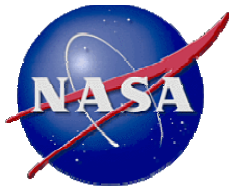
National Aeronautics and Space Administration



The Threat of Orbital Debris and Protecting NASA Space Assets from Satellite Collisions

28 April 2009

Executive Summary

- **Collision avoidance processes are in place for all NASA human space flight missions and for maneuverable robotic assets in low Earth orbit and within 200 km of the geosynchronous orbit.**
  - Required by NASA Procedural Requirements 8715.6A (Section 3.4).

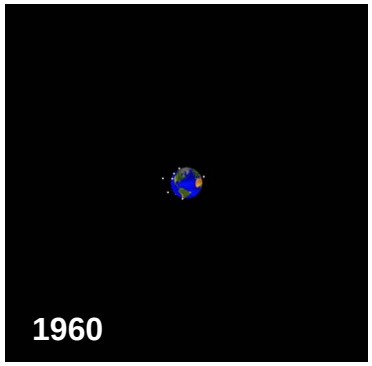
- **DoD screens for close approaches (conjunction assessments) and provides miss distance and uncertainty information to NASA.**

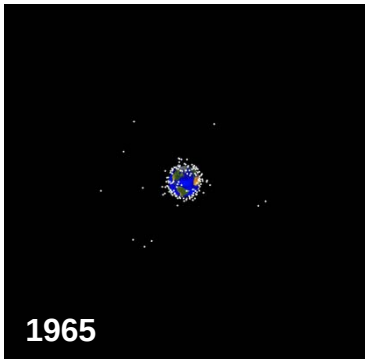
- **NASA computes the probability of collision, analyzes the risk, and makes maneuver decision.**

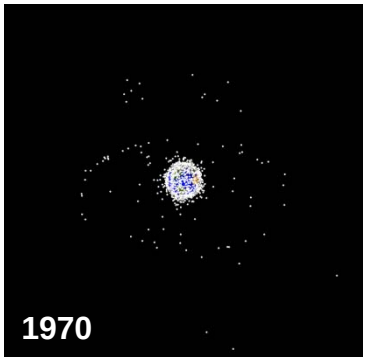
- **During 2008, this process led to five collision avoidance maneuvers:**

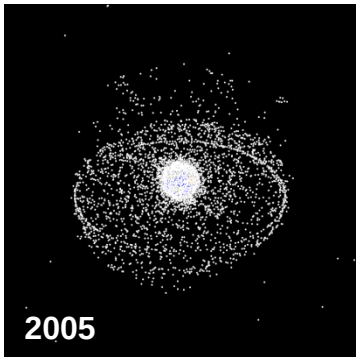
Spacecraft	Maneuver Date	Object Avoided
Aura	26-Jun-2008	TRIAD 1 debris
Cloudsat	20-Jul-2008	Delta rocket body debris
ISS	27-Aug-2008	Cosmos 2421 debris
TDRS 5	1-Oct-2008	Cosmos 1888
PARASOL (France)	19-Oct-2008	Fengyun-1C debris

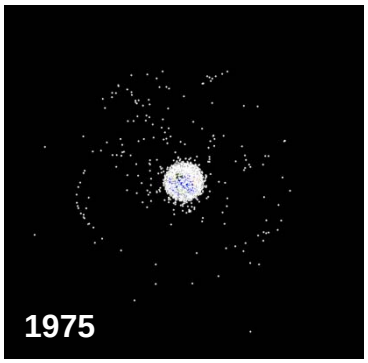
Growth of the Satellite Population

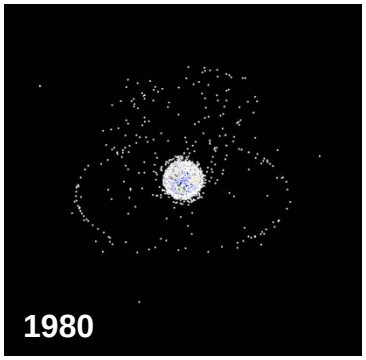


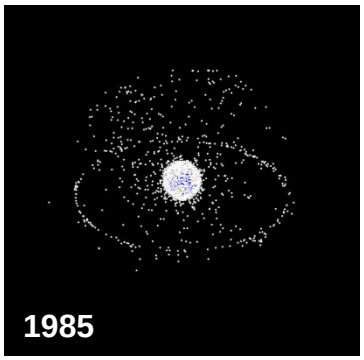


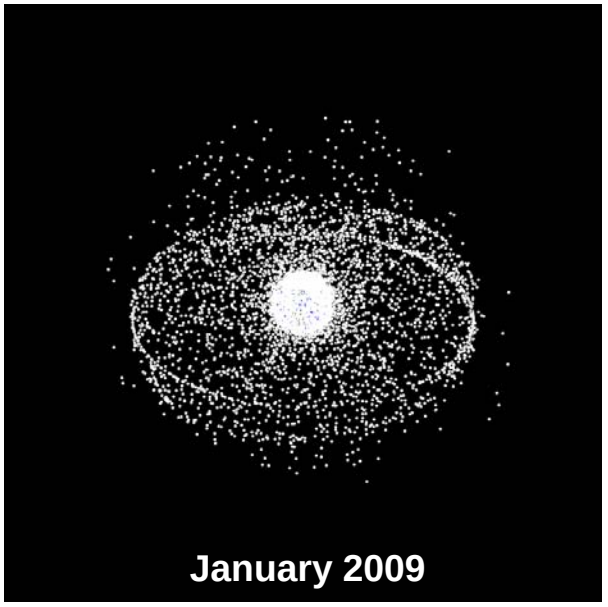


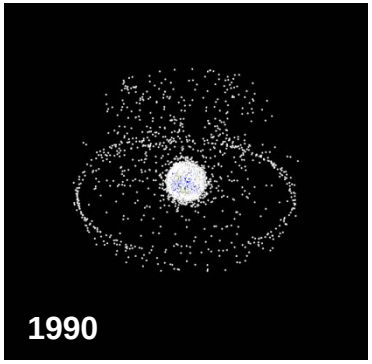


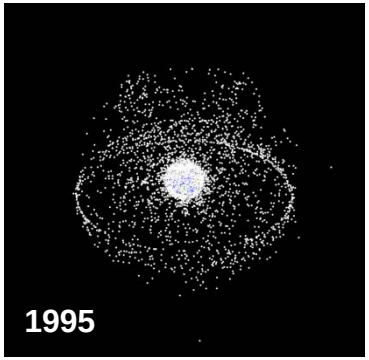


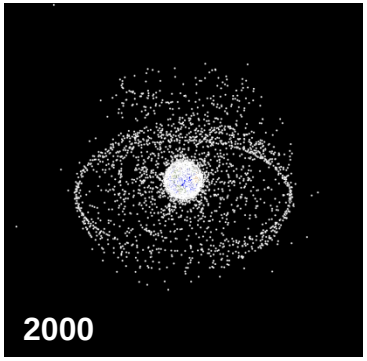






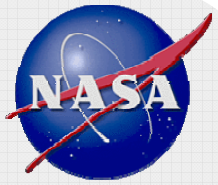






>95% of Tracked Object Population are Debris

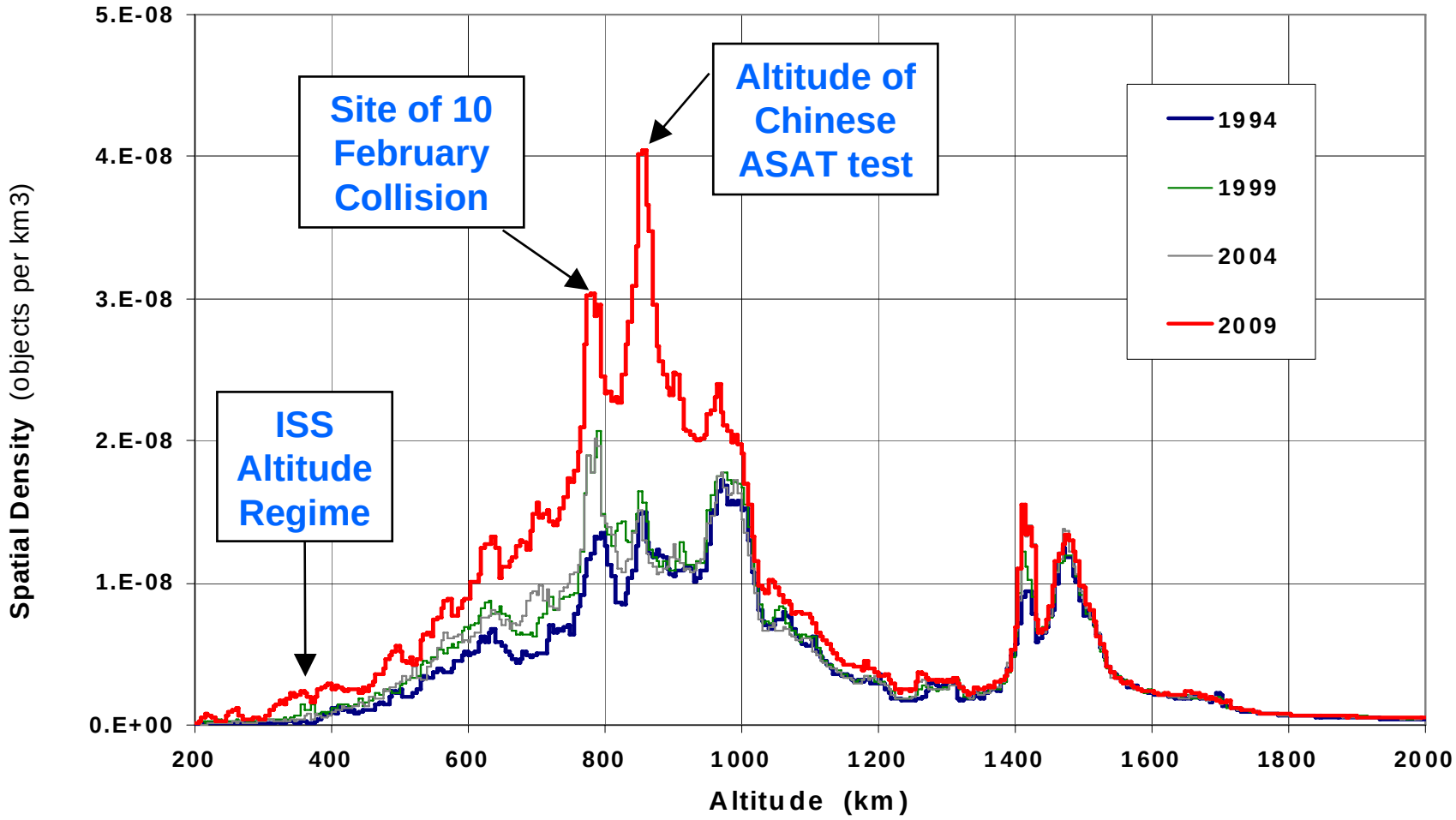
What is Orbital Debris?



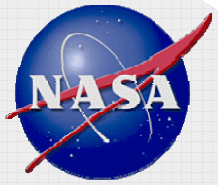
- **Space debris encompasses both natural (meteoroid) and artificial (man-made) particles.**
- **Meteoroids are in orbit about the Sun, while most artificial debris are in orbit about the Earth. Hence, the latter are more commonly referred to as orbital debris.**
- **Orbital debris is any man-made object in orbit about the Earth which no longer serves a useful function.**
  - **Non-functional spacecraft**
  - **Abandoned launch vehicle stages**
  - **Mission-related debris**
  - **Fragmentation debris**
- **For most size regimes, the flux of orbital debris within 2000 km of the Earth's surface already exceeds the flux of meteoroids.**

Recent Growth of Satellite Population in Low Earth Orbit

- **The growth of the cataloged satellite population during the past 15 years has been primarily influenced by China's ASAT test in January 2007.**



Satellite Environment Characterization



- **NASA and DoD cooperate and share responsibilities for characterizing the satellite (including orbital debris) environment.**

- **DoD's Space Surveillance Network discretely tracks objects as small as 5 cm in low Earth orbit and about 1 m in geosynchronous orbit.**

  – Currently, ~14,000 officially cataloged objects are still in orbit.
  – Total tracked objects exceeds 19,000.

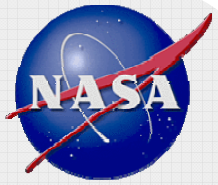
- **Using special ground-based sensors and inspections of returned satellite surfaces, NASA statistically determines the extent of the population for objects less than 10 cm.**

  – Number of debris in Low-Earth Orbit (LEO)* 1 cm or greater exceeds 300,000.

- **The combined results are used for spacecraft and launch vehicle design and operations.**

* **Low-Earth Orbit (LEO)** refers orbits ranging in altitudes from up to 2000 km above the Earth's surface; **Geosynchronous Orbit (GEO)** refers to orbits at ~36,000 km above the Earth's surface; at that distance, an orbits the Earth in a 24-hour period.

Collision Risks



- **Collision risks are divided into three categories depending upon size of threat.**

- **~ 10 cm and larger: Conjunction assessments and collision avoidance maneuvers are effective in countering objects which can be tracked by the U.S. Space Surveillance Network.**
  - Collisions of this type are potentially catastrophic.

- **1 – 10 cm: Objects in this category are usually too small to track and too large to shield against.**
  - Collisions of this type can disable or disrupt a mission.

- **< 1 cm: Debris shields can be effective in withstanding impacts of particles in this category.**
  - Unshielded portions of satellite subject can lead to mission degradation or loss.

- **The greatest risk to space missions comes from non-trackable debris.**

U.S. Space Surveillance Network

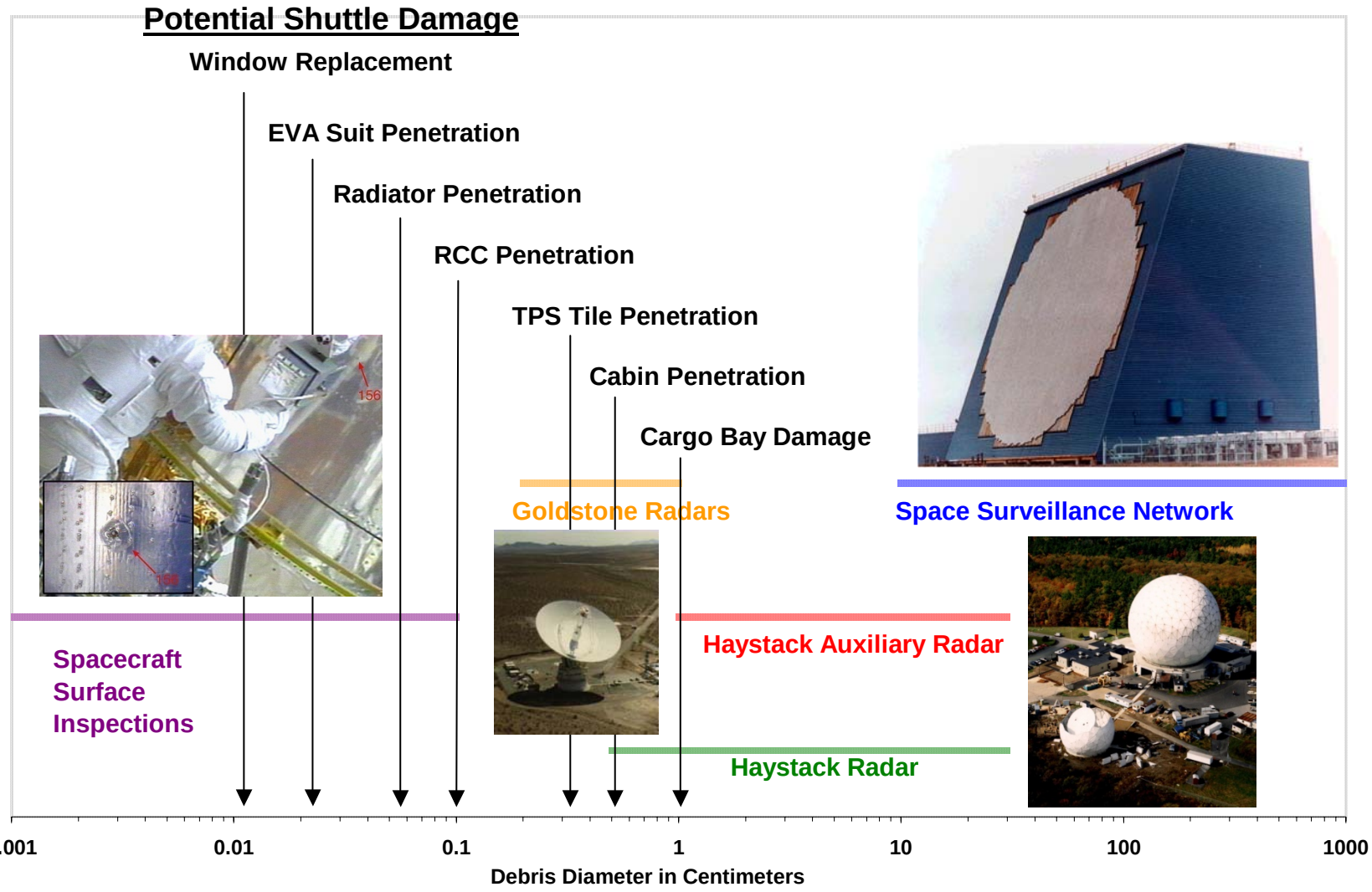
Organized as:

- Dedicated = primary
- Collateral = secondary
- Contributing = contracted services

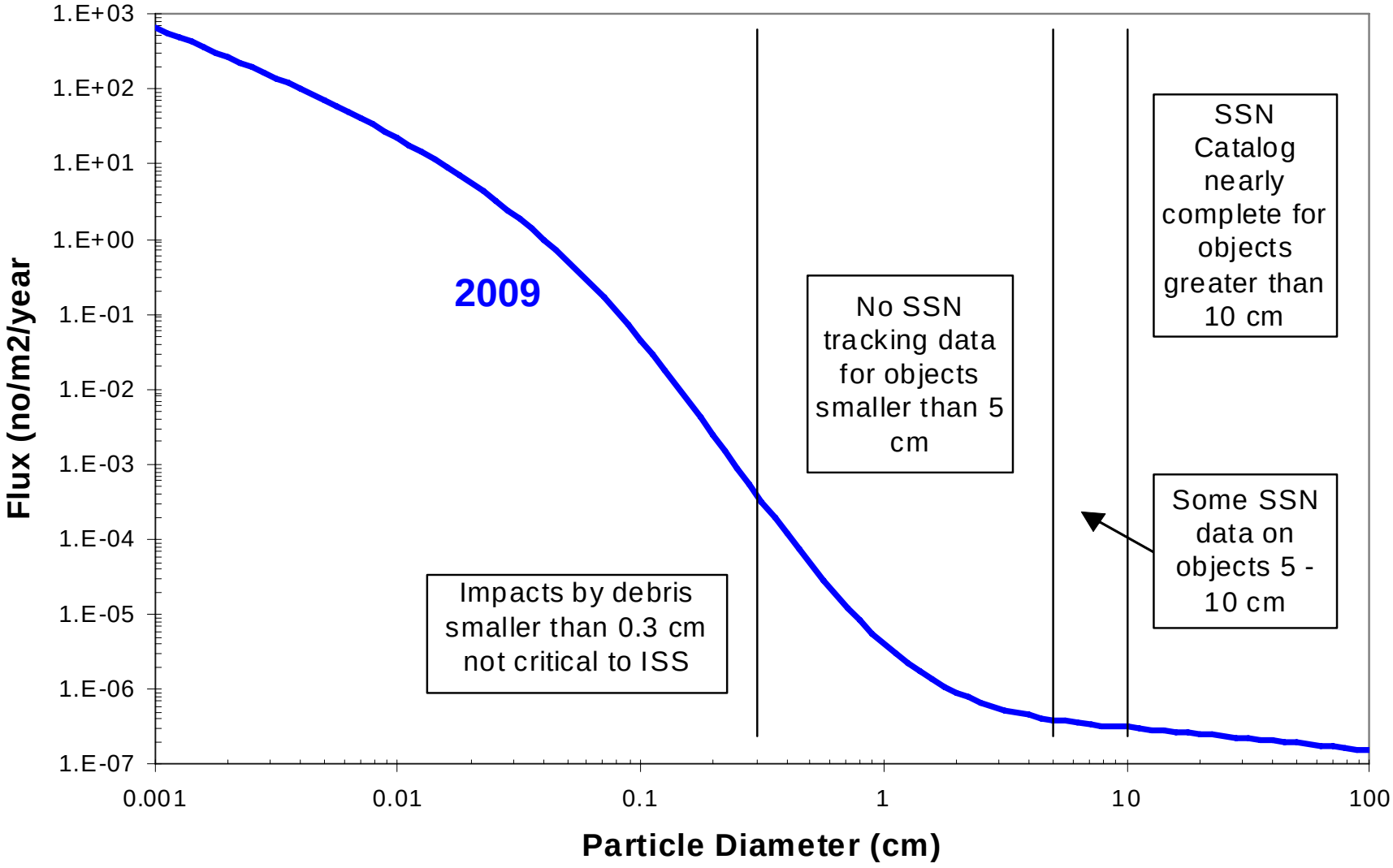
- Tracking Radar
- Detection Radar
- Imaging Radar
- Optical Telescope
- Passive Receiver

LSSC = Lincoln Space Surveillance Center
Millstone, Haystack, HAX
MSSS = Maui Space Surveillance System
(former AMOS/MOTIF site)
AFSSS = Air Force Space Surveillance System

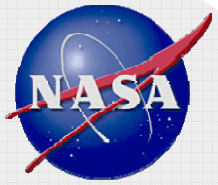
Space Shuttle Vulnerabilities



Debris Environment for International Space Station



Evolution of NASA Collision Avoidance Process



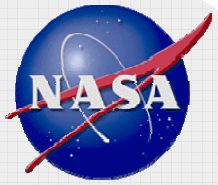
- **NASA implemented a conjunction assessment and collision avoidance process for human spaceflight beginning with STS-26 in 1988.**
  - Initially based upon simple miss distance and a 4-km by 10-km by 4-km ellipsoid (picture a protected football-shaped volume [keep out] around the Shuttle).

- **Before launch of the first element of ISS in 1998, NASA and DoD jointly developed and implemented a more sophisticated and higher fidelity conjunction assessment process for human spaceflight missions.**
  - Also adopted by other USG national space assets.

- **In 2005, NASA implemented a similar process for selected robotic assets, e.g., the Earth Observation System satellites in LEO and TDRSS in GEO.**

- **In 2007, NASA Procedural Requirements 8715.6 extended the conjunction assessment process to all NASA maneuverable satellites within LEO and within 200 km of GEO.**

Basic Conjunction Assessment and Collision Avoidance Process



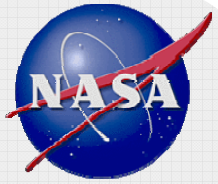
- **DoD maintains high accuracy satellite catalog on objects which pose a threat to designated NASA space assets.**
  - Lower fidelity, publicly available data ("two-line element sets") are NOT used.

- **DoD's Joint Space Operations Center (JSpOC) is responsible for performing conjunction assessments for all designated NASA space assets in accordance with an established schedule, *i.e.*, every 8 hours for human spaceflight vehicles and daily Monday through Friday for robotic vehicles.**
  - All objects tracked by SSN are considered: cataloged and uncataloged.

- **JSpOC notifies NASA (JSC for human spaceflight and GSFC for robotic missions) of conjunctions which meet established criteria.**
  - Data are exchanged 24/7 via direct links and telecon between JSpOC and JSC/GSFC.

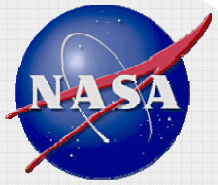
- **JSpOC tasks SSN to collect additional tracking data on threat object to improve conjunction assessment accuracy.**

Basic Conjunction Assessment and Collision Avoidance Process (continued)



- **NASA computes the probability of collision, based upon miss distance and uncertainty provided by JSpOC.**
- **Based upon specific flight rules and detailed risk analysis, NASA decides if a collision avoidance maneuver is necessary.**
- **If a maneuver is required, NASA provides planned post-maneuver orbital data to JSpOC for screening of near-term conjunctions. This process can be repeated if planned new orbit puts the NASA vehicle at risk of future collision with the same or another space object.**
- **In the case of a NASA robotic satellite, a second maneuver might be required for the vehicle to resume its mission. This maneuver also would be coordinated with JSpOC.**
- **NASA also informs JSpOC prior to normal operational maneuvers to aid future conjunction assessments.**

Debris Avoidance Maneuver Planning for Human Spaceflight Operations



- **Debris avoidance maneuvers are planned when the probability of collision from a conjunction reaches limits set in the Shuttle and ISS flight rules:**
  - Probability > 1 in 100,000: Maneuver if it will not result in significant impact to mission objectives.
  - Probability > 1 in 10,000: Maneuver unless it will result in additional risk to crew (re-flight, additional spacewalk, etc.).
- **Debris avoidance maneuvers are usually small and occur from one to several hours before the time of the conjunction.**
  - Shuttle can plan and execute a debris avoidance maneuver in a matter of hours.
  - ISS requires around 30 hours to plan and execute a debris avoidance maneuver, mainly due to dependence on Russian propulsion assets.
- **Both the Shuttle and ISS have conducted several collision avoidance maneuvers during the past 10 years.**