МГУ им. М.В.Ломоносова
Институт механики
INSTITUTE OF MECHANICS
LOMONOSOV MOSCOW STATE UNIVERSITY

ON THE ENERGY RELEASE AFTER METEOROIDS FRAGMENTATION

L.A.Egorova and V.V. Lokhin

Institute of Mechanics

Moscow State Univercity

IMC 2018
August 30–September 2, Pezinok-Modra, Slovakia

Mass distribution of destroyed body fragments

- **Fujiwara A.** et al. **1989** Experiments and scaling laws for catastrophic collisions //Asteroids II. 240-265.
- ***Fujiwara A.*** **1986** Results obtained by laboratory simulations of catastrophic impact //Memorie della Societa Astronomica Italiana. **57:** 47-64.
- ***Brown W. K., Wohletz K. H.*** **1995** Derivation of the Weibull distribution based on physical principles and its connection to the Rosin–Rammler and lognormal distributions //Journal of Applied Physics. **78:** 2758-2763.
- ***Pilyugin N.N.*** **2008** Destruction of filled polymer targets by high-velocity impact
- // Combustion, Explosion, and Shock Waves. **44**:239-247**.**
- ***Onose N., Fujiwara A.*** **2004** Mass-velocity distributions of fragments in oblique impact cratering on gypsum //Meteoritics & Planetary Science. **39:** 321-331.
- ***Okamoto C., Arakawa M.*** **2009** Experimental study on the collisional disruption of porous gypsum spheres //Meteoritics & Planetary Science, **44**:1947-1954

Catastrophic fragmentation types (Fujiwara, 1986)

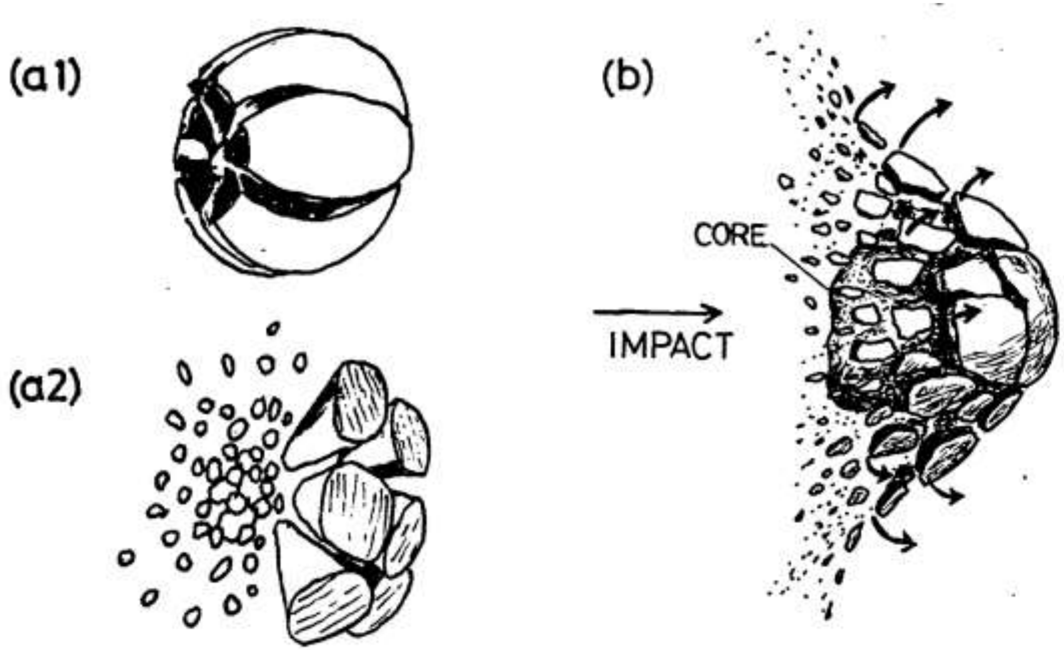
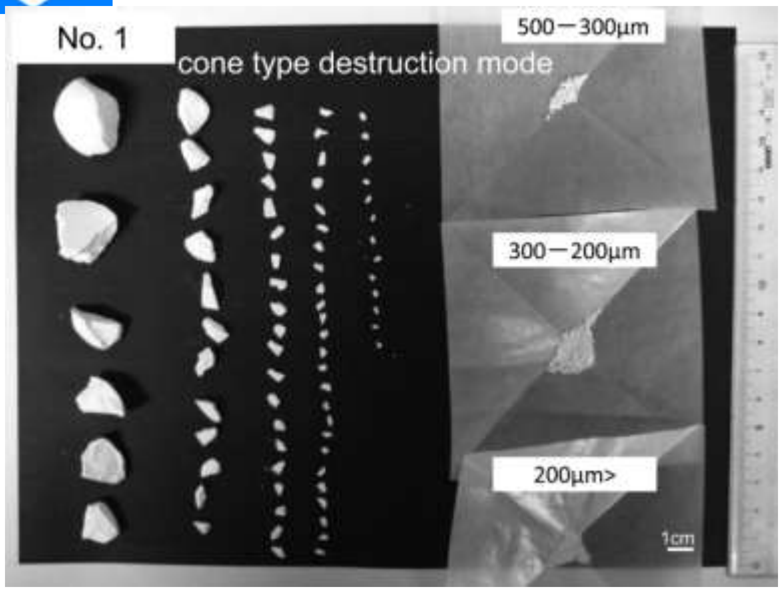
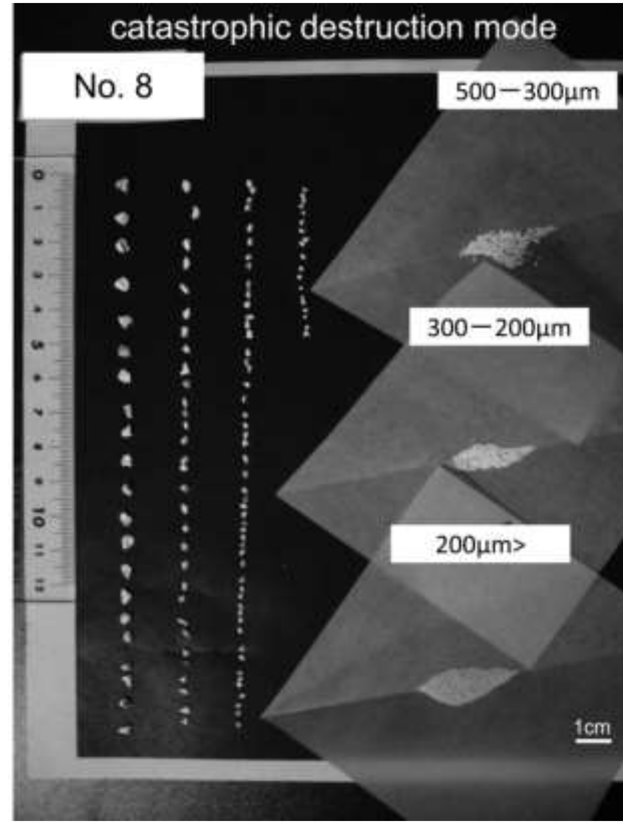


Fig. 2 (a1) Longitudinal splitting and (a2) Cone type destruction of a spherical target in low-velocity impact (following Matsui (1982)). (b) Core type destruction in high-velocity impact. Notice the core in the center of the target. Arrows show the sense of the rotation of the fragments (See section 5)

Fujiwara A. (1986) //Memorie della Societa Astronomica Italiana. **57:**.47-64.

Mass distribution of fragmented particles under different catastrophic destruction type





a) Run 1 was cone-type destruction mode. b) The specific energy of Run 8, which shows catastrophic destruction mode, was one order of magnitude larger than that of Run 1.

.

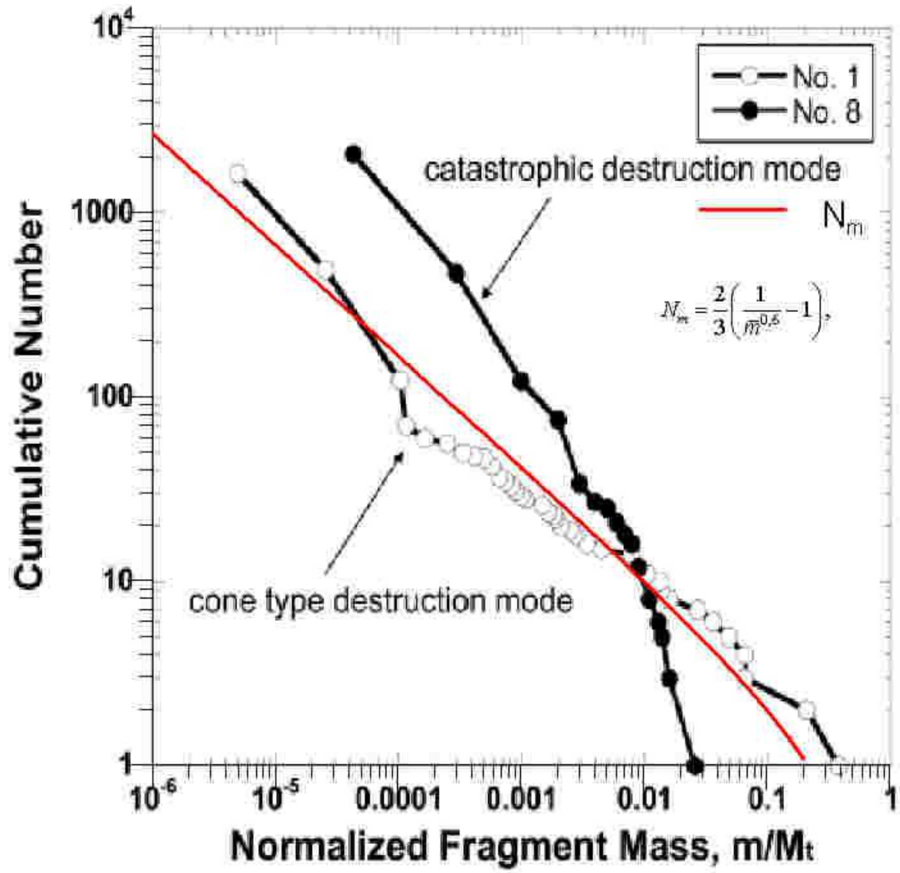
Okamoto C., Arakawa M. Meteoritics & Planetary Science. 2009. **44**. 1947-1954

Distribution of fragments

$$\frac{dN_m}{dm} = Cm^{\frac{k}{3}-2}, \quad k = 1.2$$

Fujiwara A. et al. 1989
//Asteroids II: 240-265.

$$N_m = \frac{2}{3}\left(\frac{1}{\bar{m}^{0,6}} - 1\right),$$

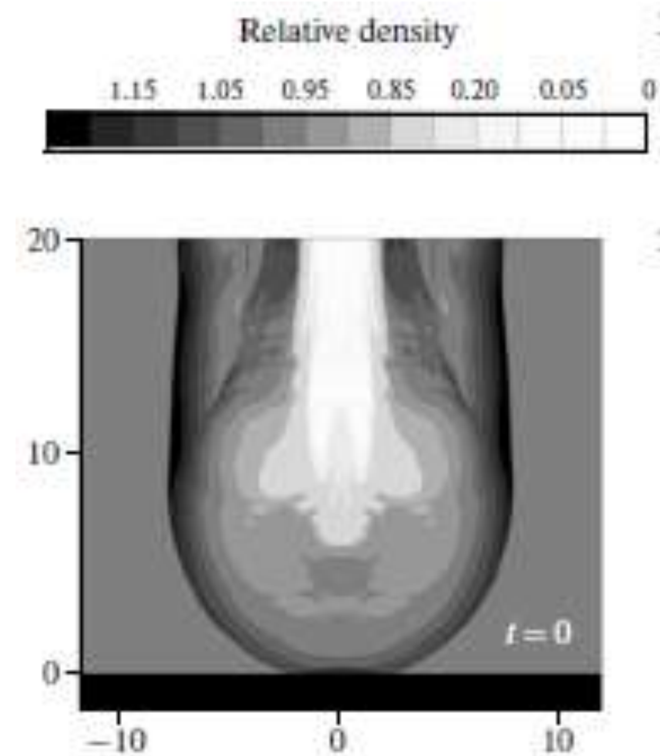


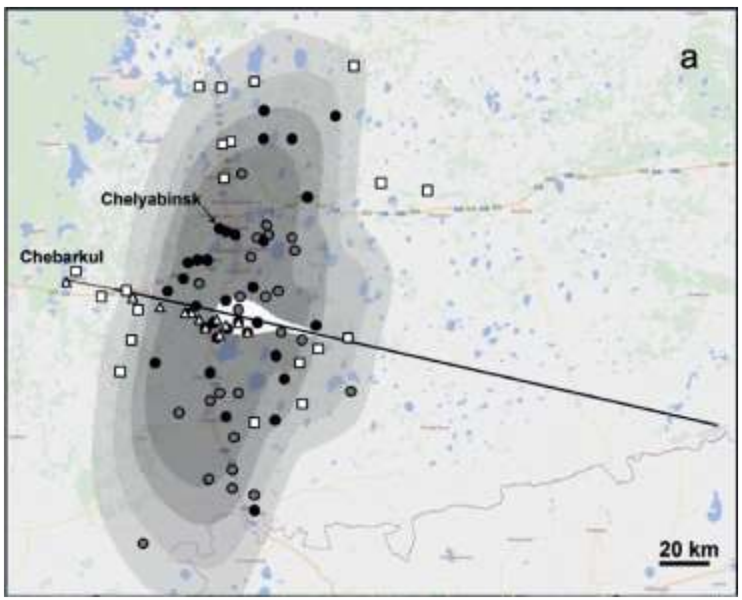
Okamoto C., Arakawa M. 2009

Models of energy release

***Shuvalov V.V., Svettsov V.V., Trubetskaya I.A.* (2013)** An estimate for the size of the area of damage on the Earth's surface after impacts of 10–300-m asteroids Sol. Sys. Res.,**47**: 284-291**.**

Flow picture for a vertical fall on the Earth of an asteroid with a diameter of 40 m: the distribution of relative density $\rho/\rho_0(z)$.

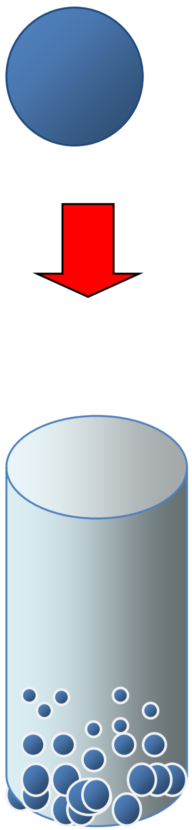




Popova, O. P., Jenniskens, P., Emel'yanenko, V.V, Kartashova A.P. et al (2013). Chelyabinsk airburst, damage assessment, meteorite recovery, and characterization. *Science*, *342*(6162), 1069-1073.

Fig.3. Map of glass damage on the ground with models of overpressure

Meteoroid fragments movement after destruction



We assumed the destruction of the meteoroid into many fragments. The part of kinetic energy of the moving particles passes into the thermal energy of the gas volume in which their motions take place.

$$M_{\Sigma} \frac{V_0^2}{2} \Rightarrow c_V T \rho^{*} \Omega$$

Ω is gas volume, c_V – heat capacity of gas, T – temperature, M_{Σ} - total mass of fragments, V_0 – meteoroid velocity at the moment of fragmentation

$$N_m = \frac{2}{3}\left(\frac{1}{\bar{m}^{0,6}} - 1\right), \qquad \bar{m} = \frac{m}{M}$$

(Fujiwara et al. 1989, Nemtchinov et al. 1999)

Equations of the Physical Theory of Meteors

$$\begin{cases} m\dfrac{dV}{dt} = -\dfrac{1}{2}C_D\rho V^2 S \\ Q\dfrac{dM}{dt} = -\dfrac{1}{2}C_H\rho V^3 S \end{cases}$$

V, m, S, Q, – velocity, mass, midsection area of particle and enthalpy of mass loss due to aerodynamic forces and heat transfer;
C_D and C_H – drag and heat transfer coefficients (constants),
ρ is atmosphere density

$$r = r_0 \exp\left[-\kappa\left(V_0^2 - V^2\right)\right],$$

$$\kappa = \frac{C_H}{6C_D Q} \qquad \kappa = \frac{C_H}{6C_D Q} << 1 \qquad \frac{V^2}{V_0^2} << 1$$

$$V = V_0 \exp\left(-A\left(1+\kappa V_0^2\right)\frac{z}{r_0}\right) \quad .$$

$$A = -\frac{3}{8}C_D\frac{\rho}{\delta}.$$

Transition of kinetic energy of particles into heat energy of a gas

$$\Delta E = M_0 \frac{V_0^2}{2} - M_0 V_0^2 \int_0^1 \left[N(\bar{r}_0) \frac{d}{d\bar{r}_0} \left(\bar{m}(\bar{r}_0) \frac{\bar{V}^2(\bar{r}_0, z)}{2} \right) \right] d\bar{r}_0$$

$\bar{r}_0 = r_0 / R$ the initial relative radius , $\bar{m}(\bar{r}_0)$ $=m_0/M$ relative mass

Temperature of a Gas Cloud

$$T = \frac{-\frac{dE}{dz} dz}{C_V \rho \pi R_*^2 dz}$$

$$T = \frac{3R^2 V_0^2 C_D}{C_V R_*^2} \left(1 + 3\kappa V_0^2\right) \left[1 - \left(\frac{3}{4} \frac{\rho C_D}{\delta} \right)^{1/5} \left(1 + 3\kappa V_0^2\right)^{1/5} \Gamma\left(\frac{4}{5}\right) \left(\frac{z}{R}\right)^{1/5} \right]$$

Here Γ is gamma function, C_V is a heat capacity

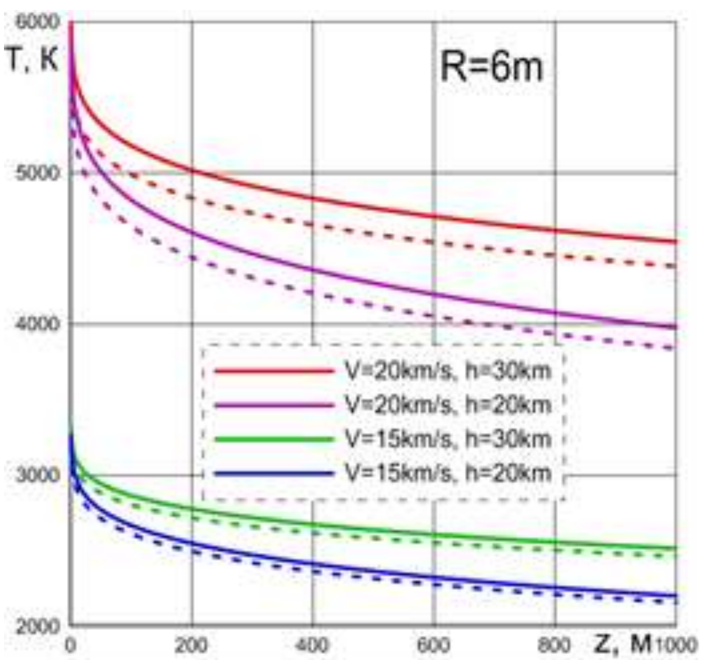
Calculation of the Temperature of a Gas Cloud

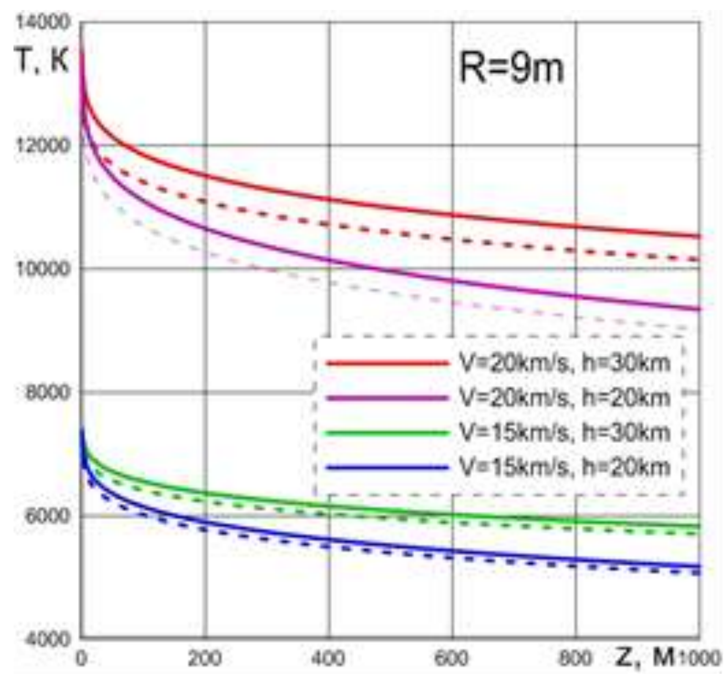
$M_0 = 1.3 \cdot 10^{10} г, \quad V_0 = 2 \cdot 10^6 см/с,$ $\quad \delta = 3.6 g/sm^3, \quad C_V = 7.2 \cdot 10^6 \frac{sm}{s^2 \cdot K}$

$R_* = 10^4 sm, \quad R_1 = 9m; R_2 = 6m, \quad C_D = 1$

$$T_{\max R} = \frac{3R^2 V_0^2 C_D}{C_V R_*^2}$$

$T_{\max}(R = 9m) = 13540K,$
$T_{\max}(R = 6m) = 6019K$





Conclusions

- Assuming a known distribution of meteoroid fragments by mass, a change in the temperature of the gas cloud after meteoroid destruction by the explosive mechanism is obtained.
- The high temperature of the gas in a cloud allows us to talk about the phenomenon of a "thermal explosion".
- Calculation of the gas cloud temperature is a first step in a problem of energy release estimation by fragmenting meteoroid in Earth atmosphere.

Thank you for your attention!