Asteroids in Retrograde Orbits: Interesting Cases

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We present the most interesting examples of the orbital evolution of asteroids in retrograde orbits ($i > 90°$). First, we used the latest observational data to determine nominal and averaged orbital elements of these objects. Next, the equations of motion of these asteroids were integrated backward 1 My, taking into account the propagation of observational errors. We used so-called 'cloning' procedure to reproduce the reliability of initial data. We obtained some possible scenarios of the orbit inversion in the past, what is often caused by the long-term influence of outer planets. For two most interesting cases (Apollo and Amor type) we did additional calculations: 100 My in the future. Additionally, we investigated the potential influence of Yarkovski/YORP effects on the long-time orbital evolution.

1 Introduction

The first asteroid in retrograde orbit, 20461 Dioretsa was discovered in 1999. Since then, the number of known retrograde asteroids orbits in the Solar System has been growing systematically. It is difficult to classify these asteroids to any particular taxonomic group. Most of them are Centaurs and TNOs; some objects have been classified as comets after the latest observations. The retrograde orbital motion is more likely found in the population of comets and meteoroids than asteroids. In our initial calculations, we took into account 19 retrograde orbits only, due to sufficiently long observational arcs (Kankiewicz & Włodarczyk, 2010). According to new observations, there are 56 asteroids in retrograde orbits (June, 2014), but in many cases orbital elements have not been well determined. There are two unusual asteroids in the retrograde orbits: 2007 VA85 and 2009 HC82 (now: 343158). They belong to the group of Amor and Apollo and can be classified as Near Earth Asteroids.

Table 1: Keplerian elements of two NEA (Amor and Apollo type) asteroids in retrograde orbits. Epoch: JD 2456400.5 (April 18, 2013).

Ast. name	$a[AU]$	e	$i[deg]$	$\Omega[deg]$	$\omega[deg]$	$M[deg]$	n_{obs}	rms [arc sec]
2007 VA85	4.228	0.7357	131.9	115.6	26.088	237.1	82	0.6413
1-σ rms	7.29E-04	3.89E-05	4.31E-04	7.03E-04	3.18E-03	6.14E-02		
2009 HC82	2.528	0.8075	154.5	294.9	298.5	38.93	104	0.5542
1-σ rms	3.25E-07	1.63E-07	1.99E-05	7.69E-05	7.02E-05	5.11E-05		

2 Data and methods

First, we determined the orbits of most known retrograde asteroids using the OrbFit software (Milani et al., 1997) and the MPC ECS database. To observe the propagation of observational errors during the long term numerical integrations, we used the 'cloning' procedure proposed by Milani et al. (2005). In the next stage, we applied the Mercury integrator (Chambers, 1999) to propagate orbital elements of 1000 clones 1 My backward. Our main aim was to find possible scenarios of the inversion from prograde to retrograde motion in the past (if occurred) with the estimation of its probability. For the most interesting cases (2007 VA85 and 2009 HC82), we decided to integrate equations of the motion in the future (100 My) as well. Additionally, in these two cases we took into account a more complicated dynamical model, with the Yarkovsky/YORP effects. At this step, we used the *swift_rmvsy* software developed by Broz (2006). Unfortunately, these results are limited by insufficient number on known physical parameters, such as spin, radius, density, thermal properties and rotation periods. We used the simplified model with typical values.

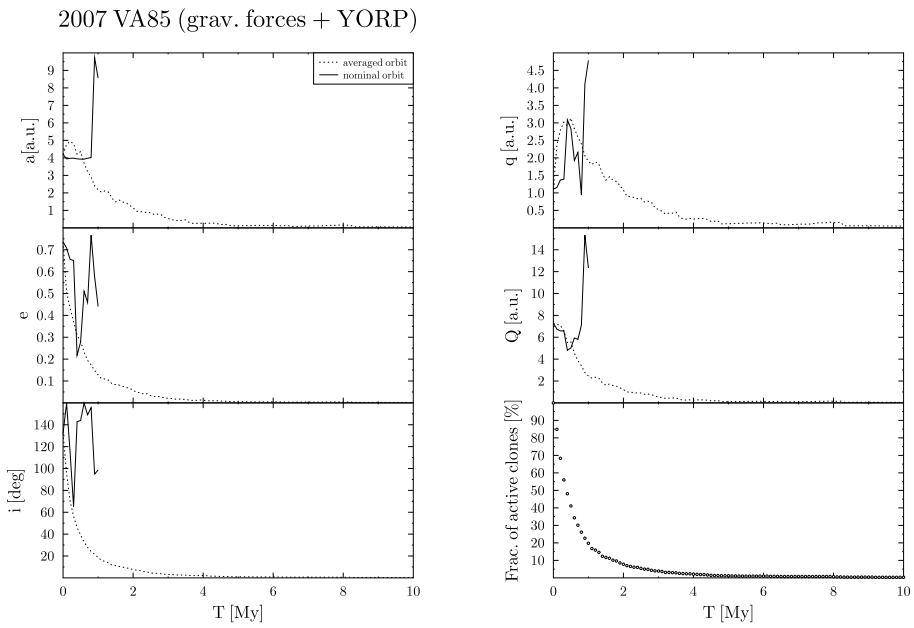

Fig. 1: The orbital evolution of the asteroid 2007 VA85.

3 Results and conclusions

- Results of backward (10^6 y) integration confirmed that the retrograde motion is most likely caused by the secular resonance with Neptune.
- We excluded any significant possibility of impact to the Earth for two examples of retrograde NEAs.

- Long time predictions are limited due to chaotic behaviour of these orbits. About 70% of clones were lost (ejected) during 10^8 y integration (Fig. 1, 2).
- Application of the Y/YORP model resulted in the different evolution of nominal orbital elements, but did not affected the averaged (mean) elements. However, the estimation of size, density, rotation, spin and thermal properties was just an approximation. We expect to improve it after obtaining new physical properties of the studied asteroids.

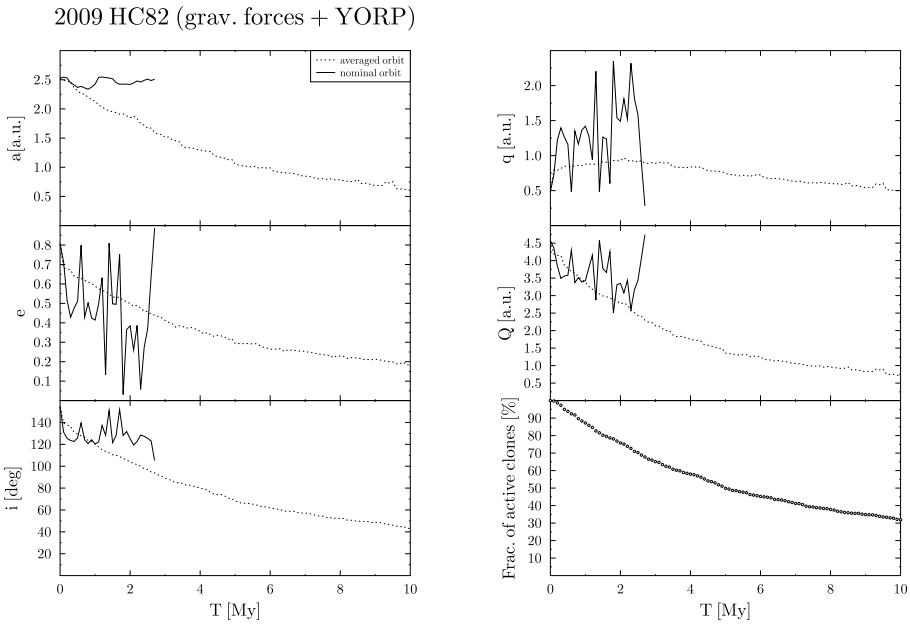

Fig. 2: The orbital evolution of the asteroid 2009 HC82.

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