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Northern Taurids in the IAU MDC Database

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Abstract. The method of indices was used to study the northern branch of the autumn (night) part of the Taurid complex. The procedure based only on mathematical statistics was applied to select the Northern Taurid meteor records from the IAU Meteor Data Center Database. Because we wanted to study especially the structure of the inner part of the Northern Taurids, we were focused on the interval of the higher activity of the stream – from the end of the Perseids activity to the beginning of the Geminids activity. We did not take into account outlying parts of the complex, which is active, according to some authors, until January. 84 orbits of the Northern Taurids were selected. 63 of 84 Northern Taurids orbits (75%) were sorted into 11 associations found in the stream. One of the associations consisting of three orbits was identified as a previously unknown northern branch of τ Arietids shower. We also found an association with orbital characteristics equal to the characteristics of showers δ Psc N and χ Ori N. Meteors in these associations were observed up to three weeks earlier compared to currently cataloged data of the showers. The orientation of the mean orbit of a 5-member association of δ Psc N, different from the general trend, indicates that this stream may not be genetically related to other members of the Taurid complex.
Key words: meteors – photographic orbits – Taurids

1. Introduction

In the period of autumn, many small showers are observed. Some of them belong to the complex system called the Taurids complex.

The aim of this paper was an analysis of the distribution of Northern Taurids (hereinafter NT) at the observation interval and consequently inside the meteoroid stream. Studied members of Northern Taurids were selected from the IAU MDC database of photographic orbits using the method of indices. Subsequently, we have analyzed a structure of the dispersed stream of meteoroids and its relationship to small autumn showers or associations.

According to the photographic observations (e. g., Porubčan *et al.*, 2006), the Taurids have two radiants – more active Southern Taurids and Northern Taurids. In this work we have studied the Northern part, which is crossed by the Earth 48 days. As already found by Plavec (1956), the transit of the Earth across the Northern branch of the stream corresponds to the transverse dimension of about 95 million km. The first photographic observations made by Whipple

(1940) confirmed the wide spread of the Taurids radiants. Moreover, it was shown that the Taurids have short-period orbits and are associated with the comet 2P/Encke (for the orbital parameters see Table 1). Porubčan and Štohl (1987 a, b) analyzed photographic meteors considered by individual authors as the Taurids. Despite to a dispersion of the Taurids orbits caused by the geometry of the collision of meteoroids with the Earth, the real observed dispersion found on the basis of precise photographic orbits is extraordinary large (semi-major axis $1.2 < a < 3.0$ AU and eccentricity $0.72 < e < 0.94$) (Porubčan, 1978).

2. Selection of Northern Taurids

The International Astronomical Union Meteor Data Center database (hereinafter IAU MDC database) of photographic orbits (Lindblad *et al.*, 2005) was used to obtain the set of the Taurids orbits. To select the Taurids, we used the method of indices (described in details by e. g. Svoreň *et al.*, 2000; Svoreň *et al.*, 2006). The method is based on a comparison of meteoroid orbits on the basis of their *indices* – set accordingly to the values of 5 orbital elements (perihelion distance q, eccentricity e, argument of perihelion ω, longitude of ascending node Ω, inclination i) and 3 geocentric parameters (right ascension α and declination δ of the radiant, and geocentric velocity v_{g}) of individual meteoroids. In accordance with previous results (Porubčan *et al.*, 1995), 46 meteors of the IAU MDC database with heliocentric velocities higher than $48\,\mathrm{km\,s^{-1}}$ were not included in the analysis. Thus the final set of database consisted of 4526 orbits. The obtained list of selected Taurids was published in the previous paper (Svoreň *et al.*, 2011).

Because the study of only the inner part of the Taurids stream was in focus, we analyzed the meteor records within the interval of the higher activity of the shower, i.e. between the end of the activity of the Perseids (beginning of September) and the early activity of the Geminids (beginning of December). We did not take into account the edge parts of the complex, although, according to some authors, the meteor shower is active until January. We selected only the meteors with a perihelion distance smaller than 0.5 AU, as for Northern Taurids $q = 0.375$ AU (e. g. Cook, 1973). Thus, we selected 84 Northern Taurids from the IAU MDC database (see Table 1).

Table 1. The mean orbit of the Northern Taurids (Svoreň *et al.*, 2011) and the orbit of 2P/Encke (in the same precision as mean orbits of the meteoroids, although the cometary orbit is known with higher precision).

	q	e	ω	Ω	i
Northern Taurids	0.352	0.833	294.9	216.3	3.1
Comet 2P/Encke	0.331	0.850	186.3	334.7	11.9

3. Associations

In the next, we were searching for associations of meteoroid orbits (i. e. at least 3 meteors with similar orbits) in the dataset of 84 meteors. Following the principles of the method of indices, we divided the least precise parameter of the set of orbits – longitude of ascending node in this case – into 2, 3, 4 and 5 intervals. Here we present the results obtained with the most reasonable division of Ω into 2 intervals. Consequently, an empirical value (2.017) was used to determine a basic division of other 4 orbital elements and 3 geocentric parameters used in the method (see Table 2).

Table 2. The standard errors (SEs) and the numbers of intervals of division for the northern branch of Taurids.

	q	e	ω	Ω	i	α	δ	$v_{\rm g}$
SE	0.066	0.040	8.0	25.1	1.4	23.7	7.3	2.22
Range	0.282	0.218	36.5	95.8	6.2	98.5	32.5	12.07
Range/SE	4.27	5.45	4.56	3.82	4.43	4.16	4.45	5.44
Range/SE/2.017	2.12	2.70	2.26	1.89	2.20	2.06	2.21	2.70
Intervals	2	3	2	2	2	2	2	3

Using this division, we found 11 associations of Northern Taurids. Dependencies of the orbital parameters and positions of radiants of 11 associations are plotted in Figs. 1 a, b, c.

We found 11 associations consisting of 3 to 18 meteors for the Northern Taurids. The total number of meteors selected in associations is 63. The mean orbits of associations are listed in Table 3 and their projection into the ecliptic plane is plotted in Fig. 2.

Looking at the plot of mean orbits of associations it is easy to distinguish two groups of orbits which are differing mainly in the argument of perihelion.

4. Structure of the Northern Taurids stream and minor autumn showers and associations

Characteristics of 11 associations were compared to those of known showers listed in several catalogues:

– a Working List of Meteor Streams (Cook, 1973)

– the list of meteor showers by Kronk (http://meteorshowersonline.com)

– the list of meteor showers provided by International Meteor Organization (http://www.imo.net)

Table 3. Mean orbits of the Northern Taurids associations. NTA – designation of Northern Taurids Association, N – number of meteors in an association. The mean orbit of all associations is in the last row.

q	e	ω	Ω	i	α	δ	v_g	NTA	N
0.253	0.863	308.1	172.5	5.4	8.2	7.4	30.49	1	5
0.399	0.869	287.0	188.4	2.5	14.4	8.63	28.47	2	3
0.380	0.807	292.7	202.5	5.2	29.8	17.2	26.85	3	5
0.277	0.870	303.3	220.9	4.1	53.9	21.9	30.91	4	3
0.290	0.875	301.1	220.4	2.6	52.5	20.8	30.85	5	5
0.327	0.828	298.7	221.7	2.8	52.8	21.2	28.43	6	5
0.364	0.849	292.1	225.0	2.4	53.0	21.0	28.66	7	8
0.391	0.819	290.0	233.6	2.6	61.1	23.1	27.25	8	18
0.387	0.812	290.9	234.4	4.1	62.3	24.8	27.10	9	3
0.330	0.862	296.0	232.1	2.9	62.4	22.8	29.80	10	4
0.464	0.764	282.8	250.5	2.5	75.9	25.5	24.45	11	4
0.351	0.838	294.8	218.4	3.4	47.8	19.5	28.50		

– catalogues of the Meteor Data Center (http://www.ta3.sk/IAUC22DB/MDC2007/)

– orbital parameters of 78 fireball streams (Terentjeva, 1990)

We also compared our findings with the results of Porubčan *et al.* (2006), who identified 15 filaments of the Taurids stream.

Table 4. Identification of Northern Taurids associations. PKW – Taurids filaments by Porubčan *et al.* (2006).
(*) – only the southern branch has been known till now.

NTA	n	q	e	identification	a	Q	PKW
1	5	0.253	0.863	N δ Psc	1.847	3.440	Tau 3
2	3	0.399	0.869		3.046	5.693	
3	5	0.380	0.807	ι Ari	1.969	3.558	Tau 6
4	3	0.277	0.870	N τ Ari	2.131	3.985	*
5	5	0.290	0.875		2.320	4.350	
6	5	0.327	0.828	N Tau	1.901	3.475	
7	8	0.364	0.849	N Tau	2.411	4.457	Tau 10
8	18	0.391	0.819		2.172	3.953	
9	3	0.387	0.812		2.059	3.730	
10	4	0.330	0.862	N Tau	2.391	4.453	
11	4	0.464	0.764	N χ Ori	1.966	3.468	Tau 13

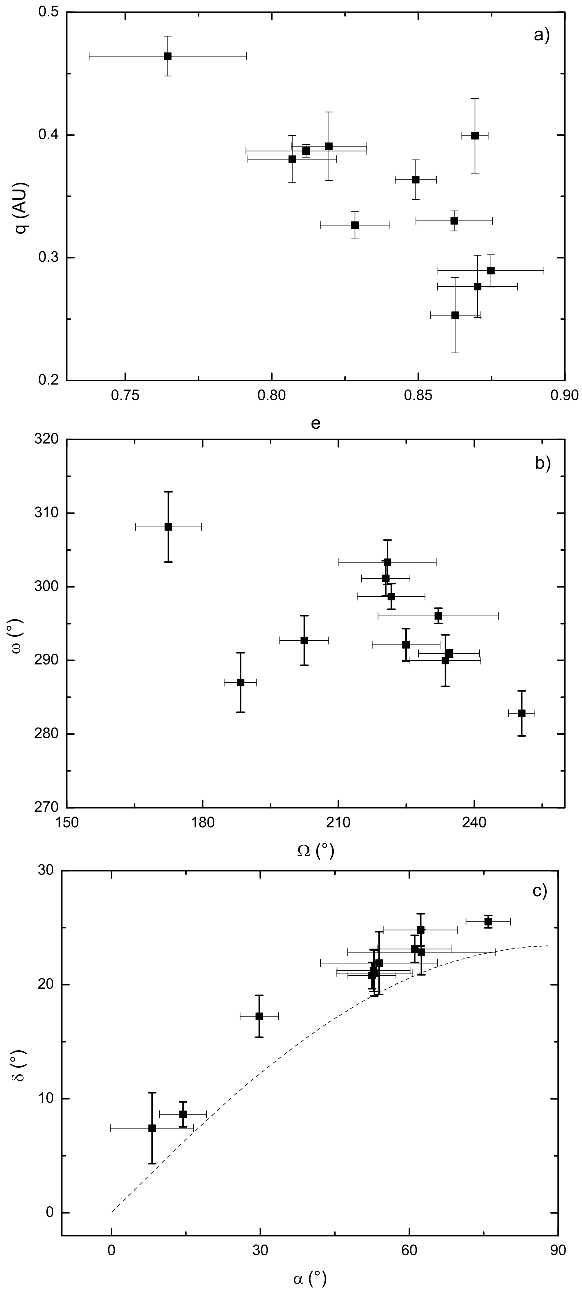

Figure 1. Dependences $q = q(e)$ and $\omega = \omega(\Omega)$ (a, b) for the selected associations of NT. c) The radiant motion of Northern Taurids is demonstrated by the radiant possitions of selected associations. A dashed line is the ecliptic.

The results of the analysis of the mean orbits of 11 associations are as follows:

– 63 of 84 (75%) Northern Taurids are selected to 11 associations designed as NTA1-NTA11

– 4 associations are identified with the known minor showers – δ Psc N, ι Ari, Taurids N, and χ Ori N

– the orbits of 4 associations are similar to the orbits of Taurids filaments found by Porubčan *et al.* (2006) utilizing the Southworth-Hawkins D-criterion. A designation of the filaments listed in Table 4 is the same as used in the referred paper.

As the activity interval of Taurids is quite long, the radiant position is changing significantly in time. That is why the identification of the associations with known showers was done mainly on the basis of the similarity of orbital elements rather than REC and DEC of radiants. It is important to note that due to the small input database (84 meteors) the majority of associations are composed of only 3 – 5 meteors. Although we considered all 11 associations in our study, it is necessary to confirm our results using an independent method and/or a more numerous input database. Also a computer modeling of the Taurids complex and its dynamical evolution could prove the reality of the picture here presented.

– In addition to the associations identified with the well known minor meteor showers, we found a very interesting association NTA4. Except for the argument of perihelion and longitude of ascending node, the orbital elements of NTA4 are similar to the orbital elements of Southern τ Arietids, listed as a bolid shower by Terentjeva (1990). However, ω and Ω rotated by 180° match well with the τ Ari S (see Table 5). Thus, NTA4 could be the north branch of τ Arietids, which has been not identified/observed yet.

Table 5. Orbital elements of τ Arietids.

	q	e	ω	Ω	i	v_g	α	δ	
3	0.277	0.870	303.3	220.9	4.1	30.9	53.9	+21.9	Association 4 – τ Arietids N – this paper
2	0.277	0.870	123.3	40.9	4.1	30.9			Association 4 – ω and Ω rotated by 180° – similar to τ Arietids S
1	0.334	0.841	117.1	41.8	5.2	31.2	52	+18	τ Arietids S – Terentjeva, 1990

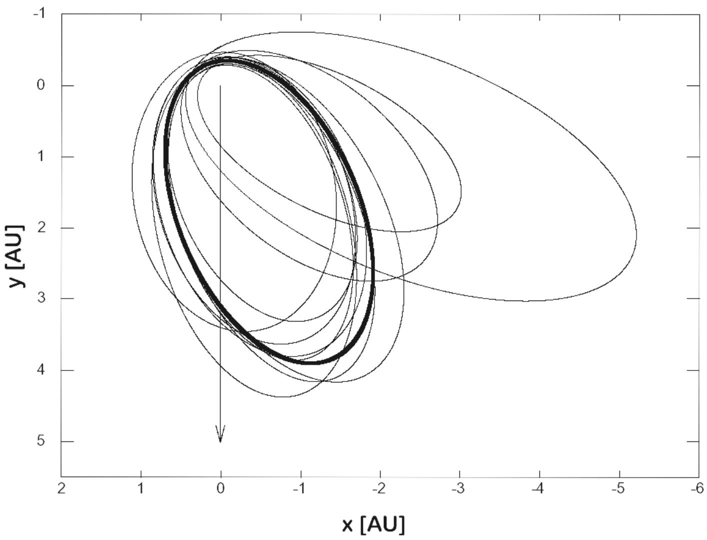

Figure 2. A projection of the mean orbits of the selected associations of Northern Taurids.

The small abundance of NTA4 (only 3 meteors) seems to be a weak point of τ Arietids N identification. However, for a very long time, there was only one photographic meteor in IAU MDC database associated to the well known shower η Aquarids (Lindblad *et al.*, 1994).

– Associations with the orbits most similar to the mean orbit of Northern Taurids (Svoreň *et al.*, 2011) are NTA6, NTA7, and NTA10.

There were found 2 associations with the orbital characteristic of well known minor showers, but active before the known showers activity intervals.

– The activity of δ Piscids N begins according to Cook (1973) on September 25, according to Terentjeva (1990) a bit earlier on September 12. However, all meteors of NTA01 identified with δ Piscids N were observed between September 3 and 22.

– Similarly, the activity of association NTA11 (November 27 – December 4) with orbital elements similar to χ Orionids N terminates before the known period of χ Ori activity (December 4 – 15; Cook, 1973).

5. Genetic relations within the associations and comet 2P/Encke

For the study of genetic relations between the orbits of associations and the orbit of accepted Taurids parent comet 2P/Encke, we calculated the values of the Southwort-Hawkins D-discriminant (Southworth and Hawkins, 1963) of all possible pairs of orbits.

Table 6. D-discriminants (×100) for northern associations of Taurids.

	1	2	3	4	5	6	7	8	9	10	11	2P
1		17	26	65	61	58	55	64	66	70	76	67
2	17		30	73	69	65	61	69	71	77	80	71
3	26	30		44	40	36	32	40	42	48	52	46
4	65	73	44		**5**	**9**	14	13	13	**8**	25	26
5	61	69	40	**5**		**6**	**10**	12	13	11	27	23
6	58	65	36	**9**	**6**		**7**	8	**10**	12	24	23
7	55	61	32	14	**10**	**7**		**10**	13	17	26	23
8	64	69	40	13	12	**8**	**10**		**4**	**10**	16	23
9	66	71	42	13	13	**10**	13	**4**		**9**	15	25
10	70	77	48	**8**	11	12	17	**10**	**9**		18	25
11	76	80	52	25	27	24	26	16	15	18		31

In Table 6, the values of $D \leq 0.10$ characterizing similar pairs of orbits are in bold. The lowest value for each association – indicating the most similar pair – is underlined. Values of the D-discriminant of associations and comet 2P/Encke are in the last column of the table. The limit D-values characterizing similar orbits are generally considered to be in the interval 0.20 – 0.30. Sekanina (1970) calculated and empirically confirmed the D-value 0.20 as a sufficiently strict criterion. But, for the study of similarity of Taurids and relevant asteroidal orbits Porubčan *et al.* (2006) used the value 0.30. Thus, as similar to the orbit of the parent comet, we considered the orbits of associations with $D \leq 0.25$. In Fig. 3 an evolution diagram of the associations is shown. It displays the most probable transits of meteoroids between the associations (black line) and associations and the parent comet (dashed lines). The analysis of D-discriminant values leads to the following conclusions:

– There is evident a very compact group in the Northern Taurids system composed of the associations NTA4-NTA10.

– Associations NTA1, NTA2, NTA3 at the beginning, and NTA11 at the end of the activity interval seem to be dynamically separated from the central part of the system. The weak dynamical connection of these associations with the rest of the system could be real and/or it could be the effect of low sensitivity of the D-criterion in the case of distant orbits.

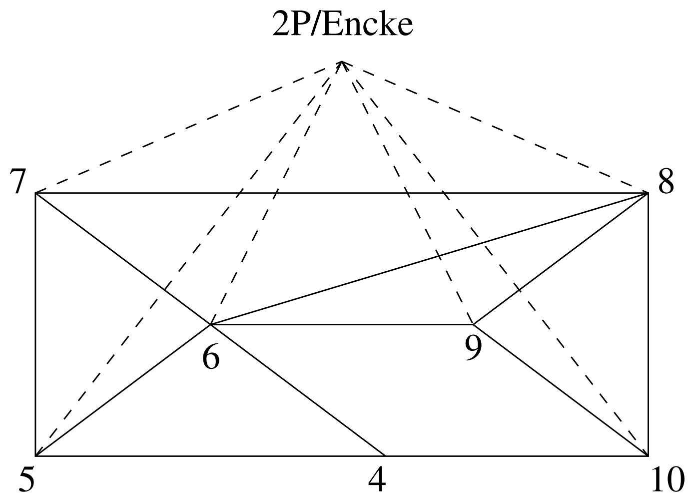

Figure 3. The scheme of the Northern branch of Taurids. For the details see the text.

6. Conlusions

We have found 11 associations of Northern Taurids selected from the IAU MDC database. Beside the identification of other well known minor meteor showers, one of the associations was identified as a previously unknown northern branch of τ Arietids shower. The low values of the D-discriminant calculated for different pairs of NT associations indicate that many catalogued minor meteor showers could be genetically related to the meteor complex of periodic comet 2P/Encke. We propose that meteoroids originating in 2P/Encke can reach the most distant orbits of the complex through some transition orbits (some associations). However, more specific studies (computer modeling) are necessary to determine if the dynamical relations found between the NT associations are sufficient to explain the existence of the whole NT complex in the case of one parent body. Otherwise, additional parent body is probably necessary to supply the complex.

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