VLBI tracking of planetary missions as a mission tool and scientific experiment

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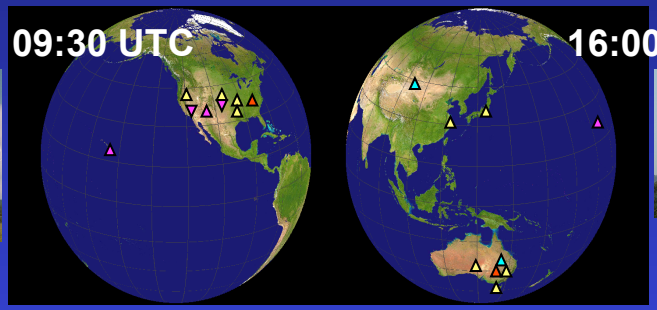
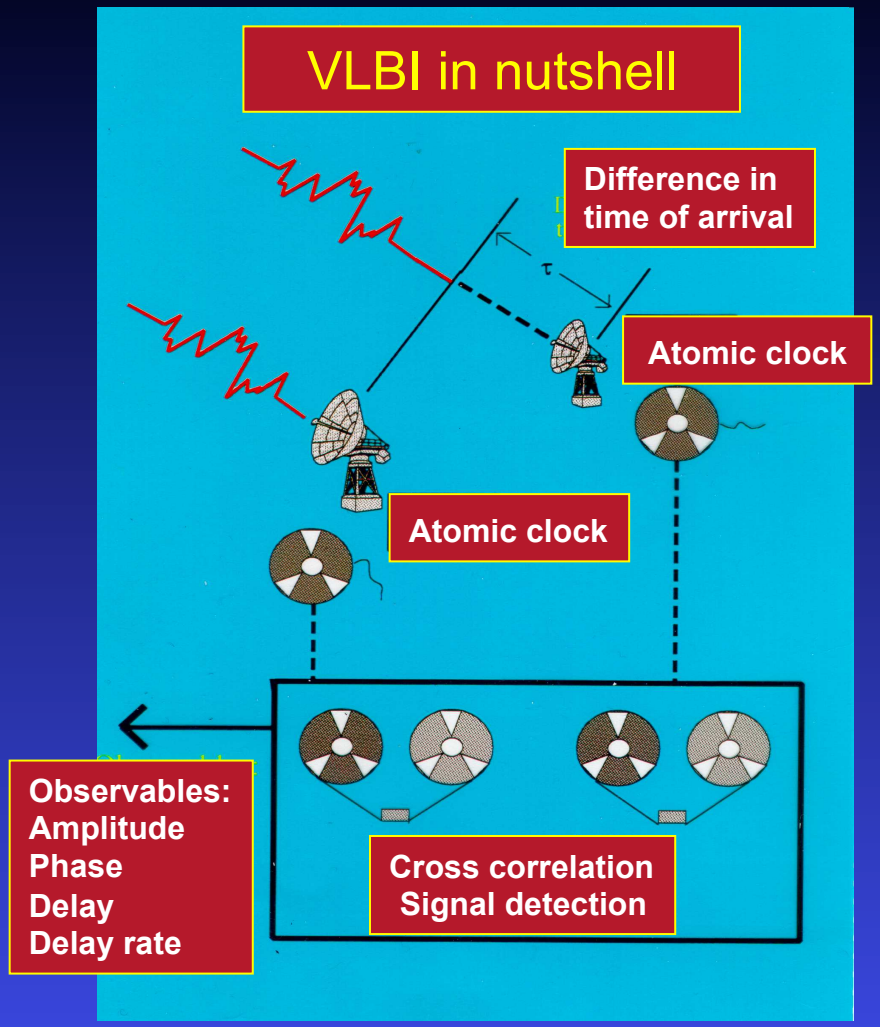
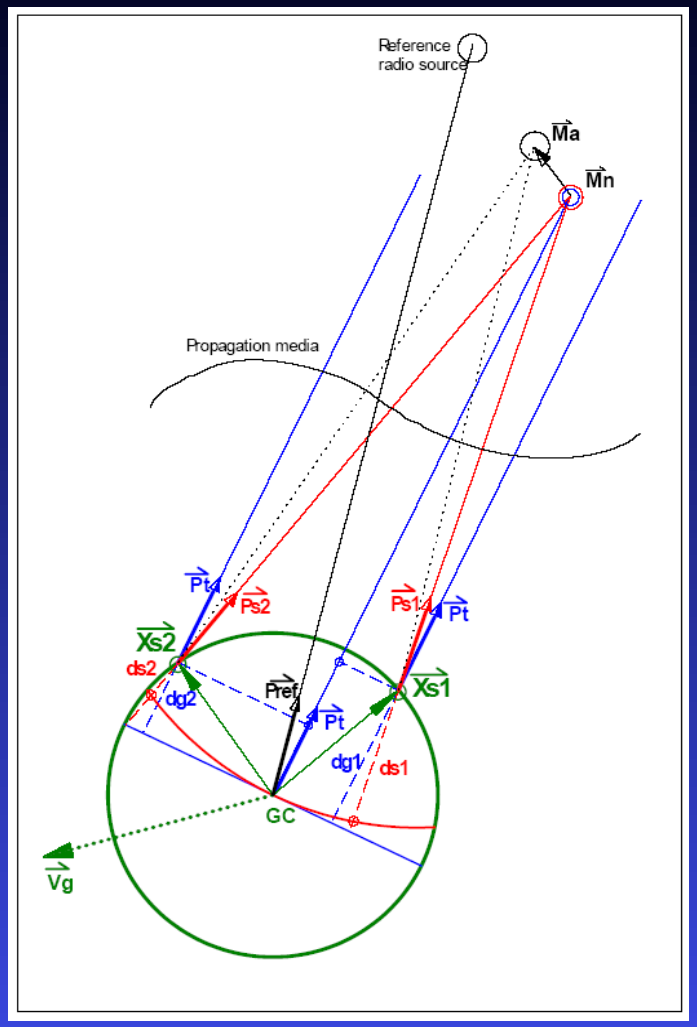
Space exploration & radio astronomy: 50 years together

- Glorious start: first sputnik and 76-m Jodrell Bank (now Lovell) telescope, 4 October 1957
- VLBI tracking of NASA planetary S/C since 1970s (see Thornton and Border 2003
- VEGA Balloons & VEGA/Giotto Pathfinder, 1984-86 (Sagdeev et al., 1992)
- Huygens VLBI Tracking experiment, 2005
- Smart-1 VLBI tracking, 2006
- Chang'E VLBI tracking, 2007 –
- What's next?



VLBI within Solar System: what's different?





Angular resolution ~ λ/B;

Near Field < B^2/λ

Algorithm of VLBI processing

"Standard" broad-band VLBI correlation on calibrators

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Imaging of calibrators and calibration definition

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Extraction of narrow-band probe's Signal from Mk5 to HSC

↓

Application of calibration corrections to the narrow-band data

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Iterative search for monocromatic (carrier) signal; Common Mode defined

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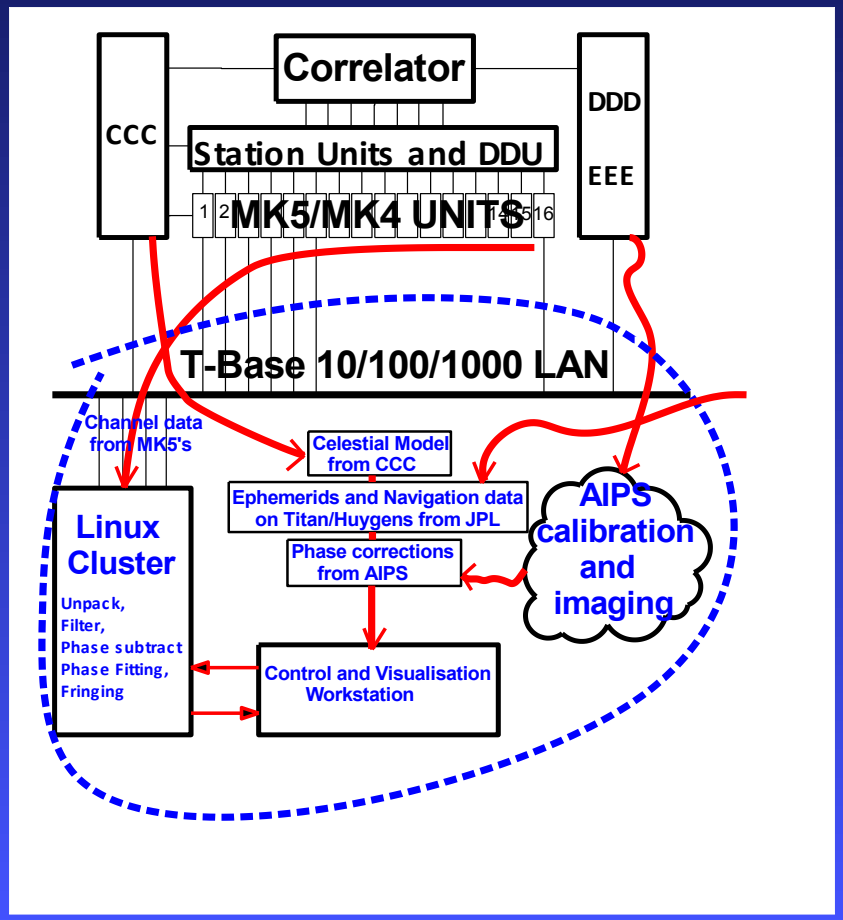
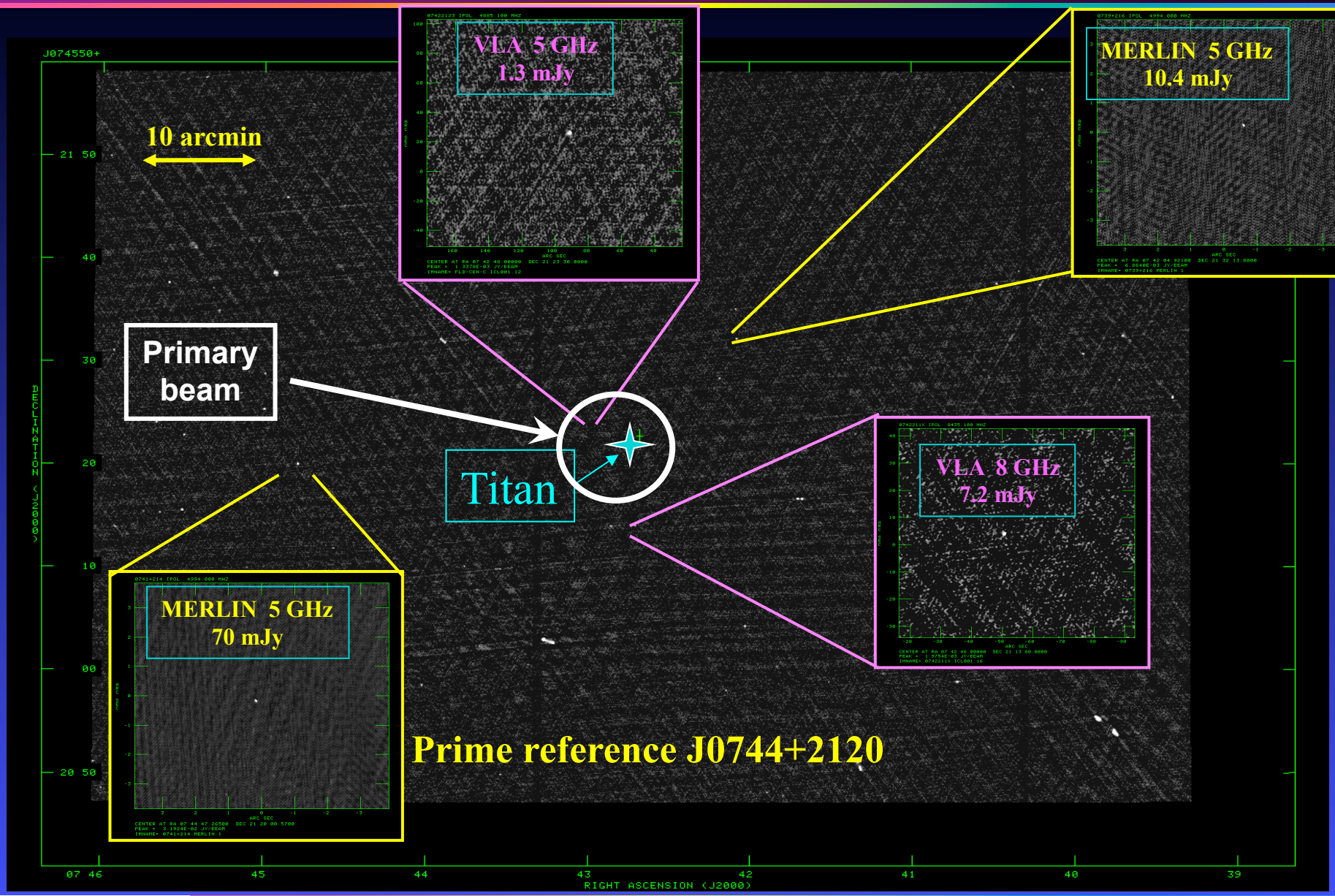
Phase-lock to Common Mode, narrowing down search window

↓

Iterative imaging (trajectory reconstruction)



Phase-referencing in the Huygens Field

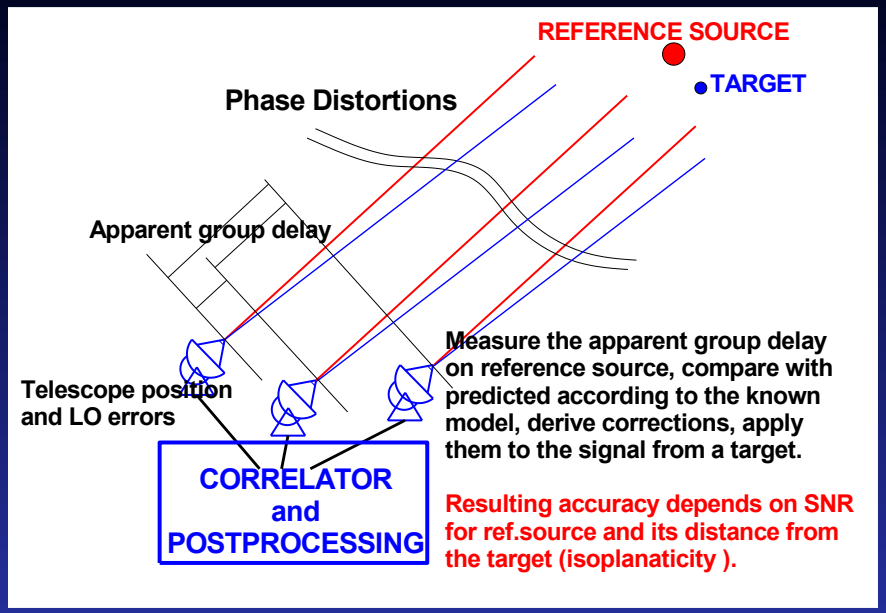


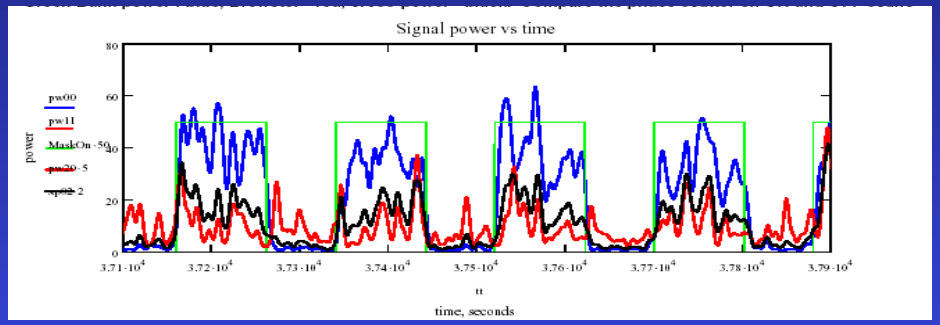
Phase-referencing: the price for being "weak"

- **Phase-referencing duty-cycle 70-110 s:**

- **Phasing-up VLBI network makes possible detection of a ~2 W transmitter at 8 AU**

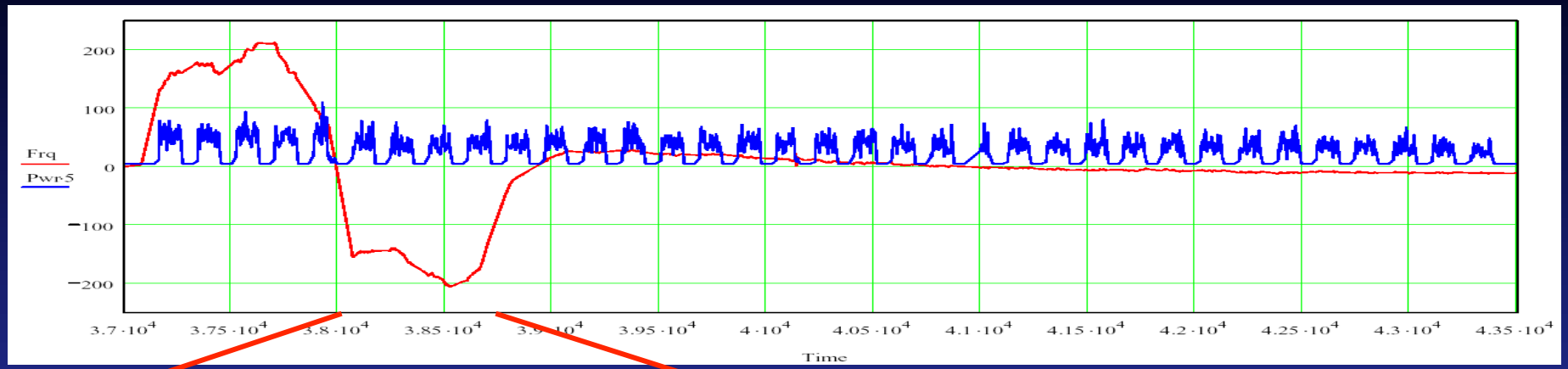
- **Can in-beam (no nodding) phase-referencing help for future missions?**

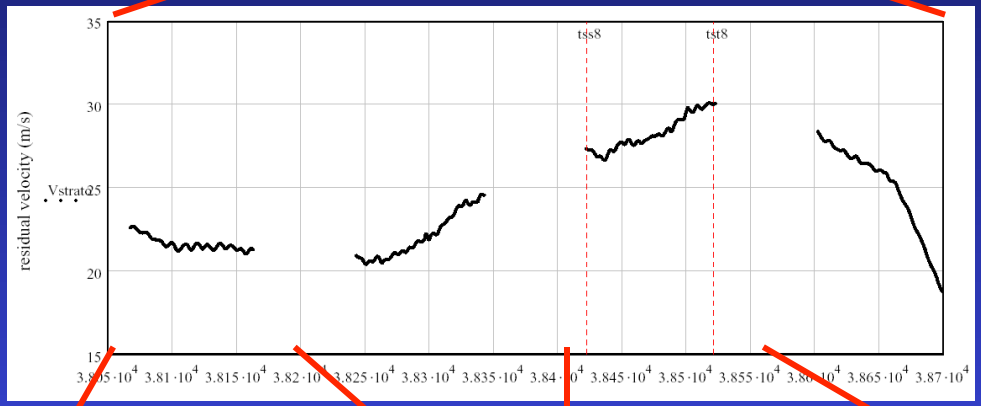


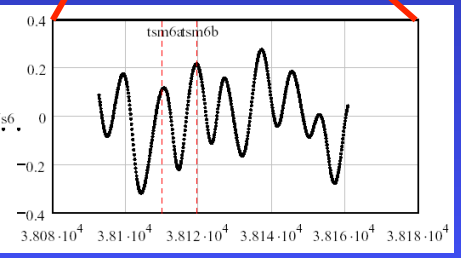


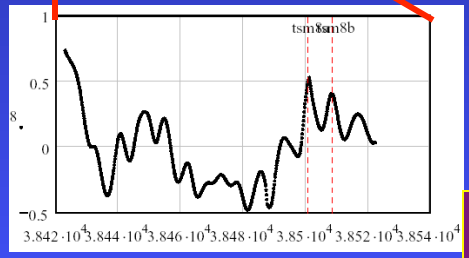
Need for strong enough and compact reference source within primary beam!

VLBI processing by-product: Doppler data (probe's motion)





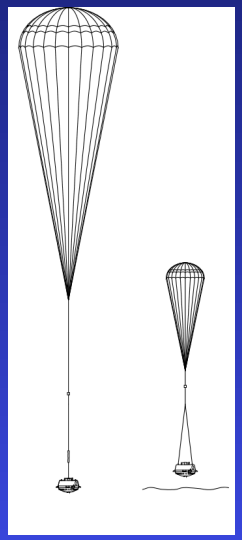


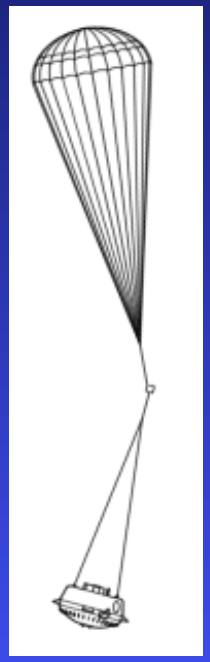


T = 8÷10 s

ΔV = 0.22 m/s

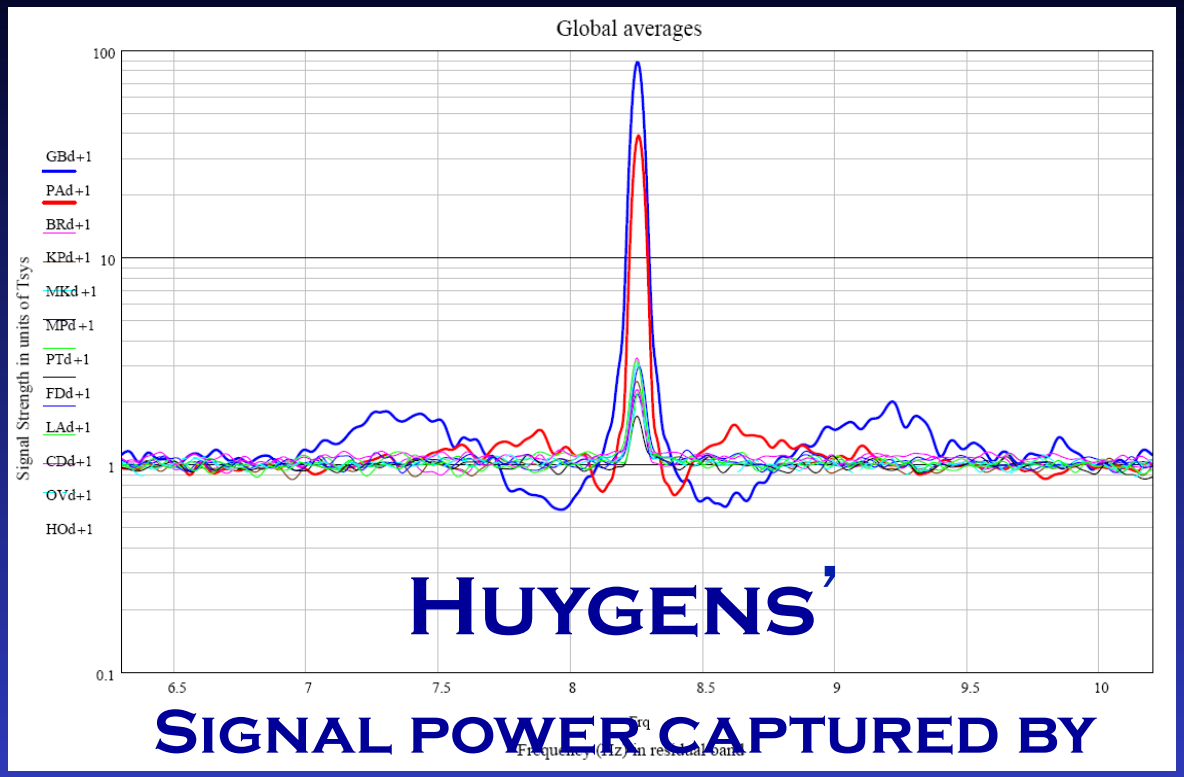
$A \approx$ 0.6 m



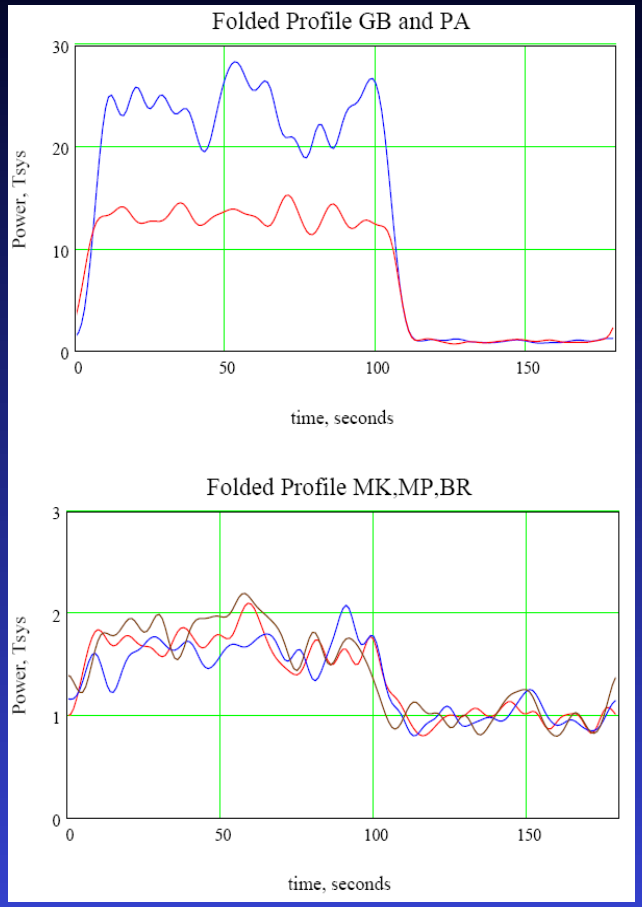


Data available for analysis!

Huygens VLBI tracking as a quantum process



Huygens' Signal power captured by Mauna Kea antenna:



20 photons per second,

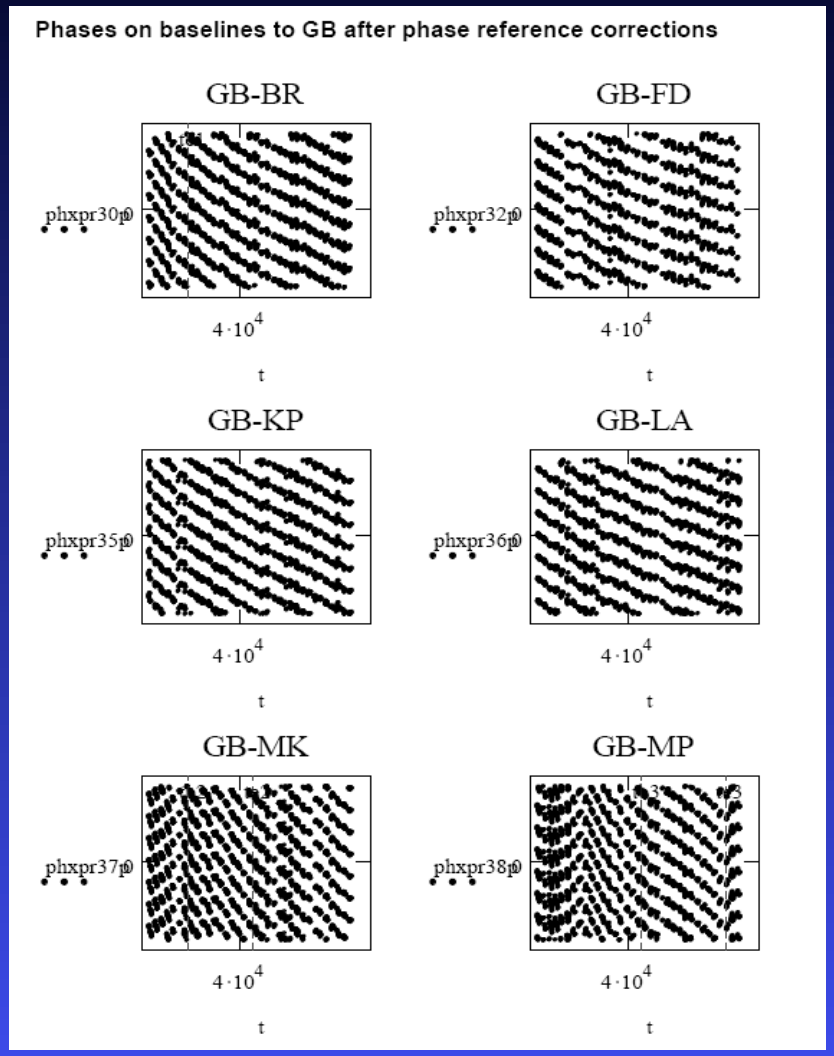
2,040 GHz photons:

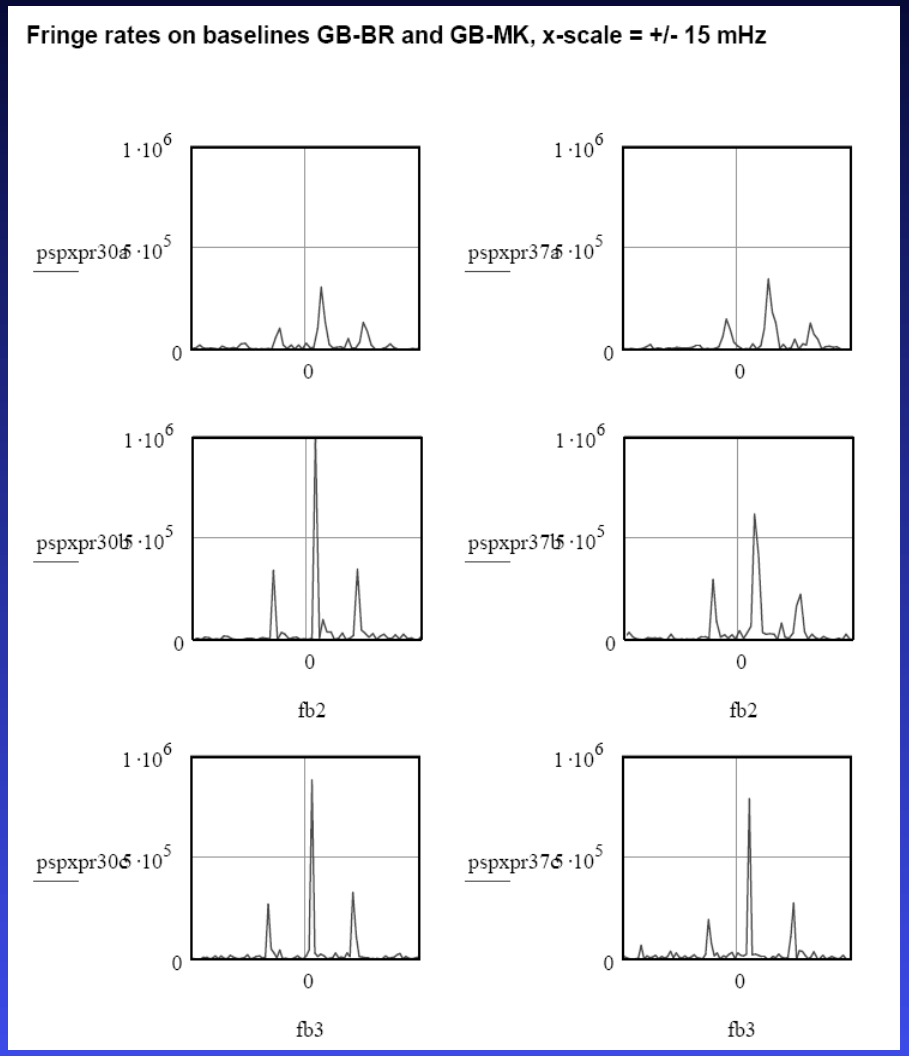
Photon Rate = P / $h\upsilon$

"Pulsar-style" folding

Near-field geometrical model verification

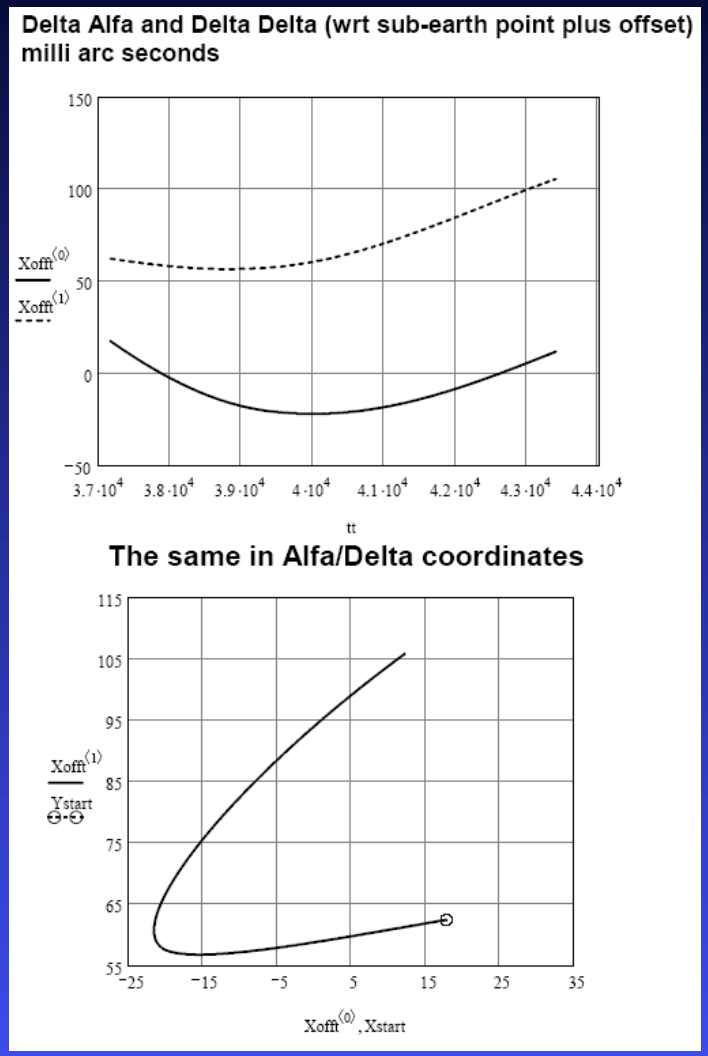
Phases and phase rates of cross-correlated signals on baselines to GBT

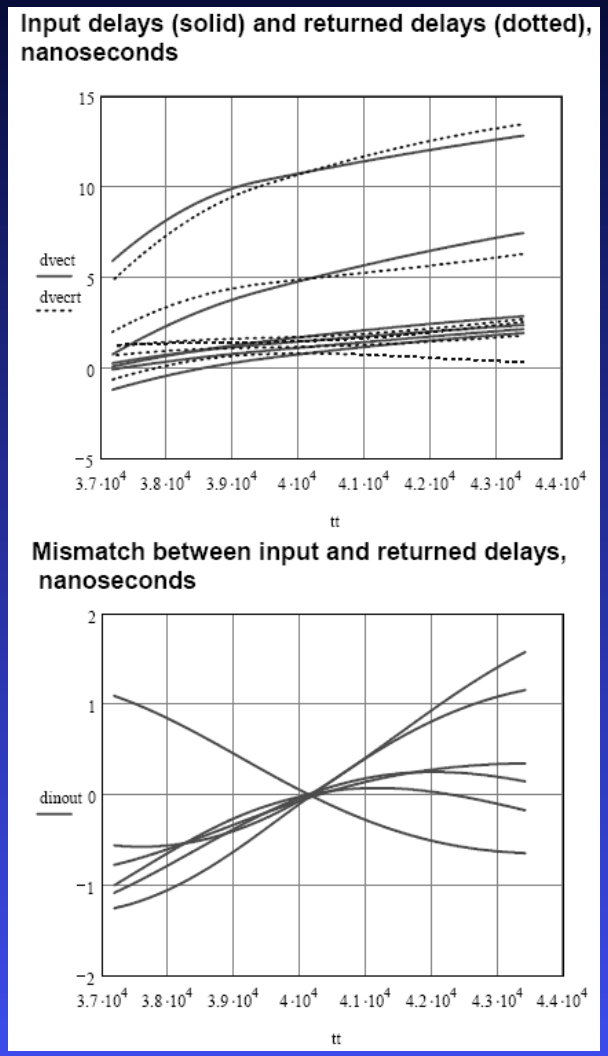




Near-field geometrical model verification

Mapping trajectory with slow delays only, solution with minimized mismatch



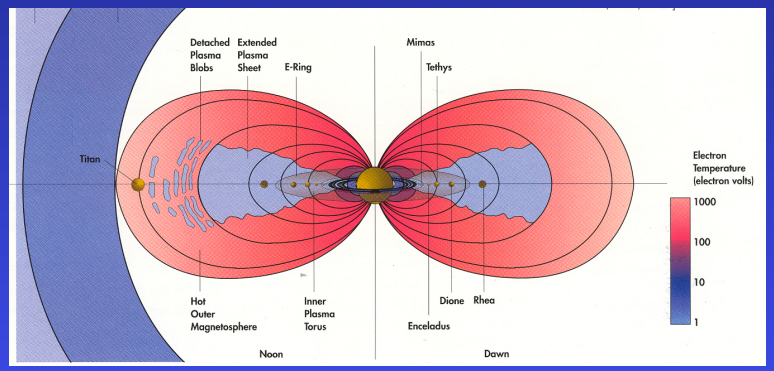


Search for 22 GHz water vapour line from Saturn system with Medicina 32 m radio telescope

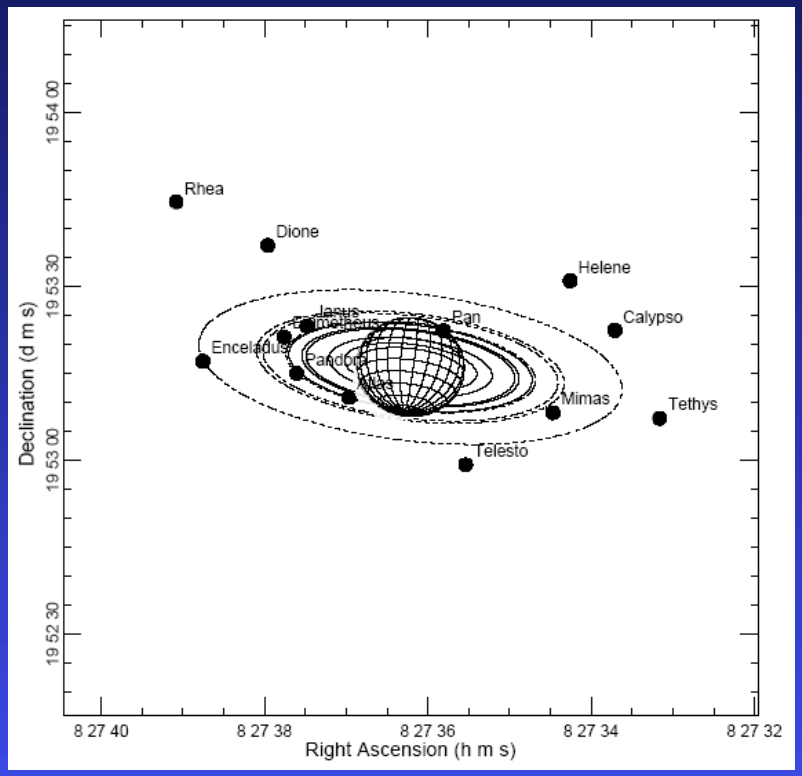
(in cooperation with S.Montebugnoli and G.Maccaferri, INAF/IRA,Italy)

- Observations prompted by Cassini's discovery of water vapor around Saturnian moon Enceladus
- Conducted in March-April 2006 with 32-m Medicina radio telescope using Mk5 recording and JIVE/Huygens software correlator

Medicina 32 m antenna



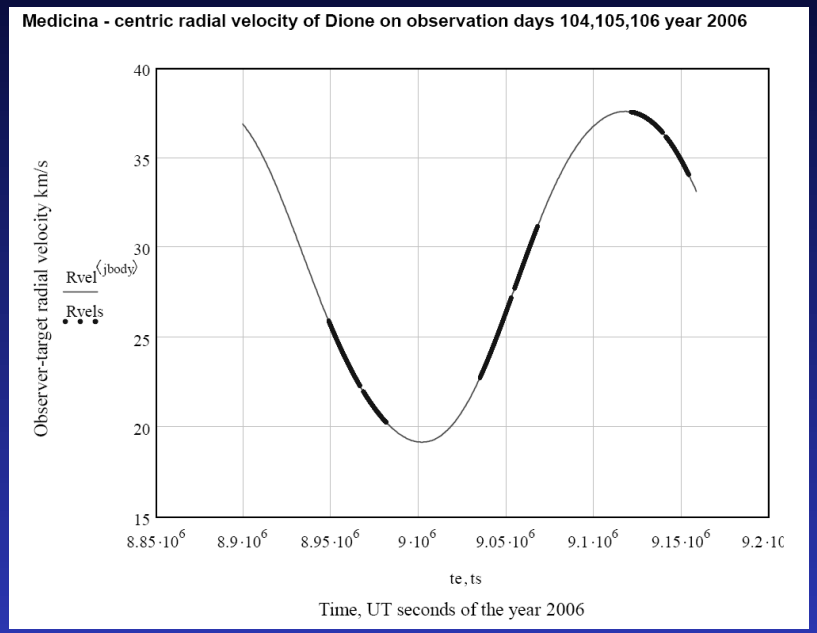
Saturnian magnetosphere, rings and satellites



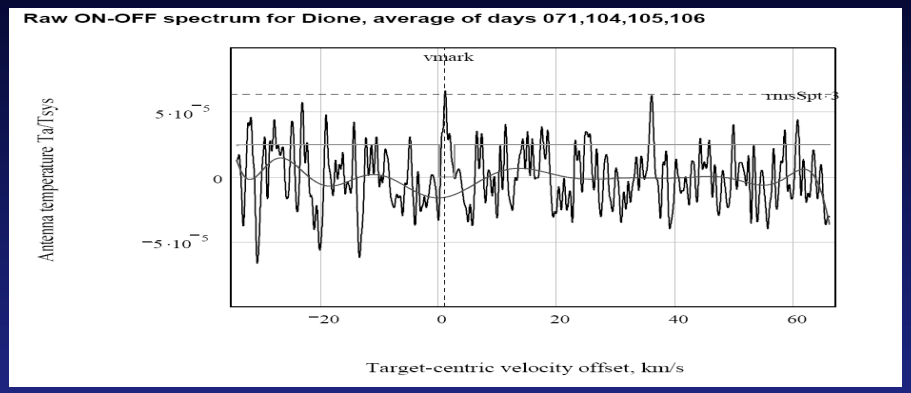
Saturn ring and satellite system as seen by Medicina telescope on 2006.04.15, 15:00 UTC

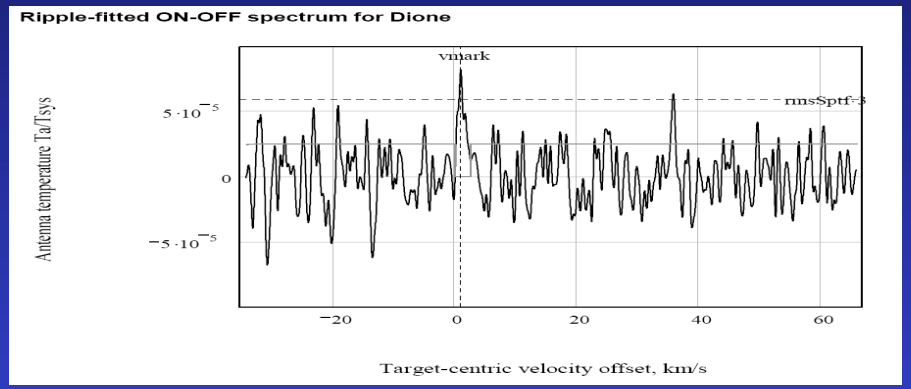
Search for 22 GHz water vapour line from Saturn system

- **No detection on Enceladus (or other 8 satellites), BUT…**



Medicina–centric radial velocity of Dione during the observation span





Possible detection of 22 GHz water vapor line associated with Dione orbital motion. Integration 30 hours, SNR 3.2 – 4.1, line width 2.5 km/s, offset 0.9 km/s

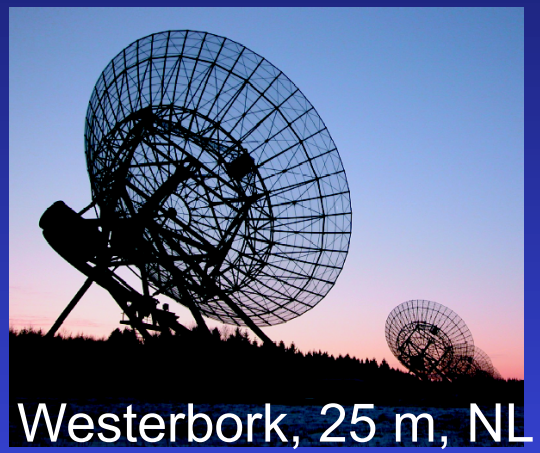
Further observations needed!

Smart-1: a VLBI target 1 light-second away…

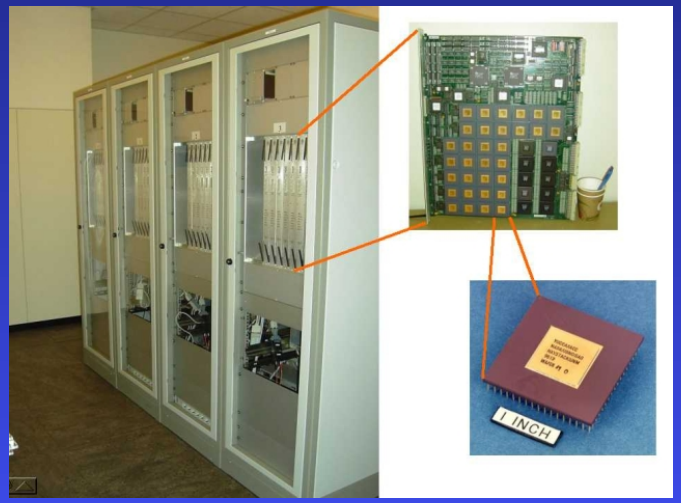
Medicina, 32 m, IT

Smart-1, circumlunar orbit

Metsähovi, 14 m, FI

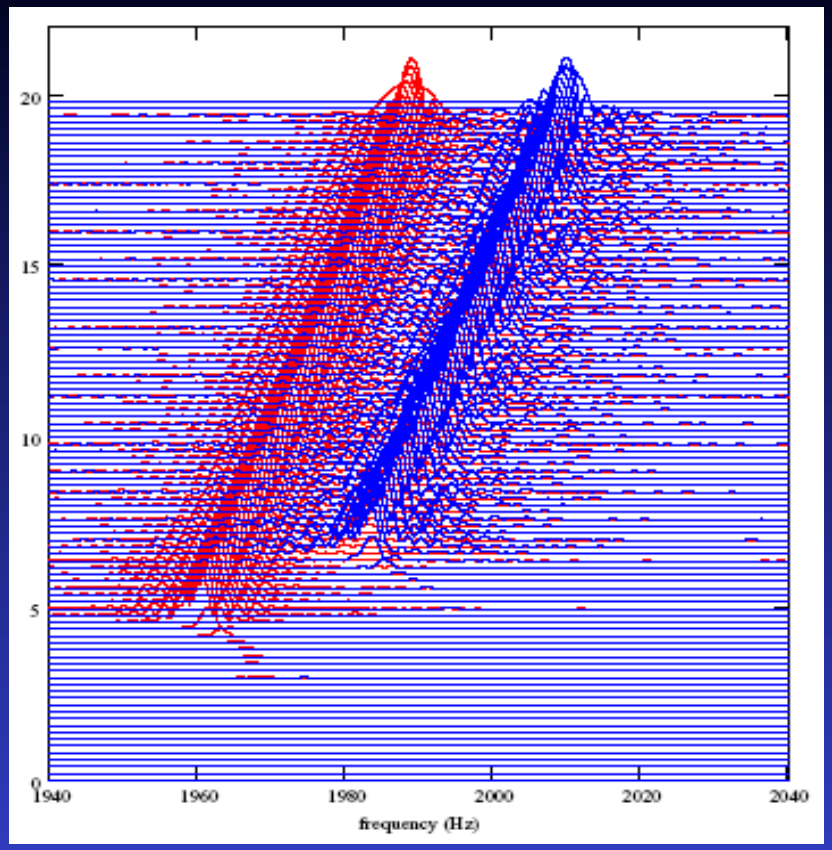

Westerbork, 25 m, NL

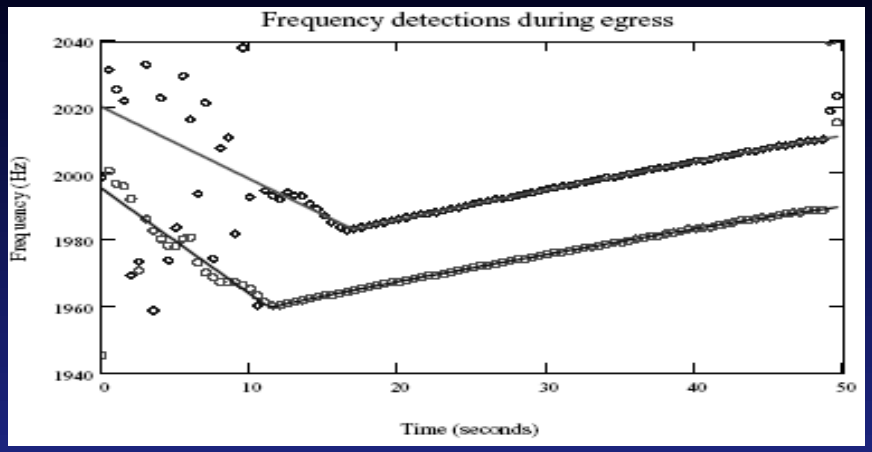
Goal: ultimate verification of the Huygens VLBI correlator

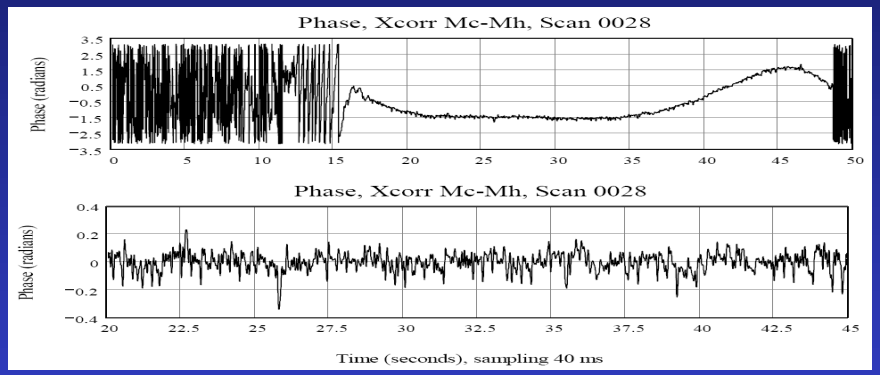


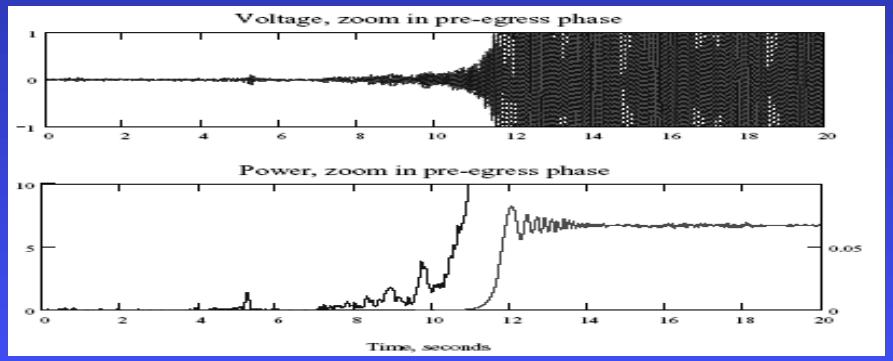
VLBI processor at JIVE, NL

Smart-1 at 2.3 GHz as seen by radio telescopes









Data show:

- Diffraction on the Lunar limb
- Propagation pattern
- "Reflection" intereferometry
- And much more …

Conclusions

- **VLBI technique offers unrivalled angular resolution AND sensitivity**
- **Rich "by-products"**
  - ***Doppler tracking data "for free" (see Huygens data);***
  - ***Near-planet propagation effects (occultations) – see Smart-1 example***
  - ***"Traditional" radio astronomy diagnostics of planets and interplanetary medium (water in the Saturnian system?)***
- **Lesson from Huygens VLBI tracking:**

  to do it right, plan it from the beginning (choice of frequencies, oscillators, polarisation specs, etc.)
- **What's next?**