Radio astronomy experiments in the context of planetary science and exploration

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IM-S3, IKI, Moscow
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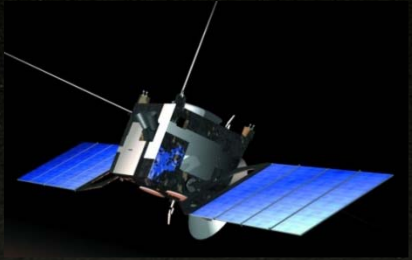
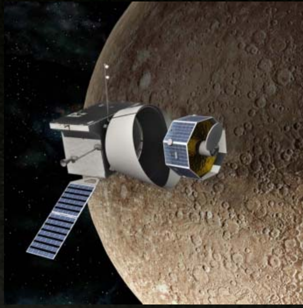
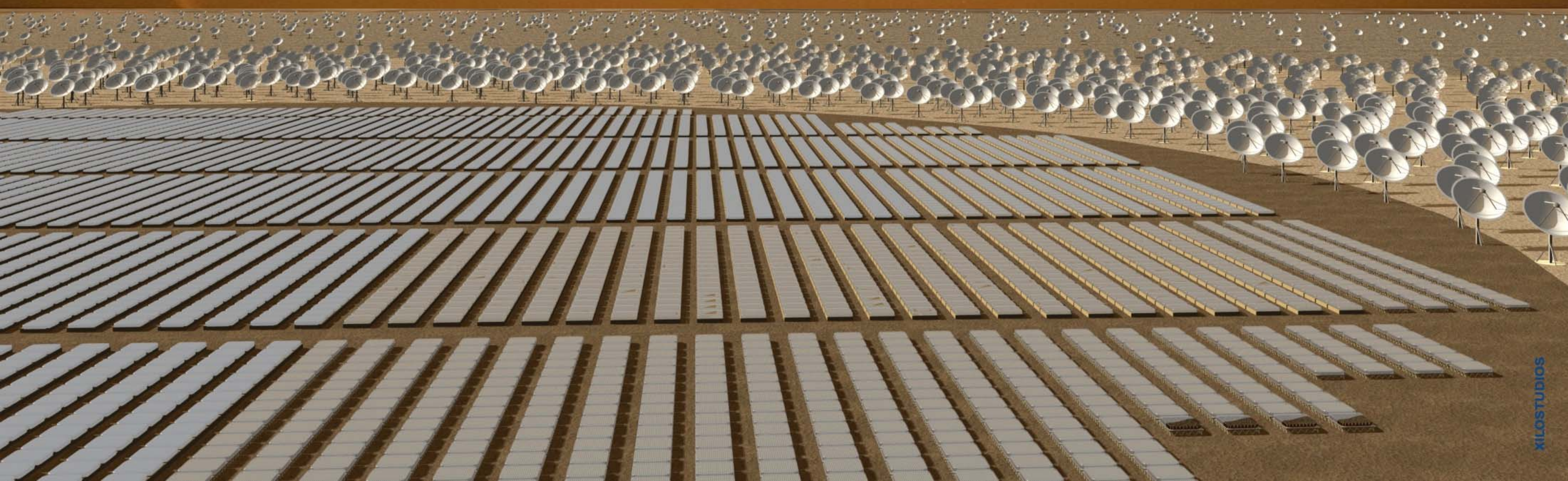




How to make good of a source of RFI



Radio science and radio astronomy

- **Spacecraft (its state vector) as a measurable**
  - ***Usually not the case for other payload (excl. accelerometers)***
- **“Radio science” – active AND passive**
  - ***Two-way link is highly desirable***
- **“Radio astronomy” – passive only**
  - ***Might operate in an “open loop” scenario***
- **Both methods “intertwine” heavily with S/C radio system**
  - ***Sharing on-board instrumentation possible***
- **Require a very complex & expensive Earth-based segment**
  - ***Radio science: DSN-like facilities***
  - ***Radio astronomy: [networks of] radio telescopes***
- **Radio experiments are multi-disciplinary!**

Spacecraft as a celestial radio source

- **Spacecraft tend to be radio loud… actually?**
  - ***Transmitter power 1 W***
  - ***Distance 5 AU (Jupiter)***
  - ***On-board antenna gain 3 dB***
  - ***Bandwidth 100 kHz***

Flux density ≈ 0.5 mJy

- **Operate at frequencies radio astronomers love (or hate):**

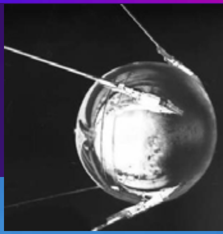
  UHF (400 and 800 MHz), S (2.3 GHz), X (8.4 GHz), Ka (32 GHz)

- **Estimates of state-vectors of spacecraft:**
  - ***Need for "higher-than-standard" accuracy in special cases***
    - Geodynamics and planetology
    - Trajectory measurements in close vicinity of Solar System bodies (e.g. landings)
    - Fundamental physics
    - Space-borne astrometry missions (e.g. GAIA)

- **Need for "eavesdropping" (sometimes, in desperation…)**

Space exploration & radio astronomy: 53 years together

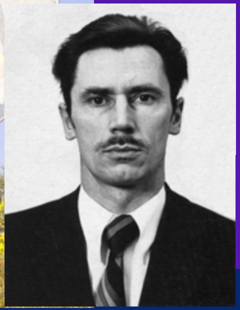
- Glorious start: Sputnik and 76-m Mk1 Jodrell Bank (now Lovell) telescope, 4 October 1957
- Parkes receives the first TV images of Appolo-11 on the Moon, 21 July 1969



Lovell 76 m, Jodrell Bank, UK

Parkes 70 m, NSW, Australia

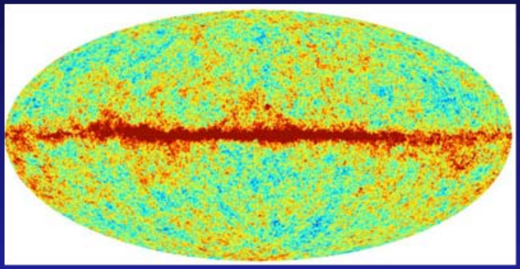
ADU-1000, Evpatoria, Ukraine

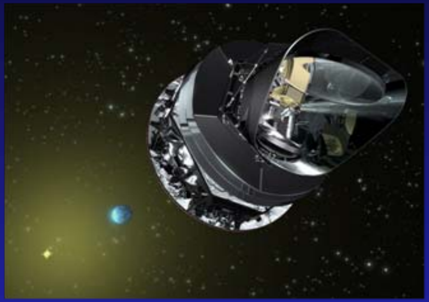


- Discovery of variability of extragalactic radio sources using deeps space communication antenna by G.B.Sholomitsky, 1965

Many faces of "space"-oriented radio astronomy

- **Space-based CMB experiments (Relikt, COBE, WMAP, Planck)**

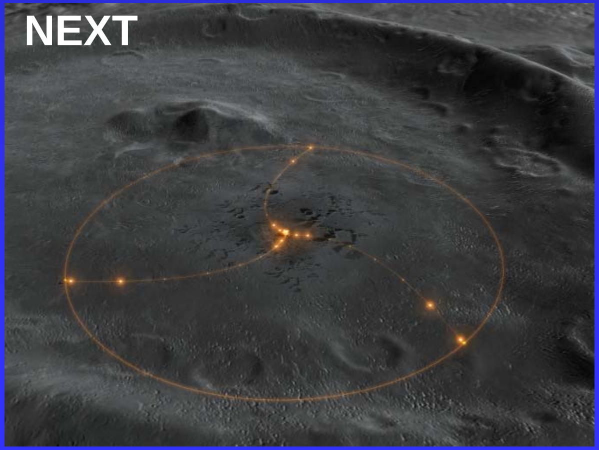


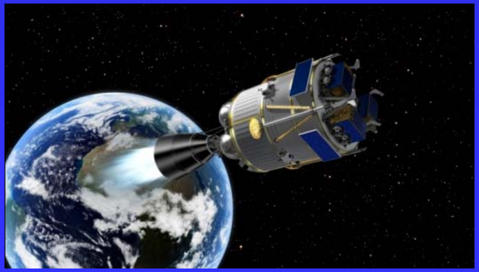


- **VLBI in Space**

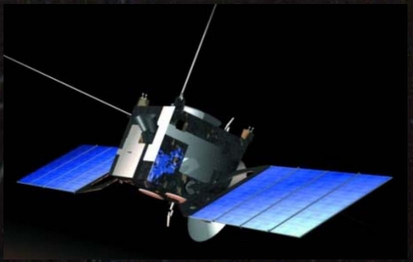
- **VLBI tracking of planetary missions**

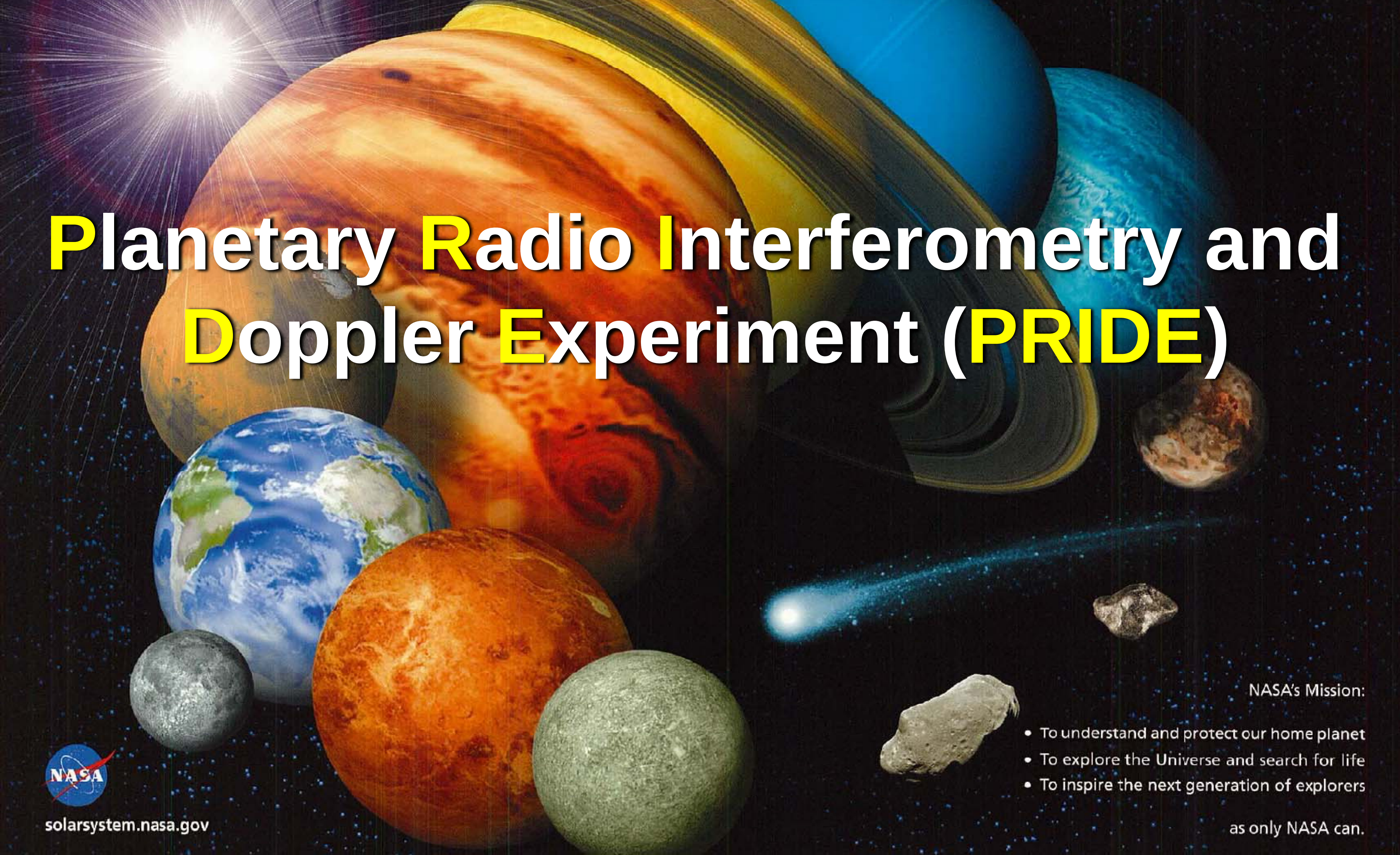
- **Space-borne Ultra Long Wavelength Astronomy (*f*<10 MHz)**



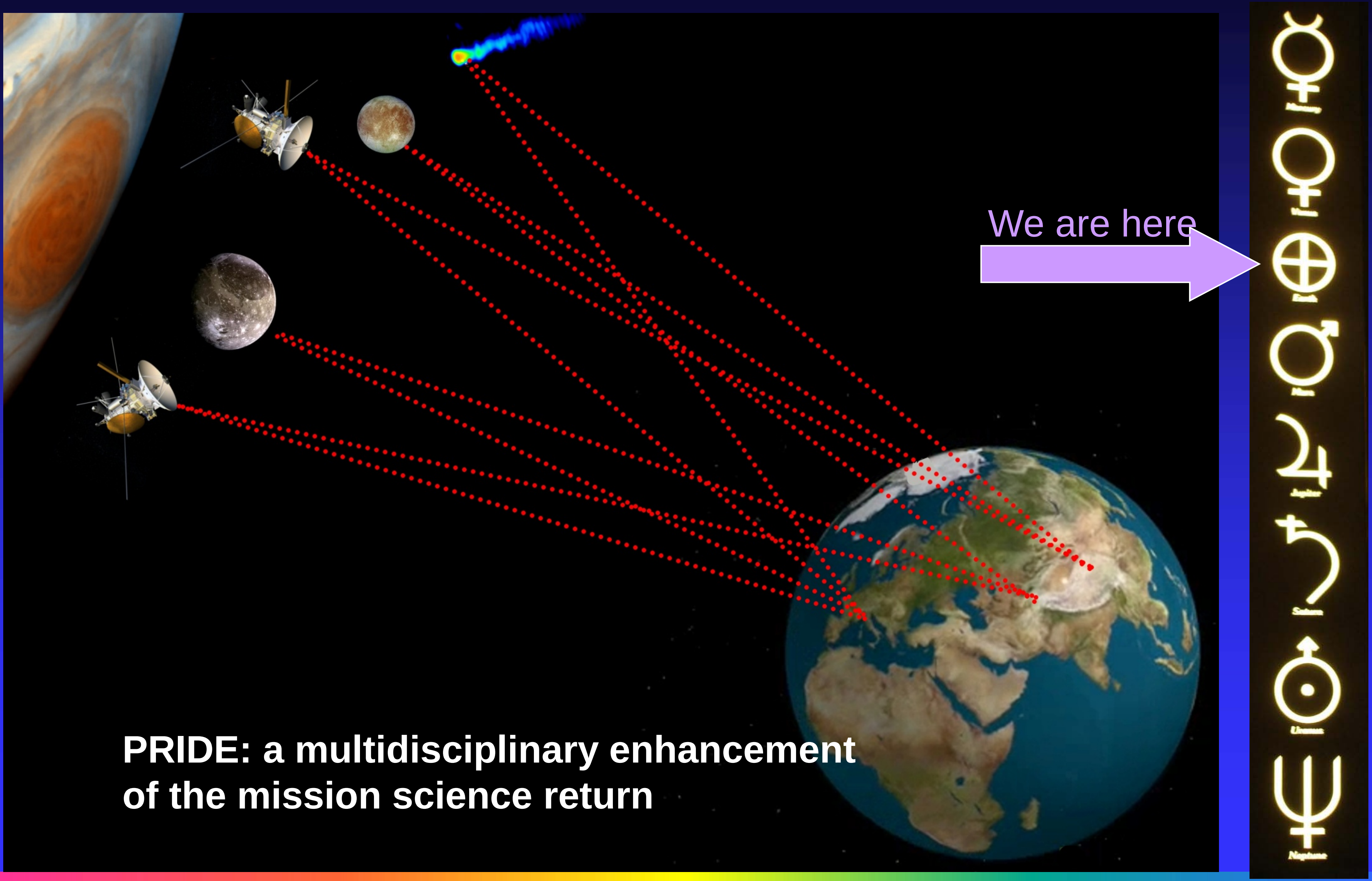


Planetary Radio Interferometry and Doppler Experiment (PRIDE)





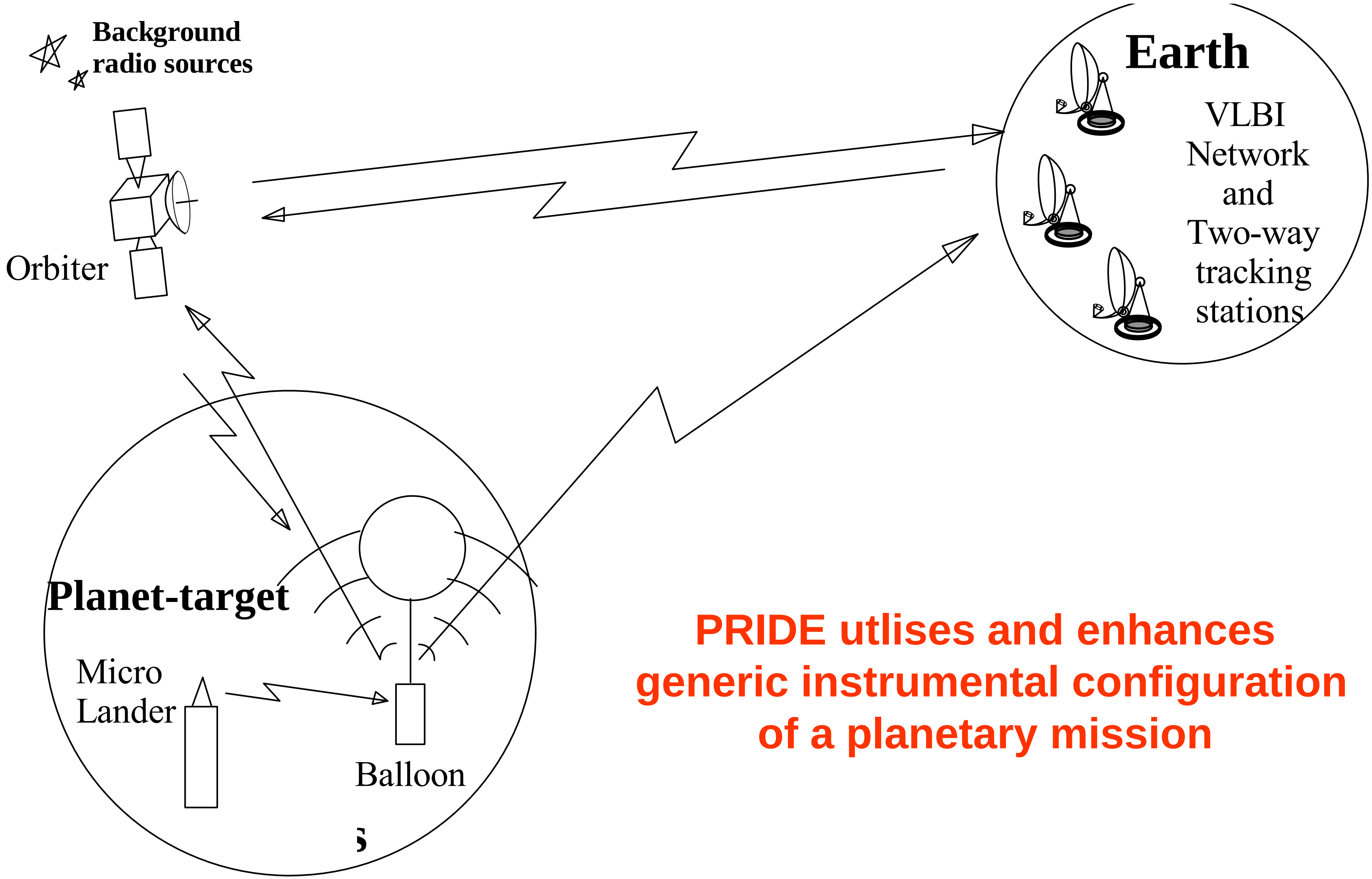
Generic PRIDE configuration



PRIDE: a multidisciplinary enhancement of the mission science return

Generic PRIDE configuration

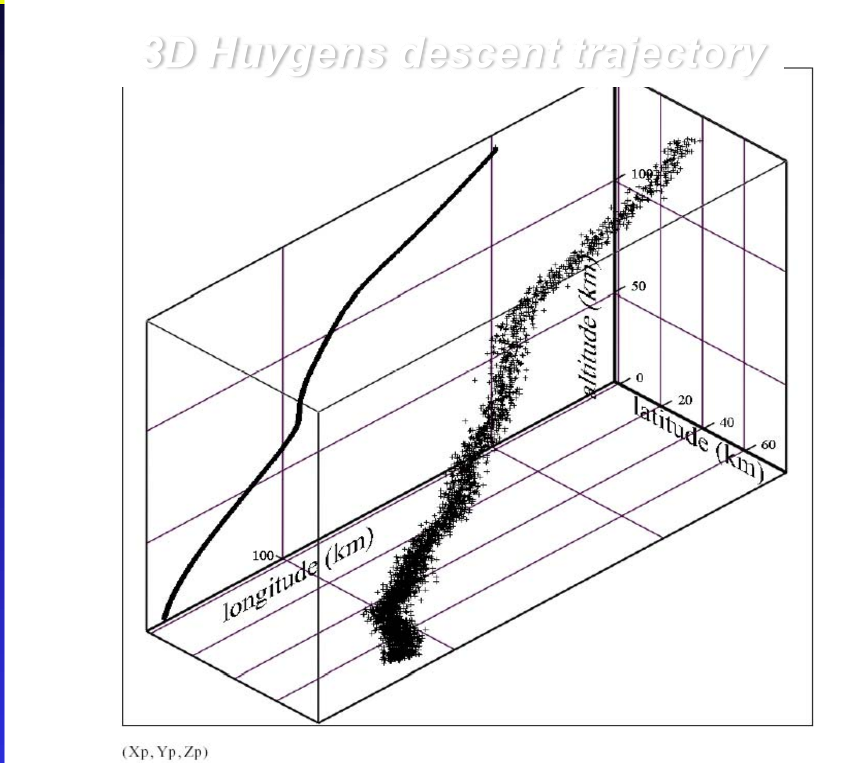
Planetary Radio Interferometry and Doppler Experiment

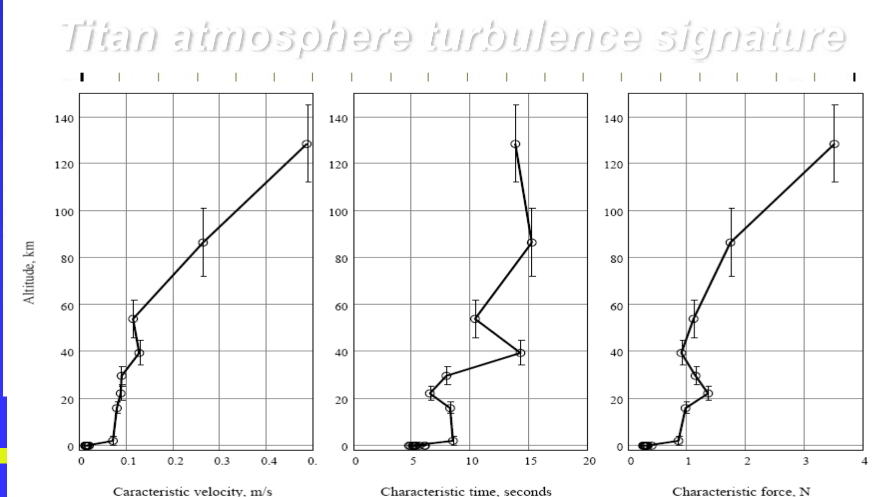


PRIDE utlises and enhances generic instrumental configuration of a planetary mission

Huygens VLBI heritage: 20 photons/dish/s

- **Ad hoc use of the Huygens “uplink” carrier signal at 2040 MHz**
- **Utilised 17 Earth-based radio telescopes**
- **Non-optimal parameters of the experiment (not planned originally)**
- **Achieved 1 km accuracy of Probe’s descent trajectory determination**
- **Assisted in achieving one of main science goals of the mission – vertical wind profile**





PRIDE-Mars vs Huygens VLBI tracking

Mission	Distance	Transmitter power/gain	Band	Time resolution	Delay noise	Positional accuracy (lateral)
	[AU]		[GHz]	[s]	[ns]	[m]
Huygens VLBI	8	3 W / 3 dBi	2.0 (S)	500	15	1000
PRIDE--Mars	1	10 W / 8 dBi	2.3 (S)	100	5	24
			8.4 (X)	10	3	14
			32 (Ka)	10	1	5

GPS accuracy anywhere in Solar System

- Conservative estimate, today's technology
- Minimal special requirements for the on-board instrumentation
- In-beam calibration can improve SNR further

Science case for generic PRIDE

- Direct characterisation of the orbiter's *and* surface elements' signal by means of "VLBI tracking" and radial Doppler measurements

- VLBI estimates of the S/C state vector
  - *Tidal deformations, seismology and tectonics of planetary bodies*
  - *Gravimetry*
  - *Atmosphere dynamics and climatology (if there is an atmosphere…)*
  - *Input into fundamental physics measurements*

- Radio occultation observations (e.g. In Martian ionosphere)
- "Cruise" science plus mission diagnostics ("health check")
- High degree of synergy with in situ measurements

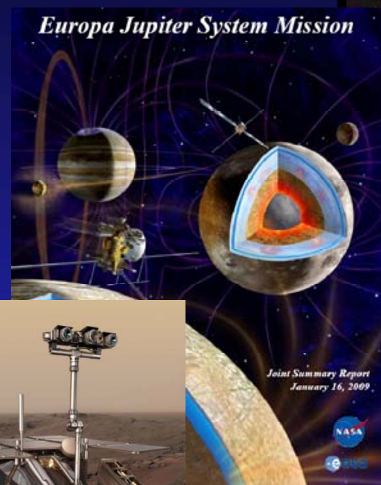
- Complementary to DeltaDOR measurements

plus

- Direct-to-Earth (DtE) delivery of critical data (e.g. via SKA for EJSM)

Planetary science missions – PRIDE customers

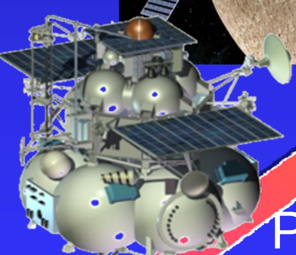
TSSM



EJSM

ExoMars

BepiColombo



Phobos-Grunt

2025

2020

2015

2010

SKA era

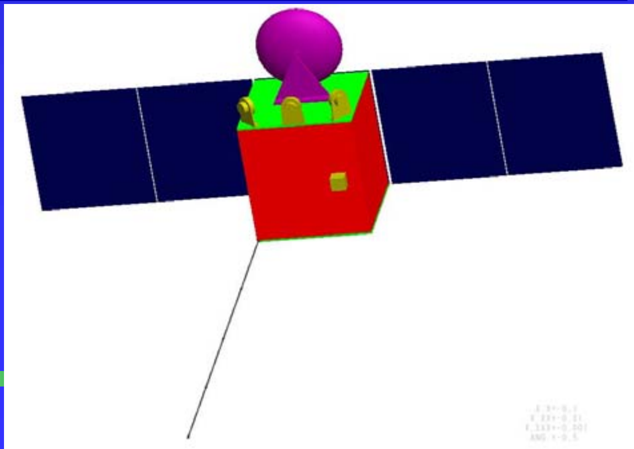
SKA pathfinders

- *Interesting match of timelines*
- *Potentially rewarding reciprocity*

Phobos-Grunt (aka Phobos Sample Return): 2011

- Gravimetry of
  - *Mars*
  - *Phobos*
- Need for precise S/C state-vector determination
- Phobos-Grunt equipped with USO – ideal for PRIDE
- X-band (8.4 GHz) signal
- *Origin of Phobos (by means of gravimetry)*

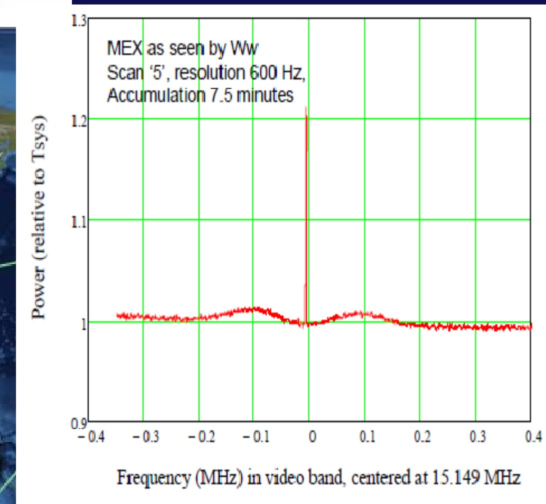
+ Chinese Mars Satellite, YingHuo-1



ESA's Mars Express: a training target

e-EVN

2010.09.08

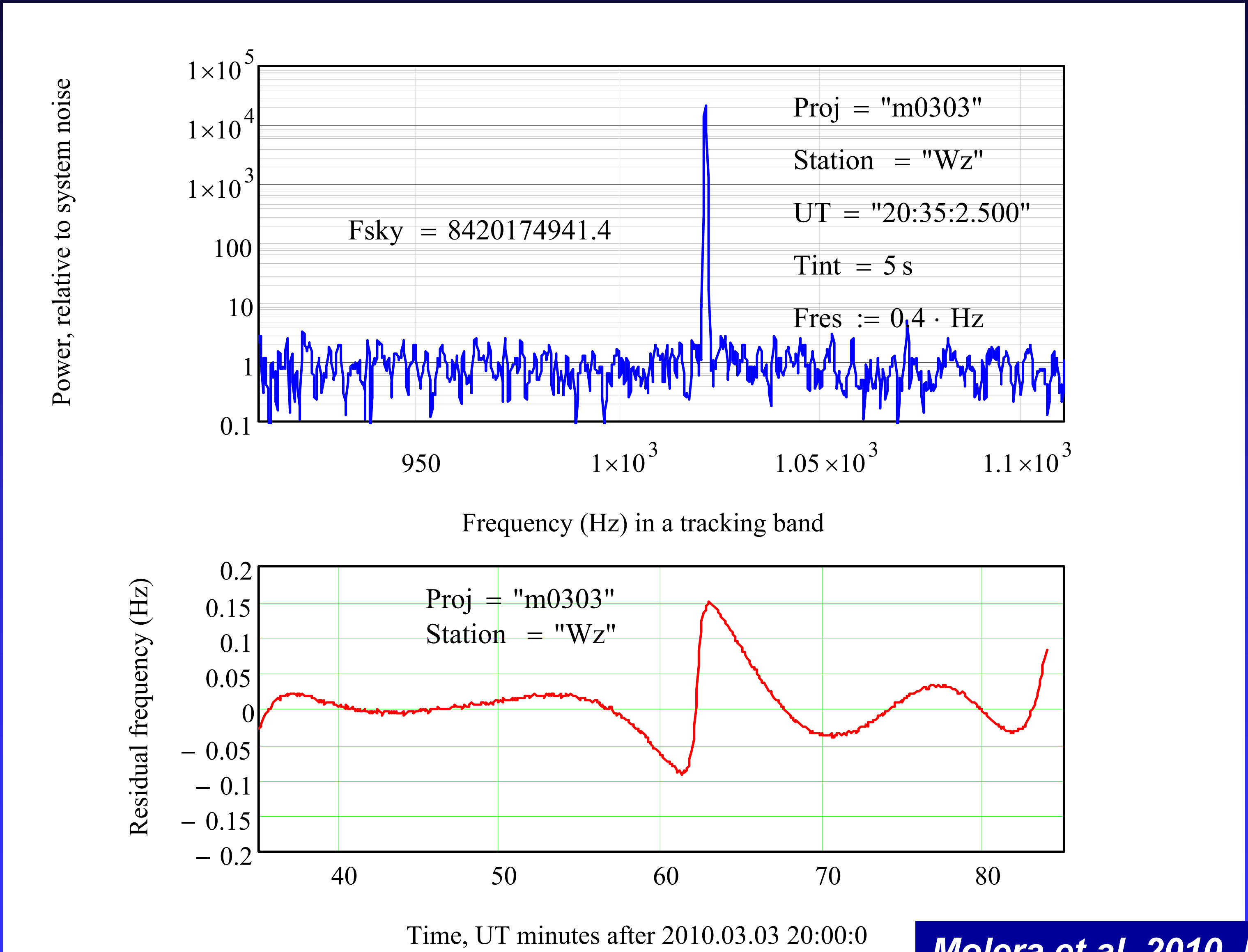


SKA Pathfinder

Warkworth, NZ

- e-VLBI data (512 Mbps) to Metsähovi in real time
- *SKA pathfinders talk to each other?*

MEX Phobos fly-by 2010.03.03 seen by PRIDE

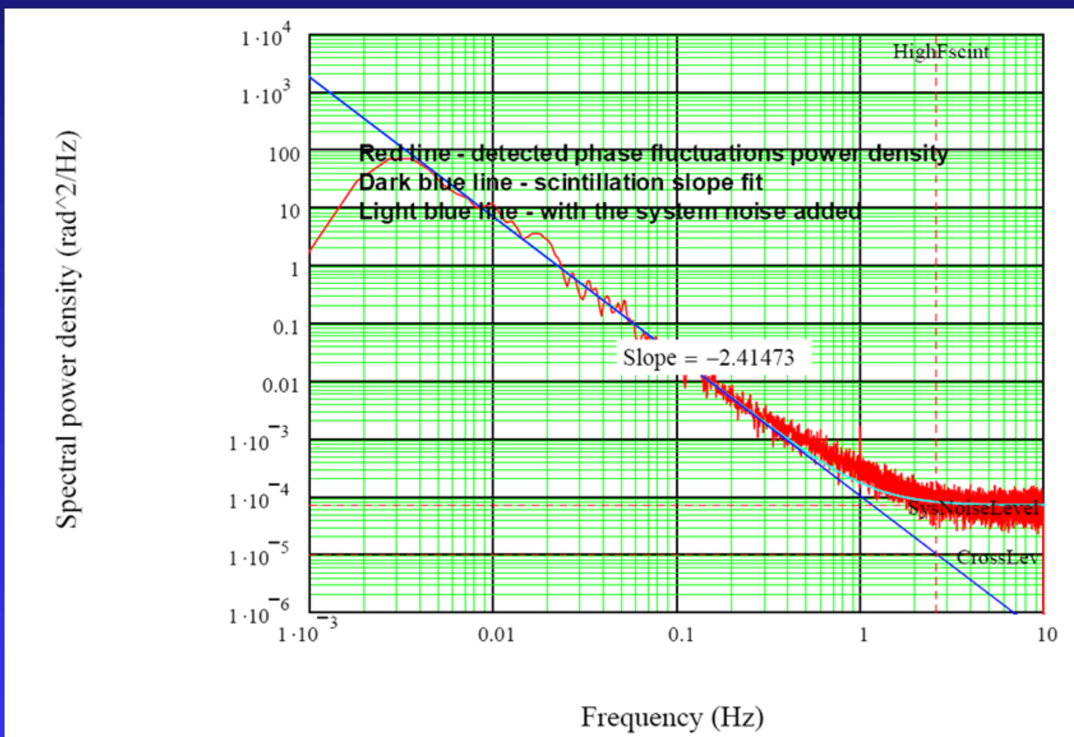


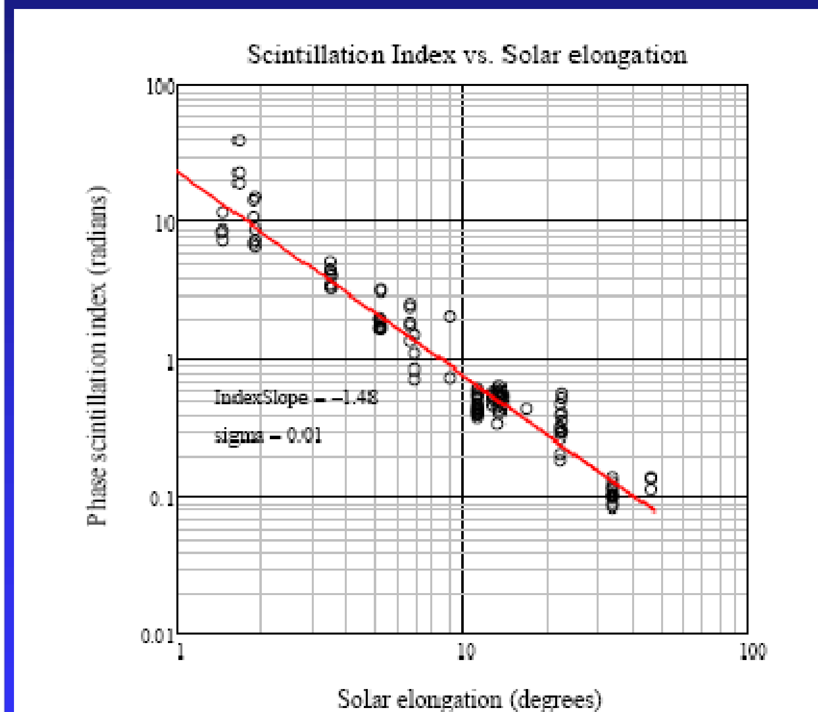
Molera et al. 2010, EPSC

PRIDE 2010: Venus Express (results so far…)

ESA's Venus Express mission as a "training" target

Spectral power density of slow fluctuation phase turbulence below 10 Hz.

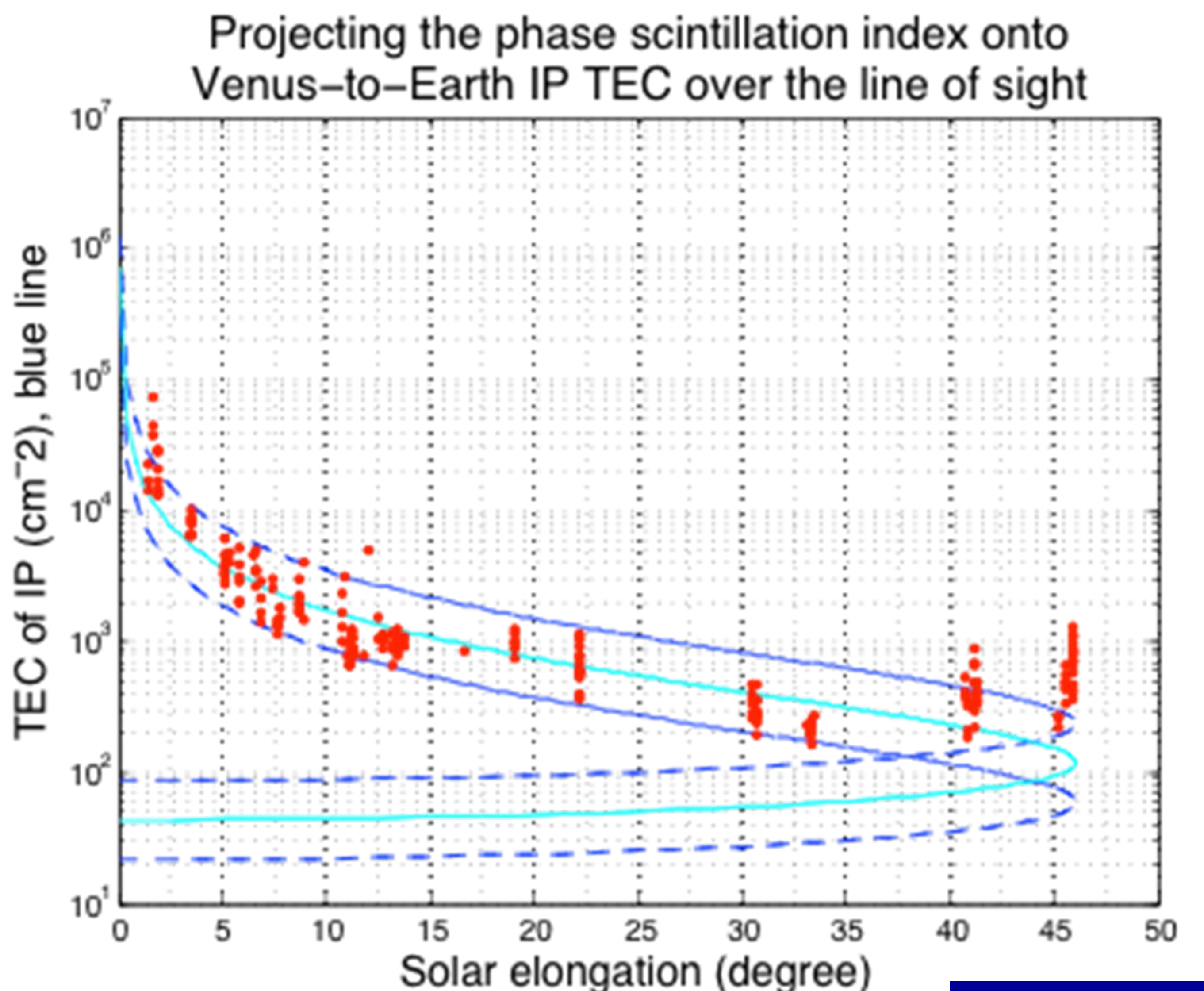




Molera, Pogrebenko et al., 2010

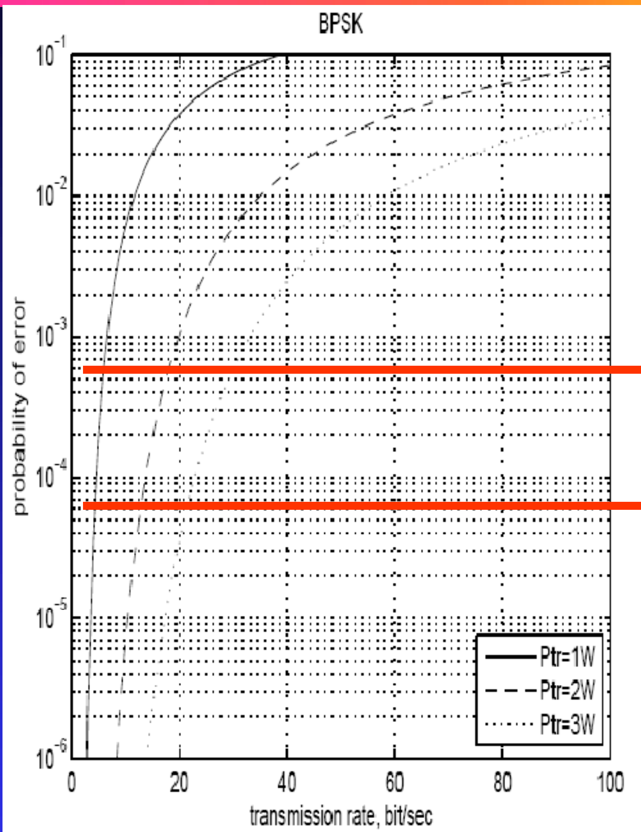
Participating stations: Medicina, Metsahovi, Noto, Wettzell, Yebes, Pushchino

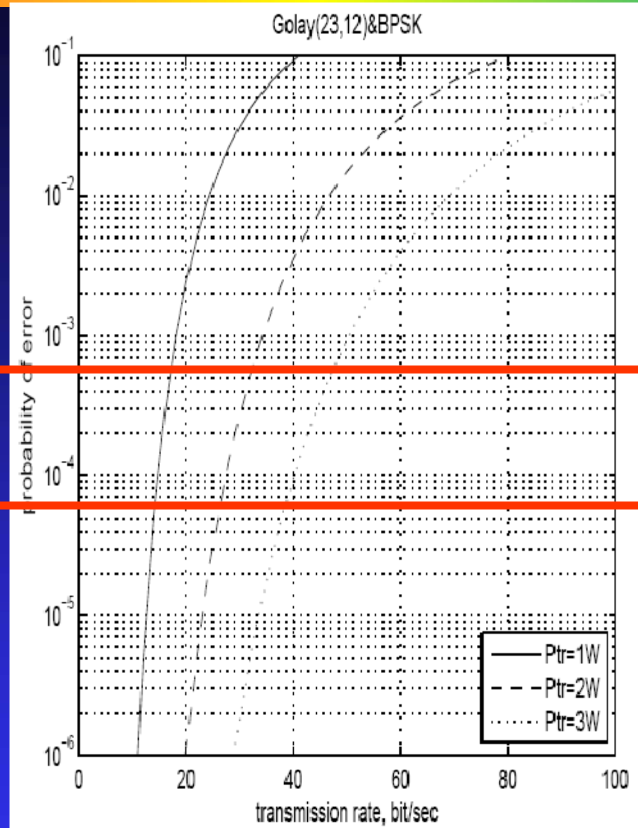
PRIDE for Solar System plasma physics

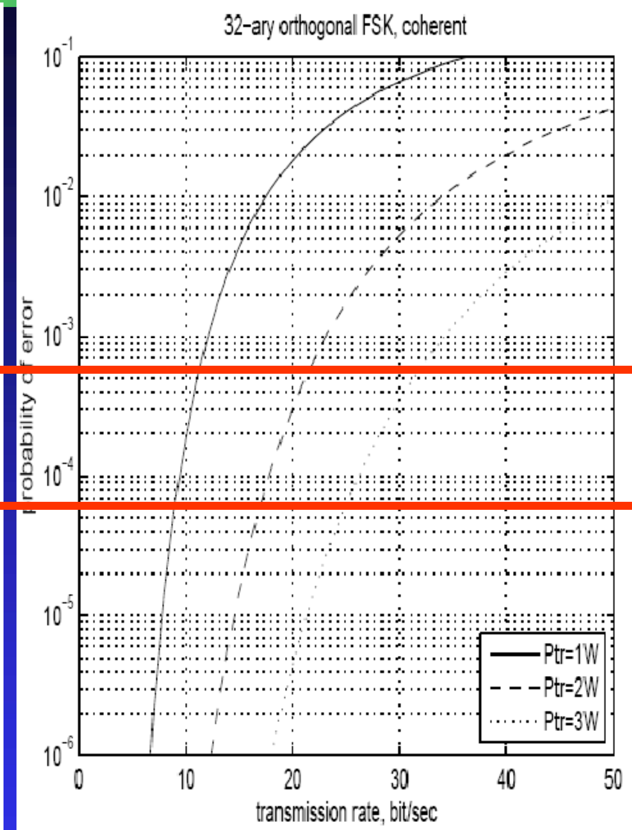


Molera et al. 2010, EPSC

Bit-error rate for EJSM-SKA DtE







BPSK	BPSK + error control coding	32-ary orthogonal Coherent modulation

30–50 bps with ~10^{-4} – 10^{-3} BER achievable

Low-gain transmission, 1 – 3 W

Further details: Fridman et al., 2008, SKA Memo No. 104