Development of the Circumpolar Stratospheric Telescope FUJIN for Observations of Planets

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Introduction

It is important to conduct long-term continuous observations for studies on time-dependent events of the planetary atmospheres and plasmaspheres. We have developed a balloon-borne telescope "FUJIN" that has the purpose of observing the atmospheres of Jupiter and Venus from the stratosphere. We are developing a second telescope "FUJIN-2" aiming the observation of these planets. This telescope took over both the control systems, BBT2009 and FUJIN-1.

About Balloon-borne Telescopes

Fig.1; FUJIN-1 appearance

Why do we observe from the stratosphere with a balloon -mounted telescope ?

- Good Visibility (~0.1")
  At ultraviolet and visible wavelength, the observation at the diffraction limit can be performed.
- Wavelength region
  The observation from 300nm wavelength can be performed.
- Long-term and continuous observation
  In the polar region, there are planets that can be observed continuously for longer than 24 hours.
- Observation from a fixed direction
  FUJIN can observe a planetary disk from a fixed direction.

Table 1 shows the history of the FUJIN project. The FUJIN project has failed to carry out observations twice in the previous attempts. The weakest point of the FUJIN project that it does not carry out observations at the optimum time for observations FUJIN-1, the first model of FUJIN-project, had an unsuccessful flight due to bad weathre conditions and a malfunction in the JAXA's bus systems. However it was concluded that FUJIN-1 can be controlled in the stratosphere from the results of ground tests. The main purpose of the development of FUJIN-1 wasn't to carry out observations but to develop the control systems. Therefore, after the development of FUJIN-1 , we started development of FUJIN-2 for planet observations.

Table.1:History of FUJIN Project

2002	Start of the project
2009	1st experiment was failed due to failure in the onboard CPU
2010	Improvement
2011	Experiment was cancelled due to development delays
2012	Cancelled due to bad wind condition
2013	Cancelled due to malfunction in the bus system
2014	Start up developing FUJIN-2

FUJIN-2 Optical System

The telescope of FUJIN-2 is a Schmidt Cassegrain type with a Nasmyth focus and has a mirror that has an effective aperture of 406mm. Table.2 shows the specifications of FUJIN-2 and Fig.3 shows the light path in the FUJIN-2 The original focal point distance of FUJIN-2 was 3000mm but this distance was extended up to 6000mm using a double sized Barlow lens. The end points of the FUJIN-2 light path are separated into two light path through the half mirror. FUJIN-2 can provide multi-wavelength observations using a filter turret in front of a CCD camera. The light into the PMT is used by the attitude control in stage 3 (accurate directivity control A signal period from PMT to TTM is approximately 1 kHz (FUJIN-1). Tab.3 shows the target wavelengths of FUJIN-2.

Table.2: FUJIN-2 telescope specifications

Telescope type	Schmidt Cassegrain with a Nasmyth focus	
Effective aperture	406	mm
Focal point distance	～6000	mm
Band-pass filter	8	Sheets
Detector	a CCD	

Table.3: Subject of research

Mercury	Venus	Jupiter(main)
	290~320nm SO_2	589nm Na
	320~400nm UV	672nm S
589nm Na	777nm O	800nm NH_3
	900nm NIR	890nm CH_4
	1270nm O_2	920~945nm H_2O

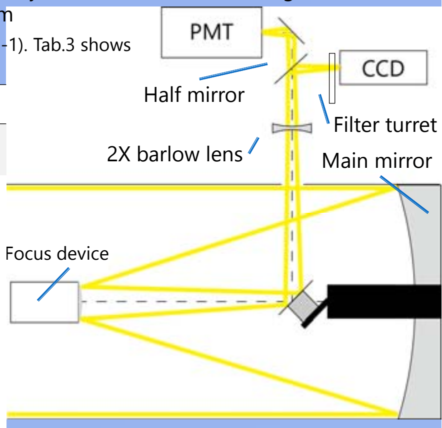

Fig4: FUJIN-2 optical system

FUJIN Control System

For realizing observations at a visibility increment of 0.1", it is necessary to have highly developed attitude controls and pointing controls. In the FUJIN-2, the attitude controls are taken from the FUJIN-1 system and are divided into 3 stages with each of these stages performed separately (Fig.2).

○Control stage 1

In the first phase, a gondola of FUJIN-2 is controlled in 3 dimensions by a decoupling mechanism (DCP) and control moment gyros (CMGs).

○Control phase 2

In the second control phase, the target is captured by the telescope using two cameras, a wide angle camera and a narrow angle camera.

○Control phase 3

In the final control phase, the target is established continuously in the center of view field by a Tip/Tilt mirror with 2 axes and a photomultiplier tube (PMT).

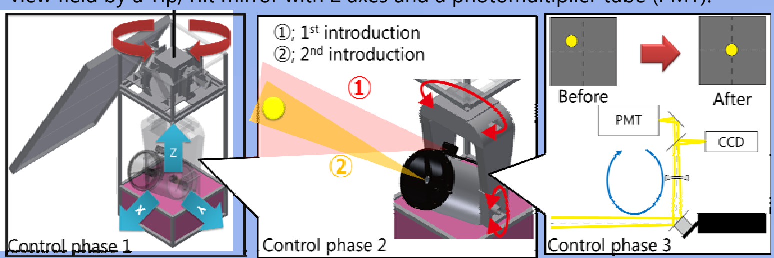

Fig.2: FUJIN-2 Control System

○Results of the attitude control tests in FUJIN-1

Fig.3-a and Fig.3-b show the azimuth and elevation amplitudes respectively when disturbances are input The pointing accuracy as RMS values are shown in Fig.3-c and Fig.3-d, respectively. The effective azimuth ratio is 45.5% and elevation ratio is 21.7% into the TTM.

- Azimuth: no significant difference was observed between the case with and without the disturbance.
- Elevation: constant vibrations every 3~4 seconds.

In the development of FUJIN-2, we introduced the 3 dimensions gondola controls to remove the pendulum movement. When the development of FUJIN-1 was completed, it was established that FUJIN-1 could attain a pointing accuracy of approximately 0.4", we finished the development of FUJIN-1.

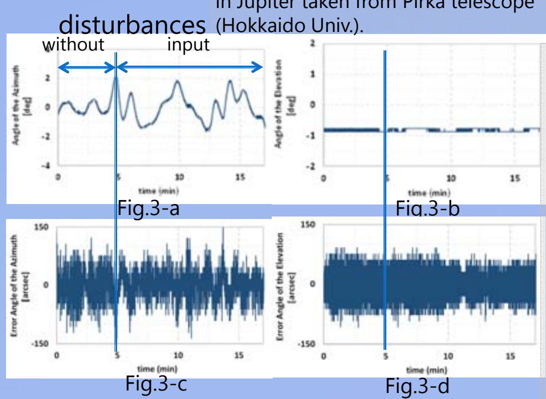

Fig.3: The integrated test results of FUJIN-1 in 2013

Subject of the Observation

○Jupiter(Main Target)

- The Rossby wave existing in the Jupiter atmosphere is important for understanding the atmosphere dynamics.
- The white edge in the polar region of Jupiter in Fig.4 shows the Rossby wave with a wave number of 12 as shown in Fig.4.
- Cumulonimbus clouds transport heat vertically in the Jupiter atmosphere and are interactive with the planetary scale zones and belts. There is a hypothesis that these structures were produced via Cumulonimbus cloud activities.

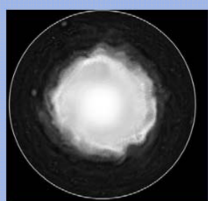

Fig.5: A region of Jovian South-pole at 890nm from Cassini. [Barrado-Izagirre et al., 2008]

For understanding the Jupiter atmosphere structure, we will obtain the following information .

- Time fluctuations and velocity of the haze wave structures in the polar region of Jupiter for several days.
- The partial distribution of the clouds and the correlation of background wind speeds and time course of these correlation at the troposphere altitude in Jupiter.

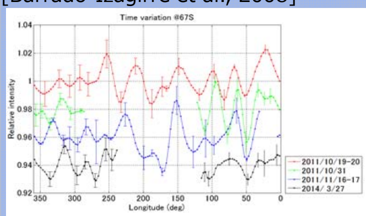

Fig.6 The time fluctuation of the longitudes profiles of the haze brightness in the 67°S in Jupiter taken from Pirka telescope (Hokkaido Univ.).

○Venus(Optional Target)

- Super rotation
- Searching for proofs of unidentified absorbed materials

○Mercury(Optional Target)

- The atmosphere light of Na

Future Plans of FUJIN-2

○The plan that starting observation from Sweden, Kiruna about a week at summer in 2017

- Flight span : About a week
- Target : Venus
- From above Atlantic

○The plan that observing at Australia at April in 2017

- Flight span : About 24
- Target : Jupiter
- Above Australia

We will finish to integrate all sub system by September, 2017, FUJIN-2 gondola will be shipped to a test region.

This document is provided by JAXA.