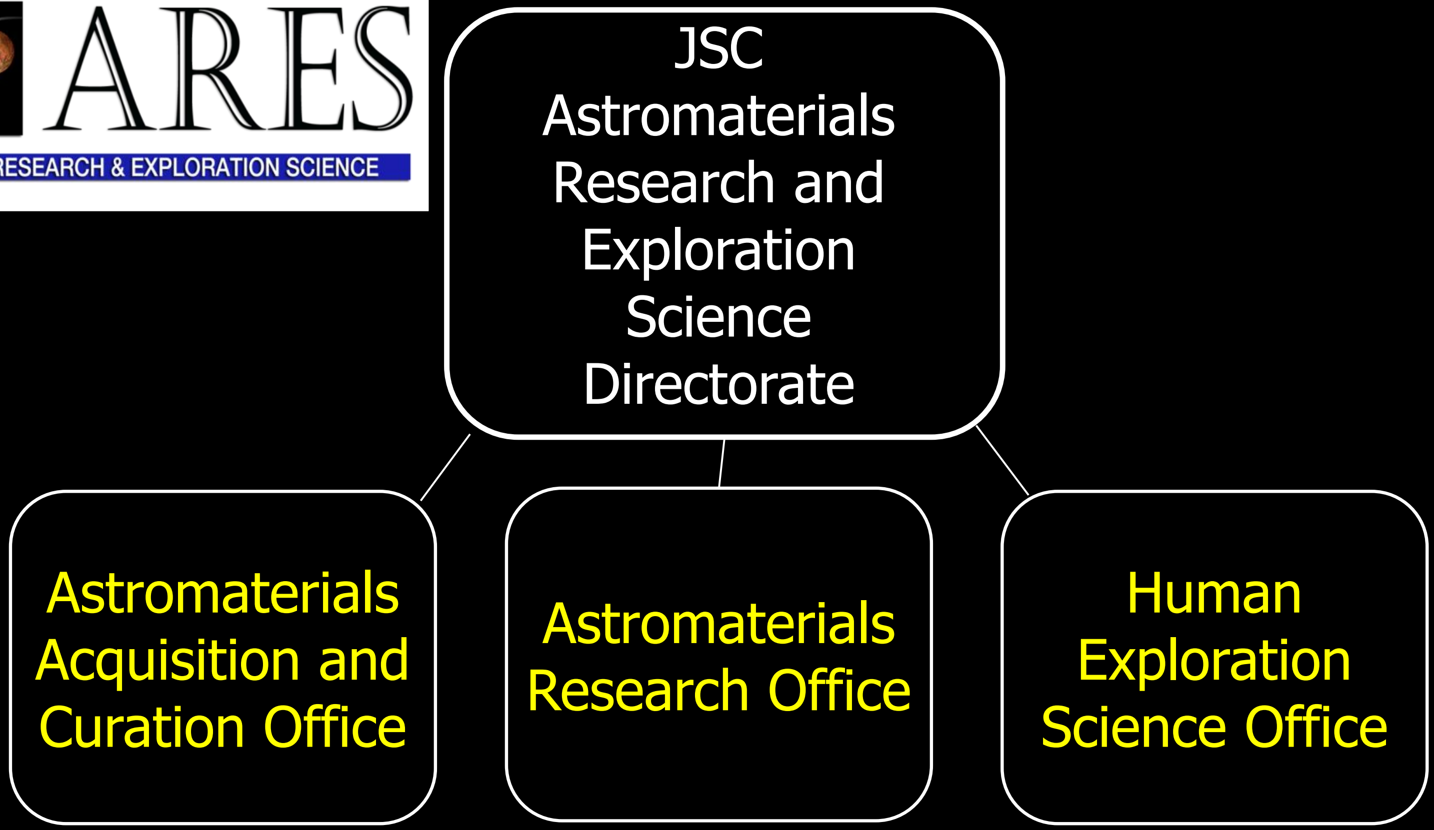
Astromaterials Research and Exploration Science At NASA Johnson Space Center

Dr. David S. Draper
NASA Johnson Space Center



- NASA Strategic Goal: Advance scientific knowledge of the origin and history of the solar system, the potential for life elsewhere, and the hazards and resources present as humans explore space.

- ARES supports NASA's strategic goal through the preservation and study of materials from space and their terrestrial analogs, simulation of solar system processes, and participation in missions.

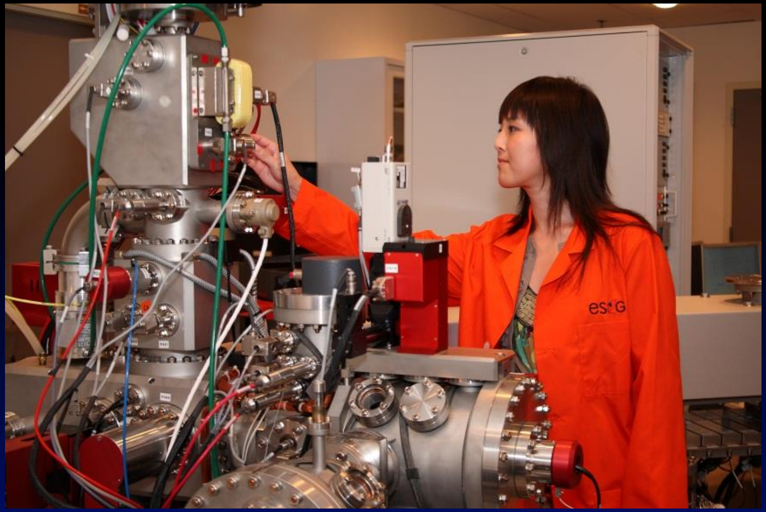
Astromaterials Acquisition and Curation

Astromaterials Curation and Research at JSC go hand-in-hand

- JSC is responsible for the curation of NASA's current and future extraterrestrial samples
  - — One-of-a-kind curation facilities
- *Current Collections interest research scientists throughout the world*
  - — Apollo Lunar Samples
  - — Antarctic Meteorites
  - — Cosmic Dust
  - — Genesis 2004
  - — Stardust 2006
  - — Space Exposed Hardware
  - — Coming soon: Hayabusa/Itokawa

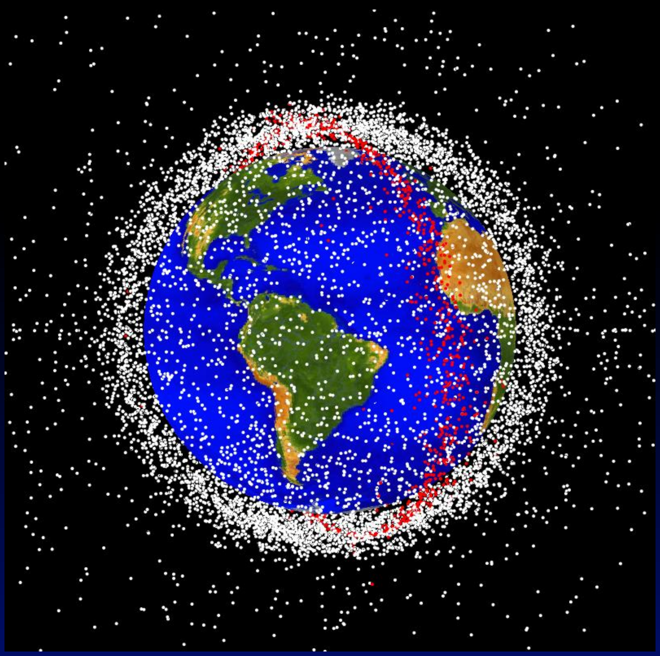
Astromaterials Research

- Study of extraterrestrial samples to understand the origin and evolution of the solar system
- Study of extraterrestrial samples and experimental simulation of planetary processes to understand the formation and evolution of the terrestrial planets, esp. Moon and Mars
- Interpretation of Mars mission data to understand the composition and chemistry of Mars' surface and interior
- Interpretation of Mars mission data integrated with sample data to study planetary evolution, possible roles of water, implications for past or present life
- Strong involvement with exploration missions (MER, MSL, Dawn etc)



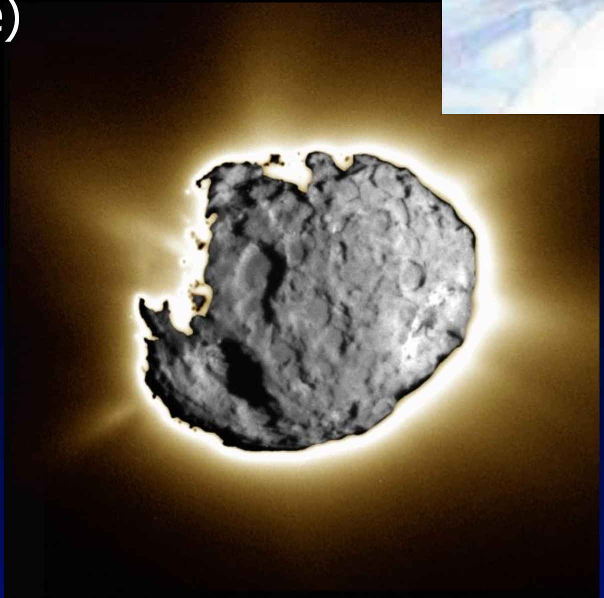
Human Exploration Science

- Provides support for human spaceflight and conducts world-class research and technology development
- Orbital debris: keeping track of tens of thousands of pieces of space jetsam
- Hypervelocity Impact testing: development of shielding for orbiting spacecraft (ISS, shuttle, Orion/MPCV)
- Earth Observations: Photos of Earth taken by astronauts from shuttle or station
- Image Science & Analysis: rapid analysis of spacecraft launch & operations to assess debris, anomalies, etc.
- Mars robotic missions: contributes to operation of orbital and landed spacecraft at Mars



Astromaterials Acquisition and Curation

- *Current Collections interest research scientists throughout the world*
  - Apollo Lunar Samples
  - Antarctic Meteorites
  - Cosmic Dust
  - Genesis 2004
  - Stardust 2006
  - Space Exposed Hardware
  - Hayabusa samples
  - Osiris-Rex returned samples (next decade)



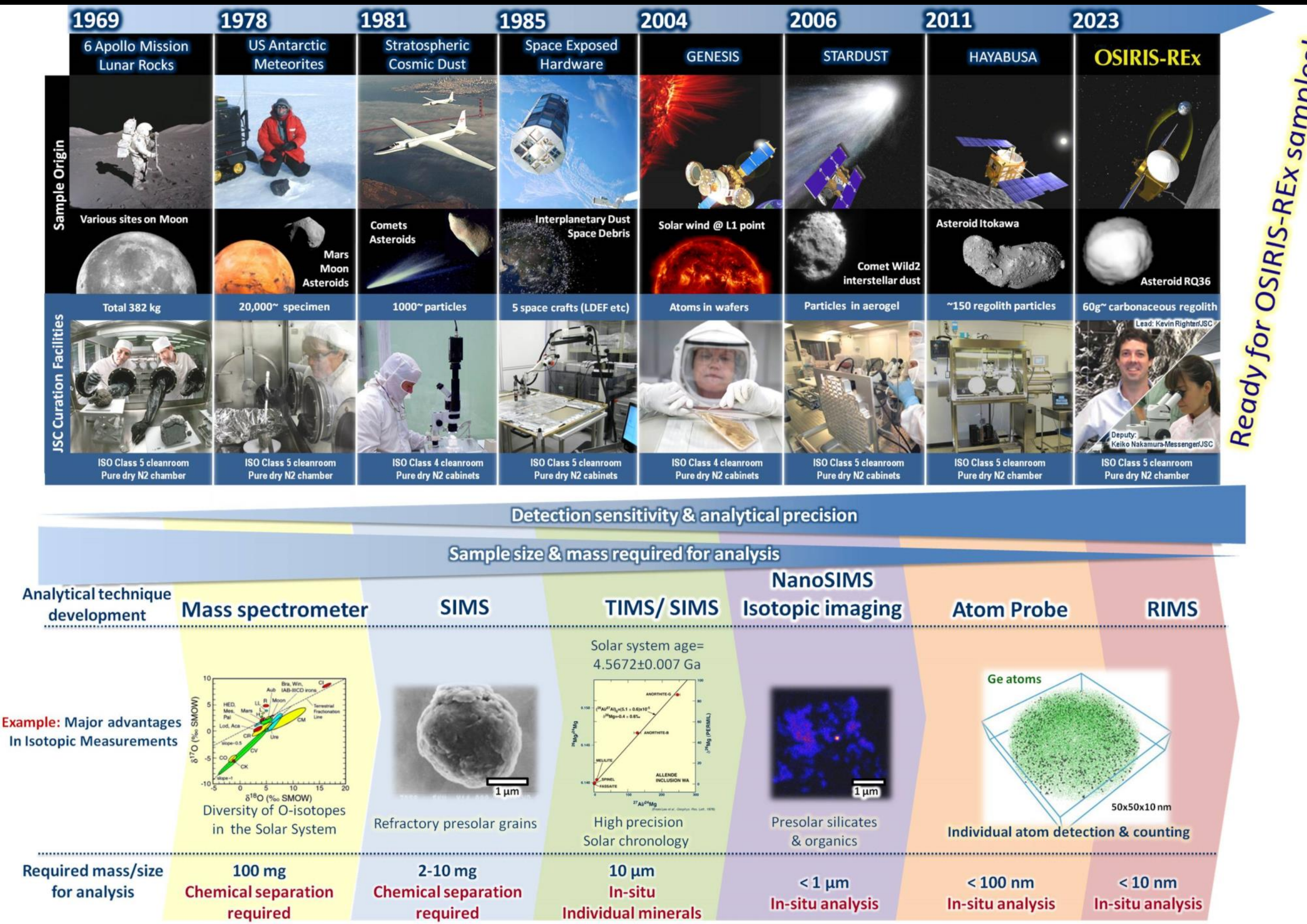
Astromaterials Acquisition and Curation

- Lunar Sample Vault
- Cosmic Dust Lab
- Meteorite Lab
- Stardust Lab
- Genesis Lab

Astromaterials Acquisition and Curation

- Allocations of samples via CAPTEM
- Planning for future robotic and human sample return missions
- Development of advanced curation techniques, e.g. cold curation
- Close ties to ANSMET expeditions to recover new meteorites from Antarctic ice fields

OSIRIS-REx
ASTEROID SAMPLE RETURN MISSION
UNIVERSITY OF ARIZONA • NASA GODDARD SPACE FLIGHT CENTER • LOCKHEED MARTIN



1969
6 Apollo Mission Lunar Rocks
1978
US Antarctic Meteorites
1981
Stratospheric Cosmic Dust
1985
Space Exposed Hardware
2004
GENESIS
2006
STARDUST
2011
HAYABUSA
2023
OSIRIS-REx
Sample Origin
Various sites on Moon
Mars Moon Asteroids
Comets Asteroids
Interplanetary Dust Space Debris
Solar wind @ L1 point
Comet Wild2 interstellar dust
Asteroid Itokawa
Asteroid RQ36
Total 382 kg
20,000~ specimen
1000~ particles
5 space crafts (LDEF etc)
Atoms in wafers
Particles in aerogel
~150 regolith particles
60g~ carbonaceous regolith
JSC Curation Facilities
Lead: Kevin Righter/JSC
Deputy: Keiko Nakamura-Messenger/JSC
ISO Class 5 cleanroom Pure dry N2 chamber
ISO Class 5 cleanroom Pure dry N2 chamber
ISO Class 4 cleanroom Pure dry N2 cabinets
ISO Class 5 cleanroom Pure dry N2 cabinets
ISO Class 4 cleanroom Pure dry N2 cabinets
ISO Class 5 cleanroom Pure dry N2 cabinets
ISO Class 5 cleanroom Pure dry N2 chamber
ISO Class 5 cleanroom Pure dry N2 chamber
Ready for OSIRIS-REx sampl
Detection sensitivity & analytical precision
Sample size & mass required for analysis
Analytical technique development
Mass spectrometer
SIMS
TIMS/ SIMS
NanoSIMS Isotopic imaging
Atom Probe
RIMS
Example: Major advantages In Isotopic Measurements
Solar system age= 4.5672±0.007 Ga
Ge atoms
50x50x10 nm
1 µm
1 µm
1 µm
Diversity of O-isotopes in the Solar System
Refractory presolar grains
High precision Solar chronology
Presolar silicates & organics
Individual atom detection & counting
Required mass/size for analysis
100 mg Chemical separation required
2-10 mg Chemical separation required
10 µm In-situ Individual minerals
< 1 µm In-situ analysis
< 100 nm In-situ analysis
< 10 nm In-situ analysis

Astromaterials Research Staff

- ~15 Principal Investigators on peer-reviewed grants
- ~40 professional contractor staff conducting research or providing laboratory services
- ~40 current peer-reviewed grants awarded competitively through NASA SMD programs
- Broad collaborations with the science community at large
- Extensive participation on advisory committees, peer-review panels, and act as society officers, journal editors, conference organizers, etc.
- Peer recognition from outside of NASA (for example, three top awards of the Meteoritical Society)
  - Leonard Medal (Top Award – Outstanding contributions to science of meteoritics)
  - Barringer Award (Outstanding work in field of cratering)
  - Nier Prize (Outstanding research by a young scientist)

Astromaterials Research

Laboratory Facilities

Micro-Analysis of Samples

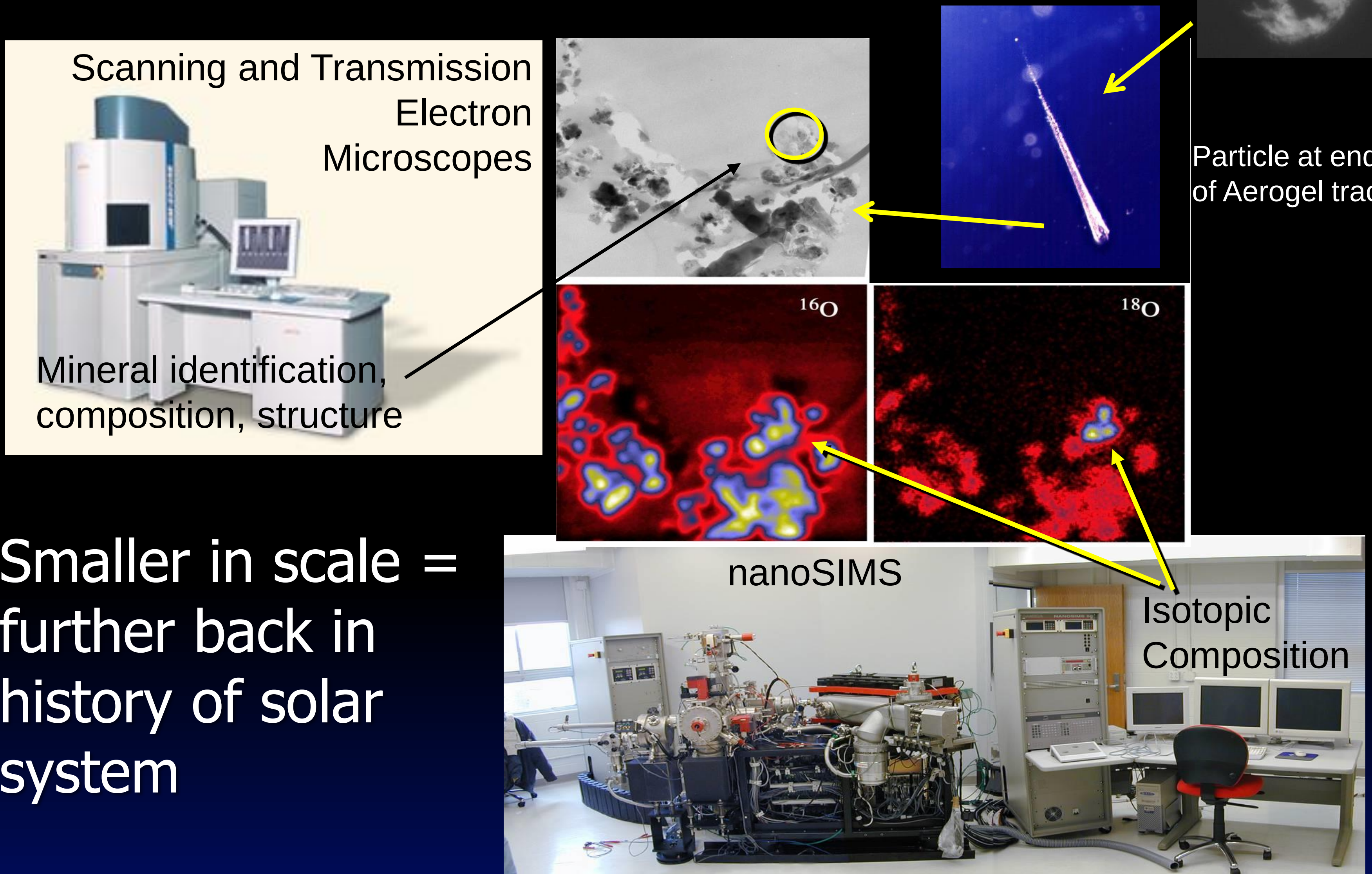
- Scanning and Transmission Electron Microscopes, Electron Microprobe
  — chemical composition, elemental mapping, mineralogy
- NanoSIMS (Secondary Ion Mass Spec)
  — Isotopic analysis with spatial resolution 50 x better than conventional instruments
- Laser Ionization Mass Spectrometer
  — Organic compound analysis
- FIB (Focused Ion Beam)
  — Nanometer-scale sampling/slicing

Recent Discoveries –

- Entire range of O isotopes found in one CAI rim
- New minerals "Brownleeite" and "Wassonite" discovered within an interplanetary dust particle and Antarctic meteorite, resp.

Micro-Analysis Example

Dust from Comet Wild 2, Stardust Mission

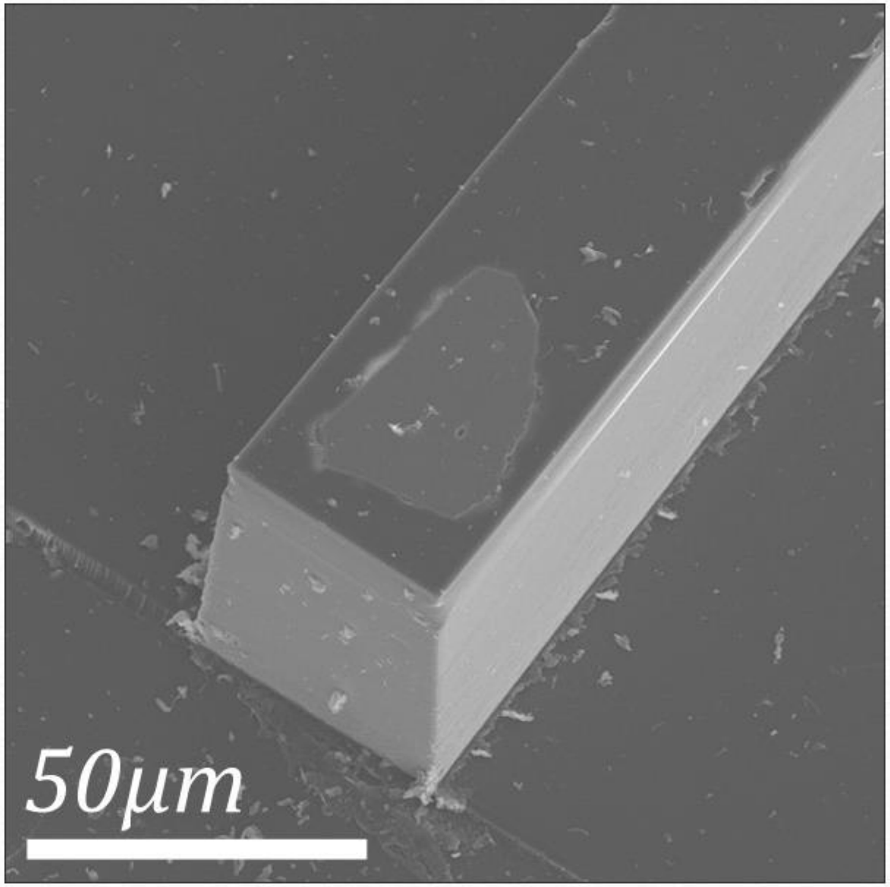


Smaller in scale = further back in history of solar system

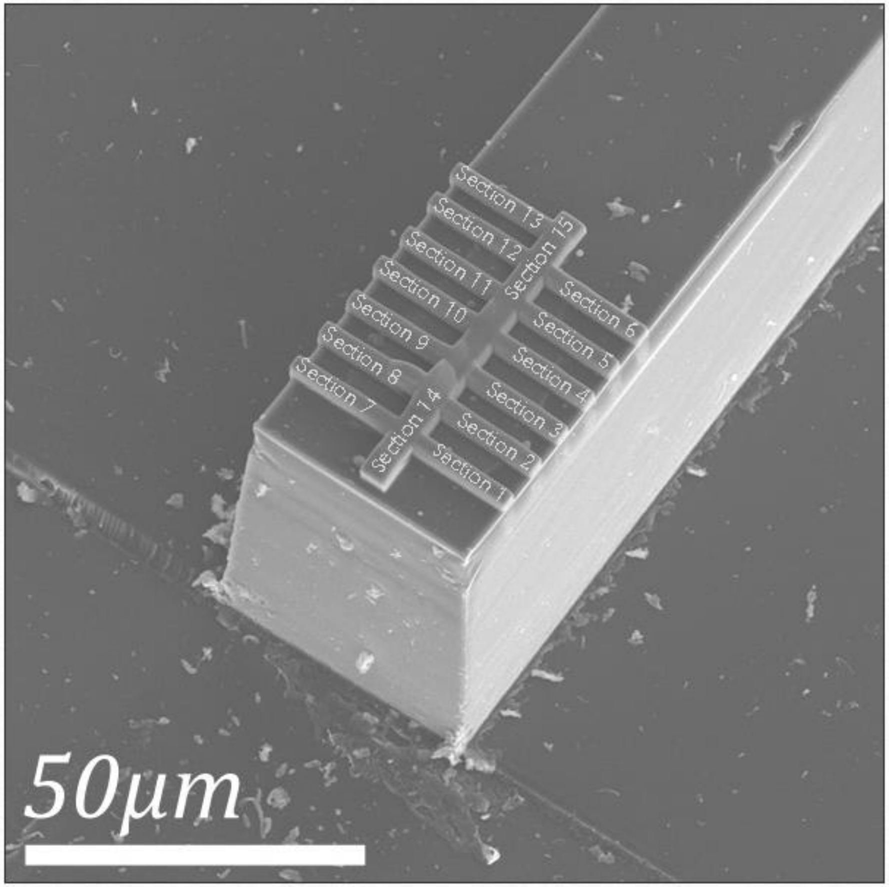
Maximizing the scientific yield from a ~40μm x 40μm x 20μm-sized particle returned by JAXA's Hayabusa Mission to Asteroid Itokawa

Traditional FIB techniques would allow for **1 to 2** electron transparent sections to be made from this particle

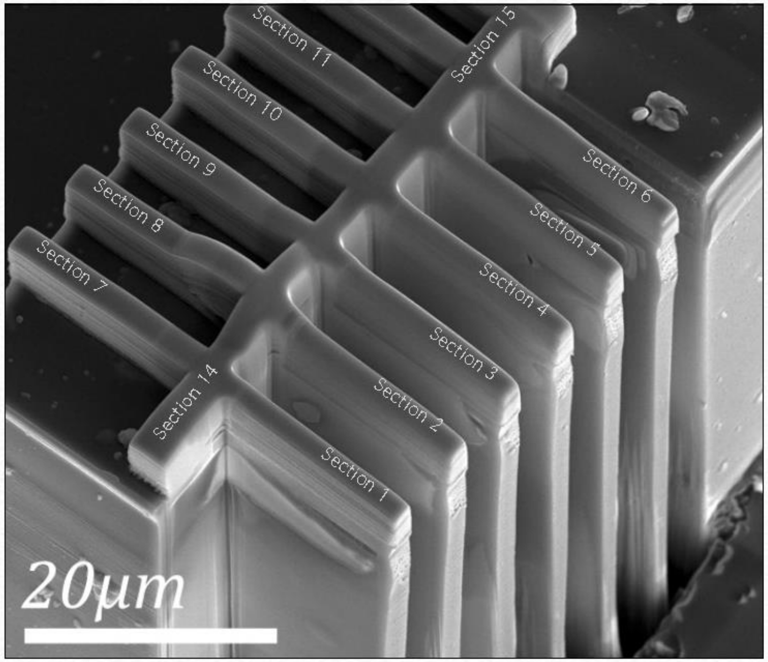
This new technique will allow for **more than a dozen** sections to be made

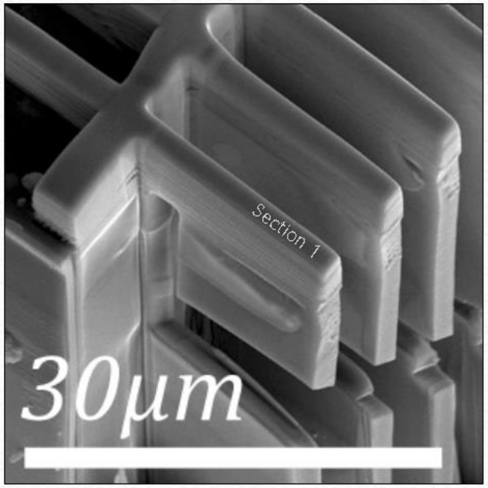


Oblique view of the grain after being embedded in epoxy and partially sectioned. The material surrounding the grain has been removed, leaving it at the end of a rectangular box sitting on top of the bulk of the substrate.

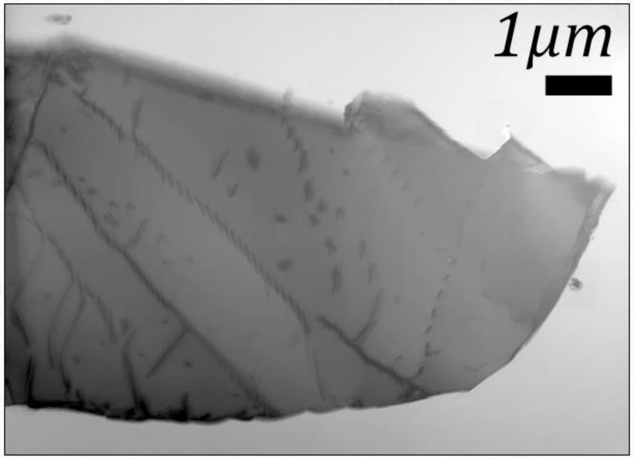


A protective carbon cap has been placed over the areas of interest. The locations of the 15 planned FIB-prepared electron transparent thin sections are indicated

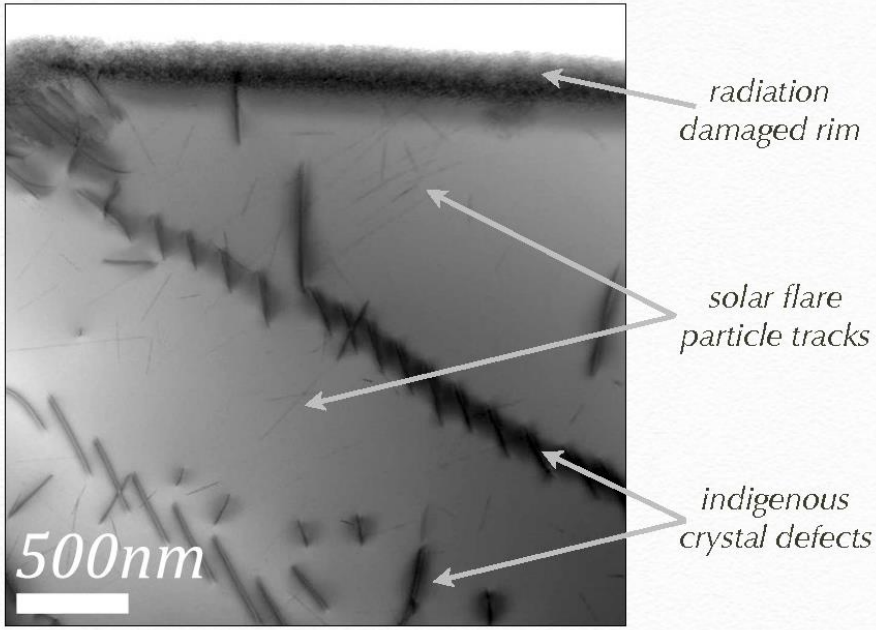




Material between sections 1 through 6 was been milled away (left). Then material under section 1 was milled away in preparation for lift out (above).



Once thinned to ~100-150nm, the section was analyzed using transmission electron microscopy. Bright field STEM images of section 1 are shown (above and to the right)

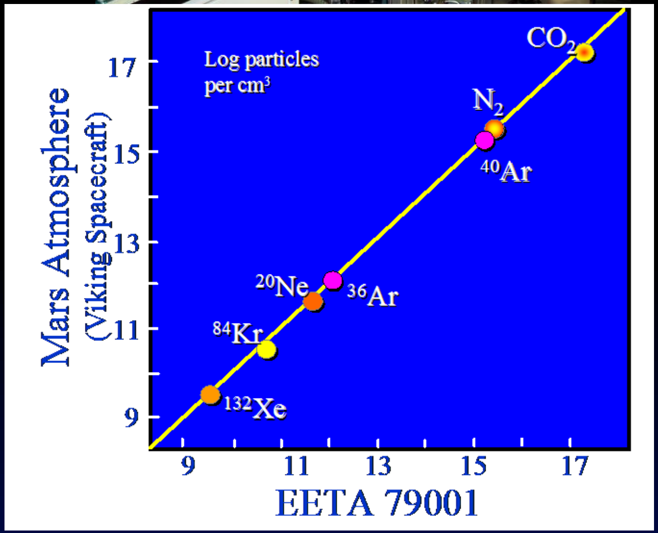


Astromaterials Research

Laboratory Facilities

Bulk Analysis of Samples

- Thermal Ionization Mass Spectrometer
  — High precision isotopic composition, geochronology
- Inductively-Coupled Plasma Mass Spectrometer
  — Elemental analysis across the periodic table
- Light Element, Stable Isotope Lab
  — Isotopic analysis of H, C, N, O
- Astrobiology Labs
  — How do prebiotic compounds develop to biotic ones?
- Spectroscopy and X-Ray Diffraction
  — Mineralogical and crystallographic characterization



Proof that SNC meteorites are from Mars

Recent Highlights –

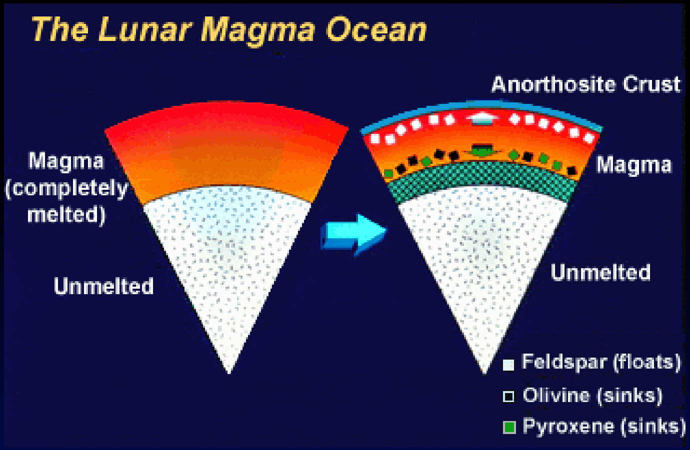
• Entire known oxygen isotopic range measured in single CAI (J. Simon)
• Discovery of two new minerals (brownleeite, wassonite)

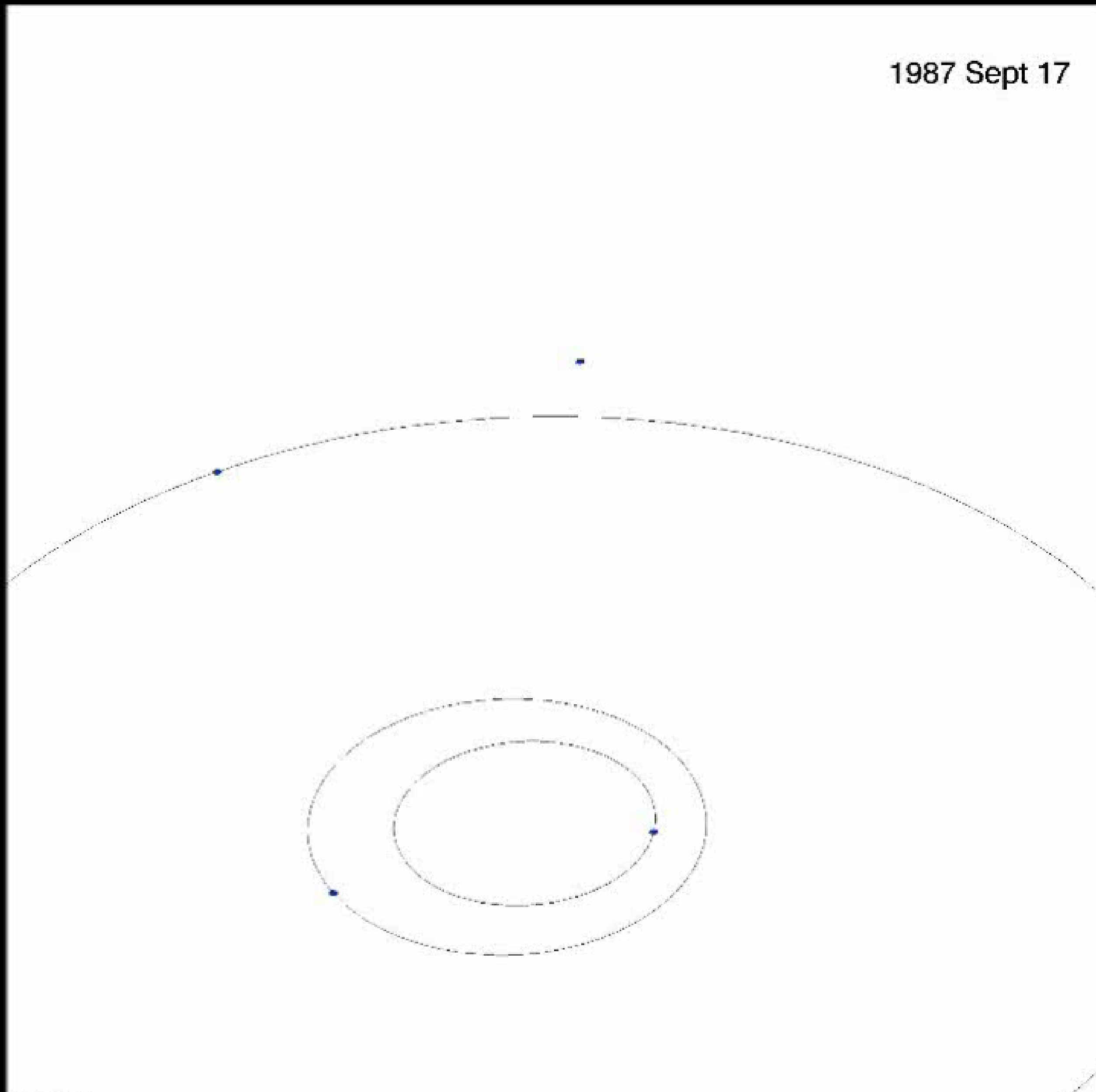
Astromaterials
Research

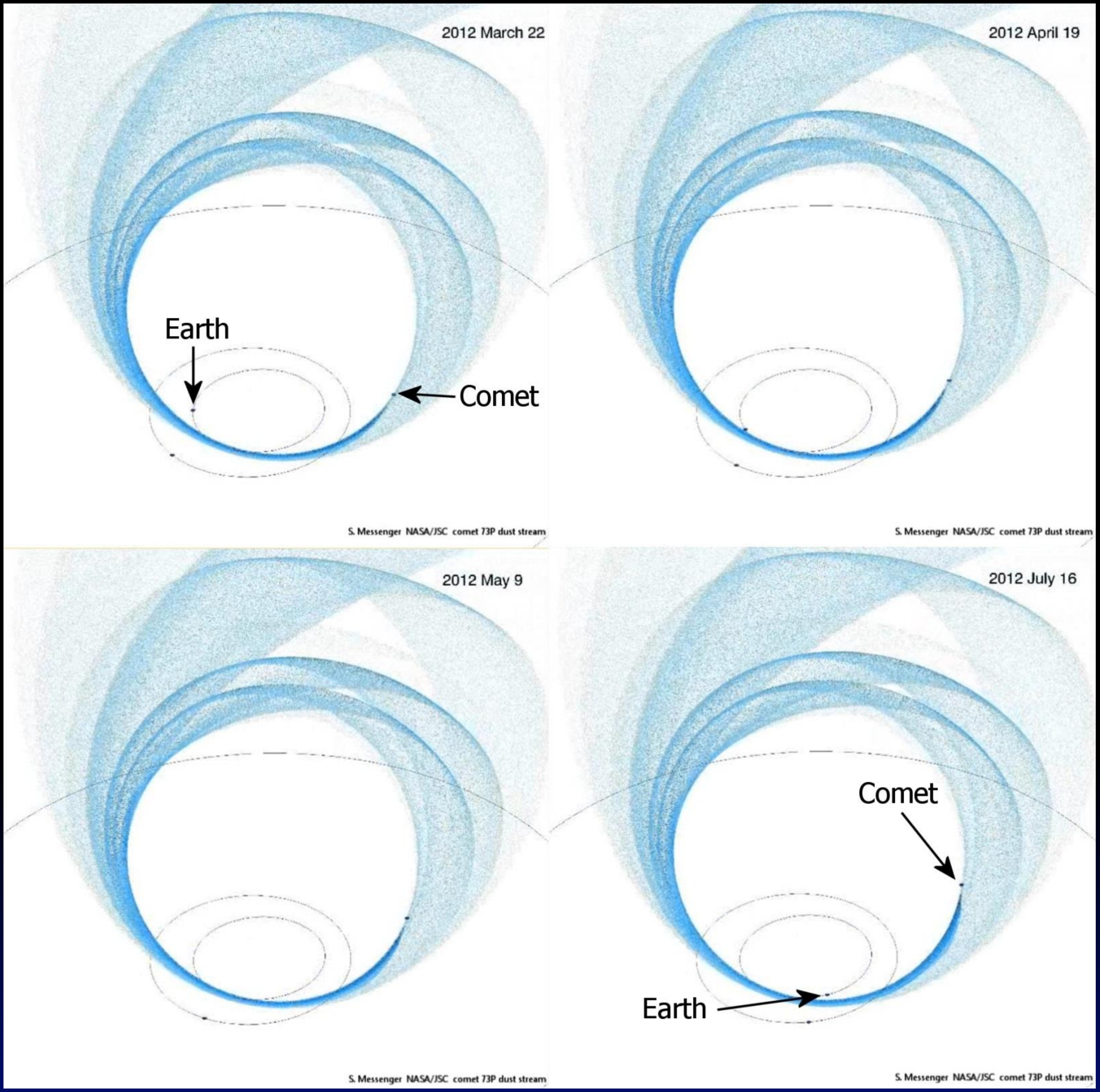
Laboratory Facilities

Planetary Process Simulation

- High Temperature, High Pressure Experimental Petrology
  — Simulate planetary interior conditions
- Experimental Impact Laboratory
  — Cratering processes, surface properties
- Mars surface simulations (soils, etc.)




1987 Sept 17


2012 March 22
Earth
Comet
S. Messenger NASA/JSC comet 73P dust stream
2012 April 19
S. Messenger NASA/JSC comet 73P dust stream
2012 May 9
S. Messenger NASA/JSC comet 73P dust stream
2012 July 16
Comet
Earth
S. Messenger NASA/JSC comet 73P dust stream

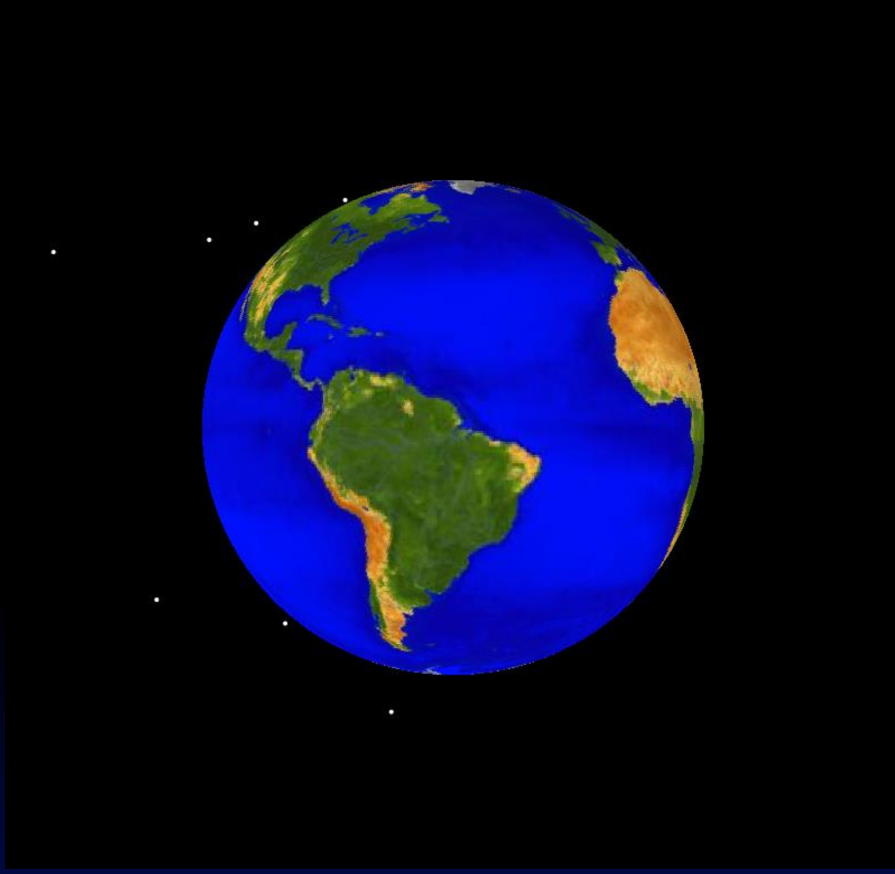
Human Exploration Science

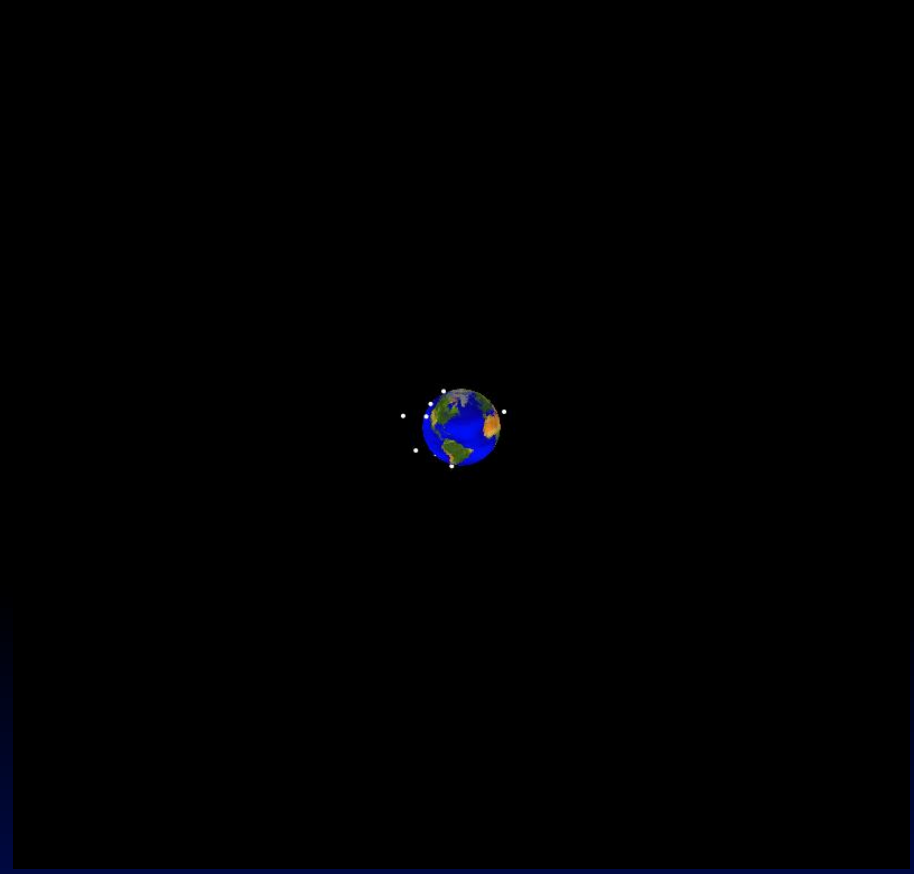
- Orbital debris: keeping track of tens of thousands of pieces of space jetsam
- Hypervelocity Impact testing: development of shielding for orbiting spacecraft (ISS, shuttle, Constellation)
- Earth Observations: Photos of Earth taken by astronauts from International Space Station
- Image Science & Analysis: rapid analysis of spacecraft launch & operations to assess debris, anomalies, etc.
- Robotic exploration missions: contributes to operation of orbital and landed spacecraft at Mars, Moon, and asteroids
- Astronaut training in field geology for eventual human exploration

Exploration: Orbital Debris

Exploration: Orbital Debris

1960

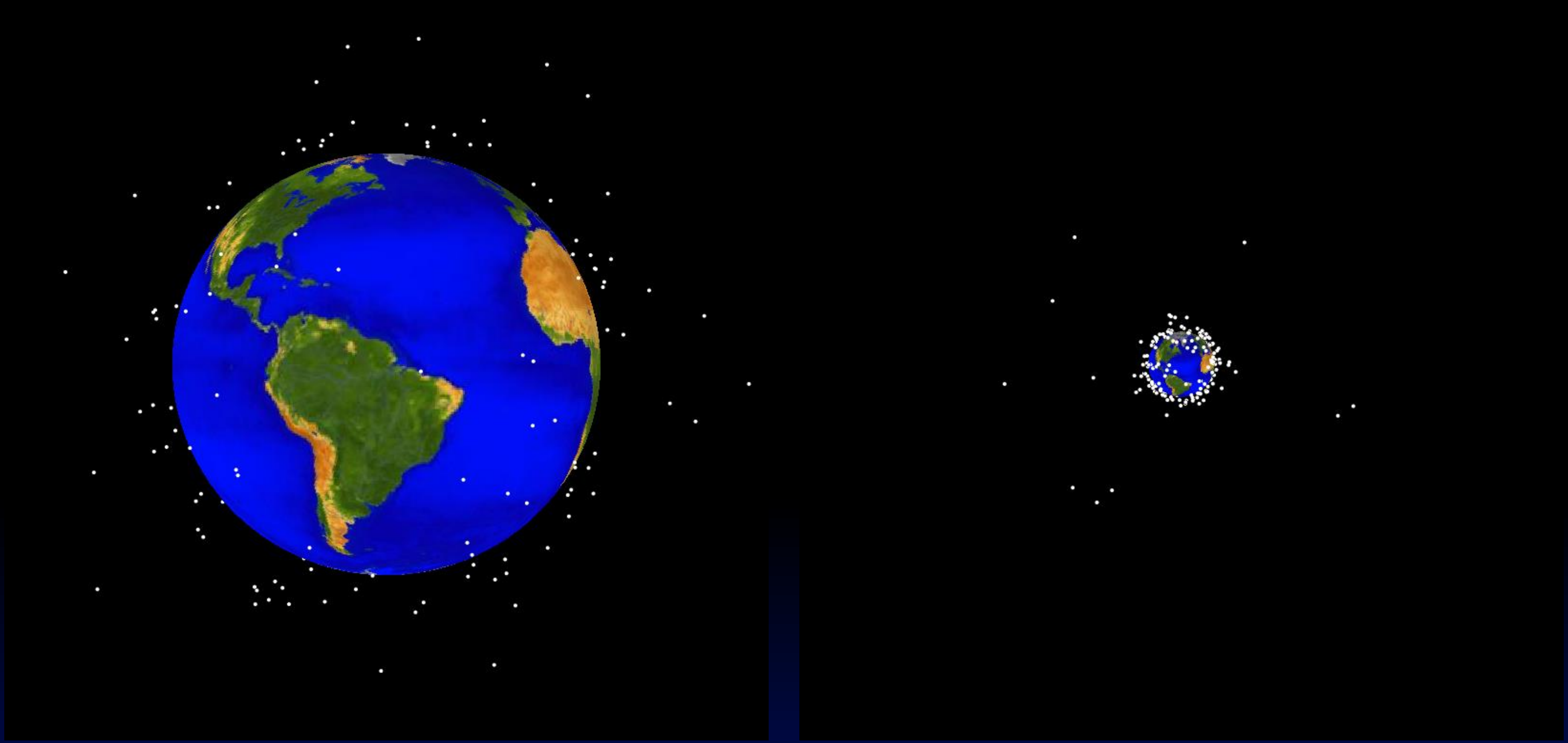




Cataloged objects >10 cm diameter

Exploration: Orbital Debris

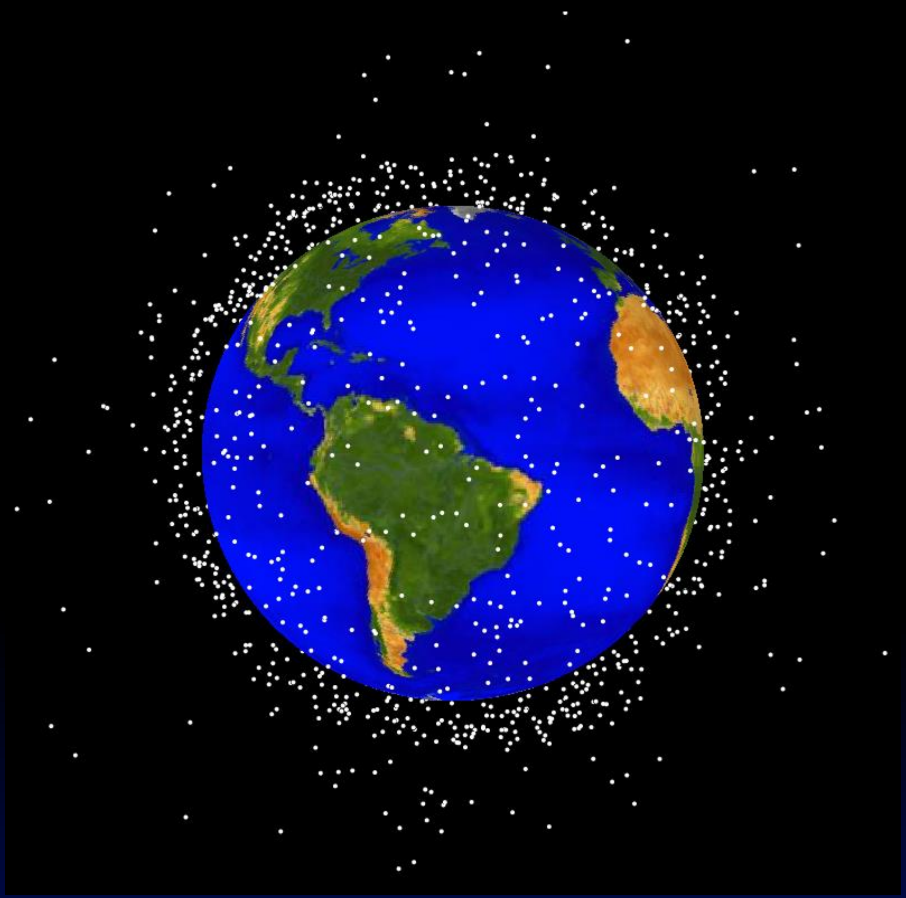
1965

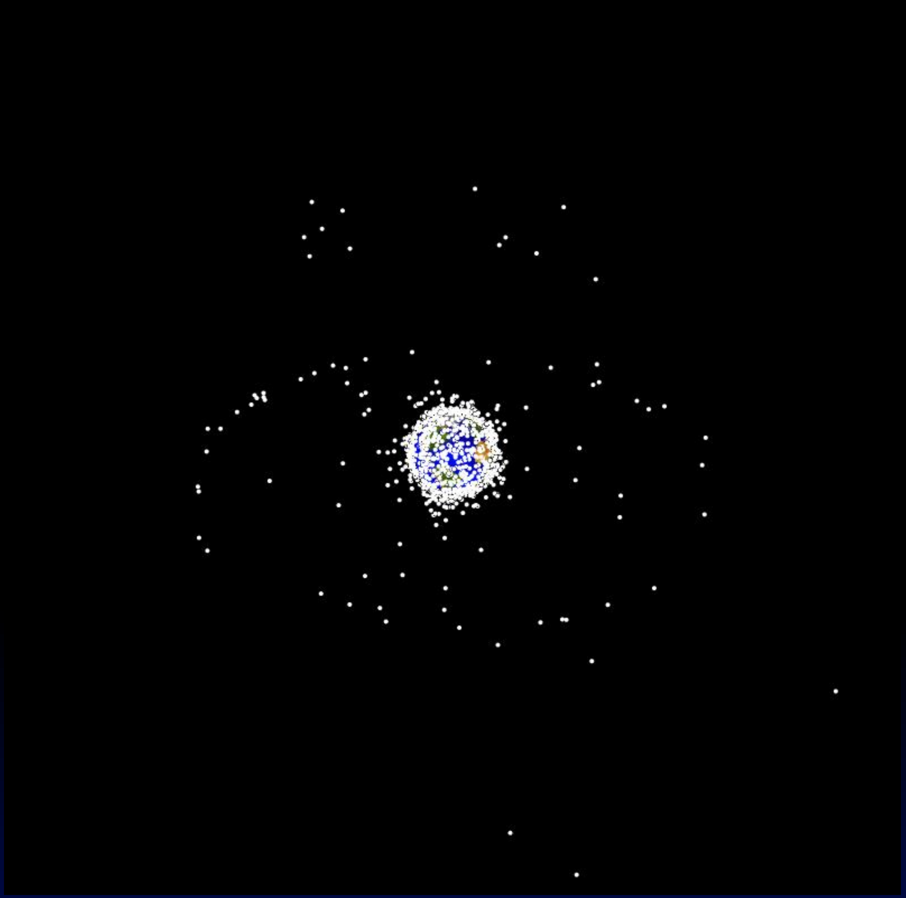


Cataloged objects >10 cm diameter

Exploration: Orbital Debris

1970

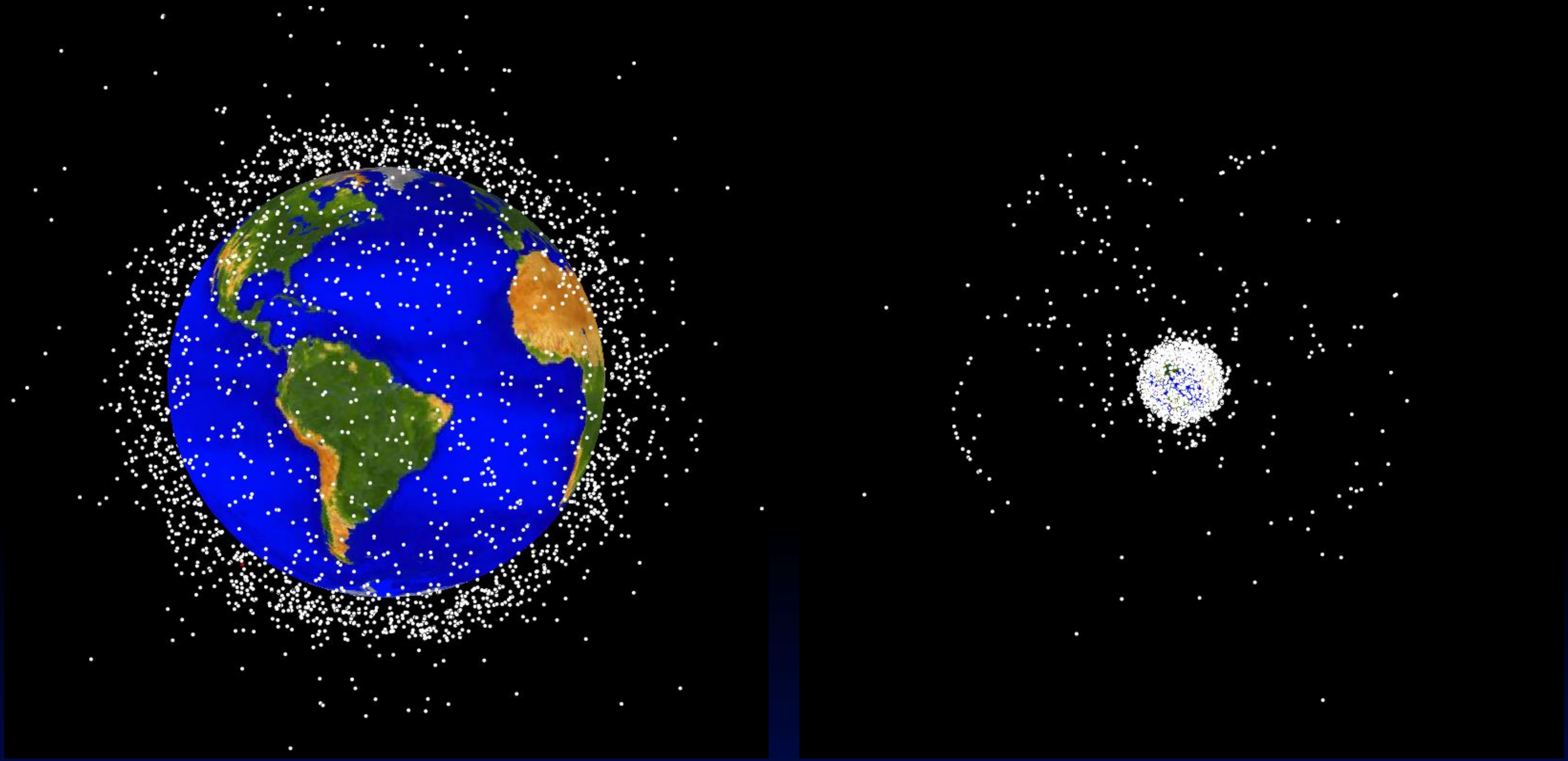




Cataloged objects >10 cm diameter

Exploration: Orbital Debris

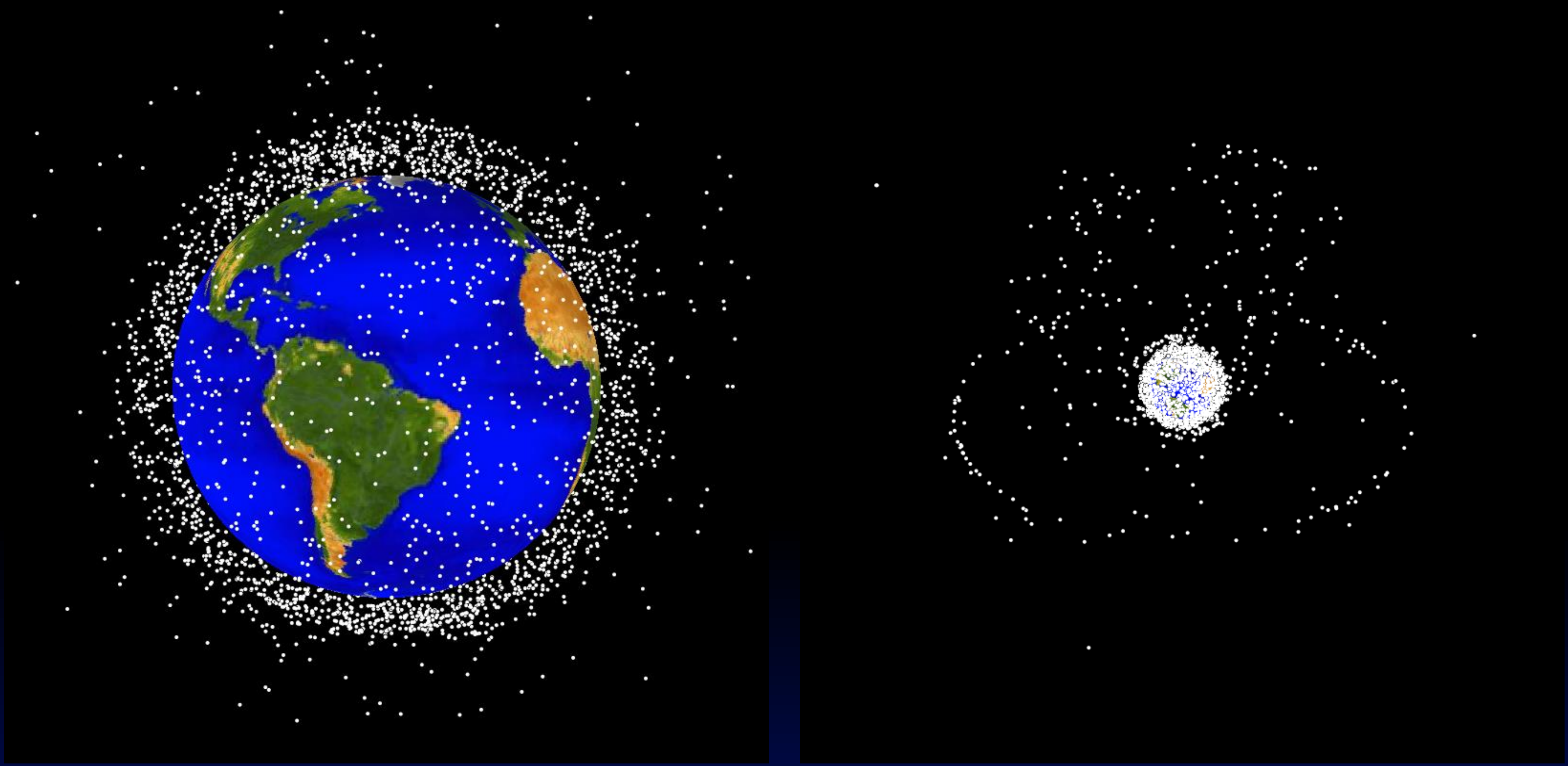
1975



Cataloged objects >10 cm diameter

Exploration: Orbital Debris

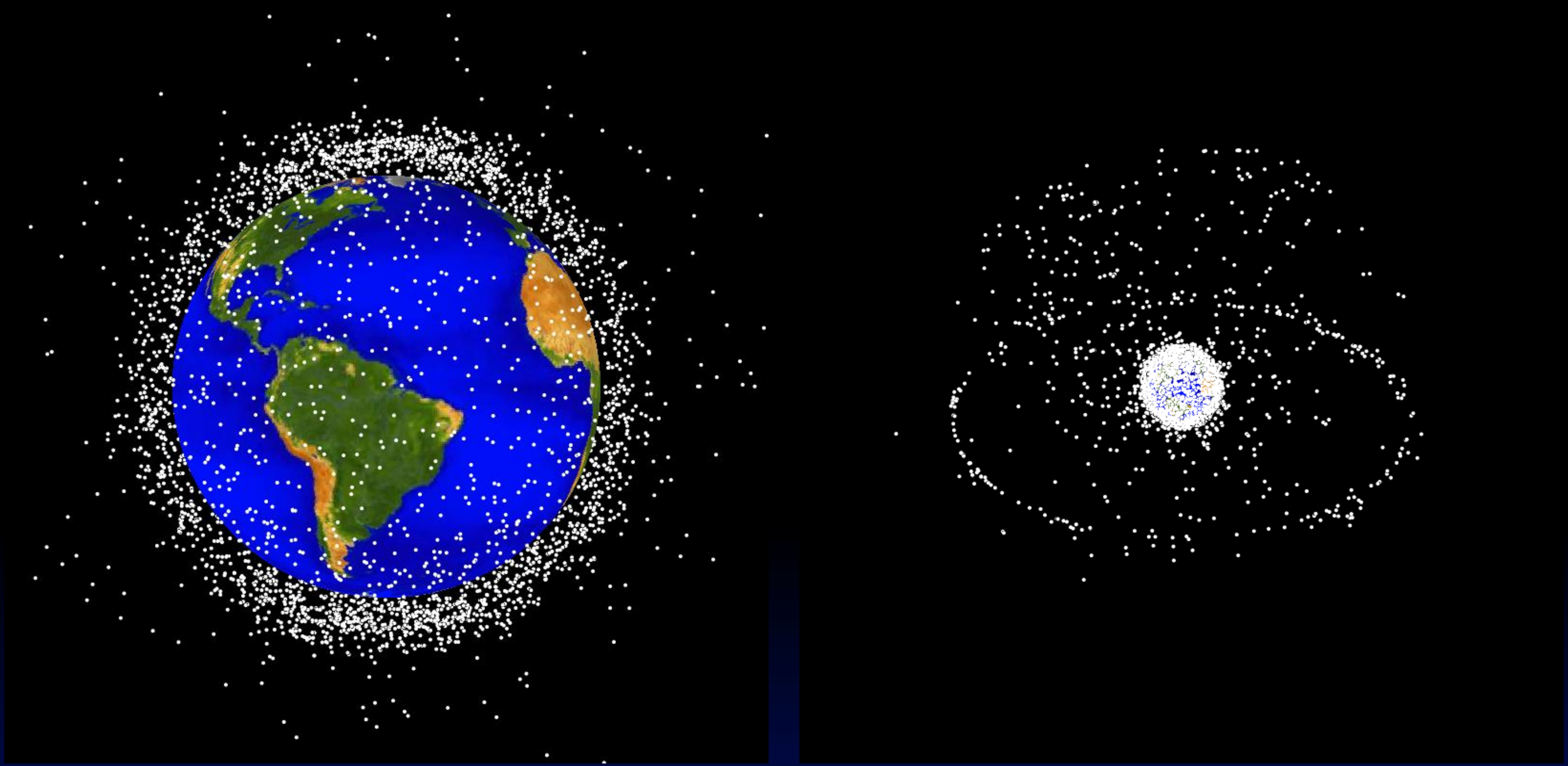
1980



Cataloged objects >10 cm diameter

Exploration: Orbital Debris

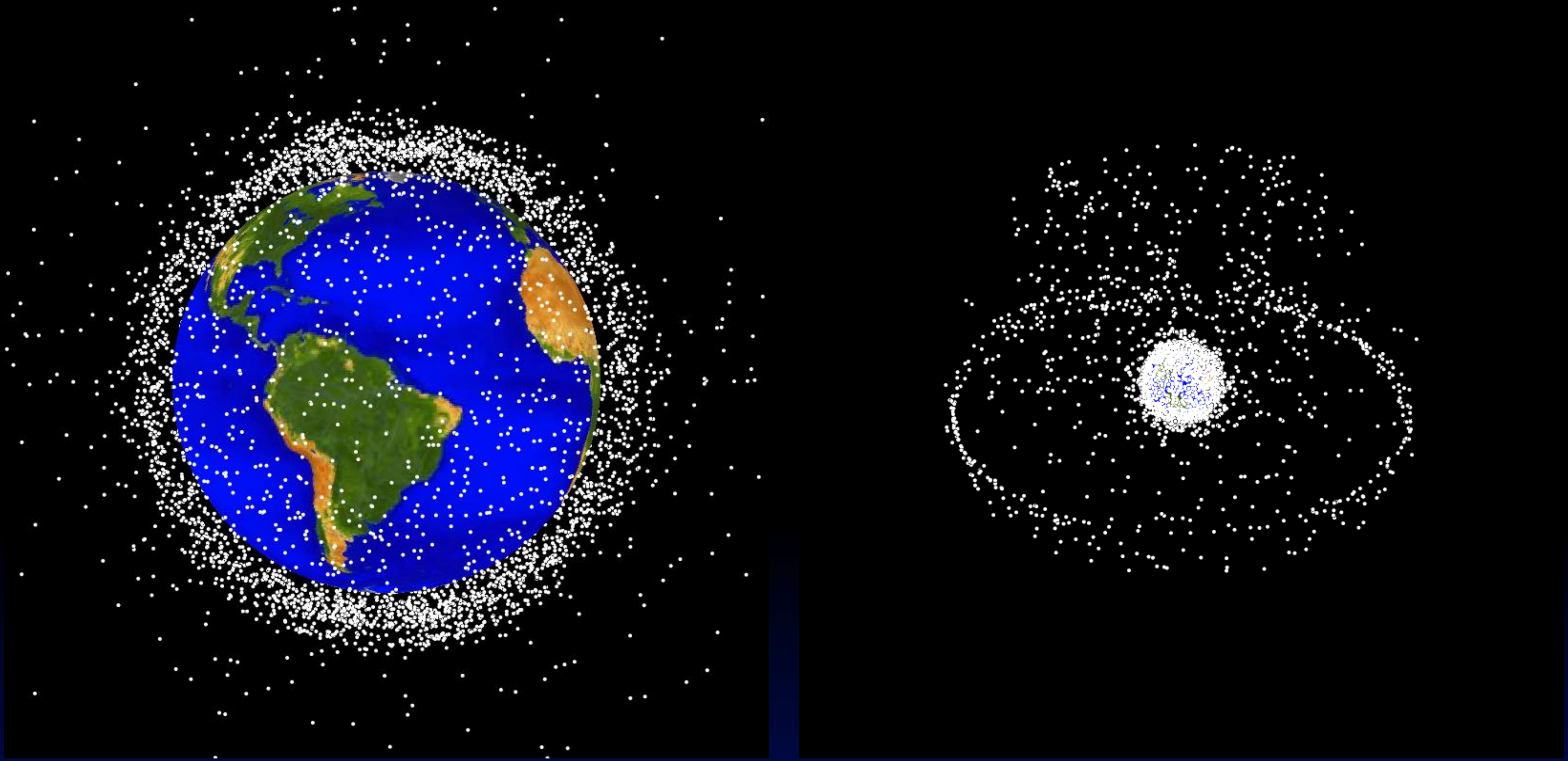
1985



Cataloged objects >10 cm diameter

Exploration: Orbital Debris

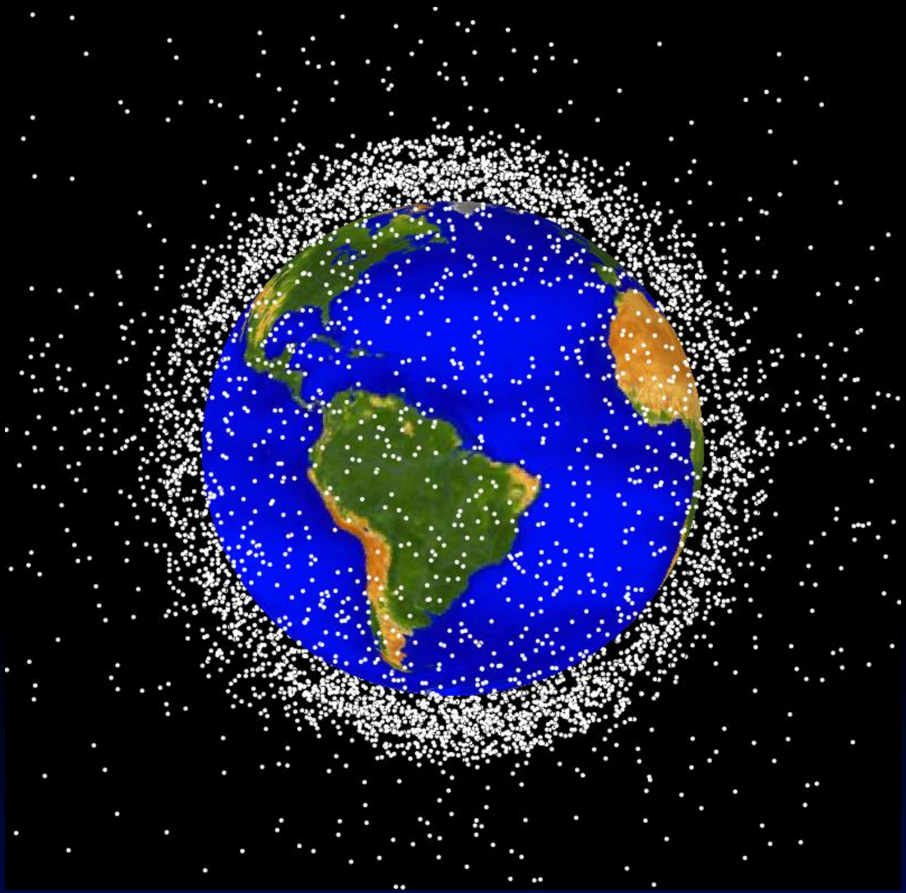
1990

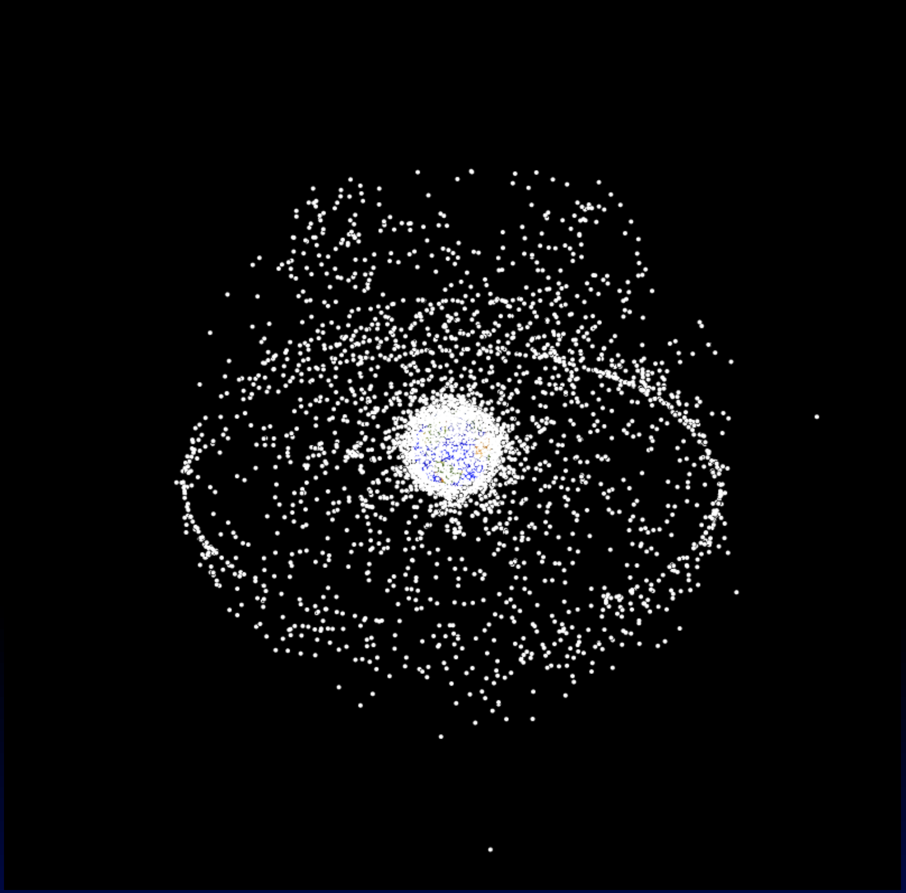


Cataloged objects >10 cm diameter

Exploration: Orbital Debris

1995

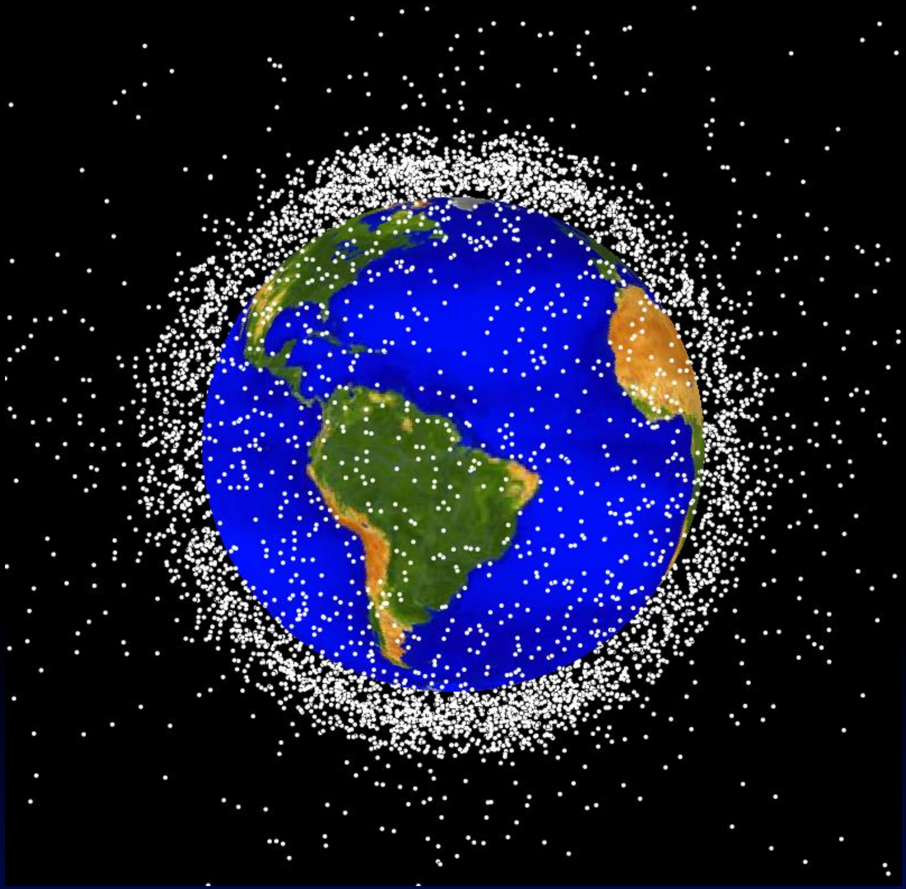


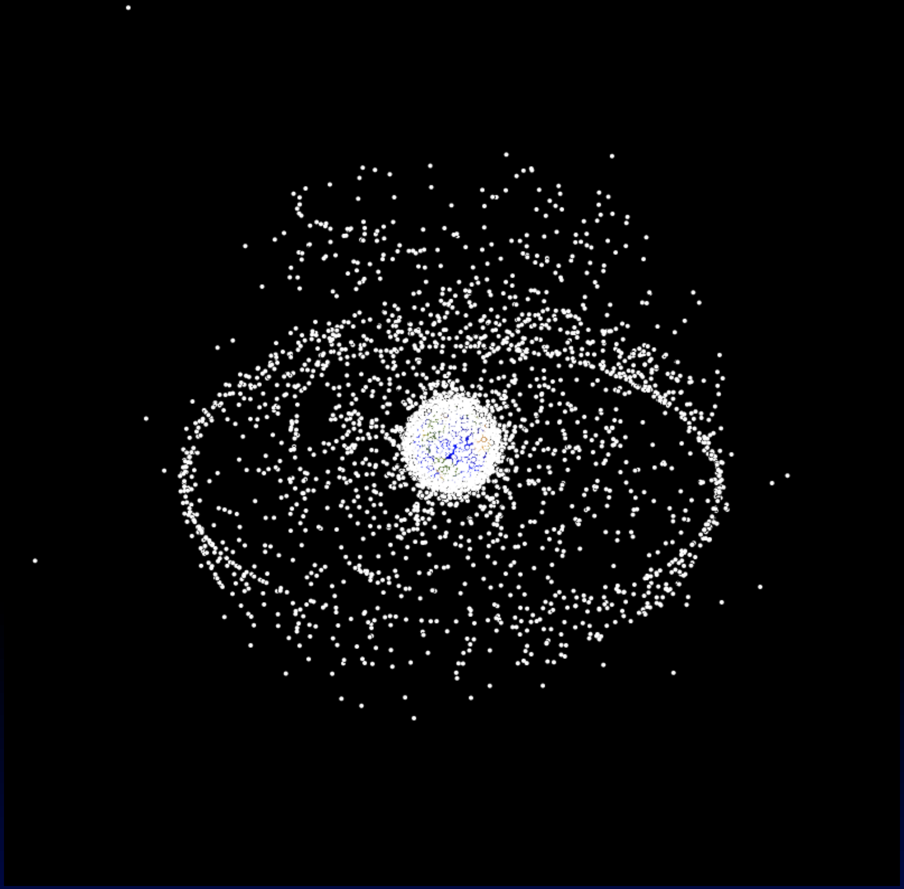


Cataloged objects >10 cm diameter

Exploration: Orbital Debris

2000

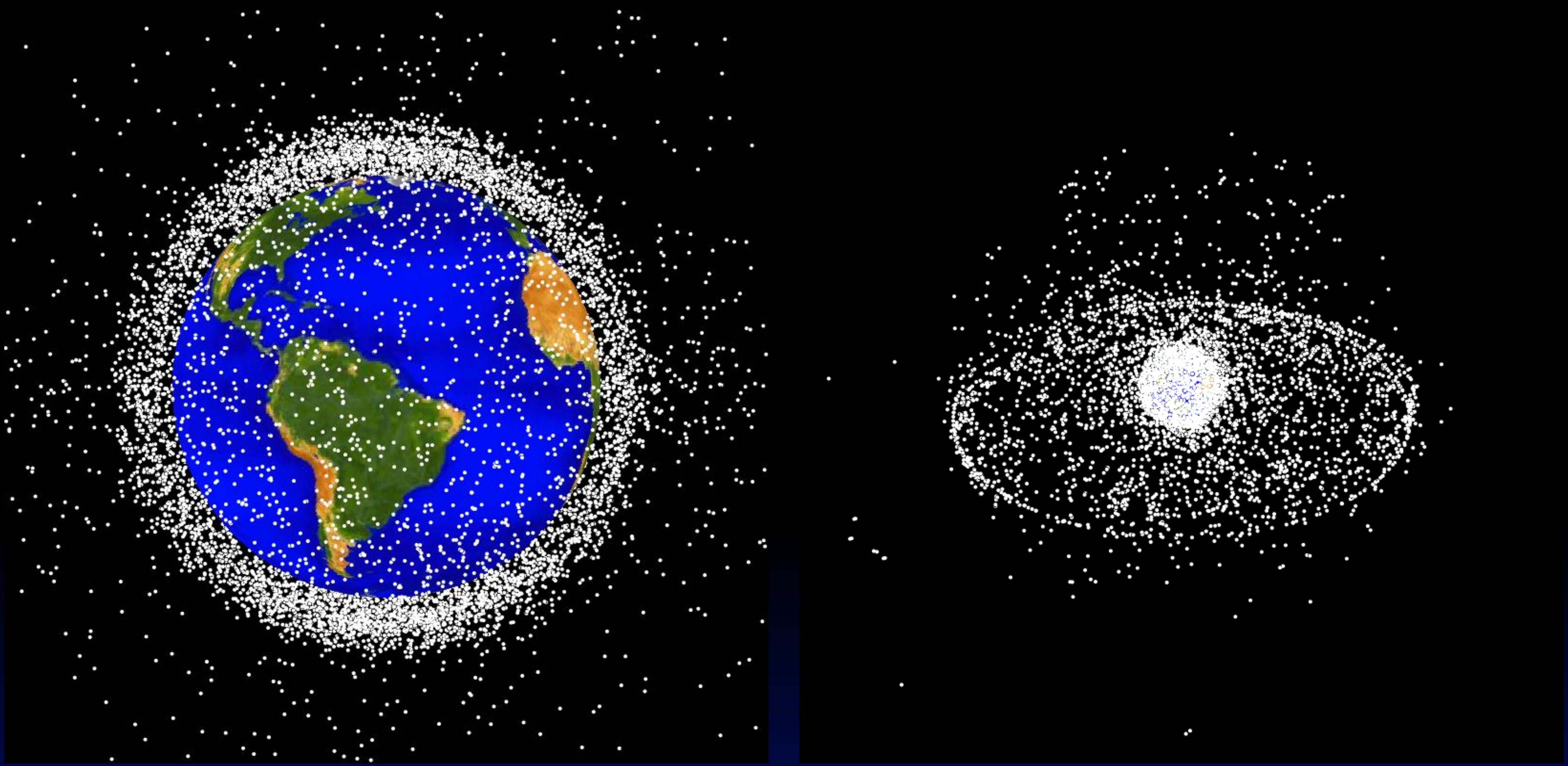




Cataloged objects >10 cm diameter

Exploration: Orbital Debris

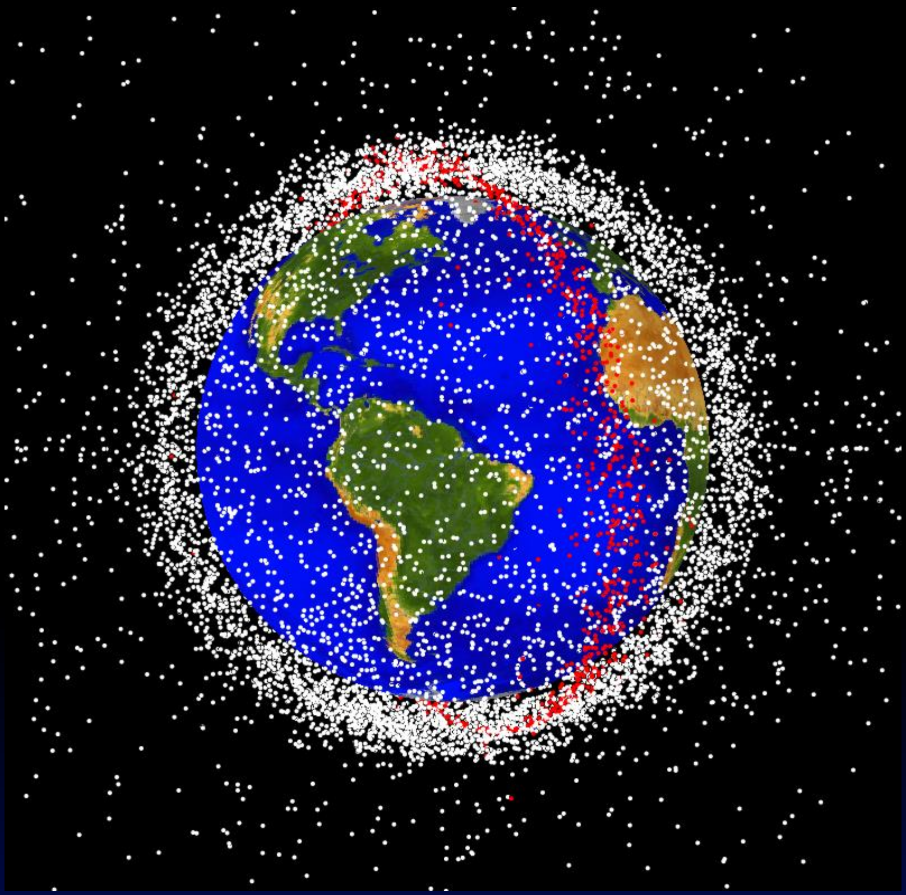
April 2006

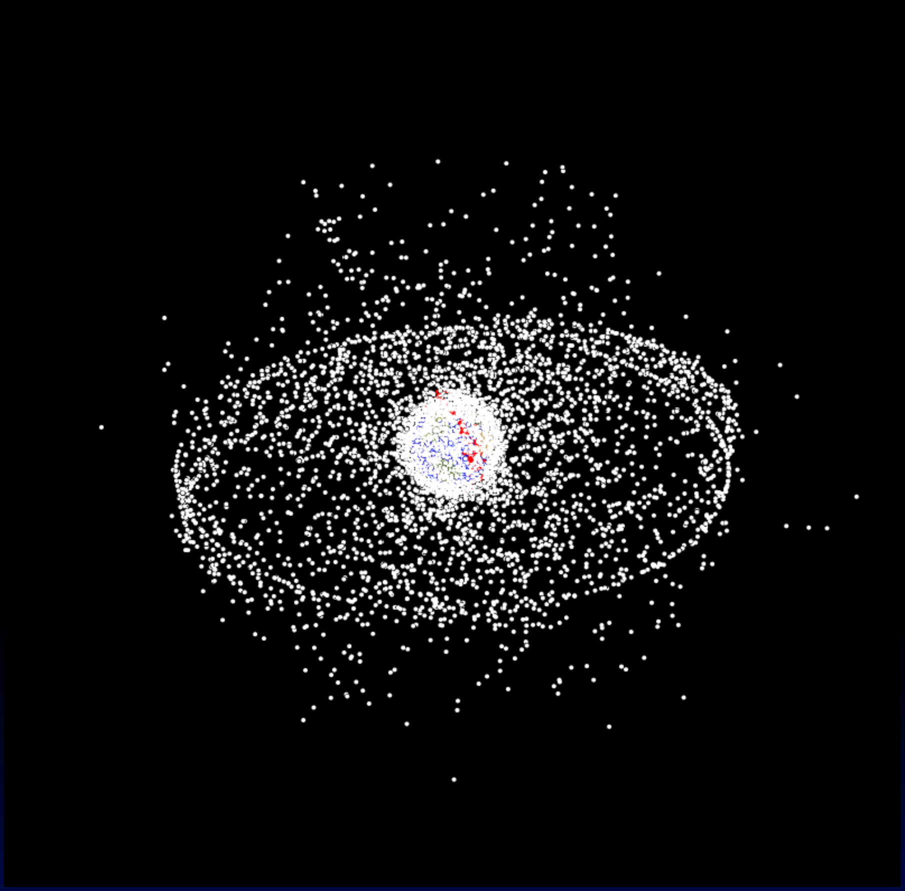


Cataloged objects >10 cm diameter

Exploration: Orbital Debris

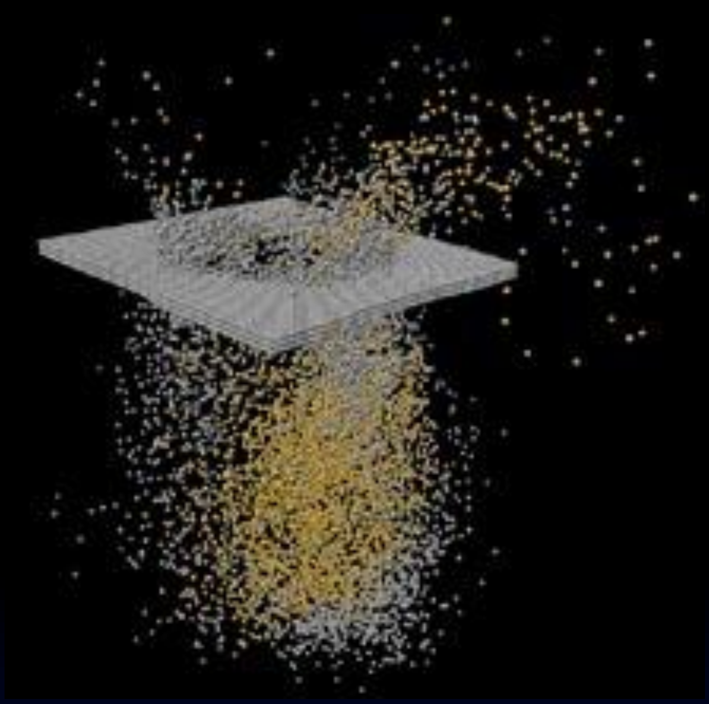
March 2007





Cataloged objects >10 cm diameter

Hypervelocity Impact Testing



Earth Observations

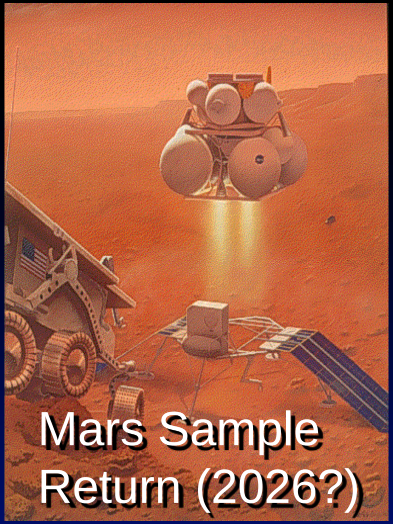
Mission Science

Mars Robotic Exploration – as science team members for Mars lander missions (including front-line mission operations)

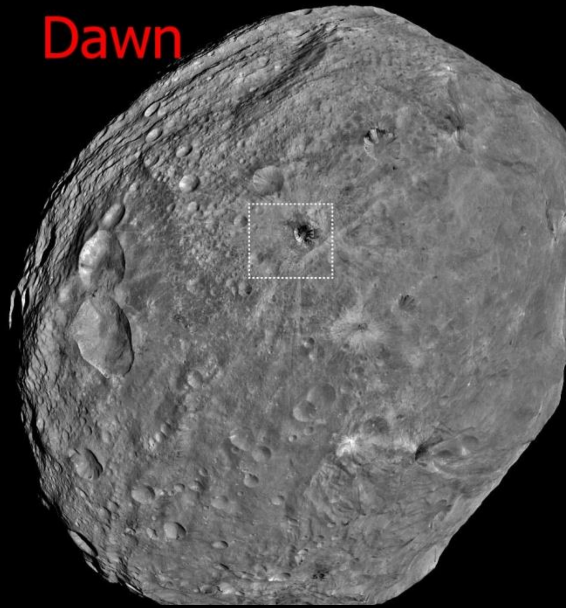
- Flight-like laboratory instruments
- — Calibration and interpretation of remote-sensed data
- Extensive collection of terrestrial analog materials for calibrating lander flight instruments

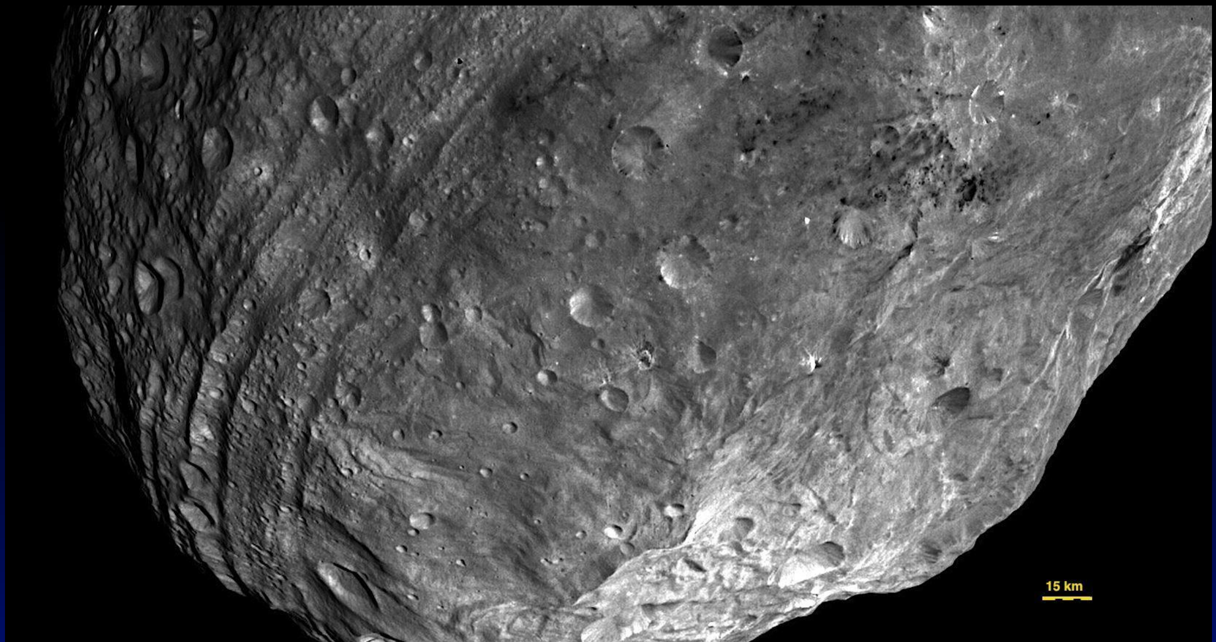
Recent Discoveries –

• Phoenix mission discovery of calcium carbonate and perchlorate on Mars (P. Niles)
• MER discovery of carbonate outcrops (D. Morris)



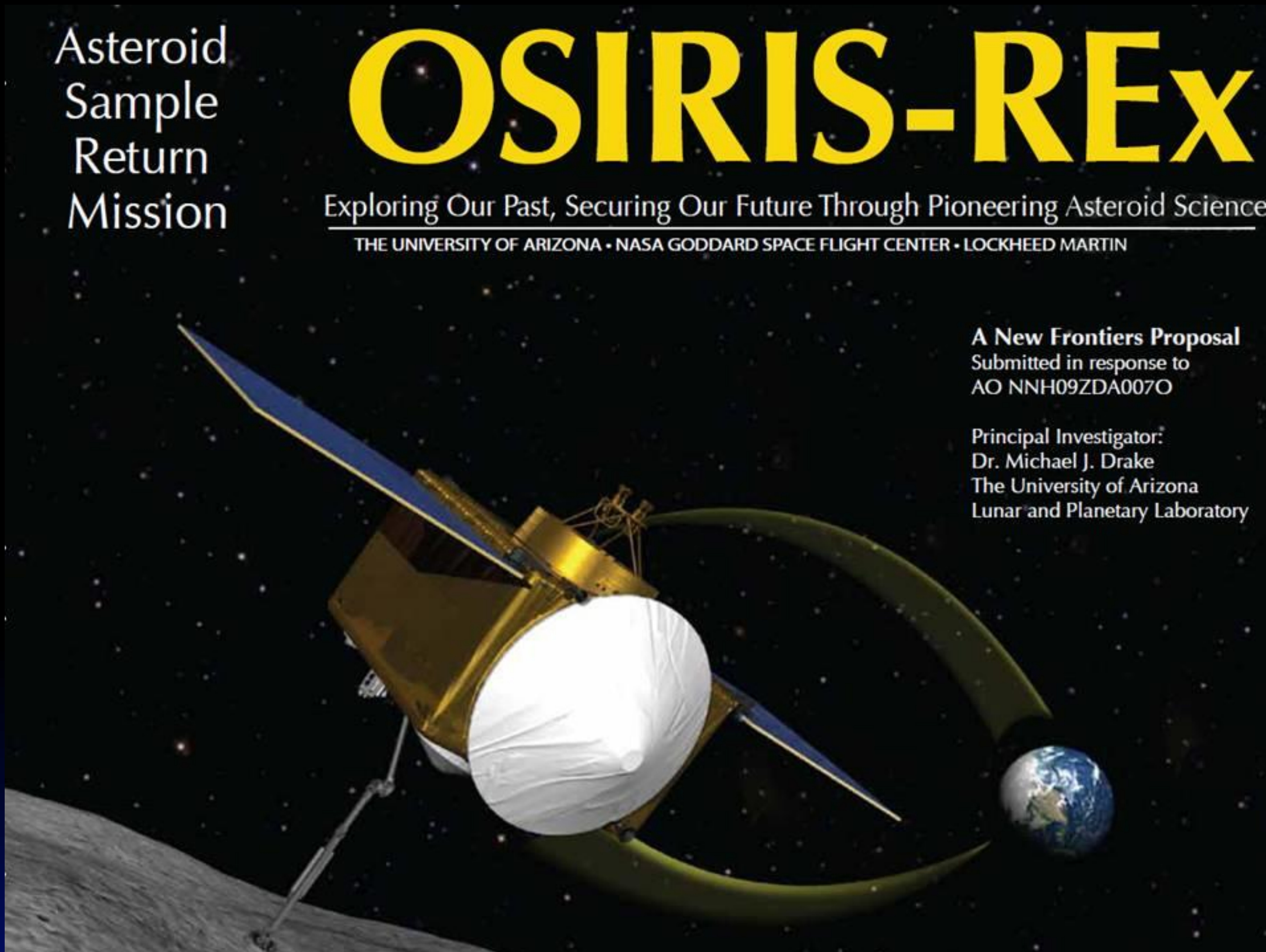
Mission Science





NASA DISCOVERY MISSION
Vesta
Ceres
Dawn
UCLA • JPL • ORBITAL • DLR • MPS • ASI • INAF • LANL

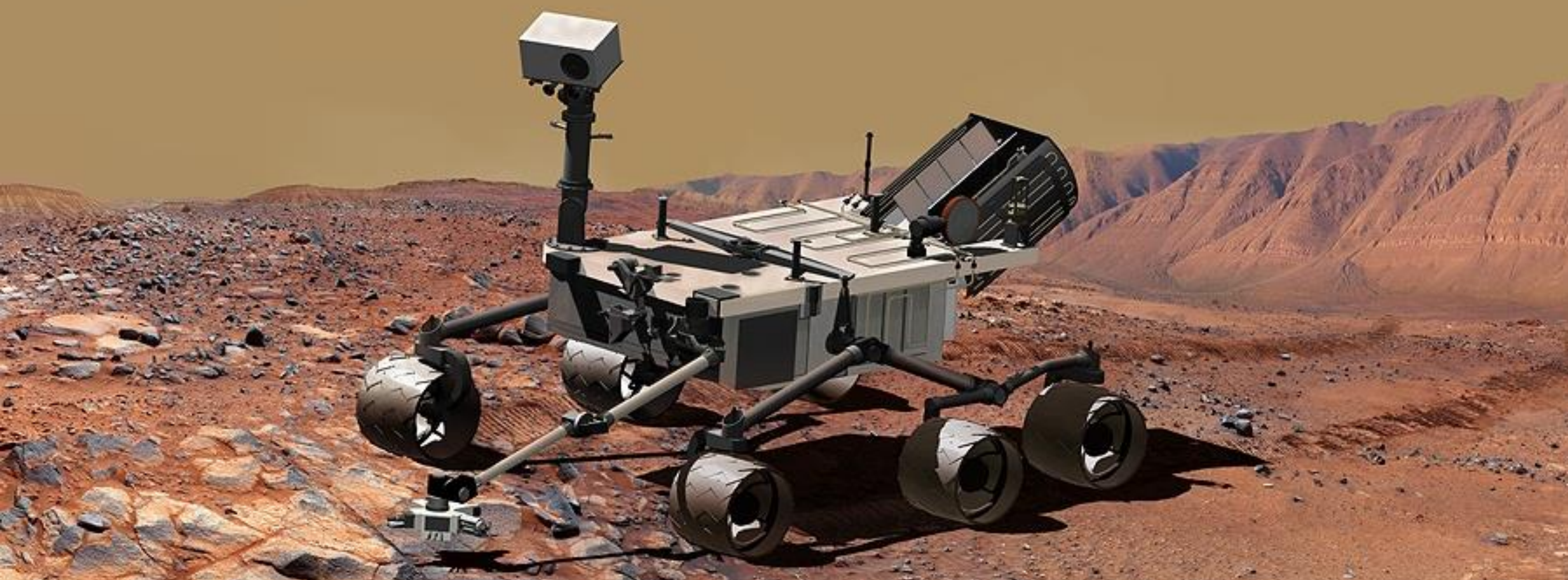
Mission Science



Mission Science

Curiosity: A Robotic Field Geologist

- Long life, ability to traverse many miles over rocky terrain
- Landscape and hand-lens imaging
- Ability to survey composition of bedrock and regolith



Astronaut Training

ARES: In Summary

- Preservation of and access to all of NASA's extraterrestrial sample collections
- Comprehensive characterization of samples
  - isotopic analysis and geochronology
  - elemental analysis
  - mineralogical analysis
- Duplication of planetary interior and surface processes
- Data interpretation critical for the scientific success of robotic exploration missions
- Support for human spaceflight operations
- Orbital debris and hypervelocity research
- Earth observations (astronaut photography)