cnes
CENTRE NATIONAL D'ÉTUDES SPATIALES

ROYAL OBSERVATORY
OF BELGIUM

ESPACE

Utilisation de GINS avec les données de survol très rapproché de Phobos par Mars Express

Rosenblatt P.[1], J.C. Marty[2], Dehant V.[1], Gurvits L.[3]
and the JIVE team

[1] Royal Observatory of Belgium, Brussels, Belgium
[2] CNES/GRGS, Toulouse, France
[3] JIVE, Dwingeloo, The Netherlands

Journée GINS – 12 Juin 2014 – Toulouse, France *(temps ensoleillé et chaud)*

Introduction

- Goal:

  To determine the first gravity coefficients of Phobos: C_{20}, C_{22} using flyby at close distance by Mars Express.

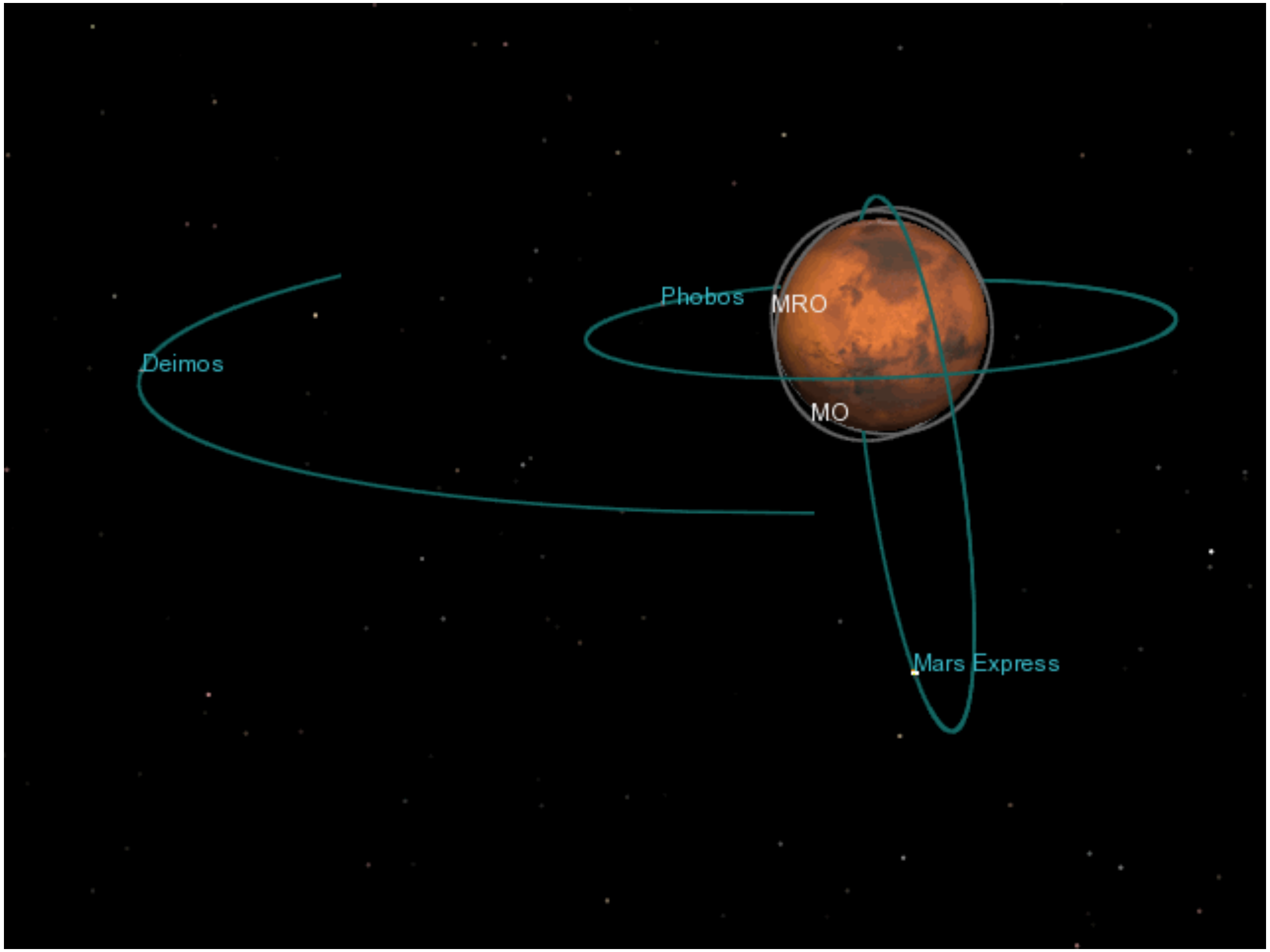
- How:

  By determining precisely the orbital perturbation of MEX motion due to the gravity field of Phobos

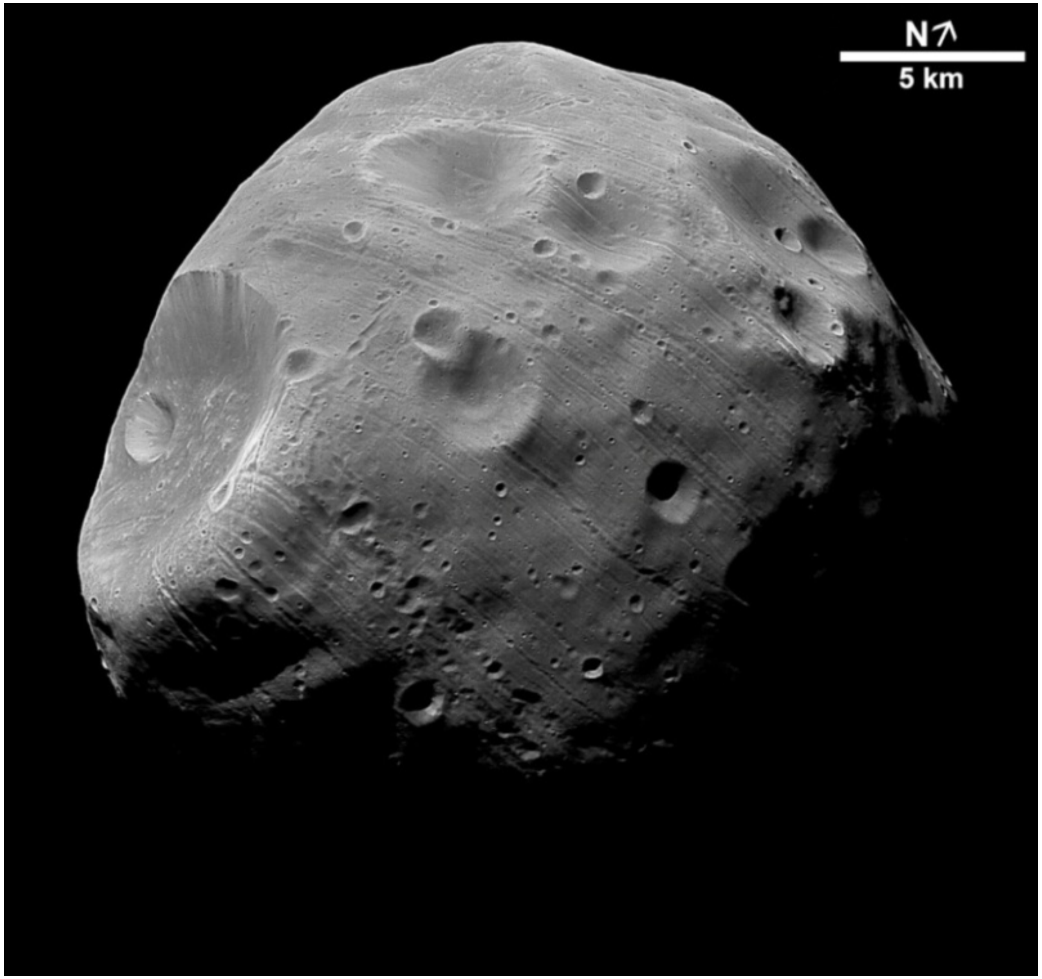
  *Using the GINS software**

(*) *Géodésie par Intégration Numériques Simultanées developed at the French Space agency (CNES) and further adapted at ROB for planetary geodesy applications*

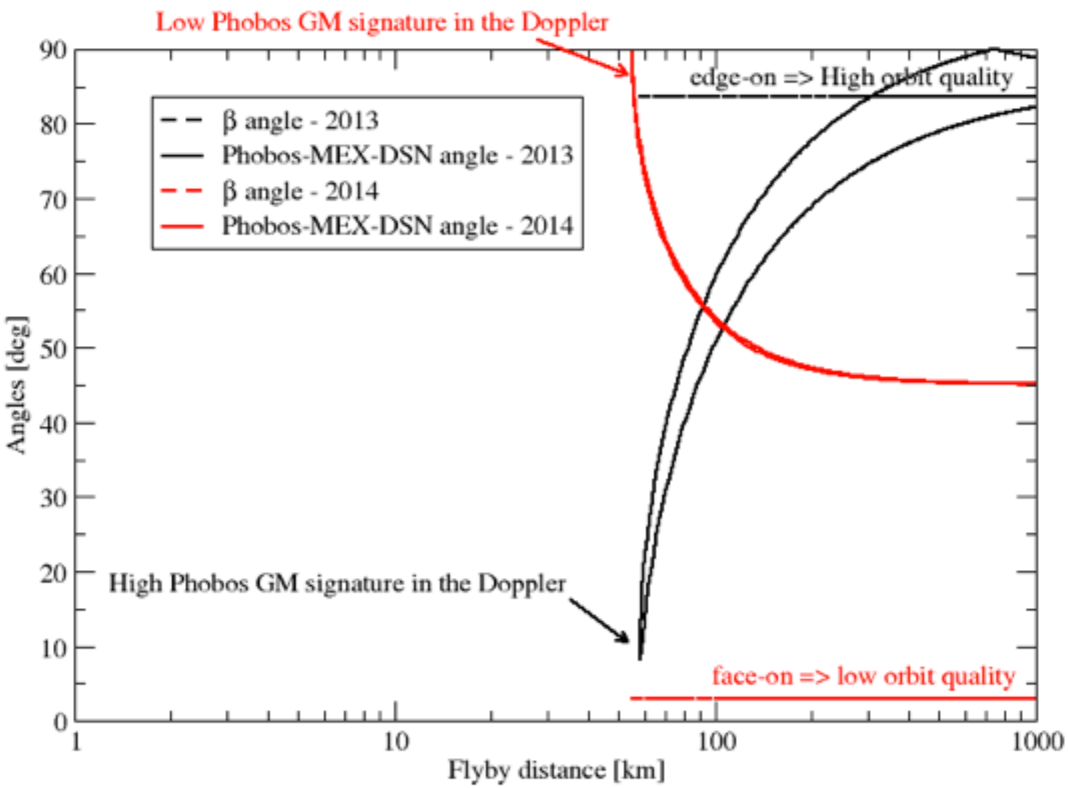
Flybys of Phobos by Mars Express



Phobos



Flyby distance and Doppler geometry:



- Good Doppler geometry for sensitivity to MEX orbital perturbations and especially Phobos GM perturbations:

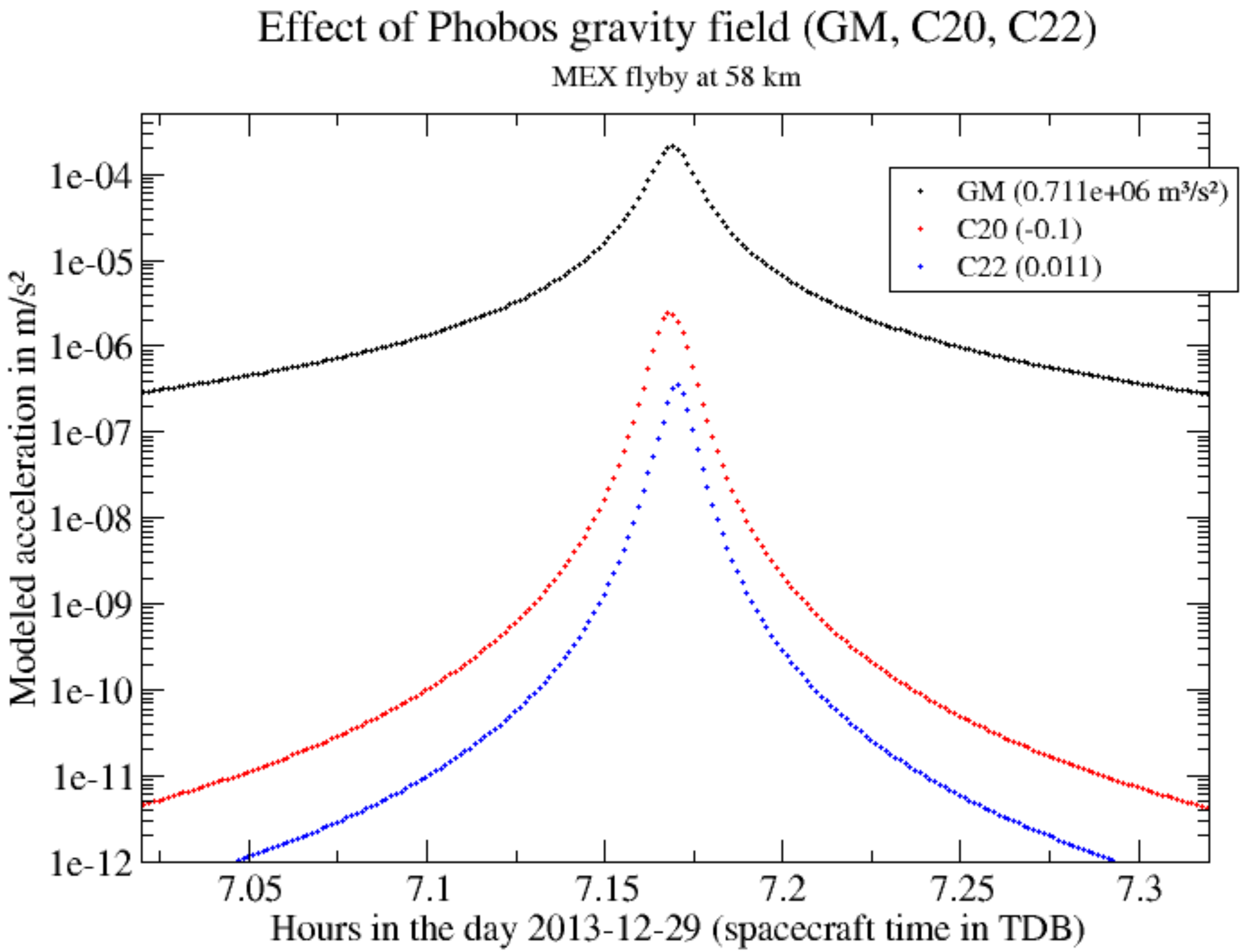
  → Phobos-MEX-Earth almost aligned (10°) at the closest approach.

- Closest approach ever:

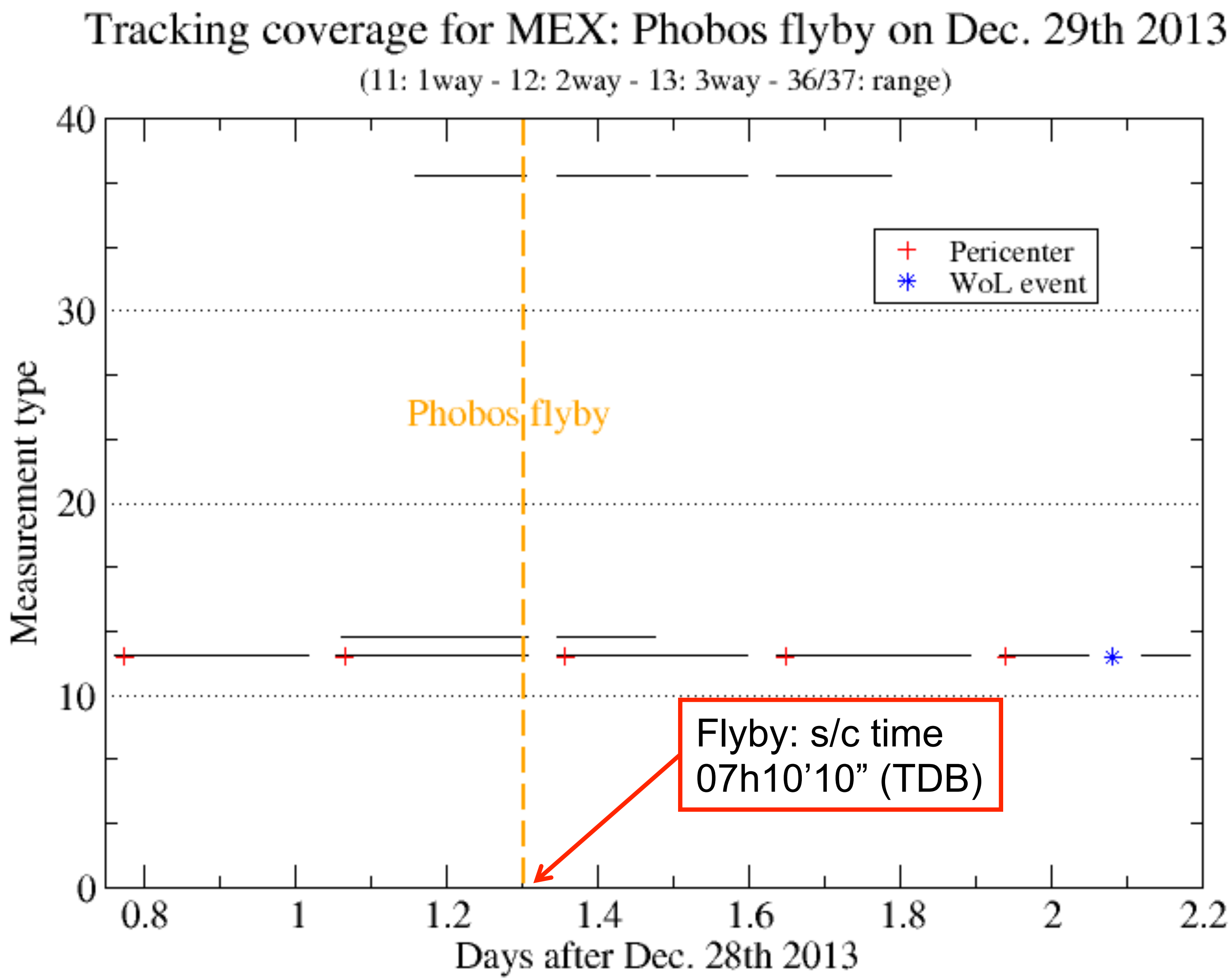
  58.71 km (from mar097 ephemeris)
  58.61 km (from New IMCCE ephemeris)

  58.77 km (from mar085 ephemeris)
  59.21 km (from Lainey et al. (2007) epehemris)

Acceleration: Order of magnitude



➢ Acceleration computed in GINS (fsana.f90) using f_potcentral.f90 of OBELIX



✓ Quasi-continuous tracking up to 2 orbital revolutions before and after the flyby.

MEX dynamical model

- Model of the forces acting on the spacecraft to be fit to the tracking data (Precise Orbit Determination)

- Gravitational forces:
  - Mars' static gravity field (JPL-JGM95J)
  - Point mass representation of other solar system bodies using JPL DE421 planetary ephemeris.

  - ***GM and C_{20}*** of Phobos using Martian moon ephemerides:

    JPL-MAR097
    IMCCE-flby-sol1

- Non-gravitational forces :
  - Atmospheric drag (atm. density, MarsGram model)
  - Solar pressure radiation.
  - Albedo & IR radiations (F. Lemoine).

Using GINS software

INPUT

Modeling all forces:

- Gravitational
- Non-gravitational (the most ill-known)

Pre-processing of:

- Initial state vector
- Attitude mode of spacecraft
- Desaturation events
- (CoM s/c) / (CoP HGA)
- Tracking data

GINS software

Numerical integration of motion
&
Iterative least-squares fit

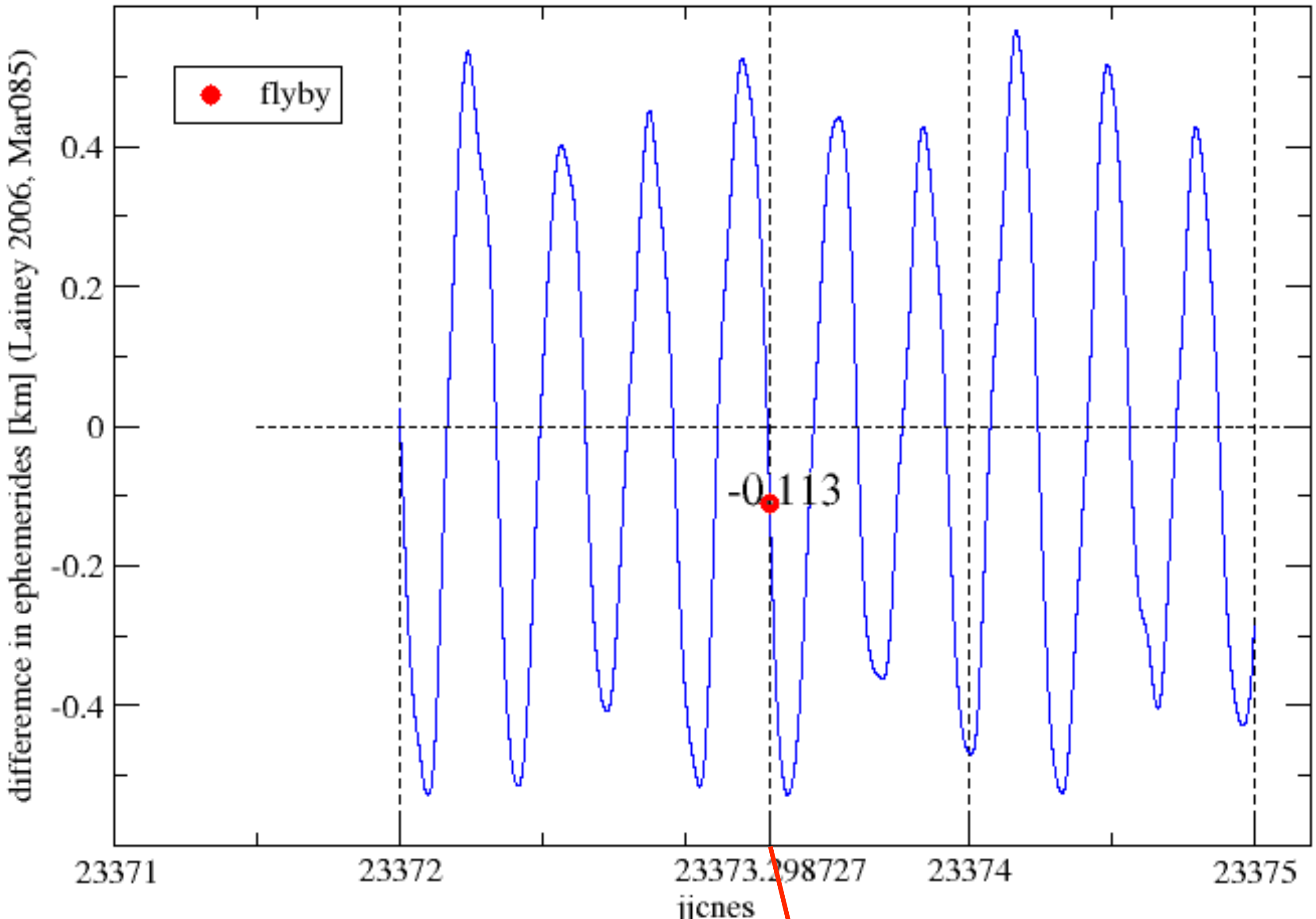
OUTPUT

- Accurate position & velocity of spacecraft
- Doppler range residuals
- Scale factor (drag, …)
- Normal matrix [illegible]ith information [illegible]s' geophys[illegible]rameter (Gra[illegible]d and its se[illegible]al changes, mass of the moons…)

Challenge !

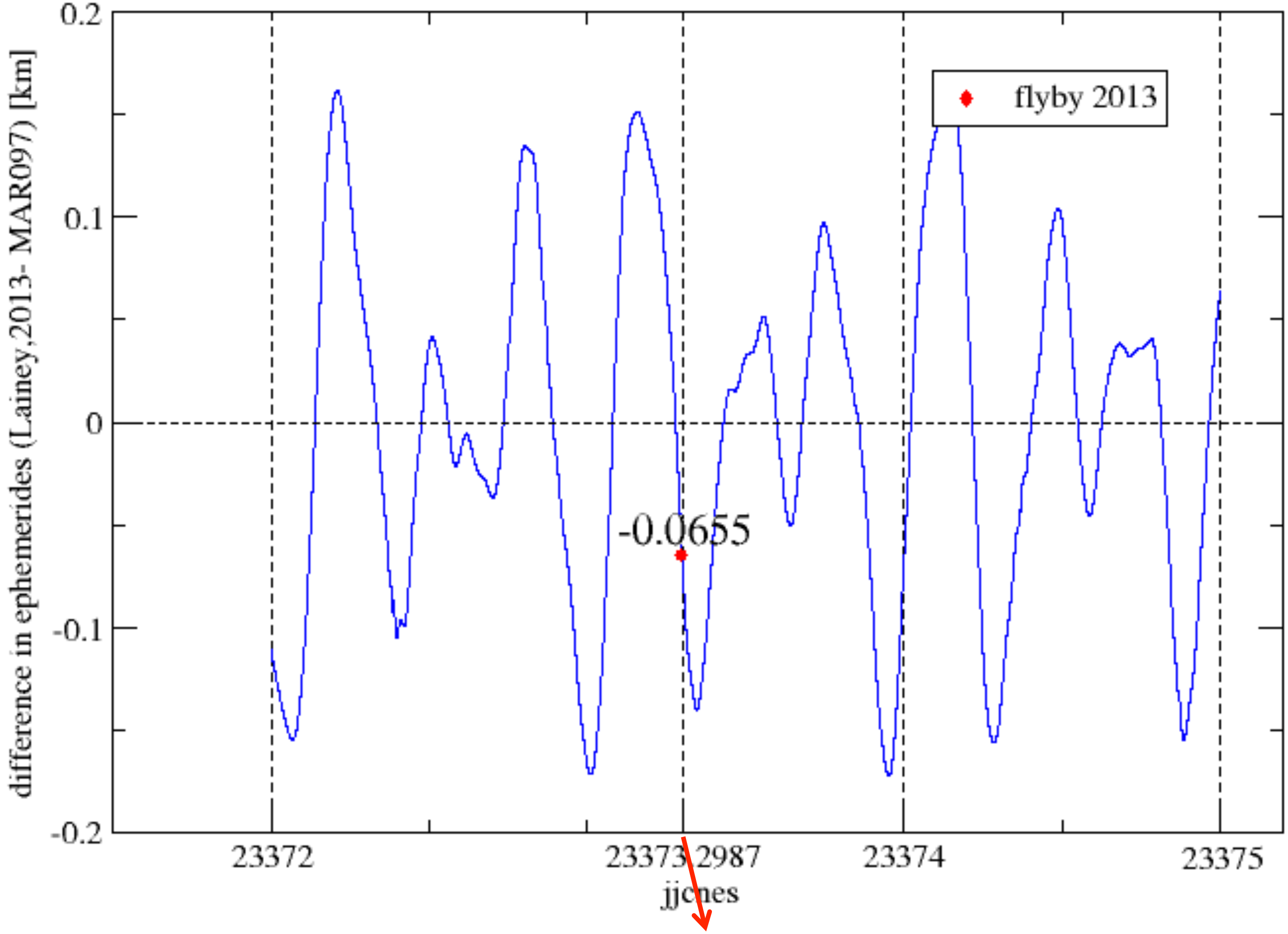
The quality of the estimated geophysical parameter strongly rely on the precision of the reconstructed orbit of the spacecraft, which itself depends on available tracking, mismodeling of dynamical model, ***moon ephemeris*** …

Difference in Phobos position between mar085 and Lainey et al. (2007) ephemerides

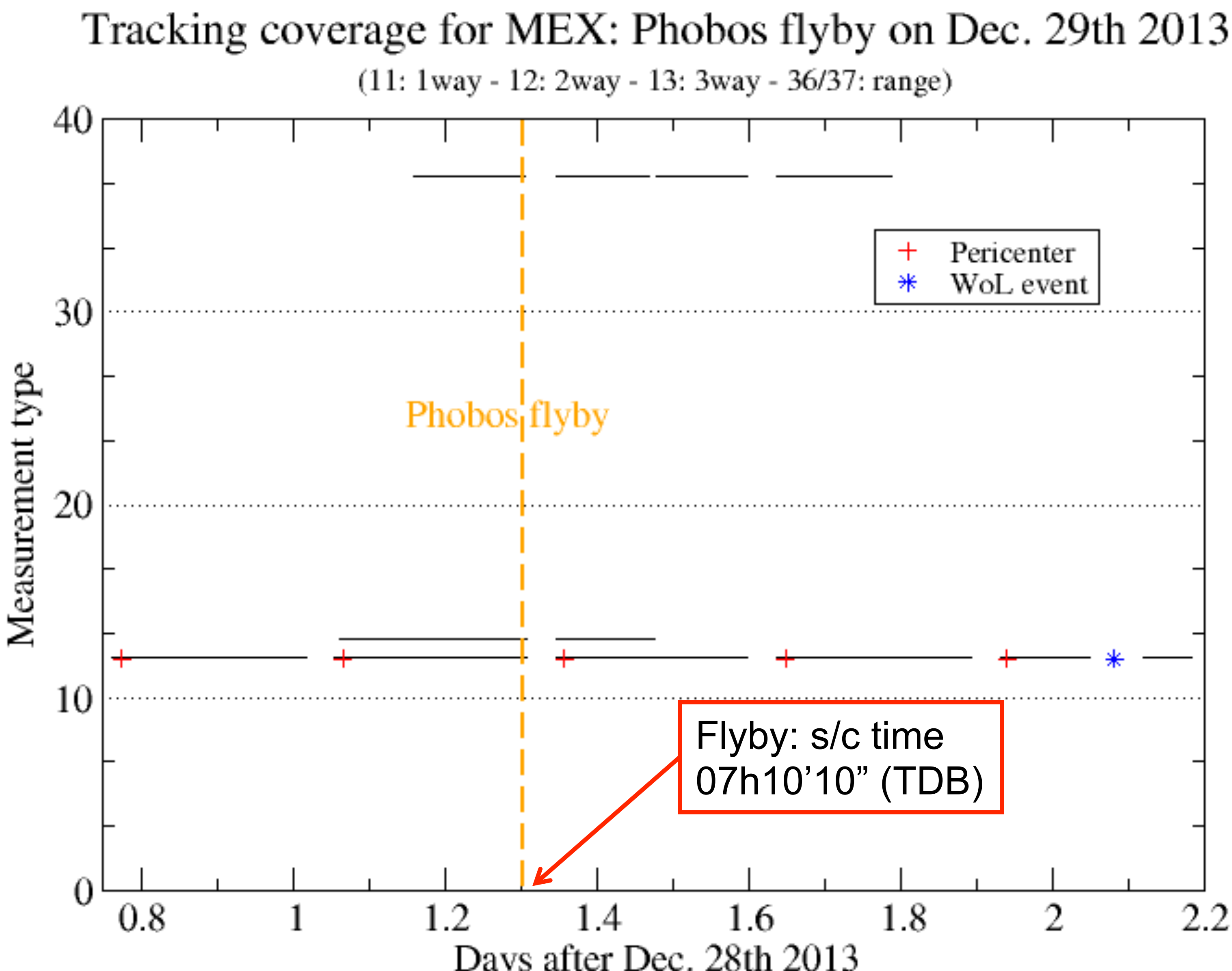


Phobos flyby Dec. 29th 2013

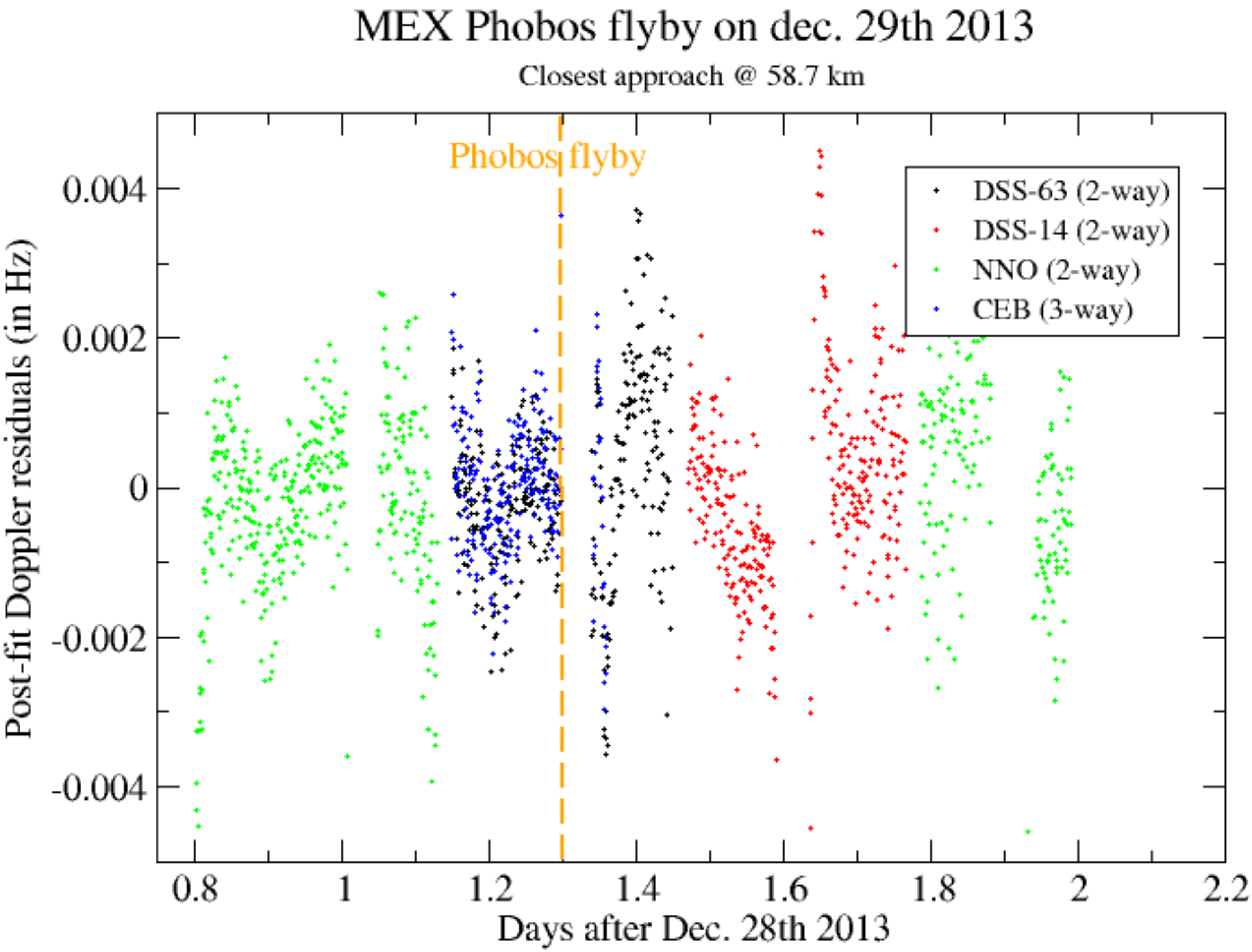
Difference in Phobos position between mar097 and ESPaCE-IMCCE ephemerides



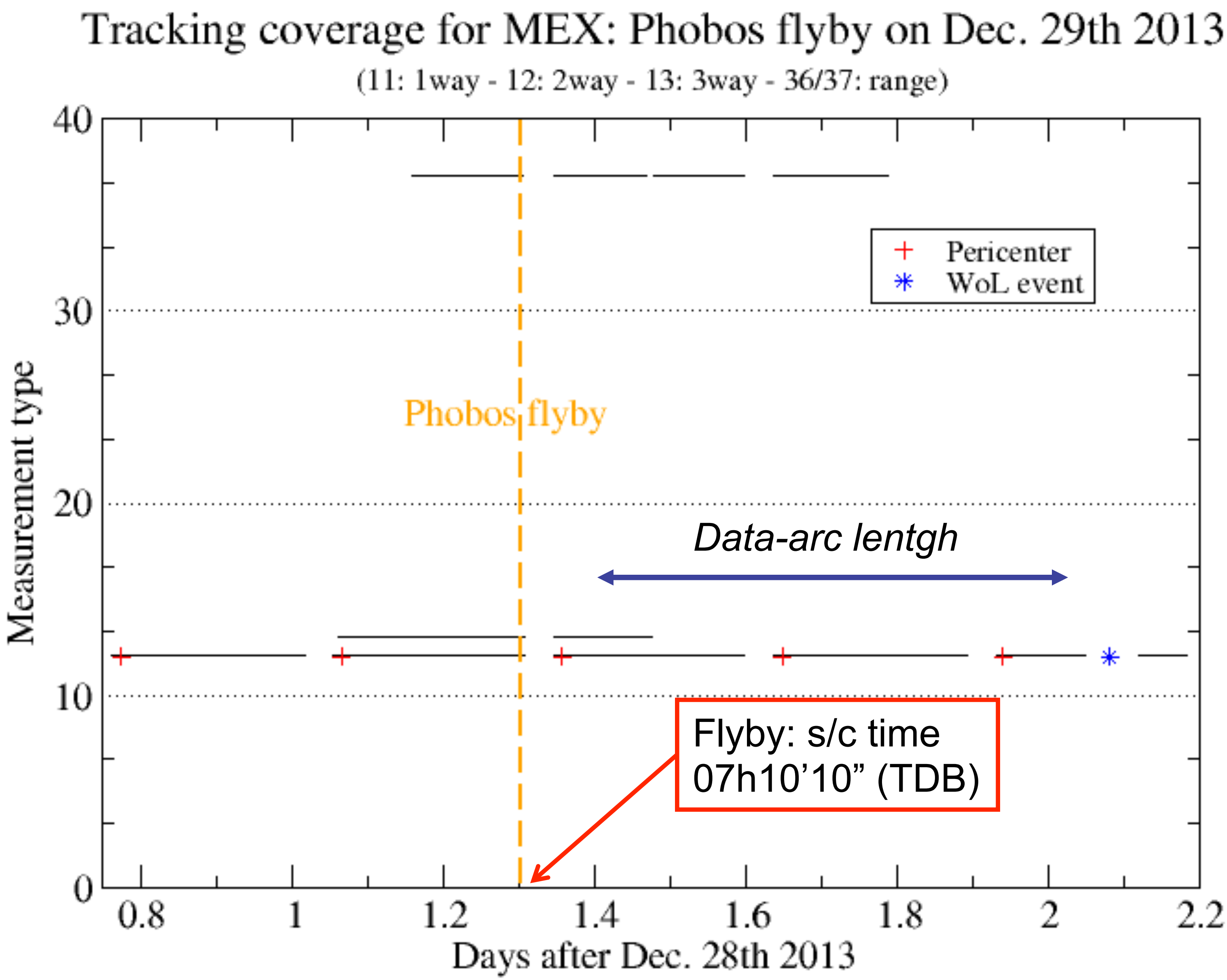
Phobos flyby Dec. 29th 2013



- ✓ Quasi-continuous tracking up to 2 orbital revolutions before and after the flyby.
- ✓ POD fit using all this tracking data: long data-arc of about 1.2 days

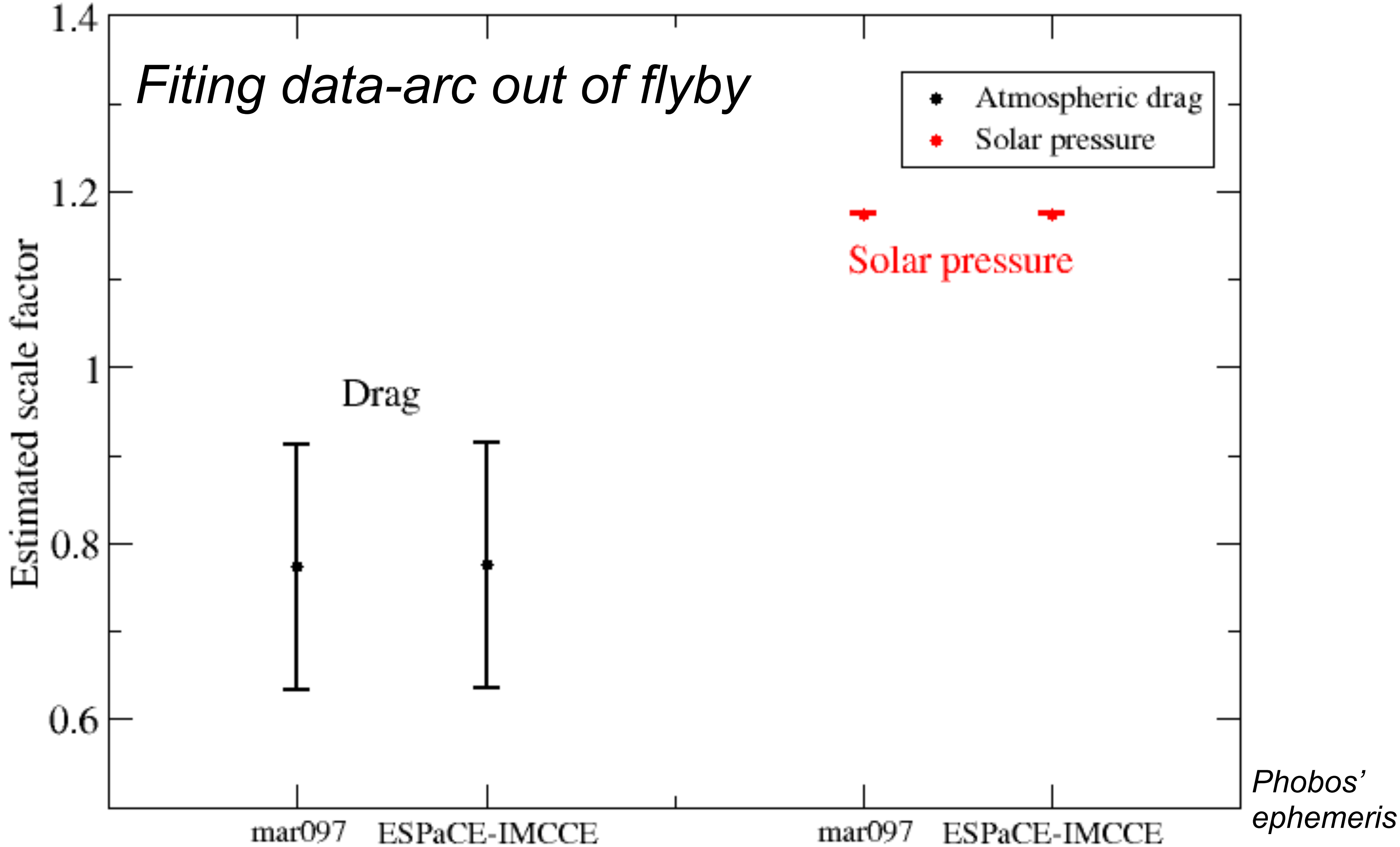


- ✓ Doppler post-fit residuals: RMS value ~ 1 mHz
- ✓ But irrealistic sclae factor (drag, solar pressure) *Not shown here*

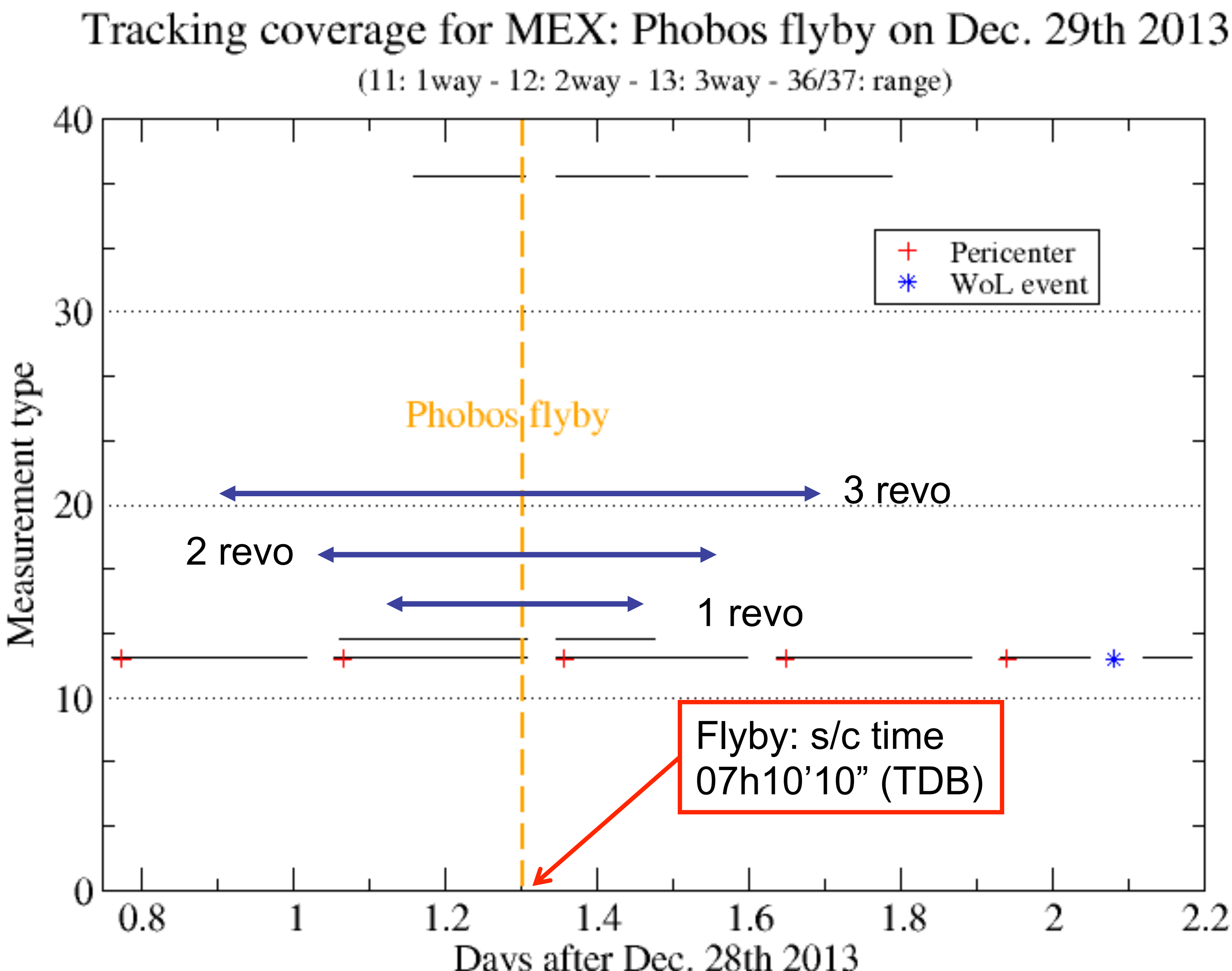


✓ Quasi-continuous tracking up to 2 orbital revolutions before and after the flyby.

Estimating dynamical parameters others than Phobos' gravity field

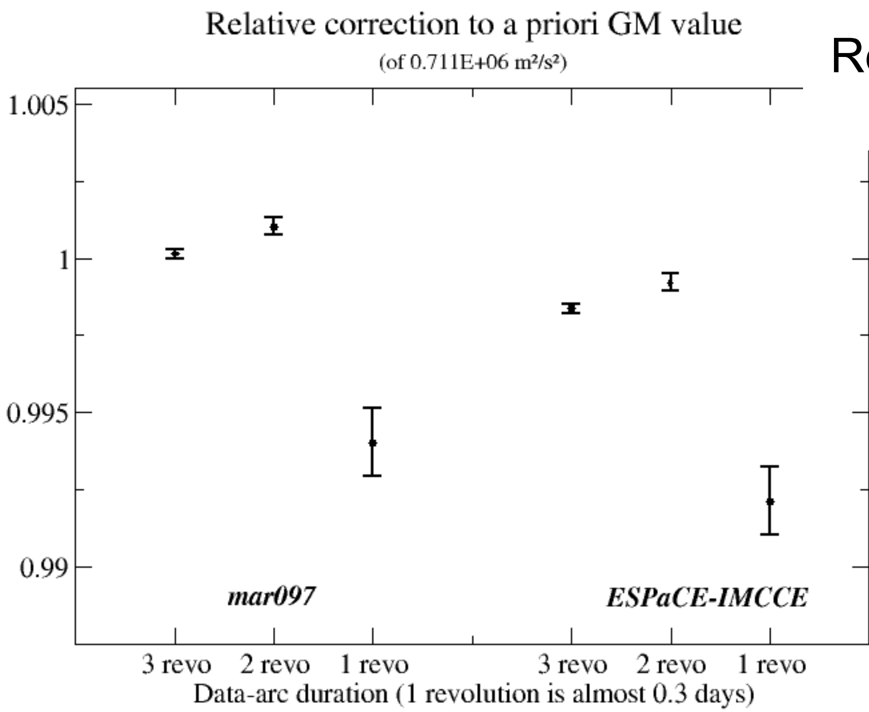


- ✓ Drag scale factor: 0.77 +/- 0.14 & Solar pressure scale factor: 1.1743 /- 0.0016
- ✓ Independent of Phobos' ephemeris.
- ✓ Taken as a priori value and constraints for GM/C20 fit with data-arcs including flyby

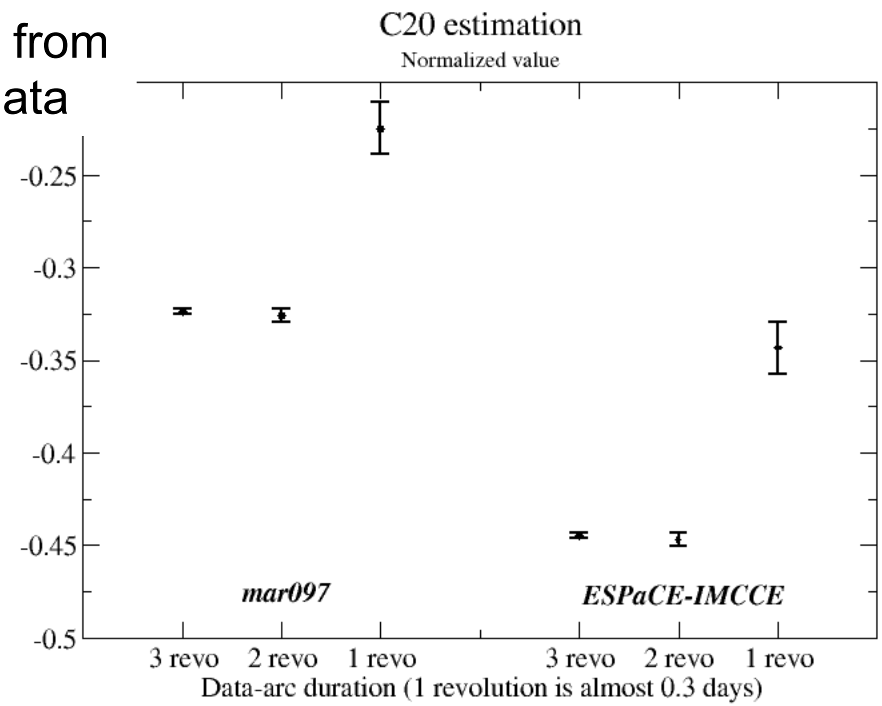


✓ Data-arc length: 3, 2 and 1 orbital revolutions centered on flyby

Estimating dynamical Phobos' gravity field from flyby



Results from true data



- ✓ GM estimated close to initial value of 0.711 E+06 m3/s2 with formal error of about 0.02%.
- ✓ C20 estimated close to about -0.32 with formal error of about 0.002 (0.6%).

- ✓ Precise solution of GM & C20 but large biais to C20 solution (physically unplausible)
- ✓ 'Slight' biais between solutions using mar097 vs ESPaCE-IMCCE ephemeris

Possible explanation → biased solutions due to error on ephemeris?

Simulation process

Simulation of Doppler tracking data:

Data-arc duration : 1 revo., 2 revo., 3 revo., around flyby
Ground station as for MEX tracking of December 29th 2013
Initial state vector (position/velocity) from FD MEX orbit
Initial GM=0.711 10^6 m^3/s^2 and C_{20}=-0.1

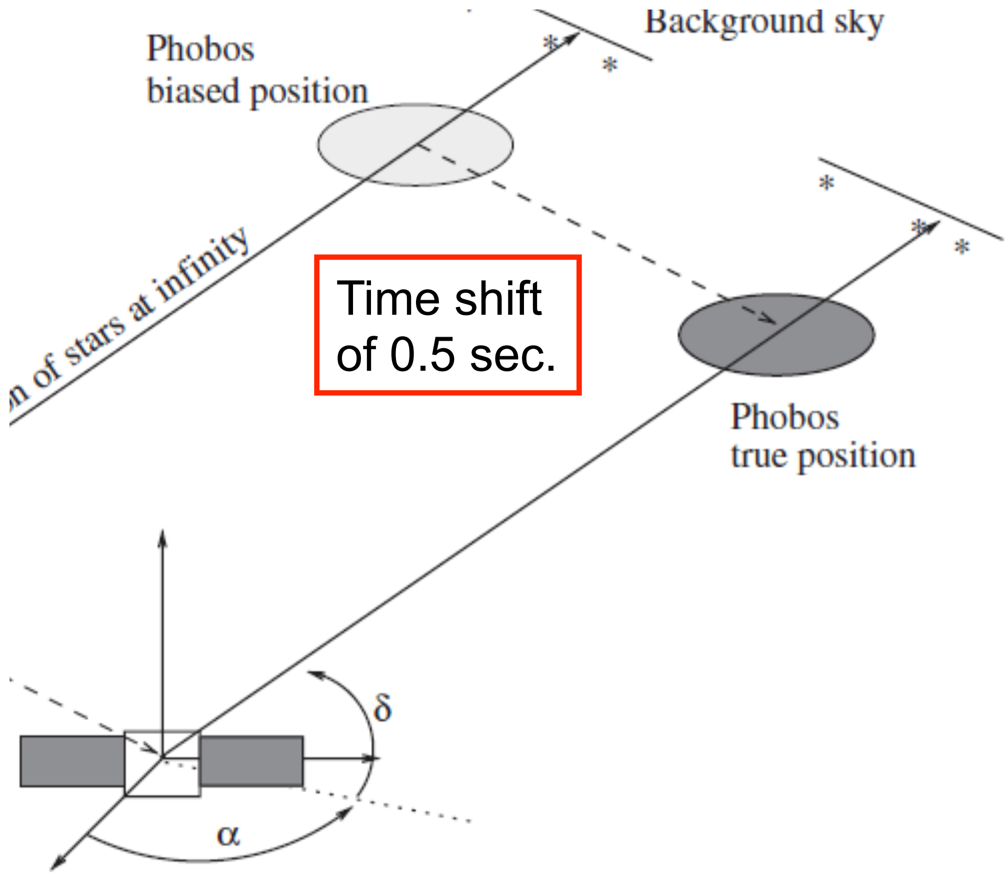
Simulated Doppler data (60sec sampling time) with white noise at 0.02 mm/s.

Modified parameter value as *a priori* value: ***GM = 0.709 10^6 m^3/s^2*** and ***C20 = 0.0*** and perturbed ephemeris at ***1000 meters, 100 meters and 10 meters level.***

Fitted parameter:
Initial state vector (position/velocity) of MEX at the beginning of the data-arc and ***GM and C20.***

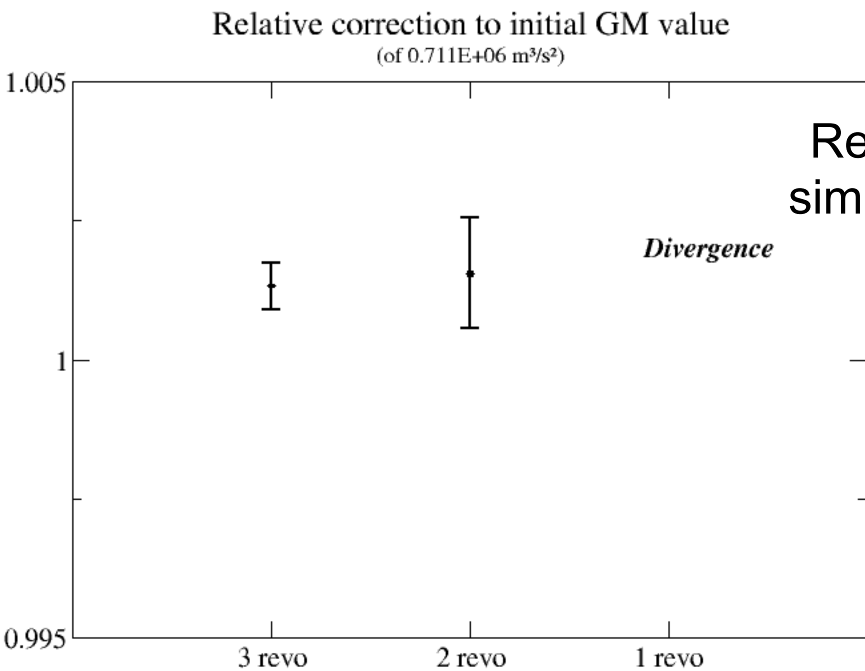
Results:
Solution of *GM* and C20 (adjusted value and formal error).
Impact of ephemeris error

Simulation of Phobos’ ephemeris error

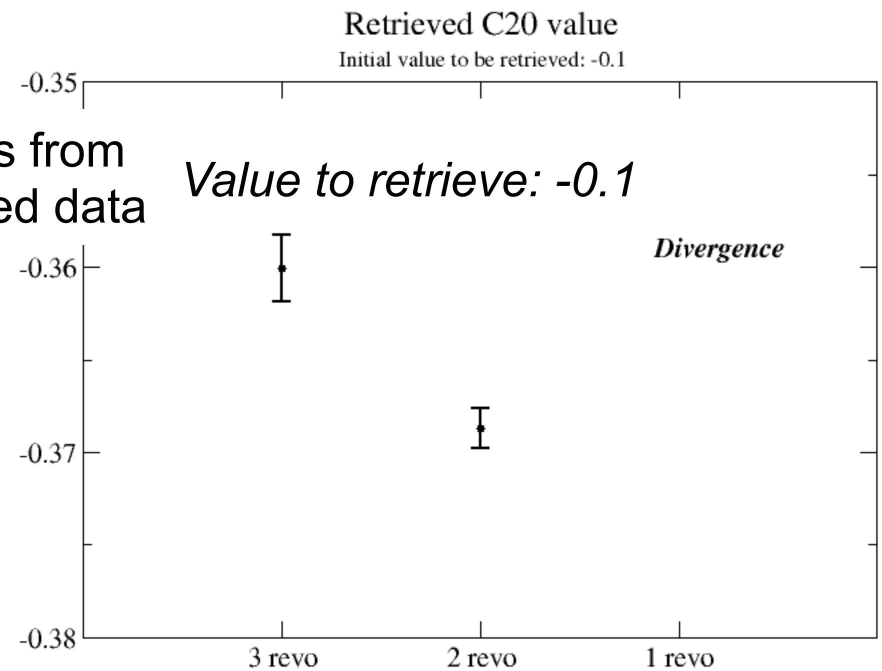


✓ Simulation of Phobos’ ephemeris error: Shifting Phobos position with a constant biais of 1km.

Result of simulations: effect of Phobos' ephemeris error



Results from simulated data



- ✓ Slight bias on GM retrieval: 0.1%
- ✓ Large bias on C20:

- ✓ Phobos ' ephemeris error of 1 km mimic the bias observed on true data for the C20 solution.
- ✓ **But V. Lainey claims error level on his ephemeris at ~200 meters instead of 1 kilometer**

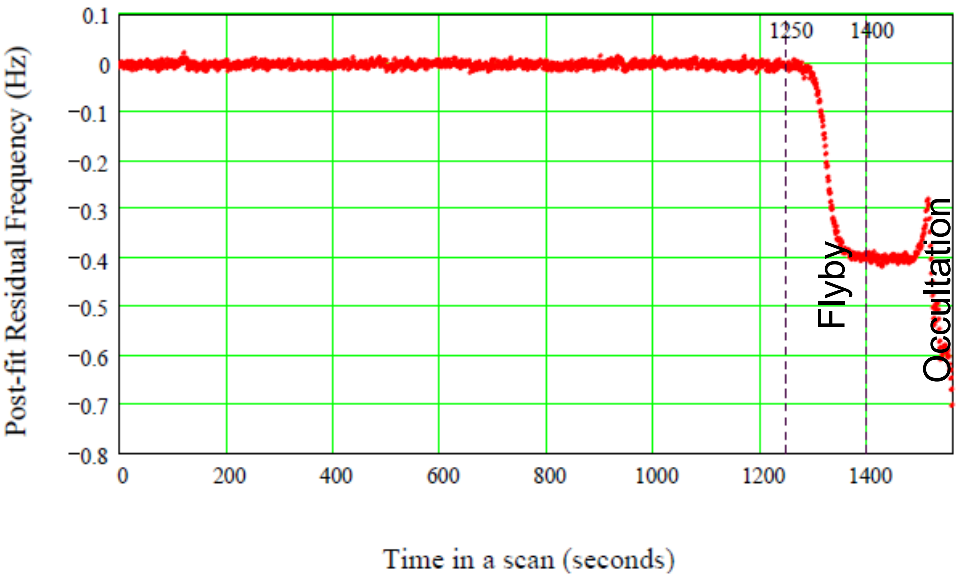
- ✓ Needs to still improve the ephemeris to get 'unbiased' C20 solution.

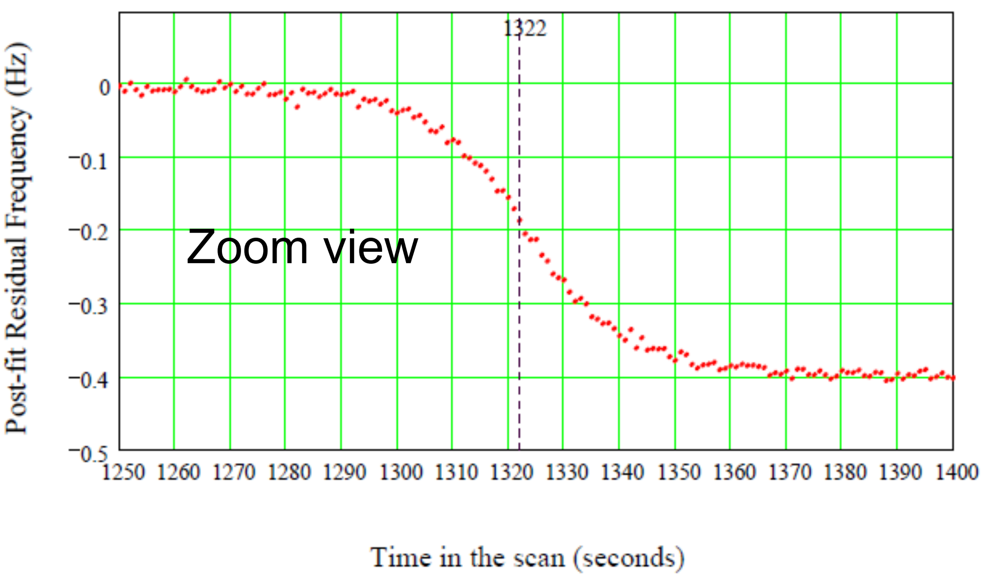
Conclusion and Perspectives

- Strong effect of Phobos' ephemeris on C20 solution (still a few tens of percent with ephemeris error of ~100 meters, from simulations).
- Still needs to improve ephemeris
- Further steps on radio-tracking data: PRIDE tracking data (35 VLBI stations used)
- Merging PRIDE, Deep Space Doppler and data from the 2010 flyby.
- Others … ?

Preview of the Hart15m X-band detections of MEX Doppler during the flyby scan

Post-fit residuals.





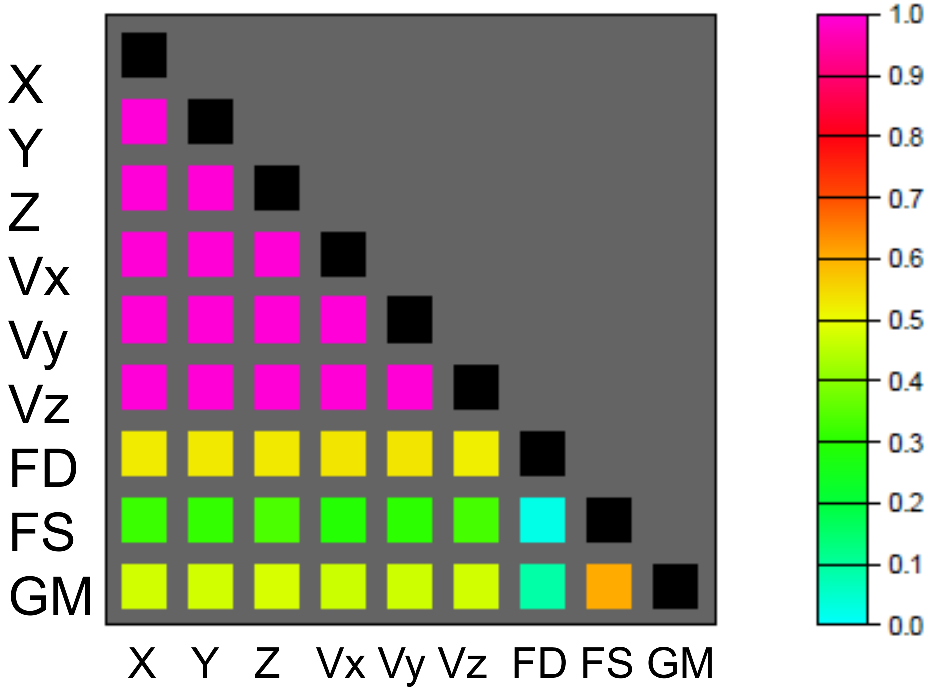
Bulk Doppler fit was done using 8^{th} order polynomial using a LMS criteria with a constraint of the best flatness of the residual before and after the flyby event, excluding the event and occultation times. Pure Math, no physics.

Detection sampling was 1 s, Doppler noise is 5 mHz in 1 s

Signal 50% higher than in 2010 flyby

Courtesy to
Sergei Pogrebenko (JIVE)

Correlation between parameters

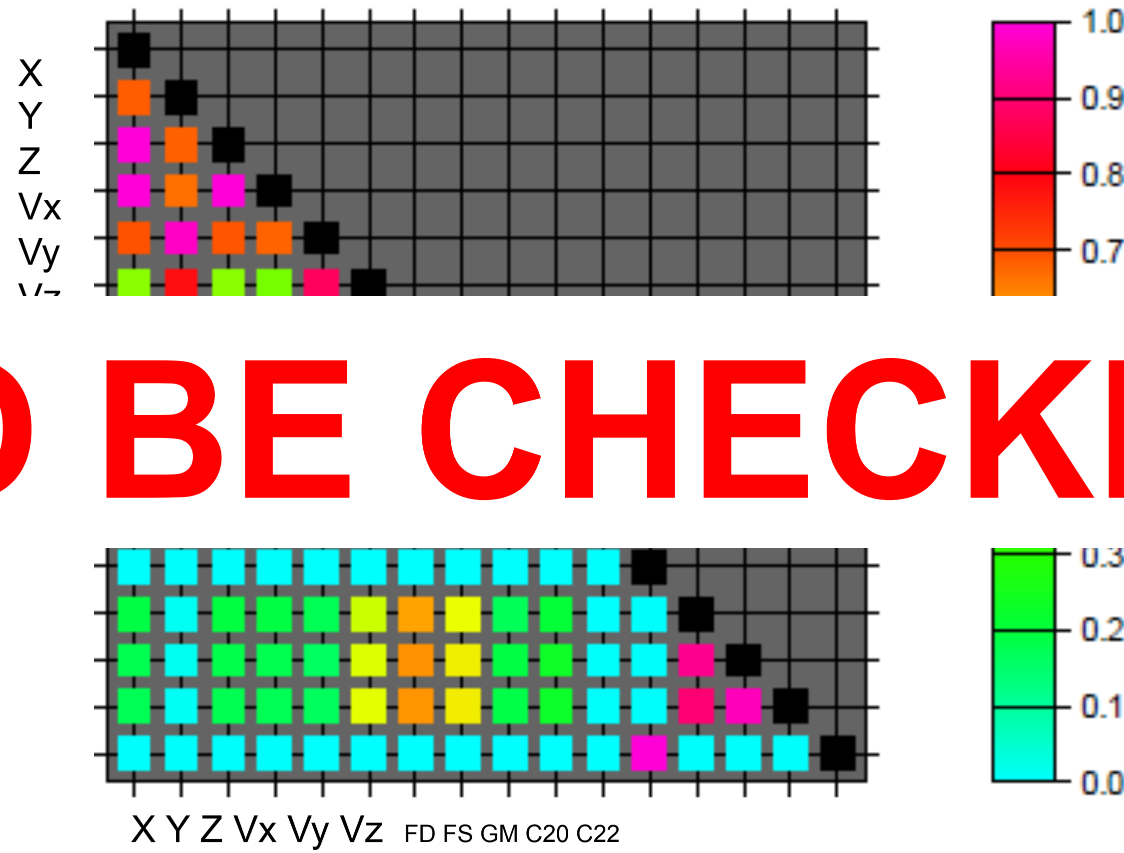


✓ High correlation between initial state vector components (>0.9).
Correlation between FD and initial state vector (~0.5)
Correlation between solar pressure factor FS and Phobos GM (~0.6)

✓ It indicates that the MEX orbit is porrly constrained.

✓ Needs to reduce these correlations to derive meaningful Phobos gravity field solutions

Correlation between parameters:
Short data-arc with Phobos gravity field estimated



TO BE CHECKED

- ➢ High correlation between scale factors and initial state vector.
- ➢ Correlation between GM and C22
- ➢ MEX orbit still poorly constrained.

New implementation into GINS

- Liste des routines modifiées (P. Rosenblatt):
  GINS : teodop23r_dsn.f90

  Raison: Affichage orientation panneaux solaires w.r.t. soleil
  antenne HGA ligne de visée Terre
  Piloté par le bloc free "TEST_QUAT MEX"

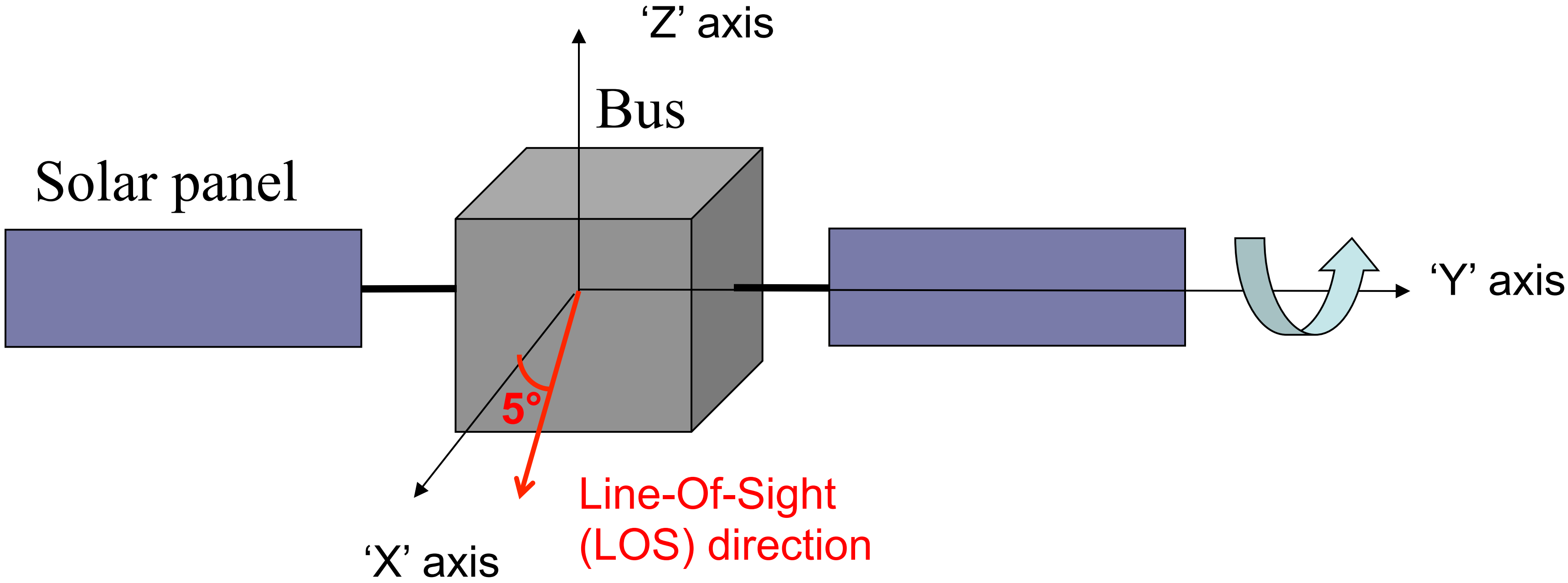
- Liste des routines corrigées (P. Rosenblatt):

  Correction indice rangement dérivées partielles des coefficients du champ gravi du troisième corps:
  GINS : lecsanarg.f90, libgmsana.f90, fsana.f90

- liste des nouvelles routines:
  GINS : matrot_satnat.f90

  Raison: Matrice de passage repère attaché au troisième corps
  → repère d'intégration

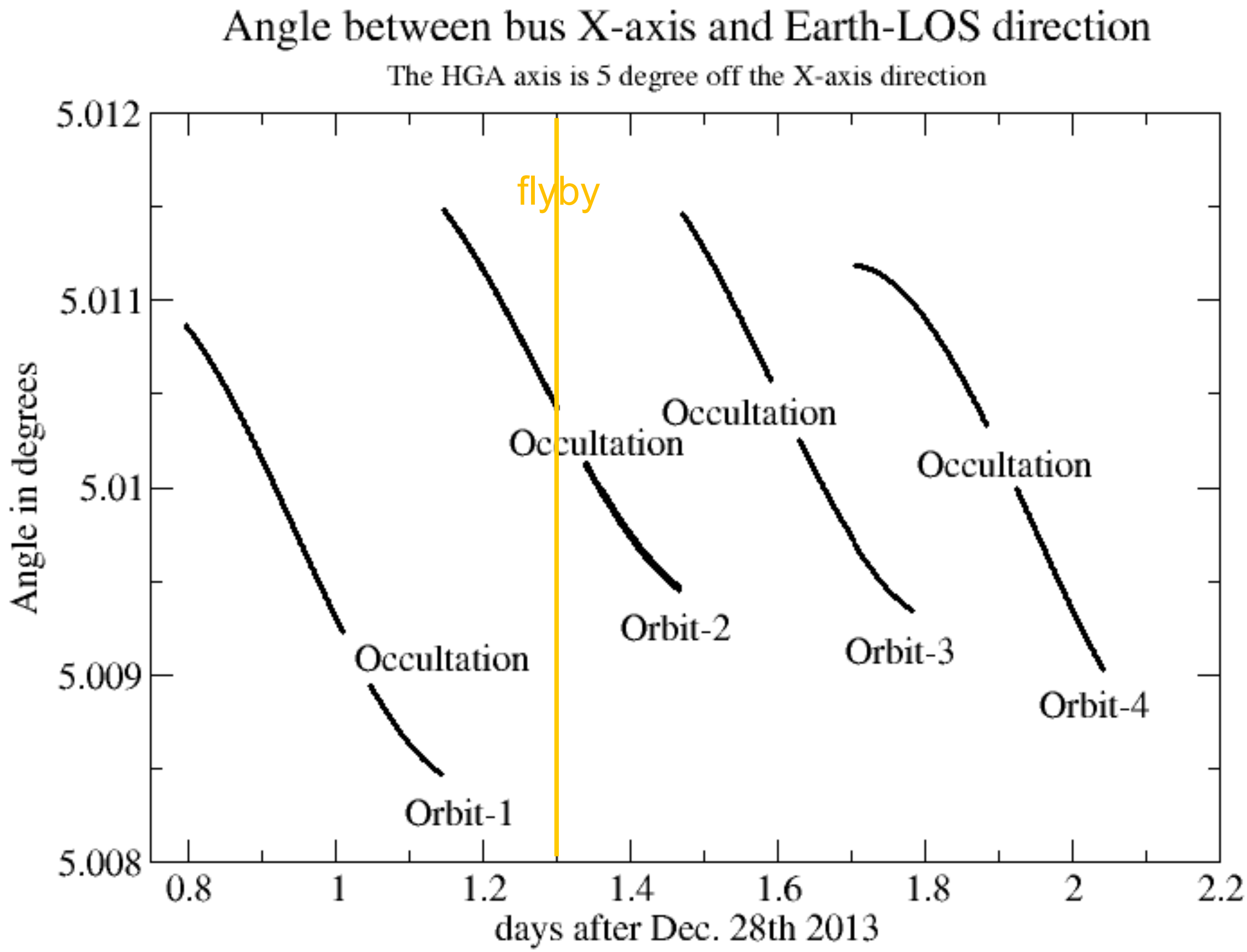
Tests of attitude mode of the spacecraft input into GINS



- ✓ *The angle between the X-axis of the spacecraft frame and the spacecraft HGA axis(not shown here) is 5 degrees. So, this should be the same angle between the X-axis and the LOS direction during the Earth-pointing attitude mode.*

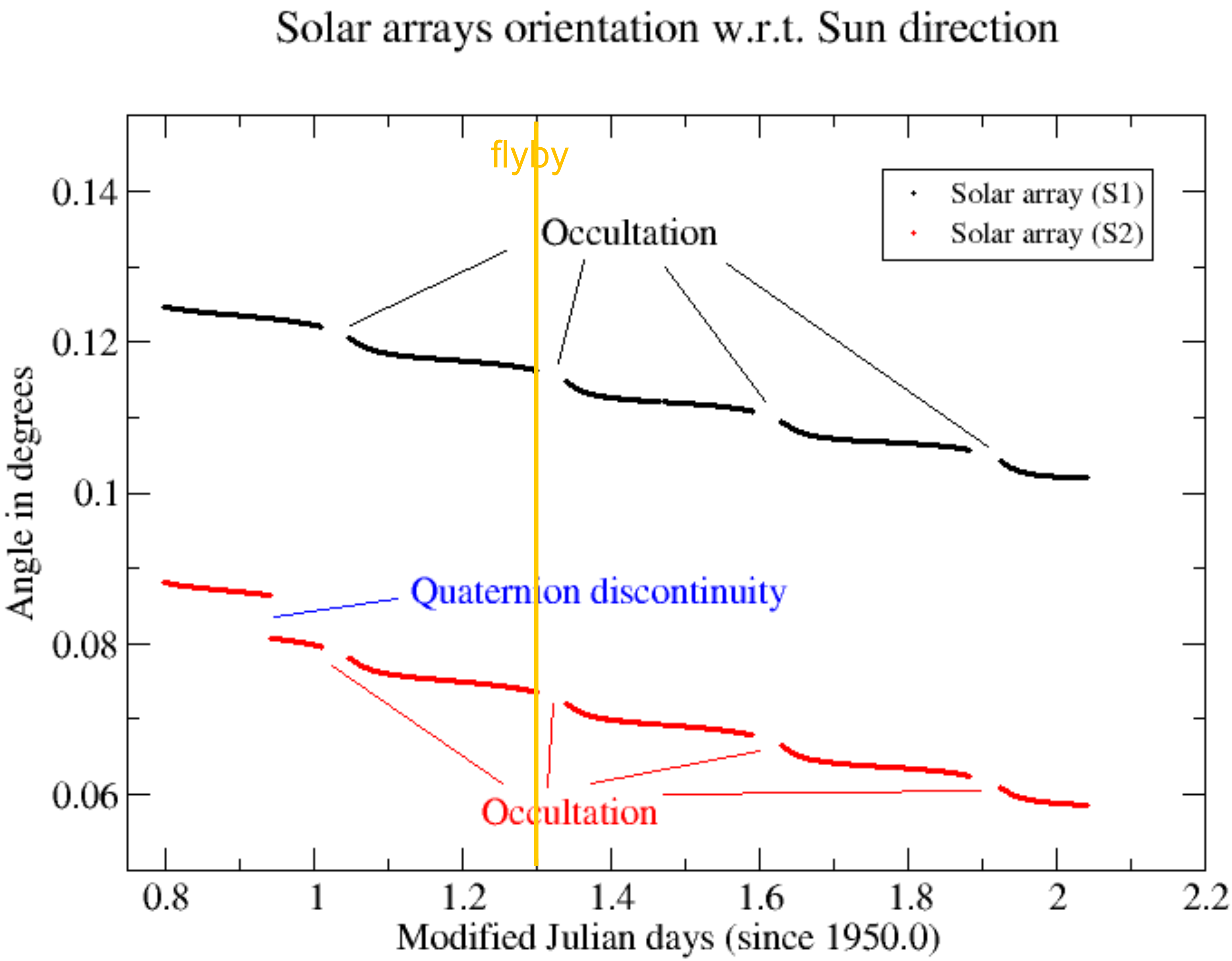
- ✓ *The solar arrays attitude mode is « pointing toward the Sun » (not shown here). So, the angle between normal to the solar arrays and the Sun direction should be near-zero.*

MEX-bus orientation during tracking: Input to GINS



- ✓ 5 degrees angle between the X-axis of the spacecraft frame and the HGA-to-Earth direction → **OK !**

MEX-Solar arrays orientation during tracking: Input to GINS



✓ Solar arrays are usually turned toward the Sun → **OK !**

Future opportunities at ROB using GINS

- ❑ NASA's MAVEN (*Mars Atmosphere and Evolution* Mission) mission. Launch Nov. 2013 at Mars Sept. 2014

  - MAGE (*Maven Atmospheric and Gravity Experiment*):
    Participating Scientist: P. Rosenblatt → PI.
    Team members: J.C. Marty & A. Konopliv (JPL).
    Cross-validation: GINS / DPODP

- ❑ NASA's InSight mission to Mars (2016-2018):

  - Lander on Mars with US X-band transponder:
    Co-I: V. Dehant. Team member: S. Le Maistre, P. Rosenblatt, A. Rivoldini

- ❑ ESA's L-class mission JUICE: Launch in 2022 at Jupiter in 2030

  - PRIDE experiment accepted as a payload: VLBI-tracking (Doppler+lateral position) of the JUICE's spacecraft.
    P. Rosenblatt (& J.C. Marty) → Co-I

Future opportunities at ROB using GINS

- ESA's call for M4 (medium-class) mission:

  - Mission to Phobos: on the basis of the GETEMME proposal submitted to the M3 call.

- Trace Gas Orbiter (TGO): ESA's spacecraft (Mars 2016 mission).

  - AO for radio-science (in 2014?).
    Circular orbit 400x400 km inclined at 75 degrees (Mars' seasonal gravity).

- Russian platform on ExoMars (Mars 2018 mission):

  - AO ESA/Roscosmos (in 2014?).
    Lander at Mars' surface: DTE radio-link useable for Mars' interior.
    Synergy with InSight.

Acknowledgements

This work was financially supported by the Belgian PRODEX program managed by the European Space Agency in collaboration with the Belgian Federal Science Policy Office.

BELGIAN SCIENCE POLICY

esa