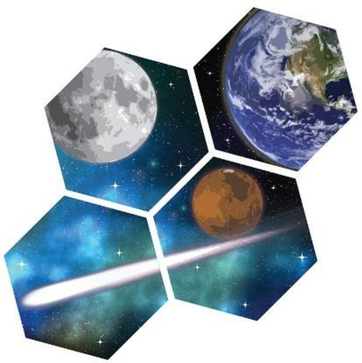
National Aeronautics and Space Administration

Analysis of Russian ASAT Debris Cloud

Orbital Debris Program Office
Mark Matney
mark.matney-1@nasa.gov

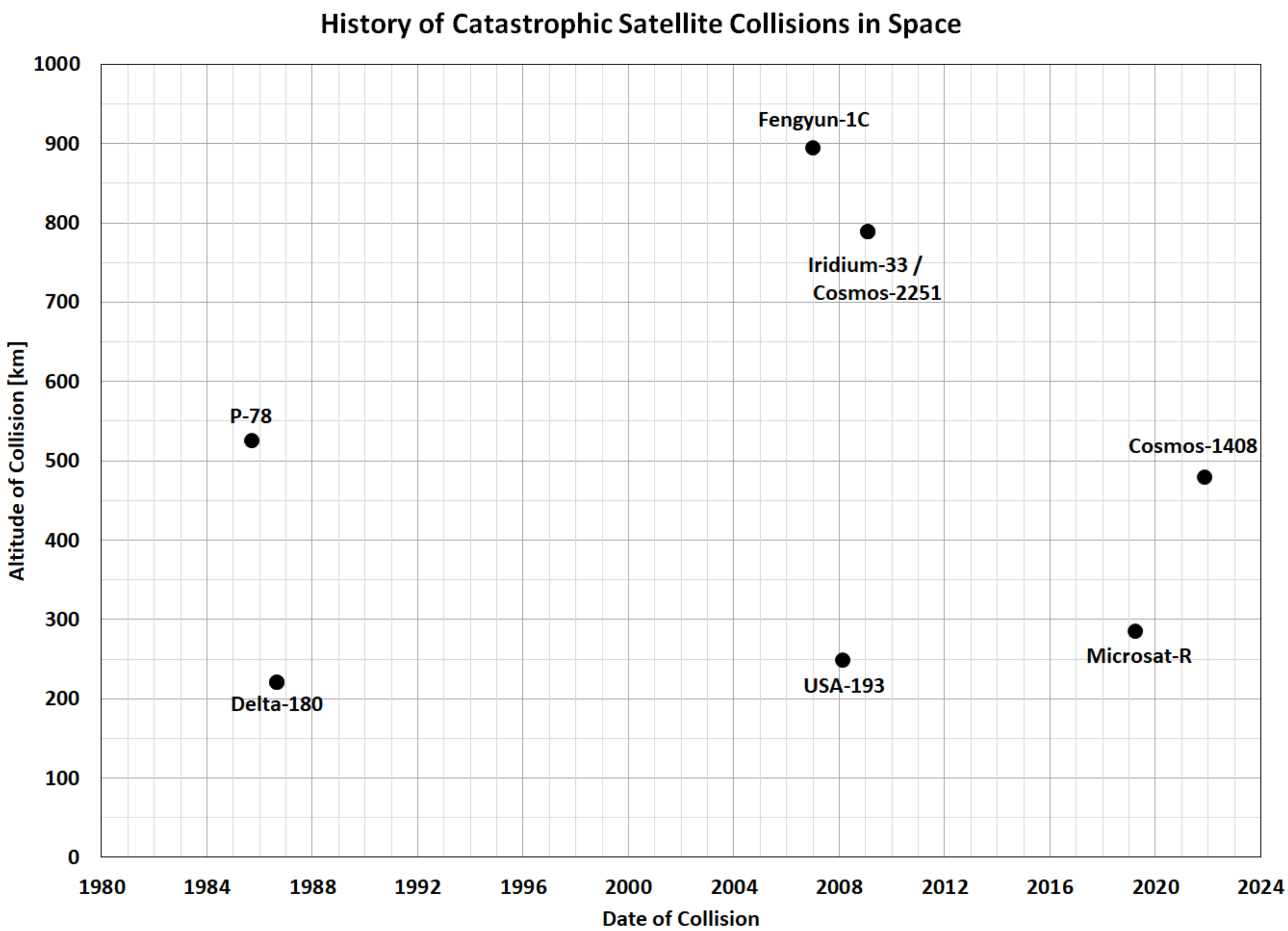


History of Major Collisions in Space

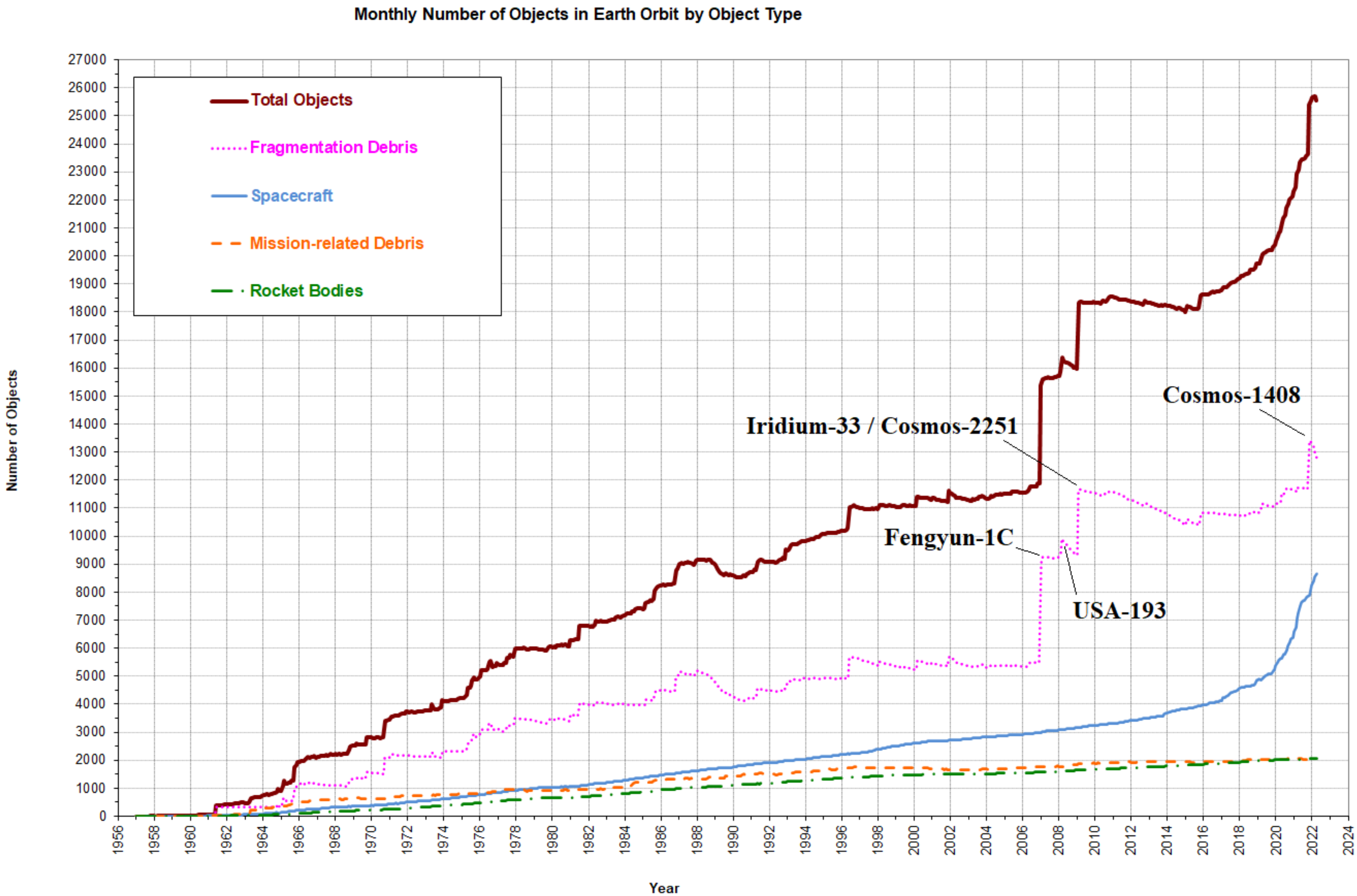
- **Since the beginning of the Space Age, there have been almost 270 breakups of objects in space (averaging more than 4 per year)**
  - The majority are explosions from on-board chemical energy sources
    - Spontaneous explosion of rocket bodies with unspent fuel
    - Spontaneous battery explosions
    - Self-destruct mechanisms
  - However, a few spectacular cases are on-orbit collisions between two high-mass objects, resulting in very large debris clouds

- **On November 15, 2021, the military of the Russian Federation conducted a "kinetic kill" ground-based anti-satellite missile test on one of their own satellites at an altitude of 479 km – slightly higher than the orbit of ISS**
  - The resulting cloud created ~1500 trackable debris greater than about 10 cm in size, and many more debris smaller than this
  - The long orbital lifetime of this debris cloud and the risk due to its proximity to the ISS created an international outcry

History of Catastrophic Collisions



History of Tracked Objects



Collisions

- Catastrophic collisions (collisions with total energy sufficient to totally break up both bodies) are major debris producers
- Of the 7 collisions shown, 6 were deliberate
- However, in the long run, we believe that the primary source of debris will be accidental catastrophic collisions between intact objects in orbit
- So, the study of collisions – even deliberate ones – offers us the chance to help understand how these events will affect the future evolution of the environment
- The data shown so far consists of objects tracked by the US Space Surveillance System, and are limited to objects > 10 cm (approximately)
- We know that for every trackable object created, many more are created that cannot be tracked

Breakup Model

- **When a breakup occurs in space (such as the Russian ASAT), we use a model cloud developed by the ODPO to make initial risk estimates**
  - Model based on laboratory breakup tests and historical measurements of breakups in space
  - The model breakup cloud is used in a software tool called the Satellite Breakup Risk Assessment Model (SBRAM) to analyze specific missions over short times (days-weeks) to assess possible risks and mitigation procedures
  - Most important user – ISS
    - After the Russian ASAT test, SBRAM was used to analyze the risk to the astronauts aboard the ISS. This resulted in unusual activities to shelter in the crew return vehicles and temporarily closing off peripheral modules until the highest predicted flux rates subsided
- **We also request specific sensors to schedule special observations of the cloud passes, to see if the actual cloud is behaving like the model predicts**
  - HUSIR (Haystack Ultrawideband Satellite Imaging Radar)
  - Goldstone

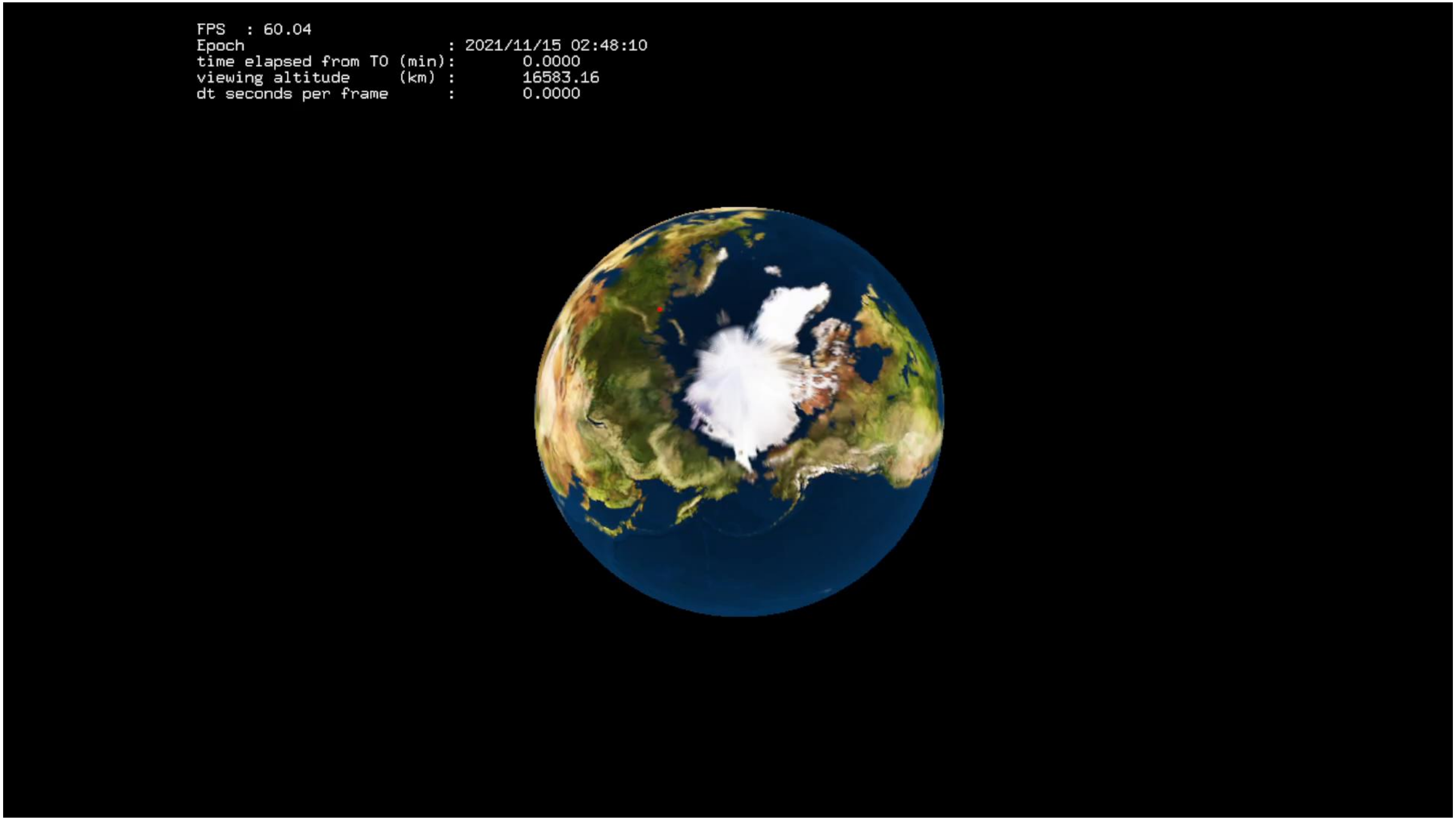
Breakup Models

- **Our breakup models are primarily based on ground tests, such as SOCIT, where a satellite was destroyed in the laboratory by a hypervelocity collision**
  - The pieces are collected and measured to determine their characteristics
    - Size distribution
    - Mass
    - Ballistic Coefficient
    - Delta-velocity
    - Material

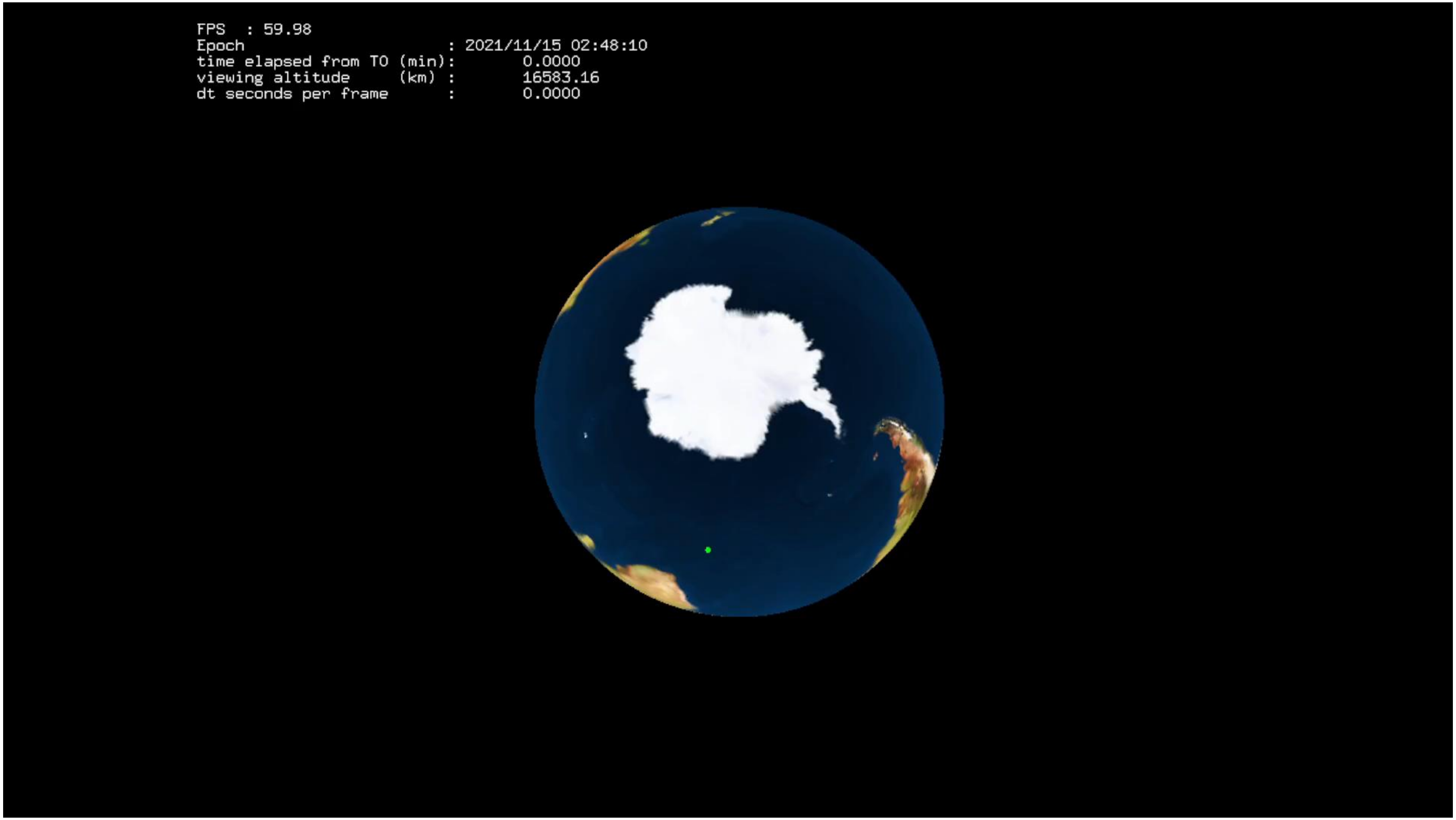
- **In addition, after large breakups, radars have been able to observe clouds and characterize them**
  - Chinese ASAT (2007)
  - Iridium-Cosmos collision (2009)

- **In general, our models are quite good at describing the debris clouds**
  - Especially for older spacecraft designs

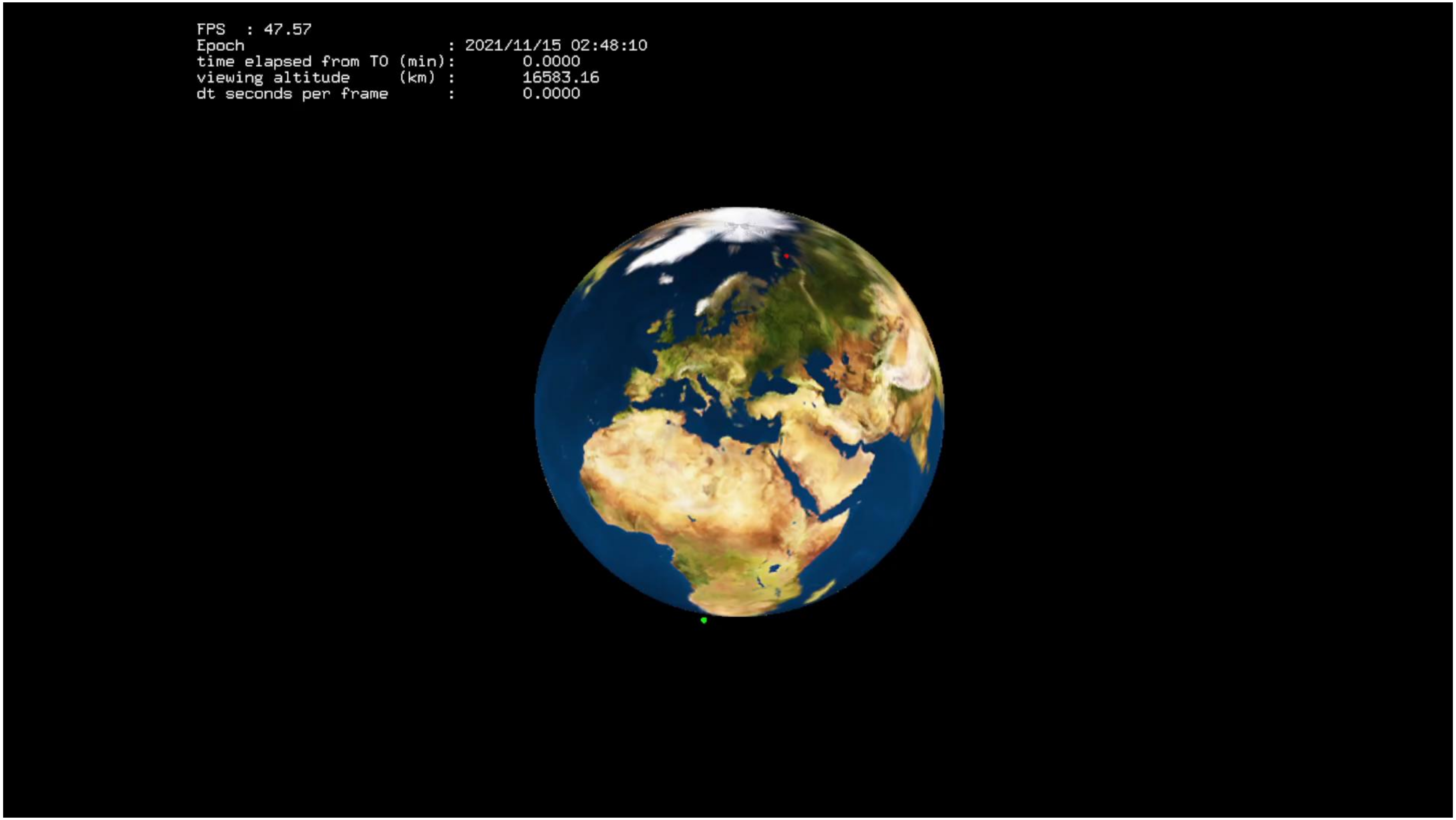
Model of Russian ASAT Test



Model of Russian ASAT

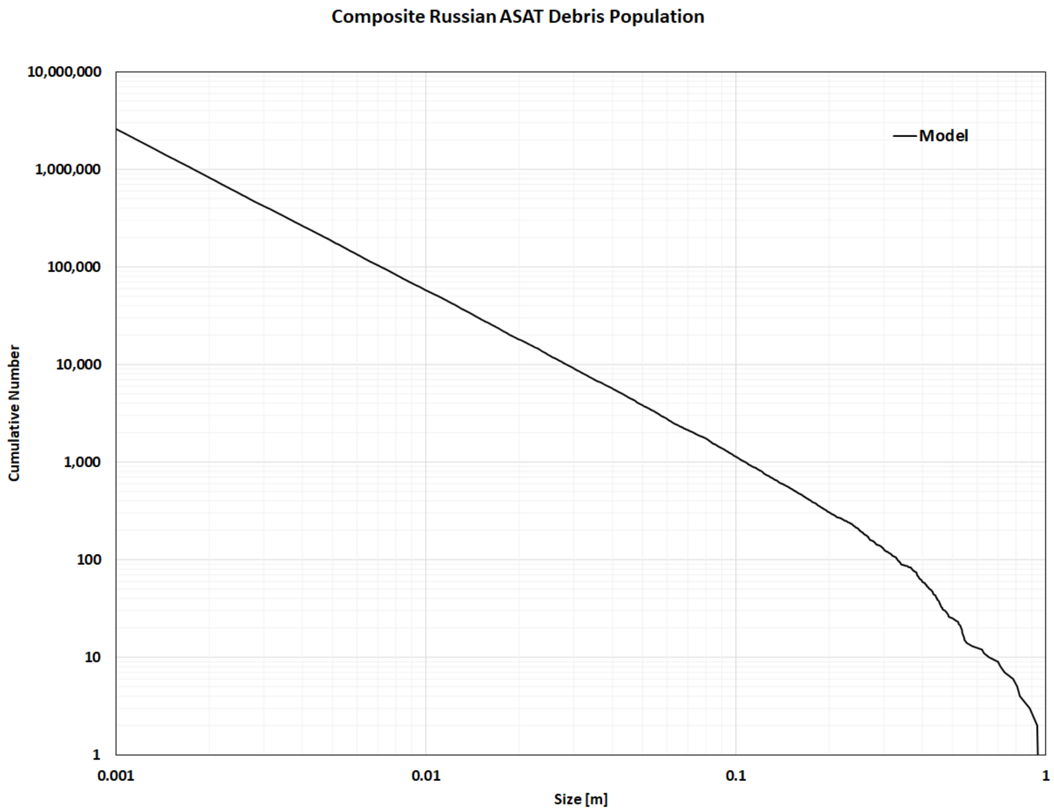


Model of Russian ASAT



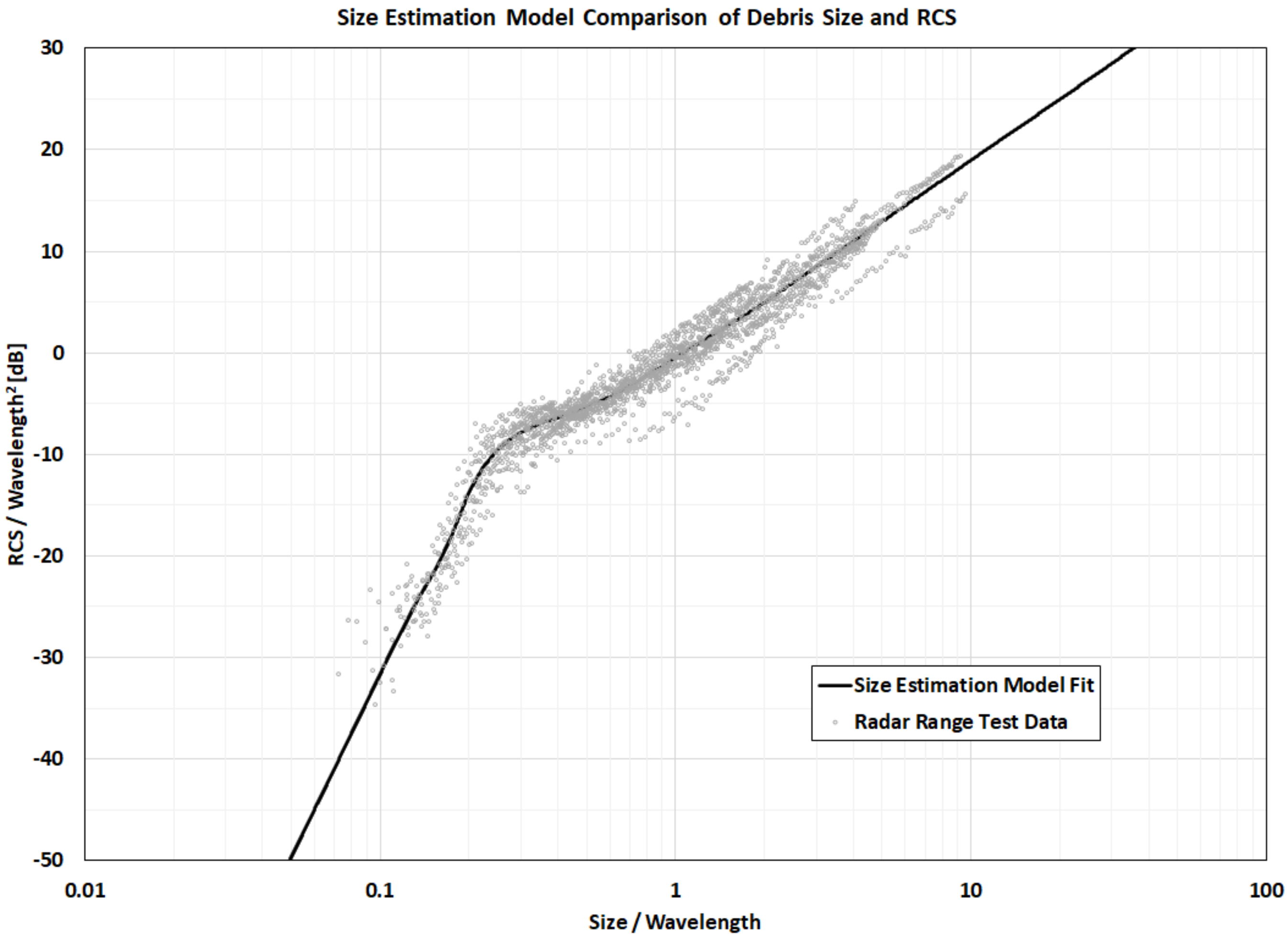
Model

- **The NASA Standard Breakup Model postulates a power law in size for debris from collisions**
- **This gives us a reference population to compare the data against**



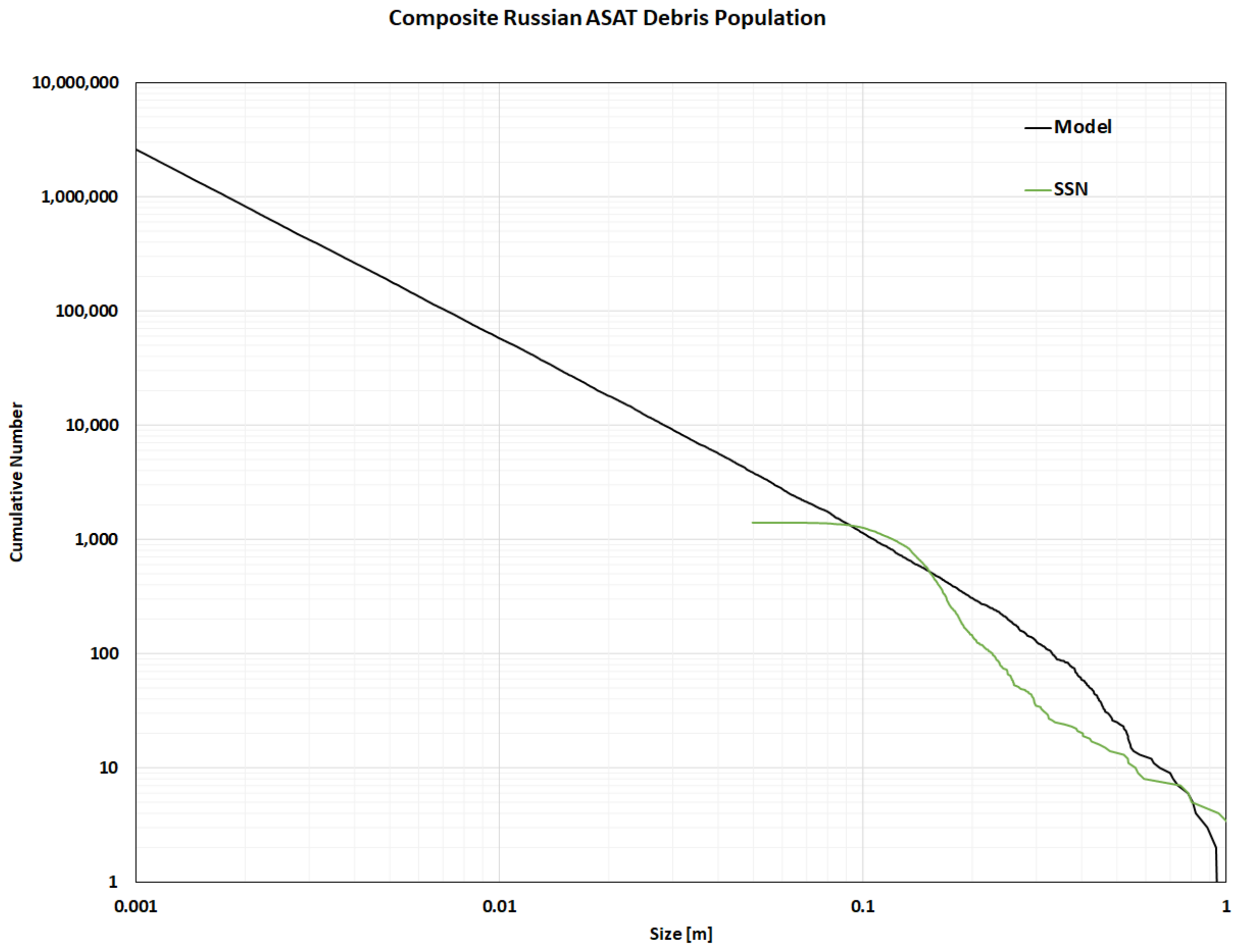
Size Estimation Model

- **Radars do not actually measure size, but measure Radar Cross Section (RCS), which is a measure of reflected energy**



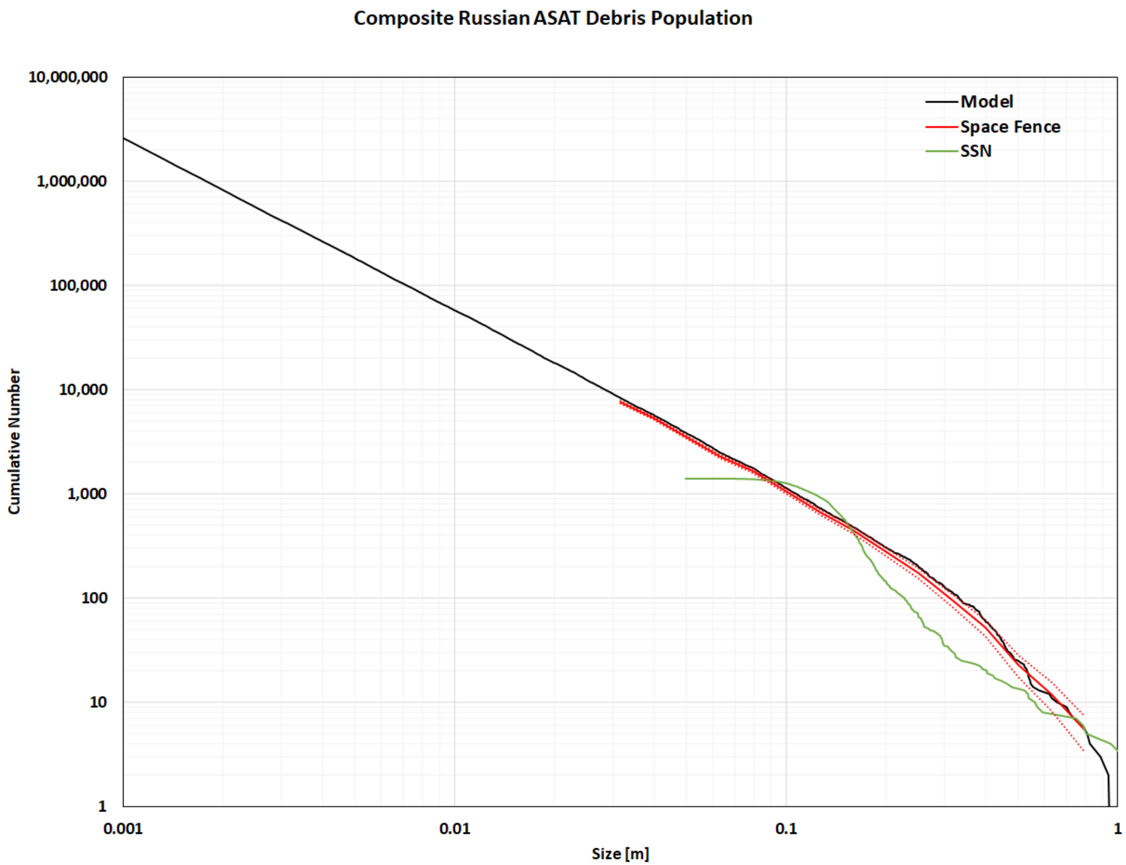
SSN Catalog

- **The Space Surveillance Network (SSN) maintains a catalog of tracked objects, along with their RCS values**



SSN Fence

- We were able to use measurements from the new SSN Fence from the initial pass of the cloud though its beam
- There is some uncertainty, as we treated it as a statistical sample



Sensors

- **HUSIR (Haystack) radar**
  - Operated by Lincoln Lab in Massachusetts
  - 3 cm wavelength
  - Can observe objects down to ~5 mm in LEO

Credit: Reprinted with permission Courtesy of MIT Lincoln Laboratory, Lexington, Massachusetts

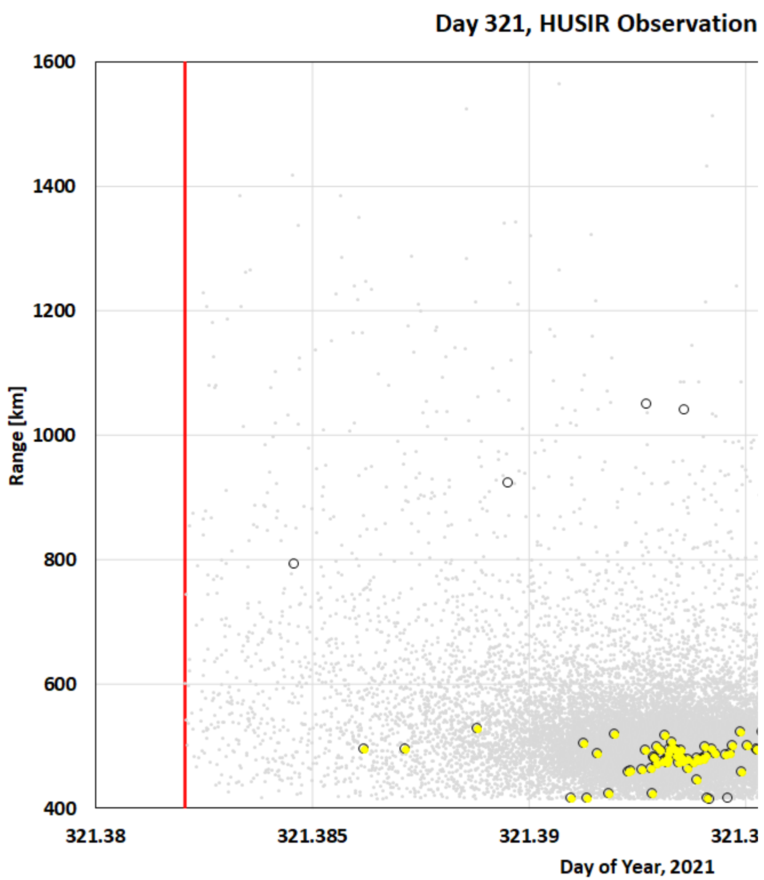
- **Goldstone 70m dish radar**
  - Operated by JPL
  - 3.5 cm wavelength
  - Limited capability, but can observe objects down to ~2 mm in LEO

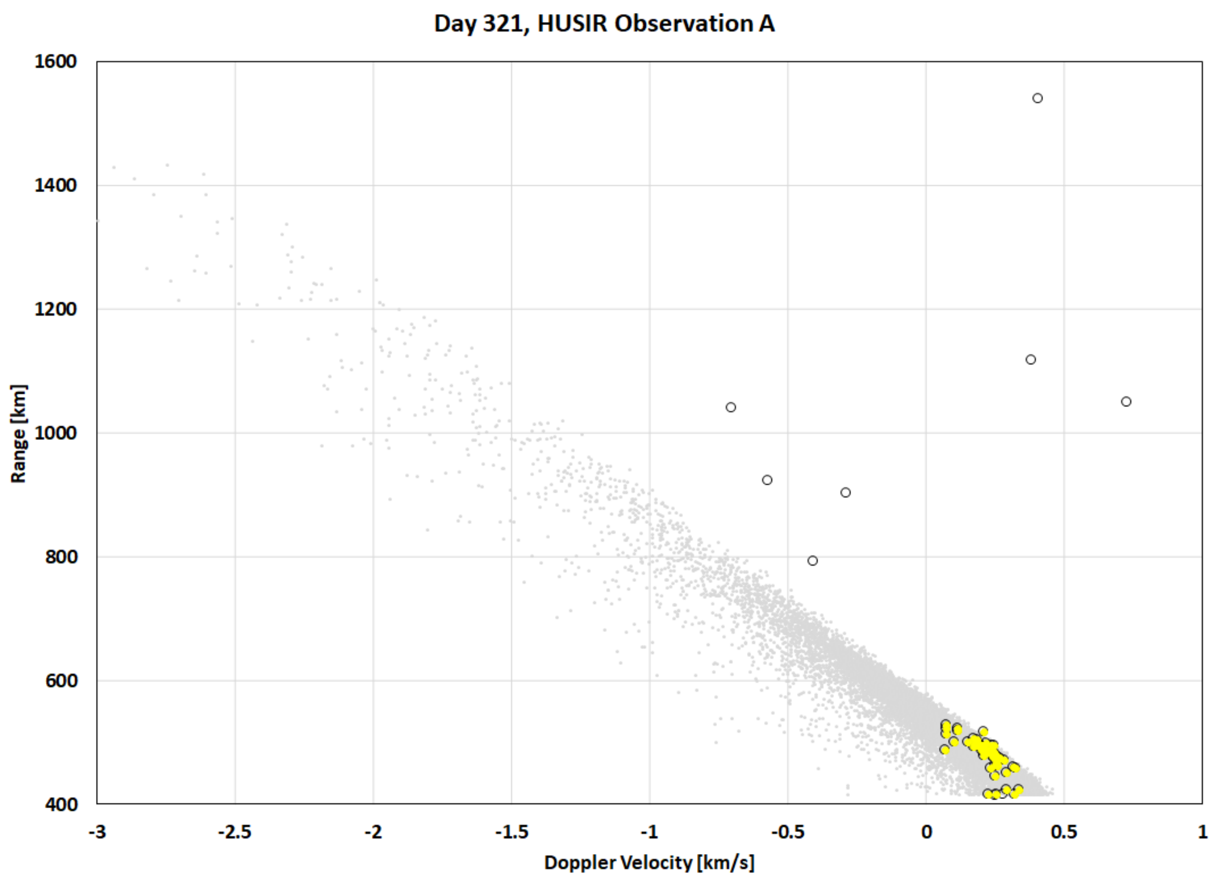
Credit: NASA JPL, https://deepspace.jpl.nasa.gov/galleries/goldstone/#gallery

- **Both radars operate in a staring mode**
  - Point in a fixed direction
  - Count objects as they pass through the beam
  - Statistical sample, cannot track

HUSIR Example

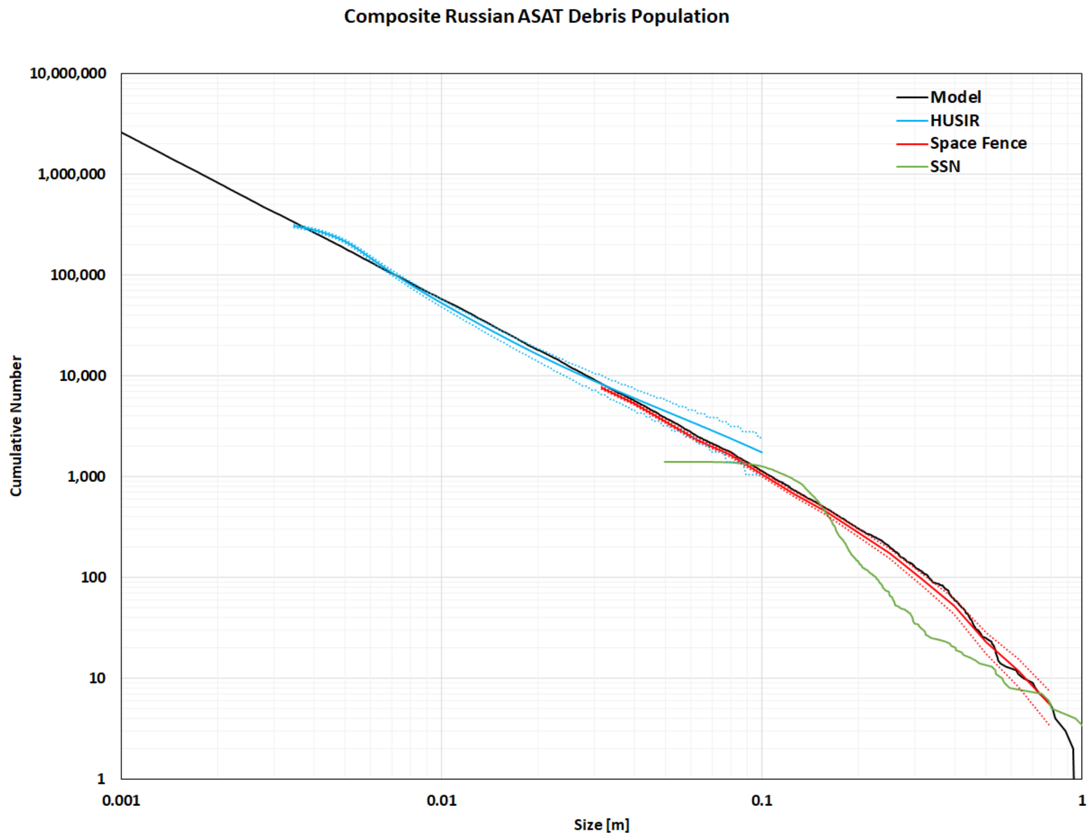
- Analyzed HUSIR data from the special data collections, and compared to the model predictions to help separate true cloud detections from background debris detections during the observation time window





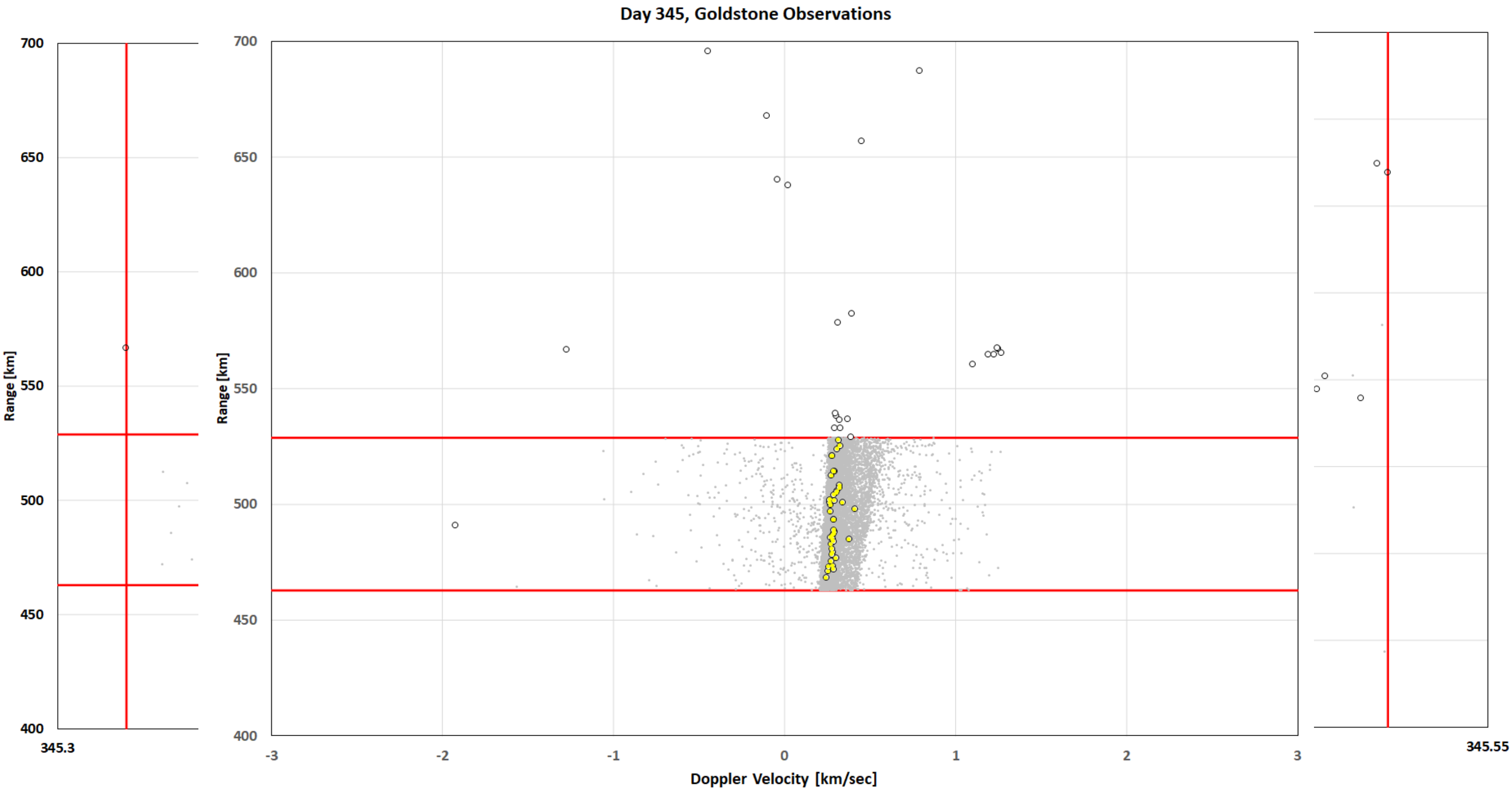
HUSIR Data

- **Conversion of RCS to size is tricky – must statistically correct for large objects with small RCS (look small) and small objects with large RCS (look large)**
- **Estimated total number is scaled based on model predictions**



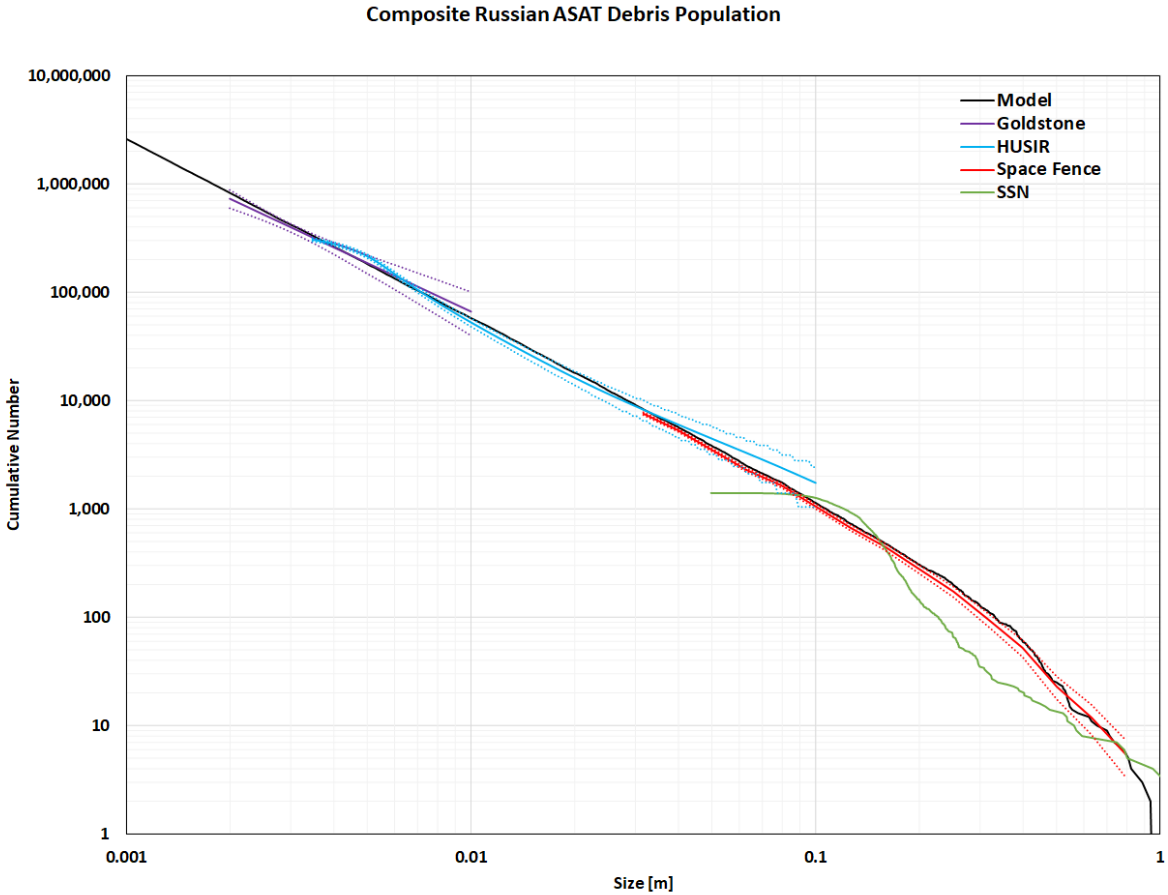
Goldstone Example

- **Goldstone data was analyzed similar to HUSIR, however the bistatic arrangements limits the altitude range visible**

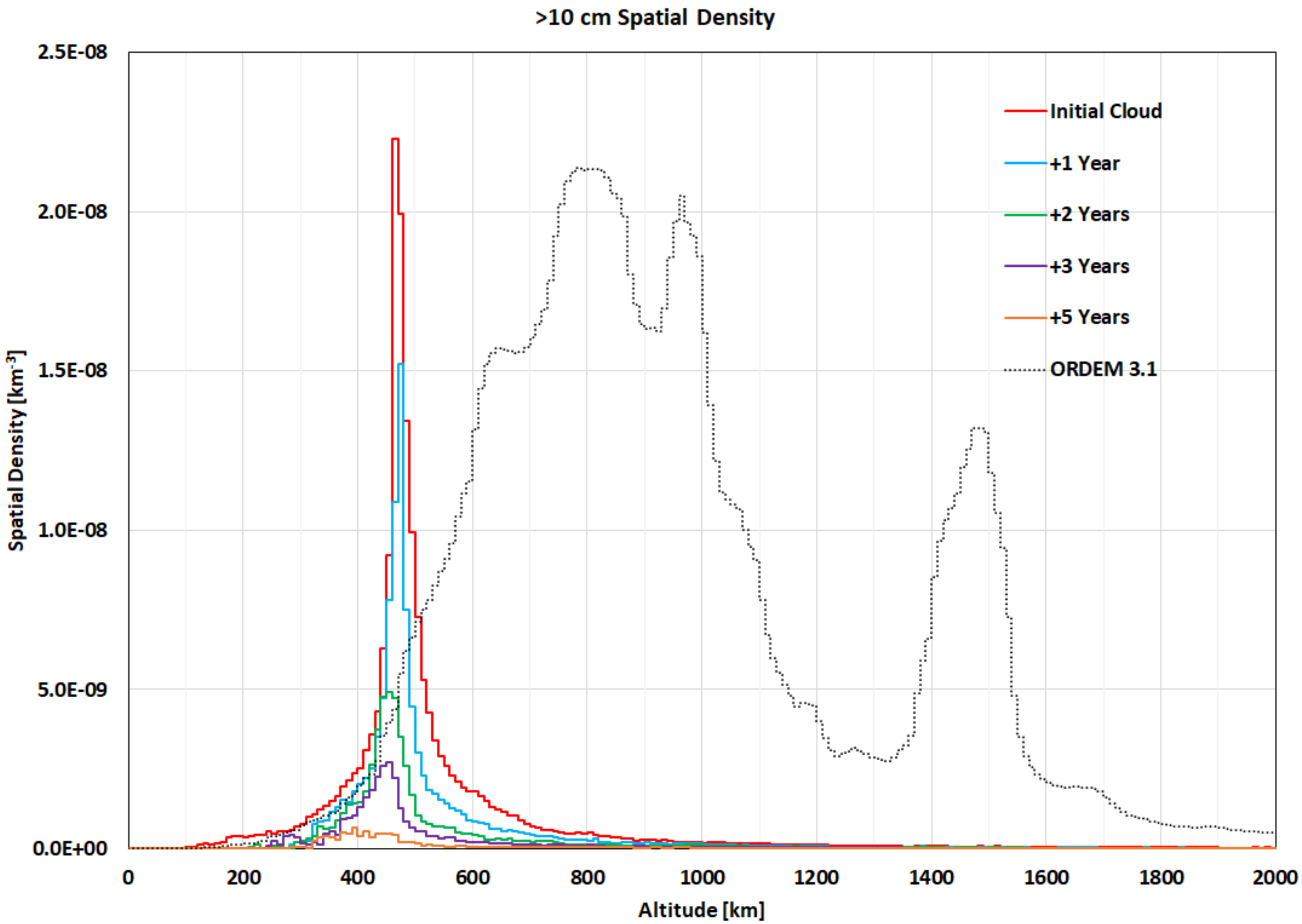


Goldstone Data

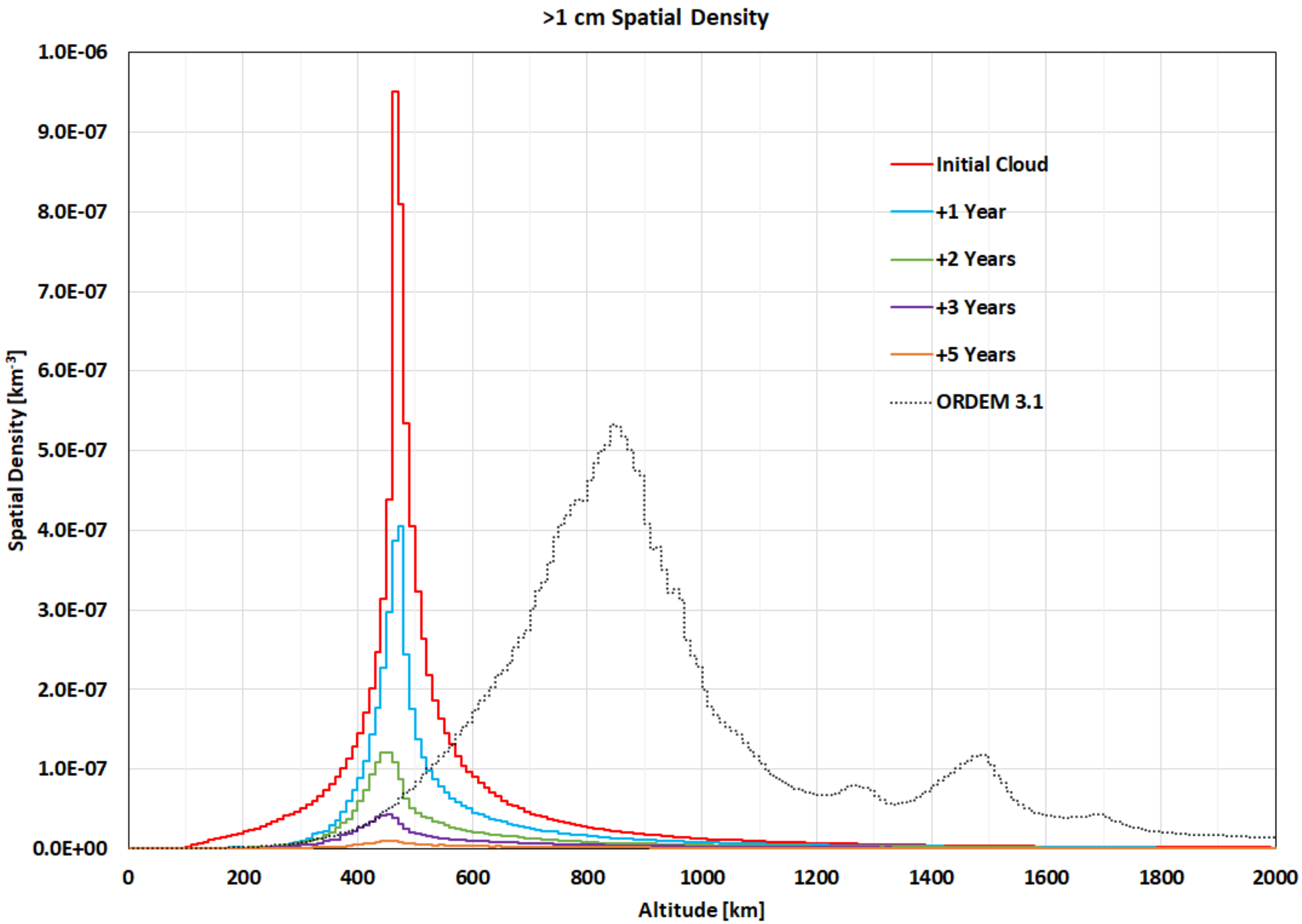
- **Conversion of RCS to size is even trickier – the Goldstone radar is incapable of determining the path through the beam, so the signal must be statistically corrected for gain of all possible paths through the beam**



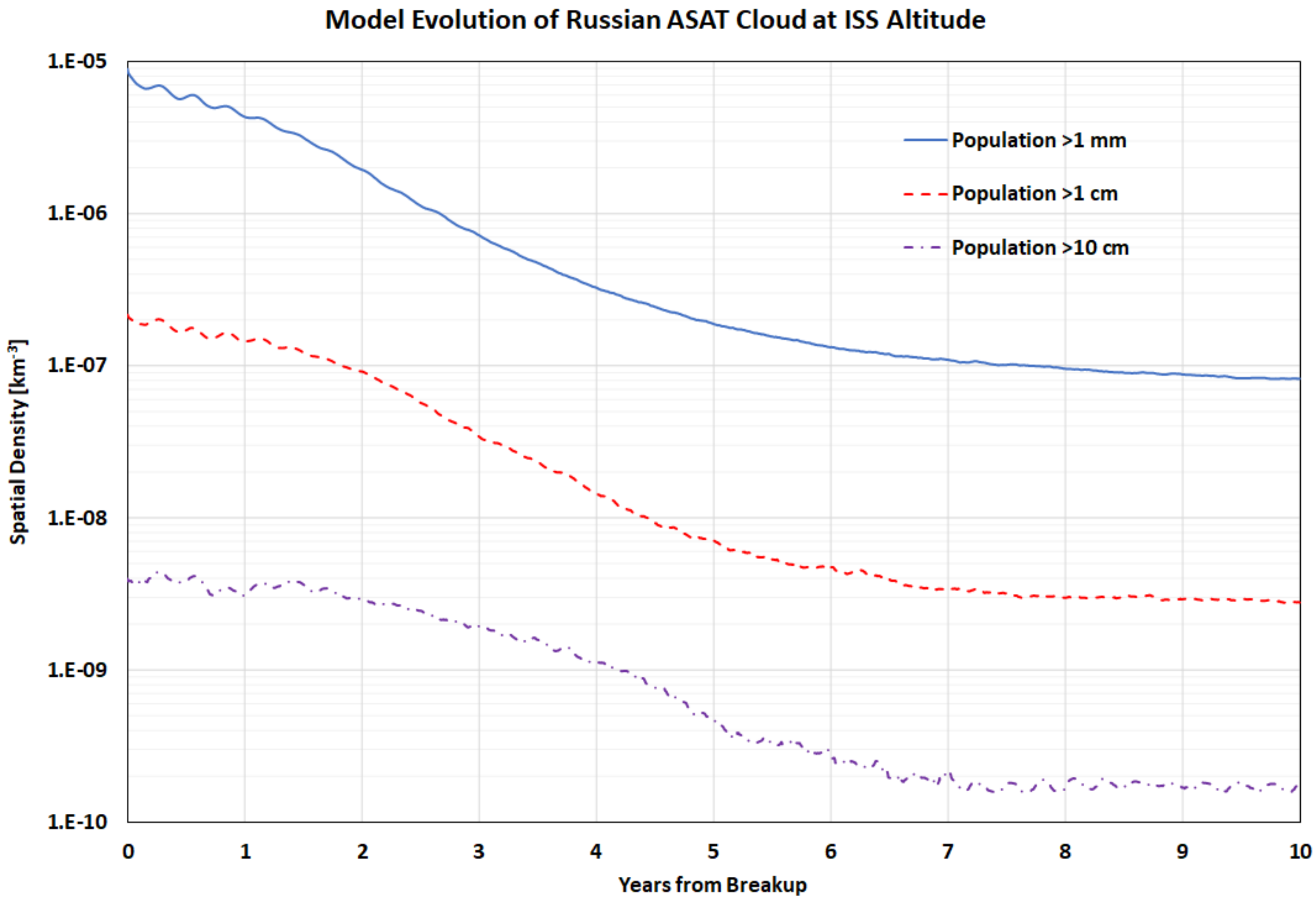
What does the model show?



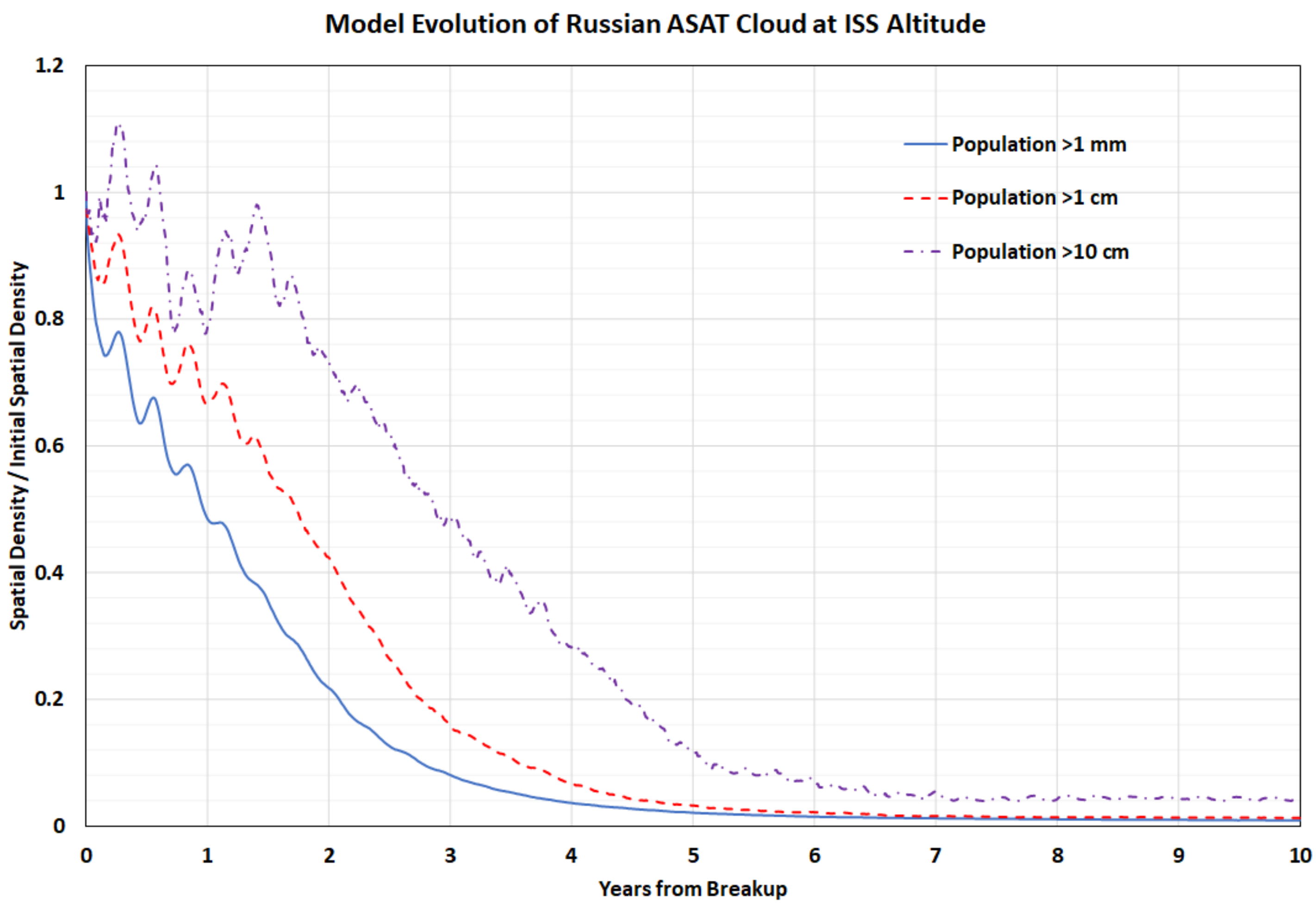
>1 cm


>1 cm Spatial Density
Spatial Density [km^-3]
1.0E-06
9.0E-07
8.0E-07
7.0E-07
6.0E-07
5.0E-07
4.0E-07
3.0E-07
2.0E-07
1.0E-07
0.0E+00
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Altitude [km]
Initial Cloud
+1 Year
+2 Years
+3 Years
+5 Years
ORDEM 3.1

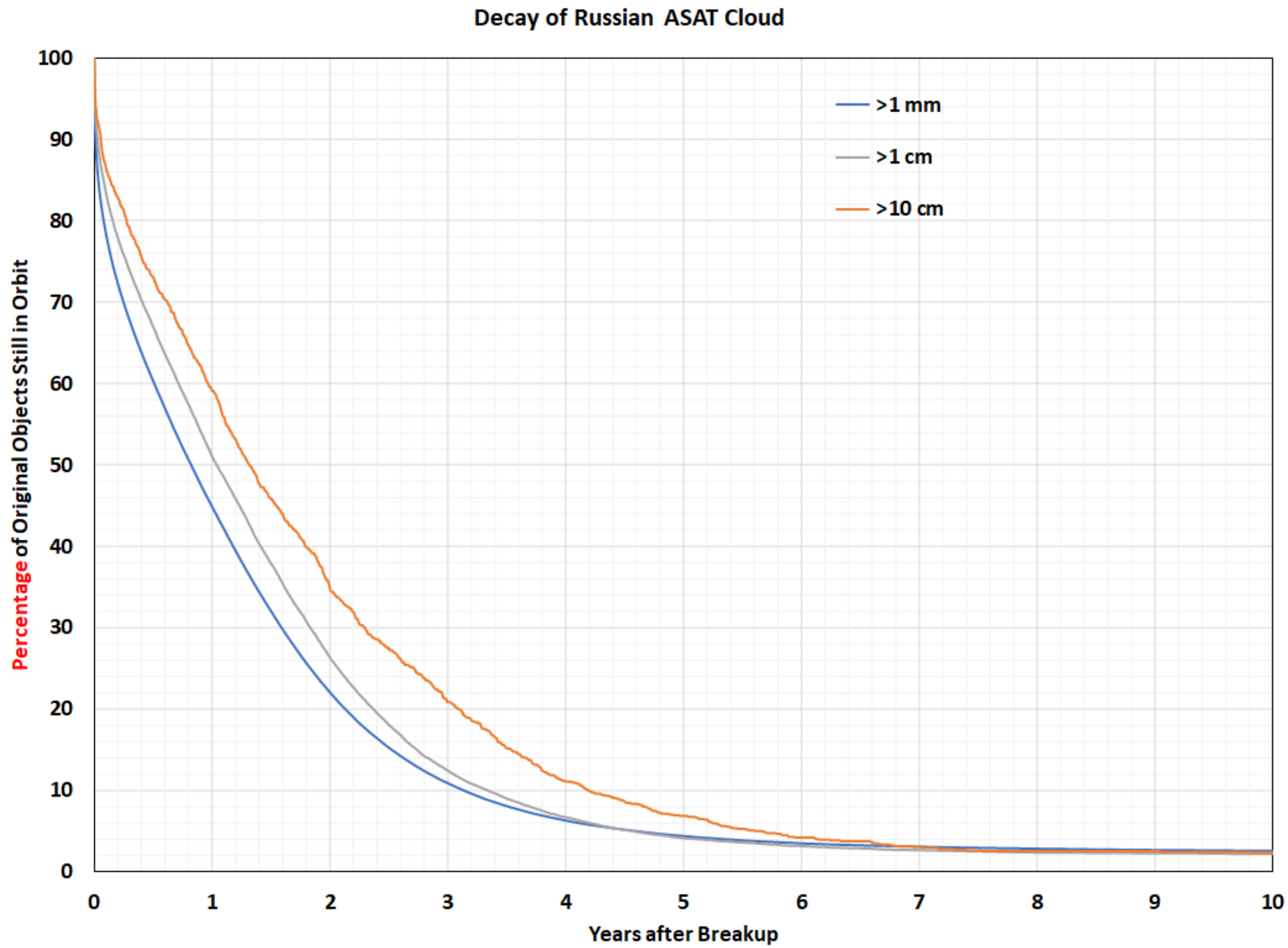
Cloud Decay at ISS Altitude



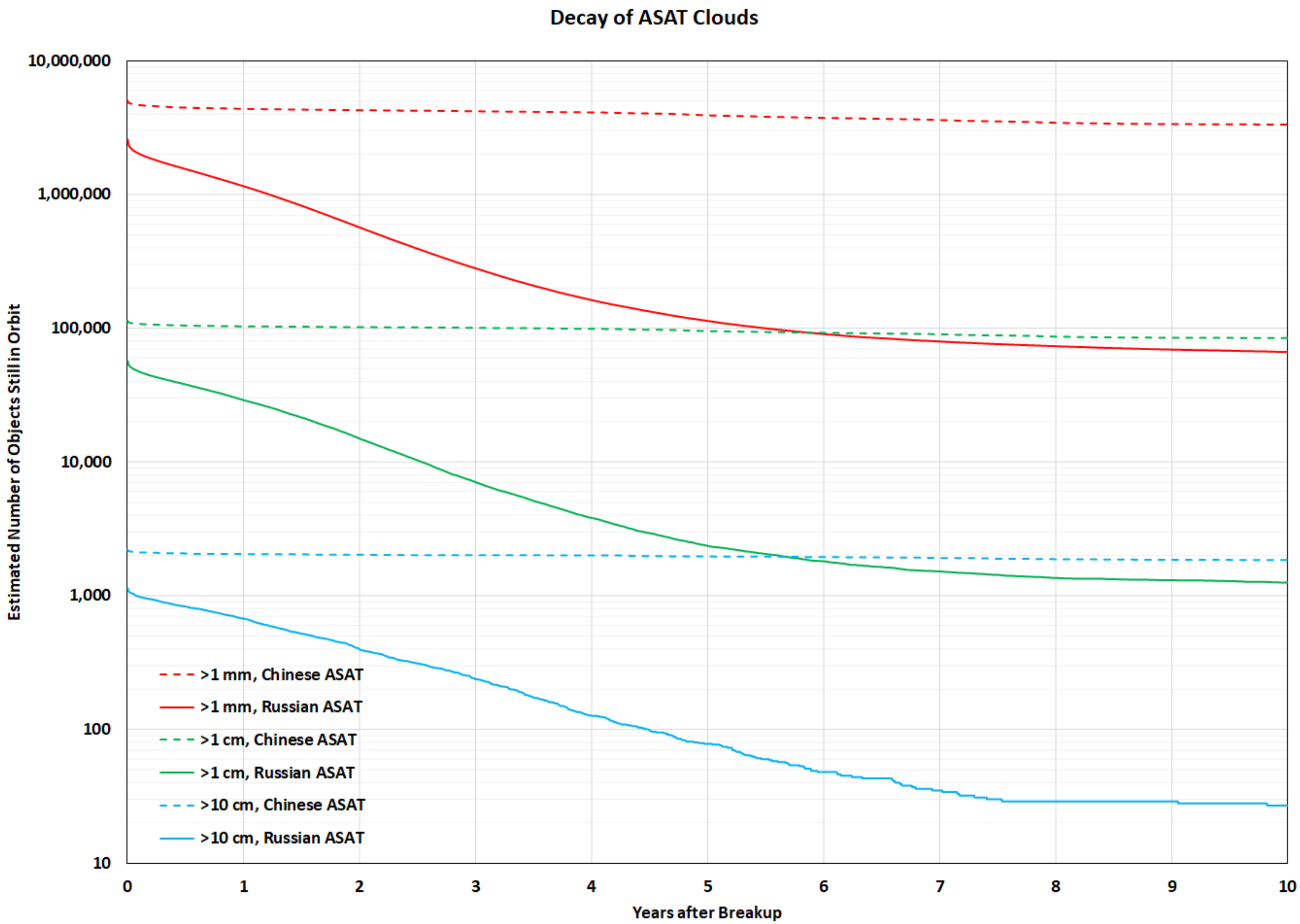
Cloud Decay at ISS Altitude



Decay of the Entire Cloud



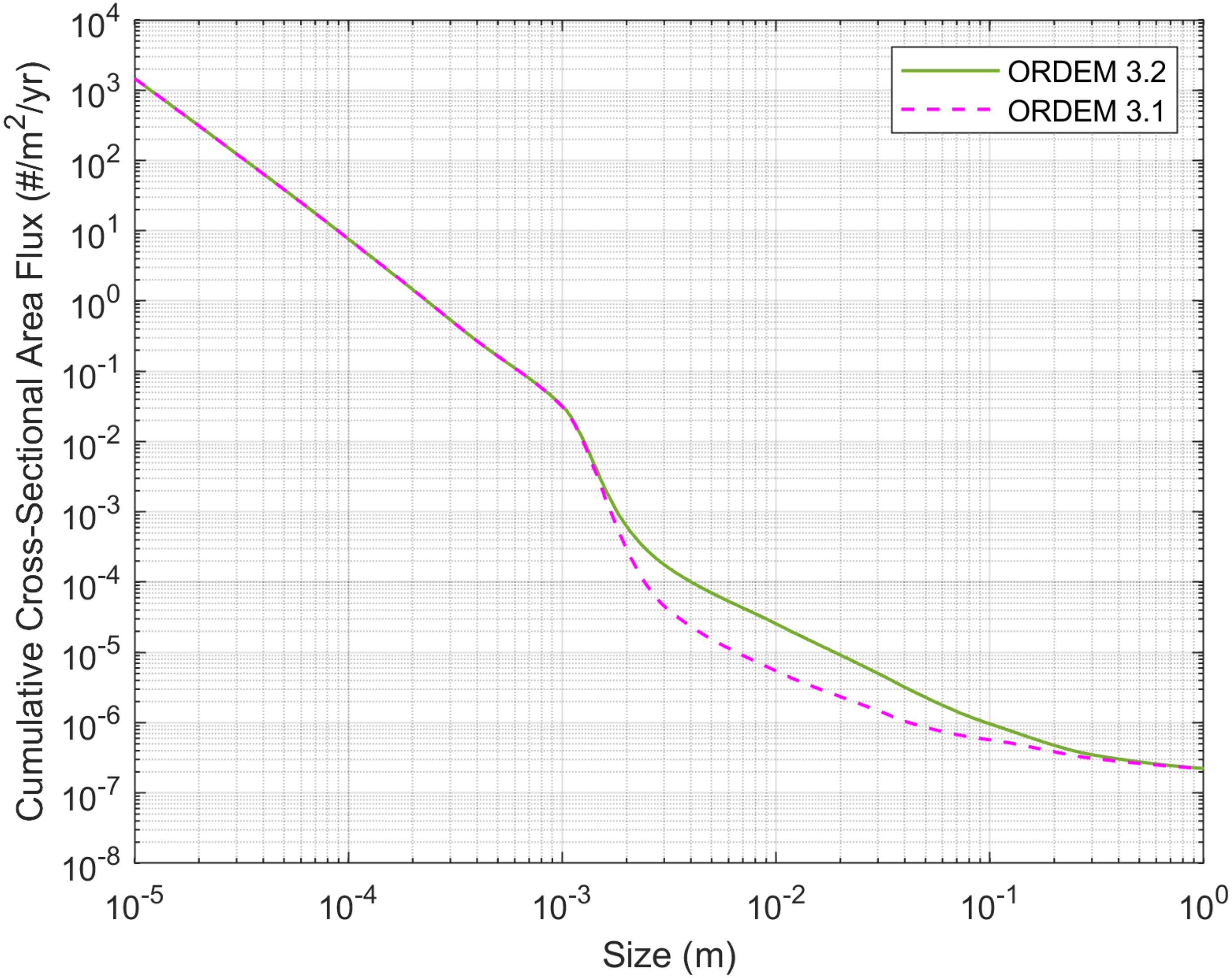
Comparison of ASAT Clouds



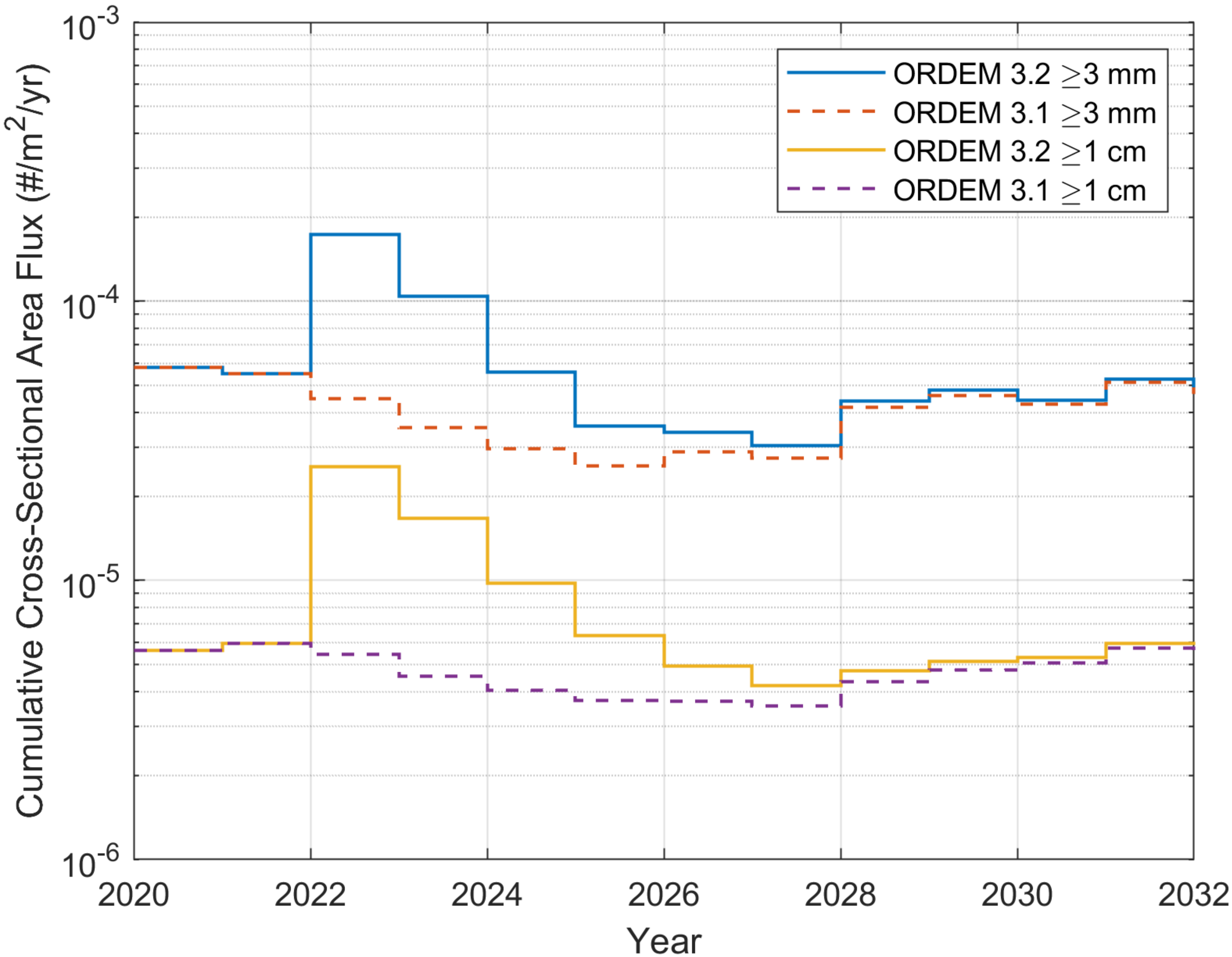
Environment Model

- **We can then modify the breakup model (if necessary) to add to our environment models**
  - The Orbital Debris Engineering Model (ORDEM) is NASA's model for calculating the orbital debris collision risk to current and future spacecraft, and guiding the design of new missions
  - It is based on a variety of data sources, and projects the growth and evolution of the environment out for several decades
    - HUSIR data is a primary contributor to ORDEM and our knowledge of the debris environment in the centimeter size regime
  - ORDEM is used by all NASA missions – robotic and human – to assess risk to their spacecraft
    - Required for conforming to NASA Orbital Debris Guidelines
  - ORDEM is also used by commercial space, DoD, and other agencies – domestic and international
  - The Russian ASAT debris cloud has now been added to ORDEM 3.1
    - New model has been released as ORDEM 3.2

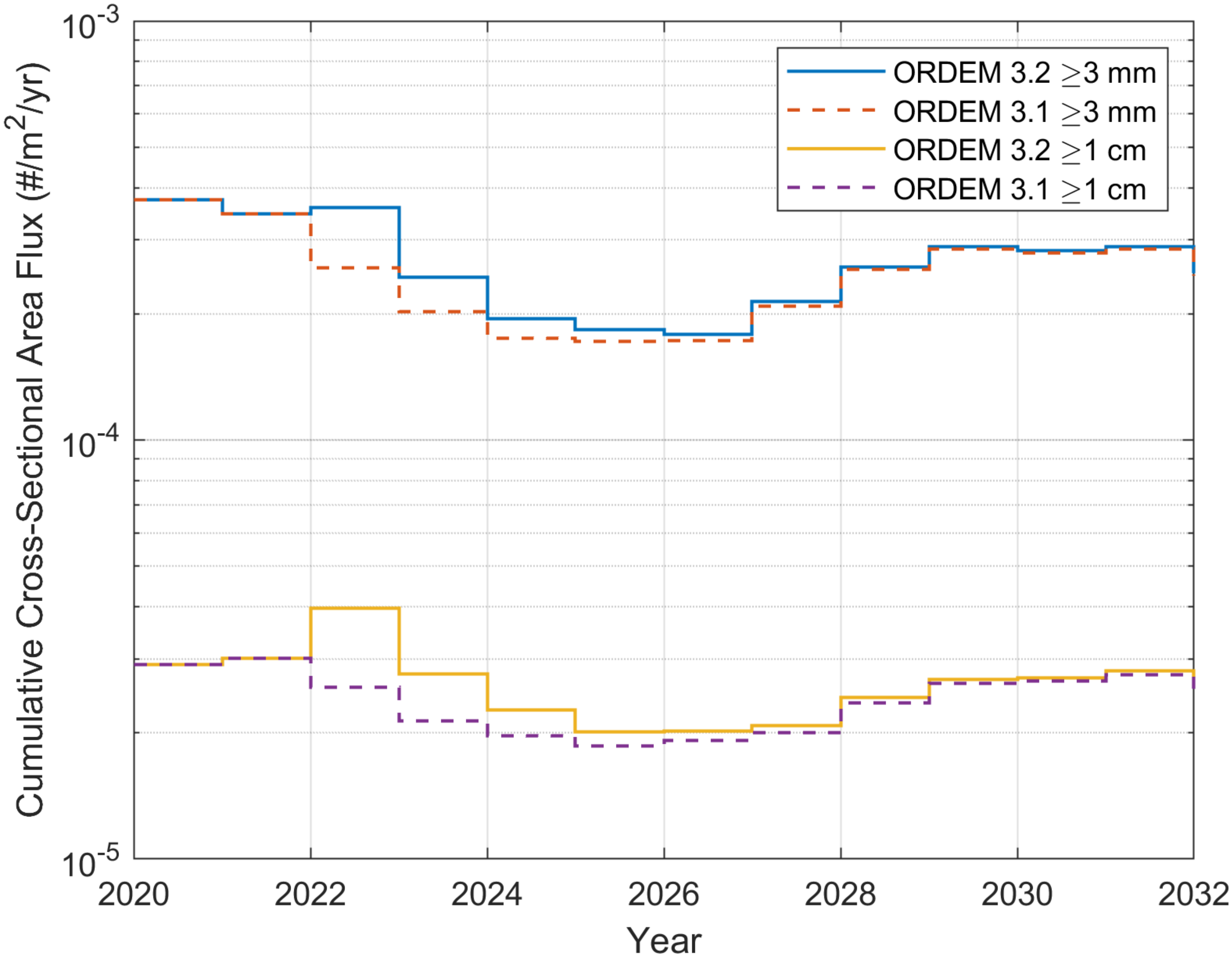
ORDEM 3.1 and 3.2 Size/Flux Comparison ISS Orbit (2022)



ORDEM 3.1 and 3.2 Altitude/Flux Comparison
ISS Orbit



ORDEM 3.1 and 3.2 Altitude/Flux Comparison HST Orbit



Conclusions

- **Catastrophic collisions in space are major debris-producers that increase risks to safe space operations**
- **In the long term, random collisions of objects in space will dominate the evolution of the debris environment**
- **By studying both planned and unplanned collisions, we can better understand how they behave and model how they will contribute to the environment in the future**
- **Our models have proven surprisingly accurate in predicting how breakup debris clouds evolve**
- **The use of “kinetic kill” anti-satellite tests at high altitudes, where the debris will remain in orbit for years/decades/centuries, can lead to serious negative consequences for space missions and the environment**