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Near-Earth Objects in the Taurid complex

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ABSTRACT

The Taurid complex consists of many substreams and has both comet 2P/Encke and several Near-Earth Objects (NEOs) moving within it. We conduct a new search for associated NEOs, investigate the orbital evolution of any identified NEO and search for meteor showers associated with these NEOs.

Key words: methods: numerical – celestial mechanics – meteors, meteoroids – minor planets, asteroids.

1 INTRODUCTION

The Taurid shower is one of the annual meteor showers and originates from a stream with very low inclination of less than 5°, so that the Earth is moving within the confines of the stream for a significant fraction of its orbit. Because of this, meteor showers are seen when the Earth is near both the ascending and descending nodes while any small variations in the orbital elements of particular meteors can lead to more substantial changes in the longitude of the nodes. Hence, the showers are long-lasting with the night-time Taurids being observed visually in the pre-perihelion stage between September 15 and December 1 (Cook 1973) while in the post-perihelion stage the day-time showers of the ζ Perseids and the β Taurids are observed by radar between May 20 and July 6 (Sekanina 1973). The stream has a perihelion distance of about 0.4 au and eccentricity about 0.85. Comet 2P/Encke has a very similar orbit, though a slightly larger inclination of about 12°. It was shown by Whipple (1940, 1954) that the meteoroids in the Taurid stream could have been ejected from this comet but that perturbations by Jupiter, affecting the comet and stream differently, have changed the orbits to their present values. The first photographic observations of the Taurids revealed an interesting feature of the shower: the radiants were grouped near two centres located symmetrically relative to the ecliptic. Whipple proposed that these two branches be called the Northern and Southern Taurids.

Early in the 20th century, Denning (1928) recognized the complex nature of the stream, identifying 13 active (visible) radiants situated in Aries and Taurus. It is now generally agreed that the stream is in fact a complex of several small meteoroid streams (Olsson-Steel 1988; Babadzhanov, Obrubov & Makhmudov 1990; Stohl & Porubcan 1990; Steel, Asher & Clube 1991; Babadzhanov 2001). Some are undoubtedly generically associated with comet 2P/Encke, but others appear to have orbits more similar to some Apollo asteroids as were first shown over two decades ago by Clube & Napier (1984). It has also been suggested (e.g. Asher, Clube & Steel 1993a) that the whole complex was generated by the fragmentation of a giant comet over the past 20–30 kyr.

Over recent years, the number of known Near-Earth Objects (NEOs) has increased significantly through the setting up of numerous search programmes driven by the need to find objects that are a potential danger to Earth. With this increase in the total number of NEOs, the number that have orbits similar to those of the Taurid complex has also increased. Because of the large spread in the longitude of the ascending node caused by the low inclination, Asher, Clube & Steel (1993b) suggested that a D criterion defined by

$$D^2 = \left(\frac{a_1 - a_2}{3}\right)^2 + (e_1 - e_2)^2 + \{2\sin[(i_1 - i_2)/2]\}^2, \qquad (1)$$

where subscript 1 and 2 refer to the two orbits being compared, was a more suitable tool for measuring orbital similarity than the more traditional $D_{\mathrm{S-H}}$ proposed by Southworth & Hawkins (1963).

Asher et al. (1993b) found 15 NEOs satisfying the above criterion, including 2201 Oljato, 4183 Cuno, 4341 Poseidon, 2212 Hephaistos, 4486 Mithra and 2101 Adonis, while Babadzhanov (2001) found 17 asteroids belonging to the complex. A search was also carried out by Porubčan, Kornos & Williams (2004, 2006).

If the complex did indeed form through the fragmentation of a giant comet, then these asteroids are in fact cometary fragments and should display cometary characteristics such as low albedo and associated meteor activity.

Since meteoroids are ejected from the parent body with a range of velocities, there is some dispersal in the initial orbital elements of such meteoroids, both from each other and from those of the parent. Because of these differences in the semimajor axis (and orbital periods), some lag behind the parent body while others overtake it, spreading meteoroids along the entire orbit and forming a complete loop in a comparatively short time (Hughes 1986; Williams 1995). As the meteoroids occupy different positions from the parent at any given time, planetary perturbations are also different and rates and cycles of variations in the angular orbital elements (the argument

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Table 1. Data regarding the seven new NEOs found in the Taurid complex. See the text for the meaning of the column headings.

NEA	a (au)	e	q (au)	i°	Ω°	ω°	π°	D	H	d (km)	R_a (au)	R_d (au)
16960	2.199	0.859	0.389	17.7	261.3	242.2	143.5	0.24	14.11	7.55	0.95	0.40
1998VD31	2.652	0.803	0.523	10.2	47.9	113.2	161.1	0.21	19.43	0.65	1.37	0.71
1999VK12	2.250	0.778	0.502	9.5	48.9	102.8	151.7	0.12	23.35	0.11	1.00	0.80
1999VR6	2.213	0.761	0.530	8.6	213.2	293.9	147.1	0.11	20.77	0.35	0.72	1.34
2003WP21	2.293	0.787	0.489	4.3	38.1	123.7	161.8	0.12	21.43	0.26	1.56	0.61
2003UL3	2.246	0.797	0.456	14.6	153.2	13.0	166.2	0.19	17.85	1.35	0.46	3.67
2004TG10	2.242	0.860	0.315	3.7	212.3	310.0	162.3	0.06	19.46	0.64	0.38	1.33

of perihelion ω, the longitude of the ascending node Ω and the inclination i). As a result, the orbits of different meteoroids will be at different evolutionary stages. This process increases considerably both the size of the meteoroid stream and its thickness. Meteoroids can be found on orbits similar to all the orbits that the parent body has occupied over a cycle and they may produce meteor showers at times other than those corresponding to the longitude of the nodes of the parent body.

During a complete orbit around the Sun, the Earth collides with those stream meteoroids that have a nodal distance of about 1 au, that is satisfying:

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

This can give four possible values of ω for given values of a and e. As a result, a meteoroid stream might produce a night-time shower with Northern and Southern branches at the pre-perihelion passage and a day-time shower with Northern and Southern branches at the post-perihelion passage.

Hence, simple comparison of orbits at the present time is not sufficient to identify showers associated with a particular asteroid, we need to calculate the length of the cycles of the variation of the orbital elements as described by Babadzhanov (1996, 2001) and Babadzhanov & Obrubov (1992).

In this paper, we carry out a further search to locate any additional members of the complex. We then investigate their orbital evolution and determine where meteor showers associated with such NEOs might theoretically be located. Finally, we carry out a search through the existing catalogues for such meteor showers.

2 SEARCH FOR NEW NEOS ASSOCIATED WITH THE TAURID COMPLEX

We have searched through the University of Pisa Catalogue http://newton.dm.unipi.it/neodys/neodys.cat for objects with orbital elements that match those of the Taurid complex. In practice, this means using equation (1) with $D \leqslant 0.2$ and $a_1 = 2.1$ au, $e_1 = 0.82$

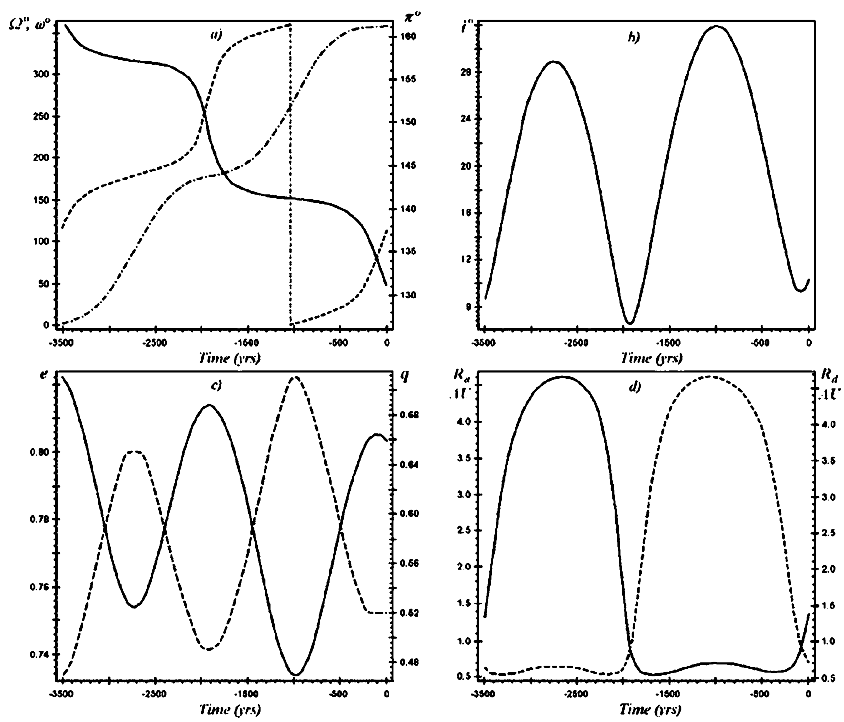

Figure 1. The variation with time in the orbital elements of NEO 1998VD31. Plot (a) shows the variation of three angular elements ω (– –), Ω (–), π (– · –). Plot (b) shows the variation of the inclination i. Plot (c) shows the variations of the eccentricity e and the perihelion distance q (– –). Plot (d) shows the variation of the two heliocentric nodal distances, R_a-ascending node and R_d-descending node (– –).

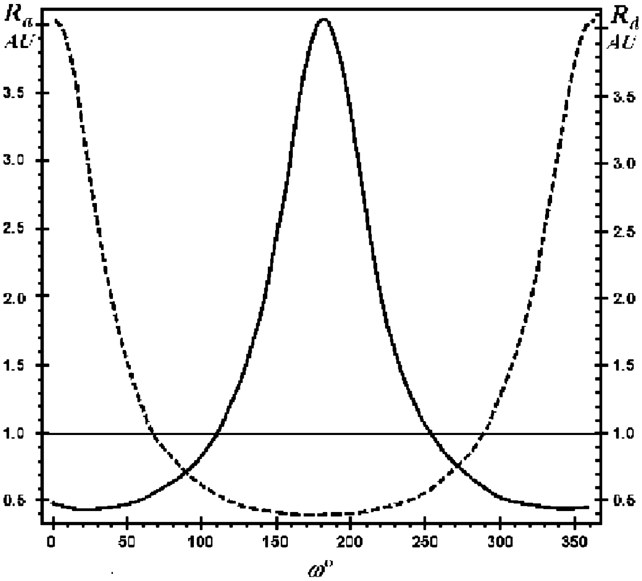

Figure 2. The variation in heliocentric distance of the ascending node R_a and descending node R_d (−−) plotted against the argument of perihelion ω for NEO 2003UL3.

and $i_1 = 4°$. We also introduce further conditions to ensure that the association is sound. Hence, in addition to a similarity of orbits using the D criterion, we require that the longitude of perihelion lies in the range $100° < \pi < 190°$ and that the Tisserand criterion $T < 3.1$. We further require that they satisfy the Whipple (1954) K criterion:

$$K = \log[Q(1-e)^{-1}] - 1 > 0, \tag{3}$$

where Q is the aphelion distance of the orbit, and the criterion of Kresak (1967, 1969) requiring $P > 2.5$

$$Pe > 2.5, \tag{4}$$

where P is the orbital period in years.

There were 3143 NEOs discovered up to 2005 January. Of these, only 17 satisfied all the above conditions. 10 of these were already known and data on them published in Babadzhanov (2001). In Table 1, we give the orbital elements a, e, q, $i°$, $\Omega°$, $\omega°$ for these seven objects.

In addition, we give the longitude of perihelion, $\pi°$, the heliocentric distances of the ascending and descending nodes, R_a and R_d. Finally, we give the estimates for the diameters d of the objects which are calculated from the absolute magnitude H using the expression of Bowell & Lumme (1982), namely

$$\log d = 3.12 - 0.2H - 0.5 \log p. \tag{5}$$

Since these objects are possibly cometary in origin, we assume that their albedo p is similar to that of comets which generally lies in the range 0.02–0.12 Jewitt (1992). For the purposes of Table 1, we have assumed a mean value of 0.07.

There are two objects in the table, 2003UL3 and 2004TG10, that were also found by Porubčan et al. (2006) and who showed that 2003UL was most probably related to the o Orionids meteor shower while 2004TG10 associated with the Northern Taurids.

3 SECULAR VARIATIONS IN THE ORBITAL ELEMENTS OF THESE SEVEN NEOS

As mentioned in the introduction, in order to establish a relationship between parent objects and meteor showers, it is necessary to follow the evolution over one cycle of the variation in the angular orbital elements. We have calculated the secular variations in the orbital elements of all seven objects given in Table 1 using the Halphen–Goryachev integration method (Goryachev 1937). The integration was carried out backwards in time, starting at the current epoch and continued until one cycle of the variation of the argument of perihelion was completed (i.e., the starting value was repeated). Gravitational perturbations from the six planets Mercury to Saturn were included.

Figs 1a, b, c and d show the variation with time of all the orbital elements as well as the heliocentric distances of the two nodes, R_a and R_d for NEO 1998VD31. The diagrams showing the variations in the same quantities for the other six NEOs are very similar, though, as might be expected, the time taken to complete a cycle of the argument of perihelion varies from 3500 yr (for 1998VD31) to nearly 9000 yr for 1999VR6. It should be noted that the variation is the same whether the integration is carried out forwards or backwards in time.

Fig. 2 shows the changes in the heliocentric distances of the nodes against the argument of perihelion for 2003UL3. It clearly shows that values of the nodal distance are 1 au (so that showers can be seen) for four different values of the argument of perihelion. For this object, these values are 75°, 105°, 252° and 288°. The behaviour is very similar for the remaining six objects. Interestingly, for all seven objects, the four values of ω lie in the ranges 58°–85°, 94°–121°, 246°–265° and 276°–304°.

Table 2. 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 NEO 16960. D and N denote day- and night-time activity, respectively.

Meteor showers	q (au)	e	$i°$	$\Omega°$	$\omega°$	$L_{\odot}°$	Date	$\alpha°$	$\delta°$	V_g	D_{S-H}	Type	Catalogue and fireballs
T	0.274	0.876	18.2	199.7	303.7	199.7	October 13	30.8	25.3	32.0		N	
O Association 161	0.203	0.950	12.0	201.7	307.0	201.7	October 15	34.7	20.2	36.3	0.17	N	K
O Association 516	0.427	0.850	12.6	111.2	283.2	211.2	October 25	31.5	26.0	27.7	0.23	N	L
T	0.297	0.865	19.9	22.4	121.0	202.4	October 16	41.4	1.4	31.5		N	
O Association 523	0.333	0.930	26.3	30.1	114.7	210.1	October 24	48.3	-0.0	34.7	0.15	N	L
O Southern Taurids	0.360	0.820	4.9	30.2	114.1	210.2	October 24	41.0	11.4	27.5	0.27	N	L
T	0.290	0.868	19.5	85.3	58.2	85.3	June 17	63.9	34.6	31.8		D	
O ζ Perseids	0.318	0.834	5.3	78.2	59.3	78.2	June 09	61.0	24.9	28.6	0.27	D	S2
O ζ Perseids	0.366	0.755	6.5	81.4	60.6	81.4	June 12	64.5	27.5	25.1	0.27	D	S3
T	0.311	0.859	18.0	263.1	240.4	83.1	June 14	67.6	8.8	30.4		D	
O β Taurids	0.370	0.800	11.0	257.7	244.9	77.7	June 09	65.1	11.6	27.1	0.15	D	L
O β Taurids	0.330	0.850	7.0	258.8	242.9	78.8	June 11	64.7	15.1	28.9	0.20	D	K

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 NEO 1998VD31. D and N denote day- and night-time activity, respectively.

Meteor showers and fireballs	q (au)	e	i°	Ω°	ω°	$L^\circ_\odot$	Date	α°	δ°	V_g	D_{S-H}	Type	Catalogue
T	0.494	0.814	6.7	243.9	277.3	243.9	November 27	64.8	29.0	25.4		N	
O Northern Taurids	0.454	0.800	3.1	242.0	282.1	242.0	November 25	66.2	25.0	25.4	0.09	N	L
O Northern Taurids	0.360	0.861	2.4	230.8	292.2	230.8	November 14	59.0	22.4	29.2	0.16	N	C
O 10 fireballs	0.380	0.832	2.8	236.4	290.9	236.4	November 18	64.4	23.8	27.5	0.20	N	
	±0.015	±0.008	±0.2	±2.2	±1.7	±2.2		±1.6	±0.5	±0.7	±0.01		
T	0.518	0.805	9.4	66.7	94.5	246.7	November 30	70.4	11.3	25.0		N	
O Southern Taurids	0.487	0.790	5.7	61.9	97.3	241.9	November 24	65.4	14.9	24.5	0.08	N	L
O Southern Taurids	0.386	0.770	1.4	50.4	114.1	230.4	November 13	60.1	19.3	25.5	0.20	N	S1
O 10 fireballs	0.427	0.784	4.6	58.7	102.6	238.7	November 21	64.5	16.1	25.2	0.18	N	
	±0.026	±0.018	±0.5	±4.0	±2.4	±4.0		±3.2	±0.5	±0.8	±0.02		
T	0.517	0.805	9.3	75.6	85.5	75.6	June 07	69.3	32.8	25.0		D	
O ζ Perseids	0.441	0.810	1.4	78.3	78.5	78.3	June 10	69.0	23.5	26.3	0.21	D	L
O ζ Perseids	0.508	0.730	5.3	78.4	80.1	78.4	June 10	71.6	28.9	22.6	0.11	D	L
T	0.494	0.814	6.6	258.6	262.6	78.6	June 10	74.1	15.4	25.4		D	
O Association 77	0.551	0.710	2.0	256.9	264.8	76.9	June 08	73.7	19.1	21.2	0.14	D	K
O Association 252	0.522	0.770	4.8	259.7	264.8	79.7	June 11	76.8	17.0	23.4	0.08	D	L

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 NEO 1999VK12. D and N denote day- and night-time activity, respectively.

Meteor showers and fireballs	q (au)	e	i°	Ω°	ω°	$L^\circ_\odot$	Date	α°	δ°	V_g	D_{S-H}	Type	Catalogue
T	0.465	0.793	7.3	229.8	281.9	229.8	November 12	51.9	27.0	25.3		N	
O Association 568 Northern Taurids	0.405	0.850	1.8	234.9	286.8	234.9	November 17	60.9	22.5	28.7	0.19	N	L
O Association 250 Northern Taurids	0.399	0.750	0.0	217.9	293.6	217.9	October 31	47.2	17.7	24.6	0.15	N	S3
O Northern Taurids	0.333	0.839	2.8	223.3	297.3	223.3	November 07	53.6	21.6	28.8	0.21	N	G
T	0.500	0.778	9.4	53.4	98.3	233.4	November 15	58.6	9.2	24.5		N	
O Southern Taurids	0.374	0.806	5.2	40.6	113.2	220.6	November 03	51.2	13.8	27.0	0.15	N	C
O Southern Taurids	0.487	0.790	5.7	61.8	97.4	241.8	November 24	65.6	14.8	24.2	0.12	N	L
O Southern Taurids	0.366	0.836	5.0	44.3	119.8	224.3	November 07	54.2	14.9	28.2	0.18	N	G
O 16 fireballs	0.374	0.839	5.1	44.8	111.5	224.8	November 07	54.4	14.8	28.2	0.18	N	
	±0.010	±0.006	±0.2	±0.9	±1.3	±0.9		±0.7	±0.2	±0.3	±0.01		
T	0.498	0.779	9.3	70.1	81.6	70.1	May 31	60.9	31.4	24.6		D	
O ζ Perseids	0.366	0.755	6.5	81.4	60.5	81.4	June 12	64.5	27.5	25.1	0.20	D	S3
O Association 249 ζ Perseids	0.441	0.810	1.4	78.3	73.5	78.3	June 09	69.0	23.5	26.3	0.15	D	L
O ζ Perseids	0.336	0.790	0.0	78.7	59.0	78.7	June 09	62.5	23.2	27.0	0.30	D	C
T	0.465	0.793	7.1	254.2	257.5	74.2	June 05	67.4	14.2	25.4		D	
O β Taurids	0.370	0.800	11.0	257.7	244.9	77.7	June 08	65.1	11.6	27.1	0.17	D	L
O β Taurids	0.330	0.850	7.0	258.8	242.9	78.8	June 09	64.7	15.1	28.9	0.20	D	K
O Association 252 β Taurids	0.522	0.770	4.8	259.6	264.9	79.6	June 10	76.6	17.1	23.4	0.19	D	L

It is also possible to calculate the theoretical coordinates of the geocentric radiant and geocentric velocity, solar longitude and the corresponding date for meteor showers associated with each crossing.

4 SEARCH FOR METEOR SHOWERS ASSOCIATED WITH THE SELECTED OBJECTS

Having calculated the properties of theoretical meteor showers as mentioned above, we undertook a search through all the following catalogues Cook (1973) (C), Kashcheev, Lebedinets & Lagutin (1967) (K), Lebedinets, Korpusov & Sosnova (1973) (L), Terentjeva (1989) (T), Sekanina (1971, 1973, 1976) (S1, S2, S3), Cannon (2005) (C1), Gajdos & Porubčan (2004) (G), Data of European Network (EN), Prairie Network (McCrosky, Shao & Posen 1978) (PN) and Canadian Network (Halliday, Griffin & Blackwell 1996) (MORP).

This search took into account the closeness in the positions of the predicted and the observed radiant (the requirement used was $\Delta\alpha = \Delta\delta \leqslant 10^\circ$), in the velocity values ($\Delta V_g \leqslant 5$ km s^{-1}) and period of activity ($\Delta t \leqslant 15$ d) for $D_{S-H} < 0.3$, where D_{S-H} is Southworth & Hawkins (1963) criterion, which serves as a measure of similarity of two orbits in the case under consideration, as a measure of the similarity between the predicted and the observed orbits.

The results are shown in Tables 2–8 (equinox 2000.0). The values of D_{S-H} given in Tables 2–8 show good agreement between the predicted and observed showers, i.e. all seven NEAs are also associated with Taurid meteor complex, that is indicative of cometary nature of these NEAs. It is notable that these associations are also supported by numerous fireballs observed at different networks (EN, PN, MORP).

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 NEO 1999VR6. D and N denote day- and night-time activity, respectively.

Meteor showers and fireballs	q (au)	e	i°	Ω°	ω°	$L^\circ_\odot$	Date	α°	δ°	V_g	D_{S-H}	Type	Catalogue
T	0.527	0.762	7.9	231.5	275.6	231.5	November 14	49.9	28.4	23.4		N	
O Association 640 Northern Taurids	0.557	0.760	11.2	241.4	271.7	241.4	November 23	58.9	34.9	23.5	0.11	N	L
O Northern Taurids	0.366	0.858	2.1	230.8	291.2	230.8	November 12	58.7	22.1	29.0	0.03	N	C1
O Association 250 Northern Taurids	0.399	0.750	0.0	217.9	293.6	217.9	October 31	47.2	17.7	24.6	0.20	N	L
O Four fireballs	0.334	0.792	3.6	225.1	291.4	225.1	November 07	52.5	22.8	26.1	0.26	N	
	±0.014	±0.014	±0.8	±4.8	±6.9	±4.8		±1.7	±1.7	±1.2	±0.01		
T	0.494	0.777	9.1	47.8	99.3	227.8	November 10	53.3	8.4	24.5		N	
O Southern Taurids	0.374	0.806	5.2	40.6	113.2	220.6	November 03	51.2	13.8	27.0	0.17	N	C
O Southern Taurids	0.487	0.790	5.7	61.8	97.4	241.8	November 24	65.6	14.8	24.5	0.18	N	L
O Southern Taurids	0.360	0.820	4.9	30.8	114.1	210.8	October 24	41.7	11.6	27.5	0.16	N	L
O 20 fireballs	0.375	0.832	4.9	44.4	111.4	224.4	November 07	53.8	14.9	28.0	0.19	N	
	±0.009	±0.009	±0.3	±1.0	±1.2	±1.0		±0.8	±0.3	±0.4	±0.01		
T	0.492	0.778	9.1	66.1	81.0	66.1	May 27	56.1	30.2	24.7		D	
O Association 192 ζ Perseids	0.520	0.740	3.8	59.4	82.2	59.4	May 20	52.4	27.7	22.6	0.13	D	L
O ζ Perseids	0.366	0.755	6.5	81.4	60.5	81.4	June 12	64.5	27.5	25.1	0.16	D	S3
O ζ Perseids	0.336	0.790	0.0	78.7	59.0	78.7	June 09	62.7	23.1	27.0	0.26	D	C
T	0.527	0.762	7.8	242.3	264.8	62.3	May 23	58.6	10.8	23.5		D	
O β Taurids	0.370	0.800	11.0	257.7	244.9	77.7	June 09	64.9	11.7	27.1	0.19	D	L
O β Taurids	0.330	0.850	7.0	258.7	243.0	78.7	June 09	64.5	15.2	28.9	0.23	D	K

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 NEO 2003UL3. D and N denote day- and night-time activity, respectively.

Meteor showers and fireballs	q (au)	e	i°	Ω°	ω°	$L^\circ_\odot$	Date	α°	δ°	V_g	D_{S-H}	Type	Catalogue
T	0.414	0.815	3.7	238.6	287.5	238.6	November 21	64.8	25.1	26.8		N	
O Association 643 Northern Taurids	0.454	0.800	3.1	242.0	282.1	242.0	November 24	66.2	25.0	25.4	0.05	N	L
O ν Taurids	0.420	0.828	2.9	242.6	285.9	242.6	November 25	67.7	22.1	27.3	0.04	N	T
O 13 fireballs	0.389	0.822	3.0	234.5	290.3	234.5	November 16	61.9	23.8	27.4	0.09	N	
	±0.018	±0.008	±0.3	±2.2	±2.2	±2.2		±1.8	±0.5	±0.6	±0.02		
T	0.437	0.805	5.9	61.0	105.1	241.0	November 23	67.9	15.8	26.2		N	
O Southern Taurids	0.487	0.790	5.7	61.8	97.4	241.8	November 24	65.6	14.8	24.5	0.11	N	L
O Southern Taurids	0.386	0.770	1.4	50.2	114.3	230.2	November 12	60.3	19.2	25.5	0.10	N	S1
O 15 fireballs	0.398	0.826	5.2	49.5	109.1	229.5	November 12	58.2	15.0	27.4	0.16	N	
	±0.014	±0.010	±0.2	±2.5	±1.5	±2.5		±2.1	±0.2	±0.5	±0.01		
T	0.436	0.806	6.0	91.1	75.0	91.1	June 23	82.5	29.2	26.3		D	
O 80 meteors	0.390	0.775	8.1	95.2	64.5	95.2	June 27	81.4	30.6	27.7	0.11	D	MODC
ζ Perseids	±0.013	±0.006	±0.6	±0.9	±1.8			±0.7	±0.5	±0.3			
T	0.414	0.816	3.5	273.8	252.3	93.8	June 25	84.9	20.0	26.9		D	
O β Taurids	0.330	0.850	6.0	277.2	245.9	97.2	June 29	86.7	19.0	30.0	0.11	D	C
O Association 252 β Taurids	0.540	0.770	4.8	259.7	264.8	79.7	June 10	76.8	17.0	23.4	0.12	D	L

As is seen all seven NEOs are associated, as the comet 2P/Encke, with night-time Northern and Southern Taurids, and with day-time ζ Perseids and β Taurids. For all of these asteroids observable showers are common.

5 CONCLUSION

It may be concluded that these asteroids having sizes in the range 0.11–7.55 km are also the fragments of comet 2P/Encke or together with comet 2P/Encke are the fragments of a larger cometary body.

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REFERENCES

Asher D. J., Clube S. V. M., Steel D. I., 1993a, MNRAS, 264, 93

Asher D. J., Clube S. V. M., Steel D. I., 1993b, in Stohl J., Williams I. P., eds, Meteoroids and their Parent Bodies. Slovak Acad. Sci., Bratislava, p. 93

Babadzhanov P. B., 1996, Sol. Syst. Res., 30, 499

Babadzhanov P. B., 2001, A&A, 373, 329

Babadzhanov P. B., Obrubov Yu. V., 1992, Celest. Mech. Dyn. Astron., 54, 111

Babadzhanov P. B., Obrubov Yu. V., Makhmudov N., 1990, Sol. Syst. Res., 24, 12

Bowell E., Lumme K., 1982, in Gehrels T., ed., Asteroids. Univ. Ariz. Press, Tucson, p. 132

Cannon E., 2005, preprint (http://web.austin.utexas.edu/edcannon/aka-date-htm)

Table 7. 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 NEO 2003WP21. D and N denote day- and night-time activity respectively.

Meteor showers and fireballs	q (au)	e	i°	Ω°	ω°	$L_\odot^\circ$	Date	α°	δ°	V_g	D_{S-H}	Type	Catalogue
T	0.453	0.802	1.5	238.6	283.2	238.6	November 20	62.7	22.7	25.6		N	
O Northern Taurids	0.454	0.800	3.1	242.0	282.1	242.0	November 24	66.2	25.0	25.4	0.04	N	L
O ν Taurids	0.420	0.828	2.9	242.6	285.9	242.6	November 25	67.7	22.1	27.3	0.11	N	T
O 12 fireballs	0.375	0.826	2.9	234.1	292.0	234.1	November 16	62.4	23.5	27.7	0.13	N	
	±0.013	±0.008	±0.2	±2.4	±1.6	±2.4		±1.9	±0.5	±0.5	±0.01		
T	0.486	0.788	3.8	62.2	99.5	242.2	November 24	66.0	17.3	24.7		N	
O Southern Taurids	0.487	0.790	5.7	61.8	97.4	241.8	November 24	65.6	14.8	24.5	0.05	N	L
O Southern Taurids	0.386	0.770	1.4	50.2	114.3	230.2	November 13	60.3	19.2	25.5	0.12	N	S1
O 14 fireballs	0.398	0.815	4.9	47.6	109.0	227.6	November 10	56.2	15.1	27.1	0.14	N	
	±0.015	±0.014	±0.4	±1.4	±1.6	±1.4		±0.9	±0.3	±0.6	±0.01		
T	0.485	0.788	3.8	81.3	80.4	81.3	June 12	74.8	26.8	24.8		D	
O 66 meteors	0.463	0.758	5.0	81.8	74.4	81.8	June 13	78.6	27.8	26.4	0.08	D	MODC
ζ Perseids	±0.013	±0.007	±0.4	±0.8	±1.7			±0.7	±0.5	±0.3			
T	0.453	0.803	1.4	264.7	257.0	84.7	June 15	77.4	21.5	25.8		D	
O Association 252 β Taurids	0.522	0.770	4.0	259.7	264.8	79.7	June 10	76.8	17.0	23.4	0.10	D	L
O β Taurids	0.324	0.825	2.2	275.4	239.0	95.4	June 27	80.2	21.4	28.2	0.17	D	S2

Table 8. 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 NEO 2004TG10. D and N denote day- and night-time activity respectively.

Meteor showers and fireballs	q (au)	e	i°	Ω°	ω°	$L_\odot^\circ$	Date	α°	δ°	V_g	D_{S-H}	Type	Catalogue
T	0.314	0.860	3.2	223.7	298.7	223.7	November 06	54.5	22.0	29.9		N	
O Northern Taurids	0.360	0.861	2.4	230.8	292.2	230.8	November 13	59.0	22.4	29.2	0.05	N	C
O Northern Taurids	0.333	0.839	2.8	222.8	297.3	222.8	November 06	53.1	21.4	28.8	0.04	N	G
O 11 fireballs	0.354	0.830	2.8	228.6	294.8	228.6	November 11	57.9	22.4	28.2	0.09	N	
	±0.014	±0.010	±0.2	±2.7	±1.7	±2.7		±2.1	±0.4	±0.5	±0.01		
T	0.294	0.869	5.0	41.0	121.4	221.0	November 03	54.3	15.7	30.6		N	
O Southern Taurids	0.374	0.806	5.2	40.6	113.2	220.6	November 03	51.2	13.8	27.0	0.16	N	C
O Southern Taurids	0.366	0.836	5.0	43.6	112.8	223.6	November 07	53.7	14.7	28.2	0.11	N	G
O 21 fireballs	0.350	0.841	5.5	41.8	114.7	221.8	November 04	52.9	14.3	28.7	0.13	N	
	±0.011	±0.006	±0.3	±1.6	±1.4	±1.6		±1.2	±0.3	±0.4	±0.01		
T	0.329	0.853	5.4	99.3	63.9	99.3	July 02	85.9	27.6	29.8		D	
O ζ Taurids	0.274	0.834	0.3	101.5	53.5	101.5	July 04	84.8	23.5	29.0	0.17	D	S3
T	0.313	0.860	2.9	281.2	241.1	101.2	July 03	87.4	21.3	30.1		D	
O β Taurids	0.330	0.850	6.0	277.2	245.9	97.2	June 29	86.7	19.0	30.0	0.06	D	C
O β Taurids	0.324	0.825	2.2	275.4	239.0	95.4	June 26	80.3	21.4	28.2	0.12	D	S2

Clube S. V. M., Napier W. M., 1984, MNRAS, 211, 953

Cook A. F., 1973, in Hemenway C. L., Millman P. M., Cook A. F., eds, Evolutionary and Physical Properties of Meteoroids. NASA SP-319, Washington, DC, p. 183

Denning W. F., 1928, J. Br. Astron. Soc., 38, 302

Gajdos S., Porubčan V., 2004, in Knezevic Z., Milani A., eds, Proc. IAU Coll. Vol. 197, Dynamics of Populations of Planetary Systems. Cambridge Univ. Press, Cambridge, p. 393

Goryachev N. N., 1937, Halphen's Method for Calculation of Planetary Secular Perturbations and its Application to Ceres. Krasnoe Znamya, Tomsk

Halliday I., Griffin A. A., Blackwell A. T., 1996, Meteorit. Planet. Sci., 31, 185

Hughes D. W., 1986, in Lagerkvist C.-I., Lindblad B. A., Lundstedt H., Rickman H., eds, Asteroids, Comets, Meteors II. Uppsala Universitet Reprocentralen, Uppsala, p. 503

Jewitt D. C., 1992, in Newburn R. L., Neugebauer M., Rahe J., eds, Comets in the Post-Halley Era. Kluwer, Dordrecht, p. 19

Kashcheev B. L., Lebedinets V. N., Lagutin M. F., 1967, in Poloskov S. M., ed., Meteoric Phenomena in the Earth's Atmosphere. Nauka, Moscow, p. 260

Kresak L., 1967, Smithson. Contrib. Astrophys., 11, 9

Kresak L., 1969, Bull. Astron. Inst. Czech., 20, 4, 177

Lebedinets V. N., Korpusov V. V., Sosnova A. K., 1973, Tr. Inst. Eksp. Meteorol., 1, 88

McCrosky R. E., Shao C. Y., Posen A., 1978, Meteoritika, 37, 44

Olsson-Steel D., 1988, Icarus, 75, 64

Porubčan V., Kornos L., Williams I. P., 2004, Earth, Moon and Planets, 95, 697

Porubčan V., Kornos L., Williams I. P., 2006, Contrib. Astron. Obs. Scalnate Pleso, 36, 103

Sekanina Z., 1971, Icarus, 13, 475

Sekanina Z., 1973, Icarus, 18, 253
Sekanina Z., 1976, Icarus, 27, 265
Southworth R. B., Hawkins G. S., 1963, Smithson. Contrib. Astrophys., 7, 261
Steel D. I., Asher D. J., Clube S. V. M., 1991, MNRAS, 251, 632
Stohl J., Porubčan V., 1990, in Lagerkvist C.-I., Rickman H., Lindblad B. A., Lindgren M., eds, Asteroids, Comets, Meteors III. Uppsala Universitet Reprocentralen, Uppsala, p. 571
Terentjeva A. K., 1990, in Lagerkvist C. I., Rickman H., Lindblad B. A., Lindgren M., eds, Asteroids, Cometrs, Meteors III. Uppsala Universitet Reprocentralen, Uppsala, p. 579
Whipple F. L., 1940, Proc. Amer. Phys. Soc., 83, 711
Whipple F. L., 1954, AJ, 59, 201
Williams I. P., 1995, Earth, Moon and Planet, 68, 1

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