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The distributions of positions of Minimal Orbit Intersection Distances among Near Earth Asteroids

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Abstract

This paper presents the distributions of the positions of the Minimal Orbit Intersection Distances (MOID) among three subgroups of the Near Earth Asteroids (NEAs). This includes 683 Atens, 4185 Apollos and 3538 Amors which makes over 15 millions combinations of the pairs of orbits. The results which are obtained in this analysis show very interesting distributions of positions of the MOIDs and circumstances of close approaches of the asteroids and emphasize influence of different orbital elements on these distributions.

Keywords: Asteroids; MOID; Close approaches; Collisions; Proximities

1. Introduction

Analysis of the distribution of orbital elements of the points corresponding to the MOIDs between the NEAs is important for several purposes. This allows the estimation of the probability of collisions between the asteroids and the most probable circumstances of these collisions, and also the close approaches. Since every collision between the NEAs can produce a new Potentially Hazardous Asteroid (PHA), it is of an essential importance to explore all circumstances under which these collisions and close approaches occur.

There are different approaches for the determination of the MOID between two confocal elliptical orbits. Most of these approaches includes the determination of all critical points of the distance function between two keplerian orbits, namely proximities (minima) among which the smallest one is the MOID, maxima and saddle points.

Generally, methods for determination of the critical points between two keplerian orbits can be divided in three groups: Numerical, analytical and combined. There are several analytical approaches to this problem. Two most frequently used are those by Gronchi (2002) which uses Fast Fourier Transform to obtain coefficients of the resultant of the two bivariate components of the gradient of d^2 (squared distance) with respect to one variable, and by Kholshevnikov and Vassiliev (1999) which relies on determination of all real roots of a trigonometric polynomial of degree 8. There are also extensions of these methods to all types of conical sections (Gronchi, 2005; Baluyev and Kholshevnikov, 2005) which present algorithms for the determination of all critical points between any combination of circular, elliptic, parabolic or hyperbolic orbits. Pure numerical methods are very simple for application but they include too much calculation to be applied on a large number of orbital pairs. They consist of the calculation of the distance between every two points on the orbits and analyzing the numerically represented distance function. There is also a recent combined method (Milisavljević, 2010; Segan et al., 2011) which uses some analytical expressions (Lazović, 1993) to transform the distance function which is the function of two eccentric anomalies, E_1 and E_2, into two numerically represented minimal distance functions which are function of only one variable,

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E_1 and E_2 respectively. Using this method, a very rare configuration of orbits with 4 proximities was found between two asteroids in the main asteroidal belt.

The objectives here are: firstly, by using already developed algorithm (Milisavljević, 2010; Segan et al., 2011) to determine all proximities between every two orbits which belong to the three subgroups of the NEAs, secondly, to determine the MOIDs between these orbits, and finally, to investigate if there are some patterns in their distributions. The main goal of this analysis is to explore the circumstances of the close approaches and possible collisions of the NEAs and also to give some ideas for the development of faster algorithms for the determination of the MOIDs.

2. Analysis

We calculated the MOIDs between every two orbits from the three subgroups of the NEAs, Atens, Apollos and Amors, which is in total 8406 asteroids and 15,244,858 pairs of orbits. The characteristics of these subgroups of asteroids are summarized in Table 1 where one can see that these three subgroups have similar values of the average mutual inclination but quite different values of the average eccentricity.

In Fig. 1 is presented the mutual geometry of two keplerian orbits with elements which are important for this analysis.

In any analyzed pair of orbits the orbit with smaller inclination to the ecliptic is stated as the first and referential. The mutual ascending node is the projection on the celestial sphere of the point in which the second orbit crosses the reference plane in the direction toward the hemisphere containing the north ecliptic pole.

3. Results

In order to estimate the possibility and circumstances of close approaches and possible collisions, we calculated the probability density functions of the different orbital parameters of the points corresponding to the MOIDs. In Fig. 2 is presented probability density function of the true longitudes of these points for all three subgroups of the NEAs together. This includes values for λ for both orbits in every analyzed pair and this is the case for each subsequent distribution in this paper. In coplanar case variable λ is undetermined and there are also some non-coplanar cases when λ takes more than one value, but there were not such cases

Table 1
Characteristics of the analyzed subgroups of NEAs.

Name of subgroup	Number of asteroids	Number of pairs	Average eccentricity	Average mutual inclination [°]
Atens	683	232,903	0.35	21.23
Apollos	4185	8,755,020	0.521	19.99
Amors	3538	6,256,935	0.414	22.01

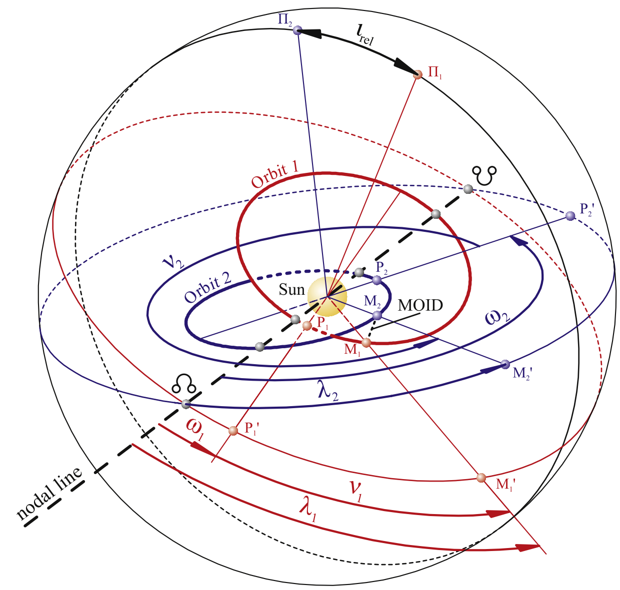

Fig. 1. Mutual geometry of two keplerian orbits.

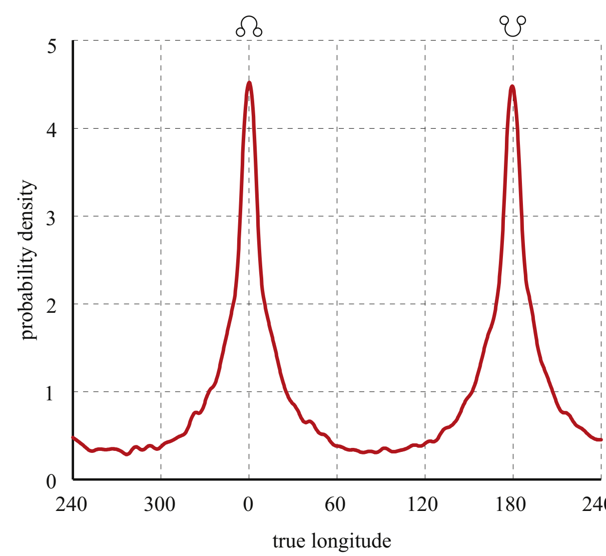

Fig. 2. Probability density function for the true longitudes of the points corresponding to the MOIDs.

in the analyzed set of orbital pairs. This probability density function and those that follow are obtained by differentiation of the splines that fitted the distribution polygons.

In this figure one can see that there is a large concentration of the MOIDs in the vicinity of mutual nodes in such a way that the probability that the MOID will take place at the nodal line is for an order of magnitude larger than that the MOID will take place between ascending and descending node at $\lambda = 90^\circ$ or $\lambda = 270^\circ$.

One more important characteristic of the distribution of the points corresponding to the MOIDs is shown in Fig. 3.

In this figure are presented the probability density functions for the eccentric anomalies of the points corresponding to the MOIDs, separately for Atens, Apollos and