Asteroid Mass Determination

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Introduction

Knowledge of asteroid masses (and densities) is important for …

- ► Better estimates of mean bulk densities, porosity etc. for different taxclasses (S,C,M etc. type asteroids)

- ► Understanding the dynamics and evolution of minor bodies and the solar system itself. Adjusting modell parameters

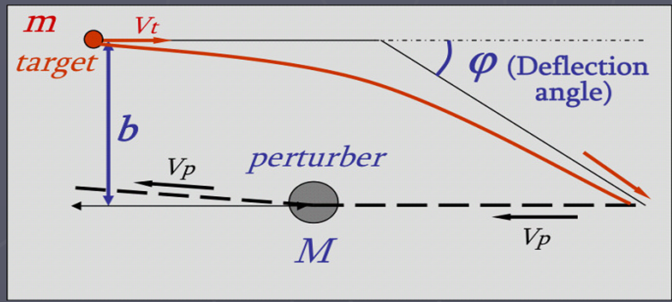
- ► Generation and improvement of high accurate planetary ephemerides like DExxx, INPOPxx etc.

  => high precision asteroidal ephemerides (spacecraft targets, occultation predictions, etc.)

- ► Planning and realizing space missions (fly-by, in-orbit)

Methods

- Gravitational asteroid-asteroid interaction:
  - culmulative effects (resonances)
  - deflection events (single / multiple) (close and/or slow encounters)



- Analysis of planetary motion (e.g. perturbations on Mars)
- Orbital motion of asteroidal satellites / binary systems: observations by spacecrafts, HST, or ground based (AO)
- Gravitational asteroid-spacecraft interaction
- Ground based radar observations (binary systems, asteroidal satellites) Problem: 1/r **4 drop of reflected signal

Least-squares fit to the observations

Correction ΔM to the mass of the (massive) perturber is computed along with the corrections $\Delta E = (E1,\ldots,E6)$ of the six initial values (or osculating elements) of the „test“ (= deflected) asteroid.

These corrections are the solution of a system of linear equations:

$$P\,\Delta E + Q\,\Delta M = R \qquad (1)$$

P: matrix of partials $\partial C_i / \partial E_k$ (Coordinates C = RA, DE)

Q: matrix of partials $\partial C_i / \partial M$

R: matrix of residuals (O-C) in RA, DE
for i=1,…,N observations and k=1,…,6 elements / initial values

Usually solved by the method of least-squares (LSQ Fit)

This differential orbit correction is performed by an so called N-body program:

1. Integration of the test asteroid taking into account the perturbations by:
   - the major planets
   - if applicable further perturbing asteroids
   - the perturbing (massive) asteroid which mass should be improved
   - other forces like relativistic effects etc.
2. Computing the residuals for the observations
3. Solving the equations of conditions (1)
4. Applying the corrections (ΔE, ΔM)
5. (Re)weighting / rejecting observations
6. Next iteration of computation until stable result is achieved

Difficulties

- Ceres contains ~1/3 of the mass of the main belt, but this is only ~1% of the mass of our moon
- As the involved masses are very small, the gravitational interactions are usually rather weak
- Numerical issues (convergence, bad conditioned equation systems, correlations, underestimated errors)
  - Careful review / preprocessing of observations
  - Careful rejection of observations (requires some experience)

Related topics

Diameters and shapes (=> bulk densities):

- Observation of occultations (diameter, profile/shape) *
- Lightcurves (shape by lightcurve inversion) *
- Radiometric and polarimetric methods (IRAS, ground based)
- Resolved imaging (HST, AO, in-situ)
- Other methods (speckle interferometry, radar, etc.)

* Mainly amateur contributions!

The past ~40 years

- First asteroid mass (Vesta) computed by Hertz in 1966
- First ~20yrs: mass estimates for only four asteroids have been published (Ceres, Pallas, Vesta, Hygiea)
- 2008: mass estimates for about 55 asteroids

  Max: 4.8E-10 (1 Ceres)
  Min : 1.9E-14 (189 Phthia : asteroid-asteroid perturbation)
  Min : 4.7E-21 (2000 UG11 : binary system: radar)

Examples (classical methods)

Asteroid	Test asteroid	References
(4) Vesta	(197) Arete	Hertz 1966, 1968, Schubart & Matson 1979
(1) Ceres	(2) Pallas, (4) Vesta	Schubart 1970, 1971, 1974
(2) Pallas	(1) Ceres	Schubart 1974, 1975
(10) Hygiea	(829) Academia	Scholl, Schmadel, Röser 1987

Examples (non-classical methods)

Asteroid	Method	References
(243) Ida 1.9E-14	Galileo spacecraft / satellite	Belton et al. 1995, Petit et al. 1997
(121) Hermione 2.705E-12	AO / satellite	Marchis et al. 2005
(25143) Itokawa 1.760E-20	Hayabusa spacecraft	Fujiwara et al. 2006
2003 YT1 6.38E-19	Radar / binary system	Brooks et al. 2006

Future prospects (GAIA)

- GAIA (due for launch in late 2011) will observe ~300000 (mainly MB) asteroids down to V ~20 with sub-mas to mas precision
- About 100 potential perturbers (mass determinations) during the 5yr operational lifetime
- GAIA will also directly measure sizes for ~1000 objects
- And much more… GAIA will have a major impact on fundamental astronomy, solar system etc.

Authors results (presented here in 2005)

Asteroid	Test asteroid(s)	Mass [Solar Mass Units]
(16) Psyche	(13206) 1997 GC22	(2.5 ± 0.2) E-11 (1.1 ± 0.04) E-11 (Bear 2008)
(29) Amphitrite	(987) Wallia (6904) McGill	(5.9 ± 0.6) E-12 (5.9 ± 0.3) E-12 (Bear 2008)
(121) Hermione	(278) Paulina (5750) Kandatei	(3.3 ± 1.1) E-12 (2.71 ± 0.15) E-12 (Marchis 2005)
(804) Hispania	(1002) Olbersia	(2.2 ± 0.9) E-12 (2.0 ± 0.4) E-12 (Bear 2008)

Authors preliminary results (2008)

Asteroid	Test asteroid(s)	Mass [Solar Mass Units]
(13) Egeria	(14689) 2000 AM2	~5E-12 (in work)
(15) Eunomia	(50278) 2000 CZ12	(1.4 ± 0.3) E-12
(16) Psyche	(13206) 1997 GC22	(1.7 ± 0.7) E-11

Observation proposals

- Galad, A. (2001). Asteroid candidates for mass determination. AA 370
- Mail list posts by the author
- Authors website: http://sky-lab.net | http://obsnn.de

2008-04-08.86: (1) Ceres / (104758) 2000 HR18
d=0.0028 AU   Vrel=3.353 km/s

2008-04-23.39: (349) Dembowska / (135356) 2001 TF83
d=0.0012 AU   Vrel=2.640 km/s

2008-10-20.03: (238) Hypatia / (128251) 2003 SA247
d=0.0016 AU   Vrel=1.079 km/s

Please monitor upcoming events and observe perturber and test asteroid to ensure that a good astrometric data sample is available over some weeks around the encounter

You can contribute to professional science with your dedicated observations !
Thank You!