THERMAL INFRARED MULTI-BAND IMAGING OF BINARY ASTEROID DIDYMOS IN HERA MISSION. T. Okada1,2, T. Fukuhara1, S. Tanaka1, T. Arai4, N. Sakatani1, Y. Shimaki1, H. Senshu3, H. Demura4, T. Kouyama7, T. Sekiguchi8, S. Hasegawa1, M. Yoshikawa1, and Hera TIRI Team, 1Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency (ISAS/JAXA), 3-1-1 Yoshinodai, Chuo, Sagamihara 252-5210, Japan, email: okada@planeta.sci.isas.jaxa.jp, 2University of Tokyo, Japan, 3Rikkyo University, Japan, 4Ashikaga University, Japan, 5PERC, Chiba Institute of Technology, Japan, 6University of Aizu, Japan, 7National Institute of Advanced Industrial Science and Technology (AIST), Japan, 8Hokkaido University of Education, Asahikawa, Japan.

Introduction: Thermal infrared multi-wavelength imaging is now under study to investigate the thermophysical properties and constituent materials of the surface of S-type binary asteroid Didymos in the Hera mission. Here we briefly introduce the characteristics of the Thermal Infrared Imager (TIRI, hereafter) on Hera mission, and discuss about its science and mission objectives.

Hera Mission: Hera [1] is the asteroid rendezvous mission to explore the S-type binary asteroid Didymos, led by European Space Agency, and part of the first international planetary defense mission AIDA (Asteroid Impact and Deflection Assessment) with the NASA DART (Double-Asteroid Redirection Test) mission [2]. DART will be launched in 2021 and perform an impact experiment to Didymos, an orbiting natural moon of Didymos, in 2022. Phenomena which occurred after the impact such as the impact flash and the change of the moon’s orbit will be observed from earth-based and space-based observatories, but details remain poorly known especially on materials and physical properties of the binary system [3]. Hera is planned to be launched in 2024 and to arrive at the binary asteroid in 2027 to explore them for half a year and probably a longer period.

Target Asteroid: Didymos is classified as S-type [4], rotates at 2.26 hours, and has its diameter of 780 m, while Didymos is still unclassified, rotates around Didymos at 11.9 hours at 1.2 km from the center of Didymos, and has the diameter of 160 m. Density of Didymos is estimated ~2100 kg m⁻³, within a range of a typical S-type asteroid of 2000 to 2700 kg m⁻³.

Hera Objectives: Its primary mission objective is to inform on the effect of impact to Didymoon by DART, such as the precise determination of the orbit around Didymos in the trajectory and the period of one revolution, the size and shape of the artificial crater that will be formed by DART impact on the surface of Didymoon, and the possible detection of sediments on Didymos ejected from Didymoon. These information will be used to verify the effect of impact deflection of small asteroids. Its secondary mission is to characterize the binary system in their materials such as mineralogy and meteoritic/rock types, detailed dimension of impact craters to understand the strength and porosity of the interior of the crater, and physical state of the binary.

Hera Instruments: Mission instruments on-board Hera will be two sets of visible to near-infrared multi-band imager AFCs (Asteroid Flaming Cameras), a thermal infrared imager (hopefully, TIRI), a scanning laser range finder, monitor cameras, and two CubeSats of APEX and Juventas. APEX is more focused on its mineralogy and material properties by visible to near-infrared spectro-imaging, mass spectroscopy of gas, and magnetometry. Juventas is more focused on its physical properties and interior structure by radar sounding, gravimetry, and accelerometry.

Hera Operations: After arrival at Didymos, Hera starts the Early Characterization Phase (ECP) observations at the altitude of 30 to 20 km at the solar phase angles of 50 to 70°. Then Hera moves to the Detailed Characterization Phase 1 (DCP1) observations at the altitude of 20 to 10 km at the solar phase angles of 70 to ~0°. CubeSats will be deployed during the Proximity Deployment Phase (PDP). Hera moves to the DCP2, and then closer operations at the altitude of 10 to 5 km during DCP3. Finally, Hera moves to the Extended Low-altitude Phase (ELP) for closer flyby or orbiting the Didymos binary system.

TIRI Instrument: TIRI is a one-box instrument that includes the sensor unit BOL and the electronics unit SHU, with the radiator, and the sunshade and the shutter. Its total mass is ~3.5 kg, the power consumption is ~25 W (max), and the size is about the size of 300 x 150 x 200 mm. 28 V unregulated power is supplied from the spacecraft power supply unit, and the survival heater is supplied from the spacecraft heater control unit. BOL and SHU are inherited from the thermal imager developed for UNIFORM2 [5].

BOL – Sensor Unit: BOL is based on an uncooled micro-bolometer array of 1024 x 768 pixels, readout the images at 30 to 60 Hz, covers the wavelength of 8 to 14 μm, and has the FOV of 10° x 7.5°. The detector is calibrated during pre-flight test to convert the digital values (DN) to brightness temperatures in K, when the instrument temperature is kept within a range. However, degradation can occur in space. The detector temperature should be kept stable using a Peltier temperature control system within 0.01 K during the operation, so that the effect of detector temperature change on DN value should be minimum and the in-flight calibration could be done during the Earth swing-by.
BOL has the function of multi-wavelength band thermal imaging using an 8-point filter wheel, in which 3 narrow band filters covers the Christensen Features (CF) around 8-10 μm, the other 3 narrow band filters covers the Reststrahlen Features (RF) around 11-13 μm, another one is a wide band filter of 8 to 14 μm or no filter for thermal imaging, and the rest is a blank as a shutter (or another option is a narrow band filter).

BOL possibly has a mechanical shutter covering a 100 mm-diameter aperture, implemented at the outside of the optics, which is preferable for the temperature calibration by monitoring its temperature. The shutter is also used to avoid direct insolation when the attitude of spacecraft is disturbed.

**SHU – Electronics Unit:** SHU has the functions of data readout from BOL, an on-board data processing, a HK data collection, a packet production, a command and telemetry control via Spacewire, a power supply control, a temperature control of BOL, and a filter wheel control, and a shutter control.

SHU captures the raw thermal images of 1024 x 768 pixels at 14 bit depth for each pixel, which are taken and output at 30 to 60 Hz by BOL. Those images are integrated until the number reaches the commanded value (typically 2N, where N = 0, 1, 2, ..., 7), and then formed as an effective 15-bit images by bit-shifting. These images are subtracted by dark frame images. The dark frame images that takes during the shutter close and/or deep sky taken, integrated, and bit-shifted in the same way are stored in the image buffer. The subtracted images are compressed using the lossless JPEG-LS algorithm, packetized in the CCSDS format. The tiles of the regions of interest are selected, if necessary, before compression. The packets are stored into the telemetry queue buffer, to be sent to the spacecraft OBC via Spacewire. The basic method is inherited from TIR on Hayabusa2 [6].

**TIRI Operations:** During ECP, TIRI observes the entire Didymos binary system from 30 km altitude, both for Didymos rotation (2.26 hours) and Didymoon revolution around Didymos (11.9 hours) to cover all the local times in an asteroid day, with typical spatial resolution of 6 m/pixel (from 30 km altitude) or 4 m/pixel (from 20 km altitude). This spatial resolution is almost the same as the Mid-Altitude Observation of asteroid Ryugu by TIR on Hayabusa2 [7]. Considering the SCI artificial crater of the diameter of > 10 m [8], which was formed by the impact of 2 kg copper at 2 km/s, the DART artificial crater should be much larger, so that this spatial resolution is good enough for characterizing the global features of the binary asteroid system as well as for investigating the difference of interior to exterior of the DART crater.

During ECP, TIRI takes not only thermal images but also the regional distribution of multi-wavelength spectral features. For the observation of Ryugu, the global thermal inertia was found very low compared to that of carbonaceous chondrites, indicating the porous nature of primitive asteroids. We are strongly curious about the thermal inertia of S-type asteroid Didymos, which is almost the same size of C-type asteroid Ryugu.

We also like to know the thermal inertia of Didymoon, several times smaller in diameter, which is still porous or not for its size. Difference of surface boulders, crater interiors and ejecta deposits, and the surroundings, or even the difference of bulk Didymos and Didymoon should be very interesting in thermal inertia and multi-wavelength spectral features. Such comparative studies could be done in this mission.

During DCP1 and 2, the thermal inertia and the spectral features are obtained at the spatial resolution of 2 m/pixel (from 10 km altitude), although Didymos and Didymoon are observed separately. Dependency of phase angles from -70° to +70° on the thermal radiative intensities and the spectral features are investigated at various solar distance during this campaign. During DCP3, the highest spatial resolution at 1 m/pixel for Didymos and Didymoon at the limited sites during the fast flybys several times. During ELP, the other types of observations will be done during the very close-up flyby observations or orbiting observations. Detailed sequence is to be determined later.

**Summary:** TIRI is a thermal infrared imager with multi-wavelength band filters to be mounted on the Hera spacecraft for characterizing the thermophysical properties and the constituent materials of S-type near-earth asteroid Didymos and its moon. It will play an essential role for understanding the nature of S-type primitive asteroid, investigating a nature of ~100 m sized small bodies, and verifying the effects by the impact by DART, for both purposes of science and planetary defense.

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**References:**