National Aeronautics and Space Administration

Enabling Mars Radio Occultation by Smallsats

Principal Investigator: Chi Ao (335); Co-Investigators: Panagiotis Vergados (335), David Kass (322), Stephen Bougher (University of Michigan), Cheng Li (University of Michigan), David Sweeney (University of Michigan), Nilton Renno (University of Michigan)

Program: FY22 SURP
Strategic Focus Area: Planetary Atmospheres and Geology

Objectives

The objective of this study is to mature a crosslink radio occultation (RO) mission concept for mapping the density, temperature, and circulation of the atmosphere of Mars, globally, with spatial and temporal resolutions high enough to eliminate an observational gap critical to the planning of entry, descent, and landing (EDL) as well as ascent of spacecraft from the surface of Mars. The same measurements will also help improve our understanding of the underlying physical processes controlling the variability of the present day Mars climate, such as the onset of dust storms, energy transport, and circulation.

Background

Radio occultation (RO) provides high vertical resolution (~1 km) temperature, pressure, density, and geopotential height profiles through precise measurement of the changes in the radio signals as they pass through the limb of the Martian atmosphere. Unlike thermal IR, ROs have little sensitivity to aerosols (dust and water ice) and can provide data down to the surface. However, ROs from a single orbiter performing atmospheric occultations require months to achieve global coverage and provide incomplete time-of-day sampling.

A small constellation of smallsats orbiting Mars can provide densely distributed RO measurements. The success of MarCO's data relay during Insight's EDL has demonstrated the capability of radio tracking achievable using smallsats. Nevertheless, a compelling RO smallsat constellation mission concept has not been fully realized.

Significance/Benefits to NASA/JPL

The results from this project will help define instrument and mission requirements to address NASA's planetary science and high-priority Mars exploration goals. RO was a key component of the Mars Orbiters for Surface-Atmosphere-Ionosphere Connections (MOSAIC) planetary science decadal survey study mission concept.

JPL has been a leader in RO since its very beginning. In recent years, it 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.

Approach and Results

To mature the smallsat RO constellation concept, key physical parameters and their requirements were first identified. Through end-to-end simulations developed and refined under this project, the instrument and mission requirements were derived.

Significant progress has been made to implement the RO end-to-end simulation software that relates the instrument requirements such as thermal and clock noise to uncertainty in physical parameters such as temperature and density. A major accomplishment made this year was to develop a Monte Carlo approach for the realistic simulation of clock noise.

A potential challenge towards cost-effective implementation of smallsat RO is the need for an ultra-stable oscillator (USO). We investigated a novel approach called dual-one-way (DOW). We showed that DOW can reduce clock errors by more than 2 orders of magnitude, thus drastically lowering the oscillator stability requirement.

Combining the uncertainty from clock and phase noises, we showed that our basic requirement of 1 K temperature accuracy below 12 km altitude could be met with the Iris-like radio transponder used in MarCO, moderate-gain patch antennas (for X-band), and sufficiently stable oscillators.

In the meantime, we have further refined our constellation design to optimize RO sounding coverage spatially and over the diurnal cycle, but also with consideration of cost and implementation (e.g., SIMPLEx like mission), showing potential benefits from just having two spacecraft.

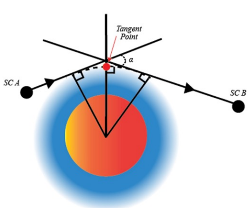

Figure 1. An illustration of spacecraft-to-spacecraft crosslink radio occultation. Through precise phase tracking, the bending angle of the raypaths due to the atmosphere layers can be inferred.

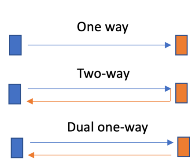

Figure 2. Different operation mode for RO depending on clock stability. One-way is the simplest but requires accurate clocks from both transmitter and receiver. Two-way is usually done when the spacecraft does not have an accurate clock but the DSN does. In dual-one-way, both spacecraft transmit and receive at the same time.

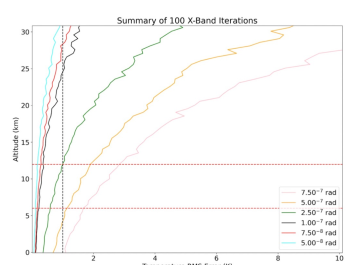

Figure 3. Temperature uncertainty as a function of altitude for different levels of bending angle error.

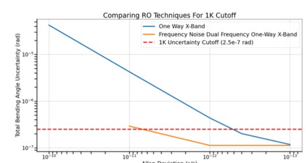

Figure 4. Dual-one-way (orange) significantly reduces the bending angle error compared to one-way occultation (blue), allowing the use of less stable clocks for our smallsats.

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

www.nasa.gov

Clearance Number: CL#
Poster Number: RPC#
Copyright 2022. All rights reserved.

PI/Task Mgr. Contact Information:
Email: Chi.O.Ao@jpl.nasa.gov