Measurements of Atmospheric Dynamics and Composition from Radiometric Tracking of an Ice Giant Entry Probe

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Background

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

- the only direct measurement of dynamics along the probe descent path;
- measure of the integrated abundance of uwave absorbing molecules along probe relay signal raypath, including ammonia (NH_3), hydrogen sulfide (H_2S), and water (H_2O).

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 (spin, pendulum, and aerodynamic buffeting).

Composition

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

DWE 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 can be reconstructed exactly → frequency residuals identically 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 on order of $T=V_{desc}/g$.
- 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

Notes

- Significantly changing probe-carrier overflight trajectory benefits wind retrieval. Carrier should not appear stationary in sky as seen from probe.

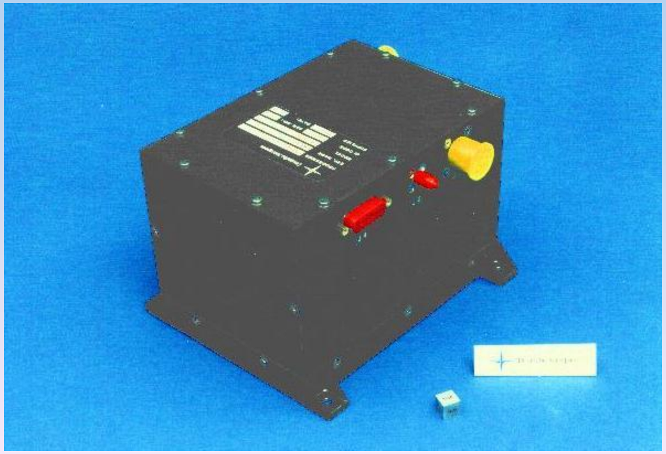
- If mission design permits, a 2nd receiving station (secondary probe or measurement from Earth) can provide 2nd component of wind and provide separation of zonal and meridional winds.

UltraStable Oscillators: Quartz vs. Rubidium

Galileo Probe USO

Quartz Xtal, Very Stable
Allan Variance (100-s): ~1e-12
Not Accurate: ~500 Hz error
Warmup time: 4-6 hours
Steady State Power: 2.2 Watts
Mass: 1.1 kg

Huygens Probe USO



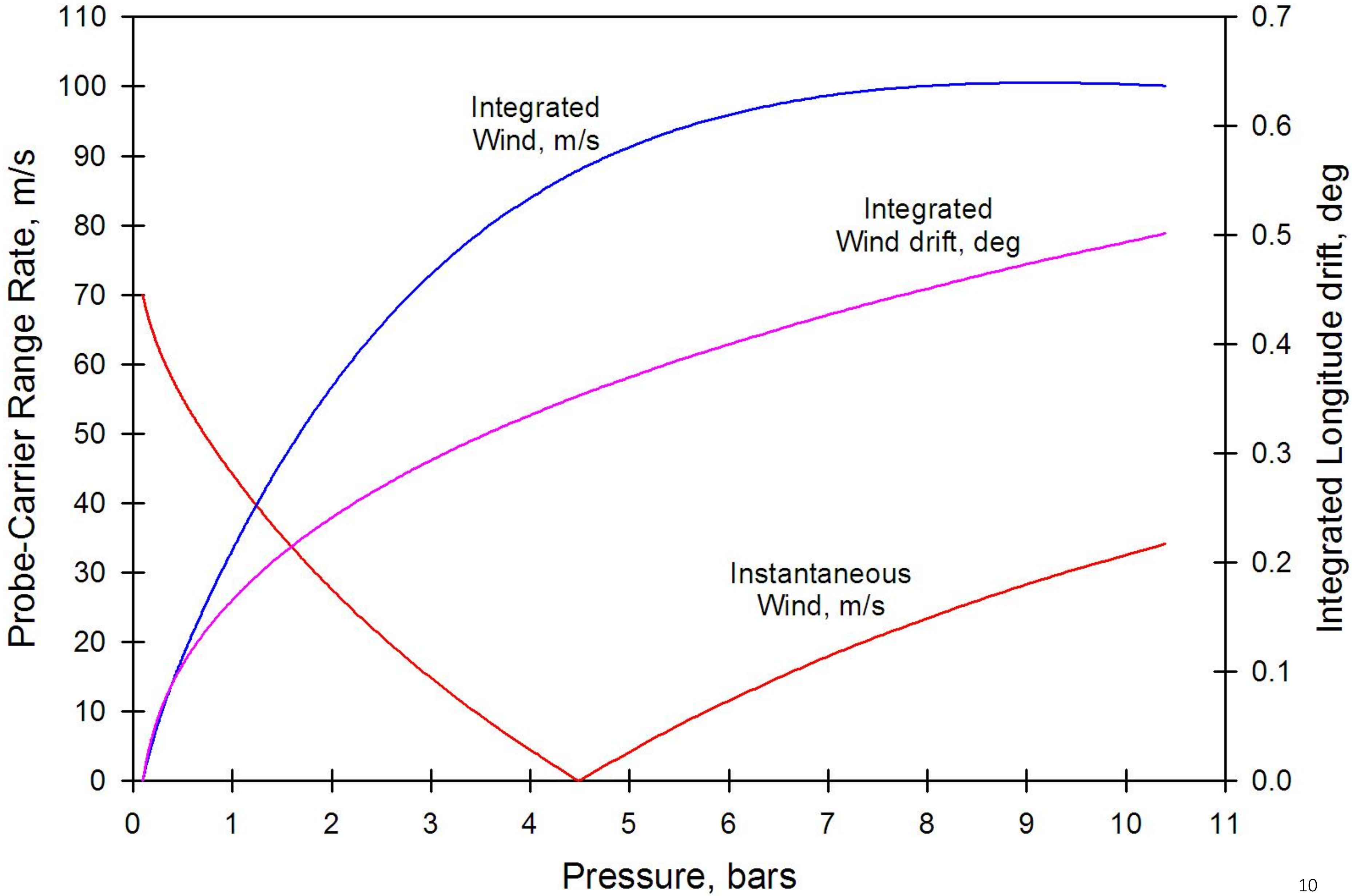
Rubidum, Very Accurate
Not Stable, Allan Var. (100-s): ~1e-10
Warmup power: 18.4 watts for 20 min
Steady State power: 7.8 watts
Mass: 1.9 kg

Partials

V_{LOS} = Line of Sight Velocity = Probe/Carrier Range Rate (m/s)

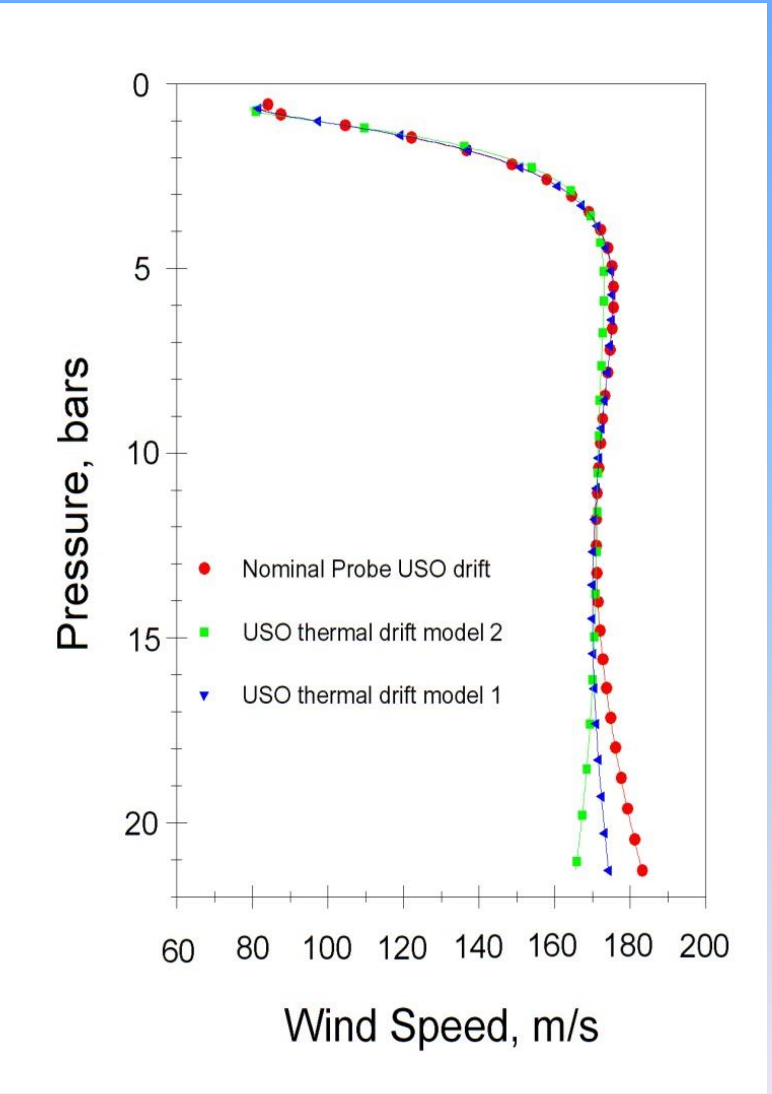
Probe Partials	Value
$dV_{LOS}/dradius$	-.074 m/s per km
$dV_{LOS}/dLat$	97.68 m/s per deg
$dV_{LOS}/dLong$	-34.34 m/s per deg
dV_{LOS}/dV_{desc}	-0.88 m/s per m/s
dV_{LOS}/dV_{merid}	0.45 m/s per m/s
dV_{LOS}/dV_{zonal}	0.17 m/s per m/s

Zonal Wind Partials	Value
dV_{Zonal}/dV_{merid}	2.66 m/s per m/s
$dV_{Zonal}/dLong$ (probe)	-204.42 m/s per deg
$dV_{Zonal}/dLat$ (probe)	581.54 m/s per deg
dV_{Zonal}/dV_{desc} (probe)	-5.23 m/s per m/s


Integrated
Wind, m/s
Integrated
Wind drift, deg
Instantaneous
Wind, m/s
Probe-Carrier Range Rate, m/s
Integrated Longitude drift, deg
Pressure, bars
0
10
20
30
40
50
60
70
80
90
100
110
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0
1
2
3
4
5
6
7
8
9
10
11

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 Doppler frequency from 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.



<u>References</u>

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

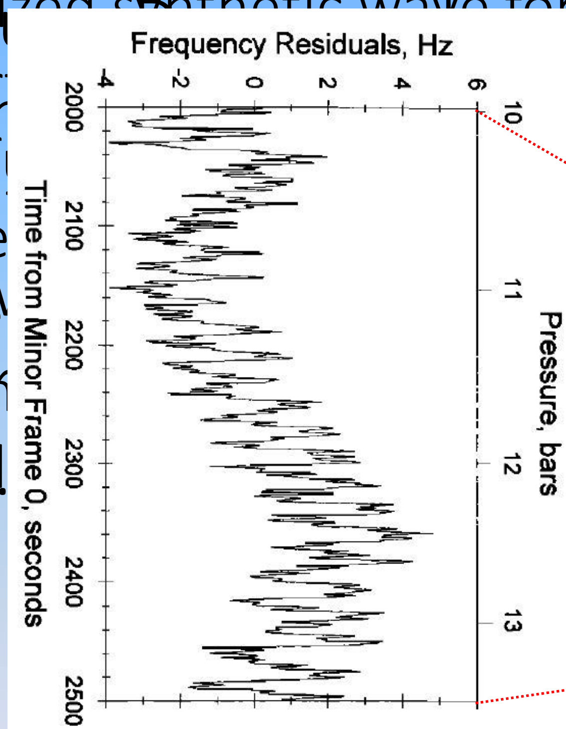
Atkinson, Pollack, and Seiff "The Galileo Doppler Wind Experiment: Measurement of the deep zonal winds on Jupiter," J. Geophys. Res., v103, E10, Sept. 25, 1998.

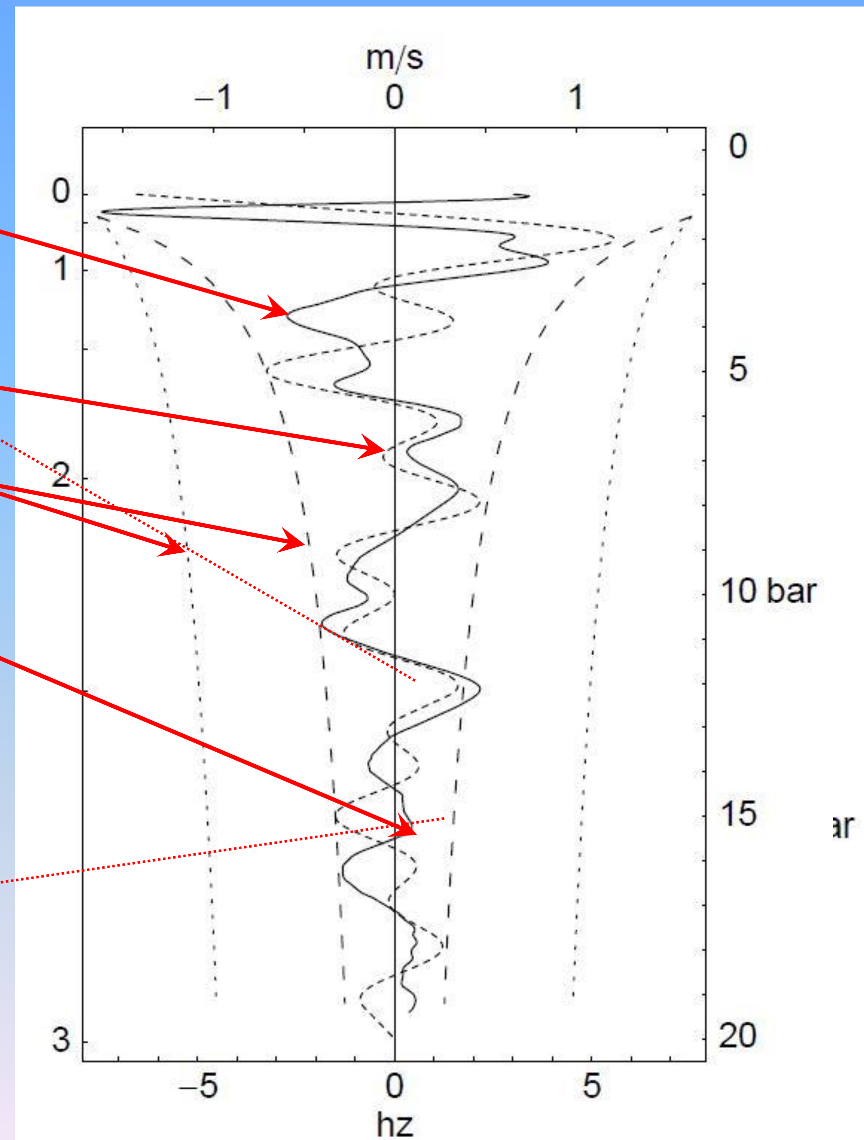
Frequency Residuals - Waves

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

Doppler residuals vs. pressu… bunch… amplit…ns below… as ver… wave!

Filtered residuals (solid) and idealized synthetic wave form (shor… The f… repre… of wave… down… stabil…





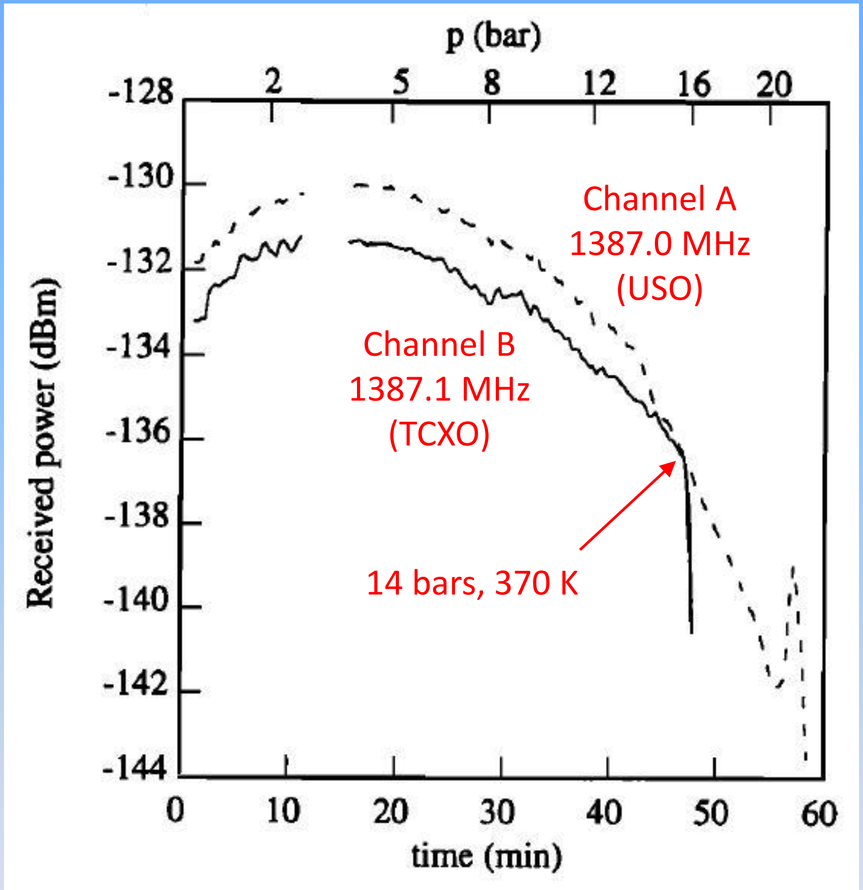
Reference
Allison and Atkinson, "Galileo Probe Doppler residuals as the wave-dynamical signature of weakly stable, downward-increasing stratification in Jupiter's deep wind layer," Geophys. Res. Lett., v28, 14, 2001.

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.

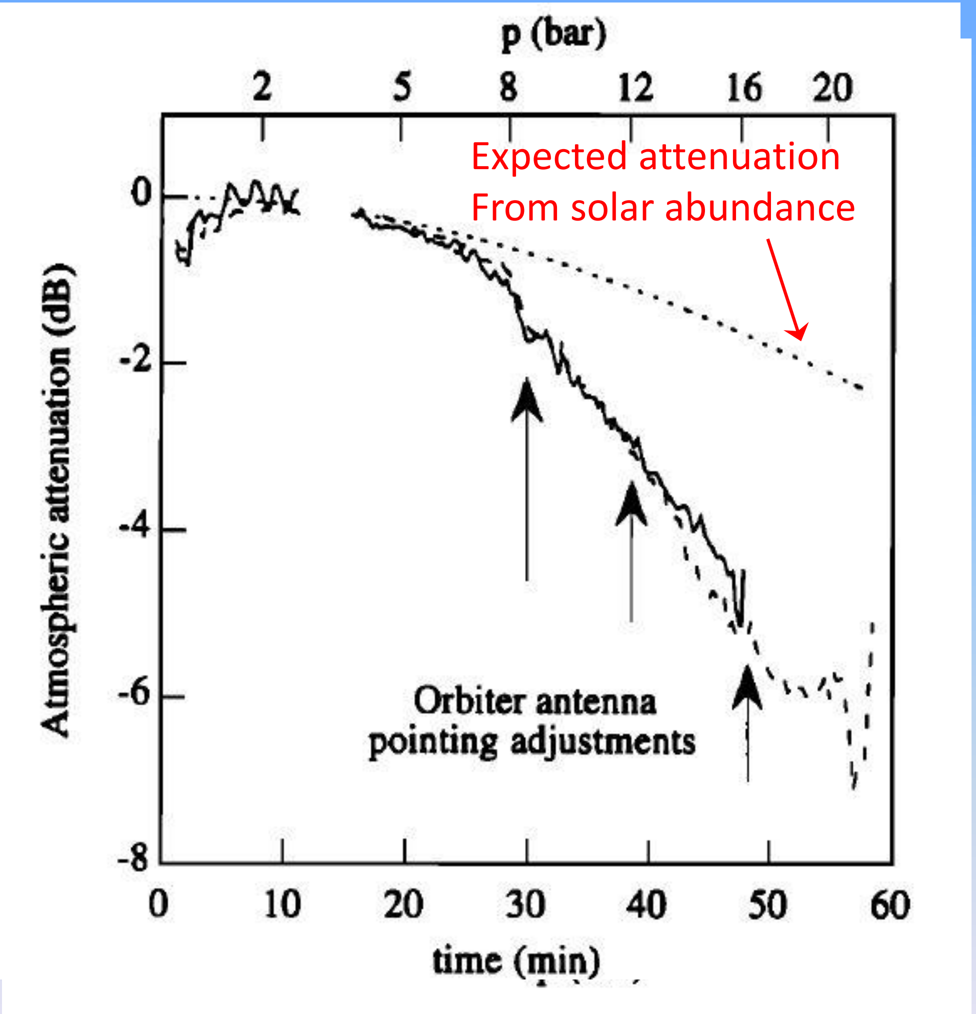


Atmospheric Absorption

Amplitude of received signal originally sampled to study refractive index fluctuations from scintillation, turbulence, etc.

Complicated probe motions during descent introduced dynamics at similar time scales as scintillation.

Slowly varying amplitude changes due to varying atmospheric attenuation.



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.

Minimum Requirements

- USOs required on both sides (Tx/Rx) of probe 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