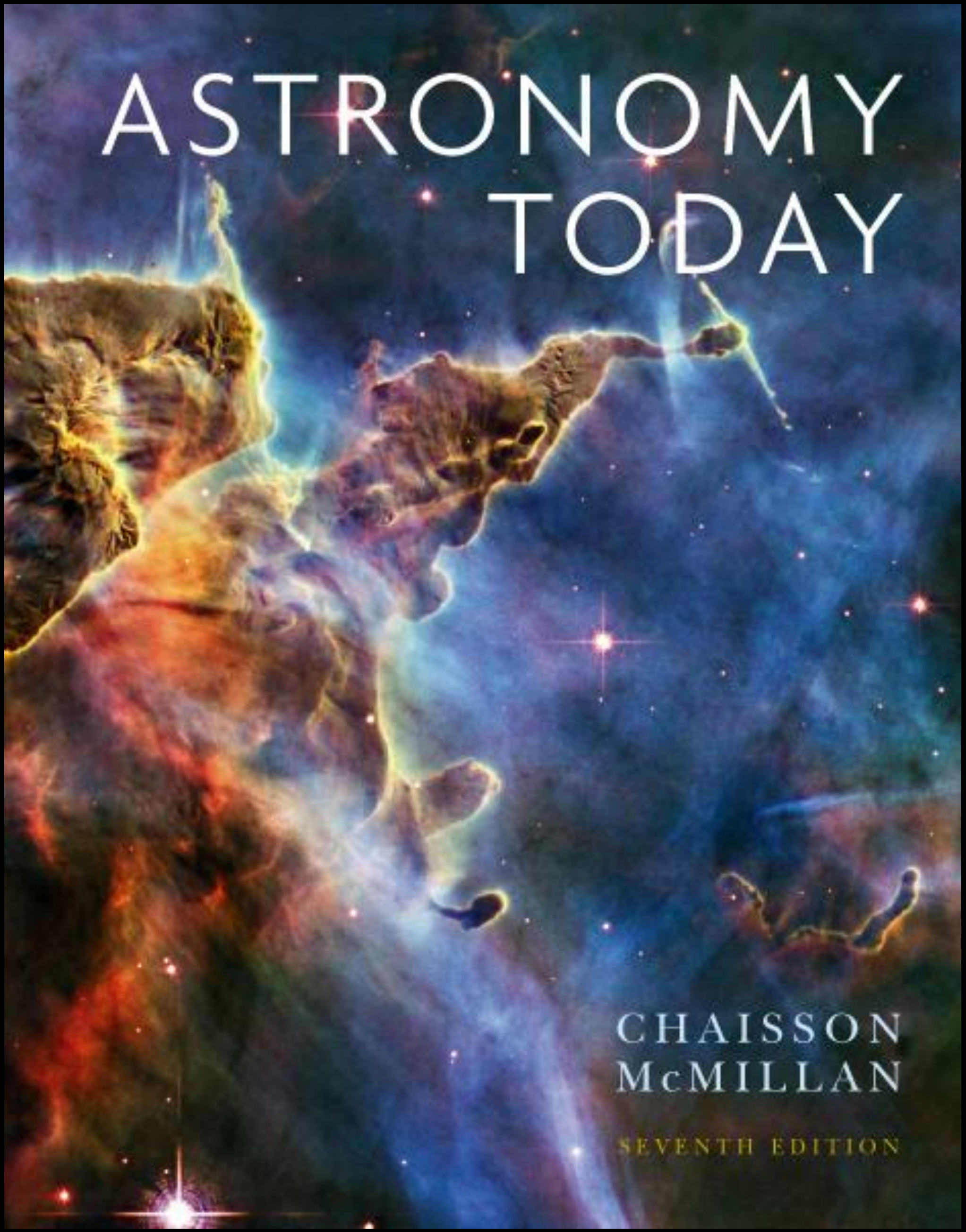


Lecture Outline

Chapter 19

*Astronomy Today*

7th Edition

Chaisson/McMillan

# Chapter 19
# Star Formation

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# Units of Chapter 19

19.1 Star-Forming Regions

Competition in Star Formation

19.2 The Formation of Stars Like the Sun

19.3 Stars of Other Masses

19.4 Observations of Cloud Fragments and Protostars

Observations of Brown Dwarfs

19.5 Shock Waves and Star Formation

19.6 Star Clusters

Eta Carinae

# 19.1 Star-Forming Regions

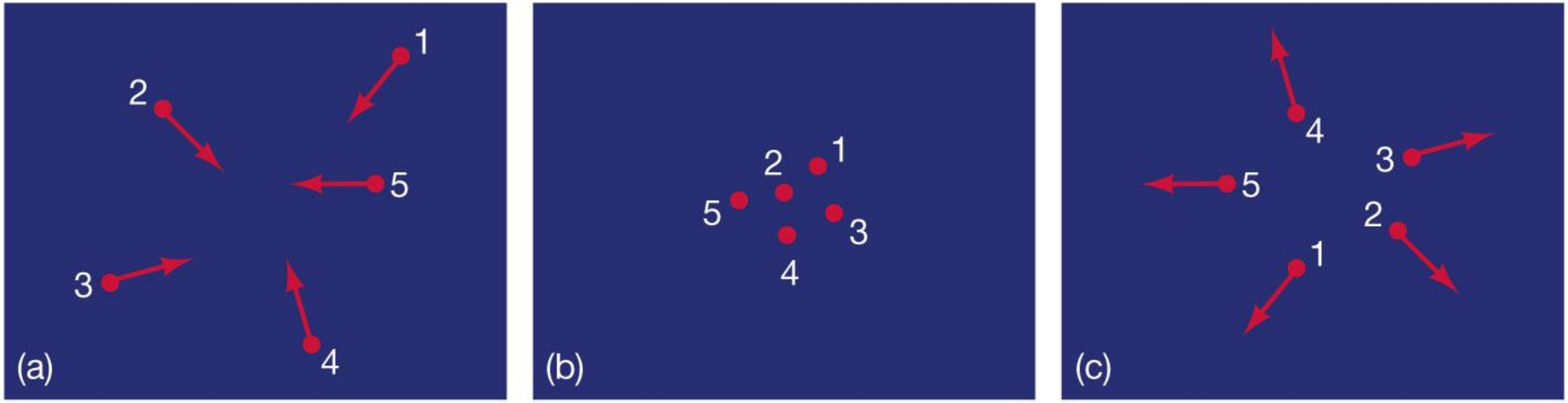
Star formation is ongoing. Star-forming regions are seen in our galaxy as well as others.

# 19.1 Star-Forming Regions

Star formation happens when part of a dust cloud begins to contract under its own gravitational force; as it collapses, the center becomes hotter and hotter until nuclear fusion begins in the core.

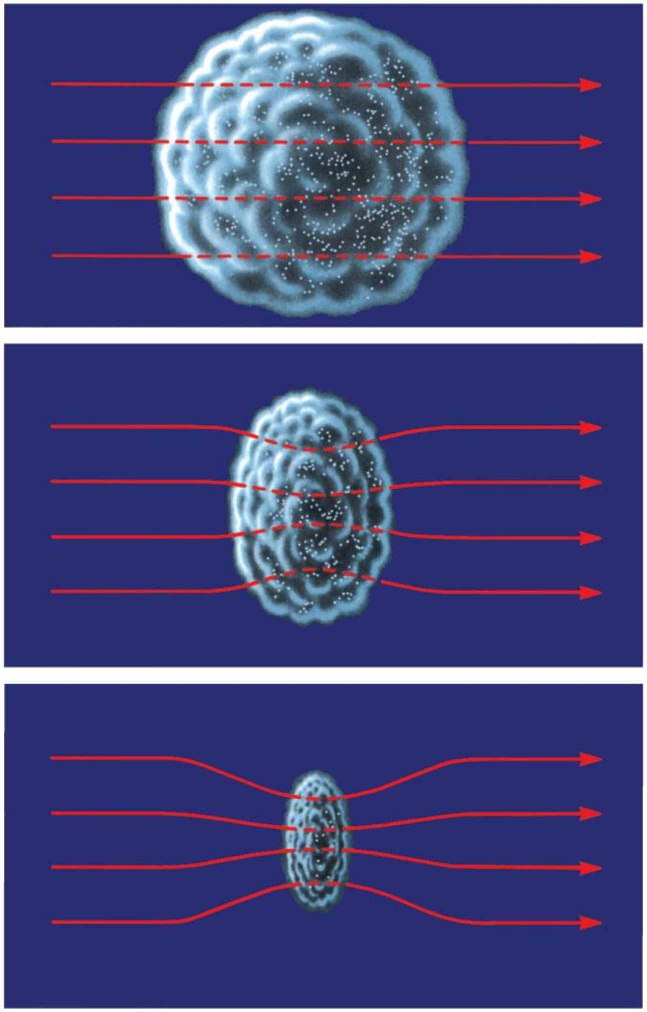
# 19.1 Star-Forming Regions

When looking at just a few atoms, the gravitational force is nowhere near strong enough to overcome the random thermal motion



# More Precisely 19-1: Competition in Star Formation

Rotation can also interfere with gravitational collapse, as can magnetism. Clouds may very well contract in a distorted way.



# 19.2 The Formation of Stars Like the Sun

Stars go through a number of stages in the process of forming from an interstellar cloud

**TABLE 19.1 Prestellar Evolution of a Solar-Type Star**

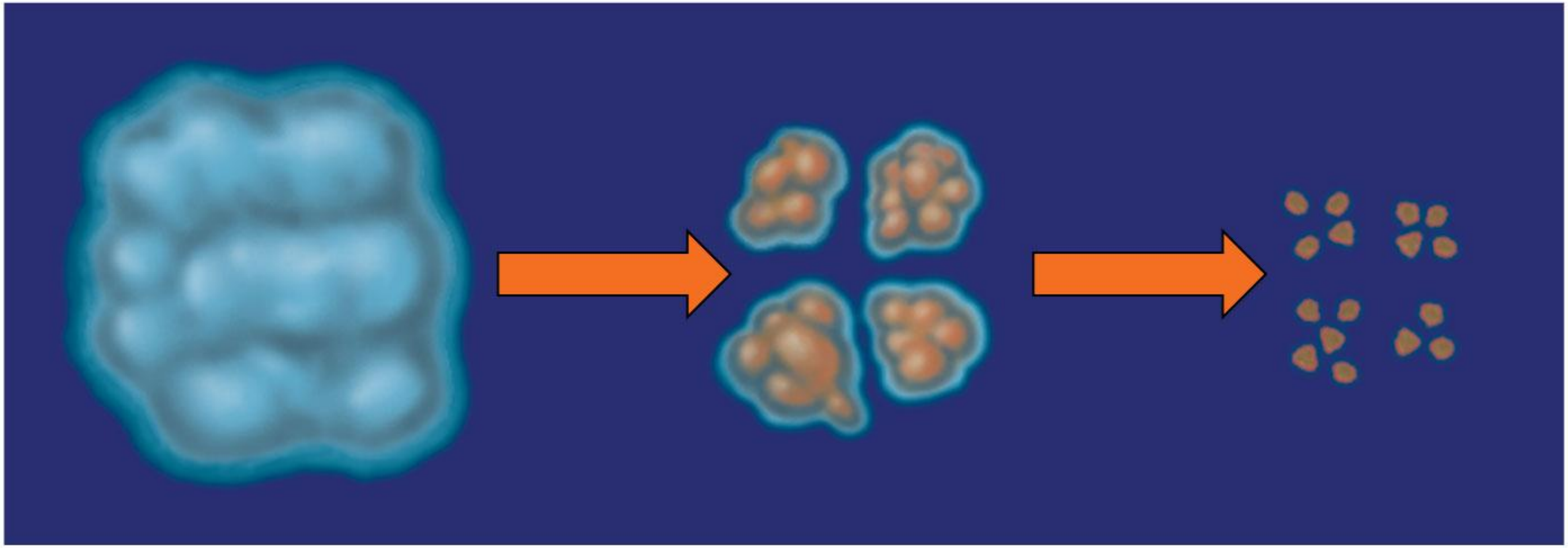
| Stage | Approximate Time to Next Stage (yr) | Central Temperature (K) | Surface Temperature (K) | Central Density (particles/m$^3$) | Diameter* (km) | Object |
|---|---|---|---|---|---|---|
| 1 | $2 \times 10^6$ | 10 | 10 | $10^9$ | $10^{14}$ | Interstellar cloud |
| 2 | $3 \times 10^4$ | 100 | 10 | $10^{12}$ | $10^{12}$ | Cloud fragment<br>Cloud fragment/protostar |
| 3 | $10^5$ | 10,000 | 100 | $10^{18}$ | $10^{10}$ | |
| 4 | $10^6$ | 1,000,000 | 3000 | $10^{24}$ | $10^8$ | Protostar |
| 5 | $10^7$ | 5,000,000 | 4000 | $10^{28}$ | $10^7$ | Protostar |
| 6 | $3 \times 10^7$ | 10,000,000 | 4500 | $10^{31}$ | $2 \times 10^6$ | Star |
| 7 | $10^{10}$ | 15,000,000 | 6000 | $10^{32}$ | $1.5 \times 10^6$ | Main-sequence star |

* *Round numbers; for comparison, recall that the diameter of the Sun is $1.4 \times 10^6$ km, whereas that of the solar system is roughly $1.5 \times 10^{10}$ km.*

# 19.2 The Formation of Stars Like the Sun

Stage 1:

Interstellar cloud starts to contract, probably triggered by shock or pressure wave from nearby star. As it contracts, the cloud fragments into smaller pieces.



# 19.2 The Formation of Stars Like the Sun

Stage 2:

Individual cloud fragments begin to collapse. Once the density is high enough, there is no further fragmentation.

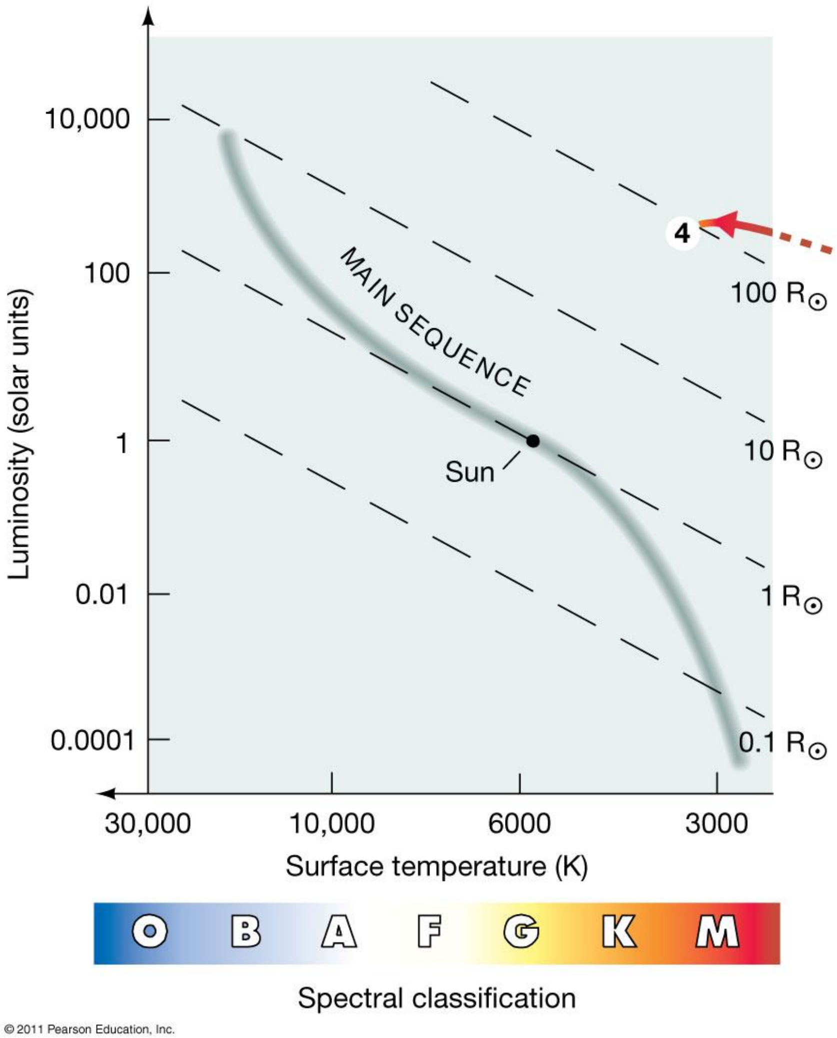
Stage 3:

The interior of the fragment has begun heating and is about 10,000 K.

# 19.2 The Formation of Stars Like the Sun

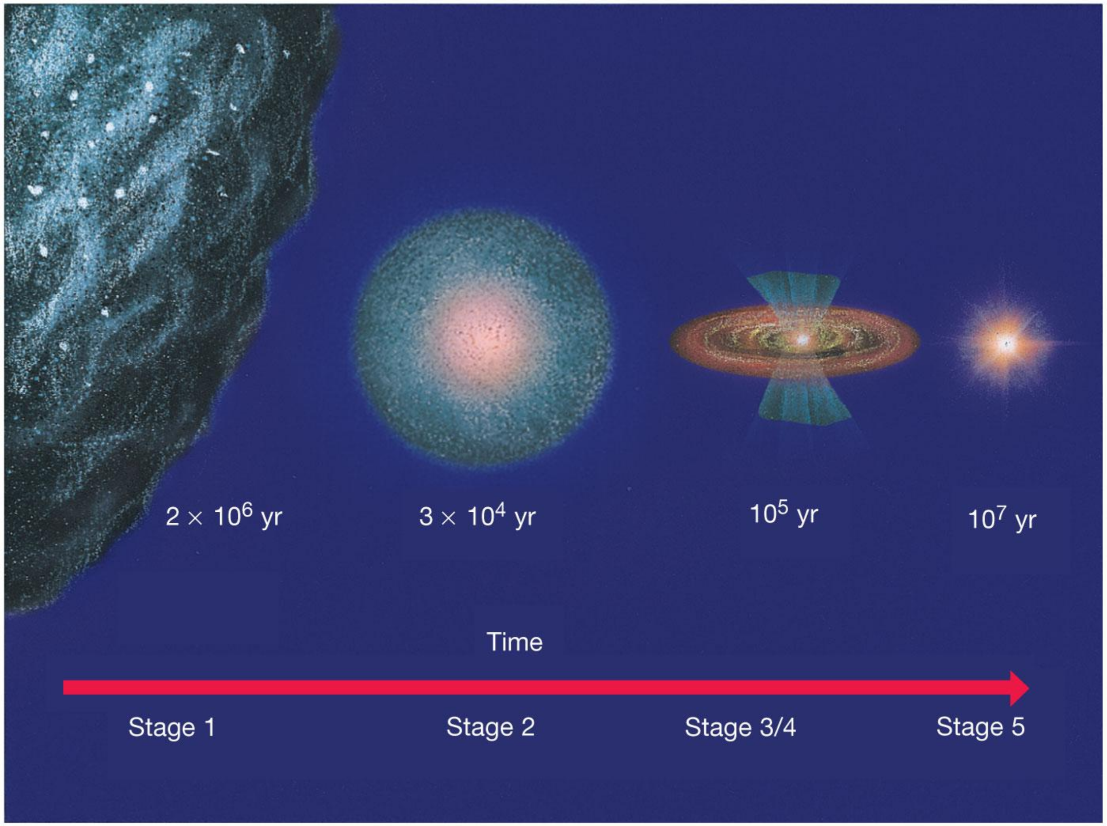
Stage 4:

The core of the cloud is now a protostar and makes its first appearance on the H–R diagram.



# 19.2 The Formation of Stars Like the Sun

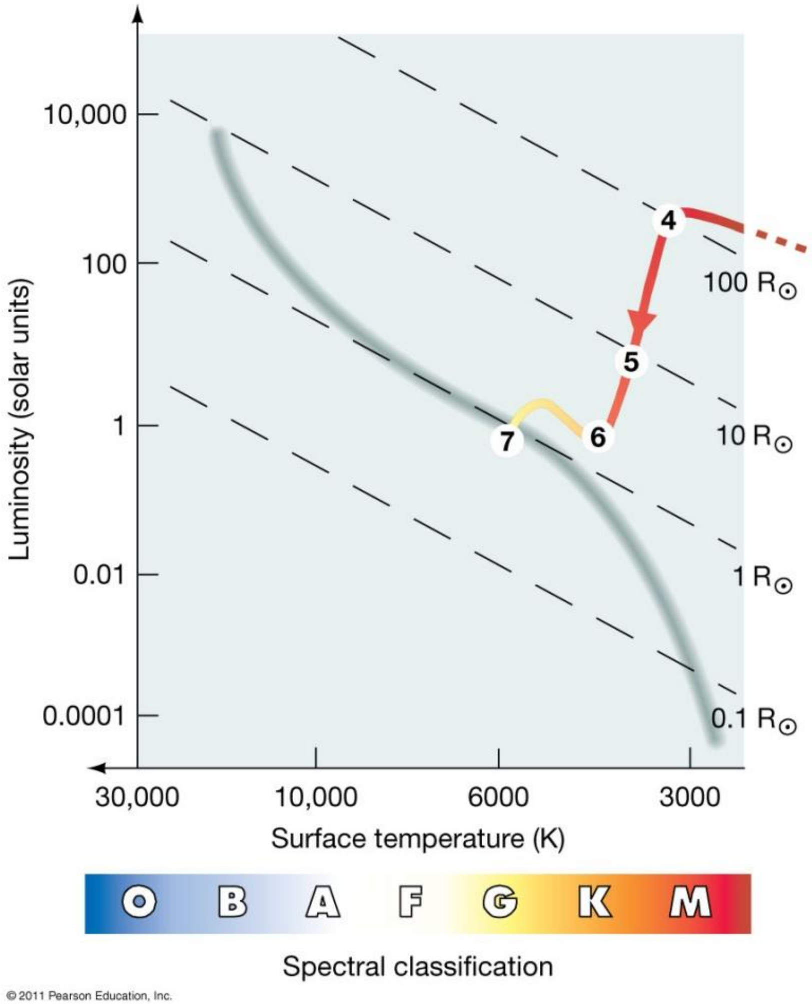
Planetary formation has begun, but the protostar is still not in equilibrium—all heating comes from the gravitational collapse.



# 19.2 The Formation of Stars Like the Sun

The last stages can be followed on the H–R diagram:

The protostar's luminosity decreases even as its temperature rises because it is becoming more compact.



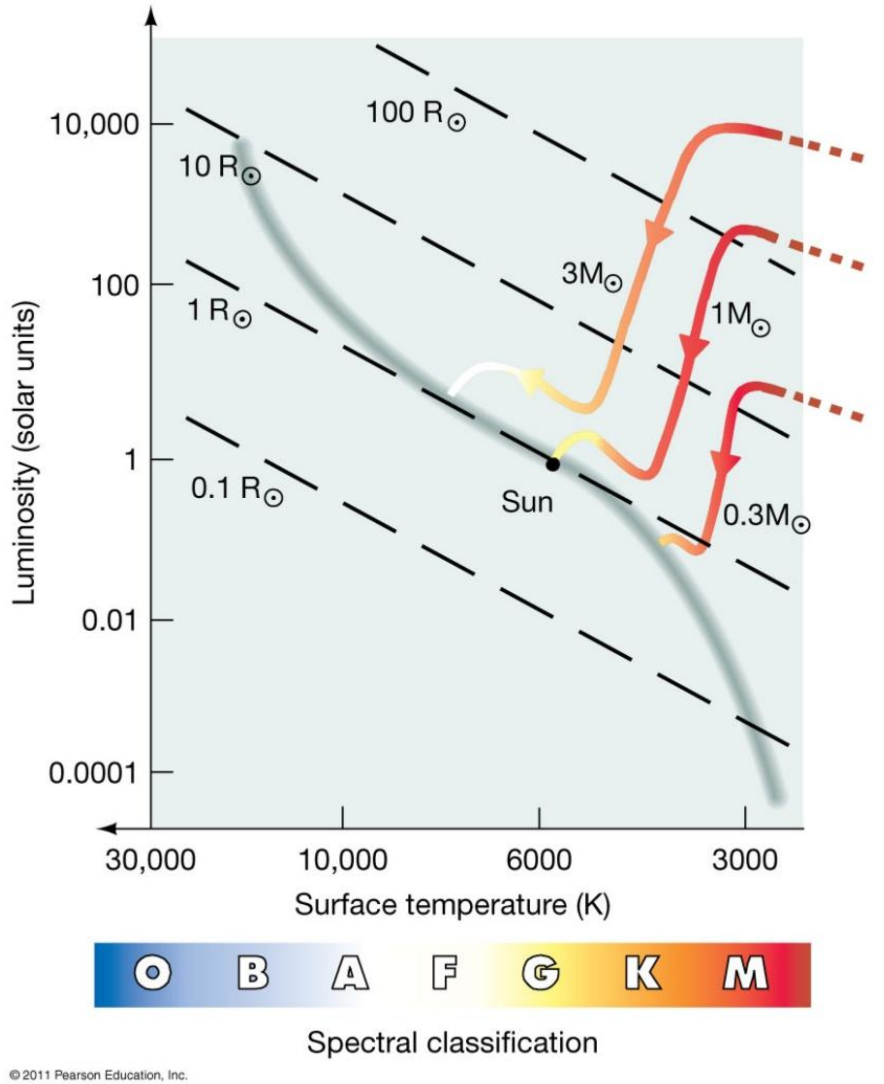
# 19.2 The Formation of Stars Like the Sun

At stage 6, the core reaches 10 million K, and nuclear fusion begins. The protostar has become a star.

The star continues to contract and increase in temperature until it is in equilibrium. This is stage 7: The star has reached the main sequence and will remain there as long as it has hydrogen to fuse.

# 19.3 Stars of Other Masses

This H–R diagram shows the evolution of stars somewhat more and somewhat less massive than the Sun. The shape of the paths is similar, but they wind up in different places on the main sequence.



# 19.3 Stars of Other Masses

The main sequence is a band, rather than a line, because stars of the same mass can have different compositions.

Most important: Stars do not move along the main sequence! Once they reach it, they are in equilibrium and do not move until their fuel begins to run out.

# 19.3 Stars of Other Masses

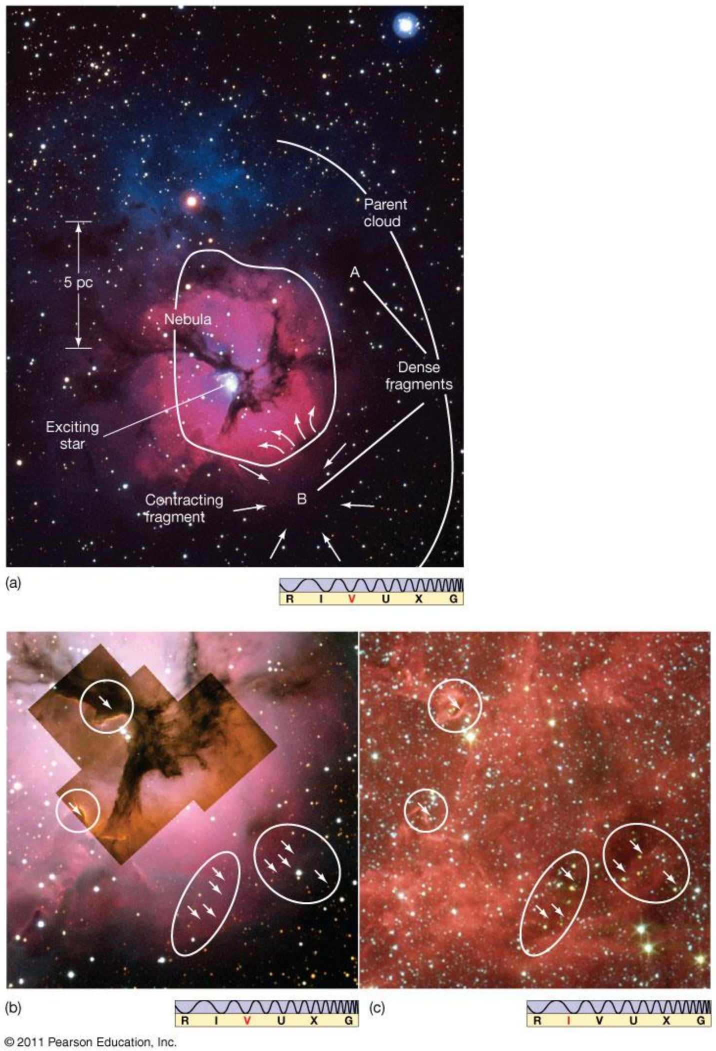
Some fragments are too small for fusion ever to begin. They gradually cool off and become dark "clinkers."

A protostar must have 0.08 the mass of the Sun (which is 80 times the mass of Jupiter) in order to become dense and hot enough that fusion can begin.

If the mass of the "failed star" is about 12 Jupiter masses or more, it is luminous when first formed, and is called a brown dwarf.

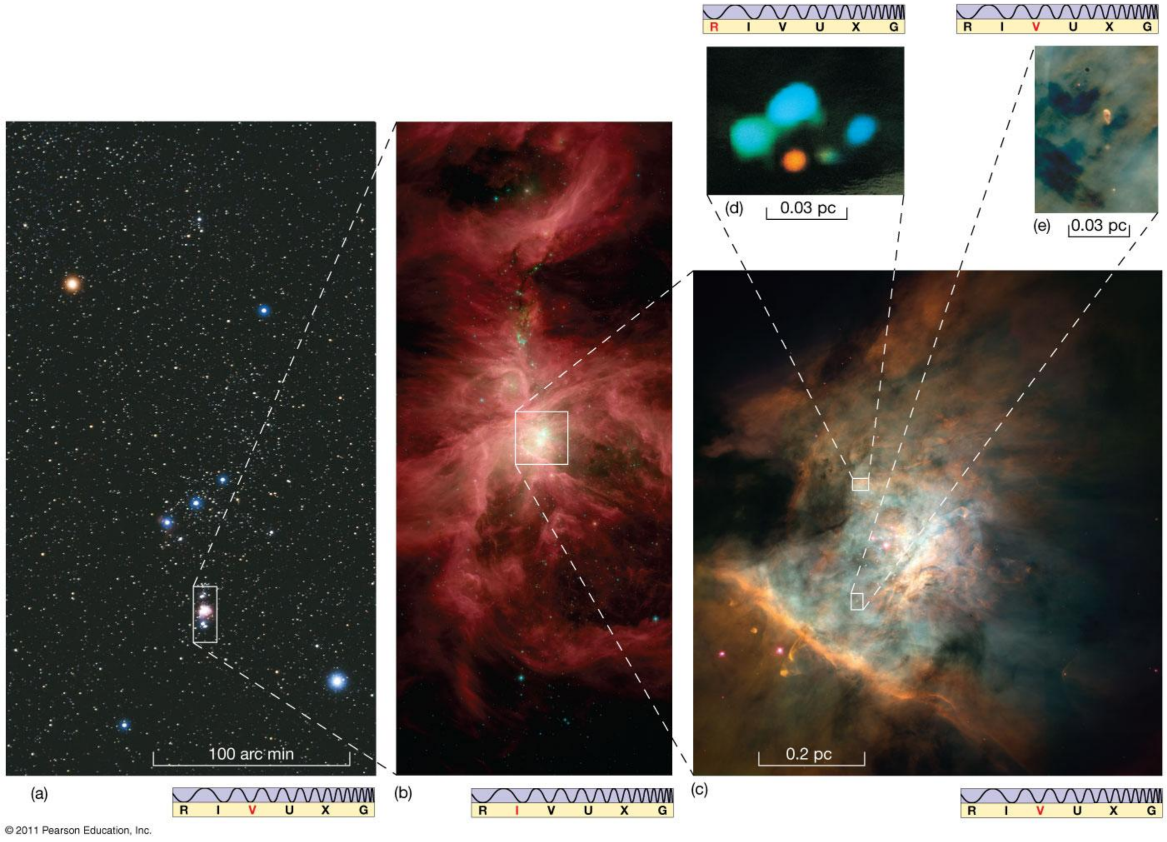
# 19.4 Observations of Cloud Fragments and Protostars

Emission nebulae are heated by the formation of stars nearby. In these images, we see the parent cloud in stage 1, contracting fragments between stages 1 and 2, and a new star in stage 6 or 7. The new star is the one heating the nebula.



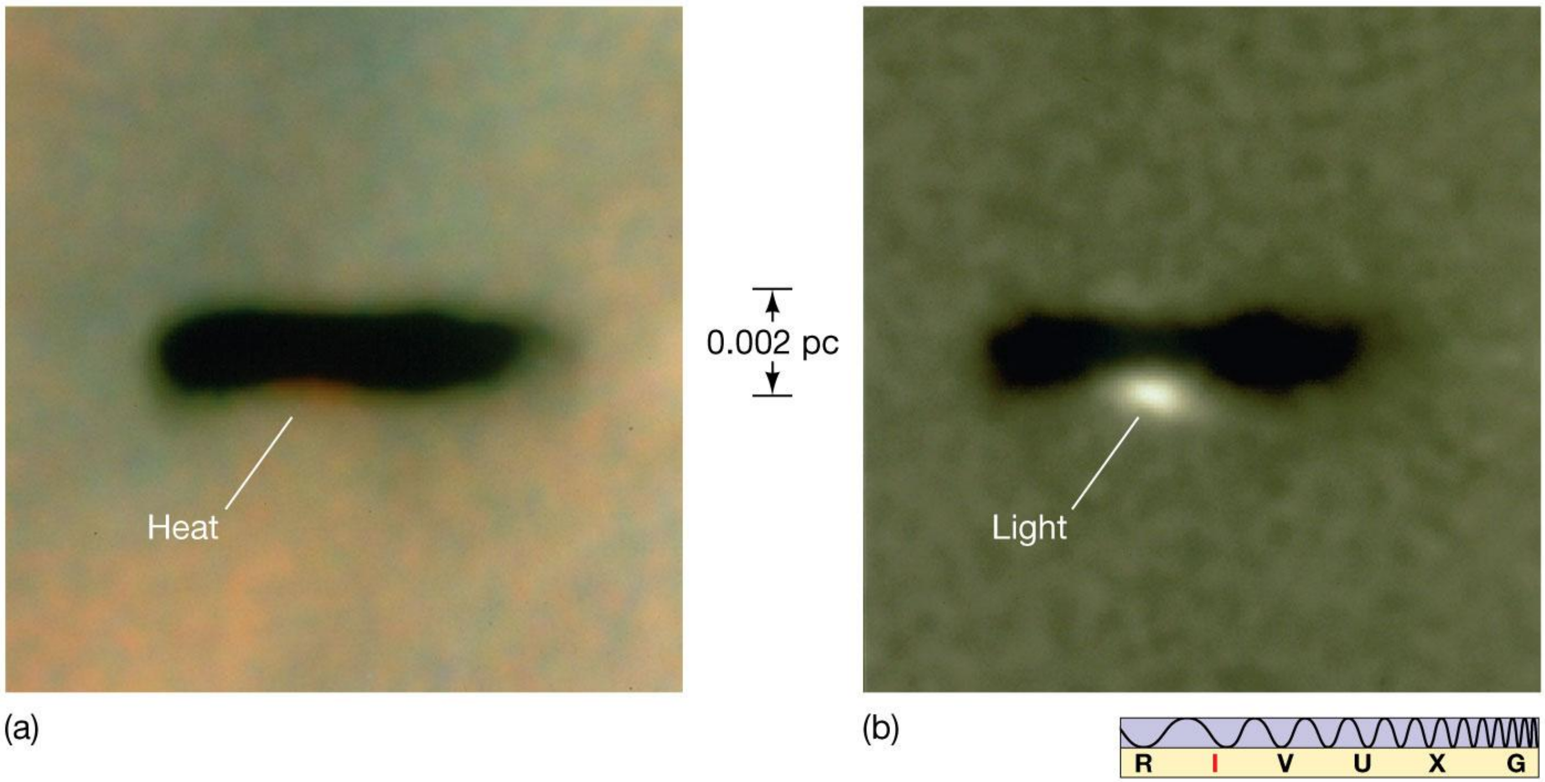
# 19.4 Observations of Cloud Fragments and Protostars

The Orion Nebula has many contracting cloud fragments, protostars, and newborn stars

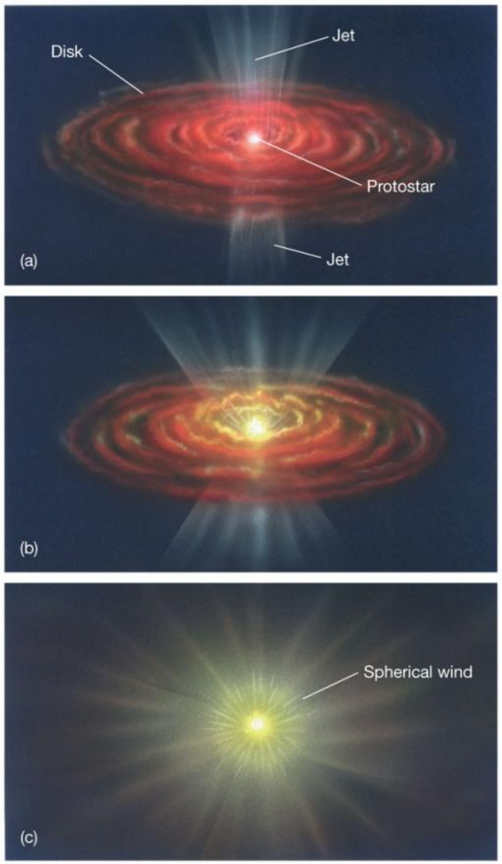


# 19.4 Observations of Cloud Fragments and Protostars

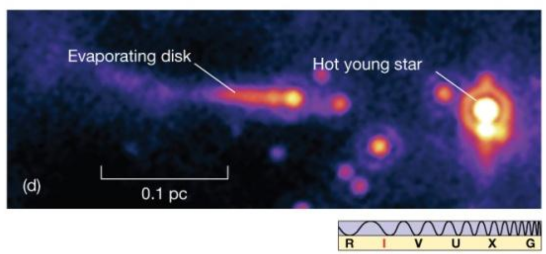
These are two protostars in the Orion Nebula, at around stage 5 in their development



# 19.4 Observations of Cloud Fragments and Protostars



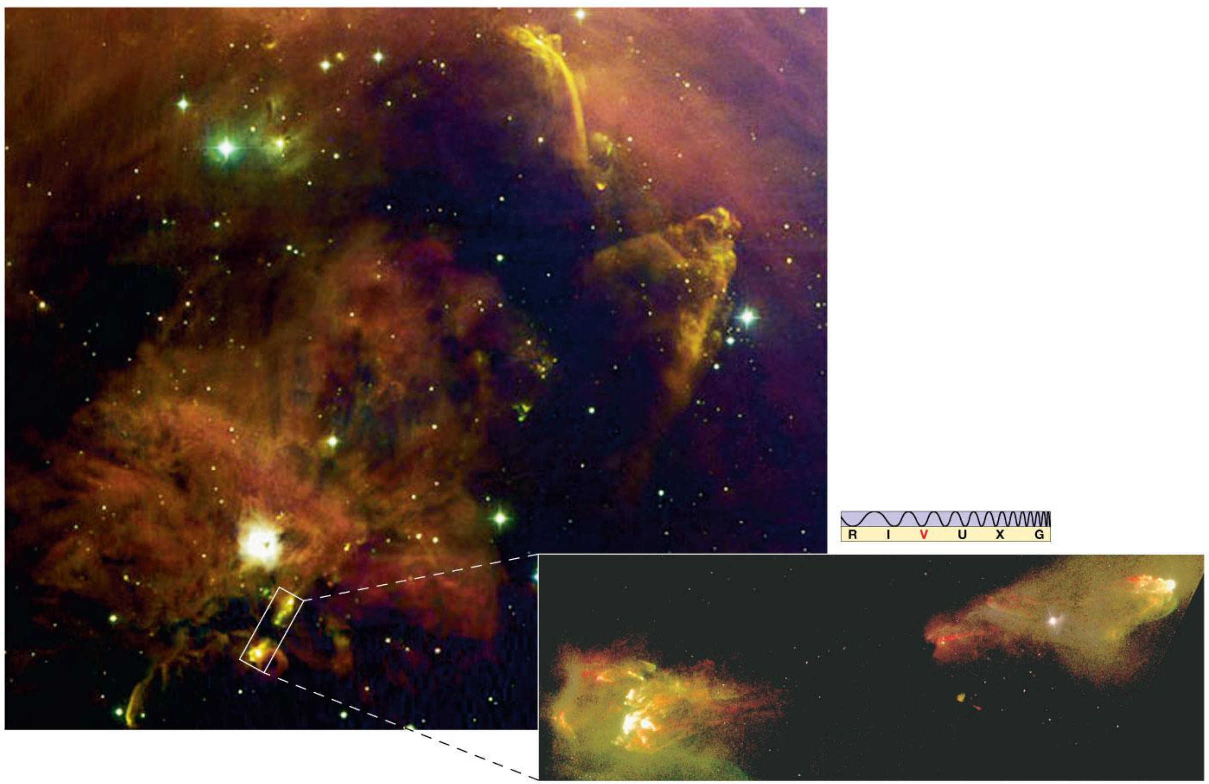





Protostars are believed to have very strong winds, which clear out an area around the star roughly the size of the solar system

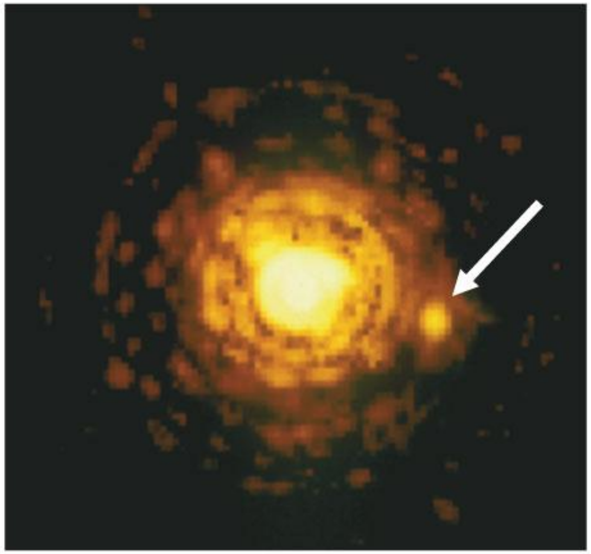
# 19.4 Observations of Cloud Fragments and Protostars

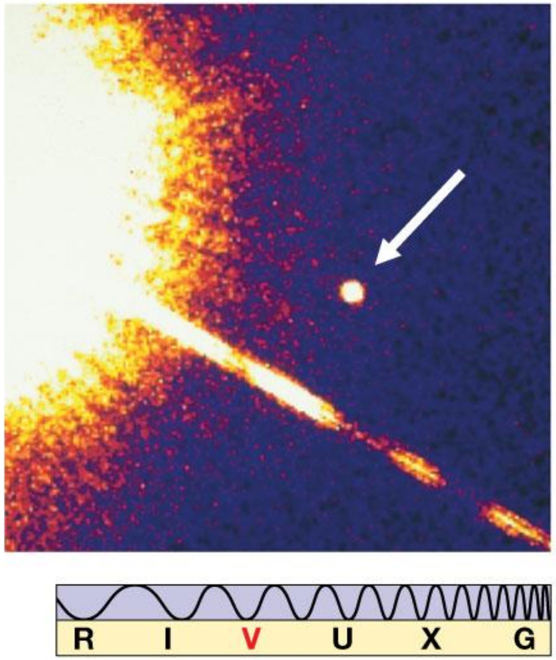
These two jets are matter being expelled from around an unseen protostar, still obscured by dust



# Discovery 19-1: Observations of Brown Dwarfs

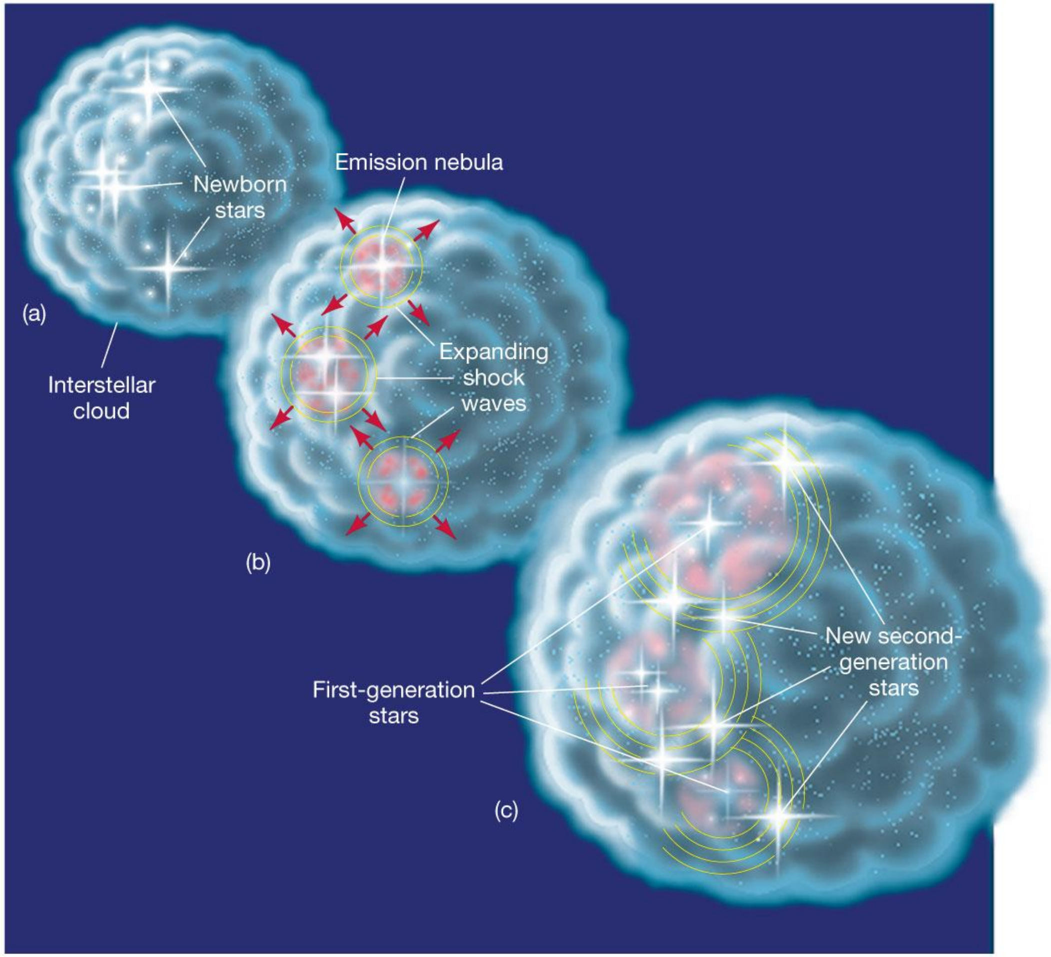
Brown dwarfs are difficult to observe directly, as they are very dim. These images are of two binary-star systems, each believed to contain a brown dwarf. The difference in luminosity between the star and the brown dwarf is apparent.





# 19.5 Shock Waves and Star Formation

Shock waves from nearby star formation can be the trigger needed to start the collapse process in an interstellar cloud



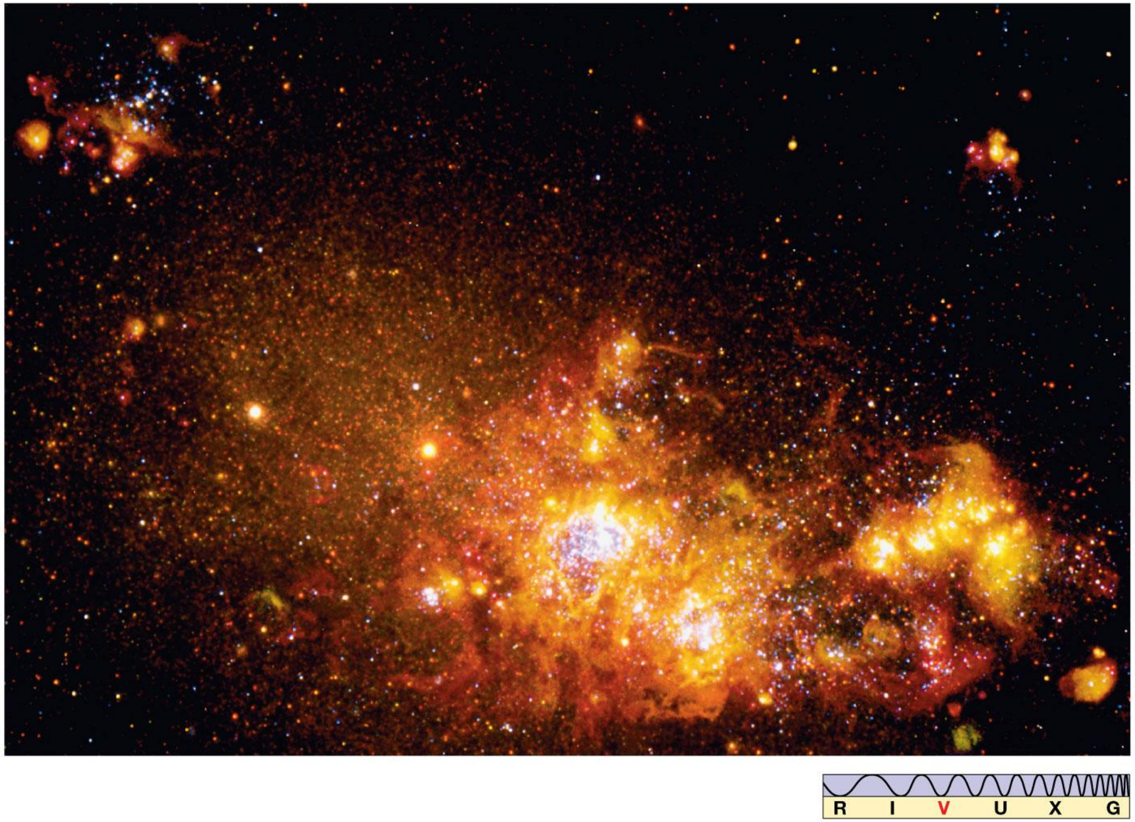
# 19.5 Shock Waves and Star Formation

Other triggers:

- Death of a nearby Sun-like star
- Supernova
- Density waves in galactic spiral arms
- Galaxy collisions

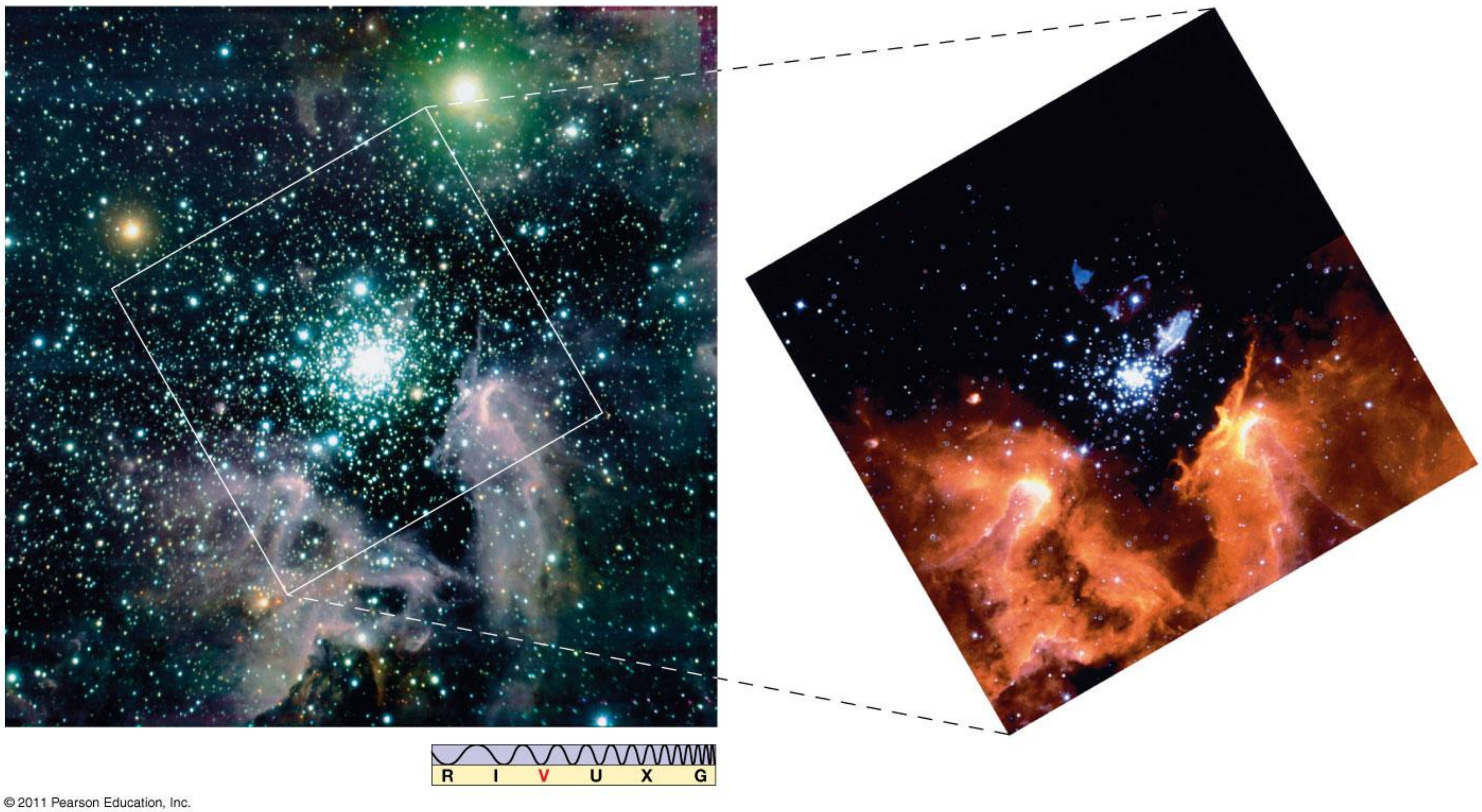
# 19.5 Shock Waves and Star Formation

This region may very well be several generations of star formation



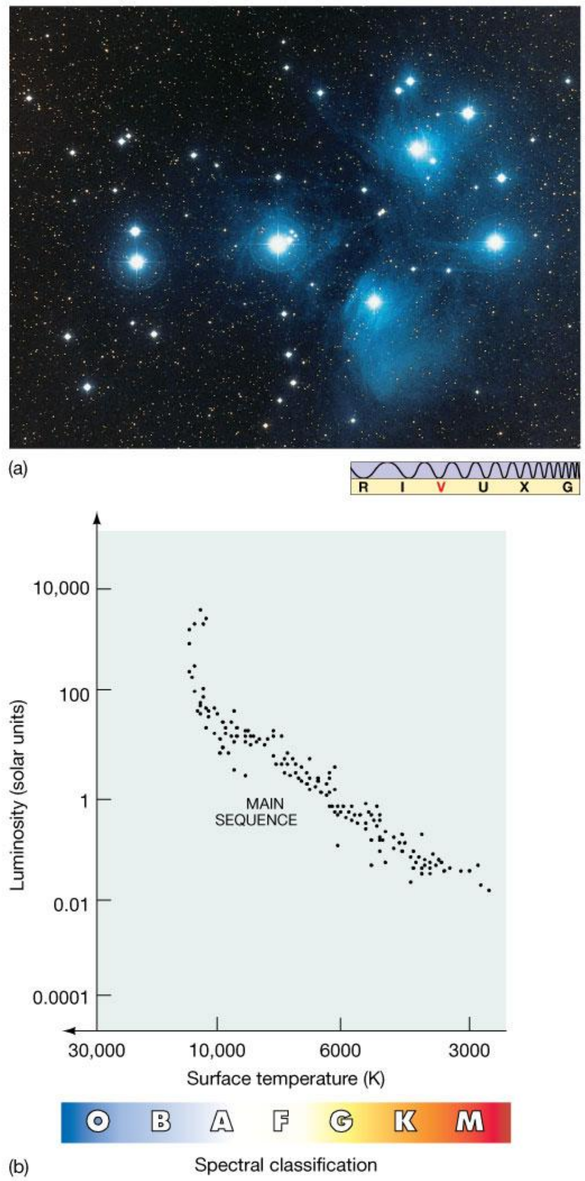
# 19.6 Star Clusters

Because a single interstellar cloud can produce many stars of the same age and composition, star clusters are an excellent way to study the effect of mass on stellar evolution.



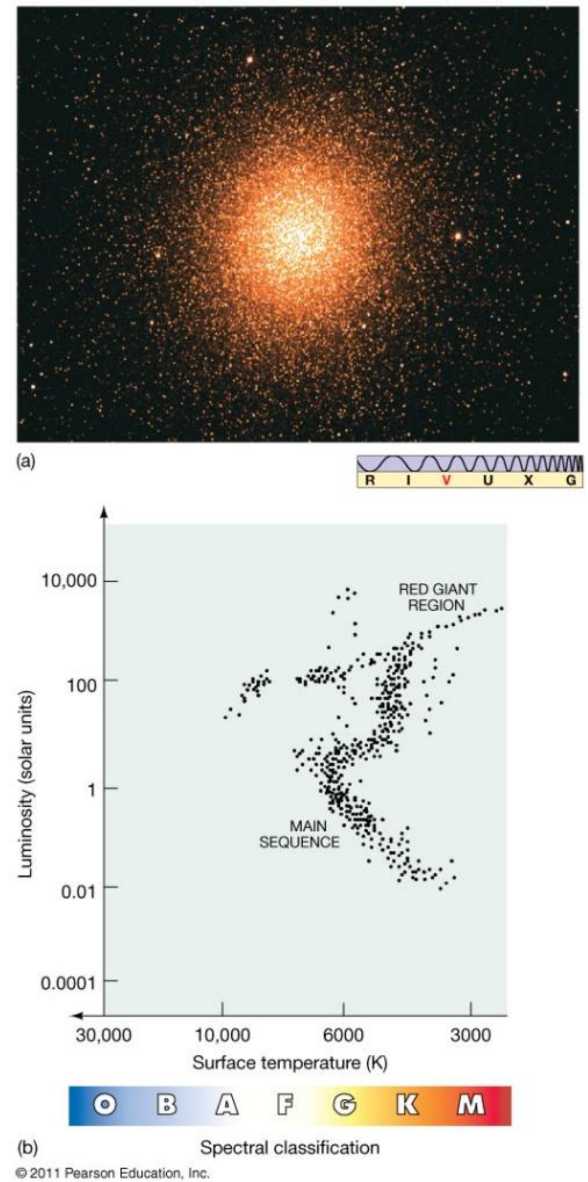
# 19.6 Star Clusters

This is a young star cluster called the Pleiades. The H-R diagram of its stars is shown. This is an example of an open cluster.



# 19.6 Star Clusters

This is a globular cluster—note the absence of massive main sequence stars and the heavily populated red giant region.



# 19.6 Star Clusters

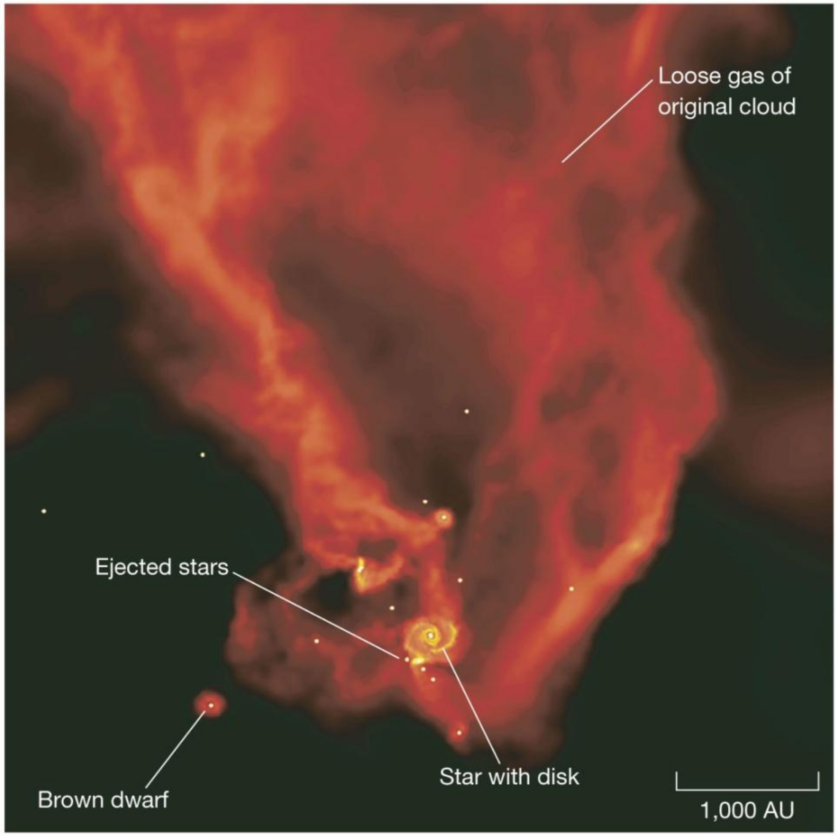
The differences between the H-R diagrams of open and globular clusters are that the globular clusters are very old, whereas the open clusters are much younger.

The absence of massive main sequence stars in the globular cluster is due to its extreme age—those stars have already used up their fuel and have moved off the main sequence.

# 19.6 Star Clusters

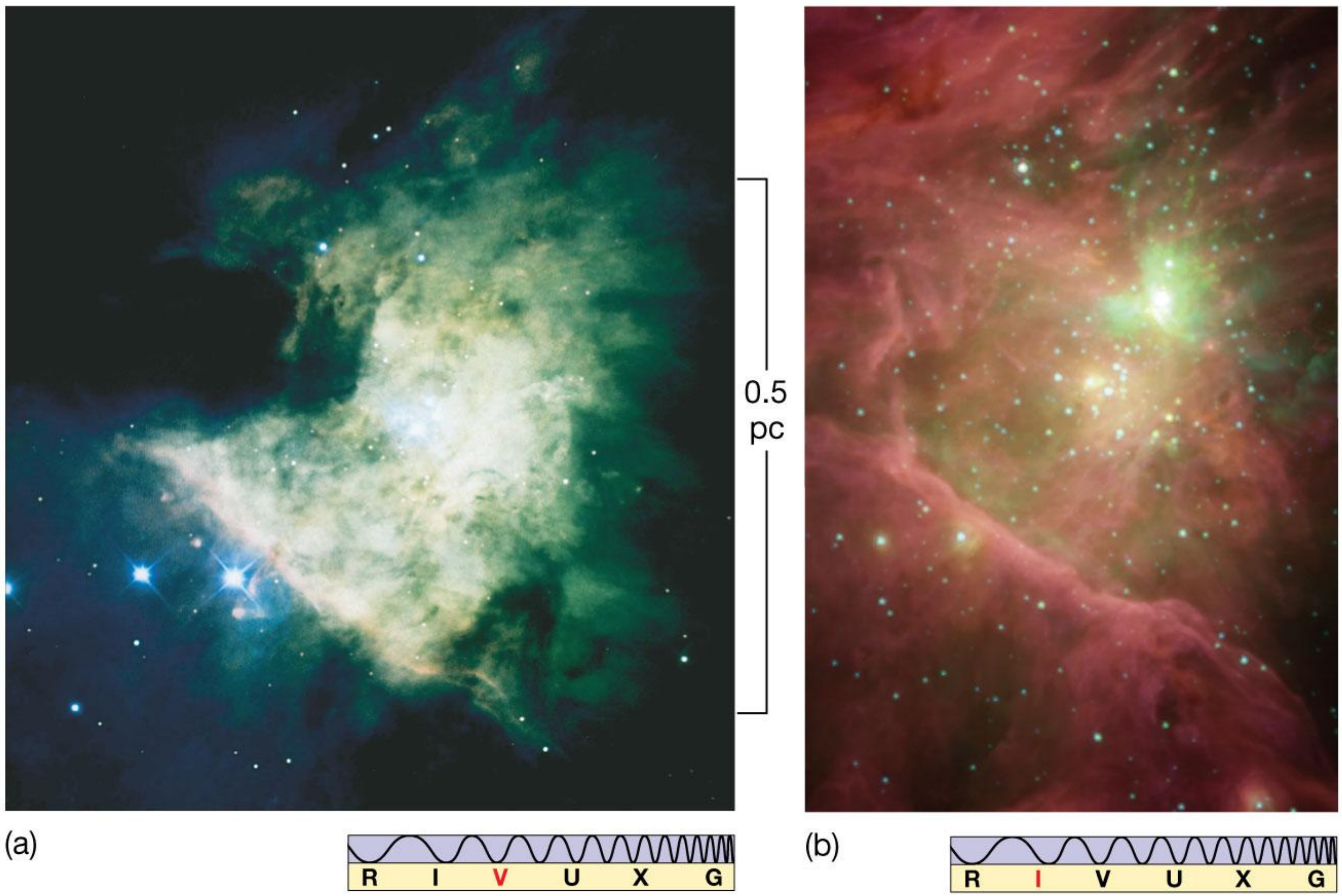
The presence of massive, short-lived O and B stars can profoundly affect their star cluster, as they can blow away dust and gas before it has time to collapse.

This is a simulation of such a cluster.



# 19.6 Star Clusters

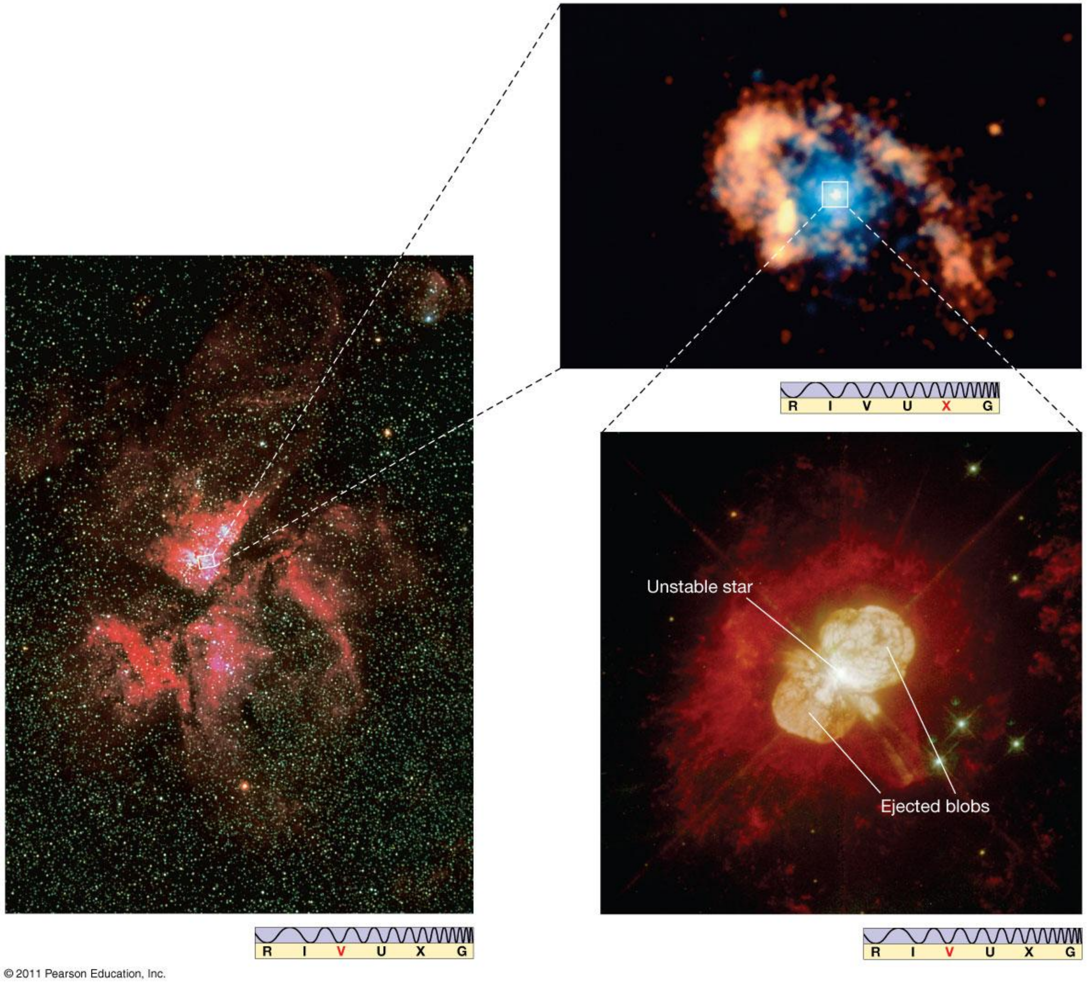
This image shows such a star-forming region in the Orion Nebula



# Discovery 19-2: Eta Carinae

Eta Carinae's mass is 100 times that of the Sun; it is one of the most massive stars known. It suffered a huge explosion about 150 years ago.

The last image shows the cloud expanding away from the star.



# Summary of Chapter 19

- Stars begin to form when an interstellar cloud begins to contract
- The cloud fragments as it contracts; fragments continue to collapse and fragment until their density is high enough to prohibit further fragmentation
- The fragment heats up enough to radiate a significant amount of energy; it is now a protostar

# Summary of Chapter 19 (cont.)

- The protostar continues to collapse; when the core is dense and hot enough, fusion begins
- The star continues to collapse until the inward force of gravity is balanced by the outward pressure from the core. The star is now on the main sequence
- More massive stars follow the same process, but more quickly
- Less massive stars form more slowly

# Summary of Chapter 19 (cont.)

- Star formation has been observed near emission nebulae
- Collapse may be initiated by shock waves
- One cloud tends to fragment into many stars, forming a cluster
- Open clusters are relatively young, small, and randomly shaped
- Globular clusters are old, very large, and spherical