Optical Tracking and Characterization of Space Objects

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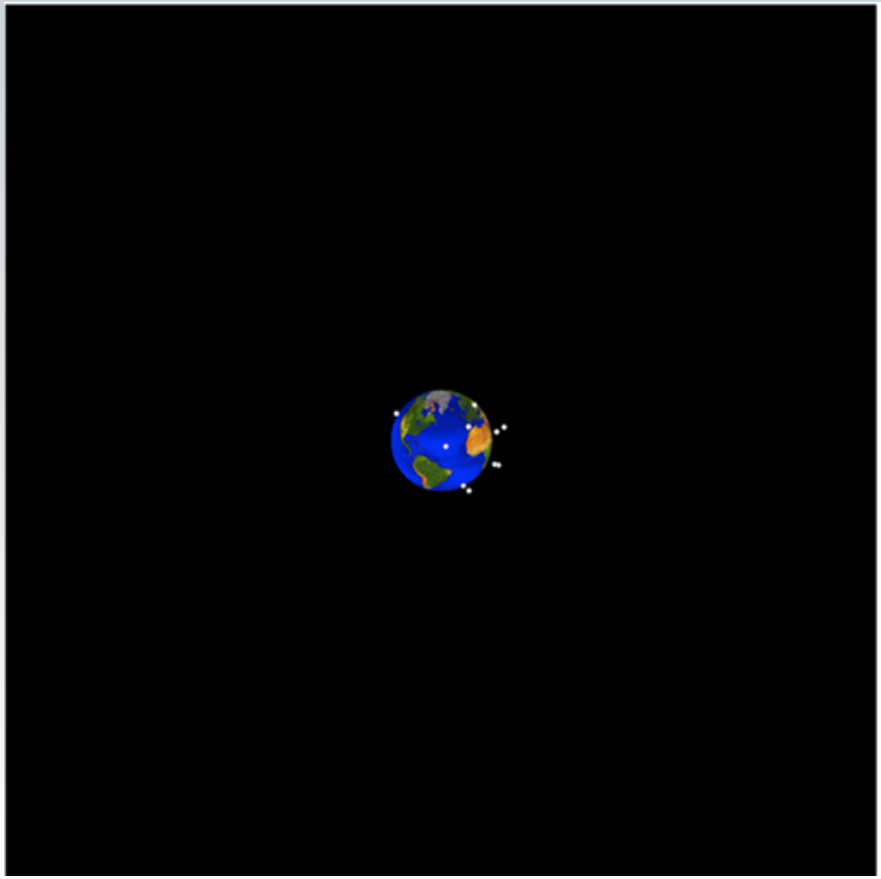
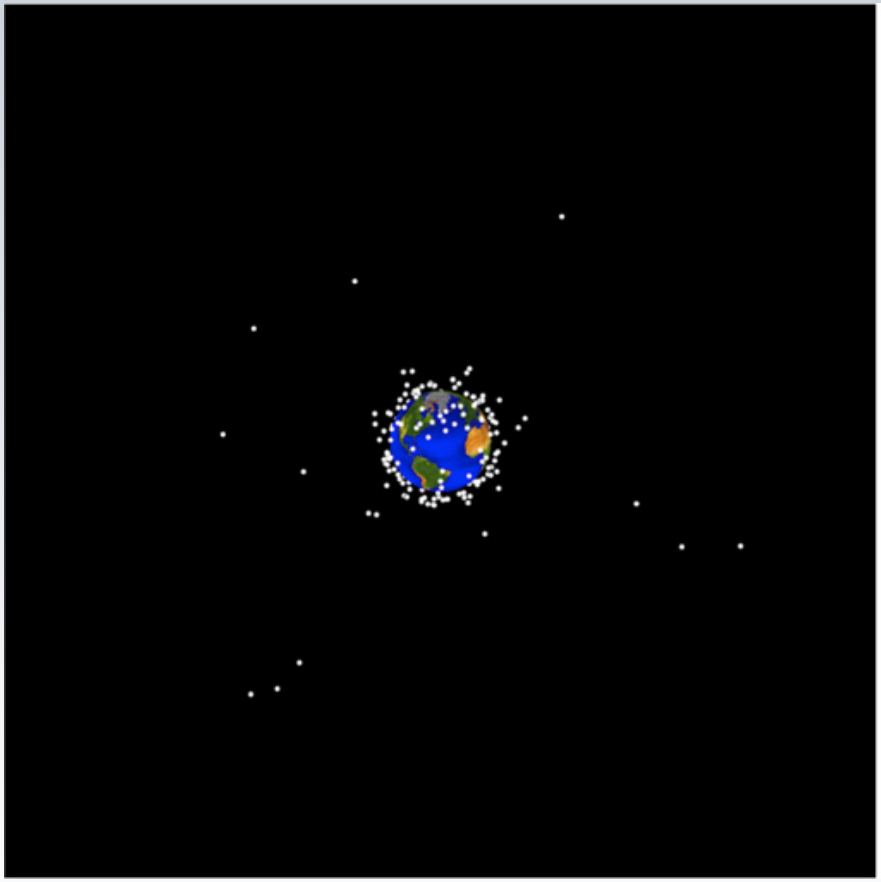
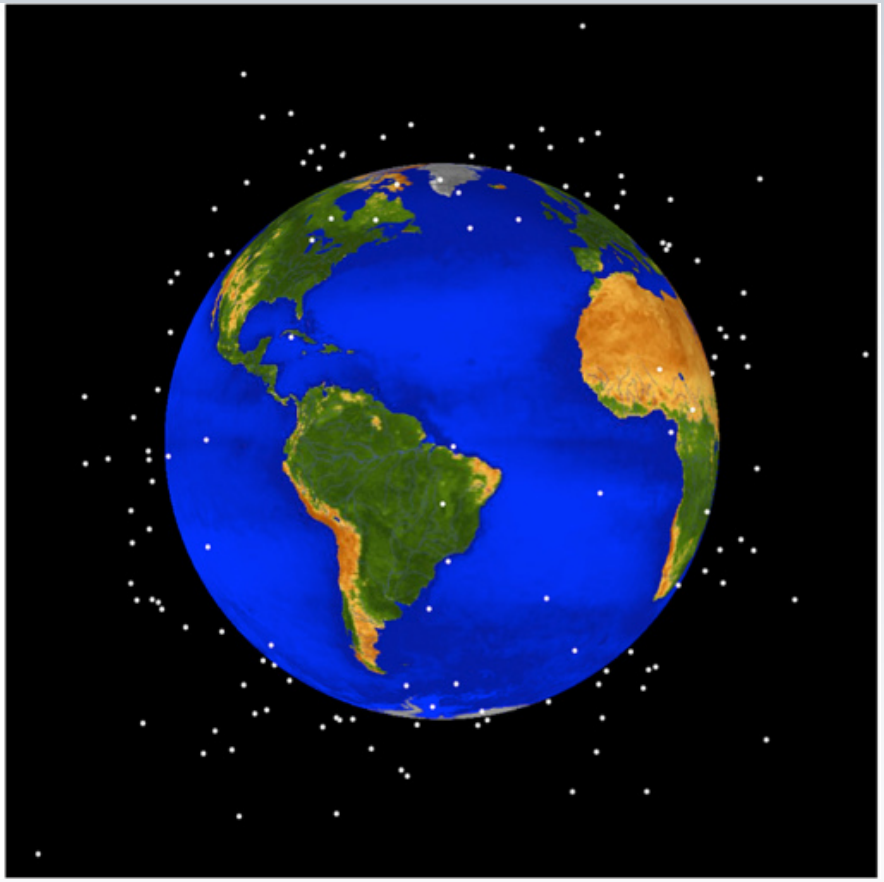
Historical Evolution



1960

Historical Evolution





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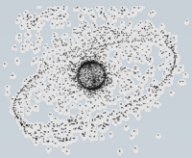

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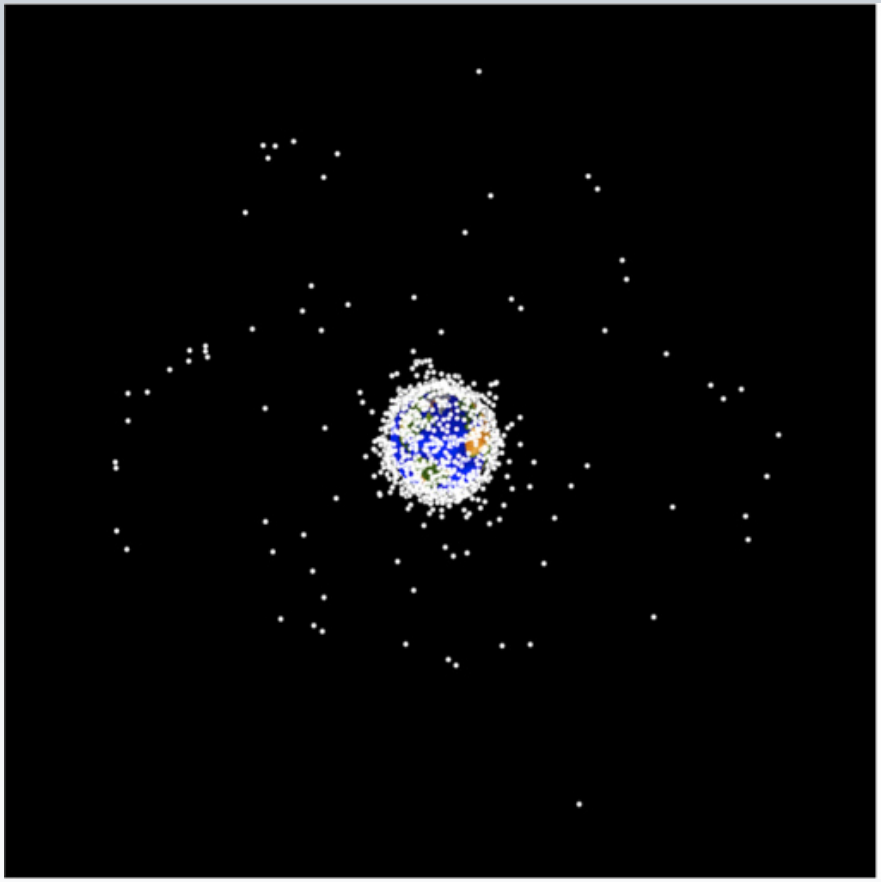

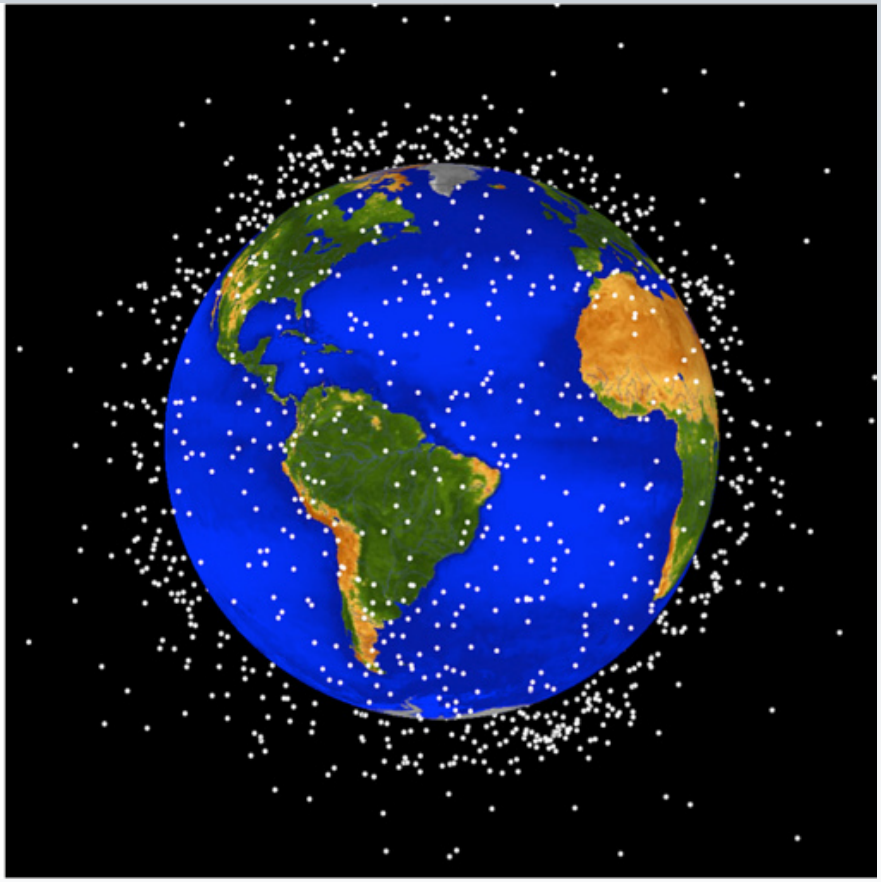

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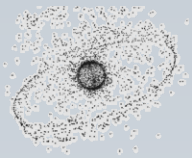

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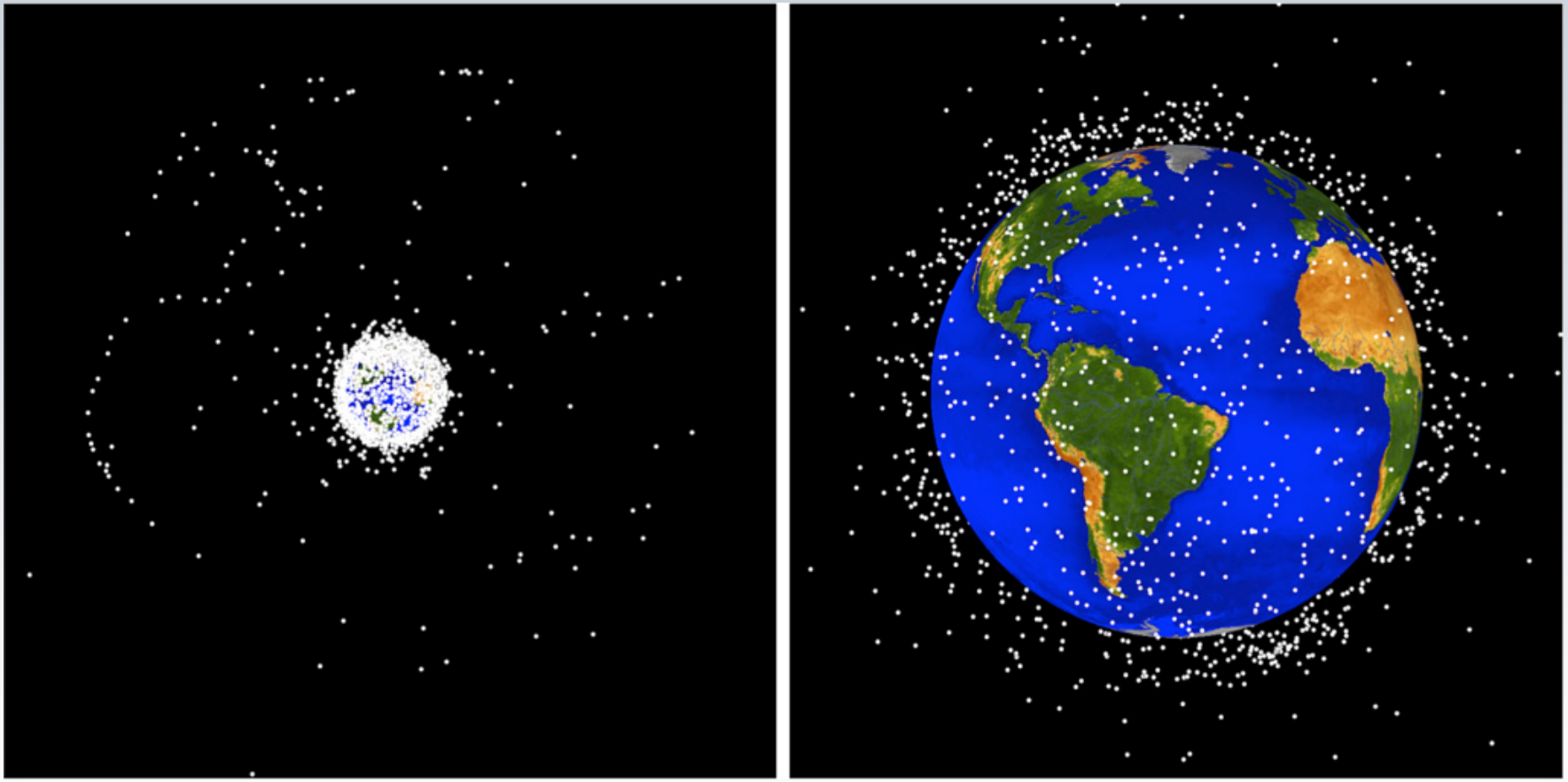

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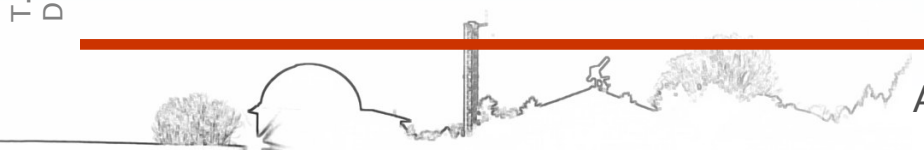

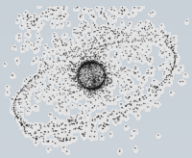

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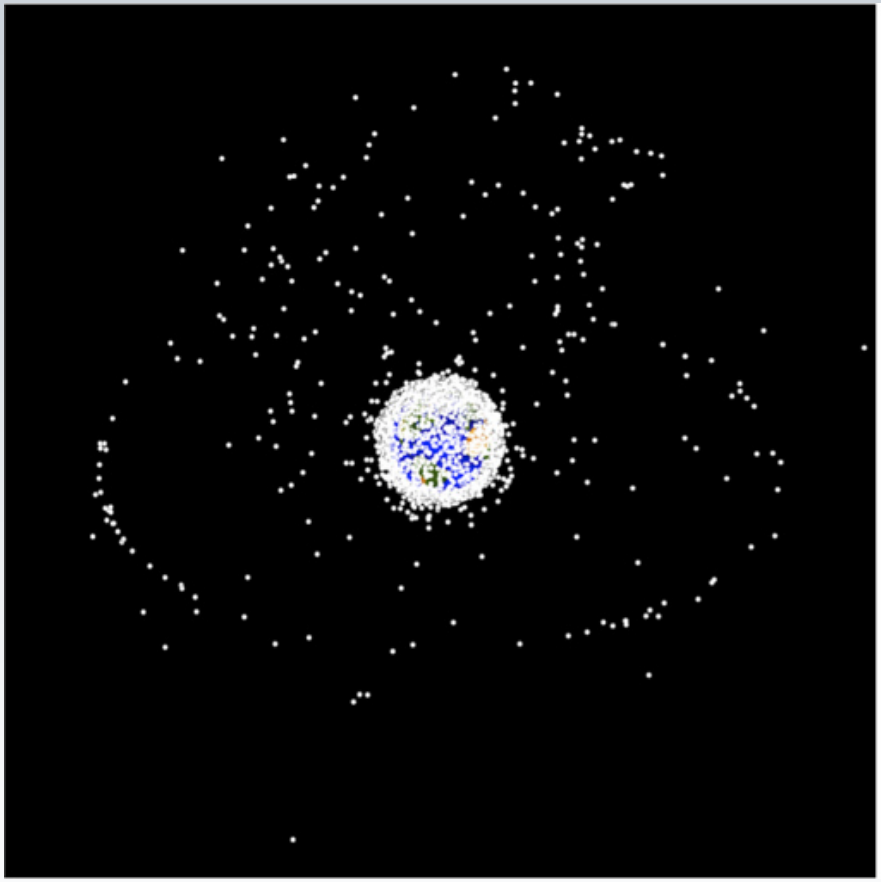

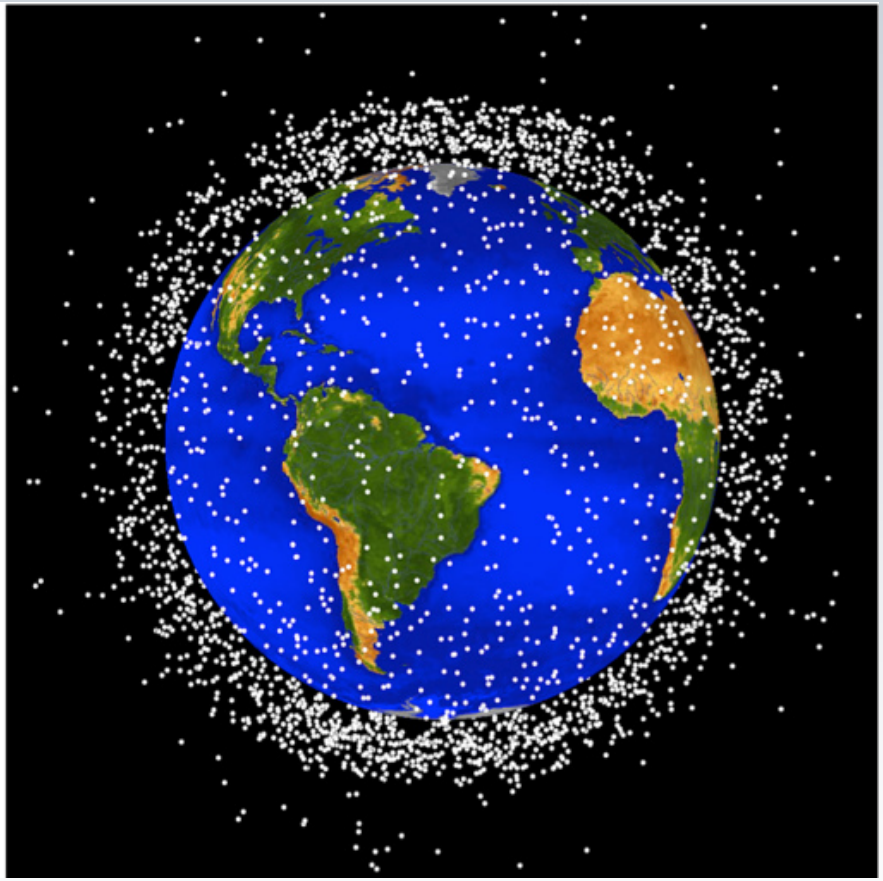

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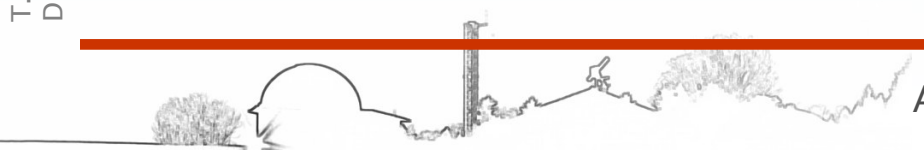

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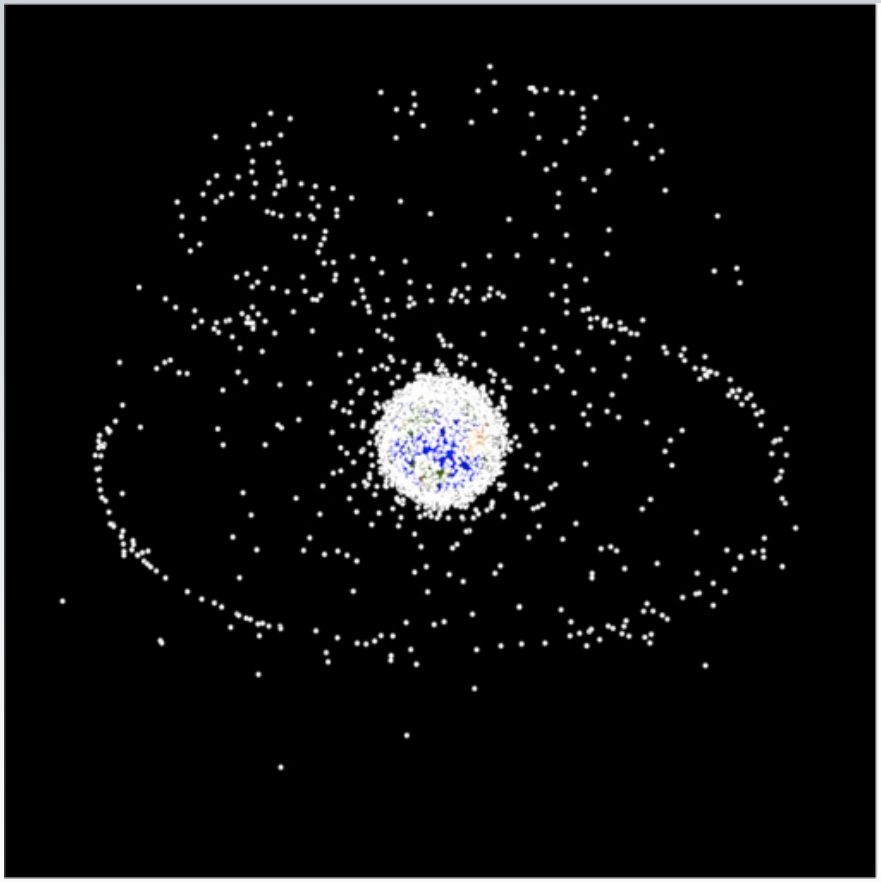

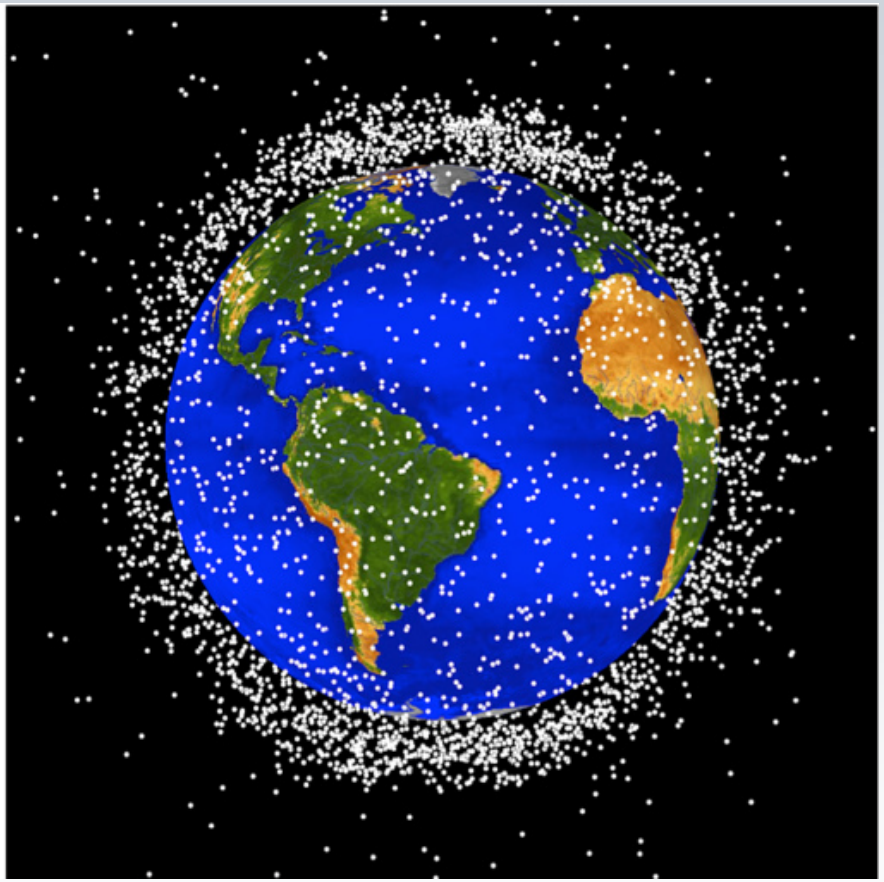

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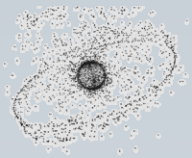

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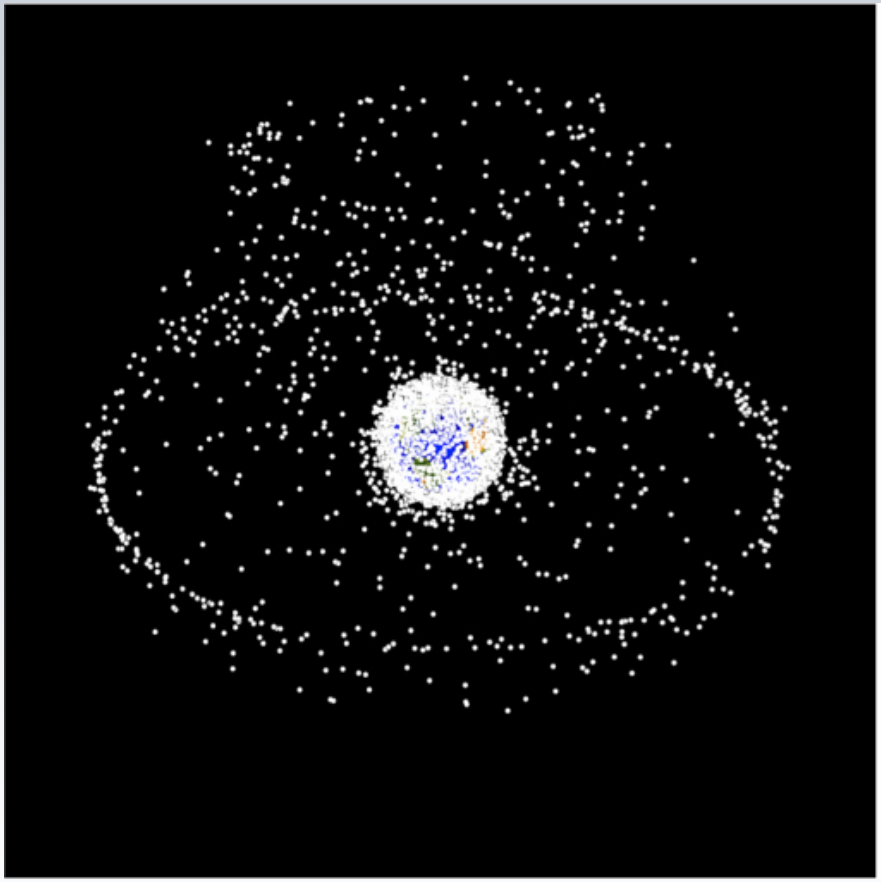
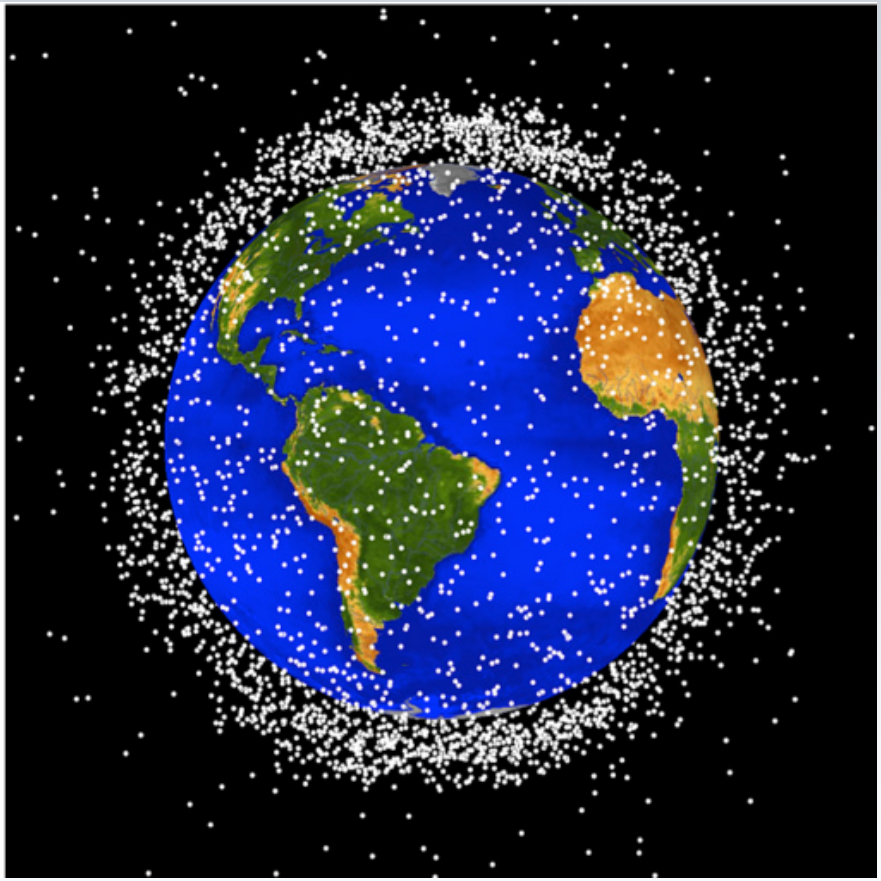
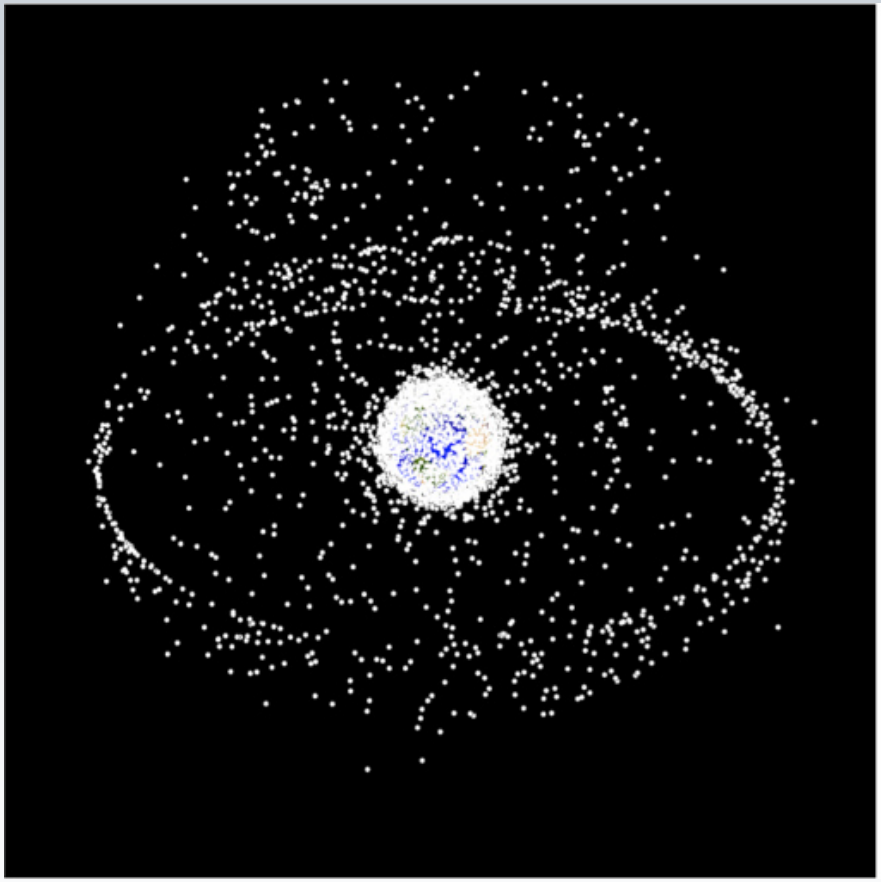
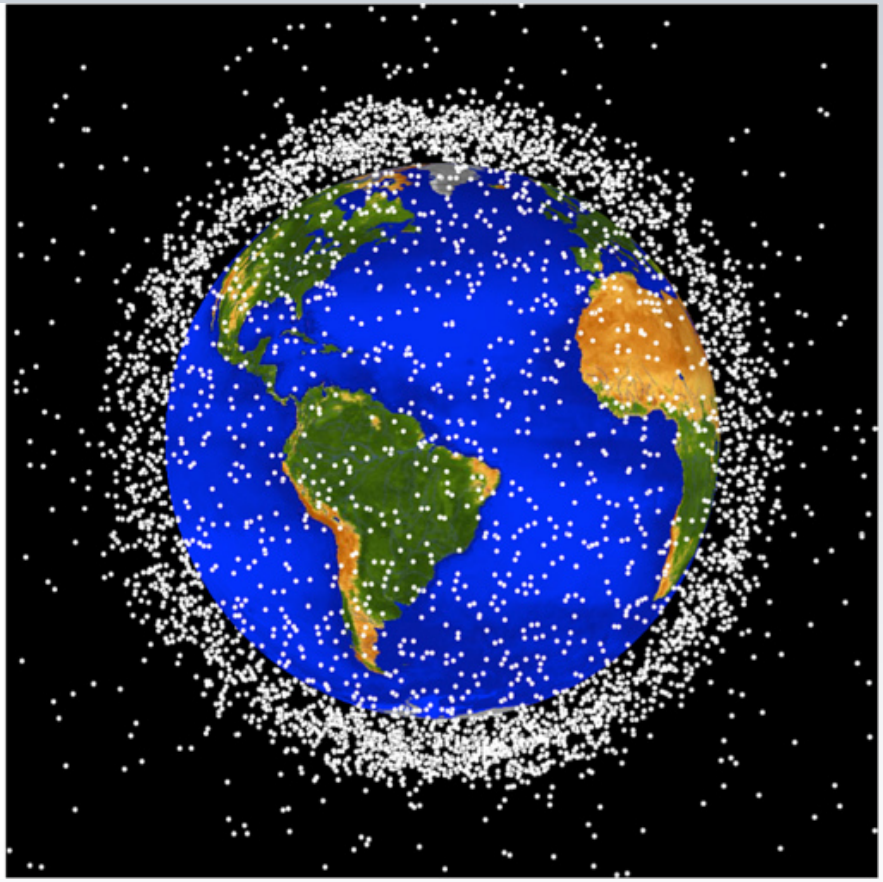




1990

Historical Evolution





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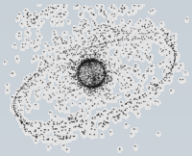

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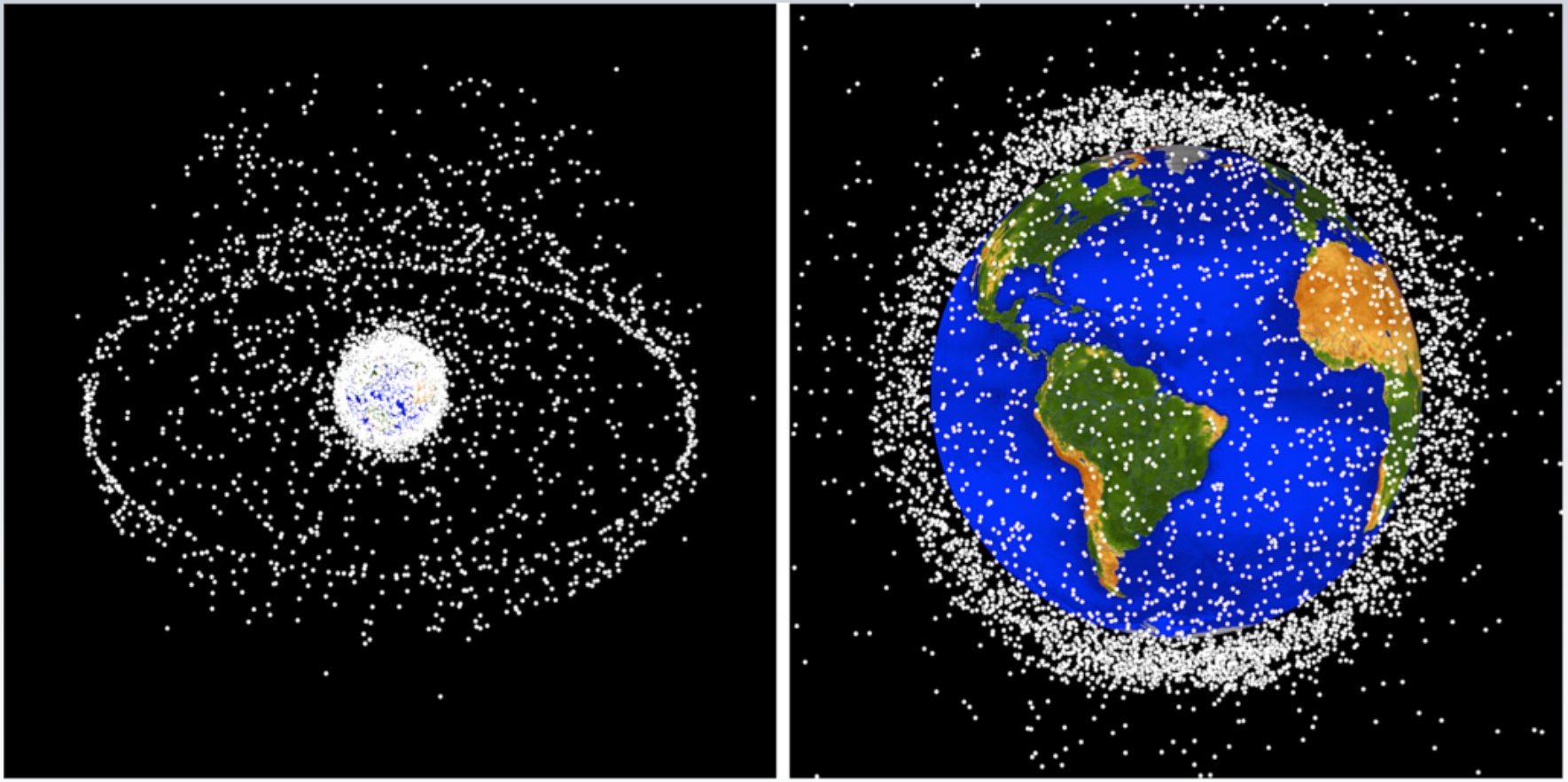

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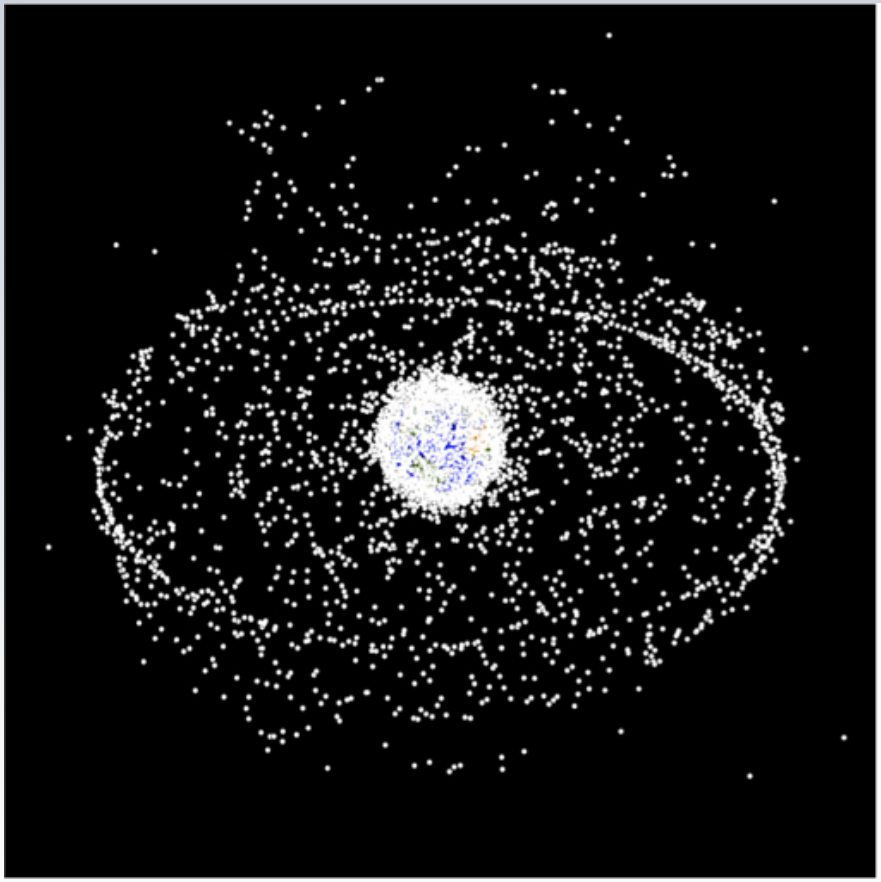
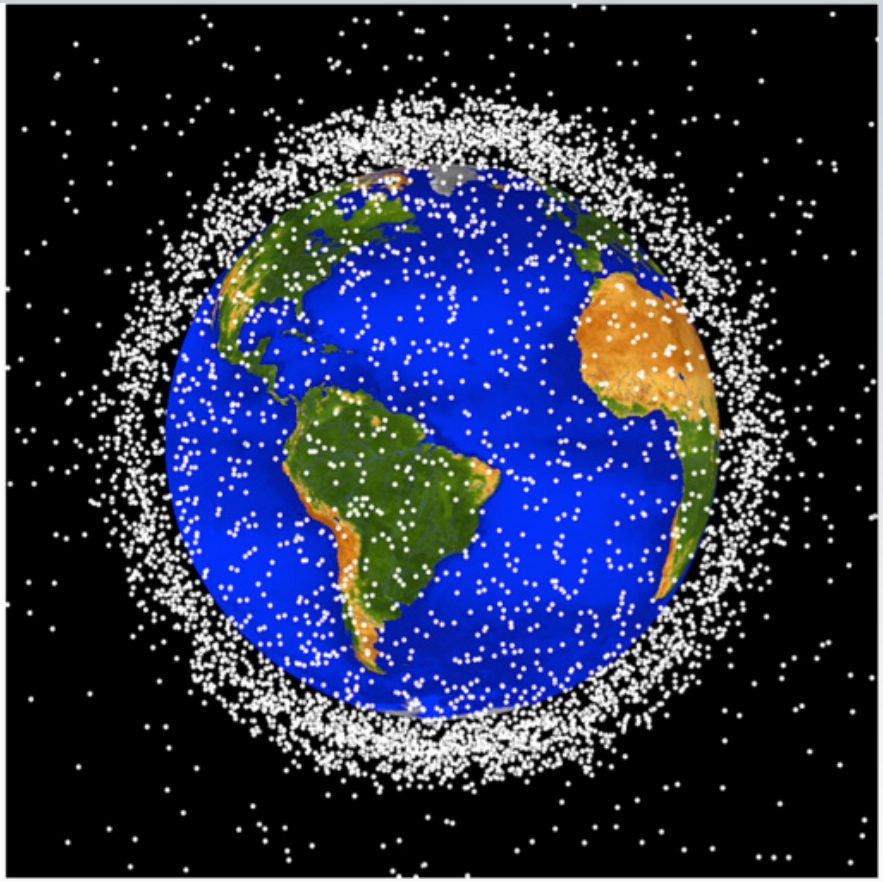
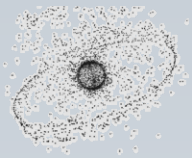
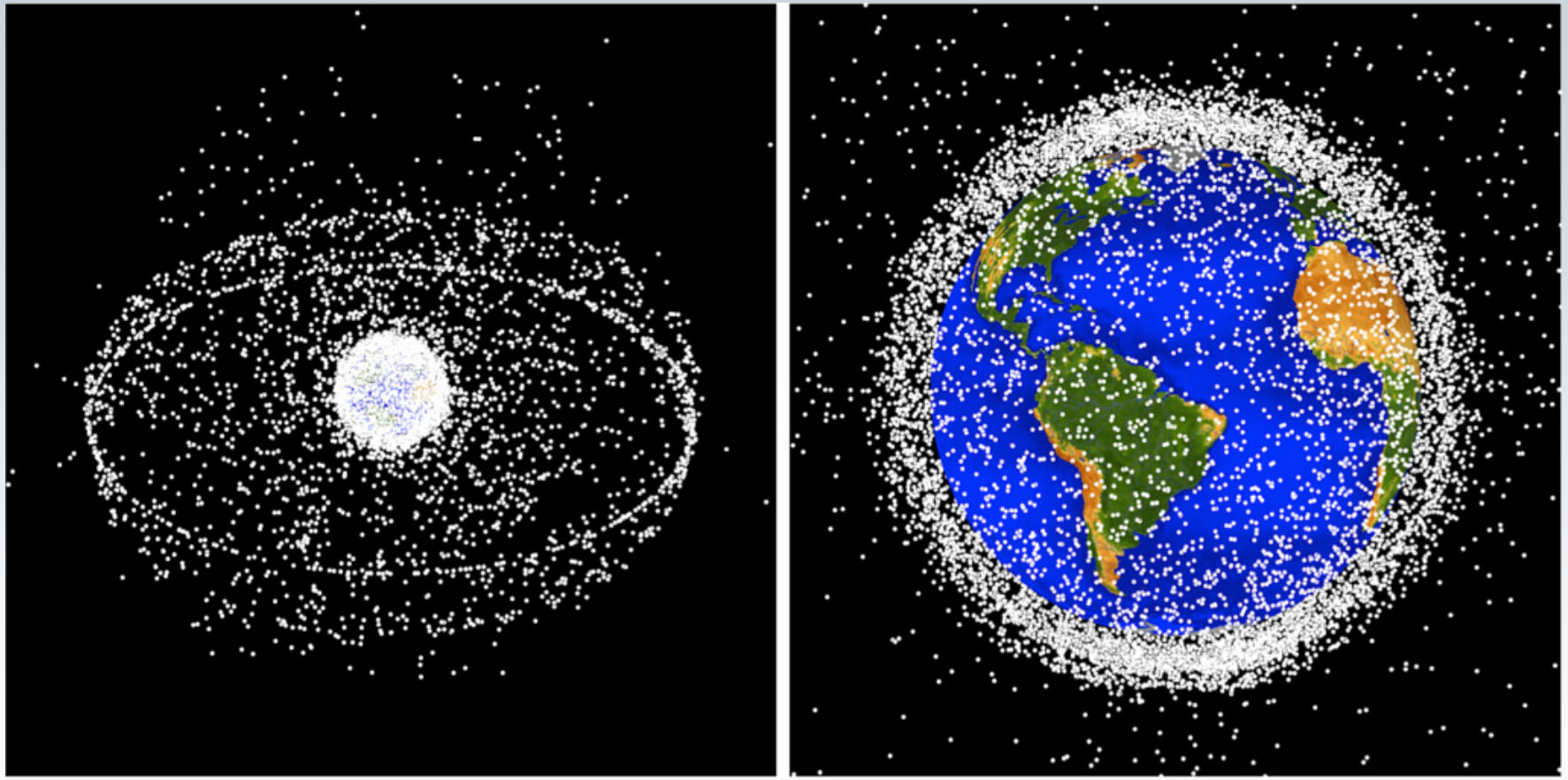




2005

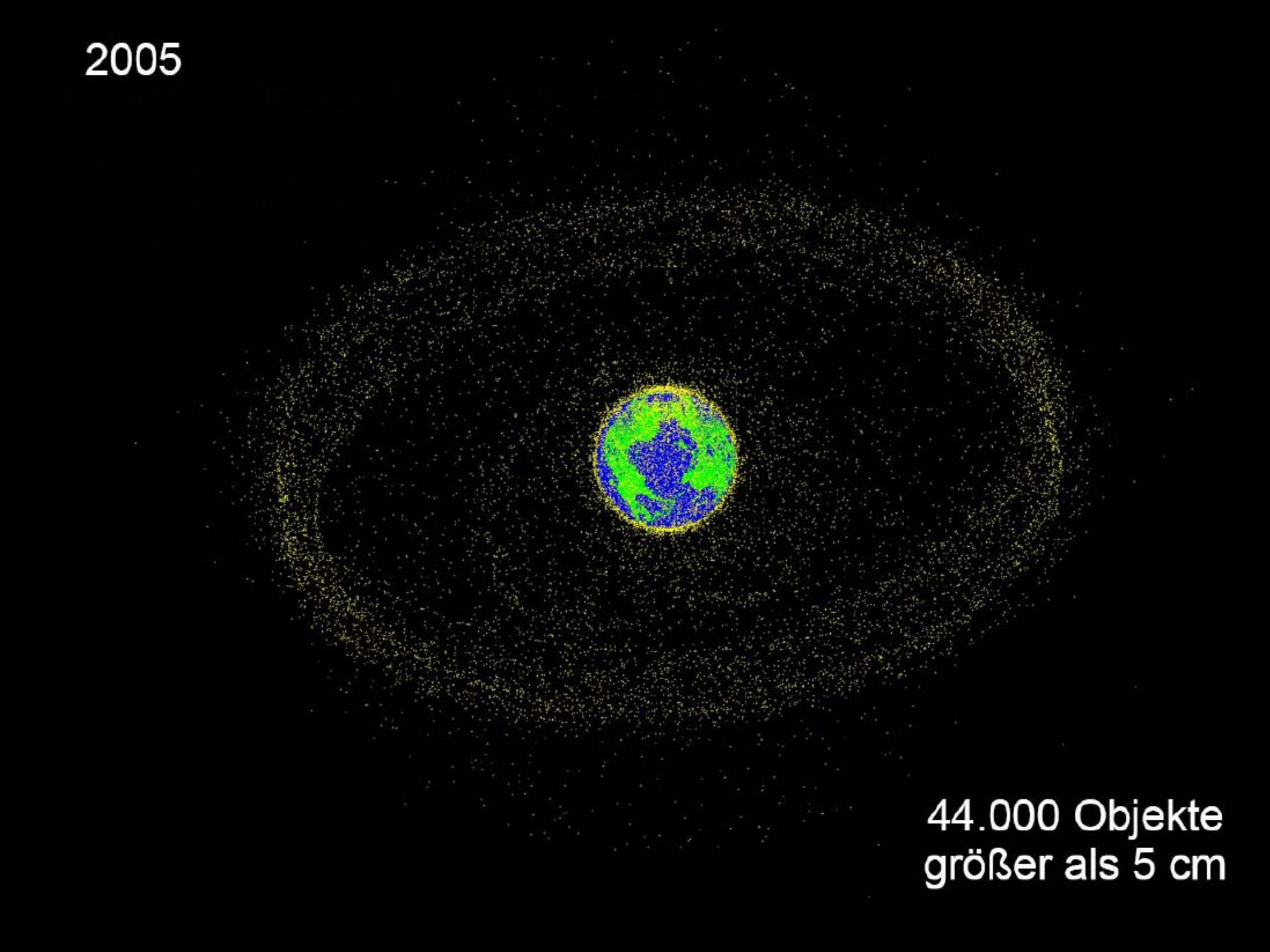


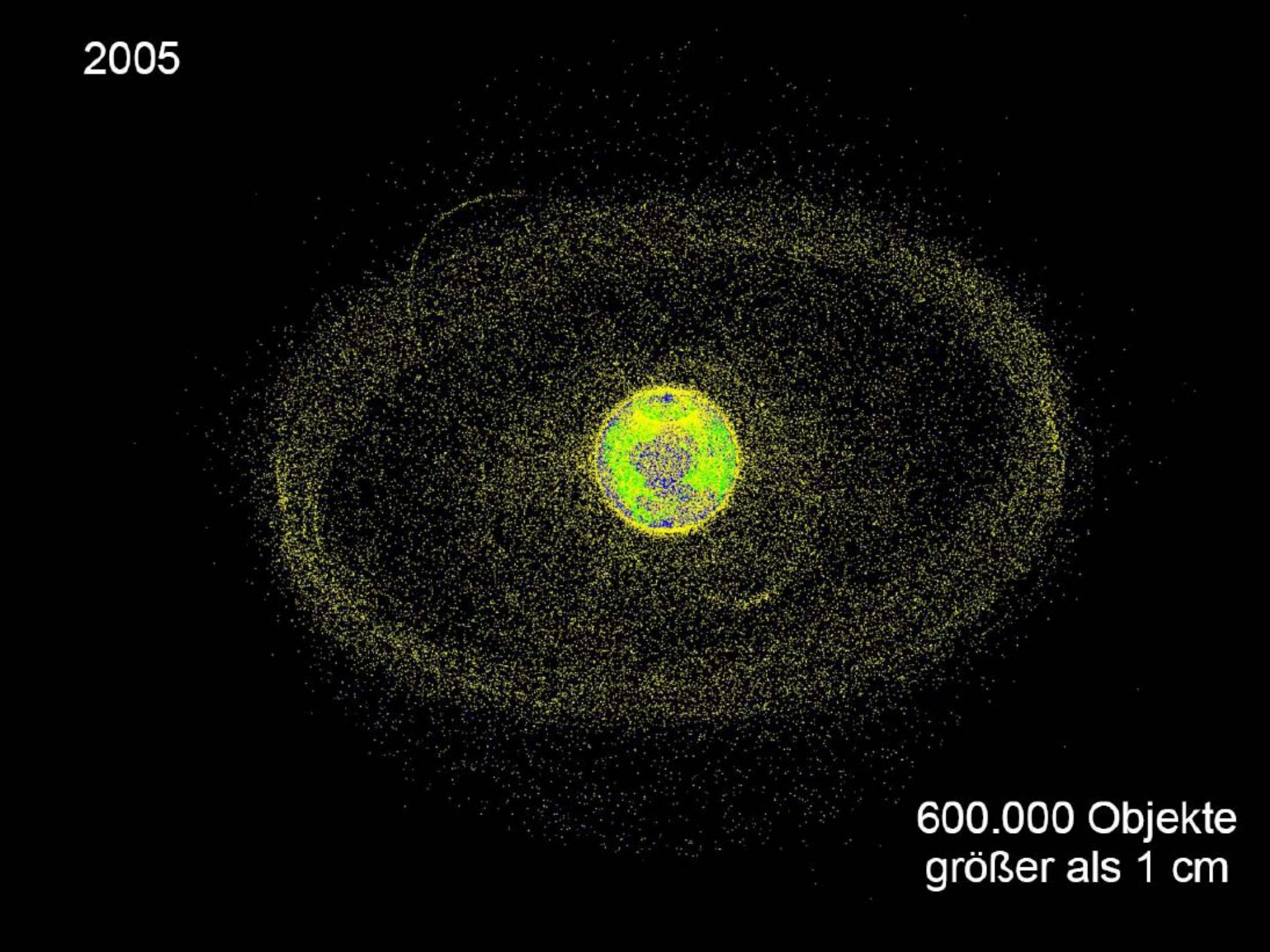
Historical Evolution



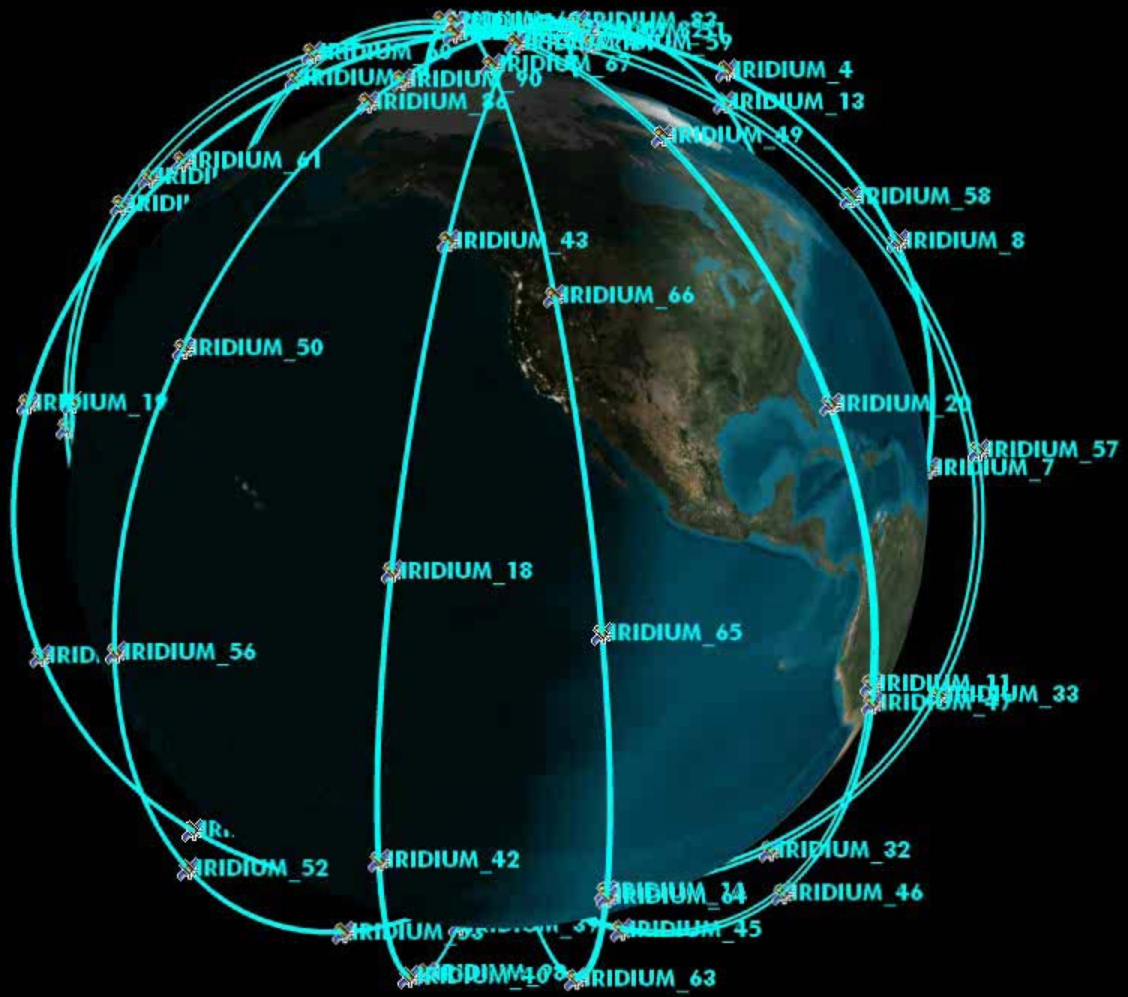
2010

Catalogue: ~20‘000 Objects >10cm


2005
44.000 Objekte
größer als 5 cm

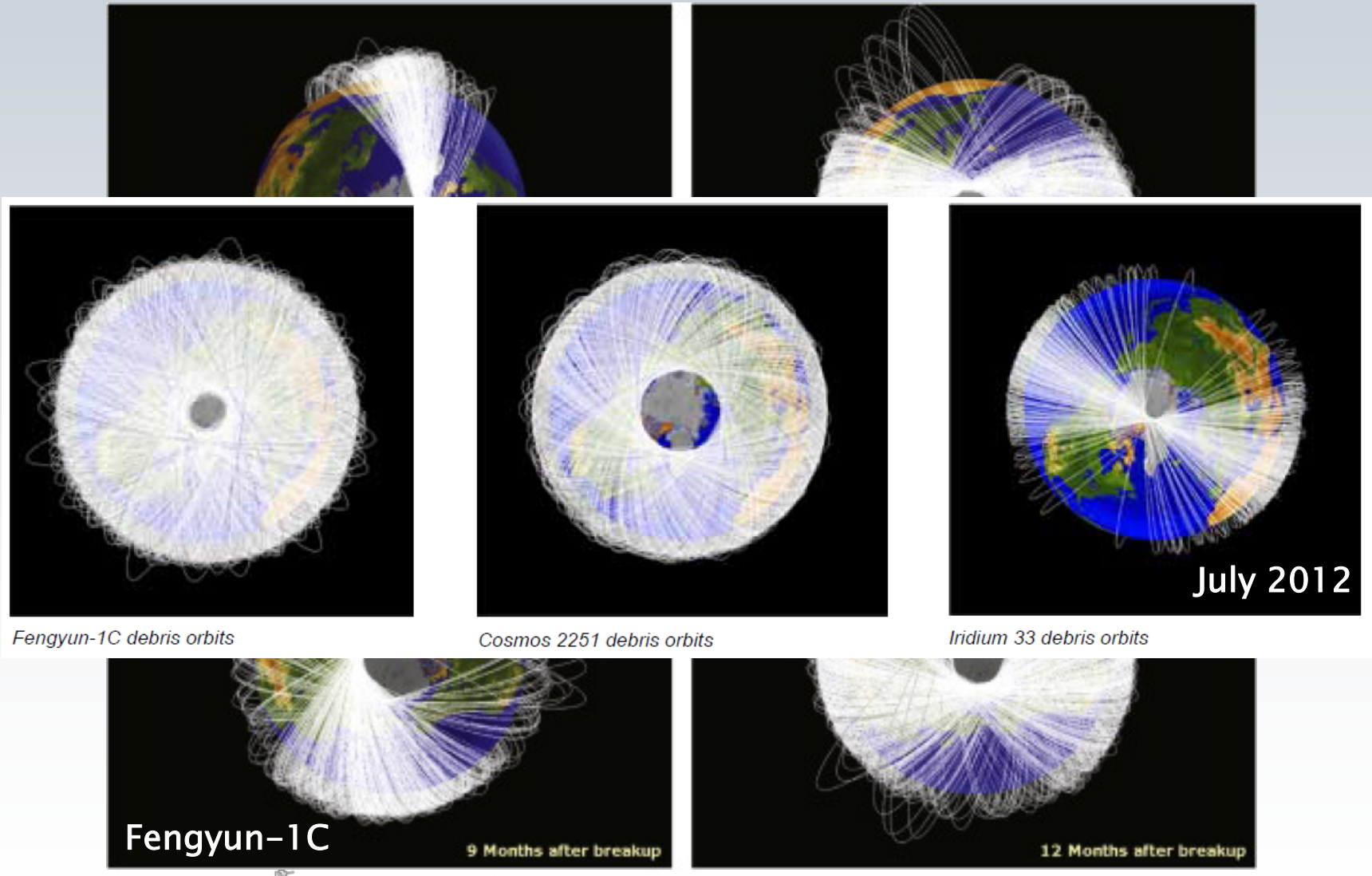

2005
600.000 Objekte
größer als 1 cm

Collision 10.2.2009, 04:50



Collision 10.2.2009, 04:50

Verteilung der Trümmer



Fengyun-1C debris orbits

Cosmos 2251 debris orbits

Iridium 33 debris orbits

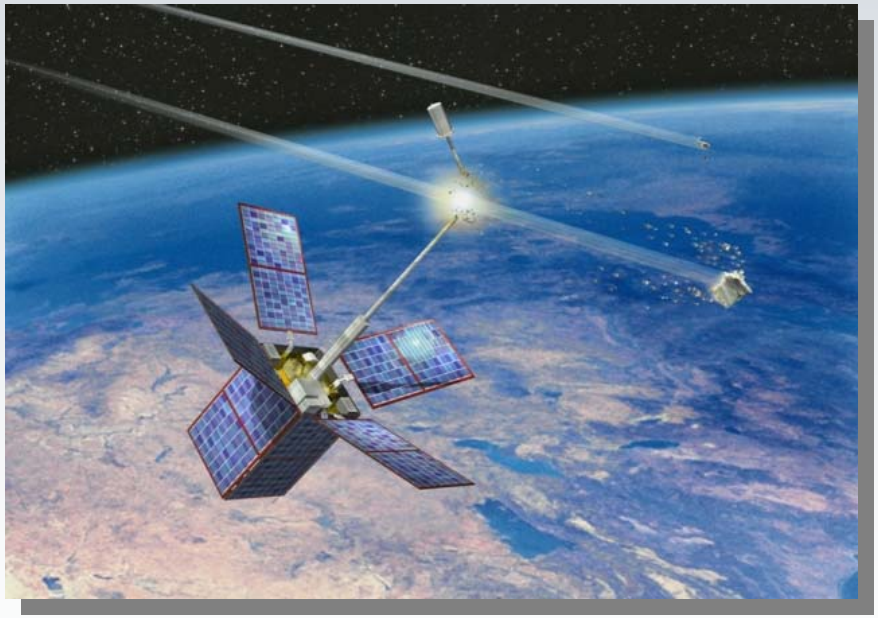
What is Space Debris?

- Over 4700 launches since Sputnik 1 on October 4, 1957
- Space Debris: any man-made object which is non-functional with no reasonable expectation of assuming or resuming its intended function
  - today: millions of fragments in orbit
  - ~ 18'000 objects tracked daily by USSTRATCOM
- ~ 100 launches each year

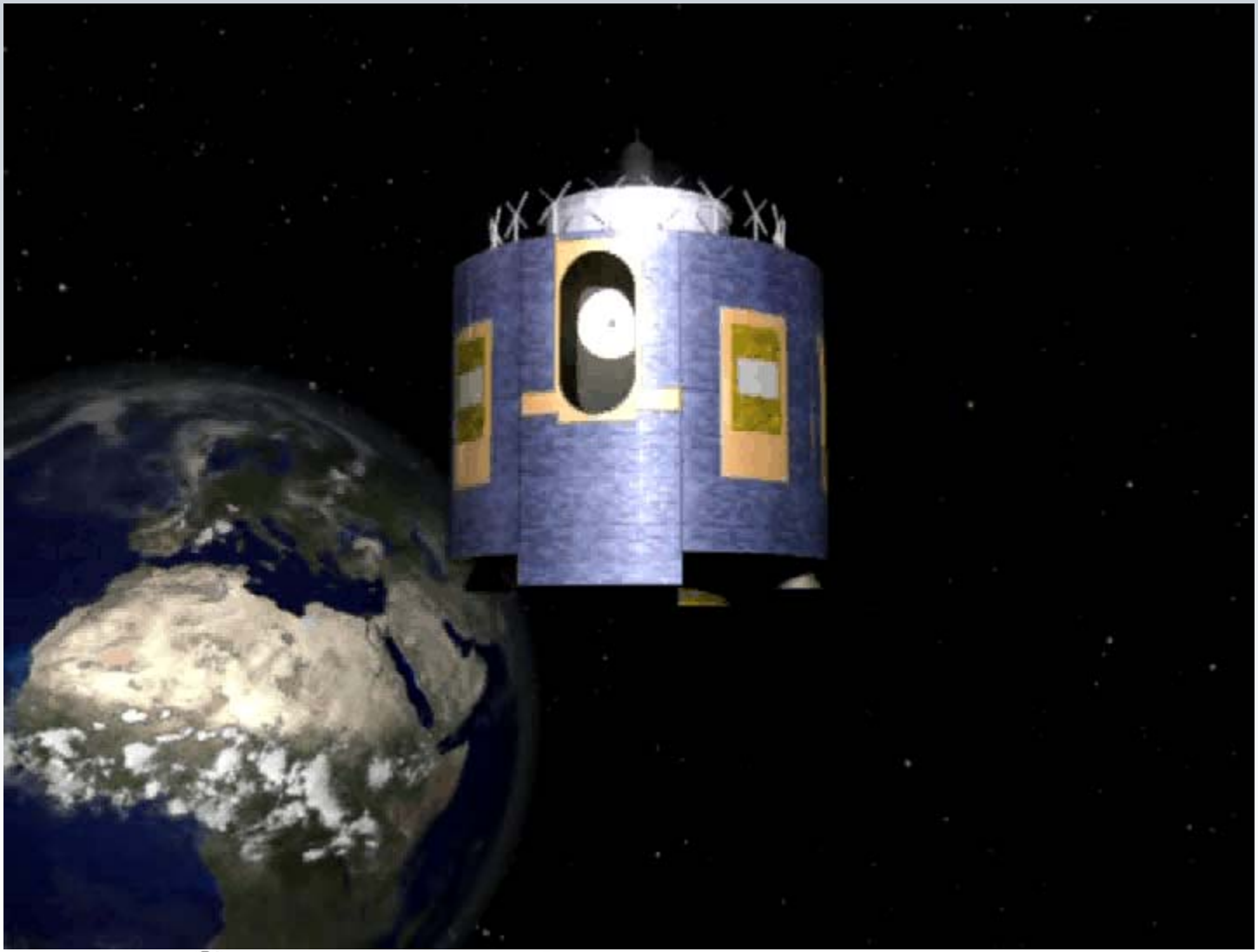
Sources of Space Debris?

- Abandoned hardware
  - rocket upper stages
  - ‚dead' satellites
  - mission-related objects
- Material degradation
  - paint flakes
  - pieces of insulation material
- Solid rocket motors
- Numbers of pieces dominated by breakups
  - > 200 known events
- Collisions
  - 2 intentional *+ 1 (2007!)* + USA 193 (21.2.2008)
  - 3 ‚accidents' + Iridium 33 (10.2.2009)

CERISE spacecraft collided on July 24 1996 with a fragment of an ARIANE upper stage



Mission-Related Objects



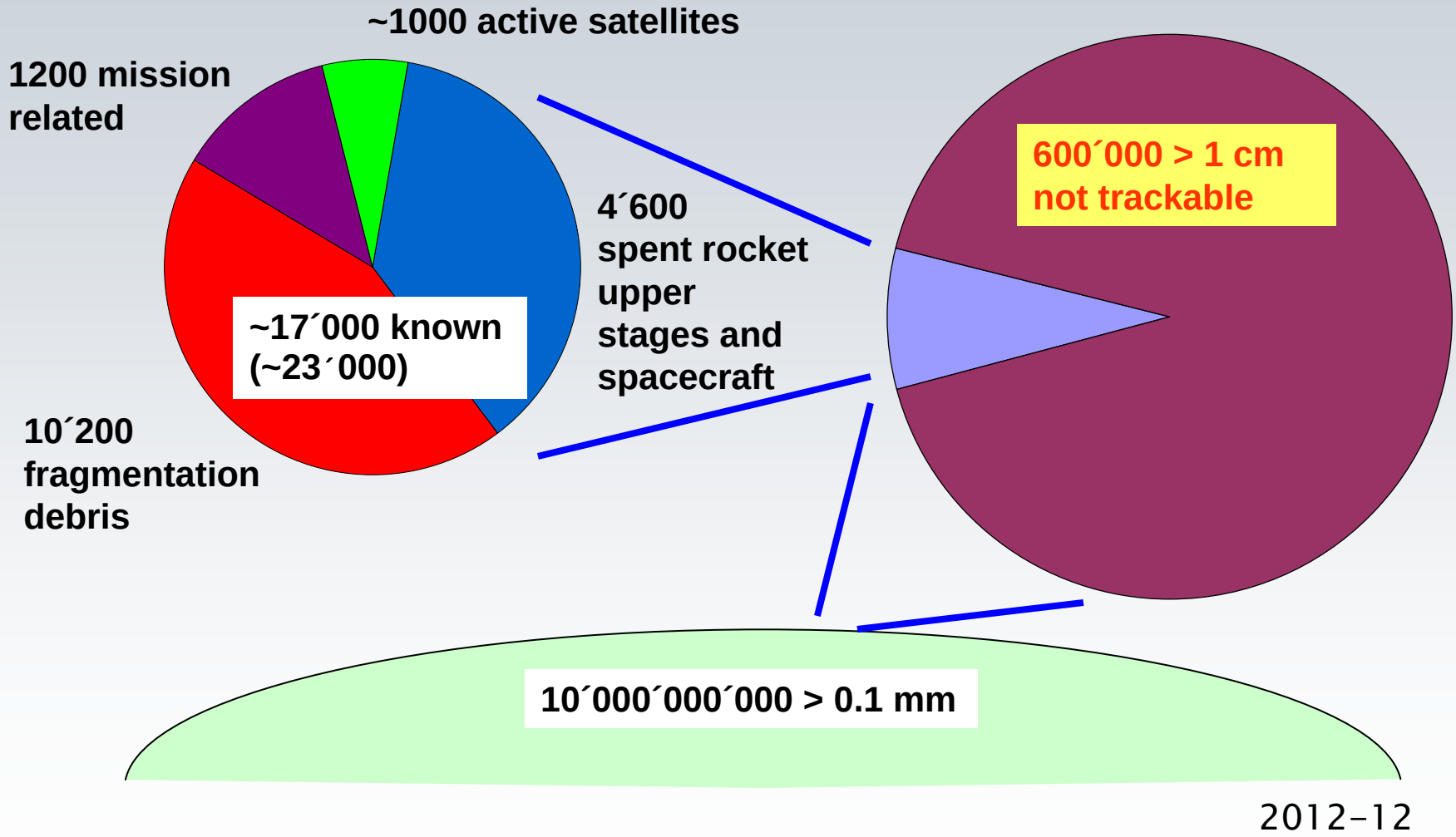
Breakups

Breakup

- Breakup of Russian upper stage BRIZ-M in February 2007

Last BRIZ-M breakup on October 16, 2012

Space Debris Population

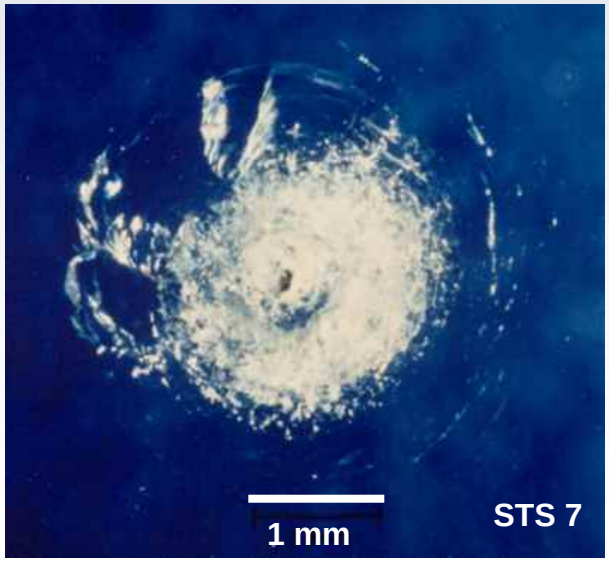


Risks in Orbit?

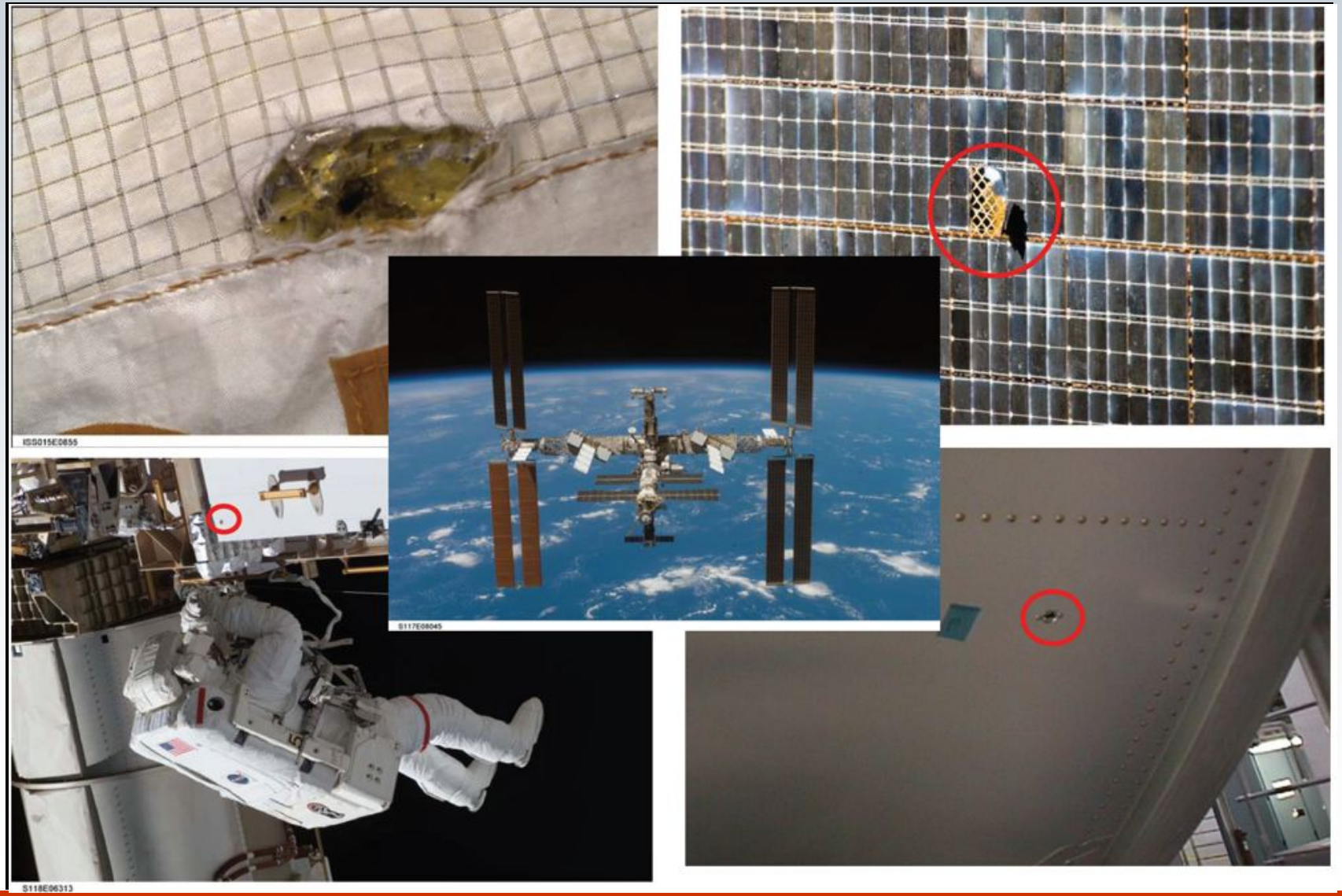
- Space debris moves at 7–8 km/s in LEO
  1mm aluminum sphere @ 10km/s = bowling @ 520km/h
- Average relative velocity of objects is ~ 10 km/s
  (may reach 16 km/s at max.)
- Shields possible for Objects < 1cm
- Space Shuttle:
  - 0.5 mm Object penetrates radiators
  - 1 mm Object penetrates wing nose
  - 5 mm Object penetrates crew cabin

Crater on window of Shuttle STS-7

Impactor 0.1 mm to 0.15 mm (aluminiumoxyd)

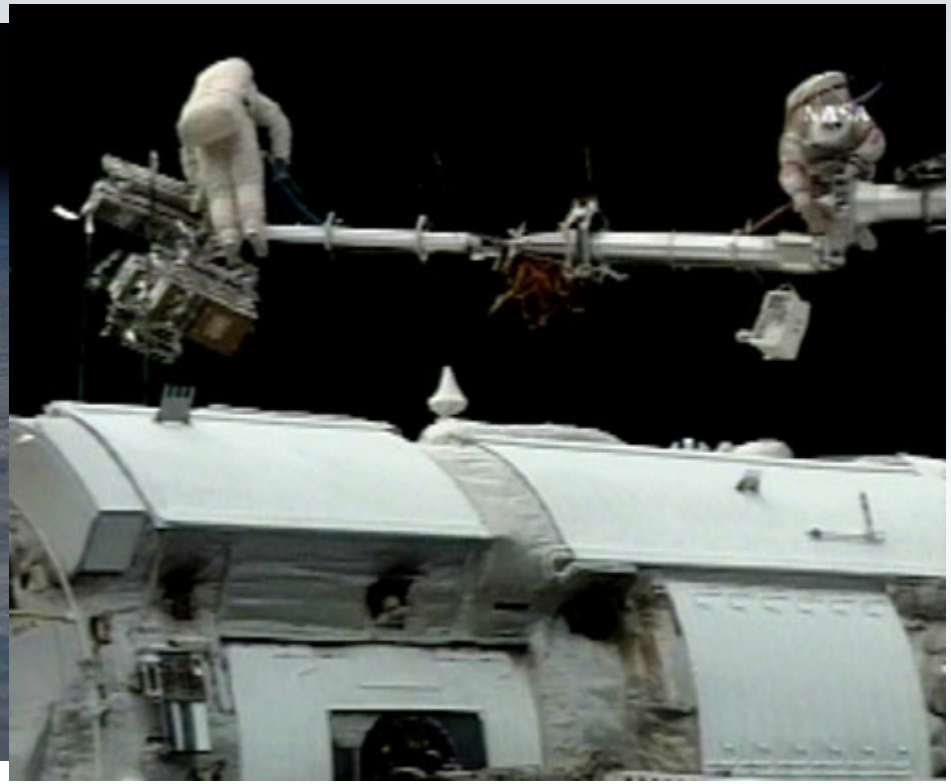


Risks in Orbit: ISS Space Station



Risks in Orbit: ISS Shielding

- May 30, 2007: Expedition 15 commander Fyodor Yurchikhin and flight engineer Oleg Kotov installed five Service Module Debris Protection (SMDP) panels to the Zvezda service module.



Headlines Nov. 1, 2012

15. maneuver of ISS to avoid collision with space debris

Blick.ch

Gefahr im All: Mit einem ausserplanmässigen Manöver ist die Internationale Raumstation ISS in der Nacht zum Donnerstag einer möglichen Kollision mit Weltraumschrott ausgewichen.

ISS raises orbit to avoid space garbage

English.news.cn 2012-11-01 16:10:22

MOSCOW, Nov. 1 (Xinhua) -- The International Space Station (ISS) has completed an emergency maneuver to avoid possible collision with space debris, the Russian Mission Control Center said Thursday.

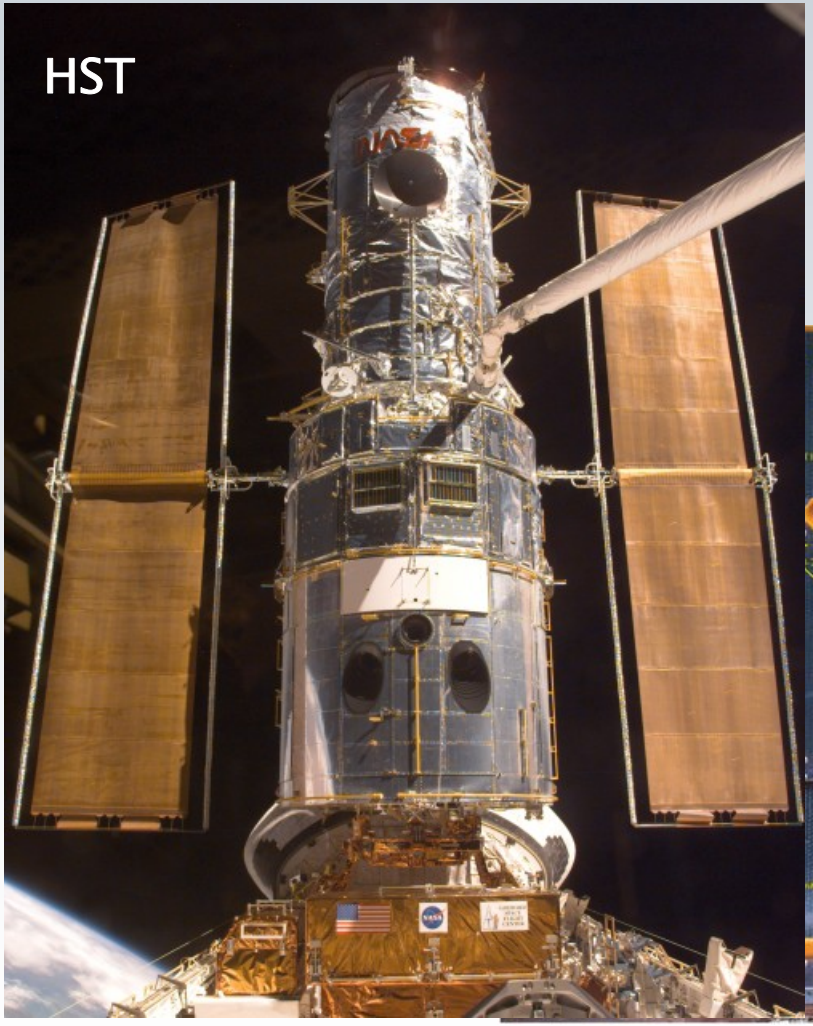
Evacuation of ISS

12.3.2009 07:39: ISS is evacuated

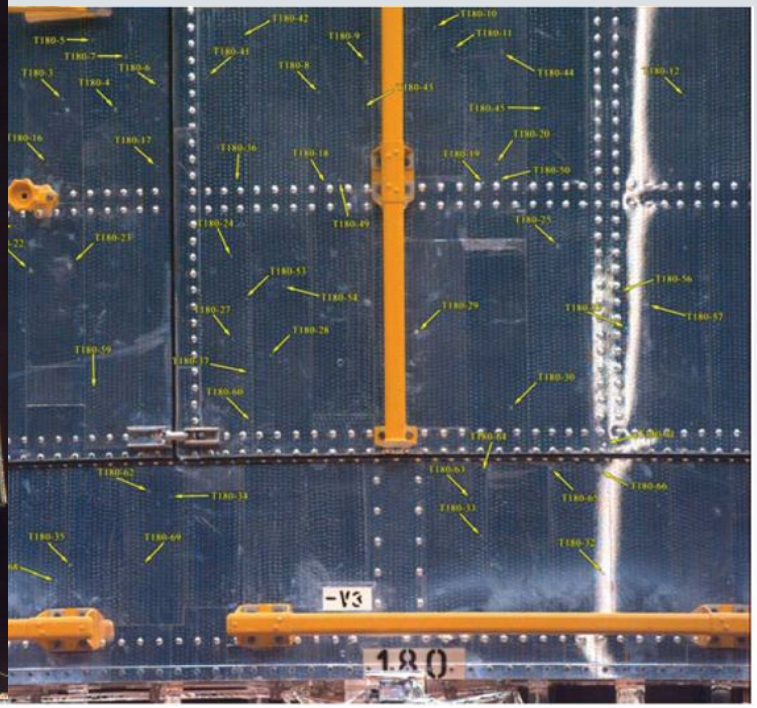
small fragment of upper stage passes by ISS

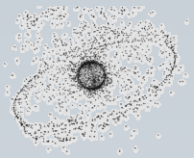
Last (3.) ISS evacuation on March 24, 2012

Risks in Orbit: HST



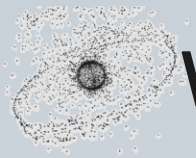
Hubble Space Telescope:
> 500 impacts on instrument cover after 7 years in orbit.





Space Debris Research

- Open Questions
  - Population
    - how many?
    - size distribution?
    - orbit regions?
    - nature of objects?
    - sources, sinks?
  - Physics/Mechanisms
    - creation
    - evolution of orbits
    - long-term evolution: → models
- Approach
  - Search for debris (surveillance)
  - Determine orbits
  - Characterize

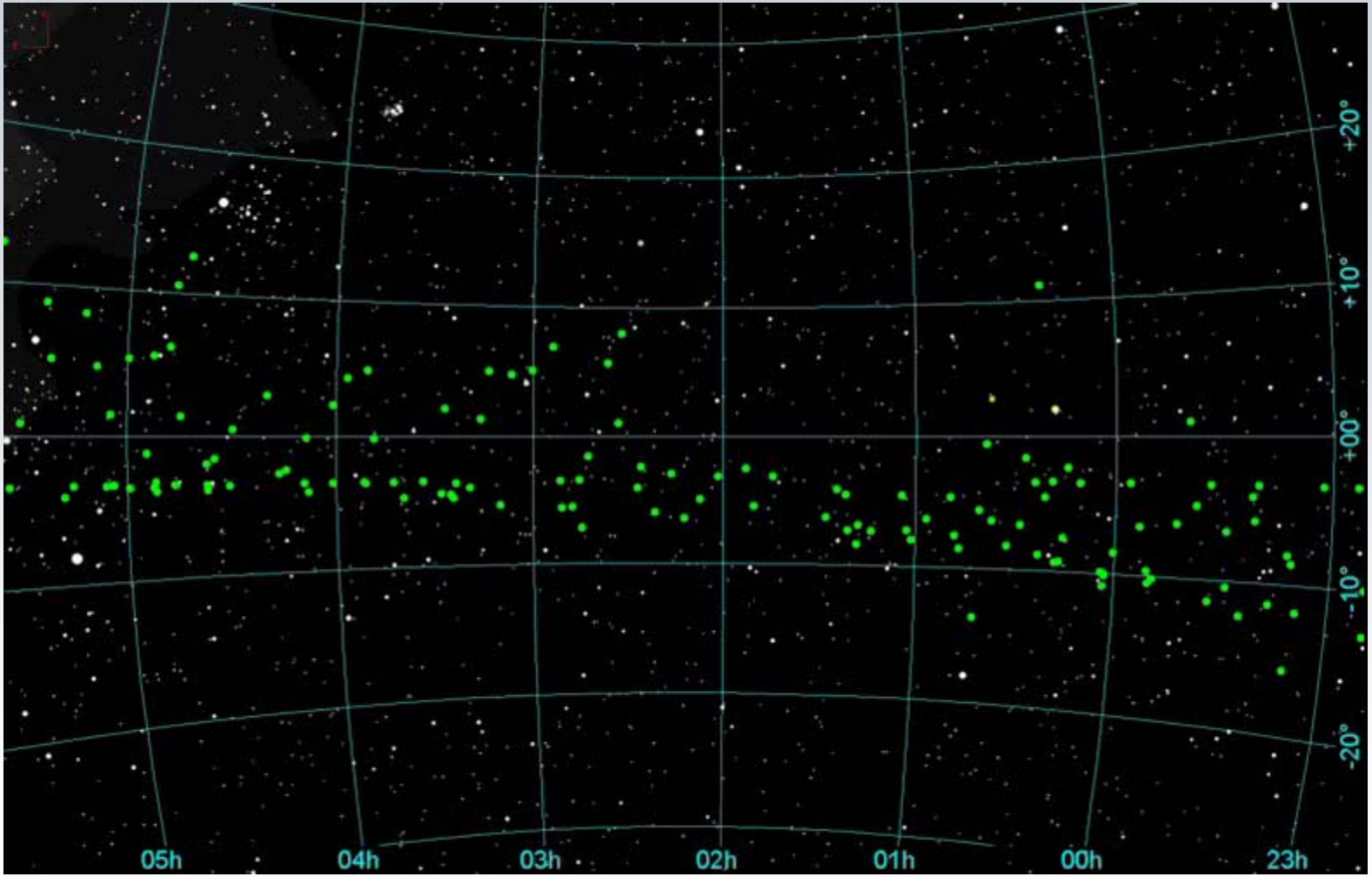


Why do we Need a Better Understanding?

- Extending the catalogues of “known” space objects towards smaller sizes (deterministic population)
  → enable active collision avoidance (safety of operations)
- Acquiring statistical orbit information on small-size objects in support of statistical environment models
  → statistical risk analysis (e.g. mission analysis, shielding, etc.)
  → input data for long-term evolution models
  → identification of debris sources
  - progenitors of debris clouds (breakup events)
  - disintegrations of spacecraft due to aging processes
- Long-term monitoring of environment
  → identification of new sources
  → verification of evolution models
  - Characterizing objects
    → identification of (new) sources

Optical Sensors

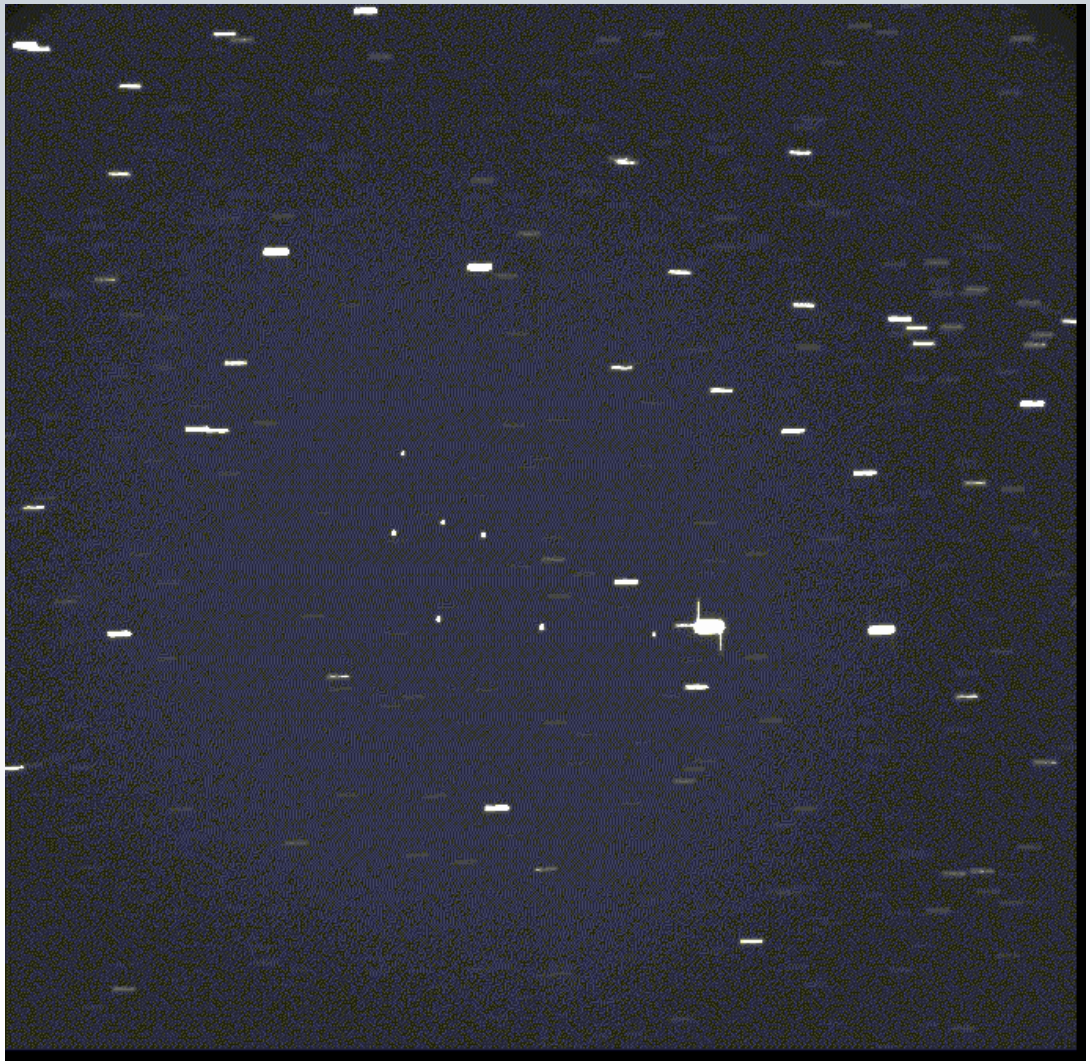
Survey Techniques



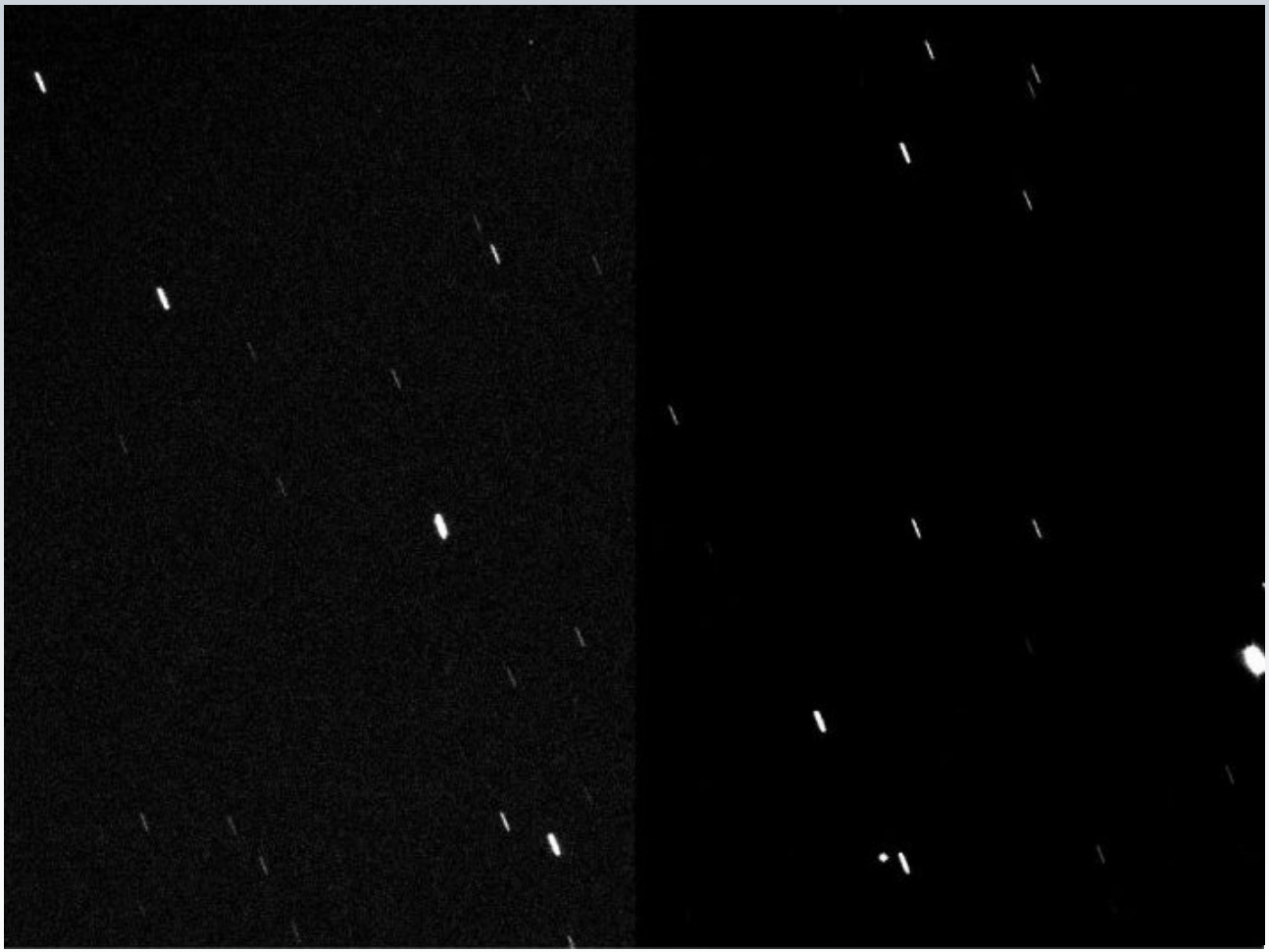
GEO Objekte vor Sternhintergrund

Survey Techniques

- 7 TV satellites (ASTRA)
- Series of exposures from Zimmerwald

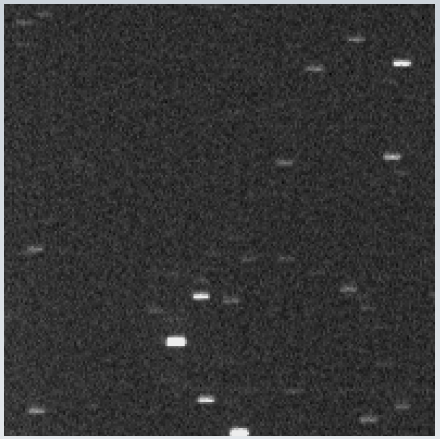
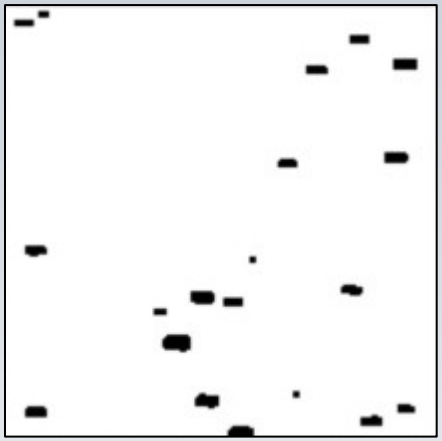
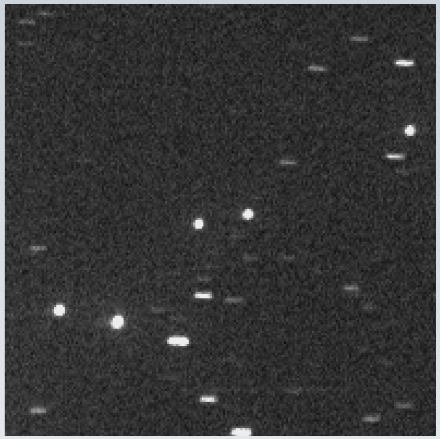
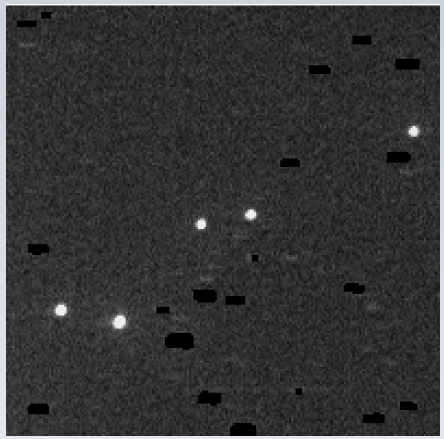


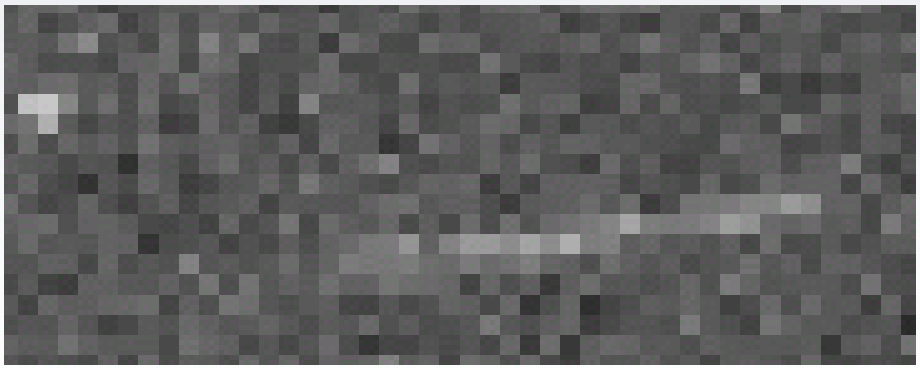
Survey Techniques

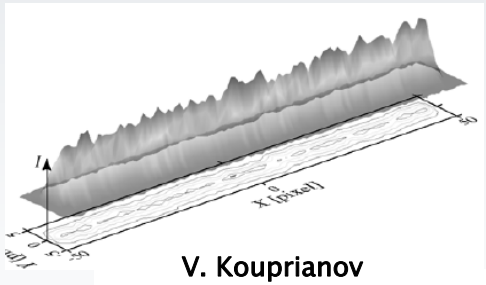


Typical result from a survey with the
ESA-Space Debris telescope at Tenerife

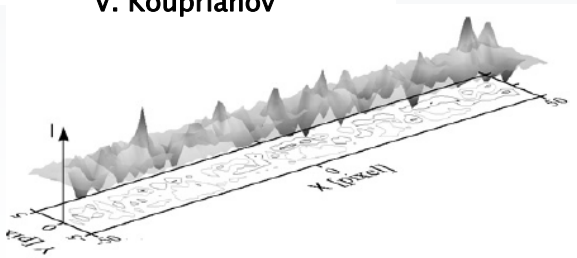
Detection Techniques

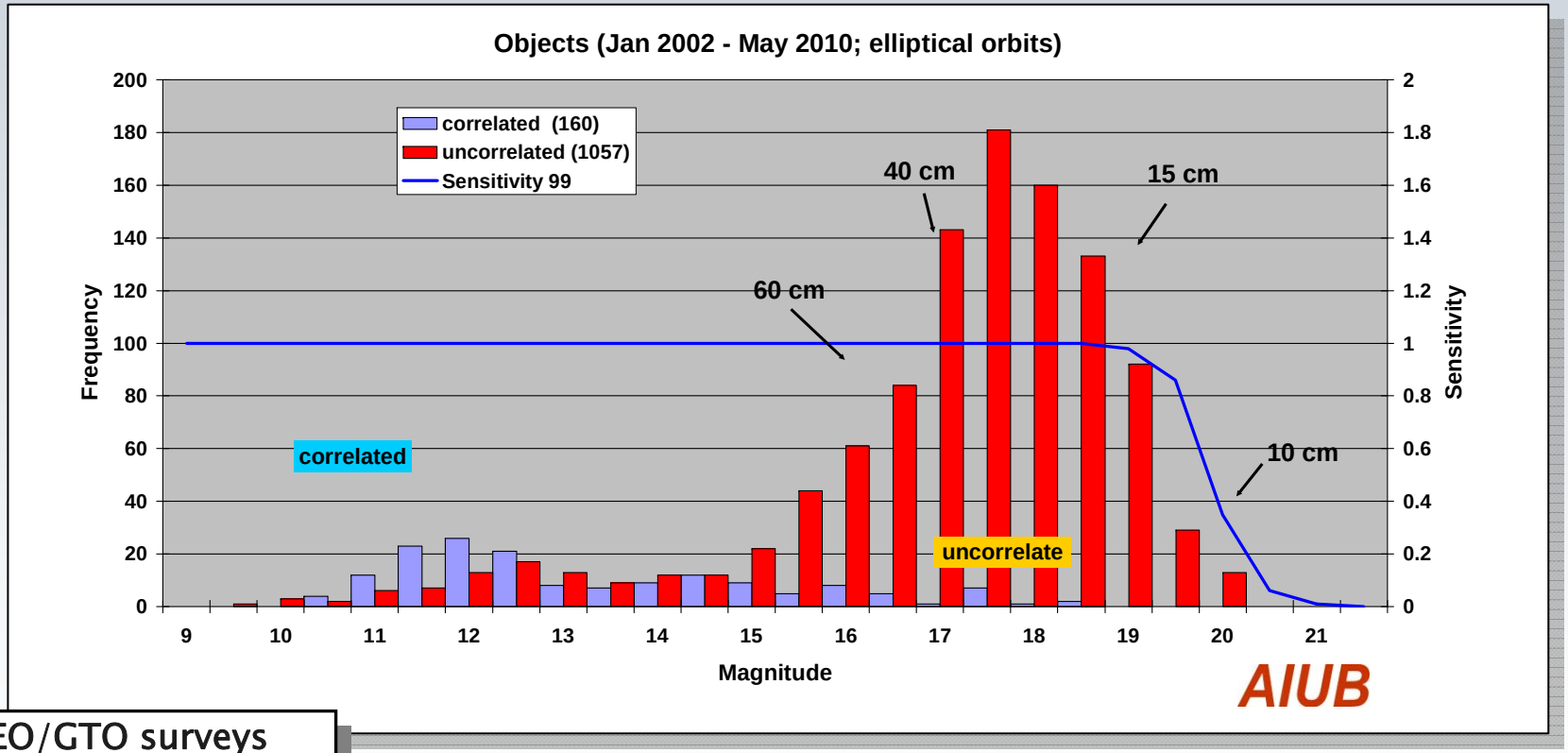




V. Kouprianov

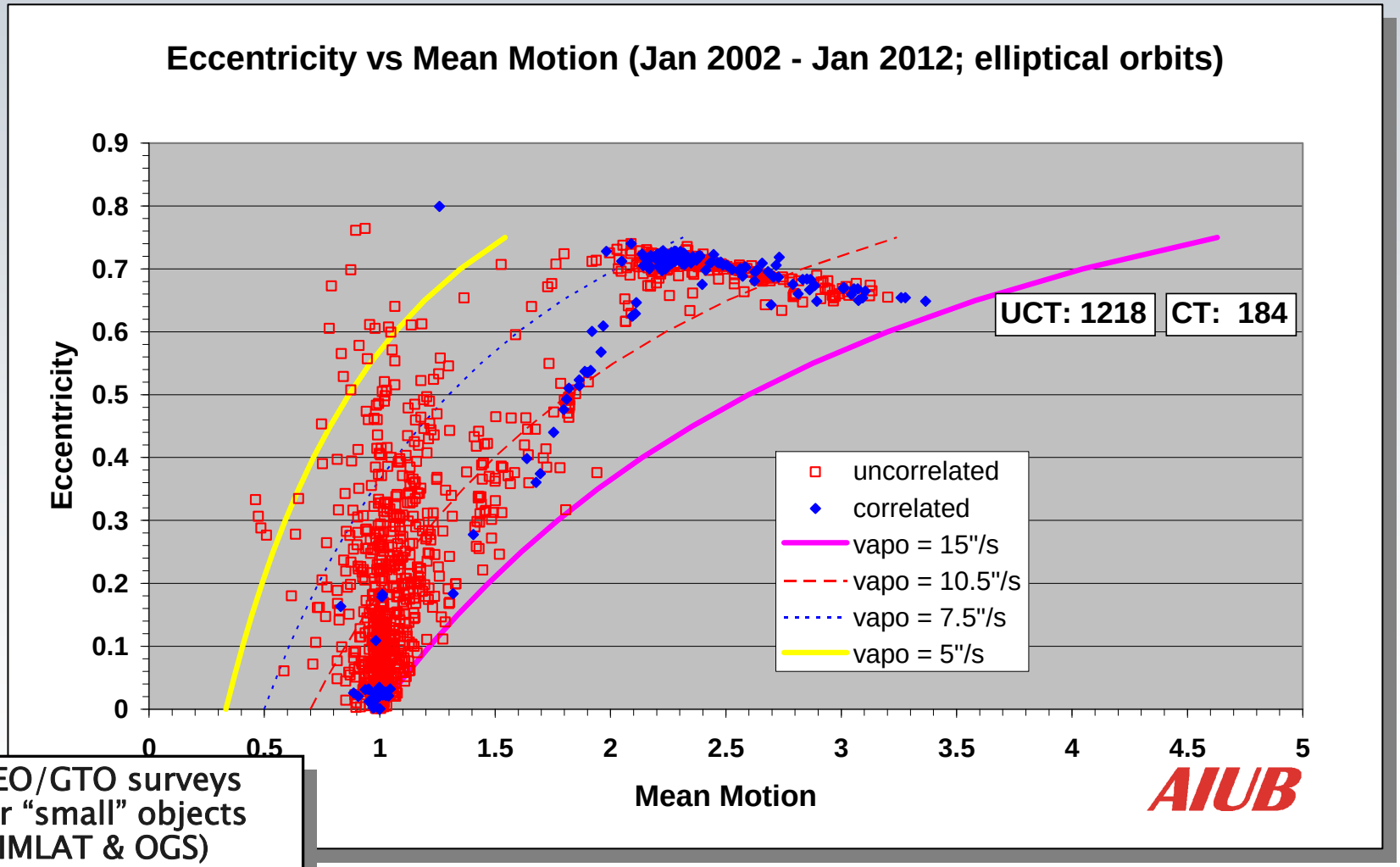


Space Debris in GEO



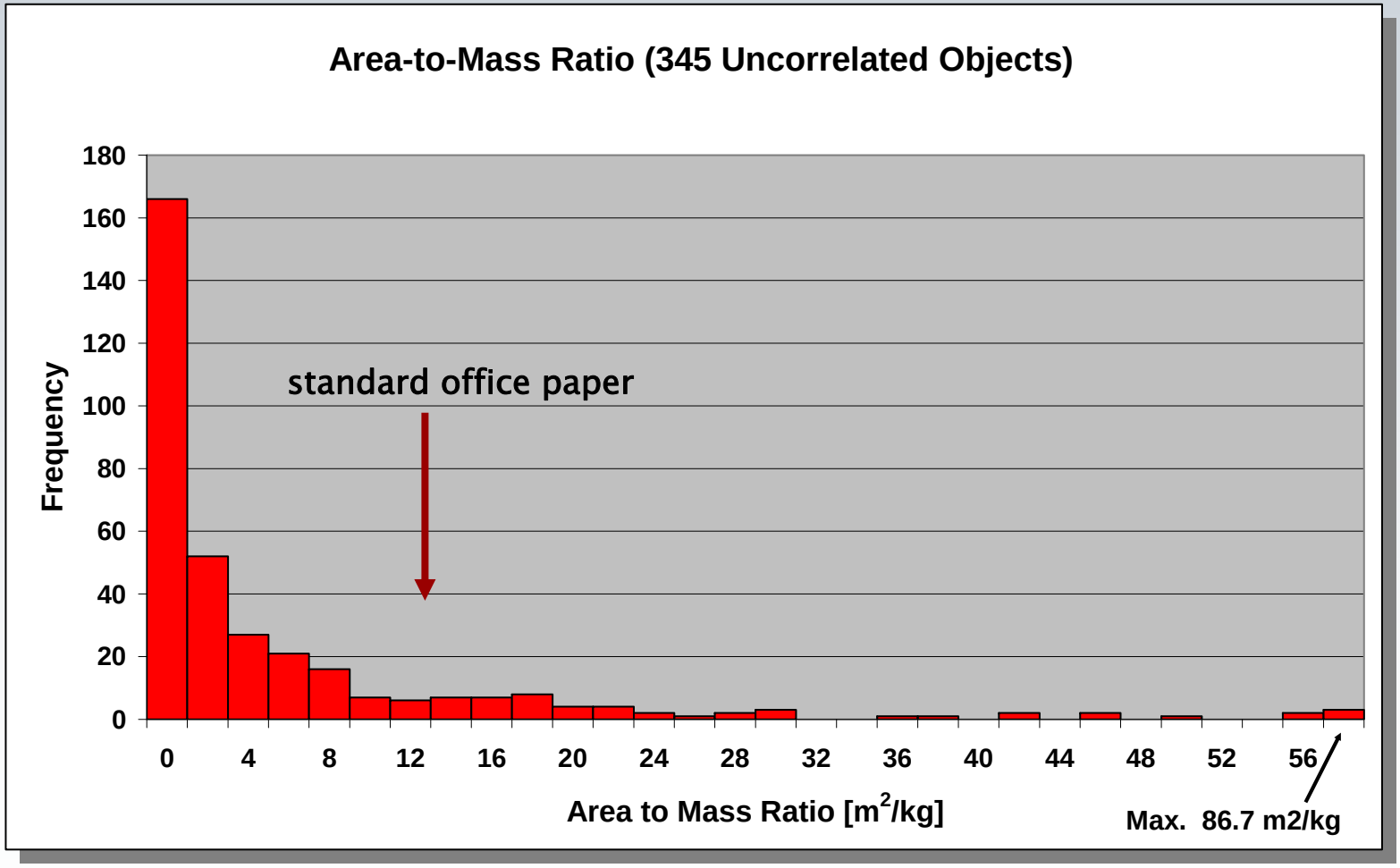
GEO/GTO surveys for "small" objects (ZIMLAT & OGS)

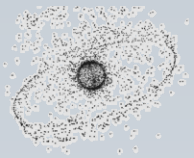
Surveys – AIUB Small Debris Catalogue



GEO/GTO surveys for "small" objects (ZIMLAT & OGS)

Surveys – AIUB Small Debris Catalogue

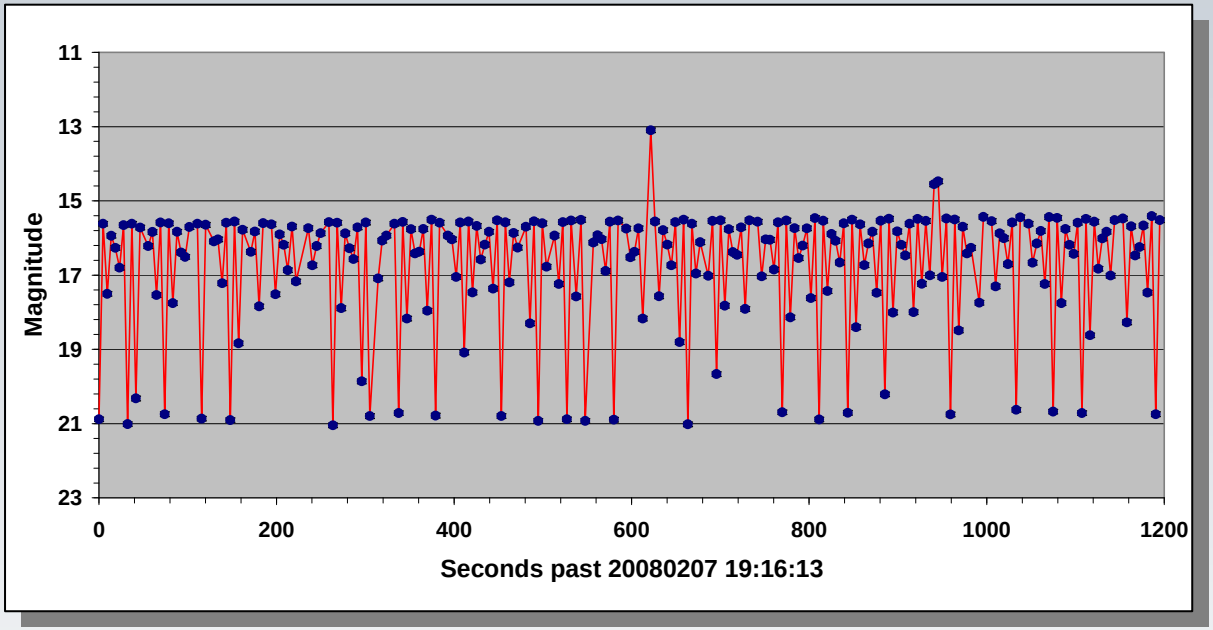


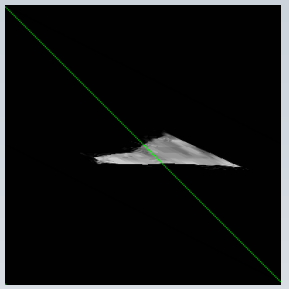


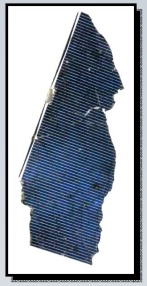
Physical Characterization

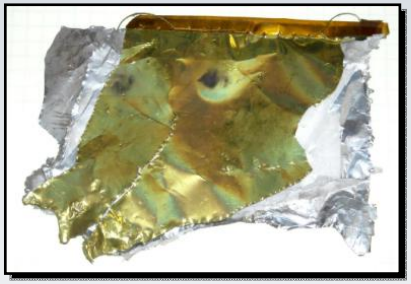
- Optical Characterization Techniques
  - Evolution of orbit
    - Area-to-mass ratio
    - Source/progenitor (e.g. for fragments)
  - Non-resolving techniques
    - infrared radiometry → size
    - polarimetry → (albedo)
    - color photometry → fingerprinting, (material)
    - light curves → attitude states (rotation rates, axis, etc.)
    - spectrophotometry → material
  - Direct imaging techniques

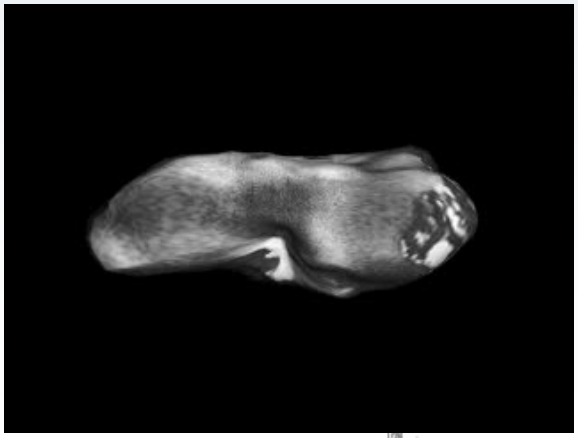
Characterization – Light Curves





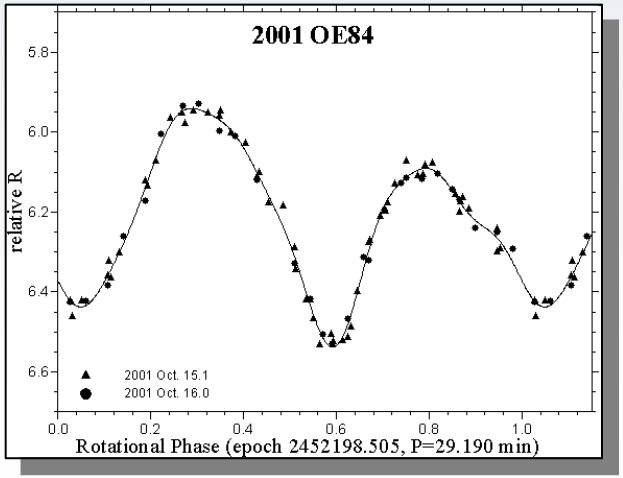






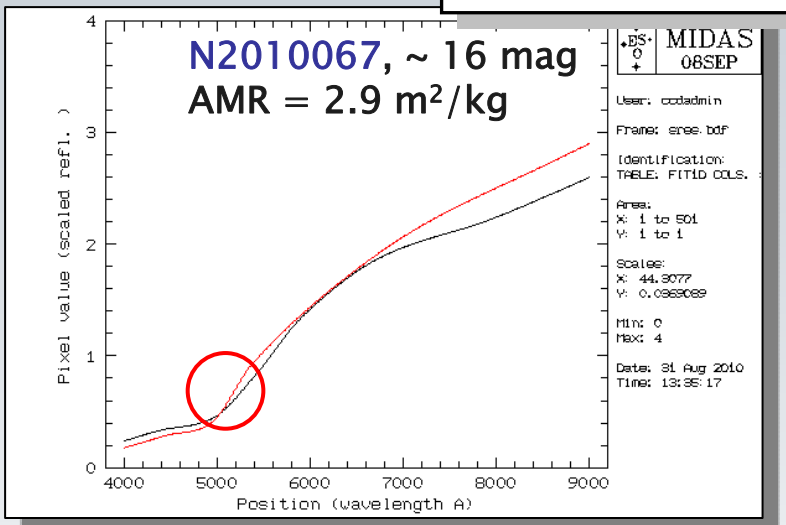
rotation period
spin axis, shape

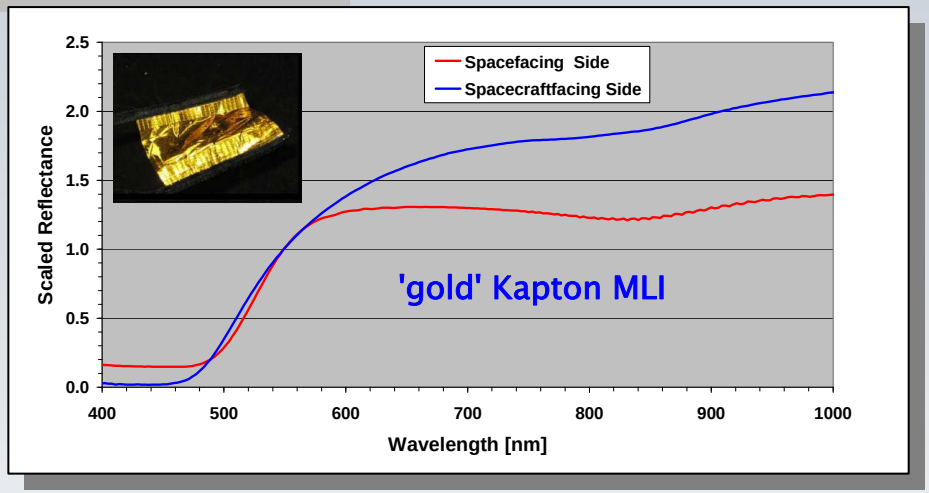
- ZIMLAT

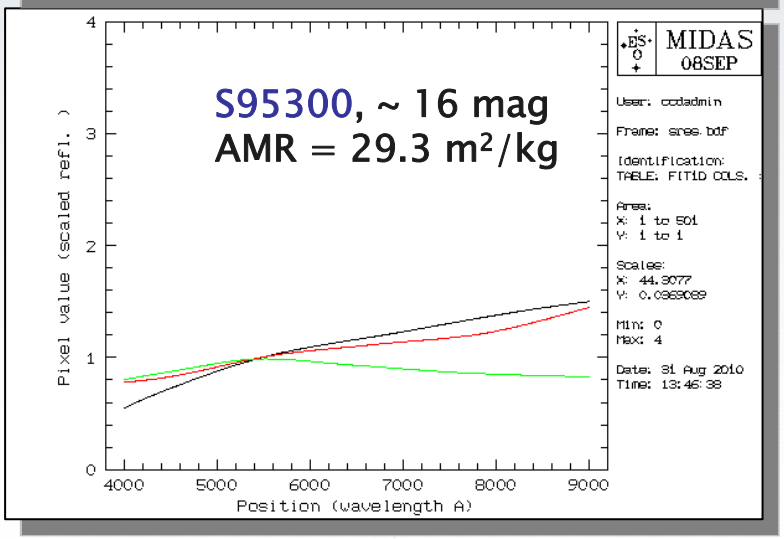


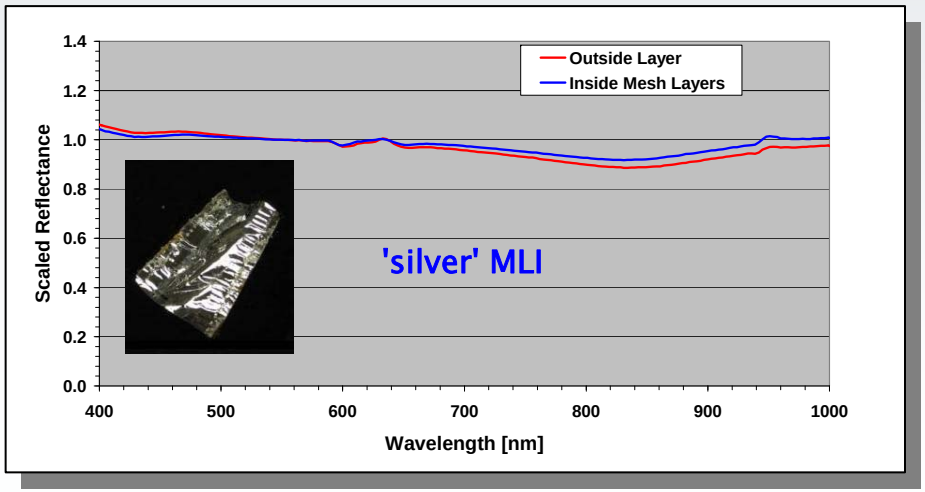
Characterization – Spectrophotometry

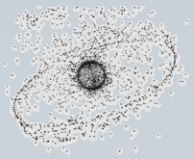
Comparison with Lab Spectra











Future? – Open Questions

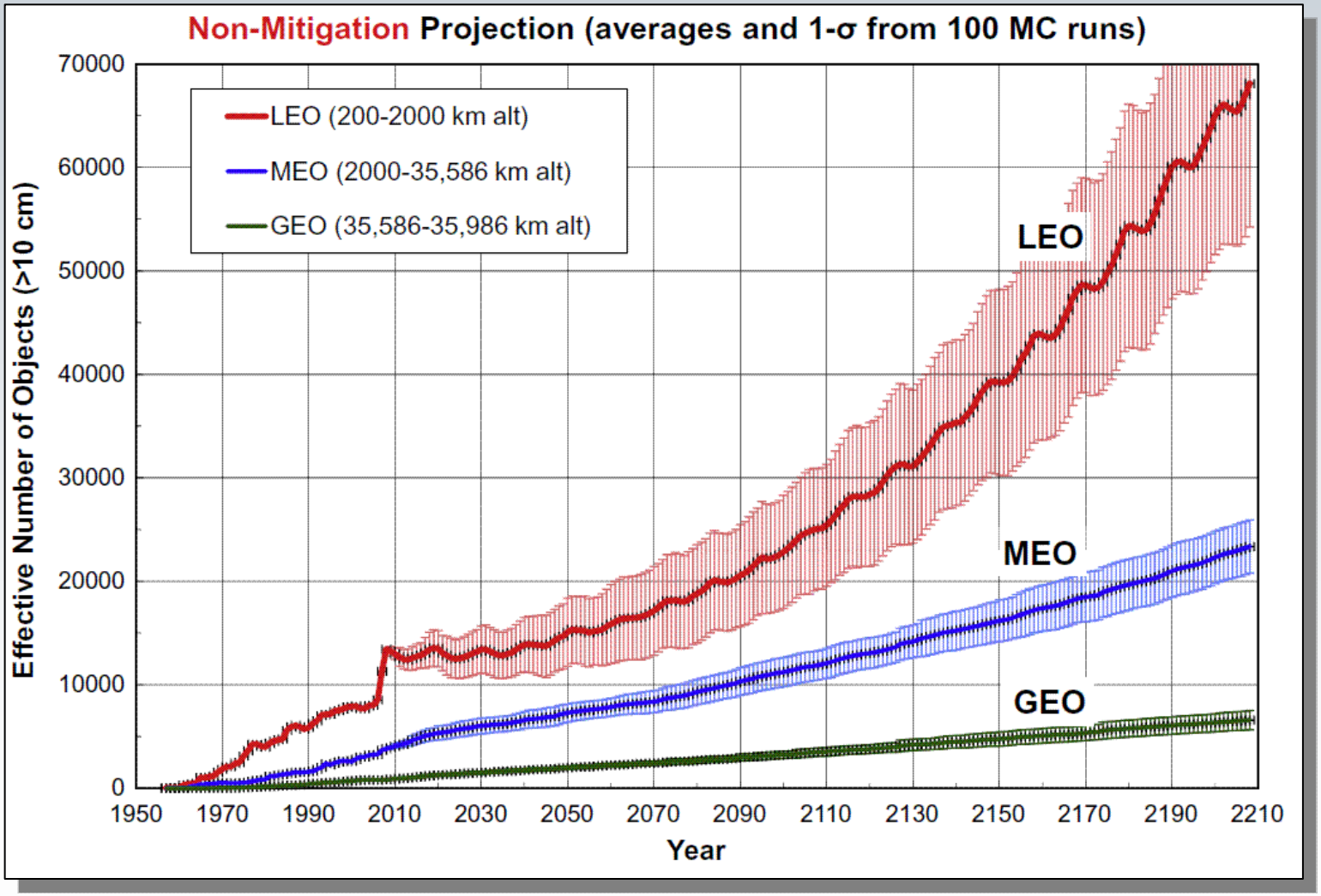
- Consequences for future of space activities?
- Increasing risk for unmanned/manned space flights?
- Increasing number of collisions?
- Evolution of space debris population?

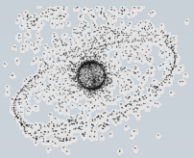
→ Population unstable?

  - exponential runaway?
  - corresponding critical density already reached in certain orbit regions?

- Countermeasures?

The Future – Population





Protection of Environment in Space

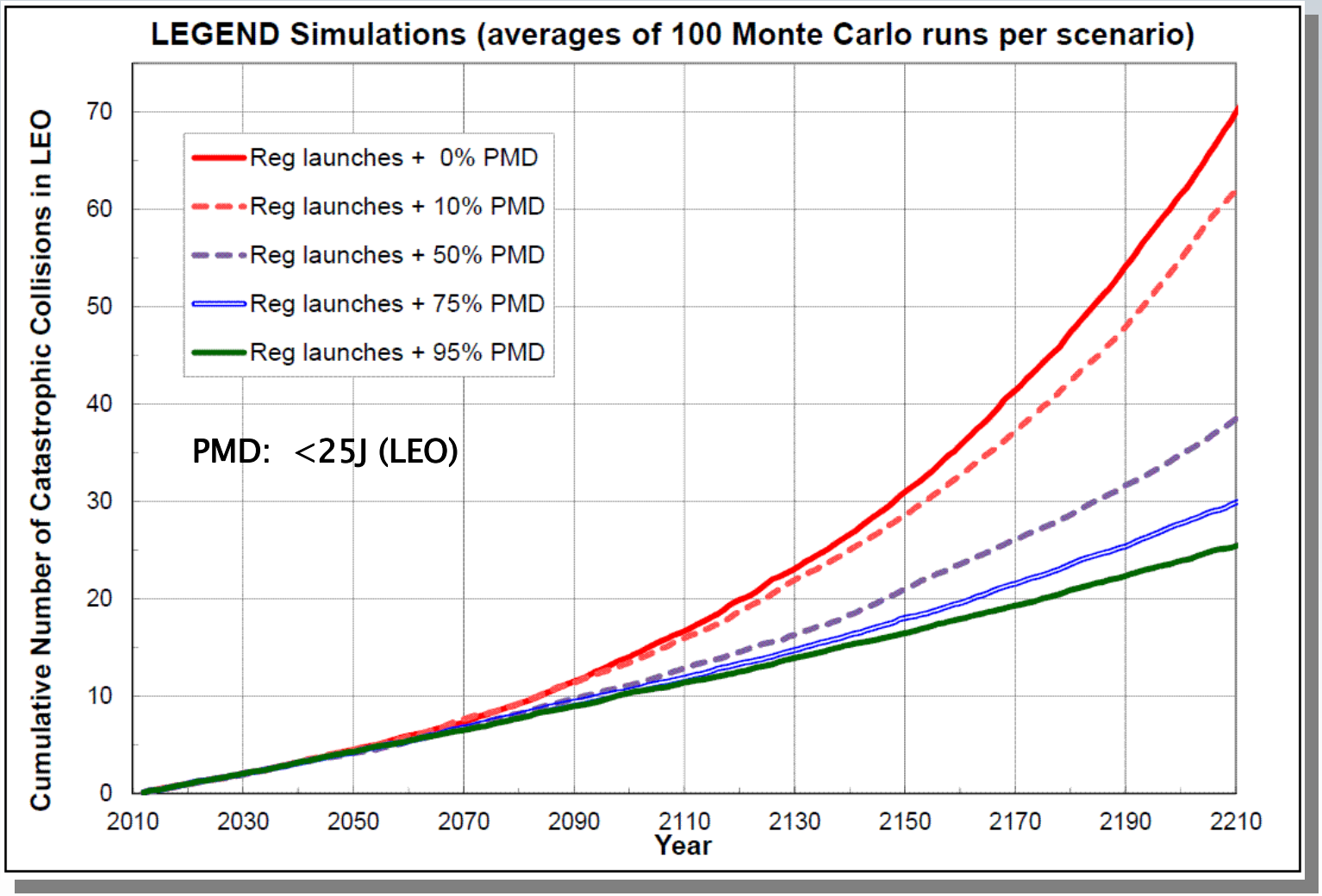
Mitigation

- Prevent explosions
- Limit orbital lifetime (<25y after end of life in LEO)
- ‚Graveyard orbits' for h > 2000 (e.g. GEO)
- Controlled de-orbit of risk objects (m > 5000kg)

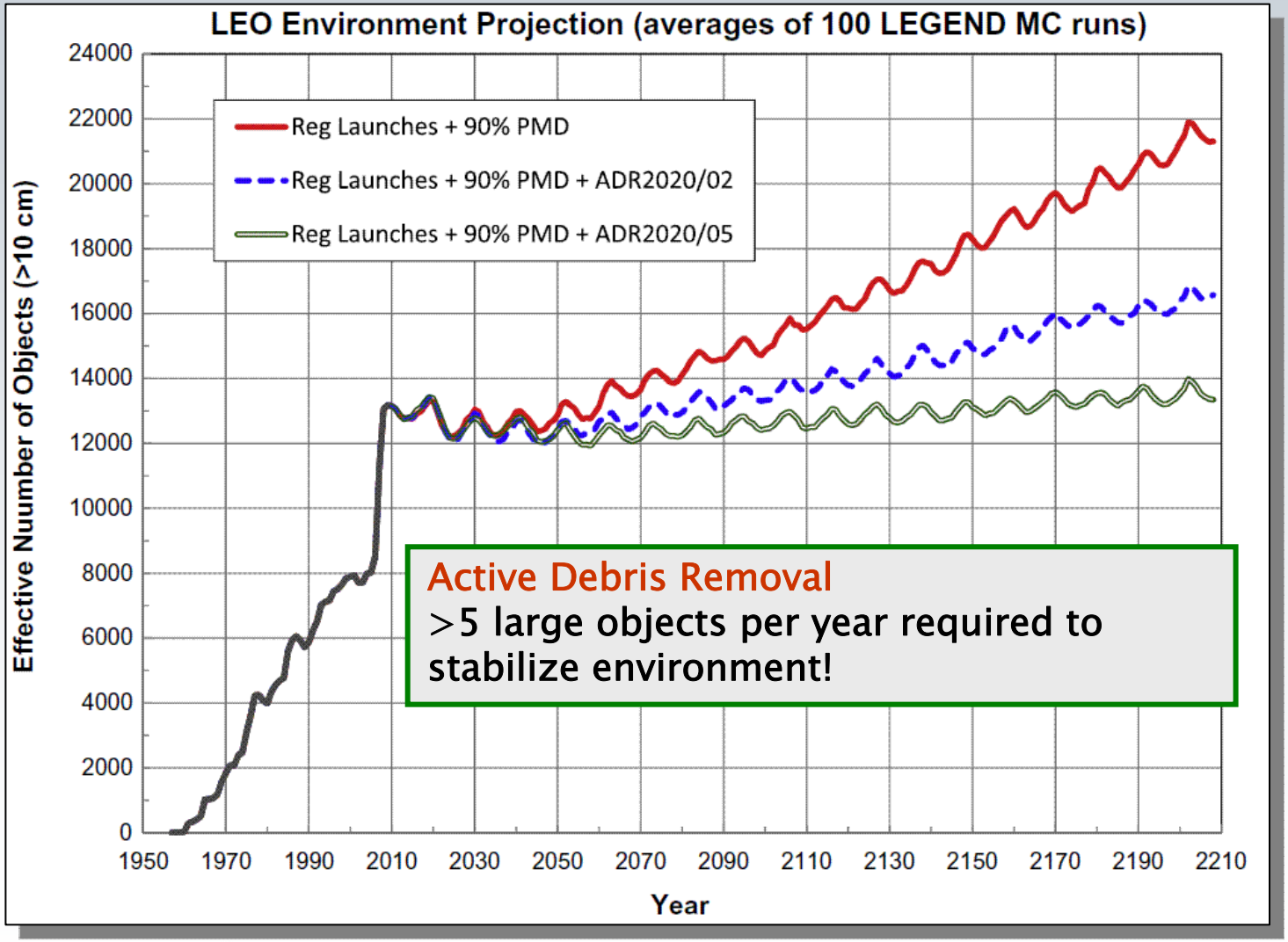
Remediation

- Collision avoidance
- Clean-up technically and economically extremely challenging (Active Debris Removal; small-size/large-size)

The Future – Collisions

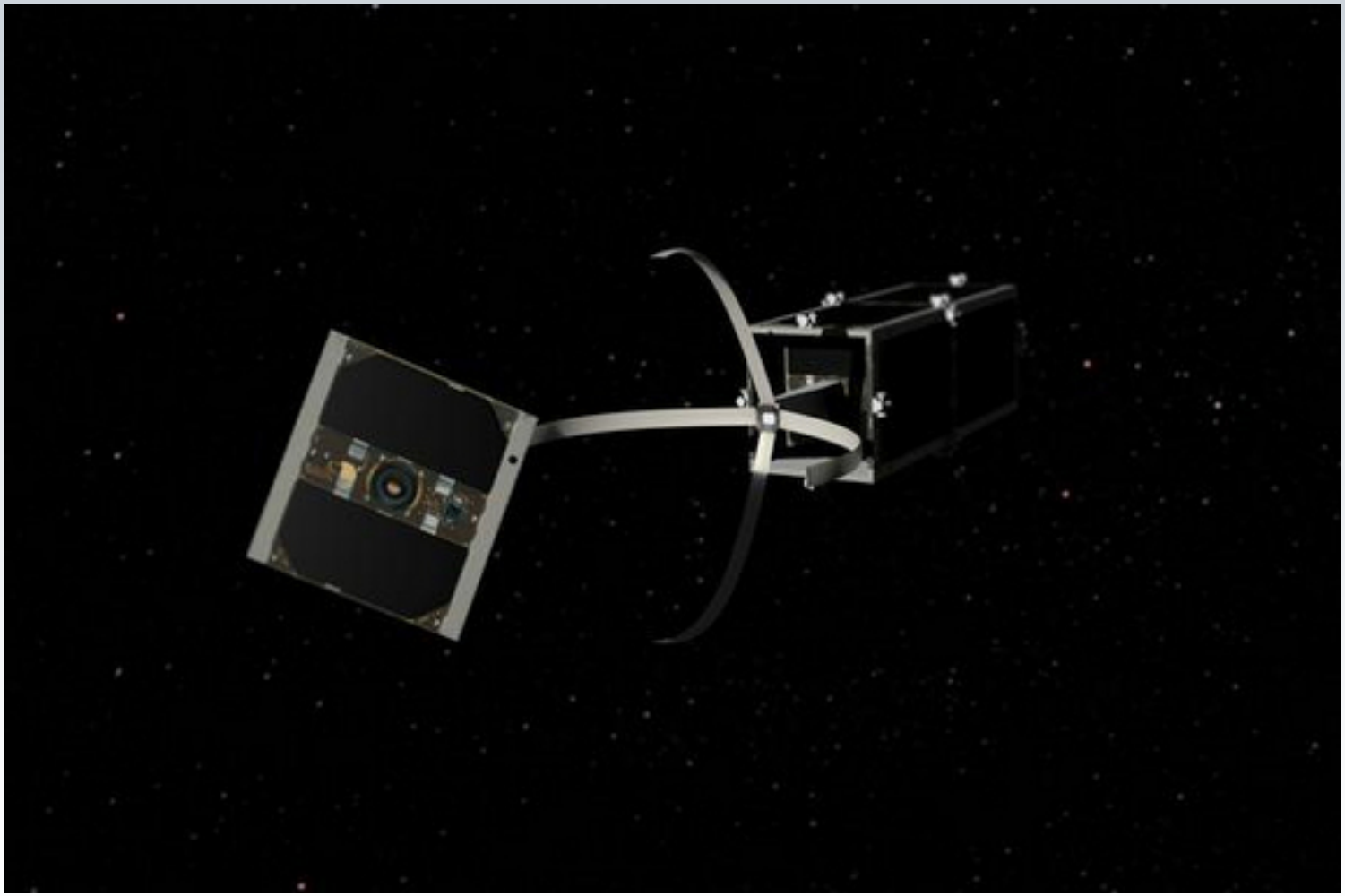


The Future – Population

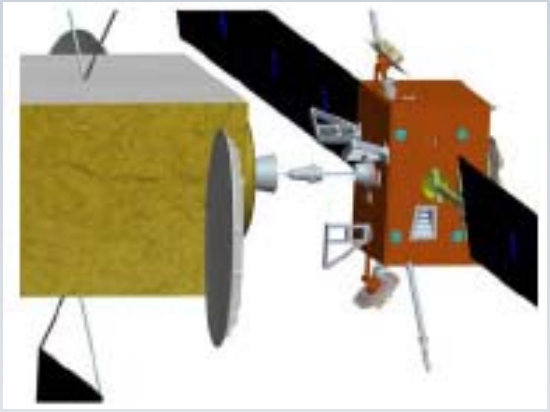


Active Debris Removal
>5 large objects per year required to stabilize environment!

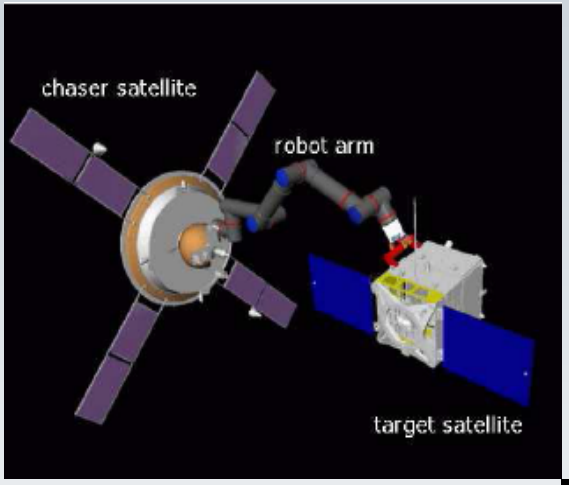
Clean-up...



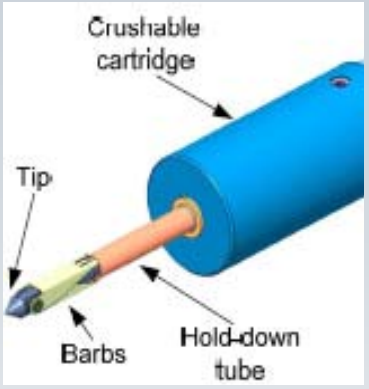
Cleanup...



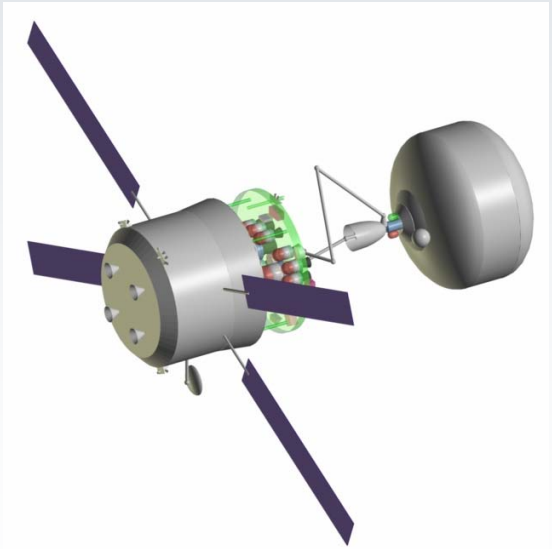
OSS: clamp inside the target nozzle



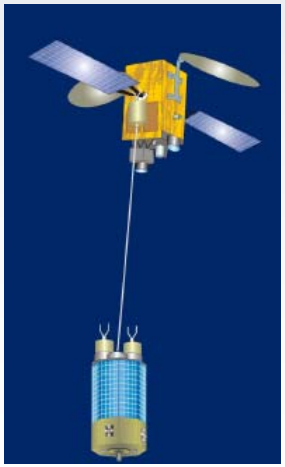
DLR: robotic arm DEOS



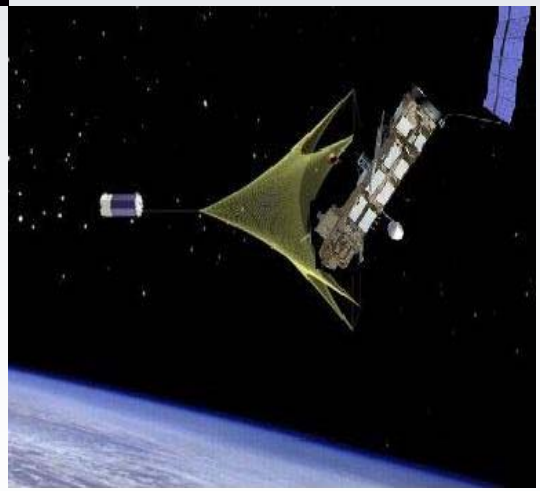
Astrium UK: harpoon



CNES: deorbiting kit with robotic operations



ESA-Astrium: hook ROGER



Astrium: net capture

Protection of Environment in Space

- Mitigation and even more so remediation comes not 'for free'
- Space agencies / individual countries take voluntary actions (regulations)
- 'Pollution' adversely affects 'polluters' (space actors)

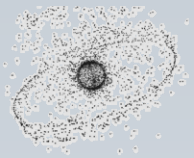
→ international regulations required

- UNCOPUOS technical and legal subcommittees (author is member of Swiss delegation)
- Inter-Agency Debris Coordination Committee (IADC) (author is member)

International Efforts

- 2007 IADC Space Debris Mitigation Guidelines
- 2008 UN Space Debris Mitigation Guidelines
- 2010 EU Draft International Code of Conduct for Outer Space Activities
- 2010/11 UN COPUOS Working Group on the Long-term Sustainability of Outer Space Activities (author is member of expert group B)

→ All non-binding guidelines



Long-Term Sustainability

Space Debris

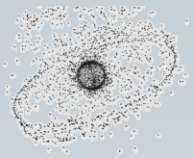
- Ensure space debris mitigation measures are implemented
- Controlled and uncontrolled reentry notifications regarding substantial space objects, and also on the reentry of space objects with hazardous substances on board

Space Operations

- Perform conjunction assessment and collision avoidance
- Provide Pre-launch and manoeuvre notifications

Support Collaborative Space Situational Awareness

- Collection, sharing and dissemination of orbital data on functional and non-functional space objects



Most Sensitive Political Issues

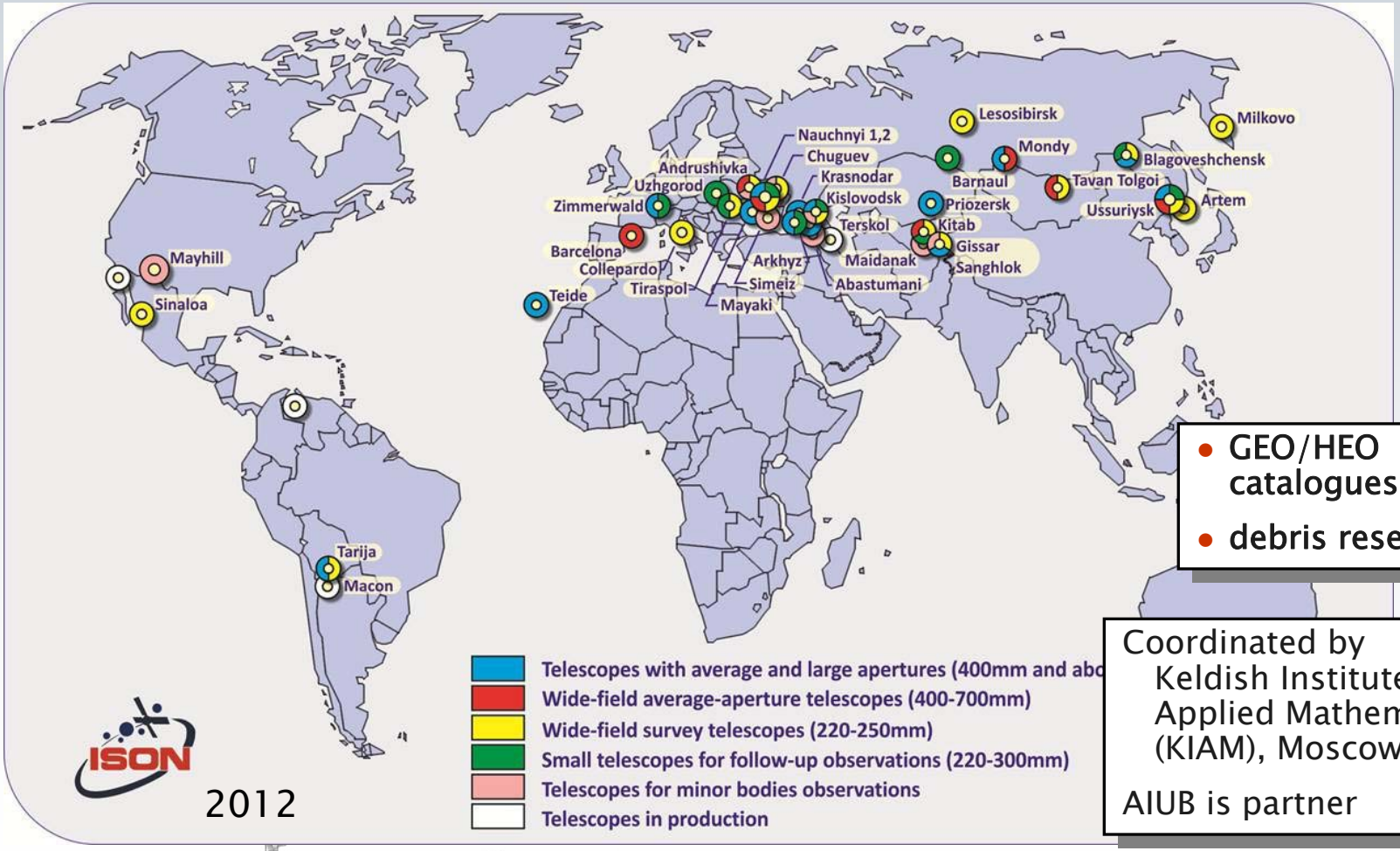
- Sharing of orbital information (orbit catalogue)
  - classified (military) objects!
  - BUT required for collision avoidance (safety of flight, long-term sustainability)
  - most existing space surveillance organizations are military entities
- Pre-launch and manoeuvre notifications

→ Required

- transparency and confidence-building measures
- collaborative space surveillance
- international, civilian space surveillance and space traffic management
- international regulations (UN, ITU)

Scientific Sensor Network

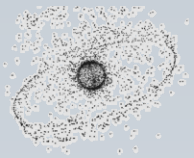
- International Scientific Optical Network (ISON)



- GEO/HEO catalogues
- debris research

Coordinated by Keldish Institute of Applied Mathematics (KIAM), Moscow

AIUB is partner



AIUB Space Debris Research

>20 Years of Space Debris Research at the AIUB

- **Optical Searches/Surveys**
  - 14 years of space debris surveys at OGS for ESA
  - operational, continuous, highly automated observation programs using the Zimmerwald sensors
- **Orbit Catalogues**
  - build-up and maintenance of space debris catalogue (GEO/GTO/MEO)
  - international collaboration
- **Physical Characterization**
  - size, shape, materials, attitude

  → source?

→ Scientific basis for sustainable use of outer space


Thank you for your attention!