National Aeronautics and Space Administration

FY23 Topic Areas Research and Technology Development (TRTD)

Determining Atmospheric Species Abundances Using Multi-Frequency Radio Signal Absorption

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Strategic Focus Area: Planetary Atmospheres

Background

The Planetary Sciences Decadal Survey (PSDS) 2023-2032 prioritized the Uranus Orbiter and Probe (UOP) Flagship mission to measure 3D atmospheric structures of ice giants. Dual-frequency X/S-band radio occultations (ROs) from Voyager-2 revealed Uranus': (a) two-layered ionosphere at 2,000 and 3,500 km extending up to 10,000 km (Tyler et al., 1986); (b) narrow eccentric sharped-edged rings in-between an extensive sheet of tenuous dusty material, and (c) tropopause located at 0.1 bar exhibiting small-scale vertical structures (Lindal et al., 1987). The UOP mission can provide orders of magnitude improvement to this observing record, but this improvement is contingent on the chosen RO experiment design. **PSDS 2023-2032 explicitly identified ROs as key observables** to answer questions about the variability and thermal structure of Uranus' thermosphere, ionosphere, and the mechanisms that maintain its ring structure, their eccentricity and inclination. The UOP mission will conduct multi-year orbital tours and deliver an in-situ probe, enabling hundreds of ROs over a range of observing geometries and ring opening angles.

Objectives

Develop a new radio science method to simultaneously retrieve vertical distributions of temperature and major atmospheric trace gases/aerosols in Uranus (CH_4 and H_2S). Under the recent announcement of a UOP Flagship Mission, and compared to the state-of-the-art (both at JPL and outside JPL), our work aims to achieve:

1. **4x better** atmospheric penetration at Uranus than what Vayager-2 has achieved, down to ~9 bar pressure level (as opposed to 2.3 bar).
2. **5x better** vertical resolution of atmospheric and trace gases profiling using Ka-band than what Voyager-2 has achieved.
3. **Successful sampling of H_2S** vertical stratification that was not captured by Voyager-2 RO experiment.
4. **Design of cross-link ROs** in a Small Satellite (SmallSat) constellation experiment for Uranus atmospheric monitoring.

Methodology & Technical Approach

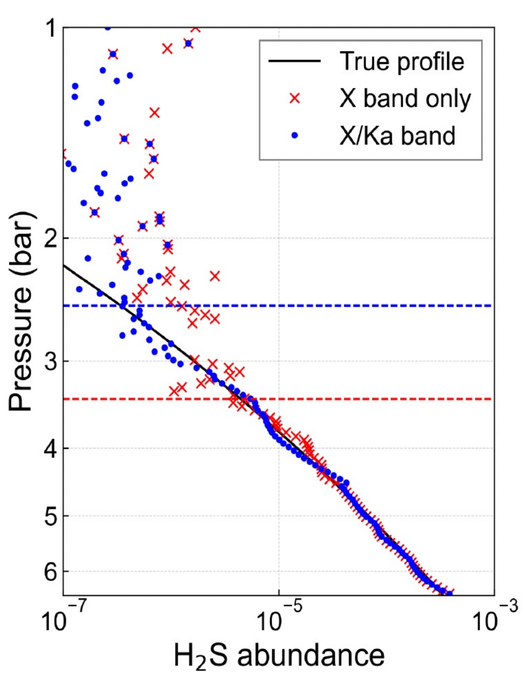
STEP 1: We used our end-to-end RO simulation software to **generate phase and amplitude measurements** for Uranus atmospheric conditions at UFH, L, X, S, and Ka-band frequencies

STEP 2: Catalogued uplink/downlink power of multiple radio telescopes, along with their antenna gain. We used data from STEP 1 to **retrieve attenuation profiles** as function of pressure level with a 4dB cut-off SNR

STEP 3: Used results from STEP 1 **to retrieve absorptivity profiles at X/Ka-band** as function of pressure level to estimate H_2S abundances from 1 and 7 bar

STEP 4: Quantified the defocusing effect at different spacecraft distances from Uranus over the entire radio frequency range selected

Results



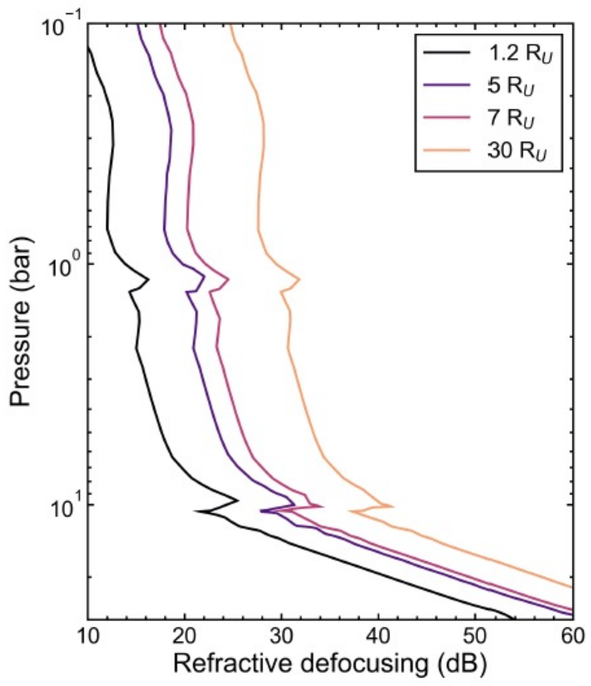


Figure 1. (Left) Simulated H_2S in Uranus atmosphere retrieval from absorptivity RO data. (Right) Refractive defocusing attenuation predicted for several spacecraft distances from Uranus.

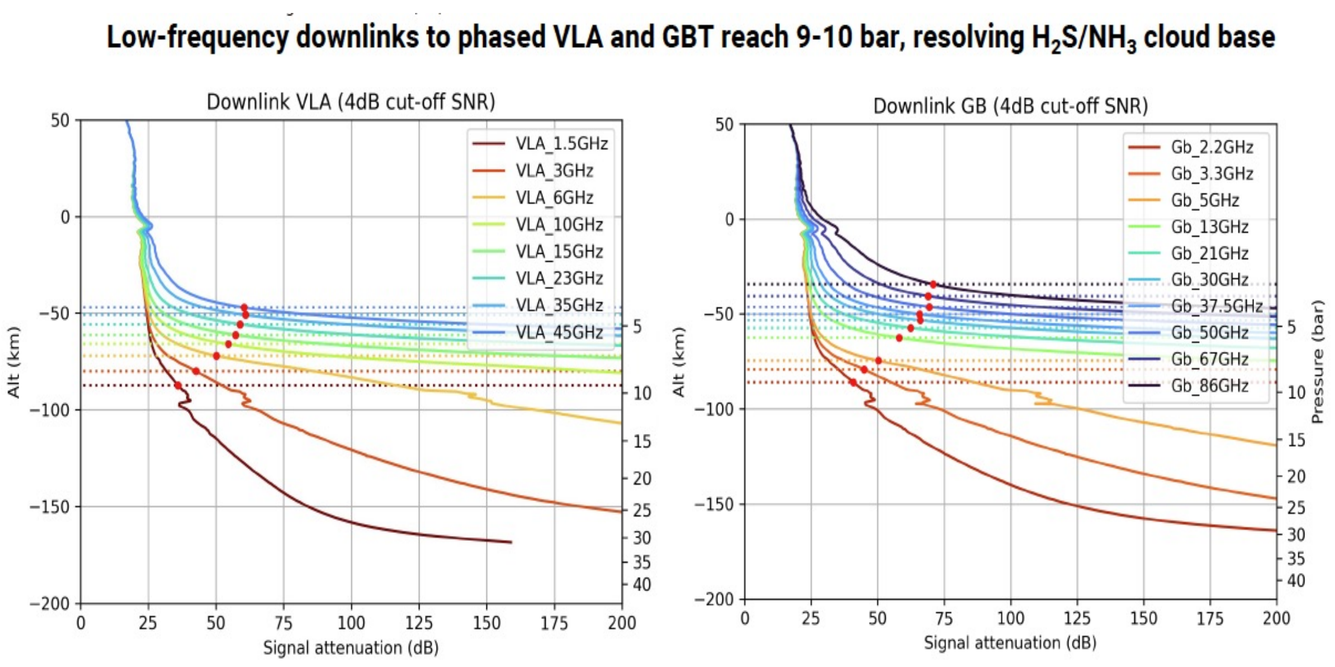


Figure 2. Radio occultation link attenuation as a function of altitude/pressure and frequency from 1.5 GHz up to 45 GHz over the Very Large Array (left) and Green Bank Telescope (right).

Significance to NASA and JPL

- **Enable** development of RO experiments for the Uranus Flagship mission directly addressing the Planetary Science Decadal Survey
- **Expand** JPL's Interplanetary Network Directorate (IND) (9x) applications, and give JPL a strong competitive edge for the Uranus Flagship mission.
- **Define** needed RO mission hardware additions, as identified in Planetary Sciences Decadal Survey 2023-2032, beyond the currently used radio hardware.

Publications

Akins, A., Bocanegra-Bahamon, T., Wang, K.-N., Vergados, P., Ao, C., Asmar, S., Preston, R. A. (2023), Approaches for Retrieving Sulfur Species Abundances from Dual X–Ka-band Radio Occultations of Venus with EnVision and VERITAS, *The Planetary Science Journal*, **4**, doi:10.3847/PSJ/accae3

Bocanegra-Bahamon, T., Ao, C., Wang, K.-N., Vergados, P. (2023), Phase Matching Method for Inversion of Venus Radio Occultation Signals, *Radio Science,* **58**(3), doi:10.1029/2022RS007579

Akins, A., Bocanegra-Bahamon, T., Wang, K.-N., Vergados, P., Ao, C., Preston, R., Asmar, S., Parisi, M., and Buccino, D. (2023), Considerations for radio occultation studies of Uranus' atmosphere, ionosphere, and rings with a flagship mission, *Uranus Flagship 2023: Investigations and Instruments for cross-discipline science*, 25-27 July 2023, Pasadena, CA

References

Lindal et al. (1987), The atmosphere of Uranus: Results of radio occultation measurements with Voyager 2, *J. Geophys. Res.: Space Physics*, **92**, pp. 14987-15001

Tyler et al. (1986), Voyager 2 Radio Science Observations of the Uranian System: Atmosphere, Rings, and Satellites, *Science,* **233**, pp. 79-84

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