What’s New in Orbital Debris?

July 18, 2017
Systems Engineering Seminar

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Code 592

Outline

- Introduction to the orbital debris environment
- New release of NPR 8715.6B
- The ODAR and EOMP review process
- Recent Activities
- ORDEM 3.0
- DAS 2.1.1
- Space Fence
- CubeSats and Mega-constellations
- Questions

ORBITAL DEBRIS ENVIRONMENT

How much stuff is up there?

Why is Orbital Debris a Concern?

- On-orbit Environment
  - Currently

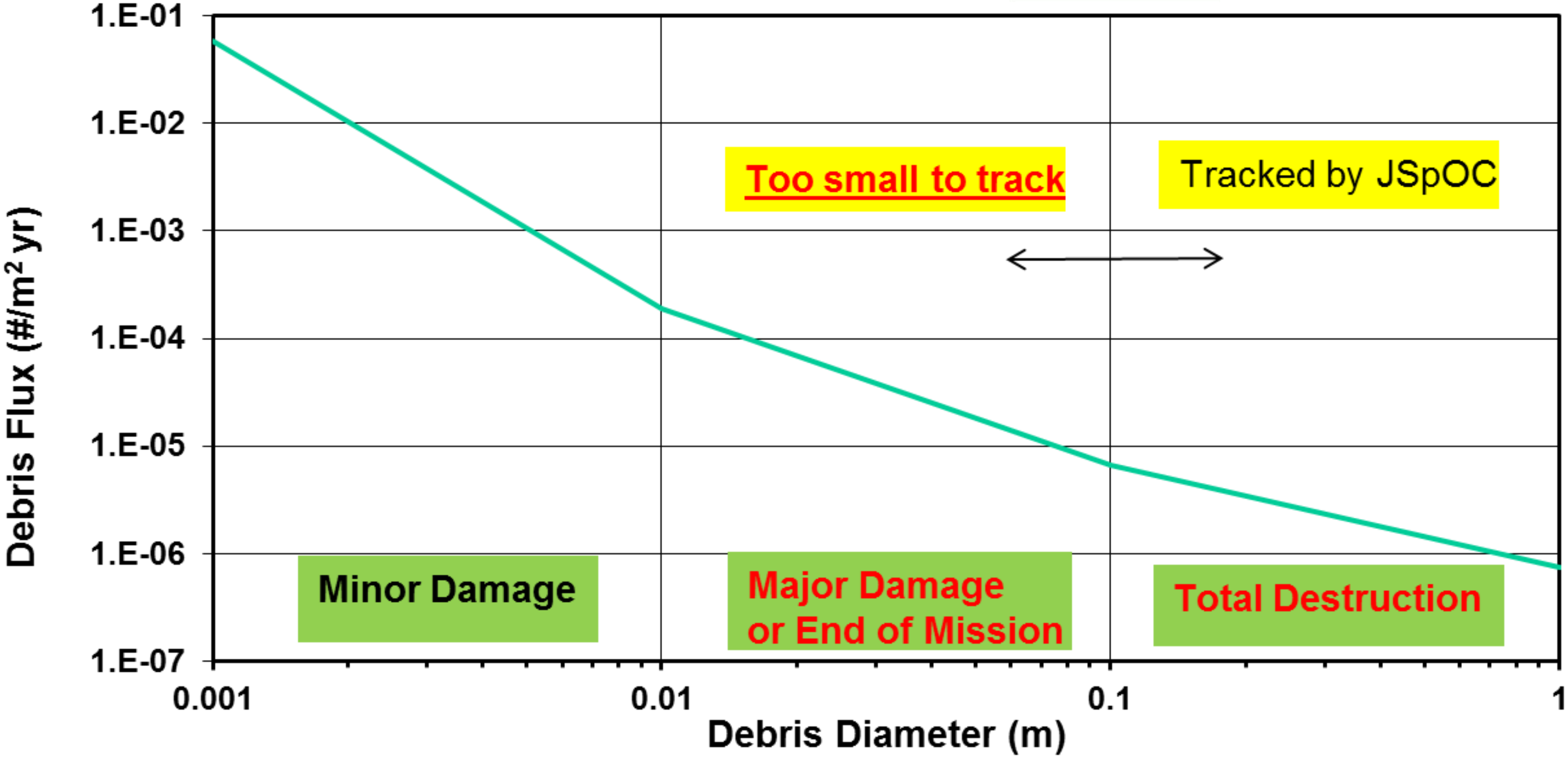
~ **18,000** objects ≥10 cm in size being tracked

~ **500,000** objects ≥1 cm in size

Many Millions of objects <1 mm in size

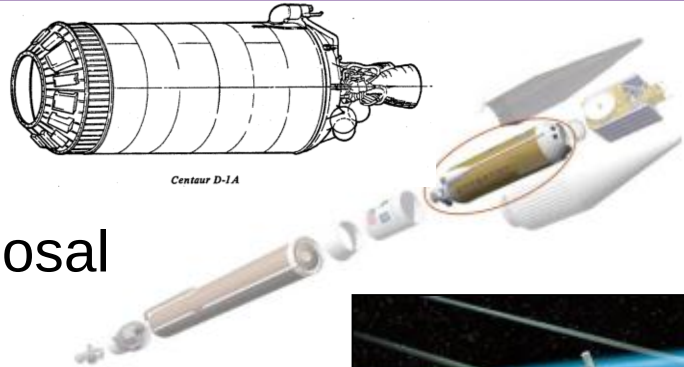
- Spacecraft damage potential
  - Moving at 7.5 km/s → ~**17,000 mph**!
  - ½ mv^2 gets to be really big, really fast
  - 1-2 mm particle can penetrate most robotic spacecraft surfaces
- Tracking limitations currently about 10 cm

Debris Flux in the A-Train Orbit

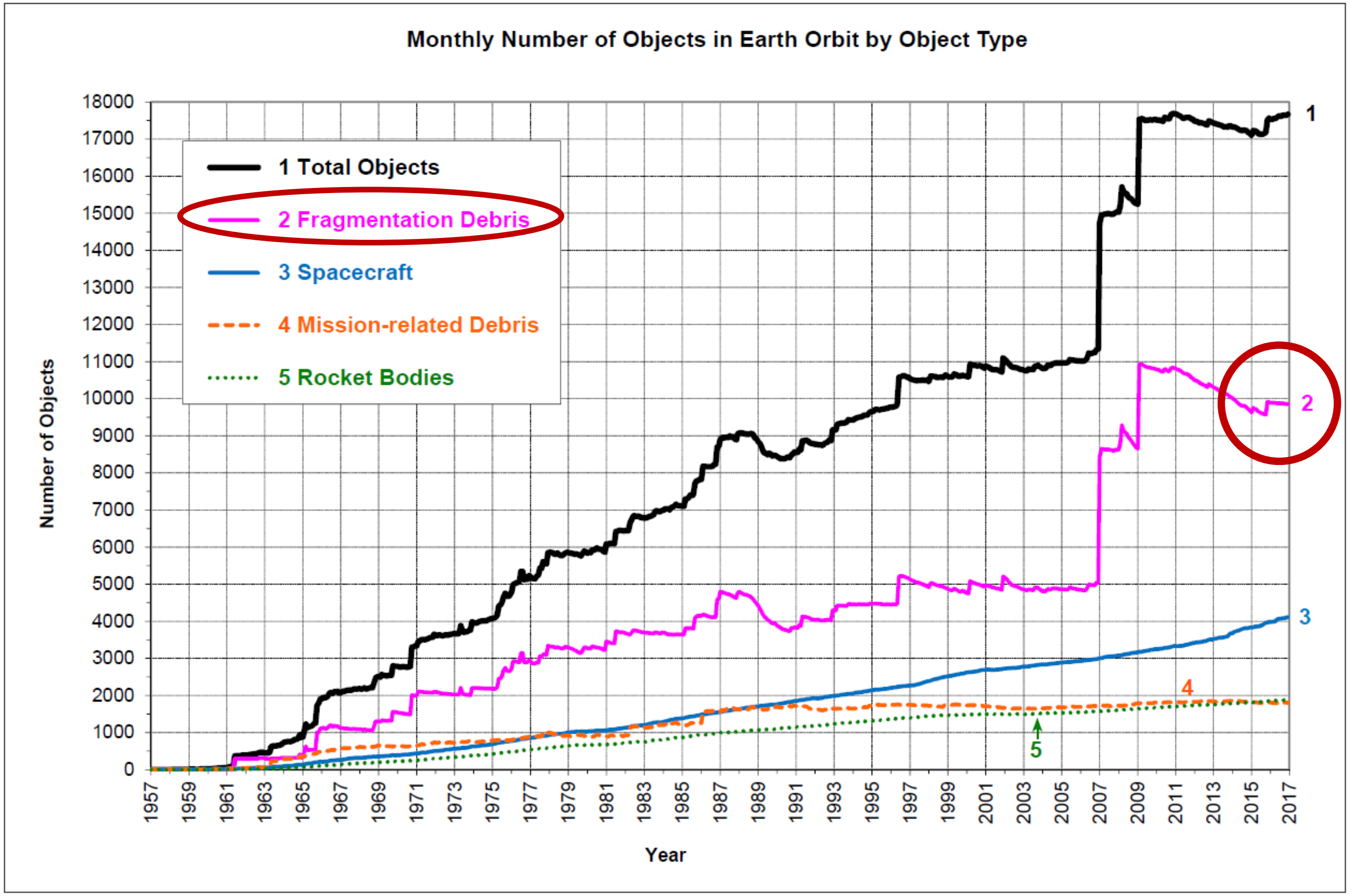


Debris Sources

- Launch Vehicles
- Spacecraft
  - Lack of proper disposal
- Collisions
  - Small collisions as well as large
- Explosions
  - Residual fuel and oxidizer
  - Batteries
  - Pressure tanks
- Meteoroids
  - Natural random environment
  - Meteor showers

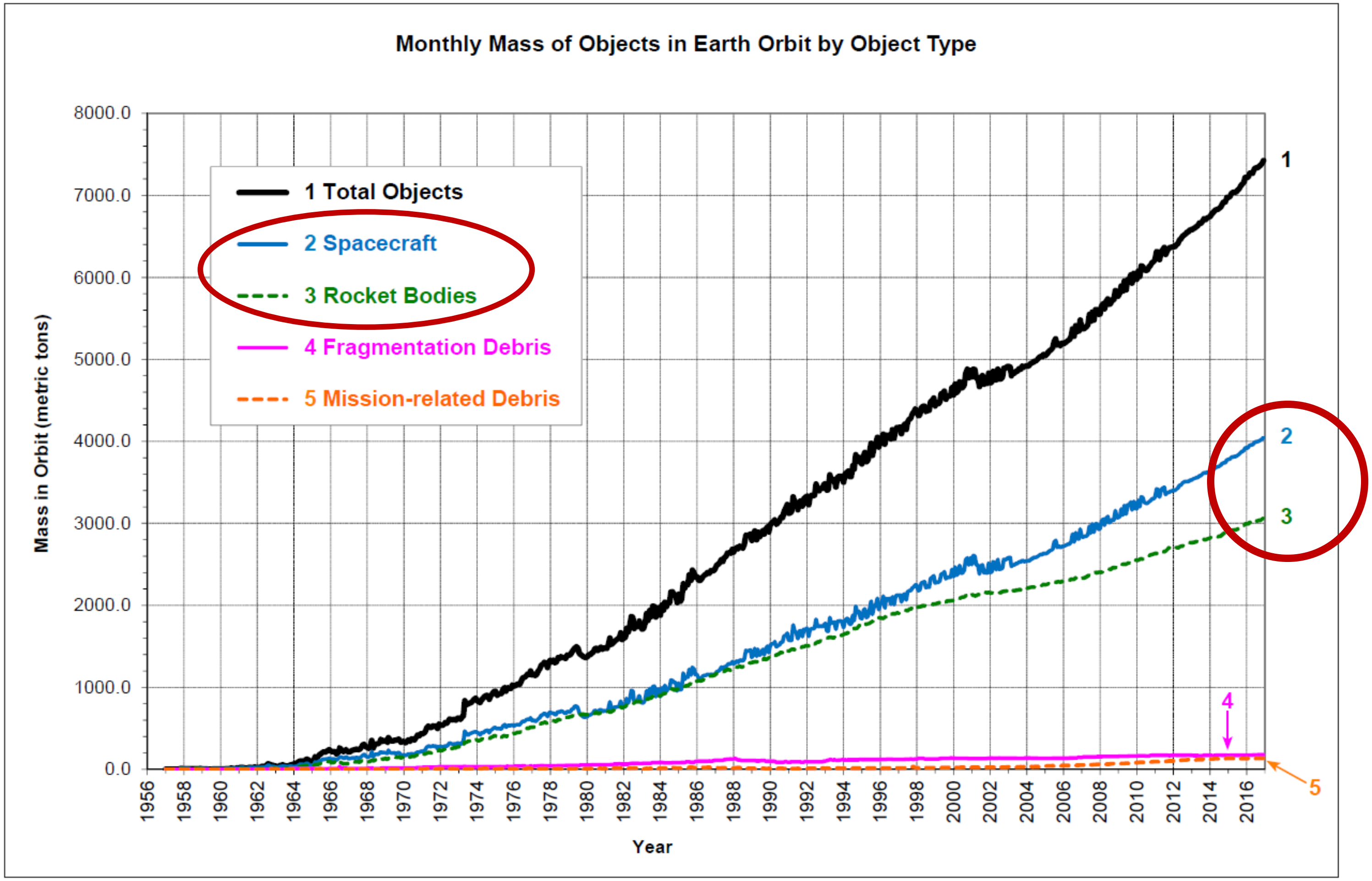


Number of Objects by Object Type



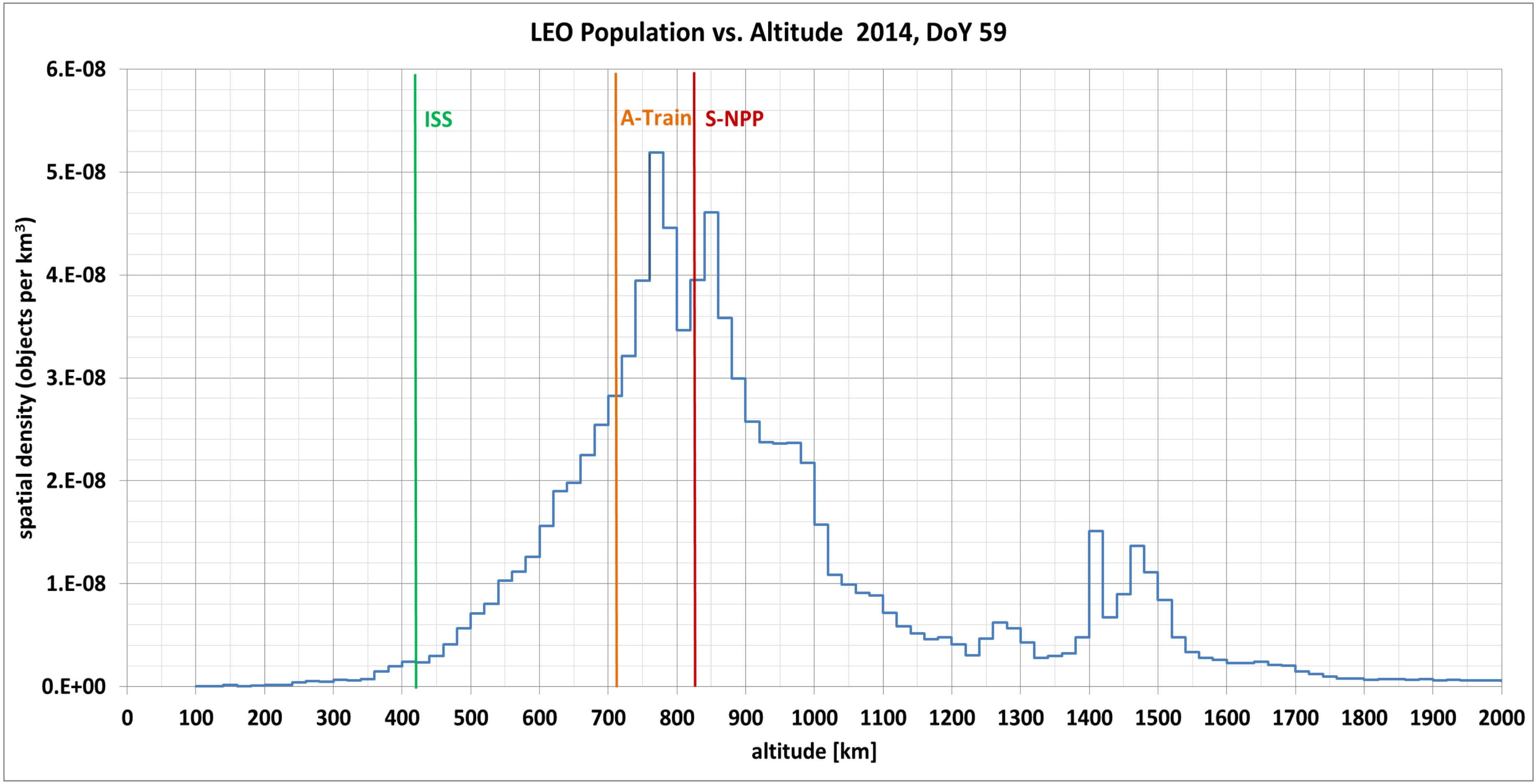
Most debris pieces are fragments

Mass of Objects by Object Type

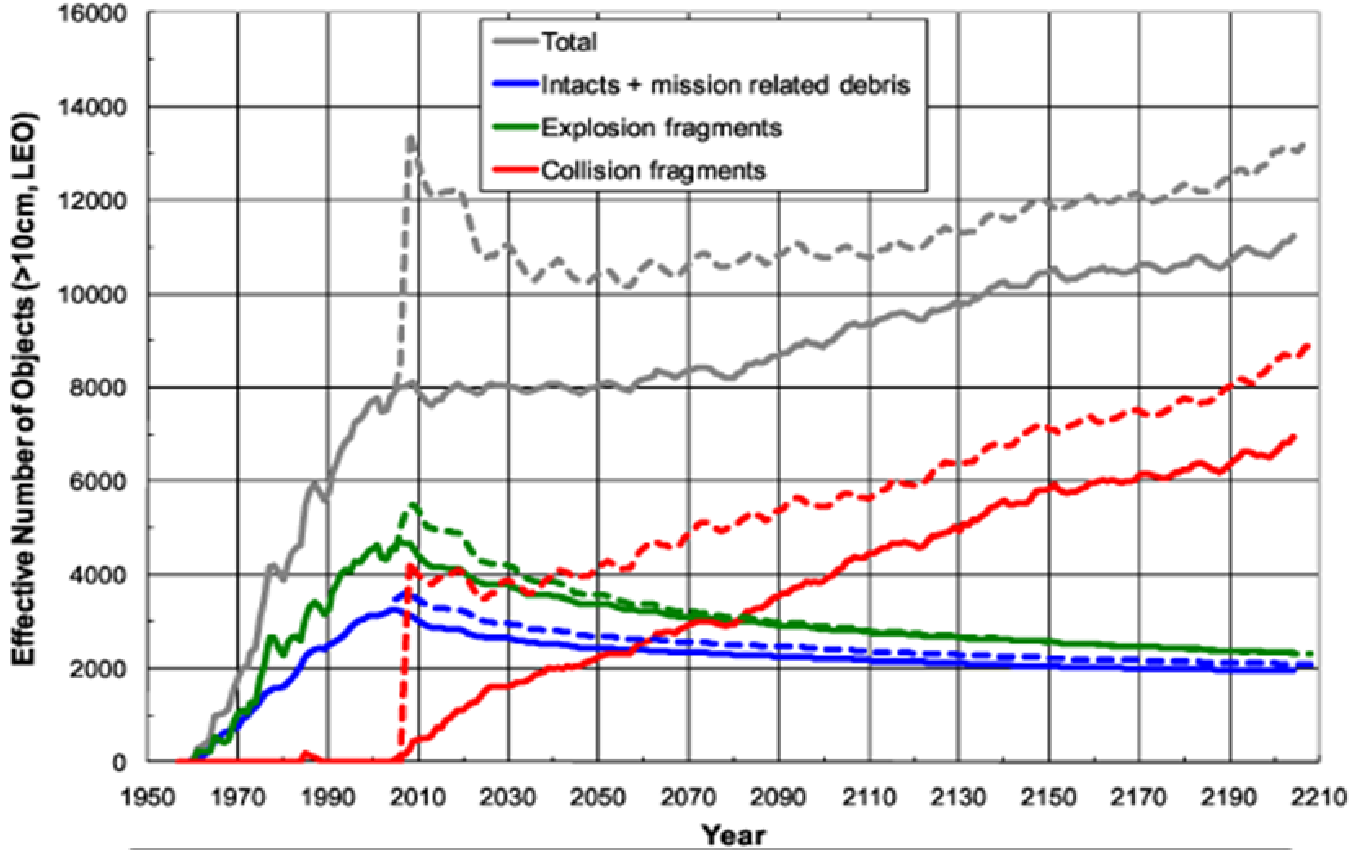


Most mass is still in big pieces

Debris Density vs. Altitude



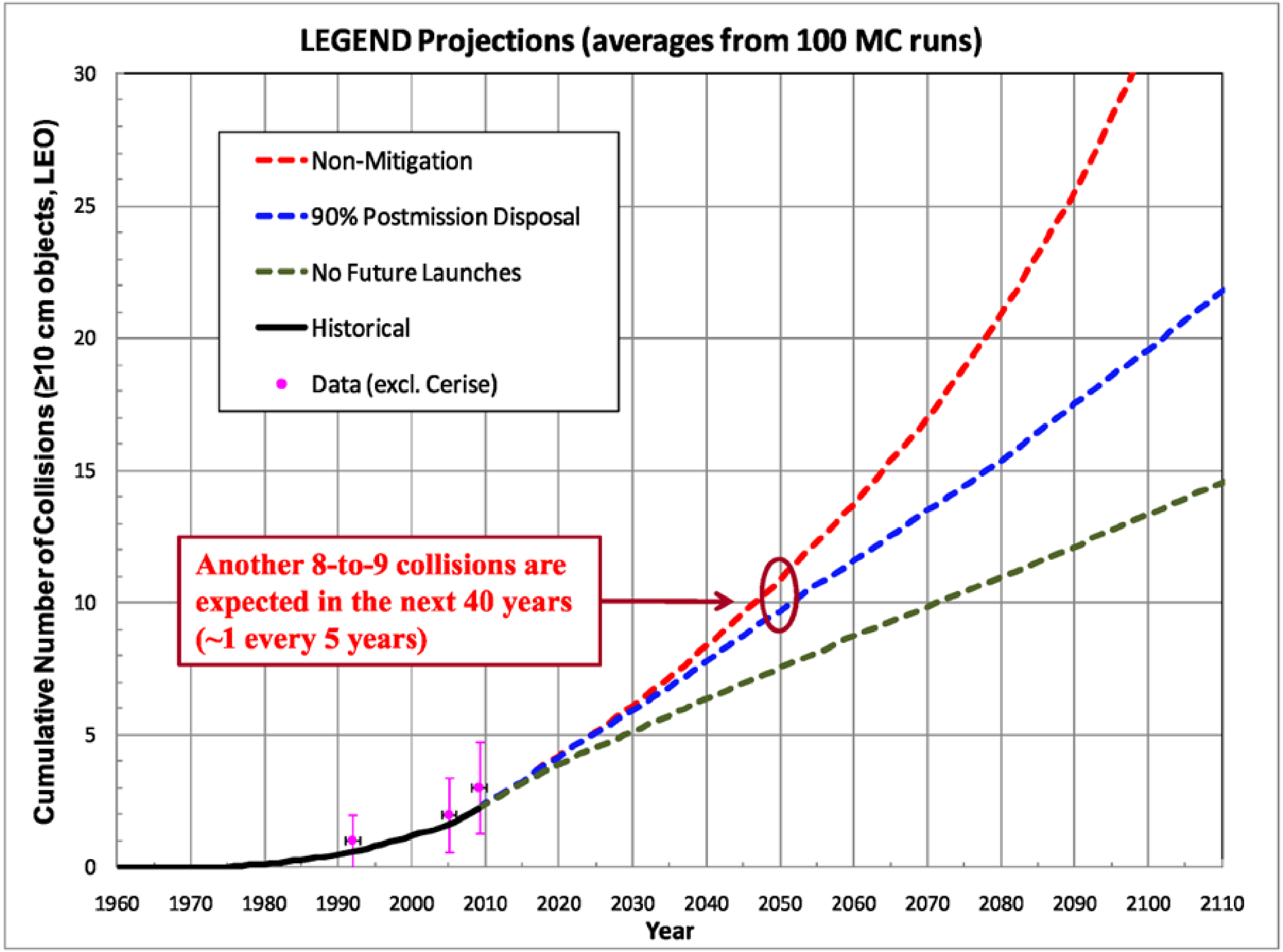
Long-term Growth of LEO Debris Population



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

The debris population is self-propagating

Collision Predictions with and without disposal efforts



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
    - Low chance of it ever happening on a GSFC mission
    - No known case to-date of a NASA spacecraft being fatally struck by MMOD
    - 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

What is NASA Doing About It?

- Environment modeling
- Penetration testing/ shielding development
- Prevention of future debris (depends on early planning)
  - Before and During the mission
    - Controlling operational debris
    - Preventing explosion risks
    - Anticipate small particle impacts
    - Conjunction assessments
  - Decommissioning and beyond
    - Minimize stored energy left on-board
    - Reduce orbital lifetime as much as possible
    - Control the risk from reentry

NPR 8715.6B

The newest procedural requirements

NPR 8715.6B Overview

- Issued February 16, 2017
- Clerical updates (SOMD → HEOMD, for example)
- Removes obsolete NSS 1740.14 references
- Streamlines and clarifies the ODAR and EOMP Headquarters review process
- Collects all requirements into one chapter
- Generously streamlines the document
- Isolates policy requirements from technical requirements
- Reduces the number of “shall” statements, obvious details, quoting reference documents, and redundancy

Reorganization

- Chapter 1 shortened
  - Just Objectives, Policies, and Relief/waivers
- Chapter 2: Roles and Responsibilities
  - Shortened list of roles (8 vs. 14)
  - No requirements in Chapter 2
  - Simply spells out who does what
- Chapter 3: Requirements
  - Organized by mission phase
  - Table A shows life cycle milestones, reports required, and who at Headquarters reviews or signs them

The Requirements

- More emphasis on HQ responsibilities, especially early in the mission
- Removal of technical requirements to the technical standard NASA-STD 8719.14
- EOMP updates at Mission Directorate reviews, “but no less than once every two years”
- Conjunction assessments required for “operational Earth-orbiting spacecraft” (had been “maneuverable”)
- Waivers are requested by the MDAA, and granted by the Chief, SMA (Project Manager supports the request)

Other Changes in NPR 8715.6B

- Milestone due dates
  - ODARs are due <u>at</u> the review, not XX days before
- MDAA Approval
  - No longer required at every milestone submittal
  - ODARs: only the Final ODAR needs MDAA approval/signature
- Combined reports at SMSR
  - "The final ODAR and initial/pre-launch EOMP may be combined and submitted as one document for the SMSR."
- CubeSats
  - For CubeSat missions that will passively reenter within 25 years, the ODAR may also serve as the EOMP.

ODAR/EOMP
GSFC REVIEW PROCESS

Document Review Process Changes

- Now following Flight Projects Directorate (Code 400) external document review and approval process
- Clerical standards per NPR 1450.10D, and FPD-specific detailed standards
- Review by Codes 100, 300, 400, and 500 prior to HQ submittal
- For practicality, Division technical and clerical reviews, then Code 380 review, precede the project configuration management process

ODAR Review Process

- Develop ODAR with Systems Engineer and project
- Division (4X0) technical and clerical review
- 380 technical review
- Project CM, including Project Manager
- **Then** follow the routing sheet

GSFC Route Sheet

Code	Name	Purpose*	Initials**	Date In	Date Out	Remarks
	Initiator					
	Initiator's Supervisor	2				
	Division Office	2				
380	J. Wonsever	2				
380	G. Maggio	2				
300	E. Isaac	2				
500	T. Trenkle	2				
500	F. Jones-Selden	2				
400	S. Straka	2				
400	T. VanSant	2				
400	N. Chrissotimos	2				
400	D. Mitchell	2				
130	N. Robey	3				
100	Code 100	2/4				

EOMP Review Process

- Develop ODAR with Mission Director and FOT
- Division (4X0) technical and clerical review
- 380 technical review
- Project CM, including Project Manager
- **Then** follow the routing sheet

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HQ		3				

RECENT ACTIVITIES

NESC Study

"Evaluation of Micrometeoroid and Orbital Debris (MMOD) Risk Predictions with Available On-orbit Assets"

- Follow-on to a NESC Study of JPSS-1 Risks
- Core Team: 8 Civil Servants, 6 contractors
- A study was performed comparing MMOD penetration risk to observed anomalies
- It included components on ISS and three satellite systems from 705 to 860 km
- Important to note that this **studied the entire risk estimation process**, <u>not just the environment model</u>

NESC Study Findings

- Predicted failures were clearly higher than reported failures, especially at higher orbits, but the difference was not quantifiable (too few observed failures)
- There are many sources of uncertainty inherent in the current risk prediction process
  - Methods, tools, and assumptions
  - Models, penetration equations, and inputs
  - Risk predictions can be very sensitive to shape assumptions
  - **Risk predictions can be very sensitive to the physical modeling of the spacecraft**

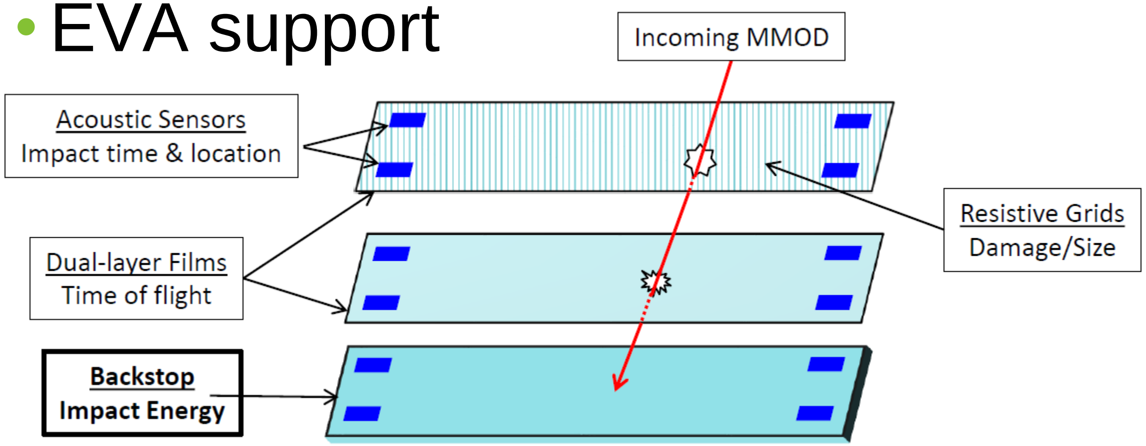
EO-1 End of Mission

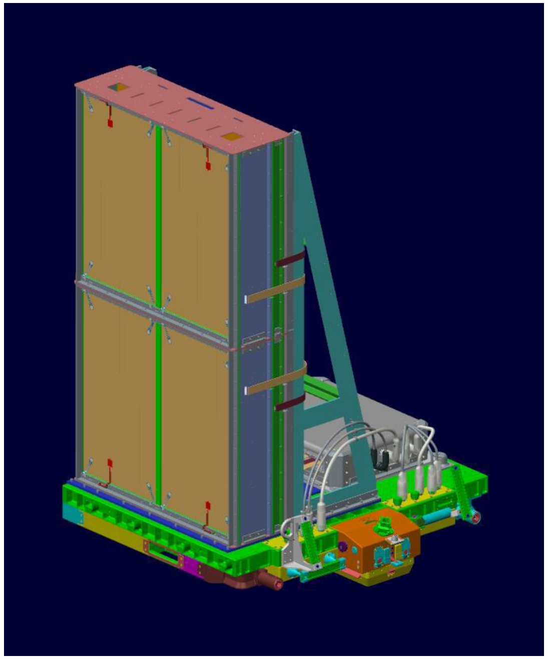
Spacecraft was decommissioned March 30, 2017

- Differential Drag Experiment
  - Re-oriented into minimum and maximum drag orientations
  - Purpose was to demonstrate differential drag at ~680 km
    - Compare observed effects to predictions
    - Study the Flight Ops aspects: logistics, spacecraft limitations, planning, etc.
  - Lessons
    - The spacecraft was displaced measurably using no propulsion
    - Much easier if the spacecraft is designed for different orientations
    - Early planning <u>and testing</u> is important; well ahead of potential need
    - A small, flexible team was key to successful experiment
    - Even an experienced team can't always predict the spacecraft response
  - Results to be presented in November at IAA Conf. on SSA

Space Debris Sensor (SDS)

- ODPO effort to place a DRAGONS sensor on ISS
- 1 m^2 area in situ detector for particles
- Built and tested; ready to fly to ISS this year
- Long-term collector
- Seasonal data
- EVA support





Conclusions/Take-aways (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.
- Orbital debris is a future problem, that we need to address today.
- The requirements document for policies and procedures has been updated and clarified.
- Center review of ODARs and EOMPs is more thorough, reflective of documents going to HQ.

Conclusions/Take-aways (2 of 2)

- An NESC study has identified several aspects of the small particle penetration risk assessment for improvement.
- We did an experiment where we moved a spacecraft without propulsion, and learned a lot about the operations considerations necessary.
- A new sensor going onto ISS will help define the small particle environment and changes over time.
- Code 592 and JSC/ODPO can assist with design optimization for limiting orbital debris and decommissioning, as well as documentation.

ORDEM 3.0

ORDEM 3.0

- The Orbital Debris Engineering Model Version 3.0 (ORDEM 3.0) is the official orbital debris environment model at NASA, and is produced by the Orbital Debris Program Office (ODPO) at Johnson Space Center.

- ORDEM 3.0, released in 2014, replaced ORDEM2000 (also known as ORDEM 2.0), which was released in 2002.
  - ORDEM 3.0 incorporates important fragmentation events from the last decade: FY-1C (2007) and Iridium-Cosmos (2009).
  - While previous versions assumed a single, average density for all particles, ORDEM 3.0 divides the orbital debris environment in five “bins” based on density.
  - ORDEM 3.0 can be requested through the NASA Software Catalog:

  https://software.nasa.gov/software/MSC-25457-1

ORDEM 3.0 Comparison with Previous Version

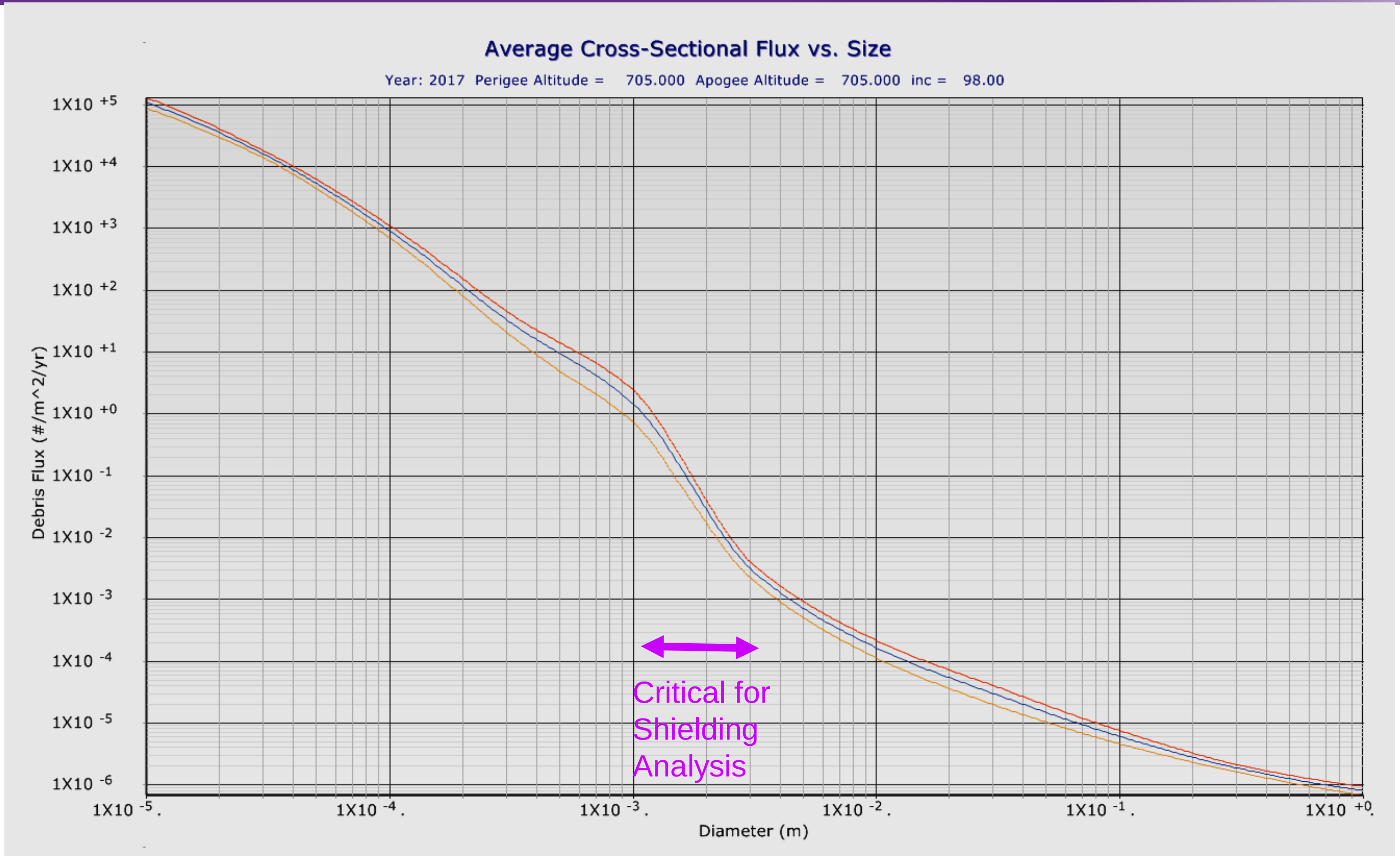
From NASA Orbital Debris Engineering Model ORDEM 3.0 – User's Guide:

Parameter	ORDEM 2.0	ORDEM 3.0
Spacecraft & Telescope/Radar analysis modes	Yes	Yes
Time range	1991 to 2030	2010 to 2035
Altitude range with minimum debris size	200 to 2000 km (>10 μm) (LEO)	100 to 40,000 km (>10 μm) (LEO to GTO) 34,000 to 40,000 km (>10 cm) (GEO)
Orbit types	Circular (radial velocity ignored)	Circular to highly elliptical
Model population breakdown by type & material density	No	Intacts Low-density (1.4 g/cc) fragments Medium-density (2.8 g/cc) fragments & microdebris High-density (7.9 g/cc) fragments & microdebris RORSAT NaK coolant droplets (0.9 g/cc)
Model cumulative size thresholds (*fiducial points*)	10 μm, 100 μm, 1 mm, 1 cm , 10 cm, 1 m	10 μm, 31.6 μm, 100 μm, 316 μm, 1 mm, 3.16 mm, 1 cm, 3.16 cm, 10 cm, 31.6 cm, 1 m
Flux uncertainties	No	Yes
Total input file size	13.5 MB	1.25 GB
Meteoroids	No	No

http://ston.jsc.nasa.gov/collections/TRS/_techrep/TP-2014-217370.pdf

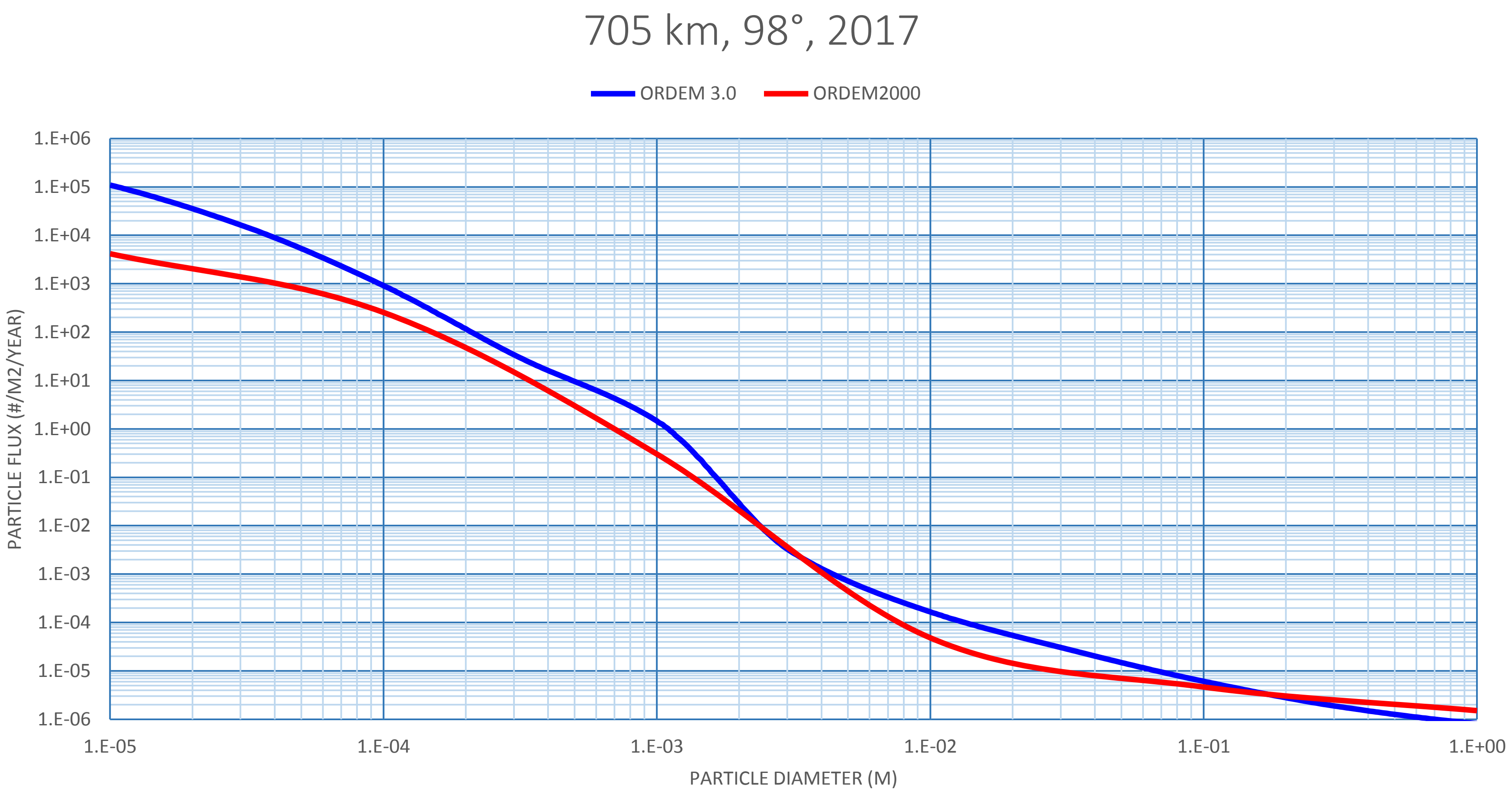
Typical ORDEM 3.0 Plot

(Example assuming 705 km altitude, 98° inclination, Year 2017)

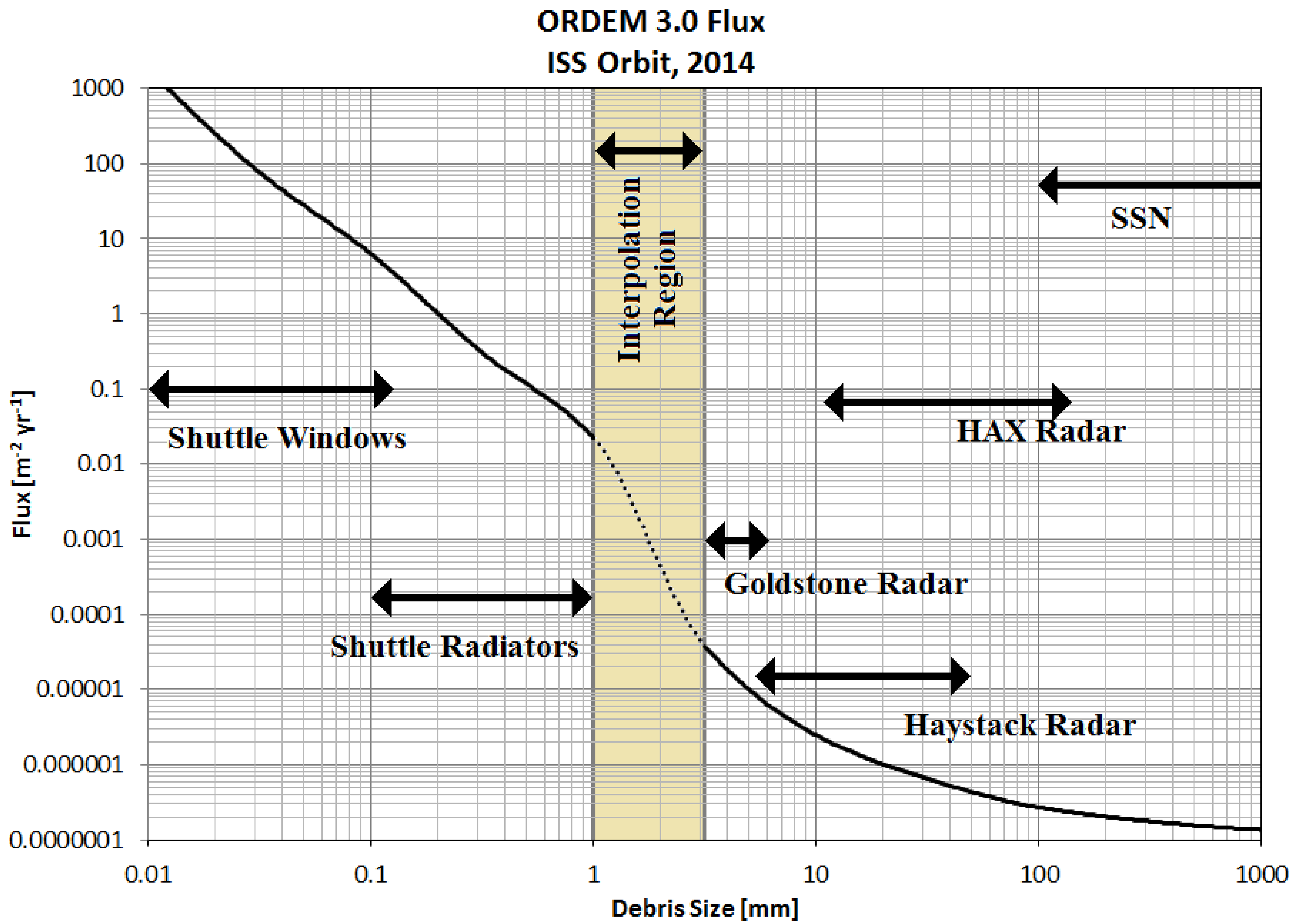


Typical ORDEM 3.0 plot: the blue line is the average orbital debris flux for a given particle size; the orange and red denote uncertainty bounds.

Comparison with Previous ORDEM version



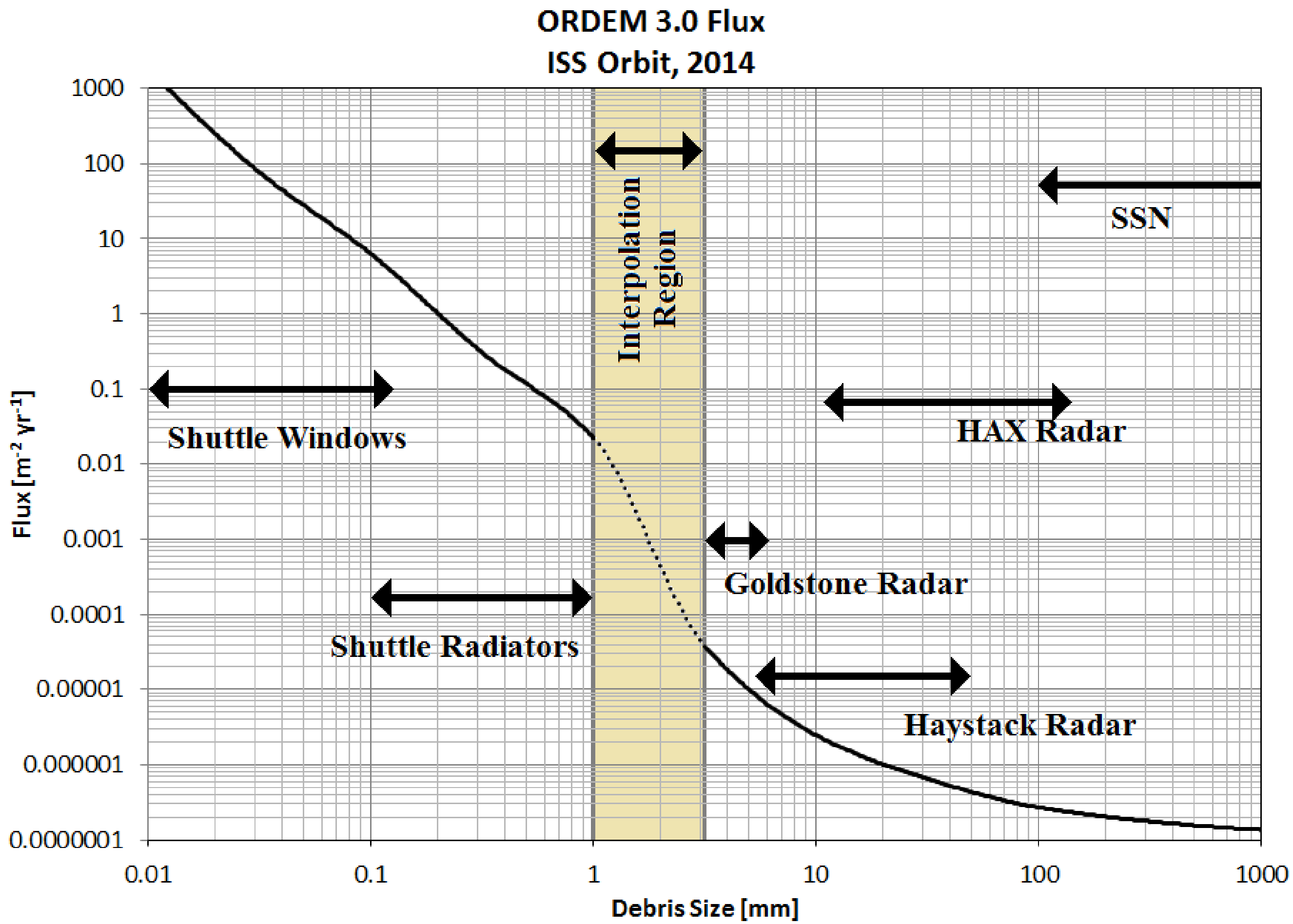
ORDEM 3.0 Data Sources



ODPO

ORDEM 3.0 Data Sources

- What we know about High Density particles originates from Shuttle data.



ODPO

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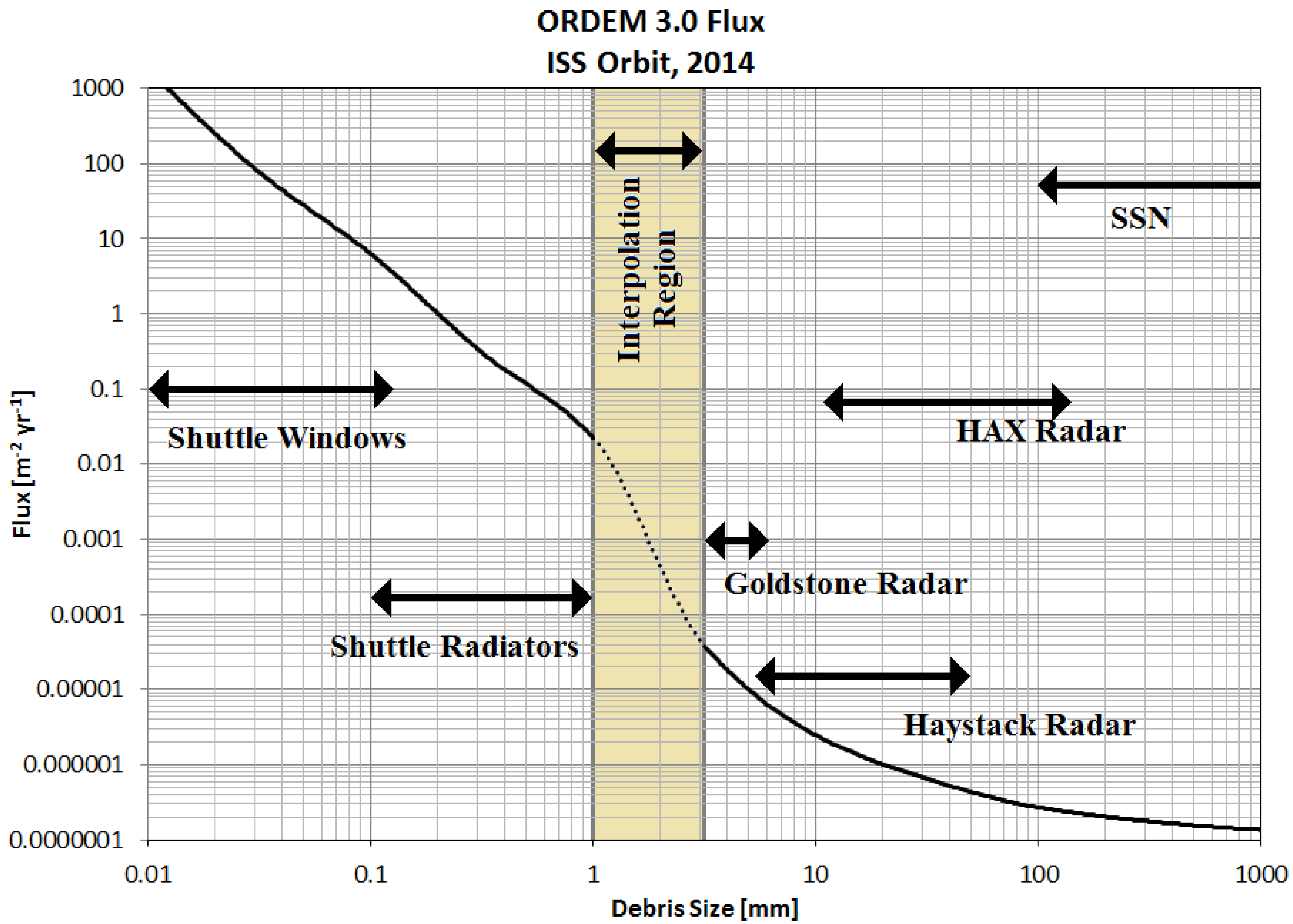
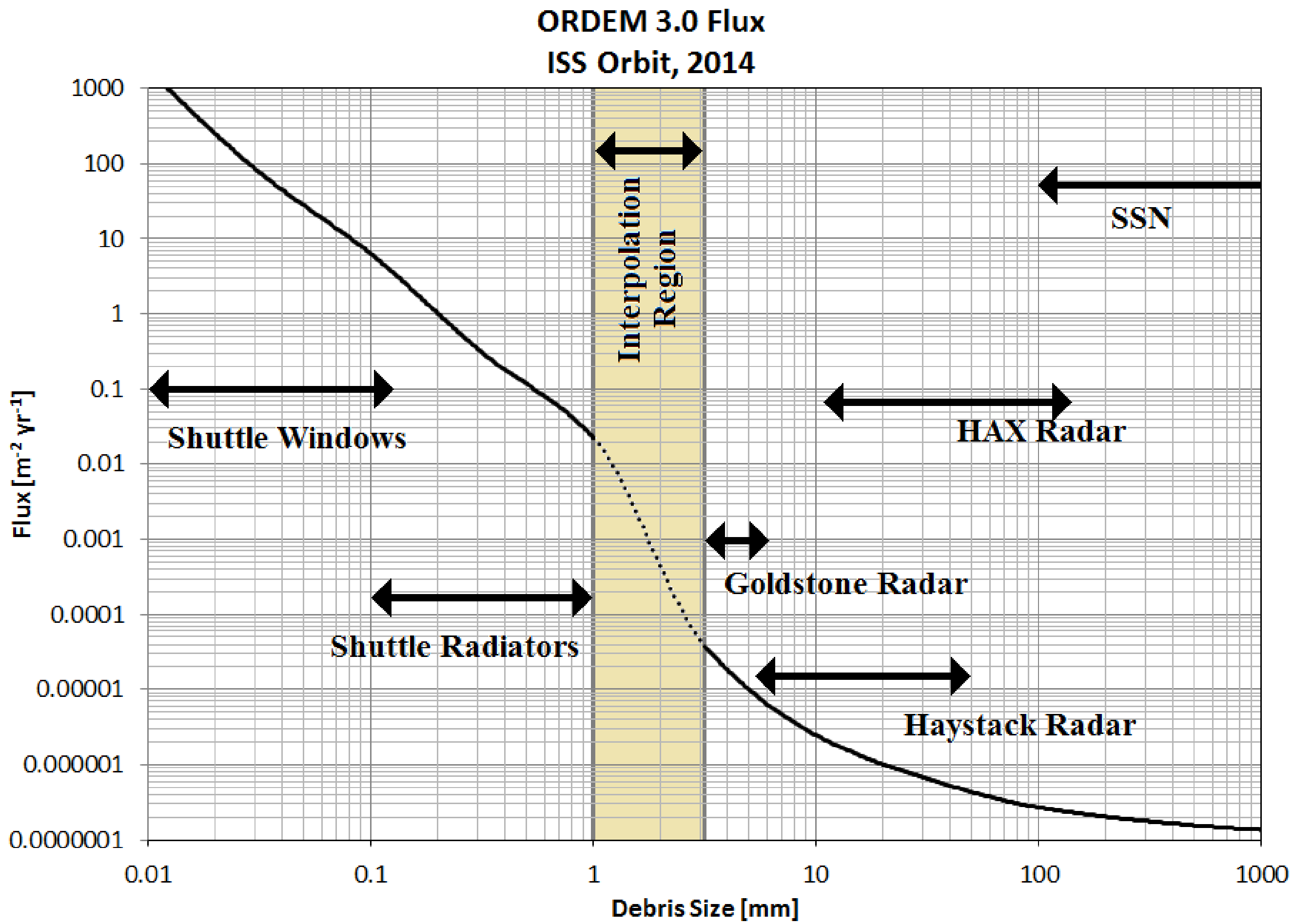
- Where those high density particles came from?



ODPO

ORDEM 3.0 Data Sources

- What we know about High Density particles originates from Shuttle data.
- Where those high density particles came from?
- Are they still being produced?



ODPO

Is That All?

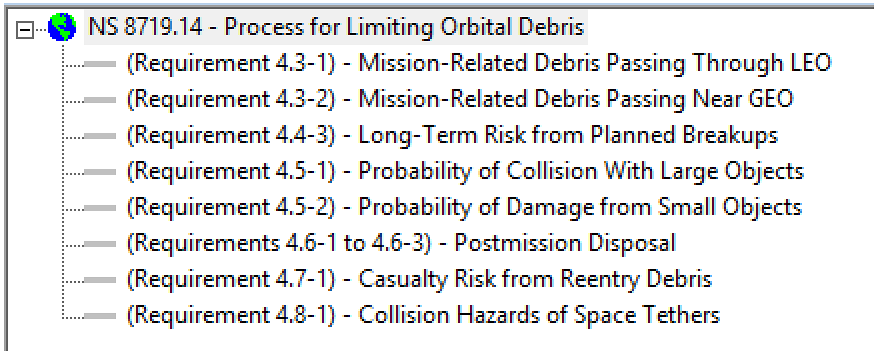
- The particle environment as described by ORDEM 3.0 gives an idea of the severity of the orbital debris population at a given altitude, inclination, and year. However, it does not provide much information on specific damage that a spacecraft can withstand. The probability of damage to an specific component is relative to its wall thickness and material, location on spacecraft, and relative shielding from other components or structures.

- For a better understanding of potential risk to a spacecraft specific component, NASA provides a high-fidelity hypervelocity impact simulation tool known as Bumper 3.0 (U.S. Government Purpose release), and a more basic simulation module as part of the Debris Assessment Software (general public release).
- For the purpose of this Seminar, we will focus on the Debris Assessment Software (DAS) because of its recent release and widespread availability.

DAS 2.1.1

Debris Assessment Software (DAS) Version 2.1.1

- DAS 2.1.1 was released by the Orbital Debris Program Office in January 2017.
- The main purpose of the DAS software is to assess spacecraft compliance with orbital debris requirements as described in the NASA-STD-8719.14A.
- To make the software “user friendly”, accessible to any spacecraft analyst, algorithms were simplified (reduced number of parameters needed), resulting in conservative results compared to more specialized tools.
- DAS 2.1.1 uses a “built-in” version of ORDEM 3.0 to predict particle flux that may produce spacecraft damage (Probability of collision with large and small objects).

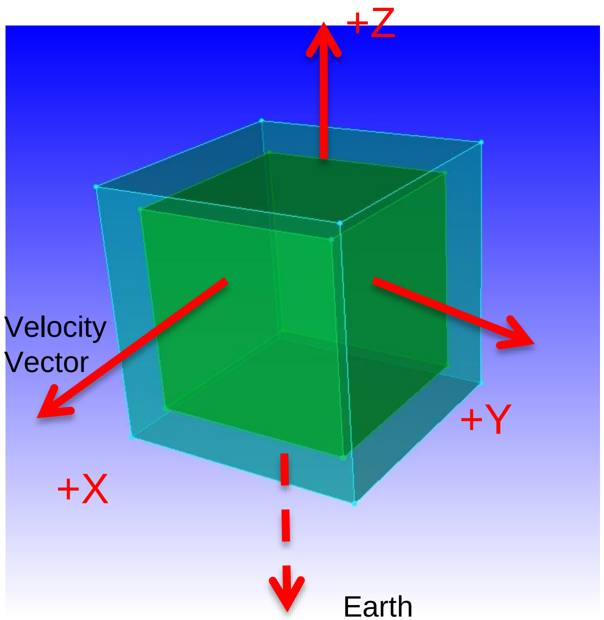


- The software is available from the NASA Software Catalog: https://software.nasa.gov/software/MSC-26234-1

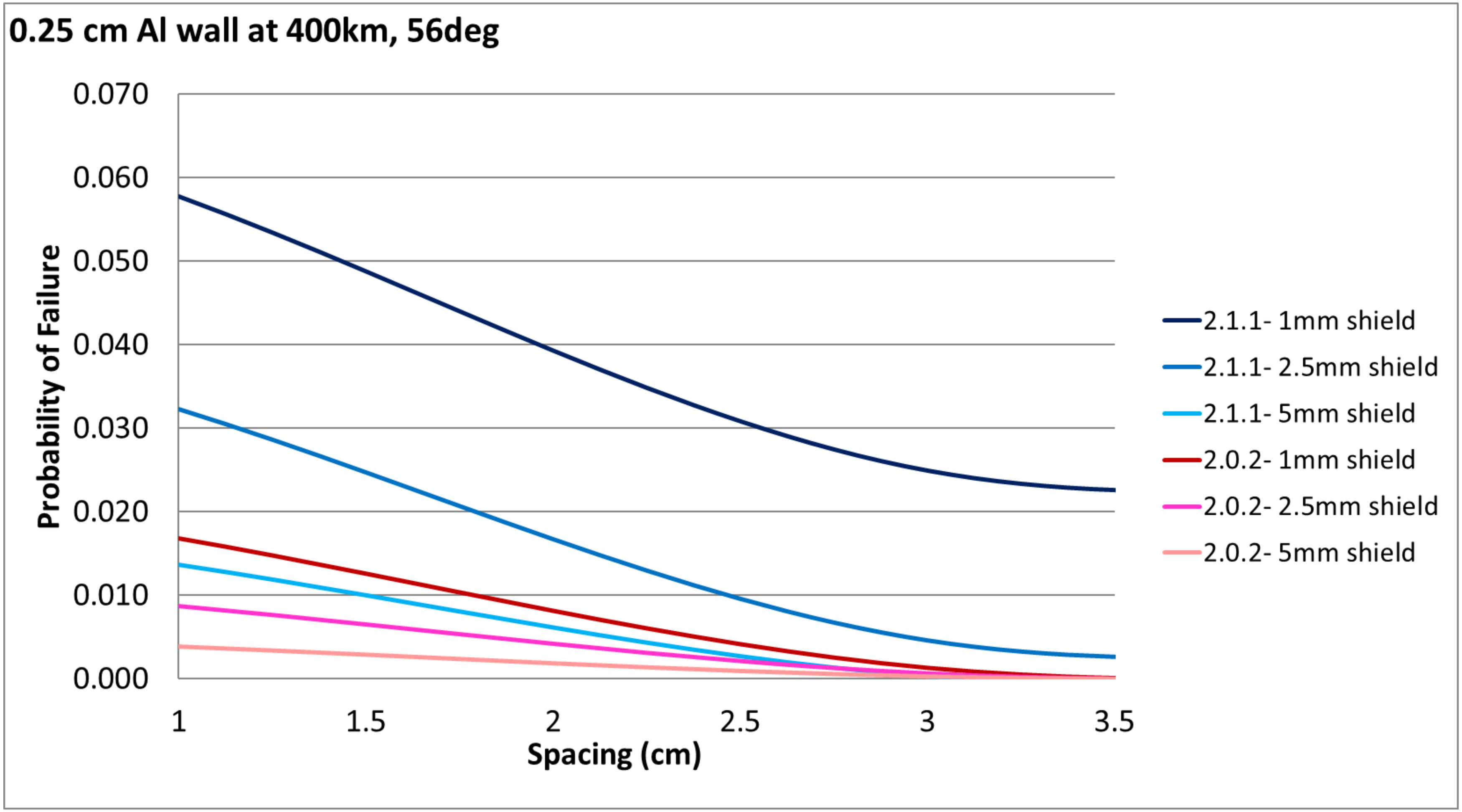
DAS Example with Cube Model

- The following analysis was run to compare a simple cube model in DAS 2.0.2 and 2.1.1. Assumptions:
  - 1m x 1m x 1m hollow cube as the critical surface; each face is an aluminum plate 0.25-cm thick.
  - Fixed orientation; unpressurized.
  - “Mission” lifetime: 1 year, starting 1/1/2020.
- A second aluminum cube (different thicknesses and separations) forms a Whipple shield that protects the inner cube.
- DAS calculates the Probability of Penetration (PP), also known as Probability of Failure, for each side and for the complete “spacecraft”.
  - See basic coordinate system at right.
  - A failure is defined as penetration of the cube’s inner wall.

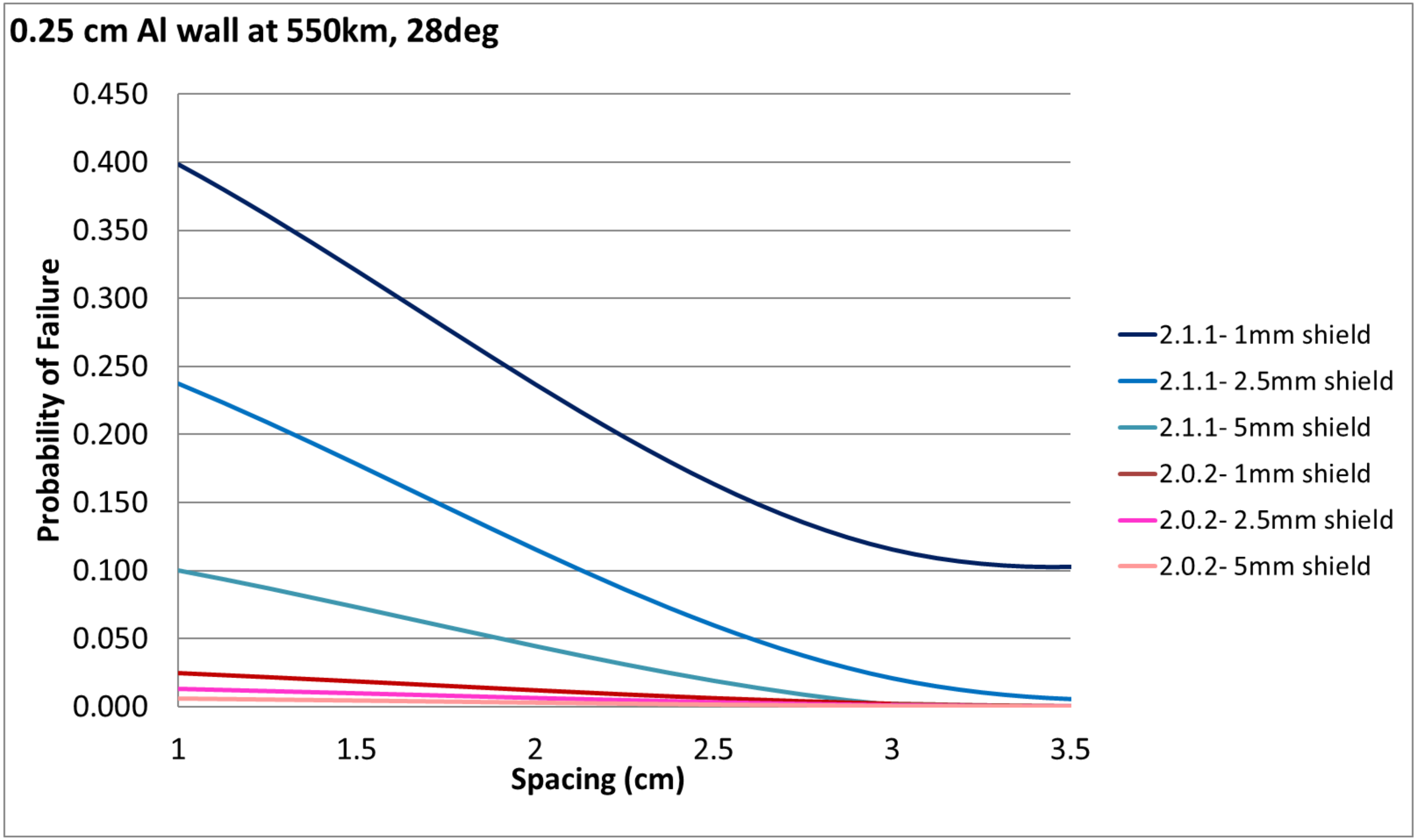
Green cube= critical surface or rear wall
Blue cube = shield



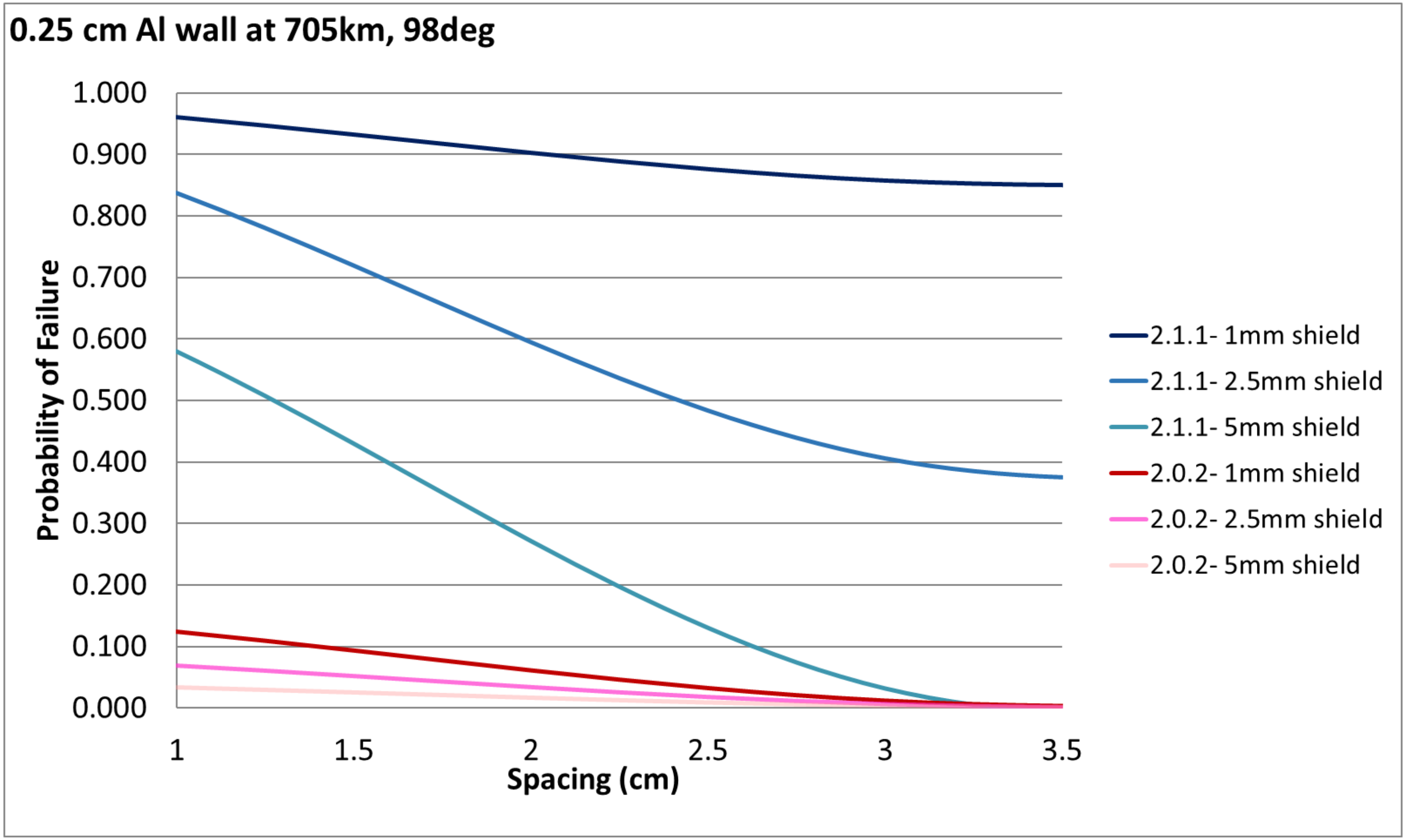
DAS 2.1.1 Example, 3 of 3



DAS 2.1.1 Example, 2 of 3

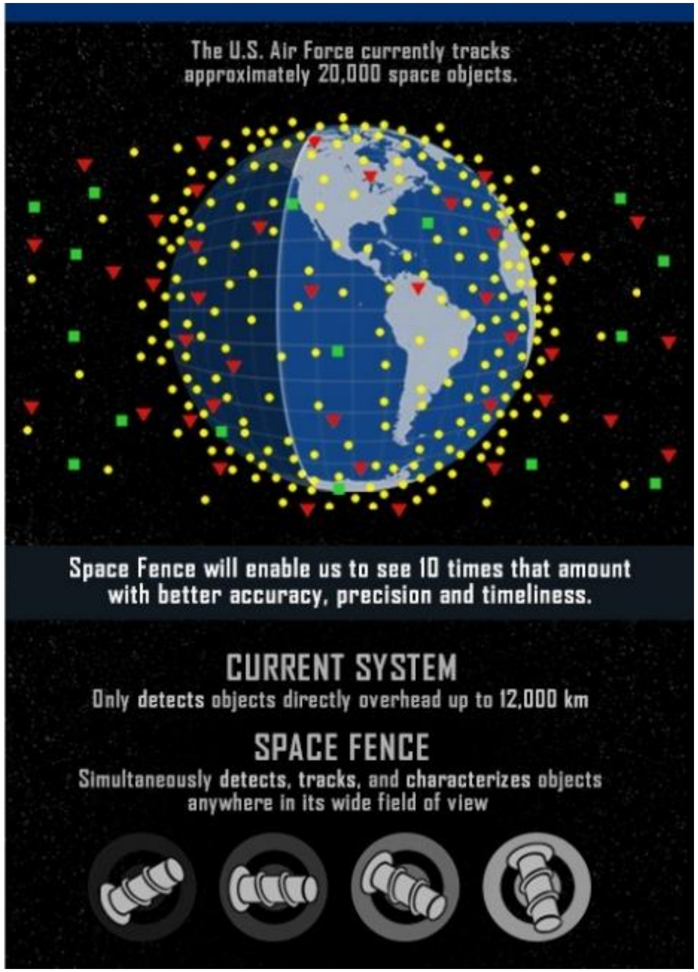


DAS 2.1.1 Example, 1 of 3



SPACE FENCE

Space Fence



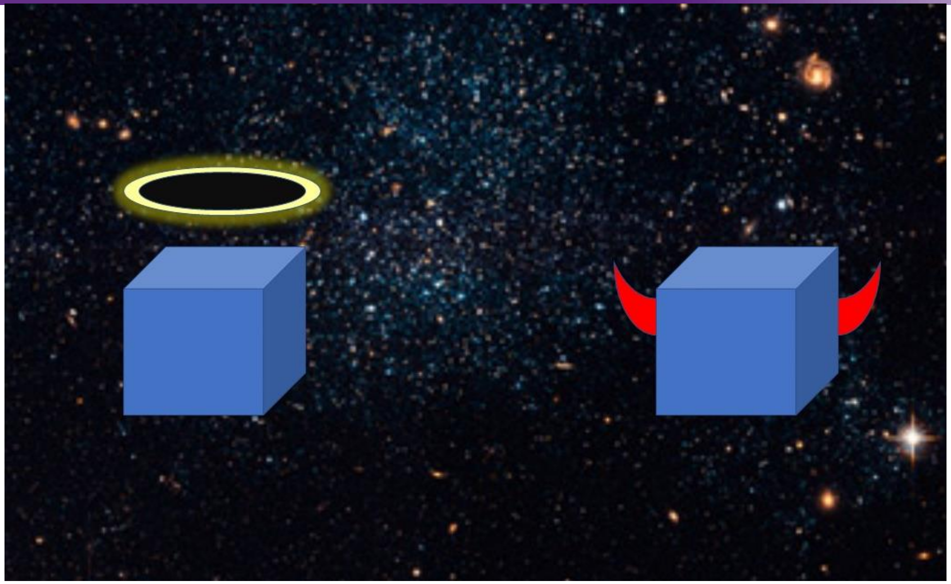
http://www.lockheedmartin.com/us/products/space-fence.html

- New S-band radar under construction on the Kwajalein Atoll in the Marshall Islands, near the equator.
- Expected to detect marble-size objects.
- Expected to be completed in late 2018.
- Lockheed Martin estimates a 10x increase in tracked objects. Other estimates propose a 3x increase.
- Projected reduction in collision avoidance maneuvers must be weighted against increased number of tracked objects.

CUBESATS AND MEGA-CONSTELATIONS

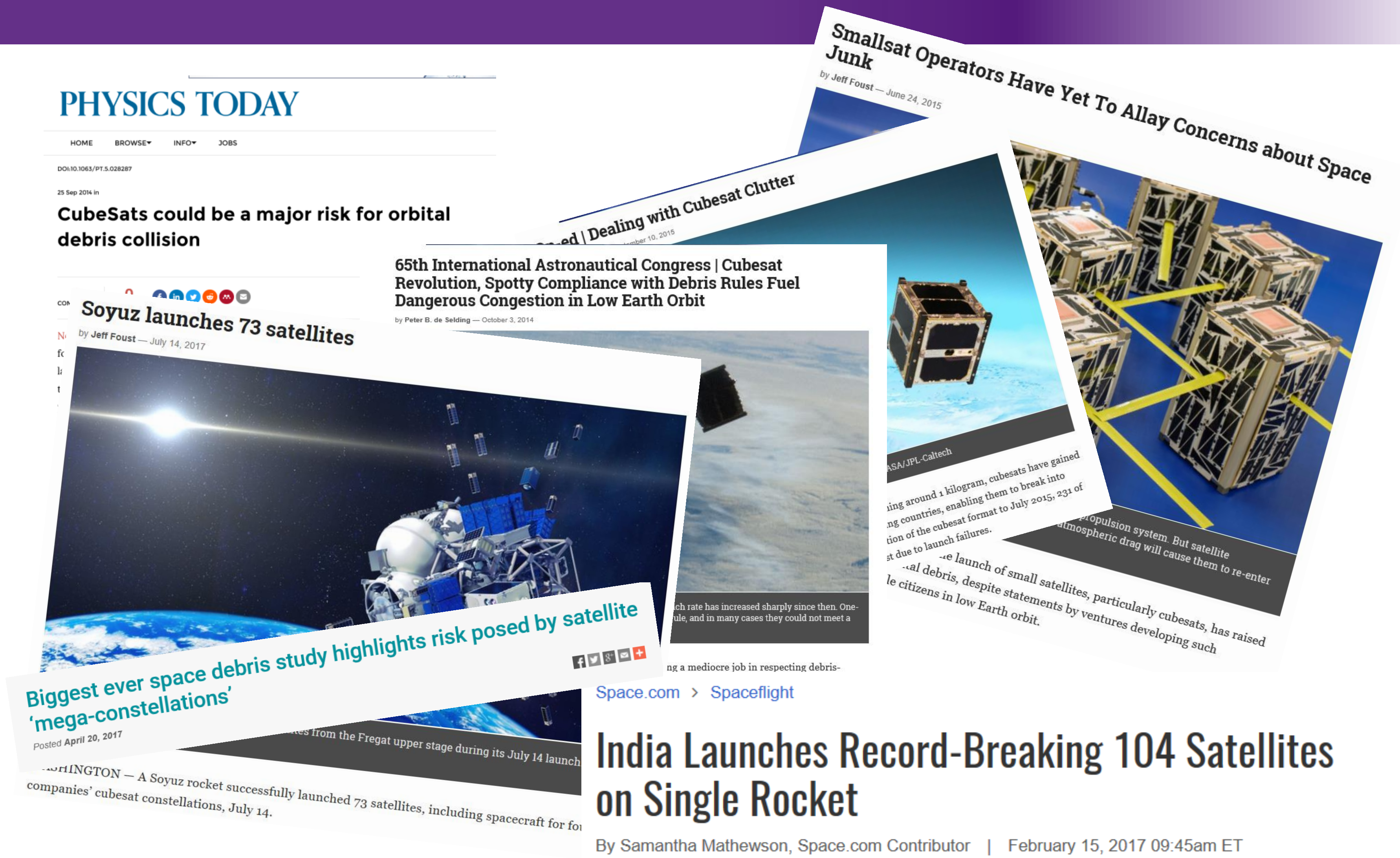
CubeSats: Friends or Enemies?

CubeSat – Small spacecraft with dimensions in multiples of 10 cm x 10 cm x 10cm cubic units. Mass is ~ 1.3 kg per unit.



Advantages over traditional satellites	Disadvantages/Challenges
Less expensive to produce	Lower reliability
Faster to produce	Shorter mission lifetime
Small area	Harder to track

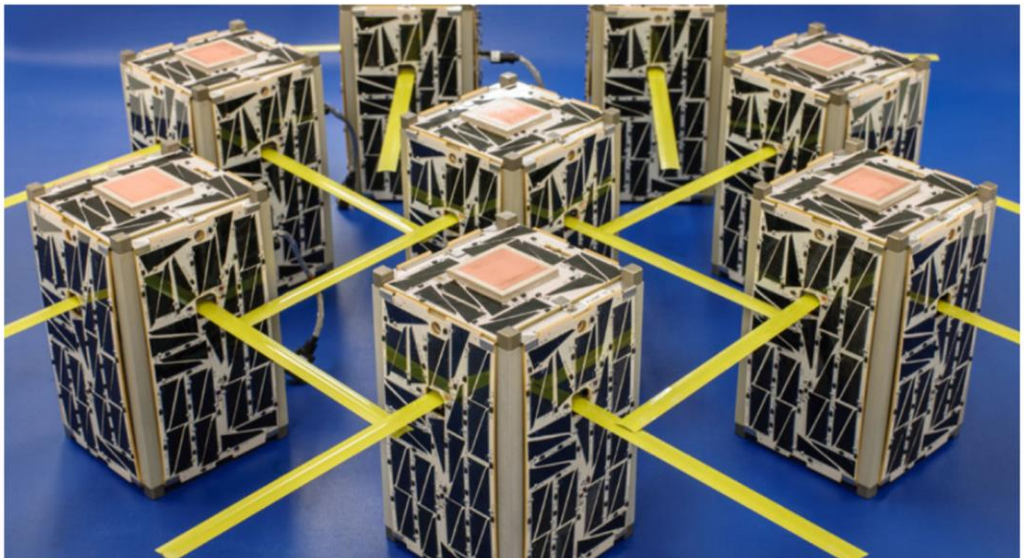
CubeSats in The News



Is my CubeSat "Evil"?

1 in 5 Cubesats Violates International Orbit Disposal Guidelines

by **Peter B. de Selding** — July 23, 2015



Most cubesats have no on-board propulsion system that can be used to de-orbit them at the end of their missions.
Credit: NASA

"More than 22,000 objects larger than 4 inches (10 cm) are currently tracked by the U.S. Space Surveillance Network. Only about 1,000 of these represent operational spacecraft; the rest are orbital debris."

https://www.nasa.gov/news/debris_faq.html

CubeSats are a small portion of objects > 10 cm in orbit

<u>In isolation</u>, the CubeSat is not worse than the traditional spacecraft in terms of orbital debris limitation.

Strength in Numbers?

Proposed constellations 100 spacecraft and larger.

In most cases, the spacecraft are larger than CubeSats.

NGSO APPLICATIONS TO FCC				
COMPANY	**LOCATION**	**NO. OF SATELLITES**	**BANDS**	**SERVICES**
SpaceX	Hawthorne, CA	7,518	V	Global broadband
SpaceX	Hawthorne, CA	4,425	Ka, Ku	Global broadband
Boeing	Seattle, WA	2,956	V	Advanced communications, Internet-based services
OneWeb	Arlington, VA	1,280	Ka, Ku, V	MEO Global broadband
OneWeb	Arlington, VA	720	Ka, Ku	First Generation LEO Global broadband
OneWeb	Arlington, VA	720	Ka, Ku, V	Second Generation LEO Global broadband
Kepler Communications	Toronto, ONT	140	Ku	Machine-to-machine communications (Internet of Things)
Telesat Canada	Ottawa, ONT	117	Ka	Wide band and narrow band communications services
Telesat Canada	Ottawa, ONT	117	V	Wide band and narrow band communications services
Theia Holdings A, Inc.	Philadelphia, PA	112	Ka, V	Integrated Earth observation and communications network
Spire Global	San Francisco, CA	100	AIS, ASM, GNSS	Maritime monitoring, meteorological monitoring, and earth imaging services

http://www.parabolicarc.com/2017/03/03/spacex-launch-12000-satellites

But They Are Small…

- The Aerospace Corporation * compared one hypothetical spacecraft with cross-sectional area of 1 m^2 with 100 spacecraft of 0.01 m^2 each.
  - Collision risk between a large satellite and a 0.01 m^2 CubeSat is not substantially less than the risk between it an a 1 m^2 spacecraft (considering miss distance, uncertainty, and cross-sectional area).
  - Constellations can increase the number of conjunctions.
- A study by Dr. Hugh Lewis showed *"…that adding a mega-constellation to the space environment resulted in a 50 per cent increase in the number of catastrophic collisions – involving the complete destruction of a satellite – over the 200 years, with potentially serious consequences for other satellites and the services they provide to the ground, as well as financial implications for the operators."* **
- Holger Krag (ESA/Space Debris Office) stated that 90% of LEO satellites must deorbit within 25 years from launch to control debris creation, but only about 20% of spacecraft above 650 km are designed to do so*. "If I had done the simulation with 20% instead of 90%, that wouldn't even work with our numerical tools. It would be overloaded with the amount of debris."* ***

* https://www.sprsa.org/17th-annual-small-payload-rideshare-symposium/cubesat-constellations-debris-risks
** http://www.technology.org/2017/04/20/biggest-ever-space-debris-study-highlights-risk-posed-by-satellite-mega-constellations/
*** http://www.thespacereview.com/article/3078/1

Experts Recommend:

1. Reduce the maximum orbital lifetime in LEO; the 25-year rule is not enough anymore.
2. Include propulsion systems or other methods to accelerate deorbit.
3. Improve maneuverability to avoid collisions.
4. Include radar reflectors and transponders, or other method to make spacecraft easier to track even when they are not transmitting.
5. Open communication between constellation owner and JSpOC regarding individual spacecraft location, to expedite the cataloging process during the critical post-deployment time.

Conclusions

- The statistical orbital debris model ORDEM 3.0 shows significant increase in the debris population over the previous version. In some orbital regions, the model may overestimate the debris population.
  - It is likely that the recent implementation of ORDEM 3.0 in the DAS 2.1.1 debris assessment tool, together with the tool's inherent conservatism, will result in frequent non-compliances with NASA requirements to limit on-orbit collisions. This will require the use of the higher-fidelity hypervelocity impact simulation tool Bumper-3 to double-check the results.

- The upcoming Space Fence system is expected to increase at least 3x the current catalog of tracked orbital debris, potentially increasing the number of conjunctions.

- The CubeSats are here to stay. NASA orbital debris requirements apply to Agency's CubeSats (no automatic exclusion).
  - Scientific CubeSats (from NASA and other scientific communities) represent a minor number of the projected small-spacecraft population. However, NASA must pave the way regarding small spacecraft debris mitigation practices as we did with traditional spacecraft back in 1995.

- CubeSats and constellation designers and operators must adhere to orbital debris limitation practices, in particular limiting the spacecraft orbital lifetime; a reduction in maximum orbital lifetime must be considered.

Resources

- Email the GSFC team any time for assistance:
  - **Scott.Hull@nasa.gov 6-2369**
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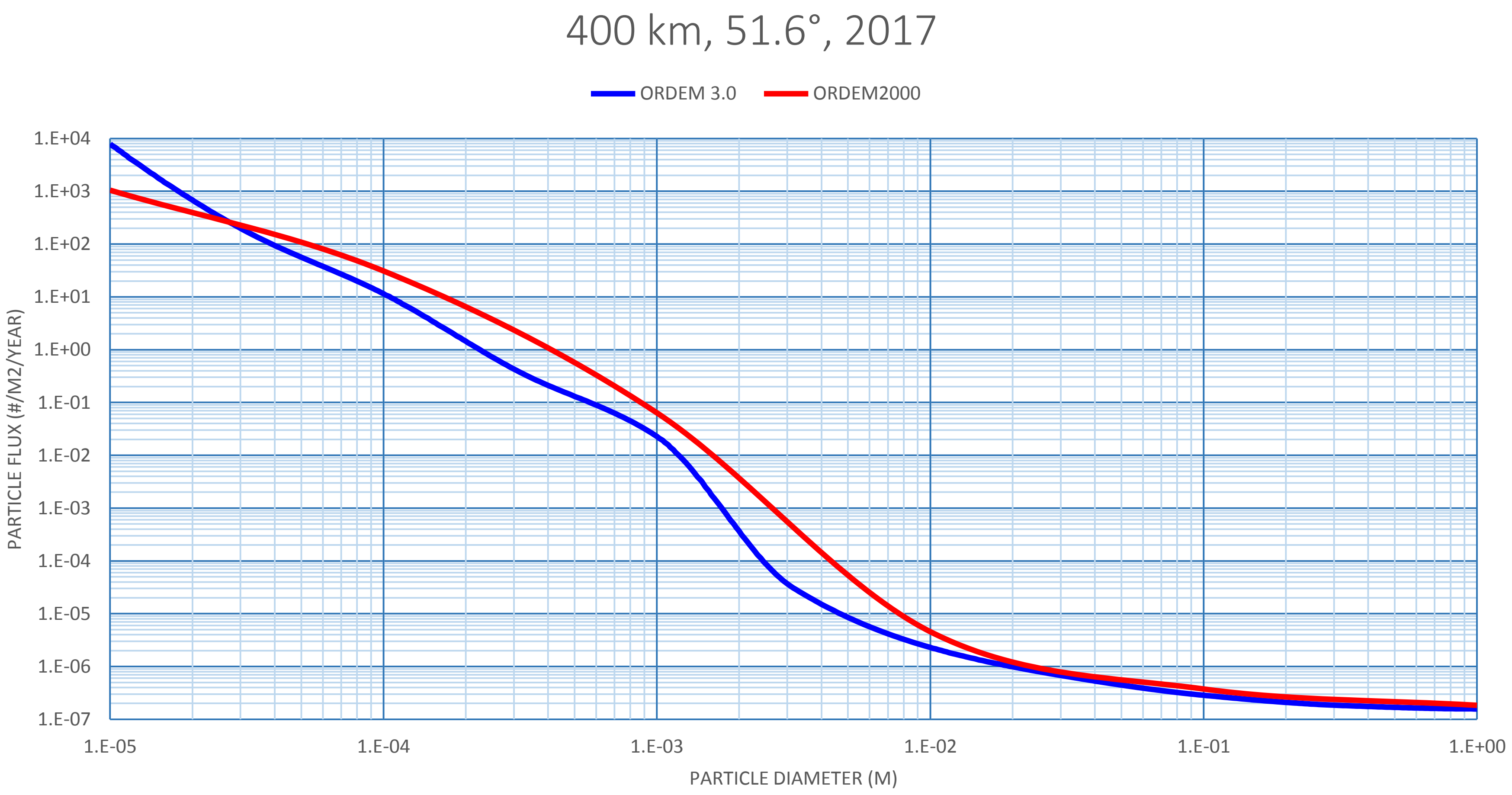
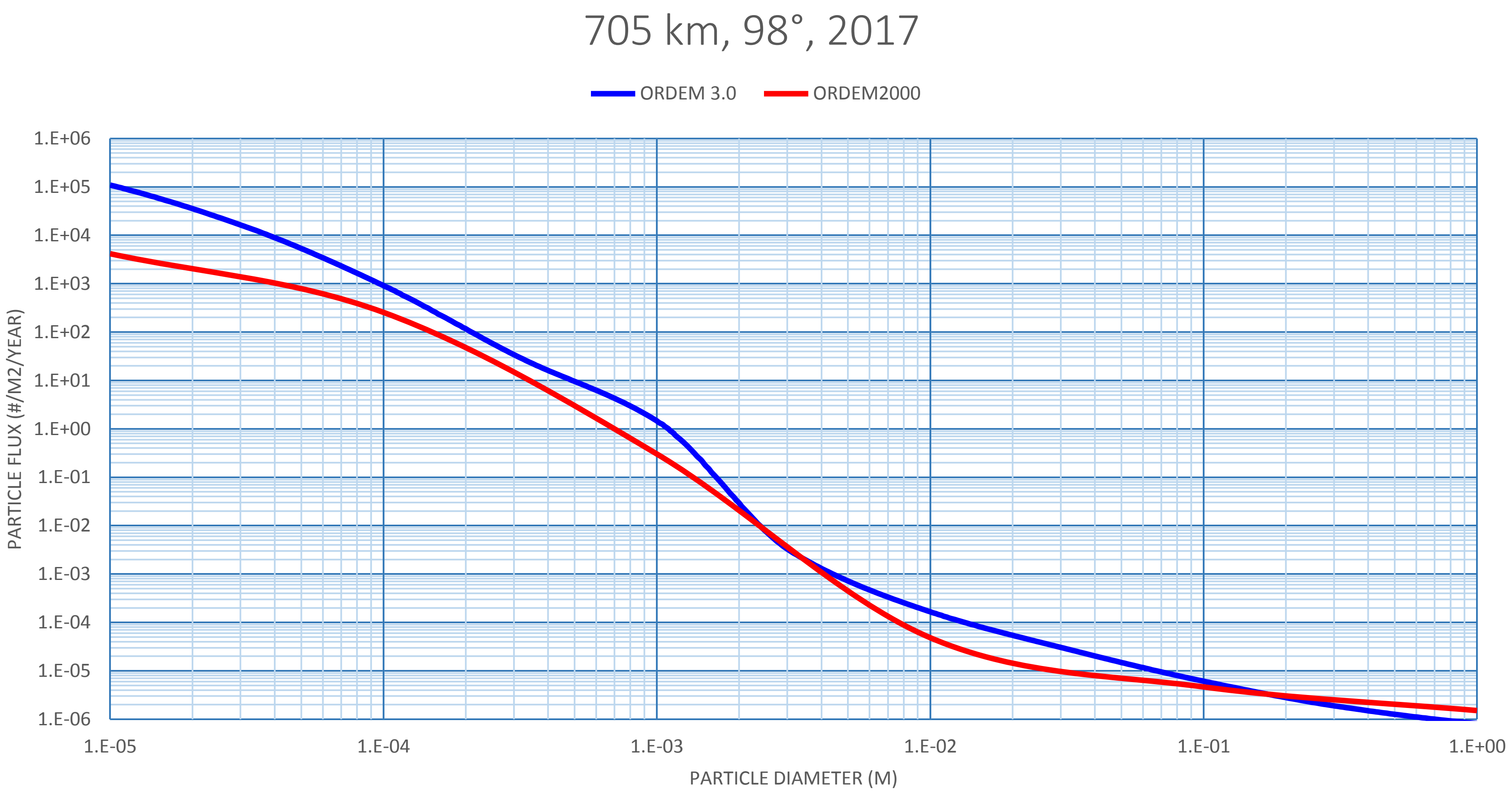
- Online Resources
  - NPR 8715.6B: https://nodis3.gsfc.nasa.gov/npg_img/N_PR_8715_006B_/N_PR_8715_006B_.doc
  - NASA-STD 8719.14A : http://www.hq.nasa.gov/office/codeq/doctree/174014.htm
  - http://orbitaldebris.jsc.nasa.gov/ (especially Orbital Debris Quarterly News)
  - http://orbitaldebris.jsc.nasa.gov/library/USG_OD_Standard_Practices.pdf

BACKUP CHARTS

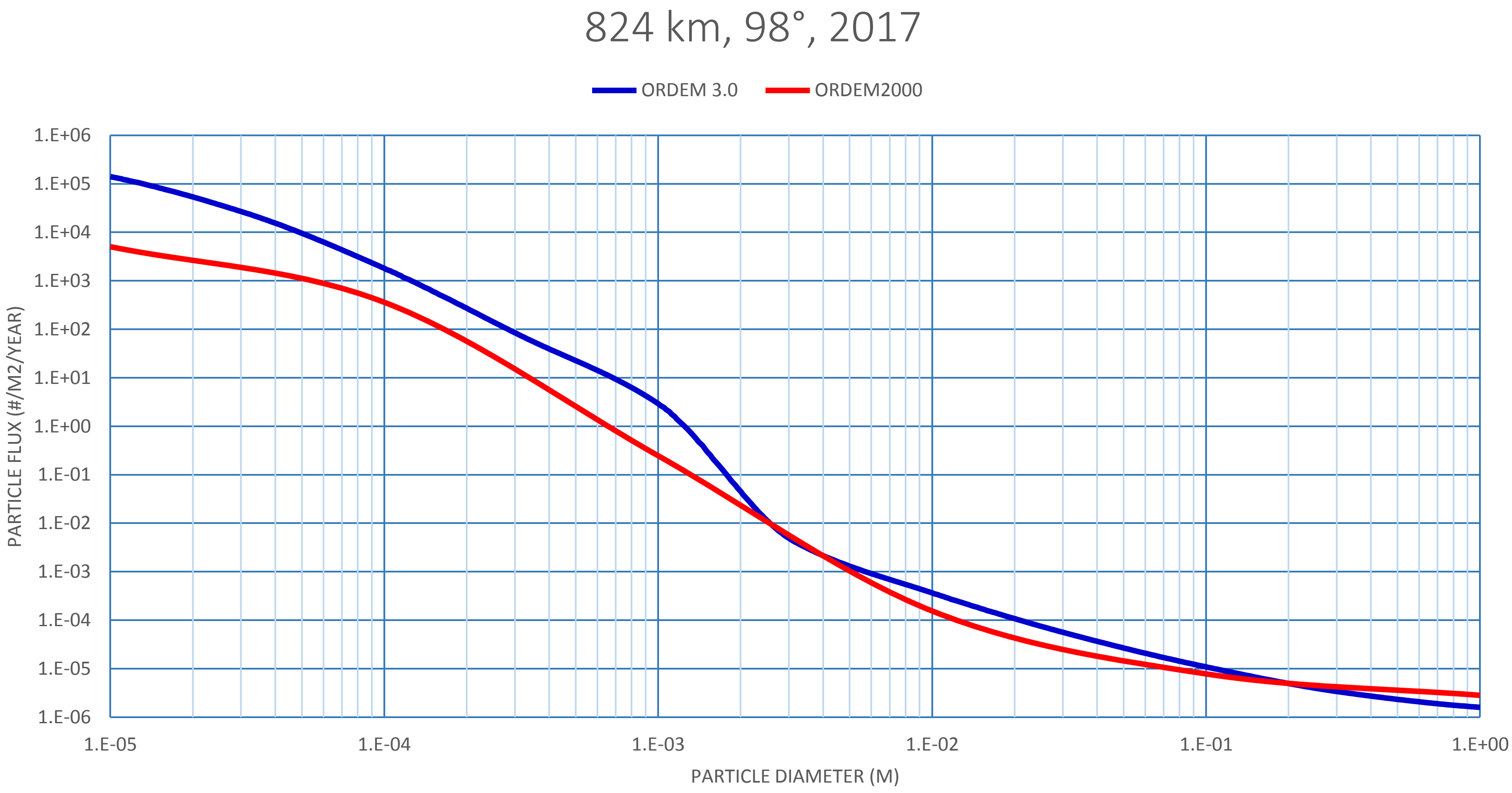
Sample Orbit (1 of 3)



Sample Orbit (2 of 3)



Sample Orbit (3 of 3)



Questions

Written questions were collected following the presentation.
The questions and answers are recorded here.

As you use drag to move a spacecraft forward and backward along the orbit, how does the altitude change?

What I believe happens is that the altitude is reduced by a small amount – on the order of a couple meters. I base that on the fact that increased drag due to solar activity generally accelerates orbit decay.

That said, orbital mechanics can play tricks on you, so I will wait to see the final analysis of the EO-1 data before saying for certain that is what happens.

A detail I did not have time to report is that the minimum drag test for EO-1 was not very successful, so we only collected data on the increased drag case.

Will DOD and foreign classified satellite locations be known for conjunction assessment purposes?

That is an interesting question, because the recent introduction of commercial tracking options has raised the question of ‘what is classified?’. I think that where we are going is that the purpose of classified assets will remain secret, but their locations will pretty much be trackable – a stealth satellite would be pretty challenging to design.

Orbit data directly from the operators of a spacecraft is always more accurate than radar, though, so there may be times when the uncertainty for conjunctions with classified assets is higher than it otherwise would be.

For spacecraft in orbit that do not have thrusters, what are the key steps (things to know) when designing and preparing for the End of Mission phase?

The key thing to understand is that all of the same requirements still apply, but your options for meeting them are more limited. In the end we do the best we can, but we can't always achieve full compliance.

The main preparations involve passivation: minimizing or depleting any stored energy on the spacecraft. Since there is no propulsion subsystem, that usually means disabling battery charging. System reliability, though, often prevents fully disabling the battery charging, so we minimize the charge rate, or sometimes we can point the solar arrays away from the Sun for the remainder of the orbital lifetime.

With more spacecraft planned to be in orbit, what is being done to verify that two maneuvering spacecraft within 24-48 hours of each other will be safe?

This is a situation hat ESMO faces frequently (and it turned out the question came from them). Currently JSpOC performs the basic conjunction analysis activities, to identify close approaches. Additional active spacecraft, and more debris objects, mean that the infrastructure for performing that role will need to be increased. But JSpOC wants to move away from that role, so they are reluctant to grow their capability.

That has created a demand for commercial equivalent services. It remains to be seen how this will all settle out, but the industry sees the need, and there are companies moving to meet the need.

What is NASA's preferred method for collecting or de-orbiting micro-debris? Is one method or material better? Or is mitigation the best approach?

Mitigation is definitely the best approach – it's much easier to prevent small debris than remove thousands of pieces.

To my knowledge, NASA does not have a 'preferred' method for removal of large or small debris. Some of the satellite servicing technology could be applied to large object removal, if the funding could be allocated to do it.

For small debris removal, I have seen literally dozens of ideas, but so far each has at least one fatal flaw (usually cost). My personal favorite is big metal foam collectors.

You mentioned that if someone provided the funding, we can remove the debris. What method did you have in mind?

Some of the satellite servicing technology could be applied to large object removal, if the funding could be allocated to do it. At GSFC, we have some of the most advanced development underway to support the RESTORE-L and similar missions. It's not really a technology problem, so much as a resources problem. (I believe that the political concerns are manageable.)

If we were to decide to remove many large debris objects, common wisdom is to deorbit many debris objects per launch. One way to do this is to use a 'mother ship' with multiple reentry mechanisms.

For the ISS particle sensor, will the sensor only detect on one side? Can the sensor determine impact angle?

Yes and yes.

The DRAGONS sensor can collect impacts from a range of directions, but predominantly in one direction. The acoustic sensors on the first two layers are used for not only timing, but also to triangulate the location where the particle penetrated each layer. That gives two ‘four-dimensional’ data points for calculating the velocity as well as the impact angle.

The grid and stopping plate provide size and impact energy information, so that with some assumptions we can imply the particle density, a key characteristic.

What debris assessments are being done for GEO?

While some of the requirements don't apply well to GEO (especially large object collision risk over the orbital lifetime, and reentry risk) most requirements still apply to GEO missions. GEO spacecraft still need to be passivated at the end of the mission, and there is a limit of the operational debris they are allowed to shed.

The primary requirement for GEO missions is postmission disposal above the GEO arc. There is an equation that we use to ensure that the disposal orbit will remain outside of the GEO region for at least 100 years. To date, GSFC GEO missions have more than met it.

What are requirements for deep space (non-Earth orbiting) spacecraft that include Earth fly-by?

At present, NASA has no orbital debris requirements specific to fly-bys. The mission still has to meet the standard requirements for the launch vehicle, though. This is such an unusual case that OSMA and the ODPO consider them on a case by case basis. If the fly-by occurs outside GEO, there should be no significant concerns.

For example, for OSIRIS ReX, GSFC SMA requested some information about the fly-by to confirm that the collision risk is minimal.

Does ORDEM take into account direction of debris velocity? For instance, relative velocity for A-Train spacecraft is smaller than for GTO.

Yes, ORDEM 3 provides a very large four dimensional matrix of fluxes based on particle size, direction, velocity, and density. The particle size ‘bins’ are half decade values from 10 µm through 1 m (10 µm, 31.6 µm, 100 µm, 316 µm, etc.). Direction is divided up into igloo bins of 10° altitude and 10° azimuth. Velocity bins are 1 km/sec wide, from 0 through 23 km/sec. There are five density bins, as shown on slide 32.

Remember that ORDEM is only an environment model. Penetration risk is estimated using Bumper or DAS, both of which incorporate the directionality and other aspects, including relative impact velocities.

What is the latest estimate as to the size of the High Accuracy Catalog after the new and improved Space Fence comes online?

The size of the catalog will be directly driven by the smallest size object that they can track reliably. I have seen two numbers on the resolution of the radar: 1 cm (see slide 47) and 4 cm. That resolution is driven by several factors including radar reflectivity, object shape, altitude, and elevation angle of the observation, so it is going to vary.

The latest study I saw (assuming 4 cm resolution) showed that we can expect a ~3X increase in conjunction warnings from Space Fence. Looking at the ORDEM 3 flux for 4 cm vs. 10 cm objects in the A-Train orbit, I see essentially a 3X increase, so I believe that number.

For conjunction assessments, from where is the object location data determined, and at what location are the assessments made? a station at Goddard?

- This is an incredibly complex topic, just outside my area of expertise. For reliable answers, I defer to Lauri Newman in CARA.

- The data used in the initial conjunction screening is obtained from either radar or optical observations, both ground-based.
- An initial screening is made at JSpOC in California, using a general purpose catalog, for each active spacecraft versus all objects. If there is a close approach within some predefined window for a seven day period, they issue a warning to the spacecraft owner. Responses to those warnings are handled differently based on the spacecraft owner. For NASA robotic missions, the CARA team at GSFC uses the best data available to generate detailed data about the close approach, including the probability of a collision.