The MASCOT Radiometer MARA for the Hayabusa 2 Mission.

M. Grott[1], J. Knollenberg[1], F. Hänschke[2], E. Kessler[2], N. Müller[1], A. Maturilli[1], J. Helbert[1], E. Kührt[1], [1]DLR Institute for Planetary Research, Berlin, Germany (Matthias.Grott@dlr.de), [2]Institute of Photonic Technology, Jena, Germany

Introduction: The MARA instrument is one of the payloads of the MASCOT lander [1], currently developed for use on the Hayabusa 2 mission. Hayabusa 2 is JAXA's asteroid sample return mission, targeted for the C-type near Earth Asteroid 1999JU3. The MASCOT lander will be deployed from the main spacecraft following an initial phase of asteroid characterization, and MASCOT will then operate for 20h on primary batteries, investigating multiple surface sites by means of a hopping mechanism. In this way, MASCOT will characterize the asteriod in situ using its four science instruments, which comprise a near infrared spectrometer, a camera, a magnetometer, and the MARA infrared radiometer. In addition to characterizing the asteroid in situ, the obtained datasets will be consulted when a site for sample collection is chosen.

Science Objectives: The MARA instrument uses 6 dedicated infrared channels to measure the radiative flux emitted from the asteroid's surface, and the primary scientific goal of the instrument is the determination of the surface thermal inertia at the landing sites. A secondary goal is the characterization of the surface mineralogy using bandpass filters, and one channel is identical to that used by the spacecraft thermal mapper [2]. This channel will provide ground truth for measurements at spacecraft altitude.

Thermal inertia determined over large spatial scales gives a non-linear average of the surface thermo-physical properties, with hotter surfaces being overrepresented. Due to its small field of view of 10°, the surface footprint of the MARA instrument is only 10 cm in diameter, and in this way estimates of the local thermo-physical properties of the regolith will be obtained. These can then be interpreted in terms of grain sizes, and MARA will provide ground truth at small scales in addition to context for the spacecraft measurements.

Instrument Description: The engineering model of the MARA sensorhead including the individual sensors is shown in Fig. 1, where the aperture cover defining the instrument's field of view of 10° has been removed. MARA uses the IPHT TS-72M thermopile sensors as sensing elements [3], which consist of 72 n-bismuth-antimony/p-antimony ($Bi_{0.87}Sb_{0.13}/Sb$) thermocouples with a Seebeck coefficient of 135 µV/K each. The incoming radiation is coupled into a circular absorber of 0.5 mm diameter, which results in a temperature increase of the hot junctions of the thermopile. The temperature difference between the hot and the cold junctions is transformed into the signal voltage due to the Seebeck effect. The PT100 sensor measures the thermopile cold junction temperature as a reference.

To check the calibration of the instrument during cruise, MASCOT carries a temperature controlled calibration target in the MARA field of view, which is mounted on the MASCOT mechanical support structure and remains on the spacecraft after MASCOT separation. The calibration target surface is covered by a high emissivity coating, and surface area is increased by micro-structuring the area. In this way, an emissivity of 0.99 is achieved in the wavelength range of 5-10 µm, and emissivity is 0.95 in the range 10-40 µm.

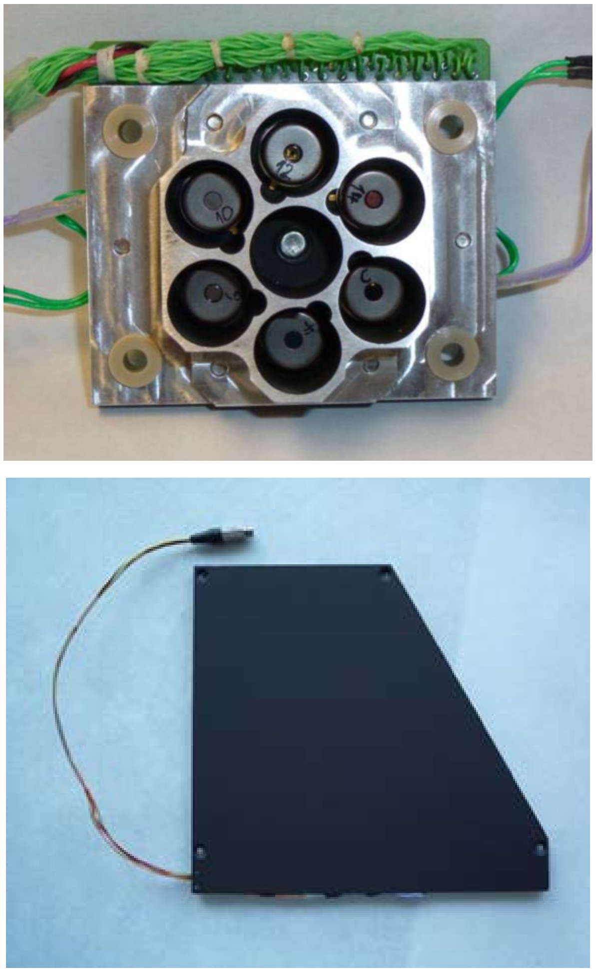

Figure 1: Top: Engineering model of the MARA Sensorhead showing 6 thermopile sensors with their individual filters. Bottom: Engineering model of the MARA inflight Calibration Target.

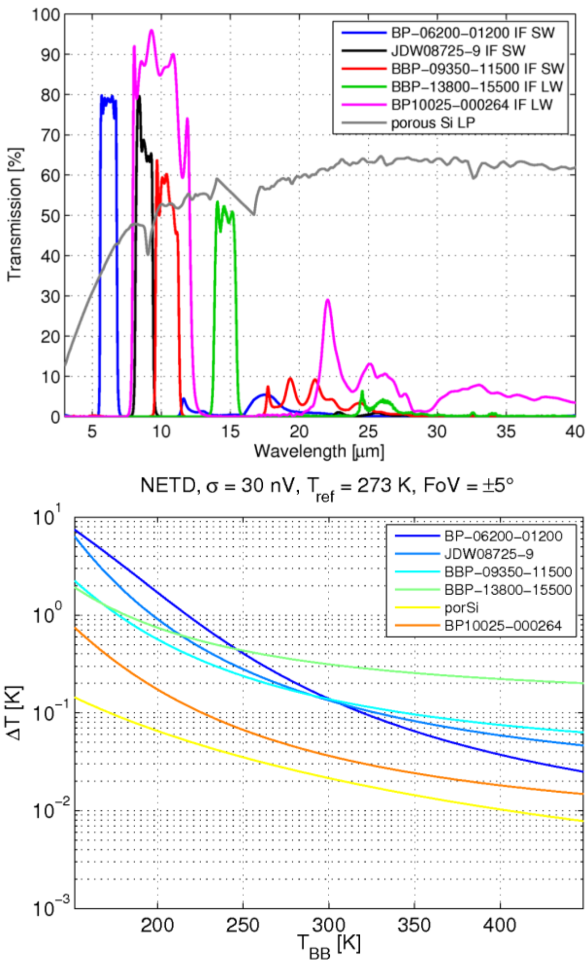

Figure 2: Top: Transmission characteristics of the filter-absorber combinations employed by the MARA instrument as a function of wavelength. Bottom: Theoretical Noise Equivalent Temperature Difference for the same filters, assuming an electronics noise level of 30 nV, as measured for the MARA engineering model.

The thermal voltage U_{th} generated by each sensor is a function of the sensor sensitivity S (in V/W), the absorber size A_d, the emissivity of the emitting surface ε, the viewfactor of the surface v, the trasmissivity of the employed filter-absorber combination τ, as well as the temperature of the target surface T and the reference junction temperature T_{ref}. In addition, radiation from the sensor housing, which has emissivity ε_H, viewfactor v_H, and is at temperature T_H , needs to be taken into account. Signal strength is then given by

$$U_{th} = SA_d\pi\left(\varepsilon v\int_{\lambda_1}^{\lambda_2}\tau(\lambda)\left(B_\lambda(T)-B_\lambda(T_{ref})\right)d\lambda + \varepsilon_H v_H\int_0^\infty\left(B_\lambda(T_H)-B_\lambda(T_{ref})\right)d\lambda\right)$$

where v_H is usually much larger than v. In order to eliminate radiation from the housing, the sensor head is temperature controlled such that $T_H = T_{ref}$.

For good temperature control, MARA sensors are embedded in an aluminum housing as shown in Fig. 1. The instrument sensor head and back-end electronics have a mass of 90 and 100 g, respectively, and power uptake of the instrument is 0.6 W. In addition, up to 2 W of heating power are required for temperature control, depending on the ambient conditions. The calibration target weights 100g, and up to 2 W of power are needed for temperature control, depending on the temperature setpoint.

Expected Performance: MARA is fitted with six individual filters, and bandpasses between 5.5-7, 8-9.5, 9.5-11.5, and 13.5-15.5 µm have been chosen. In addition, a longpass filter between 5 and 100 µm will be employed to determine surface temperature, and one filter between 8 and 14 µm will be used to provide ground truth for spacecraft measurements.

Usually, IR filters become transparent at around twice the wavelength of the optical window, and, in addition, Germanium based filters generally become transparent at $\lambda > 50$ µm. As a significant part of the signal is expected to originate at wavelength >50 µm for low night time temperatures, this signal needs to be blocked. MARA achieves this by using the IPHT interference absorbers, and the transmission characteristics of the employed filter absorber combinations are shown in the top panel of Fig. 2.

The instrument electronics employ 24 bit analogue to digital converters, and noise measurements indicate a noise level of less than 30 nV using an integration time of 1 s per channel. Calculating the expected signal to noise ratio for each filter as a function of target temperature, the resolvable noise equivalent temperature difference (NETD) can be calculated. Results are shown in the bottom panel of Fig. 2, and temperature differences of 0.2 K can be resolved even at target temperatures of 150 K using the Silicon-based filter.

To allow for different operating conditions, the instrument will be calibrated at three temperature stabilized stepoints of -10, +10, and +30 °C, using medium (400-900 K, BB900) and low temperature (100-400 K, BB100) cavity blackbodies [4], which have emissivities of 0.992 and 0.999, respectively. In this way, an absolute brightness temperature accuracy of better than 2 K of the instrument is expected.

References: [1] Lange, M., et al., Europ. Conf. on Spacecraft Struct., Materials and Environmental Testing, 20.-23.Mrch 2012, Noordwijk, Netherlands. [2] Okada, T., et al., 43rd LPSC, abstract 1498 (2012). [3] Kessler, E., et al., Proc. of Sensor 2005, 12th International Conference, Vol. I, Nürnberg, 73-78 (2005). [4] Sapritsky, V.I., et al., Temperature: Its Measurement and Control in Science and Industry, vol. 7, 619-624 (2003).