



JIVE

Joint Institute for VLBI
ERIC

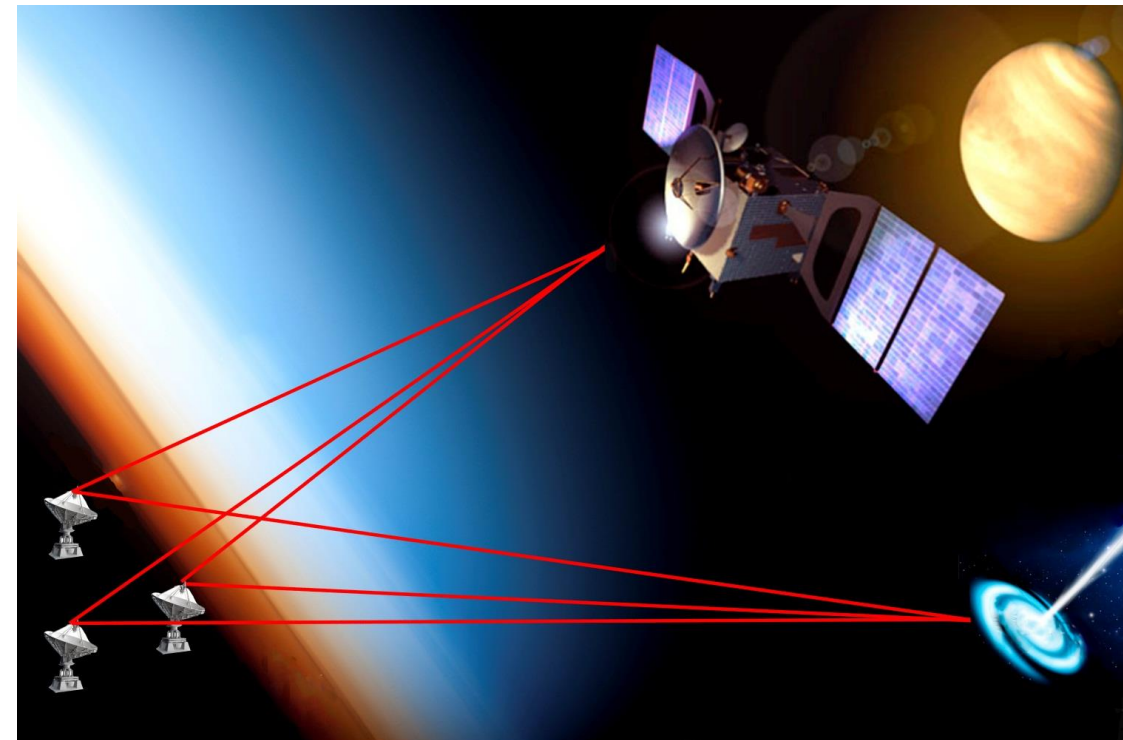
Radio Astronomy and Space Science

VLBI observations of orbiters and landers

Giuseppe Cimò

for the PRIDE collaboration

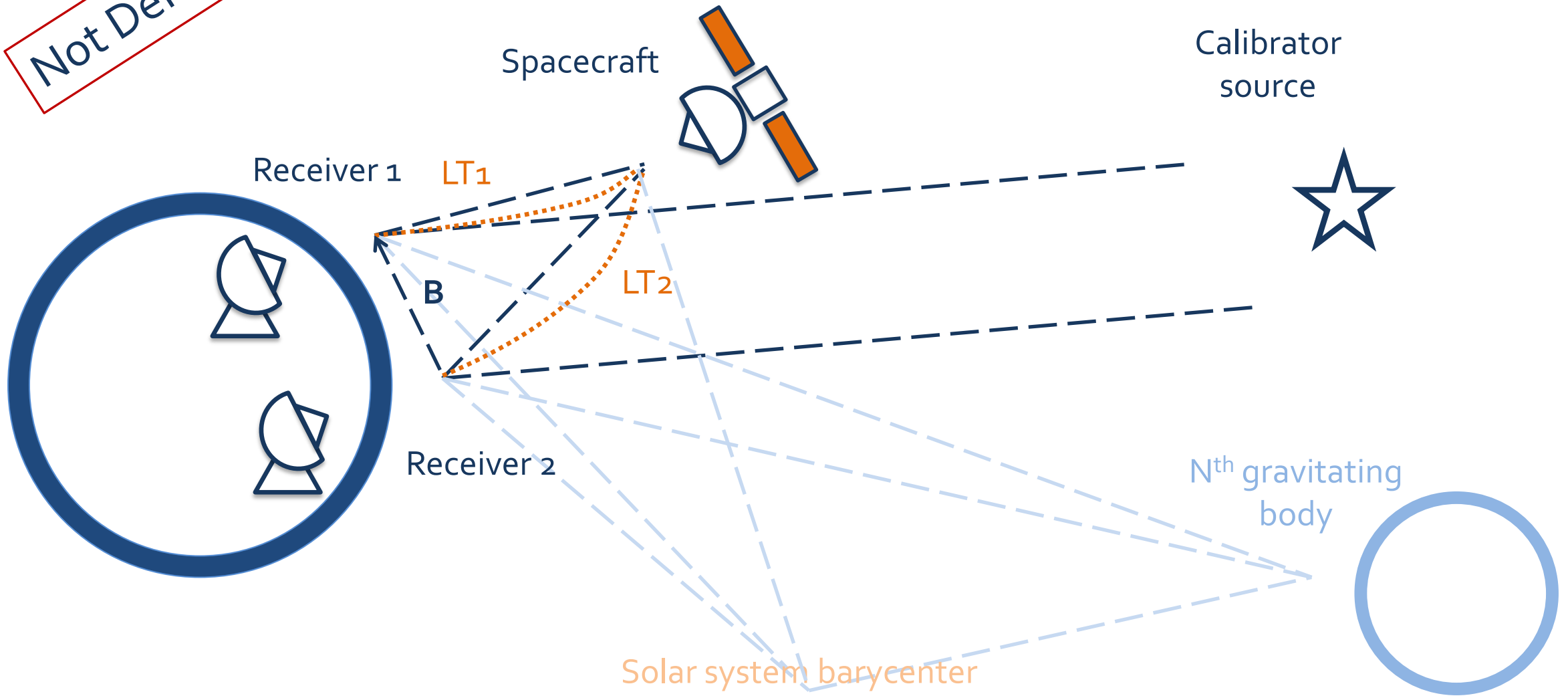
Planetary Radio Interferometry
and Doppler Experiment



Not DeltaDOR

Spacecraft as targets

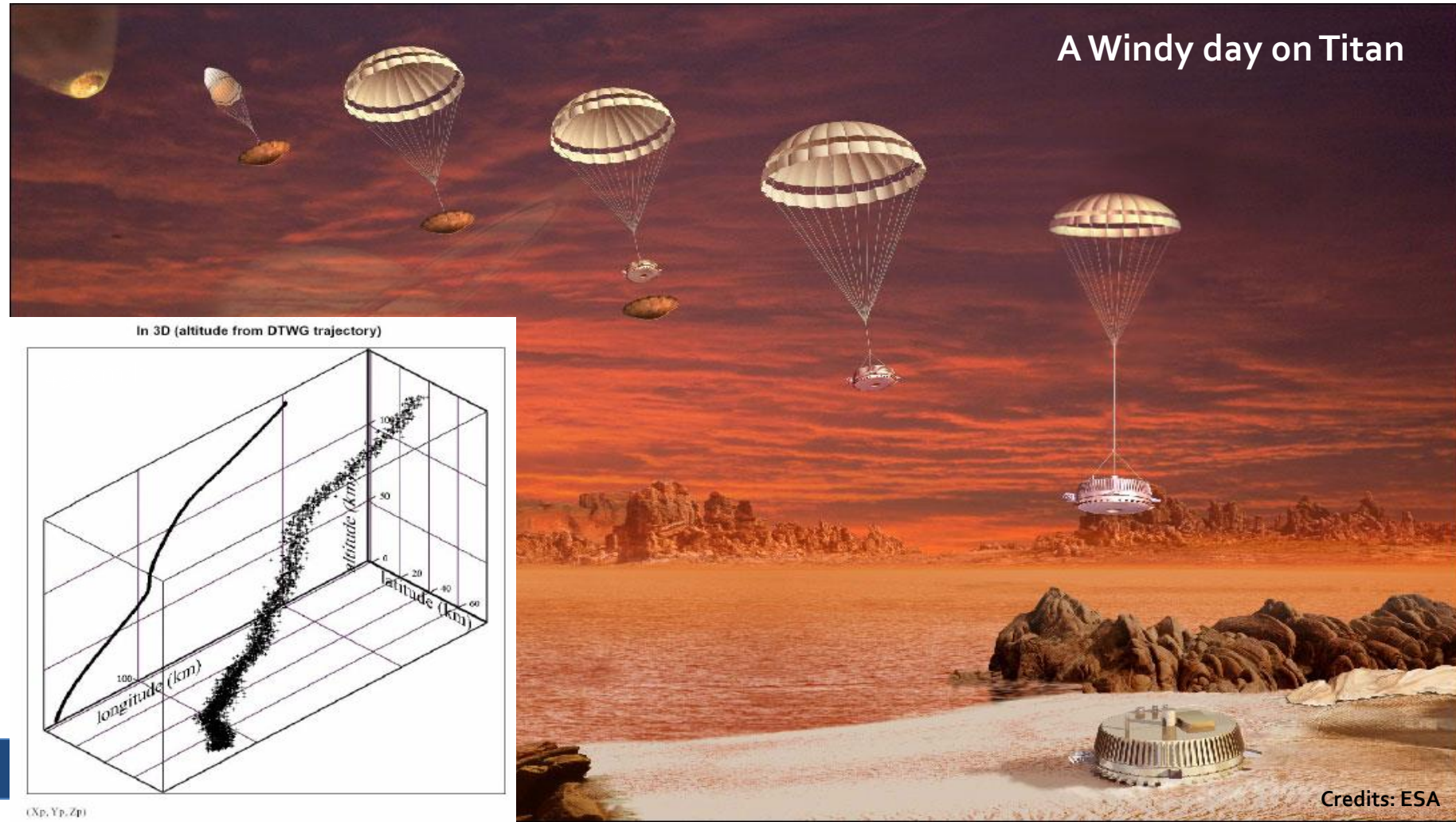
Near-field delay model for VLBI



VLBI observations of Spacecraft

Planetary Radio Interferometry and Doppler Experiment is able to provide highly accurate estimates of the state vectors for the orbiters and landers by means of Very Long Baseline Interferometry.

- Wind on other planets or moons
- Internal structure and composition
- Atmosphere dynamics
- Improve ephemeris of moons
- Interplanetary Scintillation
- General relativity experiments
- Earth geodesy





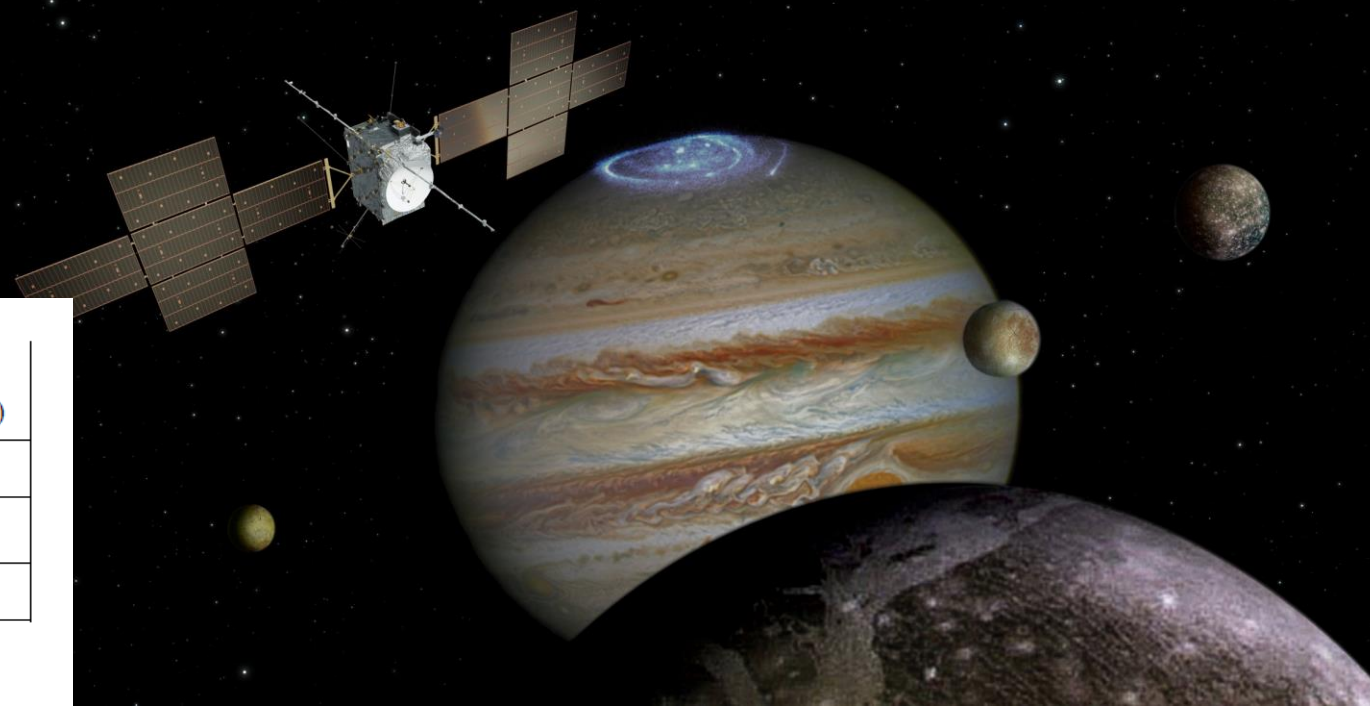
Courtesy of Olivier Witasse (ESA) – JUICE Project Scientist

JUICE

From the PRIDE Team

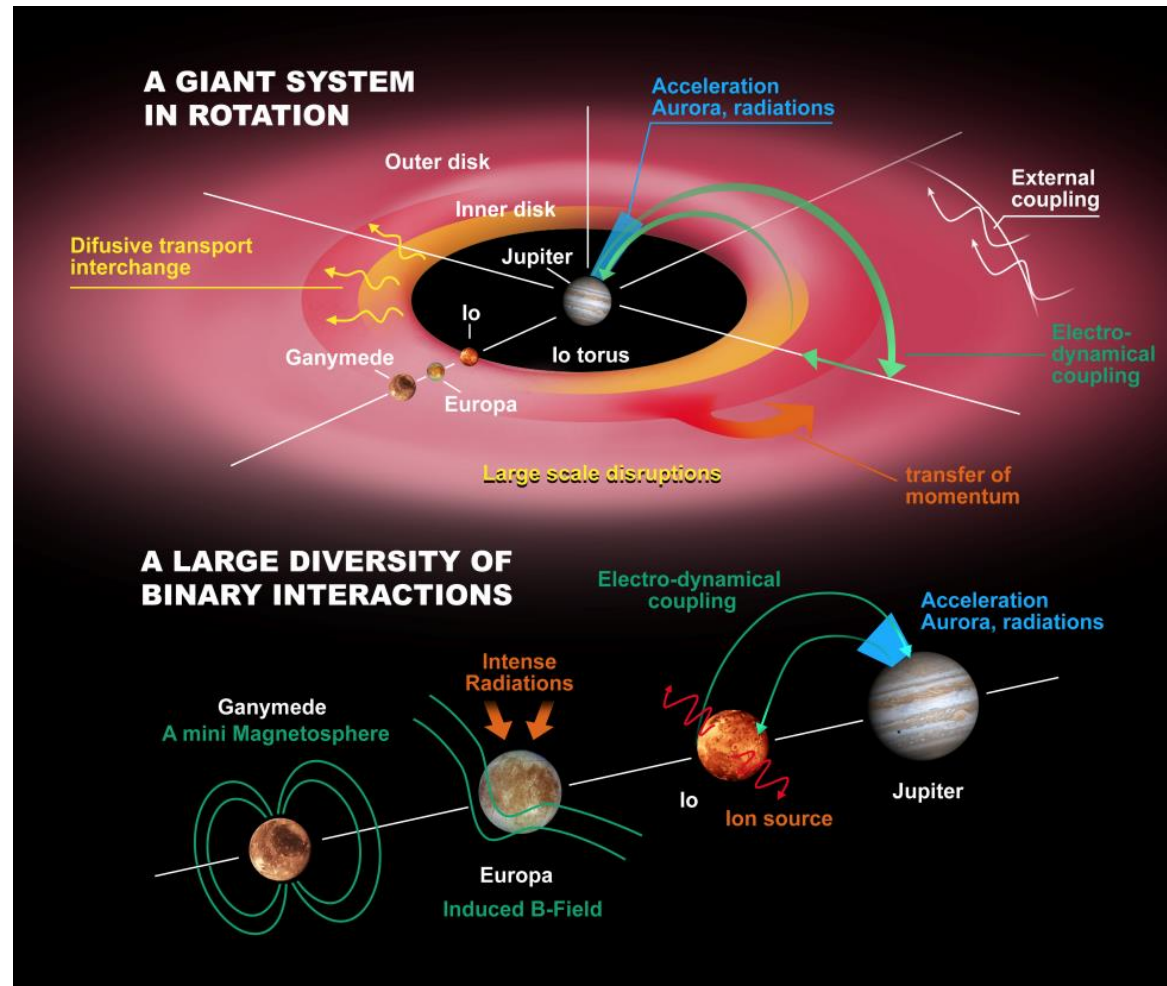
Mission	Distance (AU)	Transmitter power/gain	Band (GHz)	Time Resolution (s)	Delay Noise (ps)	Lateral Accuracy (m)
Huygens	8	3W/3 dBi	2.2 (S)	500	15	1000
JUICE	5	70W/6 dBi	8.4 (X)	10	5	60
			32 (Ka)	10	3*	20

* Limited by the propagation effects in the Earth troposphere



Emergence of habitable worlds around gas giants

- Ganymede as a planetary object and possible habitat
- Europa's recently active zones
- Callisto as a remnant of the early jovian system



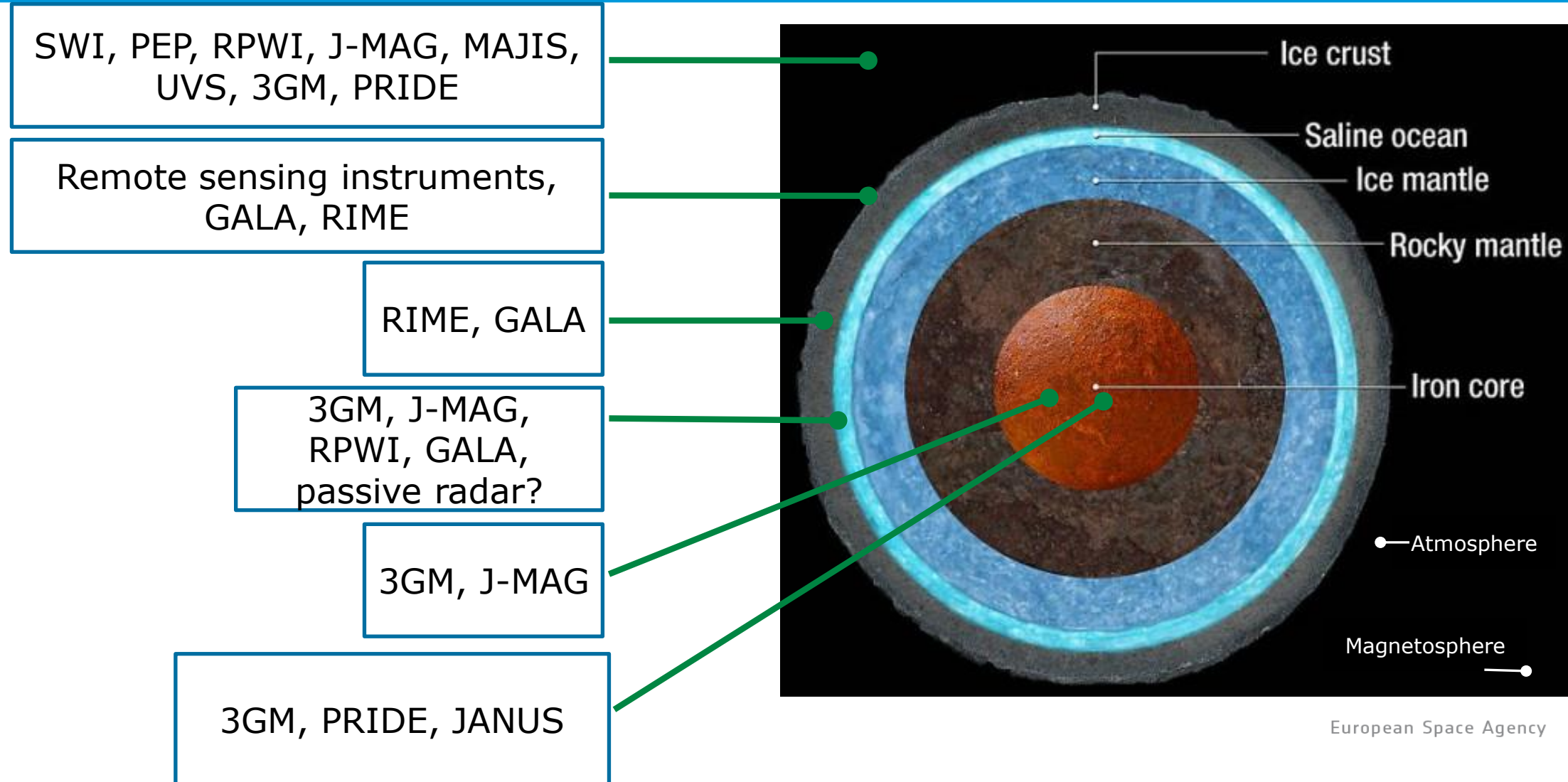
The Jupiter system as an archetype for gas giants

- Jovian atmosphere
- Jovian magnetosphere
- Jovian satellite and ring systems

Broad and interdisciplinary science

Broad science and interdisciplinary

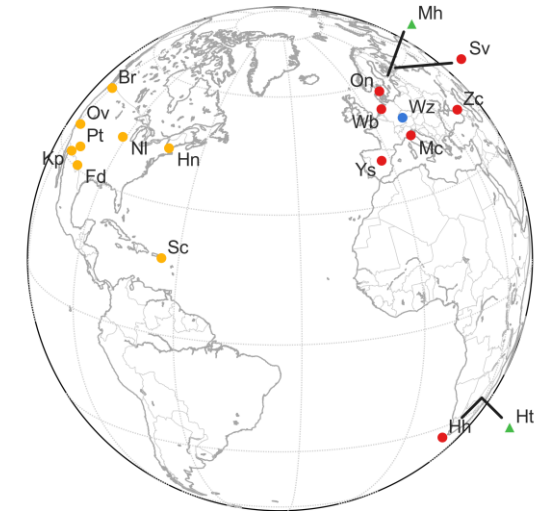
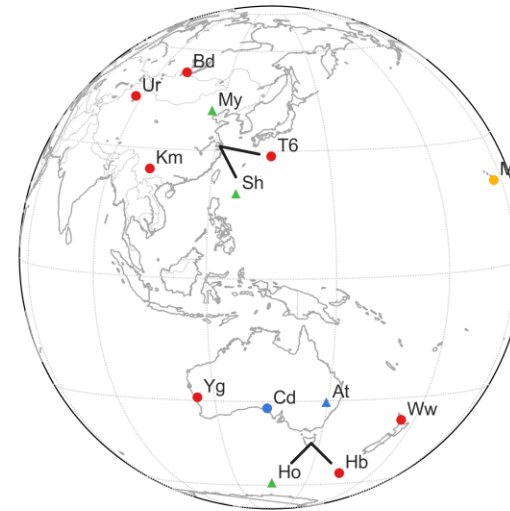
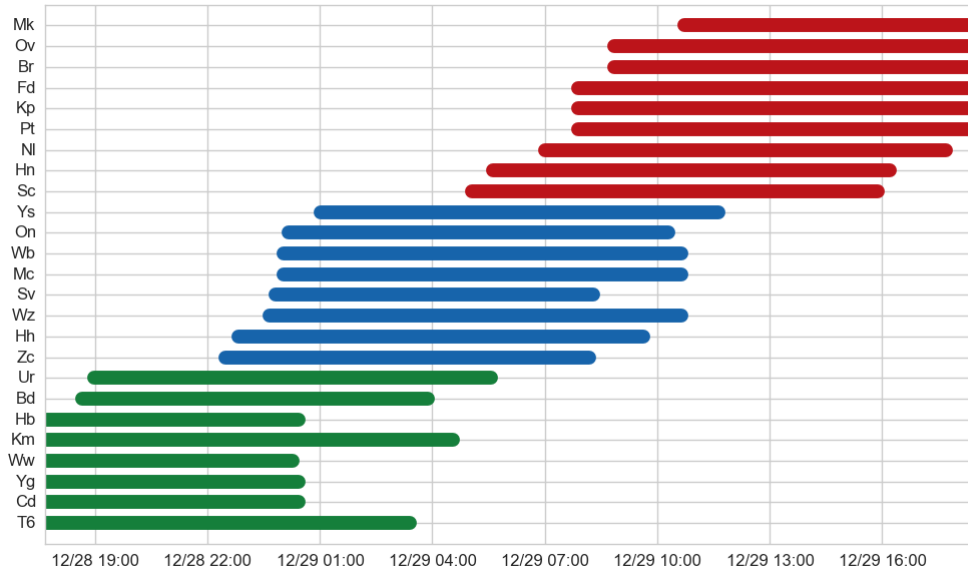
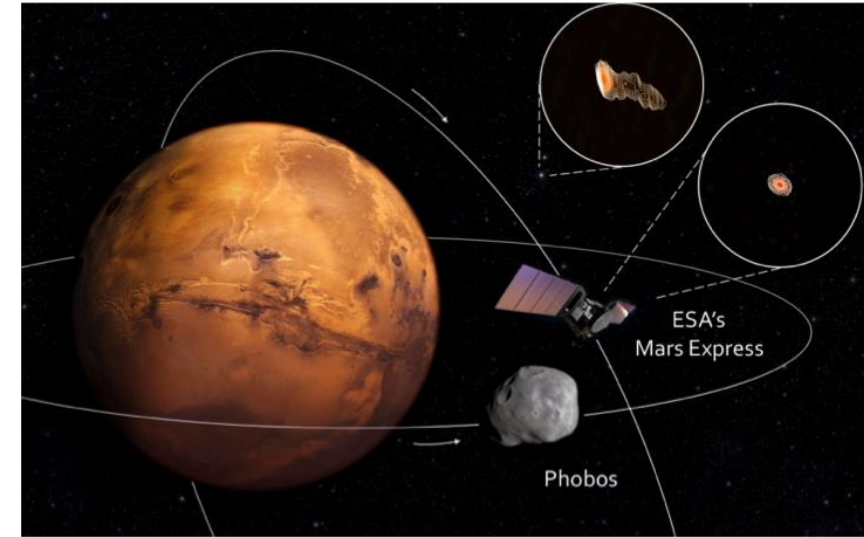
Courtesy of Olivier Witasse (ESA) – JUICE Project Scientist



ESA Mars Express Phobos fly-by

26 hours of continuous observations
30+ telescopes

- Closest flyby of MEX 45km
- Study of the Interior of Phobos
- Improving models on the origin of the Mars system
- Ephemerides

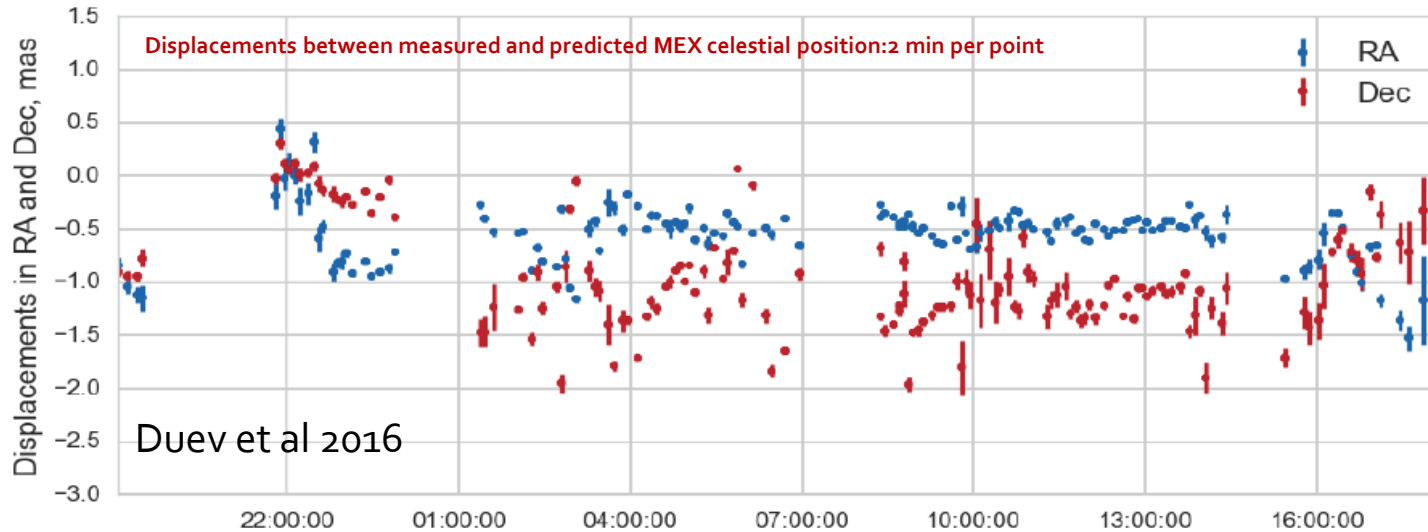
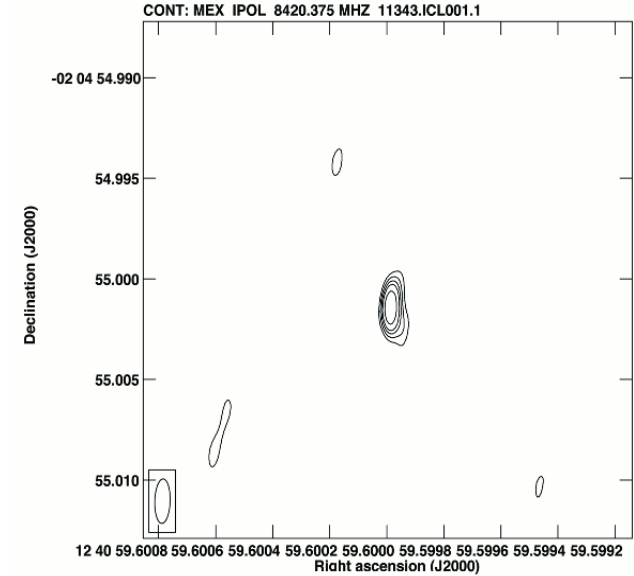
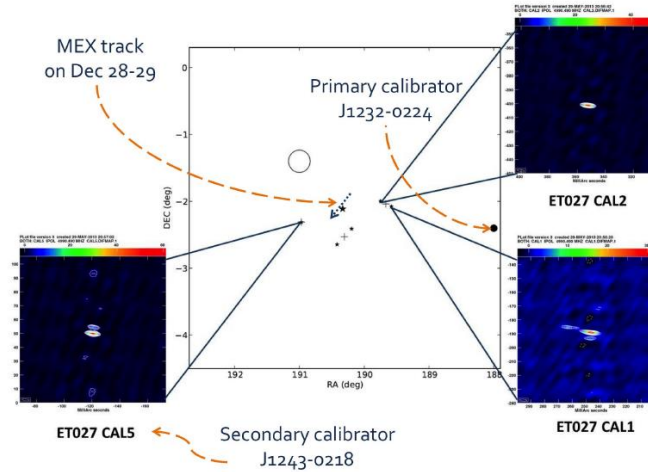


ESA Mars Express Phobos fly-by

Spacecraft astrometry

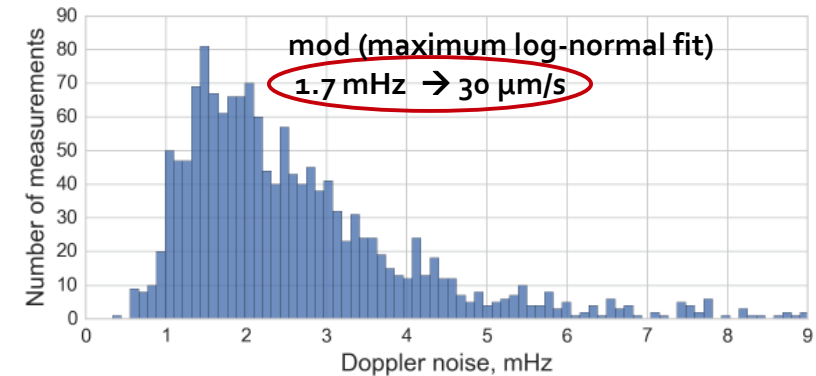
Median 3σ formal errors:

RA $34 \mu\text{s}$ \rightarrow 35 m
Dec $58 \mu\text{s}$ \rightarrow 60 m

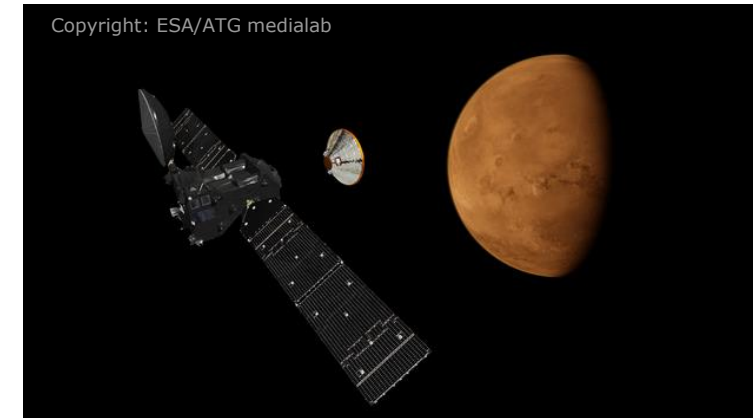
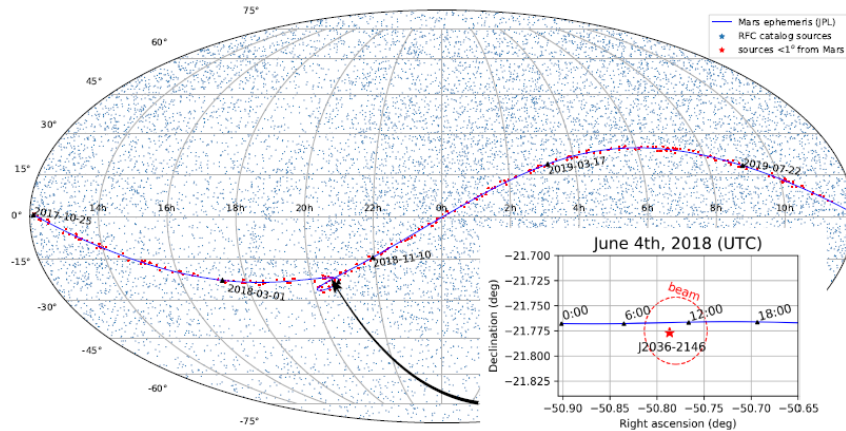


Doppler results

detection noise: 10 s integration



In-beam VLBI observations of multiple S/C



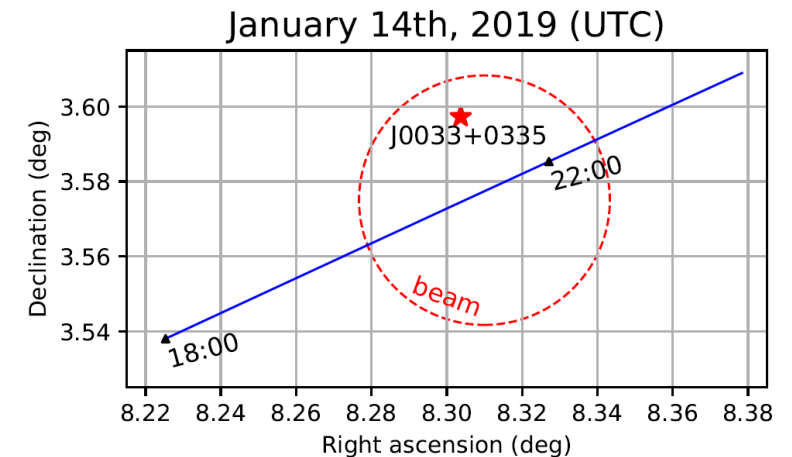
- MEX (polar orbit) + TGO (74°)
- In-beam phase referencing
- Single EVN pilot and multiple VLBA epochs
- Goals: *Study the gravity field of Mars*

Removing atmospheric and plasma effects

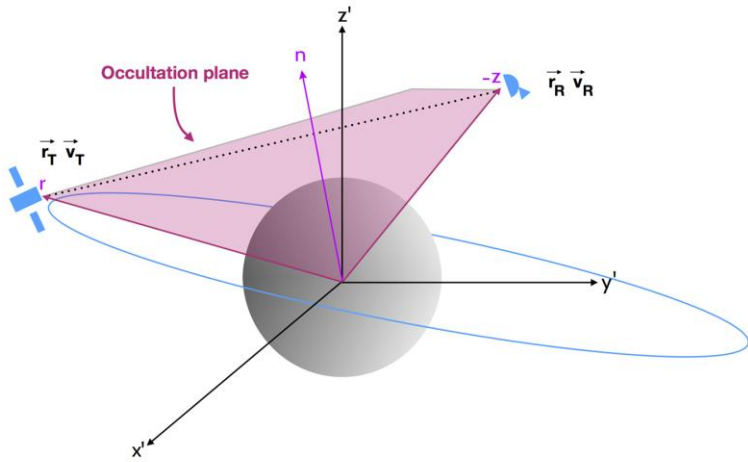
Lumping on the gravity coefficients

Tidal Love number k_2 determined with a higher accuracy

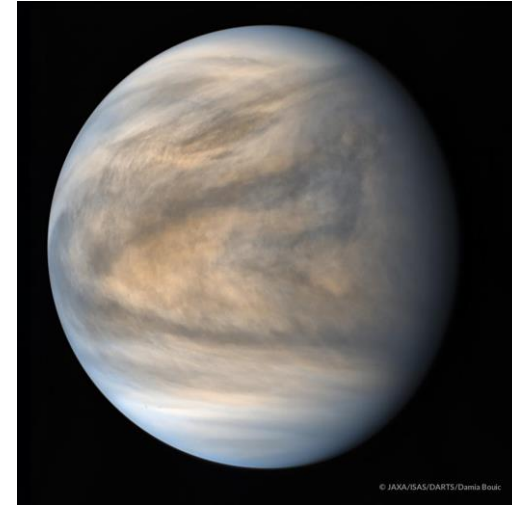
In preparation for future missions: LARA (+ all Mars orbiters) and JUICE (+ Clipper)



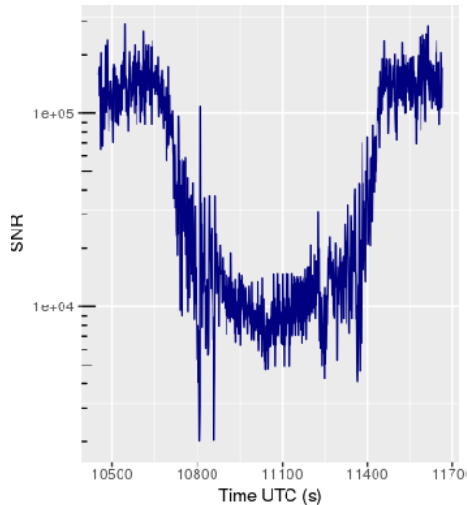
PRIDE for planetary atmospheric studies



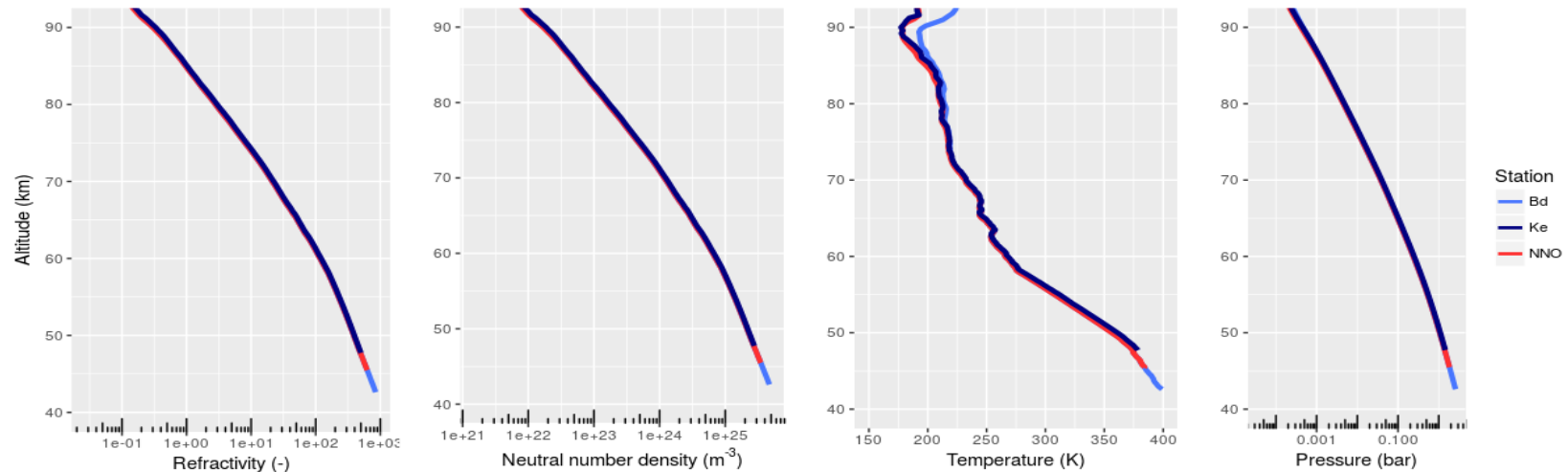
- Use of VLBI telescopes for Doppler measurements
- Complementary to Radio Science experiments
- Characterization of Venus' neutral atmosphere
- Observing deeper and longer during occultations



Detection of the carrier signal of the spacecraft throughout a complete occultation



Refractivity, neutral number density, temperature and pressure profiles

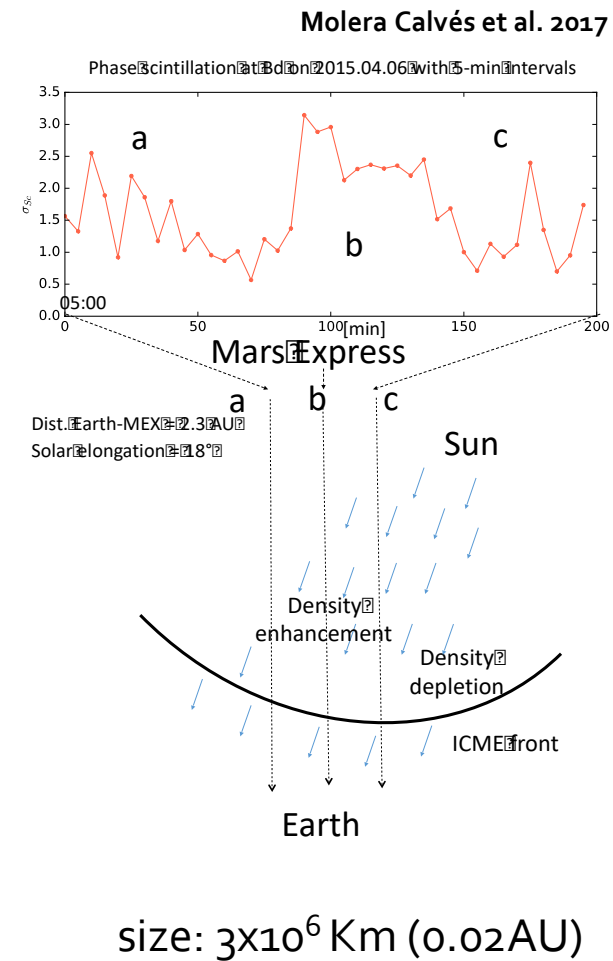
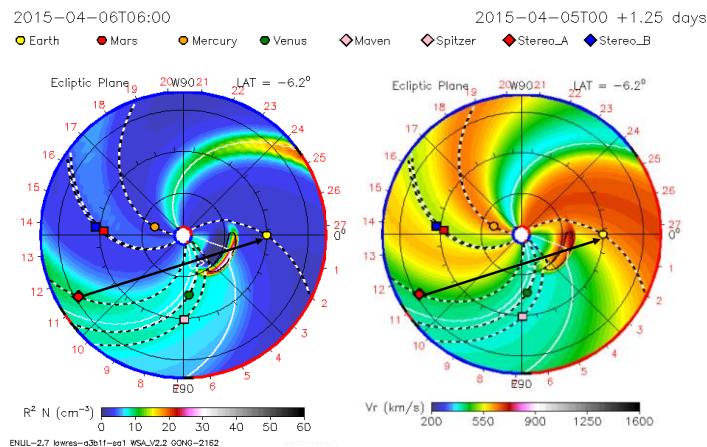
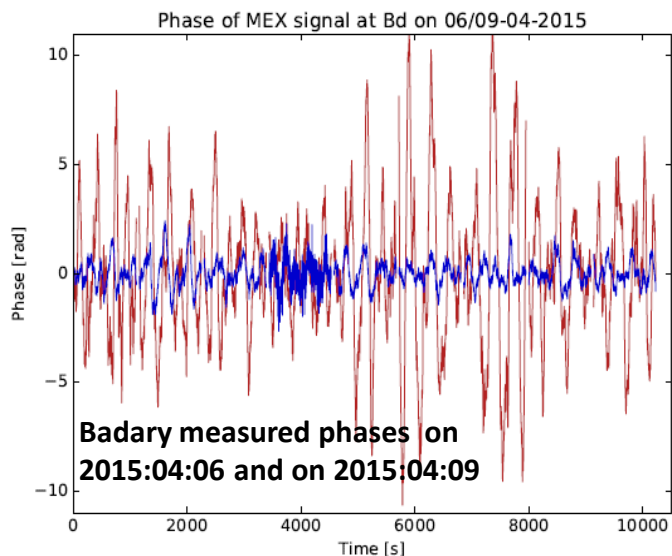
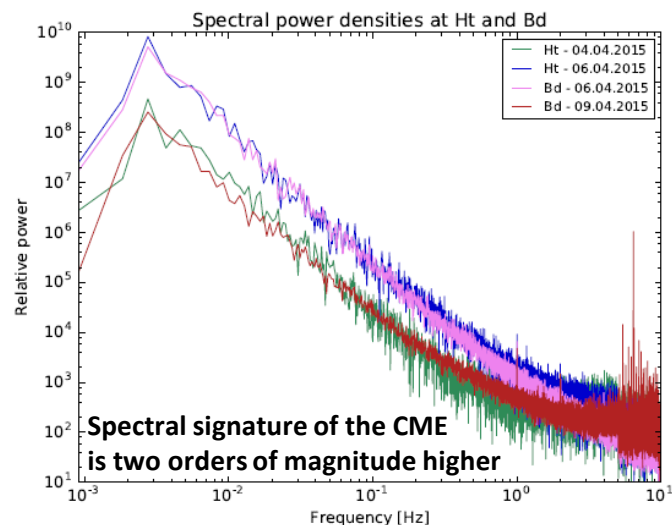


Coronal Mass Ejection

Coronal Mass Ejection on 06/04/2015 detected on single-dish observations of ESA's Mars Express

Solar Elongation → 18 degrees

- In one day, phase scintillation index increased of a factor of 3
- Total Electron Content increased of a similar factor
- TEC: 3000TECU



Conclusions

PRIDE has proven to be beneficial for a wide range of scientific applications

Ephemerides
Planetary Science
Plasma physics
Fundamental physics

We have observed the ESA's MEX spacecraft flying by Phobos using 30+ radio telescopes for 26 hours.

Radial Doppler precision: 30 $\mu\text{m/s}$
Lateral position precision: ~50 m

Synergies and complementarities with Radio Science.

Planetary atmospheres
Space weather

Ground-based experiment of the ESA's flagship mission JUICE (and other missions)

Talking to the Space community

- Different formats
- Different repositories
- Different policies
 - Proprietary windows
 - Archiving
- Different communities
 - Space agencies
 - PIs of onboard experiments
 - Planetary and space scientists

Feedback and suggestions:

- Closer interactions with planetary community
- VLBI and VO
- Explore interdisciplinary