THERMAL-INFRARED IMAGER TIR ON HAYABUSA-2 TO INVESTIGATE PHISICAL PROPERTIES OF C-CLASS NEAR-EARTH ASTEROID 1999JU3. T. Okada[1], T. Fukuhara[2], S. Tanaka[1], M. Taguchi[3], R. Nakamura[4], T. Sekiguchi[5], S. Hasegawa[1], Y. Ogawa[6], K. Kitazato[6], T. Matsunaga[7], T. Imamura[1], T. Wada[1], T. Arai[8], Y. Yamamoto[1], R. Takaki[1], S. Tachikawa[1], J. Helbert[9], T. Mueller[10] and Hayabusa2 Thermal-Infrared Imager (TIR) Team, [1]Institute of Space and Astronautical Science (ISAS), Japan Aerospace Exploration Agency (3-1-1 Yoshino-dai, Sagamihara, Chuo-Ku, Kanagawa 252-5210, Japan, okada@planeta.sci.isas.jaxa.jp), [2]Hokkaido University, Japan, [3]Rikkyo University, Tokyo, [4]National Institute of Advanced Industrial Science and Technology (AIST), Tsukuba, Japan, [5]Hokkaido University of Education, Asahikawa, Japan, [6]CAIST, University of Aizu, Aizu-Wakamatsu, Japan, [7]National Institute of Environmental Studies (NIES), Tsukuba, Japan, [8]National Astronomical Observatory of Japan (NAOJ), Mitaka, Tokyo, [9]Institute of Planetary Research, DLR, Berlin, [10]Max-Planck Institute for Extraterrestrial Physics, Garching, Germany.

Introduction: Thermal-infrared imager TIR is being prepared for thermal emission mapping of a C-class near-earth asteroid 1999JU3 in Hayabusa2. Purposes of TIR are not only for scientific investigation of physical properties of the asteroid surface derived from regional variation of thermal inertia, but also for assessment of landing site selection and safety descent operation to the asteroid surface from *in situ* measurement of thermal emission and the derived physical condition related to sand, pebbles, or rocks. This instrument is based on LIR (Long-wavelength InfraRed imager) instrument onboard Akatsuki (former Planet-C), a Japanese Venus climate orbiter, and justified to environments mounted on Hayabusa2.

Hayabusa2 Mission: Hayabusa2 is the immediately follow-on mission after Hayabusa that conducted the first round-trip to a near-Earth asteroid and the first sample-return from there in 2010. Returned samples have been investigated as initial analysis and now open to any scientists interested via international announce of opportunity.

Design of Hayabusa2 spacecraft is based on that of Hayabusa, but some repairments and redesigns must be done to achieve more exciting, optimizing mission. Hayabusa2 is primarily a sample-return mission, but remote sensing near-by 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. Active impact experiment using SCI (Small Carry-on Impactor) is planned by excavating the surface to form a crater with a few to several meters diameter to investigate physical properties and composition of the uppermost layer of asteroid through optical and thermal imagery as well as spectroscopy of the crater and surrounding ejecta.

A C-class near-earth object. 1999JU3 is the target body. Optimized set of remote instruments includes: telescopic (multi-band) and wide-angle imagers, laser ranger (LIDAR), near-infrared spectrometer to identify 3μm absorption band (NIRS3) relating to water ice or hydrated minerals. Another selected regular science instrument is the thermal-infrared imager (TIR).

TIR Imager: In Hayabusa, the only measured data of thermal emission from the surface of asteroid was obtained through thermal radiometry using temperature profile of the radiator of XRS (X-ray spectrometer). In Hayabusa2, a mid-infrared thermal emission imager will image the surface temperature profile and its temporal variation by asteroid rotation.

The former version of thermal mapper called LIR is carried on Akatsuki, renamed from Planet-C Venus climate orbiter (See. Figure 1). This instrument is originally a commertial base but was applied for imaging the moving clouds of Venus at the temperature range of 220-250K. However, LIR is expected to be used for thermal emission off the surface of asteroid in the mid-infrared wavelength. We have decided to use the helitage of Akatsuki LIR because of only 21 months remained for instrument development for Hayabusa2.

TIR adopts a non-cooled bolometer array NEC 320A, the flight-spare of LIR, with 320 x 240 effective pixel. Function of digital electronics is basically the same as that of LIR but some details have been changed. Onboard analysis such as summation of multiple images, substraction of dark images, treatment of dead pixels, and data compression can be done in the DE (Digital Electronics).

Thermal imagery of asteroid surface on each geologic unit, place to place, is essential to analyze surface physical properties and related surface conditions. Identification and calibration of absolute temperature will be done with the images taken during the shatter closed. Temporal variation of each asteroid surface unit will be obtained with images taken continuously during asteroid rotation with an interlaced set of shatter open and close.

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.

Science Objectives of TIR: Asteroid 1999JU3 is little known but possibly something like C-class asteroid 253 Mathilde which has low density and huge craters or tiny asteroid 25143 Itokawa which has a rubble-pile structure and huge boulders on its surface.

Scientific objectives of TIR are shown in Table 2. To investigate the nature and the formation processes of the asteroid, physical properties of boulders or materials inside huge crates are most important targets of TIR. We can answer wheather the asteroid is a rubble-pile or rather primordial structure. Conditions at flat surface informs on the current sedimentation at micro-gravity. Overall views of these properties we should know the homogeneity or heterogeneity of the asteroid from the surface to the interior and can answer why a C-class asteroid is so porous or less dense. Comparison with the ground-based observation is a key role of this study to verify the empirical law of asteroid thermal inertia or thermal conductivity against diameter.

Yarkovsky or YORP effects are hot topics in asteroid science and possibly evidenced by TIR observation and the change of asteroid trajectory and rotation. If the orbiting satellites are observed, the gravity is presicely determined. The surface and subsurface conditions will be measured at the active impact experiments by SCI and by impact sampling. Other kinds of geology and geophysical measurements will be conducted with TIR.

Other Objectives of TIR: Knowledge of Surface conditions is to be used for sampling site selection. Lunar regolith-like areas covered with ultra-fine particles are not recommended but the areas with millimeter-sized pebbles are highly recommended due to potentail importance for petrologic information in each particle. The areas with potentially harzardous rocks should be avoided. Thermal intertia is an essential source to determine the sampling sites. With the history of tasteroid rajectory, the highest temperature experienced at each surface can be calculated that is important to understand the thermal alteration at the suraface.

Safety assessment for descent operation in thermal analysis is much important. Thermal model of asteroid will be updated using *in situ* TIR data and reanalysis of descent sequence will be done prior to touchdown operation.

Mission Operations: Hayabusa2 downlink rate is up to 8 and 32 kbps using X- or Ka-band, respectively, during the asteroid rendezvous phase. Downlinked data should be much reduced with star-pixel software in DE. At Home-Position, TIR works in one asteroid rotation (7.6Hrs) a week. When the rotation axis is quite inclined, it is necessary to take time for whole surface mapping from large phase angles. This is what is known only after the arrival at the asteroid.

For smaller sites to be observed such as pond-like features, boulders, and inside the craters, observation of local area thermal inertia and subsurface physical parameters are requested at lower altitude or during the descent phase. Possibly the detailed shape and physical properties of the small crater produced by active impact experiment by SCI or sampling will be observed by close-up or touchdown sequences..

Table 1: Characteric Performance of TIR

Mass	3.3 kg
Power	22W (nominal)
Detector	non-cooled bolometer
Pixels (effective)	320 x 240
FOV	±8° x ±6°
IFOV	0.877 mrad
MTF(@nyquist freq.)	> 0.3
Temp. range	250 – 400 K
NETD	< 0.5K (@350K)
Absolute T resolution	< 5K (@350K)
ADC	12 Bit
Data	0.15MB/image
Temp. Calibration	Shutter Open/Close

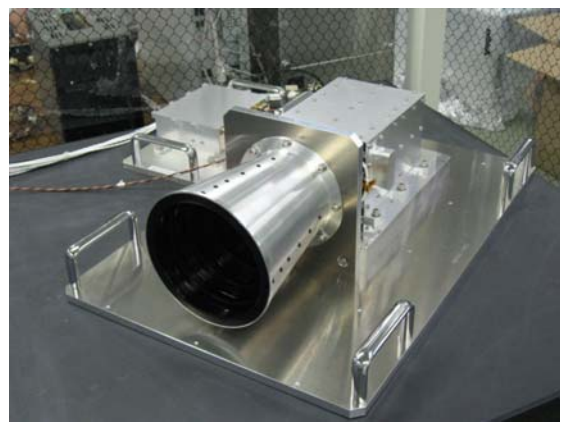

Figure 1 : Test model of the LIR on Akatsuki

Table 2: Main Objectievs of TIR Science

Target	Description	Operation
Boulders	Parent body interior materials	LA, CU, HP
Crater walls	Interior materials and structures	LA, HP
Regolith	Sedimentary processes at micro gravity	HP, LA, CU
Overall features	Comparison with ground observation, heterogeneity from surface to interior	HP, LA
Yarkovsky/ YORP	Evidence of trajectory and rotation change by thermal effect	HP
Phase func.	Updating TIR emission phase functions	HP
Satellites	Orbiting satellite for gravity measurement	HP
Shape	Asteroid shape imaged day and night	HP
Geology	Ejecta, sediments, ponds, burried rocks	LA, HP
SCI crater	Difference of surface and interior	LA,CU, TD
TD site	Touchdown site description	CU, TD

HP: Home Position (10-20km), LA: Low altitude (1-5km), CU: Close-up (0.1-1km), TD: Touch-down (<0.1km)