Orbital Debris: Time to Remove

Eugene Levin

Google TechTalk, August 11, 2011

A New Trashing Frontier

Debris in near-Earth orbits is

- Cataloged and tracked (everything over 10 cm)
- Visible to all (radars and telescopes)
- International (common swarm mixed dynamically)
- Cannot be abandoned (Outer Space Treaty, 1967)
- ‘‘Close to capacity’’ in many places

Outer Space Treaty (1967)

- No national territories
- No weapons of mass destruction
- Avoid harmful contamination
- States are responsible for acts of their subjects
- Launching States (launch / procurement / territory / facility) are liable for damage caused by space objects or their parts

Sea Launch

www.sea-launch.com

Hayabusa breakup, 2010

solarsystem.nasa.gov

Liability Convention (1972)

- Absolute liability for damage on the ground or in the airspace
  - Tracked objects (mostly debris) reenter daily
  - Large objects (spacecraft, rocket bodies) reenter weekly
  - Some parts survive and hit the ground

orbitaldebris.jsc.nasa.gov

March 2011

Colorado: Zenit 3 tank

Uruguay: Delta 2 casing

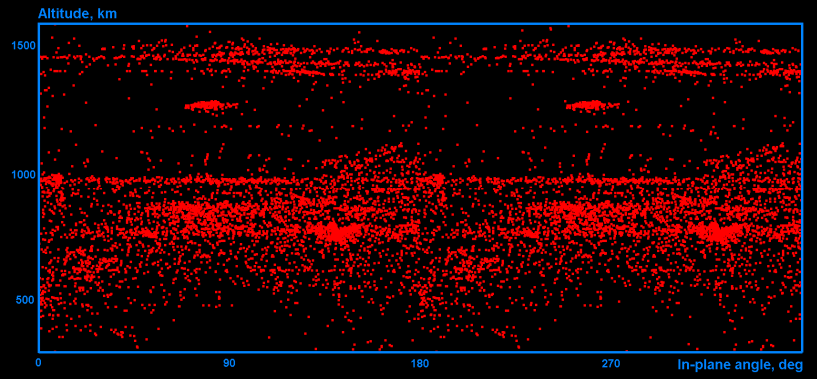
orbitaldebris.jsc.nasa.gov

- At-fault liability in space

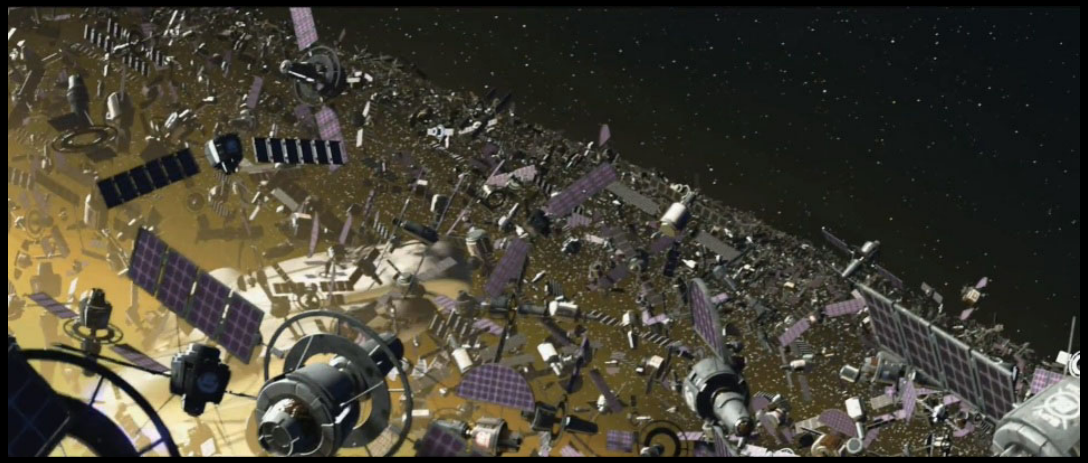
www.the3dstudio.com

What is “Capacity”

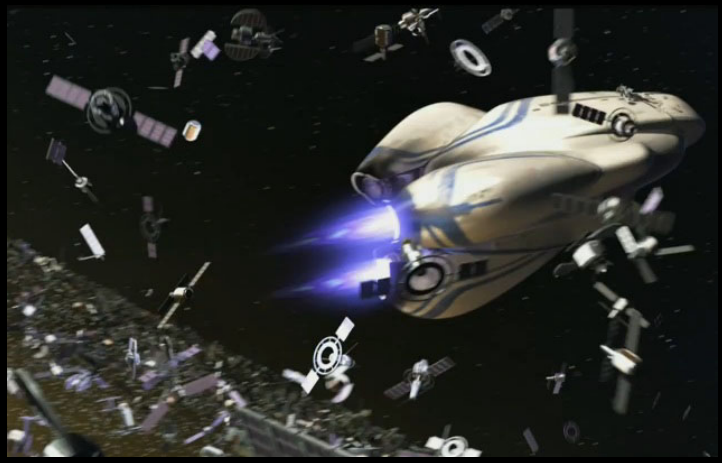
- Flux = Density x Velocity



Tracked objects crossing an orbital plane



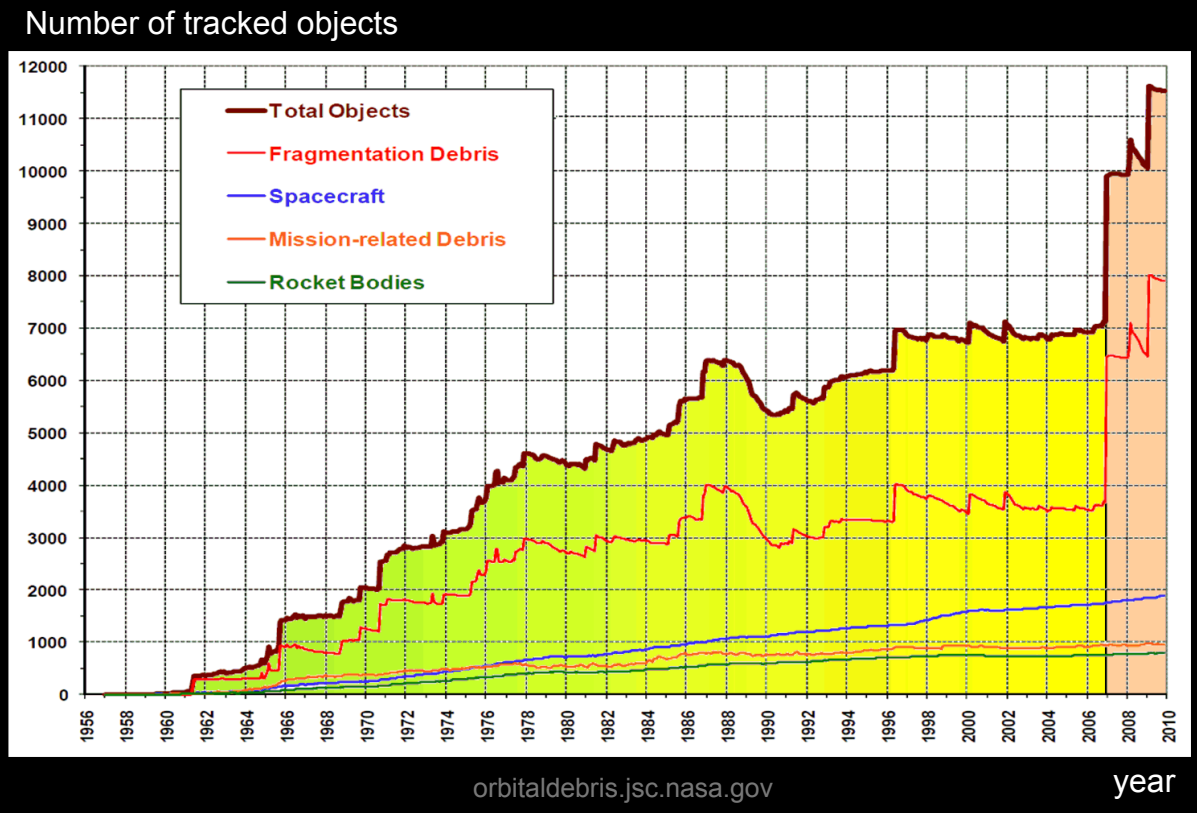
Pixar, WALL-E, 2008



www.youtube.com

Threat Level: “Orange”

- Low Earth Orbit (LEO): between 200 and 2000 km



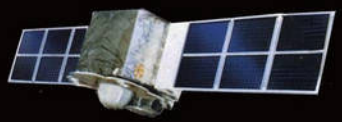
2007: ASAT Test

- Head-on hypervelocity collision (no explosives)

January 11, 2007

TNT: 5 MJ/kg
kinetic: 30 MJ/kg

Fengyun-1C at 860 km



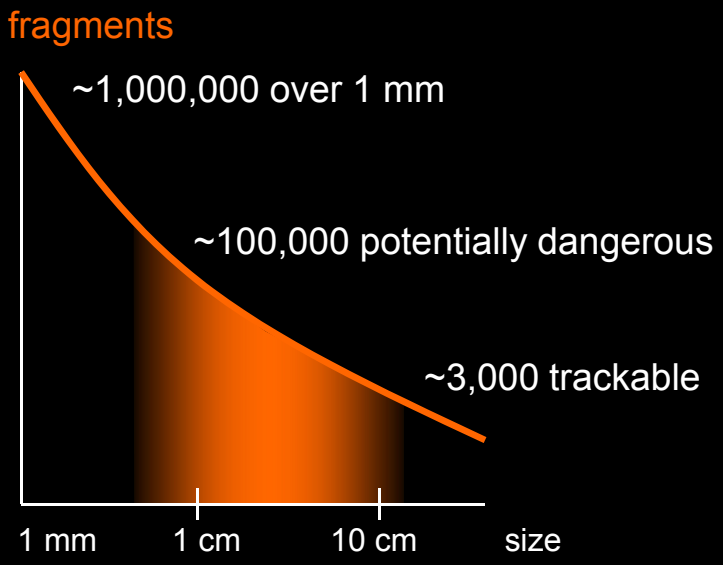
www.space.com

X

1.5 tons of "shrapnel"

missile

mt-milcom.blogspot.com



The Fallout

- 97% of tracked Fengyun-1C fragments are still in orbit
- 600 conjunctions per day with satellites (range < 5 km)

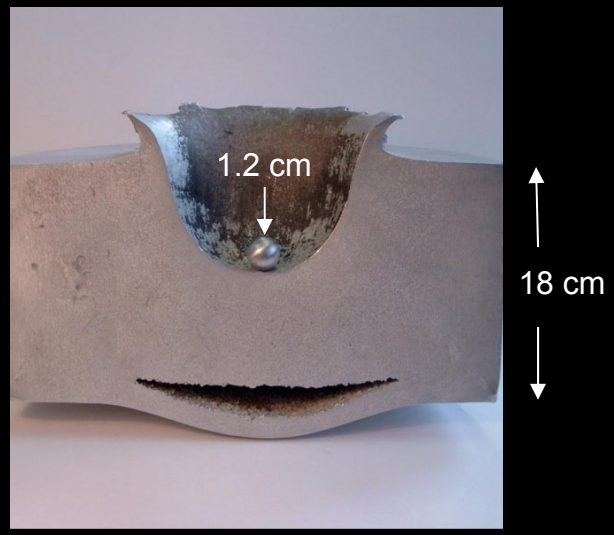
CSSI predictions for July 23, 2011:

Spacecraft	Min. range	Rel. velocity	Impact prob.
Meteor 1-21	78 m	13.9 km/s	0.8%
Cosmos 367	92 m	9.0 km/s	0.4%
Meteor 1-23	144 m	14.8 km/s	0.2%
OPS 1264	243 m	14.8 km/s	0.08%
Iridium 64	262 m	14.9 km/s	0.06%
OPS 7323	267 m	12.5 km/s	0.005%
NOAA 14	318 m	6.5 km/s	0.02%
GOSAT	370 m	12.7 km/s	0.003%
Cosmos 676	409 m	9.6 km/s	0.004%
IRS-P6	537 m	11.9 km/s	0.001%
Explorer 22	540 m	14.9 km/s	0.002%
Landsat 5	556 m	8.4 km/s	0.005%
…	…	…	…

“Shrapnel” Impacts

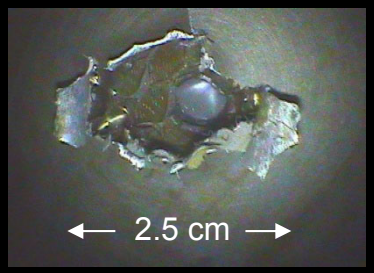
- 30-50 dangerous untracked fragments for each tracked one
- Typical size ~1 cm

ESA hypervelocity impact test



www.esa.int

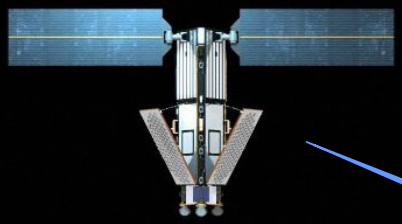
Shuttle radiator damage, 2007



ntrs.nasa.gov

2009: Cosmos-Iridium

February 10, 2009



Iridium 33 at 780 km

Cosmos 2251

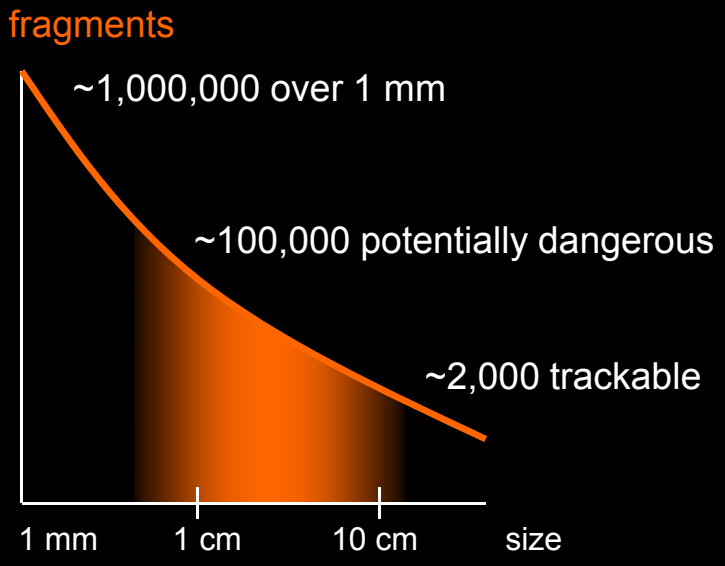
11.6 km/s

www.the3dstudio.com

X

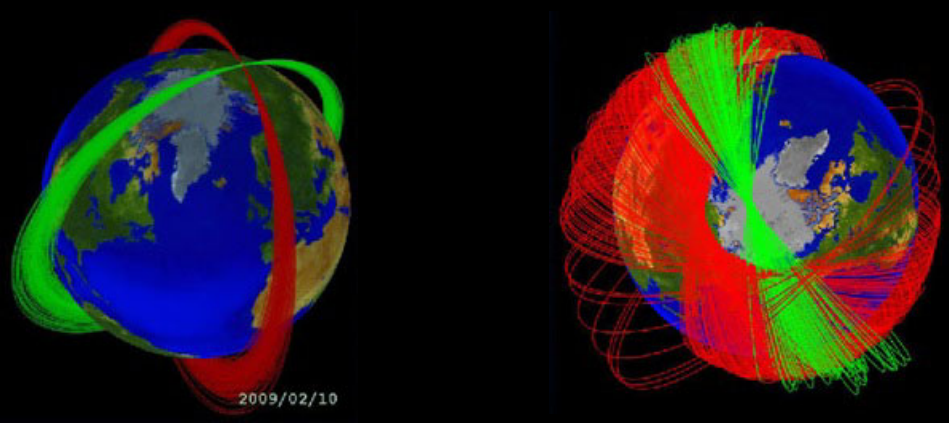
1.5 tons of "shrapnel"

- Cosmos was not operational
- Iridium could maneuver, but conjunction was low-ranked, not much different from other daily conjunctions
- The outcome was very similar to the 2007 ASAT test



The Fallout

- 93% of tracked Cosmos-Iridium fragments are still in orbit
- 30-50 dangerous untracked fragments for each tracked one
- The debris clouds have spread, engulfing the Earth



www.newscientist.com

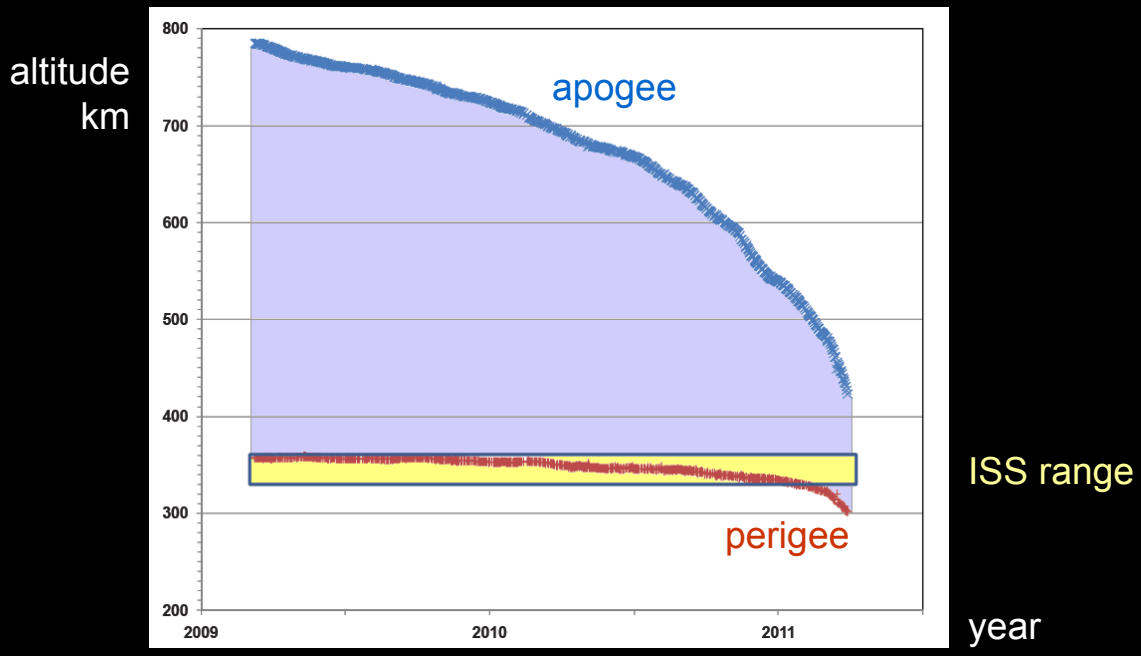
Dodging Debris

- Cosmos-Iridium fragments were the dominant cause of collision avoidance for NASA satellites in 2010
- More fuel consumed

Spacecraft	Date	Object Avoided
Terra	22 Jan 2010	Iridium 33 debris
Cloudsat	17 Aug 2010	Unidentified
Landsat 5	24 Aug 2010	Cosmos 2251 debris
Cloudsat	11 Oct 2010	Zenit rocket body debris
Cloudsat	13 Oct 2010	Cosmos 2251 debris
Aura	22 Nov 2010	Cosmos 2251 debris
Landsat 7	21 Dec 2010	USA 26 debris

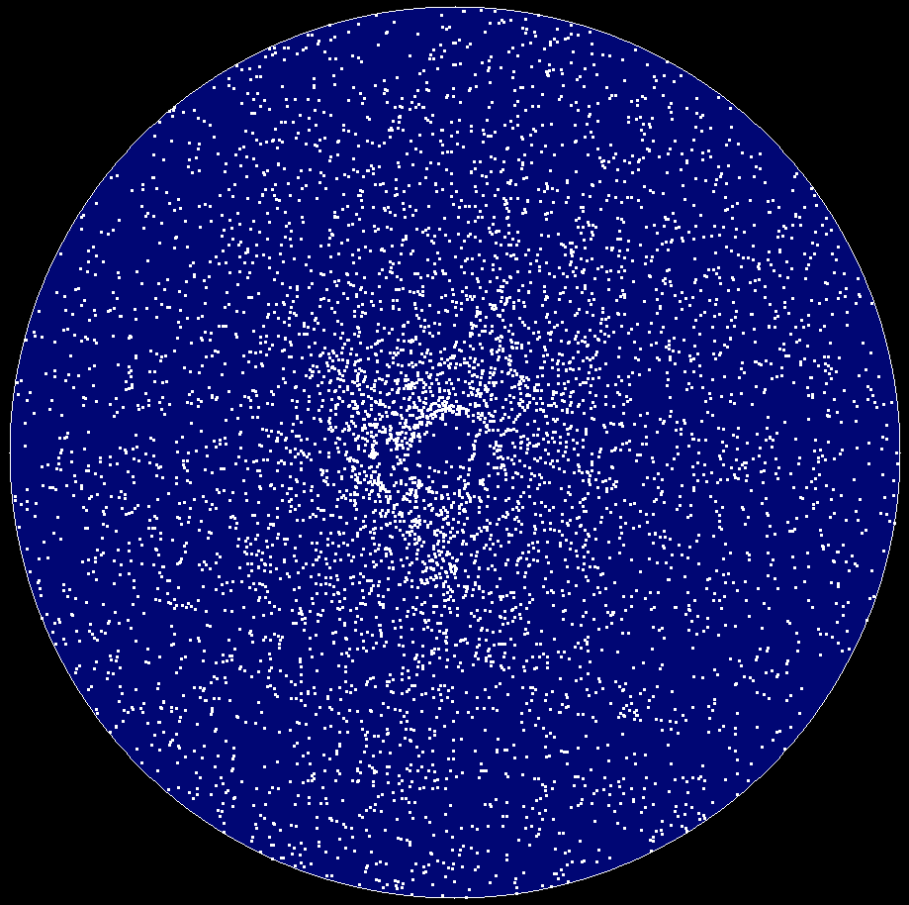
Debris Chasing ISS

- A 10-15 cm fragment of Cosmos 2251 was passing through the ISS altitude range every 1.5 hours for 2 years
- Collision risk over 0.01% predicted on April 2, 2011
- Avoidance maneuver used 70 kg of fuel



Unintended ASAT

- A slow-release random-target ASAT system is deployed in LEO
- Need to disarm this ‘‘weapon of mass conjunctions’’



The ‘‘warheads’’

Tracked debris in the Northern sky

Catastrophic Collisions

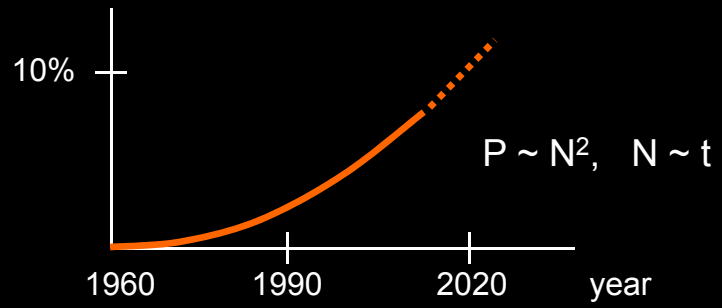
- Collisions between large objects will release more and more ‘‘shrapnel’’
- Even small objects can smash satellites and rocket bodies into pieces in hypervelocity impacts

Delta II second stage

wikipedia.org

3U CubeSat

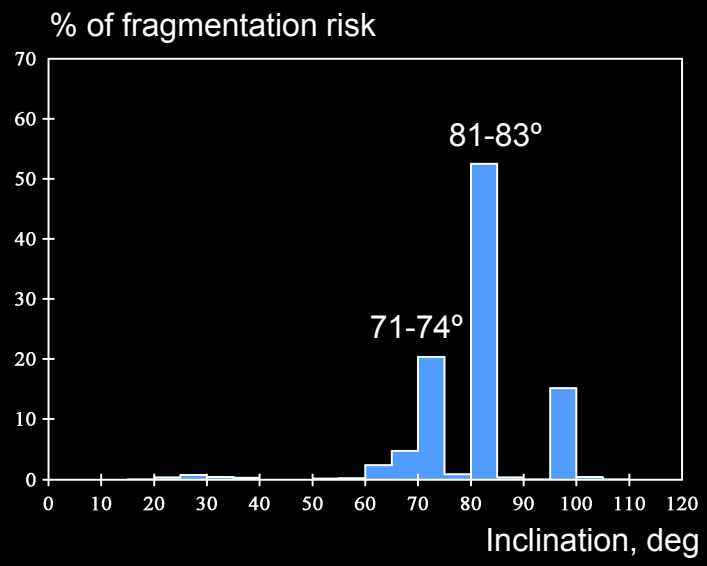
Probability of a catastrophic collision per year

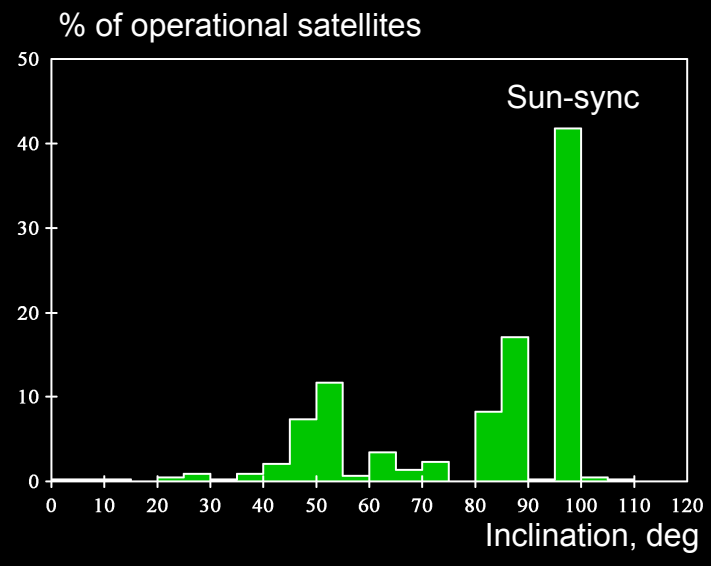


Clusters in LEO

Risk measured as statistical yield of fragments: $R = \sum M_n \cdot P_n$

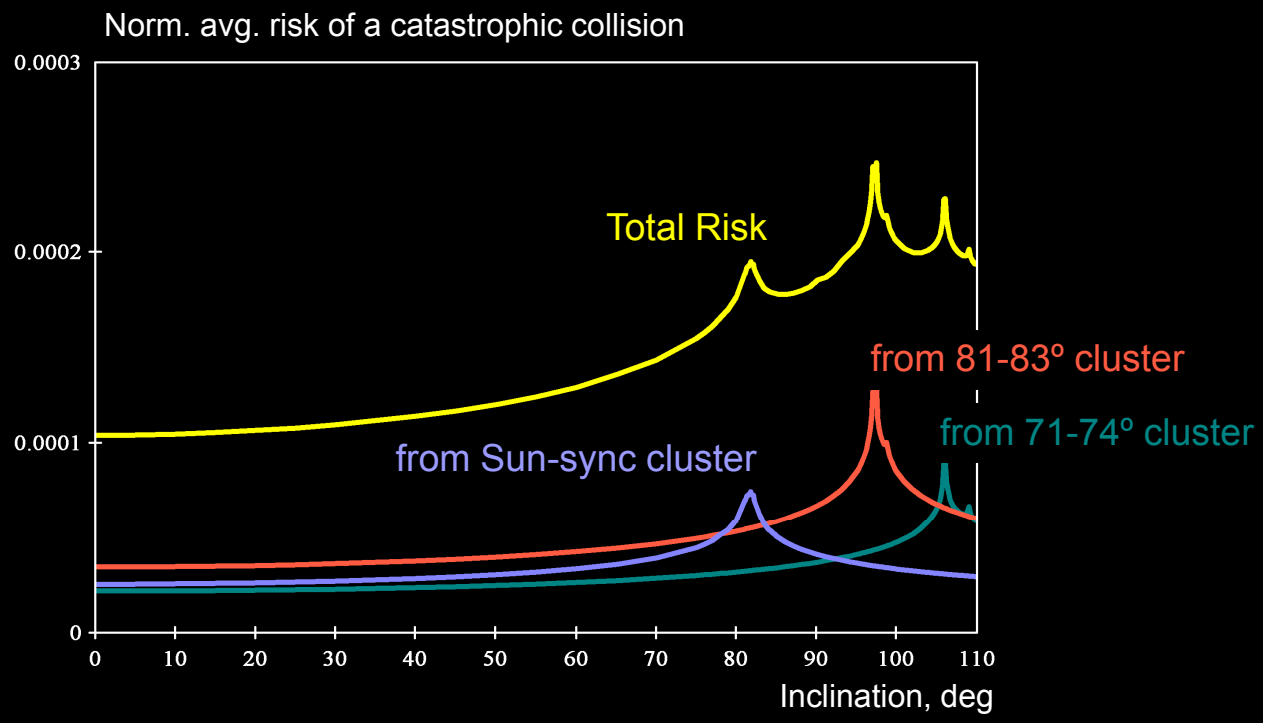
- Highest risk of debris generation: 81-83º cluster
- Highest number of satellites at risk: Sun-sync cluster





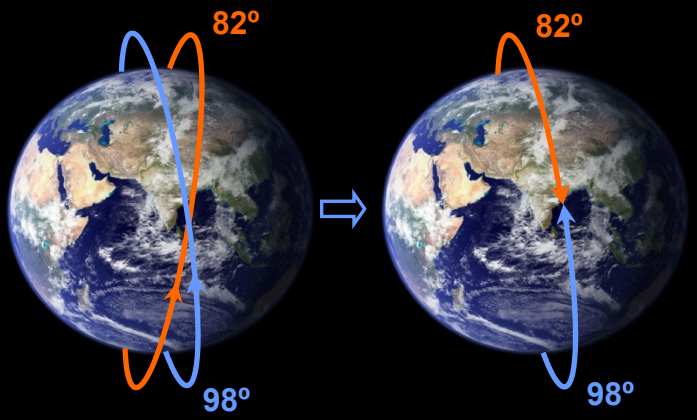
Collision Risks

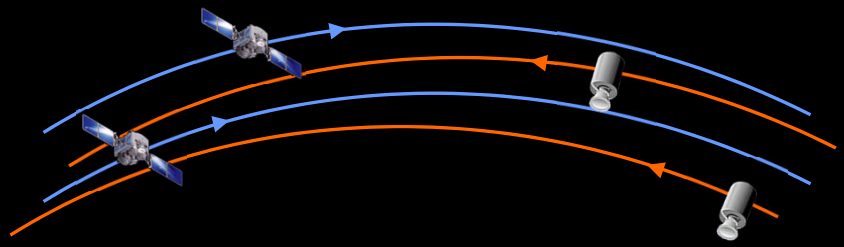
- Sun-sync and 81-83º clusters are threats to each other, increasing the risk of catastrophic collisions (Cosmos-Iridium type)



Head-on Traffic

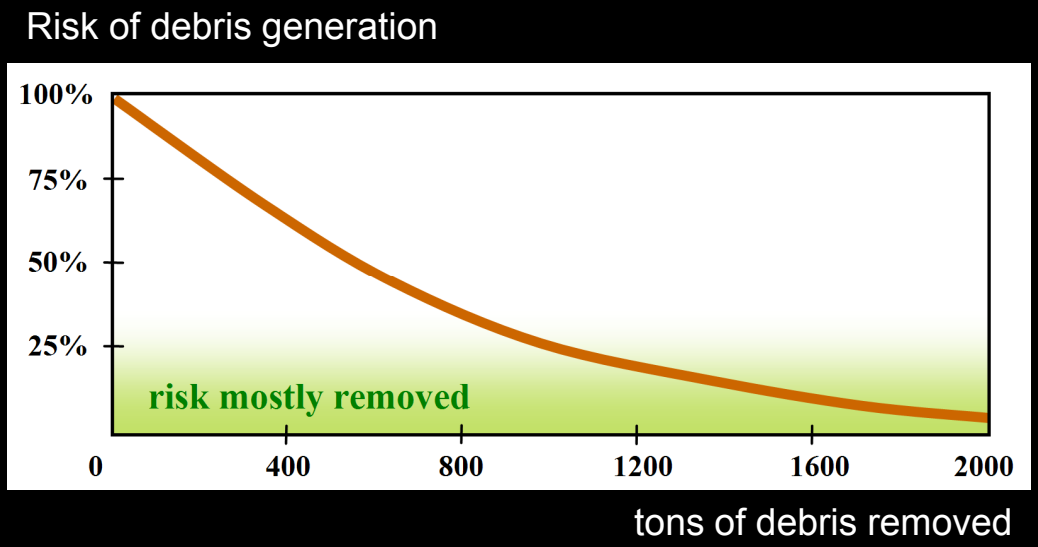
- The Sun-sync and 81-83º inclination orbits precess in the opposite directions, align periodically, and create head-on traffic





How Much to Remove

- Risk measured as statistical yield of fragments: $R = \sum M_n \cdot P_n$



- Small-scale removal won't make a difference
- Need wholesale removal

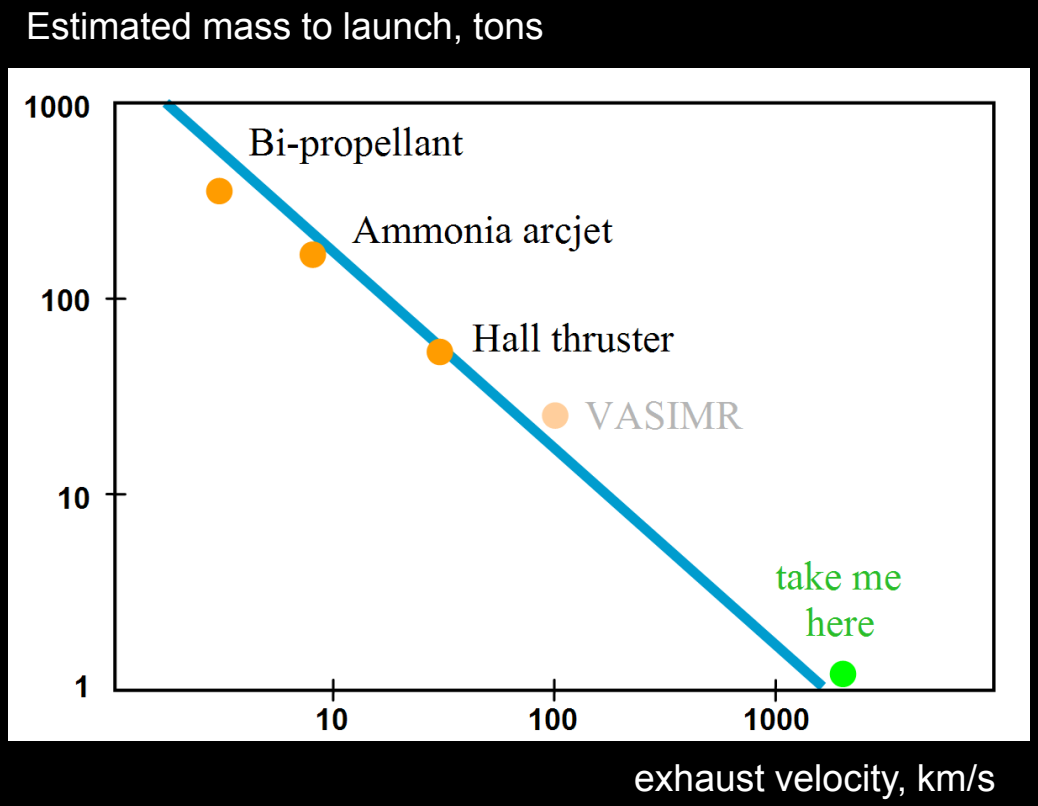
How to Remove

- 2200 dead satellites and spent stages scattered all over LEO, 2000 tons total
- Too demanding for rockets: $M = M_d \exp(\Delta V / V_e)$

vaughanling.blogspot.com

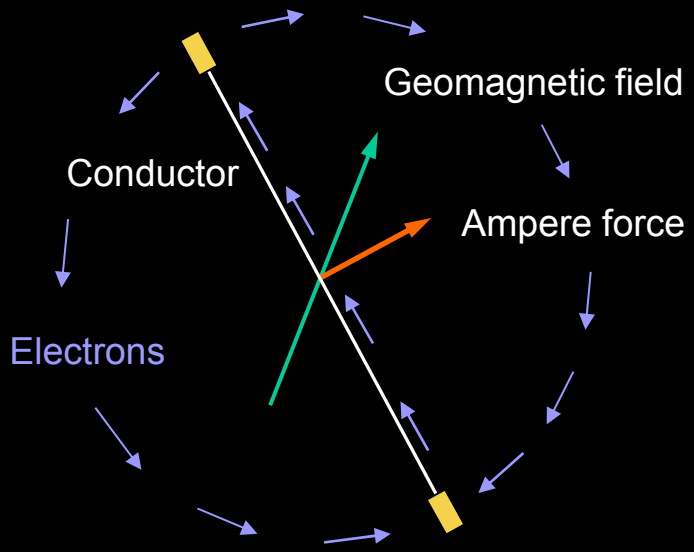
How Much to Launch

- Wholesale removal of all spent stages and dead satellites



Electrodynamic Propulsion

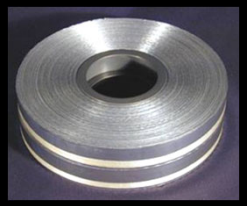
- Propellantless, electrical, solar powered



Electron emitter

Hollow cathode

Electron collector



Aluminum tape

- Circuit closing demonstrated in orbit by Plasma Motor Generator (PMG) in 1993 and Tethered Satellite System (TSS-1R) in 1996

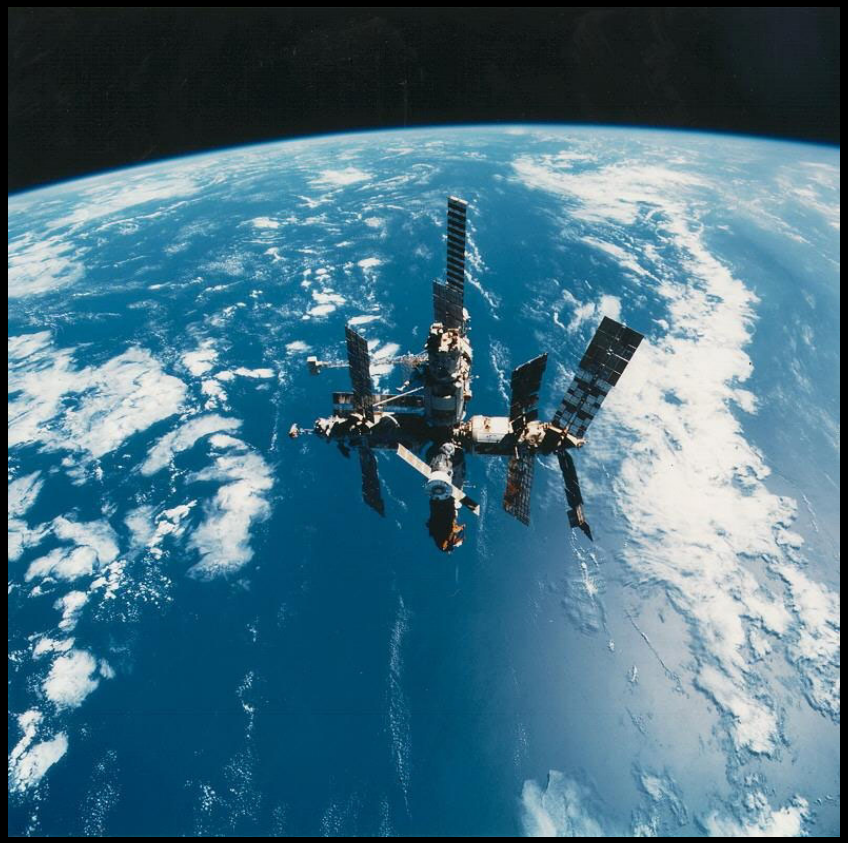
How to Think About It

- Like sailing in the ionosphere

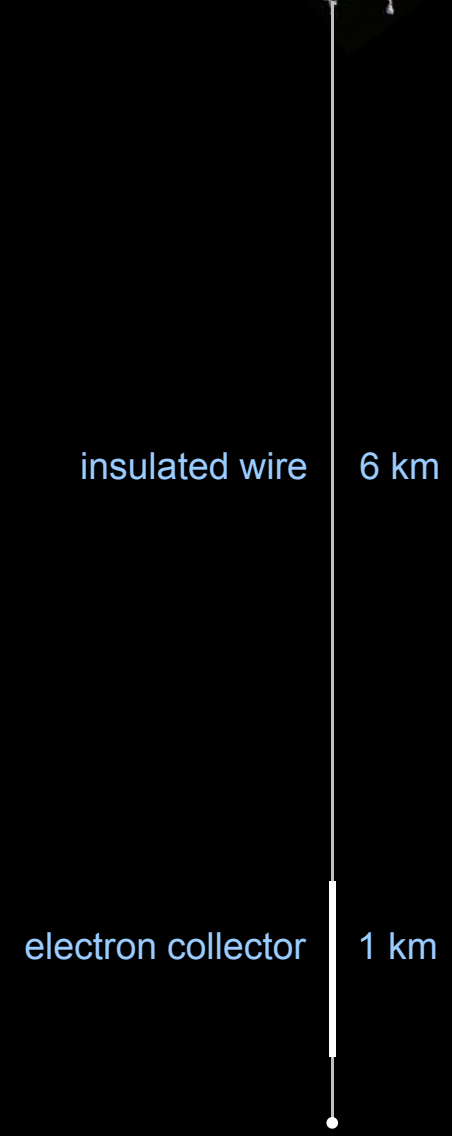
Key West, 2006

Mir Reboost

- Mir Electrodynamic Tether System (METS) was built in 2000 to keep Mir in orbit



blogspot.com



Mir Reentry

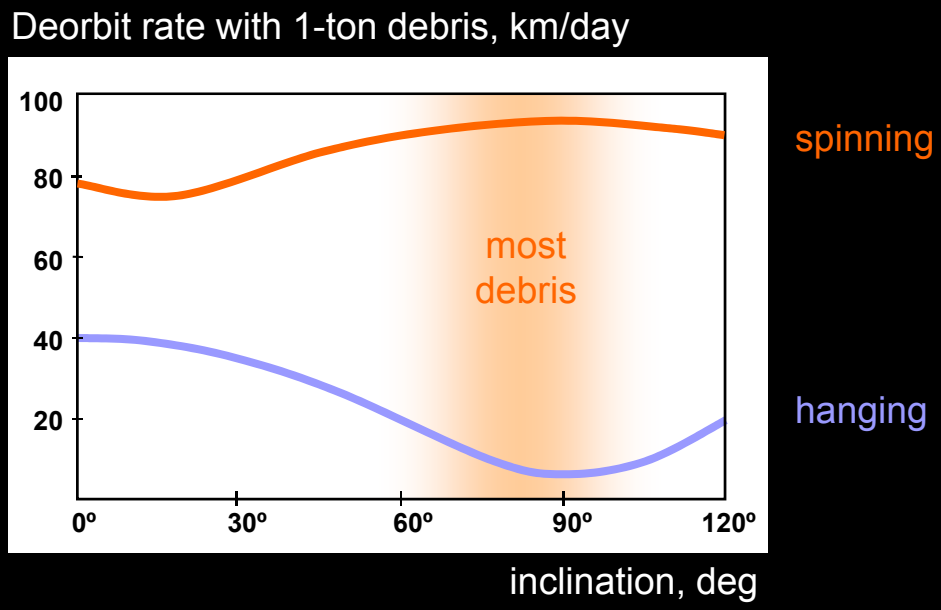
- The largest man-made object to reenter, 136 tons of debris

March 23, 2001

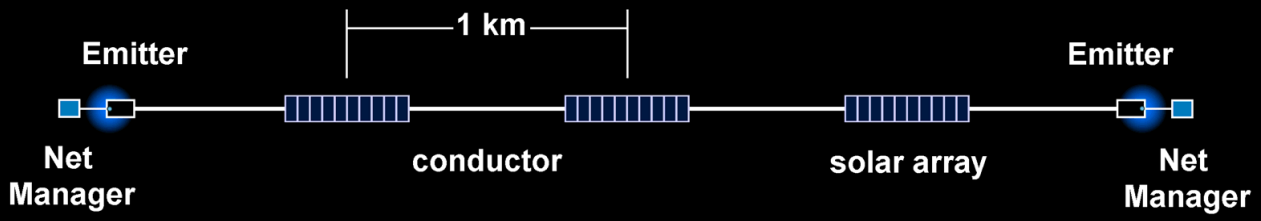
wikipedia.org

Going for a Spin

- Spinning greatly improves stability and provides much better angles with the geomagnetic field
- ~15 min rotation period



Electrodynamic "Garbage Truck"



- ElectroDynamic Debris Eliminator (EDDE)
- Only 100 kg, two fit into one ESPA secondary payload slot
- Nano-satellites "taped" together, but can move tons

Reinforced aluminum tape

www.tetherapplications.com

ESPA ring

www.csaengineering.com

Technology Status

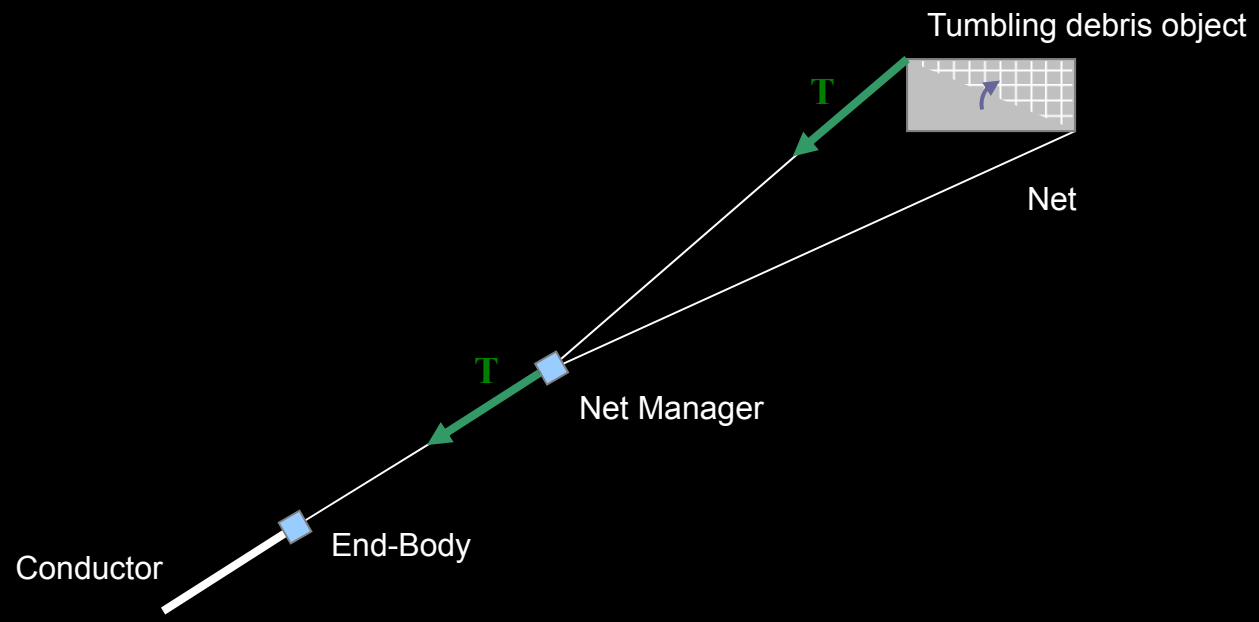
- No breakthroughs required

Component	Status
Electrodynamic propulsion	Demonstrated in space
Bare surface electron collection	Demonstrated in space
Hollow cathodes	Flown multiple times; in use on ISS
Thin film solar arrays	Tested in space
Bare tape collectors	Tested extensively in vacuum
Tether deployment	Demonstrated in space
GPS, sensors, electronics	Many models on the market
Control algorithms & software	Tested in simulators

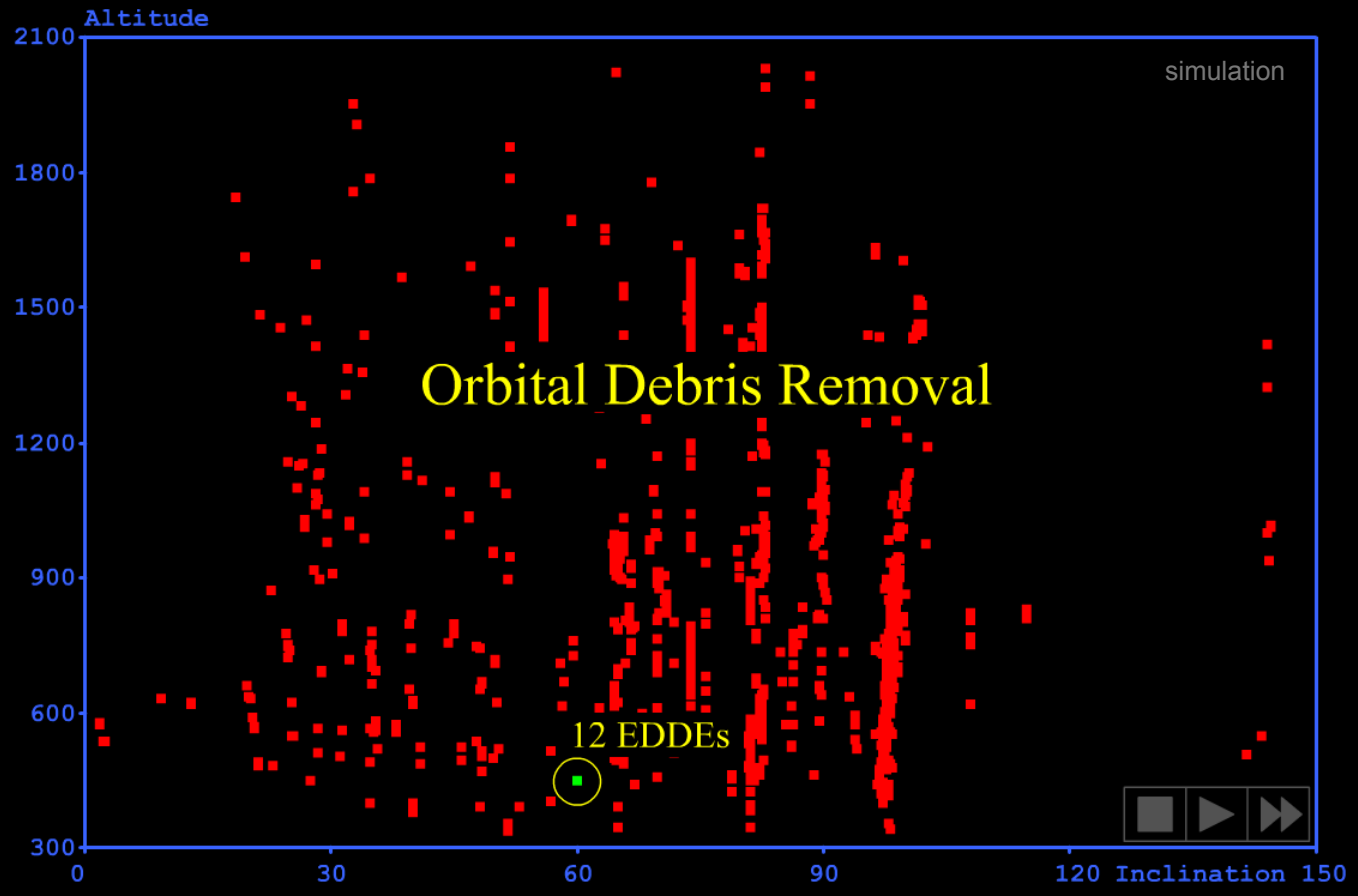
- NRL Tether Electrodynamic Propulsion Cubesat Experiment (2012)

Debris Capture

- Each Net Manager holds 100 house-size nets, 50 g each
- Passes at 2-3 m/s, captures debris in a net, and drags it to storage or short lived orbit



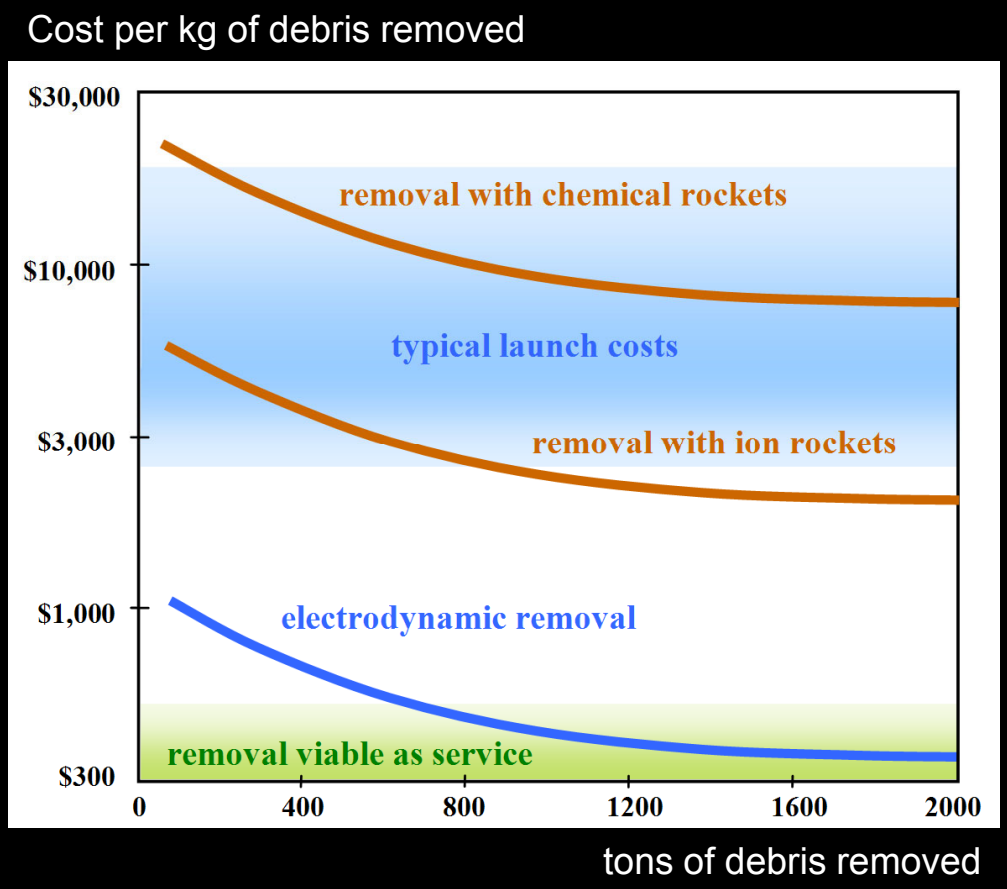
Wholesale Debris Removal



View at http://www.electrodynamictechnologies.com/animations.php

Commercial Service

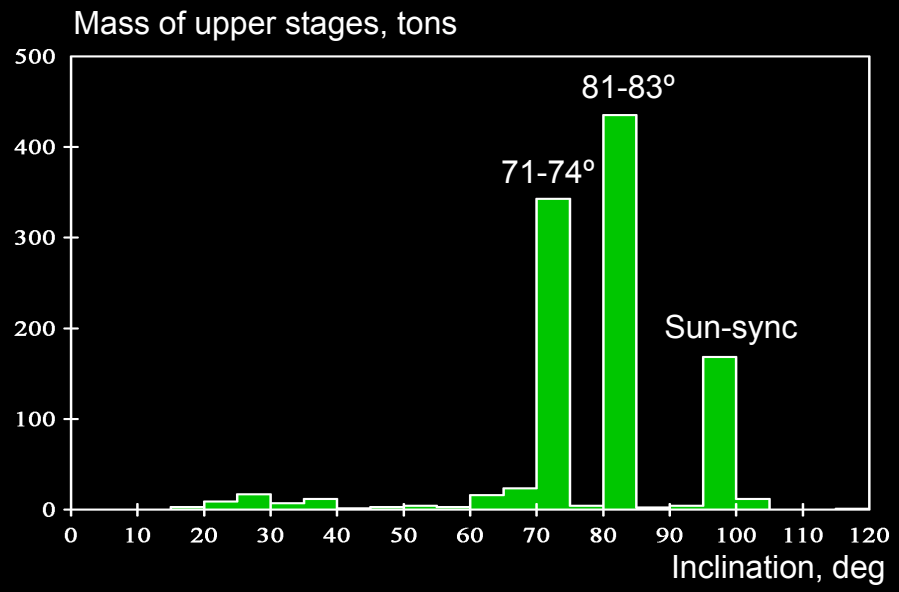
- The cost of removal must be much lower than launch costs per kg to make economic sense



Recycling

Old upper stages:

- Simple shapes and few appendages
- Less sensitivity compared to their payloads
- Highly clustered and easier to collect
- High content of aluminum for recycling



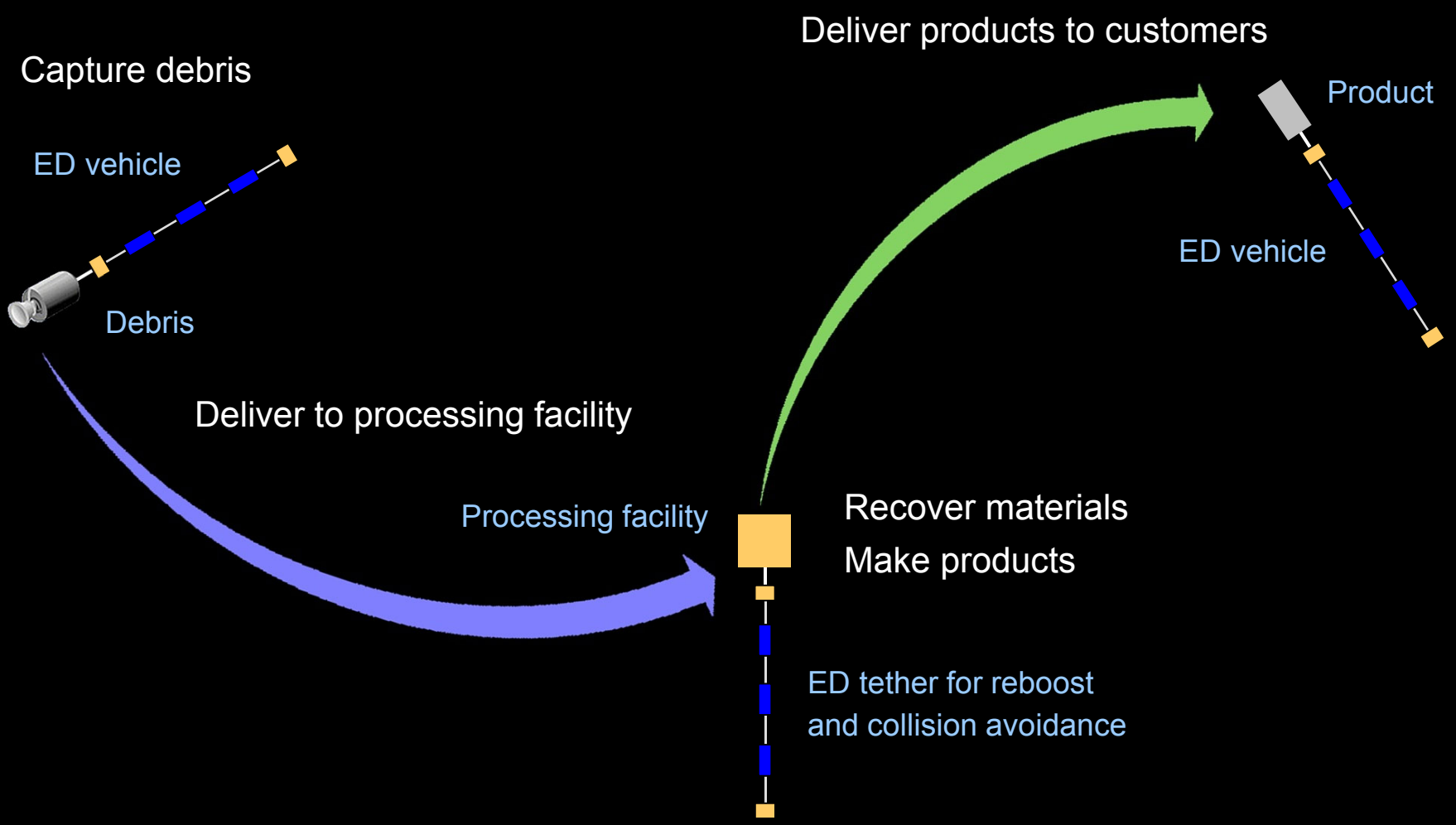
Mining and Construction

- 1000 tons of mostly aluminum in old upper stages is enough to build a 3 psi structure up to the volume of National Air & Space Museum

National Air and Space Museum in D.C.

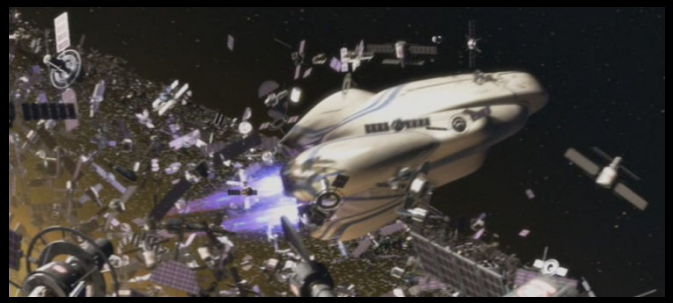
Hubble telescope inside

Space Manufacturing



The Idea of Debris Removal

- Enters public consciousness and gains popularity



WALL-E, 2008

Artist's concept, 2010

IMAX, 2012

www.melraepictures.com

Who Can Do It

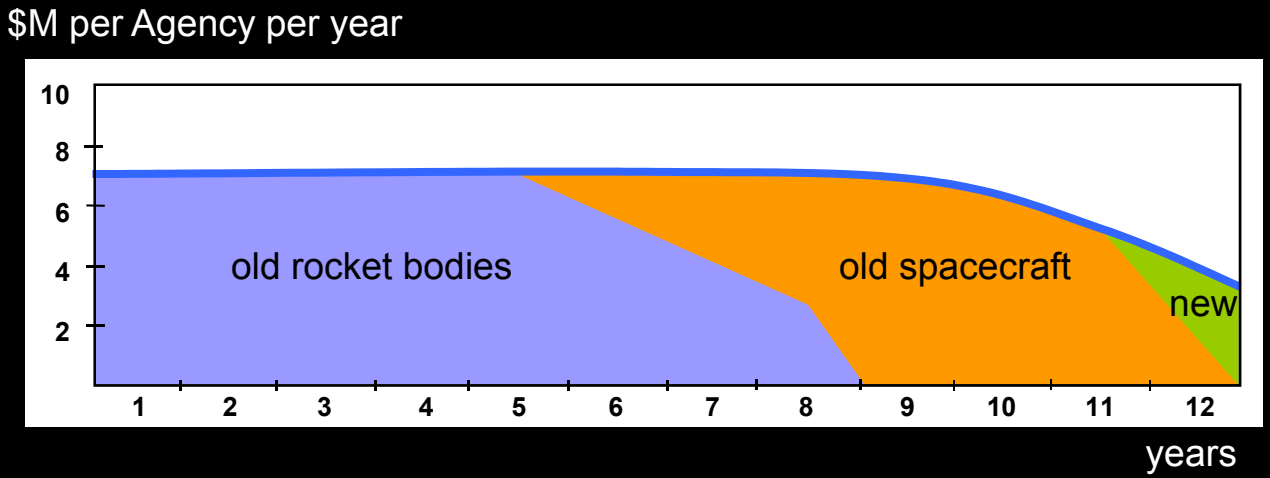
- Inter-Agency Space Debris Coordination Committee
- Presents reports to the UN Committee for the Peaceful Uses of Outer Space (UN COPUOS)
- IADC / COPUOS Debris Mitigation Guidelines adopted in 2007
- Not binding internationally
- Most fully implemented in U.S.

- Mitigation is not enough
- Single event can negate years of mitigation
- Need active debris removal

Italy
France
China
Canada
Germany
E.U.
India
Japan
U.S.
Ukraine
Russia
U.K.

What Would It Take

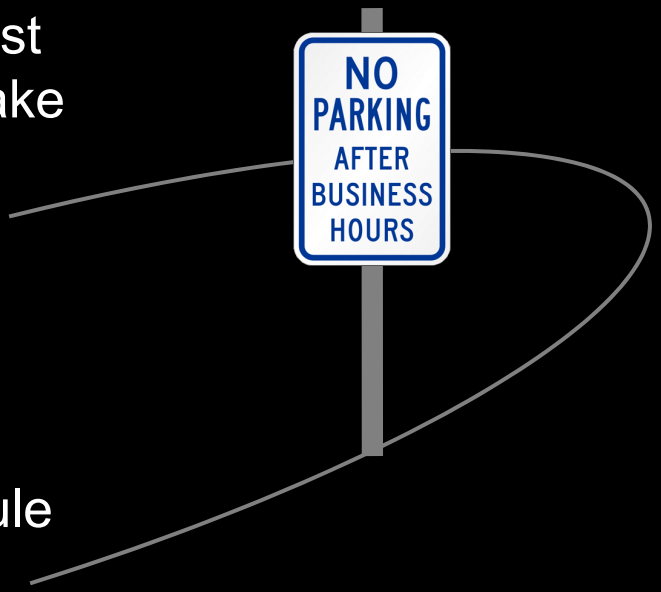
- If the IADC members decide to share the expense



- It will take competitive bidding to establish the market

New Rules

- If the IADC members decide to bear the cost of removing legacy debris, they need to make sure that it will not accumulate again
- The member states would need to accept responsibility for promptly removing their failed satellites and spent stages
- The member states can then enforce the rule on their territories
- The 25-year rule in U.S. is a prototype, but we need a much shorter time limit
- An affordable debris removal service is needed to support this regime



Time to Remove

Wholesale debris removal is

- A solvable technical problem
- Not much of a financial burden
- A solvable legal problem
- An idea gaining popularity

It is now a matter of deciding to act