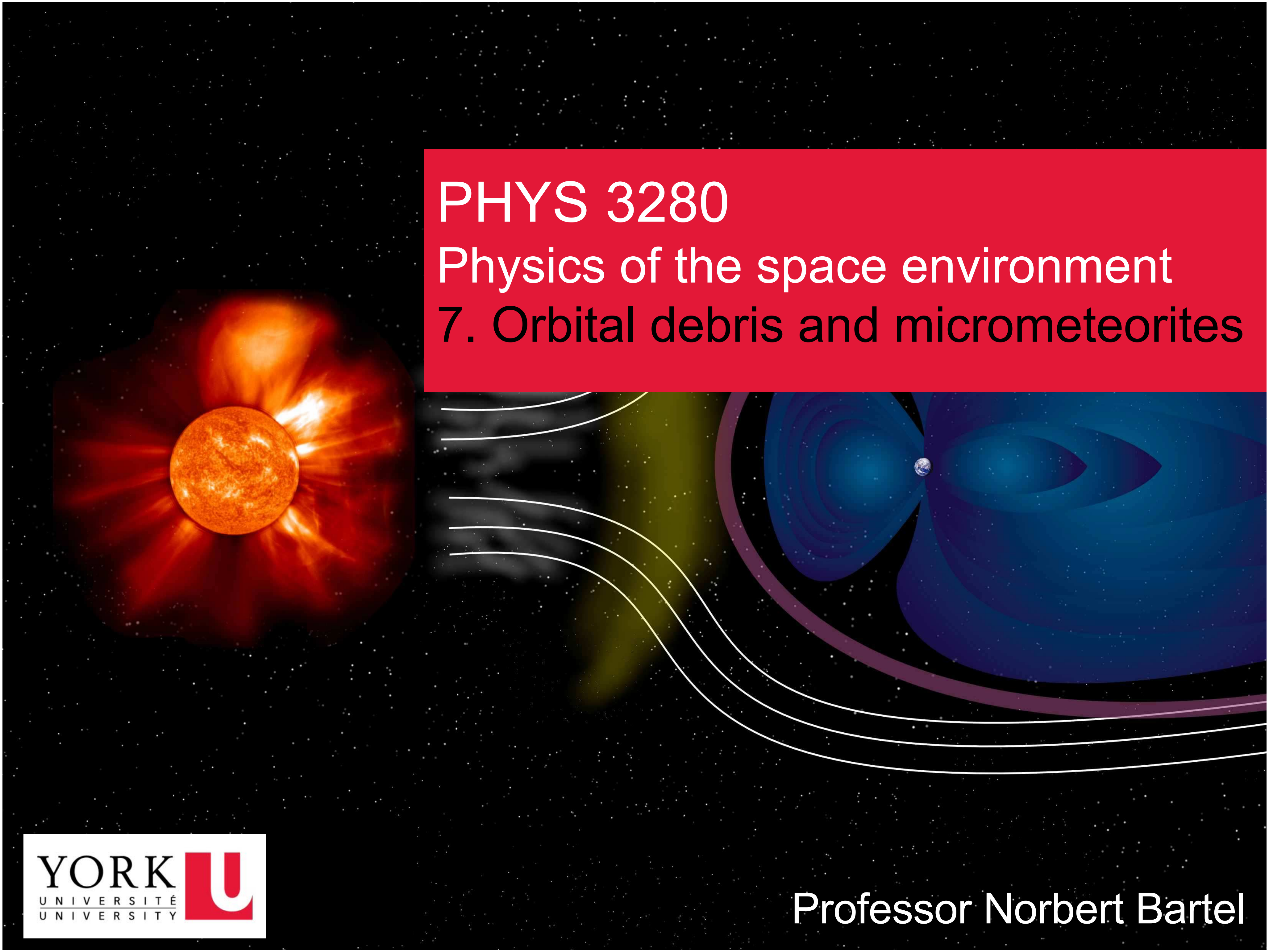
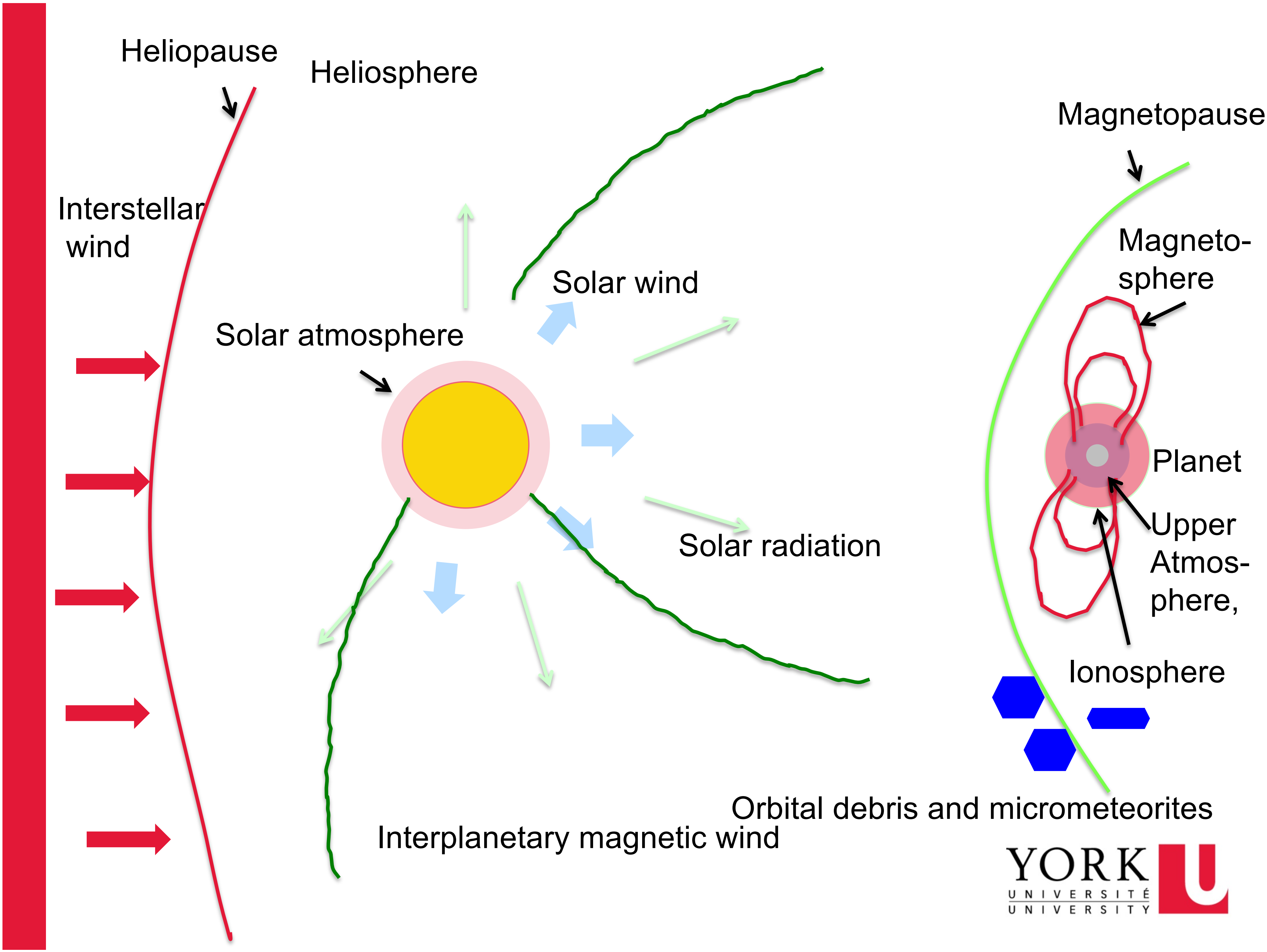


PHYS 3280
Physics of the space environment
7. Orbital debris and micrometeorites

Professor Norbert Bartel


Heliopause
Heliosphere
Magnetopause
Interstellar wind
Magneto-sphere
Solar wind
Solar atmosphere
Planet
Upper Atmos-phere,
Solar radiation
Ionosphere
Orbital debris and micrometeorites
Interplanetary magnetic wind
YORK UNIVERSITÉ UNIVERSITY

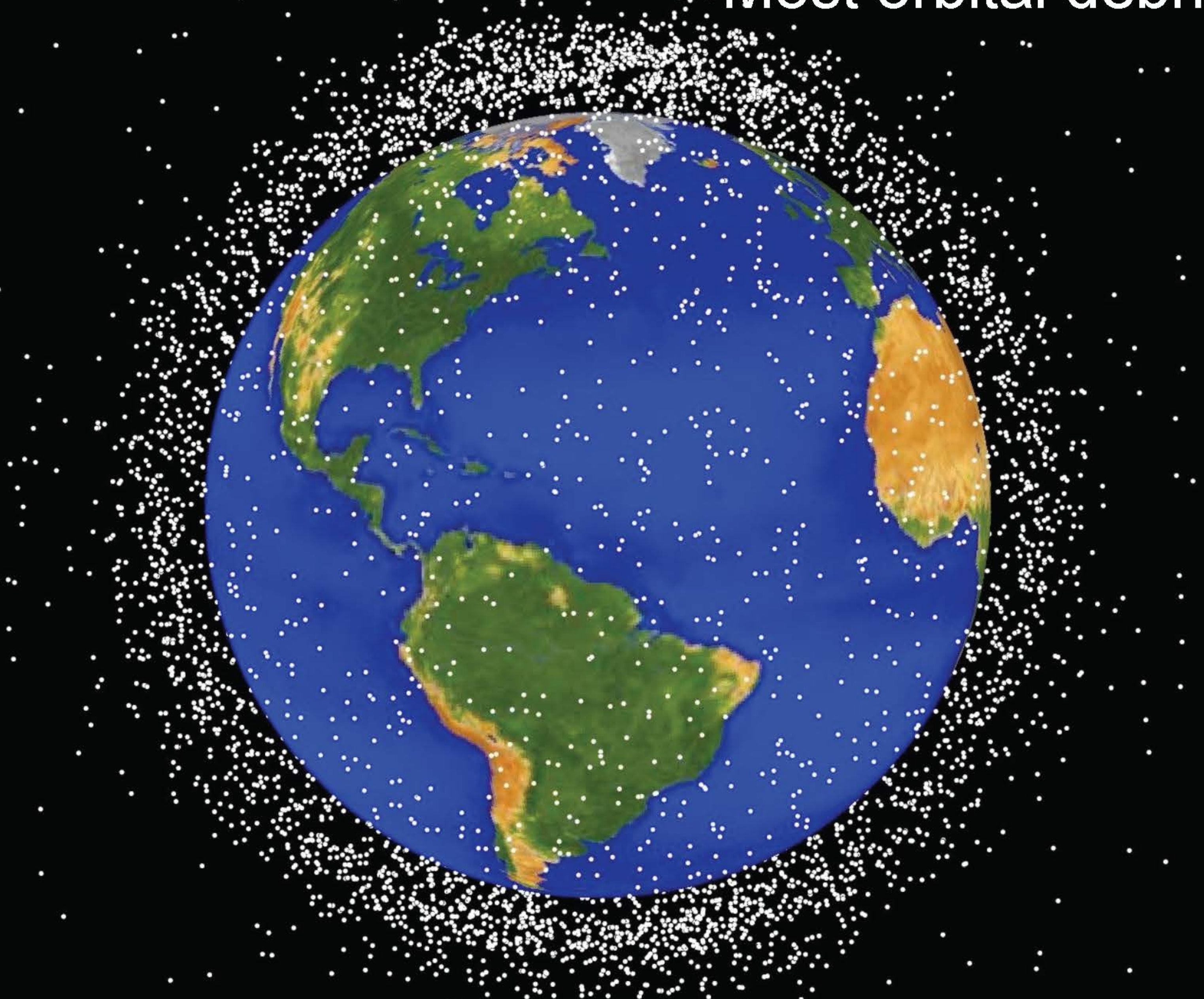
Orbital debris

- Any man-made junk in orbit
- Whole defunct satellites, parts of spacecraft, launch vehicles, fragmentation debris
- 29,000 pieces > 10 cm diameter (they are tracked)
- 750,000 pieces 1 - 10 cm diameter
- 150 Mill pieces 0.1 - 1 cm , particularly very small pieces that cannot be tracked ➔ greatest risk to space missions
- Only a few satellite to satellite disasters so far
  - 2009: Russian military satellite – Iridium

    2200 pieces were generated (tracked)

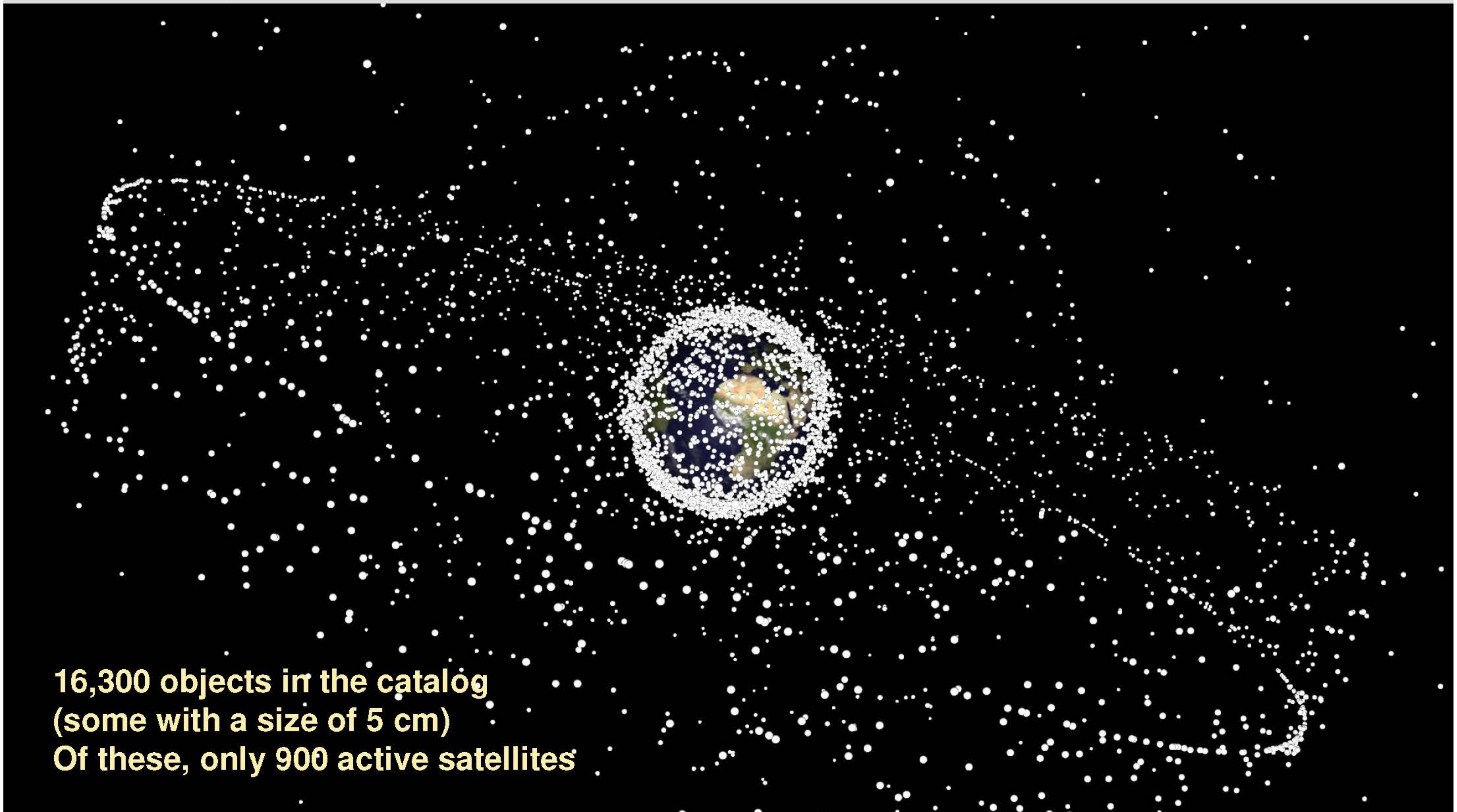
YORK UNIVERSITÉ UNIVERSITY

Most orbital debris in LEO

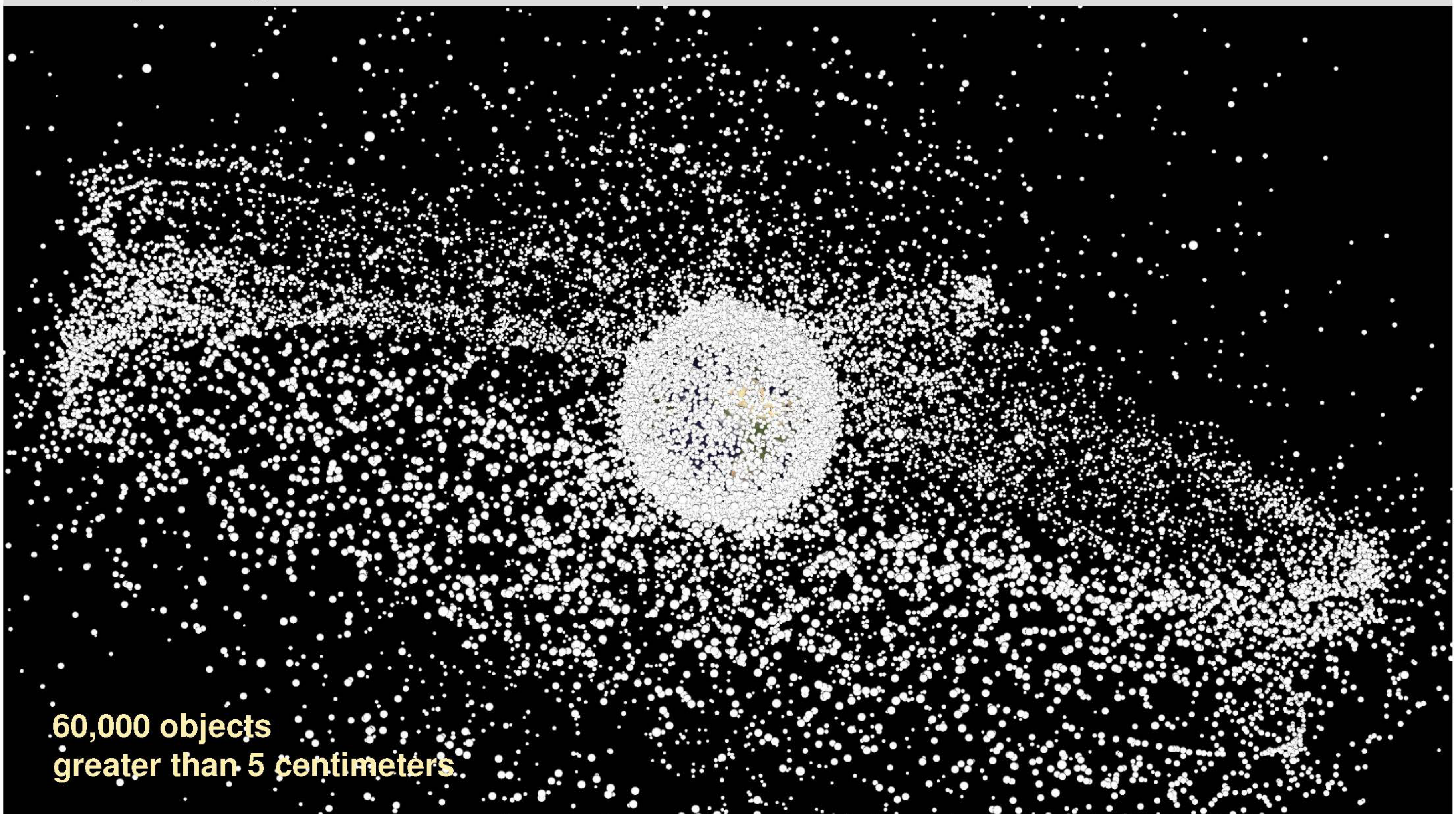


https://www.nasa.gov/mission_pages/station/news/orbital_debris.html

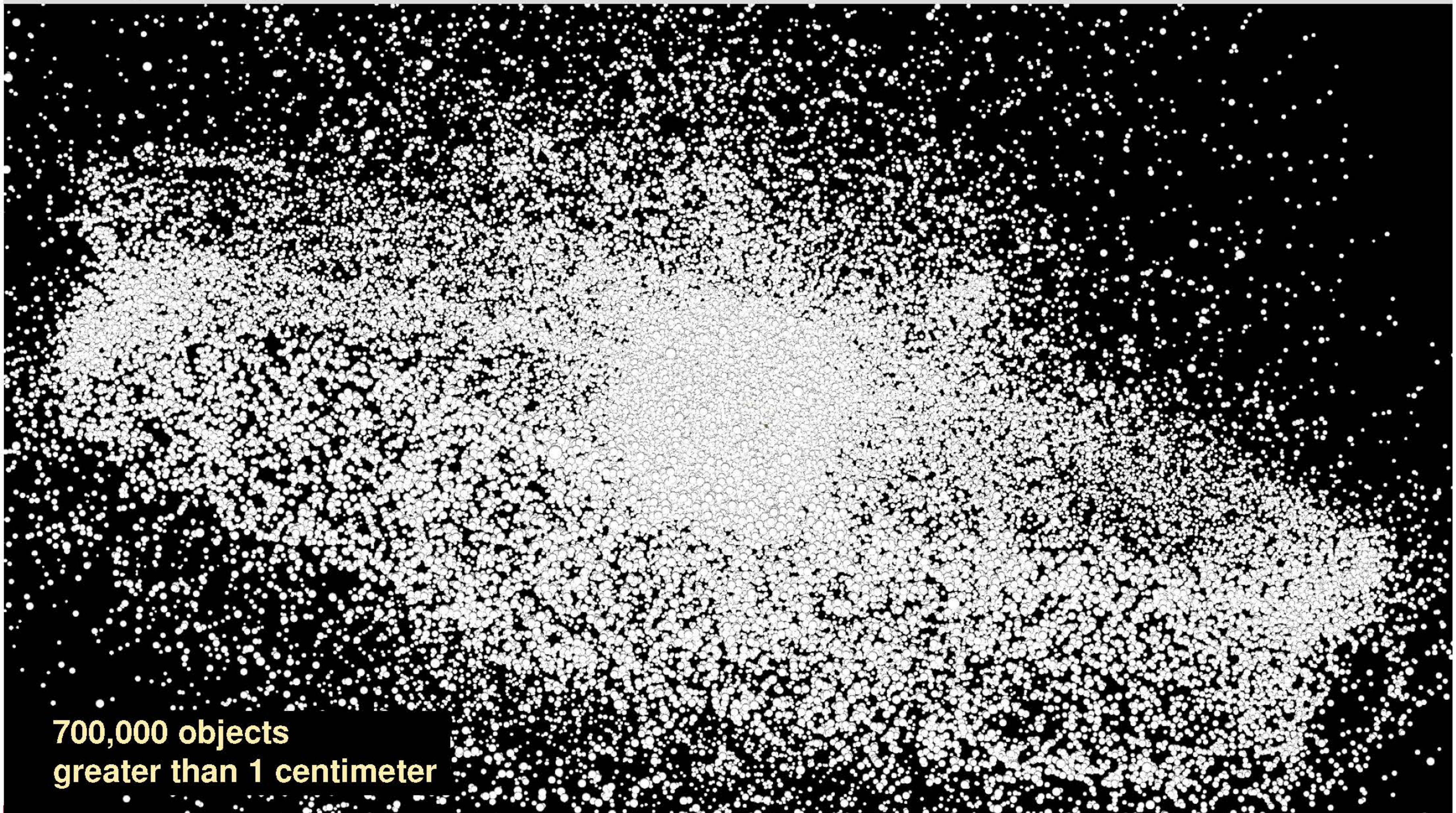
Catalog


16,300 objects in the catalog
(some with a size of 5 cm)
Of these, only 900 active satellites

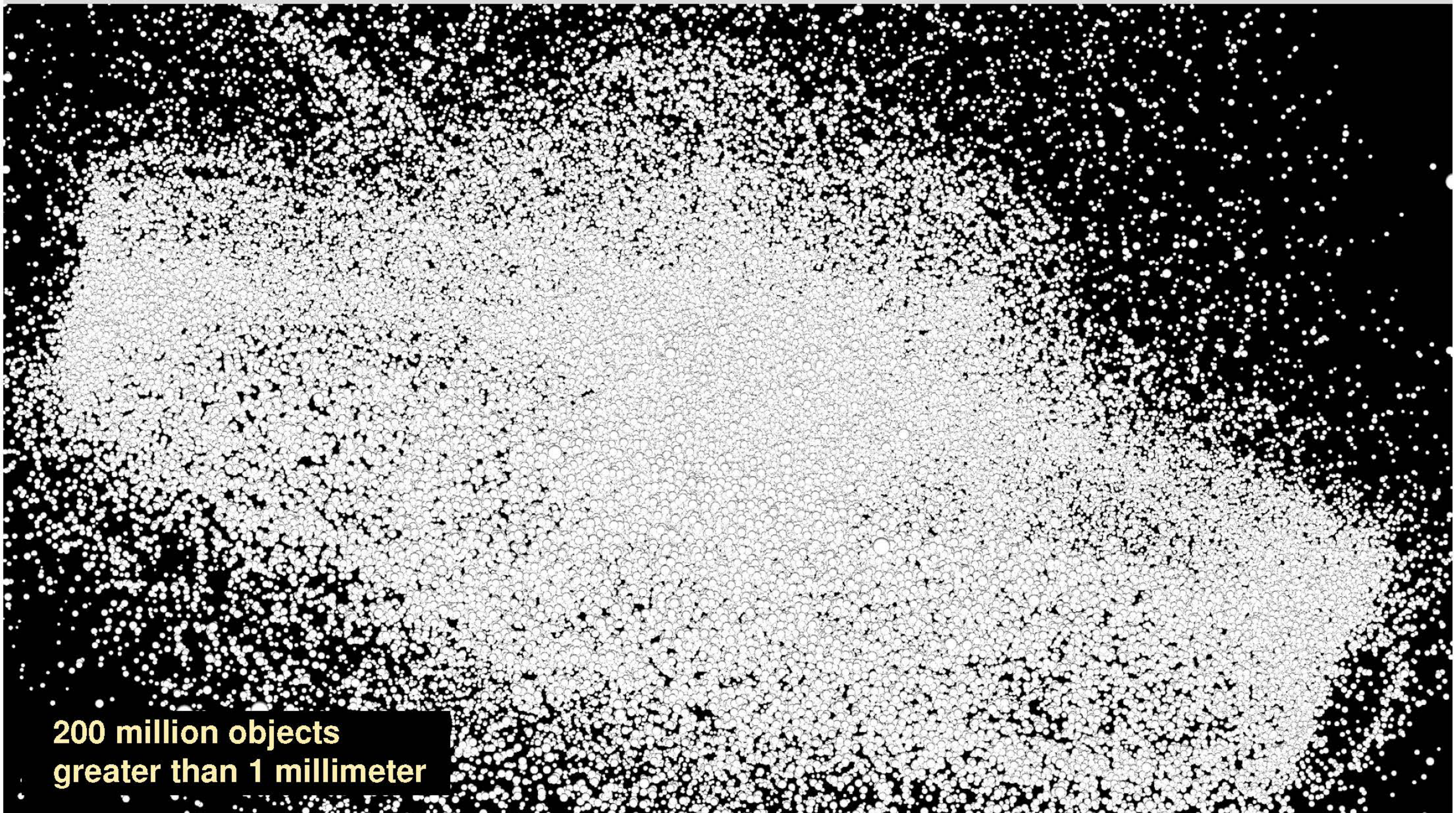
Objects greater than 5 cm



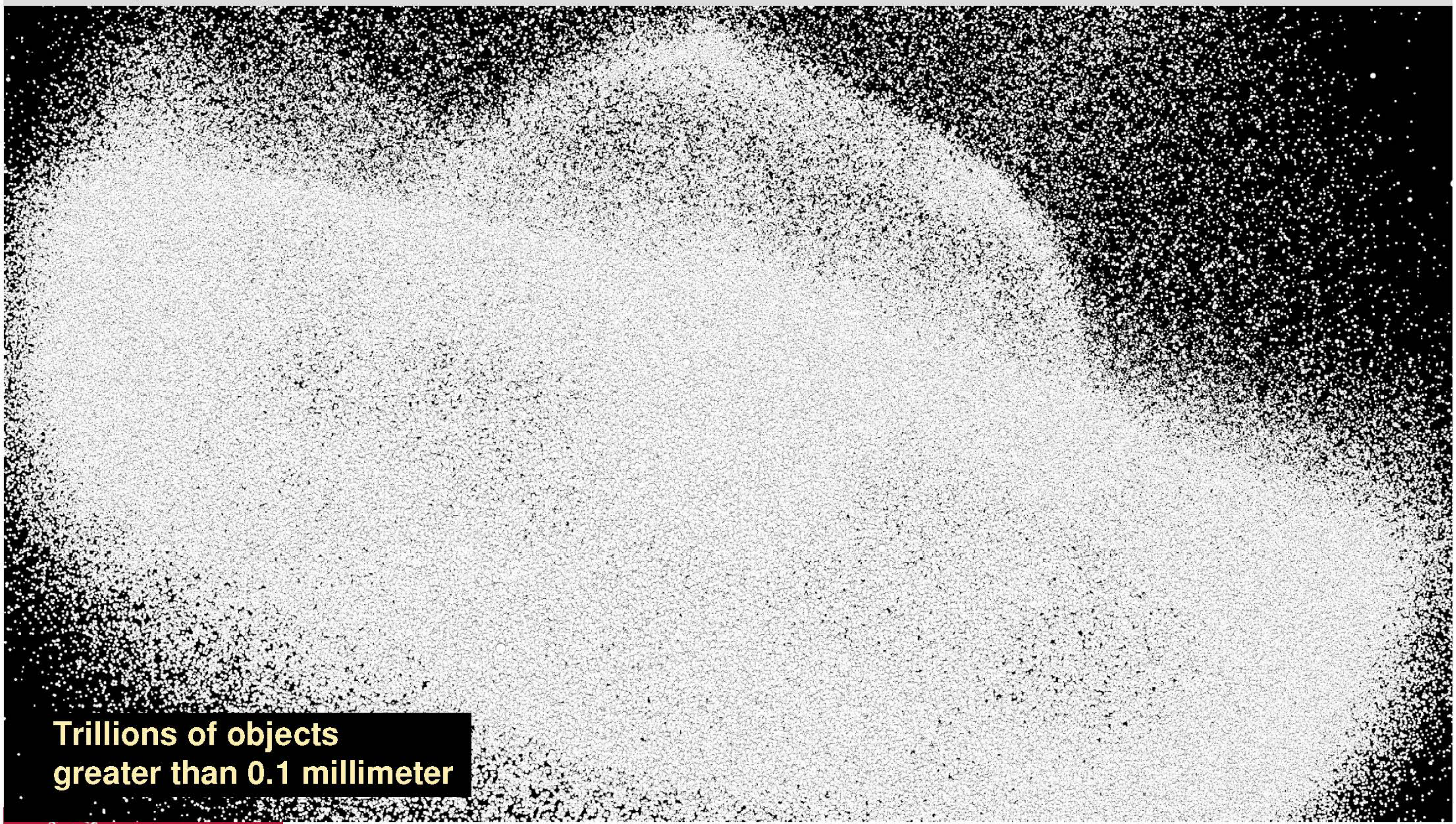
Objects greater than 1 cm



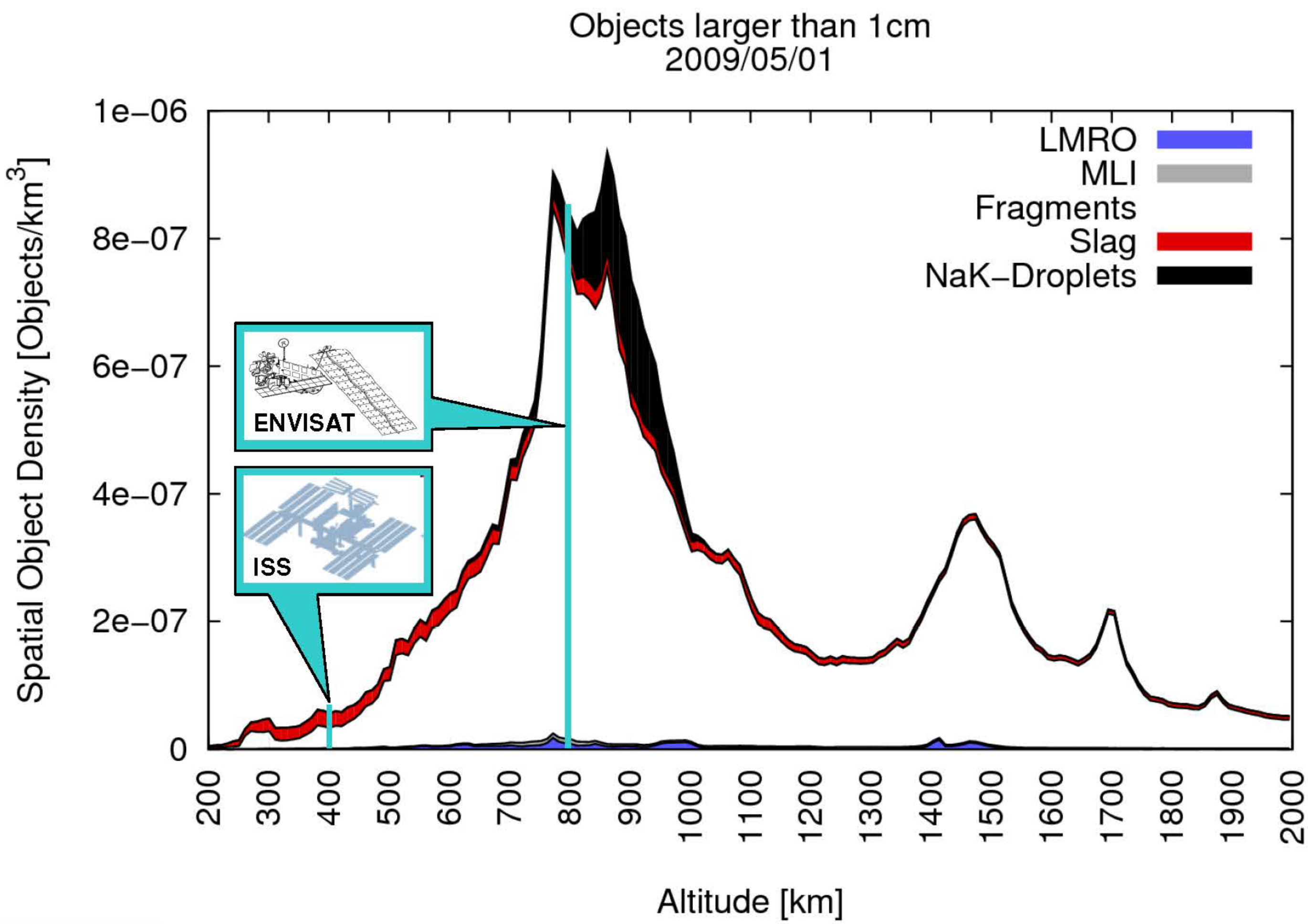
Objects greater than 1 mm



Objects greater than one tenth of a millimeter

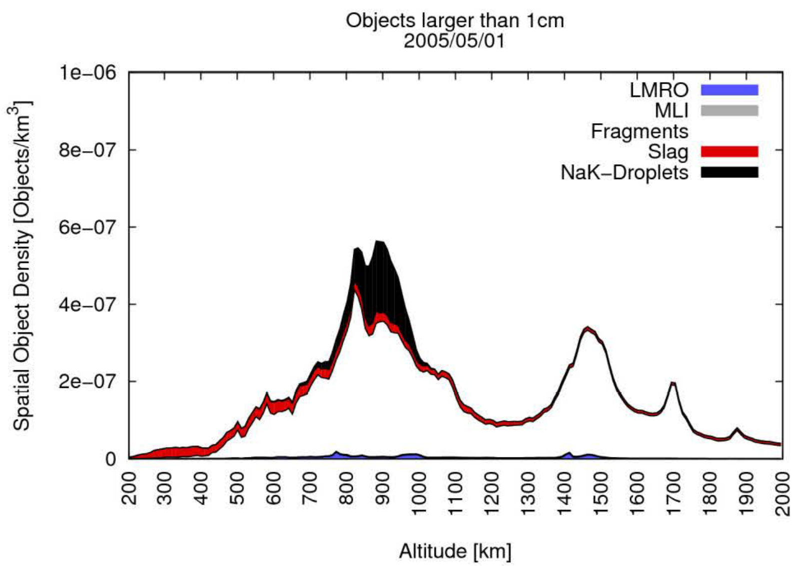


Spatial Density (2009)

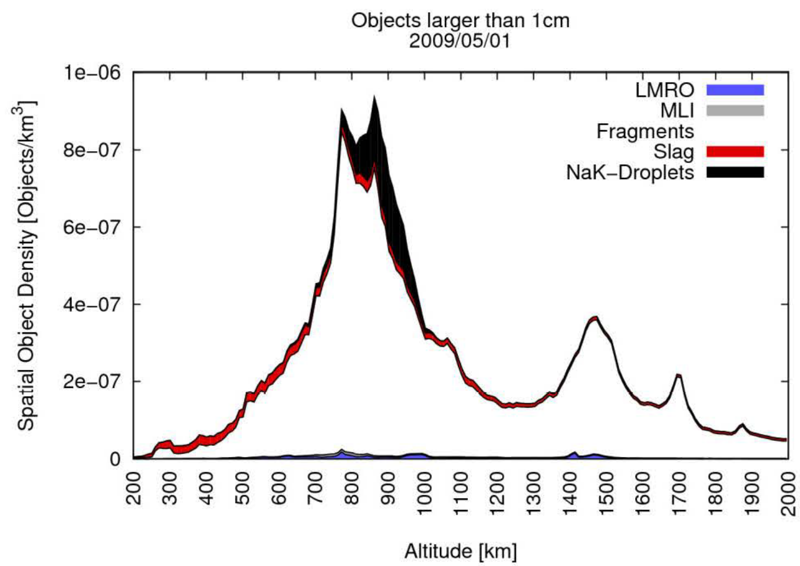


Spatial Density

Spatial density of debris larger than one centimeter according to MASTER-2009



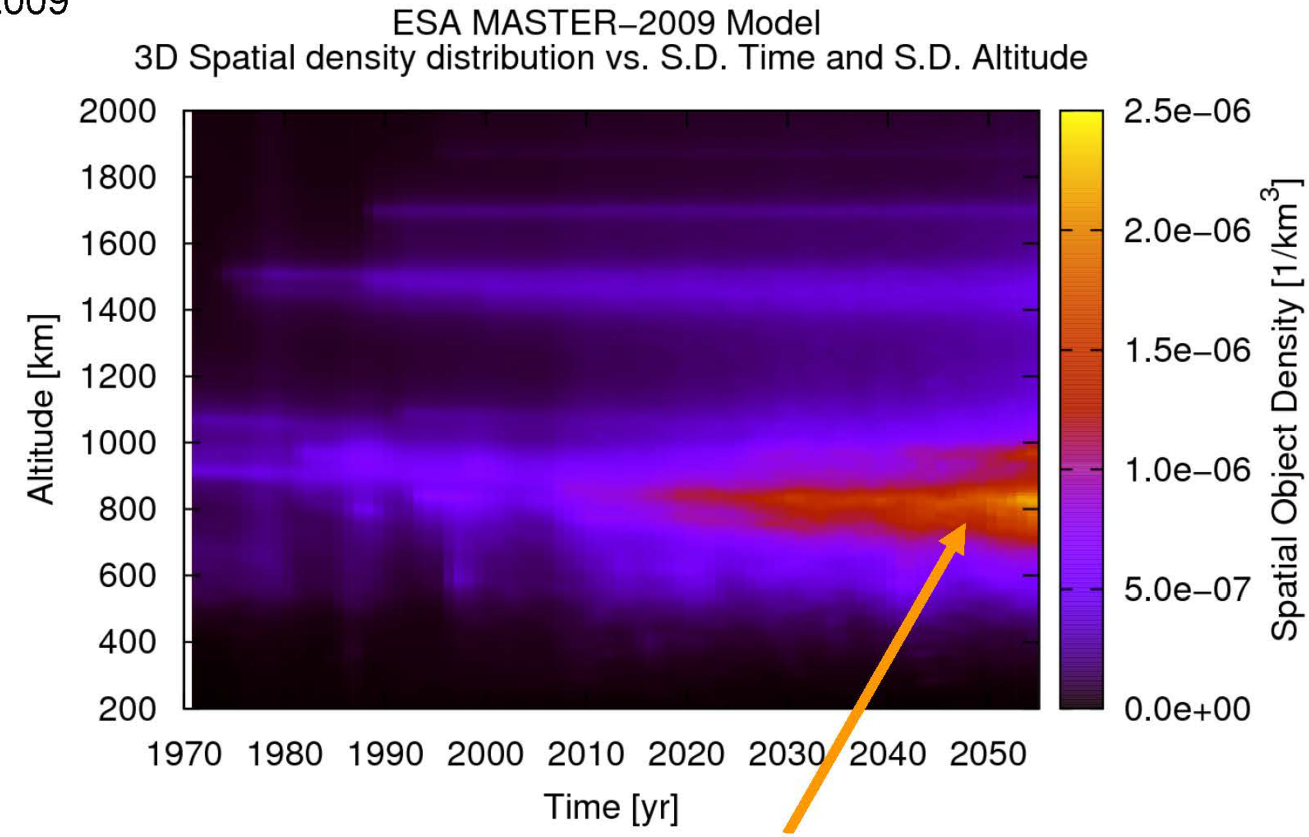
2005



2009

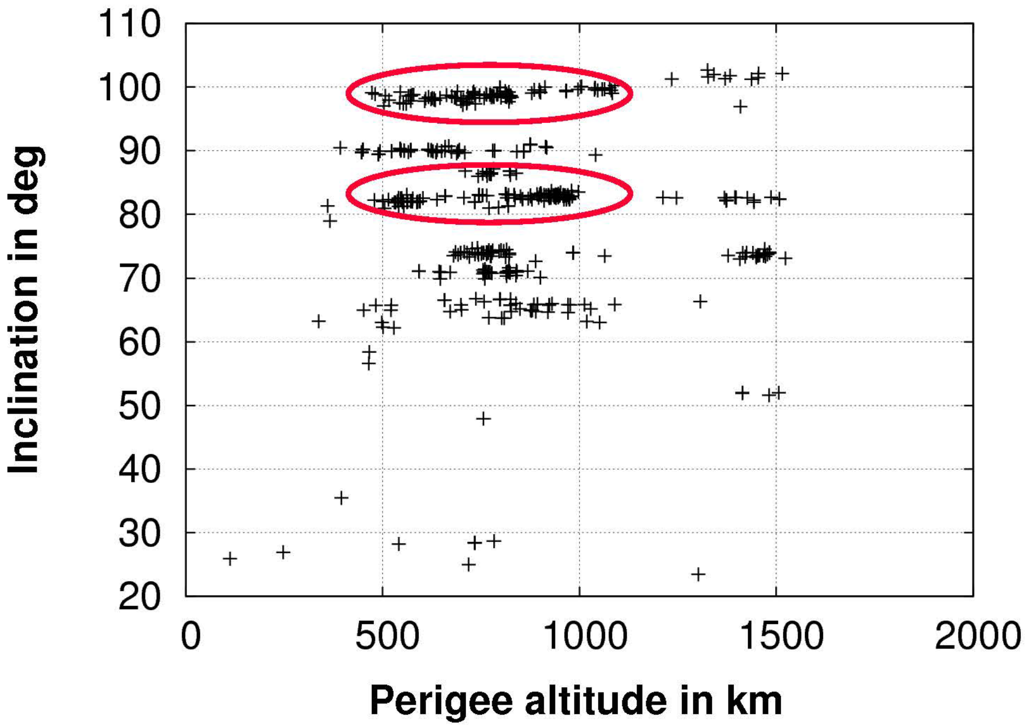
Instability of the LEO Population

Spatial density of objects larger than one centimeter versus time on LEO according to MASTER-2009

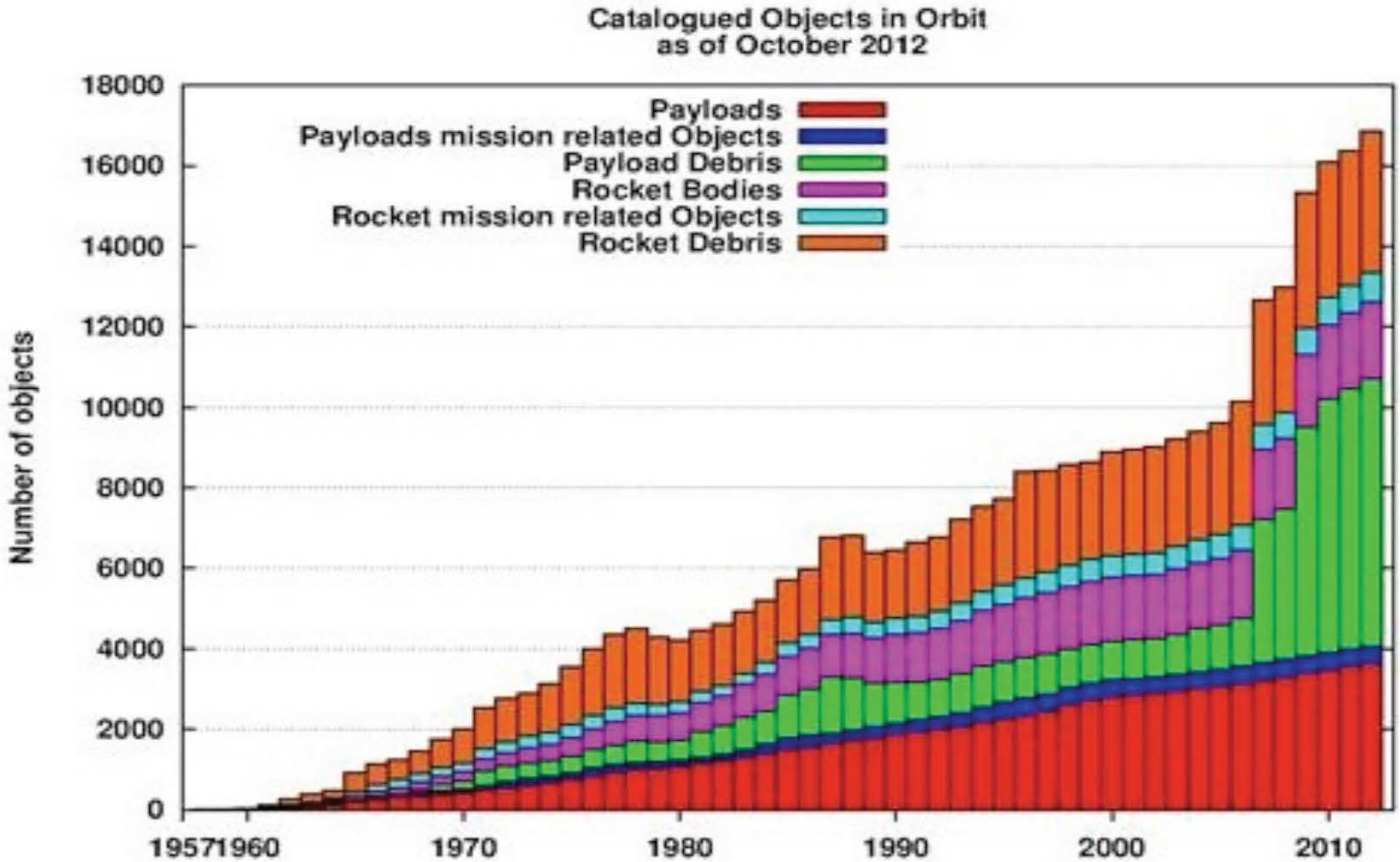


Increasing threat for the orbits used by Earth observation satellites

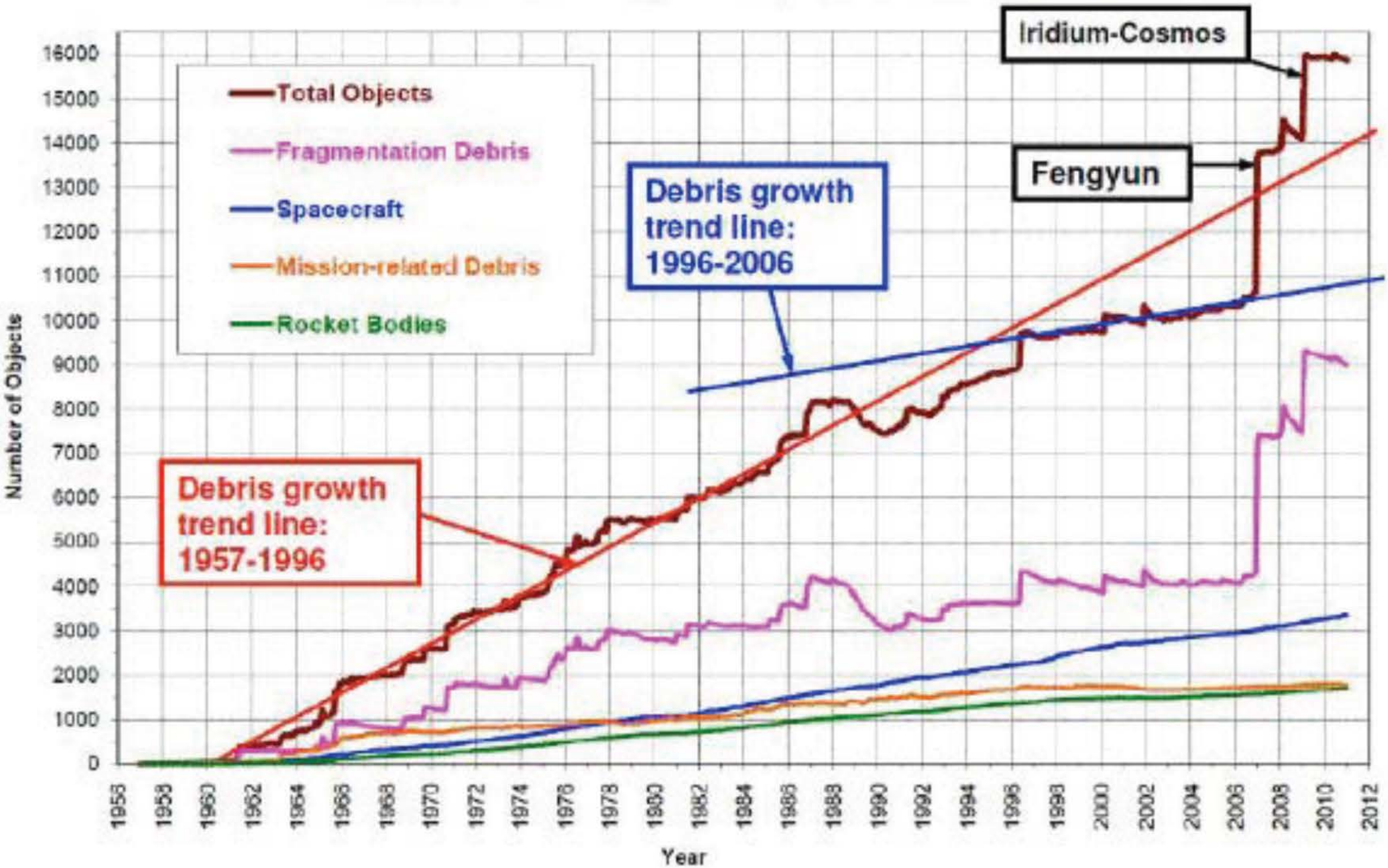
Which satellites are most likely to collide?



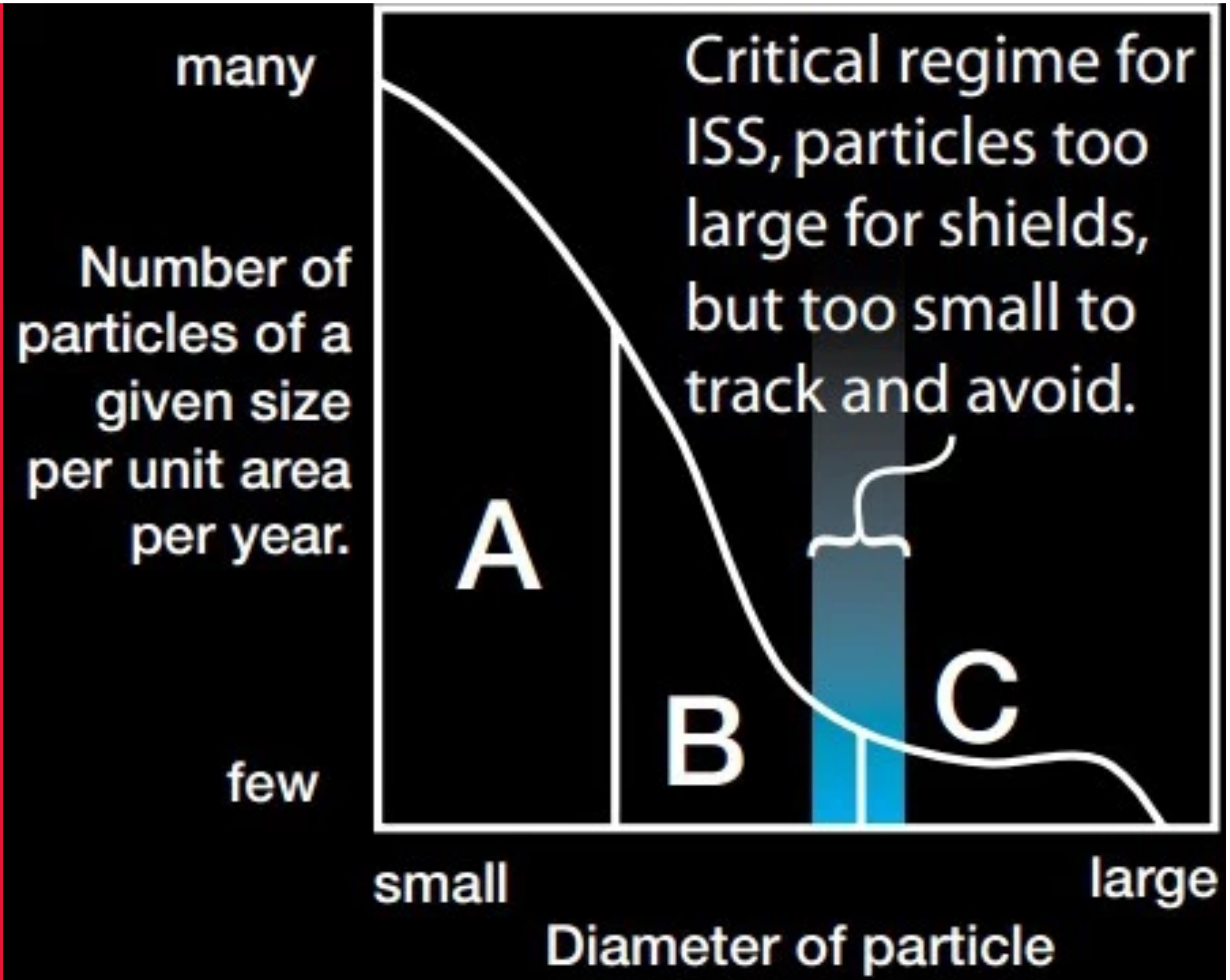
Collisions will mainly occur between sun-synchronous satellites ($i \approx 98°$) and objects at $i \approx 82°$. Basically head-on collisions with twice the orbital velocity!



http://www.esa.int/spaceinimages/Images/2013/04/Composition_of_debris_objects



Adopted from Newland



A Pressure shell penetrations unlikely

B Possible penetrations that can be mitigated with shields

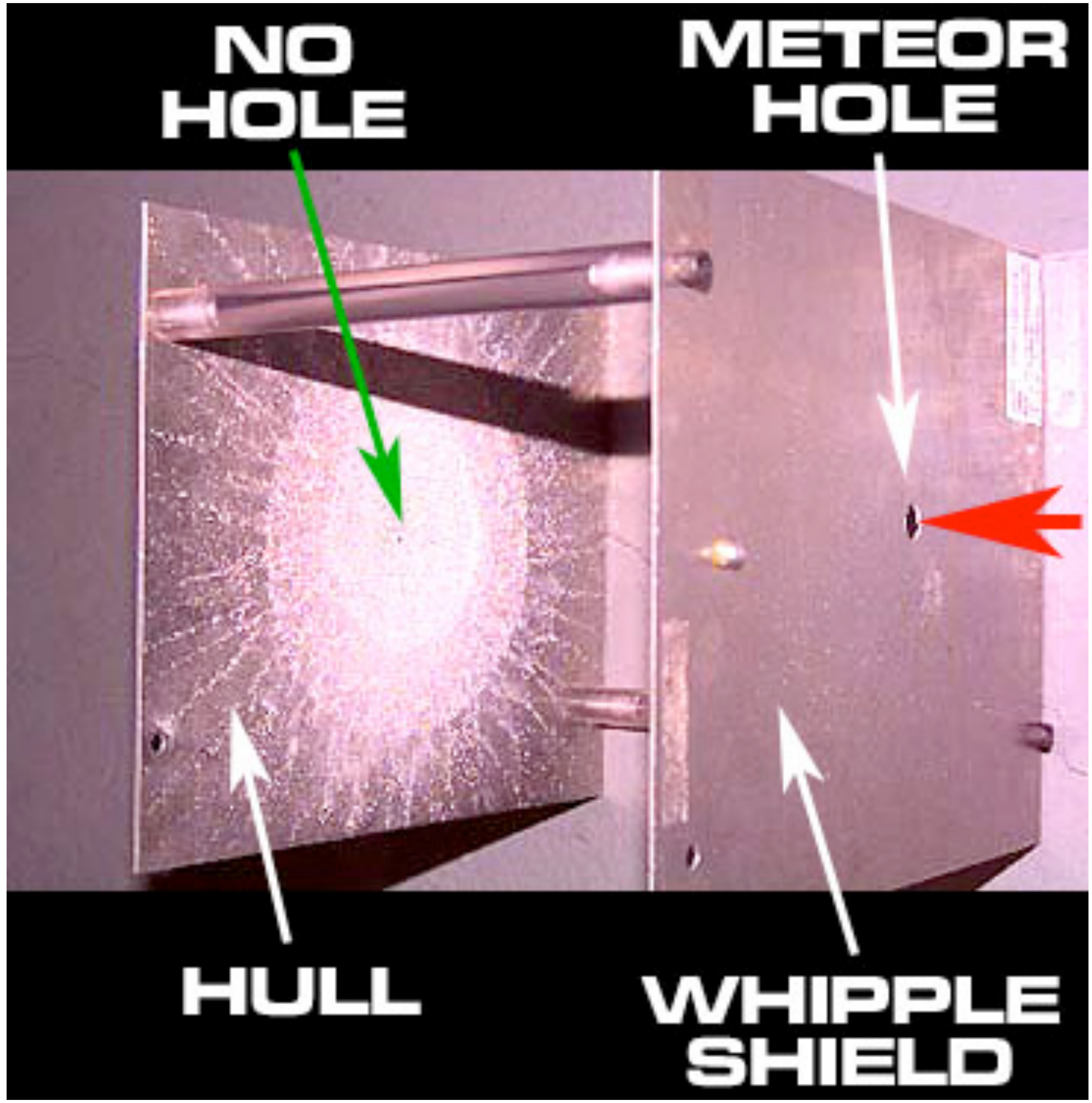
C Larger debris is tracked and ISS is maneuvered out of impact path

Adopted from Newland

Whipple shield

It is an extra wall outside the Pressure hall

More protection
The larger the spacing

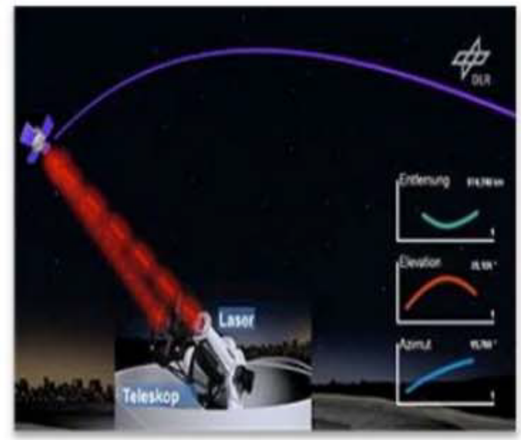


http://livedoor.blogimg.jp/drazuli/imgs/a/c/ac246e63.jpg

Detecting Space Debris

Optical

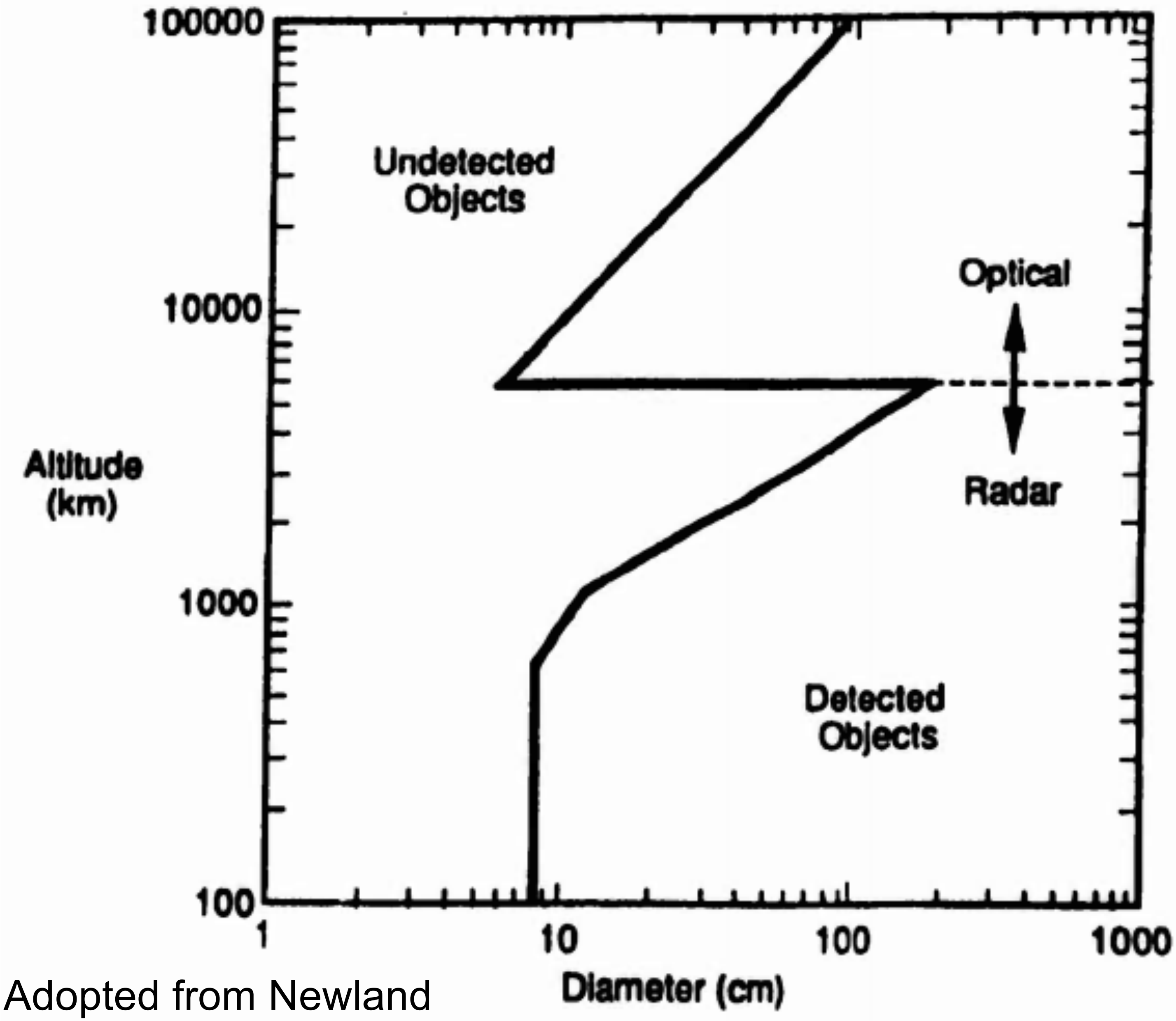
Radar



Laser

Adopted from Newland

Detection



Adopted from Newland

$$\frac{S}{N} \propto \frac{1}{R^2}$$

$$\frac{S}{N} \propto \frac{1}{R^4}$$

Optical techniques

- A 1-meter diameter telescope in darkness can theoretically detect a sunlit metal sphere 1 cm in diameter at 900-km distance.
  - Unfortunately, most debris fragments reflect much less light than a metal sphere; typically only about 10 percent of the light is reflected.
  - In addition, objects in LEO have angular velocities of at least 0.5 degree per second when viewed from the ground, which further increases the difficulty of optical detection.
  - Finally, there can be difficulty in discriminating between debris and the luminosity caused by meteors interacting with the atmosphere. Theoretically, this last problem can be solved completely by using two telescopes and determining the object's altitude with the measured parallax, or solved partially by using the object's angular velocity to approximate its altitude.
- Despite these drawbacks, ground-based telescopes engaged in sampling have provided some valuable information on the LEO population of debris around 10 cm in diameter.
- Ground-based telescopes also can be used to sample the space debris population above LEO.

YORK UNIVERSITÉ UNIVERSITY

Adopted from Newland

Haystack observatory, MA, USA

NASA’s primary radar for
detecting space debris

Radar sampling

- Short-wavelength ground-based radars have been used effectively to sample the medium-sized debris population in LEO. Radars sample debris in a "beam park" mode in which the radar stares in a fixed direction (preferably vertically to maximize sensitivity) and debris are counted as it passes through the radar's field of view.
- In 1989, the Arecibo Observatory's high-power 10-cm-wavelength radar and the Goldstone Deep Space Communications Complex's 3-cm-wavelength radar were used (with the assistance of other radars) to obtain orbital debris data. Neither was designed to track debris, but in 18 hours of operation, the Arecibo experiment detected nearly 100 objects larger than an estimated 0.5 cm in diameter and in 48 hours of observation, the Goldstone radar detected about 150 objects larger than approximately 0.2 cm in diameter.
- Since 1987, significant amounts of sampling data have been obtained by using the Arecibo, Goldstone, and Haystack radars. In addition, the longer-wavelength FGAN and MU radars have demonstrated the ability to sample the medium and large debris population.

YORK U
UNIVERSITÉ
UNIVERSITY

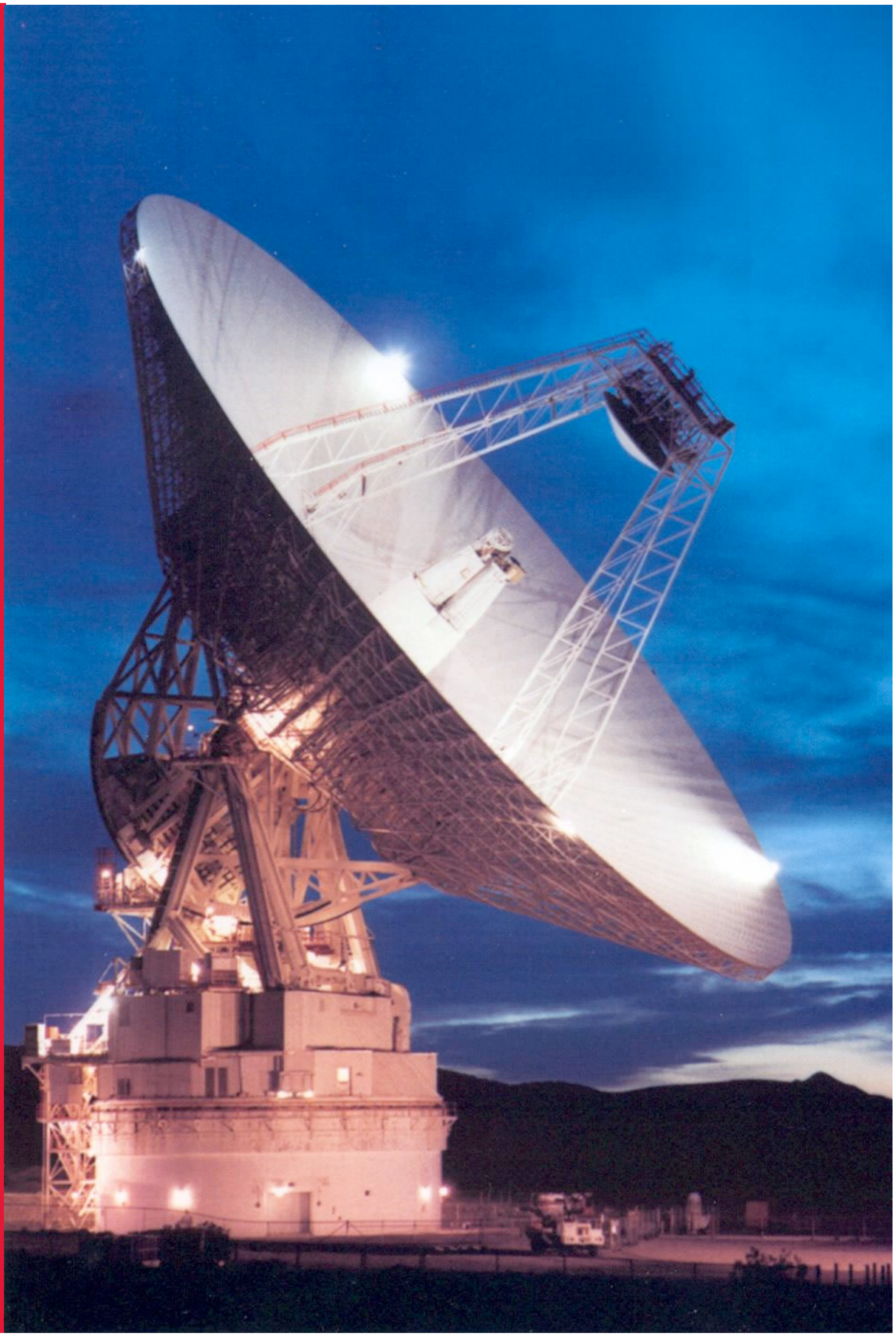
Adopted from Newland

Radar sampling

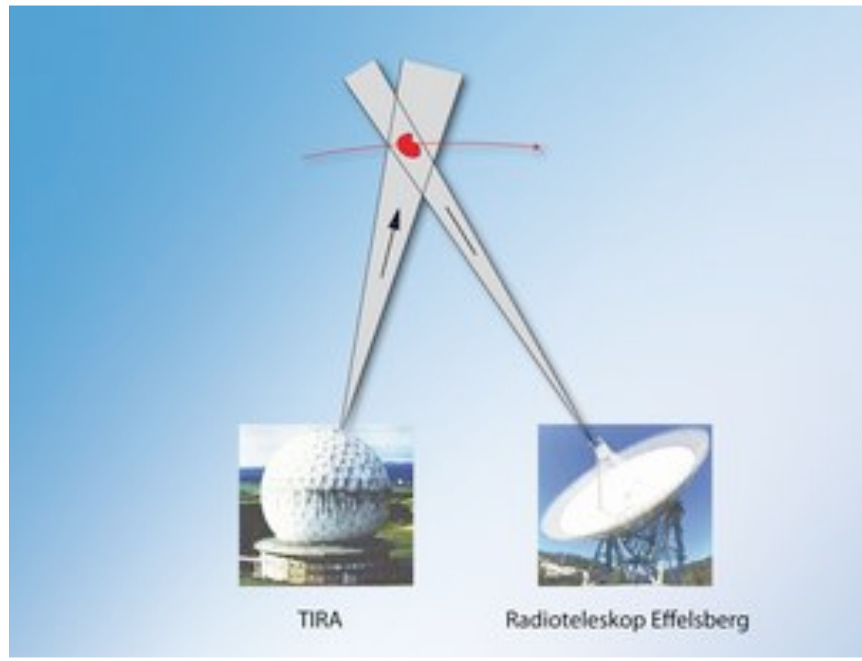
- The complete data set from the Haystack observations contains information on the size, altitude, range rate (the rate of change in the distance from the object to the radar), and direction of motion of debris at altitudes up to 1,500 km.
- The smallest objects detected range from about 0.3 cm at 350 km to 0.7 cm at 1,400 km.
- Most of the radars transmit right circularly polarized radio waves and receive both left and right circularly polarized waves. The polarization of the reflection can be used to infer the general shape of the objects detected.

YORK UNIVERSITÉ UNIVERSITY

Adopted from Newland



When used as bistatic Radar, antenna can detect 2 mm debris up to 1000 km altitude



Impact sampling

- Currently (and for the foreseeable future), space debris particles smaller than a few millimeters in diameter cannot be detected by using Earth-based measurement techniques; effective remote sensing of such particles from orbit may also be infeasible.
- In situ impact techniques, however, can be used to sample this population effectively, characterizing particle sizes and materials as well as orbital distributions and dynamics (although such characterizations can be extremely difficult).
- Such measurements can be performed either passively, by exposing surfaces in orbit and then returning them to Earth for examination, or actively, by using any of a number of techniques ranging from impact detection with simple semiconductor-based sensors to chemical composition analysis of impacting particles with complex sensors.

YORK UNIVERSITÉ UNIVERSITY

Adopted from Newland

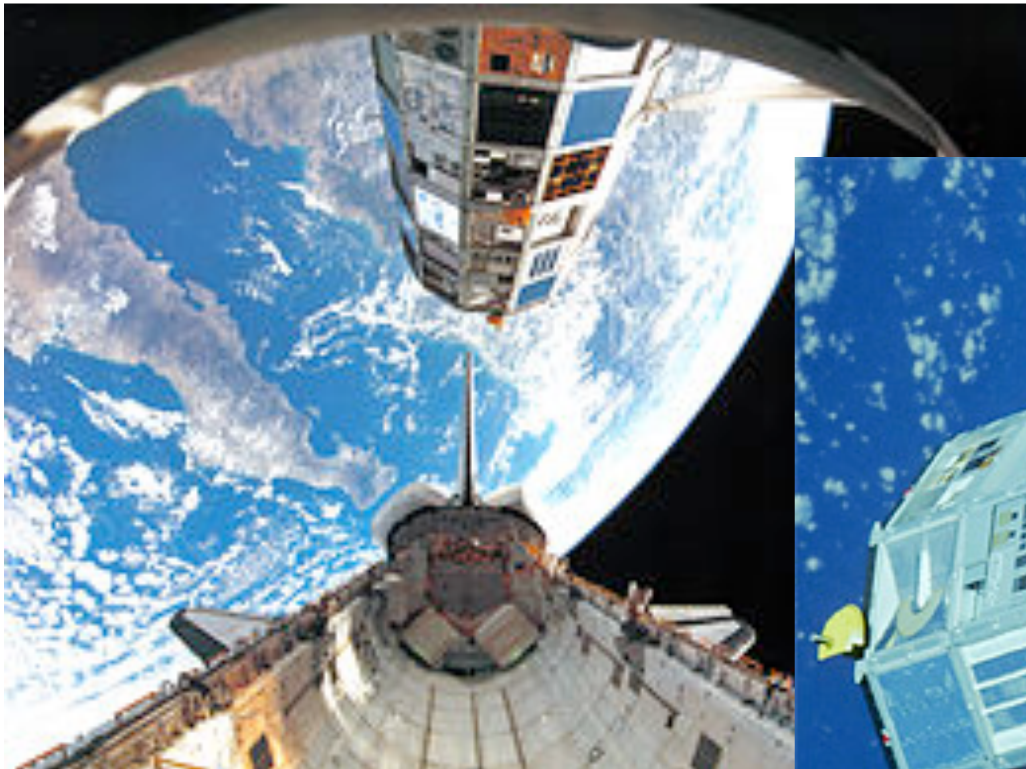
Comparison of systems

- Note that with optical systems, the signal decreases as a function of the range squared, not as a function of the range to the fourth power as it does with radars.
- This makes optical systems more sensitive at longer ranges. Another consideration is the angular rate that the object image crosses the detector. For non-tracking telescopes where the telescope is not locked on to the object's motion, the image is spread over several pixels, thus decreasing the available signal for discrimination against the background level

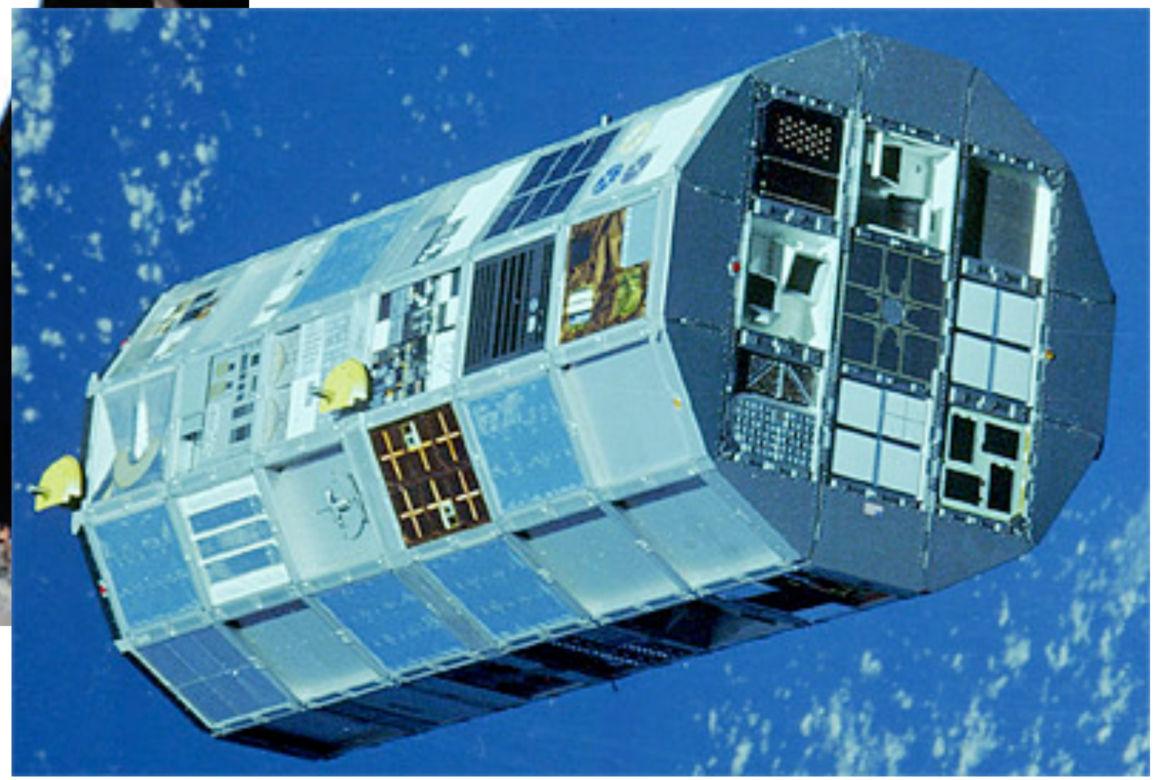
YORK UNIVERSITÉ UNIVERSITY

Adopted from Newland

Long duration exposure facility



1984 to 1990



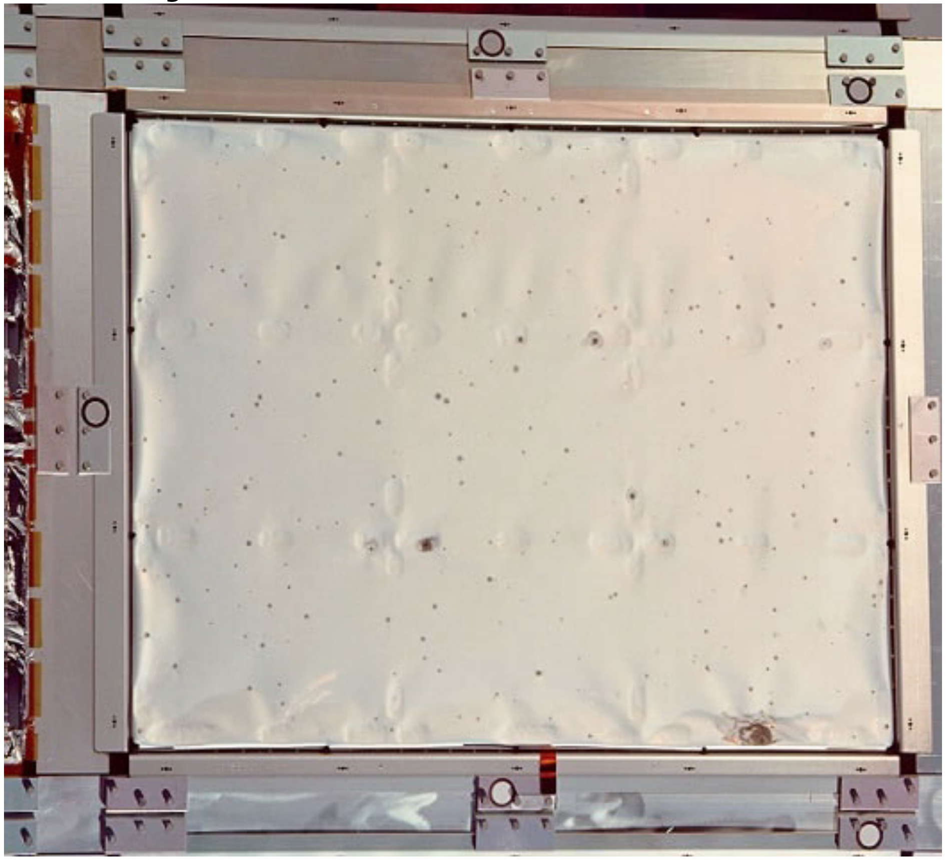
NASA

Purpose:
Characterization of orbital debris and meteoroid environment in LEO

YORK UNIVERSITÉ UNIVERSITY

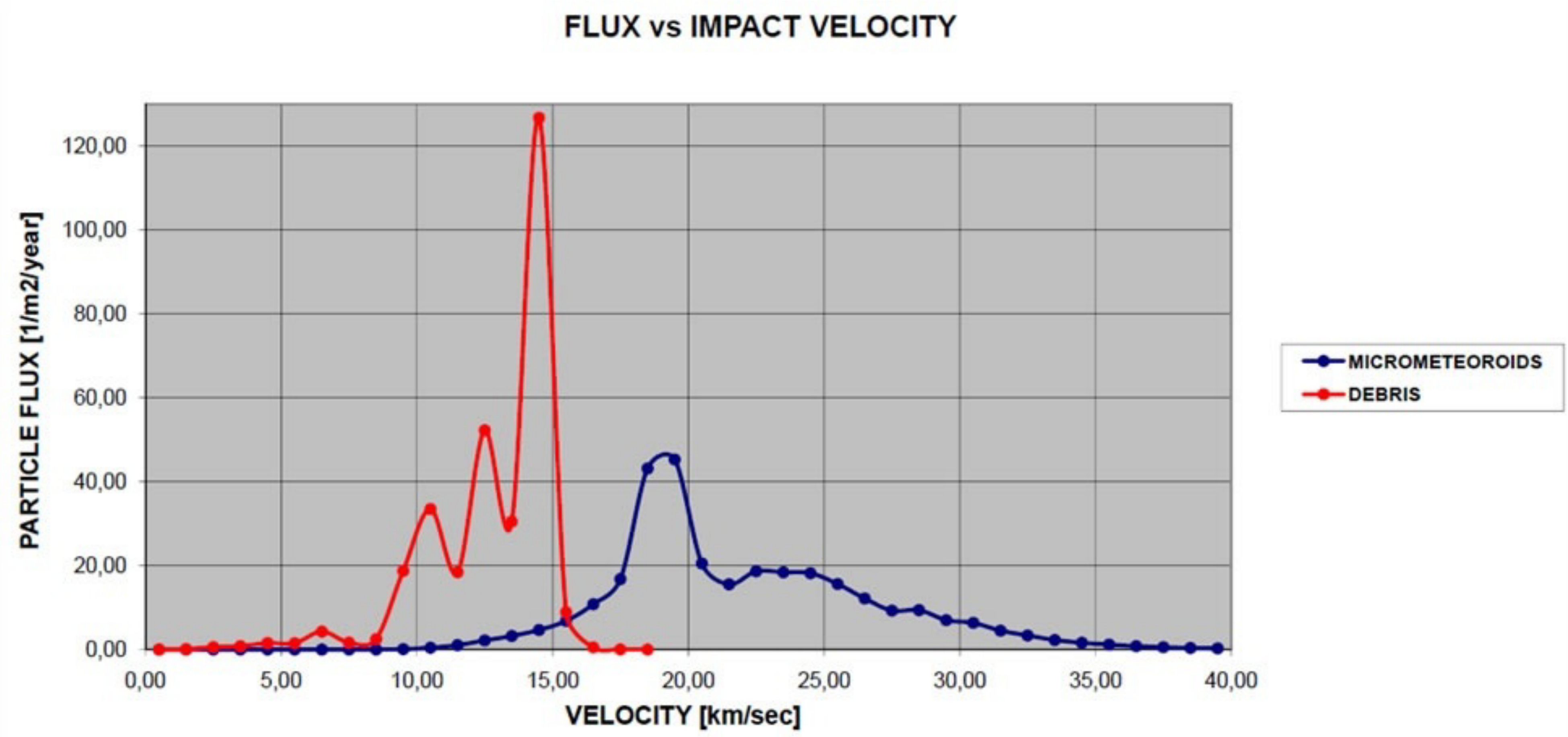
LDEF results

- ~ 15,000 impacts were found
- 30% from man-made objects
- 70% from natural objects



NASA

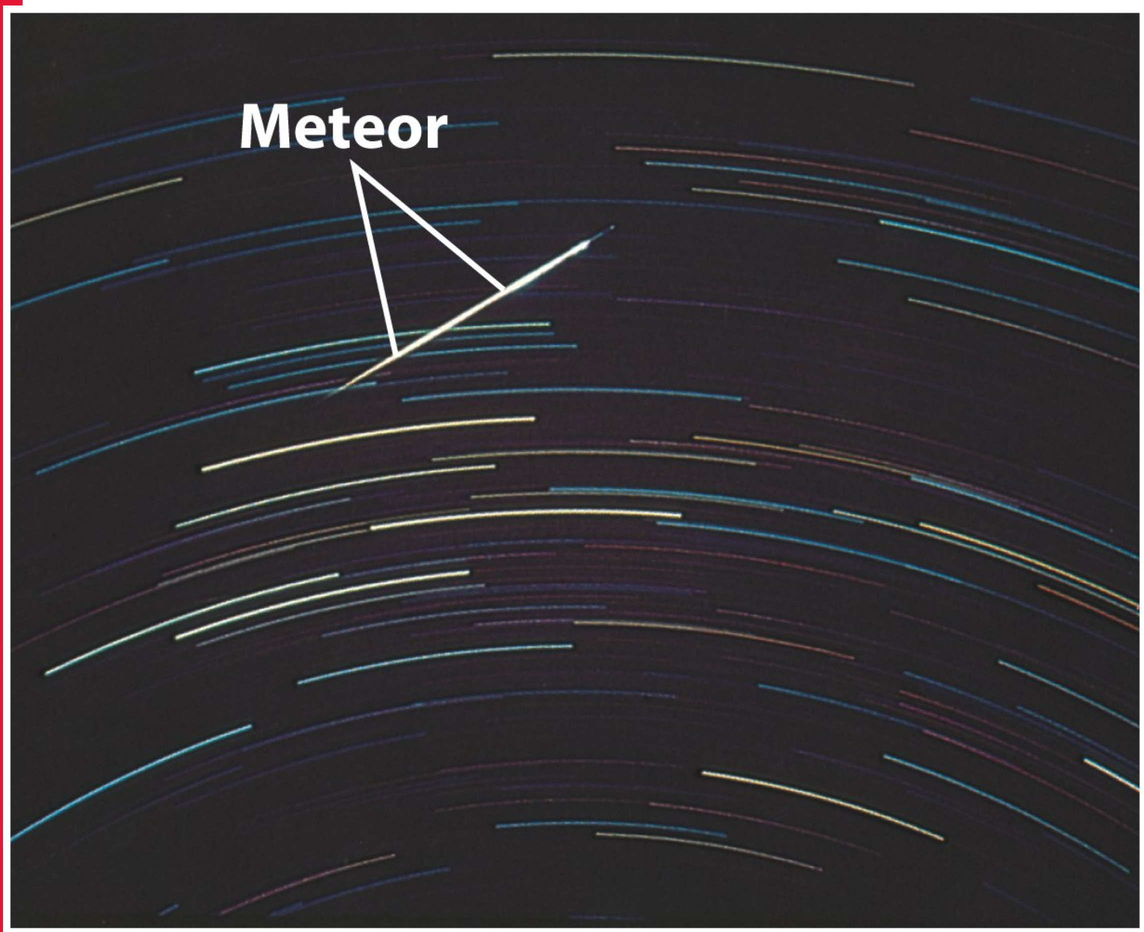
LDEF statistics



NASA

Terminology

Small rocks in space are called meteoroids



- If a meteoroid enters the Earth's atmosphere, it produces a fiery trail called a meteor
- If part of the object survives the fall, the fragment that reaches the Earth's surface is called a meteorite

An astronaut image of a Perseid meteor over Earth.

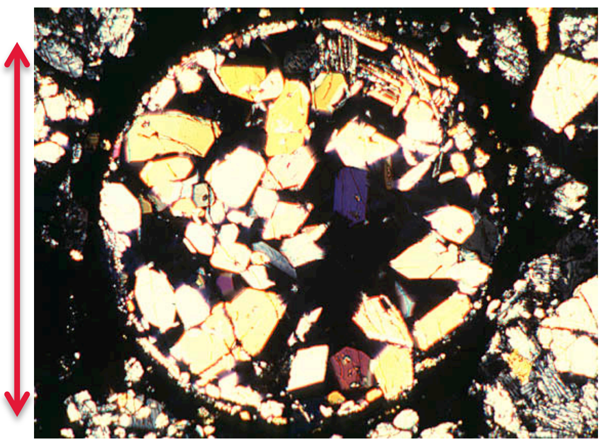
https://solarsystem.nasa.gov/planets/meteors/indepth

YORK UNIVERSITÉ UNIVERSITY


Perseid meteor and the Milky Way in Borrego
Springs, California.

Meteorite classification

- Stones (like rocks on Earth)
  - Chondrites composed of chondrules. These are small spheres formed by rapid melting and subsequent rapid cooling. Radiometric age: 4.6 Bill. Years.
  - Achondrites – same minerals but chondrules destroyed because of later heating and melting and recrystallization.



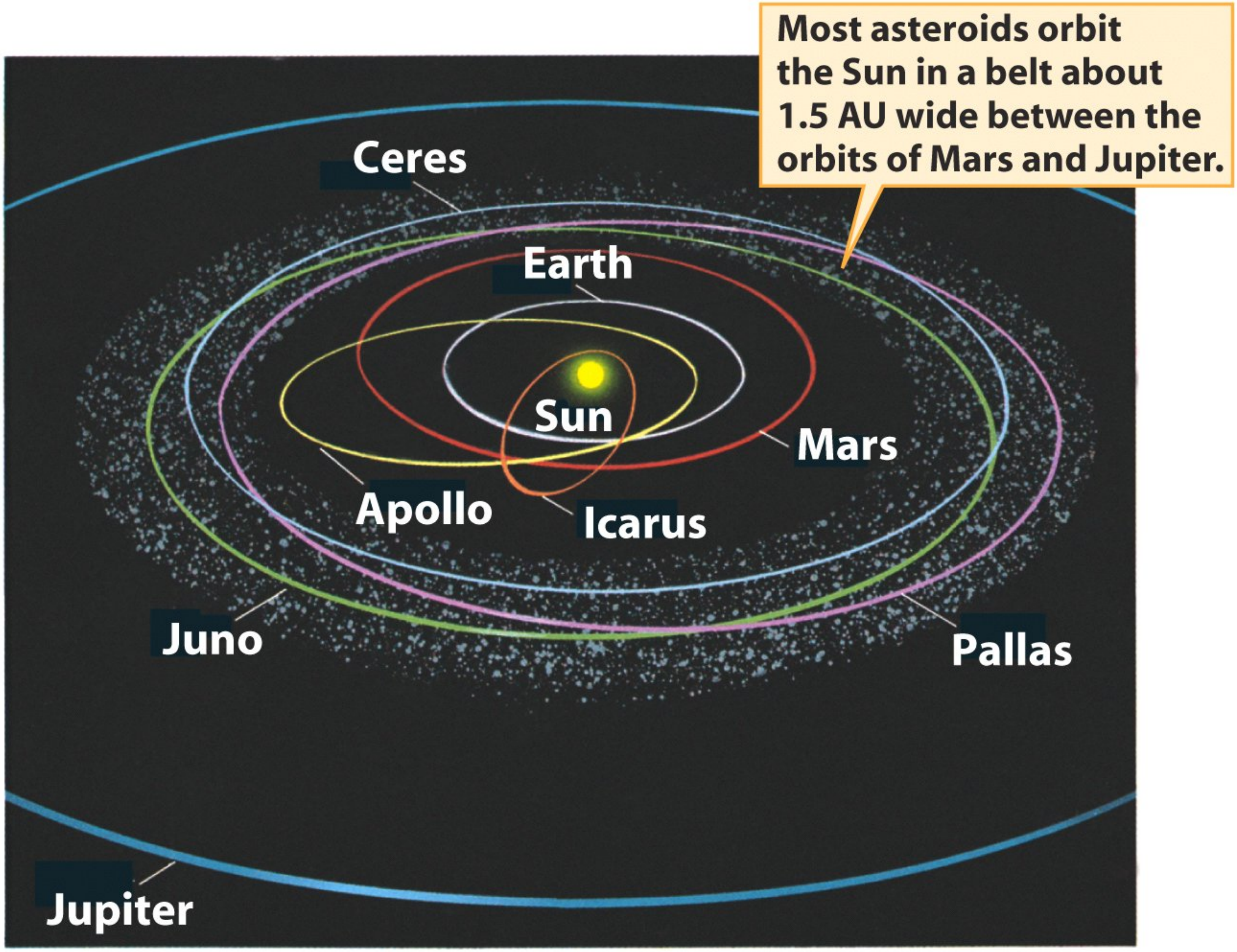
- Irons (alloys of iron and nickel)
- Stony irons (stony silicates mixed with iron)

Image: http://www.lpi.usra.edu/science/kring/epo_web/meteorites/chondrule.html

Origin of meteorites

- Asteroids
  - Collisions made fragments that found their way toward Earth
- Comets
  - Fragments and dust left behind – Earth crosses path
- Moon, Mars
  - Crustal rocks were catapulted into space when another object collided with Moon or Mars

Asteroid belt



N. F. Comins, Freedman

- Astronomers first discovered the asteroids while searching for a “missing planet”
- 100,000’s of rocky irregularly shaped and cratered bodies orbit the Sun between Mars and Jupiter.
- 4000 asteroids are catalogued and their orbits are known.
- The largest asteroids are Ceres (1000 km diameter), Juno and Pallas.
- Some, called Appollo objects, have orbital paths that cross Earth’s orbital path.
- Objects coming close to Earth are called Near Earth Objects (NEOs)
- ~150 NEO’s (1 to 8 km diameter) are known. They have unstable orbits and eventually will collide with Earth.

Giant asteroid 4-Vesta

Diameter 525 m

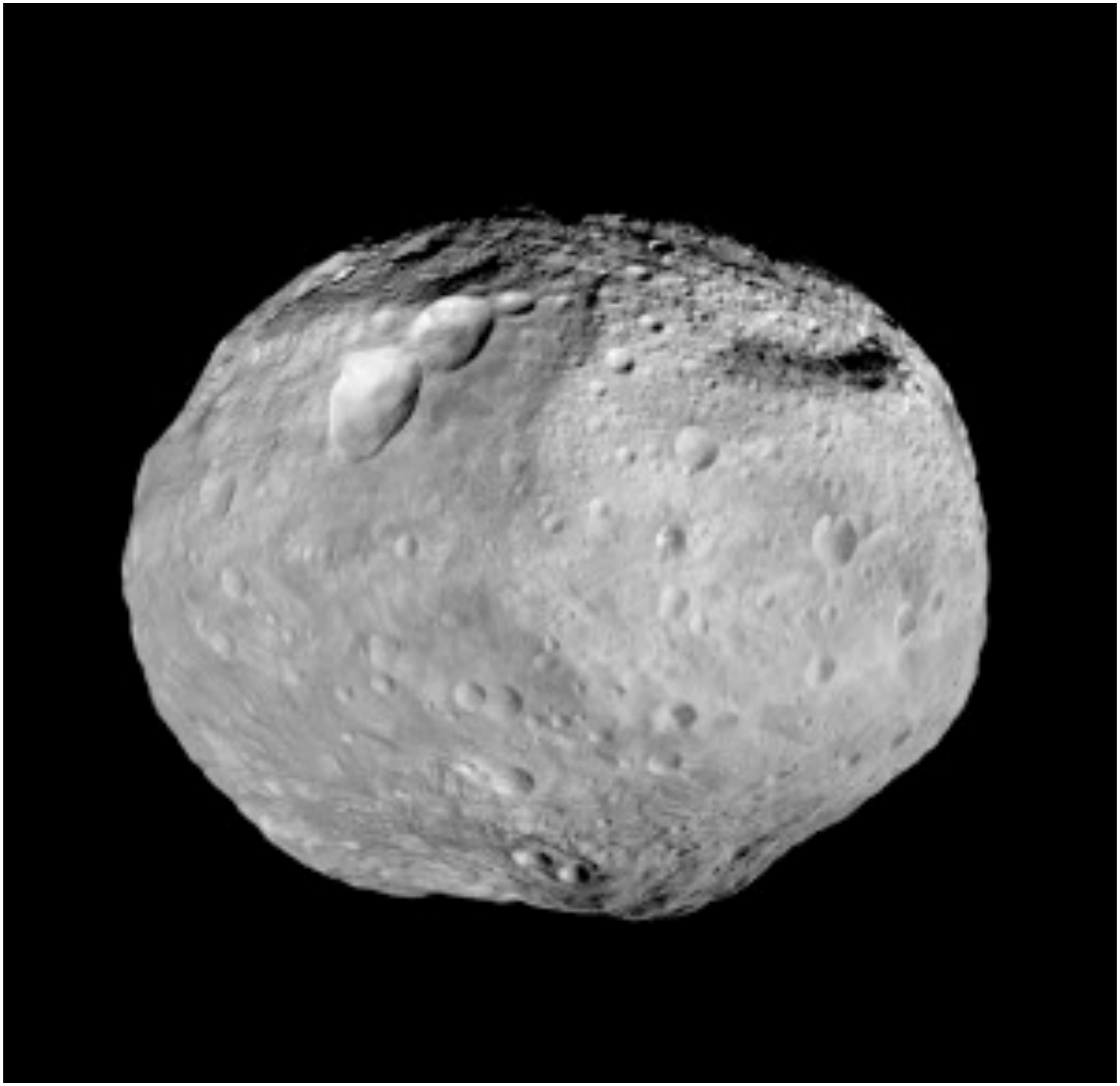
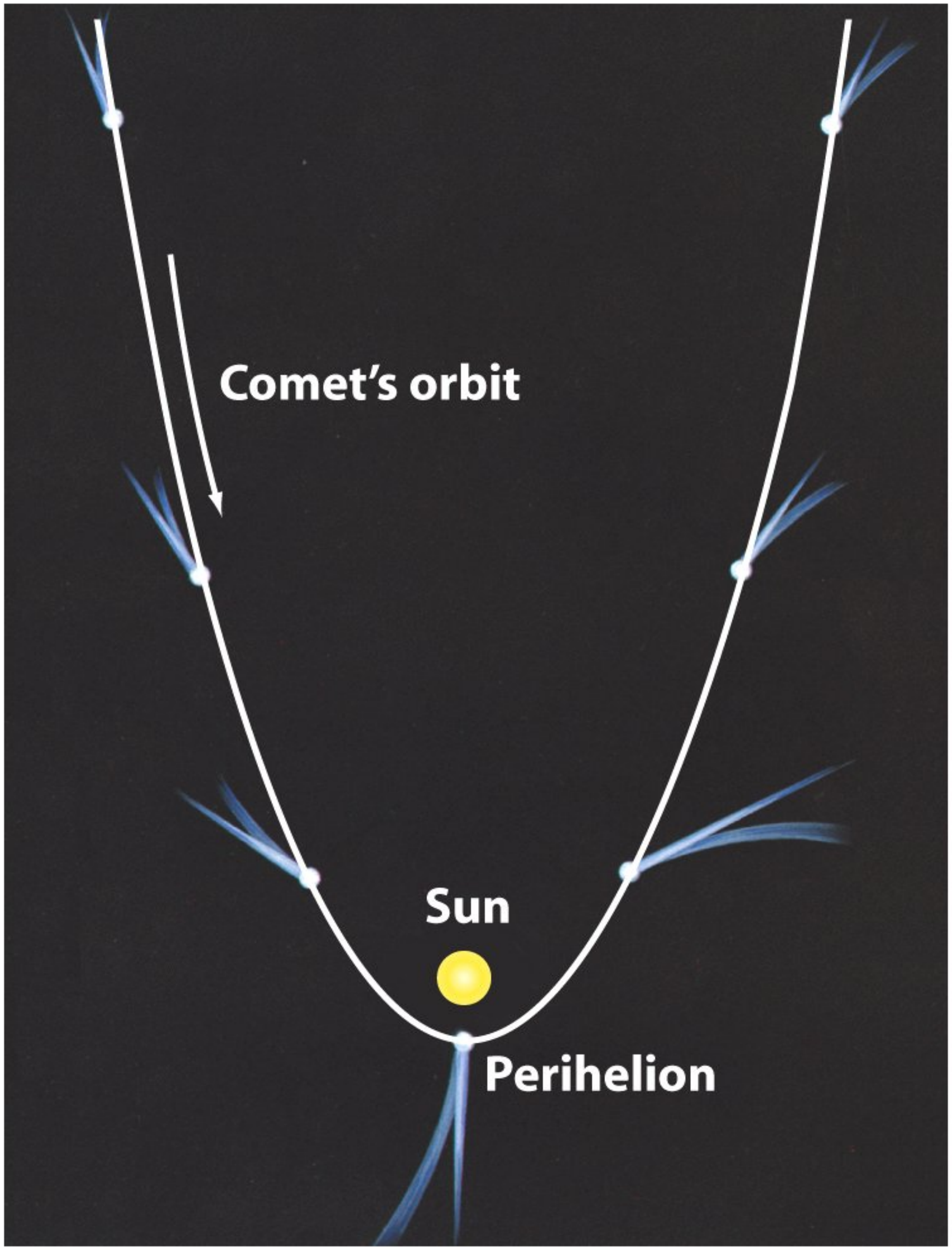


Image credit: NASA/JPL-Caltech/UCAL/MPS/DLR/IDA).



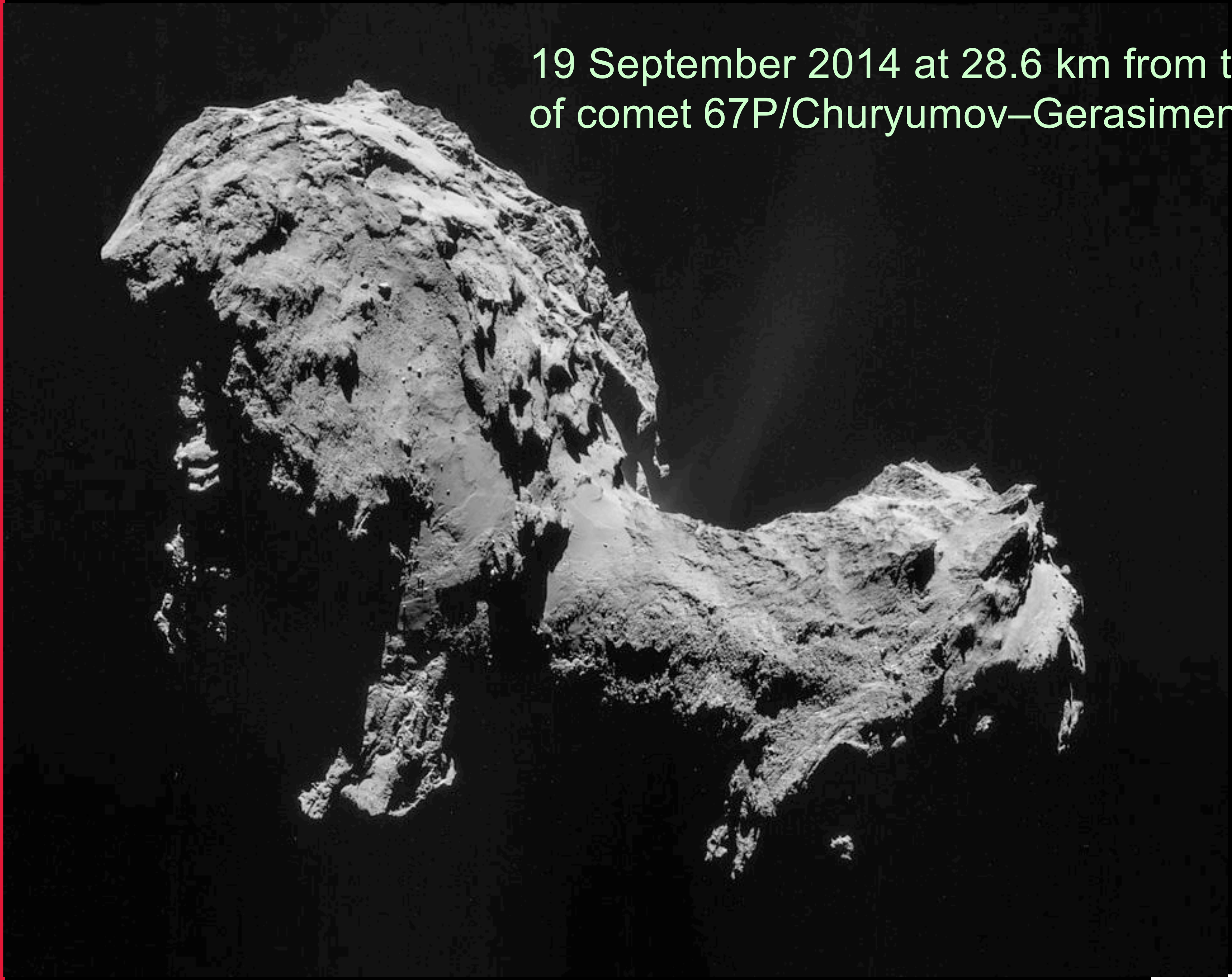
Freeman and Co

A comet is a chunk of rock with ice (dirty snowball- Fred Whipple) that generally moves in a highly elliptical and inclined orbit about the Sun

When approaching Sun, solar radiation generates evaporation of the surface ➔dust and ion tail

YORK UNIVERSITÉ UNIVERSITY

19 September 2014 at 28.6 km from the centre of comet 67P/Churyumov–Gerasimenko



YORK UNIVERSITÉ UNIVERSITY

Comets from the Kuiper belt and Oort cloud

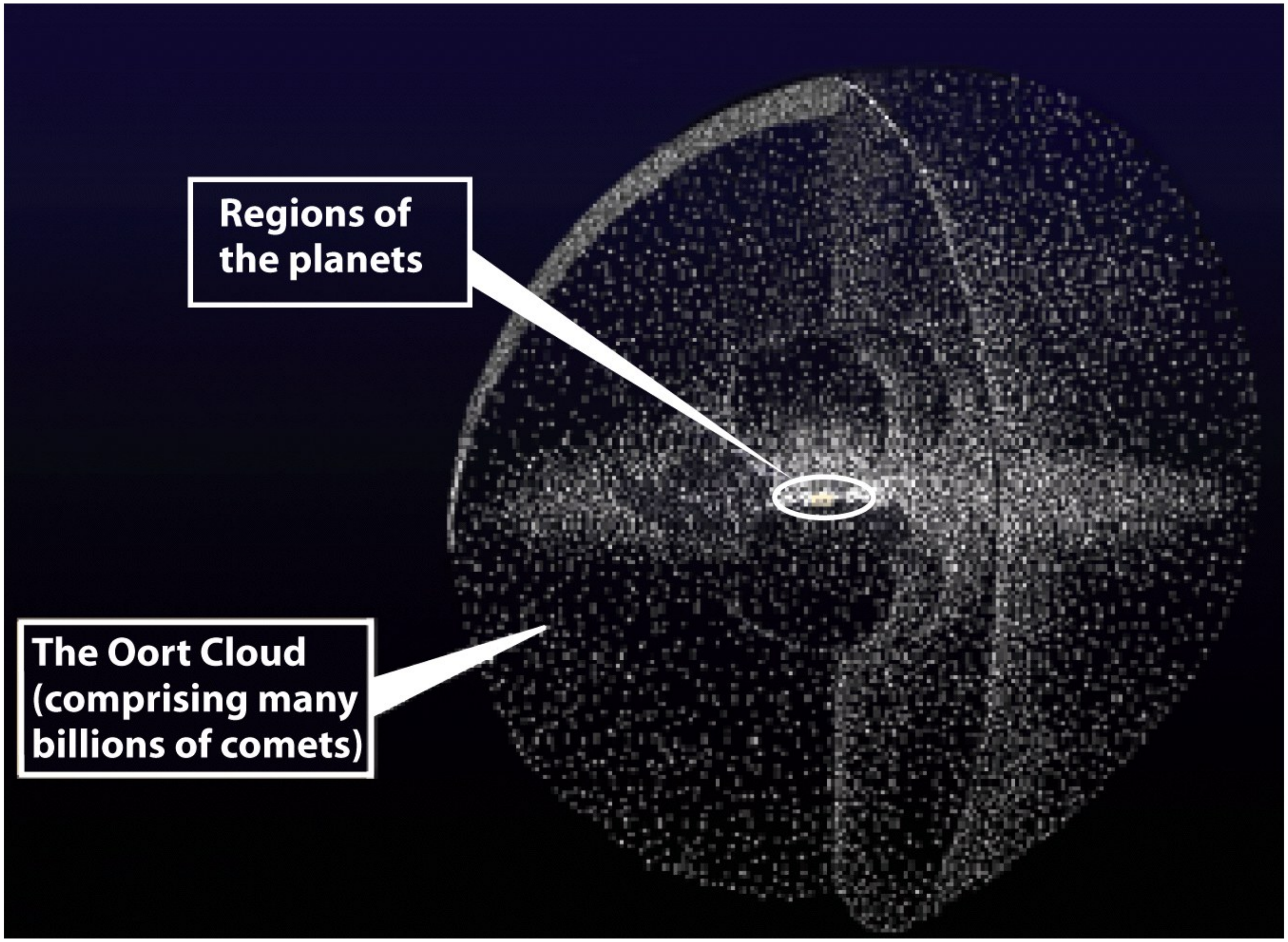


Figure 9-18a part 1
Discovering the Universe, Eighth Edition

They originate either in the Kuiper belt or the Oort cloud. The Oort cloud is thought to contain billions of comet nuclei.

Kuiper belt and Oort cloud

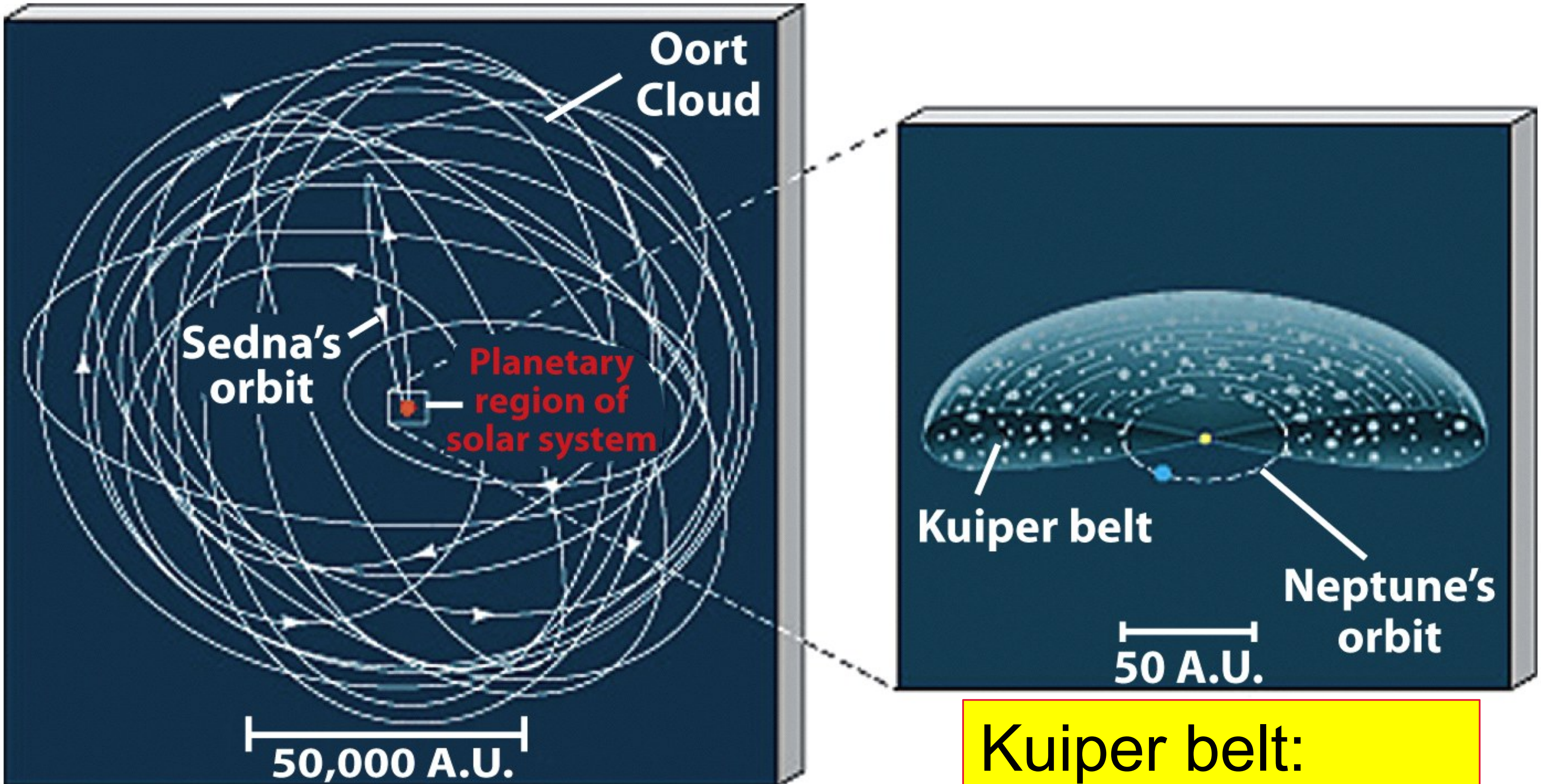


Figure 9-18a part 2
Discovering the Universe, Eighth Edition

Kuiper belt:
30 < R<=100 AU
Donut shaped

Oort cloud:
R=50,000 AU
Spherical

Kuiper belt objects (other than comets)

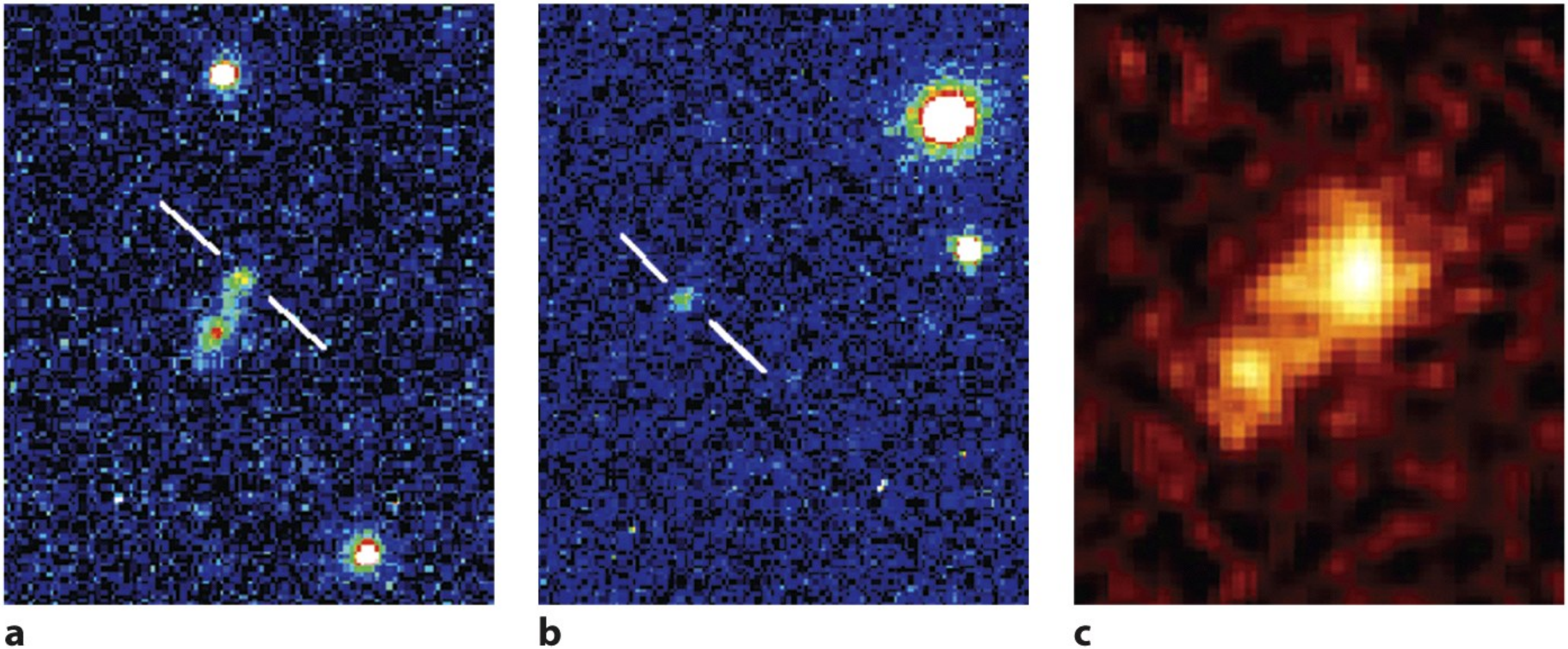


Figure 9-19
Discovering the Universe, Eighth Edition

First objects discovered in the 1990s
Biggest: Quaoar (half as large as Pluto!

Comet McNaught over the Pacific Ocean.

Credit: S. Deiries/ESO

Dissection of a comet

Ions: H_2O^+, CO^+, CO_2^+

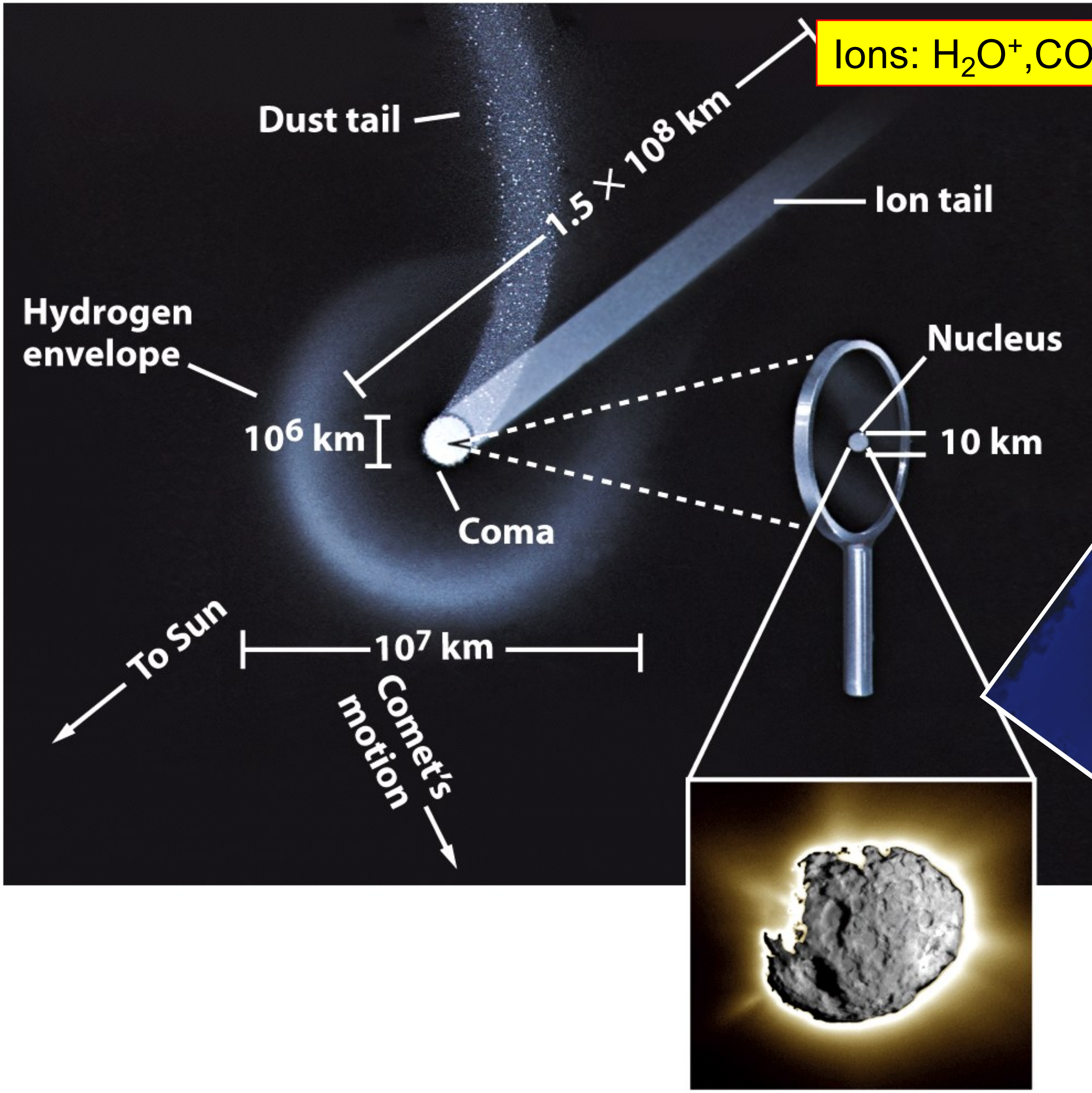
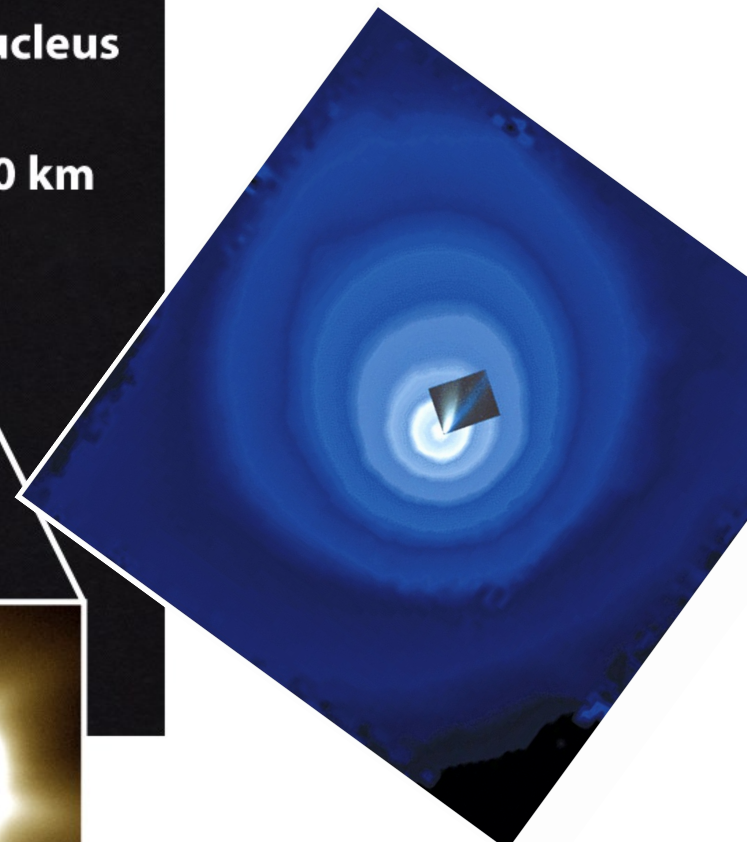


Figure 9-27
Discovering the Universe, Eighth Edition

Comet Wild



A comet can break into small pieces

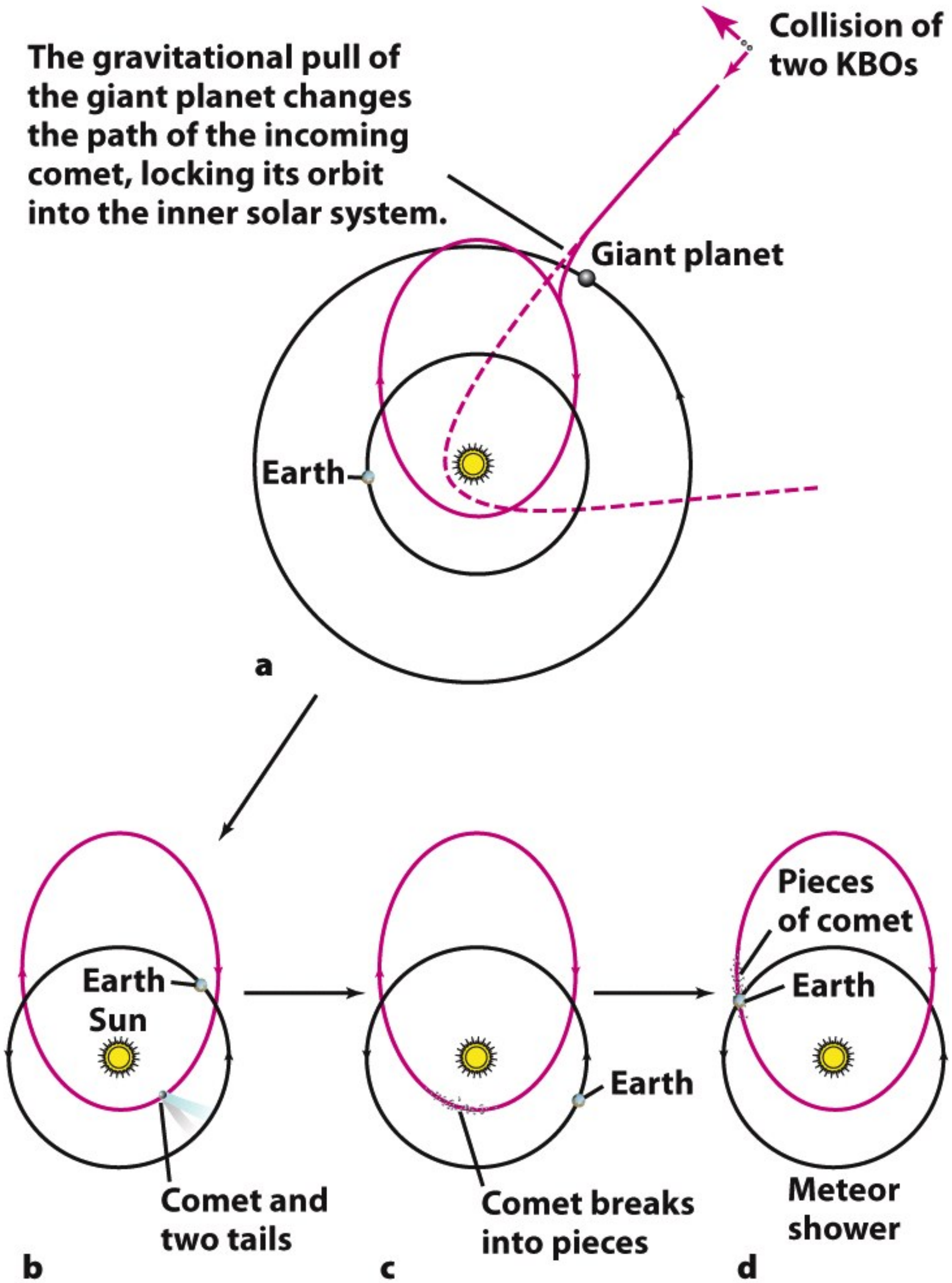


Figure 9-31
Discovering the Universe, Eighth Edition

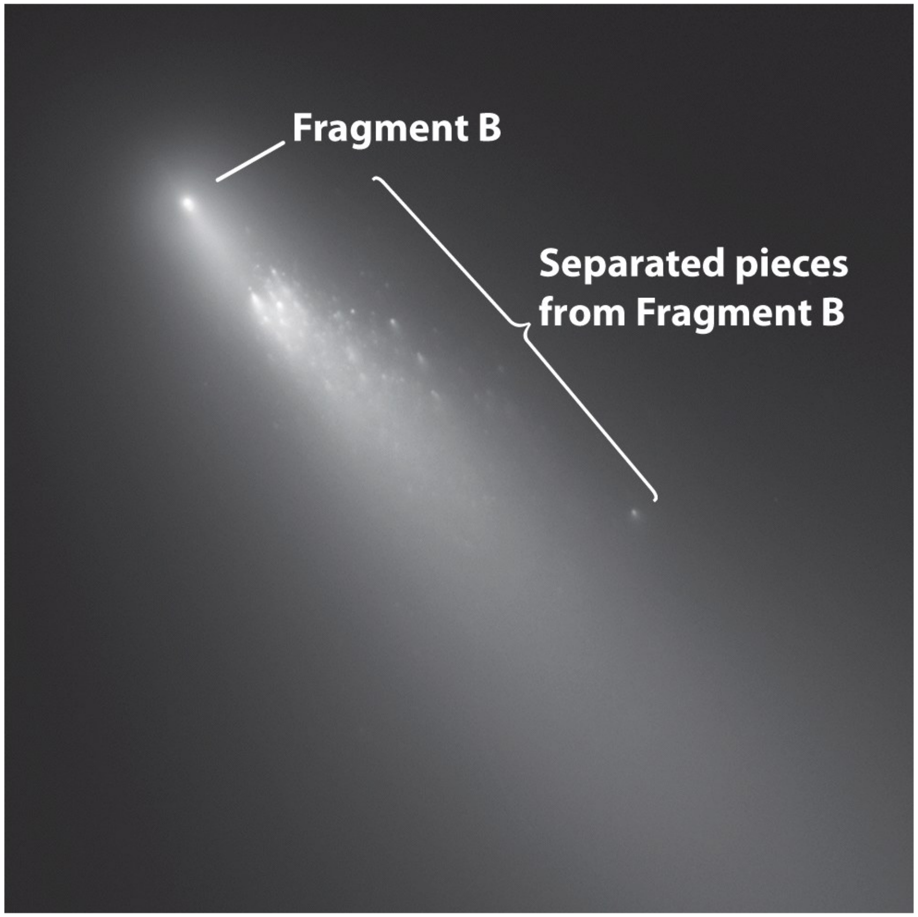


Figure 9-32
Discovering the Universe, Eighth Edition

YORK UNIVERSITÉ UNIVERSITY

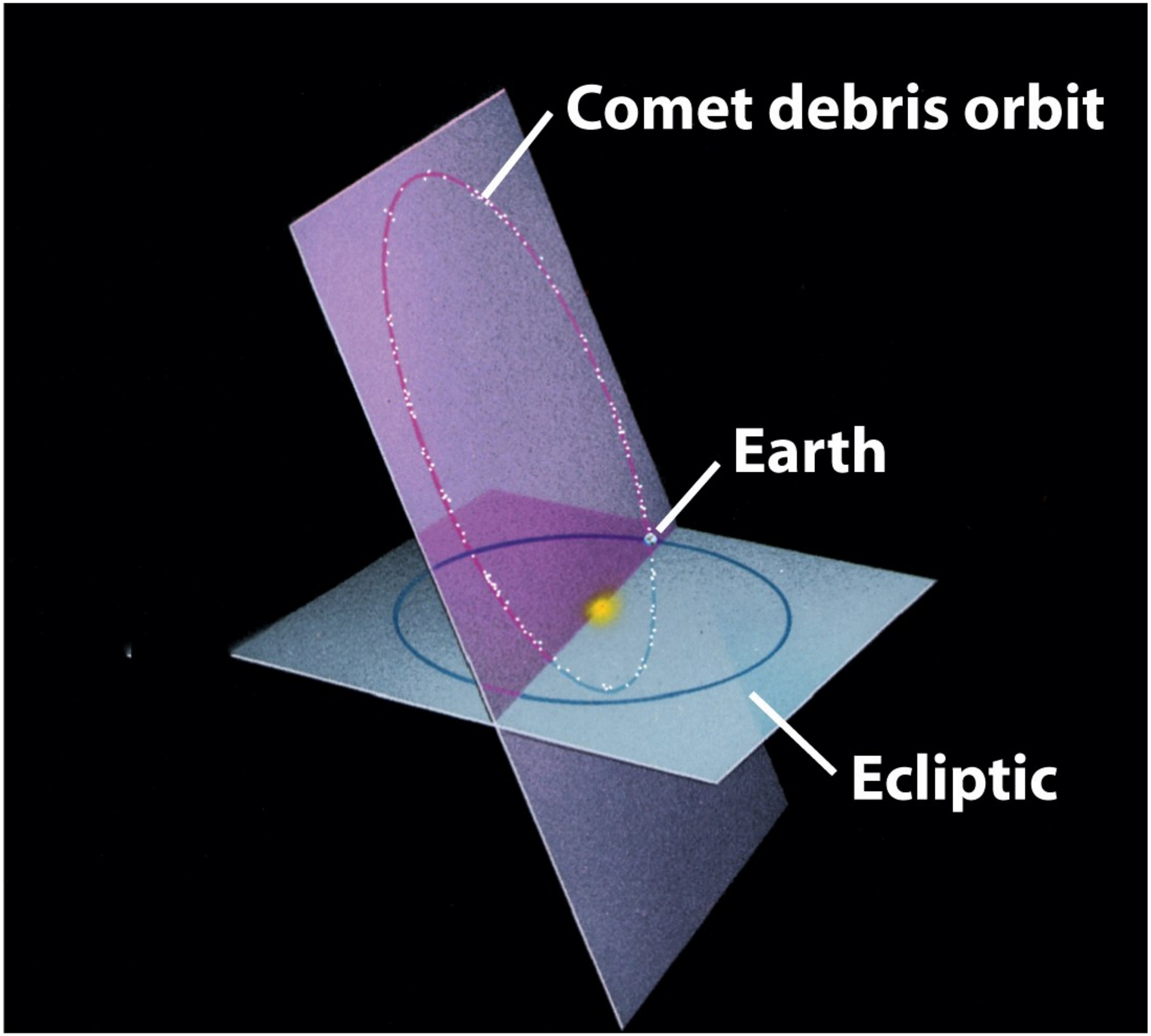


Figure 9-37
Discovering the Universe, Eighth Edition

PROMINENT YEARLY METEOR SHOWERS

Shower	Date of maximum intensity	Typical hourly rate	Constellation
Quadrantids	January 3	40	Boötes
Lyrids	April 22	15	Lyra
Eta Aquarids	May 4	20	Aquarius
Delta Aquarids	July 30	20	Aquarius
Perseids	August 12	80	Perseus
Orionids	October 21	20	Orion
Taurids	November 4	15	Taurus
Leonids	November 16	15	Leo Major
Geminids	December 13	50	Gemini
Ursids	December 22	15	Ursa Minor

Figure 9-38 part 2
Discovering the Universe, Eighth Edition

Figure 9-35
Discovering the Universe, Eighth Edition

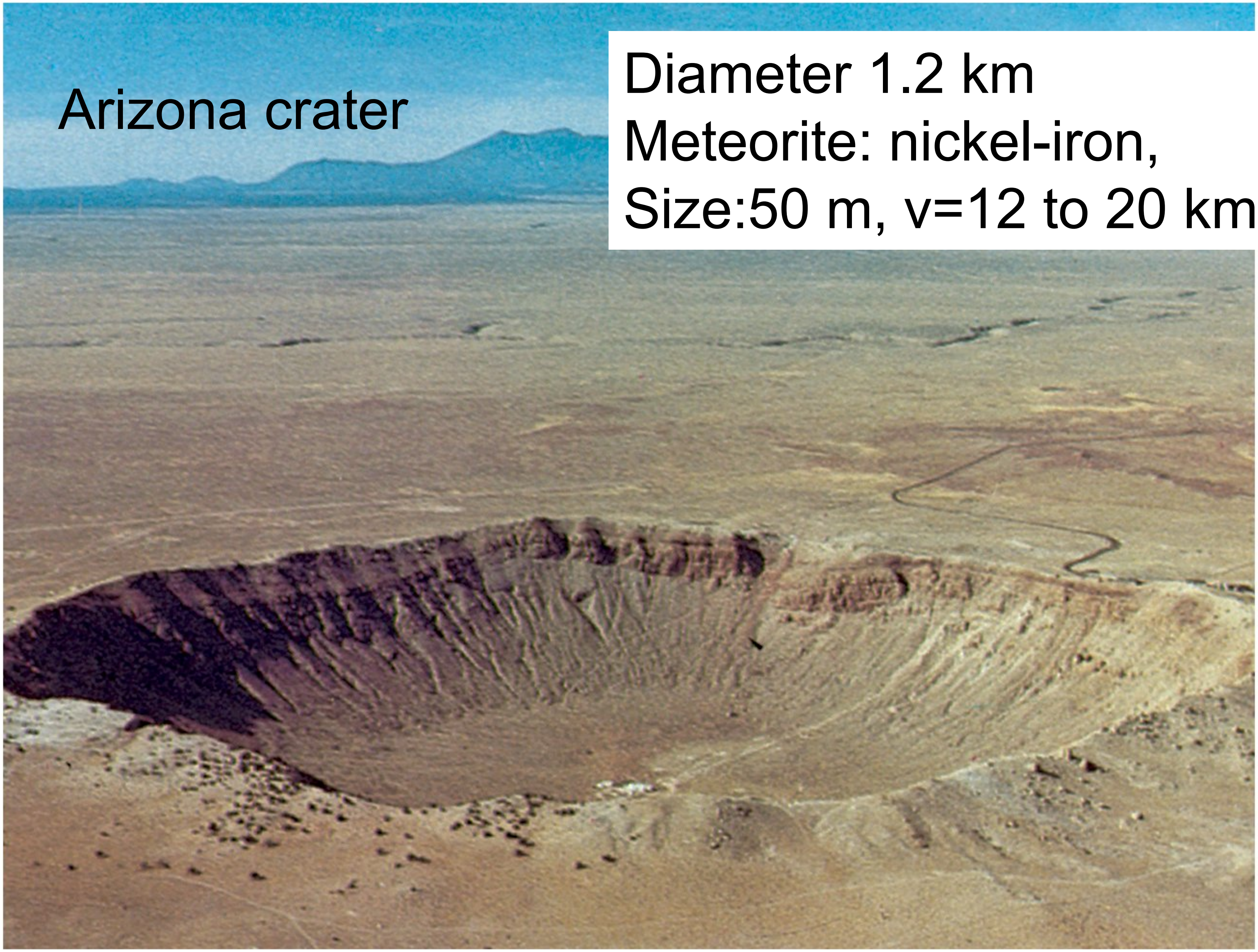
Meteorite hit car

Unnumbered 9 p273
Discovering the Universe, Eighth Edition

YORK UNIVERSITÉ UNIVERSITY

Arizona crater

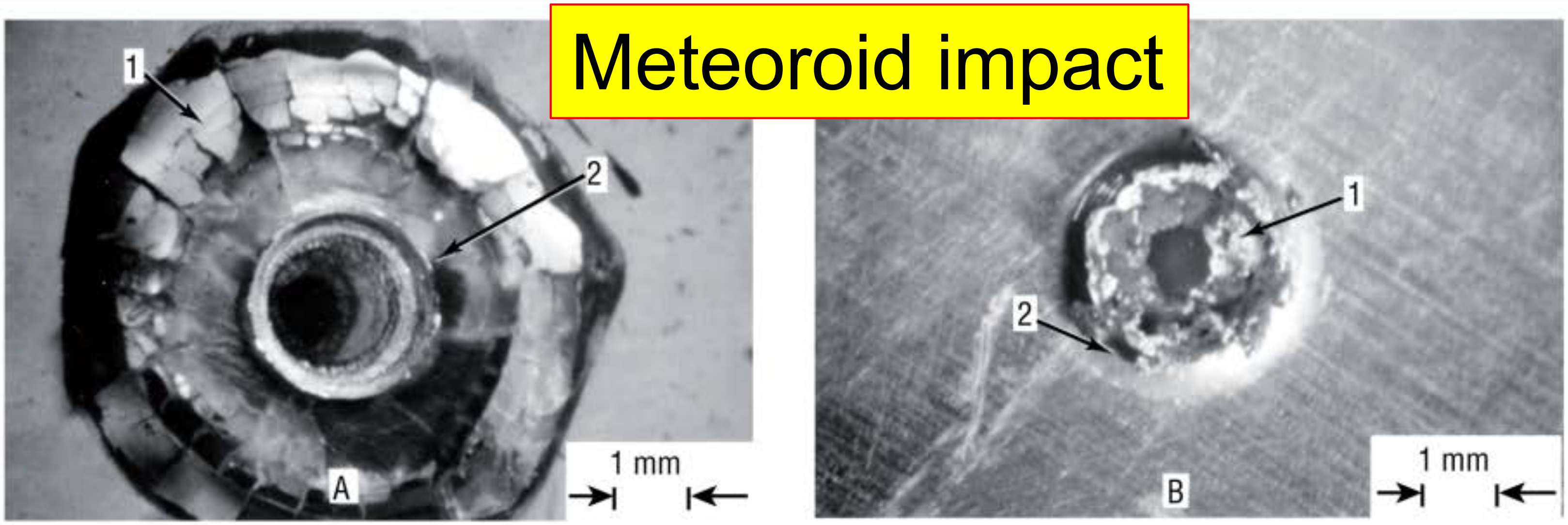
Diameter 1.2 km
Meteorite: nickel-iron,
Size:50 m, v=12 to 20 km s^{-1}



Freeman and Co

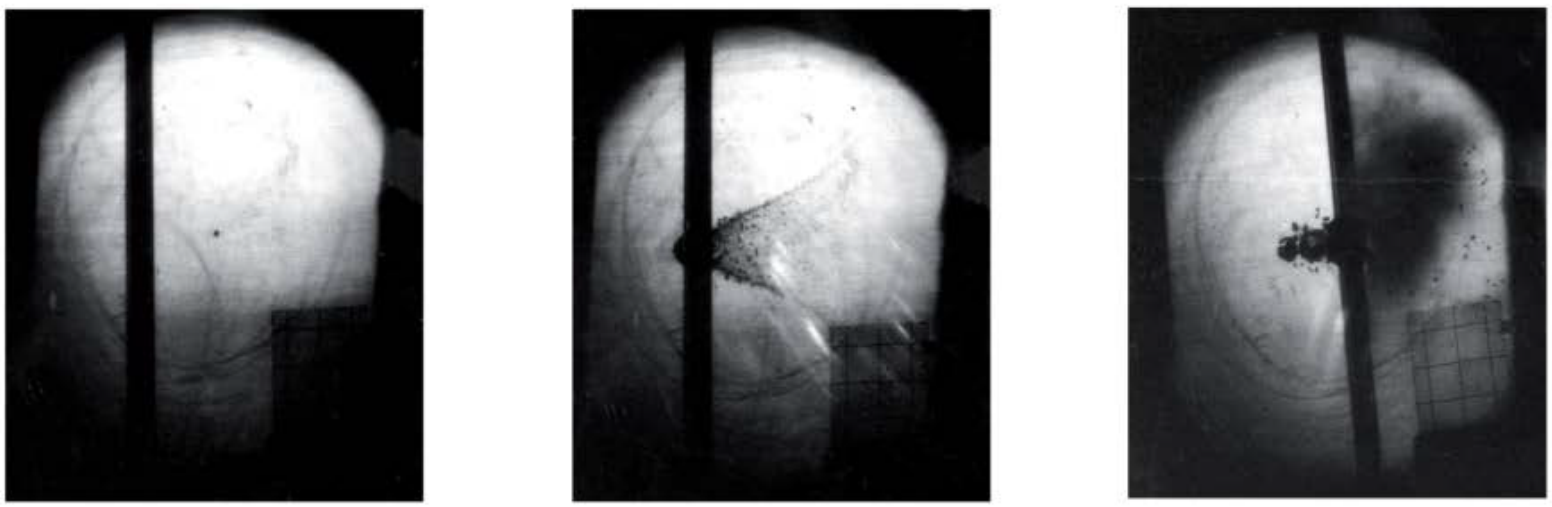
YORK UNIVERSITÉ UNIVERSITY

Meteoroid impact



Source: NASA Reference Publication 1408, "Meteoroids and Orbital Debris: Effects on Spacecraft".

Figure 1. Surface damage, punching and spalling.



Source: NASA Reference Publication 1408, "Meteoroids and Orbital Debris: Effects on Spacecraft".

Figure 2. Impact cloud.

http://media.altran.it/Documenti/tecnology/05/PDF/TechnologyReview05_5.pdf

YORK UNIVERSITÉ UNIVERSITY

Close encounters

- 1000 asteroids with size of >1 km cross Earth orbit. 30% will hit Earth eventually, 1 every 300,000 yr. Could kill 1 Bill people.
- 1178 Moon was hit. 20 km crater. 120,000 Mt explosion, 6 times Earth's atomic arsenal.
- 23 March 1989 asteroid 1989 FC missed Earth by 6 h. It was detected after passage. Explosion potential ~ 1000 nuclear bombs.
- 1908 Tunguska asteroid, size 50 m. Expectation: every 100 yr. Equivalent to 20 Mt H bomb.
- 1990 small asteroid into Pacific ocean. Explosion power: small atomic bomb.

Figure 9-35
Discovering the Universe, Eighth Edition

Meteor hit car

Unnumbered 9 p273
Discovering the Universe, Eighth Edition


Arizona crater: iron meteor, size 50 m, 50,000 yr ago

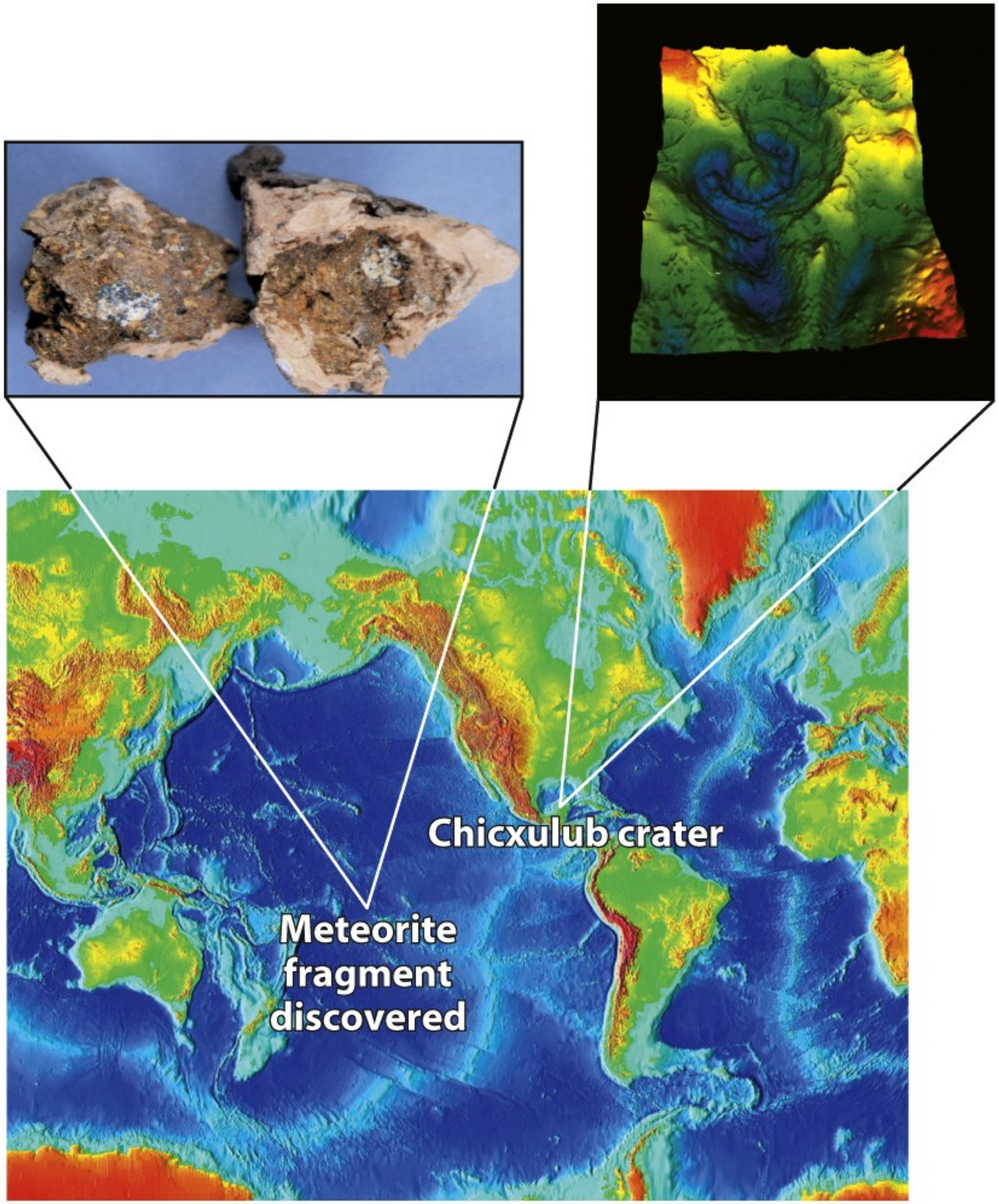


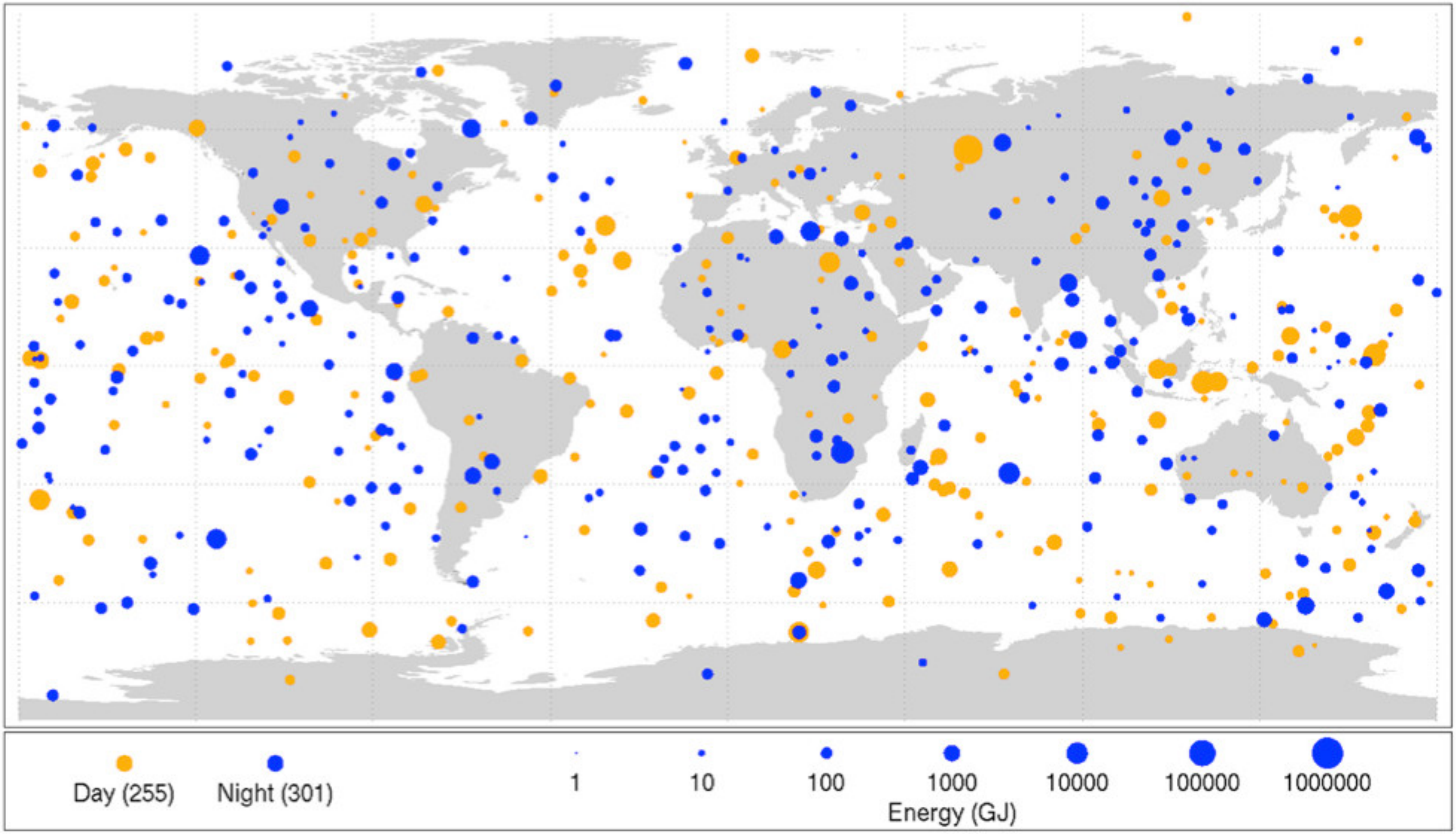
Figure 9-47
Discovering the Universe, Eighth Edition

65 Mill years ago: demise of the dinosaurs

250 Mill years ago: greater mass extinction - 80 - 90% of species of life perished

Bolide Events 1994 – 2013

Small Asteroids that Disintegrated in Earth's Atmosphere



This diagram maps the data gathered from 1994-2013 on small asteroids impacting Earth's atmosphere and disintegrating to create very bright meteors, technically called "bolides" and commonly referred to as "fireballs". Sizes of orange dots (daytime impacts) and blue dots (nighttime impacts) are proportional to the optical radiated energy of impacts measured in billions of Joules (GJ) of energy, and show the location of impacts from objects about 1 meter (3 feet) to almost 20 meters (60 feet) in size.

Meteorites were also found on Earth from impacts on Moon and Mars

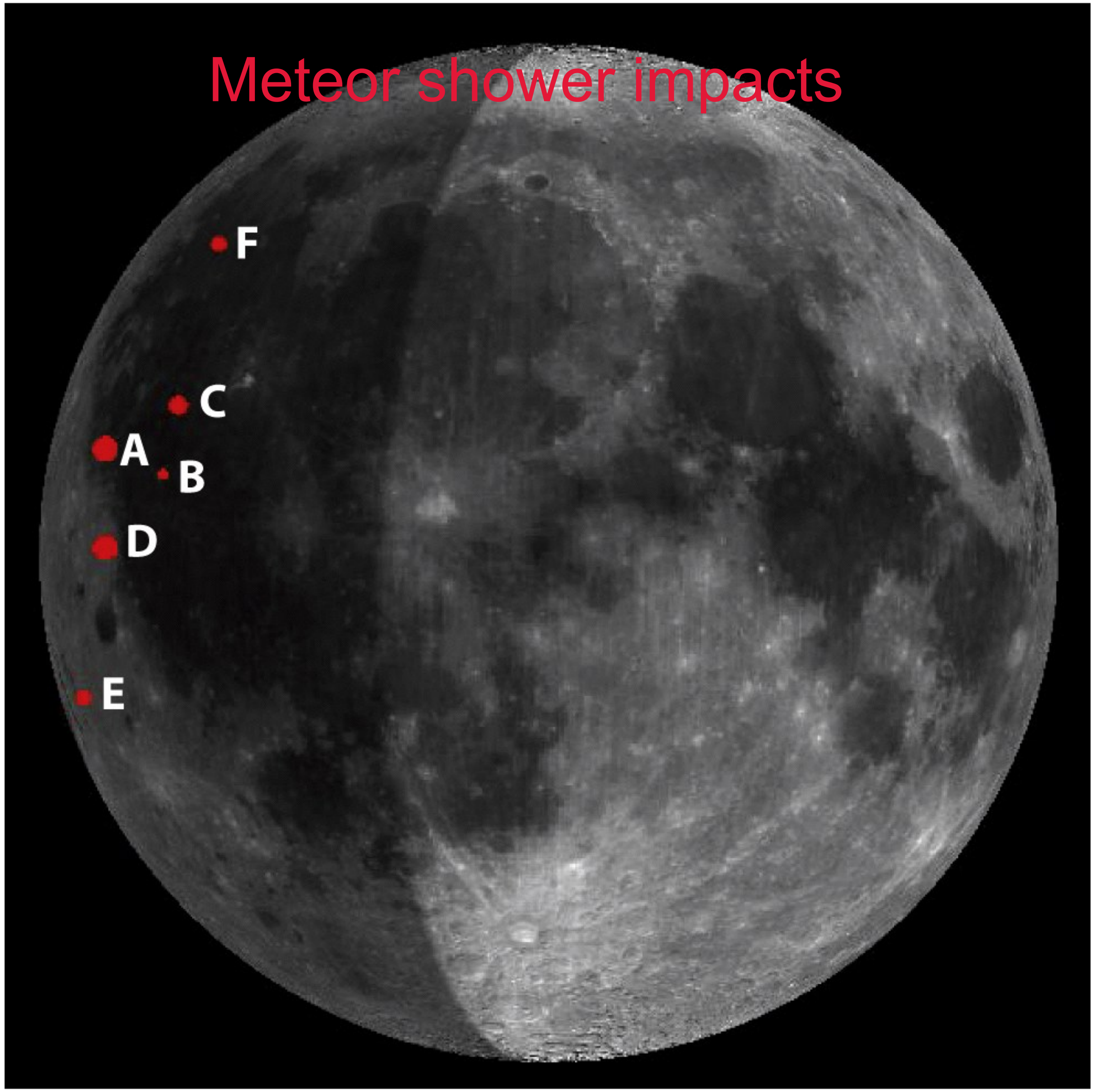


Figure 9-39
Discovering the Universe, Eighth Edition

Meteorites were also found on Earth from impacts on Moon and Mars

…but none from Mercury and Venus yet

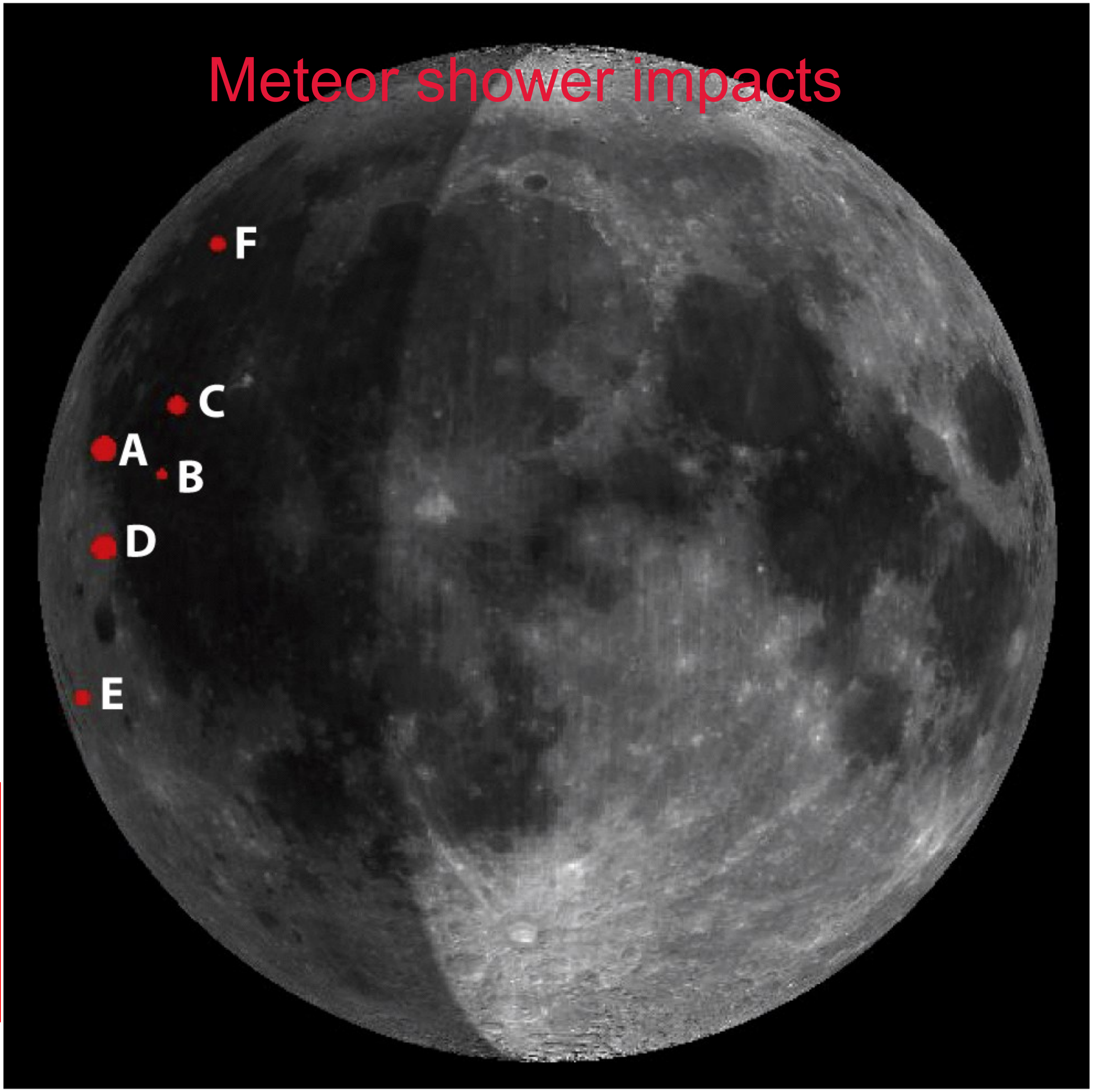


Figure 9-39
Discovering the Universe, Eighth Edition

The End