

# MODEL ORBITS OF ASTEROID 3040 KOZAI

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## Abstract

The orbital evolutions of the asteroid 3040 Kozai and model asteroids with similar orbits have been investigated. Their osculating orbits for an epoch 1991 December 10 were numerically integrated forward within the interval of 20,000 years, using a dynamical model of the solar system consisting of all inner planets, Jupiter, and Saturn.

The orbit of the asteroid Kozai is stable. Its motion is affected only by long-period perturbations of planets. With change of the argument of perihelion of the asteroid Kozai, the evolution of the model asteroid orbits changes essentially, too. The model orbits with the argument of perihelion changed by the order of  $10^\circ$  show that asteroids with such orbital parameters may approach the Earth orbit, while asteroids with larger changes may even cross it, at least after 10,000 years. Long-term orbital evolution of asteroids with these orbital parameters is very sensitive on their angular elements.

**Keywords :** main belt asteroids, near-Earth asteroids, orbital evolution

## 1. Introduction

In our paper (Solovaya and Pittich, 1993) the motion of massless fictitious asteroids with movement, which corresponds to the conditions of the Tisserand invariant for  $C = C(L_2)$  and with high orbital inclinations has been investigated. The interesting result is that some of these asteroids could be periodically delivered from the main asteroid belt to the near-Mars space and then to the near-Earth space. This important feature is common for orbits with the inclinations higher than  $40^\circ$ . The asteroid 3040 Kozai with the inclination of  $46.64775^\circ$  for the epoch 1991 December 10, belongs to this high-inclination group of asteroids. From this point of view is interesting to look on his future orbital behaviour. In this paper we present the results of orbital evolution of the asteroid Kozai and others ten model asteroids during the next 20,000 years. The commencing orbits of the model asteroids are similar to the Kozai's orbit with altered the argument of perihelion.

## 2. Computational model

We traced the 20,000 years orbital evolution of the asteroid 3040 Kozai and ten model asteroids using the numerical integration program with the integrator RA15 (Everhart, 1985). For gravitational perturbations we took a dynamical model of the solar system consisting of six major planets. The input data, ecliptic rectangular coordinates and velocities, were calculated from the orbital elements of the asteroid 3040 Kozai for the epoch 1991 December 10 (Batrakov, 1991). This date is contemporaneously the starting epoch of the numerical integration.

The input elements of the ten model asteroids were derived from the orbital elements of the asteroid Kozai. They are all the same as those of the asteroid

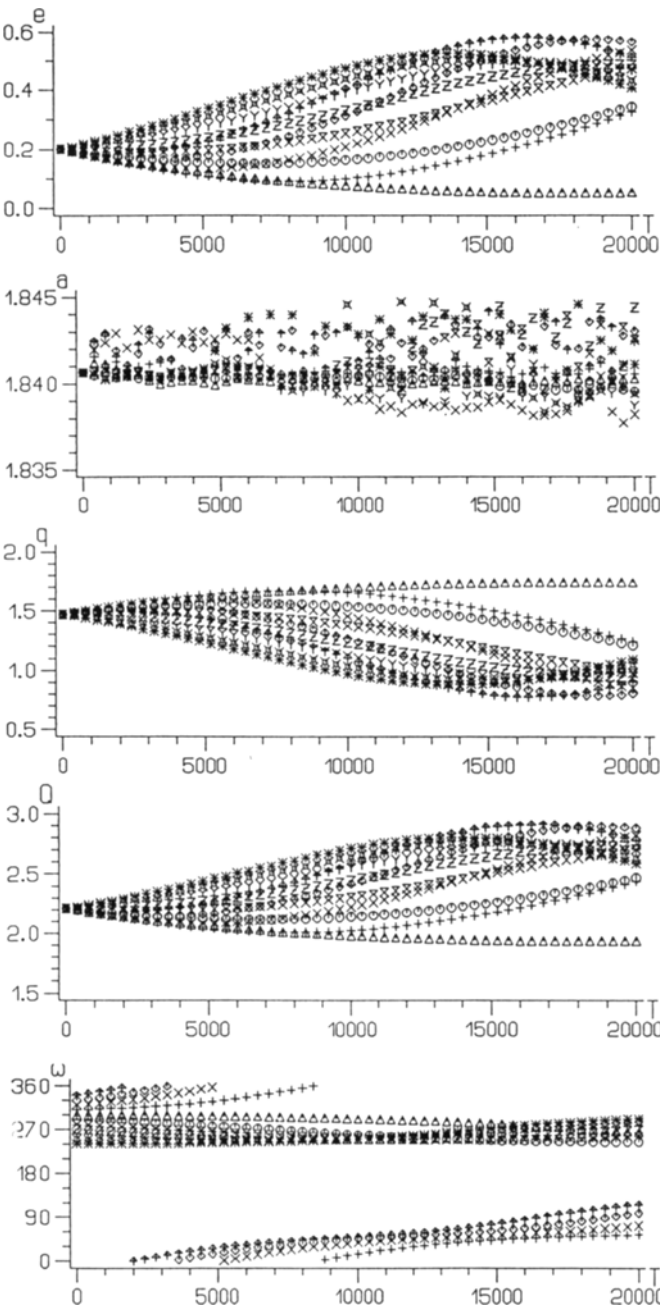
Kozai with the exception of the argument of perihelion. Its value was changed by the step  $\Delta\omega = \pm 10$ , whereby  $\Delta\omega \in (-50, 50)$ .

### 3. Results of Orbital Integrations

Results of orbital integrations we can see on Fig. 1. The symbols of orbital elements are standart :  $\omega$  – argument of perihelion,  $\Omega$  – longitude of ascending node,  $i$  – inclination,  $\pi$  – longitude of perihelion,  $e$  – eccentricity,  $a$  – semimajor axis,  $q$  – perihelion distance, and  $Q$  – aphelion distance.

The orbit of asteroid Kozai is stable in during the whole investigated period of 20,000 year and moves outside of the Earth's orbit. The model asteroids, which have  $\omega > \omega_{Kozai} + 20^\circ$  cross the Earth's orbit and move some time inside the Earth's orbit.

When the commencing orientation of the orbit of the asteroid Kozai in the argument of perigee change more than  $20^\circ$ , the evolution of model orbit gets a different result. With the increased commencing argument of perigee decreased the longitude of perigee and the inclination of the orbit but the eccentricity grows. For example : during the investigated period if  $\omega = \omega_{Kozai} + 50^\circ$  the minimum value of the longitude of the ascending node is near zero ( $\Omega \sim 70^\circ$ ), the inclination is around  $34^\circ$  ( $i_{Kozai} \sim 43^\circ$ ) and maximum value of the eccentricity reach to 0.60 ( $e_{Kozai} \sim 0.35$ ). The semimajor axis of the all investigated orbits is practically the same. It changes within the interval smaller than 0.008 AU for all commencing value of the arguments of perigees. Apparently, disturbances of the model orbits have periodical character with period longer than 20,000 year.



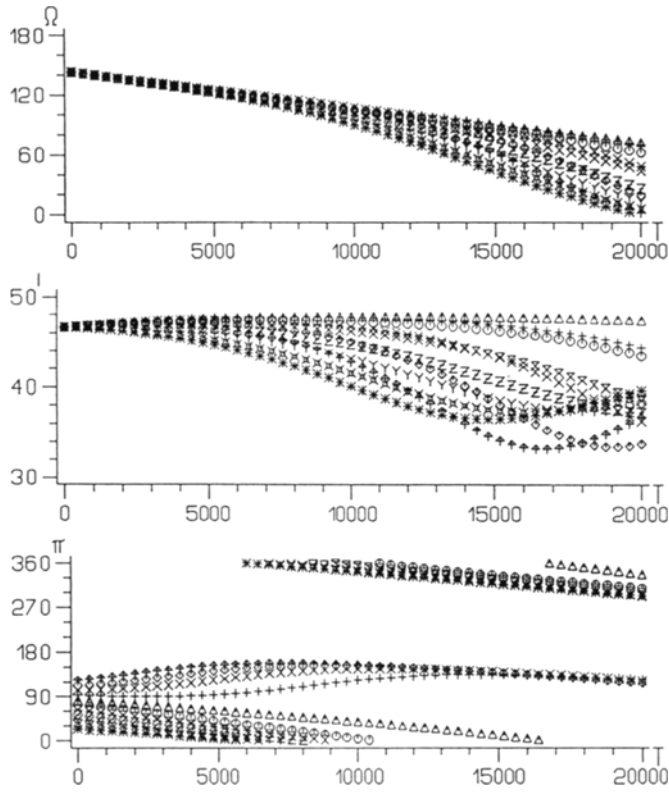


Fig. 1. Time evolution of orbital elements of the asteroid 3040 Kozai —  $\odot$  and the model asteroids disturbed by planets (excluding Uran, Neptun, Pluto) within the period of 20,000 years. The argument of perihelion for the model asteroids  $\omega = \omega_{Kozai} + \Delta\omega$ :  $\Delta$  — +10 ( $\Delta\omega$ ), + — +20,  $\times$  — +30,  $\diamond$  — +40,  $\dagger$  — +50,  $\times$  — -10, Z — -20, Y — -30,  $\ddagger$  — -40, \* — -50.

#### 4. Conclusions

The asteroid 3040 Kozai is one of observed asteroids with high inclination. It is seems that asteroids with this orbital inclination may be have a special dynamic behavior. If their orbits are suitable orientated they can periodic change the inclination and the eccentricity in large limits. A good example is the asteroid Kozai. When the orientation of it's orbit in the argument of perihelion have been different more than  $20^\circ$  from it's real value, the asteroid would periodic cross the Earth's orbit.

#### Acknowledgements

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