Cosmic Samples and the Origin of the Solar System

Chapter 14

Meteors

- Meteors are small particles that burn up in the Earth's atmosphere. They are usually less than 1g in mass, the size of a pea.
- We only see such small things because they are moving so fast they create enough friction in the atmosphere to vaporize them. Thus their other common name 'shooting stars'.
- An object the size of a golf ball will make a much bigger streak and is called a 'fireball'. An object the size of a bowling bowl might make it to the ground.


A fireball seen above the
ALMA array in Chile.

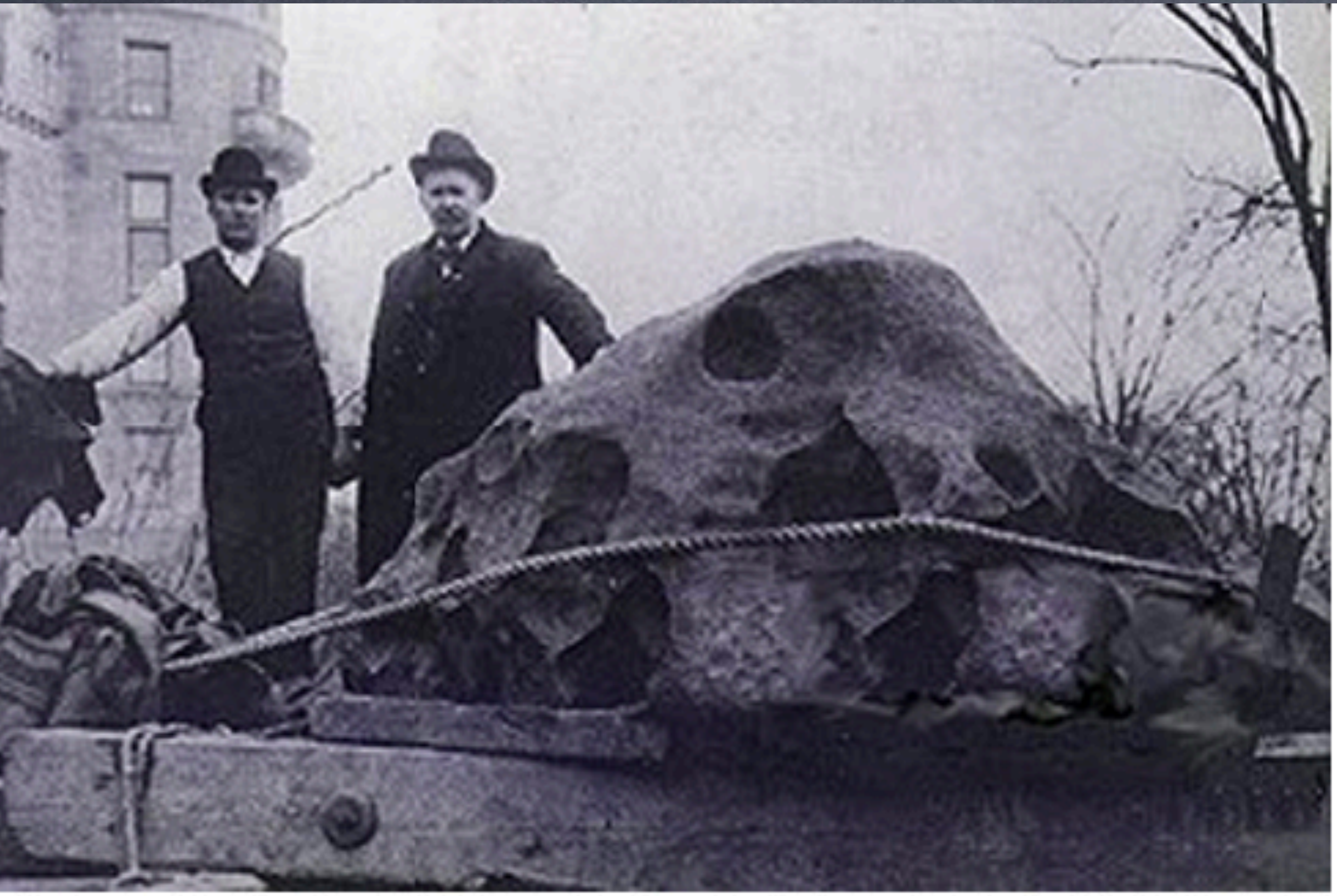
Meteor Showers

- Meteor showers occur when the Earth passes through the path of a comet. The comet leaves behind a trail of dust and pebbles that become meteors when they enter the Earth's atmosphere.
- During a meteor shower you may see hundreds per hour instead of the normal few per hour on most nights. The meteors also look like they are coming from a single point during a shower, instead of every direction.

Meteorites

- Meteorites are objects that survive the fall through the Earth's atmosphere. Thus they start off larger, but loose much of their mass to friction and may break apart, so can be very small when found on the ground.
- Most meteorites are found by people thousands of years after they fell to Earth. Many are found in Antartica where it is easier to identify them.

A 15 ton meteorite 'found' in Oregon and now in the American Museum of Natural History in New York City.



Meteorites are classified in 3 general types: iron, stony and stony-iron. The ones with iron are easiest to identify because pure iron is very rare on Earth's surface.

Almost all meteorites have ages of 4.5 billion years. Meteorites are as old as the solar system.

(a) (b) (c)

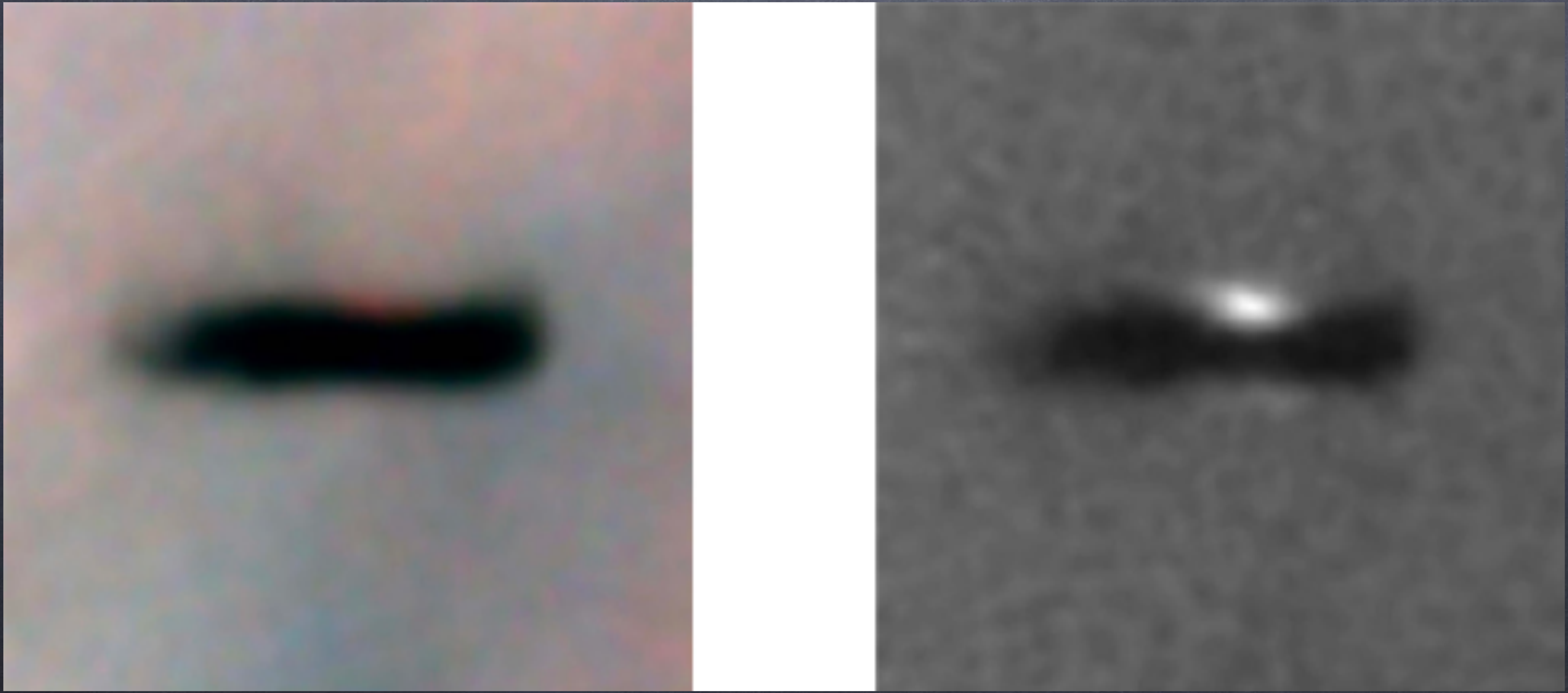
Formation of the Solar System

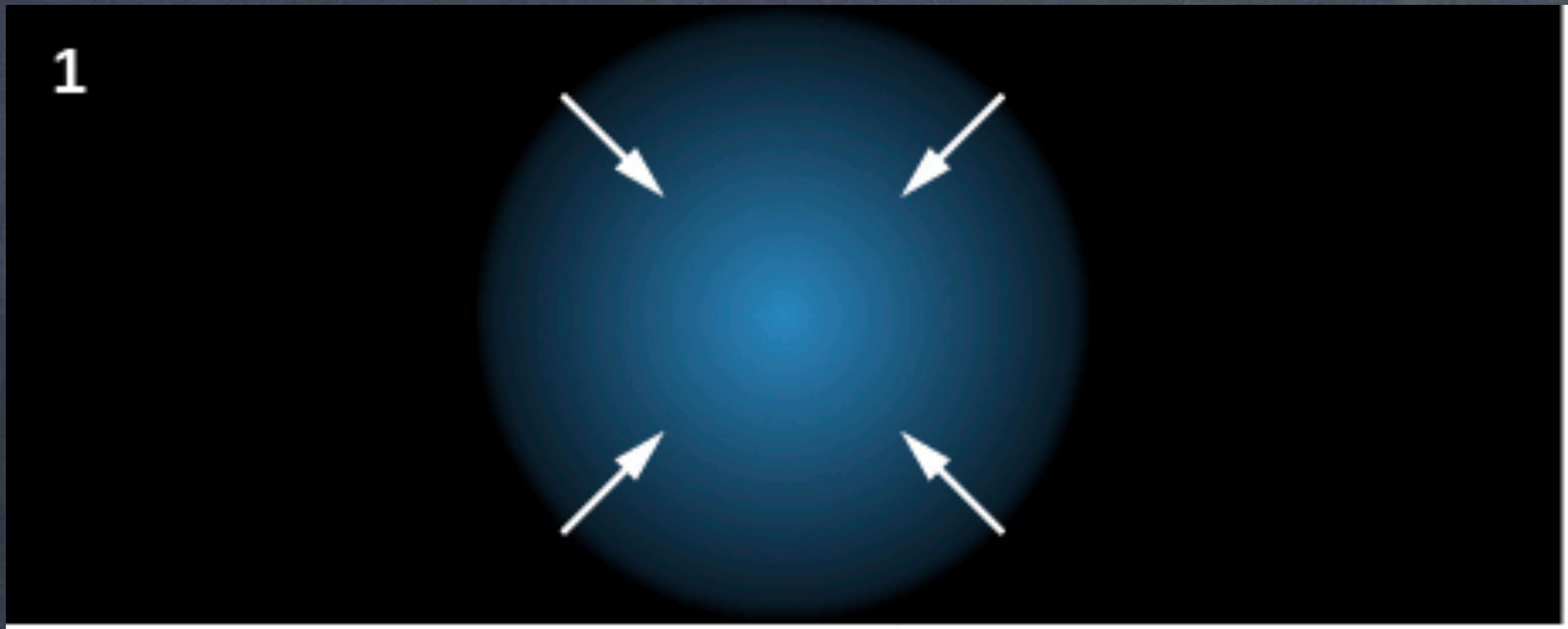
- Comets, astroids and meteorites are all remnants from the formation of the solar system. From them and observations of the sun and planets we can create a model of how the solar system formed.
- This model will need to explain a few important observations:
  - The sun rotates and most other object orbit in the same direction in a thin plane.
  - The solar system is differentiated with metal and rock near the Sun and ice and gas farther away.
  - The oldest objects are 4.5 billion years old.

Solar Nebula

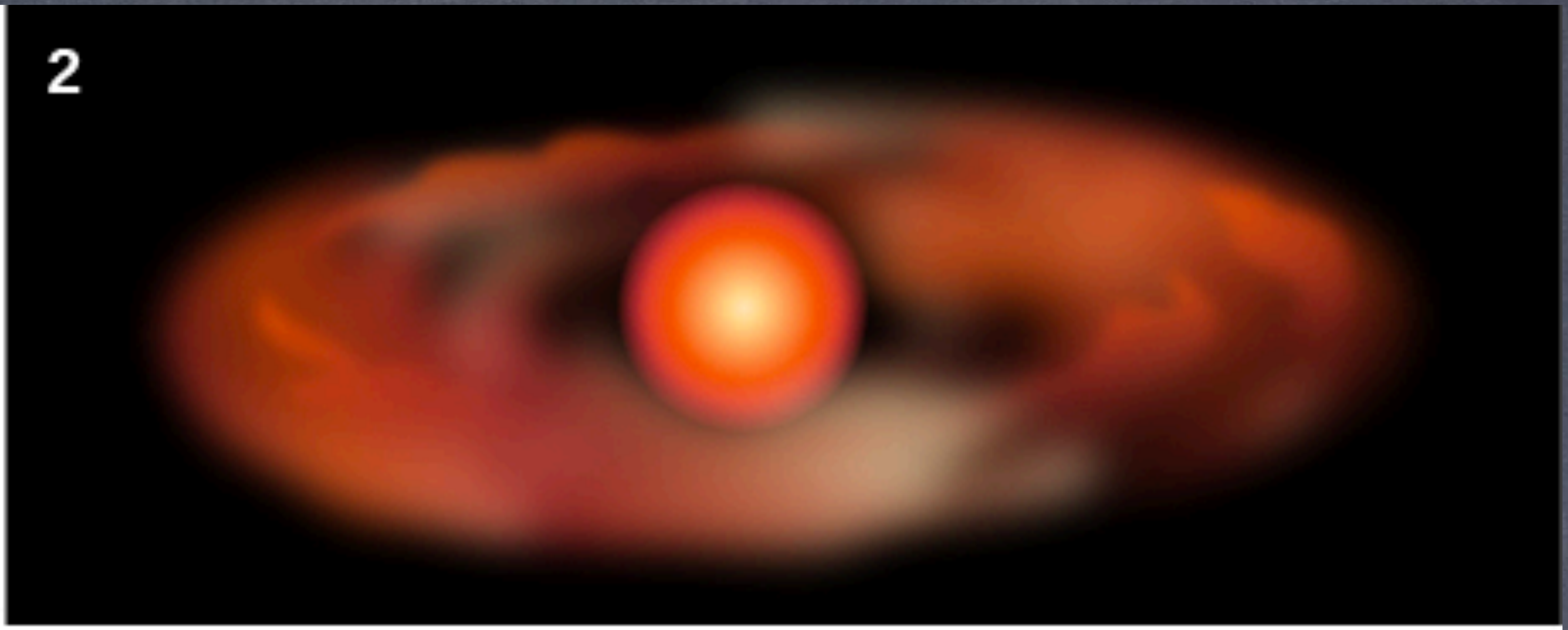
- The current model starts with a giant ball of gas and dust called the solar nebula which contracts to form the solar system.
- As it contracts, angular momentum conservation, causes it to form a thin disk with a protostar in the center. This disk shape explains the orbits of the planets and was suggest by Kant.
- The temperature in the disk decreases with distance from the Sun, so that near the sun only metals and rocks can exist as liquids and solids, while further out water, carbon dioxide and ammonia can all be liquid or solid. This causes the chemical differentiation in the solar system.

Protoplanetary disks in the Orion Nebula

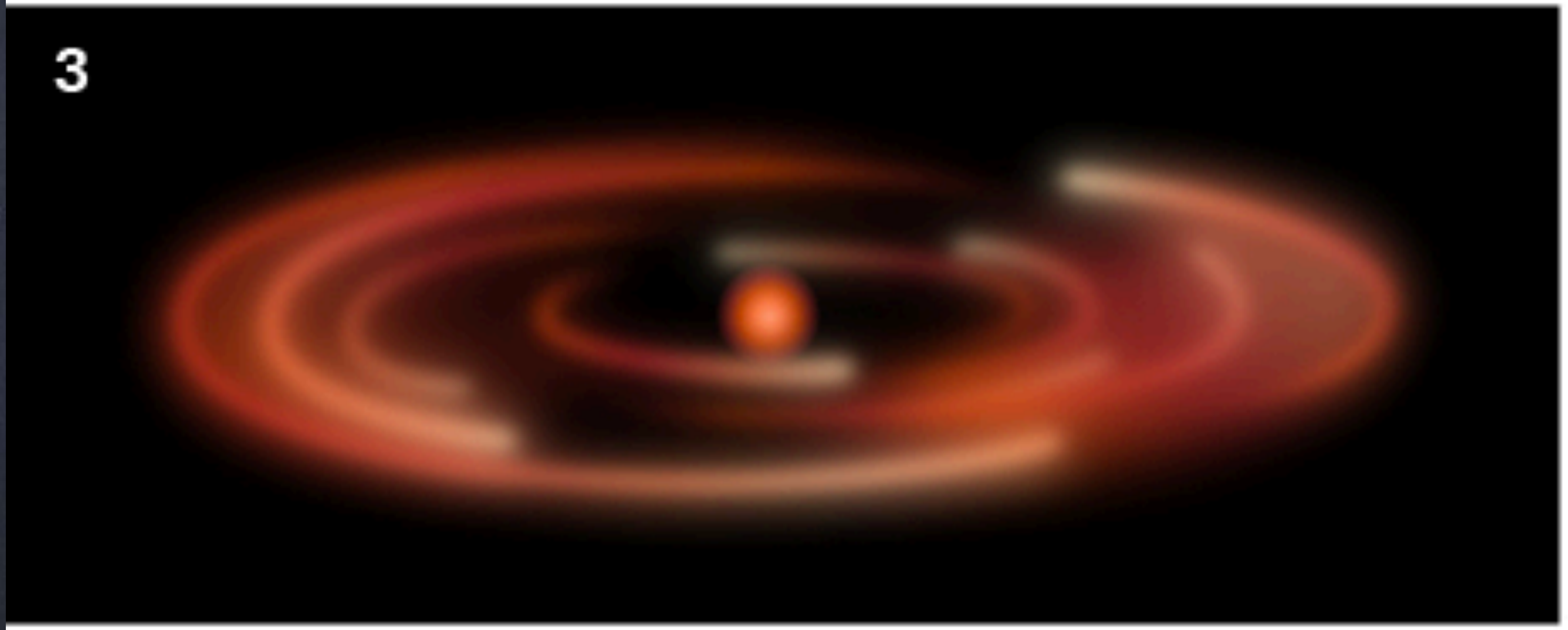




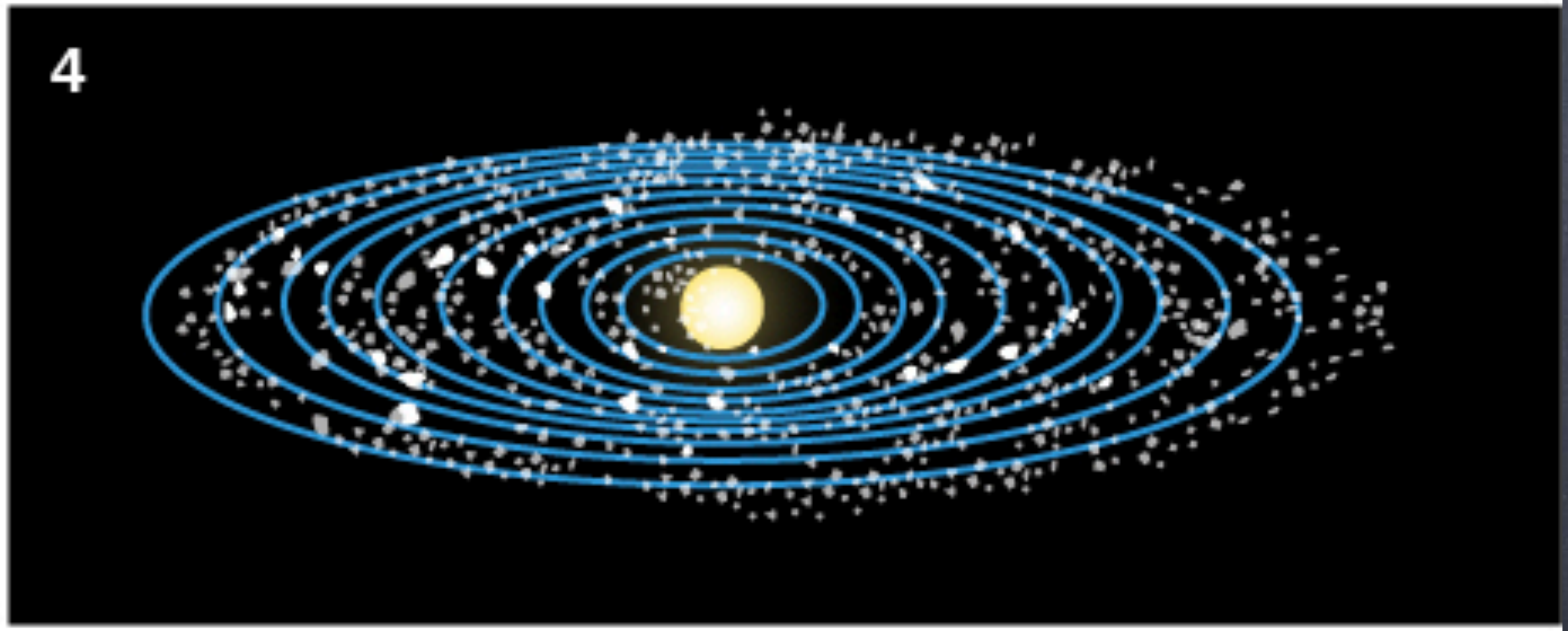
The solar nebula contracts.



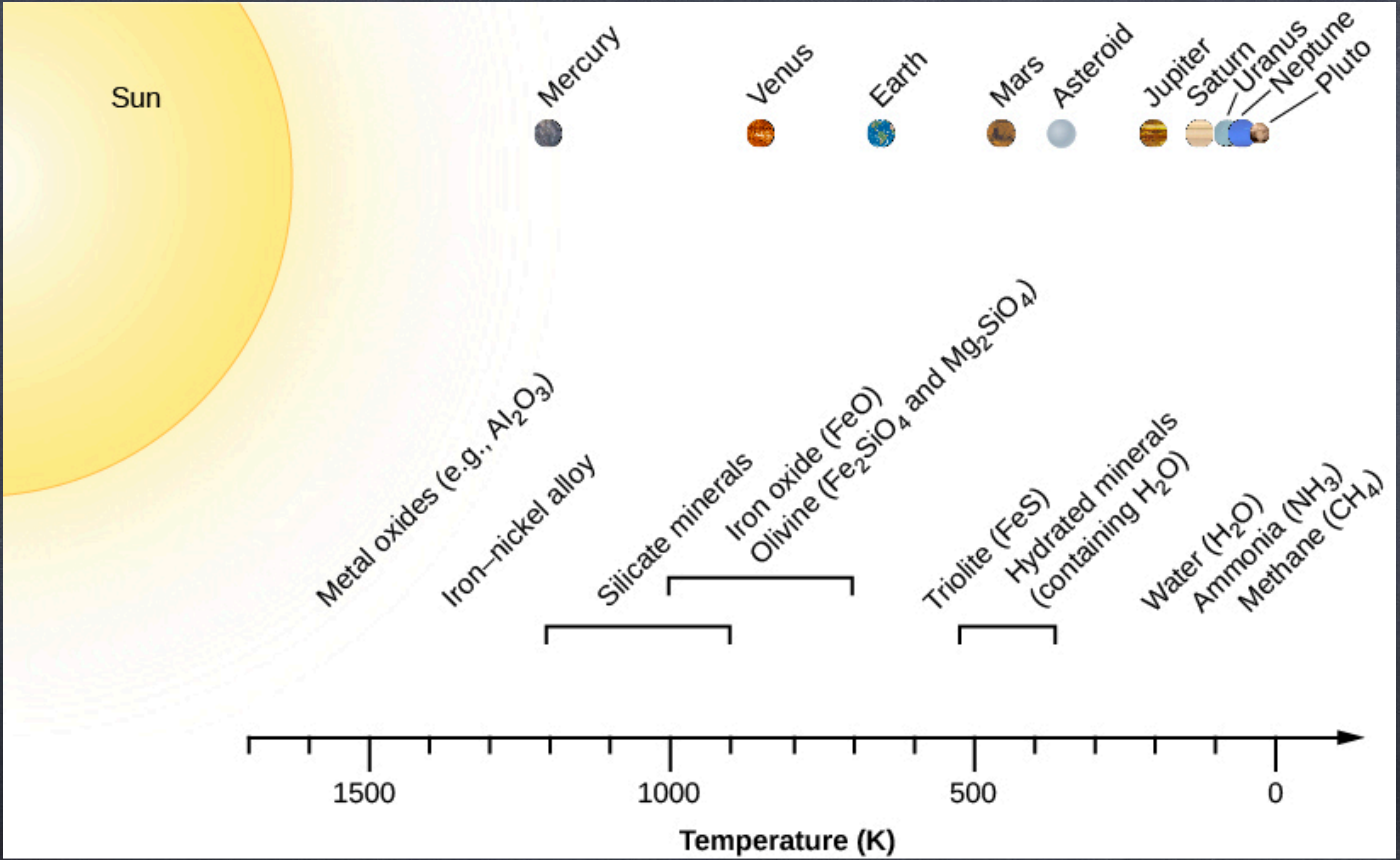
As the nebula shrinks, its motion causes it to flatten.



The nebula is a disk of matter with a concentration near the center.



Formation of the protosun. Solid particles condense as the nebula cools, giving rise to the planetesimals, which are the building blocks of the planets.


Sun
Mercury
Venus
Earth
Mars
Asteroid
Jupiter
Saturn
Uranus
Neptune
Pluto
Metal oxides (e.g., Al_2O_3)
Iron–nickel alloy
Silicate minerals
Iron oxide (FeO)
Olivine (Fe_2SiO_4 and Mg_2SiO_4)
Triolite (FeS)
Hydrated minerals (containing H_2O)
Water (H_2O)
Ammonia (NH_3)
Methane (CH_4)
1500
1000
500
0
Temperature (K)

Formation of Terrestrial Planets

- Grains of rock and metal stick together forming bigger and bigger structures until they form planetesimals, objects around 10km in diameter.
- These planetesimals grow into a few protoplanets, though many remain and become comets and astroids.
- The protoplanets continue to grow by accretion of planetesimals until there are few left. The era of meteor bombardment comes to and end. All these impacts heat the planets so that they differentiate with the metals sinking to the centers.

Formation of Giant Planets

- The same thing happens in the outer solar system, except now also ices are part of these planetesimals so they grow much bigger.
- These protoplanets grew so big that they are able to hold onto hydrogen and helium with their gravity. The addition of gas from the nebula explains why the giant planets have compositions like the sun, as the nebula has the same composition as the sun.

Further Evolution

- At this point there is still lots of planetesimals and other debris. Much of the icy bodies are flung out of the solar system into the Oort cloud, where they can someday become long period comets if perturbed.
- Some icy dwarf planets and possible short period comets are ejected to the Kuiper belt.
- Impacts between protoplanets occur creating unusual features like Earth's moon, Venus's slow-retrograde rotation and Uranus's 98° tilt.
- Icy planetismals striking the inner planets may have created oceans on Venus, Earth and Mars.

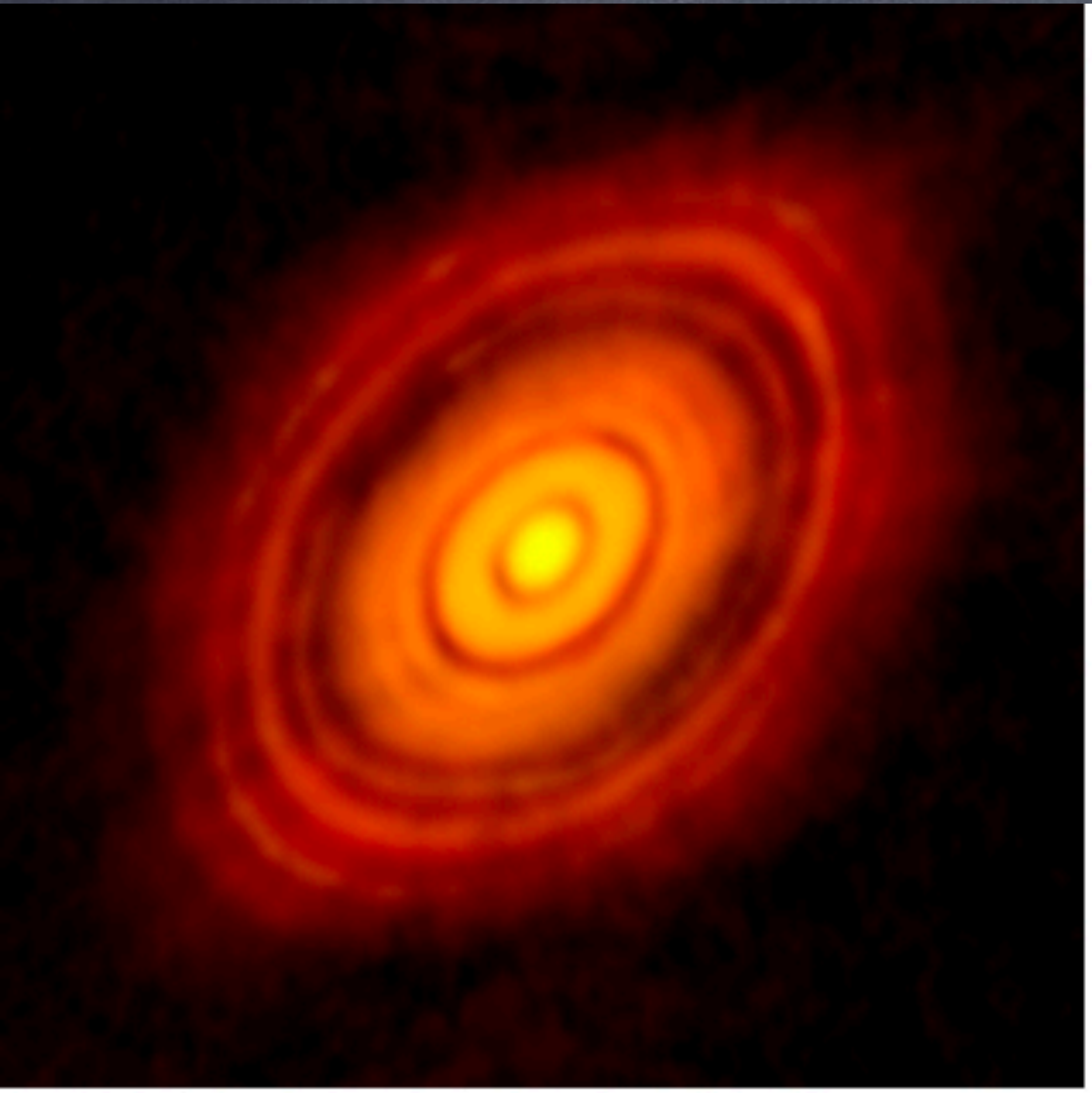
Other Planetary Systems

- We can test our ideas about solar system formation by looking at other solar systems. This gives the advantage of being about to look at solar systems at other points in their history.
- However, they are also much farther away and much harder to see. Very few other solar systems have been directly imaged, we mostly have to infer planetary properties indirectly.

Protoplanetary disks are one of the few things that can be directly imaged.

Image of protoplanetary disk taken by ALMA.

Simulation of planet forming in a planetary nebula

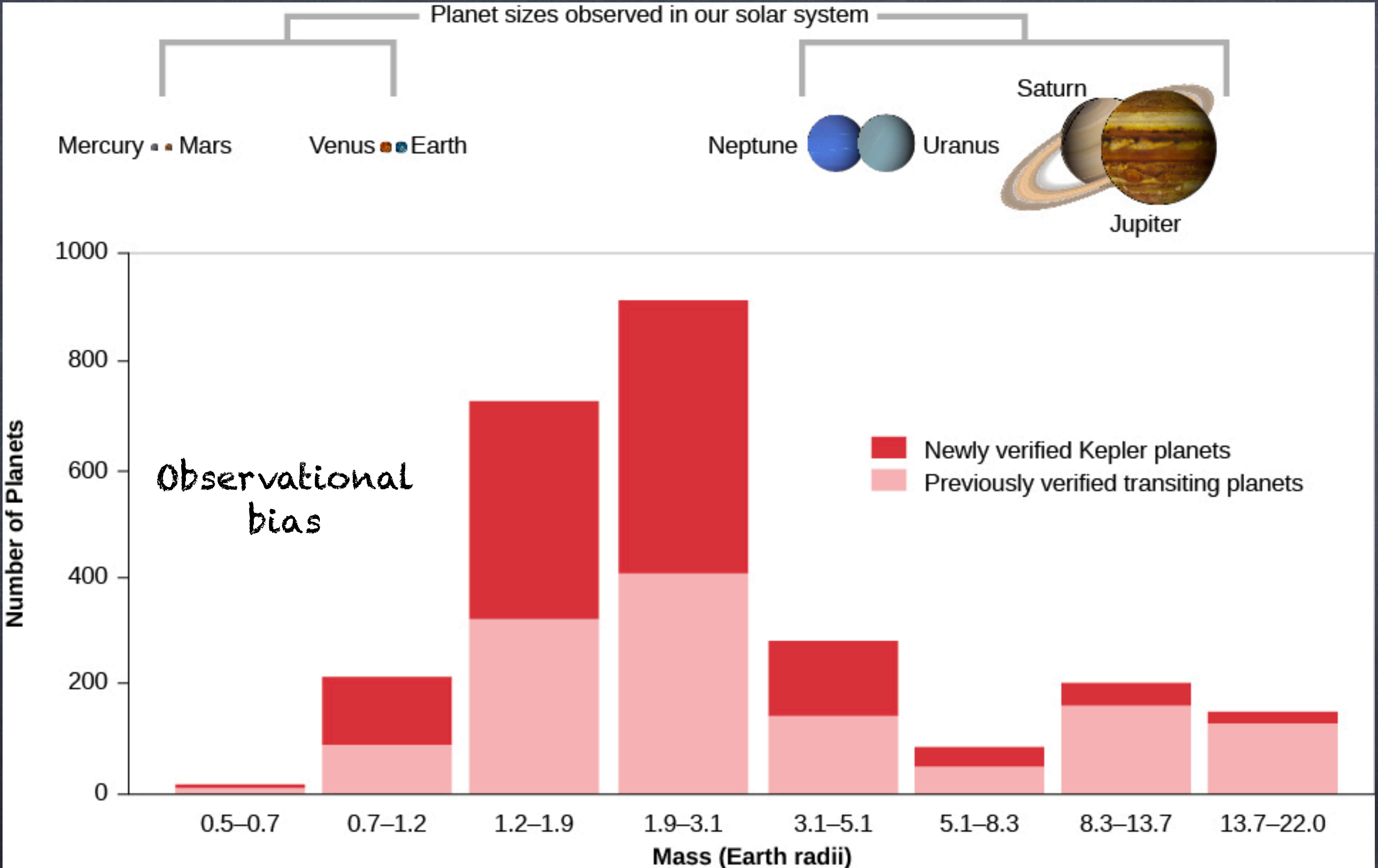


(a)

(b)

Detecting Exoplanets

- Exoplanets (planets around other stars) are mostly found using two methods:
  - radial velocity method - the slight change in the stars velocity as the planet orbits it can be measured.
  - planetary transit method - the slight dimming of a star as a planet transits in front of it can be detected.



Planet sizes observed in our solar system
Mercury
Mars
Venus
Earth
Neptune
Uranus
Saturn
Jupiter
1000
800
600
400
200
0
Number of Planets
Observational bias
Newly verified Kepler planets
Previously verified transiting planets
0.5–0.7
0.7–1.2
1.2–1.9
1.9–3.1
3.1–5.1
5.1–8.3
8.3–13.7
13.7–22.0
Mass (Earth radii)

Comparison to other Solar Systems

- Detection of extrasolar planets are highly biased because it is easier to see bigger planets with short periods.
- We have found many things that are not in our solar system:
  - hot jupiters - giant planets as close as Mercury to their stars
  - water planets - planets 2 to 5 times as massive as Earth, but to hot to be ice. Imagine Uranus or Neptune without that gas.
- Wether this means our current model is wrong in some aspects or just not diverse enough is unclear.