Solar System

A. Definitions 1
   1. Terrestrial Planet
   2. Jovian Planet
   3. Dwarf Planet
   4. Asteroid Belt
   5. Comet
   6. Kuiper Belt
   7. Angular Momentum

Solar System

B. Definitions 2
1. Differentiation
2. Condensation
3. Condensation Temperature
4. Hydrogen Compounds
5. Abundance
6. Iron Line
7. Rock Line
8. Frost Line
9. Escape Velocity

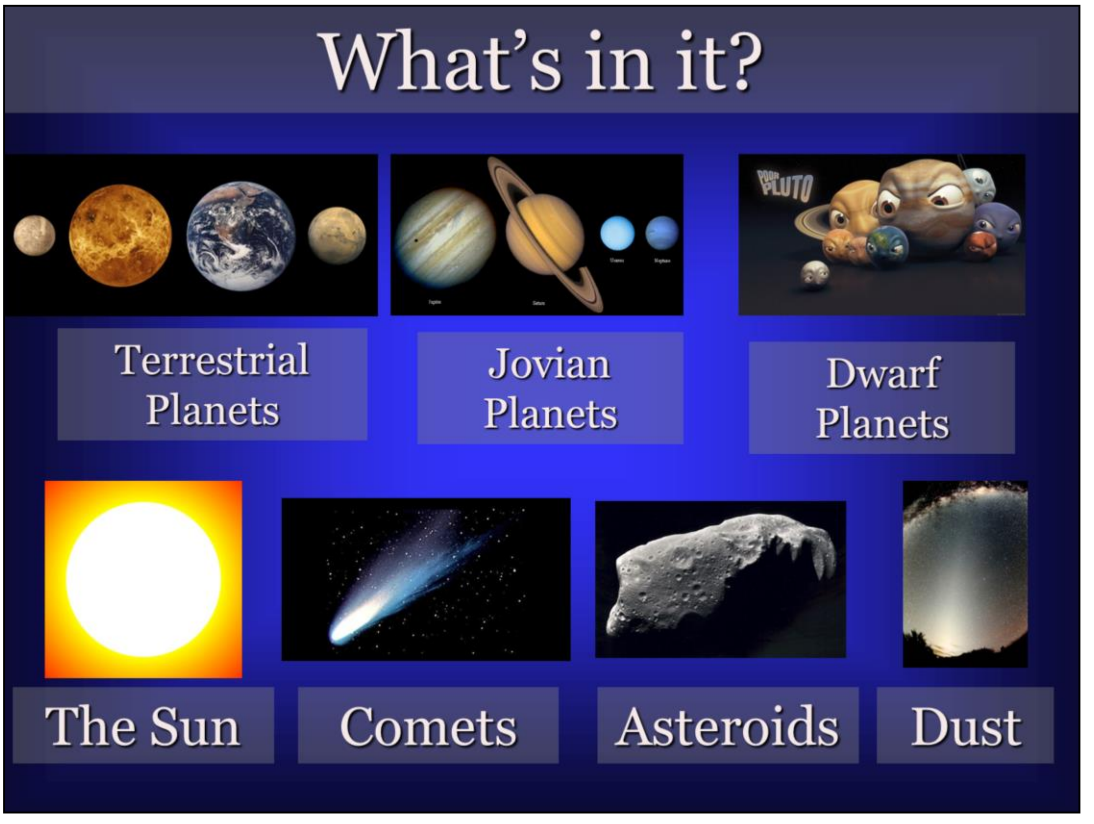
Solar System

A. Basic Features
   1. What are the components of the Solar System?
   2. What are they made of?
   3. Where are they?
   4. How do they move?
   5. How big (volume) are they?
   6. How much of the solar system (by mass) does each component represent?

Solar System

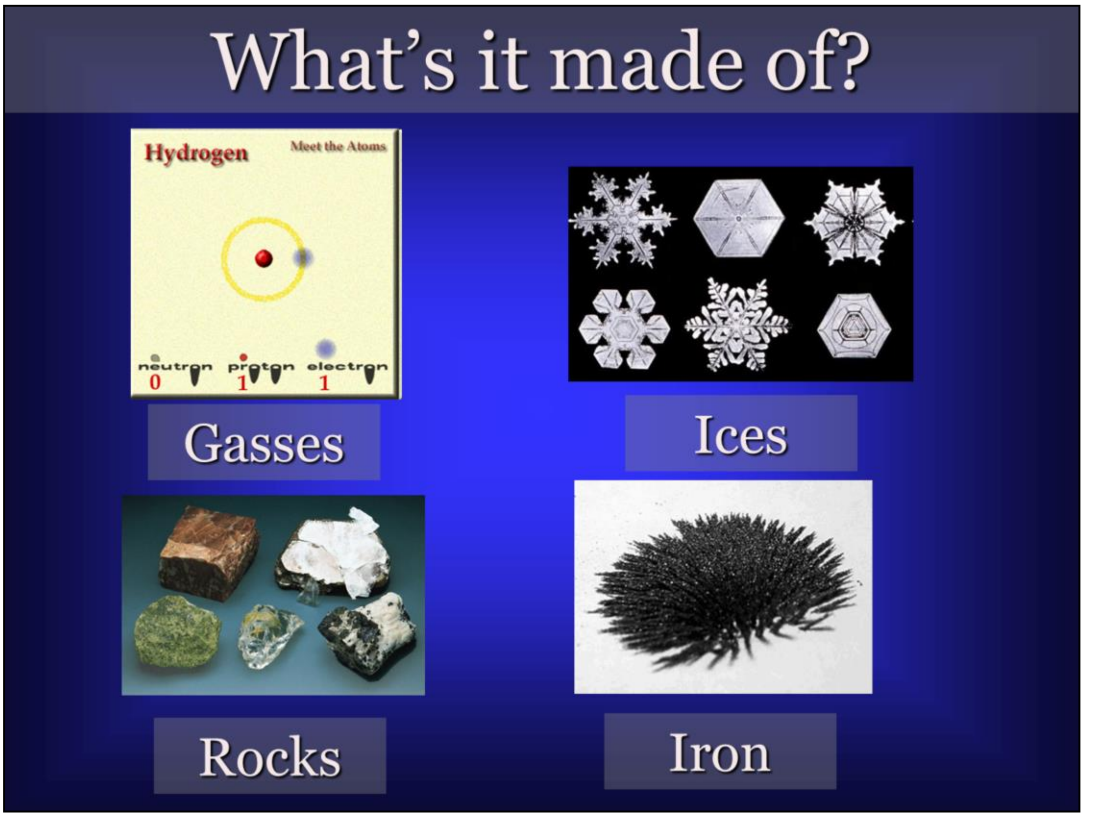
C. Formation I : The Early Days
1. What is the leading formation theory
2. Why do interstellar clouds collapse?
3. What is the cloud made of?
4. Why does a disk form?

D. Formation II : Making Planets (and stuff)
1. **What** solids form **where** in the disk?
2. Why are terrestrial planets close?
3. Why are Jovian planets far?
4. Why are Jovians HUGE?



What are the components of the solar system?

Sun, terrestrial planets, jovian planets, asteroids, comets, moons, dust



Terrestrial Planets: Primarily Rocks and Iron

Jovian Planets: Mostly Hydrogen but, in the core, rocks, iron, and ices

The Sun: Gasses (Mostly Hydrogen)

Asteroids: Rocks and Iron

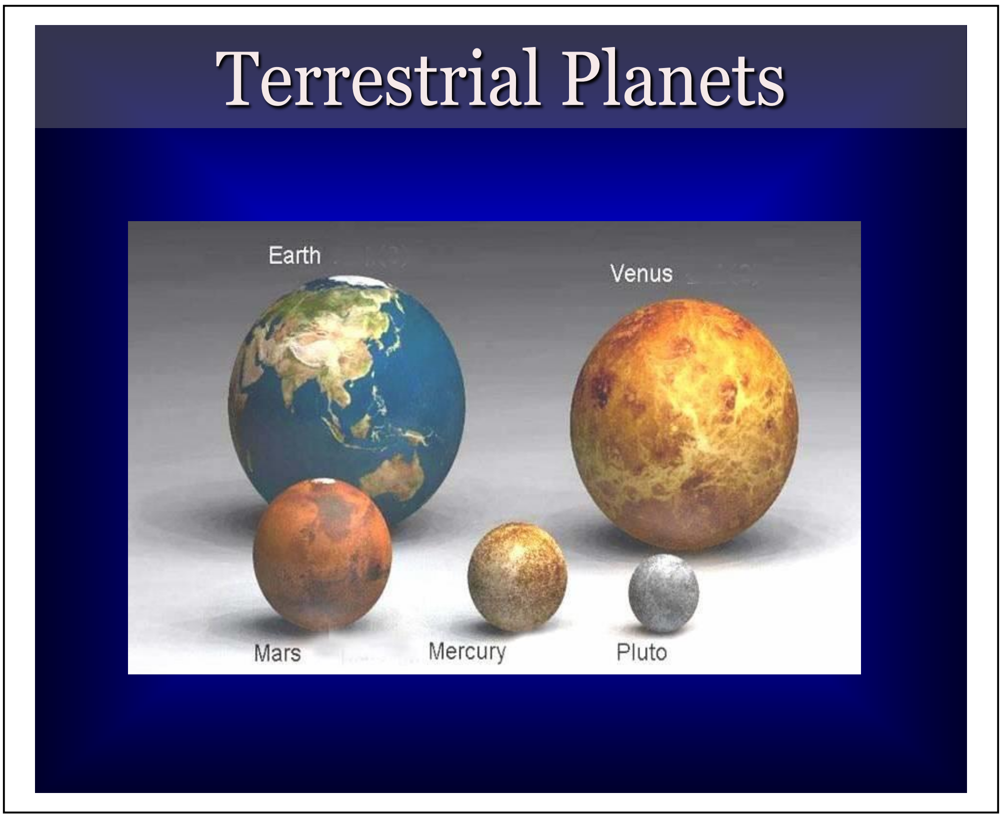
Comets: Ices, Rocks, Iron

Dust: Rocks, Iron, Ices

Dwarf Planets: Rocks, Iron, Ices.

From inside out:

Terrestrial planets, asteroid belt, Gas giants, Kuiper Belt objects, Oort cloud



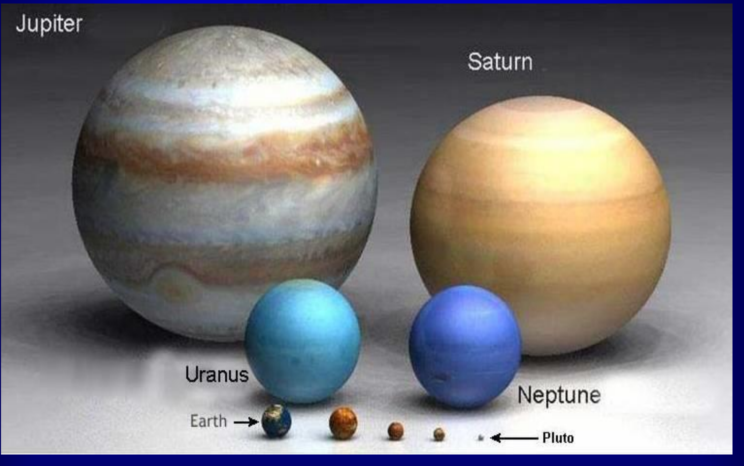
The Terrestrial Planets are smaller than the Jovian planets but bigger than the Dwarf planets (and bigge

Earth is the largest by a tiny Fraction. Venus is nearly as large.
The Moon is smaller than Mercury but larger than Pluto.

Although, Pluto is not a terrestrial planet, it’s a dwarf (made of ice, rocks, and iron)

All together, the rocky objects in the solar system account for less than 1% of the total mass.

Gassy Planets

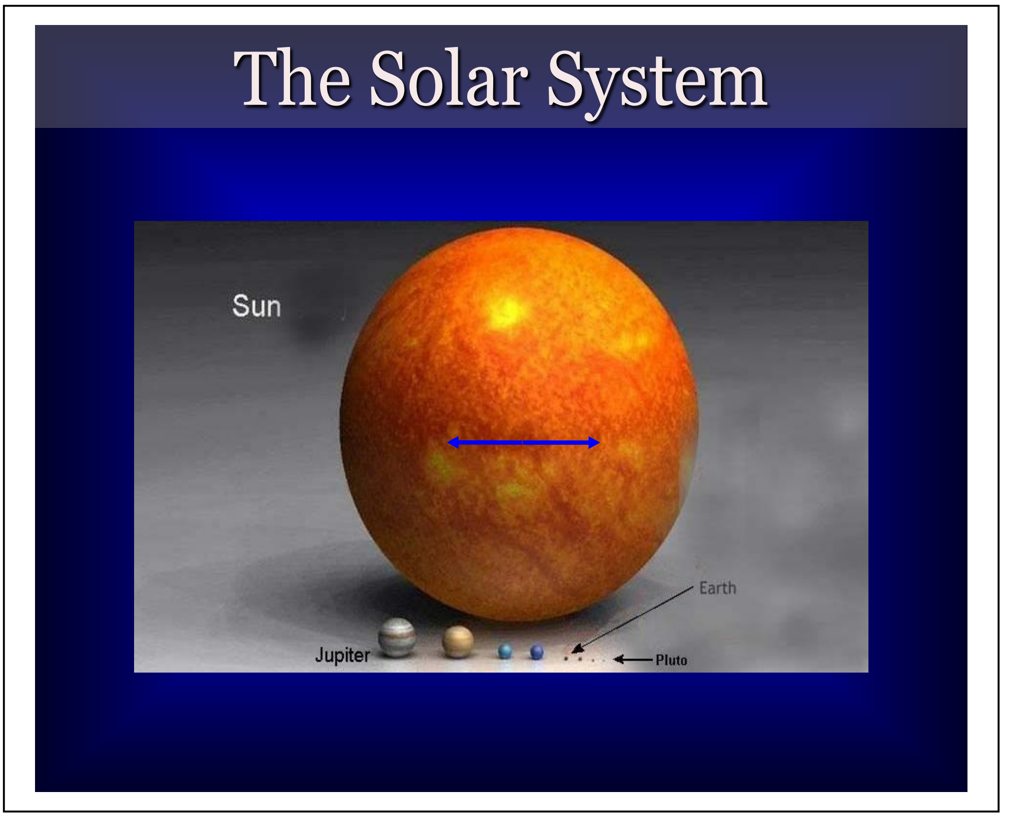


Jupiter is by far the largest planet in the solar system.

It is about 11 Earth diameters.

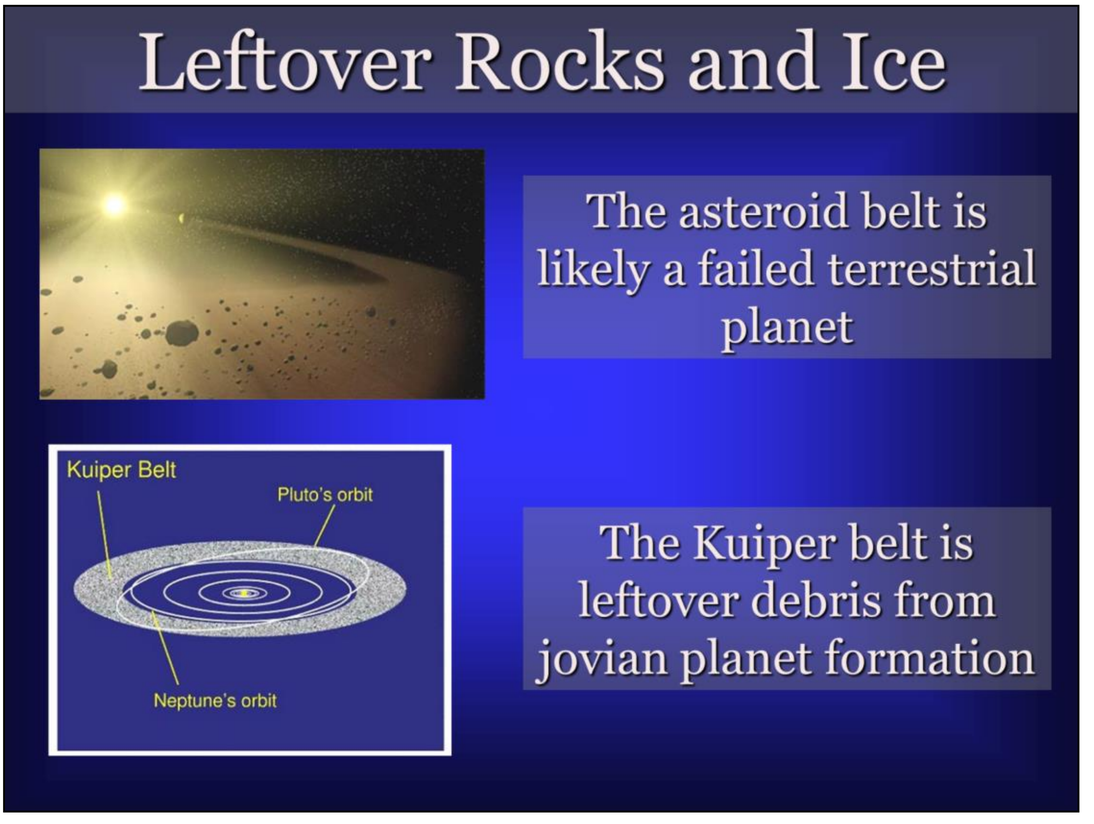
Not counting the Sun, it accounts for 71 percent of the mass in the solar system.

Saturn, the next largest planet, is only 1/3 the mass of Jupiter.



The Sun completely dominates the solar system, containing 99.87 percent of the mass.

The Earth/Moon system fits easily inside the Sun. Twice
The arrows represent the entire DIAMETER of the Moon’s orbit around the Earth.



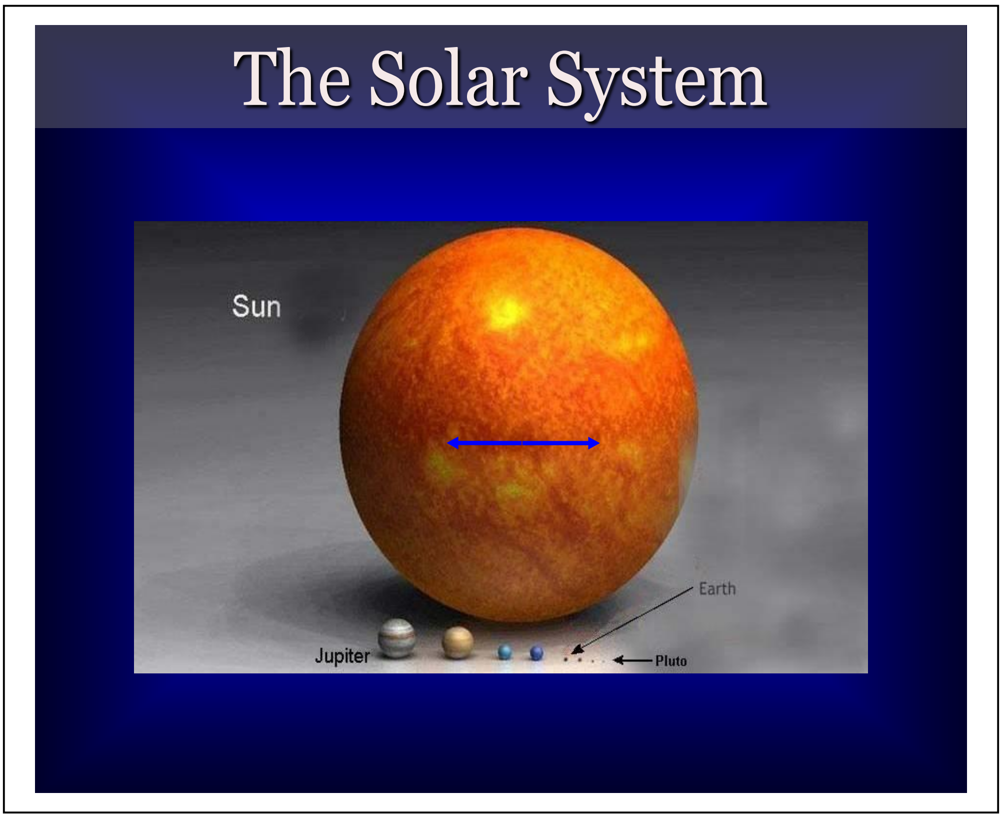
The asteroid belt appears to be a terrestrial planet that didn't form… lots of chunks of rock.

Perhaps a planet tried to form but was too close to Jupiter's influence.

The asteroid belt is not very dense, on one thousandth of a terrestrial planet. There are millions of Kilometers between asteroids.

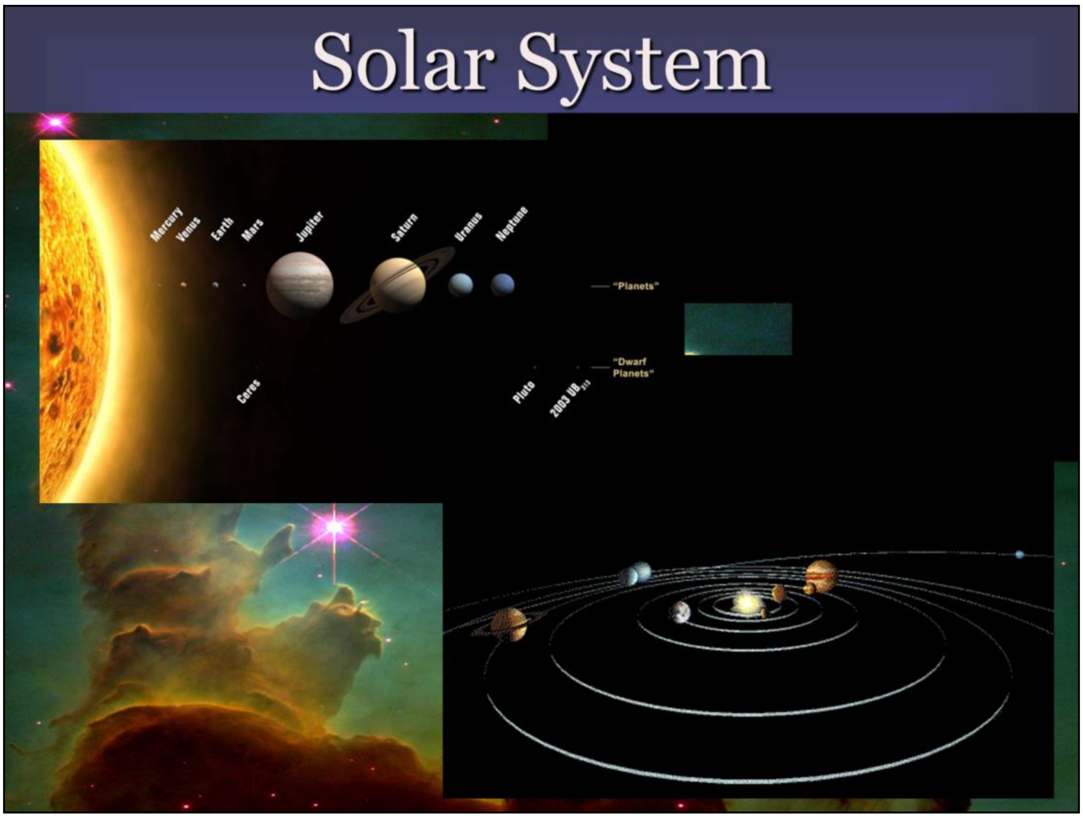
Because the density of the disk DECREASES as you move outward, the sizes of the planets decreases.

The Kuiper belt starts at around the orbit of Pluto and extends outward. It is leftover icy stuff.



The planets orbit in (mostly) circular coplaner orbits.
Planets rotate (mostly) in the same direction on their axis.
All rotational axis (mostly) are aligned.

The orbit of objects in the asteroid belt tend to be more elliptical
The orbits of objects in the Kuiper belt tend to be more elliptical and their orbital planes are at greater a



There is a high degree of order in the solar system that must be explained.

The planets all lie in a plane.

They all orbit in the same direction.

Most of them rotate in the same direction.

Most rotation axis are roughly perpendicular to the ecliptic

Rocky planets are in the interior, Gassy planets in the exterior, and icy planets waaay out there.

Close Encounter Theory:

The Sun encountered another star at some point in the distant past and great blobs of gas were ripped off.

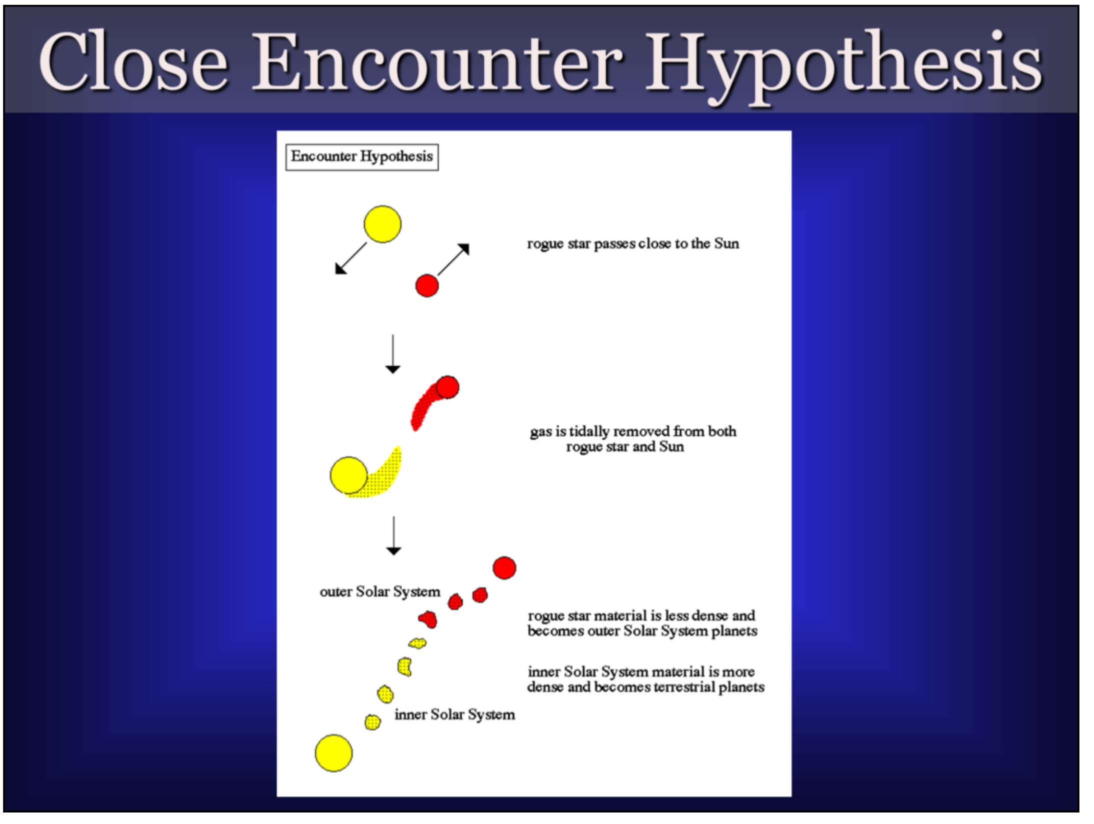
Those blobs eventually formed the planets.

Problems with this scenario the "Close encounter Theory"

Encounters are rare.

It's hard to get stable orbits when we model this in the computer.

It's nearly impossible to get a well ordered and differentiated solar system.



The Close Encounter hypothesis

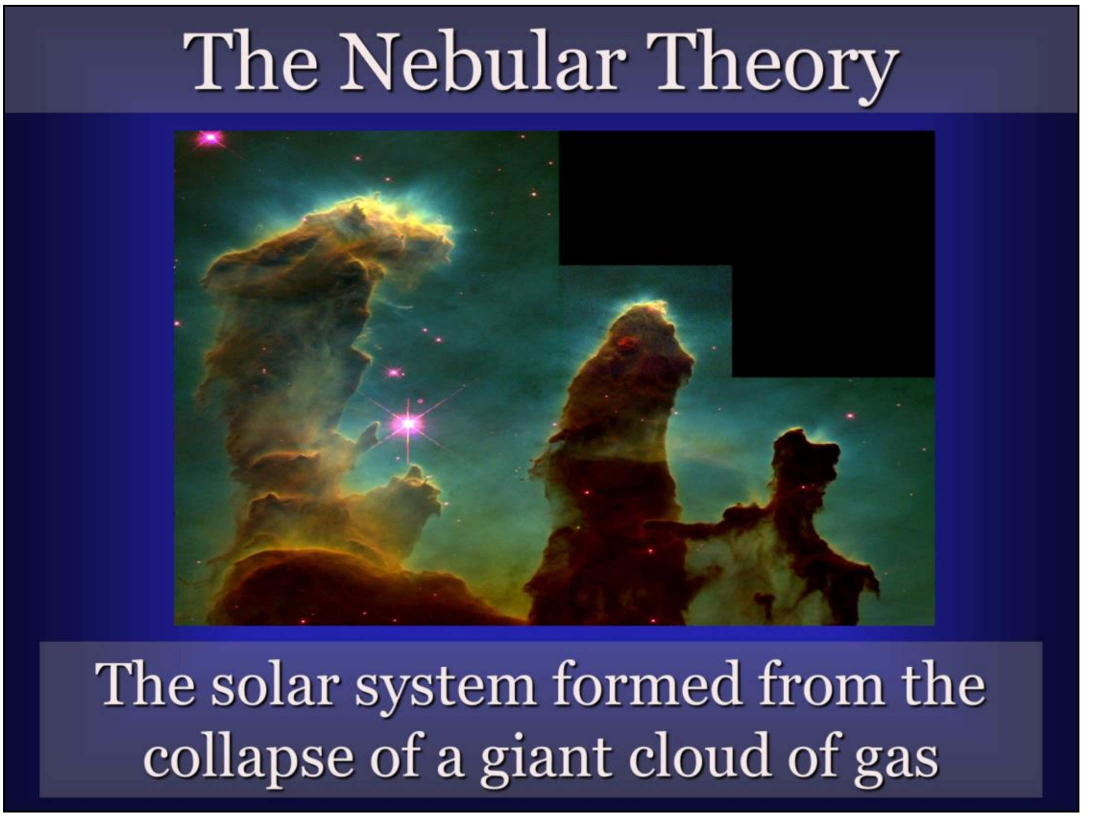
A star passes very close to the Sun.

Gravitational disruption pulls mass away.

The removed mass forms the planets.

It doesn't work. Computer simulations show that the resulting systems are very chaotic, not well ordered.

Also, star star encounters are quite rare.

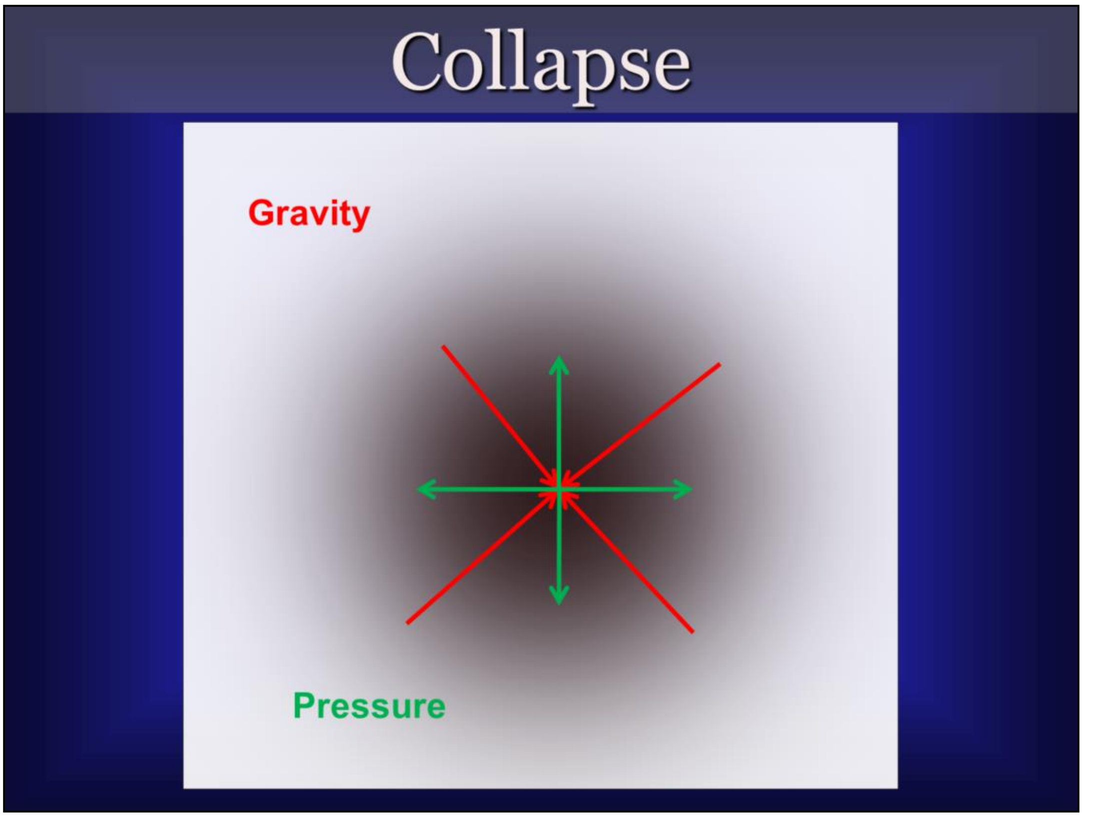


The Nebular Theory:

A cloud of interstellar gas began to collapse due to it’s own gravity.

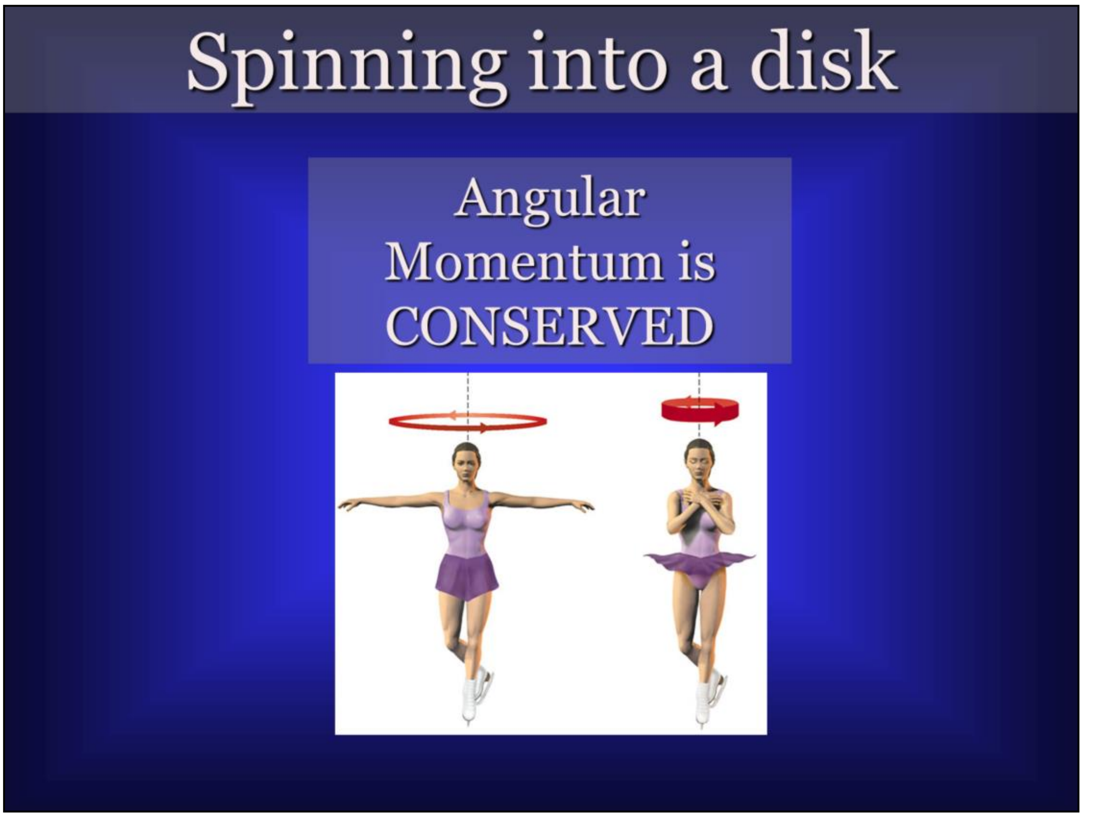
As it collapses, it conserves angular momentum and spins faster

As it the density increases, collisions between particles cause it to flatten into a disk.



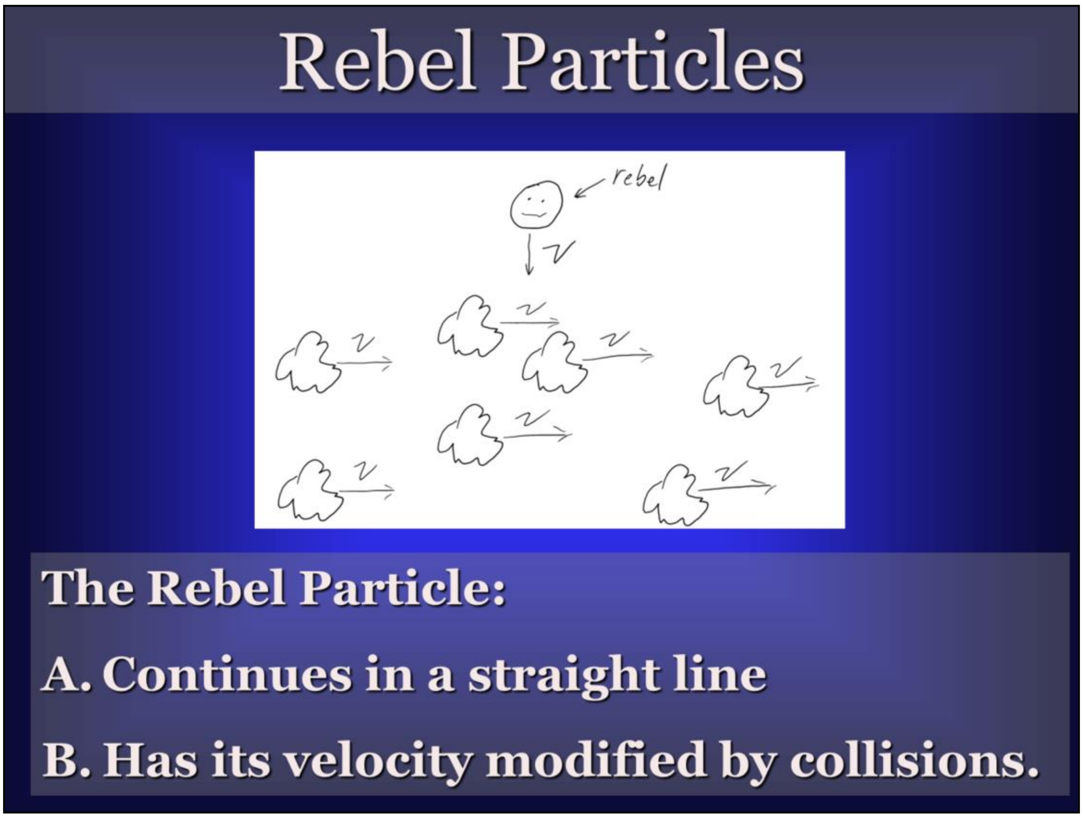
The collapse is a battle between GRAVITY and internal PRESSURE
If gravity wins, the cloud collapses.

Pressure is related to temperature.
As temperature goes up, pressure goes up.
So HOT clouds explode, COLD clouds collapse.



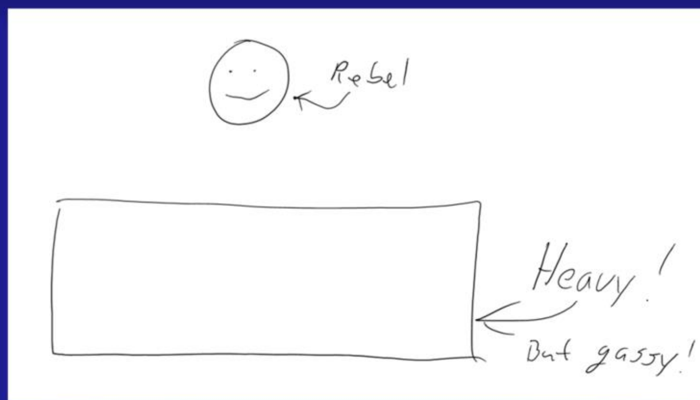
As the cloud collapses, it Conserves Angular Momentum and spins REALLY fast. The density also increases.

When the density is high, and it’s spinning really fast, it flattens into a spinning disk with a central star.


Rebel Particles
rebel
The Rebel Particle:
A. Continues in a straight line
B. Has its velocity modified by collisions.

B

Rebel Particles



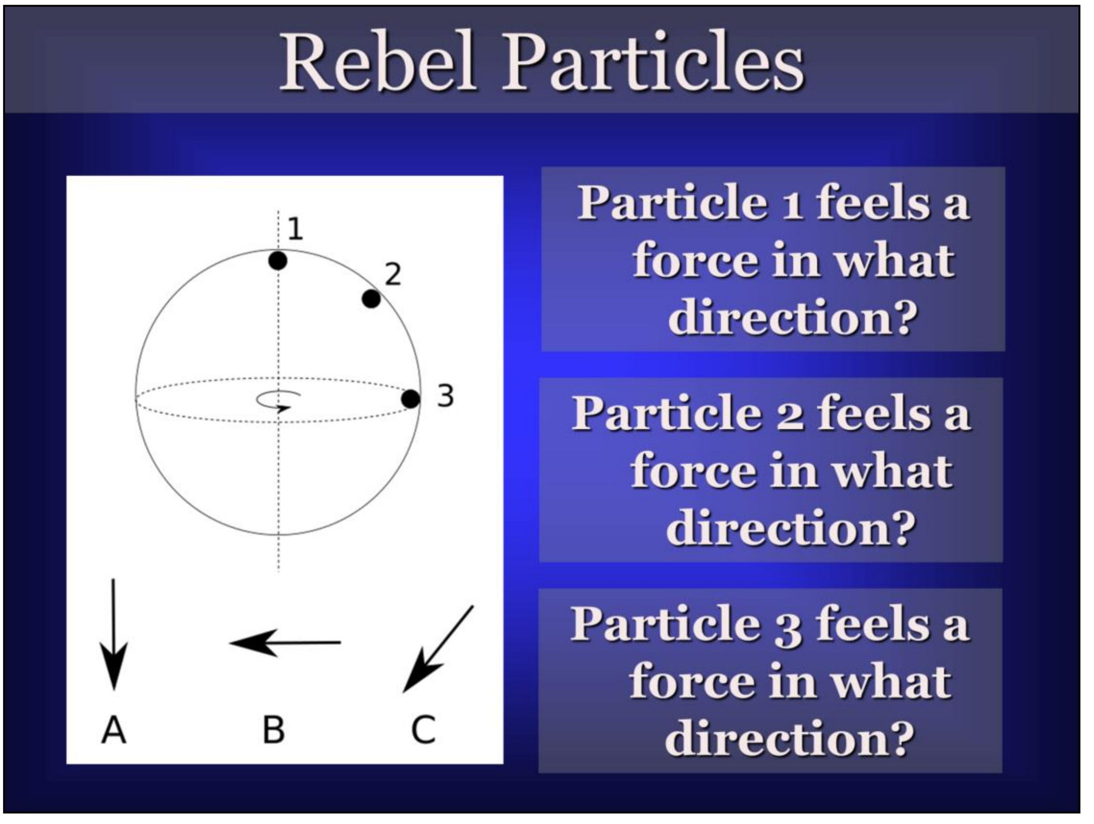
The Rebel Particle:

A. Remains at rest

B. Falls through the cloud keeps going

C. Repeatedly falls through losing energy each time.

C

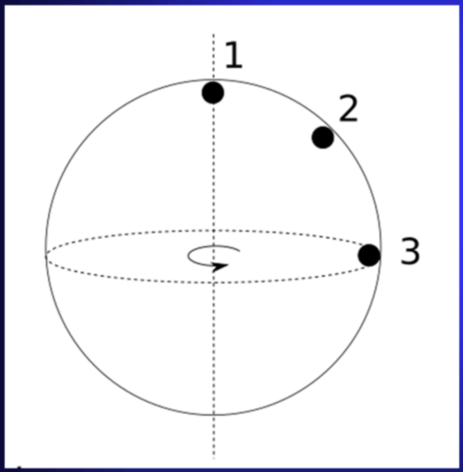

Rebel Particles
1
2
3
A
B
C
Particle 1 feels a force in what direction?
Particle 2 feels a force in what direction?
Particle 3 feels a force in what direction?

1 – A

2 – C

3 - B

Rebel Particles



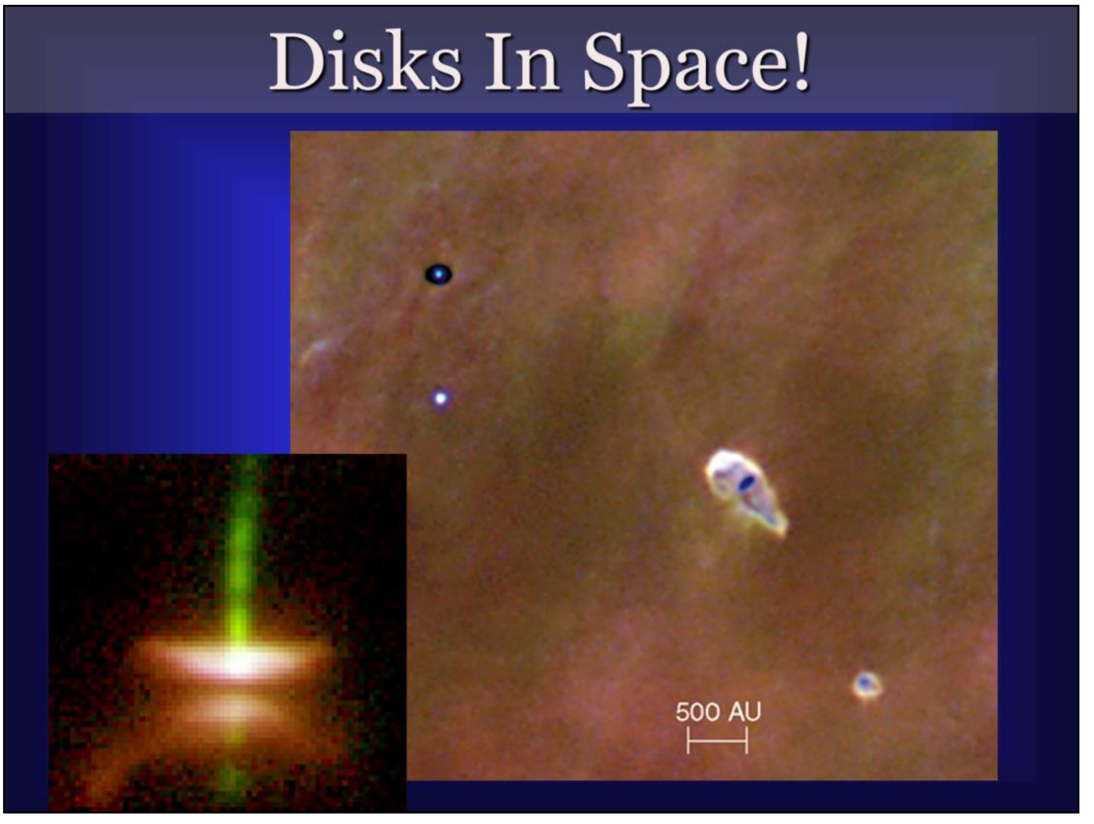
Particle n:

A. Falls towards the center and eventually settles in the middle.

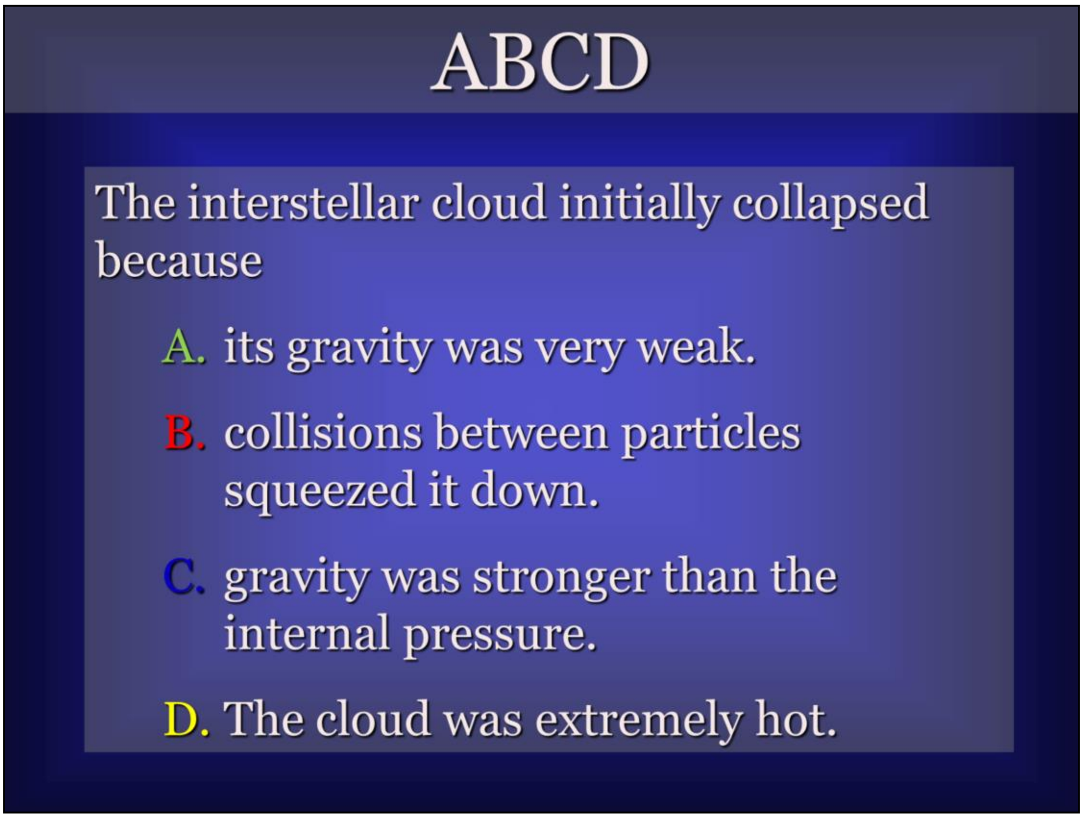
B. Goes in a circle around the central axis.

C. Goes in a circle around the central axis but slowly settles towards the equator.

1. A
2. C
3. B



Here are some images of ACTUAL spinning disks in space.



C.

Cloud collapse happens when gravitational force is greater than internal pressure.

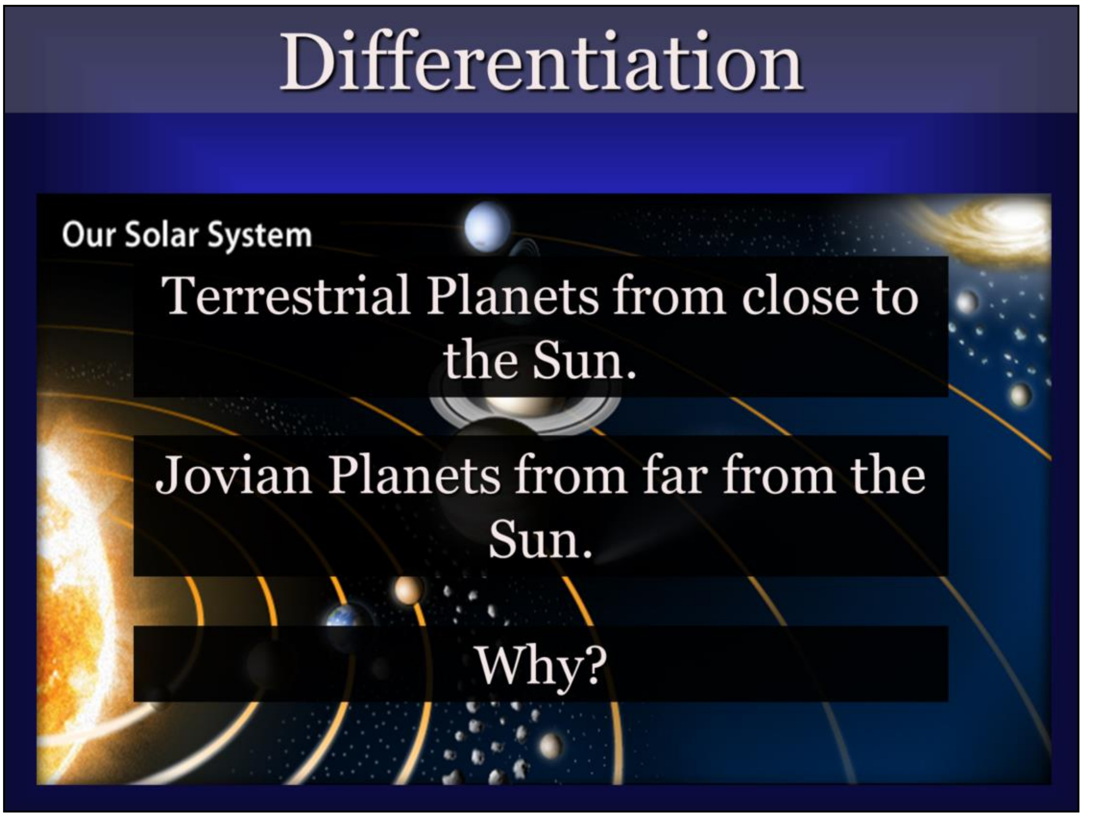
The Nebular Theory

1. A large cloud (nebula) collapses under it's own gravity.
2. As it collapses, it conserves angular momentum and spins faster.
3. Very high densities in the center give birth to a new star.
4. Particle-particle collisions cause the cloud to collapse into a disk.

Orderly Motion

The Nebular Theory explains why

1. All orbits are in the same plane
2. Everything orbits in the same direction around the sun
3. MOST things spin in the same direction
4. All of the spin axis are approximately aligned



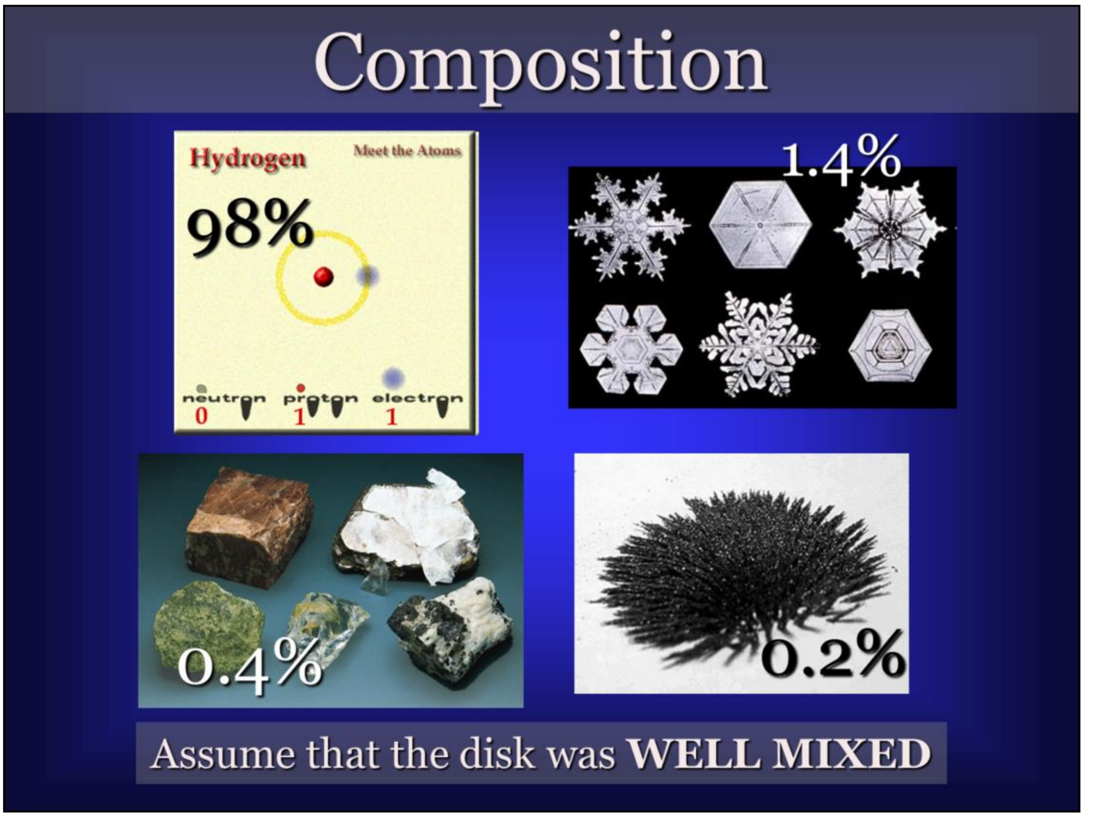
Why are the planets differentiated by composition?

Inner planets are primarily rock and iron

Jovians, at middle disttances, are primarily hydrogen gas with icey/rocky/iron cores

Dwarfs, outskirts of the solar system, are a mixture of rocks and ice.

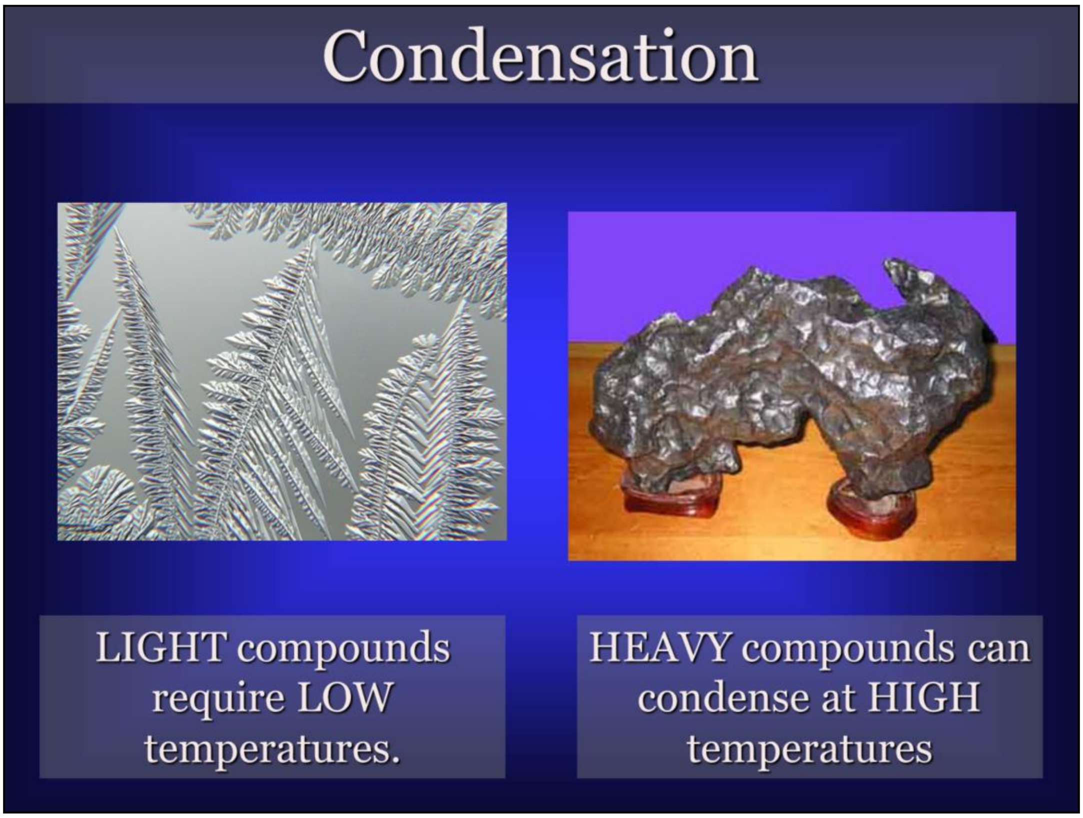
Let’s look at the proto-Planetary disk and see if we can figure out the answer.



The Pre-Solar Cloud was a well mixed and composed of the following:

The disk is made up of lots of different stuff. Some stuff is more abundant
In order of abundance:

- Hydrogen (gas), There is a LOT of hydrogen
  Most of the mass of the solar system.
- Ices (hydrogen compounds like water or methane) way more than the iron or rocks
- Rocks (silicate compounds)
  Not much, but more than Iron
- Iron (and other trace heavy metals)
  Very little

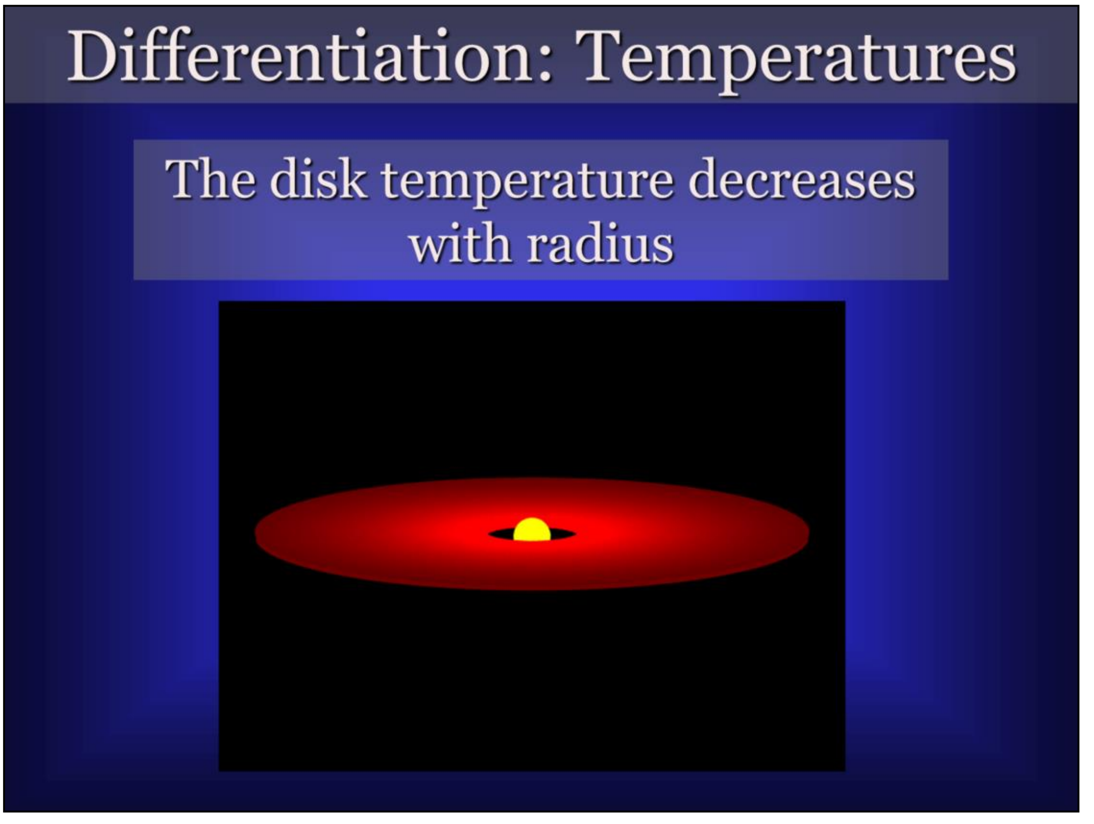


Condensation is changing from the gaseous state to the solid state.

In a proto-planetary disk, the gaseous rocks, iron, or ices condense to form solids.

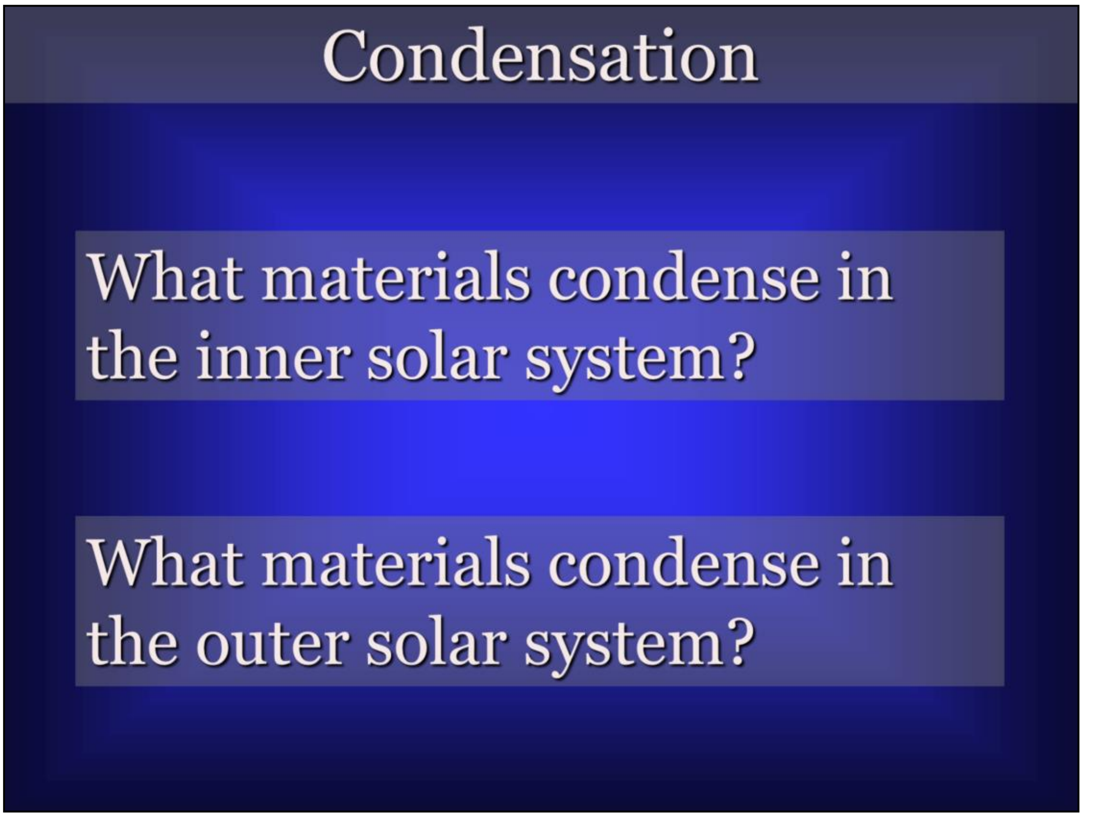
Icey compounds (hydrogen compounds) condense at low temperatures to form ices.

Rocks and Metals condense at HIGH temperatures.



The inner disk regions have a HIGH temperature because… They're close to the star.

The outer disk regions have a LOW temperature because… They're far away from the star.



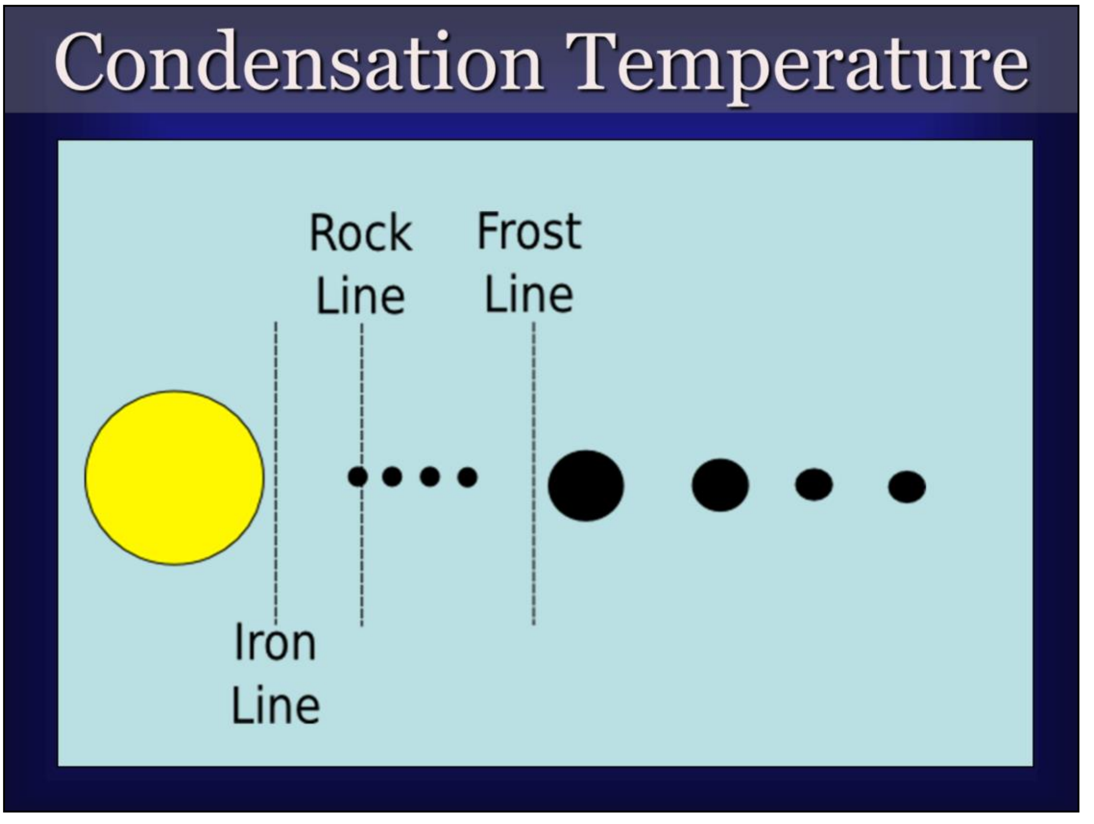
Only Iron and Rocks can condense in the inner solar system.

Why? – Because it's HOT! It's too hot for Ices (Hydrogen Compounds) to condense.

In the outer solar system, we get Rocks AND Iron AND Ices.

Why? – Because it's cold, below the condensation temperature of Ice.

And… if it's cold enough for ice to condense, then it's cold enough for rocks and iron to condense as well.

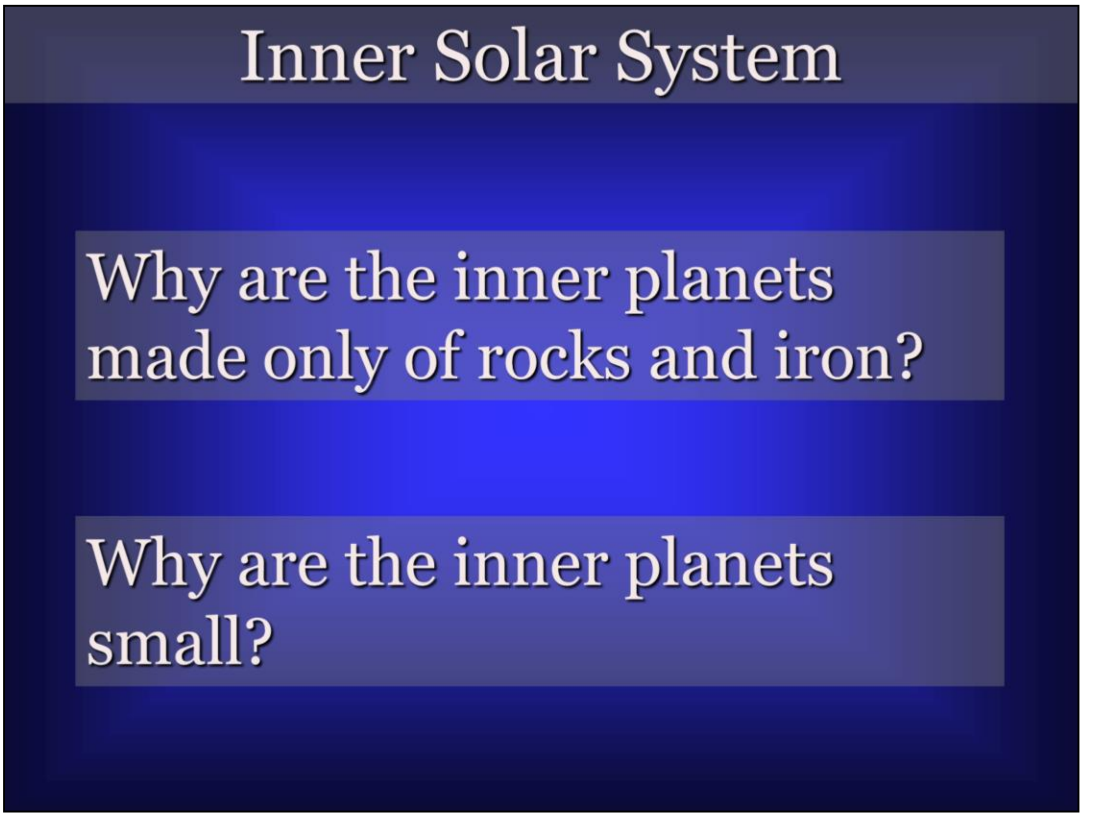


Inside the Iron Line, No solids form.

Beyond the Iron line, Iron can condenst

Beyond the rock like Rocks can condense and, if it's cold enough for rocks to condense it's cold enough for iron to condense also.

Beyond the frost line, Ices can condense. Of course, so can rocks and iron.

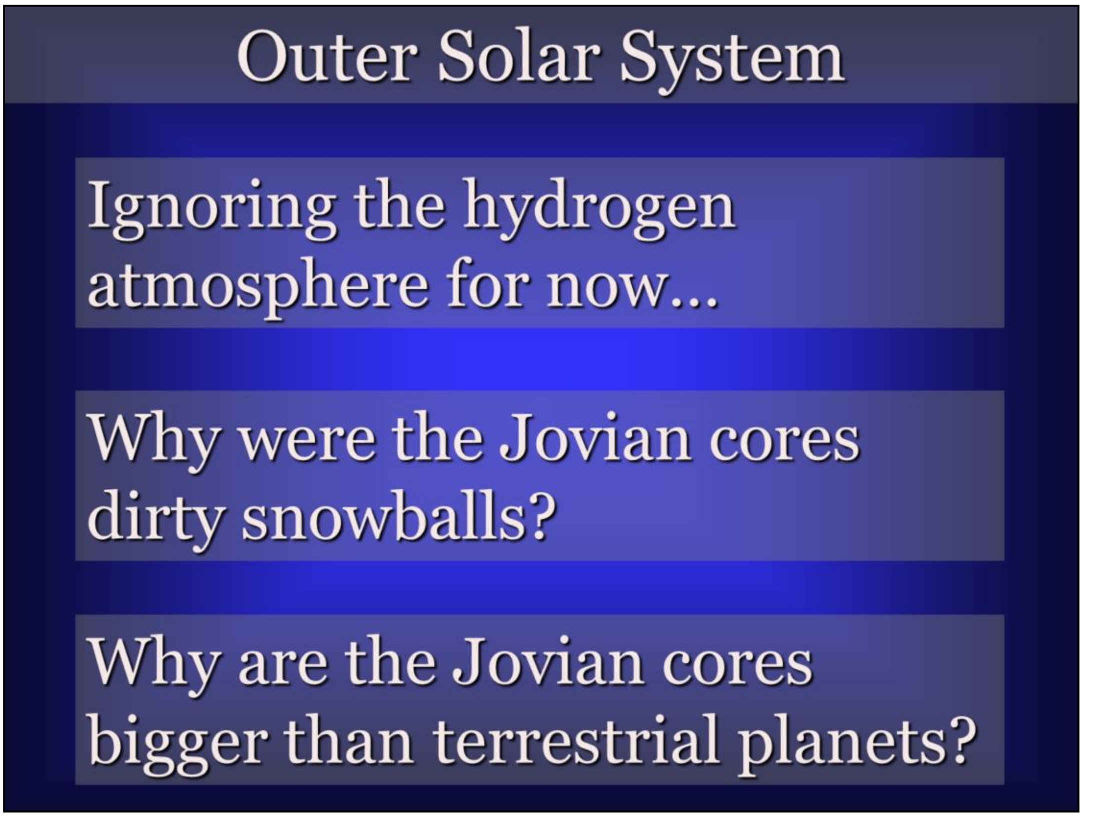


The inner planets have only rock and iron because it’s too cold for ices to form.

The inner planets are small because there isn’t very much rocky material or iron to work with.

Conversely, the Jovian cores are BIG because there is a lot more ice than rocks or iron.

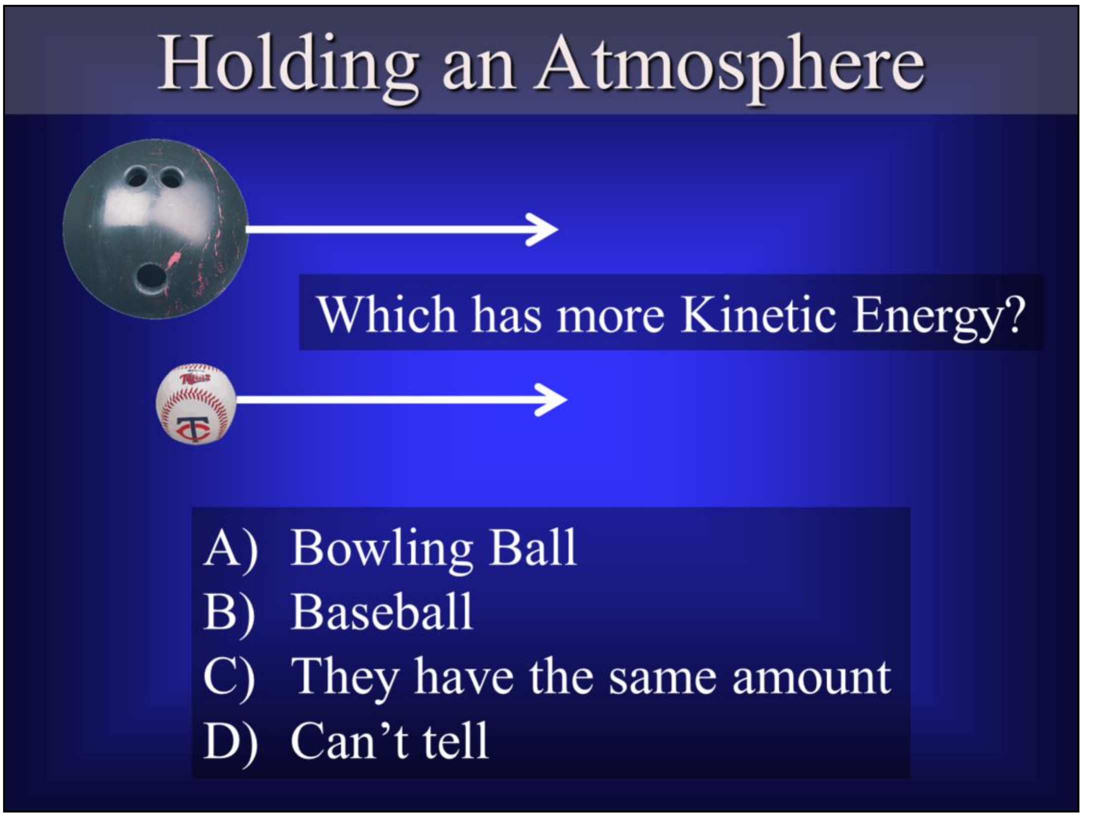
Jovian planets start as a BIIIIIIG dirty snowball.



Because they form beyond the frost line, Jovian planets have a significant icy component.

In fact, they have ice AND rocks AND iron.

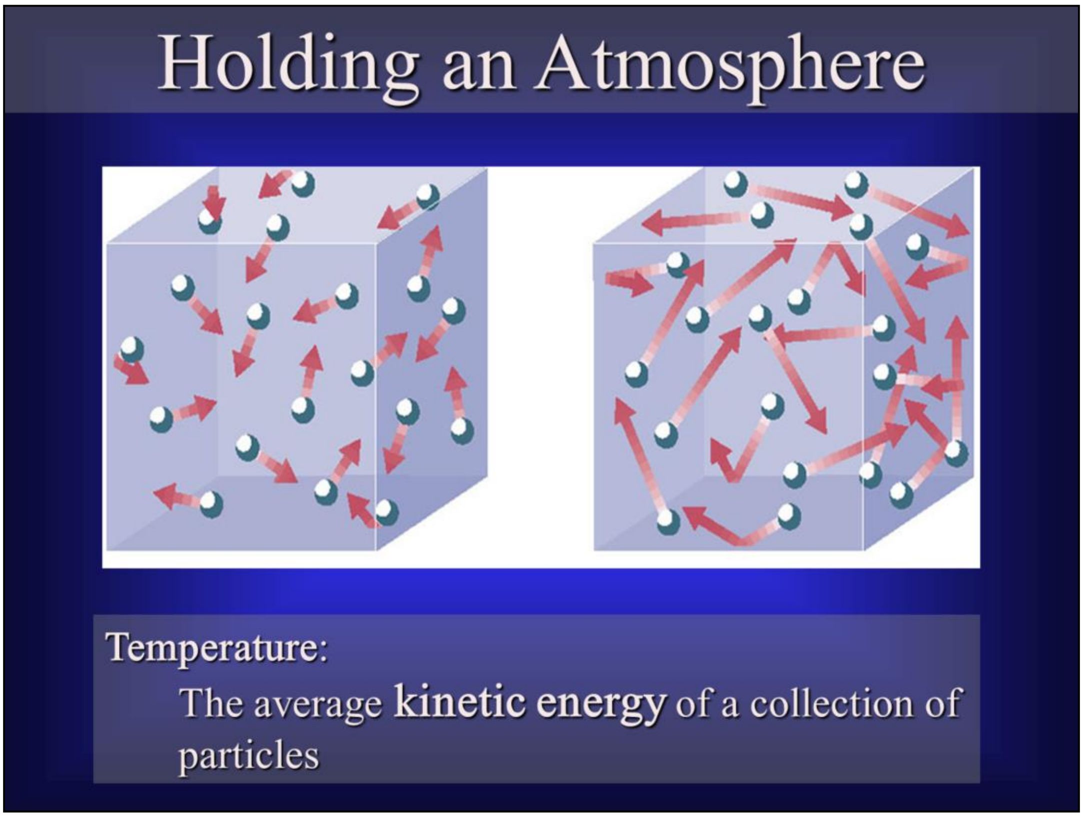
They're big because there's a lot of material to work with, compared to terrestrial planets.



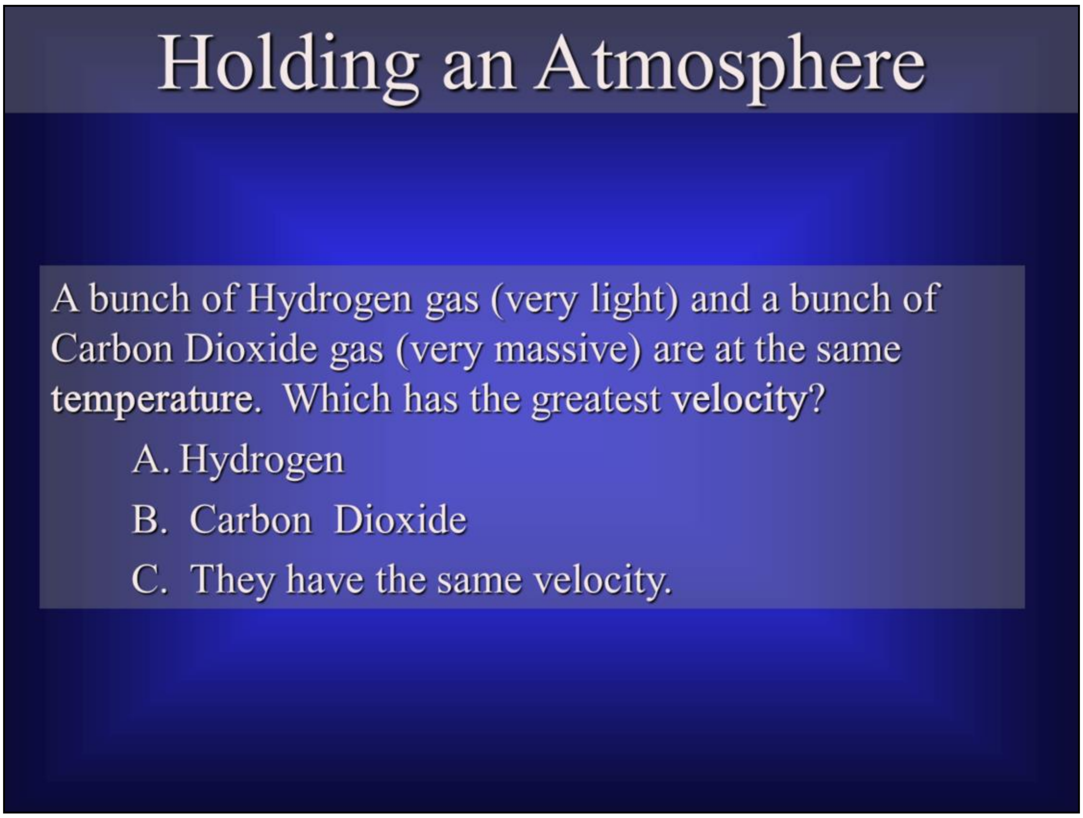
A

Because Kinetic energy involves both mass and velocity.

If they have the same velocity, but different masses, the more massive object carries more kinetic enery



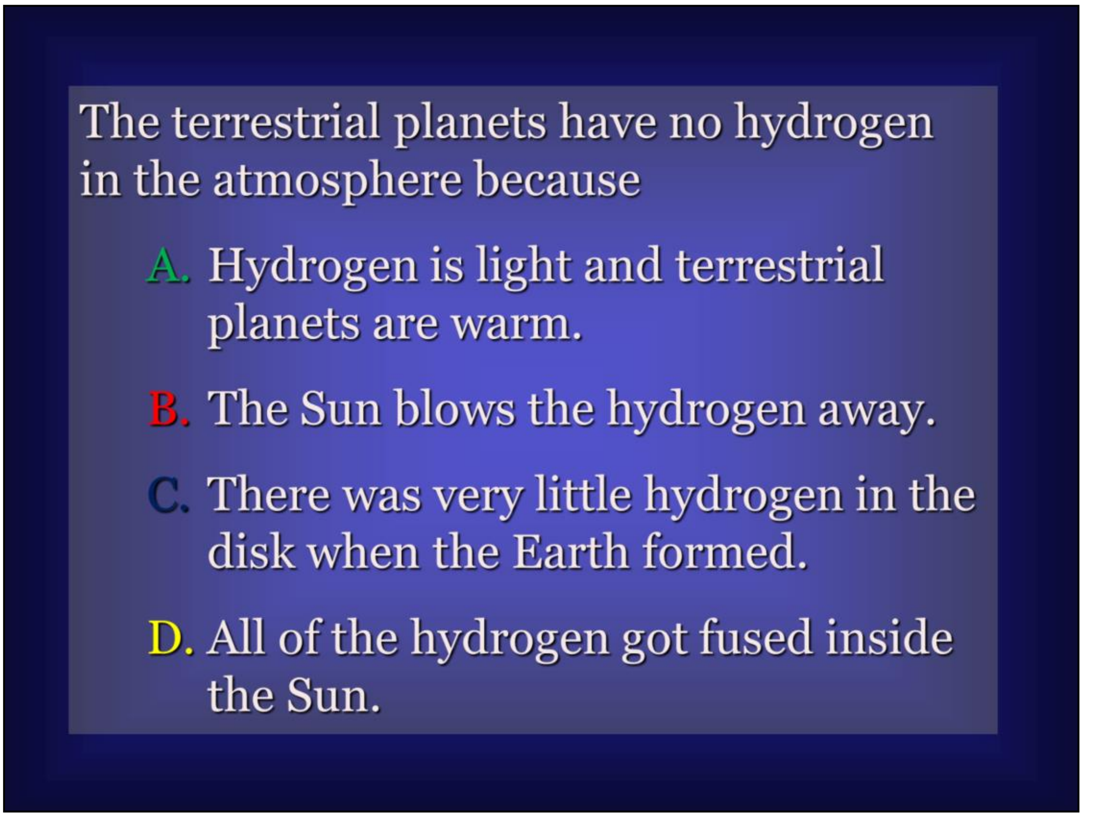
Higher temperature, higher average Kinetic energy



A. Hydrogen

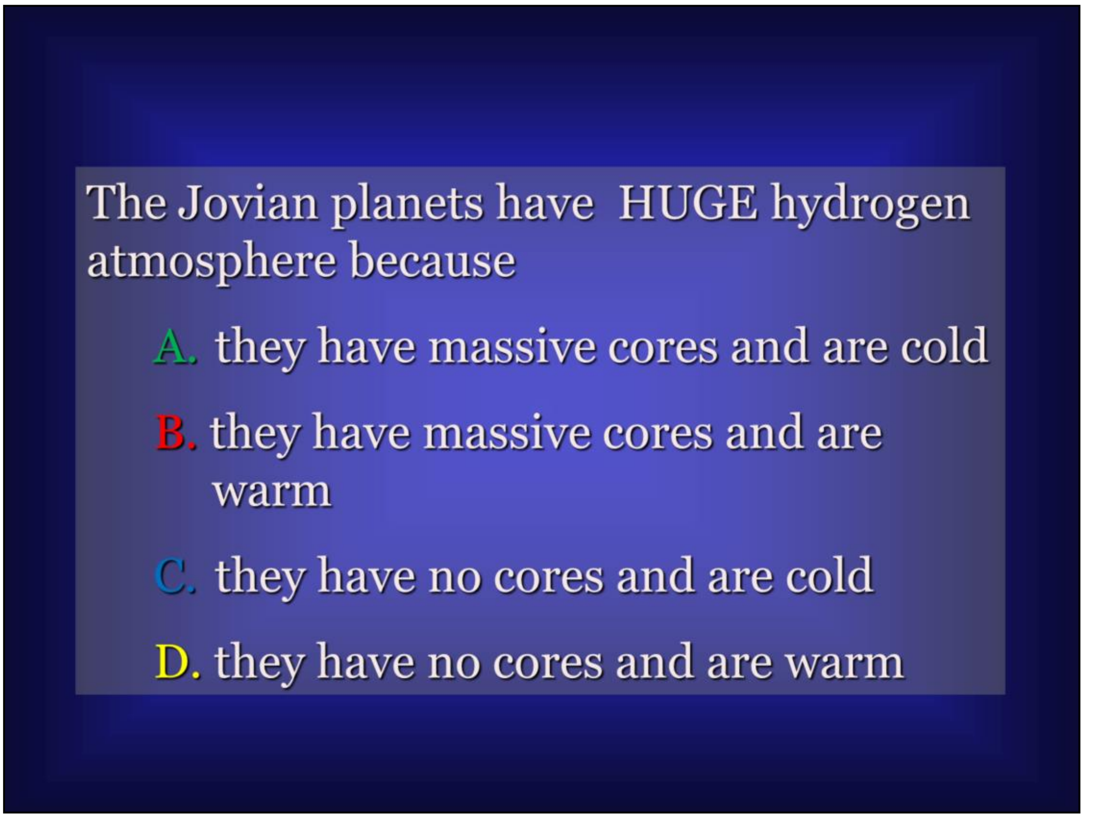
Temperature measures average Kinetic Energy.
So.. The kinetic energy of each gas is the same.
So, the velocity of the less massive gas must be higher.

If an object has a high enough velocity, it can escape from the Earth and never come back.



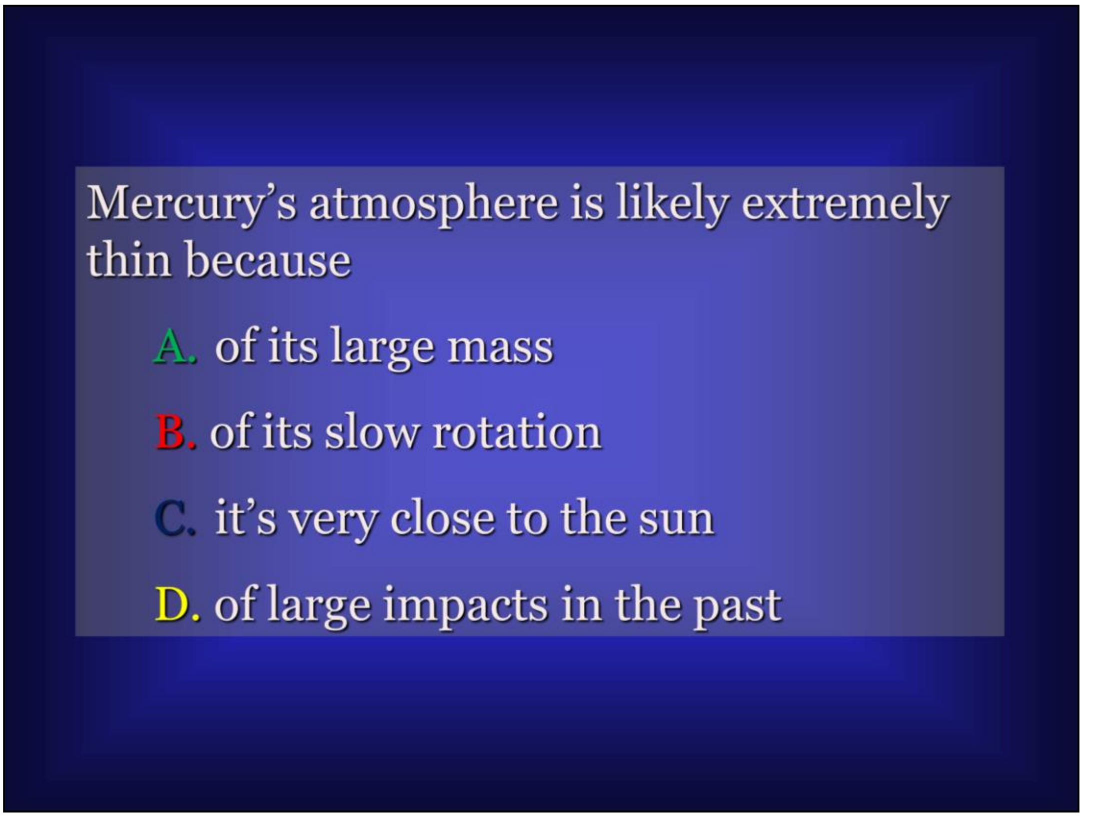
A.

It’s too warm here, and terrestrial planets aren’t very massive.
So, hydrogen exceeds the escape velocity.



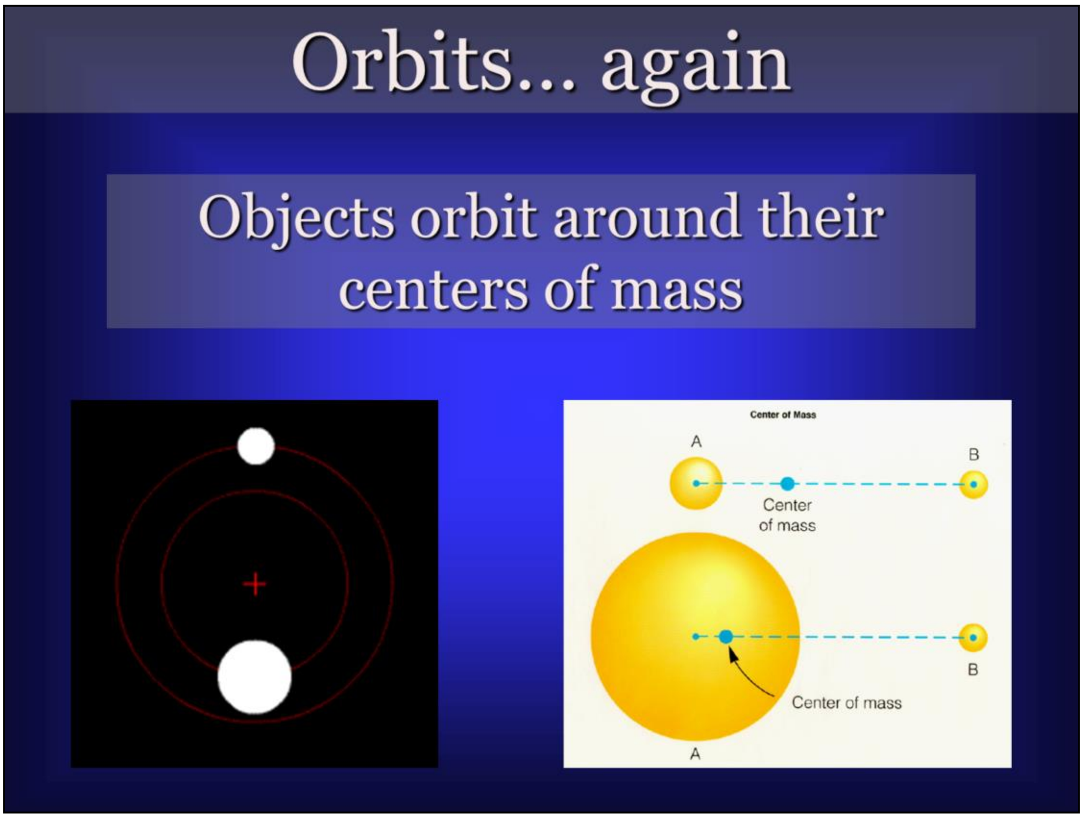
A

It’s cold where Jupiter forms. And, the jovian cores are BIG.
So, hydrogen isn’t moving very fast. It doesn’t exceed the escape velocity.

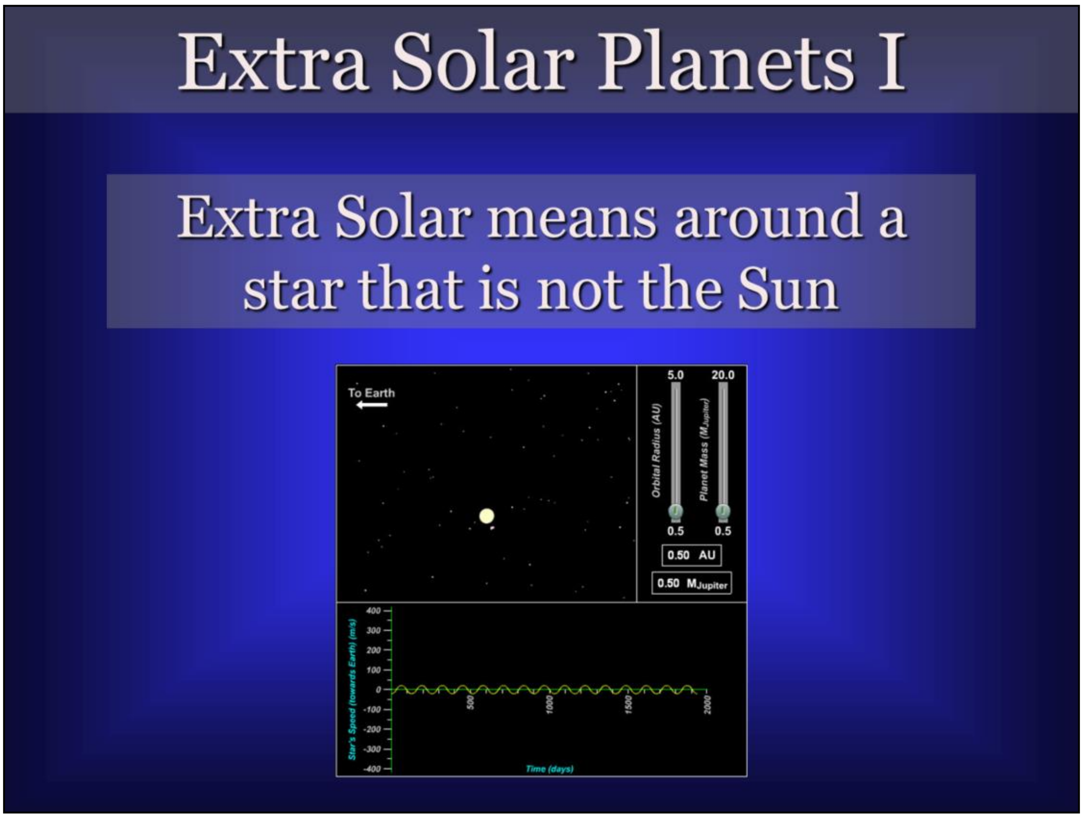

Mercury's atmosphere is likely extremely thin because
A. of its large mass
B. of its slow rotation
C. it's very close to the sun
D. of large impacts in the past

C.

HOT!



So… if something really large is orbiting a star, the star will actually wobble.

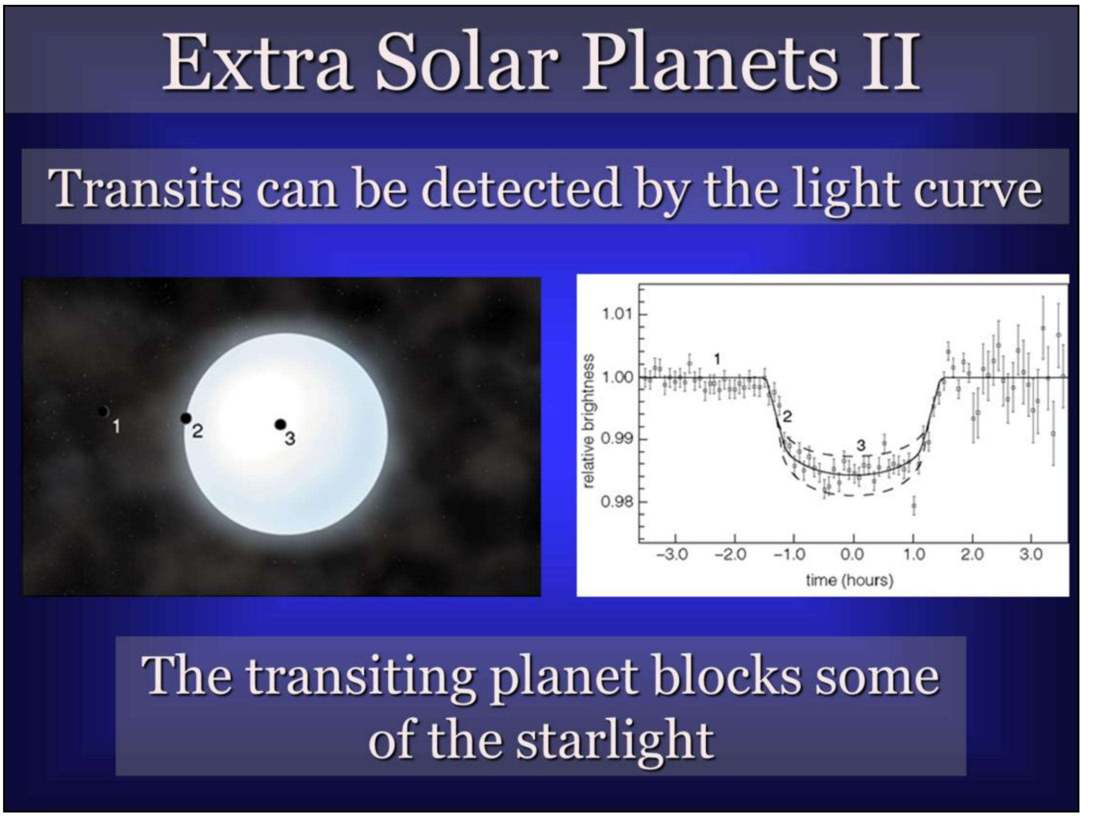


We DO NOT detect extra solar planets directly. We can only see the effect that they have on their parent stars.

So really big planets (Like the size of Jupiter) close to their parent stars (Like 0.1 AU or less) cause a significant wobble in the star.

We can detect that wobble through the **Doppler Effect**.

The absorption lines in the star shift back and forth as the star wobbles first away from us and then towards us.



We can also, if we are very lucky and happen to see a planetary system aligned juuuust right, see the starlight dim slightly as the planet passes in front of it.