EMPIRICAL FRAGMENT DISTRIBUTIONS IN METEORITES

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Introduction. Meteorite samples provide invaluable data on spectral, chemical and physical properties of interplanetary matter. The set of recovered fragments give additional insights into the history of the parent asteroid, e.g. [1]. Statistical analysis can be used complementary to study fragment distribution and to investigate if the pieces recovered within one meteorite fall belong to a single pre-entry body. This analysis is especially useful if the recovered meteorite collection is missing some (yet unrecovered) splinters.

We approximate the masses of meteorite fragments using distribution laws which were found to be the best candidates among other sigmoid functions related to the fracturing processes [2].

Normal CDF

$$F\left(x,\mu,\sigma^2\right)=\int_{-\infty}^{x}\frac{1}{\sqrt{2\pi\sigma^2}}e^{-\frac{(t-\mu)^2}{2\sigma^2}}dt \qquad \mu=\frac{1}{N}\sum_{i=1}^{N}\ln(m_i) \quad \sigma=\sqrt{\frac{1}{N-1}\sum_{i=1}^{N}\left[\ln(m_i)-\mu\right]^2}$$

Weibull CDF

$$F_W(m,\gamma,\mu)=\frac{M(\le m)}{M_0}=1-\frac{M(\ge m)}{M_0}=1-\exp\left(-\left(\frac{m}{\mu}\right)^{\gamma}\right)$$

Grady CDF

$$F_{GK}(x,\mu)=1-\frac{N(\ge m)}{N_0}=1-\exp\left(-\frac{m}{\mu}\right) \qquad N_0=\frac{M_0}{\mu}$$

Multimodal distributions

$$F_W(m,\omega,\gamma_1,\mu_1,\gamma_2,\mu_2)=\omega\left[1-\exp\left(-\left(\frac{m}{\mu_1}\right)^{\gamma_1}\right)\right]+(1-\omega)\left[1-\exp\left(-\left(\frac{m}{\mu_2}\right)^{\gamma_2}\right)\right]$$

$$N_W(\ge x,\bullet)=N\cdot\left(1-F_W(m,\bullet)\right)$$

Shape estimation

The idea of the shape-estimation technique is based on experiments that show that brittle fracturing produces multiple fragments of size lesser than or equal to the least dimension of the body [3].

A meteoroid has limited size and mass. The power law has to be constrained at the top of the sample via exponential cutoff:

$f_c(m) = ((\beta_0-1) / m_L)(m/m_L)^{-\beta_0}\exp(-m/m_U)$, where $m_L > 0$ is an arbitrary lower mass limit and $m_U > m_L$ is an upper cutoff mass.

$$N^*(m)=\frac{1}{m}\int_m^{\infty}n(x)dx \qquad n(m)=\sum_{i=1}^{N}\delta(m-m_i) \qquad \delta \text{ – Dirac delta function.}$$

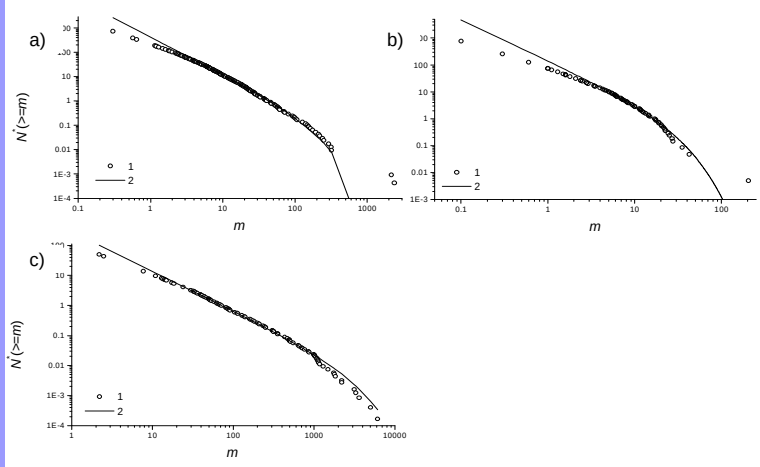

Fig.4: Complementary cumulative number of fragments $N^*(\ge m)$ vs m. 1 – Observed data, 2 – Power law distribution with exponential cutoff.
a) Košice: β_0 = 1.53, m_L = 5.64, m_U = 155.17.
b) Sutter's Mill [4]: β_0 = 1.51, m_L = 5.0, m_U = 21.0.
c) Bassikounou [5] : β_0 = 1.32, m_L = 29.9, m_U = 2839.42.

$$\beta_0=1.1-0.21d_m+0.13d_m^2 \qquad d_m=1+2(ab+ac+bc)/\left(a^2+b^2+c^2\right)$$

a, b, c are the linear dimensions of the fragment

Košice meteorite

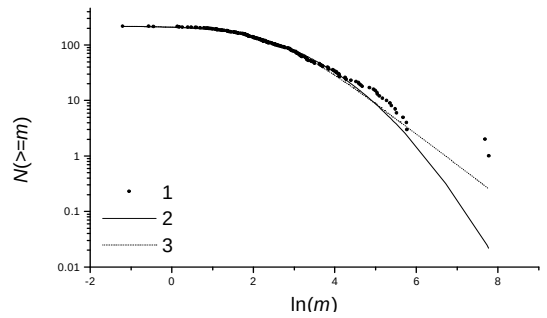

Fig.1: Complementary cumulative number of fragments $N(\ge m)$ vs $\ln(m)$. 1 – Observed data, 2 – Normal distribution for $\ln(m)$ with the mean μ=2.52 and the standard deviation σ=1.41, 3 – Logistic distribution for $\ln(m)$ with the same mean and deviation.

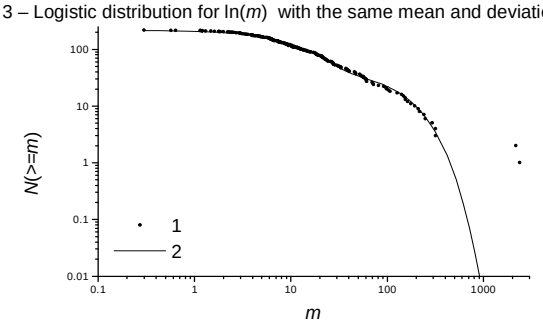

Fig.2: Complementary cumulative number of fragments $N(\ge m)$ vs m (decimal logarithm scale) for the sample. 1 – Observed data, 2 – Bimodal Weibull distribution with the weighting factor ω=0.8, γ_1=γ_2=1.14 and μ_1=13.1, μ_2=140.

Sutter's Mill meteorite

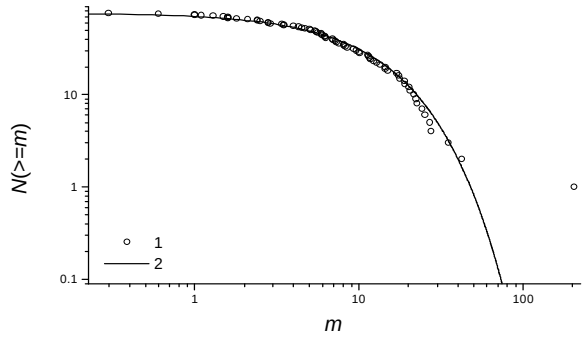

Fig.3: Complementary cumulative number of fragments $N(\ge m)$ vs fragment mass m. 1 – Observed data [4], 2 – Weibull distribution with the shape parameter μ=11 and the scale parameter γ=1.

Probabilities for missing fragments for Košice meteorite

Distribution	Probability p_s of singular fragment to occur within the gap (318; 2167.4)	Expected frequency	Probability of complete absence of any fragment from the set within the gap	Probability of 5 or fewer (at least 1) fragments to occur within the gap
Lognormal	0.011	2.34	0.095	0.874
Lognormal bimod.	0.025	5.42	0.004	0.537
Weibull bimodal	0.016	3.41	0.032	0.839
Grady bimodal	0.029	6.81	0.001	0.324

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[4] Jenniskens P. et al. Radar-Enabled Recovery of the Sutter's Mill Meteorite, a Carbonaceous Chondrite Regolith Breccia. Science, 2012, V. 338(6114), pp. 1583-1587.
[5] http://www.niger-meteorite-recon.de/img_inventar/Buhl_Baermann_Catalog.pdf