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# Chaotic scattering of main belt asteroids from Centaurs and Trans-Neptunian Objects

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## Abstract

Centaurs are objects whose orbits are found between those of the giant planets. They are supposed to originate mainly from the Trans-Neptunian objects, and they are among the sources of Near-Earth Objects (TNOs). We investigate their interactions with main belt asteroids to determine if chaotic scattering caused by close encounters and impacts by these bodies may have played a role in the dynamical evolution of the main belt. We find that Centaurs and TNOs (C+TNOs) that reach the inner Solar System can modify the orbits of main belt asteroids, though only if their mass is of the order of $10^{-9}$ $m_{\odot}$ for single encounters or, one order less in case of multiple close encounters. Current main belt asteroids that originated as C+TNOs may lie in the outer belt, most likely between 2.8 au and 3.2 au (though at larger eccentricities than typical of main belt asteroids) but also in its outer regions.

## 1. Introduction

Centaurs are objects whose orbits are contained between those of Jupiter and Neptune (Bayley et al. 2009). Currently[1] 301 Centaurs are known (JPL Small-Body Database Search Engine at http://ssd.jpl.nasa.gov/sbdb query.cgi) and the population of objects with diameters larger than 1 km is estimated to be more then ∼ 40 thousand (Horner, Evans & Bailey 2004a). Since Centaurs and their progenitors can be relatively massive (∼ lunar mass), move throughout the planetary system, and have done so throughout its existence and in much larger numbers in the past, we ponder whether close encounters and impacts by Centaurs on main belt asteroids may have played a role in the dynamical evolution of the have played a role in the recent (that is, after theLate Heavy Bombardment, from 3.8 Gyrs ago to now) dynamical evolution of the main belt and particularly asteroid families.

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## 2. Methods

We consider two time spans: (i) the present population (PP), reaching 50 Myr into the past, examines the effect of Centaurs and TNOs encounters on young asteroid families, i.e. the Karin family (5.3 Myr, Nesvorny et al. 2002). (ii) The ancient population, AP, stretches back 3.8 Gyrs ago (Hartmann et al. 2000; Kirchoff et al. 2013), the estimated age of the end of the Late Heavy Bombardment (LHB) process, and examines the effects on old asteroid families, e.g. Flora family, which is old ∼4.4 Gyr (Carruba et al. 2016). In particular, we investigate the close encounters with Centaurs and TNOs (from now on C+TNOs), with a diameter larger than 100 km, can perturbate/diffuse young and/or old main belt families (Zappala et al. 1995; Migliorini et al. 1995; Nesvorny 2012; Novakovi c et al. 2011). An example is the scattering of V-type (basaltic) asteroids from the Vesta family beyond the 3J:1 mean motion resonance,into the central and outer main belt, see also Carruba et al. (2014); Huaman et al. (2014). We also consider whether Centaurs contribute to the presence of interlopers inside families, like the case of the C-types (carbonaceous asteroids) in the Hungaria family (up to 6%, Warner et al. 2009), whose member are in majority E-types. In order to do this, we use the Lie-numerical integrator set to precision 10-13 (Hanslmeier and Dvorak 1984, Eggl and Dvorak 2010; Bancelin et al. 2012, Galiazzo et al. 2013a; Galiazzo and Schwarz 2014).

## 3. Results and conclusions

The most perturbed regions of the belt are shown in the lower panel of Fig. 1 (Galiazzo, Wiegert &

Aljbaae, 2016), which illustrates the perturbed region of the AP by a line connecting aphelion and perihelion. The most influenced region is the Outer main belt at low inclinations. Fig. 2 show a drift of a C+TNO in the main belt region.

Some C+TNOs stay for relatively long periods in the main belt in our simulations, up to 3 Myrs (3.7 Myrs for the AP case), with some low-
eccentricity orbits, e ∼ 0.1.

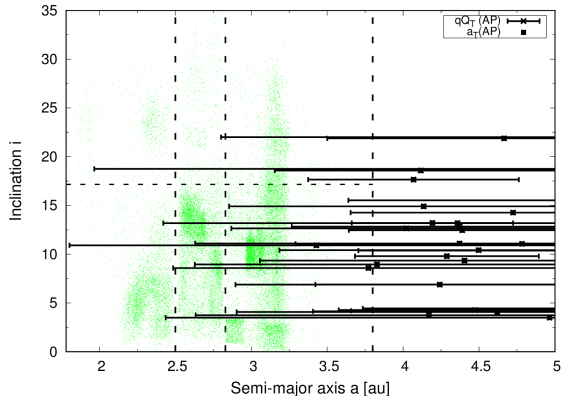


Figure 1: The semi-major axis of the main belt asteroids with H < 14 is represented with small green dots. The larger black points represent the C+TNO populations when they first enter the main-belt: their semi
-major axis (aT with aphelion and perihelion limits) versus
inclination projection of the TNOs of the Ancient Population.

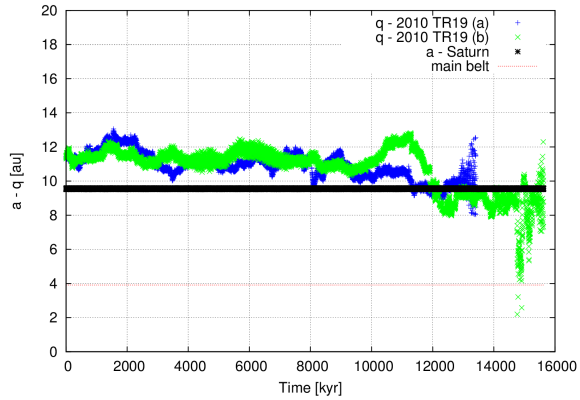


Figure 2: Drift in the main belt of 2 clones of the asteroid 2010 TR19.

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