ASTRONOMY

Chapter 21 THE BIRTH OF STARS AND THE DISCOVERY OF PLANETS OUTSIDE THE SOLAR SYSTEM

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Introduction to

Astronomy

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PRESSURE AND GRAVITY

A star is born when gravity becomes strong enough to overcome pressure within a gas cloud and compress it until nuclear fusion begins.

A star lives while the energy generated by fusion can keep pressure and gravity in steady balance.

A star dies as it exhausts its fuel for fusion and goes out of balance again.

FIGURE 21.2

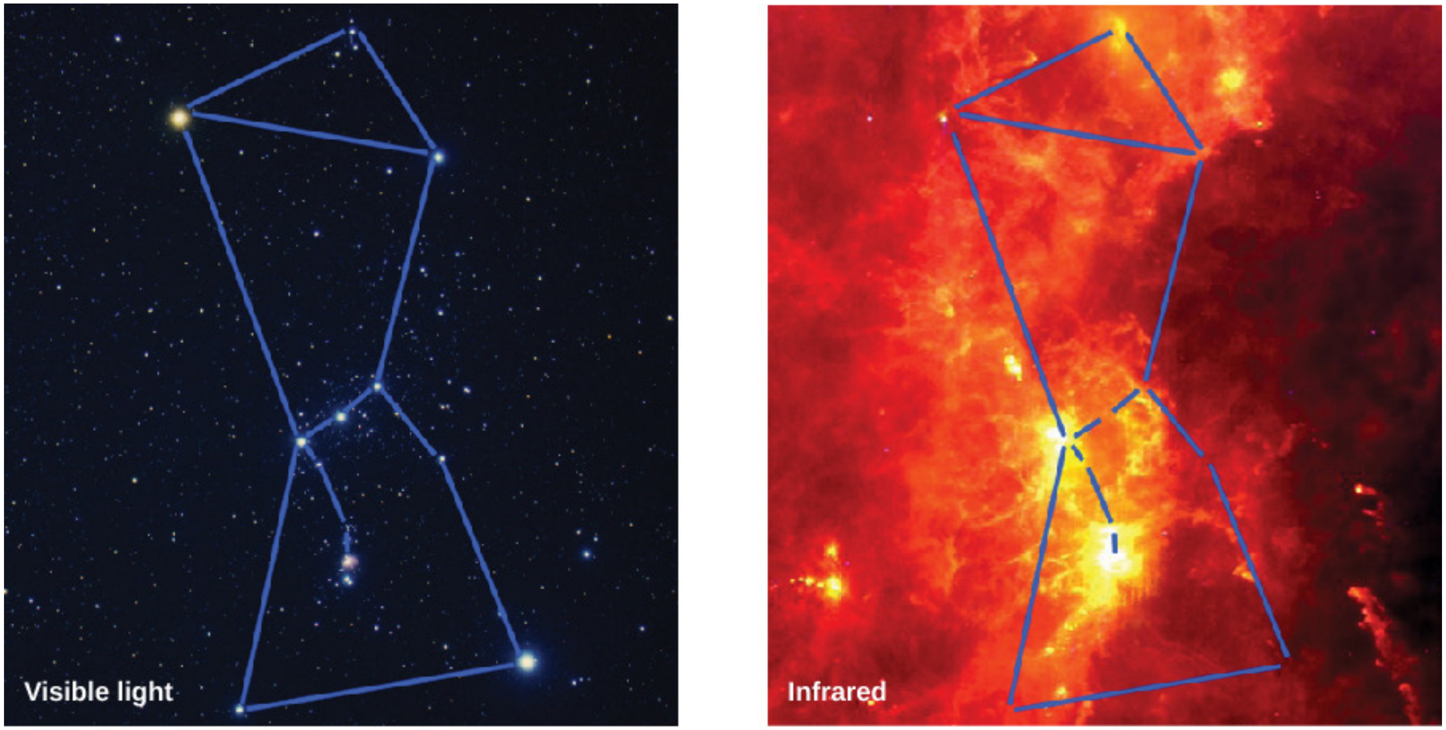

(a) (b)

Pillars of Dust and Dense Globules in M16.

(a) This Hubble Space Telescope image of the central regions of M16 (also known as the Eagle Nebula) shows huge columns of cool gas, (including molecular hydrogen, H2) and dust. These columns are of higher density than the surrounding regions and have resisted evaporation by the ultraviolet radiation from a cluster of hot stars just beyond the upper-right corner of this image. The tallest pillar is about 1 light-year long, and the M16 region is about 7000 light-years away from us.

(b) This close-up view of one of the pillars shows some very dense globules, many of which harbor embryonic stars. Astronomers coined the term *evaporating gas globules* (EGGs) for these structures, in part so that they could say we found EGGs inside the Eagle Nebula. It is possible that because these EGGs are exposed to the relentless action of the radiation from nearby hot stars, some may not yet have collected enough material to form a star. (credit a: modification of work by NASA, ESA, and the Hubble Heritage Team (STScI/AURA); credit b: modification of work by NASA, ESA, STScI, J. Hester and P. Scowen (Arizona State University))

FIGURE 21.3



(a)

(b)

Orion in Visible and Infrared.

(a) The Orion star group was named after the legendary hunter in Greek mythology. Three stars close together in a link mark Orion’s belt. The ancients imagined a sword hanging from the belt; the object at the end of the blue line in this sword is the Orion Nebula.

(b) This wide-angle, infrared view of the same area was taken with the Infrared Astronomical Satellite. Heated dust clouds dominate in this false-color image, and many of the stars that stood out on part (a) are now invisible. An exception is the cool, red-giant star Betelgeuse, which can be seen as a yellowish point at the left vertex of the blue triangle (at Orion’s left armpit). The large, yellow ring to the right of Betelgeuse is the remnant of an exploded star. The infrared image lets us see how large and full of cooler material the Orion molecular cloud really is. On the visible-light image at left, you see only two colorful regions of interstellar matter—the two, bright yellow splotches at the left end of and below Orion’s belt. The lower one is the Orion Nebula and the higher one is the region of the Horsehead Nebula. (credit: modification of work by NASA, visible light: Akira Fujii; infrared: Infrared Astronomical Satellite)

STAR BIRTH

Stars form out of interstellar gas, within clouds in which the inward pull of gravity becomes stronger than the outward push of gas pressure.

Two things can help gravity win out over pressure and start the contraction of a cloud of gas:

- (1) high density, because packing the gas particles closer together makes the gravitational forces between them stronger, and
- (2) low temperature, because lowering a cloud's temperature reduces the gas pressure.

We therefore expect star-forming clouds to be colder and denser than most other interstellar gas clouds.

MOLECULAR CLOUDS

Stars are indeed born within the coldest and densest clouds, called molecular clouds because their low temperatures allow hydrogen atoms to pair up to form hydrogen molecules.

They typically have temperatures of only 10–30 K.

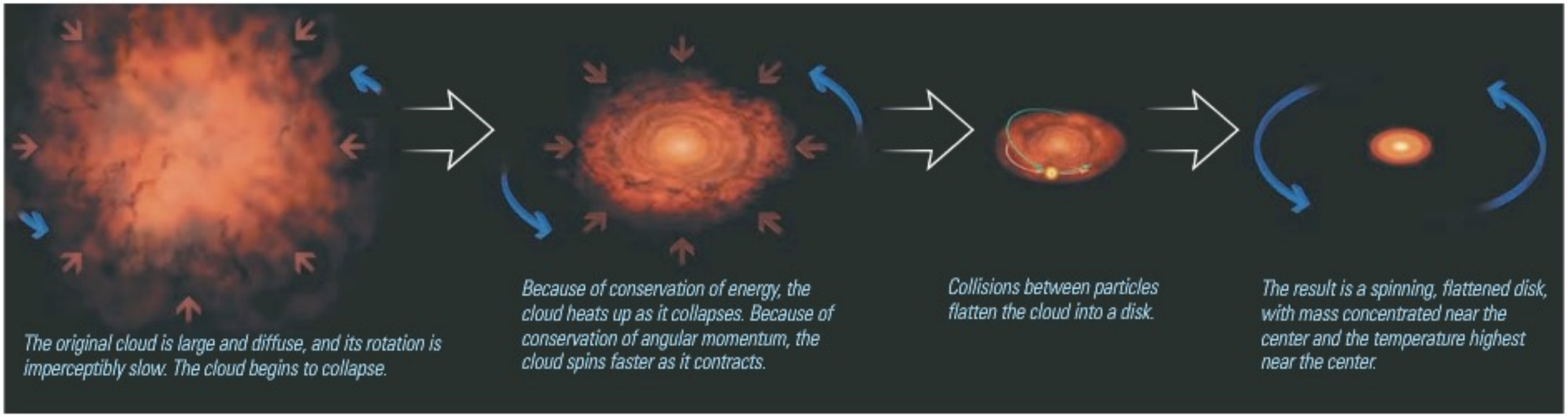
And while their densities are still low enough that they would qualify as superb vacuums by earthly standards, these molecular clouds are hundreds to thousands of times as dense as other regions of interstellar space.

The molecular clouds that give birth to stars also tend to be quite large—typically containing enough material to form thousands of stars—because more total mass also helps gravity overcome gas pressure.

Nobeyama Radio Observatory, Japan

Figure 9.1. Page 144. ***The Cosmic Perspective Fundamentals*****.**
Publisher: Addison-Wesley. © 2010

GRAVITATIONAL COLLAPSE OF A LARGE CLOUD



The original cloud is large and diffuse, and its rotation is imperceptibly slow. The cloud begins to collapse.

Because of conservation of energy, the cloud heats up as it collapses. Because of conservation of angular momentum, the cloud spins faster as it contracts.

Collisions between particles flatten the cloud into a disk.

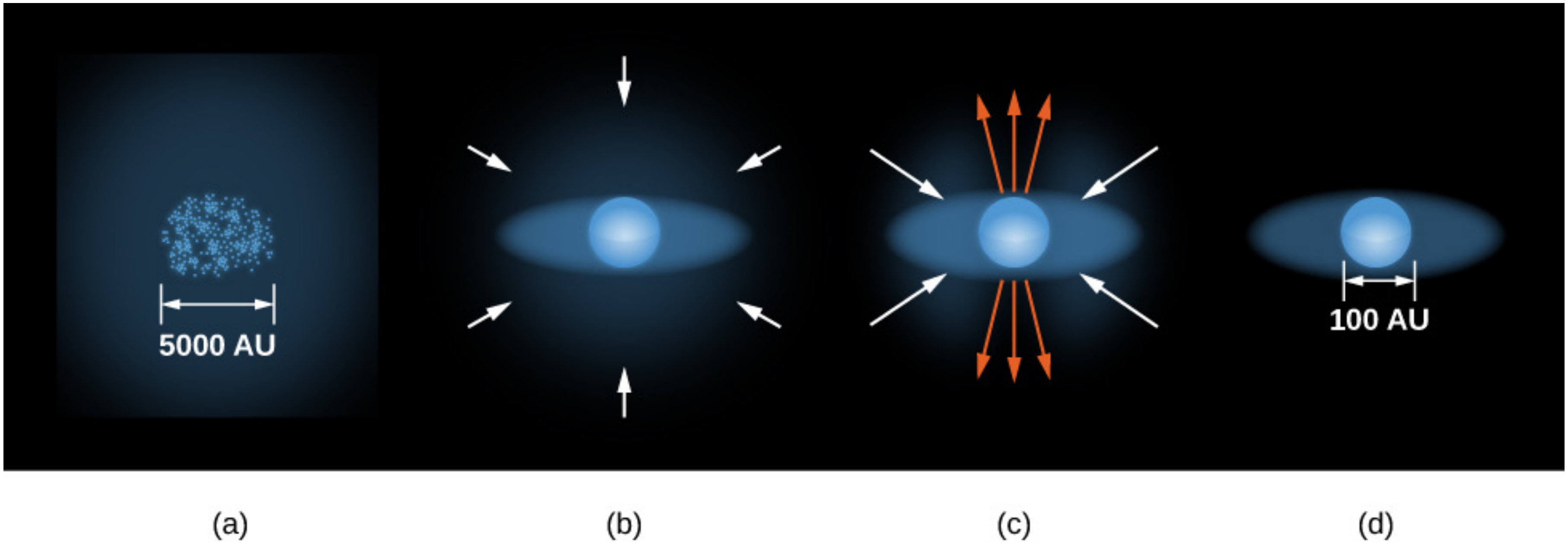
The result is a spinning, flattened disk, with mass concentrated near the center and the temperature highest near the center.

The planets orbit the Sun in nearly the same plane because they formed in a flat disk.

The direction in which the disk was spinning became the direction of the Sun's rotation and the orbits of the planets.

Figure 4.6. Page 64. *The Cosmic Perspective Fundamentals*. Publisher: Addison-Wesley. © 2010

FIGURE 21.8



Formation of a Star.

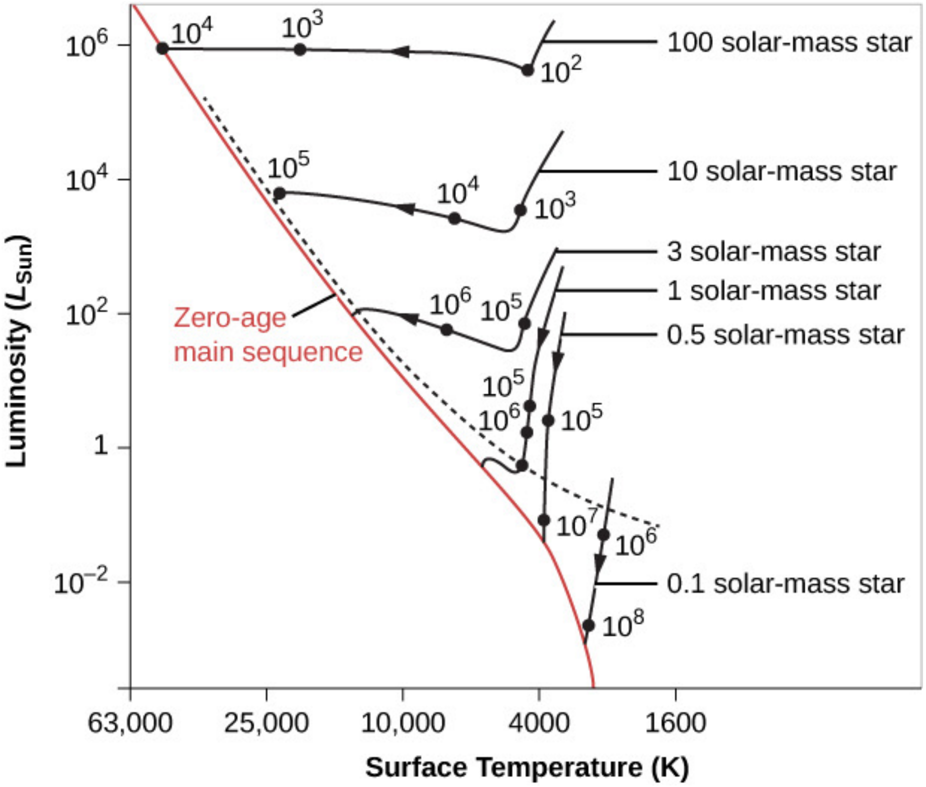
(a) Dense cores form within a molecular cloud.

(b) A protostar with a surrounding disk of material forms at the center of a dense core, accumulating additional material from the molecular cloud through gravitational attraction.

(c) A stellar wind breaks out but is confined by the disk to flow out along the two poles of the star.

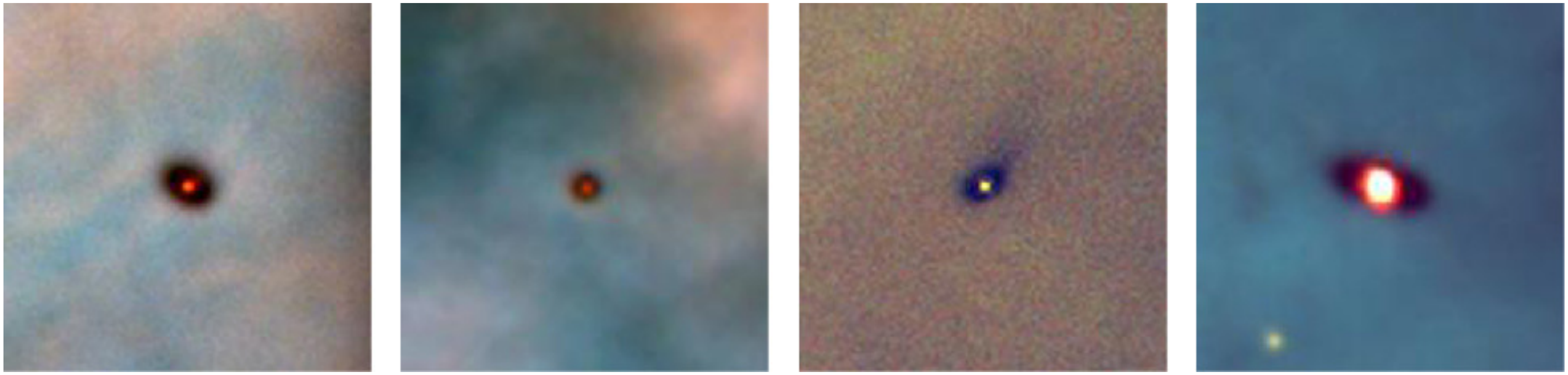
(d) Eventually, this wind sweeps away the cloud material and halts the accumulation of additional material, and a newly formed star, surrounded by a disk, becomes observable. These sketches are not drawn to the same scale. The diameter of a typical envelope that is supplying gas to the newly forming star is about 5000 AU. The typical diameter of the disk is about 100 AU or slightly larger than the diameter of the orbit of Pluto.

FIGURE 21.12



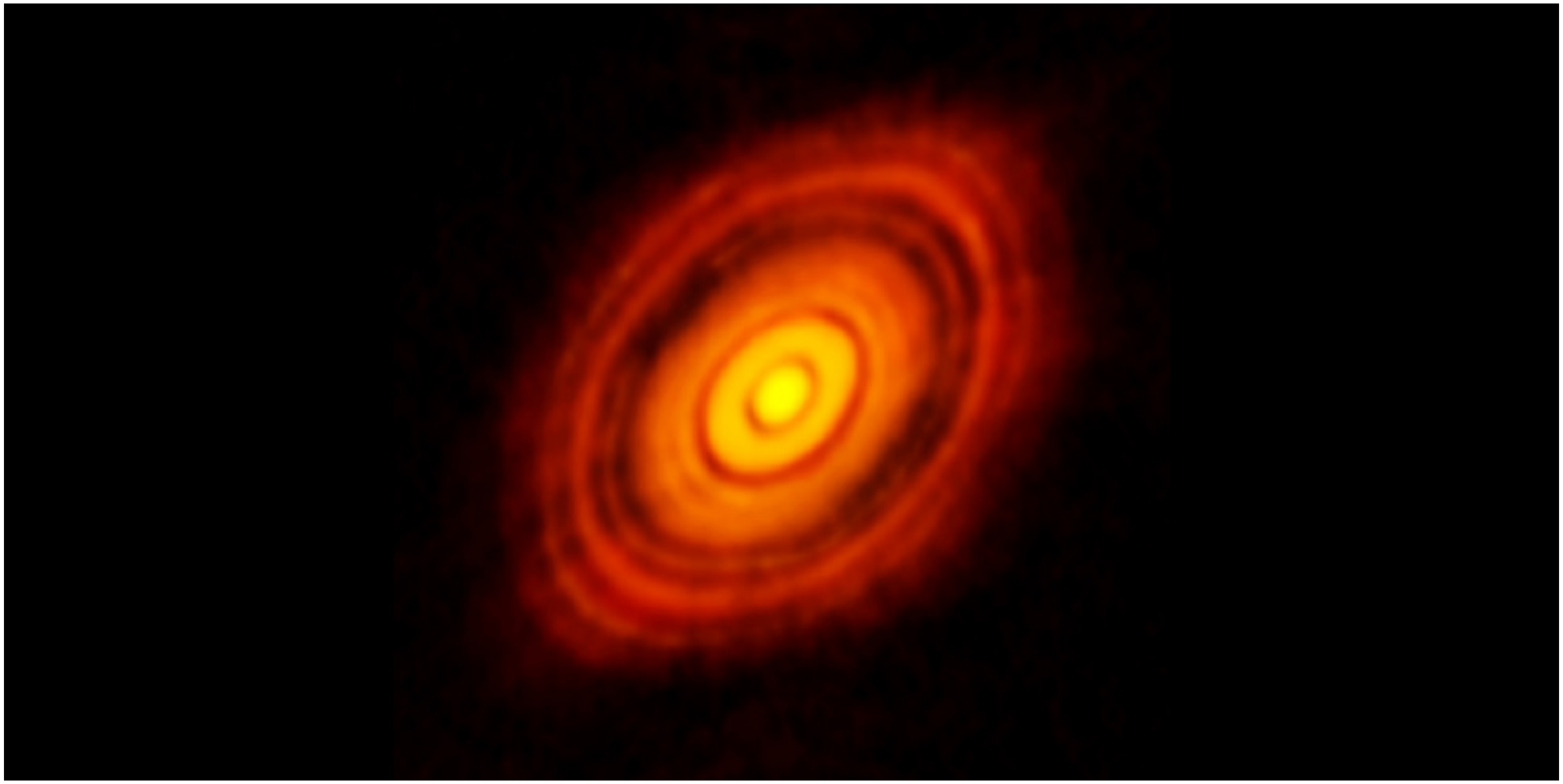
Evolutionary Tracks for Contracting Protostars. Tracks are plotted on the H–R diagram to show how stars of different masses change during the early parts of their lives. The number next to each dark point on a track is the rough number of years it takes an embryo star to reach that stage (the numbers are the result of computer models and are therefore not well known). Note that the surface temperature (K) on the horizontal axis increases toward the left. You can see that the more mass a star has, the shorter time it takes to go through each stage. Stars above the dashed line are typically still surrounded by infalling material and are hidden by it.

FIGURE 21.13



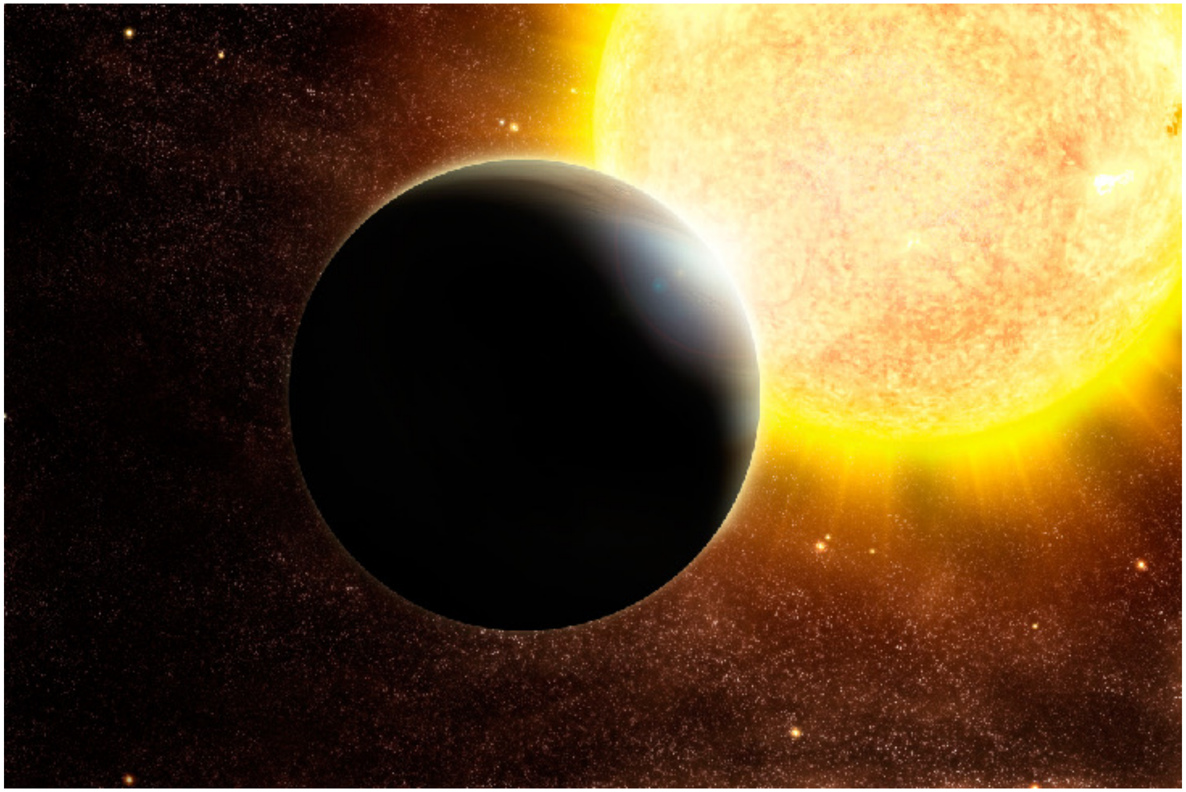
Disks around Protostars. These Hubble Space Telescope images show four disks around young stars in the Orion Nebula. The dark, dusty disks are seen silhouetted against the bright backdrop of the glowing gas in the nebula. The size of each image is about 30 times the diameter of our planetary system; this means the disks we see here range in size from two to eight times the orbit of Pluto. The red glow at the center of each disk is a young star, no more than a million years old. These images correspond to the stage in the life of a protostar shown in part (d) of **Figure 21.8**. (credit: modification of work by Mark McCaughrean (Max-Planck-Institute for Astronomy), C. Robert O’Dell (Rice University), and NASA)

FIGURE 21.15



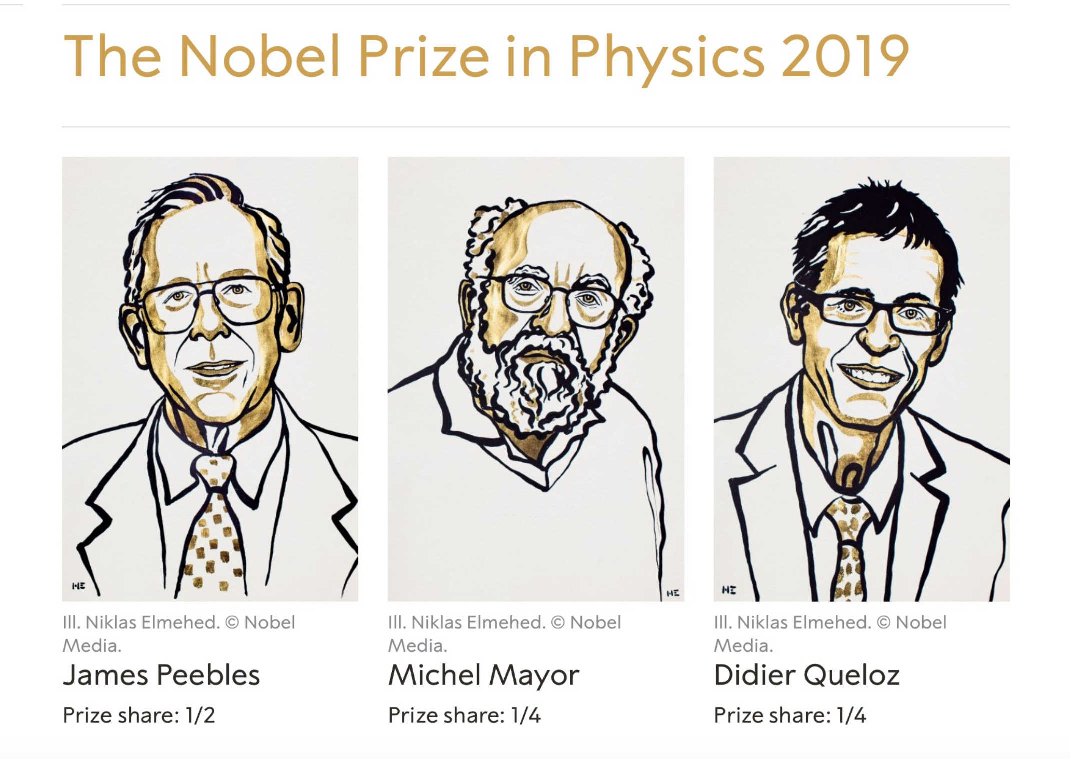
Dust Ring around a Young Star. This image was made by ALMA (the Atacama Large Millimeter/Submillimeter Array) at a wavelength of 1.3 millimeters and shows the young star HL Tau and its protoplanetary disk. It reveals multiple rings and gaps that indicate the presence of emerging planets, which are sweeping their orbits clear of dust and gas. (credit: modification of work by ALMA (ESO/NAOJ/NRAO))

FIGURE 21.18



Hot Jupiter. Artist Greg Bacon painted this impression of a hot, Jupiter-type planet orbiting close to a sunlike star. The artist shows bands on the planet like Jupiter, but we only estimate the mass of most hot, Jupiter-type planets from the Doppler method and don’t know what conditions on the planet are like. (credit: ESO)

THE NOBEL PRIZE IN PHYSICS 2019



The Nobel Prize in Physics 2019

Ill. Niklas Elmehed. © Nobel Media.

James Peebles

Prize share: 1/2

Ill. Niklas Elmehed. © Nobel Media.

Michel Mayor

Prize share: 1/4

Ill. Niklas Elmehed. © Nobel Media.

Didier Queloz

Prize share: 1/4

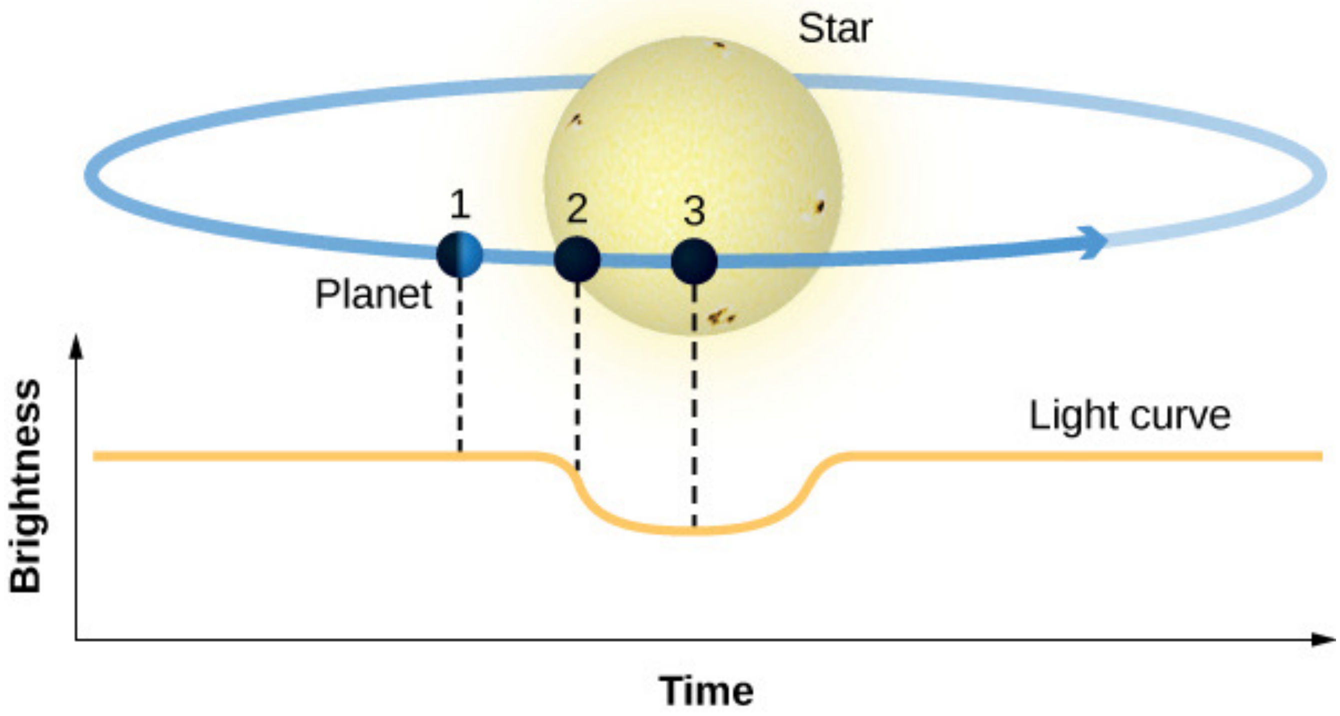
The Nobel Prize in Physics 2019 was awarded "for contributions to our understanding of the evolution of the universe and Earth's place in the cosmos" with one half to James Peebles "for theoretical discoveries in physical cosmology", the other half jointly to Michel Mayor and Didier Queloz "for the discovery of an exoplanet orbiting a solar-type star."

https://www.nobelprize.org/prizes/physics/2019/summary/

FIGURE 21.17

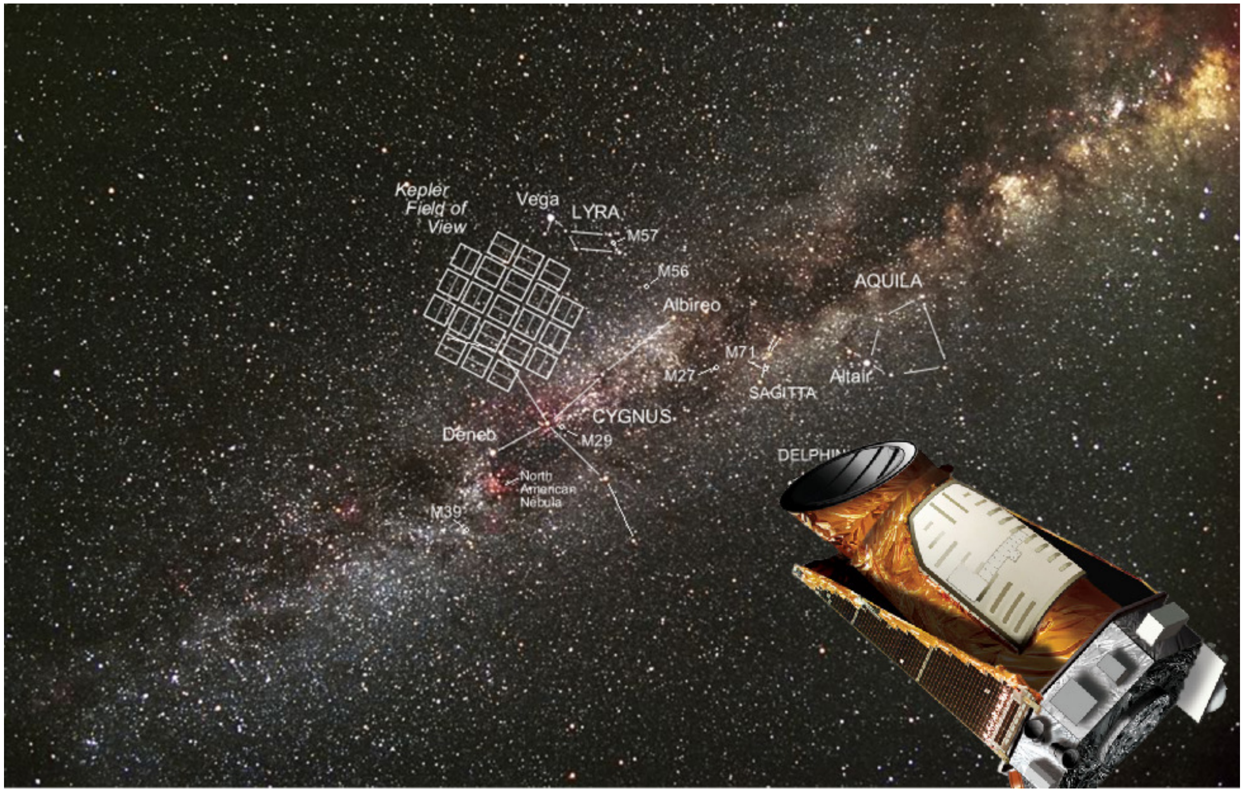
Planet Discoverers. In 1995, Didier Queloz and Michel Mayor of the Geneva Observatory were the first to discover a planet around a regular star (51 Pegasi). They are seen here at an observatory in Chile where they are continuing their planet hunting. (credit: Weinstein/Ciel et Espace Photos)

FIGURE 21.19



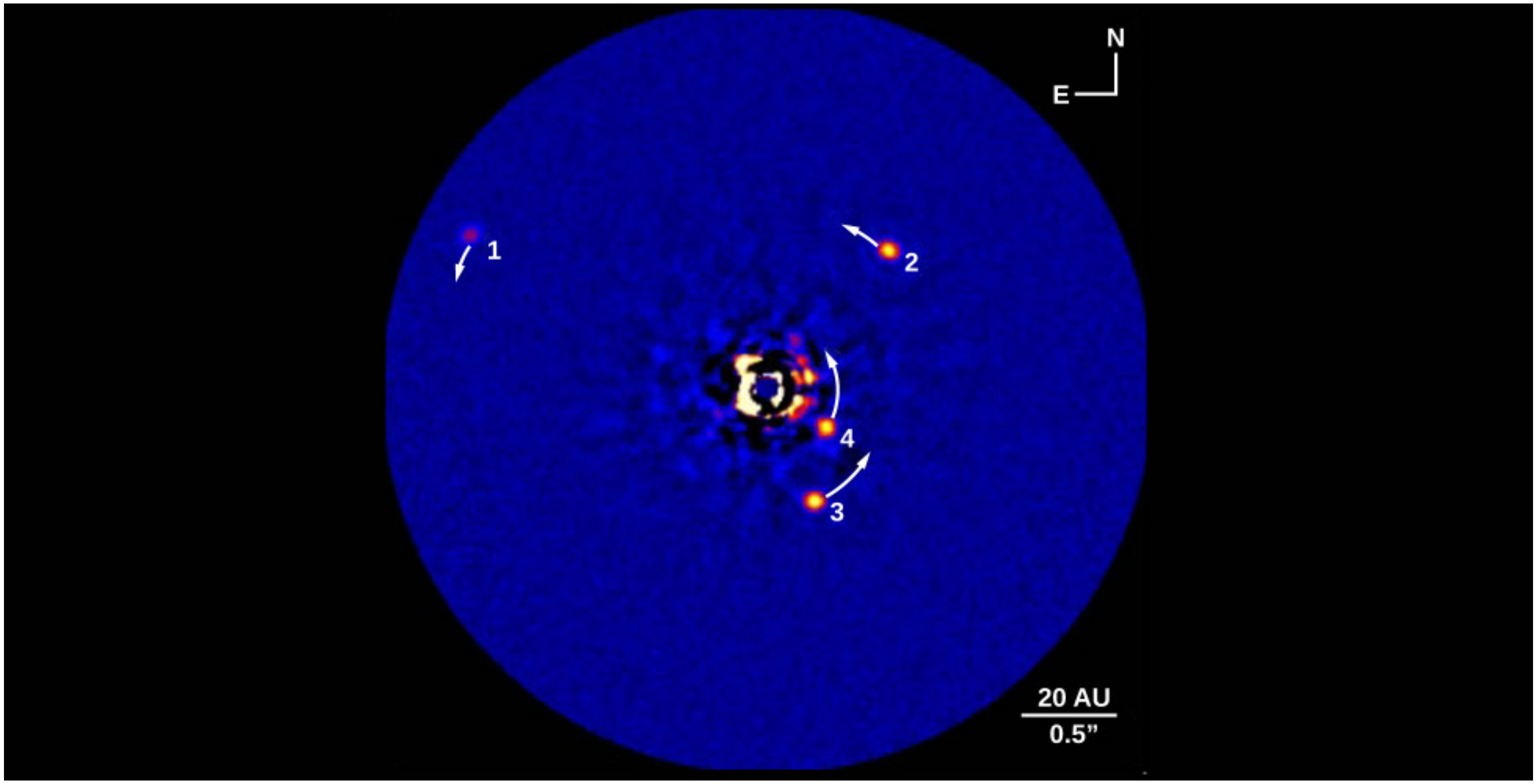
Planet Transits. As the planet transits, it blocks out some of the light from the star, causing a temporary dimming in the brightness of the star. The top figure shows three moments during the transit event and the bottom panel shows the corresponding light curve: (1) out of transit, (2) transit ingress, and (3) the full drop in brightness.

FIGURE 21.20



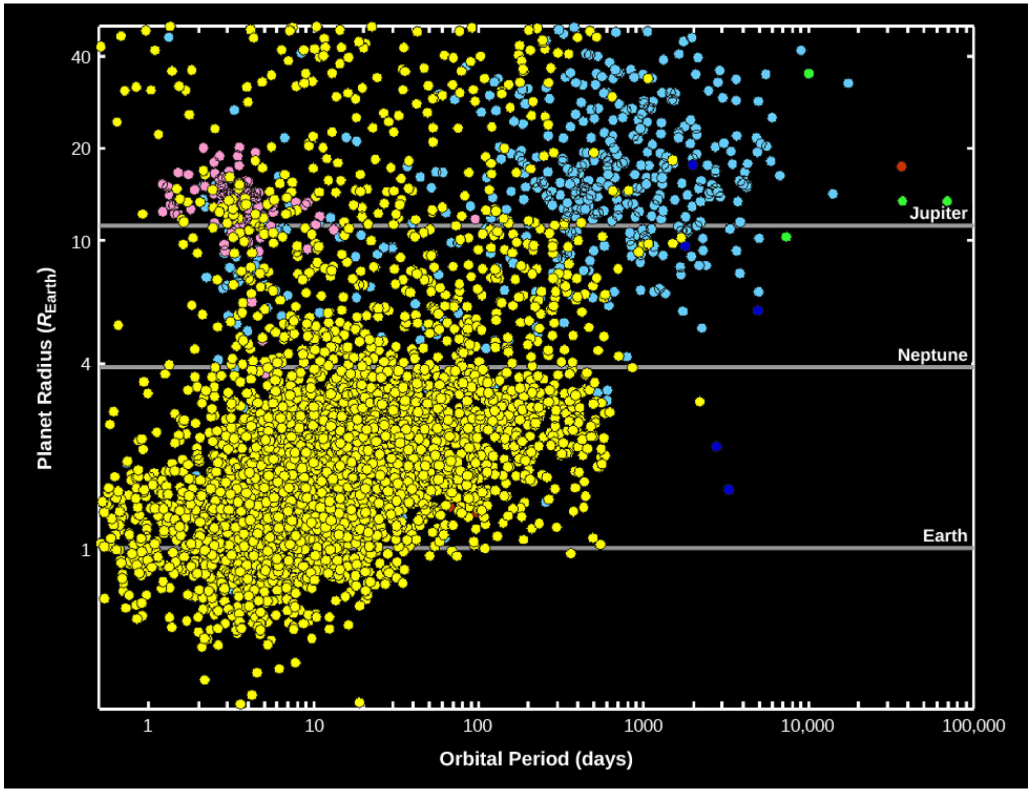
Kepler's Field of View. The boxes show the region where the Kepler spacecraft cameras took images of over 150,000 stars regularly, to find transiting planets. (credit "field of view": modification of work by NASA/Kepler mission; credit "spacecraft": modification of work by NASA/Kepler mission/Wendy Stenzel)

FIGURE 21.21



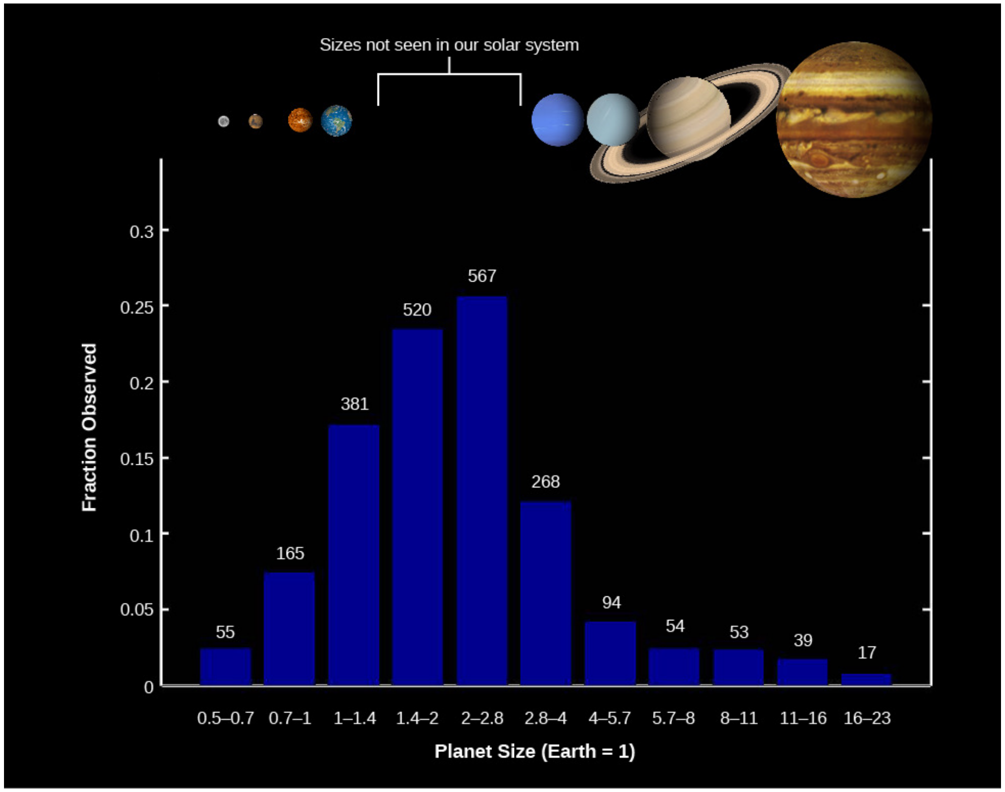
Exoplanets around HR 8799. This image shows Keck telescope observations of four directly imaged planets orbiting HR 8799. A size scale for the system gives the distance in AU (remember that one astronomical unit is the distance between Earth and the Sun.) (credit: modification of work by Ben Zuckerman)

FIGURE 21.22



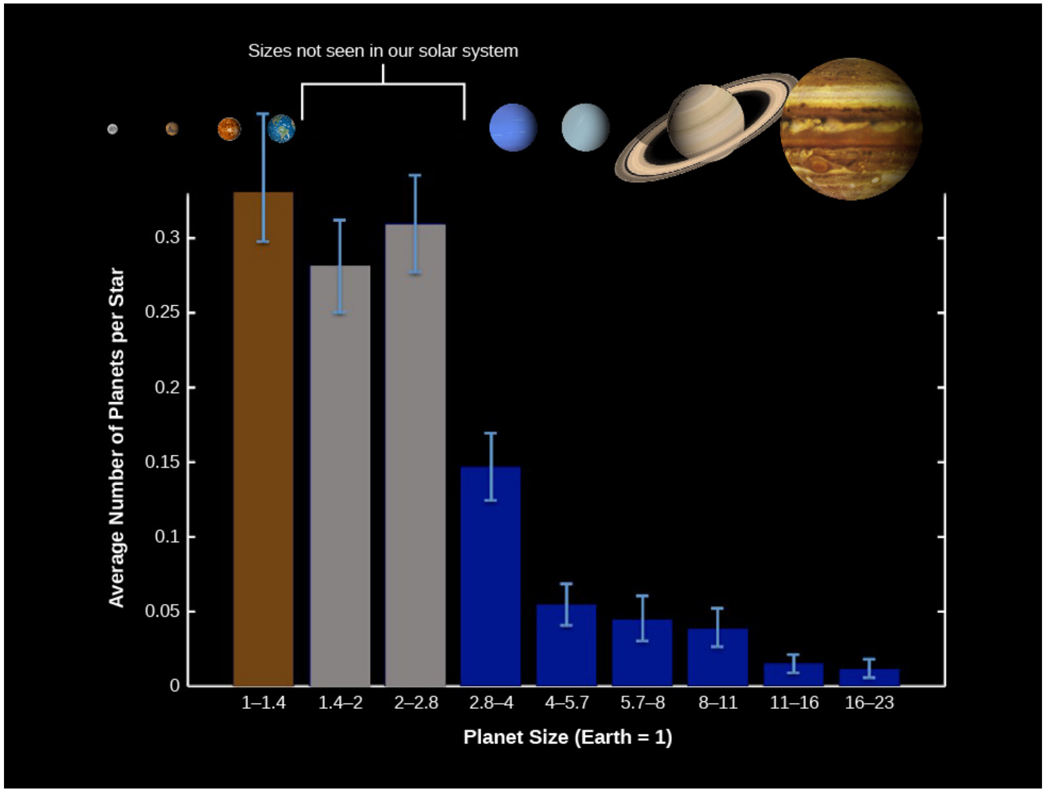
Exoplanet Discoveries through 2015. The vertical axis shows the radius of each planet compared to Earth. Horizontal lines show the size of Earth, Neptune, and Jupiter. The horizontal axis shows the time each planet takes to make one orbit (and is given in Earth days). Recall that Mercury takes 88 days and Earth takes a little more than 365 days to orbit the Sun. The yellow and red dots show planets discovered by transits, and the blue dots are the discoveries by the radial velocity (Doppler) technique. (credit: modification of work by NASA/Kepler mission)

FIGURE 21.23



Kepler Discoveries. This bar graph shows the number of planets of each size range found among the first 2213 Kepler planet discoveries. Sizes range from half the size of Earth to 20 times that of Earth. On the vertical axis, you can see the fraction that each size range makes up of the total. Note that planets that are between 1.4 and 4 times the size of Earth make up the largest fractions, yet this size range is not represented among the planets in our solar system. (credit: modification of work by NASA/Kepler mission)

FIGURE 21.24



Size Distribution of Planets for Stars Similar to the Sun. We show the average number of planets per star in each planet size range. (The average is less than one because some stars will have zero planets of that size range.) This distribution, corrected for biases in the Kepler data, shows that Earth-size planets may actually be the most common type of exoplanets. (credit: modification of work by NASA/Kepler mission)