TIR DATA PROCESSING BY HEAT DURING RENDEZVOUS OF HAYABUSA2 WITH THE ASTEROID (162173) RYUGU

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Introduction: The Hayabusa2 project is a sample return mission to the asteroid Ryugu. It was launched on Dec. 3, 2014, and it has been at Ryugu since June 27, 2018 [1]. Hayabusa2 has four optical instruments for scientific observations, one being the Thermal Infrared Imager (TIR)[2][3]. These main functions are to know natures of the asteroid and to select the candidate of safe landing sites for sampling based on thermo-physical properties of the surface. TIR records infrared radiation from the target as a digital number (DN). The infrared signal is affected by sensor-surrounding objects; lens, shutter, package, and case. TIR requires consideration about this effect when converts DN images to temperature one.

TIR observed data of the Earth and the Moon during Earth swing-by in December 2015. The converted temperatures of the Moon were lower than expected because each pixel did not cover the sunlit area entirely or due to roughness effect of the cratered terrain. TIR has been observing Ryugu in approach and rendezvous phases. The altitudes of TIR observations during the rendezvous phase range from 20 km to less than 10 m.

HEAT: Hayabusa2 TIR Science Team has developed an analysis supporting tool called Hayabusa2 Exploration Assistant for TIR (HEAT) (Fig. 1)[4].

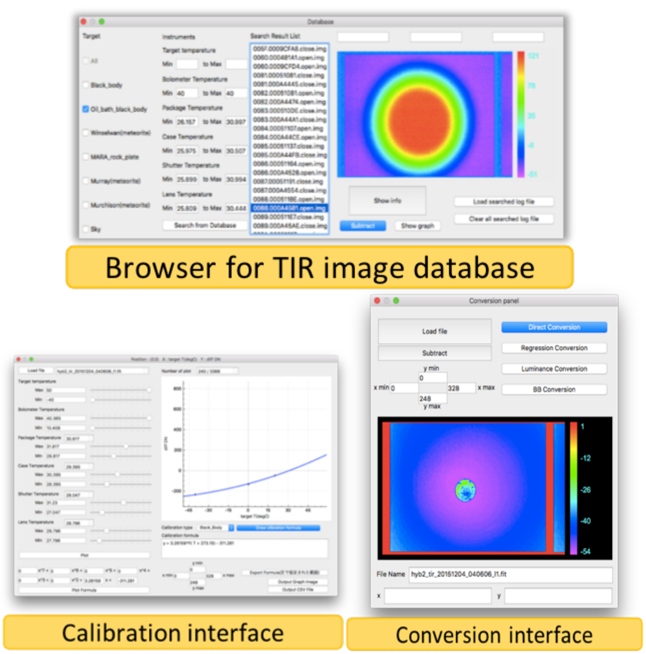

Fig. 1 Appearance of HEAT

HEAT is used to search TIR data interactively, display TIR images, and visualize thermal models.

We receive TIR raw images (Product Level 1) from ISAS/JAXA and convert them to brightness temperature images (Level 2a) and radiance images (Level 2b) using HEAT at Univ. of Aizu. The converted images are provided to the Hayabusa2 project data server.

In this study, calibration is defined as methods of making formulas to convert DN images into brightness temperature images using ground test data. This study has introduced the model considering the blackbody radiation and the transmittance of optics.

This part introduces a concept model. The spectral radiance emitted from a blackbody $B(\lambda, T)$ $(W\,sr^{-1}m^{-2})$ is given by the Planck function based on wavelength λ (m) and temperature T(K) as follows:

$$B(\lambda, T) = \frac{2hc^2}{\lambda^5}\frac{1}{exp(\lambda k_B T) - 1}$$

$h = 6.63 * 10^{34}$ $(m^2\,kg\,s^{-2}\,s^{-1})$ is the Planck constant, $c = 2.9972 * 10^8$ (ms^{-1}) is the speed of light, and $K_B = 1.38 * 10^{-23}$ $(m^2\,kg\,s^{-2}K^{-1})$ is the Boltzmann constant. The observed radiant flux per area $F(T)$ $(W\,m^{-2})$ for over all wavelengths is as follows:

$$F(T) = \pi \int_{8\mu}^{12\mu} \varepsilon\,(\lambda)B(\lambda, T)R(\lambda)d\lambda$$

$\varepsilon(\lambda)$ is the spectral thermal emissivity, and R(λ) is the response function such as the detection efficiency of the bolometer, the measured transmittance of optics including the band-pass filter and the germanium lens [5]. The calibration formula with two regressed parameters A and B is written as follows (Fig. 2):

$$DN = A\, *\, F(T) + B$$

DN is the observed data by TIR. Both A and B are free parameters in the regression by the least squares method. In the accuracy verification of HEAT using blackbody model, HEAT has achieved required accuracy, ±2 K.

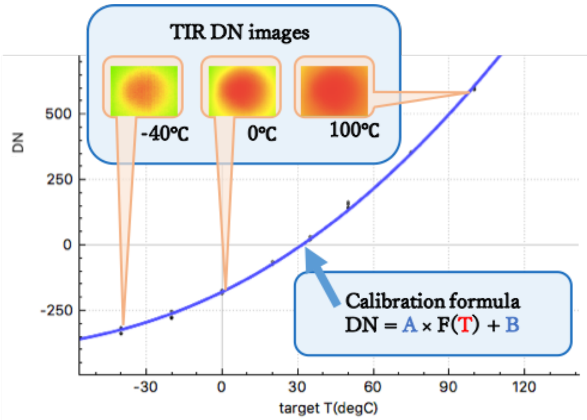

Fig. 2 Plot of a calibration formula

System Design:

Fig. 3 shows a hierarchical GUI of HEAT. The parts shown in pink are newly updated in this study. The first function is calibration, which has three steps; (1) regress calibration curve using ground test data which are narrowed manually with given temperatures of TIR sub-components, (2) draw the curve, (3) solve coefficients of the curve for each pixel. This study enhanced GUI of a function to select pixels by mouse drag where an user wants to make calibration formulas. The second function is converting the TIR raw images to brightness temperature images using the blackbody model. This study enhanced GUI of a function to select pixels with using a mouse drag where an user wants to convert. The third function is the retrieval of TIR images from TIR database. This study enhanced GUI of the TIR database for the input-output capability of FITS data.

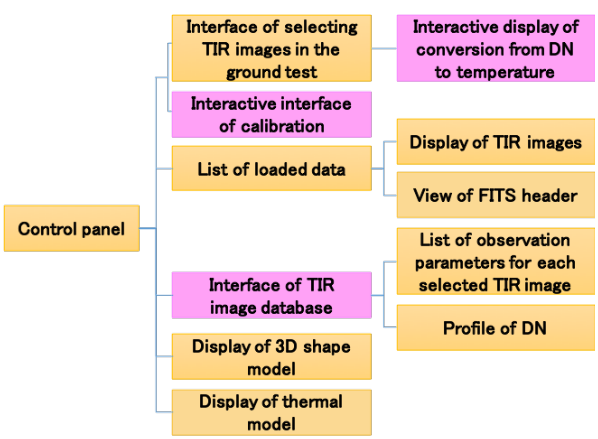

Fig. 3 Refined GUI parts of HEAT

Current status of data processing:

This study has processed about 3000 Ryugu images observed by TIR since June 2018. Fig. 4 shows a DN image of Ryugu and converted temperature one considering the sensitivity of calibration in macro-scale. The top of Ryugu in the image is the south pole. The macro-scale calibration has been established by the TIR science team based on 347 ground test data of a cavity blackbody.

The western (right) edge of Ryugu shows a lower temperature than the rest. This rim corresponds to day and night boundary. Such time-sequential variation of temperature leads us to understand thermal inertia of Ryugu [6][7].

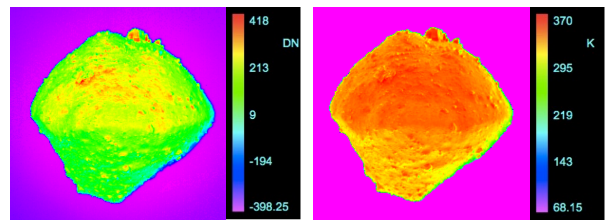

Fig. 4 Ryugu DN (Left) & temperature (Right) DN image was recorded on August 1, 2018 at Medium altitude observation of Ryugu

References:

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