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Near Earth Asteroids with measurable Yarkovsky effect

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Abstract

We report on the determination of the Yarkovsky effect among Near Earth Asteroids (NEAs). The related recoil force is modeled through an empirical transverse acceleration resulting in a secular semimajor axis drift. For a successful determination we use a precise dynamical model including perturber asteroids and planetary relativistic terms. We found a few tens of object with a significant determination, i.e., with a signal to noise ratio (SNR) larger than 2. We discuss the consequences on impact predictions.

1. Introduction

It is well known [1] that nongravitational forces, which produce small but meaningful effects on asteroids over long timescales, should be considered as important as collisions and gravitational perturbations for the overall understanding of asteroid evolution. The most important nongravitational perturbation is the Yarkovsky effect, due to radiative recoil of anisotropic thermal emission. The corresponding acceleration depends on several physical quantities such as spin state, size, mass, thermal properties, and causes asteroids to undergo a secular semimajor axis drift. So far, the Yarkovsky effect has been measured directly in only three cases, (6489) Golevka [2], (152563) 1992BF [3], and recently for (101955) 1999 RQ36 [4].

2. Empirical Yarkovsky modeling

The Yarkovsky effect depends on physical quantities that are typically unknown. However, it is possible to bypass the need of physical characterization by using a comet-like model for transverse acceleration $a_t = A_2 f(r)$, where f is a suitable function of the heliocentric distance and A_2 is an unknown parameter. This formulation allows the determination of A_2 as a result of the orbital fit and thus the estimation of the semimajor axis drift by means of Gauss' perturbative equations.

3. High precision dynamical model

To consistently detect the Yarkovsky effect we need to account for the accelerations down to the same order of magnitude. For a sub-kilometer NEA typical values range from 10^{-13} to $10^{-15}\mathrm{AU/d}^2$.

We used a N-body model that includes the gravitational accelerations of the sun, the major planets, the Moon, 16 massive asteroids and Pluto. For relativity we used the Einstein-Infeld-Hoffmann approximation for both the Sun and the planets. It is important to point out that the planetary terms (in particular the Earth's one) should not be neglected because of a significant short range effect during close approaches to a major planet.

4. Observational error model

The successful detection of the Yarkovsky effect as a result of the orbital fit strongly depend on the quality of the observations involved. In particular, the availability of radar data is often decisive due to the superior relative accuracy of radar data with respect to optical ones. Moreover, radar measurements are orthogonal to optical observations: range and range rate vs. angular position in the sky.

Since the Yarkovsky effect acts as a secular drift on semimajor axis the longer the time span the stronger the signal. However, the presence of biases in historic data and unrealistic weighting of observations may lead to inaccurate results. To deal with this problem we applied the debiasing and weighting scheme described in [5]. This scheme is a valid error model for CCD observations, while for pre-CCD data the lack of star catalog information and the very uneven quality of the observations represents a critical problem. In these cases unrealistic nominal values for Yarkovsky model parameters may point to bad astrometric treatments and have to be rejected.

5. Results

We tried to determine the parameter A_2 and the corresponding da/dt for all known NEAs. We found a few tens of significant determinations, i.e., with SNR>2. The inclusion of the Yarkovsky perturbation allowed the recovery of observations otherwise considered as outliers. The most important case is the recovery of one radar apparition for asteroid (101955) 1999RQ36, allowing an orbit improvement by two orders of magnitude.

The sign of da/dt can be related to the asteroid spin orientation, i.e., a negative da/dt corresponds to a retrograde rotator while a positive da/dt corresponds to a prograde rotator. The fraction of negative semimajor axis drifts in our sample is 82% and is then consistent with the delivery mechanism from the most NEA feeding resonances, i.e., 3:1 and ν_6 [6, 7].

6. Impact predictions

The occurrence of an impact between an asteroid and the Earth can be decisively driven by the magnitude of the Yarkovsky effect. This holds for possible impact in the next century, e.g., in the case of asteroid (101955) 1999 RQ36 [8, 4], as well as for the current century in a few very well observed few cases, e.g., asteroid (99942) Apophis [9].

We show a couple of cases in which the risk assessment is computed by taking into account the Yarkovsky along with its uncertainty as resulting from the orbital fit. We also discuss the cases in which the object is expected (because of the size) to be subject to the Yarkovsky effect, but the A_2 determination is weak, with a significant effect on the computed probability of impact.

7. Summary and Conclusions

High precision orbit estimation and trajectory propagation for small solar system objects are becoming more and more important in several applications such as linking old observations to a newly discovered object and assessing the risk of an impact. At high precision levels, the contribution of nongravitational perturbations cannot be neglected. In this work we used an empirical Yarkovsky model depending on one parameter determined, along with its uncertainty, as a result of the orbital fit. We then scanned the catalog of NEAs finding a few tens of cases with a SNR greater than 2. Finally, we discussed the implications on impact prediction probability computations.

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