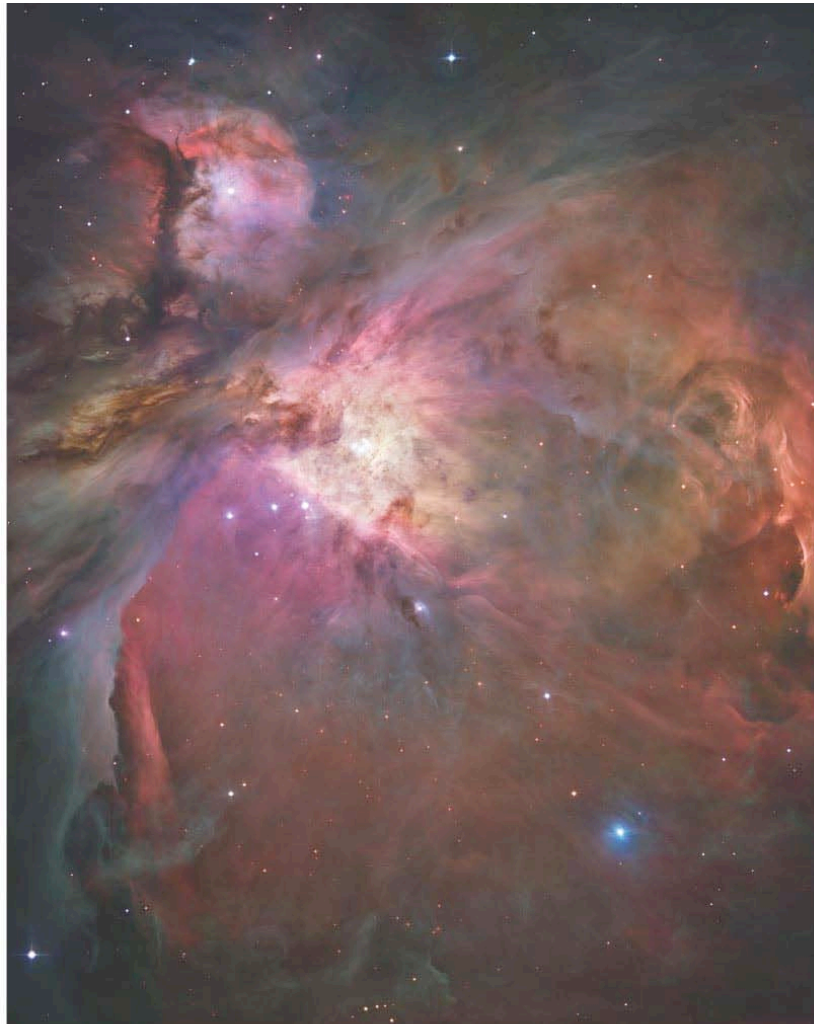


Chapter 19

Star Formation



Units of Chapter 19

19.1 Star-Forming Regions

Competition in Star Formation (means “gravity vs. other forces)

19.2 The Formation of Stars Like the Sun

(Notice H-R diagram evolution)

19.3 Stars of Other Masses

(Ditto)

19.4 Observations of Cloud Fragments and Protostars

XXObservations of Brown Dwarfs (important, but not on exam)

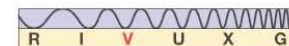
19.5 Shock Waves and Star Formation

19.6 Star Clusters

XXEta Carinae (not on exam, but great example)

19.1 Star-Forming Regions

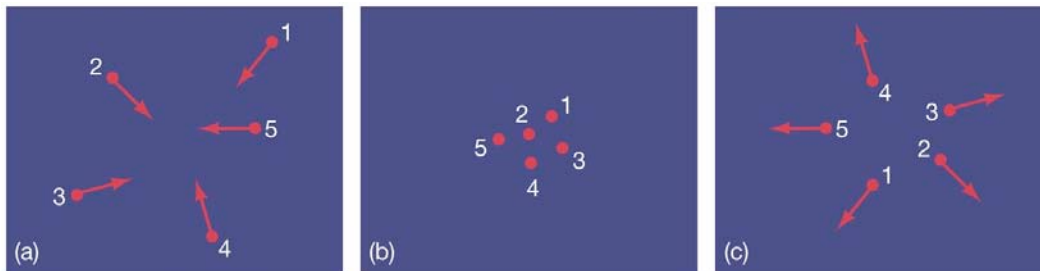
Star formation is ongoing. Star-forming regions are seen in our galaxy as well as others:



Star formation begins in massive clouds of molecular gas and dust

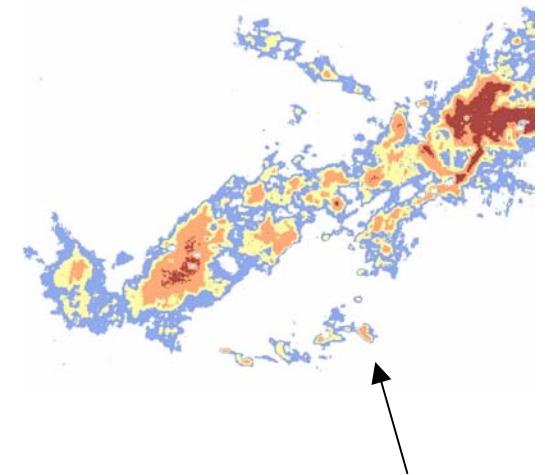
Star formation happens when part of a dust cloud begins to contract under its own gravitational force; as it collapses, the center becomes hotter and hotter until nuclear fusion begins in the core. *That is a basic and simple summary of this chapter.*

When looking at just a few atoms, the gravitational force is far from strong enough to overcome the random thermal motions:



But interstellar molecular clouds are enormous, often containing up to a million solar masses of gas (and 1% dust--it is just part of the ISM. That is a lot of self-gravity! The most massive clouds have gravity that can overcome the thermal pressure trying to resist gravity, and the cloud must collapse.

The cloud shown to the right above is a moderately-sized cloud with a size of about 10 pc and a mass of about 10 thousand solar masses. Several hundred young lower-mass stars like the sun are forming there.



“giant molecular cloud”
fragmenting under gravity into hundreds of stars. The red parts are densest, and where the stars are seen. This is a map in the CO molecule.

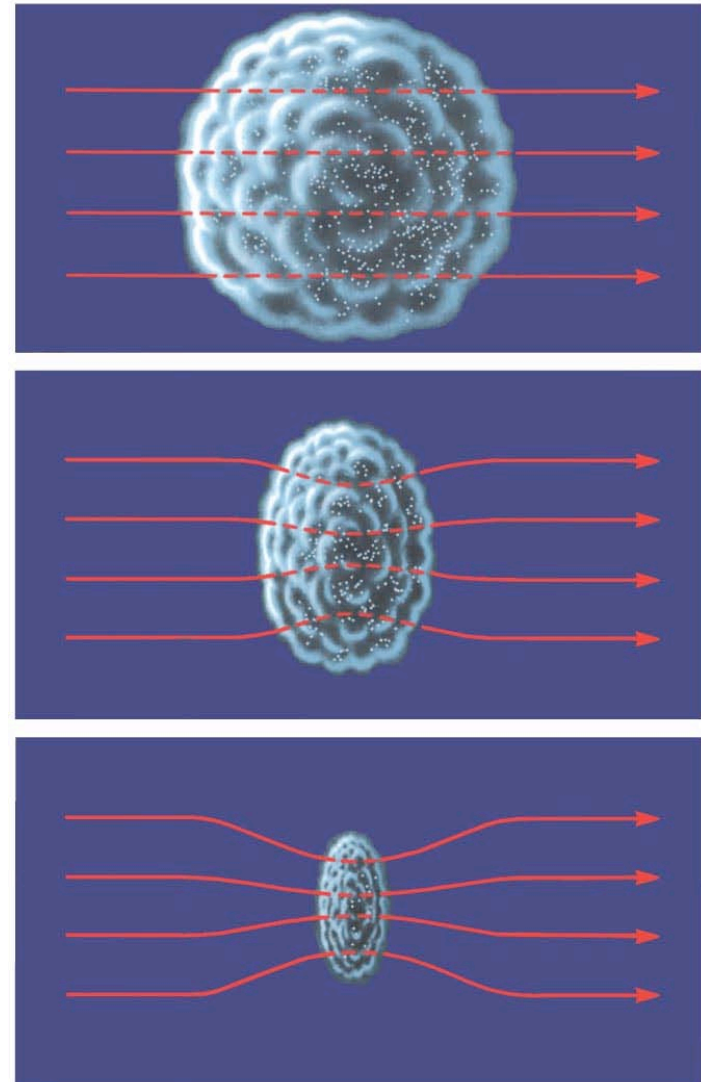
More Precisely 19-1: Competition in Star Formation

Rotation can also interfere with gravitational collapse, as can magnetism (clouds have magnetic fields).

Clouds contract in a “distorted” way:

In fact the clouds are usually *much* more irregular than shown in this textbook illustration.

(Note: all the colorful emission line nebulae shown in this chapter are just this same molecular gas after a massive stars has started pouring out photons.



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: [You don't have to memorize these numbers, but they do tell an important story, and you should understand the names of the objects on the right.]

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	2×10^6	10	10	10^9	10^{14}	Interstellar cloud
2	3×10^4	100	10	10^{12}	10^{12}	Cloud fragment 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	3×10^7	10,000,000	4500	10^{31}	2×10^6	Star
7	10^{10}	15,000,000	6000	10^{32}	1.5×10^6	Main-sequence star

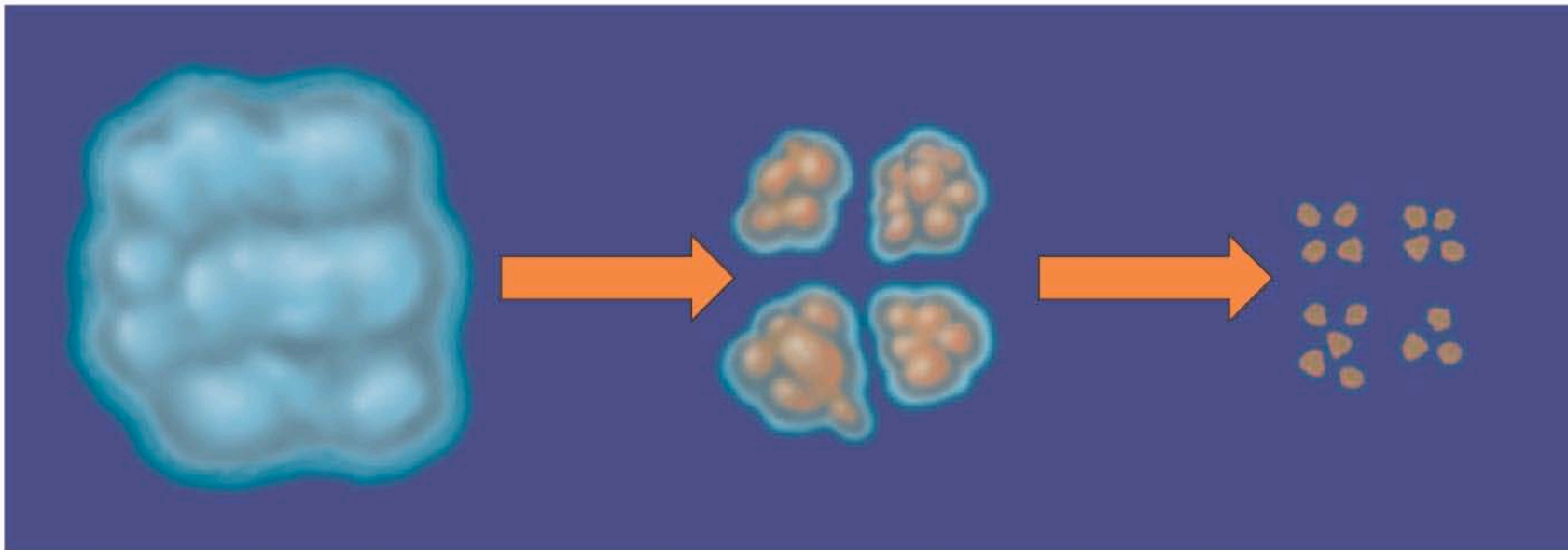
* Round numbers; for comparison, recall that the diameter of the Sun is 1.4×10^6 km, whereas that of the solar system is roughly 1.5×10^{10} km.

Notice that a solar-like star only takes a few tens of millions of years to collapse and Contact until they reach the main sequence, but they will spend 10 *billion* years burning hydrogen on the main sequence before running out of nuclear fuel.

19.2 The Formation of Stars Like the Sun

Stage 1: Fragmentation

Interstellar cloud starts to *contract*, possibly triggered by shock or pressure wave from nearby star. As it contracts, the cloud *fragments* into smaller pieces. [Note: this is a cartoon--the process is not nearly as tidy as shown here.]



19.2 The Formation of Stars Like the Sun

Stage 2: Collapse

Individual cloud fragments begin to collapse. Once the density is high enough, there is no further fragmentation. Reason: the star has become *opaque to its own radiation*: It has a photosphere! After this, the 'trapped radiation heats the interior of the object as it contracts.

Stage 3: Object becomes **opaque** and heats.

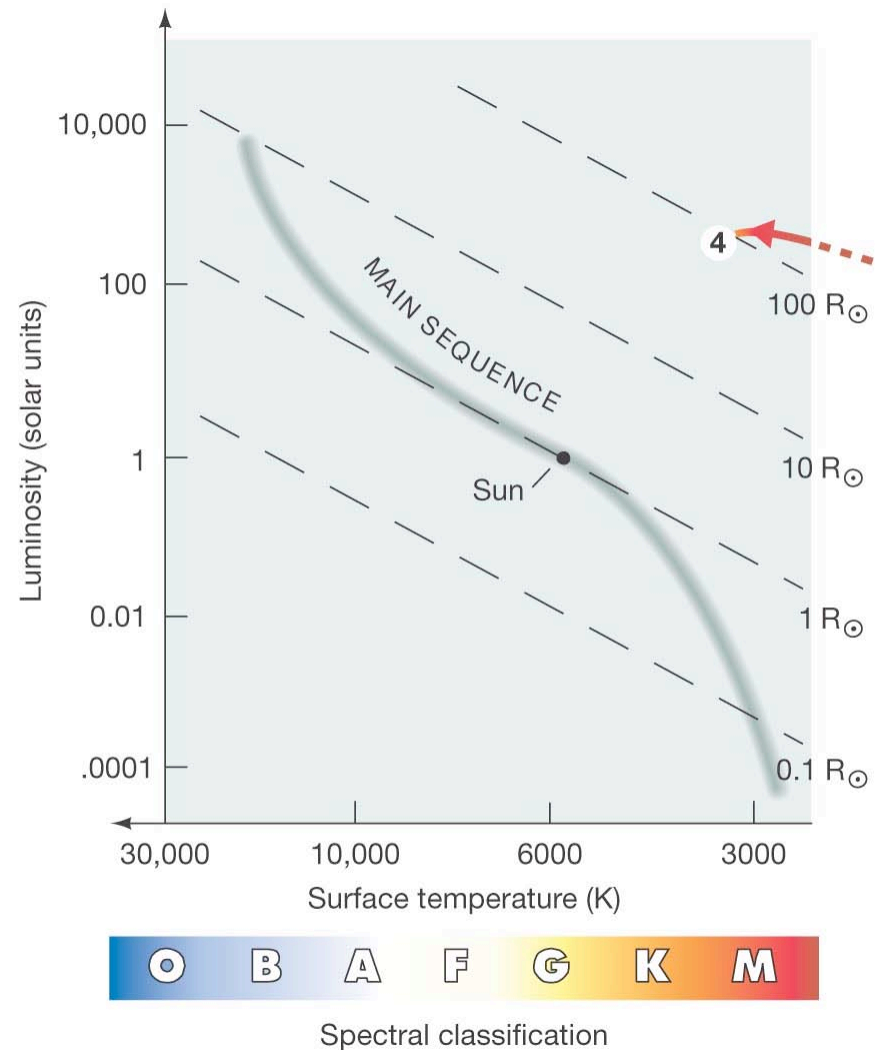
The interior of the fragment has begun heating and is about 10,000 K.

This is hot enough to ionize hydrogen, but not much else. The interior will continue to heat as it contracts, until, at several *million* degrees, something stops it (nuclear fusion will generate the heat to halt the collapse).

19.2 The Formation of Stars Like the Sun

Stage 4: protostar

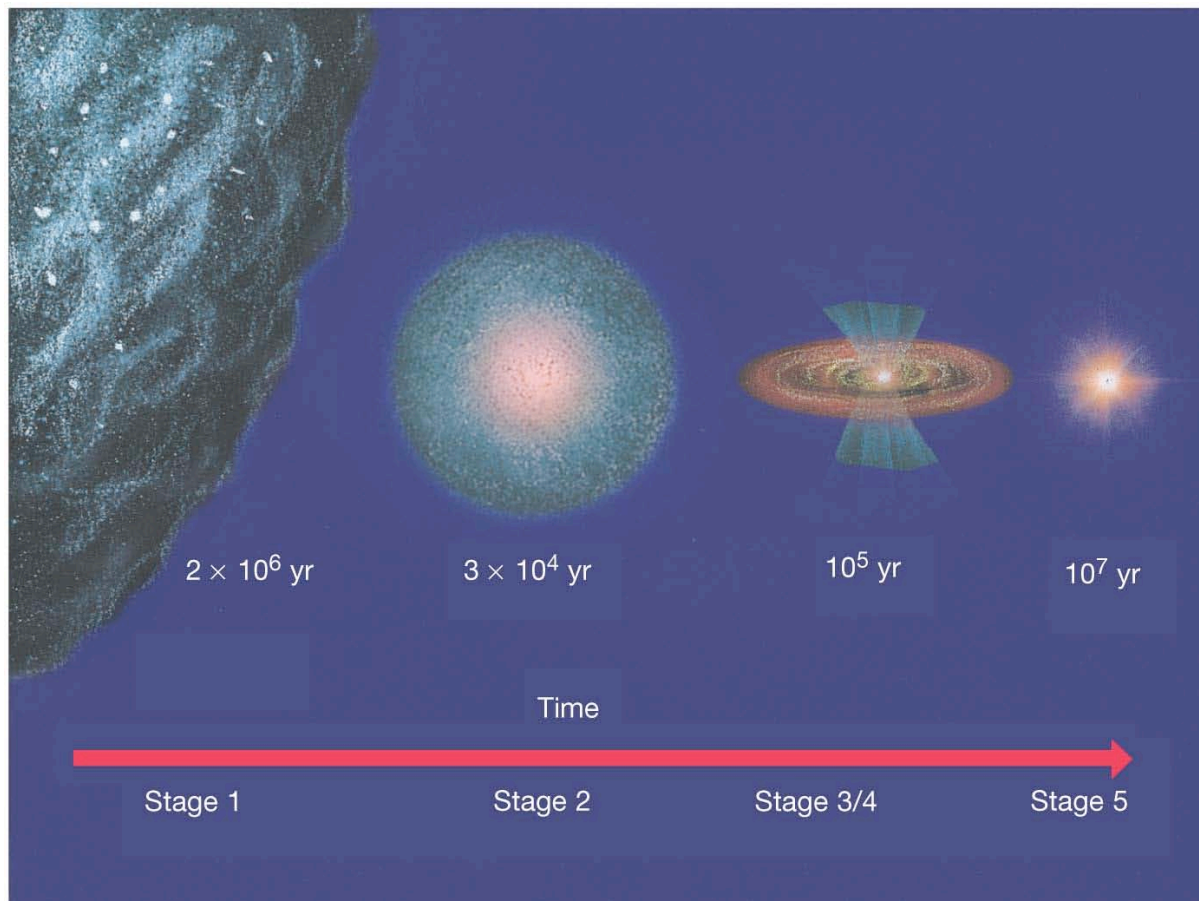
The core of the cloud is now a protostar and makes its first appearance on the H-R diagram:



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.

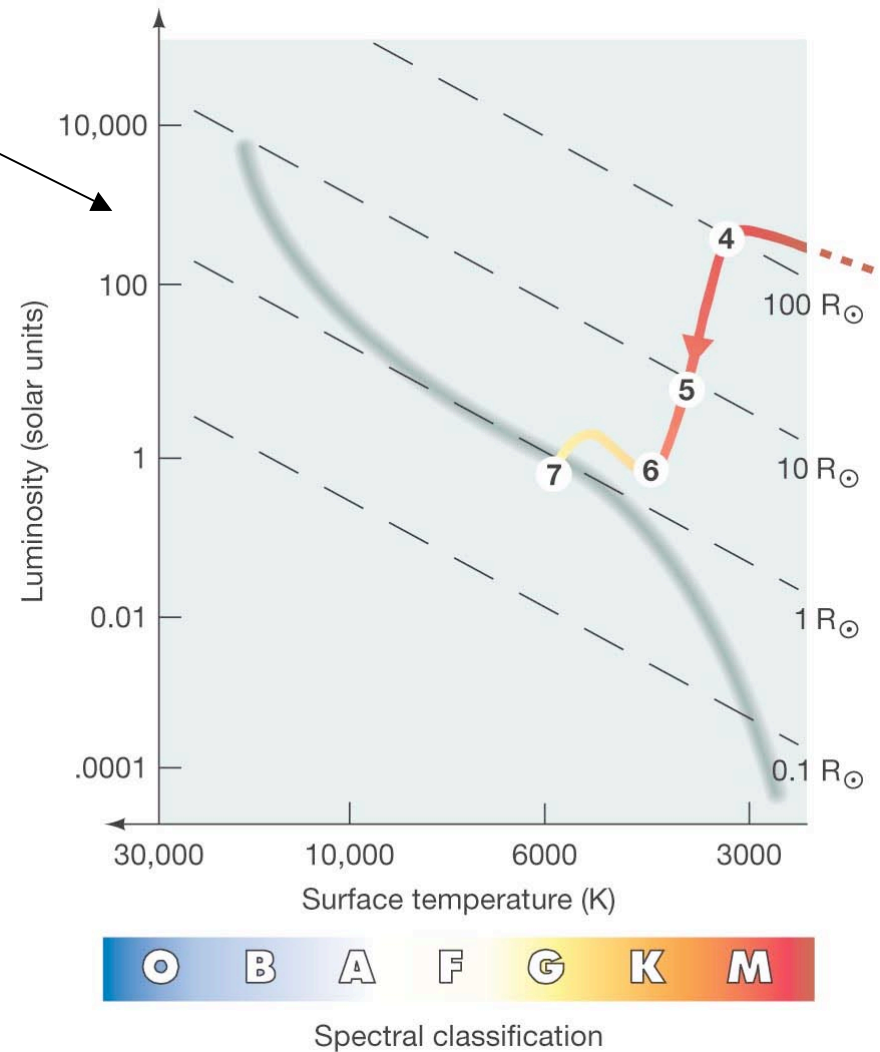
Inspect the picture and understand the different stages represented.



19.2 The Formation of Stars Like the Sun

The last stages can be followed as a path in the H-R diagram:

The protostar's luminosity decreases even as its temperature rises because it is becoming more compact (less surface area).



19.2 The Formation of Stars Like the Sun

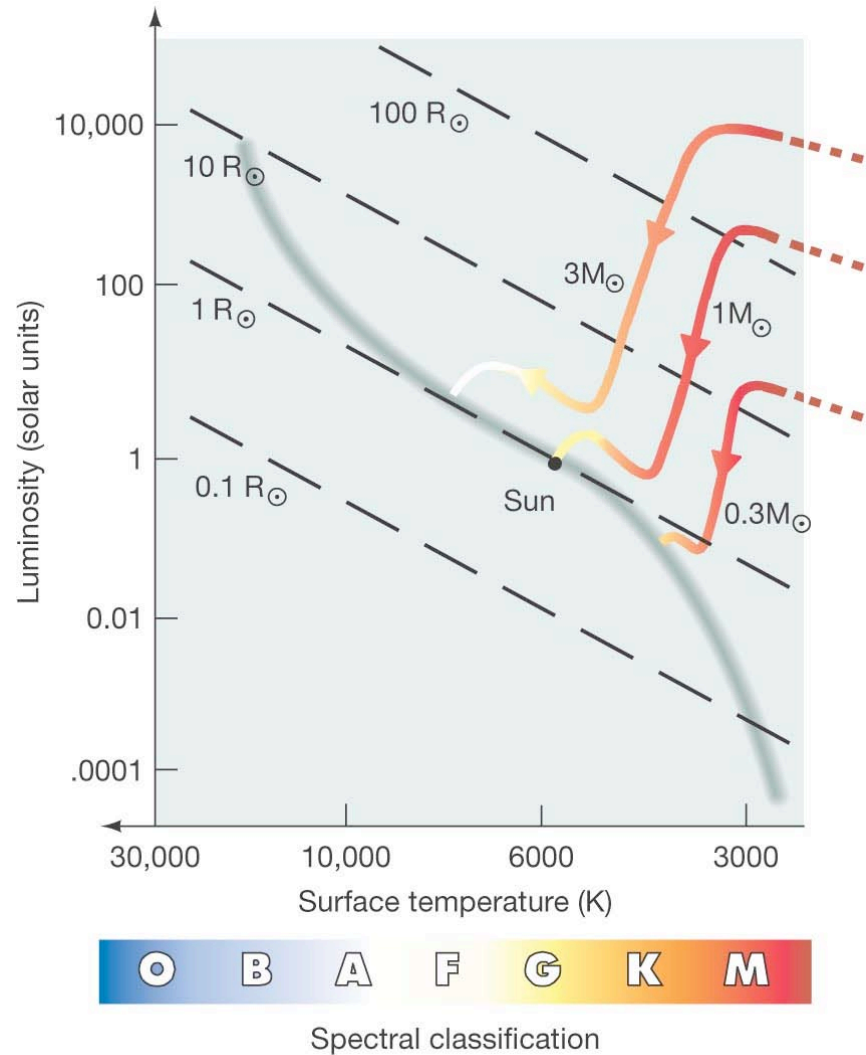
At stage 6, the core reaches 10 million K, and nuclear fusion begins. The protostar has become a star.

The star continues to contract and increase in temperature until it is in equilibrium: Internal pressure force outward, balancing the inward force of gravity, at every layer of the star's interior. This is stage 7: The star has reached the Main Sequence and will remain there as long as *it has hydrogen to fuse*.

[Don't worry about the numbers of these phases, only understand the reasons for these stages of evolution from interstellar cloud to star.]

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

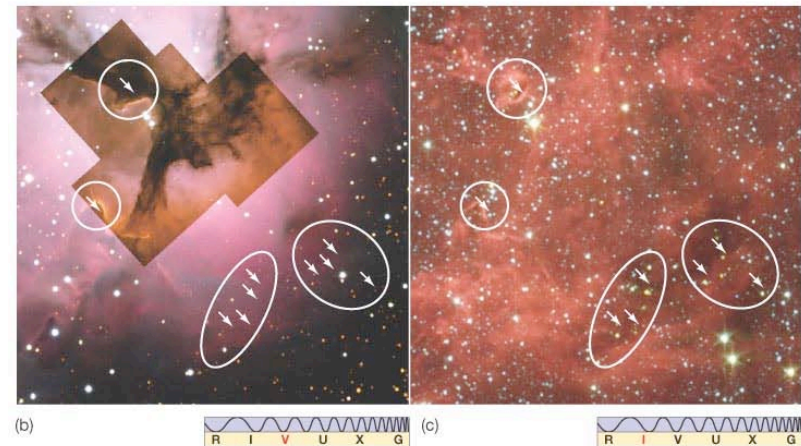
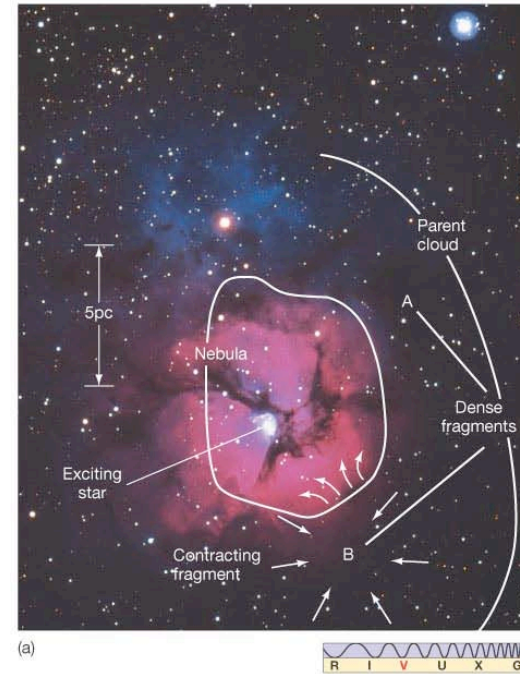
Some fragments are too small for fusion ever to begin. They gradually cool off and simply fade, radiating away whatever heat generated in trying (unsuccessfully) to ignite nuclear fusion.

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**.

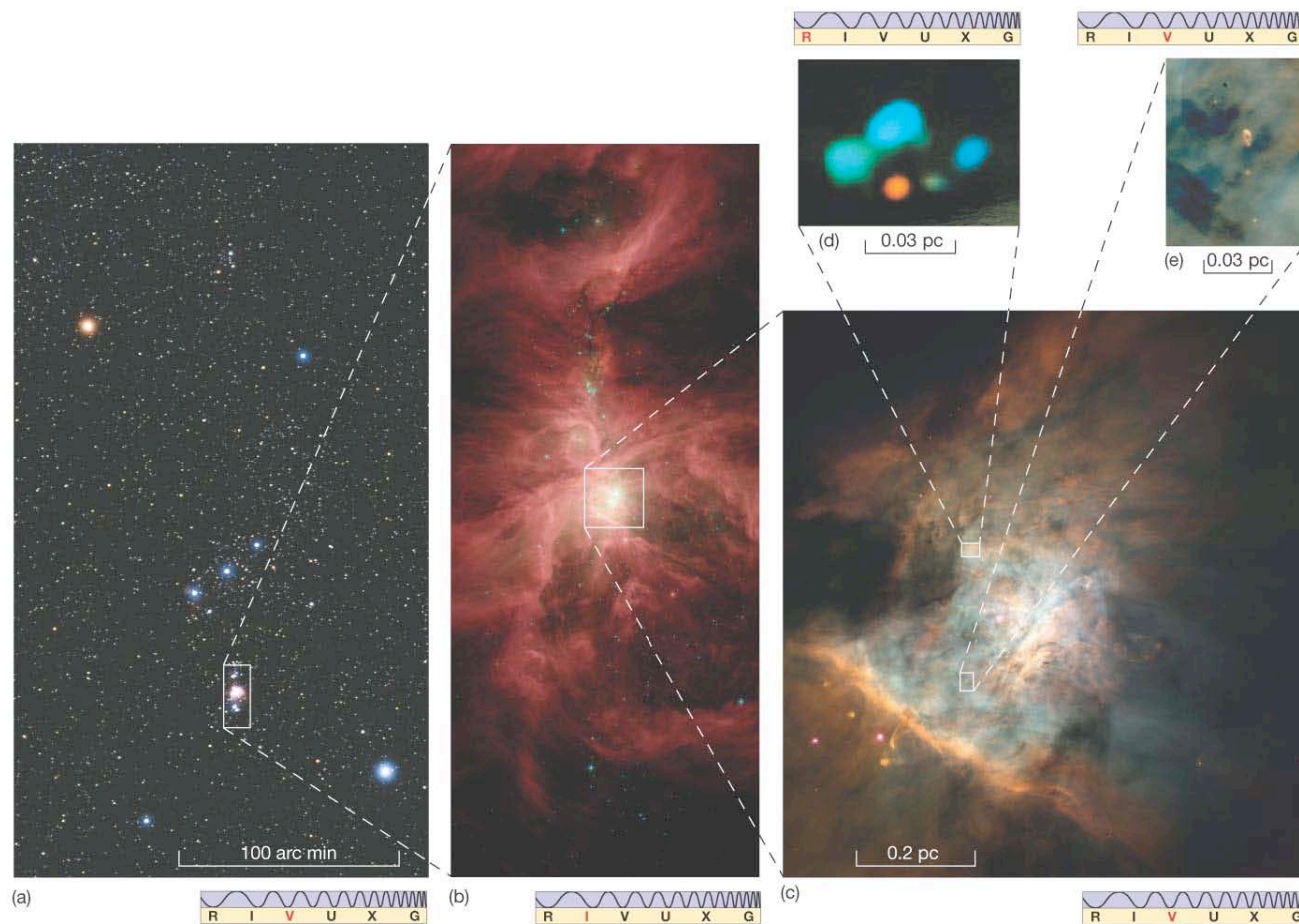
19.4 Observations of Cloud Fragments and Protostars

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.



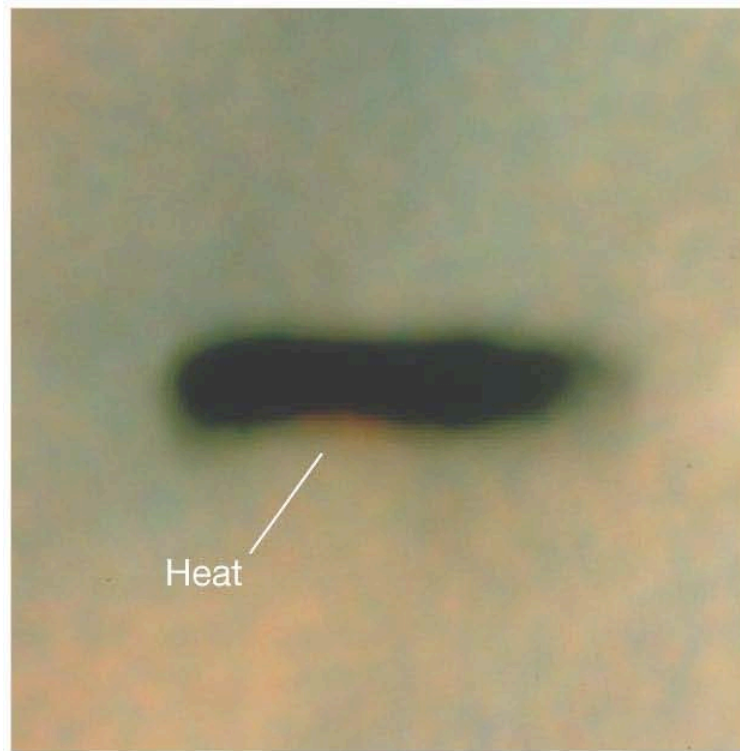
19.4 Observations of Cloud Fragments and Protostars

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



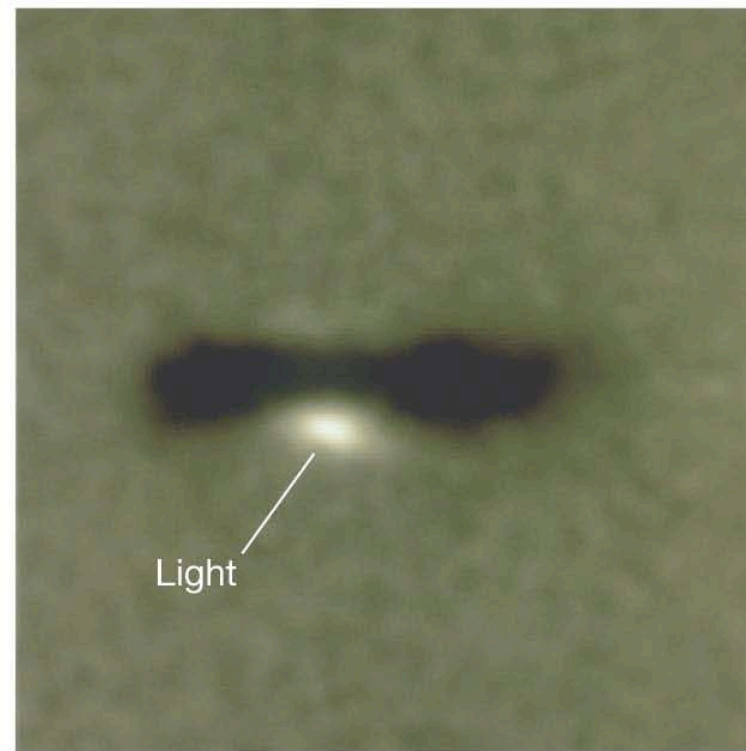
19.4 Observations of Cloud Fragments and Protostars

These are two protostars in the Orion nebula; what “stage” are they in?

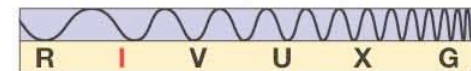


(a)

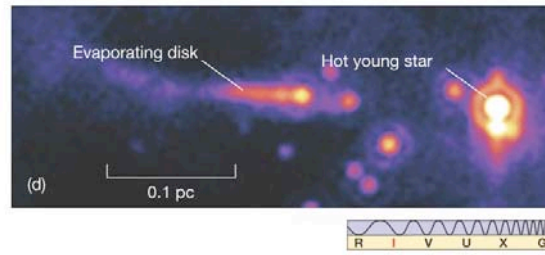
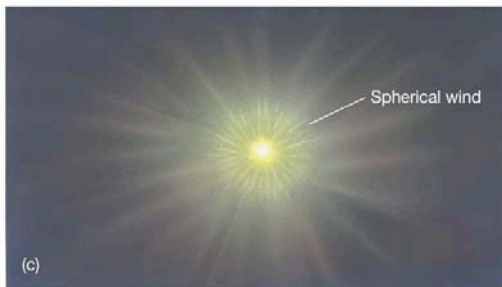
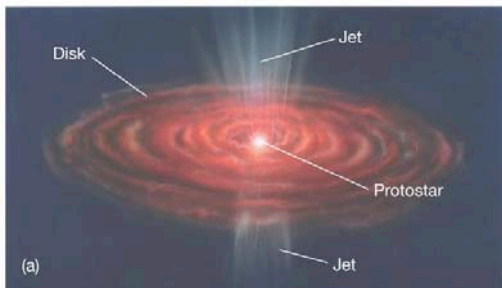
0.002 pc



(b)



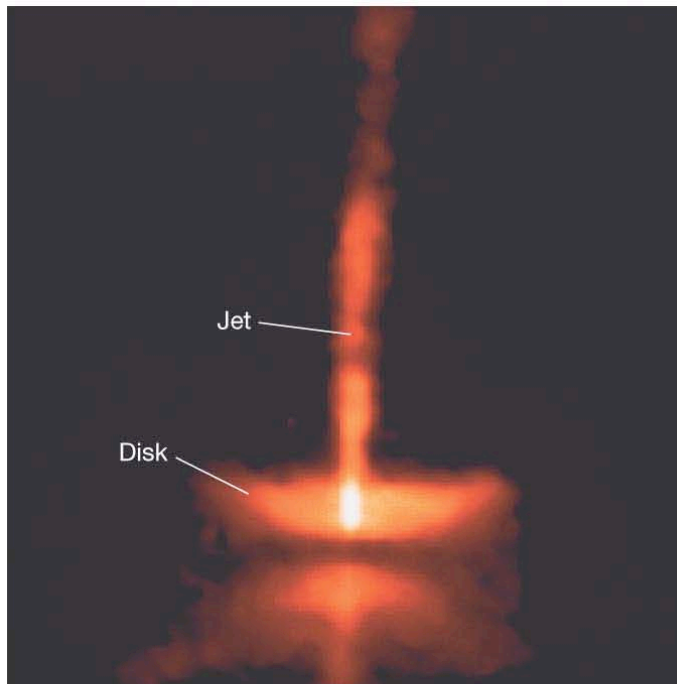
19.4 Observations of Cloud Fragments and Protostars



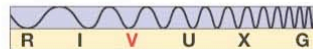
Protostars are believed to have very strong winds, which clear out an area around the star roughly the size of the solar system

19.4 Observations of Cloud Fragments and Protostars

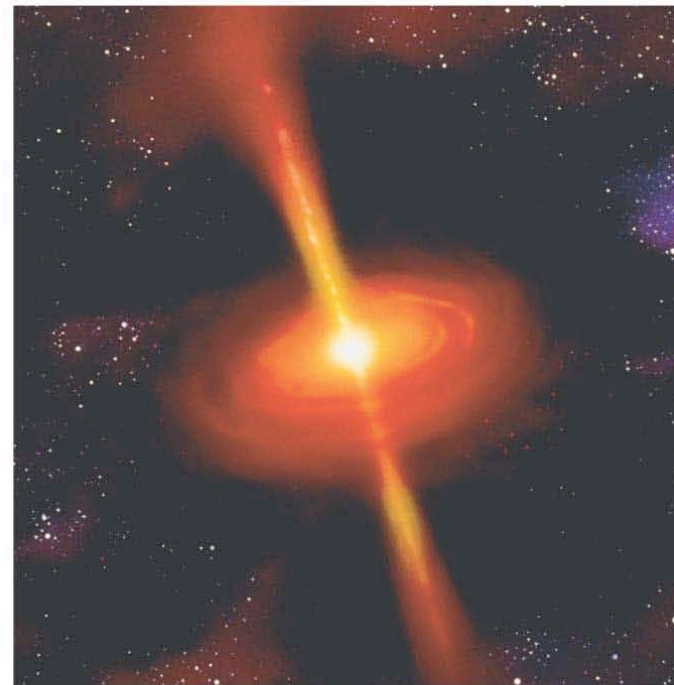
These two **jets** are matter being expelled from around an unseen protostar, still obscured by dust.



(a)



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(b)

19.5 Shock Waves and Star Formation

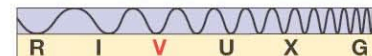
Triggers for star formation:

Shock waves generated by:

- **Death of a sun-like nearby star**
- **Supernova explosion (massive stars only)**
- **Density waves in galactic spiral arms**
- **Galaxy collisions**

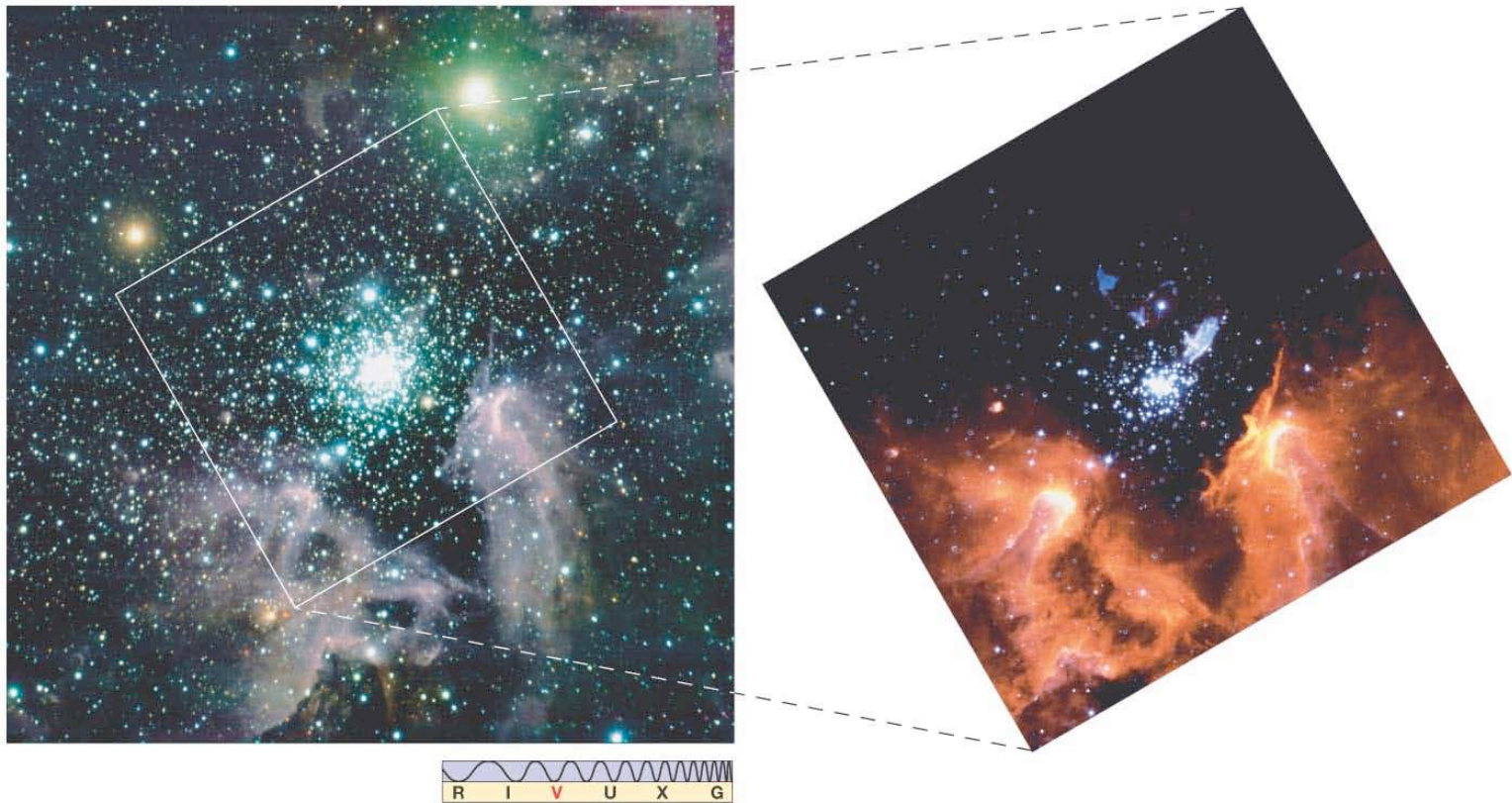
19.5 Shock Waves and Star Formation

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.

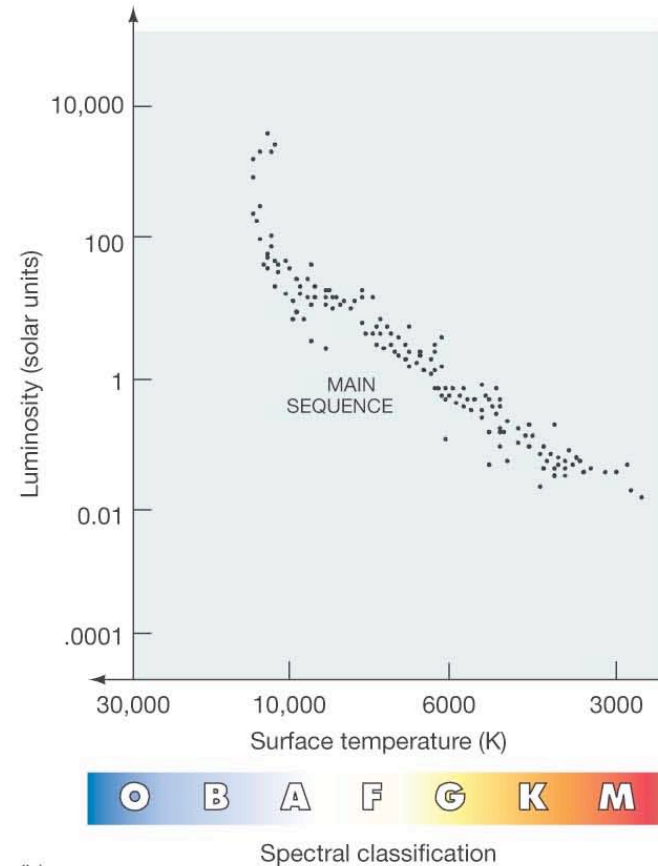


19.6 Star Clusters

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:



(a)



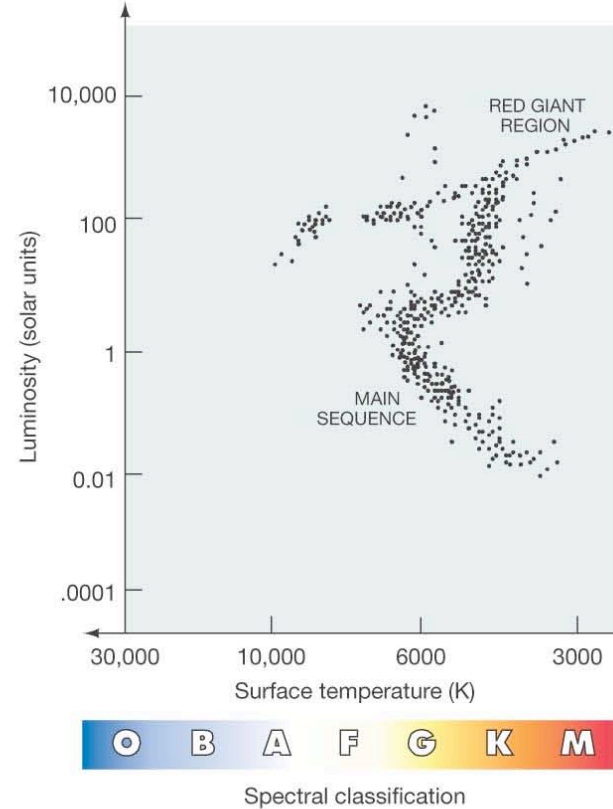
(b)

19.6 Star Clusters

This is a globular cluster—note the absence of massive Main Sequence stars and the heavily populated Red Giant region:



(a)



(b)

19.6 Star Clusters

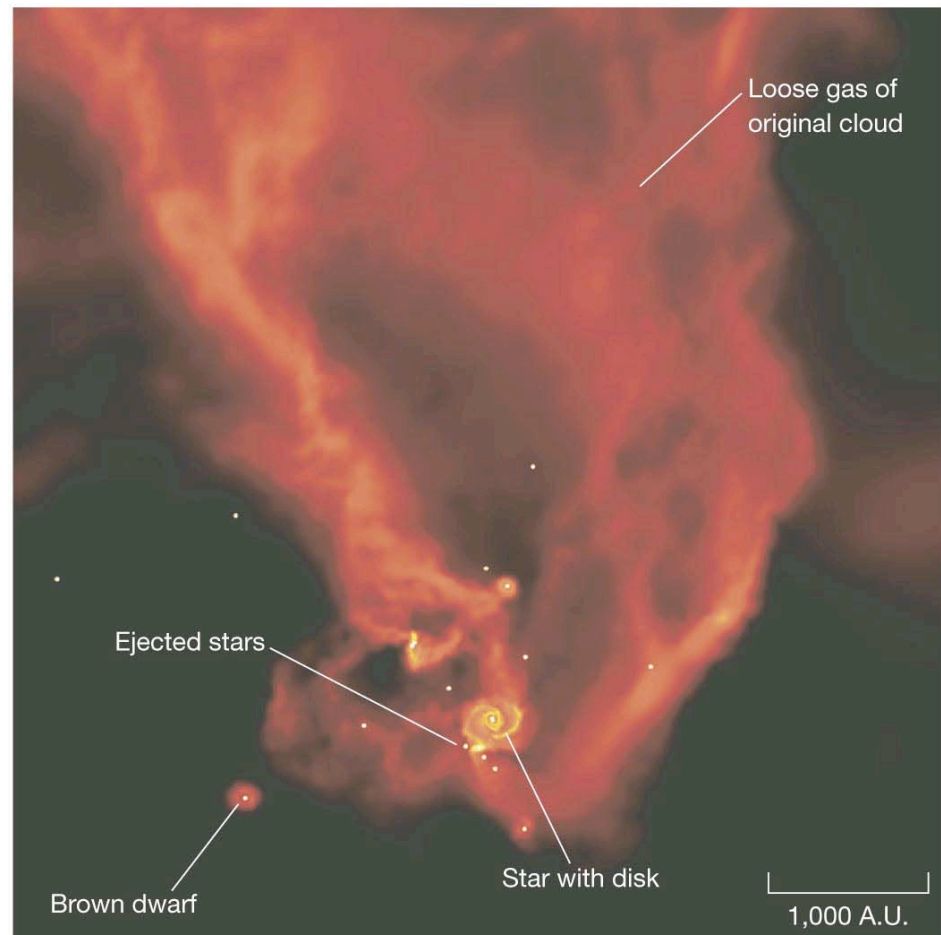
The differences between the H-R diagrams of open and globular clusters are that the globular clusters are very old, while the open clusters are much younger.

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

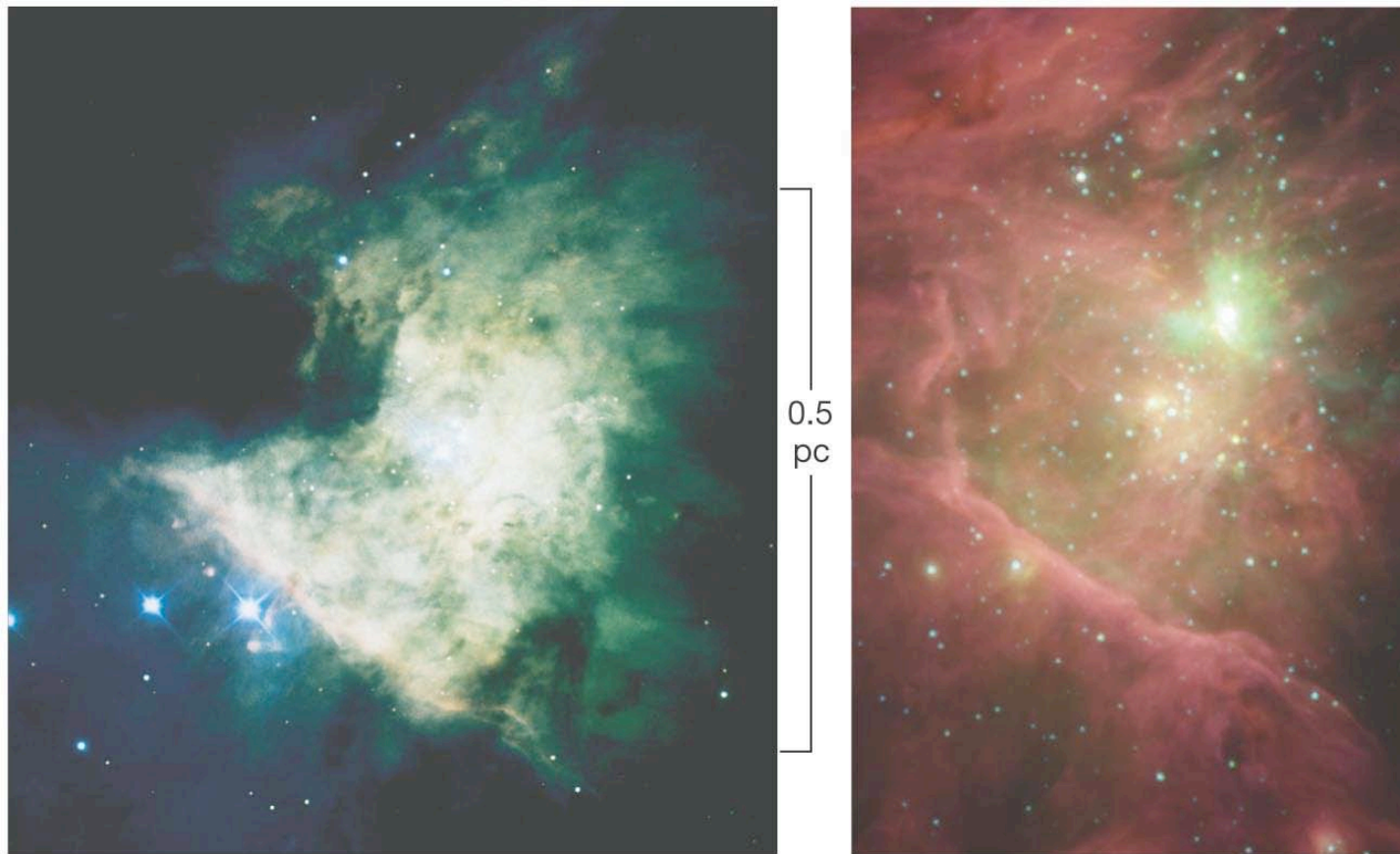
The presence of massive, short-lived O and B stars can profoundly affect their star cluster, as they can blow away dust and gas before it has time to collapse.

This is a simulation of such a cluster:

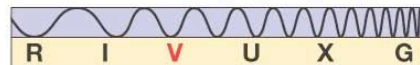


19.6 Star Clusters

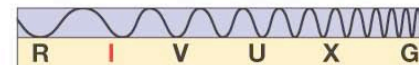
This image shows such a star-forming region in the Orion Nebula:



(a)



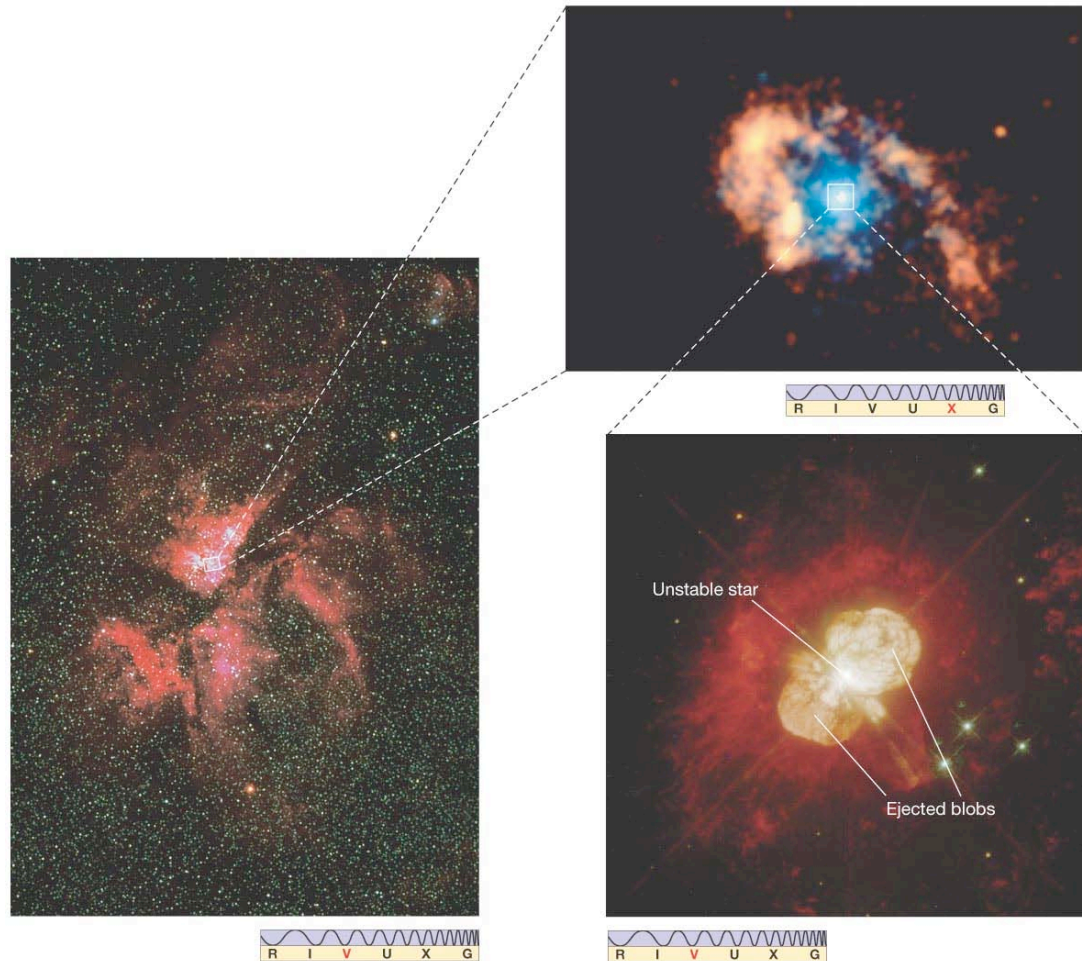
(b)



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