Large Bodies Associated with Meteoroid Streams

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Abstract It is now accepted that some near-Earth objects (NEOs) may be dormant or dead comets. One strong indicator of cometary nature is the existence of an associated meteoroid stream with its consequently observed meteor showers. The complexes of NEOs which have very similar orbits and a likely common progenitor have been identified. The theoretical parameters for any meteor shower that may be associated with these complexes were calculated. As a result of a search of existing catalogues of meteor showers, activity has been observed corresponding to each of the theoretically predicted showers was found. We conclude that these asteroid-meteoroid complexes of four NEOs moving within the Piscids stream, three NEOs moving within the Iota Aquariids stream, and six new NEOs added to the Taurid complex are the result of a cometary break-up.

Keywords near-Earth object · dormant comet · meteoroid streams · meteor showers · orbital evolution · Piscids stream · Iota Aquariids stream · Taurid complex

1 Introduction

Though there had been some prior speculation that Near Earth Asteroids could be responsible for some minor meteoroid streams, the first definite association was between the Geminid stream and asteroid 3200 Phaethon (Whipple 1983, Fox et al. 1984). A number of Near Earth Asteroids were also found to be moving on orbits within the Taurid complex, though comet 2P/Encke also moves in this complex (Asher et al. 1993). More recently asteroid 2003EH1 was identified as moving on the same orbit as the Quadrantids (Jenniskens 2003, Williams et al. 2004) and the generally accepted hypothesis is that these are the result of the fragmentation of a larger comet so that these 'asteroids' are in reality comet fragments that are dormant or dead. All the associations mentioned above are based on the similarity of the orbits of the NEO and the meteor stream that gives rise to the observed shower at roughly the present time.

2 Orbital Evolution

Gravitational perturbations from the planets change all orbits over a period of time. However in the region of the Solar system that is of interest to us (the Earth-Jupiter region), ω (the argument of

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perihelion) passes through the range of values from 0 to 2π in a period of several thousand years. We call this one cycle of ω. Though there may be short term variations, the changes in the three orbital elements q (perihelion distance), e (eccentricity) and i (inclination) over one cycle of ω are all essentially sinusoidal. The nodal distances, R_a and R_d also show the same characteristic variation. This variation is shown in Figure 1 for the three NEOs, 2002JS2, 2002PD11 and 2003 MT9. Some time ago (Babadzhanov and Obrubov 1992) pointed out that as the nodal distance will be equal to 1 AU at four different values of ω, during one cycle (clearly seen in Figure 1), four meteor showers originating from a single meteoroid stream can be formed. These four meteor showers consist of a night-time shower with northern and southern branches and of a day-time shower also with northern and southern branches.

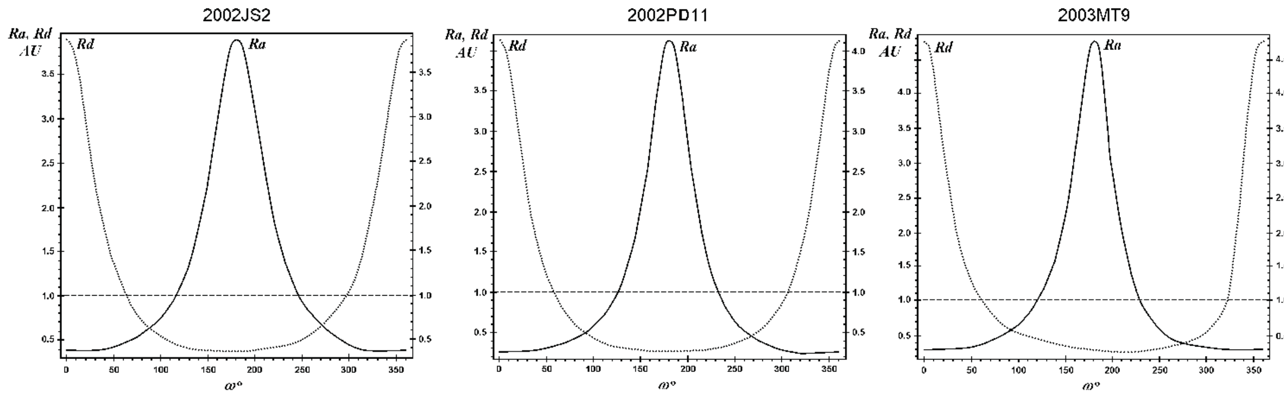

Figure 1. The variation in the nodal distances for three NEOs.

With a large number of NEOs currently being discovered, the probability that one has an orbit that is similar to a meteoroid stream at the present time by chance is high and, in order to establish a relationship with a stream, similarity of orbital evolution must be shown. This was carried out by Porubcan et al. (2004) through numerically integrating both the orbital evolution of the NEO and the meteoroid stream. Integrating the evolution of a meteoroid stream can be expensive due to the large number of particles involved and here we describe an alternative, and computationally cheaper, approach to the problem.

If the break-up of a comet was part of its history, then one might expect several large fragments to be present within the meteoroid stream. Such fragments should show the same evolutionary pattern as the stream. We thus integrate only the orbits of NEOs that might be suspected of being such fragments and calculate the characteristics of a theoretical meteor shower that would be formed at each location where the nodal distance of the NEO is 1 AU, assuming the orbital elements to be those of the NEO. We then have to ascertain whether a known meteor shower has these characteristics.

3 'Asteroids' Associated with Meteor Showers and Meteorite Streams

Babadzhanov et al. (2008a, 2008b, 2009) have used the procedure described above in order to identify NEOs that can be associated with meteor showers that are related to three well know showers, the Piscids, the Taurids and the Iota Aquariids. Such associations indicate that they are likely to be fragments of a comet. The results are summarized in Tables 1, 2 and 3. In Tables 1-3 the values of the

D-criterion which quantifies the similarity between the orbits of a meteor shower and an NEO are also given, calculated using the formula given by Steel et al. (1991) namely

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

All the determined values of the *D*-criterion satisfy $D < 0.3$ showing that the meteor showers and the NEOs under investigation move on very similar orbits implying that the meteoroid stream also contains large fragments of the parent comets.

Table 1. Orbital elements for NEOs and showers in the Piscid Complex.

Name	q	e	i	λ	α	δ	D
N.Piscids	0.40	0.80	6	174	3	8	-
1997GL3	0.49	0.78	7	178	0	8	0.09
2000PG3	0.34	0.88	12	172	0	10	0.14
2002JC9	0.38	0.85	6	169	357	4	0.05
S.Piscids	0.44	0.82	3	179	7	-1	-
1997GL3	0.45	0.80	6	173	3	-6	0.06
2000PG3	0.37	0.87	14	174	6	-1	0.21
2002JC9	0.38	0.83	6	167	0	-6	0.08
Ass.25	0.34	0.78	6	31	13	10	-
1997GL3	0.45	0.80	6	21	10	11	0.11
2000PG3	0.36	0.87	13	37	19	20	0.15
2002JC9	0.38	0.83	6	30	16	13	0.06
Ass.30	0.27	0.83	11	30	14	3	-
1997GL3	0.49	0.78	7	17	14	-2	0.24
2000PG3	0.35	0.88	13	38	28	1	0.10
2002JC9	0.38	0.85	5	28	19	3	0.15

Table 2. Orbital elements for NEOs and showers in the Taurid Complex.

Name	q	e	i	λ	α	δ	D
N.Taurids	0.36	0.86	2.4	231	59	22	-
16960	0.27	0.88	18.2	200	31	25	0.29
1998VD31	0.49	0.81	6.7	244	65	29	0.16
1999VK12	0.46	0.79	7.3	230	52	27	0.15
1999VR6	0.53	0.76	7.9	231	50	28	0.22
2003UL3	0.41	0.82	3.7	239	65	25	0.07
2003WP21	0.45	0.80	1.5	239	63	23	0.11
2004TG10	0.31	0.86	3.2	224	55	22	0.05
S.Taurids	0.37	0.81	5.2	221	51	14	-
16960	0.30	0.87	19.9	202	41	1.4	0.27
1998VD31	0.52	0.81	9.4	247	70	11	0.17
1999VK12	0.50	0.78	9.4	233	59	9	0.15
1999VR6	0.49	0.78	9.1	228	53	8	0.14
2003UL3	0.44	0.81	5.9	241	68	16	0.07
2003WP21	0.49	0.79	3.8	242	66	17	0.12
2004TG10	0.29	0.87	5.0	221	54	16	0.10
ζ-Perseids	0.34	0.79	0.0	79	62	23	-
16960	0.29	0.87	19.5	85	64	35	0.30

Table 2. (continued) Orbital elements for NEOs and showers in the Taurid Complex.

Name	q	e	i	λ	α	δ	D
1998VD31	0.52	0.81	9.3	76	69	33	0.24
1999VK12	0.50	0.78	9.3	70	61	31	0.23
1999VR6	0.49	0.78	9.1	66	56	30	0.22
2003UL3	0.44	0.81	6.0	91	82	29	0.15
2003WP21	0.48	0.79	3.8	81	75	27	0.15
2004TG10	0.33	0.85	5.4	99	86	28	0.11
β-Taurids	0.33	0.85	6.0	97	87	19	-
16960	0.31	0.86	18.0	83	68	9	0.21
1998VD31	0.49	0.81	6.6	79	74	15	0.17
1999VK12	0.47	0.79	7.1	74	67	14	0.15
1999VR6	0.53	0.76	7.8	62	59	11	0.22
2003UL3	0.41	0.82	3.5	94	85	20	0.10
2003WP21	0.45	0.80	1.4	85	77	21	0.15
2004TG10	0.31	0.86	2.9	101	87	21	0.06

Table 3. Orbital elements for NEOs and showers in the Iota Aquariid complex.

Name	q	e	i	λ	α	δ	D
N.ι-Aquariids	0.26	0.86	8	132	330	-5	-
2002PD11	0.32	0.85	7	150	342	-2	0.06
2002JS2	0.38	0.83	8	150	341	-1	0.12
2003MT9	0.16	0.94	4	116	319	-14	0.15
S. ι-Aquariids	0.26	0.86	8	134	337	-13	-
2002PD11	0.29	0.87	7	146	344	-12	0.04
2002JS2	0.34	0.84	7	147	344	-13	0.08
2003MT9	0.29	0.88	2	133	330	-13	0.11
April Piscids	0.31	0.80	4	29	10	8	-
2002PD11	0.29	0.87	7	29	11	10	0.09
2002JS2	0.33	0.84	7	22	5	8	0.07
2003MT9	0.16	0.94	4	323	10	2	0.21
April Cetids	0.28	0.83	9	29	10	1	-
2002PD11	0.32	0.86	7	26	13	0	0.06
2002JS2	0.36	0.83	8	18	8	-4	0.08
2003MT9	0.30	0.88	2	13	-1	1	0.13

4 Conclusions

In all three cases a number of NEOs were found that could have formed observable meteor showers. We thus conclude that the break up of a comet nucleus, leaving a number of fragments as well as a meteoroid stream, is common, supporting the view of Asher et al. (1993), and Jenniskens and Vaubillion (2008). We also conclude that a number of objects, currently classified as asteroids, are in fact cometary fragments.

References

D.J. Asher, S.V.M. Clube, D.I. Steel, Asteroids in the Taurid Complex. R.A.S. Monthly Notices **264**, 93-105 (1993)

P.B. Babadzhanov, Yu.V. Obrubov, Evolution of short-period meteoroid streams. Celestial Mech. Dyn. Astron. **54**, 111-127 (1992)

P.B. Babadzhanov, I.P. Williams, G.I. Kokhirova, Near-Earth asteroids amongst the Piscids meteoroid stream. Astron. & Astrophys. **479**, 149-255 (2008a)

P.B. Babadzhanov, I.P. Williams, G.I. Kokhirova, Near-Earth asteroids in the Taurid complex. R.A.S. Monthly Notices **386**, 1436-1442 (2008b)

P.B. Babadzhanov, I.P. Williams, G.I. Kokhirova, Near-Earth asteroids amongst the Iota Aquariid meteoroid stream. Astron. & Astrophys. **507**, 1067-1072 (2009)

K. Fox, I.P. Williams, D.W. Hughes, The Geminid asteroid (1983TB) and its orbital evolution. R.A.S. Monthly Notices **208**, 11-15 (1984)

P. Jenniskens, 2003EH1 is the Quadrantid Shower parent comet, Astrophys. J. **127**, 3018-3022 (2003)

P. Jenniskens, J. Vaubaillion, Minor Planet 2008ED69 and the Kappa Cygnid meteor shower. Astrophys. J. **136**, 725-730 (2008)

V. Porubcan, I.P. Williams, L. Kornos, Associations between asteroids and meteoroid streams. Earth Moon Planets **95**, 697-712 (2004)

D.I. Steel, D.J. Asher, S.V.M. Clube, The Structiure and evolution of the Taurid complex. R.A.S. Monthly Notices **251**, 632-648 (1991)

F.L. Whipple, 1983 TB and the Geminid Meteors. IAU Circular **3881**, 1W (1983)

I.P. Williams, G.A. Ryabova, A.P. Baturin, A.M. Chernitsov, The parent of the Quadrantid meteoroid stream and asteroid 2003EH1. R.A.S. Monthly Notices **355**, 1171-1181 (2004)