National Aeronautics and Space Administration

New Developments in Orbital Debris Protection and Prevention

July 1, 2014

NASA / GSFC Code 592

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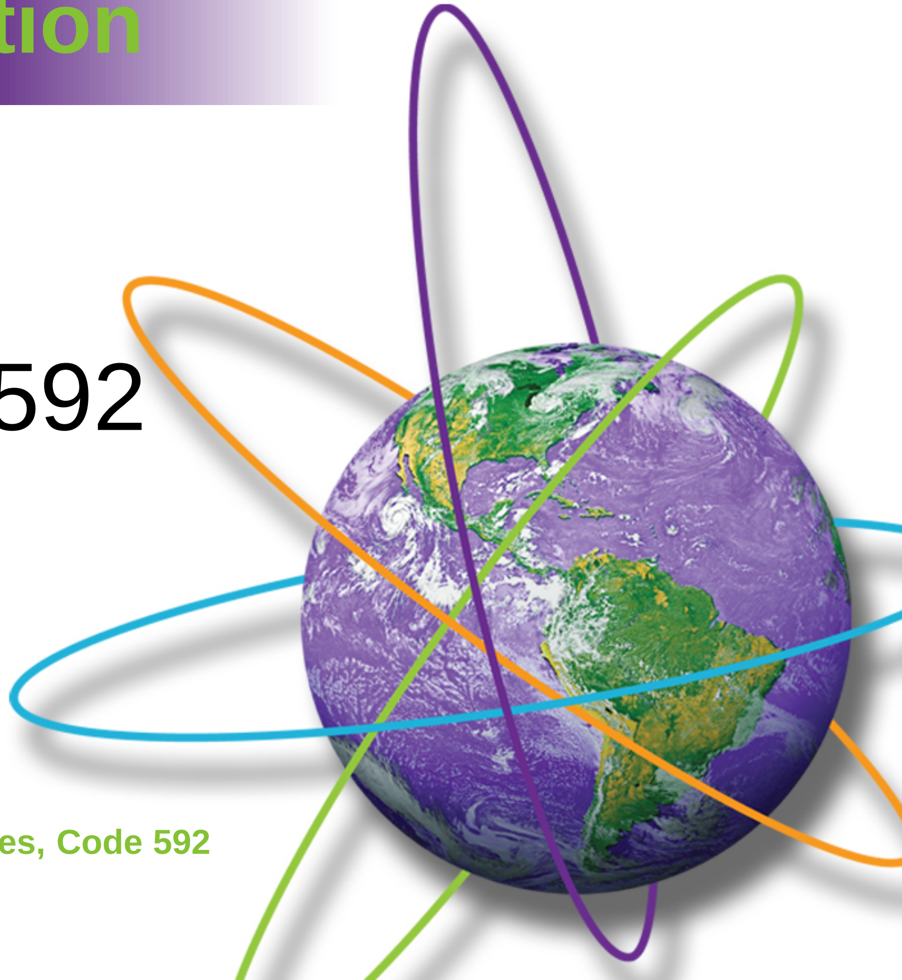
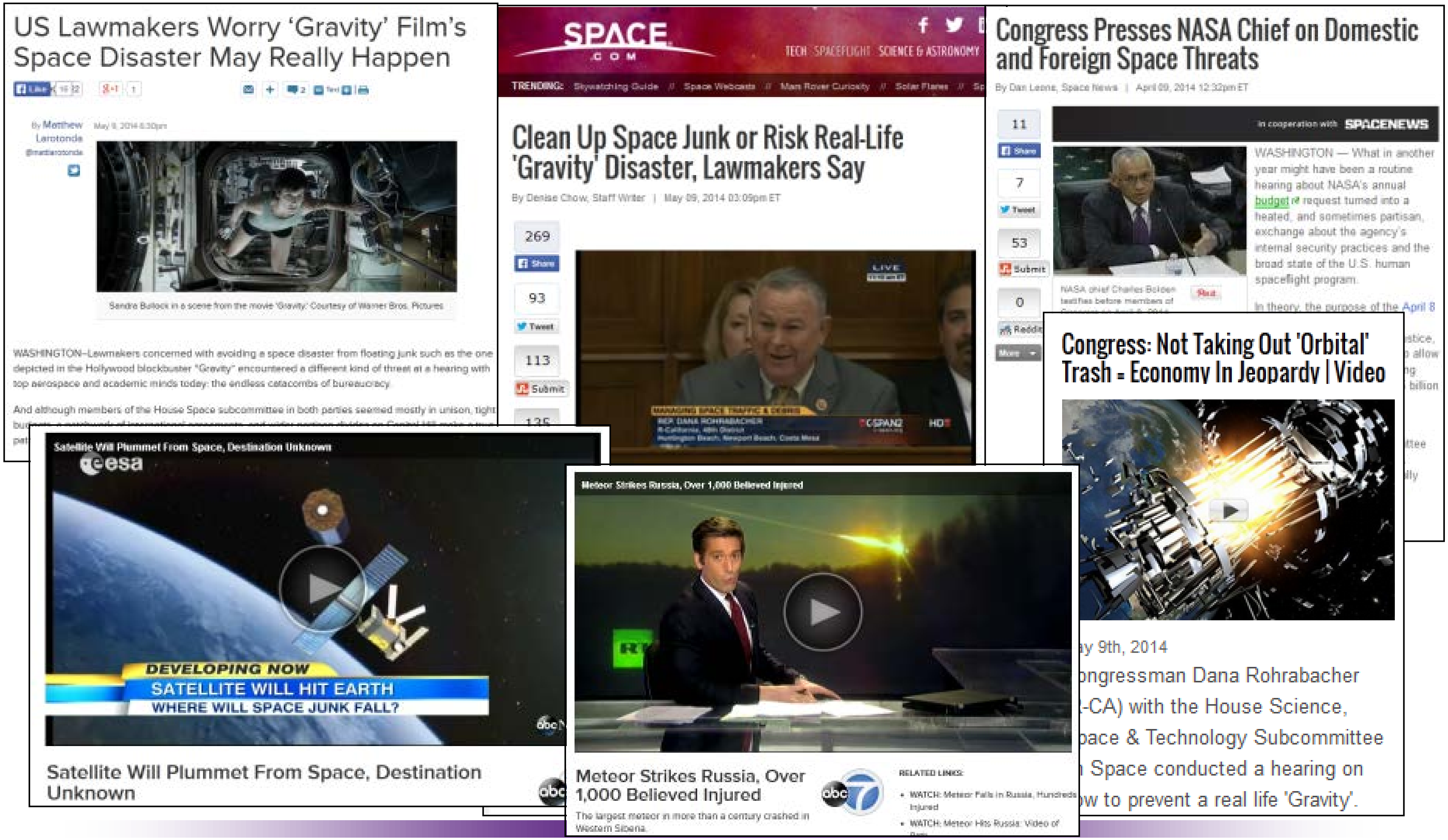


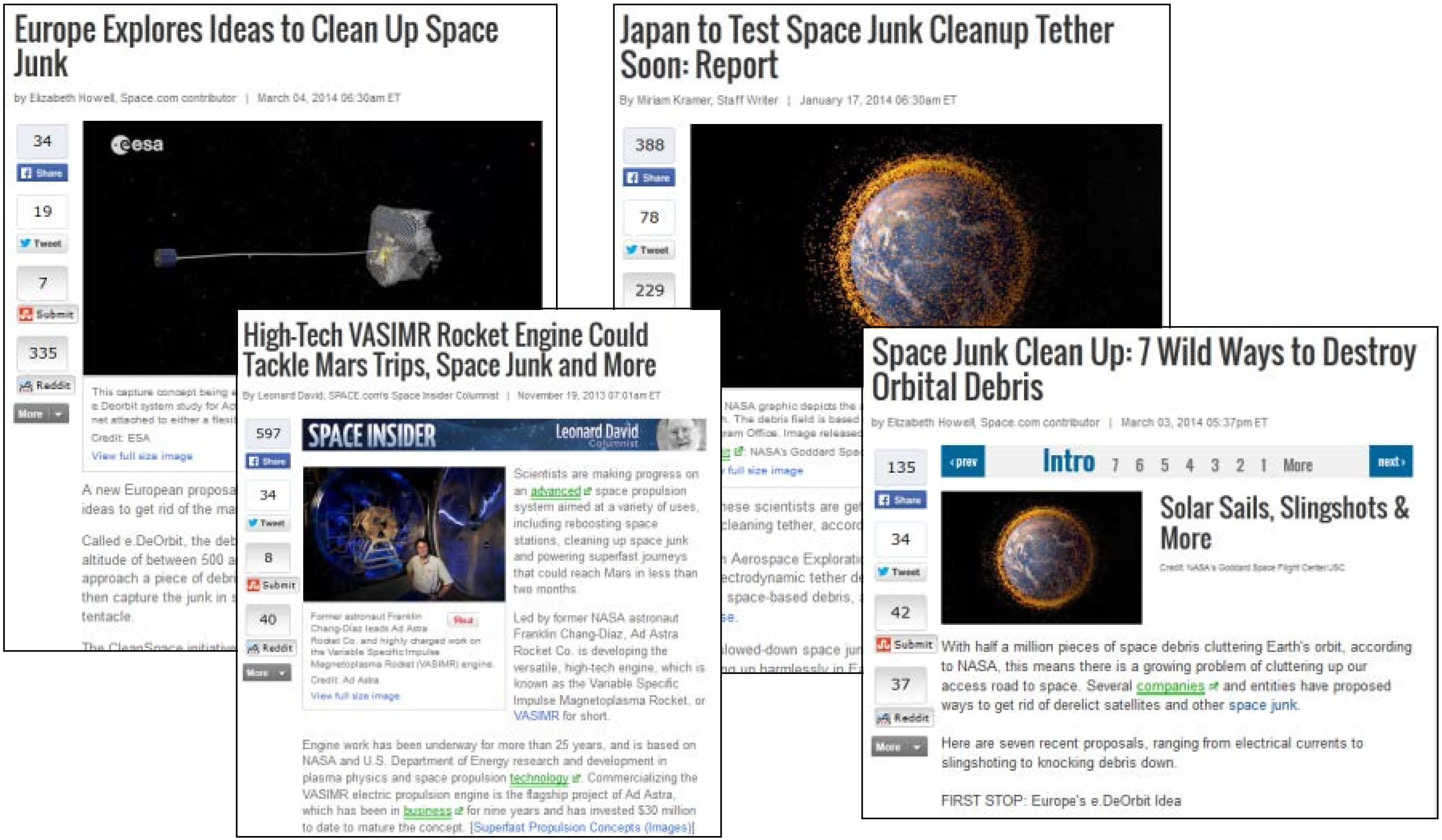
Outline

- How big a problem is orbital debris?
- Protecting the spacecraft from existing debris
- Protecting the orbital environment from spacecraft (prevention of future debris)
- Removal of existing debris objects
- NASA Requirements
- Latest Developments
- Conclusions

Recent Articles



Debris Removal Articles



Europe Explores Ideas to Clean Up Space Junk

by Elizabeth Howell, Space.com contributor | March 04, 2014 06:30am ET

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This capture concept being
e.Deorbit system study for
net attached to either a flexi
Credit: ESA
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A new European proposa
ideas to get rid of the ma

Called e.DeOrbit, the deb
altitude of between 500 a
approach a piece of debri
then capture the junk in
tentacle.

The CleanSpace initiative

Japan to Test Space Junk Cleanup Tether Soon: Report

By Miriam Kramer, Staff Writer | January 17, 2014 06:30am ET

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NASA graphic depicts the
. The debris field is based
ram Office. Image released
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full size image

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cleaning tether, accord

Aerospace Explorati
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High-Tech VASIMR Rocket Engine Could Tackle Mars Trips, Space Junk and More

By Leonard David, SPACE.com's Space Insider Columnist | November 19, 2013 07:01am ET

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SPACE INSIDER Leonard David Columnist

Scientists are making progress on an advanced space propulsion system aimed at a variety of uses, including reboosting space stations, cleaning up space junk and powering superfast journeys that could reach Mars in less than two months.

Former astronaut Franklin Chang-Diaz leads Ad Astra Rocket Co. and highly charged work on the Variable Specific Impulse Magnetoplasma Rocket (VASIMR) engine.
Credit: Ad Astra
View full size image

Led by former NASA astronaut Franklin Chang-Diaz, Ad Astra Rocket Co. is developing the versatile, high-tech engine, which is known as the Variable Specific Impulse Magnetoplasma Rocket, or VASIMR for short.

Engine work has been underway for more than 25 years, and is based on NASA and U.S. Department of Energy research and development in plasma physics and space propulsion technology. Commercializing the VASIMR electric propulsion engine is the flagship project of Ad Astra, which has been in business for nine years and has invested $30 million to date to mature the concept. [Superfast Propulsion Concepts (Images)]

Space Junk Clean Up: 7 Wild Ways to Destroy Orbital Debris

by Elizabeth Howell, Space.com contributor | March 03, 2014 05:37pm ET

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Solar Sails, Slingshots & More

Credit: NASA's Goddard Space Flight Center/JSC

With half a million pieces of space debris cluttering Earth's orbit, according to NASA, this means there is a growing problem of cluttering up our access road to space. Several companies and entities have proposed ways to get rid of derelict satellites and other space junk.

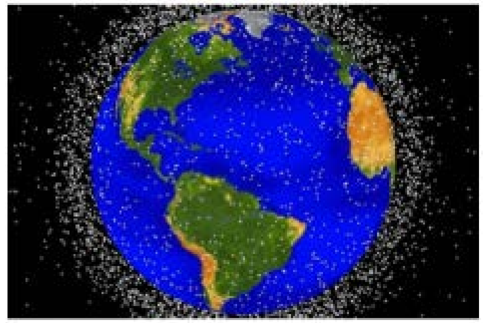
Here are seven recent proposals, ranging from electrical currents to slingshoting to knocking debris down.

FIRST STOP: Europe's e.DeOrbit Idea

Space Fence

- New S-band radar, located near the equator
- Should be able to detect smaller objects, therefore more objects
- Designed for 5 cm detection
- Slated for operations in 2018

An Air Force 'Space Fence' Will Track All the Junk Up There

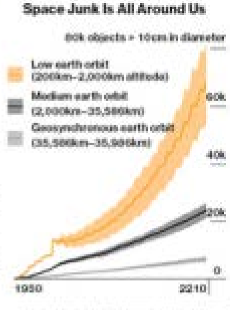


After starring in the Hollywood blockbuster *Gravity*, space junk is getting some attention from the Pentagon. The Department of Defense has designed a "space fence," a radar system designed to track more than 200,000 bits of orbiting debris with the goal of reducing the chance of satellite-killing collisions.

The Air Force awarded Lockheed Martin (LMT) a $914 million contract earlier this month to design and build the system, which will be able to track objects as small as a baseball and increase the resolution of current tracking by tenfold.

An estimated 500,000 pieces of debris, from paint flecks to partially destroyed satellite remnants, orbit the earth at speeds as high as 17,500 miles per hour. Given those enormous velocities, even tiny objects pose an enormous threat to whatever they may strike. Most of the trash is man-made, the result of 50 years of human space flight. A February 2009 crash between a 1,200-pound Iridium Communications (IRDM) satellite and a defunct Russian Cosmos satellite created an estimated 2,000 pieces of additional debris. In March 2012, U.S. and Russian authorities instructed six crew members aboard the International Space Station to take shelter in the Soyuz capsules on the ISS as a precaution as pieces of that debris passed.

Space Junk Is All Around Us



The fence is scheduled to begin operating in 2018, with construction of the first

Space Fence

Lockheed wins $915 million "space fence" contract

Gravity


SANDRA
BULLOCK
GEORGE
CLOONEY
FROM DIRECTOR ALFONSO CUARÓN
GRAVITY
WARNER BROS. PICTURES PRESENTS
IMAX 3D
10.4.13

What did Gravity get right?*

- Great props
- Debris strikes are silent – no KABOOMs!
- Collisions and explosions produce a distribution of different size pieces
- Objects with low Area to Mass Ratio arrive first at ISS
- Different ballistic coefficients evident during reentry scene
- Debris **is** potentially a real problem, if we don't do something about it

- The special feature "Collision Point" is an excellent summary of orbital debris

* the things they used 'creative license' to justify are staggering to many of us, and we don't have time for that

ORBITAL DEBRIS ENVIRONMENT

How much stuff is up there?

Why is Orbital Debris a Concern?

- On-orbit Environment
  - Currently

    ~ **22,000** objects $\geq$10 cm in size

~ **500,000** objects $\geq$1 cm in size

Many Millions of objects <1 mm in size

  - Growing rapidly: Already self-propagating
- Spacecraft damage potential
  - Moving at 7 km/s → ~**16,000 mph**!
  - ½ mv^2 gets to be really big, really fast
- Tracking limitations

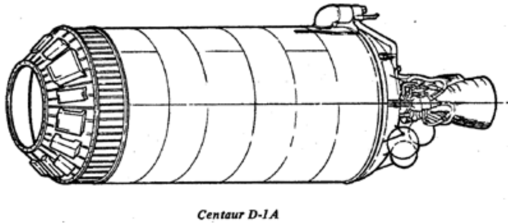
Recent Major Debris Events

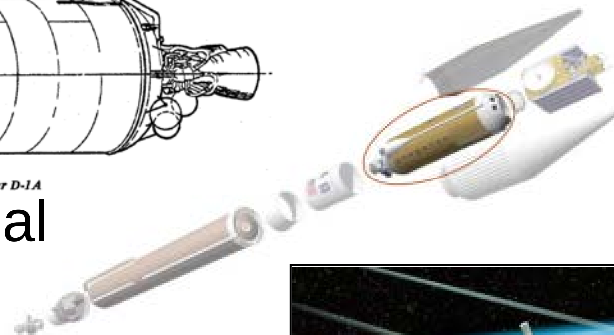
Vehicle	Type	Date	Objects*	Cause
Fengyun 1C (PRC)	Spacecraft	1/11/2007 1999-025	~2850	Deliberate destruction
CBERS 1 (PRC/BRZ)	Spacecraft	2/18/2007 1999-057	~425	Unpassivated propellant
Briz – M (CIS)	Launch Vehicle	2/19/2007 2006-006	~150	Unpassivated propellant
Iridium - Cosmos	Spacecraft x 2	2/10/2009	~1650	Collision
Briz – M (CIS)	Launch Vehicle	6/21/2010 2009-042	~85	Unpassivated propellant
Long March 3C (PRC)	Launch Vehicle	11/1/2010 2010-057	~50	Unpassivated propellant
Briz – M (CIS)	Launch Vehicle	10/16/2012 2012-044	~115	Unpassivated propellant

* Cataloged objects (> 10 cm)

Debris Sources

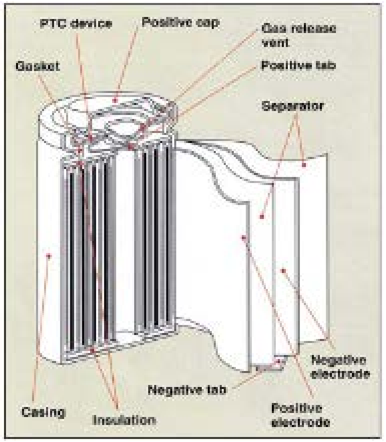
- Launch
- Spacecraft
  - Lack of proper disposal
- Collisions
  - Small collisions as well as large
- Explosions
  - Batteries
  - Pressure tanks (usually propulsion system)
- Meteoroids
  - Natural random environment
  - Meteor showers





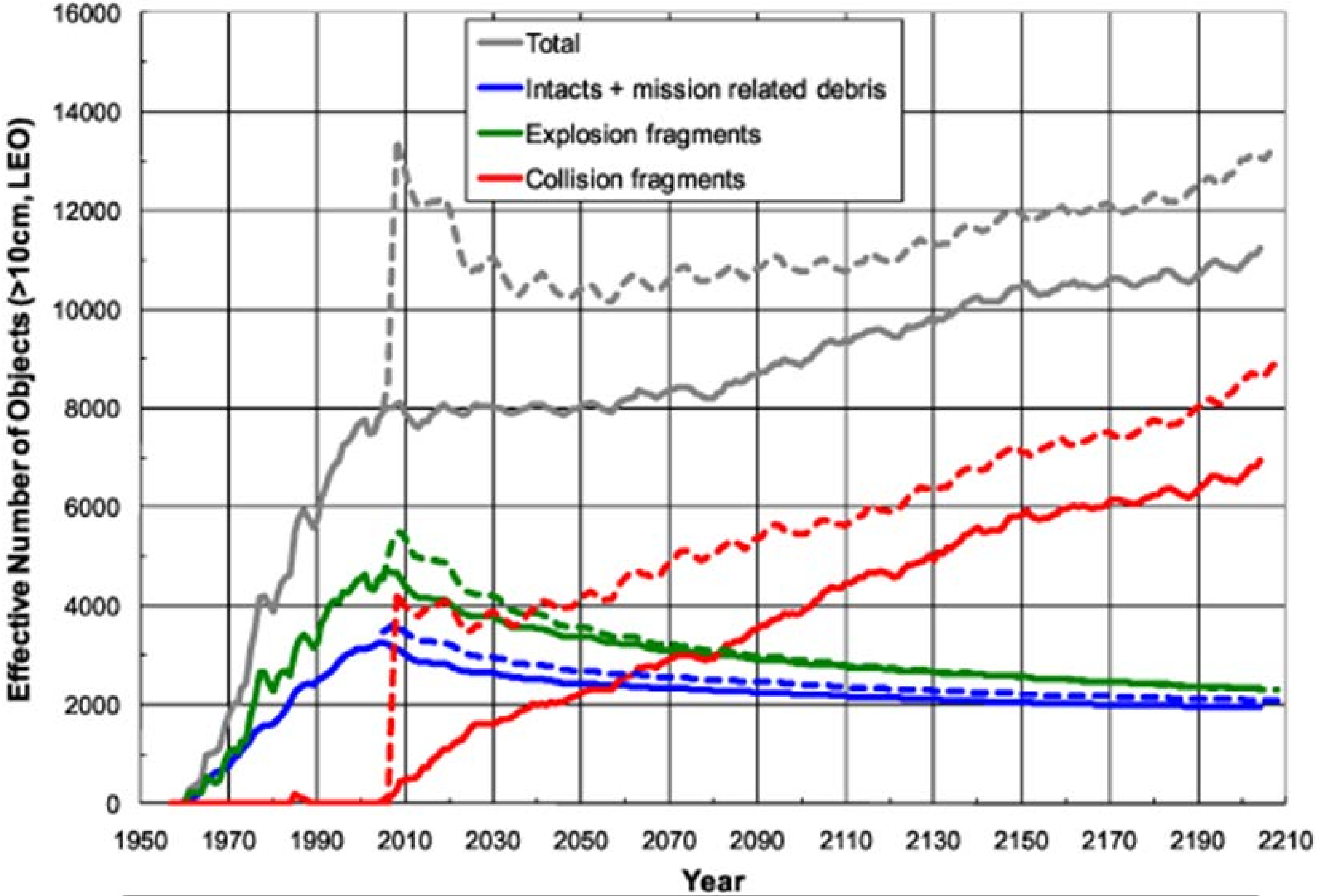
Explosions

- Batteries
  - Overcharge can generate gas pressure
  - Ni-H_2 most susceptible, Li-ion less so
    - Only known US battery explosion was a Ni-Cd
    - Some Li-ion cells have pressure cutoff switches
    - Li-ion must never be recharged after full drain



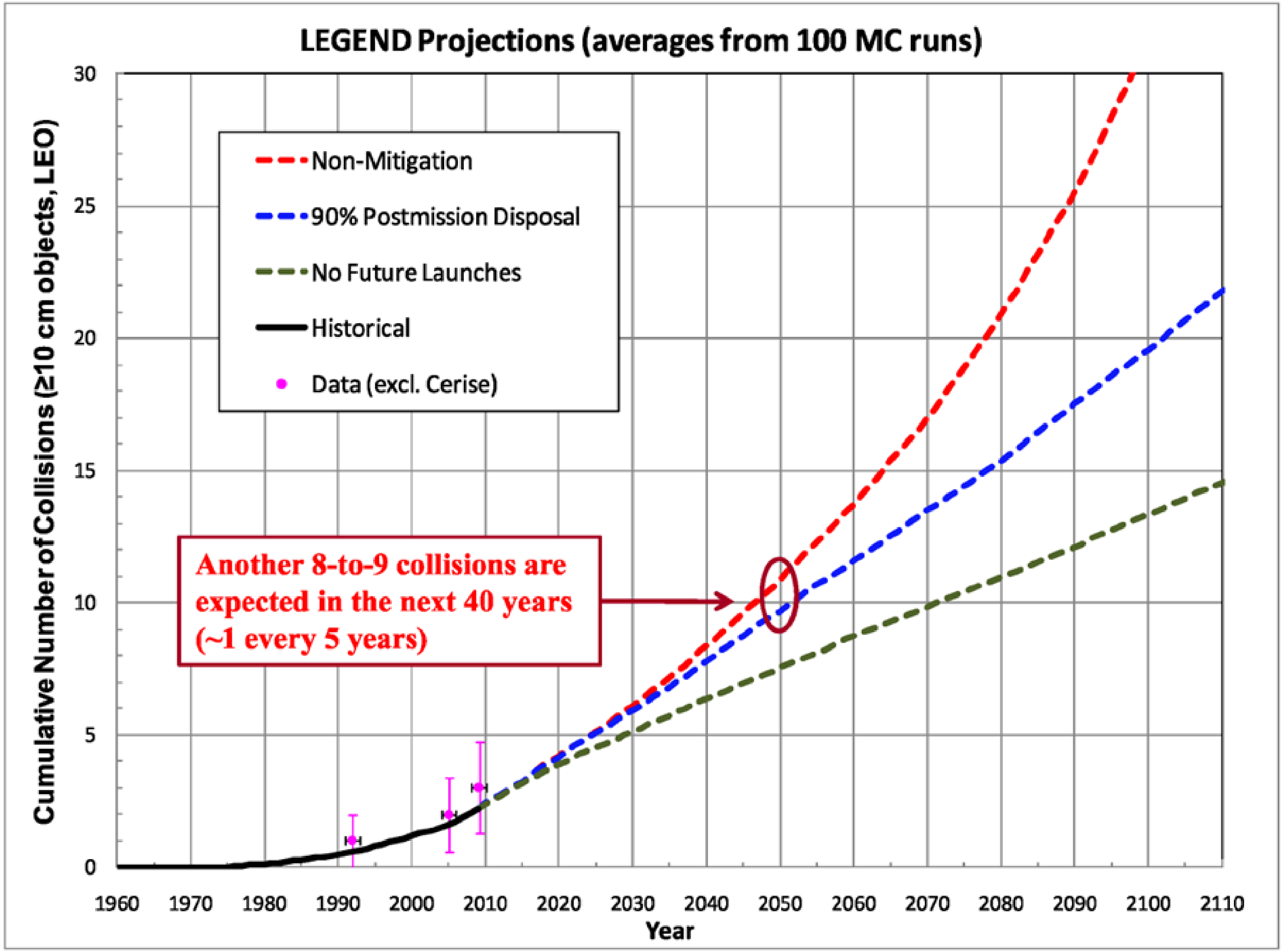
- Pressure tanks
  - Biprop: fuel and oxidizer can mix because of a leaky valve
  - Overpressure from regulator failure
  - Small debris object impact

Long-term Growth of LEO Debris Population

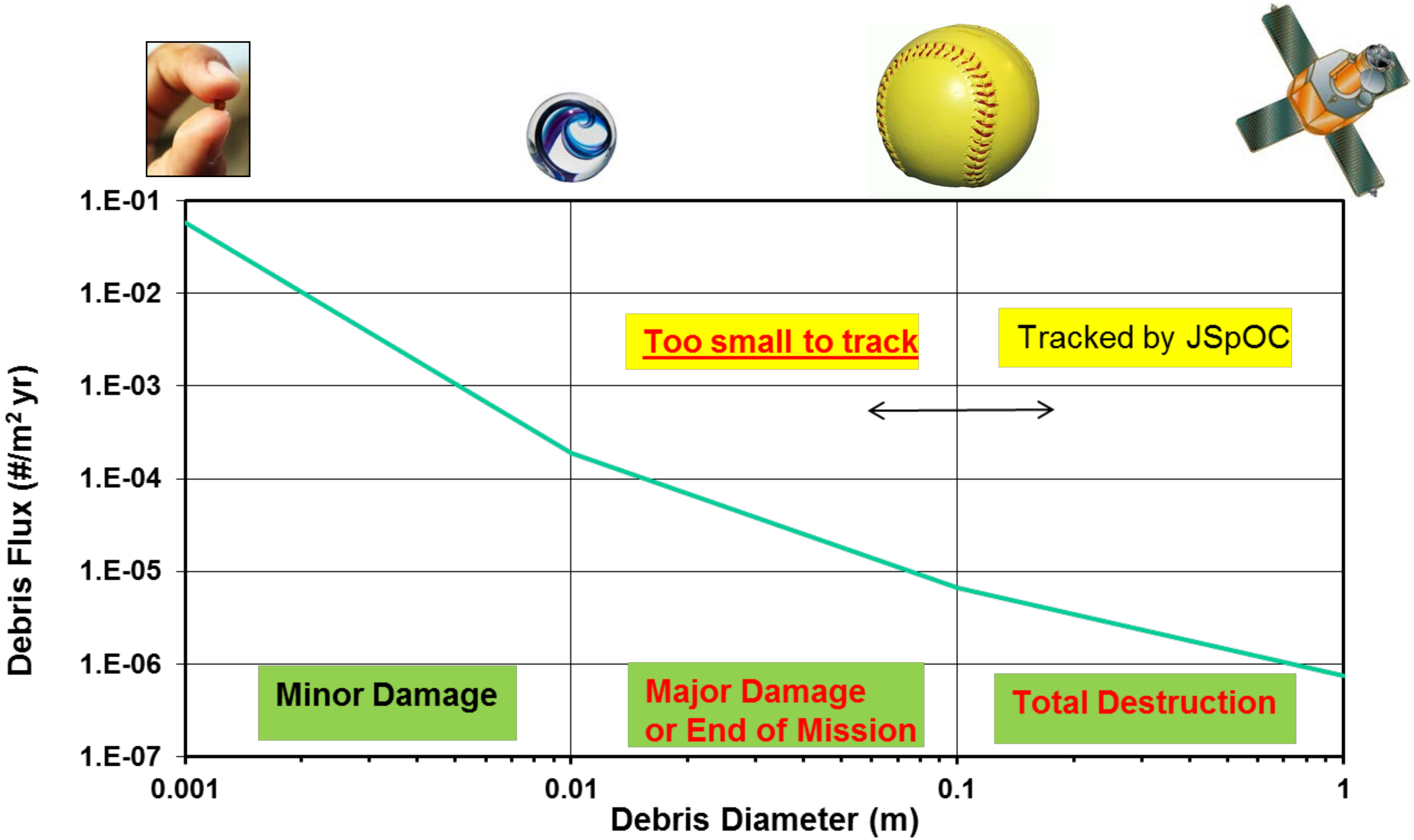


- Solid lines: 1957-to-2006, no new launches beyond 2006
- Dashed lines: 1957-to-2009, no new launches beyond 2009

Collision Predictions with and without disposal efforts



Debris Flux
in the A-Train Orbit



Reality Check
Space is still pretty big - mostly

- We’re not talking about daily major crises
  - We work to a 1% probability of a penetration that would prevent the planned disposal
    - Only about a 50/50 chance of it ever happening on a GSFC mission
    - No known case to-date of a NASA spacecraft being fatally struck
    - Benign hits might happen frequently, though, without our knowledge
    - Benign impacts might still result in shorter or reduced missions
- Daily conjunction assessments help to prevent collision with large (>10 cm) objects
- Fortunately, the cascade portrayed in Gravity wouldn’t take place nearly as fast as in the movie

The real risk is the <u>long-term</u> (decades) loss of access to the orbital environment

A Sample of GSFC Missions
(a wealth of diversity)

- Quantity
  - Typically about 20 Space Science, 6 Earth Science, and 9 TDRS missions actively operational
  - Usually ~50 total missions, including development
- Orbits
  - Typically LEO (400 to 850km)
  - A few GEO
  - A few high eccentricity, L1 and L2
  - Lunar and Mars
- Propulsion
  - About 60% have propulsion systems
- Construction
  - Many high Z materials in detectors
  - Substantial use of Titanium
  - Glass mirrors and lenses

ORBITAL DEBRIS PROTECTION

Protecting the spacecraft from debris damage

Methods of Protection

Mission Design

Hardware Design

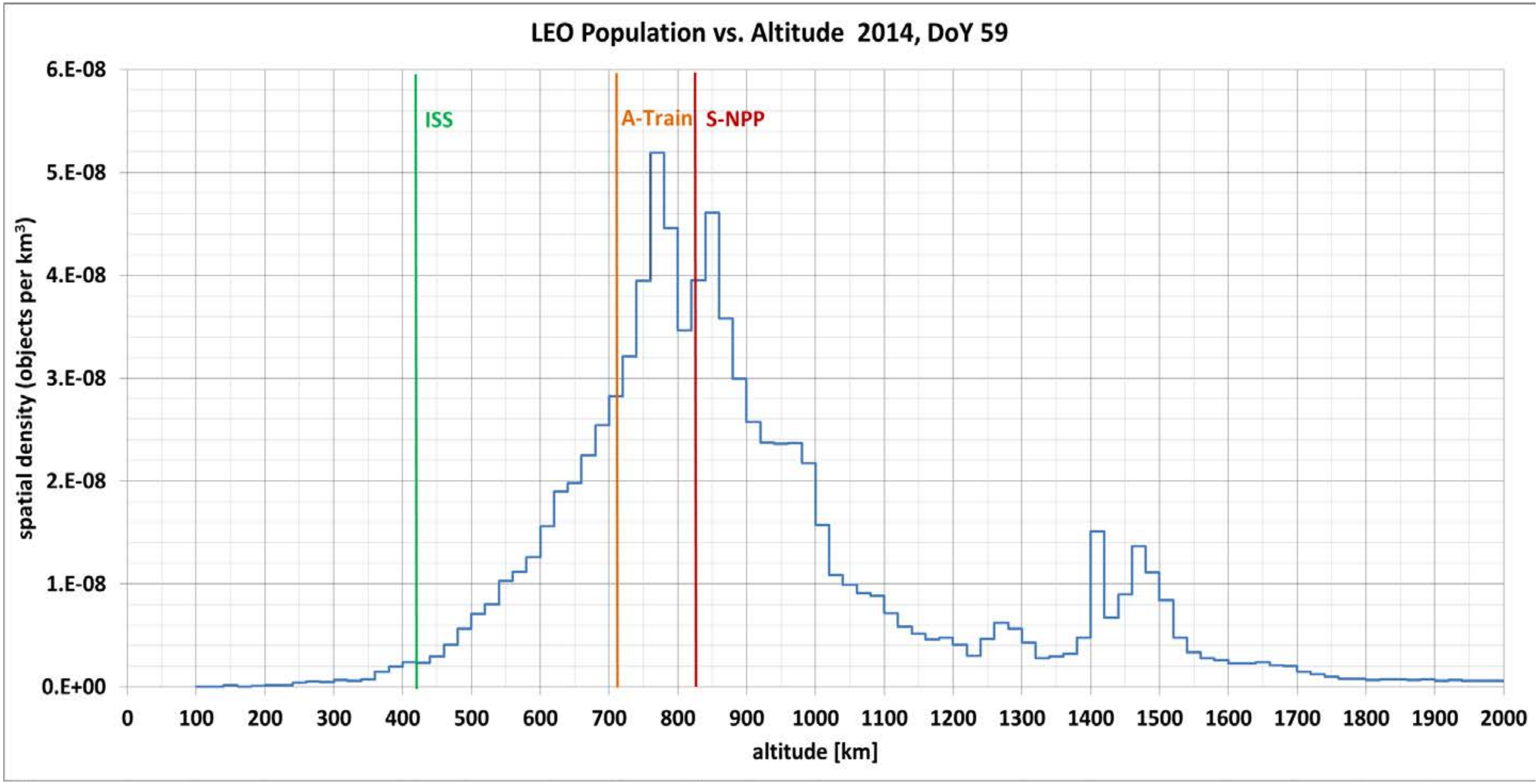
Shielding

Conjunction Assessment

Mission Design and Ops Considerations

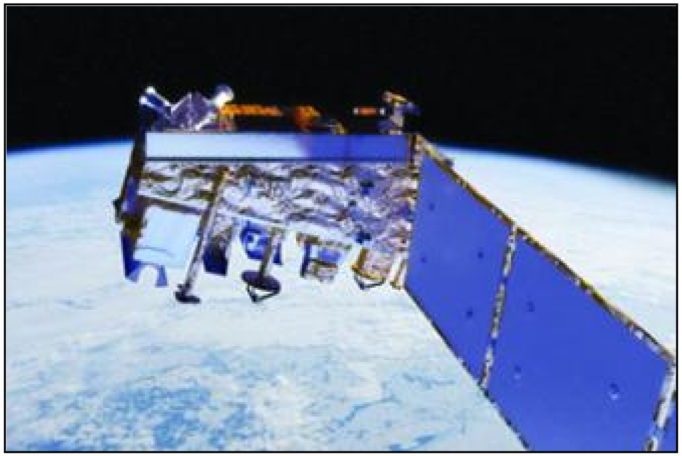
- **Orbital debris needs to be considered early**
- **Orbit selection**
  - Debris peaks at ~750, 900, and 1400 km
  - Orbit selection is usually driven by science needs, but science can be difficult in a minefield
- **Operations**
  - Orbit change maneuvers to avoid predicted close approaches
  - Reorient the spacecraft during meteor showers or close approaches
  - Have plans in place to help diagnose and/or respond to potential debris hits

Debris Density vs. Altitude



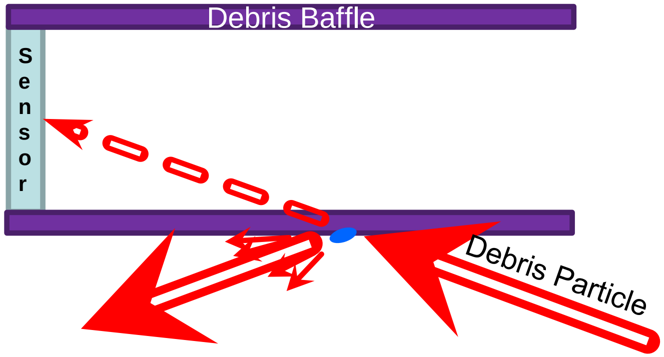
Hardware Design Considerations

- Component location
  - If possible, locate critical bus components inside the spacecraft
  - Nadir and zenith are lowest exposure
  - Ram direction and sides are highest exposure
  - Take advantage of shadowing
- Wall thickness
- Add shielding
- Redundancy

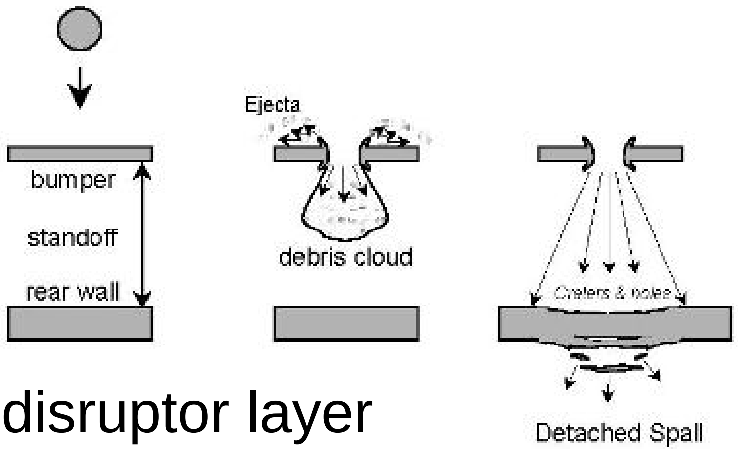


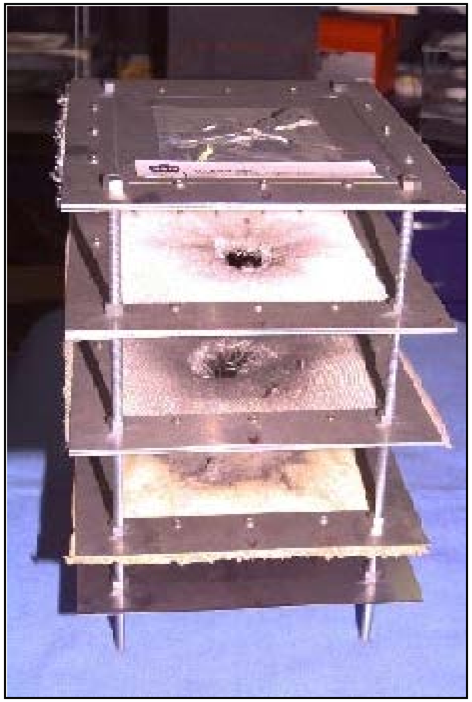
Shielding Considerations

- Mass
- Cost
- Complexity – mechanical effects on spacecraft design
- Multi-wall much more effective than a thicker wall
  - Depends on spacing
  - Material selection is important
- Direction of threat
- Use baffles to shield instruments in some cases



Multi-wall Shield Mechanisms



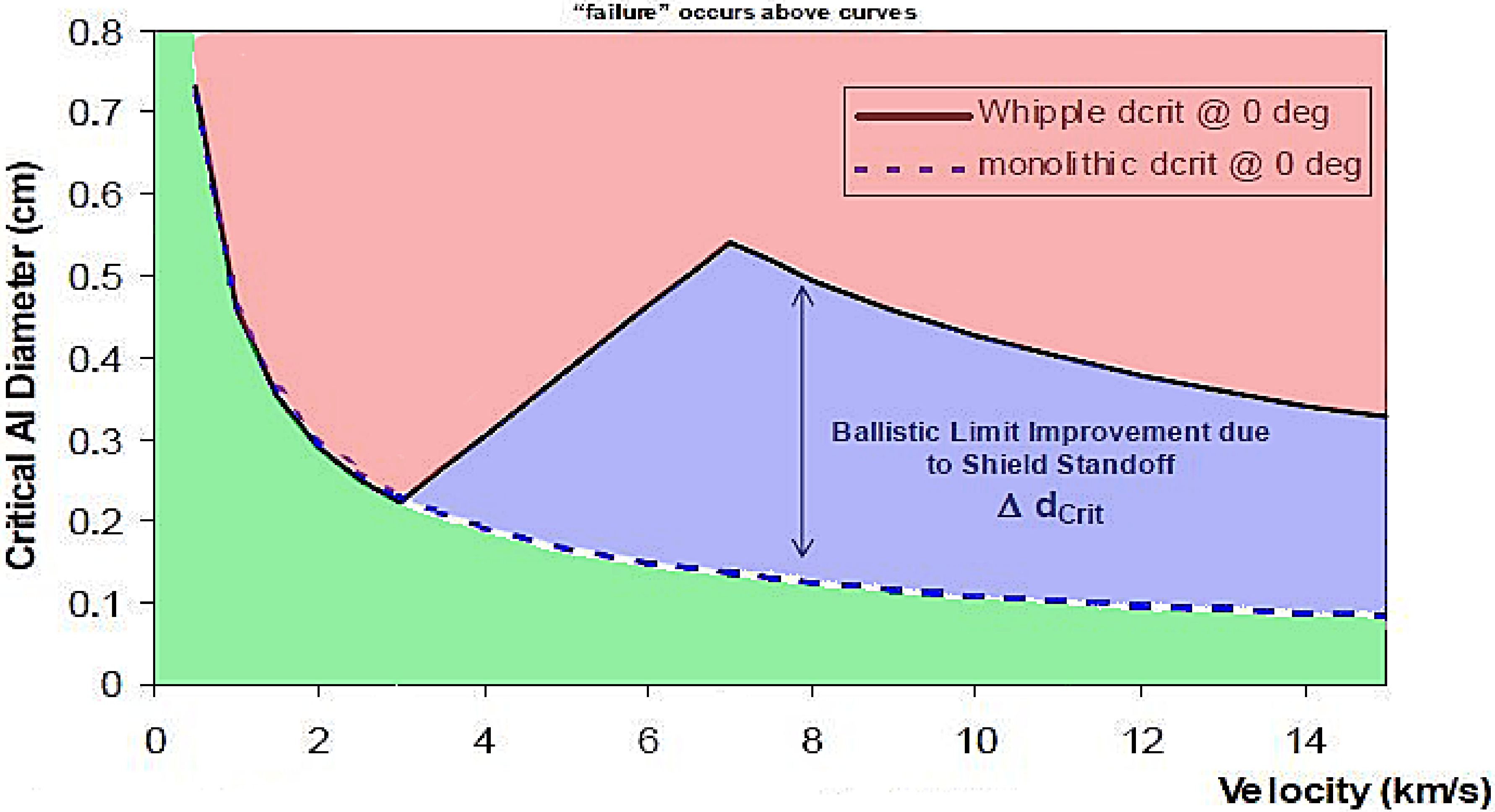


- ‘Bumper’ disruptor layer
  - Breaks up and melts projectile
  - High temperature material (Nextel does well)
- Inner stopper layer
  - Traps the slower moving secondary debris
  - High toughness material (Kevlar does well)
- Back wall
  - Usually the box wall
  - Provides the last line of defense
  - Can generate spalling from inside surface, even if not penetrated

Shield Testing

- High velocity impact guns on actual samples
  - 3 to ~7 km/sec range
    (slower than most MMOD impacts)
  - Typically >$10,000 per shot
  - 5 or 6 shots per test
- Tested across a range of velocities, sizes, impact angles, and densities
- Produces ballistic limit curves

Typical Whipple Shield Ballistic Limit Curve



ORBITAL DEBRIS PREVENTION

Protecting space from us…

Prevention Methods

- Design for Safety
- End of Mission Disposal
  - Reentry (active or passive)
  - Storage orbits

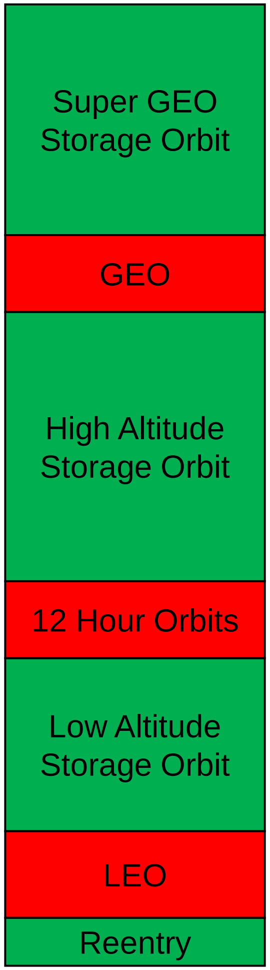
- End of Mission Passivation
  - Disconnect battery
  - Vent pressure sources
  - Essentially minimize residual stored energy

Design for Safety During and After the Mission

- Pressure tank design
  - Burst strength ≥2X MEOP recommended
- Battery selection
  - Usually driven by power demands
  - $Ni\text{-}H_2$ can be an explosion risk if overcharged
  - Li-ion less susceptible, but has strict charging considerations
- Locate pressurized components near center of spacecraft
  - Protection against debris strikes
  - Any fragmentation is more contained
- Responsible Disposal

Postmission Disposal Methods

- Reentry
  - Controlled or uncontrolled
  - With or without orbit lowering
  - Depends on reentry risk, orbit, propulsion capacity, guidance reliability
- Storage orbit
  - Can stay in LEO up to 25 years
  - 2000 km to GEO-200 km
  - Above GEO+200 km
- Retrieval



Power System Passivation

- Requires designing in an "off-switch" early

- Disconnect solar arrays (preferred)
  - Can be easier/safer to achieve
  - Passivates all electronic equipment at once
- Disconnect the battery from the charging circuit
  - Relays, instead of logic
  - Reducing charging rate is not enough
- Leave small loads attached to the bus
- Disable failure detection and correction modes at EOM
- Never recharge Li-ion after a deep discharge

Pressure Tank Passivation

- Requires designing in venting hardware

- Design for venting
  - Redundant valves in series on vent lines
  - Consider effects of cold gas thrust
  - Add vent lines for isolated pressurant tanks
  - Bypass around diaphragms

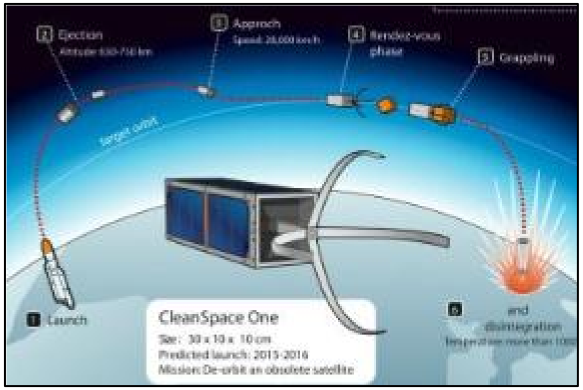
- Vent pressure as much as practical
  - Latching valves left open if possible
  - Very small amount often remains

ORBITAL DEBRIS REMOVAL

Taking out the trash

Challenges to Debris Removal

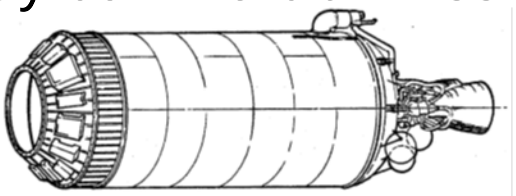
- Cost
  - Value of removing a rocket body ~$3.7M
  - Cost of removing a rocket body ~10X value
  - Ignores the less tangible value of access to the orbit



- Legal Aspects
  - Salvage rights
  - Removal responsibility
  - Could be viewed as an attack
  - No international jurisdiction or agreements
- Target Selection
- Technology

Target Selection for Debris Removal
What should we remove?

- Orbit selection
  - LEO: highest density, mostly science missions (government funding)
  - GEO: lower density, mostly commercial missions (industry funding)



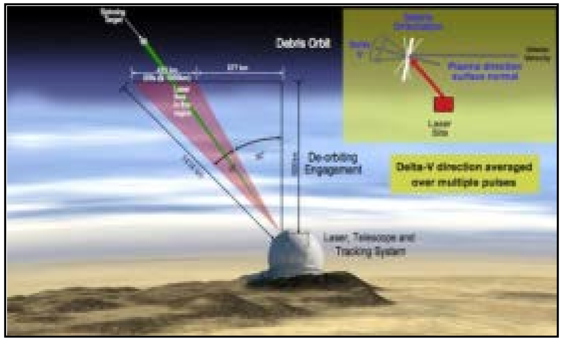
- Debris size selection
  - 1 mm to 1 cm: high quantity, low damage
  - 1 cm to 10 cm: moderate quantity, moderate damage, not trackable
  - >10 cm: low quantity, catastrophic damage, trackable
  - Rocket Bodies: can produce most smaller debris due to collisions

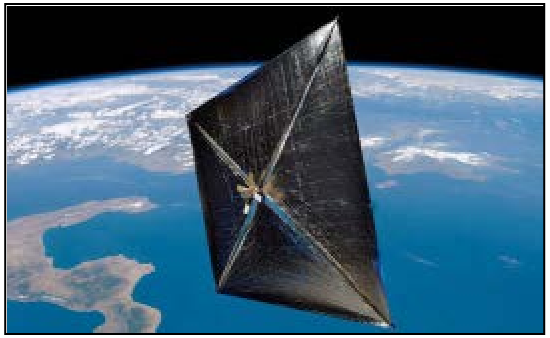
Technology Challenges for Debris Removal

- Each different approach is suited to a specific set of orbit and size conditions
- Cost varies widely
- Most techniques have yet to be demonstrated
  - Tethers have been used for electric generation, but not necessarily drag or propulsion
  - Some spacecraft retrieval and on-orbit servicing experience
- No single solution will work for all applications and orbits
- Rendezvous and capture is a common challenge for most removal methods

Examples of Removal Techniques

Technique	Target Size	Orbit Range	Relative Cost
Ground Based Lasers	1 cm to 10 cm	All of LEO	$$
Drag Enhancement	10 cm to 5 m	LEO <700 km	$$$
Sweepers	< 10 cm	LEO	$
Space Tugs (ADR)	1 m to 5 m	LEO through GEO	$$$$$

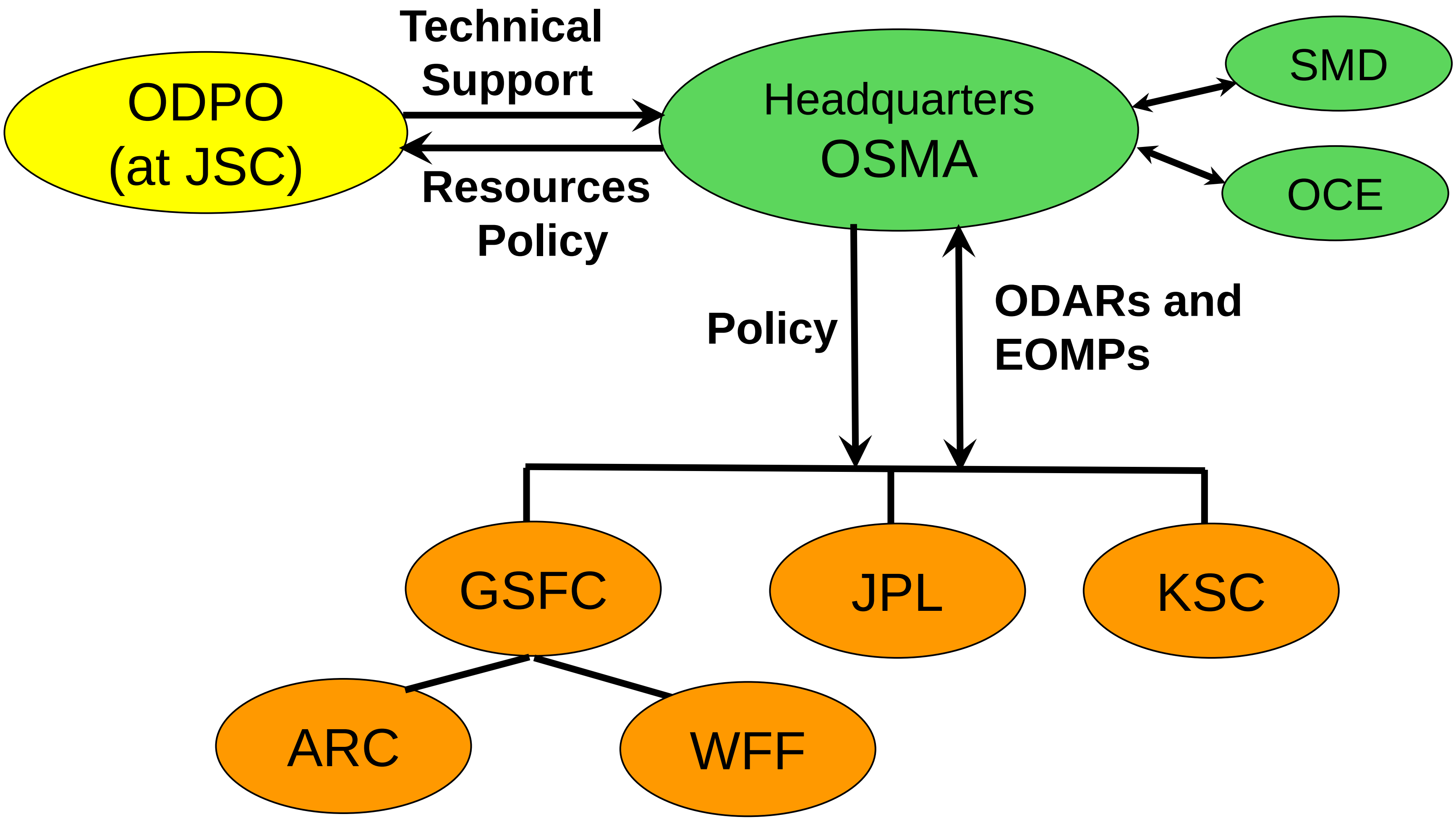





NASA ORBITAL DEBRIS REQUIREMENTS

Coloring inside the lines

NASA Orbital Debris Structure



NASA-STD-8719.14 Requirements

Section 4.3 (2)	Operational Debris
Section 4.4 (4)	Explosions, Passivation, Intentional Break-up
Section 4.5 (2)	Collisions
Section 4.6 (4)	Postmission Disposal
Section 4.7 (1)	Reentry Risk
Section 4.8 (1)	Tethers
15	Total

Requirement Group 4.4
Accidental Explosions

Req. 4.4-1: Risk of Accidental Explosions During the Mission

- Need to assess and report a **quantitative** estimate for explosion risk
- < 0.001 probability for all credible failure modes

Req. 4.4-2: Risk of Accidental Postmission Explosions

- "Deplete all onboard sources of stored energy"
- Also referred to as **passivation**
- Disconnect battery from charging circuit
- Vent pressure

- **The concern is the risk to other spacecraft, and to the long-term orbital environment**

Collision with Small Debris

- Spacecraft only; not launch vehicle
- Projectile size based on spacecraft component robustness
- Function of vulnerable component area, inherent shielding, nominal mission lifetime, and object flux
- **Each** disposal-critical component must be examined from **ALL** directions
- $\leq$ 0.01 probability of preventing disposal
- DAS 2.0.2 used for the first evaluation
- Results can be refined using Bumper 3

Large Objects vs. Small Objects

Large Objects	Small Objects
Catastrophic impact	Prevents disposal
$\geq$ 10 cm	Based on design (typically 1-3 mm)
Spacecraft average area	Critical component area
$\leq$ 0.001 (1 in 1000)	$\leq$ 0.01 (1 in 100)
Shielding ineffective	Shielding can be effective

NASA-STD 8719.14 Requirement 4.6-1

Disposal from LEO orbits (choose one)

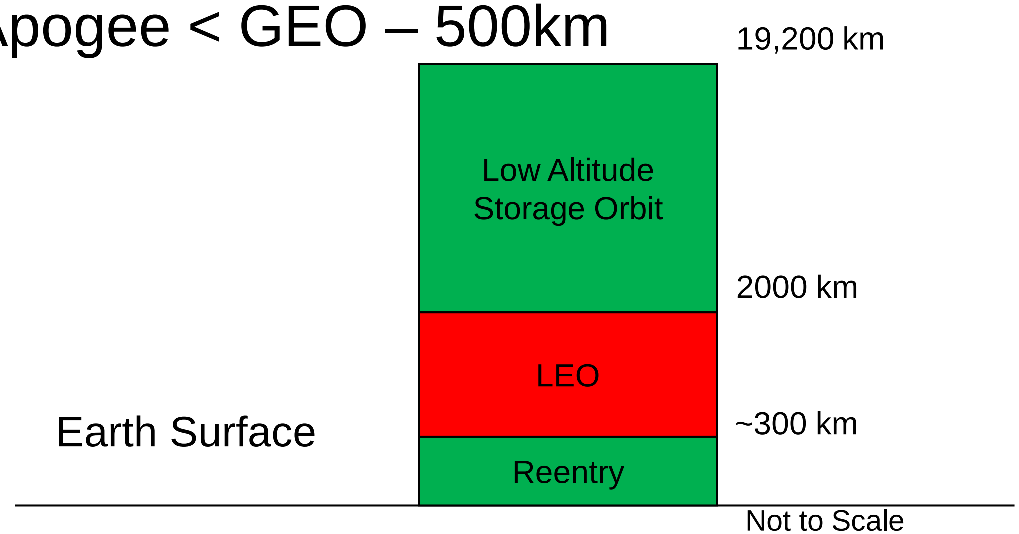
6-1 a. Atmospheric reentry

- Orbit decay within 25 years after end of mission
- No more than 30 years total orbital lifetime
- Can be Uncontrolled Reentry or Controlled Reentry

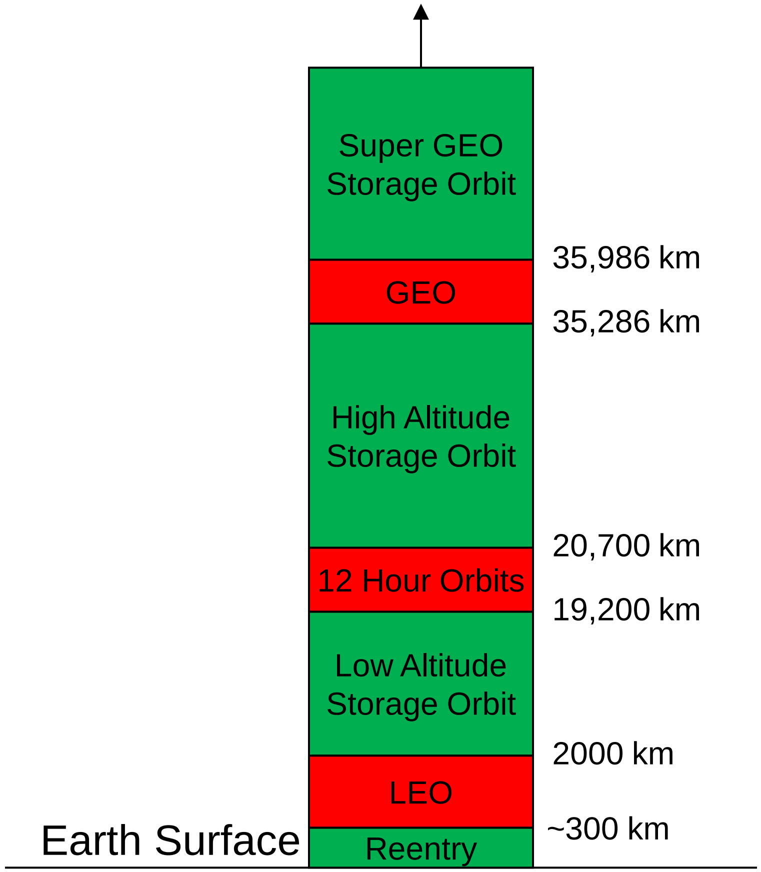
6-1 b. Maneuver to a storage orbit

Perigee > 2000 km, Apogee < GEO – 500km

6-1 c. Direct retrieval



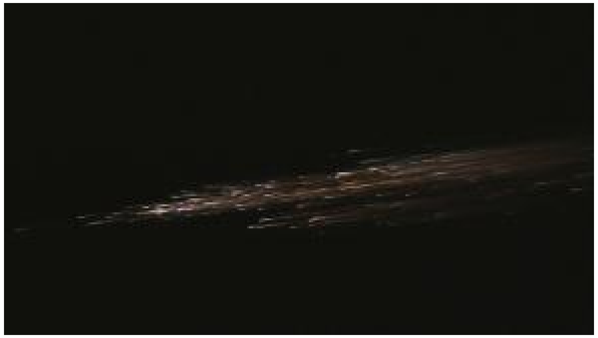
Available Storage Orbits



Not to Scale

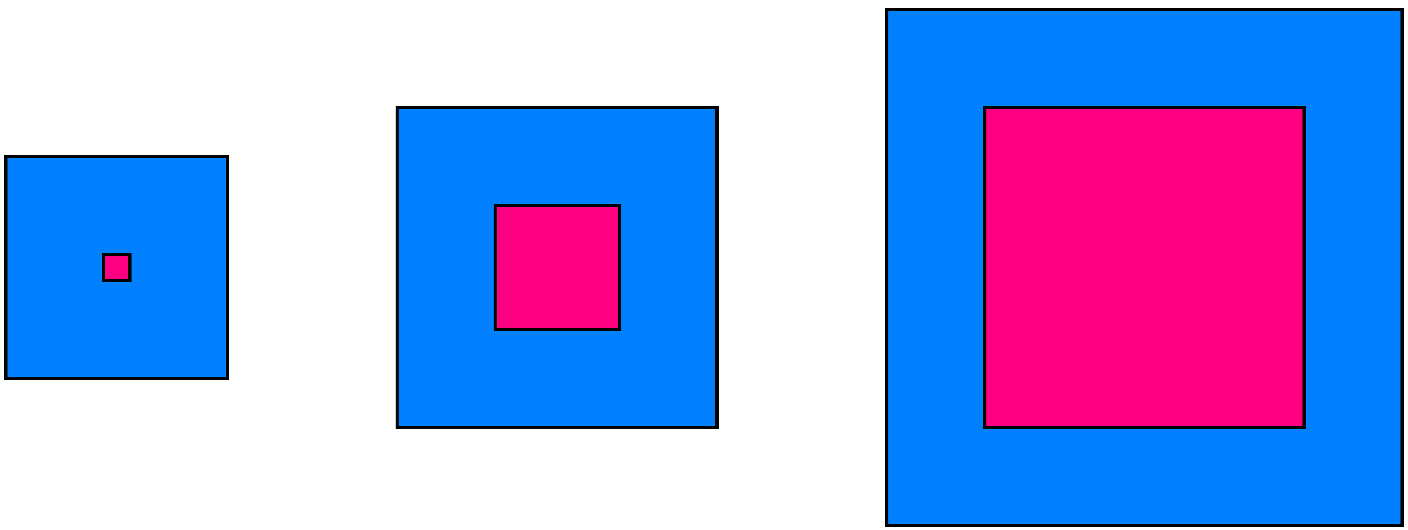
NASA-STD 8719.14 Requirement 4.7-1

- Risk of Human Casualty
  - For objects with impact energy >15J
  - Risk $\leq$ 0.0001 (1 in 10,000)
  - For controlled reentry:
    - Uncontrolled Risk X $P_f \leq 0.0001$
    - No object closer than 370km to foreign landmass, or 50km to US landmass of Antarctica
  - Hazardous materials must now be reported and considered



Debris Casualty Area (DCA)

When an object survives, a 0.3 m "person-border" is essentially added to the circumference of the object



Aref = .01 m^2 DCA = .49 m^2

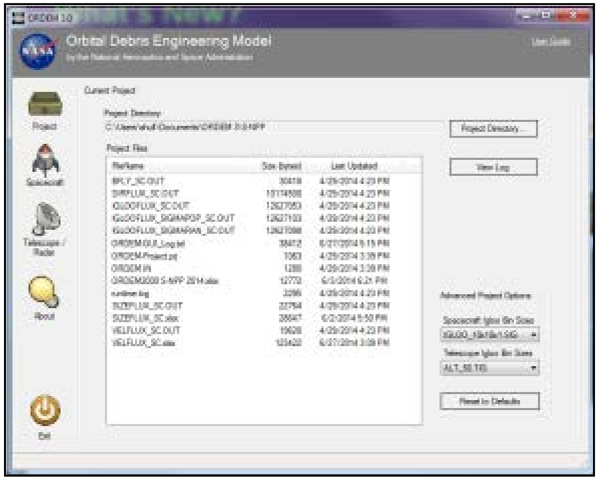
Aref = .16 m^2 DCA = 1.0 m^2

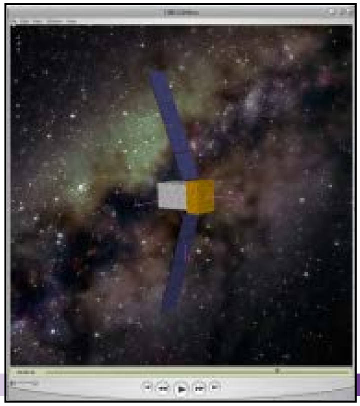
Aref = 1.0 m^2 DCA = 2.6 m^2

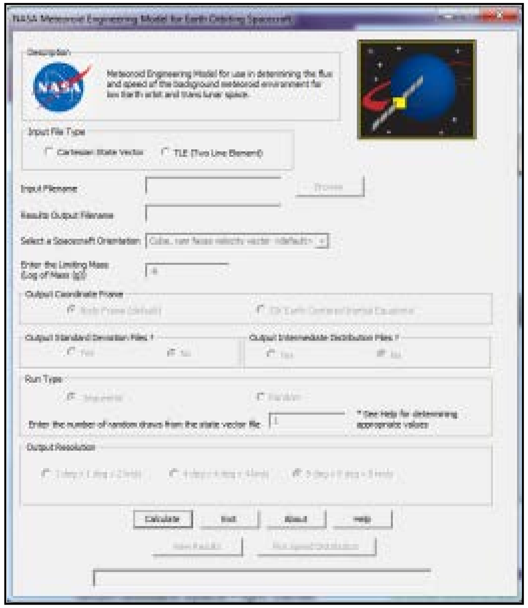
LATEST DEVELOPMENTS

What's New?

- ORDEM 3.0 Released
- John Lyver & Nick Johnson retired
- Sue Aleman is the new MMOD Program Executive
- J.-C. Liou is the new Chief Scientist for OD
- NPR 8715.6B going to NODIS review soon
- New tools in GSFC OD Group
  - Bumper 3.0
  - ORDEM 3.0
  - MEMR2
  - 42



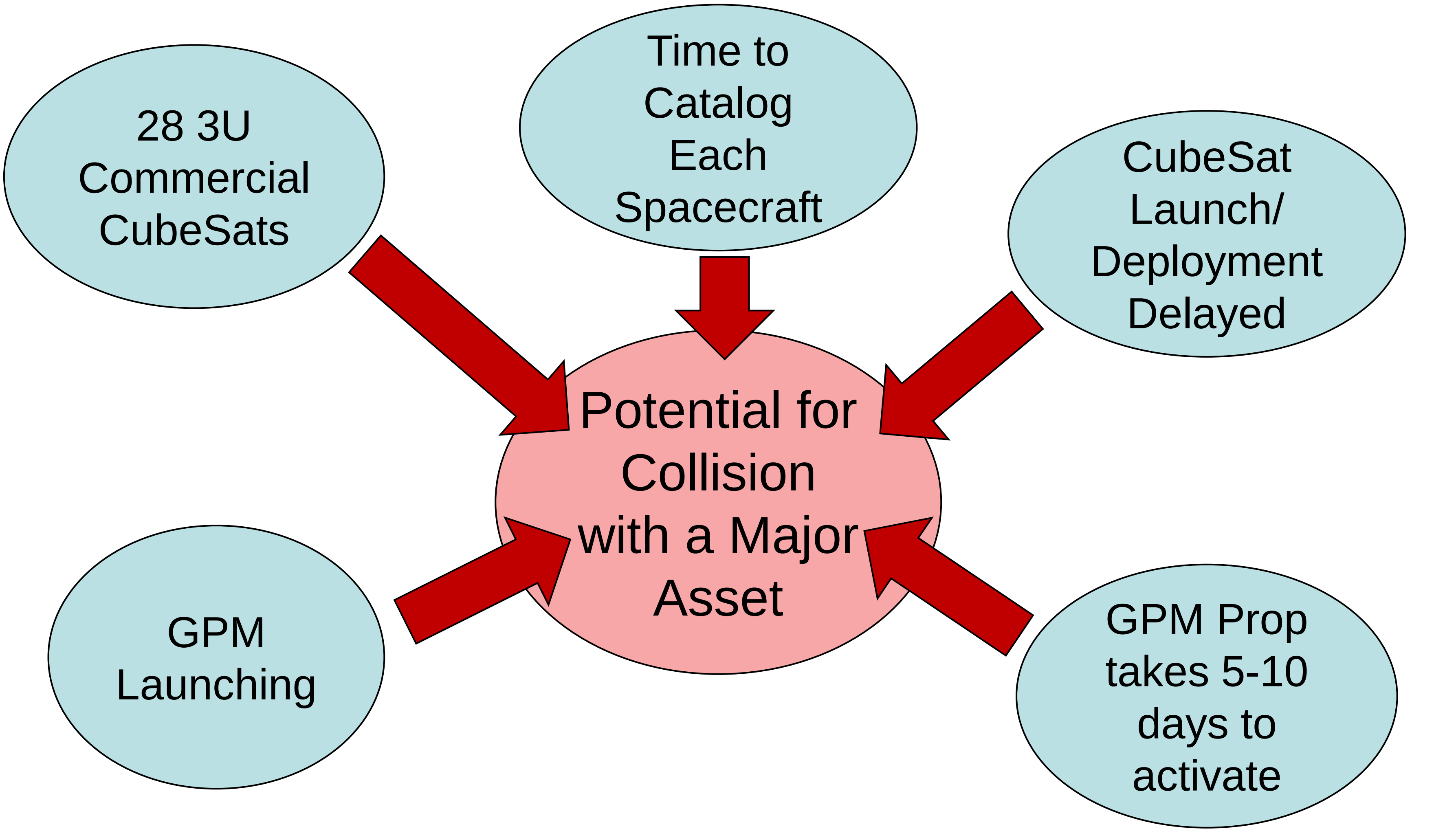




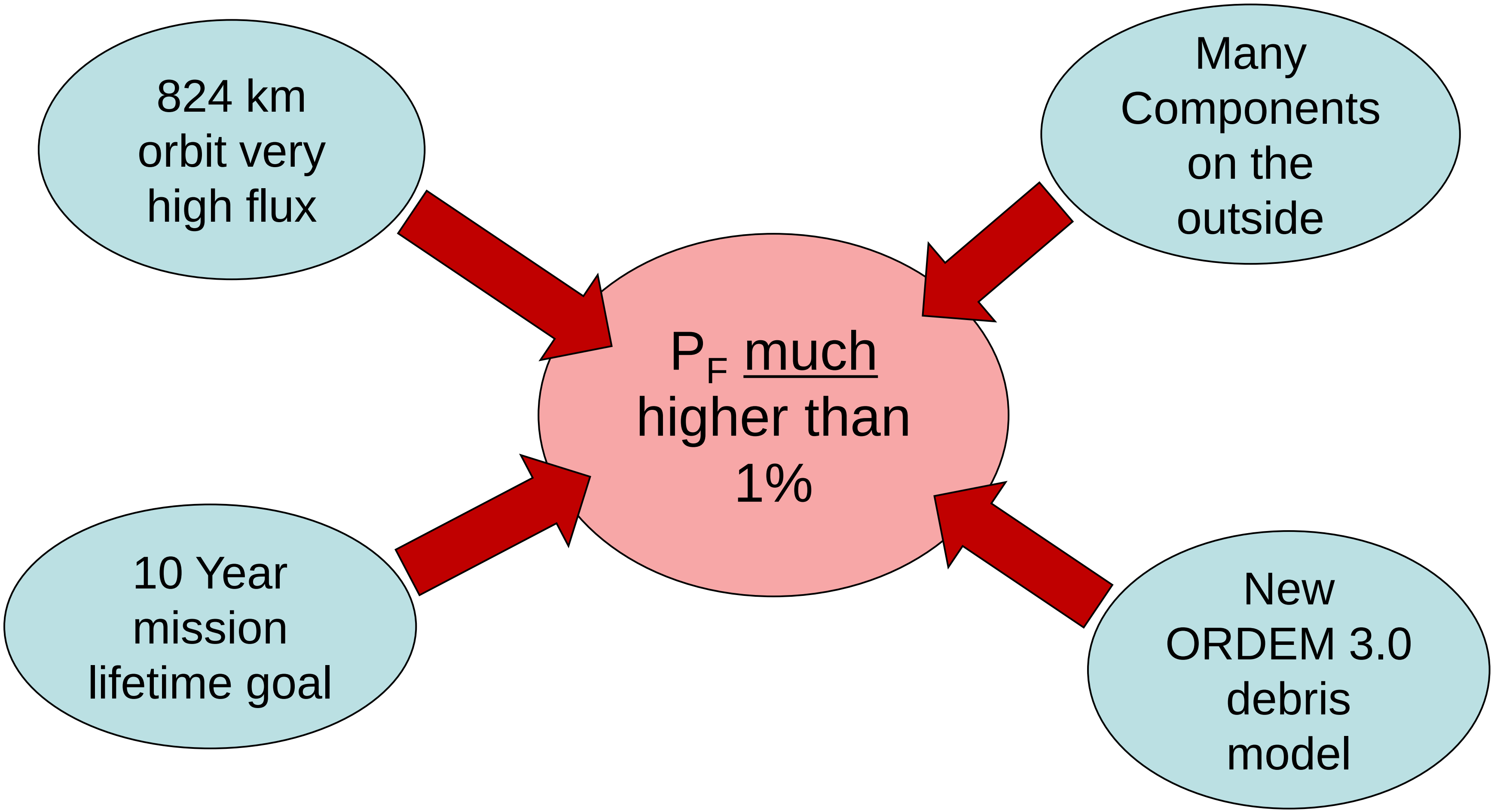
NPR 8715.6B Overview
(as of latest proposed draft)

- Updates to reflect organizational changes
  - New US Space Policy
  - New NASA top level organization (SOMD → HEOMD)
- Removes obsolete NSS 1740.14 references
- Greatly streamlines the ODAR and EOMP process
  - Most interim drafts approved at the Center level
  - HQ only signs prelaunch and final versions
- Chief/SMA now accepts risks (versus the AA/SMD)
- Generously streamlines the document
- Reduces the number of “shall” statements

Recent ‘Perfect Storm’ #1
Potential Collision Concern



Recent 'Perfect Storm' #2
JPSS-1 Small Object Collision Assessment



Conclusions (1 of 2)

- The accumulation of debris in operational orbits is a real and growing concern.
- Collisions will dominate the generation of additional debris in the future.
- There are design techniques for protecting most spacecraft and instruments from the effects of orbital debris.

Conclusions (2 of 2)

- While it is presently impractical to remove derelict objects from orbit, there are agreements and requirements in place to limit the addition of more debris.
- Disposal and passivation planning are critical to limiting the long-term rate of debris growth.
- Code 592 and JSC/ODPO can assist with design optimization as well as documentation.

Resources

- Email the GSFC team any time for assistance:
  - **Scott.Hull@nasa.gov 6-7597**
  - **Ivonne.M.Rodriguez@nasa.gov 6-5837**

- Online Resources
  - NPR 8715.6A: http://www.hq.nasa.gov/office/codeq/doctree/87156.htm
  - NASA-STD 8719.14A : http://www.hq.nasa.gov/office/codeq/doctree/174014.htm
  - http://orbitaldebris.jsc.nasa.gov/
  - http://orbitaldebris.jsc.nasa.gov/library/USG_OD_Standard_Practices.pdf

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