National Aeronautics and Space Administration

Enabling Mars Radio Occultation by Smallsats

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Program: FY21 SURP   **Strategic Focus Area: Planetary Atmospheres and Geology**

Objectives

The primary objective of this project is to mature a crosslink radio occultation (RO) mission concept for mapping the air density, temperature, and geostrophic wind structure of the Martian atmosphere with multiple orbiting small satellites. Our goal is to significantly augment existing atmospheric observations with improved spatial-temporal resolution, vertical coverage under all-weather conditions, and accuracy (e.g., temperature ~ 1 K) to eliminate an observational gap critical for Martian exploration, and important for advancing our knowledge of Martian atmosphere and climate.

Background

Existing Mars missions do not adequately sample the Martian atmosphere, especially in the lowest 10 km of the atmosphere during dust storm conditions. There is a need for better observations to improve modeling of Mars atmosphere, for high-priority science and exploration. Such needs can be met by a constellation of small satellites performing RO [Figure 1].

Approach and Results

- Our approach is to start with a Science and Applications Traceability Matrix (SATM) and develop the instrument, system, and mission requirements needed to meet the top-level mission objectives. To this end, we have developed an end-to-end observation simulation system to explore and quantify the key requirements and expected performance.
- In FY21, we have honed in on a mission concept consisting of 6 identical spacecraft in high inclination (87 deg) orbits to achieve the desired global and diurnal coverage requirements. The spacecraft are divided into two groups, with an inner group of 3 at an altitude of 300 km and an outer group of 3 at an altitude of 2400 km. The occultation events occur between an inner and an outer spacecraft, resulting in an average of 200 profiles per Martian day (sol) [Figure 2].
- Both a UHF and X band frequency simulations were carried out that include thermal and clock noise modules developed to assess the total expected bending angle noise and their error propagation to refractivity, density, temperature, pressure, and electron density profiles. Monte Carlo simulation results showed that to meet the 1 K uncertainty requirement between 6 and 12 km above the surface, an Allan Deviation (AD) of at least 4x10^{-13} is required with expected thermal noise [Figure 3]. More details can be found in Sweeny et al. (2021).
- Additional work to improve clock noise simulations as well as a novel dual-one-way approach to reduce clock stability requirements are being studied.

Significance/Benefits to JPL and NASA

Results from this project will help define instrument and mission requirements that will provide atmospheric measurements with sufficient sampling and accuracy to support of EDL operations where a current knowledge gap exists. This will help position JPL and U. Michigan as partners in a future NASA mission proposal (e.g., SIMPLEX).

Publications

D. Sweeney, C. Ao, P. Vergados, N. Renno, D. Kass, and G. Martinez, “Enabling Mars Radio Occultation by Smallsats,” in *2021 IEEE Aerospace Conference (50100)*, Big Sky, MT, USA, Mar. 2021, pp. 1–12. doi: 10.1109/AERO50100.2021.9438147.

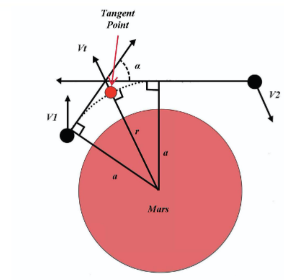

Figure 1. Mars orbiter-to-orbiter radio occultation geometry. Precise measurement of the Doppler frequency of radio signals transmitted from one orbiter to the other across the limb can be used to infer the bending of the radio signals. The bending angle profile can be used to infer temperature, pressure, and density of the atmosphere.

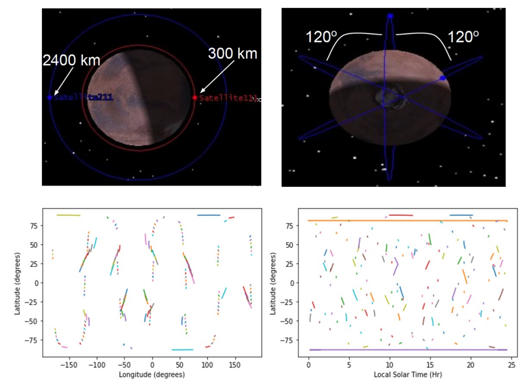

Figure 2. A constellation of 6 Mars orbiters with 3 in lower altitudes and 3 in higher altitudes is being considered for our mission concept. Such a constellation can provide good global and diurnal coverage, as shown in the lower panels for a typical Martian day.

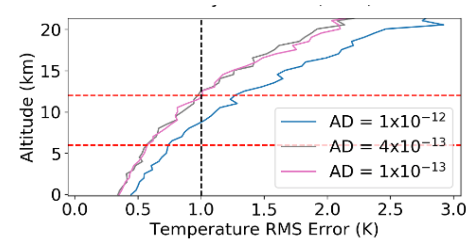

Figure 3. Estimates of temperature error from end-to-end simulations assuming various levels of clock stability given by its Allan Deviation (AD) at a fixed level of thermal noise. To achieve 1 K temperature error between 6-12 km altitude, AD must be better than 4x10^{-12} at 1-10 sec time intervals.

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