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FRAGMENTATION AND DENSITIES OF METEOROIDS

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Abstract. Photographic observations of meteors carried out in Dushanbe by the method of instantaneous exposure have shown clearly that meteoroids entering the Earth's atmosphere are subjected to different types of fragmentation. The quasi-continuous fragmentation of meteoroids is mostly widespread. Using the physical theory of meteors which takes into account the quasi-continuous fragmentation of meteoroids and on the basis of light curves of meteors the densities of meteoroids of different streams have been determined. The results enable to conclude that the densities of meteoroids are over an order of magnitude higher than they have been assumed before. Moreover they are close to the densities of carbonaceous and ordinary chondrites.

Introduction

The majority of meteoroids are products of desintegration of cometary nuclei. Thus the investigation of meteoroids' physical parameters is important not only for meteor astronomy but is of great interest for understanding of physical features of cometary nuclei. An oppinion on low values of meteoroid ensities is widely spread till the recent time. This oppinion is based on the Verniani's (1969) results deduced from photographic observations of meteors using Super-Schmidt cameras. According to these results the average density ofsporadic or stream meteoroids is equal to 0.3 g/cm^3. The same values were obtained from photographic observation of bright meteors in Dushanbe using small cameras (Babadzhanov and Khaimov 1972). McCrosky (1968) estimated the average density of fireball-producing bodies to be 0.4 g/cm^3,i.e almost the same as for more small bodies. Recently Halliday (1988) estimated the densities of Geminid meteoroids as from 0.7 to 1.3 g/cm^3. However, in these works meteoroid fragmentation in the atmosphere was insufficently taken into account or totally ignored. These results contradict Ceplecha's (1975) conclusion that the average meteoroid density varies in the range from 0.2 to 3.7 g/cm^3.

Analysing the data on photographic observations of meteors Levin (1961) distinguished four main forms of meteoroid's fragmentation: 1)the decay of a meteoroid into comparable large nonfragmenting debris; 2) the progressive disintegration of the original meteoroids into fragments, at which each fragment continue to crumble into smaller fragments; 3) the instantaneous spray of a large number of small particles that gives rise to meteor flares; 4) the quasi-continuous fragmentation-a gradual release of smallest fragments from surface of a parent meteoroid and their subsequent evaporation.

Quite probably that in the atmosphere a meteoroid may undergo the different combination of these fragmentation forms (Babadzhanov et al. 1989).

Quasi-continuous fragmentation of meteoroids

Unique meteor photographs obtained in Dushanbe by the method of instantaneous exposure (Babadzhanov 1983) with exposure of $5.6*10^{-4}$s show clearly the effects of different types of meteoroid's fragmentation. But the most common type is the quasi-continuous fragmentation forming the shortlivingmeteor wakes of up to several ten metres in length. Instantaneous images of such meteors have a drop-like shape.

A theory of quasi-continuous fragmentation developed during last decade

(Lebedinets 1980; Novikov et al. 1984; Babadzhanov et al. 1984, 1988) allow toestimate both the masses of separated fragments and the density of meteoroids. According to this theory the meteor luminosity $I(\rho)$ at the height where theatmospheric density is equal to ρ depends on the main parameters of a meteoro-id in the following way (Novikov et al. 1984; Babadzhanov et al. 1984, 1988):

(1)
$$I(\rho)=\frac{9\tau_\nu M_o V_o^3 \cos Z_R}{2H(R_o R_1)^3}\left\{F_1(\rho)\theta(a-\rho)+R_1^3 F_2(\rho)\theta(\rho-a)\theta(b-\rho)+\frac{1}{30}F_3(\rho)\theta(\rho-b)\theta(\rho_e-\rho)\right\},$$

where

(2)
$$F_1(\rho)=\rho\left\{\frac{1}{3}(\rho_e-\rho)^2\left[R_1^3-(a-\rho)^3\right]-\frac{1}{2}(\rho_e-\rho)\left[R_1^4-(a-\rho)^4\right]+\frac{1}{5}\left[R_1^5-(a-\rho)^5\right]\right\},$$

(3)
$$F_2(\rho)=\rho\left\{\frac{1}{3}(\rho_e-\rho)^2-\frac{1}{2}R_1(\rho_e-\rho)+\frac{1}{5}R_1^2\right\},$$

(4)
$$F_3(\rho)=\rho(\rho_e-\rho)^5,$$

(5)
$$a=\rho_e-R_o, \qquad b=\rho_e-R_1,$$

τ_ν, M_o, V_o are the luminous efficiency, preatmospheric meteoroid mass and velocity; H-the scale height; Z_R – the zenith distance of meteor radiant; ρ_e atmospheric density in the arbitrary point of the meteor trajectory; a –the atmospheric density at the height of complete evaporation of fragments released at the moment of fragmentation beginning; b –the atmospheric density at the height of the end of fragmentation; R_o and R_1– the parameters determining the quasi- continuous fragmentation:

(6)
$$R_o=\frac{6Q_f M_o^{1/3}\delta_o^{2/3}\cos Z_R}{\Lambda\ A\ H\ V_o^2}, \qquad R_1=\frac{6(Q-Q_f)m_o^{1/3}\delta^{2/3}\cos Z_R}{\Lambda'A'H\ V_o^2},$$

Q_f–the specific energy of meteoroid fragmentation; $Q=8*10^{10}$erg/g –the specific energy of heating and evaporation of meteoric matter; Λ, A, δ_o–the heat transfer coefficient, the shape factor and the meteoroid density respectively; Λ', A', δ – the same values for the fragments. $\theta(x)$ – Heavyside's function: $\theta(x)=1$ at $x>1$ and $\theta(x)=0$ at $x\leq 0$.

Meteoroid densities

Using the observed values of M_o, V_o, Z_R and the light curves of meteorsby the method of successive approximations we determined such values of the parameters R_o and R_1 of equation (1) for which the theoretical and observed meteor light curves would coincide in the best way.

The meteoroid density and mass of fragments may be estimated from derived values of R_o and R_1 if the values of Λ, Λ', A, A', Q_f and δ are known apriori.According to Lebedinets (1991) for large meteoroids of mass between 0.01 and 10 g the heat transfer coefficient depends on mass Mo as

(7) $$\Lambda=\Lambda_0+(1-\Lambda_0)\exp(-kM_0),$$

where $\Lambda_0 = 0.03$, $k = 0.25\ g^{-1}$. It is assumed that $A=1.5$, $A'=1.21$, $H=6$ km, $\Lambda'=1$, $\delta=3.5\ g/cm^3$. From the data of Lebedinets (1987) paper the dependence of fragmentation energy on density may be approximated as

(10) $$Q_f*10^{-10}=0.10 + 0.18\delta_0.$$

Simulation of the meteor light curves was carried out for meteoroid densities between 0 and 10 g/cm^3 and mass of fragments between 10^{-10} and 10^{-2} g As an example, Fig. 1 shows the results of simulation of two meteor light curves where the absolute meteor magnitude $\mathfrak{M}$ is plotted against the altitude. As it seen, the observed light curves of examined meteors (marked by "X") correspond to theoretical ones calculated taking account of the quasi-continuous fragmentation. The results of determination of densities of meteoroids belonging to different streams are given in Table 2. An analysis of results shows that light curves of 109 out of 361 bright meteors photographed in Dushanbe are described sufficiently well by the theory of quasi-continuous fragmentation. That is about 30% of total number of investigated meteors. About 70% of the meteoroids probably exposed to other types of fragmentations. Out of 79 meteors, which light curves are described satisfactorily by the theory of quasi-continuous fragmentation, 18 meteors were produced by the

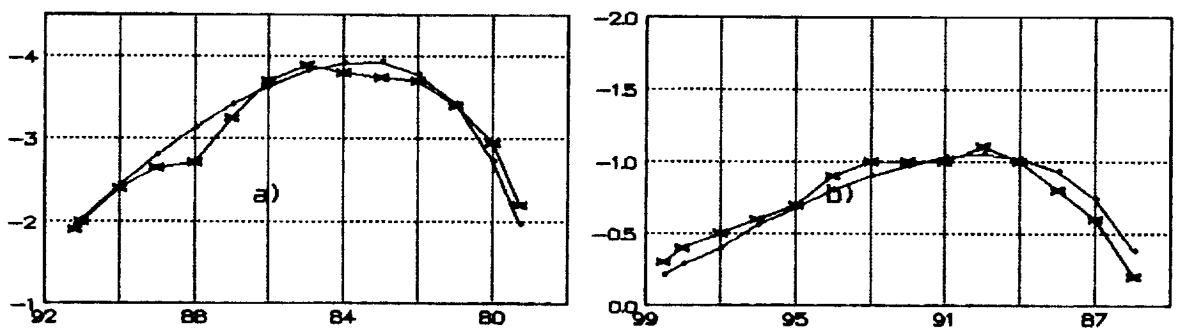

Fig.1. Observed (X) and theoretical light curves of the meteors: a) Sporadic, M_0=2.1 g, V_0=43.1 km/s, $\cos Z_R$=.794; b) Geminid, M_0=0.54 g, V_0=36.1, $\cos Z_R$=0.80

Table 2. Meteoroid densities

Shower	Parent body	Numbers of meteoroids of different densities (g/cm^3)					All	Mean density
		<1	1-2	2-3	3-5	5-8		g/cm^3
Perseids	P/Swift-Tutlle	2	4	5	27	8	46	3.8
Leonids	P/Tempel-Tutlle	1	5	1	2	1	10	2.5
Geminids	Phaethon	-	-	1	2	6	9	5.9
κ Cygnids	?	-	-	1	-	1	2	5.0
Quadrantids	P/Machholz	-	2	-	1	1	4	3.3
δ Aquarids	P/Machholz	-	-	1	4	5	10	5.3
Taurids	P/Encke	1	-	-	3	-	4	3.7
Sporadic		2	1	3	11	7	24	4.1

dense stony or chondrite type or iron meteoroids, 12 meteors – by the carbonaceous chondrites C2 and C1, and 18 meteors – by the carbonaceous chondrites CO or dustballs.

Conclusion

So taking into account the quasi-continuous fragmentation, as a result of mathematical simulation of meteor light curves it is revealed that both among stream's and sporadic meteoroids the particles of quite different densities are found. It should be noted that on the average Perseid and Leonid meteoroids are considerable less dense than Geminids or δ-Aquarids. Apparently his difference is caused by closeness of Geminid's and δ-Aquarid's perihelion to the Sun (accordingly 0.14 and 0.07 A.U.). Perihelion of the Perseids and Leonids are close to 1 A.U. These results are in accordance with the estimates of meteoroid densities derived by the Lebedinets (1987) on the basis of meteor ecelerations. On the average the densities of meteoroids are of 1-1.5 order larger than proposed before without taking into account the fragmentation.

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