Which Meteoroids Can Create Damaging Airbursts?

An Investigation Using Dynamic Trajectory Analysis

T.W.C. Stevenson[1], H.A.R. Devillepoix[1], E.K. Sansom[1,2]

[1]Space Science and Technology Centre, Curtin University, Perth, Australia

[2]International Centre for Radio Astronomy Research, Curtin University, Perth, Australia

Background

Falling meteoroids sometimes explode before reaching the ground, producing shockwaves and hundreds of meteoritic fragments. These events are referred to as **airbursts**. As the spectacular explosion above Chelyabinsk, Russia showed on 15 February 2013, airbursts can cause injury to people and damage to property.[1] The causes of airbursts, including contributing features of the meteoroids creating them, are poorly understood. We compare a selection of ~70 meteorite falls and meteor shower bodies to determine which objects are most likely to produce damaging airbursts.

Fig. 1: The dust trail created by the explosive Chelyabinsk meteoroid. Source: Marat Ametvaleev.

Methods

We reduce the dynamic features of meteoroids to three essential parameters: α, β and Pf. α and β are derived from a deceleration curve fitted to altitude vs velocity data by least squares optimisation.[2] The **ballistic coefficient (α)** indicates the ratio between the drag and weight forces acting upon a meteoroid. The **mass loss parameter (β)** indicates the efficiency of ablation.

The **pressure factor (Pf)** is a proxy for mechanical strength that relies upon velocity, mass and ram pressure calculations.[3] Ram pressures are determined using a locally calibrated atmospheric model. Pf-I, the strongest class of meteoroids, includes most stony and metallic objects. Pf-II contains more friable carbonaceous meteoroids. Pf-III and weaker classes contain meteor shower bodies that represent icy cometary remnants.

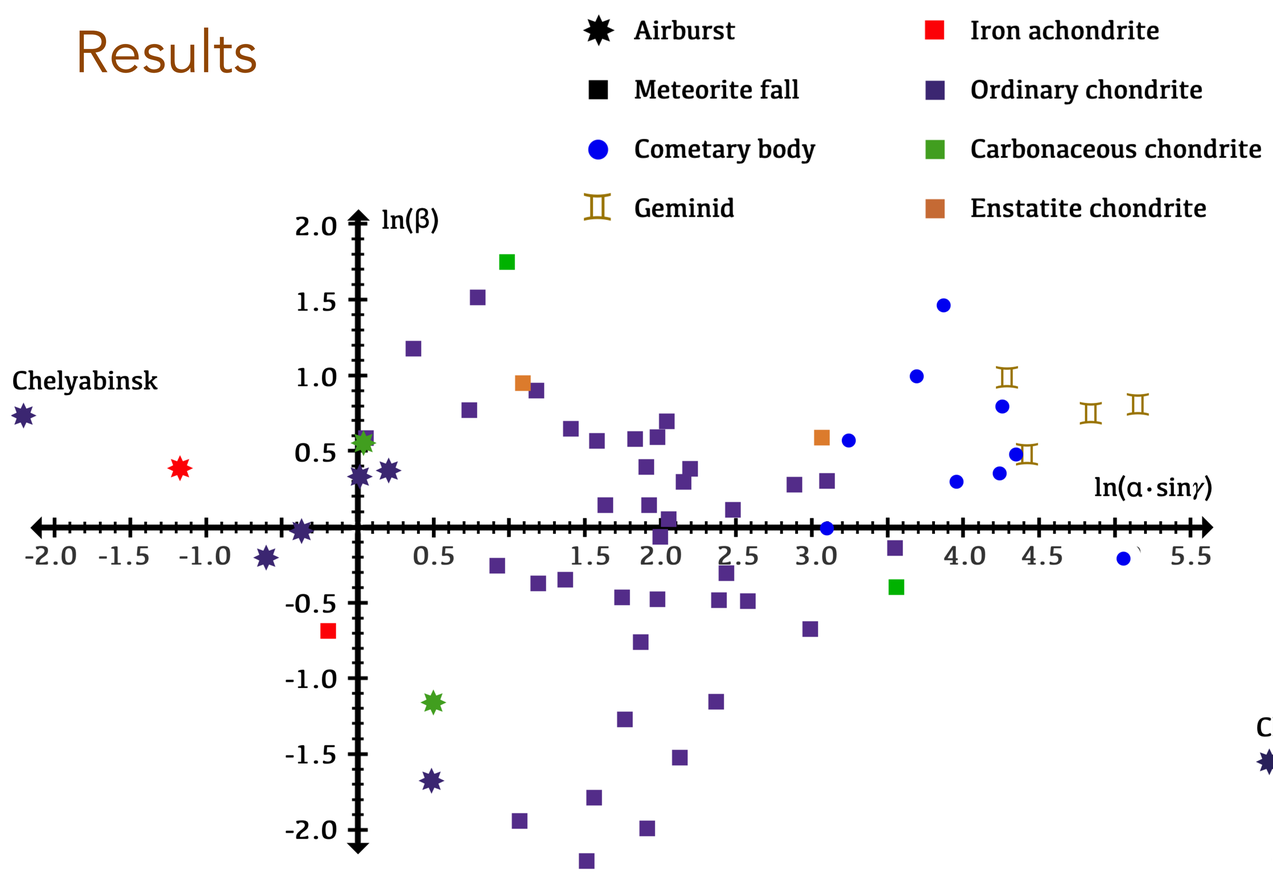
Defining Formulae

(Ask me what the symbols mean!)

$$\alpha = \frac{C_d \rho_0 h_0 S_e}{2 M_e \sin(\gamma)} \qquad \beta = \frac{(1-\mu)\sigma V_e^2}{2}$$

$$Pf = \frac{100 P_{max} M_e^{-1/3} V_e^{-3/2}}{\sin(\gamma)}$$

Results



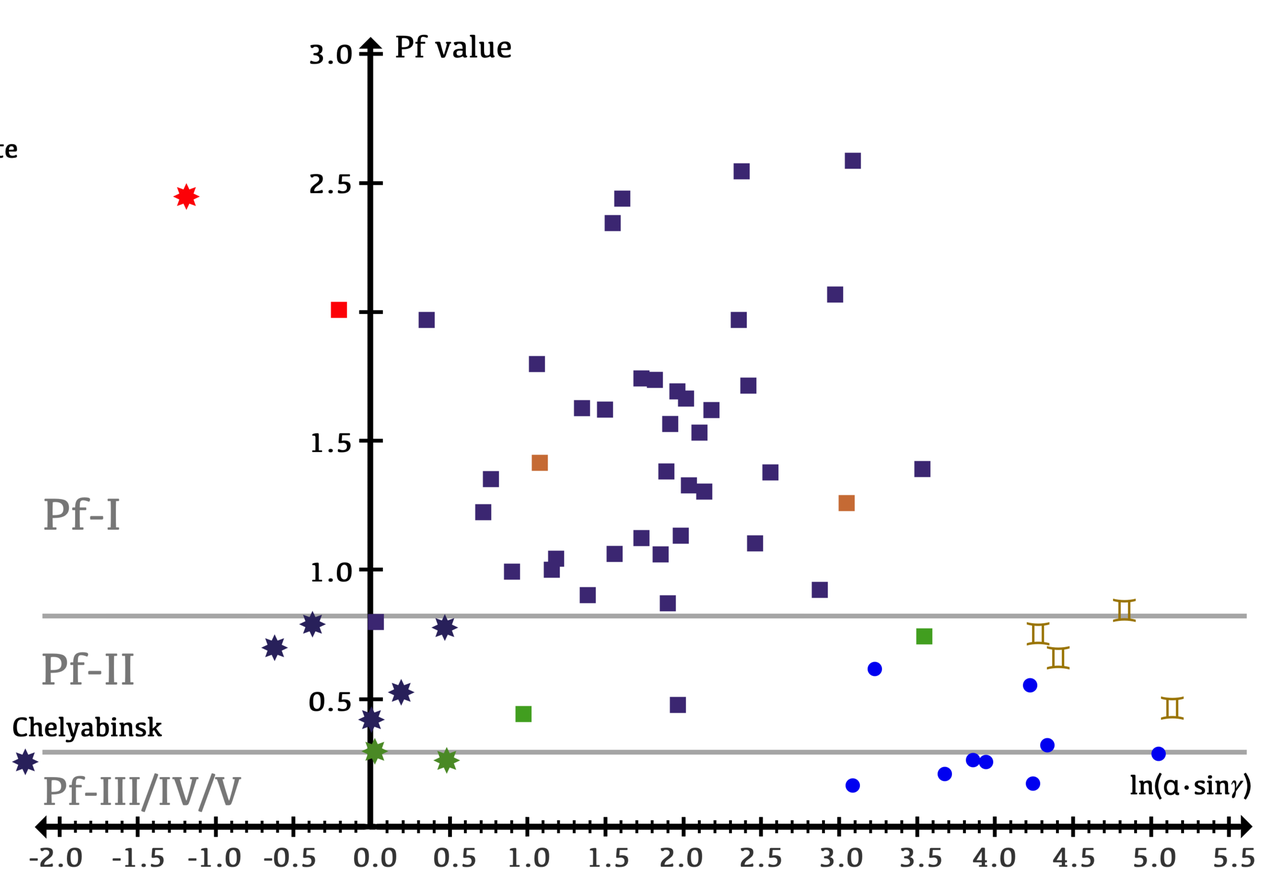


Fig. 2: Ballistic coefficients of real meteoroids plotted against their mass loss parameters (left) and pressure factors (right). Data sources: Numerous.

Key Findings

- Airbursts are controlled by mechanical, rather than compositional, properties.
- Objects of high preatmospheric mass (>1.1 tons) are most likely to produce damaging airbursts. High mass is indicated by low α and low Pf.
- Even objects with great tensile strength (i.e: Sikhote-Alin) can produce airbursts, suggesting that high mass 'overrides' mechanical strength.
- There is no indication from this study that meteor shower bodies, including Geminids, are capable of producing airbursts.
- There is no clear correlation between entry velocity and airburst likelihood.

Bottom line: Massive stony or metallic asteroids are the most likely objects to cause airburst damage if they enter Earth's atmosphere.

Key References

[1]Popova et al (2013) *Science* v342, p1069-1073.

[2]Gritsevich (2008) *SSR* v42, n5, p372-390.

[3]Borovička et al (2022b) *A&A* v667, a158.

References for all of the data included on the plots above are available upon request.

Curtin University