Phobos mass estimations from MEX and Viking1 data: influence of different noise sources and estimation strategies

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Motivation

- Origin of Martian moons?
- We can get clues from geodetic parameters: bulk density; mass distribution; composition; dissipative properties...

\[
\theta = \frac{2e}{1 - \frac{C}{3(B-A)}}
\]

- Internal mass distribution related to principal moments of inertia (A<B<C).

\[
C_{20} = \frac{(A+B)}{2} - C
\]

- Principal moments of inertia are also related to quadrupole gravity coefficients \(C_{20}\) and \(C_{22}\) and the libration amplitudes \(\theta\)

\[
C_{22} = \frac{B - A}{4Mr_0^2}
\]

Where \(M\) is the mass of Phobos, \(r_0\) is the mean radius of Phobos and \(e\) is the ellipticity of its orbit around Mars.
Why are we interested in very precise Phobos mass?

- Geodetic parameters \((C_{20}, C_{22})\) of heterogeneous interior departs by a few percents (<10%) from the homogeneous interior \((\text{Rivoldini et al., 2011, Rosenblatt et al, 2013})\);

- \(C_{00}\) (GM) is correlated with \(C_{20}\) and \(C_{22}\);

- Thus, GM need to be known with precision \(~0.1\)% \((\text{MEX simulations, Rosenblatt et al, 2013})\);
Phobos mass determination from different spacecraft/strategies

Pätzold et al., 2014
Phobos mass determination from similar strategy: Viking 1 and MEX

Estimated parameters:
- for both s/c:
  - initial state vector,
  - Phobos GM,
  - radiation pressure coefficients.
- In case of MEX:
  - atmosphere drag,
  - Doppler frequency offset,
  - range bias,
  - thruster parameters
Actual precision of Phobos mass determination

• **Aim:** to quantify the impact of different error sources on the Phobos GM estimations from flyby data.

• **Considered error sources:**
  – Phobos a priori ephemerides;
  – Phobos a priori GM value;
  – measurements noise;
  – different strategies;

• **Methods:**
  – real data analysis;
  – simulations.
Real data: sensitivity of GM estimations to the errors in a priori Phobos ephemerides

Lainey, 2007 (IMCCE), Jacobson, 2010 (JPL)
Simulations: impact of errors in a priori Phobos ephemeris on the Phobos GM

Simulations: IMCCE (Lainey, 2007) ephemeris + X-band/S-band noise level for MEX/Viking1;
Reconstruction: a) IMCCE Phobos ephemeris -1 km (perturbed) and b) IMCCE ephemeris (unperturbed) + same noise level as for simulations in all cases.
Simulations: sensitivity of the measurements to the a priori GM value

Simulations: zero noise + IMCCE a priori ephemerides + GM_{PH} = 7.16 \times 10^5 \text{ m}^3/\text{sec}^2.

Reconstruction: zero noise + IMCCE a priori ephemerides + GM_{1PH} = 7.66 \times 10^5 \text{ and } GM_{2PH} = 8.16 \times 10^5 \text{ m}^3/\text{sec}^2.

Only initial state vector is estimated during simulated orbit reconstruction.
Simulations: sensitivity of the measurements to the a priori GM value
Sensitivity of the measurements to the observational/modeling noise simulations and orbit reconstructions: IMCCE Phobos ephemeris. Viking1 data: noise level 0.06 mm/sec and 1 mm/sec decreasing the value of the noise diminish the GM formal errors and bringing the values of GM closer to one another
Sensitivity of the measurements to the observational/modeling noise

MEX data with the noise levels 0.01 and 0.02 mm/sec.

simulated MEX data

- noise = 0.01 [mm/sec]
- noise = 0.02 [mm/sec]
CONCLUSIONS

Accuracy and precision of GM estimations increase with decreasing of the value of the noise for both spacecraft.

VIKING1:
• neither distances of flybys nor a priori ephemerides show clear correlation with the GM\(_{PH}\) estimations and their formal errors;
• the post-fit Doppler residuals are not very sensitive to the errors in GM\(_{PH}\): changes of the spacecraft velocities due to \(\Delta GM_{PH} = 10^5 \text{[m}^3/\text{sec}^2]\) (14% a priori GM\(_{PH}\)) are at the level of 0.06 mm/sec which corresponds to the most optimistic estimation of the observational noise level in case of Viking 1;

Observational noise dominates all other considered sources of errors.
CONCLUSIONS

MEX:
- there is a clear dependence between Phobos GM estimations and a priori ephemerides used: the bigger the difference in a priori ephemerides (which reaches 0.5 km for the flyby of the year 2008) the bigger the difference in GM estimations.
- Changes of the spacecraft velocities due to $\Delta GM_{\text{ph}} = 10^5 \text{m}^3/\text{sec}^2$ (14% of $Gm_{\text{ph}}$) could be observed (>= noise level) from very distant flybys (at distance 467 km it produces vel changes 0.02 mm/sec) and $\Delta GM_{\text{ph}} = 5 \times 10^4$ (7% of $GM_{\text{ph}}$) can be observed starting from closer flybys (2010 at the distance about 78 km);

The uncertainties in Phobos a priori position dominate other sources of errors.
Thank you!

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