Radiometric Calibration of The MASCOT Radiometer MARA for the Hayabusa 2 Mission. M. Grott[1](Matthias.Grott@dlr.de) , J. Knollenberg[1], F. Hänschke[2], E. Kessler[2], N. Müller[1], [1]DLR Institute for Planetary Research, Berlin, Germany, [2]Institute of Photonic Technology, Jena, Germany

Introduction: The MAscot RAdiometer MARA is one of the payloads of the MASCOT lander [1], which will explore the C-type near Earth Asteroid 1999JU3 during JAXA's Hayabusa 2 mission. MASCOT will be deployed from the main spacecraft following an initial phase of asteroid characterization, and will then operate for approximately 20h on primary batteries. MASCOT is equipped with a hopping mechanism, and will in situ investigate 1999JU3 at multiple surface sites using its four science instruments, which comprise a near infrared spectrometer, a camera, a magnetometer, and the MARA infrared radiometer [3]. In addition to characterizing the asteroid in situ, the obtained datasets will be consulted when a site for sample collection is chosen.

Instrument Description: The MARA instrument uses 6 dedicated infrared channels to measure the radiative flux emitted from the asteroid's surface. The primary scientific goal of the instrument is the determination of the surface thermal inertia at the landing sites, and a secondary goal is the characterization of the surface mineralogy using bandpass filters. One channel is identical to that used by the spacecraft thermal mapper [2], and will provide ground truth for measurements at spacecraft altitude. Spectral transmission characteristics of the employed filters are shown in Figure 1, where transmission of the longpass Silicon filter, as well those of the Germanium based band passes are given as a function of wavelength.

MARA uses the IPHT TS-72M thermopile sensors as sensing elements [3], and the incoming radiation is coupled into a circular absorber of 0.5 mm diameter. The temperature difference between the hot and the cold junctions of the absorber is transformed into the signal voltage due to the Seebeck effect. PT100 sensors measure the thermopile cold junction temperature as a reference.

The thermopile signal generated at the absorbers originates from radiation emitted by the object in the instrument's field of view, as well as from radiation emitted by the instrument housing. Therefore, the net thermopile voltage is given by

$$U_{th} = SA_d(F_{obj} + F_H) \qquad (1)$$

where S is the sensor sensitivity in V/W, A_d is the area of the absorbing surface in mm^2, and F_{obj} and F_H are the radiative fluxes emitted by the object and the housing in W/m^2, respectively. As the instrument housing occupies a larger field of view than the object of interest, instrument self radiation contributes significantly to the total signal, and great care must be taken to eleminate its influence. MARA uses active thermal control of the sensor head to minimize thermal gradients between thermopile cold junctions and housing, and remaing gradients are treated in the calibration.

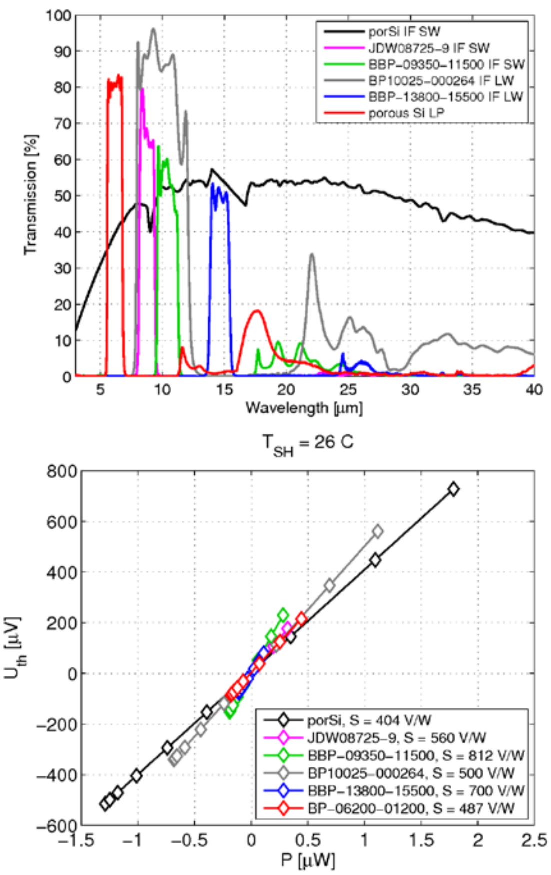

Figure 1: Top: Transmission as a function of wavelength for the six employed filters. Bottom: Thermopile voltage signal as a function of net incoming radiation for the same filters as measured during calibration. Sensor Head temperature was stabilized at 26°C.

Calibration: MARA has been calibrated in the space simulation chamber at DLR using a low temperature (100-400 K, BB100) cavity blackbody [4], which has an emissivity of 0.999. The instrument's sensor head was mounted inside a thermal enclosure to simulate environmental conditions during on-asteroid operations. To allow for different operating conditions, the instrument has been calibrated at three temperature stabilized setpoints of +0, +25, and +50 °C.

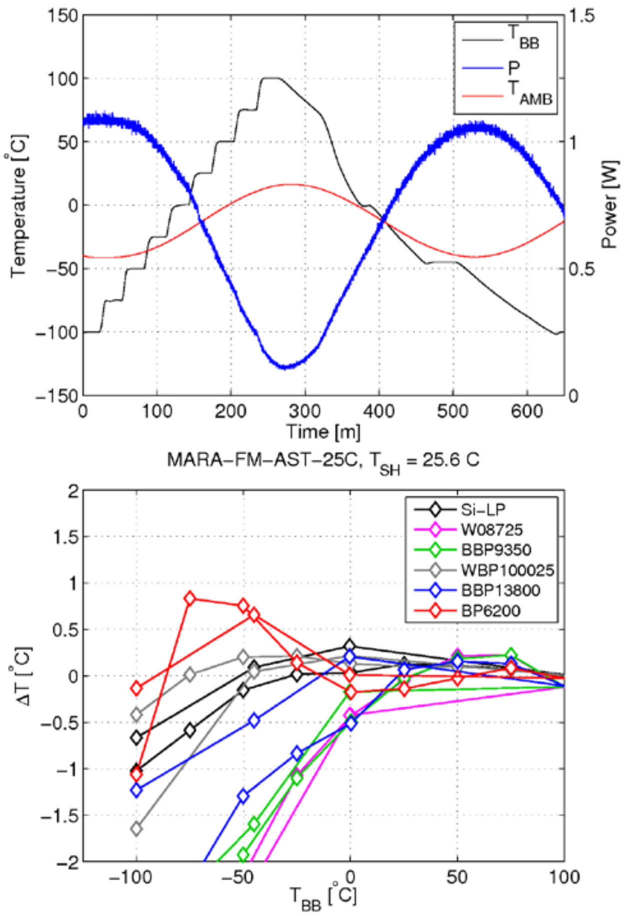

Figure 2: Top: Blackbody temperature T_{BB}, ambient temperature T_{AMB}, and heating power P required to stabilize the sensor head temperature at 25.6°C. Bottom: Difference between temperatures inverted from the measured thermopile signals and the blackbody temperatures at the constant temperature plateaus of T_{BB}.

While keeping the instrument temperature stable using MARA's active temperature control, the blackbody temperature was stepwise increased from -150°C to +100°C. The resulting thermopile signal is shown in Figure 1, where U_{th} is given as a function of radiative power P emitted by the blackbody. As is expected from Eq. 1, the relationship is linear to a good approximation. To account for non-linearities introduced by the imperfect knowledge of the filter transmission characteristics, the data was fitted to the quadratic expression

$$U_{th} = S_1 P(T_{BB}, T_{ref})^2 + SP(T_{BB}, T_{ref}) + S_{off}(P_H) \quad (2)$$

and preliminary calibration coefficients S_1, S, and S_{off} have been determined as a function of the incident radiation $P(T_{BB},T_{ref})$, where T_{BB} and T_{ref} are the blackbody and cold junction temperature, respectively. The offset voltage S_{off} is a function of the heating power P_H needed to stabilize the sensor head temperature, and is indicative of the thermal gradients across the instrument. In this way, fitting residuals below 1 µV have been obtained.

Verification: To estimate the performance of the instrument under non-constant ambient conditions, a verification measurement simulating on-asteroid operations has been performed. During the measurement, ambient temperatures have been varied between -45 and +20°C, as predicted by the MASCOT thermal model. In addition, the blackbody temperature was varied between -100°C and +100°C, while keeping the MARA sensorhead temperature stable at +25°C. Ambient temperature, blackbody temperature T_{BB}, as well as the heating power P_H are shown in Figure 2.

Measured thermopile signals were then inverted using the calibration coefficients S_1, S, and S_{off}, and T_{BB} has been determined from the measurement. These temperatures were then compared to the actual blackbody temperatures, and the residuals are shown in the bottom panel of Figure 2. For the Silicon longpass filter, residuals are below 1 K, indicating that temperatures down to -100°C can be measured with this accuracy. Accuracy of the 8-12µm (WBP100025) and 13-15 µm (BBP13800) bandpass filters is better than 2 K, while the narrow bandpass filters give good signal to noise only at temperatures above 0°C.

Conclusions: Preliminary analysis of the radiometric calibration of the MASCOT radiometer MARA already demonstrates that the instrument is capable of measuring surface brightness temperatures down to -100°C with an accuracy of approx. 1 K. The systematic deviations between measured and actual blackbody temperatures as shown in the bottom panel of Figure 2 can likely be reduced by a better calibration of the cold-junction reference temperature sensors, which will be the next step for instrument calibration.

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] [4] Kessler, E., et al., Proc. of Sensor 2005, 12th International Conference, Vol. I, Nürnberg, 73-78 (2005). [5] Sapritsky, V.I., et al., Temperature: Its Measurement and Control in Science and Industry, vol. 7, 619-624 (2003).