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Measuring Heat Flow on Mars: The Heat Flow and Physical Properties Package on GEMS

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Abstract

The Heat Flow and Physical Properties Package (HP^3) has been developed to the breadboard level and is designed to penetrate up to 5 m into the martian regolith. The instrument will measure electrical permittivity, electrical conductivity, thermal conductivity, and the temperature of the regolith. From these measurements, the planetary heat flow at the landing site will be determined with an uncertainty better than 10%.

1. Introduction

The geophysical monitoring station GEMS (Fig. 1) is a Discovery-class mission proposal to study the martian interior. The focused GEMS payload consists of a seismometer, a radio tracking experiment, and a heat flow probe, and will address fundamental questions of martian geophysics. Main mission goals are the determination of the size, physical state, and composition of the core, the thickness of the crust, and the thermal state of the martian interior.

To constrain the thermal state of the interior, GEMS will measure the planetary heat flow at the landing site. Heat flow is expected to vary with location on the surface of Mars [2], and a first measurement will provide an important baseline to constrain mantle potential temperatures and the bulk abundance of heat producing elements in the martian interior.

GEMS is capable of landing between 1°N and 14°S at altitudes below -2.5 km, and will operate for a full martian year. This general framework is ideal for heat flow measurements, as temperature signals due to the seasonal variation can be removed from long term ($\sim$1 martian year) measurements [1]. Furthermore, the influence of periodic signals due to, e.g., the martian obliquity variations, are minimized for a near equatorial landing site [3].

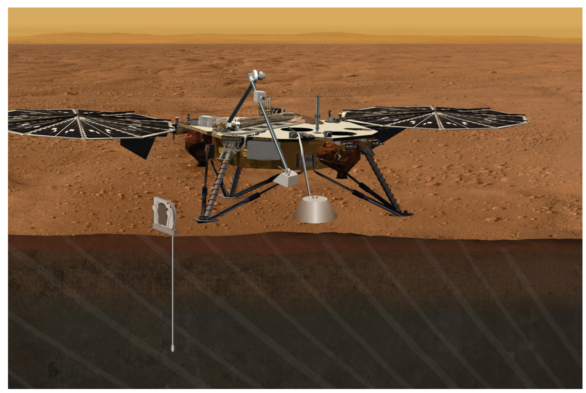

Figure 1: Conceptual view of the GEMS lander including the deployed seismometer and heat flow probe (HP^3).

2. Instrument Description

HP^3 (see sketch in Fig. 2) consists of an electro-mechanical hammering mechanism, the so-called Mole, which will emplace a suite of sensors to a depth of up to 5 m into the subsurface. The Mole pulls behind a Payload Compartment (P/C), which houses a permittivity probe to measure electrical properties of the regolith, heaters for thermal conductivity measurements, and tilt sensors to determine the position of the instrument in the ground. An instrumented tether acts as the mounting locale for temperature sensors, and connects the P/C to the support system (S/S), which stays on the surface. An engineering tether connects the S/S to the lander.

3. Projected Performance

To determine the planetary heat flow, the regolith thermal conductivity and the thermal gradient in the

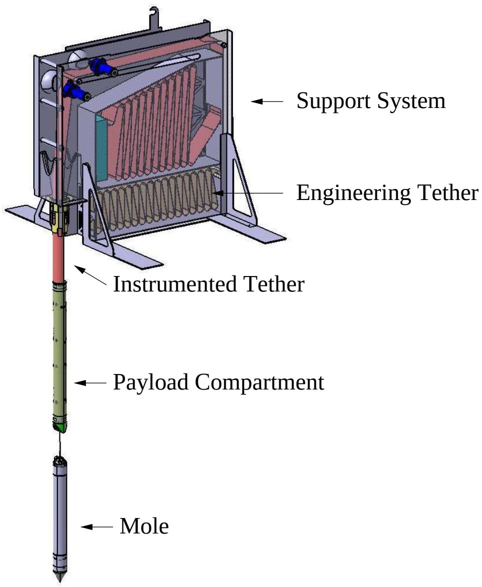

Figure 2: Schematics of the HP^3 instrument showing the functional subsystems.

ground need to be known. Thermal conductivity will be determined by operating the P/C as a modified line heat source. For the low rock abundance regions targeted by GEMS, thermal inertia is expected to be $\sim$250 J m^{-2} s$^{1/2}$ K, corresponding to thermal conductivities of $\sim$0.05 W m^{-1} K^{-1}. In this conductivity range, measurement uncertainty is expected to be 5%.

The subsurface thermal gradient will be determined from resistance temperature detectors mounted on the tether. For surface heat flows of 20 mW m^{-2}, thermal gradients of 0.3 K m^{-1} are expected. Given that sensors can be calibrated to within 50 mK and that the positioning uncertainty is expected to be a few cm, a gradient uncertainty of better than 6% is expected for a measurement baselength of 3 m. Together with the uncertainty for the thermal conductivity measurement, heat flow is therefore expected to be measured with an uncertainty of better than 10%

In addition to the thermal sensors, HP^3 is equipped with a permittivity probe, which will measure regolith electrical permittivity and conductivity in the frequency range between 1 Hz and 20 kHz. The low frequency range (<100 Hz) is especially suited for the detection of subsurface water or ice and measurement uncertainties of better than 15% have been demonstrated in the lab for the electrical permittivity. In the frequency range above 1 kHz, uncertainties are better than 5%. As for the electrical conductivity, uncertainties were found to be better than 15% for regolith conductivities larger than 10^{-11} S/m.

4. Operations

After landing, the seismometer and HP^3 will be deployed onto the martian surface by a 2.4 m long robotic arm. Deployment away from the lander will minimize the effects of lander shadows, which might otherwise alter the thermal structure of the regolith and affect the measurement [2].

After deployment, HP^3 will execute hammering cycles, penetrating 50 cm into the subsurface while executing two permittivity measurements. Thereafter, heat built up during hammering will be allowed to dissipate for 48 h, before a thermal conductivity measurement is executed for 24 h. This cycle is then repeated until the final penetration depth of 5 m is reached or further progress becomes impossible.

In this way, a target depth of 5 m can be reached within 30 days, after which the long-term monitoring phase starts. This phase consists of tether temperature measurements on the hour and lasts to the end of the mission.

Acknowledgements

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