Near-field VLBI for Planetary Science

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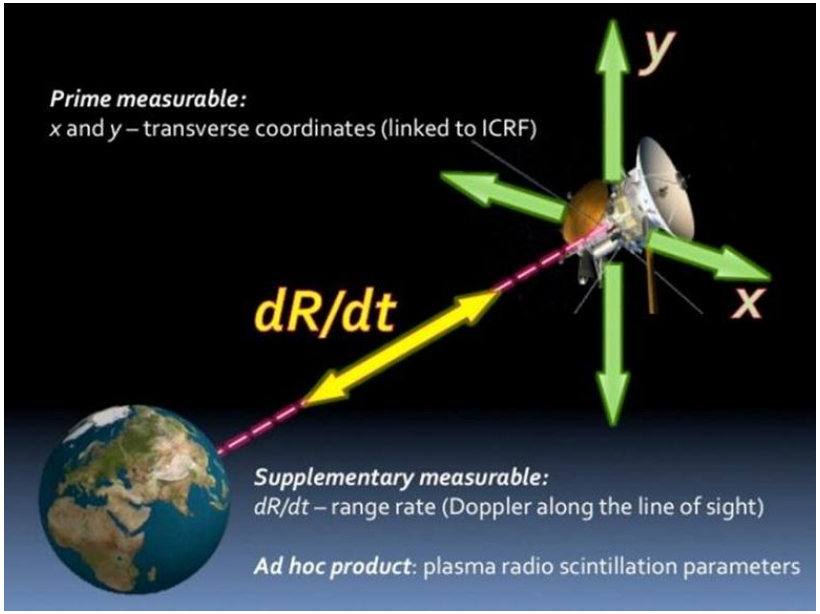
- PRIDE concepts
- Results for specific spacecraft observations
  - Huygens lander / Venus Express / Phobos fly-by
- RadioAstron // Interplanetary Medium

PRIDE Concepts

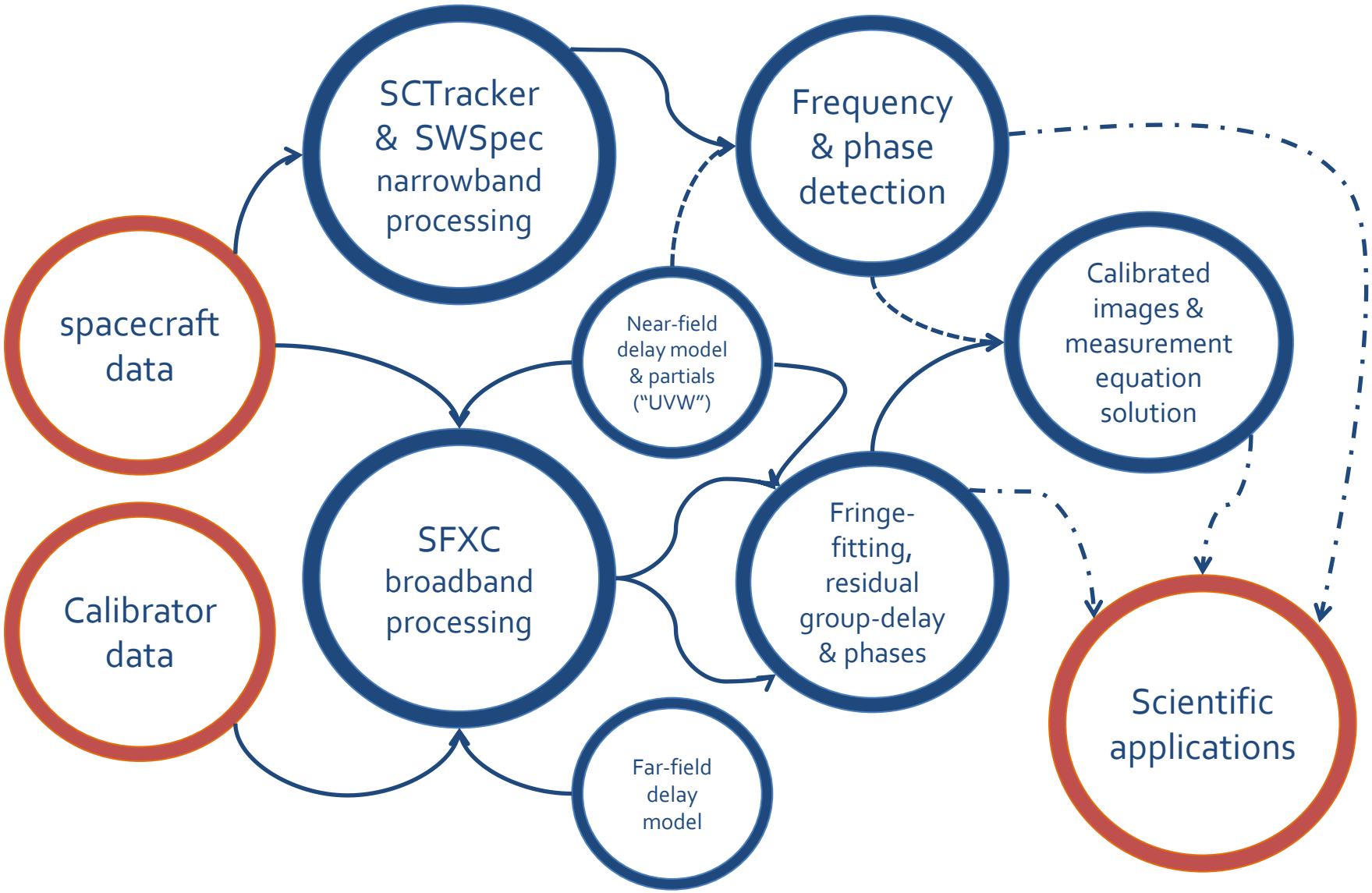
- Planetary Radio Interferometry & Doppler Experiments
  - Determe 5 of 6 components of a spacecraft's state vector
  - x, y, v_x, v_y from phase-reference VLBI; v_r from Doppler tracking
- Enhancement of mission science return, in conjunction with ESA, NASA, CNSA, JAXA, IKI

Reference for the near-field model & program interactions:
Duev, D. et al. 2012, *Astron & Astrophys*, 541, A43

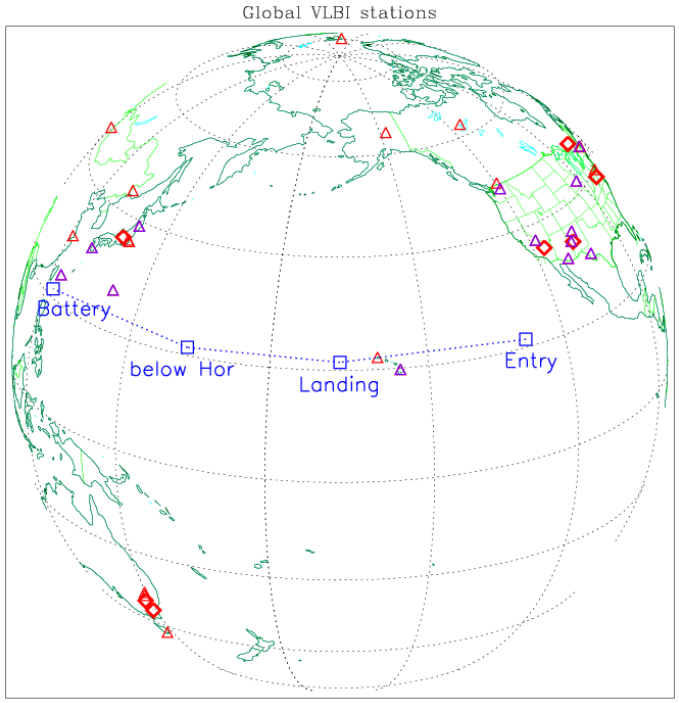
Reference for Doppler tracking:
Molera Calves, G. et al. 2014, *A&A*, 564, A4



PRIDE Data Flow



Huygens: Descent onto Titan

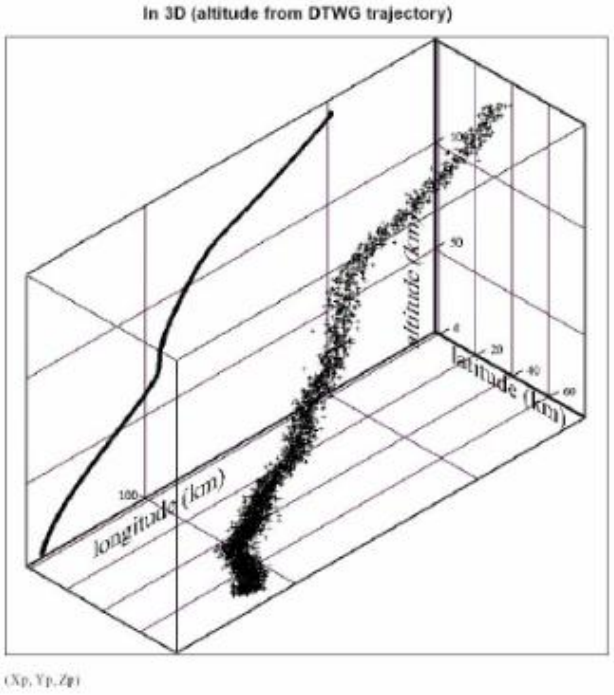


"Dropped" by Cassini to descend through Titan's atmosphere (14/i/2005)

Uplink problems → unplanned VLBI

- Awkward location, ν (2.04 GHz)

Genisis of SFXC

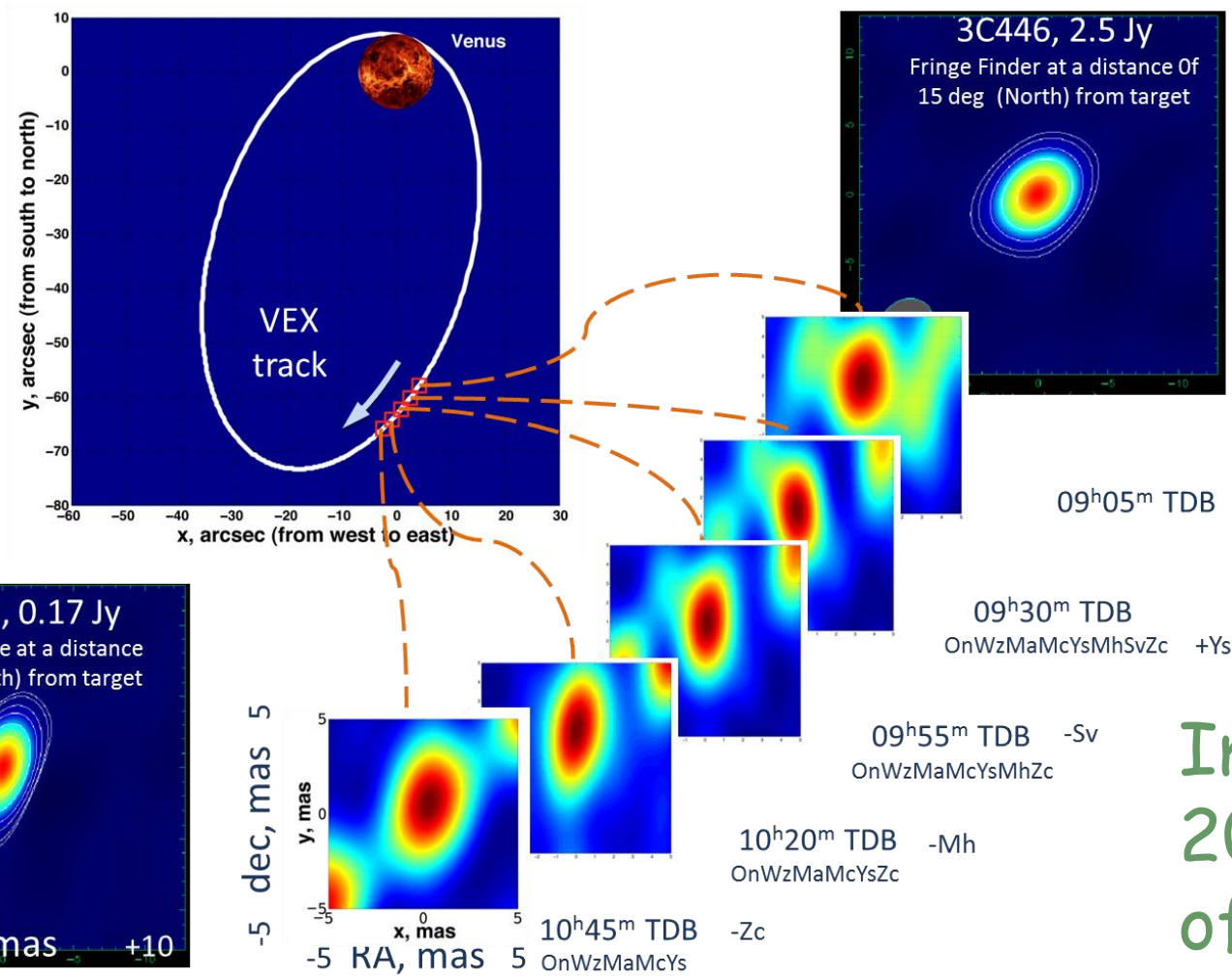


Positional uncertainties:
E-W ~260m N-S ~970m

Success led to more pro-active collaboration with ESA missions

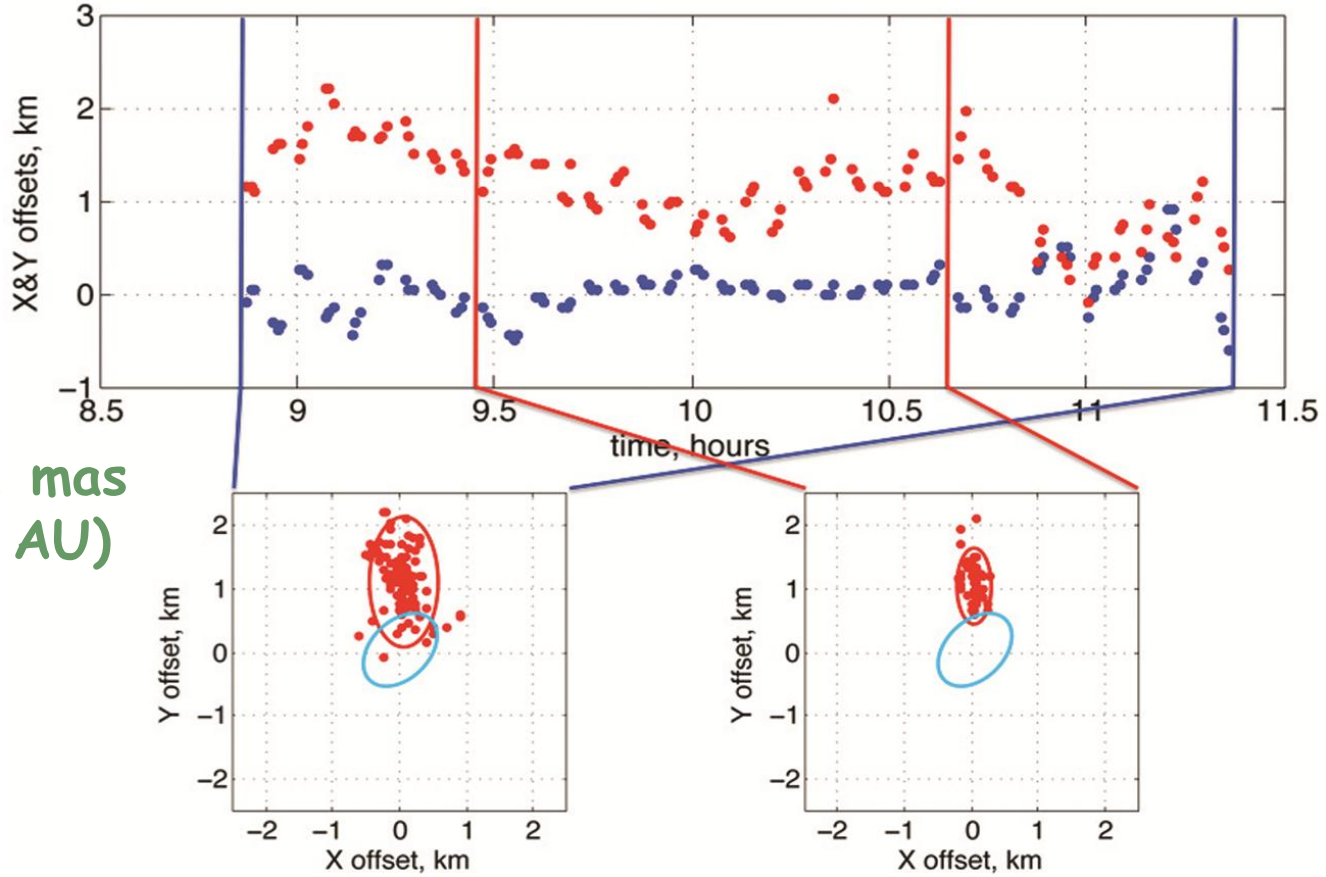
Venus Express Imaging Results

- 28/iii/2011: Hh,Mc,On,Mh,Ys,Sv,Zc, Wz,Ma, Sc



Images: 20 min of data

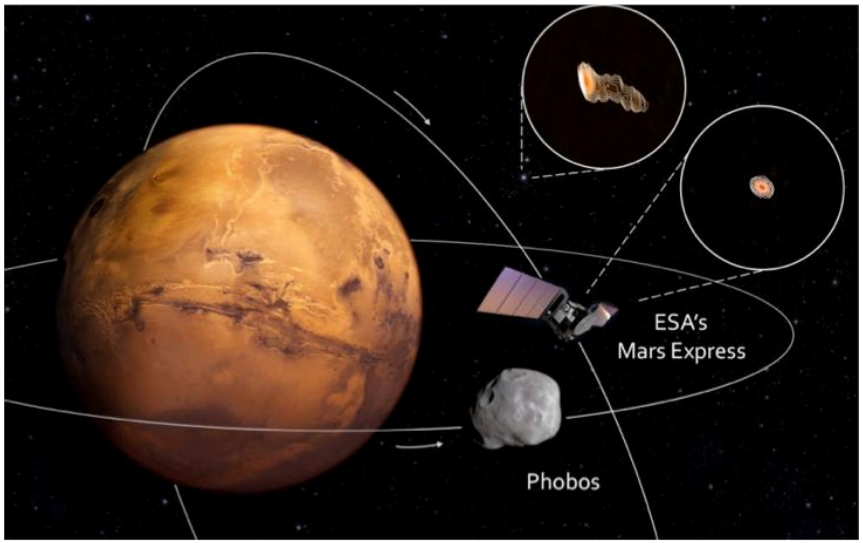
Venus Express: Position Corrections



1 km ~ 1.1 mas
(D = 1.24 AU)

- Corrections with respect to ESOC *a priori* trajectory
- Blue ellipse: *a priori*
- Red ellipse: measured 3-σ scatter (2 time-ranges fit)

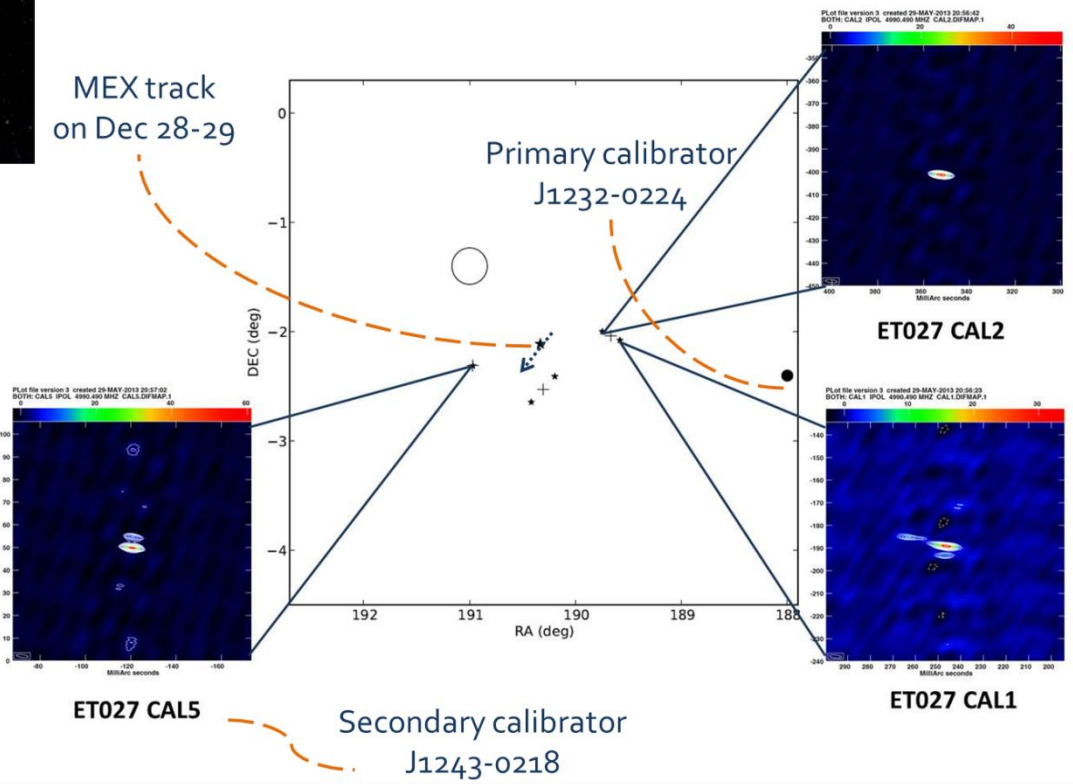
Mars Express: Phobos Fly-by



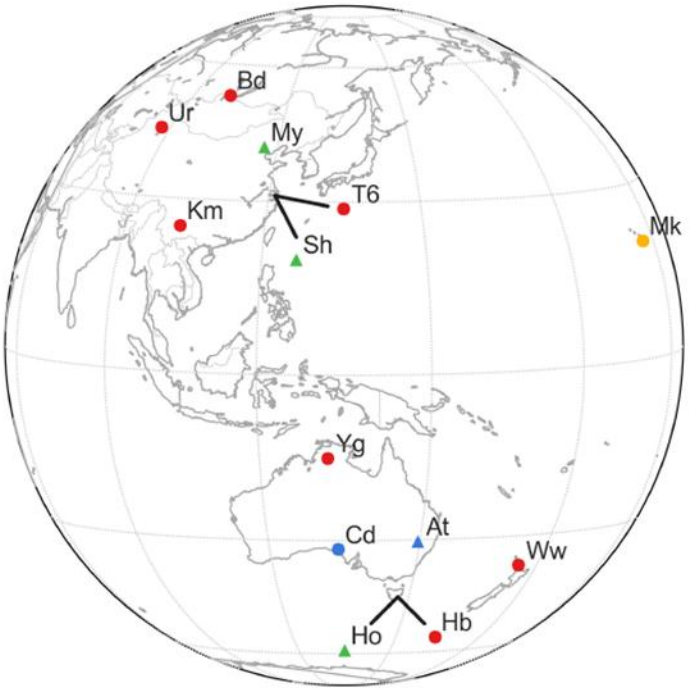
MEX passes within 45 km of Phobos on 28-29/xii/2013

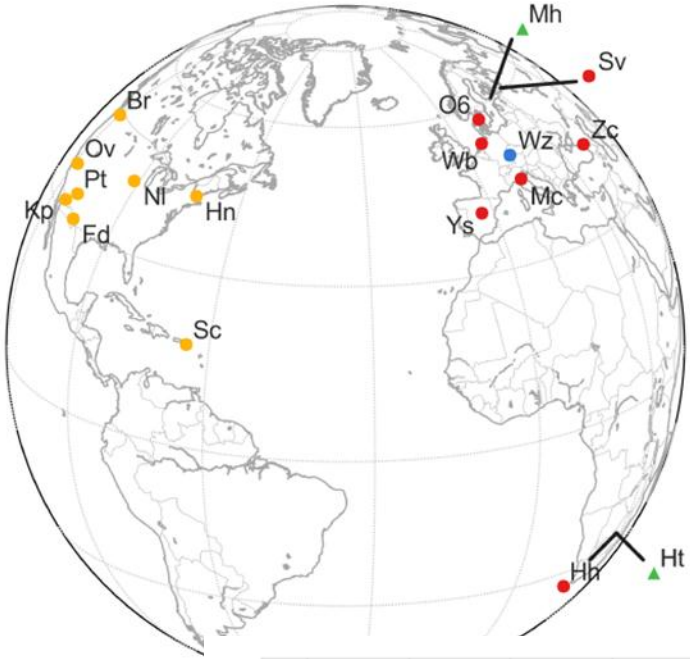
27 ants in φ-ref. VLBI
6 ants in Doppler tracking

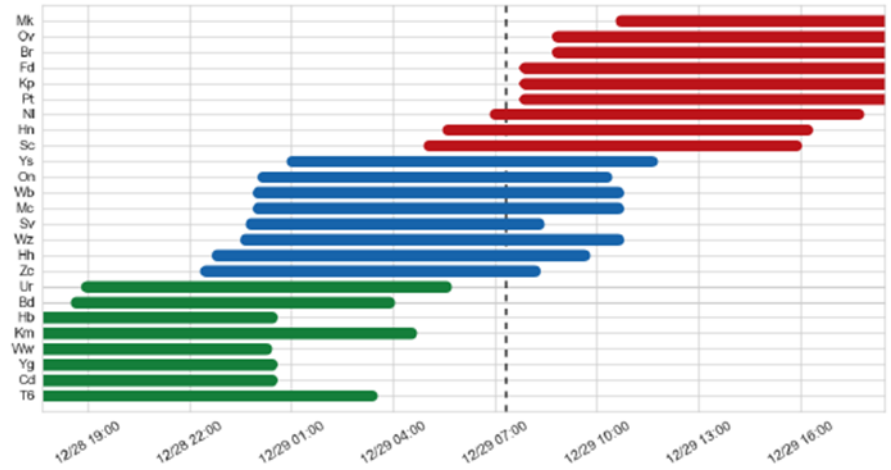
e-EVN observations conducted prior to the fly-by event to seek closer φ-ref calibrators



Phobos Fly-by: the Network







Circles = φ-ref VLBI antennas

Triangles = Doppler-tracking antennas (At,Ho,Mh,Sh,Ht,My)

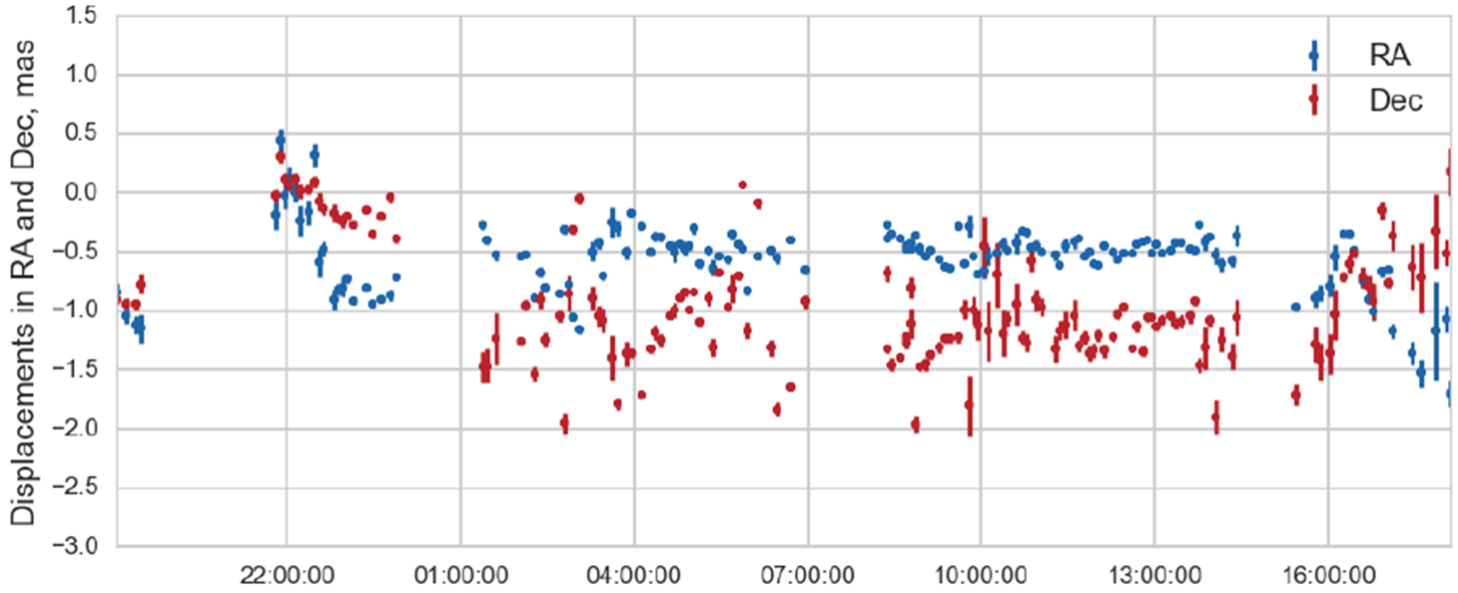
Phobos Fly-by: Astrometry & Doppler

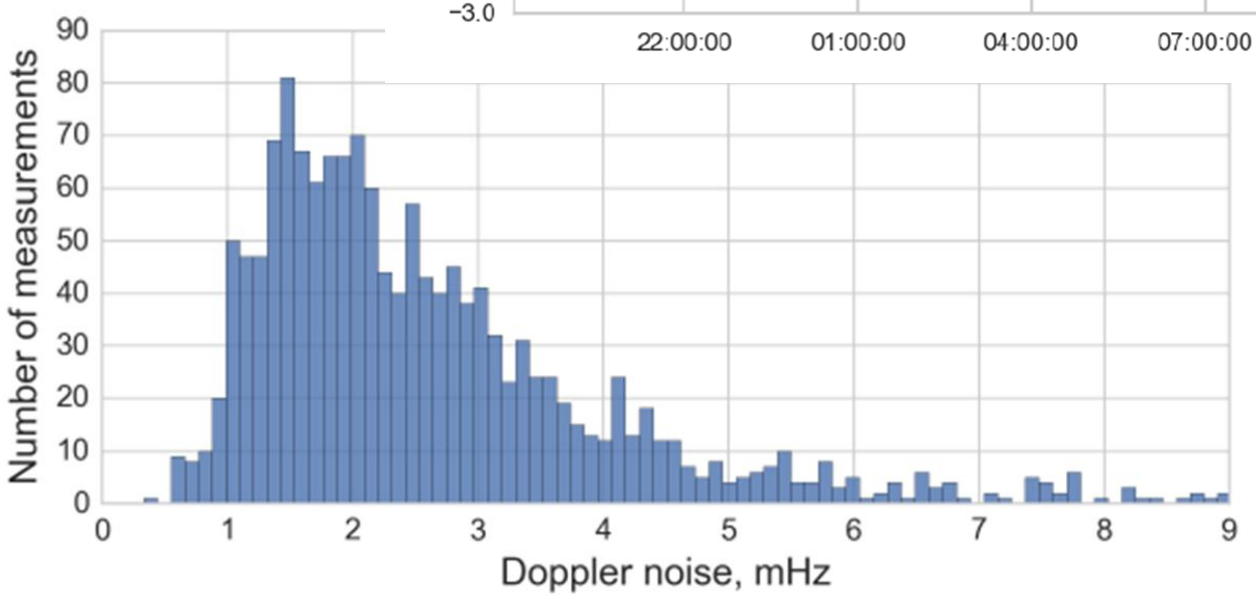
Median 3σ:

RA: 34 μas

Dec: 58 μas

(35, 60 m)





Doppler noise [mHz]

Mean: 2.5

Median: 2.2

max(log-norm): 1.7

(~30-45 μm/s †)

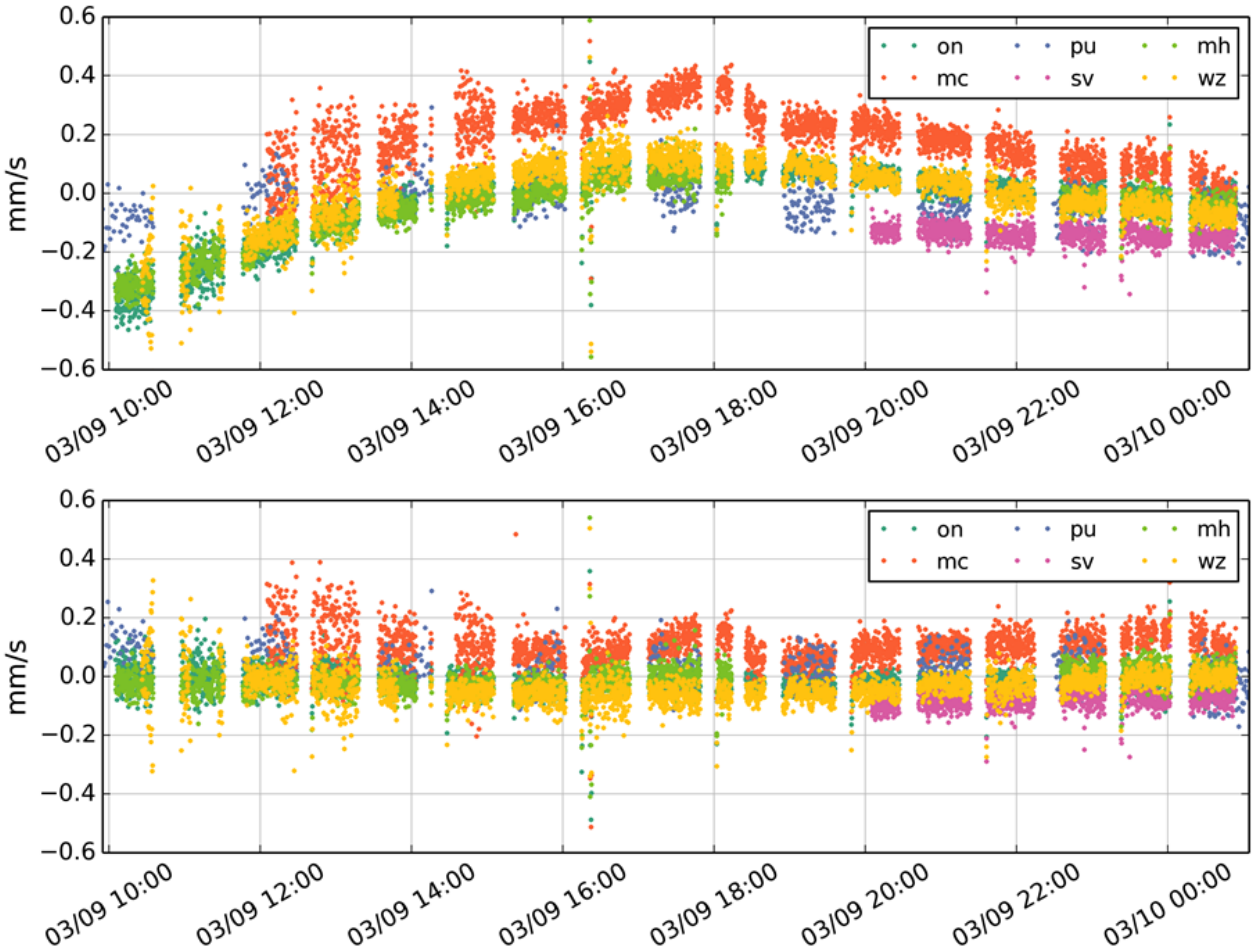
RadioAstron Overview

Moon: 357k-407k km

- Orbiting VLBI antenna
  - Orbit — perigee: 7k-81k km apogee: 280k-350k km
    P: 8.3-10.3 d, e: 0.59-0.96,
  - www.asc.rssi.ru/radioastron
- Science motivations (highlights):
  - High T_B, inner few R_S & jet-launch region
  - Gravitational redshift & equivalence principle
- Previous orbiting antenna
  - HALCA: Feb'97—Nov'05
  - Orbit: r = 12k — 27k km, P = 6.3 hr

RadioAstron: Orbit Improvement

Doppler residuals: orbit determination via ephemeris (~500m, ~2mm/s for ~2wk latency) and O.D. improved through observing RadioAstron as a near-field target.



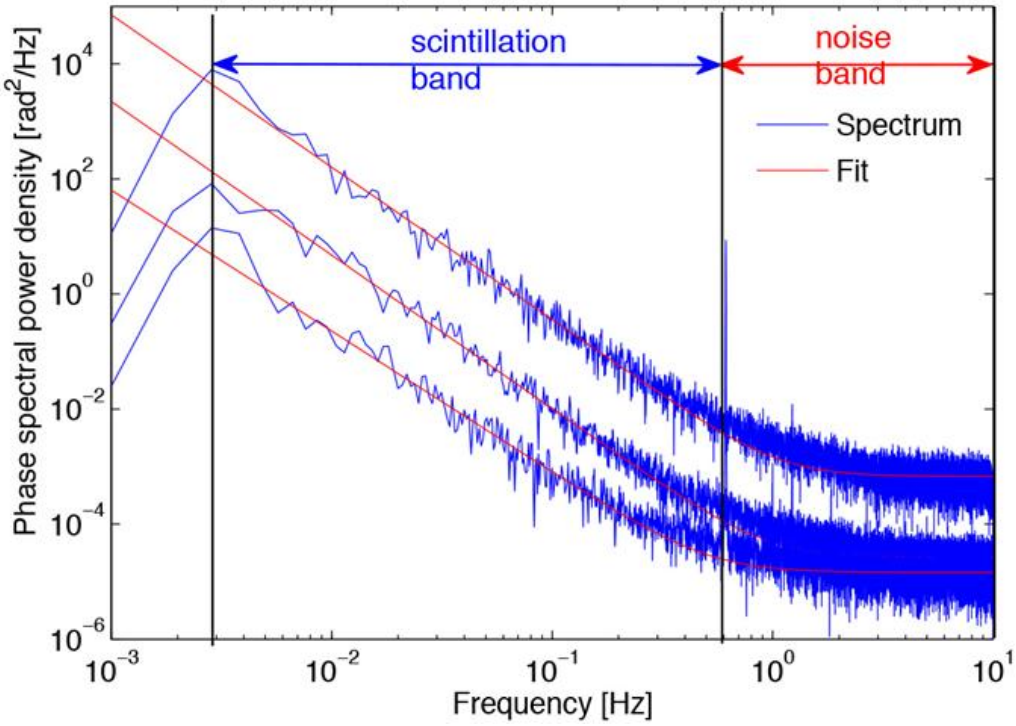
Duev, D. et al. 2015, *Astron & Astrophys*, 573, A99

IPM Scintillation

- Interplanetary medium scintillation: comes for ~free
- Phase variations in carrier → plasma density fluctuations
- SWSpec (hi-res spectrometer) + SCTracker (filter out narrow-band around carrier) + PLL (Molera et al. 2014)
- Can iterate filtering out to ~mHz accuracies

Three different solar elongations of Venus (3.4°, 19.4°, 37.2°)

Resulting slopes (m = -2.4 — -2.7) consistent with Kolmogorov
m=1-p, p = 11/3



Summary

- PRIDE = determine state-vectors of spacecraft using phase-reference VLBI + Doppler tracking
- Close work with space agencies to enhance mission science
- Dozens of observations of VEX, MEX, SMART
- Part of science payload for future ESA flagships
  - *e.g.*, JUICE (Jupiter Icy Moons Explorer), launch 2022