THERMAL-INFRARED IMAGER TIR ON HAYABUSA2: SCIENCE AND INSTRUMENTATION.

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Introduction: Thermal imagery (thermography) of asteroid is planned using the Thermal Infrared Imager (TIR) on Hayabusa2. Purposes of TIR are to investigate the nature of C-class NEA 1999JU3 and its origin and evolution processes through thermophysical properties of asteroid surface. TIR data is also used to provide information on the landing site selection for sampling and on the assessment of safe descent operation against thermal environment. This instrument is based on LIR (Long-wavelength Infrared imager) [1] onboard Akatsuki, the Japanese Venus climate orbiter, and now conducting environment tests to be mounted on Hayabusa2.Science objectives and operation plans of TIR as well as its instrumentation are described here.

Hayabusa2 Mission: Hayabusa2 is the follow-on mission after Hayabusa that successfully conducted the first round-trip to near-Earth asteroid 25143 Itokawa and the first sample-return from there in June 2010. Hayabusa2 is primarily a sample-return mission, and remote sensing of the asteroid also has strong importance to understand the nature of the asteroid and to characterize its global features, which is complementary to analysis of returned samples.

Science Objectives of TIR: Main goals of TIR by investigation of thermophysical properties of asteroid surface are 1) to understand the origin and evolution of asteroid and 2) to characterize the current state of micro-gravitational small body.

To understand the origin and evolution of asteroid;

Structure of asteroid observed on the surface or inside huge craters indicates the formation processes of asteroid: porous and homogeneous structure expected in case of simple accretion of dust/ice compounds followed by sublimation of ices, dense and homogeneous one for metamorphosed and compaction processes after accretion, and heterogeneous one composed by multi-sized boulders for rubble-piles from impact fragments.

Regional variation of surface condition or size distribution shows the history of asteroid: porosity of huge boulders indicating the degree of past compression in the parent body, porosity of smooth area for sedimentation or granular flow under micro-gravity. TIR is also expected to map the crater ejecta area formed under micro-gravity.

Reaction and alteration related to hydrated or organic materials strongly reflects the absorption of 3 micron band, and TIR date contributes to reduction of thermal radiation component.

To characterize the current state of the small body;

Orbital and rotational evolution of Near-Earth objects is caused by thermal effects called Yarkovsky and YORP effects, respectively. They are verified using the asteroid thermal model derived by TIR.

Relation of asteroid size to averaged thermal inertia or typical thermal conductivity is summarized by ground-based observations [2], but TIR will provide a disc-resolved thermal inertia map of 1999JU3, a good 'groundtruth' to verify and reconstruct it.

Thermal imagery sometimes detects the geologic features better than optical imagery can do, especially for the surface with different porosity (crater ejecta, veins, grooves, or buried structures)

Dust environments surrounding the asteroid, which might be supplied by electrostatic forces or impacts of micro-meteorites, are possibly detected by thermal emission imaging.

Other Objectives of TIR: TIR also contributes to planning key operations of Hayabusa2 such as landing site selection and safe assessment for descent and touchdown of spacecraft.

Landing site selection:

Thermal inertia derived from TIR observations reflects the typical particle size of regolith layer, so that the landing site can be selected best suitable for sample collection from the viewpoint of particle size (about 1mm diameter) even from Home Position.

The highest temperature ever experienced in the asteroid history at a given depth for each site on the asteroid is estimated using the TIR data, provided that the past trajectory of the asteroid is traced after its formation. So it is informed what kinds of organic matters are lost or still remain on the surface of asteroid.

Safe operation for descent of spacecraft to the surface: Thermal emission off the surface of asteroid and the surface temperature measured or estimated by TIR is used to confirm the safe descent and touchdown of spacecraft prior to its operation whether the solar distance and the surface thermophysical properties are suitable or not..

TIR Imager: In Hayabusa2, TIR will image mid-infrared thermal emission from the asteroid surface and its temporal variation by asteroid rotation.

LIR has flown on Akatsuki and imaged atmosphere of Venus from its trajectory [3]. Now it is a space-proven instrument and expected to be developed in a short term as the thermal emission imager on Hayabusa2. TIR adopts a non-cooled bolometer array NEC 320A, the flight-spare of LIR, with 320 x 240 effective pixels. A pair of images are taken with the shutter (target plate) open and closed. Onboard analyses are done in the DE (Digital Electronics) such as summation of multiple images, substraction of dark images, treatment of dead pixels, and data compression.

Characteric performace of TIR is shown in Table 1. Total mass is about 3.3 kg and power consumption is nominally 22W. TIR-S is the detector unit that includes hood, optics and shatter, detector and preamplifier circuit, amplifier and analog to digital converter, tememetry/command interface to DE. TIR-AE is the DC/DC converter from the unregulated 50V power supplied by the spacecraft power control unit.

Development of TIR:

Although the design of TIR is the same as LIR, its mechanical and thermal environments are different so that qualification tests are required. Shock level at frequency higher than 2KHz is stronger than that of LIR level. In the Mechanical Environment Survey Test, the Proto-model of LIR is mounted on the Hayabusa2 spacecraft to verfy its mechanical design in the shock tests such as deployment of rocket interface, solar array paddles, SCI, and Reentry Capsule.

Thermal condition is mainly verified by numerical studies of spacecraft system level, especially for the descent and touchdown operation. The hood of TIR exceeds the storage temperature (+95°C) for the worst case study. But we desided that no additional design has been conducted since a thermal cycle test has been done to the same material between +120 and -190°C.

Electric interface is not changed for TIR side but there are some changes in hardware and software for DE side. Electric interface must be checked prior to initial integration test (see Figure1). Telemetry and command test for Data Handling Unit and DE should be also conducted in detail.

Operations of TIR: From Home Position (20km altitude), TIR will image the whole asteroid and its temperature profile every 10 minute during an asteroid rotation to construct a thermal model of asteroid for scientific investigation, landing site selection, and safe assessment of operation. The image set will be obtained every week to take a trend at various solar distance (0.96 to 1.42 AU) and solar phase angle (-20° to +40°). To map the polar region in case of asteroid rotation axis is perpendicular to the direction of sun, the observation at large phase angle will be done. TIR will take more high-resolved images of the asteroid at lower altitude (1-5km) to obtain detailed thermophysical properties of each geologic feature and to confirm whether the candidate landing site is favorable. Close-up images will be taken during the descent operation for touchdown, rover/lander deployment at 100m or lower altitude for a geologic context.

Other operations will be done for searching and characterizing the impact crater or ejecta formed by SCI impact. TIR will try to image the SCI deployed from the spacecraft. Dust environments surrounding the asteroid or tiny orbiting moons are also the targets of TIR observations from Home position.

References:

[1] Fukuhara et al., 2011, Earth Planets Space **63**, 1009–1018. [2] Delbo et al., 2007, Icarus **190**, 236-249. [3] Taguchi et al., 2012, Icarus **219**, 502-504.

Table 1: Characteric Performance of TIR

Mass	3.3 kg
Power	22W (nominal)
Detector	non-cooled bolometer
Pixels (effective)	320 x 240
FOV	16° x 12°
IFOV	0.877 mrad (0.05°)
MTF(@nyquist freq.)	> 0.3
Temp. range	250 – 400 K
NETD	< 0.5K (@350K)
Absolute T resolution	< 5K (@350K)
ADC	12 Bit
Data	0.18MB/image
Temp. Calibration	Target plate Open/Close

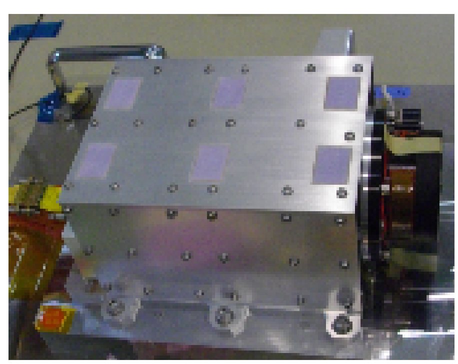

Figure 1 : Flight model of the TIR-S in Electrical test