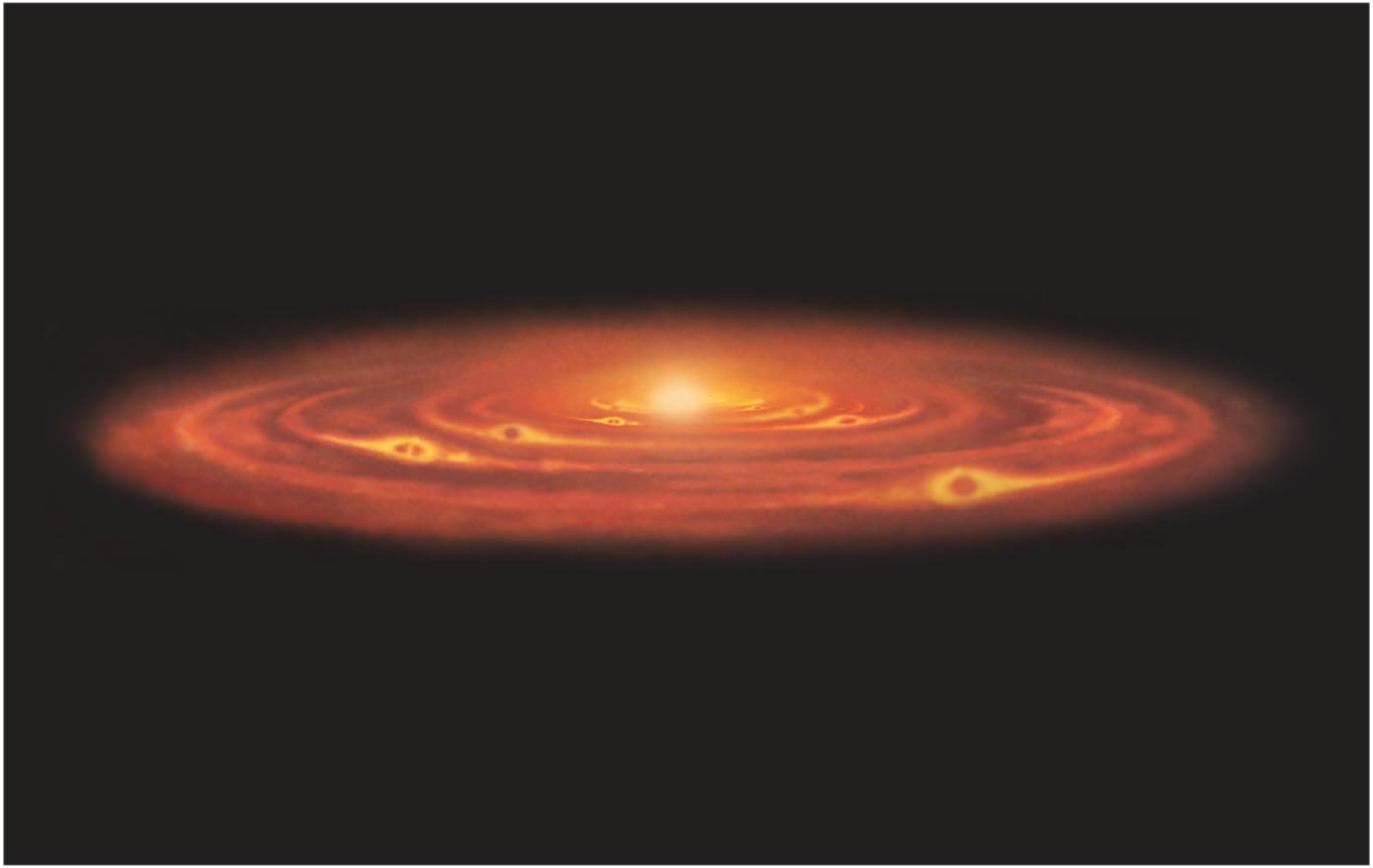
Formation of the Solar System



What properties of our solar system must a formation theory explain?

1. Patterns of motion of the large bodies
   – Orbit in same direction and plane
2. Existence of two types of planets
   – Terrestrial and jovian
   – Patterns of size, location
3. Existence of smaller bodies
   – Asteroids and comets
4. Notable exceptions to usual patterns
   – Rotation of Uranus, Earth's Moon, etc.

Early Hypotheses

Capture

Planets wandering through space were captured by the Sun's gravitational pull

Close Encounter

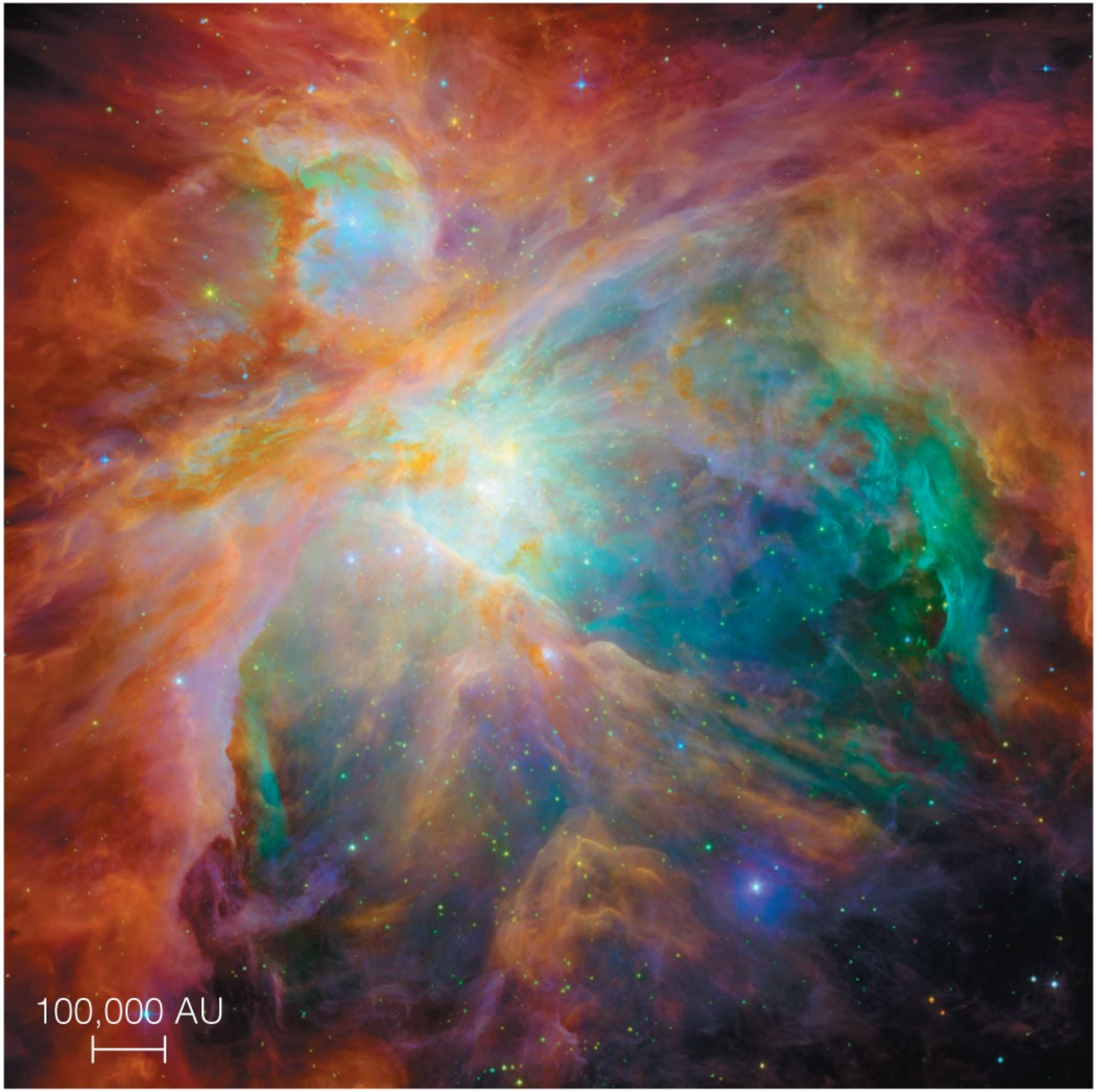
The planets formed from debris torn off the Sun by a close encounter with another star.

These hypotheses don't work!

Nebular Theory

- The *nebular theory* states that our solar system formed from the gravitational collapse of a giant interstellar gas cloud—the *solar nebula.*
  - (*Nebula* is the Latin word for cloud.)
- Kant and Laplace proposed the *nebular hypothesis* over two centuries ago.
- A large amount of evidence now supports this idea.

Where did the solar system come from?




Star Forming Clouds
(The Eagle Nebula)

Young stars in the Orion Nebula

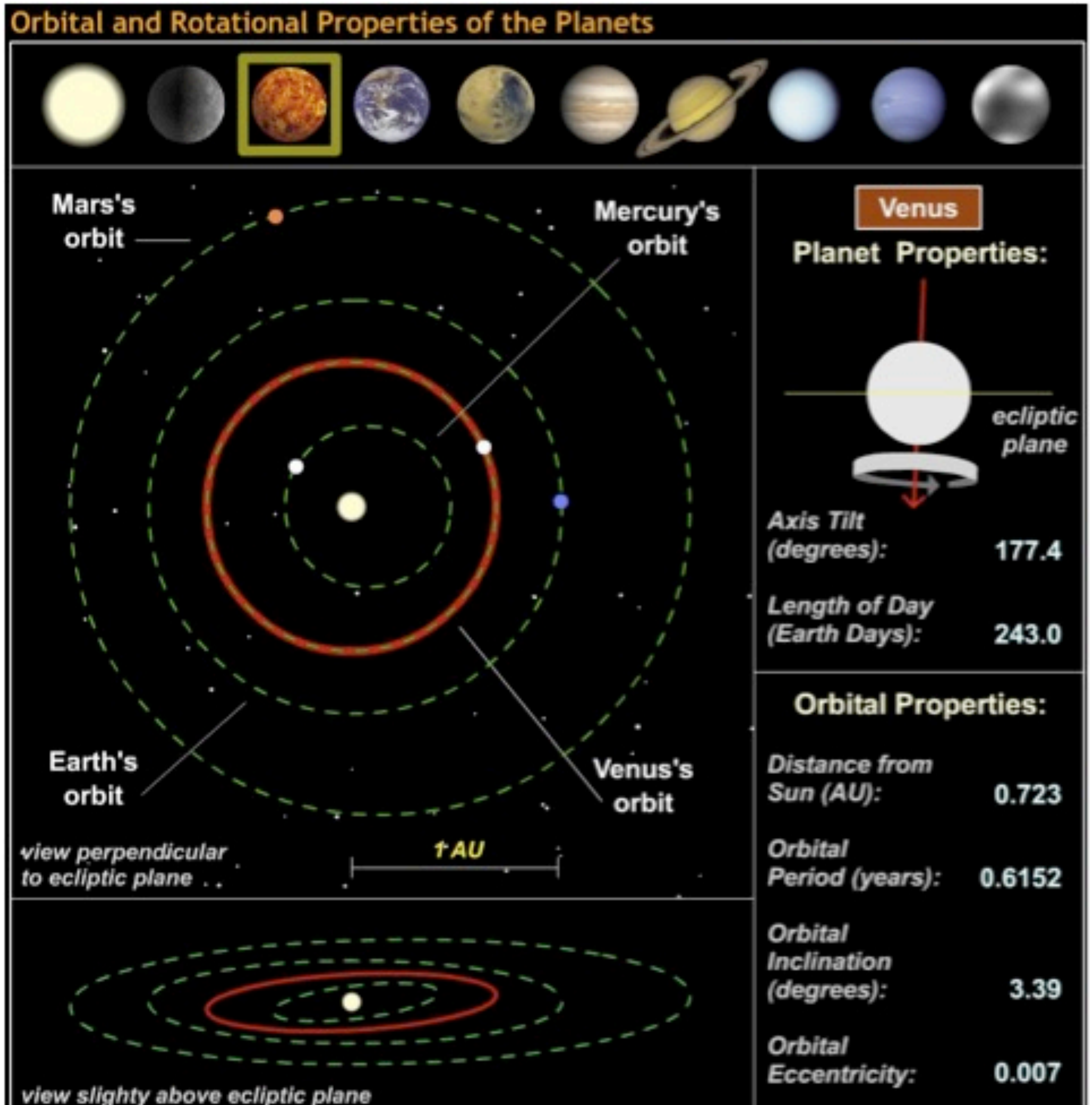
Optical Light

Infrared Light

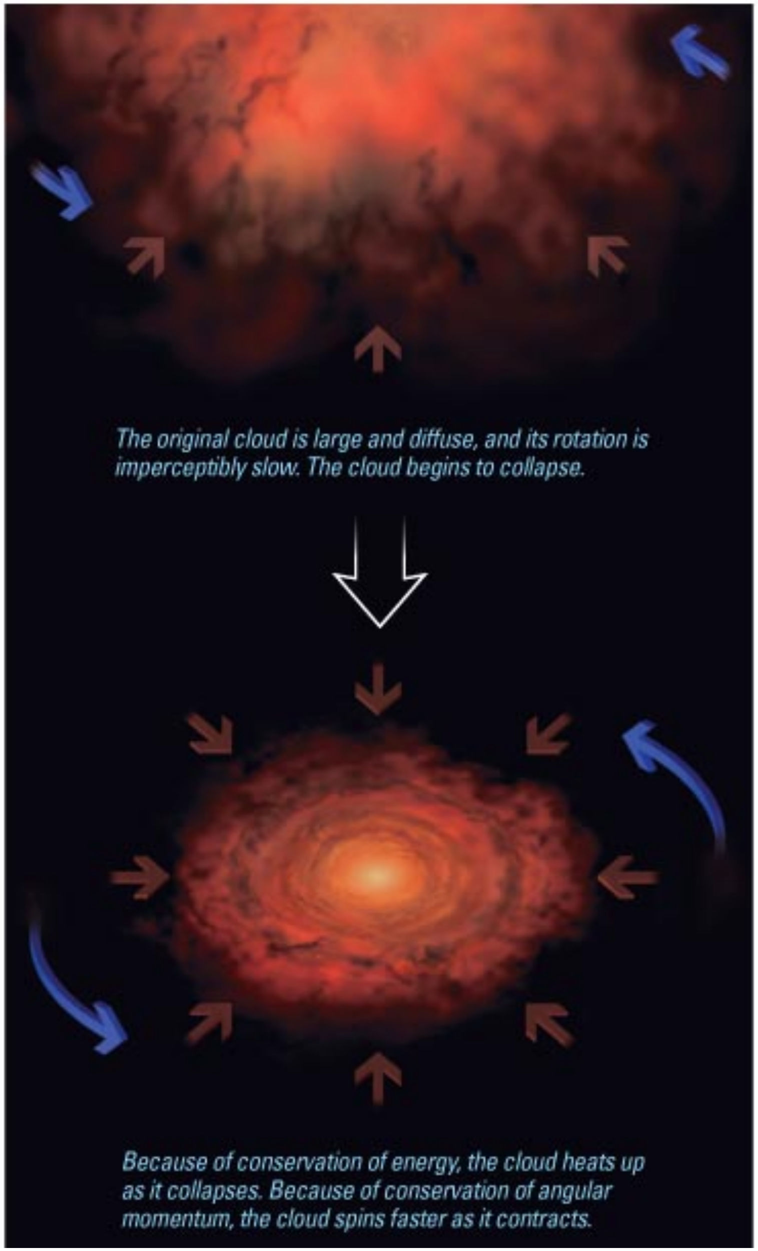
8.2 Explaining the Major Features of the Solar System

- Our goals for learning:
  - **What caused the orderly patterns of motion in our solar system?**
  - **Why are there two major types of planets?**
  - **Where did asteroids and comets come from?**
  - **How do we explain "exceptions to the rules"?**

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

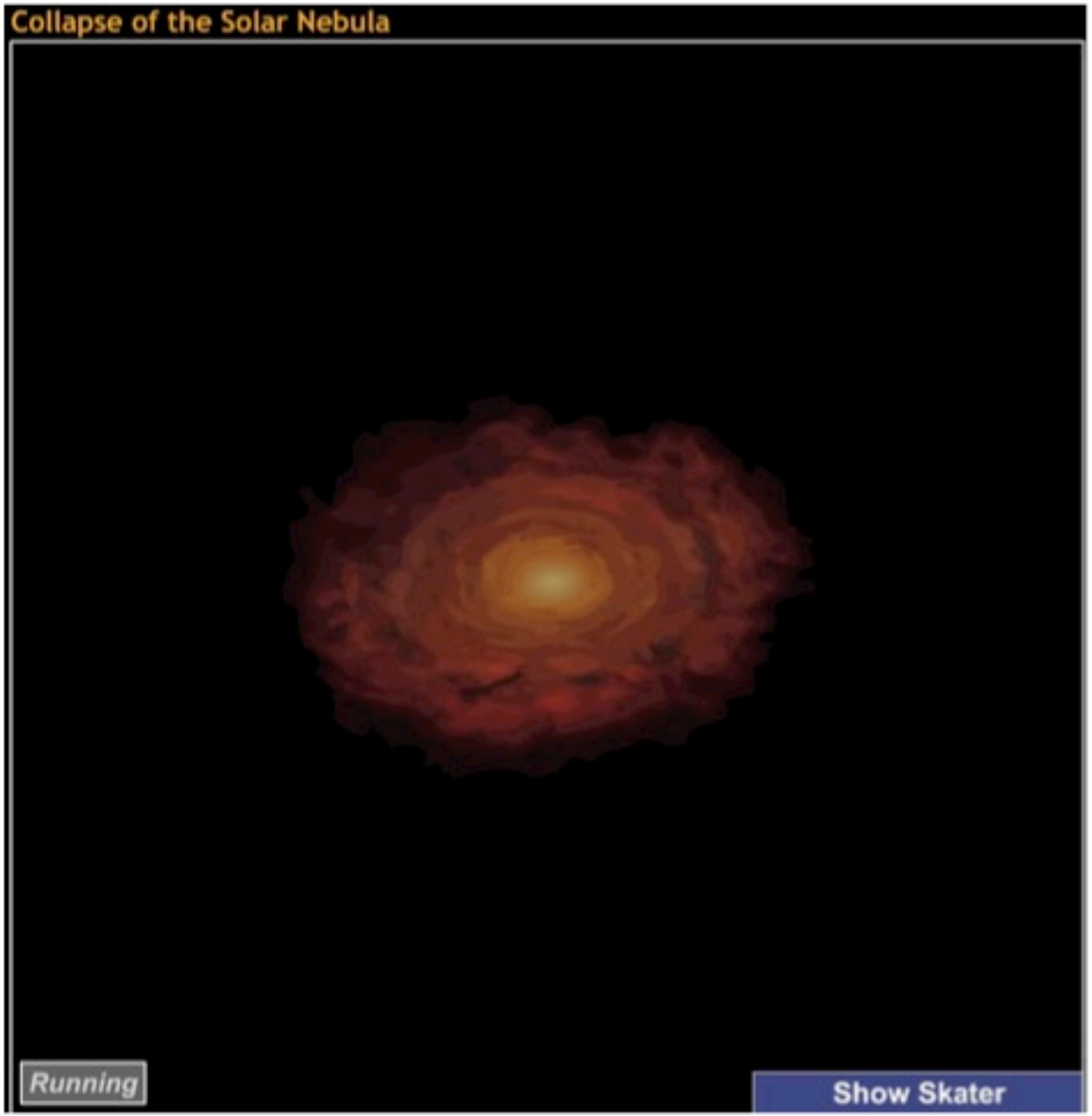


Conservation of Angular Momentum



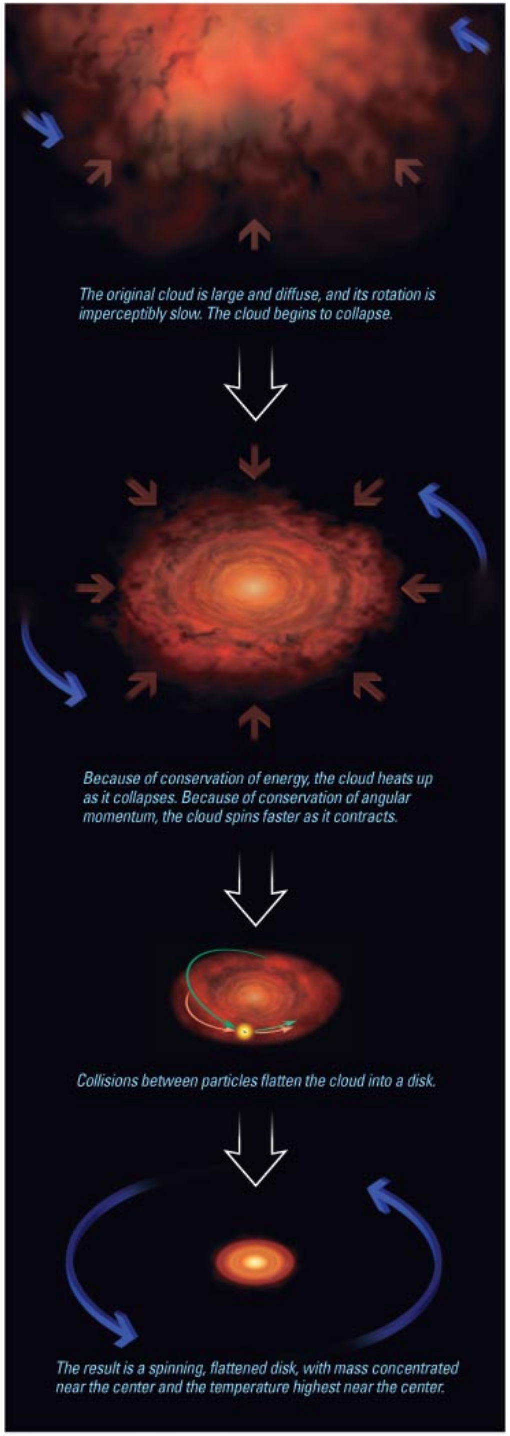
- Rotation speed of the cloud from which our solar system formed must have increased as the cloud contracted.

Conservation of Angular Momentum



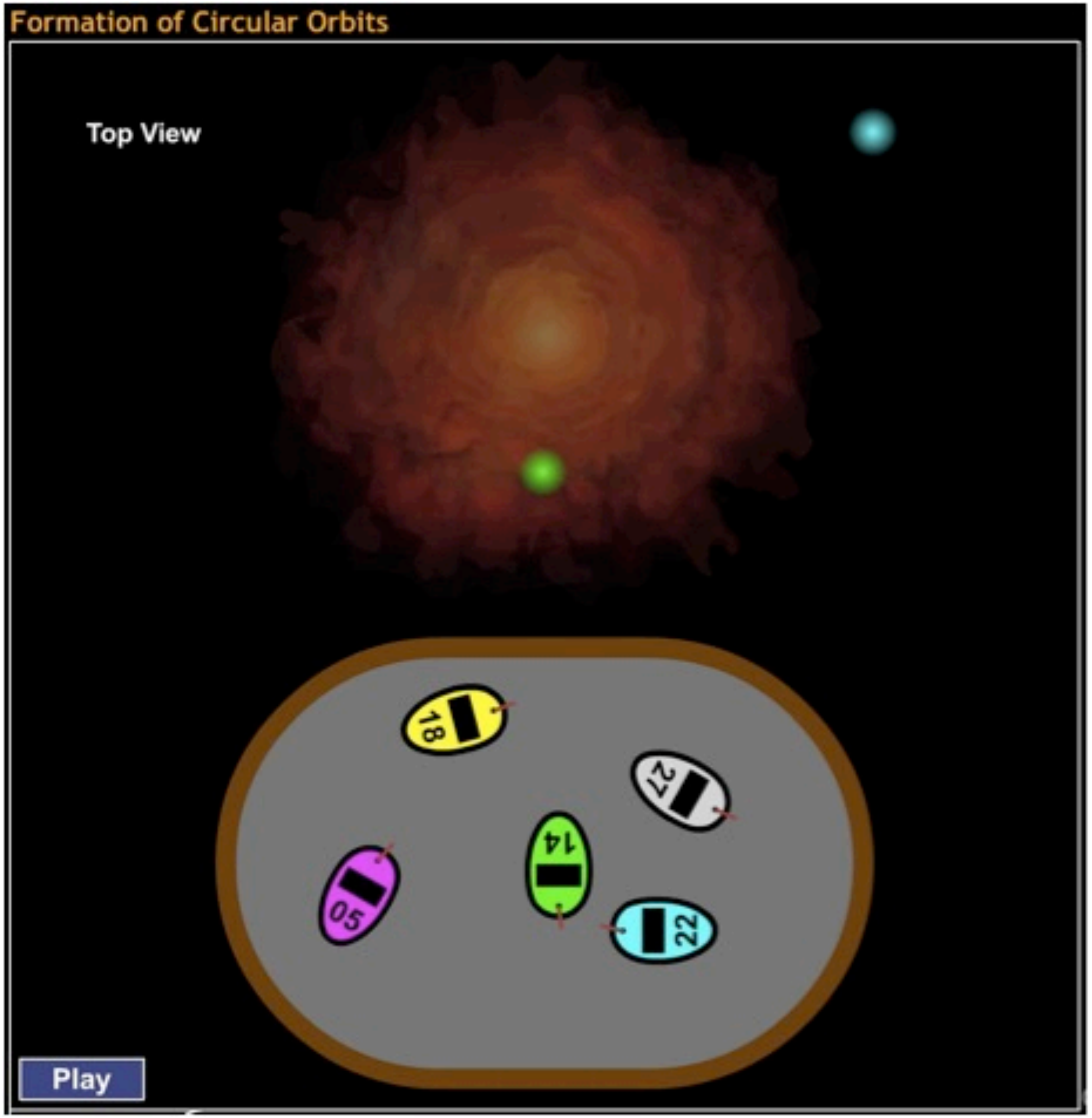
- Rotation of a contracting cloud speeds up for the same reason a skater speeds up as she pulls in her arms.

Flattening



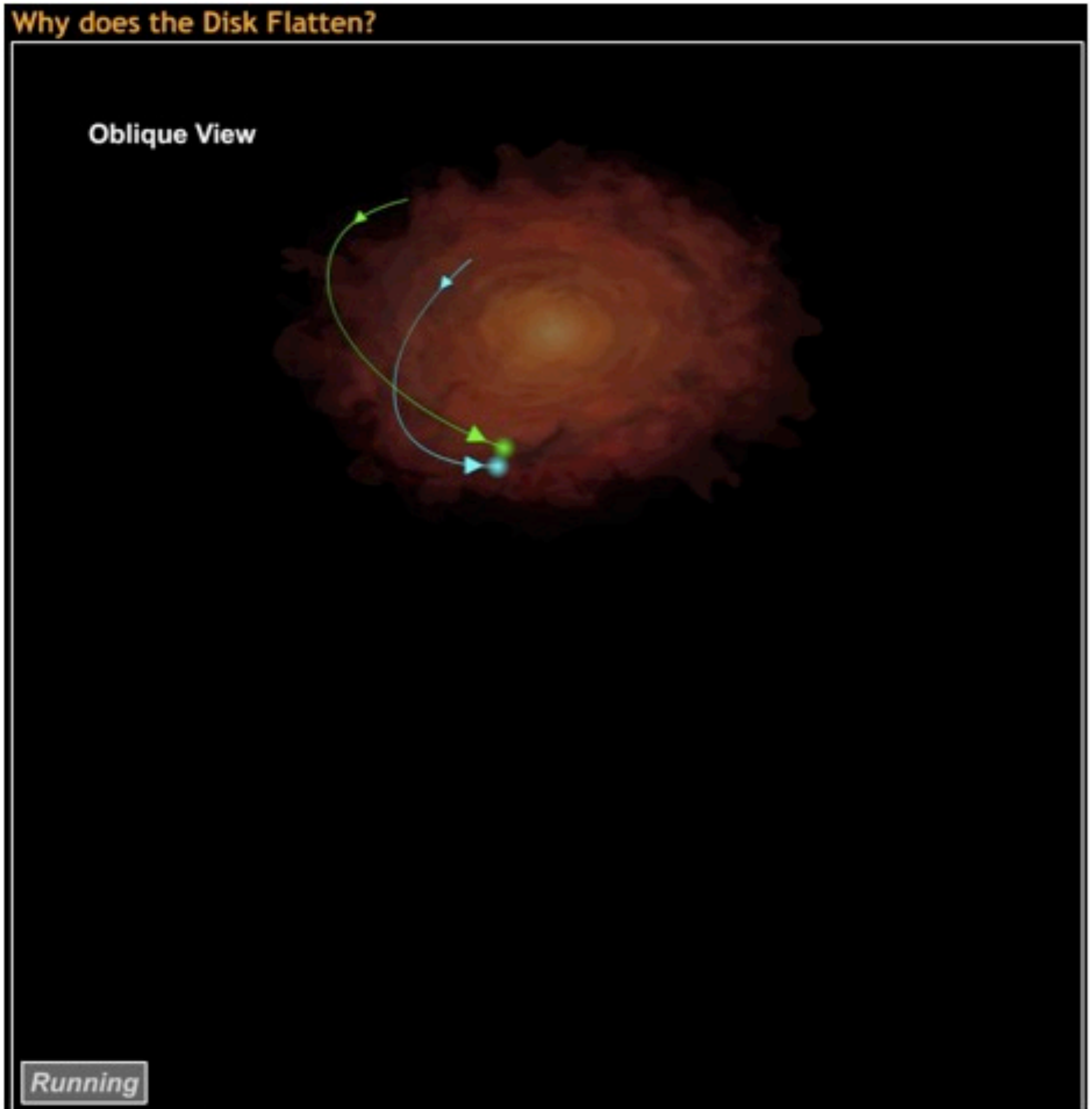
- Collisions between particles in the cloud caused it to flatten into a disk.

Flattening



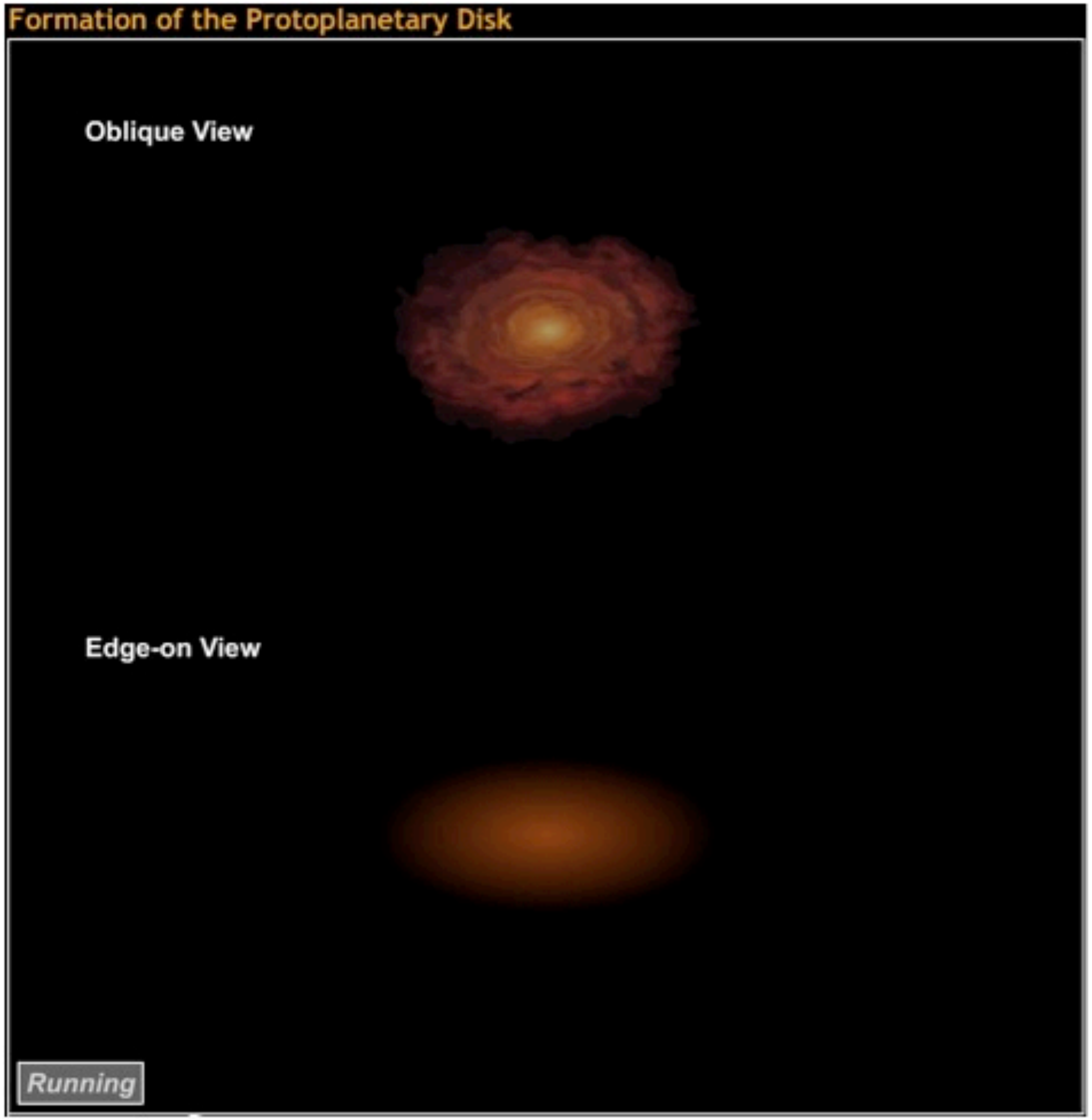
- Collisions between gas particles in cloud gradually reduce random motions.

Flattening



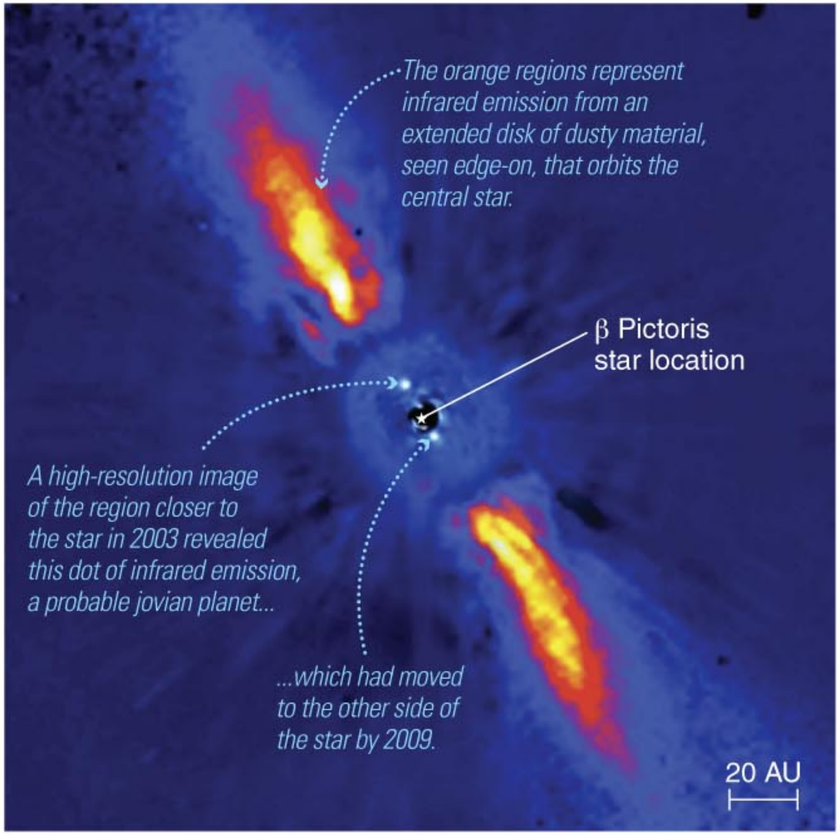
- Collisions between gas particles also reduce up and down motions.

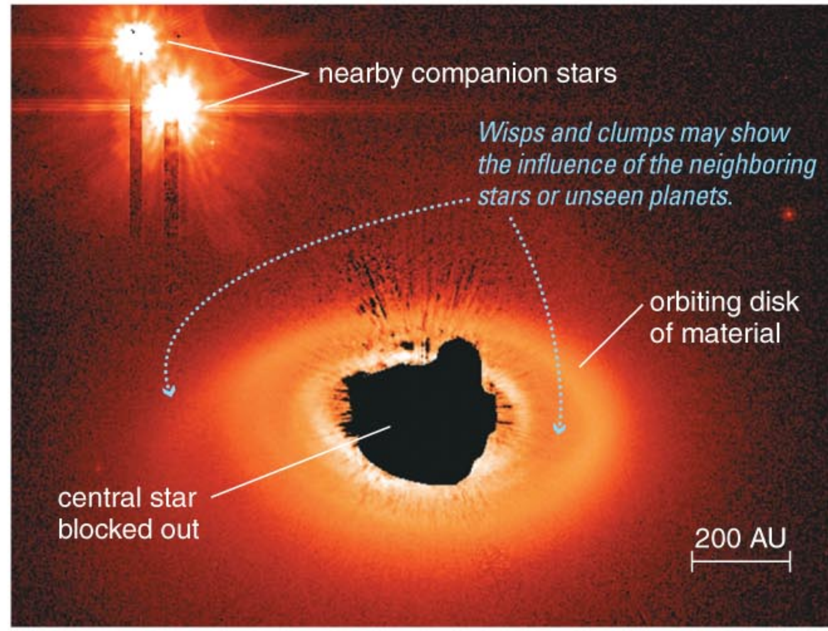
Flattening



- Spinning cloud flattens as it shrinks.

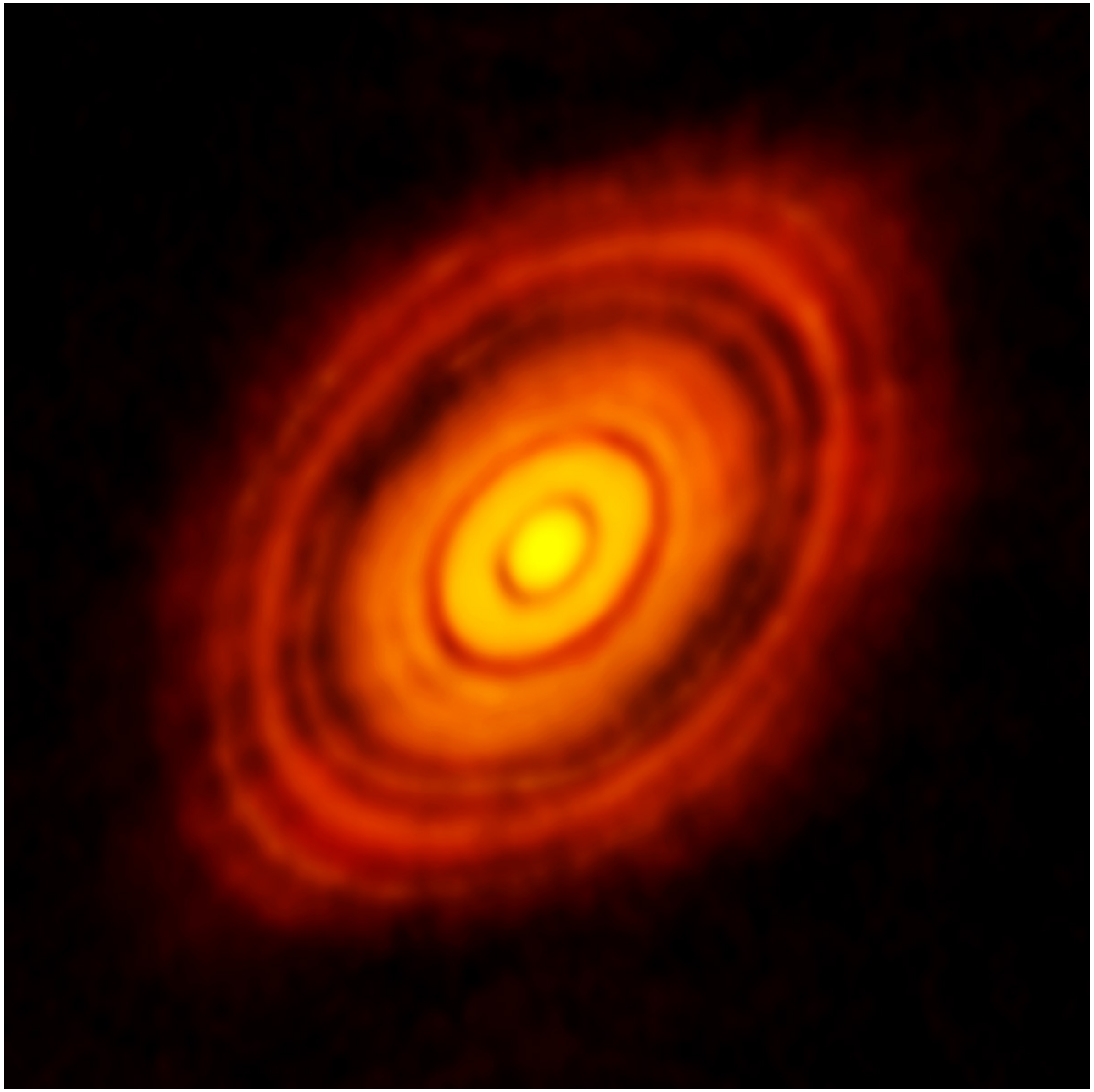
Disks around Other Stars





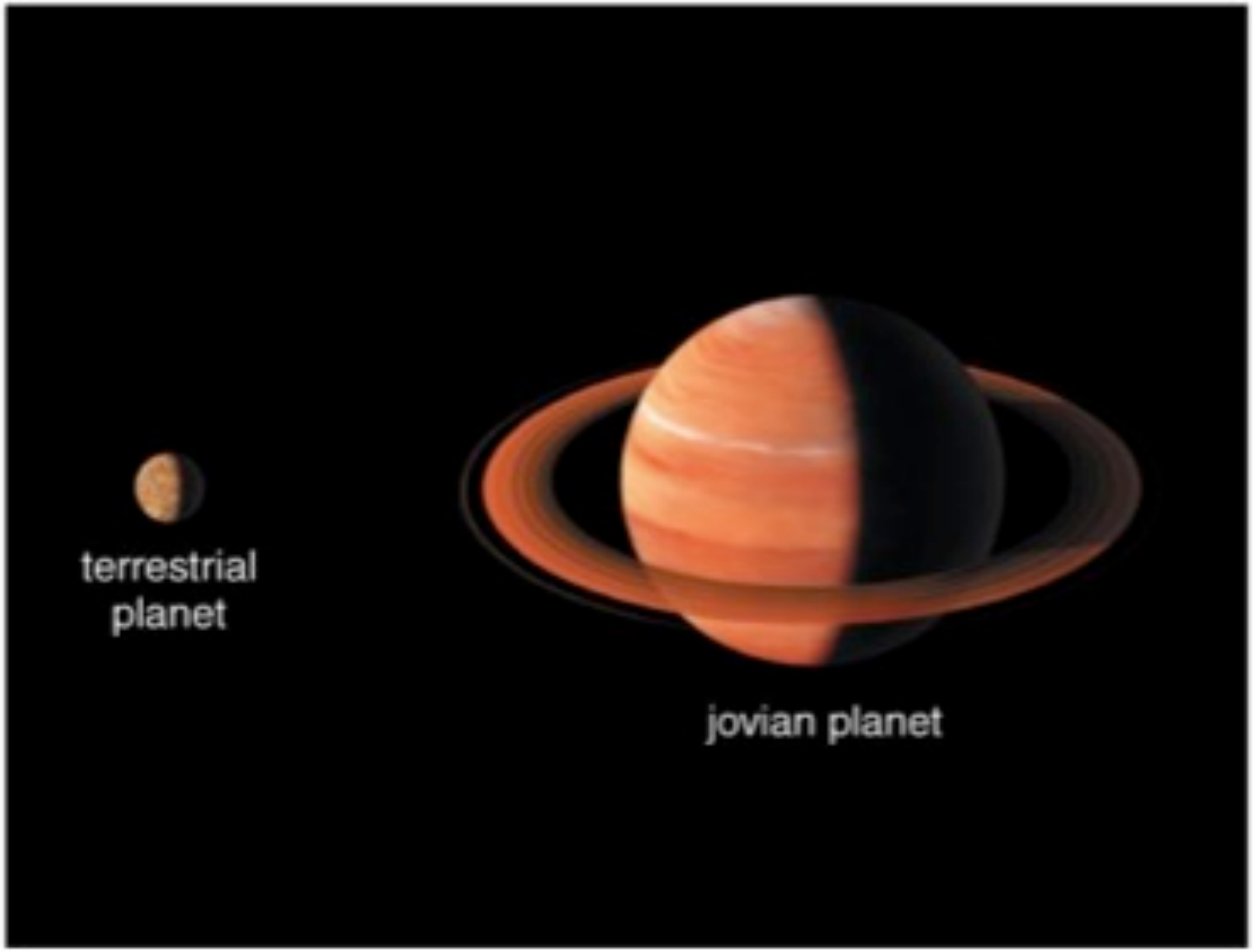
- Observations of disks around other stars support the nebular hypothesis.

Disks around Other Stars

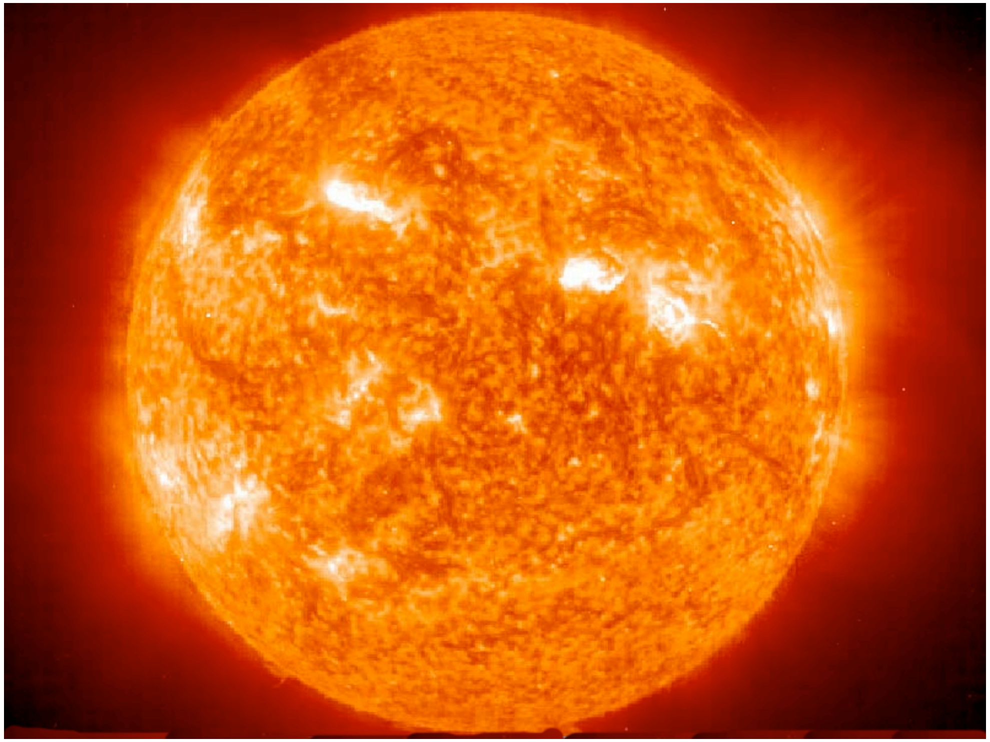


Disk around HL Tau

Why are there two major types of planets?



Composition of the Protoplanetary Disk



70% Hydrogen
28% Helium
2% everything else *(oxygen, nitrogen, carbon, iron, silicon, etc, etc)*

Conservation of Energy

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

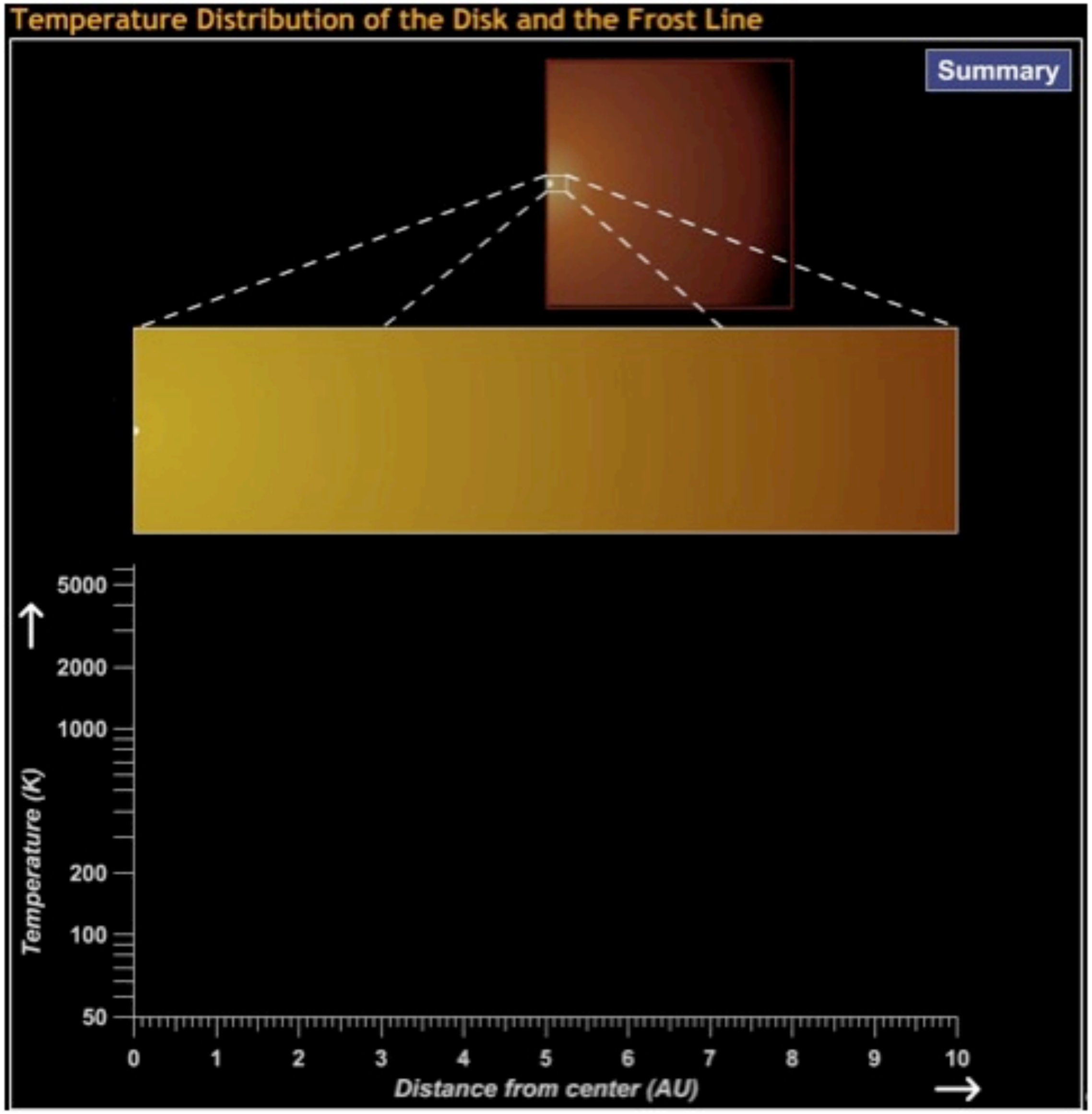
Condensation and Planetary Ingredients

Depending on the temperature, different materials can condense out of the nebula and form solids.

"Ices" →

	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	500–1300 K	0.4%
Metal 	iron, nickel, aluminum	1000–1600 K	0.2%

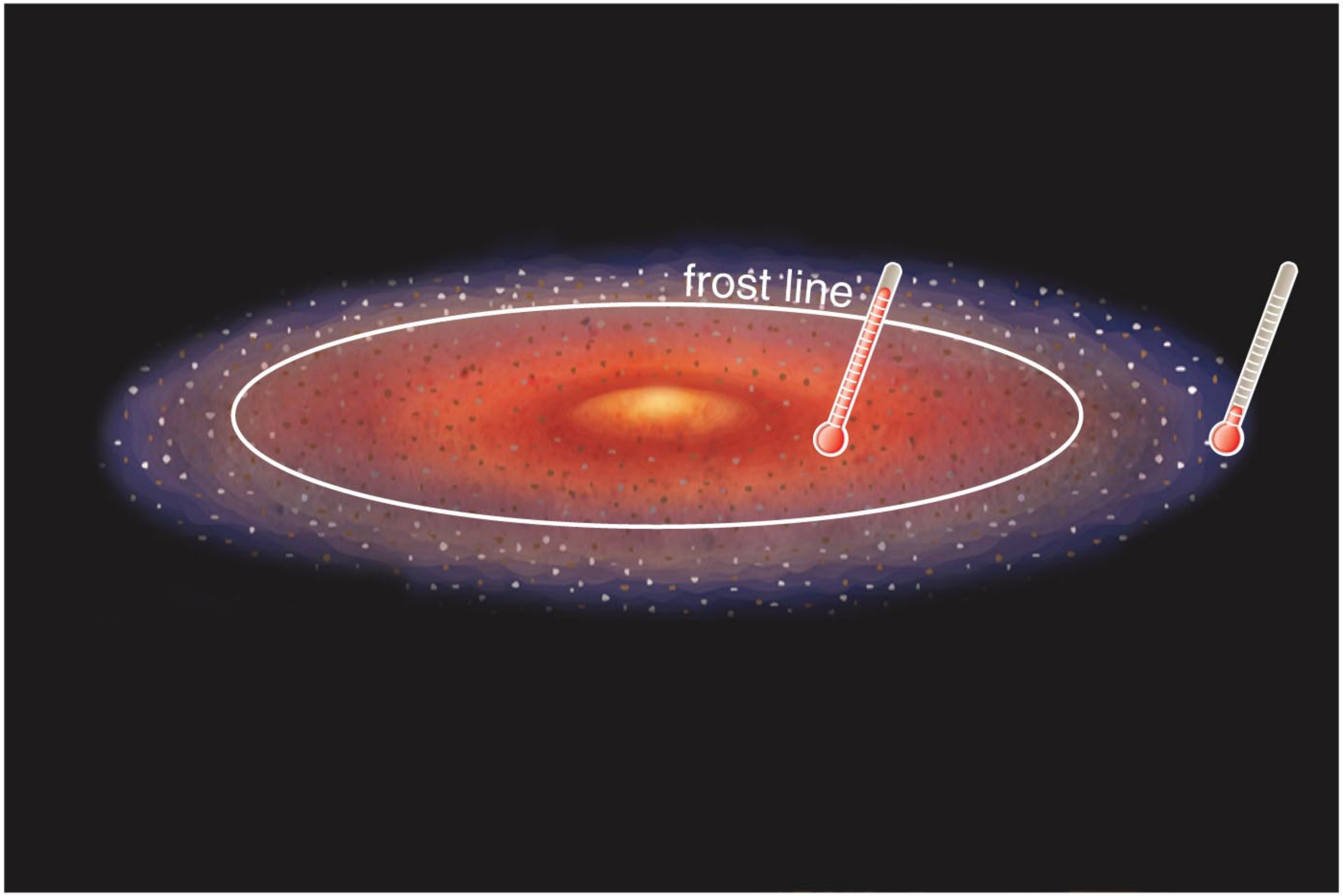
Temperature of Disk



Inner parts of disk are hotter than outer parts. The disk has lots of stuff there, but very little of it can be solid at high temperatures: small, rocky/metal planetesimals.

Outer parts are cooler, easy for hydrogen compounds ("ices") to form: bigger, icy planetesimals

Temperature of Disk

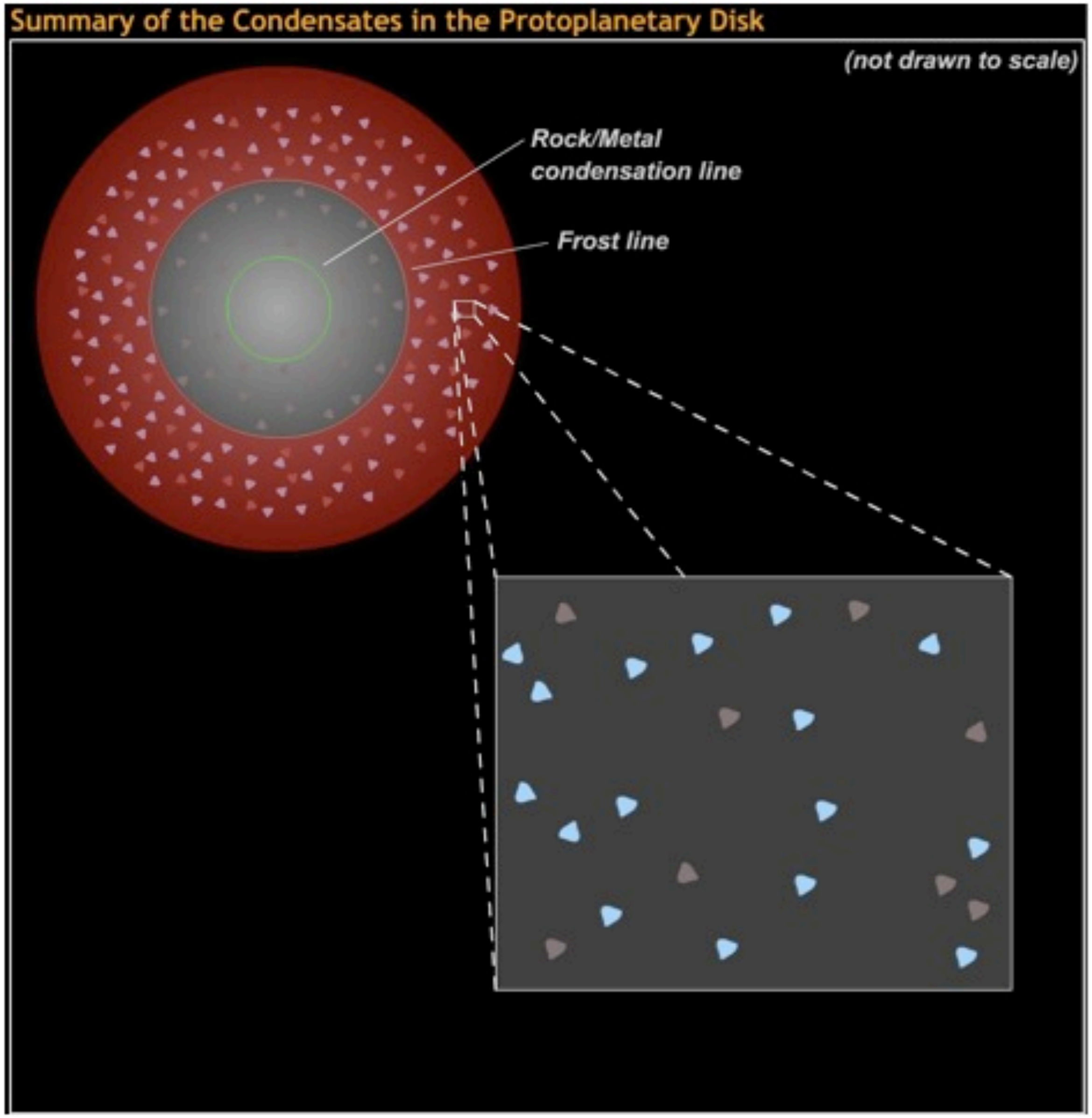


- Inside the ***frost line***: too hot for hydrogen compounds to form ices
- Outside the ***frost line***: cold enough for ices to form

How did the terrestrial planets form?

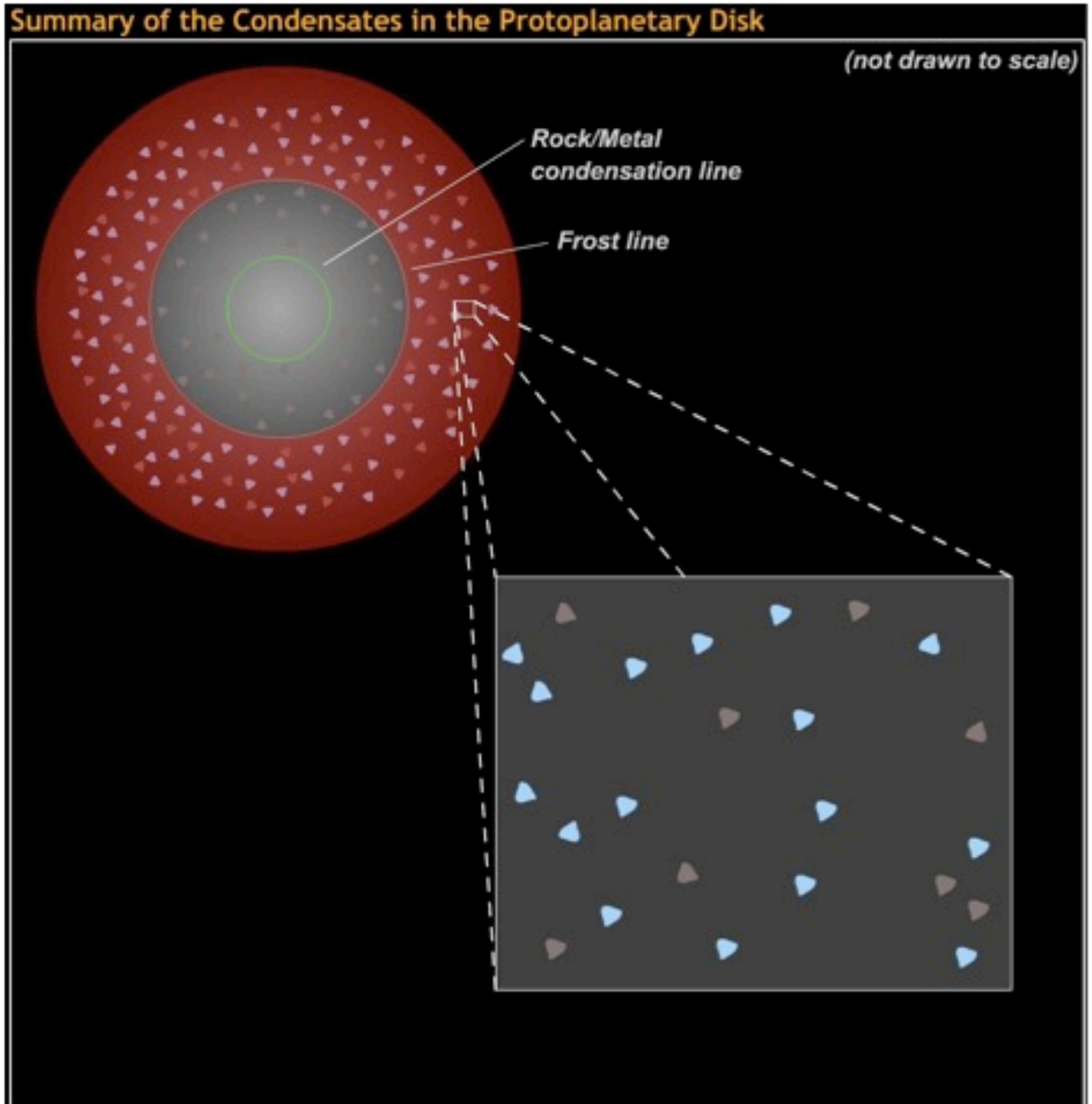
- Small particles of rock and metal were present inside the frost line.
- Planetesimals of rock and metal built up as these particles collided.
- Gravity eventually assembled these planetesimals into terrestrial planets.

How did the terrestrial planets form?



- Tiny solid particles stick to form ***planetesimals.***

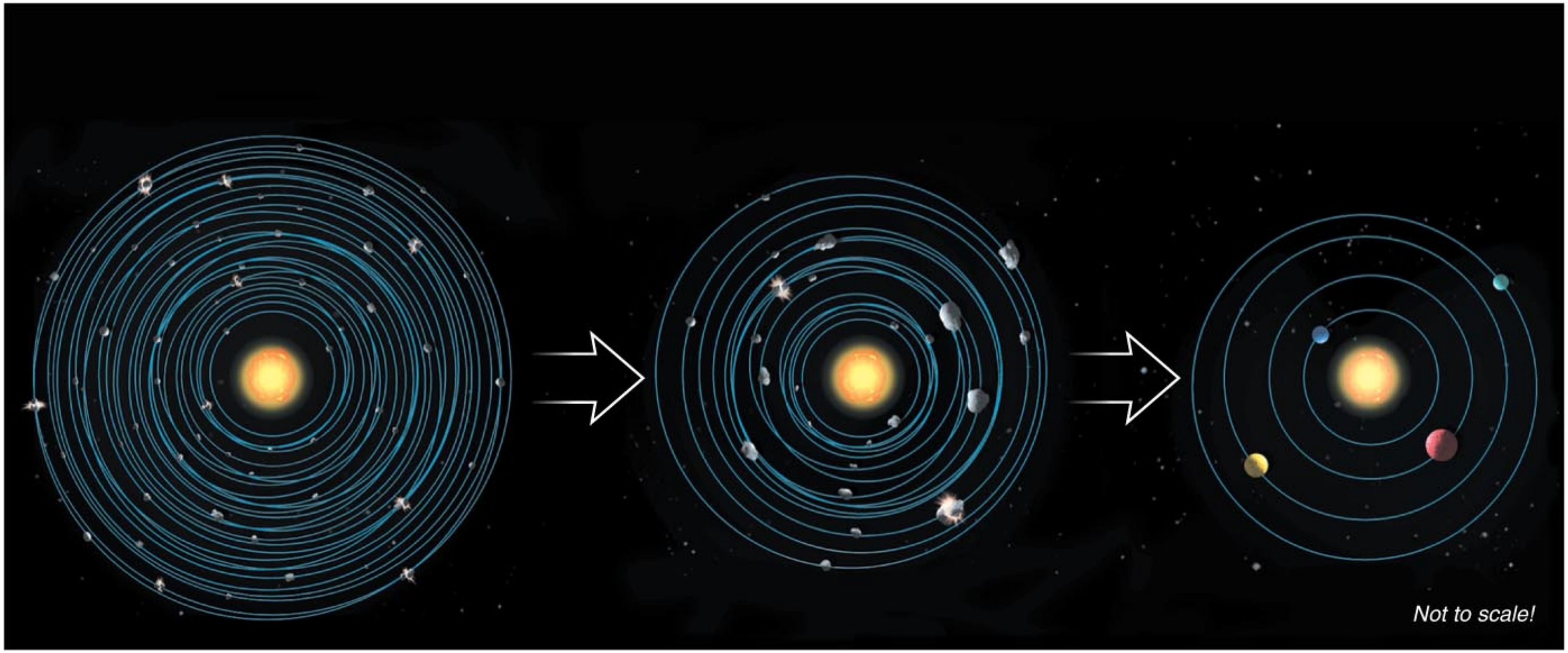
How did the terrestrial planets form?



- Gravity draws ***planetesimals*** together to form planets.

- This process of assembly is called ***accretion.***

Accretion of Planetesimals

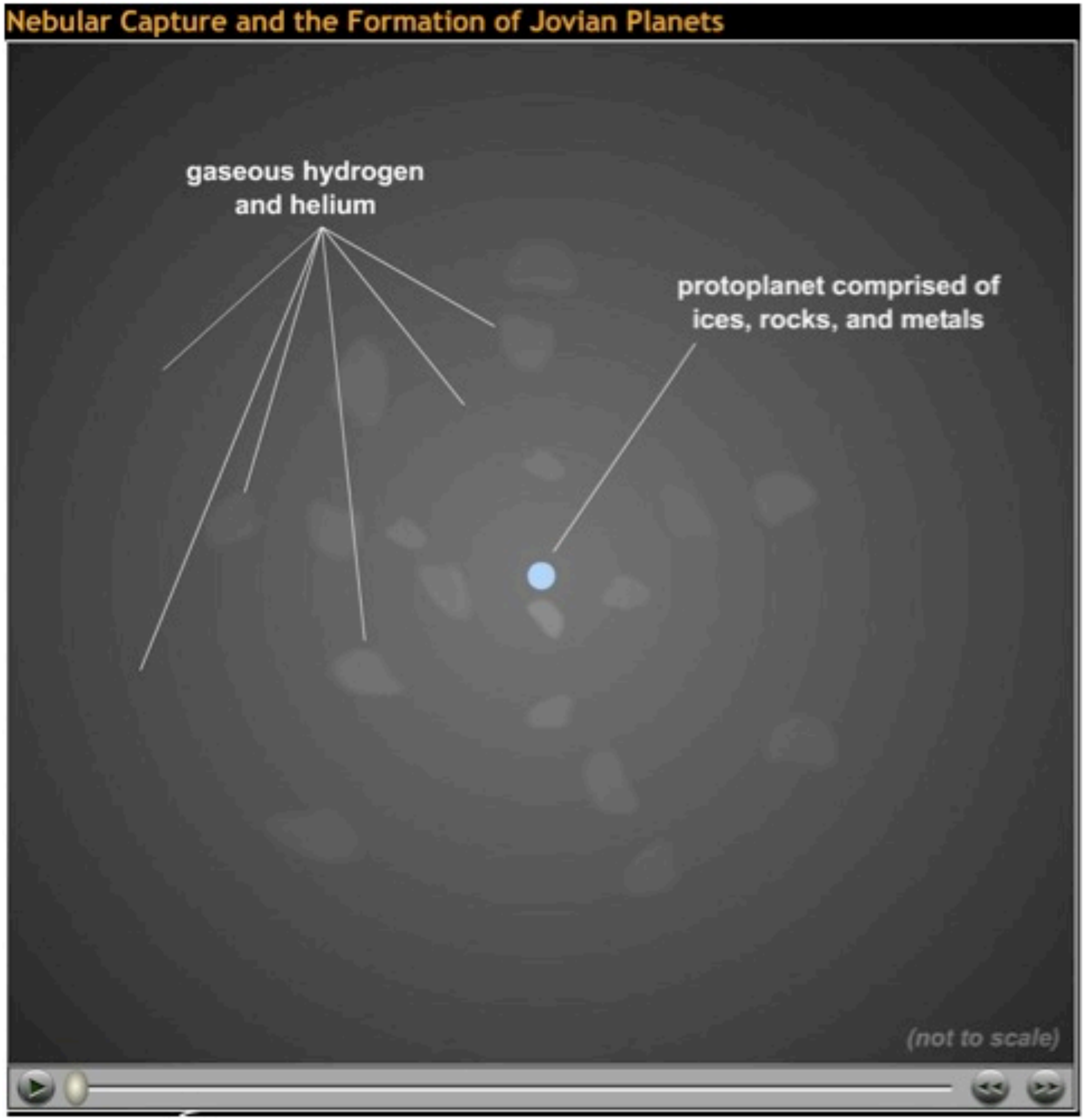


- Many smaller objects collected into just a few large ones.

How did the jovian planets form?

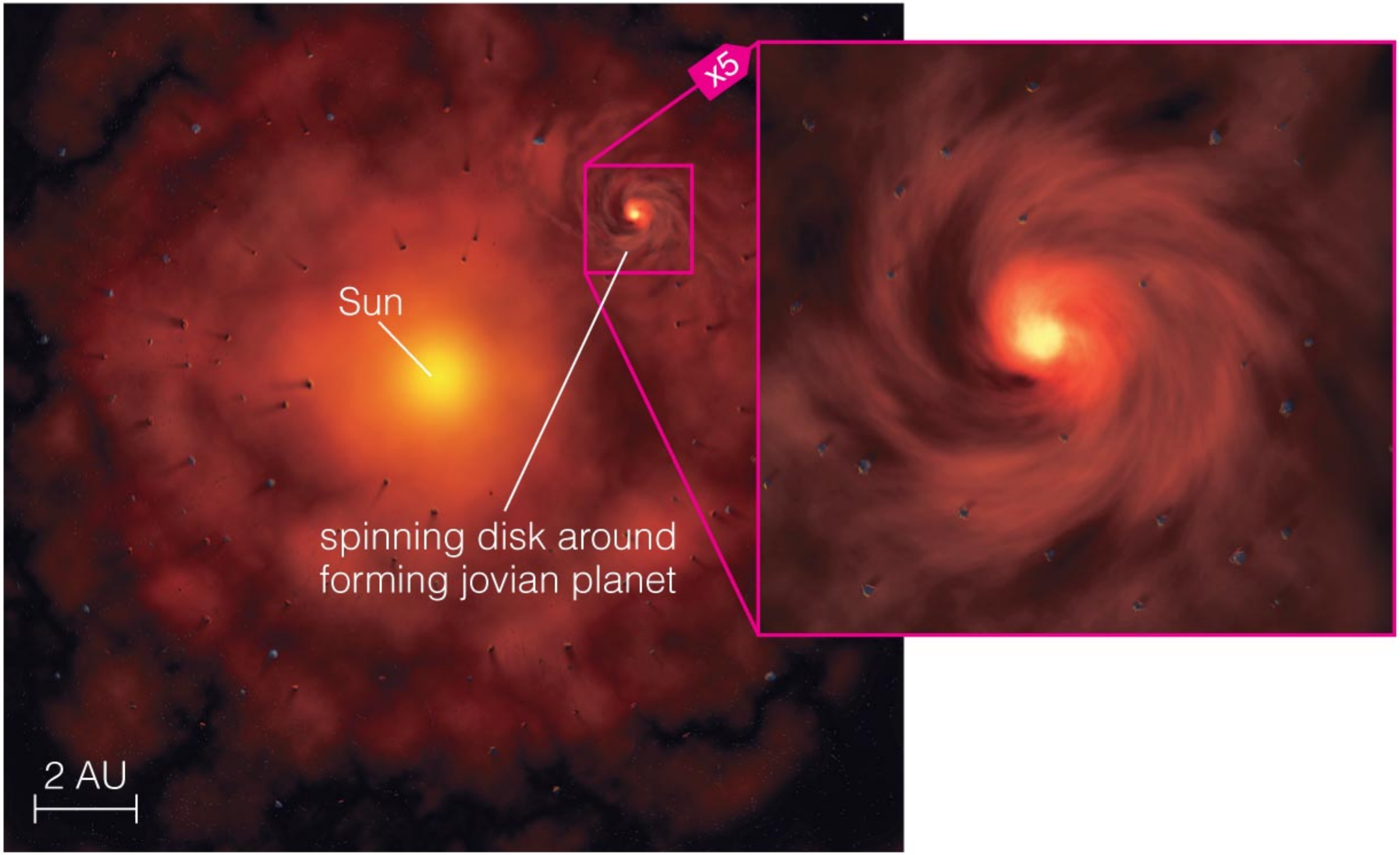
- Ice could also form small particles outside the frost line.
- Larger planetesimals and planets were able to form.
- Gravity of these larger planets was able to draw in surrounding H and He gases.

How did the jovian planets form?



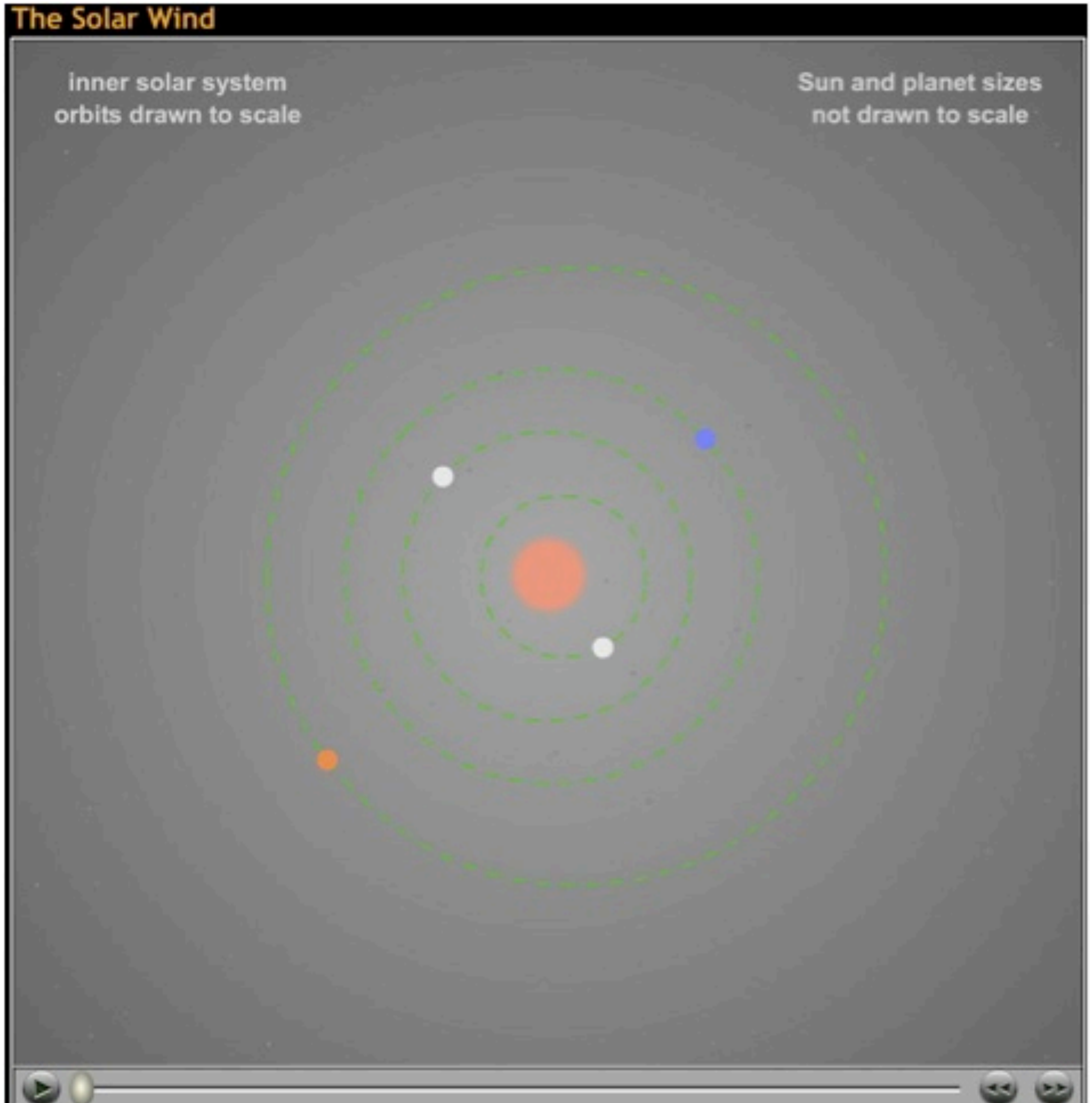
- Gravity of rock and ice in jovian planets draws in H and He gases.

How did the jovian planets form?



- Moons of jovian planets form in miniature disks.

What stopped planet formation?

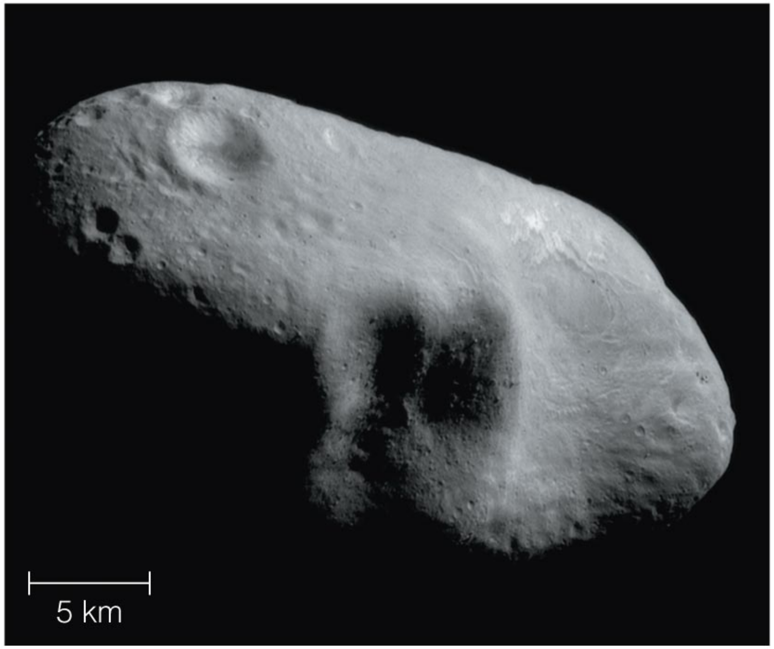


The young Sun developed a strong ***solar wind*** of particles flowing outward from the Sun.

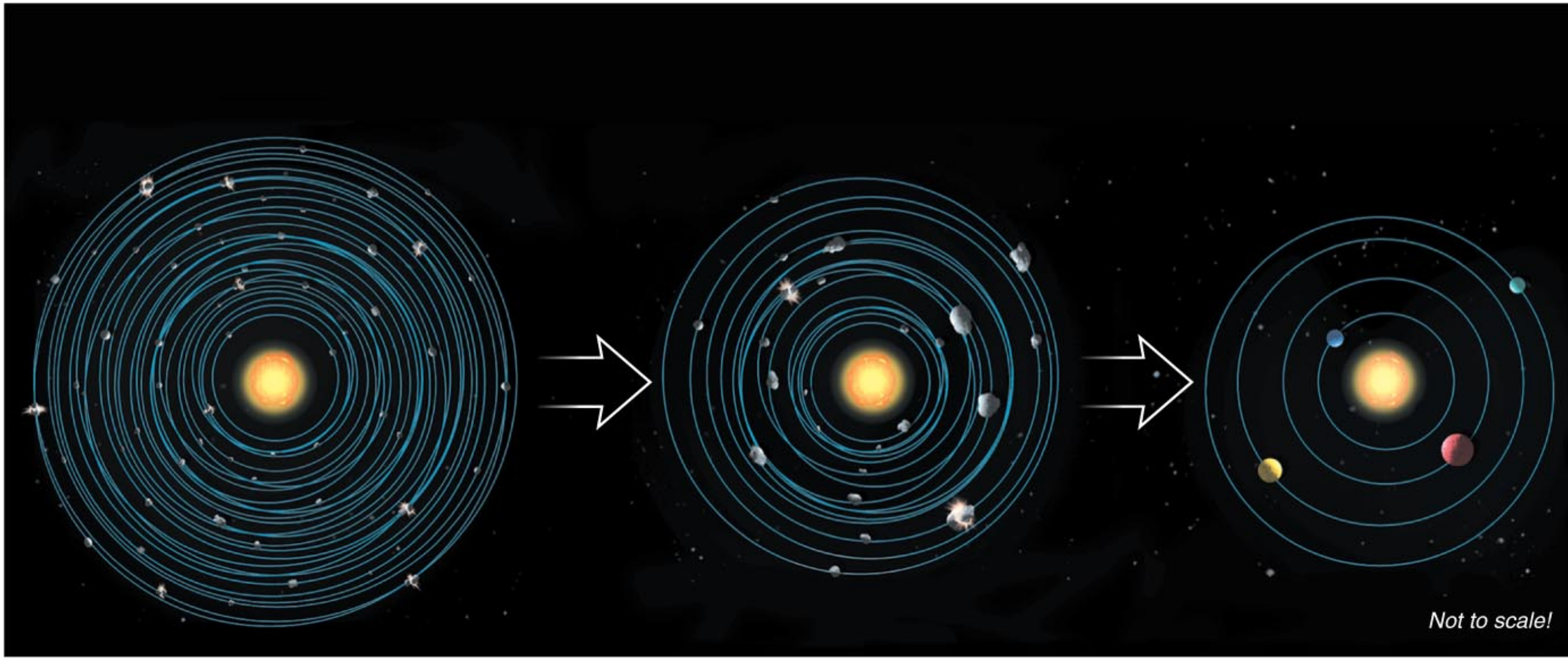
This "wind" blew away the leftover gas in the nebula.

(Solar wind today)

Where did asteroids and comets come from?

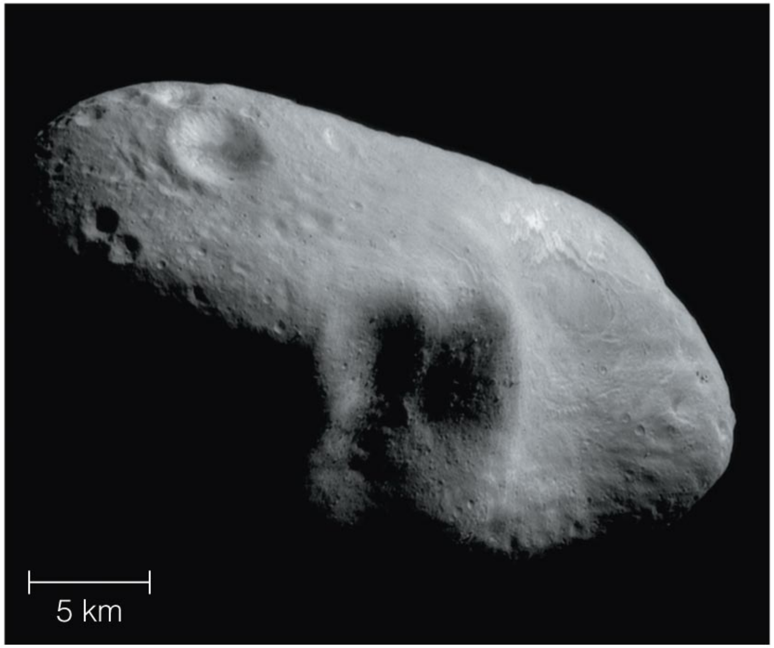


Where did asteroids and comets come from?



Leftovers from the accretion process

Asteroids



Inside the “frost line”, small rocky planetesimals exist as asteroids.

Jupiter’s gravitational tugs kept them from accreting into a bigger planet, so they remain in the asteroid belt.

Comets

Beyond the “frost line”, lots of icy planetesimals remain. These are the comet nuclei.

Comet nuclei beyond Neptune’s orbit remain in the flattened Kuiper Belt.

Comet nuclei originally near the orbits of the big planets (Jupiter, Saturn, Uranus, and Neptune) got kicked out into the far distant Oort Cloud by those planets’ gravity.