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ASTRONOMY

Chapter 14 COSMIC SAMPLES AND THE ORIGIN OF THE SOLAR SYSTEM

PowerPoint Image Slideshow

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14.3 FORMATION OF THE SOLAR SYSTEM

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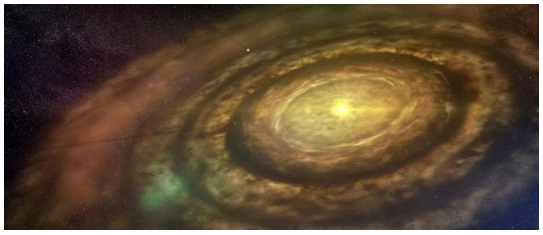
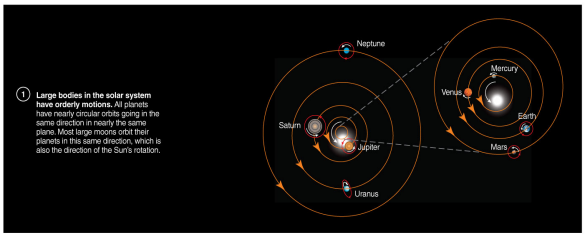


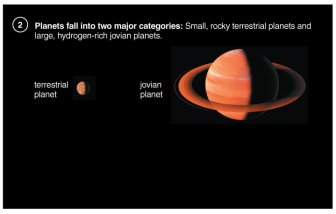
- **Planetesimals.** This illustration depicts a disk of dust and gas around a new star. Material in this disk comes together to form planetesimals.

Large Bodies in the solar system have orderly motions.



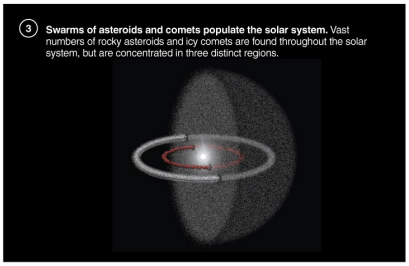
Planets and moons orbit and rotate in the same direction as the the Sun (with a few exceptions).

Two Major Planet Types



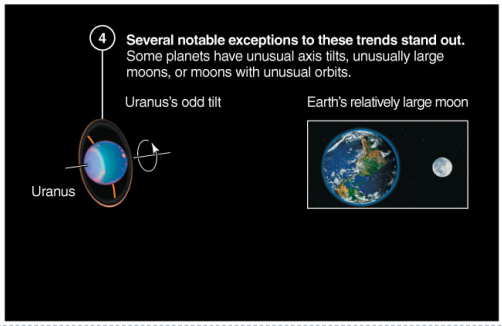
- Terrestrial planets are rocky, relatively small, and close to the Sun.
- Jovian planets are gaseous, larger, and farther from the Sun.

Asteroids and comets are concentrated in three distinct regions



- Asteroid belt
- Kuiper Belt
- Oort Cloud

Noticeable exceptions

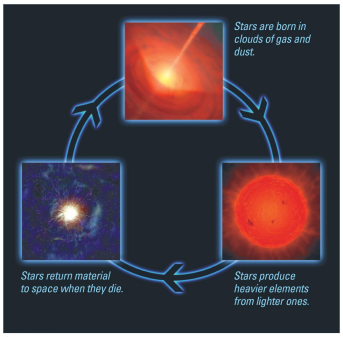


What is the nebular theory?

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

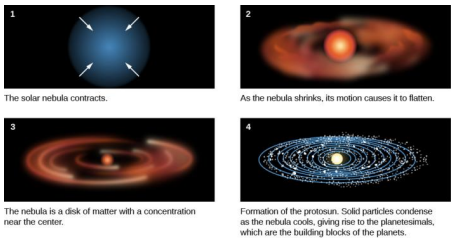
(**nebula** = cloud)

Origin of the Nebula



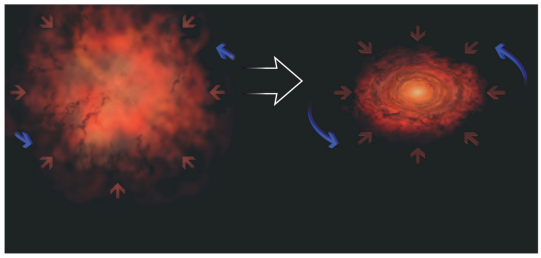
- Elements that formed planets were made in stars and then recycled over generations through interstellar space.
- Despite billions of years of recycling, the universe remains dominantly H/He

The Solar Nebula



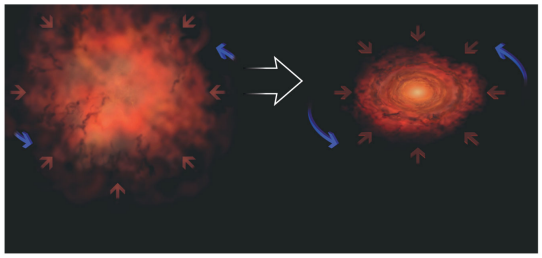
- **Steps in Forming the Solar System (Fig 14.11).** This illustration shows the steps in the formation of the solar system from the solar nebula. As the nebula shrinks, its rotation causes it to flatten into a disk. Much of the material is concentrated in the hot center, which will ultimately become a star. Away from the center, solid particles can condense as the nebula cools, giving rise to planetesimals, the building blocks of the planets and moons.

Heating



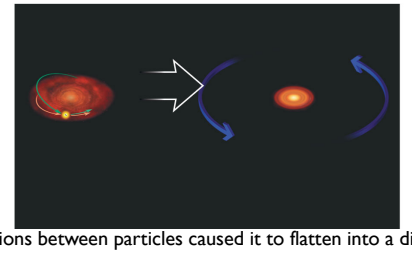
- Conservation of energy
  - Gravitational potential → kinetic → thermal

Spinning

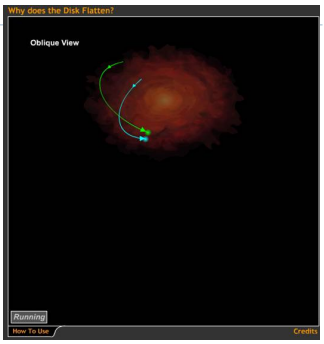


- Conservation of angular momentum
  - The rotational speed of the cloud increased as the cloud contracted.

Flattening



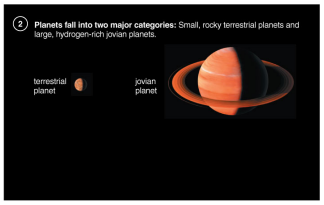
- Collisions between particles caused it to flatten into a disk.
  - Clumps collide and merge with average velocity
  - Collisions between highly elliptical orbits reduce eccentricities
  - Thus, random motions become more orderly



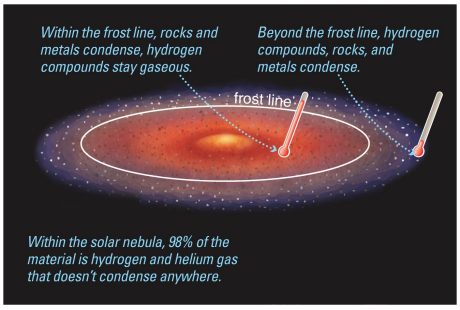
Collisions between gas particles also reduce up and down motions.

PLAY Why Does the Disk Flatten?

Why are there two major types of planets?



- The solar nebula should have had the same composition throughout.
- Why then are planets so different?
  - Key is location



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

Figure 14.12

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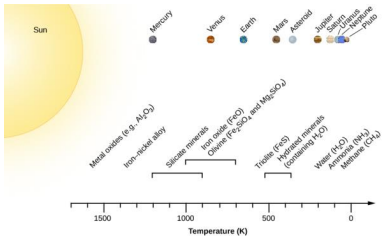


- **Chemical Condensation Sequence in the Solar Nebula.** The scale along the bottom shows temperature; above are the materials that would condense out at each temperature under the conditions expected to prevail in the nebula.

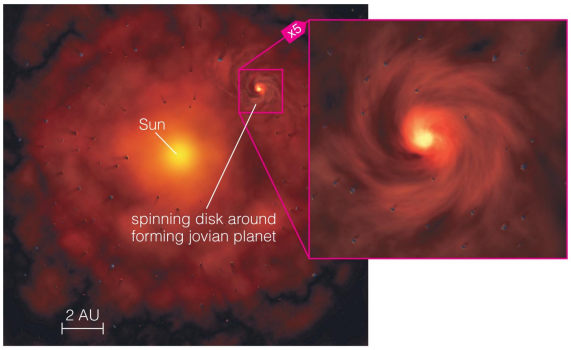
Condensation: Sowing the seeds of planets

- Terrestrials formed in the warm inner region. Jovians formed in the colder outer region.
- When temperature is low enough some atoms and molecules in gas may bond and solidify.

TABLE 6.3 Materials in the Solar Nebula

A summary of the four types of materials present in the solar nebula. The squares represent the relative proportions of each type (by mass).

	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%
Metals	iron, nickel, aluminum	1000–1600 K	0.2%



- Moons of jovian planets form in miniature disks.

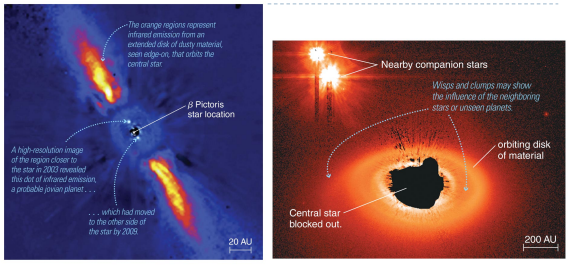
Clearing the Nebula

Radiation and outflowing matter from the Sun—the ***solar wind***— blew away the leftover gases.

Had the gases remained, it could have cooled until hydrogen compounds condensed.

PLAY The Solar Wind

Testing the Model



a This infrared image composite from the European Southern Observatory shows a large debris disk orbiting the star Beta Pictoris and a probable jovian planet that has formed from the disk. Images were taken with the star itself blocked; the star's position has been added digitally.

b This Hubble Space Telescope photo shows a disk around the star HD141569A. The colors are not real; a black-and-white image has been tinted red to bring out faint detail.

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

Figure 14.14

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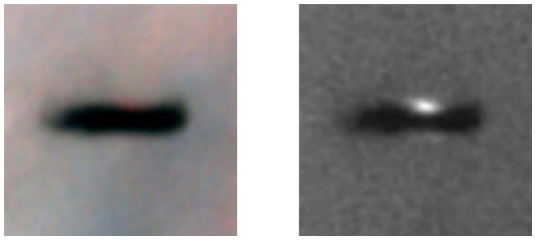

- **Protoplanetary Disk in the Orion Nebula.** The Hubble Space Telescope imaged this protoplanetary disk in the Orion Nebula, a region of active star formation, using two different filters. The disk, about 17 times the size of our solar system, is in an edge-on orientation to us, and the newly formed star is shining at the center of the flattened dust cloud. The dark areas indicate absorption, not an absence of material. In the left image we see the light of the nebula and the dark cloud; in the right image, a special filter was used to block the light of the background nebula. You can see gas above and below the disk set to glow by the light of the newborn star hidden by the disk. (credit: modification of work by Mark McCaughrean (Max-Planck-Institute for Astronomy), C. Robert O'Dell (Rice University), and NASA)

Figure 14.15

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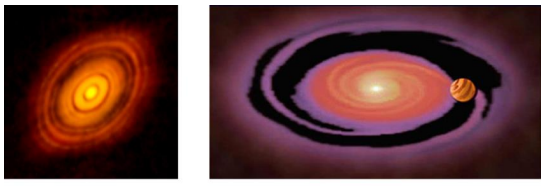


(a) (b)

- **Protoplanetary Disk around HL Tau.**

(a) This image of a protoplanetary disk around HL Tau was taken with the Atacama Large Millimeter/submillimeter Array (ALMA), which allows astronomers to construct radio images that rival those taken with visible light.

(b) Newly formed planets that orbit the central star clear out dust lanes in their paths, just as our theoretical models predict. This computer simulation shows the empty lane and spiral density waves that result as a giant planet is forming within the disk. The planet is not shown to scale.

Do we need to modify our theory of solar system formation?

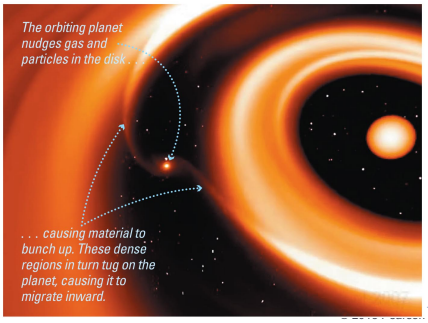
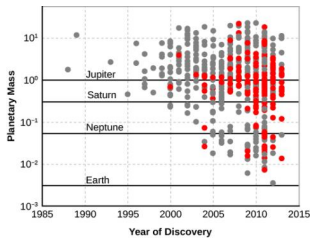


Figure 14.17



- **Masses of Exoplanets Discovered by Year.** Horizontal lines are drawn to reference the masses of Jupiter, Saturn, Neptune, and Earth. The gray dots indicate planets discovered by measuring the radial velocity of the star, and the red dots are for planets that transit their stars. In the early years, the only planets that could be detected were similar in mass to Jupiter. Improvements in technology and observing strategies enabled the detection of lower mass planets as time went on, and now even smaller worlds are being found. (Note that this tally ends in 2014.)

Revisiting the Nebular Theory

- There seem to be a much greater variety of planet types than we find in our solar system.
- This includes gas giants with very different densities and water worlds.
- Hot Jupiters
  - The nebular theory predicts that massive Jupiter-like planets should not form inside the frost line (at << 5 AU).
- *Planetary migration* or gravitational encounters may explain hot Jupiters.
  - Close gravitational encounters between two massive planets can eject one planet while flinging the other into a highly elliptical orbit.
  - Multiple close encounters with smaller planetesimals can also cause inward migration.
  - Resonances may also contribute.

Links

- VIDEO formation of SS 5 min

Reading

- 14.3