

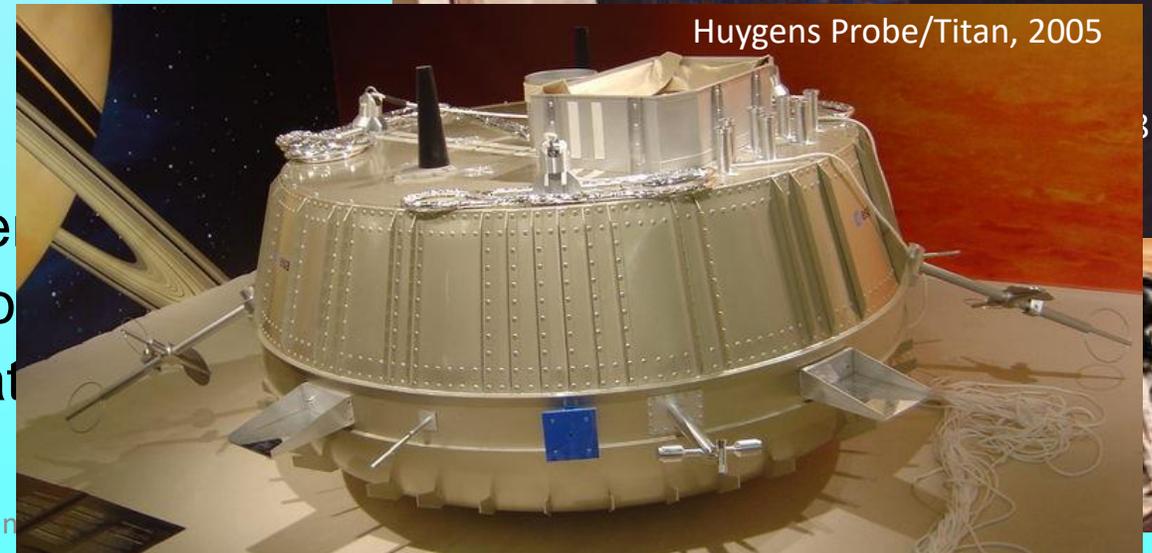
Characterization of Planetary Atmospheric Dynamics by Doppler Tracking of a Constellation of Small Entry Probes

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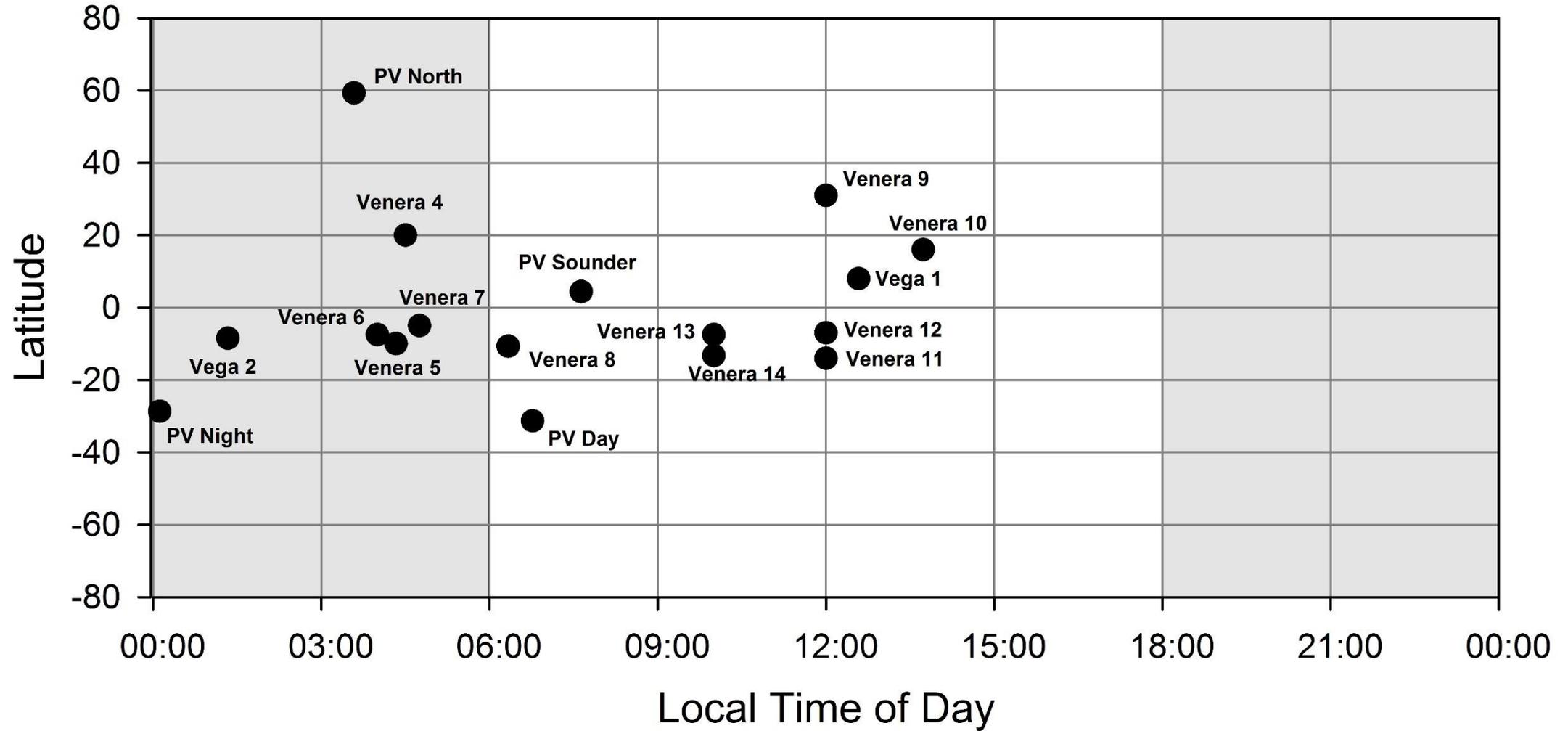
12th Low-Cost Planetary Missions Conference (LCPM-12)
Session 4b (Software, modeling and simulations)
Pasadena, California
16 Aug 2017

Motivation

- Characterization of dynamics is essential to overall understanding of planet's energy, thermal, and compositional structure.
- Doppler tracking of entry probes for in situ retrieval of winds successfully demonstrated at Venus with Venera, VEGA, and Pioneer, and at Jupiter & Titan with Galileo and Huygens.
- Only Pioneer Venus measured multiple wind profiles by simultaneously tracking several probes at different locations.
- **Important:** Variation of winds at different latitudes (solar insolation) & longitudes (time of day) needed to characterize global circulation.



Venus Probe Locations



Background

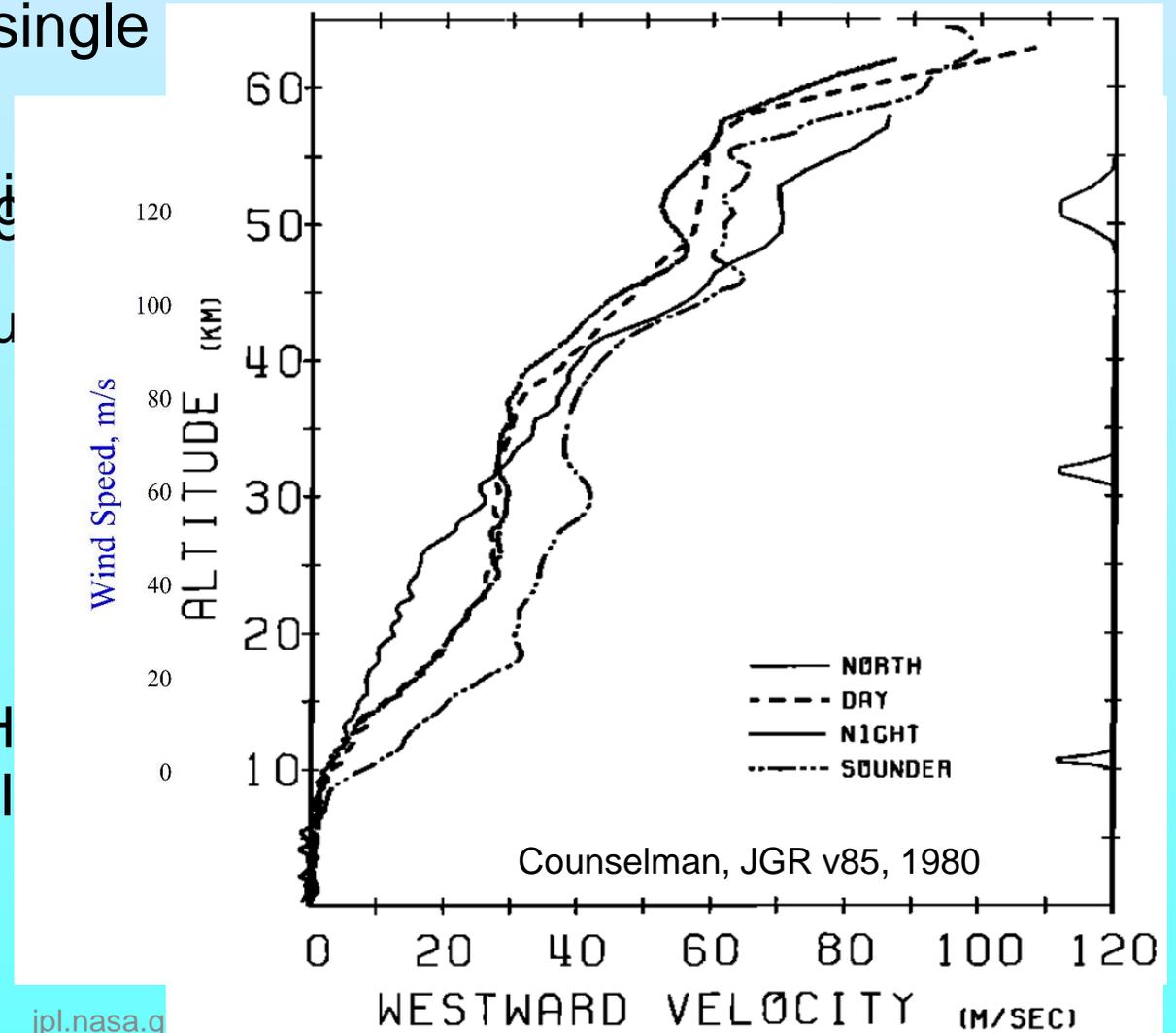
- Dynamics of atmosphere can be inferred by Doppler tracking of probe descending under parachute.
- Accurate modelling of probe entry / descent profile: location, altitude, and descent speed, and assumption of predominantly zonal (east-west) winds permits relatively small signature of probe motion due to wind (reflected as Doppler residuals in probe radio link frequency profile) to be extracted.
- From Doppler residuals, vertical profile of zonal winds retrieved utilizing iterative inversion algorithm that accounts for integrated effect of winds on probe descent longitude.
- Detailed analysis of Doppler residuals may also provide evidence of atmospheric waves and turbulence.

Heritage

With exception of Pioneer Venus and Vega balloons, previous entry probe missions provided dynamics along single slice of atmosphere.

Pioneer Venus North, Day, Night and Sounder probes (1978)
Galileo Probe / Jupiter (1995)
Huygens Probe / Titan (2005)
Probe horizontal traverse due to winds significantly larger than vertical descent under parachute.

Integrated effect of wind on probe longitude caused a Doppler contribution $> 250H$ equivalent to 310 m/s zonal wind.



Radio Science using Small Probes

(Small) probes often must compete with a perception that more is better.

- Mission duration / number of bytes returned often a metric of intrinsic value.
- Sometimes more data is better, e.g., increasing SNR, more complete spatial or temporal coverage, etc.
- All against a backdrop of limited opportunities and resources.

However – fundamental science can be provided with small returned data volume.

By their very nature - radio science experiments utilize received properties of transmitted signals - i.e., measurements are made at the receiver, not by instruments carried by probe → much less telemetered science data.

Doppler tracking of planetary probes for wind measurements requires

- i. Accelerometers for entry reconstruction
- ii. Pressure and temperature sensors to retrieve probe altitude & descent speed
- iii. UltraStable Oscillator (USO) to generate stable signal

Justification for Low Cost Small Probes

Value of small probes is in design for very specific, focused investigations, and not a Christmas tree to carry anything and everything.

→ With small, limited instrumentation and tightly defined & focused investigation, small probes can be (relatively) very low cost.

Mission comprising network of small probes can be designed and flown for << cost of single large and much more complex probe.



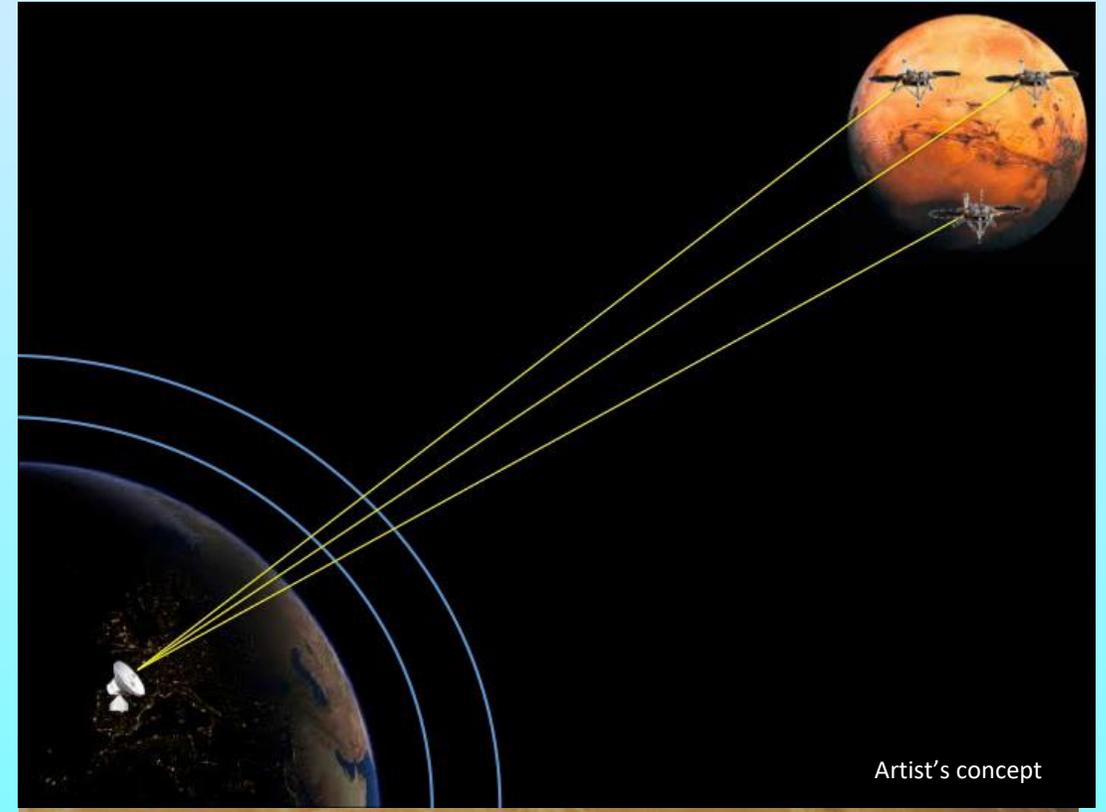
Mission Concept

Multiple (≥ 2) small probes independently targeted for entry into atmosphere.

Probe carry accelerometers to measure entry deceleration pulse, pressure and temperature sensors, and USO to generate very stable telemetry signal.

Direct transmission of entry accelerations, descent pressure & temperature to Carrier.

Bonus If probe descent sub-Earth, then signal frequency can be measured at Earth → Provides second Doppler component to refine measured winds.



Small Probe Design Elements

JPL Iris radio: UHF or S-band with external USO

0.5U, 1.5 kg, 35W
~4W RF output.

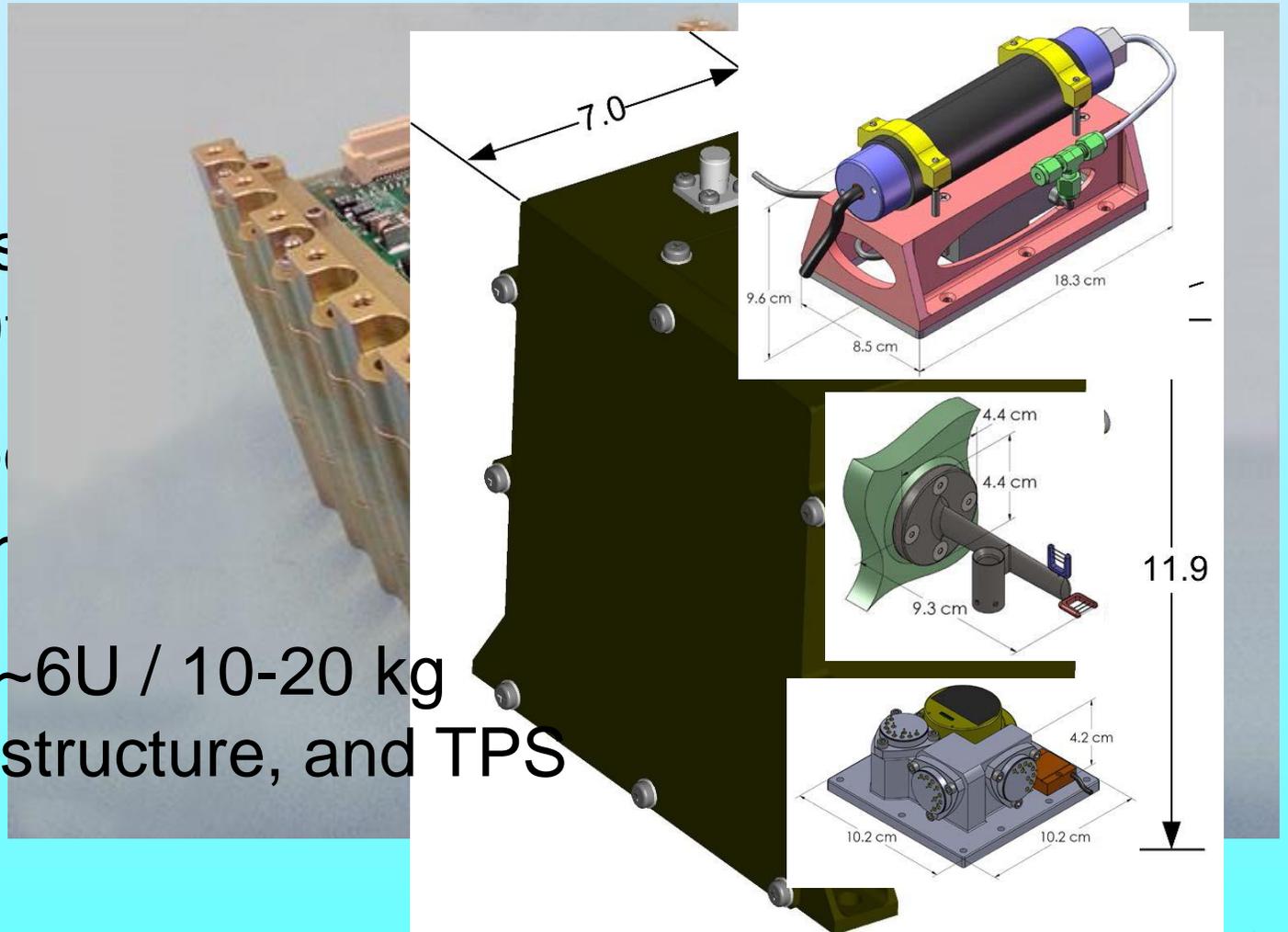
USO: ~1U, 1.5 kg, 3.2W s

Allan Deviation ~10

Sensors: Pressure, Temp

Total ~ 1.8 kg, 2W,

Strawman probe design: ~6U / 10-20 kg
including batteries, structure, and TPS



Doppler Wind Measurement Accuracy

Accuracy of Doppler Wind measurements depend strongly on

- Probe and receiver trajectories
- Accuracy of probe descent location reconstruction (accelerometers)
- Stability of clocks (USOs) on probe and in receiver
- Probe pressure and temperature measurement accuracy
- Assumption of zero meridional winds (or capability to measure second Doppler component from Earth)

Venus/Titan: wind measurement accuracy ~ 1 m/s.

Giant Planets: wind measurement accuracy several to ~ 10 m/s.

Take Away Messages

- Many essential measurements cannot be accomplished by remote sensing and require entry probes.
- Very scientifically focused low cost small probes can be introduced into more hazardous environments than flagship class probes.
- Small probe measurements of atmospheric dynamics are technically simple, with no significant technology issues.
- Required instrumentation for Doppler tracking measurement of dynamics includes USO (Tx & Rx), Pressure, Temperature, and Accelerometers.
- Full characterization of planetary atmospheric dynamics requires measurements of winds at multiple latitudes / longitudes (time of day).
- Doppler tracking measurements of atmospheric dynamics does not require large bandwidth - radio science measurements made at Rx.

Questions / Discussion