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Chapter 13

Halley's Comet Exploration in Japan—Japan's First Interplanetary Flight*

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Abstract

Since the first Japanese successful satellite *Ohsumi* launched in 1970, Japan's science made efforts in sending scientific satellites to orbit around Earth almost every year. Launch vehicles for the satellites were Mu-series which evolved step by step in response to the demand of space science of the days. When Halley's Comet was found to come back toward the Sun after 76 years in 1985–1986, ISAS (Institute of Space and Astronautical Science)—taking the opportunity—began to prepare Japan's first interplanetary spacecraft to observe the Comet. Japan had to solve four problems to achieve the task: create a new launch vehicle, a new type of spacecraft, a big antenna on Earth for spacecraft tracking, and new software to control the flight program for the interplanetary mission. The problems were overcome at last, and two Halley's Comet explorers, *Sakigake* and *Suisei*, were launched from Uchinoura launch site using the newly developed M-3SII rocket, and the tracking operation was successfully done with a 64 meter antenna newly constructed at Usuda. These two Halley's Comet missions marked the epoch in pushing Japan's space science onto the international

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stage, and, at the same time, initialized Japan's solar system exploration. This chapter reviews the process from the proposal to the end of the missions when four space agencies gathered at Vatican Palace to make reports to the Pope in 1986.

Introduction

In early 1984 Halley's Comet was making its way to the Sun after 75 years. At that time the comet was around the orbit of Jupiter with the speed of 12 km/sec. To welcome this visitor from afar, five spacecraft left Earth from the end of 1984 until the summer of 1985: two *Vega*s of the Soviet Union onboard Proton rockets from Baikonur in the Christmas season in 1984, Japan's MS-T5 (*Sakigake*) onboard M-3SII rocket from Uchinoura in January 1985, the European Space Agency (ESA) *Giotto* onboard Ariane rocket from Kourou in July 1985, and Japan's *Suisei* onboard M-3SII from Uchinoura again in August 1985. In addition, the *International Sun–Earth Explorer 3* (ISEE 3), later renamed *International Cometary Explorer* (*ICE*), of the United States, which had been working for four years at the Sun–Earth Lagrangian point, left the point in June 1982 toward the comet Giacobini-Zinner. And then *ICE* was supposed to aim at Halley's Comet.

These six spacecraft, in March 1986, would gather around Halley after it had passed perihelion. From 13 September through 15 September 1981, a meeting at Padua University in Italy was held by space scientists and engineers related to possible Halley's Comet exploration. In the Padua meeting, a framework for international cooperation with respect to Halley's Comet exploration was established, and it was named Inter-Agency Consultative Group (IACG) for Halley's Comet Exploration. Thus the space scientists and engineers returned to their respective home countries, and started to tackle their own Halley missions.

Origin of the Affair

At the end of the 1970s when the United States and the Soviet Union sent a number of spacecraft to Venus, Mars, and beyond, which provided fresh, vivid images of the planets in Earth's solar system, there was a group of scientists and engineers in the Institute of Space and Astronautical Science (ISAS), Japan, who was itching to launch its own spacecraft that could escape Earth gravitation into interplanetary space. It once proposed a series of planetary mission plans, such as a Venus orbiter, a Venus balloon, et cetera, but the plans seemed immature to some extent. Just in time a big news item caught their scientific minds.

Halley's Comet is coming back! After the comet had made the closest encounter with the Sun in 1910, it flew away as far as the orbit of Neptune, and early in 1984 it would approach the Sun and Earth after 76 years (Figure 13–1). To bring a spacecraft to a comet, scientists should know the orbital elements of the comet in some details. From this point of view, Halley is one of the most appropriate comets, because it has approached the Sun so frequently that scientists knew its orbit quite well. And, of course, research into the comet was scientifically quite important.

Figure 13–1: Halley's Comet in 1986.

The mission analysis group of ISAS started working—drawing up its Halley mission plan. The orbit of Halley is inclined by 18 degrees against the ecliptic plane. From the viewpoint of launch energy, the spacecraft and the comet should meet when the spacecraft crosses the ecliptic. The simulation concluded that the encounter would be at the descending node of Halley's orbit in March 1986. Two launch windows were prepared: early 1985 and the summer of 1985.

Four Hurdles

Looking back at the developments of rocket technology and space science in Japan, I can definitely say that we lived a full life for about five years during the first half of 1980s when we united to develop a new type of launch vehicle, M-3SII, to run toward Halley's Comet.

On the occasion of Halley's Comet exploration, ISAS of Japan launched two spacecraft, *Sakigake* and *Suisei*, both weighing around 140 kg, from Kagoshima Space Center (later Uchinoura Space Center). Many problems would occur during the implementation of the first interplanetary flight. Four hurdles were set up as the biggest tasks to be overcome, that is to say Halley's Comet project in Japan mainly consisted of four elements:

1. A new launch vehicle, M-3SII, which would enable Japan to escape Earth's gravitation for the first time by an all-solid propellant rocket;
2. A new type of spacecraft itself, that was to operate under the interplanetary environment, quite different from that of near Earth satellites;
3. A big antenna on Earth for spacecraft tracking that could communicate with spacecraft over a long distance; and
4. A variety of software to control the flight program in interplanetary space.

Hurdle One—New Launch Vehicle

To develop the M-3SII, the fourth generation of Mu-series that followed M-3S, ISAS tried to develop new versions for strap-on boosters, second stage, and third stage, while only the first stage was used just as it had been. Professor Ryojiro Akiba led the team for development, and all chiefs for development of the respective items continued to get together on the last Saturday every month. In the meeting, the chiefs reported and investigated the progress and the problems on respective works. In parallel with this meeting were held a lot of small group meetings for reviewing and discussing problems in respective items of development.

The development of M-3SII was started in fiscal year (FY) 1981, and the team carried out static firing tests for actual size motors eight times at Noshiro Testing Center in the northern part of Japan (Figure 13–2). A lot of other tests were held, including the launch of ST-735-1, a small-size rocket for the test of strap-on booster separation.

Figure 13–2: Static firing test of M-23 motor at Noshiro Testing Center.

In July 1984, a new assembly tower for the M-3SII rocket appeared on Mu Center at Uchinoura. And it was November 1984 when a majestic figure of M-3SII was set on the assembly tower in assembled form for the first time (Figure 13–3).

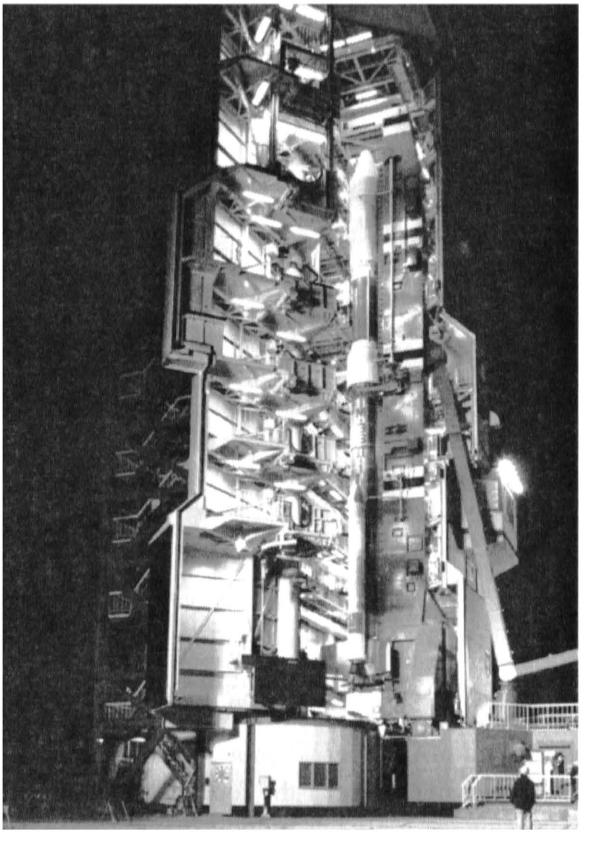

Figure 13–3: M-3SII-1 on launcher.

Hurdle Two—Interplanetary Spacecraft

Two spacecraft were to be prepared for Halley's Comet exploration by ISAS and were expected to fly in the interplanetary environment quite different from that of Earth orbit. Scientific instruments, of course, had to function under quite different situations, and, in addition, a high-gain onboard antenna (which should communicate with the Earth station from far away) and a despun mechanism (which makes the spacecraft always face Earth, even if the spacecraft is spinning) required a high level of power for an onboard transmitter and also required low noise for an onboard receiver, et cetera.

And, it was somewhat risky to develop a spacecraft under the situation that the carrier vehicle was in parallel under development. From such a standpoint, ISAS was a very convenient organization, because the leadership for developing a launch vehicle and a spacecraft both existed in the same campus (Figure 13–4).

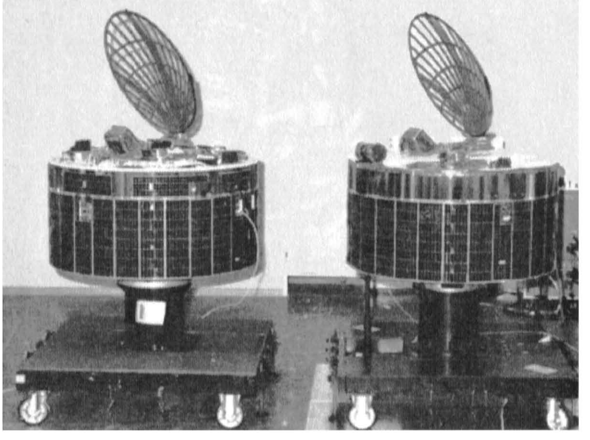

Figure 13–4: *Sakigake* and *Suisei* in clean room at Sagamihara.

Hurdle Three—Deep Space Antenna

The space where no other object could be found—only friend that spacecraft communicates with is a big antenna on Earth. Japan did not yet have such an antenna. ISAS looked for a place far from town, far from air routes, and with low city noise. The selection fell on Usuda, Nagano Prefecture. Rush work continued, and it was the end of October when a gigantic antenna of 64 m diameter (Figure 13–5) appeared majestically at the foot of Mt. Yatsugatake. The launch of the first Halley mission was only two months off.

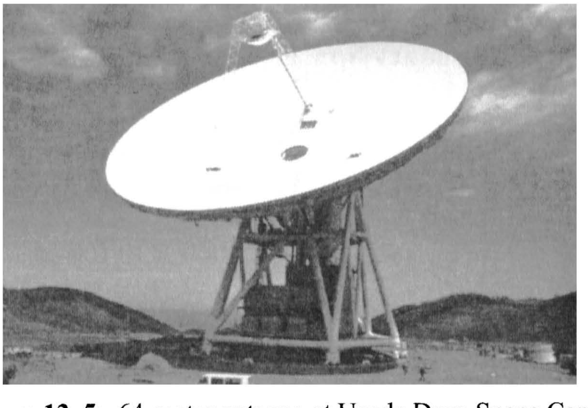

Figure 13–5: 64-meter antenna at Usuda Deep Space Center.

Hurdle Four—Computer Program for Orbit and Determination for Interplanetary Flight

The creation of a computer program for orbit determination was quite a difficult problem. Professor Toshimitsu Nishimura, who had come back to Japan from the Jet Propulsion Laboratory (JPL) to join the first interplanetary mission, took the leadership, and the team completed the program with more than 100,000 steps, taking five years.

Launch Operation

Preparatory Operation

Preparatory operations for all components of the M-3SII were carried out at Uchinoura on 2 November 1984. Every item was confirmed according to the list. An ultrasonic scan was performed on the propellants of the three rocket motors to confirm the assembling procedures of M-3SII, "Assembly Operation" were done using the actual vehicle. Thus all operations prior to the launch were finished.

Countdown

Countdown began on 24 December 1984, and ISAS started the flight operation of MS-T5. Three days later the entire staff assembled for a mutual understanding meeting concerning the fundamental items of launch operation. On New Year's Eve, the Karaoke Festival was held by the launch team at a bar in the town. Far from each family, the festival really came alive.

Launch, originally scheduled for 5 January 1985, was put off due to bad weather. During the launch schedule for the next day, an accident occurred related to a hydraulic motor for activating the strap-on booster's movable nozzles, and the launch was put off again. A small accident in the ground support systems postponed the launch once more. Finally, before dawn on 8 January 1985, the launch occurred. The team entered the time schedule in the evening of 7 January.

Launch operation went on carefully and perfectly (Figure 13–6). The wind, up to 2 km altitude, was rather strong. Launch elevation was set at 75 degrees, and launch azimuth was 91.5 degrees. Countdown continued smoothly, and the time for liftoff came at last. "5, 4, 3, 2, 1, 0! Lift off!" Under a heated and thrilling flight safety operation, M-3SII ascended, making a roaring sound (Figure 13–7). And at 365 seconds after liftoff, kick motor ignition was confirmed. "Kick motor has been ignited." "Kick motor has been ignited." Ripples of whispers spread in the control center, launch operation center, radar center, and telemetry center. Tears and sweat of probably some thousands of related people came out like this in the seven-minute drama in such a condensed fashion.

Figure 13–6: M-3SII is directed to launch azimuth along a rail.

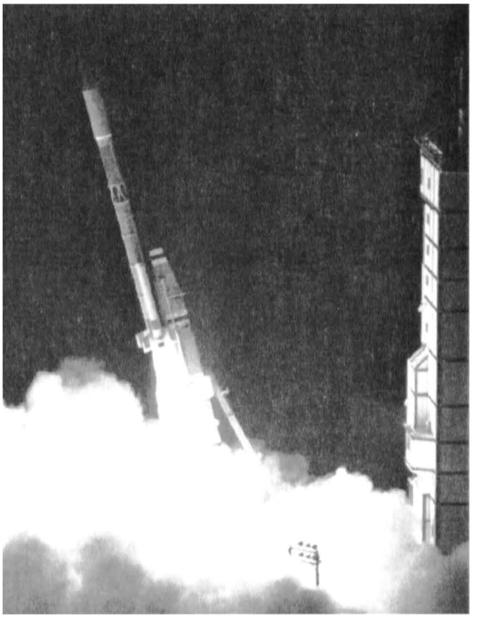

Figure 13–7: Liftoff of *Sakigake*.

Birth of Interplanetary Spacecraft

The interplanetary spacecraft was born just after "seven minutes" when the spacecraft, MS-T5, separated from the burnout kick motor and began its long journey toward Halley's Comet. The MS-T5, which was thrown into a heliocentric orbit, was named *Sakigake* (*Pioneer*).

The M-3SII rocket thus made a debut with a launch of *Sakigake* on 8 January 1985. It accomplished a great achievement of "earth escape by solid propellant rocket" for the first time in the world. On 19 August, the same year, the second flight of M-3SII carried Planet-A, Japan's second Halley mission, to heliocentric orbit (Figure 13–8). The spacecraft was named *Suisei* (*Comet*).

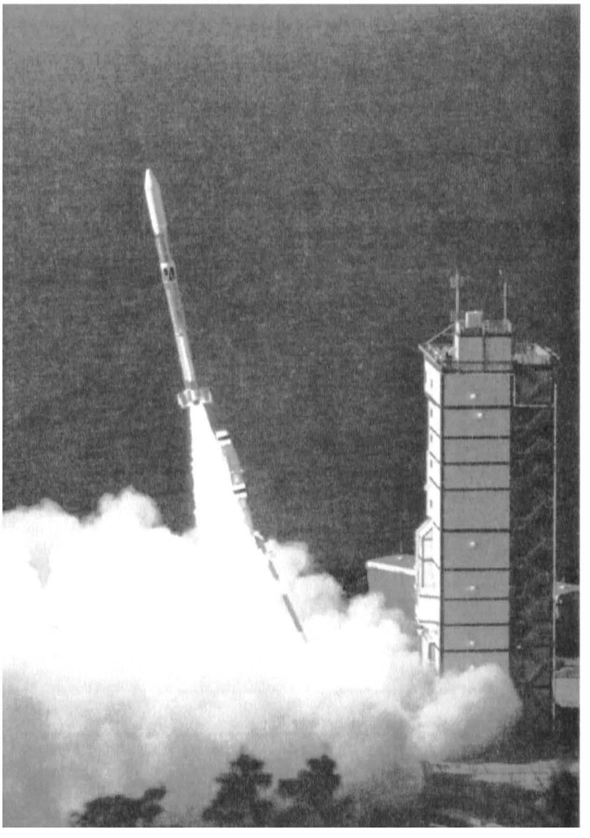

Figure 13–8: Liftoff of *Suisei*.

Encounters with Halley

As mentioned before, there were six spacecraft that approached Halley's Comet this time: two Russian *Vega*s, European *Giotto*, American *ICE*, and Japan's *Sakigake* and *Suisei*. They called these spacecraft the "Halley Armada." All of them made their respective close encounter in March 1986 (See Table 13–1).

Spacecraft	Country	Launch (UT)	Encounter (UT)	Closest Approach
Vega-1	Soviet Union	15 December 1984	6 March 1986	10,000 km
Vega-2	Soviet Union	21 December 1984	9 March 1986	8,000 km
Giotto	Europe	2 July 1985	14 March 1986	500 km
Sakigake	Japan	7 January 1985	11 March 1986	7,000,000 km
Suisei	Japan	18 August 1985	8 March 1986	150,000 km

Table 13–1: Halley Armada in March 1986.

The vanguard of *Suisei*

Japan's first interplanetary spacecraft (*Sakigake*) continued to observe the flight environment during the course toward Halley, such as interplanetary magnetic field, et cetera (Figure 13–9). Prior to the closest encounters with Halley, an ultraviolet television (TV) camera onboard *Suisei* detected a hydrogen corona surrounding Halley's nucleus several times from November until December 1985. The hydrogen was generated when water vapor, emitted from the surface of Halley's nucleus, was attacked by solar ultraviolet and spread out rapidly to the outside of Halley's coma.

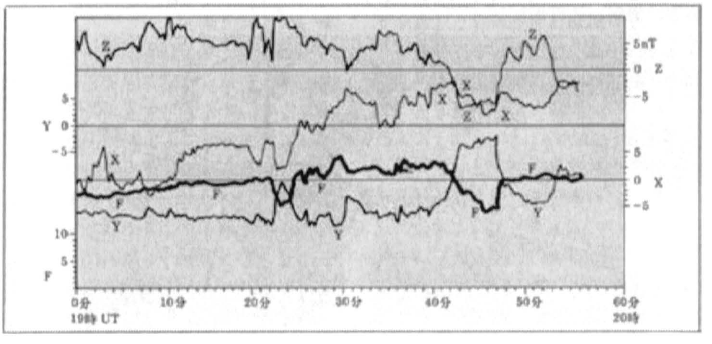

Figure 13–9: Magnetic storm taken by *Sakigake*.

Data taken by *Suisei* showed Halley's Comet was activated in a periodical fashion, sometimes powerful and sometimes weak (Figure 13–10). The *Suisei* team thought this phenomenon told that weak structures are unevenly distributed on Halley's nucleus, and when Halley's rotation forced the weak parts to face the Sun, violent jets were emitted from the surface.

Based on the rotation period of Halley's nucleus, the Suisei team warned other members of the "Armada" of the dangers of dust storms and their timings for respective members. In addition, the team worked out the quantity of emitted water from the surface to be 25–50 tons/sec. The team also estimated that most of Halley's surface would be covered by really black dust.

Closest Encounter of *Vega*

Although Japan's spacecraft were completely out of the loop for nine days, which started with *Vega*'s closest encounter with Halley on 6 March 1986 and ended with *Giotto*'s exciting closest encounter on 14 March, they were a great climax of the Halley Armada (Figure 13–11). *Vega*'s encounter, which was the opening of the drama, was played in the presence of representatives from four agencies of IACG at Moscow Mission Control (TsUP, now Korolev Space Flight Center), and sent more than 500 images of Halley and other invaluable scientific data (Figure 13–12).

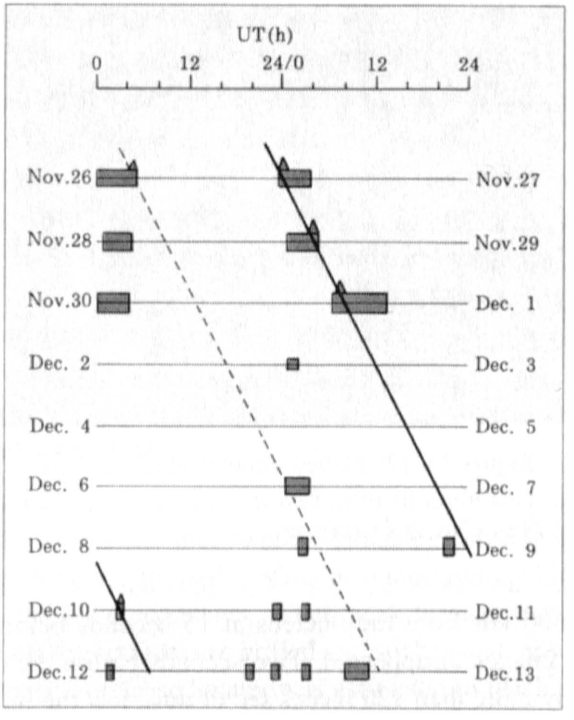

Figure 13–10: Periodical activity of Halley's Comet (*Suisei*): observation time (rectangles) and jet-detected time (triangles). The slope of thick solid lines and a broken line show a rotational period of Halley.

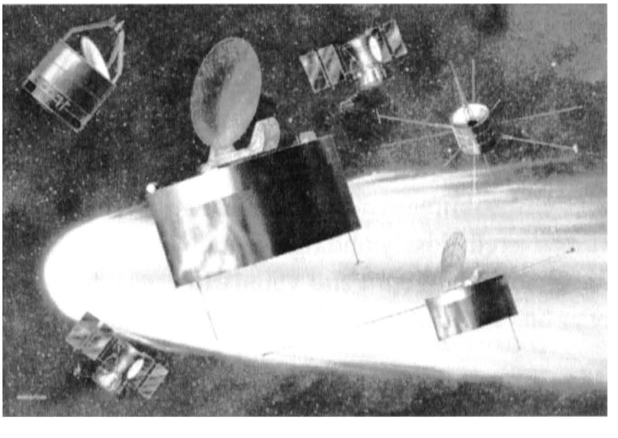

Figure 13–11: Halley Armada.

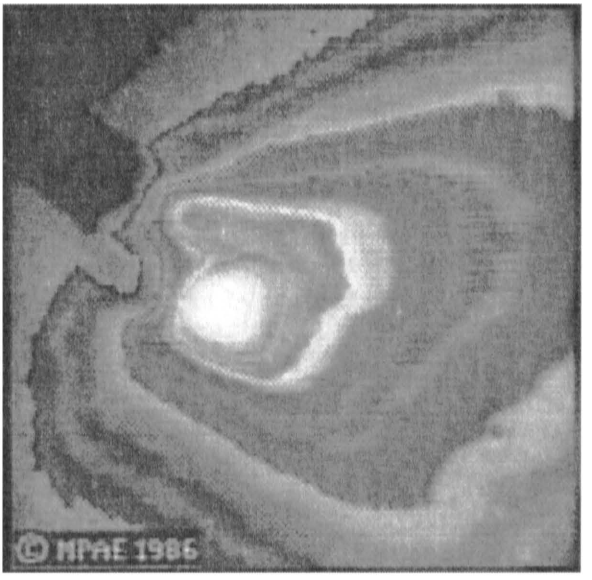

Figure 13–12: Halley's comet taken by *Vega.*

Black Snowball Has Come Onstage

On 14 March, a week later, ESA's *Giotto*, at the risk of its life, threw shots to Earth from 1,500 km from the nucleus at 15 seconds before the closest encounter, then the images disappeared. Two seconds before the closest encounter *Giotto*, attacked by more than 120 pieces/sec of dust, lost the link with Earth, but 25 seconds later the communications link was recovered. Although there would be no more images, data from the plasma instruments and mass spectrometers were excellent.

Half a day later, ESA announced a Halley's image in real color (Figure 13–13). The superstar's face without makeup was revealed through a thin veil of coma. It was really black. It was a black snowball. Halley's nucleus was 15 km by 7 km by 10 km. The estimated albedo of Halley's nucleus was 4 percent, and it was as dark as the darkest object in Earth's solar system, such as Iapetus and the rings of Uranus. Repeated encounters with the Sun grilled the surface of the snowball to vaporize or sublimate most of the volatile components, and Halley's surface came to be covered closely and tightly with black dust.

Figure 13–13: Nucleus of Halley's Comet (*Giotto*).

Spouting Gasses and Dust

Before the encounter this time, it had been thought that ices on the surface facing the Sun were uniformly melted and sublimated emitting gasses. But it was not the case with Halley. The hard surface covered with old dust is not easy to melt. Only when the icy components, which peek through crevices and grooves that are scattered on the surface, are grilled and sublimated, powerful gas jets are emitted. The quantity of released water was estimated to reach 50 tons/sec at the maximum, and summed up to be 10 million tons in total during the encounter with the Sun this time.

Dust was also emitted with the gas jets. While the gasses diffused rapidly to a uniform state, dust near the nucleus were found to distribute brindled, that is, somewhere dense and somewhere dilute. Rushed into such dust, cameras (*Giotto*) and solar cells (*Vegas*) were badly damaged. Japan's *Suisei* also collided with this dust and shook suddenly.

Halley's Coma

Emitted gasses and dusts make up the "coma" (cometary atmosphere) temporarily around the nucleus. The coma is formed only when comets have approached the Sun. In the case of Halley this time, the coma was first recognized when the comet was approximately 6 AU* from the Sun and gave off a stronger spectrum of cyanogen.

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* Astronomical Unit (abbreviated as AU, au, a.u., or ua) is a unit of length equal to 149, 597,870.700 kilometers (92,955,807.273 miles), or approximately the mean Earth–Sun distance.

Inside the coma is a stage where molecules and ions are behaving actively. Many kinds of molecules and ions were detected there this time, and especially important were the organic molecules that were found.

Suisei detected a rise and fall of hydrogen corona widely extending outside the coma. The rise and fall, as described before, came from the rotation of the comet and uneven distribution of structurally weak parts on the surface (Figure 13–14).

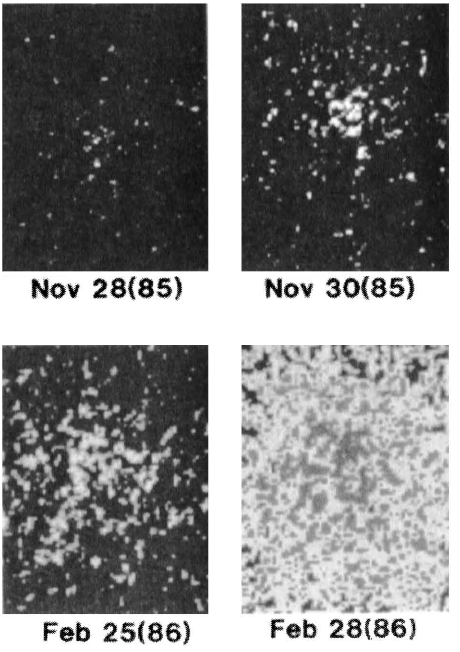

Figure 13–14: Rise and fall of hydrogen in Halley's corona (ultraviolet (UV) camera on *Suisei*).

Halley's Tails

Comet's generally have two tails (Figure 13–15). The one is a dust tail, which describes a big curve in the opposite direction of the Sun, pushed by the solar pressure. The other is a plasma tail. Detailed data has been obtained about the formation mechanism of the plasma tail. The solar wind, the high speed flow of plasma emitted from the Sun accompanied by a magnetic field, is prevented by its collision with the cometary coma to form a shock wave. Inside, the shock wave is swarming with high energy charged particles. Just in the turbulent plasma, a magnetic field of solar wind proceeds, decelerating its speed, winding the ions of the coma. *Suisei,* for the first time, caught the instant when the magnetic field trapped the cometary ions (Figure 13–16).

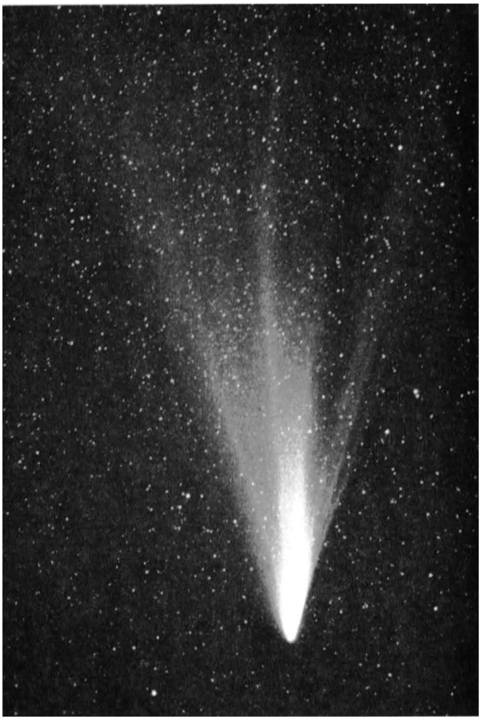

Figure 13–15: Two tails of Comet West.

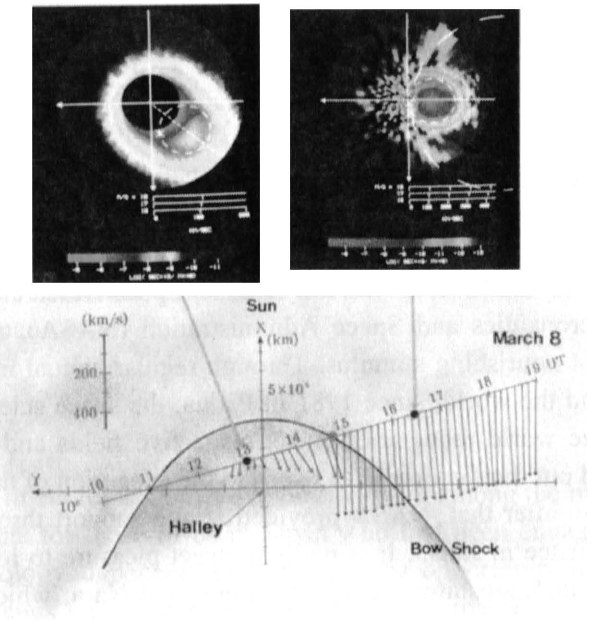

Figure 13–16: Solar magnetic field traps cometary ions (*Suisei*).

After Halley's Comet Has Gone

In the sequel, M-3SII launched a number of satellites into Earth orbit, and thus served as a midwife to send Japanese space science to the international stage:

- *Ginga* (*Astro-C*), which detected X-rays from supernova SN1987A;
- *Akebono* (*Exos-D*), which caught aurora in UV from space;
- *Hiten* (*Muses-A*), which helped ISAS master swing-by technique;
- *Yohkoh* (*Solar-A*), which continued to catch solar flares in X-ray; and
- *Asca* (*Astro-D*), which provided spectacular data in X-ray astronomy.

The experience of deep spaceflight that had been cultivated through Halley's Comet exploration, together with software and a big antenna, has been and will be utilized for the solar system exploration program in Japan hereafter. These explorations have included *Nozomi*, the first Japanese Mars orbiter, launched in 1998 by M-V; *Hayabusa*, an asteroid sample return mission, launched in 2003; *Kaguya*, a big lunar mission for mapping the surface of the Moon to be launched in 2007, and Venus and Mercury projects under preparation.

As I review the course of our history, I sometimes shudder at the mere thought of the possible absence of the M-3SII launch vehicle and all the satellites it launched. Without Halley's Comet days, with *Giotto* at the core, the approval of the development of M-3SII by the Japanese government would have reached a deadlock. Then the destiny of Japan's space science would have been situated in quite a different way. In that sense, Japan's space science today can be said to be the benefactors of the Halley mission.

Inter-Agency Consultative Group (IACG)

The formation of the Inter-Agency Consultative Group (IACG) by ESA, the Institut Kosmitscheski Isledowani or Russian Space Research Institute (IKI), the National Aeronautics and Space Administration (NASA), and ISAS, gave Japan the biggest nourishing stimulus. Through regular annual meetings, changing places around the world, since 1981 in Padua, the space science team of Japan could realize world recognition in its respective fields and obtain a lot of friends who held out their cooperative hands to the execution of the space science program of Japan after that. NASA provided strong support throughout the history of space science in Japan. It is really a sweet pleasure to look back on the IACG meetings in Kagoshima, Kyoto, Sapporo, and Nara, which were held in Japan.

The happiest time was when the IACG members were received by the Pope which, of course, was very impressive for all citizens of Japan, though living in a Buddhism country (Figure 13–17). At the meeting that year in 1986, the framework of the IACG meeting was decided to be retained to have a new theme for cooperation, solar-terrestrial physics at first, and solar system science after that.

Figure 13–17: Paulo II and IACG members (at the Vatican, 1986).

Through the whole course of this cooperation, Halley's Comet has continued to be a great symbol, and it was a starting point and the origin of every motive for Japan to join such a historical cooperation. It means that Japanese space science owes its birth to the 1980s Halley mission, which had prepared a wonderful stage that Japan.

Conclusion

The days of Halley's Comet exploration were among the most exciting and impressive events for those of us in Japan who had been engaged in space science and technology. Japanese scientists had the opportunity to get acquainted with a lot of friends for a historically significant international cooperation activity that was extolled by the Pope.

In conclusion, on behalf of all space scientists in Japan, I express our heartfelt thank you to all colleagues who participated in Halley's Comet exploration, and we hope that a large-scale international cooperation in space science opened by Halley missions would be succeeded in more exciting fashion, and space science activities in the world would be developed by younger people, full of friendships and enthusiasms as was beautifully done 20 years ago by the Halley Armada with *Giotto* as a bright flagship.

References

1 Y. Matogawa, "A Survey of Rocketry for Space Science in Japan," paper IAA-93-668 in *History of Rocketry and Astronautics*, Proceedings of the Twenty-Seventh History Symposium of the International Academy of Astronautics (held in conjunction with the 44th International Astronautical Congress, 16–22 October 1993, Graz, Austria), P. Jung, editor, Volume 22, AAS History Series (San Diego: Univelt, Inc., 1998), pp. 203–224.

2 *ISAS News*, No. 48 (March 1985).

3 *ISAS News*, No. 55 (October 1985).

4 *ISAS News*, No. 62 (May 1986).

5 K. Hirao, "The Planet—A Halley Encounters," *Nature*, Vol. 321 (1987).