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The Suisei/ Sakigake (Planet-A/MS-T5) Missions*

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1. Scientific Objectives

Japan's Institute of Space and Astronautical Science (ISAS) first decided in 1979 to send a spacecraft to Comet Halley. This decision was supported both by Japanese scientists who were anxious to carry out an interplanetary mission and by those Institute engineers who wanted to demonstrate the capabilities of a new launch vehicle. Comet Halley was considered a scientifically meaningful target because it has never been explored previously from close-range, it displays a wide range of interesting phenomema, and it returns only once every 76 years.

The Japanese mission to Comet Halley, called the 'Planet-A' mission, involved the launch of the 'Suisei', or Planet-A, spacecraft on 19 August 1985, to encounter Comet Halley in March 1986. In keeping with our normal procedure of launching a test spacecraft to confirm the flight performance of a newly developed launch system and the necessary technology for the main mission, a test spacecraft called 'Sakigake' (i.e. Pioneer), or MS-T5, was launched on 8 January 1985. Hence, the Planet-A project actually involves two spacecraft, Planet-A and MS-T5.

Initial calculations based on launcher performance and mission requirements led to a mass of about 140 kg for each spacecraft, allowing a scientific payload consisting of two or three experiments, each typically weighing 5 kg. An EUV imaging experiment and a solar-wind plasma experiment were selected from many proposed experiments for Planet-A, while MS-T5 carries three experiments for measurements of plasma waves, solar-wind plasma and the interplanetary magnetic field.

Planet-A has two major scientific objectives:

- to study the growth and the decay of the comet's hydrogen corona and to determine the total hydrogen production rate by taking UV images of the corona over an extended period
- to study the interaction of the solar wind with the cometary ionosphere by measuring the three-dimensional distributions of ions and electrons (energy range 30 eV-16 keV).

MS-T5 has as its scientific objective:

- to study the solar-wind plasma and, if possible, determine the signatures of the solar-wind/comet interaction at large distances from the comet.

The scientific experiments carried by Planet-A and MS-T5 are described below; the masses, powers and data rates are summarized later in Tables 6 and 7, respectively.

2. Experiments on the Suisei (Planet-A) spacecraft

2.1 Ultra-Violet Imager (UVI)

The main role of the Ultra-Violet Imager (UVI) is to obtain a succession of synoptic images of Halley's hydrogen corona. The latter originates from the photo-dissociation of water vapour released from the water ice, which is a major constituent of the volatile components in the comet nucleus. The imaging for several months around the

Halley encounter (November 1985 to April 1986) will have to cope with a wide range of heliocentric distances for Halley, with the Sun-Halley-spacecraft geometry changing continuously. This will allow us to obtain information about the heliocentric variation of the hydrogen production rate, velocity distributions of hydrogen atoms, etc. The significance of these observations will be enhanced if they can be combined with observations from other Halley or Earth-orbiting spacecraft (three-dimensional imaging).

Figure 1a shows a protoflight model of the UVI camera, and Figure 1b a cross-section of the instrument, with its guide mirror assembly, telescope and detector system. The later consists of a UV Image Intensifier (UVII) and Charge-Coupled Device (CCD) detector. A block diagram of the UVI is shown in Figure 2.

Since Planet-A is a spinning spacecraft, the telescope viewing direction at the time of taking the image is determined by the elapsed time between imaging and Sun-sensor output by the elevation angle of the guiding mirror. The UVII acts simultaneously as an image convertor for the CCD image pickup.

The image from the UVII lies essentially in the H alpha wavelength range, because the peak in the spectral response of the UVII photocathode material (KBr) resides in the

Figure 1a. Protoflight model of the Ultra-Violet Imager (UVI)

Figure 1b. Cross-section of the Planet-A Ultra-Violet Imager (UVI)

Figure 2. Block diagram of the Ultra-Violet Imager (UVI)

VUV-UV range. To prevent image blur due to the spacecraft’s spin and to satisfy the brightness detection limit (1 kR) requirement, the CCD is operated in Spin-Synchronized Shift (S3) drive mode. In this mode, the CCD charge pattern, which is induced by the optical image input, is transferred to the next position with the same speed of optical image shift on the CCD photo-sensitive area as the spacecraft spin. In the next position, the newly induced charge pattern is superimposed on the previous one. This produces a time-integrated image of the object by successive superposition. The UVI is only operated when the spacecraft spin is reduced to 0.2 rpm (see Section 5), in order to provide a sufficiently long integration time for the CCD. The CCP chip is cooled to - 30degC to reduce the dark current. The device’s image output is analogue-to-digital converted and read into a microcomputer. The compressed data are then read into the spacecraft’s data recorder. Table 1 summarizes the UVIs characteristics.

Table 1. Characteristics of the Ultra-Violet Imager (UVI)

Telescope	VUV-grade mirror lens, focal length 100 mm
Detector	UV Image Intensifier (UVII) plus Charge-Coupled Device (CCD)
Field of view	2.5deg x 2.5deg
Viewing direction	Derived from Sun sensor and adjustable elevation of guiding mirror
Image size	122 x 153 pixels of 8 bit each
Shutter interval	Programmable (highest repetition: 5 min; maximum

20 images/day)

The UVI works in three operational modes: 'search', 'observation' and 'photometer.' The search mode is intended for the initial finding of P/Halley. The comet 'hunt' is to be carried out over an area centred around the anticipated location of the comet, obtained from orbital calculations. After comet identification, the camera will be operated with a frequency tuned to the rate of the hydrogen corona's growth or change processes. Inside the corona, the camera will be operated in photometer mode. Because of its field of view (2.5deg x2.5deg), a photo-mosaic of the complete corona will be compiled from many pictures taken over a period of about two weeks around the closest approach to Halley.

The instrument is controlled completely by ground command and an open-loop control system has been adopted in order to reduce payload weight.

2.2 Solar-Wind Experiment (ESP)

The objective of this experiment is to measure the three-dimensional velocity distributions of the solar-wind ions and electrons in the energy range from 30 eV up to 16 keV within +/- 30deg of the ecliptic plane.

During the cometary encounter, the interaction of the solar wind with the cometary ionosphere will be investigated, paying particular attention to the mass loading of the solar wind by cometary ions, to the existence, location and strength of the upstream shock transition and of (possibly) backscattered particles from the shock and other, unexpected, plasma populations. Data will be collected on such solar-wind phenomena as the halo and core distributions of electrons, variations in the flow velocity, and the He++/He+ ratio in relation to solar rotation and longitude.

The instrument consists of one sensor for electrons and one for positive ions. As shown in Figure 3, each sensor consists of a fan-shaped collimator, a 270deg spherical electrostatic analyzer, and a Micro-Channel Plate (MCP) detector with five discrete anodes. The collimator's field of view is 5deg in azimuth and 60deg in polar angle, respectively, the latter being centred perpendicular to the spacecraft spin axis and thus in the ecliptic plane. The 270deg spherical analyzer has a better-defined response in energy-angle space than a quadrispherical analyzer.

A block diagram of the experiment is shown in Figure 4. After leaving the analyzer, particles are post-accelerated by a potential of 250 V for electron and 2500 - 3500 V for ion analysis. A Z-type three-stacked MCP detector is used to obtain a saturated pulse-height distribution over a wide dynamic range of counting rates. The anodes of

Figure 3. Schematic of the Planet-A solar-wind sensor

Figure 4. Block diagram of the Solar-Wind Instrument

CAD = Charge-sensitive Amplifier and Discriminator
CM = Command
CONT = Control
DPU = Data-Processing Unit
LVL = Level
MCP = Micro-Channel Plate
PS = Power Supply
SEA = Spherical Electrostatic Analyser
SV = Step Voltage

each MCP are split into five sections in order to provide a five-point angular distribution with a 12deg resolution in the polar direction. The output pulses from each MCP anode are amplified, shaped and accumulated in 19-bit counters. The contents of the counter are compressed into 8 bits and stored temporarily in the RAM buffer memory.

The instrument's angular distribution in the azimuthal direction, obtained by using the spacecraft spin, is 5.625deg within +/- 22.5deg of the solar direction and 22.5deg in the remaining spin phase.

The instrument has four modes of energy scanning (Table 2). In each mode the energy is scanned in steps as E(n)=30 exp (0.0066n), where E(n) is the energy of the n-th step and n=n(1), ...,n(2). Details of the energy scanning, which is synchronised to the spin phase, are shown for the E1-mode in Figure 5. During each spacecraft spin four energy steps are scanned periodically in every 22.5deg interval, i.e. the step is changed every 1.40625deg around the solar direction and 5.625deg over the remaining azimuthal directions. Consequently, it takes 24 spacecraft spins in the E1-mode to cover the complete energy range in 96 steps.

At high bit rate (2048 bit/s), three-dimensional velocity distributions will be obtained for both electrons and ions. These data, produced during one spin, will be transmitted in 10 PCM frames (5 s) during the next spin interval. At low bit rate (64 bit/s), two-dimensional distributions will be obtained for electrons and ions by summing the counts from each anode. As shown in the lower part of Figure 5, the energy scanning will be carried out over 16 spin periods once every 512 s, required to transmit these data.

The ESP instrument will be operated during the Halley-encounter phase as well as during the cruise and post-encounter phases, but only while Planet-A is in its high-spin-rate mode (nominally 6.3 rpm, see Section 5).

Table 2. Energy scanning modes of Planet-A Solar-Wind Plasma Experiment

Mode	n(1)	n(2)	delta n	Total no. of steps	Energy range (eV)	Time for one complete sequence* (s)
E1	0	95	1	96	30 ~ 15800	228.6
E2	O	63	1	64	30 ~ 1920	152.4
E3	32	95	1	64	250 ~ 15800	152.4
E4	l	95	2	48	34 ~ 15800	114.3

n(1) = lowest step number   delta n = step interval
n(2) = highest step number   * = times refer to high bit rate; always 512 s at low bit rate

Figure 5. Energy scanning scheme of the Solar-Wind Instrument. The upper panel corresponds to the high-bit-rate mode (B/R-H), the lower to the low-bit-rate mode (B/R-L) for the E1-mode. T(a) = spin period/64, T(b) = T(a)/4

3. Experiments on the Sakigake (MS-T5) spacecraft

3.1 Plasma-Wave Probe (PWP)

Many plasma-wave phenomena in the interplanetary medium are associated with turbulence in the solar-wind plasma. Plasma waves may also play an important role in the generation of the cometary ion tail, which is believed to be formed by wave - particle interactions due to the effective viscosity of the interplanetary plasma and collisions between tail plasma and solar-wind plasma.

The main objectives of the Plasma-Wave Probe (Fig. 6) are to measure electrostatic plasma waves near the local plasma frequency and whistler-mode waves. In addition, type-III radio bursts originating from electron beams ejected from the Sun and electromagnetic waves emitted from the comet will be monitored.

The plasma-wave sensors (Table 3) consist of a dipole antenna, measuring 10 m from tip-to-tip and operated over a wide dynamic frequency range (70 Hz-200 kHz), and a search coil to measure the magnetic-field components of electromagnetic whistler-mode waves in the frequency range 70 Hz-2.8 kHz. The latter employs 10**5 turns, wound on a ferrite core of 5 mm diameter.

Both sensors of the plasma-wave instrument (Fig. 7) are selectively connected to pre-amplifiers, with input thresholds of 0.1 micro V for the electric-field and 5 pT for the magnetic-field component. The amplified electric-field signals are analyzed by a

Table 3. Characteristics of the Plasma-Wave Probe

1.	Electric Field Sensor:	Dipole 5 m x 2
.	Frequency range:	Sweep 4 kHz-200 kHz Multichannel 70Hz-2.8kHz (16 channels)
.	Magnetic Field Sensor:	Search coil
	Frequency range:	Multichannel 7O Hz-2.8 kHz (16 channels)

Figure 6. The Plasma-Wave Probe, showing the two antennas with their equipment and the electronics package. The search coil is installed above the main electronics package

Figure 7. Block diagram of the MS-T5 Plasma-Wave Probe instrument. The top signal chain is the spectrum analyzer, the bottom chain the swept-frequency analyzer

A/D = Analogue-to-Digital Converter
BPF = Band-Pass Filter
DPU = Data-Processing Unit
PS = Power Supply
P/S = Parallel-to-Serial Converter

swept-frequency analyzer with a bandwidth of 2 kHz in the frequency range 4-200 kHz (128 steps), while a multichannel spectrum analyzer (32 channels) is employed for the electric and magnetic fields to analyze the low-frequency range from 70 Hz to 2.8 kHz, each channel filter having a bandwidth of 15% of the centre frequency. The output signals from both channels are converted to 12-bit words by logarithmically arranged analogue-to-digital converters.

The antenna will be deployed during the first month after launch. The PWP instrument will be operated during the cruise and encounter phases.

3.2 Solar-Wind Instrument (SOW)

The Solar-Wind Instrument on MS-T5 employs a Faraday cup to measure the bulk velocity, density and temperature of solar-wind ions. This conventional cup, mounted flush with the outer skin of the spacecraft, consists of four grids and an ion collector (Fig. 8). The front grid G(1), is connected to the satellite skin. A square-wave voltage is applied to the modulator grid G(2), alternating at 400 Hz between 0 and V volt. This produces a pulsating current by repelling and transmitting those incoming particles whose energy is between 0 and a maximum voltage V of 1.5 kV, which can be selected from the ground. The voltage will be fixed for most of the mission, although the instrument has several operating modes, such as automatic voltage change for every spin, automatic fine voltage sweep between two voltages, etc. The third grid is grounded to block any leakage of modulating voltage from G(2) to the collector. The fourth grid is negatively biased at - 100 V to suppress photo-electrons from the collector. The sensor is not sensitive to the solar-wind stream beyond an angle of attack of +/- 60deg. Table 4 summarizes the sensor's characteristics.

Figure 9 is a block diagram of the instrument. Both DC and AC collector currents are detected. The DC currents (ion current and secondary-electron current), which vary during each satellite spin, are used to check the angular characteristic of the Faraday cup itself and to monitor the photo-electron contribution to the collector current. The modulated ion current measured between 2x10**-12 A and 10**-8 A is sampled at 128 points between - 90deg and +90deg with respect to the solar-wind direction, i.e. every 180deg/128=1.4deg the collector current is sampled as a function of the spin angle. The bulk velocity and ion density are calculated from the point where the slope of the collector-current versus spin angle function becomes a maximum.

Table 4. Charactertstics of ITS Solar-Wind Instrument

Transmission of the grids	G(1) G(2), G(4) : 90%
	G(3) : 77%
	Overall : 70%
Distance between grids	4 mm
Collector diameter	90 mm
Maximum voltage to be applied to G(2)	1.5 kV +/- 40 V
Collector impedance	10 M Ohms (with 20 pF) collector-ground stray capacity

3.3 Interplanetary Magnetic-Field Experiment (IMF)

The Interplanetary Magnetic-Field Experiment is designed to study macroscopic and microscopic structures in the helio-magnetosphere and in the cometary magnetosphere, as well as large-amplitude low-frequency hydromagnetic waves in the solar wind. The data gathered will be compared with the configuration, brightness and variations of Halley's corona, which will be imaged by the UV camera on Planet-A.

The IMF is to be measured by a triaxial, ring-core, fluxgate magnetometer sensor mounted on a 2 m-long boom (Fig. 1O). This boom was extended soon after injection of the spacecraft into orbit.

Figure 8a. The MS-T5 Solar-Wind Instrument

Figure 8b. Schematic of the Faraday-cup sensor of the MS-T5 Solar-Wind Instrument

Figure 9. Block diagram of the MS-T5 Solar-Wind Instrument

BPF = Band-Pass Filter
HK = Housekeeping
LPF = Low-Pass Filter

Figure 10a. The MS-T5/IMF instrument with the boom folded

Figure 10b. The MS-T5 Interplanetary Magnetic-Field (IMF) sensor

Figure 11 is a block diagram of the IMF instrument, the dynamic ranges of which are +/- 64 nT and +/- 128 nT. Table 5 summarizes the instrument's sensitivity, resolution, bit rate, and sampling rate. The dynamic range and conversion output will be selected by ground command.

During the initial period of the mission, when the telemetry signals are strong enough, the high-bit-rate data will be used for the study of the ULF hydromagnetic waves. The low-bit-rate data will be used while the spacecraft is closer to Comet Halley to study the macroscopic structure of the helio-magnetosphere and the cometary magnetosphere.

Table 5. Characteristics of the Interplanetary Magnetic-Field Instrument

Sensitivity				Sampling rate (s)	
Dynamic range (nT)	Output (bit)	Resolution (nT/LSB)	Telemetry bit rate (bit/s)	Format-1	Format-3 & 4
			h.b.r.	1/8	1/16
+/- 64	12 (high gain)	0.03125	l.b.r.	4	2
(Narrow)	8 (low gain)	0.5	h.b.r.	1/16	1/32
			l.b.r.	2	1
			h.b.r.	1/8	1/16
+/- 128	12 (high gain)	0.0625	l.b.r.	4	2
(wide)	8 (low gain)	1.0	h.b.r.	1/16	1/32
			l.b.r.	2	1

h.b.r. = high bit rate (2048 bit/s) l.b.r. = low bit rate (64 bit/s)

4. The spacecraft

Planet-A (Fig. l2) and MS-T5 (Figs. 13, 14) are identical spacecraft except for their scientific payloads. The main spacecraft body is a cylinder, 140 cm in diameter and 70 cm high. The spinning spacecraft is about 250 cm high, from the top of the high-gain antenna dish to the bottom of the medium-gain antenna. Its outer wall is covered by solar cells which produce 100 W of power under optimum conditions. An equipment platform mounted to a central thrust tube carries most of the subsystems, including the mechanically despun, high-gain antenna, two hydrazine fuel tanks, the thrusters, and the experiment sensors (Fig. 15). A star scanner and a nutation damper are attached to the thrust tube.

Planet-A and MS-TS weigh 139.5 kg and 138.1 kg, respectively, including 10 kg of hydrazine propellant in each case. Both spacecraft are spin-stabilized, with the facility to change the spin rate (see Section 5). The spin axes of both spacecraft will be kept perpendicular to the ecliptic plane.

The spin-rate of Planet-A will be changed quite frequently. It must be reduced, for example, to 0.2 rpm during the UVI imaging operating using an onboard momentum wheel, while during communication periods and during solar-wind measurements a spin-rate of 6.3 rpm is preferable.

The spacecraft/Earth geometry and the data-rate requirements preclude the use of a single antenna for the duration of the mission. The antenna subsystem therefore consists of a high-gain antenna, a medium-gain antenna as a backup, and a low-gain antenna for near-Earth operation. The despun high-gain antenna has an offset-parabolic reflector with a diameter of 80 cm and a gain of 21.5 dB in uplink and 22.5 dB in downlink transmission. The communications subsystem operates in S-band using a 5 W transmitter.

Planet-A has two data formats: Format-1 provides Ultra-Violet Imager (UVI) data. Format-2 Solar-Wind Experiment (ESP) data (Table 6). MS-T5 has four data formats

(Table 7). The data rates of both spacecraft are 2048 bit/s (without coding) in 'high bit rate' and 64 bit/s (with convolutional coding) in 'low bit rate' mode. The bit rate used will depend on the communication distance.

The ground station for the mission has been built at Usuda, about 170 km northwest of Tokyo. The station's 64 m diameter dish antenna has a gain of approximately 63 dB (Fig. 16). A 64 bit/s communication link (convolutionally encoded PCM) is expected to be possible from 1.1 AU, which will be the comet-Earth distance during the Planet-A encounter.

Figure 11. Block diagram of the IMF instrument

BPF = Band Pass Filter
NF = Nyquist Filter
PSD = Peak Sample Detector

Figure 12. The Planet-A Spacecraft

Figure 13. The MS-T5 spacecraft

Figure 14. The MS-T5 spacecraft on top of the third stage of the M-3SII launcher

Figure 15. The interior of the MS-T5 spacecraft

Figure 16. The 64 m dish at the Usuda tracking station

Table 6. The Planet-A scientific payload

Experiment	Mass (kg)	Power (W)	Data rate (bit/s) Format 1/2	Principal Investigator
UVI	7.5	8.9	H 1568/0 L 98/0	E. Kaneda, Geophys. Res. lab., Faculty of Science, Univ. of Tokyo
ESP	4.7	4.9	H 0/1408 L 0/88	T. Mukai, Res. Div. Planetary Science, ISAS, Tokyo

Format 1 UVI and UVI check H = High bit rate
2 ESP L = low bit rate

Table 7. The MS-T5 scientific payload

Experiment	Mass (kg)	Power (W)	Data rate Format 1/2/3/4	Principal Investigator
PWP	5.2*	1.7	H 512/768/768/0 L 32/48/48/0	H. Oya, Faculty of Science, Tohoku Univ., Sendai
SOW	2.0	1.1	H 512/768/0/768 L 32/48/0/48	K. Oyama, Res. Div. Planetary Science, ISAS, Tokyo
IMF	5.4**	2.	H 400/0/768/768 L 25/0/48/48	T. Saito, Faculty of Science, Tohoku Univ., Sendai

Format 1 PWP SOW IMF H = High bit rate

2	PWP	SOW	L = low bit rate
3	PWP	IMF	
4	SOW	IMF	

* Includes dipole antenna, search coil and electronics
** Includes boom

5. The mission

Planet-A and MS-T5 were launched separately by M-3SII launchers (Fig. 17). The M-3SII launcher is a new three-stage solid-propellant rocket with a solid kick-stage motor attached. Both spacecraft were injected directly into a heliocentric comet transfer trajectory. Immediately after launch, each spacecraft was tracked for about 8 h per day. They were then despun from 120 rpm, to about 30 rpm, using the thruster subsystem. The spacecraft's attitude was initially automatically adjusted such that its spin axis was perpendicular to the Sun-spacecraft line. During the subsequent ground contact, the spin rate was further reduced to 6.3 rpm and the spin axis reoriented to be perpendicular to the ecliptic plane. After the first 4-5 d of ranging and accurate orbit determination, a mid-course correction manoeuvre was carried out. During the interplanetary cruise, attitude maintenance operations will have to be performed at 1Od intervals.

Both spacecraft will make their closest approach to Halley near the time of the comet's post-perihelion crossing of the ecliptic plane (Fig. 18).

The Planet-A spacecraft will be targeted to pass Halley's nucleus on the sunward side at a distance of 150000 km on 8 March 1986. Solar-wind measurements will be carried out continuously on Planet-A during the cruise, except during the periods of UVI imaging, and this spacecraft will be in contact with the ground station for 7-8 h per day. In this period, during which the spacecraft will be spinning at 6.3 rpm, its bubble memory will be read out, solar-wind measurements made, and commands received from the ground. During the remaining 15 h per day the spacecraft will be spinning at 0.2 rpm and taking images. It takes 5 - 10 min to spin-down and 30 min to spin-up the spacecraft. During the 15 h, six images can be taken, spaced in time, to fill the 1 Mbit bubble memory. At large distances from the Earth, data can be transmitted from the spacecraft at a rate of 64 bit/s. In this mode, each memory read-out will require about 4 h.

Figure 17. Launch of the MS-T5 spacecraft on a M-3SII vehicle from Kagoshima Space Center on 8 January 1985

Imaging is planned to start in early November 1985, when Halley crosses the ecliptic plane at a heliocentric distance of 0.85 AU. An attempt will be made to find

Figure 18. Heliocentric orbits of Planet-A and MS-T5

the comet with the camera as soon as possible, despite the large distance from the spacecraft. Imaging will continue at least until mid-April 1986, when the hydrogen corona will no longer be detectable. Halley will then be at a heliocentric distance of 1.39 AU and at the same time will be reaching its closest distance to Earth of 0.42 AU. During Planet-A's journey to Halley, an attempt may also be made to image the corona of Giacobini-Zinner if this comet's hydrogen production rate is high enough.

The MS-T5 spacecraft will be targeted to pass within 7 million kilometres of Comet Halley on 11 March 1986. About one month of this test spacecraft's initial cruise phase will be used for technical tests, including the operation of the new 64 m deep-space station at Usuda. Later, its three scientific instruments will study the solar-wind plasma and, if possible, detect the signatures of the solar-wind/comet interaction. When the other spacecraft make their closest approach to Halley, MS-T5 will be used to make complementary solar-wind measurements.