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Radar meteors range distribution model

III. Ablation, shape-density and self-similarity parameters

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Abstract. The theoretical radar meteors Range Distribution of the overdense echoes developed by Pecinová and Pecina (2007 a) is applied here to observed range distributions of meteors belonging to the Quadrantid, Perseid, Leonid, Geminid, γ Draconid (Giacobinid), ζ Perseid and β Taurid streams to study the variability of the shape-density, ablation, and self-similarity parameters of meteoroids of these streams. We have found in accordance with results of photographical observations that ablation parameter σ is higher for members of showers of clearly cometary origin, and is lower for Geminid and daytime shower meteoroids. Levin's self-similarity parameter μ was found to be much greater than the classical value 2/3 for all investigated streams with the exception of Geminids, for which the value found is almost classical, i. e. 0.66 ± 0.01. The method of getting μ by means of fitting the light curve of faint TV meteors is also suggested.

Key words: physics of meteors – radar meteors – range distribution – ablation, shape density and self-similarity parameters

1. Introduction

At the very beginning, our aim was to develop a model allowing for the computation of fluxes and mass distribution indices of meteor showers. To achieve this goal, we developed the radar meteors range distribution model (RaDiM) (Pecinová and Pecina, 2007 a) which we will refer to as Paper I. The results of the application of RaDiM concerning the flux Θ_{m_0} and mass distribution indices s on some showers have been published by Pecinová and Pecina (2007 b) (hereinafter as Paper II). It turned out, however, that the whole problem is much more complicated. The computation of two quantities describing the inner structure of meteor showers (Θ_{m_0}, s) proved to be intimately connected with several physical parameters of meteoroids. These are the shape-density parameter K, the ablation coefficient σ, and Levin's self-similarity parameter μ. This paper is a follow-up to Papers I and II. In this work, we present results on the above listed quantities and discuss the results we have arrived at. The next paper in this series will deal with the ionization coefficient β.

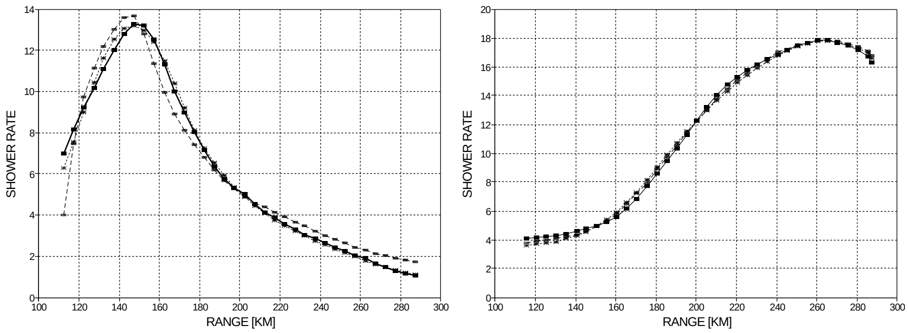

Figure 1. Left: the range distribution of meteors belonging to the ζ Perseid meteor shower observed between 3 and 7 UT on 8th June 2003. The vertical axis shows shower rates in 5-km-wide range intervals, which are represented by their mid-points on the horizontal axis. The observed range distribution is represented by squares which are connected by the full line. Both theoretical range distributions were computed using the fundamental formula (7) from Paper I. The former one, depicted by the horizontal lines and the dashed line, results from computations under the assumption $\mu = 2/3$. The latter one, represented by the stars and the dotted line, was obtained when the parameter μ was allowed to vary in the RaDiM. The result gives $\mu = 1.92 \pm 0.04$ (see Table 6). Right: the same but for the Geminid meteor shower observed between 0 and 4 UT on 14th December 1991. The result gives $\mu = 0.66 \pm 0.08$ (see Table 4).

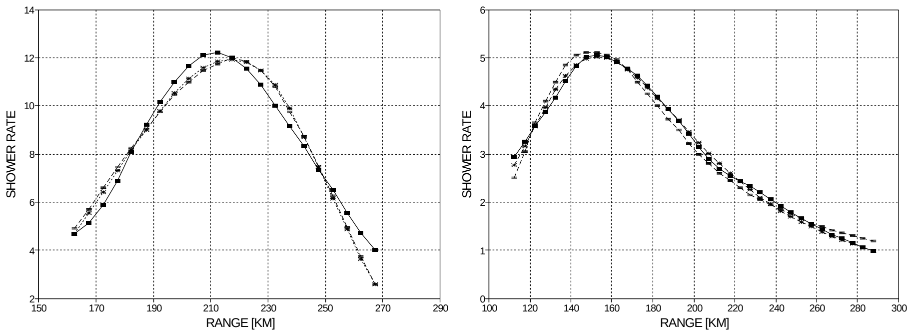

Figure 2. Left: the same as in Figure 1 but for the Giacobinid meteor shower observed between 12 and 14 UT on 8th October 1998. The result gives $\mu = 1.94 \pm 0.11$ (see Table 5). Right: the same but for the Perseid meteor shower observed between 10 and 12 UT on 12th August 1980. The result gives $\mu = 1.01 \pm 0.22$ (see Table 2).

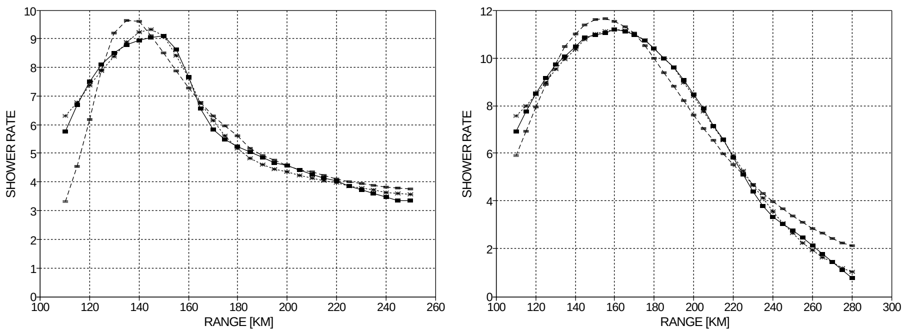

Figure 3. Left: the same as in Figure 1 but for the Leonid meteor shower observed between 0 and 2 UT on 17th November 1998. The result gives $\mu = 1.80 \pm 0.19$ (see Table 3). Right: the same but for the Quadrantid meteor shower observed between 12 and 14 UT on 3th January 1987. The result gives $\mu = 1.80 \pm 0.19$ (see Table 1).

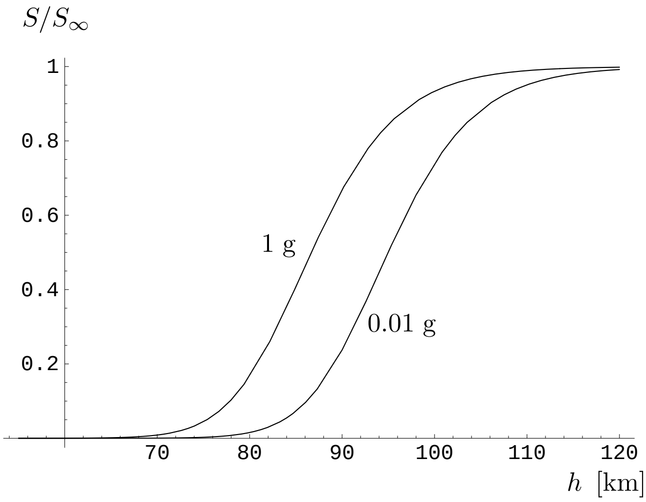

Figure 4. The dependence of the ratio S/S_∞ on the value of preatmospheric mass m_∞ is depicted in accord with (2). Both curves that are marked by the relevant value of mass, m_∞, (in grams) are computed for the case of Geminids radiant culmination and the following values: $\mu = 2/3$, $H = 5.409$ km, $\varrho_o = 56.803$ kg m^{-3} and $K \cdot \sigma = 0.01$ s^2 km^{-2}.

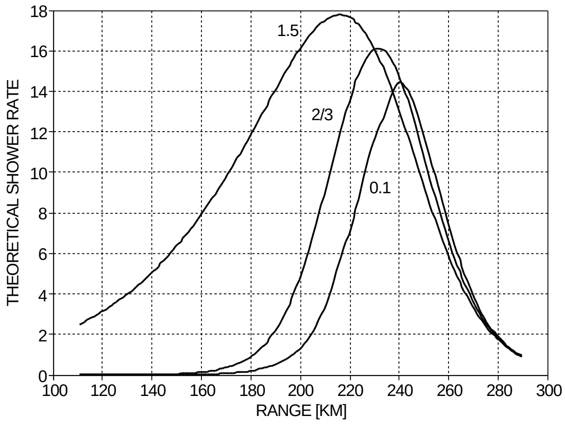

Figure 5. The theoretical range distribution as a function of Levin's parameter μ. The relevant curves are marked with the chosen value of μ. The computations were performed for the Geminids between 1 and 2 UT, on the 13th of December 2000. The constants and quantities used for the theoretical calculations were the following: mass $m_o = 10^{-5}$ kg, $v_\infty = 36$ km s^{-1}, $K \cdot \sigma = 0.01$ s^2 km^{-2}, $s = 1.5$, $\beta = 0.100$, $D_r = 4.2\,\mathrm{m}^2\,\mathrm{s}$ (height of 93 km), $H = 5.409$ km and $\varrho_o = 56.803$ kg m^{-3}.

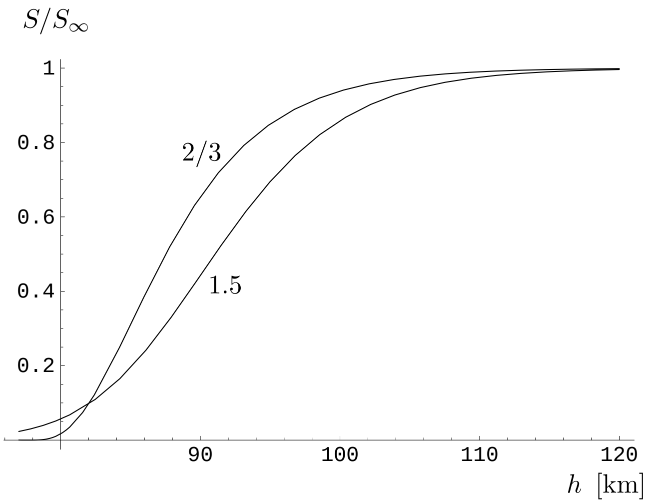

Figure 6. The dependence of the ratio S/S_∞ of a meteoroid on the height h, for two values of μ, computed according to (2). The constants and quantities used for the theoretical calculations were the same as in Fig. 5.

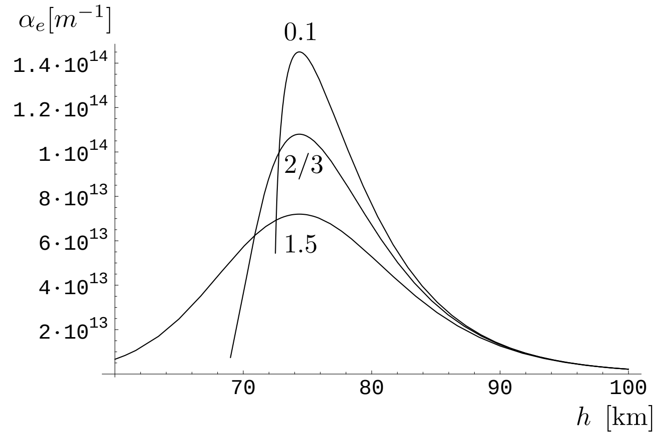

Figure 7. The ionization curve changes as Levin's parameter μ varies while the other parameters are kept constant. The relevant curves are marked by the corresponding value of μ, the value 2/3 being valid for the classical theory. The computations were performed for the same constants and quantities as in Figure 5.

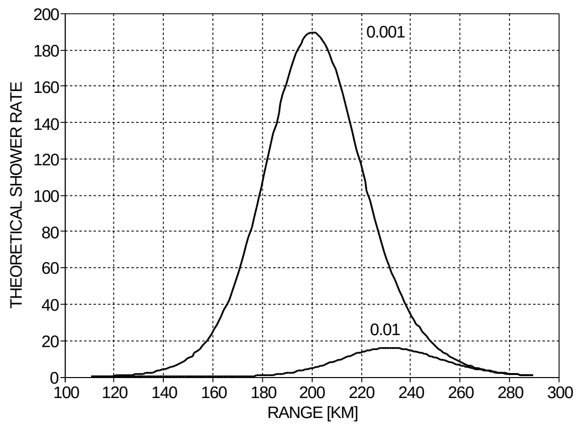

Figure 8. The theoretical range distribution as a function of the product $K \cdot \sigma$. Both curves that are marked by the corresponding value of $K \cdot \sigma$ were computed for the radiant of Geminids between 1 and 2 UT, on the 13th December 2000. The constants and quantities used for the theoretical calculations were the following: mass $m_{\rm o} = 10^{-5}$ kg, $v_\infty = 36$ km s^{-1}, $s = 1.5$, $\mu = 2/3$, $\beta = 0.100$, $D_r = 4.2\,{\rm m}^2\,{\rm s}$ (height of 93 km), $H = 5.409$ km and $\varrho_o = 56.803$ kg m^{-3}.

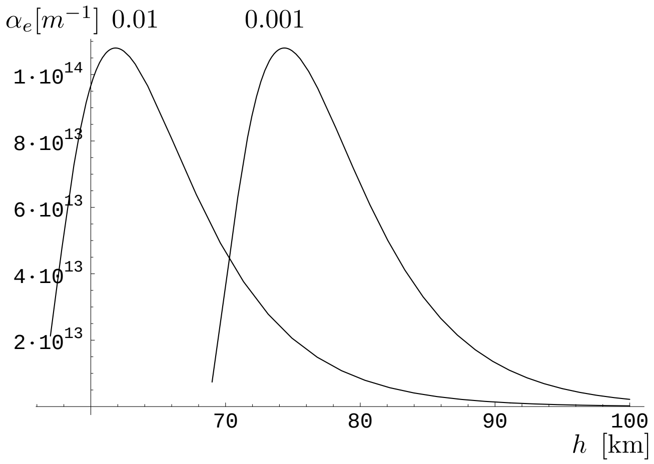

Figure 9. The ionization curve changes as the product of $K\cdot\sigma$ varies while the other parameters are kept constant. The relevant curves are marked by the corresponding value of $K\cdot\sigma$. The constants and quantities used for the theoretical calculations were the same as in Fig. 8.

2. Self-similarity parameter μ

The physical theory employed so far usually considers $\mu = 2/3$ as a standard. When we tried to develop a simple model of the range distribution with this assumption, it turned out that it did not describe the observed reality very well (as already mentioned in Paper I). To improve our model, we introduced μ in accordance with relation (11) from Paper I. Allowing $\mu \geq 0$ in our computations, we achieved a substantial improvement between the observed range distributions and the theory. This fact can easily be seen in Figs. 1 - 3. This finding, and the fact that the observed and theoretical range distributions computed under Levin's assumption correspond to each other (better correspondence for smaller distances) justifies this assumption.

We now focus on Levin's assumption in a greater detail. The law governing variability of the cross-section of a meteoroid during ablation (relation (11) from Paper I) in accordance with Levin (1956) reads:

$$S = S_\infty \, (m/m_\infty)^\mu \, . \tag{1}$$

Here, S is the instantaneous cross-section of a meteoroid and m its corresponding mass. The quantities labeled by the symbol ∞ denote their pre-atmospheric values. The pre-atmospheric shape of a meteoroid is considered to be a sphere. By substituting relation (25) from Paper I (which expresses the mass dependence on height h) into (1) we get the very useful relation:

$$S/S_\infty = \Big\{1-(1-\mu)[(HK\sigma v_\infty^2)/(m_\infty^{1/3}\cos z_R)]\,\varrho(h)\Big\}^{\frac{\mu}{1-\mu}} . \tag{2}$$

Apart from other quantities, the above mentioned S/S_∞ ratio dependence on height h is also influenced by pre-atmospheric meteoroid mass m_∞. Its connection with the ablation process is clearly visible in Fig. 4. Meteoroids with smaller mass cease ablation earlier and higher than more massive ones due to more rapid mass-loss.

The influence of the self-similarity parameter μ on the range distribution is demonstrated in Fig. 5. One of the most important pieces of knowledge is the fact that range extension of the distribution depends on the value of μ. The greater this value the wider the extent of the distribution is due to an increase of shower rates at closer ranges from the observational site (radar). This enhancement is needed due to the demand for better fitting at shorter ranges as shown in Figs. 1 - 3. The direct mathematical relation between cumulative rates of echoes and the self-similarity coefficient is not so clearly visible (see Paper I), however, we can easily demonstrate how self-similarity parameter μ influences the S/S_∞ ratio and consequently the ionization curve which is inseparably bound up with the range distribution. In Fig. 6, there are two curves that represent height dependence of the S/S_∞ ratio in accordance with (2) for two values of μ: 2/3 and 1.5. Obviously, the curve belonging to the classical case (2/3) decreases quicker than the second one, and it ceases at higher heights. The fact that the curve depicted for $\mu = 1.5$ ends lower than the classical one is related to the ionization curve. There are three ionization curves computed for three different values of μ in Fig. 7 in order to demonstrate the influence. We can see that as μ increases, the end of the ionization curve shifts to lower heights while the beginning of it remains the same. Moreover, a smaller value of μ gives a bigger value of $\alpha_{\max}$ at the point of maximum ionization. The height of the maximum does not depend on the value of μ. The mathematical formulations of these facts are described by formulas (37) and (38) of Paper I. The effect of μ on the range distributions (Fig. 5) is a direct consequence of the above effects. Because Figs. 6 and 7 are depicted for only one value of m_∞ and observed range distributions are the results of contributions of a large number of meteoroids with various mass exceeding m_o the net effect of μ cannot be clearly demonstrated. But it obviously leads to a better description of the observed reality at smaller distances from the radar (Figs. 1 - 3).

3. Ablation coefficient σ and shape-density parameter K

In RaDiM it is not possible to separate the ablation coefficient σ from the shape-density parameter K and to compute them separately. The method allows us to evaluate only their product (see Paper I for more details). This product affects the range distribution differently than μ does. Fig. 8 demonstrates the changes

Table 1. Results of the application of the RaDiM to the data of the Quadrantids. The first column contains the year when the shower was observed, the second one the day of observation, the third one the beginning hour of observation on January, bh, while the next the corresponding end hour, eh both in LT (CET). The quantity $L_\odot$ is the solar longitude of the centre of observation interval related to the equinox of J2000.0. There is the product of the ablation coefficient and the shape-density parameter, $K\cdot\sigma$, contained in the last but one column while the self-similarity parameter is included in the last column belonging to each year.

Year	Day	bh	eh	$L_\odot$	$K\cdot\sigma$	μ
1961	3	0	2	282°.931	0.024 ± 0.004	1.54 ± 0.10
1962	3	10	12	283°.093	0.047 ± 0.009	1.43 ± 0.13
1964	3	2	6	282°.270	0.061 ± 0.007	1.71 ± 0.13
1965	3	10	12	283°.331	0.036 ± 0.004	1.38 ± 0.12
1966	3	8	10	282°.983	0.058 ± 0.007	1.40 ± 0.20
1967	4	10	12	283°.821	0.047 ± 0.008	1.69 ± 0.20
1968	4	2	4	283°.227	0.035 ± 0.007	1.70 ± 0.16
1969	3	4	5	283°.007	0.018 ± 0.006	1.40 ± 0.14
1975	4	4	6	283°.511	0.049 ± 0.004	1.61 ± 0.22
1976	4	0	4	283°.130	0.055 ± 0.007	1.33 ± 0.17
1977	3	2	6	282°.953	0.028 ± 0.005	1.27 ± 0.12
1978	3	2	4	282°.647	0.042 ± 0.009	1.62 ± 0.03
1980	4	1	5	283°.140	0.055 ± 0.009	1.42 ± 0.18
1982	3	1	5	282°.626	0.061 ± 0.008	1.69 ± 0.29
1982	4	1	5	283°.646	0.038 ± 0.006	1.48 ± 0.16
1983	4	3	5	283°.422	0.041 ± 0.003	1.76 ± 0.13
1985	3	9	15	283°.240	0.034 ± 0.006	1.32 ± 0.12
1986	3	13	15	283°.060	0.047 ± 0.009	1.38 ± 0.21
1987	3	12	14	282°.757	0.030 ± 0.002	1.75 ± 0.13
1987	4	4	6	283°.437	0.055 ± 0.006	1.82 ± 0.17
1988	4	3	5	283°.132	0.031 ± 0.004	1.37 ± 0.20
1991	4	3	5	283°.366	0.039 ± 0.006	1.56 ± 0.14
1992	4	3	5	283°.110	0.039 ± 0.009	1.40 ± 0.15
1992	4	1	5	283°.067	0.051 ± 0.009	1.50 ± 0.13
1994	3	1	5	282°.545	0.050 ± 0.010	1.38 ± 0.15
1994	4	1	5	283°.564	0.040 ± 0.006	1.57 ± 0.18
1995	4	4	6	283°.390	0.035 ± 0.006	1.47 ± 0.11
1995	4	10	12	283°.645	0.043 ± 0.007	1.73 ± 0.10
1996	4	3	5	283°.083	0.040 ± 0.005	1.42 ± 0.12
1996	4	1	5	283°.041	0.047 ± 0.004	1.68 ± 0.17
1997	3	3	5	282°.820	0.064 ± 0.010	1.78 ± 0.20
1997	3	1	5	282°.778	0.067 ± 0.009	1.35 ± 0.15
1998	3	2	6	282°.558	0.050 ± 0.009	1.35 ± 0.11
1998	3	10	12	282°.855	0.042 ± 0.007	1.26 ± 0.20
1999	4	2	6	283°.311	0.032 ± 0.005	1.27 ± 0.18
1999	4	2	4	283°.269	0.052 ± 0.009	1.10 ± 0.13
2000	4	2	4	283°.012	0.031 ± 0.006	1.52 ± 0.15
2000	4	10	12	283°.351	0.042 ± 0.009	1.49 ± 0.21
2001	3	0	4	282°.710	0.041 ± 0.007	1.80 ± 0.14
2001	3	10	14	283°.135	0.036 ± 0.008	1.90 ± 0.10
2001	3	10	12	283°.092	0.043 ± 0.005	1.73 ± 0.14
2002	3	12	14	282°.913	0.058 ± 0.005	1.72 ± 0.15
2004	4	1	5	282°.986	0.041 ± 0.004	1.52 ± 0.20
2005	3	10	12	282°.568	0.051 ± 0.007	1.66 ± 0.12
2005	3	10	14	283°.109	0.034 ± 0.005	1.89 ± 0.13

of a range distribution when the value of parameter $K{\cdot}\sigma$ changes. Obviously, the higher value of this product gives a more distant and less pronounced maximum. It relates to the course of the ionization curve depending on the value of $K{\cdot}\sigma$ as visualized in Fig. 9. The ionization curve moves into smaller heights as the value of $K{\cdot}\sigma$ decreases, while the value of $\alpha_{\max}$ does not depend on it. Formulas (36) - (38) from Paper I provide us with the mathematical background of these effects.

Table 2. The same as in Table 1 but for Perseids.

Year	Day	bh	eh	$L_\odot$	$K \cdot \sigma$	μ
1980	12	10	10	140°.111	0.054 ± 0.004	1.01 ± 0.22
1981	11	22	4	139°.463	0.060 ± 0.007	1.50 ± 0.21
1981	12	0	2	139°.463	0.014 ± 0.004	0.97 ± 0.10
1982	12	22	24	140°.100	0.034 ± 0.009	0.99 ± 0.13
1982	12	22	4	140°.180	0.067 ± 0.011	1.10 ± 0.19
1983	12	22	24	139°.856	0.059 ± 0.009	1.20 ± 0.21
1983	13	0	2	139°.936	0.048 ± 0.010	1.09 ± 0.22
1985	13	2	4	140°.483	0.060 ± 0.010	1.44 ± 0.18
1985	13	12	14	140°.883	0.050 ± 0.008	0.98 ± 0.12
1986	13	0	2	140°.640	0.059 ± 0.007	0.90 ± 0.10
1989	12	8	12	139°.780	0.056 ± 0.008	1.00 ± 0.20
1991	13	0	2	139°.890	0.035 ± 0.009	0.86 ± 0.20
1992	11	22	2	139°.599	0.054 ± 0.005	1.24 ± 0.22
1993	12	12	16	139°.913	0.087 ± 0.007	1.13 ± 0.18
1995	14	4	10	141°.311	0.016 ± 0.010	0.82 ± 0.11
1996	12	0	6	139°.695	0.015 ± 0.004	1.18 ± 0.22
2000	12	6	10	139°.873	0.023 ± 0.004	0.99 ± 0.24
2000	12	6	10	139°.873	0.060 ± 0.020	1.37 ± 0.27

4. Results and discussion

We have applied RaDiM to seven meteor showers observed by the Ondřejov meteor radar. These are: the Quadrantids 1961-2005, the Perseids 1980-2000, the Leonids 1965-2002, the Geminids 1959-2001, the γ Draconids (Giacobinids) 1998, and the two day-time showers, ζ Perseids, and β Taurids 2003. In total, we make use of 127 observed range distributions to get the following five parameters: the shower flux density Θ_{m_0}, the mass distribution index s, the ionization parameter β (which will be dealt with in the next paper), the self-similarity (Levin's) parameter μ and the product of $K{\cdot}\sigma$. The results concerning the first two parameters have already been published in Paper II. This paper deals with the last two. The results achieved for a particular meteor shower are listed in Tables 1 - 6.

The quantities in Table 1 indicate that the Quadrantid meteor stream can contain meteoroids of different properties for different years. The product $K \cdot \sigma$ varies from the value $K \cdot \sigma = 0.018 \pm 0.006$ to $K \cdot \sigma = 0.067 \pm 0.009$, while the self-similarity parameter μ varies within $\mu = 1.10 \pm 0.13$ and $\mu = 1.90 \pm 0.10$. Even with this spread, the value of μ exceeds the classical value of 2/3 by a significant amount. As for the product $K \cdot \sigma$, its variability indicates a large

Table 3. The same as in Table 1 but for Leonids.

Year	Day	bh	eh	$L_\odot$	$K \cdot \sigma$	μ
1965	17	4	8	$235.^\circ 123$	0.121 ± 0.056	1.51 ± 0.21
1966	17	0	4	$234.^\circ 700$	0.097 ± 0.097	1.43 ± 0.16
1966	17	4	8	$234.^\circ 868$	0.082 ± 0.014	1.37 ± 0.30
1998	17	0	2	$234.^\circ 448$	0.095 ± 0.013	1.80 ± 0.19
1998	17	3	4	$234.^\circ 531$	0.050 ± 0.006	1.38 ± 0.15
1998	17	7	8	$234.^\circ 699$	0.079 ± 0.008	1.88 ± 0.14
1999	18	4	6	$235.^\circ 369$	0.094 ± 0.028	1.70 ± 0.29
2000	18	1	3	$235.^\circ 988$	0.084 ± 0.011	1.44 ± 0.10
2001	18	12	13	$236.^\circ 155$	0.098 ± 0.010	1.34 ± 0.16
2001	19	1	4	$236.^\circ 786$	0.079 ± 0.008	1.62 ± 0.03
2002	19	1.5	4.5	$236.^\circ 526$	0.087 ± 0.030	1.38 ± 0.44

spread in the parameter σ itself since the variability of K is namely due to different bulk densities of meteoroids which cannot change so much.

Since it is well known that the parent body of the Perseid meteor stream is the comet 109P/Swift-Tuttle, the quantities in Table 2 suggest that particles of cometary origin possess higher ablation ability. Geminids (which are considered to be of asteroidal origin with 3200 Phaeton as a parent) have a smaller value of $K \cdot \sigma$. As for the value of μ they are well near the classical value of 2/3. For another cometary based stream, the Leonids (from the comet 55P/Tempel-Tuttle), the values of $K \cdot \sigma$ are even higher when compared to the Perseids, see Table 3. The values of μ for Leonids are higher than for the Perseids. This fact may be connected with the age of the meteoroids since Leonid meteoroids observed in the 1960s and 1990s (during the last return of 55P/Tempel-Tuttle) were newly ejected in contrast to the Perseid meteoroids that were probably ejected many years (or even centuries) ago (see, e. g., Wu and Williams, 1993; Brown and Jones, 1998; Jenniskens et al. 1998).

The quantities in Table 4 show much lower values of the product $K \cdot \sigma$ when compared to showers of cometary origin so far. The same holds true with respect to values of μ. Since it is assumed that Geminids are of asteroidal origin with 3200 Phaeton as a parent body, differences suggest differences in the physical properties of meteoroids of these streams.

The meteoroids of the γ Draconid (Giacobinid) stream are known from the photographical observations as the ones having the largest ablation parameter $\sigma \simeq 0.2\,\mathrm{km\,s^{-1}}$, (see, e. g. Ceplecha et al., 1998). Table 5 supports this for the radar Giacobinid meteors. The quantity $K \cdot \sigma$ listed in Table 5 also indicates low bulk density of these meteors. The high value of μ we have arrived at seems to support this.

The daylight showers (ζ Perseids and β Taurids) are members of the vast Taurid complex stream, which includes comet 2P/Encke as well as several asteroids that are suspected to feed the stream with new particles. Low values of $K \cdot \sigma$ from Table 6 are comparable with those from Geminids. On the other hand, the high values of μ found for both showers are representative of cometary

Table 4. The same as in Table 1 but for Geminids.

Year	Day	bh	eh	$L_{\odot}$	$K \cdot \sigma$	μ
1959	13	2	6	260.°916	0.019 ± 0.002	0.56 ± 0.17
1960	13	2	6	261.°667	0.009 ± 0.001	0.43 ± 0.16
1961	14	0	4	262.°342	0.011 ± 0.002	0.70 ± 0.08
1962	12	0	4	260.°044	0.021 ± 0.004	0.68 ± 0.10
1963	12	20	24	260.°629	0.031 ± 0.004	0.63 ± 0.07
1964	11	20	24	260.°375	0.013 ± 0.004	0.78 ± 0.10
1965	12	20	24	261.°126	0.021 ± 0.007	0.69 ± 0.14
1965	13	20	24	262.°142	0.025 ± 0.003	0.56 ± 0.10
1966	14	0	2	262.°061	0.019 ± 0.005	0.50 ± 0.13
1967	13	0	4	260.°776	0.028 ± 0.005	0.60 ± 0.10
1968	13	0	4	261.°531	0.022 ± 0.003	0.67 ± 0.09
1969	12	0	4	260.°259	0.028 ± 0.004	0.70 ± 0.09
1969	12	4	8	260.°429	0.022 ± 0.004	0.81 ± 0.14
1969	14	0	4	262.°292	0.017 ± 0.005	0.67 ± 0.09
1973	12	0	4	260.°225	0.018 ± 0.005	0.68 ± 0.09
1974	14	0	4	261.°998	0.018 ± 0.002	0.68 ± 0.07
1975	13	0	4	260.°725	0.015 ± 0.004	0.70 ± 0.09
1975	14	0	4	261.°741	0.021 ± 0.003	0.79 ± 0.11
1976	13	0	4	261.°477	0.019 ± 0.004	0.70 ± 0.10
1977	12	0	4	260.°204	0.021 ± 0.002	0.71 ± 0.09
1977	13	0	4	261.°221	0.026 ± 0.003	0.65 ± 0.12
1978	12	2	4	259.°984	0.023 ± 0.002	0.67 ± 0.08
1978	14	2	4	262.°017	0.023 ± 0.003	0.66 ± 0.10
1980	12	2	4	260.°484	0.022 ± 0.003	0.64 ± 0.12
1980	13	2	4	261.°501	0.026 ± 0.003	0.71 ± 0.09
1981	10	4	6	258.°273	0.019 ± 0.003	0.70 ± 0.11
1981	12	2	4	260.°222	0.022 ± 0.007	0.68 ± 0.12
1981	14	2	4	262.°253	0.024 ± 0.004	0.70 ± 0.13
1982	13	0	6	260.°849	0.031 ± 0.004	0.82 ± 0.11
1982	14	0	6	261.°991	0.028 ± 0.004	0.68 ± 0.12
1984	10	4	6	258.°500	0.020 ± 0.002	0.70 ± 0.09
1985	13	0	4	261.°165	0.017 ± 0.003	0.62 ± 0.09
1986	13	0	4	260.°903	0.024 ± 0.008	0.61 ± 0.11
1986	14	0	2	261.°878	0.024 ± 0.004	0.63 ± 0.11
1987	15	0	4	262.°674	0.026 ± 0.004	0.67 ± 0.11
1989	13	0	4	261.°139	0.027 ± 0.003	0.70 ± 0.11
1989	14	0	4	262.°155	0.021 ± 0.003	0.64 ± 0.12
1990	13	0	4	260.°876	0.019 ± 0.002	0.69 ± 0.15
1991	14	0	4	261.°638	0.021 ± 0.003	0.66 ± 0.08
1992	12	0	4	260.°358	0.030 ± 0.004	0.54 ± 0.10
1994	12	1	5	259.°883	0.029 ± 0.004	0.71 ± 0.11
1995	13	0	4	260.°589	0.034 ± 0.004	0.68 ± 0.10
1995	14	0	4	261.°606	0.023 ± 0.004	0.78 ± 0.12
1996	12	2	4	260.°374	0.024 ± 0.003	0.54 ± 0.10
1997	13	0	4	261.°085	0.020 ± 0.003	0.62 ± 0.12
2000	12	0	4	260.°303	0.019 ± 0.002	0.71 ± 0.10
2000	13	0	4	261.°320	0.025 ± 0.003	0.68 ± 0.12
2000	14	0	4	262.°336	0.023 ± 0.003	0.66 ± 0.10
2000	13	1	5	261.°362	0.020 ± 0.002	0.49 ± 0.15
2001	13	1	5	261.°102	0.017 ± 0.002	0.57 ± 0.11

Table 5. The same as in Table 1 but for Giacobinids observed on October 8, 1998.

Year	Day	bh	eh	$L_\odot$	$K \cdot \sigma$	μ
1998	8	12	14	195°.028	0.375 ± 0.052	1.94 ± 0.11

Table 6. The same as in Table 1 but for two daytime showers belonging to the Taurid complex. The ζ Perseids were observed on June 8, 2003, while the β Taurids on June 25.

Year	Day	bh	eh	$L_\odot$	$K \cdot \sigma$	μ
				ζ Perseids		
2003	8	4	8	76°.982	0.012 ± 0.003	1.82 ± 0.02
				β Taurids		
2003	25	5	8	93°.233	0.019 ± 0.003	1.92 ± 0.04

origin meteoroids. The higher value of μ indicates a different ablation process from the typical isotropic process. The lower value of $K \cdot \sigma$ indicates the lower ablation capability similar to the Geminids. From this, it seems that the properties of the daylight shower meteoroids resemble asteroids rather than comets. Therefore, these showers may be of asteroidal origin, as well.

To compare the physical properties of various streams, it is desirable to have representative quantities at hand as it is the case for the values of σ (e.g. Ceplecha et al., 1998). We now consider weighted means of $K \cdot \sigma$ and μ from Tables 1 - 6 to provide a single value that represents a meteor stream. The resulting values of parameters of our interest were calculated with standard deviations of a particular quantity entering the process of summation as weight. They are summarized in Table 7. From Table 7, the difference among showers of different origins (whether cometary or asteroidal) is clearly visible. We can see that the showers of asteroidal origin have much lower values of σ while the difference in μ is not pronounced at all.

Since we cannot consider K independently of σ, we estimate the possible interval of σ assuming various bulk density of meteoroids. Table 8 lists this quantity for the showers included in Table 7. The possible meteoroids bulk densities were published by Babadzhanov (2002).

5. Conclusions

Based on the results summarized in the above tables, we can conclude that:

– The highest ablation ability we found is inherent to the γ Draconid (Giacobinid) meteoroids. We have thus confirmed results known previously from photographic observations as well as from radar meteors from our range distribution method. The value of the ablation parameter we have arrived at is in a good agreement with the value $\sigma = 0.2$ published by Ceplecha et al. (1998). The lowest value we have obtained is that of ζ Perseids,

Table 7. Weighted values of parameters of interest for showers we have used in our analysis.

Shower	$K \cdot \sigma$	μ
Quadrantids	0.042 ± 0.001	1.55 ± 0.02
Perseids	0.044 ± 0.003	1.06 ± 0.03
Leonids	0.082 ± 0.003	1.55 ± 0.03
Geminids	0.021 ± 0.001	0.66 ± 0.01
β Taurids	0.012 ± 0.003	1.82 ± 0.02
ζ Perseids	0.019 ± 0.003	1.92 ± 0.04
Giacobinids	0.376 ± 0.052	1.94 ± 0.06

Table 8. The possible values of the ablation parameter, σ, for various bulk density, δ, of the meteoroids of showers from Table 7. The quantity σ is expressed in $\mathrm{s^2\,km^{-2}}$ while δ in $\mathrm{g\,cm^{-3}}$. Geminids are assumed to have the bulk density $\delta = 2.5\,\mathrm{g\,cm^{-3}}$.

Shower / δ	0.5	1.0	1.5	2.0	2.5	3.0
Quadrantids	0.022	0.035	0.045	0.055	0.064	0.072
Perseids	0.023	0.036	0.048	0.058	0.067	0.076
Giacobinids	0.196	0.311	0.407	0.493	0.572	0.646
Leonids	0.043	0.068	0.089	0.108	0.125	0.141
Geminids					0.032	
β Taurids	0.007	0.010	0.013	0.016	0.019	0.021
ζ Perseids	0.010	0.016	0.021	0.025	0.029	0.033

β Taurids and Geminids, being about twice lower than that of other showers of cometary origin with the exception of Leonids and Giacobinids. In the case of Geminids this indicates different physical properties of their meteoroids when compared to cometary ones. The higher value of σ for Leonids as compared with the corresponding values for Quadrantids and Perseids suggests a younger age of the meteoroids of Leonid storms (1965 - 1966) and (1998 - 2002) in comparison with older age of Quadrantids and Perseids. As far as the daytime showers are concerned, we have got a span of σ rather low. The small values of σ may indicate membership of daytime showers meteoroids to the asteroidal component of the Taurid complex stream rather than to the cometary streams as proposed by Babadzhanov (2001).

– The values of μ much higher than the conventional 2/3 have been found in case of all cometary showers as well as for the daytime ones. The highest value has been found for γ Draconids (Giacobinids) as expected. However, rather unexpectedly high values of μ have also been obtained for both daytime showers. This would suggest a cometary origin for these meteoroids which is in sharp contrast to small values of σ. We are not currently able to interpret this fact more precisely. The lowest value of μ has been determined for Geminids which is almost conventional. This finding indicates the physical properties of Geminid meteoroids are different from cometary based showers.

In the version of the physical theory of meteors we have employed, the shapes of the ionization and light curves coincide. This yields the possibility of getting values of the parameter μ when applying this theory to the light curves of TV meteors since it is generally difficult to get the entire ionization curve from radar observations. The examples of light curves of TV meteors observed at Ondřejov have been published by Koten and Borovička (2001). They are generally more symmetrical than one would expect from the physical theory of meteors. They have arrived at the conclusion that the average value of the parameter $F_{\triangle M}$ defined by Fleming et al. (1993) is close to 0.5 documenting the symmetry of the light curves. The behaviour of faint meteors is usually explained by fragmentation of meteors behaving according to the dust ball model published by Hawkes and Jones (1975). However, another physical process could come into effect when considering Levin's proposition of the dependence of the meteoroid cross-sectional area on the mass of meteoroid in form (1). The light curves fitting using the physical theory including μ will probably be the first method of its determining which could work in practice since Bronshten (1983) states that no reliable method for its getting was developed so far.

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