RATIONALE AND CONCEPT FOR A SYNTHETIC APERTURE RADAR AND SUB-SURFACE ICE SOUNDER FOR MARS.

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Introduction: Liquid H_2O is unstable on the present-day surface of Mars due to the low atmospheric pressure; however, water ice is stable at the higher latitudes in the north polar ice cap (e.g., [1]) and the south polar remnant ice cap (e.g., [2]). There is also a large body of evidence to suggest that large volumes of ice did, or still do, exist in the "shallow" subsurface in the Martian mid-latitudes and at high elevations approaching the equator, or even at lower latitudes during periods of high obliquity (e.g., [3–8]).

The gamma ray spectrometer (GRS) onboard the Mars Odyssey spacecraft provides knowledge of the distribution of ice in the upper ~1 m of the Martian surface [9]. Based on this data, the Martian regolith is predicted to contain an extensive amount of ground ice at latitudes >40–50° and its abundance can reach >70% by volume at higher latitudes. Numerical modeling, which was confirmed by Phoenix [10], predicts that the ground ice is present close to the surface beneath a dry regolith lag. The ice table ranges from a few cm at high latitudes to >50 cm in the mid latitudes [11].

Extending the ice record to greater depths and further into the past, there is a growing body of evidence for widespread glacial activity in various regions of Mars in the geologically recent past (<300 Ma e.g., [4]). Subsurface radar sounding of glacial landforms using the SHARAD instrument suggests that water ice may be present depths of 10s to 100s metres (e.g., [6, 12]). The widespread presence of periglacial landforms, such as polygons and thermokarst depressions, in Martian mid-latitudes points to large volumes of ground-ice at 10s m depth (e.g., [13]).

Despite the large number of missions and huge number of studies, ***there exists a fundamental gap in our knowledge about the distribution and amount of ice present at depths of >1 m to ~10 m on Mars.***

This is mirrored by the findings of the Final Report of the MEPAG Next Orbiter Science Analysis Group (NEX-SAG). Importantly, the mapping and quantification of "shallow ground ice deposits across Mars" is both a high priority science objective and a resource and Strategic Knowledge Gap (SKG) objective. The report concludes that a "Polarimetric radar imaging (SAR) with penetration depth of a few (<10) meters" was critical for addressing the resource, science, and reconnaissance objectives of the Next Mars Orbiter (NeMO) mission.

This is consistent with previous studies [14, 15] and such an instrument would be complementary to the previously flown SHARAD and MARSIS radar instruments that have provided important insights into the distribution of ice in the subsurface of Mars at several 10s to 100s of metres depth.

In April 2017, MDA Corporation began a Concept Study for a Sub-Surface Ice Sounder for a future Mars orbiter under contract from the Canadian Space Agency (CSA). Such an instrument is deemed a high priority by the Canadian Planetary Geology, Geophysics and Prospecting community [Topical Team Reports on Planetary Exploration, Canadian Space Agency, 2017]. The Concept Study team comprises a Technical Team (Technical Lead: I. Bernard) and a Science Team (Principal Investigator: G. R. Osinski) led by Program Manager A. Baylis. In this contribution we provide an overview of the concept as it stands, discuss open questions, and welcome feedback and involvement from the international planetary science community.

Science objectives: For the purposes of this Concept Study, the Science Team has defined the following 5 science objectives:

1. Determine the overall spatial and vertical distribution of shallow ground ice deposits in the Martian mid- to high-latitudes;
2. Characterize the properties of the upper portion of the polar layered deposits (PLD).

3. Map and quantify shallow ground ice in areas of possible brine flow and monitor for recent RSL and gully formation activity;
4. Detect, characterize and map exposed and buried fluvial landforms in ancient Martian terrains;
5. Determine the surface properties of impact and volcanic deposits.

Requirements for radar instrument: In the following sections we outline the current status of the instrument requirements. It is important to note that these are draft and the concept is still evolving.

SAR Imaging Mode. The three classical side-looking SAR imaging geometries are: Spotlight, Strip-map, and ScanSAR. The science goals specified above can be met with a polarimetric Strip-map approach, in general. The science objectives identify the imaging characteristics of the radar in terms of high resolution (HR; 2–3 m), medium resolution (MR; ~5–7m) and low resolution (LR; <15 m). In these different modes, the desirable coverage of the instrument in a nominal 687day mission is:

- ~0.5 % of Mars in HR mode;
- ~5% of Mars in MR mode with repeat coverage by seasons;
- ~35% of Mars in LR mode with repeat coverage by seasons.

In terms of incidence angles, a range of incidence angles from ~30 to 50 degrees is currently being investigated as this is most highly desirable from a scientific point of view (e.g., higher incidence angles are preferable because they highlight small scale roughness rather than larger scale topographic variations).

Both fully polarimetric (quad-pol) and compact-pol options are currently being considered by the instrument team. Advantages of compact-pol are a lower sampling rate, resulting in a wider swath compared to quad-pol, and additional scattering information compared to single-pol. For compact-pol bases with circular transmit, the circular polarization ratio (CPR) can be derived, where high values are consistent with a coherent backscatter effect [12] linked to potential ground ice deposits.

SAR Sounder Mode. The current configuration being considered is for a nadir looking sounder mode with vertical resolution of 1 m and along track sampling of <50 m. Doppler processing can be used to achieve the target spatial resolution in the along-track direction. The target is 60% (or more) of Mars in this mode.

Onboard processing. To achieve the desired coverage areas decribed above in one Martian year and to downlink the data to Earth, some level of on-board processing is necessary. Onboard processing has the potential to greatly increase the amount of SAR on-time, since processed imagery can be significantly smaller in volume than raw SAR data. The amount of compression is most strongly driven by the processed number of looks; increasing the number of looks reduces speckle thereby improving the radiometric precision, with the downside of a degraded spatial resolution.

Operating frequency. Previous studies [15] have largely considered P-band radar operating at ~500 MHz and < 1 GHz. This selection has largely been based on the primary goal of subsurface sounding and deepest possible sub-surface imaging, with lower frequencies penetrating deeper. However, the objectives for this instrument can be split into two separate types: SAR imaging up to few m below the surface, and deep sounding extending to 15 m+ below the surface. There is, thus, an argument that can be made for using different centre frequencies depending on the measurement to be accomplished by the multi-mode radar instrument. A higher operating frequency (≥ 1 GHz) has additional hardware advantages as it decreases the required antenna size and facilitates the high pulse bandwidth necessary for 1m sounder resolution. Various options including a P-band radar (~500 mHz centre frequency), an L-band radar (~1.1 GHz) and a dual frequency solution are being studied by the instrument team.

Future work: This concept is the focus of ongoing work. We welcome input from the community as to the scientific objectives and technical requirements of this proposed instrument.

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