Today

- Solar System Formation

Events

- Homework 3 due on Thursday

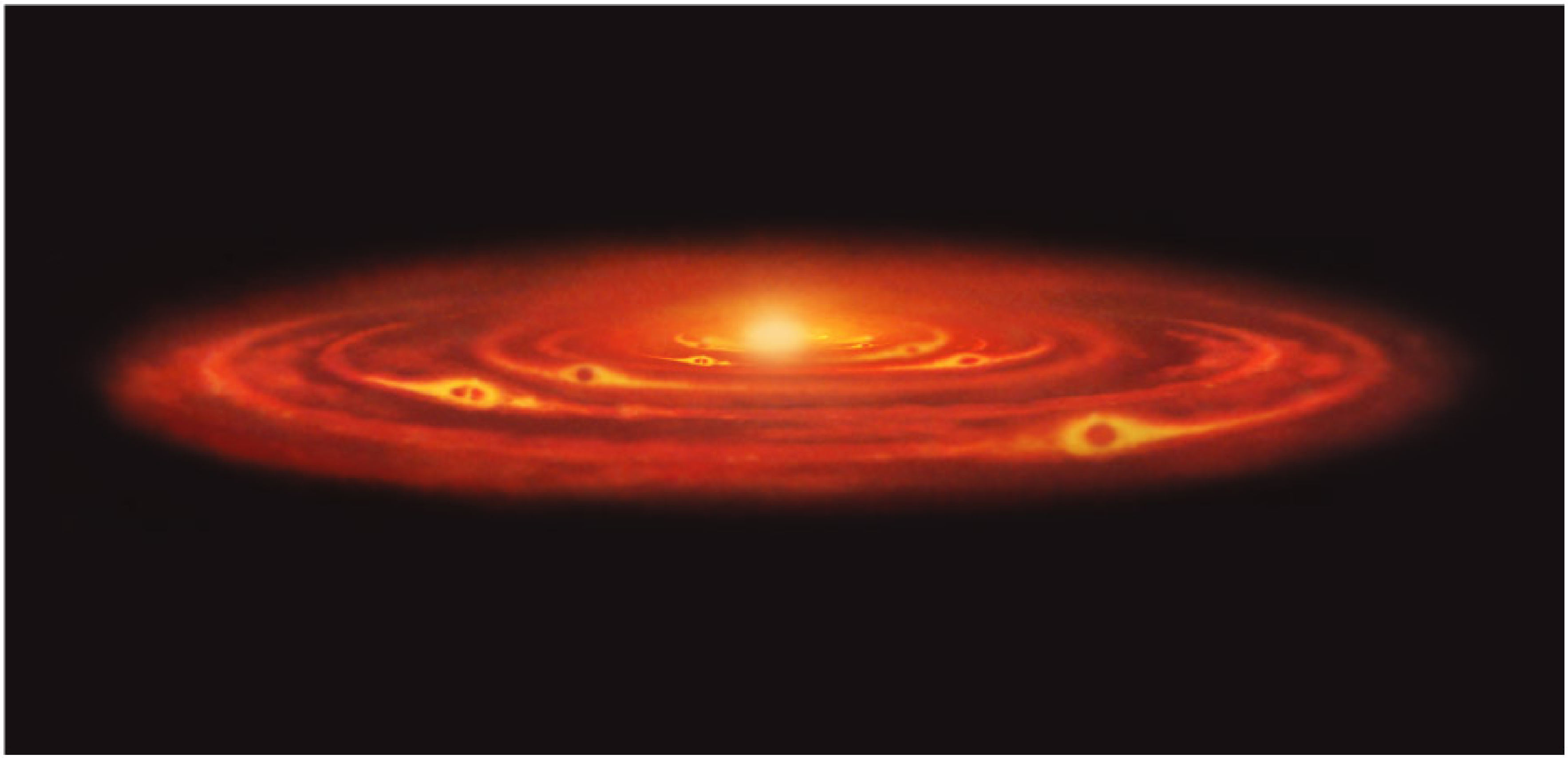
Extra credit
(2 points)

- Explain why most asteroids have different shapes than the planets

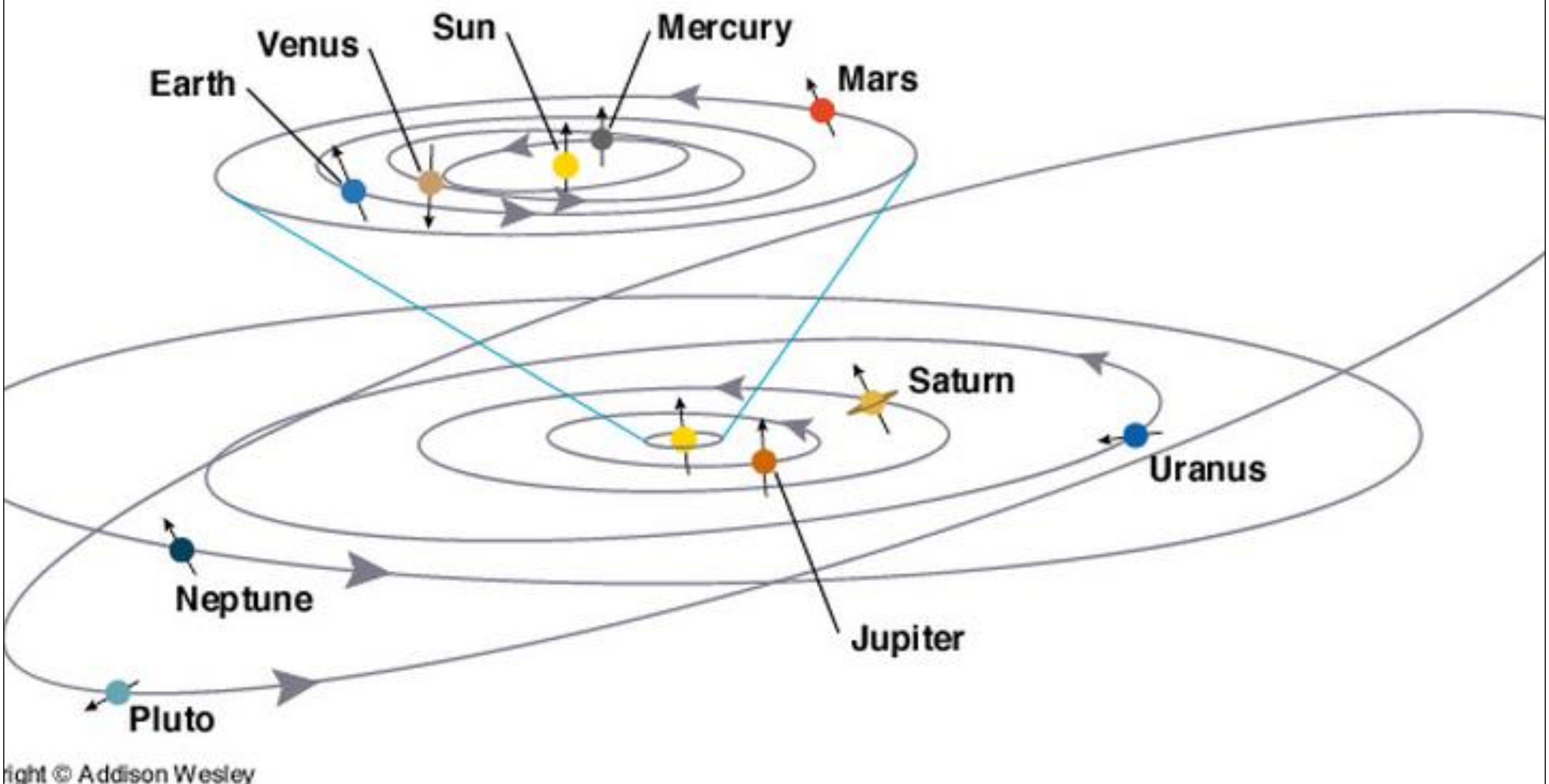
- Be sure to include your name and section number

- You may consult your notes, but do not communicate with anyone else

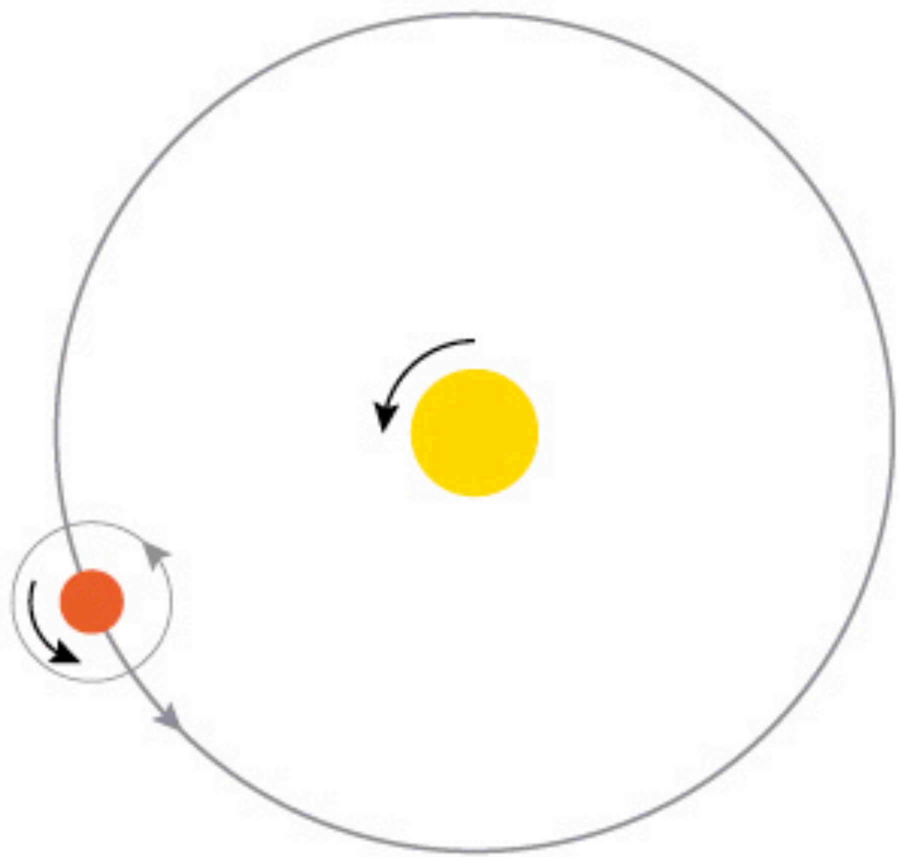
Formation of the Solar System



Clues to Solar System Formation

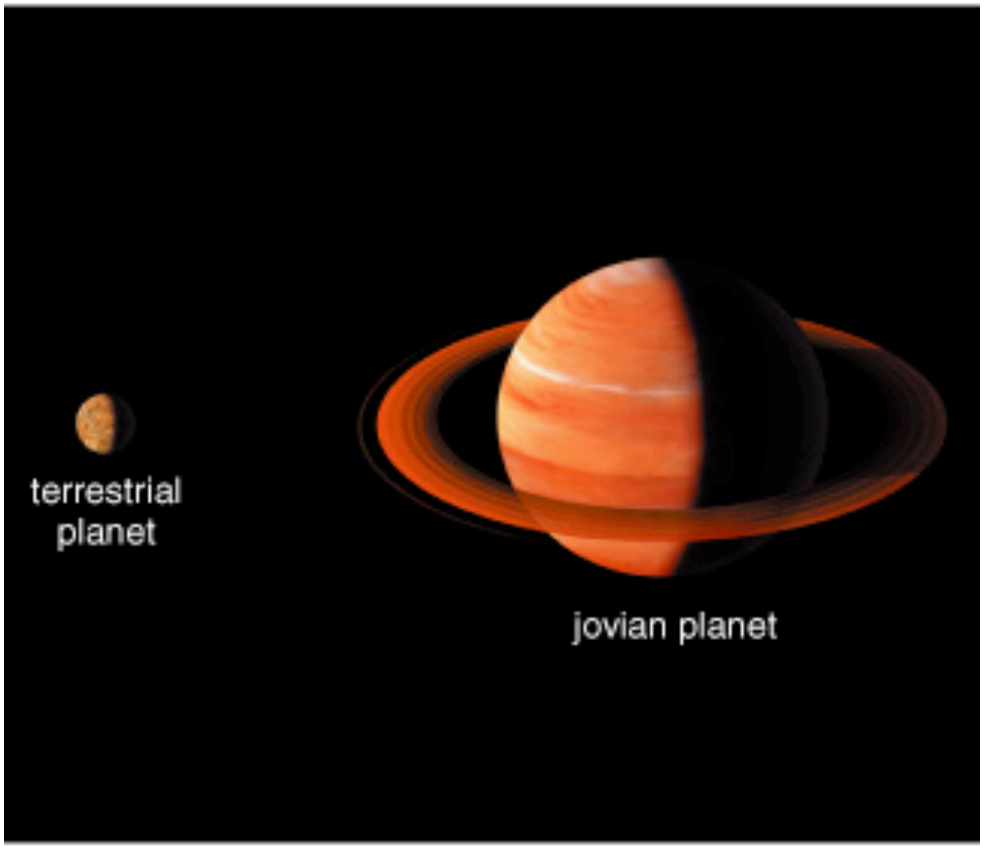


Motion of Large Bodies



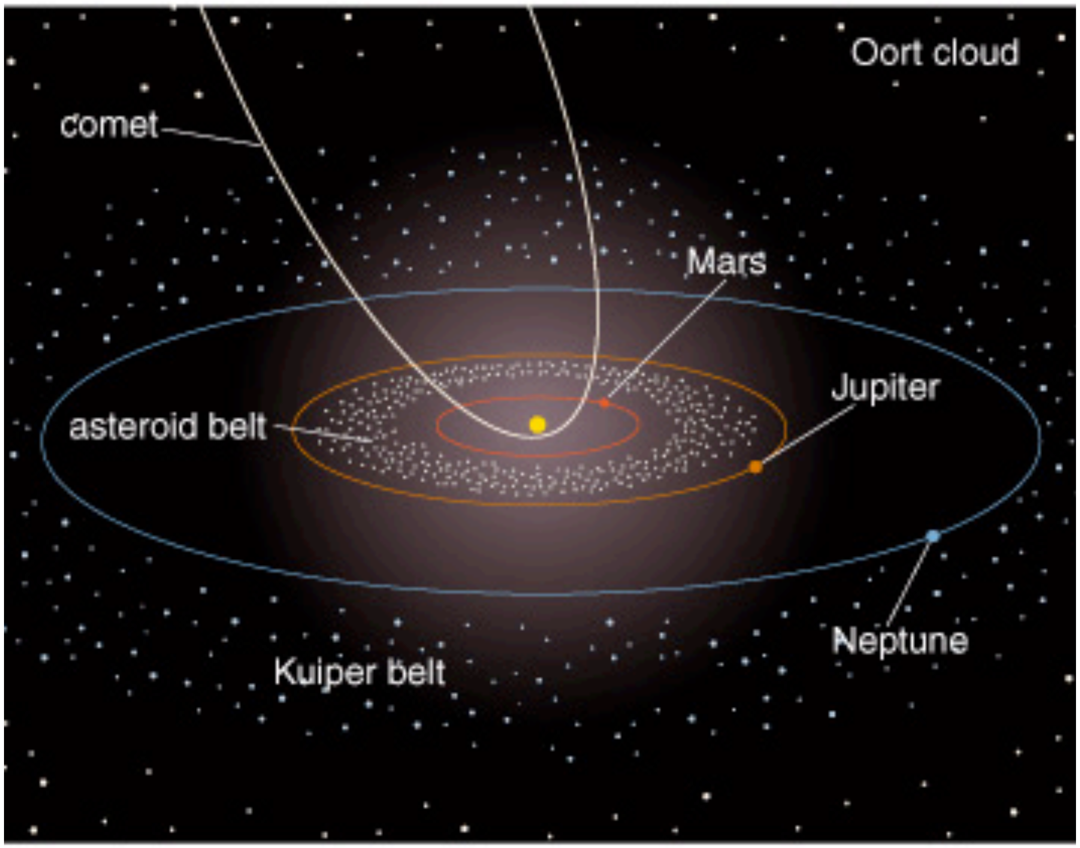
- All large bodies in the solar system orbit in the same direction and in nearly the same plane.
- Most also rotate in that direction.
  - (prograde)

Two Major Planet Types



- Terrestrial planets are rocky, relatively small, and close to the Sun.
- Jovian planets are gaseous, larger, and farther from the Sun.

Swarms of Smaller Bodies



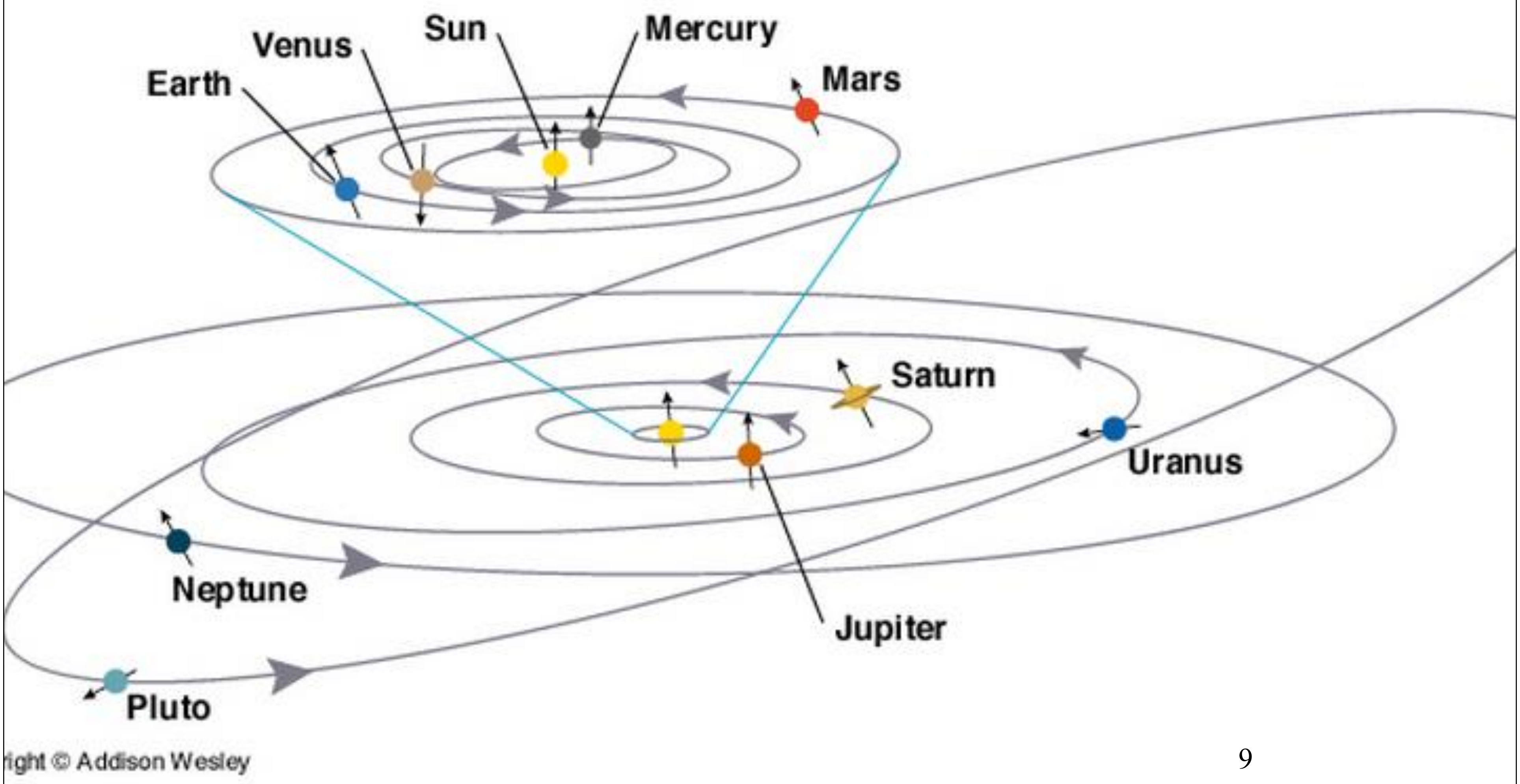
- Many rocky asteroids and icy comets populate the solar system.

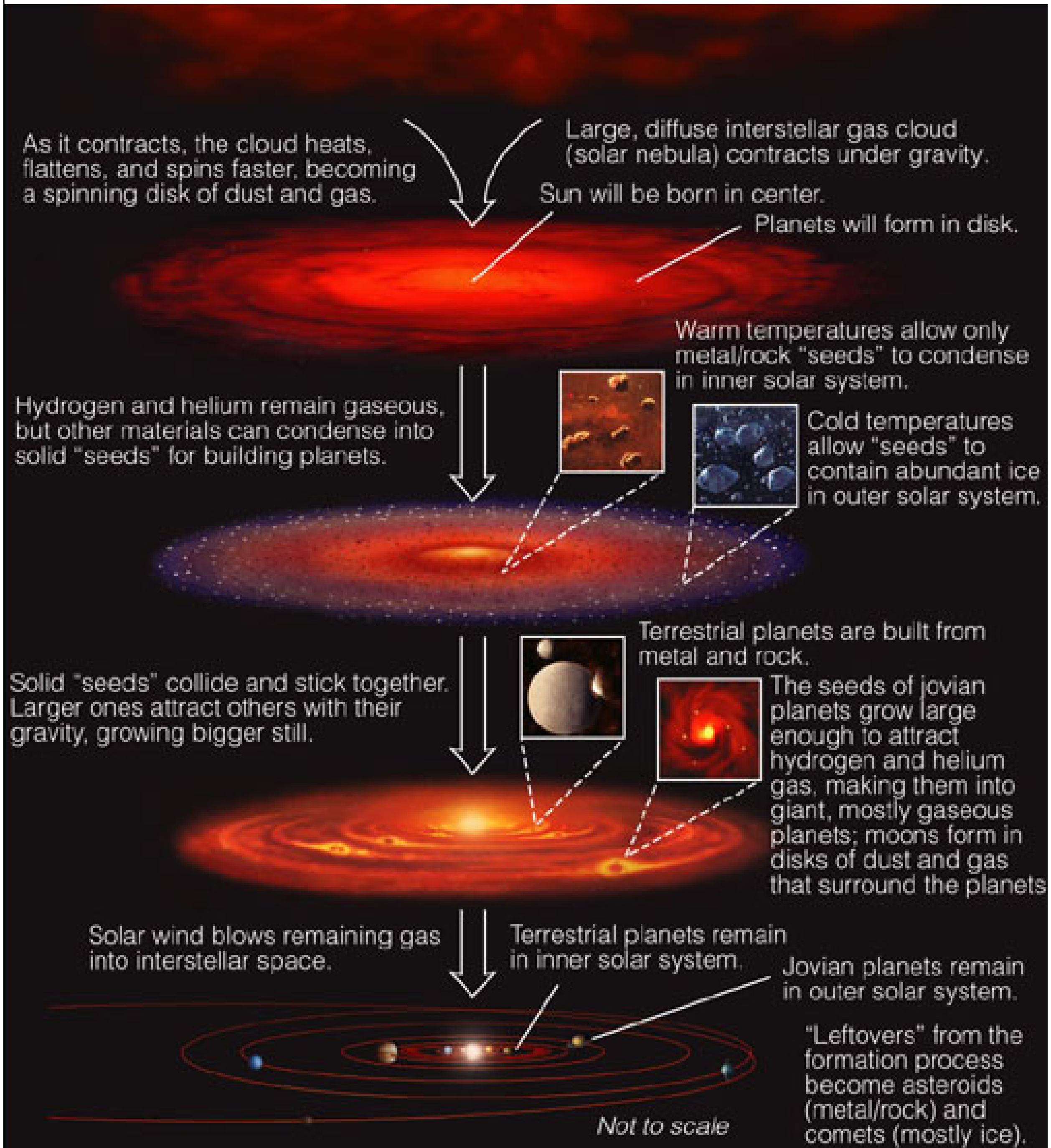
According to the ***nebular theory,*** our solar system formed from a giant cloud of interstellar gas.

(***nebula*** = cloud)

Also known as the ***solar nebula*** hypothesis

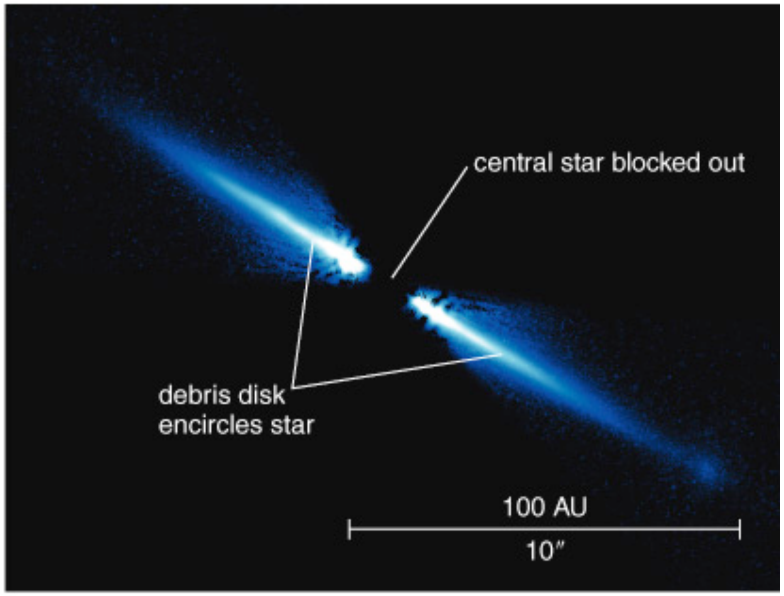
What caused the orderly patterns of motion in our solar system?

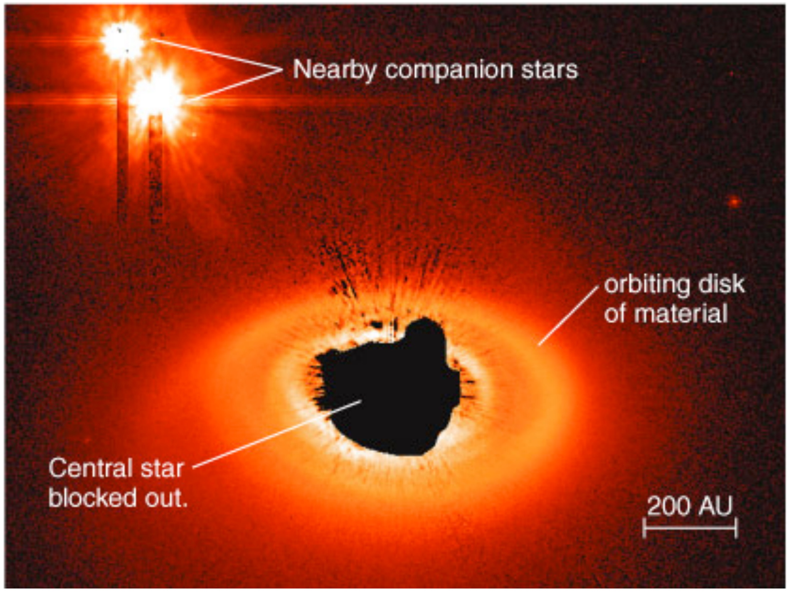




- Nebula spins up as it collapses (angular momentum conserved)
- Solid particles condense out of gas
- Particles collide; form ever larger objects
- Most mass eventually swept up into planets

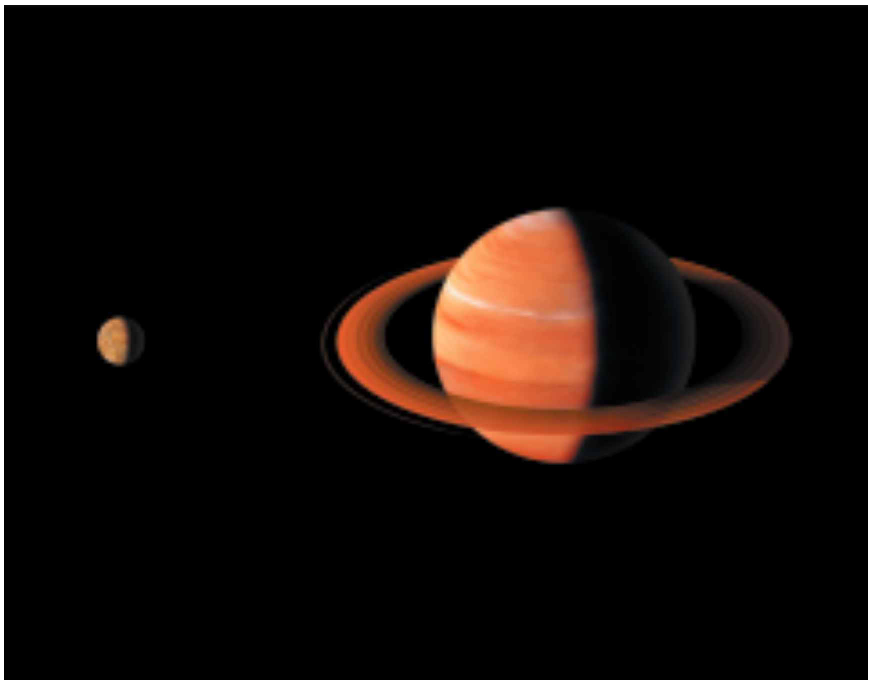
Disks Around Other Stars





- Observations of disks around other stars support the nebular hypothesis.

Why are there two major types of planets?



	Examples	*Typical Condensation Temperature*	*Relative Abundance (by mass)*
Hydrogen and Helium Gas 	hydrogen, helium	do not condense in nebula	98%
Hydrogen Compounds 	water (H_2O) methane (CH_4) ammonia (NH_3)	<150 K	1.4%
Rock 	various minerals	500–1,300 K	0.4%
Metals 	iron, nickel, aluminum	1,000–1,600 K	0.2%

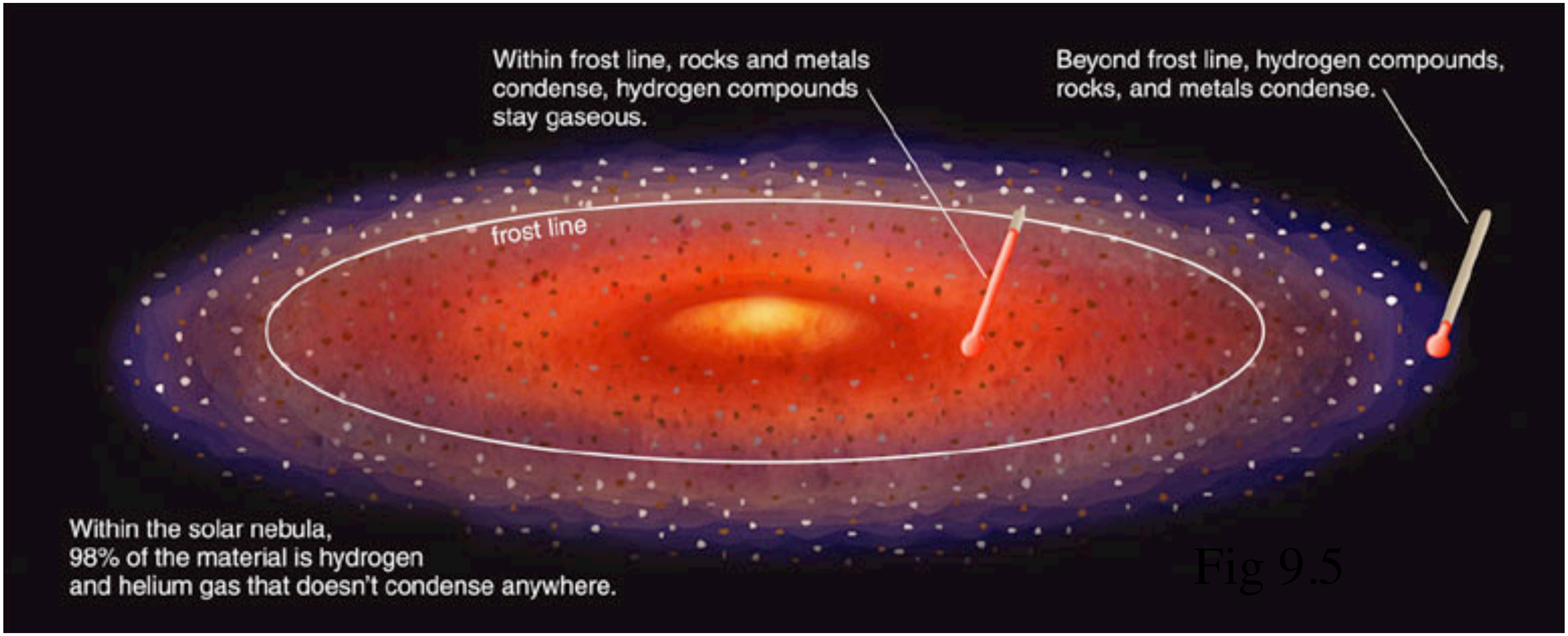


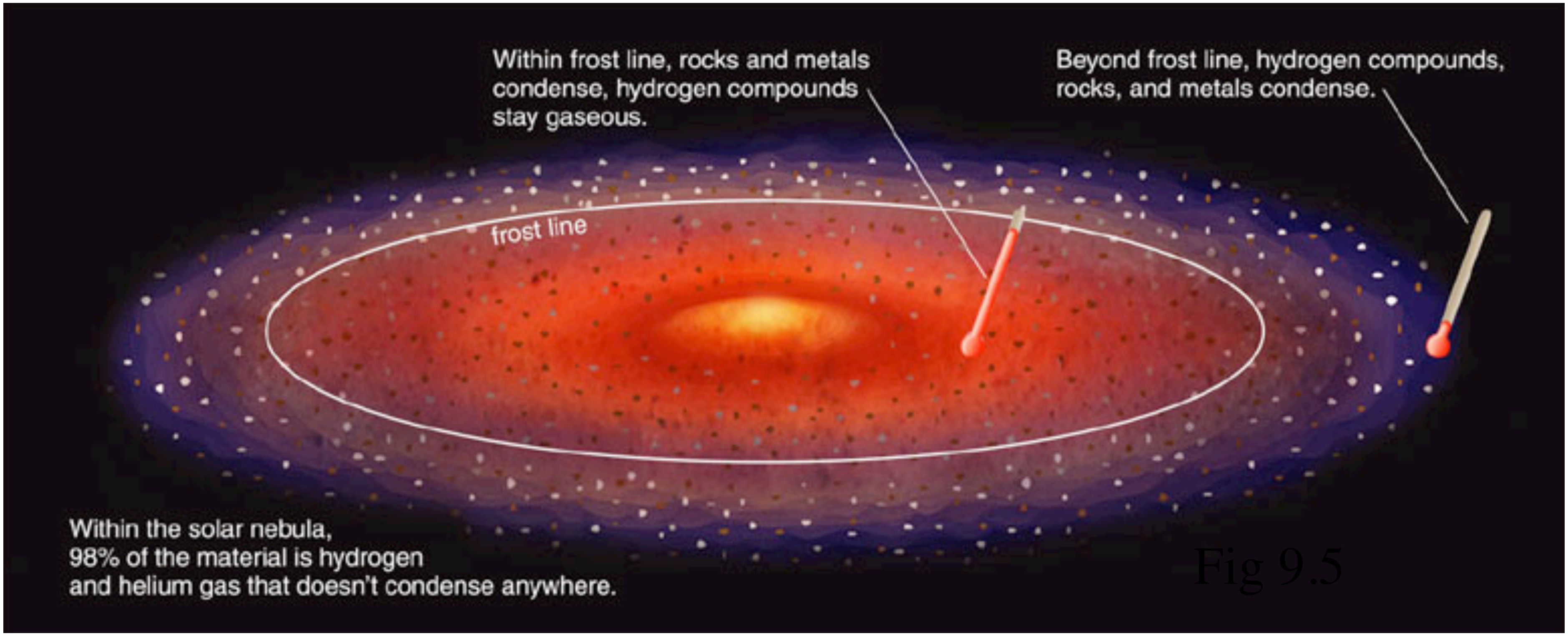
Fig 9.5

As gravity causes the cloud to contract, it heats up.

(The same process continues to heat Jupiter, a tiny bit.)

Inner parts of the disk are hotter than outer parts.

Rock can be solid at much higher temperatures than ice.



FROST LINE at about 3.5 AU

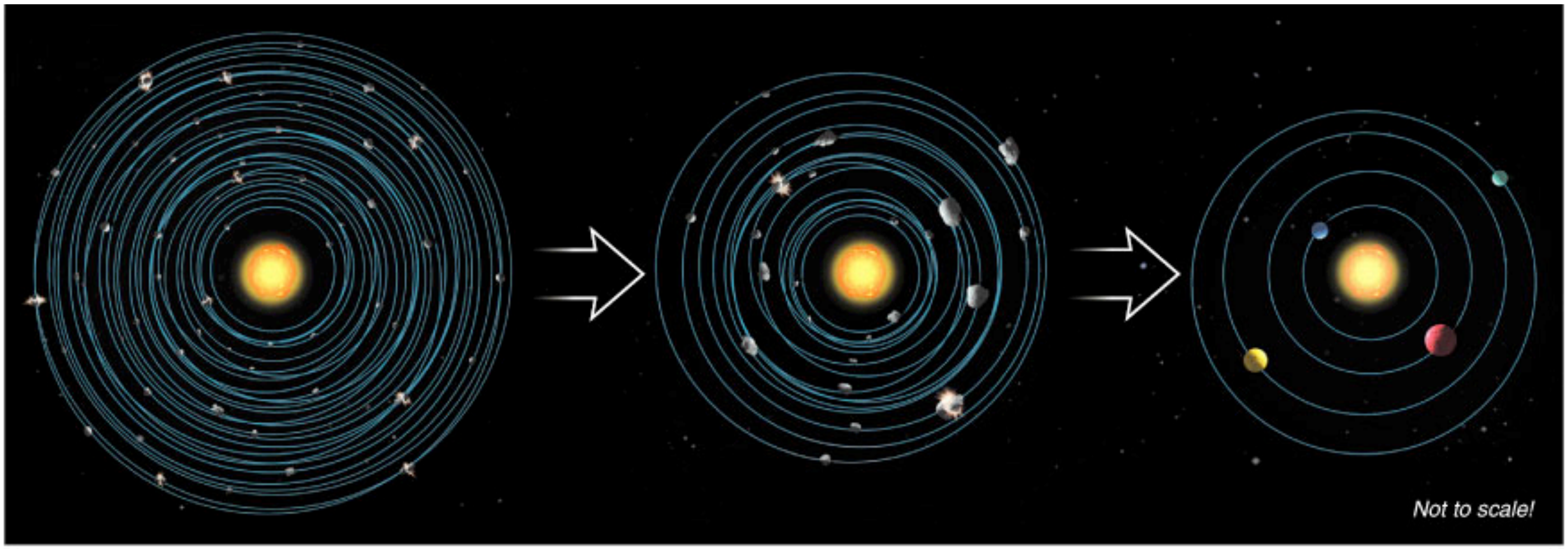
Inside the ***frost line***: Too hot for hydrogen compounds to form ices
- only get rocky asteroids and planets

Outside the ***frost line***: Cold enough for ices to form
- get icy moons and comets
- ice is a major component of their total mass

Formation of Terrestrial Planets

- Small particles of rock and metal were present inside the frost line.
- Planetesimals of rock and metal built up as these particles collided.
- Gravity eventually assembled these planetesimals into terrestrial planets.

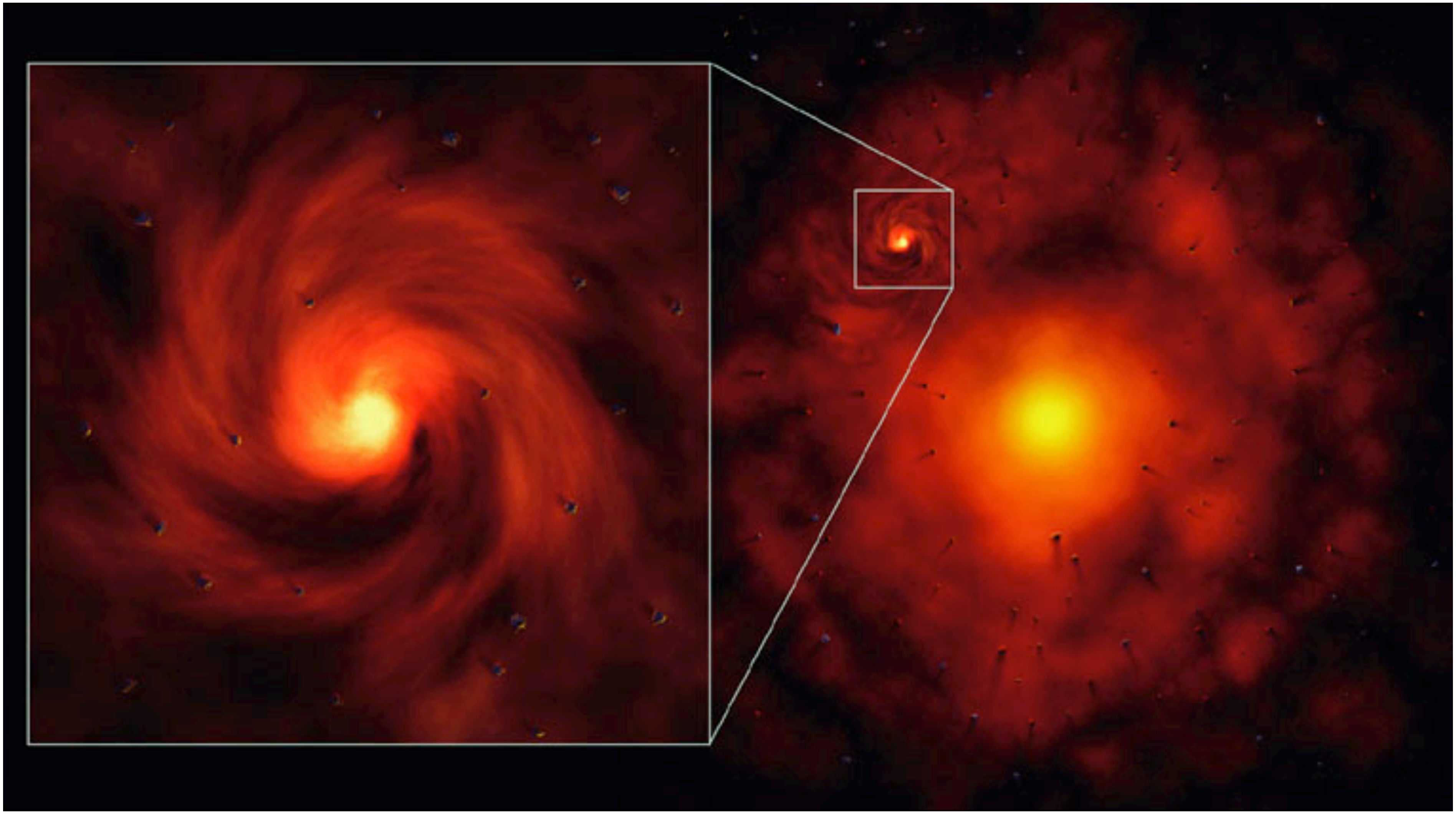
Accretion of Planetesimals



- Many smaller objects collected into just a few large ones.

Formation of Jovian Planets

- Ice could also form small particles outside the frost line.
- Larger planetesimals and planets were able to form.
- The gravity of these larger planets was able to draw in surrounding H and He gases.



Moons of jovian planets form in miniature disks - like microcosms of the solar nebula.

Extrasolar Planets

As we'll get to later, most detected planets around other stars are Jovian in size but are much closer than Earth is to the Sun. What is the most reasonable explanation?

A. They are Jovian in size but fully rocky

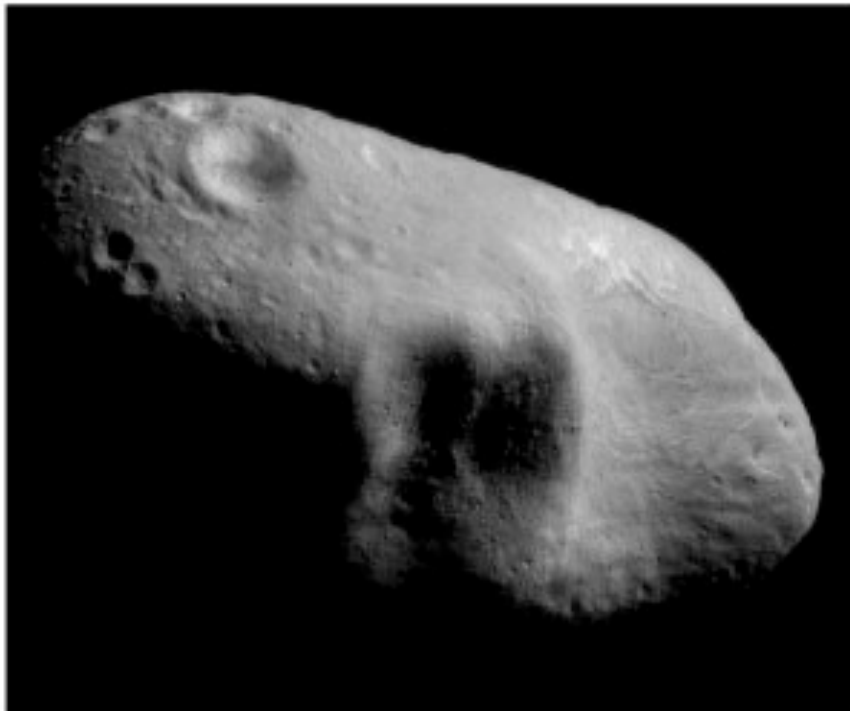
B. They formed far out but drifted in

C. Astronomers are mistaken about the size of exoplanets

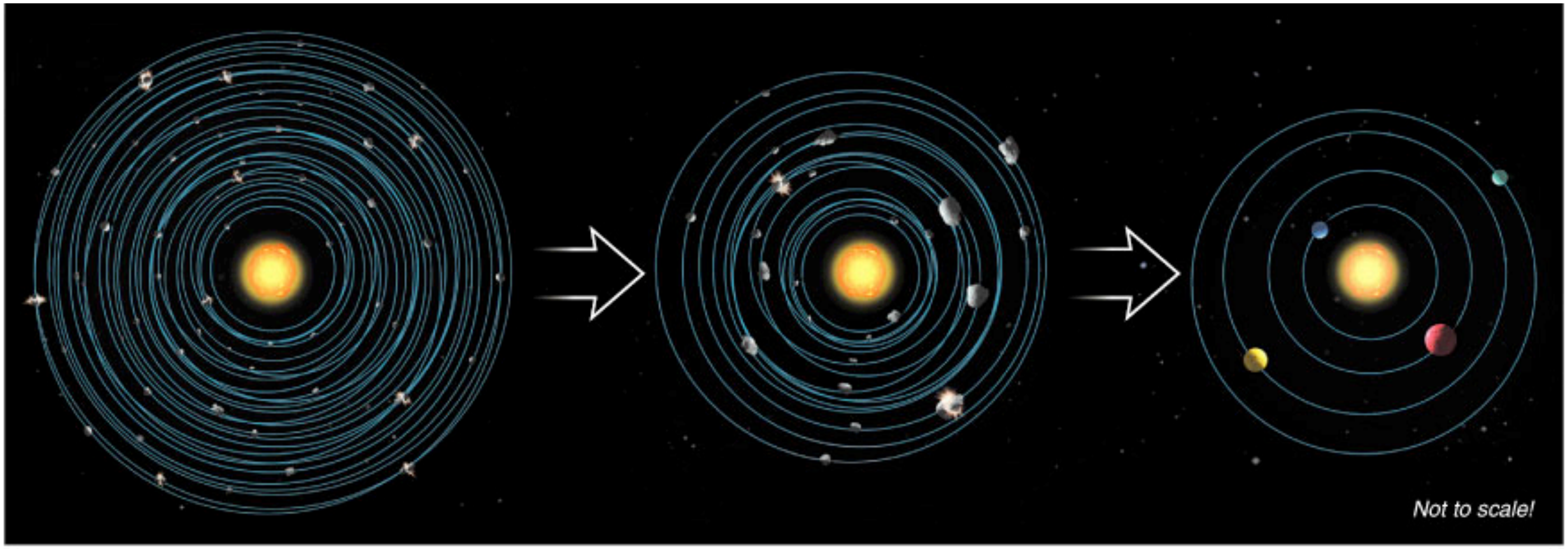
D. I lied to you about the frost line

E. No opinion

Where did asteroids and comets come from?

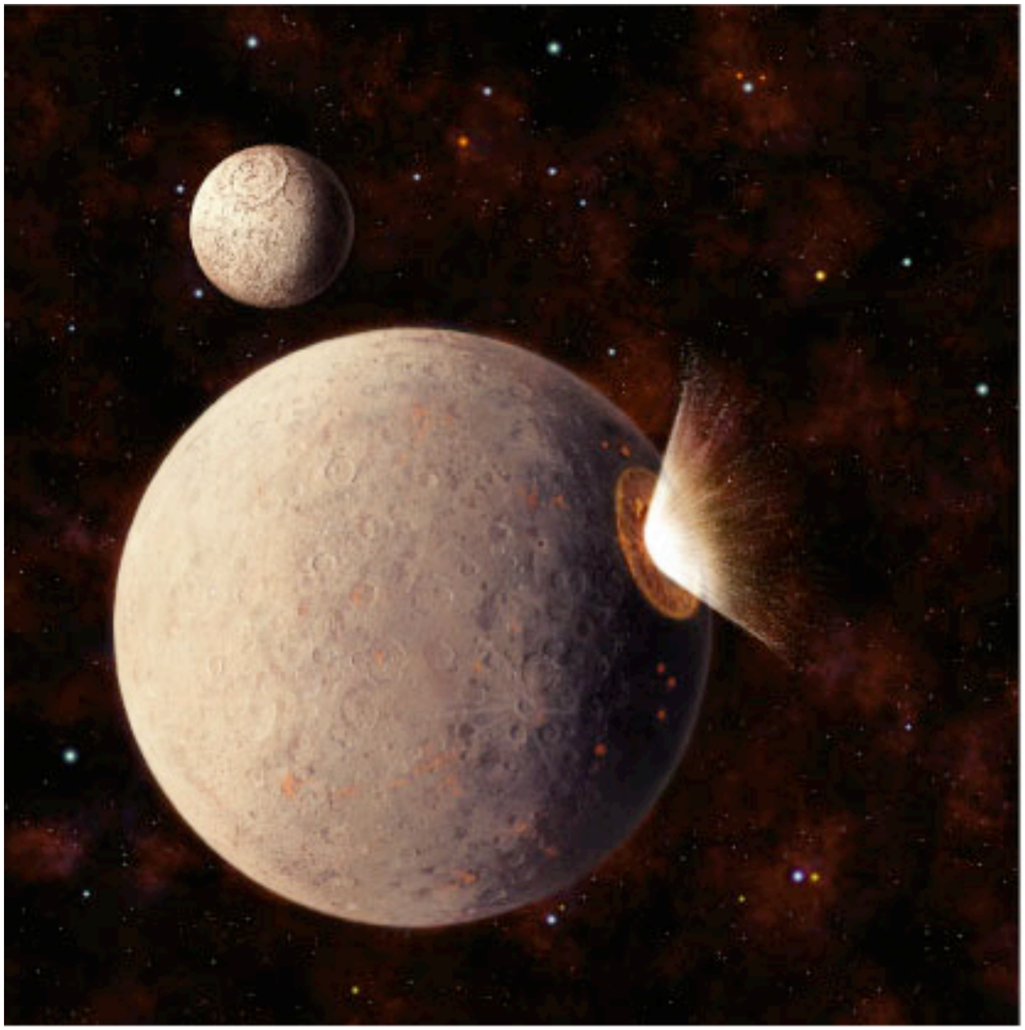


Asteroids and Comets



- Leftovers from the accretion process
- Rocky asteroids inside frost line
- Icy comets outside frost line

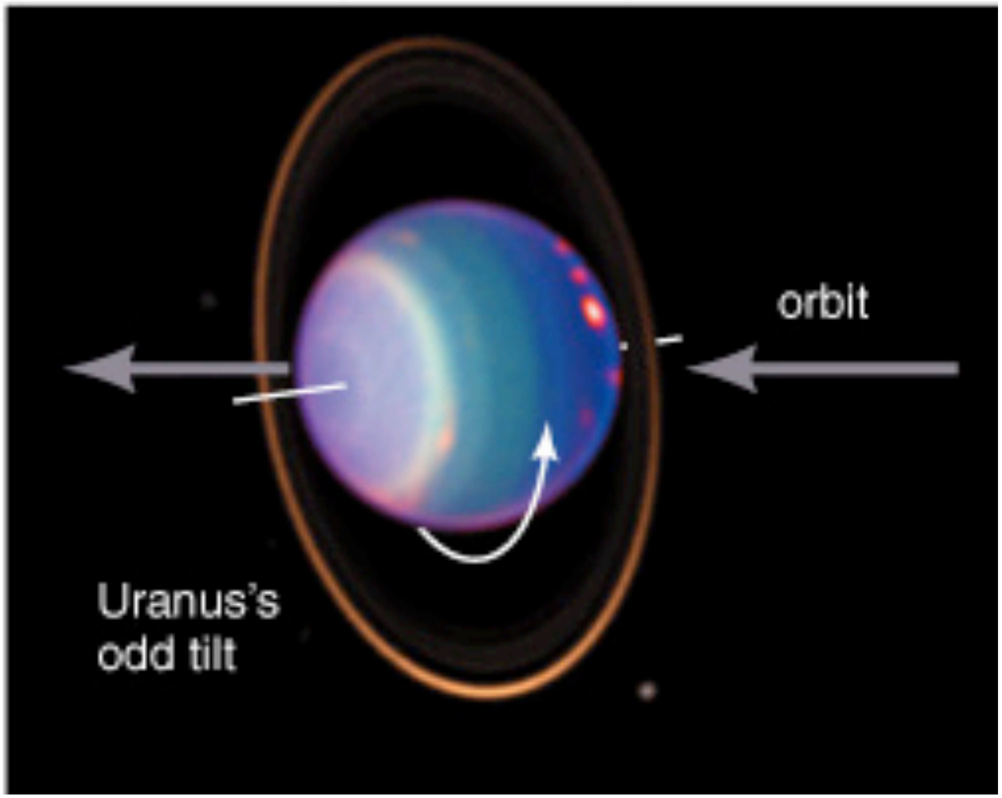
Heavy Bombardment



- Leftover planetesimals bombarded other objects in the late stages of solar system formation.

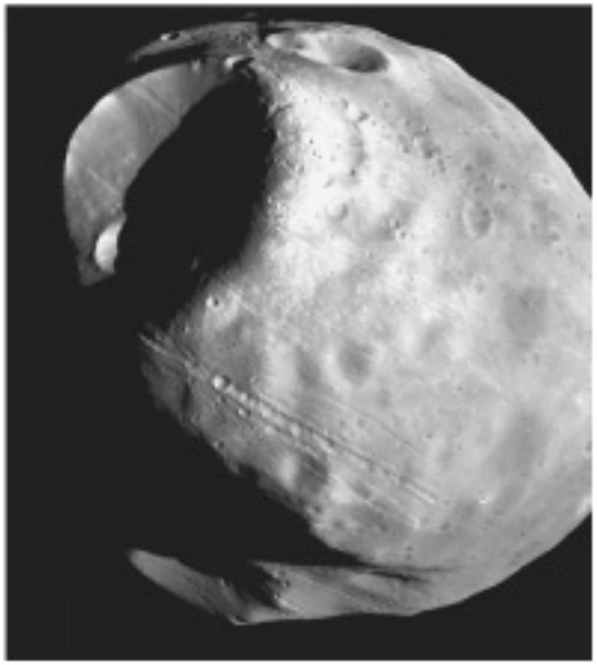
Earth's moon: Giant Impact?

Odd Rotation

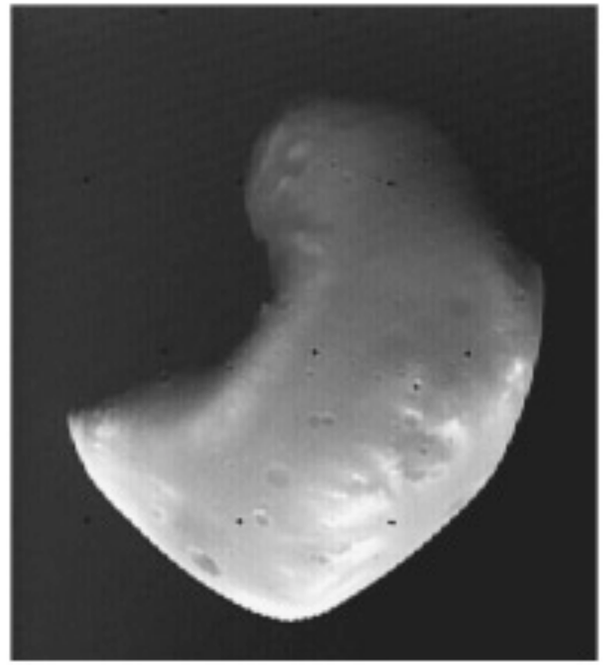


- Giant impacts might also explain the different rotation axes of some planets.
- But there are other possible explanations

Captured Moons

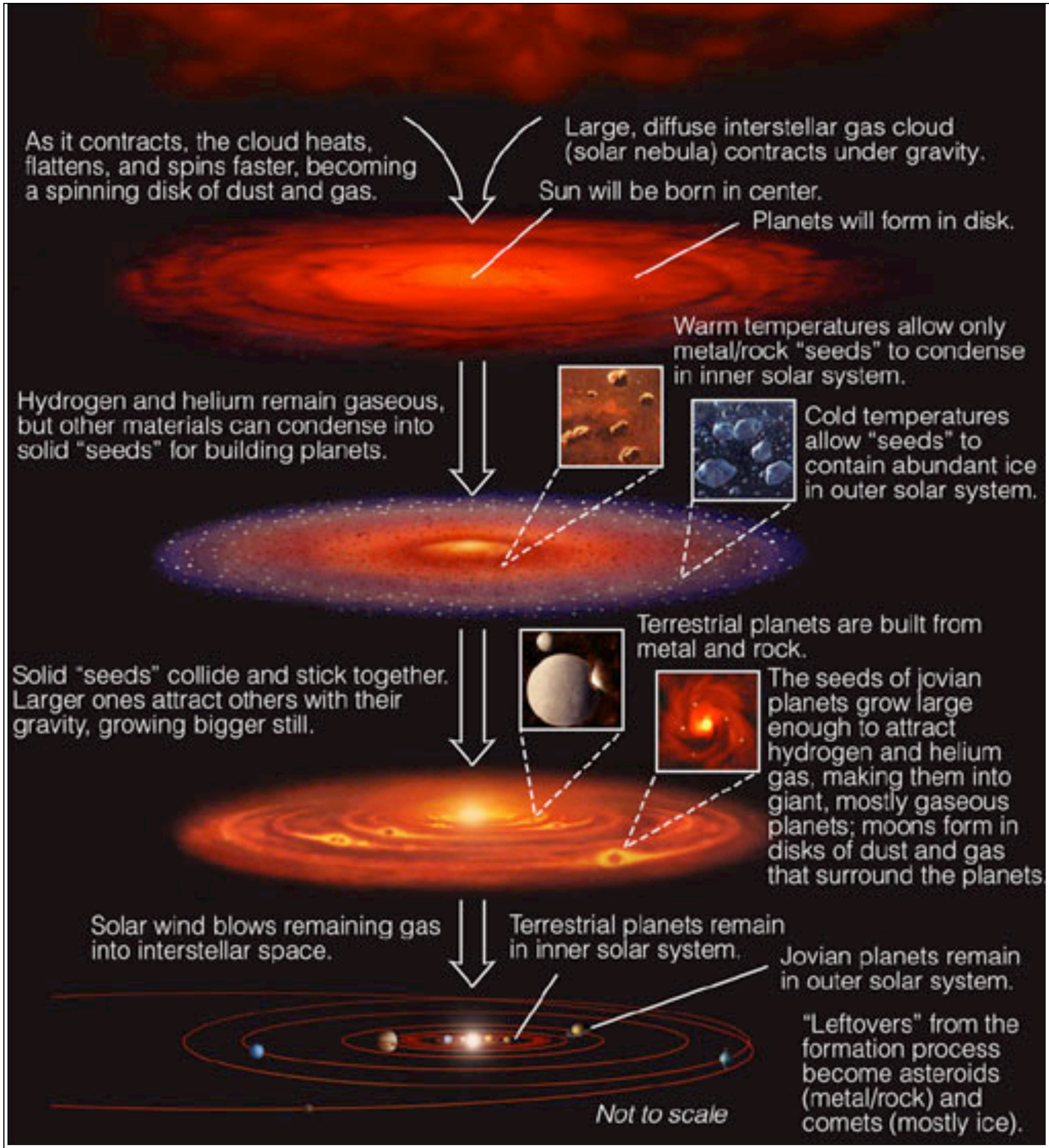


Phobos (fear)



Deimos (panic)

- The unusual moons of Mars and some other planets may be captured asteroids.
- left over planetesimals?



- Nebula spins up as it collapses (angular momentum conserved)
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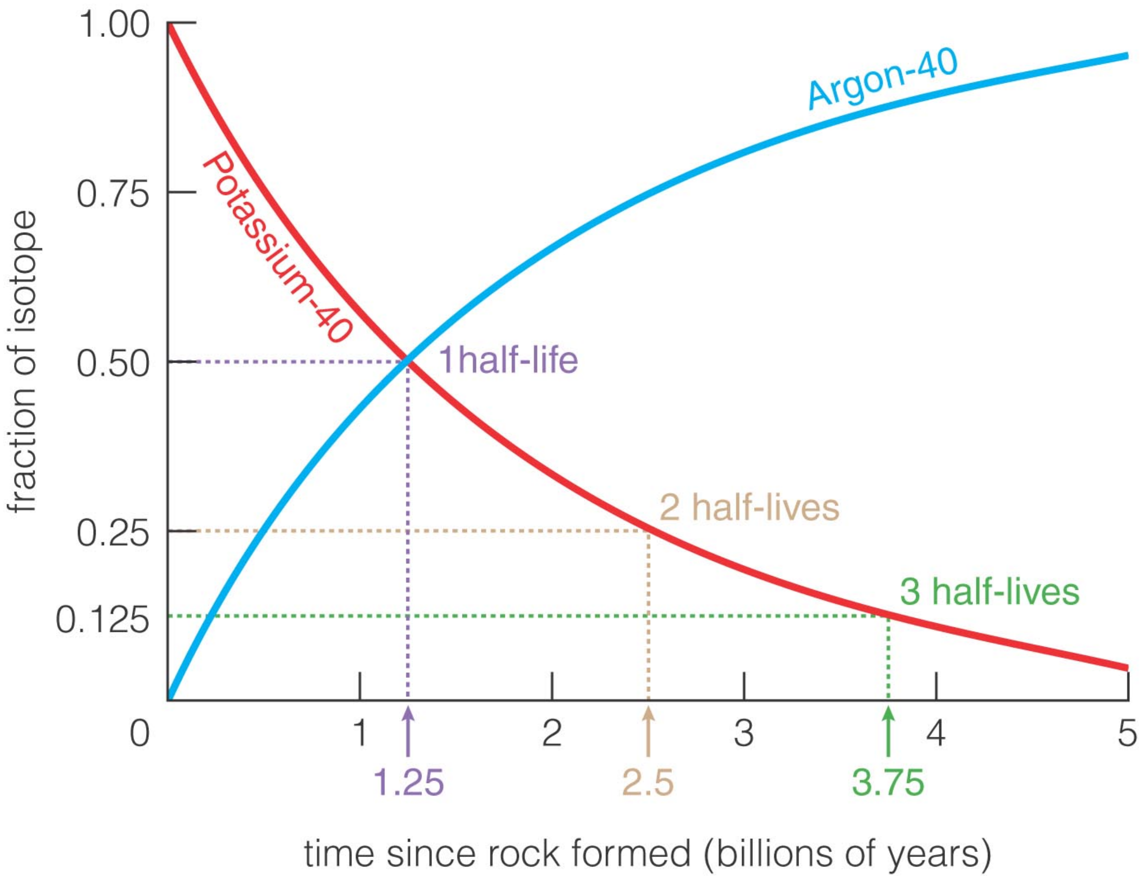
When did the planets form?

- We cannot find the age of a planet, but we can find the ages of the rocks that make it up.
- We can determine the age of a rock through careful analysis of the proportions of various atoms and isotopes within it.

Radioactive Decay



- Some isotopes decay into other nuclei.
- A **half-life** is the time for half the nuclei in a substance to decay.

Dating the Solar System

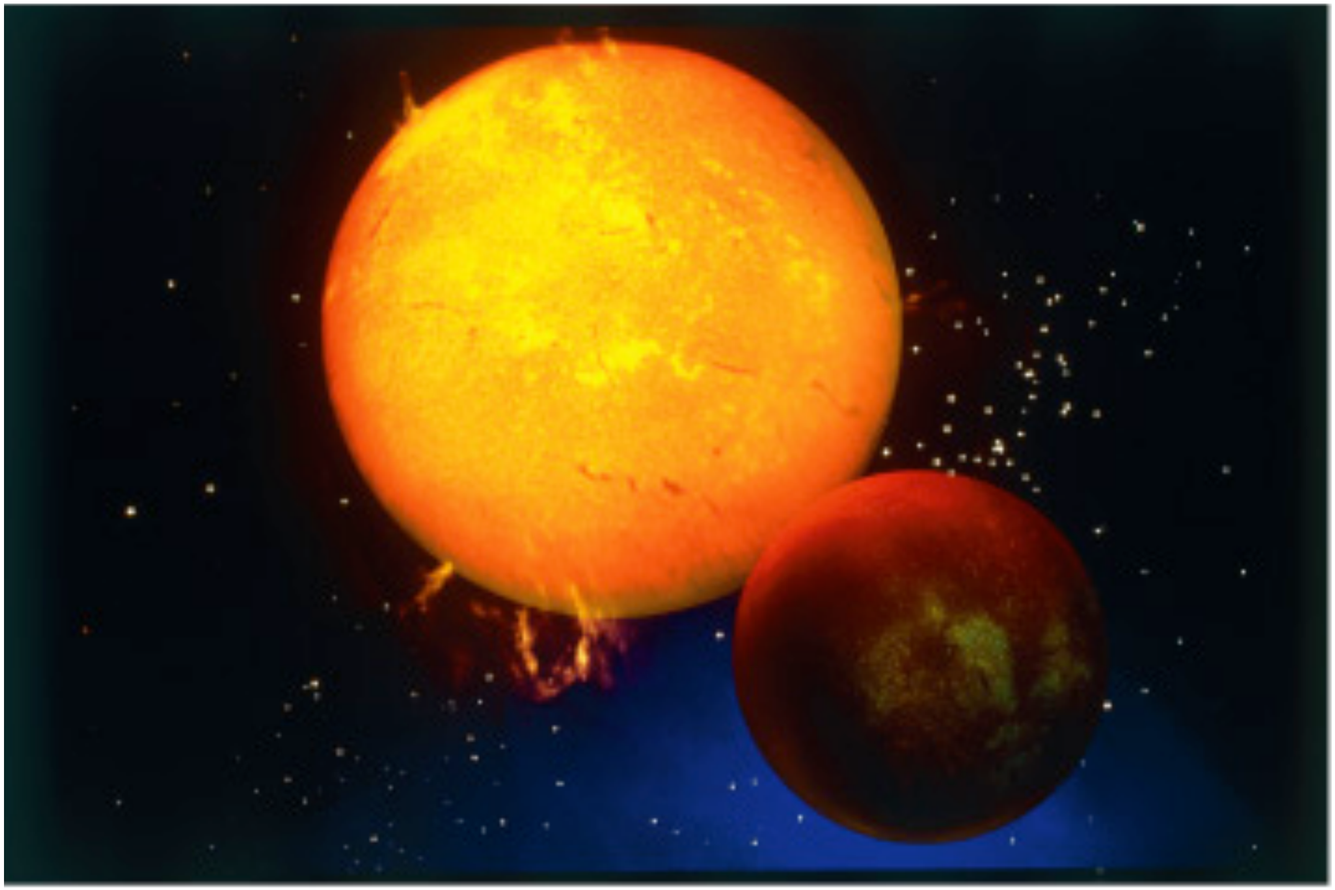
Age dating of meteorites via radio-isotopes tells us that the solar system is about 4.5 billion years old.

A similar age is found for the oldest moon rocks returned by Apollo.

Solar System Formation

- The solar system formed about 4.5 billion years ago from the collapse of an interstellar gas cloud (the ***solar nebula***).
- The planets formed by coagulation of smaller particles (planetesimals).
- Planets all lie in the same orbital plane, all orbit in the same direction, and mostly spin in the same direction because of the angular momentum of the solar nebula.
- The exceptions may record the lasting effects of the last enormous collisions, or of other effects.

Other stars have planets: Exoplanets

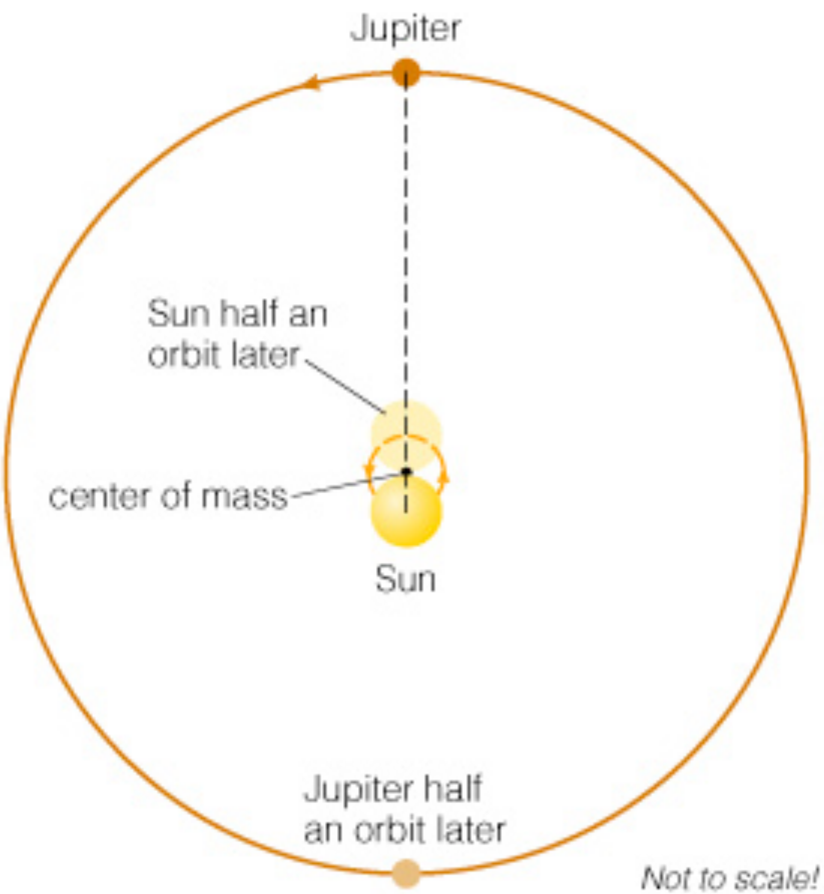


- The planet around 51 Pegasi has a mass similar to Jupiter's, despite its small orbital distance.

Other stars have planets: Exoplanet Detection

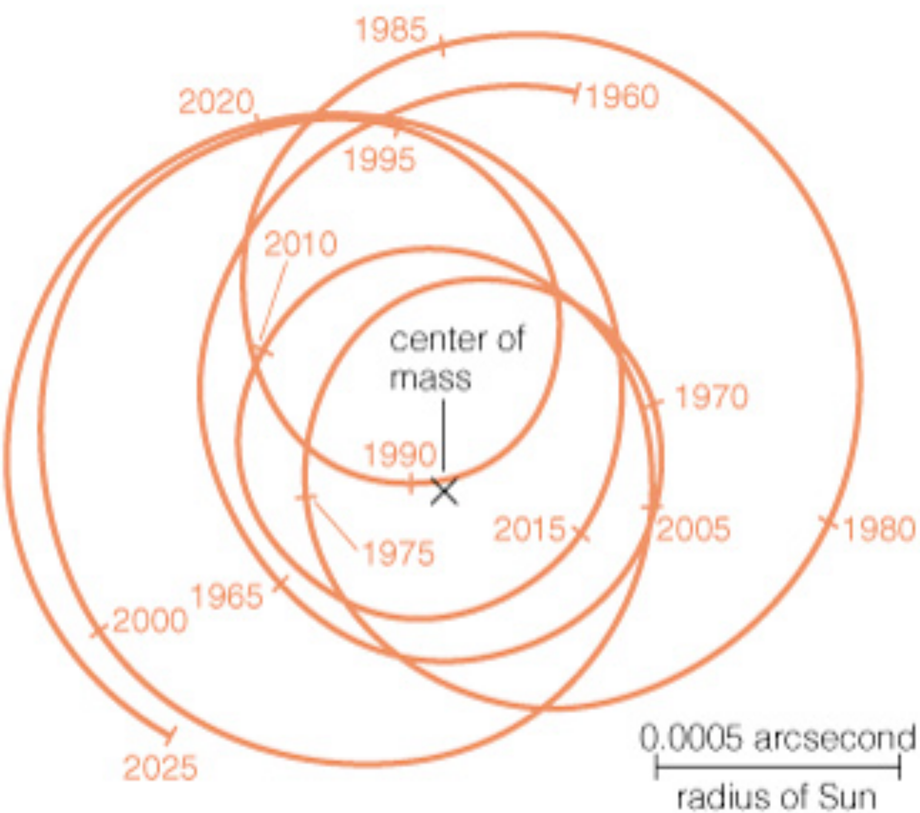
- **Direct:** Pictures or spectra of the planets themselves
- **Indirect:** Measurements of stellar properties revealing the effects of orbiting planets

Gravitational Tugs



- The Sun and Jupiter orbit around their common center of mass.
- The Sun therefore wobbles around that center of mass with the same period as Jupiter.

Gravitational Tugs

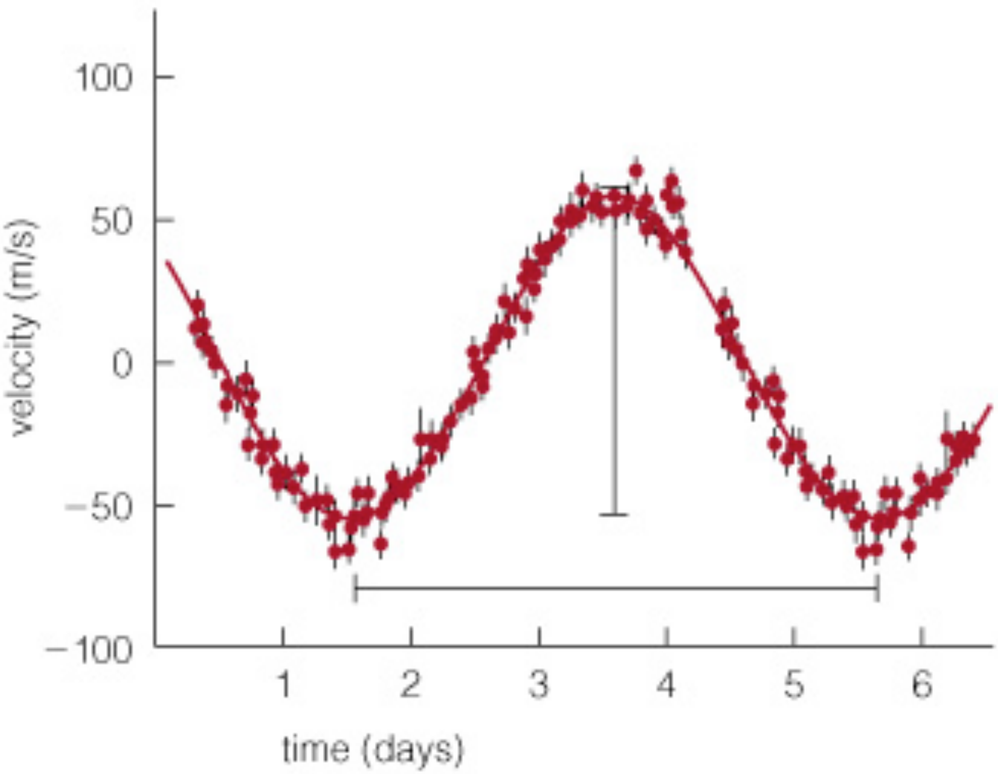


- Sun's motion around solar system's center of mass depends on tugs from all the planets.
- Astronomers who measured this motion around other stars could determine masses and orbits of all the planets.

First Exoplanets Detected

- Around a neutron star (collapsed core of a very massive star)
  Woohoo!!
- Turns out that some neutron stars emit extremely regular pulses; NS motion in response to planets can be seen
- But NS are not like our Sun, so ignored
  sniff *sulk*

First Extrasolar Planet Detected Around Normal Star

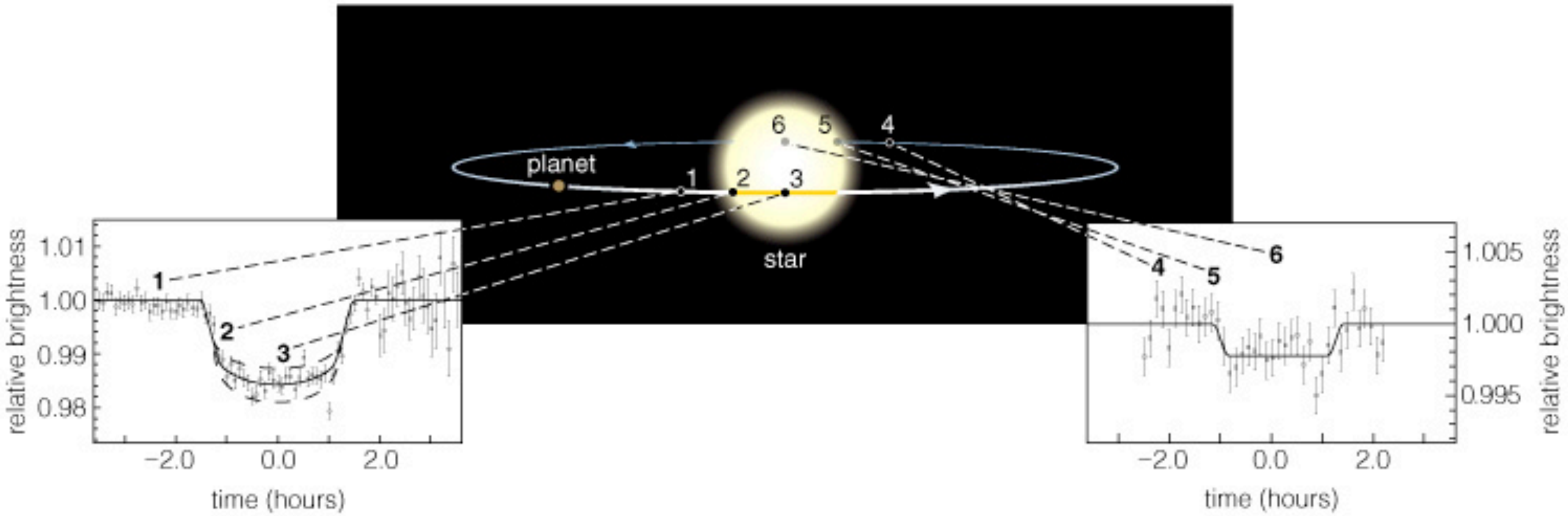


- Doppler shifts of star 51 Pegasi indirectly reveal planet with 4-day orbital period
- Short period means small orbital distance

Selection Effects

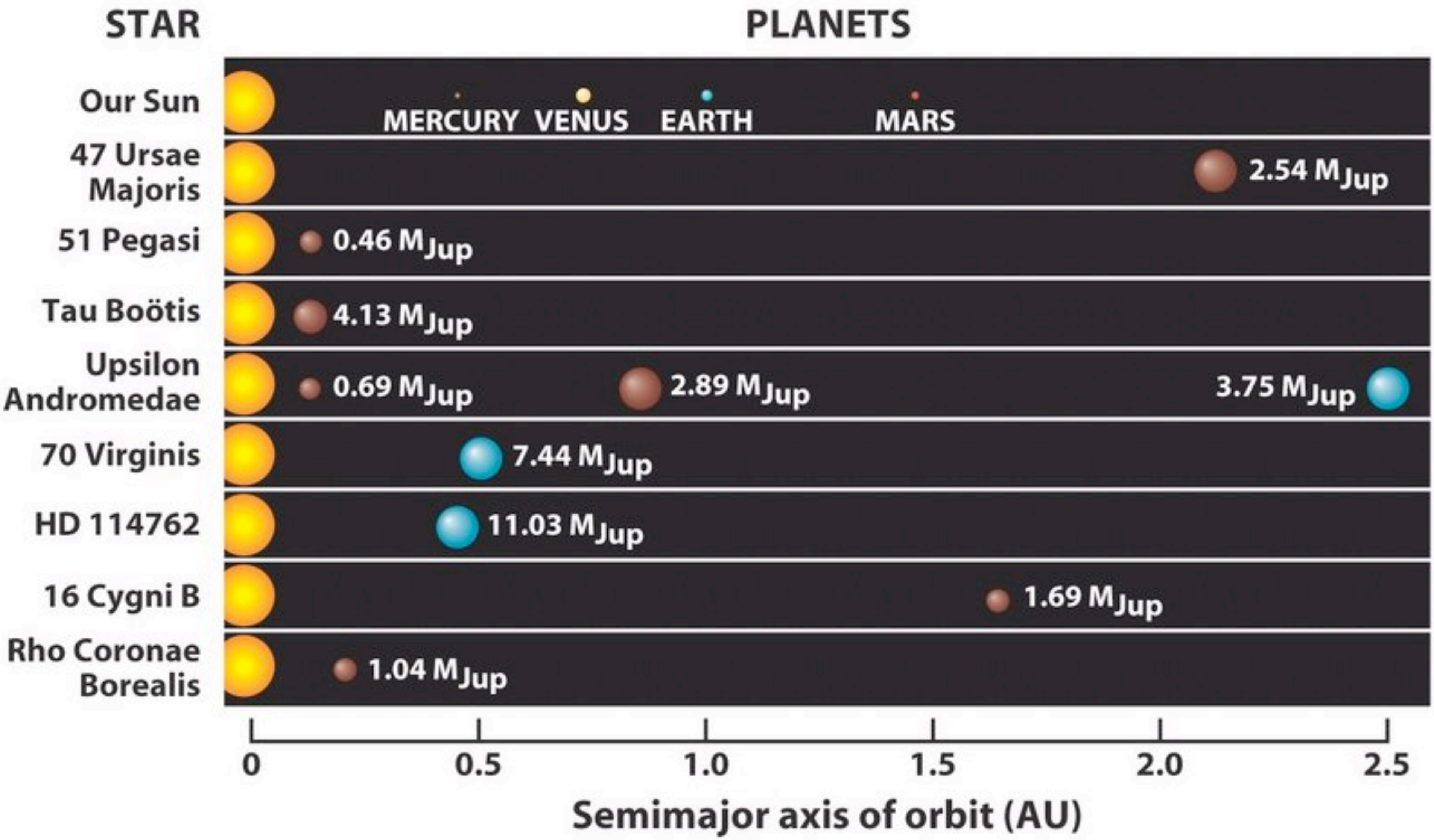
- It is much easier to see a large, massive planet than it is to see a small, low-mass planet
- It is also much easier to see the gravitational tug of a planet near its star than one far away
- Thus we see an excess of large planets nearby their stars compared to the real sample

Transits and Eclipses



- A **transit** is when a planet crosses in front of a star.
- The resulting eclipse reduces the star's apparent brightness and tells us the planet's radius.

Example planets around other stars



There are more than 1,000 exoplanets known!!