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Near-Earth asteroids among the Piscids meteoroid stream

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ABSTRACT

It is now accepted that some near-Earth asteroids (NEAs) may be dormant or dead comets. One strong indicator of cometary nature is the existence of an associated meteoroid stream with its consequent observed meteor showers. We identify a complex of four NEAs (1997GL3, 2000PG3, 2002GM2, and 2002JC9) which have very similar orbits and a likely common progenitor. We also calculate the theoretical parameters for any meteor shower that may be associated with this complex. Finally we carried out of a search of existing catalogues of meteor showers and found that activity has been observed corresponding to each of the theoretically predicted showers. We conclude that the complex of four NEAs is the result of a cometary break-up.

Key words. meteors, meteoroids

1. Introduction

The hypothesis that some asteroids are in fact either dead or dormant comet nuclei is now generally accepted and most scientific effort is directed to finding methods for distinguishing between such dormant comet nuclei and genuine asteroids which formed in the asteroid belt out of rocky material (Williams 1997). A good way is the determination of the bulk density, but this is rather difficult for isolated bodies since obtaining the masses is almost impossible. Other clues that might verify this include a low albedo for the body and an orbit with high eccentricity or inclination, though gravitational perturbations change orbits.

Another possibility is through finding a meteoroid stream associated with the body. Asteroids may form a short-lived stream as a result of a collision, but in order to form, a well determined, long-lived stream ejection of a large amount of dust over a long period is called for and this is provided through the normal outgassing process in comets as first shown by Whipple (1951) and the method has since been investigated by many other groups (e.g. Ma et al. 2002). Thus finding a meteoroid stream associated with a body is a sound indicator that the body was an active comet.

Another possible source of meteor dust is the near total break-up of a comet nucleus as observed for example in comet Schwassman-Wachmann 3. Such a mechanism may also be responsible for the formation of the Quadrantids (Jenniskens 2004; Williams et al. 2004) leaving the asteroid 2003EH1 as a small associated remnant.

A further possibility for forming a meteor stream could be the total break-up of a C, P or D asteroid with a composition corresponding to a CI chondrite which would break up into material including a considerable amount of powder. In both of these last examples, the formation is a single event taking place at a particular epoch. Such streams cannot be long lasting, as effects such as the Poynting Robertson drag will dissipate them over relatively short periods of time. Under the scenario described above, the Quadrantid stream is only 500 years old. Furthermore, only one stream is formed with orbital elements corresponding to those of the parent body at break-up. Thus the existence of a long lasting stream is a strong indicator of the cometary nature of the parent. The discussion of C, P and D asteroids being the parent also begs the question as to whether these types are not in themselves dormant cometary nuclei.

In a recent paper Babadzhanov & Williams (2007) showed that NEA 2000PG3 is associated with the meteoroid stream which generated the September northern and southern δ-Piscids and the day-time γ-Arietids and α-Piscids. As shown by Fernandez et al. (2001), 2000PG3 has a low albedo, in the range $p = 0.021$–0.015, the effective radius is 3.08–3.49 km, and moves on a comet-like orbit with $e = 0.858$ and $i = 20\overset{\circ}{.}5$, its Tisserand invariant has a value of 2.56. They concluded that 2000PG3 was of cometary origin.

A useful tool for determining orbital similarity is the D_{S-H} criterion of Southworth & Hawkins (1963)

$$\begin{aligned} D^2_{S-H} &= (e_2 - e_1)^2 + (q_2 - q_1)^2 + \left(2\sin\frac{i_2 - i_1}{2}\right)^2 \\ &\quad + \sin i_1 \sin i_2 \left(2\sin\frac{\Omega_2 - \Omega_1}{2}\right)^2 \\ &\quad + \left[\left(\frac{e_1 + e_2}{2}\right) 2\sin\frac{(\Omega_2 + \omega_2) - (\Omega_1 + \omega_1)}{2}\right]^2. \end{aligned} \quad (1)$$

One short-coming in using this for comparing orbits over long time intervals is that the angular elements Ω and ω change over a reasonable time scale so that D_{S-H} can become large simply by these changes. Steel et al. (1991) proposed a simplified D criterion which avoided this, namely

$$D^2 = (q_1 - q_2)^2 + (e_1 - e_2)^2 + \{2\sin[(i_1 - i_2)/2]\}^2. \quad (2)$$

We adopt the value $D \leq 0.3$ as showing similar orbits.

As well as the D criterion, other methods have been developed for comparing orbits. In particular Nesvorny & Vokrouhlicky (2006) use proper elements as a comparison basis

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Table 1. The values of the simplified D criterion.

Asteroid	1997GL3	2000PG3	2002GM2	2002JC9
1997GL3	0.00	0.26	0.09	0.17
2000PG3	0.26	0.00	0.30	0.13
2002GM2	0.09	0.30	0.00	0.18
2002JC9	0.17	0.13	0.18	0.00

Table 2. Orbital elements of the four near-Earth asteroids.

Asteroid	a AU	e	q AU	$i°$	$\Omega°$	$\omega°$	$\pi°$	H	d km	R_a AU	R_d AU
1997GL3	2.278	0.784	0.493	6.7	196.6	260.2	96.8	19.74	0.56	1.00	0.78
2000PG3	2.827	0.858	0.419	20.5	326.8	138.5	105.3	15.74	6.56*	2.09	0.44
2002GM2	2.202	0.807	0.425	3.4	343.5	80.0	63.5	18.51	1.00	0.67	0.88
2002JC9	2.256	0.829	0.386	13.7	77.4	21.1	98.5	19.10	0.76	0.44	3.55

while Valsecchi et al. (1999) suggest a comparison based on the more physical elements of energy and momentum. Some discussion of methods of comparison can be found in Porubcan et al. (2004). They conclude that for comparing meteor streams, D is the most useful criterion, principally because of secular changes in the angular orbital elements. Of course here we are comparing both meteor orbits and asteroid orbits, but have chosen to use the D criterion.

2. Search for similar asteroids to 2000PG3

If the comet became dormant through fragmentation of the original cometary nucleus then it may be reasonable to expect to find other smaller NEAs also associated with the given complex.

We conducted a search of the catalogue `http://newton.dm.unipi.it/neadys/neadys.cat`, date 01.01.2005, for new asteroids which may be associated with 2000PG3 by using the D criterion above and limiting to $60° < \pi < 120°$. Three new NEAs were found 1997GL3, 2002GM2, and 2002JC9. The calculated values of D for the relative pairings are given in Table 1. As can be seen, they range from 0.09 to 0.30 indicating strongly that all are on very similar orbits.

It is interesting to evaluate the probability that two asteroids are on similar orbits, as determined by the D criterion by chance.

If asteroids were uniformly distributed in space, then the maximum value of D^2 between extreme cases would be 5. However inclinations are in reality less than about 30 degrees, so that for such a set, the maximum value is 3 or 1.732 for D. Thus the probability that two objects such as 1997GL3 and 2000PG3, having $D = 0.3$, by chance is 0.3/1.732 or about 17%. For 1997GL3 and 2002GM2, where D is 0.09, the probability that this is by chance is about 5%. The probability that all four are similar by chance is thus about 0.06%.

Their actual orbital elements are given in Table 2 (equinox 2000.0). Also shown in Table 2 is H the absolute magnitude and d the equivalent diameter, calculated using the expression (Bowell & Lumme 1982)

$$\log d = 3.12 - 0.2H - 0.5 \log p. \tag{3}$$

Asteroids of cometary origin have low albedos. The albedo of comets generally lie in the range 0.02–0.12, the mean value is 0.07 (Jewitt 1992). This mean value of albedo was used for estimation of the values of d given in Table 2, except for 2000PG3 where the value of diameter is given from mean radiometric data of Fernandez et al. (2001). R_a and R_d are the heliocentric distances of the ascending and descending nodes respectively.

The nodal distances of all the NEAs, except 1997GL3, differ from 1 AU and therefore simply comparing their orbital elements will not reveal their related meteor showers. The orbit of the parent body at the time of its crossing the Earth's orbit may be determined only by studying its evolution under the gravitational perturbations of the large planets. The method described in Babadzhanov (1996, 2001, 2003), and Babadzhanov & Obrubov (1992), which takes into account orbital dispersion of ejected meteoroids from cometary nuclei and perturbing action of the large planets must be used.

Ejection velocities of meteoroids from their parent bodies and radiation pressure (for small particles) cause an initial dispersion in orbital elements of ejected meteoroids. Because of differences in the semi-major axes (and orbital periods) between the meteoroids and their parent body, some meteoroids lag behind the parent body, while others, overtaking it, spread along the entire orbit and form a complete loop in a comparatively short time (Hughes 1986; Williams 1995).

After the meteoroids are distributed along the orbit of the parent body, due to differences in the planetary perturbing action on stream meteoroids of different semi-major axes and eccentricities, the rates and cycles of variations in the angular orbital elements (the argument of perihelia ω, the longitude of the ascending node Ω, and the inclination to the ecliptic i) will be different for different meteoroids. As a result, the orbits of different meteoroids will be at different evolutionary stages, as distinguished by their arguments of perihelia, i.e. the stream meteoroids occupy all evolutionary tracks of their parent body. This process increases considerably both the size of the meteoroid stream and its thickness (the breadth of a stream is determined by the value of the meteoroids orbital semi-major axis) (Babadzhanov 2001).

The Earth's orbit can only be intersected by those stream meteoroids which have a nodal distance of about 1 AU. Hence their orbital elements must satisfy the express

$$1 \approx r = \frac{a(1-e^2)}{1 \pm e\cos\omega}, \quad \text{or} \quad \cos\omega \approx \pm\left[\frac{a(1-e^2)-1}{e}\right]. \tag{4}$$

This can give four possible values for ω for given values of a and e. In Figs. 1–4 we show the changes in the orbital elements $q, e, i, \Omega, \omega, \pi$ and R_a, R_d – the heliocentric distances of the ascending and descending nodes with time. One figure is for each of the asteroids. From these figures we can see that one cycle of the argument of perihelion has a duration between 3500–8000 years.

In Fig. 5 we show, for each of the asteroids, the variation in R_a and R_d against argument of perihelion for one cycle.

As shown earlier (Babadzhanov & Obrubov 1992; Babadzhanov 1996) the number of meteor showers produced by a meteoroid stream is determined by the Earth-crossing behaviour of the parent-body orbit. For example, during one cycle of variation of the argument of perihelion under the perturbing action of the major planets, a parent body crosses the Earth's orbit four times. The meteoroids of the stream that separated from its parent might produce a night-time shower with Northern and Southern branches at the pre-perihelion intersection with the Earth, and a twin day-time shower also with Northern and Southern branches at the post-perihelion intersection.

In order to find possible meteor showers associated with the four asteroids 1997GL3, 2000PG3, 2002GM2, and 2002JC9

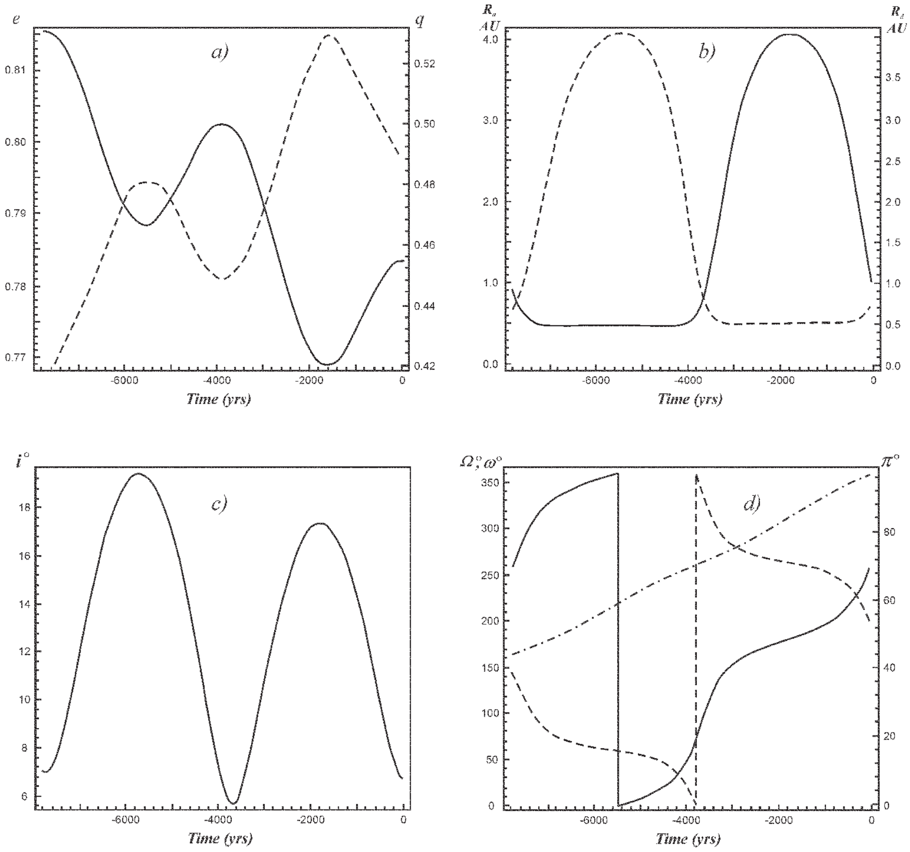

Fig. 1. Variation with time in the orbital elements of NEA 1997GL3. **a)** Variation of perihelion distance q (–) and eccentricity e(– –). **b)** Variation of the two nodal distance, R_a-ascending node, R_d-descending node (– –). **c)** Variation of the inclination i; the other three angular elements ω (–), Ω; (– · –), π (– –) are shown in **d)**.

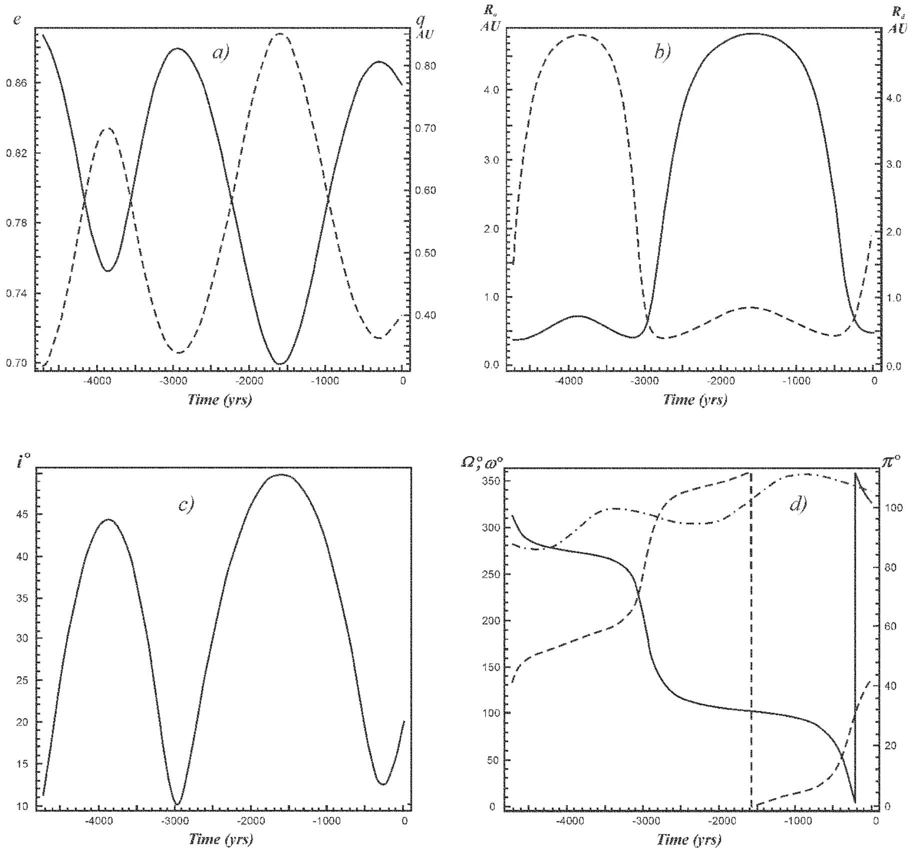

Fig. 2. Variation with time in the orbital elements of NEA 2000PG3. **a)** Variation of perihelion distance q (–) and eccentricity e(– –). **b)** Variation of the two nodal distance, R_a-ascending node, R_d-descending node (– –). **c)** Variation of the inclination i; the other three angular elements ω (–), Ω (– · –), π (– –) are shown in **d)**.

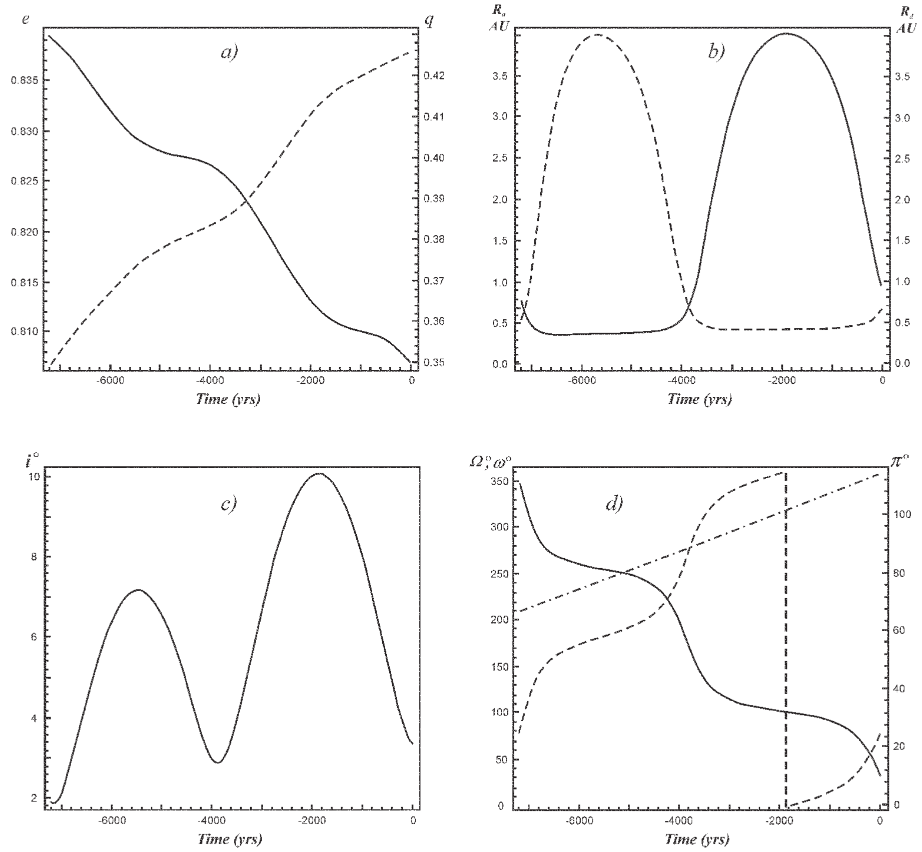

Fig. 3. Variation with time in the orbital elements of NEA 2002GM2. **a)** Variation of perihelion distance q (–) and eccentricity e(– –). **b)** Variation of the two nodal distance, R_a-ascending node, R_d-descending node (– –). **c)** Variation of the inclination i; the other three angular elements ω (–), Ω (– · –), π (– –) are shown in **d**).

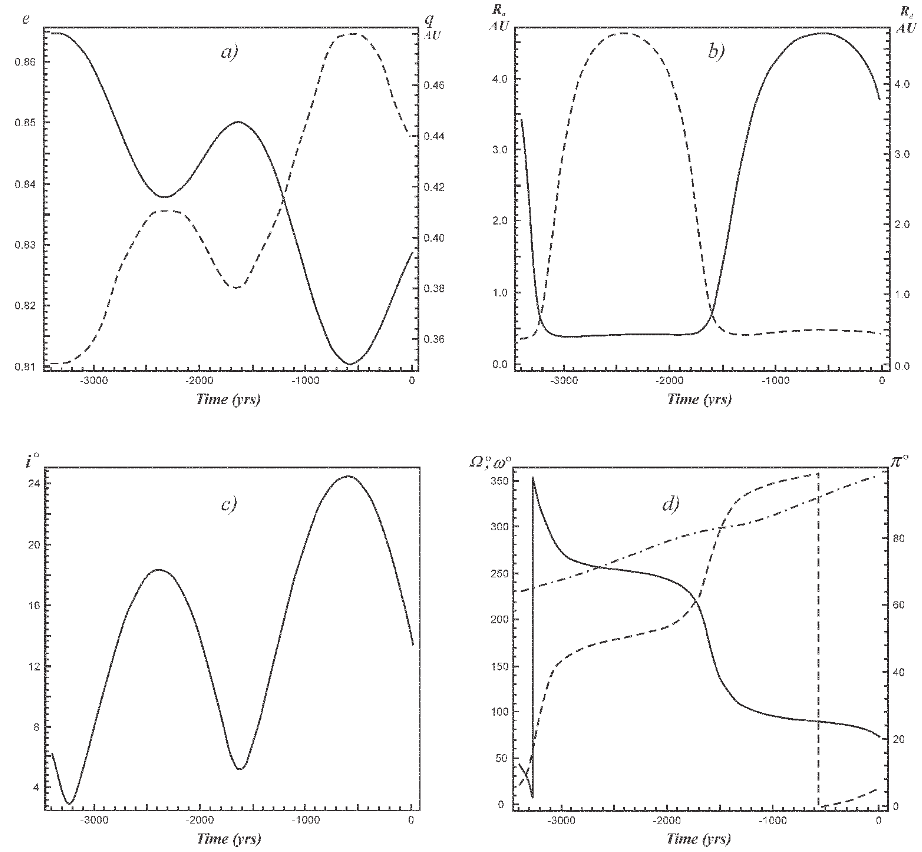

Fig. 4. Variation with time in the orbital elements of NEA 2002JC9. **a)** Variation of perihelion distance q (–) and eccentricity e(– –). **b)** Variation of the two nodal distance, R_a-ascending node, R_d-descending node (– –). **c)** Variation of the inclination i; the other three angular elements ω (–), Ω (– · –), π (– –) are shown in **d**).

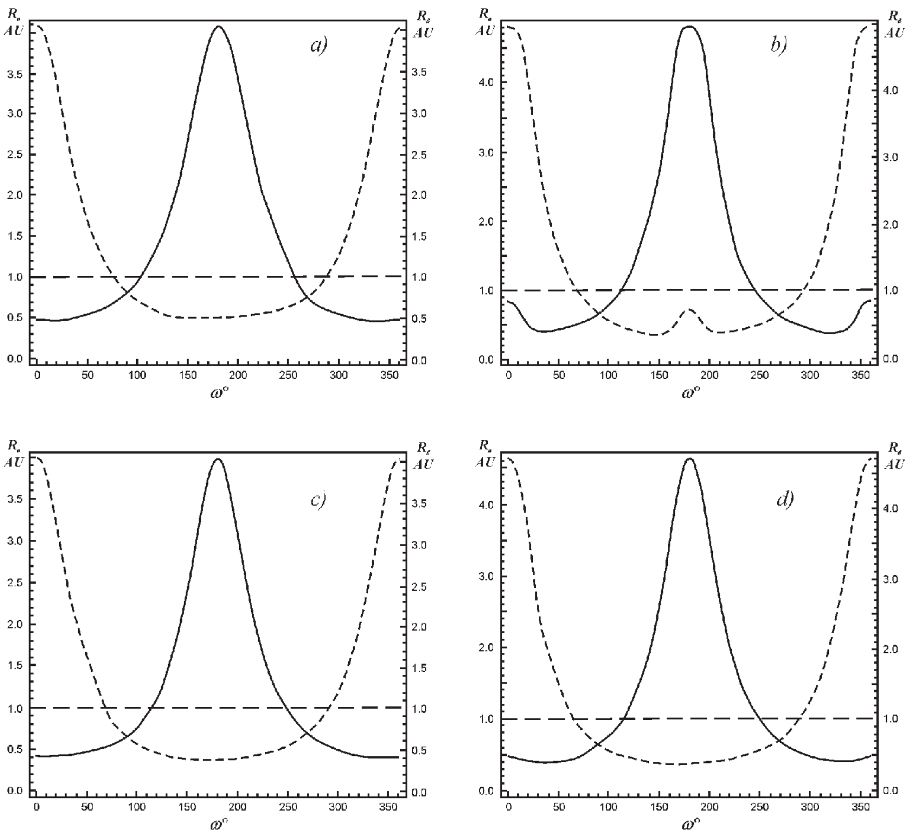

Fig. 5. Variation in heliocentric distance of the ascending node R_a and descending node R_d (– –) plotted against the argument of perihelion ω. Plot **a)** for 1997GL3, **b)** 2000PG3, **c)** 2002GM2, **d)** 2002 JC9.

Table 3. The theoretical (T) and observed (O) orbital elements, geocentric radiants and velocities (in km s^{-1}) of the meteor showers and fireballs associated with the NEA 1997GL3. D and N denote day- and night-time activity respectively.

Meteor showers and fireballs	q(AU)	e	i°	Ω°	ω°	π°	$L_\odot^\circ$	Date	α°	δ°	V_g	D_{S-H}	Type	Catalogue
T “*A*”	.490	.784	6.7	178.1	278.7	96.8	178.1	Sep. 21	359.6	8.2	24.4			
O 508	.412	.810	10.4	175.0	287.1	102.1	175.0	Sep. 18	359.7	11.0	26.3	.13	N	*L*
O δ – Piscids	.344	.816	3.8	168.3	298.5	106.8	168.3	Sep. 11	.80	3.9	27.4	.21	N	*S*2
O δ – Pscds(*N*)	.445	.775	2.7	180.3	285.8	106.1	180.3	Sep. 23	6.6	5.3	25.4	.15	N	*T*
T “*B*”	.450	.801	5.8	353.3	103.5	96.8	173.3	Sep. 16	2.5	−5.9	25.6			
O *S*.Piscids	.419	.820	2.0	357.7	107.0	104.7	177.7	Sep. 20	6.6	.3	26.3	.14	N	*C*
O δ – Pscds(*S*)	.434	.781	4.6	355.5	107.0	102.5	175.5	Sep. 18	4.6	−2.7	25.5	.09	N	*T*
O S.Piscids	.517	.844	2.2	12.2	90.0	102.2	192.2	Oct. 06	12.0	2.4	24.4	.13	N	*G*
O S.Piscid	.388	.830	2.4	352.2	112.2	104.4	172.2	Sep. 15	3.3	−0.9	27.8	.14	N	*EN*
O 195	.531	.740	4.2	2.9	96.1	99.0	182.9	Sep. 26	7.6	−2.5	22.5	.11	N	*MORP*
T “*C*”	.450	.802	5.8	20.5	76.2	96.7	20.5	Apr. 10	10.1	11.0	25.6			
O *AS*.25(Piscids)	.341	.780	6.0	30.7	59.0	89.7	30.7	Apr. 21	12.6	10.3	26.8	.15	D	*K*
T “*D*”	.490	.784	6.7	196.6	260.2	96.8	16.6	Apr. 06	13.8	−2.4	24.4			
O 8 individual	.507	.803	6.2	195.7	263.5	99.2	15.7	Apr. 05	13.1	−1.7	27.0	.14	D	*MODC*
meteors (Piscids)	±.032	±.015	±1.1	±2.6	±4.0	±.0			±1.8	±1.6	±.6			

we calculated the secular variations of the orbital elements using the Halphen-Goryachev integration method (Goryachev 1937). Gravitational perturbations from the six planets (Mercury Saturn) were included.

We see from Fig. 5 that each of these NEAs intersects the Earth's orbit four times. For all four asteroids these crossings take place at values of ω in the intervals 68°–76°, 103°–111°, 246°–260° and 278°–293°. Therefore it is theoretically possible that any meteoroid stream associated with these asteroids might produce the night-time and day-time meteor showers with their branches. The theoretical orbital elements, the radiants (right ascension α and declination δ) and geocentric velocity V_g (km s^{-1}), the solar longitude $L_\odot$ and the corresponding dates, of the possible meteor showers associated with each of the four asteroids are given in Tables 3–6.

3. Search for meteor showers associated with the four asteroids

We undertook a search for showers with elements close to the predicted values in published catalogues of observed

Table 4. The theoretical (T) and observed (O) orbital elements, geocentric radiants and velocities (in km s^{-1}) of the meteor showers and fireballs associated with the NEA 2000PG3. D and N denote day- and night-time activity respectively.

Meteor showers and fireballs	q(AU)	e	$i°$	$\Omega°$	$\omega°$	$\pi°$	$L_\odot°$	Date	$\alpha°$	$\delta°$	V_g	D_{S-H}	Type	Catalogue
T "*A*"	.340	.879	12.4	171.6	293.7	105.3	171.6	Sep. 14	359.8	10.4	30.5			
O 508	.412	.810	10.4	175.0	287.1	102.1	175.0	Sep. 18	359.7	11.0	26.3	.11	N	*L*
O Piscids	.344	.816	3.8	168.3	298.5	106.8	168.3	Sep. 11	.80	3.9	27.4	.15	N	*S*2
O δ – Pscds(*N*)	.445	.775	2.7	180.3	285.8	106.1	180.3	Sep. 23	6.6	5.3	25.4	.21	N	*T*
O 967	.435	.855	11.3	188.5	283.1	111.6	188.5	Oct. 01	10.4	16.2	27.8	.15	N	*MORP*
O 680912	.274	.860	5.1	169.7	305.3	115.0	169.7	Sep. 12	4.7	5.9	30.5	.20	N	*PN*
T "*B*"	.370	.870	13.8	354.3	111.0	105.3	174.3	Sep. 17	5.5	−1.1	29.2			
O S.Piscids	.419	.820	2.0	357.7	107.0	104.7	177.7	Sep. 20	6.6	.3	26.3	.24	N	*C*
O S.Piscids	.517	.844	2.2	12.2	90.0	102.2	192.2	Oct. 06	12.0	2.4	24.4	.28	N	*G*
O δ – Pscds(*S*)	.434	.781	4.6	355.5	107.0	102.5	175.5	Sep. 18	4.6	−2.7	25.5	.22	N	*T*
O *S.Piscid*	.388	.830	2.4	352.2	112.2	104.4	172.5	Sep. 15	3.3	−0.9	27.8	.22	N	*EN*
T "*C*"	.360	.871	13.2	36.6	68.7	105.3	36.6	Apr. 27	19.1	19.7	29.9			
O *AS*.35	.470	.790	.30	30.0	78.7	108.7	30.0	Apr. 20	22.6	10.2	24.6	.26	D	*K*
T "*D*"	.350	.876	13.0	218.4	246.9	105.3	38.4	Apr. 28	28.1	0.5	30.3			
O *AS*.41	.269	.840	5.0	232.8	232.9	105.7	52.8	May 13	33.7	9.2	28.9	.13	D	*K*

Table 5. The theoretical (T) and observed (O) orbital elements, geocentric radiants and velocities (in km s^{-1}) of the meteor showers and fireballs associated with the NEA 2002GM2. D and N denote day- and night-time activity respectively.

Meteor showers and fireballs	q(AU)	e	$i°$	$\Omega°$	$\omega°$	$\pi°$	$L_\odot°$	Date	$\alpha°$	$\delta°$	V_g	D_{S-H}	Type	Catalogue
T "*A*"	.380	.825	3.2	183.0	291.4	114.4	183.0	Sep. 26	11.0	7.9	27.3			
O Piscids	.344	.816	3.8	168.3	298.5	106.8	168.3	Sep. 11	.80	3.9	27.4	.12	N	*S*2
O Piscids	.312	.769	3.5	173.5	306.3	119.8	173.5	Sep. 16	9.1	7.2	25.6	.12	N	*S*3
O δ – Pscds(*N*)	.445	.775	2.7	180.3	285.8	106.1	180.3	Sep. 23	6.6	5.3	25.4	.14	N	*T*
O δ – Piscids	.256	.864	4.3	173.6	307.3	120.9	173.6	Sep. 16	9.1	7.1	30.6	.17	N	*G*
O 967	.435	.855	11.3	188.5	283.1	111.6	188.5	Oct. 01	10.4	16.2	27.8	.16	N	*MORP*
O 680912	.274	.860	5.1	169.7	305.3	115.0	169.7	Sep. 12	4.7	5.9	30.5	.12	N	*PN*
O 731008	.477	.700	1.0	195.8	285.4	121.2	195.8	Oct. 09	20.6	10.3	21.5	.18	N	*PN*
T "*B*"	.430	.805	3.4	7.9	106.5	114.4	187.9	Oct. 01	16.0	3.1	26.0			
O δ – Piscds	.566	.693	.7	12.1	93.8	105.9	192.1	Oct. 05	13.4	4.7	20.5	.21	N	*S*3
O δ – Pscds(*S*)	.434	.781	4.6	355.5	107.0	102.5	175.5	Sep. 18	4.6	−2.7	25.5	.17	N	*T*
O 195	.531	.740	4.2	2.9	96.1	99.0	182.9	Sep. 26	7.6	−2.5	22.5	.24	N	*MORP*
T "*C*"	.420	.807	3.5	41.0	73.3	114.3	41.0	May 01	29.3	15.7	26.1			
O *AS*.35	.470	.790	.3	30.0	78.7	108.7	30.0	Apr. 21	22.6	10.2	24.6	.11	D	*K*
O *AS*.8	.300	.700	.8	59.2	43.3	102.5	59.2	May 20	33.0	14.0	21.7	.23	D	*L*
O May Arietids	.362	.763	3.4	54.9	60.9	115.8	54.9	May 15	37.5	18.1	25.2	.08	D	*S*3
T "*D*"	.470	.788	2.2	216.4	257.9	114.3	36.4	Apr. 26	29.1	9.4	24.8			
O *AS*.41	.269	.840	5.0	232.8	232.9	105.7	52.8	May 13	33.7	9.2	28.9	.24	D	*K*

meteor showers. Sources searched were: Cook (1973) (C), Kashcheev et al. (1967) (K), Lebedinets et al. (1973) (L), Sekanina (1973, 1976) (S2, S3), Terentjeva (1989) (T), Gajdos & Porubcan (2004) (G), European network (EN), Prairi network (McCrosky et al. 1978) (PN), Canadian network (Halliday et al. 1996) (MORP), and IAU meteor orbit data Center (MODC) for individual meteors. We required the positions of the predicted and the observed radiant to be closer than ±10° in both right ascension and declination, the difference in geocentric velocity $\Delta V_g \leq \pm 5$ km s^{-1} and period of activity to be within ±15 days of each other. We also calculated D_{S-H}.

The resulting showers that were found in the different catalogues are also indicated in Tables 3–6 (equinox 2000.0). The values of D_{S-H} given in Tables 3–6 show satisfactory agreement between the predicted and observed showers.

As can be seen from the tables, all four theoretically predicted showers associated with each NEA were identified. Two were identified with the real night-time September southern and northern δ-Piscids fireball showers, meteor showers and individual fireballs, and two with the real day-time meteor associations. For all of these asteroids, observable showers are common.

Porubcan et al. (2004) noted that if a relation between NEAs and meteoroid streams exists, it will be best recognized for fireball streams represented by larger meteoroids since these are likely to have lower ejected velocities and suffer less from radiation effects. The southern and northern δ-Piscids showers, seen

Table 6. The theoretical (T) and observed (O) orbital elements, geocentric radiants and velocities (in km s^{-1}) of the meteor showers and fireballs associated with the NEA 2002JC9. D and N denote day- and night-time activity respectively.

Meteor showers and fireballs	$q(AU)$	e	$i°$	$\Omega°$	$\omega°$	$\pi°$	$L_{\odot}°$	Date	$\alpha°$	$\delta°$	V_g	D_{S-H}	Type	Catalogue
T "A"	.380	.849	5.8	169.0	289.5	98.5	169.0	Sep. 12	357.0	4.3	28.3			
O 28(Piscids)	.412	.810	10.4	175.0	287.1	102.1	175.0	Sep. 18	359.7	11.0	26.3	.11	N	L
O Piscids	.344	.816	3.8	168.3	298.5	106.8	168.3	Sep. 11	.8	3.9	27.4	.14	N	$S2$
O δ – Pscds(N)	.445	.775	2.7	180.3	285.8	106.1	180.3	Sep. 23	6.6	5.3	25.4	.15	N	T
O 680912	.274	.860	5.1	169.7	305.3	115.0	169.7	Sep. 12	4.7	5.9	30.5	.27	N	PN
O 740905	.409	.820	4.3	162.7	287.0	89.7	162.7	Sep. 05	349.6	.4	26.3	.14	N	PN
T "B"	.380	.831	6.0	347.2	111.4	98.6	167.2	Sep. 10	0.0	−5.9	27.7			
O S.Piscids	.419	.820	2.0	357.7	107.0	104.7	177.7	Sep. 21	6.6	.3	26.3	.12	N	C
O δ – Pscds(S)	.434	.781	4.6	355.5	107.0	102.5	175.5	Sep. 18	4.6	−2.7	25.5	.08	N	T
O $S.Piscid$	.388	.830	2.4	352.2	112.2	104.4	172.2	Sep. 15	3.3	−.9	27.8	.12	N	EN
O 195	.531	.740	4.2	2.9	96.1	99.0	182.9	Sep. 26	7.6	−2.5	28.5	.14	N	$MORP$
T "C"	.380	.833	6.3	30.4	68.2	98.6	30.4	Apr. 20	16.0	12.8	27.8			
O AS.25	.341	.780	6.0	30.7	59.0	89.7	30.7	Apr. 21	12.6	10.3	26.8	.16	D	K
T "D"	.380	.850	5.4	208.2	250.3	98.5	28.2	Apr. 18	18.8	2.8	28.3			
O AS.30	.274	.830	11.0	209.7	233.0	82.7	29.7	Apr. 20	13.6	3.3	28.9	.28	D	K

in September, from the data of the Prairi and MORP networks consist of fireballs brighter than –15 mag produced by bodies of decameter sizes (Terentjeva 1989).

4. Conclusions

We have shown that the four NEAs 1997GL3, 2000PG3, 2002GM2, and 2002JC9 are all associated with each other. We have calculated possible orbits, geocentric radiants, and velocities for meteor showers associated with their asteroids. We found for each theoretical shower, real meteor showers and individual fireballs.

We conclude that this complex is composed of fragments from a larger cometary body.

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