Orionids

The 2007 Orionids from visual observations

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Following up on the enhanced activity of the 2006 Orionids, we present an analysis of the 2007 Orionids based on visual observations. A maximum activity of ZHR $= 80 \pm 5$ meteors per hour is found at a solar longitude of $208\overset{\circ}{.}45$ (eq. J2000.0) corresponding to about 2007 October 22, 08^{h} UT. The peak was preceded by another maximum of 70 ± 4 meteors per hour near a solar longitude of $280\overset{\circ}{.}1$, corresponding to about 2007 October 22, 0^{h} UT. The visual activity was a bit higher than in 2006 when ZHRs reached values near 60 meteors per hour. The population index was slightly below 2.0, while it went down to 1.6 in 2006. During the times of highest activity, the population index was 2.1 and 2.2, respectively. The maximum spatial number density was about 100 particles in a cube with edges of 1000 km length, which corresponds to a flux density of 0.024 particles per square kilometer per hour. The mass index was around 1.7 with 1.6 being the minimum value. Enhanced rates above the average pre-2006 profile were observed for a duration of at least 5 days. The enhanced rates in 2006 and 2007 are likely due to dust in 1:6 mean motion resonance with Jupiter, according to Sato & Watanabe (2007). The corresponding dust trails were laid down during perihelion passages of 1P/Halley 30–45 revolutions ago.

1 Introduction

After the great surprise of the 2006 return of the Orionid meteor shower with Zenithal Hourly Rates (ZHR) of about 60, the 2007 maximum of the Orionids was awaited with fairly high expectations. The vast majority of data is submitted by electronic mail, with a substantial part making use of the electronic visual report form on the IMO web site. The form has the advantage that reports are checked for consistency before being submitted. Note that the data are not directly going into the VMDB, since quality evaluation, additional requests for details from observers, and possible amendments of the reports are still best done manually. But the standardized output style and the consistency checks are already of great help for the maintenance of the VMDB. Observers are highly encouraged to make use of the form, even though it may initially look complicated to casual observers, and error messages are more 'inexorable' than a human data recipient.

The Orionid meteor shower is caused by dust from the most famous comet, 1P/Halley. The particles encounter Earth near the ascending nodes of their orbits. The radiant at maximum activity is located near a position of $\alpha = 95°$ and $\delta = +16°$, and the entry velocity in the Earth's atmosphere is about 66 km/s. The data are taken from the shower list by Arlt & Rendtel (2006). The orbit of 1P/Halley does not come very close to that of the Earth. It takes the particles quite a few revolutions (roughly more than 20) to get into Earth-crossing orbits and to produce Orionid meteors. For that reason, observations of the Orionids provide suites of particle flux profiles which are interesting for long-term evolution models of streams at considerable distance from their parent object's orbits. The present analysis computes profiles of the population index and the ZHR of the Orionid meteor shower, and mass index and spatial number density profiles of the corresponding meteoroid stream.

In 2007, 83 observers reported their data from the Orionid activity period, covering $546\overset{\mathrm{h}}{.}6$ of observing time. The total number of Orionids seen was 6179. We are grateful to the following observers who sent in their data to the Visual Meteor Database of the IMO (showing name, (IMO observer code, hours of observation, number of meteors seen)):

> Salvador Aguirre (`AGUSA`, $19\overset{\mathrm{h}}{.}10$, 244), Plamena Aleksandrova (`ALEPL`, $3\overset{\mathrm{h}}{.}75$, 19), Pierre Bader (`BADPI`, $10\overset{\mathrm{h}}{.}15$, 18), Felix Bettonvil (`BETFE`, $3\overset{\mathrm{h}}{.}03$, 134), Jean-Marie Biets (`BIEJE`, $9\overset{\mathrm{h}}{.}08$, 66), Michael Boschat (`BOSMI`, $1\overset{\mathrm{h}}{.}00$, 5), Gennadij Bugarevych (`BUGGE`, $9\overset{\mathrm{h}}{.}06$, 10), Dushyant Chauhan (`CHADU`, $1\overset{\mathrm{h}}{.}18$, 32), Neha Das (`DASNE`, $0\overset{\mathrm{h}}{.}96$, 5), Namrata Date (`DATNA`, $1\overset{\mathrm{h}}{.}48$, 7), Daniel Delaney (`DELDA`, $1\overset{\mathrm{h}}{.}00$, 9), Peter Detterline (`DETPE`, $8\overset{\mathrm{h}}{.}33$, 230), Sietse Dijkstra (`DIJSI`, $19\overset{\mathrm{h}}{.}12$, 274), Todor Dimitrov (`DIMTO`, $4\overset{\mathrm{h}}{.}17$, 19), Irena Divisova (`DIVIR`, $36\overset{\mathrm{h}}{.}75$, 38), Dariusz Dorosz (`DORDA`, $1\overset{\mathrm{h}}{.}33$, 62), Audrius Dubietis (`DUBAU`, $1\overset{\mathrm{h}}{.}00$, 3), Frank Enzlein (`ENZFR`, $7\overset{\mathrm{h}}{.}84$, 235), Eric Flescher (`FLEER`, $2\overset{\mathrm{h}}{.}00$, 9), George W. Gliba (`GLIGE`, $2\overset{\mathrm{h}}{.}00$, 89), William Godley (`GODWI`, $8\overset{\mathrm{h}}{.}00$, 44), Sylvie Gorkova (`GORSY`, $3\overset{\mathrm{h}}{.}00$, 2), Mitja Govedic (`GOVMI`, $0\overset{\mathrm{h}}{.}85$, 26), Robin Gray (`GRARO`, $3\overset{\mathrm{h}}{.}08$, 4), Wayne T. Hally (`HALWA`, $19\overset{\mathrm{h}}{.}05$, 167), Vilem Heblik (`HEBVI`, $7\overset{\mathrm{h}}{.}75$, 42), Carl Hergenrother (`HERCR`, $5\overset{\mathrm{h}}{.}46$, 67), Carl Johannink (`JOHCA`, $11\overset{\mathrm{h}}{.}63$, 221), Kearn Jones (`JONKR`, $1\overset{\mathrm{h}}{.}42$, 5), Kundan Kadam (`KADKU`, $4\overset{\mathrm{h}}{.}08$, 18), Jay Kansara (`KANJA`, $3\overset{\mathrm{h}}{.}67$, 37), Roy Keeris (`KEERO`, $0\overset{\mathrm{h}}{.}90$, 13), André Knöfel (`KNOAN`, $8\overset{\mathrm{h}}{.}97$, 5), Jakub Koukal (`KOUJA`, $69\overset{\mathrm{h}}{.}91$, 191), Pete Kozich (`KOZPE`, $1\overset{\mathrm{h}}{.}25$, 64), Dovilė Krauleidienė (`KRADO`, $1\overset{\mathrm{h}}{.}00$, 2), Peter van Leuteren (`LEUPE`, $6\overset{\mathrm{h}}{.}00$, 153), Xiaoyun Ma (`MA XI`, $2\overset{\mathrm{h}}{.}08$, 26), Adam Marsh (`MARAD`, $3\overset{\mathrm{h}}{.}50$, 54), Paul

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Martsching (`MARPA`, $16\overset{\mathrm{h}}{.}00$, 151), Pierre Martin (`MARPI`, $8\overset{\mathrm{h}}{.}69$, 313), Antonio Martinez (`MARTI`, $1\overset{\mathrm{h}}{.}00$, 13), Alastair McBeath (`MCBAL`, $5\overset{\mathrm{h}}{.}50$, 58), Bruce McCurdy (`MCCBR`, $3\overset{\mathrm{h}}{.}50$, 6), Frédéric Merlin (`MERFR`, $1\overset{\mathrm{h}}{.}75$, 29), Koen Miskotte (`MISKO`, $20\overset{\mathrm{h}}{.}45$, 378), Sabine Wächter (`MORSA`, $4\overset{\mathrm{h}}{.}29$, 4), David Moyer (`MOYDA`, $1\overset{\mathrm{h}}{.}00$, 33), Sven Näther (`NATSV`, $21\overset{\mathrm{h}}{.}22$, 81), Tereza Novotna (`NOVTE`, $1\overset{\mathrm{h}}{.}50$, 22), David Oesper (`OESDA`, $4\overset{\mathrm{h}}{.}00$, 46), Daniel van Os (`OSVDA`, $0\overset{\mathrm{h}}{.}72$, 4), Swapnil Pawar (`PAWSW`, $3\overset{\mathrm{h}}{.}30$, 24), Richard Pollard (`POLRI`, $3\overset{\mathrm{h}}{.}50$, 30), Jürgen Rendtel (`RENJU`, $25\overset{\mathrm{h}}{.}84$, 259), Mileny Roche Lamas (`ROCMI`, $1\overset{\mathrm{h}}{.}99$, 1), Amanda Rowan (`ROWAM`, $1\overset{\mathrm{h}}{.}00$, 11), Tomoko Sato (`SATTM`, $1\overset{\mathrm{h}}{.}32$, 34), René Scurbecq (`SCURE`, $3\overset{\mathrm{h}}{.}23$, 89), Ulrich Sperberg (`SPEUL`, $2\overset{\mathrm{h}}{.}30$, 58), Octaaf Steen (`STEOC`, $2\overset{\mathrm{h}}{.}13$, 18), Boris Stoilov (`STOBO`, $1\overset{\mathrm{h}}{.}92$, 1), Con Stoitsis (`STOCO`, $2\overset{\mathrm{h}}{.}25$, 6), Wesley Stone (`STOWE`, $1\overset{\mathrm{h}}{.}79$, 100), Richard Taibi (`TAIRI`, $1\overset{\mathrm{h}}{.}16$, 16), Rafaél R. Torregrosa Soler (`TORRQ`, $1\overset{\mathrm{h}}{.}08$, 3), Blanca Troughton Luque (`TROBL`, $2\overset{\mathrm{h}}{.}33$, 20), Shigeo Uchiyama (`UCHSH`, $3\overset{\mathrm{h}}{.}40$, 20), Devdatta Urankar (`URADE`, $1\overset{\mathrm{h}}{.}50$, 13), Simona Vaduvescu (`VADSI`, $6\overset{\mathrm{h}}{.}45$, 159), David Vansteelant (`VANDV`, $1\overset{\mathrm{h}}{.}58$, 28), Hendrik Vandenbruaene (`VANHE`, $1\overset{\mathrm{h}}{.}66$, 15), Michel Vandeputte (`VANMC`, $40\overset{\mathrm{h}}{.}53$, 727), Valentin Velkov (`VELVA`, $3\overset{\mathrm{h}}{.}34$, 20), Rita Verhoef (`VERRI`, $5\overset{\mathrm{h}}{.}25$, 151), William Walbek (`WALWI`, $1\overset{\mathrm{h}}{.}33$, 36), William Watson (`WATWI`, $12\overset{\mathrm{h}}{.}06$, 341), Thomas Weiland (`WEITH`, $4\overset{\mathrm{h}}{.}90$, 65), Roland Winkler (`WINRO`, $3\overset{\mathrm{h}}{.}93$, 3), San Zhan (`ZHASA`, $1\overset{\mathrm{h}}{.}18$, 33), Jin Zhu (`ZHUJI`, $1\overset{\mathrm{h}}{.}38$, 40), Jurga Zieniūtė (`ZIEJU`, $1\overset{\mathrm{h}}{.}00$, 4), Koos Van Zyl (`ZYLKO`, $8\overset{\mathrm{h}}{.}40$, 67)

2 Analysis steps

The correction of meteor observations to a standard limiting magnitude of +6.5 requires the knowledge of the population index r. If the fraction of bright meteors in a meteor shower is relatively large, the correction for limiting magnitudes lower than +6.5 will be smaller than if there is a large fraction of faint meteors. In order to reduce the influence of very high corrections upon observations with low limiting magnitudes, we selected only observations with $\mathrm{lm} \geq +5.8$ for the entire analysis. Out of 881 observing periods for rate data, we retained 663 records obtained under good conditions. From the total of 384 magnitude distributions, a set of 258 distributions with $\mathrm{lm} \geq +5.8$ was used. The data set is about half the size of the 2006 one when 12 000 Orionids were available.

The population index is determined from the magnitude distributions of Orionids. The method described in Arlt (2003) was used to derive a profile of the population index versus time. Again, an adaptive bin-size algorithm is used for constructing averaging windows which are the result of the compromise between a minimum number of meteor magnitudes and an acceptable window length. More details are given below for the ZHR averaging which uses the same principle. Error margins depend non-linearly on r and the meteor number involved; the values have been derived by Monte Carlo simulations and are also given in Arlt (2003).

The activity of a meteor shower is measured with the Zenithal Hourly Rate (ZHR) which is the hourly meteor number corrected for a limiting magnitude of +6.5 and a radiant elevation of 90°. The ZHR profile is based on the population index profile. Values in between the individual population indices obtained above are interpolated linearly. We employ a weighted averaging for the ZHR with the total correction coming from the stellar limiting magnitude lm (thereby using the population index), possible obstructions of the field of view expressed by F, the radiant elevation h_{R}, and the effective observing time T_{eff}. The average ZHR is given by

$$\overline{\mathrm{ZHR}} = \left(\sum_{i=1}^{N} n_i + 1 \right) \Big/ \sum_{i=1}^{N} C_i \,, \qquad (1)$$

where the n_i and the C_i are the number of Orionids and the total correction factors of the N individual observing periods, respectively. The total correction is computed by

$$C = \frac{r^{6.5-\mathrm{lm}}\, F}{T_{\mathrm{eff}}\, \sin h_{\mathrm{R}}} \qquad (2)$$

Upon averaging the rate data, a maximum correction factor $r^{6.5-\mathrm{lm}}\, F/\sin h_{\mathrm{R}} < 5$ was applied. Additionally, the radiant elevation was limited to a minimum of 20° in order to avoid large corrections which may bring along systematic errors. Other corrections like perception differences among observers or non-geometrical corrections for the radiant elevation (zenith exponent) were not applied.

The averaging is adaptive in that the bin size varies according to the number of meteors available from the data records. A minimum and maximum window length are given together with an optimum meteor number, which the algorithm tries to collect in an averaging bin. Until a solar longitude of 205°, we tried setting the window width to vary between $0\overset{\circ}{.}5$ and 1° requesting an optimum meteor number of 100. This was never achieved, so the averaging bins have always been 1° as it turned out during the analysis. These steps are fine, though, during the periods away from the activity maximum. In a second part between $\lambda_{\odot} = 205°$ and 209°, we set the window length to be between $0\overset{\circ}{.}08$ and $0\overset{\circ}{.}16$ and again requested a meteor number of 100. Because of rather unevenly distributed observing periods, all three possible cases were encountered by the algorithm: a meteor number of (just below) 100 was matched with a bin width between the two extrema, not enough meteors were found when the bin width had been extended to the maximum of $0\overset{\circ}{.}16$, and the meteor number already exceeded 100 when starting with the minimum bin width of $0\overset{\circ}{.}08$. In principle, with minimum and maximum set to zero and infinity, respectively, a profile with a constant meteor number in each average can be achieved (constant only to a degree which the reported Orionid numbers in observing intervals allow, since individual meteors are not accessible in the VMDB). The distribution of averages will be very uneven, however, and details, although less significantly documented, may be lost.

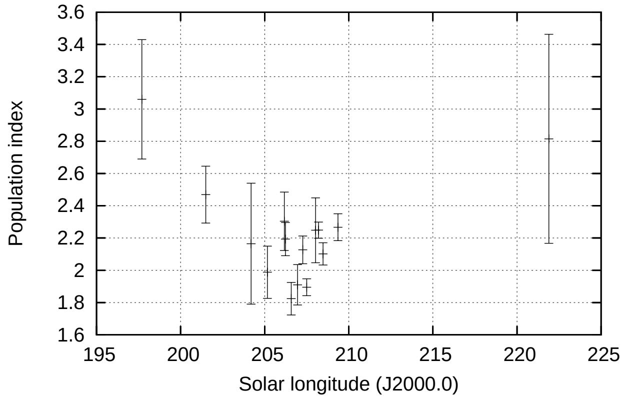

Figure 1 – Population index profile of the 2007 Orionids over the entire activity period.

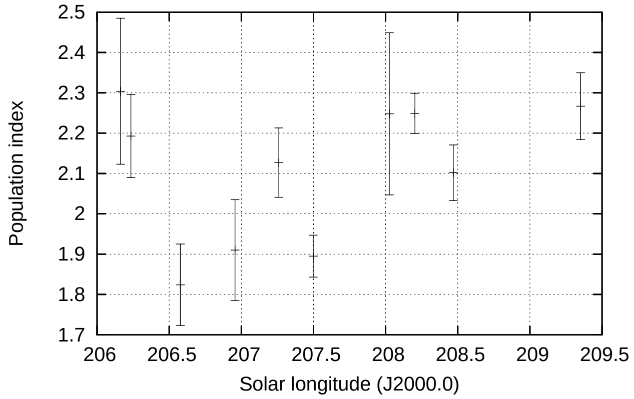

Figure 2 – Population index profile of the 2007 Orionids near their maximum.

3 Results

The full profile of the population index r of the 2007 Orionids is shown in Figure 1. The activity period of the shower begins with a high population index of 3; the r-value drops gradually to 2.0 at about a solar longitude of 205°. A larger amount of data allowed for a more highly resolved profile between solar longitudes 205° and 209°. The results show a rather variable population index. The values lie between 1.9 and 2.5 for a long period of about 18 days, before r goes back to high values of $r \approx 3$ at $\lambda_\odot = 219°$ (roughly November 2).

A magnification of the profile shown in Figure 1 is shown in Figure 2. We find two main minima of r near $\lambda_\odot = 206\overset{\circ}{.}6$ (corresponding to about October 20, 12^h UT) and $\lambda_\odot = 207\overset{\circ}{.}5$ (October 21, 09^h UT). While the error margins indicate these are significant features, their distance of exactly one day lead us to be cautious. The periods around these points are characterized by observations with high limiting magnitudes. If the observers did not report an adequate number of faint meteors, their magnitude distributions will lead to underestimated population indices. We conclude here, that the r-value may not have been below 2.0 at these two instances, but still relatively low and definitely at $r < 2.5$.

For comparison, we repeat the results from the analysis of the 2006 Orionids (Rendtel, 2007) in Figure 3. A much higher sampling was used for the 2006 profile; one has to look at the result in a smoothing manner to see whether there are features repeating in 2007. On average, the r-values were significantly lower in 2006 than in 2007. While r varied between 1.6 and ~ 2.2 in the former, it was just below 2.0 and reached up to 2.3 in 2007 during the same window of solar longitudes. In other words, the unusually large fraction of bright meteors in 2006 was not seen in October 2007. The peculiarly low value of 1.6 in 2006 coincides with the minimum population index in 2007 of $r = 1.9$ around or shortly after $207\overset{\circ}{.}5$. One should be careful though to conclude that the particular part of Orionid activity was caused by the same part (dust trail or filament) of the Orionid meteoroid stream, just from that single fact. Interestingly, also the highest r-value in that period occurs at the same time in both 2006 and 2007 with $r \approx 2.3$ near or shortly after $\lambda_\odot = 208°$.

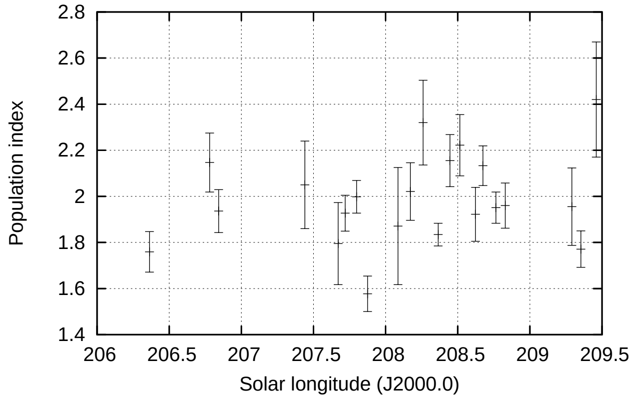

Figure 3 – Population index profile of the 2006 Orionids near their maximum.

The ZHR profile determined from the above mentioned 663 observing periods with Orionid rate data is shown in Figure 4. The averaging is done by employing Equation 1 and the error margins refer to $\mathrm{ZHR}/\sqrt{\sum n_i + 1}$. The profile is based on the population index derived earlier and shown in Figure 1. The r-profile is interpolated linearly; a method considered sufficiently accurate given the fact that the averaged population indices have non-negligible error bars on their own. The dashed line in Figure 4 is an average activity profile derived from all VMDB observations of 1984–2005 applying a population index of 2.3. Orionid ZHRs were above the average over the last decades for at least 5 days in 2007.

The full numerical data of the ZHR profile are given in Table 1 along with the interpolated population indices from the curve in Figure 1. Note that nearly all average limiting magnitudes are above +6 as a result of the selection made above.

A magnification of the identical ZHR profile is shown in Figure 5 where the short-term variations of the Orionid activity become visible. Variations in the ZHR profile are not particularly linked to the low-r features discussed above. The two population index minima seem to have a minor influence on the curve.

Finally, we also repeat the ZHR profile of the 2006 Orionid analysis by Rendtel (2007). Again, we overplot the 'annual' ZHR curve based on 1984–2005 data for comparison. The 2007 ZHRs actually exceed the 2006 rates by about 20%. The results are certainly not in-

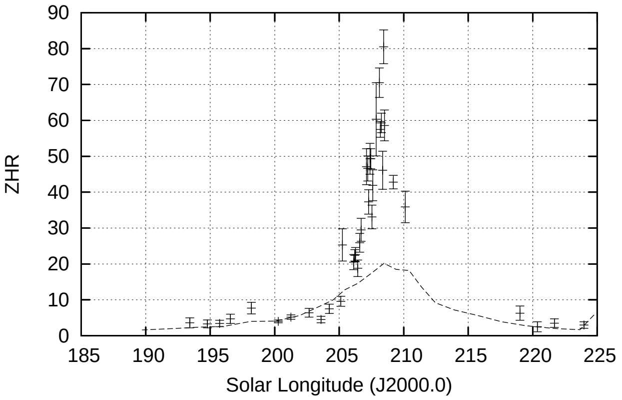

Figure 4 – ZHR profile of the 2007 Orionids. The dashed line shows an average profile of the Orionids of 1984–2005.

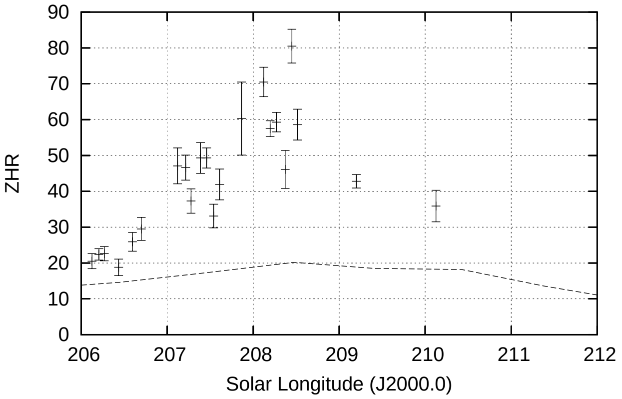

Figure 5 – Magnification of Figure 4 with the ZHR profile of the 2007 Orionids around their maximum.

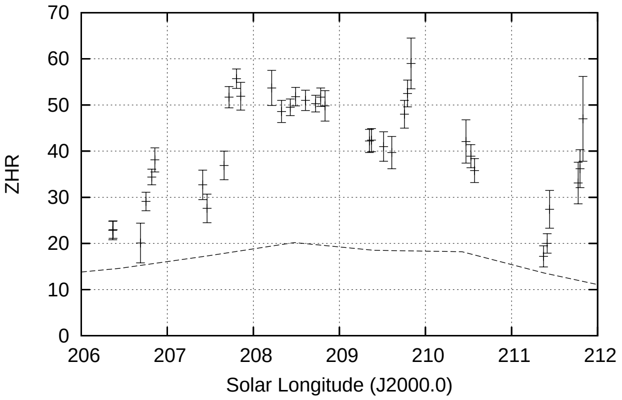

Figure 6 – ZHR profile of the 2006 Orionids around their maximum.

Table 1 – Numerical data of the visual activity of the 2007 Orionids after averaging. The ZHR data are the same as shown in Figure 4. Dates are in UT and refer to October and November 2007, solar longitudes $\lambda_\odot$ refer to equinox J2000.0. The population indices r are interpolated values from Figure 1.

Date	$\lambda_\odot$	n	ZHR	$\overline{\mathrm{lm}}$	r
7.17	193.°418	6	3.6 ± 1.4	6.07	3.06 ± 0.37
8.56	194.°787	8	3.3 ± 1.1	6.19	3.06 ± 0.37
9.52	195.°729	14	3.4 ± 0.9	6.13	3.06 ± 0.37
10.37	196.°574	11	4.7 ± 1.3	6.11	3.06 ± 0.37
12.00	198.°190	22	7.7 ± 1.6	6.27	2.98 ± 0.35
14.12	200.°280	87	4.0 ± 0.4	6.38	2.66 ± 0.24
15.11	201.°262	81	5.2 ± 0.6	6.29	2.50 ± 0.19
16.53	202.°670	25	6.4 ± 1.2	6.32	2.34 ± 0.26
17.46	203.°597	25	4.5 ± 0.9	6.48	2.24 ± 0.33
18.10	204.°233	30	7.5 ± 1.3	6.44	2.16 ± 0.36
19.00	205.°127	43	9.6 ± 1.4	6.08	2.00 ± 0.17
19.13	205.°248	30	25.3 ± 4.5	6.47	2.02 ± 0.16
20.01	206.°125	97	20.5 ± 2.1	6.33	2.29 ± 0.18
20.09	206.°206	188	22.4 ± 1.6	6.31	2.24 ± 0.13
20.15	206.°269	123	22.6 ± 2.0	6.31	2.16 ± 0.10
20.32	206.°436	67	18.8 ± 2.3	6.12	1.97 ± 0.10
20.48	206.°596	97	25.9 ± 2.6	6.29	1.85 ± 0.10
20.59	206.°699	82	29.5 ± 3.2	6.84	1.85 ± 0.11
21.01	207.°121	89	47.1 ± 5.0	6.36	2.03 ± 0.10
21.11	207.°216	174	46.6 ± 3.5	6.31	2.09 ± 0.09
21.17	207.°278	120	37.3 ± 3.4	6.37	2.11 ± 0.08
21.28	207.°387	130	49.3 ± 4.3	6.25	2.00 ± 0.07
21.35	207.°459	300	49.3 ± 2.8	6.31	1.93 ± 0.06
21.43	207.°541	100	33.1 ± 3.3	6.58	1.92 ± 0.06
21.50	207.°609	94	41.9 ± 4.3	6.90	1.97 ± 0.08
21.76	207.°864	34	60.3 ±10.2	5.95	2.14 ± 0.16
22.02	208.°123	292	70.5 ± 4.1	6.16	2.25 ± 0.12
22.09	208.°197	680	57.5 ± 2.2	6.32	2.25 ± 0.06
22.17	208.°270	484	59.3 ± 2.7	6.35	2.22 ± 0.05
22.27	208.°372	74	46.1 ± 5.3	6.10	2.15 ± 0.06
22.35	208.°450	297	80.5 ± 4.7	6.25	2.11 ± 0.07
22.41	208.°516	184	58.6 ± 4.3	6.26	2.11 ± 0.07
23.10	209.°200	492	42.8 ± 1.9	6.23	2.24 ± 0.08
24.03	210.°125	66	35.9 ± 4.4	6.26	2.30 ± 0.11
1.94	219.°013	9	6.3 ± 2.0	5.95	2.69 ± 0.52
3.28	220.°360	2	2.5 ± 1.4	6.39	2.74 ± 0.58
4.60	221.°681	7	3.5 ± 1.2	6.27	2.81 ± 0.64
6.89	223.°979	9	3.0 ± 0.9	6.13	2.82 ± 0.65

flated by unfavourable conditions, since we selected only observations with limiting magnitude of $\mathrm{lm} \geq +5.8$ and radiant elevations of $h_\mathrm{R} \geq 20°$. We believe that systematic radiant-height effects can only have a minor effect on the absolute level of maximum Orionid activity. The result will thus be very interesting for stream modeling which may give new insights in the dynamics of far-Earth streams such as the Orionids when explaining the peaks of both 2006 and 2007. We are discussing a recent attempt in the Conclusions.

The coverage of the 2007 activity of the Orionids by visual observations gradually decreases after a solar longitude of $\lambda_\odot = 208.°5$ because of the increased interference with the Moon. While we do not detect any recurrence of the short Orionid maximum just before $\lambda_\odot = 210°$ found in the 2006 data, a short-lived peak may be hidden in the longer averages over the sparser data. The duration of enhanced rates (again meaning $\mathrm{ZHR} > 25$) was about the same in 2006 with about 5 days as in 2007.

The ZHR is an observational measure of the shower's activity from the viewpoint of a visual observer, since it refers to a typical field of view of a visual observer and is not corrected for the reduced perception of meteors towards the limiting magnitude. It is appropriate to convert the ZHR into a number density of particles within the Orionid meteoroid stream (Koschack & Rendtel 1990). The conversion again involves the population index making the results critically depending on the accuracy of r. Since this analysis is based on a relatively limited sample of magnitude distributions, we cannot hope to interpret details of the number density profile, but the order of magnitude of the density may be of good enough quality for comparisons of the densities in different years, i.e. in different sections of the stream. Computing the spatial number density of a meteoroid stream requires the geocentric velocity. The values here are computed assuming a geocentric velocity of 66.9 km/s accounting for the 1:6 resonance particles modeled by Sato & Watanabe (2007). Figure 7 shows the result for particles causing meteors of magnitude +6.5 or brighter near the Orionid maximum. These are particles with $3 \cdot 10^{-5}$ g and larger, according to the mass-magnitude relations based on Verniani (1973) and re-written by Koschack & Rendtel (1990). The number densities can be converted into a meteoroid flux density by dividing it by the geocentric velocity (caring for the units though). The flux density at maximum is 0.024 meteoroids per hour per km^2. The spatial number density of the pre-2006 Orionid profile is about 30 particles per 10^9 km^3, corresponding to a flux density of 0.007 km^{-2} h^{-1}. The number is based on the average ZHR profile shown as a dashed line in Figures 4–6 and a population index of 2.3.

Note how the influence of the population index revealed that the first peak with a ZHR near 70 was formed by a stream density which is actually larger than that for the second maximum with a ZHR of 80. Since the population index during the latter was lower, there were actually not very many particles missed by the observers. Of course, the error margins on the spatial number densities are large and the differences are not significant, but the comparison is still good for an illustration of the effects at work.

We also converted the population index profile into a mass index profile and show the result in Figure 8. We follow the same conversion of mass into intensity as was used above for the mass limit and was based on Verniani (1973) and employ – only using the definition of stellar magnitudes – the relation

$$s = 1 + 2.3 \log r \qquad (3)$$

and approximate the error margins by

$$\Delta s = 2.3 \Delta r / r. \qquad (4)$$

The lowest mass index found for the 2007 Orionids is 1.6, while values varied around 1.7±0.1 during the time of maximum activity.

4 Conclusions

The Orionid meteors showed significantly heightened activity in 2007 compared to their long-term behavior of pre-2006 data covered by the Visual Meteor Database (Dubietis, 2003), and compared to the long-term analysis by Rendtel (2008) going back from 2006 to 1944. Even more than 60 years ago, the Orionid ZHR was very likely between 20 and 30.

The evolution of particle orbits of the parent Comet 1P/Halley was studied by Sato & Watanabe (2007). According to their computations, the 2006 outburst of the Orionids was caused by particles in orbits resonant with Jupiter. These orbits were fed by Comet Halley at three perihelion passages about 40 orbital periods ago. The authors also suggest encounters with similar particles in 2007 to 2009. Their figure 1 actually seems to suggest near-Earth nodes of similarly old particle orbits until 2011.

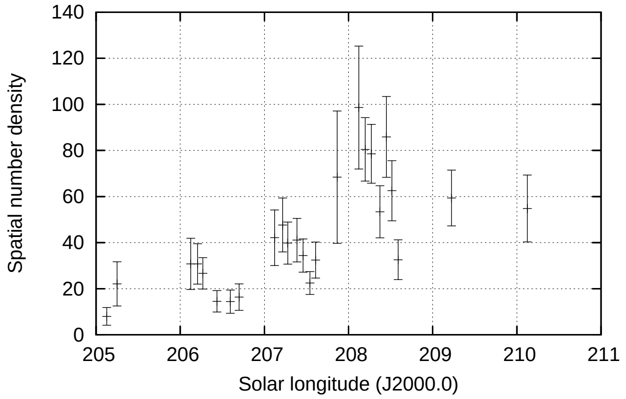

Figure 7 – Spatial number density of Orionid particles causing meteors of at least magnitude +6.5 in a cube of 10^9 km^3 during the 2007 maximum. Note that the plotted solar longitude range is different from the ZHR plots.

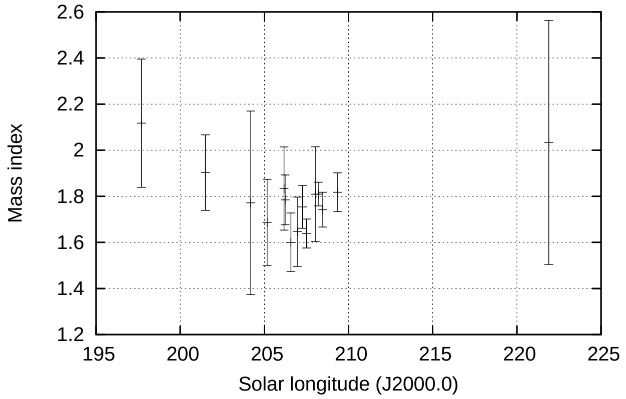

Figure 8 – Mass index in the 2007 cross-section of the Orionid meteoroid stream. It represents the differential decrease of particle numbers with increasing mass.

A follow-up of these computations is shown on the web page of Mikiya Sato (2007). Dust trails are found close to the orbit of the Earth in 2007 on October 19, around $23^{\rm h}$ UT, and on October 21, near $17^{\rm h}$ and $20^{\rm h}$UT, corresponding to solar longitudes of $206\overset{\circ}{.}07$, $207\overset{\circ}{.}81$, and $207\overset{\circ}{.}94$, respectively. We do not find significant enhancements in Orionid activity at these times. The chances to detect activity from these specific dust trails were indeed stated to be weak by Sato. There is a first, weak maximum in activity after the encounter with the 1265 BC trail at $\lambda_{\odot} = 206\overset{\circ}{.}25$ with a ZHR of 22.5 which exceeds an apparent 'background profile' of 18–20 only marginally. As for the second encounter possibility, if the low population index r at $207\overset{\circ}{.}8$ is not caused by a systematic problem, it may be an indication of the encounter with the dust trail of 1197 BC, found by Sato (2007). When looking back at 2006, we also see some discrepancy between the dust trail timings from the model and the observed peaks as reported by Rendtel (2007). Of the trails or trail parts with three highest f_{M}-values, the one at $\lambda_\odot = 209\overset{\circ}{.}824$ has a nice match, while the ones at $\lambda_\odot = 207\overset{\circ}{.}464$ and $\lambda_\odot = 209\overset{\circ}{.}824$ do not have any dramatic association with an observed peak. Given the age of the trails, one certainly has to assume larger time-spans for the peaks to fall into, than for young trails which were encountered e.g. during the 1999 and 2001 Leonids.

Old trails can be rather wide in solar longitude as we have seen with the 1998 Leonid fireball storm and the related dust trail of 1333; see Arlt (1998) for observational results and Asher et al. (1999) for the modeling. Looking at the results by Sato and Watanabe, the origin of both the 2006 and 2007 enhanced rates appears to be dust from the perihelion passages of Comet 1P/Halley 30–45 revolutions ago. All the relevant particles are in 1:6 mean motion resonance with Jupiter. The modeling is also in line with the absence of enhanced Orionid rates in the past, at least back to 1966.

We conclude that the Orionid meteor shower delivered enhanced activity in 2007 with maximum ZHRs of about 80 near a solar longitude of $208\overset{\circ}{.}45$ (2007 October 22, 8^{h} UT), whereas the annual Orionid activity is typically 20–25 meteors per hour during a wide maximum centered on $\lambda_\odot = 209^\circ$. The 2007 Orionid maximum is actually split, and exhibits an earlier peak of ZHR $= 70 \pm 4$ at $\lambda_\odot = 208\overset{\circ}{.}12$ (2007 October 22, $0^{\mathrm{h}}30^{\mathrm{m}}$ UT). The activity in 2007 was even higher than in 2006. The amount of data is smaller though, and the absolute ZHR figures are more uncertain. More generally, we conclude that the heightened Orionid activity of $\lambda_\odot = 208^\circ$–$209^\circ$ occurred again in 2007, while later peaks near 210° and 212° were not detected, possibly because of lack of data.

Maximum spatial number densities of Orionid particles were near 100 in cube of 1000 km edge length. This corresponds to a flux density of about 0.024 $\mathrm{km}^{-2}\ \mathrm{h}^{-1}$. The differential mass index dropped to values of $s = 1.7 \pm 0.1$.

If the Orionid meteor shower persists in showing ZHRs of 60–70 until about 2011, observers' efforts will be rewarded with the longest major-shower maxima for which catching the right geographical longitude is not overly important. We would like to encourage all observers to plan meteor watches and report their data in 2008, despite the last-quarter moon. Observing fields west of the radiant, in Aries and Cetus, are recommended to avoid too much disturbance from the Moon which is at high declination and hence at high elevations above the horizon in the northern hemisphere. Observations from the southern hemisphere are also encouraged, where the Moon is a bit lower in the sky than the Orionid radiant, and observing directions to the south-west and south are moon-free.

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