ROCKS AND ROUGHNESS: TIR MEASUREMENTS OF RYUGU FROM HAYABUSA-2

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The Hayabusa-2 mission will return the most detailed thermal infrared measurements ever acquired of an asteroid; both from the thermal infrared imager (TIR) on the spacecraft itself and the Mobile Asteroid Surface Scout (MASCOT) lander [1]. These measurements will enable a better understanding of the composition and thermophysical properties of asteroid 162173 Ryugu and their underlying processes. The combination of in-situ and remotely sensed observations will provide an unprecedented set of observations that link small scale surface properties to large scale remotely sensed measurements. These measurements can be also used as a framework for understanding telescopic and spacecraft datasets of other airless bodies throughout the solar system.

In many cases, TIR observations of airless bodies have displayed confusing or surprising characteristics. In particular, anisothermality can have large and often unanticipated effects on thermal infrared measurements of planetary surfaces. The effects of surface roughness, layering, rocks, and directional emissivity in conjunction with viewing geometry must be considered for the proper interpretation of the measurements.

A combination surface roughness and thermal model has been developed for the analysis of lunar and martian thermal infrared datasets [e.g., 2–3] and has been adapted for application to Hayabusa-2 TIR Ryugu observations using orbital, shape, and thermophysical properties as they are currently known or estimated [4–8]. The roughness model assumes a simple Gaussian distribution of slopes. For each individual surface location, the temperatures of 738 slope and azimuth combinations are modeled using a one-dimensional heat diffusion model [9]. These temperatures are converted to radiance and added in proportion to their statistical occurrence and weighted by their projection to the field of view of the observer (i.e., slopes facing away from the observer contribute less to the measurement than slopes facing the observer).

The spacecraft will typically have a synoptic view from the day side of the asteroid, providing excellent diurnal and seasonal thermal imaging coverage. However, the typically fixed vantage of Ryugu results in most surfaces being imaged from a variable off-nadir orientation. In addition, periodic descent observations will allow for portions of the asteroid to be measured down to cm scales. With the presence of a potentially rough, heterogeneous surface, the variable emission and azimuth viewing angle needs to be taken into account and the measurements cannot be treated in the same manner as nadir observations that are common with other spacecraft investigations. In a sense, the Hayabusa-2 TIR images will have a vantage similar to telescopic observations because of its non-orbiting, Earth-pointed orientation.

A series of modeled observations have been produced to better understand how emissivity, surface roughness, thermal inertia, vertical layering of thermophysically distinct units, and rock abundance will influence TIR measurements. For example, surface roughness and viewing orientation can influence measured brightness temperatures by as much as 40K (Fig. 1). Viewing geometry alone can cause brightness temperature differences that are comparable to variations in thermophysical properties.

Roughness, rock abundance, thermal inertia, layering, and directional emissivity effects all influence brightness temperatures and do so in a unique manner when taking into account the range of local times, seasons, and viewing angles that will be acquired by Hayabusa-2. Although the relationships between these factors can be complicated, the modeling shows that there is a wealth of useful information to be gleaned from the measurements.

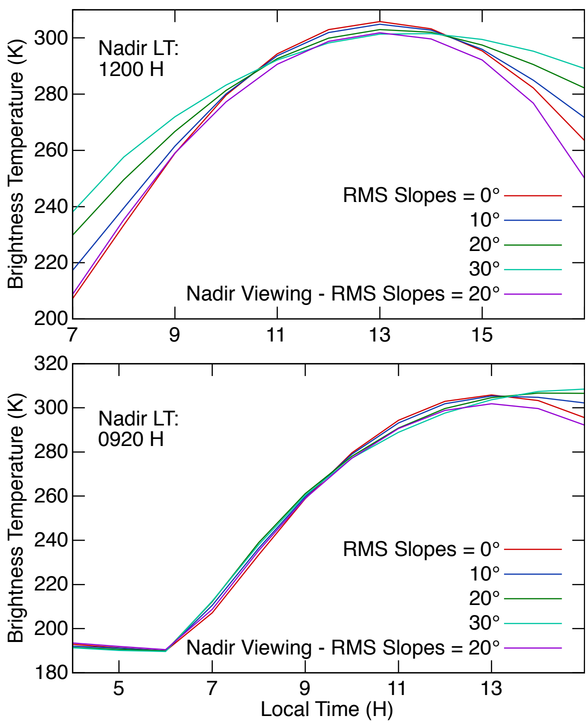

Fig 1. The effects of surface roughness on modeled brightness temperatures of Ryugu at 0°N and northern fall equinox. Both plots show the same surface (TI of 200 J m^{-2} K^{-1} $s^{-½}$) at the same season, but the top plot is at 0° and the bottom plot is at 40° phase angle.

References: [1] Tsuda Y. (2013) *Acta. Astron.*, 10.1016/j.actaastro.2013.06.028. [2] Bandfield J. L. and Edwards C. S. (2008) *Icarus*, 10.1016/j.icarus.2007.08.028. [3] Bandfield J. L. et al. (2015), *Icarus* 10.1016/j.icarus.2014.11.009. [4] Müller T. G. et al. (2011) *A&A*, A14510.1051/0004-6361/201015599. [5] Kawakami K. et al. (2010) *Japan. Soc. Planet. Sci.,* 19, 4–11. [6] Moskovitz N. A. et al. (2013) *Icarus*, 10. 1016/j.icarus.2013.02.009. [7] Kim M. -J. et al. (2013) *A&A*, L1110.1051/0004-6361/201220673. [8] Hasegawa S. T. G. et al. (2008) *Ast. Soc. Japan*, 60, 399-405. [9] Kieffer H. H. (2013) JGR, 10.1029/ 2012JE004164.