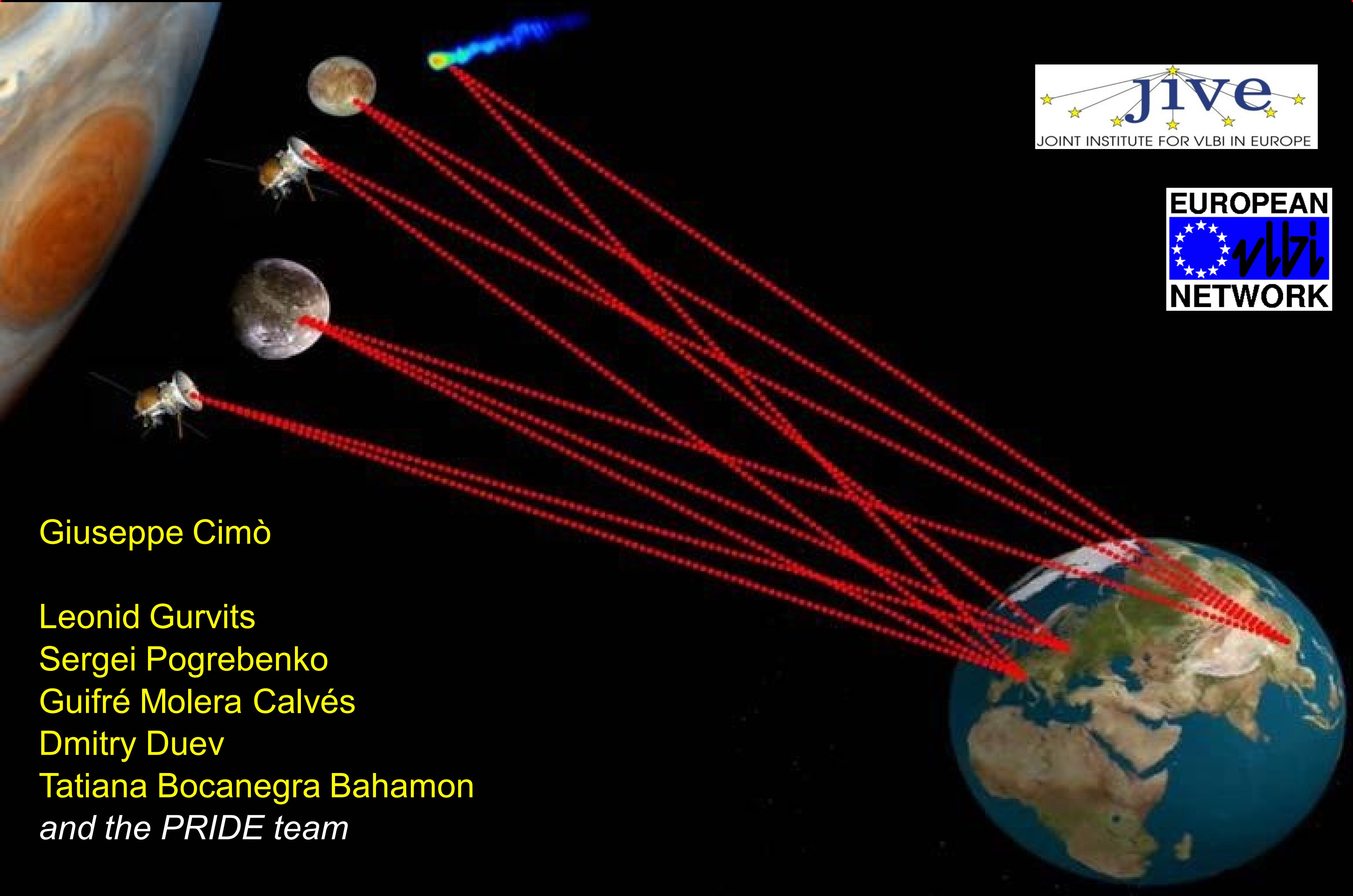
# Planetary Radio Interferometry and Doppler Experiment
# PRIDE

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*and the PRIDE team*

# Summary:

- VLBI for planetary science
  - the PRIDE technique
  - the Huygens VLBI tracking
- Space mission requirements
  - Phobos-Soil cruise phase experiments
  - Astrometry and other technical requirements
- Current Work:
  - EVN experiments
  - Results and achievements

**The PRIDE team**

Lead Institute: Joint Institute for VLBI in Europe

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# PRIDE

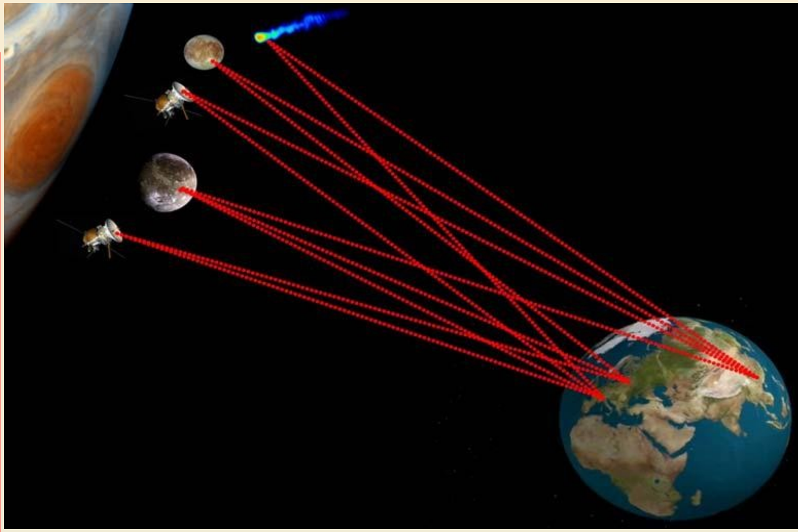
## Planetary Radio Interferometry and Doppler Experiment

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 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.

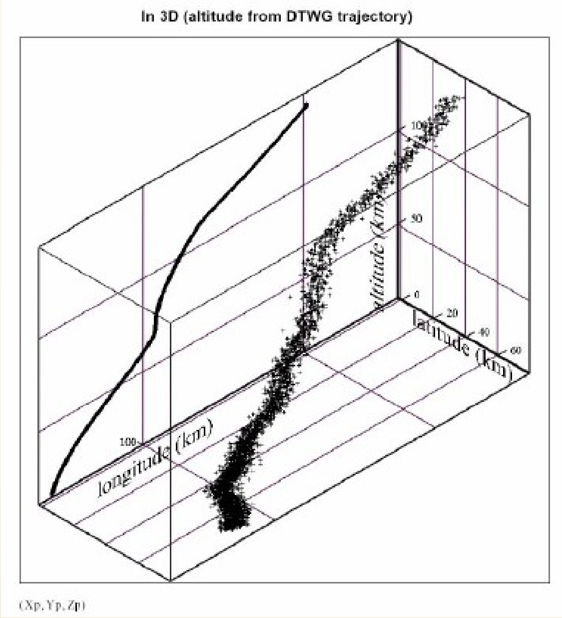
# PRIDE Science

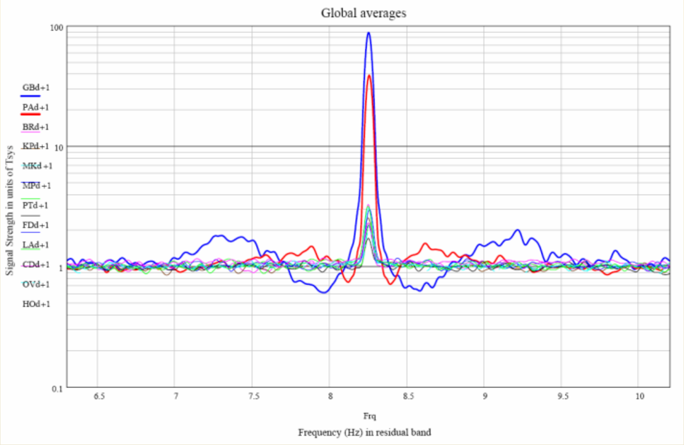
It is a multi-disciplinary enhancement of the scientific suite of current and future planetary missions.
Close collaborations with: ESA, NASA, CNSA, JAXA, IKI

- 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.
- *Vectorization* of the acceleration of deep space probes and ***fundamental physics effects***.

# 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-optimal 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.

# Space Science VLB
# Cassini-Huyg

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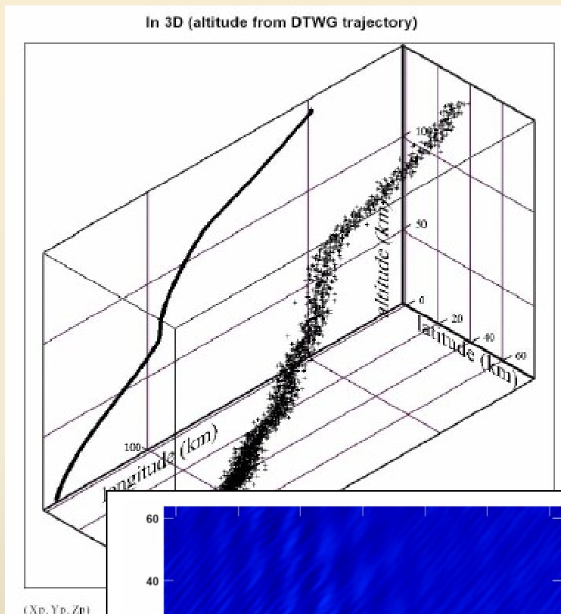
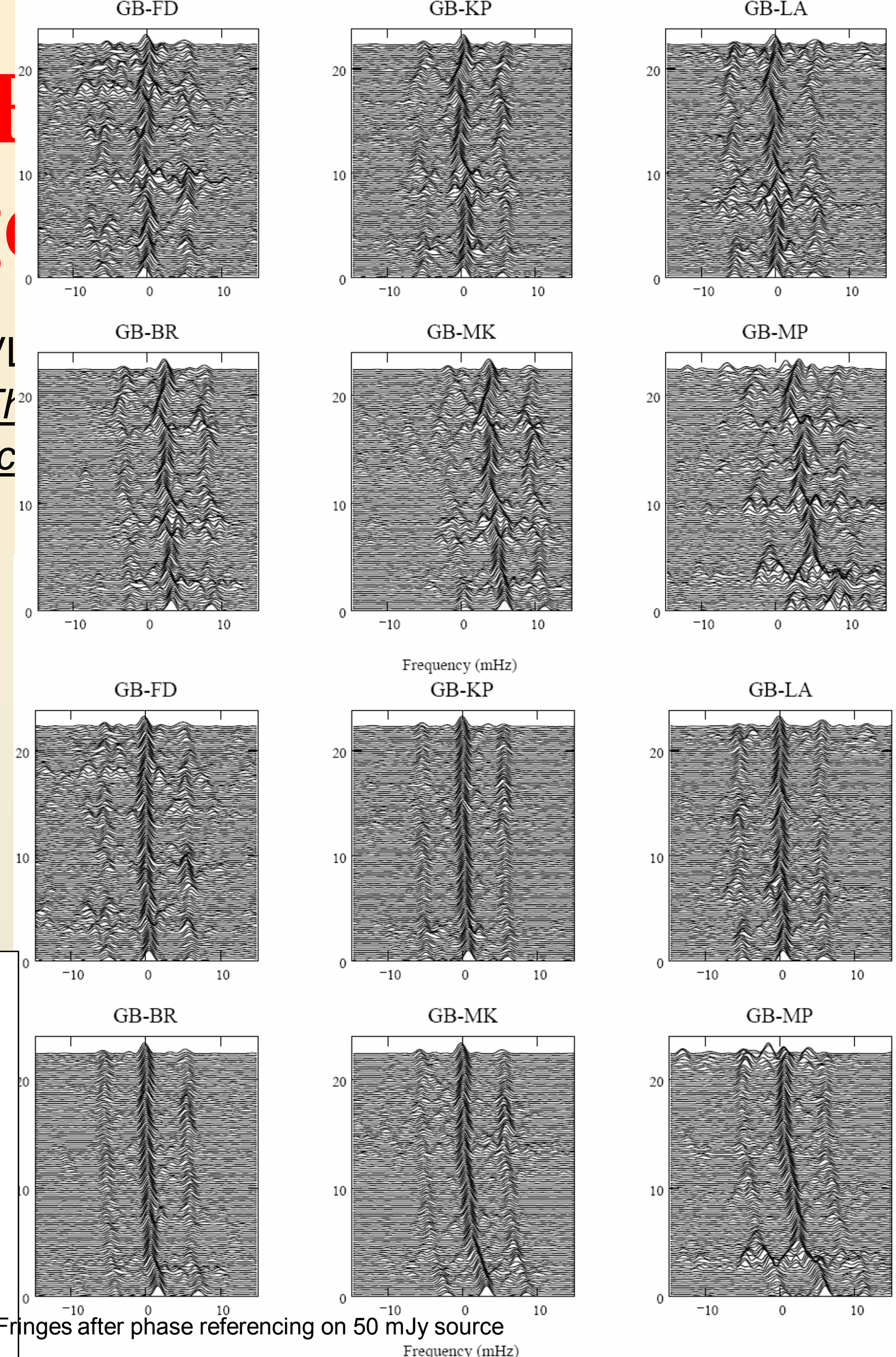
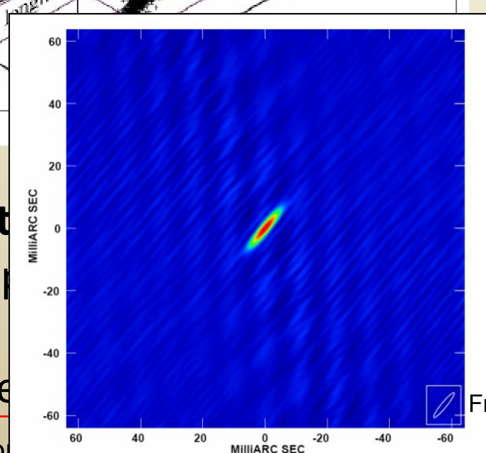


Fringes after phase referencing on 50 mJy source

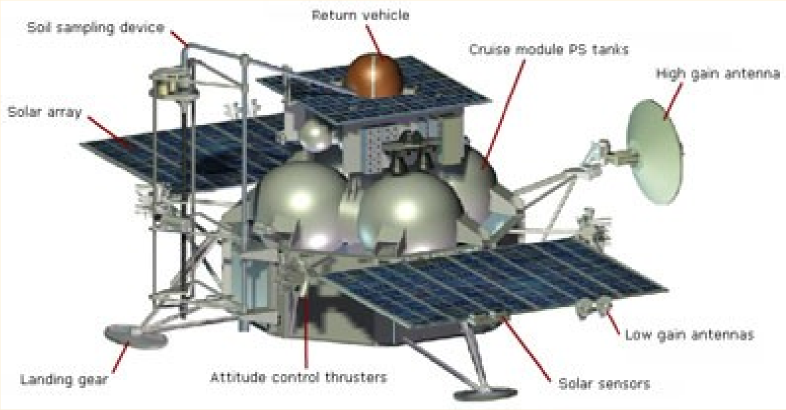



**3-D traject**

Position error scatter ellip

Phase

# Phobos-Soil



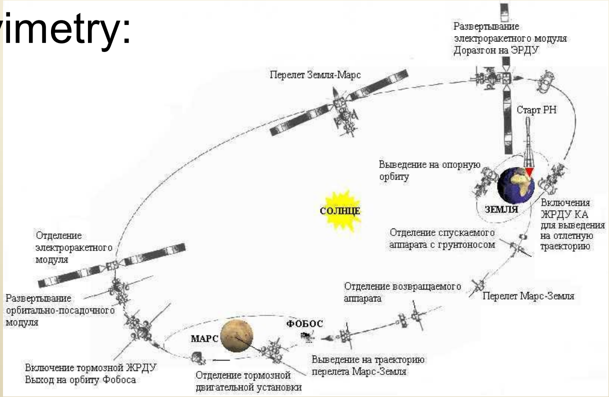

Phobos-Soil (Russia) and YinHua-1 (China) will be launched with the same rocket in November 2011 with the expected time of arrival to the destination, the Martian system, in September 2012.

Characterisation of the parameters of the gravitational field of Phobos and plasma physics studies.

## PRIDE during the cruise phase:

Calibration and comparison of Phobos-PRIDE measurements with other navigation techniques for combined use in the interests of celestial mechanics and gravimetry:

- *measurements of space curvature around the sun;*
- *the time-rate-of-change of the gravitational constant, G;*
- *gravitational inverse square law at 1.5 AU distances.*




(see Turyshev 2009 , Turyshev et al 2010)

Precise orbit determination is needed for relativistic celestial mechanics experiments.

**We need good and close-by calibrators!**

# PRIDE mission requirements

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.

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- **Near-GPS accuracy celestial mechanics of the Jovian system;**
- **Measurements of tidal deformations;**
- **Geodynamics, internal structure and composition of Ganymede and Europa;**
- **Shape and gravimetry of Callisto;**
- **Electric properties of icy satellite surfaces and their plasma environments can be measured during the S/C occultation by Jovian moons;**
- **Fundamental physics effects.**

## Positional accuracy of PRIDE

| Mission | Distance | Transmitter power/gain | Band | Time resolution | Delay noise | Lateral Positional Accuracy |
|---|---|---|---|---|---|---|
| | AU | | | s | ps | 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 |

# 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-Soil, 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.

**Need of good calibration!**

# Observing campaigns:

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).

| | 2009 | 2010 | 2011 |
|---|---|---|---|
| MEX | | 3 | |
| VEX | 14 | 22 | 11 |
| EM081 | | A & B | D |

**The Array:**

Metsähovi (Finland)
Medicina, Noto, Matera (Italy)
Wettzell (Germany)
Yebes (Spain)
Pushchino, Svetloe, Zelenchukskya (Russia)
Onsala (Sweden)
Warkworth (New Zealand)
Hartebeesthoek (South Africa)
Fortaleza (Brazil)
VLBA antennas (USA)

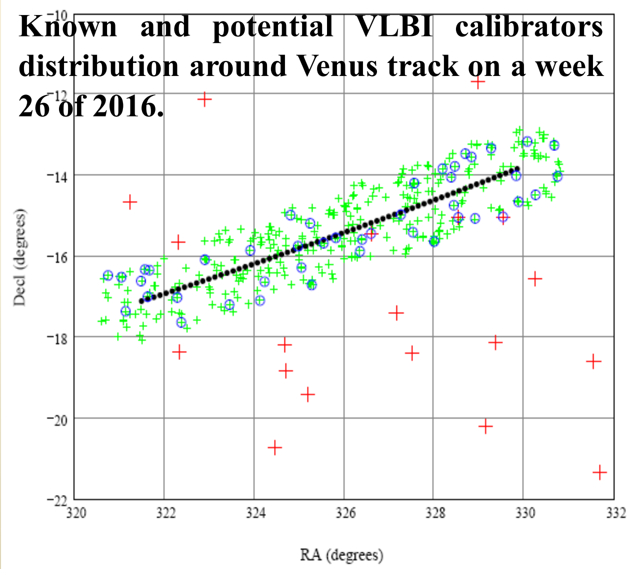
## Search for suitable calibrators:

Dedicated radio astronomical surveys of the areas of interest are required.

Target-focused astrometric surveys are needed to improve phase-referencing quality of S/C VLBI experiments.

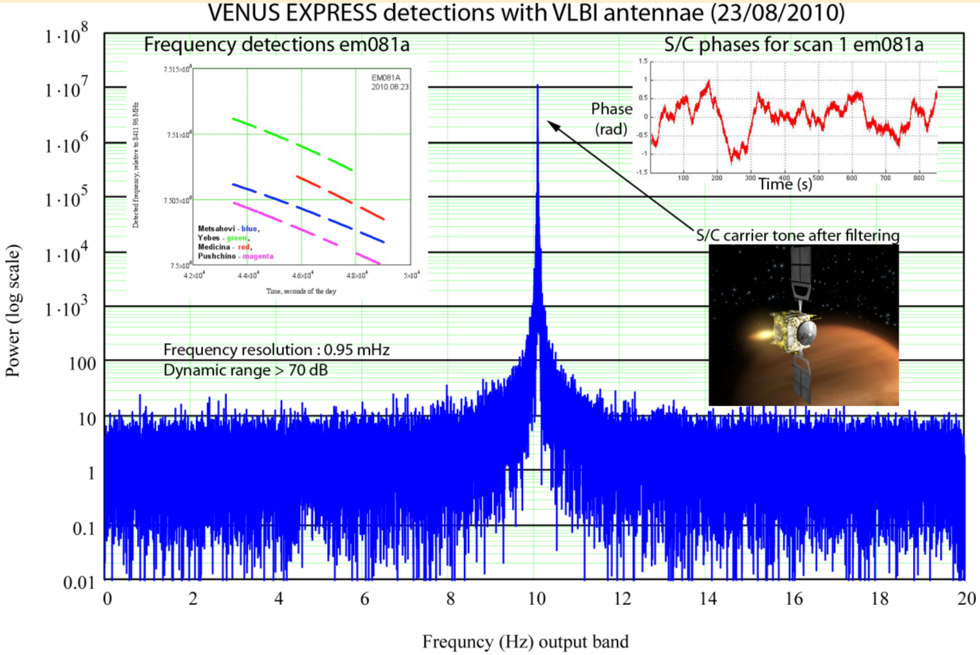
Goal to use <50 mJy sources for phase referencing.

**Known and potential VLBI calibrators distribution around Venus track on a week 26 of 2016.**




**Red crosses – sources from astro2008a (L. Petrov)**
**Blue circles - 87GB/PMN sources (C-band)**
**Green dots - NVSS (L-band) with flux > 20 mJy.**

# Ongoing tests and Recent results:




**Venus Express:**
EVN experiment
23 August 2010 X-band

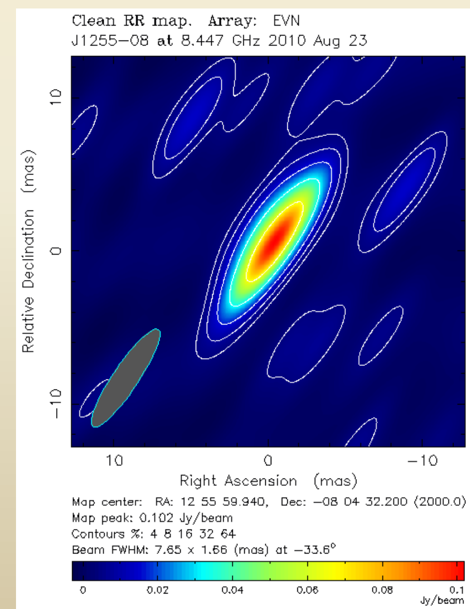
- Sub-milliHz spectral resolution, >70dB dynamic range.
- Picosecond level accuracy of phase/delay tracking in 10-100s.

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.

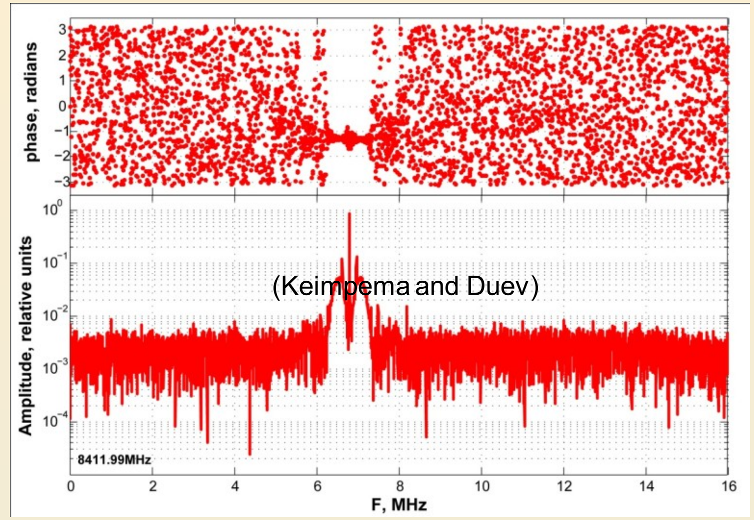
With such multi-station observations the phases can be calibrated per-baseline basis using phase referencing observations of near-by quasars and using the far-field VLBI delay model for quasars and near-field model for spacecraft.

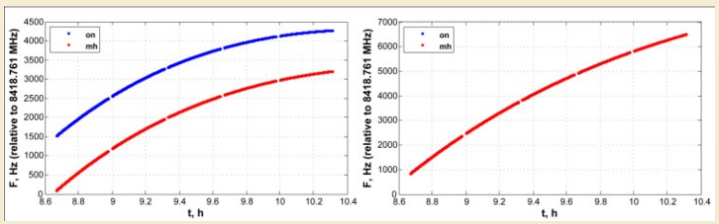


# Ongoing tests and recent results:

## JIVE Software Correlator and signal analysis

Broadband correlation of the VEX signal on the baseline Onsala – Metsähovi, 25.03.2011 with the SFX correlator at JIVE: amplitude and phase of the cross-correlation function, averaging – 20 seconds. Most of the power of the spacecraft signal is concentrated within ~ 1 MHz wide band around the carrier line.

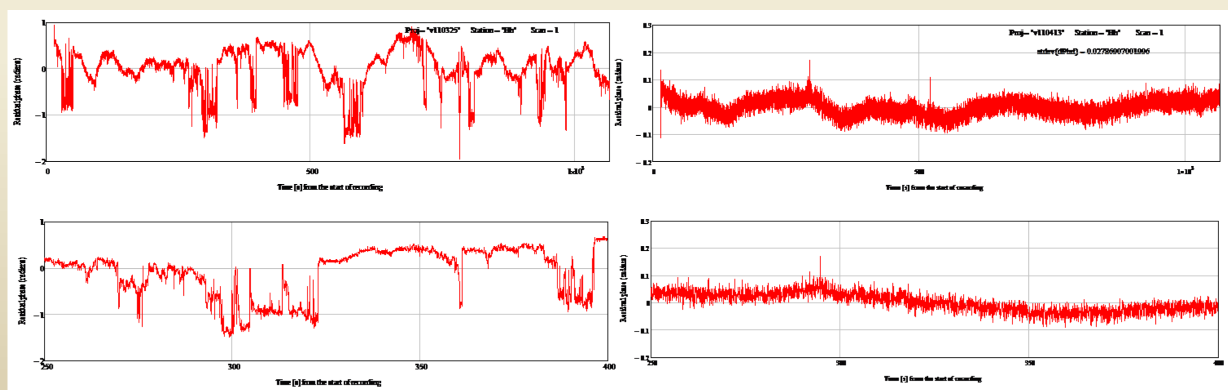



Left – topocentric detections of the VEX carrier frequency at Onsala and Metsähovi, 25.03.2011
Right – frequencies reduced to the geocentre.

## Performance checks:

Hh phase noise, problems at the stations. Help with the diagnosis and correction.



Before

After

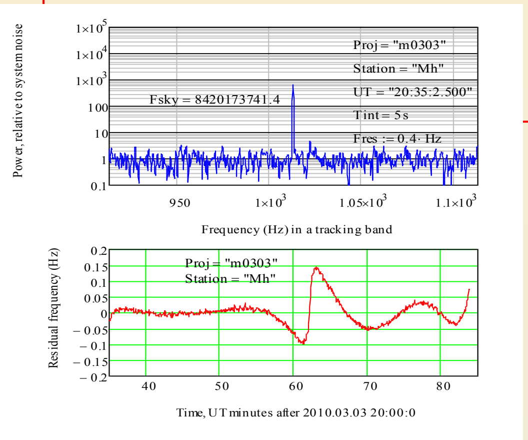
# Ongoing tests and Recent results:

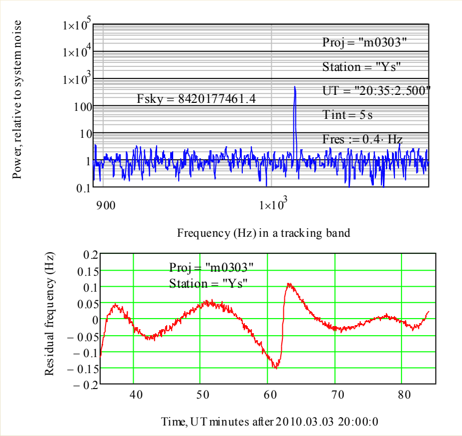
**Phobos fly-by:**

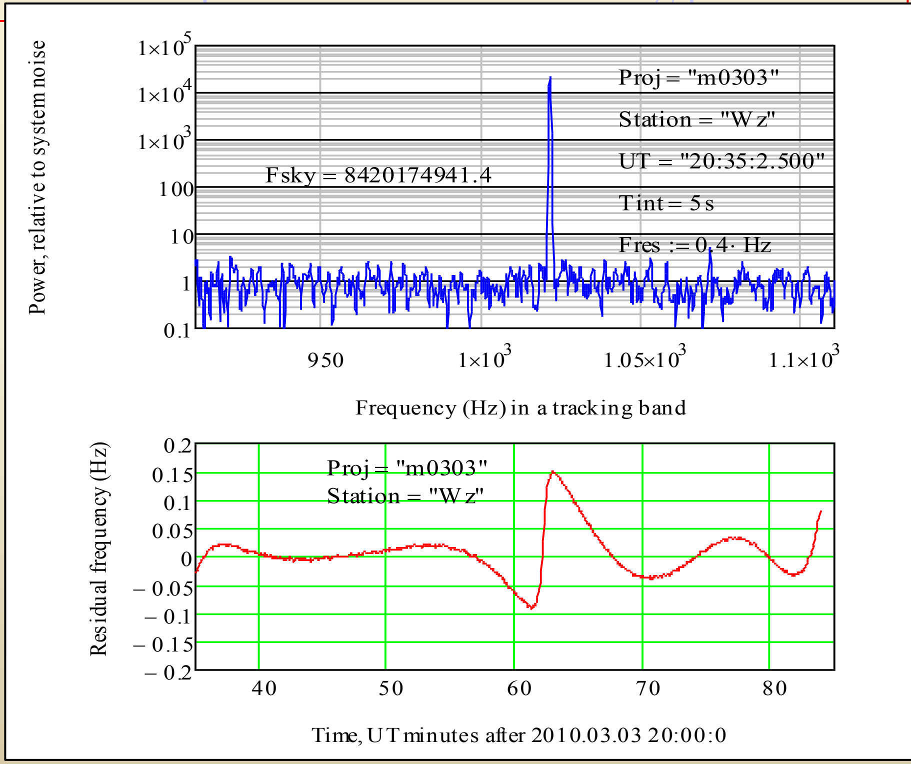
3 March 2010
Simultaneous observations at 3 stations: Metsähovi, Wettzell and Yebes.
Frequency detection noise is at a level of 2-5 mHz in 5 seconds.

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

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




<u>Future work:</u>

Better determination of the Phobos gravity field and, together with phase referencing, to provide additional geometrical constrains on the orbiter/Phobos trajectories. Participation to the Phobos-Soil lander mission.

# More results:

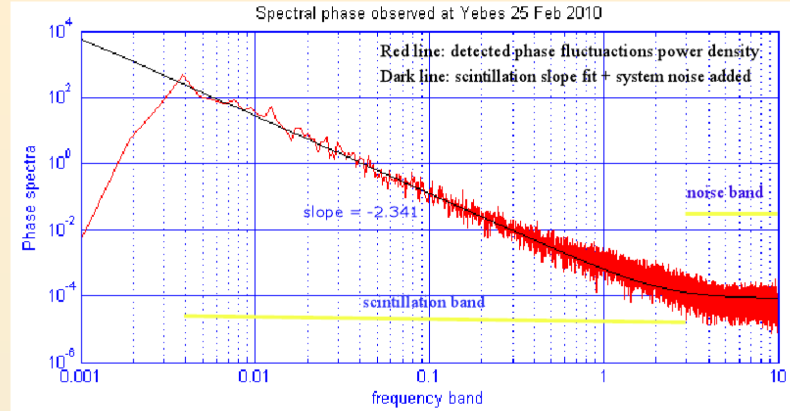
**Scintillation:**

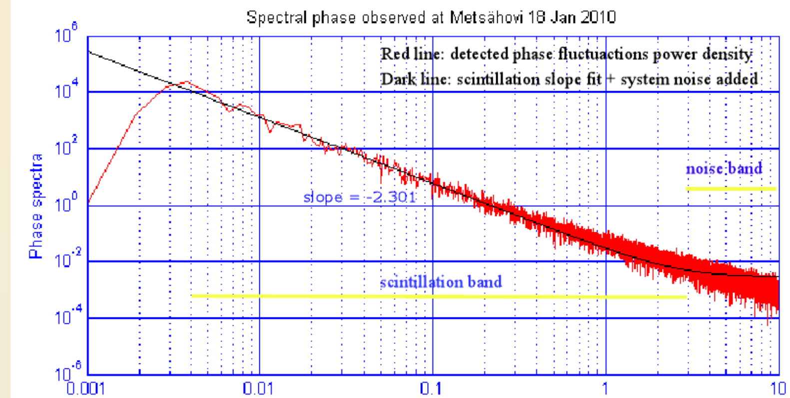
VLBI observations of Venus Express allow an opportunity to study the Interplanetary plasma scintillations (IPS).

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.

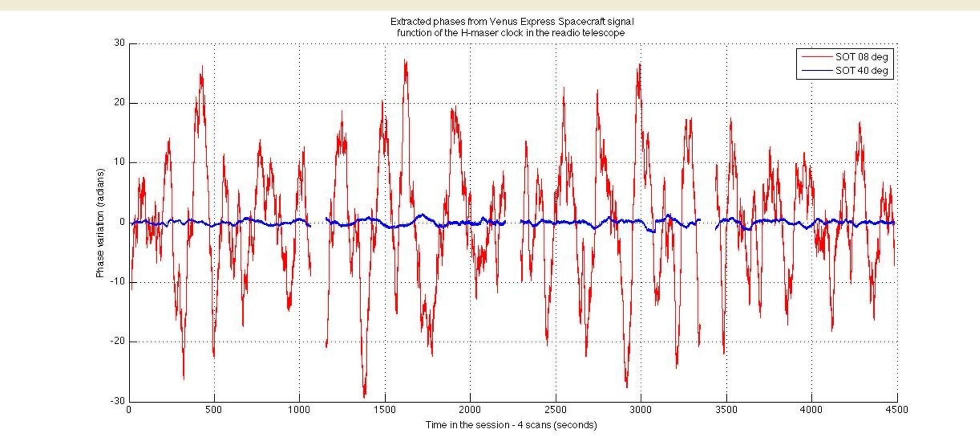
near-Kolmogorov spectrum

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

- Close collaborations with ESA, NASA, CNSA, JAXA, IKI
PRIDE-EVN observations of the **Phobos-Soil** Lander, Bepi-Colombo, ExoMars, EJSM,...

- Technical developments at JIVE and EVN

- Main limitation: Calibration!

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

- ***GAIA as a Target?***