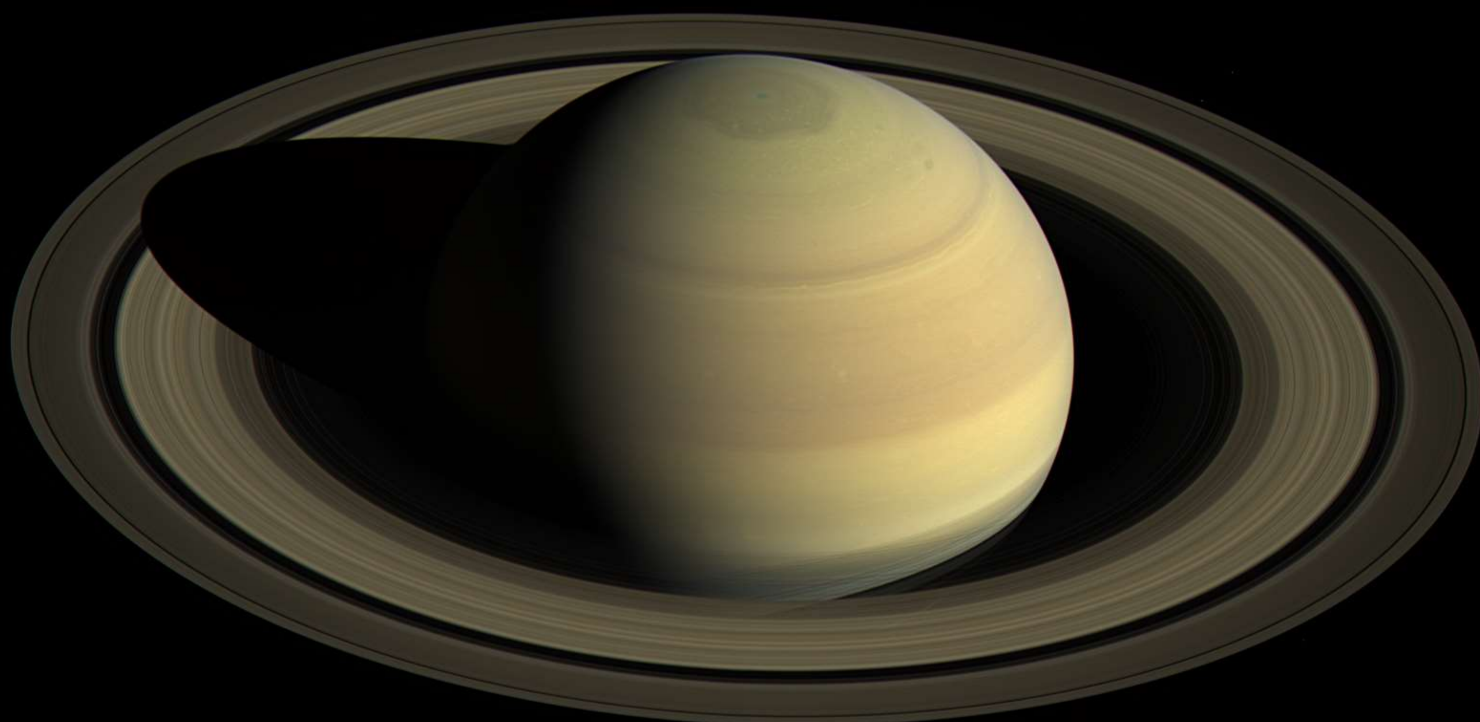
AST 2002
Introduction to Astronomy



A Few Quick Things…

E-mailing me: Must have AST2002 in the subject

Mary Hinkle, Graduate Teaching Assistant:
Office Hours: Mon 1:30-3:30pm. PSB 316

My office hours: Mon 3:00-4:00pm. PSB 308
Tue 3-4 pm. PSB 308

First Mid-term was last week… Friday 9th February.

I will arrange one last make-up class. I need the times you are available.

Next Knights Under the Stars Event – Thur 22nd Feb 7-8:30pm

Summary of Last Time

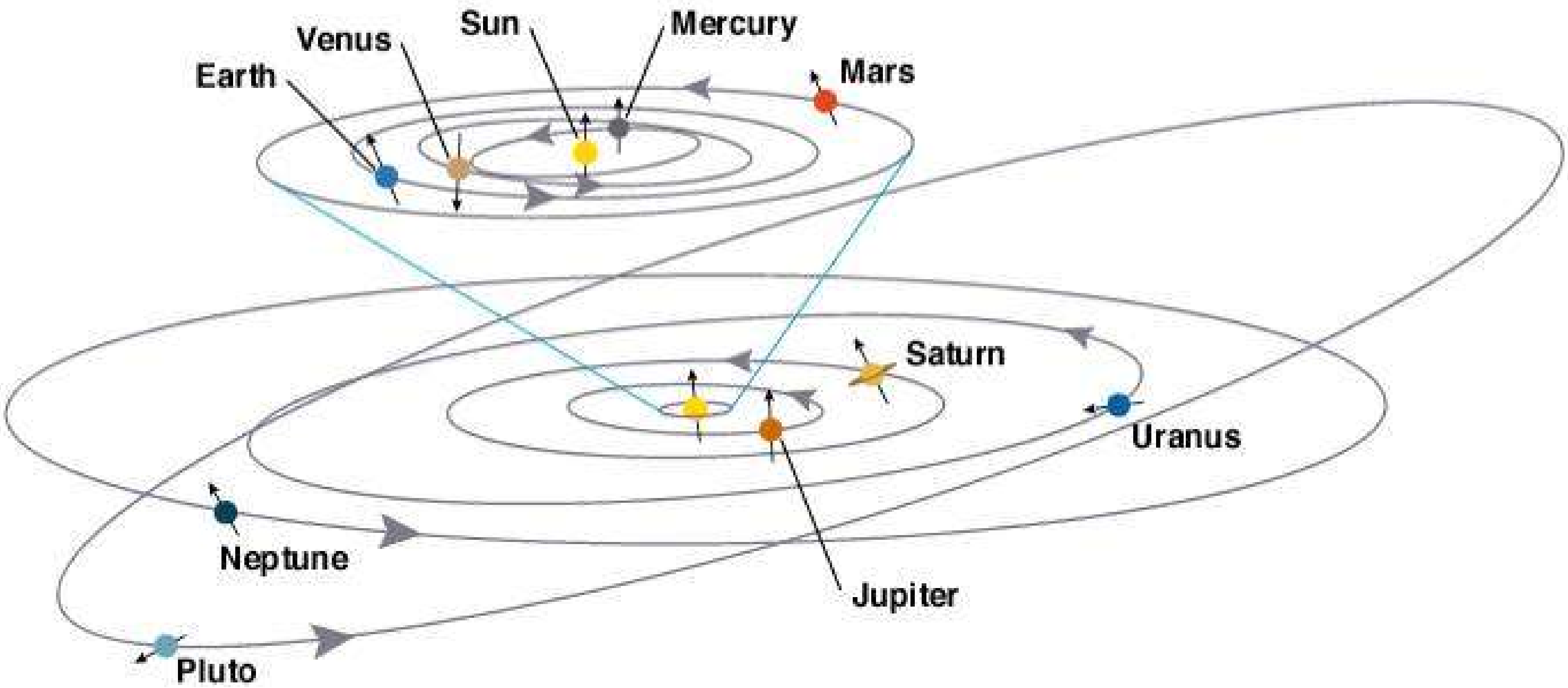
Part III – Learning from other Worlds

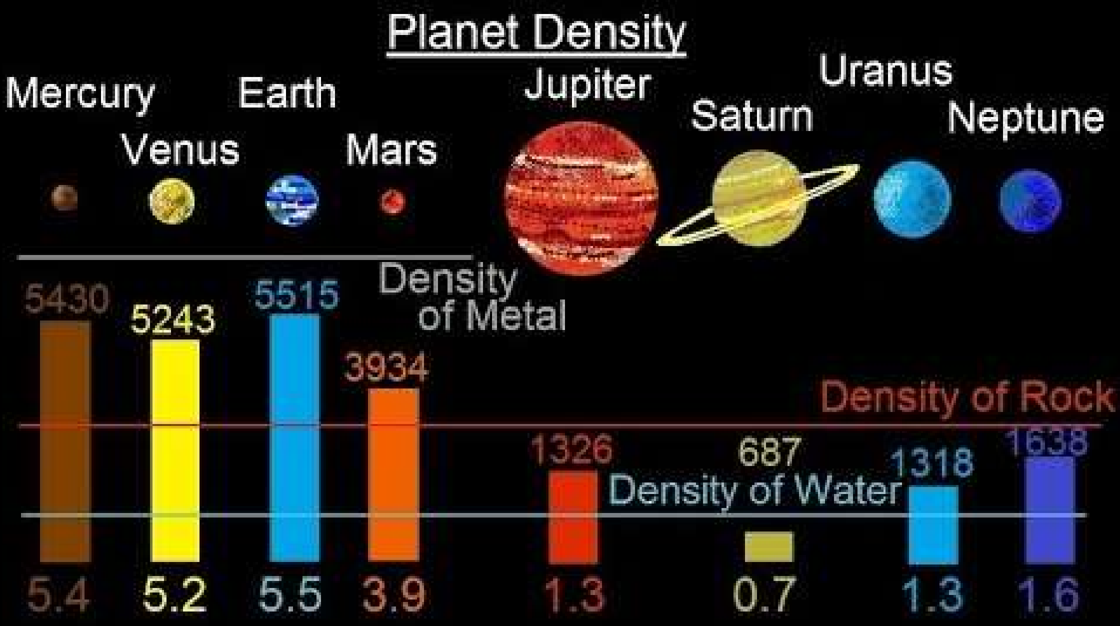
- **Chapter 6:** Formation of the Solar System

  Tour of the Solar System… Nebula Hypothesis

Today – more about Solar System Formation

A Brief Tour of the Solar System





Trends

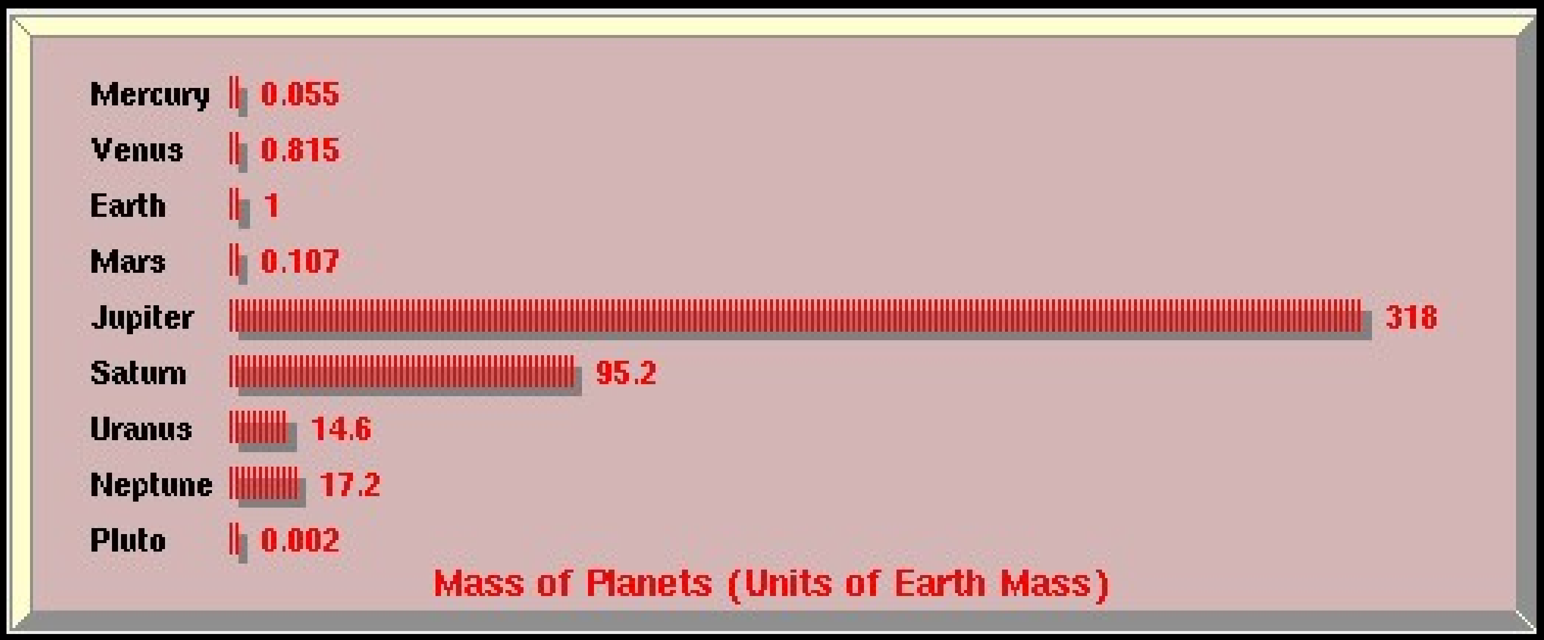
Density = mass/volume

(g/cm^3) = (g/ml) = (kg/dm^3) = (kg/l) - *bottom values*

(if in kg/m^3 it is 1000x larger number) – *top values*

Terrestrial planets are small (low mass) and dense

Jovian planets are large and mostly gaseous



Planetary Trends

- **Planets fall into two main categories:**
  - **Terrestrial (i.e. Earth-like)**
  - **Jovian (*i.e.* Jupiter-like or gaseous)**

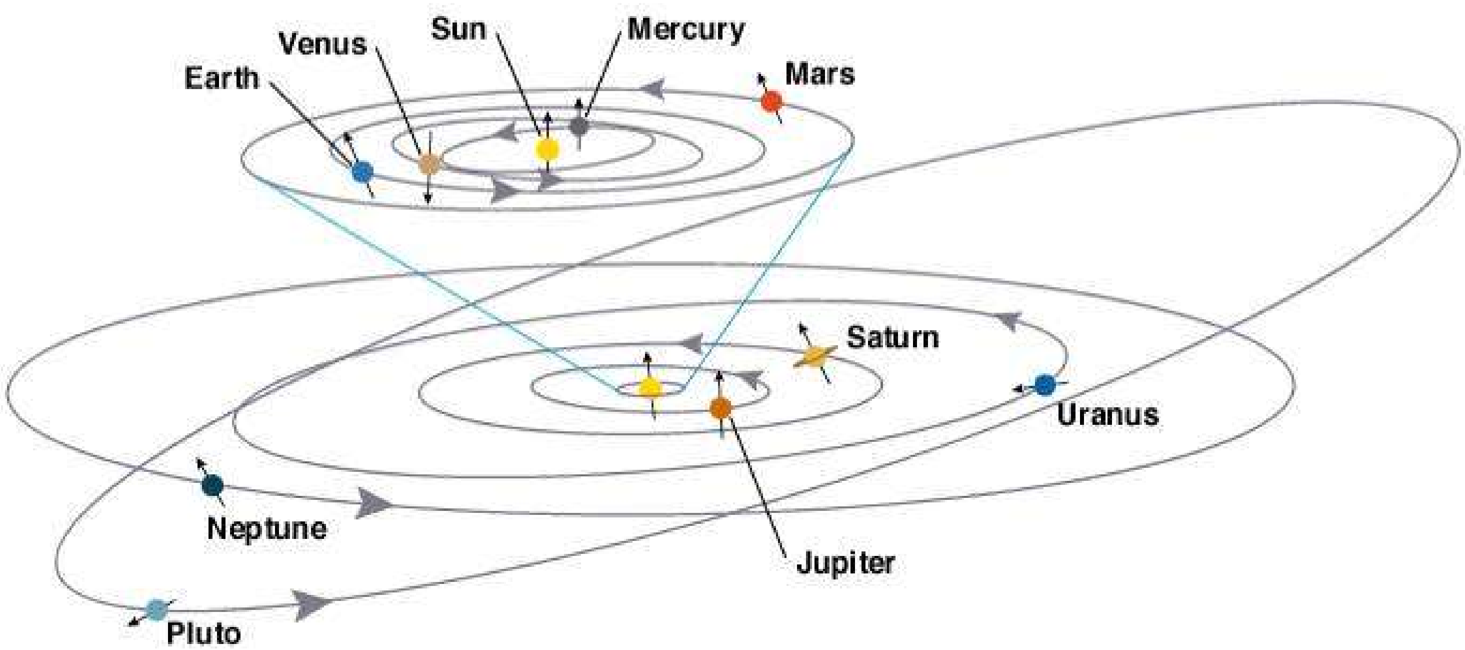
Planet	Mass (Earth Masses)	Radius (Earth Radii)	Density gm/cm^3
Mercury	0.055	0.38	5.5
Venus	0.815	0.95	5.2
Earth	1.000	1.00	5.5
Mars	0.107	0.53	3.9
Jupiter	318	10.8	1.4
Saturn	95	9.0	0.7
Uranus	14.5	3.93	1.3
Neptune	17.2	3.87	1.6
Pluto	0.002	0.178	2.1

Terrestrial Planets	Jovian Planets
Smaller size and mass	Larger size and mass
Higher density (rocks, metals)	Lower density (light gases, hydrogen compounds)
Solid surface	No solid surface
Closer to the Sun (and closer together)	Farther from the Sun (and farther apart)
Warmer	Cooler
Few (if any) moons and no rings	Rings and many moons

The Layout of the Solar System

The bodies in the Solar System have orderly motions

- **the <u>Sun rotates counterclockwise</u>**
- **planets <u>orbit counterclockwise</u> in same plane**
  - **orbits are almost circular**
- **<u>most moons orbit counterclockwise</u>**



Our Explanation of Solar System Formation Must Explain:

Feature #1: Patterns of Motion Among Large Bodies

- All orbits are circular and in the ecliptic plane
- The suns rotation, planetary rotation, orbits of the planets and (most) satellites are counterclockwise (and in the same plane)

Feature #2: Two Types of Planets

- Terrestrial planets are close to the Sun, have low mass, but high density (rocks and metals)
- Jovian planets are far from the Sun, have high mass but low density (mostly gaseous)

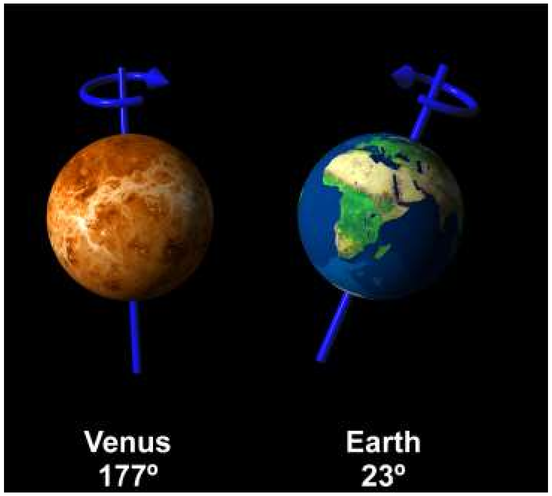
Feature #3: Asteroids and Comets

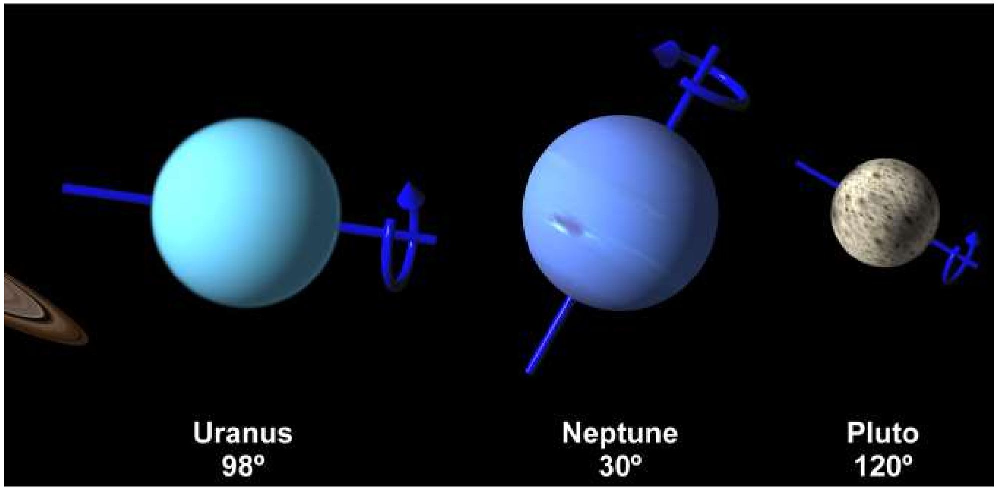
- Must be able to explain the formation of the asteroid belt, the Kuiper belt, and the Oort Cloud

Feature #4: Must be able to Explain Exceptions to the Rules…

A Few Exceptions to the Rules…

- Both Uranus (& Pluto) are tilted on their sides.
- Venus rotates "backwards" (i.e. clockwise).
- Triton orbits Neptune "backwards."
- Earth is the only terrestrial planet with a relatively large moon.





iClicker Question

Which Planet has a volcanically active moon?

A. Earth
B. Jupiter
C. Saturn
D. Mercury
E. Uranus

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iClicker Question

Which of the following planets has the coldest nighttime temperature?

A. Mercury
B. Venus
C. Earth
D. Mars

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Which of the following planets have rings?

A. Saturn
B. Uranus
C. Jupiter
D. Neptune
E. All of the above

iClicker Question

Which of the following planets have rings?

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E. **All of the above**

A Few Theories on Solar System Formation

Capture Theory:

The same way some planets seem to have captured moons, some thought that the Sun may have captured wondering planets, or perhaps passed through a cloud and some of this material coalesced to form planets later

Close Encounter:

A passing star of different mass, density and composition passed close by the Sun, and ripped off the outer layers which then form planets of different compositions

Nebula Theory:

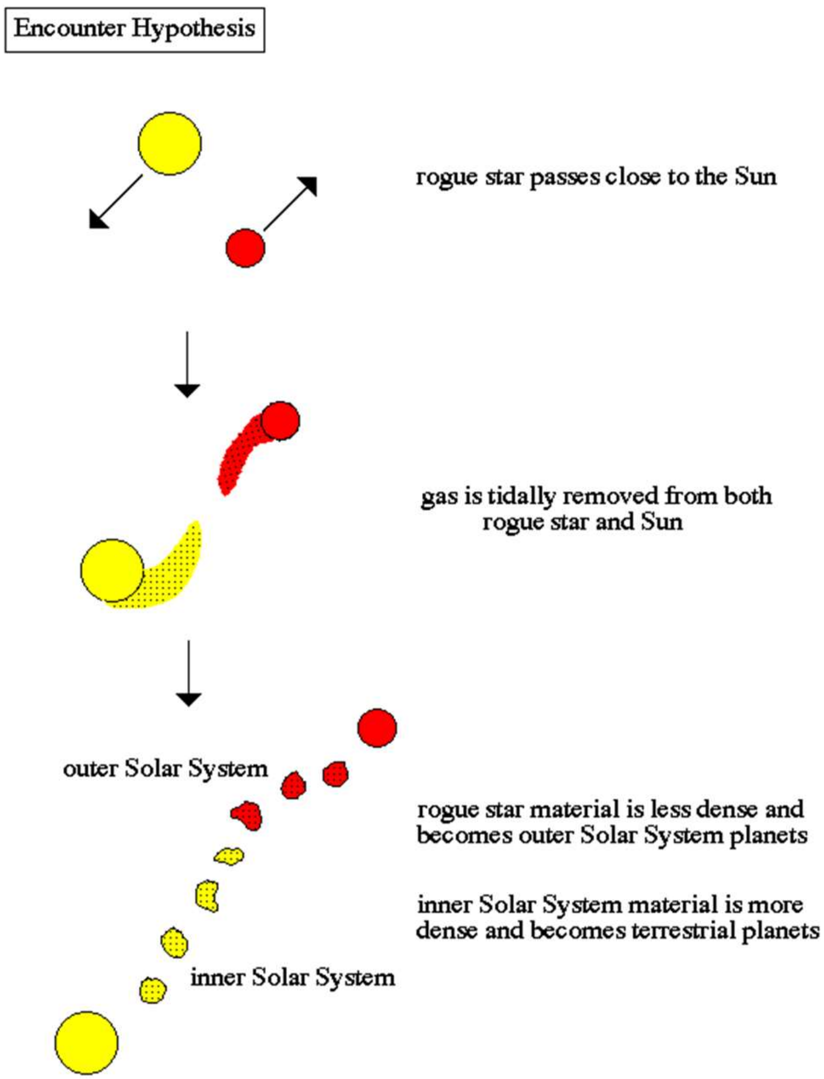
States that our Solar System formed from the gravitational collapse of a giant interstellar dust cloud – the solar nebula.

(Nebula is the Latin word for cloud)

Planetesimal Theory:

(A modern version of nebula theory)

The Close Encounter Hypothesis



☑ All bodies would have same rotation as the Sun

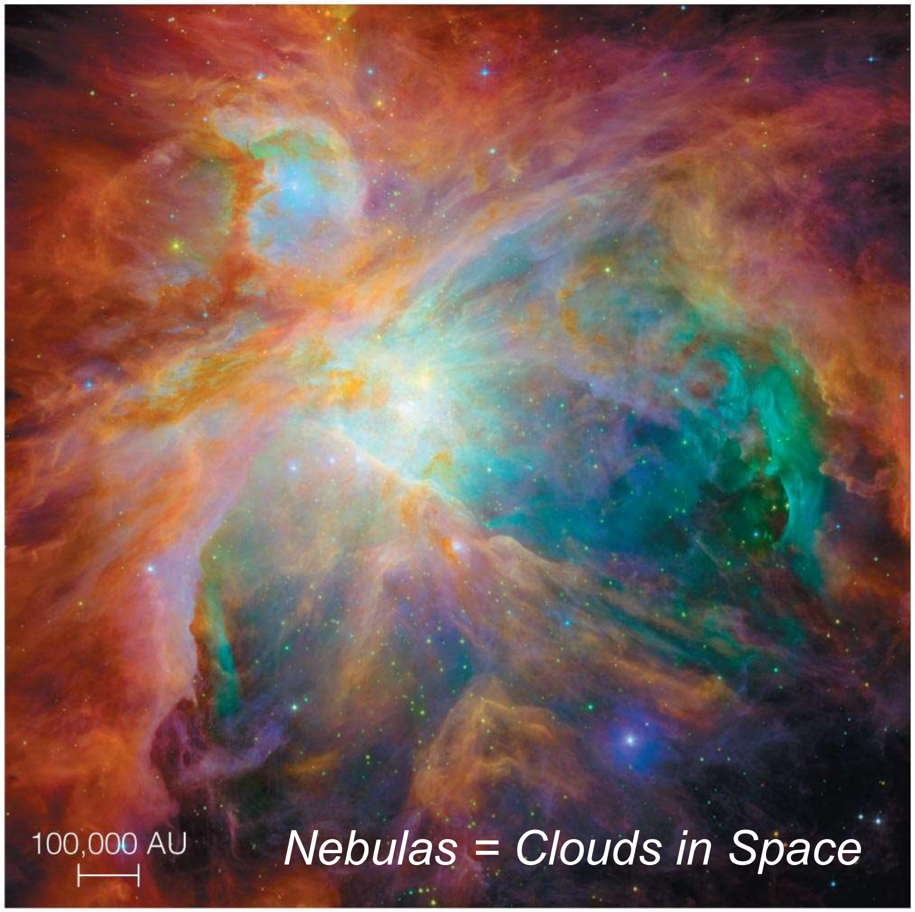
☑ Could perhaps explain why different compositions of Terrestrial *vs.* Jovian planets?

☒ No, the outer layers of the stars would not be able to form planets

☒ Not very probable – our studies of Exoplanets prove planetary formation is common

Our telescope observations support Nebula/Planetesimal theories

Nebula Theory



Nebulas = Clouds in Space

Proposed by Kant and Laplace (independently) over 200 years ago.

Solar System formed from a huge cloud of interstellar dust and gas.

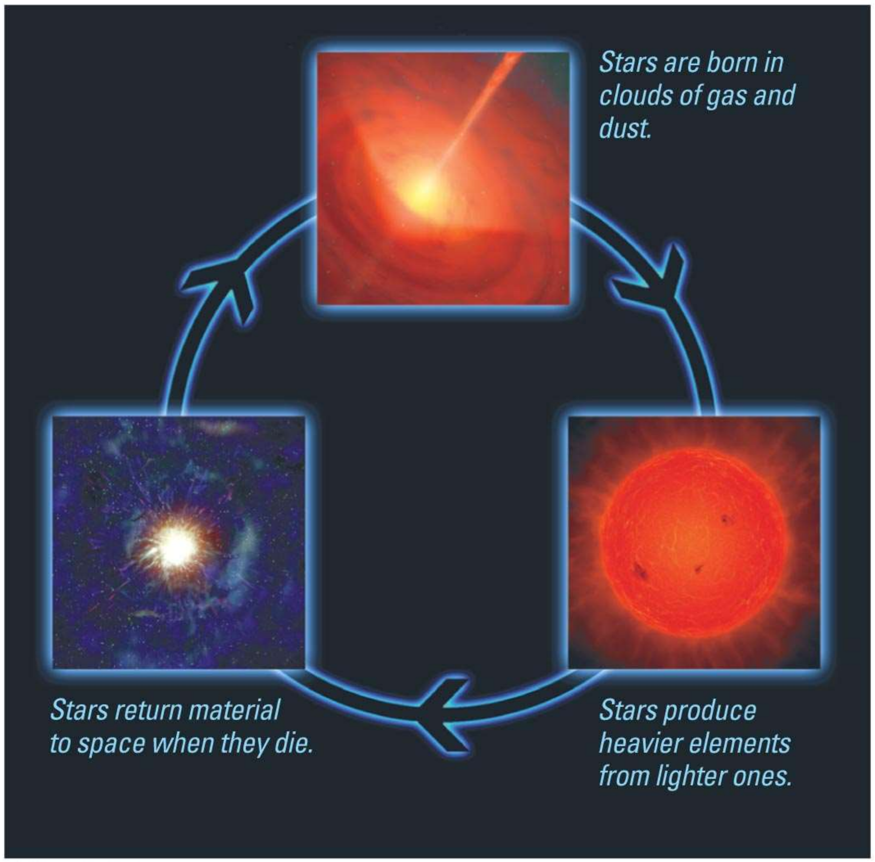
Two Guiding Physical Laws:

i) Gravity: (also that potential energy -> kinetic energy/heat)

ii) Conservation of Angular Momentum

Also need to consider some physical properties of elements and molecules…

What is the Nebula made from?



Our Sun is only ~ 1/3 the age of the Universe…

Many stars lived and died beforehand, which generated heavier elements and dispersed them into interstellar space… (*we are all made of star dust*)

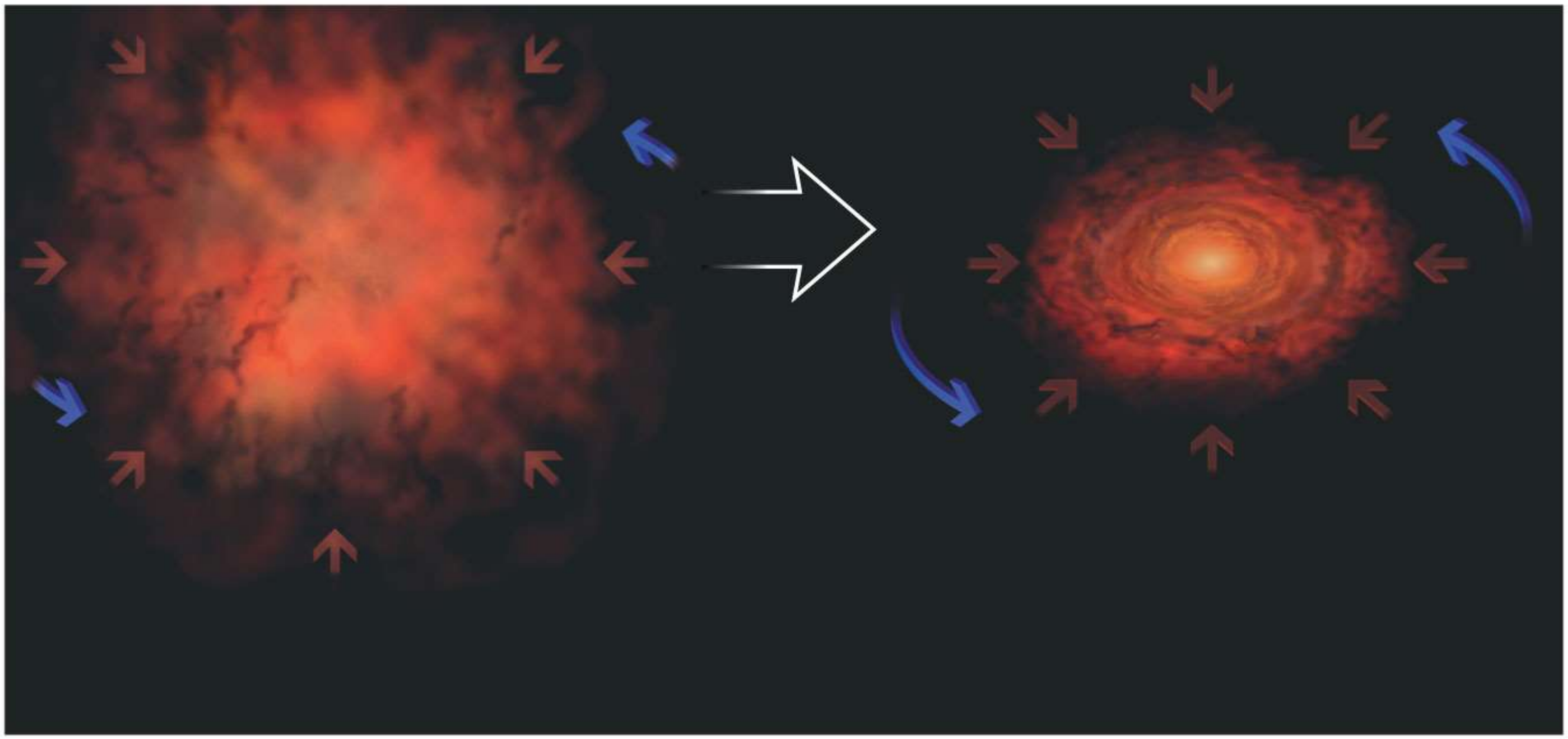
We can see from their composition (spectra of light = elements) that *older stars contain more heavier elements* compared to newer stars!

Evidence from Star Birthing Clusters

In Orion, there is a cloud where lots of young stars are being born in different stages.

These all seem to be born with clouds of gas/dust around them, which starts to flatten out into disks…

Cloud Collapse – Conservation of Angular Momentum (=m×v×r)



An initial cloud, a few light years across at low temperature (~10 K), roughly spherical, with imperceptible levels of angular rotation visible… *process may be nudged into starting to contract.*

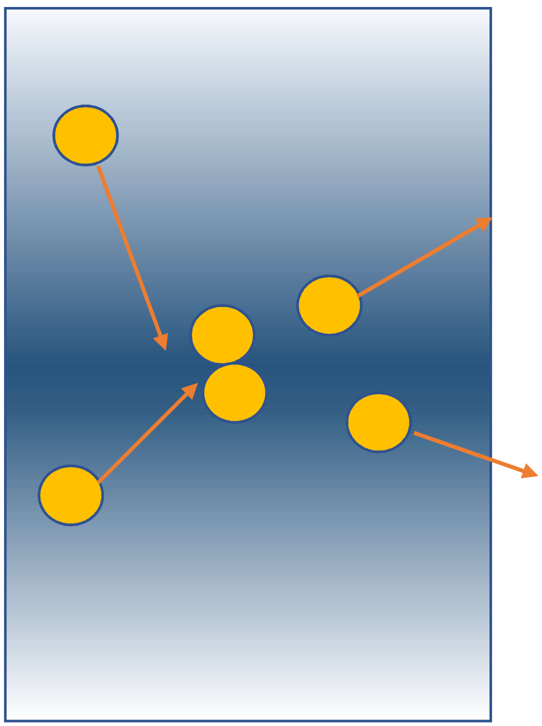
As it collapses under gravity, it becomes smaller (a few hundred AU) and hotter (P.E. → K.E.). Gravity and temperature will be greatest at the center…

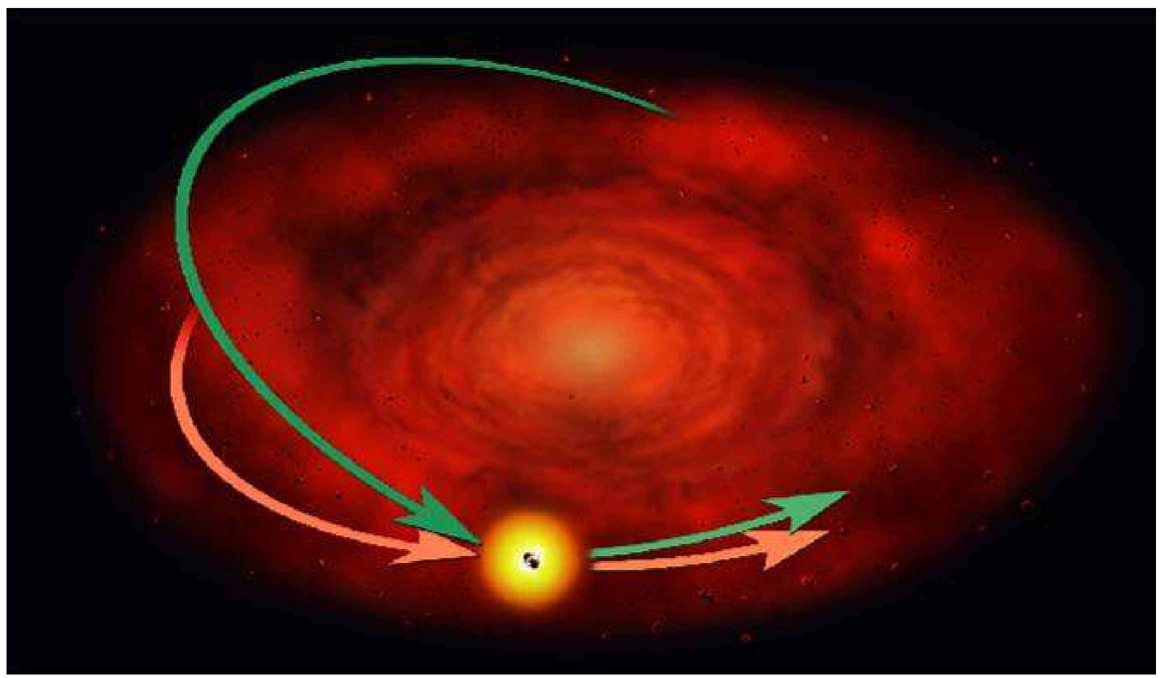
The smaller it gets, the faster it spins

Flattening of the Solar Nebula

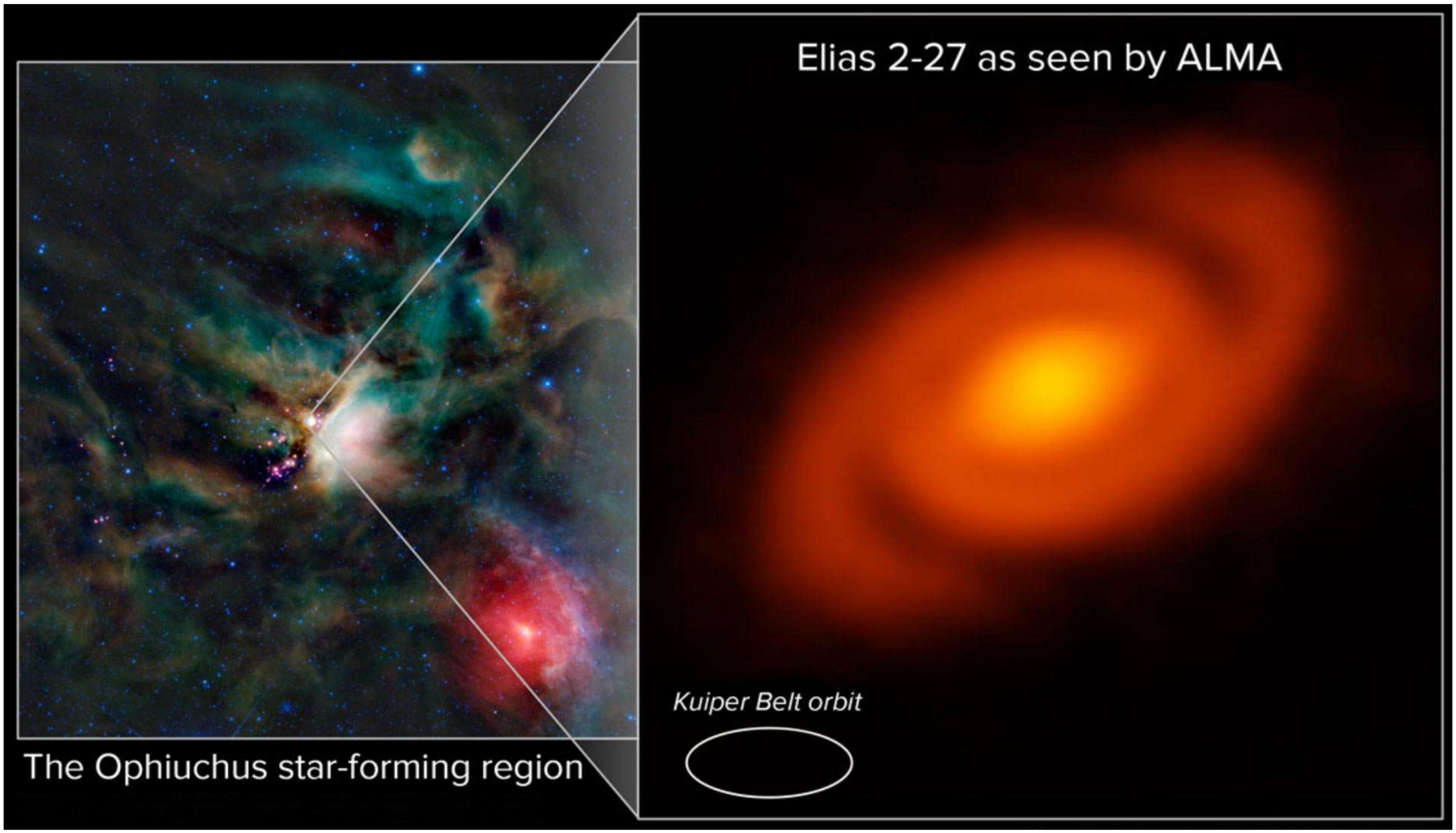
As the nebula collapses, clumps of gas collide & merge.

- Their random velocities average out into the nebula's direction of rotation.
- Gravity also plays a role in flattening; heavier objects will be confined to plane.
- The spinning nebula assumes the shape of a disk.





Protoplanetary Disks Around other Stars!



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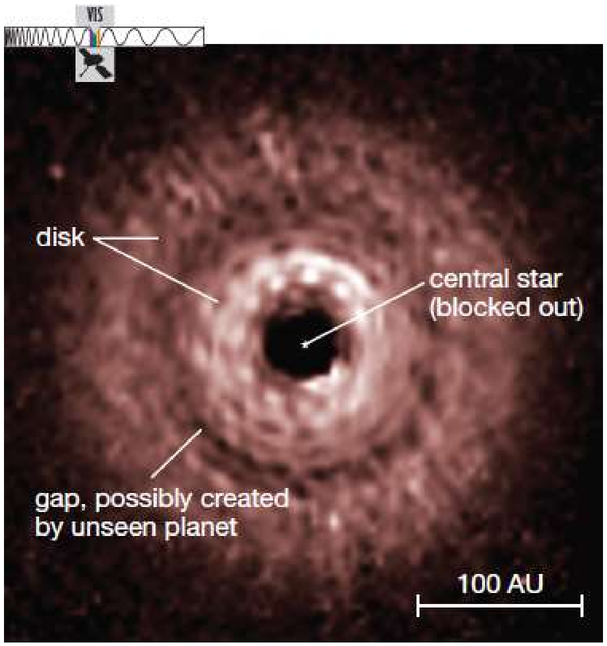
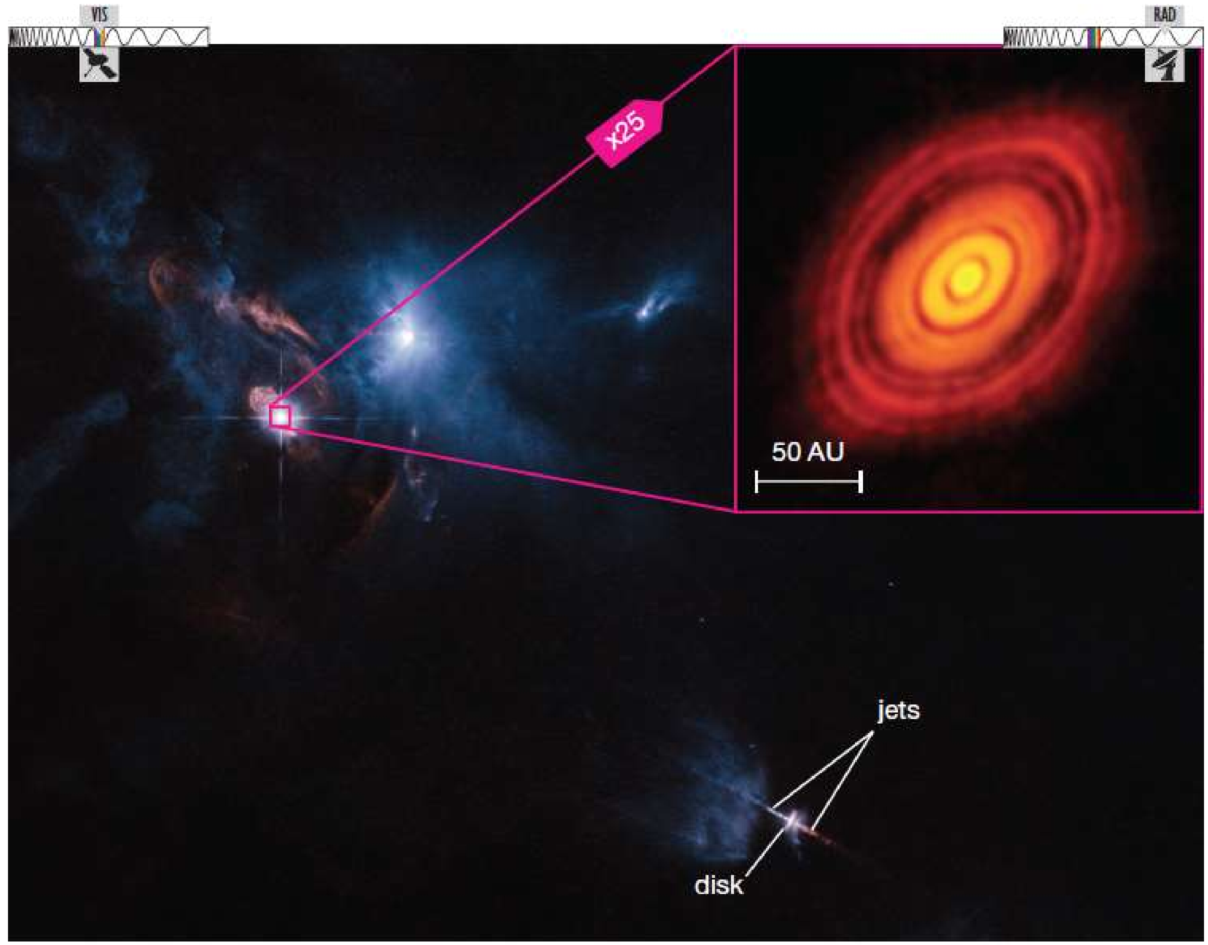
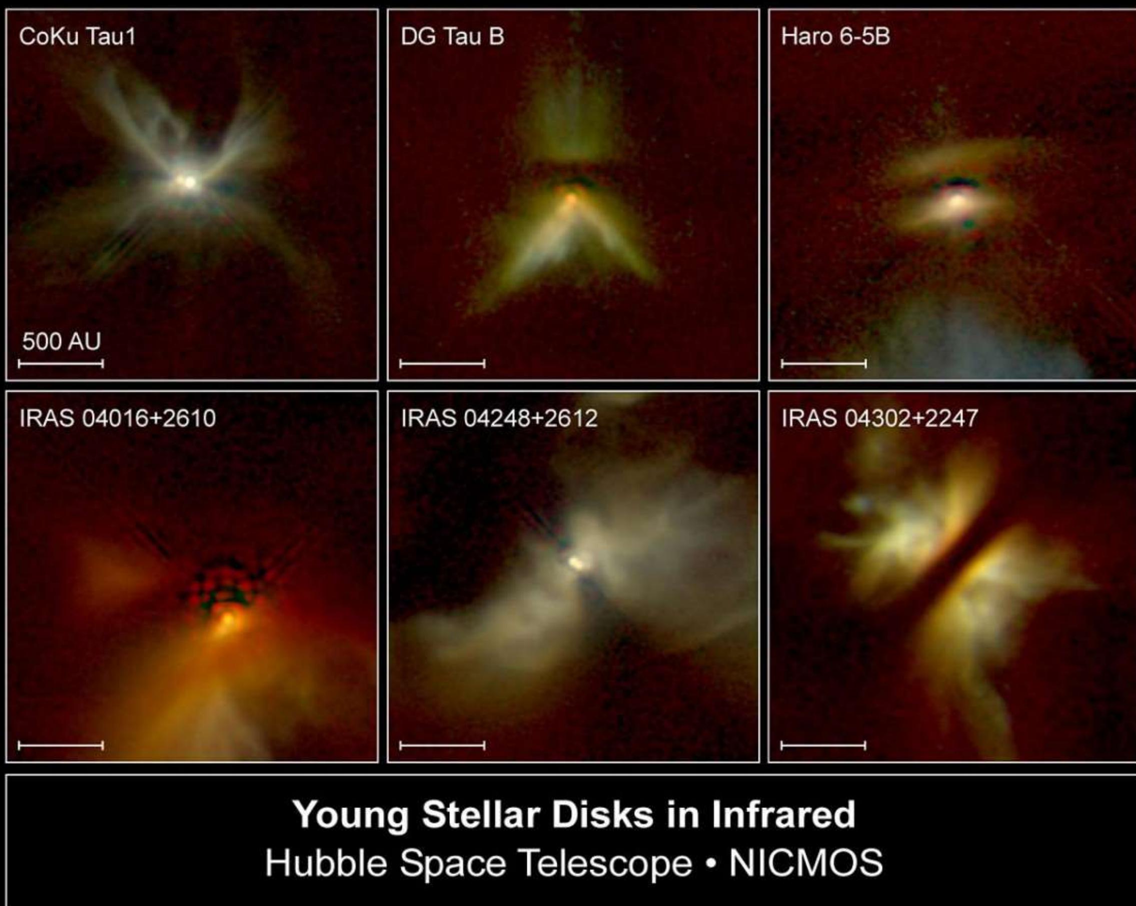


a This Hubble Space Telescope image shows a flattened, spinning disk around the star TW Hydrae. This particular disk also shows at least one circular "gap" in which material seems to have been cleared away, probably by a planet forming in the disk, which would have a gravitational attraction that would tend to sweep up material along its path.



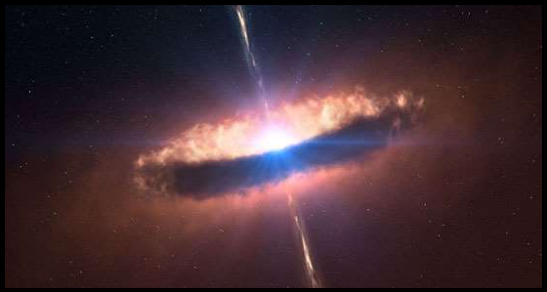
b The inset, from the Atacama Large Millimeter/submillimeter Array (ALMA), shows a disk around a star named HL Tauri; the concentric gaps in the disk are almost certainly regions being cleared as planets form. The disk diameter is about three times that of Neptune's orbit around the Sun. The background image, from the Hubble Space Telescope, shows the star-forming region in which this disk is located. Another disk, seen edge-on with jets extending outward, appears at lower right.

Protoplanetary Disks Around other Stars!



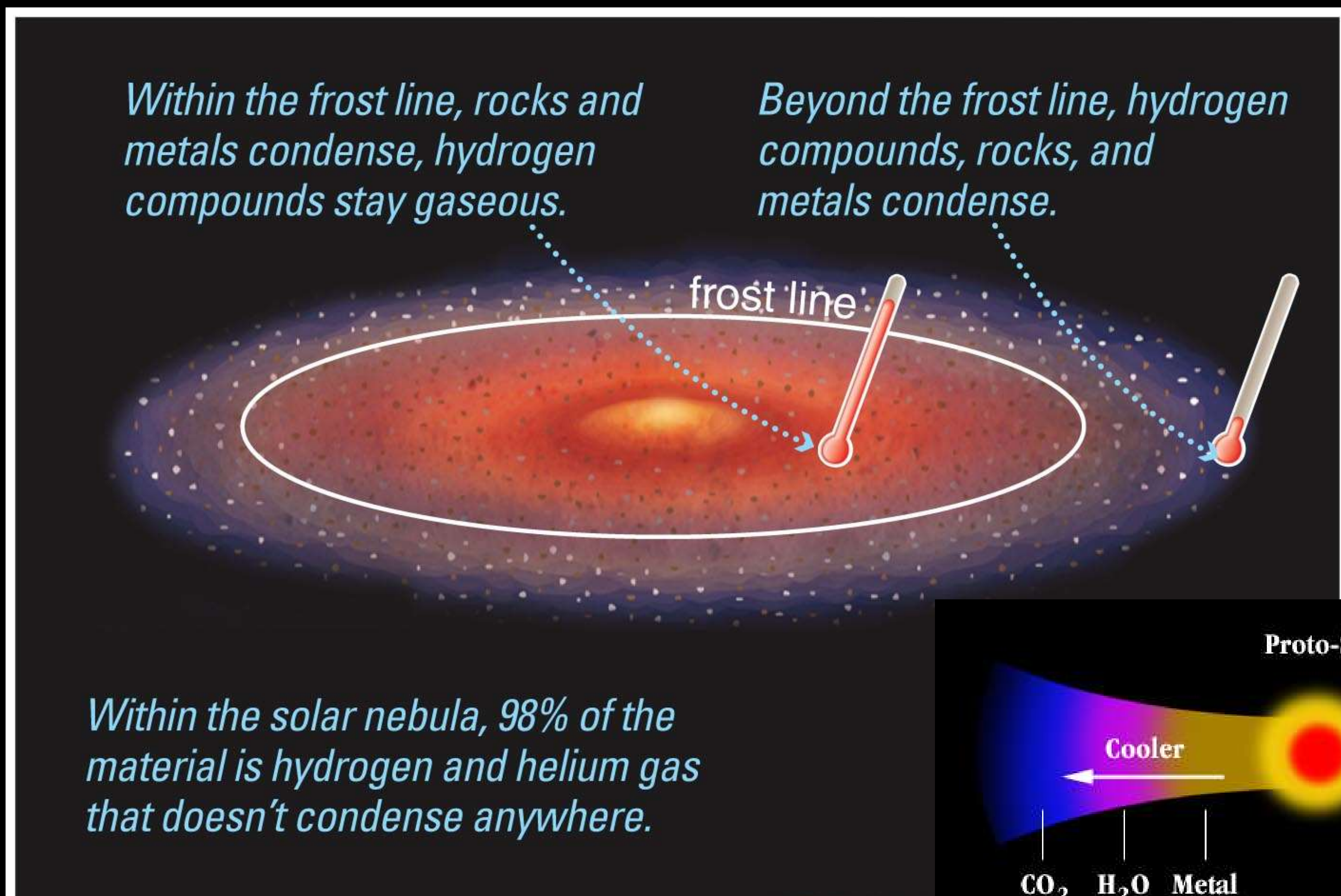
PRC99-05a • STScI OPO • D. Padgett (IPAC/Caltech), W. Brandner (IPAC), K. Stapelfeldt (JPL) and NASA

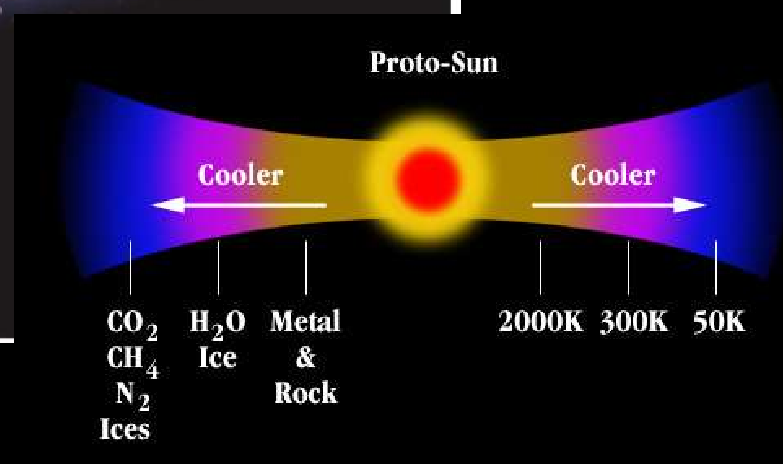
Artistic concepts



Why are there Two Types of Planets?

Condensation: As you move away from the Sun, it - more material can form solids





Why are there Two Types of Planets?

Materials in the Solar Nebula	Metals	Rocks	Hydrogen Compounds	Light Gases
				
Examples	iron, nickel, aluminum	silicates	water (H_2O) methane (CH_4) ammonia (NH_3)	hydrogen, helium
Typical Condensation Temperature	1,000–1,600 K	500–1,300 K	<150 K	(do not condense in nebula)
Relative Abundance (by mass)	(0.2%)	(0.4%)	(1.4%)	(98%)

There are A LOT more hydrogen compounds than silicates/metals

→ *Explains why Jovian planets grew so large*

Planets Form from Planetesimals

During collisions, sometimes they stick together to form larger and larger objects

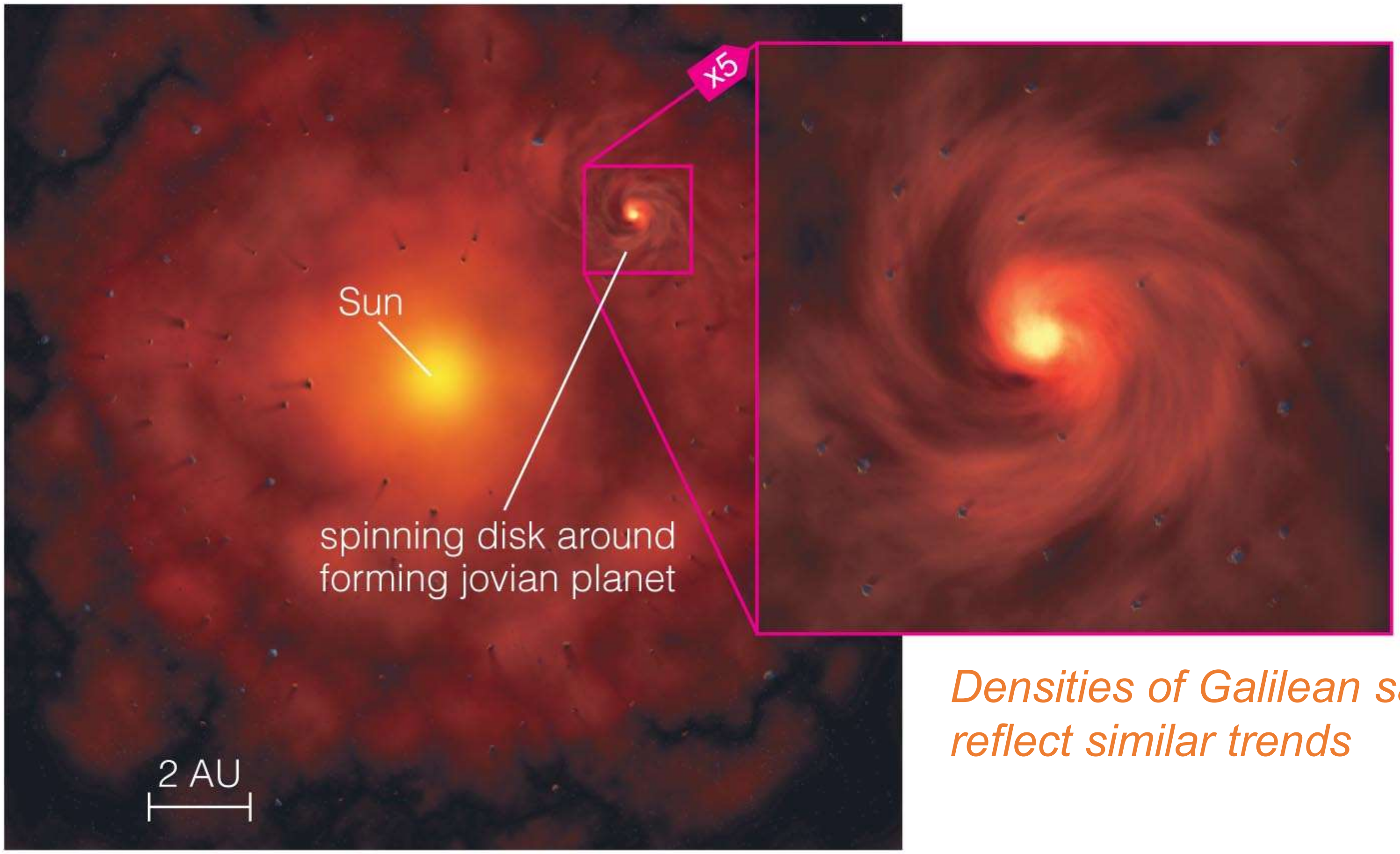
Planetesimals begin to form which can attract more objects under their own gravity

Planetesimals are often classed as boulder to few 100 km-sized objects

Collisions between planetesimals:

i) Eventually grew into planets
ii) Made orbits more circular

How did Jovian Planets Form?

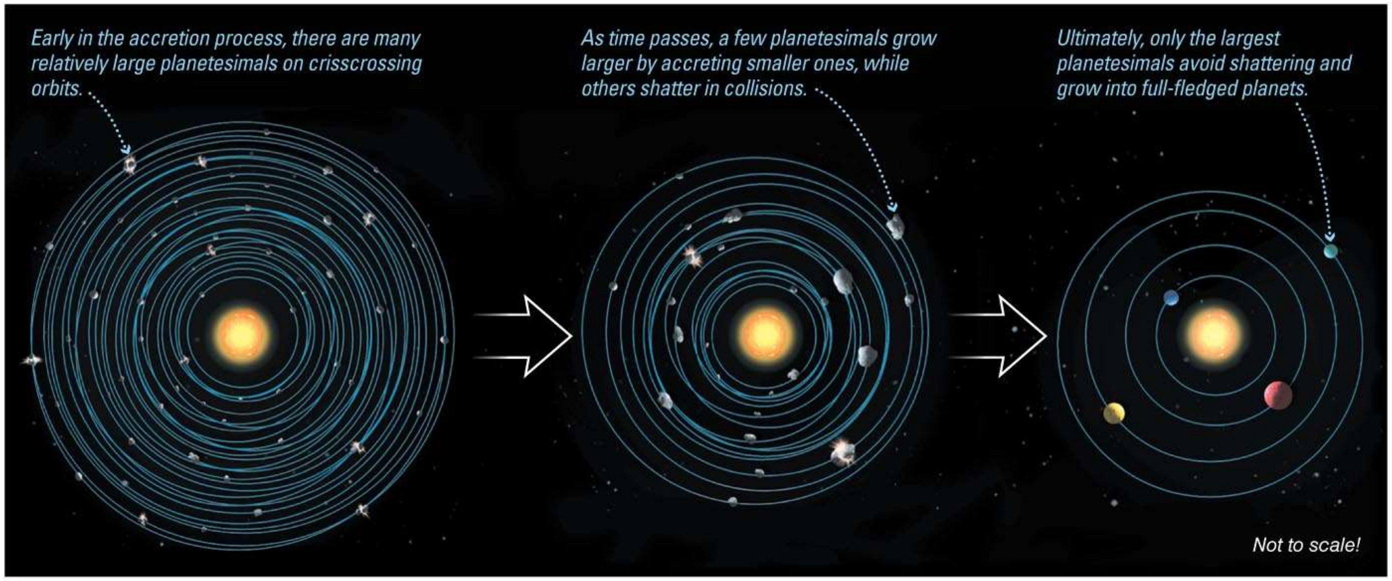


Densities of Galilean satellites reflect similar trends

Models show that as Jovian planets form, they have their own disks → Jovian system is like a miniature solar system. Obtains enough mass to capture H/He

Where do Asteroids and Comets Come From?

They are all left over planetesimals!



Asteroids from inside the frost line, comets from outside (C-type asteroids may have also come from outside the frost line)

Icy planetesimals forming beyond Neptune and make up the flattened Kuiper Belt

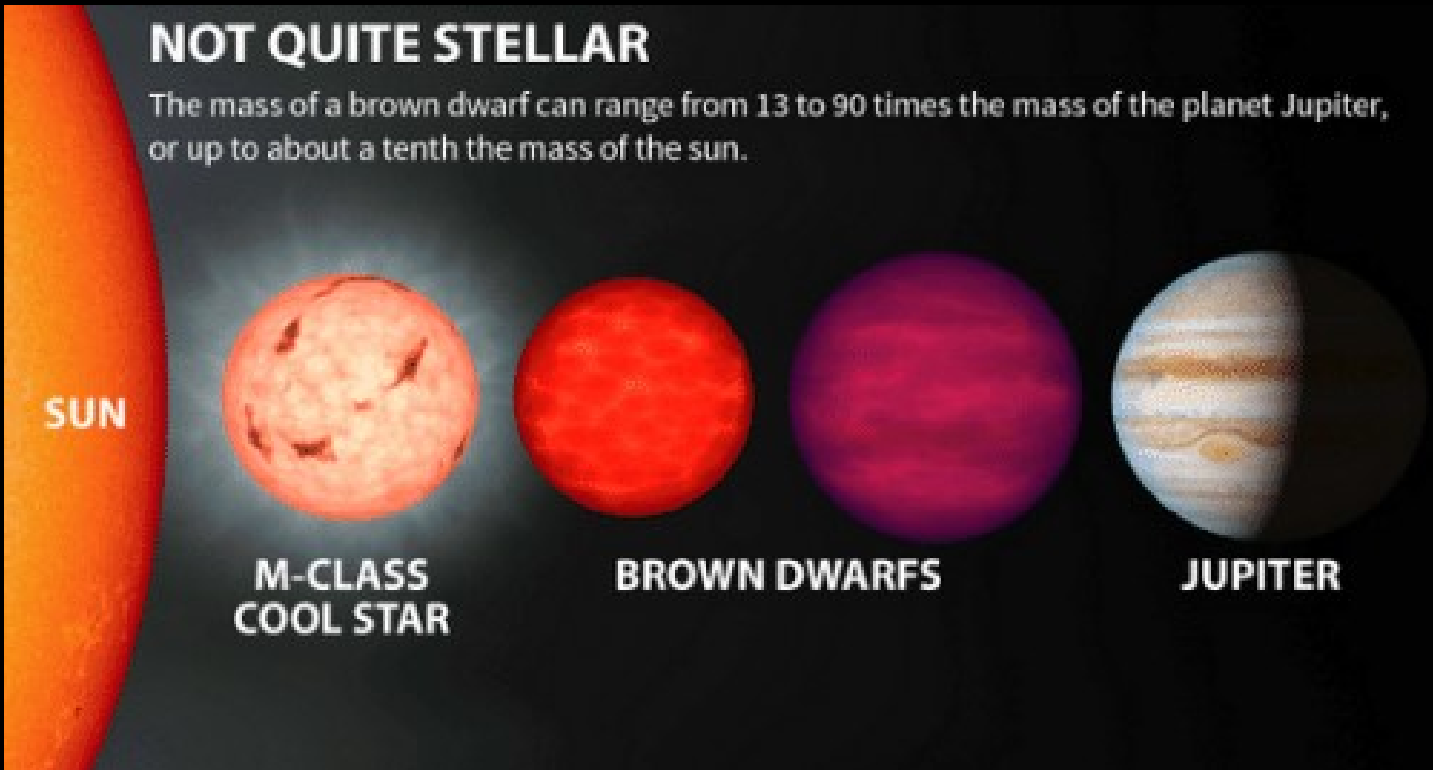
Many Icy planetesimals that formed near the orbits of the Jovian planets got kicked out into the Oort cloud

Planetary Migration may have disrupted planetesimals → Late Heavy Bombardment (Nice model)

Jupiter almost made it!

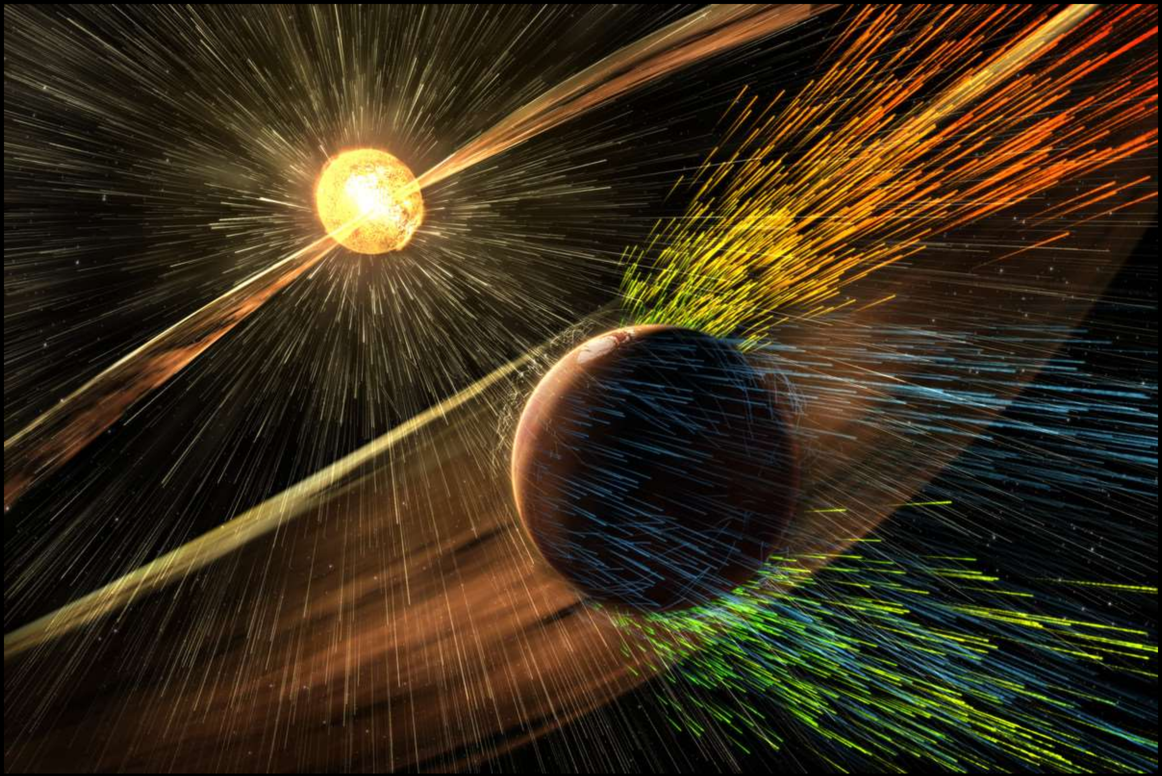
Jupiter (and the other Jovian planets) became massive enough to capture H/He, but not massive enough for fusion to begin…

There are 'missing links' that show hot Jupiter's and Brown Dwarfs orbiting regular stars… (binary stars are common)



What ended Planetary Formation in the Solar System Formation?

Once the Sun started Fusion, it developed a *Solar Wind*, which was initially very unstable and unbalanced. This likely removed most of the gaseous material from the Solar System



iClicker Question

Question: Why do we think the terrestrial planets became more dense than the Jovian planets?

A. In the collapsing solar nebula, denser materials sank toward the center

B. The sun's gravity pulled denser materials toward the center

C. The inner nebula was so hot that only metals and rocks were able to condense

D. The rotating disk in which the planets formed spun lighter elements outward by centrifugal force

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Orderly Motions in the Solar System

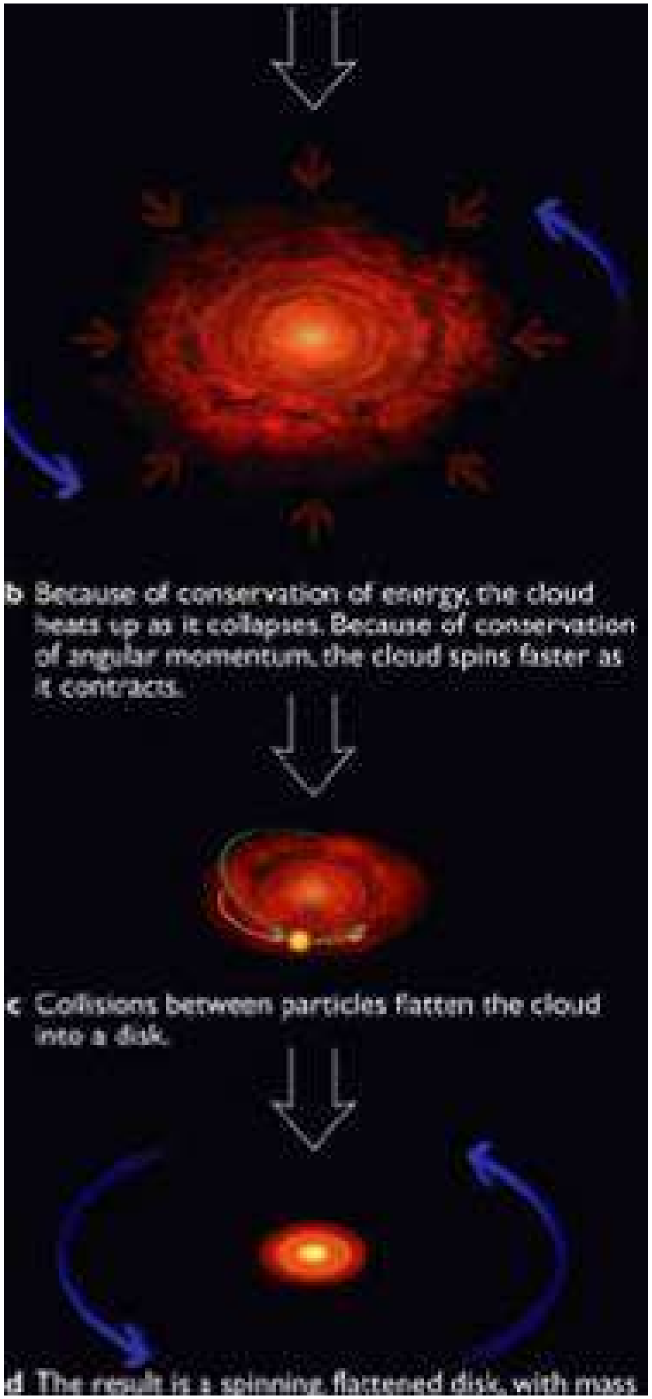
The Sun formed in the very center of the nebula.

- **temperature & density were high enough for nuclear fusion reactions to begin**

The planets formed in the rest of the disk.

This would explain the following:

- **all planets lie along one plane (in the disk)**
- **all planets orbit in one direction (the spin direction of the disk)**
- **the Sun rotates in the same direction**
- **the planets would tend to rotate in this same direction**
- **most moons orbit in this direction**
- **most planetary orbits are near circular (collisions in the disk)**



Exceptions to the Rules

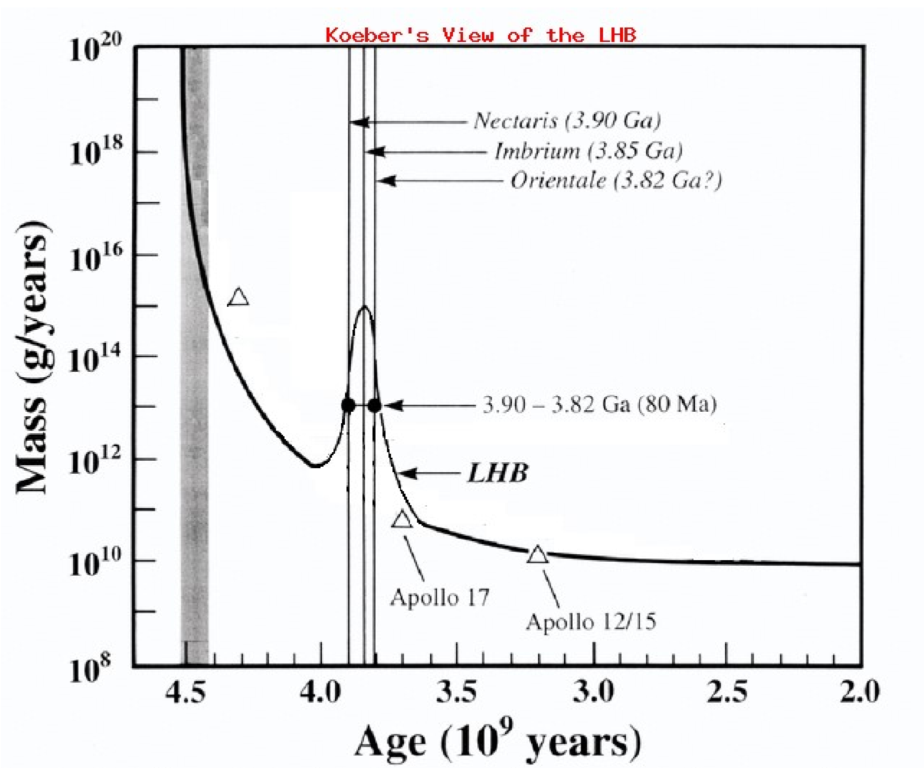
Close encounters with and impacts by planetesimals could explain:

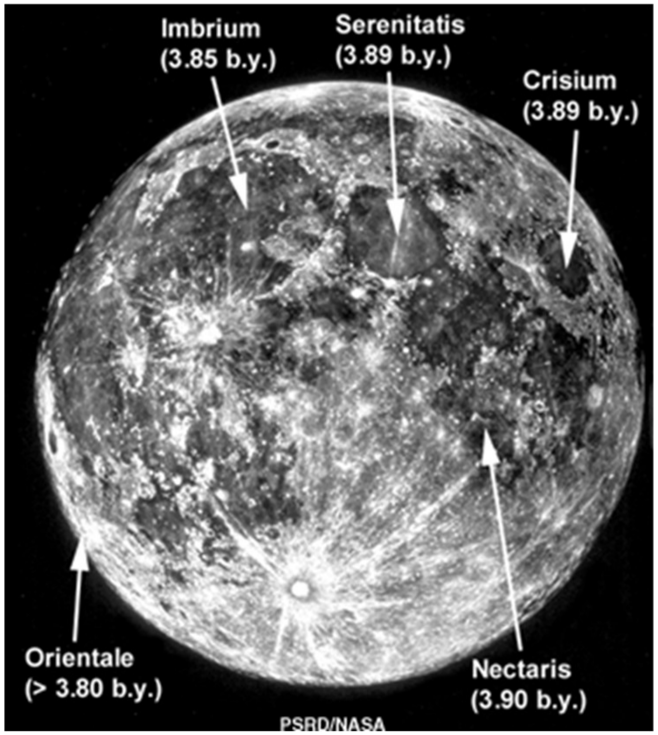
- Why some moons orbit opposite their planet's rotation
  - captured moons (e.g. Triton)
- Why rotation axes of some planets are tilted
  - impacts "knock them over" (extreme example: Uranus)
- Why some planets rotate more quickly or slowly than others
  - impacts "spin them up" or down…..
- Why Earth is the only terrestrial planet with a large Moon
  - giant impact

Do We have Any Evidence of the Late Heavy Bombardment?

YES!

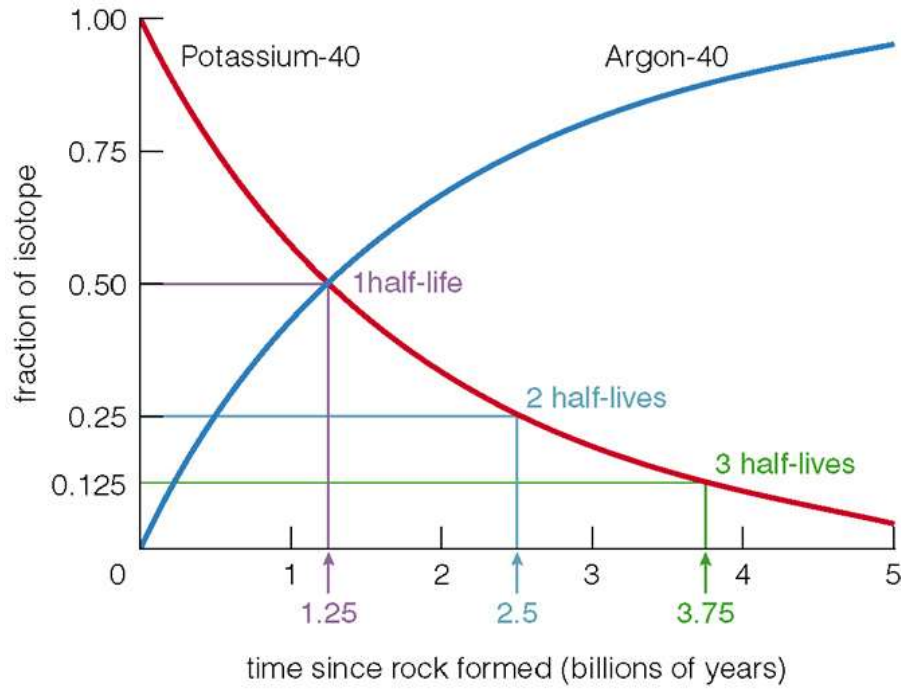
Well, we have about 3 data points which were determined by radiometric dating of rocks, from crater impacts on the Moon…





What is Radiometric Dating?

- Elements have isotopes which are unstable i.e. **radioactive**.
- Take Potassium…0.011% of all Potassium is K-40, which is radioactive. It spontaneously changes in to Argon-40 in a process called **radioactive decay**. *Careful with those Bananas!*
- **Probability:** The time it takes half the amount of a radioactive isotope to decay is called its **half life**. For K-40, this is about 1.25 billion years



- By knowing rock chemistry, we chose a stable isotope which does not form with the rock…its presence is due solely to decay.
  - → **K-40 (potassium) is incorporated into rocks, but Ar-40 is not!**
- Measuring the relative amounts of **BOTH** isotopes and knowing the half life of the radioactive isotope tells us the age of the rock.

Ages of Solar System Bodies

By picking appropriate isotopes we can determine the ages of rocks from the date that they solidified (accuracy limited to ~10 half-lives… K-40 to ~10 billion years)

Meteorites are the oldest objects in the Solar System

- NWA 2364 is 4.5682 billion years old
- Gives a good indication to the age of the Solar System

Rocks on Earth not dated to more than 4.4 most nots older than 3.9-.1 Billion (Heavy Bombardment?

End of Todays Lecture