ADDRESSING MARS ATMOSPHERIC SCIENCE AND EXPLORATION KNOWLEDGE GAPS WITH SMALLSAT RADIO OCCULTATIONS.

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Introduction: Radio Occultation (RO) has a long heritage in planetary exploration, in particular at Mars with measurements from Mariner 4 in the 1960s to Mars Reconnaissance Orbiter (MRO) and MAVEN today. RO relies on measuring the delay or Doppler shift in radio frequency signals as they pass through the atmosphere [1]–[3] (Figure 1). Traditional RO experiments at Mars were performed using links between an orbiting spacecraft and a ground based Deep Space Network (DSN) station [2]–[4]. However, limited spatiotemporal profiles (Mars Global Surveyor could perform ~10 profiles per day) are caused by limited viewing geometry and DSN communications time available. The limited measurements cause a knowledge gap identified by the science community that are critical to safely land humans on the surface.

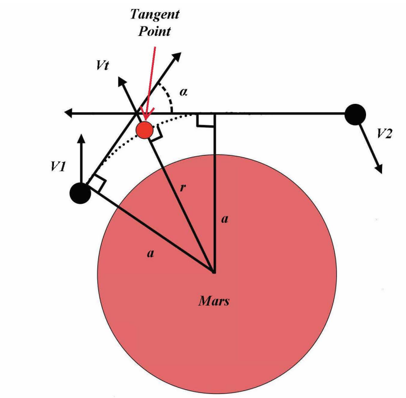

Figure 1. Spacecraft RO geometry (Adapted from [1], [3]). The dashed line represents the radio wave ray bending due to the presence of the Martian atmosphere. The tangent point velocity (Vt) and sampling rate affect the accuracy of vertical atmospheric profile me

Motivation: One of the high-risk portions of any surface mission is Entry, Descent and Landing (EDL), where fast varying atmospheric conditions could lead to a mission failure. The Mars Exploration Program Analytics Group (MEPAG) has identified four high priority investigations [5] that fall under the goal of preparing for human exploration. Investigation A1.1 calls for measurements of the global temperature field from the surface up to 80 km with 5 km resolution. Investigation B3.3 focuses on temperature profiles within dust storms in the lowest 20 km with <5 km resolution, and B3.2 calls for surface pressure and near surface meteorology over various temporal scales.

The mission concept we propose utilizes a fleet of 6 smallsats capable of making hundreds of vertical RO profiles per day for high temporal and spatial measurements globally. RO is capable of high vertical (~1 km) resolution, and it is insensitive to aerosols (dust) near the surface, contrary to thermal infrared (IR) measurements. Considering the recent interest of smallsats for interplanetary RO missions [6], [7], we leverage similar technologies in the development of this mission concept. The preliminary mission requirements are developed from the MEPAG as well as input from scientists and engineers at the Jet Propulsion Lab (JPL).

Methodology: In a typical RO experiment, the doppler shift is determined from the relative motion of the spacecraft from the phase shift of the radio signal. Iterative methods are used to determine the impact parameter and bending angle (a and α in Figure 1) from the position and velocity. The bending angle is then converted to refractive index via the Abel Inversion method [8] where a simple relationship exists between refractivity, pressure, temperature and density [9], [10] in the form of a neutral and ionosphere term. To separate the neutral atmosphere from the ionosphere electron populations we plan a sampling method using dual frequencies since a linear combination will solve for both terms.

The goal of this concept study is to determine the measurements errors and to map them into functional instrument requirements. Since RO relies on determination of the phase and Doppler shift, a highly precise clock, or Ultra Stable Oscillator (USO) is needed in order to reduce the uncertainty of the measurements. Clock uncertainty is characterized by the Allan Deviation of the USO, or how much the clock deviates over different timescales. The communications system can affect the quality of the retrieved measurements in the form of thermal noise characterized by the signal-to-noise ratio.

We begin the study by simulating orbital configurations in the Systems Toolkit (STK) that will yield global profiles at all latitudes. The position and velocity data is then fed into a simulation code that will determine uncertainty in pressure, temperature and number density.

Results: We consider three different orbital configurations at high inclinations. All contain low altitude (~250 km) spacecraft that pair with high altitude (~7,000 km) spacecraft which yield profiles from the surface up to ~200 km. The number of vertical profiles per day range from 180 to 360 which meet the preliminary requirements of ~100 global profiles per day. Of the 3 configurations, 2 are considered viable due to the low insertion delta-V of around 1.88 km/s.

Determining the bending angle uncertainty was accomplished through using the simulation code. We consider 3 AD values as taken from realistic capability for smallsats and current capabilities of spacecraft performing RO experiments. The communications system characterized is based off the Iris V2.1 transmitter at a gain of 8 dBi, at X and UHF frequencies in order to sperate neutral and ionosphere terms. The Monte Carlo simulation was taken over 100 iterations which yield bending angle uncertainties as listed in Table 1.

Allan Deviation	X-Band Total Bending Angle Uncertainty (μrad)	UHF Total Bending Angle Uncertainty (μrad)
1.00E-12	0.376	0.402
1.00E-13	0.229	0.269
4.00E-13	0.256	0.293

Table 1. Total thermal and phase uncertainties converted to bending angle uncertainties for different Allan Deviations.

The neutral atmosphere simulations of interest utilize X-Band values (Table 1) from the surface up to ~40 km. Typical parachute deployment during EDL occurs between 6-12 km above the surface (red dashed lines in Figure) where the temperature requirement is 1 K accuracy. We note that only the USOs of 10^{-13} are able to meet this requirement (Figure 2).

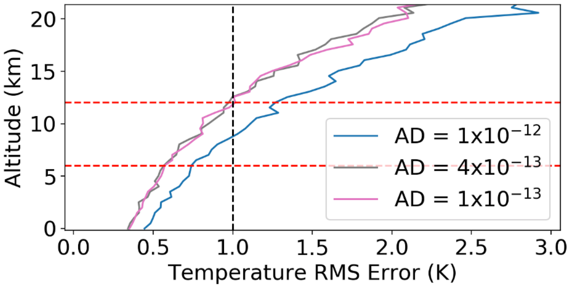

Figure 2. Neutral atmosphere uncertainties for X-band derived from 100 Monte Carlo simulations. Each profile is for a different USO Allan Deviation. Vertical black line shows requirement of 1K uncertainty between 6 km – 12 km (red lines).

Unlike the neutral atmosphere, the ionosphere does not appear to be sensitive to clock noise but it is dominated by thermal noise. Using realistic values of 5 W transmitting power and 8 dBi of gain we determine the UHF frequency is capable of resolving electron density populations within the 5% error requirement from ~110 km to ~135 km above the surface (Figure 3).

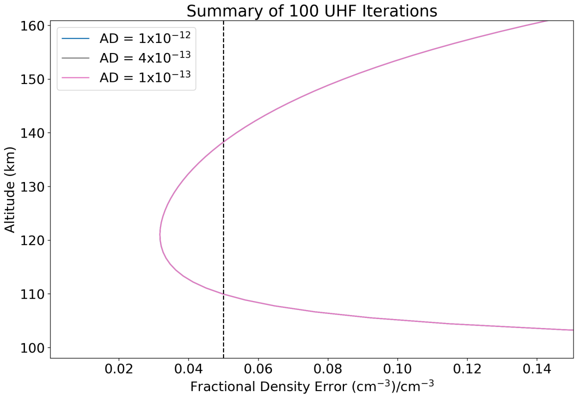

Figure 3. Electron number density uncertainties for UHF band derived from 100 Monte Carlo simulations. Each profile is for a different USO Allan Deviation. Vertical black line shows requirement of ≤5% uncertainty.

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