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Jupiter family comets in near-Earth orbits: Are some of them interlopers from the asteroid belt?

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ABSTRACT

We analyze a sample of 58 Jupiter family comets (JFCs) in near-Earth orbits, defined as those whose perihelion distances at the time of discovery were $q_{disc} < 1.3$ au. In our definition JFCs have Tisserand parameters $2 < T < 3$ and orbital periods $P < 20$ yr. We integrated the orbits of these objects, plus 50 clones for each one of them, for 10^4 yr in the past and in the future. We find that most of them move on highly unstable orbits, having fallen in their current near-Earth orbits in the recent past, going from less than one hundred years to a few thousands years. They experience frequent close encounters with Jupiter down to distances $\lesssim 0.1$ au. This is the expected behavior for comets whose limited physical lifetimes in the near-Earth region make them unlikely to survive there for more than about a few hundred revolutions. In this sense the orbits of most JFCs are typically “cometary”, and they should be regarded as newcomers in the near-Earth region. Yet, a minor fraction of JFCs (less than about one third) are found to move on stable orbits for the past $\sim 10^4$ yr, and in some cases are found to continue to be stable at 5×10^4 yr in the past. They also avoid very close encounters with Jupiter. Their orbital behavior is very similar to that of NEAs in cometary orbits. While “typical” JFCs in unstable orbits probably come from the trans-Neptunian region, the minor group of JFCs in asteroidal orbits may come from the main asteroid belt, like the NEAs. The asteroidal JFCs may have a more consolidated structure and a higher mineral content than that of comets coming from the trans-Neptunian belt or the Oort cloud, which could explain their much longer physical lifetimes in the near-Earth region. In particular, we mention comets 66P/du Toit, 162P/Siding Spring, 169P/NEAT, 182P/LONEOS, 189P/NEAT, 249P/LINEAR, 300P/Catalina, and P/2003 T12 (SOHO) as the most likely candidates to have an origin in the main asteroid belt. Another interesting case is 207P/NEAT, which stays near the 3:2 inner mean motion resonance with Jupiter, possibly evolving from the Hilda asteroid zone.

1. Introduction

Jupiter family comets (JFCs) are assumed to come from the trans-Neptunian region after a dynamical process in which they pass from the gravitational control of Neptune to the control of the other Jovian planets until ending under the dynamical control of Jupiter (Fernández, 1980; Duncan et al., 1988; Levison and Duncan, 1997). While in the trans-Jovian region, the transit bodies are called Centaurs, the direct progenitors of the JFCs. Once Centaurs fall under the gravitational control of Jupiter, their dynamical lifetimes should be short. Furthermore, given their icy nature and brittle structure, we should expect that physical lifetimes for JFCs coming close to the Sun should be a tiny fraction of the dynamical lifetime, since phenomena such as sublimation, outbursts and splittings will limit enormously the number of passages in the Sun's vicinity. The observational evidence supports this conjecture (Kresák, 1981; Sekanina, 1984).

The dynamical lifetime of JFCs is found to be about 1.5×10^5 yr, but they stay in near-Earth orbits ($q < 1.3$ au) for only a fraction of this time (~a few 10^3 yr) (Fernández et al., 2002). As mentioned before, these comets should have short physical lifetimes, so it is very likely that they will fade before being ejected, or their perihelia raised to distances such that their sublimation rate becomes negligible. From the analysis of the periodic comets that ceased to be observed in favorable apparitions, Kresák (1981) estimated a mean physical lifetime of ~ 400 revolutions for a comet in a short-period orbit with $q \simeq 1.5$ au (about 2500–3000 yr). Later, Kresák and Kresáková (1990) reanalyzed this problem by considering the secular brightness decrease in JFCs. They found a decrease rate of ~0.015 mag per revolution for a comet with $q \simeq 1.5$ au, which amounts to about 500 revolutions in good agreement with the previous result. Fernández (1985) and Sosa et al. (2012) used a

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different approach to estimate the dynamical lifetime that consisted in the comparison of the past evolution of the average perihelion distance, $\bar{q}$, of the observed near-Earth JFCs with the evolution of $\bar{q}$ in the future. A rapid drop of $\bar{q}$ in the past, as compared to a slow increase in the future, was interpreted due to a finite physical lifetime between about 3000 and 12,000 yr for comets with $q \lesssim 2$ au. From numerical simulations that considered dynamical as well as physical losses, di Sisto et al. (2009) found a mean physical lifetime of ~150–200 revolutions ($\sim 10^3$ yr) for JFCs with radii $R > 1$ km and $q < 1.5$ au. Summing up, there are several pieces of evidence suggesting short physical lifetimes – of the order of a few 10^3 yr – for JFCs in Earth-approaching orbits ($q \lesssim 1.5$ au).

We should also mention that, besides disintegration, active comets may become dormant or extinct by building insulating dust mantles (Shul'man et al., 1972; Brin, 1980; Rickman et al., 1990). In this case they will look as asteroids. Yet, dynamical studies suggest that most near-Earth asteroids in seemingly “cometary” orbits move on dynamically stable orbits coming from the main asteroid belt, in particular the 2:1 mean motion resonance (Fernández et al., 2002, 2014). Therefore, NEAs in cometary orbits do not necessarily have a comet origin, and it is even possible that the great majority of them are *bona fide* asteroids. The most common end state of comets in the near-Earth region seems to be disintegration into meteoritic dust and chunks of devolatized material (Sekanina, 1984; Weaver et al., 2001). In this scenario, an object like 2003 WY25, identified with comet 289P/Blanpain (Jewitt, 2006), could actually be a big fragment of the comet that has passed through a steady devolatilization and disintegration process.

This paper is a spinoff of a previous work in which we studied the dynamical histories of NEAs in cometary orbits (defined as those with aphelion distances $Q > 4.8$ au), aimed at detecting comet interlopers in the NEA population (Fernández et al., 2014). In order to distinguish a typical “asteroidal” orbit from a typical “cometary” one, we also integrated the orbits of a sample of near-Earth JFCs. We actually found that most NEAs move on stable orbits on the studied time scale (10^4 yr in the past and 10^4 yr in the future), with a few exceptions of objects whose orbits were quite unstable, suggesting a recent capture by Jupiter in their current near-Earth orbits. The latter objects were found to have very frequent close encounters with Jupiter, so their orbital evolution resemble that of JFCs. We considered these objects to be prime candidates to have a comet origin whose lack of observed activity may be due to their being covered by insulating dust mantles. On the other hand, we were surprised to find that not all the near-Earth JFCs of our sample had rapidly-evolving orbits subject to frequent close encounters with Jupiter. The orbits of some of these JFCs looked quite asteroidal, remaining stable during all the studied period. It is therefore the aim of this paper to analyze in more depth the orbital characteristics of the sample of near-Earth JFCs (NEJFCs) to try to find out if there are some “asteroids disguised as comets” among the objects in our sample.

Table 1
List of Jupiter family comets

comet	Disc. yr	q (au)	a (au)	i (deg)	H_T	H_N
3D/Biela	1772	0.990	3.612	17.1	6.9	–
5D/Brorsen	1846	0.650	3.141	30.9	8.6	–
6P/d'Arrest	1851	1.173	3.443	13.9	8.7	16.5
7P/Pons-Winnecke	1819	0.772	3.140	10.7	8.6	16.3
11P/Tempel-Swift-LINEAR	1869	1.063	3.109	5.4	11.1	>17.6
15P/Finlay	1886	0.997	3.533	3.0	7.5	17.2
18D/Perrine-Mrkos	1896	1.110	3.454	13.7	10.0	–
21P/Giacobini-Zinner	1900	0.932	3.472	29.8	9.8	17.6
24P/Schaumasse	1911	1.225	4.001	17.7	7.6	17.8
26P/Grigg-Skjellerup	1808	0.732	2.856	3.5	12.2	17.2
34D/Gale	1927	1.214	5.032	11.6	9.4	–
41P/Tuttle-Giacobini-Kresak	1858	1.140	3.058	18.9	10.4	18.4
45P/Honda-Mrkos-Pajdusakova	1948	0.559	3.009	13.2	10.7	20.0
54P/deVico-Swift-NEAT	1844	1.186	3.100	2.9	7.8	18.5
66P/duToit	1944	1.277	6.023	18.7	9.6	19.3
67P/Churyumov-Gerasimenko	1969	1.285	3.502	7.1	8.3	16.0
72P/Denning-Fujikawa	1881	0.725	4.232	6.9	8.3	–
73P/Schwassmann-Wachmann 3	1930	1.011	3.080	17.4	11.6	17.7
79P/duToit-Hartley	1945	1.250	3.034	6.9	11.2	17.2
85P/Boethin	1975	1.094	4.955	5.9	7.8	–
103P/Hartley 2	1986	0.952	3.398	9.3	8.6	17.2
141P/Machholz 2-A	1994	0.753	3.015	12.8	10.4	20.6
162P/Siding Spring	2004	1.227	3.047	27.8	13.5	13.7
169P/NEAT	2002	0.605	2.602	11.3	13.7	15.8
181P/Shoemaker-Levy 6	1991	1.132	3.849	16.9	12.0	19.0
182P/LONEOS	2001	0.976	2.928	16.9	17.6c	19.7
185P/Petriew	2001	0.946	3.114	14.0	10.4	>16.9
189P/NEAT	2002	1.174	2.916	20.4	15.8	18.7
197P/LINEAR	2003	1.063	2.868	25.5	16.6c	17.7
207P/NEAT	2001	0.937	3.872	10.2	15.0c	18.4
209P/LINEAR	2004	0.912	2.932	19.1	16.6	17.4
210P/Christensen	2003	0.549	3.211	10.1	12.8	>17.9
217P/LINEAR	2001	1.254	3.968	13.5	10.1	>15.9
222P/LINEAR	2004	0.782	2.864	5.1	16.0	>19.0
225P/LINEAR	2002	1.192	3.548	20.7	16.7c	>19.8
249P/LINEAR	2006	0.511	2.777	8.4	17.1c	>17.2
252P/LINEAR	2000	1.003	3.058	10.4	18.2c	>19.4
255P/Levy	2006	0.989	3.015	18.3	9.2	>19.5
263P/Gibbs	2006	1.251	3.029	14.5	16.0c	>18.5
289P/Blanpain	1819	0.892	2.963	9.1	8.3	21.7
300P/Catalina	2005	0.826	2.693	5.7	15.6	18.7
317P/WISE	2010	1.198	2.918	10.6	–	>18.4
D/1884 O1 (Barnard)	1884	1.279	3.067	5.5	8.2	–
D/1894 F1 (Denning)	1894	1.147	3.797	5.5	10.0	–
D/1895 Q1 (Swift)	1895	1.298	3.729	3.0	10.7	–
D/1978 R1 (Haneda-Campos)	1978	1.101	3.287	5.9	11.4	–
P/1999 RO28 (LONEOS)	1999	1.232	3.527	8.2	17.8c	20.8
P/2003 O3 (LINEAR)	2003	1.246	3.105	8.4	17.6c	>19.8
P/2003 T12 (SOHO)	2003	0.575	2.569	11.5	–	–
P/2004 R1 (McNaught)	2004	0.988	3.107	4.9	17.1c	>18.6
P/2007 T2 (Kowalski)	2007	0.696	3.093	9.9	15.0c	>19.4
P/2008 S1 (McNaught)	2008	1.190	3.568	15.1	14.7c	>17.4
P/2008 Y1 (Boattini)	2008	1.272	4.798	8.8	13.0c	>16.2
P/2009 L2 (Yang-Gao)	2009	1.296	3.419	16.2	13.8	>19.1
P/2009 WX51 (Catalina)	2009	0.798	3.077	9.6	17.6c	>19.9
P/2011 NO1 (Elenin)	2011	1.243	5.565	15.3	13.0c	>17.8
P/2013 CU129 (PANSTARRS)	2013	0.798	2.879	12.2	15.2c	>18.1
P/2013 TL117 (Lemmon)	2013	1.118	3.604	9.4	16.5c	>18.9

2. The sample

We analyzed a sample of 58 JFCs with Tisserand parameters $2 < T < 3$ and orbital periods $P < 20$ yr (Table 1). This sample includes all the JFCs discovered through 2013 that reached perihelion distances $q < 1.3$ au at the moment of their discovery. The constraint of near-Earth orbit allows us to have a more complete sample, with the additional advantage that these comets are excellent probes to analyze their survival through successive perihelion passages close to the Sun. Furthermore, objects with some volatile content that approach the Sun will probably develop some activity, that otherwise would not be present or detectable were these objects on more distant orbits.

2.1. Absolute total and nuclear magnitudes

Total and nuclear magnitudes are both very important for the characterization of a certain comet population. The nuclear magnitude is related to the size and albedo of the comet nucleus; the total magnitude gives information on the activity and the