EPSC Abstracts
Vol. 6, EPSC-DPS2011-536-1, 2011
EPSC-DPS Joint Meeting 2011

Production of Retrograde NEAs

S. Greenstreet (1,2), H. Ngo (3), B. Gladman (1,2), M. Granvik (4) and S. Larson (5) (1) University of British Columbia, Vancouver, British Columbia, Canada (sarahg@phas.ubc.ca), (2) Institute of Planetary Science, Vancouver, British Columbia, Canada, (3) Queen's University, Kingston, Ontario, Canada, (4) University of Helsinki, Helsinki, Finland, (5) University of Arizona, Tucson, Arizona

Abstract

A new NEO orbital distribution model was computed (see Ngo et al., this meeting) in order to optimize a pointing strategy for Canada's space telescope NEOSSat (Near-Earth Object Surveillance Satellite), set to launch in early 2012. Analysis of our NEO model integrations uncovered the unexpected production of retrograde orbits from main-belt asteroid sources. This population of retrograde NEAs makes up only ∼0.1% of the total steady-state NEA population ($q < 1.3$ AU). These objects typically flip to a retrograde state while in the 3:1 mean motion resonance with Jupiter and then live in this retrograde state for about 0.001 to 100 Myr. Given our integration and the estimated total NEA population, the existence of roughly a few retrograde 1 km NEAs is expected, in line with the recent identification of two such objects.

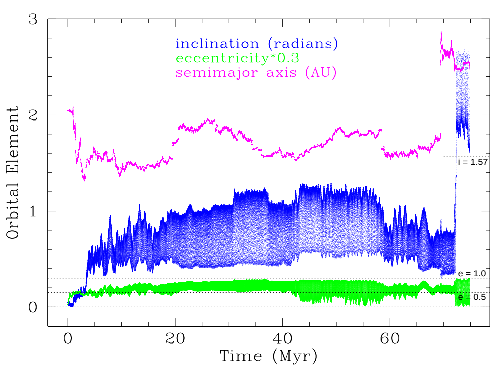

Figure 1: The a, e, i history of a sample retrograde NEA from our NEO model integrations. This particle originates in the ν_6 secular resonance with low e and i. After a ∼70 Myr sojourn as a high-i Apollo, it flips to a retrograde state crossing $i = 1.57 rad = 90°$ and lives for another ∼3 Myr before colliding with the Sun.

1. Introduction

The numerical integrations for this NEO model were performed using SWIFT-RMVS4. The typical path taken by the particles which become retrograde begins with a random walk in semimajor axis due to planetary close encounters with the terrestrial planets after leaving their asteroidal source regions. Most evolve to $a < 2$ AU and spend many Myr in this state before returning to larger a. Many of the particles exhibit Kozai oscillations in e and i during this random walk phase. A key part of this sequence seems to be that i rises above $30°$ in the random walk before returning to $a > 2$ AU. The majority of the particles that become retrograde find their way into the 3:1 mean motion resonance. Kozai oscillations inside the resonance are observed to bring the particle's inclination to nearly $80°$. Some mechanism in the resonance then causes the particle to flip past $90°$ inclination; the nature of this mechanism is still unclear. If the retrograde particle stays in the resonance it can terminate almost immediately (as little as 1000 years later) when the resonance pushes the high-e particle into the Sun. Roughly 97% of the retrograde NEAs are eliminated from the integrations because they reach perihelia distances which lie inside the Sun [2]. The remaining are either thrown out of the Solar System ($a > 19.0$ AU), most often by Jupiter, or suffer planetary collisions. The median lifetime once they become retrograde is ∼3000 years, but if kicked out of the resonance due to a planetary close encounter, they can live tens of millions of years.

2. Sample Retrograde Production

Figure 1 shows an example of the orbital history of a NEA which emerges from the main belt via the ν_6 secular resonance. This particle gets kicked out of the resonance then random walks in a from planetary close encounters for most of its lifetime. It begins to have Kozai oscillations in e and i at t∼10 Myr, reaching inclinations up to $75°$. Near 70Myr, the particle has a planetary close encounter which puts it on an orbit near the 3:1 resonance and it flips to a retrograde state at t$\sim$72Myr. This particle then lives for another 3 Myr before colliding with the Sun. A more detailed analysis of the epoch around the flip shows the particle enters the 3:1 resonance. Less than 50,000 years later, the particle flips to a retrograde orbit.

The longest-lived retrograde particle found in our integrations lives for $\sim$210 Myr, spending $\sim$98% of its lifetime in a retrograde state. It flips $\sim$5Myr into its lifetime while still in the 3:1 resonance. $\sim$15 Myr later, it gets kicked out of the resonance by a planetary close encounter and then random walks to lower a until it encounters the ν_6 resonance and hits the Sun.

To monitor the orbital evolution of each particle in our integrations, a grid of a, e, i cells with a volume of 0.05 AU x 0.02 x $2.00°$ was placed throughout the inner Solar System ($a < 4.2$ AU, $e < 1.0$, and $i < 180°$). The cumulative time spent by each particle in each cell was normalized to the total time spent by all particles in all cells. This determines the steady-state distribution [1] of NEAs in orbital parameter space (Figure 2). The dominant 3:1 resonance path at 2.5 AU to a retrograde state is visible. Our calculation results in an estimate of $\sim$0.1% of the steady-state NEO population being retrograde. To order of magnitude, given there are $\sim$1500 $D > 1$ km NEOs, this $\sim$0.1% estimate implies there should be of order 2 escaped NEAs of this size in retrograde orbits at any time, with more at smaller diameters.

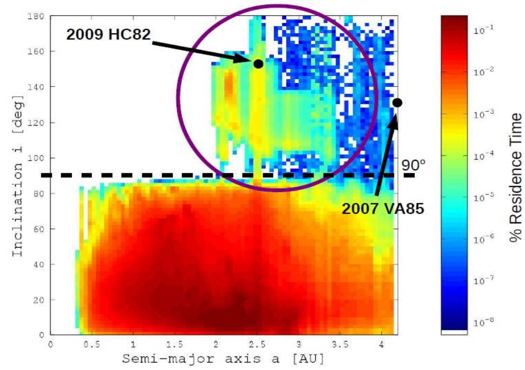

Figure 2: Steady-state residence time probability distribution for inclinations from our new orbital model. The color scale depicts the logarithm of the fraction of time spent by particles in each cell. The known retrograde NEA 2009 HC82 is located beside the 3:1 resonance which is the dominant mechanism producing retrograde NEAs in our integrations. The concentration of residence time at around 2.2 AU and $i = 140°$ is due to the single long-lived ($\sim$210 Myr) retrograde particle which escapes the 3:1 and then lives most of its life in this region of phase space.

3. Two Known Retrograde NEAs

The two known retrograde NEAs, 2007 VA85 and 2009 HC82, were found by LINEAR and the Catalina Sky Survey, respectively. The Catalina team has looked carefully for any evidence of a coma in their images of both objects and have found none. This being the case, we believe these objects could be asteroids that have become NEAs and found their way to i >$90°$ orbits rather than retrograde comets. We do find examples of particles which exit a resonance after flipping and then migrate to larger a; 2007 VA85 has $a = 4.23AU$. However, 2007 VA85's current orbital nodes are outside of Jupiter's orbit, so a past close encounter with Jupiter to put it on its current orbit is possible and it may be of cometary origin.

2009 HC82 on the other hand, is on an orbit very near the 3:1 resonance where it most likely flipped. This object looks much more like the typical retrograde NEA we find in our integrations. Integrations of 2009 HC82's nominal orbit show it not to be currently in the 3:1 resonance. Our integrations show that the long-lived (and thus most likely to be observed) NEAs are those which no longer reside in the resonance.

4. Summary and Conclusions

We have identified a supply path to retrograde orbits from main-belt asteroid sources. The 3:1 mean motion resonance with Jupiter is the dominant mechanism which can flip NEAs to a retrograde state. The median lifetime once they become retrograde is $\sim$3000 years. The existence of one or two non-cometary retrograde objects is in agreement with our model's expectations.

References

[1] Bottke, W. et al.: Debiased orbital and absolute magnitude distribution of the near-Earth objects, *Icarus*, Vol. 156, pp. 399-433, 2002.

[2] Farinella, P. et al.: Asteroids falling into the Sun, *Nature*, Vol. 371, pp. 314-317, 1994.