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On the association of the daytime Taurid complex meteor streams with asteroids

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Summary. — The Taurid meteor complex daytime streams Zeta Perseids and Beta Taurids are investigated from the viewpoint of their orbital evolution and relation to the streams of the preperihelion branch of the complex. A search for potential co-parents among NEOs known until mid-June 2005 is made and two candidates for the association with the Zeta Perseids and two for the Beta Taurids are found. The Beta Taurids are shown to be postperihelion continuation of the Northern Taurids and Zeta Perseids are continuation of two complex filaments related to the Southern Taurids.

PACS `96.50.Kr` – Meteors and meteoroids.
PACS `95.85.Bh` – Asteroids.

1. – Introduction

Whipple already in 1940 in his analysis of photographic meteor orbits of the Taurid stream [1] suggested that due to a low inclination the stream has to cross the Earth's orbit also in its postperihelion passage in June-July and could be observed as a daytime stream. The stream was first detected at the Jodrell Bank Observatory in 1947 [2] by the observatory radio equipment as the Zeta Perseids active in June 2-17 and Beta Taurids active in June 20-27. The radio observations in the following years carried out at Jodrell Bank and other observatories revealed longer activity periods of the streams in the period May-July and enabled to determine also the orbits of individual meteors, *e.g.* [3-7].

There were practicaly no studies of the activity of the streams after 1960's. The most current investigation of the activity and mass distribution based on forward scatter observations by the BLM equipment (Budrio-Lecce-Modra, Italy-Slovakia) and backscatter radio observations by the Ondřejov meteor radar (Czech Republik) was performed by Pupillo *et al.* [8] and Pecina *et al.* [9].

TABLE I. – *The mean orbits of the Zeta Perseids and Beta Taurids derived from radio observations (postperihelion), the associated Taurid filaments derived from photographic data (preperihelion) and NEOs potentially related to them.*

Stream	q (AU)	a (AU)	e	i (°)	ω(°)	Ω(°)	π(°)	Number
Zeta Perseids								
Cook [13]	0.34	1.6	0.79	0.0	59.0	78.7	137.7	
Sekanina [6]	0.319	1.918	0.834	5.3	59.2	78.3	137.5	73
Beta Taurids								
Cook [13]	0.34	2.2	0.85	6.0	246.0	277.1	163.1	
Sekanina [6]	0.325	1.853	0.825	2.2	239.2	275.2	154.4	57
Taurid filaments [10]								
Tau 04	0.338	1.465	0.770	6.1	121.8	359.5	121.3	5
Tau 05	0.318	1.925	0.837	5.7	120.1	10.9	131.0	5
Southern Taurids	0.365	2.187	0.833	5.3	113.1	43.3	156.4	56
Northern Taurids	0.358	2.174	0.835	2.7	293.7	228.6	162.3	38
1999 RK45	0.363	1.598	0.773	5.9	4.0	120.1	124.1	
2003 QC10	0.369	1.377	0.732	5.0	120.4	0.3	120.7	
2003 UV11	0.344	1.451	0.763	5.9	124.6	32.2	156.8	
2004 TG10	0.315	2.242	0.860	3.7	310.0	212.3	162.3	

In the present paper a possible association of the near-Earth's objects (NEOs) moving close to the Taurid meteor complex daytime streams the Zeta Perseids and Beta Taurids is investigated. The study is based on following the orbital similarity and orbital evolution of both streams and NEOs potentially associated with them.

2. – Analysis

Porubčan *et al.* [10] have recently investigated the structure of the Taurid meteor complex (TMC) and searched for potential co-parents of the complex or its streams and filaments among all NEOs known until the mid-June 2005 (3380 objects in the Asteroid Orbital Elements Database managed by T. Bowell, Lowell Observatory). In the first step a stream search utilizing the Southworth-Hawkins D criterion [11] was applied to the sample of photographic meteor orbits of the Meteor Data Center catalogue [12]. To get the cores or central parts of the streams or sub-streams a strict limiting value of $D \leq 0.1$ was applied and up to twenty filaments relating to the Taurid complex could be selected.

Further a search for NEOs to be potentially associated with the Taurid filaments was made. In the first step orbital similarity was verified by comparing the mean orbits of the filaments with the orbits of NEOs applying the D criterion which for two orbits in space defines a distance function in terms of the osculating orbital elements (q, e, i, ω, Ω). 91 asteroids were found moving close to the complex within the value of $D \leq 0.3$. In the next step their potential association with the filaments was verified by following the orbital evolution of both the asteroids and filaments. As a result, possible associations between 8 TMC filaments and 15 NEOs were revealed.

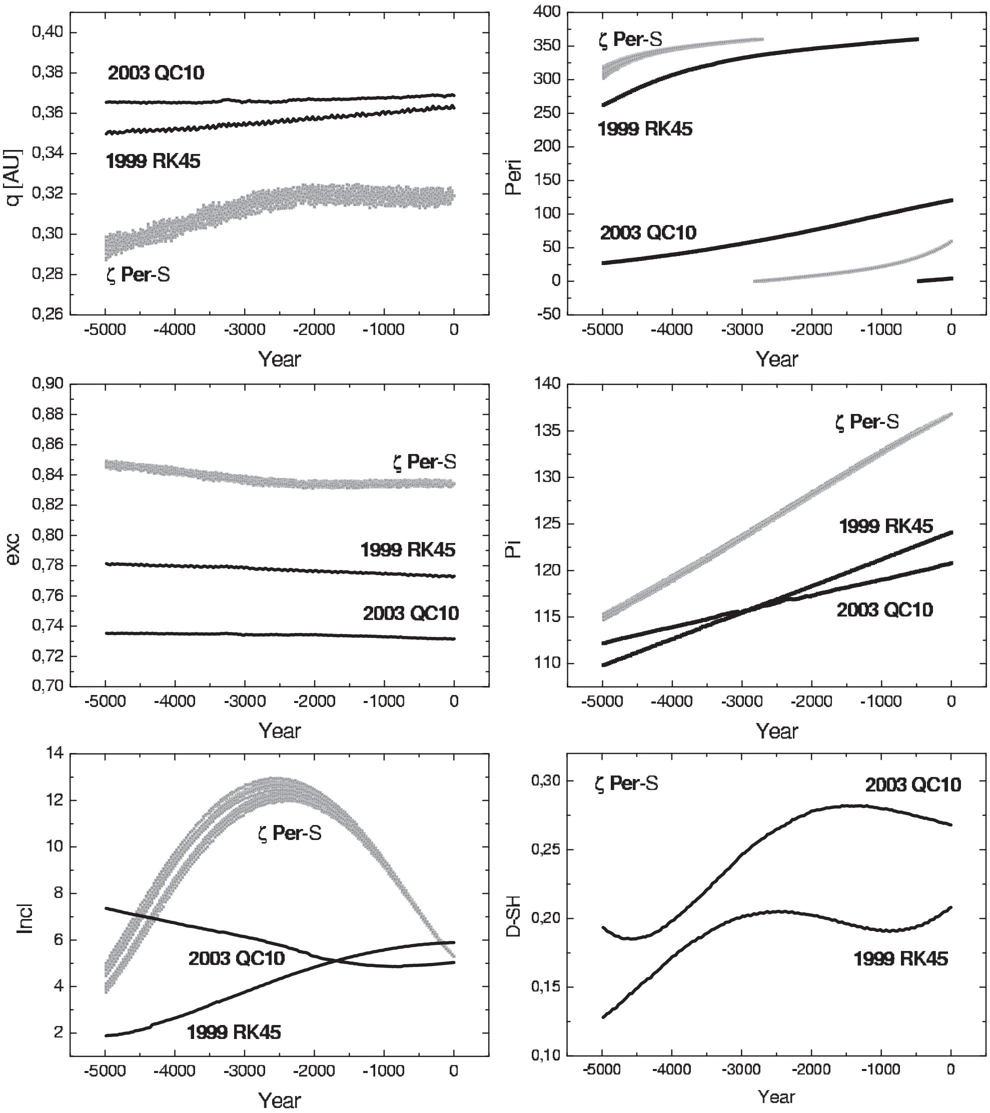

Fig. 1. – Backward integration of the orbits of the Zeta Perseids and asteroids 1999 RK45 and 2003 QC10 over 5000 years and related Southworth-Hawkins *D* criterion value.

For the present analysis, we have applied the same procedure in order to look for asteroids moving close to the streams of the Taurid meteor complex in its postperihelion passage observed as the daytime streams Zeta Perseids and Beta Taurids. Both streams are members of a huge complex of different sub-streams belonging to the TMC and one can expect that the same bodies or at least the majority of them will be close to both preperihelion and postperihelion branches of the TMC.

The orbital elements of the Zeta Perseids and Beta Taurids can be obtained from radio observations only and the most compact information so far, including all basic parameters, the activity periods, radiants, velocities and mean orbits were published by

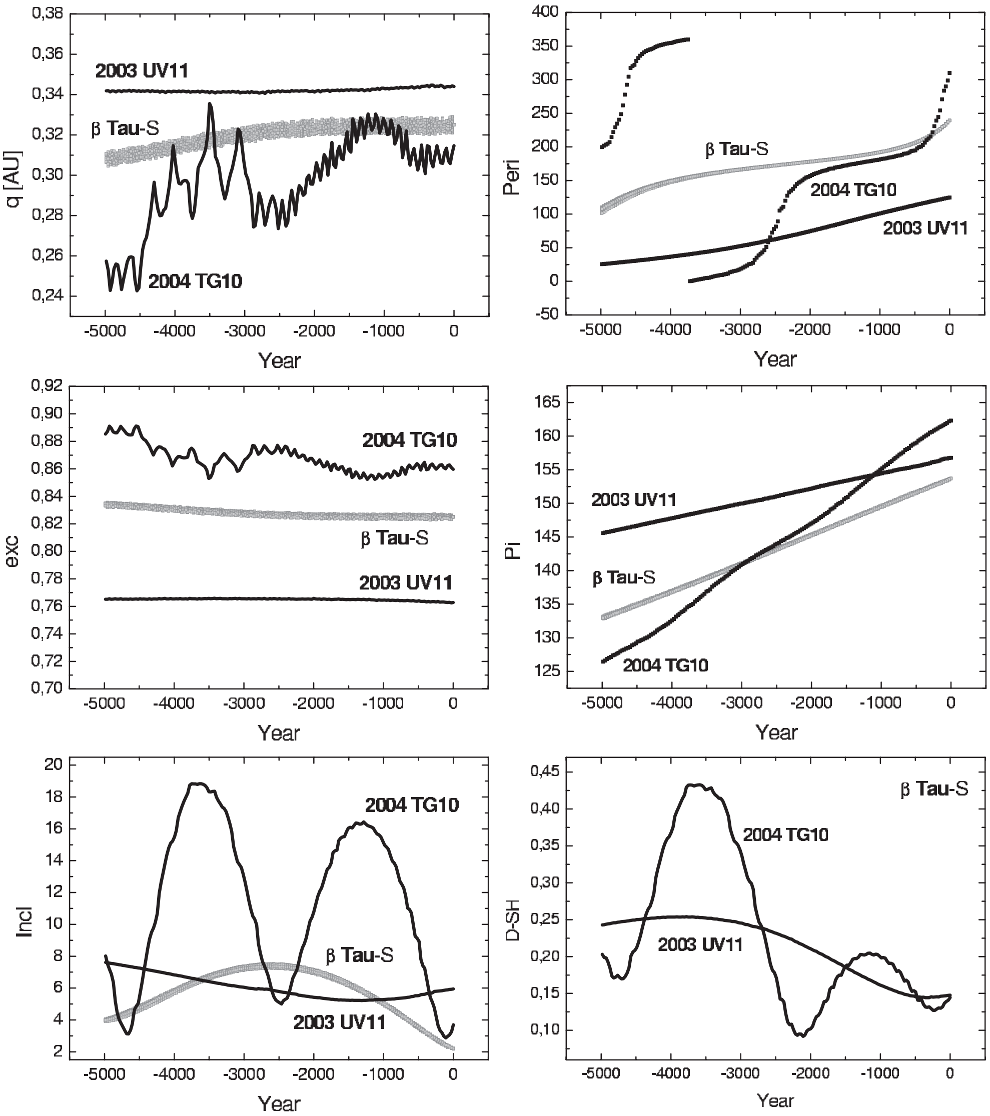

Fig. 2. – Backward integration of the orbits of the Beta Taurids, asteroids 2003 UV11 and 2004 TG10 over 5000 years and related Southworth-Hawkins D criterion value.

Cook [13] and Sekanina [6, 7]. The corresponding mean orbits for both the streams are listed in table I. The mean orbits by Sekanina are based on 73, respectively 57, individual orbits and were obtained in the frame of the Harvard Radio Meteor Project in 1960th. The angular elements in table I are referred to equinox 2000.0.

In the first step of the analysis the NEOs moving close to the streams were searched for by comparison of the osculating orbits of known NEOs (3380 objects known until mid-June 2005) with the mean orbits of the Zeta Perseids and Beta Taurids listed in table I. Due to the fact that the mean orbits published by Sekanina [6] are based on relatively large sets of individual orbits and were obtained by the same equipment (Cook does not

TABLE II. – *Basic parameters of the Taurid meteor complex postperihelion streams and potentially associated asteroids.*

Stream	R.A. (∘)	Dec. (∘)	V_g (km/s)	H (mag.)	Diameter (m)	D_{SH}	Period (y)
Zeta Perseids [6]	60	25	29				
1999 RK45	47	21	24	19.32	360	0.12-0.20	1700
2003 QC10	43	19	24	17.83	800	0.18-0.20	1000
Beta Taurids [6]	80	22	28				
2003 UV11	83	25	26	19.30	410	0.20-0.15	2000
2004 TG10	88	23	30	19.40	390	0.20-0.08	2500

list from how large sets are the mean orbits of the streams derived, neither sources), the Harvard orbits were chosen as the reference mean orbits for the Zeta Perseids and Beta Taurids. For the analysis only asteroids for which the value of $D \leq 0.3$ were selected and thus 19 NEAs were found moving close to the both daytime streams.

The orbital similarity of two osculating orbits cannot be conclusive for a decision about an association between bodies moving in them. More conclusive is a study of the orbital evolution. Followingly, to study the associations between the Zeta Perseids, the Beta Taurids and asteroids the orbital evolution of the mean orbits of the streams and all 19 asteroids was investigated. We have applied for the backward integration of the orbital evolution the multistep procedure of Adams-Bashforth-Moulton's type up to 12th order, with variable step-size, developed by Shampine and Gordon [14]. Though meteoroid streams can be typically recognized over a time scale 10^3–10^4 years, we have followed the orbital evolution of all the bodies for 5000 years, the time which could be considered sufficient to indicate on potential associations between the studied objects.

In the next step only asteroids for which the value of D over the period of integration was $D \leq 0.20$, were considered for relatively close to the streams and as possible candidates for co-parents. In this way asteroids 1999 RK45, 2003 QC10 can be associated to the Zeta Perseids and asteroids 2003 UV11 and 2004 TG10 to the Beta Taurids.

The results of integration are presented on plots in fig. 1 and fig. 2. In the plots, there are diagrams depicting the evolution of the orbital elements: perihelion distance (q), eccentricity (e), inclination (i), argument of perihelion (ω) and longitude of perihelion (π) over 5000 years. Figures 1 and 2 also show the variation of the D criterion describing the degree of similarity between the orbits of the Zeta Perseids, the Beta Taurids and corresponding asteroids, respectively.

All the four asteroids are moving close also to the autumn Taurid stream [10] and are probable co-parents of the N and S Taurids (2003 UV11, 2004 TG10) and of two filaments Tau 05 and Tau 07 from the beginning of the Taurid complex activity related to the S Taurids (1999 RK45 and 2003 QC10). The mean orbits of the filaments as well as of the associated asteroids are listed in table I.

Basic information on "possible" associations between the Zeta Perseids, the Beta Taurids and NEOs are summarized in table II, where besides the theoretical meteor radiants [15] and geocentric velocity are listed also the absolute magnitude of the asteroid H, the diameter in meters defined from the albedo $A = 0.05$, the change of D criterion value and period of integration in which $D \leq 0.20$.

Comparison of the orbital evolution of the Zeta Perseids and Beta Taurids with the probable associated asteroids over the period of integration of 5000 years (figs. 1, 2) assessed by the Southworth-Hawkins criterion $D_{\rm SH}$ indicates a close association between the Beta Taurids and asteroids 2003 UV11 and 2004 TG10 over the last 2000–2500 years. The radiant position and geocentric velocity in table II refer to the osculating orbits. On the association of the Zeta Perseids with asteroids 1999 RK45, 2003 QC10 can be inferred for about 5000-3000 years ago when the asteroids were very close to the stream and could take part in the stream generation.

3. – Conclusions

The spring/summer Taurid complex meteoroid streams, the Zeta Perseids and Beta Taurids with the peak activity about June 9 and June 29, respectively, were searched for potential co-parents. Of the 3380 NEOs known until the mid-June 2005, 19 objects were found to move close to the streams satisfying the Southworth-Hawkins criterion value $D \leq 0.30$.

Following the orbital evolution of the streams and NEOs over 5000 years, four asteroids over the period of integration kept the value of $D \leq 0.20$ and can be considered for related to the streams: 1999 RK45, 2003 QC10 to the Zeta Perseids and 2003 UV11, 2004 TG10 to the Beta Taurids. All four asteroids are moving also close to the autumn Taurids and are probable co-parents of their northern and southern branches.

The Beta Taurids are postperihelion continuation of the Northern Taurids. The Zeta Perseids are continuation of the Southern Taurids and of two filaments from the ascending branch of the TMC activity related to the Southern Taurids.

The asteroids moving within the Zeta Perseids and Beta Taurids are small bodies, in size smaller than one kilometer and taking into account present systematic monitoring of the sky, it can be expected that new additional NEOs of sizes up to few hundred meters moving in the Taurid meteor complex will be discovered soon.

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REFERENCES

[1] Whipple F. L., *Proc. Am. Philos. Soc.*, **83** (1940) 711.
[2] Kronk G. W., *Meteor Showers: A Descriptive Catalogue* (Enslow Publ., Hillside, USA) 1988.
[3] Aspinall A. and Hawkins G. S., *Mon. Not. R. Astron. Soc.*, **111** (1951) 18.
[4] Kashcheyev B. L. and Lebedinets V. N., *Smithson. Contrib. Astrophys.*, **11** (1967) 183.
[5] Gartrell G. and Elford W. G., *Aust. J. Phys.*, **28** (1975) 591.
[6] Sekanina Z., *Icarus*, **18** (1973) 253.
[7] Sekanina Z., *Icarus*, **27** (1976) 265
[8] Pupillo G., Porubčan V., Pecina P., Pecinová D., Cevolani G. and Zigo P., *Nuovo Cimento C*, **28** (2006) submitted.
[9] Pecina P., Porubčan V., Pecinová D. and Tóth J., *Earth, Moon and Planets*, **95** (2005) in print.
[10] Porubčan V., Kornoš L. and Williams I. P., *Contrib. Astron. Obs. Skalnate Pleso*, **36** (2006) submitted.

[11] Southworth R. B. and Hawkins G. S., *Smithson. Contrib. Astrophys.*, **7** (1963) 261.
[12] Lindblad B. A., Neslušan L., Porubčan V. and Svoreň J., *Earth, Moon, and Planets*, **93** (2003) 249.
[13] Cook A. F., *Evolutionary and Physical Properties of Meteoroids*, edited by Hemenway C. L., Millman P. M. and Cook A. F. (1973), p. 183.
[14] Shampine L. F. and Gordon M. K., *Computer Solution of Ordinary Differential Equations* (Freeman and Comp., San Francisco) 1975.
[15] Neslušan L., Svoreň J. and Porubčan V., *Astron. Astrophys.*, **331** (1998) 411.