

The Formation of the Solar System



Characteristics of the Solar System

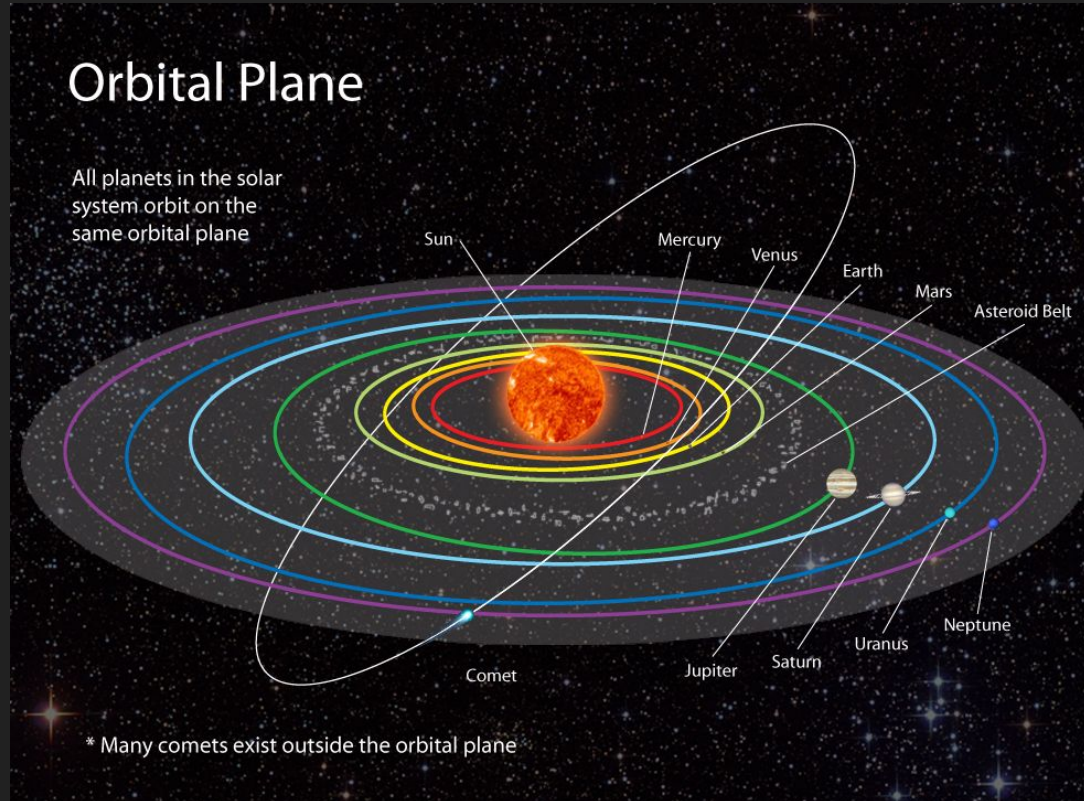
- Most of the mass in the Solar System (99.85 %) is concentrated in the Sun.
- Outer planets are more massive than the inner planets.
- Inner planets are rocky and Outer planets are gaseous.
- (Almost) all planets revolve around the Sun in flat, circular orbits and rotate counter clockwise.
- Asteroids, moons, and Outer Solar System objects.
- A sound formation hypothesis must explain all of these.

Characteristics of the Solar System



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Characteristics of the Solar System

Age

- Earth: Oldest rocks are 3.8 billion years old
- Moon: Oldest rocks are 4.4 billion years old
- Meteorites: All about 4.6 billion years old
- Sun: Stellar evolution models based on the nuclear fusion in the Sun's core gives an age of about 4.6 billion years old

Solar Nebular Theory



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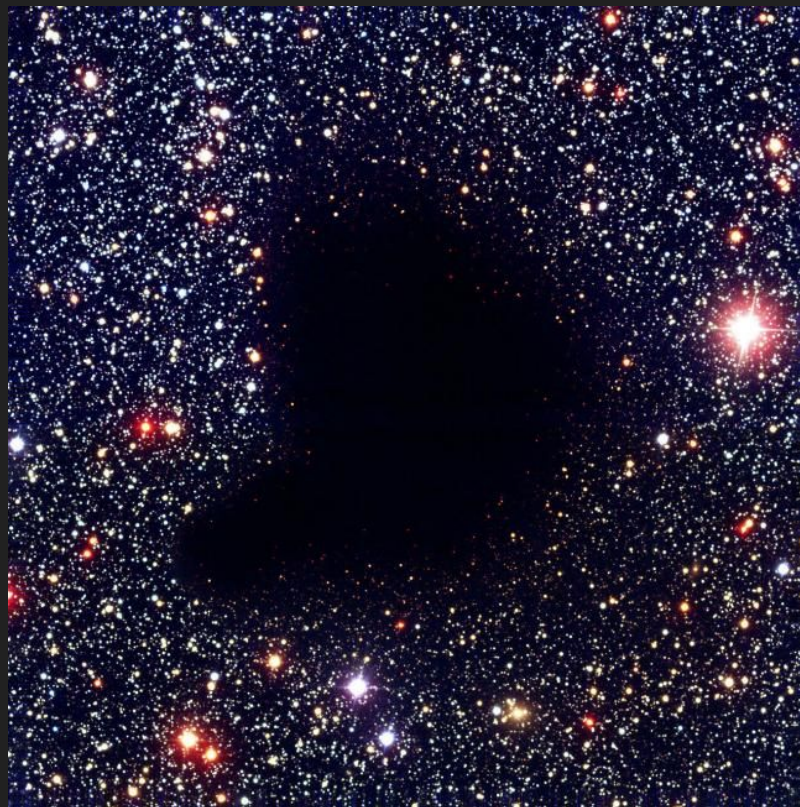
- Proposed by German philosopher Immanuel Kant
- The Solar System formed from a spinning cloud of gas, dust, and ice.
 - Gas- hydrogen and helium
 - Dust- Complex molecules
 - Ice- Volatiles that are frozen (e.g. Water, Ammonia, Methane, etc.)
- This cloud is a molecular cloud.

Solar Nebular Theory



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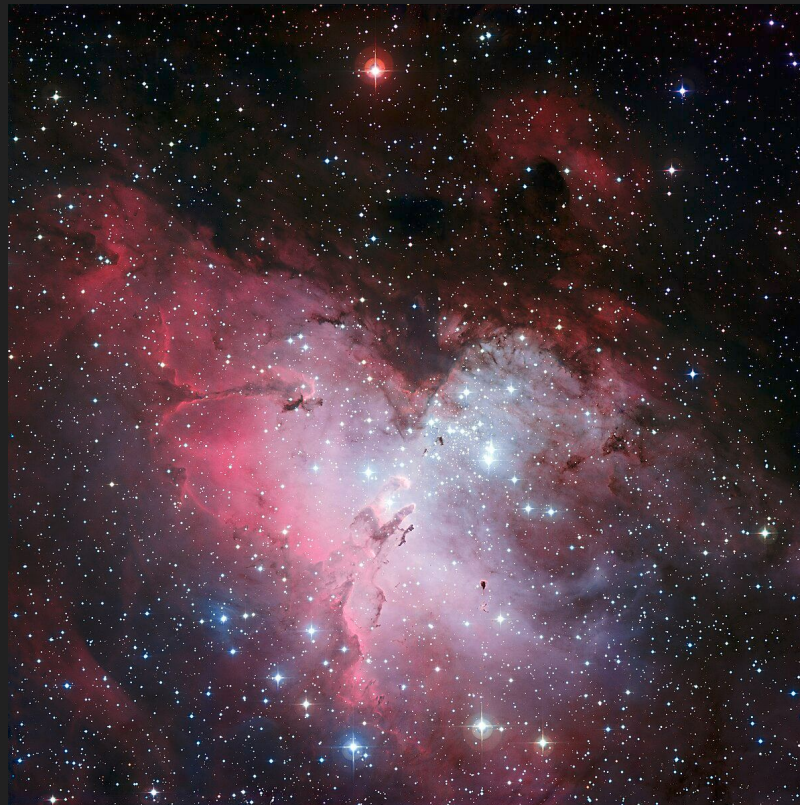


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- The gas and the dust in the cloud have mass, interact gravitationally.
- Gravitational attraction pulls the matter towards the center, the cloud contracts.



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- Not all mass falls in directly
- The gas cloud (three dimensional, spherical) is spinning slightly
- As the gas cloud collapses, it spins faster
- Conservation of angular momentum.

$$L \propto \frac{D^2}{P}$$

- D- diameter of disk, P- orbital period
- Disk flattens as speeds up.



Solar Nebular Theory



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results

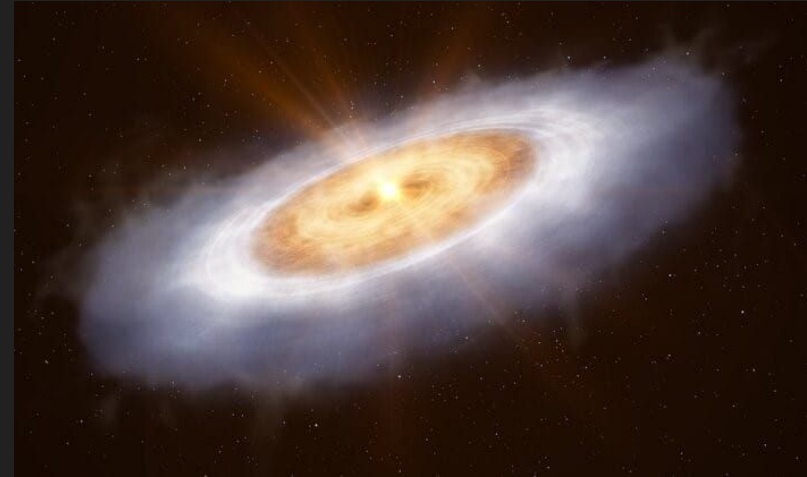
Protostars



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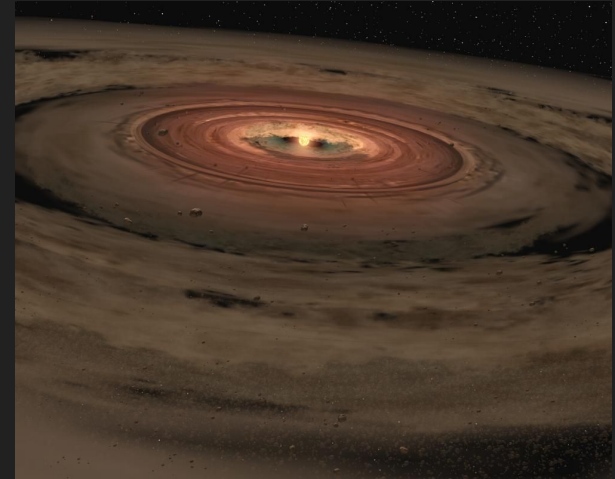
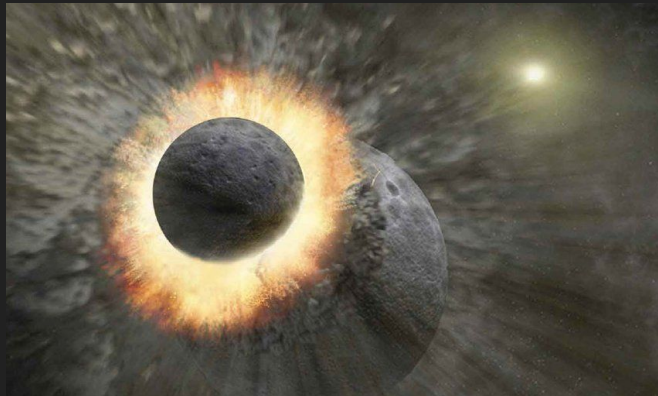
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- At the center of the cloud, energy from infall turns to heat.
- The gas and dust at the center heat up and give off light
- A protostar forms
- Not a star yet
- Light comes from contraction
- The protostar becomes so dense
- Nuclear fusion begins after 50 million years



Planet formation

- Gas, dust, pebbles collide and clump together
- Planetesimals form, like asteroids
- Bigger planetesimals collide and combine
- Collisions build the inner planets and the outer planet cores.

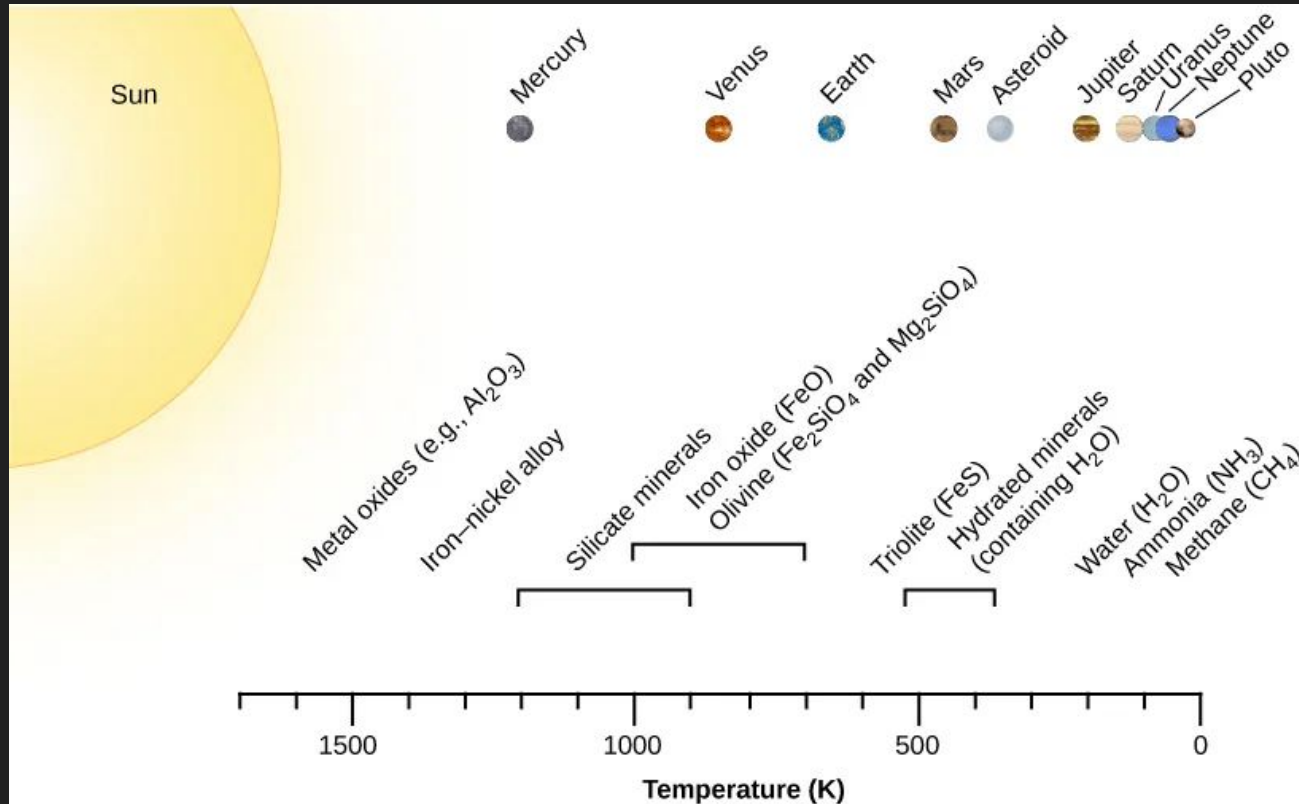


Planet formation



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Planet formation

- Temperature explains why planets are so different.
- Inner planets are hot.
 - Light elements and ices are vaporized.
 - Gases are blown out of the inner solar system by solar wind
 - Only heavy elements and rocks are left.
- Outer planets are cold.
 - Rock and ice planetesimals grow large enough to hold onto hydrogen and helium



Heavy bombardment

- Many planetesimals in the early Solar System.
- Many collided with the young planets.
- Called the Heavy Bombardment
- Lasted for the first few hundred million years of the Solar System.

Heavy bombardment



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- Craters on the Moon are from heavy bombardment.
- Lunar *maria* formed later (less craters)



Water



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- Earth was too hot to have water
- Earth and Mars have or, show evidence for, significant water
- One hypothesis is that water was brought to the inner planets by comets during the heavy bombardment.



Comets and Asteroids



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- Some planetesimals never combined and remain in the Solar System.
- They are the minor bodies in the Solar System
- Mars-Jupiter
 - Asteroids
- Jupiter-Saturn
 - Centaurs
- Neptune and beyond
 - Trans Neptunian objects (TNOs), Kuiper belt, Oort cloud





Extrasolar planets

- Do other stars have planets?
- Is our Solar System typical?
- If we think the Sun formed from a disk of gas and dust, do we see disks around young stars?

Extrasolar planets



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- Look at other star-forming regions
- Gas and dust obstruct visible light
- Use other wavelengths
- Orion Nebula from JWST

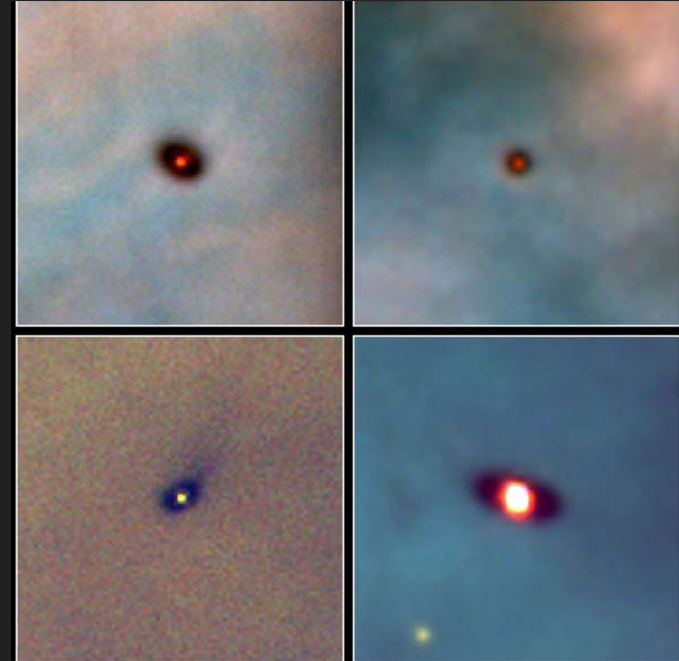
Extrasolar planets



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- Protoplanetary disks around young stars are common.



**Protoplanetary Disks
Orion Nebula**

HST • WFPC2

PRC95-45b • ST ScI OPO • November 20, 1995

M. J. McCaughrean (MPIA), C. R. O'Dell (Rice University), NASA

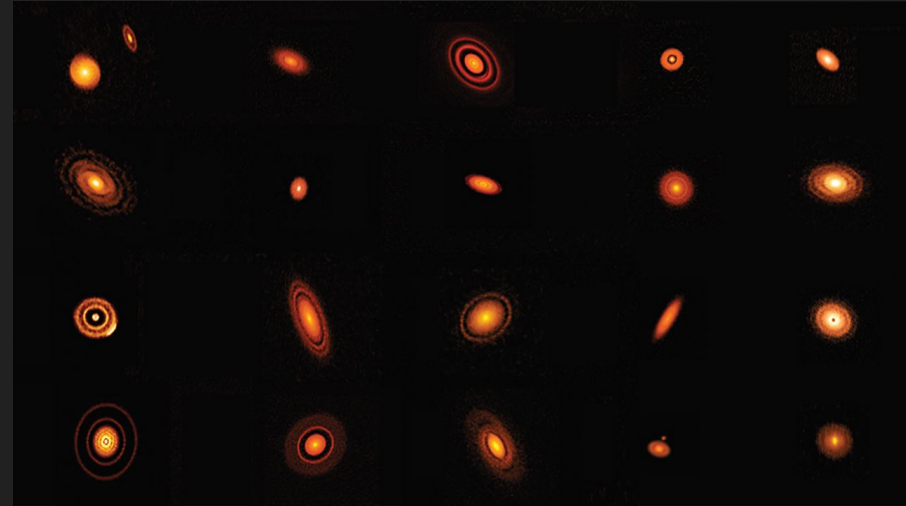
Extrasolar planets



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- ALMA (radio) reveals diversity of shapes
- Different shapes due to projection effects
- Gaps due to planets forming



Extrasolar planets



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- 6,000 confirmed exoplanets
- Range of detection methods
- Help test planet formation hypotheses

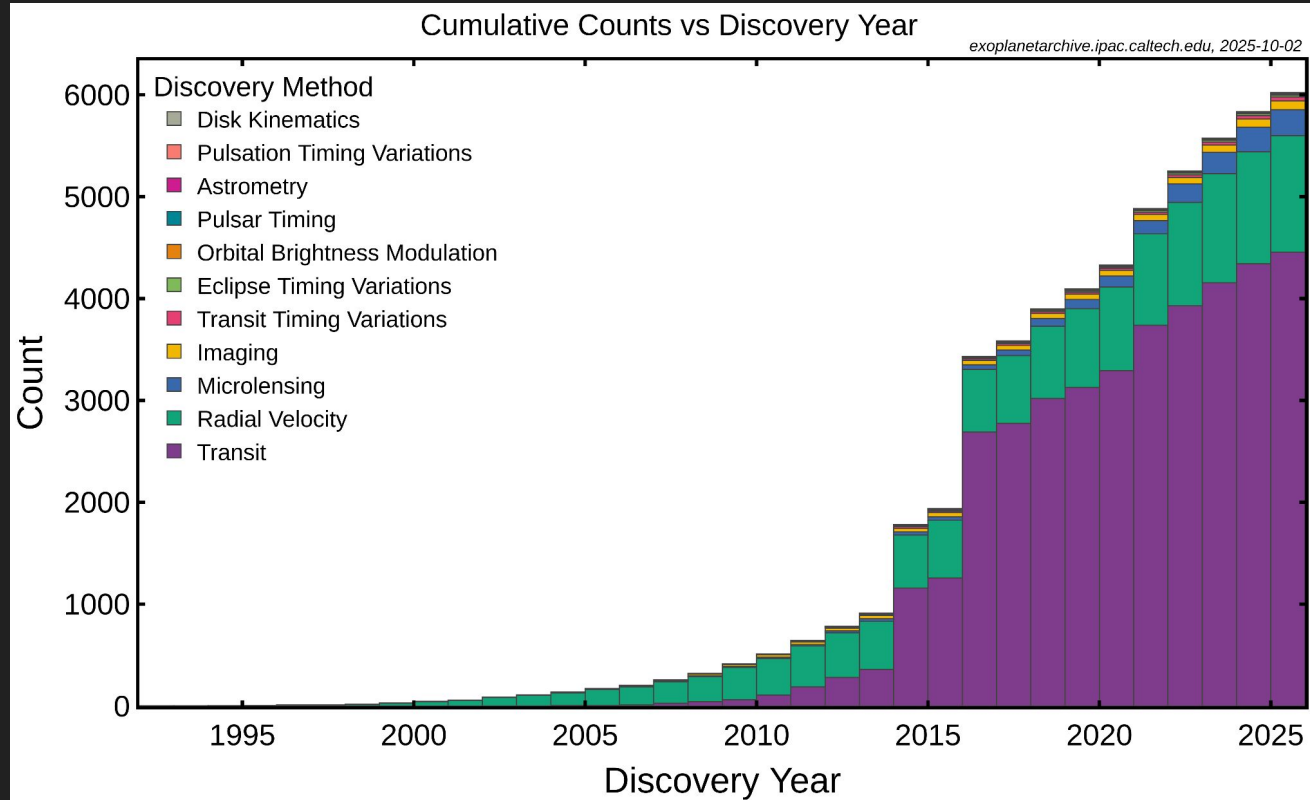


Extrasolar planets



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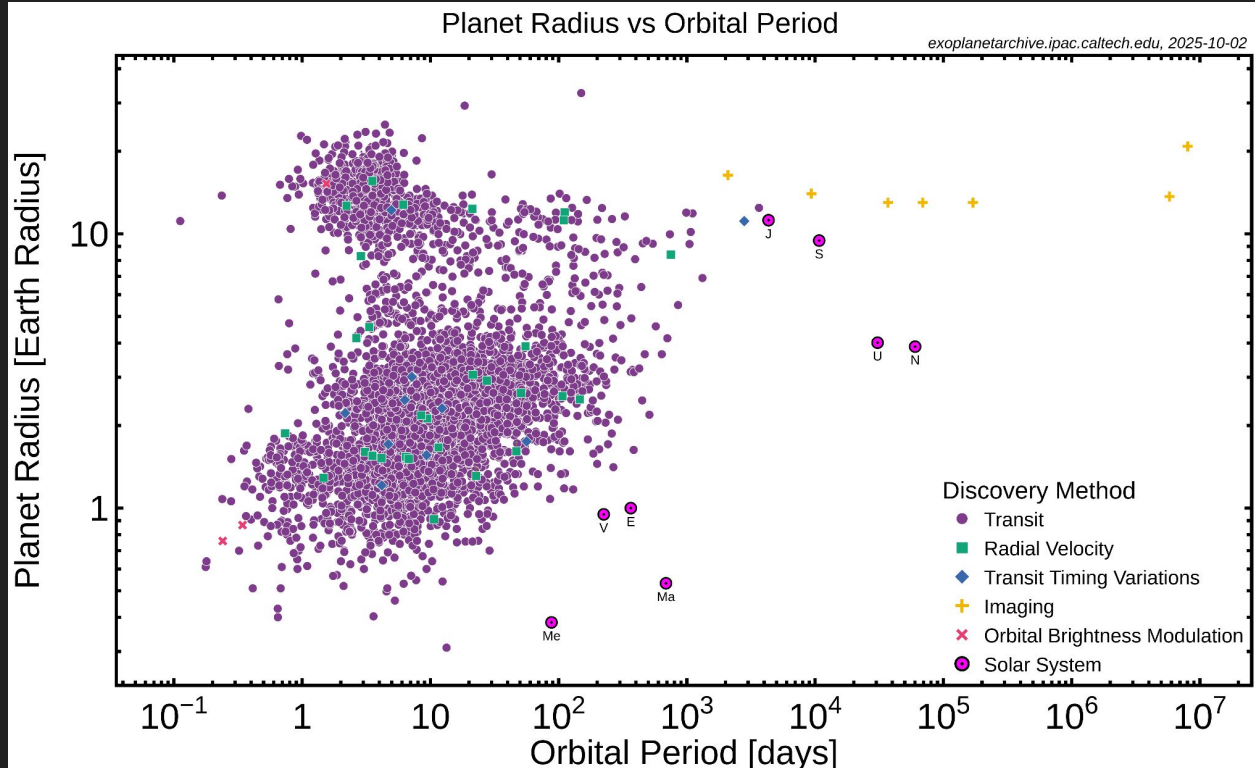


Extrasolar planets



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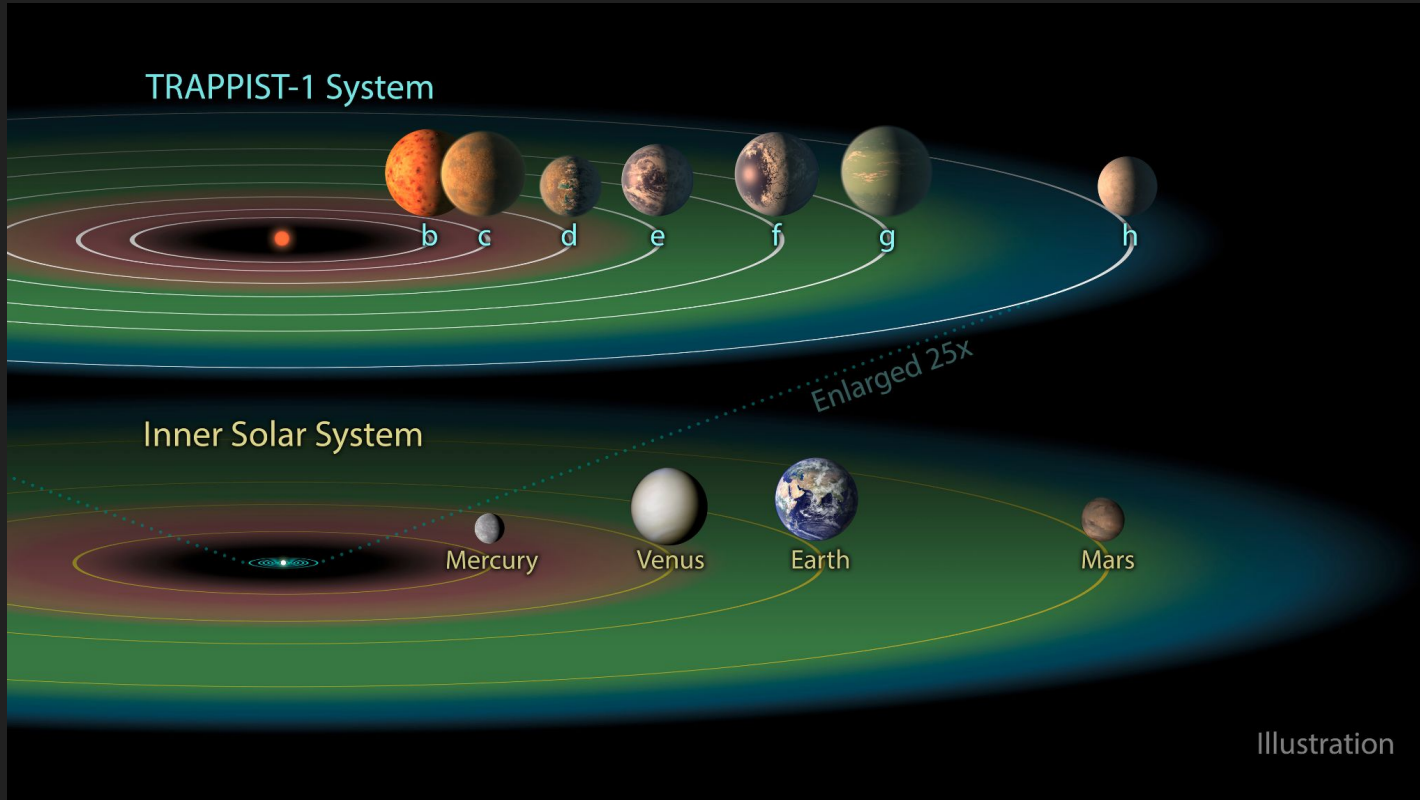


Extrasolar planets



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Announcements

- N/A

Next time

- The structure and composition of the Sun.