OUTER PLANET DOPPLER WIND MEASUREMENTS

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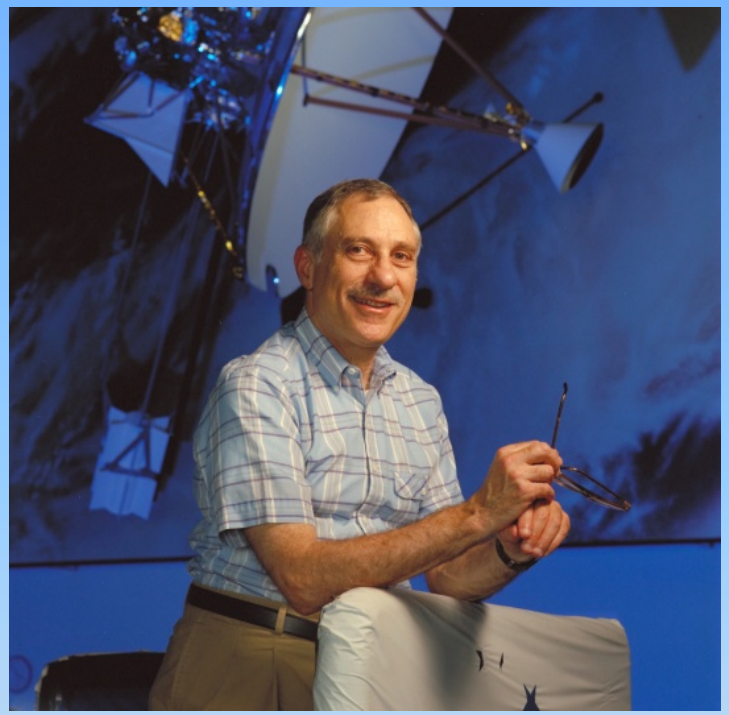
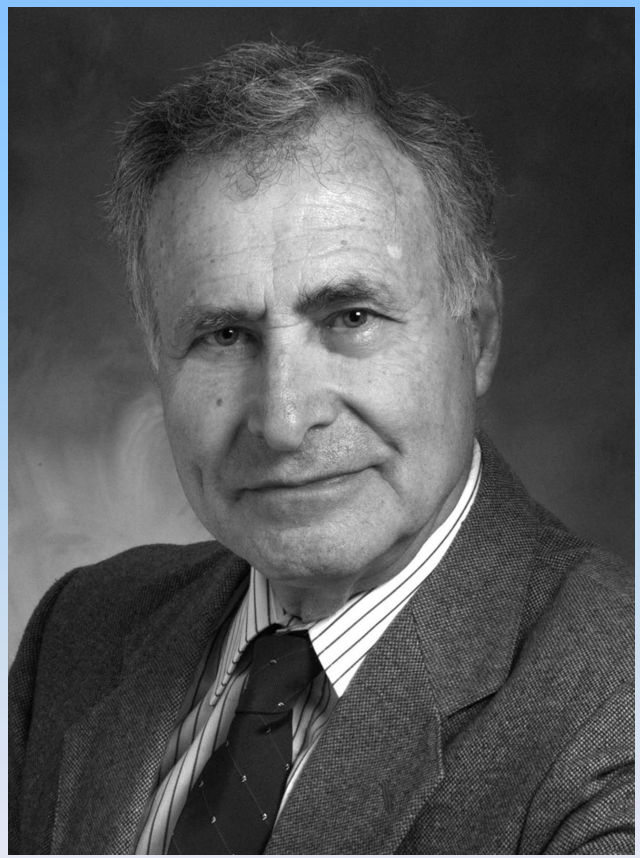


Dr. James B. Pollack



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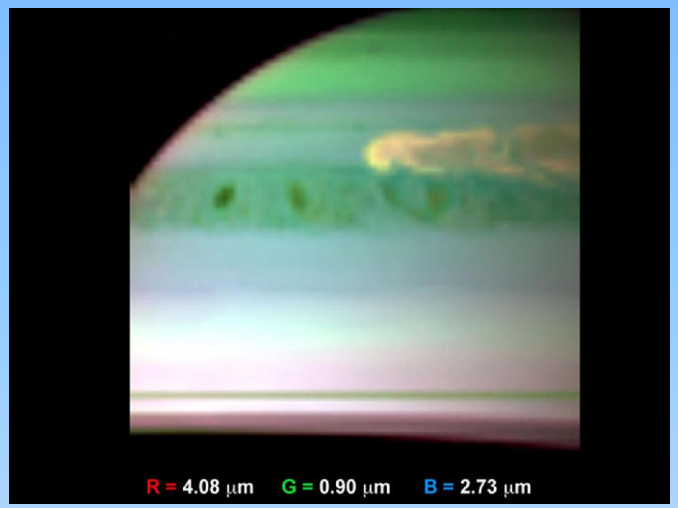
Key Questions

- Why are measurements of dynamics important?
- How are in situ measurements of planetary winds made?
- What is the impact and cost of Doppler wind measurements on Comm System Design?

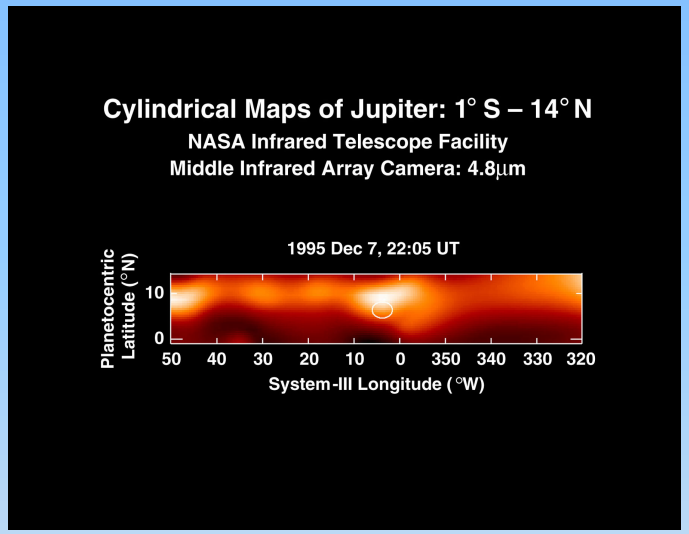
Atmospheric Energy and Circulation



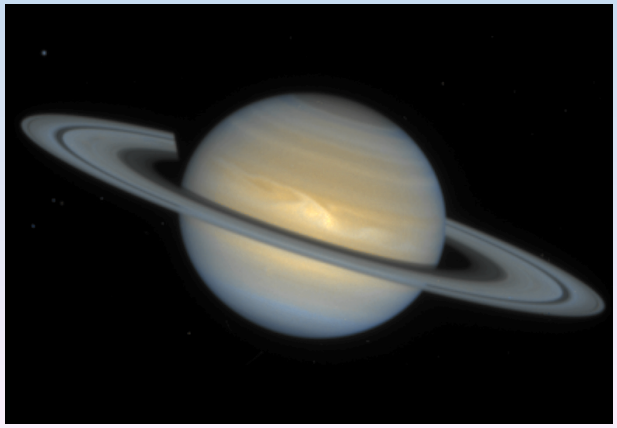
Profile of deep winds can provide constraints on wide variety of possible energy sources that drive atmospheric circulation, including solar, latent heat, ortho/para hydrogen conversion, and energy advected from deep interior.

Atmospheric Composition

Dynamics contribute to the distribution and mixing of atmospheric constituents.



Convective upwelling provides transport for trace constituents to upper atmosphere, and is diagnostic of deep interior processes as evidenced by disequilibrium species such as PH3, CO, AsH3, GeH4, and SiH4.

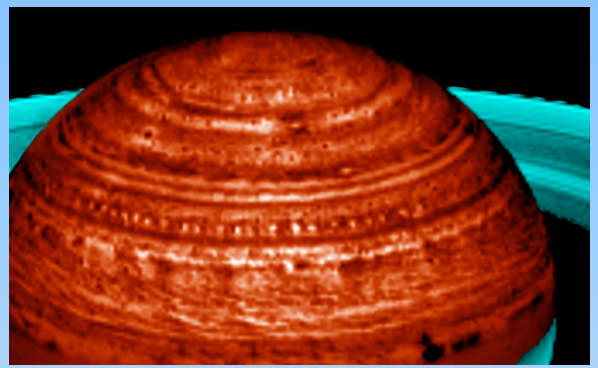


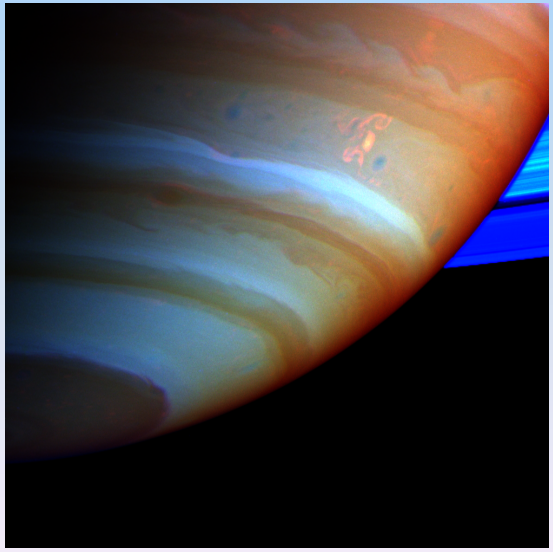
Strong convection can affect location of cloud bases.

Atmospheric Structure

Structure, location, and life cycle of clouds coupled to winds, waves, and convection.

Thermal structure affected by radiative heating / cooling, turbulent convection, and large scale atmospheric circulation.





Radiative heating / cooling strongly affected by presence & distribution of clouds and hazes.

Character of gravity waves diagnostic of deep atmosphere stratification.

How are *in situ* measurements of planetary winds made?

Doppler Wind Experiment Goals

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).

DWE Background – Basics

Frequency of probe radio link measured at receiver. If transmitted frequency and all positions and velocities of the probe and receiver are known, then frequency measured at receiver can be reconstructed exactly.

Doppler residuals assumed to be probe motion due to unmodeled probe dynamics.

Under assumption that probe descent speed is well known, Doppler residuals → probe/receiver range rate residuals. When projected into local horizontal at probe → horizontal winds.

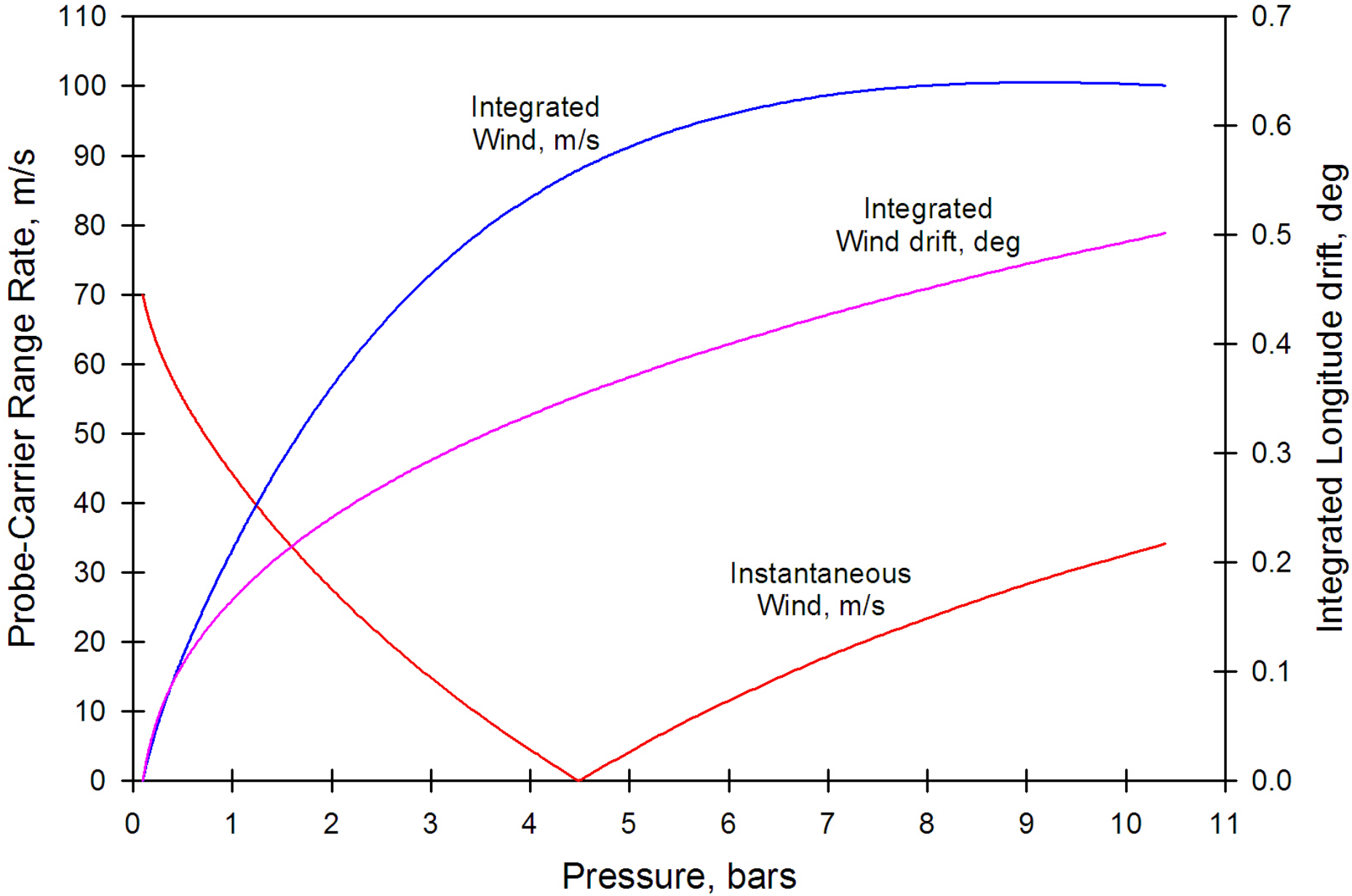
Background – Simple Theory

Doppler Residual $$\Delta f_{Dopp} = -\frac{f_0}{c}\delta v_{LoS} = -\frac{f_0}{c}\vec{v}_{zonal}\cdot\hat{n}_{LoS}$$

$$\delta v_{LoS} = \frac{\partial v_{LoS}}{\partial \dot{\phi}}\delta\dot{\phi} + \frac{\partial v_{LoS}}{\partial \phi}\delta\phi$$

$\delta\dot{\phi}$ = change in zonal motion due to winds

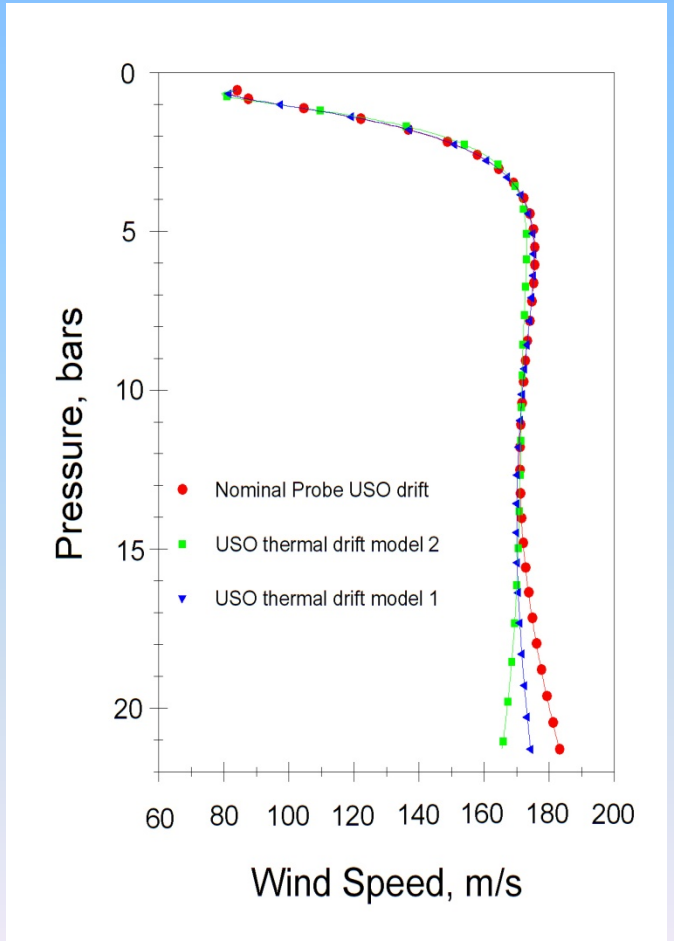
$\delta\phi$ = change in probe longitude due to integrated effect of winds


Probe-Carrier Range Rate, m/s
Integrated Longitude drift, deg
Pressure, bars
Integrated
Wind, m/s
Integrated
Wind drift, deg
Instantaneous
Wind, m/s
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

Doppler Wind Heritage

Type I DWE: Giant Planet

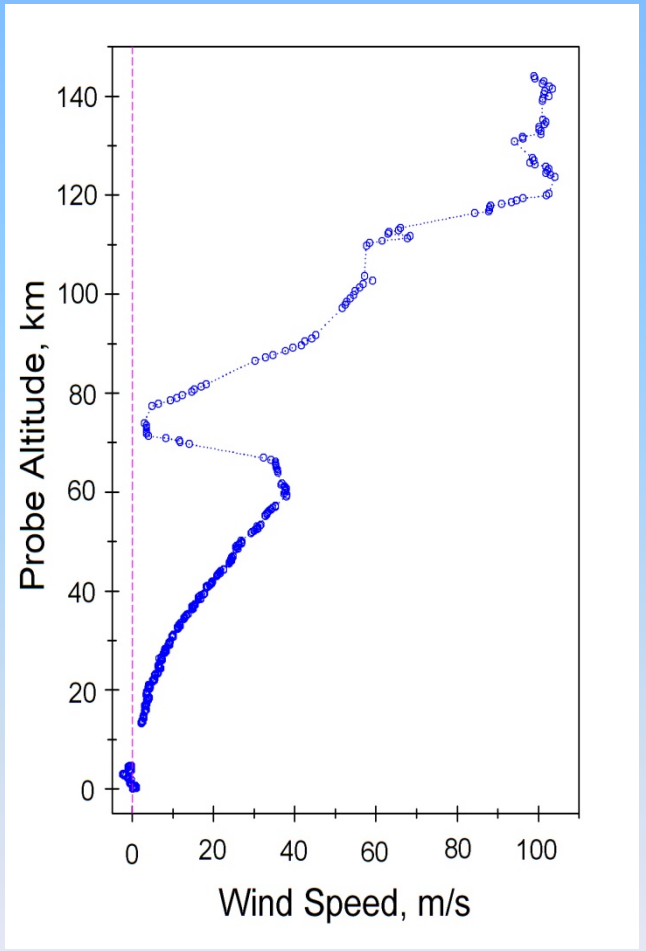
- Galileo / Jupiter, 1995
- Probe horizontal traverse due to winds significantly larger than vertical descent under parachute.
- Probe longitude delivery error of . 07 degree → Doppler equivalent to 300 m/s zonal wind.
- Integrated effect of wind on probe longitude caused a Doppler contribution > 250 Hz → equivalent to 310 m/s zonal wind.



Doppler Wind Heritage

Type II DWE: Titan

- Huygens, 2005
  - Probe – Cassini orbiter link failed. Huygens DWE receivers on Earth: Green Bank, WV / Parkes, Australia.
  - Propagation delay: Earth = 67^{min} (compare: Orbiter = 0.2^{sec})
- Integrated effect of wind on probe longitude caused a zonal drift of approx. 3.56 deg → $f_{Doppler}$= 16.6 Hz; Equivalent to 4.2 m/s zonal wind.



What is the impact and cost of Doppler wind measurements on Comm System Design?

DWE Instrumentation

Stable frequency references needed for accurate measurement of wind-induced Doppler shifts.

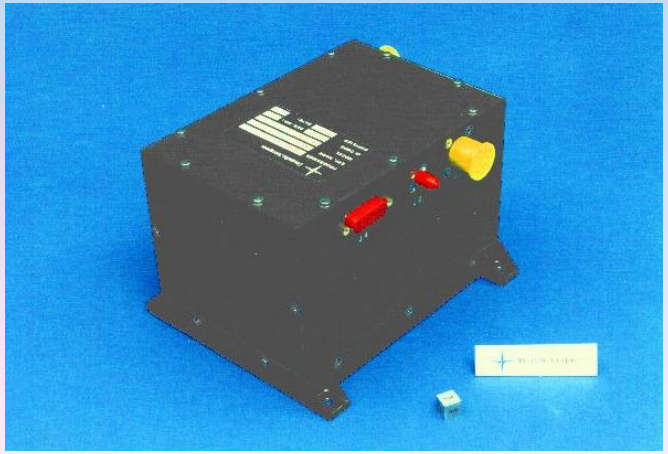
Ultrastable Oscillator (USO) required on both sides of radio link: transmitter (probe) and receiver.

Quartz vs. Rubidium

Galileo Probe USO

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

Huygens Probe USO



Rb, 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

Cost

- Cost of APL USOs has increased significantly over past few years, to ~$1M/unit. Total mission cost ~$3M (probe, receiver, and 1 flight spare/EM).

- Alternate vendors (e.g., Symmetricom) can provide USOs of similar quality and performance for about one quarter the price.

  Flight Heritage: LRO

Summary and Conclusion

- In situ measurements of planetary atmospheric dynamics are possible if the descent probe and the receiver both are equipped with ultrastable oscillators, and with the design of a reasonable overflight trajectory.
- The total cost of a Doppler Wind Experiment is significantly less than the cost of most instruments comprising the probe science payload.
- The Doppler Wind Experiment can significantly enhance total mission science return for relatively small impact on mission resources (cost, mass and power) and mission design.

Questions?