NEW APPROACH TO ASTEROID MODELING IN A PLANETARY EPHEMERIS

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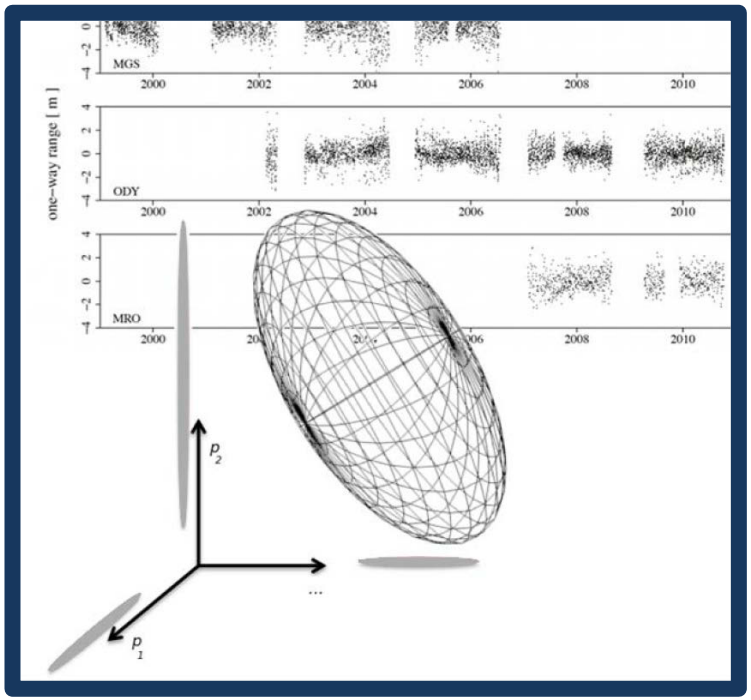

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PROBLEM STATEMENT

- 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

STANDARD APPROACH

- 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
  Hellings et al. 1983

  prior information =

  asteroid diameters
  + asteroid taxonomies
  + hypothesis of constant "taxonomic" densities

  ~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

- 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

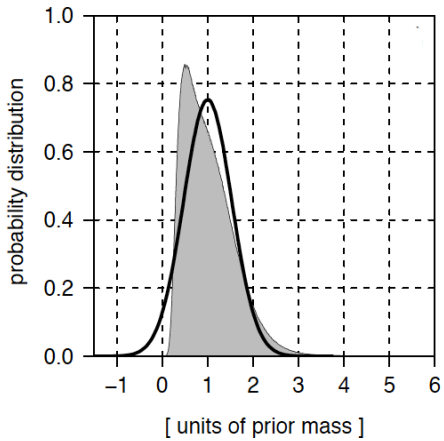
  sophisticated selection process

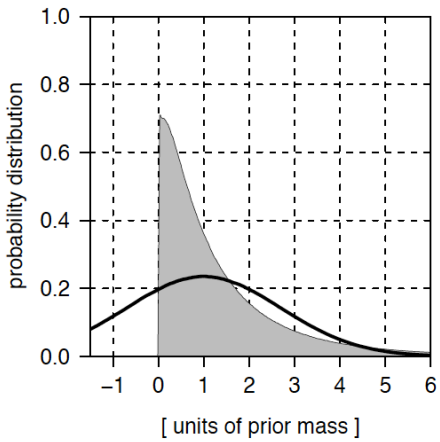
NEW APPROACH

- Regularization : all asteroids considered individually
  Kuchynka 2010, Fienga et al. 2011, 2012, Kuchynka & Folkner 2012

- masses adjusted using prior uncertainties on the masses
  Tikhonov regularization

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

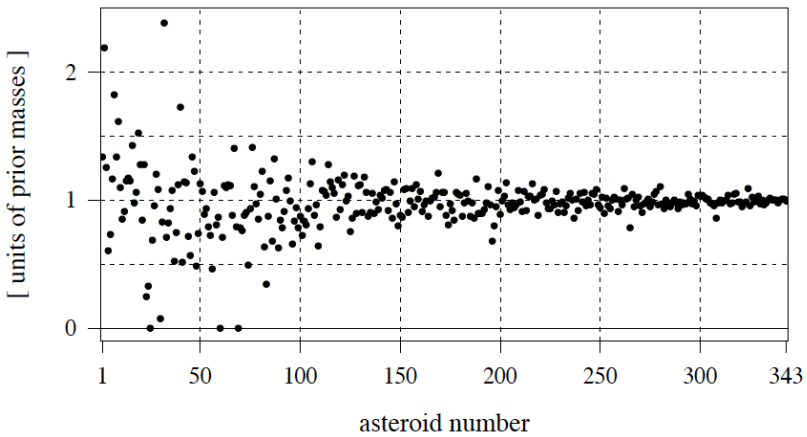
it is not necessary to decide which asteroids to consider individually
= significantly easier to implement

RESULTS

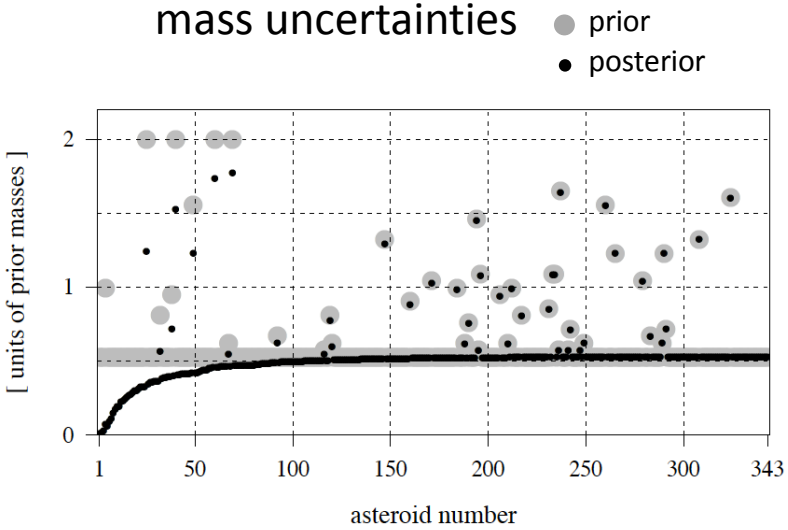
- using the new approach to adjust the asteroid model in the JPL planetary ephemeris

  - 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



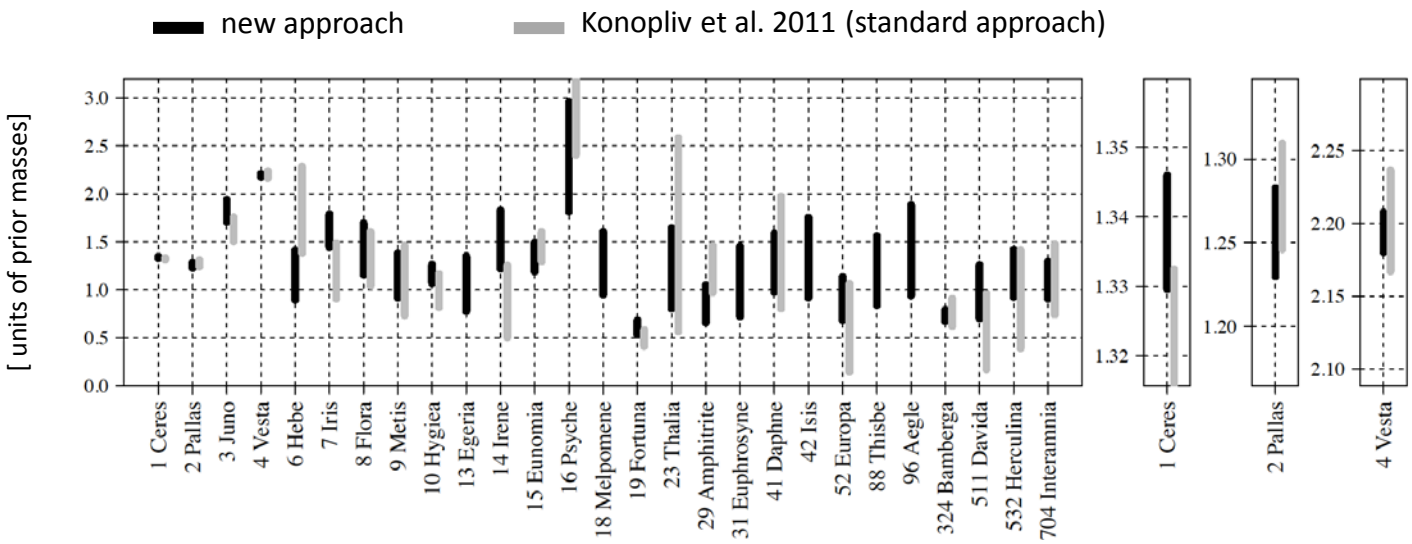
mass uncertainties

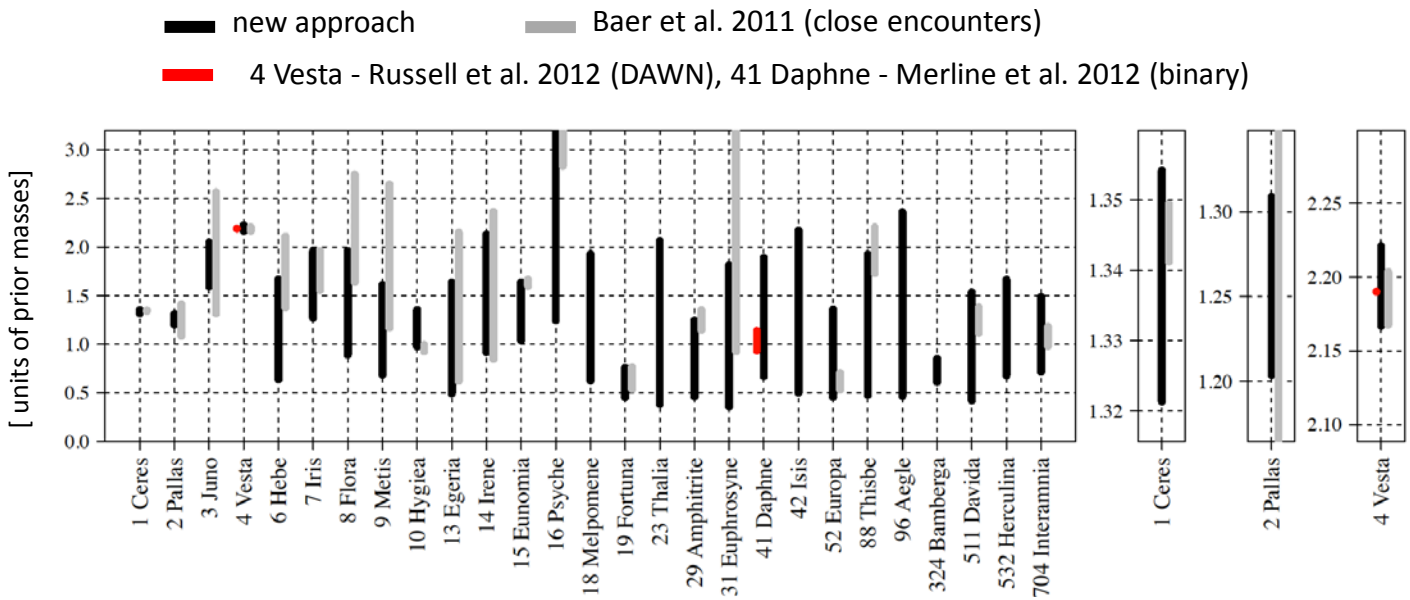


- 27 asteroid masses adjusted to better than 35%

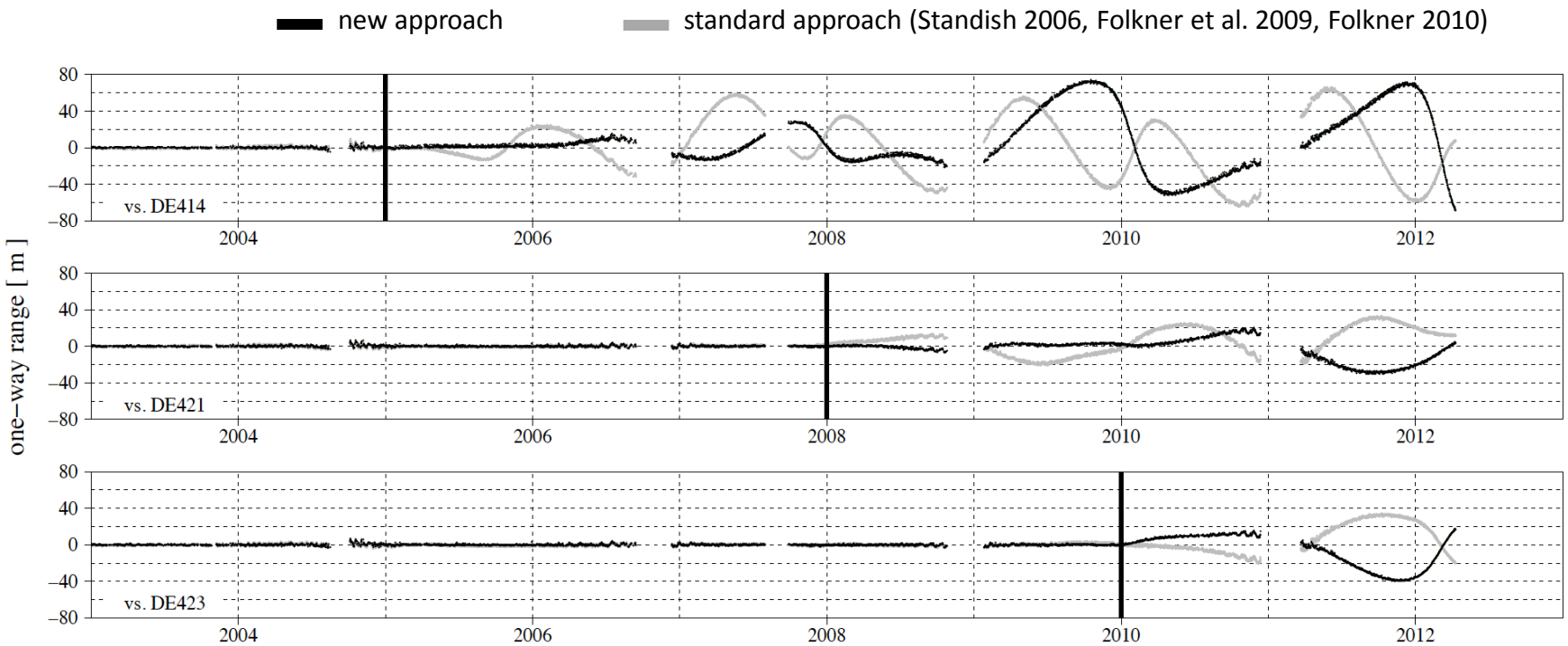
  21 masses in Konopliv et al. 2011 (DE423), using the standard approach

adjusted masses compare well with previous estimates





new approach 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

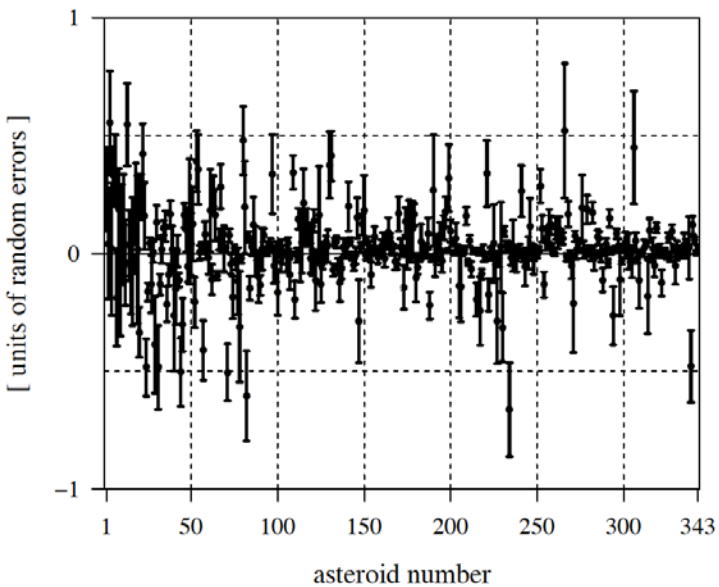
SYSTEMATIC ERRORS

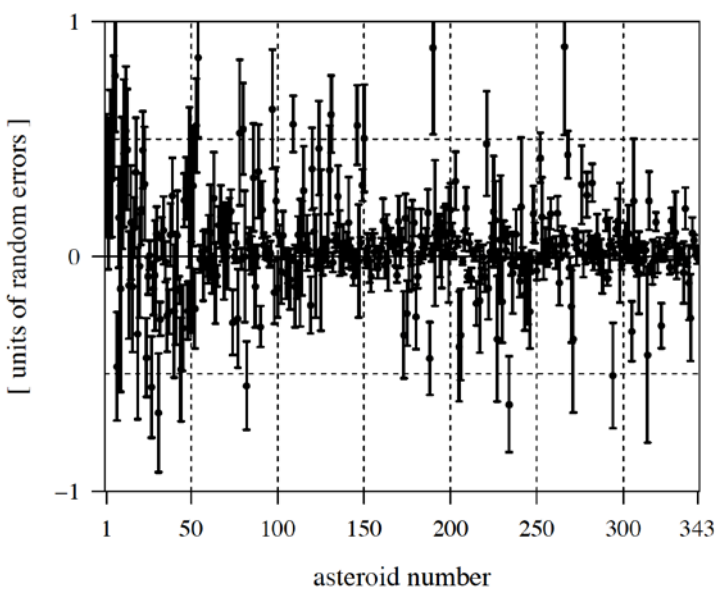
prior uncertainties on asteroid masses allow estimating systematic errors

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 } covariance analysis (Konopliv et al. 2011)





systematic errors due to selection are smaller than random errors

systematic errors, for the selection of 343 asteroid, may thus be neglected

CONCLUSIONS

- 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