# Meteors, Meteorites and Impacts

I. **Small Solar System Bodies**
II. **Meteors**
III. **Meteorites**
IV. **Impacts**

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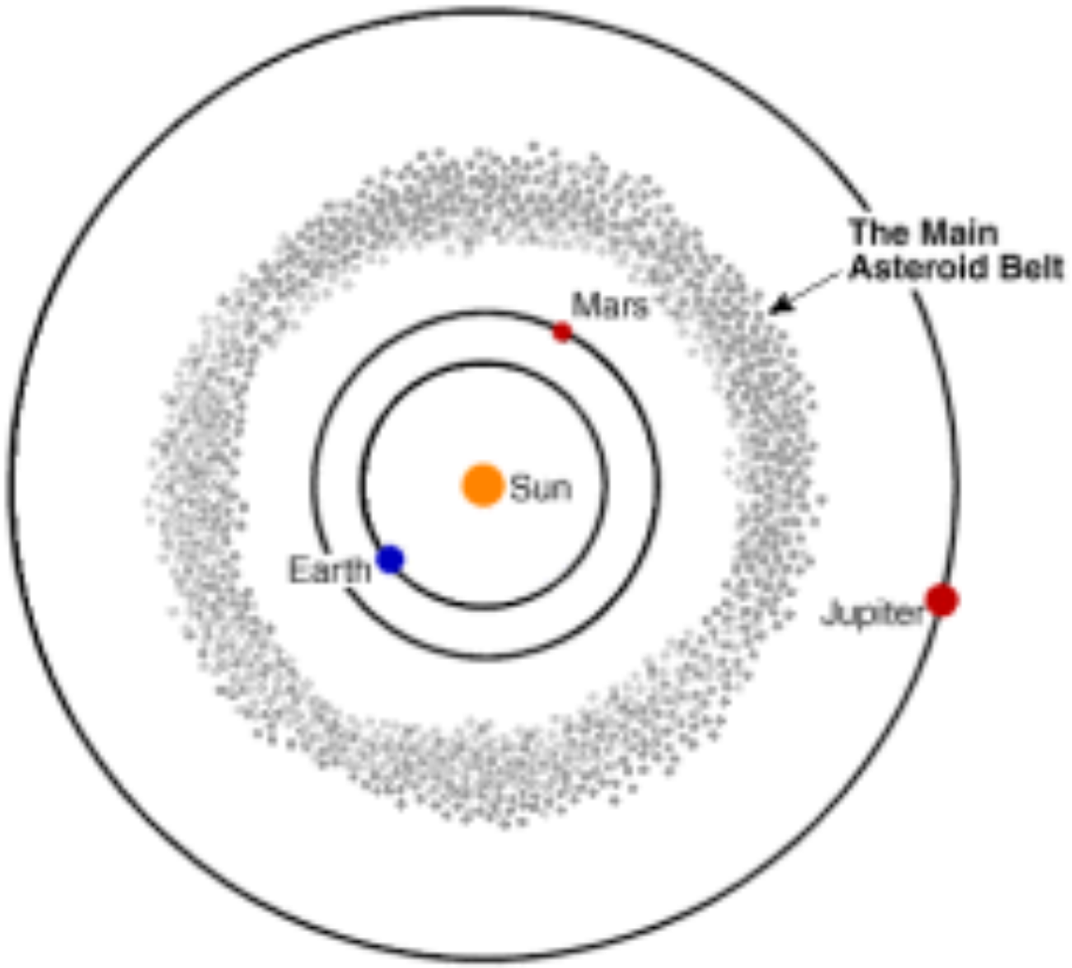
# I. Small Solar System Bodies

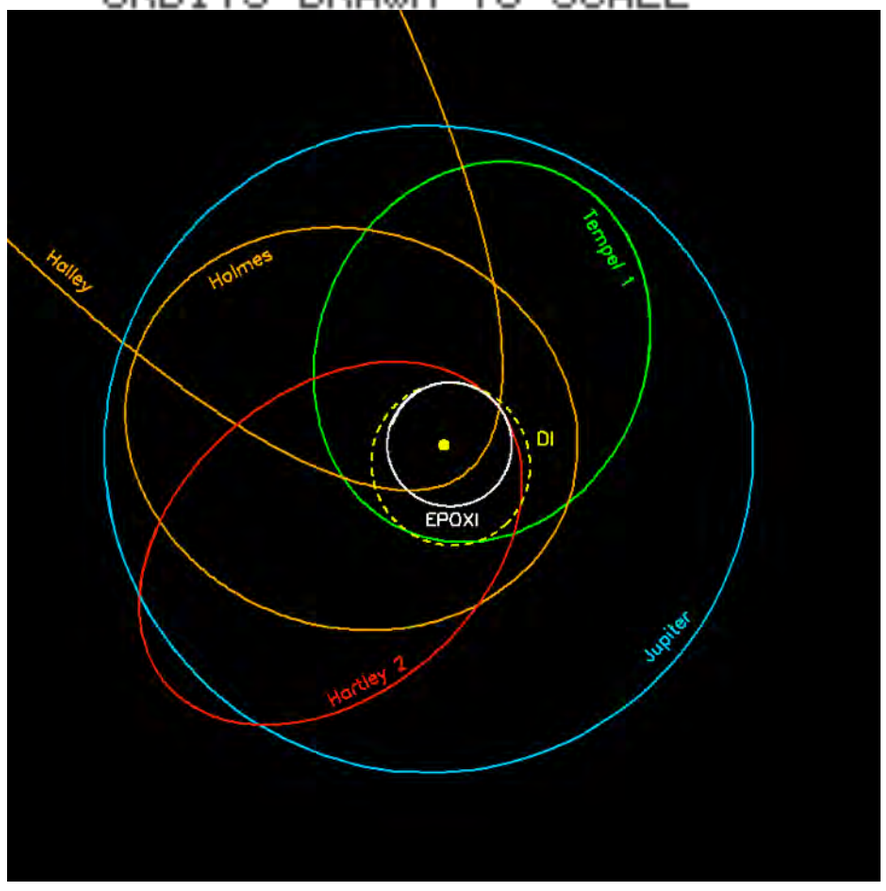
*Small Solar System Bodies* (SSSB, as defined by the IAU) are objects in the Solar System that are neither *planets* nor *dwarf planets* - this includes comets, most asteroids and trans-Neptunian objects.

This definition excludes satellites.




NASA/Goddard Space Flight Center

The orbits of several comets are shown in the bottom image.

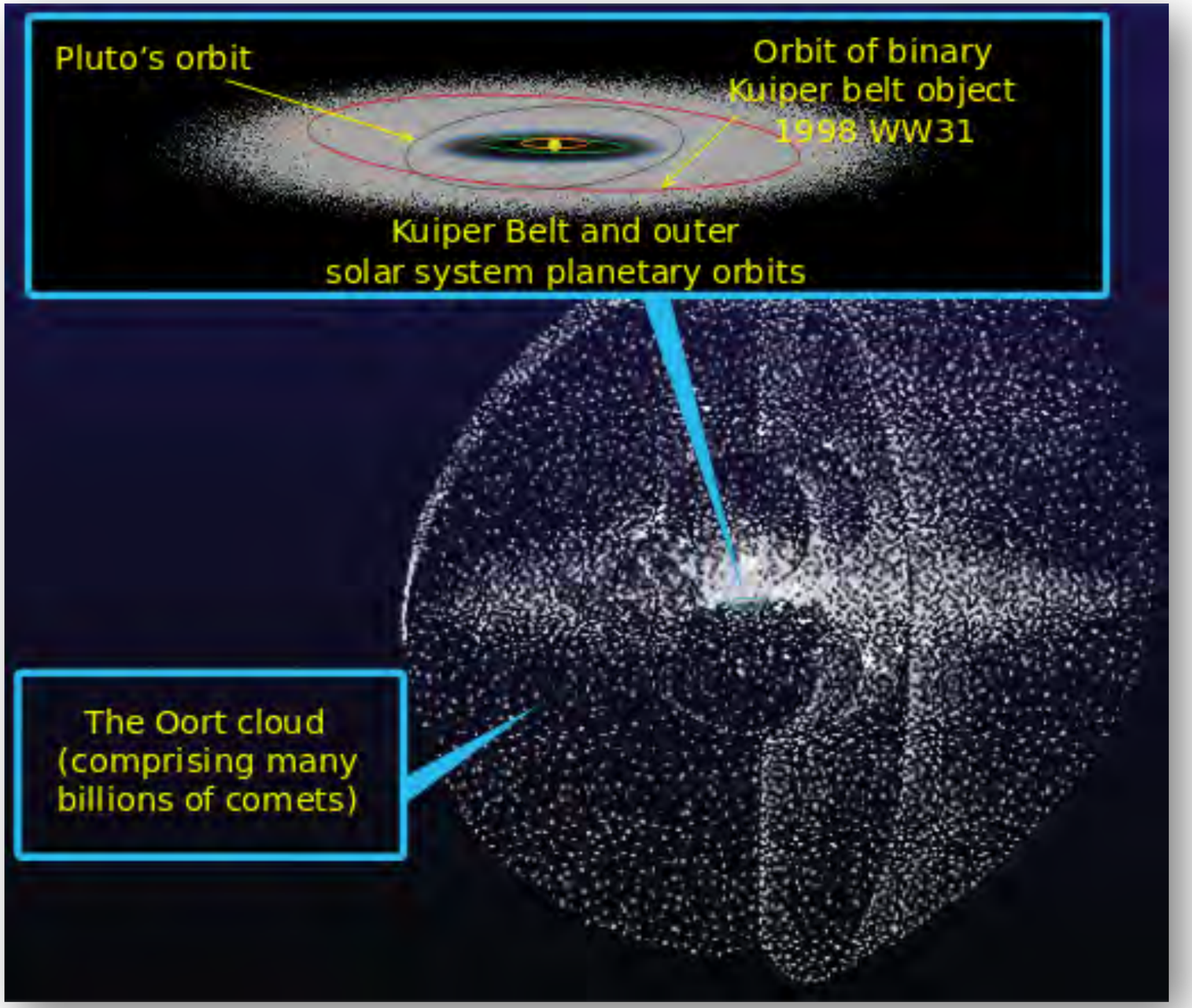



Credit: NASA/JPL-Caltech/UMD/GSFC/Tony Farnham

Most *Small Solar System Bodies* are in found several regions:

*Asteroid belt* - region of rocky and icy bodies between the orbit of Mars and Jupiter.

*Kuiper belt* - a disk-shaped region extending from the orbit of Neptune (at 30 AU) to approximately 55 AU from the Sun consisting mostly of icy objects.



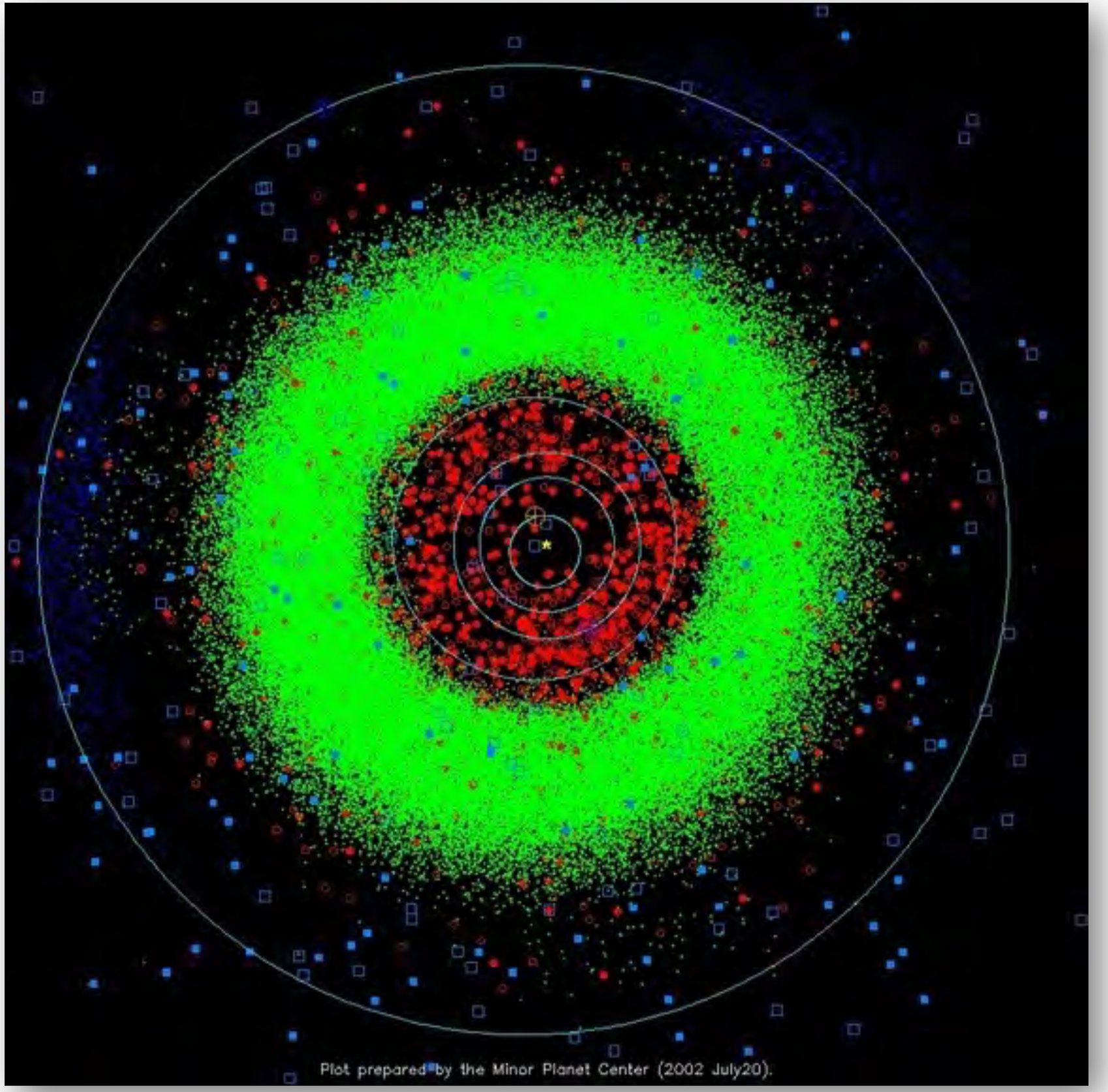

NASA

*Scattered disk* - thinly populated disk-shaped region of icy bodies that overlaps with the outer Kuiper belt and extends out to the Oort cloud.

*Oort cloud* - a spherical cloud of comets extending ~50,000 AU (nearly a light-year) from the Sun.

The figure shows the distribution of asteroids in the inner solar system. Main-belt asteroids are shown as green dots, Near-Earth asteroids as red dots, and comets as blue squares.

Over 1200 "Earth-approachers" >1 km in diameter have been cataloged.

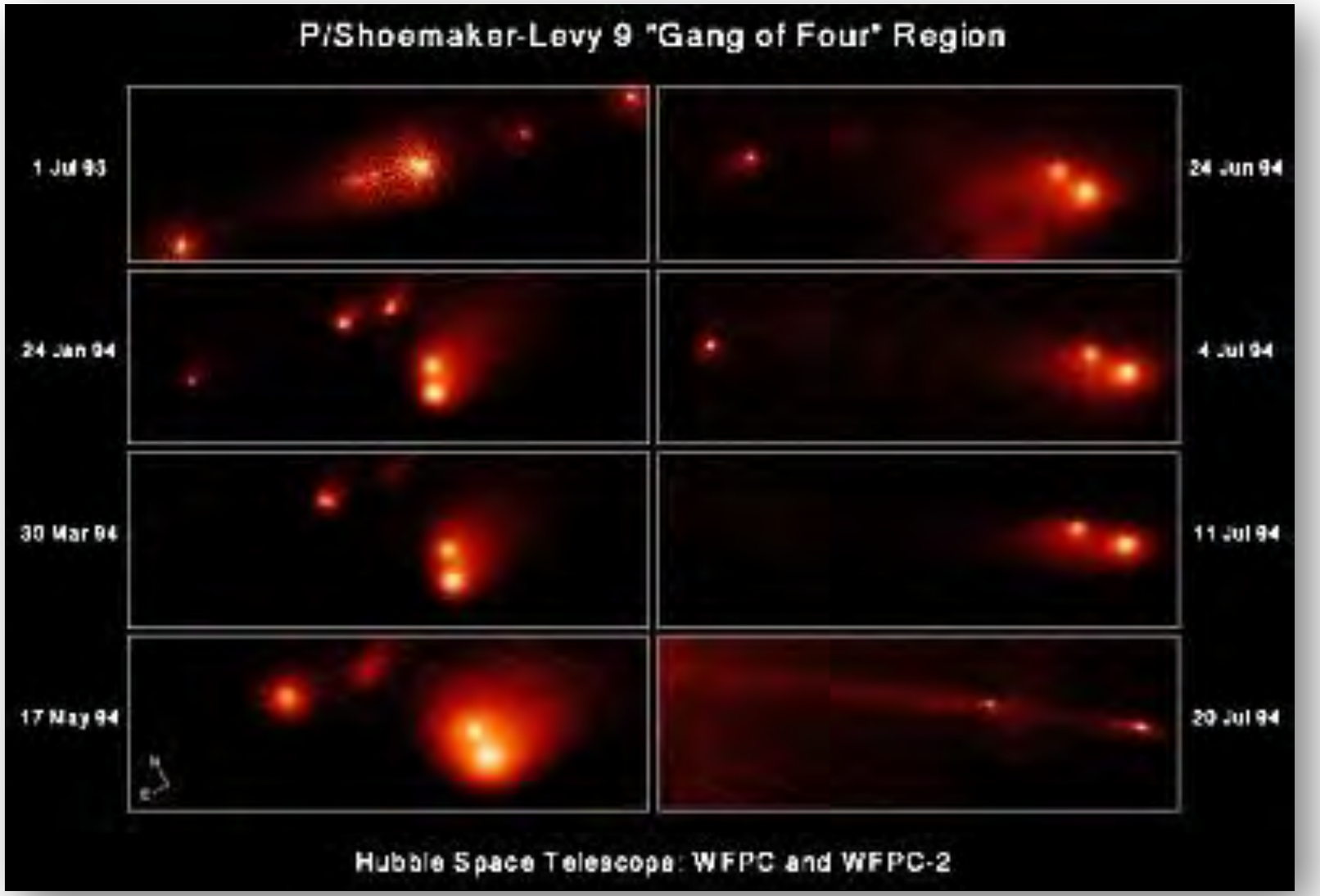



MPC, CBAT, Harvard CfA, IAU

**Small solar system bodies may meet several fates:**

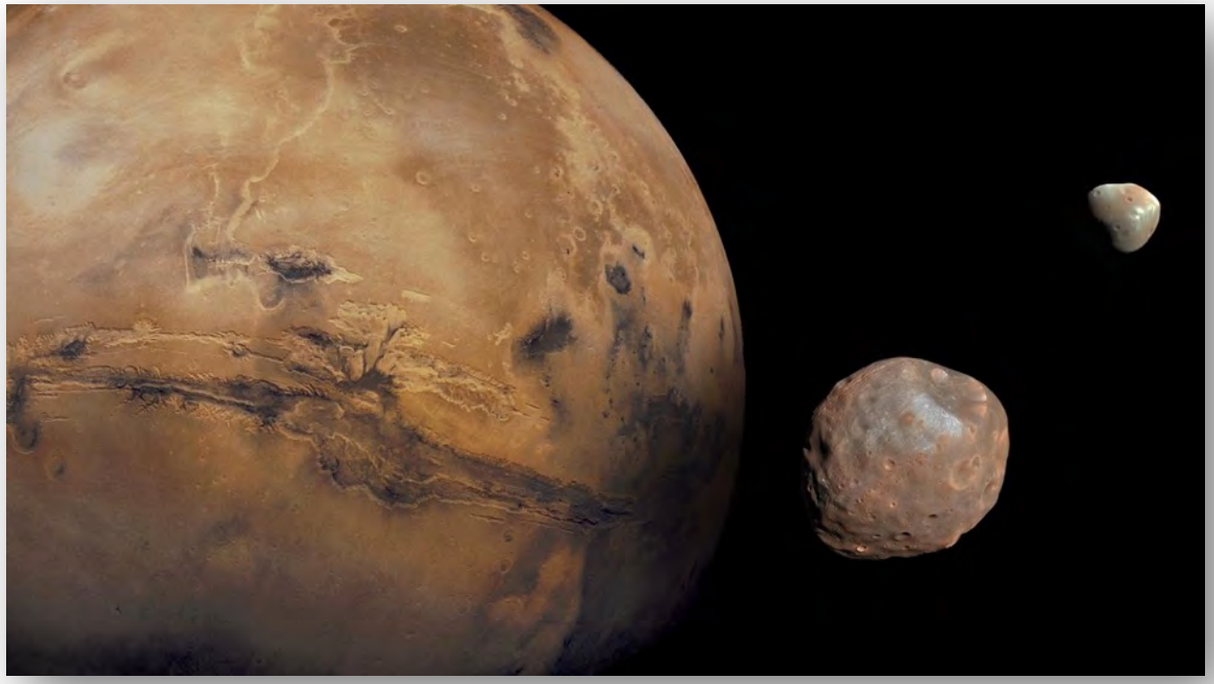
1. Ejection from the solar system — when an asteroid approaches a planet, it may be kicked into a hyperbolic orbit (highly eccentric) and may eventually leave our solar system.

2. Fragmentation — planetesimals may be fragmented by gravitational forces such as the comet Shoemaker-Levy encounter with Jupiter.




In addition, the mean collision speed between asteroids in the asteroid belt is ~5 km/s — results in catastrophic fragmentation.

3. Capture — a planetesimal may be captured into orbit around a planet (captured moon) such as the moons of Mars (Phobos and Deimos) or into a $L_4$ or $L_5$ Langrangian point like the Trojan asteroids of Jupiter.



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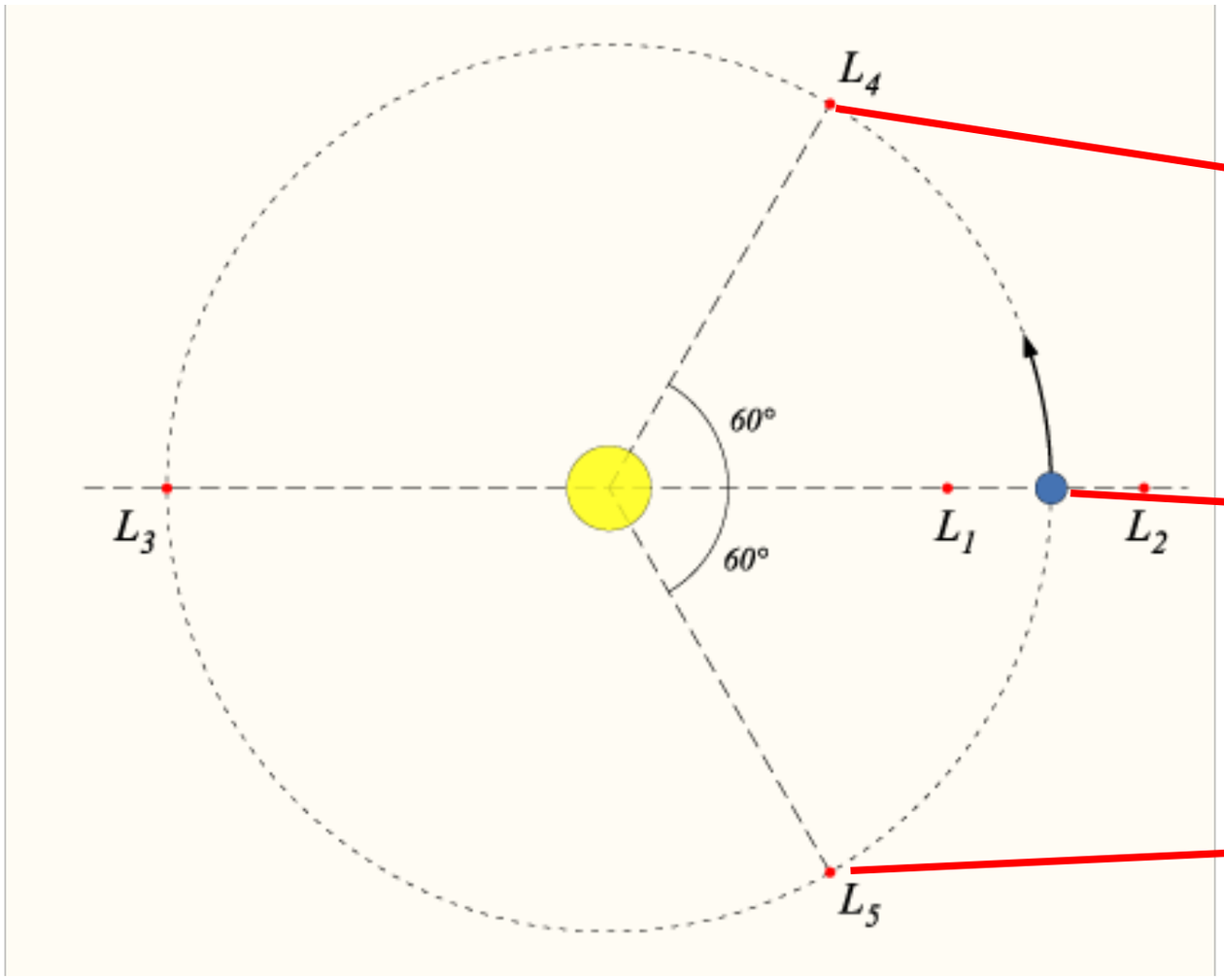


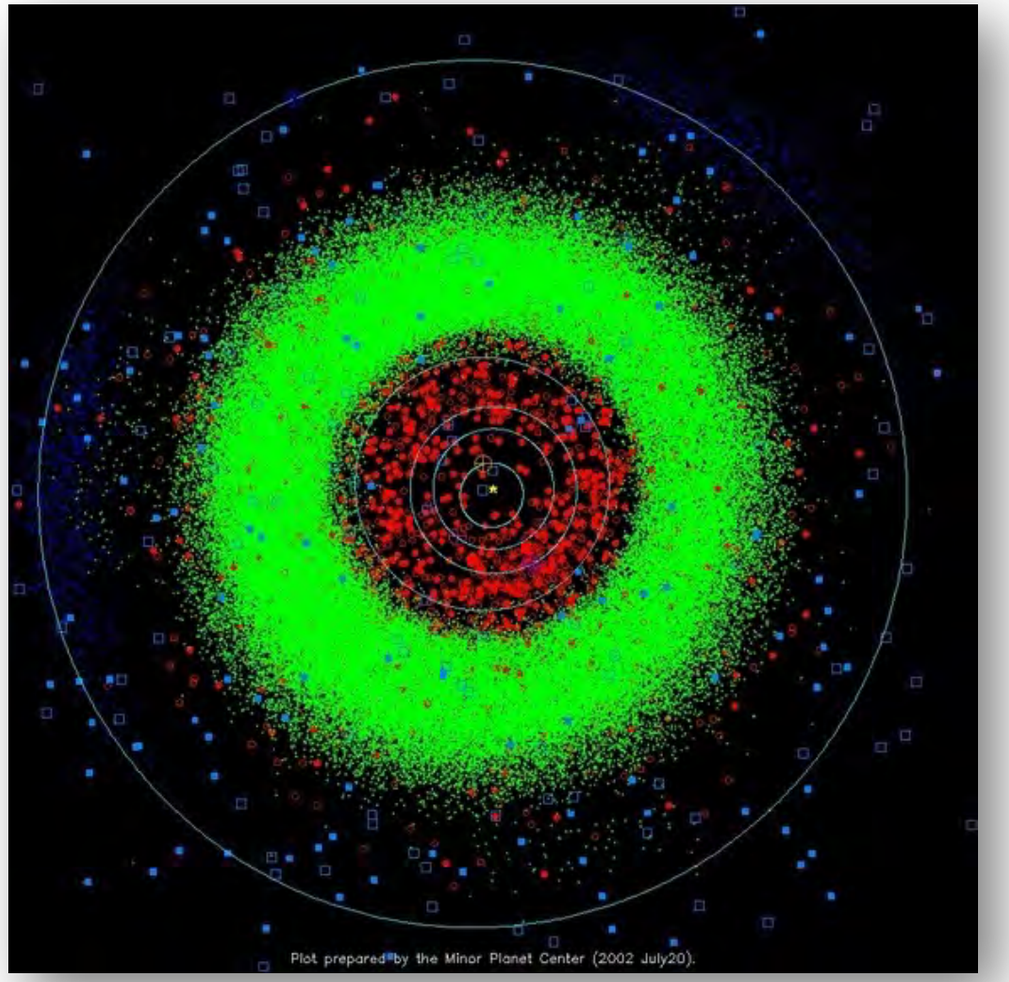

David Darling, Internet Encyclopedia of Science



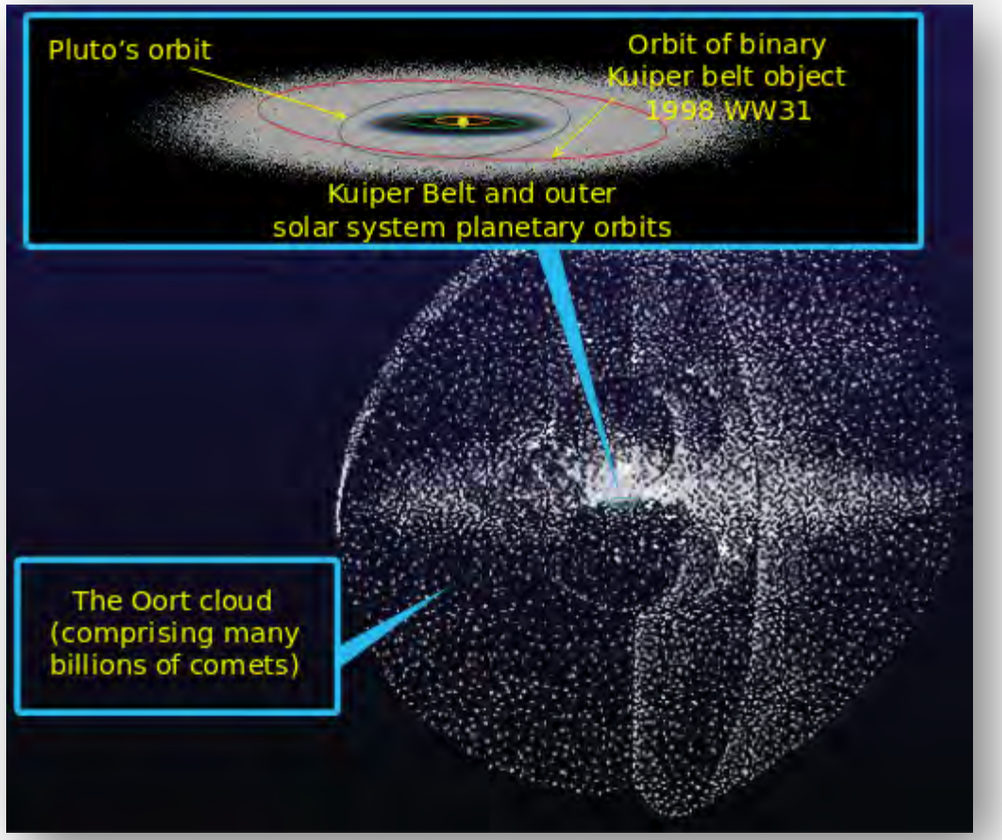

Scott S. Sheppard

4. Preservation — the asteroid belt between Mars and Jupiter and the Kuiper belt outside the orbit of Uranus represent two reservoirs of planetesimals in relatively stable (circular) orbits that have survived since the formation of our solar system.

   Interactions between asteroids and Kuiper objects with one another and planets may fling them into more eccentric  planet-crossing orbits.




MPC, CBAT, Harvard CfA, IAU

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5. Collision with a planet — this is a common occurrence considering the number of impact craters throughout the solar system. There is a steady supply of impactors from the asteroid belt, Kuiper belt and Oort cloud.


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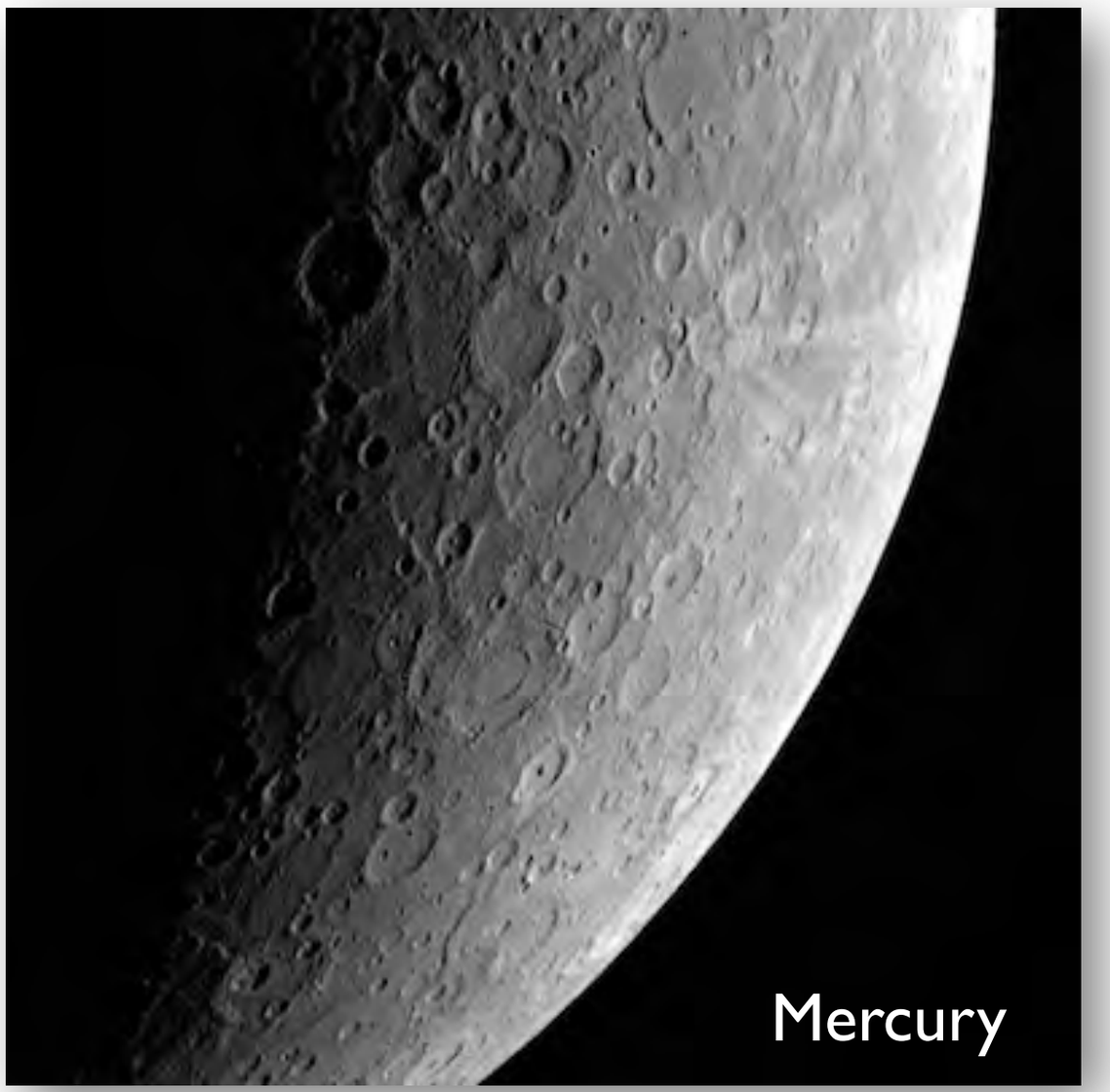


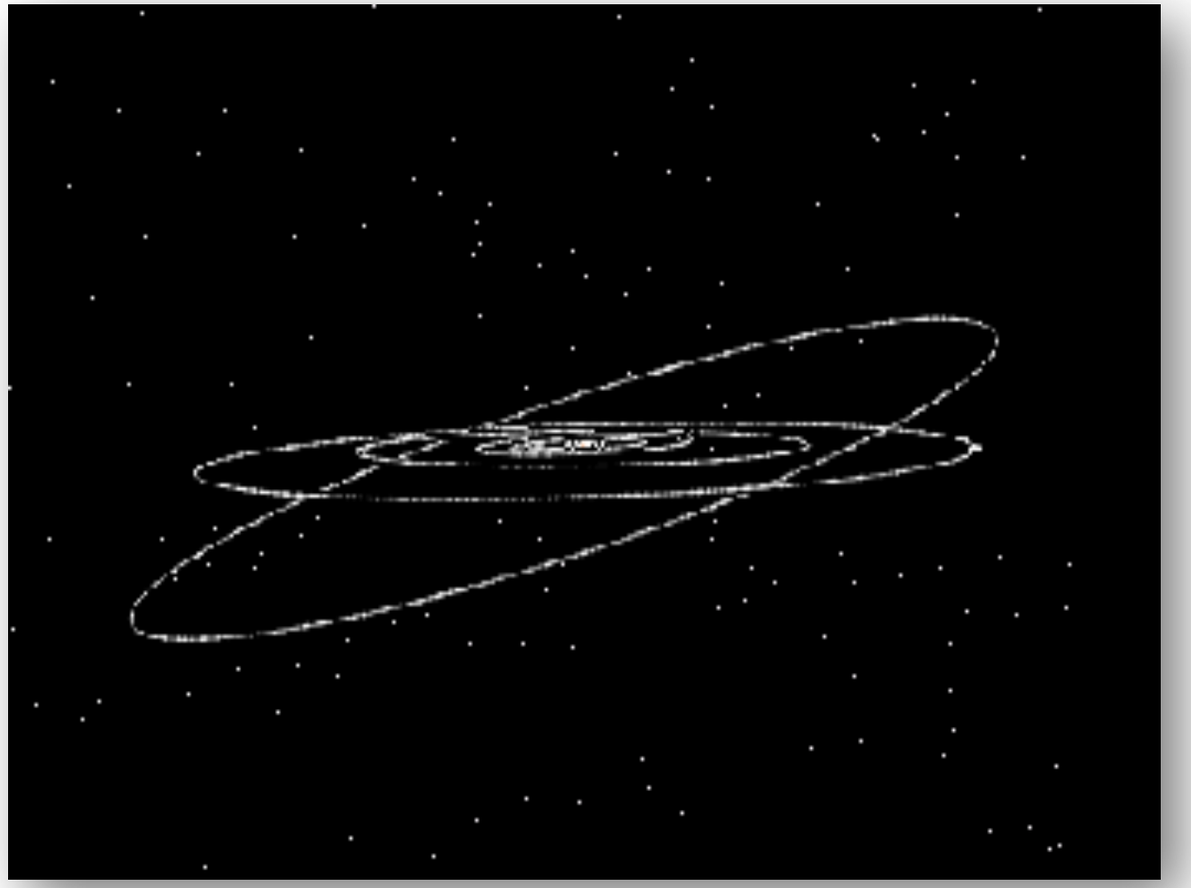

NASA


Steve Jurvetson

The orbits of Earth-crossing bodies are typically inclined to the orbit of Earth.

However the object will intersect the ecliptic plane twice in its orbit - *nodes*.

Eventually, the Earth and a planetesimal will meet near a *node* - statistical analysis indicates that these sorts of objects will interact with the Earth within ~ 20 My.



The most common fate is that the orbit of the object is altered by the encounter.

# II. Meteors

*Meteors* are produced when small fragments of interplanetary debris enter the Earth's atmosphere and are vaporized.

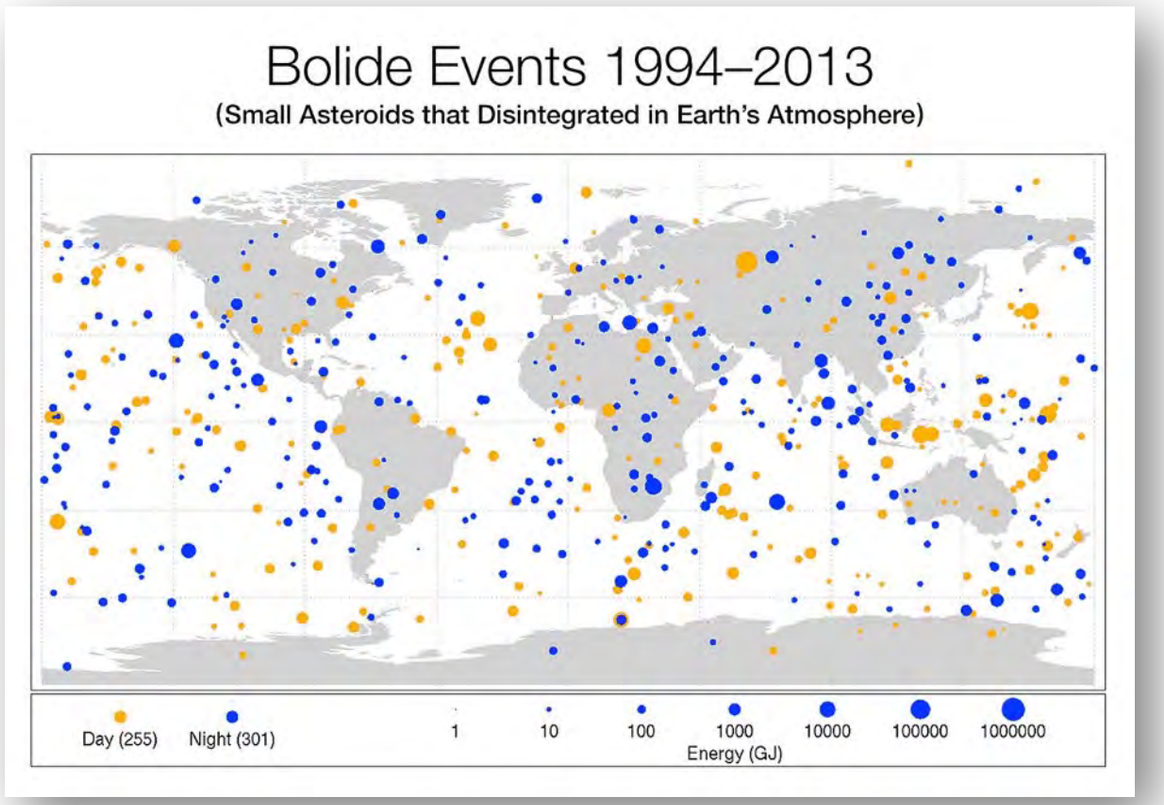
Estimates for the mass of material that falls on Earth each year range from 37,000-78,000 tons. Most of this mass would come from dust-sized particles.

Millions of meteors enter the Earth's atmosphere everyday and typical velocities in the atmosphere are around 30 km/sec.

The photos show bright meteors known as *fireballs* or *bolides*.

NASA

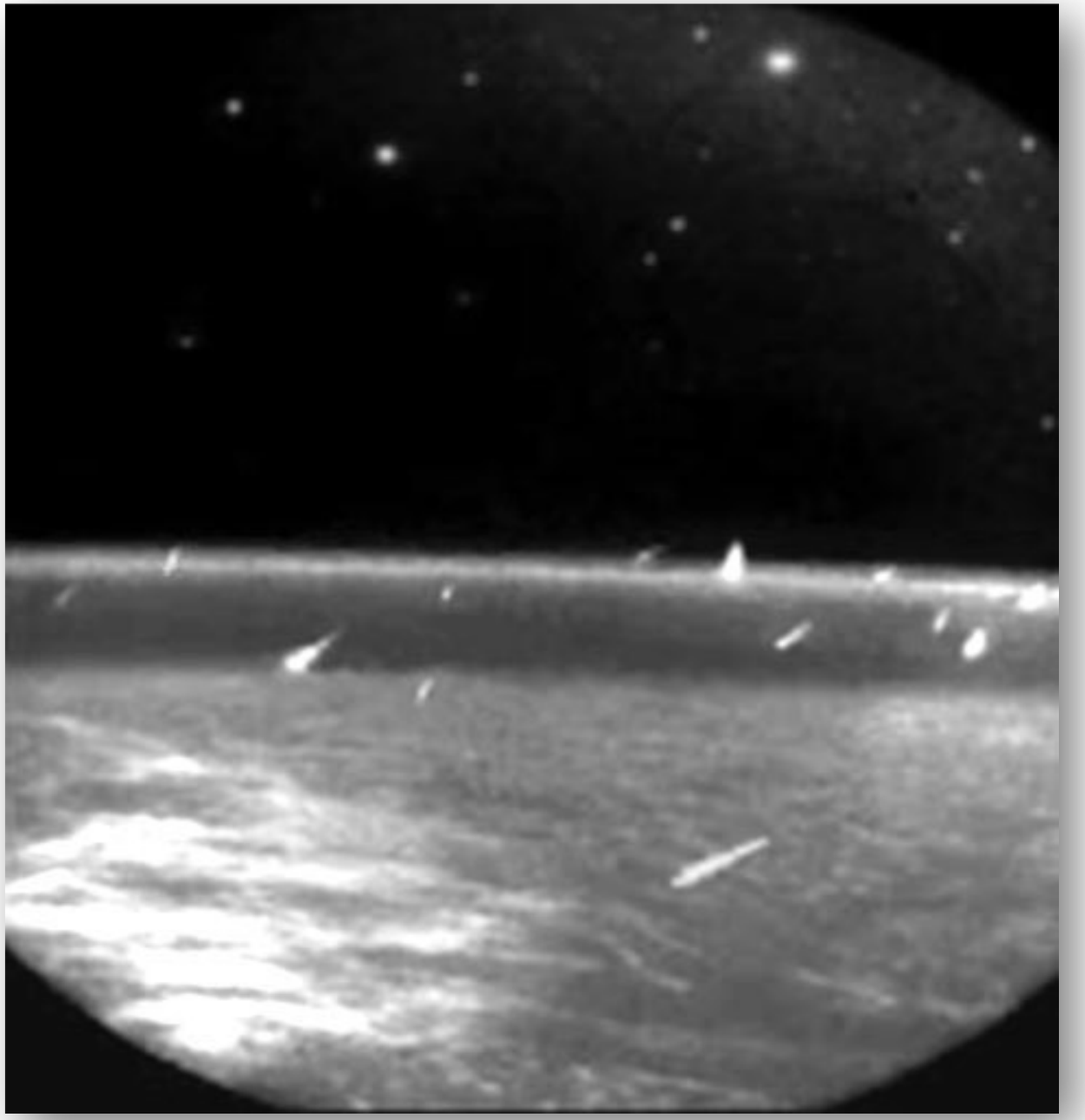
Thomas Grau




Planetary Science

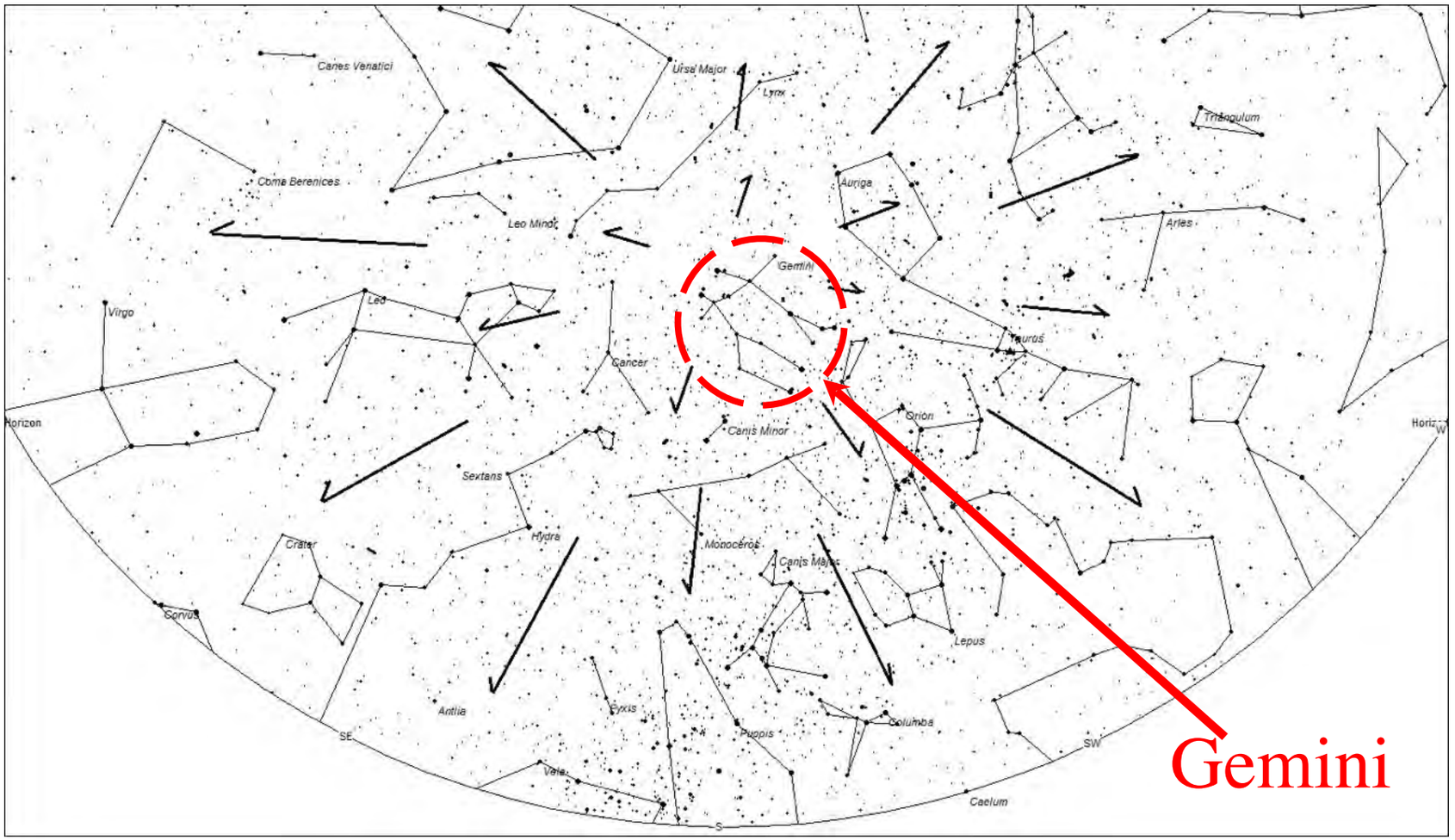
The map shows the occurrence of fireballs (bolides) over a 20 year period.

Meteors commonly occur in “showers” because comets produce large amounts of small particles along its orbital path to form a meteoroid "stream." If the Earth's orbit intersects the comet's orbit, then the Earth will pass through this stream for a few days at roughly the same time each year, producing a meteor shower.



Leonid meteor shower (1997) as seen from Earth orbit by the MSX satellite.

Meteors in a particular shower appear to diverge from a particular point in the sky (called a radiant). Meteor showers are named for the apparent constellation that they seem to eminate from.



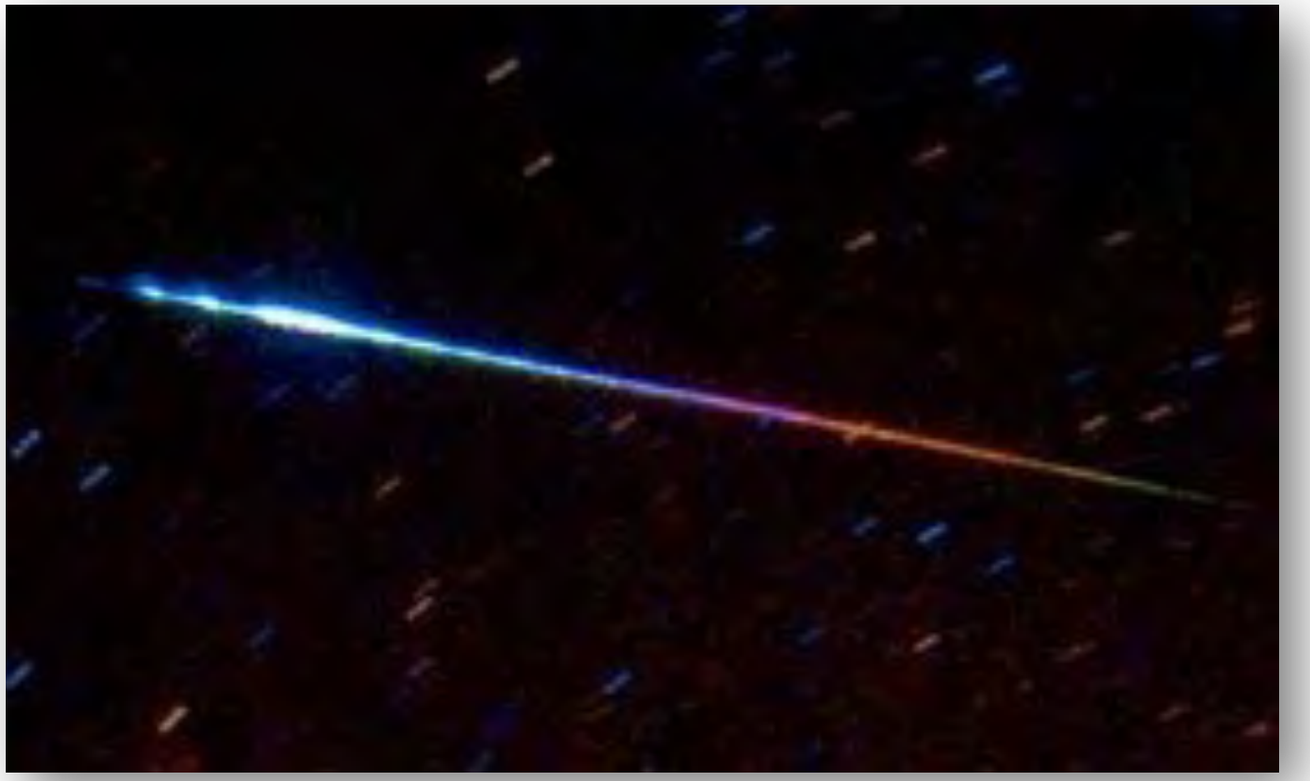


Cody Limber

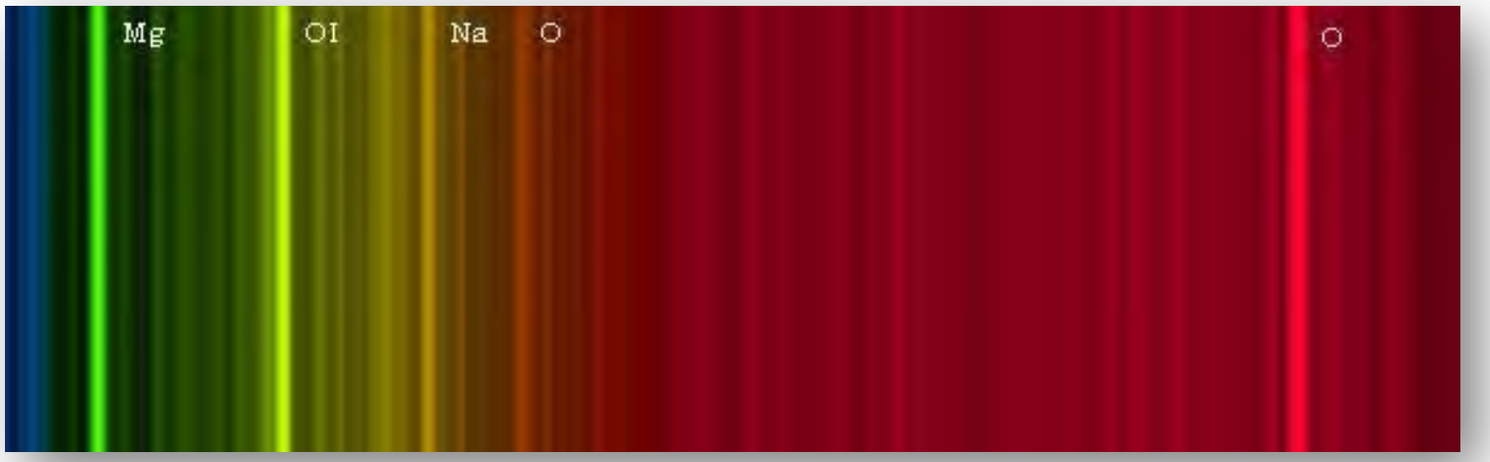
The photo shows a long exposure of the Geminid shower.

The size of most visible meteors is estimated to be from 1 mm and 1 cm in diameter and travel ~10-70 km/second. The meteor vaporizes in the Earth's atmosphere.

The color of meteors is caused by light emitted from metal atoms and by atoms and molecules of the air.



S. Kohle & B. Koch




Bill Ward, Society for Popular Astronomy

## Definitions

*Meteor* - an incandescent meteoroid passing through our atmosphere (shooting star).

*Fireball* - fireballs are very bright meteors with some being as bright as the Moon or Sun.

*Meteorite* - a body that has impacted on the Earth's surface

*Fall* - a meteorite that was observed to fall to the ground.

*Find* - a meteorite that was not observed to fall but is recovered from the Earth's surface. The vast majority are iron meteorites.

*Parent body* - meteorites are thought to be fragments of larger parent bodies such as asteroids, planets and the Moon.

# III. Meteorites

Approximately 5-10 recoverable meteorites fall on Earth each year. Most meteors burn up in the atmosphere and it is only the larger objects that actually make it to the Earth's surface.

The study of meteorites is *meteoritics*.

*Meteoritics* gives us very valuable information about the origin, evolution and composition of our solar system.

A number of meteorites have come from other worlds (Mars and the Moon) and give us valuable information about them. Indeed, Martian meteorites are the only samples that we have of the planet Mars.

The photo shows the 1992 Peekskill meteorite that crashed into a Chevy Malibu.

R.A. Langheinrich Meteorite

# Park Forest Meteorite

Meteorite fragments fell on Chicago's southern suburbs on the night of March 26, 2003. Although no one was injured, plenty of roofs and cars were damaged.

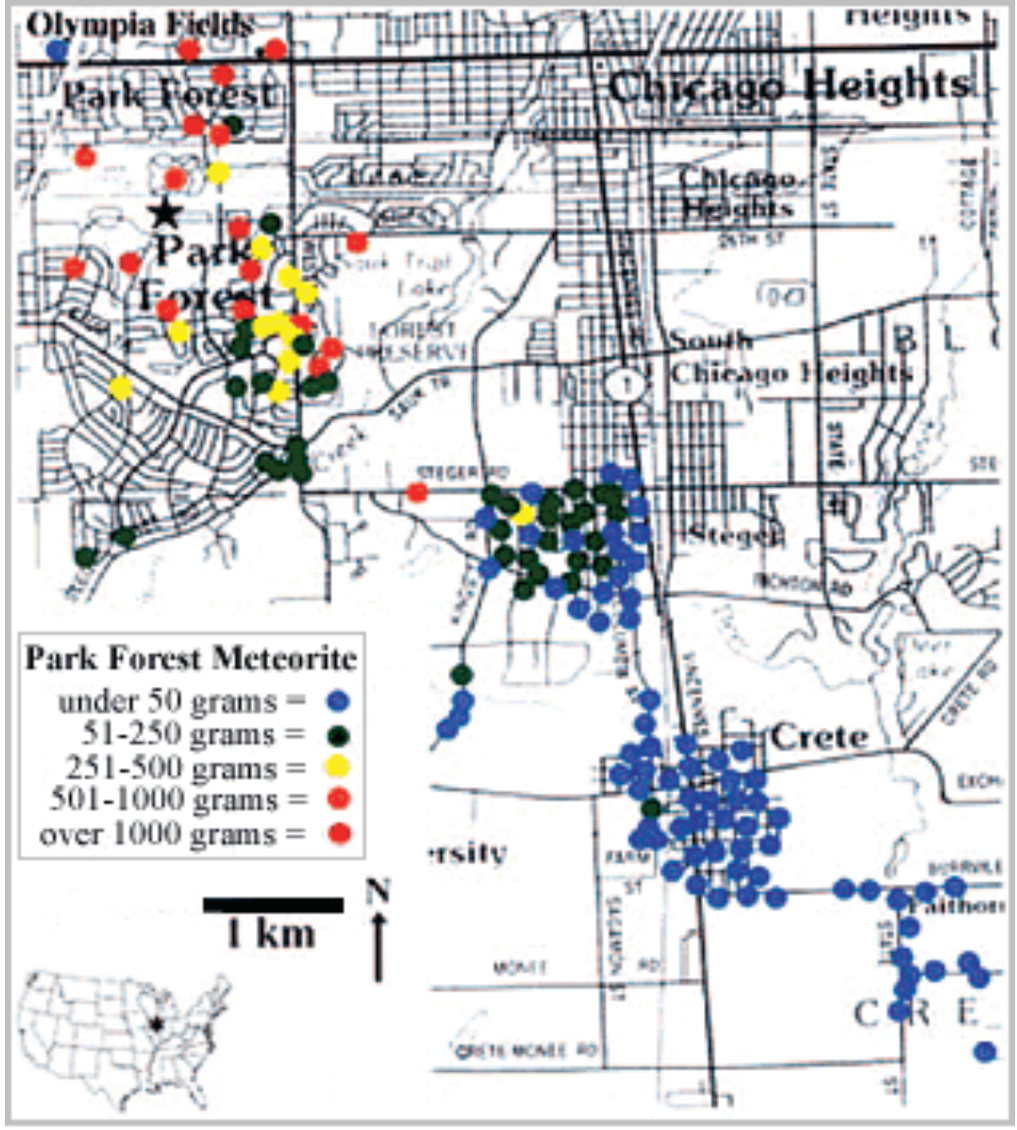

LEFT: Holes in a bedroom ceiling caused by infalling meteorites.

RIGHT: Impact damage to window blinds and sill.

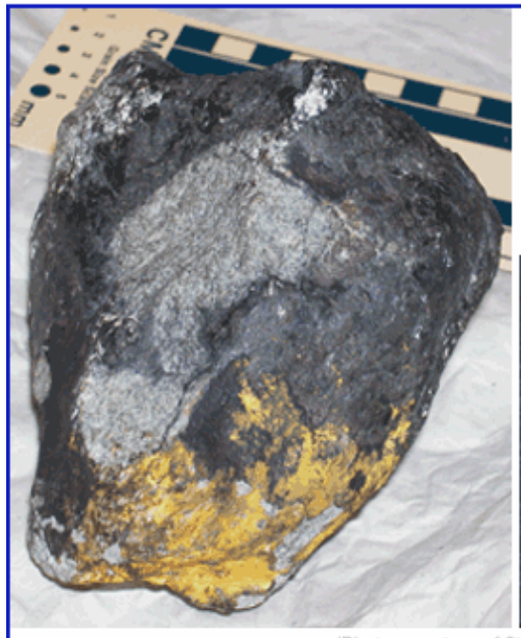
The 2.5-kilogram meteorite fragment that caused the damage. It displays a typical black fusion crust, which is broken in places revealing the lighter-colored interior.

(From Simon *et al.*, 2004, *Meteor. & Planet. Sci.*, v. 39, p. 627.)

It is thought that the meteor was 900 - 7000 kg of which only ~30 kg have been recovered.




(From Simon *et al.*, 2004, *Meteor. & Planet. Sci.*, v. 39, p. 626.)



## Park Forest Meteorite

LEFT: One piece shows colorful proof of where it landed.

BELOW: The impact site on a Park Forest street.

(Photos courtesy of Steven Simon, Univ. of Chicago.)

# Berthoud Meteorite

On October 5, 2004, at 1:30 in the afternoon, a meteorite fell in Berthoud, CO. The Whiteis family had just walked out of their house when they were distracted by whistling noise and a thump on the ground. Megan Whiteis observed some dust kicked up in a horse pen about 100 feet away.

Chirs L. Peterson, Cloudbait Observatory

Chirs L. Peterson, Cloudbait Observatory

After a short search, they recovered a baseball-size meteorite weighing about 2 pounds.

# Carancas Meteorite

On Sept. 15, 2007, a meteorite struck the ground near the town of Carancas, Peru. The impact left a crater ~13.5 meters in diameter and ejected material up to 200 meters away.

The object may have had an initial mass of 6-10 metric tons. Ablation in the atmosphere resulted in the size of the object being greatly reduced before it impacted.

There were initially reports of many illnesses of local residents associated with the impact that were greatly exaggerated.

Meteorite Gallery

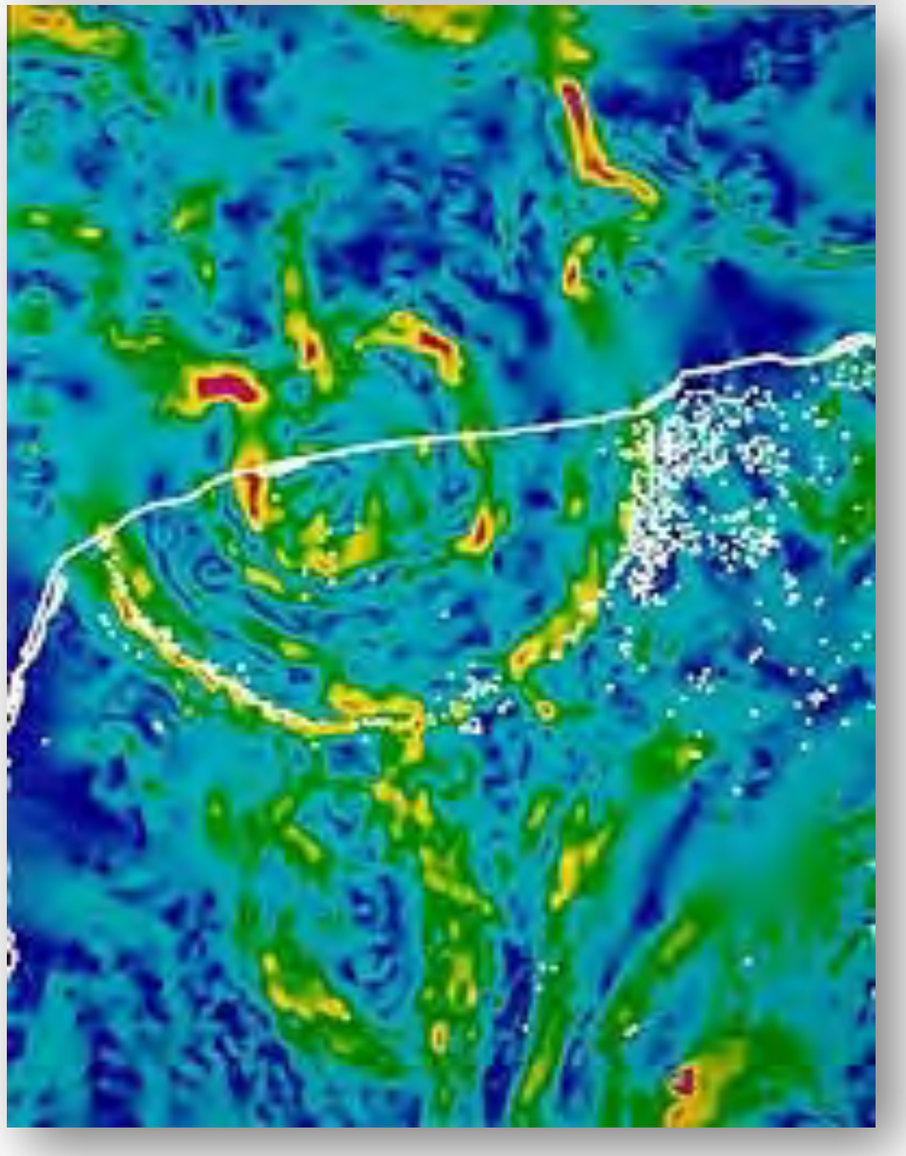

Meteorite Recon

# Chicxulub Crater

It has been hypothesized that the major dinosaur extinction event 65 million years ago (K-T boundary) was, at least in part, the result of an enormous meteorite impact. 85% of the species went extinct around this time period.

A layer of ash has been identified around the world at the K-T boundary that correlates in time with this extinction event. It is believed that this ash layer was produced by the massive impact.

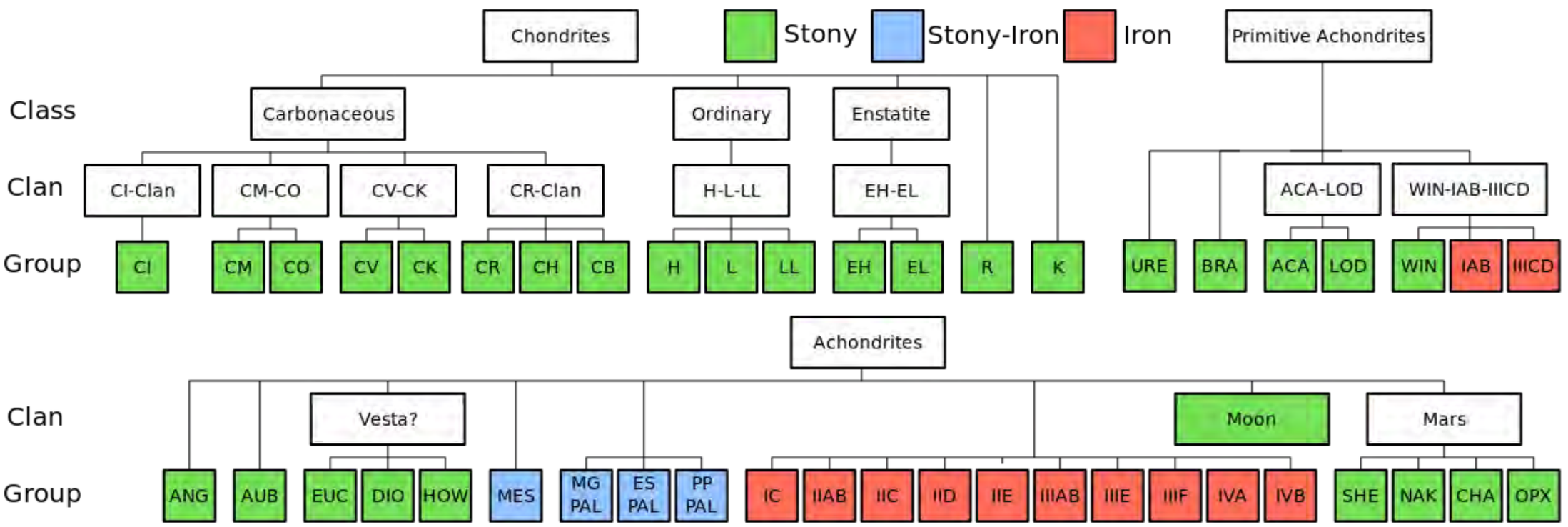
The Chicxulub crater in the Yucatan peninsula of Mexico has been identified as the site of this impact.

NASA

# Meteorite Classification

The primary classification of  meteorites is based on composition, mineralogy and the fabric/texture of the minerals in the meteorite.




Tobias 1984

There are three main categories of meteorites:

- Stony meteorites (stones) - predominantly silicate material
- Iron meteorites - pure Ni-Fe metal alloy
- Stony-iron meteorites - mixed iron and stony parts

# Tektites

Tektites are small glass objects composed of silica-rich (~73% $SiO_2$) glass - similar to obsidian. They commonly have rounded and aerodynamic shapes.

They are commonly found in distinct fields spread over hundreds of kilometers.

tektites.co.uk

The current hypothesis for their origin is that they were blasted into the atmosphere by impacts. They are commonly associated with an impact craters of the same age.

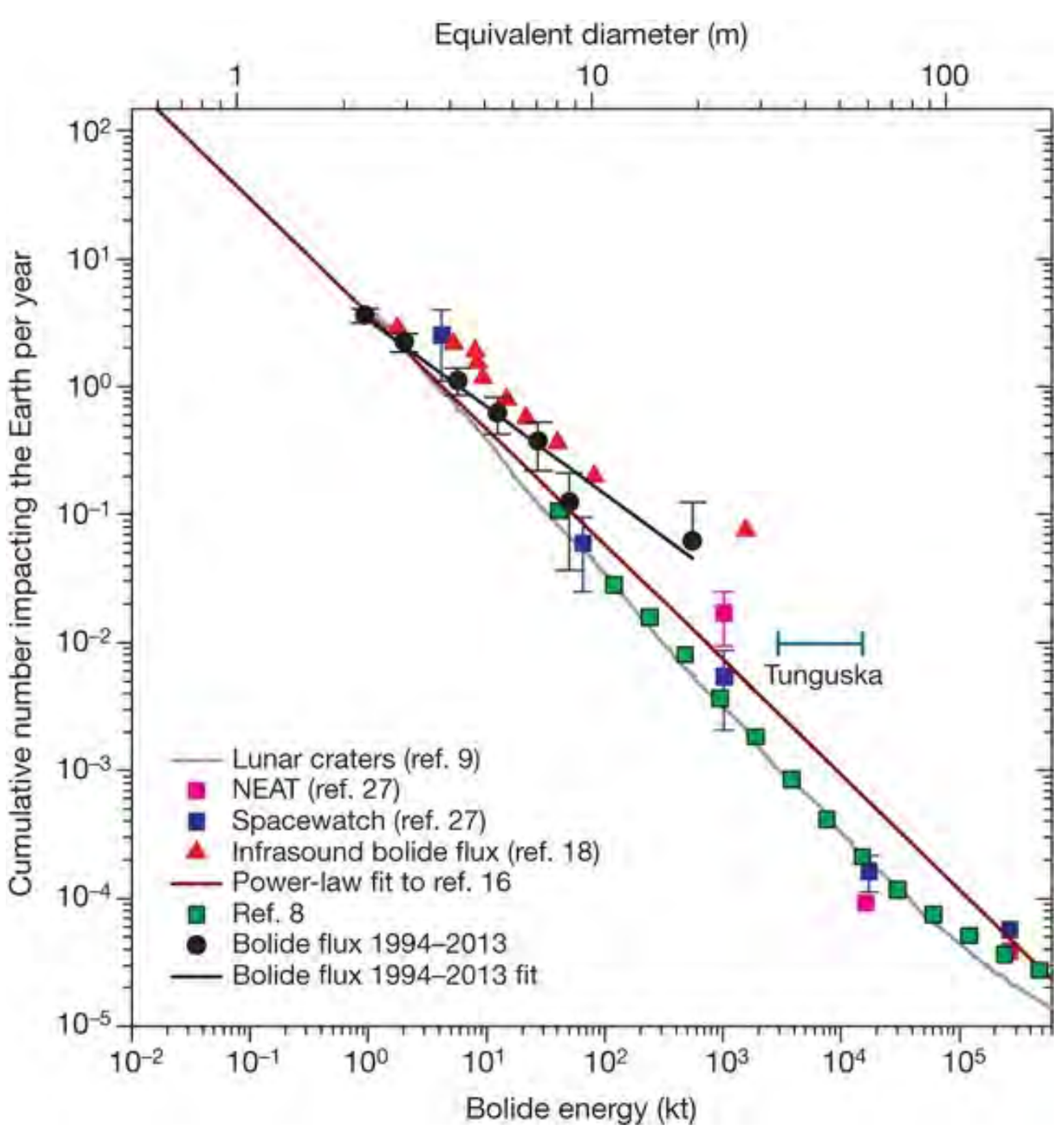
Cosmic ray exposure ages indicate that they have not spent significant time in space (<300 years) - probably just minutes.

# Meteoroid Flux

Small meteorites strike the Earth's surface every year. Large impacts occur approximately once or twice a century.

Most of the impacts occur in the Earth's oceans.

Very large events occur every 10,000's of years – these could be events that end our civilization.

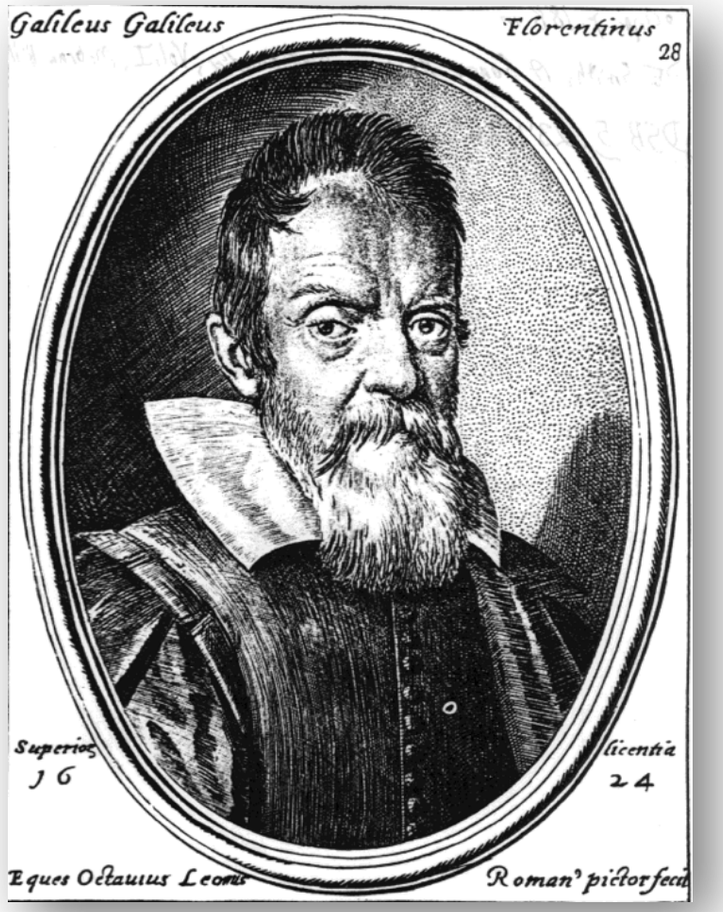


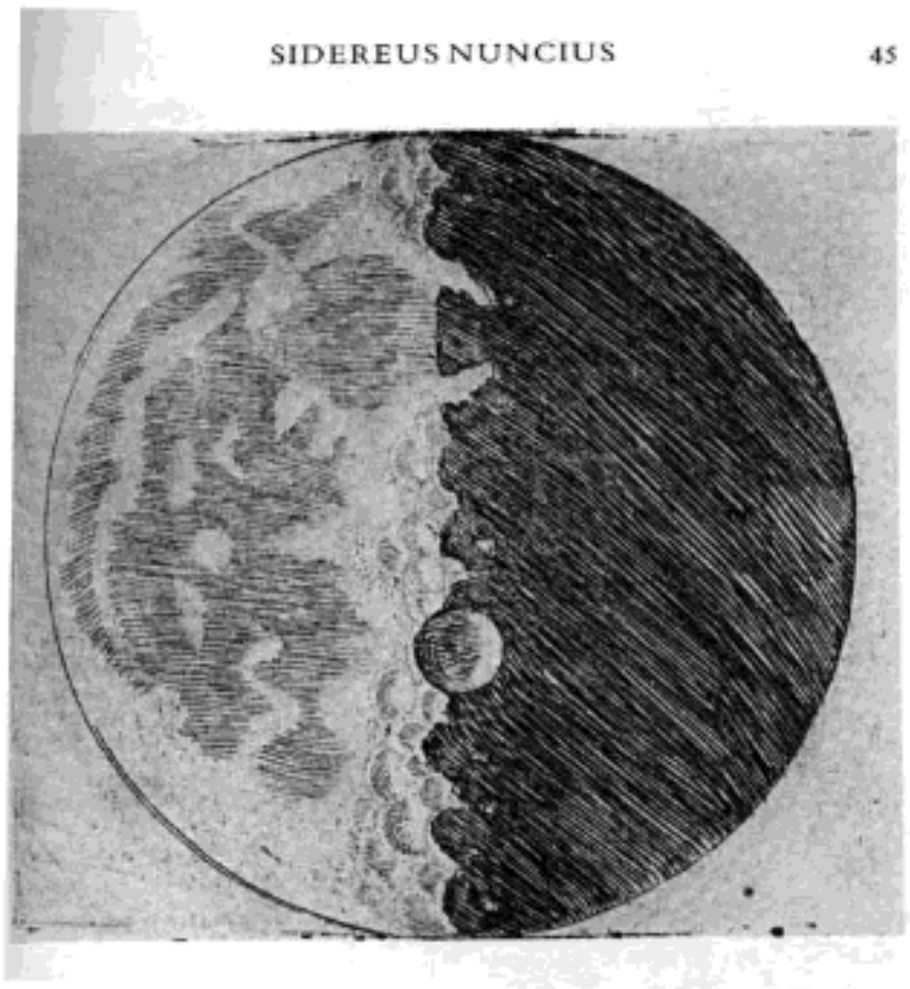

Brown et al. (2013) Nature

# IV. Impacts

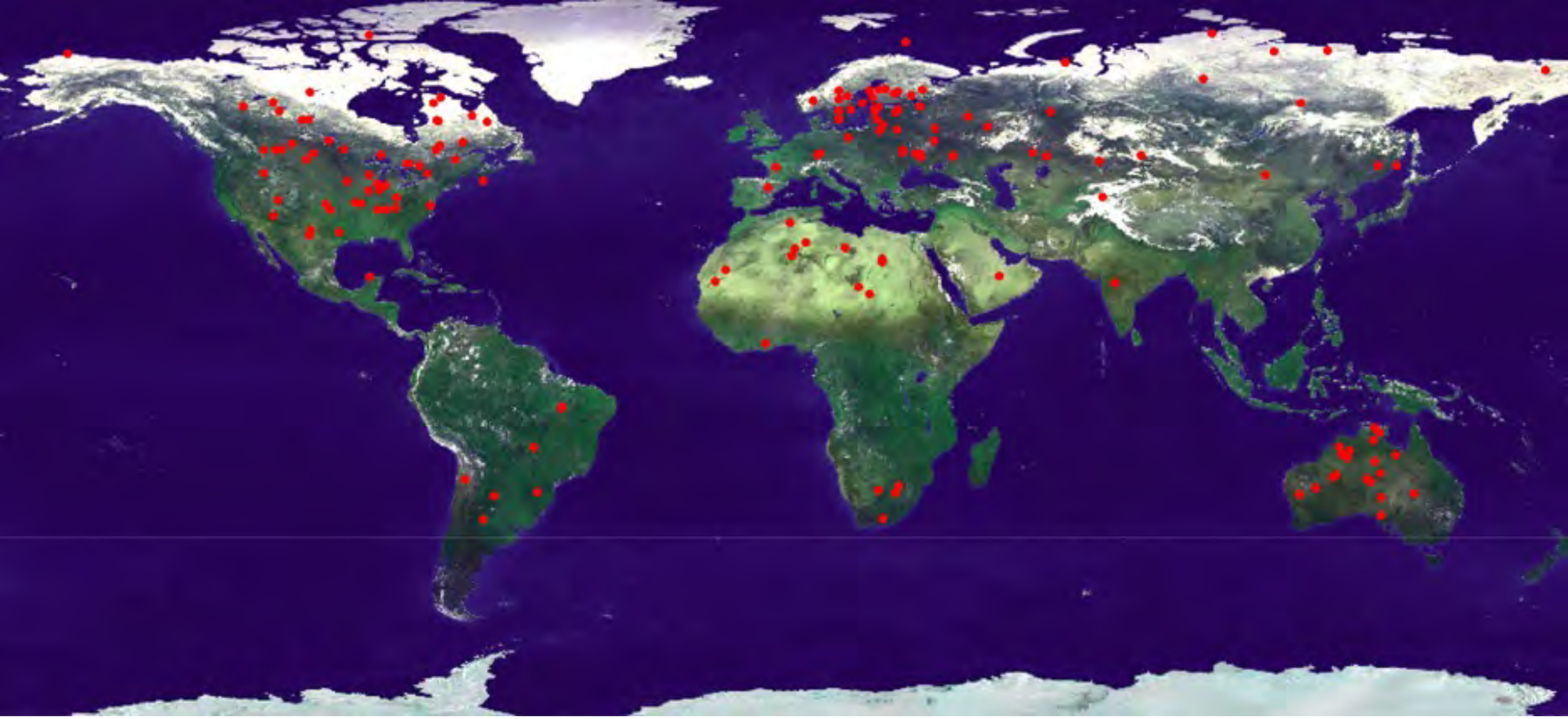
Galileo described the cup-shaped features on the Moon that he named craters after the Greek word for cup.

Their origin was debated until the 20th century when similar features were identified on Earth and recognized to be the result of an impact.




One of Galileo's drawings of the Moon (~1610).



Lunar and Planetary Institute

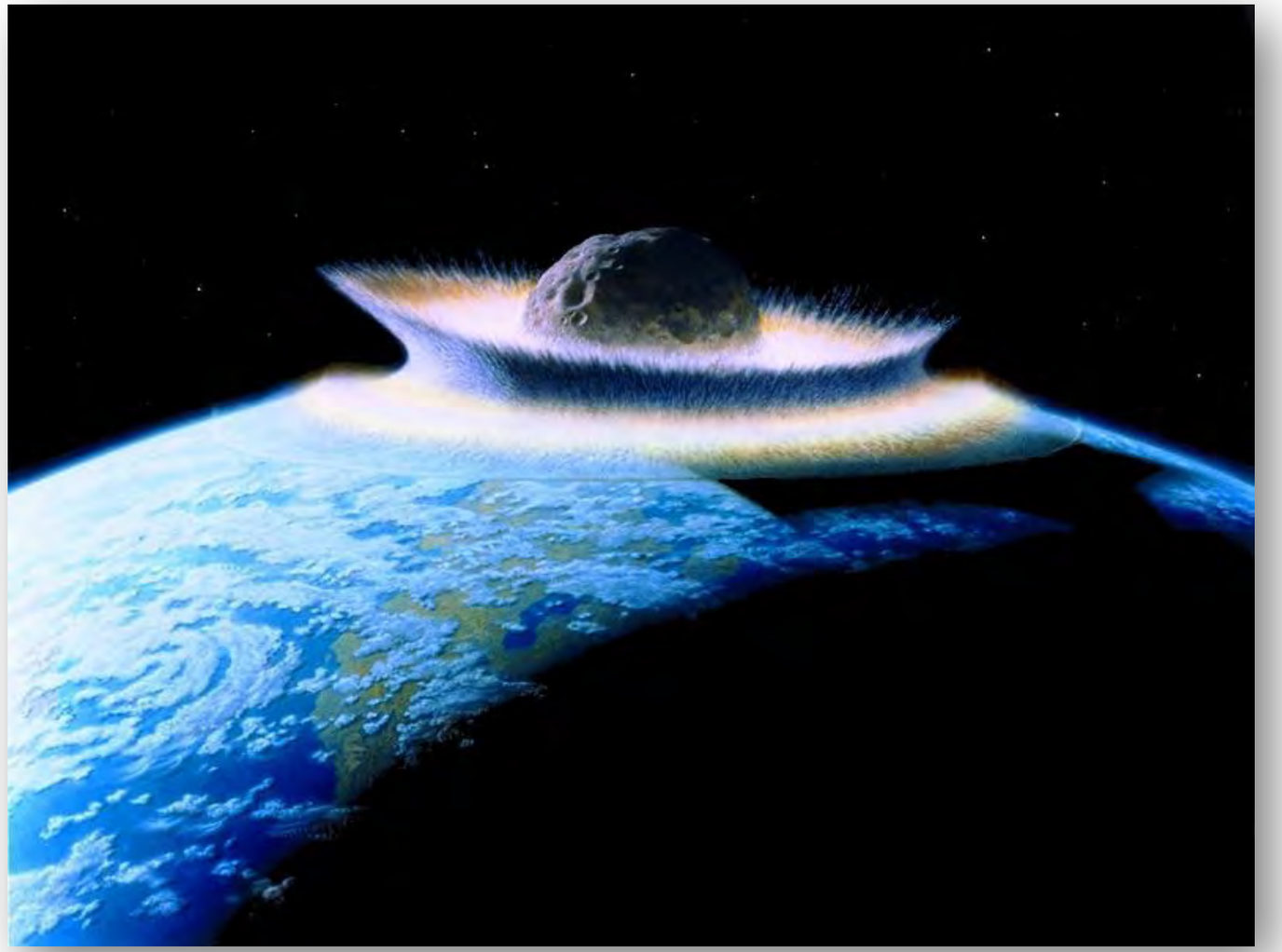
~120 impact craters have been identified on the Earth. They are found on the continents - seafloor is too young to preserve them.

The number of impact craters on Earth is much lower than on other worlds such as our own Moon because of resurfacing processes such as plate tectonics and erosion.

Meteorites typically strike planetary surfaces at 10's km/sec or more.

If the planet has a substantial atmosphere, smaller meteorites are slowed and do not form impact craters.

When a hypersonic meteorite strikes a surface, it is moving into the surface faster than the seismic velocity (1-4 km/sec) - forming a highly compressed shock wave in front of the impactor.



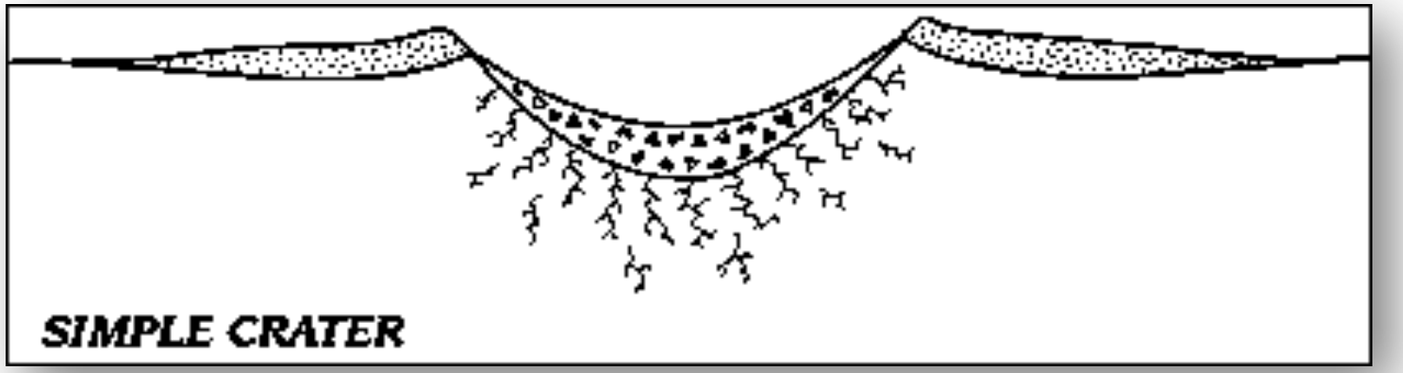
NASA

The result is that it can be modeled as an explosion centered below the surface at a depth of a few meteorite diameters.

*Simple craters* (Earth & Moon) tend to have smooth, bowl-shaped interiors and are ~1 km in diameter.

Note the development of a blanket of material ejected from the crater by the impact.

During impact, the impactor is vaporized and fragmented. It is common to find fragments of an impactor (meteorites) in the blanket of ejected material.




Lunar and Planetary Institute

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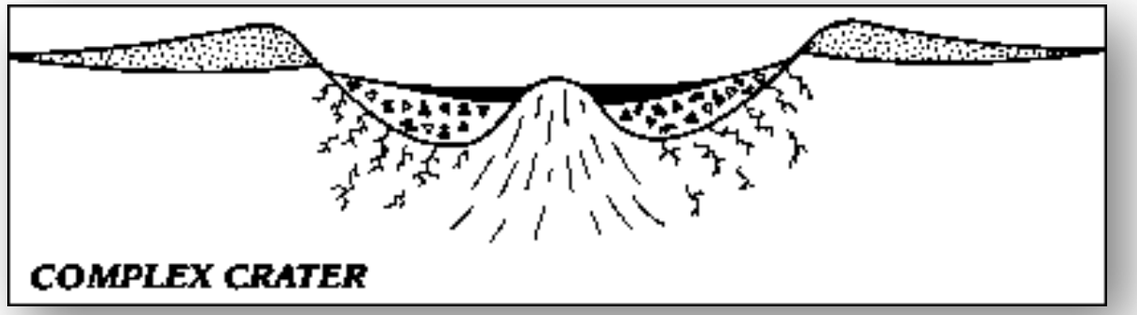
Larger craters tend to have flattened floors.

Central peaks may form from rebound. In addition, large craters may have terraced inner walls. These are known as *complex craters*.

Complex craters have large blankets of material ejected from the impact.

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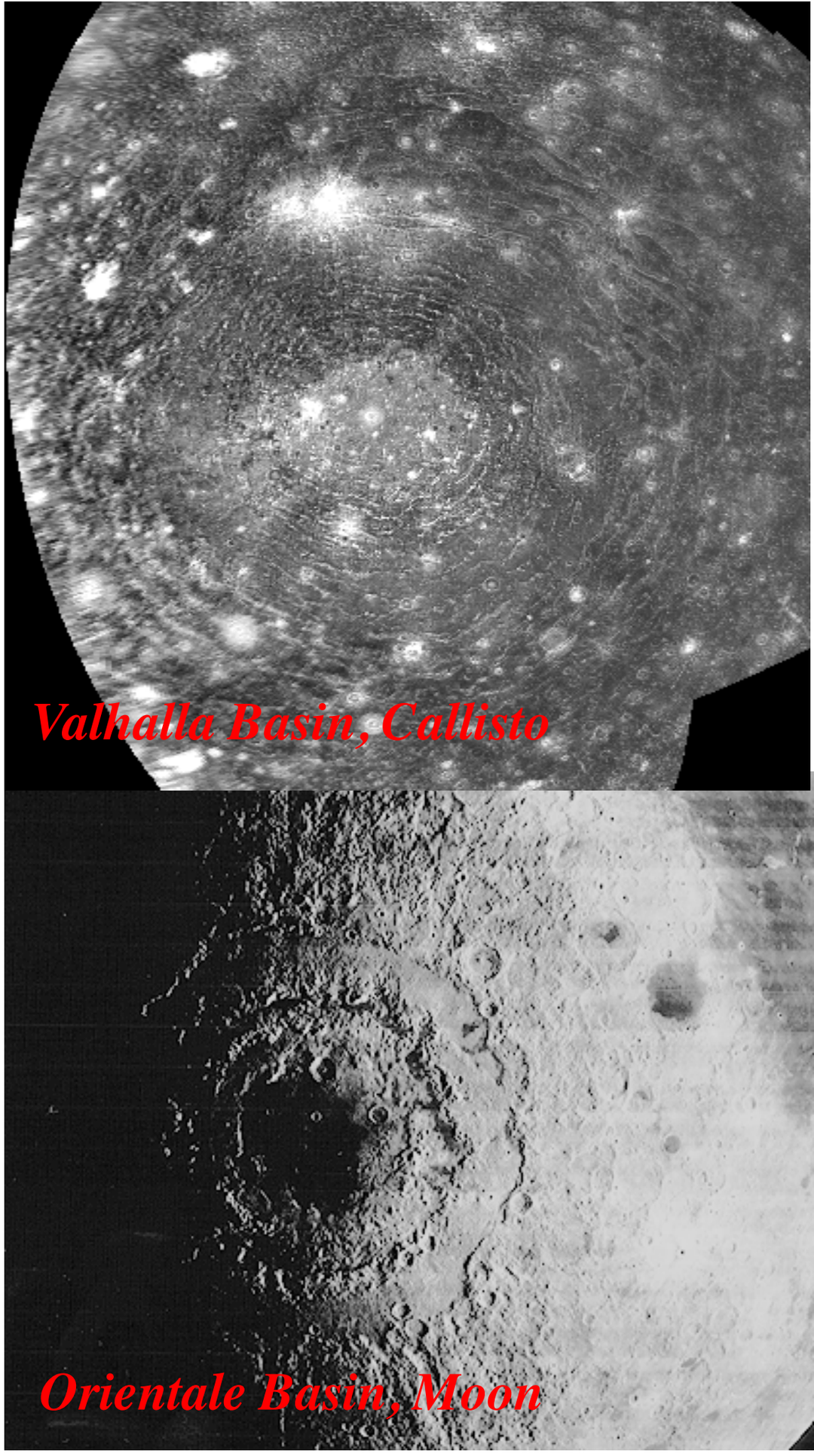
The largest impact events produce huge systems of concentric rings known as *multiring systems*.

They are defined by concentric rings of hills and usually partially filled with basalt.

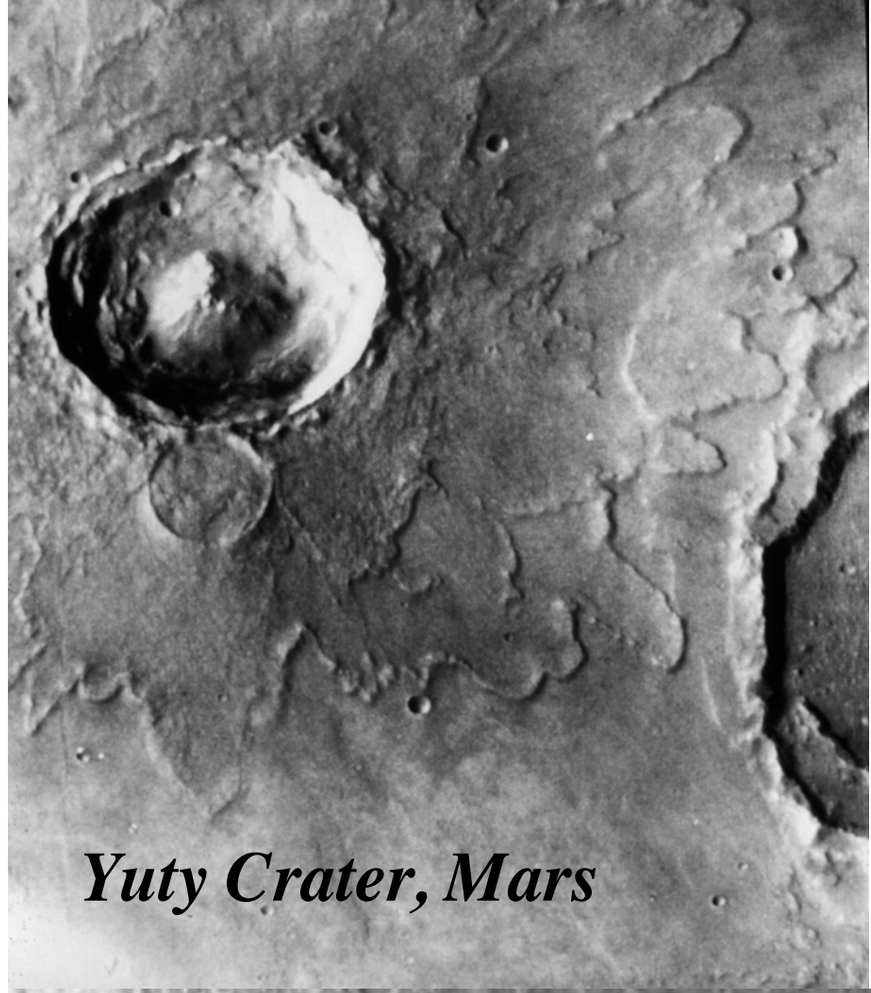



NASA

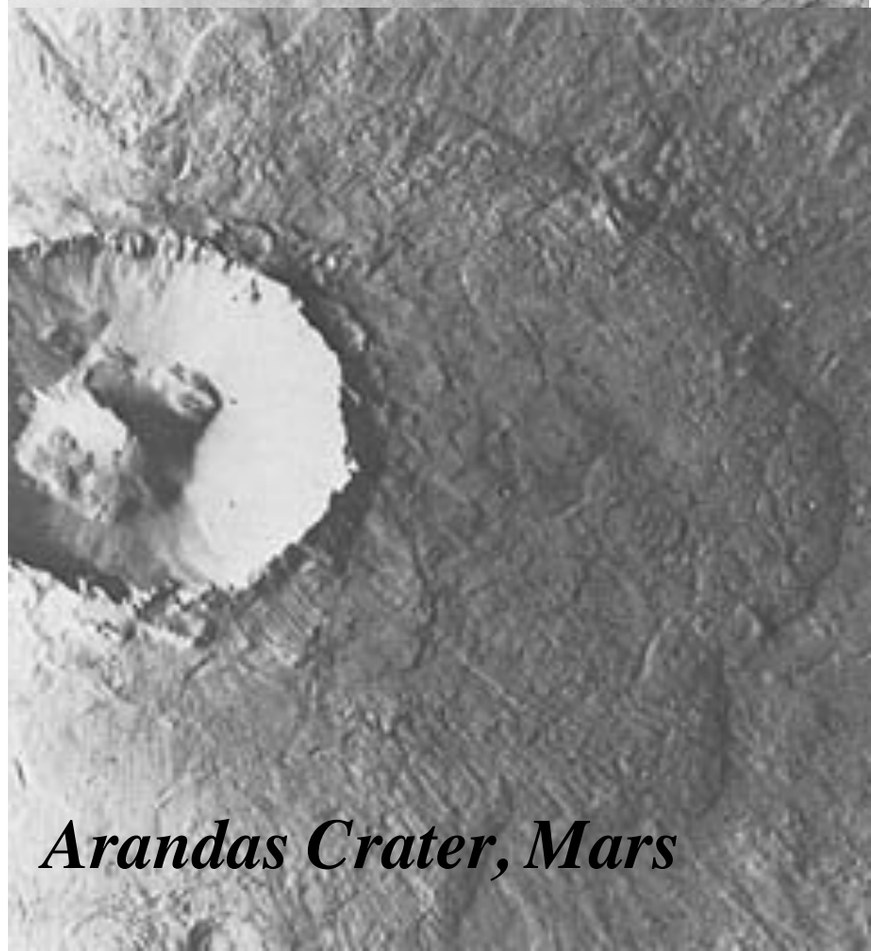
The ejecta blanket of many craters on Mars have lobate structures that suggest that they may have occurred in soils rich in water or ice - there appear to be muddy "ejecta flows." These types of craters are known as *rampart craters*.

These features not observed on dry worlds such as the Moon and Mercury.

Rampart craters occur commonly on Mars. However in some areas, the lobate structures do not form and suggests that these may be drier regions.



***Yuty Crater, Mars***



***Arandas Crater, Mars***