4.5 FIREBALLS AS AN ATMOSPHERIC SOURCE OF METEORITIC DUST

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This note emphasizes the importance of very bright fireballs as a powerful source of meteoritic dust in the upper atmosphere and on the Earth's surface. Recently we obtained a direct observational evidence when we photographed the Šumava Fireball, an object of -22 absolute stellar magnitude, on Dec. 4, 1974 at $17^h57.5^m$ UT. This is the brightest object on the European Network photographic records during almost 12 years of systematic fireball observations. We obtained 4 all-sky-camera records of the Šumava Fireball from two Czech and one German station of the Network. The most important combination for the trajectory computations proved to be station No. 5 at Ondřejov (Astronomical Institute of the Czechoslovak Academy of Sciences) and station No. 65 at Bernau (Max-Planck-Institut für Kernphysik, Heidelberg). The results are given in Table 1. At Ondřejov we also obtained 4 spectral records of the Šumava Fireball; the most detailed record has a dispersion of 5 Å/mm.

The fireball began the luminous trajectory at a height of 99 km with a velocity of 27 km/s. A very steep increase of brightness took place starting at 82 km height. The maximum brightness of -22 stellar absolute magnitude was achieved at 73 km height. The maximum was a flare of long duration: 14 additional shorter flares were observed: four of them were extremely intense, occurring at heights of 73, 68, 65 and 61 km. The meteor ended its luminous trajectory at 55 km height with a small flare and with almost unchanged initial velocity. The trajectory was inclined by 27^o to the horizon of the terminal point. The 90 km long luminous trajectory was traversed in 3.4 seconds.

Using the luminous efficiency given by Ayers et al. (1970) and by McCrosky (1973), the initial mass was computed as 200 metric tons. This might seem to be an excessively large value, but we note that the measured energy radiated within the panchromatic bandpass (from 3600 to 6600 Å) is 10^{19} erg (300 000 kWh). If the entire kinetic energy of the meteoroid would be radiated within the panchromatic bandpass, 3 metric tons are still needed to produce the Šumava Fireball. Taking the experimentally measured value of the luminous efficiency (between 1 and 2 % for this velocity), we see that 200 tons were necessary to produce the fireball. Owing to an insignificant change of velocity and a very high termination height the terminal mass had to be virtually zero. Any significant mass at a height of 55 km cannot move with velocity higher than 20 km/s without ablation being observed. The entire mass has ablated during the short interval of 3.4 seconds. The structure of the body was very fragile and it resembles the weakest known meteoroids of the Draconid shower. A striking difference between two photographic fireballs with the same velocity is demonstrated in Table 2, which compares the Šumava Fireball with a fireball photographed within the Prairie Network by McCrosky (1973), PN 40660 B. (This is the closest fireball in velocity and in inclination to the surface, which we could find among all PN and EN photographic records). The ratio of brightness is almost 5 orders of magnitude, still the terminal point of the fainter PN-fireball is 26 km lower!

Ceplecha and McCrosky (1976) have recently finished a thorough study of PN-fireballs. Three groups according to the structure of meteoroids were found: group I has the structural strength and density of ordinary chondrites; group II belongs to the carbonaceous chondrites; group III consists of weak material of cometary origin. Group III contains meteoroids of type IIIA, the "stronger" cometary material, and of type IIIB, the "Draconid type" cometary material. The number of fireballs observed in each group is about the same, i.e. about 1/3 of all observed fireballs are of type I, 1/3 of type II and 1/3 of type III. The Šumava Fireball is of type IIIB and the Prairie Network fireball 40660 B is of type I. The Šumava Fireball probably belongs to the meteor shower of Northern Chi Orionids. (Table 1).

The spectral records of the Šumava Fireball do not differ from spectra of fireballs of about -10 stellar magnitude. The emission line spectrum contains FeI, CaI, CaII, MgI, NaI, CrI, MnI, AlI (preliminary indentification). There is some hope that the 5 Å/mm spectrum might permit a study of the line profiles, namely for the brightest feature, the sodium D-doublet. Iron is the most important radiator: more than 2/3 of the observed lines belong to it; multiplet 15 of FeI is the strongest one, not much fainter than the sodium D-lines.

Let us now study the contribution of such big bodies to the Earth's environment. The total area-time coverage of the European Network is about 4×10^{23} $cm^2 s$ up to now; (this is approximately equivalent to a 1 day coverage of the entire Earth's surface). If N is the number of bodies per cm^2 per second having 200 metric tons and more, we have $\log N \approx -23.6$. If we extrapolate the data given by McCrosky (1968;

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Fig. 2 and 3) almost two orders towards bigger masses, we find log N $\approx$ -24.3, and doing the same in the energy plot, we find log N $\approx$ -24.5. This is a relatively good order of magnitude agreement showing that the large number of fireballs given by McCrosky (1968) having masses of up to 5 metric tons is still observed for objects with masses of 200 tons. It is important to emphasize that the Šumava Fireball is not a statistical freak: within the EN coverage we have photographed 4 objects of -17 magnitude, 2 objects of -18 magnitude and 1 object of -19 magnitude. These statistics are well in accordance with fireball data published by McCrosky (1968; Fig. 1).

If we adopt log N $\approx$ -24.0, we arrive at an impact rate of 1 kg/s for the whole Earth's surface from bodies of 200 tons and more, and at about 2 days between successive fireballs belonging to bodies of 200 tons or larger hitting the Earth's atmosphere. This infall produces a practically continuous source of fine dust between heights of 100 and 50 km. If we assume that the 200 tons will be converted into grains of 10^{-15} g, then one such particle per cm^2 is available every 5 seconds (2000 particles of 10^{-15} g/m^{2}s). If we assume that the fireball body is converted into particles of 10^{-6} g, we have one such particle per m^2 every six days. These values are close to the observed numbers of meteoritic dust particles in the Earth's atmosphere, which are known to be significantly higher (by orders of magnitude) than the numbers observed at 1 AU free space.

I think that there is enough evidence (obtained from photographic records of fireballs within the PN- and EN-network) that fireballs are the most important source of meteoritic dust in the Earth's atmosphere (and on the Earth's surface). It is concluded that bodies of dimensions from tens of centimeters to tens of meters, i.e. with masses from 10^5 to 10^9 grams are decisive in producing the atmospheric dust of meteoritic origin.

The physical details of the conversion of a large fireball mass into dust particles are beyond the scope of this contribution. Apart from direct fragmentation into fine dust, a significant fraction of the mass has to evaporate, since we observe most of the fireball light as the emission lines of hot gas. Subsequent condensation may play an important role in forming the tiny dust particles.

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Table 1.: Šumava Fireball (EN 041274)

date		Dec 4, 1974	initial mass	2×10^8 g
time UT		17^h 57.5^m	terminal mass	virtually zero
max.brightness		-22 abs.stel.mag.	radiant α_R app.	75^0
initial velocity		27 km/s	radiant δ_R app.	28^0
beginning	height	99 km	shower(Lindblad)	Northern χ Orionids
beginning	λ	$14^0 38' 24''$ E.Gr.	orbit a	2.0 a.u.
beginning	φ	$49^0 16' 38''$	e	0.76
end	height	55 km	q	0.47 a.u.
end	λ	$13^0 31' 20''$ E.Gr.	Q	3.5 a.u.
end	φ	$49^0 08' 10''$	ω 1950.0	282^0
inclination to the surface		27^0	Ω 1950.0	251.9^0
			i 1950.0	2^0
length		90 km	π 1950.0	174^0
duration		3.4 s	spectral records	FeI, CaI, CaII MgI, NaI, CrI, MnI, AlI

Table 2.

fireball	EN 041274 Šumava	PN 40660 B
initial velocity	27 km/s	26.5 km/s
cos Z_R	0.46	0.60
beginning height	99 km	93 km
terminal height	55 km	29 km
max. brightness	-22 abs.mag.	-10 abs.mag.
initial mass	200 000 kg	8 kg
terminal velocity	$\approx$ 26 km/s	6.5 km/s
terminal mass	$\approx$ 0	30 g
probable structure	very weak cometary material	compact stone
type	IIIB (Draconid type)	I (ordinary-chondrite type)

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