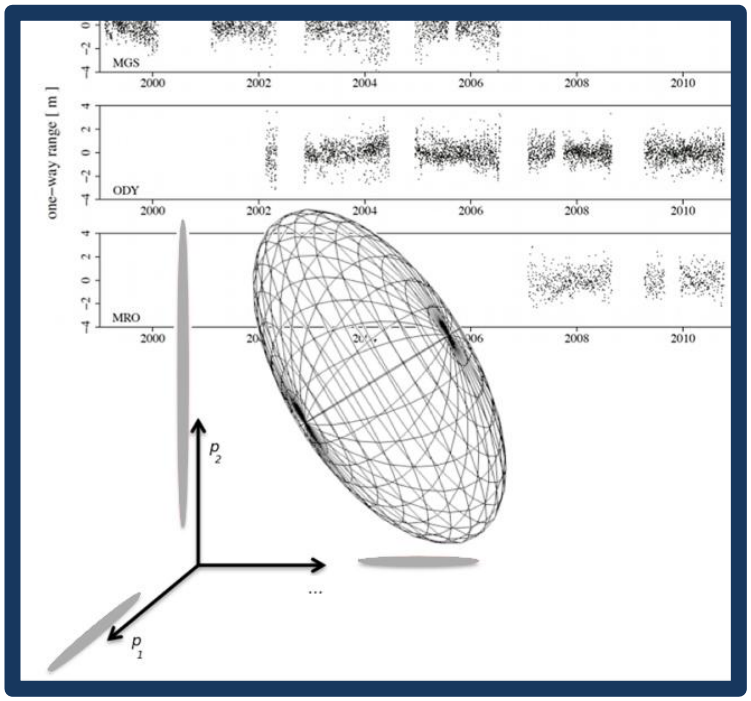
NEW APPROACH TO ASTEROID MODELING IN A PLANETARY EPHEMERIS

Petr Kuchynka

Jet Propulsion Laboratory, California Institute of Technology

NASA POSTDOCTORAL PROGRAM
Administered by Oak Ridge Associated Universities



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
- 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 limiting the extrapolation capacity of the ephemeris

STANDARD APPROACH

- Selection : current dynamical models include about 300 asteroids

  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

- requires deciding which asteroids to consider individually

  trial & error optimization based on criteria such as extrapolation,
  or adjusting realistic and stable asteroid masses

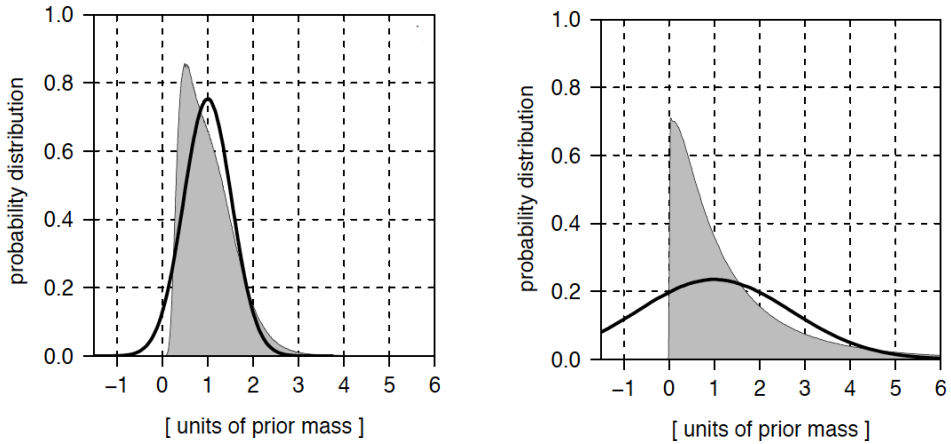
NEW APPROACH

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

- masses adjusted using Gaussian priors on the masses = Tikhonov regularization

  - prior mass (density = 2 g cm^{-3})
  - corresponding prior uncertainty (0.55 to 2 prior masses)

prior information = asteroid diameters + asteroid densities between 0.0 g cm^{-3} and 5 g cm^{-3}
+ ~~asteroid taxonomies~~ + ~~hypothesis of constant "taxonomic" densities~~



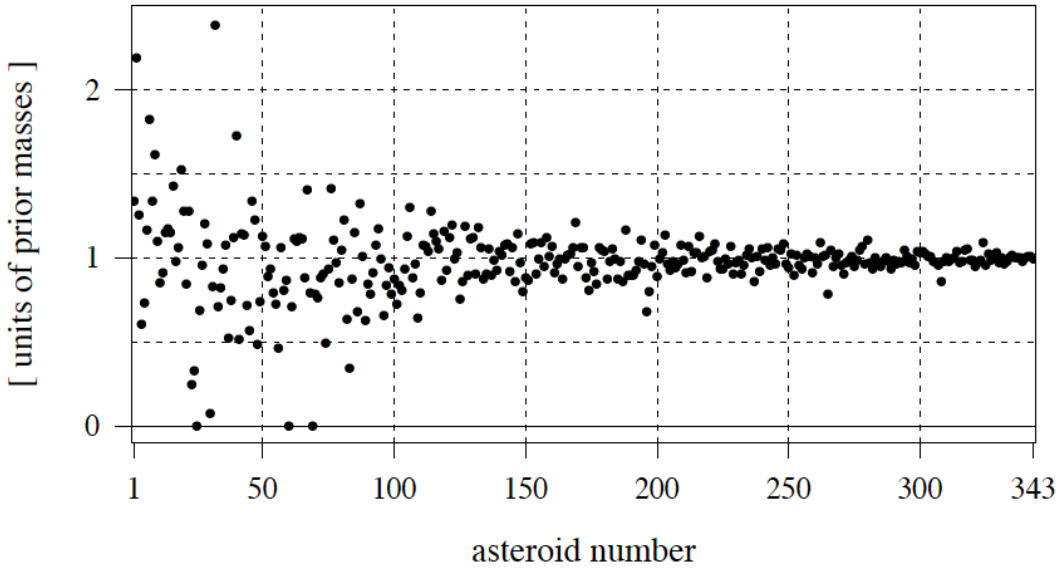
- it is not necessary to decide which asteroids to consider individually
  = significantly easier to implement

RESULTS

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

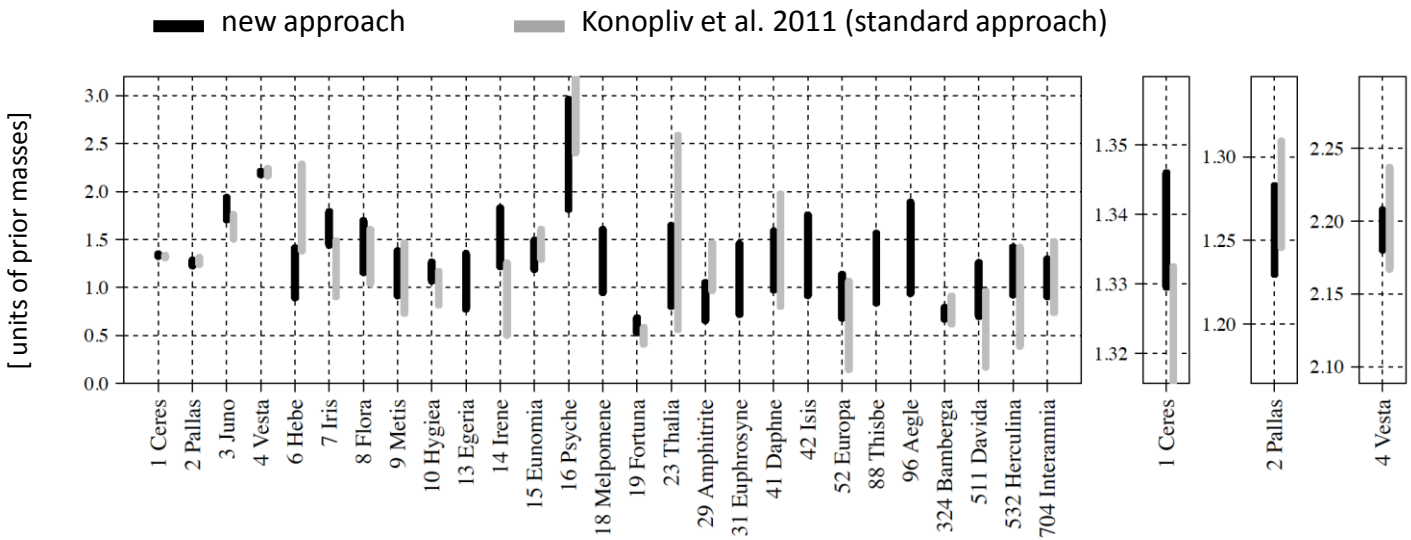
  - only Mars range data: MGS, ODY, MRO (1999-now) and Viking (1976-1983)
  - adjusted parameters: **343** asteroid masses, Earth and Mars state vectors, solar corona scaling parameter, biases
  - other parameters maintained fixed to values in DE423

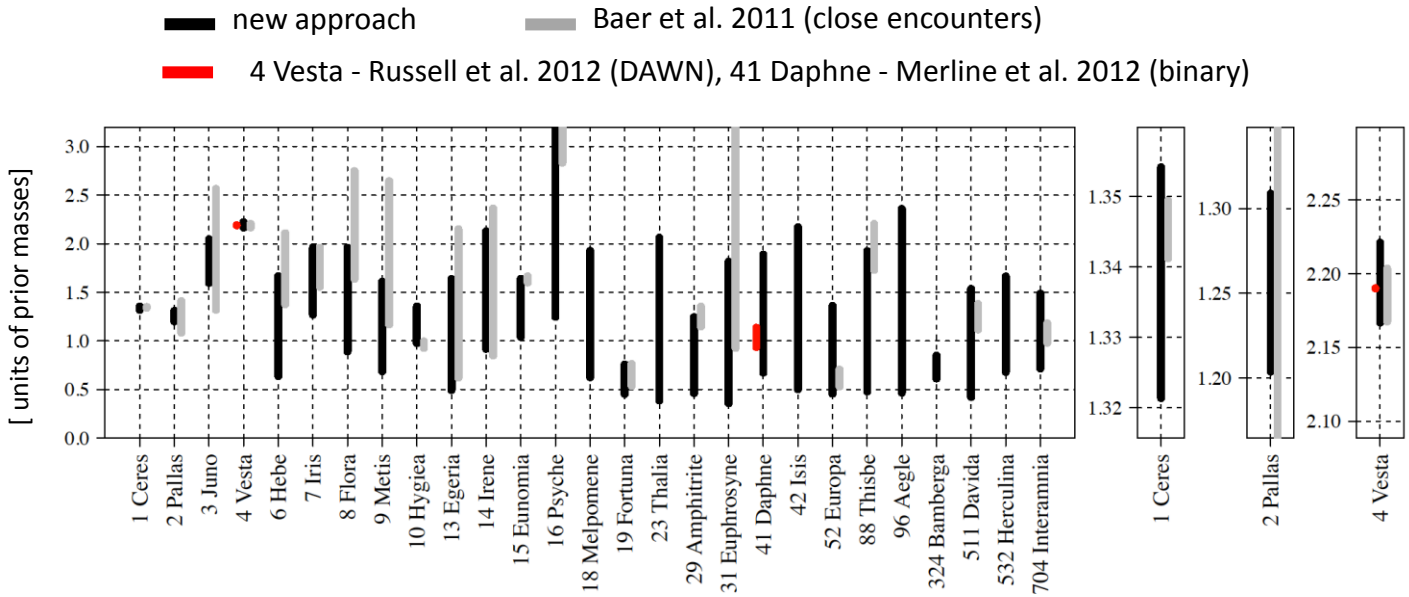
- adjusted asteroid masses



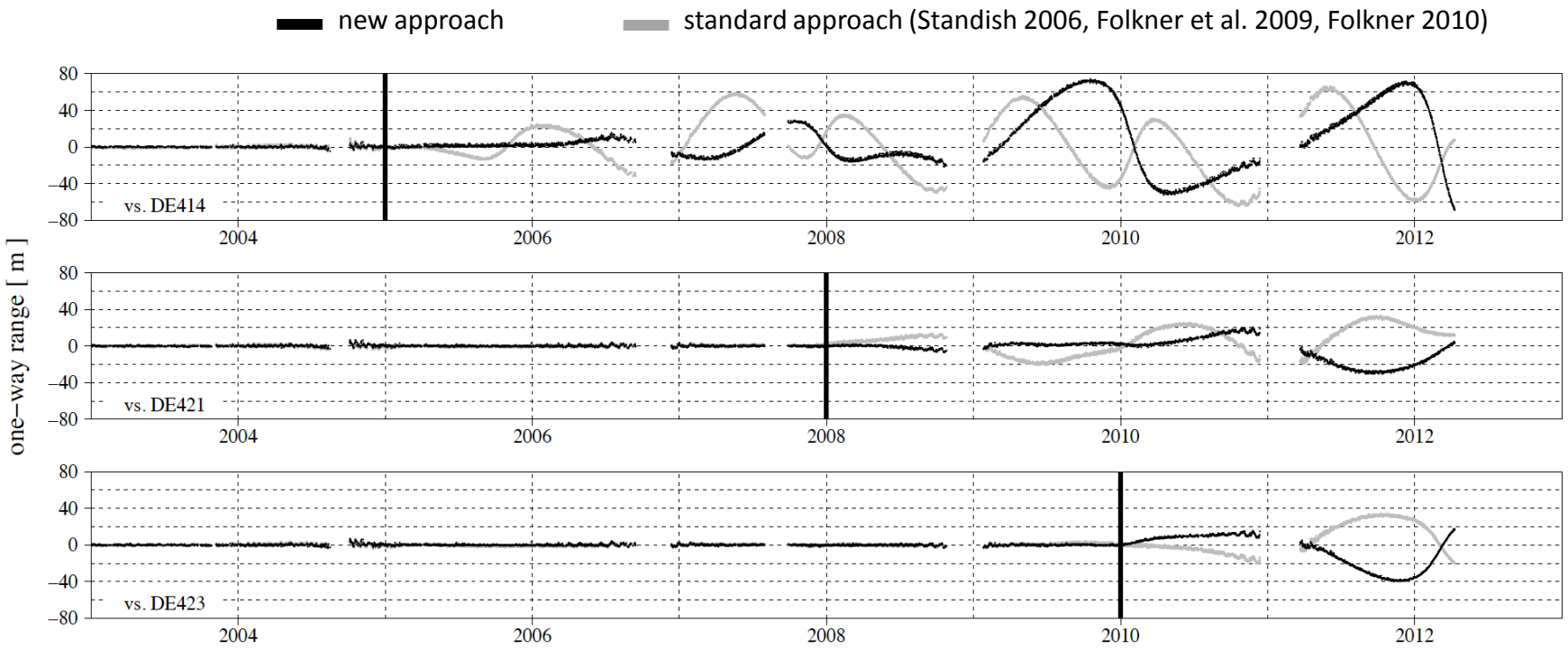
- 27 asteroid masses adjusted to better than 35%
  21 masses in Konopliv et al. 2011 (DE423), using the standard approach

- compare well with previous estimates




new approach
Baer et al. 2011 (close encounters)
4 Vesta - Russell et al. 2012 (DAWN), 41 Daphne - Merline et al. 2012 (binary)
[units of prior masses]
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1 Ceres
2 Pallas
3 Juno
4 Vesta
6 Hebe
7 Iris
8 Flora
9 Metis
10 Hygiea
13 Egeria
14 Irene
15 Eunomia
16 Psyche
18 Melpomene
19 Fortuna
23 Thalia
29 Amphitrite
31 Euphrosyne
41 Daphne
42 Isis
52 Europa
88 Thisbe
96 Aegle
324 Bamberga
511 Davida
532 Herculina
704 Interamnia
1.35
1.34
1.33
1.32
1 Ceres
1.30
1.25
1.20
2 Pallas
2.25
2.20
2.15
2.10
4 Vesta

new approach provides good extrapolation



new approach performs at least as well as the standard approach

does not require optimizing a list of individually adjusted masses = easy to implement

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

Thanks to Bill Folkner, Don Yeomans and the NASA Postdoctoral Program