KINETIC DAMAGE FROM METEORITES

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1. Danger from meteorite fragments

Individuals struck by falling meteorites have been recorded in two cases: the 1954 Sylacuga, Alabama meteorite of 4 kg mass, which indirectly hit Ann Hodges – (upper left image) and the 1992 Mbale meteorite fall where a 4g-sized meteorite struck a young boy. Neither event was fatal. Structures damaged by meteorites are much more common and include mailboxes (Figure 1) and cars (Figure 2). Figure 3 shows that meteorite fragments of order 0.1 kg may cause serious human injury/fatality. Halliday et al (1985) estimated a human is struck once per decade by a meteorite (most likely gram-sized) while more than a dozen structures should be impacted annually by meteorite fragments.

Figure 1: The Claxton, Georgia meteorite fall in 1984 included a 1.5 kg meteorite which struck a mailbox.

Figure 2: The Peekskill, New York meteorite (12 kg) struck a Chevy Malibu in 1992.

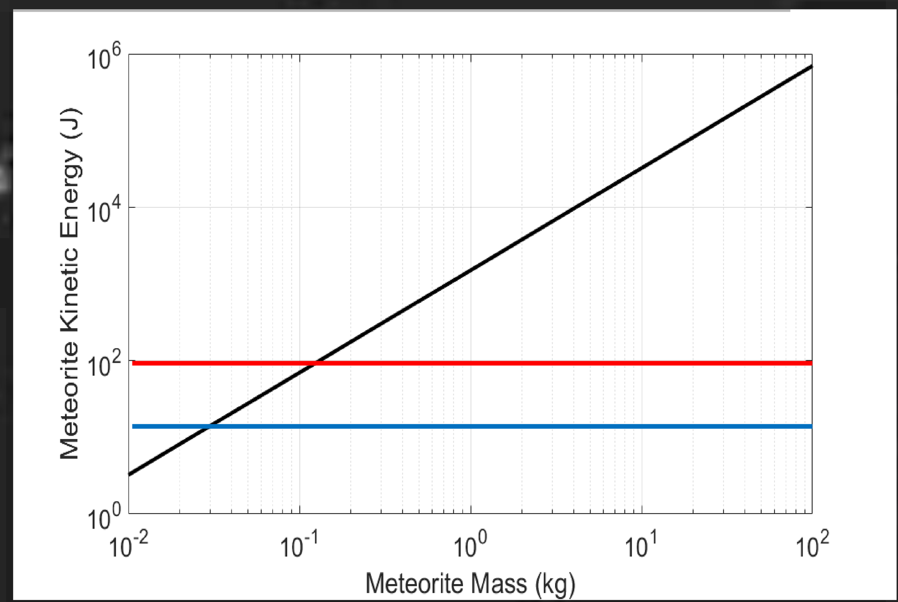

Figure 3: Kinetic energy of individual meteorite fragments at impact assuming terminal velocity. Horizontal red line is KE limit for 50% probability of human fatality based on Swisdak et al (2007) analysis. Blue line is estimated 1% lethality from Janser (1982).

2. Updated flux estimates and impactor sizes

The original Halliday et al (1985) analysis used an early flux estimate of meteorite falls based on MORP data and several assumptions.

Bland and Artmeieva (2006) provide estimates of the relative number of impactors at the top of the atmosphere to meteorite fragments reaching the surface. Their results suggest that the ground-level flux of meteorites is one order of magnitude lower than the flux at the top of the atmosphere (Figure 4). Using this relationship, assumptions from Halliday et al (1985) about human footprint and structure footprint are combined with modern estimates of flux. The space debris re-entry flux is also shown; here the survival fraction would be expected to be much larger and very different in nature. Table 1 summarizes expected kinetic damage frequency to humans and structures at various thresholds.

Given the large number of uncertainties in this analysis, a bounding range and estimate of the best value is provided together with the underlying assumptions.

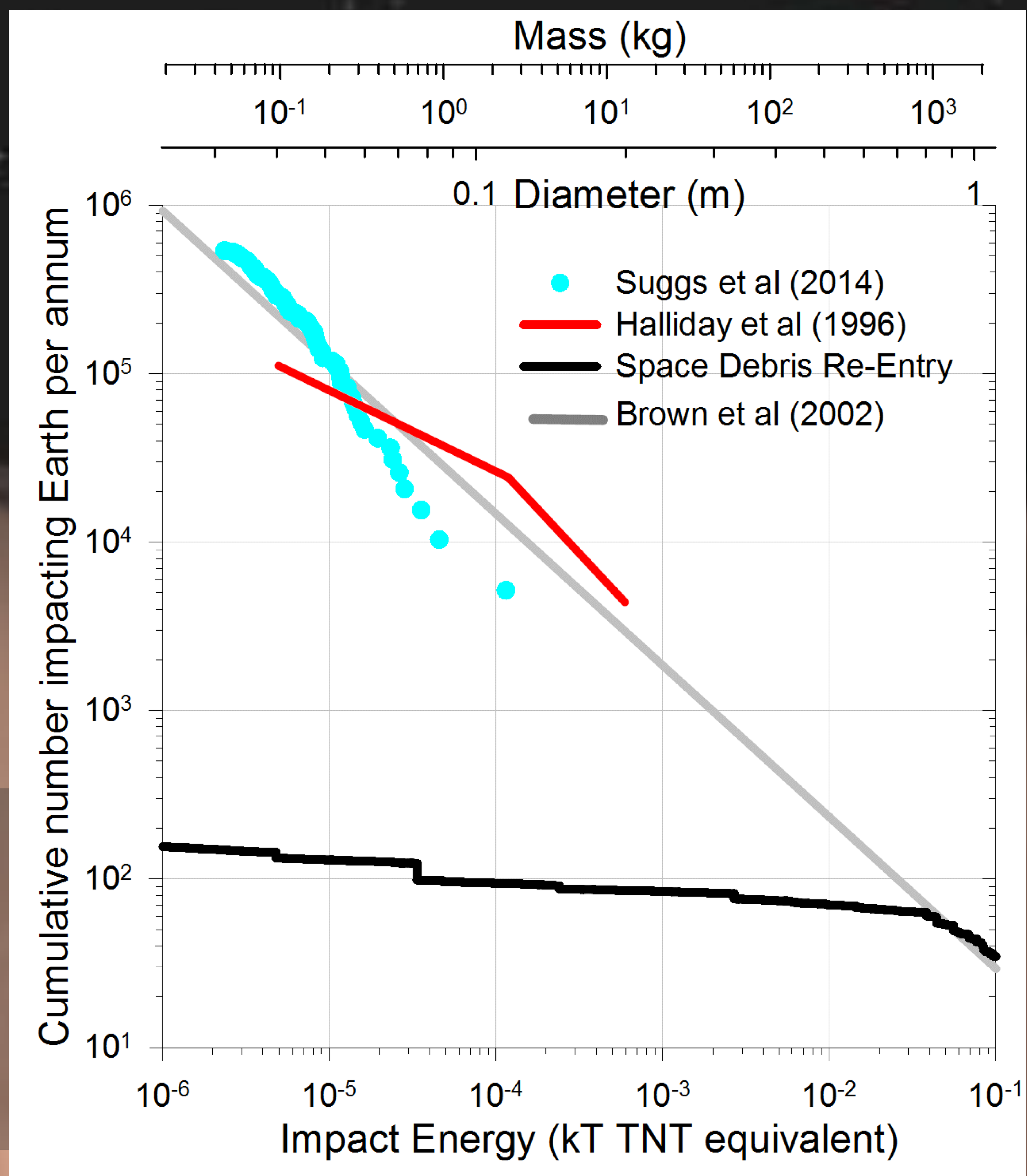

Figure 4: Meteoroid flux at the top of the atmosphere based on photographic network measurements of the Meteorite Observation and Recovery Project [MORP] (Halliday et al, (1996), lunar impact flashes (Suggs et al, 2014) and global bolide flux estimates (power law fit to data shown) for impactors with energies larger than 0.1 kT (Brown et al, 2002). Also shown for comparison are the cumulative annual number of space debris re-entries, where the mass of the debris at the top of the atmosphere is shown.

Table 1: Estimate of recurrence interval of kinetic damage to various thresholds for humans and structures. The human fatality/injury range encompasses the extreme upper limit of estimated top of atmosphere flux, current world population and assumes everyone is outside all the time. The lower limit assumes current world population and 5% outdoor exposure and lower limit of atmosphere flux.

Type of Damage	Limiting mass at the ground (kg)	Number of years between events
Human fatality (50% probability)	> 0.1	140 < Y< 8500 ~thousands of years (best estimate)
Human Injury (1% probability	> 0.03	50 < Y < 3000 ~few hundred to a thousand
Detectable fragment hitting a person	>0.005	2 < Y < 120 ~decade
Fragment hitting structure which may cause noticeable damage	> 0.03	0.03 < Y < 0.1 Several tens of structures per year
Fragment hitting structure and penetrating roof/causing significant damage	> 0.3	0.2 < Y < 0.5 (2-5 buildings per year globally) North America only (3 < Y < 5)

3. Recorded kinetic damage events

Following Halliday et al (1985) we limit our statistics of structures damaged to reports from North America. From 1962-2016 there were 48 recorded meteorite falls in North America (Meteoritical Bulletin). Of these, 23 were associated with roofs/buildings being struck and 3 more struck cars. Among these, 13 reports included roof penetration which occurred for masses >0.3 kg. From our roof penetration rate estimate of once every 3-5 years in North America, we would predict 11 - 18 such incidents - in good agreement - and suggest that roof penetration increases recovery probability. One person has been recorded hit by insulation from re-entering rocket debris, but no other kinetic damage reported from space debris.

4. Discussion and Conclusion

Comparing the natural meteorite flux at the Earth's surface to that of space debris, re-entering debris is ~2 orders of magnitude less of a kinetic hazard at all but the very largest (and therefore rarest) sizes compared to natural impactors. Debris re-entries over several metric tonnes are roughly as frequent as natural impactors, but the survival fraction is expected to be much higher.

Kinetic hazards from meteorites are very small, with only one recorded (indirect) injury reported. We expect fatalities to be even more rare, on the order of one person killed per several millennia. That several reports exist of small fragments/sand hitting people during meteorite falls is consistent with our prediction that this should occur every decade or so.

References

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