THERMAL INFRARED IMAGER ONBOARD HERA TO OBSERVE S-TYPE BINARY ASTEROID DIDYMOS. T. Okada[1,2], T. Fukuhara[3], S. Tanaka[1], N. Sakatani[3], Y. Shimaki[1], T. Arai[4], H. Senshu[5], H. Demura[6], T. Kouyama[7], T. Sekiguchi[8], and Hera TIRI Team, [1]Institute 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, [2]University of Tokyo, Japan, [3]Rikkyo University, Japan, [4]Ashikaga University, Japan, [5]PERC, Chiba Institute of Technology, Japan, [6]University of Aizu, Japan, [7]National Institute of Advanced Industrial Science and Technology (AIST), Japan, [8]Hokkaido University of Education, Asahikawa, Japan.

Introduction: A thermal infrared imager with multi-wavelength bands is being developed to investigate thermophysical properties and constituent materials of the surface of S-type asteroid Didymos and its moon Dimorphos in the European Space Agency (ESA) Hera mission. Here we briefly introduce the characteristics of the Thermal Infrared Imager (TIRI, hereafter), and discuss about its science and mission objectives.

Hera Mission: Hera [1] is an asteroid rendezvous mission to explore the S-type binary asteroid Didymos and Dimorphos led by ESA, 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 conduct a kinetic impact to Dimorphos in 2022. The phenomena which occurs due to the impact including the impact flash and the change of rotation period of the moon will be observed from earth-based and space-based observatories, but details of impact phenomena and efficiency remain poorly known especially on physical properties of the target such as composition, strength, amount of ejecta, and the crater size, as well as the overall characteristics 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.

Target Asteroid: Didymos is classified as S-type [4], rotates at 2.26 hours, and has its diameter of 780 m, while Dimorphos 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}, similar to a ruble pile S-type asteroid Itokawa of ~1900 kg m^{-3} [5]

Hera Objectives: The primary objective of Hera mission is to inform the effect of kinetic impact to a small asteroid on its trajectory change. It includes the precise determination of the co-rotation of Didymos binary system, the density of Dimorphos, the size and shape of the artificial crater formed by DART impact, and the possible detection of sediments on Didymos ejected from Dimorphos. These information will be used to verify the effect of impact deflection of small asteroids. The science objectives as byproducts are to characterize the binary system in their materials such as physical properties, mineralogy and meteoritic/rock types, the dimension of impact craters to understand the strength and porosity of the crater interior, and the physical state of the binary system.

Hera Instruments: Science instruments on the Hera spacecraft include a couple of visible imagers AFC (Asteroid Flaming Cameras), a thermal infrared imager TIRI, a time-of-flight laser altimeter PALT, and two CubeSats of Milani and Juventas. Milani is focused on surface composition to mount a visible to near-infrared spectro-imager and a thermogravimeter. Juventas is focused on physical properties to mount a HF radar, a gravimeter, an accelerometer, the guidance and navigation sensors, and a wide-angle camera.

Hera Operations: After arrival at Didymos binary, Hera will start observations as Early Characterization Phase (ECP) at the altitude of 30 to 20 km at the solar phase angles of 50° to 70°. The shape model of both asteroids, the binary co-rotation, and the surface geology, composition, and thermal properties will be mapped. Then Hera deploys two CubeSats one by one to investigate the Dimorphos and the DART crater on it in detail as Proximity Deployment Phase (PDP). Hera moves to Detailed Characterization Phase (DCP) to observation at the altitude of 20 to 10 km at the solar phase angles of 70° to ~0°. Hera moves to the close operation phase (COP) to fly by the binary system within 5 km to observe at a higher spatial resolution, followed by the very close fly by (VCFB) phase to observe within 2 km to characterize the DART crater. After the nominal operations, more challenging technology demonstration tests will be planned.

TIRI Instrument: TIRI is a one-box instrument that includes the sensor unit BOL and the electronics unit SHU. Its total mass is 4.2 kg, the power is 30 W with margins, and the envelope is 190 x 180 x 280 mm. 28 V unregulated power is supplied from the spacecraft power supply unit, and 2 channel system heaters and temperature sensors are equipped for temperature control. BOL are inherited from the thermal imager developed for UNFORM2 [6], while the logics of SHU are inherited from Hayabusa2 TIR [7].

BOL – Sensor Unit: BOL is based on an uncooled micro-bolometer array of 1024 x 768 pixels, readout the images at 30 Hz, covers the wavelength of 7 to 14 µm, and has the FOV of 13.3° x 10.0°, with the IFOV of 0.013°/pixel (0.23 mrad). It will be 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. The temperature of BOL is kept stable by the temperature control system within 1 K during the TIRI operation, so that the effect of detector temperature change on DN value should be minimized. The in-flight calibration of TIRI could be performed during the Mars 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 7-10 µm, the other 3 narrow band filters covers the Reststrahlen Features (RF) around 10-13 µm, another one is a wide band filter of 7 to 14 µm, and the rest is to be used as a shutter and a reference temperature plate.

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.

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 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. The dark frame images for each of 8 positions of the filter wheel will be stored in the image buffer by taking the dark sky images, integrated, and bit-shifted in the same way. Those images that observe the target are subtracted by the dark frame images as signed integer 16 bit image data, and compressed using the lossless JPEG-LS algorithm, packetized in the CCSDS format. The tiles of the regions of interest can be selected, if necessary, before compression. The packets are stored into the telemetry queue buffer, to be sent by RMAP via the SpaceWire to the spacecraft OBC.

For the onboard GNC utilization, the subtracted images are formed into 8 bit images every 10 second, and packetized into CCSDS packet to be sent via RMAP.

TIRI Operations: During ECP, TIRI observes the entire Didymos and Dimorphos binary system from 20 to 30 km distance, both for Didymos rotation (2.26 hours) and Dimorphos revolution around Didymos (11.9 hours) to cover all the local times, with typical spatial resolution of 6 to 4 m/pixel (from 30 to 20 km distance). This spatial resolution is almost the same as 4.5 m/pixel during the Mid-Altitude Observation (5 km altitude) of asteroid Ryugu by TIR on Hayabusa2 [8]. Considering the SCI artificial crater of the diameter of > 10 m [9], which was formed by the impact of 2 kg copper liner at 2 km/s, the DART artificial crater that will be formed by a 500-kg spacecraft impacting the surface at 6 km/s should be much larger, so that this spatial resolution will be good enough to characterize 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 the C-type asteroid Ryugu, the global thermal inertia was found very low compared to that of typical carbonaceous chondrites, indicating the porous nature of primitive asteroids [8]. It is strongly curious about the thermal inertia of S-type asteroid Didymos, which is almost the same size of Ryugu, as well as the thermal inertia of Dimorphos, several times smaller size, whether it is porous or not. Dependence of size and spectral type of asteroid will be investigated on the thermal properties and surface materials in this mission.

During PDP and DCP, the thermal inertia and the spectral features are obtained at the spatial resolution of 2 m/pixel (from 10 km altitude), although Didymos and Dimorphos are observed separately. Dependency of thermal radiation on the observed phase angles from -70° to +70° are also investigated. During COP and VCFB, the spatial resolution at 1 m/pixel or smaller will be achieved during the fast flybys.

For the purpose of GNC, TIRI will contribute to the construction of the precise shape models for binary asteroids and also to the test of spacecraft navigation using the TIRI thermal images, since the whole shape of asteroids including the night areas can be observed by thermal imaging.

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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