A&A 590, A111 (2016)
DOI: 10.1051/0004-6361/201628184

Astronomy & Astrophysics

Comet candidates among quasi-Hilda objects

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Received 25 January 2016 / Accepted 9 April 2016

ABSTRACT

Aims. We present the results of a search for quasi-Hilda comets. We wanted to find objects that have recently arrived from the Centaur zone that could became active near the perihelion of their orbits.

Methods. Two hundred and seventy-seven objects from the ASTORB database were selected following a dynamical criteria to constrain the unstable quasi-Hilda region. These objects were integrated backward 50 000 yr in order to identify those that have recently arrived from the outer regions of the solar system.

Results. The backward integration showed that 11 objects could be Centaurs or transneptunian objects that ended their dynamical evolution as quasi-Hilda comets. The dynamical evolution of these objects from a statistical point of view was studied by computing the time-averaged distribution of a number of clones as a function of the aphelion and perihelion distances. All the candidates show a dynamical behavior that is expected for comets injected in the inner solar system from the Centaur or transneptunian regions and reaching the quasi-Hilda region.

Key words. minor planets, asteroids: general – comets: general

1. Introduction

Comets are objects that have a nucleus of mixed ice and dust and are characterized by their activity when they reach the inner solar system. Among them, the Jupiter-family comets (JFCs) are a group of the cometary population with unstable orbits that are strongly affected by the gravitational perturbation of Jupiter. These objects have evolved from the transneptunian region and have reached the zone inside the Jupiter orbit after suffering the perturbations of the external planets during the period they behaved as Centaurs (Fernández 1980; Duncan et al. 1995; Levison & Duncan 1997).

One of the outermost dynamically stable zones of the asteroid belt is the Hilda region, where a group of asteroids is trapped in the 3:2 mean motion resonance with Jupiter (Schubart 1968, 1982, 1991; Nesvorný & Ferraz-Mello 1997; Ferraz-Mello et al. 1998). These objects have semimajor axes in the range $3.7 \leq a \leq 4.2$ au, eccentricities $e \leq 0.3$, and inclinations $i \leq 20°$; the critical argument for the resonance librates around 0° (Zellner et al. 1985). During the last century, several JFCs have stayed in the Hilda region, but in an unstable 3:2 mean motion resonance with Jupiter. They have moved from outside of Jupiter's orbit to inside the orbit, and some of them have undergone a temporary satellite capture by this planet (e.g., Carusi & Valsecchi 1979). These objects were called quasi-Hilda comets (QHCs) by Kresak (1979) and currently there are several comets in this region, including the pre-captured orbit of D/Shoemaker-Levy 9 (Chodas & Yeomans 1996).

The quasi-Hilda region is not only occupied by the QHCs, but it is also visited by Hilda objects escaping from the stable mean motion resonance. Di Sisto et al. (2005) performed numerical simulations to study the dynamical evolution of Hilda asteroids and found that 99% of the objects escaping from the resonance behave like JFCs, at least during the first 1000 yr. From the physical point of view, it is not easy to differentiate between escaped Hildas and QHCs because both populations are mainly D- and P-types (Fitzsimmons et al. 1994; Dahlgren & Lagerkvist 1995; Dahlgren et al. 1997, 1999; Jewitt 2002; Gil-Hutton & Brunini 2008); to distinguish comets from asteroids in the external zone of the main belt it is necessary to study the orbital evolution of these objects.

After the suggestion of Di Sisto et al. that escaped Hildas and asteroids in the quasi-Hilda region could show a dynamical behavior similar to that of JFCs, Toth (2006) gave an update of the QHCs in this zone, found new members of this cometary group, and identified 23 objects that could be dormant or extinct comet nuclei. Recently, Cheng & Ip (2013) have detected coma activity in the quasi-Hilda object 2000 YN$_{30}$, presently known as 212P/NEAT, and have shown that 47 000 yr ago it could have been captured into a short-period orbit from a Centaur-like orbit as a result of a close encounter with Jupiter.

We searched for new QHCs candidates by looking for objects that have recently arrived in the quasi-Hilda region from the Centaur zone. In Sect. 2 we explain how the objects were selected and in Sect. 3 we present the results. Finally, in Sect. 4 we summarize our conclusions.

2. Selection criteria

We extracted from the ASTORB database[1] the orbital elements for all the asteroids with semimajor axis in the range $3.7 \leq a \leq 4.2$ au and an orbital arc spanned by the observations used in the orbit computation greater than 180 days. This first sample includes 2439 objects that fulfill the selection criteria.

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[1] See `ftp://ftp.lowell.edu/pub/elgb/astorb.html`

Table 1. Quasi-Hilda objects coming from the outer solar system.

Object		a	e	i deg.	H	T yr
(18916)	2000 OG_{44}	3.847	0.586	7.42	14.5	–10 200
(371837)	2007 VM_{318}	3.975	0.199	17.45	14.2	–8700
	2001 QG_{288}	4.074	0.426	3.99	16.2	–2200
	2002 UP_{36}	3.946	0.442	1.35	16.5	–13 000
	2003 UR_{267}	3.795	0.528	6.14	16.9	–12 400
	2006 XL_{5}	3.727	0.514	4.52	16.8	–21 000
	2007 UC_{9}	3.833	0.314	19.81	15.2	–16 000
	2008 GO_{98}	3.978	0.284	15.46	15.1	–1700
	2009 KF_{37}	4.071	0.321	11.49	15.9	1100
	2009 SR_{143}	3.872	0.524	5.90	16.4	–1000
	2013 QR_{90}	3.720	0.220	7.04	16.3	–29 500

Notes. The columns list the asteroid number, semimajor axis, eccentricity, inclination, absolute magnitude, and the time when the object reached $a > 5.2$ au.

Then, following Toth (2006) we define the quasi-Hilda region in Lagrangian elements where the orbits are unstable. The horizontal and vertical components of the eccentricity in Lagrangian elements are

$$k = e\cos(\varpi - \varpi_J), \qquad h = e\sin(\varpi - \varpi_J), \tag{1}$$

where e and ϖ are the eccentricity and the longitude of perihelion of the object, respectively, and ϖ_J is the longitude of the perihelion of Jupiter. The objects in the unstable quasi-Hilda zone are those that have elements outside a circle with center $(k, h) \simeq (0.075, 0)$ and radius ~0.24 (Toth 2006). This final sample contains 277 objects.

Since we are interested in objects that have recently arrived in the quasi-Hilda region, we integrate these 277 objects backward in time for 50 000 yr looking for changes in their semimajor axes that put them into the Centaur zone ($a > 5.2$ au). We used a Bulirsch-Stoer integrator with a step size of 1 day, and included all the planets from Mercury to Neptune. We found 11 objects that had a dynamical evolution showing they could recently have come from the outer solar system. They are listed in Table 1.

As an example, in Fig. 1 we show the evolution of the semimajor axis, and the perihelion and aphelion distances of (18916) 2000 OG_{44} during the 50 000 yr backward integration. This object jumps to a Jupiter's external orbit at −10 200 yr changing its perihelion distance with the semimajor axis and semimajor axis with the aphelion distance. Later, it is captured in several mean-motion resonances and reaches the transneptunian belt at ≈−27 000 yr. The other objects have a similar behavior.

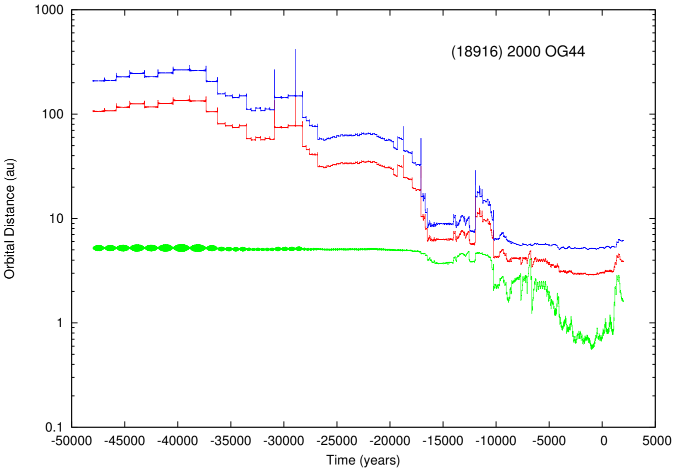

Fig. 1. Dynamical evolution of the semimajor axis (red line), perihelion (green), and aphelion (blue) distances for the object (18916) 2000 OG_{44} during the numerical integration.

3. Results

The backward integration showed that these objects could be Centaurs or transneptunian objects that ended their dynamical evolution as QHCs, but owing to the uncertainties in their initial orbital elements the integration scheme could be affected by numerical effects that produce an incorrect final result. Then, it is important to study the dynamical evolution of these objects from a statistical point of view by integrating clones of each candidate and following the same procedure used to identify them and computing the time spent by each particle in different combinations of orbital elements to obtain statistical results of the dynamical behavior of the original object. One possibility for estimating the dynamical evolution of these QHCs is to obtain the time-averaged distribution of the clones as a function of the aphelion (Q) and perihelion (q) distances (e.g., Tiscareno & Malhotra 2003) dividing the coordinate plane into grids of 0.5 au × 0.5 au. Figures 2 and 3 show in a gray scale the time spent by 100 clones of each candidate per 0.25 au^2 in the (Q, q) plane during a backward integration of 50 000 yr, which could be interpreted as the probability of finding a clone in a certain point of the grid in that period.

In all the cases shown in Figs. 2 and 3 it is possible to observe a strong influence of Jupiter and Saturn on the dynamical evolution of these objects indicated by horizontal strips with q almost fixed at ~5 au and, to a lesser extent, ~10 au. These two patterns are produced by the gravitational scattering of the particles by these planets to larger aphelion distances. This behavior is what would be expected of comets injected in the inner solar system from the Centaur or transneptunian regions and is similar to that found by Tiscareno & Malhotra (2003) for the Centaur population, indicating that the candidates found could have originated in the outer solar system and reached the quasi-Hilda region by the gravitational scattering of the giant planets.

On the other hand, the probability distributions shown in Figs. 2 and 3 indicate that almost all the candidates could visit the region where $q < 1$ au. If these objects were in fact comets they could be affected by strong activity due to the outgassing

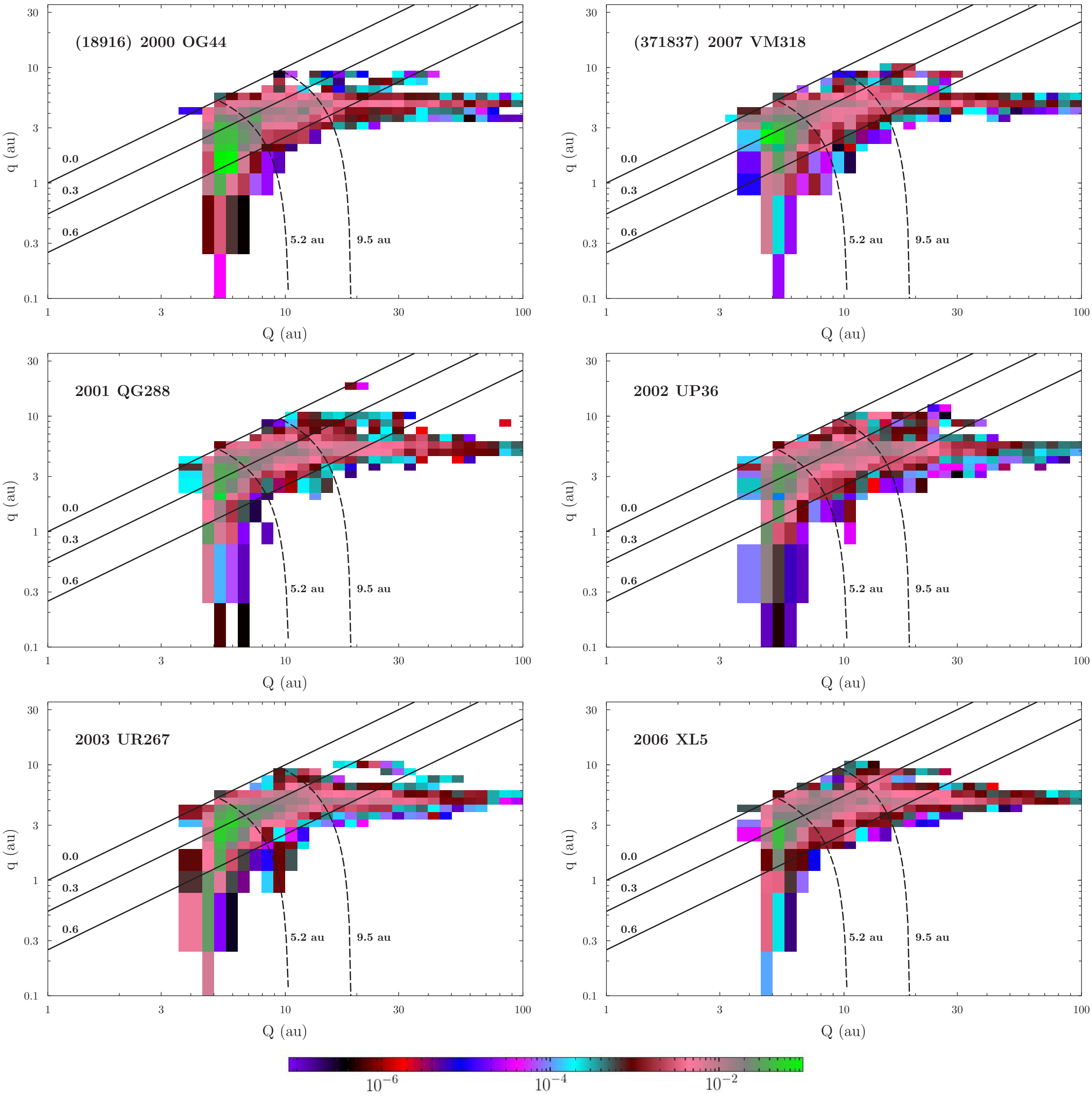

Fig. 2. Probability distribution per square au in (Q, q) space for the clones of (18916)2000 OG$_{44}$, (371837)2007 VM$_{318}$, 2001 QG$_{288}$, 2002 UP$_{36}$, 2003 UR$_{267}$, and 2006 XL$_5$. Continuous black lines indicate eccentricities of 0.0, 0.3, and 0.6, and dashed lines indicate semimajor axes of 5.2 and 9.5 au.

produced by their perihelion passage and they could become dormant or inactive comets. Fernández (1984) found that the average physical lifetime for short-period comets with $q \sim 1$ au is ≈500–1000 revolutions or ≈4–8 × 10^3 yr for objects in an orbit with a semimajor axis of ~4 au. Since this period is not very long and it is also an order of magnitude shorter that the total integration time used, it is important to test if any one of the comet candidates remained in an orbit with $q < 1$ au for at least $\approx 10^3$ yr since this could indicate that it has a high probability of becoming inactive. The average time that the clones of the comet candidates stay in orbits with $q < 1$ au is 429 ± 21 yr for (18916)2000 OG$_{44}$, 162 ± 13 yr for (371837)2007 VM$_{318}$, 189±14 yr for 2001 QG$_{288}$, 349±19 yr for 2002 UP$_{36}$, 733±27 yr for 2003 UR$_{267}$, 93 ± 10 yr for 2006 XL$_5$, 174 ± 13 yr for 2007 UC$_9$, 387 ± 20 yr for 2008 GO$_{98}$, 104 ± 10 yr for 2009 KF$_{37}$, 494 ± 22 yr for 2009 SR$_{143}$, and <1 ± 0.05 yr for 2013 QR$_{90}$. Thus, the best candidates that will show cometary activity in the near future are (371837)2007 VM$_{318}$, 2013 QR$_{90}$, 2006 XL$_5$, 2009 KF$_{37}$, 2007 UC$_9$, and 2001 QG$_{288}$.

The best way to test whether these objects are comets is to observe them near the perihelion of their orbits and to search for cometary activity. They will be difficult to observe because these objects are very small: assuming a 4% albedo and the absolute magnitudes listed in Table 1, their diameters are between 9.6 and 2.8 km. Three of our best candidates (2007 VM$_{318}$, 2013 QR$_{90}$, 2006 XL$_5$) are now near the aphelion of their orbits: 2009 KF$_{37}$ had its perihelion passage in July 2015, and the other two, 2007 UC$_9$ and 2001 QG$_{288}$, will be at perihelion in September 2017 and February 2018, respectively. The other five objects in our list will be at perihelion during 2016 (2000 OG$_{44}$, 2008 GO$_{98}$, and 2009 SR$_{143}$) and 2018 (2002 UP$_{36}$ and 2003 UR$_{267}$), but the simulations show a high probability

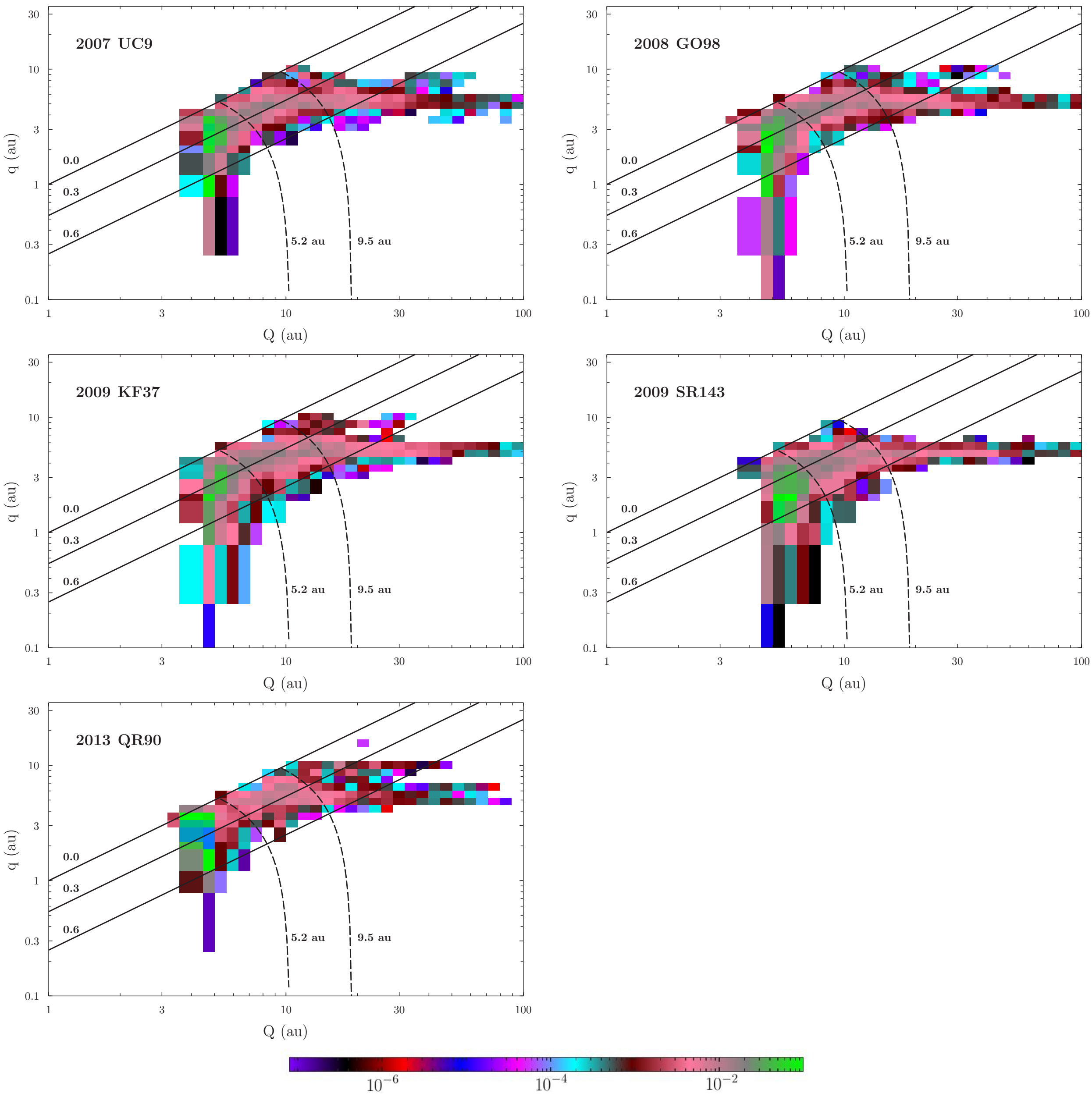

Fig. 3. Probability distribution per square au in (Q, q) space for the clones of 2007 UC$_9$, 2008 GO$_{98}$, 2009 KF$_{37}$, 2009 SR$_{143}$, and 2013 QR$_{90}$. Continuous black lines indicate eccentricities of 0.0, 0.3, and 0.6, and dashed lines indicate semimajor axes of 5.2 and 9.5 au.

that they spent some time in orbits with $q < 1$ and therefore they have already exhausted their volatile material.

4. Conclusions

The dynamical evolution of 277 objects with unstable orbits in the quasi-Hilda region were analyzed to search for those that have arrived in the last 50 000 yr and could have their origin in the Centaur region. These objects were originally selected from the ASTORB database considering asteroids with semimajor axes in the range $3.7 \leq a \leq 4.2$ au, orbital arcs spanned by the observations greater than 180 days, and Lagrangian elements indicating that their orbits are unstable (Toth 2006).

The orbits of these objects were integrated backward in time to look for changes that put them into the Centaur zone; there are 11 candidates that had a dynamical evolution showing they could have recently come from the outer solar system.

The analysis indicates that almost all the candidates could visit the inner region of the solar system and five of them could be affected by strong activity, occasionally becoming dormant or inactive comets. The remaining five candidates have a good chance of still being active and will pass the perihelion of their orbits during the following 2–3 yr, offering a good opportunity to detect activity on them.

Acknowledgements. The authors thank the referee, J. A. Fernández, for his useful review, which led to an improvement of the paper. R.G.H. gratefully acknowledges financial support by CONICET through PIP 114-201101-00358.

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