National Aeronautics and Space Administration

FY23 Strategic Initiatives Research and Technology Development (SRTD)

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

Principal Investigator: Mark Hofstadter (322)**; Co-Investigators:** Alexander Akins (386), Marzia Parisi (332), Andrew Friedson (322)

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

The Take-Away:

We have combined new ground-based radio observations of Uranus with an historical record going back to 1981 to determine that:

- The large-scale circulation pattern of the atmosphere weakens each summer, and that a polar cyclone exists as do previously unresolved zonal wind patterns.
- Either the composition of the atmosphere is surprisingly different from solar, or unknown processes sequester some species in the interior.

We have also analyzed how gravity measurements from a spacecraft orbiting Uranus could:

- Detect normal-mode oscillations that discriminate among models of the interior.
- Determine the depth of zonal winds.

These results lead to recommended orbits and instruments for future Uranus missions.

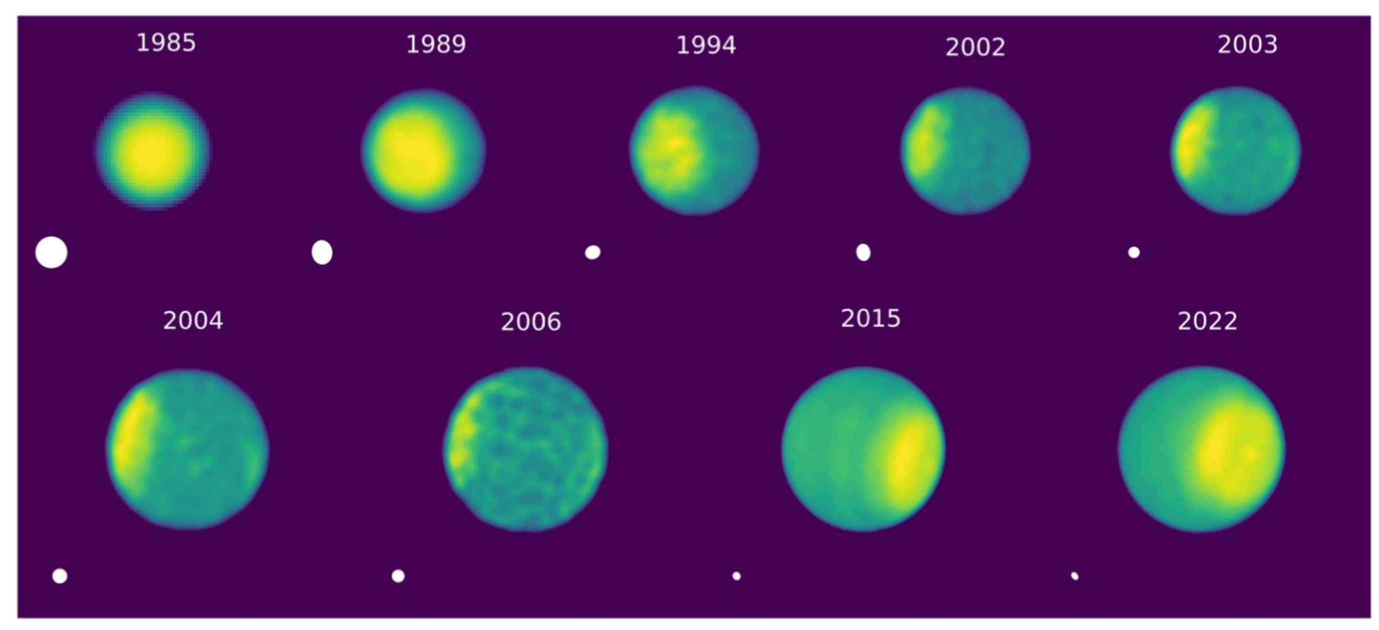

Fig 1: Radio images of Uranus. In 1985 the bright South Pole pointed towards us while by 2022 the bright North Pole swung into view. Banding is seen clearly in 2015.

Objectives:

This proposal is designed to establish 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.

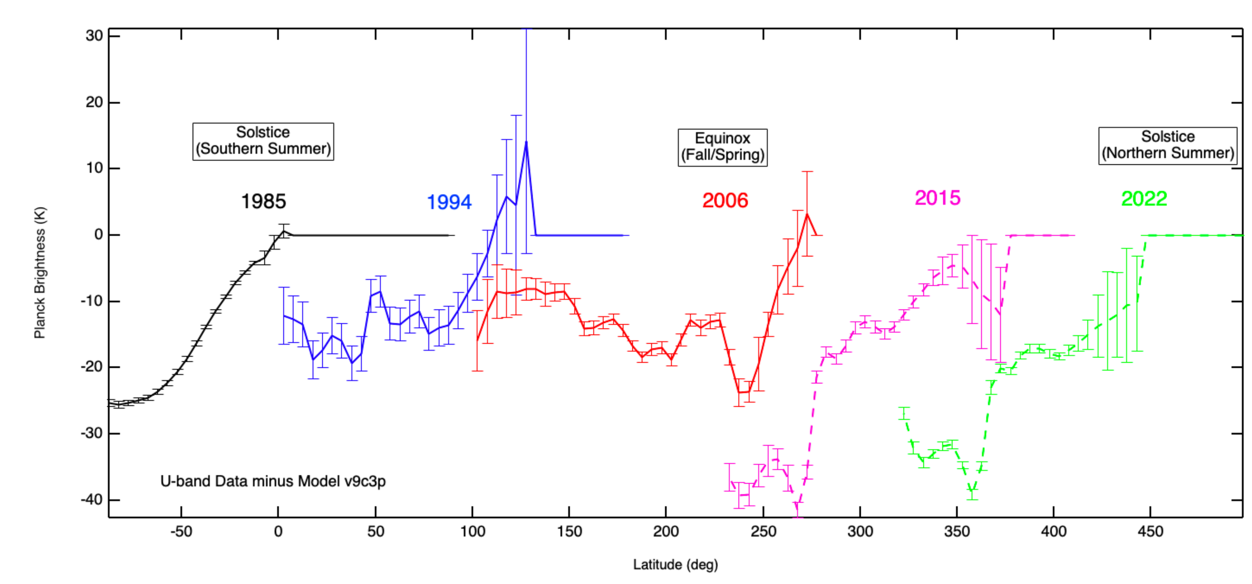

Fig 2: The brightness of Uranus at 2 cm as a function of latitude, relative to a reference model.

Background:

The composition, formation, and evolution of the Ice Giant planets, Uranus and Neptune, are clearly different from those of the Gas Giants, and basic questions about them are in dispute. For example, it is generally thought Uranus and Neptune are primarily water by mass, but some argue for them being primarily silicates (and they suggest "Rock Giant" is a better name for this class of planet). The importance of understanding the Ice Giants is highlighted by the recently released Decadal Survey and its selection of a Uranus Orbiter with Probe mission as the highest priority Flagship mission.

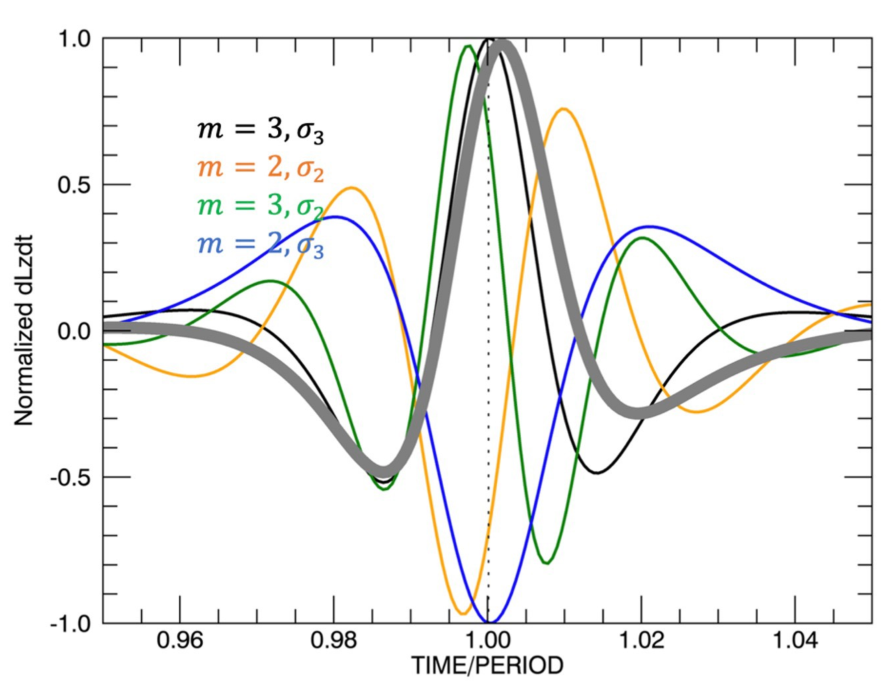

Fig 3: Colored curves are analytical calculations of torques on a s/c near periapse due to various normal modes. The wide grey curve is the torque from simulated data in which an m=3 mode existed in Uranus. Note the good agreement between the simulation (grey) and that predicted by a simplified analytical model (black).

Approach and Results:.

Using ground-based radio to study atmospheric properties:

- We find that equatorial regions are 10 to 100x more opaque than polar regions in the 5 to 50-bar region, opacity varies by ~30% in bands near ±20˚ latitude, and that the bright polar spot seen in the North and the dark collar around it are indicative of a polar cyclone (Fig. 1).
- We find that during/near summertime (~1985 and today) global-scale circulations weaken (Fig. 2).
- We observed Uranus at wavelengths out to ~1 meter using the GMRT telescope, but have not yet analyzed the data. These observations may constrain atmospheric conditions to ~kbar pressures, deeper than ever seen before.
- The observed atmospheric opacity requires either non-solar S/N, S/C, and C/H ratios in the planet, or an unknown process sequestering S and N to different extents in the interior.

Determining interior structure using normal mode oscillations:

- We calculated normal mode frequencies for "end-member" interiors, demonstrating differences among models with solid vs. liquid interiors, with smoothly varying densities, and with sharp boundaries.
- We developed a new technique for detecting normal modes that analyzes torques, not accelerations of the s/c (Fig. 3).
- For a given orbit type and normal-mode amplitude, we have identified what technique is optimal for detecting oscillations.
- We also demonstrated how gravity measurements could discern the depth of zonal winds.

We have prepared recommendations for the architecture and instrumentation of missions to Uranus.

Significance/Benefits to JPL and NASA:

Our results have been reported to the scientific community and will impact the design of any future microwave instrument flown to Uranus, as well as the orbits selected for that mission. We have mentored early-career JPL scientists and expanded their visibility both inside and outside JPL. This work has enhanced JPL's competitive position and helps maximize the scientific return from any future Uranus mission NASA flies.

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Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

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Publications:

Alex Akins, M. Hofstadter, B. Butler, A.J. Friedson, E. Molter, M. Parisi, and I. de Pater, *"Evidence of a Polar Cyclone on Uranus from VLA Observations"*, GRL 50:10 (2023) https://doi.org/10.1029/2023GL102872.

Also three conference abstracts this fiscal year (one at DPS and two at AGU).

PI/Task Mgr. Contact Information:

Mark Hofstadter
626-318-1074, mark.hofstadter@jpl.nasa.gov