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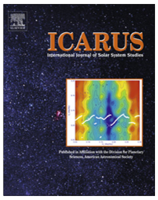

Assessing the physical nature of near-Earth asteroids through their dynamical histories

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We analyze a sample of 139 near-Earth asteroids (NEAs), defined as those that reach perihelion distances $q < 1.3$ au, and that also fulfill the conditions of approaching or crossing Jupiter's orbit (aphelion distances $Q > 4.8$ au), having Tisserand parameters $2 < T < 3$ and orbital periods $P < 20$ yr. In order to compare the dynamics, we also analyze a sample of 42 Jupiter family comets (JFCs) in near-Earth orbits, i.e. with $q < 1.3$ au. We integrated the orbits of these two samples for 10^4 yr in the past and in the future. We find that the great majority of the NEAs move on stable orbits during the considered period, and that a large proportion of them are in one of the main mean motion resonances with Jupiter, in particular the 2:1. We find a strong coupling between the perihelion distance and the inclination in the motion of most NEAs, due to Kozai mechanism, that generates many sungrazers. On the other hand, most JFCs are found to move on very unstable orbits, showing large variations in their perihelion distances in the last few 10^2–10^3 yr, which suggests a rather recent capture in their current near-Earth orbits. Even though most NEAs of our sample move in typical 'asteroidal' orbits, we detect a small group of NEAs whose orbits are highly unstable, resembling those of the JFCs. These are: 1997 SE5, 2000 DN1, 2001 XQ, 2002 GJ8, 2002 RN38, 2003 CC11, 2003 WY25, 2009 CR2, and 2011 OL51. These objects might be inactive comets, and indeed 2003 WY25 has been associated with comet Blanpain, and it is now designed as Comet 289P/Blanpain. Under the assumption that these objects are inactive comets, we can set an upper limit of ~0.17 to the fraction of NEAs with $Q > 4.8$ au of cometary origin, but it could be even lower if the NEAs in unstable orbits listed before turn out to be *bona fide* asteroids from the main belt. This study strengthens the idea that NEAs and comets essentially are two distinct populations, and that periods of dormancy in comets must be rare. Most likely, active comets in near-Earth orbits go through a continuous erosion process in successive perihelion passages until disintegration into meteoritic dust and fragments of different sizes. In this scenario, 289P/Blanpain might be a near-devolatized fragment from a by now disintegrated parent comet.

1. Introduction

The traditional difference between comets and asteroids based on the type of orbits (e.g. the Tisserand parameter) and/or on whether they show or not gaseous and/or dust activity has become increasingly blurry with the unexpected discovery of activity on some typical main-belt asteroids, the so-called main-belt comets (Hsieh and Jewitt, 2006), and the discovery of objects on typical cometary orbits that do not show any activity at all. The spectra of some bodies of the latter group with low values of the Tisserand parameter T (<2.7), typical of Jupiter family comets, are found to be very red, compatible with dead or dormant comets, but also with Trojan and Hilda asteroids (Licandro et al., 2008).

The lack of observable activity is particularly striking in the case of bodies that approach the Earth, the Near-Earth Asteroids (NEAs), for which one should expect to find activity if they contain volatiles, namely if they are of cometary nature, once they are exposed to the more intense Sun's radiation. One way out of the puzzle is to assume that comets build insulating dust mantles after their perihelion passages, that turn them into inactive, asteroid-looking bodies (Shul'man, 1972; Brin, 1980; Rickman et al., 1990). Therefore, the possibility that comets pass through periods of dormancy, or become extinct is one of the issues to solve, and also how widespread is the phenomenon. This has to be confronted with the observation of several comets that disintegrated near perihelion owing to their volatile composition and fragile structure (Sekanina, 1984; Weaver, 2001; Battams, 2013). Several authors have suggested a possible cometary origin for some or most NEAs (Wetherill, 1988; Levison and Duncan, 1994; DeMeo and Binzel,

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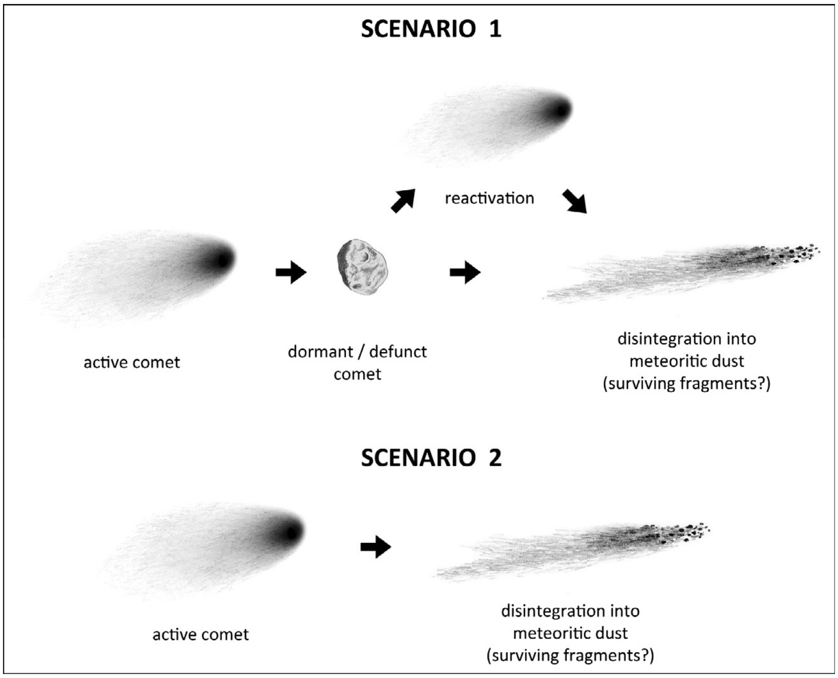

Fig. 1. Two possible scenarios for the physical evolution of comet nuclei in the inner planetary region. In both cases, and unless the comet is ejected or collides with the Sun or a planet first, disintegration will be the ultimate fate after a varying number of perihelion passages.

2008), though it has been argued that the transfer process of bodies from the asteroid belt to NEA orbits is efficient enough to keep the current observed population of NEAs in steady-state without needing to invoke an extra comet source (Rabinowitz, 1997; Fernández et al., 2002). The similarities between the spin rate and shape distribution of NEAs and main-belt asteroids also led Binzel et al. (1992) to conclude that most NEAs must come from the main belt.

We have two possible scenarios for the physical evolution of periodic comets in which: (1) they get insulating dust mantles during their perihelion passages becoming dormant or extinct; or (2) they keep active all the way until disintegration into meteoritic dust and, perhaps, leaving behind large fragments of devolatized material (Fig. 1). The first scenario may also foresee the possibility of intermittent activity, during which the comet passes through alternate periods of dormancy and activity until complete disintegration (or dynamical ejection, or collision with the Sun or a planet).

We plan to deal with bodies of different characteristics (asteroids, comets, Earth-approaching objects, main-belt objects, etc.) so, in order to simplify the language, we will use different acronyms to refer to them. A summary of the acronyms used here is presented in Table I. We note that the acronym 'NEA' might include objects of cometary origin that happen to be inactive at present.

This work has been motivated by a previous work (Sosa et al., 2012) that studied the time-evolution of the average perihelion distance, $\langle q \rangle$, of samples of JFCs with $q < 1.3$ au and NEAs for 10^3 yr in the past and in the future. A comparison of the time evolution of $\langle q \rangle$ between NEAs and JFCs showed striking differences: it stayed more or less constant during the studied period for NEAs, whereas it showed a steep increase in the past and a more moderate increase in the future for JFCs. This asymmetry in the evolution of $\langle q \rangle$ for JFCs was interpreted as due to the short physical lifetime of JFCs with $q < 2$ au, of a few 10^3 yr to about 10^4 yr, that favors the discovery of those comets that evolve fast enough to low-q orbits (where they are more easily detected) before they disintegrate. Our aim in this work is to extend the integrations for a longer period ($\pm 10^4$ yr) and to check if the NEAs have indeed dynamical evolutions quite different from those showed by JFCs. A byproduct of this study is to detect potential inactive comets among NEAs.

2. The method

2.1. The samples and data sets

We analyzed a sample of 139 NEAs with the same orbital characteristics as the JFCs, namely Tisserand parameters $2 < T < 3$, and orbital periods $P < 20$ yr. Furthermore, we imposed the condition that they are Jupiter-approaching or crossing objects, namely with aphelion distances $Q > 4.8$ au. We also restrict the sample to those orbits of better quality, as given by the condition codes $\leqslant 5$ in the JPL scale 0–9 (from the best to the poorest quality). For comparison purposes, we also studied a sample of 42 NEJFCs in orbits with the same constraints as those for the asteroid sample. The orbits of NEJFCs were integrated neglecting nongravitational (NG) forces. To check the influence of these forces on the evolution, we also integrated the orbits including NG terms in the cases they were estimated. We did not find significant differences, in statistical terms, in the orbital evolution of comets with and without NG forces. A more thorough discussion of this topic will be given in a forthcoming paper. The orbital data were extracted from the NASA/JPL Small-Body Database,[1] as known by the end of 2012.

2.2. The numerical integrations

We integrated the orbits of the considered objects in a heliocentric frame for 10^4 yr, in the past and in the future with respect to the present epoch, which was defined as JD 2456200.500, i.e. CE 2012 September 30, 00:00:00 UT, Sunday. The output interval was 1 yr. We considered for each object five clones, where each clone was generated by means of a random Gaussian distribution in the 6-orbital parameters space, with a mean value equal to

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[1] http://ssd.jpl.nasa.gov/sbdb.cgi.