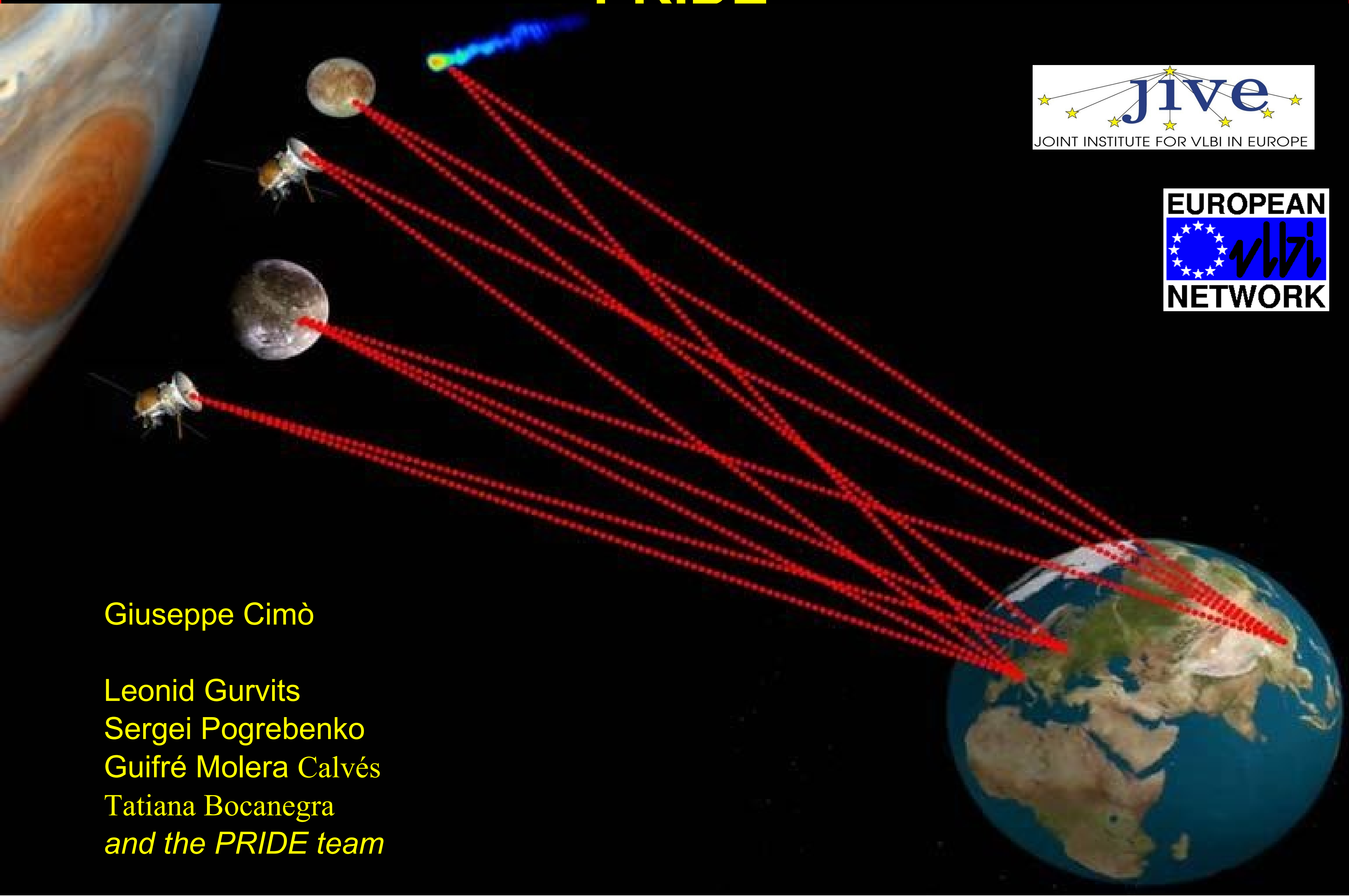
Planetary Radio Interferometry and Doppler Experiment
PRIDE



JIVE
JOINT INSTITUTE FOR VLBI IN EUROPE

EUROPEAN
vlbi
NETWORK

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Summary:

- VLBI for planetary science
  - the PRIDE technique
  - the Huygens VLBI tracking
  - Mission requirements
- The EVN experiments:
  - Tests
  - EVN experiments
  - Results and achievements

The PRIDE team

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PRIDE

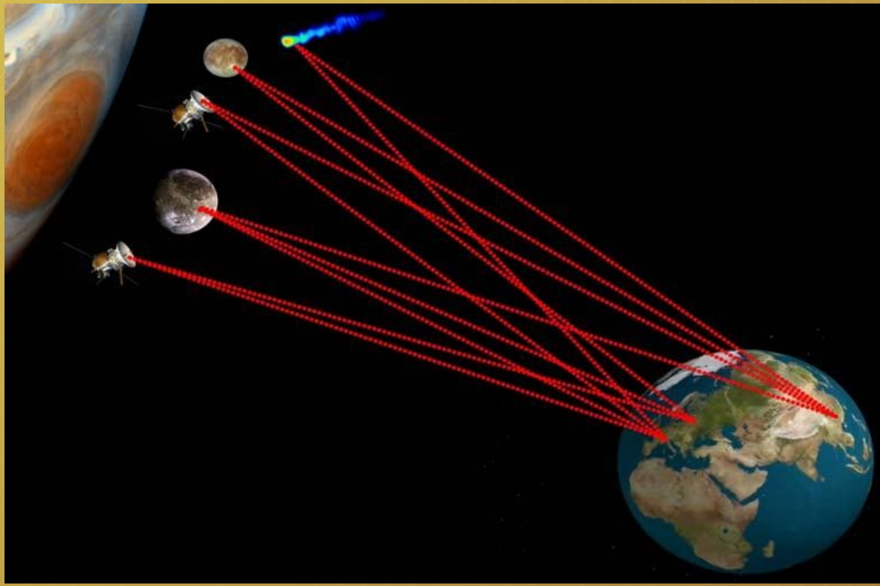
Planetary Radio Interferometry and Doppler Experiment

It is a multi-disciplinary enhancement of the scientific suite of current and future planetary missions.

- Ultra-precise celestial mechanics of planetary systems;
  - measurements of tidal accelerations of the satellites may be possible
- Geodynamics, internal structure and composition;
  - Powerful constraints on the interior structure of the moons can be obtained from the joint analysis of topography and gravity field data.
- Shape and gravimetry;
  - multiple flybys can be used to define the low order gravity field parameters.
- Electric properties of icy satellite surfaces and their environments;
  - PRIDE will bring in multi-antenna detections enabling “stereoscopic” view on the phenomena under study.
- Anomalous accelerations of deep space probes and other fundamental physics effects.

The technique

PRIDE will exploit the technique of Very Long Baseline Interferometry observations of spacecraft and natural celestial reference radio sources by a network of Earth-based radio telescopes.



Phase referencing:
The phase corrections are derived and applied to the data of the (much!) weaker spacecraft signals!

Calibration accuracy depends on the SNR.

Observations of calibrators require as wide a bandwidth as possible to achieve the desired accuracy.

In our experiments, we focus on the detection of the spacecraft's narrow band signal carrier.
The position and the velocity is determined by Doppler analysis on narrow bands: sub-mHZ!
The spacecraft data are reduced using the Sekido-Fukushima near-field delay model.

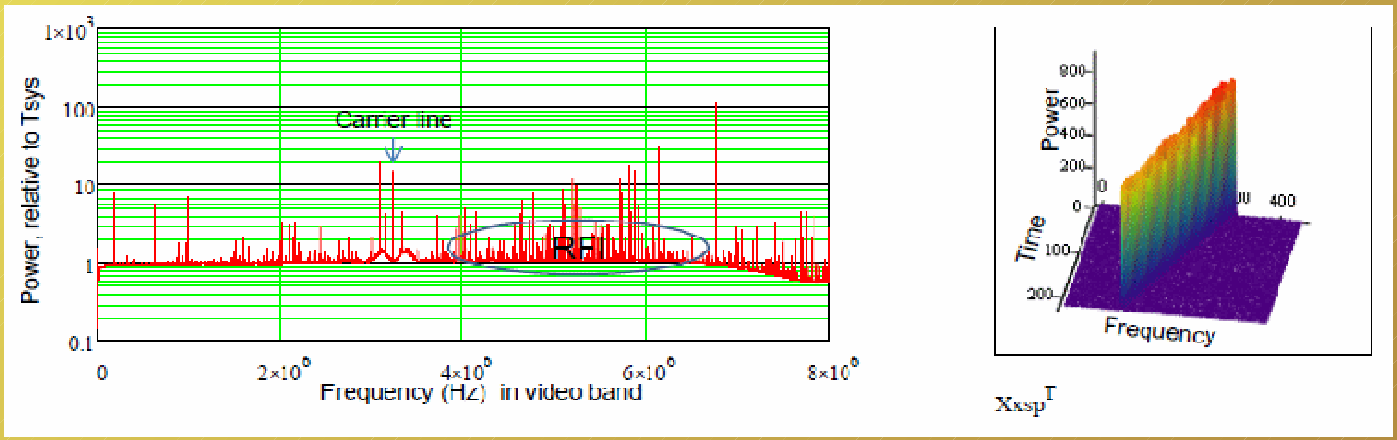
Spacecraft and phase-reference sources are recorded on the same medium. Broad- and narrow-band signal are analyzed separately at the processing center.

Signal analysis: *working on the pipeline*

High Resolution Spectrometer

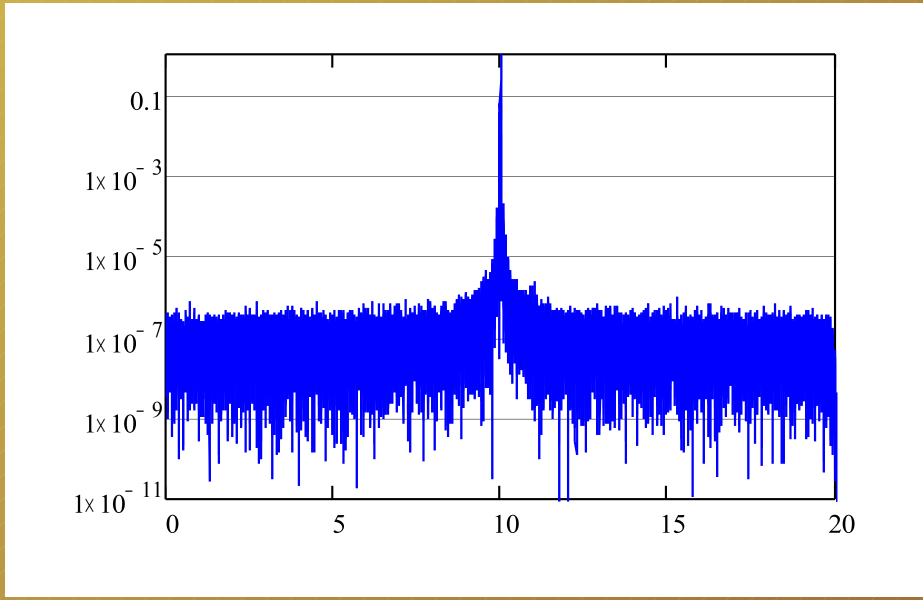
Left panel: 10Hz resolution
19 minutes averaged spectrum

Right panel: temporal evolution of the carrier line spectrum. Frequency of the carrier line changes with a rate of ~ 0.1 Hz/s.



Spacecraft tone tracking and Phase-Lock Loop software will extract the final signal spectrum.

Narrow bands are extracted around each tone frequency. The narrow bands, with the tone in the center, are filtered out and written on a file for further processing.



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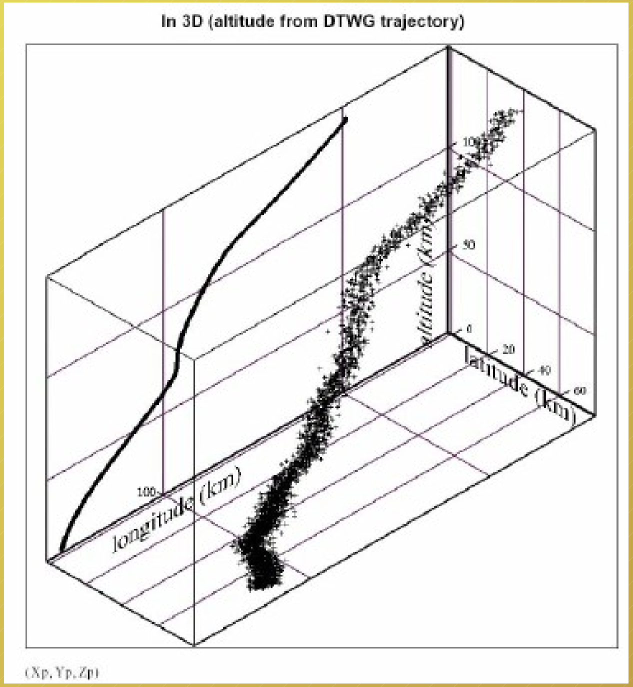
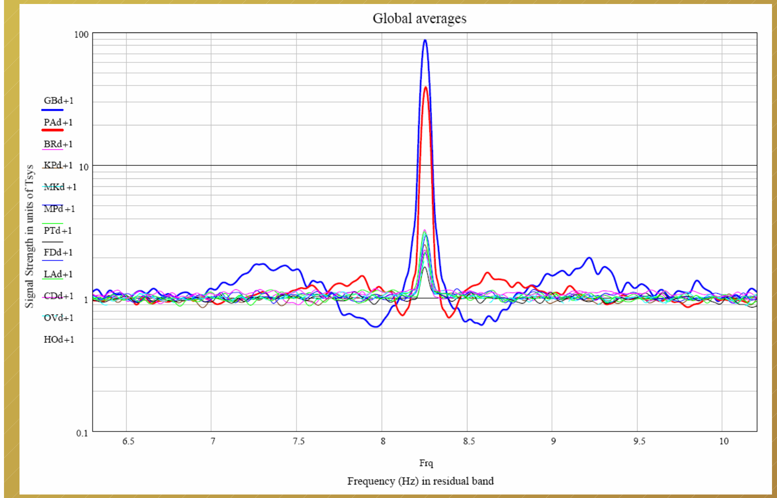
Space Science VLBI Experiments: Cassini-Huygens on Titan

This technique proved to be very efficient in the VLBI Experiment with the Huygens Probe carried out during its descent on the surface of Titan. *This experiment, conducted with a non-optimum setup yielded a reconstruction of the descent trajectory with the accuracy of ~1 km.*





Pre-correlation spectra of the Probe's carrier line, resolution 30 mHz

3-D trajectory of the Huygens probe, reconstructed from VLBI data.

Position error scatter ellipse is 2km by 0.5 km (1 sigma) in Titan-centric frame.

Phase-delay error of 10-15 picoseconds at 25 m antennas.

PRIDE mission requirements

Positional accuracy of PRIDE

Mission	Distance AU	Transmitter power/gain	Band	Time resolution s	Delay noise ps	Lateral Positional Accuracy m
Huygens	8	3W/3 dBi	S	500	15	1000
Europa Jupiter Space Mission	5	10W/6 dBi	S	100	5	120
			X	10	3	70
			Ka	10	1	23

The on-board set of PRIDE instruments includes:

- Transmitter(s) and/or transceiver(s).
- Ultra Stable Oscillator.
- Antenna.

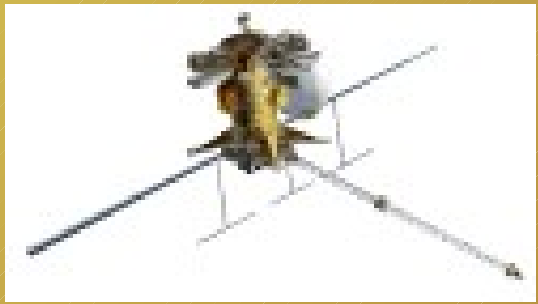
None of the above is a PRIDE-only device. However, it is essential to optimize parameters of these devices in view of their inclusion in PRIDE.

Earth-based assets of PRIDE are:

- Network of radio telescopes.
- Specialized data processing center.

PRIDE mission requirements

On-board instrumentation:



PRIDE can operate with both specially designed radio science devices (transponders, transceivers, antennas) and spacecraft service radio systems.

·It is therefore important to discuss the optimization of the on-board radio devices for PRIDE. This will make possible a broad sharing of resources between PRIDE and other mission systems and experiments: PRIDE is an active participating in the EJSM mission (and in most of the forthcoming space missions: Phobos-Grunt, Bepi-Colombo, ExoMars,...)

Network of radio telescopes and **specialized data processing center**:

These components of PRIDE constitute a backbone of the European and global VLBI networks.

The work in progress at JIVE and other EVN institutes will extend the broad-band capability of the European radio telescopes and data processing facility (correlator) to 4 Gbps and higher data rates. This will further advance the capability of PRIDE by enabling high-accuracy observations with weaker celestial background reference radio sources.

The time-frame of this EVN development is well within the time-line of the EJSM implementation.

Ongoing tests and Recent results:

The campaign is in a framework of the assessment study of the possible contribution of the EVN to upcoming space missions

Observations are carried out either in single- or multi-dish mode when spacecraft is locked to the ESTRACK ground station (Cebreros or New Nortia) observing the two-way link (up- and down-link channel).

The Array:

Metsähovi (Finland)
Medicina, Noto, Matera (Italy)
Wettzell (Germany)
Yebes (Spain)
Pushchino (Russia)

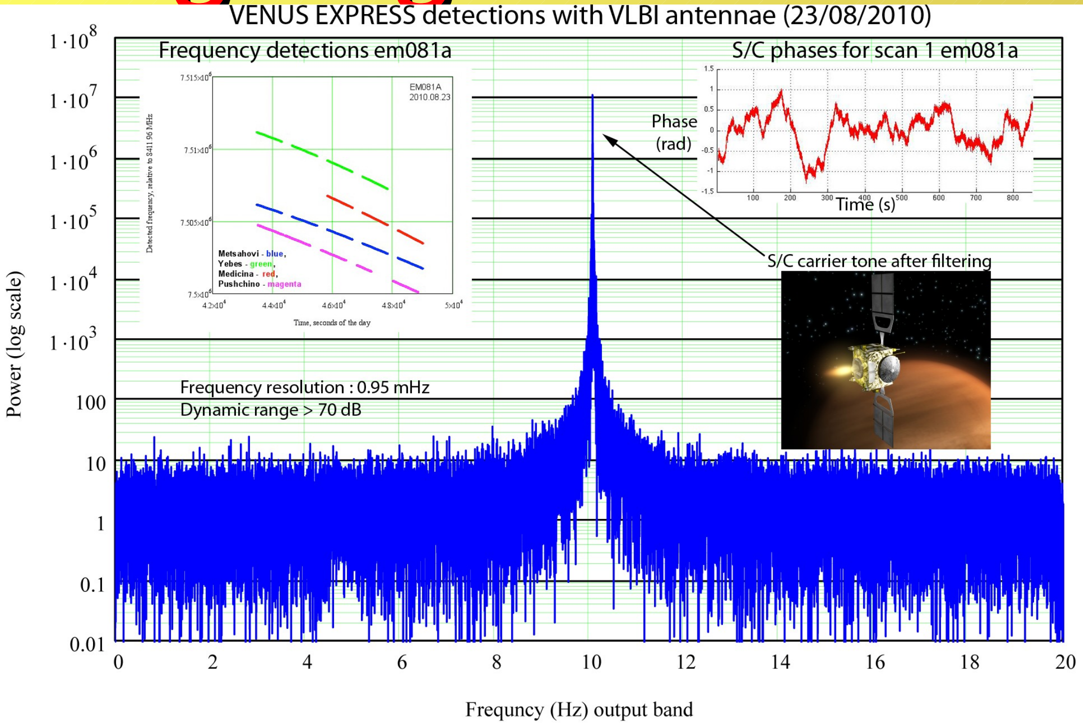
Onsala (Sweden)
Warkworth (New Zealand)

	2009	2010
MEX		3
VEX	14	22
EM081		A & B

Few days ago (Early September 2010), a team of Warkworth and Metsähovi scientists tested a direct eVLBI streaming of MEX data from New Zealand to Finland at data rate of 512 Mbps.

The data were streamed from the Warkworth PC-EVN directly to Metsähovi using the tsunami protocol (see Tim Natusch's poster).

Ongoing tests and Recent results:



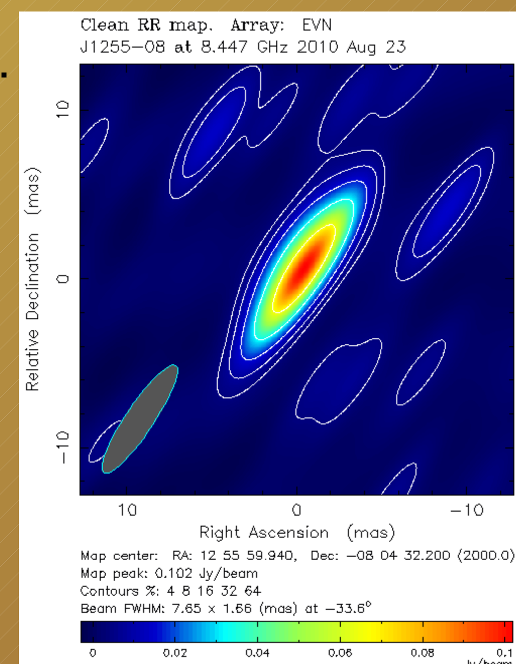
Venus Express:
EVN experiment
23 August 2010 X-band

- Sub-milliHz spectral resolution, >70dB dynamic range.
- Picosecond level accuracy of phase/delay tracking in 10-100s.

Potential of up to 50AU capability with 14m dish on VEX-class transmitter..

EM081A: 23 August 2010 VEX and the sources J1256-0547 for 6 hours.

- Metsähovi, Medicina, Onsala, Yebes and Puschino.
- VLBI standard recording + e-transfer using tsunami-UDP to Metsähovi Radio Observatory and to JIVE.



With such multi-station observations the phases can be calibrated per-baseline basis using phase referencing observations of near-by quasars and using the far-field VLBI delay model for quasars and near-field model for spacecraft.

Ongoing tests and Recent results:

Phobos fly-by:

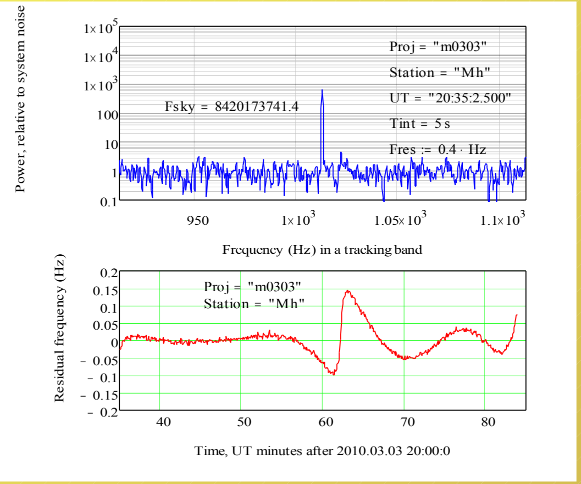
3 March 2010

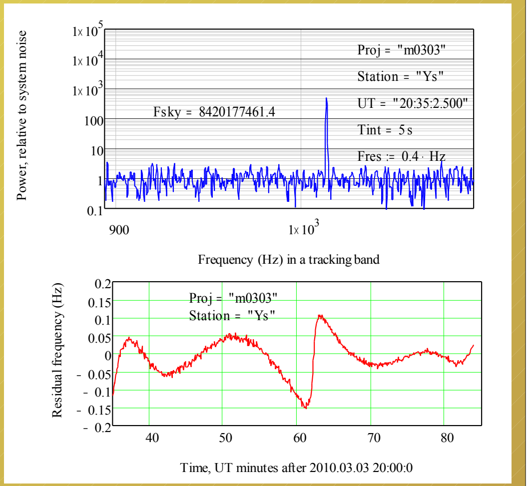
Simultaneous observations at 3 stations: Metsähovi, Wettzell and Yebes.

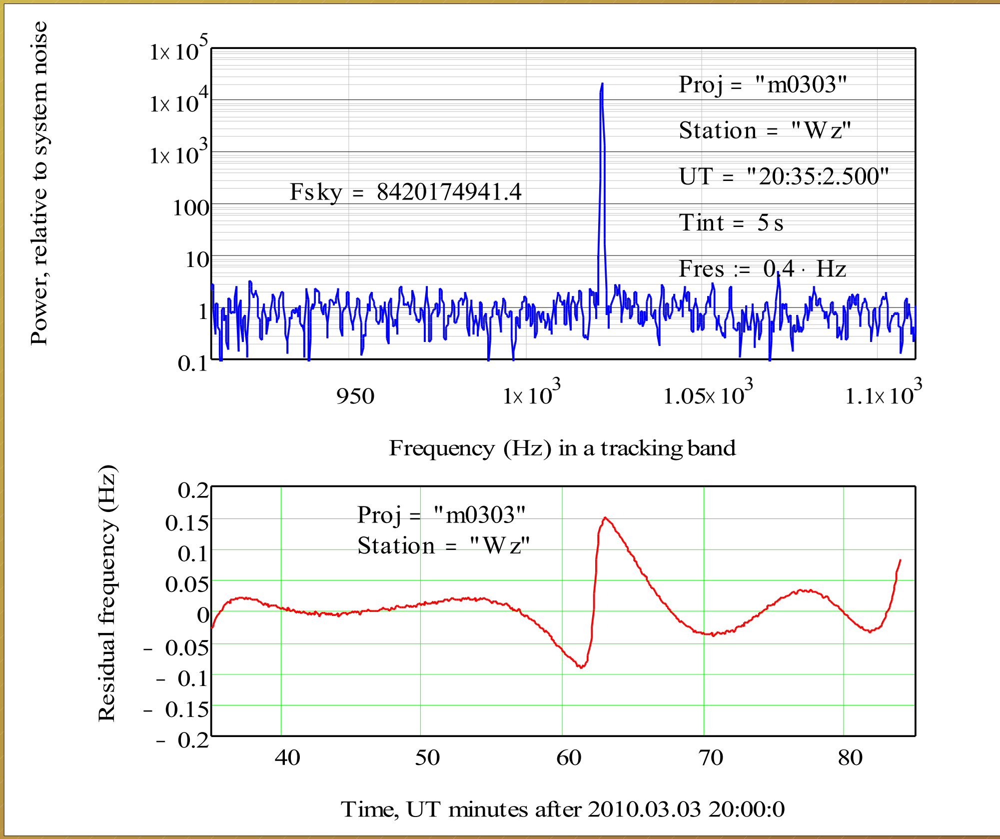
Frequency detection noise is at a level of 2-5 mHz in 5 seconds.

Doppler shift due to Phobos during a close fly-by in March 2010.

http://webservices.esa.int/blog/post/7/1037







Future work:

to better determine the Phobos gravity field and, together with phase referencing, to provide additional geometrical constrains on the orbiter/Phobos trajectories. Participation to the Phobos/grunt lander mission.

More results:

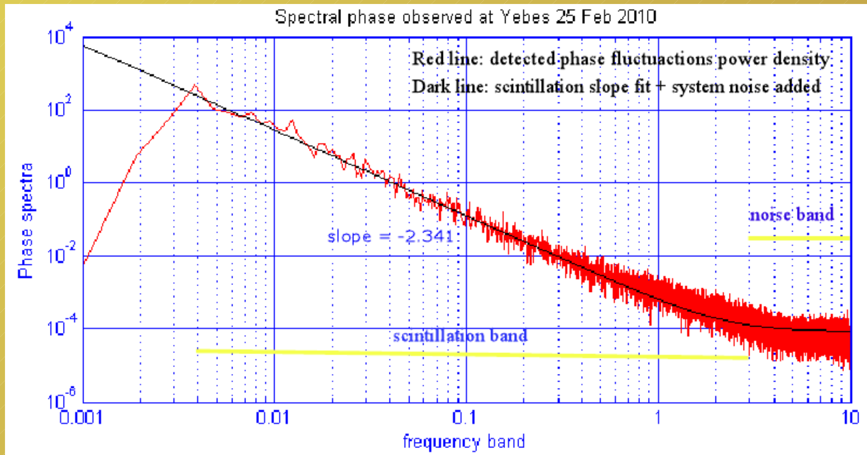
Scintillation:

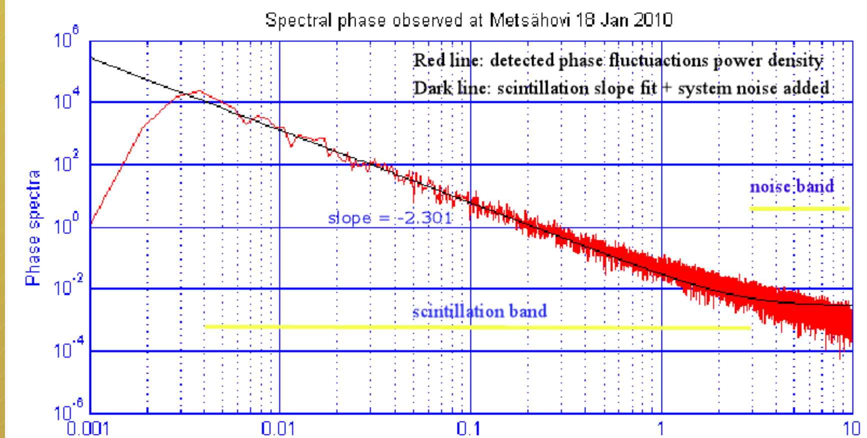
VLBI observations of Venus Express allow an opportunity to study the Interplanetary plasma scintillations (IPS).

The phase fluctuations of the spacecraft signal carrier line can be used to characterise the interplanetary plasma density fluctuations along the signal propagation line at different spatial and temporal scales at different Solar elongations.

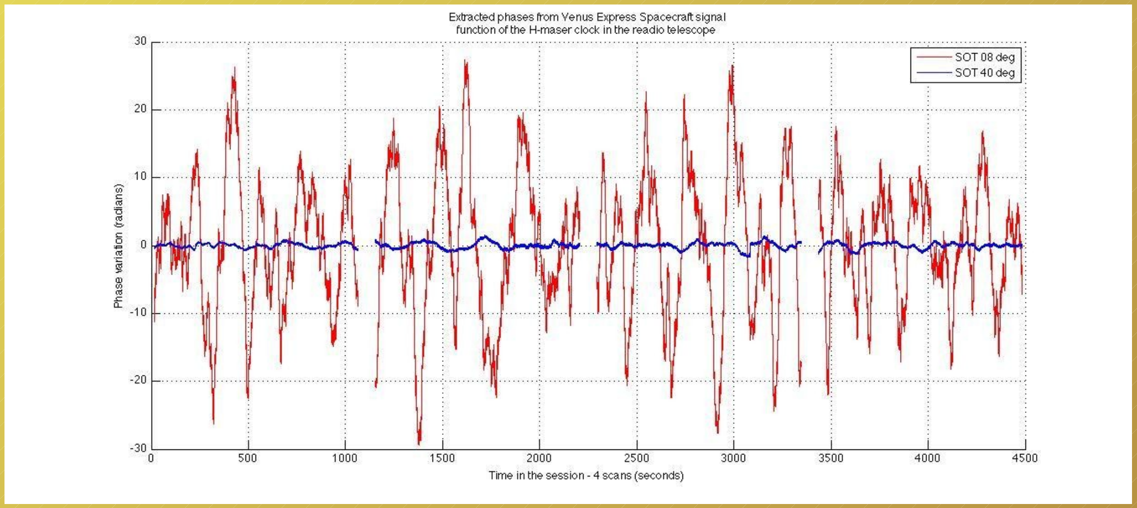
near-Kolmogorov spectrum

The measured phase fluctuations of the carrier line at different time scales can be used to determine the influence of the Solar wind plasma density fluctuations on the accuracy of the astrometric VLBI observations of planetary probes.





Molera Calvés et al. 2010



Extracted phases for sessions v1601 and v0307 observed with Metsähovi radio telescope. The red line shows a high phase variation caused by the Interplanetary Plasma media when the Solar Elongation was 8 °.
Blue line at 41°.

Conclusions

- Success of Space Science VLBI

- PRIDE: Planetary Radio Interferometry and Doppler Experiment is a 'free' contributions to space mission:

  - Ultra-precise celestial mechanics
  - Geodynamics, Shape and gravimetry, internal structure and composition of moons
  - Electric properties of icy satellite surfaces and their environments;
  - “stereoscopic” view due to the multi-antenna nature
  - Fundamental physics effects.

- Close collaborations with ESA, NASA, JAXA, IKI

PRIDE-EVN observations of the Phobos-Grunt Lander,Bepi-Colombo,ExoMars, EJSM,...

- Technical developments at JIVE and EVN

- Ongoing tests, EVN experiments and first scientific results:*scintillation.*

Thank you!