In-Situ Radiometric Investigation of Phobos using the MMX Rover's miniRAD Instrument. M. Grott[1], J. Knollenberg[1], M. Hamm[1,2], J. Biele[3], J. Helbert[1], K. Gwinner[1], A. Maturilli[1], E. Kuehrt[1], [1]German Aerospace Center (DLR) (Matthias.grott@dlr.de), Berlin, Germany, [2]Free University Berlin, Berlin, Germany, [1]German Aerospace Center (DLR), Cologne, Germany.

Introduction: The JAXA MMX sample return mission to the martian moons will deliver a rover to the surface of Phobos that will investigate the landing area using its navigation cameras (NavCams), its regolith facing cameras (WheelCams), its Raman spectrometer (RAX), as well as its mid infrared radiometer (miniRAD) [1]. The distance that can be travelled by the Rover depends on the yet unknown terrain properties, but is estimated to range from a few meters to hundreds of meters. The rover and its instruments will operate on the surface of Phobos for at least 100 days.

The rover will perform ground truth measurements and provide geological context for the samples that will be returned by the mission with the aim to help clarify the origin and history of Phobos and Deimos. Rover instruments will investigate the surface composition, surface physical properties, surface dynamics, and the degree of surface alteration.

Science Objectives: The miniRAD instrument will measure surface brightness temperatures in six dedicated infrared channels. From these measurements, surface thermophysical properties can be estimated by fitting thermal models to the observed fluxes for given illumination conditions [4,5]. In this way, surface thermal inertia [4], porosity [6], and particle size [7] may be estimated. Further, the presence or absence of a dust layer covering the surface, which may not be readily detectable in image data, may be identified [8].

The interpretation of thermal infrared data is complicated by the fact that surface roughness can have a significant influence on the emitted fluxes [9,10]. As surface roughness effects are most pronounced at low solar incidence angles and disappear at night, this effect is best studied using data acquired under changing illumination conditions.

Instrument Description: The miniRAD instrument design is based on the Hayabusa2 MASCOT MARA [2] and InSight HP^3 RAD instruments [3]. miniRAD sensors have a field of view of 45° and will observe a spot with a diameter of approximately 1.3 m in front of the rover. The radiometer field of view will be located within the field of view of the stereo navigation cameras (NavCams), which will provide context for the brightness temperature measurements. Stereo images will also be used to build a local terrain model and thus constrain the illumination conditions during miniRAD observations.

The instrument uses 6 infrared channels to measure emitted radiative flux and employs the IPHT TS-72M thermopile sensors as sensing elements [11]. These 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.

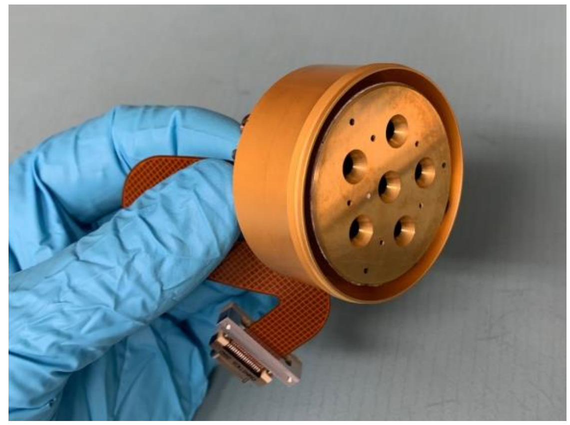

Figure 1: *Qualification model of the miniRAD sensor head showing the six aperture openings for the individual infrared channels. The radiation cover thermally decouples the sensor head from the surroundings. The flex-harness connects the sensor head to the miniRAD electronics.*

Sensors are integrated into a temperature stabilized sensor head which is thermally decoupled from the environment. The latter is achieved by minimizing conductive heat losses through the harness as well as minimizing radiative losses using gold coating and a radiation shield. A picture of the sensor head's qualification model is shown in Fig. 1.

The instrument electronics employ 24-bit analogue to digital converters, and noise measurements indicate an electronics noise level of less than 20 nV using an integration time of 1 s per channel. Residual thermal fluctuations add another source of noise, which amounts to about 80-100 nV, thus representing the dominant noise source.

Infrared filters have been chosen to fulfill the following functions: 1) Two long-pass filters with good signal to noise during nighttime will be used to determine surface thermal inertia. 2) A short-wavelength bandpass will be used to characterize surface roughness. 3) Three bandpass filters which are located near the expected location of the Christiansen feature will be used for a basic mineralogical characterization of the surface. Throughput of the filters, i.e., the combined instrument response of thermopile absorbers and filters, is shown as a function of wavelength in the top panel of Fig. 2.

The total mass of the instrument is 330 g including margins. The sensor head mass is 90 g and the electronics box mass including the printed circuit board and electrical components is 240 g. Total average power uptake including thermal stabilization is 1.5 W during normal science operations.

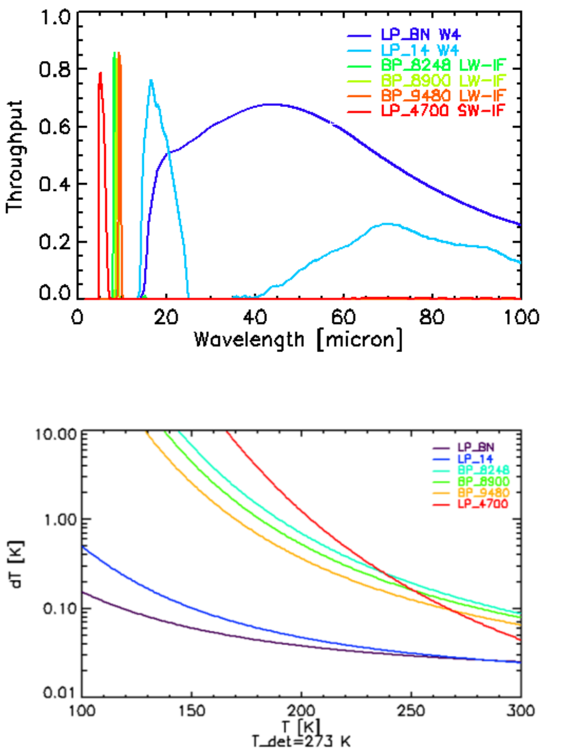

Figure 2: Top: *Throughput of the infrared filters used for the six miniRAD channels as a function of wavelength. Two longpass filters collect flux at wavelengths >14µm to maximize the signal during nighttime, while the bandpass filter between 3 and 7 µm is most sensitive to surface roughness effects. Three bandpasses around 8.3, 8.9, and 9.5 µm will be used for mineralogical investigations.* ***Bottom****: Noise equivalent temperature difference as a function of target temperature for the six miniRAD channels.*

Expected Instrument Performance: The expected noise equivalent temperature difference (NETD) for all sensors is shown in the bottom panel of Fig. 2. The two broadband channels show good NETD < 1 K even for the low night-time temperatures expected on the surface of Phobos. The short-wave channel and the narrow bandpass filters placed around the Christiansen feature provide good signal-to-noise only for temperatures above 210 K. However, this is well within the range of expected daytime temperatures on Phobos, which are estimated to range from 290 to 330 K in the afternoon.

Summary: The miniRAD instrument is a payload on the MMX rover, which will investigate the surface of this martian Moon in late 2026 or early 2027. The rover will likely traverse a few tens of meters, thus enabling a study of different geological units including boulders and regolith. miniRAD will characterize these units in terms of their thermal inertia and perform a first order mineralogical characterization by studying the location of the emissivity maximum (Christiansen feature) using an approach that is similar to that employed by the lunar DIVINER investigation [12].

The instrument is light-weight and low-power, and total temperature uncertainty is expected to be less than 1 K even during nighttime. This will enable deriving surface thermal inertia with uncertainties similar to those achieved for the heritage instruments [2,3].

References: [1] Michel et al., *EPS*, 2022. [2] Grott, M., et al., *SSR*, 208, 413, 2017. [3] Spohn et al., *SSR*, 214, 5, 2018. [4] Hamm, et al., *MNRAS*, 496, 3, 2776–2785, 2020. [5] Hamm, et al., *PSS*, 159, 1-10, 2018. [6] Grott, M., et al., *Nat. Astr.*, 3, 971, 2019. [7] Ogawa et al., *Icarus*, 333, 318-322, 2019. [8] Biele et al., EPS, 6, 48, 2019. [9] Kuehrt et al, *Icarus* 96, 213–218, 1992. [10] Davidsson et al., *Icarus*, 252, 1–21, 2015. [11] Kessler, E., et al., *Proc. of Sensor*, 2005, 12th International Conference, Vol. I, Nürnberg, 73-78 2005. [12] Greenhagen et al., Science, 329, 5998, 1507, 2010.