Mineralogical Surface Characterization using the MASCOT Radiometer MARA on the Hayabusa 2 Mission.
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Introduction: The MASCOT lander [1] is part of the payload of JAXA's Hayabusa 2 mission, which will investigate the C-type near Earth Asteroid 1999JU3 and return samples from the asteroid in 2020. The MASCOT lander will be deployed from the main spacecraft following an initial phase of asteroid characterization, and MASCOT will then investigating multiple surface sites by means of a hopping mechanism.

The MASCOT radiometer MARA is one of four instruments on MASCOT, and will determine the radiative flux from the asteroid's surface in six infrared wavelength bands. Out of these channels, four are designed as band passes at wavelengths of 5.5-7, 8-9.5, 9.5-11.5, and 13.5-15.5 µm [2], and these channels can be used for a mineralogical characterization of the investigated surface sites. In order to obtain clean bandpasses, MARA combines IR filters with interference absorbers [2], and the overall instrument sensitivity is shown in Figure 1. The MARA instrument uses thermopile sensors to determine the radiative flux, and the instrument's field of view is 10° [3]. This implies an instrument footprint of the order of 10 cm in diameter if the MASCOT lander is oriented horizontally.

The target asteroid is classified as Cg - type asteroid [4] based on its 0.36-0.92 µm spectrum acquired in 1999 by the Palomar Mountain Observatory [5]. The Cg subclass is characterized by stronger UV absorption short of 0.55 µm and a relatively flat spectrum between 0.55-0.85 µm [4]. Additional spectra of 1999JU3 were acquired by the Multi Mirror Telescope (MMT) in 2007 [6], and the median of these spectra is also flat between 0.55-0.85 µm. However one spectrum shows an absorption feature at 0.7 µm, which is typical of the Ch and Cgh subclasses. This could indicate the presence of hydrous alteration (thus the h in Ch) for C-type main belt asteroids [4]. The 0.7 µm absorption feature matches a feature of antigorite, an iron rich phyllosilicate that forms by hydrous alteration [6] of olivine, and it has been proposed that the apparent variation of the spectrum in time indicates a variegated surface composition [6].

1999JU3 has an effective diameter of 0.92 ± 0.12 km and a low visual geometric albedo of 0.063, compatible with a C-type taxonomic-type classification. Estimates of the surface averaged thermal inertia range from 200 to 600 J m^{-2} K^{-1} $s^{-1/2}$ [7], and it is likely larger than 500 J m^{-2} K^{-1} $s^{-1/2}$ [8]. Thus, thermal inertia is about a factor of 2 lower than the value for 25143 Itokawa [7], indicating that surface texture lies somewhere between a thick-dust regolith and a gravel-dominated surface.

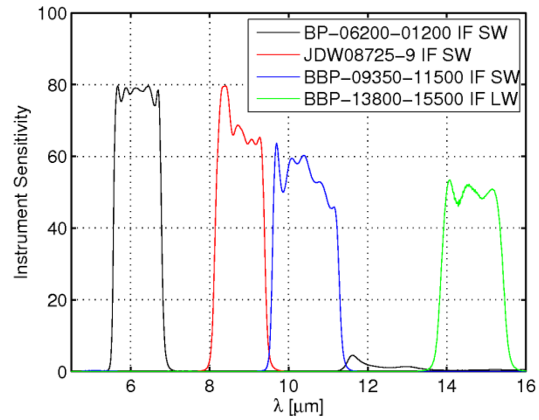

Figure 1: Sensitivity of the combined filter-absorber combination for the 4 bandpasses implemented in the MARA instrument.

Sample Spectra: In order to demonstrate the capability of the MARA instrument to distinguish between different surface compositions, measurements have been simulated using laboratory sample spectra of two likely and one unlikely candidate composition.

In the Planetary Emissivity Laboratory (PEL) at the Institute for Planetary Research of the German Aerospace Center (DLR) in Berlin, we measured emissivity spectra for a suite of asteroid analogues, by using an evacuated (10^{-4} bar) Bruker Vertex 80V FTIR spectrometer coupled with an external evacuated (10^{-4} bar) emissivity chamber. To cover the 1 to 16 µm spectral region we measured the spectra using a nitrogen cooled detector MCT and a KBr beamsplitter.

To maintain the set-up as close as possible to conditions expected on the asteroid, we measured the sample in vacuum at low surface temperature, chosing 70° C as a good approximation of daily maximum surface temperature. However, given that emissivity is almost independent of the target temperature, this choice does not influence the spectral measurements. Details on measurement procedures and the spectrometer calibration method can be found in [9].

As analogue materials, we chose meteorite Allende, representing the CV group of the Carbonaceous Chondrites meteorites, the mineral graphite because of its carbonaceous composition, and the clay mineral serpentine, because phyllosilicates have been discussed as possible asteroids surface components [6]. Where possible, we chose the smallest available grain size range for the analogues to reproduce a fine dusty asteroid surface. It should be noted, however, that emissivity spectra can depend strongly on particle grain size, and a small and an intermediate grain size range should in principle be chosen. However, these measurements are not yet available and will be conducted in the near future.

Instrument Sensitivity: MARA measurements were simulated by calculating the average emissivity $\bar{\epsilon}$ which would be obtained in the different band passes taking the transimissivity $\tau(\lambda)$ of the corresponding infrared filters as well as the sensitivity of the detectors into account. Average emissivity is then given by

$$\bar{\epsilon} = \frac{\int \tau_\lambda \epsilon_\lambda B_\lambda(T_{Obj}) d\lambda}{\int \tau_\lambda B_\lambda(T_{meas}) d\lambda}$$

where T_{Obj} is the radiative temperature of the target object and T_{meas} is the measured radiative temperture as determined by the instrument. $B_\lambda(T)$ is the Planck function giving the blackbody radiation emitted at wavelength λ and temperature T, and ϵ_λ is surface emissivity. Therefore, for a perfect band-pass between λ_1 and λ_2, $\bar{\epsilon}$ will simply be the average of the emissivity in this wavelength band, while contributions from other wavelength regions will be mixed in for real filters.

Given a noise equivalent temperature difference (NETD) for the MARA instrument of better than 0.3 K at object temperatures in excess of 300 K [3], we will here assume that combined instrument noise and calibration uncertainties contribute 1 K to the temperature uncertainty, i.e., $T_{meas} = T_{Obj} \pm 1$K. Results of the calculations are then shown in Figure 2, where emissivities determined by MARA are shown for the three candidate material along with the associated errorbars, which are indicated by rectangles.

For T_{Obj} = 373 K and σ = 1 K, the resulting measurement uncertainty for the emissivity is 2-3%%, where smaller uncertainties are associated with longer wavelengths. Due to the reduced flux, these uncertainties increase at lower object temperatures, and are 2.5-5% for T_{Obj} = 273 K. Similarly, uncertainties increase for larger temperature uncertainties, and emissivity uncertainty is 3-5.5% for T_{Obj} = 373 K and σ = 2 K.

Conclusions: The MARA instrument will measure the emitted surface flux of the Hayabusa II target asteroid 1999JU3 using 4 bandpass channels to determine surface emissivity. Instrument sensitivity will allow for a determination of ε to within 2-3%. This will enable a robust determination of the spectral slope along with a good determination of emissivity in the spectrally flat region beyond 15 µm. Taken together, this information will help to constrain the surface composition.

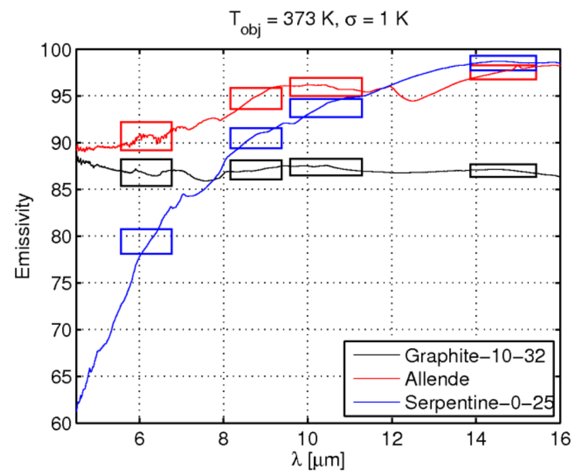

Figure 2: Emissivity of fine-grained Graphite, Serpentine, and meteoritic material (Allende) as measured in the Berlin Emissivity Lab [9]. Simulated MARA measurements in 4 wavelength bands are indicated. An object temperature of 373 K and an instrument temperature uncertainty of σ = 1 K have been assumed. Squares then indicate the emissivity uncertainty associated with σ.

References: [1] Lange, M., et al., Europ. Conf. on Spacecraft Struct., Materials and Environmental Testing, 20.-23.Mrch 2012, Noordwijk, Netherlands. [2] Grott, M., et al., EPSC Abstracts, 7, EPSC2012-50-3 (2012). [3] Grott, M., et al., this meeting. [4] Bus, S.J., Binzel, R.P., Icarus 158, 146–177 (2002). [5] Binzel, R.P., et al., Icarus 151, 139–149 (2001). [6] Vilas, F., Astron. J., 135:1101–1105 (2008). [7] Müller, T.G. , et al., Astron. Astrophys., 525, A145 (2011). [8] Hasegawa, S., et al., PASP, 60, 399-405 (2008). [9] Maturilli, A., et al., EPSC Abstracts, Vol. 7, EPSC2012-487 (2012).