A Review of Communications and Radio Science with Planetary Entry Probes

S. W. Asmar[1] , D. H. Atkinson[1], I. G. Clark[1], F. Ferri[2], D. Firre[3]
R. E. Gladden[1], O. Karatekin[4], S. M. Krasner[1], J. Lazio[1], M. Mercolino[3]

[1]NASA's Jet Propulsion Laboratory, California Institute of Technology

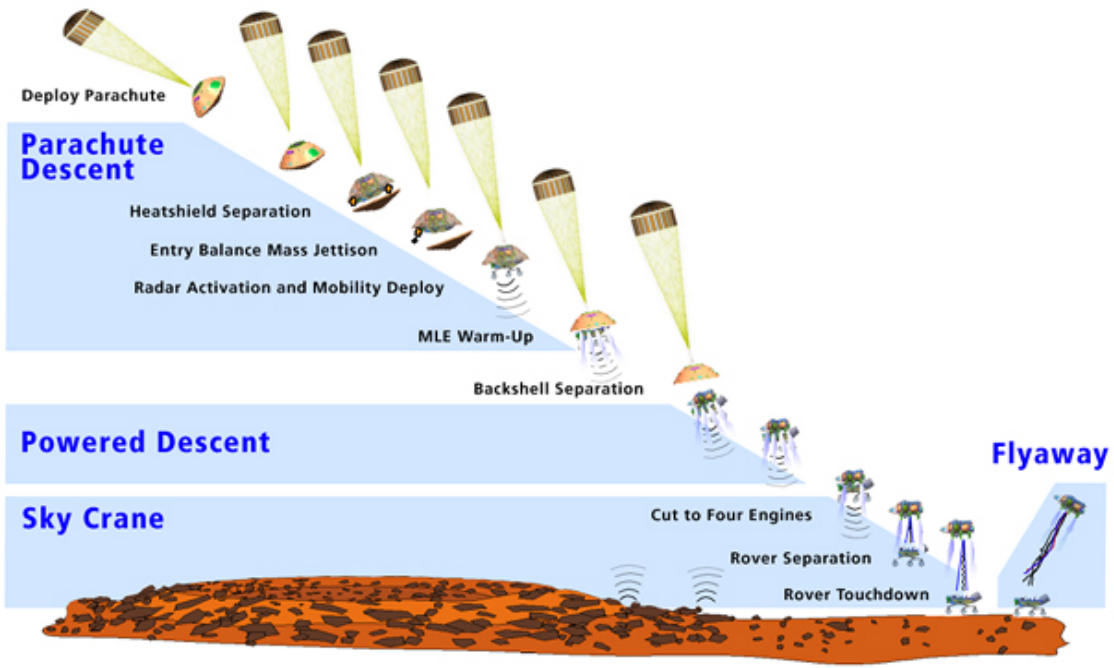
[2] Università degli Studi di Padova [3]European Space Agency [4]Royal Observatory of Belgium

Jet Propulsion Laboratory
California Institute of Technology

© 2019 California Institute of Technology.
Government sponsorship acknowledged.

Overview

- A big challenge for entry probes is communicating critical information during descent
  - Complex sequence: heat shield release, parachute deployment, switching antennas, surface detection, . . ., soft landing!
  - High dynamics in spacecraft motion cause very large Doppler profile
  - Low and highly variable signal level
- Compelling atmospheric science during descent
- Review advances in radio communications
  - Venus
  - Jupiter
  - Titan
  - Mars



Planetary Entry Missions: Communications & Radio Science

Mission	Target	Entry	Signal(s)	Telescopes	"Relay"	"Bent Pipe"	Science
Galileo Probe	Jupiter	1995	1387 MHz (L-band)	VLA, Narrabri		Galileo Orb.	Wind
Mars Pathfinder	Mars	1997	X-band Semaphores	DSN Madrid	- -	- -	
MER A & B	Mars	2004	UHF & X-band tones	Parkes			
Huygens	Titan	2005	2 GHz	GBO, Parkes	Cassini		Wind/Surface
Phoenix	Mars	2008	UHF & X-band tones	GBO	MRO	ODY	
Curiosity	Mars	2012	UHF & X-band tones	Parkes, DSN	MRO	ODY	
Schiaparelli	Mars	2016	UHF	GMRT	TGO		
InSight	Mars	2018	UHF	GBO & Effelsberg	MRO	MarCO	
Mars 2020	Mars	2021	UHF & X-band tones	GBO & Effelsberg	MAVEN	MRO (dev)	
ExoMars 2020	Mars	2021	UHF	GBO & Effelsberg	TGO		

"Relay": Open-Loop *"Bent-Pipe": Store-and-Forward*

S. Asmar

Planetary Entry Missions: Communications & Radio Science

Historical Missions

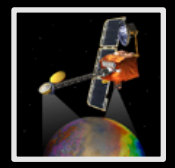
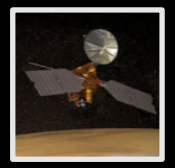
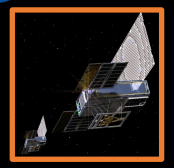
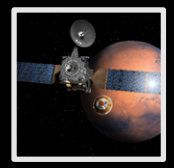
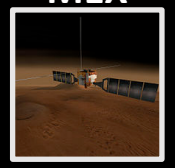
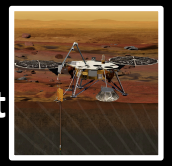
Mission	Target	Entry	Signal(s)	Telescopes		Relay	Science
Mars 6 (USSR)	Mars	1974					
Venera landers	Venus	1970s	VHF/UHF			Relay S/C	Wind
Viking 1 & 2	Mars	1976	UHF & S-band	DSN		Viking Orb.	Mars spin
Pioneer Probes	Venus	1978				Pioneer 13	Scintillation
VeGa balloons	Venus	1985		20 telescopes			Wind

S. Asmar

Mars UHF Relay Communication

Contemporary Multi-Agency Community Compatibility

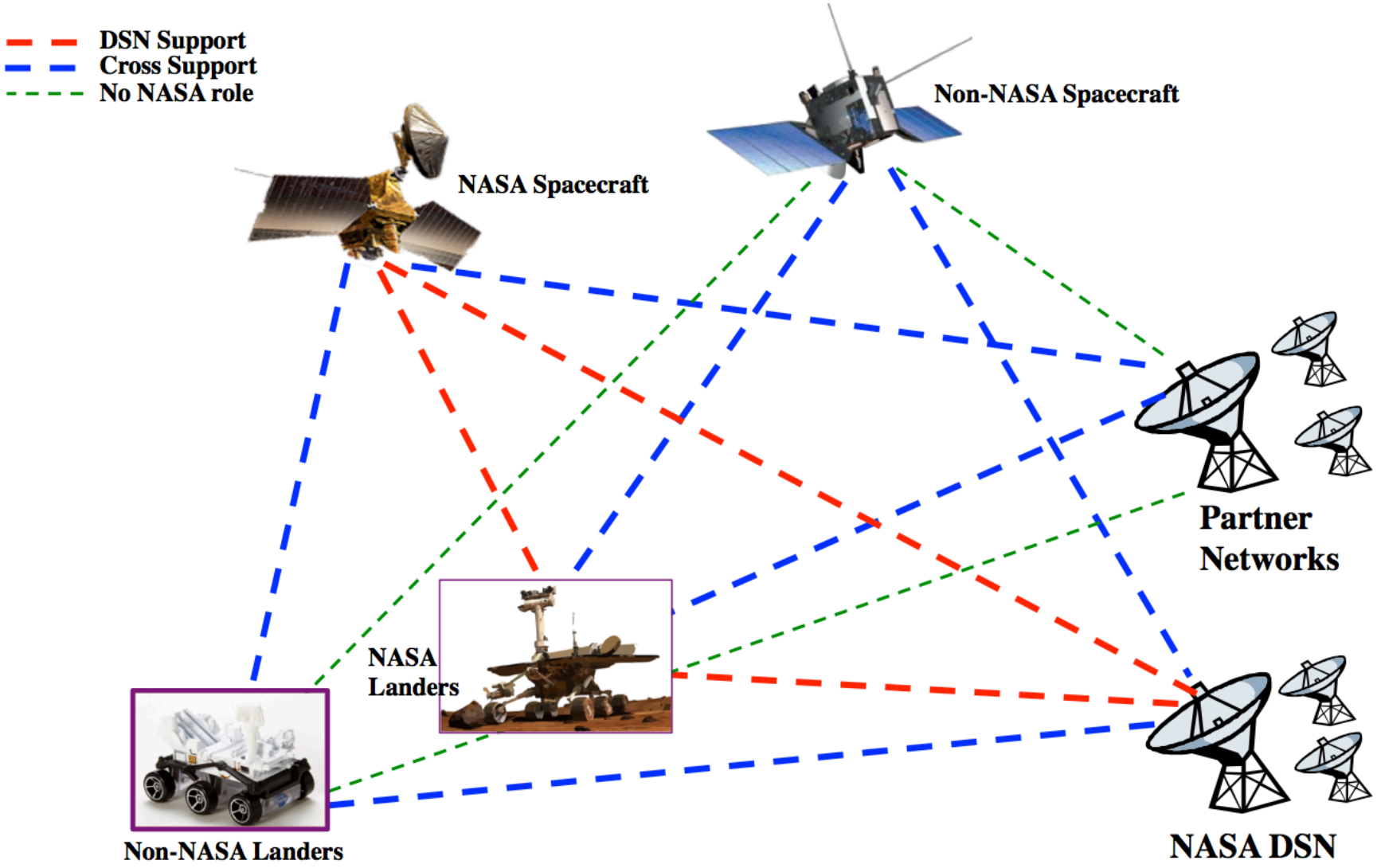
Adapted from
Kris Angkasa
NASA-JPL

	ODY 	MRO 	MAVEN	MarCO 	ExoMars TGO 	MEX 
MSL	*EDL*	Surface *EDL*	Surface		Surface	Surface
InSight 	Surface	Surface *EDL*	Surface	*EDL*	Surface	Surface
M2020	Surface	Surface *EDL*	Surface		Surface	
ExoMars 2020		Surface	Surface *EDL*		Surface *EDL*	

UHF Radio List

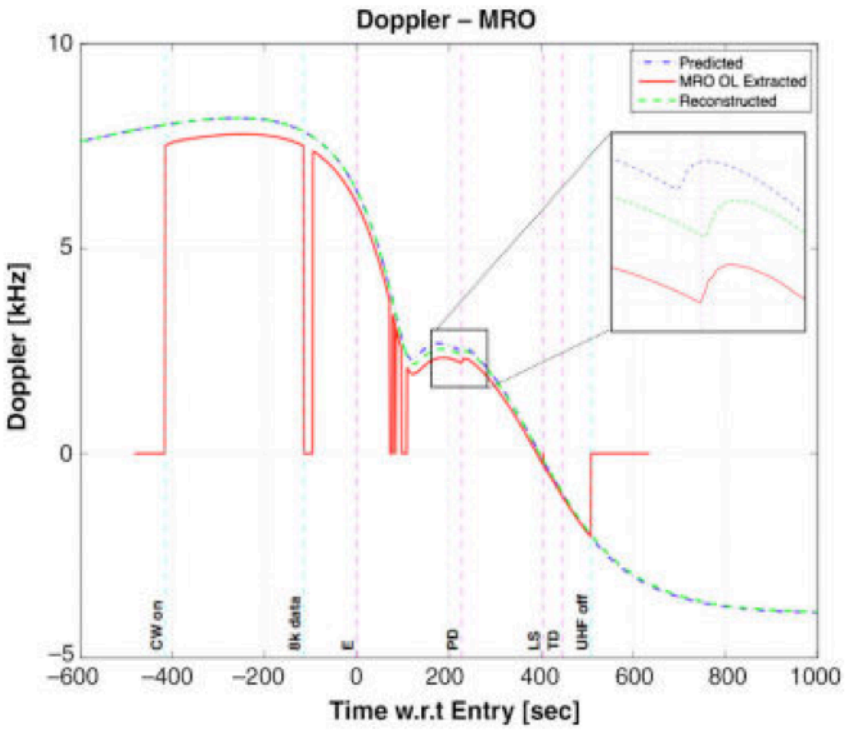
ExoMars RSP	QinetiQ
ExoMars TGO	Electra
MRO	Electra
MAVEN	Electra
M2020	Electra Lite
MSL	Electra Lite
InSight	CE-505
MER-B	CE-505
ODY	CE-505
MarCO	Iris
MEX	Melacom

NASA-ESA Communications Cross Support



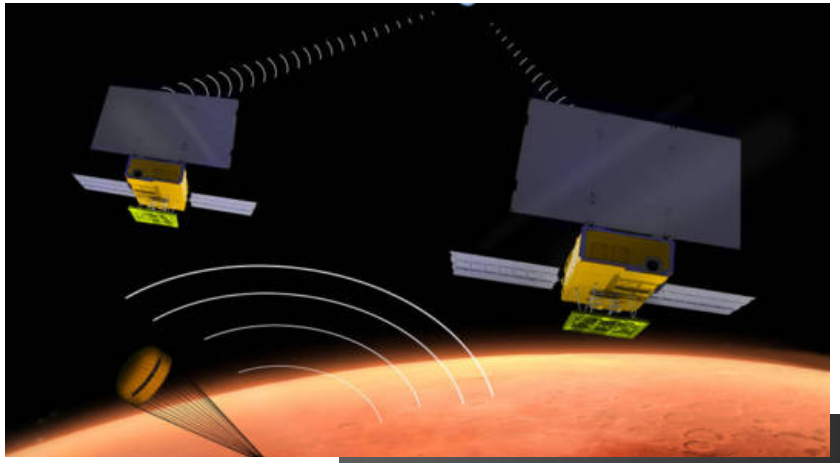
Communications Method 1: Relay (Open-Loop)

- Orbiter receives UHF signal from entry probe
- Relays telemetry to DSN/ESTRACK at X-band
- Open-loop data processing has time latency
  - Work to reduce latency on MRO for M2020

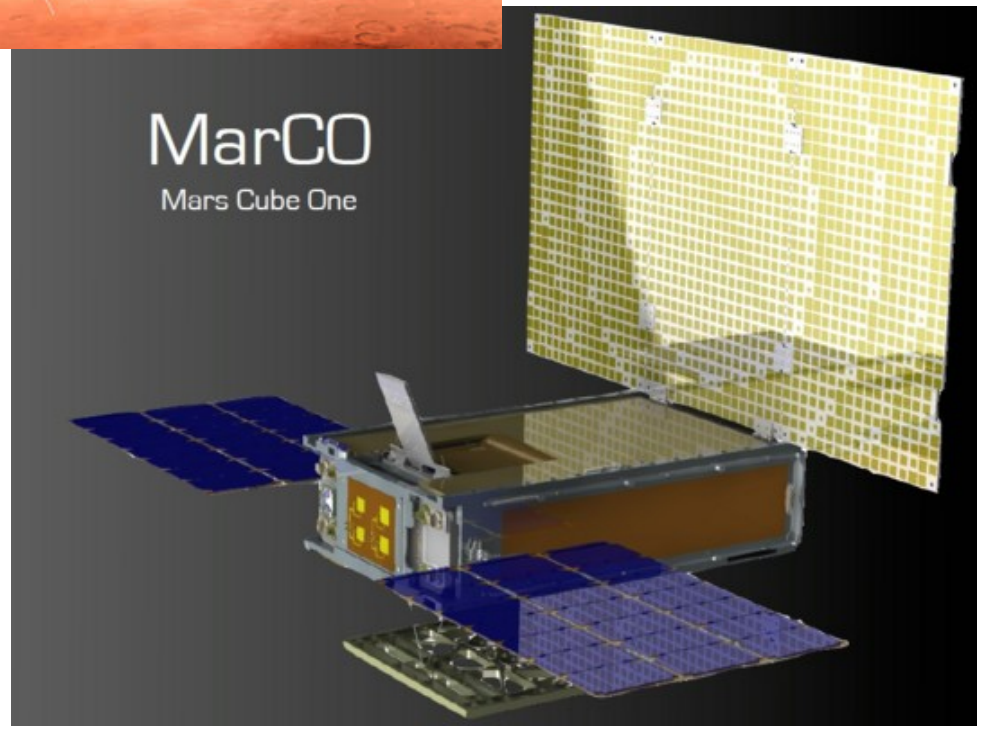


The Doppler profile of the EDL sequence of the Phoenix mission as captured and relayed through the MRO spacecraft in 2008.

Communications Method 2: Bent-Pipe (Closed-Loop)

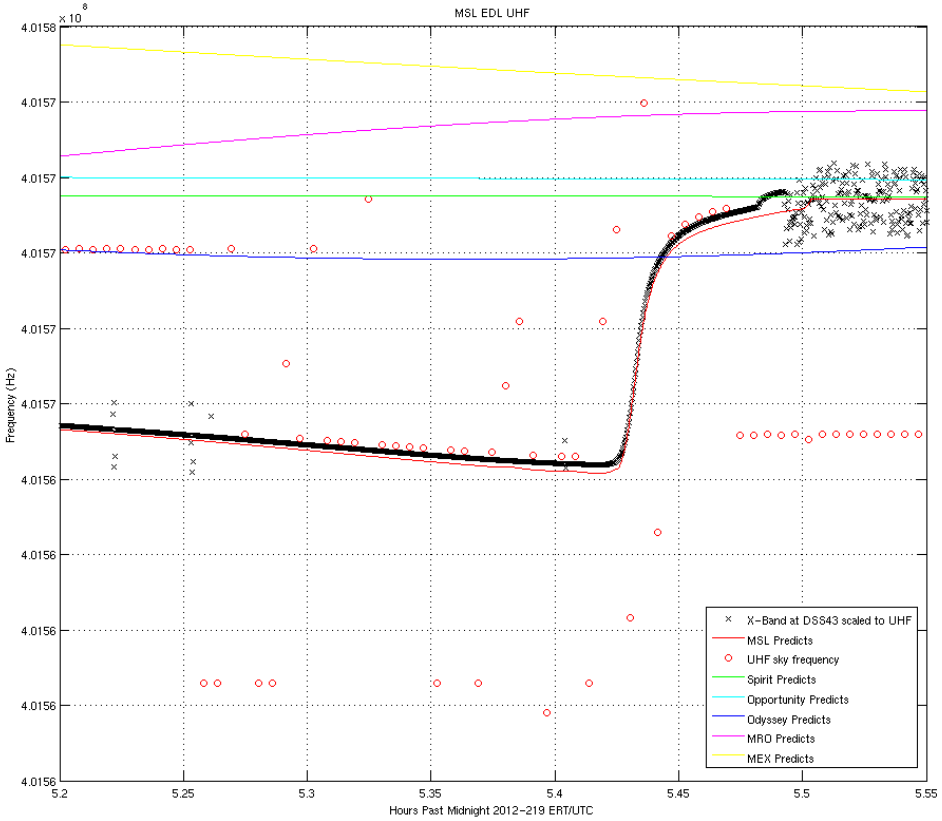


- **Mars Odyssey performed (closed-loop) store-and-forward with slight delay**
  - **Not true bent-pipe**
- **What if no orbiter or mothership available**
- ***"Carry Your Own Relay"***
  - *Asmar & Matousek (2016) "Mars Cube One (MarCO) Shifting the Paradigm in Relay Deep Space Operation," 14th SpaceOps Conference*
- **Succeeded for InSight**
  - **Not planned for Mars 2020**



Communications Method 3: Direct to Earth

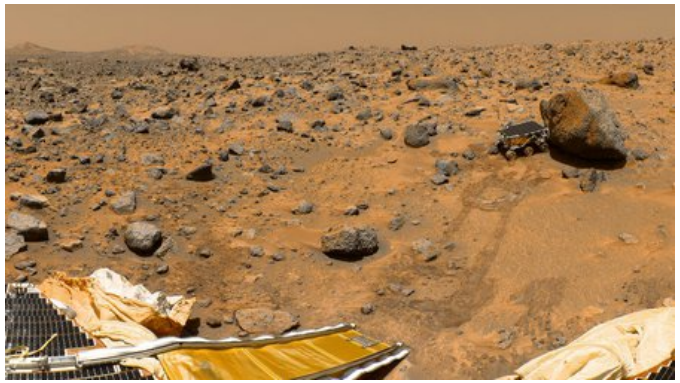
- If no sufficient telemetry link budget, Doppler profile reveals very important information
- Critical events have Doppler signature
- UHF eavesdropping or X-band tones/semaphores
- If signal level is above receiver threshold & signal dynamics within acquisition limits
- An open-loop receiver is typically used
- From monitoring the carrier Doppler profile, important information about critical events, such parachute release, thruster firing, etc. are deduced in real-time

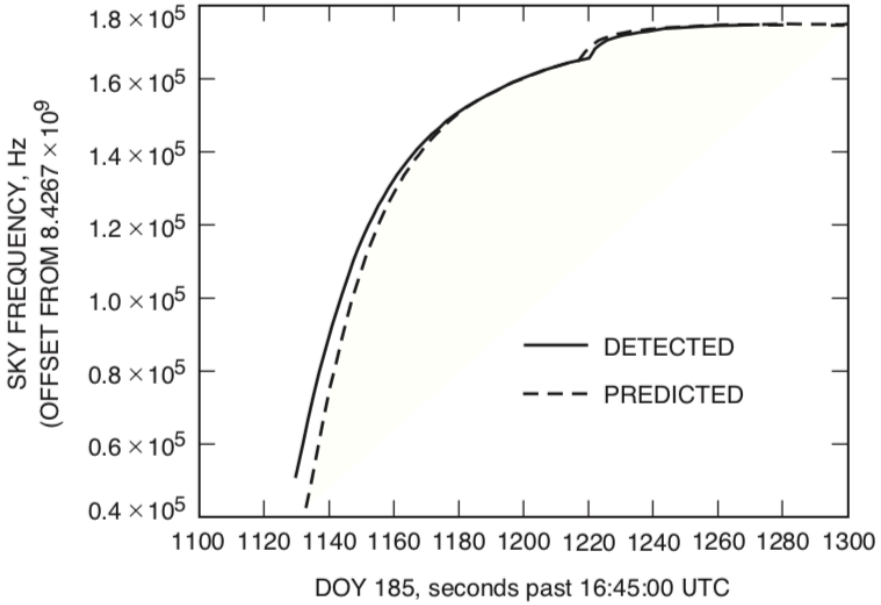


Curiosity UHF Doppler profile received at Parkes Radio Telescope in 2012

Communications by Tones & Semaphores

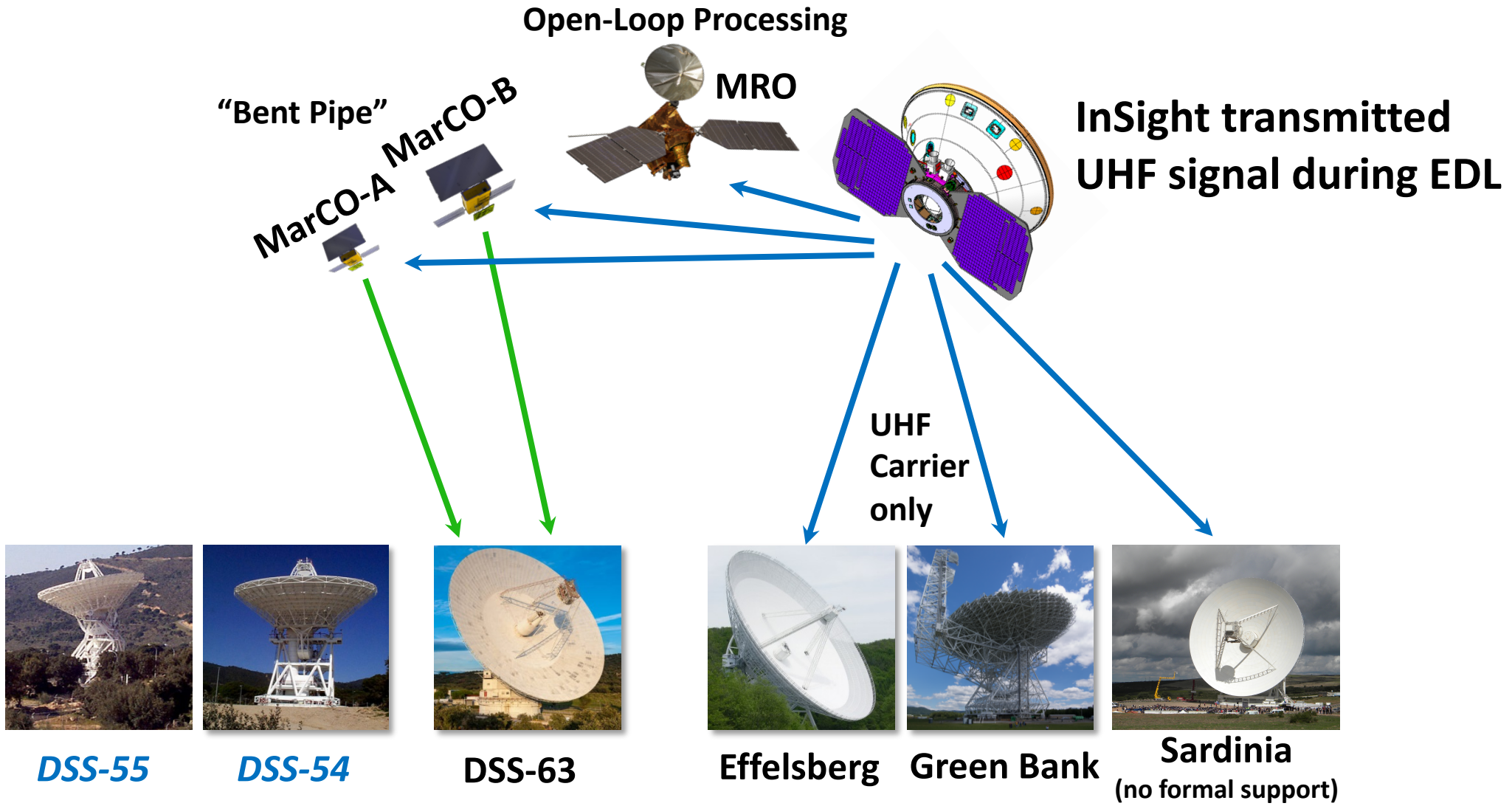
- **Re-invention of "primitive" techniques**
  - *G. Wood, S. W. Asmar, T. Rebold, R. Lee, (1997) "Mars Pathfinder entry, descent, and landing communications." TDA Progress Report 42-131*
- **1997 Mars Pathfinder (Sojourner) Entry, Descent, and Landing (EDL) signaling**
- **Challenge to receive telemetry during the critical 7 minutes of atmospheric descent to surface**
- **Innovatively utilized semaphores of carrier alone to deliver key information**
- **Concept carried to orbit insertion maneuvers**
  - **Saturn, Jupiter, and other critical maneuvers**





A closer view of the signal after return from peak deceleration, including parachute deployment at 1221 s (17:05:21 UTC).

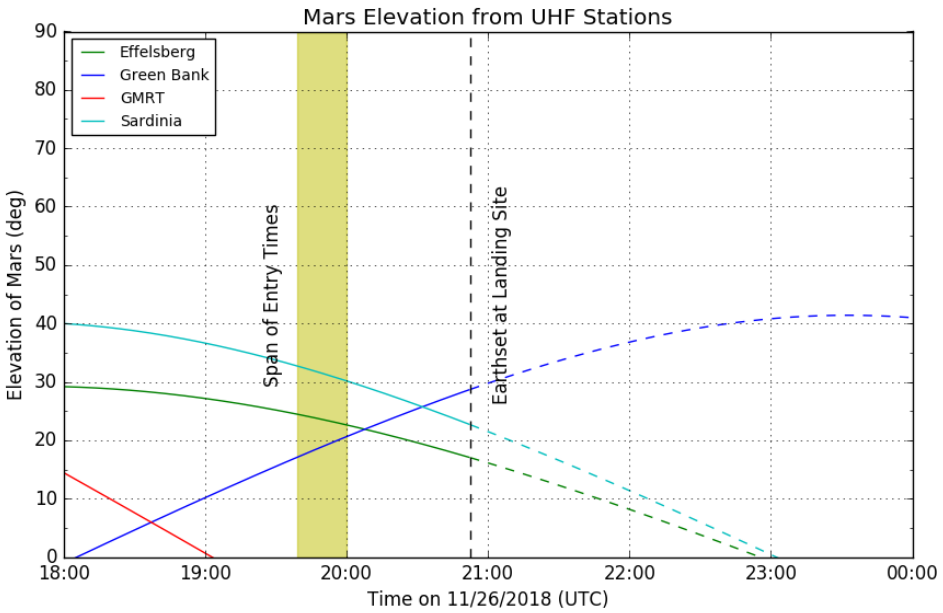
InSight EDL Utilized Three Communications Methods

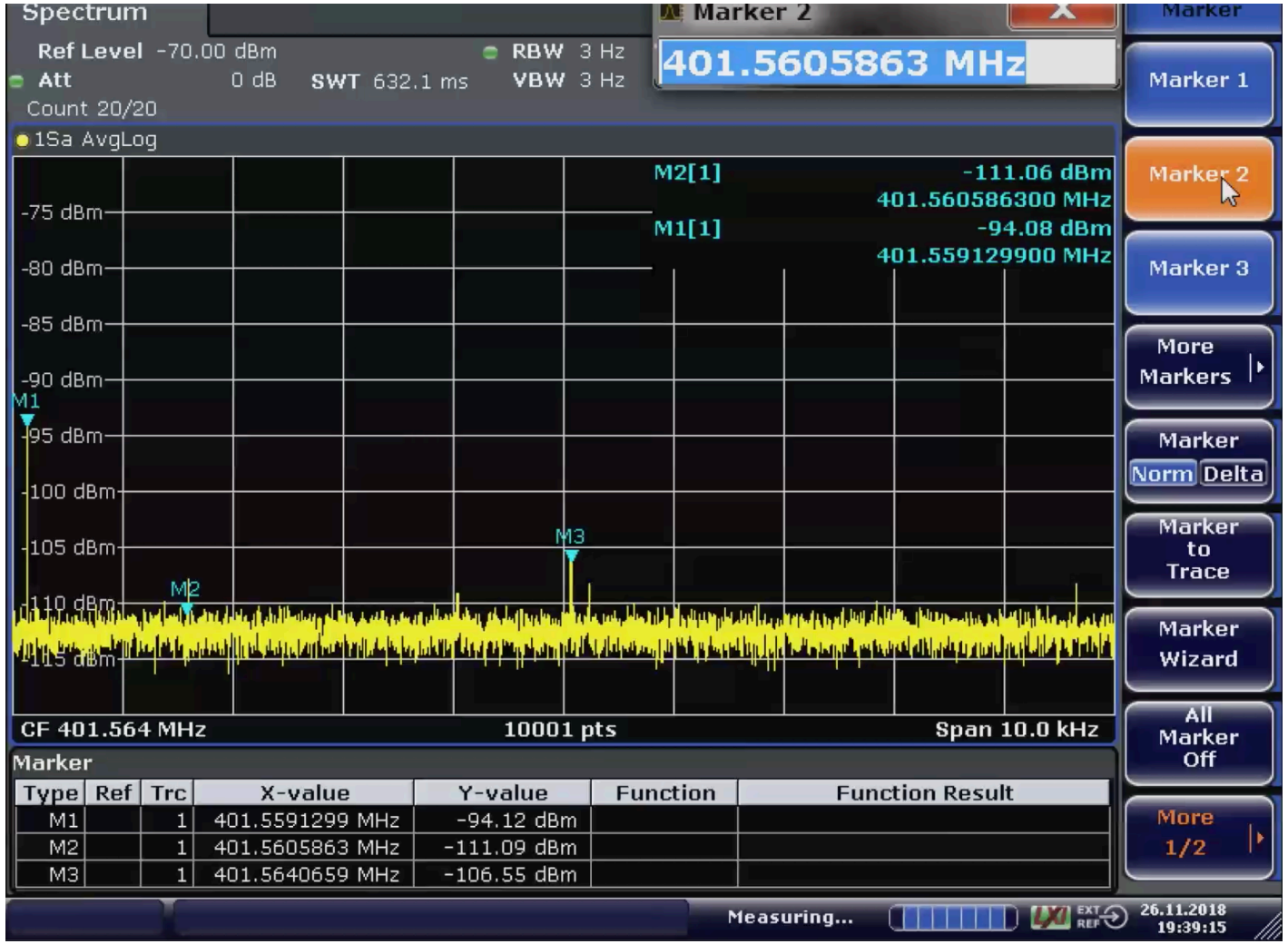


Sardinia's Insight

Source: Italian Space Agency:

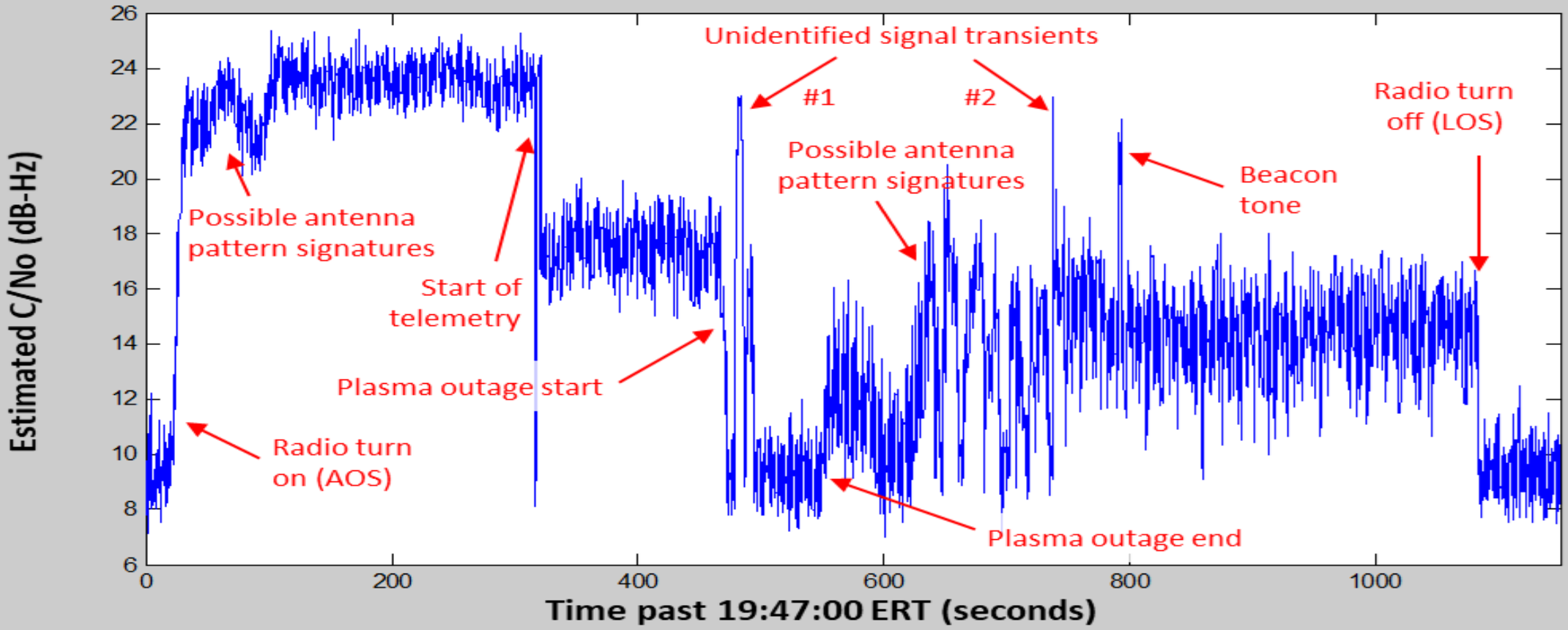
Gabriele Impresario & Salvatore Viviano





EDL UHF DTE *(the alphabet soup)*

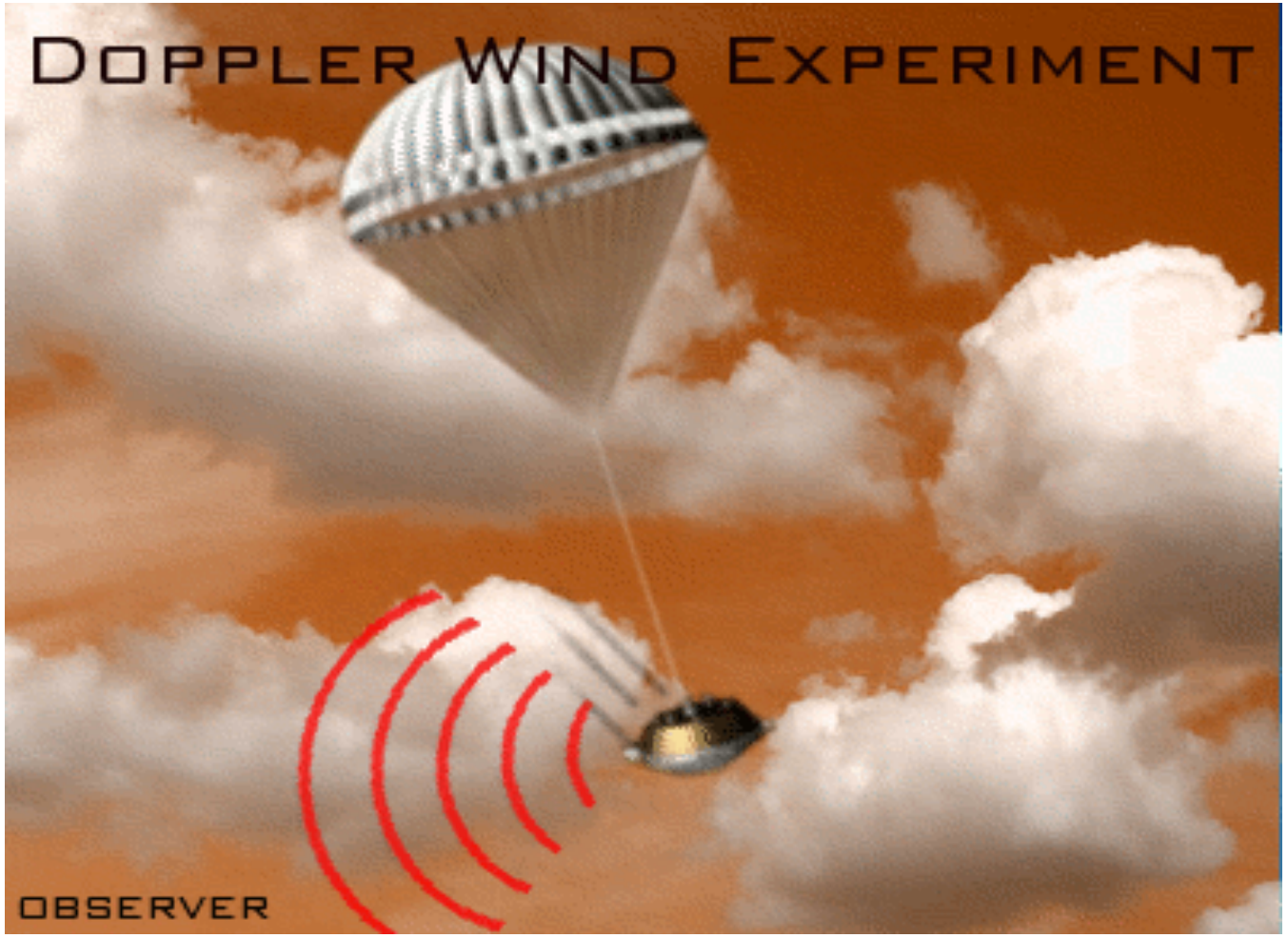
InSight EDL UHF Carrier Received by Green Bank – Signal-to-Noise Ratio



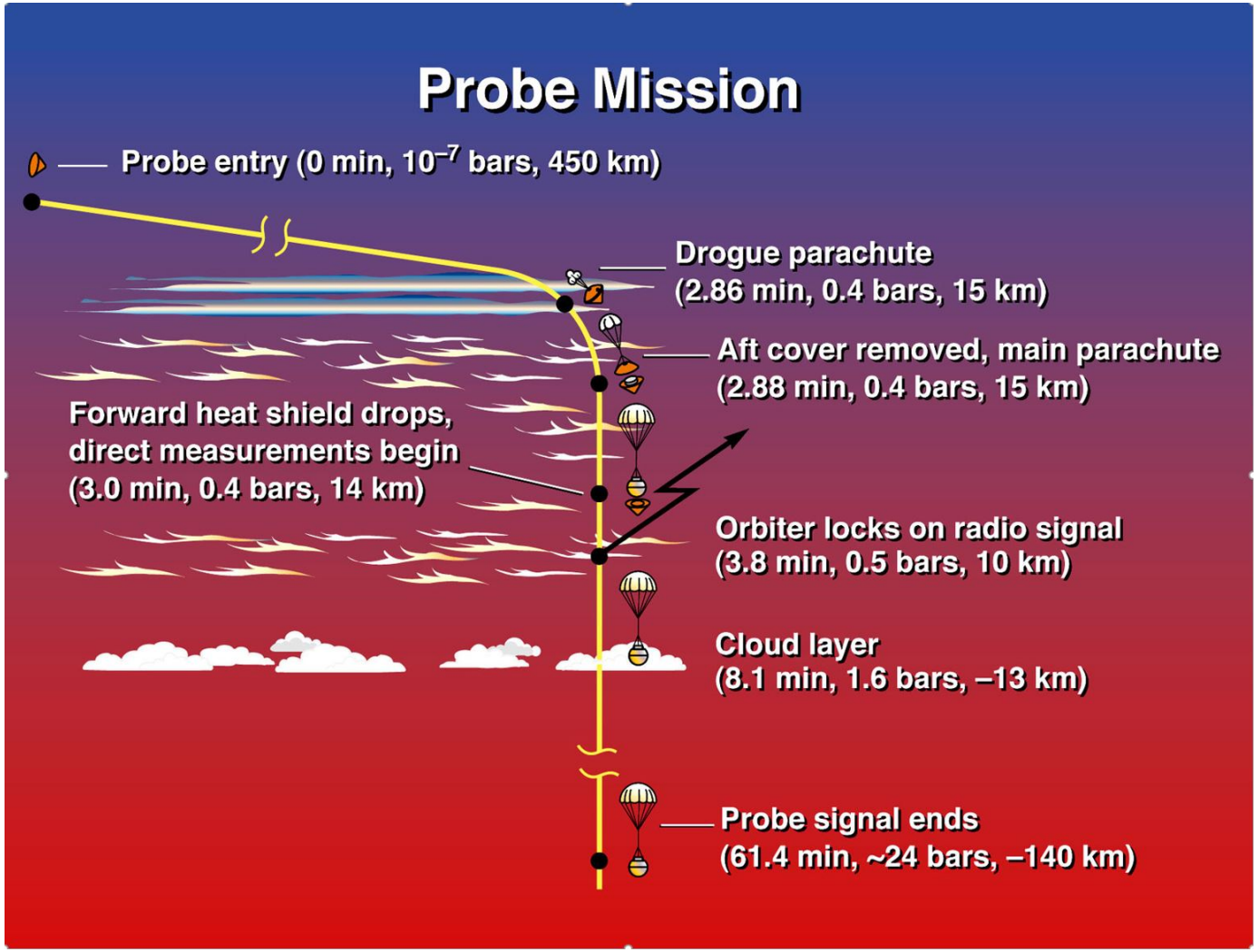
Source: S. Krasner, JPL

Science

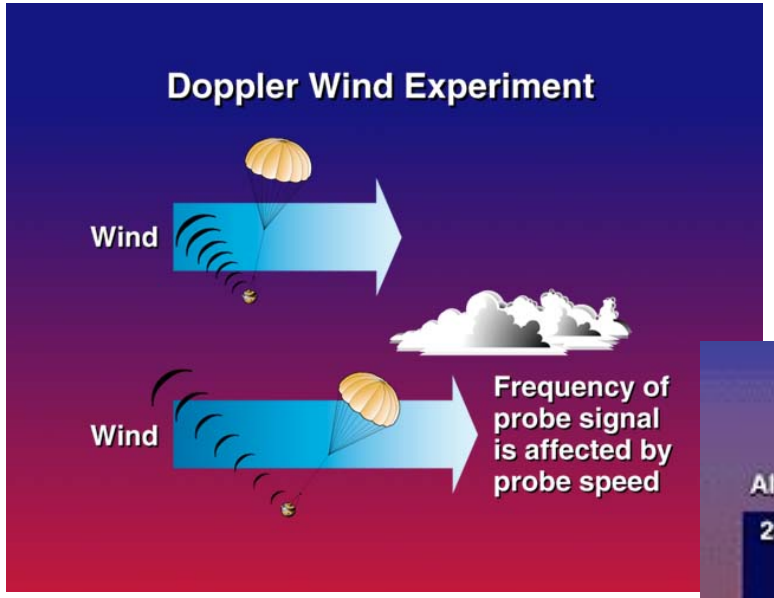
- Planetary atmospheric entry probes provide an opportunity to examine the Doppler profile resulting atmospheric dynamics
- Study winds, waves, tides, and turbulence
- Measure the integrated abundance profile of constituents that absorb at the microwave frequency of the probe's radio signal

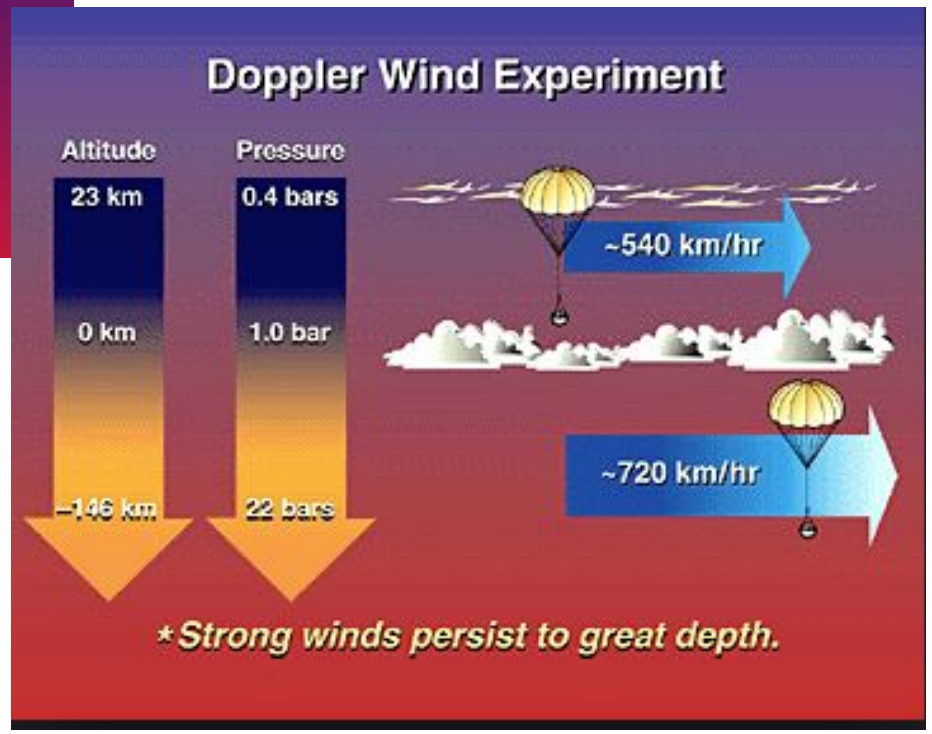


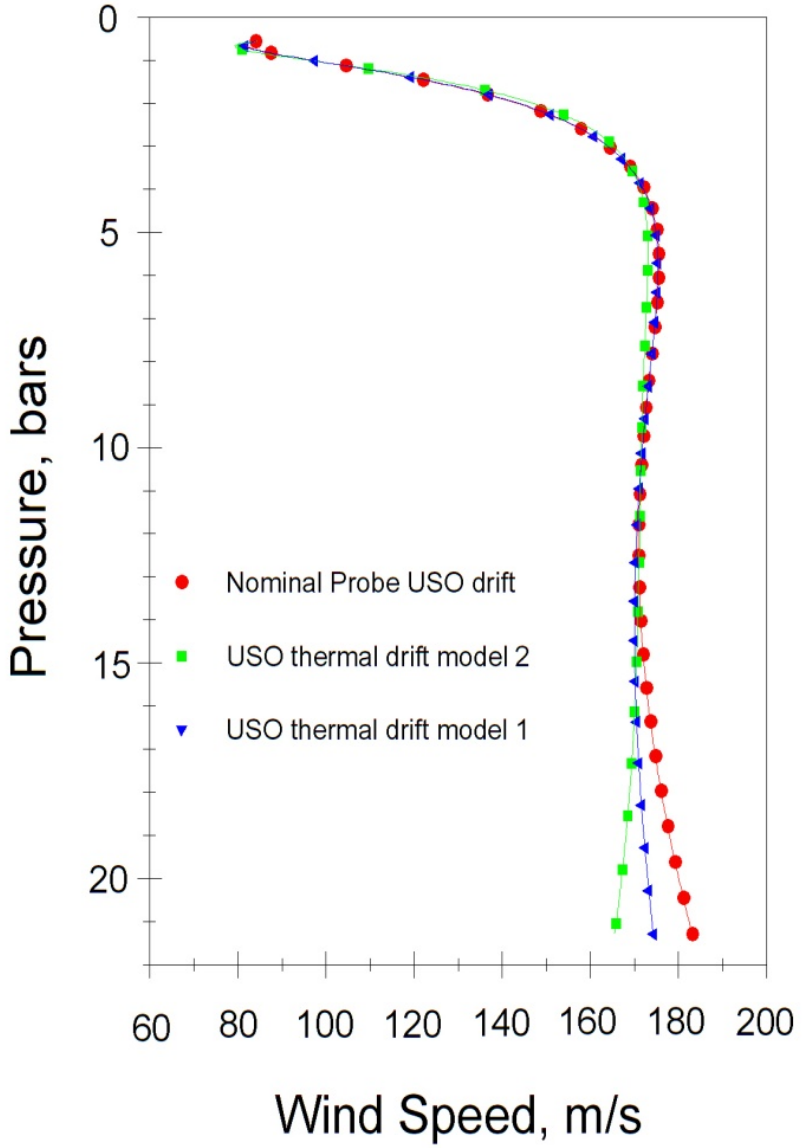
Science: Galileo probe at Jupiter



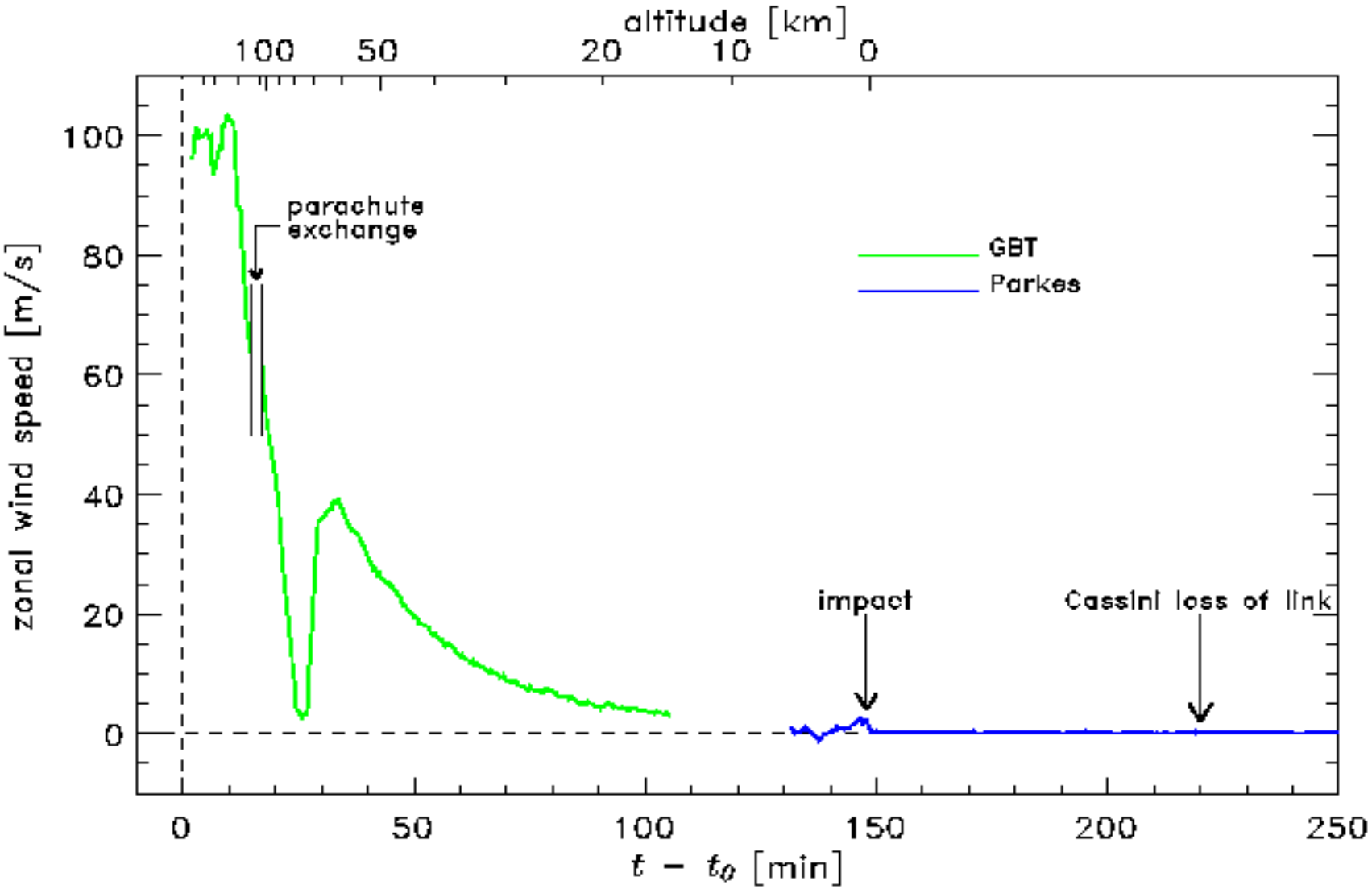
Galileo probe at Jupiter



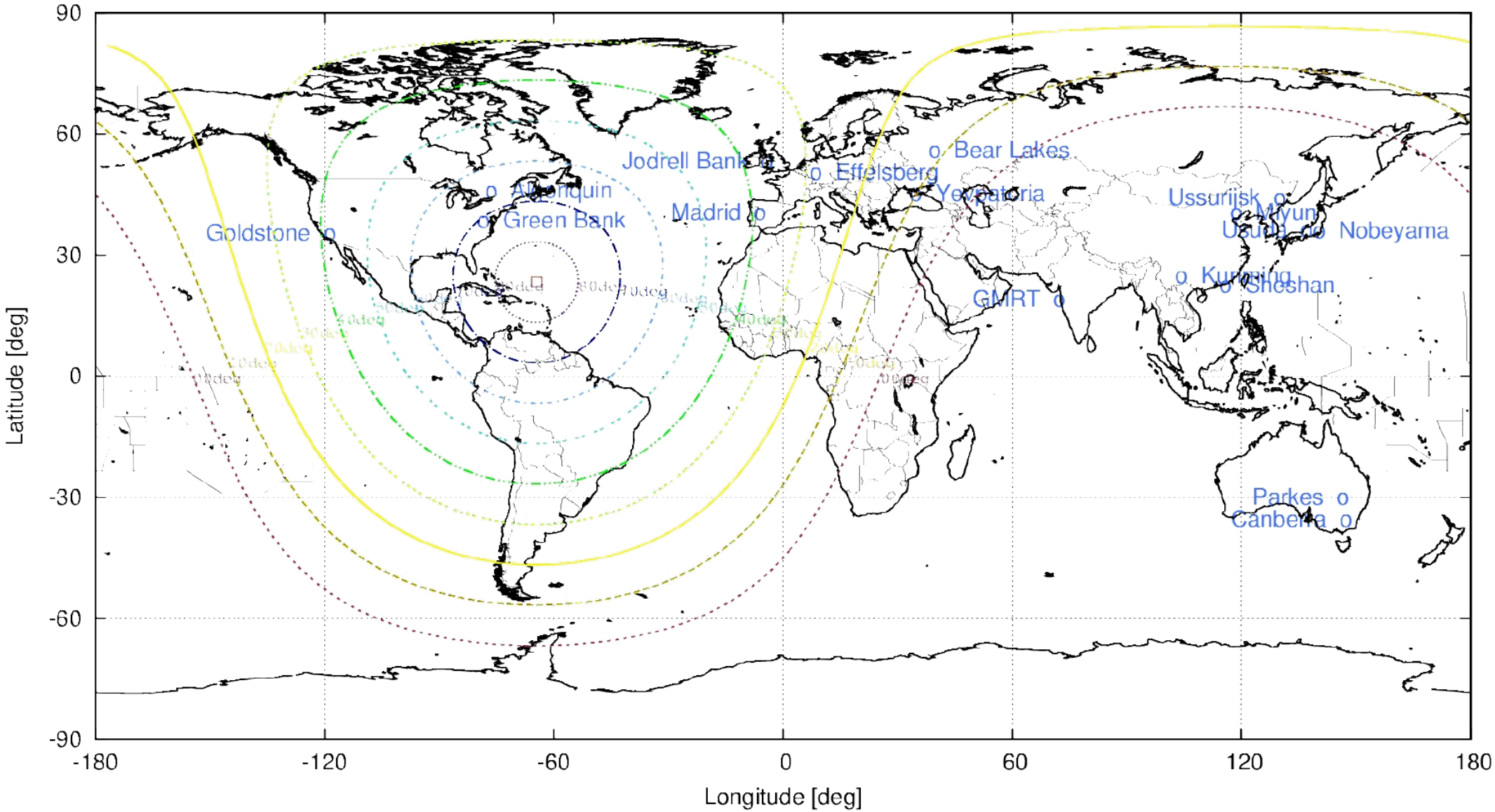




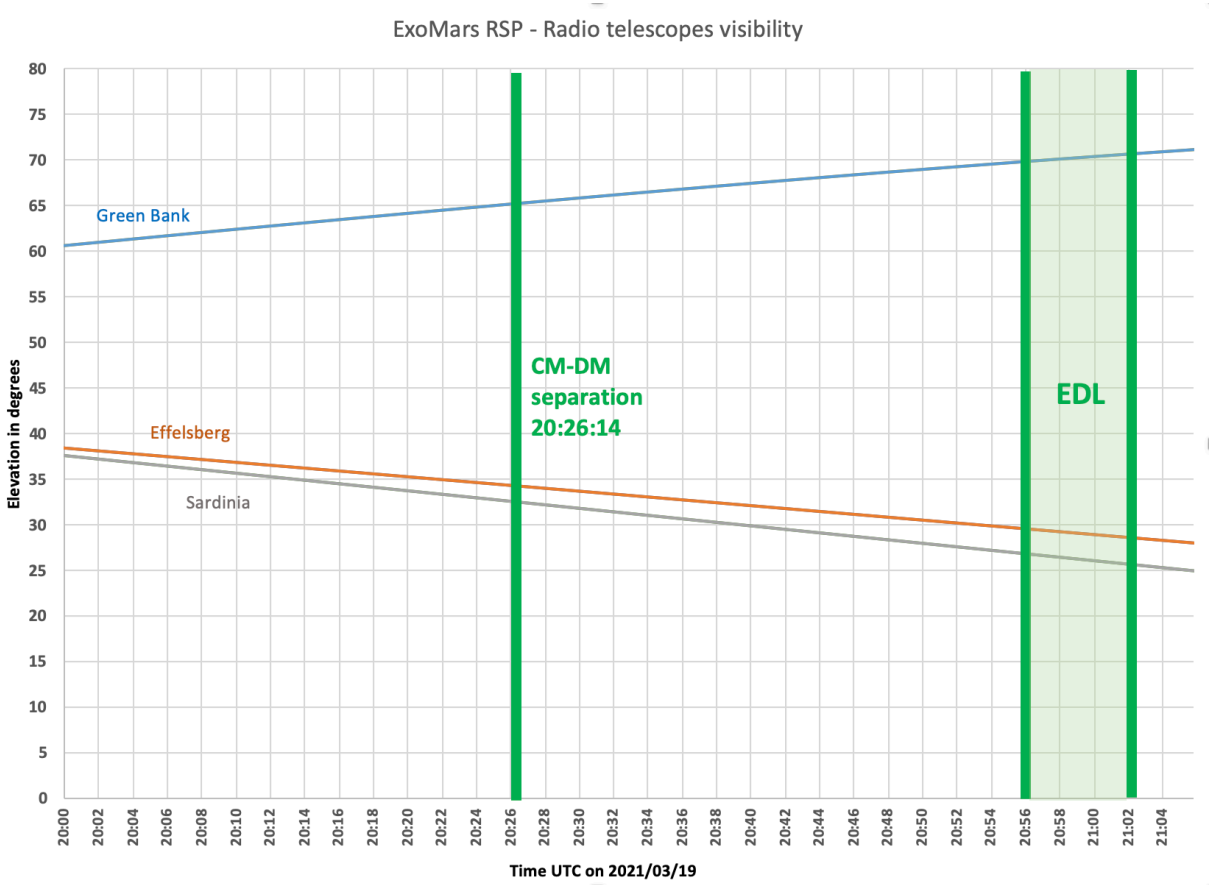
Science: Huygens Probe Measures Titan's Zonal Wind Speed



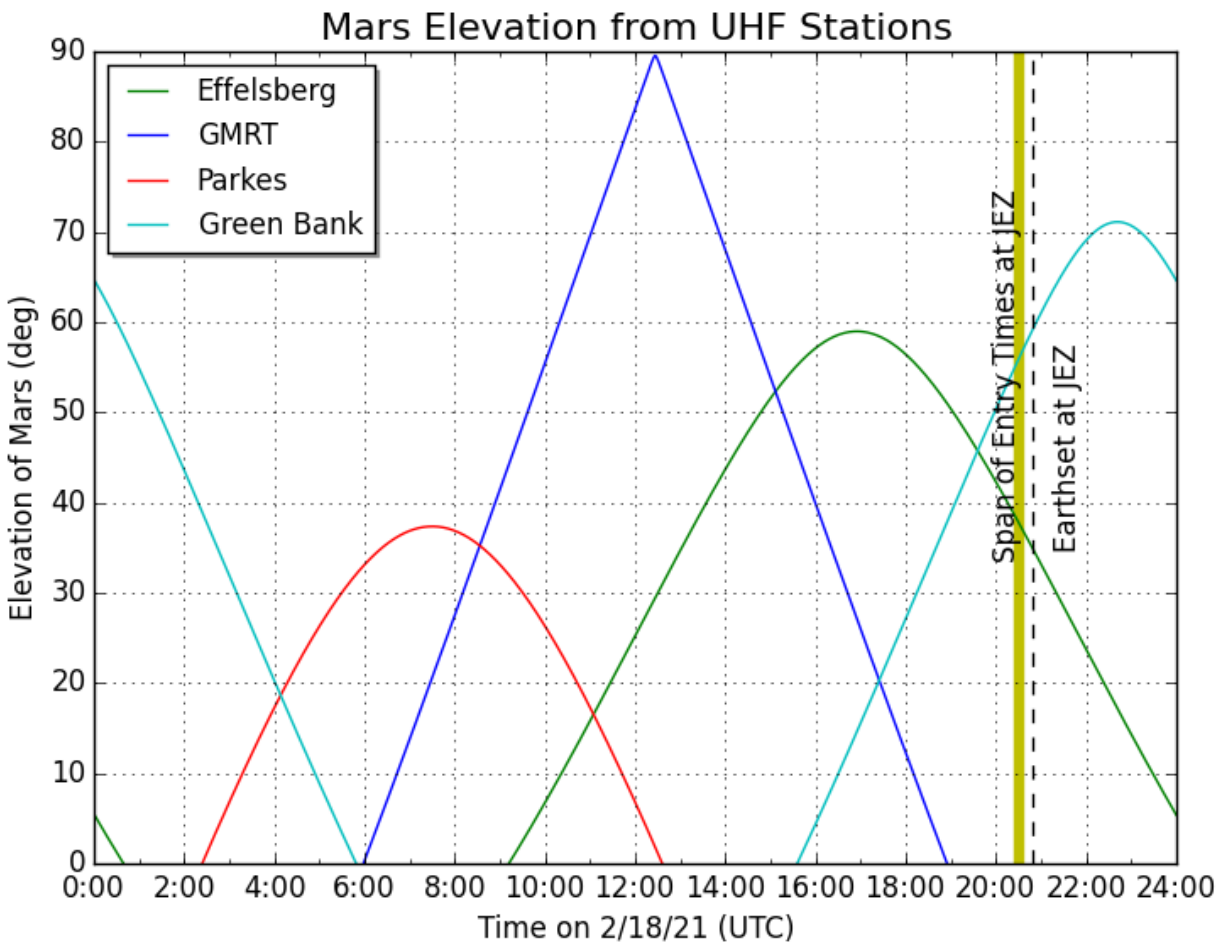
Looking Forward to More Success
Two Landing Events at Mars in Early 2021



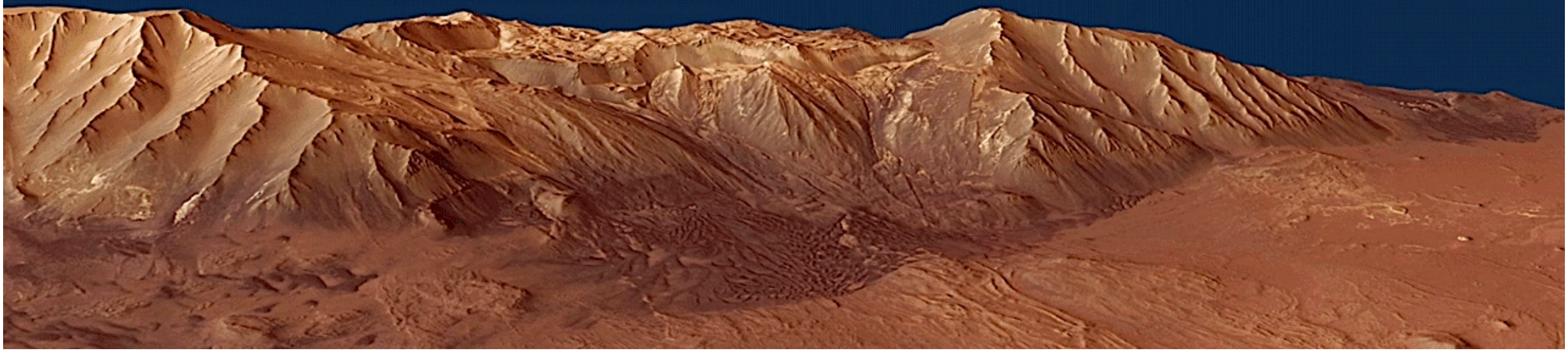
ESA Exo Mars 2020 Visibility of Mars from Radio Telescopes at EIP, OP LPO Case



ESA Exo Mars 2020



NASA Mars 2020

MARS 2020 ROVER

TERRAIN RELATIVE NAVIGATION