# REVEALING ASTEROID (162173) RYUGU'S THERMOPHYSICAL PROPERTIES WITH DATA ASSIMILATION

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## 1 Introduction

The Near-Earth Asteroid (162173) Ryugu has been investigated by the JAXA Hayabusa2 mission [1]. Hayabusa2 successfully returned samples from two sites of Ryugu's surface to Earth in December 2020. Part of this mission was the deployment of the MASCOT lander [2] which studied Ryugu's surface in detail. Ryugu is a rubble-pile asteroid covered in boulders and large pebbles [3-5]. Remote sensing in the visible and near-infrared wavelength range indicated that Ryugu is darker than any measured meteorite sample and that the closest match are thermally metamorphosed carbonaceous chondrites [5-7]. MARA observed a single boulder of the most common type on the surface of Ryugu through six channels with different filters, two broadband filters and four narrowband filters. MARA thus provides the only spectrally resolved mid-infrared observations of Ryugu within the Hayabusa2 mission prior to the sample analysis.

## 2 Thermophysical Parameter Estimation

For the simultaneous estimation of multiple thermophysical parameters, the Ensemble Kalman Filter (ENKF) data assimilation method [8] in combination with our thermal model [9] is used. The ENKF is a Monte Carlo approximation of the classic Kalman filter adapted for non-linear models. Its main advantage is that computational cost scales well with the increase in free parameters. ENKF is a sequential data assimilation method. The observation is predicted using a forward model based on a random distribution of parameters which is iteratively narrowed by comparing the model forecast to the MARA observation in all six channels. The forward model is a combination of a multi-scale thermal model and the instrument function. The thermal model calculates the diurnal temperature variation of each facet of a combined shape model of the boulder in front of MASCOT, incorporated into a digital elevation model of the landing site [10]. The efficiency of the ENKF allowed for simultaneous estimation of the thermophysical properties as well as the emissivity within the four narrow MARA bands.

## 3 Comparison to Chondrite Spectra

The estimated emissivity can be compared to laboratory spectra of carbonaceous chondrites and OTES spectra of Bennu [11-15]. The comparison reveals that within the MARA bands, Ryugu, Bennu, CI and CM chondrites are systematically different from dehydrated and thermally metamorphosed chondrites. The group of CI chondrites is closest to Ryugu, but individual CM chondrites are also within the range of uncertainty. Given that remote sensing data indicated dehydrated surface materials, it was a surprise to find similarity of the mid-infrared emissivity of the observed boulder to the most aqueously altered chondrites. Yet, signs of aqueous alteration in the mid-infrared observations are consistent with the latest measurement of Ryugu samples during initial curation processes [16,17], suggesting that mid-infrared is powerful wavelength for finding signs of aqueous alteration.

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