# MICROPOWER INSTRUMENTATION NEEDS FOR AN RHU-POWERED MARS MINI-NETWORK MISSION

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**Introduction:** A network of Mars landers ('MASER') able to operate year-round at high latitudes could be enabled by a power system using radioisotope heater units (RHUs) as an energy source. The MASER design reference mission would use 6 RHUs per lander with a total budget of 240mWe : the instrument power allocation can only be half of this due to the demands of data handling and communication. We therefore challenge the instrument community to explore seismometer designs with as broadband a capability as possible with ~50mW power. Current Mars anemometer designs require 250-500mW and so must be operated at a low duty cycle : continuous measurements would require a new design able to operate on ~50mW. Innovative design to enable seismic and wind measurements at such low power levels is enabling to permit affordable multi-station networks.

**Reference Mission**: MASER (Meteorology and Seismology Enabled by Radioisotopes) is a reference mission concept [1] designed to demonstrate the science potential of a small semi-hard lander powered by RHU-based thermoelectric power systems. Guided by Decadal Survey and MEPAG priorities [2,3], and to exploit the ability of such a system to operate in Martian winter, a four-station regional network would be deployed in the northern plains where they could monitor the strong seasonal changes at those latitudes, and be reasonably close to the system of graben radiating from Alba Patera (figure 1) which may plausibly be associated with regional seismicity (and would complement the InSight mission at Elysium). These plains, whose surface properties are already well-characterized by the Phoenix lander, are benign for a semi-hard landing using a simple crushable impact absorber in conjunction with parachute descent.

Overall the scale of the landers is similar to the small landers of the Mars-96 mission [4], although with a somewhat reduced instrument complement and power level (the Mars-96 stations had a nominally 440We RTG). On the other hand, the established communication relay infrastructure at Mars may permit a larger overall data return than was foreseen in the 1990s. In many ways the meteorological [5] and seismological [6] objectives and instrumentation of MASER are similar to what was flown on Mars 96. In fact larger networks of less capable meteorology stations have also been proposed in the past [7].

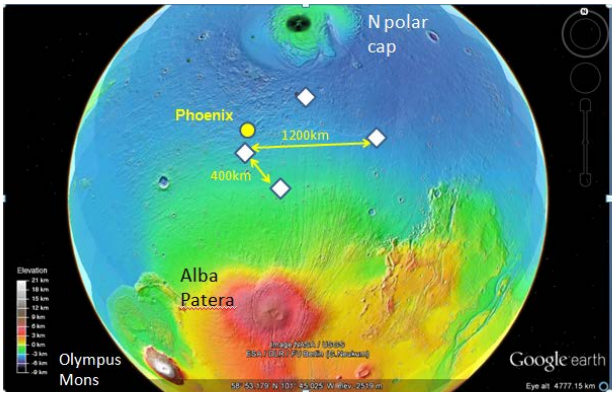


*Figure 1. Four stations (white diamonds) would be delivered to the northern plains between the heavily-tectonized flanks of the Alba Patera volcano and the north polar cap. Inter-station distances range from 400-1,200km. The terrain is well-characterized by the Phoenix mission.*

The power system foreseen for the MASER network is based around RHU (Radioisotope Heater Unit) heat sources coupled to a thermoelectric converter. Each such unit (which have demonstrated ~1000g tolerance compatible with the landing system planned here) provides about 1Wth and 40mWe [8]. In this application, the small individual unit size, while slightly less mass-efficient than a multi-RHU package, is in fact more convenient for integration (figure 2) in the small allowable volume around the seismometer cavity, which lets the lander act as the seismometer windshield.

Use of individual RHU-RPSs enables a more robust sparing philosophy for a multi-lander development, and (in the limit) relatively simple augmentation of the power and/or heat budget in response to design or environment changes. In any case, it is clear that the overall mission power budget without attempting any solar augmentation (which would be possible, and even significant, for some locations/seasons) that the system must work on <~300mWe, and that the payload - which for seismic and meteorological measurements should desirably operate with a 100% duty cycle – must function at a power level of the order of ~150mWe total.

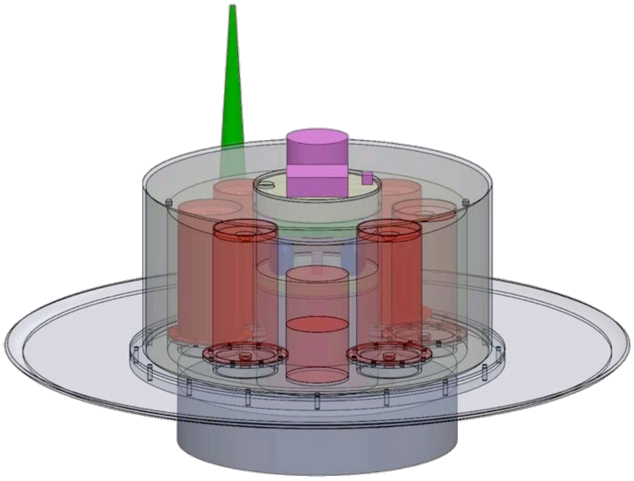
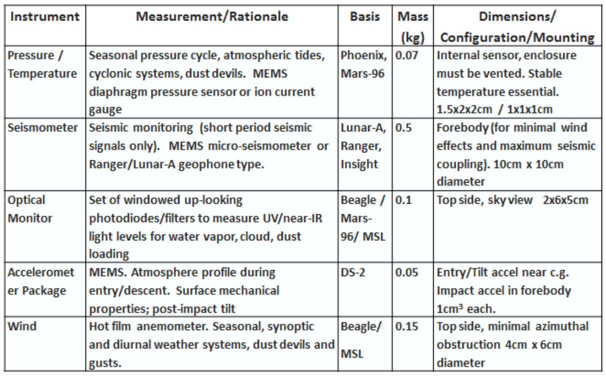


*Figure 2. Semitransparent view of the landed configuration. The bottom cylinder is a crushable impact attenuator, while the wide skid-plate helps ensure upright orientation. The seismometer in the central cylinder drops down to the ground where it contacts the ground, but is shielded from the wind. The meteorological instruments are on the top of the lander, and the DS-2 derived telecommunications antenna is at the back in this view. The six red cylinders are the RHU-RPS power sources.*

## Instrument Payload:

The principal notional instruments are a seismometer and a meteorology package - see table 1. Other possible payloads were considered (e.g. camera, magnetometer, mineralogy experiments), but were considered of lower scientific priority due to too resource-demanding, or incompatible with a small hard-landed vehicle. The meteorology package includes an accelerometer for entry measurements, pressure and temperature sensors, an optical monitor for dust/water vapor/cloud measurements and a wind sensor.



| Instrument | Measurement/Rationale | Basis | Mass (kg) | Dimensions/ Configuration/Mounting |
|---|---|---|---|---|
| Pressure / Temperature | Seasonal pressure cycle, atmospheric tides, cyclonic systems, dust devils. MEMS diaphragm pressure sensor or ion current gauge | Phoenix, Mars-96 | 0.07 | Internal sensor, enclosure must be vented. Stable temperature essential. 1.5x2x2cm / 1x1x1cm |
| Seismometer | Seismic monitoring (short period seismic signals only). MEMS micro-seismometer or Ranger/Lunar-A geophone type. | Lunar-A, Ranger, Insight | 0.5 | Forebody (for minimal wind effects and maximum seismic coupling). 10cm x 10cm diameter |
| Optical Monitor | Set of windowed up-looking photodiodes/filters to measure UV/near-IR light levels for water vapor, cloud, dust loading | Beagle / Mars-96/ MSL | 0.1 | Top side, sky view 2x6x5cm |
| Accelerometer Package | MEMS. Atmosphere profile during entry/descent. Surface mechanical properties; post-impact tilt | DS-2 | 0.05 | Entry/Tilt accel near c.g. Impact accel in forebody $1cm^3$ each. |
| Wind | Hot film anemometer. Seasonal, synoptic and diurnal weather systems, dust devils and gusts. | Beagle/ MSL | 0.15 | Top side, minimal azimuthal obstruction 4cm x 6cm diameter |

*Table 1. Mission payload*

The seismometer would not be required to be an elaborate and delicate broadband instrument, such as that to be flown on the InSight mission. The ‘added value’ of a seismometer network is in the identification of source locations and propagation speeds and thus a large long-period seismometer is not justified. Short-period devices can be small, simple and robust: an end-member is an entirely passive geophone (the Ranger moon landers were to have geophone-type instruments, which could tolerate 2,000g), although modern signal conditioning techniques allow higher sensitivity. It would be desired to have the instrument operating continuously and thus instrument power is a key consideration: force-feedback instruments presently qualified for space have powers that are too high (e.g. [9]). Advanced conditioning on geophone-type instruments (e.g. Lennartz LE-1DV) yields quite good (3nm/s) noise levels, yet with a (non-space-rated) power draw of 36mW: we therefore allocate 50mW to the measurement.

The principal meteorological measurement would be a pressure sensor. Time series pressure data yields insight on the annual $CO_2$ frost cycle, atmospheric waves, the passage of frontal systems, and the presence of dust devils. The combination of time series from a regional network allows the propagation of waves and systems to be observed by cross-correlation and the influence of terrain on local weather to be exposed. Compact and accurate pressure sensors have flown on Viking, Pathfinder, Phoenix and Curiosity. This sensor has a minimal power draw and would operate continuously for maximum measurement stability. Semiconductor or thermocouple temperature sensors would be installed at a few locations on the vehicle. Although it is recognized that some lander thermal perturbations will be inevitable, azimuth diversity ensures at least one sensor will be upwind. A deployable mast would obviate such issues, but is challenging to accommodate on a hard-landing vehicle.

An optical monitor comprises simply a set of photodiodes with wavelength filters and collimating masks to measure the direct and scattered solar beam, at a set of wavelengths to discriminate dust and ice, and (via differential absorption in a water band, e.g. at ~900nm) the column abundance of water vapor. Such monitors were developed for Netlander and Mars 96, and flew on Beagle 2 and Curiosity. Brief measurements (e.g. a few seconds once/hr) would be made.

Wind speed and direction is in some ways the most important measurement, in that as well as the scientific information it provides to improve understanding of meteorological processes, it contributes to the (presently very small) inventory of surface wind speed measurements, which are of importance in Entry, Descent and Landing (EDL) and surface operations for future missions. Additionally, the wind data will provide a quality flag for seismometer data, which will (despite the direct emplacement of the seismometer on the ground and the shielding afforded by the lander body) increase the seismic noise background via wind loads on the ground and lander. Seismic signals may also be correlated (as on the moon) with solar heating of the ground, and with passing pressure systems.

Wind sensing in the thin Mars atmosphere is challenging - mechanical wind sensors are difficult to use (especially given the landing scenario) and ultrasonic methods require computationally-demanding cross-correlation, which drives the required power. Ion anemometers and thermal (hot-film or hot-wire, as flown on Viking and Pathfinder) anemometers, and optical wind/dust sensors are all well-suited mechanically to this application, and relatively low-power, but this still means a draw of 0.25-0.5W which is prohibitive. Some entirely passive possibilities exist to detect high winds (e.g. a whisker driving a flexible piezoelectric element), but are not likely to be quantitatively accurate. Another possibility that would require modest mechanical development might be a telltale indicator like that on Phoenix, but with an optical or magnetic sensing system rather than an imaging-based one. Pending such a development, we consider that the wind sensing objective can be adequately met by a Beagle-2 type wind sensor [10] operated at a modest duty cycle (presently ~8%, but could be scaled up after the on-Mars power budget is better understood and margins can be released).

Impact energy is absorbed by a 6cm-thick crushable glass-phenolic honeycomb (4cm stroke) which limits deceleration to an average of ~600g: the peak might be higher, especially if a rock results in uneven crush of the material. Design to 600g is driven largely by expectations of the likely tolerance of the RPS [8] and should be borne in mind for instrument designs.

**Conclusions:** A mission concept for a RHU-RPS-enabled mission has identified instrumentation needs with low power and modest g-tolerance. Such instrumentation could permit affordable missions with global year-round coverage, scaled up to multiple stations and enabling revolutionary network science.

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