

Astronomy

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Small 239

Office hours:

MTWR 10-11am

The Birth of Stars

- ◆ Stellar evolution
- ◆ Interstellar nebulae
- ◆ Start of the formation of a Star
- ◆ Stages of growth of a main sequence star
- ◆ Stars gain and lose mass
- ◆ Star clusters
- ◆ Where new stars form in galaxies
- ◆ The death of a star can trigger the birth of a new star.

[http:// physics.wm.edu/~hancock/171/](http://physics.wm.edu/~hancock/171/)

The life of a Star

A Star has a life cycle. It is born, consumes its nuclear fuel and eventually dies. A star's life can be short (only millions of years) or nearly as old as the age of the universe. A star's life is the story of two competing forces:

- The inward pull of gravity
- The outward pressure due to nuclear fusion.

Eventually gravity wins and the star dies. The death of a star often seeds new stars in a renewable cycle.

Interstellar Gas and Dust - Nebula



A closeup of the Orion Nebula

Figure 18-1b

Universe, Tenth Edition

NASA, ESA, M. Robberto [Space Telescope Science Institute/ESA] and the Hubble Space Telescope Orion Treasury Project Team

The space between stars is not completely empty. There is gas and microscopic dust. The gas is very thin (what would be considered a good vacuum on Earth). If you look at Orion near the 'sword' you can see a giant tenuous gas cloud known as the Orion nebula. The spectrum is of a hot, thin gas. It is an emission nebula because it emits its own light. The emission is because of high energy photons from nearby star. The density of the gas is a few thousand H atoms per cm^3 . Nebula are common and can have masses of $10^2 - 10^4 M_{\odot}$. They are many light years across.

Emission Nebula

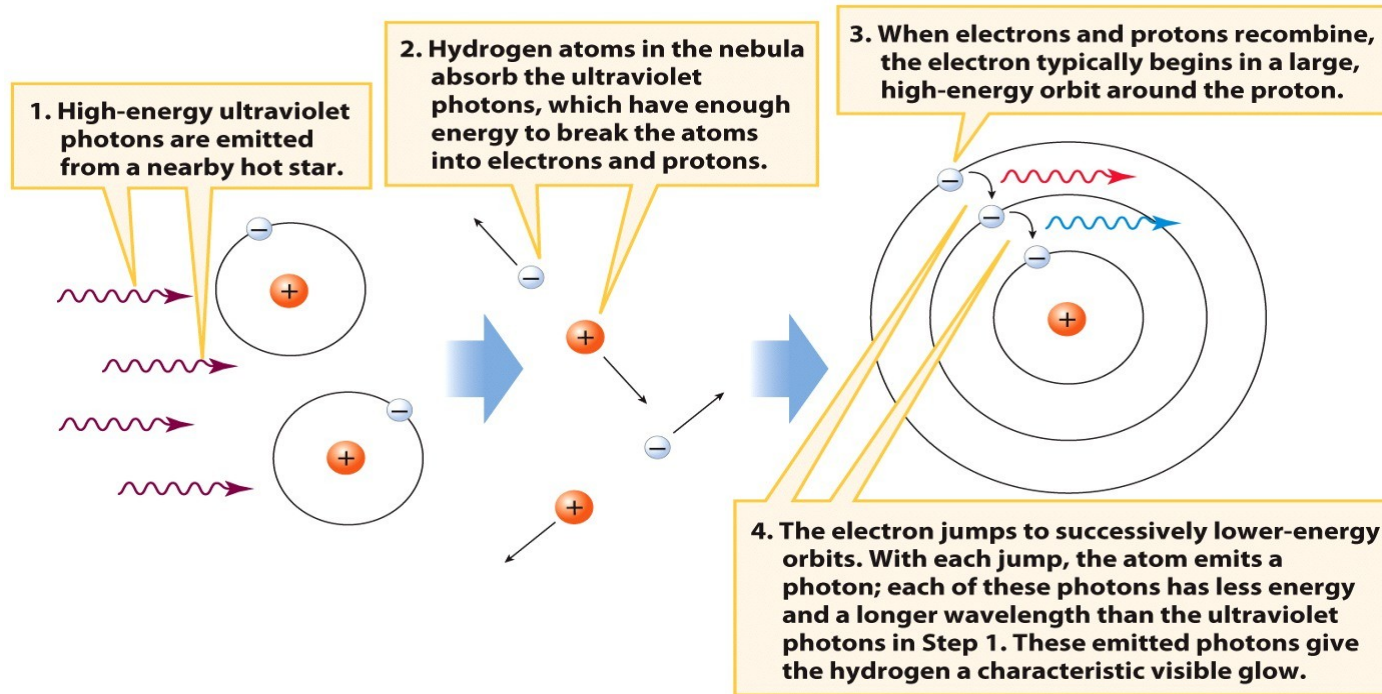
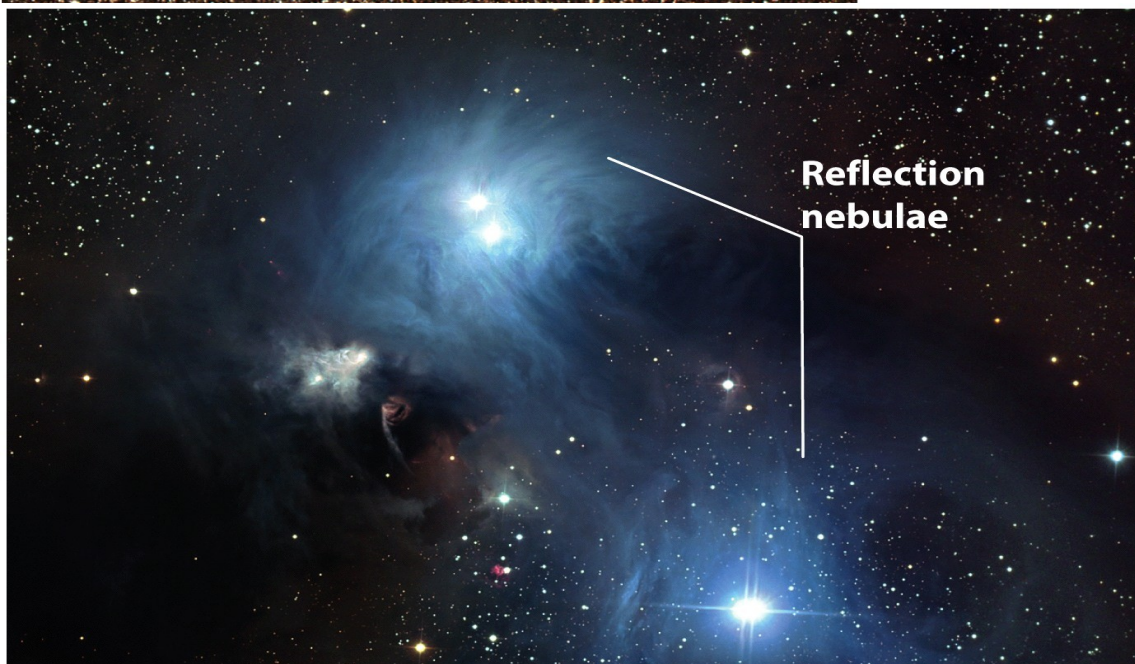
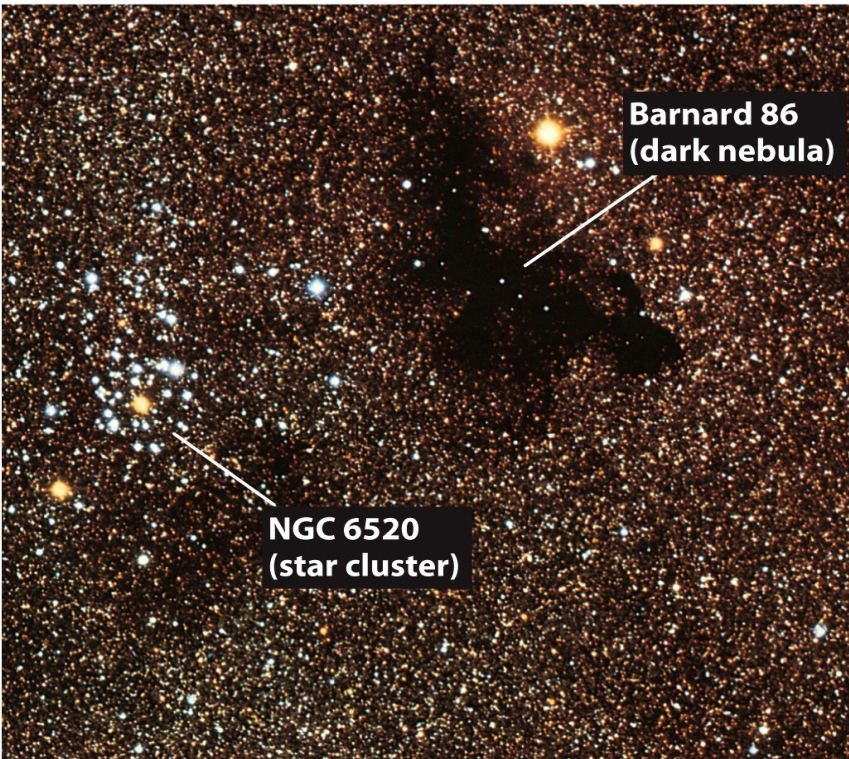


Figure 18-3
Universe, Tenth Edition
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A emission nebula is normally powered by spectral type O or B star. These are very hot stars (20,000 K) which emit large amounts of UV radiation. H atoms in the nebula absorb these photons and become ionized (H II). When the electron and proton **recombine**, the electron cascades down through the energy levels. When the electron cascades from the $n=3$ to $n=2$ level a red photon (656nm) is emitted giving the nebula its reddish color.

Dark and Reflection Nebulae



Dark and Reflection Nebulae show the presence of dust in Nebulae. A dark nebula occurs when dust blocks the light from stars behind the gas and dust cloud. If the dust is fine and in lower concentration, star light will reflect off of the dust and create a reflection nebula.

Interstellar Extinction

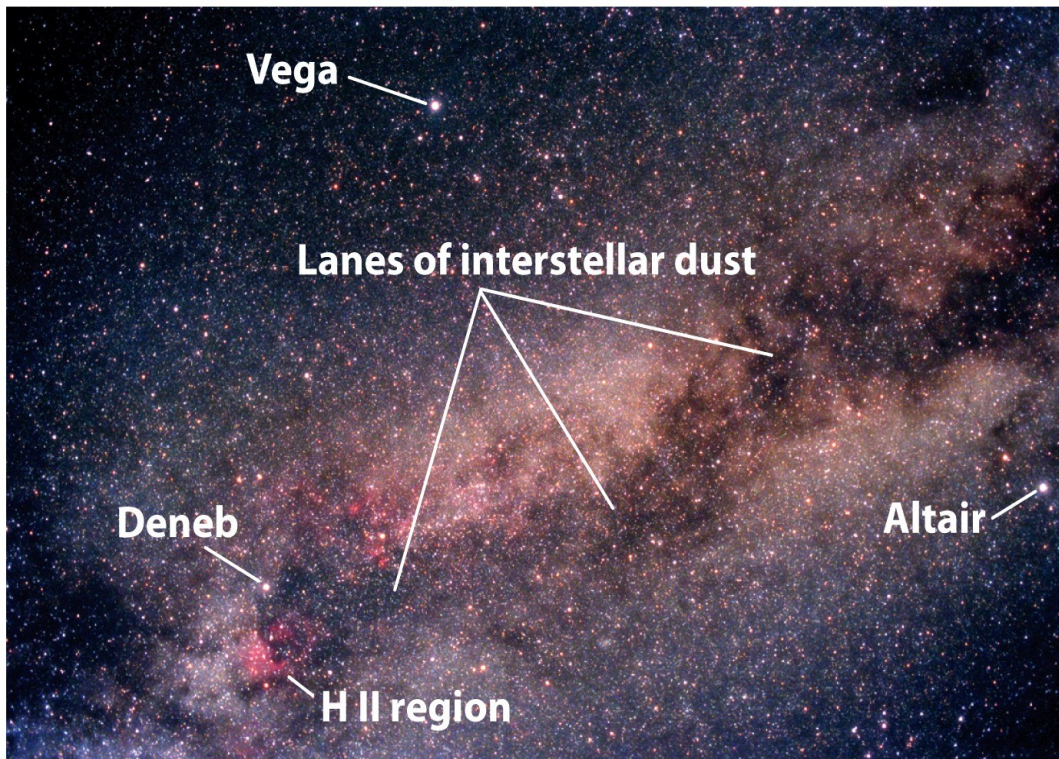


Figure 18-7
Universe, Tenth Edition
Jerry Lodriguss/Science Source

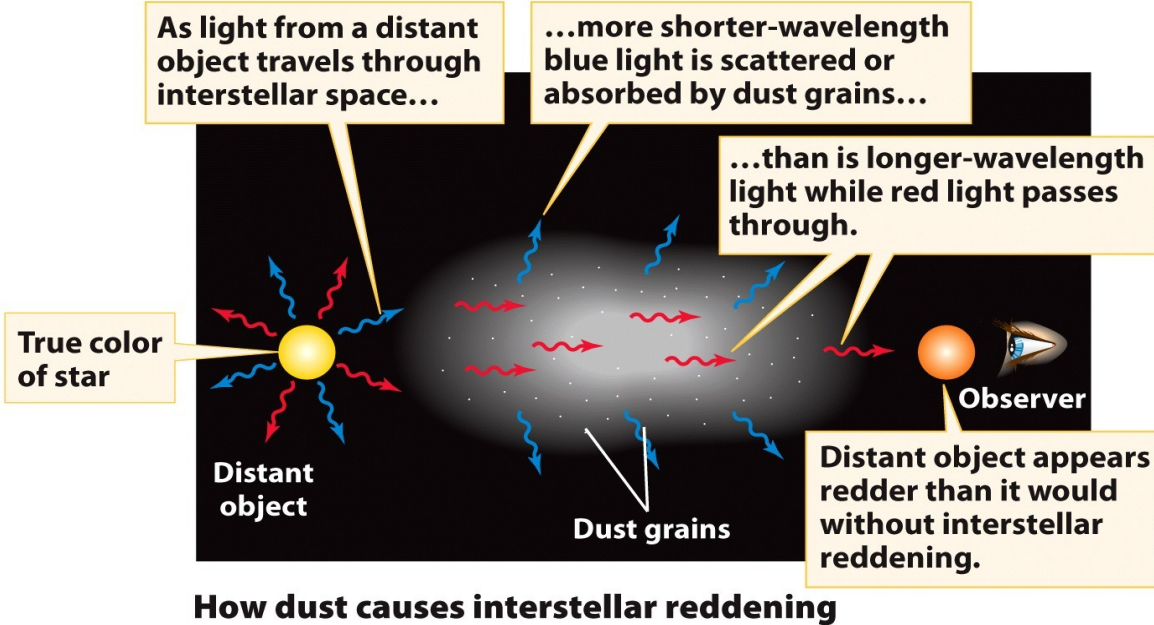


We see spiral galaxy NGC 891 nearly edge-on

Figure 18-8b
Universe, Tenth Edition

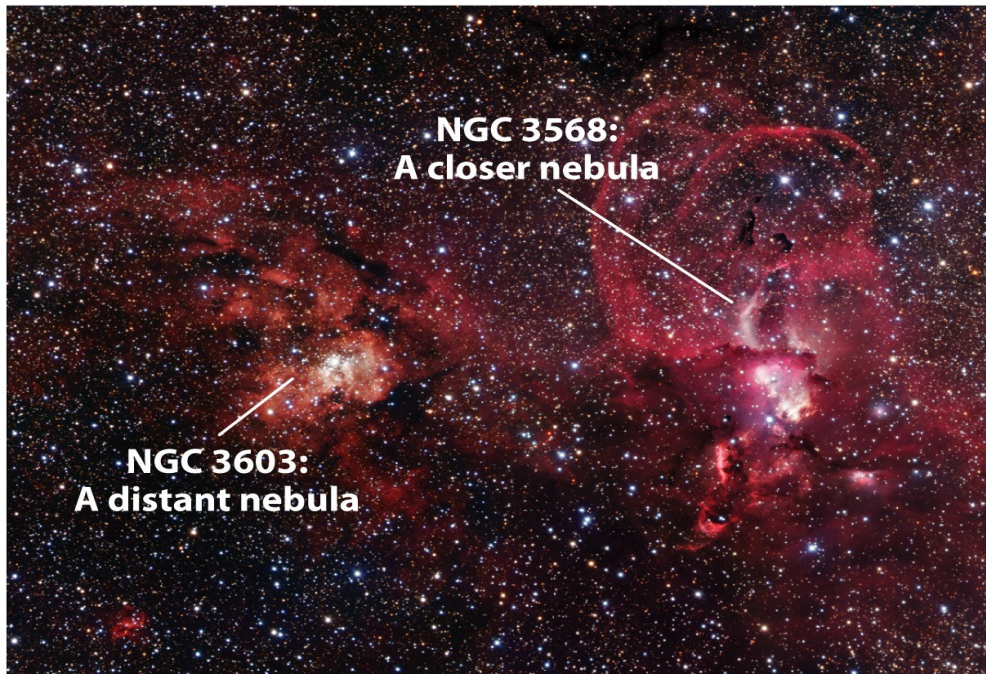
Dust in the interstellar regions can block or scatter the light. In our Milky way galaxy, the interstellar dust and gas diffuse the light of the many stars near the center of the galaxy so we see only a diffuse whitish band. The interstellar dust is concentrated in the plane of a spiral galaxy. Other galaxies seen edge on from our viewpoint show a dark band where interstellar dust has blocked the light.

Interstellar Reddening



Interstellar dust and gas scatter or absorb blue light (shorter wavelengths) more than red light (longer wavelengths). The larger the distance, the larger the effect. This **interstellar reddening** depends on the distance of the objects. It is a similar effect as a red sunsets.

Figure 18-6a
Universe, Ten
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Reddening depends on distance

Figure 18.6b

Protostars

For a protostar to form, the density must be high and the temperature low. A dark nebula has both properties. Densities in a dark nebula can be $10^2 - 10^4$ particles per cm^3 compared to 0.1-20 particles per cm^3 in the normal interstellar medium. The temperature is only about 10 K. Dark nebula are also known as Barnard objects. These objects have a few thousand M_{\odot} and are ~ 10 pc across. A Barnard object with the less dense outer region stripped away is known as a Bok globule. A Bok globule is about 1/10 as large. The composition is the typical 74% H, 25% He and 1% other

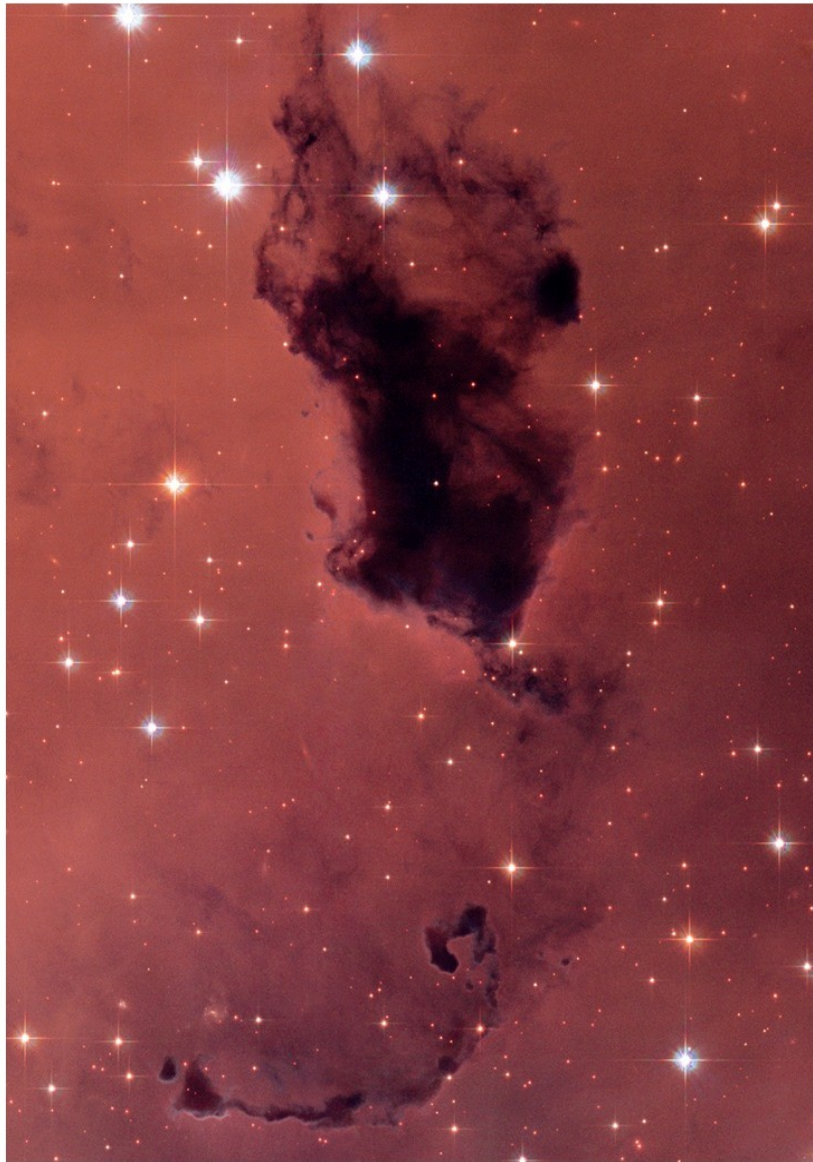


Figure 18-9
Universe, Tenth Edition
NASA, ESA, and The Hubble Heritage Team [STScI/AURA]

Evolution of a Protostar

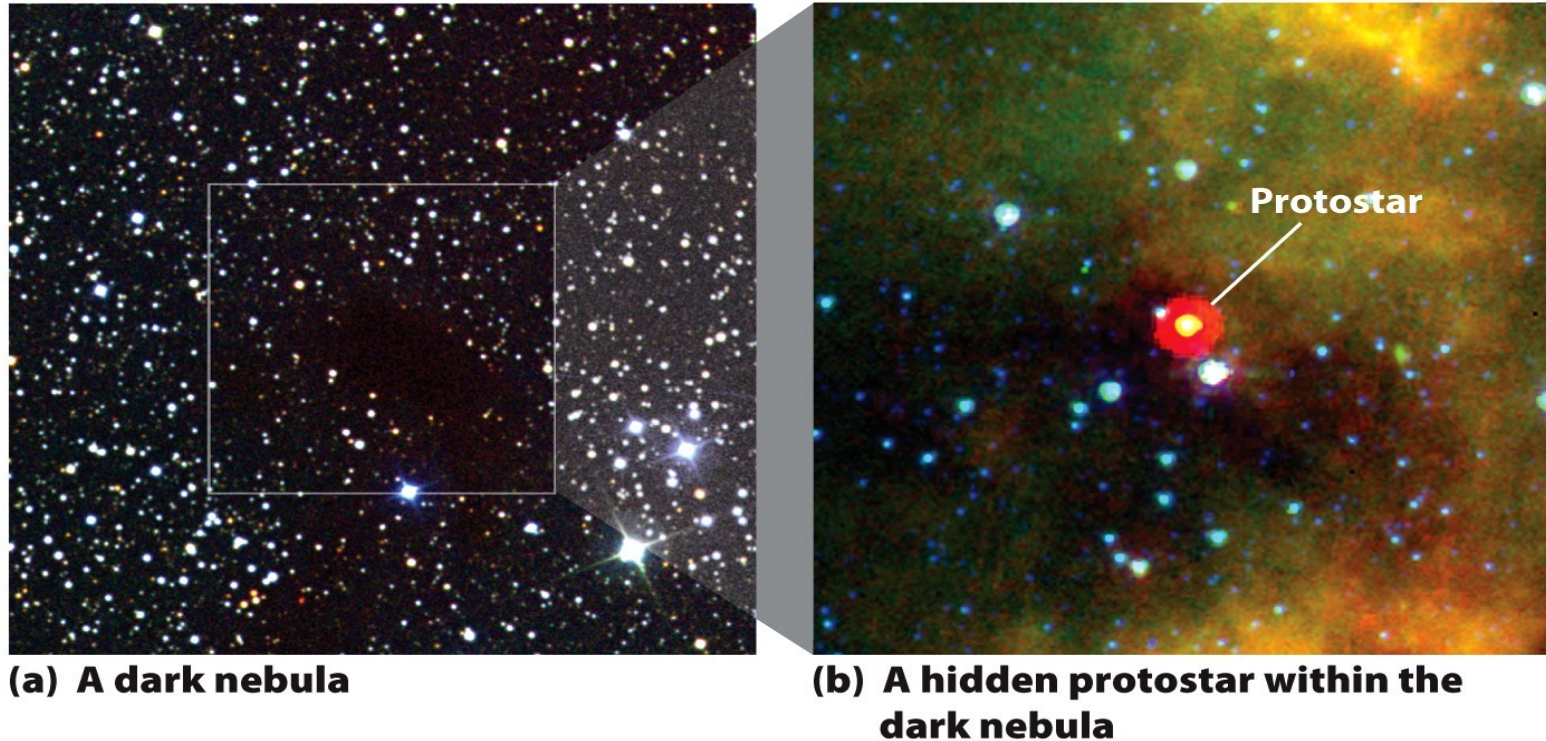
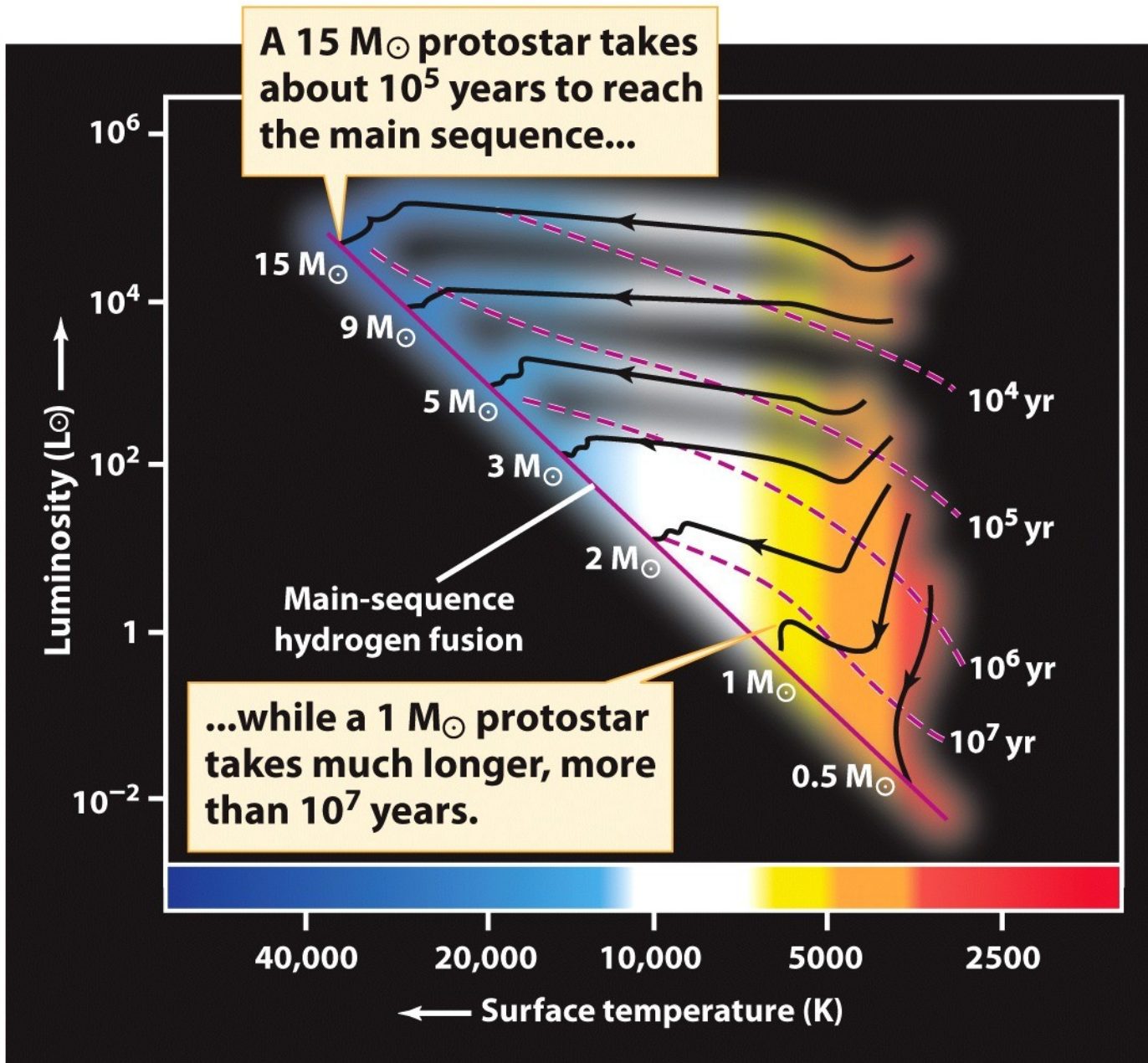


Figure 18-11
Universe, Tenth Edition
NASA/JPLCaltech/N. Evans [University of Texas at Austin]

Gravity contracts the gas and dust over time in a volume several times the size of the solar system to form a protostar. The pressure is too low to counteract the force of gravity. After a few thousand year, the Kelvin-Helmholtz contraction raises the temperature to 2000-3000K. After only 1000 years the protostar of $1 M_{\odot}$ can be 20 times larger than the sun and have a luminosity of $20 L_{\odot}$ because of the large surface area.

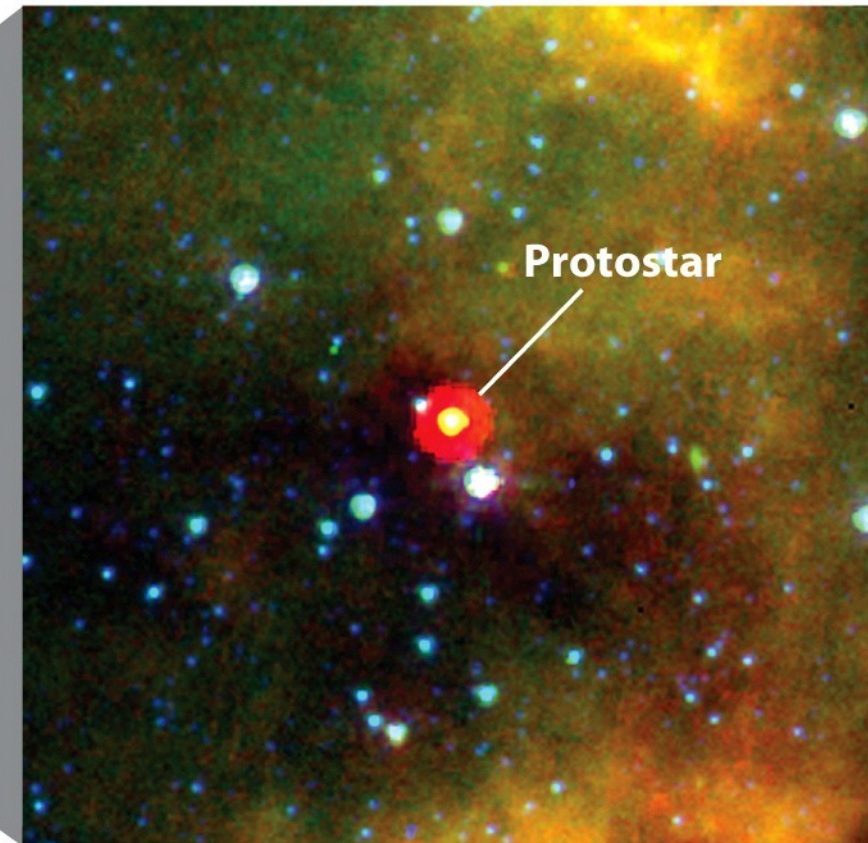
Evolution of a Protostar



Computer models similar to models of the Sun, show the evolution of a protostar. A $15 M_{\odot}$ protostar take only 10^5 year to become a main sequence star. Protostars like the Sun ($1 M_{\odot}$) take 10^7 years to become main sequence stars.

Figure 18-10
Universe, Tenth Edition
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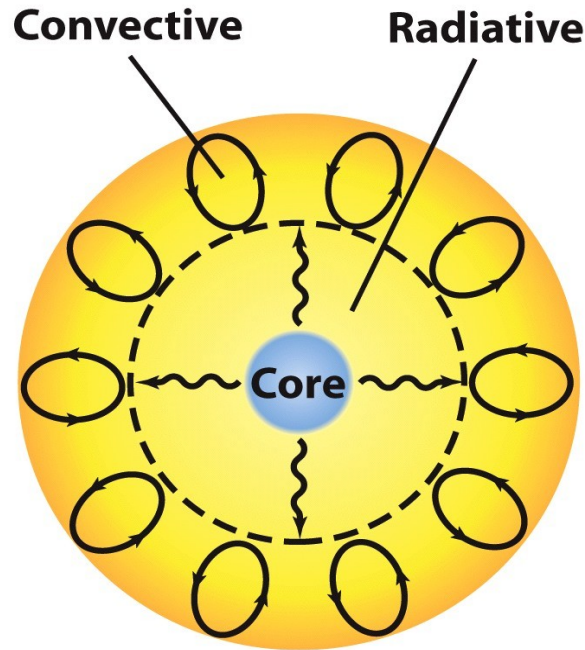
Observing a Protostar



A Protostar has large luminosity but we can not see it in the visible spectrum. It is hidden by the dust and gas of the dark nebula where it formed. Protostars can be seen inside their cocoon nebula in the infrared spectrum.

(b) A hidden protostar within the dark nebula

Evolution of a $\sim 1 M_{\odot}$ Protostar

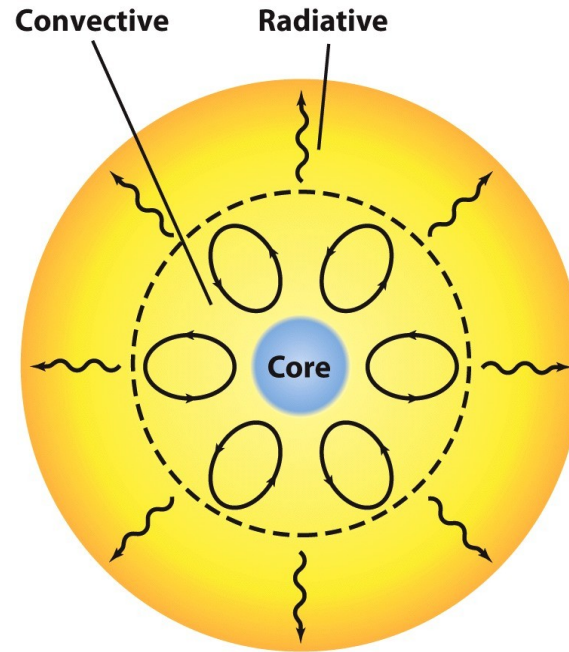


Mass between about $4 M_{\odot}$ and $0.4 M_{\odot}$: Energy flows by radiation in the inner regions and by convection in the outer regions.

Figure 18-12b
Universe, Tenth Edition
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Luminosity is proportional to r^2 and T^4 . For a Sun sized protostar, the outer layer is relatively cool and opaque. Energy from the core reaches the surface through first radiation in the inner region and then convection. The temperature of the outer layer remains relatively constant as the core contracts so the luminosity decreases as r decreases. As fusion begins in the core, the gas becomes ionized and heat is more effectively transferred by radiation and the luminosity increases. This can be seen in the H-R diagram

Evolution of a high mass Protostar

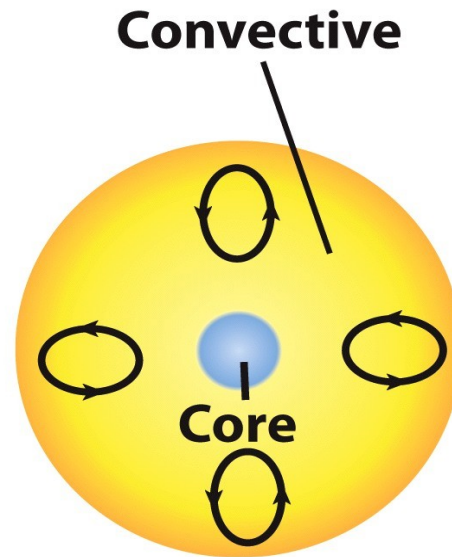


**Mass more than about $4 M_{\odot}$:
Energy flows by convection in
the inner regions and by
radiation in the outer regions.**

Figure 18-12a
Universe, Tenth Edition
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A protostar with $>4 M_{\odot}$ contracts more rapidly and fusion begins early. The greater temperature causes energy to flow from the core to the inner region by convection and the luminosity reaches its final value quickly. The temperature continues to rise as the protostar contracts. Lower density in the outer region allows energy to flow by radiation.

Evolution of a Low mass Protostar



**Mass less than $0.4 M_{\odot}$:
Energy flows by convection
throughout the star's interior.**

Figure 18-12c
Universe, Tenth Edition
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For a protostar with $< 0.4 M_{\odot}$ the interior temperature is never high enough to fully ionize the material. Energy is transported from the fusion core to the surface only by convection.

Arriving on the Main Sequence

Main sequence stars are stars that are 'burning' hydrogen to helium through nuclear fusion. Protostars end up on the main sequence line. Protostars that are larger than $>200 M_{\odot}$ do not end up on the main sequence. They are so large the fusion expels the outer layers into space and disrupt further development of the star. Stars with $<0.08 M_{\odot}$ are not large enough to start the fusion process and end up as brown dwarfs.

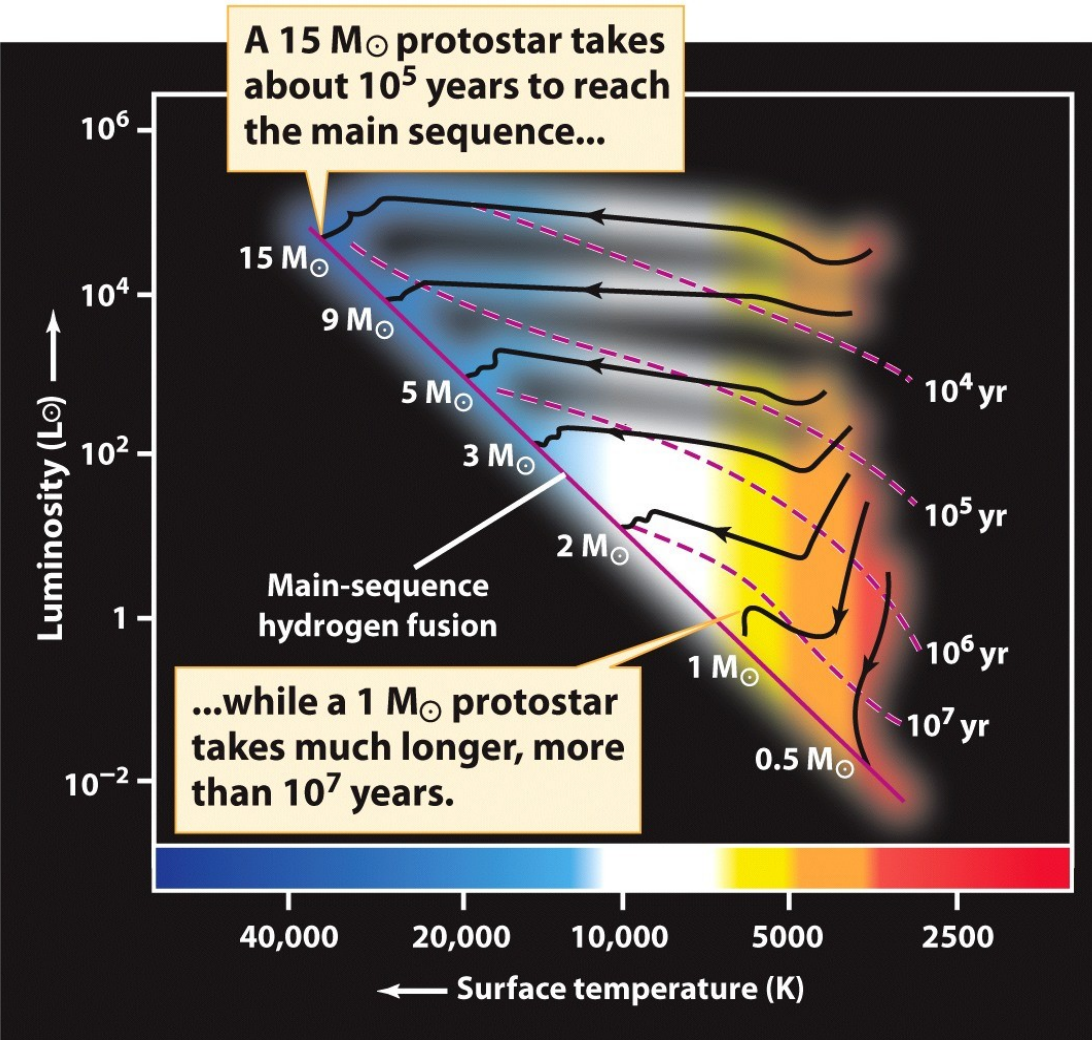


Figure 18-10
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Changes in Mass as Stars are Born

Dark nebula not only collapse into protostars. Mass is also ejected in the process of star formation. T Tauri stars are protostars with final masses of $\sim 3 M_{\odot}$ and ages of about 10^6 years. They eject gas at high speeds (80 km/s) and show both emission and absorption lines in their spectra. Over their lifetimes they can eject mass equal to the mass of the Sun. Their luminosity can change over short periods of time (days).

Larger protostars do lose mass but do not vary in luminosity like a T Tauri protostar.

Bipolar Outflows and Herbig-Haro Objects

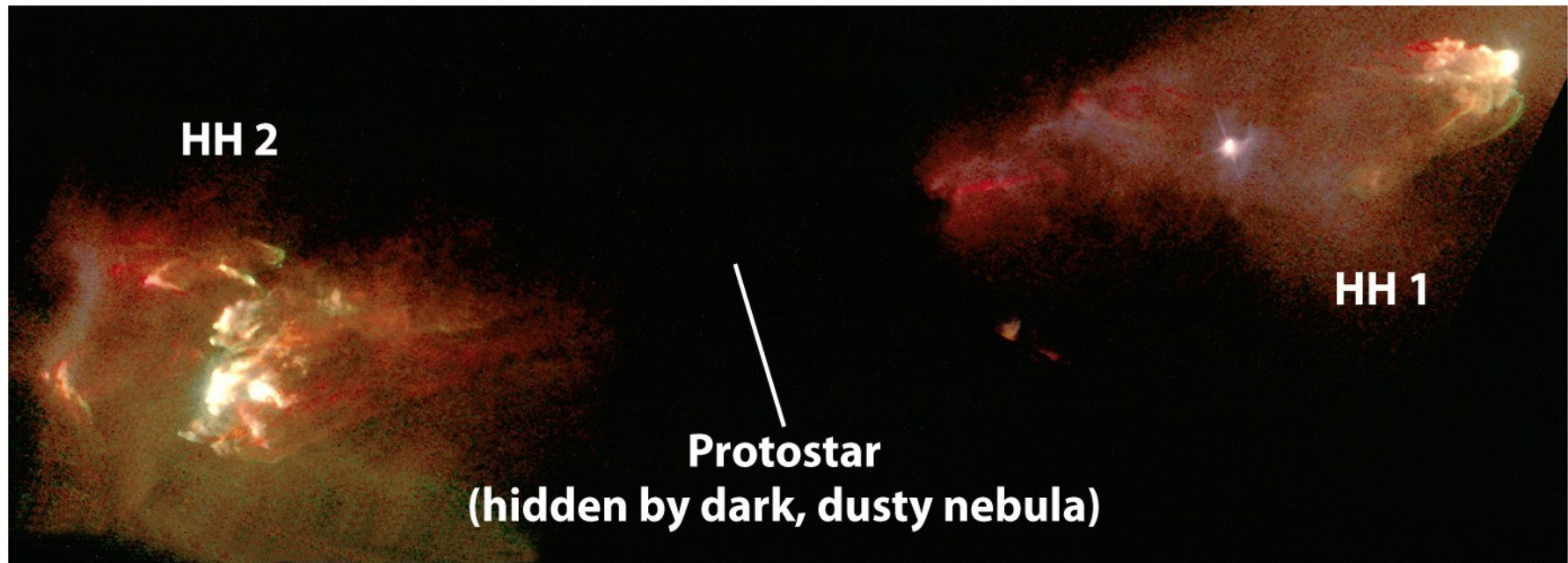


Figure 18-14

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J. Hester [Arizona State University], the WFPC-2 Investigation Team, and NASA

In the 1980s it was discovered that many young stars eject gas at high speed along two narrow oppositely directed jets called **bipolar outflow**. The jets only last for 10^4 - 10^5 years. The bipolar outflows collide with the surrounding interstellar medium and produce knots of hot ionized gas that glow with an emission spectrum. The knots are called **Herbig-Haro objects**. One object ejects material with large amounts of water.

Accretion Disks and Bipolar Outflow Jets

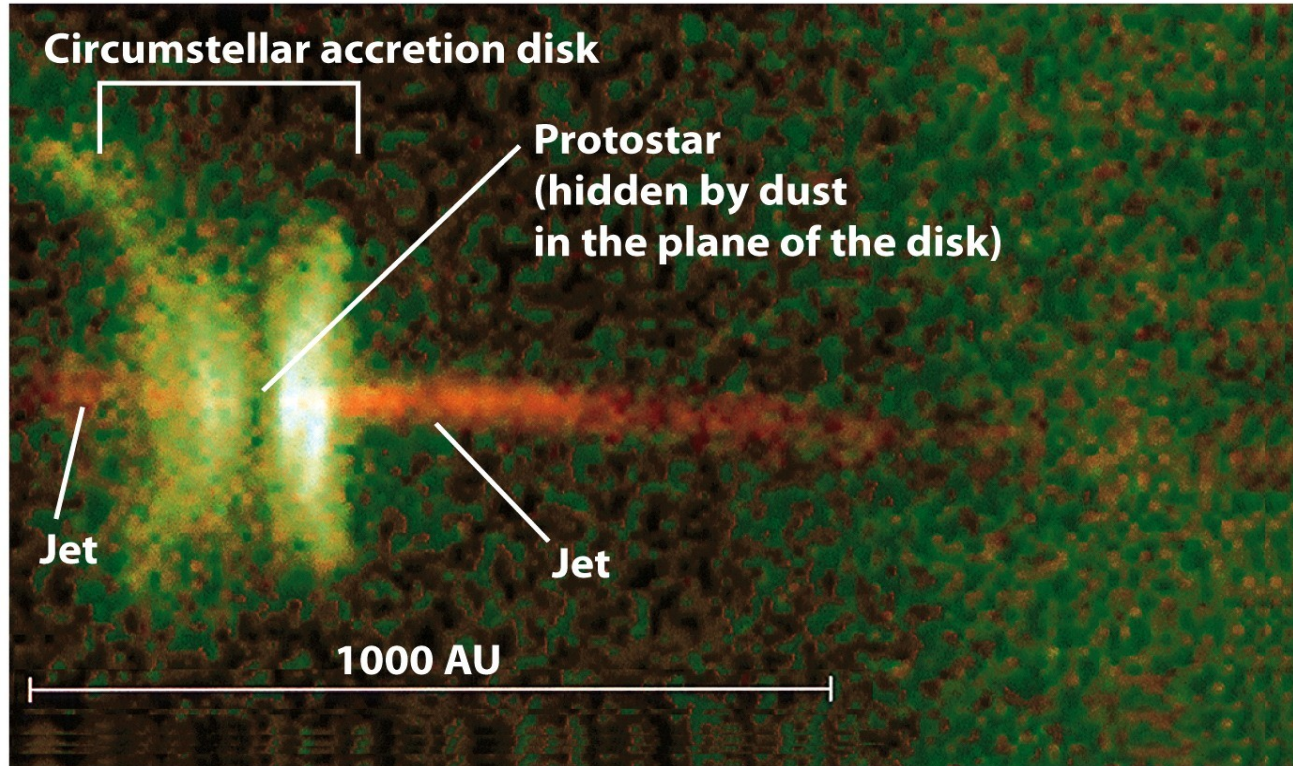


Figure 18-15
Universe, Tenth Edition
C. Burrows, the WFPC-2 Investigation Definition Team, and NASA

Protostars also add mass even as they are ejecting mass. As a protostar nebula contracts, the material spins faster and flattens into a disk. Particles orbiting the protostar in the disk collide and lose energy and spiral into the protostar. The process is called **accretion**. The flattened disk is called the circumstellar accretion disk.

Magnetic Model of Bipolar Outflows

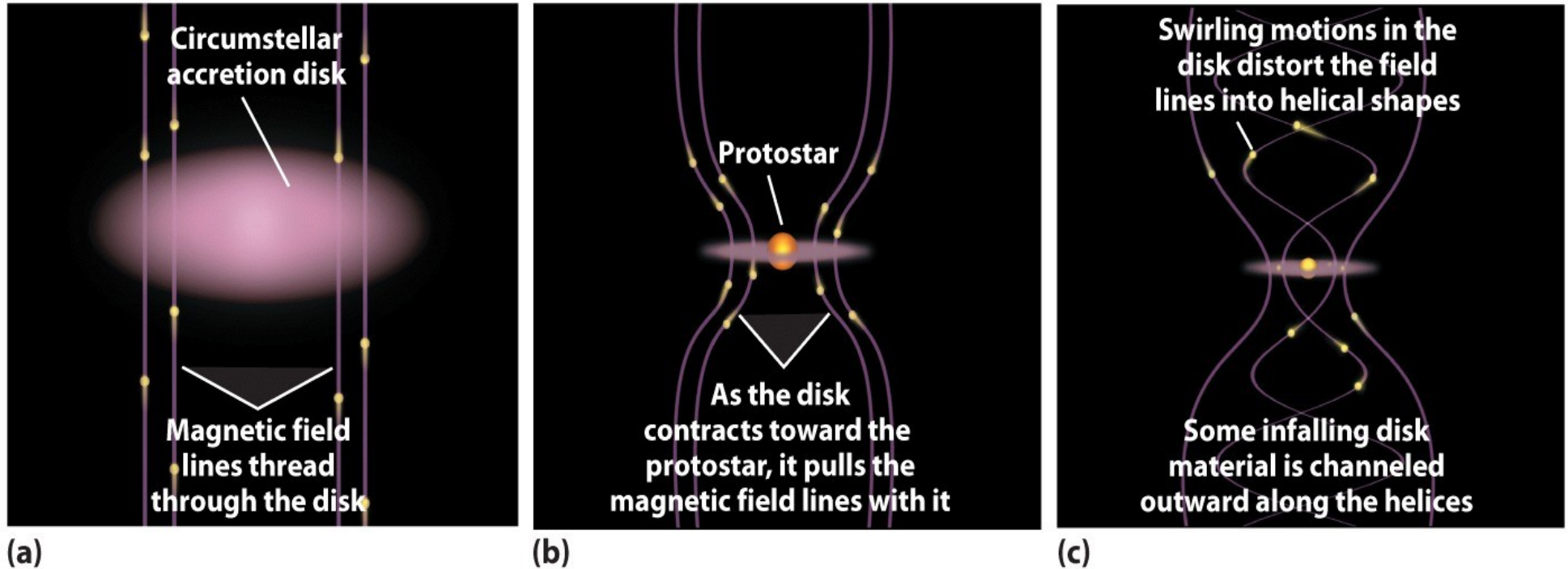


Figure 18-16

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© 2014 W. H. Freeman and Company [Adapted from Alfred T. Kamajian/Thomas P. Ray, "Fountain of Youth: Early Days in the Life of a Star," *Scientific American*, August 2000]

The circumstellar accretion disk are treaded with perpendicular magnetic field lines. The field lines move with the material of the disk. The contraction and rotation of the disk causes the magnetic field lines to twist into helices. The helical field lines channel the material in the disk into jets perpendicular to the plane of the disk.

Protoplanetary Disks



Figure 18-17
Universe, Tenth Edition
NASA, ESA, and M. Livio and the Hubble 20th Anniversary Team [STScI]

In the 1990s Hubble images showed protoplanetary disk (or proplyds) that surround new stars within a nebula. These protoplanetary disk contain material which can form planets. Stars larger than $3 M_{\odot}$ and binary systems don't seem to form protoplanetary disk. Most lower mass stars do form protoplanetary disk.

Young Star Clusters

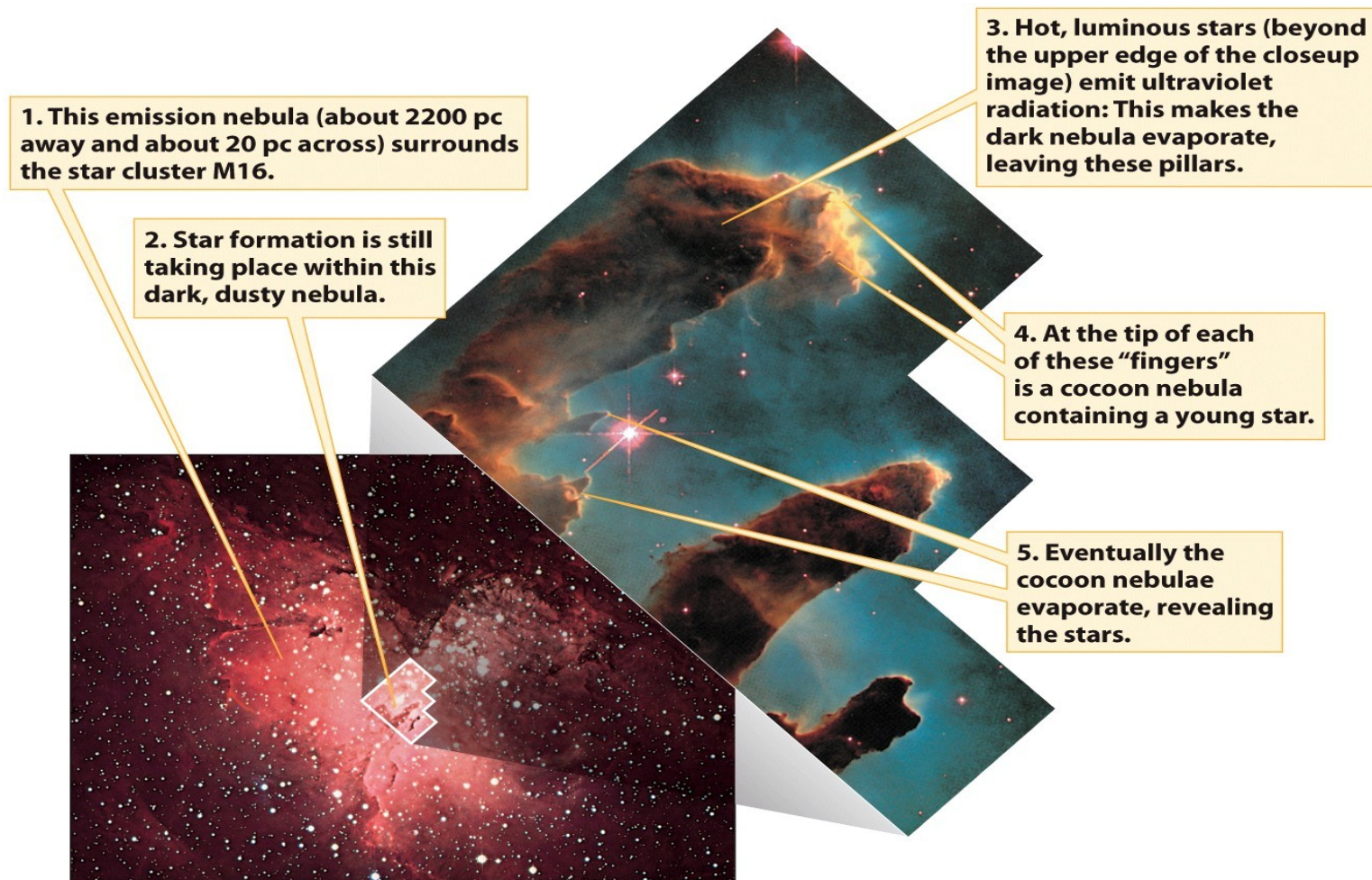


Figure 18-18
Universe, Tenth Edition
Australian Astronomical Observatory; J. Hester and P. Scowen, Arizona State University; NASA

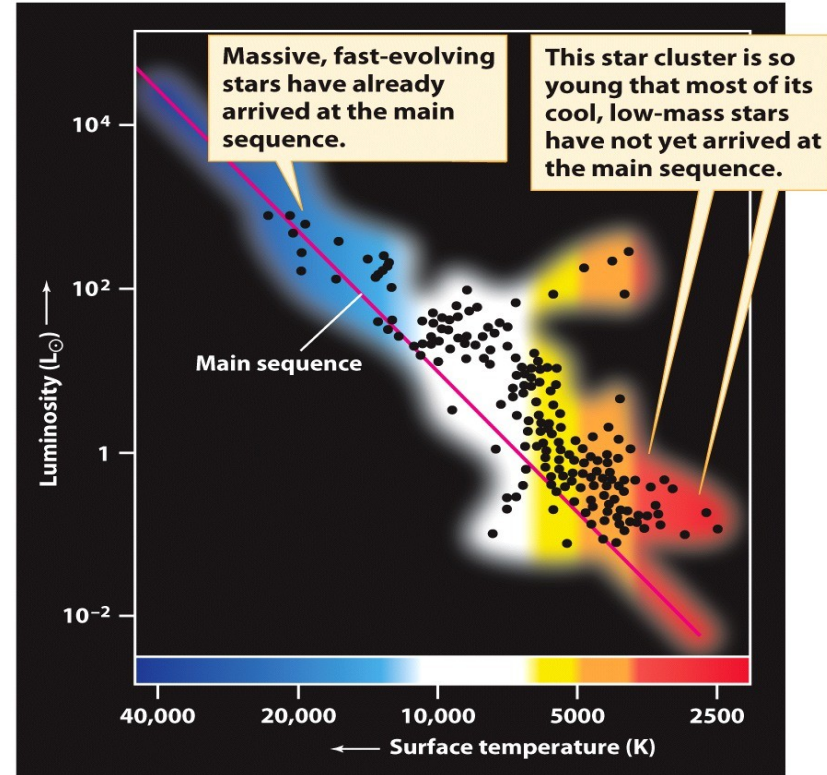
Since dark nebula contain enough material for many stars, dark nebula tend to form clusters of young stars. As the stars grow the nebula glows with a reddish H II color

Star Cluster show the Evolution of Stars



The star cluster NGC 2264

Figure 18-20a
Universe, Tenth Edition
© 2004–2013 R. Jay GaBany, Cosmography.com



An H-R diagram of the stars in NGC 2264

Figure 18-20b
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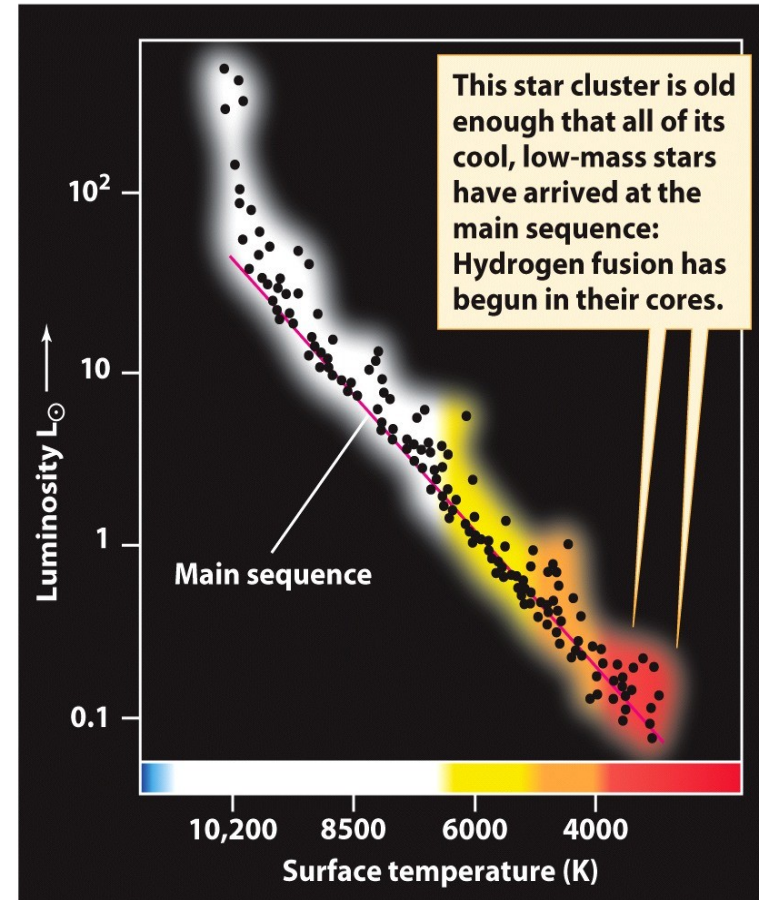
Star cluster may start forming at the same time but larger stars evolve more rapidly than low mass stars. When they reach the main sequence, high mass hot O and B spectral type stars are very luminous and emit large amounts of UV radiation. This ionizes the surround interstellar medium to produce the characteristic redness of a H II region. The radiation can disturb the formation of lower mass stars in the nebula.

Star Cluster show the Evolution of Stars



The Pleiades star cluster

Figure 18-21a
Universe, Tenth Edition
Australian Astronomical Observatory/David Malin Images



An H-R diagram of the stars in the Pleiades

Figure 18-21b
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Older star cluster show the different ranges of mass and luminosity. After about 50 million years, all of the stars in the Pleiades cluster have moved onto the main sequence line and their cores have begun hydrogen fusion.

Giant Molecular Clouds

In the 1970's astronomer started to map the sky in millimeter (microwave) wavelengths. Dark nebula emit millimeter wave radiation. Millimeter wavelengths are not effected by interstellar dust. Carbon monoxide (CO) is shown in red in this false color image of Orion.

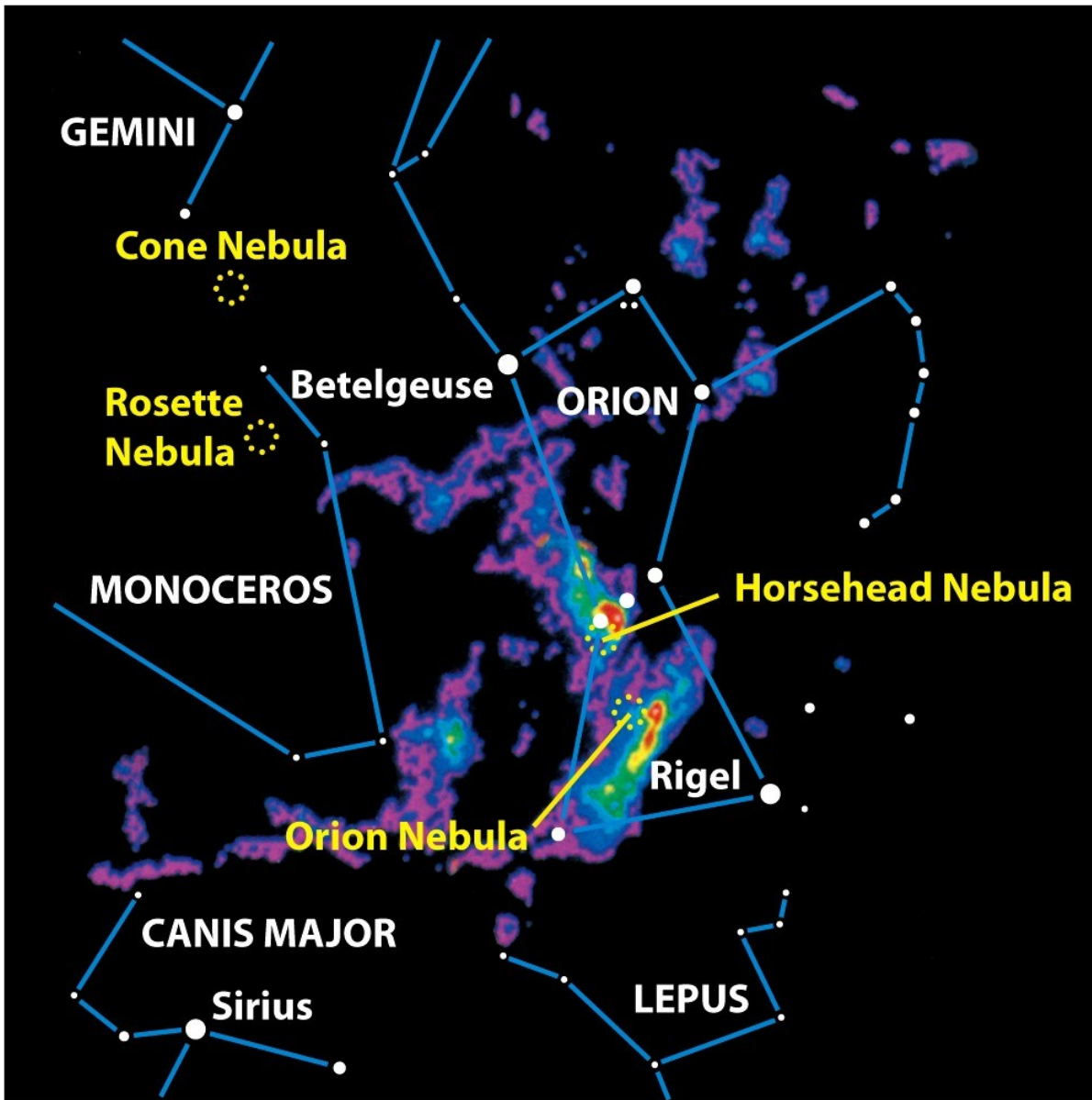
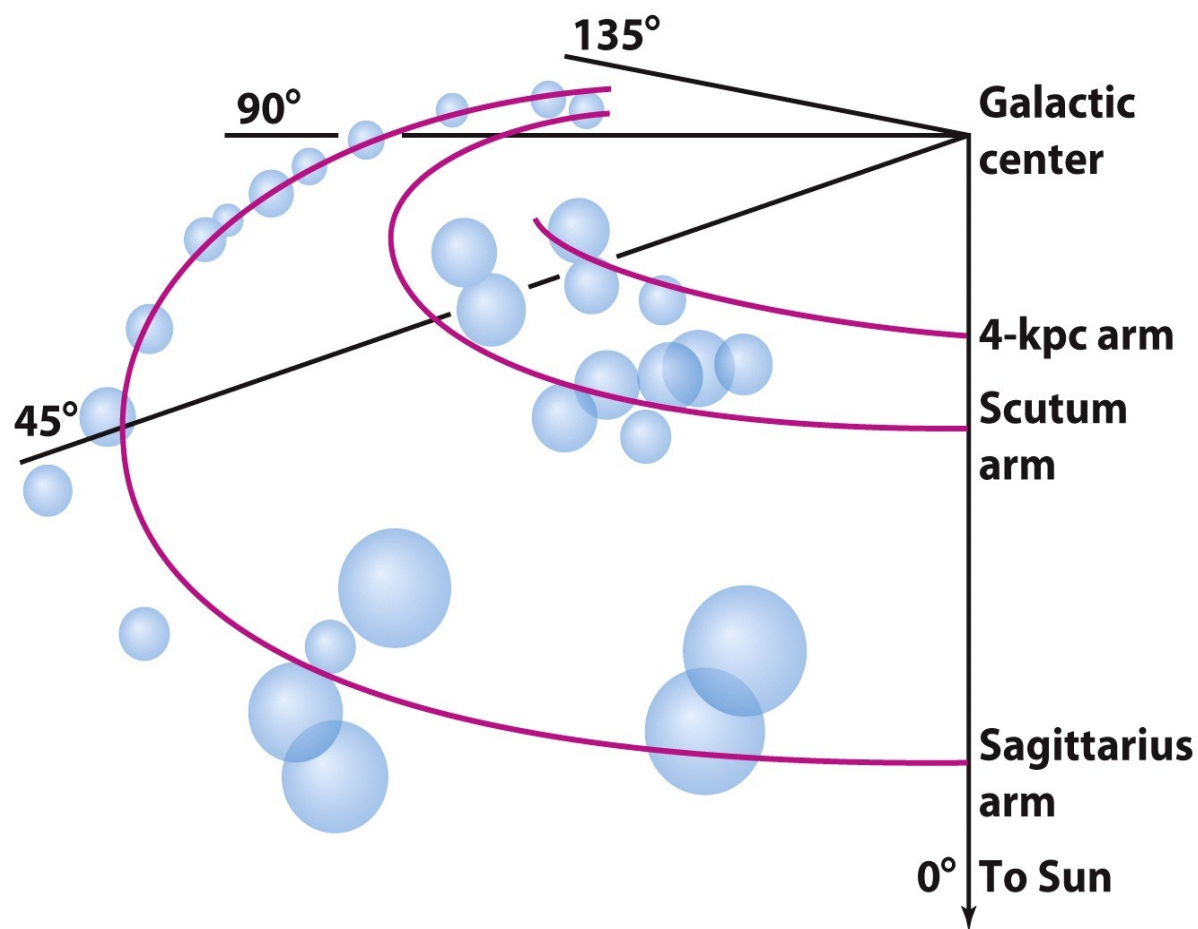


Figure 18-22
Universe, Tenth Edition
Courtesy of R. Maddalena, M. Morris, J. Moscowitz, and P. Thaddeus

Giant Molecular Clouds



These giant molecular clouds also contain huge amounts of hydrogen. They can have masses of 2 million M_{\odot} and are 15-100 pc. These giant molecular clouds are associated with star formation. This drawing shows the location of these giant molecular clouds as viewed from our position in the galaxy. The red lines are spiral arms of the Milky Way.

Figure 18-23
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Star Formation in Spiral Arms

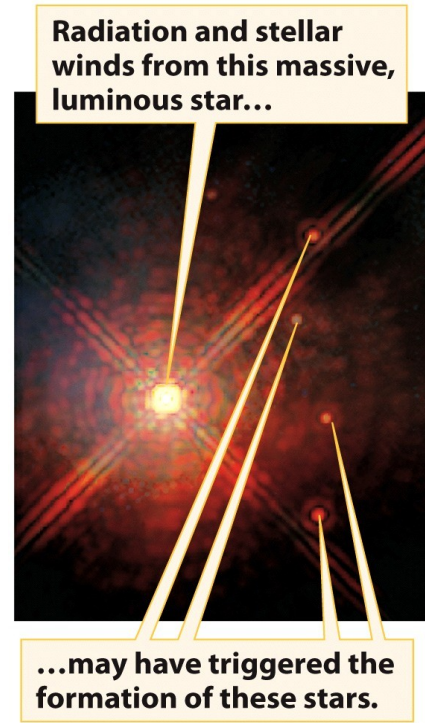
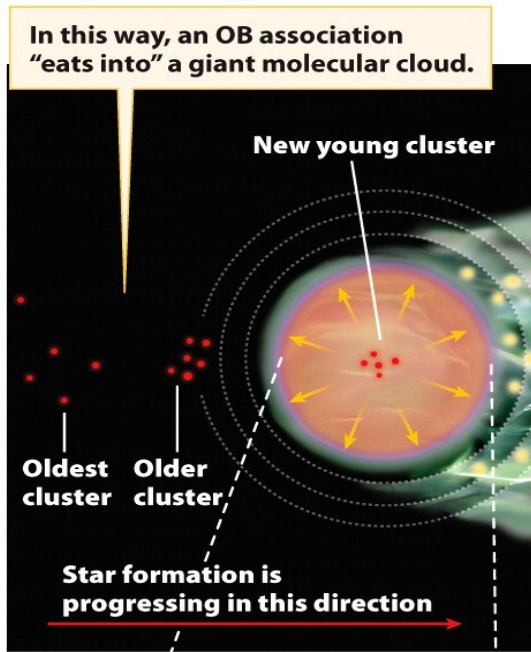
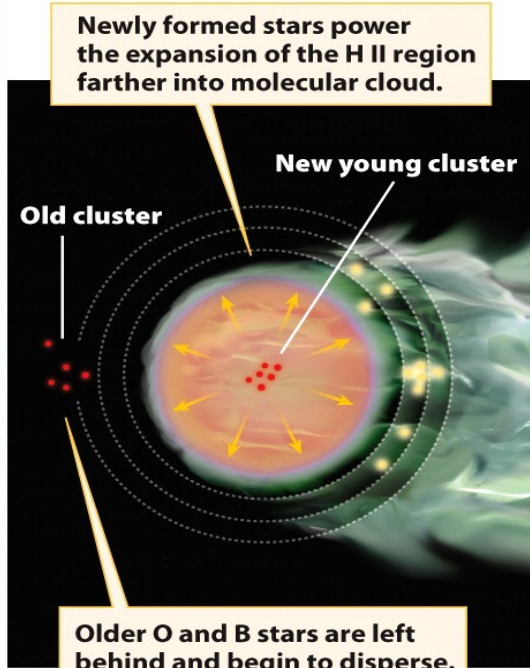
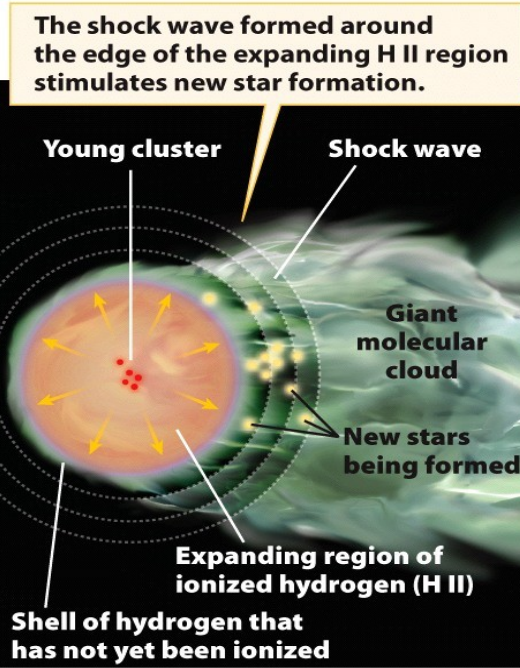


Figure 18-25 part 1
 Universe, Tenth Edition
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Figure 18-25 part 2
 Universe, Tenth Edition
 R. Thompson, M. Rieke, G. Schneider, and NASA

When O and B stars form, they emit UV light that ionizes the surrounding hydrogen. This forms a 'hot spot' in the molecular cloud. The UV and stellar wind produce a cavity in the cloud. The H II region expand into this cavity at supersonic speeds and new stars form in the region. The original O and B stars disperse leaving new stars forming in their wake. In a sense, the O and B stars 'eat' into the cloud.

Supernovae and Star Formation



Figure 18-27
Universe, Tenth Edition
Davide De Martin

Anything that compresses the interstellar medium can induce star formation. Supernovae are massive explosions of old stars. The shock wave from a supernova can compress the surrounding interstellar medium and produce stars. A supernova a few light years away may have triggered the formation of the Sun. This image shows new stars forming around the the remnant of the Canis Major R1 supernova. 27