DEVELOPMENT OF THERMAL INFRARED MULTIBAND IMAGER TIRI FOR HERA MISSION. T. Okada[1,2], S. Tanaka[1], N. Sakatani[3], Y. Shimaki[1], T. Arai[4], H. Senshu[5], H. Demura[6], T. Sekiguchi[7], T. Ishizaki[1], T. Kouyama[8], J. Blommaert[9,10], Ozgur Karatekin[11], and the Hera TIRI Team, [1]Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, 3-1-1 Yoshinodai, Chuo, Sagamihara 252-5210, Japan, email: okada@planeta.sci.isas.jaxa.jp, [2]University of Tokyo, Japan, [3]Rikkyo University, Japan, [4]Maebashi Institute of Technology, Japan, [5]PERC, Chiba Institute of Technology, Japan, [6]University of Aizu, Japan, [7]Hokkaido University of Education, Asahikawa, Japan, [8]National Institute of Advanced Industrial Science and Technology (AIST), Japan, [9]VITO, Belgium, [10]Vrije Universiteit Brussel, Belgium, [11]Royal Observatory of Belgium, Brussels, Belgium.

Introduction: TIRI is a thermal infrared imager with the multi-band filters and being developed for the ESA Hera mission [1] to investigate thermophysical properties and composition of the surface of S-type asteroid 65803 Didymos and its moon Dimorphos. Here the characteristics of TIRI is introduced and its science and mission objectives are discussed.

Hera Mission and Objectives: Hera is an asteroid rendezvous mission to explore S-type binary asteroid 65803 Didymos and its moon Dimorphos. It is a part of the first planetary defense mission AIDA (Asteroid Impact and Deflection Assessment) with the NASA DART (Double-Asteroid Redirection Test) mission [2], which was launched in Nov 2021 and will perform a kinetic impact to the surface of Dimorphos in 2022. Impact flash will be observed by ground-based and space-based observations and the asteroid deflection will be detected as a change of rotation period around Didymos. Detailed information regarding the impact phenomena and effects on asteroid deflection will be investigated by Hera [3], which will be launched in 2024 and rendezvous at the asteroid binary system in 2027 for a half year long mission. Physical properties, composition, and strength of the asteroid as well as the dimension of the crater formed by DART impact will be investigated by Hera. The primary objective of the Hera mission is planetary defense, while planetary science will be performed as by-products.

Target Binary Asteroids: Didymos is among a potentially hazardous asteroid with a minimum orbital intersection distance (MOID) is 0.04014 au (15.6 lunar distance) from the Earth. Its orbital period is 2.108 years, and the perihelion and aphelion are 1.0134 au x 2.2753 au. Its absolute magnitude (H) is 18.07 and the derived geometric albedo is 0.15, and its diameter is ~780 m. Its taxonomic class is like an Xk-type for SMASS II but maybe more like an S-type [4] since it has a slight absorption around 1 µm. The density is ~2100 kg m^{-3}, similar to a ruble pile S-type asteroid Itokawa of ~1900 kg m^{-3} [5].

Dimorphos is a synchronous binary with Didymos, still unclassified in taxonomy, and poorly known about its physical properties. Dimorphos orbits in an almost circular orbit, with the eccentricity of <0.05, around Didymos in 11.9 hours at 1.19 km from the center of Didymos, and has the derived diameter of ~160 m.

Hera Instruments: TIRI is among the remote sensing instruments on the Hera spacecraft, together with a couple of visible imagers AFCs, a time-of-flight laser altimeter PALT, a 25-color hyperspectral imager HyperScout-Hera, and two 6U CubeSats Milani and Juventas. All these instruments will be mounted on the top panel of the Hera spacecraft and point in the same direction, to observe the target asteroids concurrently. Milani is to observe composition of the asteroid using a visible to near infrared spectro-imager and a thermo-gravimeter. Juventas is to measure physical properties of the asteroid using a HF radar, an accelerometer, a gravimeter, the guidance and navigation sensors, and a wide-angle camera.

TIRI Instrument: TIRI is a one-box instrument consisted of the sensor unit BOL and the electronics unit SHU. Its total mass is 4.0 ± 0.4 kg, the power is 17 ± 3 W, and the envelope size is 190 x 230 x 263 mm including the radiator and six legs. 28 V unregulated power is supplied from the spacecraft power supply unit, and 2 channels of heaters and thermistors are equipped in TIRI for survival and operational thermal control by the spacecraft temperature control system. SpaceWire is used for telecommands and telemetry to communicate with the spacecraft data handling system. BOL are inherited from the thermal imager developed for UNFORM2 [6], while the logics of SHU are inherited from Hayabusa2 TIR [7].

Sensor Unit BOL: BOL is based on an uncooled micro-bolometer array (Lynred PICO1024 Gen2) of 1024 x 768 pixels, takes the images at ~30 Hz, covers the wavelength of 8 to 14 µm, and has the FOV of 13.3° x 10.0°, with the IFOV of 0.013°/pixel (0.23 mrad). The calibrated thermal images of temperature controlled targets (set at 150 to 400 K) will be obtained during the pre-flight tests to convert digital values (DN) to brightness temperatures (K) when the detector temperature is kept at a range (typically ± 0.1℃ at 25-27℃). The opportunity for in-flight observation of a known target could be only during the Mars swing-by. The dark frame images will be obtained also during the pre-flight tests and during the in-flight observations of dark sky, compared with the shutter close images.

BOL has the function of multi-band imaging using an 8-point filter wheel, in which 3 narrow band filters cover the Christensen Features (CF) around 7-10 µm (centered at 7.8, 8.6, and 9.6 µm), the other 3 narrow band filters cover the Reststrahlen Features (RF) around 10-13 µm (centered at 10.6, 11.6, and 13.1 µm), another one is a wide band filter of 8 to 14 µm, and the rest is to be used as a shutter to protect insolation and as a reference temperature plate.

Electronics Unit SHU: SHU is an FPGA based electronics box. It has functions of a data readout from BOL, an on-board image data processing, a house-keeping data collection, a CCSDS packet production, a command and telemetry control and interface via SpaceWire, a power control for the 28V unregulated power supply, a fine control of BOL temperature, and a filter wheel 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 Hz from BOL. Those images are integrated to improve a signal-to-noise ratio by a commanded number (typically 2N, where N = 0, 1, 2, …, 7), and then formed as an effective 15-bit images by bit-shifting. The dark frame images for each of the 8-position filter wheel will be taken and stored in the corresponding image buffers by taking the dark sky images, integrated, and bit-shifted in the same way. Those images that observe the target with each filter are subtracted by the dark frame images are stored into a flash memory, with the information of image-ID, on-board spacecraft time, status at the time of image take. Nominally each of these images will be transferred to the spacecraft data handling system (OBC/MMU) via SpaceWire, while requested continuously.

These image data will be packetized in the CCSDS format, with the image information and the image data, which, selected by command, can be raw image or compressed using the lossless JPEG-LS algorithm, 16bit or 8bit, and the entire or region of interest. The packets are sent by RMAP via the SpaceWire to the spacecraft OBC/MMU.

For the onboard GNC utilization, the subtracted images are formed into raw, 8 bit, entire images.

TIRI Operations: After the launch in 2024, TIRI will conduct its health check and full-function check in a few months. During the cruise, TIRI will perform dark sky observations almost once a month for its health check, monitoring its degree of degradation, and adjusting the temperature control. During the Mars flyby in March 2025, TIRI will observe the Mars and its moons as a calibration using pre-known targets. During the approach to Didymos in Jan 2027, TIRI will start observations of the binary asteroids at the distance from 2,000 to 30 km. For the request of temperature stability, if possible, TIRI will keep turn-on.

After arrival at the binary asteroids, TIRI will start observations. During the Early Characterization Phase (ECP, 20-30 km from Didymos), TIRI will observe the entire Didymos and Dimorphos binary system for one-rotation period of Didymos (2.26 hours) and for one-revolution period of Dimorphos around Didymos (11.9 hours) from the dawn and dusk directions and from the north-pole and south-pole directions. TIRI will cover all the local times, with a spatial resolution of 4.5-6.9 m/pixel (from 30 to 20 km distance), almost the same as 4.5 m/pixel during the Mid-Altitude Observation Campaign (5 km altitude) of asteroid Ryugu by TIR on Hayabusa2 [8]. The DART crater that will be formed by an impact of a 500 kg spacecraft at 6 km/s will be considered much larger than the SCI crater [9] of ~15 m diameter, which was formed by the impact of 2 kg copper liner at 2 km/s. In this case, the DART crater should be identified during ECP. Multi-band imaging by TIRI is expected to map the material distribution of interior and exterior of the DART crater as well as to compare between Didymos and Dimorphos.

During the Payload Deployment Phase (PDP), TIRI will track the release of CubeSats as in the same way as TIR tracked the SCI in Hayabusa2.

During the Detailed Characterization phase (DCP, 8-20 km from Didymos), TIRI will observe Didymos for its one-rotation period and Dimorphos for its one-revolution period from a nearer distance at the local time of around noon. TIRI will map thermal inertia and spectral features of the binary asteroids at the spatial resolution of 1.8 m/pixel (from 8 km distance).

During the Close-up Operation Phase (COP, 4-22 km from Didymos), TIRI will observe Didymos for a half-rotation several times and for a local time area including the DART crater at higher spatial resolution of < 1 m/pixel (from 4 km distance).

During the Extended Phase (EXP, close to 1 km from Didymos), TIRI will perform consecutive thermal imaging of local areas of Didymos and Dimorphos for detailed mappings at the spatial resolution of <0.25 m/pixel.

Those data with the results by other instruments will bring a new insight of planetary science and also planetary defense in Hera mission.

Acknowledgments: This work is supported by the ISAS/JAXA as one of a Strategic Overseas Joint Space Science Mission.

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