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Hilda asteroids among Jupiter family comets

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Abstract

Hilda asteroids and comets are similar from the compositional point of view. The D-taxonomic class prevailing among Hildas has all the characteristics found in cometary spectra. Jupiter Family Comets (JFCs) coming from the trans-neptunian region are under the gravitational control of Jupiter, making them a dynamically unstable population with a mean dynamical lifetime of 10^4 to 10^5 years. In contrast, Hilda asteroids residing in the 3:2 mean motion resonance with Jupiter are a very stable population. But once they escape from the resonance, they are dynamically controlled by Jupiter, and in this sense their behavior resembles that of JFC. We performed a numerical simulation to analyze the dynamical evolution that Hildas follow after escaping from the resonance, and their contribution to the JFC population. We found that 8% of the particles leaving the resonance end up impacting Jupiter. 98.7% of the escaped Hildas live at least 1000 years as a JFC, with a mean lifetime of 1.4×10^6 years. In particular, escaped Hildas stay mainly in the region of perihelion distances greater than 2.5 AU. On the other hand, the number of escaped Hildas reaching the inner Solar System ($q < 2.5$ AU) is negligible. So, there are almost no Hilda asteroids among the NEO population. We also analyzed the possibility that the Shoemaker–Levy 9 were an escaped Hilda asteroid. In this case, it would be possible to give stronger constraints to its pre-capture orbital elements.

Keywords: Comets; Asteroids; Dynamical evolution; Resonance

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1. Introduction

Comets are one of the most primitive bodies of the Solar System. They are formed by a solid nucleus consisting of intimately mixed ices and dust, while asteroid composition goes from heavy elements in the inner belt to volatile ones in the outer zone. Asteroids and comets are differentiated by their observational properties and orbital characteristics, rather than by their chemical composition. Comets are characterized by their *coma* of sublimated ices and dust, which gives them their typical appearance in the sky. Asteroids, on the other hand, appear as points of light in the sky. However, comets show their characteristic tails when they reach the inner Solar System, and they warm enough to sublimate the trapped ices (this happens at a distance of ∼4 AU from the Sun (Weissman et al., 2002)). Asteroids with semimajor axis greater than 4 AU may be composed of the same volatile materials, dust and organic molecules as comets, but their orbits are not eccentric enough to approach the Sun and sublimate their ices, in such a way that they could show the activity observed in comets. In this sense, Hartmann et al. (1987) proposed a more specific definition of comets and asteroids, and analyzed the possibility that Trojan asteroids and some Hildas could be dormant comets (a comet nucleus with no detectable activity, but if delivered to smaller semimajor axis, it could be reactivated). So, from the point of view of the chemical composition, it is a bit arbitrary—or at least difficult—to distinguish between asteroids from the external zone of the asteroid belt and comets.

The models of the composition of these bodies are based upon the reflectance spectra. The asteroids of the external zone of the asteroid belt, with semimajor axis $a > 3.3$ AU have a low albedo and C-, P-, and D-taxonomic classes. P- and D-type asteroids have a mixture of organic, anhydrous silicates, dust and ice (Bell et al., 1989; Gaffey et

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al., 1989; Vilas et al., 1994). Fitzsimmons et al. (1994) have performed a spectroscopy survey of D-type asteroids to investigate their reflectance and compositional properties. They found that the majority of those asteroids have the reflectance slope or "color" and albedo in the same ranges. But cometary nuclei, though having albedos very similar to those of D-type asteroids, show a wider range of colors. This difference may be due to the dynamical history of comets and the processes that have affected their surfaces, while asteroids, being in more stable orbits, have conserved their primordial surfaces. Thus, they conclude that D-type asteroids can be regarded as the spectral analogues of comets. In this aspect, the fact of distinguishing comets from asteroids of the external zone could be limited to orbital evolution, rather than to chemical composition.

At present, there is substantial evidence that Jupiter Family Comets (JFCs) have evolved from the trans-neptunian region (Fernández, 1980; Duncan et al., 1998; Levison and Duncan, 1997; Bottke et al., 2002). JFCs have very unstable orbits, subject to strong perturbations by Jupiter. Numerical integrations have suggested that Trojan asteroids also contribute to the JFC population, with probably 10% or less (Marzari et al., 1995; Levison et al., 1997).

Hilda asteroids in the 3:2 mean motion resonance with Jupiter are at ∼4 AU from the Sun, the D- and P-taxonomic classes dominate the group (Dahlgren et al., 1997). It is a dynamically stable population (Ferraz-Mello et al., 1998) but, as Trojan asteroids do, one could expect them to evolve dynamically as JFCs after escaping from the resonance, contributing to some extent to the JFC population.

In this paper we study the Hilda asteroid family as another probable source of JFCs. We follow the dynamical evolution of Hilda asteroids after their escape from the resonance in order to determine if they spend some time as JFCs, assessing the population that is presently contaminating the "genuine" population of JFCs coming from the trans-neptunian region.

In Section 1 we characterized the Hilda resonant group, describing its dynamical and compositional properties. In Section 2 we describe the initial conditions and the numerical simulation devised to analyze the fate of Hilda asteroids escaping from the resonance. Section 3 is devoted to asses the contribution of Hilda asteroids to the JFC population. In Section 4 we analyze other dynamical routes of escaped Hildas, and the last two sections are devoted to the discussion and the conclusions.

2. Hilda asteroids

Hilda asteroids form a compact group, orbiting at ∼4 AU from the Sun, where the orbital period is exactly $2/3$ of the orbital period of Jupiter (i.e., the 3:2 mean motion resonance with Jupiter). Since October 1, 2003, 879 Hilda asteroids have been cataloged in the asteroid data base of the Lowell Observatory. The observed sample is probably complete for asteroids with diameters greater than 12 km. The population is characterized by a power law size distribution function in diameter, with an exponent $q = -2.11$, which agrees with an outcome of a collisional cascade (Davis et al., 1989).

The Hilda resonant group is a population characterized by a great dynamical stability. In the central zone of the resonance, an asteroid can last for the age of the Solar System (Nesvorný and Ferraz Mello, 1997; Ferraz-Mello et al., 1998). However, the stable zone is surrounded by a strongly unstable region, where the characteristic permanence times are very short. An asteroid moved out of the boundaries of the resonance will escape shortly after.

The exchange of impulse during mutual collisions is the most efficient mechanism that is presently injecting Hilda asteroid fragments into the unstable regions beyond the boundaries of the resonance.

As objects from the external asteroid belt, Hildas should have ices in their composition. In fact, spectroscopic studies reveal mainly D- and P-taxonomic classes (Dahlgren and Lagerkvist, 1995; Dahlgren et al., 1997). Dahlgren et al. (1997) found that 36, 28, and 2% are D-, P-, and C-type asteroids respectively. There is a relation between the spectral slope (asteroid taxonomy) and the asteroid size among Hildas, implying a size-dependent surface composition (see Figs. 18 and 19 in Dahlgren et al., 1997). There are more D-type particles among the smaller sizes. The mean diameter is 85 km for P-type asteroids and 49 km for D-type asteroids. This correlation was also found in Trojan asteroids (Jewitt and Luu, 1990) and D-type asteroids observed by Fitzsimmons et al. (1994), but it was not observed among small main belt asteroids (Xu et al., 1995). Therefore, this correlation seems to hold only for primitive taxonomic classes (Dahlgren et al., 1997). According to the picture described by Bell et al. (1989), D-, P-, and C-class asteroids are at the beginning of the condensation sequence in the solar nebula. Dahlgren et al. (1997) suggested two possible explanations for the spectral-size dependence. First, they discuss size-dependent heating mechanisms that explain how metamorphic heating acts for different asteroid sizes. But these processes do not seem to explain how heating affects larger diameters, and consequently favor larger P and C asteroids. The other explanation is based on the fact that mutual asteroid collisions affect size distribution. On the one hand, being the D-type asteroids the most primitive ones, they are more fragile, and so more easily disrupted. In this sense one could expect D asteroids to be smaller than P or C ones. On the other hand, collisions on P- or C-type asteroids produce small fragments from their less heated upper layers. These fragments are probably more like the D type, and so also contribute to the population of small D asteroids.

In Fig. 1 we show the distribution in the space (a, e) of the observed Hilda asteroids and of the discovered JFC. The curves corresponding to orbits that can intersect Jupiter's Hill sphere and the ones corresponding to a Tisserand constant $T = 2$ are also shown (see Section 4).

It is noticeable that the more eccentric Hilda asteroids are inside the JFC zone; so, the only distinction between them

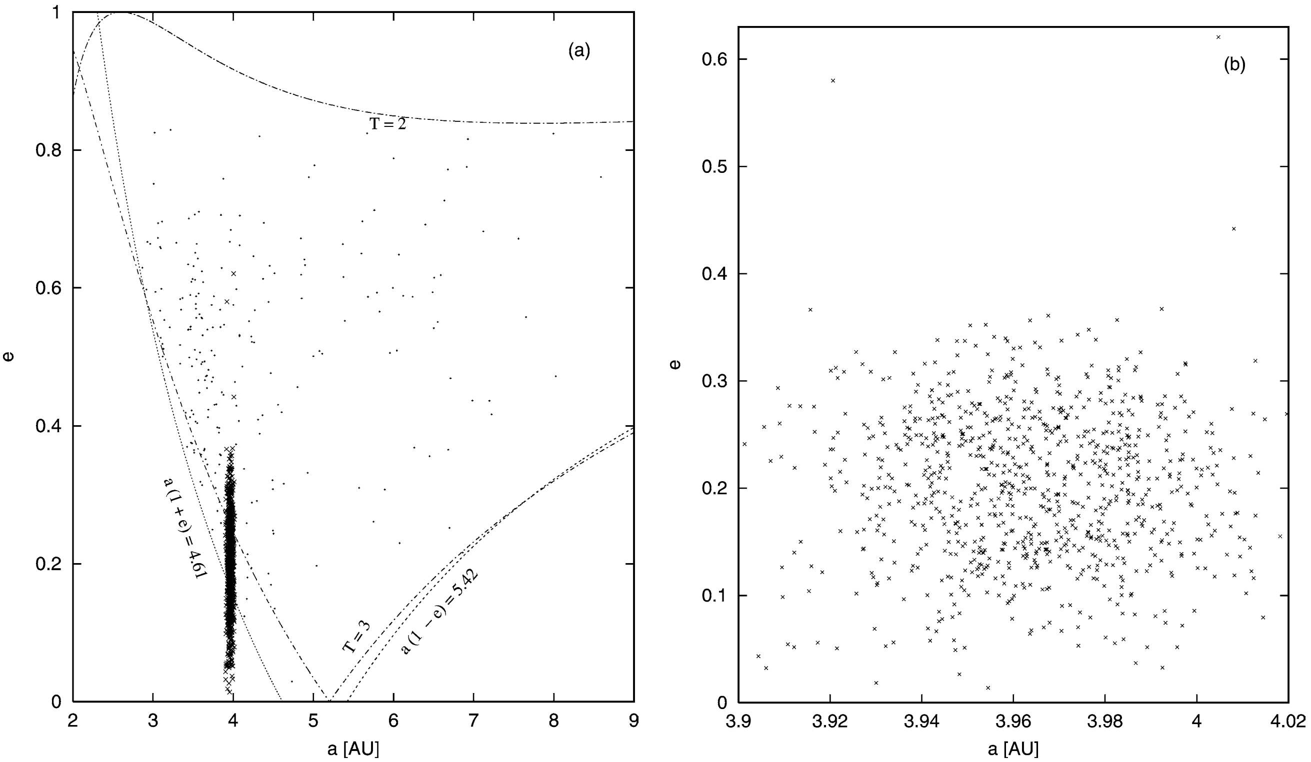


Fig. 1. (a) Observed JFCs (points) and Hilda asteroids (crosses) on the semimajor axis-eccentricity plane. The curves of Tisserand constant $T = 2$ and $T = 3$ are also shown. The limits of the JFC zone are the curves of perihelion distances equal to 5.42 AU and aphelion distances equal to 4.61 AU. (b) Enlarged zone of Hilda asteroids in the semimajor axis-eccentricity plane.

is the fact that the asteroids are in the 3:2 mean motion resonance whereas comets are outside it.

3. Numerical simulation and general outcomes

In order to investigate the dynamical evolution of Hilda asteroids after their escape from the resonance, we have performed a numerical integration of 500 fictitious Hilda asteroids under the gravitational influence of the Sun and the planets from Mercury to Neptune, with our hybrid integrator EVORB (Fernández et al., 2002). The initial conditions of the objects in semimajor axis, eccentricity, and inclination were generated at random, but following the distributions of the orbital parameters of the real Hilda asteroids taken from the asteroid database of the Lowell Observatory. The sample was integrated for 1×10^9 years. When a particle collides with the Sun or a planet, it is taken out of the integration. It is also eliminated when it reaches a hyperbolic orbit. The spacing in our output file is 1000 years.

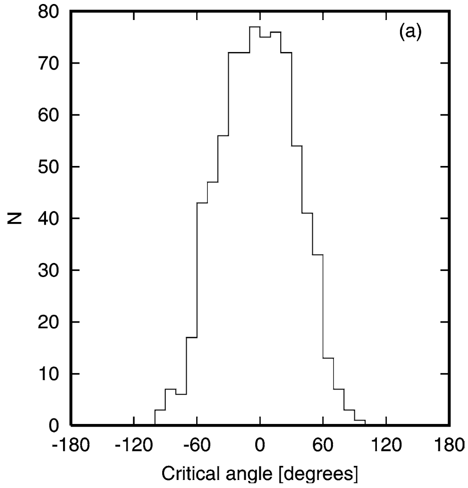
We are interested here in the dynamical evolution of asteroids after their escape from the resonance. For this reason, the longitude of the perihelion, ascending node and mean anomaly was generated at random, so our test particles are representative of fragments recently moved from their original stable orbits (Dell'Oro et al., 2001) and are, in general, nonresonant asteroids.

Being collisions the main mechanism of evaporation of the resonance, we also modeled in Brunini et al. (2003) the collisional evolution of Hilda asteroids, using a numerical code which combines recent calculations of the intrinsic collision probabilities and impact speeds in the Hilda group (Dell'Oro et al., 2001) with our current understanding of the outcomes of high-velocity collisions between asteroid-sized bodies (Davis et al., 1989). Using plausible collision parameters and an energy scaling of impact strength with size, we obtained the rate of escape from the Hilda group for different fragment sizes. With the same model, we estimate the rate of escape from the Trojan swarms. These estimates are shown in Table 1.

Table 1
For each planet, N_e is the number of encounters, N_p is the number of particles that enter within 3 Hill's radii of the given planet, and P is the percentage of N_p with respect to the escaped particles

Planet	N_e	N_p	P (%)
Venus	55	21	5.4
Earth	182	33	8.4
Mars	137	43	11
Jupiter	248,360	392	100
Saturn	42,492	368	94
Uranus	9259	326	83
Neptune	10,115	295	75

As was already mentioned in the introduction, mutual collisions are the way Hilda asteroids escape from the resonance. The impulse imparted at collision may change the angular orbital elements in a considerable way. So fragments originated in a collision (future escaped particles) would



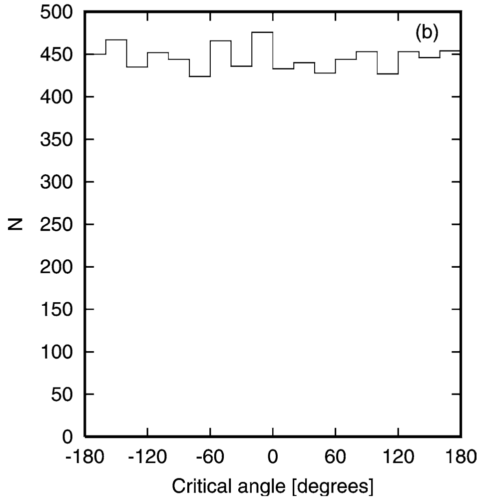


Fig. 2. (a) Critical angle distribution of real Hildas. (b) Critical angle distribution of fragments produced in catastrophic collisions between Hilda asteroids.

have critical angles far from the resonant values. That is why, in our experiment, we generated the initial angular orbital elements randomly. To prove that this is correct, we calculated the critical angles of the real Hildas, and showed them in Fig. 2a. They are, of course, resonant objects whose critical angle is near zero.

In a catastrophic collision the velocity distribution of the fragments is given by the equation:

$$f(>V) = (V/V_0)^{-9/4}, \qquad (1)$$

where $f(>V)$ is the fraction of objects moving faster than V, and V_0 is a lower cutoff of the fragments velocities. We have included in our code of collisional evolution the computation of the variation of the critical angle for the escaping fragments. The initial orbital elements of each of them were extracted at random from the orbital elements of the real Hildas. In this way, we have obtained the position and velocity of 8000 fragments that escaped from the resonance due to catastrophic collisions. The distribution of the resulting critical angles is shown in Fig. 2b, where it can be seen that it is almost uniform. This result justifies the way we have generated the initial conditions.

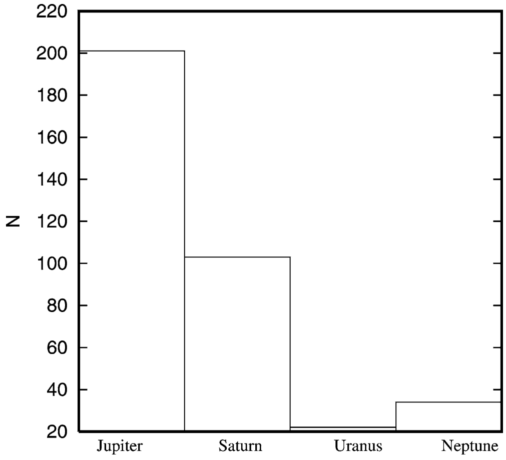


Fig. 3. Number of Hilda asteroids ejected by each planet.

3.1. General results

We analyzed the dynamical evolution the asteroids follow after escaping from the resonance in order to obtain some statistical results. From the 500 initial particles, 391 (78.2%) leave the region of the resonance, and the rest (21.8%) remain in it, being so in stable resonant orbits. From the 391 bodies that escape 40% are in resonant unestable orbits and 60% are in nonresonant orbits. The average escape time from the resonance is: 1.3×10^7 years for the resonant particles in unestable orbits and 1.6×10^4 years for the nonresonant particles. 8% of the objects leaving the resonance end up impacting Jupiter. The consequences of this high impact rate on the jovian satellite system were analyzed in Brunini et al. (2003).

In most cases, the asteroids left the resonance increasing their eccentricity, and then their semimajor axis, in such a way that in their dynamical evolution they pass through the outer Solar System having successive encounters with the giant planets, mainly with Jupiter. This is evident from the results displayed in Table 1, where the total number of encounters with each planet, the number of particles that encounter each planet and the percentage with respect to the total escaped particles are shown.

We considered an encounter with a planet if the closest approach is less than 3 Hill radii. The total number of encounters that all the particles have with all the planets is 310,600. Therefore, Jupiter has 80% of the encounters, Saturn 14%, Uranus and Neptune 5.9%, and the terrestrial planets, all together, 0.1%.

Therefore, the general dynamics of the escaped particles is dominated by Jupiter's scattering. In Fig. 3 we show the number of particles ejected by each planet. We recognized the ejector planet as the one that has the last encounter with the escaped Hilda before it is ejected from the Solar System in hyperbolic orbit.

4. Escaped Hildas behaving like JFC

4.1. *The Jupiter family comet region*

JFCs are under the gravitational control of Jupiter, passing frequently through the Hill's sphere of Jupiter. This condition is satisfied if their aphelion distances (Q) are greater than 4.61 AU and their perihelion distances (q) are less than 5.42 AU. These conditions are almost equivalent to having a Tisserand constant in the range $2 < T < 3$, a condition proposed by Levison (1996) to identify JFCs. There are 245 active JFC discovered so far (taken from the Web site: http://ssd.jpl.nasa.gov/), that fulfill $q < 5.42$ AU and $Q > 4.61$ AU. 95% of them (233 comets) have a semimajor axis a in the zone 2 AU $< a <$ 9 AU. In addition, they have $e < 0.9$.

So, we have defined the *JFC region* as the zone limited by the conditions

- $q < 5.42$ AU and $Q > 4.61$ AU;
- 2 AU $< a <$ 9 AU;
- $0 < e < 0.9$;
- $a > 4.02$ AU and $a < 3.9$ AU.

The last item means that the particle is out of the 3:2 resonance zone (Ferraz-Mello et al., 1998) since, as we have already mentioned, it is occupied by Hilda asteroids, and we are interested in the fates of escaped objects.

4.2. *Method and results*

From the 391 bodies that left the resonance in our simulation, 386 (98.7%) live at least 1000 years in the JFC region. The other five particles that leave the Hildas group have a mean lifetime of less than 1000 years as a JFC. In order to find the number of JFC that are escaped Hildas, we calculated the total time that all 386 particles spend in the JFC zone, estimating also the average residence time, *tm*, in this region of phase space. We found $tm = 1.4 \times 10^6$ years. So, the number of escaped Hildas that are presently in the JFC region may be calculated as:

$$N_{HC} = \frac{dN}{dt} 0.987 tm, \tag{2}$$

where, dN/dt is the rate of escape from the Hildas population. This quantity and the number of escaped Hildas that are in the JFC zone are shown in Table 2. The number of Trojan asteroids that are expected to be in this same situation is also shown. Those numbers correspond to particles larger than a given diameter D_0.

302 of our escaped Hildas spend in average 1.1×10^5 years with perihelion distances q less than 2.5 AU, where comets are active and easily detectable. In the region $q > 2.5$ AU, the escaped Hildas in the JFC zone spend in average 1.33×10^6 years. It is possible to estimate the number of escaped Hildas in each of these zones. This is also shown in Table 2.

Table 2
Rate of escape of asteroids larger than a given diameter D_0 from the Hilda region, and estimated number of Hilda asteroids within the dynamical niche of JFCs

D_0 [km]	$dN(D > D_0)/dt$ [year^{-1}]	$N_{H,q<2.5}$	$N_{H,q>2.5}$	N_{HC}	N_{TC}
0.5	5.7×10^{-4}	48	742	787	21
1.0	1.1×10^{-4}	9	143	152	5
1.5	4.0×10^{-5}	3	52	55	2
2.0	2.0×10^{-5}	2	26	27	1

As a comparison, the last column is the computed number of Trojan asteroids within the same dynamical niche (see text). Those numbers correspond to particles larger than a given diameter D_0.

On the other hand, it is interesting to know how the escaped Hildas populate the JFC zone. We have computed the probability distribution of the residence times of escaped Hilda asteroids in the region of orbital elements also occupied by JFCs. It is shown in Fig. 4. These maps were obtained as follows: we subdivided the JFC zone into cells of 0.1 AU in semimajor axis, 0.01 in eccentricity and 1° in inclination. Then we estimated the time δt_i that each particle visits each cell. The total time a cell is occupied is then:

$$\delta t = \sum_{i=1}^{386} \delta t_i . \tag{3}$$

Finally, the cell residence time was normalized to the total time that all the particles spend in the JFC orbital region. In this picture, the observed JFCs (red circles) are also shown. The particles spend a considerable time just in the limits of the resonance, increasing their eccentricities, and then their semimajor axis, crossing the Jupiter orbit until they leave the JFC region. In this route, they spend more time in the zone corresponding to middle eccentricities. Once the eccentricity grows, they cross the zone quickly. The majority of comets are found in the zone where the residence time of escaped Hildas is long, located near the boundaries of the resonance. The time between the escape from the resonance and the first cross of Jupiter's orbit is 2.7×10^7 years. In this interval of time, the particles populate the zone near the resonance in orbits that are not Jupiter crossing.

We have also analyzed the dependence of the post-capture behavior on the initial conditions. There is no evident correlation between the lifetime and any of the initial orbital elements but, on the other hand, we have found that the lifetime shows a strong correlation with the initial critical angle. This behavior is shown in Fig. 5. It is evident from Fig. 5a that particles that have the longest lifetime as a JFC have initial critical angles near 90° or 270°, so they are nonresonant particles, but they are initially in an intermediate situation between the protected 0° critical angle and the chaotic 180° one. In a zoom view of that plot, shown in Fig. 5b, it could be seen that there is an accumulation of particles near 180° with a relatively short lifetime. This behavior is expectable, since those particles have close encounters with Jupiter that quickly eject them from the JFC zone.

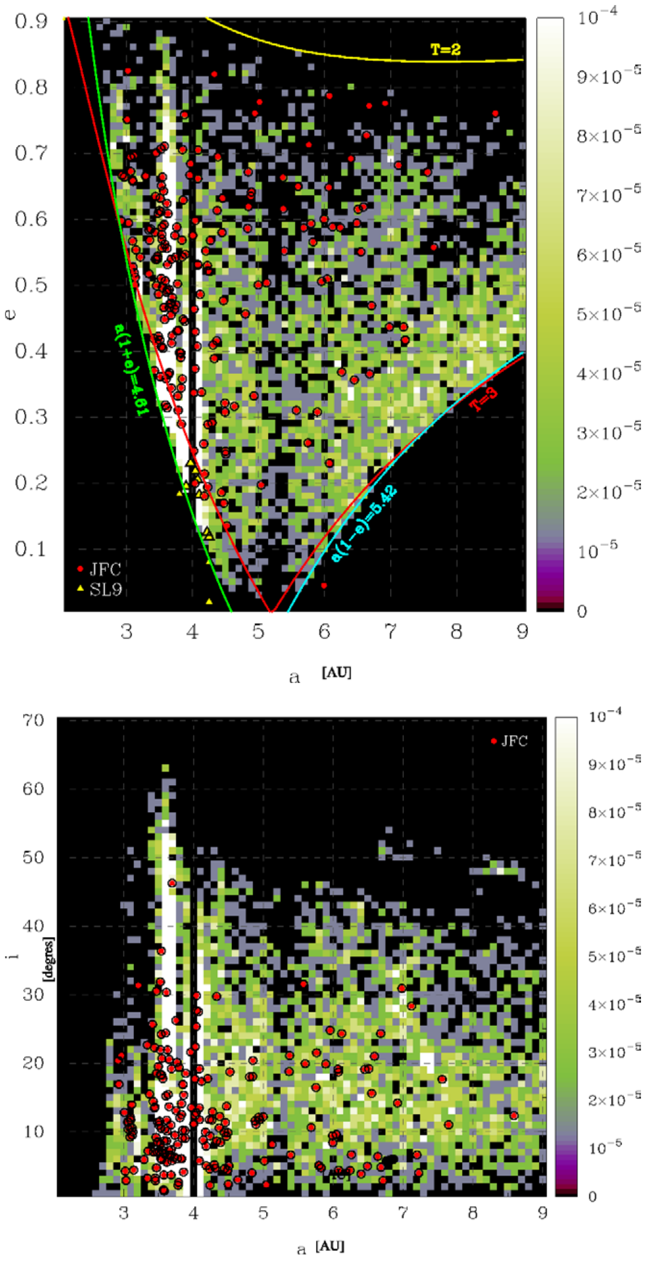


Fig. 4. Probability distribution of the residence times of escaped Hilda asteroids in the region of orbital elements also occupied by JFCs. The red circles are the observed JFCs. The yellow triangles are the pre-capture orbital elements of SL9 fragments (Chodas and Yeomans, 1996)

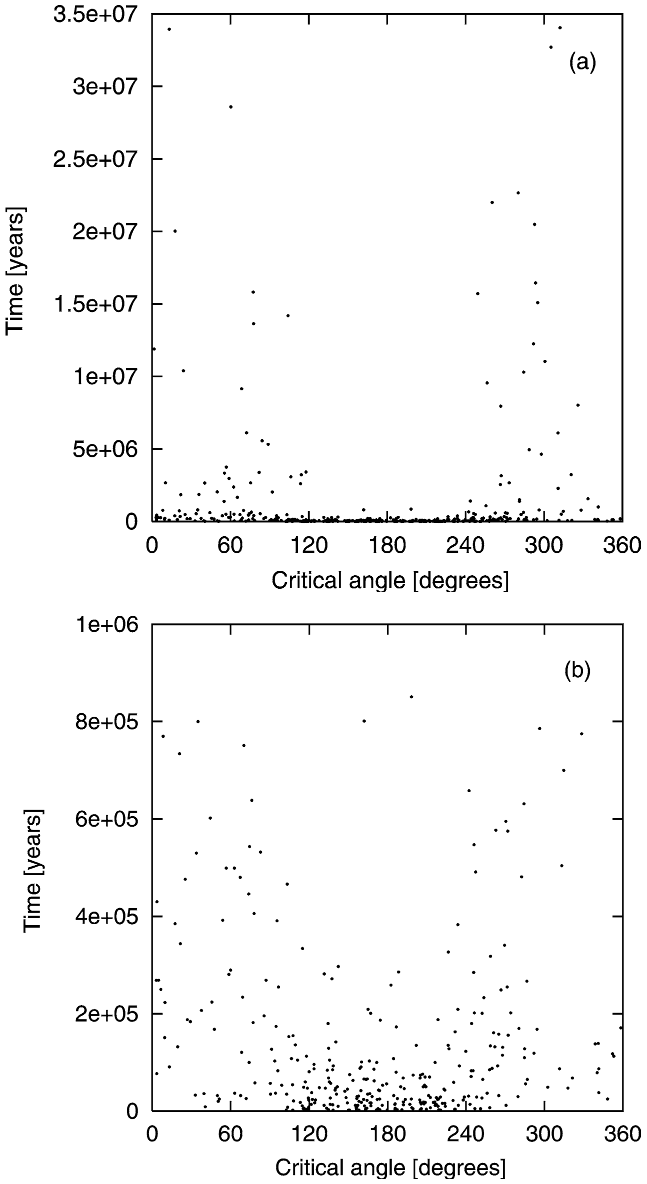


Fig. 5. Lifetime of test particles as JFCs versus initial critical angle. (a) Complete sample, the longest lifetimes as a JFC have initial critical angles near 90° and 270°. (b) Zoom view of (a) plot. There is an accumulation of particles near the unstable region corresponding to 180° with a relatively short lifetime.

4.3. *The number of JFCs and the contribution of Hildas*

Fernández et al. (1999) have estimated the population of active JFC for different values of q. They obtain a population of 800 active JFC with $q < 2.5$ AU and an absolute total magnitude $H_N < 18.5$ (km-size objects). In the inner planetary region ($q < 5.2$ AU) they estimate a lower limit of 1800 kilometer-size comets. But considering some factor of incompleteness, this number should rise to 10,000 comets. Levison and Duncan (1997) suggest that the rate of extinct comets to active comets is 3.5, so the total number of JFC (active and extinct) would be:

$$N_{\mathrm{JFC}} = N_a(1 + 3.5), \tag{4}$$

where N_a is the number of active comets.

Therefore, the number of JFC with $q < 2.5$ AU and brighter than $H_N = 18.5$ would be 3600, with 2800 of them being extinct. JFCs come from the trans-neptunian region, and are injected into the inner Solar System by the perturbations of Jupiter. This action reduces the perihelion distances of those objects until they become observable. Then, JFCs lose their activity more quickly for smaller q. Therefore, the rate of extinct comets to active ones would be a function of q. It is very difficult to obtain such a function from the observational data available today. But at first it seems probable that in the region of perihelia greater than 2.5 AU, the population of extinct comets should be negligible. Moreover, probably the vast majority of the JFCs with $q > 2.5$ AU are dormant comets. So we take as the total number of kilometer-size JFC in the region $q > 2.5$ AU the estimation by Fernández et al. (1999) of ~9000.

From Fig. 4, and also from Table 2, it is evident that escaped Hildas mainly populate the JFC zone with $q > 2.5$ AU, and the contribution to the inner zone is negligible. We can expect ~143 Hilda asteroids with a diameter greater than 1 km to be at present among the population of JFCs with $q > 2.5$ AU. However, the expected number that might be recognizable as active comets should be smaller, because comets are active only for a small fraction of their dynamical lifetime (only 5–20% of their dynamical lifetime). So, it could be the case that almost all the kilometer-size Hildas were dormant comets. Whether this occurs depends on the physical lifetime, the instant of escape from the resonance, and whether the escaped Hildas contain enough volatiles to become active comets.

5. Other dynamical routes of escaped Hildas

Of the 391 objects that left the region of the Hilda asteroids, some of them follow some remarkable dynamical paths:

- *The Shoemaker–Levy 9 (SL9) case*: Comet Shoemaker–Levy 9 (SL9) struck Jupiter in 1994 after its break-up in 1992, 2 hours after its perijove passage (at a distance less than 1.62 jovian radii). There is not a generalized consensus about its physical composition. It could have been an asteroid or a comet. Dust tails from the fragments were observed, but there was also evidence of outgassing. Leaving this point aside, we focused our attention on the dynamical aspects of the problem. Benner and McKinnon (1995) calculated the pre-capture orbital elements of SL9. They found two possible pre-capture orbits because of the chaoticity of the encounter with Jupiter. The orbital elements of these two possible orbits, extracted from that paper, are shown in Fig. 6. In order to identify those groups we have named the group of orbital elements in the zone near 4 AU (filled squares) Z1, and the group near 6.5 AU (empty squares) Z2. In the same figure the curves that define the JFC zone and the Hilda asteroids (dots) are also shown. Figure 4 shows the Z1 group of pre-capture orbital elements of SL9. It could be seen that this set of pre-capture elements overlaps the space of orbital elements occupied by escaped Hildas. The other set, Z2, is outside the JFC region. So, at first, by virtue of the Z1 overlapping, we can say that an escaped Hilda asteroid could have been the parent body of the fragments that struck Jupiter a decade ago.

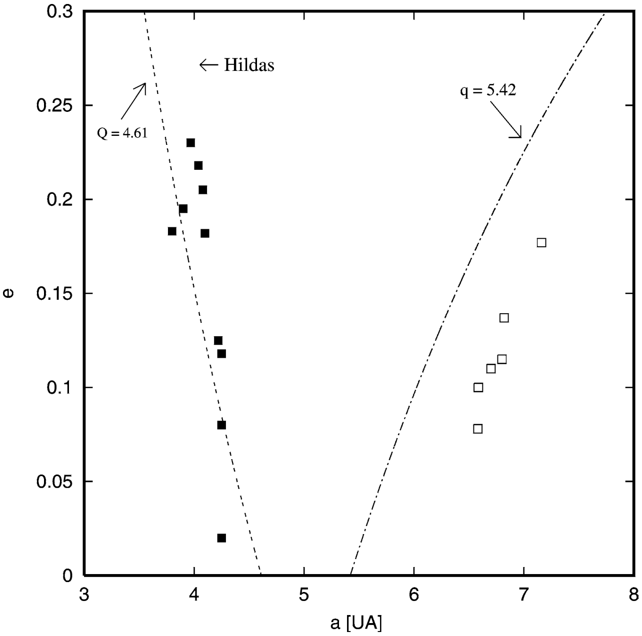


Fig. 6. Pre-capture orbital elements of Shoemaker–Levy 9. The filled squares correspond to the Z1 group of orbital elements in the zone near 4 AU, and the empty squares to the Z2 group near 6.5 AU. The curves representing aphelion distances $Q = 4.61$ and perihelion distances $q = 5.42$ define the JFC zone. The Hilda asteroids (dots) are also shown.

  In our simulation 8% of the escaped Hildas impact Jupiter. So, the rate of collision on Jupiter of Hilda asteroids with a diameter greater than 1 km is 8.8×10^{-6} year^{-1}, i.e., one impact on Jupiter every 110,000 years. For objects larger than 0.5 km we would have one impact every 22,000 years. However, if an object passed inside the Roche radius of Jupiter, i.e., at a distance less than 2.5 jovian radii from the planet, as the SL9 did, the tidal force of the planet could fragment it. Then, by tidal dissipation, those objects could reduce their planetocentric semimajor axis and hit Jupiter. From our simulation, there are 55 escaped Hildas that have at some time pericentric distances less than 2.5 Jupiter radii, being 14% of the escaped particles. So, actually, Hilda asteroids with diameter greater than 1 km would impact Jupiter every 65,000 years, and those greater than 0.5 km every 12,500 years.
- There is one escaped Hilda that behaves as a transneptunian object. It experiences successive encounters with Jupiter, Saturn, and Uranus until it enters under the gravitational control of Neptune, living as a scattered disk object for 3.6×10^8 years.
- A frequent state of escaped particles is the passage through Kozai resonances.
- Hilda asteroids fulfill the conditions required to be a possible source of water on Earth. They can survive in the resonance for the age of the Solar System, so they are a continuous source of fragments that can be delivered to the inner planetary zone after the time of planet formation. The accretion of the terrestrial planets was essen-

tially completed in 10^8 years (Wetherill, 1985), leaving it free of megaimpacts that could volatilize the icy material previously accreted. On the other hand, the central parameter that allows us to rebuild the origin of water in the Solar System is the water Deuterium/Hydrogen (D/H) isotopic ratio. It has been suggested that comets could have been an important source of terrestrial water. However, D/H ratio has been measured in three comets, and an average value of 3.16×10^{-4} has been found (Delsemme, 1999), while for the oceans we have $D/H = 1.56 \times 10^{-4}$, half the value observed in comets. Delsemme (1999) has argued that in the Jupiter zone, the high temperatures have depleted the water of deuterium up to the value observed on the Earth.

But, as Table 1 shows, the escaped Hildas have few encounters with the terrestrial planets, making evident the low injection of particles into the inner Solar System (see $N_{H,q<2.5}$ in Table 2). So, the contribution of Hilda asteroids to the water on Earth and also to the NEO population is negligible, as conjectured by Fernández (2001).

- A passage through a mean motion resonance with Jupiter is a common behavior of escaped Hildas. In particular, there are two particles in the 1:1 resonance with Jupiter for 150,000 years and 100,000 years respectively. However, they are not exactly in the Lagrangian points L4 or L5.

6. Discussion

There are two main ways to approach the question of whether an object is an asteroid or a comet. One is to consider its physical and compositional characteristics, the other; its dynamical behavior. As we have already said, the spectra of comets and D-type asteroids are very similar. The fact that we do not have meteorites from the external zone of the asteroid belt is an obstacle to verify the icy composition. As asteroids have stable orbits and comets unstable ones, the question from the dynamical point of view favors the distinction between them, but this is an incomplete view of the problem. As we have proved, Hilda asteroids behave like JFCs once they escape from the resonance. So, dynamically, there is no distinction between them. The spectral similarity also puts them in equal conditions but, as we have already said, we do not know how many of volatile elements the Hildas have, and if they are able to develop activity.

Another possible link between JFCs and Hilda asteroids are some comets that lie just in the limits of the resonance. These are the cases of P/Gehrels 3, P/Oterma, P/Helin–Roman–Crockett and P/Smirnova–Chernykh. They have been or will be temporary satellites of Jupiter (Tancredi et al., 1990), and this group was called quasi-Hilda by Kresák (1979). As is seen in Fig. 3, the lifetime is long near the borders of the resonance, so it is probable that objects observed in that zone are escapees from the resonance. If they were, the activity observed on them reinforces the idea of the icy composition of Hildas.

On the other hand, the 3:2 resonance with Jupiter is a very stable zone, and so, the Hilda asteroids have stayed there for a long time, and could have slowly lost their superficial ices by the distant action of the Sun. But it is a collisional active population, so, the fragments produced by collisions could expose their trapped ices and then escape like potential (and perhaps ephemeral) comets. If we suppose that Hilda asteroids are really dormant comets, this population could be a source for JFCs. They could be active or dormant, depending on their real composition and the time they have been exposed to the solar radiation until they reach the observable comet region.

7. Conclusions

Our study reveals that ∼143 Hilda asteroids could be at any time within the JFC population with $q > 2.5$ AU. The mean lifetime in that region is of 1.33×10^6 years. Almost all the escaped Hildas pass through the dynamical region occupied by JFCs, and the mean dynamical lifetime there is 1.4×10^6 years. The most abundant taxonomic class in the Hilda group is the D-class, with more D asteroids with small diameter. Then, as escaped Hildas are fragments resulting from a catastrophic collision, it is more probable that the escaped objects are D types. This is the most primitive class and the most similar to comets. One of the two sets of pre-capture orbital elements of SL9 obtained by Benner and McKinnon (1995) overlaps the orbital elements of the Hildas in the JFC zone, supporting the idea that it could be a Hilda asteroid. The contribution of Hildas to the NEO population is negligible.

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