Taurids

Spectacular Taurid meteor shower in 2005

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We present a short summary of observations of the Taurid meteor shower in 2005. Visual data revealed an enhanced Taurid activity from October 29 to November 12, which peaked on the night of November 1/2 with ZHR $= 15.3 \pm 2.6$. An increased number of Taurid fireballs was reported by observers worldwide. The heightened activity is attributed to the appearance of a resonant meteoroid swarm in the Taurid Complex.

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1 Introduction

The Taurid meteoroid complex and the associated meteor showers (namely Piscids, Taurids, and χ-Orionids) attract much interest from professional and amateur meteor astronomers. The reasons for this continuous attention are manyfold, and many different tasks are pursued. Unlike most ecliptical meteoroid streams producing meteor showers throughout the whole year, the Taurid Complex has a well established parent comet, 2P/Encke (Whipple 1940), and its evolution over many ages is well understood (Steel *et al.*, 1991). Deeper insight into the structure and origin of the Taurid Complex revealed that a number of Near-Earth (Apollo-type) asteroids might contribute to the meteoroid stream (Olsson-Steel, 1987; Klačka, 1995; Klačka & Pittich, 1998; Babadzhanov, 2001). Such a complex membership of parent objects has produced some real foundations for the hypothesis of a disintegrated giant comet (Clube & Napier, 1984). The famous Tunguska impact is also linked to the alleged activity of the Taurid Complex (Asher & Steel, 1998).

From the long-term photographic and visual observations in the past, the Taurid meteor shower has been designated a complex radiant structure with clear Northern and Southern branches that develops under planetary perturbations on a large time scale (Jones, 1986). Numerous smaller theoretical radiants, related to the asteroidal counterpart of the stream, and spread throughout the constellations of Taurus, Aries, Cetus and Pisces, have also been predicted (Babadzhanov, 2001). However, recent analysis of about 58 000 video meteors (Triglav-Čekada & Arlt, 2005) revealed just a distinct double radiant of the Taurids, with clearly separated Northern and Southern branches (referred as Northern Taurids, NTA and Southern Taurids, STA, respectively). The same double structure has been found persistent also for Piscids and χ-Orionids.

The Taurid meteoroid stream produces quite a remarkable ecliptical meteor shower visible in October and November with the maximum extending through the first decade of November. There are some indications that the Taurids produced a prominent meteor shower some thousand years ago (Ahn, 2003), although the distinction between Taurids and Leonids is not reliable. Nowadays activity of the Taurid meteor shower is rather modest, with rates not exceeding 10 meteors per hour at their best (Bone, 1991; Jenniskens, 1994; Rendtel *et al.*, 1995).

It has been widely recognized that the Taurid meteor shower, despite its moderate activity, produces a great number of bright fireballs in some years. A Taurid swarm being in 7:2 resonance with Jupiter was proposed by Asher (1991) to produce occasional enhanced activity. A comparison of the swarm model with visual regular and fireball observations of the Nippon Meteor Society by Asher and Izumi (1998) was indeed successful in finding a correlation. The proposed model describes a meteoroid swarm of trapped particles, which evolves as a consequence of the 7:2 resonance of Comet 2P/Encke with Jupiter. In the course of the 'swarm model', an enhanced Taurid activity, in particular that for the bright fireballs, was predicted for the years 1998 and 2005. Indeed, an exceptional Taurid fireball activity has been detected in 1998. There was also an indication of increased numbers of visual Taurid meteors in that year (McBeath, 1999), however no detailed analysis has been performed so far. More recently, an extended analysis of the Taurid fireball activity from six independent sources just confirmed the model predictions (Beech *et al.*, 2004). Therefore, in agreement with predictions of Asher and Izumi (1998), 2005 appears to be a special year for Taurids.

In this Paper we provide an evidence of an exceptional Taurid activity in 2005 based on the available records collected in the Visual Meteor Data Base (VMDB).

2 Observations

2005 was a promising year for Taurid observations from the point of view of visual observations, as the most intense part of the shower was not interfered with by the full moon. The Taurid activity period was proposed to be October 1 to November 25 by Rendtel *et al.* 1995, but mainly in order to avoid confusing overlaps of designations, and to a lesser extent from actual activity graphs. This period corresponds to the solar longitude

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interval of between $\lambda_\odot = 180°$ and $\lambda_\odot = 245°$.

Over that period, 59 observers worldwide reported a total of more than 5000 meteors in 363.51 h of net observing time to the IMO. Out of these, 1199 meteors were associated with the Taurids (287 NTA, 368 STA and the remaining 544 simply as TAU). For simplicity we made no distinction between the NTA and STA branches, further referring to the shower as the Taurids.

By January 5, 2006, the following observers had submitted their reports to the IMO, to whom we are very grateful :

> Jure Atanackov (`ATAJU`, $4\overset{\mathrm{h}}{.}32$, 36), Pierre Bader (`BADPI`, $11\overset{\mathrm{h}}{.}90$, 38), Ričardas Balčiūnas (`BALRC`, $8\overset{\mathrm{h}}{.}50$, 18), Jean-Marie Biets (`BIEJE`, $3\overset{\mathrm{h}}{.}50$, 16), Jiang Chang-gui (`CHAJI`, $2\overset{\mathrm{h}}{.}10$, 3), Rong Chen (`CHERO`, $2\overset{\mathrm{h}}{.}10$, 5), Tim Cooper (`COOTI`, $1\overset{\mathrm{h}}{.}30$, 1), Tibor Csörgei (`CSOTI`, $0\overset{\mathrm{h}}{.}50$, 1), Nadka Dankova (`DANNA`, $1\overset{\mathrm{h}}{.}82$, 0), David Dickinson (`DICDA`, $1\overset{\mathrm{h}}{.}10$, 4), Jaka Dobaj (`DOBJA`, $3\overset{\mathrm{h}}{.}03$, 15), Audrius Dubietis (`DUBAU`, $15\overset{\mathrm{h}}{.}64$, 64), Bo Gao (`GAOBO`, $1\overset{\mathrm{h}}{.}10$, 0), George W. Gliba (`GLIGE`, $3\overset{\mathrm{h}}{.}00$, 17), William Godley (`GODWI`, $11\overset{\mathrm{h}}{.}25$, 42), Mitja Govedič (`GOVMI`, $1\overset{\mathrm{h}}{.}33$, 8), Robin Gray (`GRARO`, $15\overset{\mathrm{h}}{.}15$, 17), Daniel Grün (`GRUDA`, $1\overset{\mathrm{h}}{.}01$, 3), Davood Hemati (`HEMDA`, $1\overset{\mathrm{h}}{.}00$, 0), Yandong Hu (`HU YA`, $1\overset{\mathrm{h}}{.}00$, 0), Andrey Igoshev (`IGOAN`, $5\overset{\mathrm{h}}{.}00$, 2), Carl Johannink (`JOHCA`, $10\overset{\mathrm{h}}{.}20$, 25), Bhargav Joshi (`JOSBH`, $2\overset{\mathrm{h}}{.}45$, 0), Javor Kac (`KACJA`, $12\overset{\mathrm{h}}{.}36$, 73), Soheil Khoshbin Far (`KHOSO`, $1\overset{\mathrm{h}}{.}00$, 0), Velislava Kiryakova (`KIRVE`, $3\overset{\mathrm{h}}{.}75$, 0), Dovilė Kraulaidienė (`KRADO`, $2\overset{\mathrm{h}}{.}15$, 4), Jens Lacorne (`LACJE`, $3\overset{\mathrm{h}}{.}60$, 3), Peter van Leuteren (`LEUPE`, $0\overset{\mathrm{h}}{.}50$, 6), Anna S. Levina (`LEVAN`, $4\overset{\mathrm{h}}{.}84$, 73), Michael Linnolt (`LINMI`, $1\overset{\mathrm{h}}{.}92$, 5), Ming-hui Liang (`LINMN`, $2\overset{\mathrm{h}}{.}48$, 0), Xuan Liu (`LIUXU`, $2\overset{\mathrm{h}}{.}72$, 0), Jin Ma (`MA JI`, $2\overset{\mathrm{h}}{.}45$, 0), Veikko Mäkelä (`MAKVE`, $1\overset{\mathrm{h}}{.}12$, 0), Paul Martsching (`MARPA`, $12\overset{\mathrm{h}}{.}75$, 9), Pierre Martin (`MARPI`, $14\overset{\mathrm{h}}{.}81$, 78), Mikhail Maslov (`MASMI`, $12\overset{\mathrm{h}}{.}29$, 16), Alastair McBeath (`MCBAL`, $14\overset{\mathrm{h}}{.}35$, 14), Koen Miskotte (`MISKO`, $19\overset{\mathrm{h}}{.}66$, 115), Markku Nissinen (`NISMA`, $1\overset{\mathrm{h}}{.}25$, 0), Sven Näther (`NATSV`, $21\overset{\mathrm{h}}{.}63$, 45), Robert Pomohaci (`POMRO`, $1\overset{\mathrm{h}}{.}22$, 0), Jürgen Rendtel (`RENJU`, $22\overset{\mathrm{h}}{.}87$, 66), Mikiya Sato (`SATMK`, $1\overset{\mathrm{h}}{.}50$, 0), Tomoko Sato (`SATTM`, $1\overset{\mathrm{h}}{.}50$, 0), Alex Scholten (`SCHAE`, $4\overset{\mathrm{h}}{.}11$, 20), Svetlana Slavova (`SLASV`, $5\overset{\mathrm{h}}{.}57$, 5), Wesley Stone (`STOWE`, $1\overset{\mathrm{h}}{.}50$, 0), Richard Taibi (`TAIRI`, $1\overset{\mathrm{h}}{.}20$, 2), Kazumi Terakubo (`TERKA`, $1\overset{\mathrm{h}}{.}50$, 0), Josep M. Trigo Rodríguez (`TRIJO`, $1\overset{\mathrm{h}}{.}94$, 0), Alexandru Tudorica (`TUDAL`, $5\overset{\mathrm{h}}{.}16$, 4), Shigeo Uchiyama (`UCHSH`, $10\overset{\mathrm{h}}{.}26$, 30), Nejc Ucman (`UCMNE`, $2\overset{\mathrm{h}}{.}46$, 11), Michel Vandeputte (`VANMC`, $35\overset{\mathrm{h}}{.}71$, 173), Valentin Velkov (`VELVA`, $5\overset{\mathrm{h}}{.}76$, 19), Kim S. Youmans (`YOUKI`, $12\overset{\mathrm{h}}{.}05$, 81), Jurga Zieniūtė (`ZIEJU`, $4\overset{\mathrm{h}}{.}34$, 24).

The IMO observer code, the effective observing time, and the number of Taurids reported are given in brackets. The observers are from the following 20 countries:

> Belgium, Bulgaria, Canada, China, Finland, France, Germany, India, Iran, Israel, Japan, Lithuania, the Netherlands, Russia, Slovakia, Slovenia, South Africa, Spain, the UK, and the USA.

3 Activity profile

First we calculated the population index. The procedure involved a calculation of average differences lm-m, where lm is the limiting stellar magnitude and m is the magnitude of a meteor, and subsequent conversion into the population index. The full description of the method and conversion tables are given in (Arlt, 2003). Following this procedure we obtained a population index of $r = 1.90 \pm 0.04$ for lm ≥ 5.5, based on available 978 magnitude estimates.

For the ZHR calculations we used a mean Taurid radiant position of $\alpha = 52\overset{\circ}{.}0$ and $\delta = +17\overset{\circ}{.}9$ (for November 5, $\lambda_\odot = 222°$) with an averaged daily drift of $\Delta\alpha = +0\overset{\circ}{.}82$ and $\Delta\delta = +0\overset{\circ}{.}18$. This simplified ephemeris is based on the radiant positions recently derived by Triglav-Čekada and Arlt (2005). One may ask whether this linear drift for the combined branches is too much of a simplification. If more accurate radiant positions are used, the question of which radiant position was adopted by each individual observer also arises. We believe that a more sophisticated radiant ephemeris will not improve the reliability of the results significantly, unless one goes back to the original meteor positions and analyzes these. The ZHR profile was calculated using a standard IMO procedure:

$$\overline{\mathrm{ZHR}} = \frac{1 + \sum\limits_i n_i}{\sum\limits_i \frac{T_{\mathrm{eff},i}}{C_i}}, \tag{1}$$

where n_i is the individual number of shower meteors observed during a time period $T_{\mathrm{eff},i}$, and C_i is the total correction for a limiting magnitude lm, field obstruction factor F, and the radiant elevation h_R:

$$C_i = \frac{r^{(6.5-\mathrm{lm})} F}{\sin h_\mathrm{R}}. \tag{2}$$

For the sake of simplicity, we have not applied other radiant-height corrections such as $\sin^\gamma h_\mathrm{R}$ with $\gamma \neq 1$. Individual perception coefficients were all taken to be unity. Data discrimination according to $C_i \leq 5$ as usually, was applied. The error margins were estimated as

$$\Delta\mathrm{ZHR} = \frac{\overline{\mathrm{ZHR}}}{\sqrt{1 + \sum\limits_i n_i}}. \tag{3}$$

Figure 1 shows the activity profile of the Taurids. Most of the data points in the ZHR-profile plot were calculated using a 1° bin size; only in marginal cases, where the data was not sufficient, we used an average over 2° in solar longitude. Although there is a good observational coverage of the entire Taurid activity window, there is an open gap in the data points between $\lambda_\odot = 202°$ and $\lambda_\odot = 212°$. The very few observations available at that time were much constrained by the full moon, and hence did not produce any meaningful data. Another paucity of data affects the time around the maximum at $\lambda_\odot = 220 - 221°$.

The plotted ZHR-profile clearly shows an enhanced Taurid activity with ZHR ≥ 10 for the solar longitude interval within $\lambda_\odot = 215 - 228°$ (see also tabulated ZHR values in Table 1). The highest Taurid activity with

Table 1 – Activity profile of the 2005 Taurids around their maximum. $n_{\rm obs}$ is the number of observers, $n_{\rm int}$ is the number of observing intervals, $N_{\rm TAU}$ is the number of Taurid meteors.

Date		$\lambda_\odot$	$n_{\rm obs}$	$n_{\rm int}$	$N_{\rm TAU}$	ZHR
Oct	29	215.80	5	7	59	9.0 ± 1.2
Oct	29–30	216.75	10	24	153	8.4 ± 0.7
Oct	30	217.51	6	8	67	9.1 ± 1.1
Oct	31	218.50	5	7	54	12.1 ± 1.6
Nov	1–2	219.62	2	4	35	15.3 ± 2.6
Nov	4–5	222.57	10	26	171	13.3 ± 1.0
Nov	5–6	223.66	7	20	126	10.8 ± 1.0
Nov	6–7	224.47	7	10	47	7.1 ± 1.1
Nov	7–8	225.55	3	4	19	12.1 ± 2.7
Nov	8–9	226.63	8	17	106	7.3 ± 0.7
Nov	9–10	227.67	3	10	60	8.0 ± 1.0
Nov	10–11	228.59	2	3	16	10.5 ± 2.6
Nov	11–12	229.56	4	6	24	7.5 ± 1.5

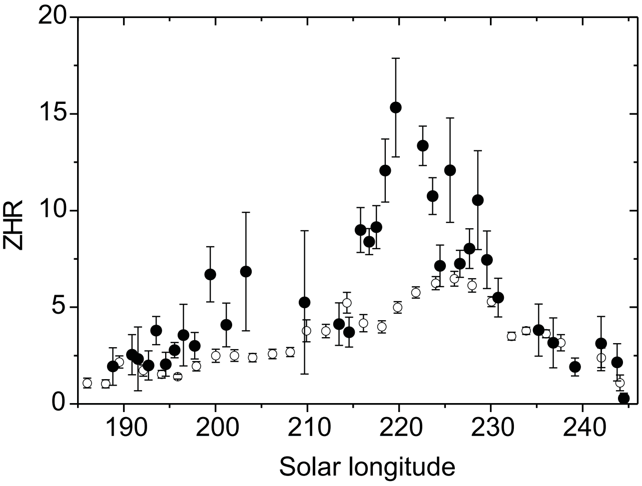

Figure 1 – ZHR profile of the 2005 Taurids (full circles) and the annual activity curve, compiled from the observations in 1997 and 1999 (open circles).

Figure 2 – A bright Taurid meteor photographed by R. Balčiūnas nearby Ignalina, Lithuania at $19^{\rm h}43^{\rm m}$ UT, October 31. The bright lights near the horizon are from an aurora seen at the time.

ZHR $= 15.3 \pm 2.6$ was recorded on the night of November 1/2 ($\lambda_\odot = 219.\!^\circ6$), almost a week earlier than the 'traditional' Taurid maximum. It is worth remembering that local maxima of the Southern and the Northern counterparts of the shower are near November 5 and November 10, respectively, so altogether producing an extended maximum, centered on November 7/8 (Rendtel *et al.*, 1995). An annual Taurid activity curve in Fig. 1 is added for a comparison, as derived from the VMDB records of 'ordinary' years 1997 and 1999, showing a flat 'traditional' maximum with ZHR $= 6.5 \pm 0.4$ at $\lambda_\odot = 226^\circ$.

4 Fireballs

The Taurid meteor shower is famous for its bright and numerous fireballs. Beech *et al.* (2004) have proved that enhanced fireball activity is indeed linked to so-called 'swarm years'. Therefore something special was expected in 2005. Indeed, numerous fireballs were recorded during the 2005 Taurid return. Observers from the Polish Fireball Network captured two fireballs on the night of October 30 and a sequence of six brilliant Taurid fireballs (magnitudes -7 to -10) that occurred in a short period of time between $22^{\rm h}55^{\rm m}$ UT and $01^{\rm h}00^{\rm m}$ UT on the night of October 31/November 1 (Olech, 2005). Another brilliant fireball of magnitude -15 was photographed by the same Network at $20^{\rm h}19^{\rm m}$ UT on November 4. Unusually high fireball activity has also been detected by the American observers and casual witnesses on Halloween night, October 31 (Drobnock, 2005). These observations, of course, provide just a fragmented picture and more detailed analysis on the fireball activity should be done, however it seems to be well linked to the enhanced visual rates.

Magnitude records gathered by visual observations also show a high proportion of fireballs and bright meteors in the 2005 Taurid meteor shower. The calculated population index of $r = 1.90$ is significantly lower than the average for the Taurids, as the main sources based on long-term observations provide a typical value of $r = 2.30$ (Jenniskens, 1994; Rendtel *et al.*, 1995). In

2005, 190 Taurids of the total 978 reported with magnitude estimates, had magnitudes of 0 and brighter, and 43 of them might be classed as fireballs (brighter than or equal to -3). The vast majority of bright meteors and fireballs (147 and 36, respectively) appeared within the two-week interval of enhanced shower activity with ZHR ≥ 10 within $\lambda_\odot = 215{-}228°$. In Fig. 2 is presented a photograph of a bright Taurid casually captured by Ričardas Balčiūnas in Lithuania, while taking pictures of the northern lights, visible on that evening.

5 Conclusions

In conclusion, the year of 2005 has brought a nice display of the Taurid meteor shower in good agreement with Taurid swarm predictions by Asher and Izumi (1998). Exceptional fireball activity has been witnessed worldwide, being a typical signature of a Taurid 'swarm year'. Moreover, IMO observers reported an enhanced activity of visual Taurid rates as well, extending for more than two weeks with ZHR ≥ 10 in the solar longitude interval of $\lambda_\odot = 215 - 228°$ (October 28 – November 11). A high proportion of bright Taurid meteors has to be noted, and is reflected by an unusually low population index of $r = 1.90$. Preliminary analysis based on the available data suggests the maximum on $\lambda_\odot = 219\overset{\circ}{.}6$ (November 1/2) with ZHR $= 15.3 \pm 2.6$, which in fact is a week earlier and two times stronger than the 'traditional' maximum of the annual Taurid meteor shower.

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