Statistical approach to meteoroid shape estimation based on recovered meteorites

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Each meteorite sample can provide data on the chemical and physical properties of interplanetary matter. The set of recovered fragments within one meteorite fall can give additional information on the history of its parent asteroid. A reliably estimated meteoroid shape is a valuable input parameter for the atmospheric entry scenario, since the pre-entry mass, terminal meteorite mass, and fireball luminosity are proportional to the pre-entry shape factor of the meteoroid to the power of 3 [1]. We present a statistical approach to the estimation of meteoroid pre-entry shape [2], applied to the detailed data on recovered meteorite fragments. This is a development of our recent study on the fragment mass distribution functions for the Košice meteorite fall [3]. The idea of the shape estimation technique is based on experiments that show that brittle fracturing produces multiple fragments of sizes smaller than or equal to the smallest dimension of the body [2]. Such shattering has fractal properties similar to many other natural phenomena [4]. Thus, this self-similarity for scaling mass sequences can be described by the power law statistical expressions [5]. The finite mass and the number of fragments N are represented via an exponential cutoff for the maximum fragment mass m_U. The undersampling of tiny unrecoverable fragments is handled via an additional constraint on the minimum fragment mass m_L. The complementary cumulative distribution function has the form

$$F\left(m\right)=\frac{N-j}{m_j}\left(\frac{m}{m_j}\right)^{-\beta_0}\exp\left(\frac{m-m_j}{m_U}\right).$$

The resulting parameters sought (scaling exponent β_0 and mass limits) are computed to fit the empirical fragment mass distribution:

$$S\left(\beta_0,j,m_U\right)=\sum_{i=j}^{N}\left[F\left(m_i\right)-\frac{N-j}{m_j}\right]^2, m_j=m_L.$$

The scaling exponent correlates with the dimensionless shape parameter d [2]:

$$0.13d^2-0.21d+1.1-\beta=0,$$

which, in turn, is expressed via the ratio of the linear dimensions a,b,c of the shattering body [2]:

$$d=1+2\left(ab+ac+bc\right)\left(a^2+b^2+c^2\right)^{-1}.$$

We apply the technique of scaling analysis to statistically abundant empirical data on the mass distributions for the Košice, Sutter's Mill, Almahata Sitta, and the Bassikounou meteorites.

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