National Aeronautics and Space Administration

Using microwave radiometers and gravity science to probe Uranus' deep atmospheric circulation and interior structure

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Program: FY22 R&TD Strategic Initiative

Strategic Focus Area: Ice Giant Science Leadership - Strategic Initiative Leader: David H Atkinson

Objectives:

To position JPL as the scientific leader in studies of the deep troposphere and interior of Ice Giant planets and to improve JPL's competitive position in the selection of future science teams, flight instruments, and missions. Each phase of this work includes mentoring and a transfer of responsibilities to early-career personnel. The major efforts in the 3-year plan are:

Year 1: Analyze pre-2014 radio observations of Uranus to constrain the tropospheric circulation and its seasonal variations.

Year 2 (Current Year): Develop a dynamical model of the atmosphere that explains the features observed in Year 1, calculate the gravitational signature of that model. Begin the development of coupled atmosphere/interior models and the calculation of the frequencies of their normal-mode oscillations. Carry out new radio observations of Uranus.

Year 3: Complete modeling of normal-mode oscillations and their gravitational signals. Explore innovative instrument and mission architectures to test the atmospheric and interior models developed in Year 2.

Background:

The composition, formation, and evolution of the Ice Giant planets, Uranus and Neptune, are clearly different from those of the Gas Giants, Jupiter and Saturn, and even basic questions about the Ice Giants are in dispute [1]. The importance of understanding the Ice Giants is highlighted by the recently released Decadal Survey [2] and its selection of a Uranus Orbiter with Probe mission as the highest priority Flagship mission. Our initiative advances our understanding of both the atmosphere and interior structure of Uranus. Specifically, we will determine the large-scale circulation patterns in the deep troposphere (pressures ~5 to 100 bars) and how the circulation changes seasonally. We will use this information to improve models of the coupled atmosphere and interior system, and predict the frequency of normal-mode oscillations which can be used to discriminate among competing interior models. We also will design instruments and mission architectures that can test our predictions for the circulation and interior of Uranus.

Approach and Results:

Develop a dynamical model of the atmosphere. Our Year-1 analysis of radio data from 1981 to 2013 suggested an ad hoc circulation pattern (Fig. 1). We developed a global circulation model that creates a circulation pattern similar to that inferred from the radio data (Fig. 2), and that is also consistent with Voyager 2 gravity measurements. Work remaining is to quantify how the model circulation alters the meridional abundance of condensable species and then determine the model dynamical damping time that optimizes the fit to the radio data.

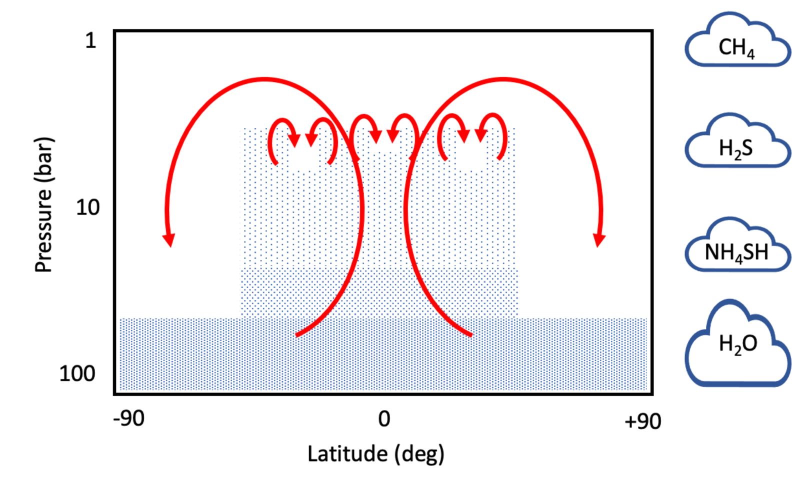

Figure 1: Atmospheric circulation inferred from the radio data.

Calculate the gravitational signal of the atmospheric circulation. Using the method of [3] we have calculated the perturbations to the gravity field due to our dynamical model (Fig. 3). We find that a spacecraft at Uranus measuring gravity with a precision comparable to that achieved by the Juno-spacecraft at Jupiter will be able to test the validity of our dynamical model.

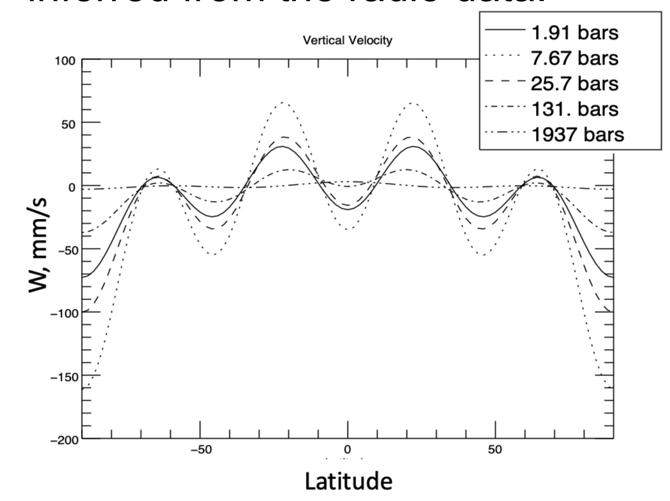

Figure 2: Vertical wind velocities for a dynamical model with weak turbulence.

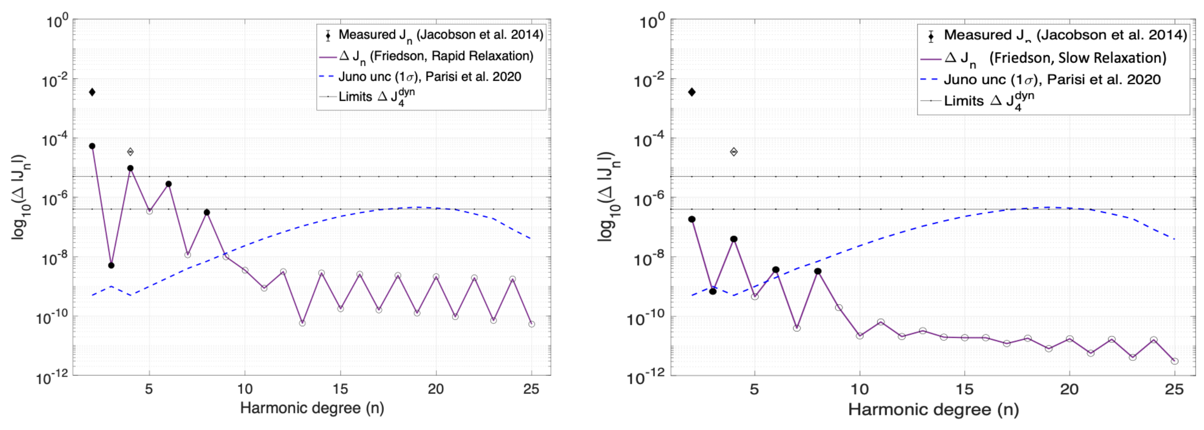

Figure 3: Gravitational signal of our dynamical model for two values of atmospheric turbulence (solid purple lines), along with expected measurement accuracy (blue dashed curve). See full report for additional details.

Carry out new radio observations of Uranus. Observations were made this year, calibrated, and analyzed (Fig. 4), giving us our first clear look at features at the North Pole of Uranus. The new results show differences from older observations which could be a sign of seasonal changes between ~2012 and ~2022.

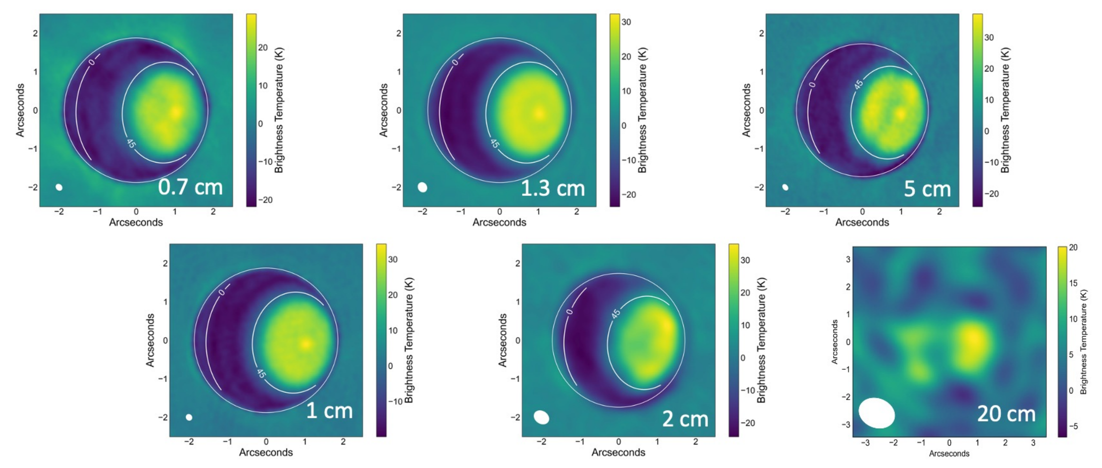

Figure 4: Radio images with wavelength and the size of the observing beam indicated in white. Note the bright spot right at the North Pole and the darker latitude band around it, as well as fainter banding at lower latitudes.

Significance/Benefits to JPL and NASA:

We have developed the first dynamical model of Uranus's atmosphere that predicts the deep tropospheric circulation and is consistent with the available radio and gravity observations. This model makes predictions that can be tested by future missions to Uranus. Our new observations of Uranus have been compared against 40 years of historical observations to study seasonal change in the deep Uranian atmosphere. Each of these efforts significantly advances our understanding of giant planet atmospheres, guides the design of future NASA missions, and positions JPL to lead the development of instruments and missions to Uranus and the scientific interpretation of the returned data.

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References:

[1] Fletcher et al., *Phil. Trans. Roy. Soc. A,* **374**:2187 (2020).
[2] National Academies of Sci., Eng., Med., Origins, Worlds, and Life (2022).
[3] Kaspi et al., *Nature* **497**, 344-347 (2013).

Publications: In preparation

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