NEW APPROACH TO ASTEROID MODELING IN A PLANETARY EPHEMERIS

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Mars range measurements: more than 13 years of data with accuracy of about 1 m. Data with greater uncertainty is available since the 1980s from the Viking landers.

Several hundreds of asteroids may affect Mars range to more than 1 m.

**SELECTION**

**WHICH** asteroids should be accounted?
- Accounting for > 300000 objects is impractical/impossible
- Asteroid masses are poorly known
- Small effects may add up and become significant

**REGULARIZATION**

**HOW** should we adjust the ast. masses?
- Asteroid masses are poorly known and need to be adjusted
- Effects on range measurements are highly correlated, masses cannot be determined solely from range measurements

Imperfections in selection/regularization will induce systematic errors, limiting the reliability of adjusted parameters and extrapolation capacity of the ephemeris.
Selection: current dynamical models include about 300 asteroids. Various schemes used (analytical / numerical).

343 asteroids in JPL planetary ephemeris, based on frequencies and amplitudes of analytically estimated perturbations of the longitude of Mars.

Regularization: asteroids split into 2 groups.

~20 individual asteroids
masses adjusted individually

remaining asteroids
each assigned with a taxonomy (C,S,M) and a diameter estimate
all masses determined by adjusting only 3 "taxonomic" densities

Prior information =
asteroid diameters
+ asteroid taxonomies
+ hypothesis of constant "taxonomic" densities

Systematic errors are estimated empirically.
Requires deciding which asteroids to consider individually.
Trial & error optimization based on criteria such as extrapolation, or adjusting realistic and stable asteroid masses.

Sophisticated selection process.
NEW APPROACH

Regularization: all asteroids considered individually

masses adjusted using prior uncertainties on the masses
Tikhonov regularization

different prior information:
- asteroid diameters
- asteroid densities between 0.5 g cm\(^{-3}\) and 5 g cm\(^{-3}\)
- asteroid taxonomies
- hypothesis of constant "taxonomic" densities

fewer systematic errors in regularization
it is not necessary to decide which asteroids to consider individually
= significantly easier to implement
RESULTS

using the new approach to adjust the asteroid model in the JPL planetary ephemeris
- only Mars range data: MGS, ODY, MRO (1999-now) and Viking (1976-1983)
- adjusted parameters: *343* asteroid masses, Earth and Mars state vectors, solar corona scaling parameter, biases
- other parameters maintained fixed to values in DE423

adjusted masses

mass uncertainties

27 asteroid masses adjusted to better than 35%
21 masses in Konopliv et al. 2011 (DE423), using the standard approach
adjusted masses compare well with previous estimates

- new approach
- Konopliv et al. 2011 (standard approach)

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- new approach
- Baer et al. 2011 (close encounters)
- 4 Vesta - Russell et al. 2012 (DAWN), 41 Daphne - Merline et al. 2012 (binary)
new approach provides good extrapolation

new approach performs at least as well as the standard approach
relies on less prior information (less systematic errors?)
does not require optimizing a list of individually adjusted masses = easy to implement
prior uncertainties on asteroid masses allow estimating systematic errors introduced by selection = omission of asteroids from the model

the systematic errors depend linearly on the masses of the omitted asteroids

for a given "complete" model with thousands of asteroid, we can estimate the systematic errors and their uncertainties committed on adjusted masses in a restricted dynamical model containing only 343 asteroids

\text{covariance analysis} (Konopliv et al. 2011)

\begin{itemize}
\item systematic errors due to selection are smaller than random errors
\item systematic errors, for the selection of 343 asteroid, may thus be neglected
\end{itemize}
new approach to asteroid modeling in a planetary ephemeris
  successfully tested on the JPL planetary ephemeris (tested also in INPOP, Fienga et al. 2011, 2012)

all asteroid masses are considered individually
  and adjusted using prior uncertainties \(=\) Tikhonov regularization

performs at least as well as previous approach
  27 asteroid masses adjusted to better than 35\%, good extrapolation

easy to implement and apply to new data
  does not require empirically optimizing the list of asteroids considered individually,
  with respect to new data, no modifications of the asteroid model are necessary

allows a rigorous control of systematic errors introduced by
  the omission of asteroids from the dynamical model