Huygens Doppler Wind Experiment

Initial Results of the Winds on Titan

Sami Asmar

Jet Propulsion Laboratory, California Insitutute of Technology

For the Huygens Doppler Wind Experiment Team

Third International Planetary Probe Workshop
Greece

27 June 2005

FRANCO / 2004

DWE Team

- **M.K. Bird, R. Dutta-Roy, Y. Dzierma**

  Radioastronomisches Inst., Univ. Bonn, Auf dem Hügel 71, 53125 Bonn, Germany

- **M. Allison**

  NASA Goddard Inst. for Space Studies, 2880 Broadway, New York, NY 10025, USA

- **D.H. Atkinson, J. Malecha**

  Dept. of Elec. & Computer Engineering, Univ. of Idaho, Moscow, ID 83844, USA

- **S.W. Asmar, W.M. Folkner, D.V. Johnston, R.A. Preston**

  Jet Propulsion Laboratory, Caltech, 4800 Oak Grove Dr, Pasadena, CA 91109, USA

- **P. Edenhofer**

  Institut für HF-Technik, Universität Bochum, 44780 Bochum, Germany

- **D. Plettemeier**

  Elektrotechnisches Institut, Technische Univ. Dresden, 01062 Dresden, Germany

- **G.L. Tyler**

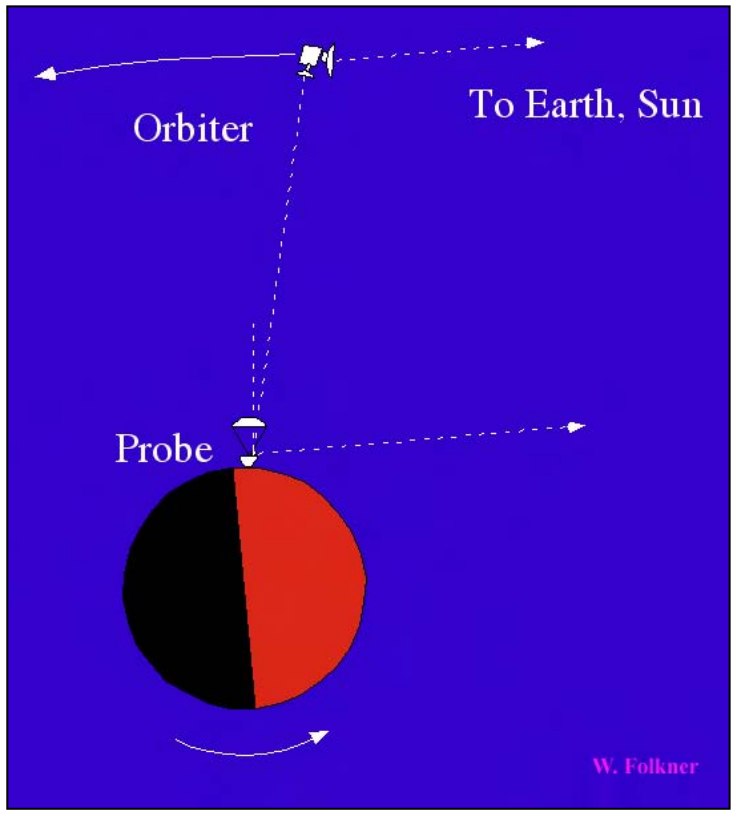
  Center for Radar Astronomy, Stanford University, Stanford, CA 94305, USA

- **L.I. Gurvits, S.V. Pogrebenko, I.M. Avruch**

  Joint Inst. for VLBI in Europe, P.O. Box 2, 7990 AA Dwingeloo, The Netherlands

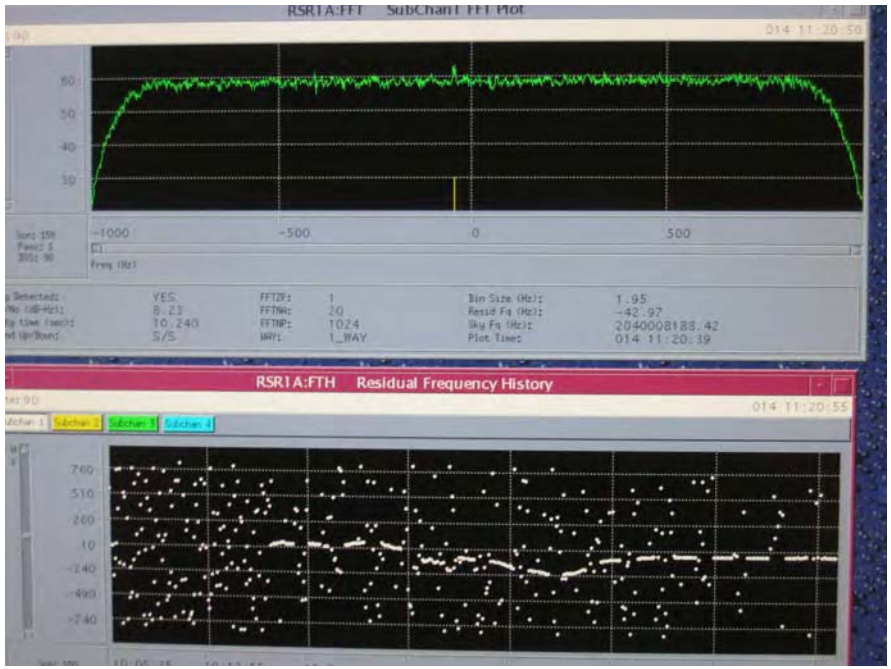
Planetary Wind Measurements

- Deduce wind speed and direction when planetary probe descends into atmosphere
  - Huygens Probe at Titan
  - Galileo Probe into Jupiter
  - Russian probe(s) at Venus
- Observable is Doppler profile: shift in radio frequency after removing all other velocity effects
- Instrument configuration:
  - USO on probe and USO on orbiter
  - Spacecraft-to-spacecraft links
  - When possible, receive signal on Earth



Huygens Doppler Wind Experiment

- Experiment planned with Huygens-Cassini link
- In situ determination of Titan‘s zonal wind speed along Huygens descent path
- ***Experiment lost***
  - Link did not function due to sequencing error
  - Power not applied to oscillator on receiver side
- ***Experiment Recovered***
- Huygens signal carrier received on Earth:
  - 100-m diameter Green Bank Telescope
  - 64-m diameter Parkes radio observatory
  - Four smaller observatories
- Planned as science enhancement
  - Eavesdropping on probe-orbiter link
- NASA receivers & staff sent to observatories
- Hoped for real-time detection



Probe Support Avionics
TCXO
Receiving

Cassini

Probe Support Avionics
RUSO
Not Receiving

2098 MHz RCP

Channel B
Transmitting data
Carrier not stable

Channel A
Transmitting data
Carrier stable

2040 MHz LCP

Earth
Radio Telescopes
Receiving
stable carrier

"Channel C"
Direction: ~ 30 degrees
Light Time: ~ 1 hr 7 min
SNR: ~ 7 dBc
Outside DSN band

Huygens Signal paths

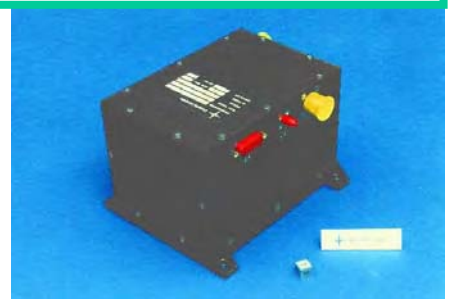
Why Need USO Or RSR

Radio Science Receiver

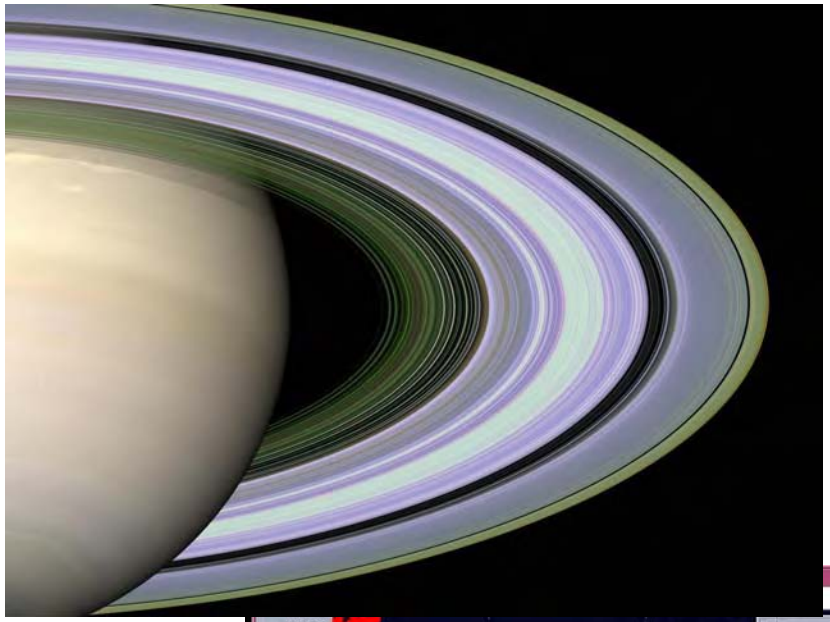
- Open-loop down-conversion
  - No "lock-up," no "tracking"
- Tuned by prediction file generated by navigation
  - Include atmospheric model
- Operated directly by scientists in order to make real time experimental decisions
  - Better stability in design of each component
  - Capture signal dynamics
  - Capture multi-path
  - Choice of bandwidth and sampling
  - Higher quantization
  - Creative post-pass processing, arraying, landing tone processors, etc.

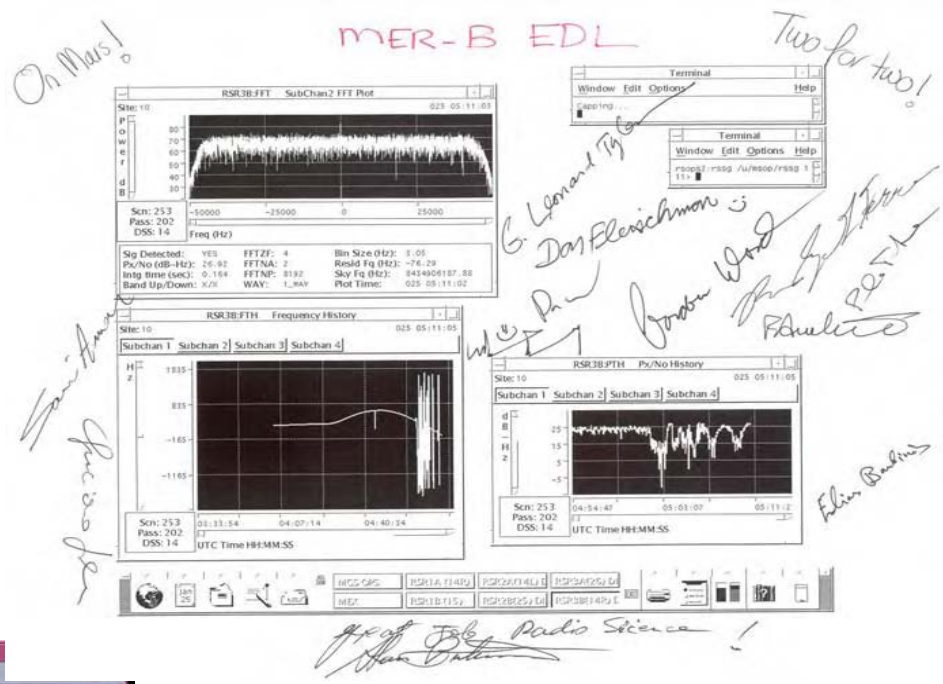
T & R Ultra Stable Oscillator

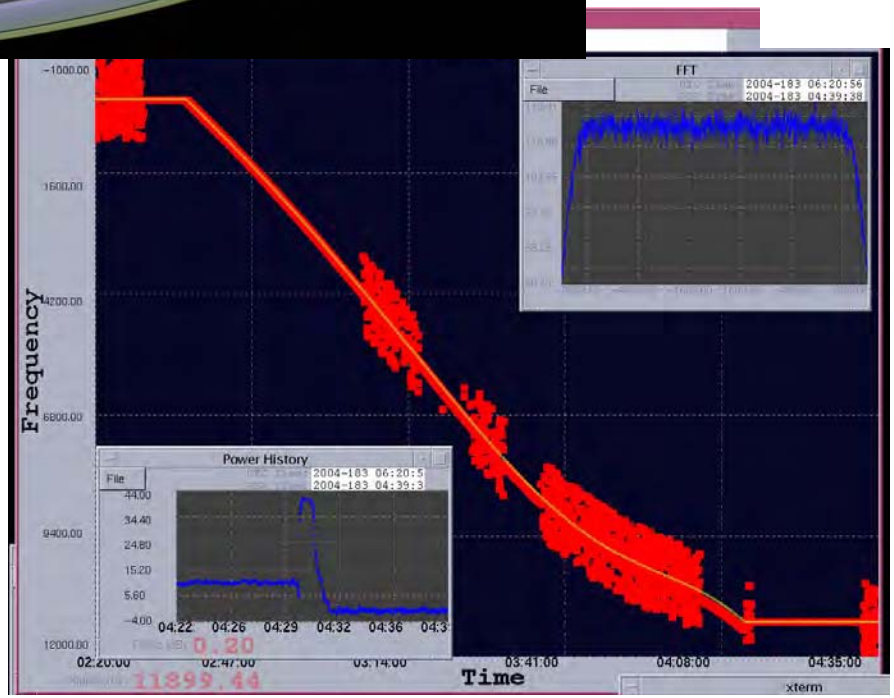
- Rubidium atomic clock
  - Low mass, volume, & power
- Allan Deviation: ~ 1×10^{-11} at 10 s
- USO >100x stability than TCXO
  - TCXO drift >1 kHz after 1 hour
  - 6 m/s apparent zonal wind after 100 sec (~300 m/s after 1 h)
  - Could not be modeled
- Other missions use quartz USO
  - Allan Deviation: ~ 1×10^{-13} at 10 s
  - But take longer to reach stability



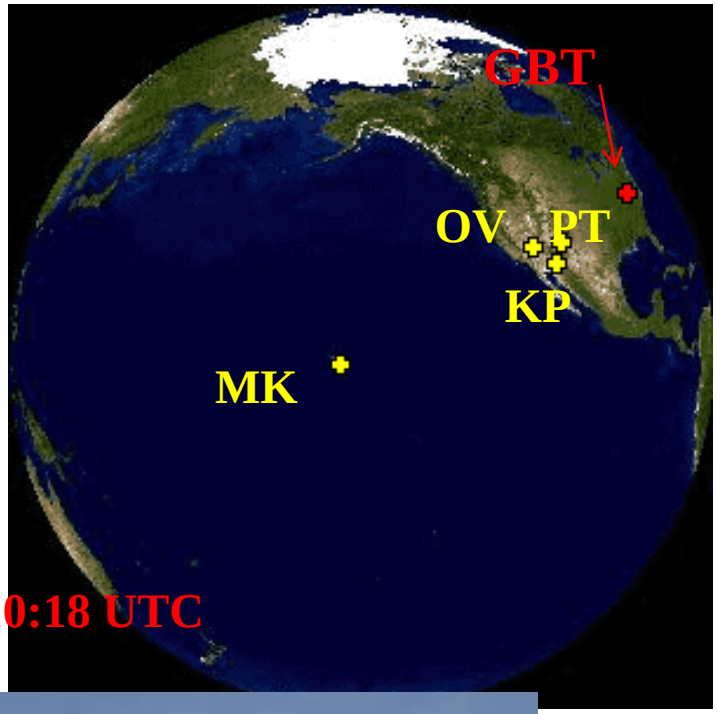
Other Recent RSR Successes



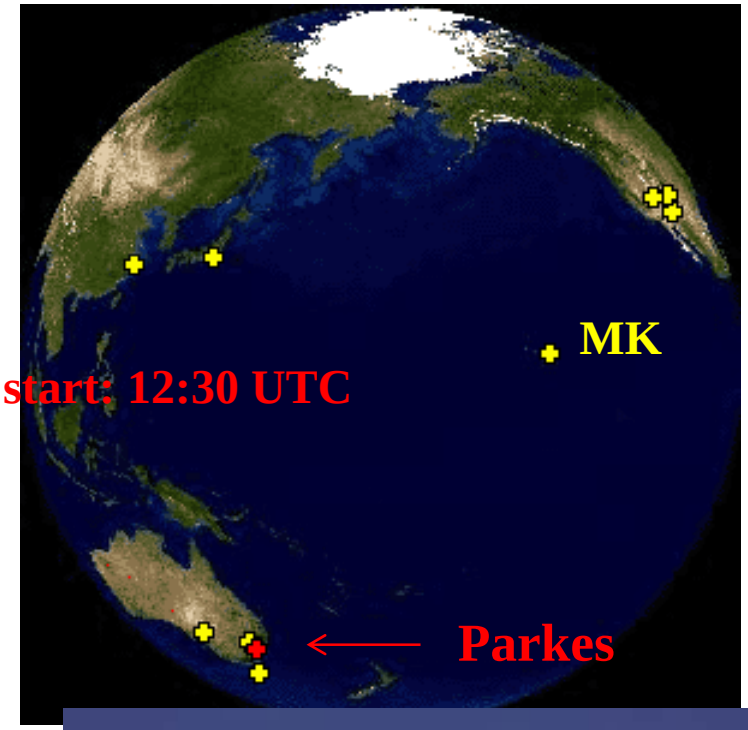




- **Mars Exploration Rovers Entry Descent and Landing**
- **Cassini Saturn Orbit Insertion**
- **Cassini Ring Occultation**

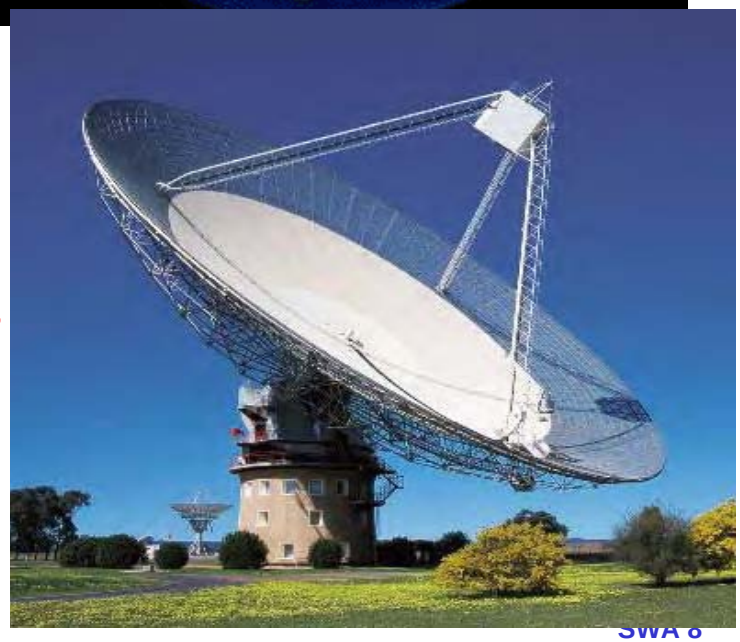


GBT start: 10:18 UTC



Parkes start: 12:30 UTC

GBT
100 m



Parkes
64 m

Doppler Budget

	Range Rate, m/s	Doppler, Hz	Notes 1,2
Receiver Trajectory	-1323.524	9006.193	3
Probe Descent	41.162	-280.093	
Zonal Winds	-57.455	390.967	4
Total Doppler	**- 1339.817**	**9117.067**	

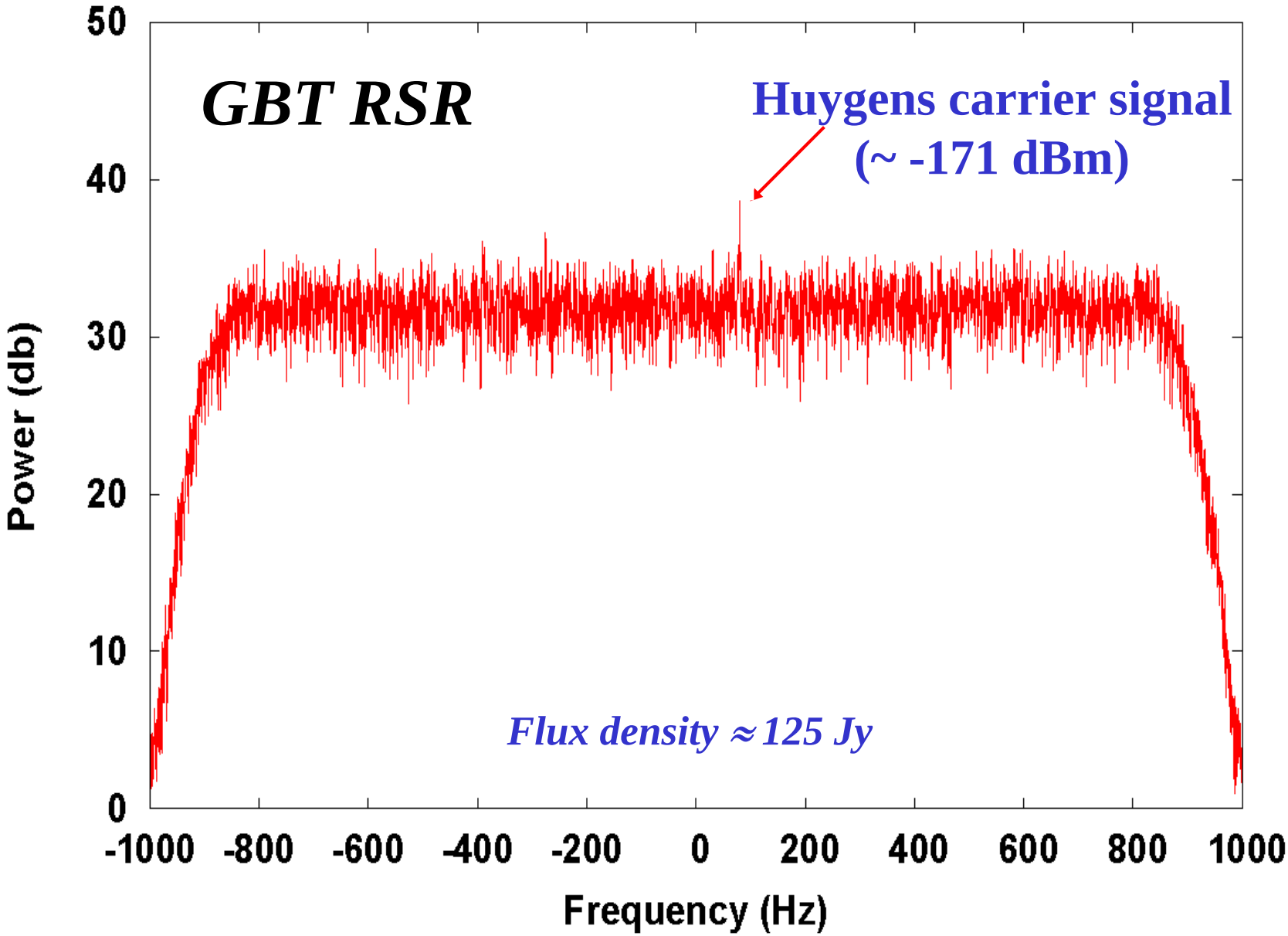
Trajectory Effect	Frequency Hz	Zonal Wind Equivalent, m/s	Notes 2
1 m/s Meridional Wind	1.676	.4233	7
1 m/s Zonal Wind	3.959	1	8
1 m/s Descent Velocity	5.274	1.332	9
1° Probe Longitude	4.402	1.111	10
1° Probe Latitude	1.601	.404	11
1 km probe radius	0.018	.0045	12

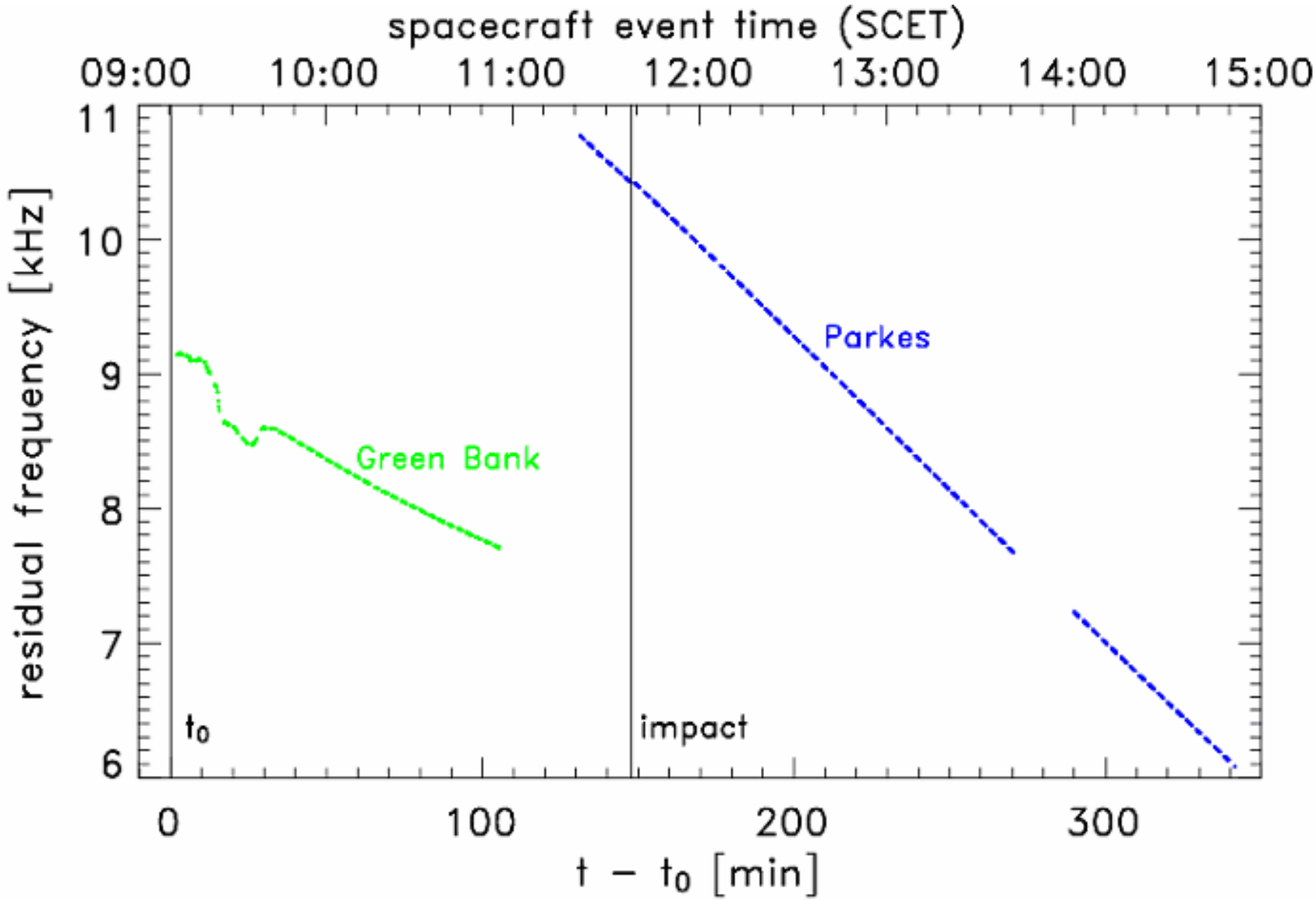
	Link Start Hz	Zonal Wind Equivalent, m/s	Notes
Gravitational Redshift	+18.879	4.752	5
Transverse Doppler	-7.399	1.862	6
Higher Order Doppler	.0407	.010	

1. At first Doppler measurement, 390 s after interface; 121.6 s after T_0; altitude = 144 km, pressure = 2.95 mb
2. At nominal frequency of 2040 MHz; 1 m/s ~ 6.8 Hz
3. Positive range rates → increasing probe/receiver distance
4. 390 seconds after interface; zonal winds 98.417 m/s.
5. Sun: +18.248; Titan: -0.075; Saturn: - 0.7145; Earth: +1.42
6. Time dilation effect of Special Relativity; Always negative
7. Meridional Wind projection onto line of sight: dV_{LOS}/dV_{merid} = -.24662 m/s per m/s
8. Zonal Wind projection onto line of sight: dV_{LOS}/dV_{Zonal} = -.58380 m/s per m/s
9. Probe radial velocity projection onto line of sight: -.77354 m/s per m/s
10. $dV_{LOS}/d\varphi_p$ = 0.68614 m/s per degree (φ_p=probe longitude)
11. $dV_{LOS}/d\theta_p$ = 0.25194 m/s per degree (θ_p = probe latitude)
12. dV_{LOS}/dr_p = -0.00263 m/s per km.

Link Budget (Huygens-GBT)

Transmitter Parameters					
	RF Power, dBm	40.66			10.66 dBW
	(Watts)		11.64		
	Mismatch Loss, dB	-0.20			
	Circuit Loss, dB	-0.22			
	Antenna Gain, dBi	3.46			3.46 dB
	Antenna diameter, m		0.09		arbitrary
	Wavelength, cm		14.71		
	Efficiency		0.58		
	Pointing Error, dB	0.00			
	EIRP, dBW	13.70			13.70 dBW
Propagation Loss					
	Space Loss, dB	-280.27			
	Range, km		1.21E+09		8.05 AU
	Wavelength, cm		14.71		
	Titan atmosphere loss, dB	-0.05			
	Earth Atmosphere Loss, dB				????
	Xmit polarization loss, dB	-0.19			
	Total Propagation Loss, dB	-280.51			-194.45
Receiver Parameters:					
	Antenna Gain, dBi	65.04			
	Antenna diameter, m		100.00		
	Wavelength, cm		14.71		
	Efficiency		0.70		
	Pointing Loss, dB	0.00			0 dB
	IF Mismatch Loss, dB				
	Circuit Loss, dB	0.00			
	Noise Spectral Dens, dB-Hz	-183.83			
	System Temp, K		30.00		
Power Summary:					
	Received Power, dBm	-171.77			
	Received Pt/N0, dB-Hz	12.06			
	SNRV(1-sec)	5.67			
	Modulation Loss, dB	-4.45			
→	Received Pc/N0, dB-Hz	7.61			
	SNRV carrier (1-sec)	3.40			


GBT RSR
Huygens carrier signal
(~ -171 dBm)
Flux density ≈ 125 Jy
Power (db)
50
40
30
20
10
0
-1000
-800
-600
-400
-200
0
200
400
600
800
1000
Frequency (Hz)



Huygens Frequency: GBT + Parkes

Doppler Components

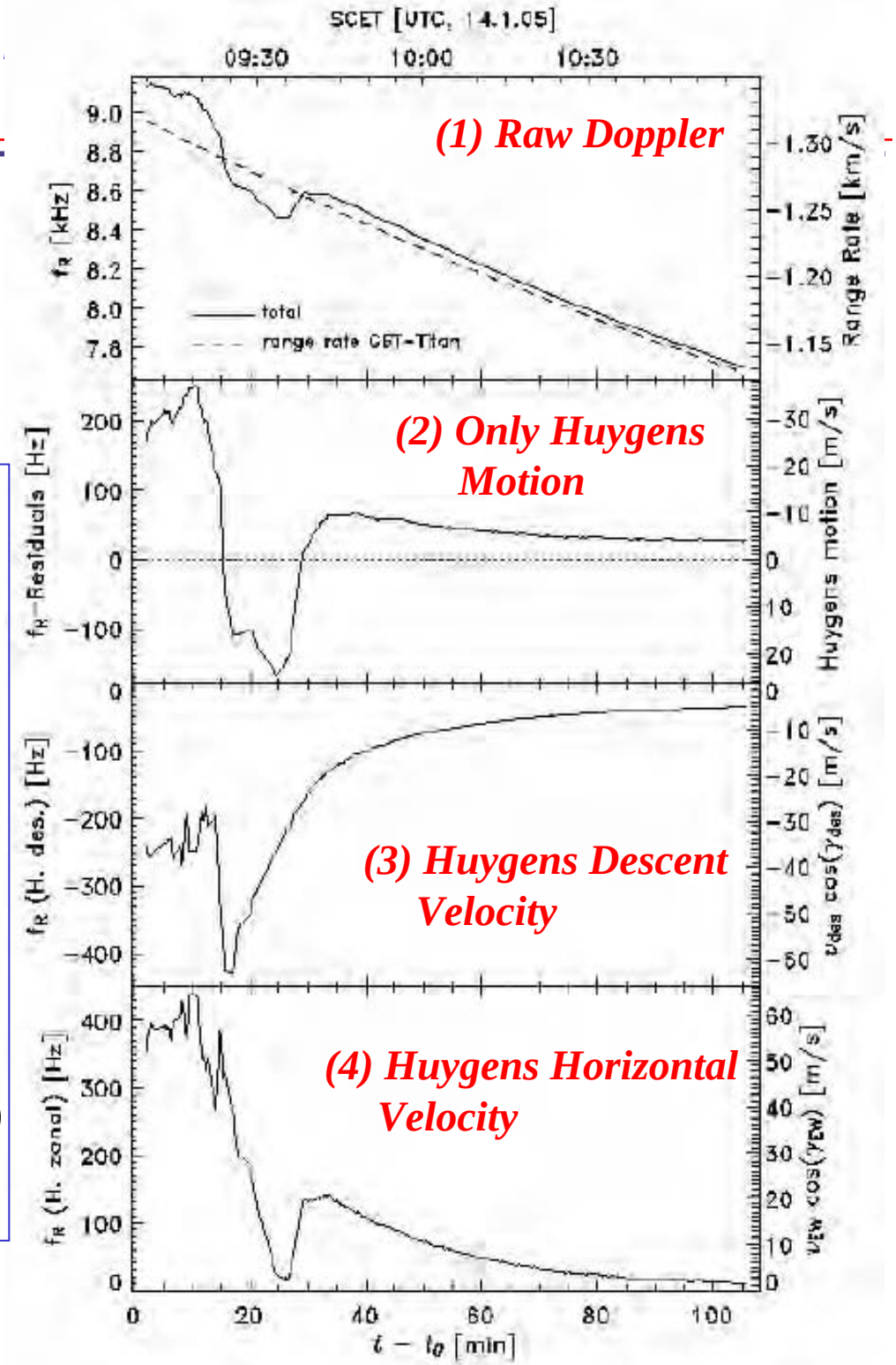
Zonal Wind Retrieval

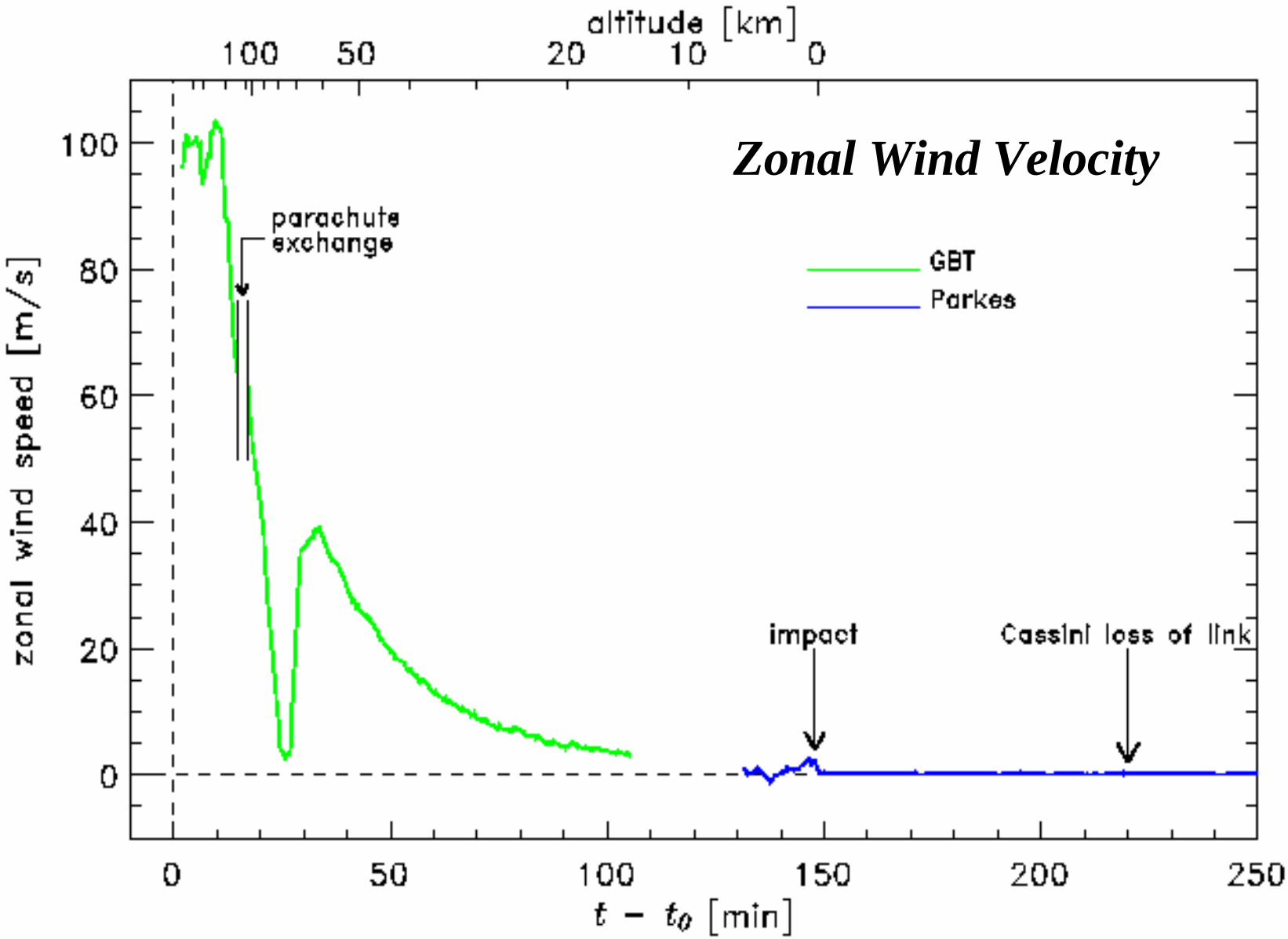
Doppler shift: $$f_R = -\frac{v_{LS}}{c} \cdot f_0$$

where $$v_{LS} = (\vec{v}_{des} + \vec{v}_{NS} + \vec{v}_{EW} - \vec{v}_C) \cdot \vec{n}_{LS}$$

= radial velocity between transmitter and receiver

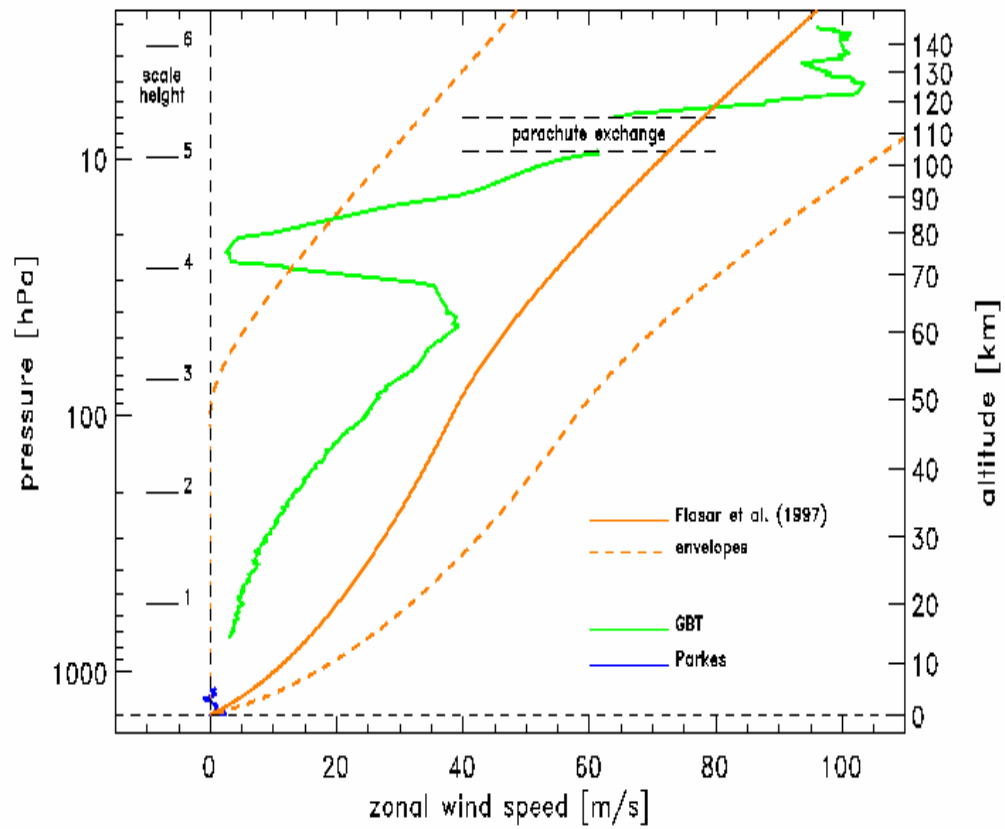
$$\Rightarrow v_{EW} = \frac{1}{\cos\gamma_{DWC}} (v_{LS} + v_C \cdot \cos\gamma_C - v_{des} \cdot \cos\gamma_{des} - v_{NS} \cdot \cos\gamma_{NS})$$




Zonal Wind Velocity
altitude [km]
100
50
20
10
0
parachute exchange
GBT
Parkes
impact
Cassini loss of link
zonal wind speed [m/s]
100
80
60
40
20
0
0
50
100
150
200
250
t − t0 [min]

DWE Preliminary Results

- Zonal winds West to East
- Prograde above boundary layer
- Turbulent above 100 km
- Strong wind: Maximum ~ 430 km/hr
- Shear layer 60-100 km (10-50 mbar)
  - Strong positive/negative wind shear unexpected but evident in some GCMs
- Significant structure in lowest 5 km
- Huygens drifted 3.58º (158.3 km) eastward
- Wind results have implications for super rotational cyclostrophic flow
- **Work in progress to improve data quality, resolution, filling the gaps, and interpretation of atmospheric dynamics**



Lessons for Future Missions

- **Plan on ground observations up front**
- **Use link frequencies compatible with Earth-Space assignments**
- **Plan for residual carrier, accepting minor loss in data rates**
- **Check sequence for completeness.**

- **Huygens had two Doppler problems**
  - **The first was solved by re-designing the Cassini tour!**
  - **The second was solved by utilizing the world's largest steerable radio telescope!**