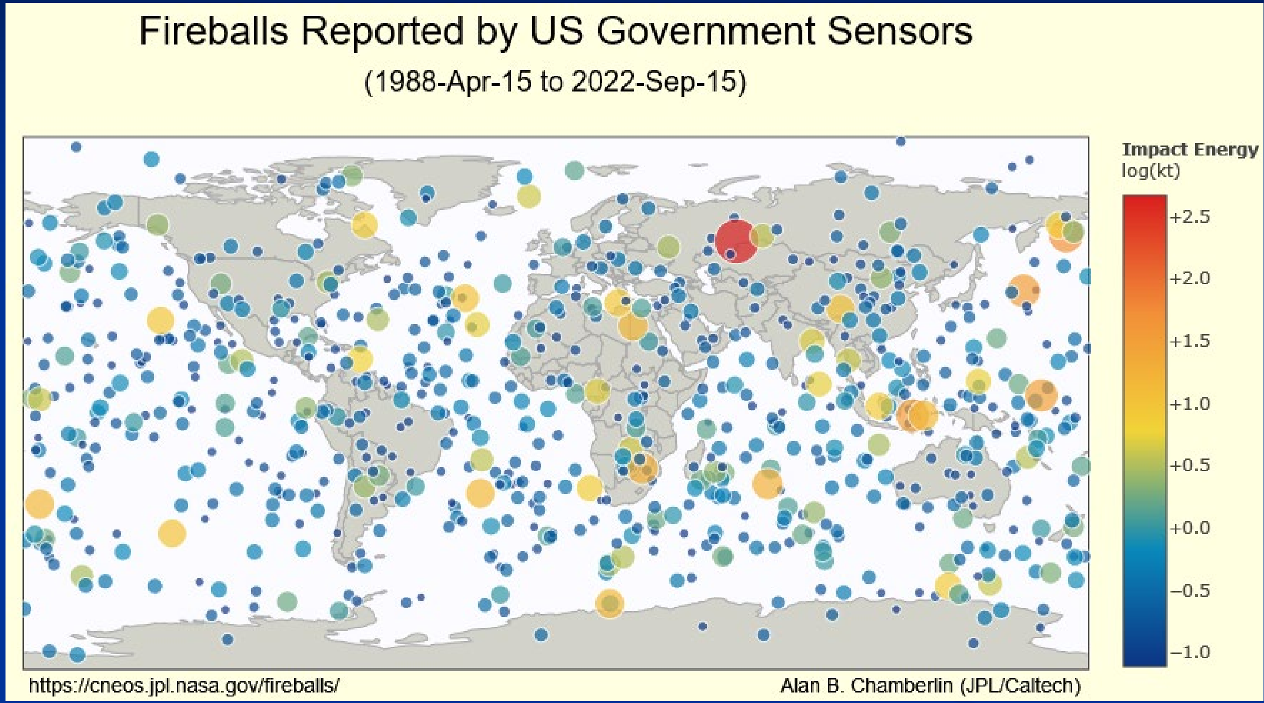
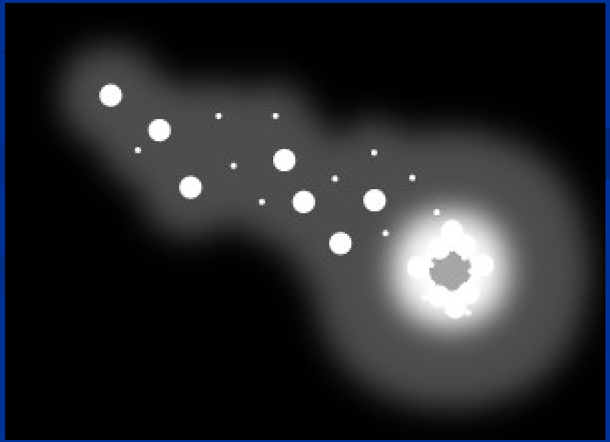
An unusual population of weak meteoroids observed by US Government Sensors



P. Brown[1,2] & D. Vida[1,2]

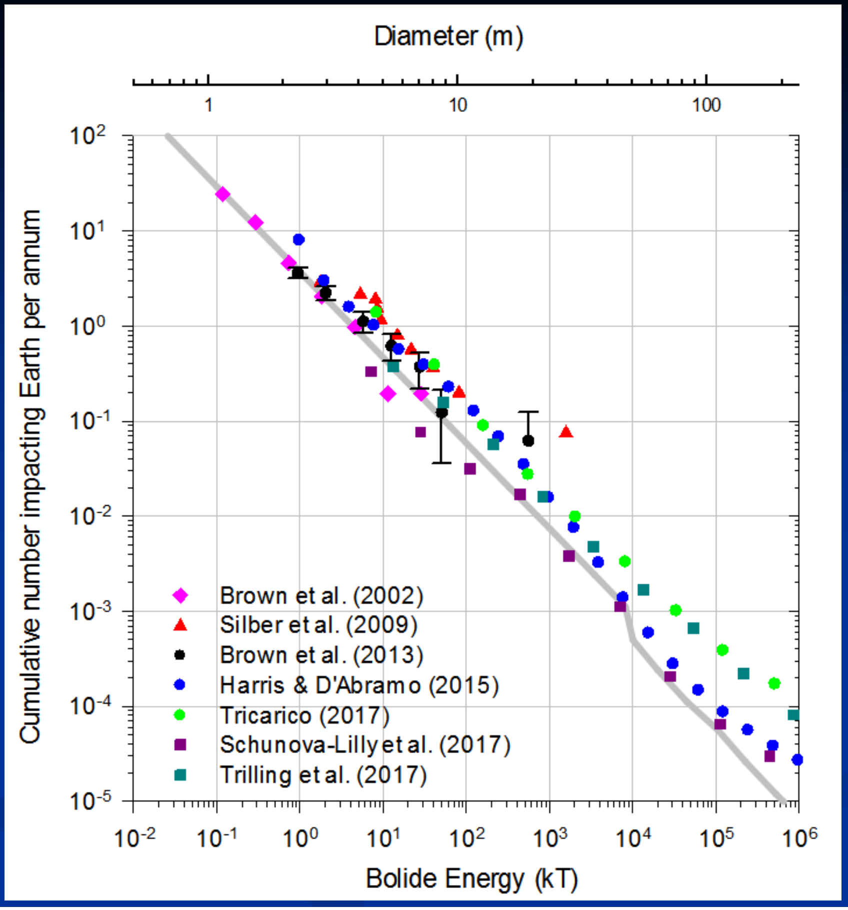
[1]Department of Physics and Astronomy
[2]Institute for Earth and Space Exploration
University of Western Ontario
London Ontario, CANADA

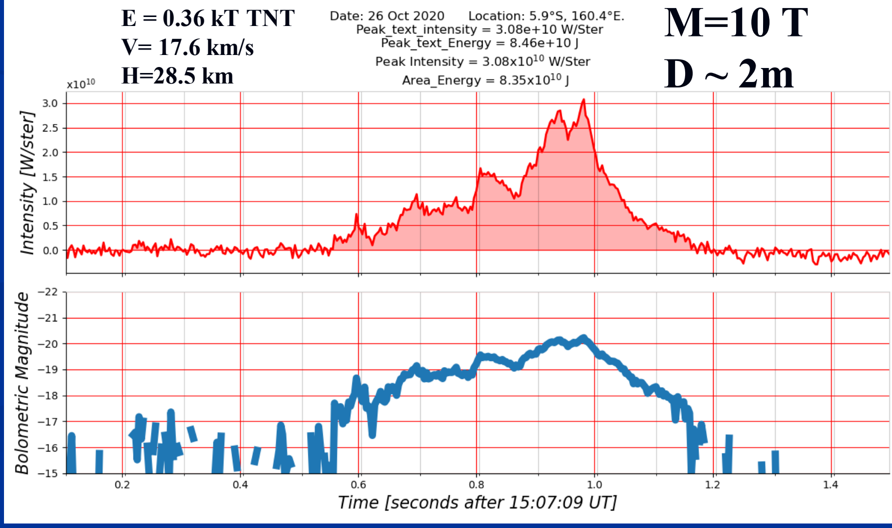


Workshop on NEO Imminent Impactors Warning Coordination
Dec 13, 2022

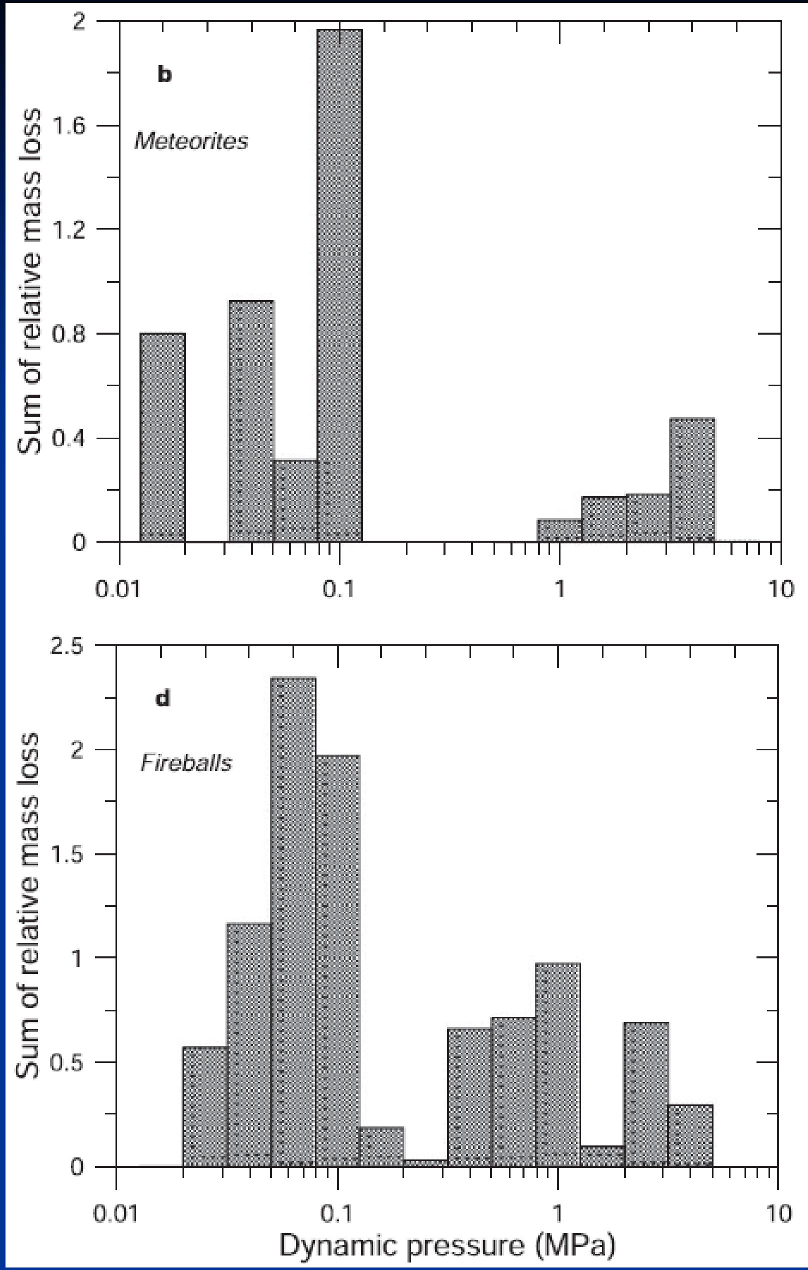
Meter-sized NEO Impactors

- Meter-sized objects impact Earth once every ~2 weeks
  - E ~ 0.1 kT; mass ~2 T
  - Required collecting area product ~10^{11} km^{2}h
  - Single site on the ground records a meter-sized impactor once every ~20-30 years
- Fireball networks (EN/PN/MORP) have recorded 7 over many decades of monitoring (4 meteorite producers)
- Meteorite-producing fireballs produced by meter-sized or larger bodies : 11 [4 Carbonaceous Chondrites]
- Main dataset: US Government sensors (2006-present)[1]:
  - 270 total fireballs have trajectories and lightcurves (latter are new as of May 2022)
  - Height of peak brightness, energy and location most precise; velocity and (in particular) radiant less precise (Devillepoix et al (2018)





[1] https://cneos.jpl.nasa.gov/fireballs/



Borovička et al., 2020. Two strengths of ordinary chondritic meteoroids as derived from their atmospheric fragmentation modeling. *The Astronomical Journal*, *160*(1), p.42.

- Fireballs lose mass through erosion and fragmentation – ablation secondary
- Chondritic fireballs/meteorites show two primary strengths associated with fragmentation:

0.04 - 0.12 MPa : Weakly cemented material

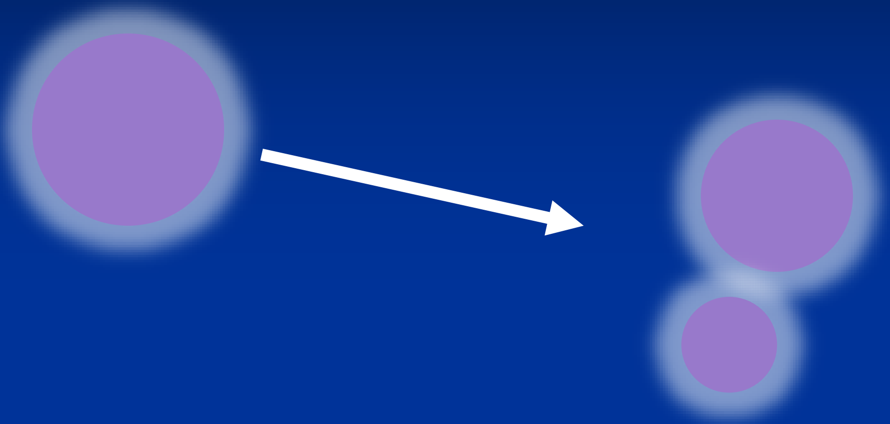
0.5 – 5 MPa: Material weakened by collisional cracks

Masses: 1 kg – 4T (median 10 kg – decimeter sized objects)

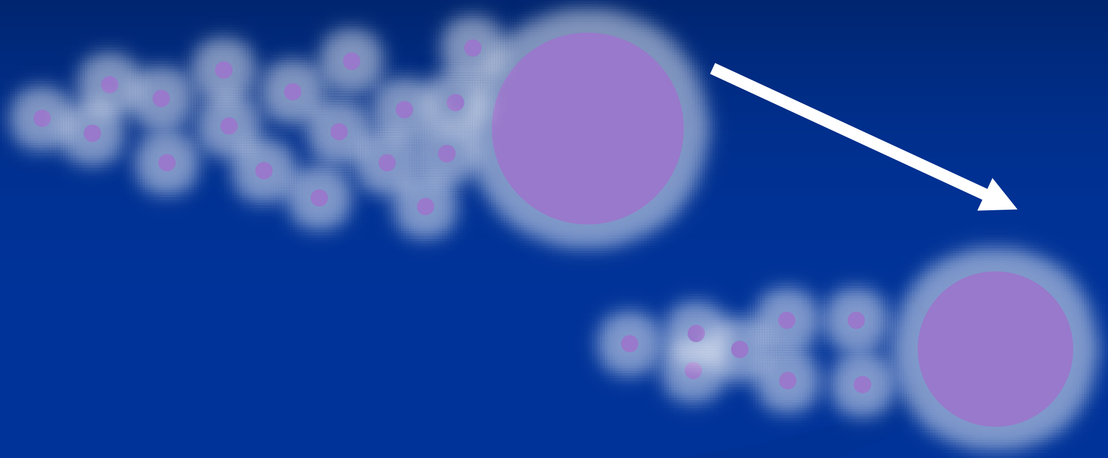
Modelling fragmentation

Popova O. P., Borovička J., and Campbell-Brown M. D. 2019. Modelling the entry of meteoroids. In *Meteoroids: Sources of Meteors on Earth and Beyond*, edited by Ryabova G. O., Asher D. J. and C.-B. M. D. Cambridge University Press. p. 9.

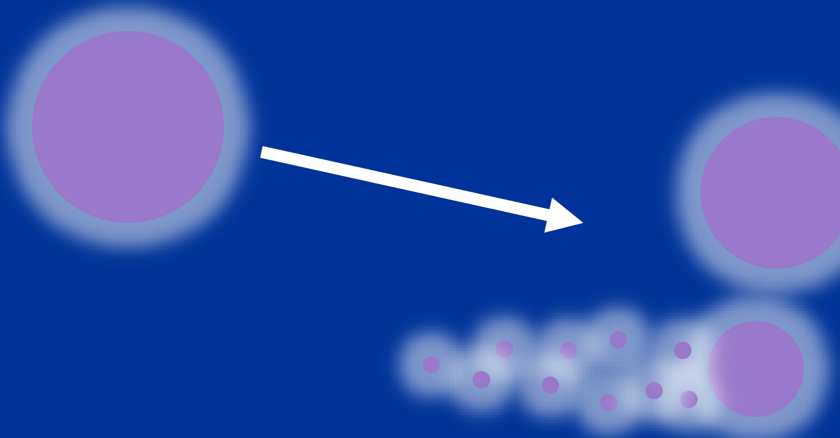
Single-body ejection/disruption



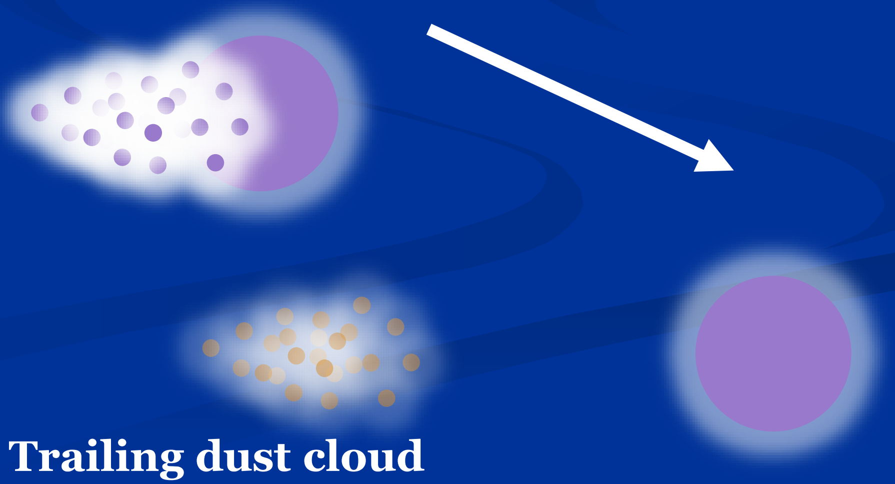
Erosion – continuous ejection of mm-sized grains



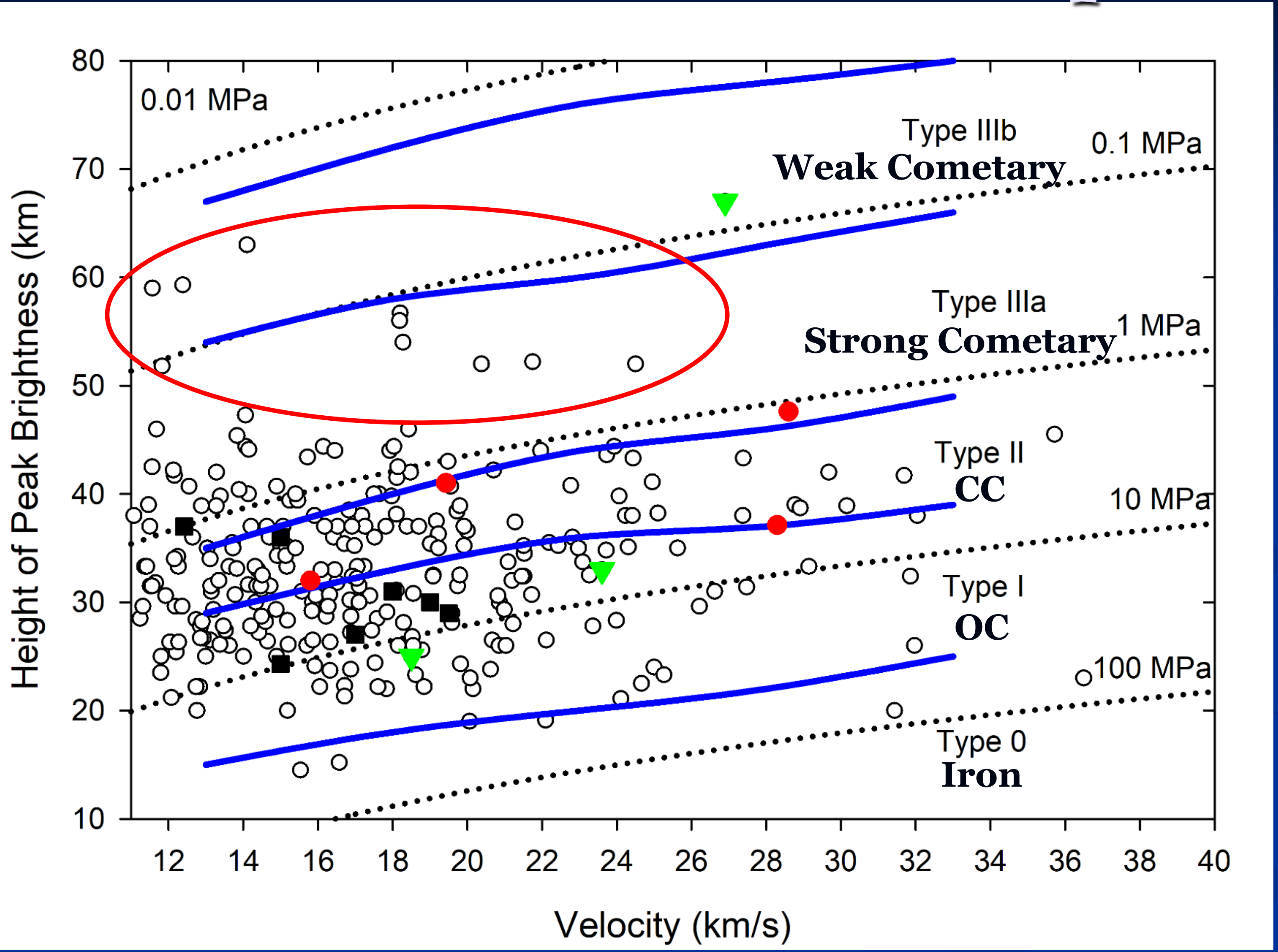
Eroding fragment



Dust release – sudden release of lots of grains (flare)

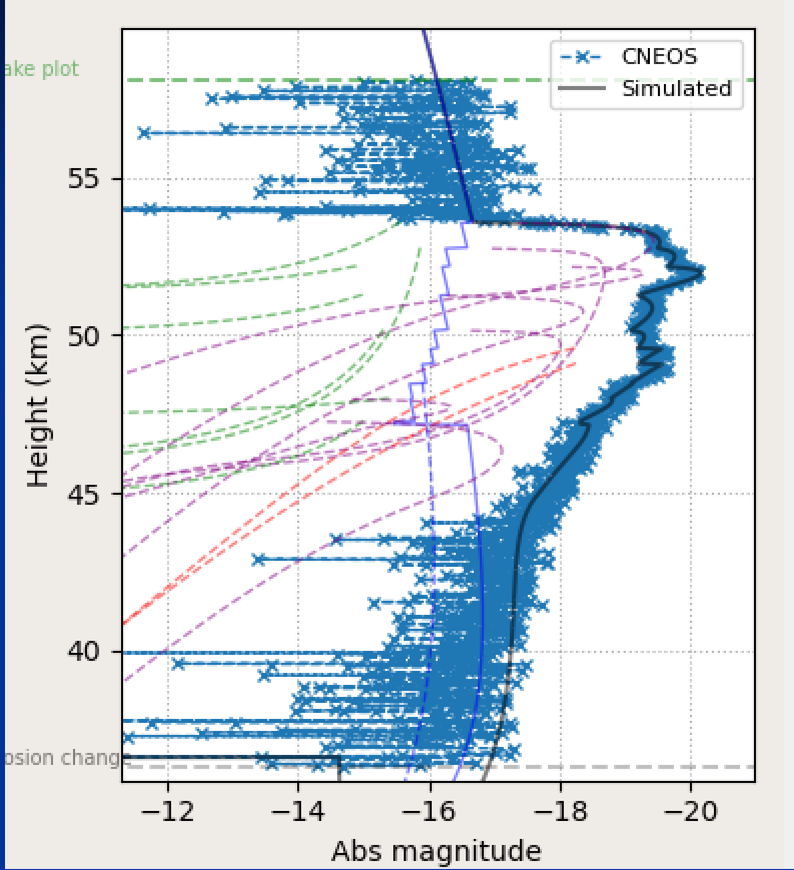


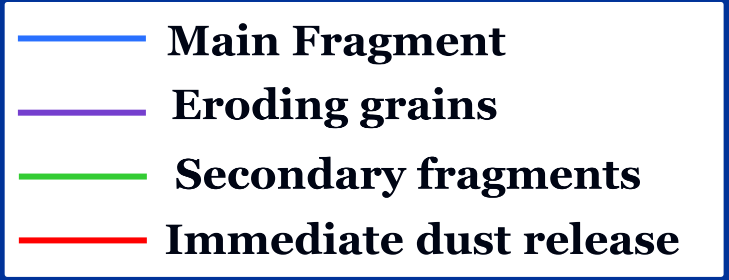
Meter-Sized Impactors



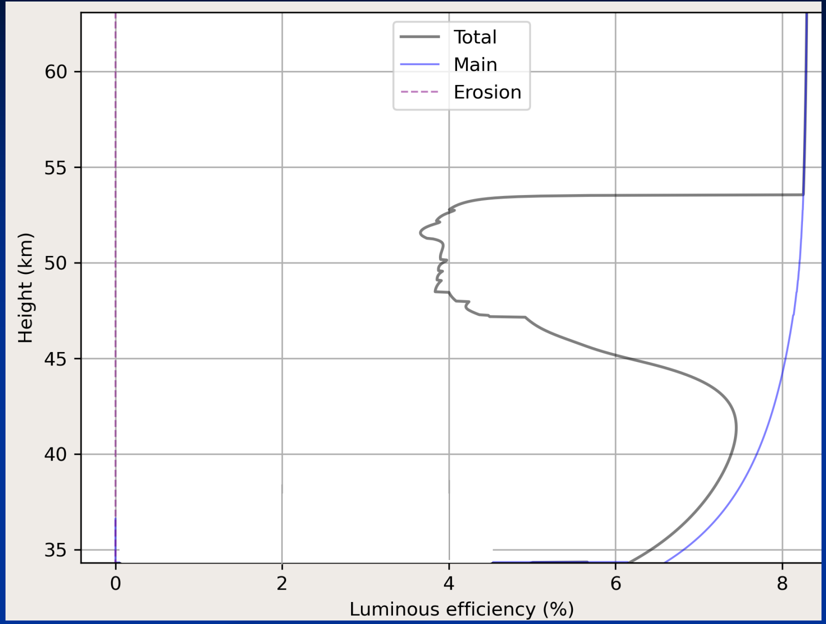
- USG Fireballs
- CC Meteorites
- Meteorite – dropping fireballs
- Network Fireballs (No meteorites recovered)

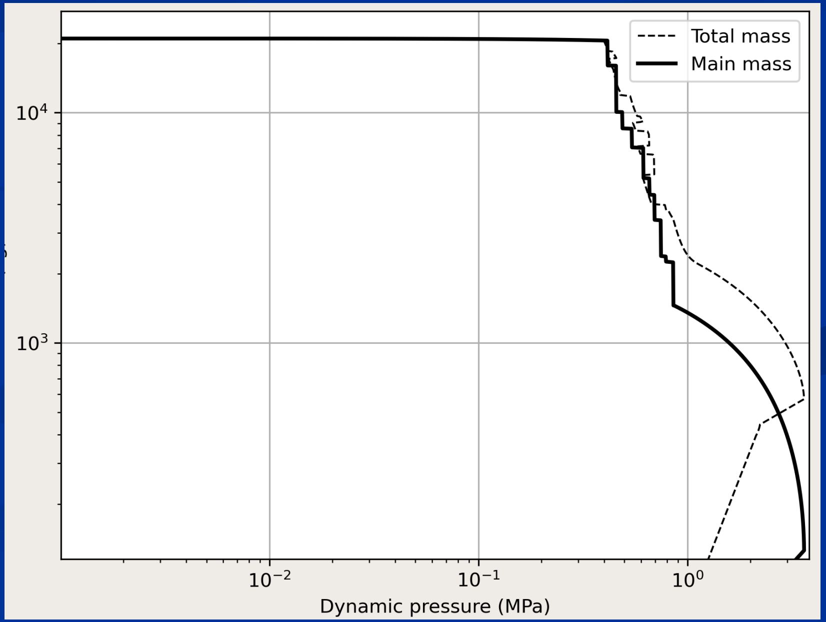
Erosion Model example: USG 20100308



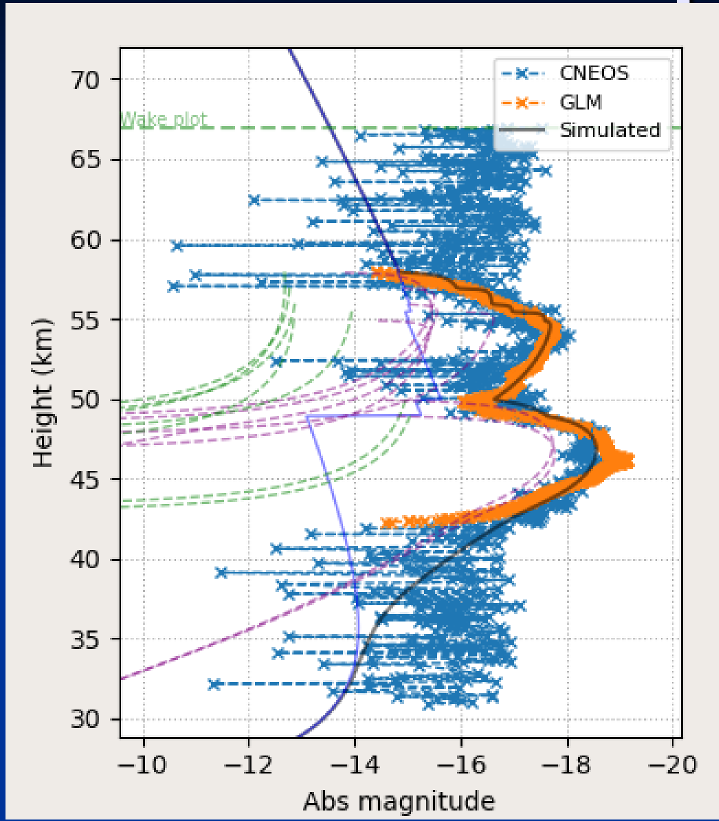


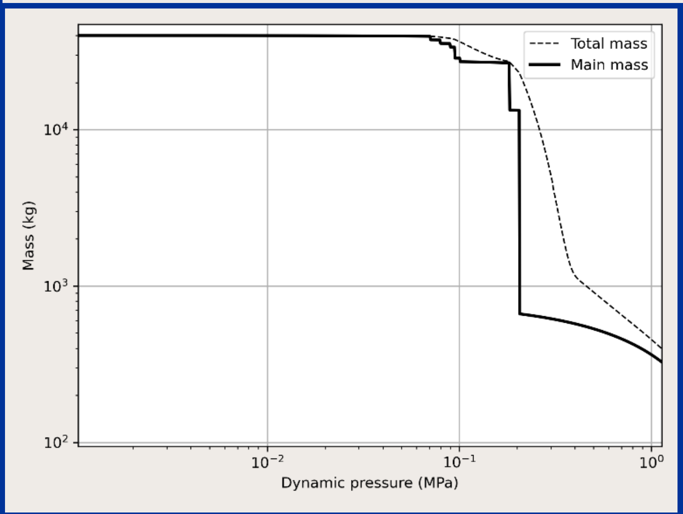
- Impact Energy: 0.9 kT
- Mass ~ 20 T
- Velocity = 24.5 km/s
- Diameter 3m
- Catastrophic breakup (<50% of mass remaining in main fragment) @ 0.4 MPa at 54 km
- Most light production from sub-gram sized eroding grains



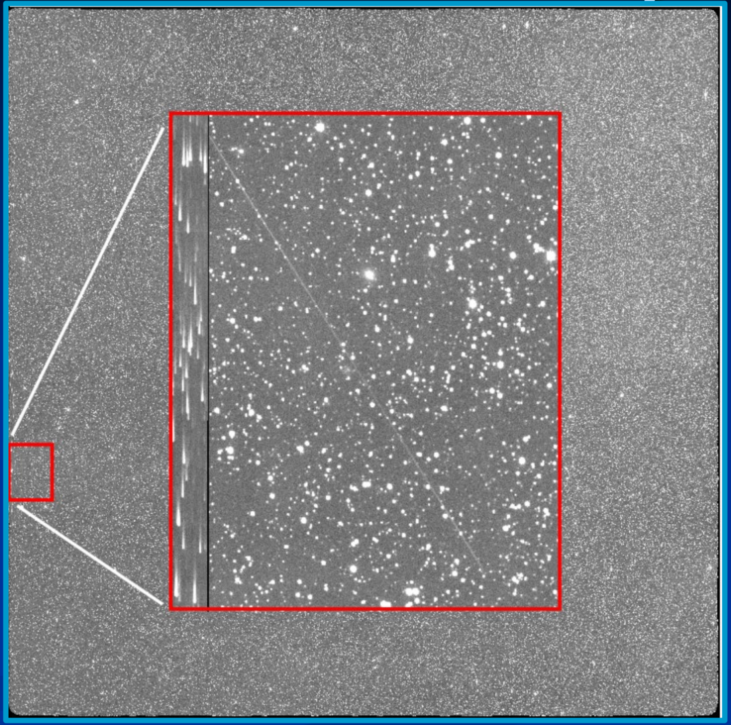


Model Example: USG 20200918 (Clark et al 2022)





- Main Fragment
- Eroding grains
- Secondary fragments
- Immediate dust release



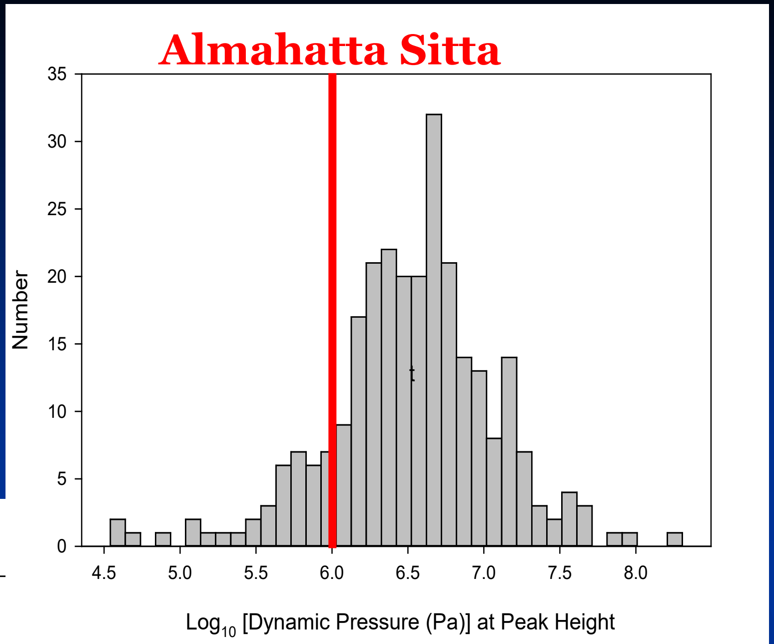
- Detected by ATLAS 10 min prior to impact
- Impact Energy: 0.4 kT
- Mass ~ 20 – 40 T
- Velocity = 12.7 km/s

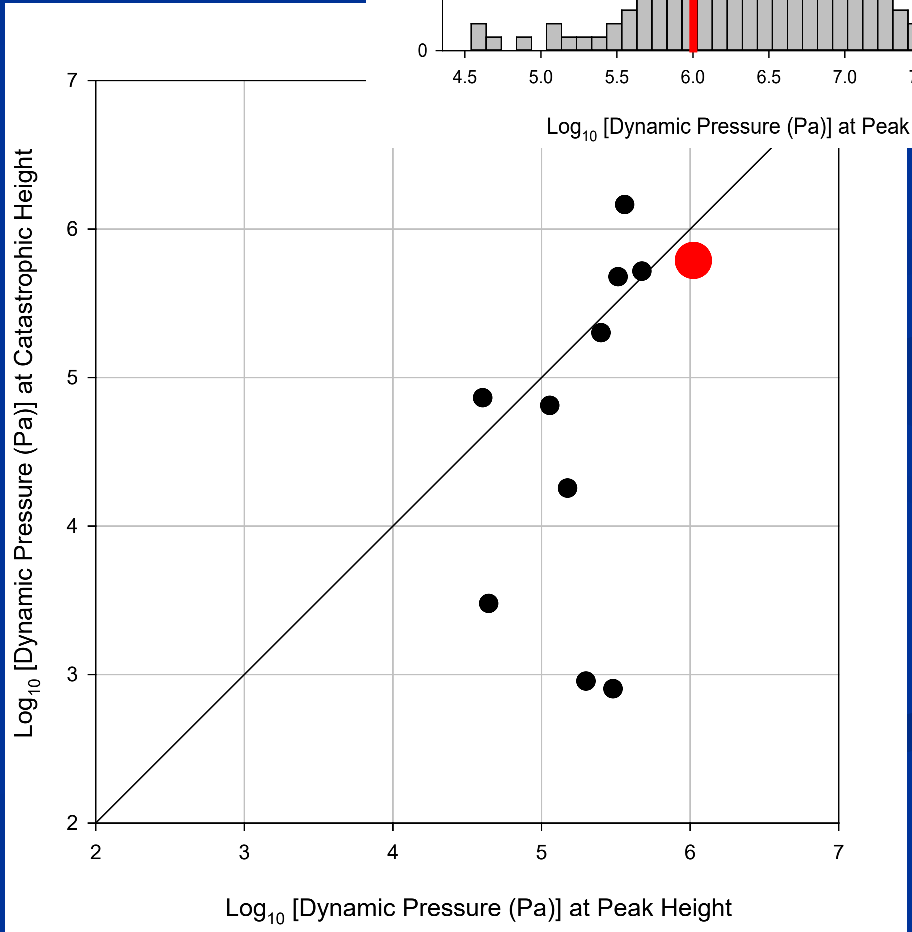
[Semi-empirical Erosion model of Borovicka et al (2020)]

- Diameter 3m / Albedo 0.02
- Catastrophic breakup (50% of mass remaining in main fragment) = 0.2 MPa at 50 km
- Initial fragmentation = 0.07 MPa at 57 km
- Most light production from small fragments of order grams to hundreds of grams

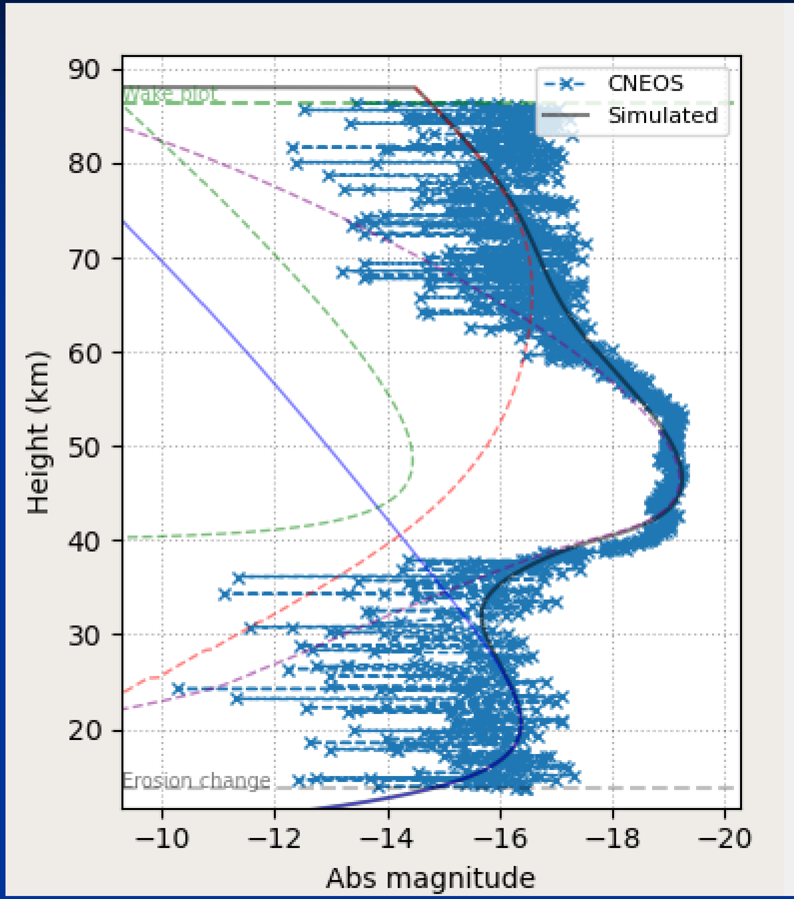
- Most consistent with C-complex NEO

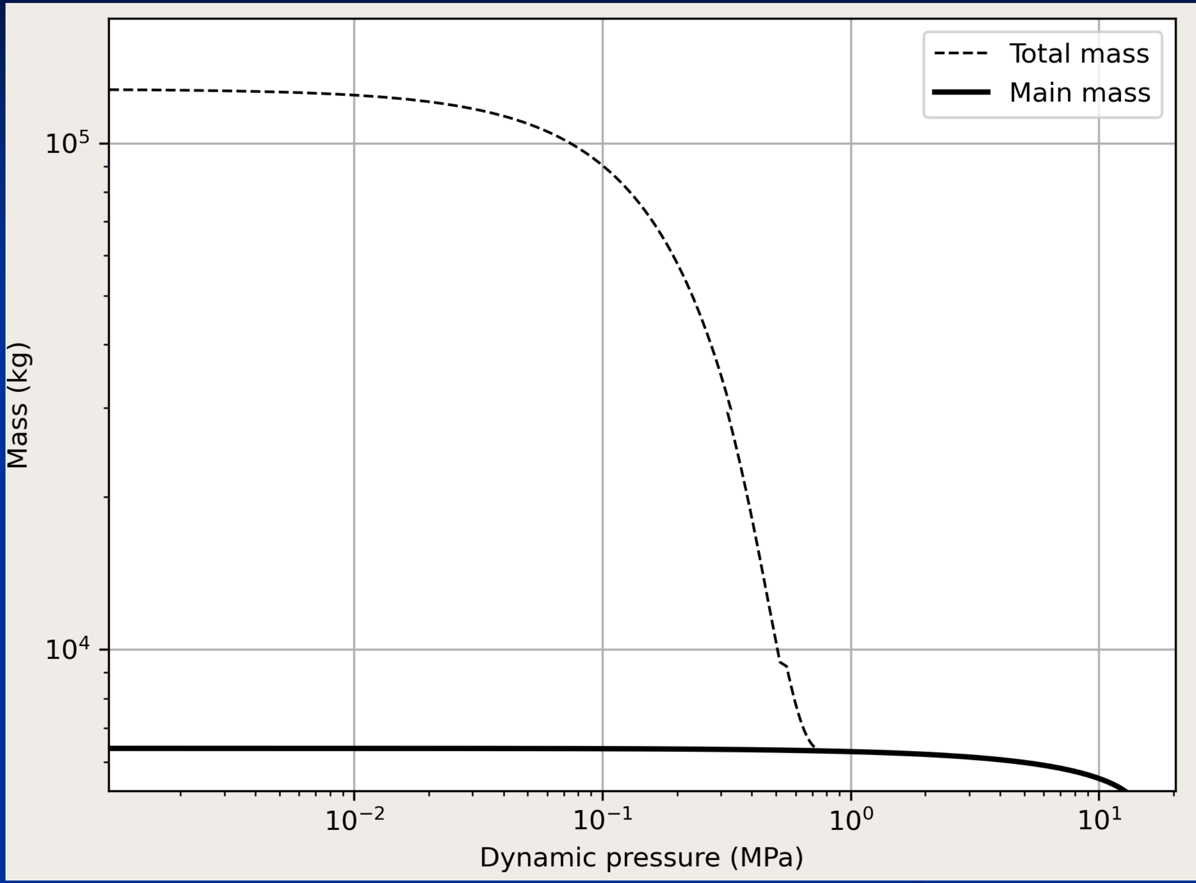
- Distribution of dynamic pressures at peak brightness shows broad maximum with tails
- Almahatta Sitta – best evidence for weakly bound meteoroid (Borovicka and Charvat, 2009; Kohout et al., 2011)





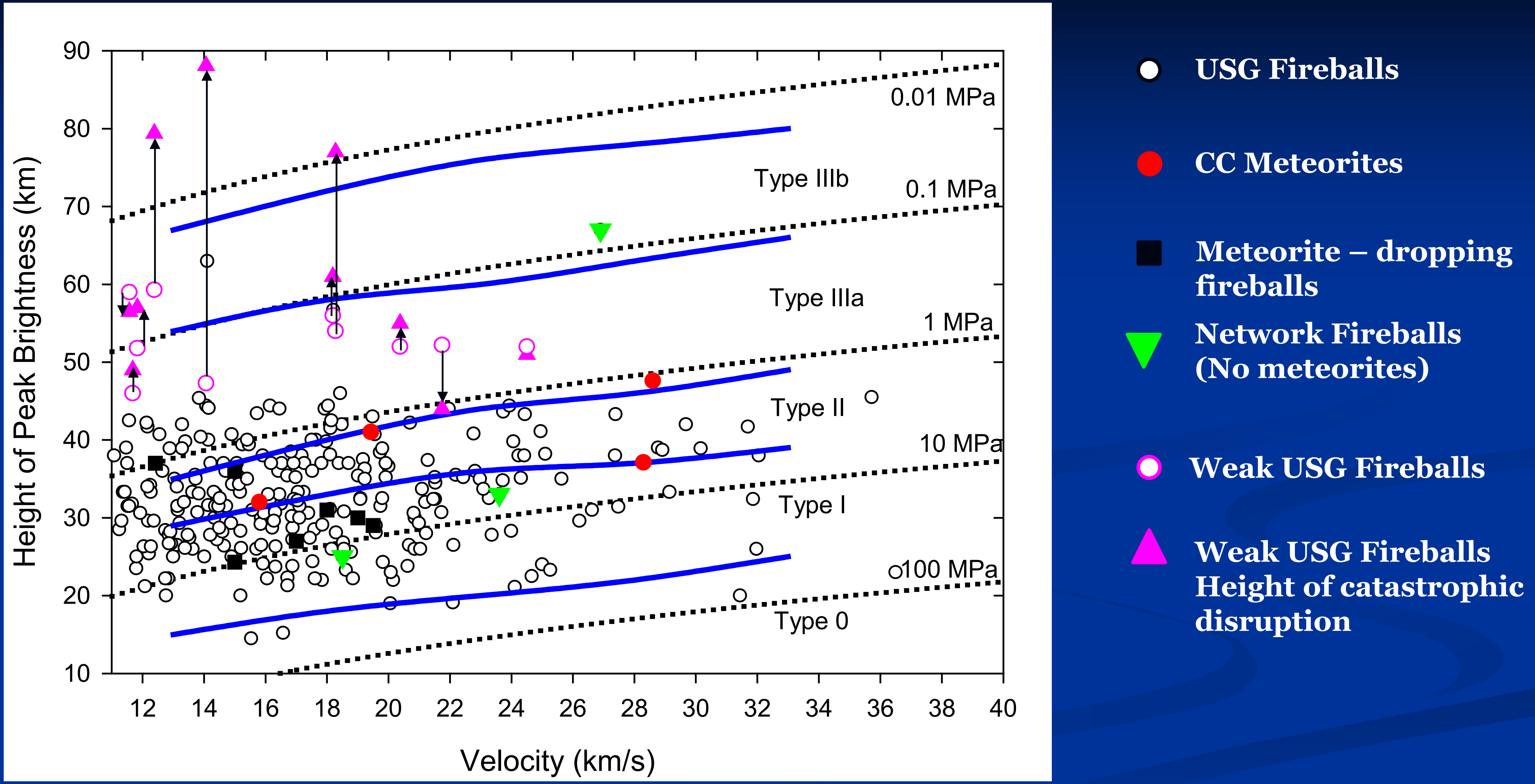
Extreme Event – USG 20191010





Main Fragment
Eroding grains
Secondary fragments
Immediate dust release

- Energy ~ 0.6 kt
- Diameter ~4-5 m
- V = 14 km/s; entry angle 60 degs
- Catastrophic breakup at 0.0008 MPa



Height of Peak Brightness (km)
Velocity (km/s)
0.01 MPa
0.1 MPa
1 MPa
10 MPa
100 MPa
Type IIIb
Type IIIa
Type II
Type I
Type 0
USG Fireballs
CC Meteorites
Meteorite – dropping fireballs
Network Fireballs (No meteorites)
Weak USG Fireballs
Weak USG Fireballs Height of catastrophic disruption

Summary

- 3% of asteroidal-orbit USG events show evidence of extreme weakness compared to whole population
- 16% of USG fireballs are weaker than Almahatta Sitta (2008TC3)
- Weaker material mostly erodes releasing grains of mg – gram masses
- Orbits are $0.7<a<1.4$, $e<0.6$ and $i<30$ degs
  - Primary ER is υ_6 (>70%) using Granvik et al (2018) model suggesting inner main belt origin