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Southern Taurids in the IAU MDC Database. Taurid complex.

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Abstract. The method of indices was used to study the autumn (night) part of the Taurid complex. The procedure based only on mathematical statistics was applied to select the Southern Taurid meteor records from the IAU Meteor Data Center Database (IAU MDC). 143 orbits of the Southern Taurids were selected. 114 orbits (80% of 143) are grouped into 13 associations.

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.

In the previous work (Kaňuchová and Svoreň, 2012), we have studied the Northern branch of the stream. We have selected 84 orbits of Northern Taurids (NT) from the International Astronomical Union Meteor Data Center database (IAU MDC database) of photographic orbits (Lindblad et al., 2003) using the method of indices (described in detail by, e.g., Svoreň et al., 2000, and 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, and inclination i) and 3 geocentric parameters (right ascension α and declination δ of the radiant, and geocentric velocity v_g) of individual meteoroids.

Here we present the analysis of 143 orbits of Southern Taurids (ST) selected from the IAU MDC database using an analogous procedure as in the previous work, and provide a global view of the Taurids complex. The lists of selected 84 NT and 143 ST from the IAU MDC Database were published in our previous paper (Svoreň et al, 2011). The mean orbits of the selected Northern and Southern Taurids, together with the orbit of their parent comet 2P/Encke, are given in Table 1.

1.1. Taurids associations

To provide a whole view of the Taurid complex in the IAU MDC database, we present an analysis of the southern branch as well as some findings from the

Table 1. The mean orbit of NT (Svoreň et al., 2011) and ST (Kaňuchová and Svoreň, 2012) 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; taken from http://ssd.jpl.nasa.gov/ for epoch 1995-10-10).

	q	e	ω	Ω	i
Northern Taurids	0.352	0.833	294.9	216.3	3.1
	±0.066	±0.040	±8.0	±25.0	±1.4
Southern Taurids	0.347	0.826	116.4	32.9	5.4
	±0.064	±0.455	±8.2	±18.9	±1.5
Comet 2P/Encke	0.331	0.850	186.3	334.7	11.9

previous study of NT associations (Kaňuchová and Svoreň, 2012), whose mean orbits are listed in Table 3.

Using the method of indices we were searching for associations of ST (i.e. at least 3 meteors at similar orbits) in the dataset of 143 orbits. Following the principles of the method of indices, we divided the least precise parameter of the set of orbits - the perihelion distance q - into 2, 3, 4 and 5 intervals. Taking into account the quantity of the ST dataset and the number of selected meteors into the associations, we consider the results obtained with the division of q into 2 intervals as the most reasonable. Consequently, an empirical value (2.429) was used to determine 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 of ST.

	q	e	ω	Ω	i	α	δ	v_g
SE	0.064	0.046	8.3	19.0	1.5	16.4	4.9	2.33
Range	0.274	0.245	38.0	94.7	9.7	85.6	26.0	12.11
Range/SE	4.28	5.33	4.58	4.98	6.46	5.22	5.31	5.20
Range/SE/2.429	1.76	2.19	1.88	2.05	2.66	2.15	2.19	2.14
Intervals	2	2	2	2	3	2	2	2

Using this division, we found 13 associations of ST formed by 114 orbits (80% of 143). The mean orbits of associations are listed in Table 4 and dependences of their orbital parameters are plotted in Fig. 1. (Analogous figures for NT are presented in the previous work (Kaňuchová and Svoreň, 2012)).

Positions of the radiants of both Northern and Southern Taurids associations are plotted in Fig. 2. The projection of the orbits of the ST associations into the ecliptic plane is plotted in Fig. 3b. 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.

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 NTA is given in the last row. Taken from Kaňuchová and Svoreň (2012).

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	28.5	mean or.	

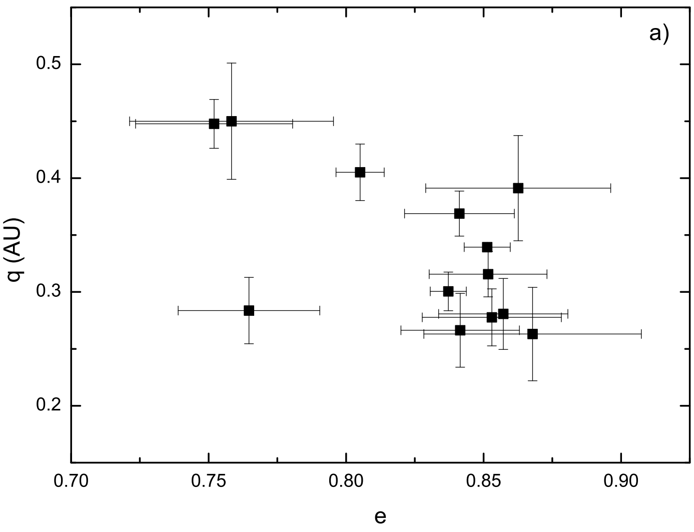
2. Structure of the Taurids stream and minor autumn showers and associations

Characteristics of 13 ST associations, (and 11 NT associations in the previous case) 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 the International Meteor Organization (www.imo.net).
- Catalogues of the Meteor Data Center (Jopek and Kaňuchová, 2014).
- Orbital parameters of 78 fireball streams (Terentjeva, 1990).

We also compared our findings with the results of Porubčan et al. (2006), who identified 13 filaments of the Taurids stream.

Eleven NTA and thirteen STA were identified with 9 known minor showers and the north branch of Tau Arietids, which has not been detected yet. Nine



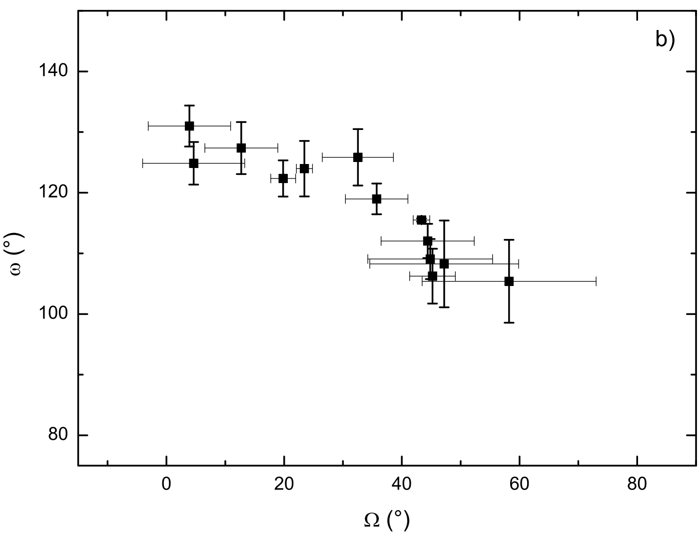


Figure 1. Dependences $q = q(e)$ and $\omega = \omega(\Omega)$ (a, b) for the selected associations of ST.

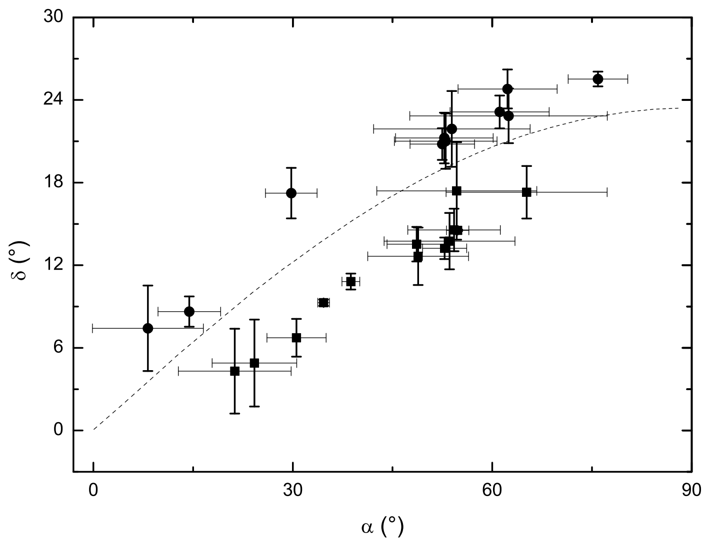
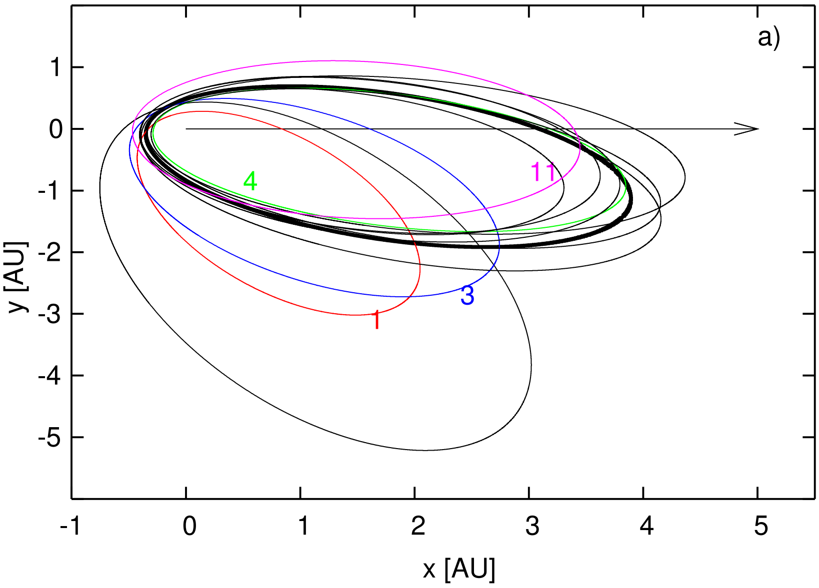


Figure 2. The radiant motion of NT and ST is demonstrated by the radiant positions of selected associations. The dashed line is the ecliptic.

associations have similar characteristics as the filaments found by Porubčan et al. (2006) using the Southworth-Hawkins D-criterion. A designation of the filaments listed in Table 5 in the column "PK" 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 α and δ of the radiants. It is important to note that due to the small input database (84 and 143 meteors) a majority of associations are composed of only 3-6 meteors. Although we considered all 24 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 support the picture presented here.

The structure of Taurids divided into the southern and northern branch is preserved also in a finer division - 6 filaments of the NT-system have their counterparts in ST. These are NT1 and ST7, and ST9 NT2, NT3 and ST6, and ST5 and NT4, ST8 and NT10, NT11 and ST13. In addition to the associations identified with the well-known minor meteor showers, we found a very interesting association NTA4 which could be the northern branch of Tau Arietids, which has not been identified/observed yet - see more details in Kaňuchová and Svoreň



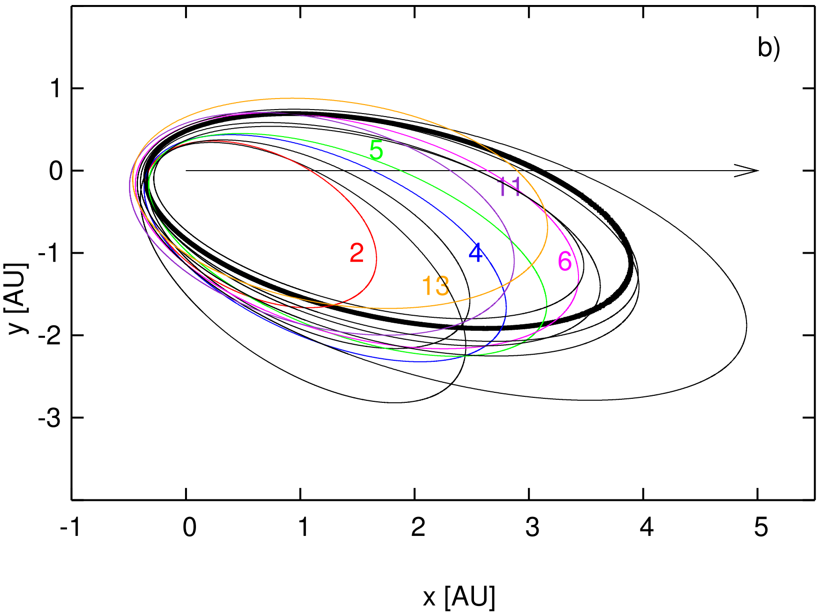


Figure 3. The projection of the mean orbits of the selected NT (a) and ST (b) associations. Numbers indicate designations of associations (see Table 4; the thick line is the orbit of 2P/Encke.

Table 4. Mean orbits of the Southern Taurids associations. STA designation of Southern Taurids Association, n - number of meteors in an association. The mean orbit of all STA is given in the last row.

q	e	ω	Ω	i	α	δ	v_g	STA	n
0.278	0.853	124.9	4.6	5.9	21.3	4.3	29.91	1	10
0.284	0.765	131.0	3.9	5.8	24.2	4.9	25.50	2	3
0.266	0.842	127.4	12.7	7.6	30.6	6.7	29.55	3	6
0.301	0.837	122.4	19.8	5.6	34.6	9.3	29.01	4	6
0.281	0.857	124.0	23.5	5.8	38.7	10.8	30.13	5	6
0.405	0.805	109.1	44.8	5.2	53.6	13.7	26.57	6	19
0.263	0.868	125.8	32.5	7.5	48.9	12.7	31.05	7	6
0.316	0.852	119.0	35.7	5.5	48.6	13.5	29.55	8	14
0.391	0.863	108.3	47.2	1.8	54.7	17.4	28.50	9	5
0.369	0.841	112.0	44.4	5.2	54.3	14.6	28.37	10	27
0.448	0.752	106.3	45.2	5.1	52.8	13.2	24.20	11	6
0.339	0.851	115.5	43.3	6.0	54.8	14.5	29.26	12	3
0.450	0.758	105.4	58.2	3.5	65.2	17.3	24.42	13	3
0.347	0.826	116.4	32.9	5.4	50.2	13.3	28.2	mean or.	

(2012).

3. 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 Southworth-Hawkins D-discriminants (Southworth and Hawkins, 1963) of all possible pairs of orbits. The values of D-discriminants muliplied by 100 are listed in Table 5. Pairs of similar orbits are in bold, whereby associations are defined as similar by the rescaled D value ≤10; and the orbit of association is similar to the orbit of the parent comet if its rescaled D≤25 (see Kaňuchová and Svoreň, 2012). As the values of the Southworth-Hawkins D-discriminant define the probability of the transition between the orbits from the energetic point of view, we display the high probability of meteoroids' transits between associations (black line) and between the associations and the parent comet (dashed line) in the evolution diagram (Fig. 3). A table of D-discriminant values for NT and the scheme of genetic relations within the northern branch of Taurids are given in Kaňuchová and Svoreň (2012), and they are not repeated here.

The analysis of D-discriminant values leads to the following conclusions:

Table 5. Identification of Northern and Southern Taurids associations.

ID	n	q	e	identif.	a	Q	PK	IAU
NT1	5	0.253	0.863	N δ Psc	1.847	3.440	Tau 3	NPI
NT2	3	0.399	0.869		3.046	5.693		
NT3	5	0.380	0.807	ι Ari	1.969	3.558	Tau 6	IOA
NT4	3	0.277	0.870	N τ Ari	2.131	3.985		*
NT5	5	0.290	0.875		2.320	4.350		
NT6	5	0.327	0.828	N Tau	1.901	3.475		NTA
NT7	8	0.364	0.849	N Tau	2.411	4.457	Tau 10	NTA
NT8	18	0.391	0.819		2.172	3.953		
NT9	3	0.387	0.812		2.059	3.730		
NT10	4	0.330	0.862	N Tau	2.391	4.453		NTA
NT11	4	0.464	0.764	N χ Ori	1.966	3.468	Tau 13	ORN
ST1	10	0.278	0.853	S Psc	1.891	3.504		SPI
ST2	3	0.284	0.765		1.208	2.132	Tau 4	
ST3	6	0.266	0.842		1.684	3.102		
ST4	6	0.301	0.837	S Psc	1.847	3.393	Tau 7	SPI
ST5	6	0.281	0.857	S τ Ari	1.965	3.649		**
ST6	19	0.405	0.805	S ι Ari	2.077	3.749	Tau 11	
ST7	6	0.263	0.868	S Tau	1.992	3.721	Tau 8	STA
ST8	14	0.316	0.852	S Tau	2.135	3.954		STA
ST9	5	0.391	0.863		2.854	5.317		
ST10	27	0.369	0.841	S Tau	2.321	4.273	Tau 9	STA
ST11	6	0.448	0.752	S χ Ori	1.806	3.164		ORS
ST12	3	0.339	0.851		2.275	4.211		
ST13	3	0.450	0.758	S χ Ori	1.860	3.270		OSR

* only the southern branch has been known till now
** Terentjeva, 1990

– There is evident a very compact group within the Southern Taurids system composed of the associations ST6 - ST10 and ST12.

– Associations ST1 and ST2 at the beginning, and ST13 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 an effect of a low sensitivity of the D-criterion in the case of distant orbits.

– There are six associations in the Southern Taurids system, ST6, ST7, ST8, ST9, ST10, and ST12, whose orbits could be considered as transition orbits for meteoroids passing from the comet to the more distant parts of the ST system. Practically, there is no preferred association for a transition.

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

	ST1	ST2	ST3	ST4	ST5	ST6	ST7	ST8	ST9	ST10	ST11	ST12	ST13	2P
ST1		12	16	19	27	38	43	38	41	41	37	44	52	49
ST2	12		11	13	20	29	35	30	33	33	28	35	42	40
ST3	16	11		**6**	12	25	27	23	28	27	27	29	39	35
ST4	19	13	**6**		**8**	20	25	19	23	22	22	25	35	32
ST5	27	20	12	**8**		17	17	12	18	16	21	18	31	27
ST6	38	29	25	20	17		17	**10**	**9**	**6**	**8**	11	15	**24**
ST7	43	35	27	25	17	17		**9**	17	12	24	**9**	24	**20**
ST8	38	30	23	19	12	**10**	**9**		**10**	**6**	17	**7**	21	**21**
ST9	41	33	28	23	18	**9**	17	**10**		**7**	15	**10**	17	**22**
ST10	41	33	27	22	16	**6**	12	**6**	**7**		14	**5**	16	**21**
ST11	37	28	27	22	21	**8**	24	17	15	14		18	16	28
ST12	44	35	29	25	18	11	**9**	**7**	**10**	**5**	18		17	**20**
ST13	52	42	39	35	31	15	24	21	17	16	16	17		26

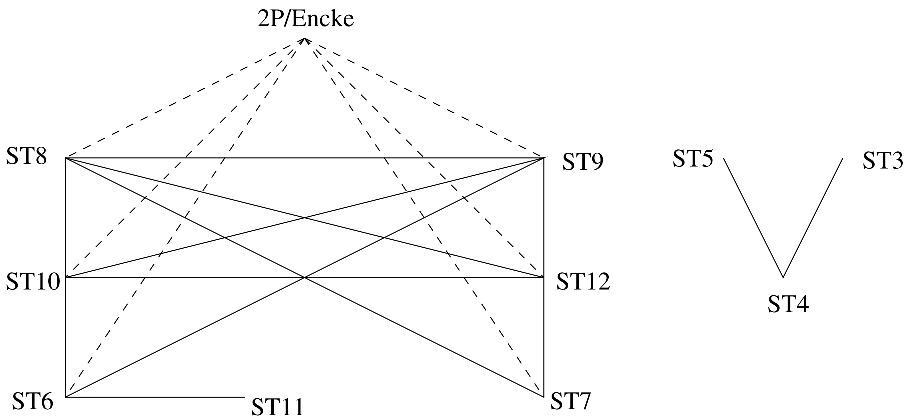


Figure 4. The scheme of the Southern branch of Taurids. Probable transitions of meteoroids between associations are shown. For the details, see the text.

- Association ST11 is not directly dynamically connected with the parent comet. Meteors of this association could come only from ST6.
- The association ST8 has the most important position in the evolution diagram. Without exception, all associations which are dynamically close to the parent comet are also connected with ST8, thus meteoroid transitions from ST8 into those associations are possible. ST8 is one of the most numerous associations, consisting of 14 meteors.
- The associations of ST3, ST4 and ST5 create an isolated group.

4. Conclusions

We have found 11 associations of Northern Taurids and 13 associations of Southern 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 the Tau Arietids shower (see Kaňuchová and Svoreň, 2012). The low values of the D-discriminant calculated for different pairs of NT and ST associations indicate that many catalogued minor meteor showers could be genetically related to the meteor complex of the 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 or ST associations are sufficient to explain the existence of the whole Taurid complex in the case of a single parent body. Otherwise, additional parent body is probably necessary to supply the complex.

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