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New members of Datura family

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ABSTRACT

Asteroid families are groups of minor planets which have a common origin in catastrophic disruptions. Young asteroid families are very interesting because they represent the product of their parent body's fragmentation before orbital and physical evolutionary processes could have changed them. A group of minor asteroids associated with the largest body (1270) Datura is of particular interest because it has enough known members and resides in the inner part of the main asteroid belt and is easier to observe than families (with similar physical characteristics on their surfaces) at further distances. Up to now, 7 members of this family are known. Here we discuss three new members of the Datura Family: (338309) 2002 VR_{17}, 2002 RH_{291} and 2014 OE_{206}. To prove that these recently-discovered members belong to the Datura family, we conducted numerical orbit integrations with all gravitational perturbation over the last 800 kyrs. In the results, we have found that (338309) 2002 VR_{17} and 2002 RH_{291} are very close to the mean orbit of this family throughout the calculation. In the case of 2014 OE_{206}, it has a strongly chaotic orbit.

1. Introduction

Observations of the main asteroid belt have brought the discoveries of asteroid families, which are groups originating from collisions between larger asteroids. Up to now, more than 122 asteroid families have been discovered Nesvorny et al. (2015). Most of the large asteroid families are at least 1 Gyrs old (Milani et al., 2016; Carruba et al., 2016). The dynamic history of old asteroid families is complicated by a number of limiting factors such as the incomplete data of the influence of the Yarkovsky effect, chaos effect, subsequent collisions, etc. (Marzari et al., 1999; Bottke et al., 2005; Nesvorny et al., 2006). The YORP effect (Carruba et al., 2016) and the chaotic scattering by large trans-Neptunian objects on the older families (Galiazzo et al., 2016) can contribute to complications of the age estimation. The younger an asteroid family is, the more straightforward it is to analyse because they represent the product of their parent body fragmentation before orbital and physical evolutionary processes have changed them.

2. Datura family

A group of minor planets associated with the largest body (1270) Datura, is of particular interest because it has enough known members and resides in the inner part of the main asteroid belt, which make observations clearer. The Datura family was discovered by Nesvorny et al. (2006), after which, both its dynamical evolution and physical properties were rigorously studied. The Datura family consists of one large 10 km-sized asteroid (parent body) and a few small minor planets; possible fragments of a catastrophic breakup. Up to now only 7 members of the Datura family were known (Nesvorny et al., 2015, 2006; Vokrouhlický et al., 2009), all of them are S-type asteroids (Tholen, 1984).

3. The three new members of the Datura family

Nesvorny et al. (2006) and Vokrouhlický et al. (2009) underline that the Datura family needs more investigation, therefore the possible discovery of new members is important. Here, we report on three new members of the Datura family. We considered the osculating elements of 634,109 orbits of asteroids from the Lowell Observatory catalogue (Bowell et al., 1994), in order to find new members of the Datura family. This datafile was downloaded on Jan. 19, 2015. We extracted the bodies which possess the values of the orbital elements in intervals according to the values of the orbital elements of (1270) Datura and known members of the Datura family (Nesvorny et al., 2006): $2.234 < a < 2.236$, $0.2 < e < 0.21$, $5.9 < i < 6.1$. After that, we obtained the initial elements of the orbits of all the family members. We used the Horizon website[1] to gather the data necessary for intregration with the start date as JD2451000.5 (July 6, 1998). We tested these bodies and

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

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100 of their clones (10 clones on each asteroid) by numerical integration. Firstly, we integrated all the planets from Mercury to Neptune + Pluto, considering only gravitational perturbations, after which we added the asteroids of the greatest mass ((1) Ceres, (4) Vesta and (2) Pallas). We have not taken into account non-gravitational forces because we assume this lifespan to be short enough to be of no major influence for Yarkovsky drift and other non-gravitational effects. However it could be of interest to clearly define, in a future work, if there exists a powerful enough influence as to have any significant effect on young families such as the Datura family.

The equations of the motion of the systems were numerically integrated backwards 800 kyrs into the past, using the N-body integrator Mercury version 6[2] (Chambers, 1999) and the Everhart integration method (Everhart, 1985). In accordance with previous Datura family age estimations (Nesvorny et al., 2006; Vokrouhlický et al., 2009), this integration interval is sufficient for our study. The initial state vectors for planets were obtained from JPL DE405 ephemerides at the same time as the elements of the Datura-group asteroids (Standish et al., 1995).

In our research, we have found three new members of the Datura family in addition to those listed in Nesvorny et al. (2015, 2006); Vokrouhlický et al. (2009). These three new members are ***(338309) 2002 VR$_{17}$***, ***2002 RH$_{291}$*** and ***2014 OE$_{206}$*** (Rosaev and Plavalova, 2015). Table 1. shows the osculating elements for the seven old members and the three new ones (in bold). Assuming the same albedo as was calculated for (1270) Datura, ($A = 0.288$)[3] for all the members of a given family, the radius of an asteroid in dependence of absolute magnitude H, may be estimated according to (Bowell et al., 1989) as:

$$R\,(km) = \frac{1329}{2}\frac{10^{-H/5}}{\sqrt{A}} \tag{1}$$

Using the above equation and the aforementioned value of (1270) Datura's albedo, we have calculated the theoretical radiuses of all ten family members (Table 2). These new members of the Datura family are small: as expected by absolute magnitudes, they are from 330 meters (2014 OE$_{206}$) up to 700 meters (2002 RH$_{291}$ and 2002 VR$_{17}$) in diameter (in assumption of equal albedo), making them comparable with known member 203370 (Table 2). It is self-evident, that the orbits of the two new members 2002 VR$_{17}$ and 2002 RH$_{291}$ are determined, on the basis of longer observation in arcs, much better than the orbit of 2003 UD$_{112}$ which was initially included in the Datura family (Nesvorny et al., 2006), and the precision of the orbit of 2014 OE$_{206}$ is comparable to 2003 UD$_{112}$ (Table 2).

The distribution of Datura family members in the coordinates (a, e) and (i,e)[4] is given in Fig. 1, where the new members are shown as red dots and the original members as blue triangles. All the asteroids of the Datura family, including new members, form a compact group in the orbital element's phase space. In Fig. 2, the evolution of the angular elements for the two new members of the family are given, relative to (1270) Datura's angular elements. It is evident that the values of the angular elements of the new members are close to the largest member of the family in all considered time intervals (the differences are less than 5 degrees; which we consider an optimal limit). All elements are changing quasi-linearly and have zero values in the range of 400–600 kyr. In contrary, a typical interloper (for example (433382) 2013 ST$_{71}$) reaches differences of 40–50 degrees during a time interval of 800 kyrs. For other orbital elements we have similar behaviours throughout the whole interval of integration. Of particular interest is the comparison of the time evolution of the semi-major axis between family members (Fig. 3). The evolutions of the semi-major axis of all the members of the family have similar trends, even if there is a chaotic variation close to epoch −50 and −300 kyrs. We also highlight the presence of a 9:16 mean motion resonance with Mars.

The age of the Datura family is estimated to be 450 ± 50 kyrs old according to Vokrouhlický et al. (2009) and 530 ± 20 kyrs old according to (Nesvorny et al., 2006); that is to say that a question still lingers over the most precise age estimate. This inconsistency could mean that the question of the Datura family's age is still open. That said, the question of age estimation remains open for almost all the asteroid families (Spoto et al., 2015).

As it seems in Fig. 2, the orbital evolution of the new members of the Datura family is not in conflict with the estimated age of Vokrouhlický et al. (2009) being 450 ± 50 kyrs. The argument of the perihelion is somewhat more accurate than the node longitude for the determination of age. In the case of 2014 OE$_{206}$, we have a stronger chaotic orbit than the other Daturas. According to our results, the semi-major axis of 2014 OE$_{206}$ significantly increased about 50 kyrs ago (Fig. 4). This effect presents a small variation of the initial data of this asteroid in the range of $2.2348 < a < 2.2360$ au for the semi-major axis and at least $36.79° < M < 36.81°$ for the range of the mean anomaly. In fact, the orbit of 2014 OE$_{206}$ is a typical example of so-called stable chaotic orbit (Milani et al., 1997). A possible explanation of this is in the resonance character of its orbit or the Yarkovsky effect that we did not consider because it is inversely proportional to the size of the body and asteroid 2014 OE$_{206}$ is much smaller than the other Daturas. However, we are more in favor of the first option: as it was adopted by Nesvorny et al. (2006), the orbit of (89309) 2001 VN$_{36}$ was assumed to be too uncertain because of resonance-related chaoticity (mean motion resonance 9:16 to Mars at a = 2.2359 au). The initial mean anomalies of 2001 VN$_{36}$ and 2014 OE$_{206}$ are very close, so we can suppose a finite range in the mean anomaly of the instability of the orbit caused by resonance. Resonance is also presented in the orbital evolution of the other members of the family but in a weaker form. The variations of the initial values of other orbital elements (eccentricity, inclination, pericenter and node longitude) have a relatively small effect on the orbital evolution of 2014 OE$_{206}$.

Our consideration has shown that there has been no encounter with Mars closer than 0.1 au. However, the change of semi-major axis in the case of 2014 OE$_{206}$ is significant; 50 kyrs ago, this asteroid leapt from one side of 9:16 resonance to another.

An additional argument which favours these new members belonging to the Datura family, is the calculation of the average orbital elements over the last 800 kyrs. Through numerical integration, we made a linear approximation of node longitudes. For (338309) 2002 VR$_{17}$ and 2002 RH$_{291}$, we have very close comparisons for all the orbital elements (standard deviations are 0.00074 in semi-major axis, 0.0017 in eccentricity and 0.07 - 0.09 in inclination in a time interval of 800 kyrs). Proper elements, calculated by Knezevic and Milani (2003) confirm that (338309) 2002 VR$_{17}$ and 2002 RH$_{291}$ belong to the Datura family (Table 3). In particular, we can point out a very close match of our calculations of averaged semi-major axis with proper values.

A trait common in the Datura family is a linear dependence between Ω and ω (Fig. 5). This dependence is unique for the Datura family and remains unfound in other young asteroid families (e.g. 1992YC2, Emilkowalski, etc.; see Nesvorny et al. (2006)), and studying it may be key to successfully reconstructing the dynamic history of the Datura family.

4. Encounters in the Datura family

As noted above, if we accept the hypothesis about the origin of all the members of the Datura family in the same event, the new members of the Datura family's orbital evolution does not conflict with the suggested age of 450 ± 50 kyrs.

Here we give a few arguments in favour of the subsequent breakup. Numerical integration shows, that two new members of the Datura

[2] last modified March 1, 2001
[3] http://ssd.jpl.nasa.gov/horizons.cgi
[4] Throughout the article we have used standard notations for orbital elements a – semi-major axis in au, e – eccentricity, i – inclination, Ω – longitude of ascending node, ω – perihelion argument, π – longitude of perihelion (the angular elements are in degrees).