On new members of asteroid clusters similar to asteroid pairs

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Introduction

Here we report about results of search for new members of young asteroid families. We have found six possible new members of Rampo asteroid family and one possible new member of Hobson asteroid family. We also have discovered two new asteroid clusters, each includes three asteroids.

Search for new candidates

- The search of new candidate asteroids within families has been carried out by means of the computation of the values of the natural metrics ϱ_2 and ϱ_5 (Kholshevnikov et al. 2016). The metric ϱ_2 is the distance between two orbits in the five-dimensional space of Keplerian orbits. The metric ϱ_5 is a distance in three-dimensional factor-space of positional orbital elements. Osculating elements of orbits were used to calculate the metric ϱ_2 and proper elements of orbits were used to calculate the metric ϱ_5. Orbital elements of asteroids have been taken from Asteroids Dynamic Site – AstDyS. Criterias for finding the new asteroids within clusters were value of metrics for all pairs in cluster $\varrho_2 < 0.004$ au$^{1/2}$ and $\varrho_5 < 0.001$ au$^{1/2}$.
- As it is well known, non-gravitational tangential acceleration may be expressed as (Marsden 1973):

$$a_\tau = A_2 \left(\frac{r_0}{r}\right)^d t$$

- Here $r_0 = 1$, $d \approx 2.25$, r is heliocentric distance of asteroid, t is a time. Coefficient A_2 depends on physical parameters of asteroid. After the integration of equation above it is possible to obtain (Vokrouhlicky 1998):

$$\frac{da}{dt} = -\frac{8}{9}\frac{(1-A)\,\Phi}{n} W(K,R)\cos\phi\,.$$

- Here n is the mean motion; Φ is the standard radiation force factor, which is inversely proportional to the bulk density ρ, the diameter of asteroid D, and the square of the orbital distance r. The Bond albedo A expressed through geometric albedo p_v as $A = 1/3\,p_v$. Function $W(K,R)$ is determined by the thermal parameters of the body and a frequency. From (Vokrouhlicky 1998), we have:

$$W(K,R) \approx -\frac{1}{5}\,.$$

- Simple account of the Yarkovsky effect in semimajor axis may be obtained by normalization using (101955) Bennu parameters, because it is known with smallest error (Spoto et al. 2015):

$$\dot{a} = \frac{da}{dt} = \left(\frac{da}{dt}\right)_B \frac{\sqrt{a_B}(1-e_B^2)D_B}{\sqrt{a}(1-e^2)D}\frac{\rho_B\cos\phi}{\rho\cos\phi_B}\frac{1-A}{1-A_B}.$$

- The symbols with a "*B*" refer to asteroid (101955) Bennu. The value of $\dot{a}_B = (19 \pm 0.1)\cdot 10^{-4}$ au/Myr and not critically depends on d (Farnocchia et al. 2013). After the substitution of (101955) Bennu physical parameters (Del Vigna et al. 2018), we obtain for the Yarkovsky semimajor axis drift (in au/Myr):

$$\dot{a} = \frac{da}{dt} = 12.09\cdot 10^{-4}\frac{\cos\phi}{\sqrt{a}(1-e^2)D}\frac{1-A}{\rho}.$$

- For the obliquity we have $-1 \le \cos\phi \le 1$, for the density we can accept $1.0 \le \rho \le 3.3$ g/cm^3. However for more exact estimation, we can take into account spectral type of studied asteroids. Exact determinations of first of all density and obliquity from observations is difficult. On the other word, we can give restrictions on density and obliquity of asteroids in assumption of forming breakup at encounter close to epoch *T*.
- The coefficient $(1-A)$ usually is very close to the unit. By acception for density value $\rho = 1.1$ g/cm^3 and for obliquity $\cos\phi = \pm 1$ we obtain the maximal value of modulus of semimajor axis drift $|\dot{a}|$ for any studied asteroid. This value is slightly overestimated due to the underestimated value of density.
- In assumption of equal albedo *A*, radius *R* of asteroids in dependence of absolute magnitude *H* may be estimated by (Bowell et al. 1989):

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

- The values of absolute magnitudes and albedo was taken in Horizons web site (https://ssd.jpl.nasa.gov/horizons.cgi).

Numerical Simulation

- We perform numerical integrations of the orbits of all pairs of asteroids within clusters backward in time with the code known as Orbit9. It is necessary to take into account the Yarkovsky effect accurately to carry out precise simulations of the dynamical evolution of asteroid pairs. We estimated the Yarkovsky semimajor axis drift for all asteroids in this clusters according to (see Tables 1-4).

Table 1. Keplerian elements of Rampo and six new family members at epoch MJD58400.0

Asteroid	H [mag]	a [au]	e	i [deg]	Ω [deg]	ω [deg]	$\lvert\dot{a}\rvert\cdot 10^4$ [au/Myr]
(10321) Rampo	14.2	2.32902	0.094412	6.059	53.930	278.874	0.79
2009 SR371	18.7	2.32898	0.094711	6.070	56.788	274.624	5.01
2013 RL101	18.4	2.32765	0.094099	6.091	61.665	267.151	4.30
2013 VC30	18.4	2.32800	0.094574	6.081	59.355	270.502	4.32
2015 TA367	18.8	2.32921	0.094422	6.056	53.308	279.728	5.12
2015 TM372	18.5	2.32876	0.093933	6.073	57.712	273.399	4.63
2017 UH21	18.4	2.32849	0.093907	6.090	60.373	269.12	4.40

Table 2. Keplerian elements of Hobson and one new family member at epoch MJD58400.0

Asteroid	H [mag]	a [au]	e	i [deg]	Ω [deg]	ω [deg]	$\lvert\dot{a}\rvert\cdot 10^4$ [au/Myr]
(18777) Hobson	14.9	2.56213	0.184068	4.323	105.45	180.896	0.94
2017 SQ83	18.4	2.56524	0.179669	4.315	105.60	180.833	3.89

Table 3. Keplerian elements of asteroids from first new discovered cluster at epoch MJD58400.0

Asteroid	H [mag]	a [au]	e	i [deg]	Ω [deg]	ω [deg]	$\lvert\dot{a}\rvert\cdot 10^4$ [au/Myr]
(381362) 2008 EP15	18.6	2.2386	0.103787	2.048	147.705	309.138	3.39
(405843) 2006 BT227	17.9	2.2381	0.103974	2.059	146.866	310.418	2.46
2012 XC32	18.9	2.2378	0.104567	2.056	147.448	309.818	4.13

Table 4. Keplerian elements of asteroids from second new discovered cluster at epoch MJD58400.0

Asteroid	H [mag]	a [au]	e	i [deg]	Ω [deg]	ω [deg]	$\lvert\dot{a}\rvert\cdot 10^4$ [au/Myr]
(338073) 2002 PY38	18.6	2.1965	0.175942	0.888	159.451	161.024	3.34
2010 TZ97	18.7	2.1964	0.176467	0.913	157.581	163.680	3.79
2016 SQ14	18.8	2.1972	0.176036	0.911	157.835	163.152	4.05

Results and Discussions

- In our results, six new members of Rampo family (2009 SR371, 2013 RL101, 2013 VC30, 2015 TA367, 2015 TM372, 2017 UH21), not listed in (Pravec and Vokrouhlicky 2009), were detected (see Table 1).
- One new member of Hobson family (2017 SQ83), not listed in (Rosaev and Plavalova 2017), was detected (see Table 2).
- The two new clusters comprising three asteroids ((381362) 2008 EP15, (405843) 2006 BT227, 2012 XC32 and (338073) 2002 PY38, 2012 TZ97, 2016 SQ14) in each, not listed anywhere, was discovered (see Tables 3 and 4).

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