The flux of small near-Earth objects colliding with the Earth

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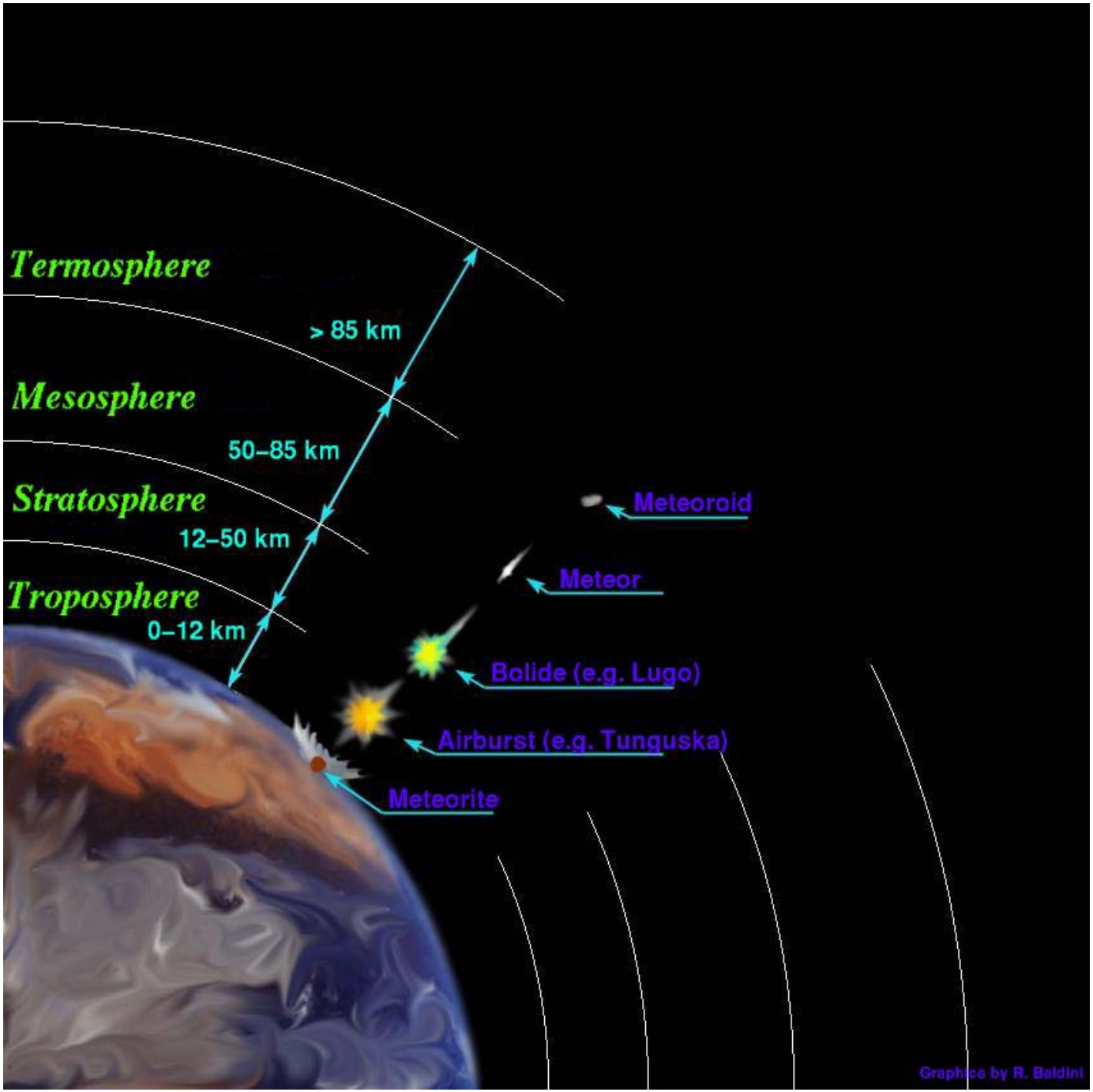
Terminology

- Comet – “dirty snowball”;
  - survive only few thousand orbits around the sun
  - long period comets originate in the Oort cloud, short period comets originate in Kuiper belt
  - not as numerous as asteroids in sub-km size
- Meteoroids – solid bodies, < ~10 m
  - creates an optical phenomenon known as a meteor when it hits the earth’s atmosphere (> 1 gm)
  - ~100,000 kg of meteoritic material hits earth each day
  - Bright meteor is called a bolide
  - Called a meteorite when it hits the earth
    - Chondrites (stones, incl iron), carbonaceous chondrites (weaker)
  - Typical speeds are 10-70 km/s
- Asteroids – large meteoroids, > 10 m
- ~ 1 km asteroid thought to be responsible for mass extinction of the dinosaurs 65 million years ago at end of Cretaceous period


Termosphere
> 85 km
Mesosphere
50–85 km
Stratosphere
12–50 km
Troposphere
0–12 km
Meteoroid
Meteor
Bolide (e.g. Lugo)
Airburst (e.g. Tunguska)
Meteorite
Graphics by R. Baldini

Rates & Risks from Asteroids

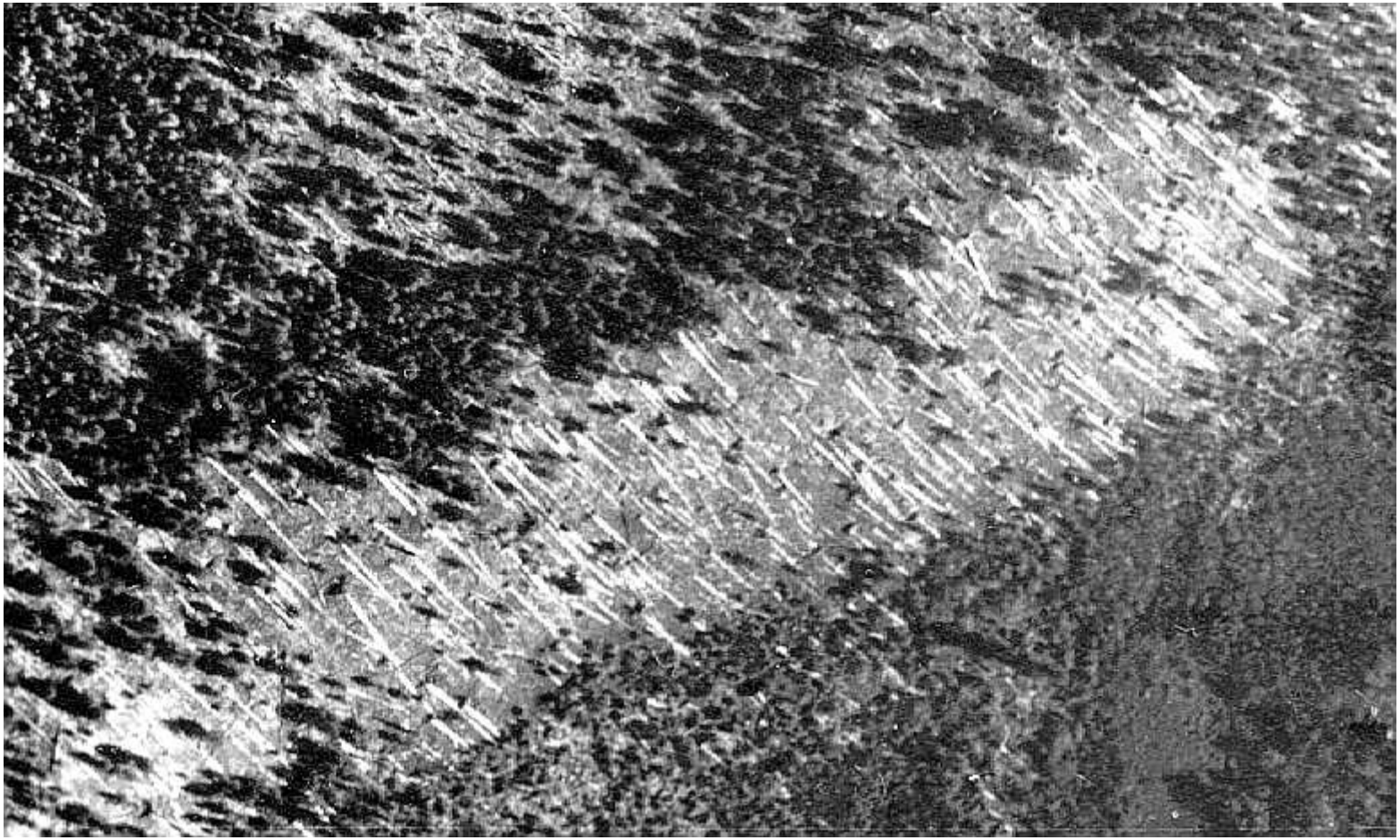
Asteroid or comet diameter [metres]	Chance of occurring during the 21st century	Total energy, and where deposited	Estimated damage
10	6 per century	0.1 MT[6] upper atmosphere	Extraordinary explosion in sky; broken windows, but little major damage on ground.
30	1/2.5	2 MT stratosphere	Devastating stratospheric explosion; shock wave topples trees, wooden structures and ignites fires within 10 km; many deaths likely if in populated region.
100	1/100	80 MT lower atmosphere or Earth's surface	Low-altitude or ground burst larger than biggest-ever thermonuclear weapon, regionally devastating. Shallow crater approximately 1 km across.
300	1/500	2,000 MT local crater	Crater approx. 5 km across & devastation of area the size of a small nation, or ocean-wide tsunami.
1,000	1/5000	80,000 MT major regional destruction	Destruction of entire region (e.g., Europe) or ocean rim. Potential global climate disruption.
10,000	less than 1/1,000,000[7]	80,000,000 MT	Global catastrophe. Possible mass extinctions.

From the final report of the OECD Global Science Forum, Workshop on NEO, Jan 2003

Tunguska Event – June 30, 1908 Siberia

- Seen by many observers, recorded at several seismic stations
- Most likely a main belt asteroid that exploded about 8 km above surface
- Energy estimated at 10-20 Mton, corresponding to diameter of ~60m
- Devastated an unpopulated area of about 2000 square km; 600x as powerful as Hiroshima atomic bomb
- Thought to occur once every 100 – 300 years on average (prior to this paper)

Tunguska Event – June 30, 1908 Siberia

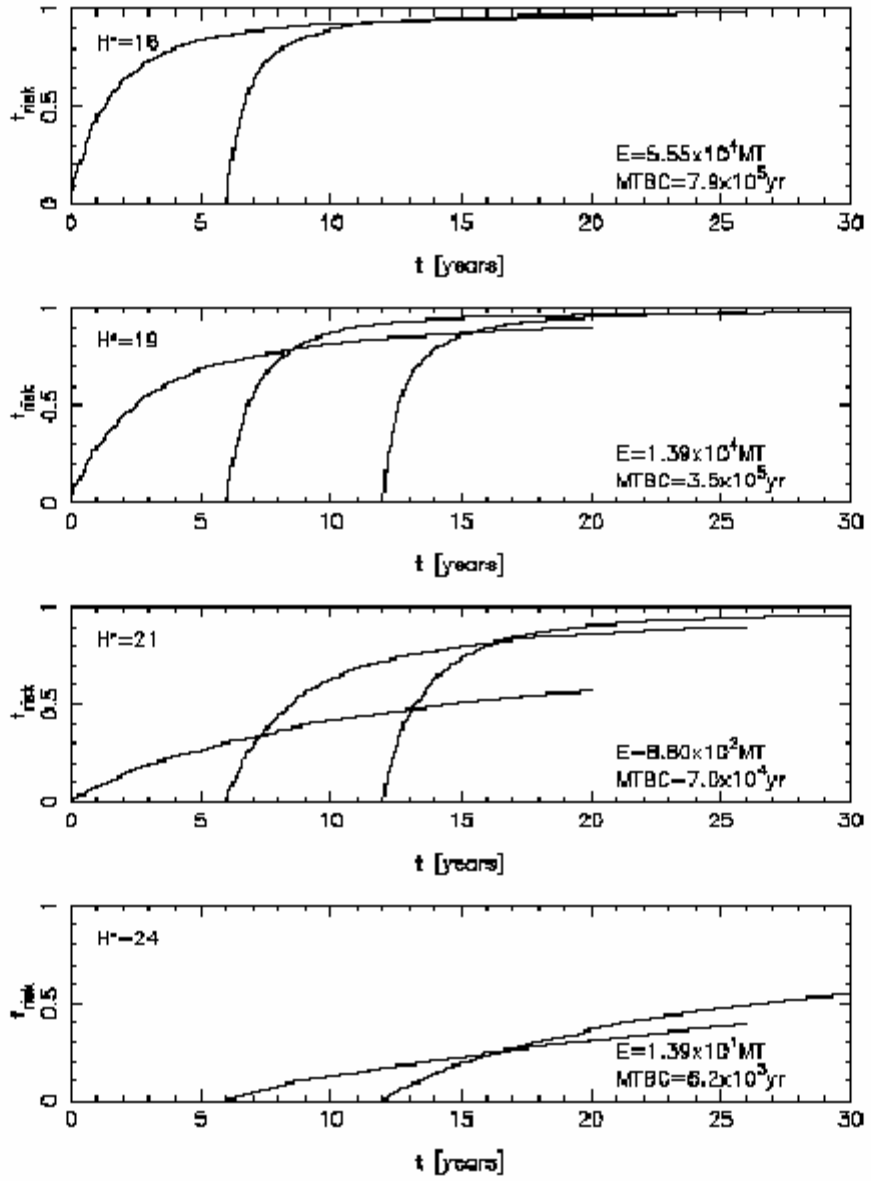


1938 aerial photo shows trees blown down by blast

Decadal Survey & NEO's

- Detection of potentially hazardous asteroids (PHAs) > 200 m is a main driver for a large, dedicated wide field telescope
  - PHA is one that passes within 0.05 AU of earth; approx 200 estimated to exist with diameter > 1 km (global catastrophe)
  - US Congress has mandated that 90% of PHA's > 1 km diameter be discovered and orbits determined by 2010
  - LINEAR and NEAT are surveys that have responded to this mandate
- Air Force is funding Pan Starrs for this purpose – 4 small telescopes (1.8 m), with first light expected in 2006 for first telescope and rest to be completed in another 2 years
- This is also a major driver for the 8.4m LSST proposal design and survey strategy

Pan Starrs projections



55000 MTon

14000 MTon

8800 MTon

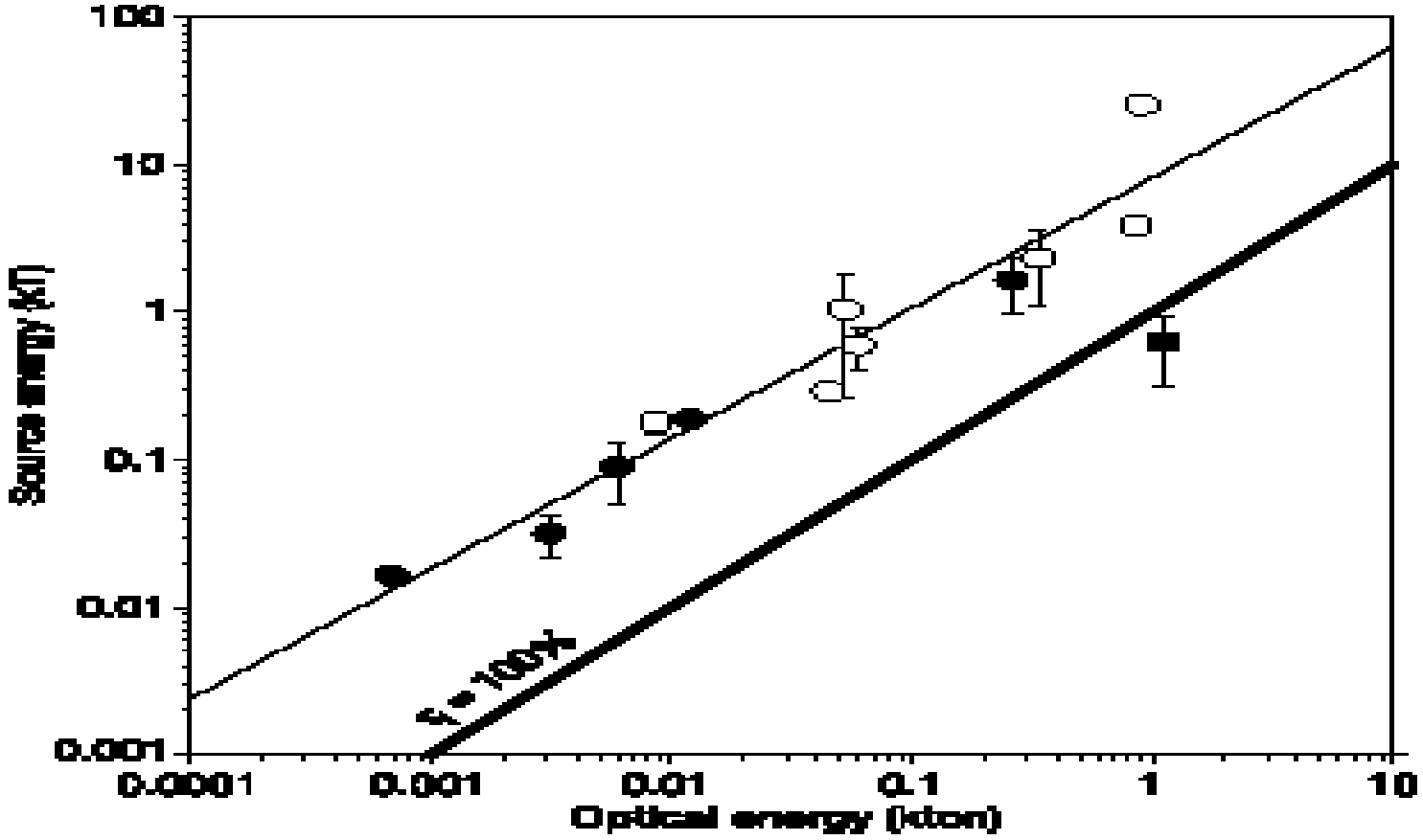
1.4 MTon

Fig. 34.— Completeness of reduction of collision hazard for various collision energies (by panel) and for detection limits of $m_{\rm lim} = 21, 24, 25$ (curves from left to right). Note that the start time of the different assumed detection limits are different.

This paper

- Use Air Force data taken 1994 – 2002 to estimate rate of small asteroids (1-10m) that collide with earth
- 300 “probably bolides” with time-intensity optical data
  - Get peak brightness and integrated energy
  - Use optical energy as indicator of kinetic energy
  - Large errors due to unknown spectrum, and unknown fraction of kinetic energy converted to light
    - Assume 6000K blackbody
    - Analyze 13 events with both optical data and independent energy estimate to obtain a relation between optical and total energy
  - Convert total energy into diameter, assuming velocity of 20.3 km/s and density of 3000 kg/cubic meter
  - Also correct for fraction of earth’s surfaced viewed (60-80%)

Calibration of optical vs total energy



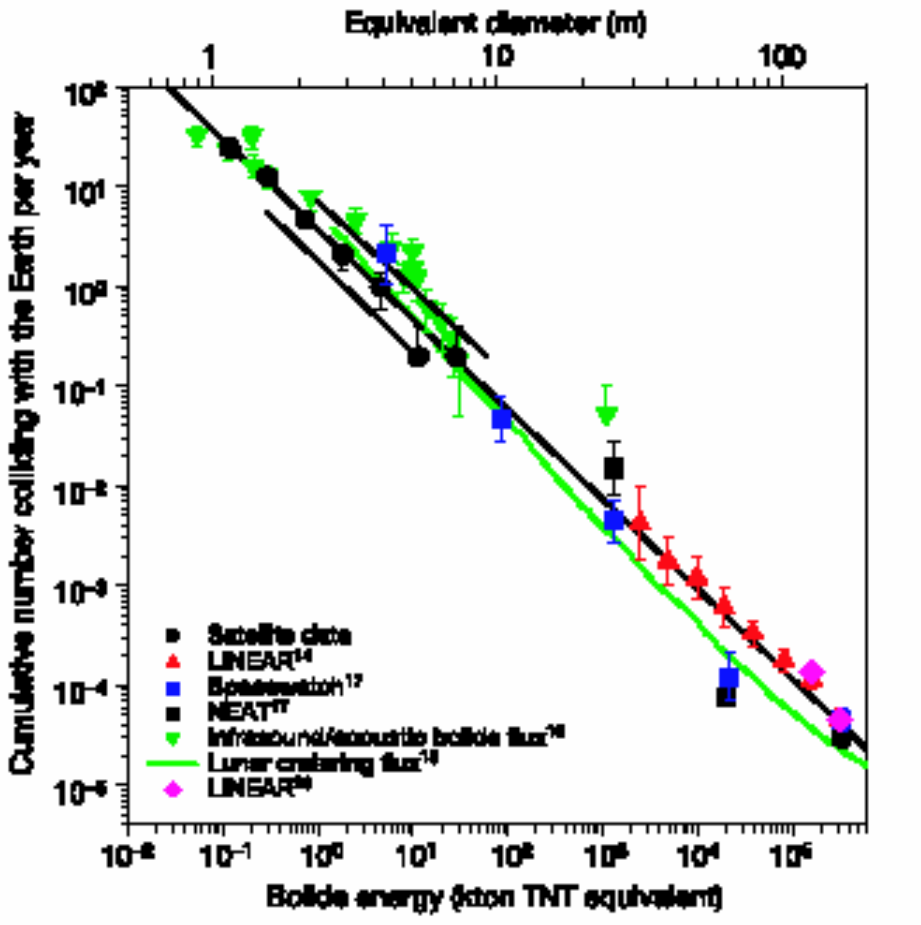
Energy & Diameter vs Collision rate with earth, per year

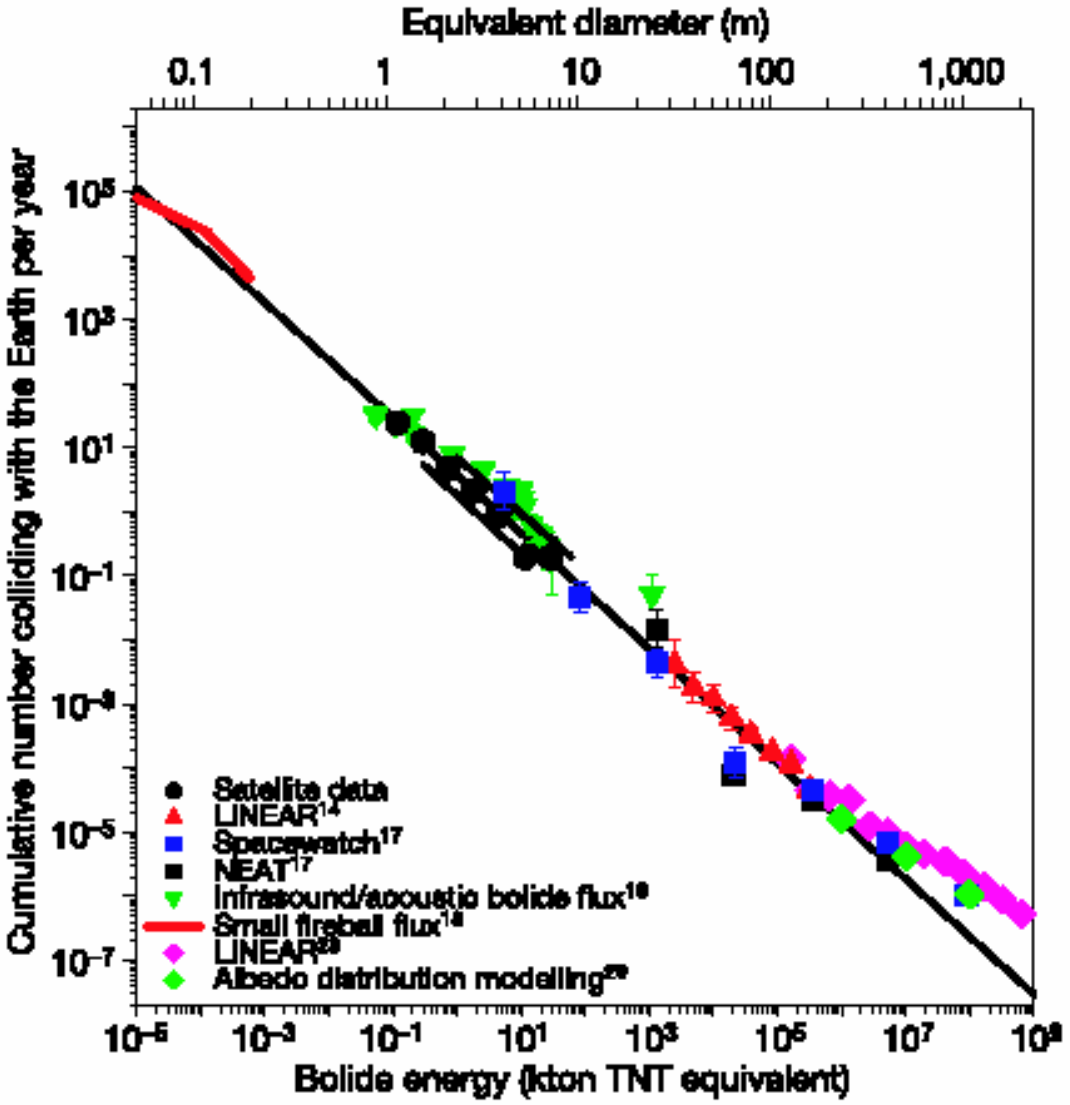
Filled black circles – this work (stat errors only)
Black line – best fit
Upper and lower black lines – Systematic error range

LINEAR and NEAT rates (red, pink, filled squares)

Infrasonic/acoustic bolide rate
Green triangles

Lunar crater counts
Solid green line




Equivalent diameter (m)
0.1
1
10
100
1,000
Cumulative number colliding with the Earth per year
10^{5}
10^{3}
10^{1}
10^{-1}
10^{-3}
10^{-5}
10^{-7}
Satellite data
LINEAR[14]
Spacewatch[17]
NEAT[17]
Infrasound/acoustic bolide flux[18]
Small fireball flux[14]
LINEAR[29]
Albedo distribution modelling[29]
10^{-5}
10^{-3}
10^{-1}
10^{1}
10^{3}
10^{5}
10^{7}
10^{9}
Bolide energy (kton TNT equivalent)

Conclusions

- Asteroids impacting the earth follow a power law distribution
- 10 Mton event (Tunguska) occurs every 1000 (+800, -200) years (400 – 1800 years with extreme systematic errors)
- 2-10 kton objects hit earth annually, on average, and 50 kton every ten years on average