National Aeronautics and Space Administration

FY24 Strategic Initiatives Research and Technology Development (SRTD)

The Golden Era for Radio Occultation Experiments in Solar System Exploration

Principal Investigator: Panagiotis Vergados (335)

Co-Investigators: Tatiana Bocanegra-Bahamon (335), Kuo-Nung Wang (335), Alexander Akins (386), Chi Ao (335), Robert Preston (330)

Strategic Focus Area: Radio and Gravity Science | **Strategic Initiative Leader:** Sami W Asmar

Background

The Planetary Sciences and Astrobiology Decadal Survey (PSADS) 2023-2032 prioritized the Uranus Orbiter and Probe (UOP) flagship mission to measure 3D atmospheric structures of ice giants. Studying their atmospheric vertical coupling and dynamics is key to understand our solar system's evolution and nature of "Super-Earths", the most abundant class of exoplanets.

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 [*Tyler et al*., 1986], and (c) tropopause located at 0.1 bar exhibiting small-scale vertical structures [*Lindal et al*., 1987].

PSADS 2023-2032 identified ROs as key observables to answer questions about the variability and thermal structure of Uranus' thermosphere and ionosphere. 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, but this improvement is contingent on the chosen RO experiment design.

Objectives

OBJECTIVE: Develop a *novel multi-frequency RO remote sensing technique for the UOP flagship mission* to help us understand Uranus' 3D atmospheric dynamics and composition, general ionospheric structure, and its rings' particle size distribution.

Uranus priority science questions identified in PSADS 2023-2032, include:

a) What processes drive Uranus 3D atmospheric structure?
b) How does Uranus ionosphere interact with the solar wind?
c) What processes maintain Uranus ring integrity?

In FY24, we demonstrated that multi-frequency RO observations can help us exceed state-of-the-art milestones by achieving: 1) better atmospheric penetration at Uranus down to ~10 bars as opposed to Vayager-2 2.5 bars; 2) ~5x better vertical resolution of atmospheric and trace gases profiling using Ka-band; 3) sampling of H_2S vertical stratification not captured by Voyager-2 RO experiment, and 4) cloud aerosol sampling at the Mie scattering regime to remote sensing number densities of larger particles. **The above 4 successfully completed objectives could serve as guidelines to an RO instrument.**

Methodology

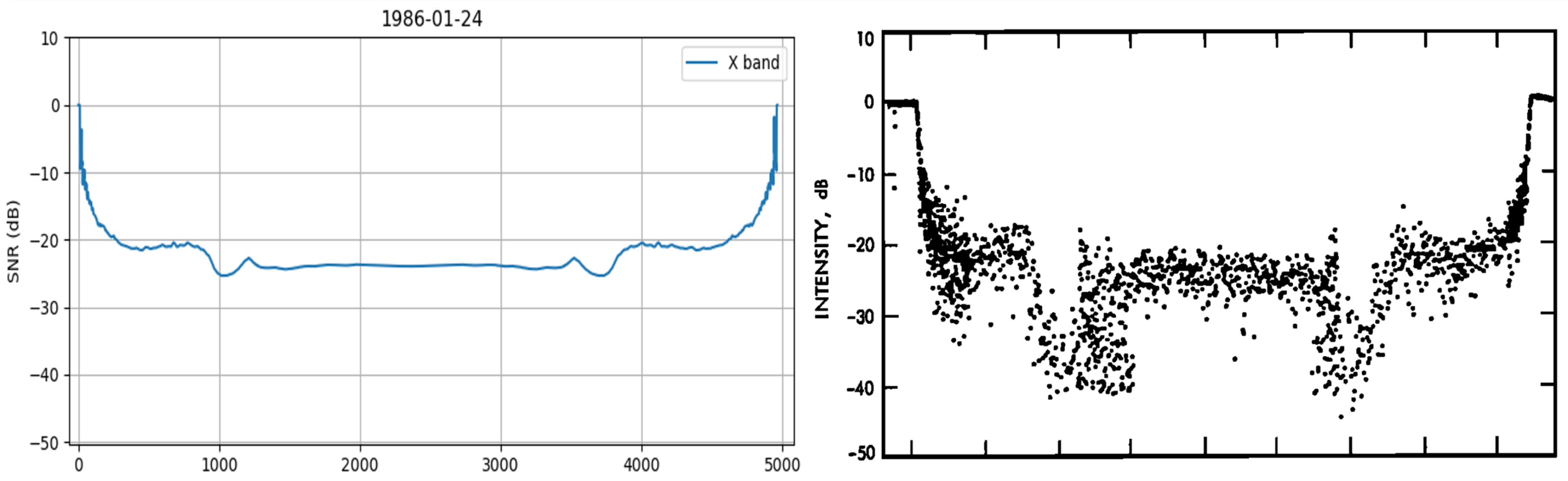
STEP-1: We **developed a novel 1D RO ray-tracing algorithm** to reconstruct the signal-to-noise ratio (SNR) from the Voyager-2 fly-by at Uranus at X-band.

STEP-2: We **developed an axisymmetric model** of Uranus atmosphere to account for the divergence of the gravitational potential due to horizontal wind field.

STEP-3: We **validated our 1D RO ray-tracing algorithm** using publicly available Juno orbits around Jupiter, which contain RO events.

STEP-4: We **included Mie Scattering theory on our microwave propagation model** to sample larger aerosol clouds and ring particles at the 1-10 cm regime.

Results



[Lindal et al., 1987]

Figure 1. (Left) Reconstructed SNR of Voyager-2 Uranus fly-by at X-band and (right) the observed SNR.

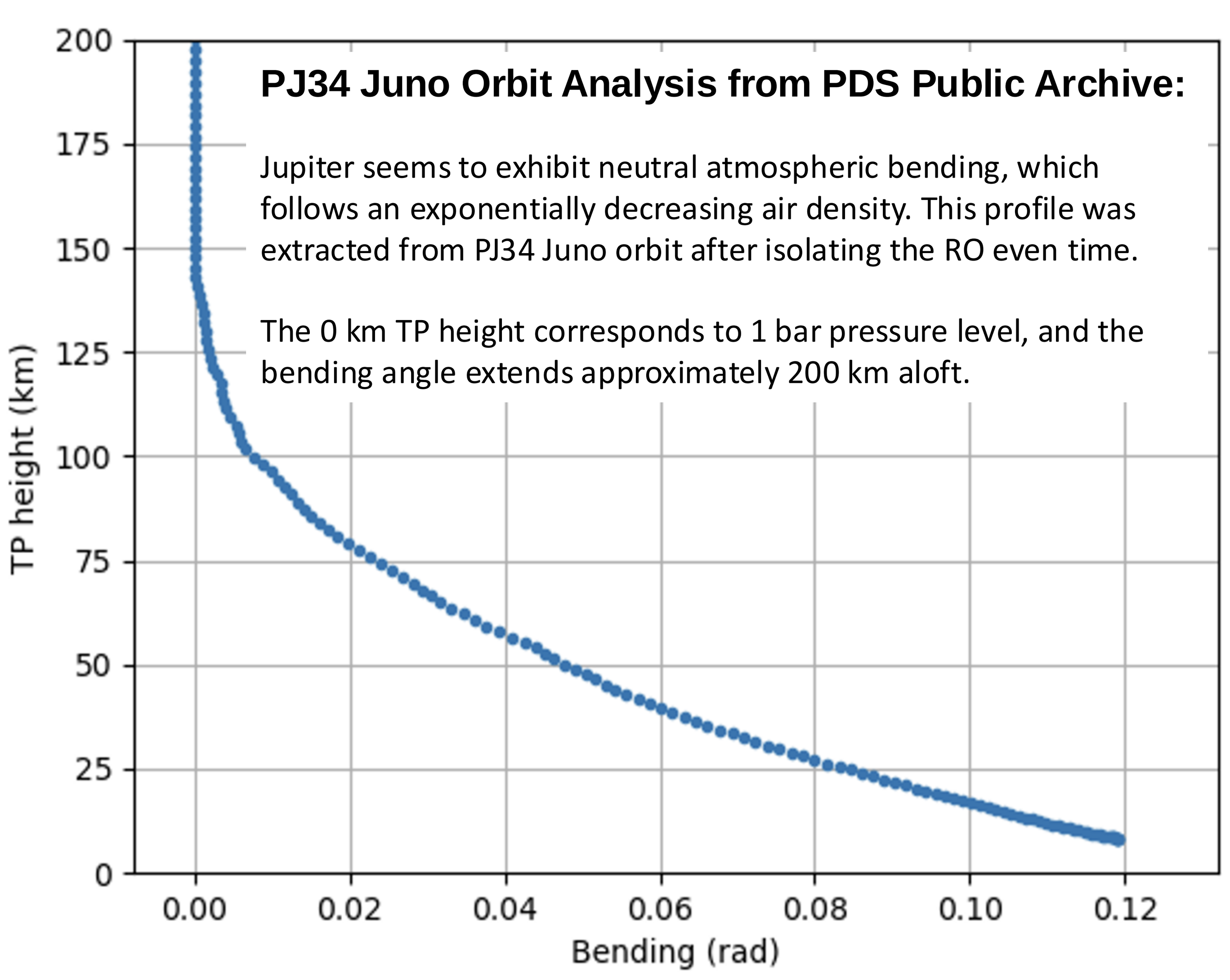


Figure 2. Vertical bending angle profile derived from PJ34 orbit available in PDS.

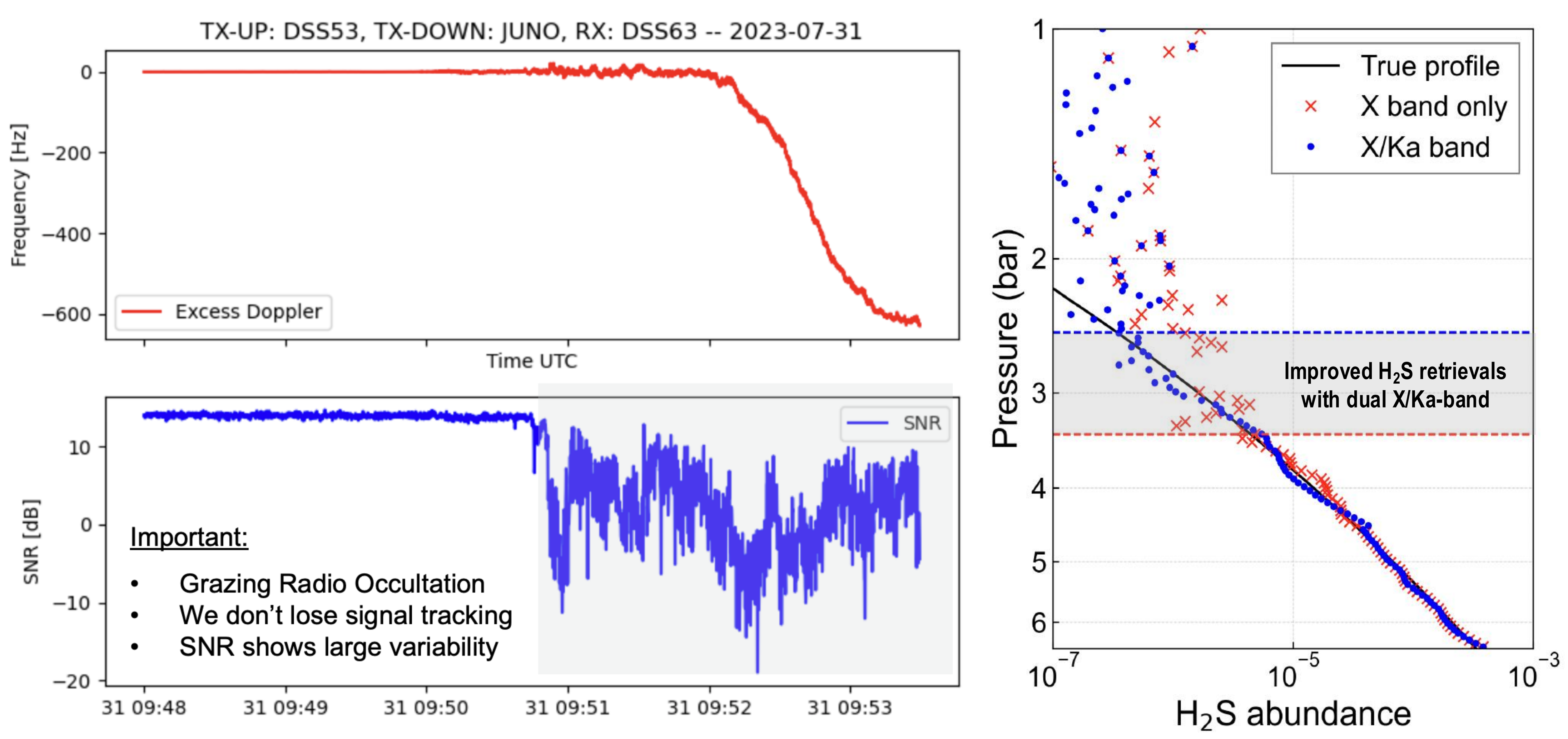


Figure 3. (Top left) Time series of excess Doppler frequency shift, (bottom left) time series of computed SNR, and (right) retrieved hydrogen sulfide abundance using our microwave propagation model demonstrating improvement below Voyager-2 lower pressure level limit (gray rectangular area) through dual X/Ka-band RO measurements (blue dots).

Significance to NASA and JPL

Our concept aims to provide JPL a competitive advantage in developing RO payloads for future planetary missions enabling:

- Potential increase of JPL's VERITAS science return via X/Ka-band ROs analysis
- Potential prototype system-level design of an RO payload for the UOP flagship mission
- New planetary mission concepts and radio science observing techniques for search for life
- Stronger JPL IND presence and role on the UOP flagship mission

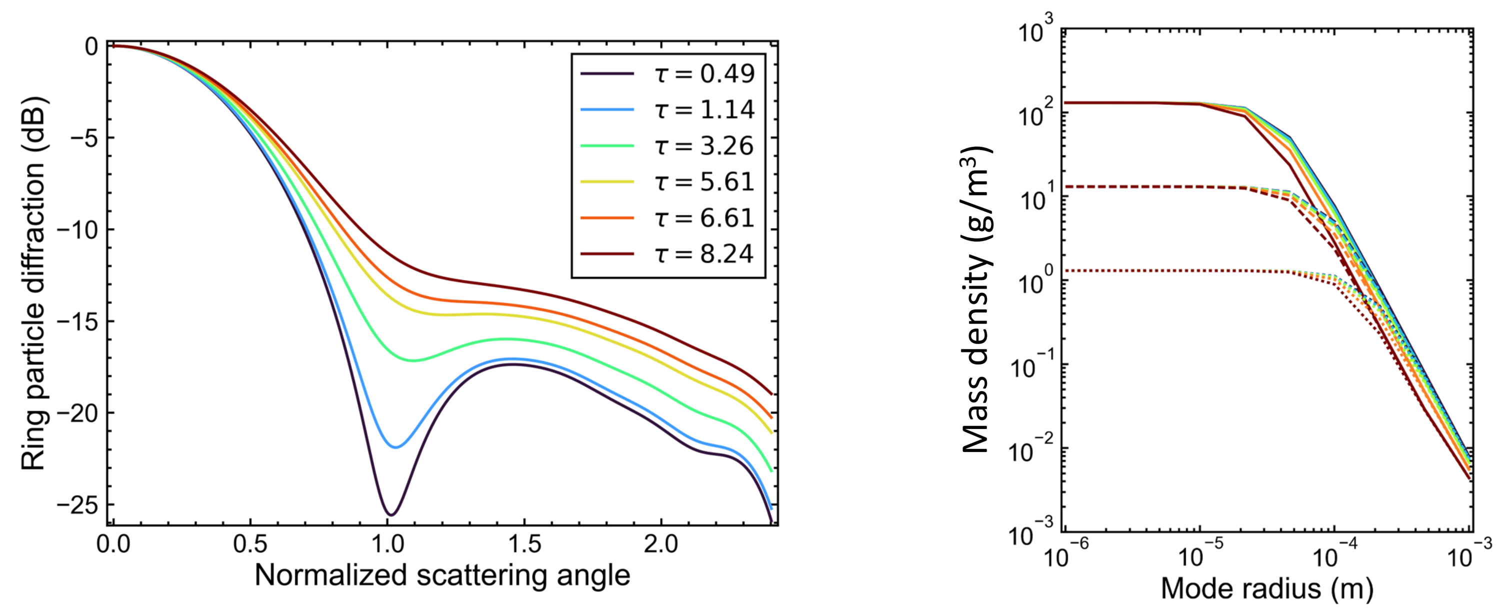


Figure 4. (Left) Simulated diffraction scattering of RO signals through Uranus rings with different opacity levels. (Right) Simulated aerosol number density as a function of particle size at Ka-band (32 GHz) with different dielectric constant.

Publications:

(1) Tatiana Bocanegra-Bahamon, Chi Ao, Lisa Mauger, Kuo-Nung Wang, Panagiotis Vergados, and Christopher Volk "Revisiting the Magellan radio occultation experiment and considerations for the upcoming Venus missions" submitted to *AGU Fall Meeting*, 11-15 December 2023, San Francisco, CA.

(2) Panagiotis Vergados, Sami Asmar, Tatiana Bocanegra-Bahamon, Alex Akins, Kuo-Nung Wang, Chi Ao, Robert Preston and Joseph Lazio "The Golden Era for Planetary Radio Occultation Science Experiments", submitted to *AGU Fall Meeting*, 11-15 December 2023, San Francisco, CA.

(3) Sami Asmar, Alex Akins, Chi Ao, Tatiana Bocanegra-Bahamon, Joseph Lazio, Robert Preston and Panagiotis Vergados "Technologies required to enable crosslinks to investigate planetary atmospheric structures", submitted to *AGU Fall Meeting*, 11-15 December 2023, San Francisco, CA.

PI/Task Mgr. Contact Information: Panagiotis.Vergados@jpl.nasa.gov | **Tel.: (818) 354-4969**

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

www.nasa.gov

RPD-000 Clearance Number: CL#00-0000