ASTEROID MASS DETERMINATION WITH THE GAIA MISSION

S. MOURET[1], D. HESTROFFER[1], F. MIGNARD[2]
[1] IMCCE-Paris observatory
77, avenue Denfert-Rochereau, 75014 PARIS, France
mouret@imcce.fr, hestroffer@imcce.fr
[2] OCA/Cassiopée
Boulevard de l'Observatoire, B.P 4229, 06304 NICE CEDEX 4, France
francois.mignard@obs-nice.fr

ABSTRACT. The ESA astrometric mission Gaia, due for launch in late 2011, will observe a very large number of asteroids ($\sim$ 500,000 brighter than V = 20) with an unprecedented positional precision (at the sub-milliarcsecond level). This precision will play an important role for the mass determination of about hundred minor planets. Presently, due primarily to their perturbations on Mars, the uncertainty in the masses of the largest asteroids is the main limiting factor in the accuracy of the solar system ephemerides[1]. Here we present the main features of the astrometric observations of asteroids with Gaia. The high precision astrometry will enable to considerably improve the orbits of almost all observed asteroids, yielding masses of the largest from mutual approaches. As an illustration we apply the overall procedure under development to the close approaches between Ceres and smaller targets observable with GAIA and assess the expected precision on the mass of Ceres at mission completion.

1. SOLAR SYSTEM OBJECTS OBSERVATIONS

Gaia is an astrometric cornerstone mission of the European Space Agency. With a launch due in late 2011, Gaia will have a much more ambitious mission than its precursor Hipparcos: obtain a "3D census" of our galaxy with astrometric, photometric and spectroscopic observations. It will pinpoint its sources with an unprecedented positional precision (at the sub-milliarcsecond level for single observation) which will allow it to observe about 500,000 asteroids (mainly main belt asteroids) brighter than V = 20. The scanning law of the satellite is very specific (Hipparcos-like) yielding observation sequences much different from the classical ground-based ones, with no observation at opposition and solar elongations symmetrically distributed around the quadratures. These elongations will range from $L_1 = 45°$ to $L_2 = 135°$. There is no dedicated observation mode for these resolved and moving targets which are observed like any other stellar source, but quickly identified from their motion. Their size and motion degrades the astrometry compared to stars, but it essentially remains a function of the target brightness. The astrometric precision σ_λ is found from simulation with GIBIS [2] and Pyxis [3] of the focal plane images for these objects. These estimates represent the precision for a single 'observation' in the along-scan direction (the astrometry in the perpendicular direction is much less precise so that the measure is essentially one dimensional).

The astrometric precision is defined by the approximations: $\sigma_\lambda \sim 0.2 - 0.3$ for $V < 14$, and $\sigma_\lambda \sim 10^{0.15V-2.7}$ elsewhere. This precision is one of the key factor impacting on the mass determination of minor planets.

2. METHOD FOR ASTEROID MASS DETERMINATION

The technique used here for the mass determination is based on the gravitational perturbation during a close approach [4] from which it is expected to obtain about 100 asteroids masses with Gaia. The present simulation considers close approaches during the mission operations between the perturber asteroid Ceres and 19 smaller and massless target asteroids, which belong to the 20,000 first main belt asteroids. These 19 targets will be perturbed by Ceres and observed by Gaia. The aim is to find the formal precision, the best precision $\sigma(m_p)$ that we expect, on the mass determination of Ceres from the Gaia astrometry of the targets.

The mass of the perturber is derived by least-squares together with a correction to the initial conditions of each target orbit. The vector *(O-C)* gives the difference between the observed and calculated position for each observation of every target asteroid. It can be written $(O-C) = A\Delta u_0 + B\Delta m_p$ where A is a matrix representing the partial derivatives, for each observation time, of the Gaia-centred longitude of asteroids relative to their initial positions and velocities while B is a matrix depending on the partial derivatives of the longitude of asteroids with respect to the perturbing mass m_p. The unknowns of the problem Δu_0 and Δm_p are respectively the correction to the initial conditions of each asteroid $\Delta u_0 = (\Delta x, \Delta y, \Delta z, \Delta \dot{x}, \Delta \dot{y}, \Delta \dot{z})$ and to the mass of perturber Ceres Δm_p.

We computed the matrices A and B by numerically integrating the motion of the targets and their variational equations. Then we assessed the formal precision $\sigma(m_p)$ from matrices A and B.

3. RESULT AND PROSPECT

The formal precision that we find is $\sigma(m_p) \sim 4.8 \times 10^{-14} M_\odot$, which represents 0.01 % of the mass of Ceres ($4.5 \times 10^{-10} M_\odot$), two orders of magnitude better than the latest ground-based estimates [4]. This method will be further extended to solve for many perturbers simultaneously. The plan is to consider ∼300 perturbers and ∼10,000 targets observed with Gaia conditions. A future work will be devoted to apply this mass determination to all these perturbers and will consider the cases where certain perturbers are also targets. Besides, other global parameters will be added, like the PPN parameter β, the solar quadrupole $J2$, and the rotation W of the ecliptic.

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