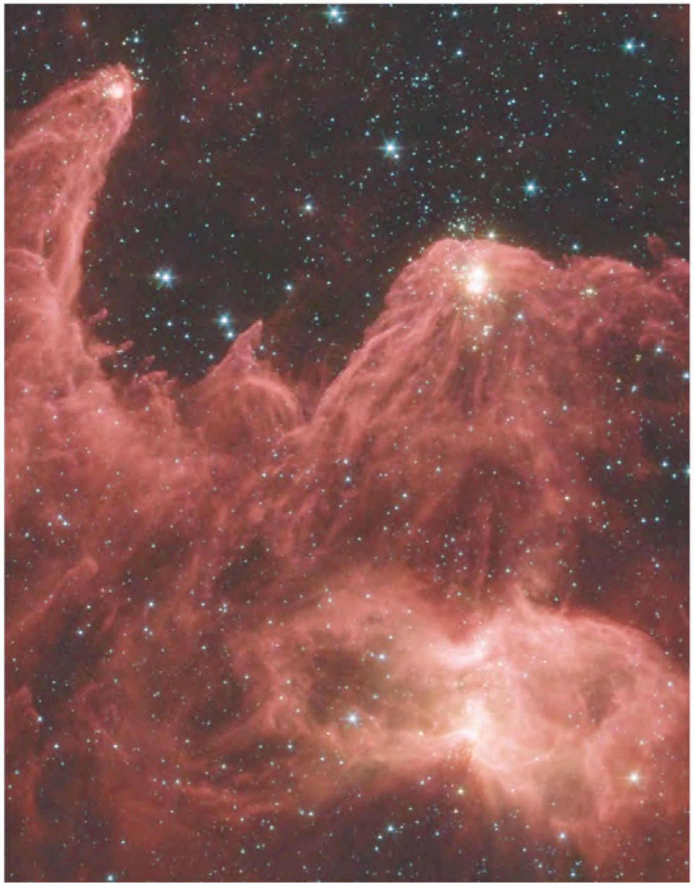
Chapter 15
The Formation of Planetary Systems



Units of Chapter 15

15.1 Modeling Planet Formation

Any model must explain:

1. Planets are relatively **isolated** in space
2. Planetary orbits are nearly **circular**
3. Planetary orbits all lie in (nearly) the same **plane**
4. **Direction** of orbital motion is the same as direction of Sun's **rotation**
5. **Direction** of most planets' rotation is also the same as the Sun's

15.1 Modeling Planet Formation (cont.)

6. Most moons' **orbits** are also in the same sense
7. Solar system is highly **differentiated**
8. **Asteroids** are very old, and not like either inner or outer planets
9. **Kuiper belt**, asteroid-sized icy bodies beyond the orbit of Neptune
10. **Oort cloud** is similar to Kuiper belt in composition, but farther out and with random orbits

15.1 Modeling Planet Formation

Solar system is evidently not a random assemblage, but has a single origin.

Planetary condensation theory, first discussed in Chapter 6, seems to work well.

Lots of room for variation; there are also irregularities (Uranus's axial tilt, Venus's retrograde rotation, etc.) that must be allowed by the model.

15.2 Formation of the Solar System

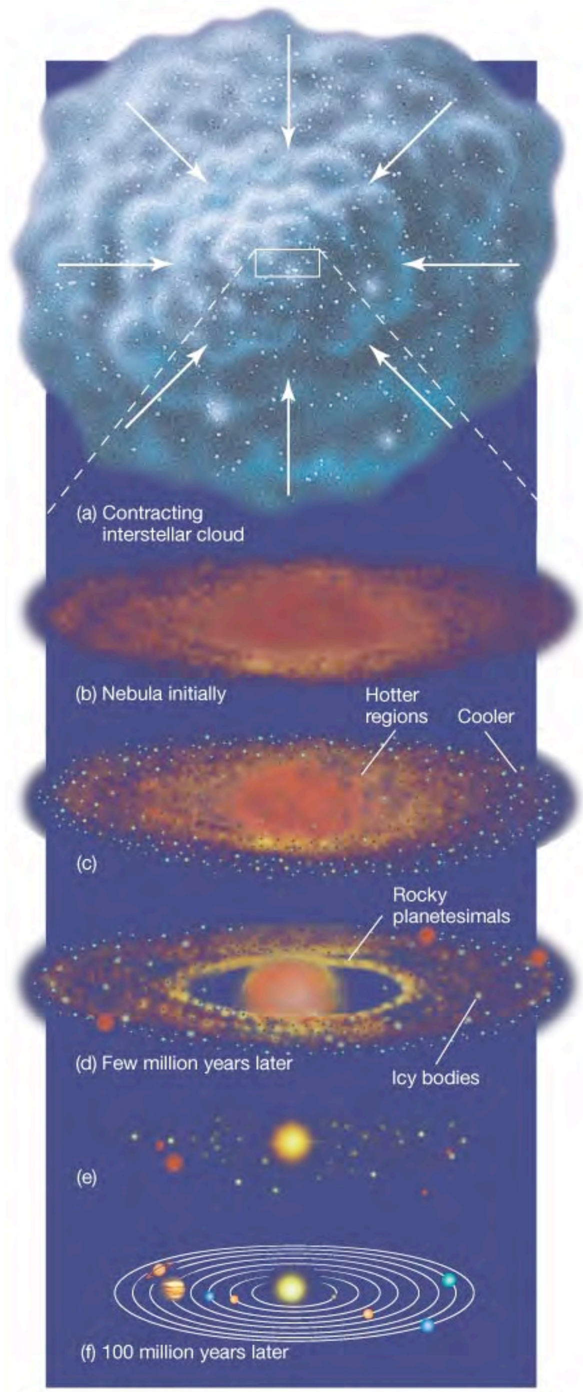
Review of condensation theory:

- Large interstellar cloud of gas and dust starts to contract, heating as it does so.

- Sun forms in center; residual material forms a disk because of the influence of *rotation*, may fall into the growing Sun, or condense into planets.

- The dust in the disk provides condensation nuclei, around which planets form.

- As planets grow, they sweep up ("accrete") smaller debris near them

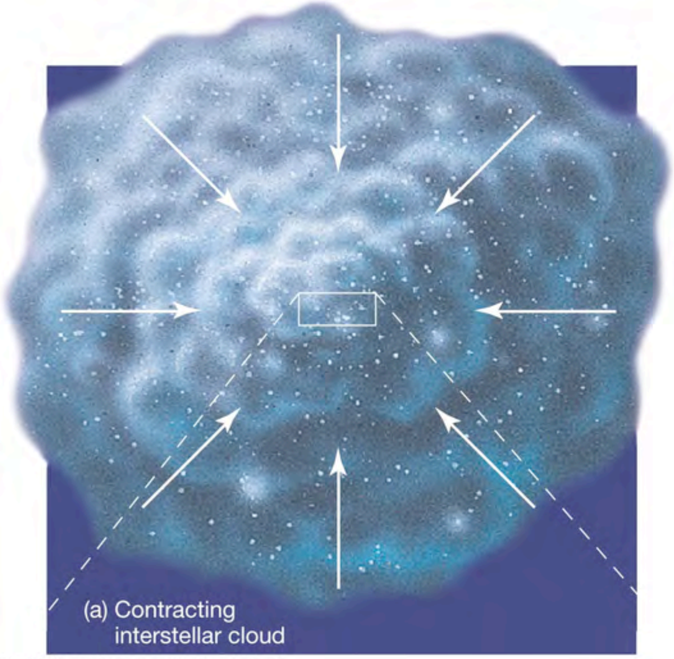


15.2 Formation of the Solar System

First stage: the Sun forms from an interstellar cloud of gas and dust

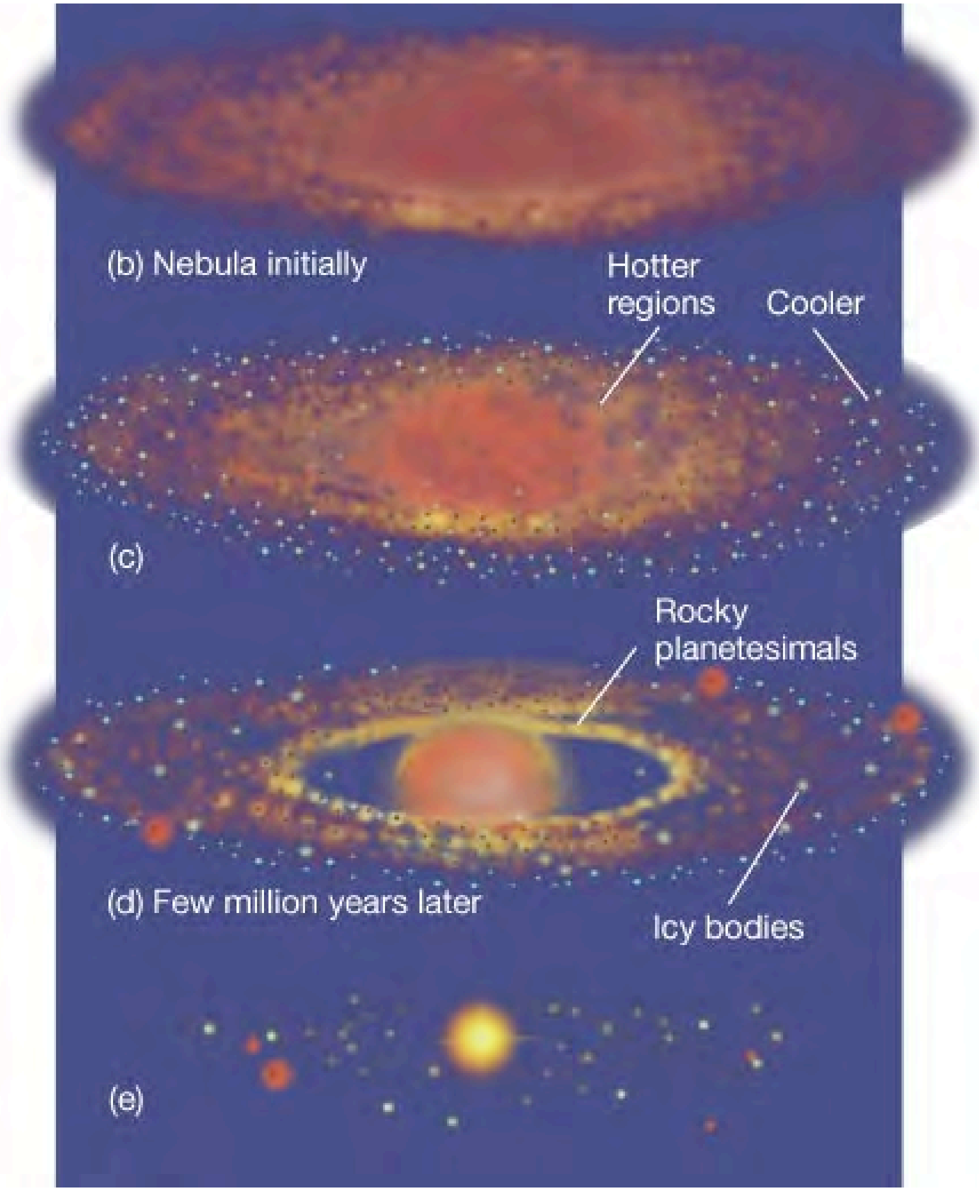
This “dark” dust cloud is believed to be a site of star formation:

Subregions within a large cloud collapse under their own gravity, Forming clusters of stars



15.2 Formation of the Solar System

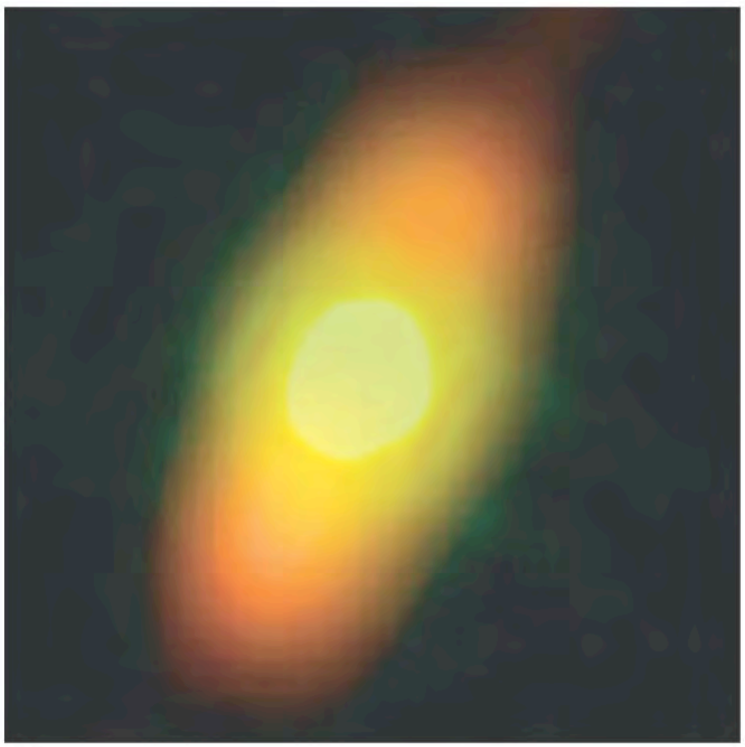
The difficult part is the formation of planets from a disk of dust grains and gas:



Is there observational evidence for disks around young stars?

15.2 Formation of the Solar System

These accretion disks surrounding stars in the process of forming are believed to represent the early stages of planetary formation. An important observation is that nearly *all very young stars are surrounded by dusty disks.*



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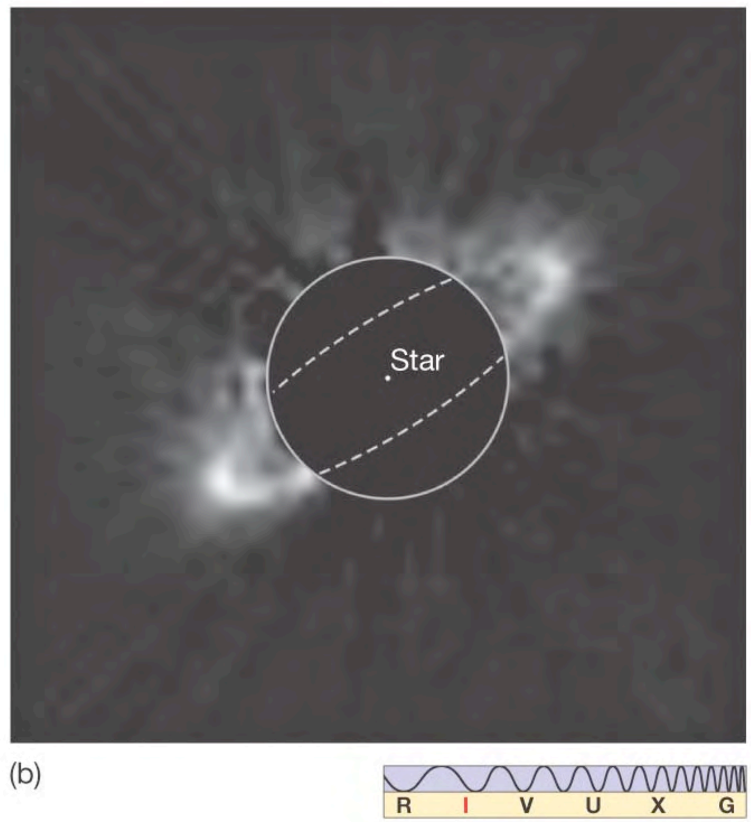


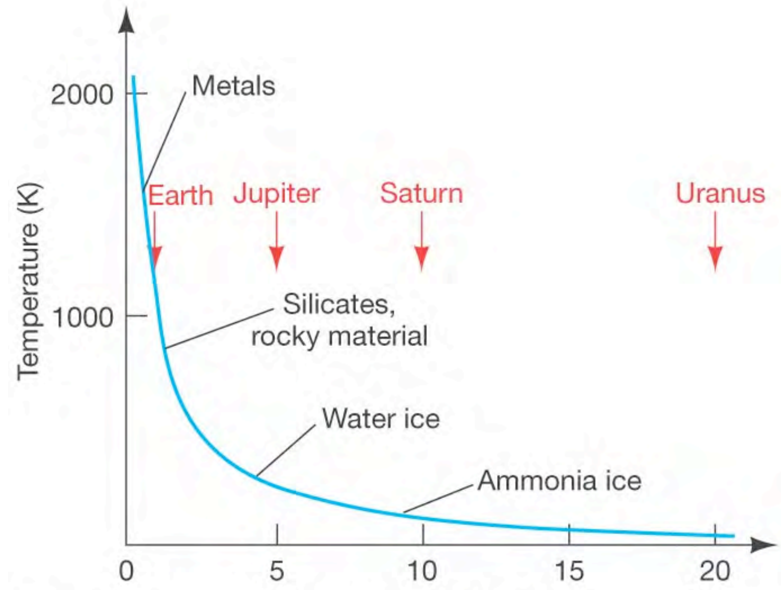
(b)

15.2 Formation of the Solar System

The following fact explains many of the properties of the planets, especially the difference between terrestrial and gas giants:

The farther away one gets from the newborn Sun, the lower the temperature. This caused different materials to predominate in different regions—rocky planets close to the Sun, then the gas giants farther away.

Study illustrations to the right.



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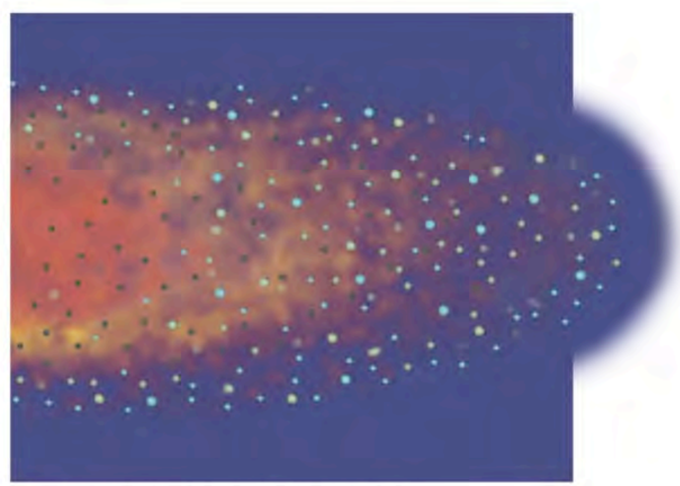

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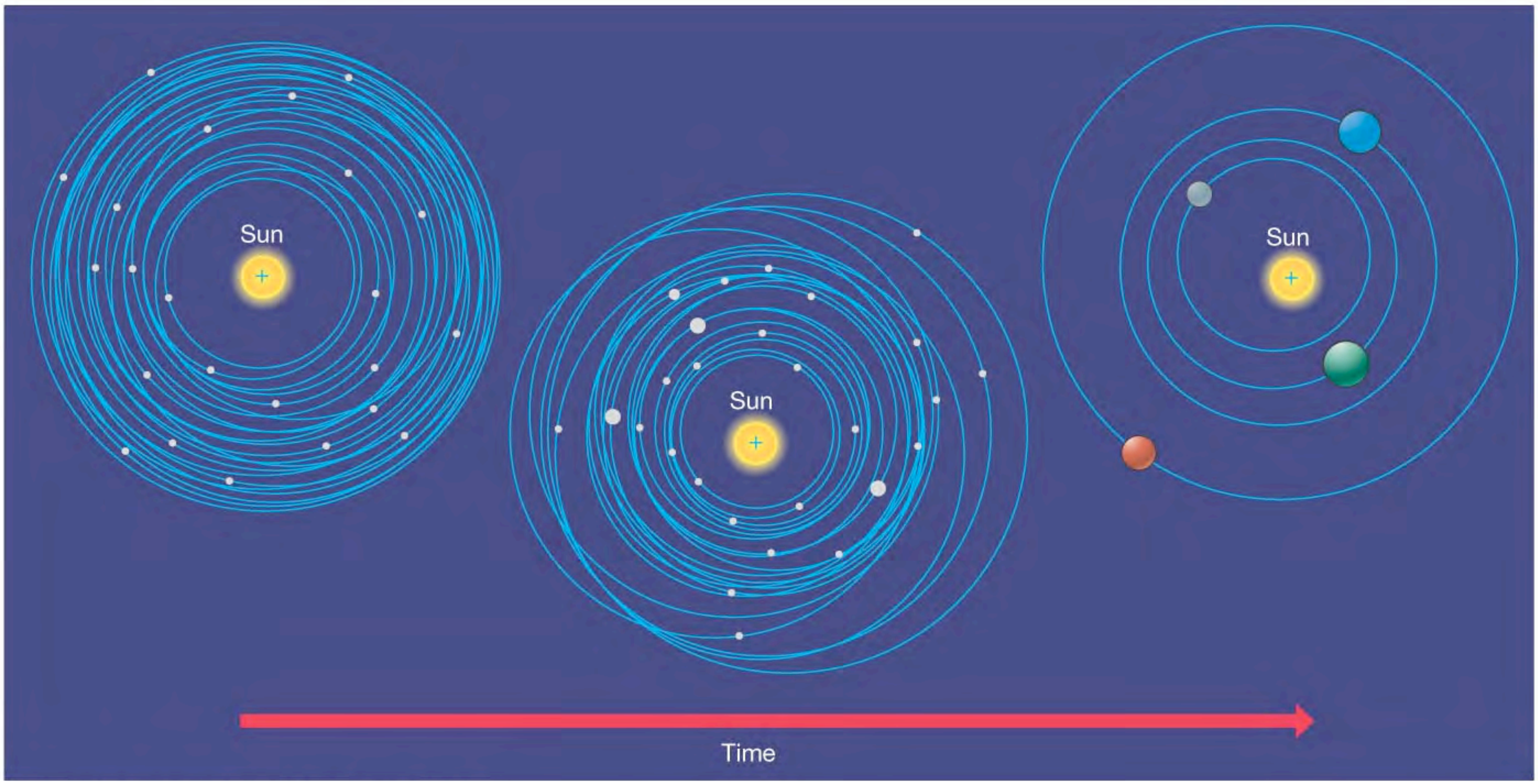
15.3 Terrestrial and Jovian Planets

Terrestrial (rocky) planets formed near Sun, due to high temperature—nothing else could condense there. Ices all vaporize at temperatures above about 100K.



15.3 Terrestrial and Jovian Planets

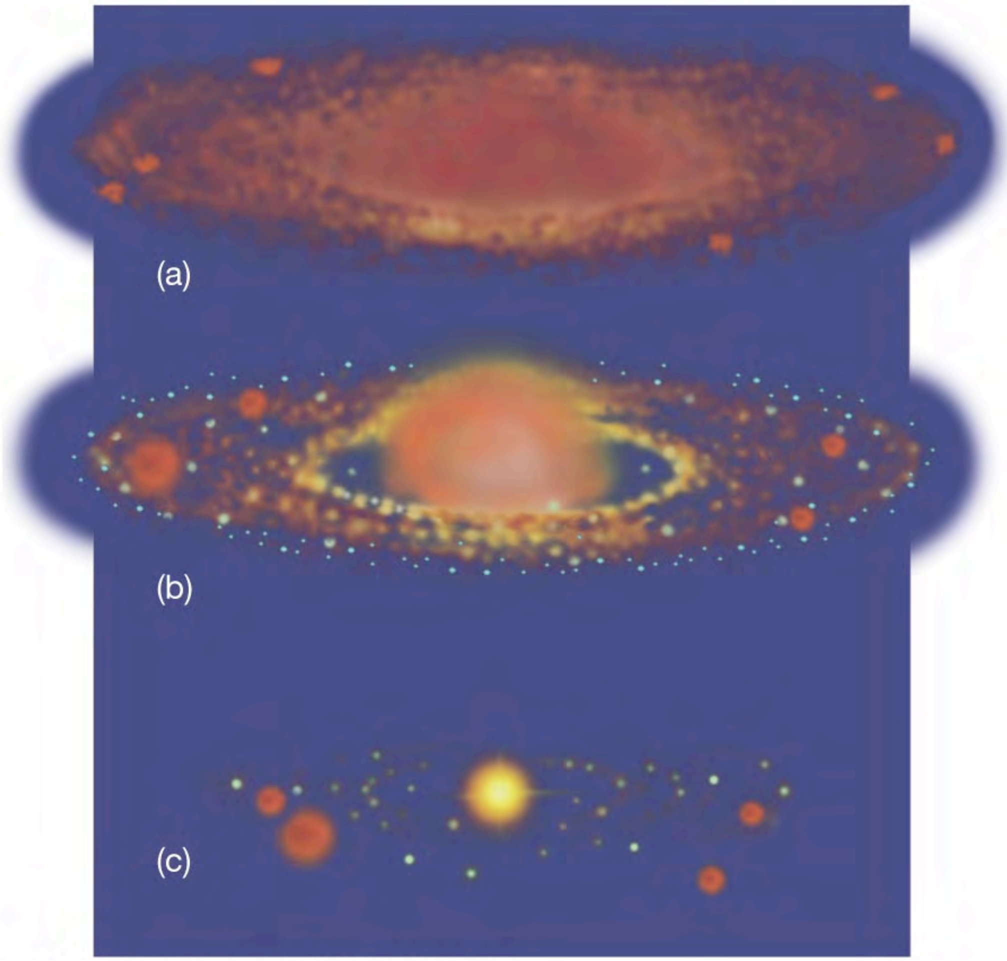
Jovian planets:

- Once they were large enough, may have captured *gas* from the contracting nebula

- Or may have formed from instabilities in the outer, cool regions of the nebula. The main instability involves the gravity of a large clump causing it to collapse.

Detailed information about the cores of jovian planets should help us distinguish between the two possibilities.

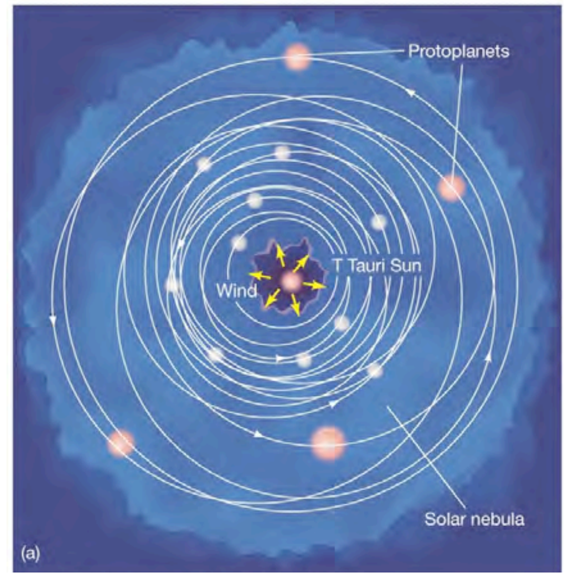
Also possible: The jovian planets may have formed farther from the Sun and "migrated" inward.

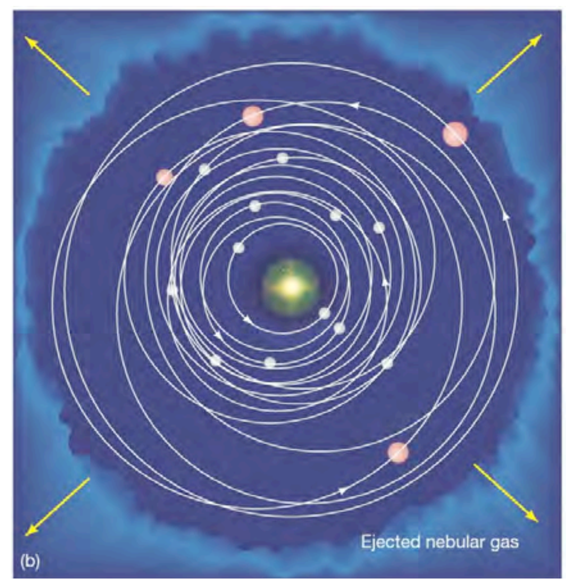


15.3 Terrestrial and Jovian Planets

A problem for forming giant planets: You have to form them quickly, because the gas in disks is observed to disappear in a relatively short time, about 5 million years. Where does it go? The central star probably blows it away.

T Tauri stars are in a highly active phase of their evolution and have strong solar winds. These winds sweep away the gas disk, leaving the planetesimals and gas giants.





15.4 Interplanetary Debris

Asteroid belt:

- **Orbits mostly between Mars and Jupiter**
- **Jupiter's gravity kept them from condensing into a planet, or accreting onto an existing one**
- **Fragments left over from the initial formation of the solar system**

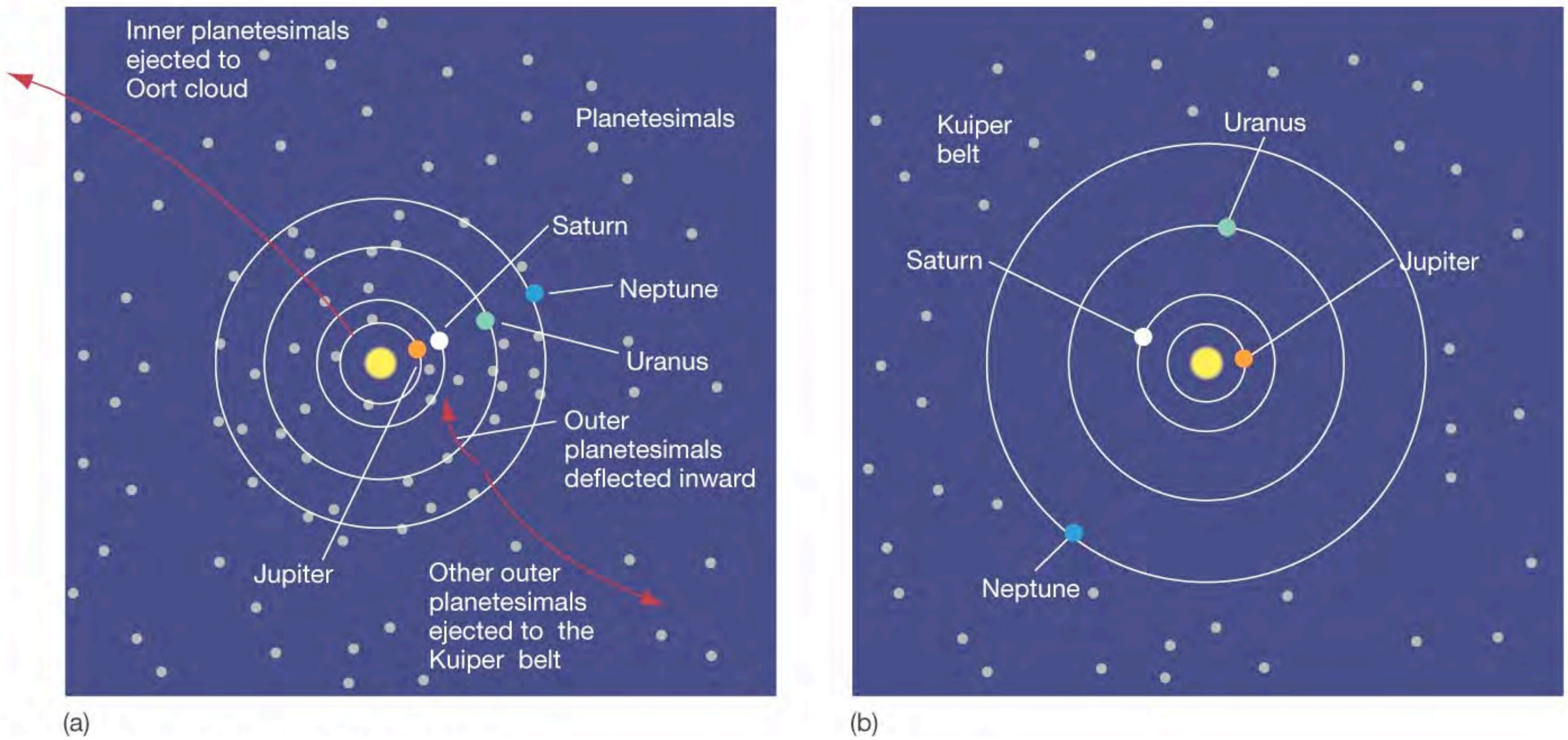
15.4 Interplanetary Debris

Icy planetesimals far from the Sun were ejected into distant orbits by gravitational interaction with the jovian planets, into the Kuiper belt and the Oort cloud.

Kuiper-belt objects have been detected from Earth recently; a few are as large as, or larger than, Pluto, and their composition appears similar.

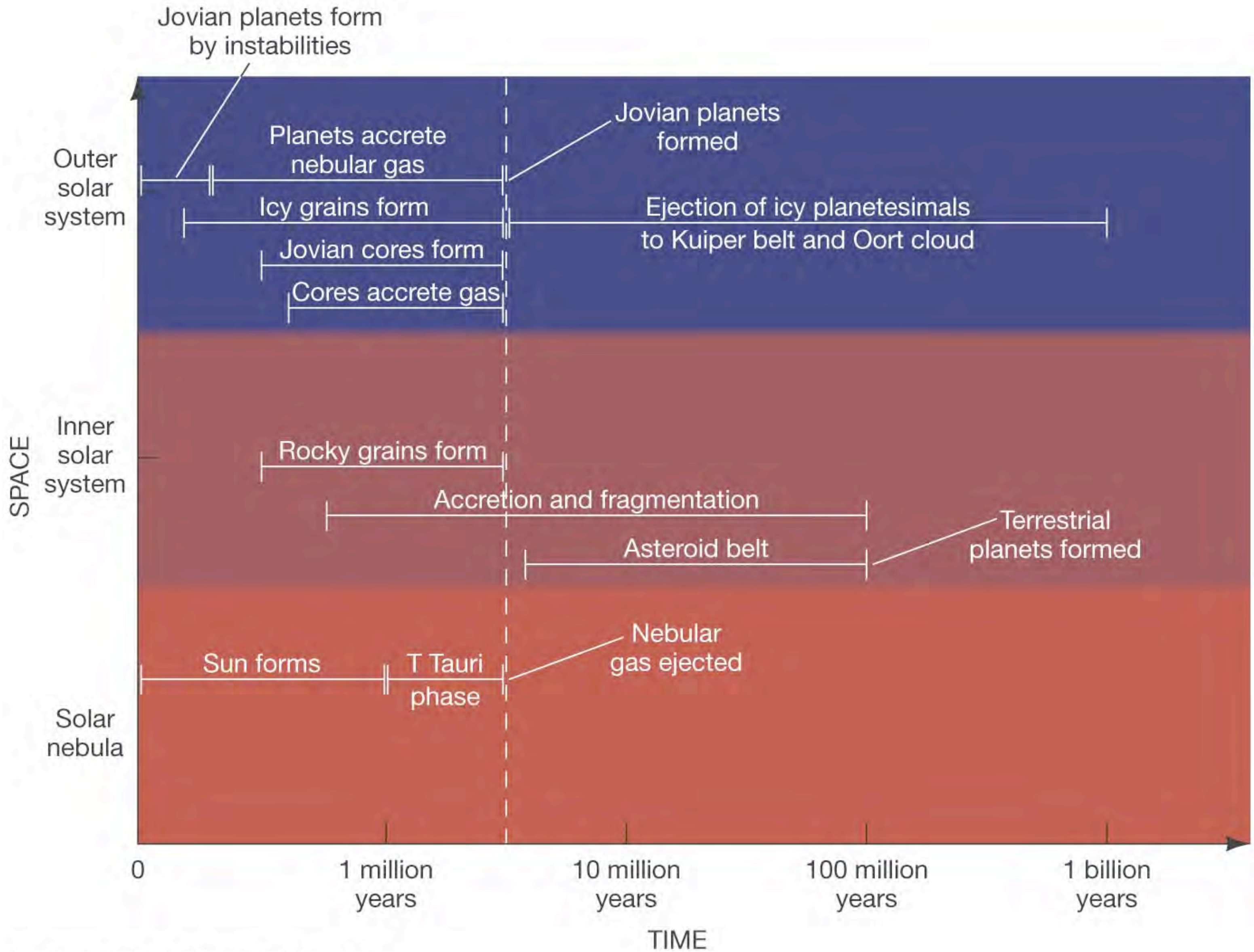
About 1/3 of all Kuiper belt objects (including Pluto) have orbits that are in a 3:2 resonance with Neptune; such objects are called “plutinos.”

Some were left with *extremely eccentric orbits* and appear in the inner solar system as comets.



15.4 Interplanetary Debris

General **timeline** of solar system formation:



15.5 Solar System Regularities and Irregularities

Condensation theory covers the 10 points mentioned at the beginning.

What about the exceptions?

1. **Mercury's** large metallic **core** may be the result of a collision between two planetesimals, where much of the mantle was lost.

2. Two large bodies may have merged to form **Venus (to explain strange rotation)**

3. **Earth–Moon system** probably formed after a collision.

15.5 Solar System Regularities and Irregularities (cont.)

4. Late collision may have caused **Mars's north–south asymmetry** and stripped most of its atmosphere.

5. **Uranus's** tilted axis may be the result of a glancing collision.

6. **Miranda** may have been almost destroyed in a collision.

7. Interactions between jovian protoplanets and planetesimals could be responsible for **irregular moons.**

15.5 Solar System Regularities and Irregularities (cont.)

Many of these explanations have one thing in common—a **catastrophic**, or near-catastrophic, **collision** at a critical time during formation.

Normally, one does not like to explain things by calling on one-time events, but it is clear that the early solar system involved almost constant collisions. Some must have been **exceptionally large**.

Discovery 15-1:
The Angular Momentum Problem

As it collapsed, the nebula had to **conserve** its angular momentum.

However, at the present day, the Sun has almost **none** of the solar system's angular momentum:

- **Jupiter** alone accounts for 60%
- **Four jovian planets** account for more than 99%

Discovery 15-1:
The Angular Momentum Problem

Theory: The Sun transferred most of its angular momentum to outer planets through friction.