Today

- Solar System Formation

Events

- Homework Due

Why are the orbits of the planet so well aligned? Daniel Bernoulli, 1734

What are the odds that the orbital planes of the planets are so well aligned by chance?

tes de ces deux Orbites. On verra par-là que cette probabilité eſt ſi petite, qu'elle doit paſſer pour une impoſſibilité morale.

"We will see thence that this probability is so small, that it must to be received as a moral impossibility."

About 1 in 1 Million (10^{-6})

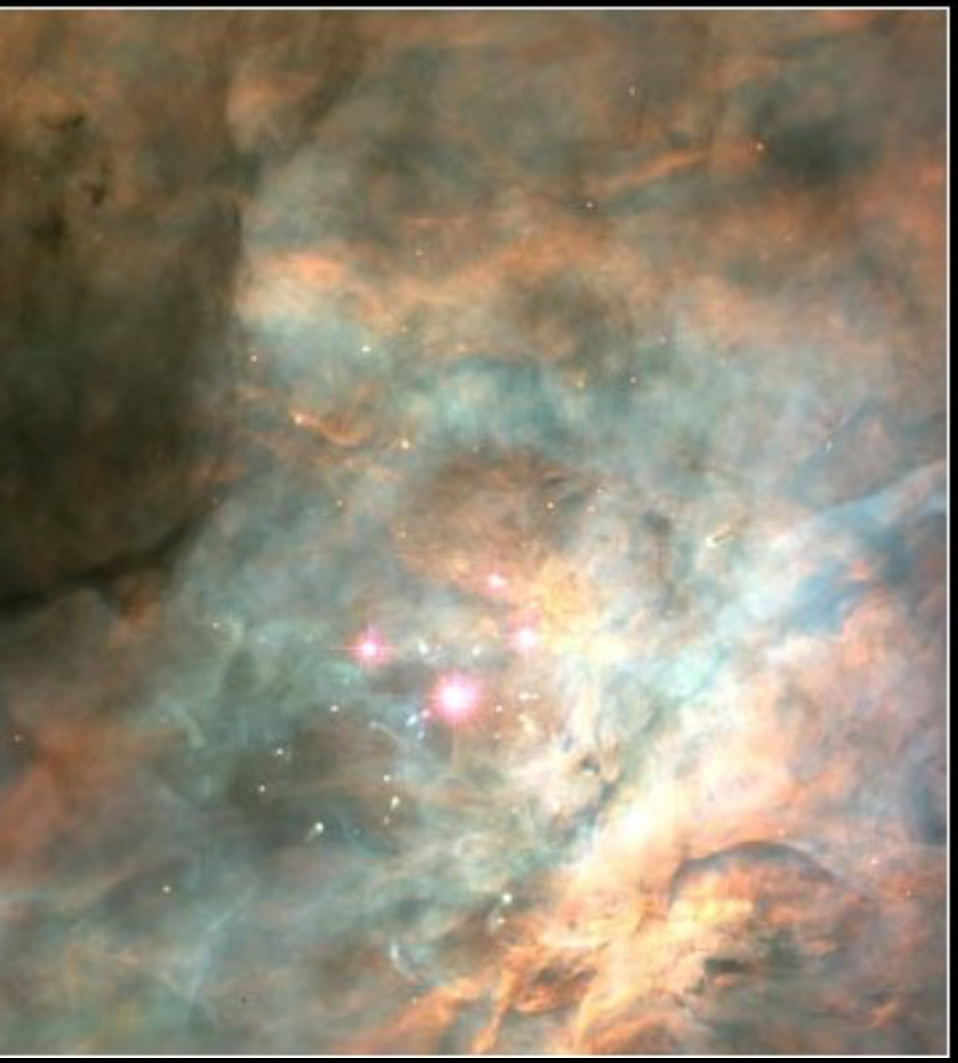
Need to explain why the solar system is so structured

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

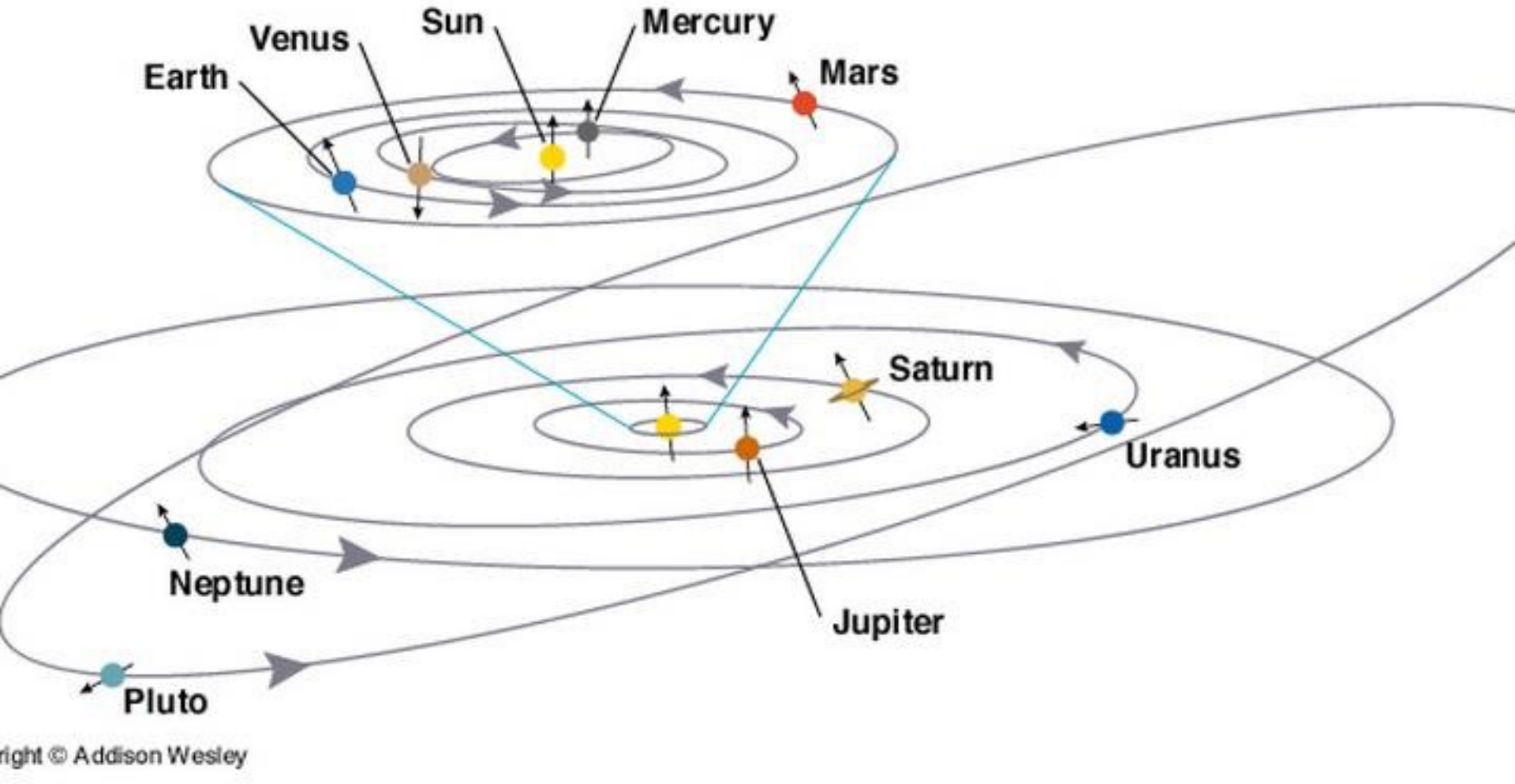
Proposed early:
- Immanuel Kant (1755)
- Pierre-Simon Laplace (1796)

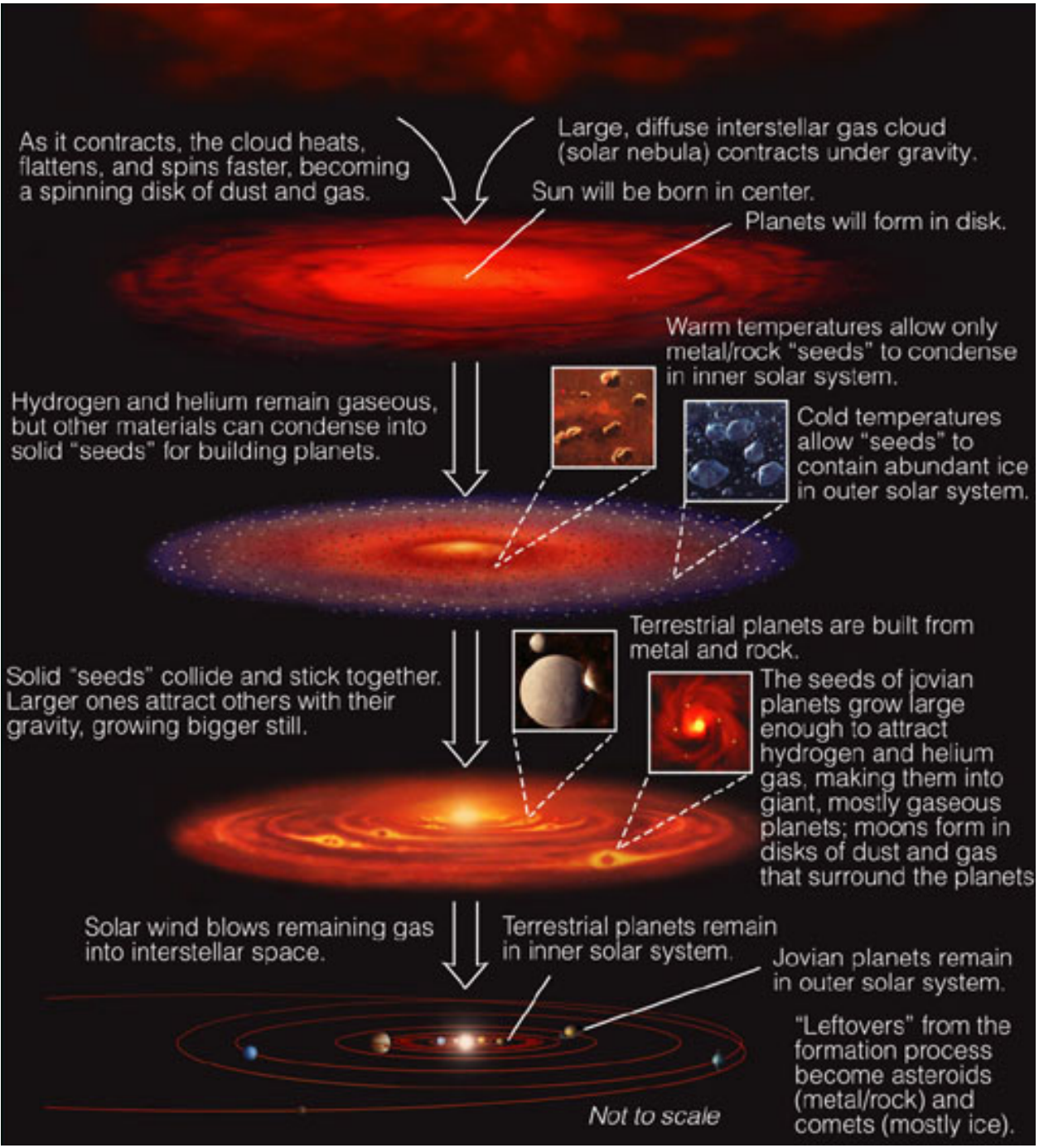


optical

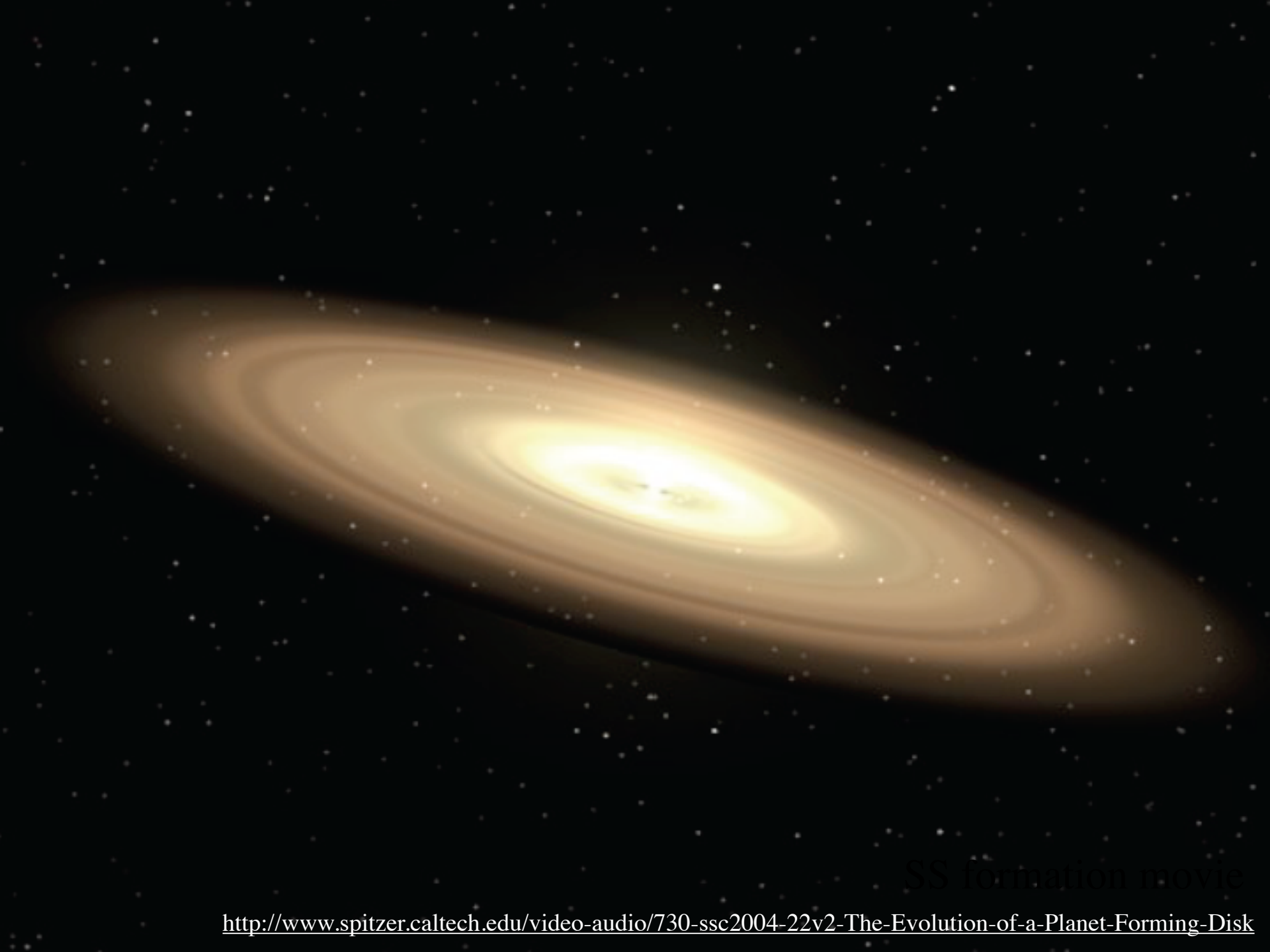
infrared

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



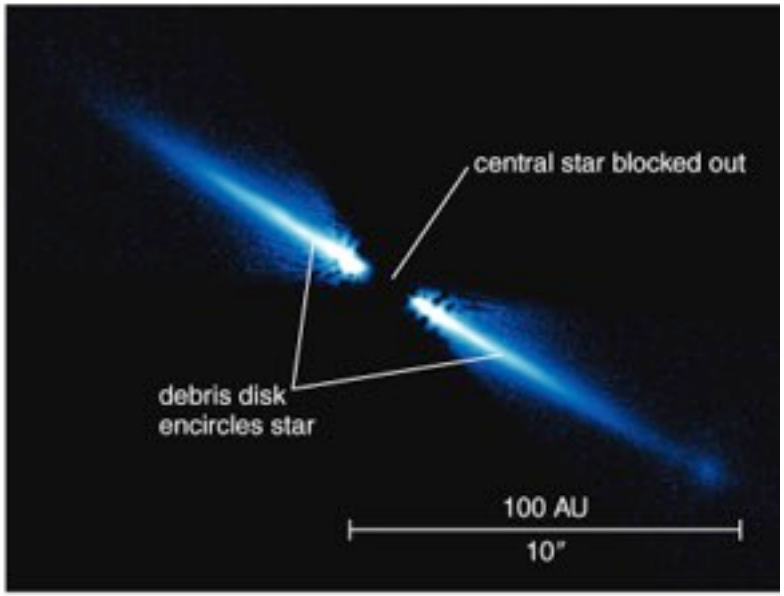


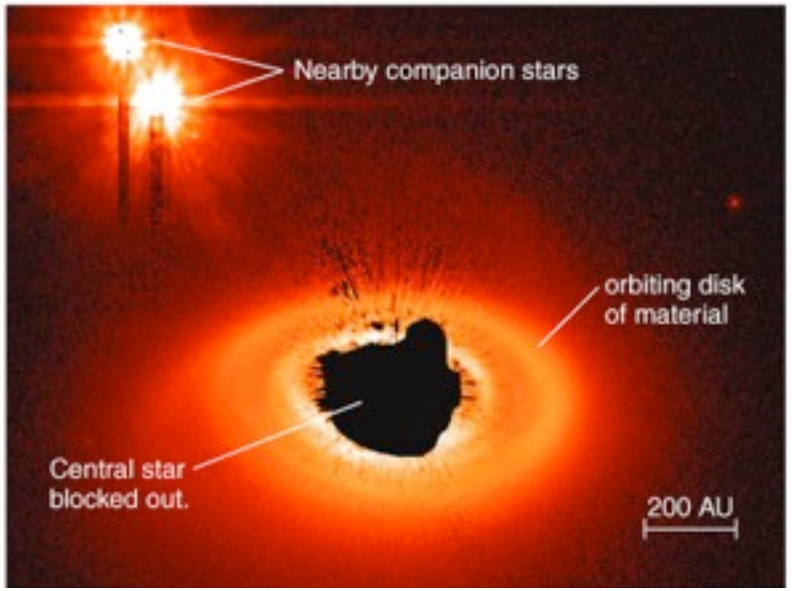
- Nebula spins up as it collapses (angular momentum conserved)
- Solid particles condense out of gas
- Particles collide; form ever larger objects
- Most mass eventually swept up into planets



http://www.spitzer.caltech.edu/video-audio/730-ssc2004-22v2-The-Evolution-of-a-Planet-Forming-Disk

Disks Around Other Stars

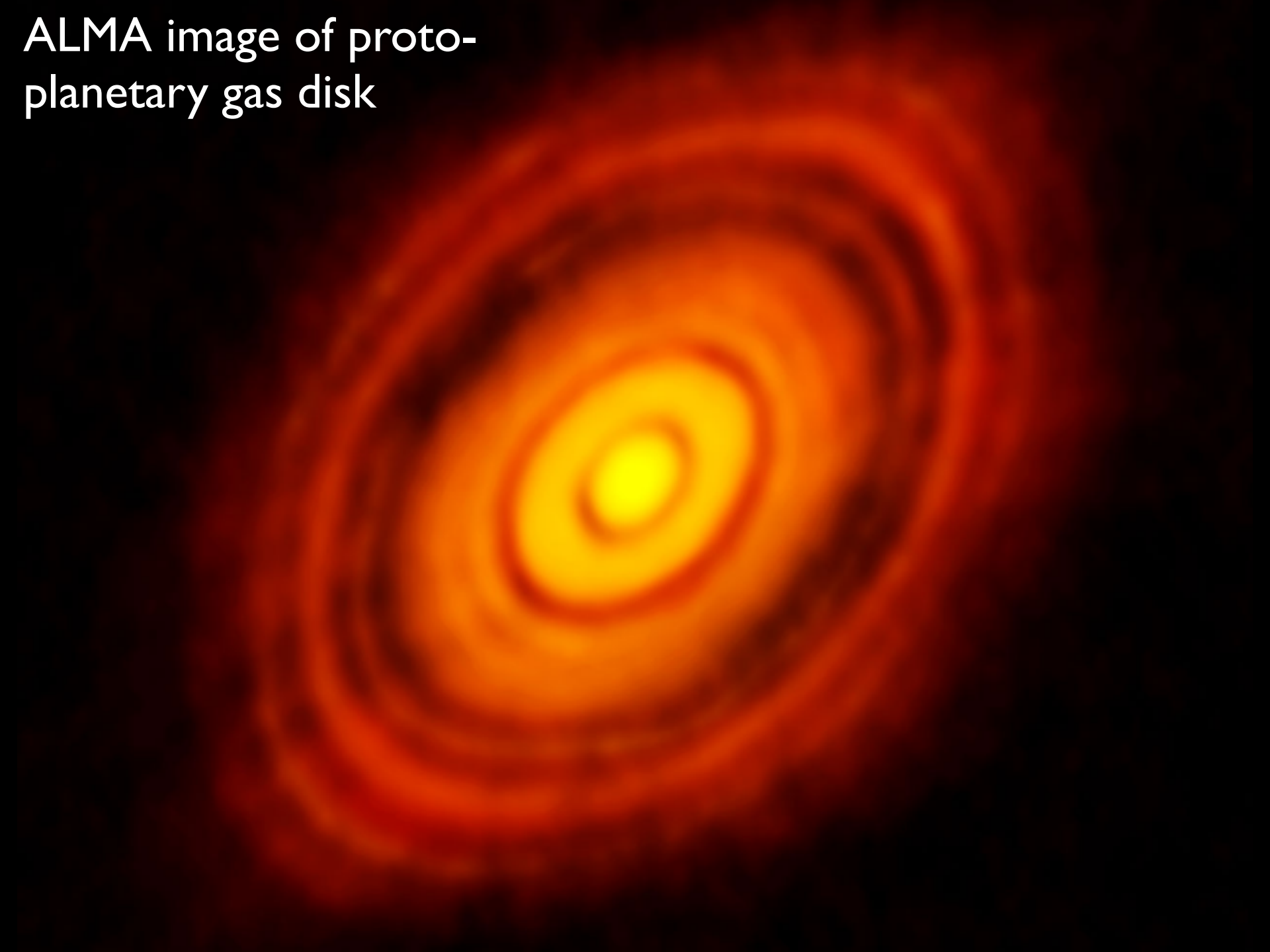




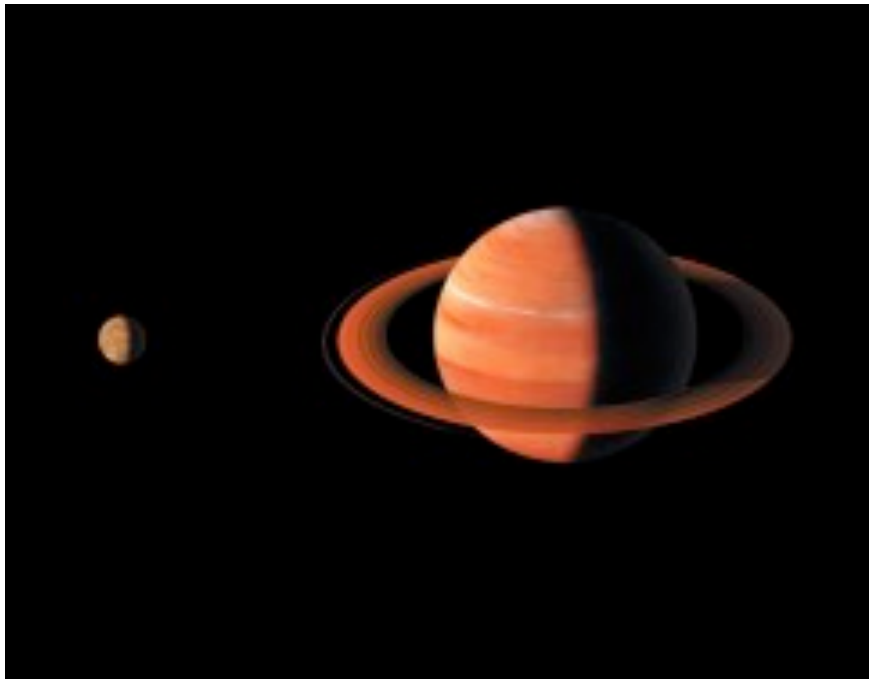
- Observations of disks around other stars broadly support the nebular hypothesis.

Protoplanetary Disks HST • WFPC2

ALMA image of proto-planetary gas disk



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%

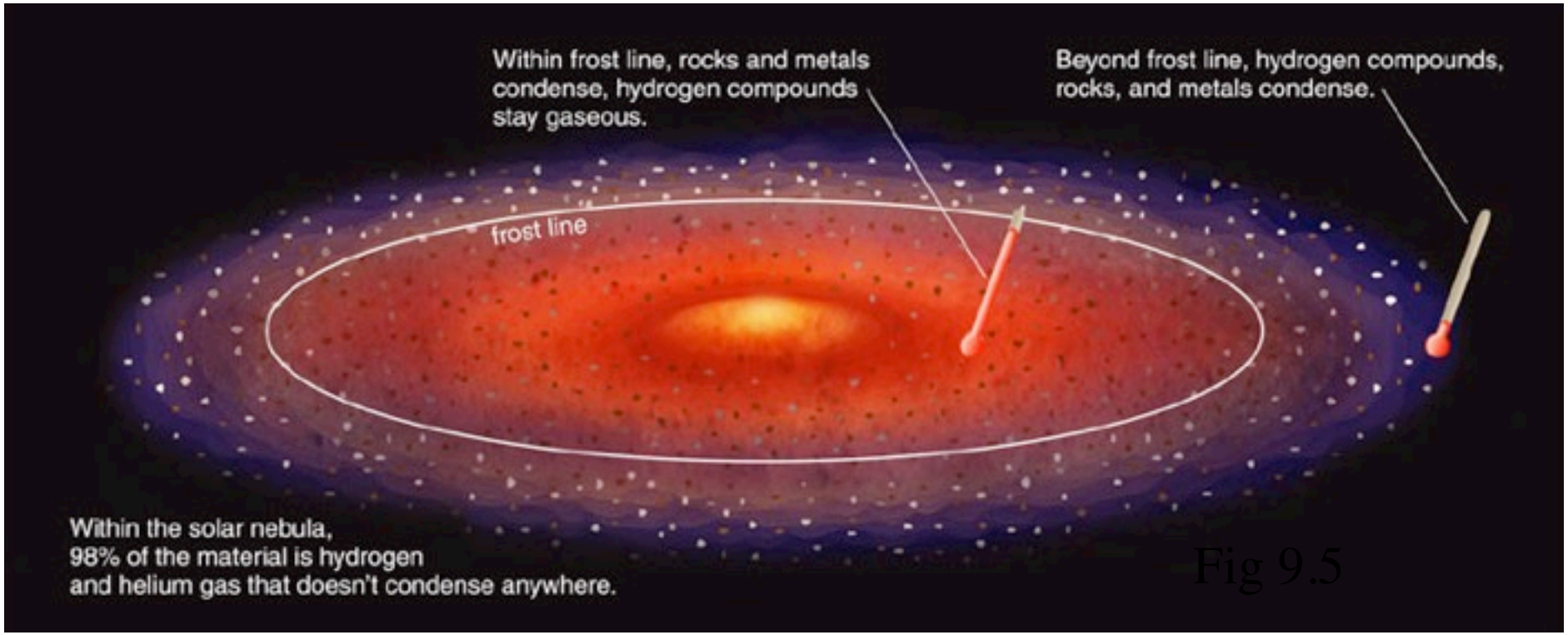


Fig 9.5

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.

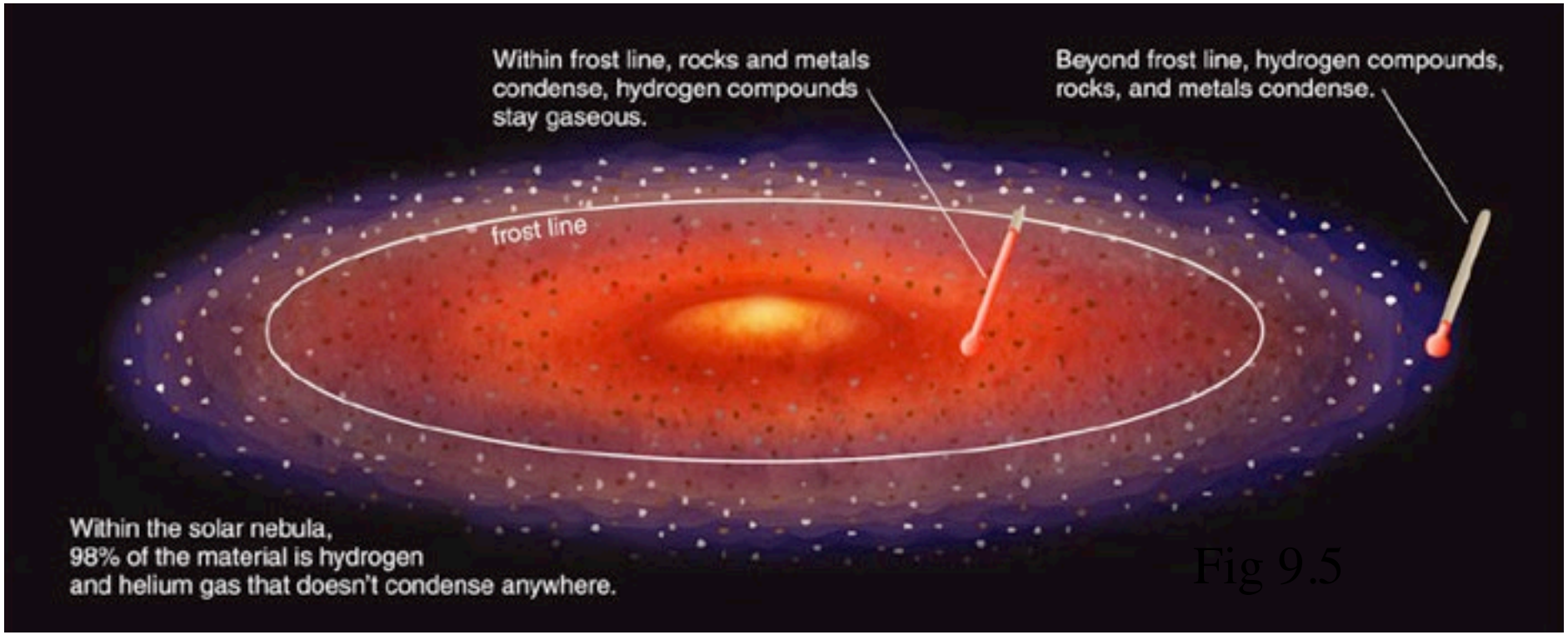


Fig 9.5

<u>FROST LINE</u> <u>at about 3.5 AU</u>

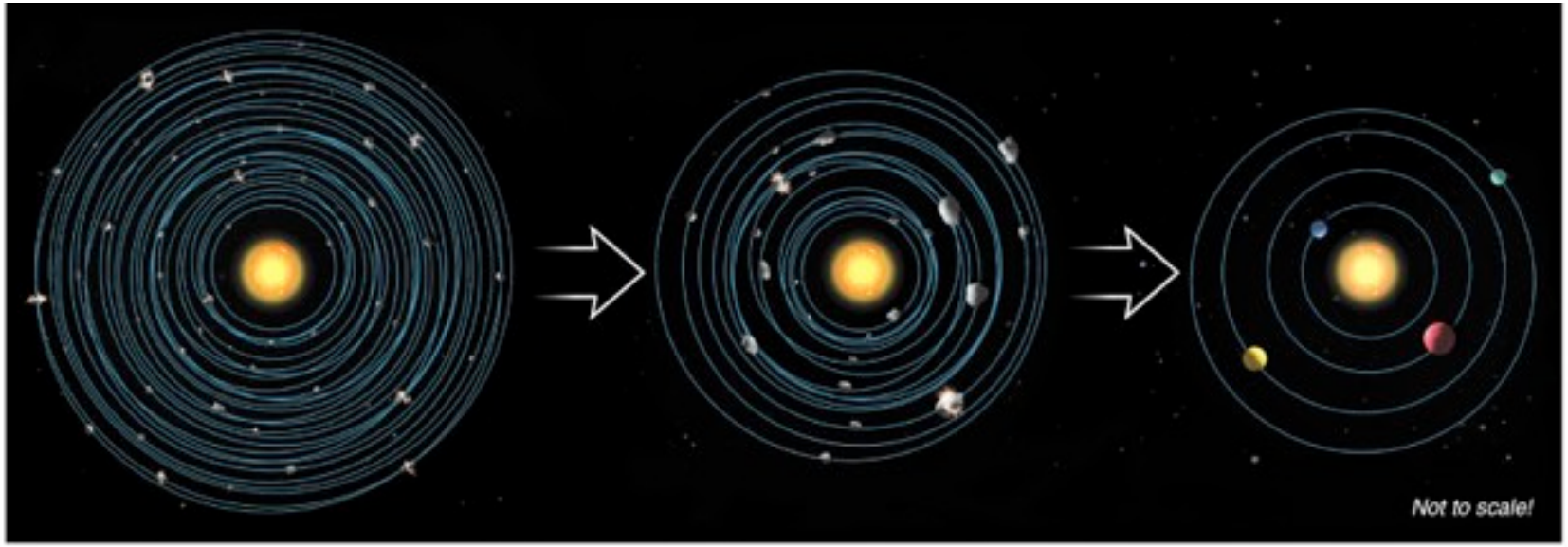
Inside the ***frost line***: Too hot for hydrogen compounds to form ices
- only get rocky asteroids and planets

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.

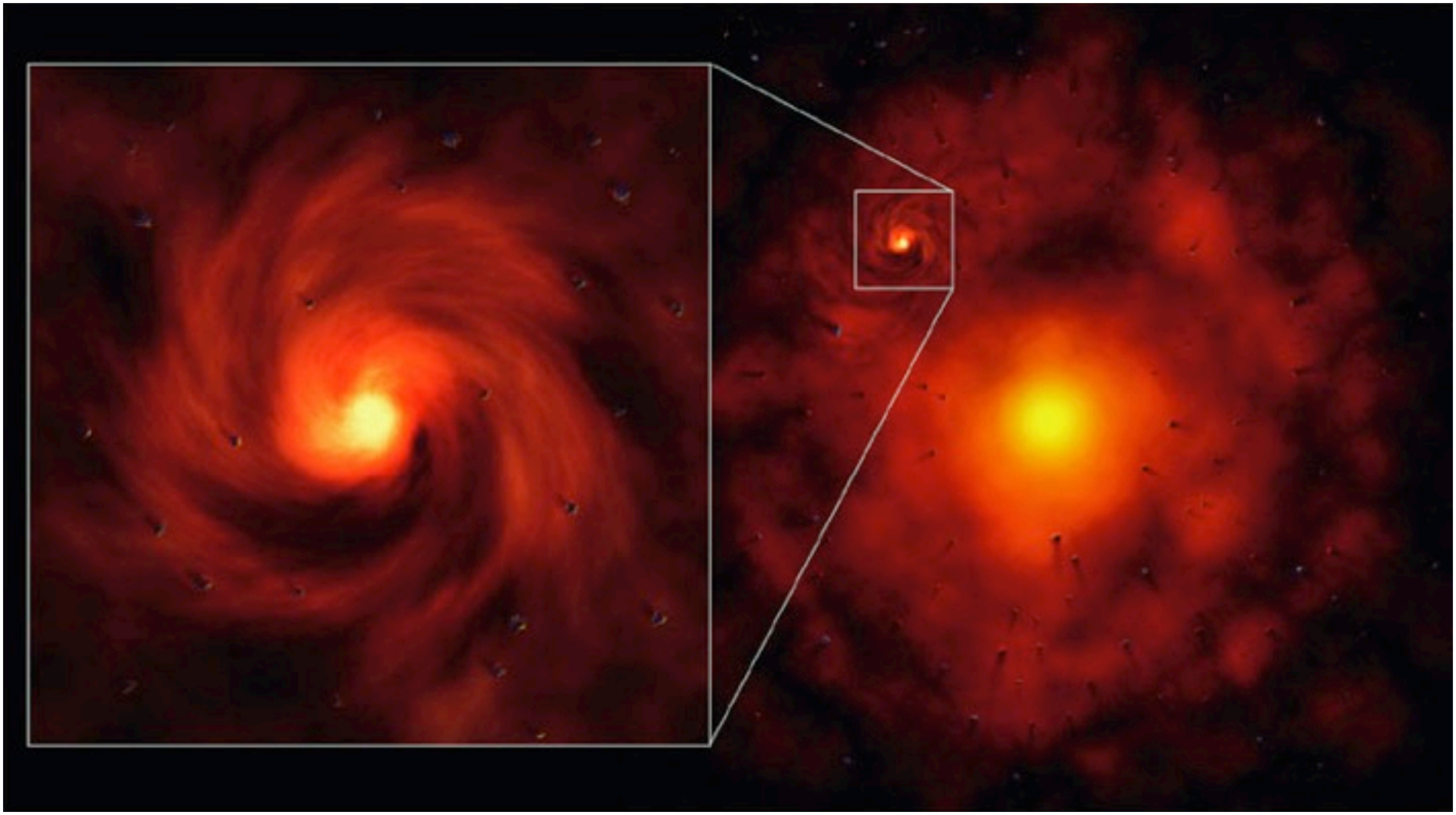
Accretion of Planetesimals



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

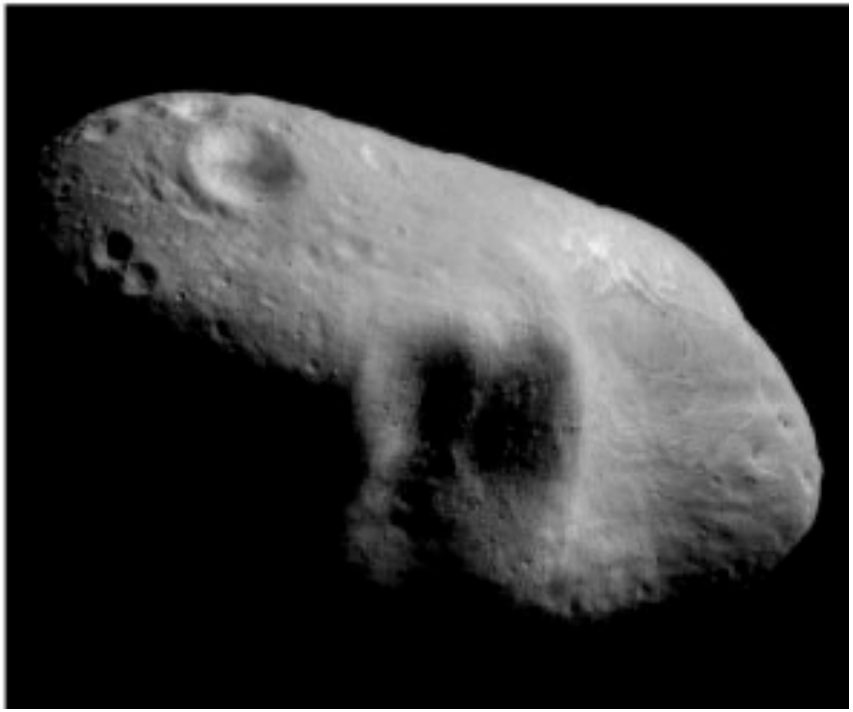
Formation of Jovian Planets

- 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.

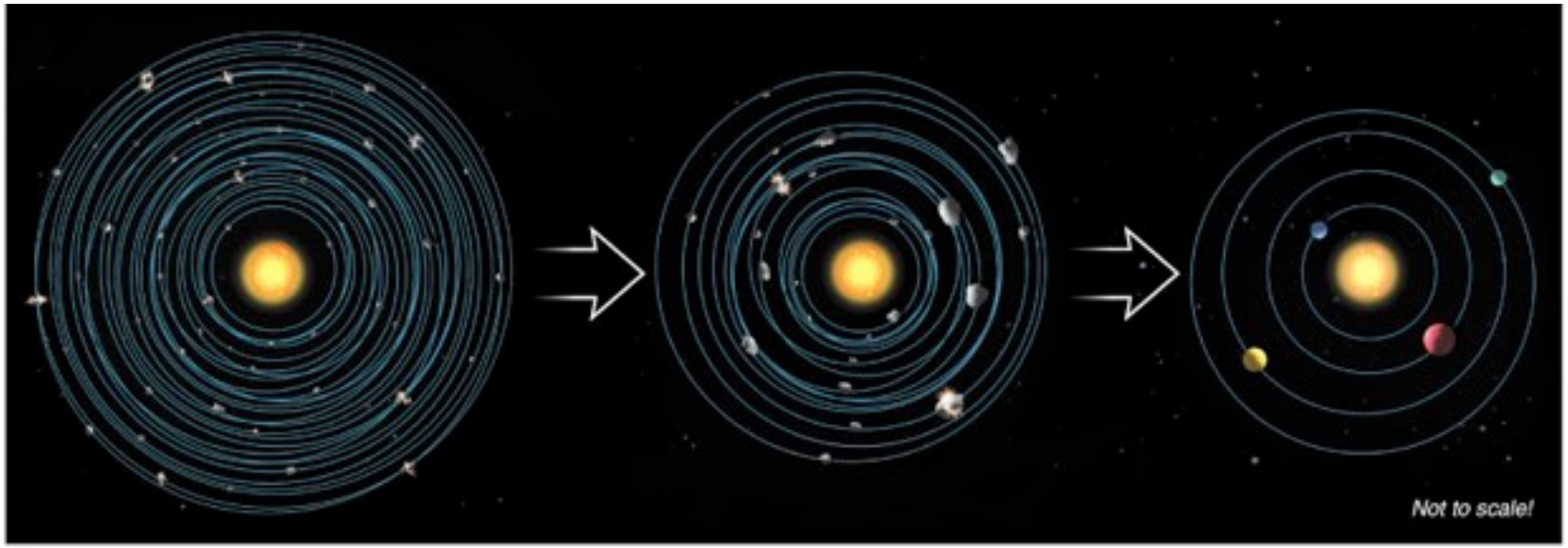


Moons of jovian planets form in miniature disks - like microcosms of the solar nebula.

Where did asteroids and comets come from?



Asteroids and Comets

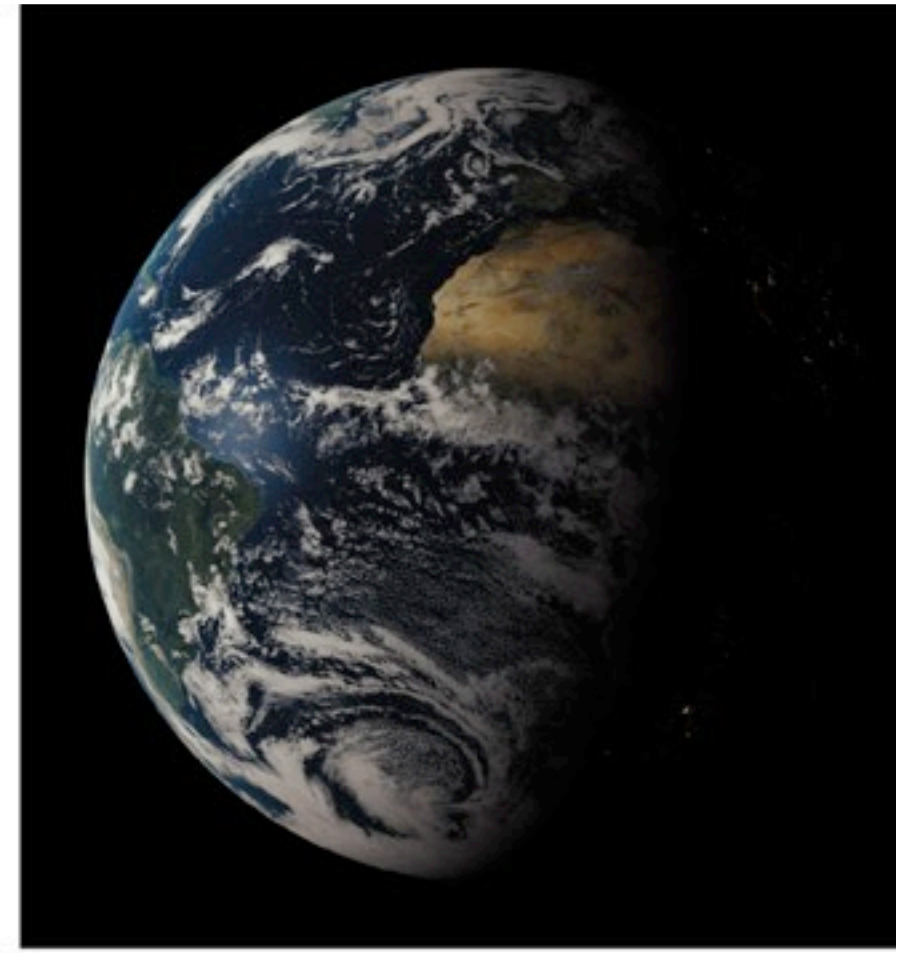


- Leftovers from the accretion process
- Rocky asteroids inside frost line
- Icy comets outside frost line

Heavy Bombardment

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

Origin of Earth's Water

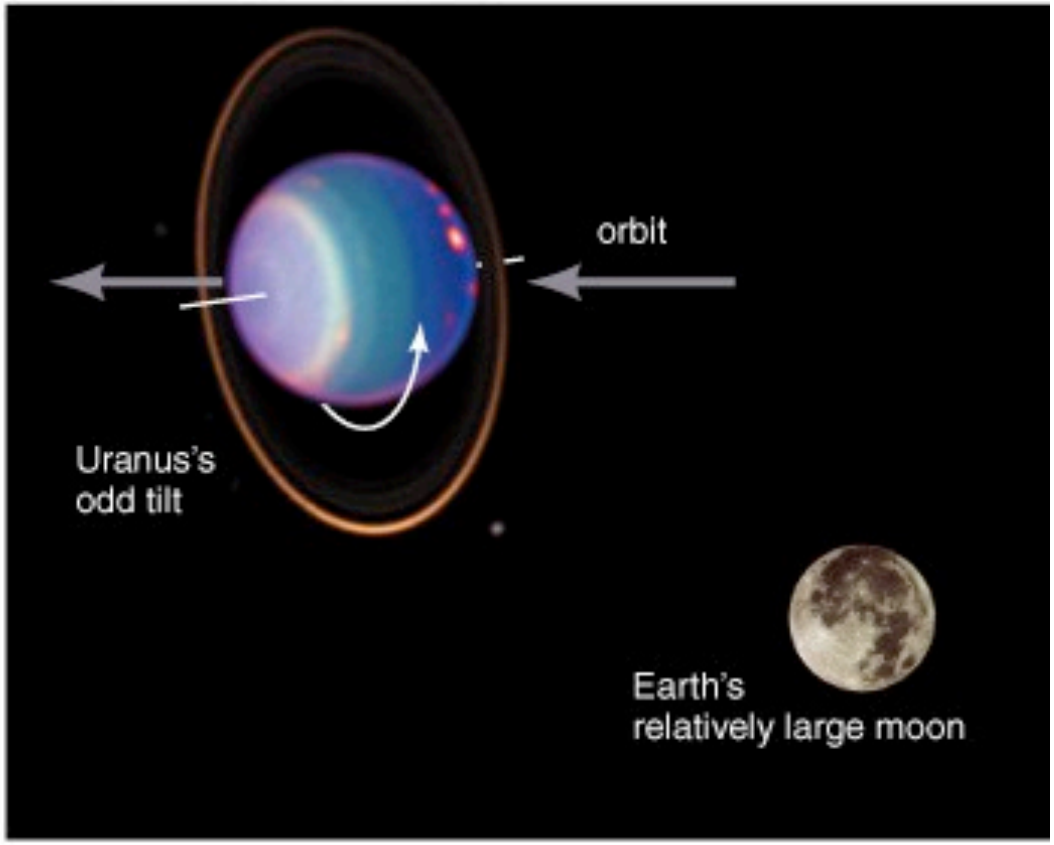


- "Exhaled" by volcanos, or
- Water may have come to Earth by way of icy planetesimals from the outer solar system.

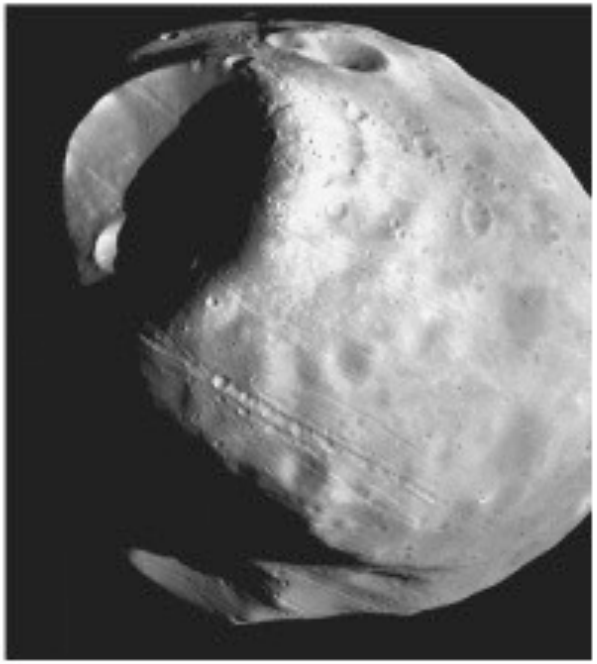
What about the exceptions?

- Venus spins retrograde
- Uranus tipped almost perpendicular
- Why do we have a moon?

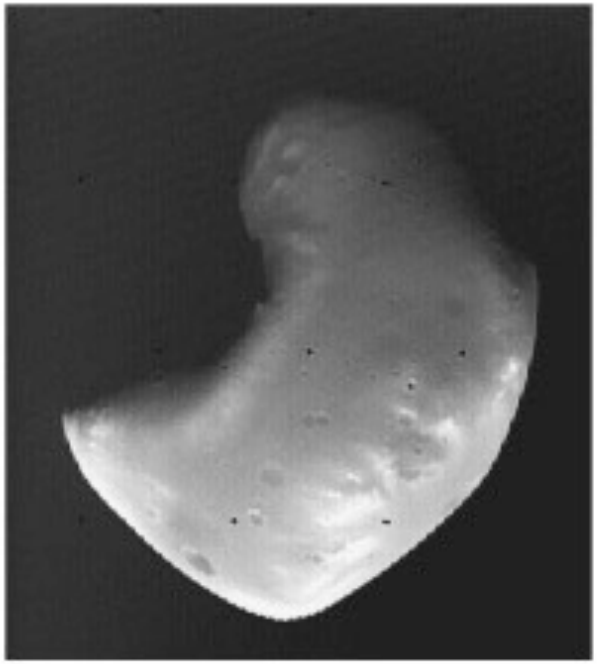
Thought to be due to the last big collision.



Captured Moons



Phobos (fear)

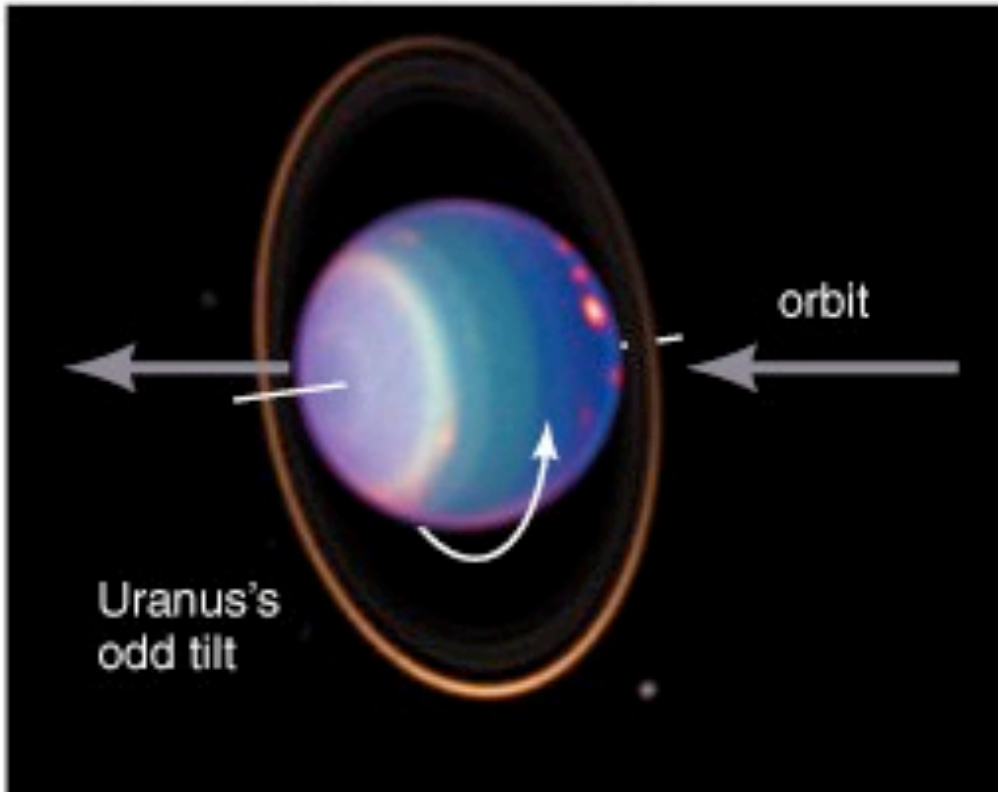


Deimos (panic)

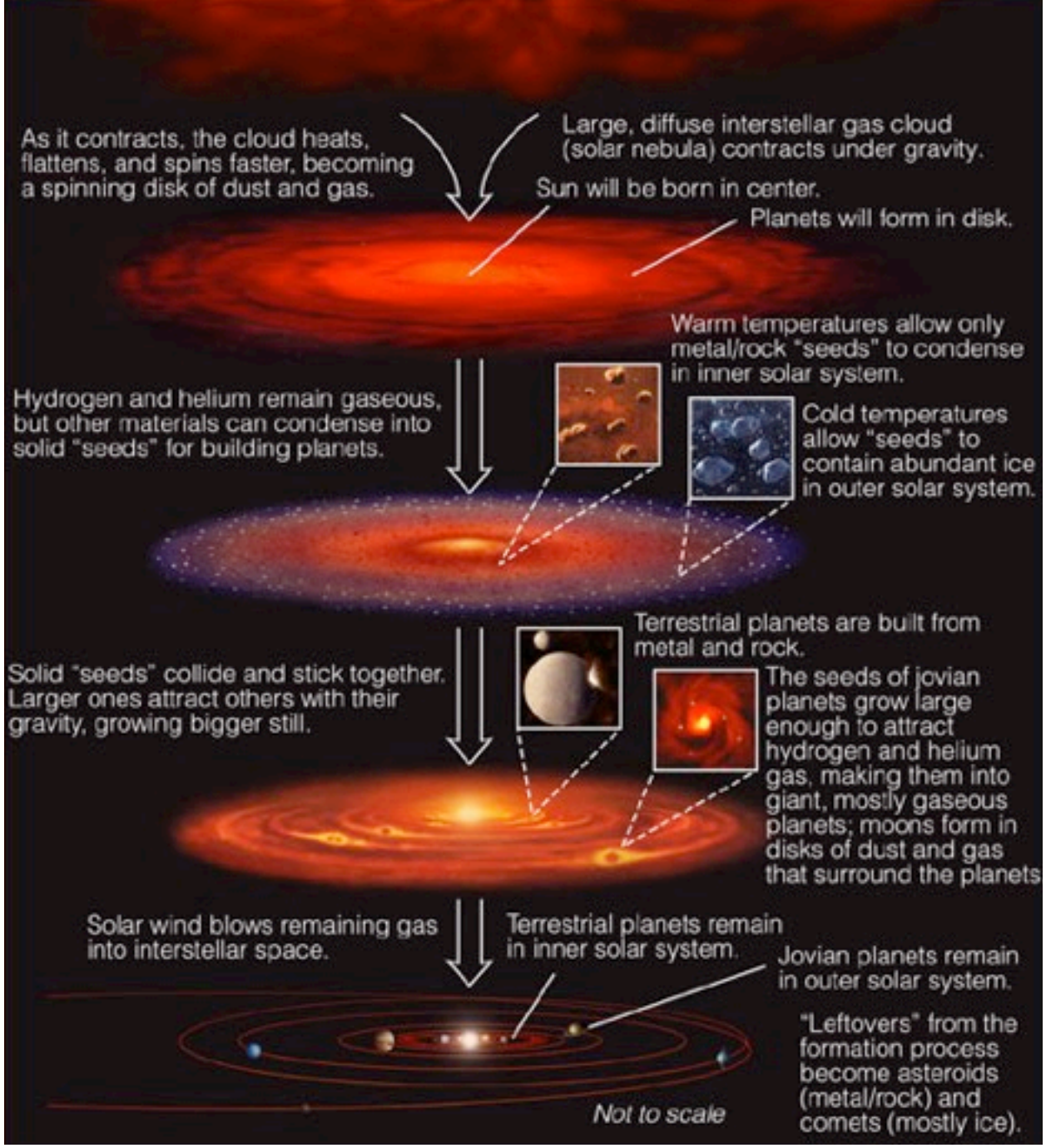
- The unusual moons of Mars and some other planets may be captured asteroids.
- left over planetesimals?

Earth's moon: Giant Impact?

Odd Rotation



- Giant impacts might also explain the different rotation axes of some planets.



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