On future opportunities to observe gravitational scattering of main belt asteroids into Near Earth Object source regions

Anatoliy Ivantsov, Siegfried Eggl, Daniel Hestroffer, William Thuillot

IMCCE, Observatoire de Paris, Avenue Denfert Rochereau 77, 75014 Paris, France

ivantsov@imcce.fr

1. ABSTRACT

Orbital resonances are believed to be responsible for the delivery of main belt asteroids to the inner Solar System. Several possibilities have been suggested to transport asteroids and their fragments into mean motion and secular resonances including non-gravitational forces and gravitational scattering. We investigate future resonance crossings of known asteroids that occur in the main belt over the next century. Our goal is to in order to identify potentially observable injections of asteroids into source regions for Near Earth Objects (NEOs) as well as to determine the role of close encounters among main belt asteroids in this process.

2. INTRODUCTION

Physical and orbital properties of the current NEO population can be explained when one assumes that their primary origin lies in the asteroid main-belt and Jupiter-family comet ($P < 20$ years) regions (Bottke et al., 2000a, 2002; Greenstreet et al., 2012; Mainzer et al., 2012). Orbital resonances with the Gas Giants within the main-belt which cause strong eccentricity-pumping are transport mechanisms that can carry main belt asteroids into the inner Solar System. Two well known resonances in this respect are the 2:1 and 3:1 mean-motion resonance with Jupiter as well as the ν_5 and ν_6 secular resonances. Since the average life-time of asteroids in resonances is much shorter than the age of the Solar System, a constant flux of asteroids into resonant regions is necessary in order to sustain the observed NEO population(Morbidelli et al., 2002). Non-gravitational forces such as the Yarkovsky effect can cause a slow drift into resonance (Bottke et al., 2000b). Also, close encounters among asteroids lead to orbital migration (Delisle & Laskar, 2012; Carruba et al., 2012, 2013). Yet, the importance of gravitational interactions between asteroids with respect to further moving future NEOs towards resonances is not well understood. This is due to computational difficulties arising with the numerical solution of gravitational N-body problem. Results of multiple scattering events, for instance, strongly depend on the number of interacting bodies considered. Using high precision orbit predictions over one hundred years, we identify main belt asteroids that are injected into - or stay in the vicinity of relevant resonant regions that might cause them to become NEOs in the far future. The relevance of asteroid-asteroid gravitational scattering in the main belt in this respect will be investigated. We, thus, intend to provide interesting targets for astrometric observation campaigns which may lead to a better understanding of the processes involved in the generation of NEOs.

3. METHOD

In a first step, we identified those asteroids that are likely candidates to be scattered into a resonance. For this purpose the analytically calculated proper element catalog from AstDys has been searched and asteroids that are close to secular and mean motion resonances have been identified. The mean motion resonances (MMR) considered are 3:1, 5:2, 2:1, and 7:3 between asteroids and Jupiter. Secular resonances were included up to second order in g and s (e.g. Machuca & Carruba, 2012, misprinted frequency values were corrected). Our current sample encompasses asteroids with a distance of no more than 0.5 ["/yr] from the secular resonant frequencies and a maximum proper semi-major axis distance of 10^{-3} au from the locations of the four MMRs that are considered to be source regions for Near Earth Objects (NEOs).

In order to determine, whether any of the sampled asteroids will be pushed into or at least closer to a resonance within the next century, we performed an exploratory numerical propagation of 1273 asteroids that where closest to the investigated secular resonances, and 52 asteroids that were close to the previously mentioned MMRs. Perturbations from all planets (DE431) as well as from the biggest 16 asteroids were considered. The equations of motion include all relevant post-Newtonian terms, as well as the J2 form factor of the Sun. Initial conditions of the main belt objects (MBOs) were acquired from the HORIZONS for consistency. The proper elements of asteroids were computed using OrbFit 4.2 (Milani & Gronchi, 2010).

MMR	IAU number
3J:7A	271956, 299835, 332810, 338943
SECULAR Resonances	IAU number
$\nu_6 + \nu_{16}$	11094, 112561, 112588, ...
$2\nu_5 + \nu_6$	103395, 127993, 13106, 132964,...
$2\nu_6 + \nu_5$	103774, 104624, 195280, 321328, ...
$2\nu_6 - \nu_5 - \nu_{16}$	108497, 148758, 177861, 203561, ...
$3\nu_6 - \nu_5$	146121, 176517
$2\nu_6 + \nu_{16}$	6234, 47790, 146664, 90239,...
$3\nu_6 - 2\nu_5$	54486, 367618
$\nu_6 + 2\nu_{16}$	164537
$2\nu_6 - \nu_5$	75399, 233930
$2\nu_6 + \nu_{16}$	24986, 252191, 234075

TABLE 1: Identified asteroids that may experience resonance crossing over the next century.

4. PRELIMINARY RESULTS

A comparison of analytical proper elements of calculated for all numbered asteroids once for J2000 and once a century later yields that, in fact, 18 out of the 52 near mean motion resonant asteroids stay in the vicinity of their respective MMRs over 100 years, and 4 of them might even become resonance crossers during this time. For nearly secular resonant asteroids, 455 out of 1273 remained close to their resonance and 128 potential resonance crossing events were recorded. A shortened list of possible resonance crossing asteroids is given in Table 1.
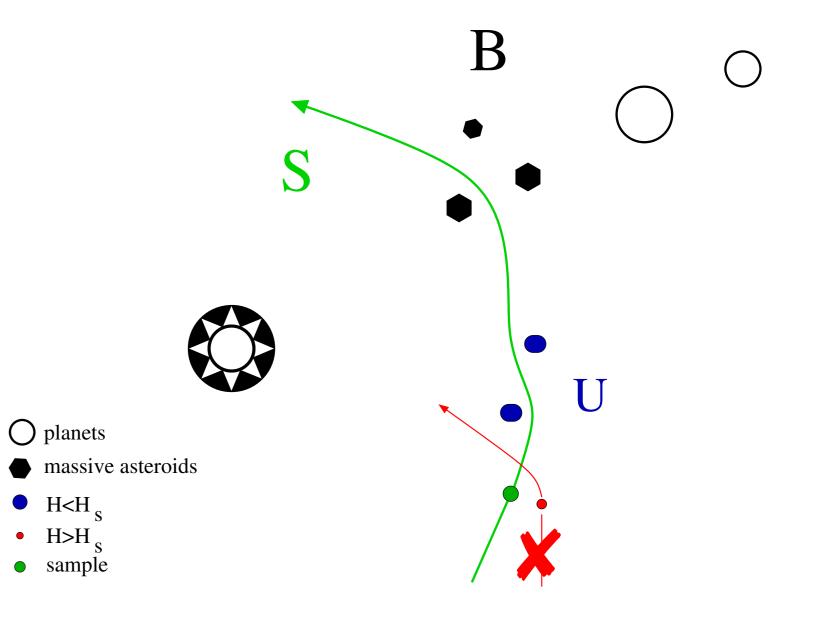
5. FUTURE WORK

Having identified candidates that might be susceptible to influence of asteroid-asteroid scattering to push them closer to a NEO source region, we intend to perform a more detailed analysis of the candidates' orbit evolution. In order to avoid the full brunt of N^2 operations that come with the introduction of all asteroids as self-gravitating entities, we will set magnitude based interaction cut-offs. Three groups of asteroids are considered: the sample asteroids (S), asteroids that will perturb S but remain themselves unperturbed (U) and the fully interacting big asteroids (B), see Figure 1.

FIGURE 1: Interactions between different groups of main belt asteroids and the sample asteroids (S). Asteroids with absolute magnitudes (H) much fainter than S will be neglected. Asteroids with $H > H_s$ (U) will perturb S but remain themselves unperturbed by S. Very large asteroids (B) will gravitationally interact among each other and influence S.

6. CONCLUSIONS

We have found that a considerable number of main belt asteroids may enter NEO source regions within the next 100 years. A more detailed modeling of the gravitational scattering processes will provide information on the importance of asteroid-asteroid interaction around resonances relevant to NEO production.

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