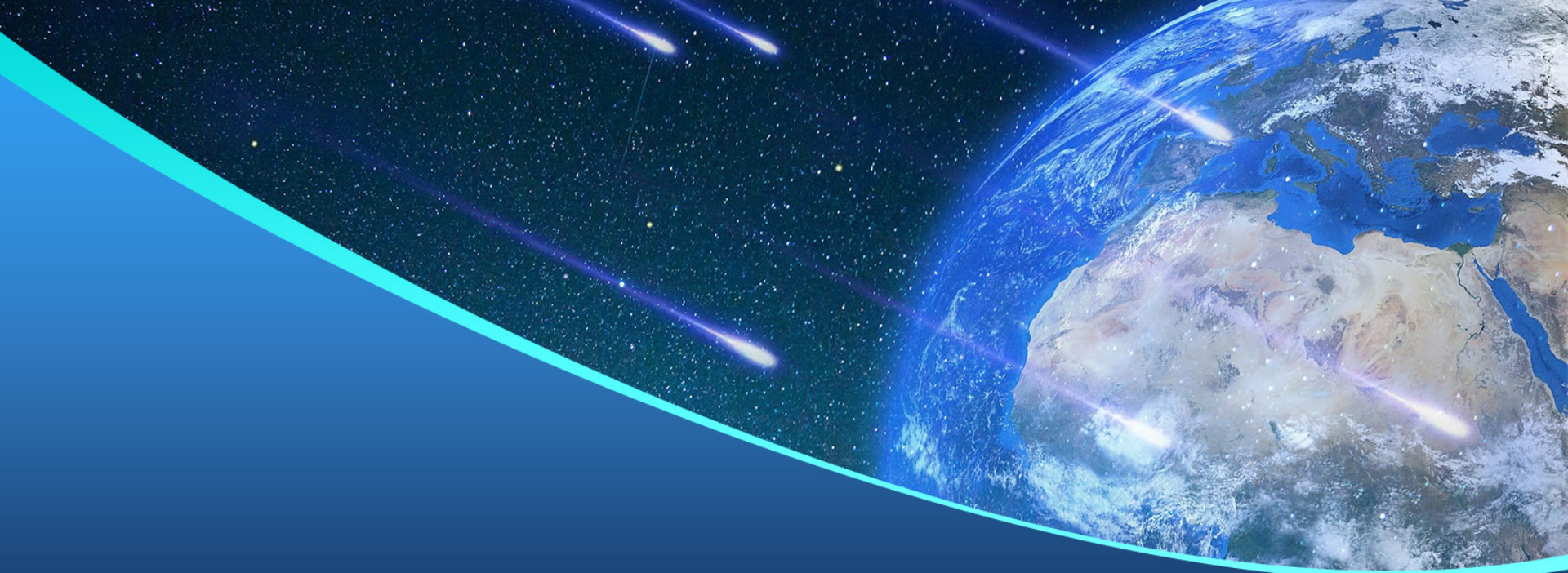




Space Debris: Overview and Hazard

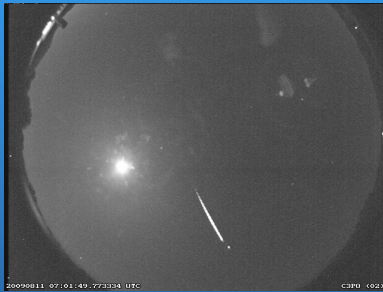
Bill Cooke

Definition

- In the U.S., “space debris” is usually used to refer to the combined meteoroid/orbital debris environments near Earth (same as *MMOD* – *M**icro* *M**eteoroids and* *O**rbital* *D**ebris*).
- Europeans also consider asteroids as “space debris.”



How NASA handles space debris



Meteoroids and meteors



Meteoroid
Environment
Office (MSFC)

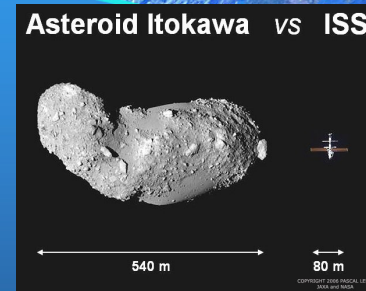


Man-made orbital debris

OSMA



Orbital Debris
Program
Office (JSC)



Earth-approaching asteroids



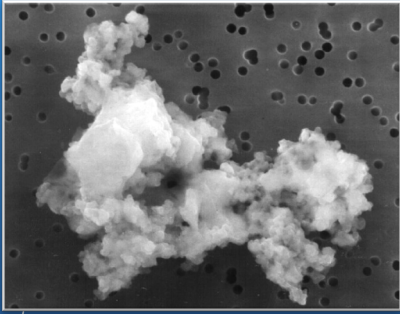
SMD

Planetary Defense
Coordination
Office/Center for
Near Earth
Object Studies
(HQ/JPL)

Meteoroids

A wide-angle view from space looking down at the Earth. The horizon is a thin blue line separating the dark, star-filled sky from the planet's surface. A bright, white streak of light, likely a meteor, is visible in the upper right quadrant of the frame. In the foreground, parts of a satellite or space station are visible, including a large, rectangular solar panel array on the right and a smaller, truss-like structure on the left. The Earth's surface is covered in a dense layer of white clouds, with some darker patches of land visible.

Terminology



Meteoroids

- Chunks of rock and ice out in space.
- About the size of a boulder or smaller (1 meter upper limit)



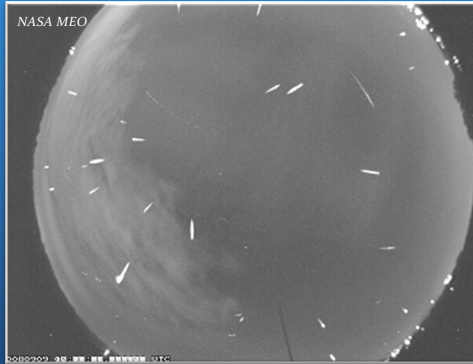
Meteors

- Streaks of light that you see as a meteoroid *ablates*, or burns up, in the Earth's atmosphere.
- Commonly called a 'shooting star' or 'falling star'.



Meteorites

- What is left of the meteoroid/asteroid if it survives the trip through the atmosphere and hits the Earth.
- Made of silicate minerals and/or iron-nickel.



Fireballs or Bolides

- Bright meteors.
- Peak magnitude brighter than Venus, $m_{app} = -4$.



Superbolides

- VERY bright meteors.
- Peak magnitude brighter than the full Moon, $m_{app} = -17$.
- Detectable by ground and space-based sensors

Sources of meteoroids



Comets (>90%)



Asteroids

(Meteoroids can also come from the Moon or other planets, but this is VERY rare.)



2 main categories of meteoroids/meteors

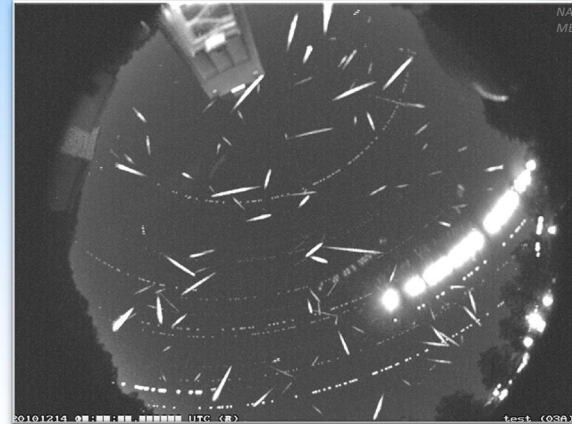
Shower

- Meteors associated with a particular comet (or asteroid, in the case of the Geminids)
- Caused by Earth passing through dust trails left by comets in their orbits
- Observed specific times during the year
- Rates are variable, they differ shower to shower and year to year



Sporadic

- Meteors not associated with a particular comet/meteor shower
- Drifted from their original orbit (from comet or asteroid) over time
- Observed all year round with rates higher just before dawn
- Rates vary slightly during the year, about 5-8 meteors per hour can be seen on any given evening



Annual Meteor Showers

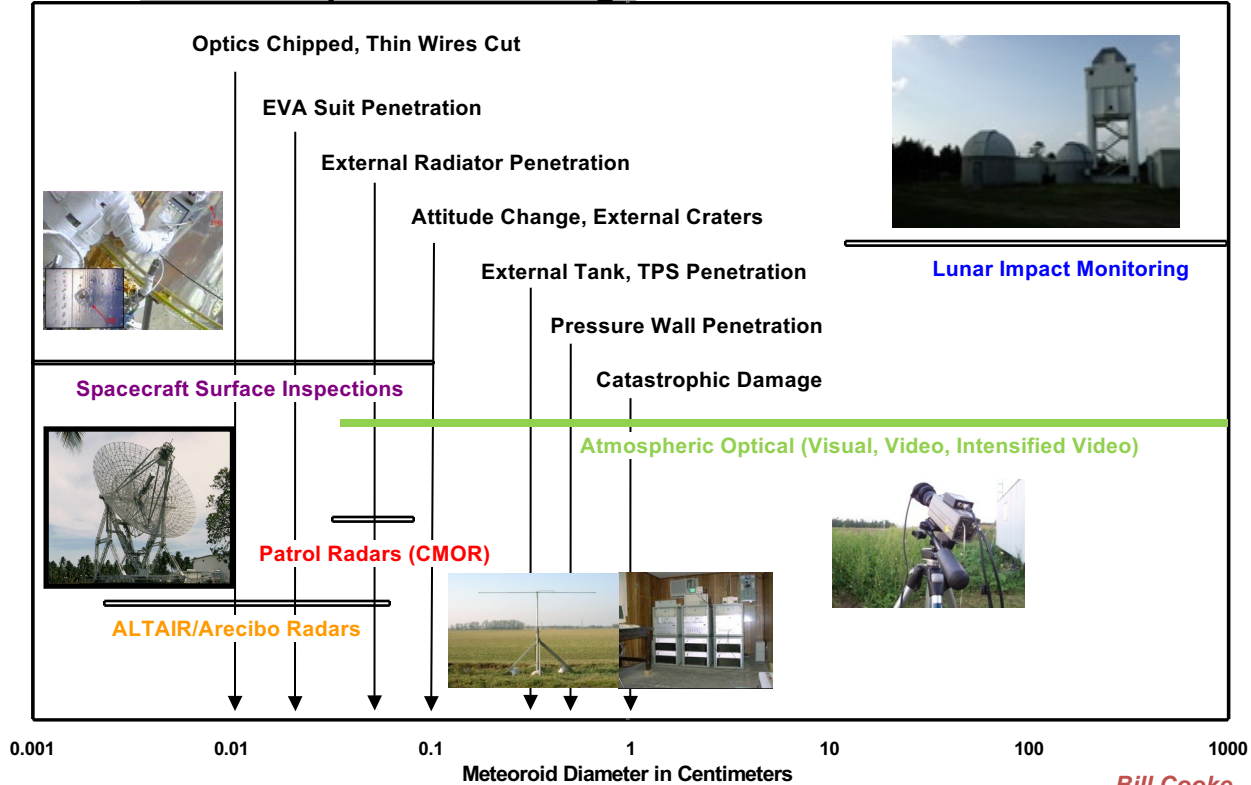
Shower (3 letter code)	Activity	Peak	Radiant		ZHR (meteors/hr)
			α	δ	
Quadrantids (QUA)	Dec 28 - Jan 12	Jan 04	230°	+49°	120
Lyrids (LYR)	Apr 16 - Apr 25	Apr 22	271°	+34°	18
η -Aquariids (ETA)	Apr 19 - May 28	May 06	338°	-01°	70*
June Bootids (JBO)	Jun 22 - Jul 02	Jun 27	224°	+48°	Var
South. δ -Aquariids (SDA)	Jul 12 - Aug 23	Jul 30	340°	-16°	16
α -Capricornids (CAP)	Jul 03 - Aug 15	Jul 30	307°	-10°	5
Perseids (PER)	Jul 17 - Aug 24	Aug 13	48°	+58°	100
Draconids (DRA)	Oct 06 - Oct 10	Oct 08	262°	+54°	Var
Southern Taurids (STA)	Sep 10 - Nov 20	Oct 10	32°	+09°	5
Orionids (ORI)	Oct 02 - Nov 07	Oct 21	95°	+16°	25*
Northern Taurids (NTA)	Oct 20 - Dec 10	Nov 12	58°	+22°	5
Leonids (LEO)	Nov 06 - Nov 30	Nov 18	152°	+22°	20+*
Monocerotids (MON)	Nov 27 - Dec 17	Dec 09	100°	+08°	2
σ -Hydriids (HYD)	Dec 03 - Dec 15	Dec 12	127°	+02°	3
Geminids (GEM)	Dec 07 - Dec 17	Dec 14	112°	+33°	120
Dec. Leonis Minorids (DLM)	Dec 05 - Feb 04	Dec 20	161°	+30°	5
Ursids (URS)	Dec 17 - Dec 26	Dec 23	217°	+76°	10

2023

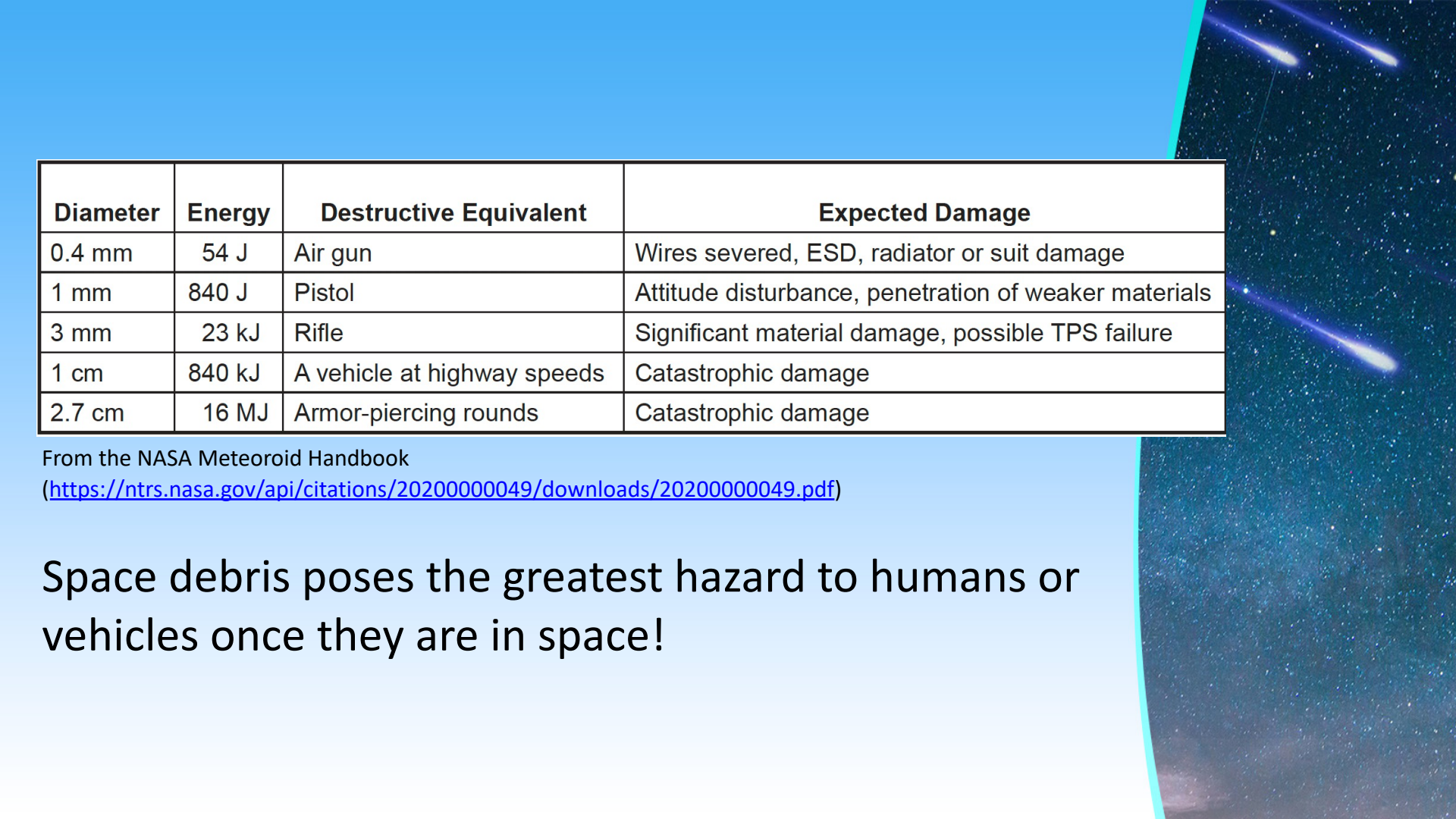
2033

Worth viewing

Potential Spacecraft Damage



Bill Cooke



Diameter	Energy	Destructive Equivalent	Expected Damage
0.4 mm	54 J	Air gun	Wires severed, ESD, radiator or suit damage
1 mm	840 J	Pistol	Attitude disturbance, penetration of weaker materials
3 mm	23 kJ	Rifle	Significant material damage, possible TPS failure
1 cm	840 kJ	A vehicle at highway speeds	Catastrophic damage
2.7 cm	16 MJ	Armor-piercing rounds	Catastrophic damage

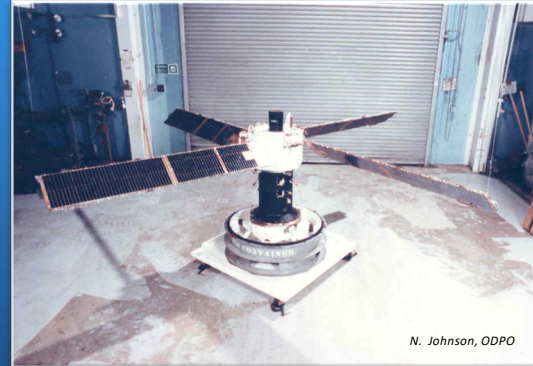
From the NASA Meteoroid Handbook

(<https://ntrs.nasa.gov/api/citations/20200000049/downloads/20200000049.pdf>)

Space debris poses the greatest hazard to humans or vehicles once they are in space!

Laboratory example – Navy Transit Satellite

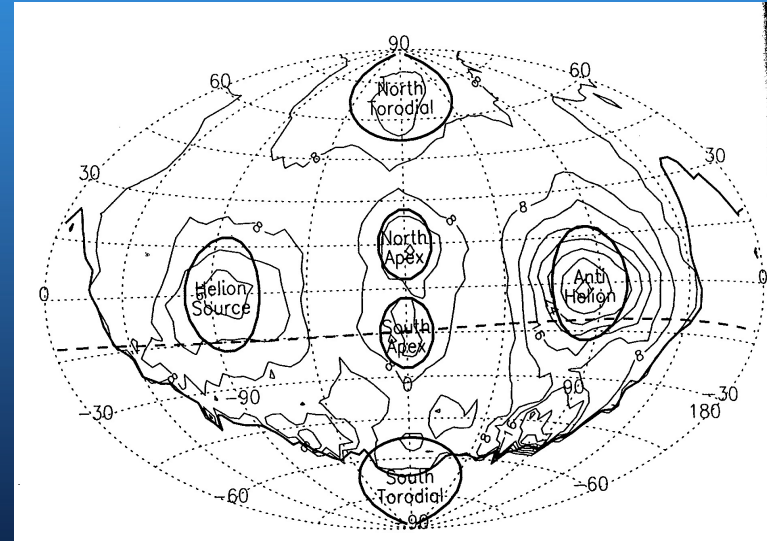
BEFORE being shot with a 5 cm aluminum ball moving at 6 km/s



AFTER being shot with a 5 cm aluminum ball moving at 6 km/s

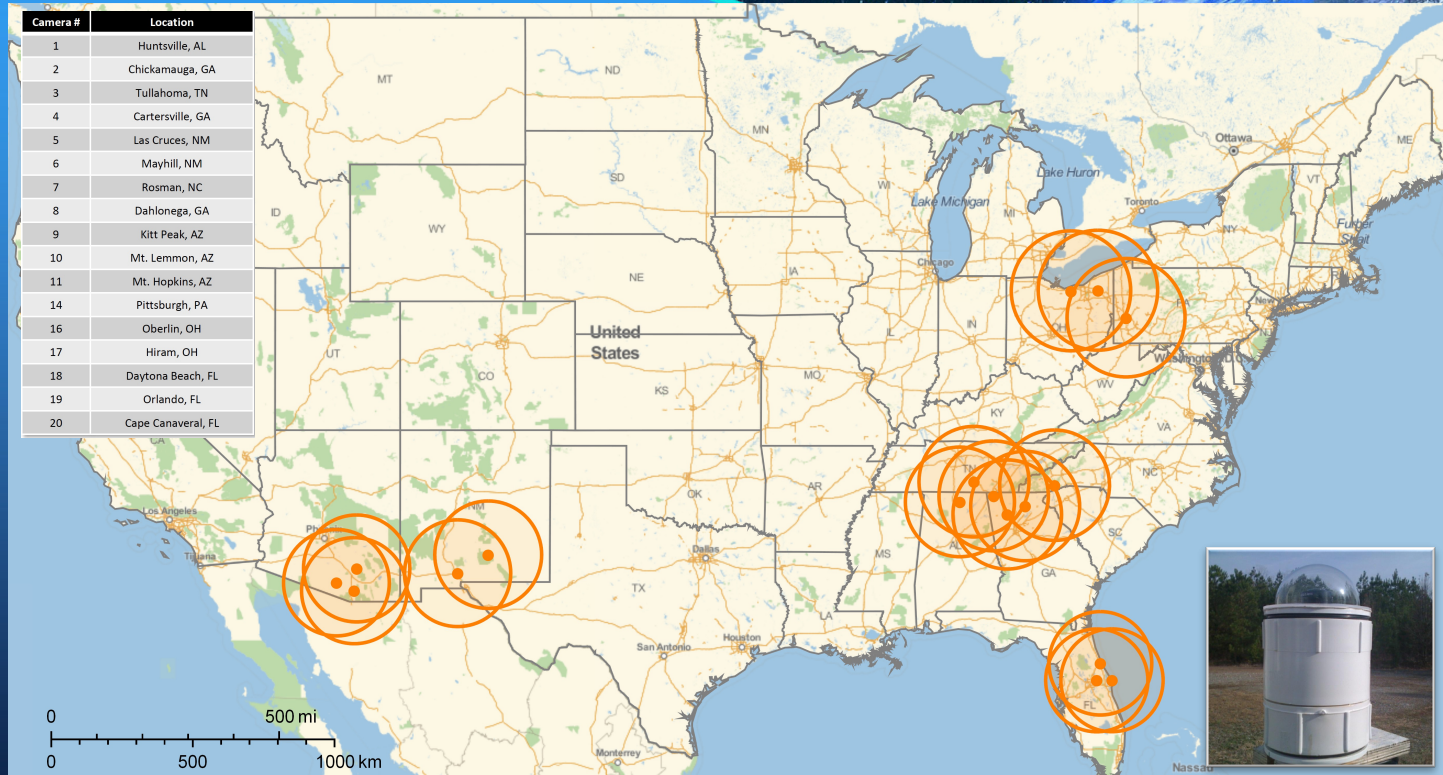


- Sporadic meteoroid background is directional (not isotropic) and accounts for 90+% of the meteoroid risk to a typical spacecraft.
- Meteor showers get all the press, but account for <10% of spacecraft risk.
 - Bias towards assigning meteoroid cause to anomalies during meteor showers.
- High speed meteoroids ($\sim 50 \text{ km s}^{-1}$) can induce electrical anomalies in spacecraft through discharging of charged surfaces.
- Meteoroids are everywhere in the Solar System – orbital debris is just in Earth orbit.

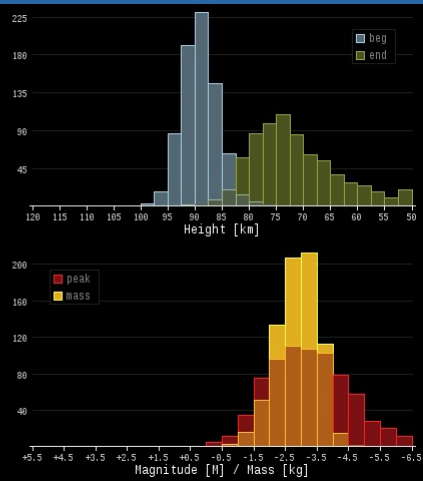
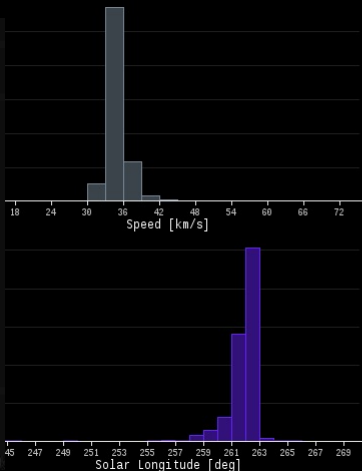
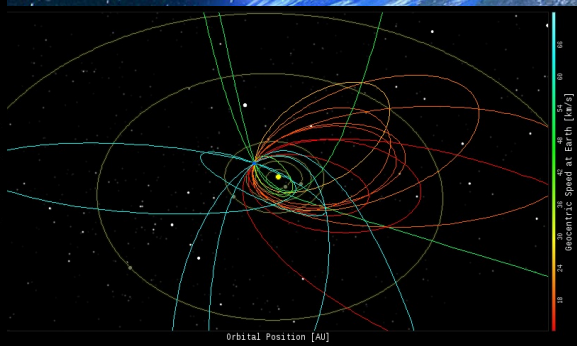
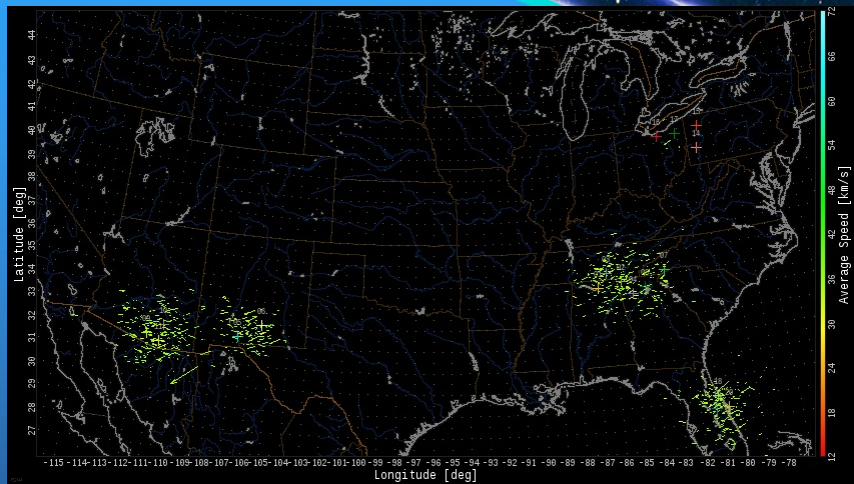


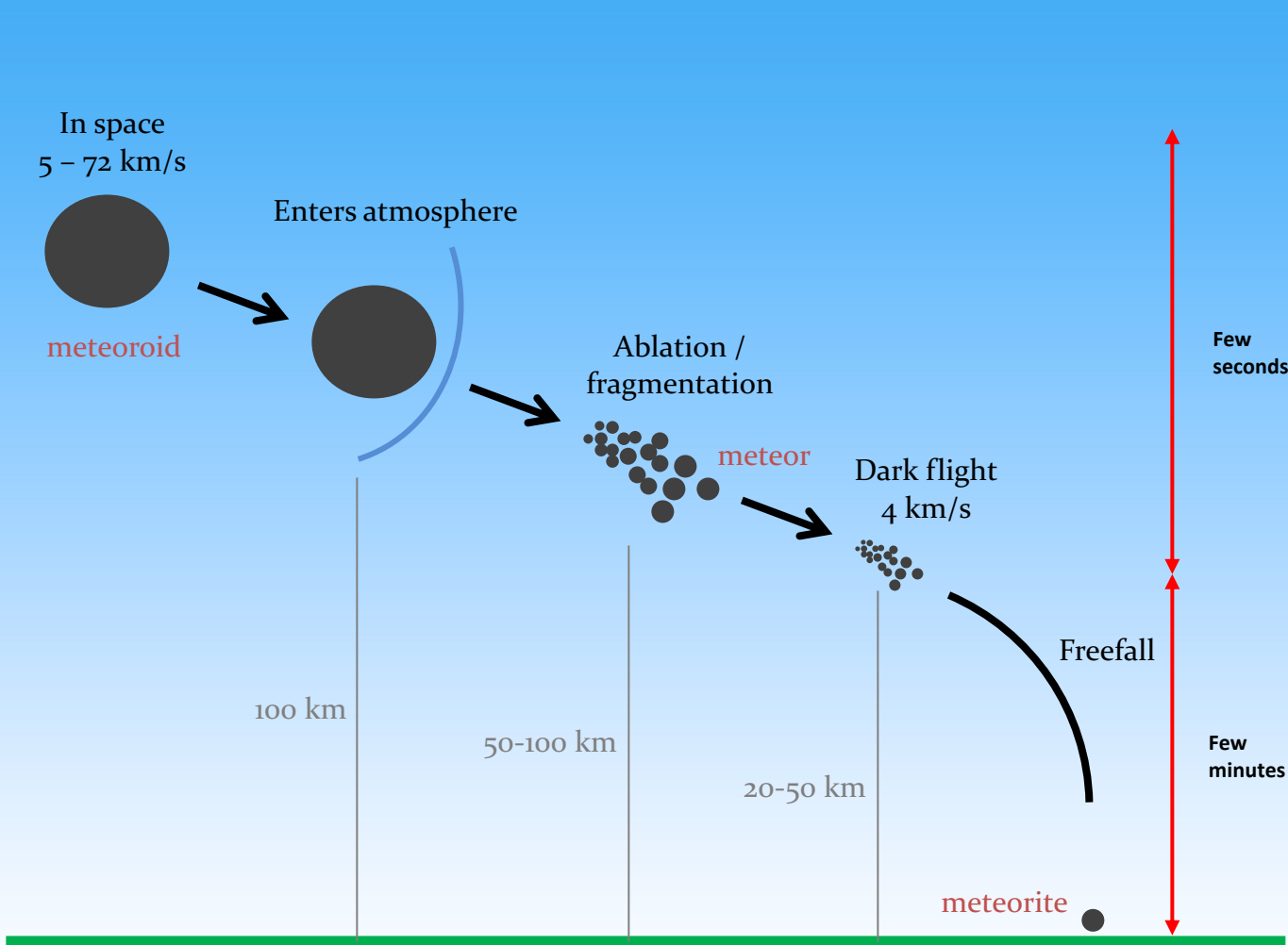
Jones & Brown (1999)

The NASA all sky fireball network



The NASA all sky fireball network consists of 17 cameras that detect and track bright meteors (fireballs) entering Earth's atmosphere. The stations within a camera group are spaced 50-80 miles apart, which allows overlaps in coverage with the other stations in that group. Meteors detected in more than one camera can be tracked using triangulation, and their trajectories/speeds can be used to determine their orbits before they hit the atmosphere. This data helps to establish the major sources of meteoroids and can be folded into environment design models and used to improve meteor shower forecasts. The colored circles give the approximate range of detection for a camera and illustrate the degree of overlap between the stations.





A few meteorite falls

Peekskill, NY – 1992

Witnessed by thousands

16 video recordings during HS football games

Damage: 12.4 kg meteorite struck a Chevy Malibu

Total meteorite mass: 12.5 kg

Type: Ordinary chondrite, H6

Initial size: 50-100 cm, 2-15 metric tons

Speed: 15 km/s

Peak Magnitude: -13



Park Forest, IL – 2003

Hundreds of eyewitnesses

A handful of video recordings

Damage: 2 houses & fire station struck by meteorites

Total meteorite mass: >18 kg

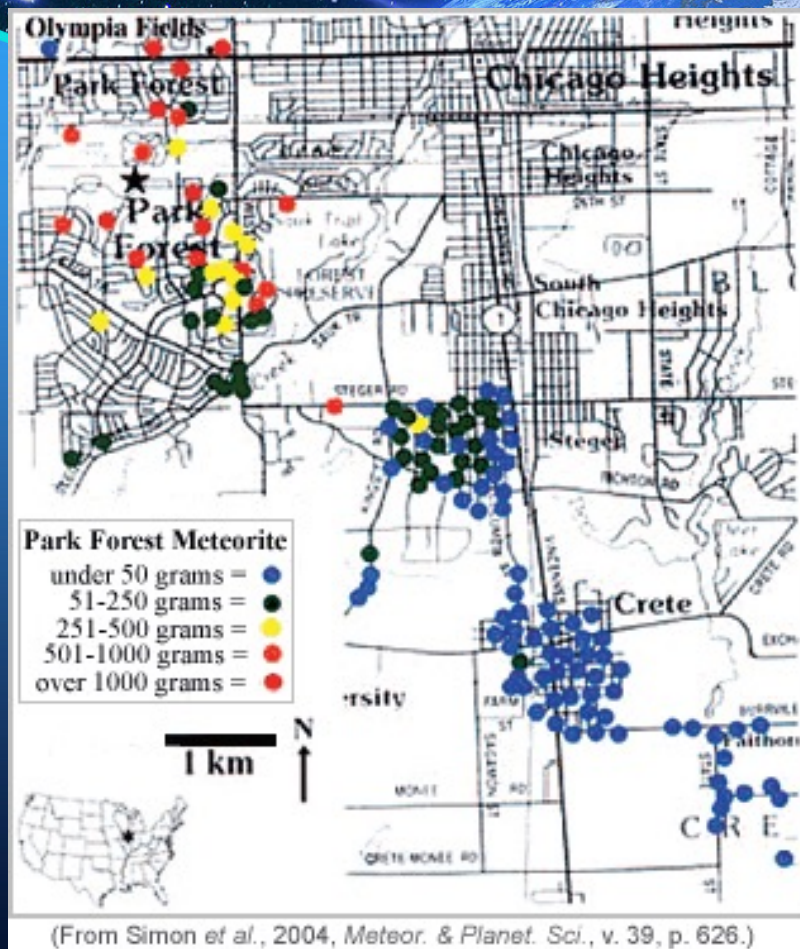
Type: Ordinary chondrite, L5

Initial size: 1.8 m (11,000 kg)

Speed: 19 km/s

Peak Magnitude: -22

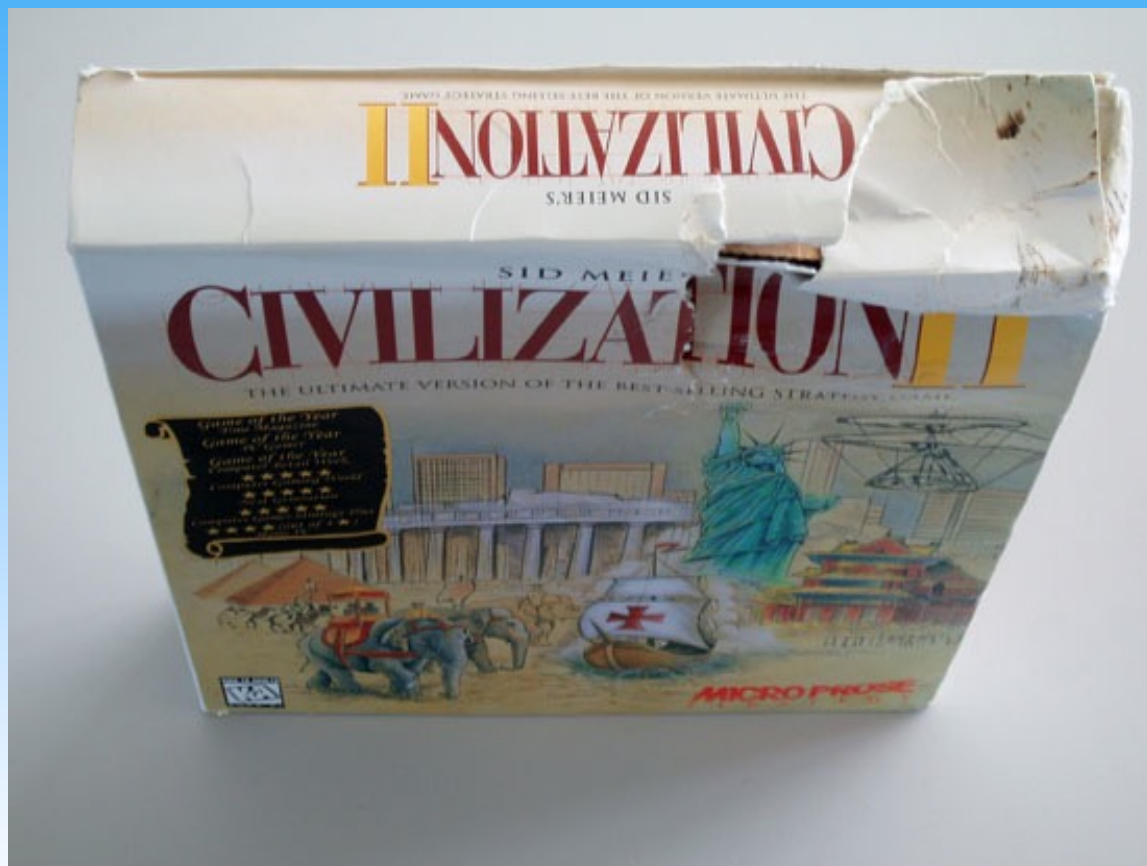






638g individual of Park Forest found by Rich and Larry Atkins





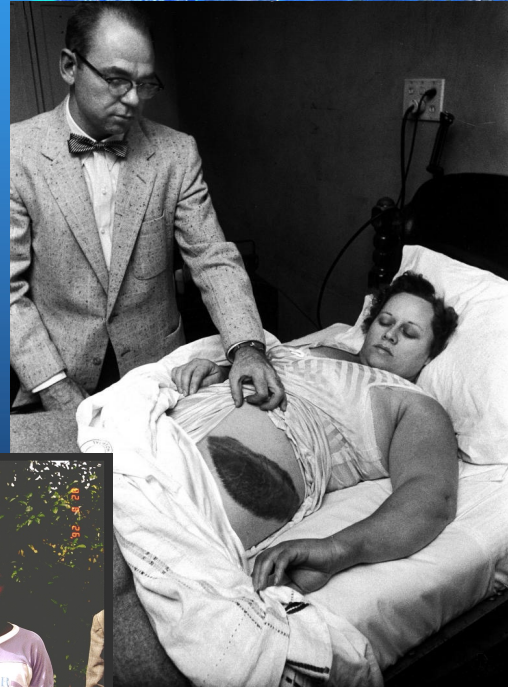
Claxton, GA 1984



Mailbox hit by 1.5 kg meteorite

Meteorites hitting humans

- Tortona, Italy manuscript dated to 1677 states that a Milanese friar was killed by a stone “projected from the clouds.”
- Sylacauga (Hodges) – On November 30, 1954, a 3.9 kg fragment crashed through the roof of a house, ricocheted off a big wood radio, and struck Ann Hodges , who was napping on a couch. Her side was badly bruised.
- On August 14 1992, a small boy in Mbale, Uganda was struck by a 3g meteorite fragment, which had been first slowed by banana tree leaes. No injury.



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 ($3 < Y < 5$)

Meteorites are not “flaming rocks of death”!

- By the time they reach ground, meteorites:
 - Have slowed to terminal speed (300 mph)
 - Have cooled to the point where you can pick them up



Orbital Debris



Types of orbital debris

- Dead satellites
- Rocket bodies – used upper stages (hopefully empty)
- Mission-related debris – payload/instrument covers, shrouds, gloves, tools, etc.
- Fragmentation debris – remnants of explosions

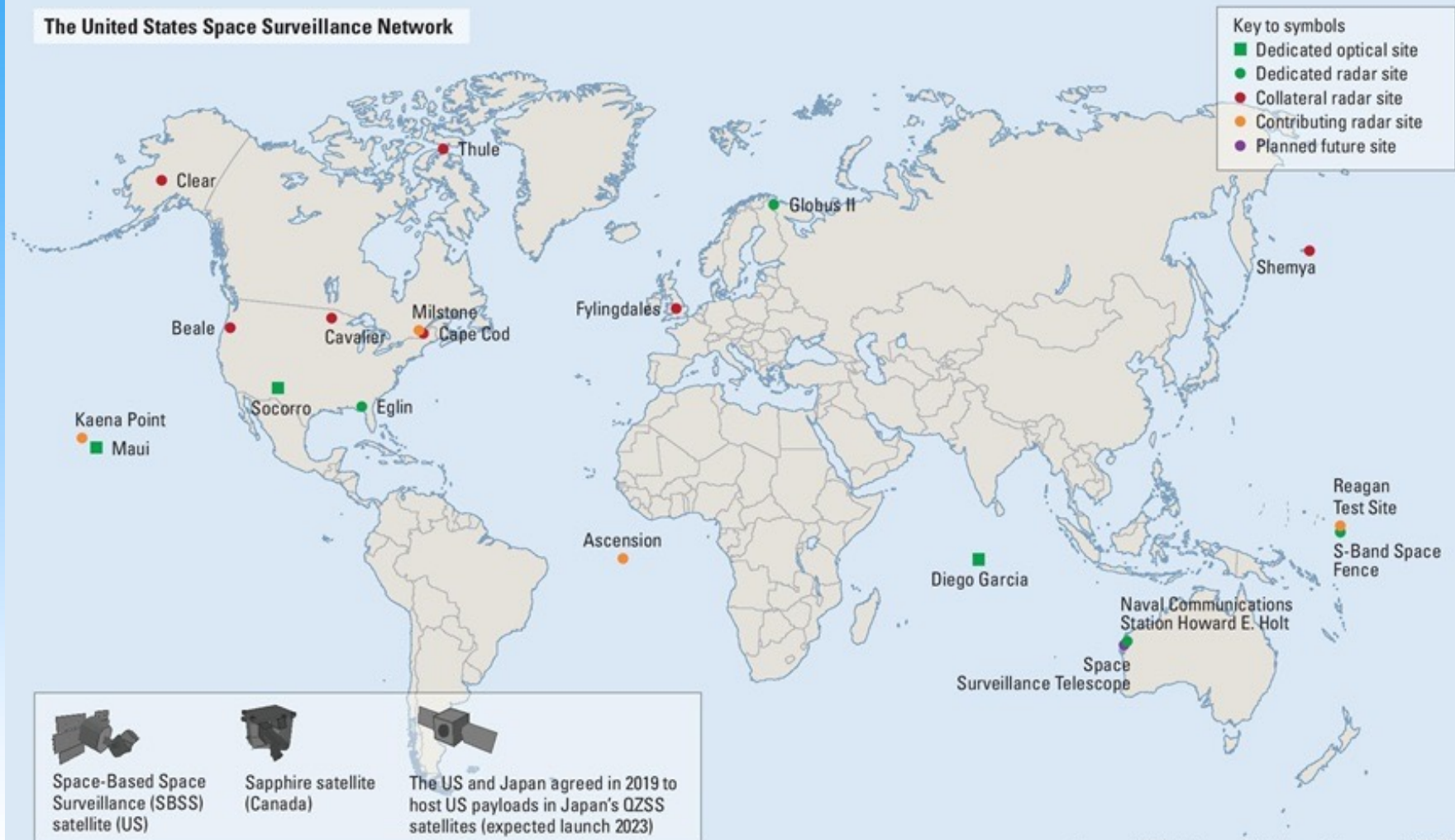


Keeping track...

- The Space Surveillance Network (SSN) is a global suite of radar and optical sensors (plus SBSS), operated by DoD (US Space Force).
- Designed for tracking incoming missiles.
- Effective size limit for tracking is 10 cm; some sensors can track down to 5 cm.
- Data is sent to JSPOC command/analysis center.



The United States Space Surveillance Network



Sensors of the SSN

Ground-based ElectroOptical
Deep Space Surveillance
(GEODSS)

US Army ALTAIR Radar

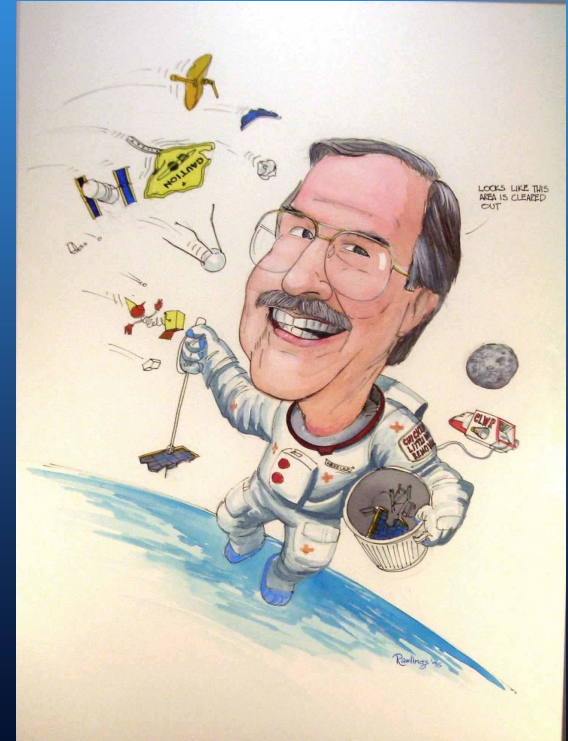


Haystack (r) and Haystack
Auxiliary (l) Radars



The Kessler Syndrome

- If the number of objects occupying a given altitude gets too big, a collisional cascade can occur.
- It's sort of like a runaway nuclear reaction – a collision creates debris, which in turn plows into other objects, producing yet more debris, which strike other things. Eventually (over many decades) everything gets pulverized at that altitude, rendering it unusable.
- Altitudes near 800 km (500 miles) have exceeded this limit.



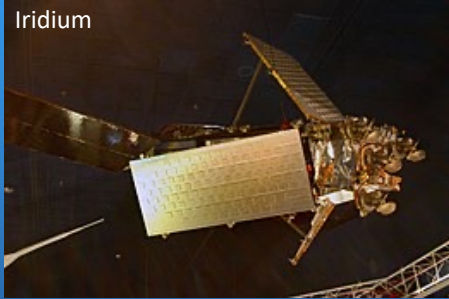
Collision avoidance

- JSPOC (and, more recently, LEOLABS) provides warnings of close approaches with trackable debris (>10 cm) to spacecraft operators
- Operators decide if collision risk warrants changing satellite orbit
- ISS **MUST** move if collision risk is > 0.0001 (1/10,000)

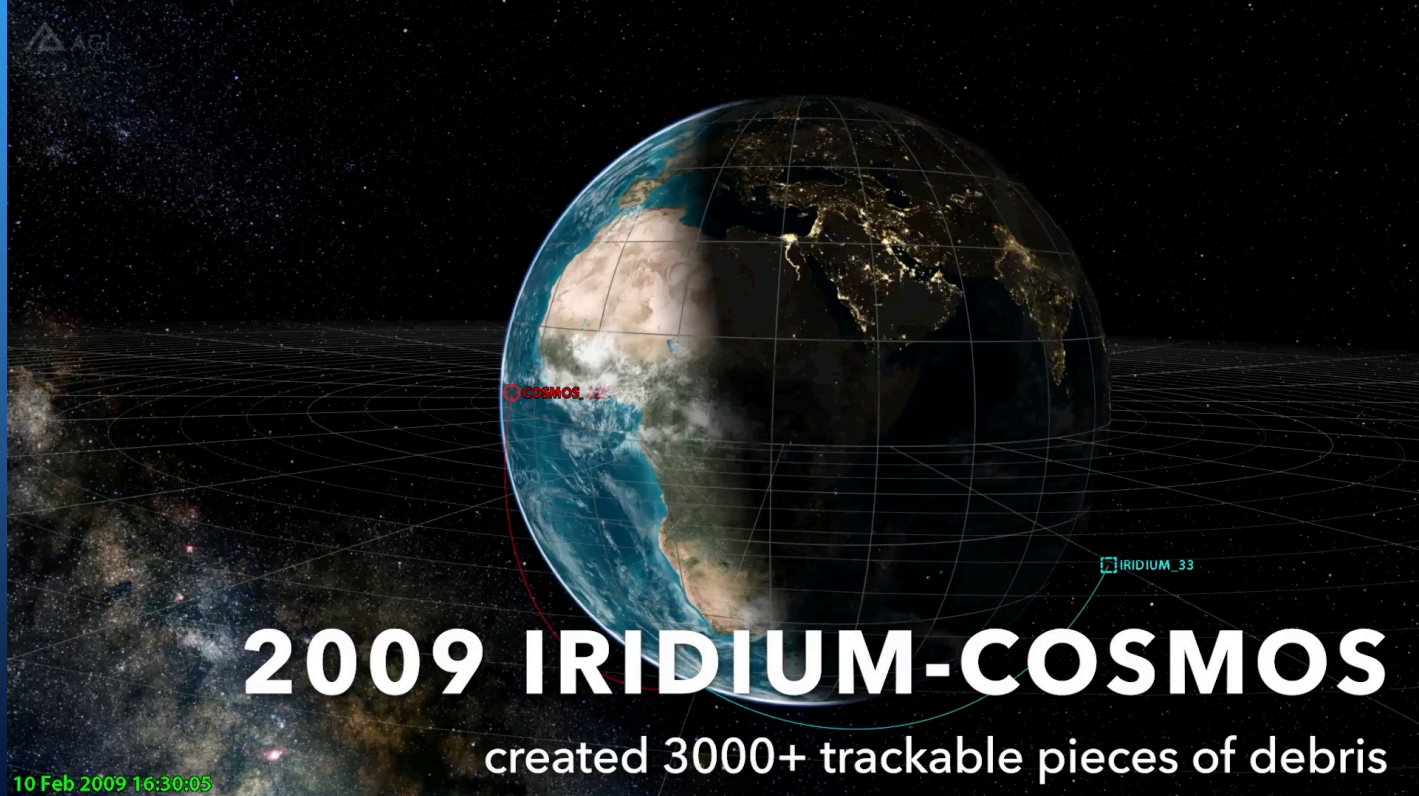


What can happen if you can't/don't move

Iridium



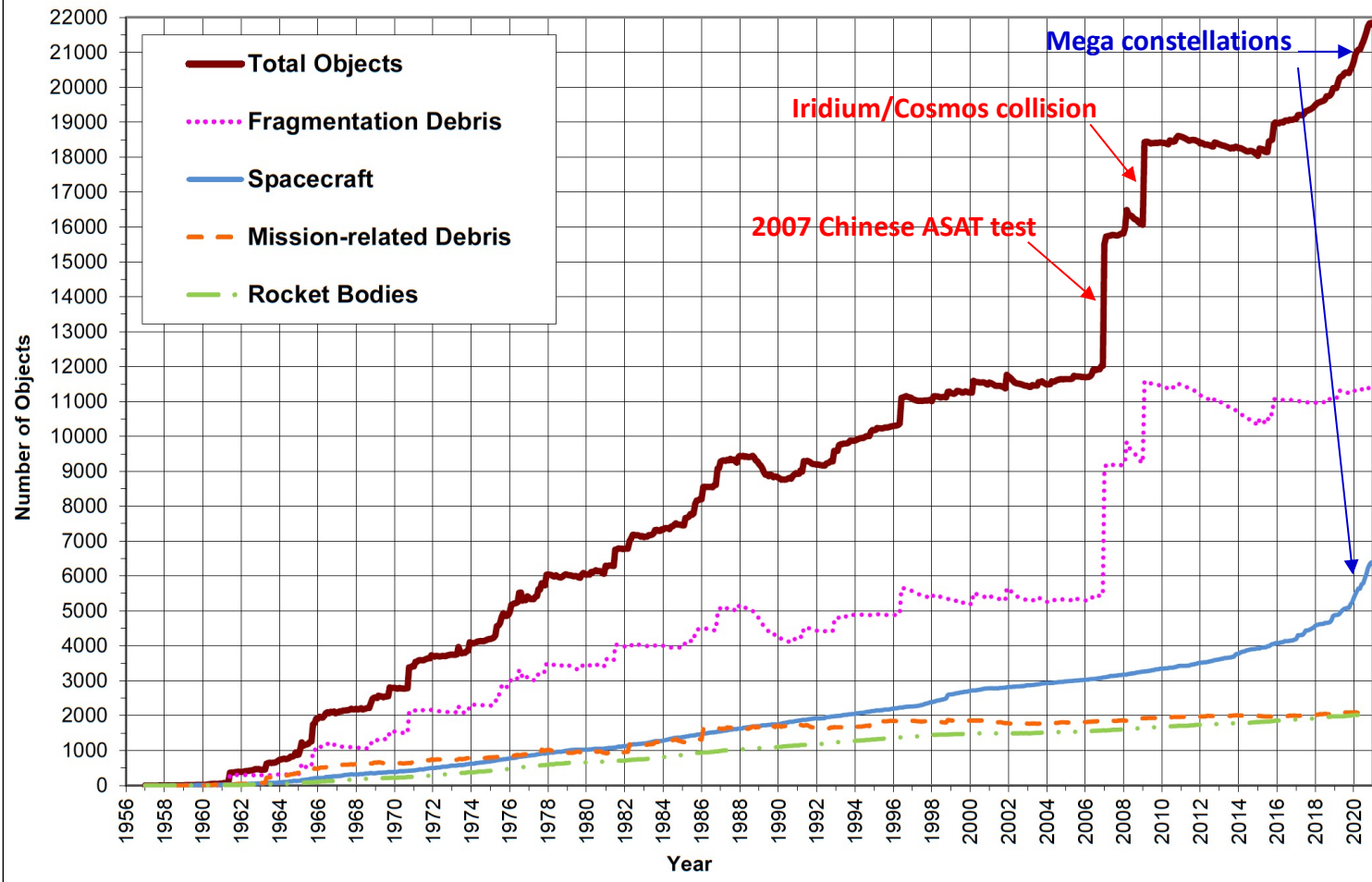
Cosmos 2251



2007 Chinese ASAT Test

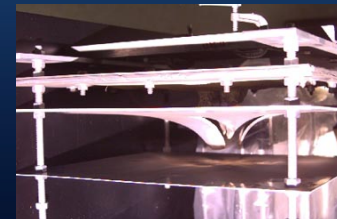
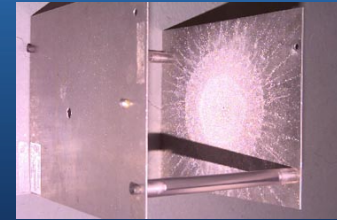
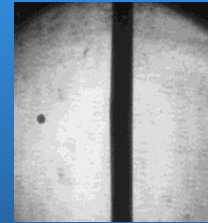
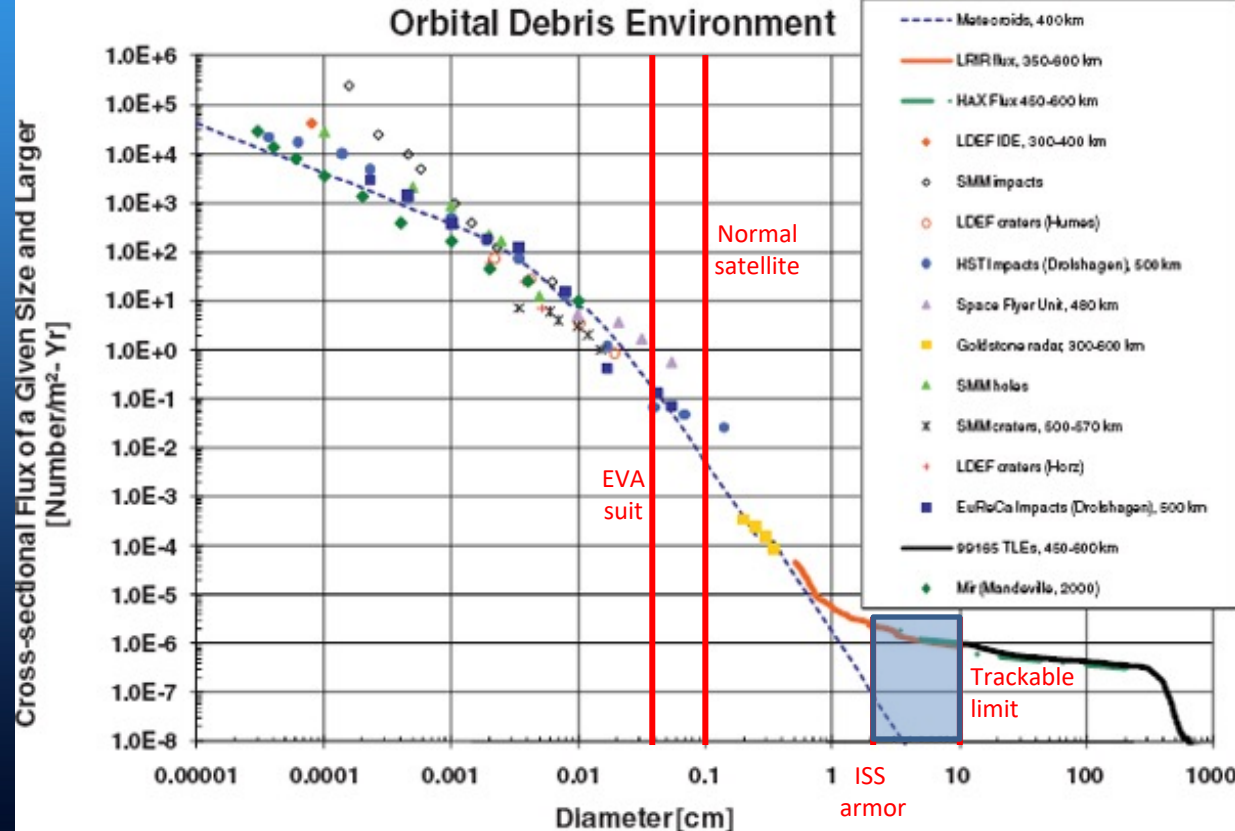


Monthly Number of Objects in Earth Orbit by Object Type



Monthly Number of Cataloged Objects in Earth Orbit by Object Type as of 5 January 2021. This chart displays a summary of all objects in Earth orbit officially cataloged by the U.S. Space Surveillance Network. "Fragmentation debris" includes satellite breakup debris and anomalous event debris, while "mission-related debris" includes all objects dispensed, separated, or released as part of the planned mission.

Untracked debris – the big risk



Astronaut's biggest worry on EVA

- Too small to track – no warning
- You won't see it coming – too fast (unlike in movie "Gravity")



Cosmos 954

- Soviet spy satellite (RORSAT) launched mid-September of 1977
- Reentered January 24, 1978
- Scattered radioactive debris over northern Canada
- Canadian government successfully invoked the Space Liability Treaty, billing the USSR \$6 million for clean up
- USSR paid half

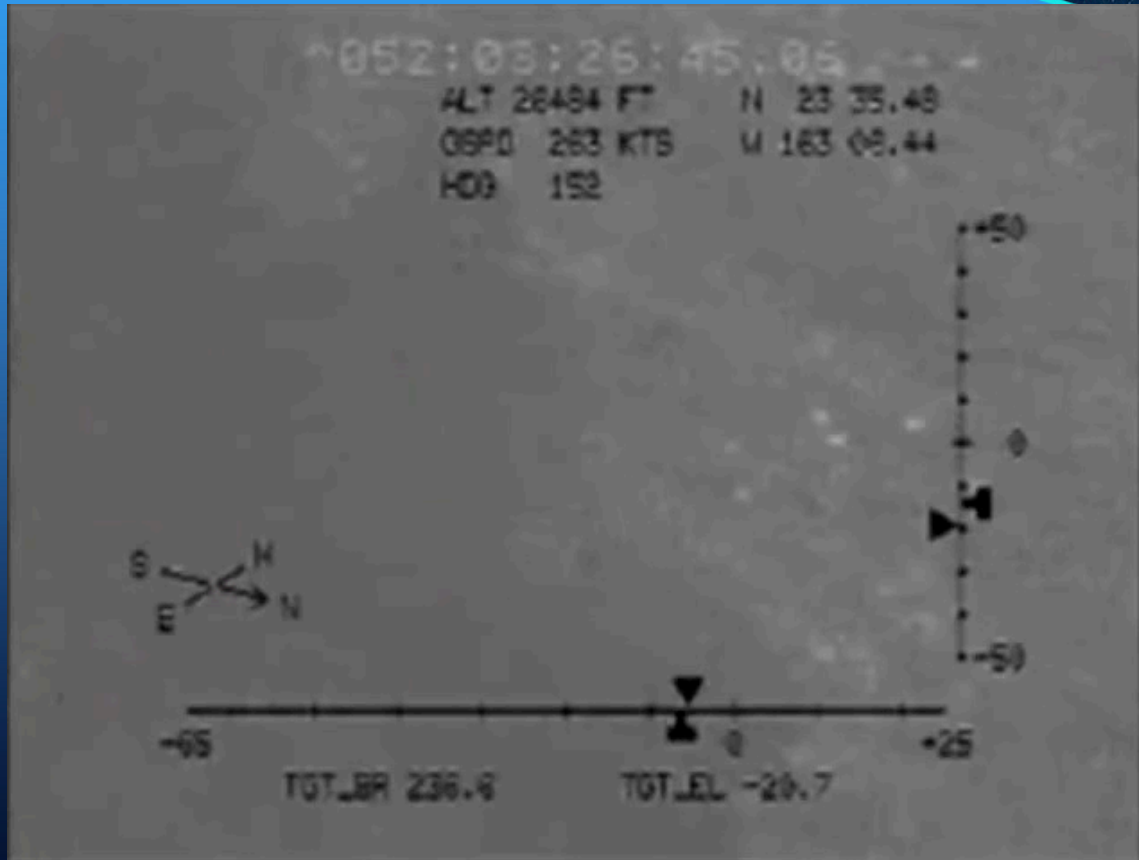


USA193 (NRO L-21)

- 5000 lb spy satellite
- Malfunctioned within hours of launch
- 1000 lbs of hydrazine in a spherical titanium tank ~1 meter in diameter
- Tank would survive re-entry, which was predicted for February of 2007
- Heavily populated areas in ground track

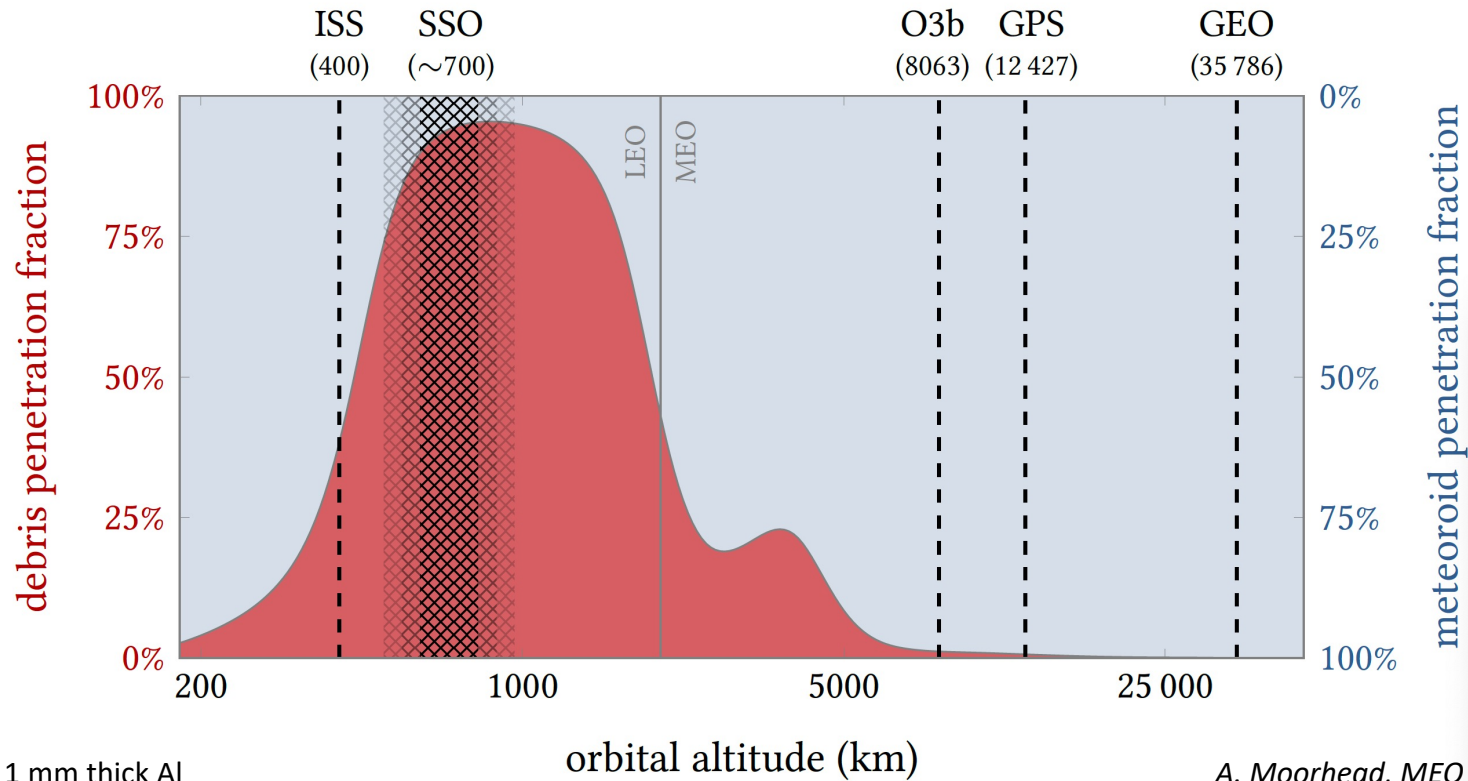


“Burnt Frost” – 2008 February 20, 10:56 PM EST



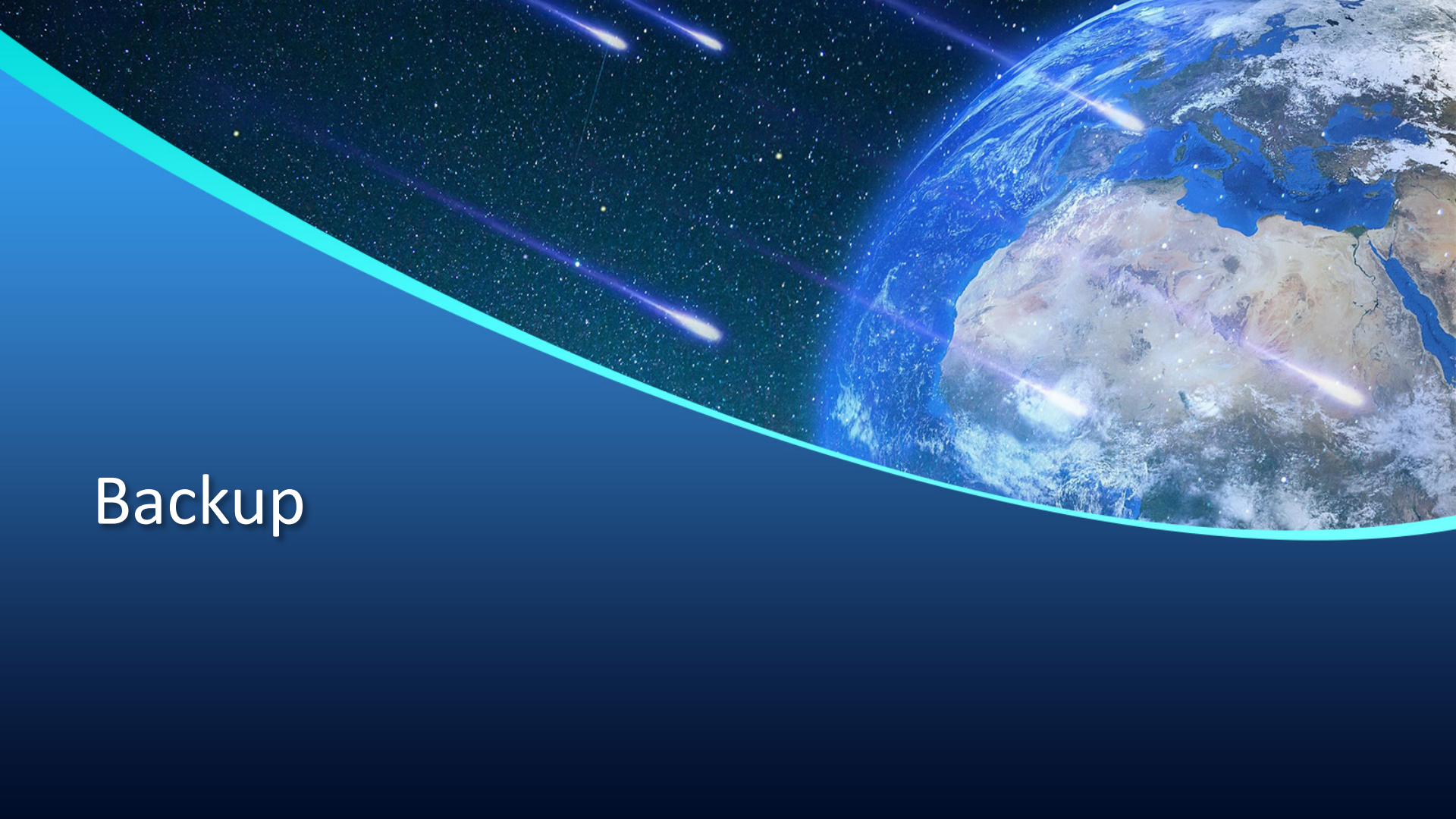
- Modified Navy SM-3 missile
- Launched from USS Lake Erie, north of Hawaii
- Intercepted target 4 minutes after launch
- “kinetic kill” – no explosive warhead

Meteoroid/Orbital Debris comparison



A. Moorhead, MEO

GEO: geosynchronous orbit
GPS: Global Positioning System
ISS: International Space Station
LEO: low Earth orbit
MEO: medium Earth orbit
O3b: O3b MEO constellation
SSO: sun-synchronous orbit



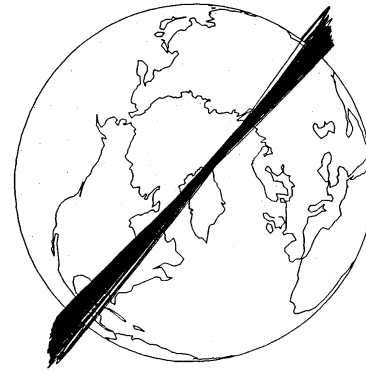
Backup

“Impact” upon spacecraft operations

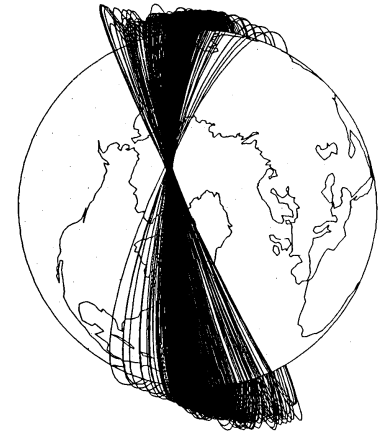
Spacecraft	When	Cause	Consequences
Mariner IV	1967 September 15	Unknown meteor stream between Earth and Mars	Large number (thousands) of small impacts ripped away MLI and torqued spacecraft about roll axis
STS-51/Discovery	1993 August	Perseid meteor outburst	Launch delayed due to inability to forecast shower intensity
Olympus (ESA commsat)	1993 August 11	Perseid hit on array/ESD	Satellite tumbled out of control; fuel exhausted in attempt to recover. Moved into disposal orbit 200
XMM-Newton (ESA X-Ray)	2001 September 17	Sporadic hit	27 pixels destroyed; more damage induced by impacts in October 2000, August 2002, and March 2005
Chandra	2003 November 15	Sporadic hit	Sudden spacecraft attitude change
Landsat 5	2009 August 13	Perseid meteor outburst	Temporary loss of control due to ESD disturbance of gyro
Artemis P1	2010 October 14	Sporadic hit	Part of boom and sphere 2 cut away; change in spacecraft CG.
GOES-13	2013 May 22	Sporadic hit	Attitude change caused spacecraft to enter safe mode, which was exited 7 days later.
MMS	2016 February 2	Sporadic hit	Impact destroyed one of four solar array shunt resistors

Spreading out...

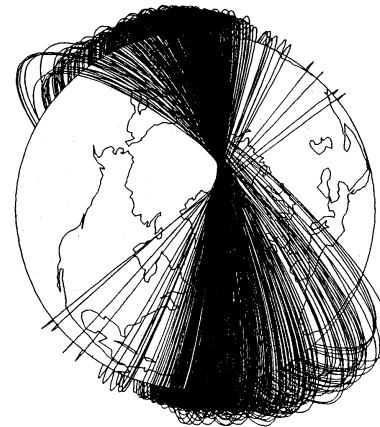
Over time, the slightly different orbits of the fragments, combined with gravity perturbations (the Earth is not a perfect sphere) spread the debris into a shell about the Earth



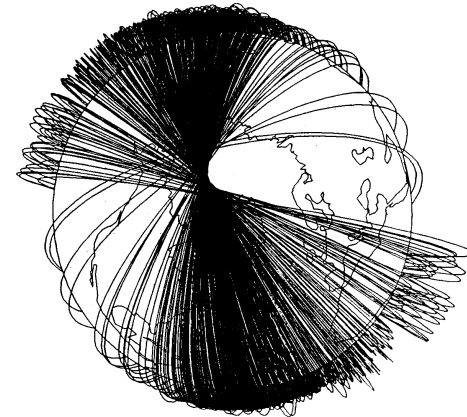
EVENT PLUS 3 WEEKS



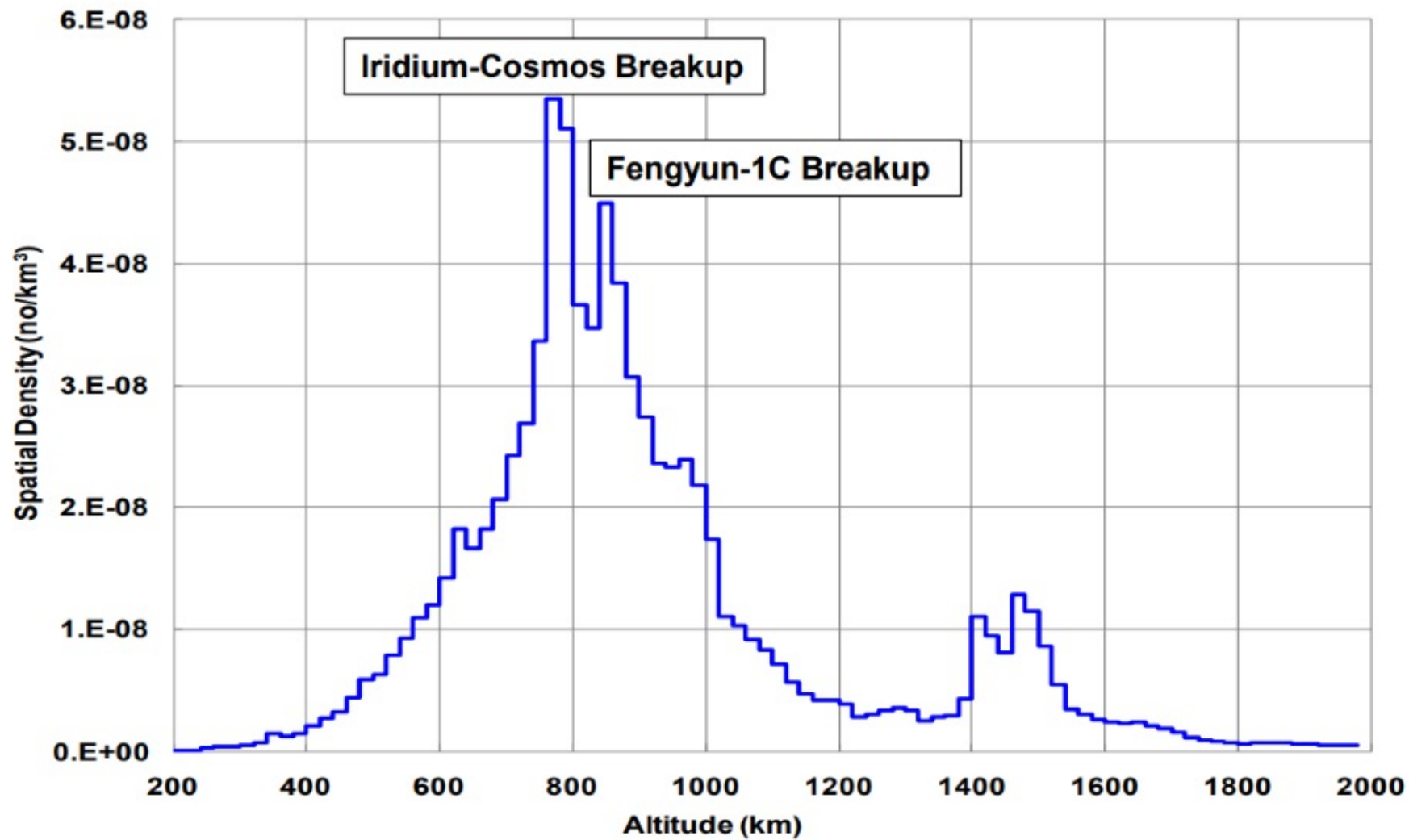
EVENT PLUS 3 MONTHS



EVENT PLUS 6 MONTHS



EVENT PLUS 9 MONTHS



Mitigating the risk

- In response to a 1995 Interagency report, the USG developed orbital debris mitigation standard practices based upon NASA Safety Standard 1740.14 (NASA NPR 8715.6B)
- Standard Practices cover four major areas:
 - Control of debris released during normal operations
 - Minimization of debris generated by accidental explosions
 - Selection of safe flight profile and operational configuration
 - Post mission disposal of space structures
- Standard Practices are used to help develop international guidelines.



Mitigation Commandments



- Thou shalt passivate thy upper stages (get rid of stored energy – vent fuel, safe batteries, etc.).
- If in LEO, thou shalt remove thy satellite's carcass within 25 years from thy mission end.
- If in GEO, thou shalt park thy dead satellite no closer than 200 km to the GEO belt.
- Being merciful, thy satellite and its operational debris shalt have less than 1 in a million chance of colliding with any other active satellite.
- The flaming wreckage of thy satellite shalt not have a chance greater than 1 in 10,000 of bonking a ground-dweller on his head.



Current focus is on mitigation, not removal

Outer Space Treaty

- The Outer Space Treaty, formally the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies, is a treaty that forms the basis of international space law.
 - Went into effect in October, 1967
 - Full text at <https://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/introouterspacetreaty.html>



1972 Space Liability Treaty

- Countries bear international responsibility for all space objects that are launched within their territory, regardless of who launches the space object. If it was launched from a state's territory, or from a state facility, or if the state caused the launch to happen, then the state is fully liable for damages that result from that space object.
- Individuals injured by a space object wishing to seek compensation under the Liability Convention must have their country file a claim against the offending state.
- Full treaty here:
<https://treaties.un.org/doc/Publication/UNTS/Volume%20961/volume-961-I-13810-English.pdf>

