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Dynamical evolution of Centaurs and impacts with planets

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Abstract

Minor bodies in between Jupiter and Neptune are called Centaurs. Most of them are related to the Trans-Neptunian objects (TNOs), and are sources of some Near-Earth Objects. Thus, it is important to understand their orbital evolution and their possible collisions with terrestrial planets. In particular, we study the orbital evolution of the Centaurs toward the inner solar system, and estimate the number of close encounters and impacts with the planets after the Late Heavy Bombardment (LHB) and assuming a steady state populations of bodies. We also compute the crater sizes and the approximate amount of water released: on the Earth, which we find to be approximatively 10^{-5} the total water currently present. Collisions could be catastrophic on the Earth and crater sizes could extend up to hundreds of kilometers in diameter. However, given the presently known population of Centaurs, the sizes would be in general less than ∼10 km. For an average impactor size of ∼12 km in diameter and for all the planets the average impact frequency since the Late Heavy Bombardment is one every ∼1.9 Gyr and~2.1 Gyr respectively for the Earth and Venus. For smaller bodies (e.g. > 1 km), the impact frequency in the recent solar system is one every 14.4 Myr, 13.1 Myr and 46.3 respectively for the Earth, for Venus and for Mars. Only 53% of the Centaurs can enter into the terrestrial planet region and ∼ 7% can interact with terrestrial planets.

1. Introduction

Centaurs are objects in the solar system, with their orbits situated between 5.5 au and 30 au. There is the lack of general agreement, but we assume this range in semi-major axis. Trans-Neptunian Objects (TNOs) are among their main source, and thus should have generally lower density than the asteroids of the main belt. Centaurs can become comets and can contains a significant amount of volatile material. Centaurs have a short lifetime compared to the main belt objects, and survive on timescales of only a few million of years (Di Sisto, Brunini & de Elıa 2010; Galiazzo, Wiegert & Aljbaae 2016). These bodies are also sources of Near-Earth Objects (NEOs). Thus, it is crucial to investigate their orbital evolution , also in order to understand their interactions with terrestrial planets which might and in an impact. Because about 11% (Guilberte-Lepoutre, 2012) of the Centaurs can become comets, they can be source of water for planets.

2. Methods

Orbital evolution is computed via the Lie-Integrator (Hanslmeier & Dvorak, 1984, Eggl & Dvorak, 2010, Galiazzo, Dvorak & Bazso, 2013) and crater size using iSALE-2D, a multi-material,multi-rheology shock physics code (Melosh, Ryan & Asphaug 1992; Ivanov, Deniem & Neukum 1997; Collins, Melosh & Ivanov 2004; Wunnemann, Collins & Melosh 2006), an extension of the SALE hydrocode (Amsden, Ruppen & Hirt 1980).

For the orbital evolution we consider in a simplified solar system (we consider all the planets and apart Mercury, whose mass is added to the Sun). We forward integrate 319 Centaurs (data from JPL Small-Body Database Search Engine: http://ssd.jpl.nasa.gov/sbdbquery.cgi, for 30 Myr, which is enough to seek an entire average lifetime of Centaurs (removed from the solar system on timescales of only a few million years Dones, Levison & Duncan 1996; Levison & Duncan 1997; Tiscareno & Malhotra 2003; Horner, Evans & Bailey 2004a; Di Sisto & Brunini 2007; Bailey & Malhotra 2009), or until the body has a collision (see Table 1), or reaches a hyperbolic orbit and escapes. For each Centaur we consider 14 clones (4785 orbital evolutions, considering real initial orbits plus each clone orbits), distributed as described in Horner, Evans & Bailey (2004a); Galiazzo, Wiegert & Aljbaae (2016). We consider an impact with the Sun when the body reaches a distance of 0.00465 au relative to its center. Some comets were observed to survive in relatively close proximity to the Sun, such as C/2011 W3 (Lovejoy) which survived at a distance of 0.0055 au (Sekanina & Chodas 2012).

Table 1: Close encounter and impact radii per planet. = the “Earth” is in reality the Earth and Moon together in the barycentric position.

Target/Planet	r_{CE} [10^{-3} au]	R_{IMP} [10^{-3} au]
Venus	6.71	0.04045
Earth*	9.88	0.04259
Mars	6.66	0.02266
Jupiter	4.38	0,46733
Saturn	5.33	0.38926
Uranus	5.84	0.16953
Neptune	10.00	0.16459

3. Summary and Conclusions

The approximate amount of water released on the Earth, is approximatively 10^{-5} the total water currently present and a minor amount of water is released on Venus and Mars, too. Collisions could be catastrophic on the Earth and crater sizes could extend up to hundreds of kilometers in diameter. However, given the presently known population of Centaurs, the sizes would be in general less than ∼10 km (see Fig. 1 for a possible crater formation). For an average impactor size of ∼12 km in diameter and for all the planets the average impact frequency since the LHB is one every ∼1.9 Gyr and ~2.1 Gyr respectively for the Earth and Venus. For smaller bodies (e.g. > 1 km), the impact frequency in the recent solar system is one every 14.4 Myr, 13.1 Myr and 46.3 respectively for the Earth, for Venus and for Mars. 53% of the Centaurs enter into the terrestrial planet region (source regions in Fig. 1 and 2) and ∼7% have close encounters with them.

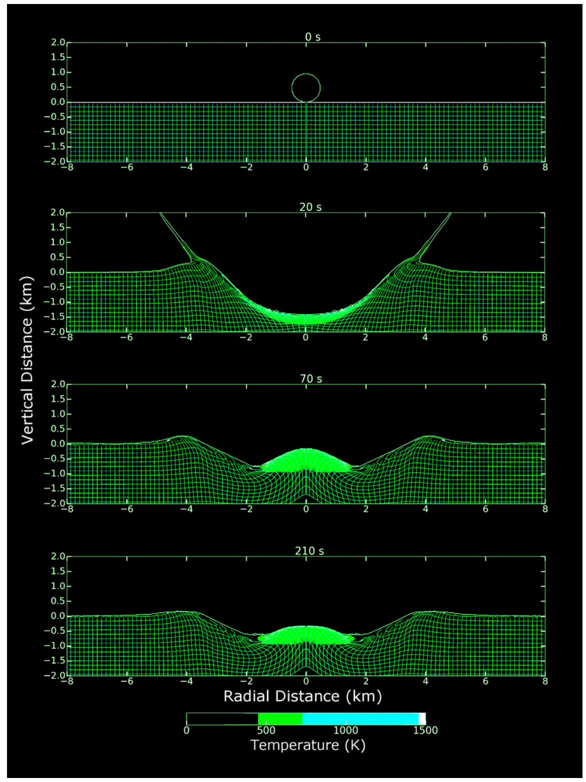

Fig 1: The time series of the impact crater as a result of a Centaur from a collision with the Earth. When the collision with the surface starts, the initial time is set at 0s. The cratetr collapse to finish in ∼3 minutes. The impactor is large 1 km. Considering that the simulations are axisymmetric, the impact velocity was scaled to the vertical component only. The non-scaled impact velocity is v_i = 9.4 km/s (at 45° and scaled to the vertical component is v_i = 6.6 km/s.

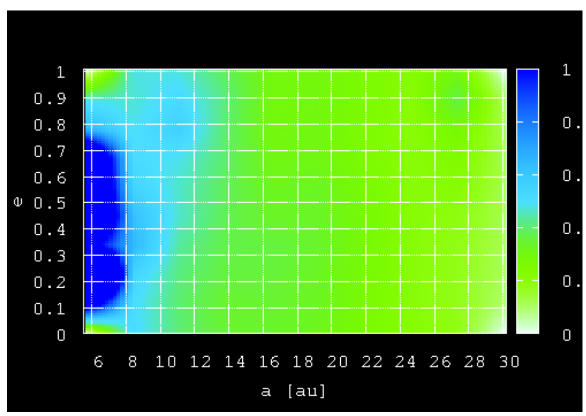

Figure 2: Source regions: a-e phase space. The color code is the density of the relative points in each region and gaussian scaled. The color bar scale is not the same in each panel.

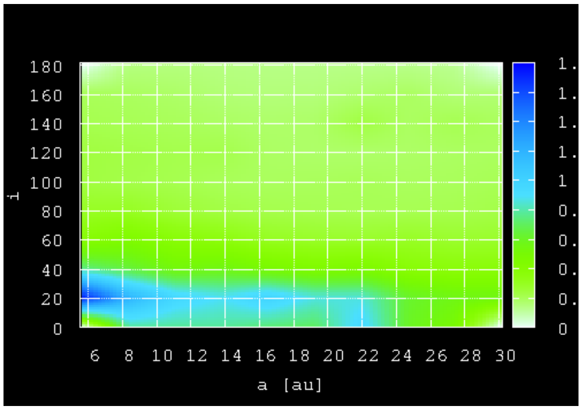

Figure 3: Source regions: a-i phase space. The color code is the density of the relative points in each region and gaussian scaled. The color bar scale is not the same in each panel.

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