Thermal infrared spectroscopic features of meteorites, rocks, and minerals for the application to future planetary missions

Soichiro Furukawa[1,2], T. Okada[1,2], Z.-L. Li[1,2,] Y. Shimaki[1], N. Sakatani[1], H. Senshu[3], T. Sekiguchi[4], H. Demura[5], T. Arai[6], T. Kouyama[7], M. Kanamaru[1], T. Ishizaki[1], S. Tanaka[1], A. Yamaguchi[8], N. Imae[8]

[1]Institute of Space and Astronautical Science, JAXA, Sagamihara, Japan, [2]University of Tokyo, Tokyo, Japan, [3]Chiba Institute of Technology, Narashino, Japan, [4]Hokkaido University of Education, Asahikawa, Japan, [5]University of Aizu, Aizu-Wakamatsu, Japan, [6]Maebashi Institute of Technology, Japan, [7]National Institute of Advanced Industrial Science and Technology, Japan [8]National Institute of Polar Research, Tachikawa, Japan.

Introduction

The ESA-led asteroid explorer Hera plans to investigate physical properties and composition of the materials of S-type asteroid Didymos, as well as the effects of the kinetic impact to Dimorphos (Didymos' satellite) by the NASA-led asteroid impactor DART [1]. Among various analytical methods, thermal infrared spectroscopy is effective to investigate thermal metamorphism and crystallinity in addition to the composition of materials (component analysis).

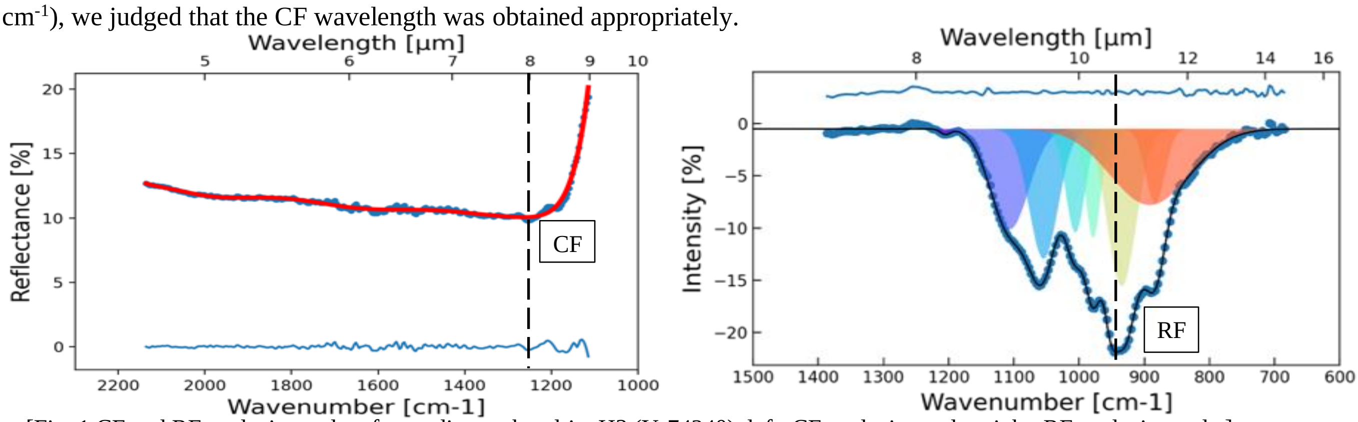
A thermal infrared imager TIRI, an advanced version of the TIR [2] onboard Hayabusa2, will be onboard the Hera to perform the first-ever thermal infrared multi-band spectroscopic imaging of an S-type asteroid [3]. Thermal infrared spectral profile indices characterizing rock and mineral types are Christiansen Features (CF), which are reflectance minima at around 7-9 µm depending on the SiO_2 content, and Reststrahlen Features (RF), which are reflectance maxima at around 9-12 µm depending on the SiO_2 content and crystallinity [4]. Despite of a wide variety of meteorites, including ordinary chondrites, which are associated with S-type asteroids in composition, there are limited examples of obtaining information on CF and RF by direct measurements as bare rocks in the thermal infrared region. This study aims to obtain CF and RF information by thermal infrared spectroscopy of a wide variety of meteorite samples in addition to minerals and rocks with newly developed analysis methods and to build a database for comparative analysis for the application to future thermal infrared surveys including Hera. In addition, we will simulate and verify whether CF and RF information can be obtained by multi-band observation of TIRI onboard Hera.

Methods

The samples used for the thermal infrared spectral analysis were thin and thick sections of Antarctic meteorites of the NIPR meteorite collection (217 in total) as well as several minerals (olivine, pyroxene, quartz, labradorite, obsidian) and rocks (anorthosite, hypersthene-augite andesite, olivine basalt, peridotite) of the ISAS laboratory. The meteorite samples used were Petrologic types 3-7 Ordinary chondrites (H, L, LL) which are like S-type asteroids in composition, primitive achondrites (acapulcoite, diogenite, eucrite, lodranite, ureilite, winonaite), and carbonaceous chondrite (CM2, CO3, CR2) for comparison. In the measurement of the samples, spectral data in the TIR region were acquired using FTIR (Agilent Handy FTIR 4300), which can acquire spectral data in the 650-4000 cm^{-1} range and has a resolution of 8 cm^{-1} [5]. In the analysis of the acquired spectral data, CF and RF information were extracted using the newly developed fitting analysis methods: for CF analysis, fitting with a 10th-order polynomial, and for RF analysis, baseline estimation [6] and fitting with multiple Gaussian functions [7].

Results

The results of CF and RF fitting analysis of an ordinary chondrite H3 (Y-74240) are shown in Figure 1. In the CF analysis, the minimum reflectance of the fitting spectrum (red line) was defined as the CF. In the RF analysis, the RF was defined as the minimum value of the Intensity (emissivity) of the composite waveform (black line). Since the CF wavelength estimated in this study is almost the same as that in the previous study [8] for quartz (previous study (α-quartz): 1360 cm^{-1}, current study: 1365 cm^{-1}), we judged that the CF wavelength was obtained appropriately.

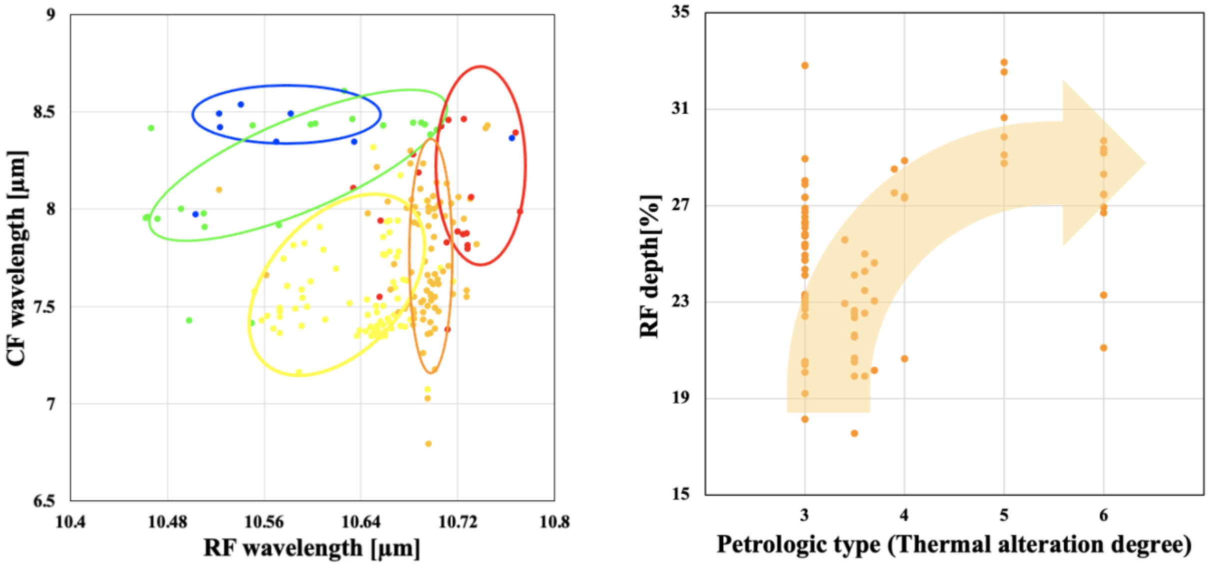


[Fig. 1 CF and RF analysis results of an ordinary chondrite H3 (Y-74240), left: CF analysis results, right: RF analysis results]

Discussion

CF and RF tend to shift to shorter wavelengths with increasing SiO_2 content [4]. The relationship between CF and RF wavelengths (Fig. 2, left) confirms that CF and RF shift to longer wavelengths in the order H < L < LL for ordinary chondrites. Therefore, it is expected that ordinary chondrites tend to have lower SiO_2 content in the order of H > L > LL. Carbonaceous chondrites and primitive achondrites also showed a shift of RF to shorter wavelengths than ordinary chondrites. In the relationship between petrologic type and RF depth (Fig. 2, right), the RF depth tends to be larger (smaller emissivity and larger reflectivity) with a higher degree of thermal modification, indicating lower absorption due to lower crystallinity of Olivine.

In conclusion, it was found that the application of the thermal infrared spectroscopy and the CF and RF analyses developed in this study can generally distinguish between different meteorite types and degrees of thermal modification. We are planning to report on the results of the multi-band transformed spectroscopic data corresponding to TIRI, which will perform multi-band spectroscopic observations in the thermal infrared region and verify whether CF and RF information can be obtained, and meteorite types and degrees of thermal modification can be discriminated.



[Figure 2: On the left, the relationship between RF and CF wavelengths (ordinary chondrites: H yellow, L orange, LL red, carbonaceous chondrites: blue, primitive achondrites: green); on the right, the relationship between petrologic type and RF depth (ordinary L chondrites)]

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