An Incoherent Scatter Radar Mission to Mars (ISR2M)

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Overview

This work presents a concept for a lander- or orbiter- based implementation of incoherent scatter radar (ISR) mission to Mars. ISR builds upon an instrument technique that has been extensively proven on Earth [1].

Motivation

The thermal properties of an ionized region of the atmosphere of Mars have only been partially measured by descending and orbiting spacecraft. The measurements do not reconcile with theory [2] and the resulting discrepancy has implications for human habitability, surface-to-space radio communication, and atmospheric dynamics and evolution at Mars [3]. To address this discrepancy and obtain a more comprehensive picture of the thermal properties in the atmosphere requires ISR technology deployed to Mars.

Science Goals

ISR2M would be able to routinely measure electron temperature (T_e), ion temperature (T_i) and electron density (N_e) in the ionized region of the atmosphere, at altitudes that no existing spacecraft at Mars can probe. These seminal measurements would allow identification of heating sources and sinks that determine Mars' atmospheric energy budget, constrain electrodynamical variability and planetary loss to space, facilitate spacecraft communications – particularly during entry, descent, and landing, and would aid in the interpretation of data from past and present orbiting spacecraft.

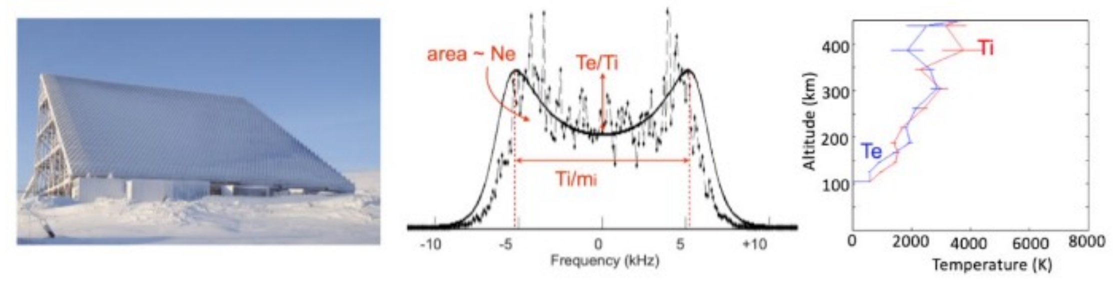

Figure 1. Left: Phased-array ISR @Resolute Bay, Canada. Center: Sample of measured normalized ISR spectrum (dots) compared to the theoretical ISR power spectrum in the Earth's ionosphere (solid). The spectral width is a function of ion temperature, which can be well resolved for a dominant (single-ion) plasma, as is the case for Mars. The valley between the peaks is a function of the electron-to-ion temperature ratio; the area under the spectrum is proportional to plasma density within the probed volume. Right: Range-resolved ISR spectra enable the creation of altitude profiles of N_e (not shown) and plasma temperatures, T_e (blue) and T_i (red) along the radar line-of-sight.

Design Resource Constraints	Upper Limit
Lander structure mass	350 kg
Power system mass	400 kg
Radar system mass	200 kg
Secondary system mass	50 kg
Total Payload Mass Limit	1000 kg
Radar RF average DC power	3000 W
Radar processing power	50 W
Secondary system power	500 W
Power efficiency losses (80%)	700 W
Total Average Power Limit	4250 W

Table1. Upper limits to ISR2M payload as lander concept.

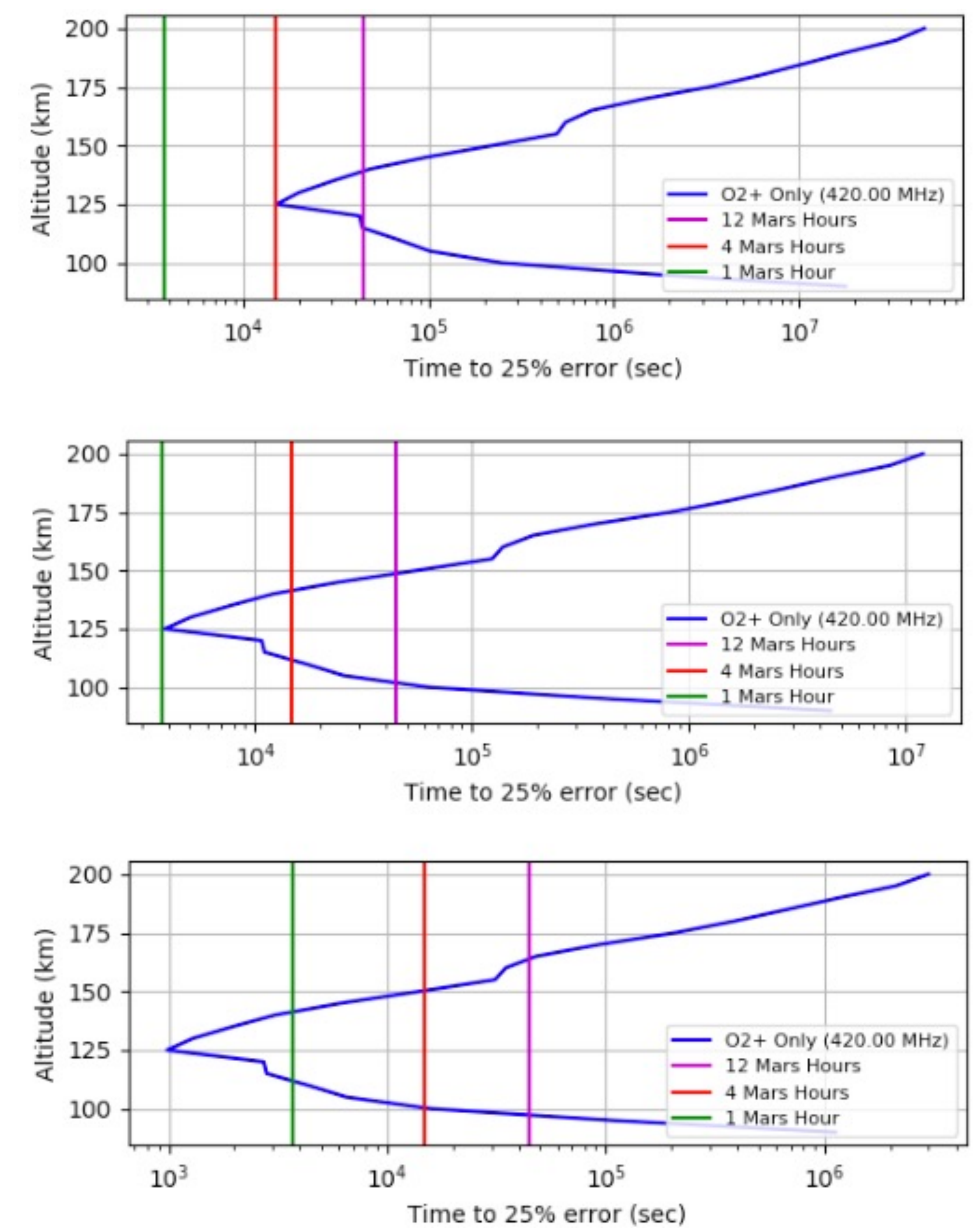

Figure 2. Performance estimates for ISR2M, assuming typical plasma characteristics at Mars, and targeting measurements made of the lower altitudes of the ionized region of the atmosphere – where key observations presently do not exist. Top: a single sub-array arrangement uses 361 elements. Middle: a dual sub-array arrangement uses 722 elements. Bottom: a quad sub-array arrangement uses 1444 elements. Vertical lines indicate variable integration times of 1 hour (green), 4 hours (red), and 12 hours (purple) for reference. The intersection points of each vertical line with the estimated O_2^+ measurement speed (blue) shows the range of altitudes where plasma density and temperature profiles can be achieved at 25% uncertainty. Longer integration times would translate into wider altitude coverage.

References: [1] Dougherty, J. and D. Farley (1960), A theory of incoherent scattering of radio waves by a plasma, Proc. Roy. Soc. London, A, 259, 79–99 [2] Hanley, G., et al. (2021), In Situ Measurements of Thermal Ion Temperature in the Martian Ionosphere, doi:10.1029/2021JA029531. [3] Matta, M. et al. (2014), Numerical simulations of ion and electron temperatures in the ionosphere of Mars: Multiple ions and diurnal variations, doi:10.1016/j.icarus.2013.09.006

Requirements

The ISR2M design targets a highly compact system to make recurring measurements. It would utilize automated deployment, low average power consumption, high peak radio frequency (RF) power, and environmentally tolerant electronics. To achieve the large aperture required for the ISR technique, ISR2M will benefit from integration with solar arrays, e.g., adopting an unfurlable antenna to utilize Martian air as the bulk of the antenna area. The electronic components would be included with the solar panel plates for efficiency and would require minimal power. Dust-mitigating technologies and power optimization technologies would be of relevance. Participation in this Tech Showcase is to solicit: (1) most updated options for such technologies, as well as (2) options for extremely low power instrumentation to be piggy-backed onto the lander or orbiter design (e.g., wind and temperature instrumentation).

Current Technologies with TRL

The ISR2M concept would require development of a miniaturized, low-power, radar (hardware and software component). We plan to leverage existing inflatable reflector antennas. One option to lower resource requirements would be to integrate into solar panels with dust-mitigating technology to accommodate solar panel utility. Sample performance metrics for the radar are shown in Figure 2. At present, components of the ISR2M design include a Deployable Array Radar Aperture hardware component (current TRL 2), and a low size weight and power (SWAP) Mars Radar software component (current TRL 2). Complementary relevant low-SWAP technologies would be of interest.

Operations

As a lander, the ISR2M concept will likely require an EDL design like that of MSL and/or Mars2020.