Cosmic Samples and the Origin of the Solar System

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Outline

1) Explain the phenomena of meteors and meteorites.

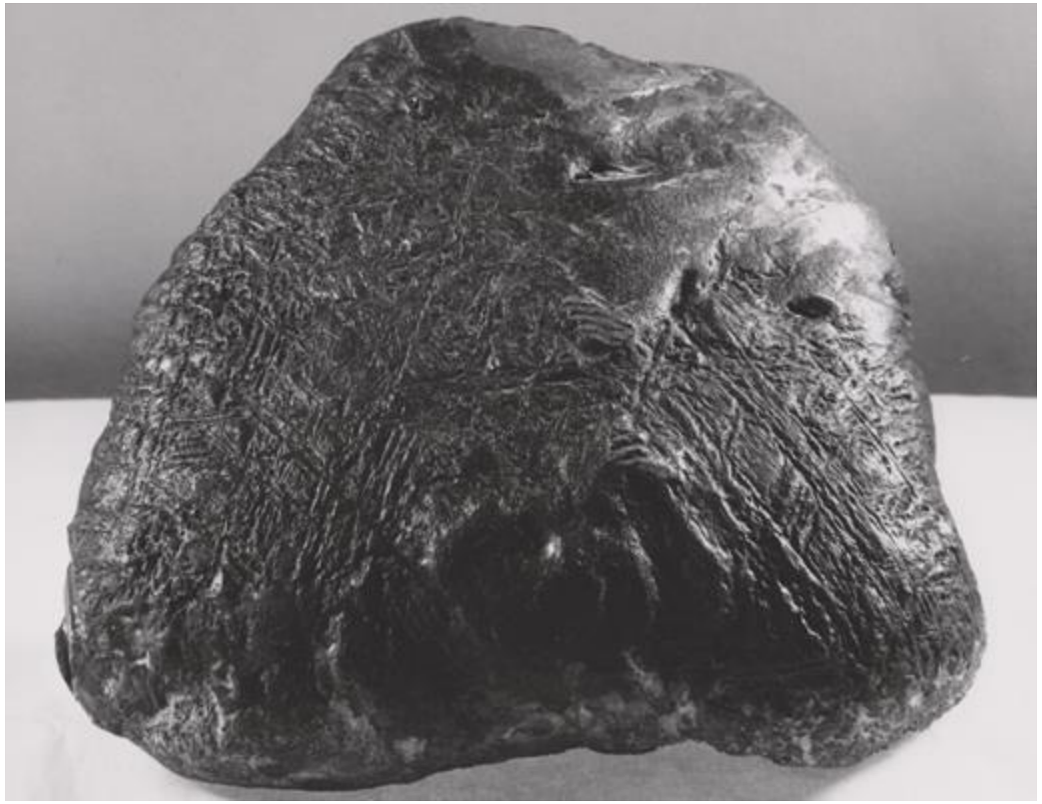
2) Evaluate the information provided by meteorites.

3) Develop a model for the formation of the solar system.

4) Compare and contrast our solar system with those around other stars

5) Explore the evolution of the planets in our solar system.

Lecture Section 1: Meteors and Meteorites



Meteors

Fireball. When a larger piece of cosmic material strikes Earth’s atmosphere, it can make a bright fireball. This time-lapse meteor image was captured in April 2014 at the Atacama Large Millimeter/Submillimeter Array (ALMA). The visible trail results from the burning gas around the particle. (credit: modification of work by ESO/C Malin)

Meteor Showers

Meteor showers at certain times of year.

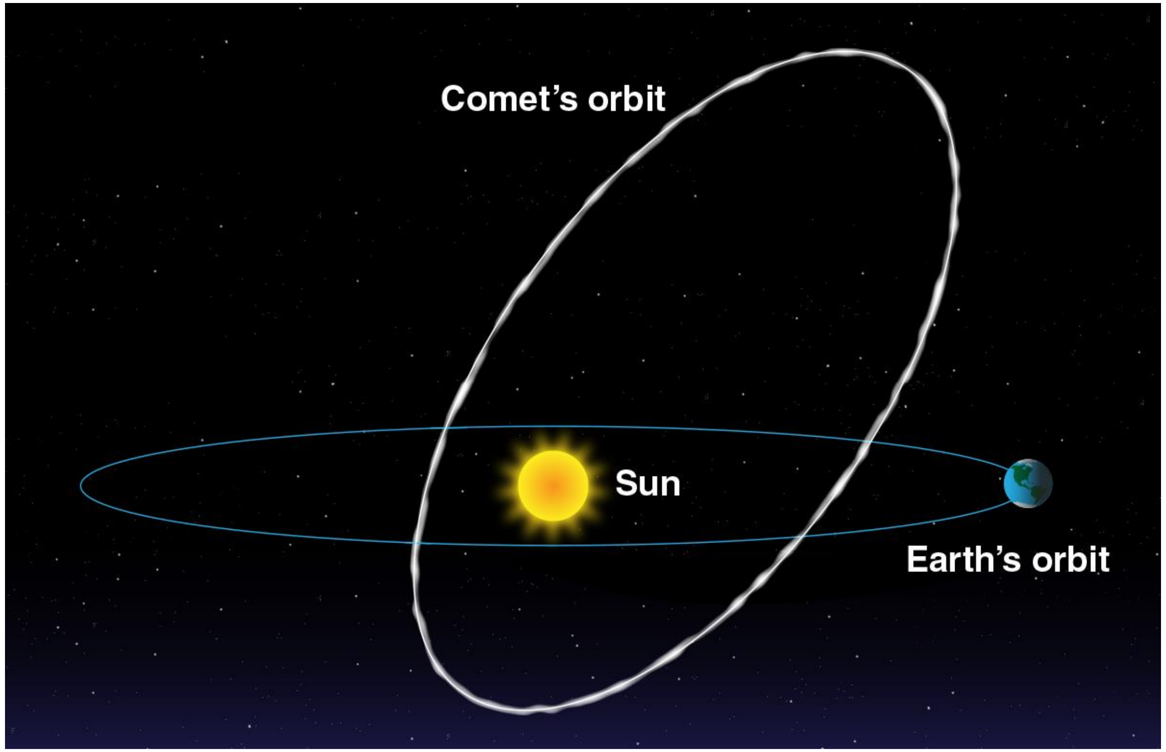
Time-lapse image of the 2009 Perseid shower as captured by NASA/JPL.

These are small pieces of debris from cometary material left in the orbital path of comet Swift-Tuttle.

Notice that all of the meteor ‘streaks’ originate from the direction of the constellation Perseus.

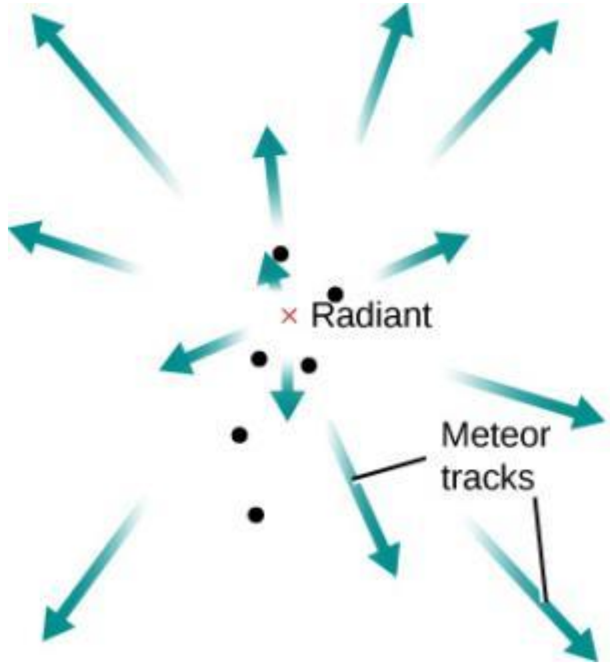
These occur regularly on specific days of the year

Meteor Showers



Crossing Paths. The dust left by a comet stays in orbit around the Sun. When the Earth's orbit crosses that path, we observe dust and debris entering the atmosphere. This creates the meteor shower.

Meteor Showers

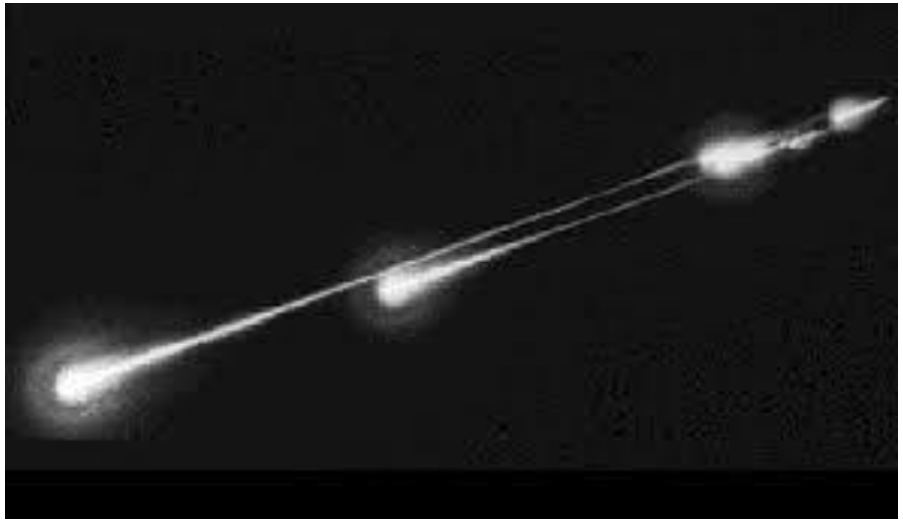


Radiant of a Meteor Shower. The tracks of the meteors diverge from a point in the distance, just as long, parallel railroad tracks appear to do. (credit “tracks”: Nathan Vaughn). The radiant is the direction of the Earth’s motion during the meteor shower.

Meteors to Meteorites

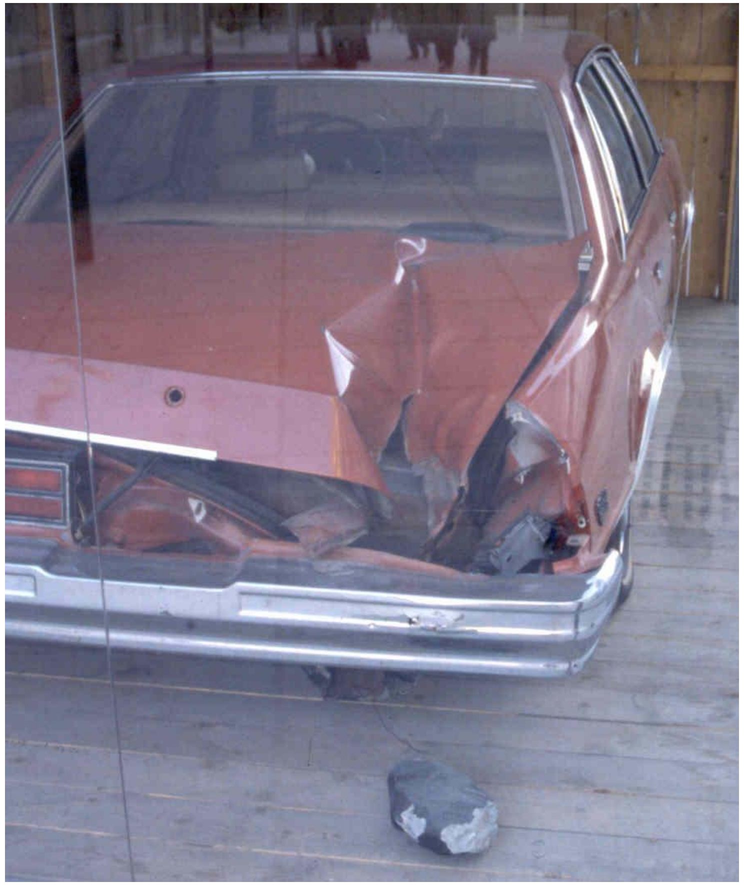
Peeksill, NY meteor. On a Friday night in 1992, a meteor arrived over Peekskill, NY which was captured on several cameras.

The footage helped trace the path of the meteor



Meteorites

Peeksill, NY meteor. The footage helped trace the path of the meteor, which led to the discovery of the corresponding meteorite.



Meteorite Hunters

Meteorite Find.

a) This early twentieth century photo shows a 15-ton iron meteorite found in the Willamette Valley in Oregon. Although known to Native Americans in the area, it was “discovered” by an enterprising local farmer in 1902, who proceeded to steal it and put it on display.

(a)

(b)

Meteorite Hunters

Meteorite Find.

b) It was eventually purchased for the American Museum of Natural History and is now on display in the museum’s Rose Center in New York City as the largest iron meteorite in the United States. In this 1911 photo, two young boys are perched in the meteor’s crevices.

(a)

(b)

Meteorite Types

Types.

Carbonaceous – dark with white inclusions.

Metallic – piece of the iron meteorite responsible for Meteor Crater

Stony – mixture of the mineral olivine and metallic iron. (credit a: modification of work by James St. John; credit b: modification of work by “Taty2007”/Wikimedia Commons; credit c: modification of work by Juan Manuel Fluxa)

(a) (b) (c)

Identifying Meteorites

To look for:

No air pockets. Meteorites formed in the vacuum of space.

Many times they are magnetic.

Fusion crust and “dented” look.

Dead giveaway – Widmanstätten pattern, metal crystal structure (credit: wikipedia; commons)

Data from Meteorites

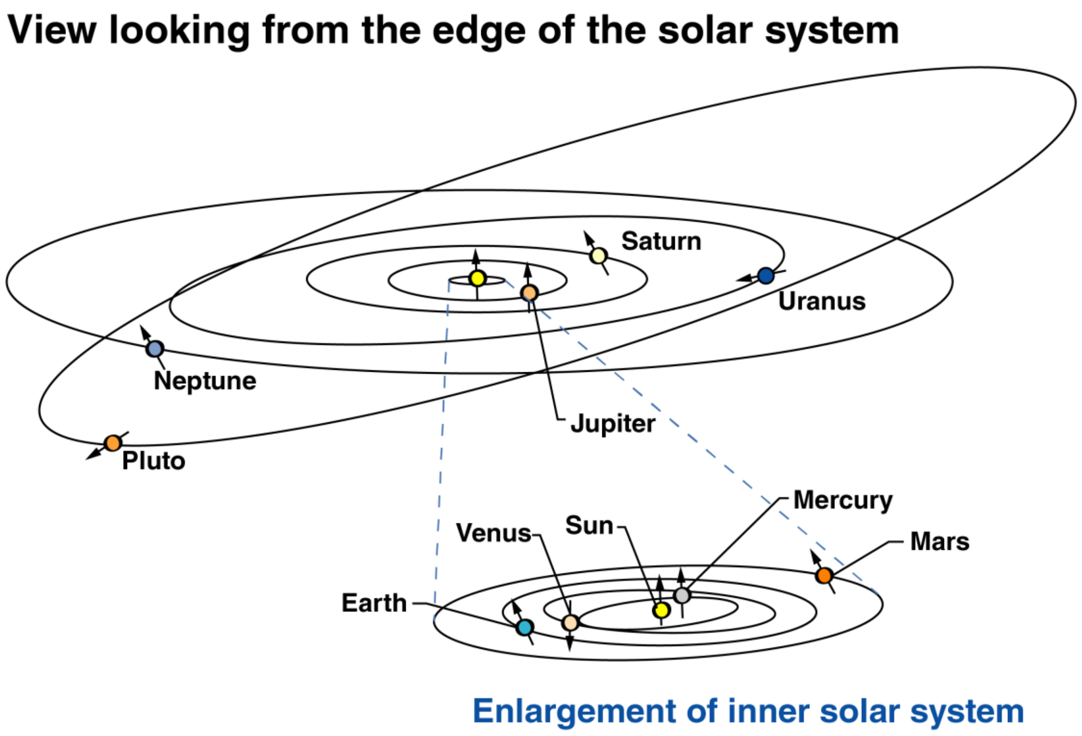
Murchison Meteorite. A fragment of the meteorite that fell near the small town of Murchison, Australia, is shown next to a small sample of its material in a test tube, used for analysis of its chemical makeup.

Lecture Section 2: Formation of the Solar System

Evidence to Consider

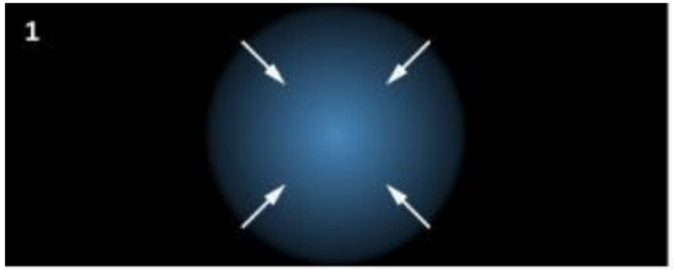
Key traits of the solar system.

1) Planets all orbit counter-clockwise
2) Almost every planet rotates counter-clockwise
3) All orbits lie close to the ecliptic plane
4) Rocky/terrestrial planets in close to the Sun, Jovian/gaseous planets out further with larger separations
5) 2 major ‘belts’ of debris: asteroid and Kuyper

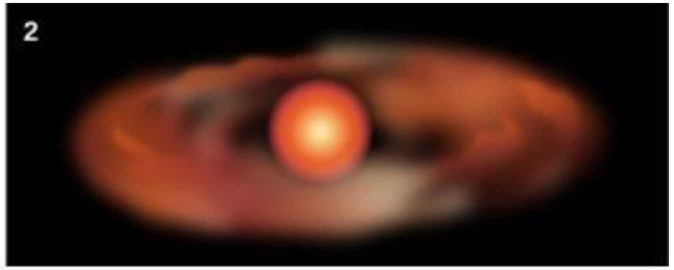


The Nebular Theory

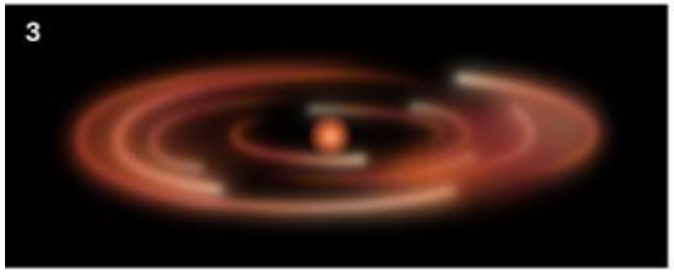
Steps in Forming the Solar System. This illustration shows the steps in the formation of the solar system from the solar nebula. As the nebula shrinks, its rotation causes it to flatten into a disk. Much of the material is concentrated in the hot center, which will ultimately become a star. Away from the center, solid particles can condense as the nebula cools, giving rise to planetesimals, the building blocks of the planets and moons.



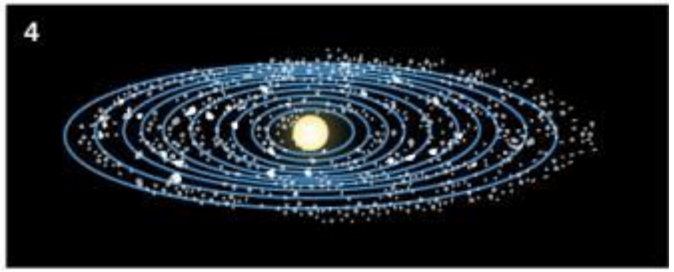
The solar nebula contracts.



As the nebula shrinks, its motion causes it to flatten.

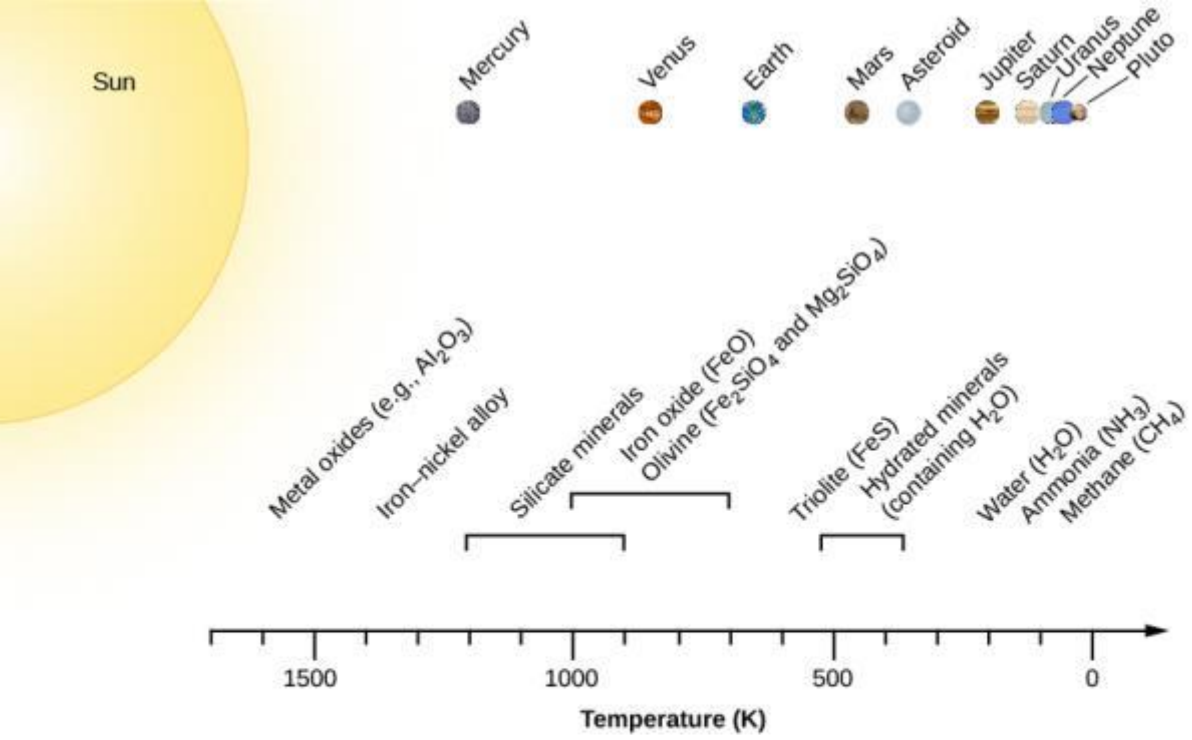


The nebula is a disk of matter with a concentration near the center.



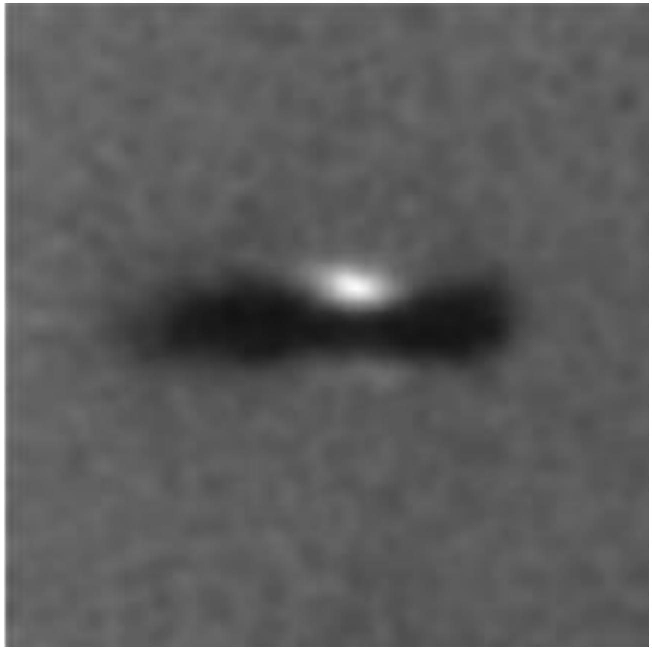
Formation of the protosun. Solid particles condense as the nebula cools, giving rise to the planetesimals, which are the building blocks of the planets.

The Nebular Theory



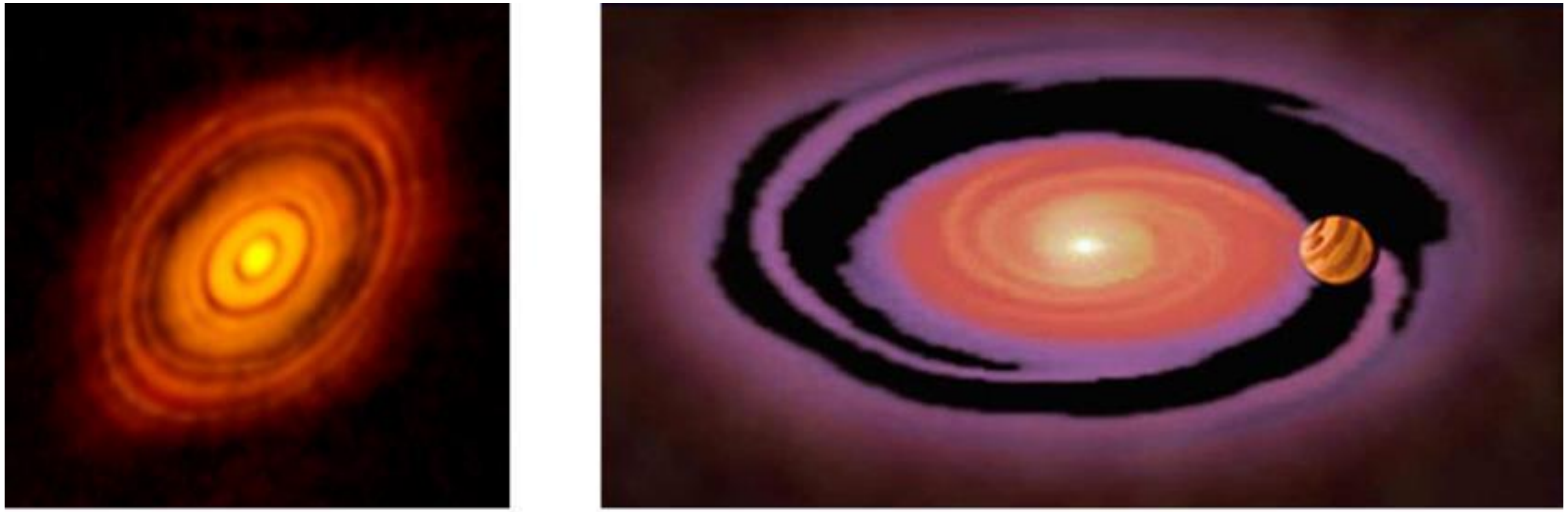
Chemical Condensation Sequence in the Solar Nebula. The scale along the bottom shows temperature; above are the materials that would condense out at each temperature under the conditions expected to prevail in the nebula.

More Supporting Evidence



Protoplanetary Disk in the Orion Nebula. The Hubble Space Telescope imaged this protoplanetary disk in the Orion Nebula, a region of active star formation, using two different filters. The disk, about 17 times the size of our solar system, is in an edge-on orientation to us, and the newly formed star is shining at the center of the flattened dust cloud. The dark areas indicate absorption, not an absence of material. In the left image we see the light of the nebula and the dark cloud; in the right image, a special filter was used to block the light of the background nebula. You can see gas above and below the disk set to glow by the light of the newborn star hidden by the disk. (credit: modification of work by Mark McCaughrean (Max-Planck-Institute for Astronomy), C. Robert O’Dell (Rice University), and NASA)

More Supporting Evidence



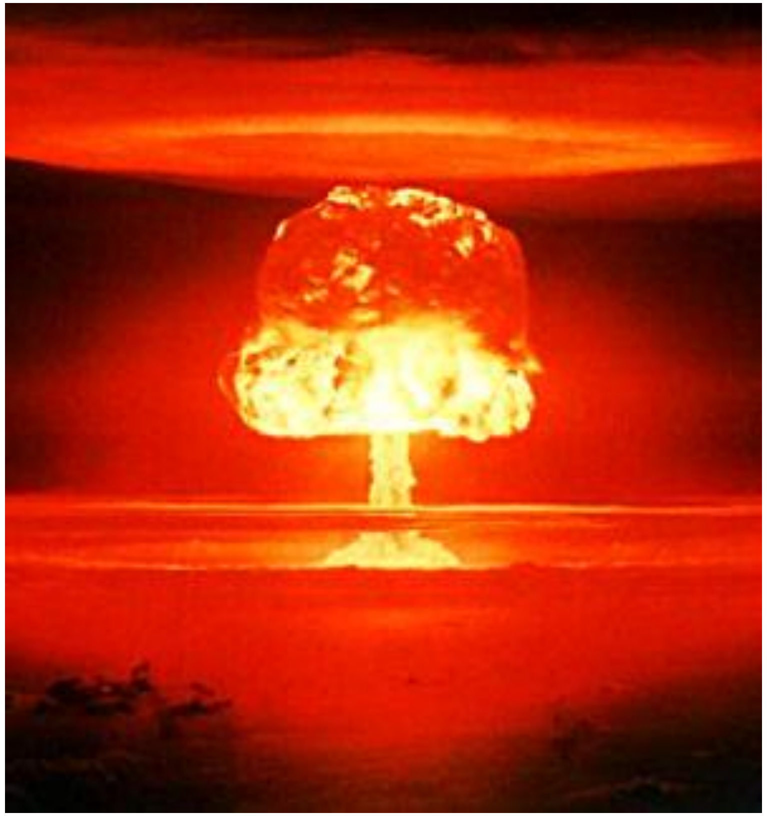
(a) (b)

Protoplanetary Disk around HL Tau.

(a) This image of a protoplanetary disk around HL Tau was taken with the Atacama Large Millimeter/submillimeter Array (ALMA), which allows astronomers to construct radio images that rival those taken with visible light.

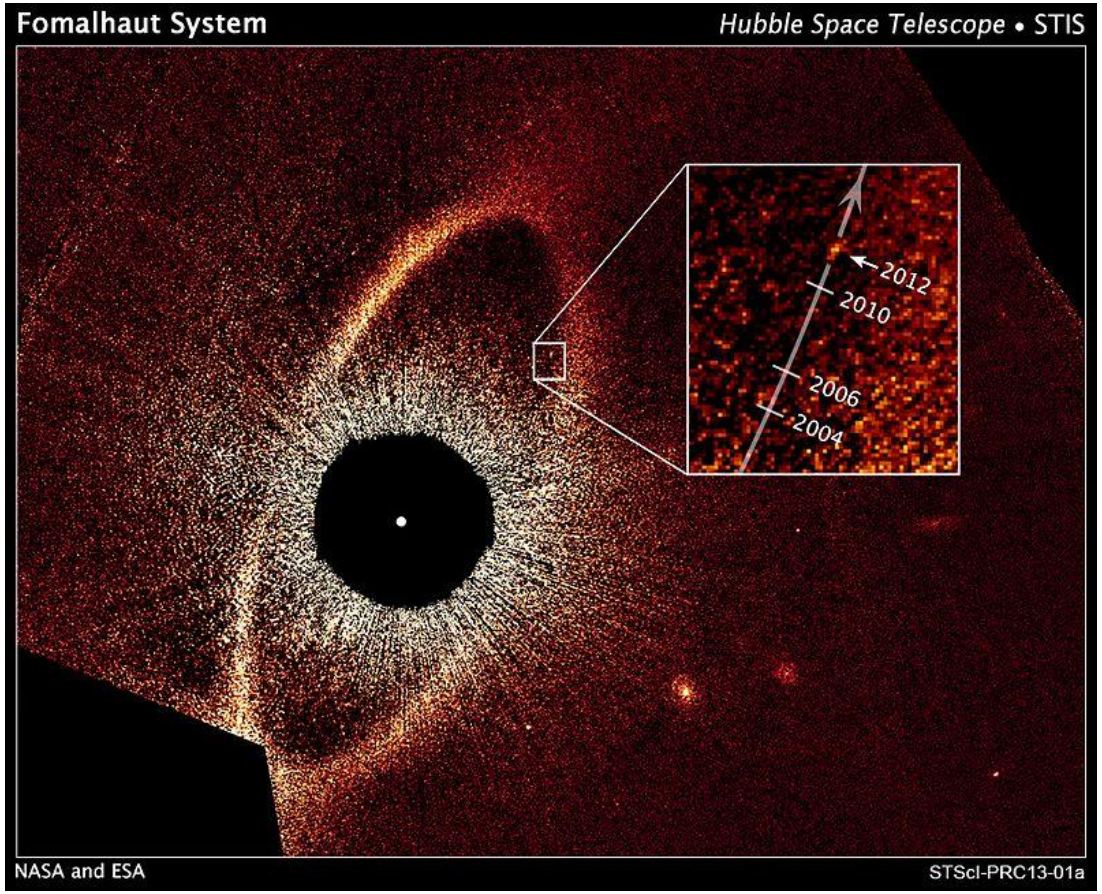
(b) Newly formed planets that orbit the central star clear out dust lanes in their paths, just as our theoretical models predict. This computer simulation shows the empty lane and spiral density waves that result as a giant planet is forming within the disk. The planet is not shown to scale. (credit a: modification of work by ALMA (ESO/NAOJ/NRAO); credit b: modification of work by NASA/ESA and A. Feild (STScI))

Detecting Planets



Brightness Problem. To detect a planet around a star directly, imagine trying to pick out a flashlight 1 block away from a nuclear explosion on the east coast of the US from the west coast.

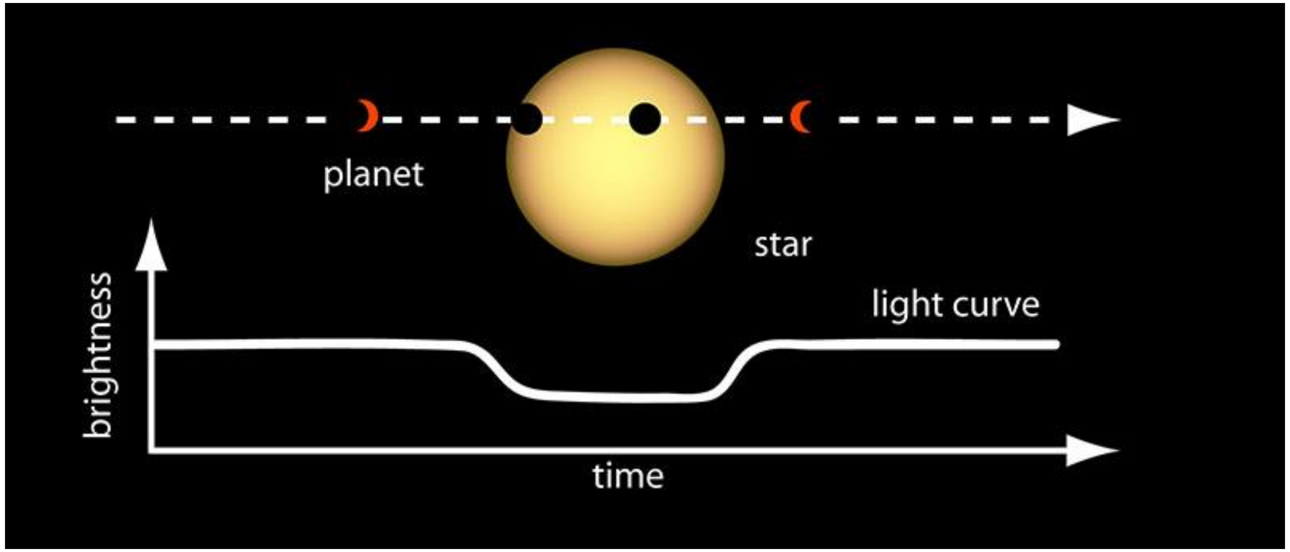
Exoplanets: Fomalhaut



Direct images of Fomalhaut b.

Imaged directly in 2004, astronomers have been tracking this planet’s motion the subsequent 8 years. It is extremely far from its host star with a highly elliptical orbit and an average distance of 175 AU.

Easier Detection Method

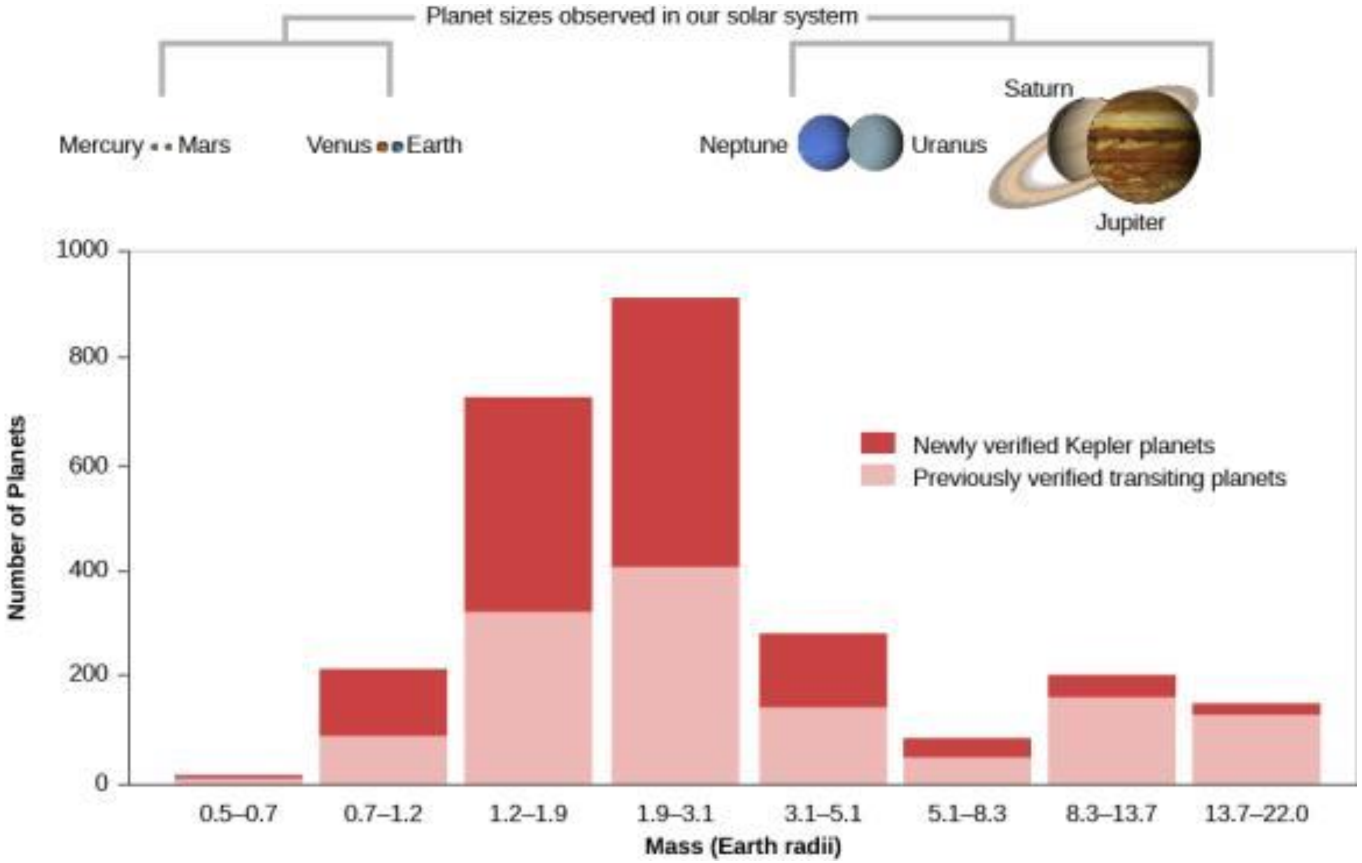


Indirect detection methods - transits.

Using data from sources such as the Kepler Space Telescope, astronomers watch star light over long periods of time and wait for periodic dimming as planets transit their host stars. From this technique, we have discovered thousands of exoplanets.

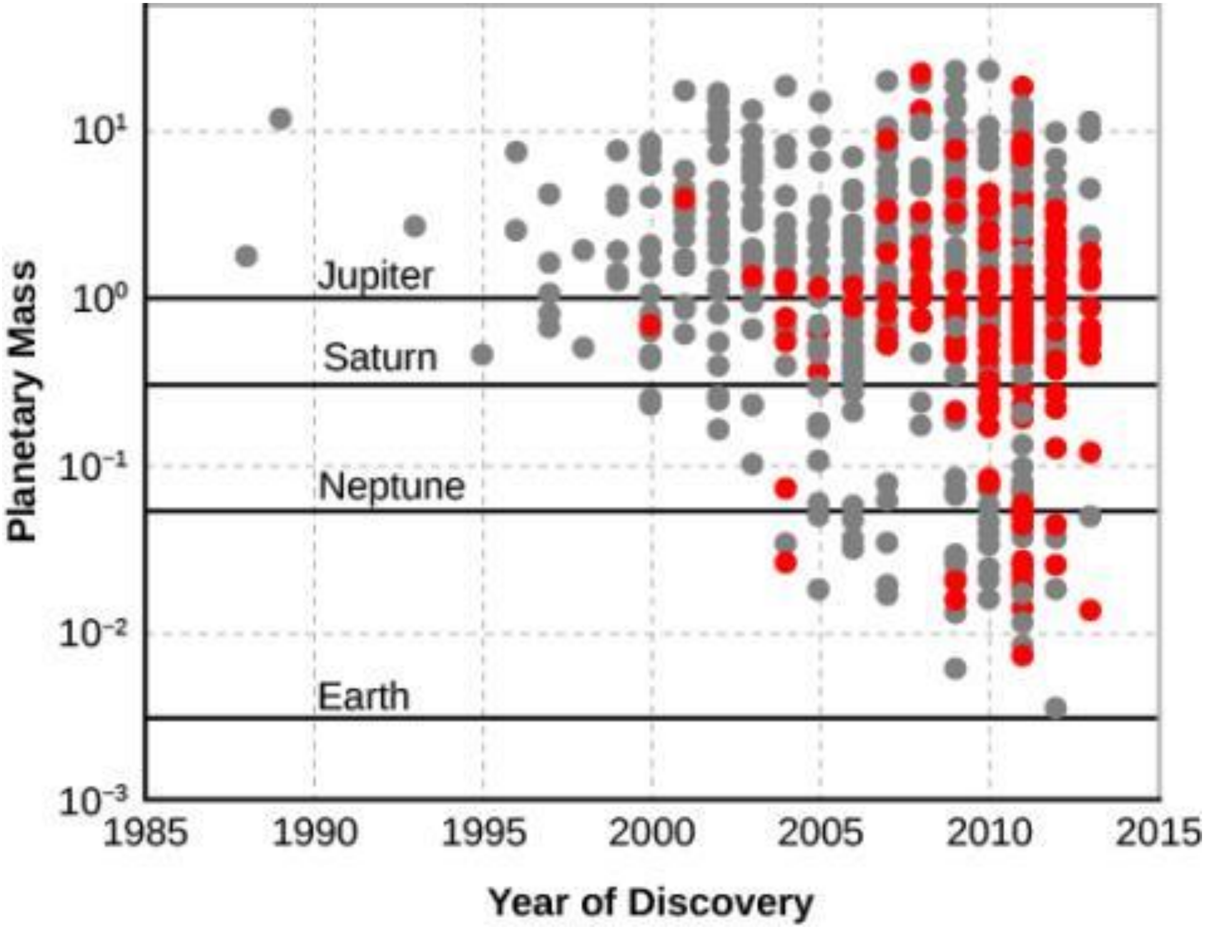
Planetary Systems

Transiting Planets by Size. This bar graph shows the planets found so far using the transit method (the vast majority found by the Kepler mission). The orange parts of each bar indicate the planets announced by the Kepler team in May 2016. Note that the largest number of planets found so far are in two categories that we don't have in our own solar system—planets whose size is between Earth's and Neptune's. (credit: modification of work by NASA)

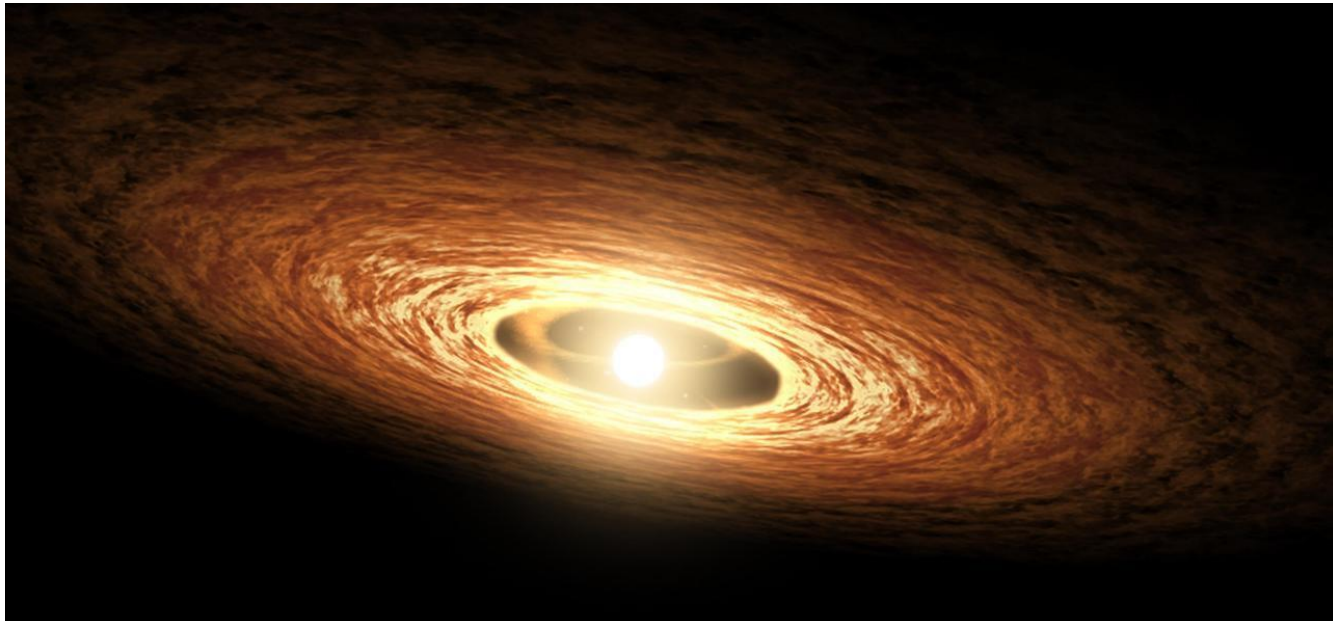


Planetary Systems

Masses of Exoplanets Discovered by Year. Horizontal lines are drawn to reference the masses of Jupiter, Saturn, Neptune, and Earth. The gray dots indicate planets discovered by measuring the radial velocity of the star, and the red dots are for planets that transit their stars. In the early years, the only planets that could be detected were similar in mass to Jupiter. Improvements in technology and observing strategies enabled the detection of lower mass planets as time went on, and now even smaller worlds are being found. (Note that this tally ends in 2014.)

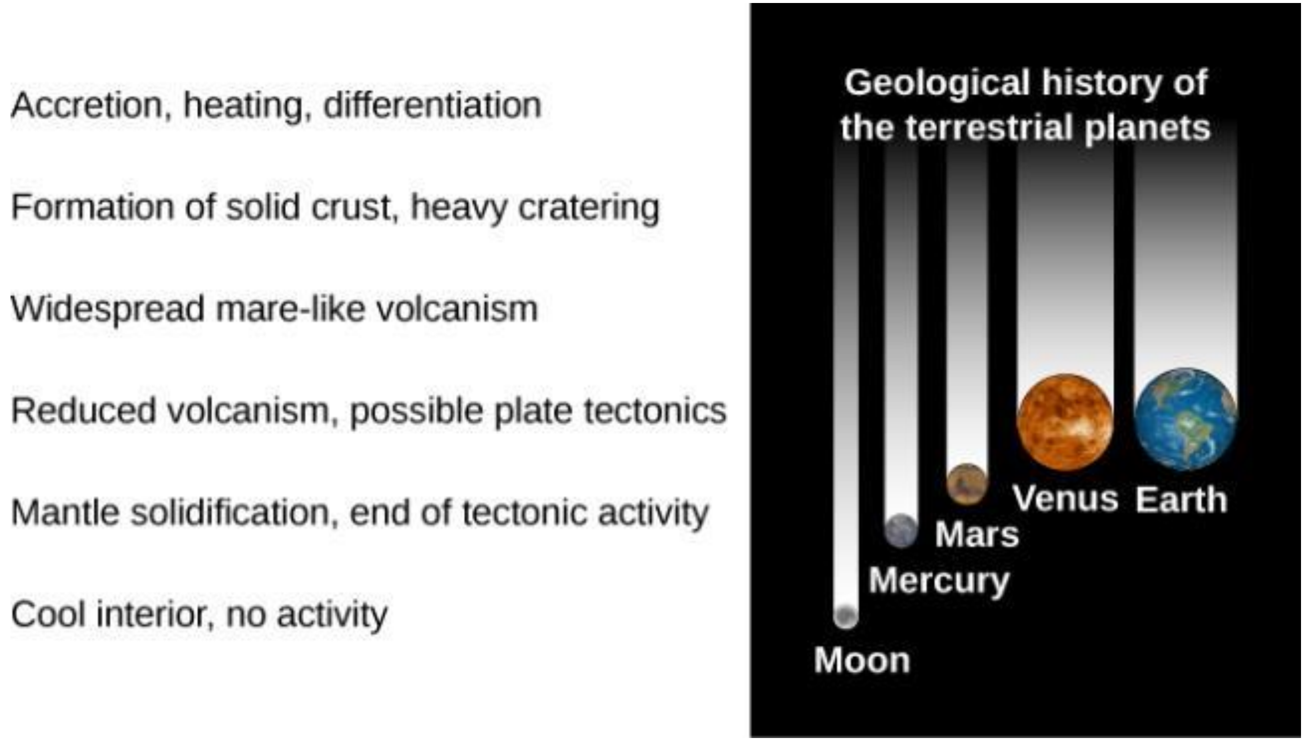


Planetary Migration



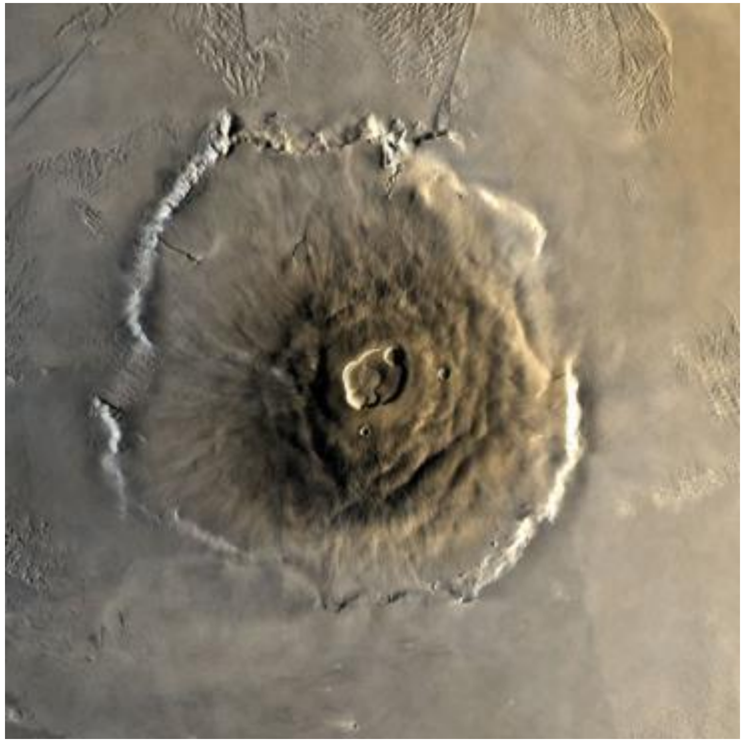
Why so different? The discovery of many 'hot Jupiters' led to the modification of the Nebular Theory. How do so many Jupiter-like planets form so close to their parent star. The answer is that we don't believe they do. They form at large distances in the cooler part of the nebula and then migrate inward.

Planetary Evolution

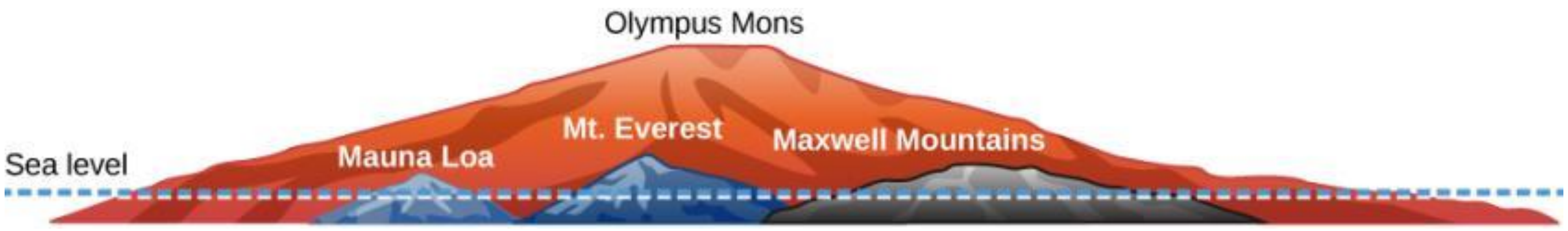


Planetary Evolution - Volcanism

Olympus Mons. The largest martian volcano is seen from above in this spectacular composite image created from many Viking orbiter photographs. The volcano is nearly 500 kilometers wide at its base and more than 20 kilometers high. (Its height is almost three times the height of the tallest mountain on Earth.) (credit: modification of work by NASA/USGS)

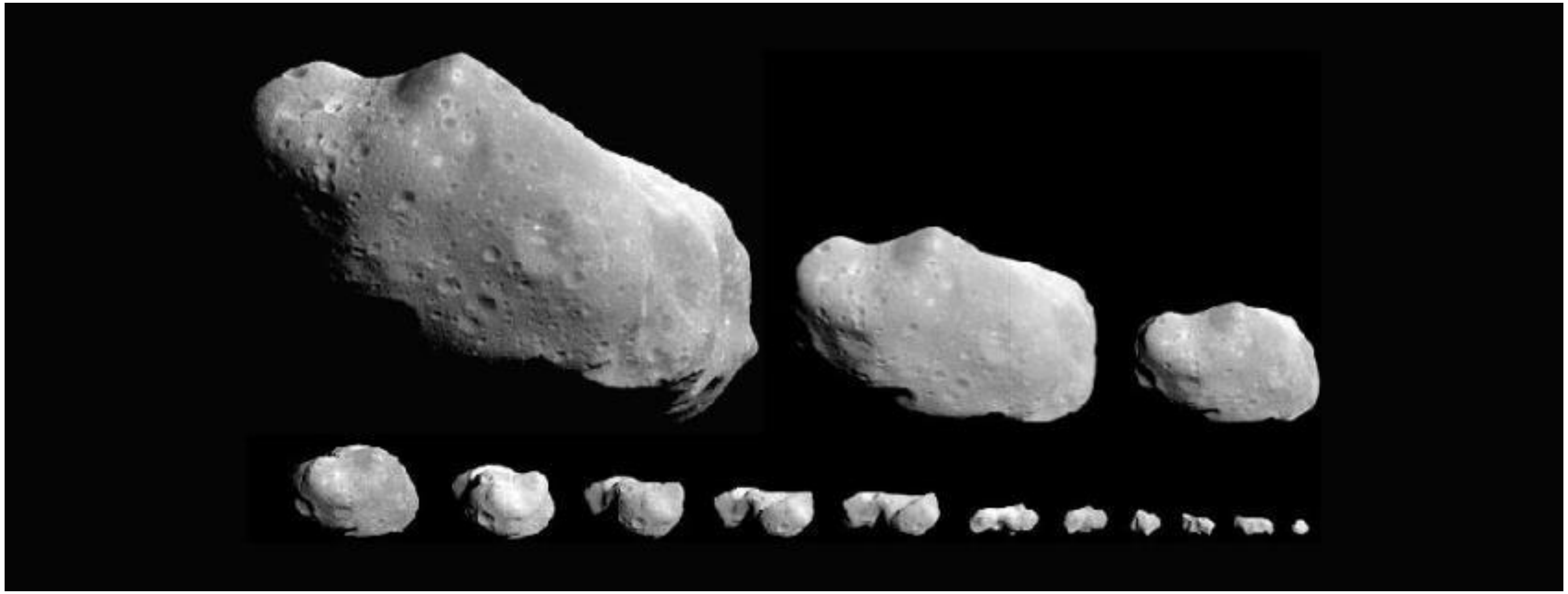


Planetary Evolution - Volcanism



Highest Mountains on Mars, Venus, and Earth. Mountains can rise taller on Mars because Mars has less surface gravity and no moving plates. The vertical scale is exaggerated by a factor of three to make comparison easier. The label "sea level" refers only to Earth, of course, since the other two planets don't have oceans. Mauna Loa and Mt. Everest are on Earth, Olympus Mons is on Mars, and the Maxwell Mountains are on Venus.

Planetary Evolution - Debris



Irregular Asteroids. Small objects such as asteroid Ida (shown here in multiple views taken by the Galileo spacecraft camera as it flew past) are generally irregular or elongated; they do not have strong enough gravity to pull them into a spherical shape. Ida is about 60 kilometers long in its longest dimension. (credit: modification of work by NASA/JPL)

Review Questions

Short: What is the difference between meteors, meteorites, and meteroids?

Short: What are the three different types of meteorites?

Short: What is the source of meteor showers?

Short: Why is detecting exoplanets so difficult?

Short: What was weird about the exoplanets we found (as compared to our own solar system)?

Short: What has been the most successful method of detecting exoplanets?

Long: What is the theory that describes the formation of the solar system and what evidence do we have to support that theory?

Credit

Credit: Openstax