Virtual Research Presentation Conference

Enabling Mars Radio Occultation by SmallSats

Principal Investigator: Chi Ao (335)
Co-Is: David Kass (322), Nilton Renno, Stephen Bougher, David Sweeney (U. Michigan)
Program: SURP

Assigned Presentation # RPC-265

Jet Propulsion Laboratory
California Institute of Technology

Tutorial Introduction

Radio occultation (RO) is remote sensing technique that uses radio signals to measure the vertical profiles of atmospheric density, pressure, and temperature. It has been a part of planetary exploration since the 1960s. These measurements are very useful, but we don't get enough of them due to limited viewing geometry between the spacecraft and an Earth tracking station.

A constellation of orbiting smallsats transmitting and/or receiving radio signals can yield a large number RO measurements with global and diurnal coverages. Our work is to develop a mission concept from such a constellation that will address high-priority Mars atmosphere science as well as current knowledge gap for Entry Descent and Landing (EDL) and ascent operations at the surface of Mars.

Through the development of a custom simulation software, we will determine functional instrument requirements (such as radio frequencies and antenna gain) and mission requirements (such as number of smallsats and orbital configuration) needed to achieve the mission objectives.

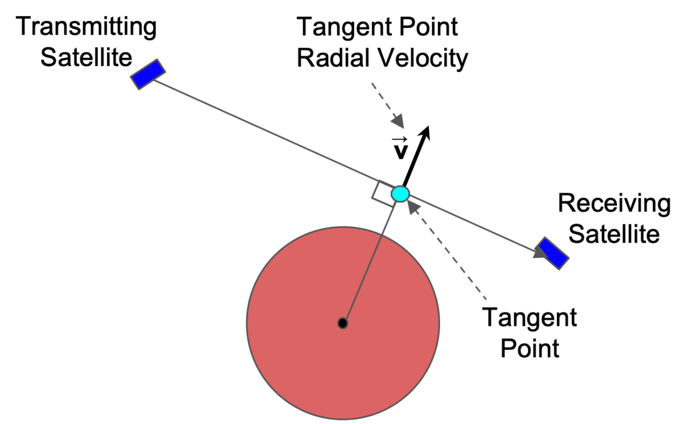

Figure 1. Example of spacecraft geometry during an occultation. Through the motion of the spacecraft, the radio signals will descend (or ascend) the atmosphere during an occultation, providing vertical information on the atmosphere near the tangent point from the surface up.

Problem Description

- Current planning for EDL relies on a combination of data and atmospheric models in order to determine conditions prior to landing. However, data available from current in-situ and orbital sensors are incomplete.
- RO can provide useful density profiles up to ~ 60 km and accurate, high vertical resolution temperature and pressure profiles from the surface up, even during large dust storms.
- A constellation of RO smallsats can sample the full diurnal cycle.

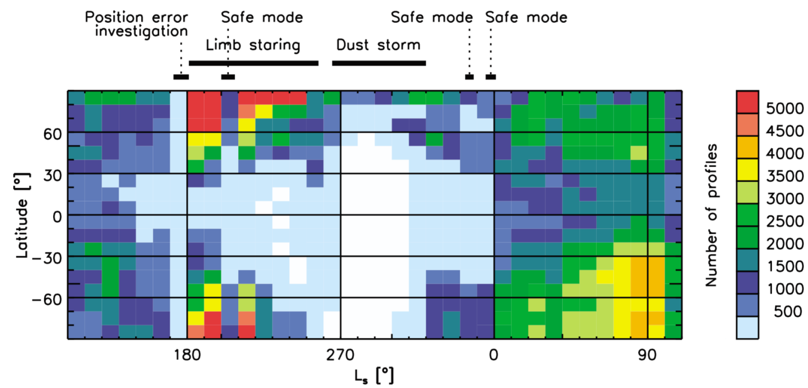

Figure 2. Number of profiles retrieved from Mars Climate Sounder (MCS) on MRO during its first year of operation. Note the significant drop in observations during a global dust storm (L_s=270-300°). The advantage of RO is that the radio signals are not degraded by dust and aerosols and can provide information not currently accessible from an orbiter. Figure from Kleinböhl et al. (2009).

Relevance to NASA and JPL

The proposed mission will help reduce EDL risks where a current knowledge gap exists and benefits future Mars exploration. JPL has been a leader in radio occultation and has invested in the development of a future radio science instrument for small satellites. Results from this project will benefit the maturation of this instrument. In turns, this can lead to future mission proposals that utilize the JPL instrument.

Methodology

A fully integrated RO constellation and instrument simulation software is used to derive key instrument and mission requirements traceable to the mission objectives.

- **Orbit optimization**: Used STK to simulate orbits and search for RO opportunities. [Figure 3]
- **Instrument/retrieval simulation:** Developed a set of Python codes to propagate instrument errors into physical parameters. [Figure 4]

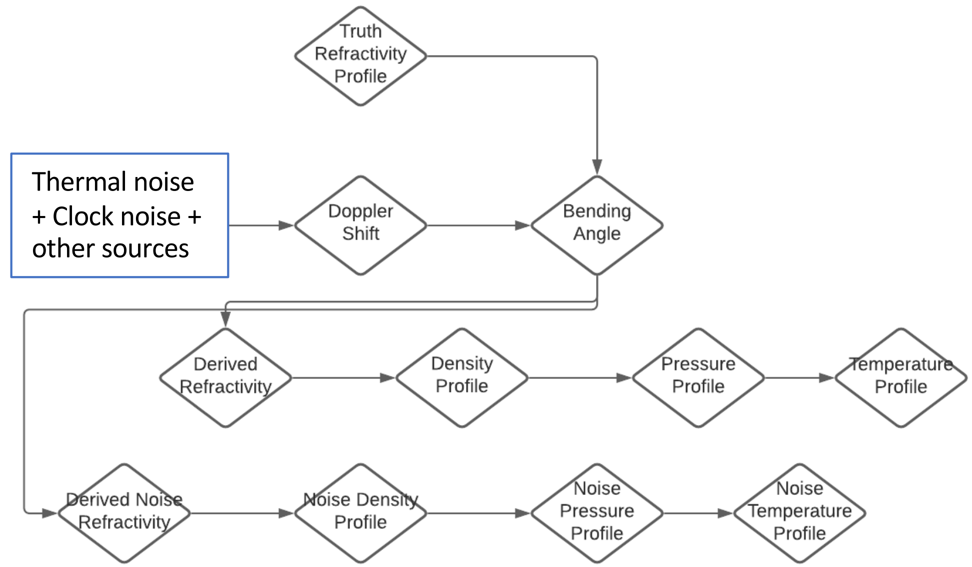

Figure 4. Flowchart illustrating how simulation code converts doppler shift to temperature, and how noise propagates into retreival uncertainty.

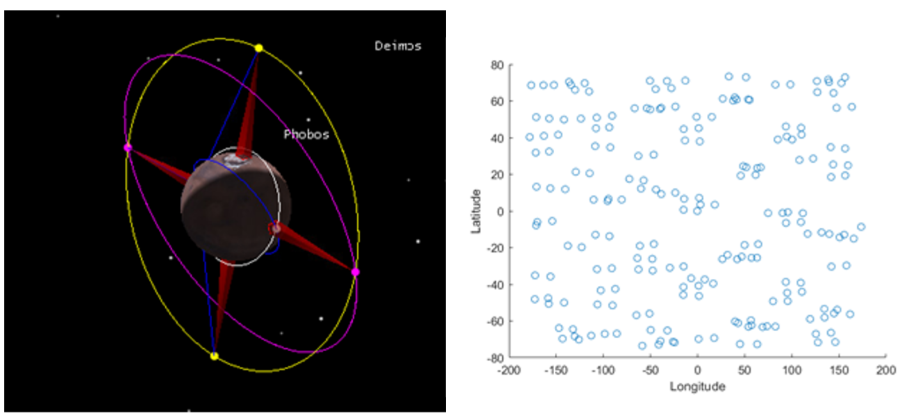

Figure 3. Example of orbital configuration with 4 outer polar orbiting spacecraft in 2 planes. 2 inner spacecraft, 2 orbital planes with 70 degree inclination provide around 200 RO opportunities per day.

Results

Accomplishments

- We have made significant progress in developing the simulation tools necessary to map the requirements on physical parameters (density, temperature, etc.) to the instrument.
- We have also developed the capability to simulate occultation coverage from any constellation, which allows us to optimize the orbital parameters to achieve the desired coverage requirements.

Next steps

- Complete key trades and establish a baseline mission concept that includes the following specifications: number of satellites, orbital configurations, radio frequencies, antenna gains, clock stability.
- Submit journal paper describing the mission concept.

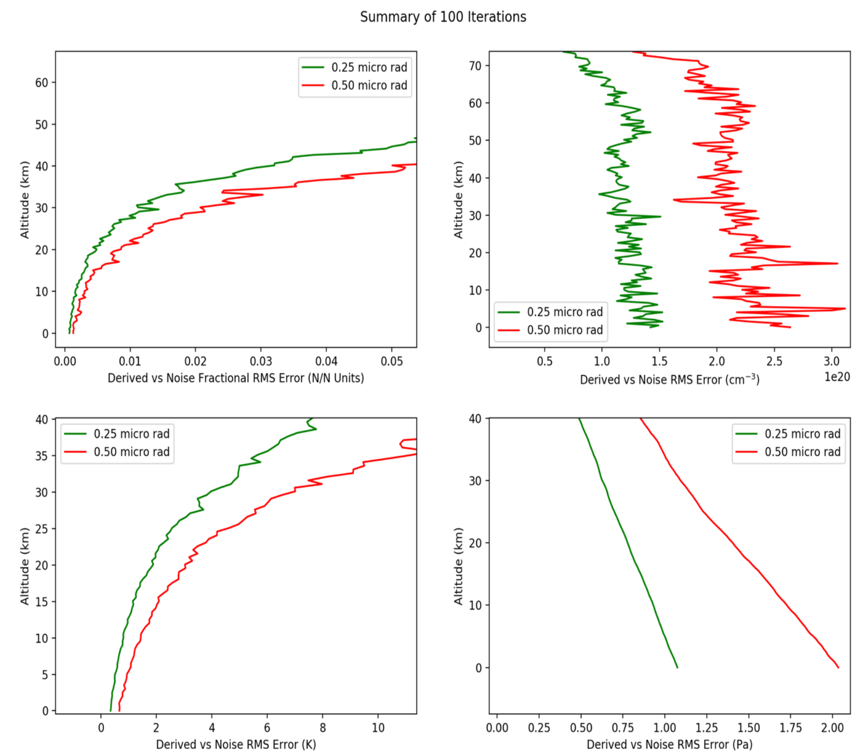

Figure 5. Preliminary results of derived error in lower atmosphere physical parameters with 0.25 and 0.50 micro-radians of noise added. RMSE computed over 100 ensembles of each noise value.

Publications and References

Publications:

[1] David Sweeney, “Enabling Mars Radio Occultation by Smallsats,” submitted to *2021 IEEE Aerospace Conference,* Big Sky, MT, 2021.

References:

[1]. Ao, C. O., Edwards, C. D., Kahan, D. S., Pi, X., Asmar, S. W., & Mannucci, A. J. (2015). A first demonstration of Mars crosslink occultation measurements. *Radio Science*, *50*(10), 997–1007. https://doi.org/10.1002/2015RS005750

[2]. Hajj, G. A., Kursinski, E. R., Romans, L. J., Bertiger, W. I., & Leroy, S. S. (2002). A technical description of atmospheric sounding by GPS occultation. *Journal of Atmospheric and Solar-Terrestrial Physics*, *64*(4), 451–469. https://doi.org/10.1016/S1364-6826(01)00114-6

[3]. Ho, C., Golshan, N., & Kliore, A. (n.d.). *Radio Wave Propagation Handbook for Communication on and Around Mars*. 116.

[4]. Withers, P. (2009). A review of observed variability in the dayside ionosphere of Mars. *Advances in Space Research*, *44*(3), 277–307. https://doi.org/10.1016/j.asr.2009.04.027