IPPW-2019 Short Course
Ice Giants: Exciting Targets for Solar System Entry Probes Exploration

Radio Science from an Ice Giant Entry Probe

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Background

Radiometric tracking (telemetry signal frequency and signal strength) of an ice giant entry probe provides

- the only direct measurement of atmospheric dynamics along the probe descent path;
- A measure of the integrated abundance of μwave absorbing molecules along probe relay signal raypath, primarily ammonia (NH_3), hydrogen sulfide (H_2S), and H_2O (very deep).

Science Objective

Highest Priority Science Objective for a Uranus Orbiter and Probe mission (PSDS 2013-2022):

"Determine the atmospheric zonal winds, composition, and structure at high spatial resolution, as well as the temporal evolution of atmospheric dynamics."

Entry Probe Radio Science Goals

Dynamics

Primary: Retrieve a vertical profile of the horizontal wind structure of the atmosphere along the path of probe descent.

Secondary: Detect and measure atmospheric waves, convection, turbulence, and probe microdynamics such as spin, pendulum, and aerodynamic buffeting.

Composition

Measure integrated atmospheric abundance of microwave absorbers along probe radio raypath.

Doppler Wind Background – Basics

- Frequency of probe radio link measured at receiver.
- Assuming Tx frequency and probe/receiver positions & velocities known exactly, then frequency measured at receiver should be reconstructed exactly → frequency residuals identically zero.
- Non-zero Doppler residuals assumed to be probe motion due to unmodeled probe dynamics.
- Under assumption that probe descent speed is well known, probe/receiver range rate residuals (Doppler residuals) projected onto local horizontal at probe location → horizontal winds.

Notes

- Wind speed not measured directly. Dynamics inferred from assumption that probe traces atmospheric motions.

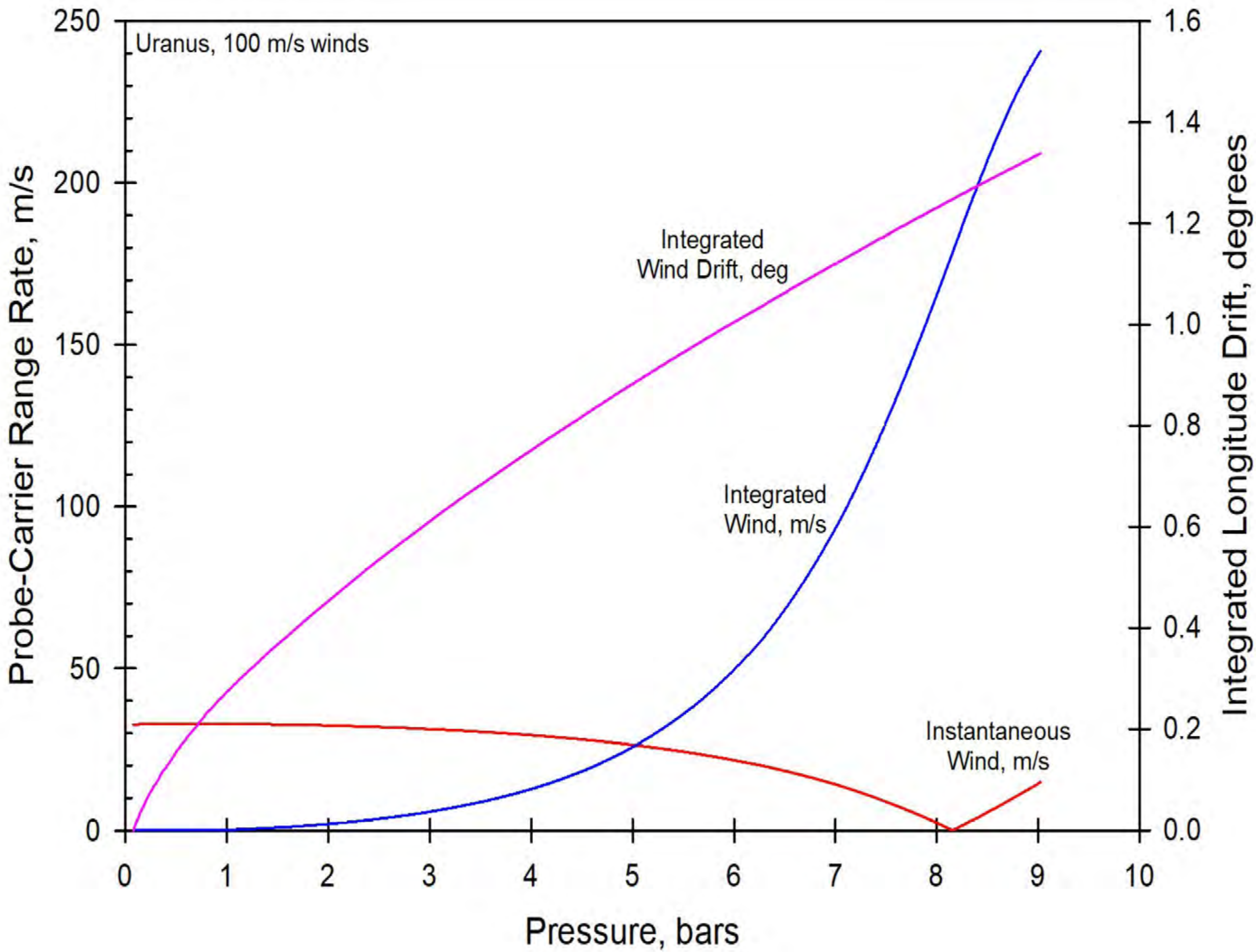
  Finite response time of descent system may be important.

- Probe response time ~$T=V_{desc}/g$

- For a probe descending at 50 m/s:

  Uranus (g=8.7 m^2): T = 5.7 sec; Δz = 287 m

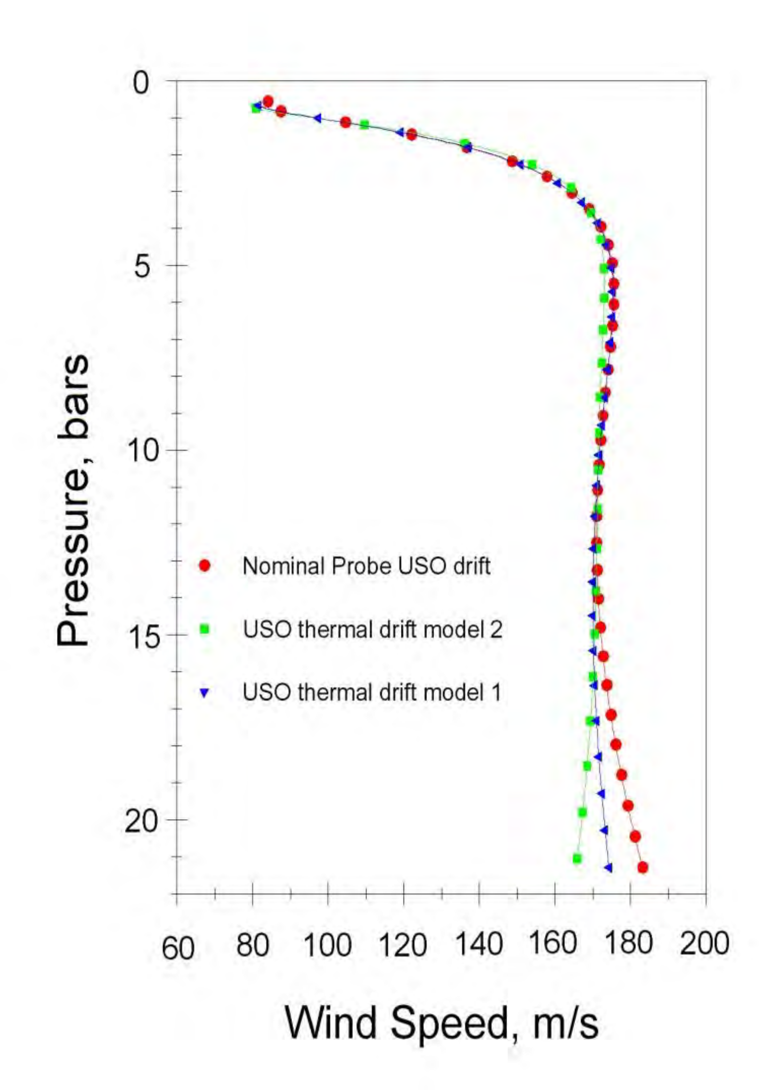
  Neptune (g=11.2 m^2): T = 4.5 sec; Δz = 223 m



Uranus, 100 m/s winds
Integrated Wind Drift, deg
Integrated Wind, m/s
Instantaneous Wind, m/s
Probe-Carrier Range Rate, m/s
Integrated Longitude Drift, degrees
Pressure, bars
0
50
100
150
200
250
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
0 1 2 3 4 5 6 7 8 9 10

Heritage – Galileo / Jupiter, 1995

- Probe horizontal traverse due to winds significantly larger than vertical descent under parachute.
- Probe longitude delivery error of .07 degree → equivalent to Doppler effect of 300 m/s zonal wind.
- Integrated effect of wind on probe longitude caused a Doppler contribution > 250 Hz → equivalent to ~310 m/s zonal wind.

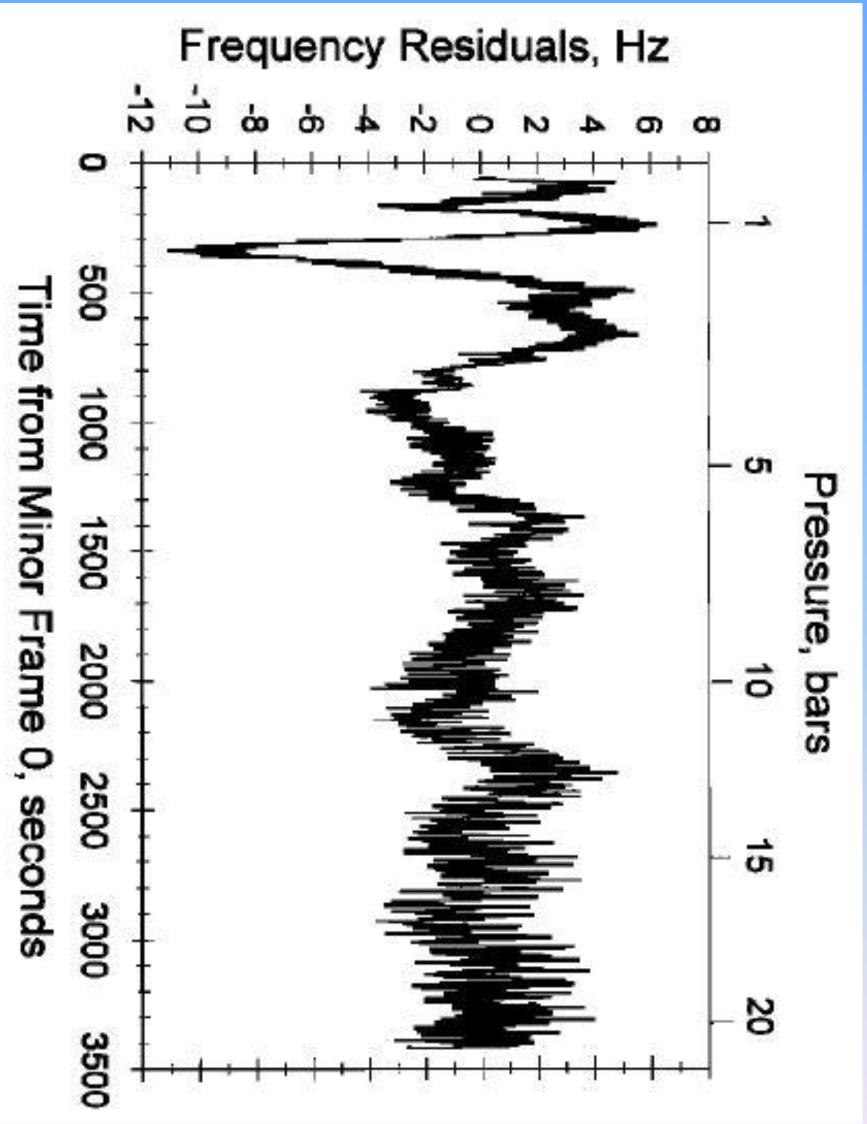


References

Atkinson, Ingersoll, and Seiff "Deep winds on Jupiter as measured by the Galileo probe," Nature, v399 14 Aug 1997.

Atkinson, Pollack, and Seiff "The Galileo Doppler Wind Experiment: Measurement of the deep zonal winds on Jupiter," J. Geophys. Res., v103, E10, Sept. 25, 1998.

Frequency Residuals - Waves

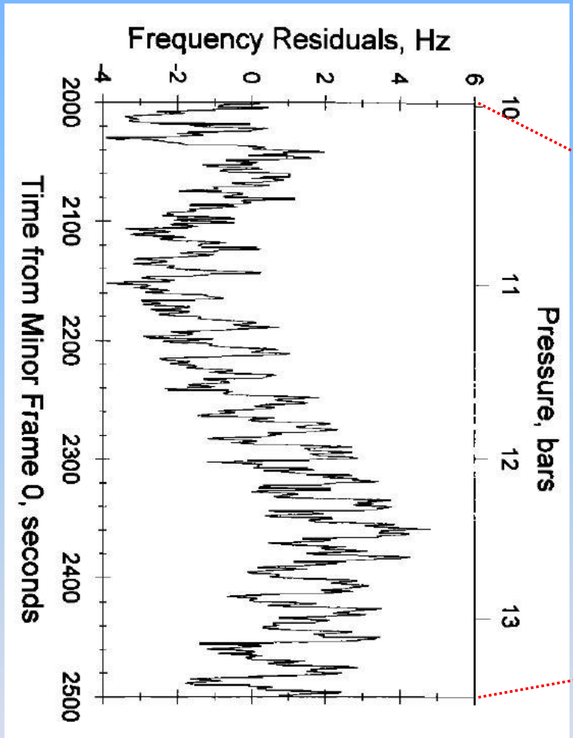


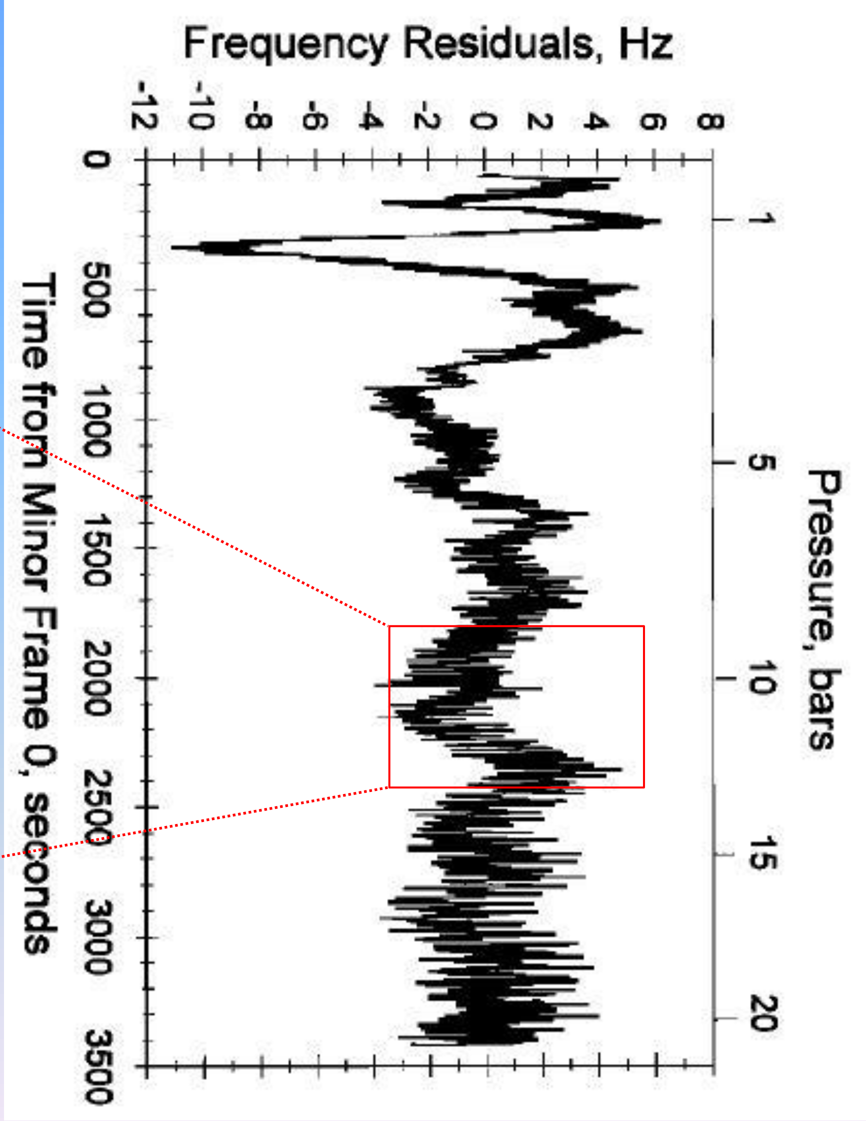
<u>Reference</u>

Allison and Atkinson, "Galileo Probe Doppler residuals as the wave-dynamical signature of weakly stable, downward-increasing stratification in Jupiter's deep wind layer," Geophys. Res. Lett., v28, 14, 2001.

Frequency Residuals - Waves

Fine structure from probe spin, pendulum, turbulence, and aerodynamic buffeting.





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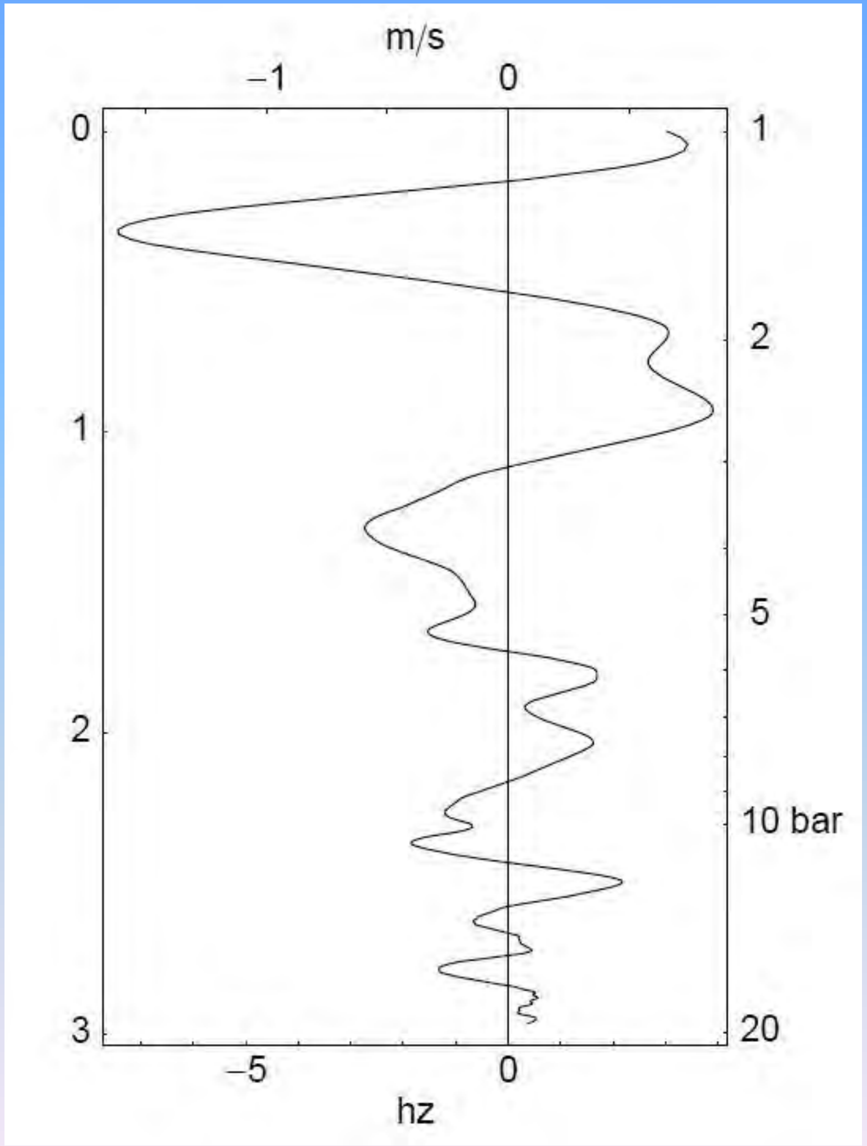
Frequency Residuals - Waves

Filtered residuals show downward bunching below ~ 4 bar interpreted as vertically propagating wave.

Decreasing wave amplitude Indicative of downward increasing static stability.



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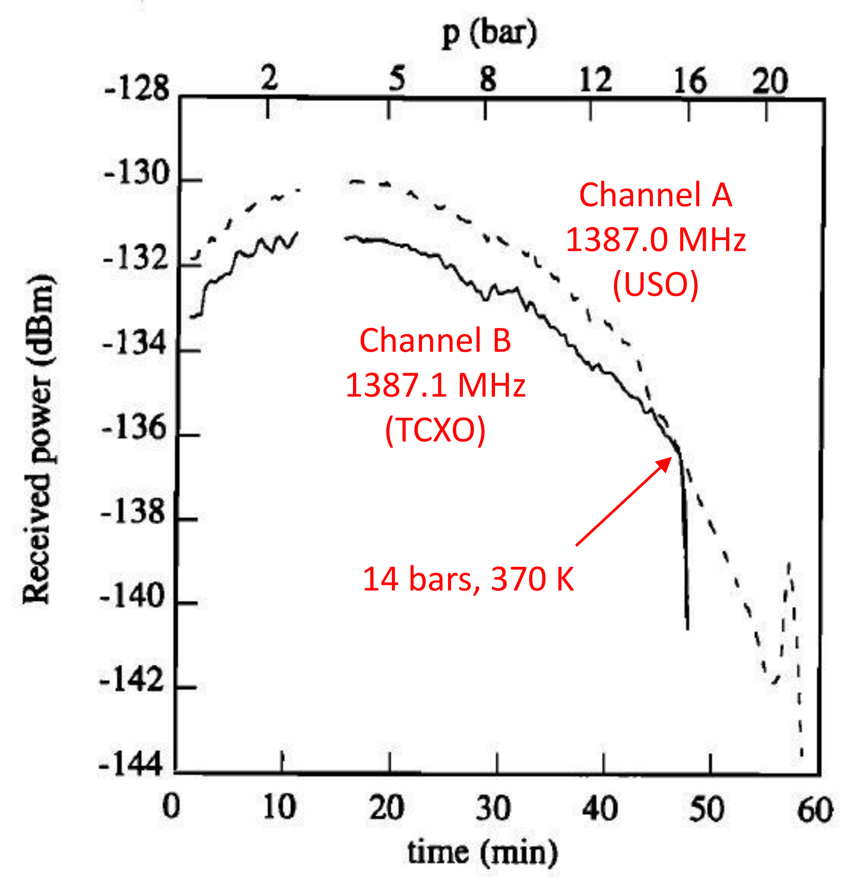
Atmospheric Absorption

The radio signal from the Galileo probe to the orbiter experienced significant atmospheric attenuation during probe descent.

Inversion of attenuation profile provided atmospheric ammonia abundance as function of depth.

Each point represents average of 400 samples at 47 ms interval.



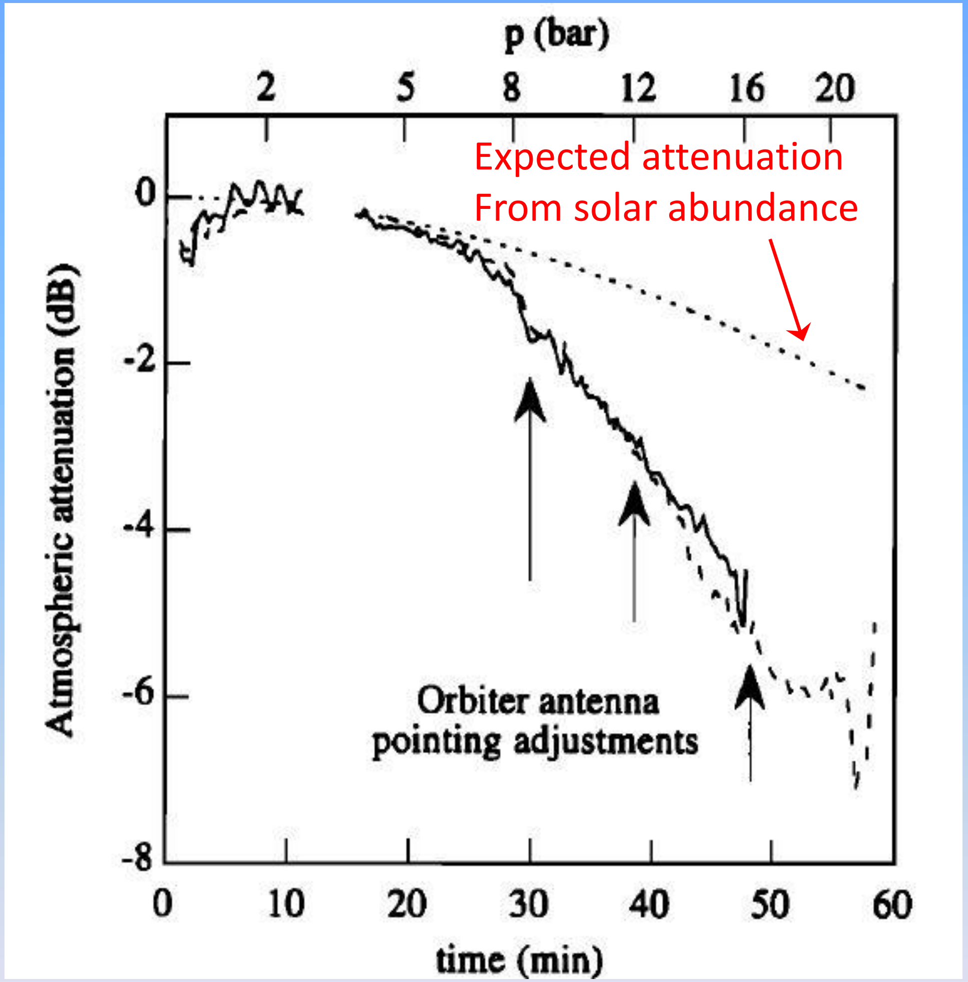
Folkner, W., et al. “Ammonia abundance in Jupiter's atmosphere derived from the attenuation of the Galileo probe's radio signal,” JGR, 103, El0, Sept. 25, 1998.

Atmospheric Absorption

Amplitude of received signal originally sampled to study index of refraction fluctuations due to atmospheric scintillation, turbulence, etc.

Complicated probe motions during descent introduced dynamics at similar time scales as scintillation making this measurement very difficult.

Slowly varying amplitude changes due to varying atmospheric attenuation.



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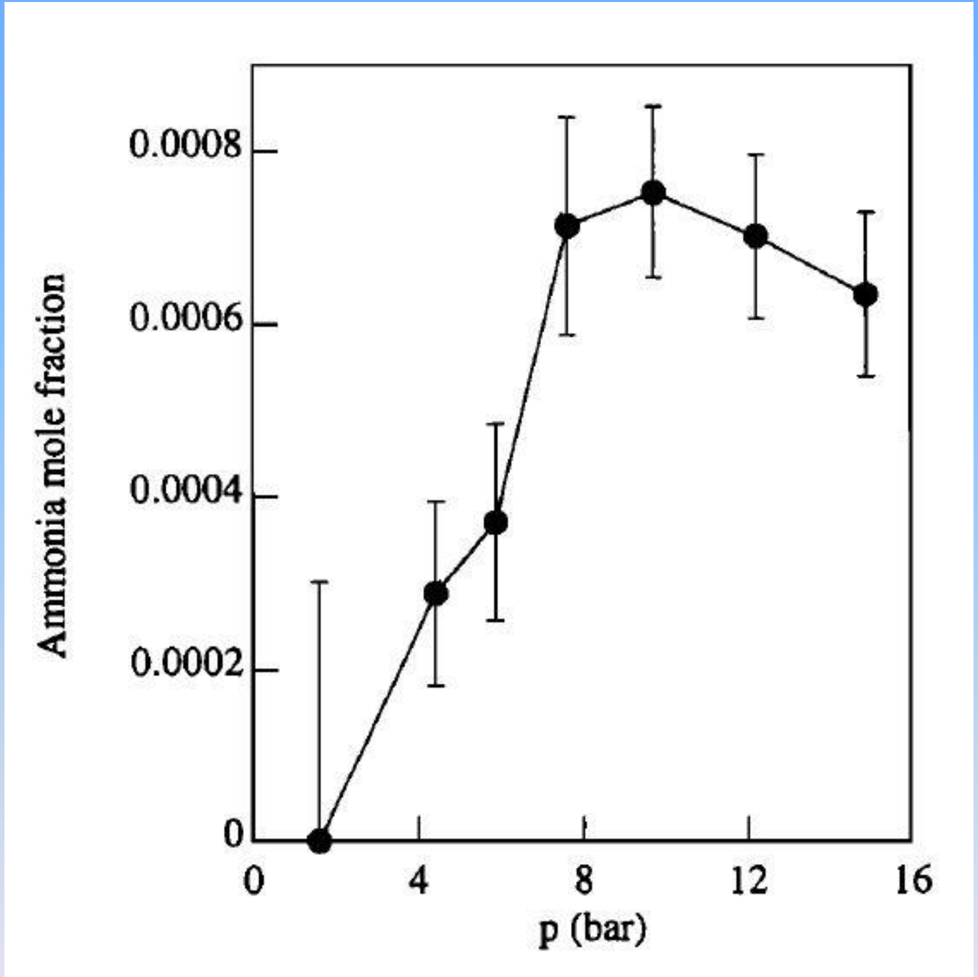

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Minimum Requirements

- USOs required on both sides (Tx/Rx) of probe to receiver (carrier or Earth) telecomm link
- Frequency sampling rate ~10/sec
- Frequency resolution ~0.1 Hz
- Signal strength measurement (Galileo 47 ms)
- Accurate reconstruction of probe delivery, entry trajectory and dynamics, atmosphere descent speed, and carrier trajectory
  - Overflight trajectory: time variation, geometry
  - Reconstruction of probe descent speed via ASI

Summary and Conclusion

- In situ measurements of planetary atmospheric dynamics possible if descent probe & receiver both equipped with ultrastable oscillators, and with the design of a reasonable overflight trajectory.

- Probe Radio Science Experiment can significantly enhance total mission science return for relatively small impact on mission resources (cost, mass and power) and mission design.

Questions/Discussion