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Thermophysical modelling of Ryugu: pre-mission and approach-phase observations

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Abstract

A recent work [13] described the Hayabusa2-TIR measurements of the Earth and the Moon before and after the Earth swing-by on 3 December 2015. Based on these measurements, it was possible to predict and characterize the TIR detectability of Ryugu (and potential moons) during the Hayabusa2 spacecraft approach phase in June 2018. We use the TIR lunar observations to establish an independent flux calibration which allows to convert the observed 10-μm TIR signals of Ryugu (during the approach phase in June 2018) into accurate flux densities. The TIR observations also include two full thermal lightcurves taken on June 7 and June 18, 2018. We interprete these Hayabusa-2 approach-phase TIR measurements, as well as all existing pre-mission thermal-IR measurements (Spitzer-IRS/-IRAC, Subaru-COMICS, AKARI-IRC, WISE, Herschel-PACS) with thermophysical model concepts. We also discuss our results in the context of radiometric studies for near-Earth objects in general.

1. Introduction

The exisisting (non-resolved) thermal-IR measurements of Ryugu were presented in [12]. Here, we add the Hayabusa-2 TIR measurements taken during the Hayabusa2 approach phase in June 2018. These data were calibrated via TIR Moon observations, taken in late 2015 during the Hayabusa2 Earth swing-by manoeuver (see Fig. 1). This calibration approach required mid-IR modelling of the disk-integrated Moon at high phase angles (close to half-Moon). Our thermophysical model of the Moon was tested and verified against multi-channel HIRS measurements of the Moon obtained by different meteorological satellites (NOAA-15/-17/-18/-19, MetOp-A, MetOp-B). The HIRS channels No. 8, 9, 10, and 11 cover nicely the TIR 8-12 micron band (see Fig. 1) and provide high-quality disk-integrated flux densities of the Moon at different phase angles.

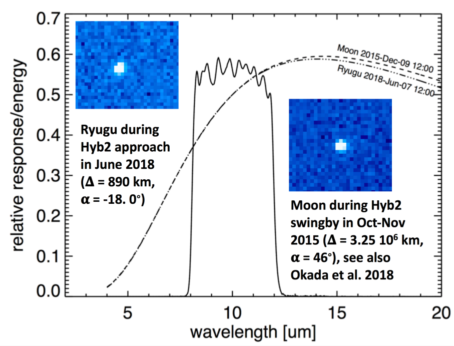

Figure 1: *The TIR filter response, together with the model thermal SED of the Moon and Ryugu. The small figures show the TIR images of the Moon (at 3.25 Mio km) and Ryugu at 870 km distance. The Moon observations provide excellent means for calibrating Ryugu measurements.*

2. Disk-integrated thermal emission measurements of Ryugu

The Moon-calibrated TIR observations of Ryugu are presented and interpreted in the thermophysical context: on absolute flux level, and also for the rotational variations during the measurements. As input for the thermophysical model (TPM) we used the in-situ spin-shape solution, global object properties

[14], and the true TIR observing geometries (extracted from the SPICE kernels). In parallel, we revisited the work done by [3], [11, 12] based solely on remote (non-resolved) observations of Ryugu from different ground- and space-observatories: a full Spitzer-IRS spectrum [1], Herschel-PACS measurements at far-IR wavelengths, re-analysed AKARI-IRC measurements at 15 and 24 μm, and Subaru-COMICS observations in N-band, warm-Spitzer IRAC observations with a sequence of point-and-shoot measurements (Jan to May 2013), two full lightcurves (in Feb. and May 2013 at -83° to -85° phase angles) from the project by [7], and another set of IRAC channel 2 measurements from 2017 (M. Mommert, priv. communications). We also added an unpublished WISE detection from Sep. 2016 (J. Masiero, priv. communication).

3. TPM of Ryugu

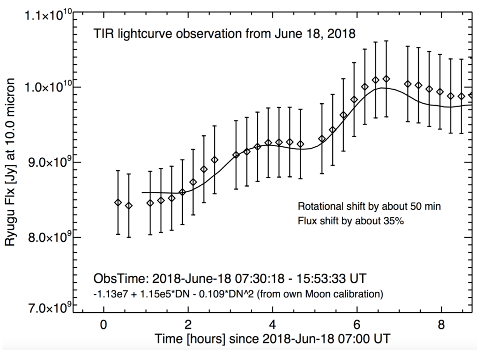

Figure 2: *The TIR lightcurve measurements (calibration via a preliminary model of the Moon's thermal emission) of Ryugu on Jun 18, 2018 during Hayabusa2 approach phase. The TPM solution (using the in-situ spin-shape properties are shown as solid line).*

For the interpretation of the measurements we use the model code by [4, 5, 6], [8, 9]. Since spin and shape properties of Ryugu are well known from in-situ measurements, we focus on the global thermal properties (thermal inertia), the thermal emission variations with the object's rotation (see Fig. 2), for a wide range of phase angles (-89° to +53°), for a wavelength range from about 3.55 to 70 μm, and for the different heliocentric distances (0.99 to 1.42 AU). We also look into the (thermal) effects of surface roughness and the link between thermal emission and grain-sizes distributions on the surface [2]. The conducted analysis is similar to the work on Itokawa [11], where the remote thermal observations were revisited with having the in-situ object properties in hand. Our findings are also relevant for radiometric studies of other near-Earth objects where only (very limited) remote observations are available, often restricted to single-epoch or to short-wavelength measurements.

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