EPSC Abstracts
Vol. 8, EPSC2013-501, 2013
European Planetary Science Congress 2013

Observational program for determination of asteroid masses with Gaia from ground and space-based astrometry

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Abstract

The European space mission Gaia to be launched this autumn will perform astrometric observation of small Solar system bodies with precision of 0.3-5 mas. Thus, it should allow determination of masses for large asteroids by dynamical method which is by measuring perturbation effects produced by larger asteroids on the motion of smaller ones passing by. As far as Gaia will not be able to observe the maximum perturbation effect to be occurred before the probe launch, but will observe the lesser perturbing effect after this event, the possible solution is to make ground-based observations of selected perturbed asteroids beforehand and then to link them with the Gaia observations. The predictions of such encounters between asteroids were made from 1-1-2013 till 1-1-2015. We have found more than 800 encounters of all presently known 360,190 asteroids with the largest 50 asteroids. This project will allow to significantly increase the number of large asteroids for which Gaia will produce masses.

1. Introduction

The idea of linking ground-based astrometric observations of asteroids with Gaia measurements for the purpose of asteroid mass determinations was presented in [1]. There were already predictions of such events using different criteria, overview of which one can find in [3], [4]. The main difference between the previously made calculations, besides of different criteria used, is the number of asteroids for which predictions were made. Since 2007 the number of known asteroids increased two times, so new candidates as perturbed asteroids became available which can have greater perturbation effects, thus allowing more precise determinations of asteroid masses.

2. Visual Deflection Criterion

The intensity of gravitational interaction between "perturbed" and "perturbing" asteroids can be estimated by a deflection (scattering) angle using the two-body problem approximation [2]. This criterion considers both an estimate of the mass (through assumed density and diameter) of perturbing asteroid and dynamical parameters of encounter (minimal distance between the bodies and relative speed at the time of close approach), see self-explanatory Figure 1.

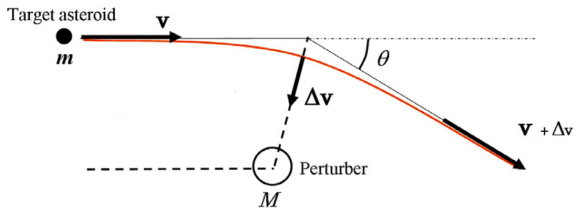

Figure 1: Scattering in the two-bodies problem.

However, the plane of two-body interaction can have different position with respect to the line of sight that makes the ordinary calculations of the deflection angle useless for observational planning. We introduce here a "visual deflection angle" θ_{vis} (iin arcsec) which considers the above mentioned defect and assuming the larger asteroid has spherical form and density 3 g/cm^3:

$$\theta_{vis} = 9.6\times10^{-17}\frac{D^3}{v_{min}^2 r_{min}}\sqrt{1-\left(\frac{\boldsymbol{\Delta}\cdot\boldsymbol{E}}{\Delta E}\right)^2} \qquad (1)$$

where D is the diameter of the larger body in *km*, vectors $\boldsymbol{\Delta}$ and $\boldsymbol{E}$ correspond to the relative distance between the interacting bodies and the direction to

the Earth, the rest quantities have the usual dimensions in *au/day*, *au.*

This two-body approximation works well while the encounters between asteroids are short, so that we can neglect changes in the forces of the rest of the bodies. This idea allows us to introduce a simple time interval for limiting ground-based observations of an encounter. It consists in observing the perturbed body while the absolute value of acceleration of the small asteroid caused by the larger asteroid is greater or equal than the resulting acceleration caused by planets. This constrain was implemented in the current integrations.

3. Dynamical Model

The dynamical model of motion of asteroids accounts for gravitational forces from the Sun and all large planets; we neglected the gravitational interaction between asteroids. The positions and velocities of the Sun and planets were issued from DE405. The initial conditions of asteroids in the form of orbital elements were taken from on-line JPL Small-Body Database, http://ssd.jpl.nasa.gov. Numerical integrations were performed by Adams-Moulton method of variable-order and variable-step. The local error of integration was adjusted in order to keep absolute difference 10^{-6} *au* in the coordinates and 10^{-6} *au/day* in the components of velocity in comparison against the HORIZONS system of JPL.

4. Observational Program

Search of encounters was made between the largest 50 asteroids which diameters are larger than 200 *km* and semi-major axis less than 30 *au* and all presently known 360,190 numbered asteroids, to be taken place from 1-1-2013 till 1-1-2015, just in time before and at the early launch of Gaia mission. The integrations were made for each pair of asteroids (exhaustive search), all local minima of distances between asteroids were examined for the value of visual deflection angle. For the current calculations, we have eliminated from the further research all encounters between asteroids where it was less than 0.1 arcsec. In order to characterize observational conditions besides time moments there were also calculated elongations of the perturbed asteroids from the Sun and the Moon, visual magnitude of perturbed asteroid and fractional lunar illumination, so that the observer can easily select possible encounters for observations. The complete table of the predictions is available upon the request from the authors. Also, there will be available predictions of the asteroid encounters at the end of Gaia mission, after 2018.

Considering the best precision limit of differential ground-based astrometry of 0.05 arcsec, it is believed to measure perturbations greater than 0.15 arcsec using contemporary stellar catalogues, like the UCAC4. Actually, the dedicated observational program lead by F. Colas (IMCCE) has already begun at the 1-m telescope of Pic-du-Midi Observatory (France) and 1-m telescope of TUBITAK National Observatory (Turkey).

5. Conclusions

A criterion for selection of perturbed asteroids by deflection angle in the two-bodies approximation was improved for considering relative orientation of the produced perturbation in the motion with respect to the Earth. The improvement significantly reduces the number of close encounters for further detailed research.

We have found more than 800 close encounters between the largest 50 asteroids and all known asteroids for which visual deflection angle was greater than 0.15 arcsec within the period from 1-1-2013 till 1-1-2015. Astrometric observations of these encounters (namely perturbed asteroids) also from other sites will be useful for asteroid mass determinations with Gaia.

References

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