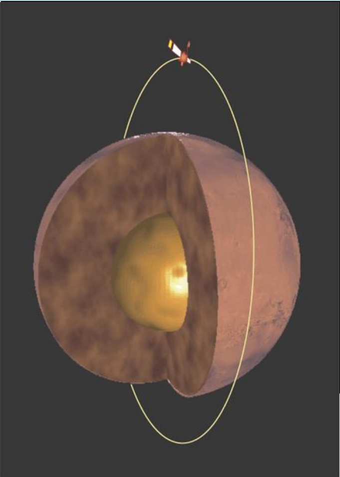
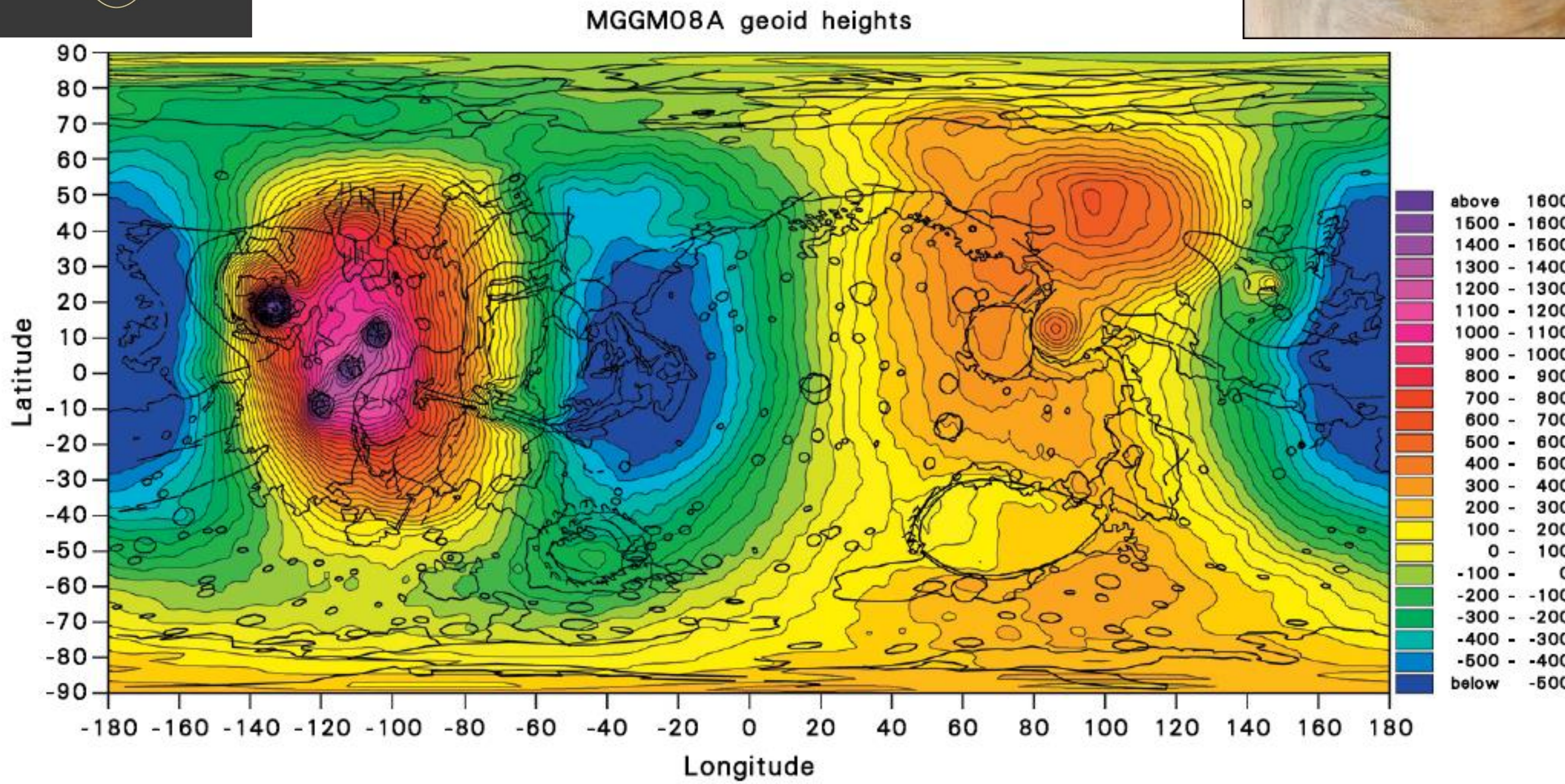


GINS at ROB: Achievements & Opportunities

by Pascal Rosenblatt
(*Royal Observatory of Belgium*)



Journée GINS: June 4th 2015 (première présentation de la journée)

Data processed at ROB/GRGS

- Achievements:
  Current mission: **Mars Express, Venus Express, MAVEN**
  Mars Odyssey, Mars Reconnaissance Orbiter
  Opportunity
  Past mission: Mariner-9, Viking 1-2 (Orbiter+Lander),
  Spirit, Phobos-2, Galileo, **Mars Global Surveyor**

- New Opportunities:
  JUICE: ESA's L-class mission (2031): Jovian system orbiter, 'Ganymede orbiter'
  INSIGHT: Mars' deep interior

- Current or upcoming proposals:
  ExoMars 2016 (**TGO)** 2018 (Platform): ESA optional program
  PADME (Phobos/Deimos flybys): NASA Discovery program

Mars gravity from tracking

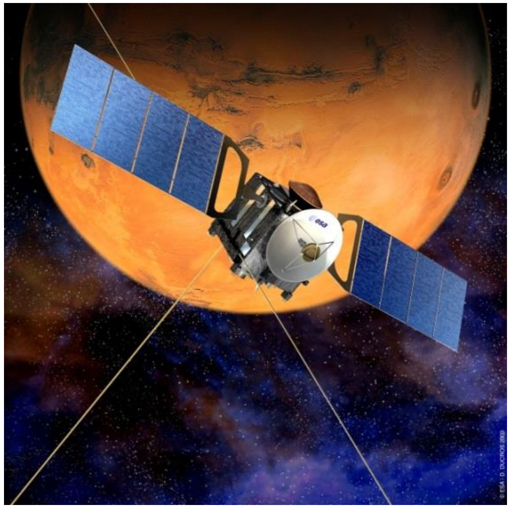
From NASA

Near-circular orbits at altitude of 400 km

From NASA

From NASA

Near-circular orbits at altitude of 250 x 320 km



From ESA

MEX

2003-now

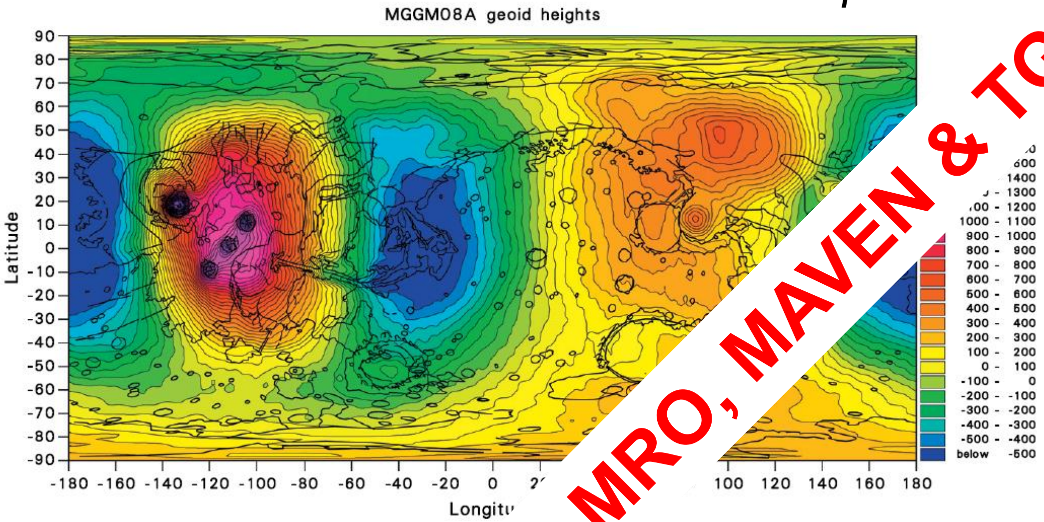
Elliptical orbit at altitude 250x10400 km

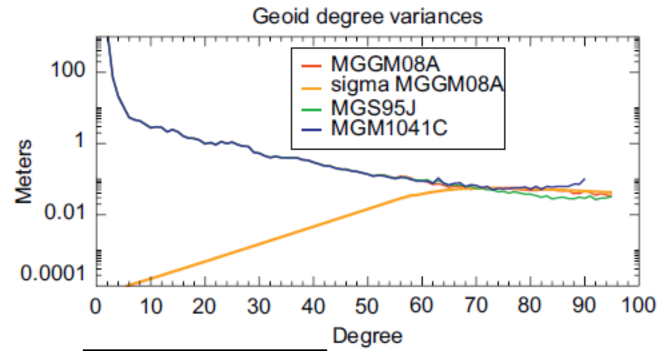
Achievement: Mars' static gravity field

GRGS/ROB solution, Marty et al., 2009

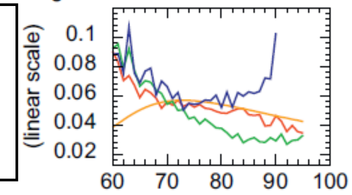
Spatial resolution about 300 km

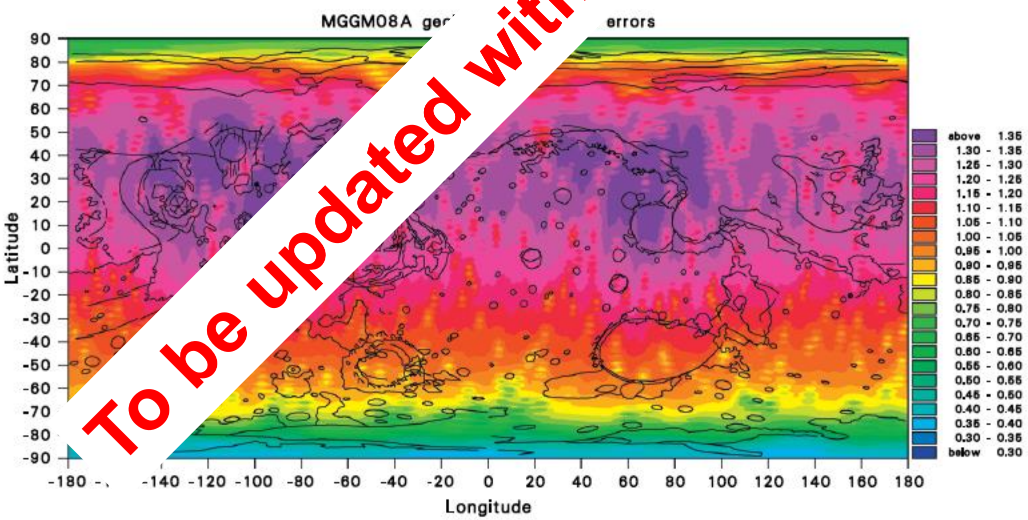
To be updated with MRO, MAVEN & TGO





Solutions from:
GRGS/ROB
JPL
GSFC

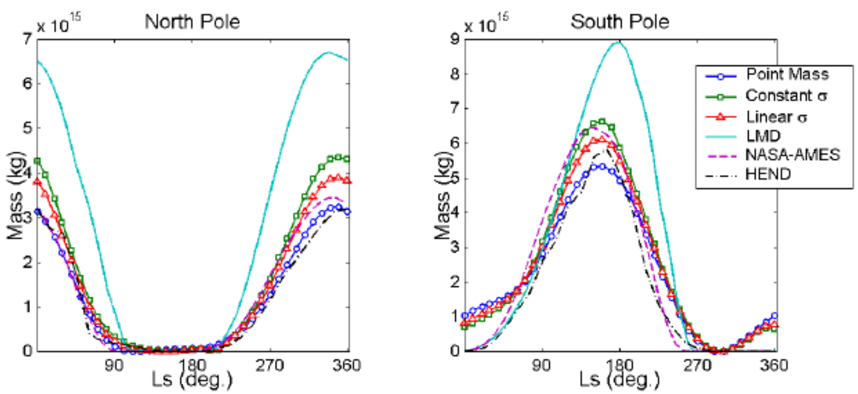




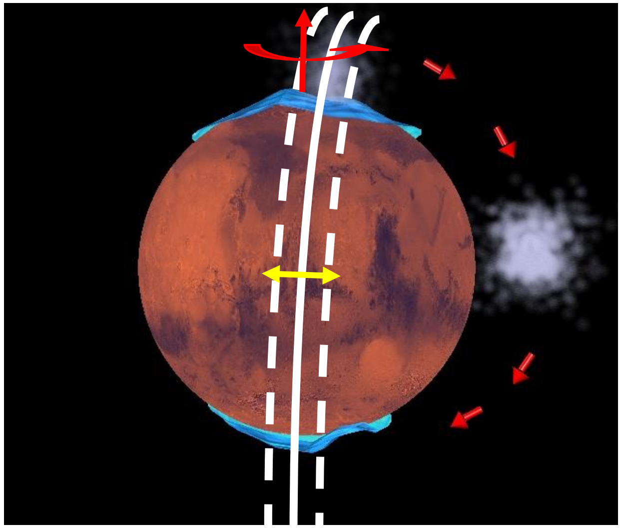
Limitation due to the orbit sensitivity to Doppler tracking precision and to non-gravitational forces:
Degree strength around 70.

Challenge: To detect fine temporal variations of the first zonal harmonics and the k_2 tidal Love number

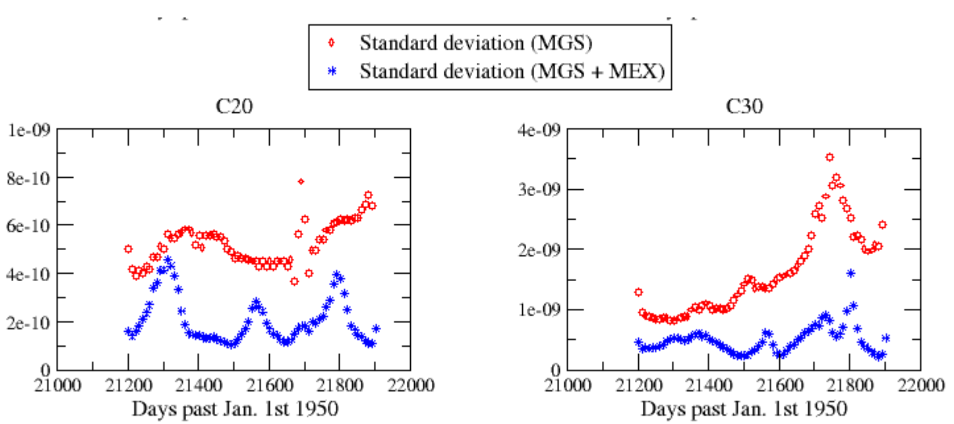
Achievement: Seasonal gravity field changes



Seasonal gravity field to determine mass transfer budget, but insufficient precision to constrain the models of CO_2 seasonal deposits (*Karatekin et al., JGR, 2006*).



Mars' atmosphere CO_2 seasonal cy



GINS simulations (Rosenblatt et al., AGU fall meeting 2005)

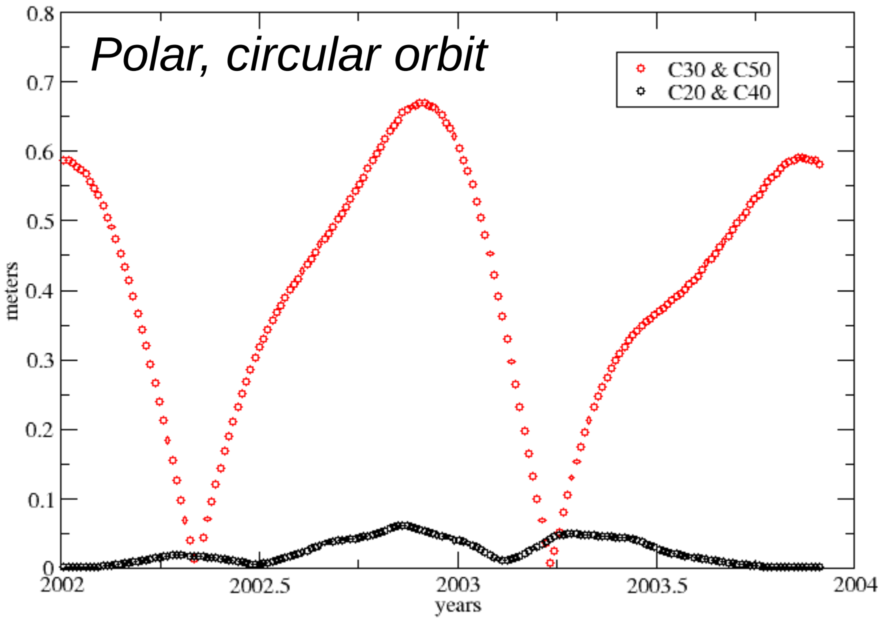
MEX + MGS can improve the solution of first zonal harmonics variations, thus the seasonal mass budget, given the orbits are well resolved.

We need to perform an accurate spacecraft orbit.

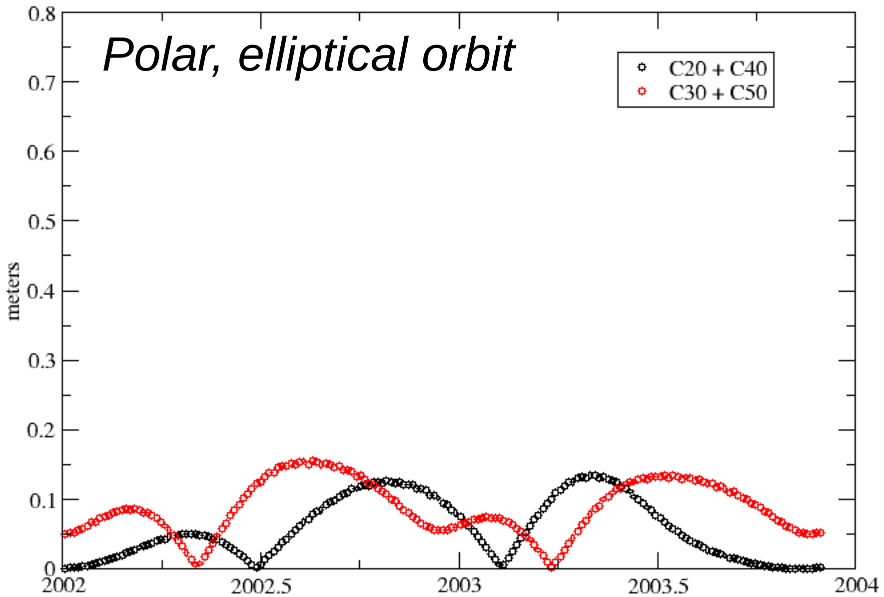
Yes, but how much accurate?

Achievement: Perturbation of spacecraft position due to Mars' time variable gravity field

Simulated MGS orbit



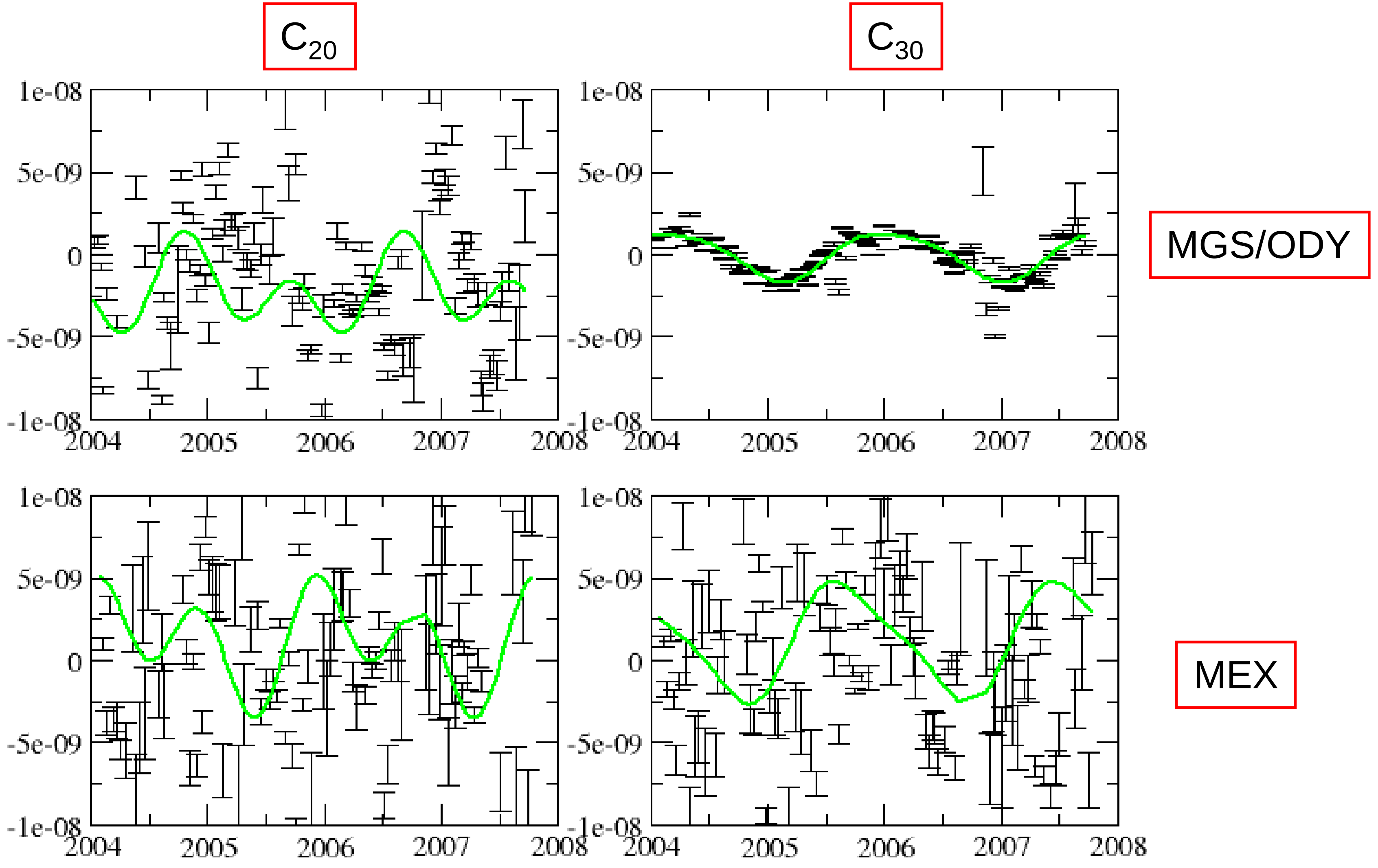
Simulated MEX orbit



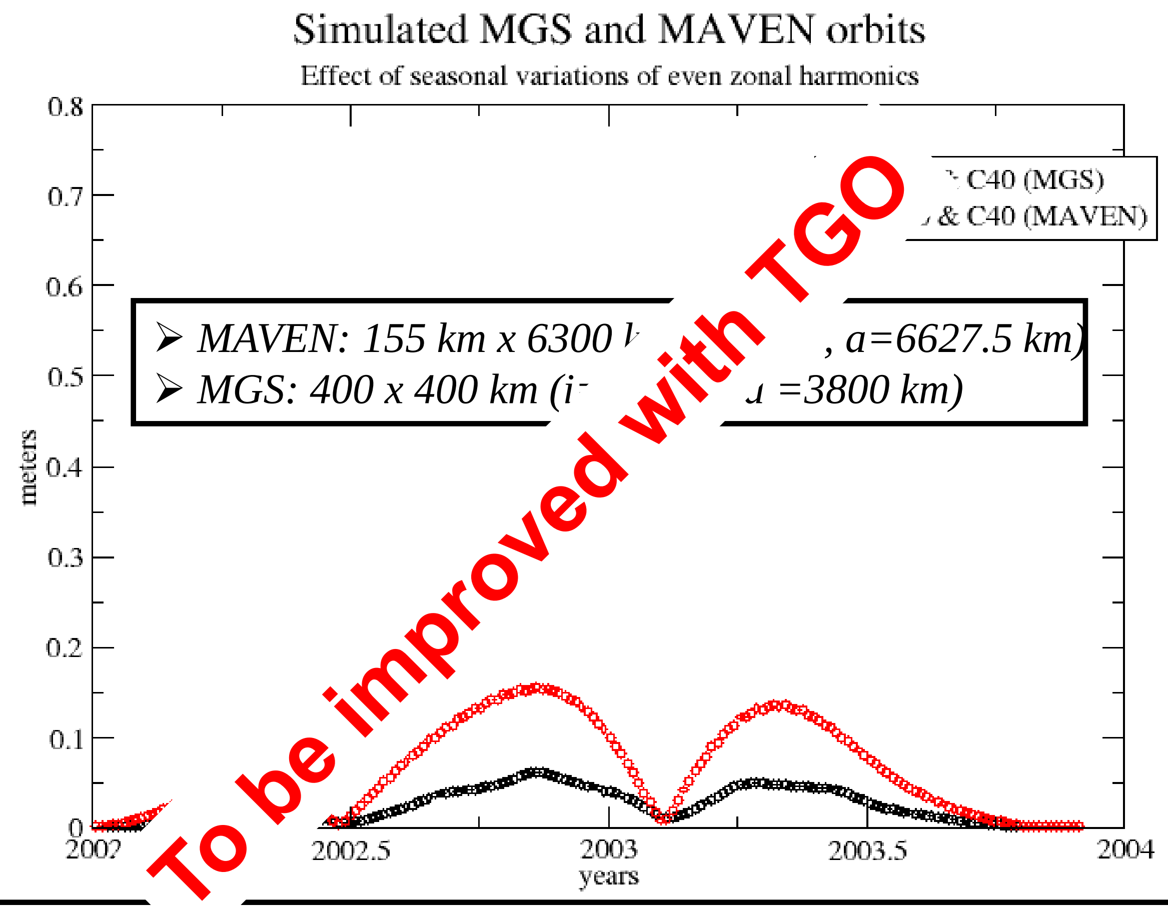
- **MGS orbit** (actual orbit **accuracy is 1-2 meters** on average): Signature of **odd zonal harmonics < 1 meter & even zonal harmonics < 10 cm**

- **MEX orbit** (actual orbit **accuracy is 20 meters** on average): Signature of time variable **zonal harmonics < 20 cm !**

Achievement: Fit of time variable C_{20} & C_{30} from MGS/ODY and from MEX

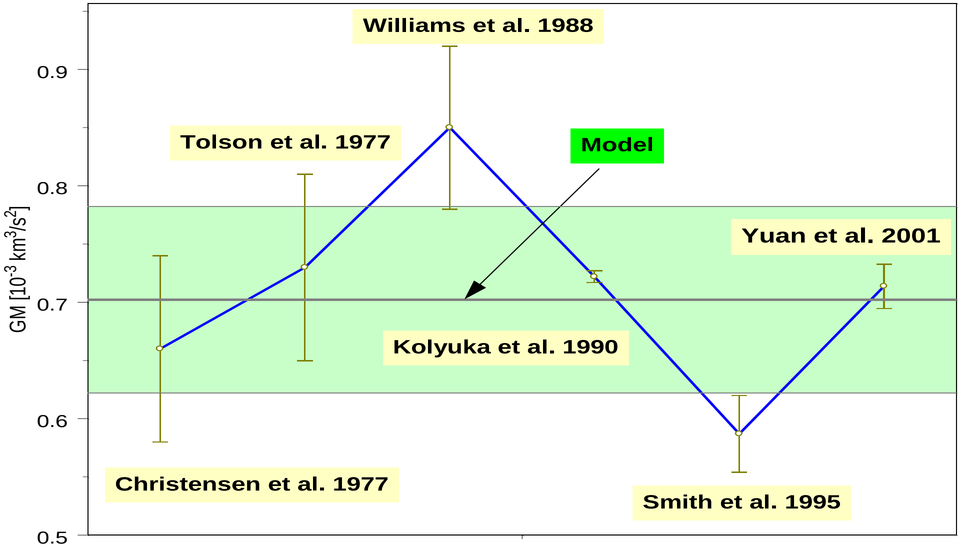


New Opportunity: ESA's Trace Gas Orbiter (TGO)



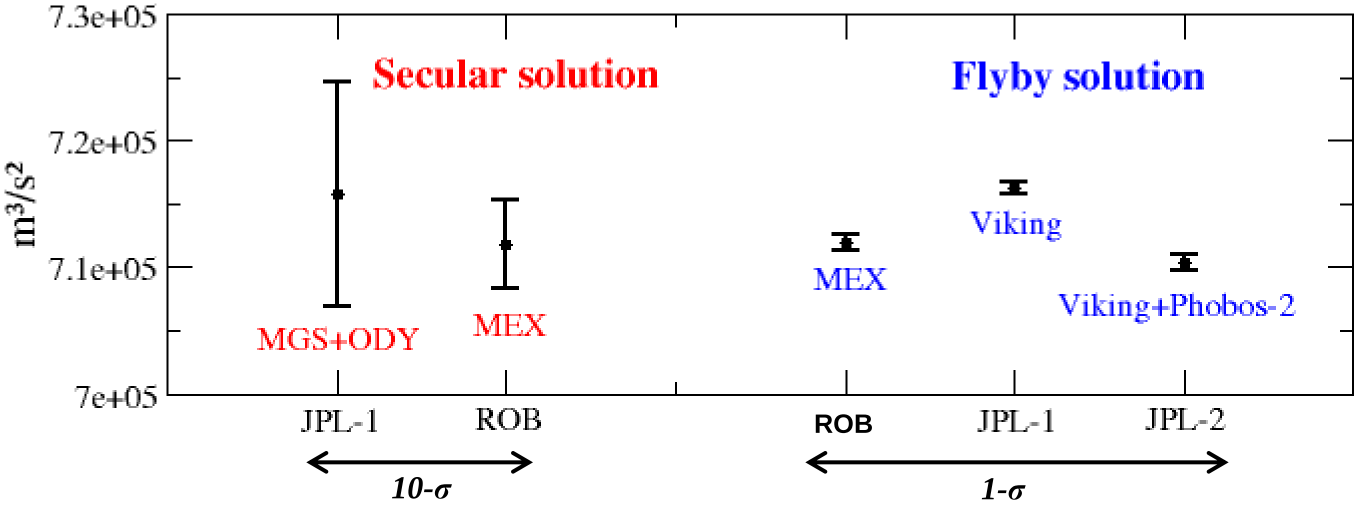
- MAVEN vs MGS: The larger semi-major-axis almost remove the again in sensitivity due to the lower inclination
- Confirmed by analytical approach (Kaula).
- ESA's TGO spacecraft: ***400x400 km, i=74˚*** . Analytical approach → Sensitivity x 10

Achievement: Much better determination of Phobos mass



Before Mars Express:

8.8 10^15 kg - 1.27 10^16 kg
~40% of error

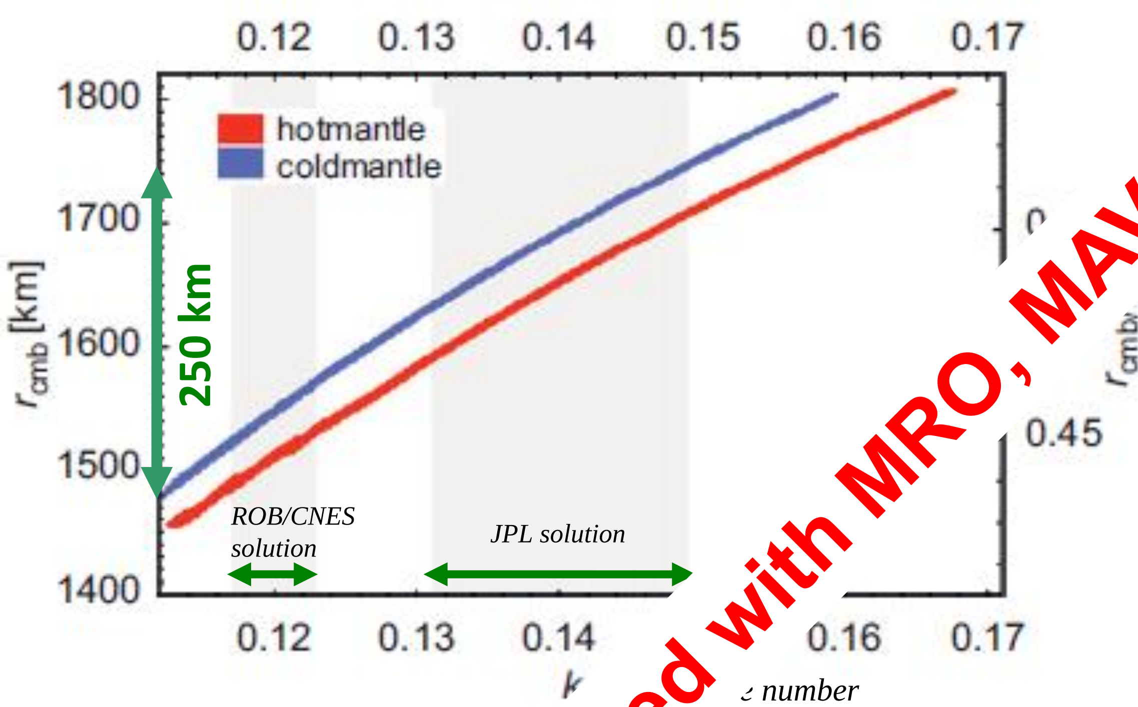


After Mars Express:

1.06 10^16 kg
~0.4% of error

Achievement: Martian core from geodetic data

(e.g. Yoder et al., 2003; Konopliv et al., 2006; M... et al., 2009)



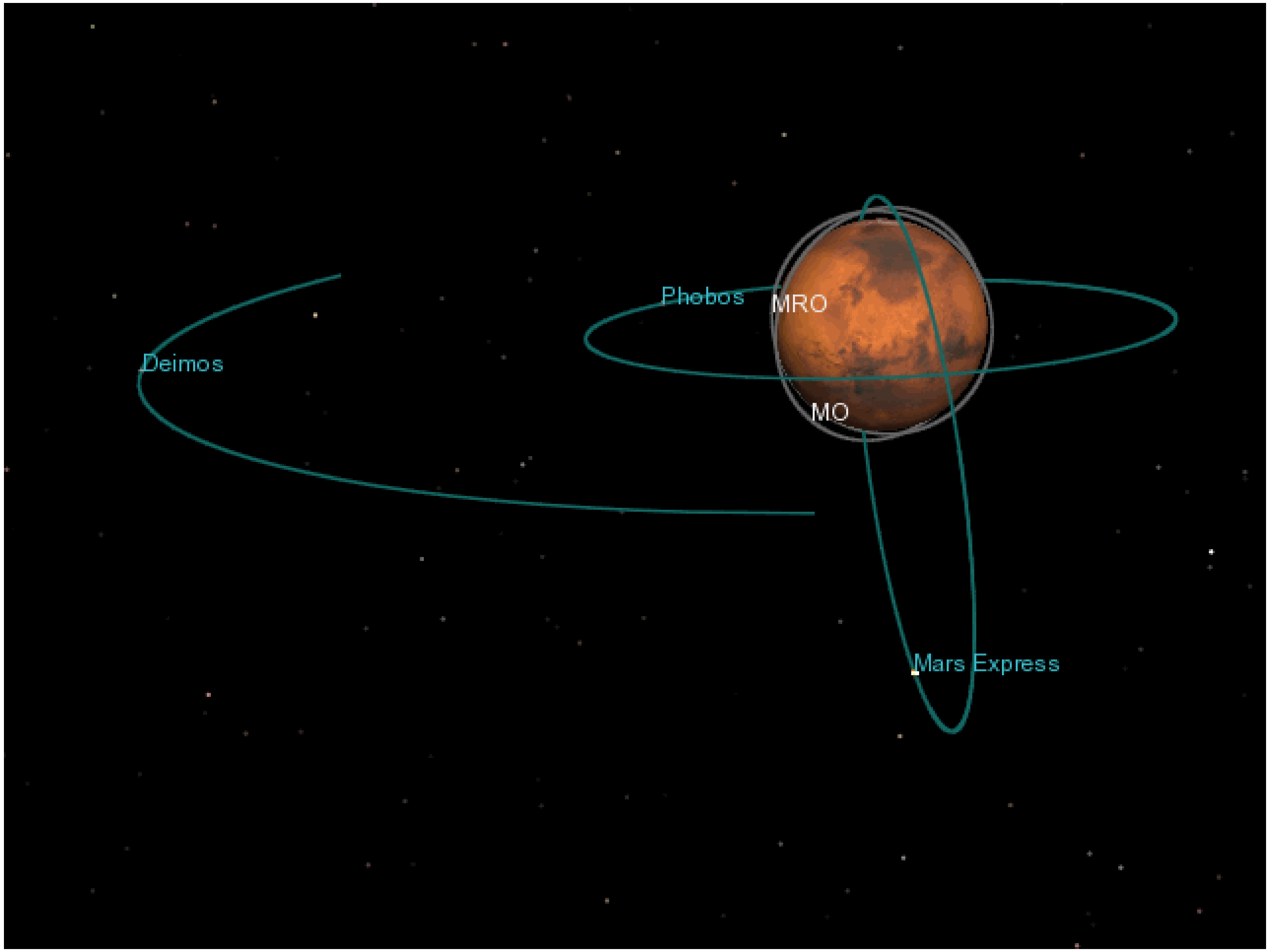
Core radius estimates given possible mantle temperature end-members, mantle rheology, and crust density and thickness range (from A. Rivoldini, ROB).

To be updated with MRO, MAVEN, TGO

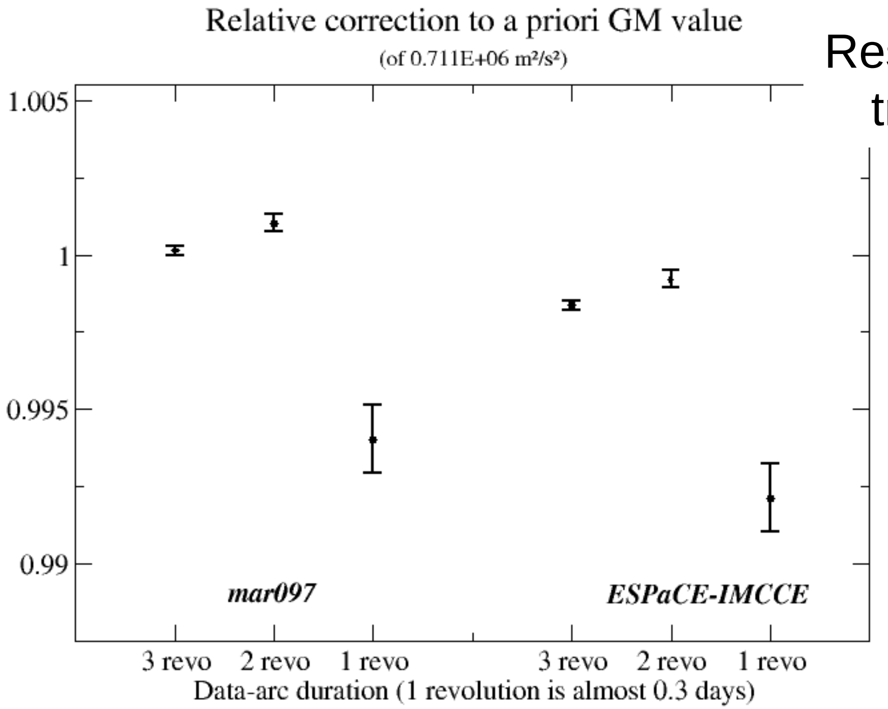
All solutions of *k* ...e a liquid core inside Mars (k_2 > 0.08), but discrepancies still remain, th... ...ying a too large uncertainty for core radius estimate **(+/- 250 km**... ...er constrain Mars' deep interior structure (sulfur content).

This is due ... the difficulty to extract the weak signal of the k_2 from the current reconstructed orbits of the Martian spacecraft.

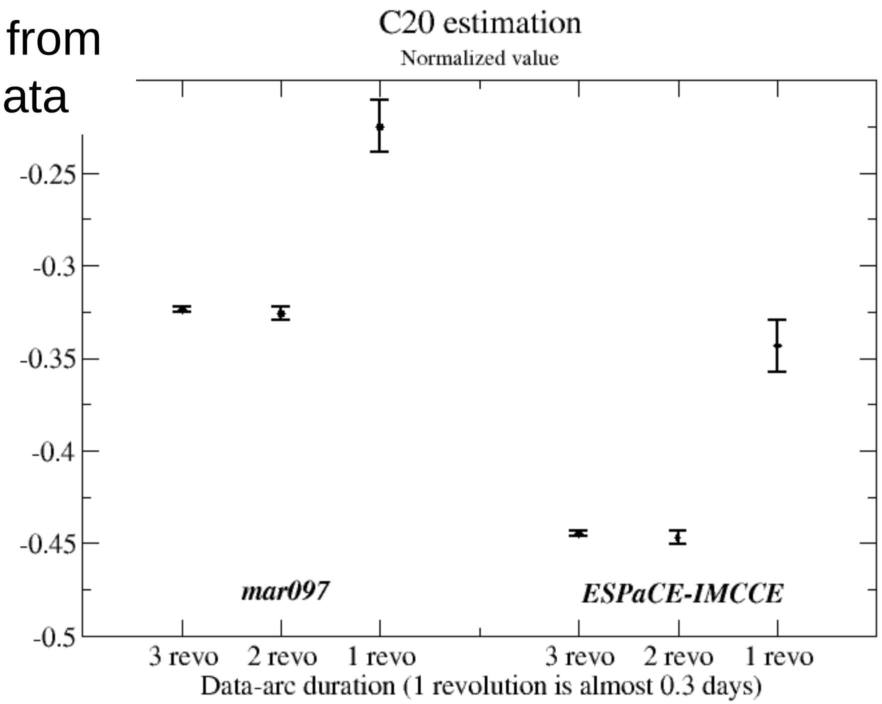
Very close flybys of Phobos by Mars Express (Dec. 29th 2013)



Achievement: Estimating dynamical Phobos' gravity field from flyby



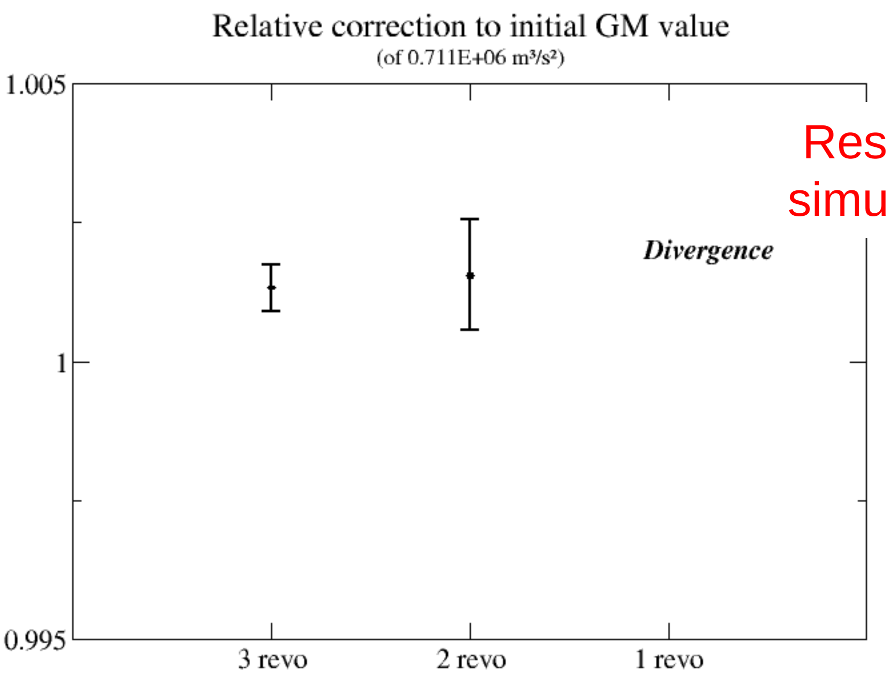
Results from true data



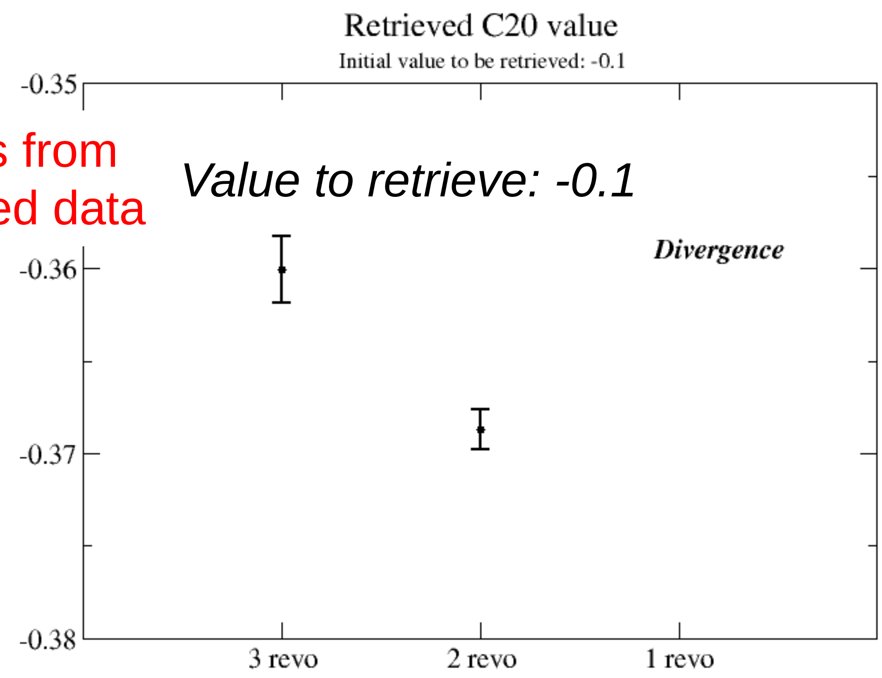
- ✓ GM estimated close to initial value of 0.711 E+06 m3/s2 with formal error of about 0.02%.
- ✓ C_{20} estimated close to about -0.32 with formal error of about 0.002 (0.6%) Large bias more than 100%.

✓Solutions due to error on ephemeris !

Achievement: Simulations of Phobos' ephemeris error



Results from simulated data



Value to retrieve: -0.1

- ✓ Slight bias on GM retrieval: 0.1%
- ✓ Large bias on C_{20} retrieval

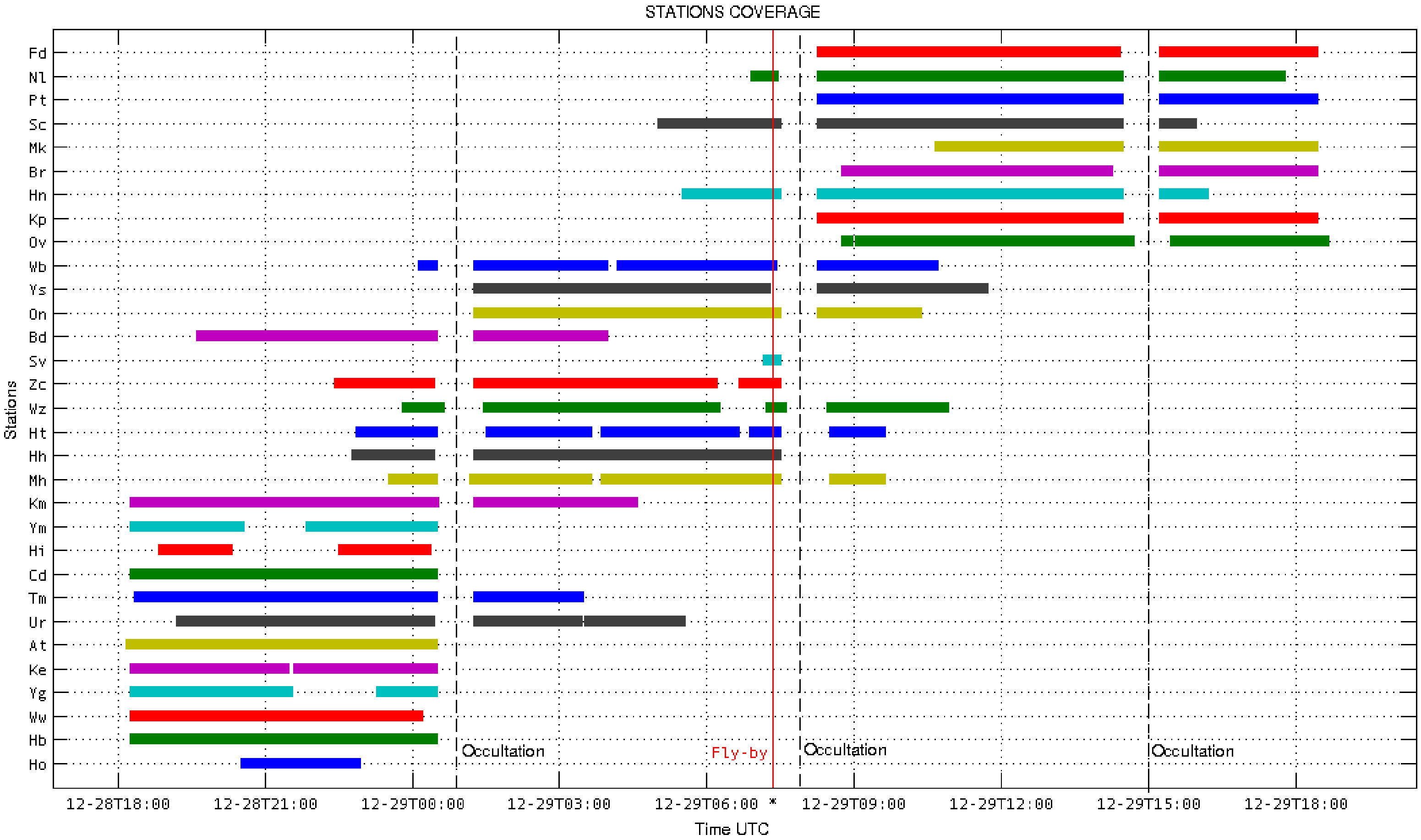
✓ Phobos ' ephemeris error of 1 km mimics the bias observed on true data for the C_{20} solution (*better simulation adding the C_{22} to be done*)

✓ 100 meters on ephemeris bias → about 10% of biais on C_{20}
10 meters on ephemeris bias → about 1% of bias on C_{20}

MEX/Phobos flyby experiment 29.12.2013

GR035 Proposal PI: P. Rosenblatt (ROB)

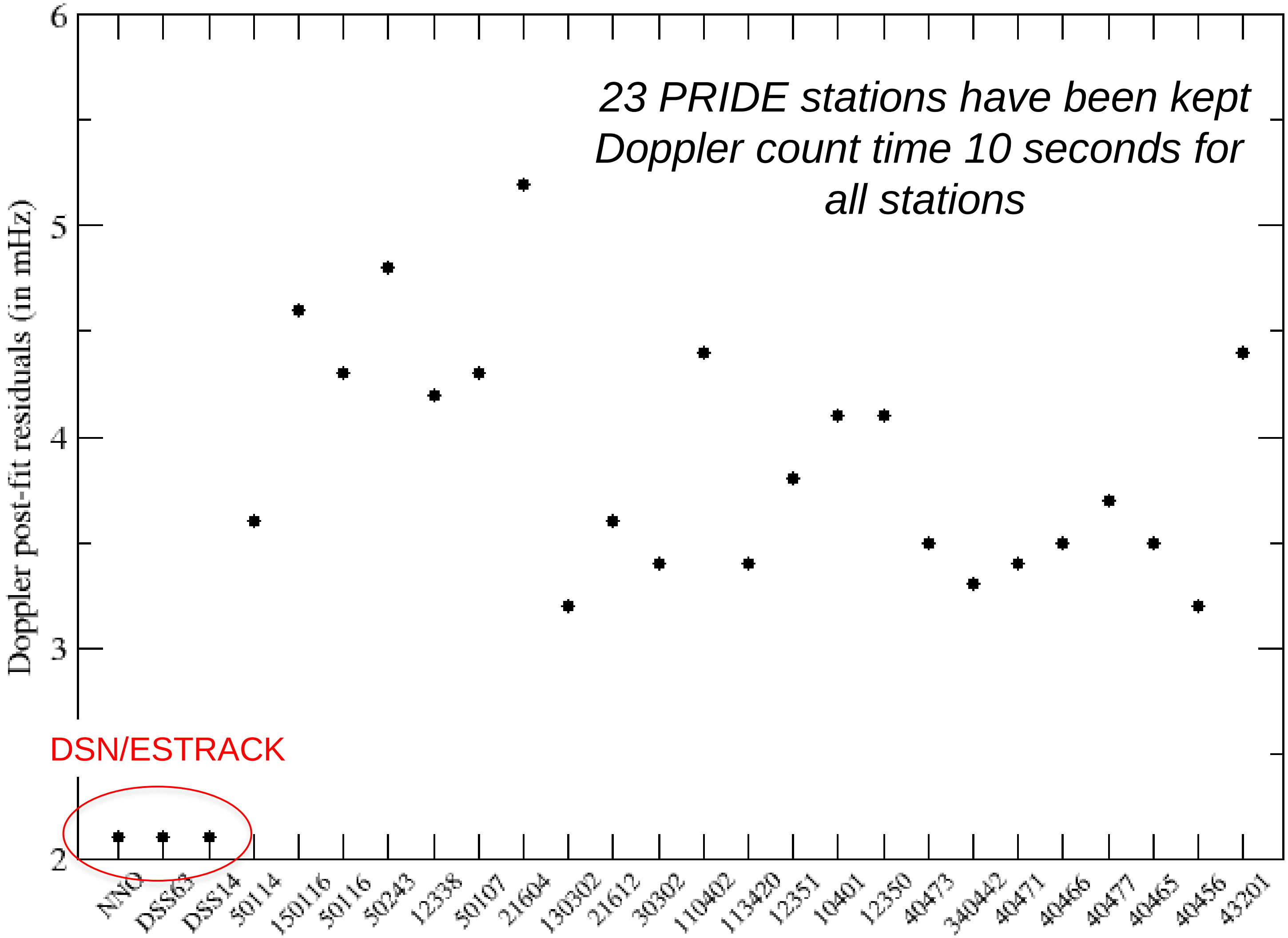
GR035: Global coverage



Asia-Oceania – Europe-South/Afr. -- North-America

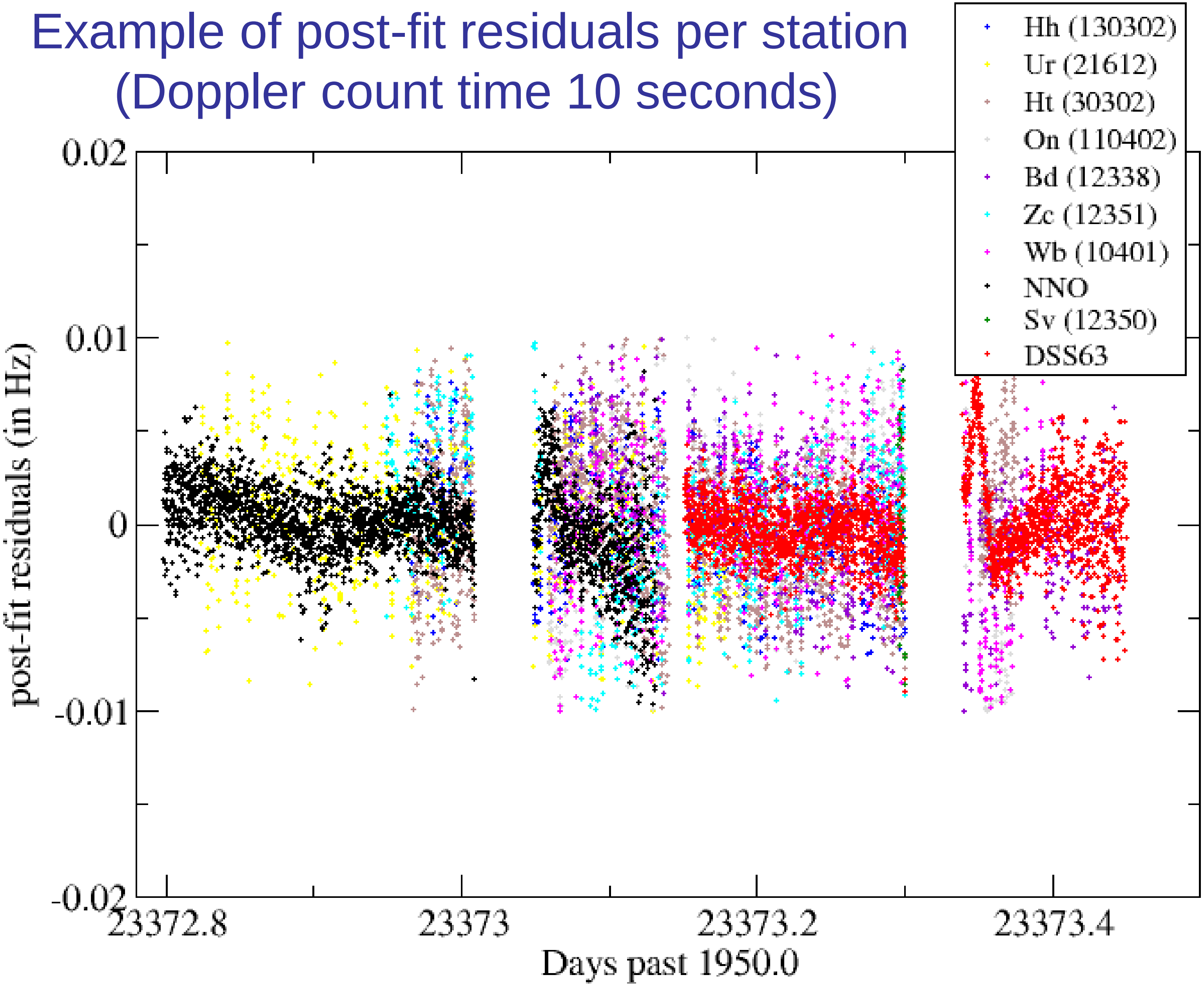
- ✓ 24 hours of continuous tracking using 31 radio-telescopes
- ✓ 9 to 11 telescopes used simultaneously to track MEX

Achievement:
RMS of post-fit residuals DSN/ESTRACK vs PRIDE



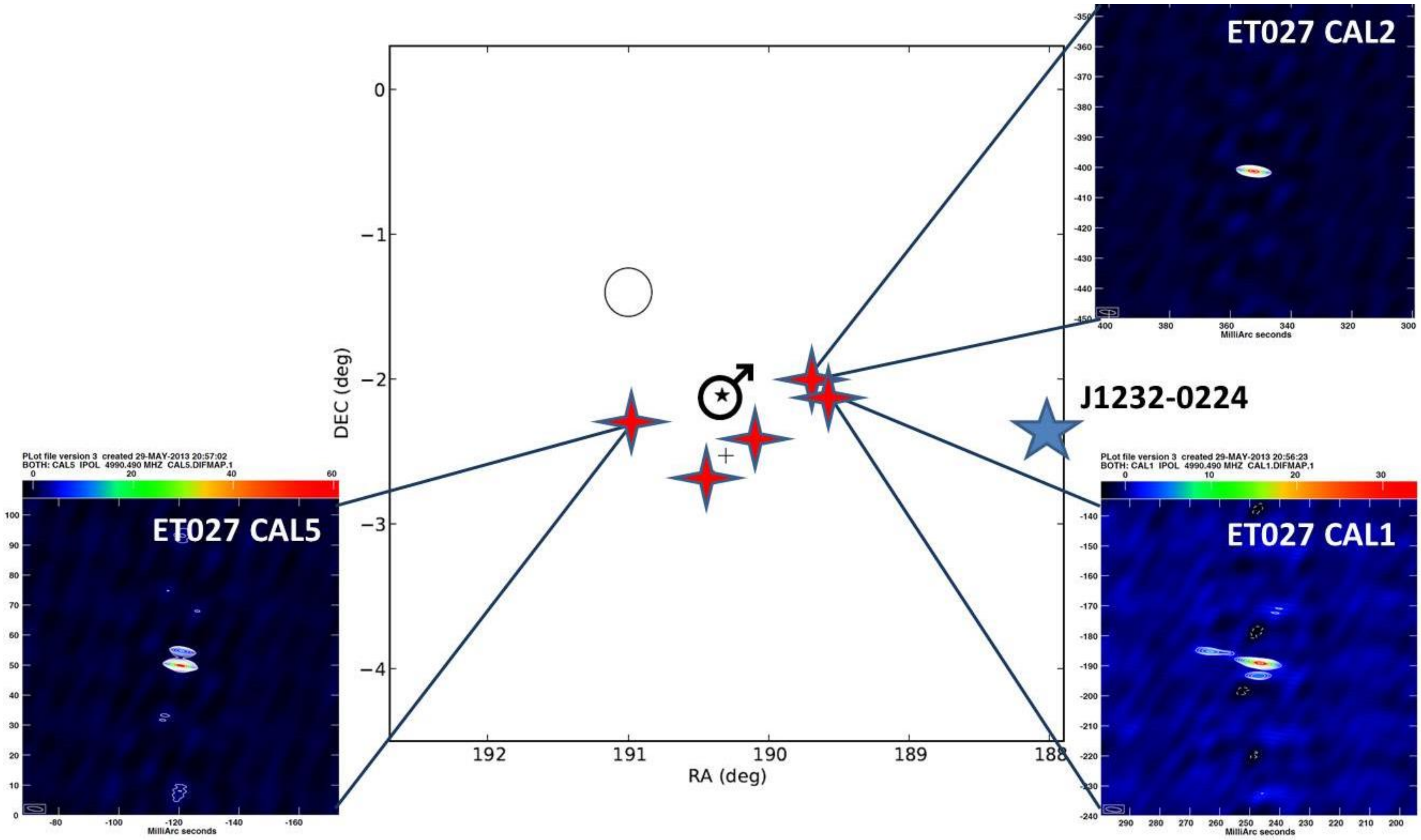
- PRIDE residuals are worse than DSN/ESTRACK stations by a factor between 1.5 and 2.5

Example of post-fit residuals per station (Doppler count time 10 seconds)



- Improvement is ongoing on the JIVE pre-processing side

GR035: MEX/Phobos flyby finding chart



- ✓ MEX position in the plane-of-sky relative to identified quasar sources
- ✓ → Huge task given 31 telescopes:

  GINS process validated with Venus Express data.

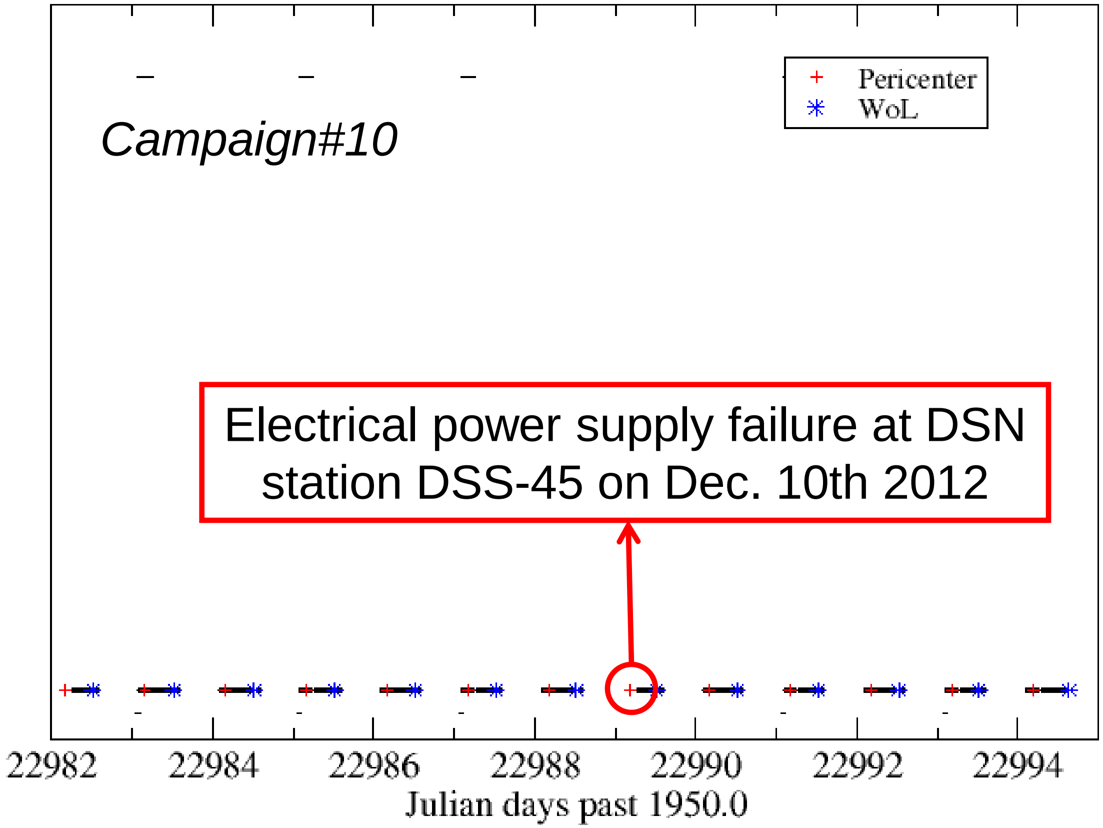
  Still needs to assess improvement of MEX orbit.

ROYAL OBSERVATORY OF BELGIUM

VExADE drag campaign#1 to #10 (Tracking data)

Rosenblatt P., Bruinsma S., Müller-Wodarg I.C.F., Svedhem H., and Häusler B.

VExADE: Tracking coverage



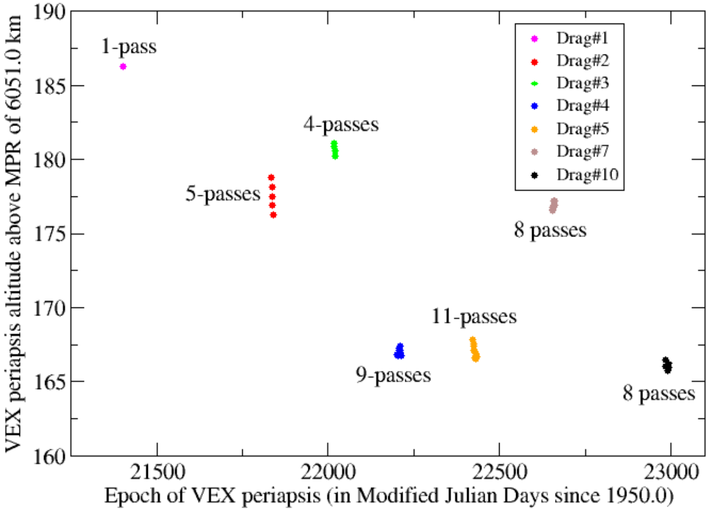
- 12 pericenter passes (6 DSN + 6 NNO)
- 4 hours around pericenetr + 8 hours on higher altitude part (Cebreros)

- Precise Orbit Determination (POD) on successive data-arcs starting just after a WoL event and ending just before the next one → One revolution.

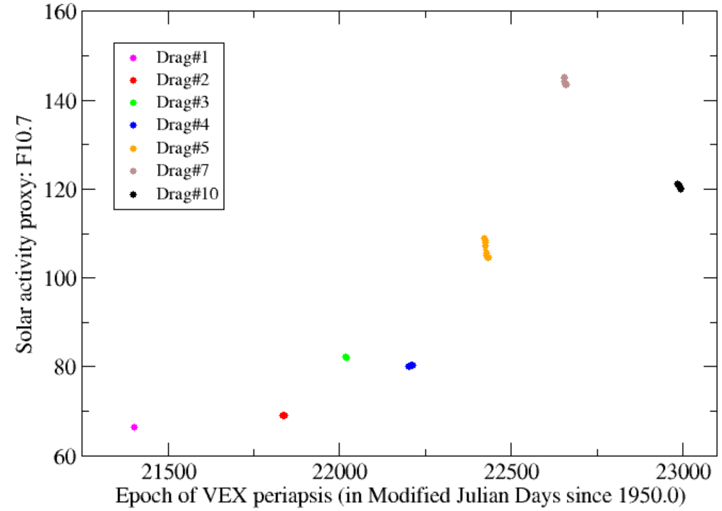
- Each data-arc is foreseen to provide one estimate of the atmospheric density at pericenter.

VExADE drag campaign#1 to #10: Dataset

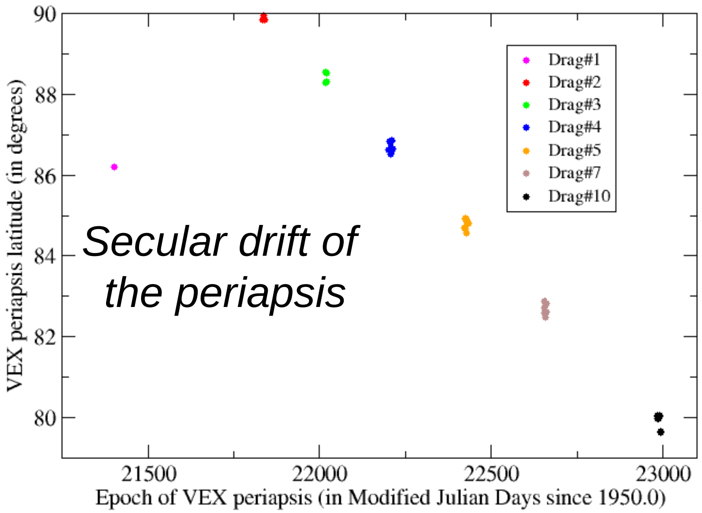
Altitude sampling



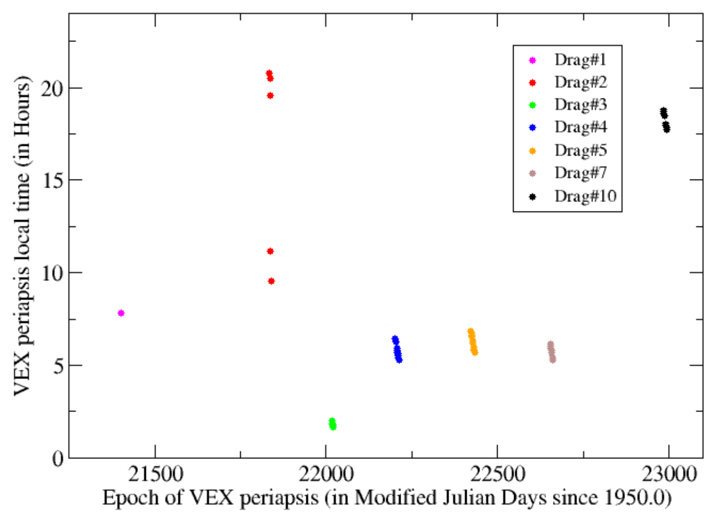
Solar activity sampling



Latitude sampling

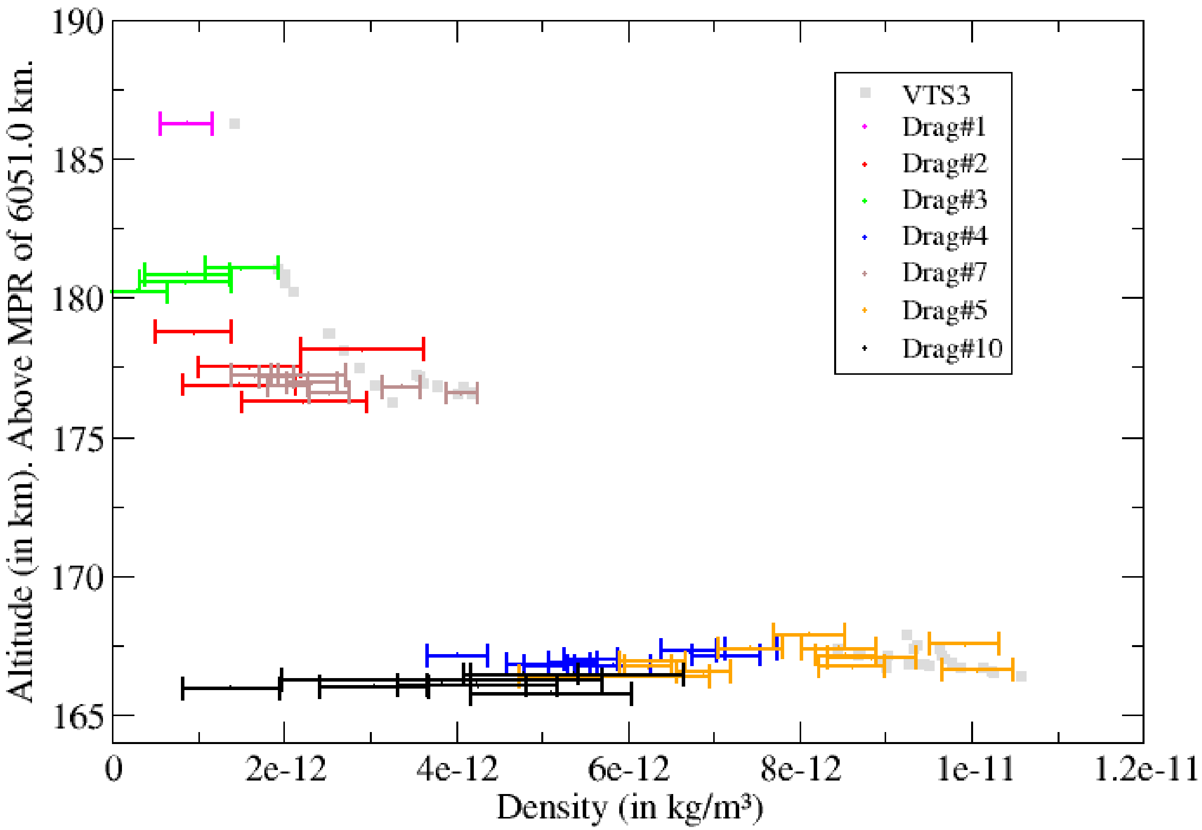


Local time sampling



✓ **46 reliable density estimates**, but limited sampling. Altitude range: 165-185 km; Latitudes: 80° -90° ; local time: 1h, 7h, 18h ; Solar activity F10.7: 66-145.

Achievement: VExADE campaigns#1 to #10



$$\rho_{VExADE} = F_D \cdot \rho_{mod}$$

<u>Where:</u>

ρ_{VExADE} is the VExADE density (data-points with error bars as calibrated formal errors)

F_D is the drag scale factor

ρ_{mod} is the HEDIN-VTS3 density

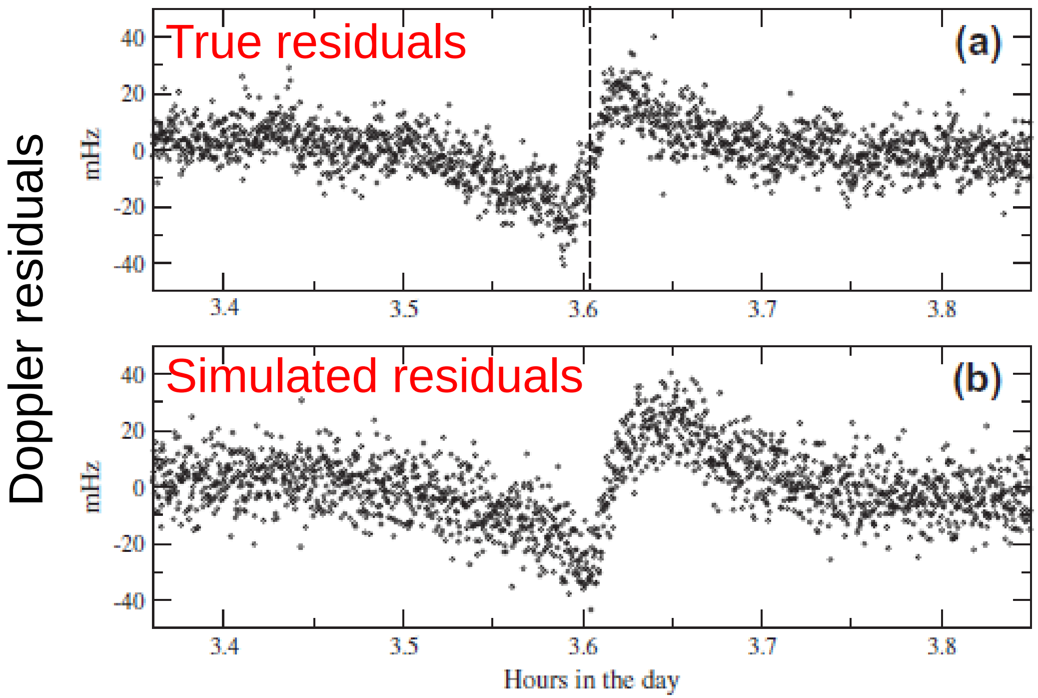
Rosenblatt et al., Icarus, vol. 217, pp. 831-838, 2012

(method & result for campaign#1 to #3)

- Venus' upper atmosphere density at polar areas is about half the predicted density by model (Hedin-VTS3), *Except* some passes of campaign#5, #7 (up to 0.8) and of campaign#10 (down to 0.3)
- Checked by independent method using the inertial wheels of the spacecraft.
- ***Accuracy on density limited by accuracy on gravity field harmonics?***

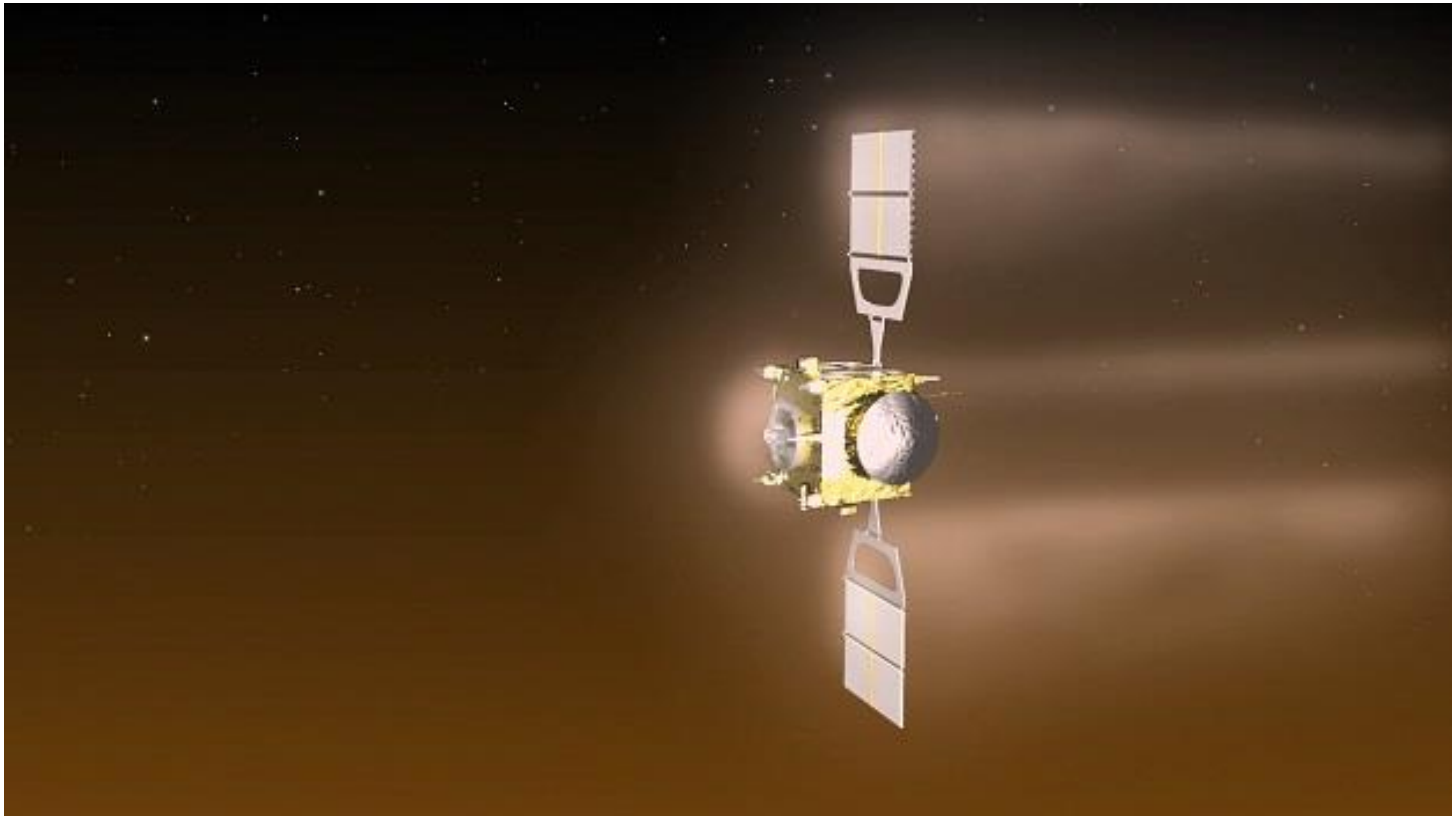
Achievement: Realistic error on density estimate from POD

Rosenblatt et al., Icarus, 217, p. 831, 2012.



- Observed Doppler signature at pericenter can be reproduced by simulating the effect of long wavelength gravity field errors.
- The drag scale factor estimate has a bias at around 6 times its formal error.
- Density estimate error had to be scaled by a factor of 6 (5% → 30%).

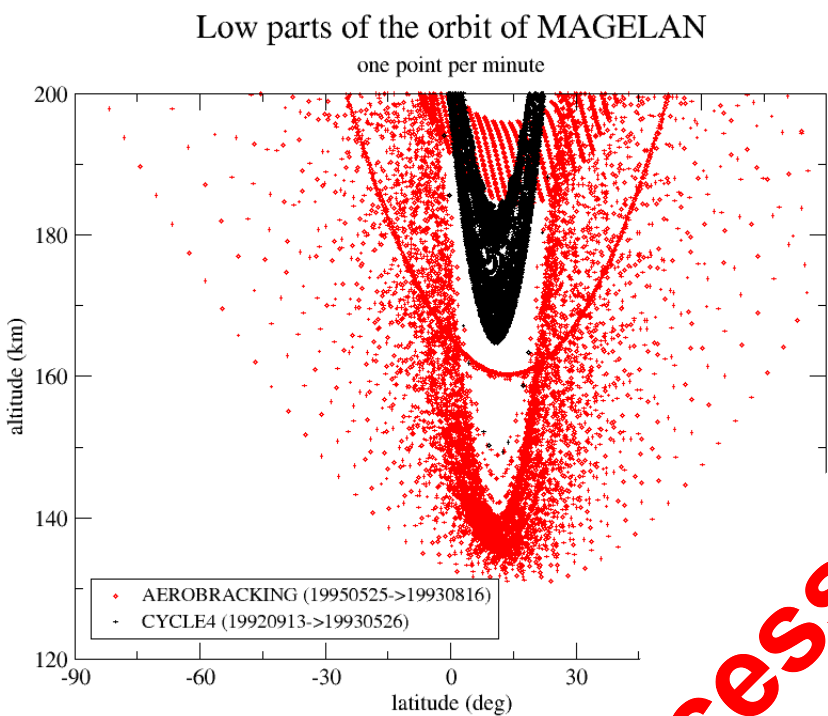
2015 January 15th
Final diving into the atmosphere



Farewell and thank you Venus Express (snif !)

New data with accelerometer *(under investigation)*

New opportunities: Re-processing Magellan data:
PMDAP project with GODDARD (S. Goossens & F. Lemoine)



Solar activity (M
F10.7 flux p → Magellan
140 → VEX

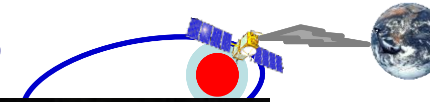
Peri ude:
1 → Magellan
km (down to 165 km) → VEX

apsis latitude:
Near-equatorial → Magellan
Polar → VEX

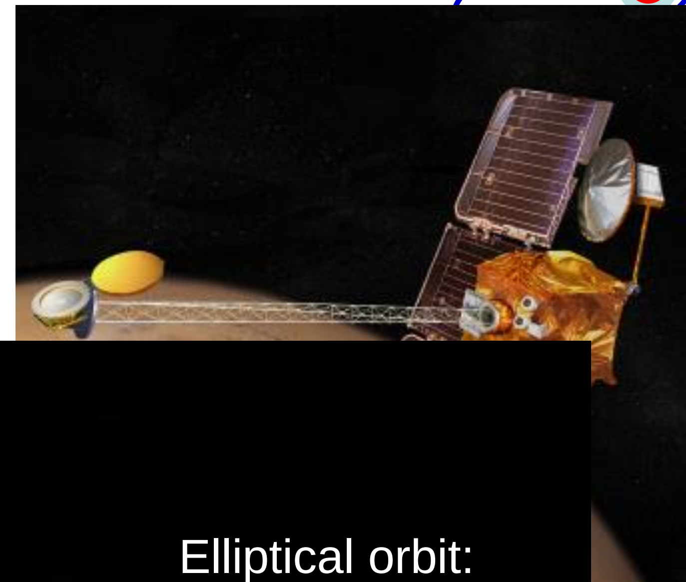
Re-processing Magellan

- Re-processing M ta with the same POD technique:
  Der ions at equatorial latitudinal?
- Magellan track data (cycle 4 and Aerobraking phase) are required as well as ancillary information about the spacecraft (box-and-wings model or similar)

Drag from tracking for Mars



Fro



MAGE

m NASA

Near circular

rbit at

50x10400 km

From NASA

From ESA

New opportunity:
Participating Scientist: MAGE
(Maven Atmospheric and Gravity Experiment)

MAGE

ROYAL OBSERVATORY OF BELGIUM

P. Rosenblatt
M. Beuthe

cnes
CENTRE NATIONAL D'ÉTUDES SPATIALES

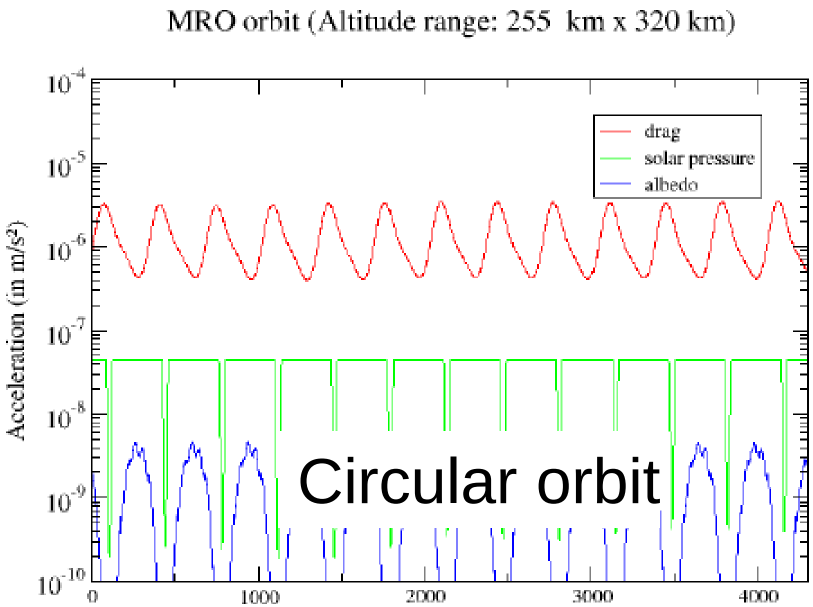
J.C. Marty

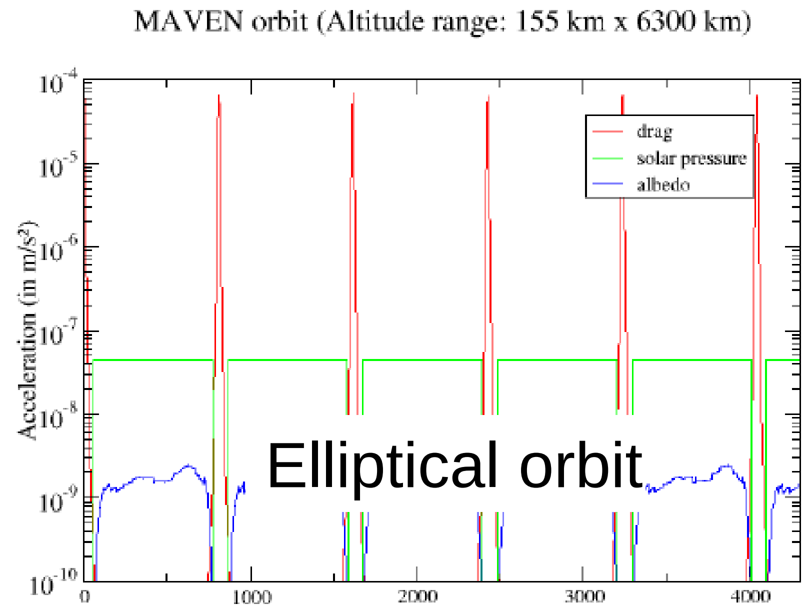
JPL
Jet Propulsion Laboratory
California Institute of Technology

A. Konopliv
J. Castillo-Rogez

- Deriving Mars' upper atmosphere density
- Improvement of Mars static gravity field

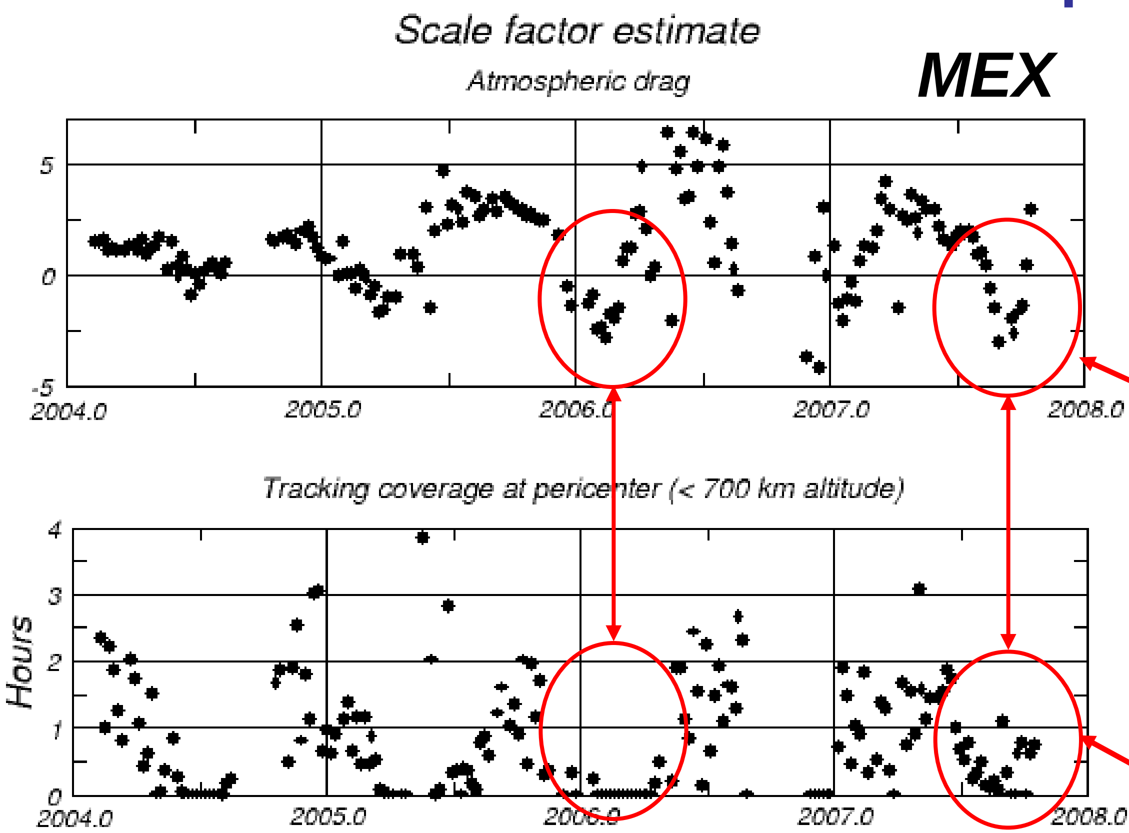
Drag acceleration: MRO vs MAVEN





- Strong atmosphere signal on Maven: 10^{-4} m/s^2 vs 10^{-6} m/s^2 for MRO
- *From Nav. Team: 2 successive passes will be tracked every 6 orbits (mainly using LGA)*
- As for VEX, we will use the ‘short data-arc’ approach.

Achievement: Drag scale factor from Mars Express



Drag factor to scale high atmospheric density model to tracking data

Bad negative values

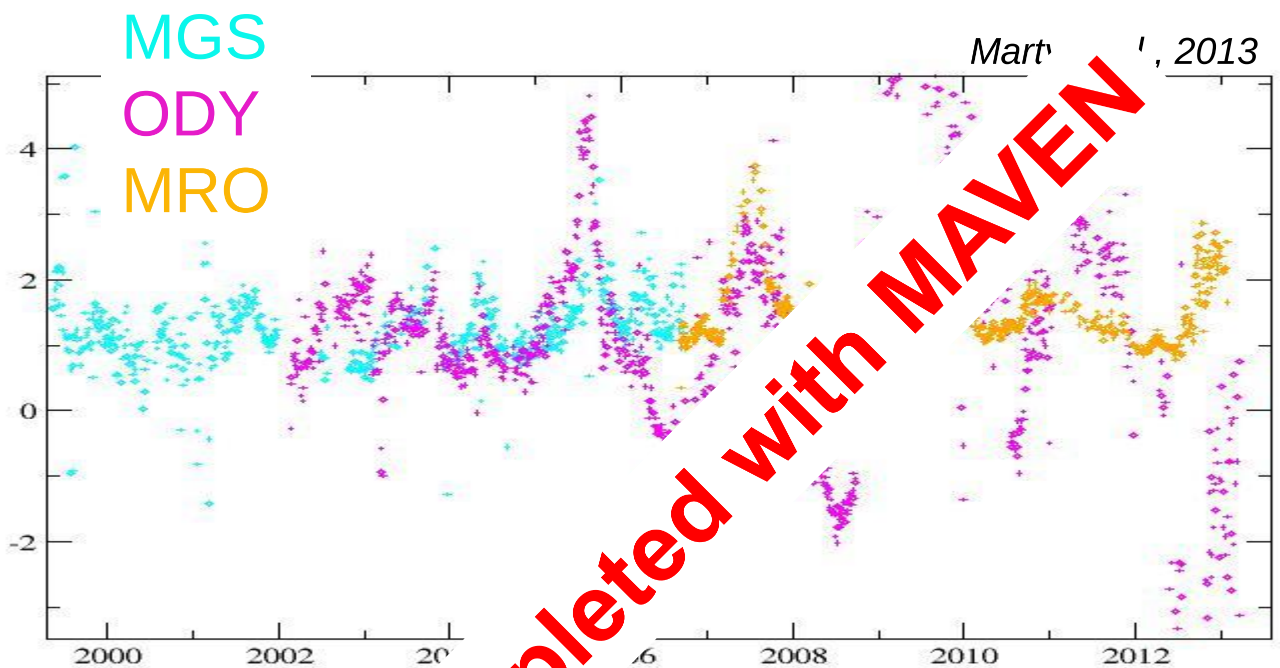
Tracking coverage at pericenter passes

Lack of tracking

- Very poor tracking coverage at MEX pericenter passes at some periods prevents reliable drag scale factor estimates from successive 6-day data-arcs.

- Alternative approach: short data-arc with one single pericenter pass as successfully performed with Venus Express (Rosenblatt et al., Icarus, 2012).

Achievement: Drag scale factor estimates from MGS, ODY and MRO



To be completed with MAVEN

- ✓ Results obtained […] GINS software by processing successive 2-4 days long […] covering a period of almost 13 years.
- ✓ Reliable […] for all spacecraft, except for ODY after 2005. ODY-P[…] be reprocessed for period after 2005.
- ✓ MAVEN: Completion macro-model not achieved.

Summary

- Updating Mars static gravity field:
  MRO, **MAVEN, TGO**
- Mars' J2 seasonal gravity changes:
  TGO
- Mars' K_2 Love number improvement:
  MRO, **MAVEN, TGO**
- Mars' thermosphere: 2 solar cycles
  MGS, MO, MRO, MEX, **MAVEN, TGO?**
- Venus' thermosphere:
  Magellan re-processing

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.