ESTIMATES OF FIREBALL’S MASS BASED ON LUMINOSITY CURVES

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Investigation of the PN and EN bolides gives data on the apparent strength of the meteoroids, and permits to estimate mass influx of meteoroids with various size onto the Earth.

In our model the radius of the cosmic body is obtained from the luminosity data [1]. If fragmentation of the body occurs it may lead to the increase in the radius and the decrease in the average density of the body. Using observed intensities, velocities and heights versus time we can find the instantaneous radius of the body or of the cloud of fragments. The body’s radius was determined by the following expression [2,3]:

\[ I = \frac{R^2}{2} \left[ C_D + C_H \left( \frac{V^2}{2Q} \right) \right]^{1/2} \]

Here \( I \) is the intensity of radiation, \( R \) is the effective radius of the body, \( \rho_a \) is the atmosphere density at the height \( h \), \( V \) is the velocity of the body, \( C_D \) is its drag coefficient (\( C_D = 1 \) for a sphere), \( C_H \) is the heat transfer coefficient [3] (\( C_H, f_v \) depend on \( V, R, h \)), \( Q \) is the specific ablation energy.

Value of radiation efficiency \( f_v \) is defined in assumption that the radiation is the radiation of shock compressed and heated air and vapor layers and means that \( f_v \% \) of the energy release is converted into radiation of corresponding bandpass. The meteoroids were supposed to be H-chondrite bodies and self-consistent values of ablation rate and luminosity were obtained in the course of systematic radiation-hydrodynamic ablating piston simulation for H-chondrites similar to that for irons [3].

The time of the flight and entry velocity are known from the catalogue [1] and more detail data, which were obtained due to courtesy of Dr. Ceplecha [4]. Modeling began at the altitudes of about 55\(+60 \) km, where local thermodinamical equilibrium approximation becomes to be valid. Using determined value of radii and assuming various masses we determine the body’s density, and by comparing the velocities-height curve with the observed one it is possible to check obtained estimates.

Our model was applied to 12 bolides, with the estimated photometric masses greater 30 kg. All of them were previously classified as belonging to types I or II (i.e. with density about 3.7 and 2 g/cm^3) [5]. Our masses are much lower (about 1.5-10 times, an average value 3-5 times, in dependence of used energy conversion factor) than photometric ones. This statement is in agreement with our previous assertions [2] and with recent conclusions of Ceplecha [5] that so called "photometric masses" may not be used without having the full knowledge, how they were derived. As for the famous Lost-City meteorite is concerned (which was exactly H-chondrite), we obtained following characteristics: \( M \sim 50-140 \) kg, \( R \sim 20-40 \) cm. Earlier, other investigators have given estimates for the Lost City meteorite: 80-250 kg, \( R_\infty = 21-35 \) cm [6], and 52 kg, \( R_\infty = 15 \) cm [8]. Our result also is in vicinity to recent parameters reestimate done by Ceplecha [5]: \( M \sim 160 \) kg, \( R_\infty \sim 25 \) cm.

The duration of the main flash in the new data file has drastically decreased in comparison to the duration of the light flash of the “old” data [1]. For example, for PN 40503 it is no more than 0.1 sec (previously 0.6 sec). The theoretical estimate of the flash duration is several times larger than \( t_f = \frac{(R_b/V)}{\sqrt{\rho_b/\rho_a}} \), that is about \( 10^{-2} \) sec (\( \rho_b \) is the body’s density). Thus the flash duration of such small body at sufficiently low altitude (about 23 km) may not be resolved even by the new data file. Nevertheless, it is possible to identify some major light flashes with the breakup process and to denote breakup points. Four bolides out of 12 have been identified as being fragmented at the pressure loading from 20 up
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to 100 Mdyn/cm², three bolides were classified as nonfragmented while the pressure achieved 13-50 Mdyn/cm², and the others cannot be identified. Our estimates of breakup are close enough to Ceplecha ones, which were obtained using quite another technique [5,8].

Integral luminous efficiency (averaged over the entire trajectory, in panchromatic bandpass) increases with the value of the total energy emitted during the flash (see Fig.). For the biggest bolide is as large as 3-5% while for the light impulse smaller three orders of magnitude it is as low as 0.1%

There is a rather large scatter in the values of luminous efficiencies which may be explained that the luminous efficiency depends on the velocity, not only on the energy of light impulse. But we see that there is a clear tendency of the luminous efficiency values to increase with the energy of the light flash (and of the meteoroid) which may be explained by the increase in the size of the bolides and increase in the optical thickness of the air (and vapor) plasma. We do not want to recommend the usage of these values as universal absolute values but the tendency is clearly demonstrated. That means that we can not use the values of luminous efficiency obtained in the experiments with artificial meteors for the case of large bolides and that if experimental data in the range of 50-500 kg have been or would be obtained we can not use these date for the case of bolides with the masses in the range of about 50-500 tons detected by satellite network [9] without caution.

References: