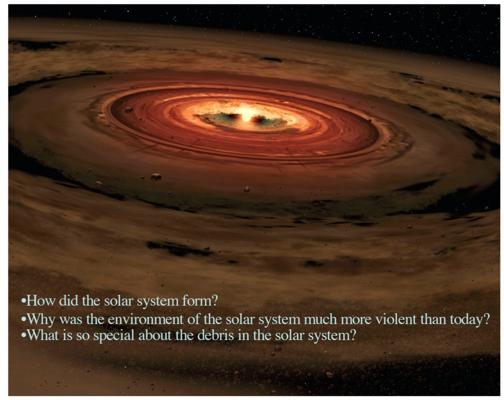
Discovering the Essential Universe

Neil F. Comins

CHAPTER 4
Formation of the Solar System

1



Chapter 5 Opener
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2

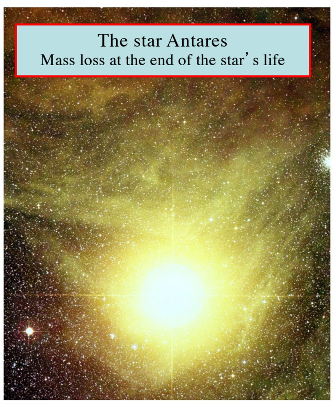

Figure 5-1a
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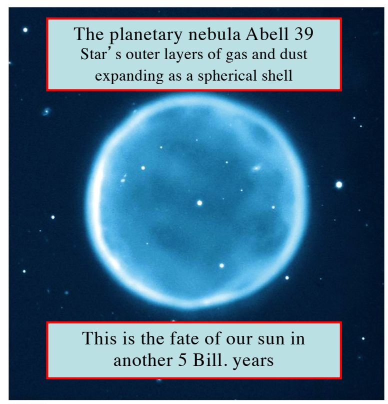

Figure 5-1b
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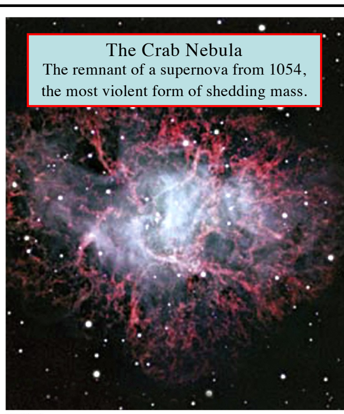

Figure 5-1c
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Our solar system formed from a similar fragment

Figure 5-2a
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Newly formed stars in the Orion Nebula
Figure 5-2b
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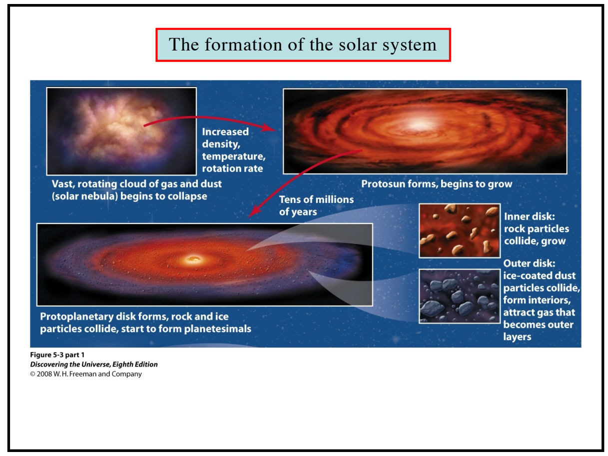
The formation of the solar system
Increased density, temperature, rotation rate
Vast, rotating cloud of gas and dust (solar nebula) begins to collapse
Protosun forms, begins to grow
Tens of millions of years
Inner disk: rock particles collide, grow
Outer disk: ice-coated dust particles collide, form interiors, attract gas that becomes outer layers
Protoplanetary disk forms, rock and ice particles collide, start to form planetesimals
Figure 5-3 part 1
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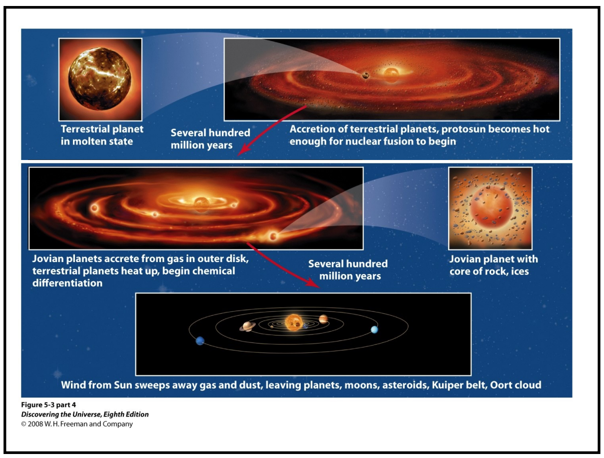
Terrestrial planet in molten state
Several hundred million years
Accretion of terrestrial planets, protosun becomes hot enough for nuclear fusion to begin
Jovian planets accrete from gas in outer disk, terrestrial planets heat up, begin chemical differentiation
Several hundred million years
Jovian planet with core of rock, ices
Wind from Sun sweeps away gas and dust, leaving planets, moons, asteroids, Kuiper belt, Oort cloud
Figure 5-3 part 4
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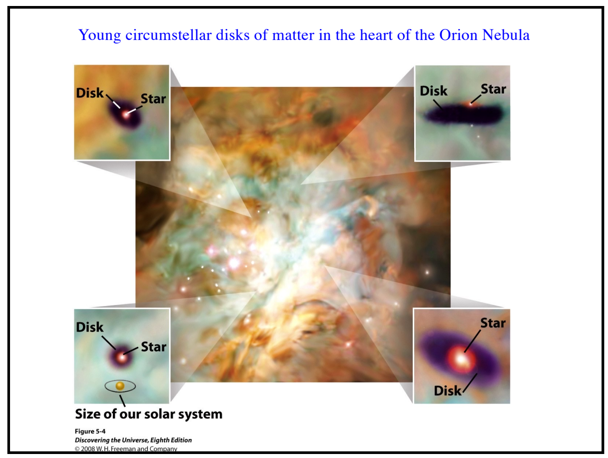
Young circumstellar disks of matter in the heart of the Orion Nebula
Disk
Star
Disk
Star
Disk
Star
Star
Disk
Size of our solar system
Figure 5-4
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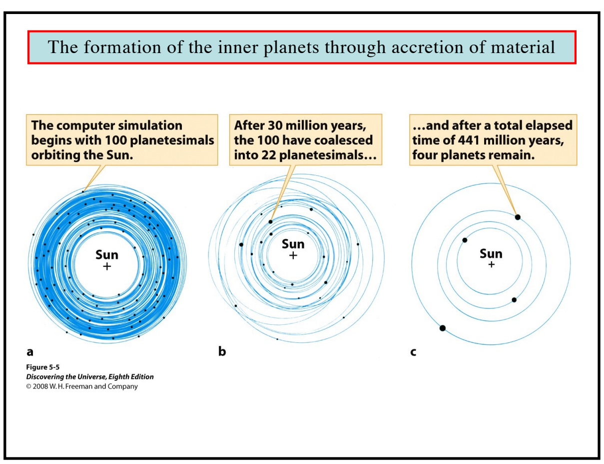
The formation of the inner planets through accretion of material
The computer simulation begins with 100 planetesimals orbiting the Sun.
After 30 million years, the 100 have coalesced into 22 planetesimals…
…and after a total elapsed time of 441 million years, four planets remain.
Sun
Sun
Sun
a
b
c
Figure 5-5
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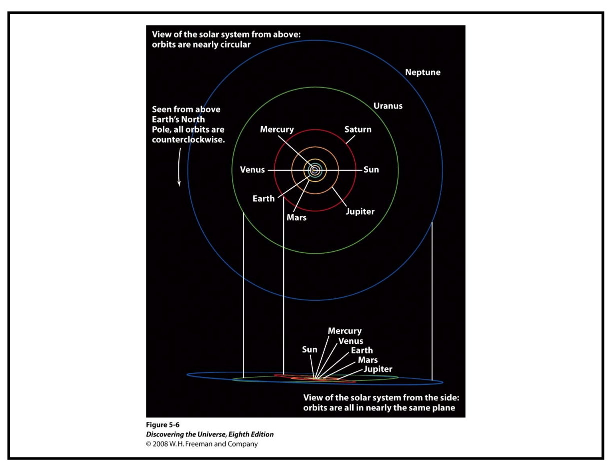
View of the solar system from above: orbits are nearly circular
Neptune
Uranus
Seen from above Earth's North Pole, all orbits are counterclockwise.
Mercury
Saturn
Venus
Sun
Earth
Jupiter
Mars
Mercury
Venus
Sun
Earth
Mars
Jupiter
View of the solar system from the side: orbits are all in nearly the same plane
Figure 5-6
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Our moon

Most craters are impacts from leftover rocky debris from the formation of the solar system.

Age-dating reveals an age of 4.5 Bill years.

Figure 5-7
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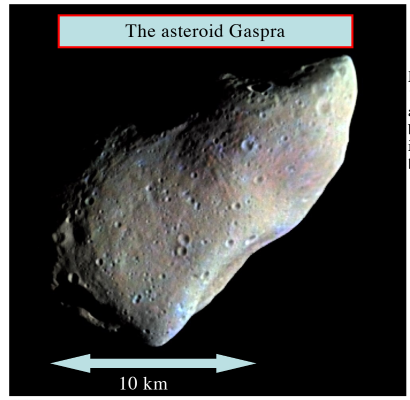
The asteroid Gaspra



More than 100,000 asteroids have been observed in the asteroid belt.

Figure 5-8
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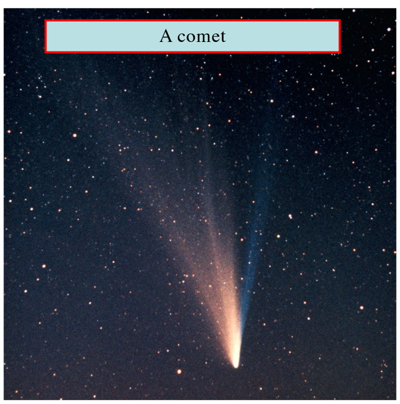
A comet



This is another example of leftover debris from the formation of the solar system.

The comet nucleus is typically 10 km in size.

Figure 5-9
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TABLE 5-1 Orbital Characteristics of the Planets

	Average distance from Sun (AU)	Average distance from Sun (10^6 km)	Orbital period (year)
Mercury	0.39	58	0.24
Venus	0.72	108	0.62
Earth	1.00	150	1.00
Mars	1.52	228	1.88
Jupiter	5.20	778	11.86
Saturn	9.54	1427	29.46
Uranus	19.19	2871	84.01
Neptune	30.06	4497	164.79

Table 5-1
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The sun and the eight planets
drawn to size scale

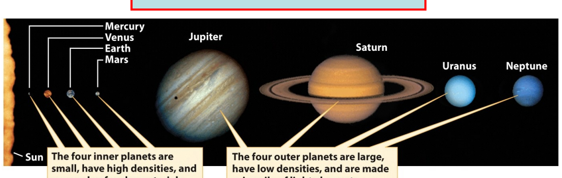

Figure 5-10
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$$D = \frac{m}{V}$$

- The average density, D, of any substance depends in part on its composition
- An object sinks in a fluid if its average density is greater than that of the fluid, but rises if its average density is less than that of the fluid
- The terrestrial (inner) planets are made of rocky materials and have dense iron cores, which gives these planets high average densities
- The Jovian (outer) planets are composed primarily of light elements such as hydrogen and helium, which gives these planets low average densities

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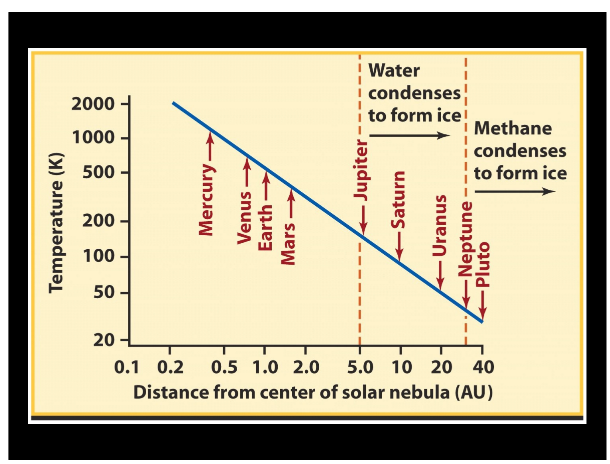

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Why do some gases remain in an atmosphere and not others?

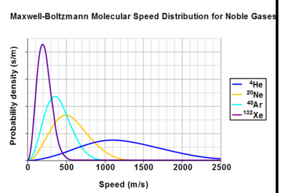
Kinetic energy, E_k, of a gas atom (or molecule)

$$E_k = ½ m v^2 = 3/2 k T$$

m = atom mass (kg)
T = temperature (K)
v = atom velocity (m/s)
k = Boltzmann's constant
1.38 10^{-23} J/K

==> v_{rms} = SQRT (3 kT / m)

If $6v_{rms} > v_{esc}$, then, over time, gas escapes the planet's gravity.



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Example:

H atom

m = 1.66 x 10^{-27} kg
T = 300 K
v_{esc} = 11,185 m s^{-1}

v_{rms} = SQRT(3 x 1.38 x 10^{-23} x 300 / 1.66 x 10^{-27})

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Example:

H atom

m = 1.66 x 10^{-27} kg
T = 300 K
v_{esc} = 11,185 m s^{-1}

v_{rms} = SQRT(3 x 1.38 x 10^{-23} x 300 / 1.66 x 10^{-27})
= 2735 m s^{-1}

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Example:

H atom

m = 1.66 x 10^{-27} kg
T = 300 K
v_{esc} = 11,185 m s^{-1}

v_{rms} = SQRT(3 x 1.38 x 10^{-23} x 300 / 1.66 x 10^{-27})
= 2735 m s^{-1}

$6v_{rms}$= 16410 m s^{-1}

➡ $6v_{rms} > v_{esc}$ H escapes Earth

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TABLE 5-2 Physical Characteristics of the Planets

	Diameter		Mass		Average density
	(km)	(Earth = 1)	(kg)	(Earth = 1)	(kg/m³)
Mercury	4878	0.38	3.3×10^{23}	0.06	5430
Venus	12,100	0.95	4.9×10^{24}	0.81	5250
Earth	12,756	1.00	6.0×10^{24}	1.00	5520
Mars	6786	0.53	6.4×10^{23}	0.11	3950
Jupiter	142,984	11.21	1.9×10^{27}	317.94	1330
Saturn	120,536	9.45	5.7×10^{26}	95.18	690
Uranus	51,118	4.01	8.7×10^{25}	14.53	1290
Neptune	49,528	3.88	1.0×10^{26}	17.14	1640

Table 5-2
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The diversity of the solar system is a result of its origin and evolution

table 7-3 Comparing Terrestrial and Jovian Planets

	Terrestrial Planets	Jovian Planets
Distance from the Sun	Less than 2 AU	More than 5 AU
Size	Small	Large
Composition	Mostly rocky materials containing iron, oxygen, silicon, magnesium, nickel, and sulfur	Mostly hydrogen and helium
Density	High	Low

The planets, satellites, comets, asteroids, and the Sun itself formed from the same cloud of interstellar gas and dust

The composition of this cloud was shaped by cosmic processes, including nuclear reactions that took place within stars that died long before our solar system was formed

Different planets formed in different environments depending on their distance from the Sun and these environmental variations gave rise to the planets and satellites of our present-day solar system

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Any model of solar system origins must explain the present-day Sun and planets

The terrestrial planets, which are composed primarily of rocky substances, are relatively small, while the Jovian planets, which are composed primarily of hydrogen and helium, are relatively large.

All of the planets orbit the Sun in the same direction, and all of their orbits are in nearly the same plane.

The terrestrial planets orbit close to the Sun, while the Jovian planets orbit far from the Sun.

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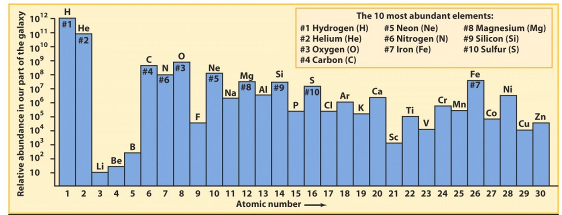
The abundances of the chemical elements are the result of cosmic processes



The vast majority of the atoms in the universe are hydrogen and helium atoms produced in the Big Bang

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