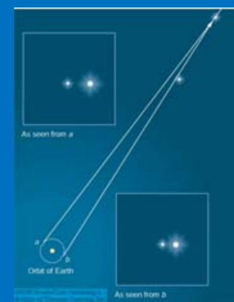
Chapter 15

Uranus, Neptune and the Kuiper Belt

Uranus

Chance discovery by William Herschel in 1781

Hershel was scanning the sky for nearby objects with measurable parallax: discovered Uranus as slightly extended object, ~ 3.7 arc seconds in diameter.

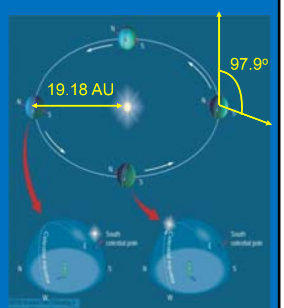


The Motion of Uranus

Very unusual orientation of rotation axis: Almost in the orbital plane.

Possibly result of impact of a large planetesimal during the phase of planet formation.

Large portions of the planet exposed to "eternal" sunlight for many years, then complete darkness for many years!



The Atmosphere of Uranus

Like other gas giants: No surface.

Gradual transition from gas phase to fluid interior.

Mostly H; 15 % He, a few % methane, ammonia and water vapor.

Optical view from Earth: Blue color due to methane, absorbing longer wavelengths

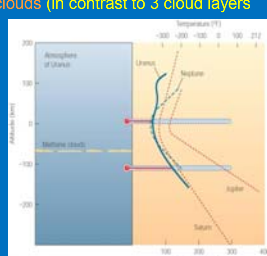
Structure of Uranus's Atmosphere

Only one layer of methane clouds (in contrast to 3 cloud layers on Jupiter and Saturn).

3 cloud layers in Jupiter and Saturn form at relatively high temperatures that occur only very deep in Uranus's atmosphere.

Uranus's cloud layer difficult to see because of thick atmosphere above it.

Also shows *belt-zone structure*



→ Belt-zone cloud structure must be dominated by planet's rotation, not by incidence angle of sun light!

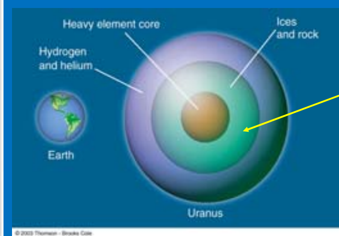
Cloud Structure of Uranus

Hubble Space Telescope image of Uranus shows cloud structures not present during Voyager's passage in 1986.

→ Possibly due to seasonal changes of the cloud structures.

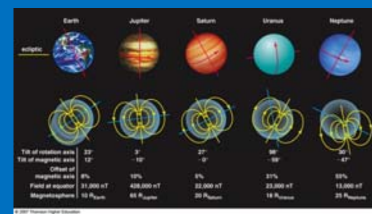
The Interior of Uranus

Average density ≈ 1.29 g/cm^3 → larger portion of rock and ice than Jupiter and Saturn.



Ices of water, methane, and ammonia, mixed with hydrogen and silicates; source of magnetic field?

Magnetic Field



The magnetic fields of Uranus and near neighbor Neptune are unusual in that they are at a large angle to their axis of rotation and offset from their centers. This suggests that the dynamo effect operates differently on these two planets.

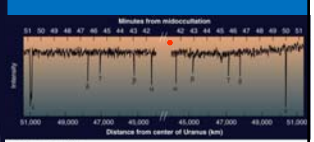
http://planet.infowars.com/science/explanation-for-why-satellites-shift

The Rings of Uranus

Rings of Uranus and Neptune are similar to Jupiter's rings.

Confined by shepherd moons; consist of dark material.

Rings of Uranus were discovered through occultations of a background star



The Moons of Uranus

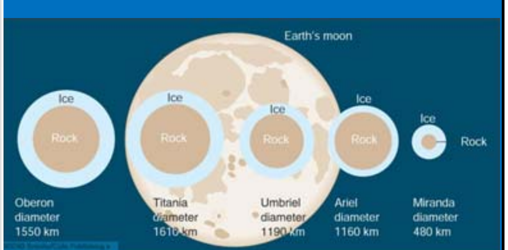
5 largest moons visible from Earth.

10 more discovered by Voyager 2; more are still being found.

Dark surfaces, probably ice darkened by dust from meteorite impacts.

5 largest moons all tidally locked to Uranus.

Interiors of Uranus's Moons

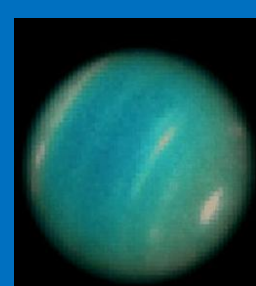


Large rock cores surrounded by icy mantles.

Neptune

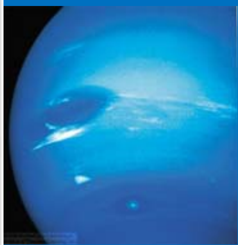
Discovered in 1846 at position predicted from gravitational disturbances on Uranus's orbit by J. C. Adams and U. J. Leverrier.

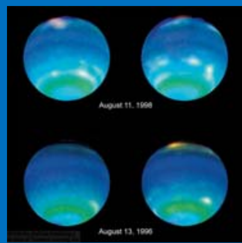
Blue-green color from methane in the atmosphere



4 times Earth's diameter; 4% smaller than Uranus

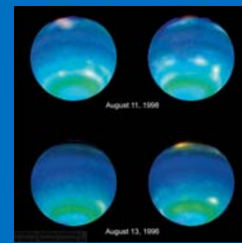
The Atmosphere of Neptune (1)





Cloud-belt structure with high-velocity winds; origin not well understood.

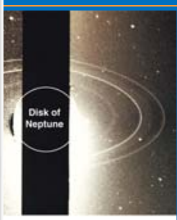
The Atmosphere of Neptune (2)



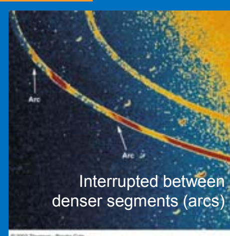
Darker cyclonic disturbances, similar to Great Red Spot on Jupiter, but not long-lived.

White cloud features of methane ice crystals

The Rings of Neptune (1)

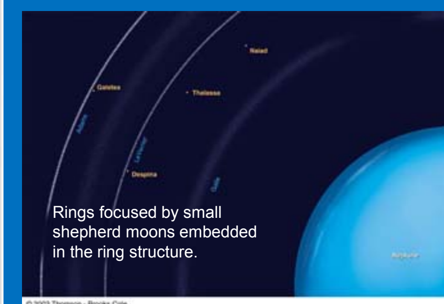


Made of dark material, visible in forward-scattered light.



Ring material must be regularly re-supplied by dust from meteorite impacts on the moons.

The Rings of Neptune (2)



Neptune's Moon Triton

→ Triton can hold a tenuous atmosphere of nitrogen and some methane; 10^5 times less dense than Earth's atmosphere.

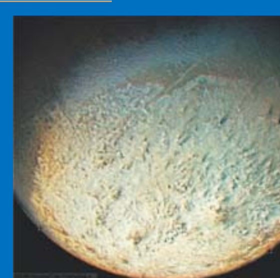
Surface composed of ices: nitrogen, methane, carbon monoxide, carbon dioxide.

Very low temperature (34.5 K)

Neptune's Moon Triton

Possibly cyclic nitrogen ice deposition and re-vaporizing on Triton's south pole, similar to CO_2 ice polar cap cycles on Mars.

Dark smudges on the nitrogen ice surface, probably due to methane rising from below surface, forming carbon-rich deposits when exposed to sun light.

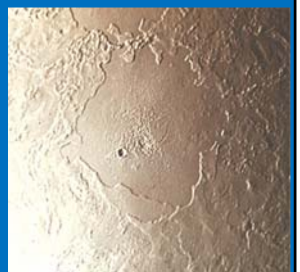


Neptune's Moon Triton (2)

Ongoing surface activity: Surface features probably not more than 100 million years old.

Large basins might have been flooded multiple times by liquids from the interior.

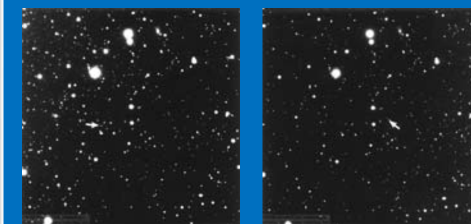
Triton has nitrogen volcanoes!



Ice equivalent of greenhouse effect may be one of the heat sources for Triton's geological activity.

Pluto

Discovered 1930 by C. Tombaugh.



Existence predicted from orbital disturbances of Neptune, but Pluto is actually too small to cause those disturbances.

Pluto as a Planet

Virtually no surface features visible from Earth.

~ 65% of size of Earth's moon.

Highly elliptical orbit; coming occasionally closer to the sun than Neptune.

Orbit highly inclined (17°) against other planets' orbits

→ Neptune and Pluto will never collide.

Pluto as a Planet

Surface covered with nitrogen ice; traces of frozen methane and carbon monoxide.

Daytime temperature (50 K) enough to vaporize some N and CO to form a very tenuous atmosphere.

Pluto and Charon

Orbit highly inclined against orbital plane.

From separation and orbital period:

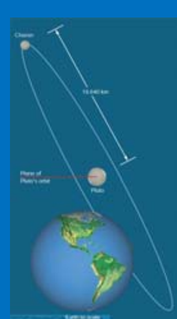
M_{pluto} ~ 0.2 Earth masses.

Density ≈ 2 g/cm³

(both Pluto and Charon)

→ ~ 35 % ice and 65 % rock.

Large orbital inclinations → Large seasonal changes on Pluto and Charon.



The New Horizons Mission

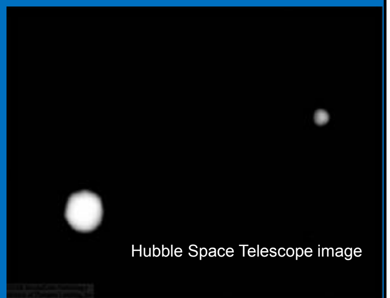
New Horizons launched on Jan. 19, 2006; it swung past Jupiter for a gravity boost and scientific studies in February 2007, and conducted a six-month-long reconnaissance flyby study of Pluto and its moons in summer 2015, culminating with Pluto closest approach on July 14, 2015.

NASA/Johns Hopkins University Applied Physics Laboratory/Southwest Research Institute

Pluto's Moon Charon

Discovered in 1978; about half the size and 1/12 the mass of Pluto itself.

Tidally locked to Pluto.



Hubble Space Telescope image

The New Horizons Mission

Image of Charon taken by New Horizons spacecraft.

The New Horizons Mission

Image from the closest approach fly-by of New Horizons. Ice mountains several km high!

NASA/Johns Hopkins University Applied Physics Laboratory/Southwest Research Institute

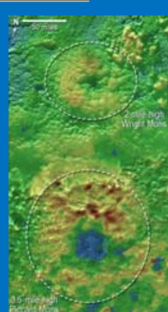
The New Horizons Mission

Best overall view of Pluto made by combining images made by New Horizons.

NASA/Johns Hopkins University Applied Physics Laboratory/Southwest Research Institute

The New Horizons Mission

Ice-volcanic Mountains called Wright Mons and Piccard Mons on Pluto.



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The New Horizons Mission

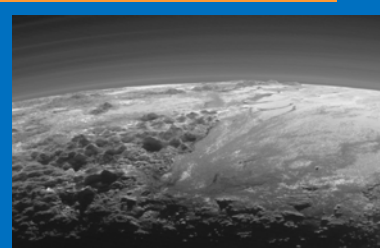
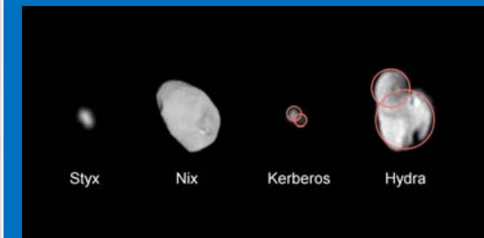


Image of Pluto showing mountains, plains and the thin atmosphere of the planet.

NASA/Johns Hopkins University Applied Physics Laboratory/Southwest Research Institute

The New Horizons Mission



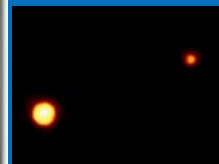
Pluto's smaller moons, showing indications that they were once separate objects that merged together.

NASA/Johns Hopkins University Applied Physics Laboratory/Southwest Research Institute

The Origin of Pluto and Charon

Probably very different history than neighboring Jovian planets.

Older theory: Pluto and Charon formed as moons of Neptune, ejected by interaction with massive planetesimal.

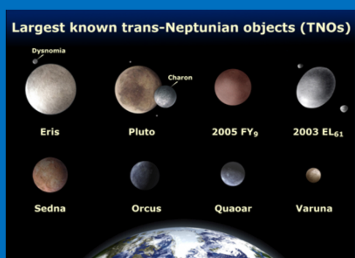


Mostly abandoned today since such interactions are unlikely.

Modern theory: Pluto and Charon members of Kuiper belt of small, icy objects.

Collision between Pluto and Charon may have caused the peculiar orbital patterns and large inclination of Pluto's rotation axis.

Objects of the Kuiper Belt



Pluto is part of a family of dwarf planets that exist far out on the edges of the solar system. Known as TNOs, these objects are all similar to each other (mostly ice) but dissimilar to planets.

http://www.universetoday.com/13573/why-pluto-is-no-longer-a-planet/

Chapter 16

Meteorites, Asteroids, and Comets

Meteorites

Distinguish between:

Meteoroid = small body in space

Meteor = meteoroid colliding with Earth and producing a visible light trace in the sky

Meteorite = meteor that survives the plunge through the atmosphere to strike the ground...

- Sizes from microscopic dust to a few centimeters.
- About 2 meteorites large enough to produce visible impacts strike Earth every day.
- Statistically, one meteorite is expected to strike a building somewhere on Earth every 16 months.
- Typically impact onto the atmosphere with 10 – 30 km/s (≈ 30 times faster than a rifle bullet).

Finding Meteorites

Most meteorites are small and do not produce significant craters.

Good place to find meteorites: Antarctica!

Distinguish between:

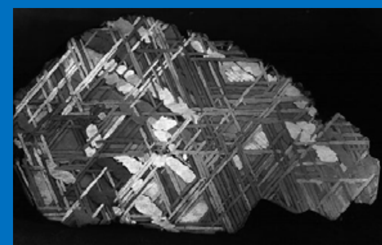
- Falls = meteorites which have been observed to fall (fall time known).
- Finds = meteorites with unknown fall time.

Inside Meteorites

3 broad categories:

Widmanstätten Patterns

A Widmanstätten pattern develops in iron meteorites and indicates slow cooling, allowing the mineral crystals to intergrow.



http://www.daviddarling.info/encyclopedia/W/Widmanstatten_pattern.html

Chondrites

Chondrites (such as NWA 869 shown here) are stony meteorites that have not been modified due to melting or differentiation of the parent body. They formed during the early history of the solar system when various types of dust and small grains accreted. They are the most common type of meteorite that falls to Earth (~86% of falls).

http://en.wikipedia.org/wiki/Chondrite

Carbonaceous Chondrites

Carbonaceous (C) chondrites, such as the Murchison, Australia chondrite shown here, are some of the most complex of all meteorites. They are rare, primitive and contain organic compounds. Most importantly they contain water-bearing minerals which is evidence of water moving slowly through their interiors not long after formation.

http://www.meteorlab.com/METEORLAB2001dev/carbchon.htm

Meteor Showers

Most meteors appear in showers, peaking periodically at specific dates of the year.

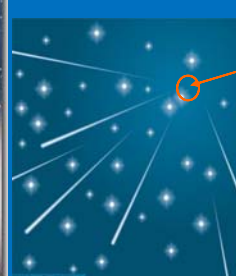
Table 25-1 Meteor Showers

Shower	Dates	Hourly Rate	Radiant* R. A.	Radiant* Dec.	Associated Comet
Quadrantids	Jan. 2–4	30	15^h24^m	50°	
Lyrids	April 20–22	8	18^h4^m	33°	1861 I
η Aquarids	May 2–7	10	22^h24^m	0°	Halley?
δ Aquarids	July 26–31	15	22^h36^m	10°	
Perseids	Aug. 10–14	40	3^h4^m	58°	1982 III
Orionids	Oct. 18–23	15	6^h20^m	15°	Halley?
Taurids	Nov. 1–7	8	3^h40^m	17°	Encke
Leonids	Nov. 14–19	6	10^h12^m	22°	1866 I Temp
Geminids	Dec. 10–13	50	7^h28^m	32°	

*R. A. and Dec. give the celestial coordinates (right ascension and declination) of the radiant of each shower.

Radiants of Meteor Showers

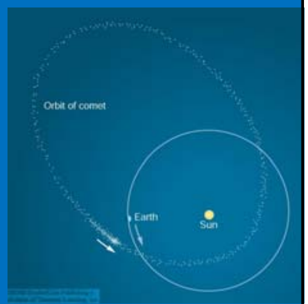
Tracing the tracks of meteors in a shower backward, they appear to come from a common origin, the radiant.



↔ Common direction of motion through space.

Meteoroid Orbits

- Meteoroids contributing to a meteor shower are debris particles, orbiting in the path of a comet.
- Spread out all along the orbit of the comet.
- Comet may still exist or have been destroyed.



Only a few *sporadic meteors* are not associated with comet orbits.

The Origins of Meteorites

- Probably formed in the solar nebula, ~ 4.6 billion years ago.
- Almost certainly not from comets (in contrast to meteors in meteor showers!).
- Probably fragments of stony-iron planetesimals
- Some melted by heat produced by ^{26}Al decay (half-life ~ 715,000 yr).
- ^{26}Al possibly provided by a nearby supernova, just a few 100,000 years before formation of the solar system (triggering formation of our sun?)

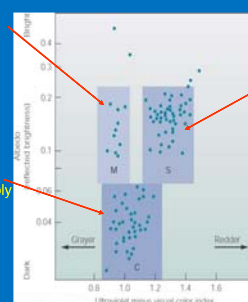
Asteroids

Last remains of planetesimals that built the planets 4.6 billion years ago!

Colors of Asteroids

M-type: Brighter, less reddish asteroids, probably made out of metal rich materials; probably iron cores of fragmented asteroids

C-type: Dark asteroids, probably made out of carbon-rich materials (carbonaceous chondrites); common in the outer asteroid belt

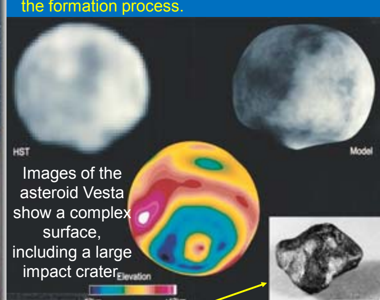


S-type: Brighter, redder asteroids, probably made out of rocky materials; very common in the inner asteroid belt

"*Colors*" to be interpreted as albedo (reflectivity) at different wavelengths.

The Origin of Asteroids

Distribution: S-type asteroids in the outer asteroid belt; C-type asteroids in inner asteroid belt → may reflect temperatures during the formation process.



Meteorite probably fragmented from Vesta

However, more complex features found:

Vesta shows evidence for impact crater and lava flows.

Heat for existence of lava flows probably from radioactive decay of ^{26}Al.

The Asteroid Belt

Small, irregular objects, mostly in the apparent gap between the orbits of Mars and Jupiter.

Thousands of asteroids with accurately determined orbits known today.

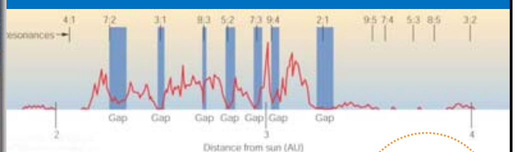
Sizes and shapes of the largest asteroids, compared to the moon

Kirkwood's Gaps

• The asteroid orbits are not evenly distributed throughout the asteroid belt between Mars and Jupiter.

• There are several gaps where no asteroids are found:

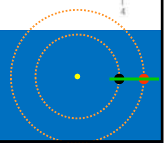
Kirkwood's gaps (purple bars below)



These correspond to resonances of the orbits with the orbit of Jupiter.

Example:

2:3 resonance



Non-Belt Asteroids

Not all asteroids orbit within the asteroid belt.

Apollo-Amor Objects:

Asteroids with elliptical orbits, reaching into the inner solar system.

Some potentially colliding with Mars or Earth.

Trojans: Sharing stable orbits along the orbit of Jupiter:

Trapped in the Lagrangian points of Jupiter.

Comets

Comet Ikeya-Seki in the dawn sky in 1965

Comets of Note

Throughout history, comets have been considered as portents of doom, even very recently:

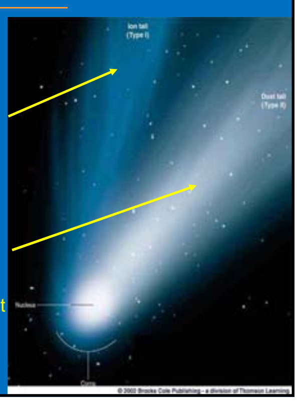
Appearances of comet Kohoutek (1973), Halley (1986), and Hale-Bopp (1997) caused great concern among the superstitious.

Comet Hyakutake in 1996

Two Types of Tails

Ion tail: Ionized gas pushed away from the comet by the solar wind. Pointing straight away from the sun.

Dust tail: Dust set free from vaporizing ice in the comet; carried away from the comet by the sun's radiation pressure. Lagging behind the comet along its trajectory



Comet Hale Bopp (1997)

The Geology of Comet Nuclei

Comet nuclei contain ices of water, carbon dioxide, methane, ammonia, etc.:

Materials that should have condensed from the outer solar nebula.

Those compounds sublime (transition from solid directly to gas phase) as comets approach the sun.

The Geology of Comet Nuclei (2)

Comet nuclei contain ices of water, carbon dioxide, methane, ammonia, etc.:

Materials that should have condensed from the outer solar nebula.

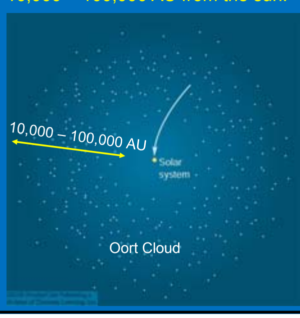
Densities of comet nuclei: ~ 0.1 – 0.25 g/cm^3

Not solid ice balls, but fluffy material with significant amounts of empty space.

The Origin of Comets

Comets are believed to originate in the Oort cloud:

Spherical cloud of several trillion icy bodies, ~ 10,000 – 100,000 AU from the sun.



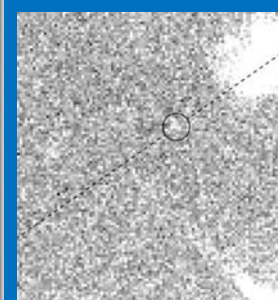
Gravitational influence of occasional passing stars may perturb some orbits and draw them towards the inner solar system.

Interactions with planets may perturb orbits further, capturing comets in short-period orbits.

The Kuiper Belt

Second source of small, icy bodies in the outer solar system:

Kuiper belt, at ~ 30 – 100 AU from the sun.



Some Kuiper belt objects can be observed directly by Hubble Space Telescope.

Pluto and Charon may be captured Kuiper belt objects.

Impacts on Earth

Over 150 impact craters found on Earth.

Famous example: Barringer Crater near Flagstaff, AZ:

Formed ~ 50,000 years ago by a meteorite of ~ 80 – 100 m diameter

Impact Craters on Earth

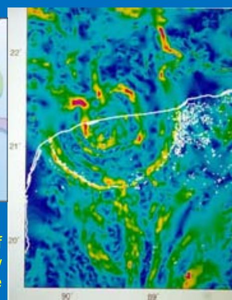
Barringer Crater: ~ 1.2 km diameter; 200 m deep

Much larger impact features exist on Earth:

- Impact of a large body formed a crater ~ 180 – 300 km in diameter in the Yucatán peninsula, ~ 65 million years ago.
- Drastic influence on climate on Earth; possibly responsible for extinction of dinosaurs.

Impacts on Earth

The impact of a small asteroid produced the **Chicxulub crater** ~ 65 million years ago, probably causing major climate change, leading to the extinction of many species, including dinosaurs.



Gravity map shows the extent of the crater hidden below limestone deposited since the impact.

Impacts on Earth (2)

The primary evidence cited for the Chicxulub impact being responsible for the extinction of the dinosaurs (and 75% of all species on Earth at the time) is an unusually high amount of iridium in a clay layer at the K-T boundary.

Iridium is common in meteorites and perhaps asteroids, but not in the Earth's crust.

Iridium is found in higher concentrations in some volcanic and intrusive igneous rocks where the magma origin is within the mantle.

Given the number of mass extinction episodes in Earth's past and the likelihood of major impacts, some scientists have concluded that asteroid impacts may be the culprit. The jury is still out however, as there is not the same level of evidence for other extinction events.