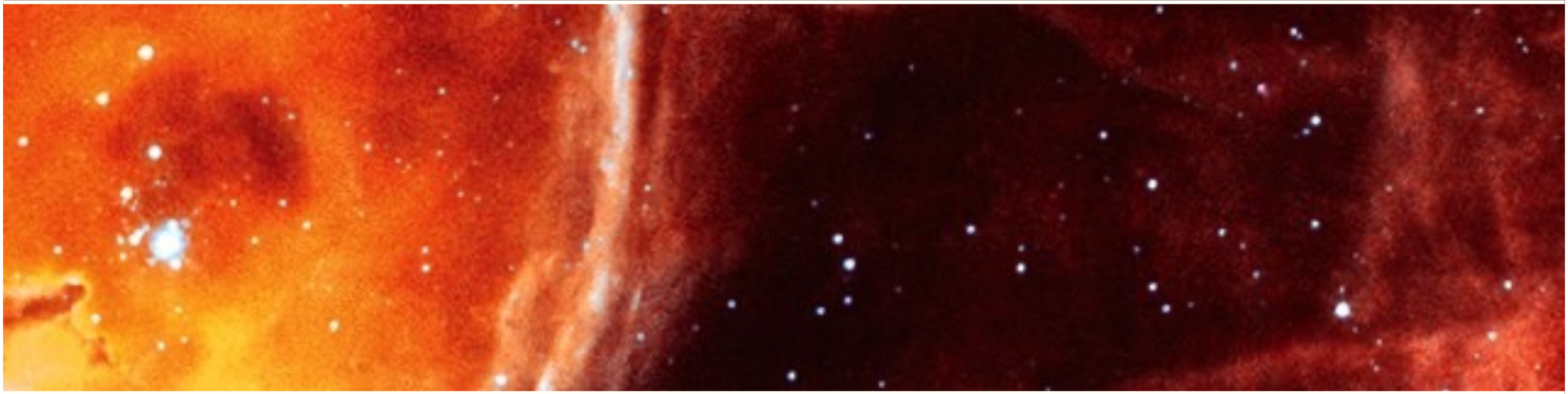
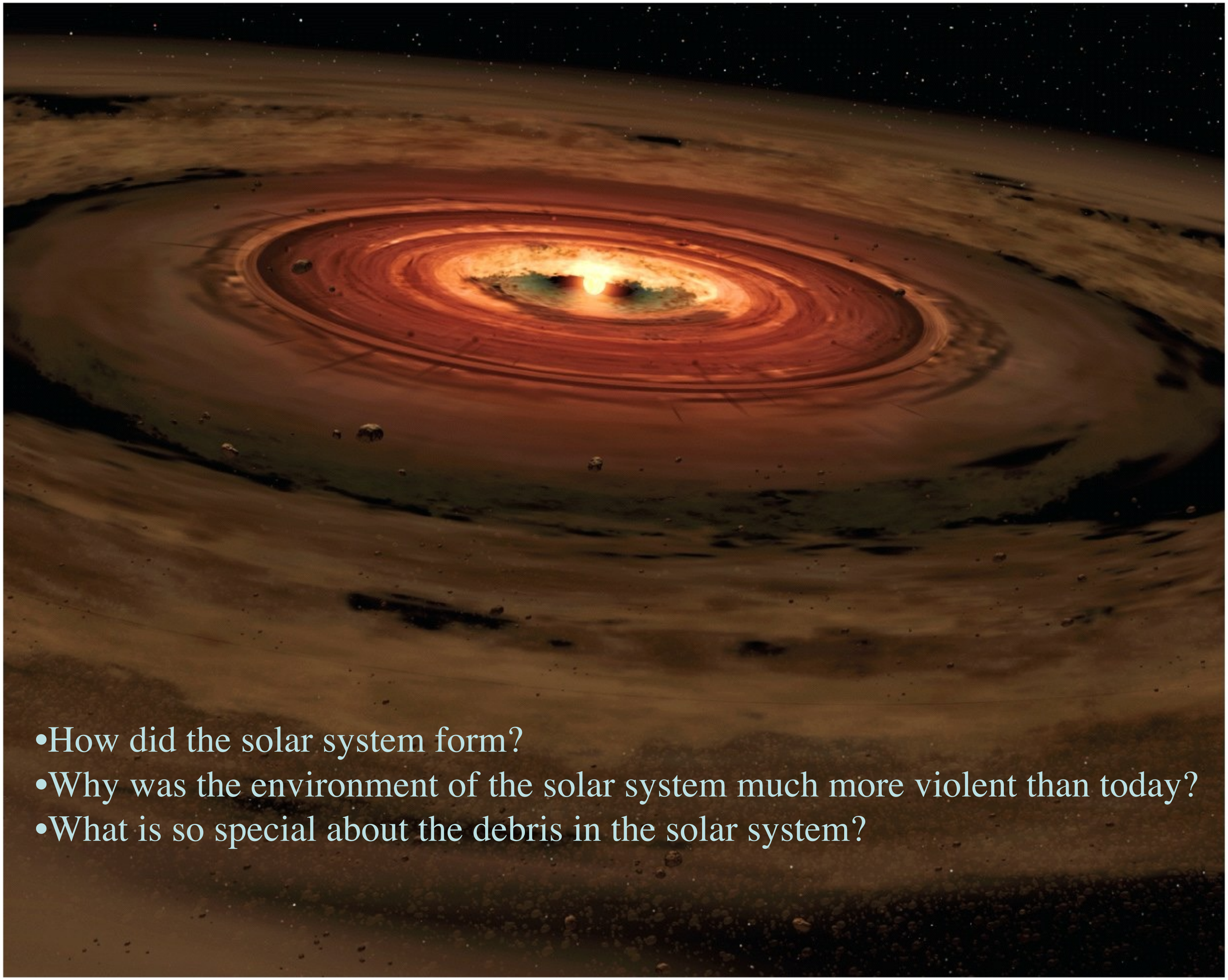
Discovering the Essential Universe



Neil F. Comins

CHAPTER 4
Formation of the Solar System



Chapter 5 Opener
Discovering the Universe, Eighth Edition

The star Antares

Mass loss at the end of the star’s life

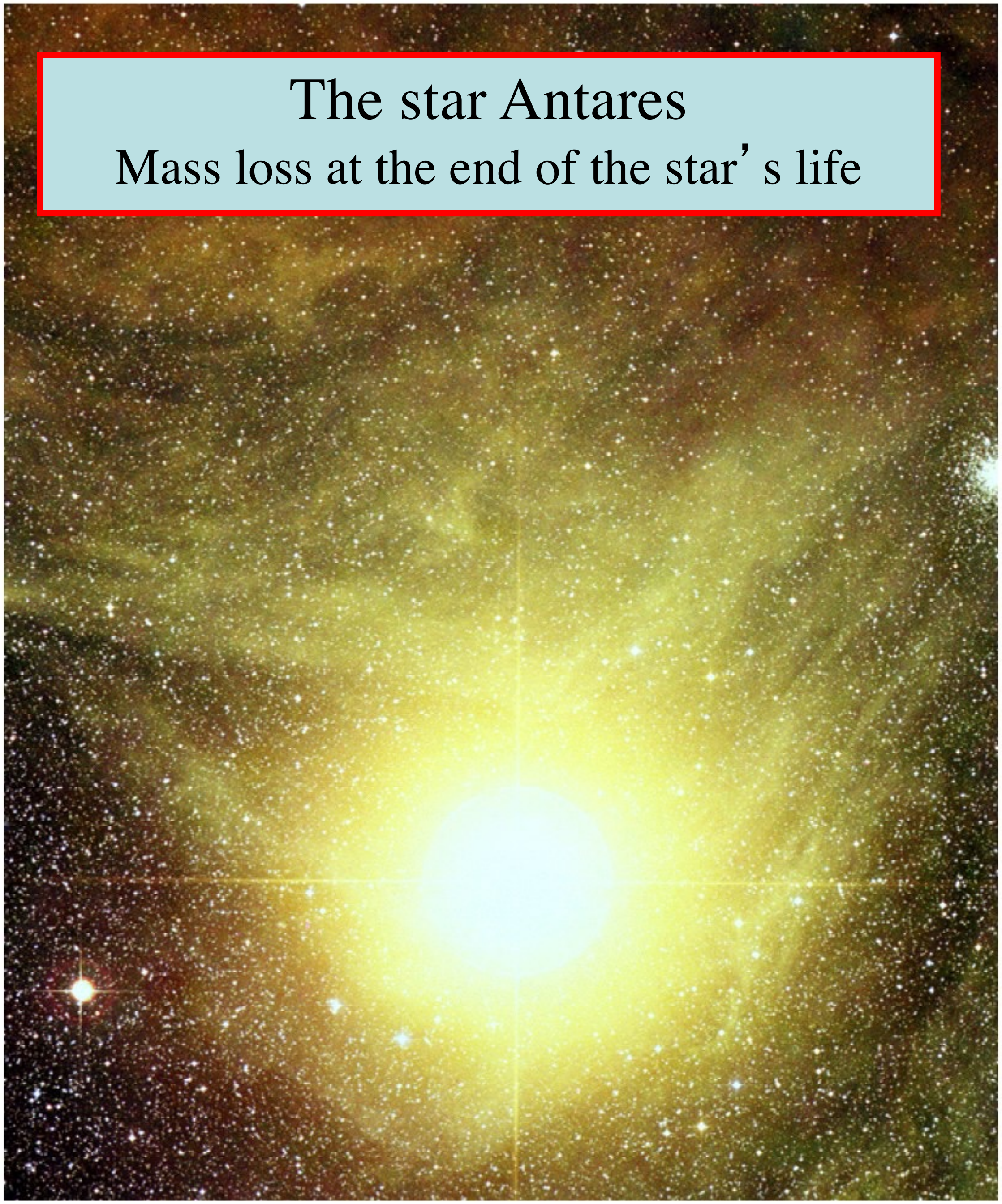


Figure 5-1a
Discovering the Universe, Eighth Edition

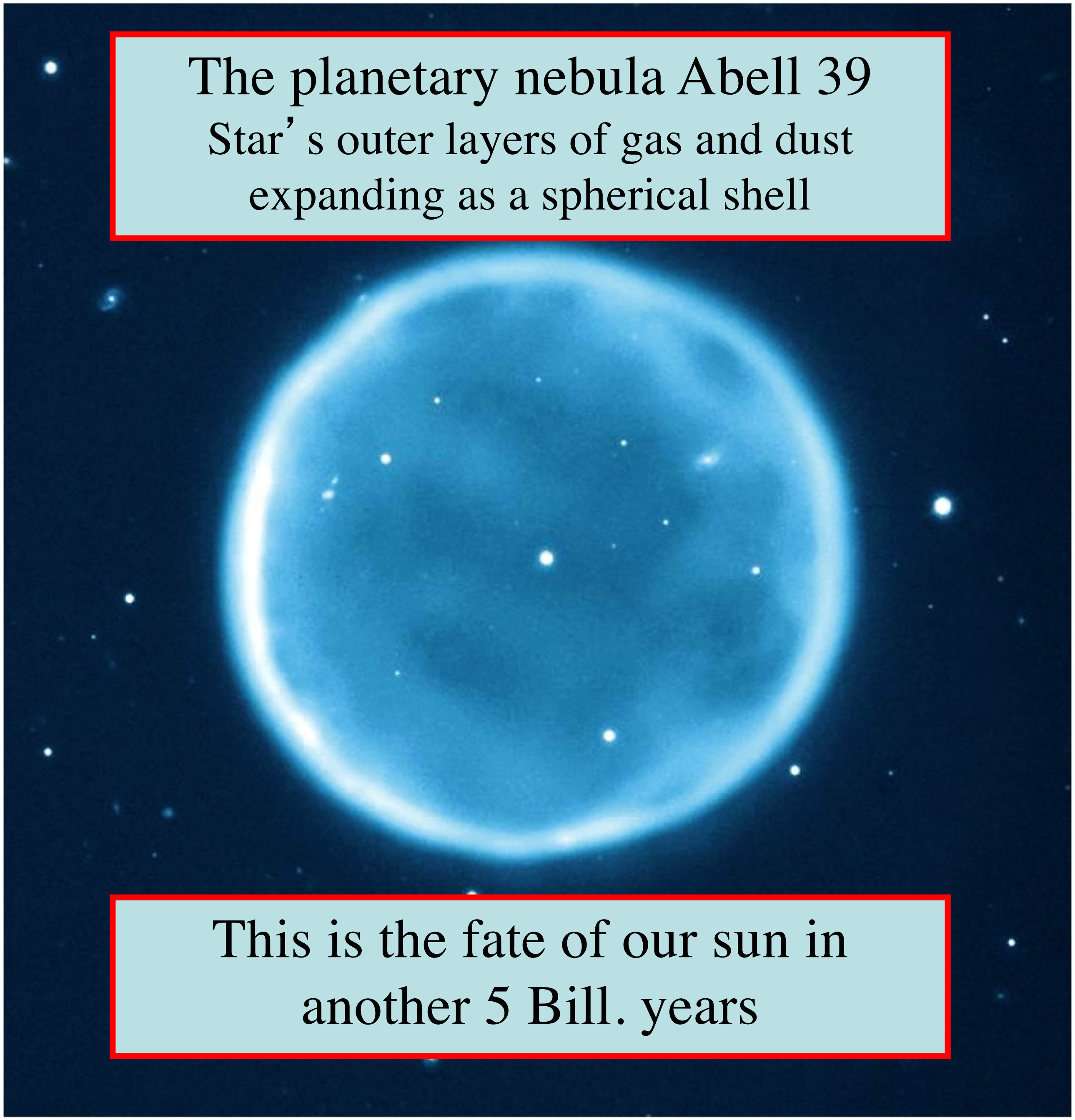


Figure 5-1b
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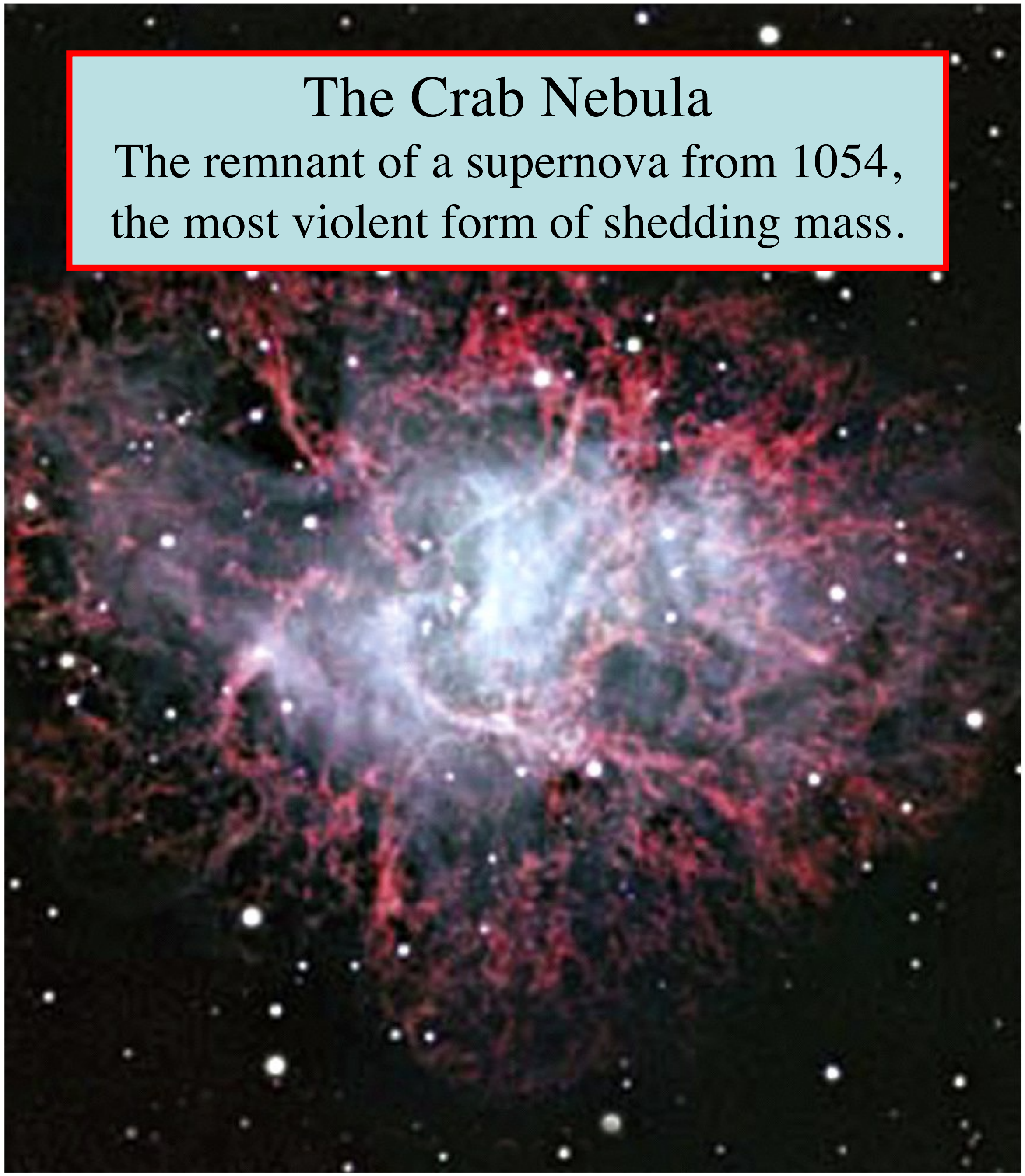

Figure 5-1c
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Dusty regions of star formation in the Cone Nebula

Our solar system formed from a similar fragment

Figure 5-2a
Discovering the Universe, Eighth Edition

Figure 5-2b
Discovering the Universe, Eighth Edition

The formation of the solar system

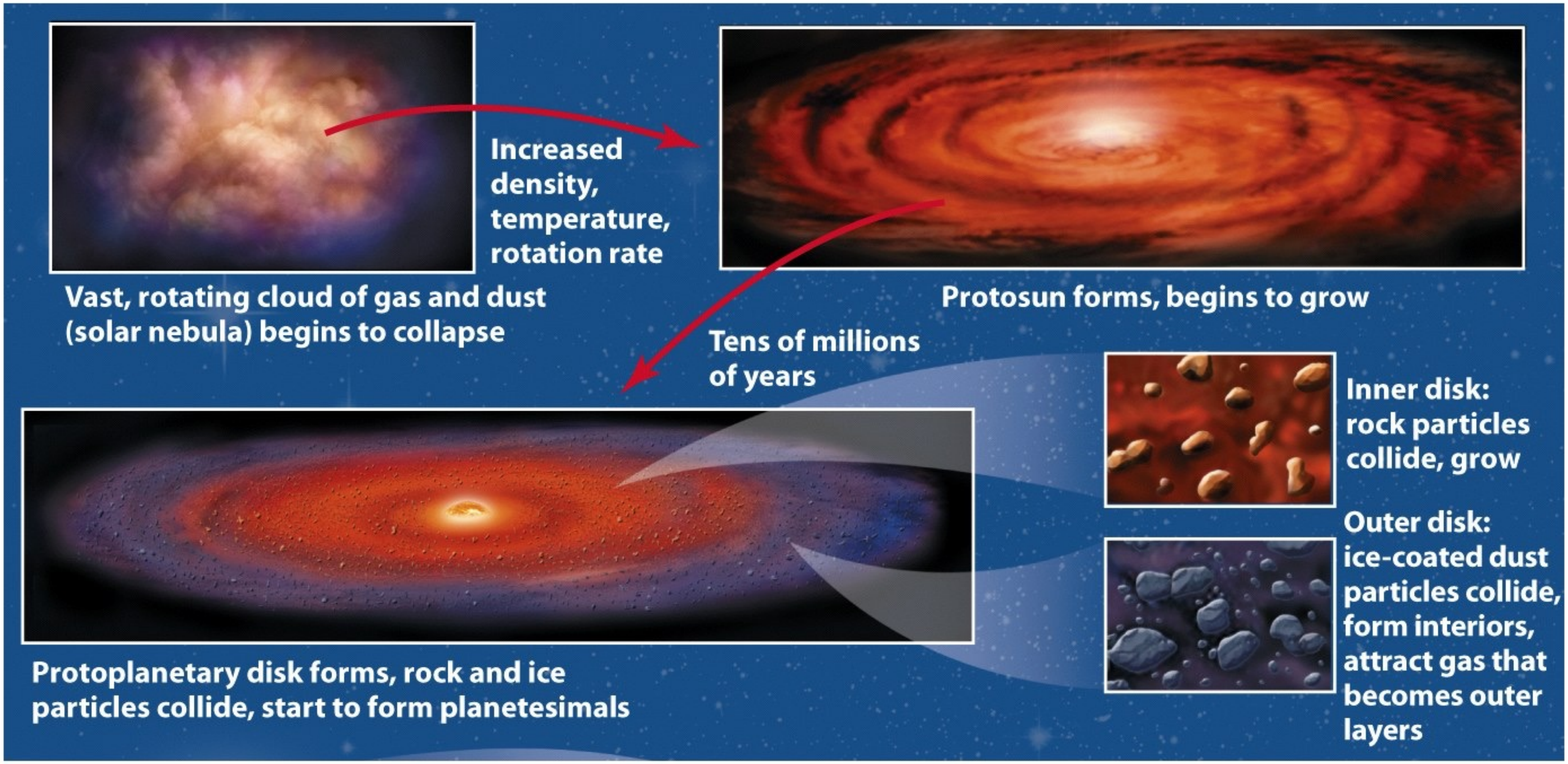

Figure 5-3 part 1
Discovering the Universe, Eighth Edition

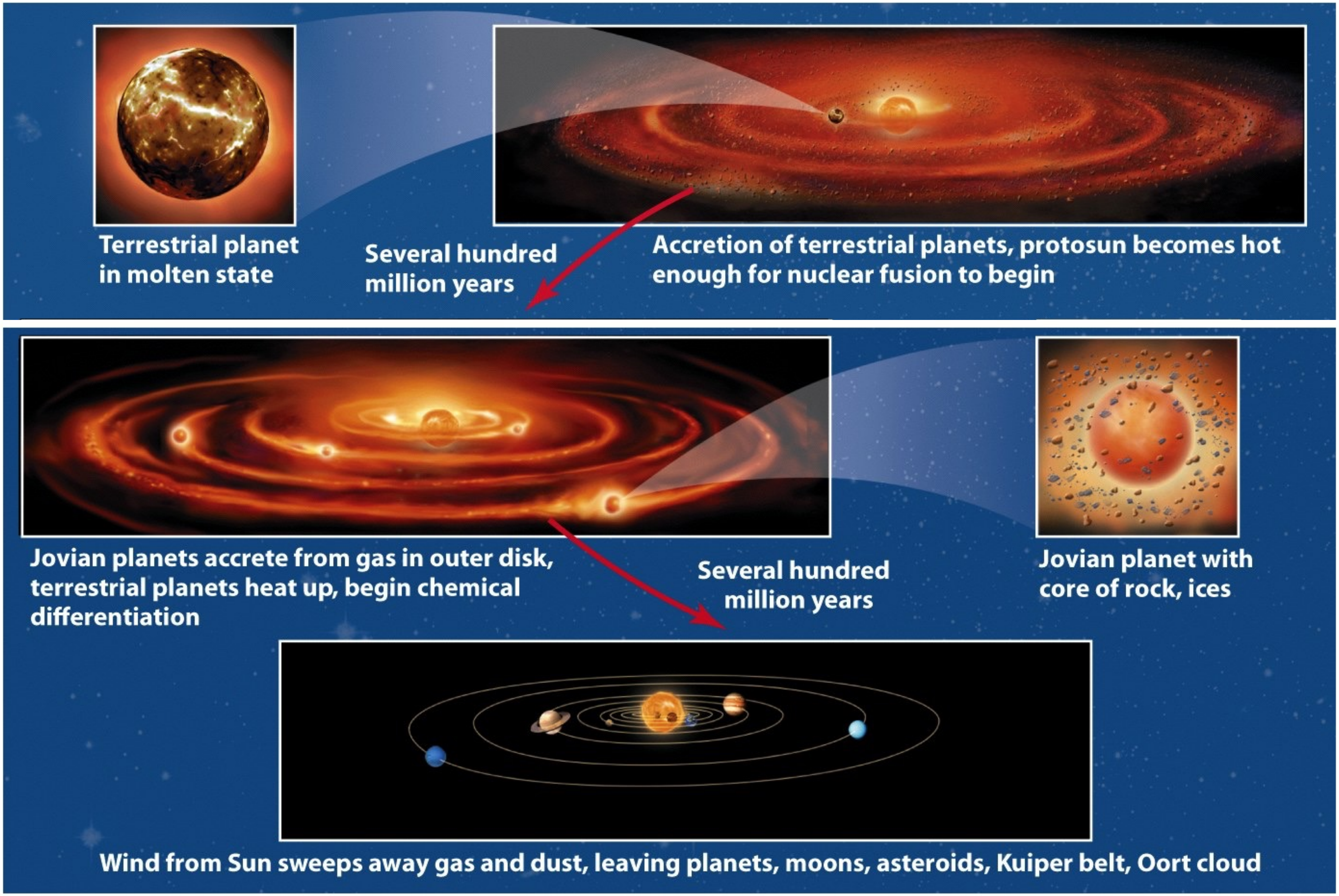

Figure 5-3 part 4

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Young circumstellar disks of matter in the heart of the Orion Nebula

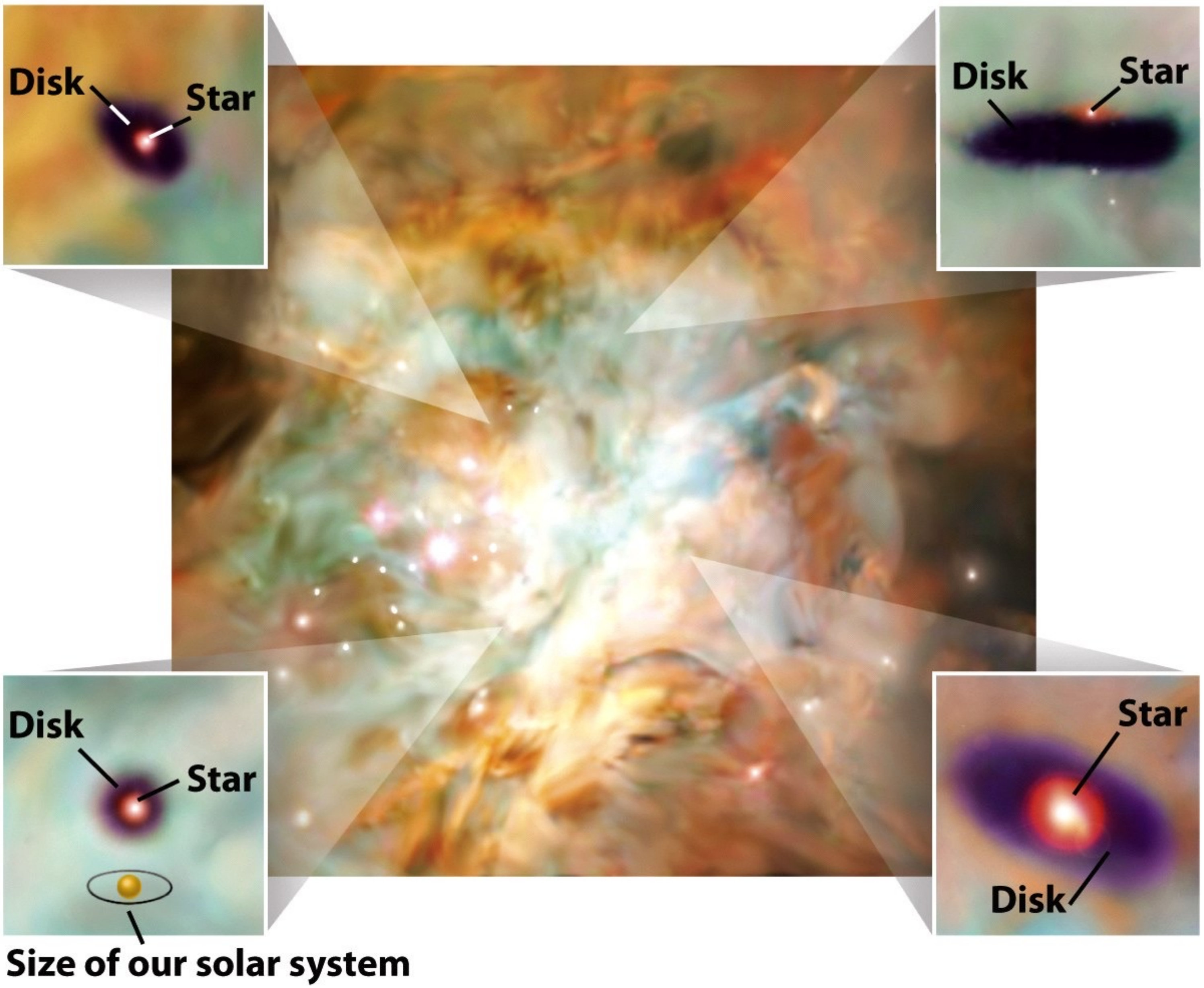

Figure 5-4
Discovering the Universe, Eighth Edition

The formation of the inner planets through accretion of material

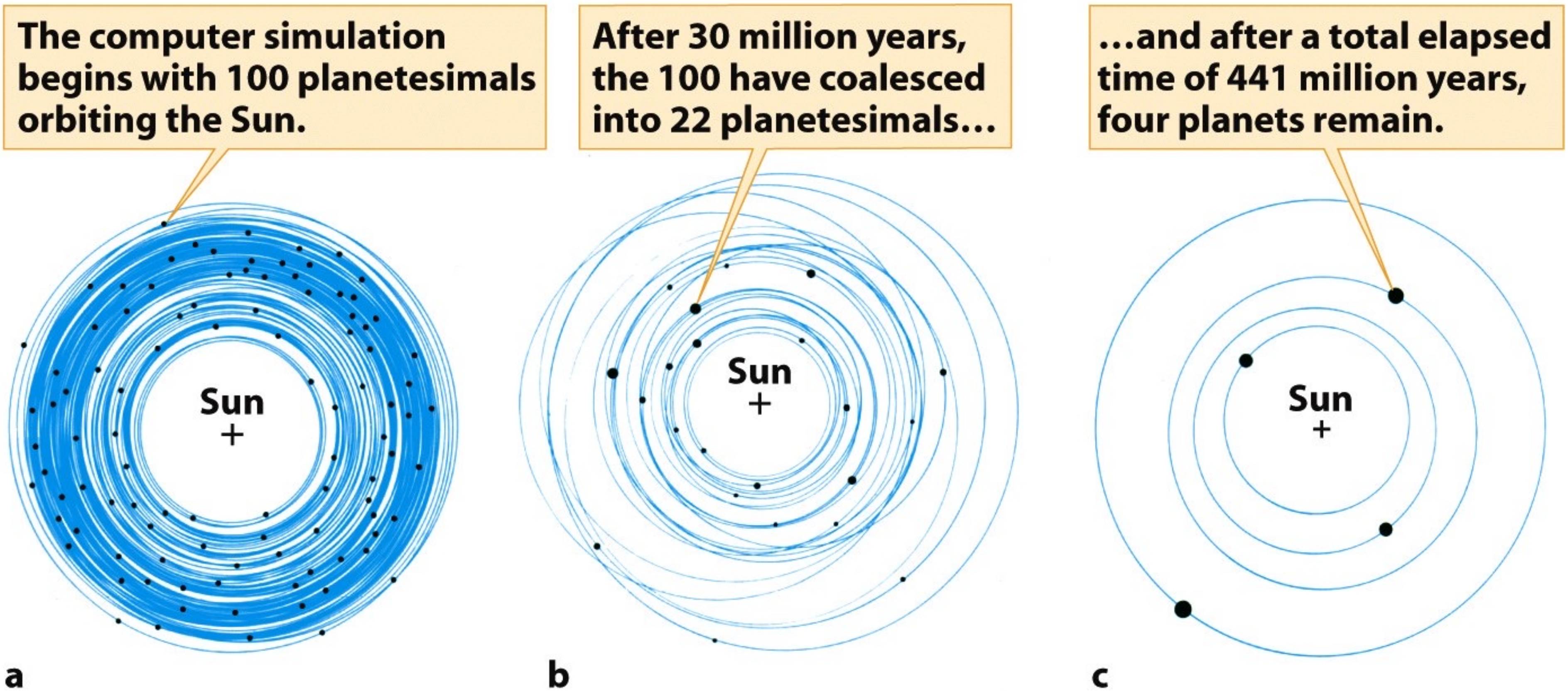

Figure 5-5
Discovering the Universe, Eighth Edition

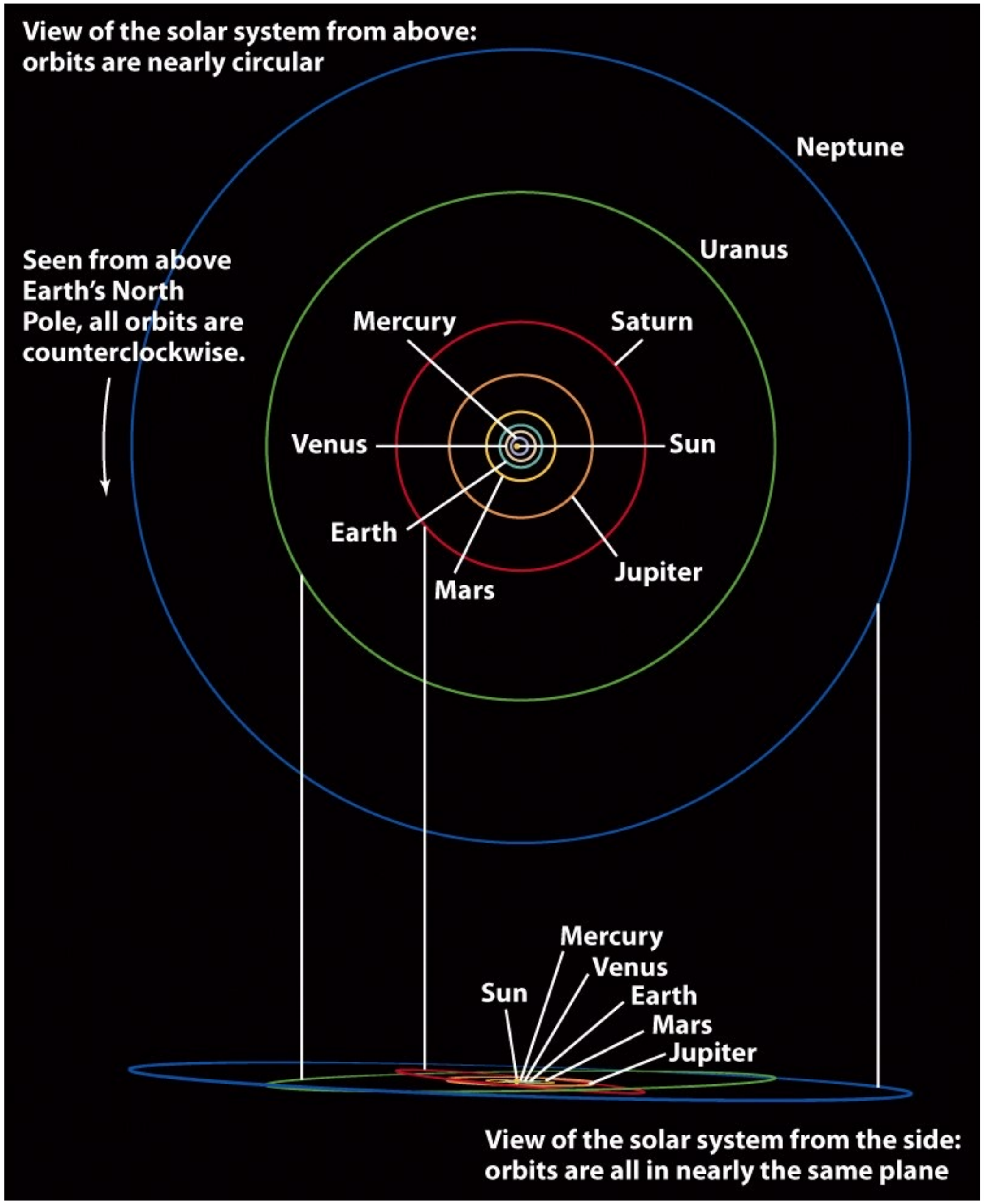

Figure 5-6

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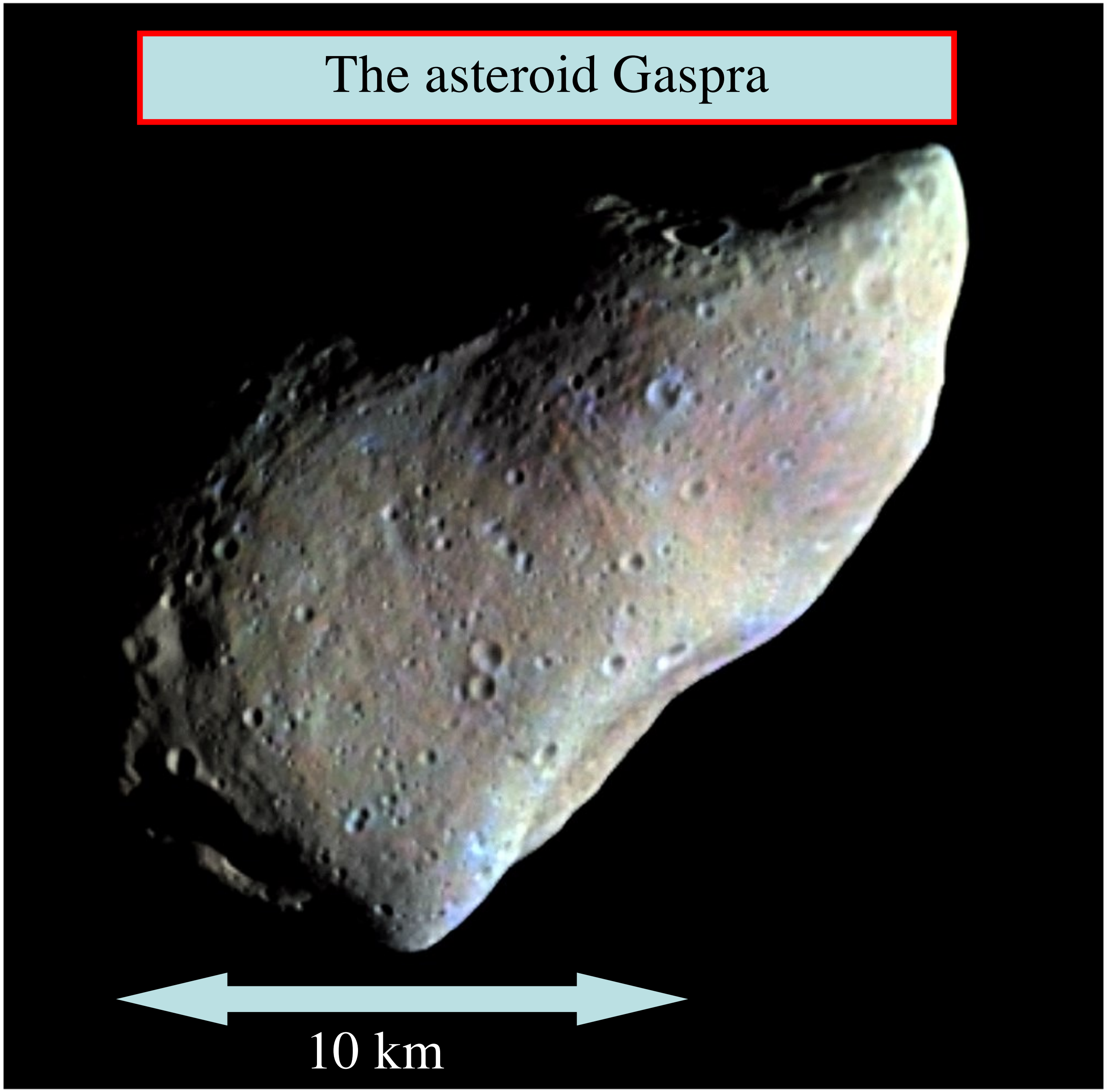
Our moon

Figure 5-7
Discovering the Universe, Eighth Edition

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.



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

Figure 5-8
Discovering the Universe, Eighth Edition

A comet

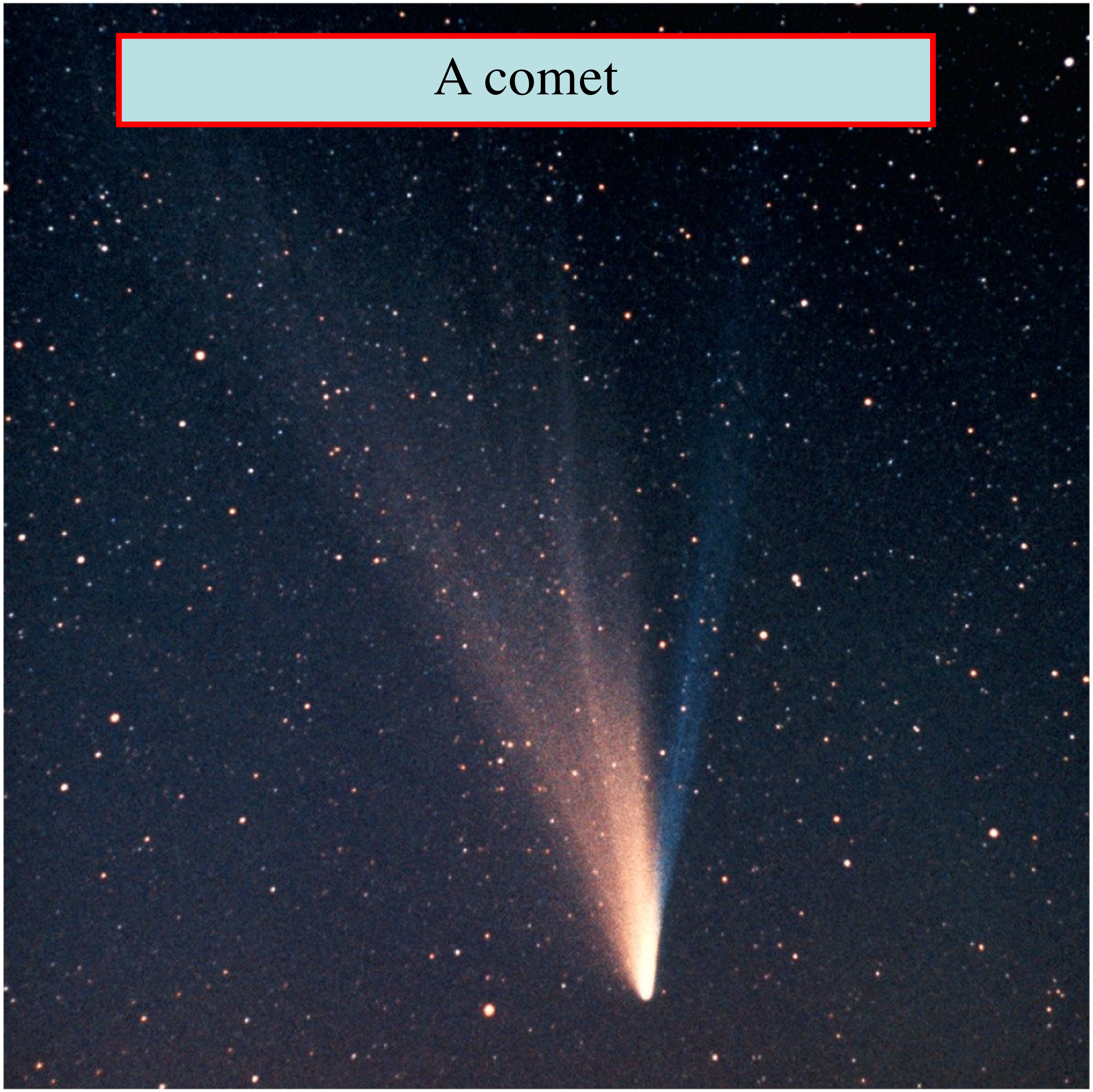


Figure 5-9
Discovering the Universe, Eighth Edition

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

The comet nucleus is typically 10 km in size.

TABLE 5-1 Orbital Characteristics of the Planets

	Average distance from Sun		Orbital period
	(AU)	(10^6 km)	(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
Discovering the Universe, Eighth Edition

The sun and the eight planets
drawn to size scale

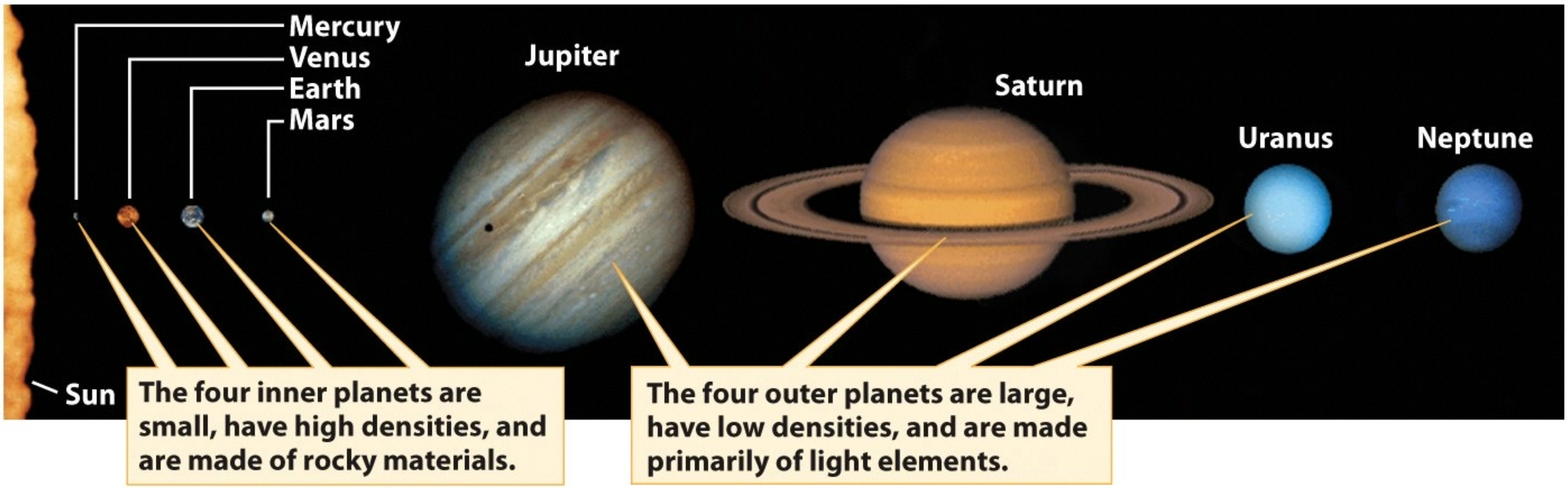
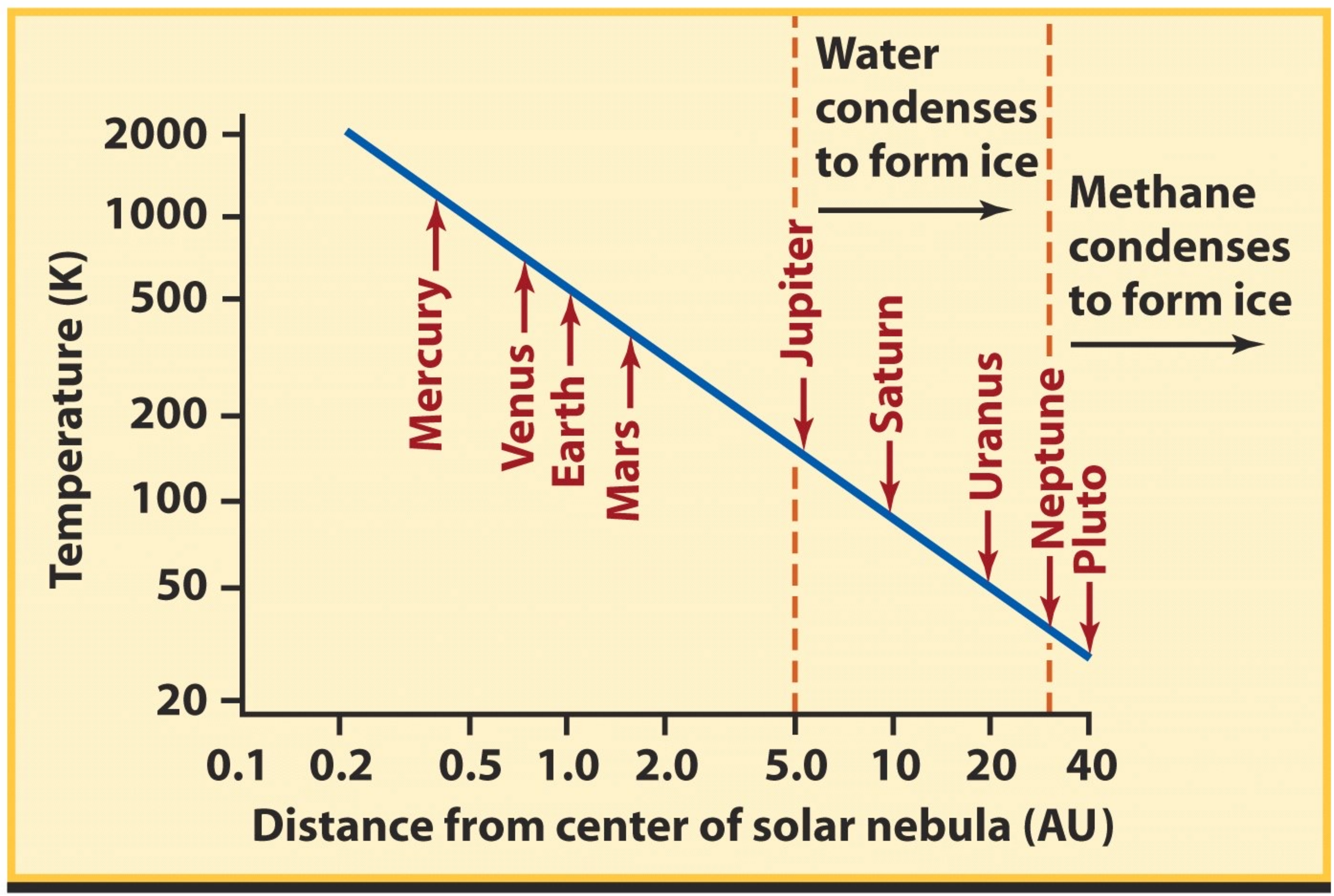


Figure 5-10
Discovering the Universe, Eighth Edition

$$D = \frac{m}{V}$$

- 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



Water condenses to form ice
Methane condenses to form ice
Temperature (K)
2000
1000
500
200
100
50
20
Mercury
Venus
Earth
Mars
Jupiter
Saturn
Uranus
Neptune
Pluto
0.1
0.2
0.5
1.0
2.0
5.0
10
20
40
Distance from center of solar nebula (AU)

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

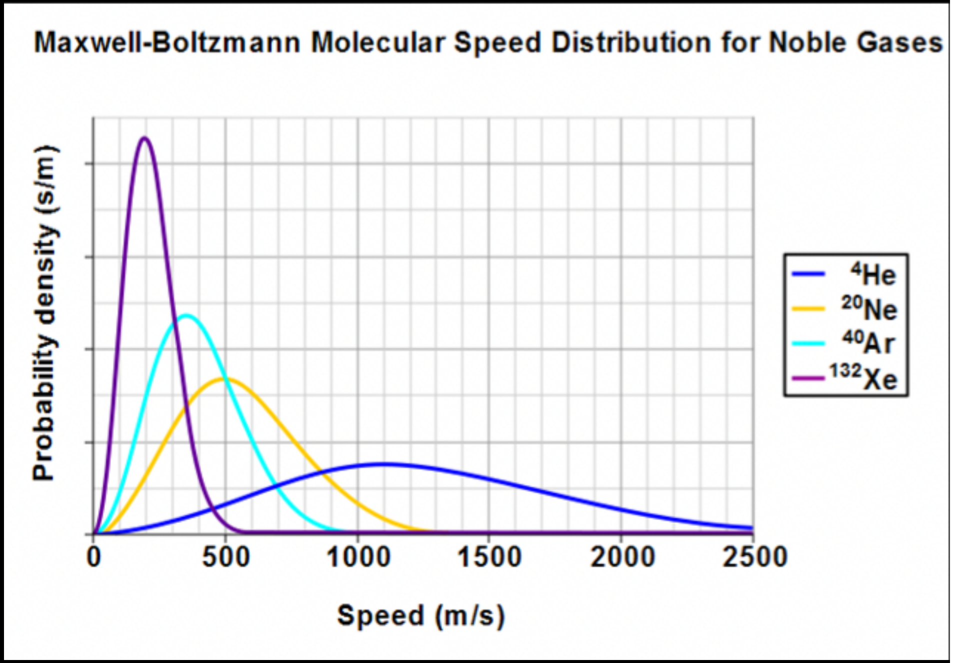
Kinetic energy, E_k, of a gas atom (or molecule)

$$E_k = \frac{1}{2} m v^2 = 3/2\ k\ T$$

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

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

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



Example:

H atom

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

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

Example:

H atom

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

$$v_{rms} = \mathrm{SQRT}(3 \times 1.38 \times 10^{-23} \times 300 / 1.66 \times 10^{-27})$$
$$= 2735 \text{ m s}^{-1}$$

Example:

H atom

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

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

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

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

TABLE 5-2 Physical Characteristics of the Planets

	Diameter		Mass		Average density
	(km)	(Earth = 1)	(kg)	(Earth = 1)	(kg/m^3)
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
Discovering the Universe, Eighth Edition

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

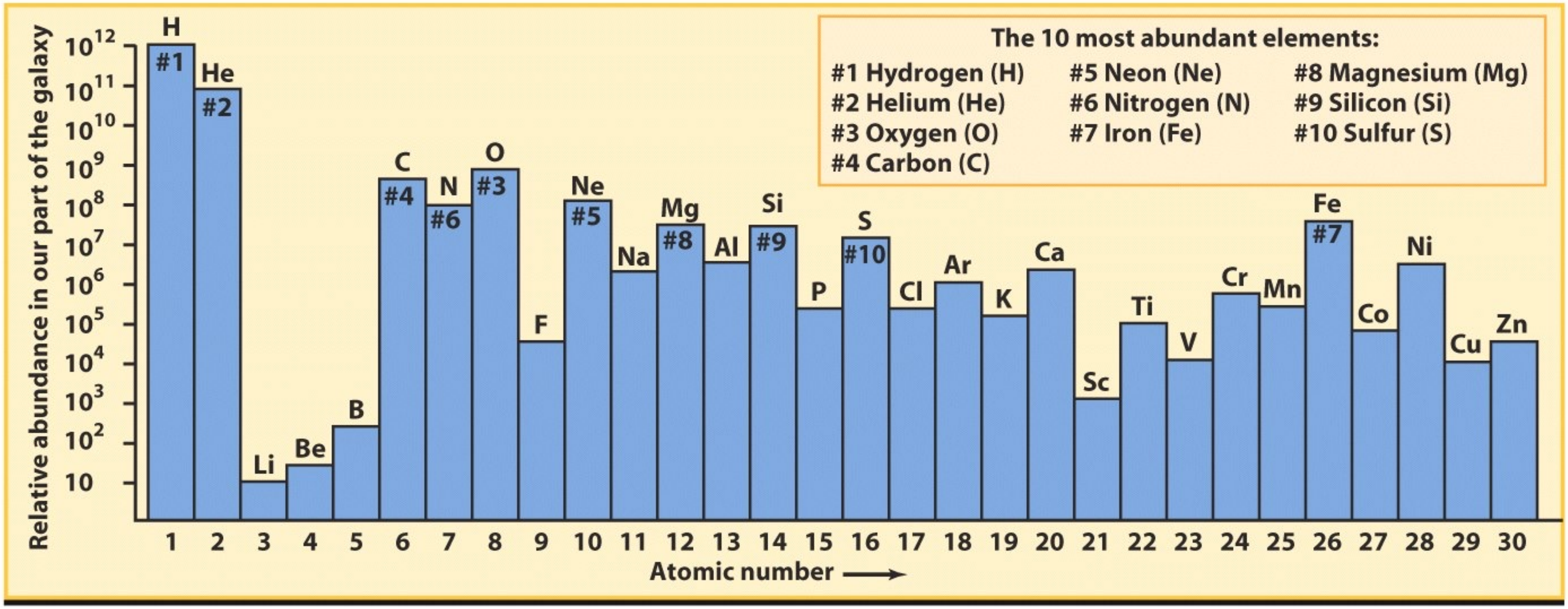
Any model of solar system origins must explain the present-day Sun and planets

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.

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