Development of the Venus Climate Orbiter PLANET-C (AKATSUKI)

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Abstract

Launched successfully on May 21, 2010, PLANET-C (AKATSUKI) is Japan's first inner planet exploration spacecraft. Although it failed in the Venus orbit insertion mission, it is still continuing the flight and it is now targeting a successful insertion attempt in six years time. This paper introduces the system design of the PLANET-C explorer and its associated technologies.

Keywords

Venus, deep space explorer, system design, un-cooled, IR rays, bolometer, MEMS, vacuum package

1. Introduction

The Venus Climate Orbiter PLANET-C is Japan's first inner planet exploration spacecraft. It is also the world's first planetary meteorology satellite for investigating the activity of the Venusian atmosphere and for defining its meteorology in the context of comparative planetary meteorology. NEC has developed, manufactured and tested the entire system of the PLANET-C under the guidance of the Japan Aerospace Exploration Agency (JAXA). The PLANET-C was launched from the JAXA Tanegashima Space Center on May 21, 2010, using the H-IIA No. 17 launch vehicle. This paper gives an outline of the system design of the PLANET-C explorer and introduces the specifically adopted technological elements.

2. Objective of PLANET–C

The planet Venus has almost the same size and weight as the Earth and it is considered that a clear understanding of issues concerning Venus, will result in a deeper understanding of the Earth. Our twin sister, Venus still presents us with a major unresolved mystery as its atmosphere is rotating at a 60-times higher speed than the rotation of the planet itself. To solve this mystery known as super rotation is the main objective the PLANET-C mission.

3. Characteristics of the PLANET–C Missions

The three dimensional motion of the clouds surrounding the planet Venus can be recorded by imaging views of clouds at various altitudes using cameras based on various wavelengths. **Fig. 1** shows the cameras that are mounted on the PLANET-C and their relationships with the imaging targets.

The PLANET-C travels along an extended elliptical orbit approximately above Venus's equator. The altitude is about 300 km at the closest point to Venus and about 80,000 km at the most distant point. When PLANET-C is at its most distant point from Venus, the orbiter will move in synchronization with the Venusian atmosphere to observe changes in a targeted cloud formation over a long period of time. When the PLANET-C is at its closest point to Venus, the orbiter will change its relative positional relationship with the Venusian atmosphere and move over different atmospheric locations.

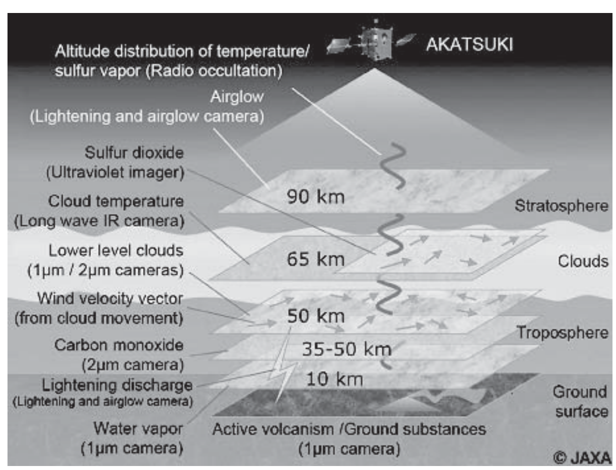

Fig. 1 Imaging targets of cameras mounted on PLANET-C (AKATSUKI).

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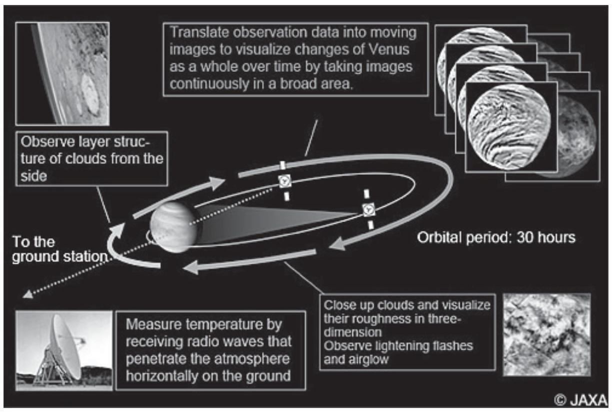

Fig. 2 Venus Orbit and Mission objectives of PLANET-C (AKATSUKI) .

Fig. 2 shows the mission objectives of PLANET-C in Venus orbit.

4. System Outline of PLANET–C

The PLANET-C probe is the latest deep space explorer to inherit the bus module of the MUSES-C (HAYABUSA) that succeeded in returning asteroid samples for the first time. The light weight of 517.6 kg at launch is less than half the weight of the Venus exploration mission “Venus Express” of the European Space Agency (ESA). The main body has a rectangular parallel pipe shape of 1,450 × 1,040 × 1,400 mm, and a φ900 mm X-band (about 8 GHz) high-gain antenna for transmission on the +Z panel side and a φ900 mm rocket coupling ring on the - Z panel side. At the center of the rocket coupling ring is a bipropellant 500 N orbital maneuvering engine with a length of about 450 mm. In the ±Y direction, a solar paddle panel measuring 923 × 1,440 mm is held by means of a 1,088 mm boom. **Table** shows the bus specifications of the PLANET-C and **Fig. 3** its external dimensions.

The PLANET-C controls attitude with the triaxial attitude control of the zero-momentum method and adopts an attitude similar to that of a geostationary satellite by installing the SAP (Solar Array Paddle) shaft in the orbit plane. The SAP attitude is controlled so that the solar cells always face the Sun using an SADA (Solar Array Drive Assembly) as the rotation drive system. The ±Y panels are used as the heat radiating surfaces on which the high-heat-generating equipment and the observation equipment are mounted. The attitude control in the

Table Bus specifications of PLANET-C (AKATSUKI).

Item	Value	Unit	Conditions
Generated power	≥480	W	@ 1.0781 AU
	≥700	W	@ 0.7 AU
Weight at launch	517.6	kg	WET
Data rate	≥2	kbps	@ Earth distance 1.7 AU
DR capacity	1,020	MB	Reproduce/recording area
	2	GB	Backup flash memory
Attitude determination precision	0.1°		3σ, steady state
Attitude stability	0.01°	/45 sec.	3σ, steady state
Design service life	4.5	years	
Launch vehicle	H-IIA carrier rocket		Type 202, 4S fairing

Item	Description
Attitude system	Triaxial control with low angular momentum, RW 4 skews
BAT	Li-ion secondary batteries, 23.5 Ah × 2
SAP	InGaP/GaAs/Ge, 1,430 × 810 mm (× 1 paddle)
Noninal bus voltage	50 V
C&DH bus	RS485, PIM bus
Command method	CCSDS telecommand
Telemetry method	CCSDS AOS
Up-/down-link band	X-band
Structure	Rectangular parallelepipe shape, thrust tubes, Al honeycomb
Propulsion system	3N class monopropellant RCS (N2H4) × 1, 23N class monopropellant RCS (N2H4) × 8, 500N class bipropellant RCS (N2H4,NTO) × 1
Propellant on board	RCS propellant: 196.3 kg

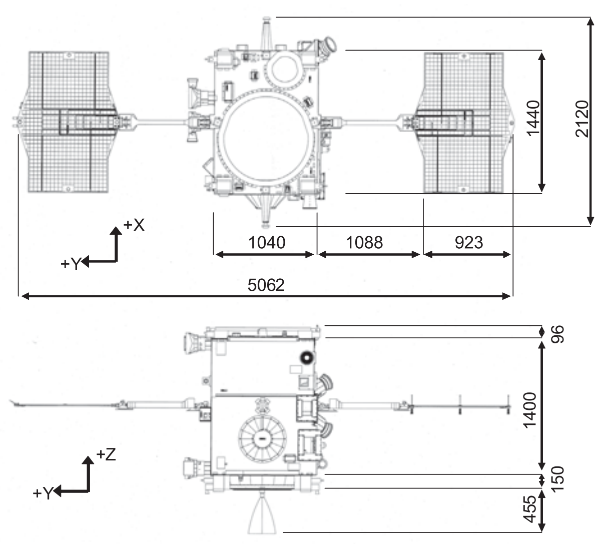

Fig. 3 External dimensions of PLANET-C (AKATSUKI).

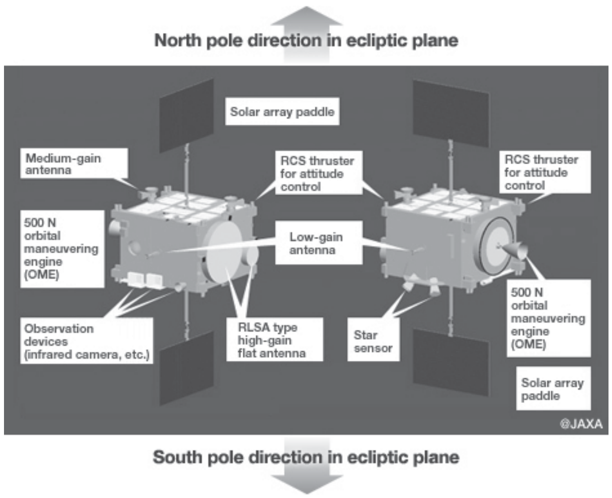

Fig. 4 Configuration of PLANET-C (AKATSUKI).

orbit plane is performed by eight monopropellant 23N thrusters and control outside of the orbit plane is performed by four 3N thrusters. **Fig. 4** shows the configuration of the PLANET-C.

5. PLANET–C Technologies

NEC has been acting as the system integrator of the PLANET-C mission, playing a key role in the system design from the initial stage of the project. In the fabrication (MONODZUKURI) phase, we designed and manufactured the structural and thermal control subsystems as well as the bus equipment; including the power, communications, data processing, and attitude and orbit control subsystems. The newly developed mission equipment includes the UV imager (UVI) and the longwave IR camera (LIR).

5.1 Features of the Bus Module

(1) Overall bus system

By handling the three panels on which the main equipment is installed as one unit, we wired the electrical system instrumentation (cables) without relay connectors, thereby reducing the weight of the overall bus system.

(2) Structural subsystem

We used a thrust tube incorporating an aluminum honeycomb core and CFRP skin as the main load path (main structure) to reduce the weight of the system. **Fig. 5** shows the PLANET-C panel configuration.

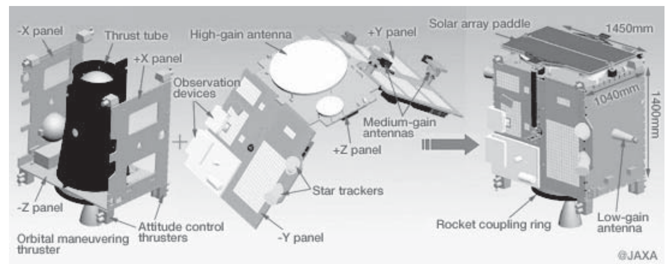

Fig. 5 PLANET-C (AKATSUKI) Panel Configuration.

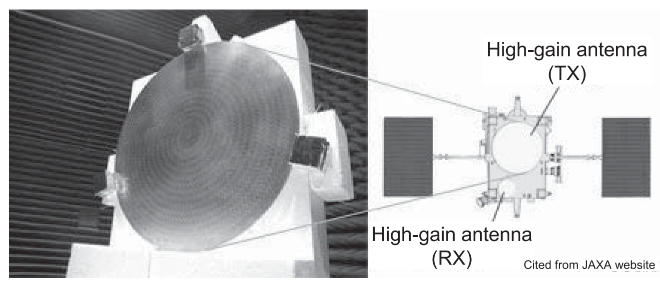

Fig. 6 High-Gain Antennas Mounted on PLANET-C (AKATSUKI).

(3) SAP (Solar Array Paddle)

We developed an SAP that is resistant to high and low temperatures and can withstand twice the sunlight intensity of that on the Earth as well as the low temperatures experienced during the shade period of 90 minutes maximum.

(4) Thermal control subsystem

To supply the required electrical power by using the SAP, which was reduced in size to lighten the weight of the orbiter, we used software capable of leveling out the heater power supply and preventing peak power output.

(5) Power subsystem

We used a series-switching regulator that makes it possible to always output the peak power even if the distance to the sun and the solar cell voltage are changed. In addition, we developed two secondary lithium-ion batteries for the orbiter; each consisting of 11 cells in series and having an electric charge of 23.5 Ah.

(6) Communications subsystem

We used radial line slot-array antennas as the X-band high-gain antennas to avoid light condensing and to reduce the weight of the system. **Fig. 6** shows an image of the high-gain antennas used for the PLANET-C. For the main power amplifier, we adopted a small, lightweight 20 W traveling wave tube amplifier.

(7) Data processing subsystem

We used an on demand telemetry method that makes it possible to freely output desired telemetry data (information on the temperatures of satellite parts and the operating status of the payload equipment) within the previously determined range. In particular, this makes it possible, by defining report packets, to output short packets indicating changes in the orbiter status so that the ground station can collect and check data at the start of the communication that is held as soon as the orbiter becomes visible from the ground station. The PLANET-C also incorporates an automated autonomous function with a high degree of flexibility.

(8) Attitude and orbit control subsystem

We used a triaxial attitude control subsystem that determines the attitude by using a combination of various attitude sensors (two star trackers, three inertial reference units, one fine sun sensor, and five coarse sun sensors) and controls the attitude by using four diagonally placed reaction wheels. This configuration is made highly reliable by its advanced failure detection, isolation, and recovery features.

5.2 Features of the Mission Payload

Fig. 7 shows an image of PLANET-C during the overall testing of the FM (Flight Model). The two sensors developed by NEC are visible in the picture.

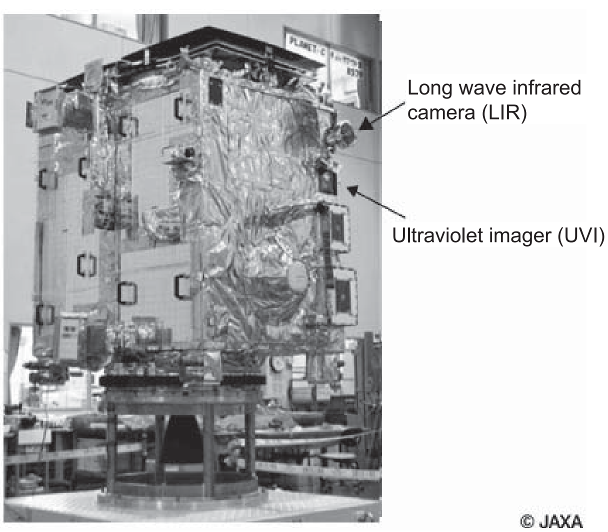

Fig. 7 Overall view and mounted cameras of PLANET-C (AKATSUKI).

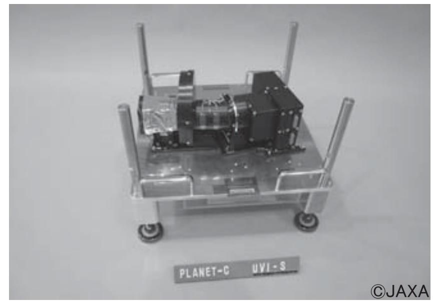

Photo 1 UVI.

Photo 2 Earth image by the UVI.

The UV imager (UVI) captures the distribution of sulfur dioxide involved in the formation of clouds and the distribution of unknown chemicals that have absorptive properties of UV wavelengths using UV rays and, based on the variations of these distributions, determines the wind speed distribution at the cloud-top altitude. **Photo 1** shows an image of the UVI.

Photo 2 shows an image of the Earth obtained with the UVI when the orbiter was at a distance of 250,000 km immediately after the launch.

The long-wave IR camera (LIR) uses IR rays that have a wavelength of 10 μm to create an image of the cloud temperature, and to clarify undulations and convection currents in the upper cloud layer, as well as the wind speed distribution at the cloud-top altitude on the night side. **Photo 3** shows an image of the LIR.

Photo 4 shows an image of the Earth obtained with the LIR when the orbiter was at a distance of 250,000 km immediately after the launch. Compared to the UVI image above, the Earth in the UVI image is imaged like a thin crescent moon but the Earth in the 10 μm IR image shows the overall shape regardless of the brightness of the visible light.

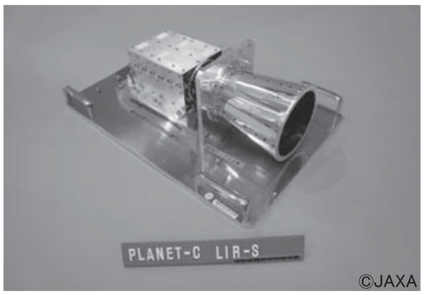

Photo 3 LIR.

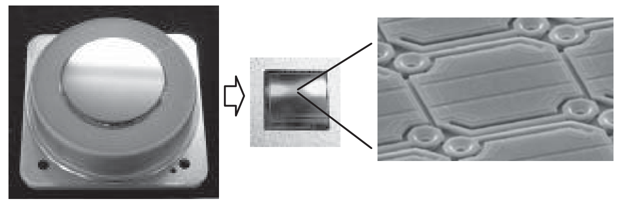

Fig. 8 Un-cooled IR sensor of the LIR.

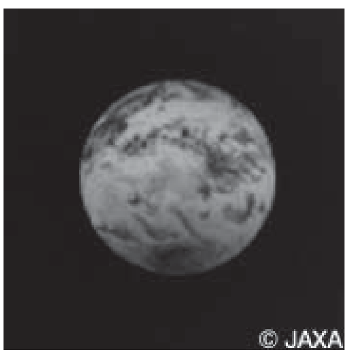

Photo 4 Earth image by the LIR.

5.3 Bolometer

The LIR uses a bolometer that mounts an un-cooled IR sensor. Previous IR sensors used a special chip that needed to be cooled to -196°C. However, as the cooled IR sensor required refrigeration, the bulky system size and high system cost posed problems.

On the other hand, the un-cooled IR sensor features: a thermal type IR sensor with a temperature resolution of below 0. 1°C, non-necessity of cooling and compact size and low price. These advantages are due to the development of; 1) the MEMS (Micro Electro-Mechanical Systems) device that is thermally isolated from the IC chip used as the substrate by applying the chip microfabrication technology; 2) deposition/processing technology of the bolometer material (vanadium oxide) film with a property of a large resistance variation against heat; 3) signal processor circuit for reading trace IR signals, and; 4) vacuum package to insulation the MEMS structure device from the heat generated from the IC chip used as the substrate. **Fig. 8** shows an external view of the un-cooled IR sensor package installed on the LIR, the 320 × 240-pixel sensor chip and the 37μm-pitch sensor MEMS pixel [1)].

6. Conclusion

The PLANET-C attempted the Venus orbit insertion (VOI) by firing its 500N thruster on December 7, 2010. Unfortunately it failed to enter the Venus orbit due to an irregularity in the propulsion system (this function was not managed by NEC). However, as a second opportunity will come in another six years, we are planning to retry the VOI at that time. After the MUSES-C and PLANET-C, NEC intend to go on to help pioneer the Age of Geographical Discovery in the Solar System under the guidance of JAXA with an eye to subsequent explorations of the planets Mercury, Mars and Jupiter.

Reference

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