermal-insulation techniques and the miniaturisation of equipment, with the goal of reducing heat losses, as well as the sensitivity to vibrations. The development of high-conductivity thermal busses and connections (e.g. heat pipes), low-conductivity or disconnect supports, heat switches, temperature-stabilisation units and low-temperature measurement techniques, are all necessary to improve cryogenic payloads further.

In this article we have discussed the dominant space-engineering trends and the guidelines along which cryogenic technologies are expected to develop in the next 10 years. The importance assigned to it by the leading space organisations indicates that cryogenics is going to play a strategic role for many future space missions. esa

Flow Analyses for Spacecraft

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The design and construction of International Space Station elements such as Columbus, the Automated Transfer Vehicle and the Cupola are inherently different from those of classical spacecraft due largely to the need for pressurisation of the structure. Air revitalisation in the crew areas and prevention of the accumulation of pockets of dangerous gases in stagnant regions require a well-controlled flow field, for both safety and comfort. Conductive and radiative heat fluxes are then no longer the only heat-flow mechanisms and heat transfer by forced convection also needs to be taken into account*. The characteristics of this type of flow can either be derived analytically or obtained via empirical correlations. Flow patterns in large volumes such as crew cabins are far from homogenous, which makes mass and heat flow prediction very difficult. One therefore needs to resort to an experimental investigation of the flow field or to the numerical solution of the flow equations, usually referred to as Computational Fluid Dynamics (CFD).

An experimental set-up is essential for validating and fine-tuning the correlations used in flow-analysis tools. A numerical tool, however, allows the designer to understand the physical behaviour of flows and to optimise the final design by setting up and studying different configurations more easily and more cheaply. Consequently, the Agency decided to extend its existing thermal tools with a CFD tool, i.e. CFD-RC, in order to address convection-dominated heat-transfer problems in space. At the same time, the outcome of a CFD analysis can also be used to fine-tune the classical tools, such as ESATAN, thereby exploiting the strengths of all available approaches. CFD is now being used extensively for ventilation and heat-transfer analyses for the pressurised module of the Automated Transfer Vehicle (ATV). Another application is to the venting of payload chambers in the Columbus module, which could perturb the Space Station's microgravity environment.

* Although convection is also present in unpressurised spacecraft, it is mainly limited to fluid flows in tubes or other confined geometries, for which the flow pattern is generally known.

CFD: a versatile tool for multi-disciplinary analyses

To generate the output of a flow analysis (e.g. forces, heat fluxes, mass flows and concentrations) efficiently, a whole battery of software and hardware tools is required. The following paragraphs attempt to describe the different steps and needs in the 'computational' process to analyse engineering problems in this area.

Pre-processing: mesh generation

Pre-processing consists of defining the geometrical description of the to-be-studied model and the discretization of the two- or three-dimensional domain within or around the model. Contrary to most thermal analyses, where the calculation of conductive and/or radiative heat fluxes only requires surface discretization of the model geometry, a fluid-dynamic computation also requires the volume in or around the geometry to be discretized. Hence, the number of computational nodes needed increases very rapidly with the detail in the model. For 3D-geometries, this easily reaches from 100 000 to 1 000 000 nodes and even higher. This vast number of nodes, along with the description of complex geometries, necessitates the use of a powerful mesh-generation tool that allows the user to produce a computational mesh in a (semi)-automatic way. Although these tools are commercially available, the mesh generation might still require quite a lot of effort. The effort largely depends on the requested grid quality, the mesh type (structured vs. unstructured) and the geometrical complexity.

In general, unstructured meshes (Fig. 1a) can be easily generated independently of the geometrical complexity, both in 2D and 3D. Although structured meshes (Fig. 1b) are to be preferred for reasons of accuracy in cases of aligned flow, e.g. boundary or shear layers, their generation can sometimes be difficult and cumbersome. Owing to their nature, they generally tend to generate more points than in the unstructured case. The possibility of constructing a hybrid grid (Fig. 1c), to combine the advantages of both a structured mesh (accuracy) and an unstructured grid (fewer points and easier to produce), is a valuable asset to have within a mesh-generation tool.

Solvers: incompressible vs. compressible

To evaluate the velocity, temperature or pressure field, the highly non-linear Navier-Stokes equations need to be solved. In the past, many techniques for solving the flow equations numerically have been studied. The majority of them can be divided into two major schools: the density-based and the pressure-based methods. The latter method originated from techniques elaborated for the incompressible limit of the flow equations. In this case the density hardly varies, as is the case for example for gases at low speed or liquids (water, oil, etc.). Once these techniques were well-developed and understood, improvements and extensions were introduced to handle also compressible flows up to supersonic speeds.

The density-based methods were initiated to tackle problems where compressibility of the fluid is an essential feature. The variability of the density is used to iterate towards a solution. Methods of this kind are generally employed by the aeronautical and aerospace community, where high speeds, compressibility and shocks are common features dominating trans-, super- or hypersonic flows. Here also, however, once the techniques reached maturity, the need emerged to extend this approach towards the incompressible limit.

Nowadays, the commercially available CFD-codes generally follow one of the schools, inspired by their original customers. Only a few codes incorporate both schools into their package. This extra possibility would allow the user to choose the appropriate technique for his/her particular flow problem.

Multi-disciplinarity: the way to fully coupled solutions

In parallel with the evolution of numerical techniques, the need to extend the flow-analysis tools to closely related disciplines or to completely different fields quickly emerged.

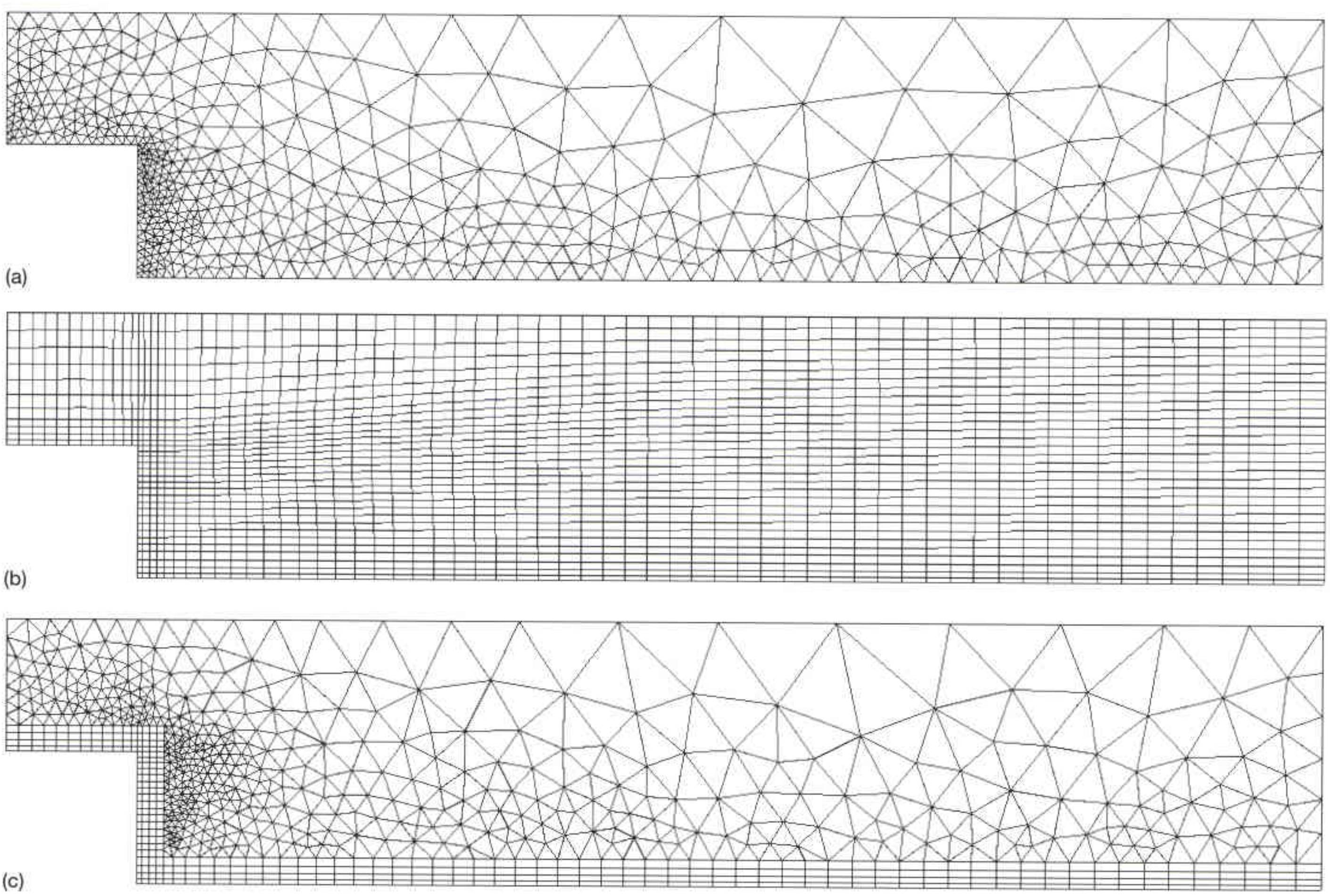


Figure 1. Different mesh-types for sudden tube enlargements:
(a) unstructured mesh with 579 nodes,
(b) structured mesh with 2044 nodes,
(c) hybrid mesh with 1002 nodes

Species transport, chemistry, combustion, two-phase flows, free surfaces, radiation, etc. coupled with the flow equations are some of the topics that were gradually investigated once CFD-techniques became more established. Also the coupling of CFD with heat propagation in solids (conjugate heat transfer), the interaction with structures (steady or modal analysis) electro-magnetic interactions, etc. has resulted in a very versatile evaluation tool applicable across various disciplines.

Post-processing: visualisation and interpretation
The large number of nodes together with the numerous variables, e.g. velocity, temperature, pressure, stresses, gas composition, etc., necessitates the aid of a post-processing tool to visualise, to interpret and to manipulate this vast amount of data. Visualisation enables the user to evaluate the computed information rapidly. Interpretation allows an in-depth analysis of the physical behaviour, and can be as simple as plotting contours, but the tools generally also allow mathematical manipulation of the data. As an example, the calculation of vorticity using the velocity components eases the detection of swirl in the flow field, while the use of traces allows visualisation of the path travelled by a small particle. Many other features are available to facilitate the user's interpretation of the computed data.

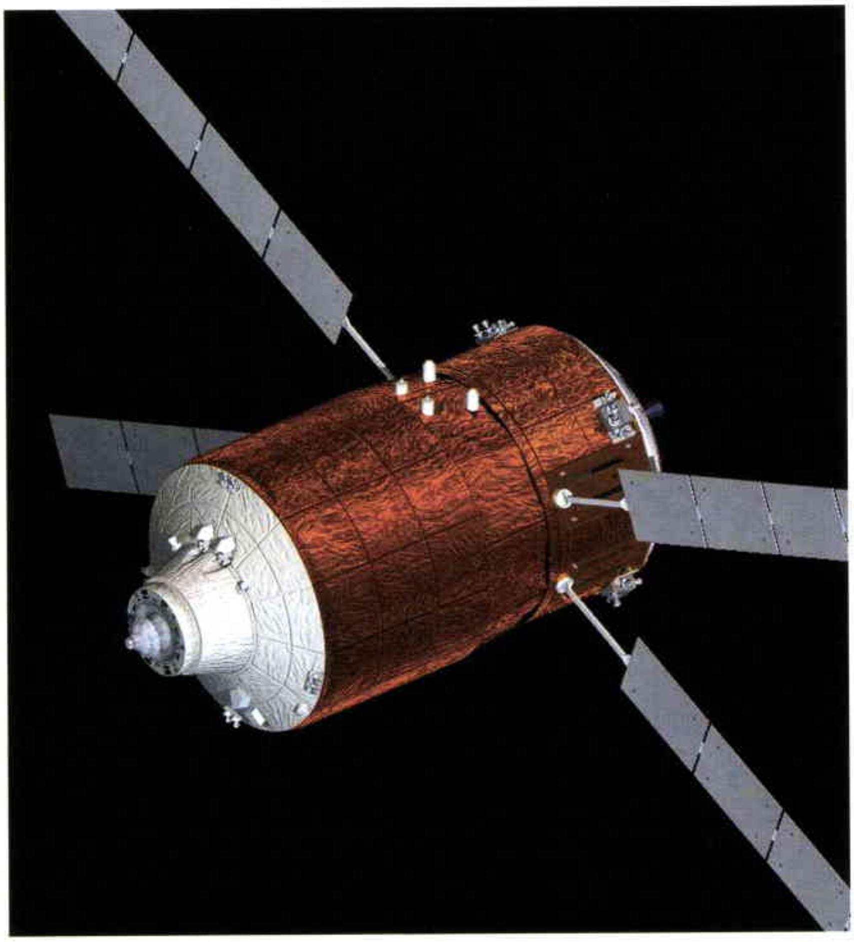


Figure 2. View of the Automated Transfer Vehicle (ATV) with the Integrated Cargo Carrier (ICC) at the front, the propulsion bay at the rear, and the avionics bay in between

Computer science and CFD: harmonisation at its best
Finally, one must not forget that the computational effort itself is an important parameter, especially for three-dimensional problems. This makes CFD a discipline where the relentless increase in computer power enhances its potential. Besides numerical acceleration techniques (multi-grid, pre-conditioning), the use of parallel computers (distributed- or shared-memory computers), the organisation of data-structures (cash hit rates) and communication bandwidths are some of the many hardware aspects to be considered in the efficient coding of CFD-tools. This makes the task both challenging and demanding. The clustering of cheap personal computers to act as a large highly performant computing facility is yet another recent evolution in the continuing quest to accelerate the analysis process.

Applications

ATV: Automated Transfer Vehicle
The low orbital altitude of the International Space Station (ISS) means that it is still susceptible to atmospheric friction, causing it to lose height throughout its lifetime. Hence orbital re-boosting will occasionally be needed to take it back to higher altitude (maximum 460 km). This is one of the tasks foreseen for the ATV, using the propulsion bay located at the rear of the vehicle (Fig. 2). A second task consists of delivering equipment and consumables (food, oxygen, propellant, etc.) to the Station, carried in the vehicle's Integrated Cargo Carrier (ICC) module. This module, located at the front of the ATV, also contains the mechanism needed to dock with the ISS. All dry cargo will be placed in up to 8 racks mounted in the cylindrical portion of the ICC (Fig. 3). The fronts of the racks face a central (2 m x 2 m) corridor, allowing the crew to unload the cargo, whereas their backs form a small air gap with the structural shell. Air revitalisation is provided by blowing air into the ICC (at a rate of 180 m^3/h) from the Russian 'Zvezda' module through a flexible hose.

Hence no advanced ECLS-system is required onboard the ATV itself. Still, to guarantee good ventilation and to ensure an adequate air distribution velocity for crew comfort, a cabin fan mounted in the ICC circulates the air at a rate of 264 m^3/h via appropriately positioned diffusers. Their primary goal is to avoid any stagnant/recirculating flow regions in which toxic gases could accumulate. This might eventually lead to the suffocation of an astronaut, should he/she venture into one of these 'dead-air' zones. The air-conditioning and ventilation is, however, also constrained by

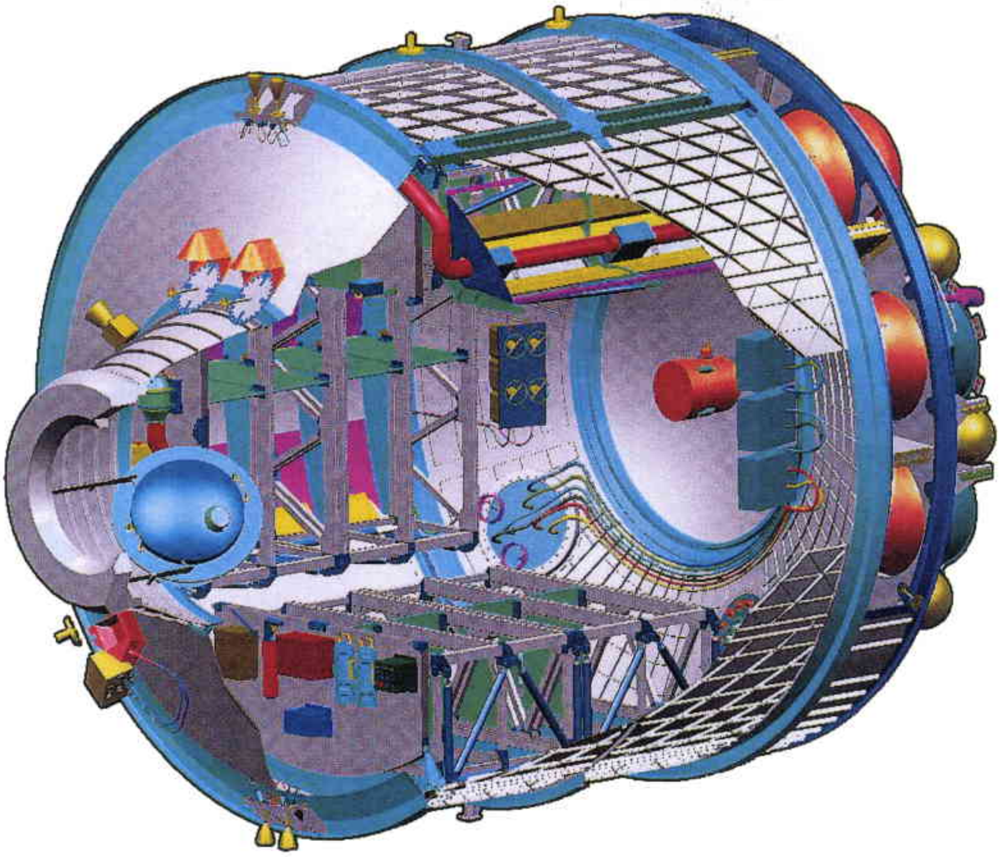


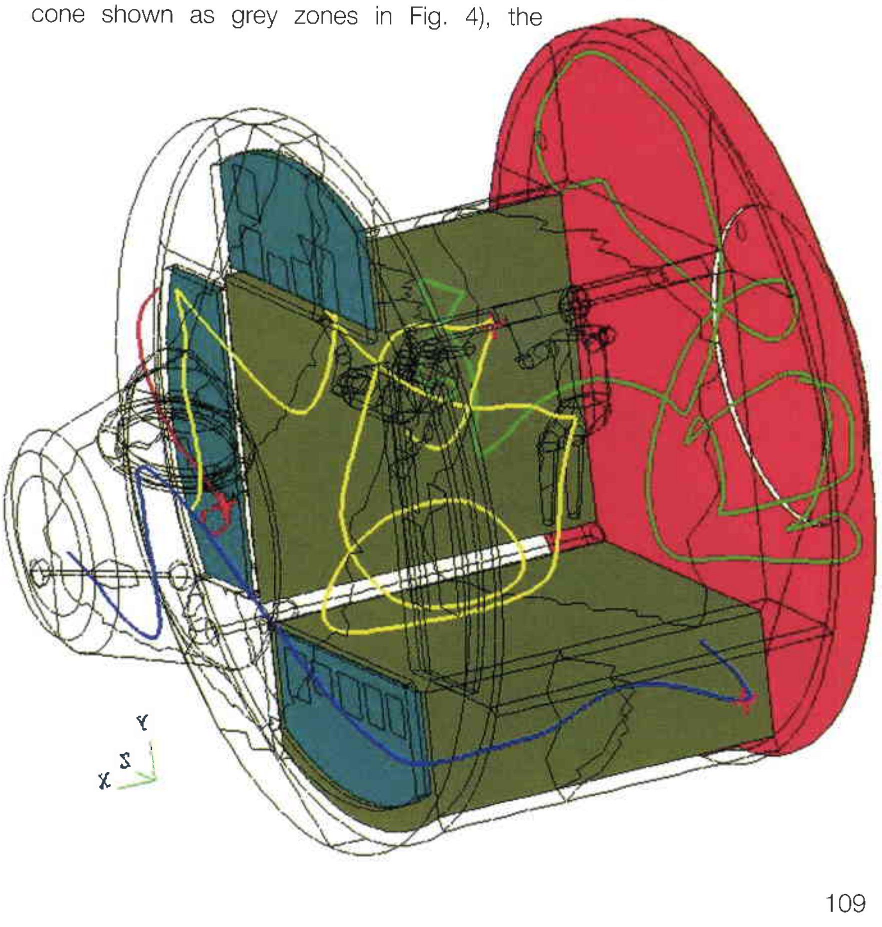
Figure 3. Internal view of the Integrated Cargo Carrier (ICC) with the racks mounted in the centre

certain limits. The air speed should be always lower than 0.25 m/s in the crew cabin, whereas the air temperature should be less than 28°C, but more than the minimum dew temperature of 16°C. Also, the 'touch temperatures' of surfaces exposed to the crew should not exceed 45°C.

The particle traces plotted in Figure 4 are based on the calculated flow field when the ATV is docked to the ISS. The aft diffusers and the flexible hose deliver a high-momentum jet impinging on the rear bulkhead of the ICC, thereby guaranteeing a good washing out of the aft part (green line). The total injected mass flow rate of 240 m^3/h is then deflected towards the front, passing through the crew cabin and the lower stand-offs (blue and green lines). Also four extra cabin diffusers (flow rates of 50 m^3/h each) placed in a staggered way in the upper corners ventilate the central corridor (yellow line). The air flow exiting the cabin and stand-offs is partly deflected towards the main cabin fan sited off-axis in the front cone (red line). The remaining flow (180 m^3/hr) is driven back into the Russian module through the docking port (blue line). Although this visualisation provides a qualitative idea about the flow pattern, it does not provide absolute certainty that every corner is perfectly washed out. To allow a quantitative measurement, therefore, the analytical module is artificially filled up with a trace gas (e.g. CO_2) and then ventilated through the different diffusers with air. The presence of dead/recirculating regions would result in finite concentrations of the trace gas once the ventilation has converged to its final flow field.

Coupled with the flow field, the temperature field is calculated taking into account the heat dissipation of numerous electronic boxes (rectangular areas on the panels in the front cone shown as grey zones in Fig. 4), the

Figure 4. Particle traces inside the pressurised module of the ATV: in the rear (green line), in front of a cabin air diffuser (yellow), in a lower stand-off (blue), and in front of the cabin main fan (red)



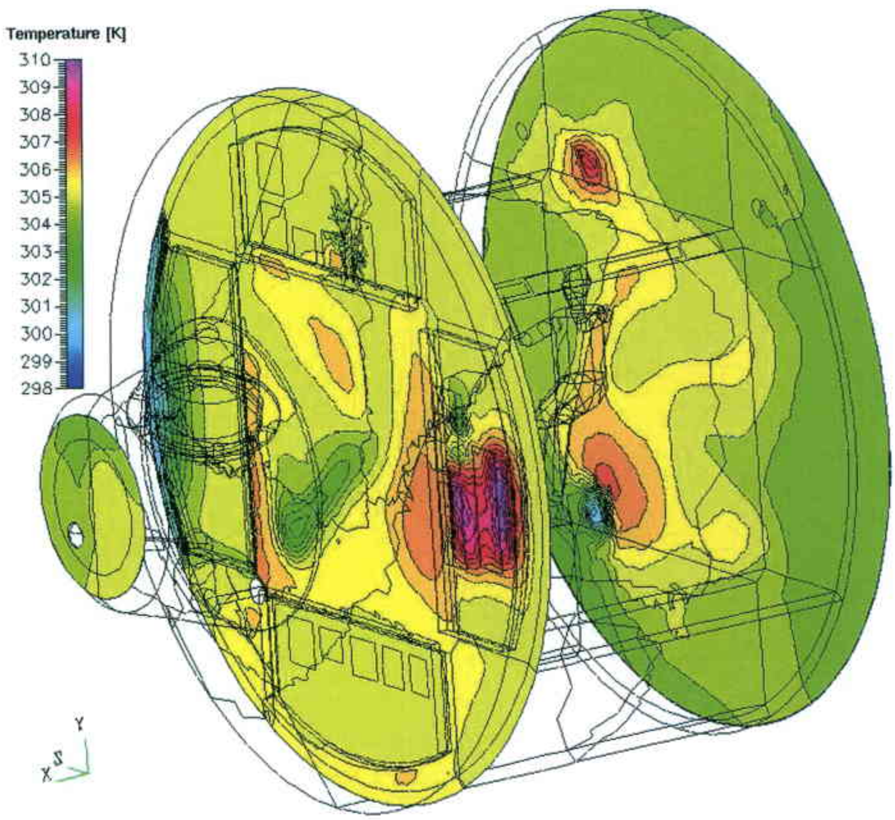


Figure 5. Temperature contours in two planes; the front plane, which also intersects the equipment panels, gives the temperatures in both the fluid and solid elements

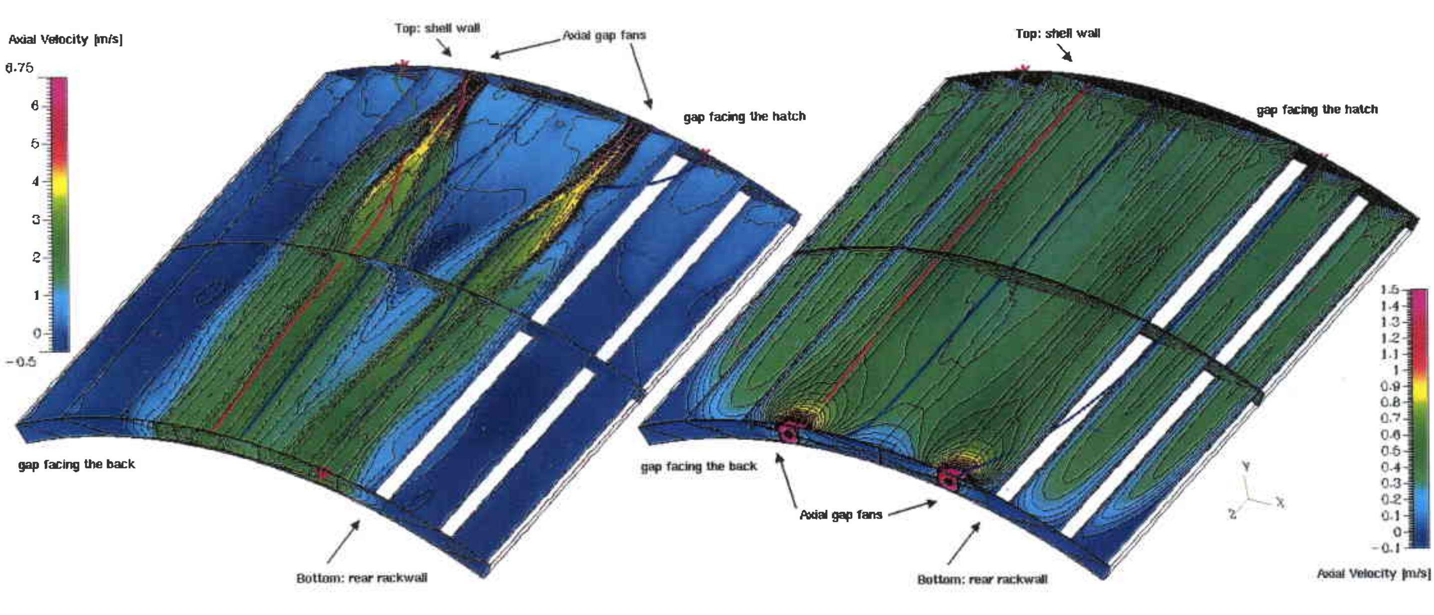
Figure 6. Flow field for a ventilated air gap with: (a) fans placed at the front end pushing air into the gap, (b) fans placed at the rear end sucking air from the gap

metabolic heat from two crew members, lights, etc. Figure 5 gives an indication of the temperature field in two planes perpendicular to the main axis. The front plane intersects the equipment panels on which the electronic boxes are mounted. One can clearly see the higher temperatures inside the panels due to the conductive heat transfer. This allows the evaluation of surface touch temperatures, which depend strongly on the convective, conductive and radiative cooling.

Within the global ventilation analysis, a specific issue investigated was the possible effect that gap ventilation behind the racks might have on the overall flow and temperature field. The idea is to take advantage of the air heat exchange with the outer ICC shell to improve the cabin air temperature. The optimal location for auxiliary fans needed to be identified to realise as uniform a flow field as possible. Different configurations were investigated, of which only two are shown here. The configuration with two axial fans pushing air into the slot only delivers two fast jets along the axes of the fans covering only a third of the cross-sectional area (Fig. 6a). This flow pattern is far from ideal and a large portion of the shell wall is unaffected. On the other hand, closing the rear gap end apart from openings for the two sucking fans allows the generation of an almost uniform flow field in the air gap (Fig. 6b).

Columbus: venting payload chambers

The International Space Station (ISS) is designed for carrying out experiments without the influence of gravity. The equipment on the ISS, however, includes many potential vibration sources that could disturb the microgravity environment. All such equipment therefore has to be designed and verified against strict specifications. The perturbations are due to the acceleration and deceleration of moving parts (pumps, fans, motors...), impact forces (opening or closing of valves), or they can be of fluid-dynamic origin. The latter happens, for instance, when a payload chamber needs to be evacuated via Columbus' vacuum and venting system. The air or other gas is released via a shut-off valve into a duct, which is connected to a venting nozzle at the port cone of Columbus. The outlet is designed to produce minimal thrust and therefore minimal microgravity disturbance. The gas plume, however, expands at high velocity once it has left the venting nozzle and impinges on the surrounding module surfaces. Figure 7 shows



that the nozzle is located in a rather narrow space between Columbus, Node 2 and the Centrifuge Accommodation Module (CAM). Gas released from the venting nozzle will therefore impact several surfaces and the resulting reaction forces are not easy to predict.

The CFD tools allow calculation of the flow field and plume-impingement forces. Figure 8 shows the pressure contours on the port cone of Columbus and on the shell of Node 2. The main plume impingement is on the base plate of the venting nozzle, on a part of Node 2's surface, and on the docking adapter of the CAM. The four black lines represent the traces of the particles leaving the venting device. Figure 9 shows a more detailed pressure map in the vicinity of the venting nozzle. The results of the analysis can serve to evaluate different venting scenarios in which the gas is released in a controlled way by slowly opening the shut-off valve at the payload chamber. In this way, the microgravity disturbances can be kept to a minimum.

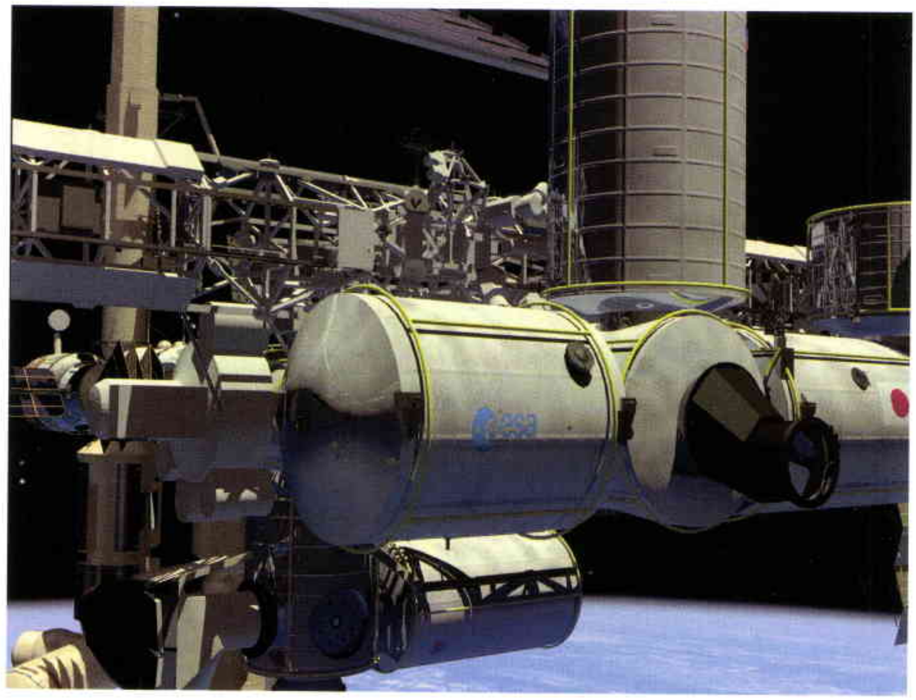


Figure 7. The European Columbus laboratory attached to Node 2, to which the Japanese laboratory (right) and the Centrifuge (top) are also docked

Conclusions

The design and evaluation of manned spacecraft habitats require an investigation of both the ventilation flow and temperature fields, driven mainly by crew comfort and safety requirements. Convection needs to be properly addressed in the prediction and analysis of the overall heat and mass transfer. Computational Fluid Dynamics has been shown to be valuable in this context, and has been successfully applied to the ATV project. Other areas of interest where the use of CFD has strong potential are, for example, heat exchangers, tuning of thermal protective systems for re-entry vehicles and combustor liners, furnaces, microgravity payloads, coolers, etc. The microgravity perturbation study for the Columbus' venting device clearly demonstrates this potential. The versatility of present CFD codes permits the simultaneous coupling of CFD analyses with other approaches, allowing a more complete analysis and optimisation to be made for any given problem.

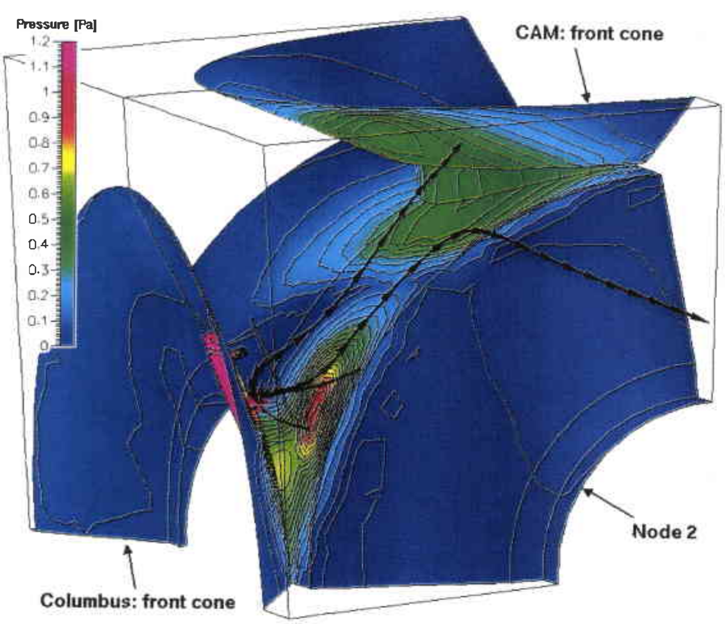


Figure 8. Pressure map for the front cone of the Centrifuge Accommodation Module and for the shell of Node 2 due to the expulsion of air into space

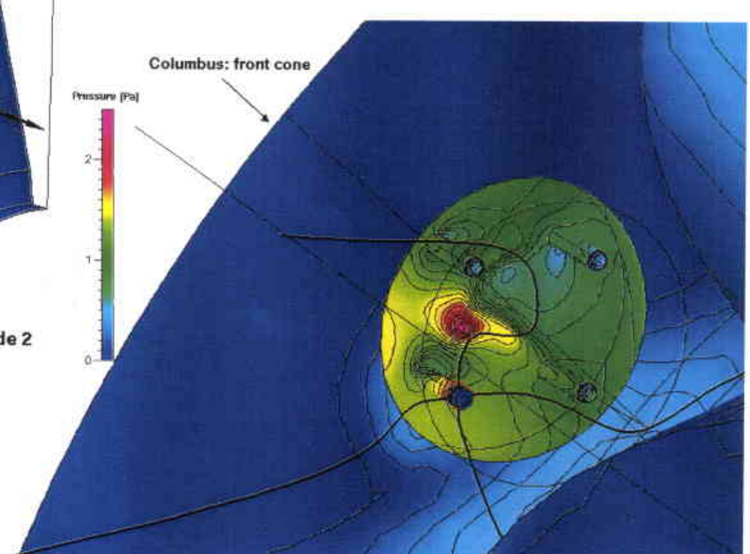


Figure 9. Pressure map showing particle traces in the vicinity of the venting device sited on the front cone of Columbus

SPiCE for SPACE: A Process Assessment and Improvement Method for Space Software Development

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As part of an ESA-sponsored programme for software process improvement, a method for software process assessment has been developed that is conformant with the requirements of the international standard ISO/IEC TR 15504, commonly known as 'SPiCE'. An initiative of the Agency's Product Assurance and Safety Department, in co-operation with the Mathematics and Software Division, the 'SPiCE for SPACE' (S4S) method aims to encourage the production of the best possible software products and services within the European space industry.

Introduction

The S4S method includes an assessment model incorporating space software practices following ECSS (European Cooperation for Space Standardization) standard requirements for the production of space software, a documented approach and a software assessment tool, together with templates of key outputs that support the performance of S4S assessments. Four pilot assessments of space software projects were performed in late 1999 to validate the method, followed by a series of eight trial assessments in 2000 and 2001. In addition, a further programme of assessments encouraging the use of S4S over the next three years has already begun.

As part of the same contract, a method of software process improvement has been developed that provides the structure necessary for space-software organisations to make effective improvements based on the results of S4S assessments. Meanwhile, a new version of the S4S method called SPiCE for SPACE-Risk, or S4S-R, is being developed that will enable software suppliers to target those processes that lead to the highest risks and to make the most effective use of limited improvement resources.

By promoting the best-practice concepts of SPiCE and addressing the specific needs of space software, ESA expects S4S to emerge as the prevailing vehicle for process improvement within the European space-software industry.

The S4S method

Software process assessment is used to establish a baseline for an organisation's capability to develop quality software. As such, it is a critical part of the cycle of continuous process improvement. The in-depth knowledge provided by a process assessment may be used to identify improvements to the processes that an organisation applies to software development. In addition, the process models on which assessment methods are based provide examples of industry best practices integrated into the complete development process. Thus, it is desirable to provide space-software suppliers with a method to evaluate their processes in order to identify potential improvement needs within their organisations. The same assessment method may be used by space-software customers to evaluate the capabilities of current and potential suppliers. The method may also be used by suppliers to verify their compliance with ESA process requirements (ECSS).

The assessment model

In designing the S4S assessment model, the exemplary assessment model from ISO/IEC TR 15504 was taken as a reference. It was then tailored using both ECSS requirements on the production of space software, and software process models developed by ESA in previous study projects. ISO 15504 is an international standard for software process assessment.

The ISO 15504 model itself has two dimensions: process and capability. The process dimension consists of a comprehensive set of processes describing all activities in software development. The process dimension consists of forty software processes. These processes are closely mapped to the software lifecycle processes in ISO 12207 and cover all of the different activities that are involved in software development.

The processes are organised into five categories: Customer-Supplier, Engineering, Support, Management, and Organisation. These range in scope from customer-supplier processes like supplier selection, to engineering processes such as software design and management and organisation processes such as project management and human-resource management, respectively. Each ISO 15504 process has a defined purpose and set of outcomes that should result from performing the process. In addition, each process includes a list of base practices, actions that may be performed to achieve the process outcomes. Finally, input and output work products are defined for each process. Work products are the artefacts that are used, produced or transformed by the process, such as documents or code.

The capability dimension provides a six-level rating scheme against which each process is independently evaluated. Results range from 0 (Incomplete) to 5 (Optimising). The six capability levels are based on nine process attributes. In addition, the capability dimension contains management practices, indicators of capability for each level.

When performing an assessment, there is no mandatory set of processes that must be evaluated. Rather, the model offers a modular approach in which the organisation selects the processes to assess based on business goals.

ESA space systems must be developed according to the requirements published by the European Cooperation for Space Standardization (ECSS), which are to be applied in the management, engineering, and product assurance of space projects and applications. The standards are written in the form of requirements and expected outputs. All of the ECSS Level-1 standards were used as primary input in developing the S4S assessment model. Of particular importance were the two standards that focus on software: ECSS-E-40, 'Space Engineering – Software', and ECSS-Q-80, 'Space Product Assurance – Software Product Assurance'. In addition, several internal space-software process models derived from these standards were used to refine the S4S assessment model.

In forming the S4S process dimension, all processes and base practices were adopted 'as is' from the ISO 15504 assessment model in Part 5 of ISO 15504. Requirements from ECSS documents or activities from space-software process models were matched with assessment model processes and base practices. In addition, the process dimension was augmented with processes, base practices and notes created to reflect activities not present in ISO 15504-5. All of the exemplary model work products were either matched with the expected outputs of ECSS requirements or, where no match was found, were kept in S4S 'as is'. New work products and work-product characteristics were formed to represent ECSS outputs not covered by the exemplary model. These new processes and process indicators incorporate space-software needs into S4S. The common origin of ECSS-E-40 and ECSS-Q-80 (i.e. ISO 12207) made this tailoring approach feasible. Figure 1 indicates the relationship between S4S, ECSS-E-40, ECSS-Q-80, ISO 12207, and ISO 15504.

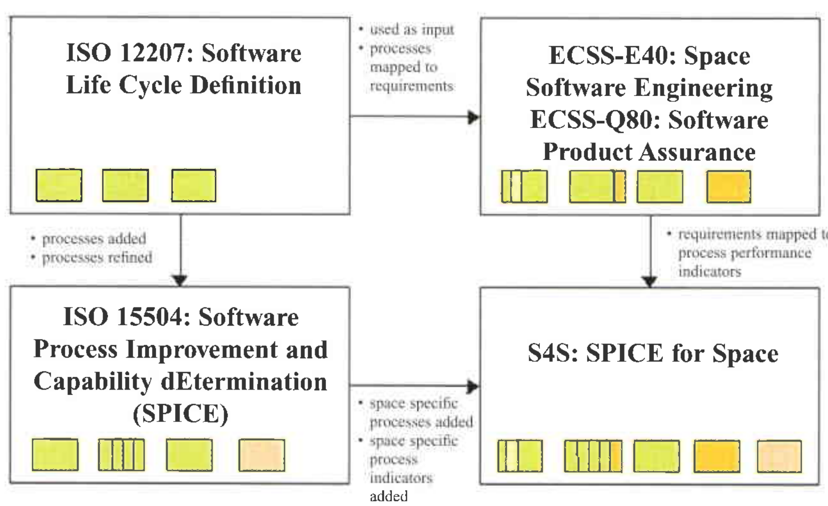

Figure 1. The relationship between S4S, ECSS-E-40, ECSS-Q-80, ISO 12207, and ISO 15504

As a result of these efforts, the process dimension of S4S has been considerably expanded from the exemplary model. Four new processes, about 50 base practices, and about 60 new notes have been added to reflect ECSS activities. The process dimension of the S4S model is shown in Figure 2. Processes new to the ISO 15504 model are shaded in light-grey, while processes with base practices added are represented in bold. Processes with notes added are underlined. Figure 2 shows clearly that enhancements have been made throughout the entire process dimension.

Of the four new processes, two extend the exemplary model to cover issues particular to

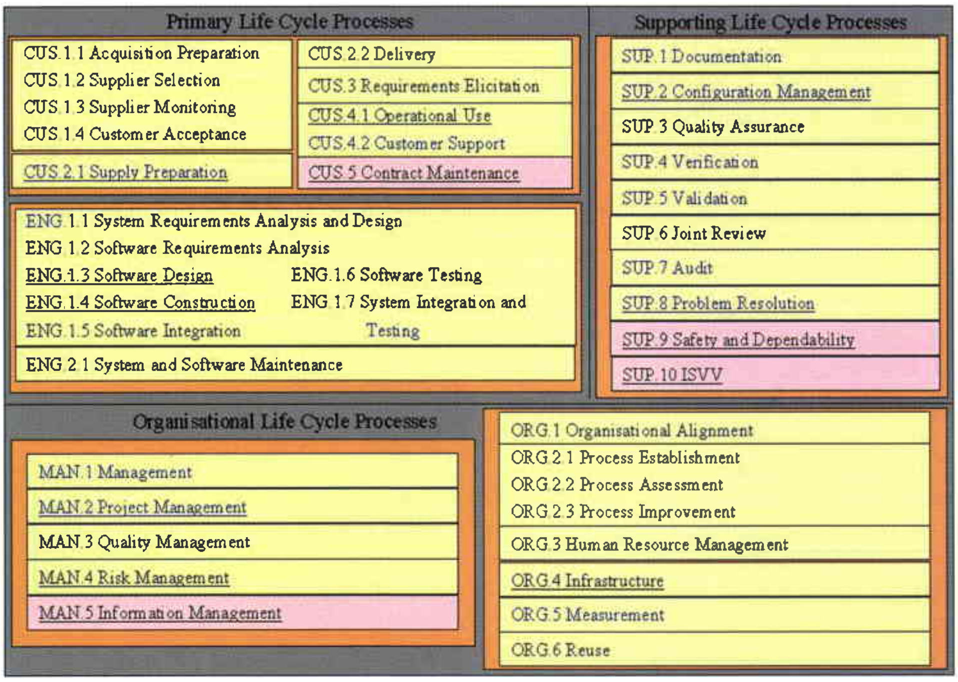

Figure 2. S4S processes and process categories. Processes new to the ISO 15504 exemplary assessment model are shaded in light-grey. Processes with base practices added are represented in bold. Processes with notes added are underlined. Note that CUS.2 from ISO 15504 has been split into two component processes, CUS.2.1 and CUS.2.2

the highly complex and often safety- and mission-critical software produced by the space industry. The new process Independent Software Verification and Validation (ISVV) describes the activities that occur when, for highly critical software, a subset of the standard verification and validation processes is repeated by a third party completely independent from the supplier. The Safety and Dependability Assurance process ensures that the requirements on safety and dependability are defined, that the criticality of each software module is analysed, and that the analyses are updated in accordance with modifications to the software design. Both the ISVV and the Safety and Dependability Assurance processes have been added to the Support category.

Two new processes address general customer and management activities not found in the exemplary model. In the customer category, Contract Maintenance describes the process of maintaining and modifying the contract. Information Management is added to the Management category. This process concerns the installation, maintenance and use of a project information system. Such systems are becoming more common in space projects to facilitate the exchange of project information as teams increase in size and complexity and often work at different locations in different organisations.

Finally, two new component processes stem from splitting the Supply exemplary model process into two processes: Supply Preparation and Delivery. With these two processes, supply activities at the beginning and end of the project life cycle may be assessed separately.

In addition to the new processes, references to and notes explaining the application of ECSS requirements have been added throughout the process model. Inputs and outputs of the S4S processes reflect the ECSS expected outputs. This fusion of ECSS with a comprehensive process framework makes the S4S assessment model a useful guide for companies currently in transition between the PSS-05-0 and ECSS standards.

The assessment process

S4S contains a documented assessment process, which includes a step-by-step breakdown of assessment activities, the definition of key assessment roles, and a description of assessment input and output work products. An S4S assessment is divided into the following seven activities: Initiation, Planning, Briefing, Data Acquisition, Data Validation, Process Rating, and Reporting. In addition to describing the assessment activities, the method offers detailed guidance to assist S4S assessors in each phase of the assessment. For example, experiences from the pilot assessments revealed that during the planning phase, assessors need to clearly understand the customer-supplier contractual relationship and the applicability of standards used in the project to be assessed. Space projects tend to be based on multi-tiered contracts with many levels managed by a prime contractor. Thus, when evaluating space projects, S4S assessors found they had to carefully separate the responsibilities of the project from those of the next-level customer. Expert guidance of this type has been added to the assessment process to incorporate lessons from the space-software perspective into each phase of an S4S assessment.

The S4S method provides three modes of assessment: process improvement, capability determination, and ECSS conformance. The mode selected depends upon the purpose of the assessment. Particular guidance is given for each mode, as the assessment for each is conducted in a different manner. Assessments for the purposes of process improvement focus on identifying areas of improvement or confirming recently implemented improvements in software processes. The results of these assessments are typically for internal use only.

Assessments for the purpose of capability determination may also be motivated by internal initiatives, but are more often the result of customer requirements. Such assessments provide software customers with assurance of the maturity of software suppliers. Assessment results may be used for the selection of suppliers before a project begins, or for monitoring the performance of an on-going project. With this assessment mode, the S4S method provides a valuable tool for space-software purchasers at all levels of the contractual chain to evaluate and monitor their software suppliers.

In ECSS conformance mode, organisations can use an S4S assessment to determine their compliance with ECSS requirements. In these assessments, the same phases of initiation, planning, briefing, data acquisition, data validation and reporting occur as in assessments for process improvement or capability determination. Identical data may be collected for evaluation. The main difference lies in the interpretation of the data and in the rating scheme.

The tools

To facilitate the efficient performance of S4S assessments, a software assessment tool has been developed, which can be used to view the process model during the assessment, to record process ratings, and to produce the assessment report. This tool has been developed using a commercial SPiCE 1-2-1 assessment-tool engine with a database containing the entire S4S process model. The assessors may view all of the elements that define a given process: purpose, outcomes, base practices and input and output work products. Pop-up windows provide work-product characteristics and process-attribute definitions. A dedicated window allows the user to record the ratings of process attributes. The assessor may also record notes describing the objective evidence found to support his or her judgement. Ratings are displayed in easy-to-read charts. Target profiles may be loaded into the tool and compared with actual results. The S4S data file created by the tool serves as part of the assessment record and can easily be re-examined for future analysis.

Charts, assessor notes, and data recorded in the tool may be exported in standard formats to assist in the production of the assessment report. A standard S4S assessment-report template is provided with macros that automatically import assessment data. Additionally, a set of templates is provided with the method, including Pre-Assessment Questionnaires, Assessment Plans, a Statement of Confidentiality, and Assessor Logs. Sample presentation briefing materials are also provided.

Experiences with pilot and trial assessments

Pilot assessments

To validate the S4S method, four pilot assessments were performed in the last quarter of 1999 at Intecs Sistemi in Pisa and Rome, and at Alcatel Space in Cannes. Their primary purpose was to validate S4S and to provide feedback to further refine the method. A second goal was for the assessors to gain experience in performing assessments in the context of space projects. A third and final goal was to provide potential improvement suggestions to the assessed organisations.

Nine different assessors from ESA, SYNSPACE, and InterSPICE participated in the pilot assessments. The assessment team leaders guided the team in a step-by-step 'walk through' of the method. Feedback was collected from assessors and participants in the form of problem reports. A total of 210 such reports were generated, resulting in a revision of the method to its current version.

Trial assessments

In February 2000, a programme of trial assessments sponsored by ESA to promote the S4S method began. It assessed seven space-software suppliers, in Austria, Belgium, Denmark, Germany, Italy, Sweden and the United Kingdom. A final trial assessment in Belgium is planned for July 2001. The organisations assessed represent space contractors at all levels: prime contractors, equipment/software system suppliers and software companies.

All of these trial assessments were performed with the sole purpose of providing benefits to the host organisations. Indeed, the scope of the assessment, including the choice of processes or projects to assess, was determined by the host. The assessment results, including a measured baseline of process capability and suggested improvement opportunities, remain the property of the host organisations. For their part, the latter agreed to provide feedback concerning their experiences with the S4S assessment, including any suggestions for improvement to the method itself. In addition, they agreed to initiate an improvement programme based on the assessment results and to provide feedback about the efficacy of this programme six to twelve months after the performance of the assessment. Some external support for planning and implementing improvements was also allocated by ESA as part of the trial-assessment programme.

Assessment planning and performance

Initial planning of the S4S assessments began on average one to two months before the on-site phase. For each trial, two external assessors (from ESA, SYNSPACE or InterSPICE) were provided to plan and conduct the S4S assessment at the host organisation. In several cases, staff from the host organisation also played a role on the Assessment Team, either as assessors or as observers. In general, the assessment teams consisted of two to three people. Whenever possible, assessment planning was expedited through pre-assessment visits by the external assessors, who also provided guidance in selecting the projects and processes to be assessed, with the constraint that the on-site phase should last no longer than one week.

At the beginning of the on-site phase, the assessment team delivered a briefing to the host participants to familiarise them with the S4S model and method. During the rest of the week, the team collected objective evidence of process performance and capability through interviews with project staff and by examining project documents. Evidence was recorded in the assessment record and compiled with the assistance of the S4S software tool. Based on the objective evidence found, the team rated the processes through discussion and consensus. At the end of the on-site phase, the preliminary results were presented to the host organisation to allow for feedback. After the assessment, the team delivered a final report on the results to the host organisation.

Assessment results

Prior to the performance of S4S assessments, confidentiality agreements were made between the assessment teams and the host organisations (hence no company or project names are mentioned and no specific assessment results are presented here). Within the one-week on-site period of an assessment, 10 to 16 processes were assessed for between one and three software projects. On average, approximately 14 process instances were assessed (where one process instance equals one process assessed on one project). In the fourteen projects assessed, on-board and ground-segment projects were equally represented. The projects reflected the five software criticality classes A through E as defined in ECSS–M–00A, with an approximate distribution as follows:

Criticality class	*Percentage of projects assessed*
A	15%
B	15%
C	27.5%
D	27.5%
E	15%

Figure 3. Typical capability levels observed in the S4S trial assessments

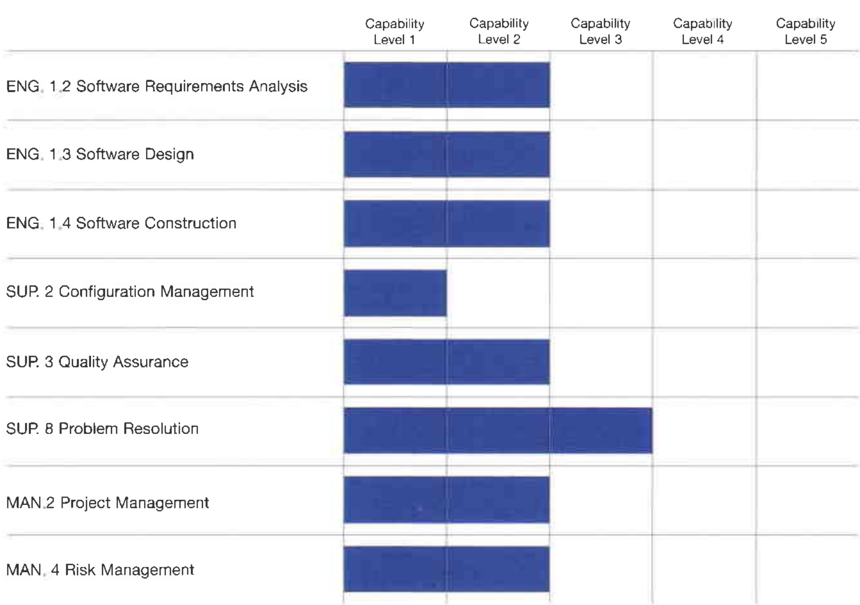

Figure 3 shows the typical capability levels measured for software, on a scale of 0 ('Incomplete') to 5 ('Optimising'). The processes selected for display here are among those most commonly chosen for assessment by the host organisations. For key engineering, support and management processes, typical capability levels of 2 ('Managed') are observed. The Problem Resolution process is often observed at Level-3 ('Established').

Post-assessment improvements

Subsequent to the S4S assessments, improvement efforts based on assessment results have been undertaken at four of the five host organisations. They have already reported initial benefits from the assessment findings, implementing several 'quick fix' improvement suggestions made by assessors with little effort. In several cases, dedicated software process improvement programmes have been initiated; in other cases, improvement actions have been integrated into existing programmes.

For most trial assessments, external support for improvement efforts has also been provided to the host. S4S assessors have supported assessed software suppliers by leading improvement workshops. In these brainstorming sessions, improvement suggestions are discussed, prioritised and grouped. Assessors have also provided support through reviewing improvement plans. Several S4S assessors are currently working with host organisations to determine how to best implement specific improvement suggestions resulting from the S4S assessment.

Feedback from the host organisations about the assessment results has been overwhelmingly positive. Managers found that there was *"significant value"* in having *"shortcomings independently identified and objectively recorded"*, and viewed the S4S method as *"a very professional way of performing an assessment and receiving useful results within one week."* In addition to the process capability ratings, some felt that the set of recommendations was the most valuable outcome of the assessment. The cost in terms of workload on the assessed projects was considered 'acceptable' for the benefits gained.

Fulfilling a secondary goal of the programme, the trial assessments have gathered feedback on the S4S method from the host organisations and the assessment teams. These improvement suggestions will be incorporated into future versions of S4S for further refinement of the method.

Owing to the resounding success of the trial programme, a frame contract has been established by ESA to perform more S4S assessments over the next three years. They will focus on the capability-determination assessment mode. The first S4S capability-determination assessment was performed in May 2001 in Spain under this contract. Further assessments are planned, with the next one expected to take place in Portugal.

Process improvement with S4S

As mentioned above, an ESA method of Software Process Improvement (SPI) has been developed for the European space industry. Uniting the continuous improvement cycle of ISO 15504 with SPiCE for SPACE, this approach to SPI provides European software suppliers with the framework necessary for successful process improvement.

The method is based on the eight-step improvement cycle of ISO 15504, Part Seven, with additional guidance incorporated to help space-software suppliers put process improvement into practice. The eight-step model is shown in Figure 4. In the first steps, an SPI programme for the software organisation is established in which target profiles of process capability are defined based on business goals. Periodic software process assessments using the SPiCE for SPACE (S4S) method are performed to provide baselines of the organisation's current process capability. Detailed analysis of the assessment results leads directly to the identification of corrective actions to be performed in the following improvement cycle. These actions are grouped into separate improvement projects, co-ordinated within the overall improvement programme. To confirm that improvements are realised, process metrics are collected throughout the improvement cycle. These steps are described below in more detail.

Examine organisation's needs

In launching a programme of process improvement, a critical first step is the identification of the organisation's needs and business goals. Guided interviews with local management (business, marketing, technical, and quality) may be organised to understand which business drivers (typically quality, cost, schedule or product issues) are of the highest priority. A high correlation has been found between lasting programmes and business-management involvement (and understanding) from the beginning.

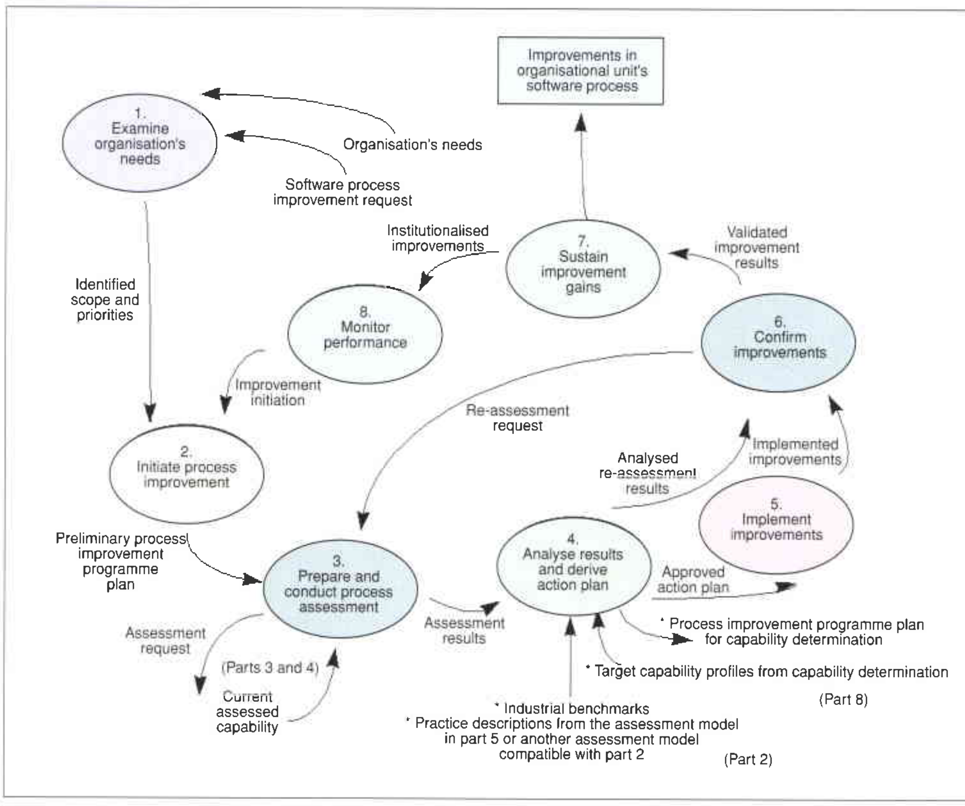

Figure 4. Software process improvement cycle from ISO/IEC TR 15504-7

Based on an analysis of these needs and goals, processes in the SPiCE for SPACE process model are selected for improvement and target capability levels are defined for these key processes. Preliminary target profiles for software criticality classes A to D, following ECSS definitions, are provided in the S4S method and are recommended input. These target profiles will be refined on the basis of benchmarking of the results of assessments performed.

Initiate process improvement
In order to succeed, improvement projects must be managed like any other within the organisation. An overall SPI plan is developed identifying the various phases of the improvement programme and defining goals for each phase. In the subsequent steps, process-improvement projects are initiated based on assessment results and are described in action plans. The overall co-ordination of these individual projects is described in the process-improvement programme plan.

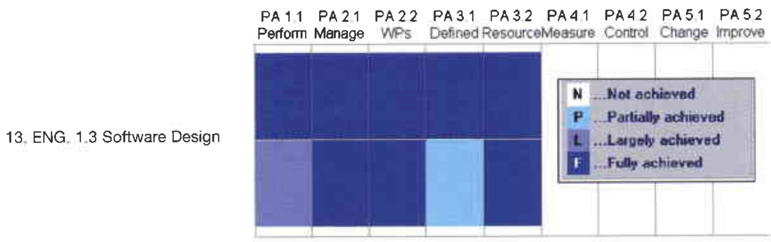

Figure 5. Example of target (top) and measured (bottom) profiles from a S4S assessment

Typically, the duration of one iteration of the process-improvement cycle is defined by the time between two assessments. Since the delta-assessment should demonstrate a measurable increase in capability levels, this period should not be less than 9 months. At each of the milestone reviews, the results achieved are evaluated against the business goals of the organisation.

Prepare and conduct process assessment
In this step, the S4S method is used to conduct an ISO 15504 conformant assessment for the purpose of process improvement. Outcomes of the S4S assessment include a baseline of the organisation's current process capability. In addition, the Assessment Team compiles a list of general observations, perceived strengths, and potential improvement suggestions for the assessed projects and organisational unit as a whole. The scope of the assessment is chosen so as to cover all processes selected for improvement, and each process is assessed at least up to its desired capability level in the target profile.

In assessments for process improvement (as opposed to those for capability determination or ECSS compliance), the assessment record may be more detailed. As in all assessments, the record contains a justification of the ratings, but here detailed records are included, noting incomplete or unachieved process indicators (base practices, work products or management practices). In particular, anytime the Assessment Team rates a process attribute as less than 'Fully' achieved on any given process, the unachieved process indicators leading to the reduced rating are recorded.

In addition, for unachieved or incomplete indicators, the assessment team records at which level (or levels) in the organisation improvements are needed (e.g. project level, organisational unit, business unit, etc). Certain base practices or management practices in the S4S assessment model are applicable both to specific project environments and to the organisation as a whole.

Figure 5 shows an example, to illustrate the method in practice. It consists of sample assessment results for a project where the process ENG.1.3 Software Design has been assessed up to capability level 3. Five process attributes (indicated on the x-axis) representing capability levels 1 through 3 have been rated for this process. Coloured squares denote ratings for each process attribute (Not, Partially, Largely or Fully achieved). These ratings form a process profile. The top profile represents the target profile (as determined by the organisation before the assessment), and the bottom profile represents the measured profile.

Analyse assessment results and derive action plans
In this step, the results of the S4S assessment are analysed in detail to derive a list of actions for process improvement. This step may be accomplished through workshops held with process performers and other improvement team members post-assessment. After the assessment results are complete, the gap between the target and the measured capability profile is analysed for unachieved or incomplete process indicators. From these unachieved indicators of process performance and capability, a list of corrective actions can be directly derived. This novel step of tracing all corrective actions back to the assessment results keeps the S4S improvement programme on track, ensuring that the knowledge gained in the assessment drives the next round of improvements.

Once the list of corrective actions is complete, an analysis is performed to determine the root cause of the problems identified. In some cases, it may be that the organisational unit was simply not aware that they had to perform certain activities. However, in most cases, an underlying problem prevents the project or organisational unit from fully achieving the indicator(s), although project staff may be aware that this is undesirable. In these cases, it is more important to analyse the assessment data to determine the root cause of the indicators' absence. From this analysis, meaningful corrective actions may be derived. Note that at this stage corrective actions are generic in nature and indicate what should be done, rather than how it should be accomplished. For each corrective action, there are typically many ways in which it could be implemented. These details are defined in subsequent phases.

Once the corrective actions have been identified, the next step is to group them together based on relationships and inter-dependencies between them. At this point it is essential to gain a more concrete commitment from management concerning the resources that it is willing to consider allocating, and the time frame in which expected improvements are to occur. This knowledge is needed to prioritise the actions and focus the action planning in the following steps. Next, the action groups are validated and prioritised and a strategy is determined for their implementation. For this, the method advises holding work-shops with larger groups of staff within the organisation. Involving process performers at this stage ensures the selection of the most relevant improvements and facilitates their ultimate buy-in within the organisation. Current efforts to incorporate process risk into the S4S assessment method will enable a risk-based prioritisation of corrective actions in a future version of the method (see below). The actions can also be prioritised to reflect the organisation's business goals.

Improvement projects should be classified as short-, medium-, and long-term. Typically, short-term improvements take less than one man-month to implement, medium-term ones take one to three man-months, and long-term ones require more than three man-months. The timeframe for implementing the selected improvement projects can be estimated based on the resources management is willing to allocate for implementation, and dependencies on other initiatives within the organisation.

Confirm improvements, sustain gains, and monitor performance

The method strongly recommends trying out specific improvements with a pilot project, before applying the improvement actions to the organisation as a whole. Process metrics are a key part of the improvement initiative, providing data to confirm gains and monitor performance. A review of process metrication schemes is provided in the method to help software suppliers develop their own customised measurement programmes.

Adding risk analysis to S4S

The S4S method is currently being enhanced by adding process risk as a third dimension to the model. The new version, called SPiCE for SPACE-Risk (S4S-R), will enable software suppliers to target those processes that lead to the highest unacceptable risks, and to make the most effective use of limited improvement resources.

The current S4S assessment method identifies strengths and weaknesses in software organisations and projects. Risks arising from inappropriate process performance or process management are not directly addressed by the method. However, the approach defined in Part Eight of ISO 15504 provides a consistent framework to address such risks. This approach infers process-oriented risks from the existence of process attribute gaps between target capability and assessed capability. The wider the gap, the higher the probability of the related risk. As to the risk's impact, it depends upon the capability level at which the gap occurs.

This approach sets the basis for integrating process-oriented risk analysis into the S4S method where, along with the process and capability dimensions, risk can be considered as a new third dimension. Within the S4S-R framework, a risk analysis is executed post-assessment to help software suppliers select the necessary and minimum improvement actions that meet the organisation's constraints (resources, finance) and goals. As such, the risk analysis provides a powerful tool to help define a programme of software process improvement.

The S4S-R tool is expected to provide a new view on process-assessment results, which will:
- highlight the most significant software process risks, and
- focus process-improvement activities on the key problems of the organisation.

The extended tool may also be used to generate effective process improvement actions that reduce the magnitude of the most significant risks.

Conclusion

Founded on international and European standards and supported within a framework of process improvement and process risk analysis, the S4S assessment method is the cornerstone of an emerging initiative of process improvement across the European space industry.

The work reported has been conducted under an ESA/ESTEC Contract. esa

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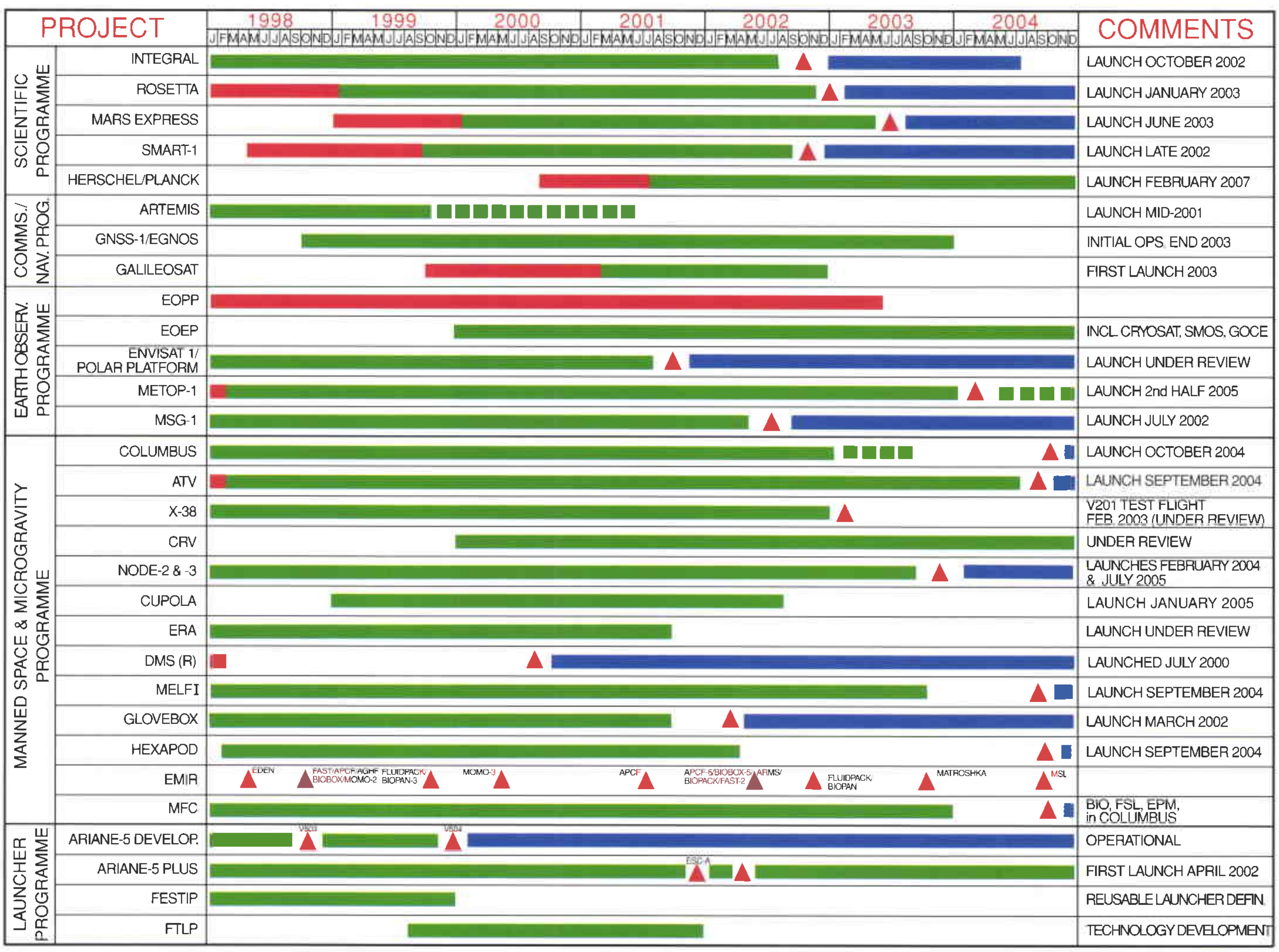
Under Development



DEFINITION PHASE — MAIN DEVELOPMENT PHASE — LAUNCH/READY FOR LAUNCH

OPERATIONS — ADDITIONAL LIFE POSSIBLE — RETRIEVAL — STORAGE

XMM-Newton

The XMM-Newton observatory is now routinely producing and distributing data and first-level analysis products for over 75% of all XMM-Newton observations. The remaining 25% will be dealt with through dedicated re-processing and/or patches to the processing software.

The inclusion of a third operational antenna in the XMM-Newton ground segment (in Santiago, Chile) has now been finalised, and this antenna is routinely being used for communicating with the observatory around apogee, a sector of the orbit previously inaccessible using the Perth and Kourou antennas. The efficiency of the observatory has been increased by approximately 10% because of the use of the Santiago antenna, and the observing efficiency now frequently reaches the theoretical maximum of 70%.

The second call for observing proposals will be issued around 1 September, and the targets relating to these proposals will start to be observed in June/July 2002; assuming that mission operations are extended beyond their current March 2002 end-date.

At the end of April, XMM-Newton observed a galaxy known as M81, which is a so-called 'LINER' (Low-Ionisation Nuclear Emission Line Regions) galaxy. It contains a lot of bright young stars, and is situated some 12 million light-years away from Earth. It is one of the most luminous galaxies in the Northern Hemisphere, and probably forms a pair with its next-door neighbour M82. These two galaxies may have had a close encounter some ten million years ago. One of XMM-Newton's unique features is that it has a sensitive optical/UV telescope amongst its instrumentation, and for this particular galaxy this allowed a unique false-colour UV image to be made (see accompanying figure).

Regular updates on the most striking results obtained by the XMM-Newton observatory can be found at:

http://sci.esa.int/xmm.

This ultraviolet image of M81 was obtained by the Optical Monitor (OM) on XMM-Newton in April 2001. The image is formed from three 1000 second exposures taken with different ultraviolet filters, centred on approximately 2000, 2300 and 2800 angstroms, respectively. It covers a region one quarter of a degree square and frames the M81 galaxy, which is at least 22 000 light-years across. The group studying M81 with the OM is led by Alice Breeveld of Mullard Space Science Laboratory (MSSL), University College London, UK

Integral

The Spectrometer (SPI) has been successfully integrated with the spacecraft at Alenia Spazio's facilities in Turin (I). The Optical Monitoring Camera (OMC) has been integrated on the spacecraft since last October.

The spacecraft has successfully passed the System Validation Test (SVT D) and System Functional Test (SFT) and is now ready to be packed and shipped to ESTEC in Noordwijk (NL) for the environmental test campaign.

The instrument teams for the imager (IBIS) and X-ray monitor (JEM-X) have taken steps to overcome their difficulties in the development of their flight models, committing themselves to deliver the flight models to ESTEC by November this year. Because of this delay, the structural models of these instruments will replace the flight models during the first part of the spacecraft environmental test campaign. The new spacecraft testing and launch-preparation schedule allows launch in October 2002.

The ground-segment activities are progressing satisfactorily, with the latest satellite SVT confirming a high degree of readiness. The remaining ground-segment development tasks have been rescheduled to take into account the delayed instrument flight-model deliveries and the resulting delay in the start of the mission's operational phase.

The launcher Mission Critical Design Review (MCDR) has been successfully completed. A concise data package was submitted allowing a systematic review, the main objective of which was to verify the adaptation of the Proton rocket and Baikonur launch facilities to the specific requirements of Integral.

The mission's Time Allocation Committee (TAC) has made major progress in the guest-observer selection process. The task is a challenging one because the observation time requested in the proposals received far exceeds that available to the guest observers.

Rosetta

The first phase of electrical-qualification-model testing has been completed, with successful integrated system tests on all subsystems and payload units and an electromagnetic-cleanliness (EMC) test. The second phase will test software functions, including reference tests and autonomy.

The flight model is undergoing electrical functional testing and the first two flight instruments have been delivered. The major concern is still the schedule delay caused by late delivery of units and the flight software. The transponder is still the most critical unit, which has not yet completed its full qualification programme.

The mission Critical Design Review process was successfully completed in May. Various technical issues were highlighted and close-out actions agreed. The status of these will be reported in August to the Review Board, which has also emphasised the criticality of this schedule-driven programme.

The experimenter teams are in the process of finalising the testing of the payload and lander flight models, which will be delivered to the spacecraft integration site before the end of September. Various problems have been identified during the final environmental and functional test programmes, which need to be corrected before delivery. The calibration of the large imaging instruments (OSIRIS and VIRTIS) is still critical and the dust analyser (COSIMA) is having difficulties in meeting its specified performance.

The preparation of the ground segment is going according to plan, including the assembly of the New Norcia antenna. Detailed interfaces with the Rosetta Science Operation Centre (RSOC) have been defined and the RSOC work plan agreed by all parties.
The contract with Arianespace for the provision of the launch vehicle and associated services has been signed, and agreement has been reached on all technical interfaces and details of the launch campaign.

The start of Integral Spectrometer (SPI) flight-model integration to the spacecraft at Alenia Spazio's facilities in Turin (I)

Mars Express

The mating of the flight structure and the flight propulsion system continues at Astrium Stevenage, UK. All indications are that the delivery of the combined model from Stevenage to Alenia Spazio, planned for late July, will take place on time.

The project work was dominated by major activities related to the Critical Design Review (CDR). The latter activity includes reviews of the scientific payload, the ground segment, the launcher interface and the spacecraft. The instrument reviews were completed in early May. The status of all spacecraft subsystems was reviewed through subsystem design reviews for new elements, and so-called 'equipment suitability reviews' for units in common with Rosetta. The prime contractors submitted a very comprehensive data package on all aspects of the missions and the outcome of the lower-level reviews. This data package was presented to the Science and Engineering Review Team (SERT) and the Mars Express Project Team in late May. It was scrutinised in great detail during a week-long meeting at Astrium SAS by about 60 experts. The group included the review team, representatives of the major industrial contractors and the launcher authority (Starsem), and an independent scientist representing the teams of the Mars Express Principal Investigators (PIs). The findings of the review team and the report of the SERT Chairman will be presented to the Review Board at its meeting on 6 July.

Concerning the Soyuz launcher, the first issue of the tri-party Interface Control Document (ICD) between Starsem, the spacecraft prime contractor, Astrium SAS, and ESA was agreed and signed off. Two milestones towards improved launcher performance have been achieved, namely the first successful launch of the Soyuz FG launch vehicle with modified engines, and the confirmation of the optimised drop zones for the Mars Express fairing.

The Mars Express project visited the Starsem assembly facilities in Baikonur and the Soyuz launcher production plant in Samara. Representatives from the Prime Contractor and the AIV (Assembly, Integration and Verification) contractor (Alenia Spazio) participated in this visit. The visit was very successful in the sense that all participants were impressed by the quality of the infrastructure at Baikonur.

SMART-1

Spacecraft

The development work is proceeding and the second phase of electrical system testing has been almost completed at the Swedish Space Corporation's (SSC) premises in Solna near Stockholm. This test involves the payload electrical models and most of the spacecraft equipment, including the electric propulsion. Development of the on-board software is proceeding at Spacebel (B) for the data-handling part and at SSC for the application cores. The Structural Test Model (STM) structure and mass dummies, together with some proto-flight units, have been integrated by SES (Saab Ericsson Space) in Linköping (S) and sent to ESTEC in Noordwijk (NL) for structural tests. All mechanical tests (mass properties, acoustic, sine and shock) have been successfully completed. The Critical Design Review has been kicked off on 29 June, according to schedule. The Flight Acceptance Review is currently planned to be held in October 2002, in time for an envisaged launch opportunity at the end of the year.

Payload

The development of all six payload instruments is generally proceeding according to schedule. Most of the electrical-model tests have been completed, with only two payloads (SPEDE and KaTE) still to complete them. The Critical Design Reviews have also been successfully held for four (D-CIXS, EPDP, SIR, AMIE) out of six instruments during May and June.

Electric propulsion

The procurement of the Electric Propulsion System (EPS) by ESA for delivery to SSC as customer-furnished equipment is proceeding. The qualification of the new engine (PPS-1350G) has been completed, while the lifetime test will run until the third quarter of 2002. The Power Processing Unit (PPU) flight model has been manufactured by ETCA (B). The Pressure Regulation Electronics (PRE), a new development specifically for SMART-1, has been tested with the SMART-1 system unit at SSC.

Operations

The ground-segment preparations are proceeding according to plan. The interfaces between the Mission Operations Centre, the Science and Technology Operations Coordination and the PI/TI have been defined.

Launcher

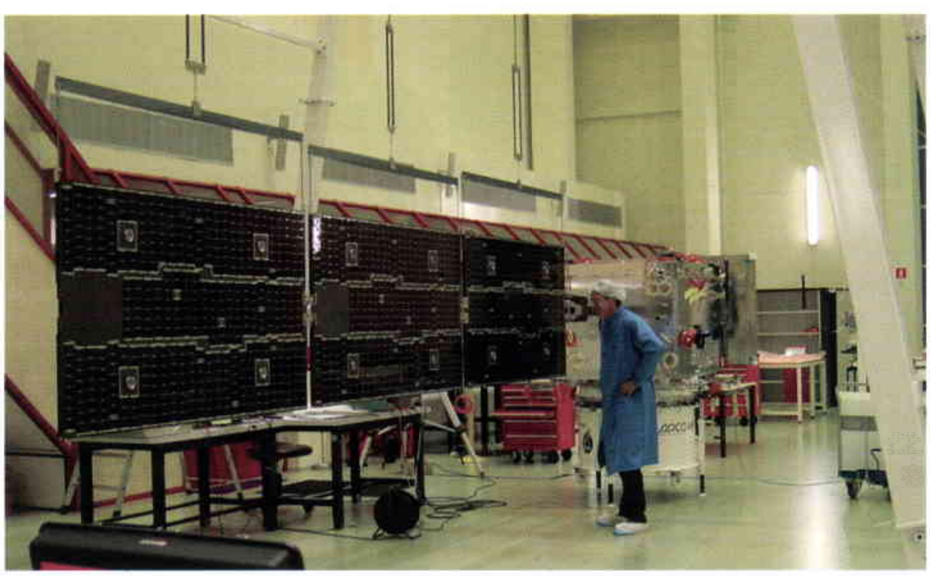
All activities are proceeding on schedule. Refinements to the interface-control dossier have been agreed with Arianespace. The Safety Data Package has been commented upon by Arianespace. The vibro-acoustic qualification of the spacecraft has been partly witnessed and agreed by Arianespace personnel. Launch is expected to take place in December 2002, depending on the main passenger.

Herschel/Planck

On 14 March, ESA's Industrial Policy Committee (IPC) approved the selection of Alcatel Space Industries (Cannes, F) as Prime Contractor for Herschel/Planck's development. The industrial core team starting up the preliminary design phase consists of Alcatel Space Industries (France), Astrium GmbH (Germany) and Alenia Spazio (Italy). Alcatel is the Prime Contractor and is also responsible for the Planck Payload Module and spacecraft testing. Astrium is responsible for the development of the Herschel extended Payload Module (Cryostat) and the Herschel spacecraft testing, while Alenia is responsible for the development of the Service Modules (spacecraft bus) for both Herschel and Planck. Following a clarification meeting with industry in the last week of March, the activities were formally started in early April, two months earlier than originally expected.

The main activities in the near term are the completion of system trade-offs and a consolidation of the baseline design concept. The major upcoming development milestone is the System Requirements Review, being conducted

The SMART-1 Structural Test Model (STM) with flight wing deployed in the HYDRA integration room at ESTEC (NL)



throughout the summer period and due to be completed by October. A further major activity is the preparation and release of the first Invitations to Tender (ITTs) for the Herschel and Planck subsystems and units. These procurement activities will produce a set of more than 100 tenders over the next year, and will end with completion of the build-up of the Herschel/Planck industrial team by mid-2002.

At the end of March, NASA informed ESA that the funding for its planned contribution of the Herschel telescope could not be obtained. Following this announcement, ESA had to initiate the procurement of the telescope itself. The Request for Quotation was released to Astrium SAS (France) upon authorisation by the IPC. The proposal has been received and is currently being evaluated. The start of the activities with Astrium SAS for the development of the 3.5 m diameter silicon-carbide Herschel telescope is planned for this summer.

The Invitation to Tender for the Planck telescope reflectors, a contribution by the Danish Space Research Institute to Herschel/Planck, was released earlier this year and the responding proposals have been received and evaluated. The next activities planned by the Danish partner are the approval of the available funding and project kick-off with the selected contractor.

Installation of the Proba ground station at Redu, in Belgium

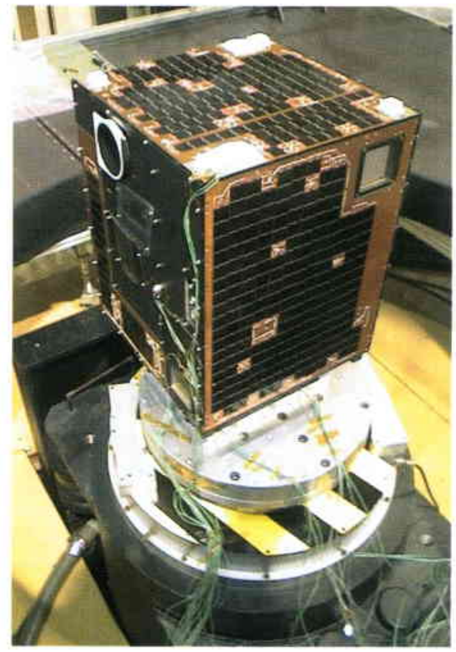
The development of the three Herschel instruments and the two Planck instruments is proceeding according to plan. The second formal ESA review cycle with all five Herschel and Planck instruments was performed in the spring. Some major issues raised by the review boards are being followed up, for close-out by the autumn. The transfer of the day-to-day management of the instrument interfaces from ESA to industry has started, and industry has organised a set of technical working sessions with all instrument groups.

The co-ordinated parts procurement, initiated to support the scientific-instrument development, is progressing nominally. The activities to hand over the contract to the Prime Contractor have started.

Following a tender exercise, the development of a facility to allow vibration testing of the Herschel instrument's focal-plane units at cryogenic temperatures was started with CSL (Belgium) in May. The facility will be ready for testing of the instrument units by end-2002.

Proba

The test campaign with the spacecraft at Intespace has been completed. The team is now completing the operations, software-validation and end-to-end testing (System Validation Testing) for 1 September, the date when the spacecraft will be shipped to India (Antrix) for its launch on 25 September. The Project Flight Acceptance Review has been concluded and the Review Board's recommendations are now being implemented. The final milestone before shipment will occur when the completeness of the validation is reviewed and a launch decision taken. The Proba ground station has been installed at ESA's Redu (B) facility and is currently undergoing final testing.



Proba at Intespace in Toulouse (F)

Earth Observation Envelope Programme (EOEP)

The Agency's Programme Board for Earth Observation (PB-EO) has given its authorisation to proceed with full implementation of the CryoSat project. On 27 June, the ESA Industrial Policy Committee (IPC) approved the proposal to place a contract with Astrium GmbH for Phase-C/D/E1 of the space segment.

After the completion of Phase-B, the Prime Contractor has concentrated on the consolidation of the design of the CryoSat satellite, taking into account the recommendations made by the System Design Review Board. In particular, the specifications for the power subsystem have been significantly improved. The procurement of long-lead Items and, more generally, preparatory activities for the Phase-C/D have been initiated in areas that were recognised as schedule-critical.

Phase-B of the GOCE space segment has reached its mid-point. The status of the consolidation activities carried out by Alenia Spazio and the other core-team members was assessed during a Preliminary Baseline Meeting, which took place in mid-June. There it was concluded that good progress has been achieved in the main trade-off analysis and in the requirements consolidation, but that additional efforts are still needed to improve the mass and power budgets. The competitive selection process for the various equipment suppliers is in progress. Presently, two possible satellite configurations are being maintained in parallel, based on two different micro-propulsion technologies: cold gas and Field Emission Electric Propulsion (FEEP). This selection is critical in order to freeze the overall satellite configuration and to consolidate the related budgets.

The PB-EO also adopted the Declaration covering the Second EOEP Phase, to be submitted to the next ESA Council at Ministerial Level in November.

In June, the ESA Council approved the resolution enabling the start of the Earth Watch Programme. The first five elements of this Programme are also due to be submitted to the Ministerial Council in November. Potential Participant meetings will take place during the summer to prepare the relevant Declaration and Implementing Rules to be submitted to the Ministers.

The PB-EO also approved the start of the Phase-A studies relating to the Ocean Earth Watch element, to be carried out in coordination with Eumetsat.

The IPC approved the procurement proposal for the pre-development of the L-band SAR.

The two parallel design studies for the spaceborne ALADIN instrument, led by Alcatel Space Industries and Astrium SAS, were completed in April. Both teams have generated designs and concepts for the pre-development model. The proposals for the second phase of the pre-development programme are being evaluated. The contractor competitively selected for this second phase, which involves the manufacture and testing of a pre-development model of the instrument, will also become the instrument subcontractor for Phase B of the project.

In the Market Development area, four proposals have been selected for longer-term contracts.

Earth Observation Preparatory Programme (EOPP)

Step 2 of the implementation mechanism for the second cycle of Earth Explorer Core Missions (mission assessments) is in progress. A mid-term review of the industrial pre-Phase-A studies of the five missions under consideration – ACE, EarthCARE, SPECTRA, WALES and WATS – took place in June.

Work on the preparation of the Third Earth Explorer Consultation Meeting, which will take place in Granada (Spain) in October, is progressing apace. The ESA Reports for Mission Assessment will be completed this summer for submission to the Meeting. Some candidate missions currently show considerable complexity and will require notable effort to make them fit within the programmatic constraints.

The Joint Euro-Japanese Science Preparatory Groups and Engineering Teams met in Japan in June, and satisfactory results were achieved within the framework of the EarthCARE mission.

The successful mid-term review for SMOS took place in April, and the development plan leading to full SMOS implementation has been agreed.

The Call for Proposals for the second cycle of Earth Explorer Opportunity Missions was released in June.

Envisat

System

The system activities have been focused on:
- reviewing and validating the Flight Operations Procedures (FOP), with simulations at ESOC
- progressing the Ground Segment Overall Validation (GSOV) tests
- finalising the early in-orbit operations, in particular the payload switch-on phase
- performing the on-site installation and integration of the software tools for instrument engineering calibration and for generating and maintaining the mission reference operation plan.

Launch campaign

The launch campaign, which started with the arrival of the satellite in Kourou (French Guiana) on 15 May, has progressed well in the new payload-preparation facilities (S5), which came on stream at exactly the right moment for Envisat. The first part of the campaign has run very smoothly and is nearing completion, on schedule. The complete satellite (except for flight batteries and solar array) has been integrated and satellite integrity verified, including a combined functional test of the total spacecraft and a mini Satellite Verification Test (SVT4) conducted from ESOC.

The campaign in Kourou will be put on hold from mid-July until mid-August, and will resume with flight-battery and solar-array integration prior to satellite fuelling and mounting onto the launcher. The holding phase has been implemented to cope with the launch delay imposed by Arianespace. Launches towards the north, as required by the Envisat Sun-Synchronous Orbit (SSO), cannot be performed from June until end-September for population-safety reasons due to the prevailing easterly winds. The launch is therefore planned for the first half of October.

Arianespace has confirmed the satellite's qualification for an Ariane-5 launch, but is still working to finalise specific qualification of the launcher for Envisat's SSO.

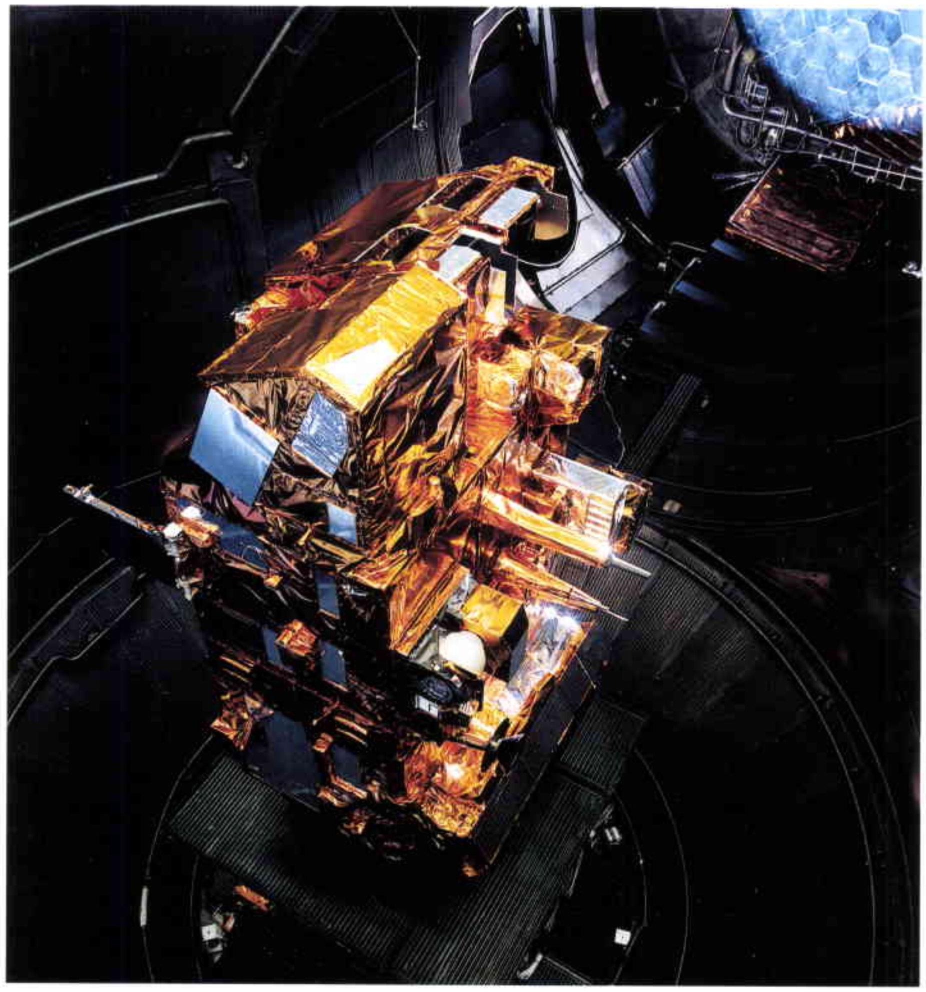
Ground segment

The Flight Operations Segment (FOS) activities have been focused on the simulation

Mating of the Envisat Payload and Service Modules at CSG in Kourou, French Guiana campaigns to validate the operational procedures, and on the validation of the mission-planning system.

As far as the Payload Data Segment (PDS) is concerned, an onsite acceptance test of version V3 has been performed. The Payload Data Handling Stations at ESRIN (PDHS-E) and Kiruna (PDHS-K) and the Payload Data Control Centre (PDCC) are being used to finalise the Ground-Segment Overall Validation (GSOV), to conduct operator training, and to implement corrections for the remaining anomalies detected in version V3. These interleaved activities are requiring special attention and the progress/achievements will be reviewed in a delta Ground-Segment Readiness Review planned for end-July.

Several Processing and Archiving Centres (PACs) are ready for integration testing with the ESA PDS. These GSOV tests are to be performed during the summer.



The MetOp engineering-model Payload Module in ESTEC's Large Space Simulator (LSS)

The Calibration and Validation preparation activities are well under control: all groups are finalising their pre-launch activities according to established plans, updated simulated products have been released, and a new rehearsal data-circulation campaign, involving use of the Envisat User Service Facilities, is in progress. For the data dissemination by satellite, tests are ongoing with two transmit stations at Kiruna and ESRIN, and 13 receiving stations already installed at critical sites supporting the Commissioning Phase. A large Workshop, held at ESTEC on 16/18 May, reviewed and confirmed the validation approach for the atmospheric instruments. For the near-real-time products addressing the meteorological user community, a Workshop is being held at ESRIN in Frascati (I) on 5 July. For the projects selected as part of the Announcement of Opportunity for data exploitation (almost 700 projects selected in 1998), the respective Principal Investigators (PIs) are being approached to clarify/update their requirements.

The children's Envisat launch flag drawing competition attracted more than 11 000 entries. The 16 pre-selected winners (one per participating country) were invited to the Le Bourget Airshow on 17 July for the announcement of the overall winner. The winner, a 12 year-old German girl, has been invited to the Envisat launch, and her drawing will be displayed on the Ariane-5 fairing.

As part of the Envisat promotion campaign, a touring exhibition has been organised, starting with major museums in several countries.

MetOp

The last few months have been very busy in the ESTEC test facilities, with the completion of the mechanical testing of the structural-model MetOp satellite in the acoustic, vibration and shock environments, and the thermal-balance and thermal-vacuum testing of the engineering-model Payload Module in the Large Space Simulator (LSS).

The testing has generally been very successful, demonstrating the structural qualification of the satellite for flight on both the Soyuz-ST and Ariane-5 launch vehicles, and proving the thermal design and electrical functioning at the expected payload temperatures. However, some critical questions have emerged, the most notable concerning the ability of the US instrument AVHRR to withstand the vibration levels that it will experience on MetOp. Here a gap in the understanding of the instrument became apparent, and it has proved necessary for the US supplier (NOAA/NASA) to prepare a dedicated instrument-level characterisation test. The results of this test should be available towards the end of the year, and will determine whether modifications to the instrument are required.

Although compatibility with Ariane-5 is retained, the Soyuz-ST launcher is now baselined for the MetOp programme, with full compatibility expected to be achieved by September.

The test campaign at ESTEC continues with the important radio-frequency compatibility testing taking place on the engineering-model Payload Module during the summer. In the meantime, preparations continue for the Satellite System Critical Design Review, scheduled for September.

Eumetsat has been making progress with its development of the EPS Ground Segment, with the Preliminary Design Review now being finalised.

Finally, work continues with industry to restructure the MetOp Programme to cope with the late delivery of Eumetsat-provided, third-party instruments, and to better align the programme with the readiness of the Eumetsat Ground Segment, which allows the first MetOp launch to take place only in the second half of 2005.

Meteosat Second Generation (MSG)

The launch of MSG-1, initially foreseen for October 2000, had to be re-planned for January 2002 due to the delay in readiness of the Eumetsat Ground Segment. This has resulted in storage of the engineering model and first flight model (MSG-1) since mid-January 2001. Meanwhile, Eumetsat has announced a further delay to July 2002, which will be the last opportunity to launch on an Ariane-4 vehicle.

Work in industry is now concentrated on MSG-2 and MSG-3, while ESA is waiting for a 'de-storage' request from Eumetsat in order to prepare MSG- 1 for launch. The need to add a shock-test programme in order to qualify MSG-2, MSG-3 and follow-on models for an Ariane-5 launch is still under investigation, but is becoming more likely.

International Space Station

ISS Overall Assembly Sequence

A successful assembly flight to the ISS took place during the second quarter of 2001. Flight 6A (STS-100) was launched from Kennedy Space Center (KSC) on 19 April. During the mission, an Ultra-High Frequency Antenna and the Space Station Remote Manipulator System arm, Canadarm2, were installed, and several scientific and system racks were transferred from the second MPLM ('Rafaello') flight to the ISS. This flight marked the first visit by a European Astronaut to the ISS, with Umberto Guidoni completing a very successful 13 days in space (see article by U. Guidoni elsewhere in this issue).

NASA has been faced with a stringent request from the new US Administration to eliminate the projected cost overrun for the ISS and intensive efforts are ongoing within NASA, and with the International Partners, to overcome this situation and to protect the Station's overall schedule and configuration.

Columbus laboratory

Functional-module system qualification testing began on the electrical test model in May. A significant milestone has been achieved with the successful completion of the first ESA/NASA bilateral test, in which the data-communications exchanges between Columbus and the rest of the ISS were tested.

Flight-unit mechanical assembly is well underway, following installation of the structure on the integration stand. The subsystem racks and the stand-offs are being pre-integrated outside the module, and internal harness installation is also underway.

Columbus launch barter

Nodes-2 and -3

The Node-2 proof pressure and leakage tests have both been successfully completed, and preparations are underway for the modal-survey test to be performed in August.

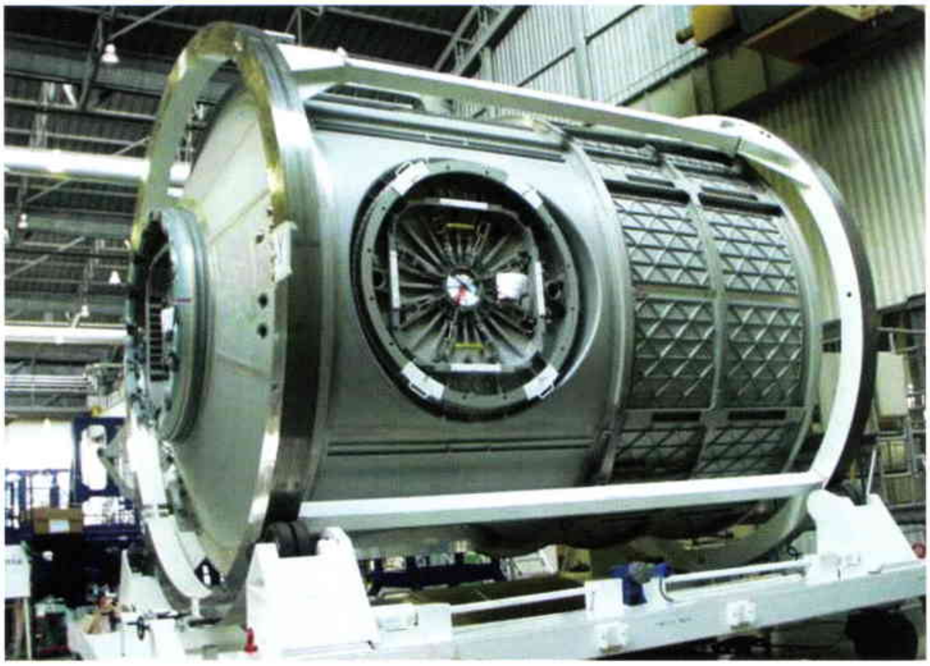
Crew Refrigerator / Freezer (RFR)

The Preliminary Design Review is in progress and the Board is scheduled to meet in late-July.

Cryogenic Freezer (CRYOS)

Two offers for Phase-B/C/D activities were received early in the year and, having obtained clarification on some issues, the Tender Evaluation Board (TEB)

The MSG FM2 Radiometer prior to integration



The Node-2 flight-unit structure

report was completed in June. Currently, Phase-B is foreseen to start no earlier than September this year.

Cupola
The modal-survey test has been successfully completed, with very high fundamental frequencies, demonstrating good de-coupling from the launch support configuration in the Space Shuttle. A second 1-g mock-up campaign has been performed, verifying that the internal ergonomic changes recommended by the crew after the first campaign have been properly incorporated. The thermal-vacuum qualification test on the shutter mechanism and the associated life-cycle tests have been completed.

Automated Transfer Vehicle (ATV)
Following consolidation of the system baseline at the Preliminary Design Review (PDR), detailed design of the vehicle is now progressing well, concentrating for the moment on the functional architecture and avionics-box / system-software development. ESA, NASA and Rosaviakosmos have signed the overall Interface Requirements Document (IRD).

The System Requirements Review (SRR) for the ATV Control Centre has been successfully completed. Assembly of the dynamic model / structural-thermal test article is well advanced, in preparation for the qualification test campaign.

X-38/CRV and Applied Re-entry Technology (ART)
The second V131R drop test was performed on 10 July at Dryden Flight Research Centre in California, following intensive evaluation of the anomalous behaviour observed during the first (November 2000) test. Wind-tunnel and CAD evaluations performed in Europe were an integral part of this investigation.

The V201 vehicle's integration is progressing ahead of the first mechanical test campaigns, which are due to start towards the end of the year.

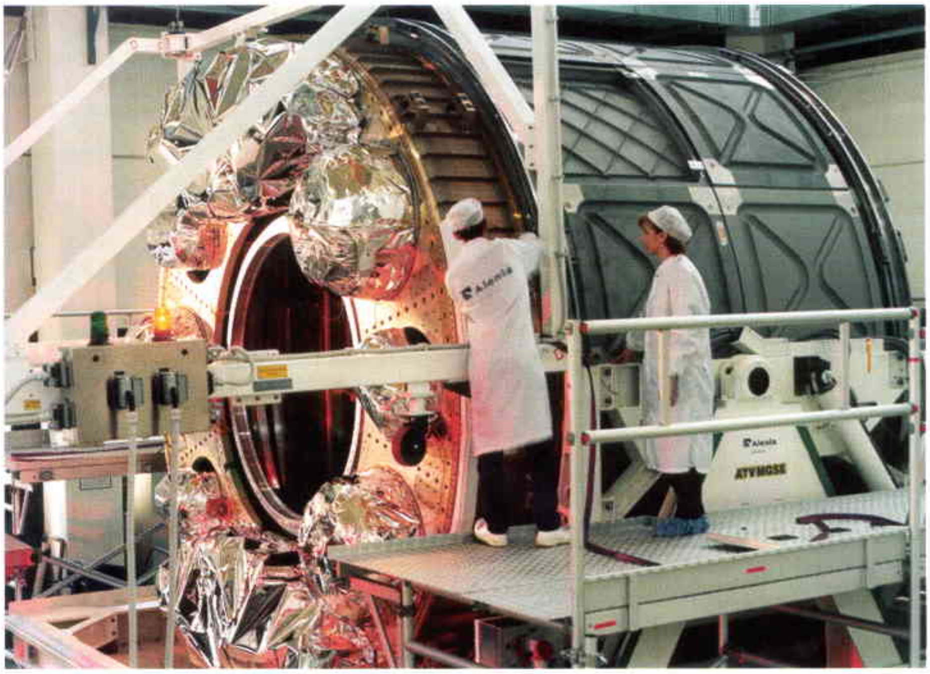
Industry has generated a revised CRV Phase-1 proposal that is a good basis for negotiation, and the first two rounds of discussions have taken place, enabling initial tasks to be released.

Ground-segment development and operations preparation
The Request for Quotation (RFQ) for the Columbus Control Centre has been released. Due to the number of changes brought about by the System Requirements Review (SRR) decisions, a three-month schedule slip has been announced. This starts to become critical especially with respect to the readiness date for the first ATV flight.

The RFQ for the ATV-CC Operations Preparation Definition Phase has been released to CNES, and the RFQ for the equivalent contract with DLR has been prepared for release in July.

Utilisation
Preparation
The Forum 2001 Space Station Utilisation Symposium took place in Berlin on 5 - 7 June, with over 800 participants from the user communities, industry, government ministries and agencies and the commercial world. Although the major emphasis was on utilisation of the Space Station for commercial purposes, its exploitation for fundamental research, education and outreach was also addressed.

The International Forum for the Scientific Uses of the Space Station (IFSUSS), which is a loose federation of the scientific



The ATV structural model nearing completion of integration advisory committees from the Space Station partners, met during the Berlin Symposium. Following discussions on the availability of crew-time on the Space Station, a recommendation to representatives of the US Congress to restore the seven-crew capability, currently not planned by NASA for the early years, was drafted.

Hardware development
The cost issues surrounding the European Drawer Rack (EDR) video management system were settled with industry. Rosaviakosmos/Energia accepted the Global Transmission System (GTS) flight model for launch to the Space Station in August this year.

Studies for the relocation of the external payloads to the Columbus External Payload Facility (EPF) were in progress. The formal start of the SOLAR/EXPORT Phase-C/D took place after its approval by the Agency's Industrial Policy Committee (IPC), meeting on 11 May. The EuTEF Project has concluded its Phase-B extension successfully and was preparing to enter into Phase-C/D.

Astronaut activities
During the STS-100 Shuttle mission from 19 April to 1 May, Umberto Guidoni and his crewmates outfitted ISS with the Canadarm2 and successfully delivered the second Italian-built MPLM module, known as 'Raffaello'. Four ESA astronauts are involved in the first international ISS Advanced Training class, which started on 2 April in Houston. The ESA part of the training will be provided at the European Astronaut Centre (EAC) near Cologne (D) during the second half of 2002.

ESA astronaut Claudie Haigneré has started her crew integrated training for the Andromède mission at Star City. She will fly as Board Engineer n°1 and the Russian cosmonaut K. Kozeiev as Board Engineer n°2.

On 20/21 June, the Multilateral Crew Operations Panel (MCOP) met and finalised a document covering the selection, assignment, training and certification of ISS crew members. The document is now with the Multilateral Control Board (MCB) for approval.

Early deliveries
Data-Management System for the Russian Service Module (DMS-R)
The DMS-R is operating successfully in orbit, with no problems or anomalies reported.

Definition of and negotiations with European industry and the Russians on long-term engineering support for DMS-R are in progress. This needs to be concluded as soon as possible as the current Inter-Agency Arrangement for DMS-R officially expired three months after US-Lab (Destiny) launch, which took place in January.

European Robotic Arm (ERA)
The ERA flight model has completed its structural qualification programme; testing continues on the ERA engineering qualification model. Further tests on the Mission Preparation and Training Equipment (MPTE) showed a marked improvement in its quality, although there are some issues that still need to be resolved.

The ERA Phase-III Safety Review was held with the NASA Safety Review Board, and has been successfully completed.

A delay of several years (to 2005/2006), compared with the official Science Power Platform (SPP) launch date of October 2002, has been confirmed by the Russian Partner, as no funding has been made available for the SPP development programme.

Laboratory Support Equipment (LSE)
ESA confirmed that the Microgravity Science Glovebox (MSG) engineering model would be delivered to NASA in July, and the flight model in August 2001, in line with the need date for the UF-2 flight. Delivery of the MELFI (-80°C Freezer) flight model is planned for December.

ISS Exploitation Programme
The industrial tasks for the Early Activities have been adjusted to cover only the most urgent procurement and definition activities needed to safeguard the exploitation planning schedule. The Exploitation Contract TEB on 11 June agreed that the RFQ for the operations contract could be released as soon as the legal entity issue of the main industrial contractors has been satisfactorily resolved. The RFQ is ready to be released.

During the ISS Forum 2001 in Berlin, the access rules for all Partners and the prices of ESA, NASA and Rosaviakosmos for commercial utilisation of the ISS were published.

The first commercial contract has been signed between ESA and Intospace for an amount of 2 MEuro to be received by ESA for services to be provided to Intospace. Further studies in preparation for Public-Private Partnerships (PPPs) between ESA and private/institutional investors have been conducted.

Microgravity

EMIR programmes
On 11 April, the contract between ESA and Rosaviakosmos for ESA's participation in the Russian M-1 Foton retrievable-capsule flight was signed. The flight will take place in October 2002. The STS-107 Spacehab flight is now scheduled for May 2002. Training of the crew and mission time-line verification has continued for the ARMS respiratory monitoring system at NASA-JSC (Houston) and at the Spacehab Payload Processing Facility (SPPF) at Port Canaveral.

A Maxus-4 long-duration sounding-rocket flight took place on 29 April. All experiment modules worked well, sending back full telemetry of science data.

In the third week of May, an ESA parabolic aircraft flight took place, with fourteen experiments being carried out, three of them student experiments.

Microgravity Facilities for Columbus (MFC)
Testing of the Biolab engineering model was successfully completed in June. Performance figures have been found to meet, and in some cases even exceed, specifications.

The Critical Design Reviews (CDRs) for the Fluid-Science Laboratory (FSL) and the Materials-Science Laboratory (MSL) were successfully completed in April. The FSL system-engineering-model integration was completed in May and system testing was initiated in June. The MSL in US Lab system-engineering-model integration should be completed by end-July.

Phase-A/B for the MSL using Electro-Magnetic Levitation (MSL-EML) technology was initiated in June, in co-operation with DLR (D). esa

In Brief

New Director of Strategy and External Relations Appointed

Jean-Pol Poncelet has been appointed to the post of ESA Director of Strategy and External Relations (D/SER) for a period of four years. He will take up duty on 15 August.

Mr Poncelet, of Belgian nationality, studied engineering and physics at the University of Louvain. On graduating, he worked on a number of science programmes at the same university, moving on to a research position with the Luxembourg University Foundation. He later had an advisory role with the Ministries of Economic Affairs and Scientific Policy, and was advisor to the State Secretary for Environment on matters of nuclear security.

He began his political career in 1991 as a Member of the Belgian House of Representatives and, from 1995 to 1999, was Vice-Prime Minister, Minister of Defence and Minister of Energy. He is currently a Member of the Belgian House of Representatives and President of the Social Christian parliamentary group.

Jean-Pol Poncelet has always been active in the fields of science, technology and education and has, during his political career, been closely involved in space and technology matters. esa

Artemis Recovery Well Under Way

ESA's Artemis satellite successfully reached a circular parking orbit, at an altitude of 31 000 km, on 24 July. The necessary manoeuvres were carried out from the ground control station in Fucino, Italy, by the operations team and system engineers from the Altel (Alenia Spazio-Telespazio) consortium, supported by ESA specialists.

The satellite, launched from Kourou by an Ariane-5 on 12 July, had been put into the wrong orbit due to a failure in the launcher's upper stage. The erroneous injection orbit had a perigee of 590 km, an apogee of 17 487 km and an inclination of 2.94°, compared to the intended values of 858 km, 35 853 km and 2°, respectively. Otherwise, since its injection into orbit, the spacecraft's behaviour has been nominal.

ESA rapidly designed a recovery strategy that will take the satellite to its nominal geostationary operating altitude of about 36 000 km, whilst at the same time maximising the mission's remaining lifetime. This recovery strategy consists of four steps, the first two of which have now been successfully completed. In Step 1 (18 to 20 July), the satellite's apogee boost motor (chemical propulsion) was fired during five perigee passes (i.e. when Artemis was closest to Earth) to increase the orbit's apogee (maximum distance from Earth) to about 31 000 km without significantly changing the perigee. In Step 2 (22 to 24 July), the elliptical orbit was made circular by three consecutive apogee motor burns. The satellite is therefore now in a circular parking orbit at approximately 31 000 km altitude, with an orbit duration of about 20 hours and an inclination of 0.8°. On completion of this step, the solar arrays and two antenna reflectors were fully deployed.

Artemis is now operating in quasi-nominal mode, under the control of the ESA/Alenia Spazio-Telespazio team, pointing at the Earth and with its solar panels tracking the Sun, but not yet in geostationary orbit. In the current Step 3 with the satellite in parking orbit, new control modes for orbit-raising using Artemis' ion engines for propulsion will have to be patched in (by software uploads to the satellite) and commissioned. The ion engines themselves will then be initialised and checked out.

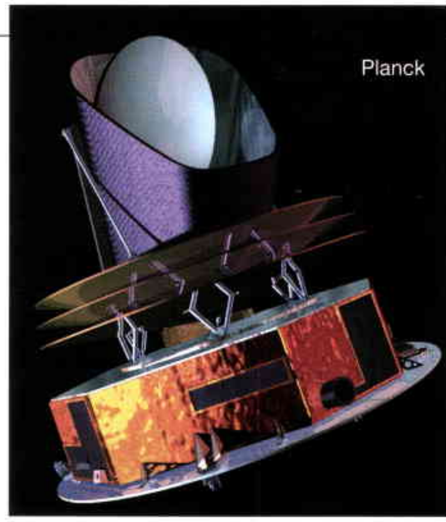
In Step 4, which is expected to start in late-September and last several months, the satellite will be 'spiralled' from its parking to nominal geostationary orbit using its novel electrical ion-propulsion system. The latter was originally included on Artemis to demonstrate this novel technology for maintaining satellites in their geostationary orbits, but it is now being used in earnest to help rescue the mission.

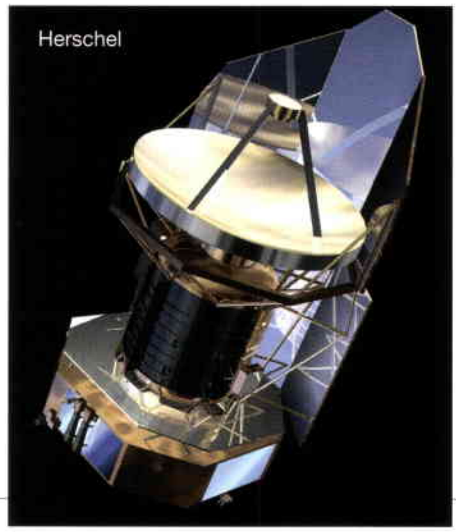
The next progress update will be released with the start of Step 4 operations, in late September. esa

Largest Ever Space Astronomy Contract Goes to Alcatel Space

The largest contract ever in the history of European space astronomy has been awarded to Alcatel Space Industries (France) as Prime Contractor, with Astrium GmbH (Germany) and Alenia Spazio (Italy) as main contractors. Worth a total of 369 million Euros, the contract is for the building of two ESA astronomy satellites, the Herschel Space Observatory and Planck. The companies will design, develop, manufacture, test and launch the two satellites, and commission them once in orbit.

The decision to combine the two missions under one contract was taken due to the significant cost savings that could be achieved, and in view of certain technical similarities between the two satellites. For instance, their final orbits are such as to allow both spacecraft to be launched together on the same rocket. Their launch is scheduled for early 2007 from Kourou.





Once in operation, however, Herschel and Planck will work as completely independent satellites, with different scientific goals and different orbits. In fact, this will be the first time that two satellites aimed at solving different astronomy problems will be launched together and subsequently injected into different orbits.

Alcatel Space will mainly take care of the Planck Payload Module's development and the assembly and testing of Planck. Astrium will have the same responsibilities for the Herschel Payload Module, as well as the assembly and testing of the spacecraft, while Alenia Spazio will be responsible for the Service Modules for both spacecraft.

The list of European companies taking part in this large industrial undertaking does not stop there. The subcontractors involved in this contract will come from all 15 of the Agency's Member States including Portugal, which is participating for the first time in an ESA scientific project.

esa

ESA and China Joining Forces for 'Double Star'

ESA and China are going to work together on the 'Double Star' project, in which European instruments will be flown on Chinese satellites for the first time. The historic agreement between the European Space Agency and the Chinese National Space Administration (CNSA) was signed in Paris on 9 July by ESA's Director General Antonio Rodotà, and Luan Enjie, Administrator of CNSA.

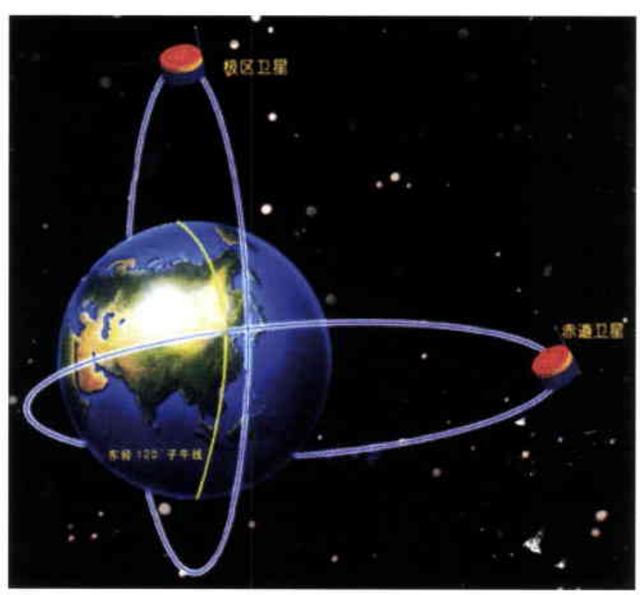
Double Star, two satellites developed, launched and operated by China, and flying in complementary orbits around the Earth, will study the effects of the Sun on the Earth's environment. They will carry 10 instruments that are identical to those currently flying on the four Cluster spacecraft, with another eight instruments from Chinese institutes. Conducting joint missions with Cluster and Double Star should increase the overall scientific returns from both missions, for example in terms of the exploration of the magnetotail.

ESA will contribute eight million Euros to the Double Star programme. The money will be used for the refurbishment and pre-integration of the European instruments, the acquisition of data for four hours per day, and the coordination of scientific operations.

"This agreement marks a significant advance for international cooperation in the exploration and peaceful use of outer space," said Mr Rodotà. *"It is one of the most important landmarks in scientific collaboration since ESA and the People's Republic of China first agreed to exchange scientific information more than 20 years ago."*

"The Double Star programme will be just the first step in substantial cooperation between the Chinese National Space Administration and ESA," said Mr Luan Enjie. *"The signing of today's agreement paves the way not only for reciprocal cooperation between scientists, but for the establishment of comprehensive cooperation between the two agencies".*

esa



The opening of the ESA 2000 Exhibition in Greifswald

ESA 2000 at Max-Planck Institute (IPP)

The ESA 2000 Space Science Exhibition has paid a visit to the Max-Planck Institute for Plasma Physics (IPP) in Greifswald, Germany, where it attracted some 1500 visitors. It was opened on 'Sun-Earth Day', on 27 April, by Martin Huber (ESA Science Advisor), Friedrich Wagner (Director of IPP) and high-level representatives from the regional government, the city, and the university of Greifswald.

IPP is one of the largest fusion research centres in Europe, investigating the underlying physical principles of nuclear – and hence also solar – fusion. The location and timing were therefore perfect for the opening of an exhibition that includes the many discoveries made by ESA's solar observatories like SOHO, Cluster and Ulysses. The 90 display panels that make up ESA 2000 now also include the first results from the XMM-Newton mission and describe future missions such as BepiColombo, Solar Orbiter, GAIA, NGST and LISA.

Following the opening ceremony, Frank Jansen from the Space Weather Observatory Greifswald, ESA's consultant for the exhibition, invited the visitors to a tour through the exhibition. There were also lectures open to the public on the ESA Space Science Programme, fusion/plasma physics, radio astronomy and space weather. These activities, together with the models of ESA's Ariane-5 launcher and Cluster-II, ERS-2, HST, ISO, SOHO, Ulysses and XMM spacecraft on display, as well as interactive CD-ROMs and various publications from ESA and the IPP, the more than 1500 visitors who attended the exhibition in Greifswald were treated to an impressive overview of contemporary space science, fusion research and space-weather phenomena.

About 100 visitors celebrated Sun-Earth Day by attending the opening of the ESA 2000 Exhibition in Greifswald. esa

ATV at ESTEC

A new pressurised module for the International Space Station (ISS) arrived at ESTEC in late July. This cargo carrier, built by Alenia Spazio in Turin, will be integrated with the rest of ESA's Automated Transfer Vehicle (ATV) and prepared for structural and thermal tests. Beginning in August 2004, the 20 t ATV will be launched by Ariane-5 to ferry propellants, water, air, equipment and other supplies to the ISS. Up to 10 ATVs are planned for ISS operations by 2012.

The unmanned ATV will dock with the Station automatically. Astronauts will enter the pressurised compartment to unload the provisions and then fill it with rubbish from the ISS. ATV will also be responsible for an important manoeuvre: using its main engines to boost the Station's altitude. This process must be carried out periodically to combat the gradual decay in the orbit caused by atmospheric drag. After up to 6 months attached to the Station, ATV will then be commanded into a destructive atmospheric reentry. esa

In front of the 1/4-scale model of SOHO during the opening of the Exhibition: left Prof. F. Wagner (Director of IPP) and Prof. M.C.E. Huber (ESA Science Advisor)

Space Education for ESA Children: The Cannes Space Camp

Between 14 and 28 July this year, nearly 70 children of ESA staff from all Agency Establishments gathered in Cannes, in the South of France, for the annual Space Summer Camp. The Camp was organised by the ESA Children's Camp Club (CCC), under the guidance of the ESA Education Office and in collaboration with the French organisations Provence Sciences Techniques Jeunesse (PSTJ) and PARSEC.

The Educational Office wants the younger generation to feel part of the ESA space family and to develop space awareness, better understanding and exchanges between children of different cultures and nationalities. The Office offered its sponsorship on condition that there would be a strongly space-related programme – no problem for the two French associations that receive groups of children and offer them a wide range of space-related activities on a regular basis throughout the year.

The children were divided into two age groups. PSTJ took care of the youngsters (8 to 13) and introduced them to astronomy, the building and launching of micro-rockets and the conception of experiments for a stratospheric balloon. The teenagers (13 to 18) were under the wing of PARSEC, and their main activities were lectures on space, the building and launching of water rockets, astronomy, the building of satellite mock-ups and an industrial visit to Alcatel Space.

Both groups visited the 'Astrorama' in Nice and the Nice and Calern Observatories. One of the highlights was on the afternoon of 25 July when ESA Astronaut Ulf Merbold visited the Camp. The children built lunar and martian bases with Ulf's help and listened to stories about his space missions.

Cultural programmes were not forgotten, to balance the space content. The space campers visited a perfume factory, the cities of Nice and Monaco, the palaeontology excavation of Lazaret, a museum for rural life, a grotto, the islands of Lérins, and the medieval city of Eze. Even after all this, there was still time to go to the swimming pool or the beach, have fun and relax in the French sunshine.

During the camp, the children also met renowned astronomers, palaeontologists and engineers and, of course, made lots of new friends from many different countries. Although the activities themselves were in French and partly English, you could hear many other European languages being spoken, including Italian, German, Dutch, Spanish and even Russian.

The ESA Education Office hopes to be able to sponsor this corporate activity with a programme of an equivalent quality again, so see you at the next Space Camp in 2002!** esa

** ESA and other partners have recently signed an agreement with PARSEC to collaborate in space educational matters. Among the first actions is the contribution ESA has made to help setting up courses for teachers of different European countries so that their schools can benefit from the same type of activities that up to now have only been held at French schools.

Summer School Alpbach 2001 – Satellite-Navigation Systems for Science and Applications

62 students from various ESA Member States (including for the first time two students from Canada) attended the annual Alpbach Summer School from 17 to 26 July. The Summer School is organised by the Austrian Space Agency together with the Austrian Federal Ministry of Transport, Innovation and Technology, ESA and the national space authorities of its Member States. The project for this year's summer students was to define innovative satellite-navigation missions.

As part of the curriculum, about 30 experts taught the students about the international GPS (Global Positioning System) service, signal propagation, reference systems, data processing, signal architecture and signal structure, space-based and terrestrial augmentation systems, precise orbit determination for gravity-field recovery, geodynamics applications, kinematic positioning, location-based services and atmospheric topics.

Throughout the two weeks, the summer students participated in a series of workshops. Divided up into six working groups, they discussed three different workshop themes:
- Sounding the atmosphere with space-borne satellite-navigation receivers
- Telematics applications
- Futuristic applications of satellite navigation and their economic potential.

The students were expected to come up with their own ideas for satellite navigation missions. Their work therefore culminated in the design of the following space missions:

PANIC (Personal Assistant for Navigation, Information and Communication)
This working group's aim was to develop a navigation/information system for pedestrians in urban areas. The functionalities of the system include position determination, route planning/guidance, and information querying. The positioning unit would use GPS and other integrated sensors (stepper, compass, Loran-C). Communication would rely on existing terrestrial networks or/and a satellite communication infrastructure. The basic information (maps, etc.) would be stored in a Processing and Display Unit (PDU), whereas dynamic information (events, news, etc.) would be in a central database accessible via a communications link.

The PDU would consist of a PDA (Personal Digital Assistant), a Webpad or a similar unit. Input would be possible using a touch screen or speech recognition. The output would be on the screen and/or using voice. In the advanced version of the system, Augmented Reality (AR) would be used to provide the information in a more comfortable way.

The target groups would be tourists, drivers and all pedestrians. In addition, it would be possible to subscribe to various information channels (e.g. news and weather, sports, restaurants, stock quotes, etc.).

Sonar Underwater Navigation System (SUNS)
SUNS would provide autonomous underwater position determination by means of small buoys that broadcast their position and time references as sonar signals. The positions of the buoys would be accurately derived from GNSS. The potential applications would range from amateur diving to professional companies exploring the seabed.

The SUNS system would use an array of buoys on the sea's surface. These buoys could be manufactured using existing components, making them not much larger than the Inmarsat-E distress beacons. The challenge would be to develop the model for the propagation of the sonar signals. A prototype could be built within about a year, and the deployment costs for the initial system would be in the order of 20 000 Euros, making it affordable to amateur divers and certainly to professionals.

The SUNS solution would extend GNSS for underwater navigation, making use of the same reference frames. The operations could be largely autonomous, with no restriction on the number of users.

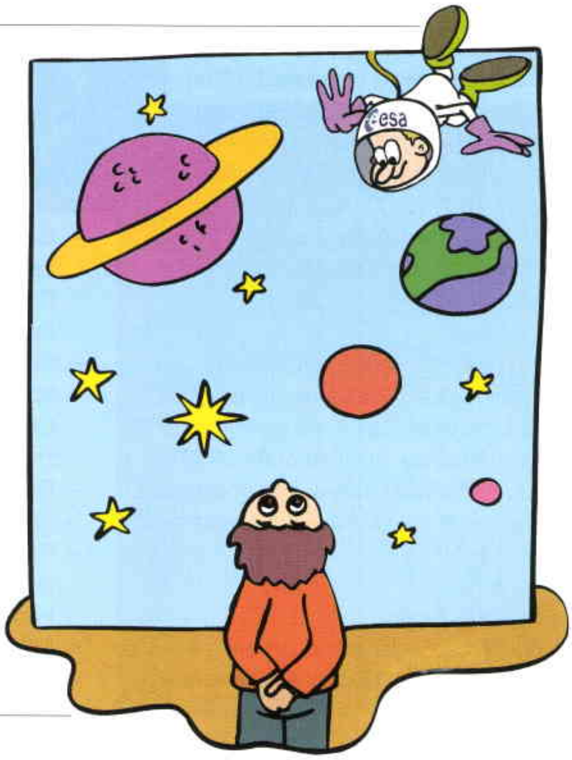
continued>>

'TEACH SPACE 2001' – A Marketplace for Educational Ideas

"There are two subjects with which you can capture the attention of any child: dinosaurs and space. If you can combine the two - bingo! You will teach them everything they need."

Who should know this better than a someone who teaches 14 to 15 year olds? What do teachers do when the teach about space? And what would they like from ESA?

ESA is organising a special forum for teachers of pupils between 6 and 18 years of age – TEACH SPACE 2001, the first International Space Station Education Conference. From 26 to 28 October, teachers of all disciplines and from all across Europe will be at ESA's European Space Research and Technology Centre (ESTEC) in Noordwijk (NL), to present their ideas on how space can be integrated into the teaching of almost all subjects at school. The participants will not only be meeting colleagues from other countries and talking to ESA's astronauts, but will also be competing with their individual projects for the title *"Most Inspiring Project 2001"*.



Traffic Solutions for the Future

This working group decided to focus on one application that can be realised in the near future and several applications with the potential for later implementation. Underlying assumptions for all selected applications were the global availability of a combined UMTS/GNSS/Galileo network and the availability of GNSS receivers at very low cost. The group proposed:

- a solution for finding parking spaces in inner cities
- a navigation system for pedestrians in cities
- a navigation and guidance system for the visually impaired
- a flexible fleet management system for public transportation
- an intelligent guidance system to avoid congestion of the available infrastructure
- a drive-on-demand system for individual users.

Mission Ionosphere

The mission proposed by this working group would investigate the use of GNSS receivers onboard commercial geostationary satellites for sounding the ionosphere and plasmasphere. GNSS receivers are a cheap and efficient method of determining the positions of geostationary satellites to an accuracy of better than 100 m, which is sufficient to allow the data collected to be used for ionospheric remote sensing. The project anticipates that in the near future more and more GEO satellites will be equipped with GNSS receivers and that the data would be available for scientific investigations. It is proposed to use the data to resolve exciting and interesting phenomena in the outer atmosphere. The mission would also have important implications for the observation and prediction of space weather.

SAUMEO (Sounding the Atmosphere Using Medium Earth Orbiters)

SAUMEO is intended to improve the observational database for weather forecasting, climate-change monitoring and disaster management. Using Galileo satellites as orbital platforms for GPS receivers to perform radio-occultation measurements of the atmosphere would seem to be a promising possibility. Simulations show that the number of possible occultation events would be at least 1200 within 24 hours. The duration of the occultation measurements would be long (~15 min), making the data suitable for use in numerical weather-forecast models. Because of the long-term stability of the whole experimental setup, the retrieved data would be ideal for evaluating external forcing (e.g. the greenhouse-gas effect) in climate-change models.

ACRONIM (Advanced Counter-rotating Radio Occultation Neutral Atmosphere and Ionosphere sounding Mission)

This working group proposed a low-cost test mission involving two satellites, which could be operationally extended to include more satellites, with the objectives of:

- measuring the electron density in the plasmasphere
- sounding of the Ionosphere
- sounding of the neutral atmosphere.

On the last day of the Summer School, the six missions were presented to a Review Panel which, in selecting SUNS as the winning project, congratulated all of the teams on their achievements during the two weeks. The Panel was suitably impressed by the students' accomplishments and suggested publication of a more extensive report on the results of Alpbach 2001in a forthcoming issue of the ESA Bulletin.

Additional information and the individual working-group presentations can be found at:
http://www.asaspace.at (news section, Summer School Alpbach 2001)

World Space Congress 2002 / 34th COSPAR Scientific Assembly

The Second World Space Congress will be a joint meeting between the Committee on Space Research (COSPAR) and the organisations that meet during the International Astronautical Congress, i.e. the International Astronautical Federation (IAF), the International Academy of Astronautics (IAA), and the International Institute of Space Law (IISL).

The meeting will take place on 10 – 19 October 2002 in Houston, Texas, USA. The local organisation will be in the hands of the American Institute of Aeronautics and Astronautics (AIAA), and under the auspices of the US National Academy of Science (NAS).

COSPAR Topics:
Approximately 80 events covering the fields of COSPAR Scientific Commissions and Panels:

- Commission A: The Earth's Surface, Meteorology and Climate
- Commission B: The Earth-Moon System, Planets, and Small Bodies of the Solar System
- Commission C: The Upper Atmospheres of the Earth and Planets including Reference Atmospheres
- Commission D: Space Plasmas in the Solar System, including Planetary Magnetospheres
- Commission E: Research in Astrophysics from Space
- Commission F: Life Sciences as Related to Space
- Commission G: Materials Sciences in Space
- Commission H: Fundamental Physics in Space
- Panel on Satellite Dynamics (PSD)
- Panel on Scientific Ballooning (PSB)
- Panel on Potentially Environmentally Detrimental Activities in Space (PEDAS)
- Panel on Standard Radiation Belts (PSRB)
- Panel on Space Weather (PSW)
- Panel on Planetary Protection (PPP)
- Panel on Space Research in Developing Countries (PSRDC)
- The Public Understanding of Space Science
- Space Science Education and Outreach.

COSPAR Abstract Deadline: 1 May 2002

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or visit the following Web sites:
http://www.copernicus.org/COSPAR/COSPAR.html or www.cosparhq.org

For further information about the IAC technical events programme, please visit:
http://www.iafastro.com/

New Mission Scenario for Cassini-Huygens

No data will be lost when the Cassini-Huygens mission reaches Saturn and its moon Titan. A joint ESA/NASA Huygens recovery task force, including senior management from the two space agencies and members of the Cassini-Huygens scientific community, have designed a new mission scenario in order to solve the Huygens radio-communications problem and fully recover the scientific return from the Cassini-Huygens mission.

The modifications have been introduced to overcome a design flaw in Huygens' communications system, which means that the Huygens receiver is unable to compensate for the frequency shift between the signal emitted by the Probe and the one received by the Orbiter, due to the Doppler shift. This would have resulted in the loss of much of the unique data that will be gathered by the Probe during its descent through Titan's dense atmosphere.

In order to ensure that as much data as possible is returned from the pioneering Probe, the Huygens Recovery Task Force proposed a new schedule for Cassini's early orbits around Saturn. The agreed scenario involves shortening Cassini's first two orbits around the ringed planet and inserting an additional orbit that provides the new geometry needed for the Huygens mission to Titan.

With the new scenario, the arrival at Saturn on 1 July 2004 remains unchanged, but Cassini's first flyby of Titan will now occur on 26 October, followed by another on 13 December. The Huygens Probe will be released towards Titan on 25 December, for an entry into the moon's atmosphere 22 days later, on 14 January 2005, seven weeks later than originally planned.

In order to reduce the Doppler shift in the signal from Huygens, the Cassini Orbiter will fly over Titan's cloud tops at a much higher altitude than originally planned – 65 000 km instead of 1200 km. This higher orbit has the added advantage that Cassini will be able to maintain its four-year baseline tour through the Saturnian system, by resuming its original orbital plan in mid-February 2005. esa

The Solar Eclipse in Africa 21 June: Eyewitness Report

Perhaps it's the sheer experience of an eclipse that causes all of the excitement. As the last direct rays quickly contract into a sliver of light, thousands of surrounding upturned faces cheer in thrilled anticipation. Individually though, you realise that it's really our Moon up there, whose disc is blacking out the Sun's surface in breathtaking cosmic perfection, creating a stunning, bright flower in space ... and darkness on Earth.

The University of Zambia, in Lusaka, has wide-open fields of dry grass and large, square 1970's style buildings. On 21 June, total-eclipse day, there was an African rock group playing in the festival there, a market, buskers, thousands of local people, and an acute shortage of eclipse viewing glasses! The shops in Lusaka had sold out days before. The Physics Department had issued some students with the necessary chromium foil to fashion their own home-made glasses, but for the most part the crowd was desperate, the local papers having warned of the dangers of looking directly at the Sun before and after totality. Surely the visiting scientists and tourists must have brought some glasses with them?

An international organisation, Cosmos Education, had organised a Conference at the University during eclipse week for just under 600 local people, focusing on space science, technology and education. The 20 representatives of Cosmos had brought about 1500 pairs of eclipse glasses with them, something they kept secret until shortly before the eclipse began. They closed the doors of the Conference Hall and urged those inside to remain calm whilst everyone received a pair of glasses. During the proceedings, however, cries and banging were heard from behind the bulging doors. The remaining glasses were therefore quietly smuggled out of the room via a side door, the plan for their further distribution not yet in place!

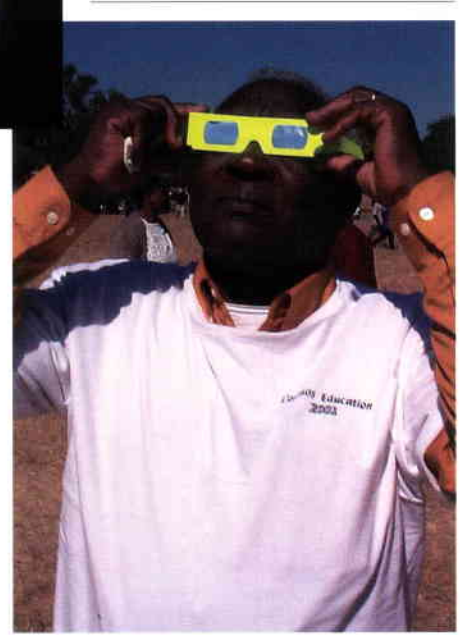
A little later, hoards of people began to run at top speed towards a point in the festival grounds, for no apparent reason. It was soon confirmed, however, that a group of Zambian marines attending the festival had agreed to distribute the remaining glasses. Soon thereafter, and fortunately with no reported injuries, the crowd set about enjoying the eclipse's spectacular show.

Before totality, the partially eclipsed Sun shone through the trees and between the throngs of people, covering the ground with an astounding display of miniature Sun-crescent shadows. Then as the Moon and Sun neared totality birds took flight from the trees and swooped about the clear but dimming sky. Just as the Sun was covered, tiny red loops, prominences of hot solar gas, were visible around the edge of the Sun's disc. The Sun's corona streaked blue and yellow into a dark sky, Jupiter bright and glimmering beneath it, a spectacle not easily recorded on film.

Some traditional African legends had been related earlier during eclipse day, re-enacted in stories, poems and drama. They told of fear of the total eclipse, seen as an omen of a journey, an order of the King, or a cause for animals to leave the bush and kill in fear.

Science has since explained the true workings of the eclipse. Nevertheless, those still present after the eclipse that day, huddled in animated groups on the dry grass – now littered with discarded eclipse glasses – reported more than just a scientific phenomenon, they described a true personal 'experience'.

Julia Birch
ESA Education Office esa



photos: Cosmos Education

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 inside the back cover

ESA Newsletters

REACHING FOR THE SKIES – VERSION FRANÇAISE (JUIN 2001)
PERIODIQUE DE LA DIRECTION DES LANCEURS
WILLEKENS PH. (EDS. H. SAWAYA-LACOSTE & B. BATTRICK)
GRATUIT

EUROCOMP NO. 4 (SUMMER 2001)
NEWSLETTER OF THE SPACE COMPONENTS STEERING BOARD
WONG J. (ED. B. BATTRICK)
NO CHARGE

ESA Annual Report

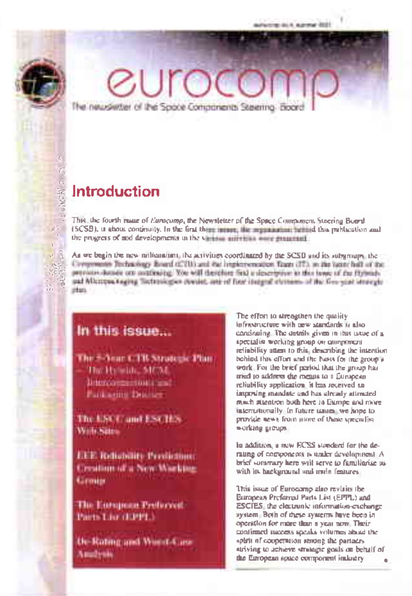
ANNUAL REPORT 2000 (JULY 2001)
ED. B. BATTRICK
ESA ANNUAL REPORT 2000 // 109 PAGES
NO CHARGE

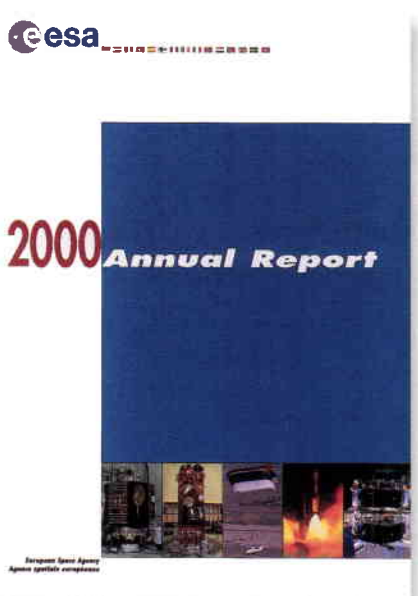
RAPPORT ANNUEL (AOUT 2001)
EDS. H. SAWAYA-LACOSTE & B. BATTRICK
RAPPORT ANNUEL ESA // 117 PAGES
GRATUIT

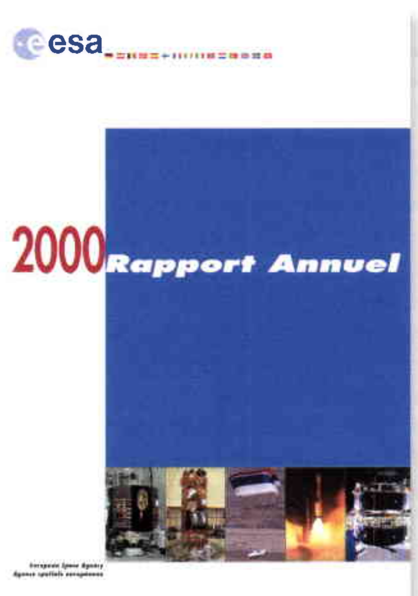
ESA Brochures

ESOC: DAS EUROPÄISCHE SATELLITEN-KONTROLLZENTRUM (JULI 2001)
LANDEAU-CONSTANTIN J.
(EDS. B. WARMBEIN & B. SCHÜRMANN)
ESA BR-110 (UPDATED) // 32 PAGES
PRICE: 10 EURO / 25 DFL

MARS EXPRESS: EUROPE GOES TO MARS (JULY 2001)
SCIENCE PROGRAMME COMMUNICATION SERVICE
(ED. B. BATTRICK)
ESA BR-174 // 27 PAGES
PRICE: 7 EURO / 15 DFL







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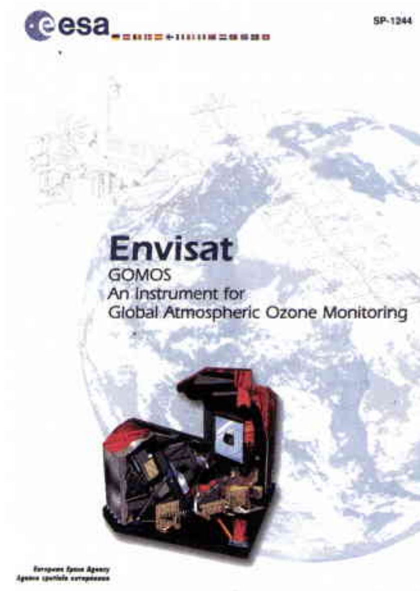

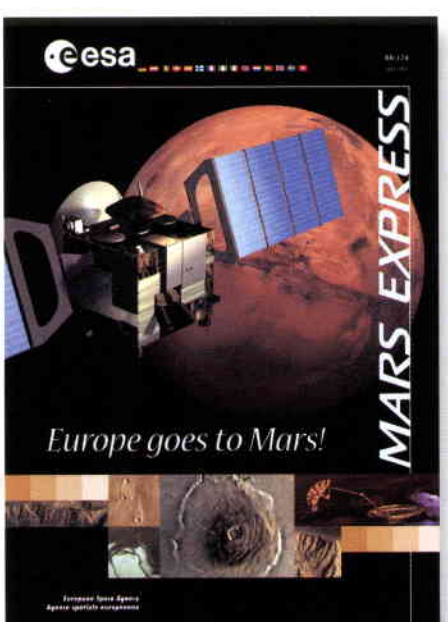

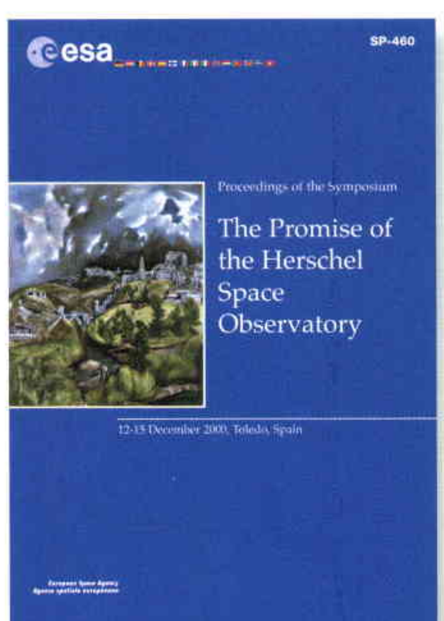

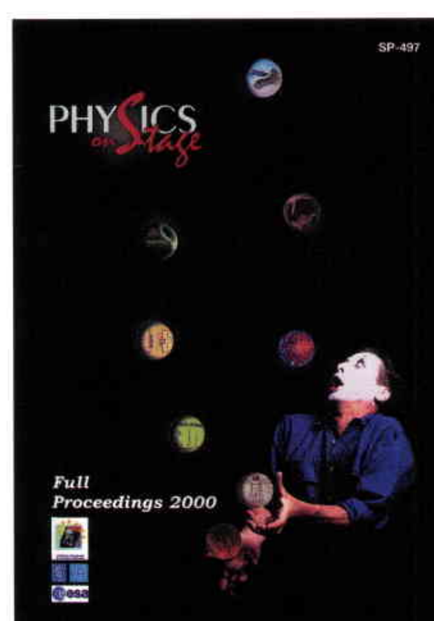

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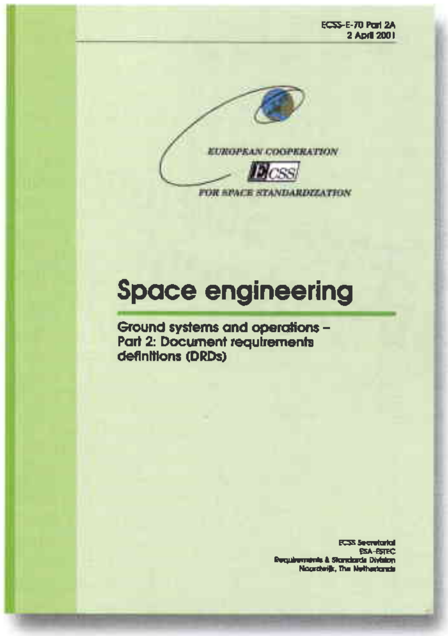

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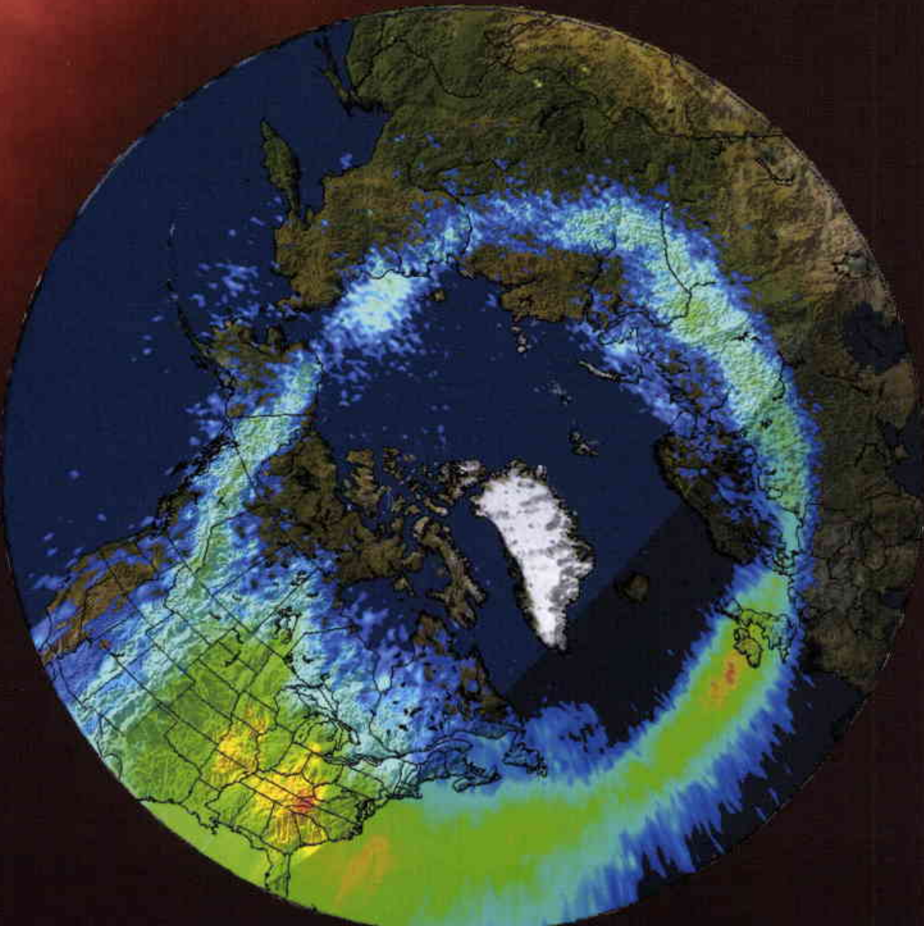

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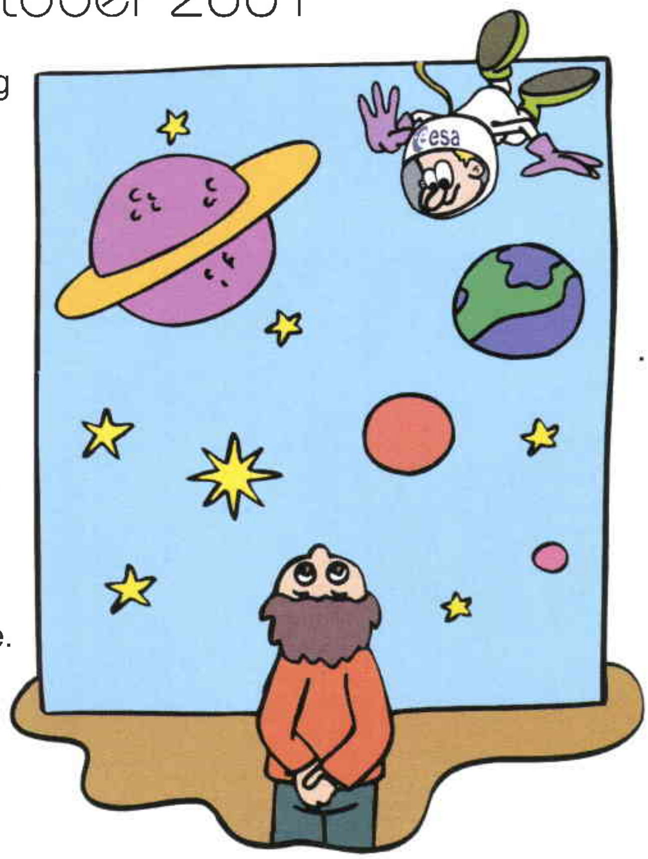

Conference Highlights:

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- Opportunity to see projects by teachers, for teachers.
- Network with teachers from all over Europe.
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Open call:

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'Space' is not only about science,
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