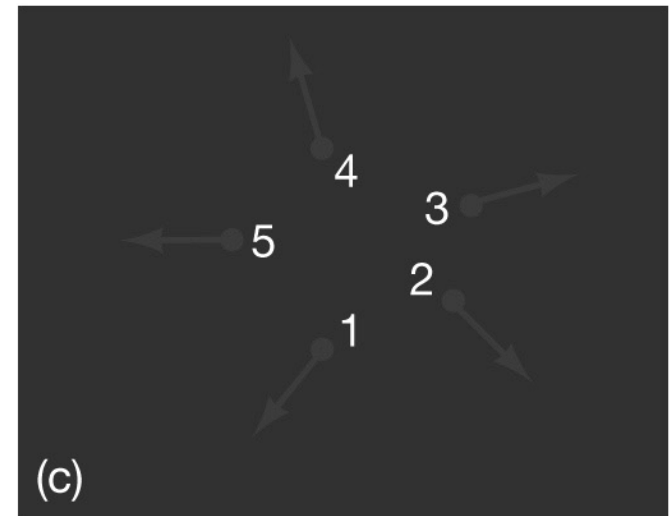
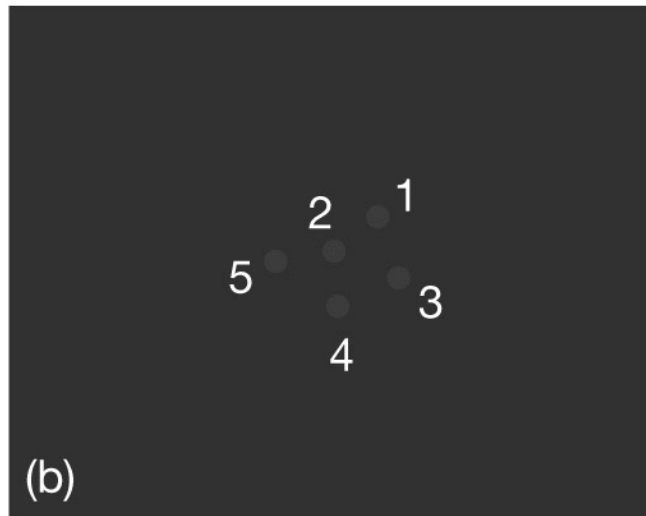
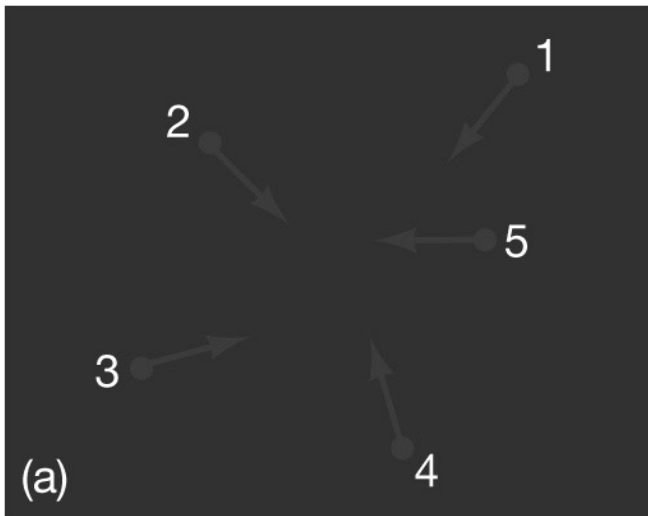


11.4 Formation of Stars Like the Sun

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.

11.4 Formation of Stars Like the Sun

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



11.4 Formation of Stars Like the Sun

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

TABLE 11.2 Prestellar Evolution of a Sun-like Star

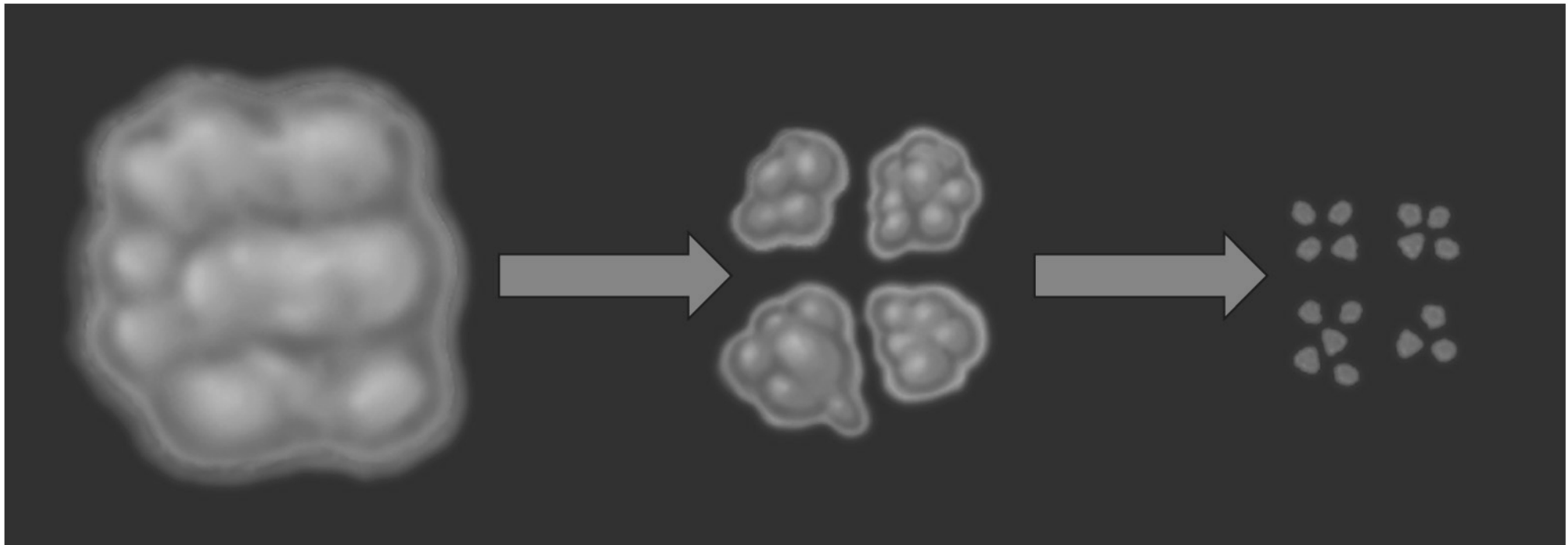
STAGE	APPROXIMATE TIME TO NEXT STAGE (yr)	CENTRAL TEMPERATURE (K)	SURFACE TEMPERATURE (K)	CENTRAL DENSITY (particles/m ³)	DIAMETER ¹ (km)	OBJECT
1	2×10^6	10	10	10^9	10^{14}	Interstellar cloud
2	3×10^4	100	10	10^{12}	10^{12}	Cloud fragment
3	10^5	10,000	100	10^{18}	10^{10}	Cloud fragment/protostar
4	10^6	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

¹For comparison, recall that the diameter of the Sun is 1.4×10^6 km and that of the solar system roughly 1.5×10^{10} km.

11.4 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.



11.4 Formation of Stars Like the Sun

Stage 2:

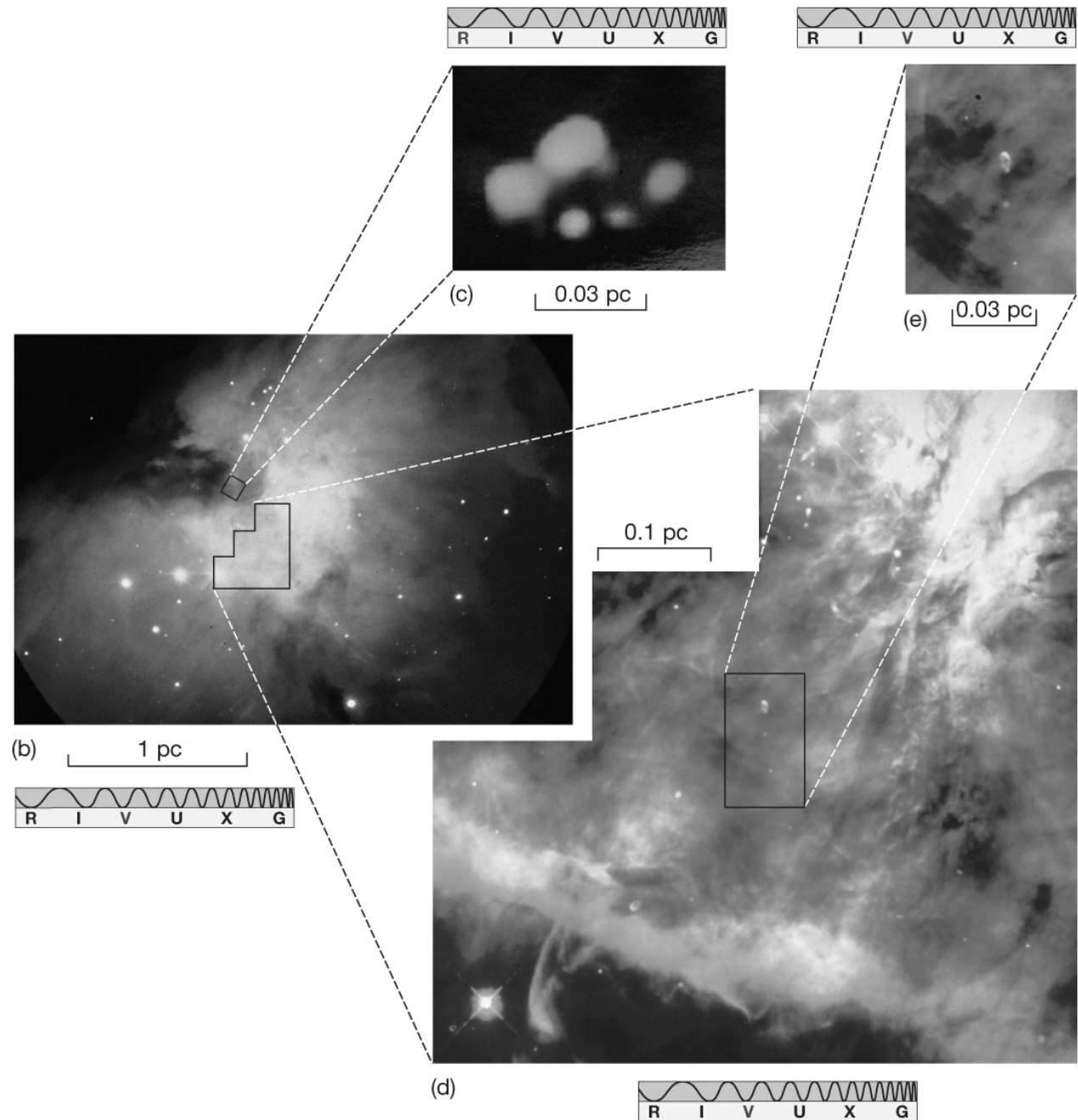
Individual cloud fragments begin to collapse. Once the density is high enough, there is no further fragmentation.

Stage 3:

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

11.4 Formation of Stars Like the Sun

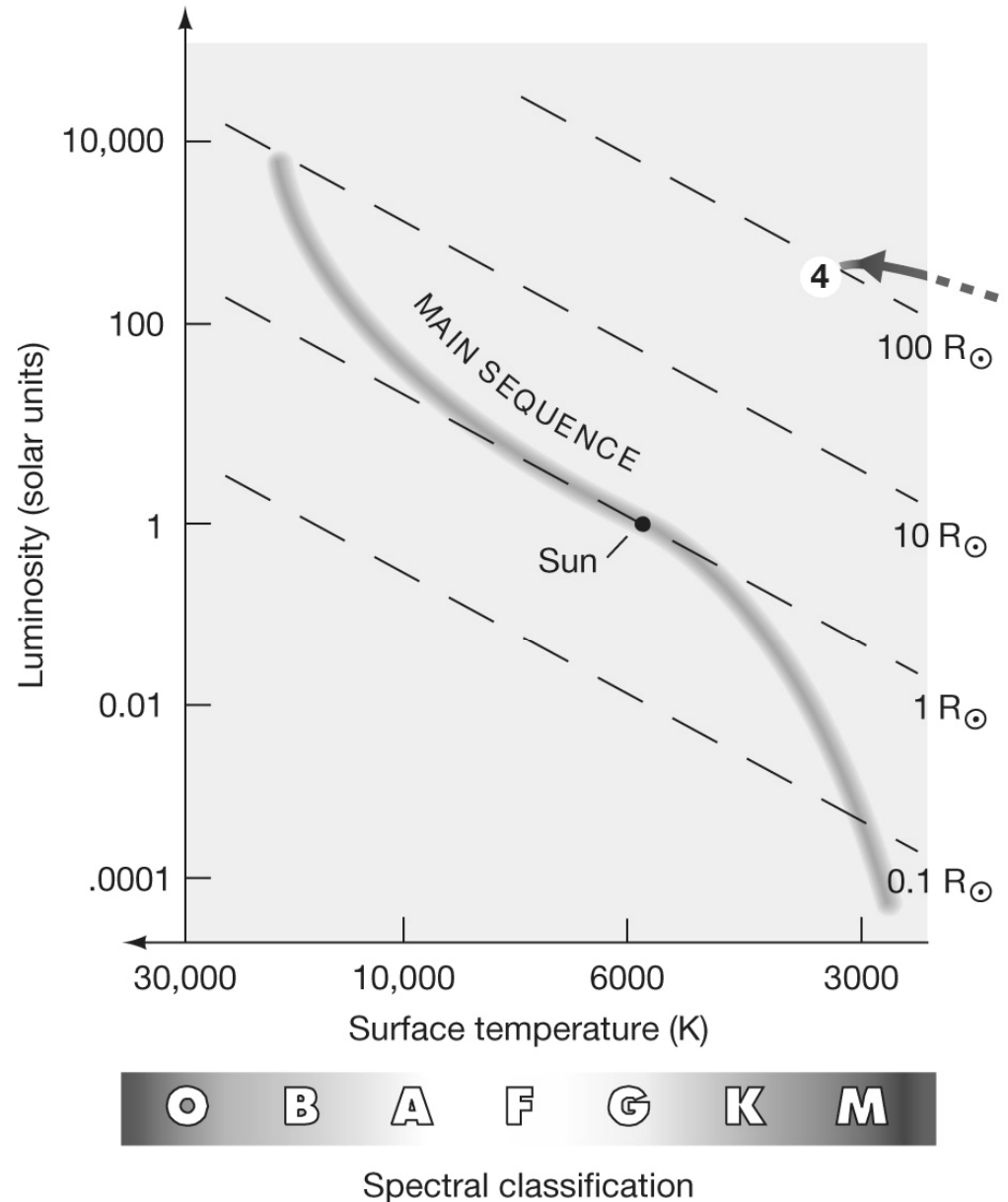
The Orion Nebula is thought to contain interstellar clouds in the process of condensing, as well as protostars.



11.4 Formation of Stars Like the Sun

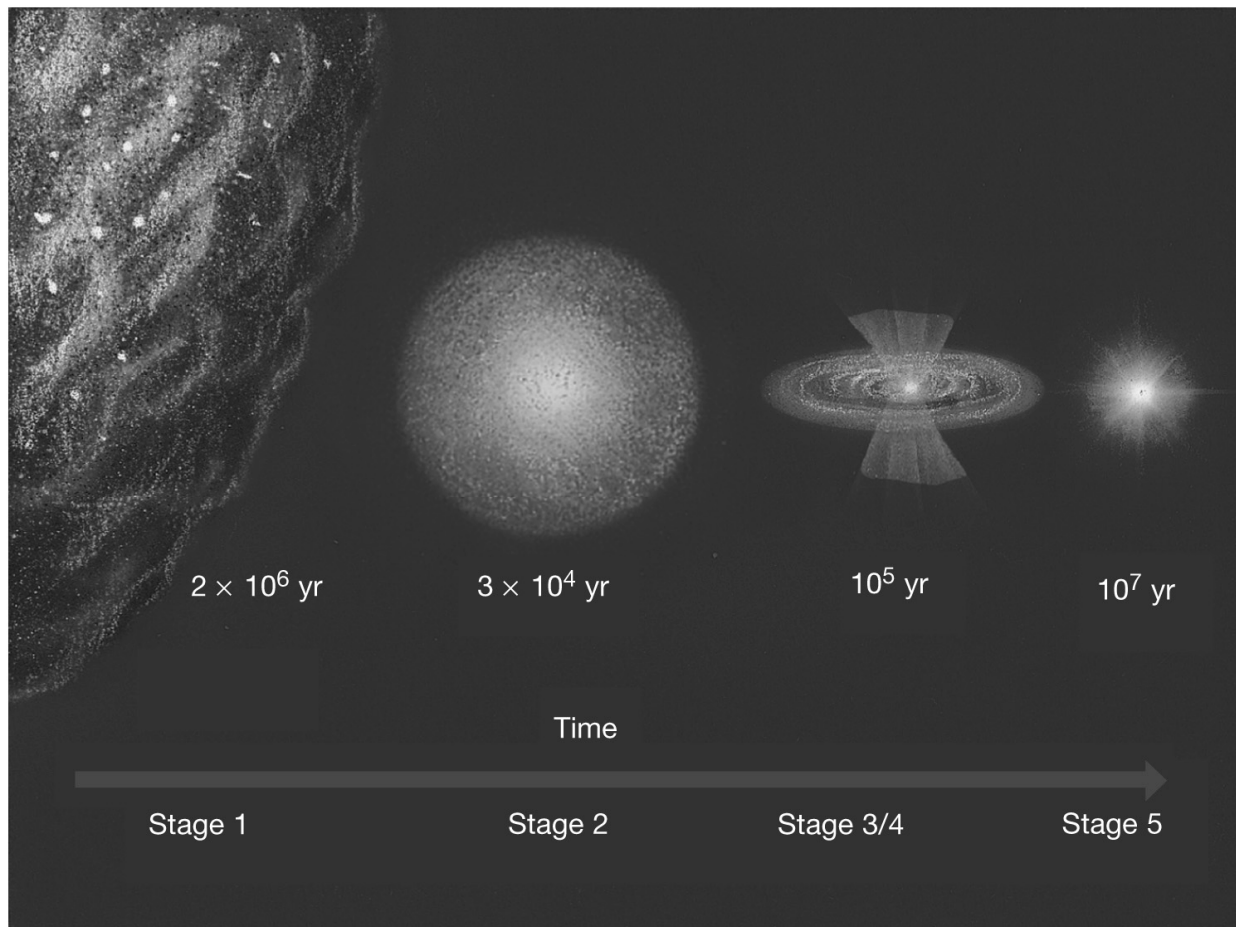
Stage 4:

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



11.4 Formation of Stars Like the Sun

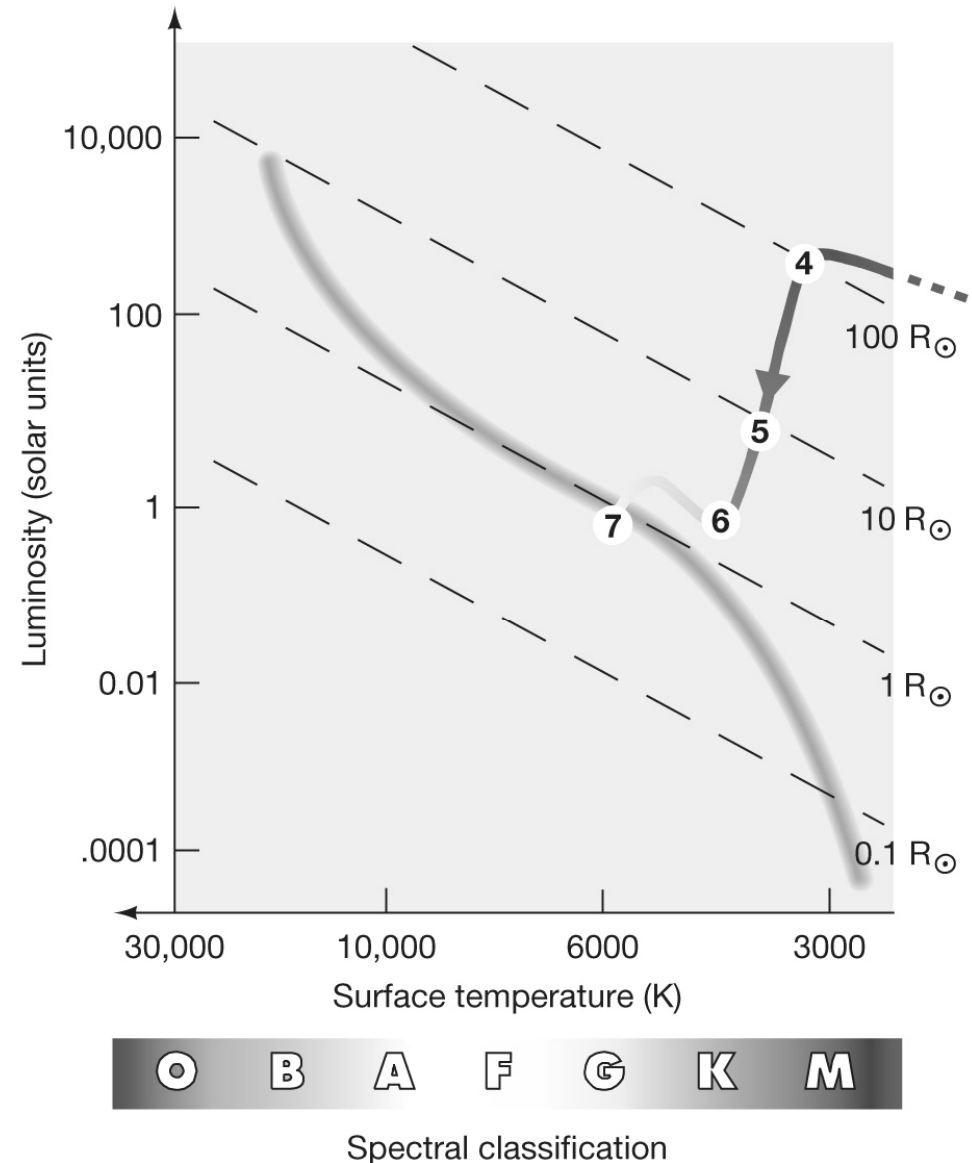
Planetary formation has begun, but the protostar is still not in equilibrium – all heating comes from the gravitational collapse.



11.4 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.



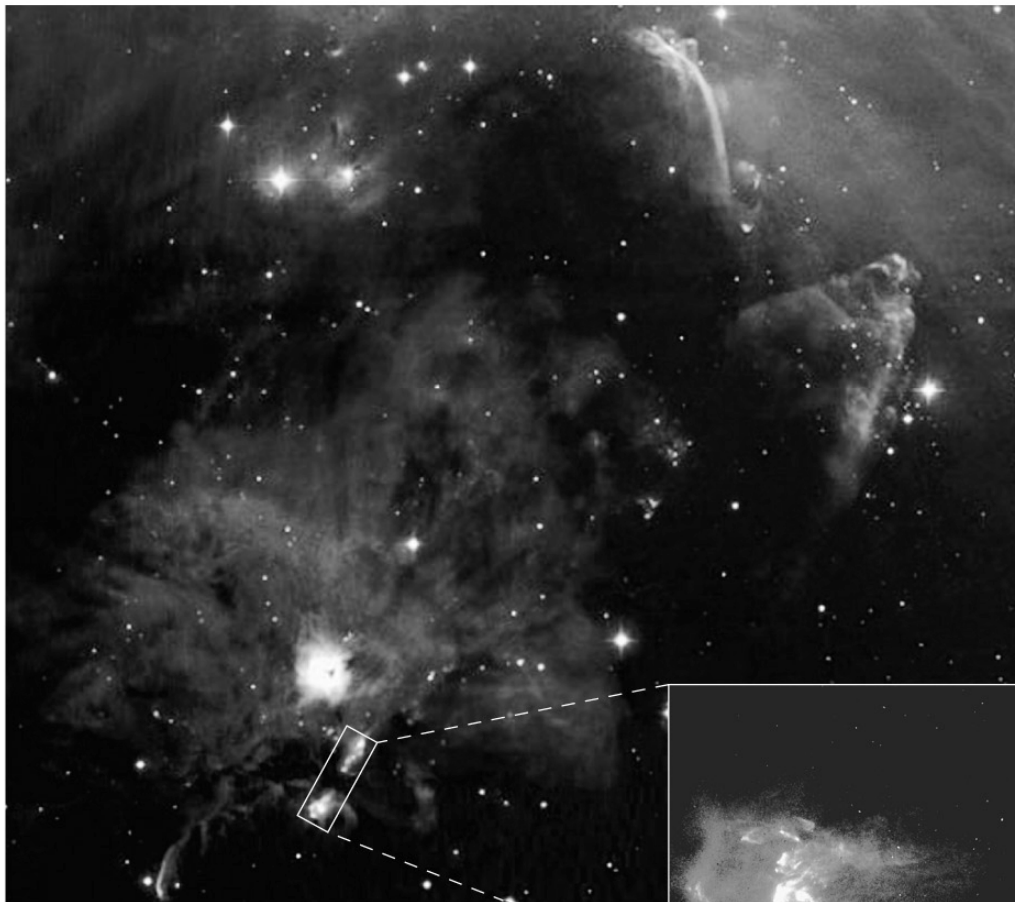
11.4 Formation of Stars Like the Sun

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

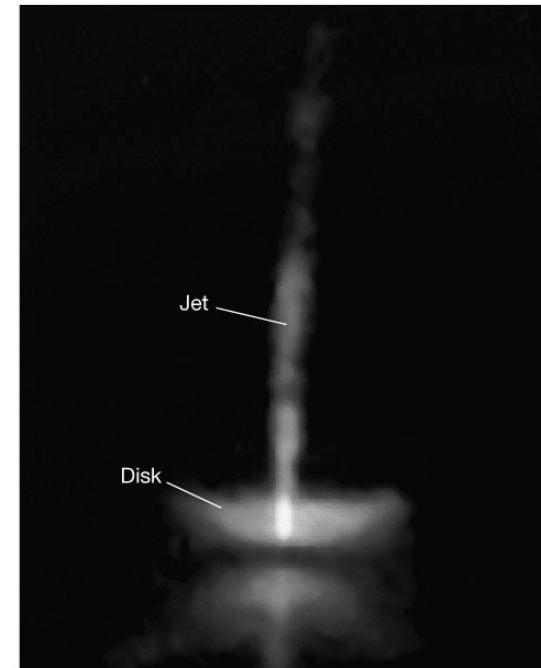
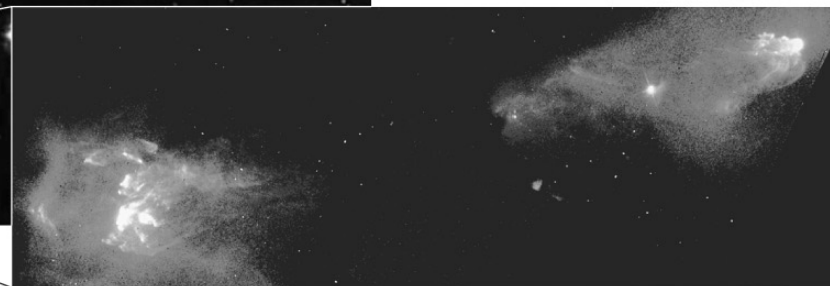
The star continues to contract and increase in temperature, until it is in equilibrium. This is stage 7: the star has reached the Main Sequence and will remain there as long as it has hydrogen to fuse in its core.

11.4 Formation of Stars Like the Sun

These jets are being emitted as material condenses onto a protostar.



(b)

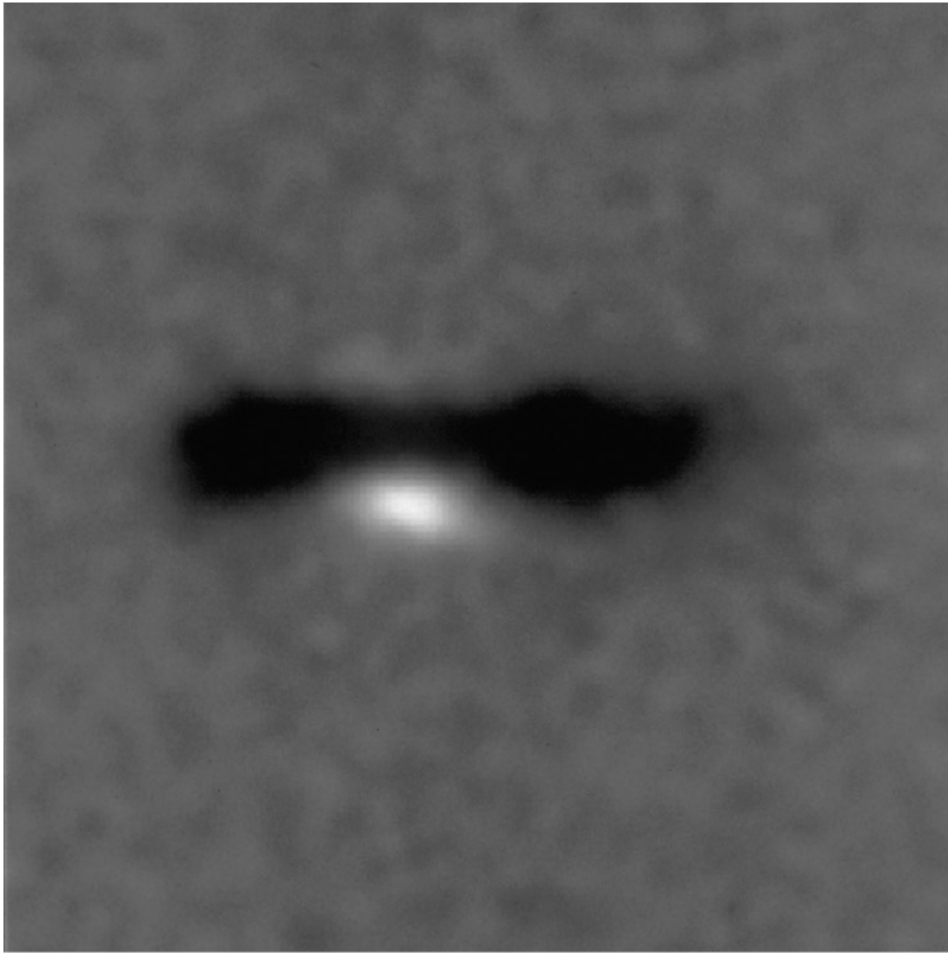


(a)

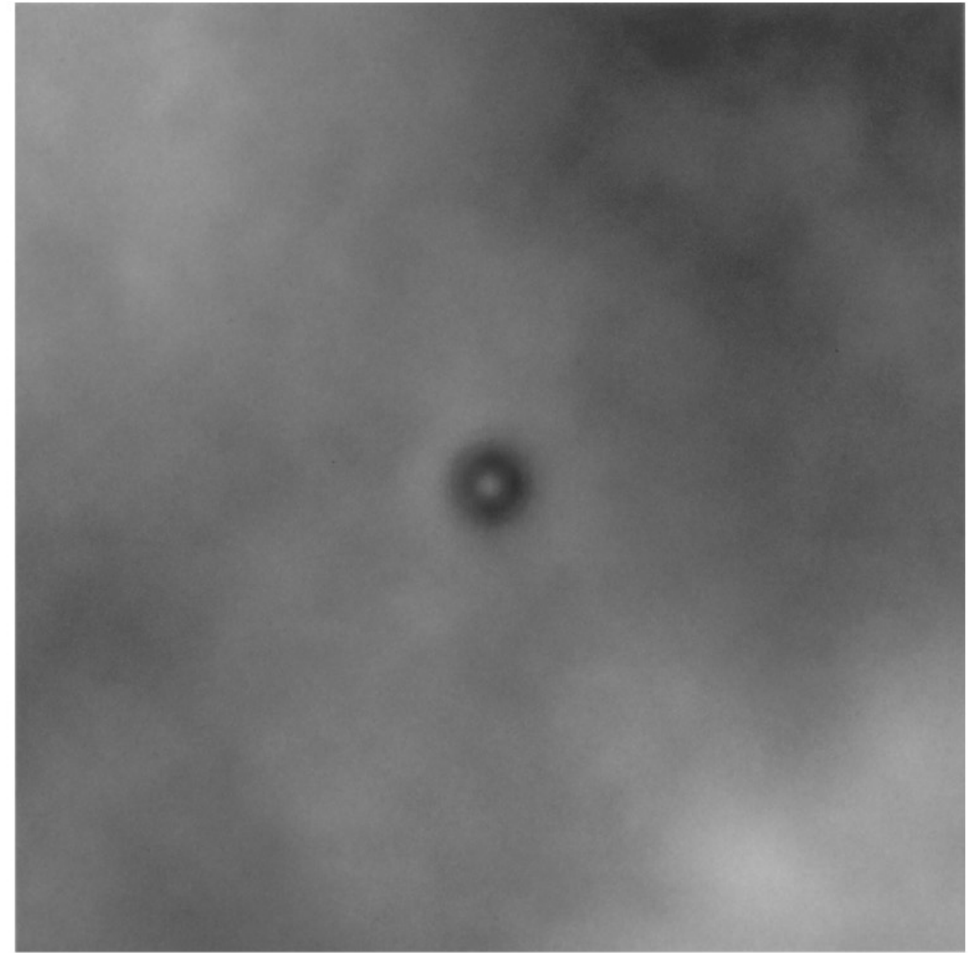
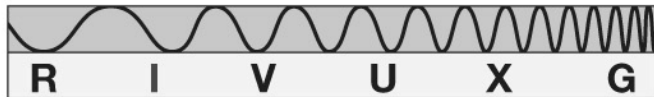


11.4 Formation of Stars Like the Sun

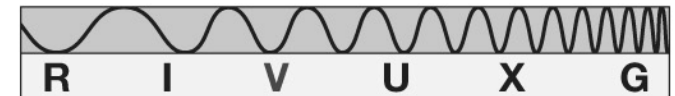
These protostars are in Orion.



(a)

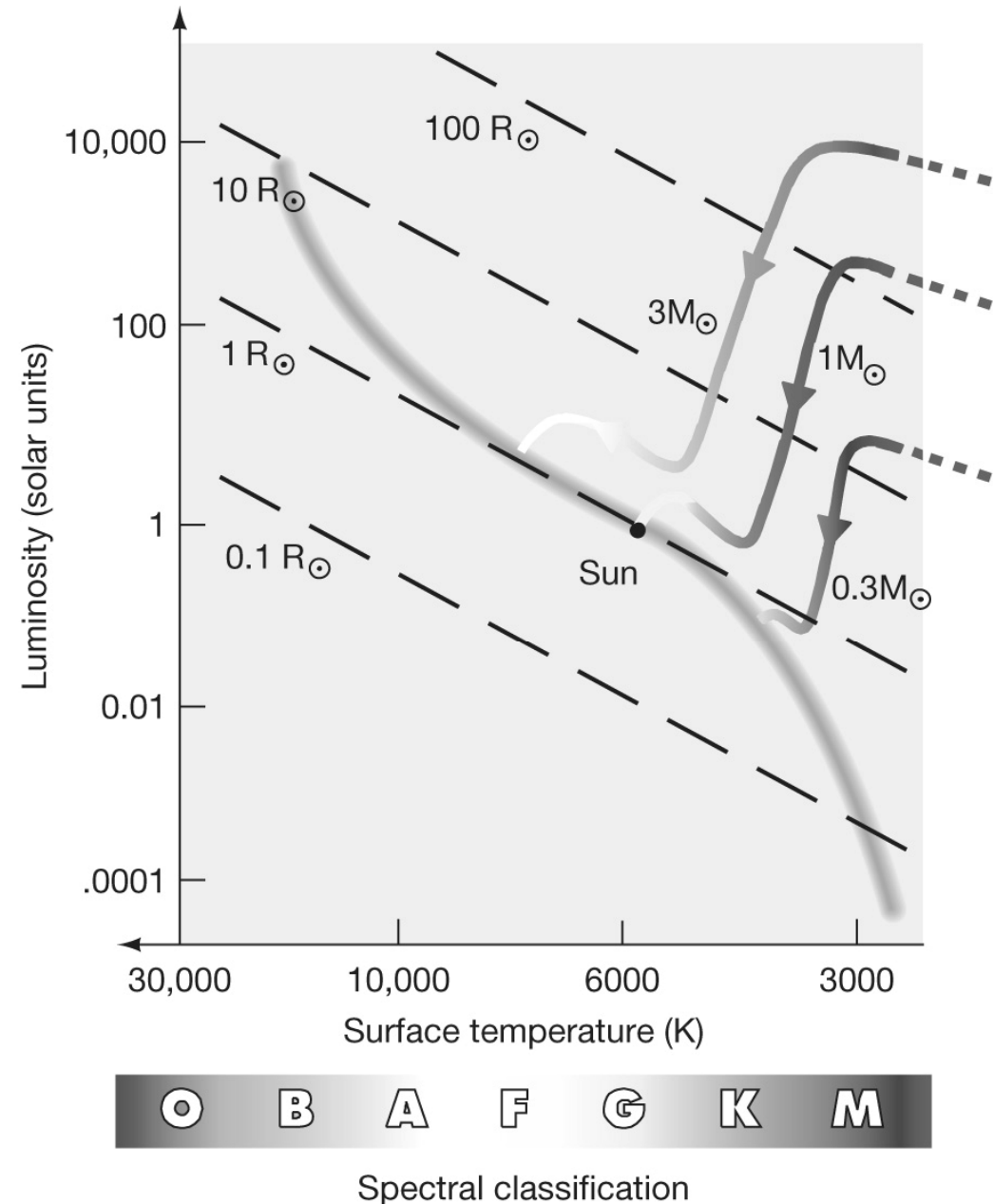


(b)



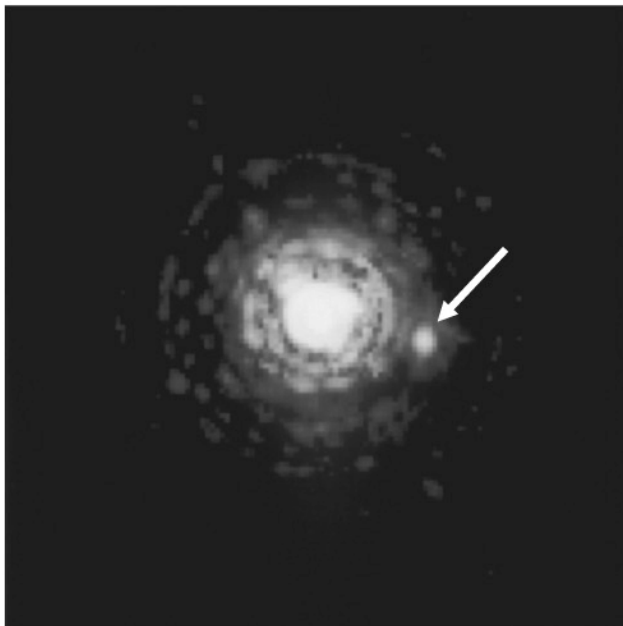
11.5 Stars of Other Masses

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.

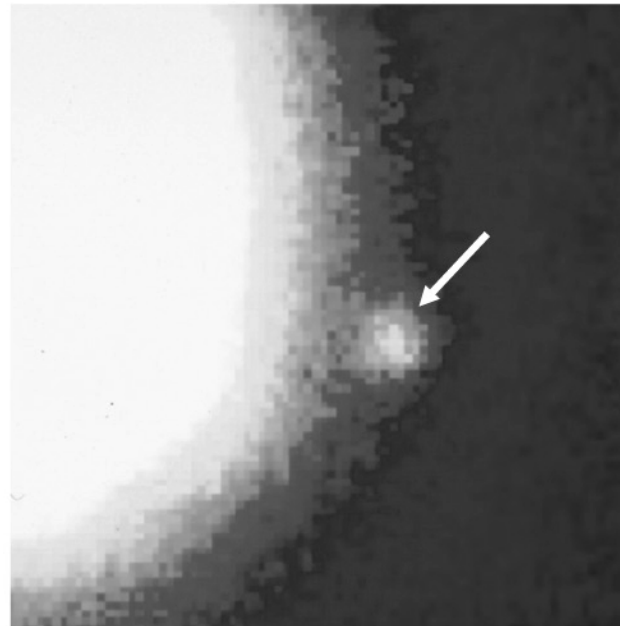


11.5 Stars of Other Masses

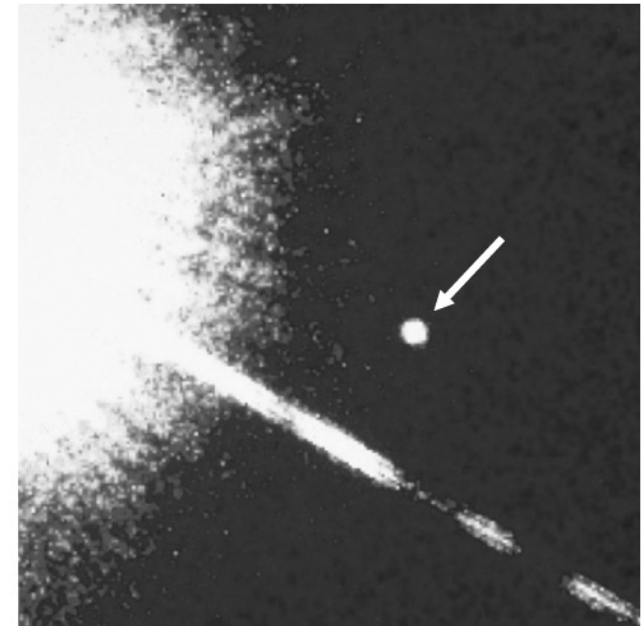
If the mass of the original nebular fragment is too small, nuclear fusion will never begin. These “failed stars” are called brown dwarfs.



(a)



(b)

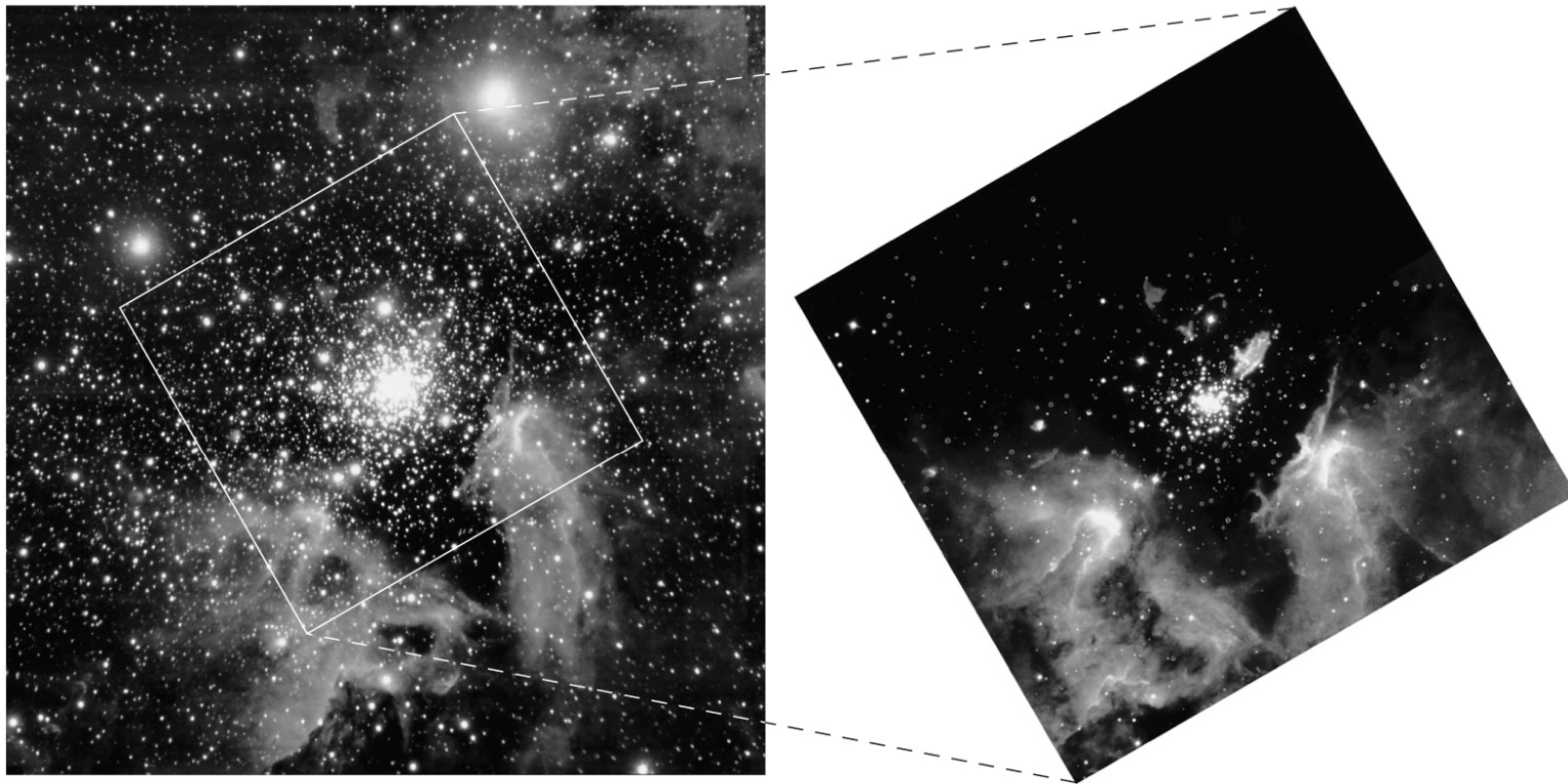


(c)



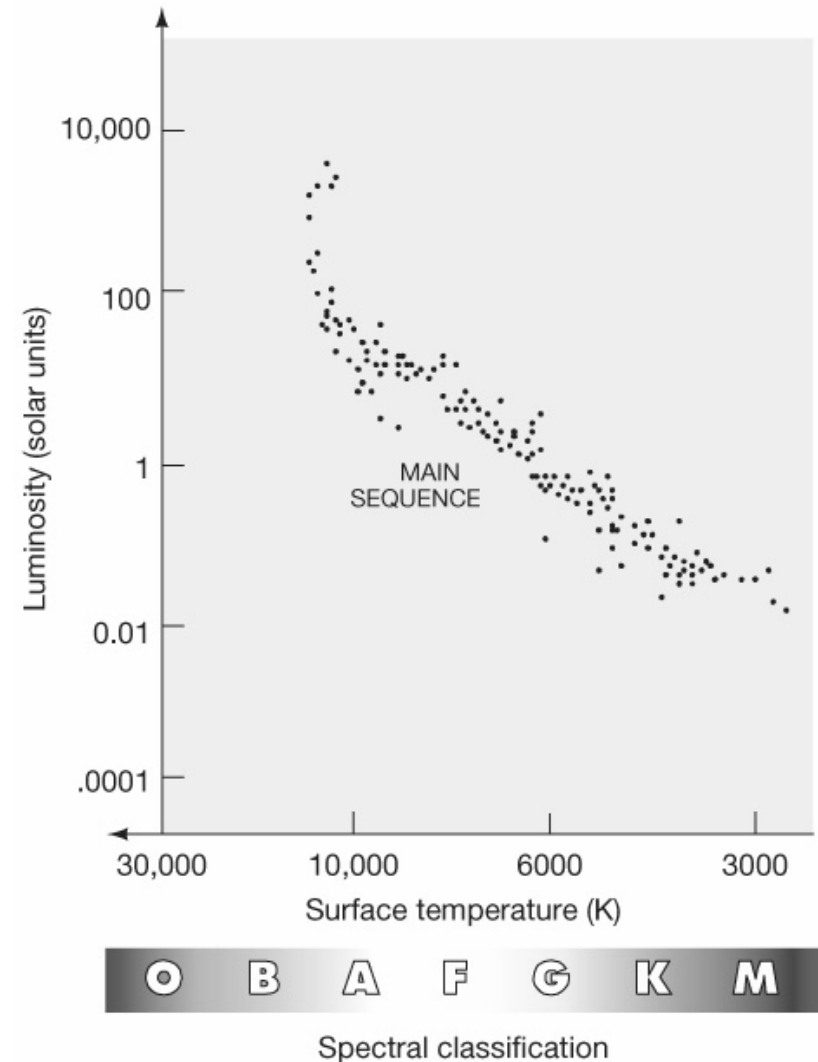
11.6 Star Clusters

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.



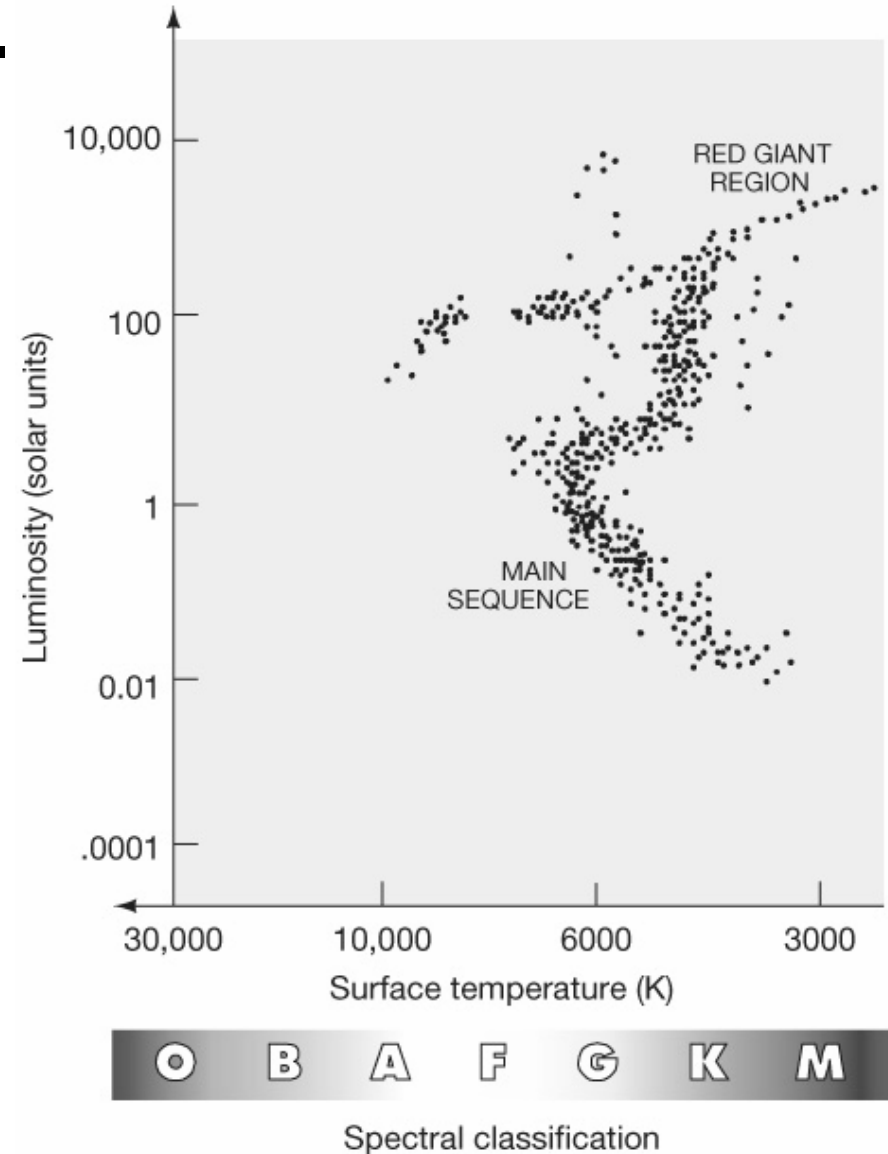
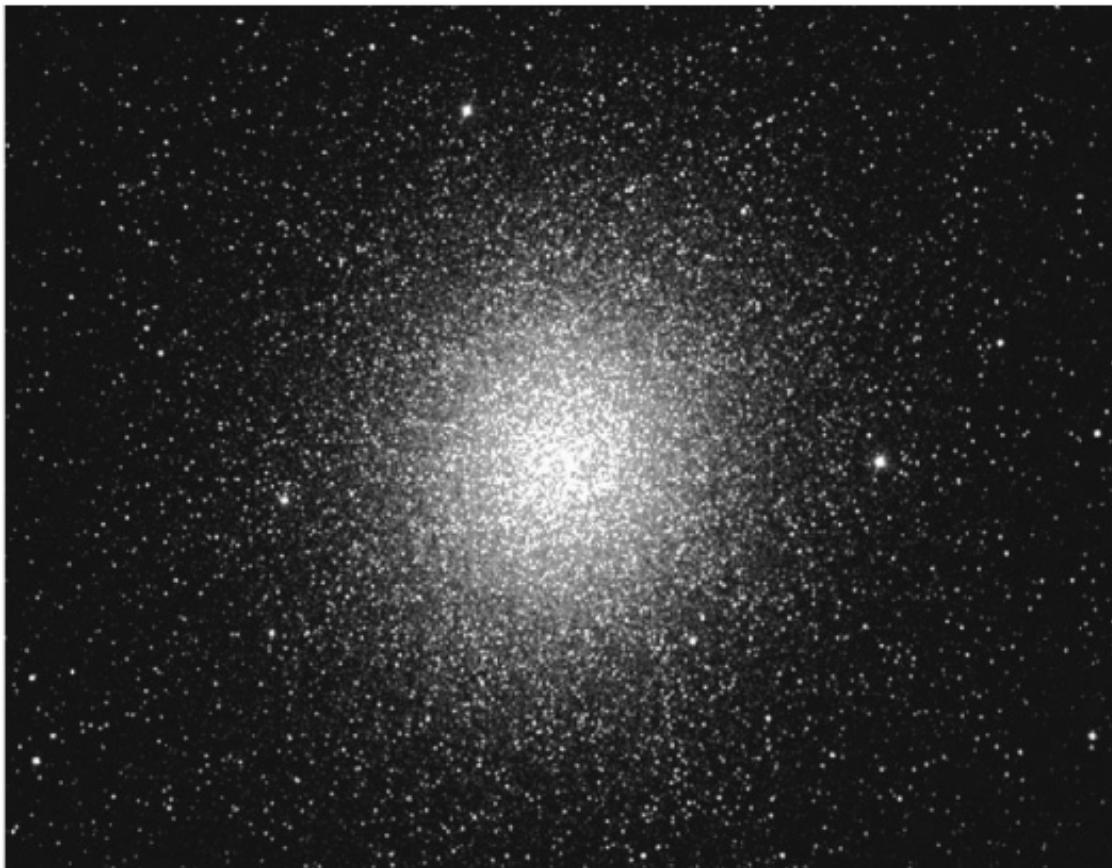
11.6 Star Clusters

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



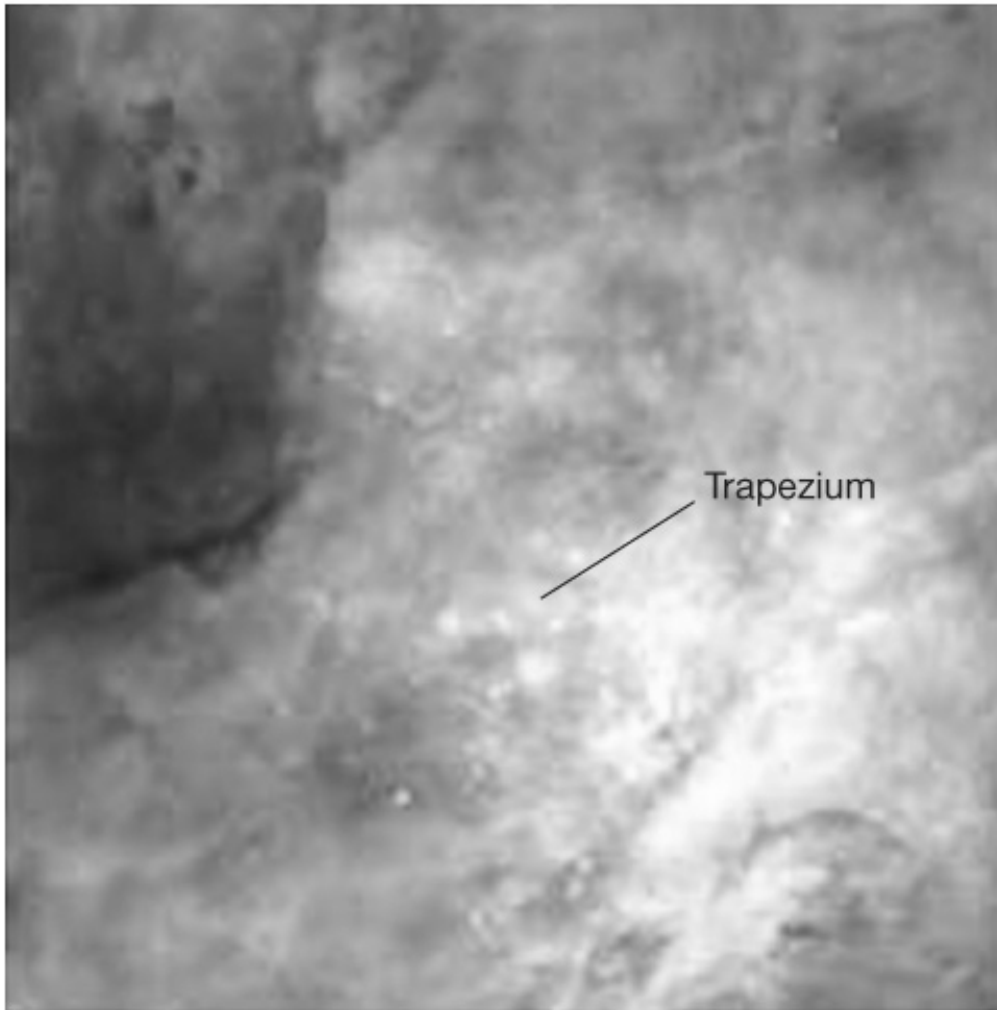
11.6 Star Clusters

This is a globular cluster – note the absence of massive Main Sequence stars, and the heavily populated Red Giant region.

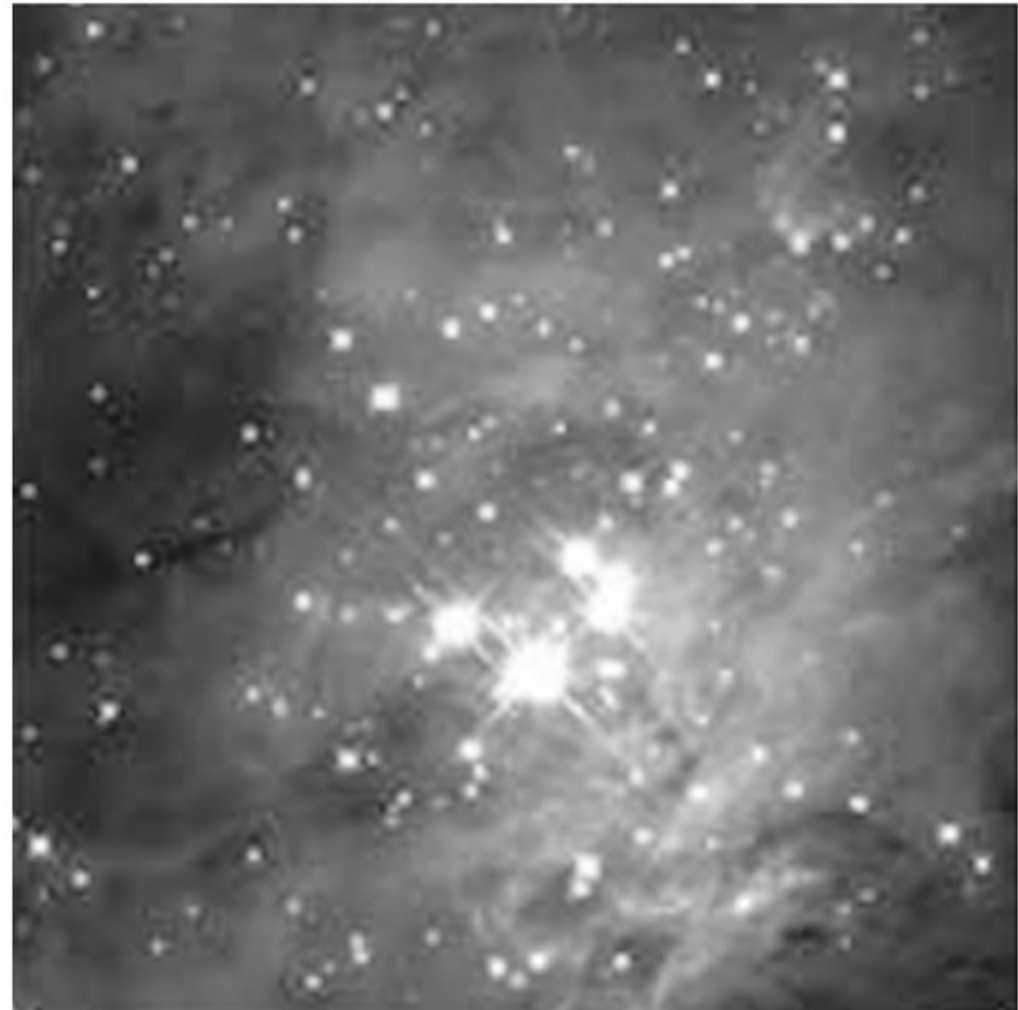


11.6 Star Clusters

These images are believed to show a star cluster in the process of formation within the Orion nebula.



(a)



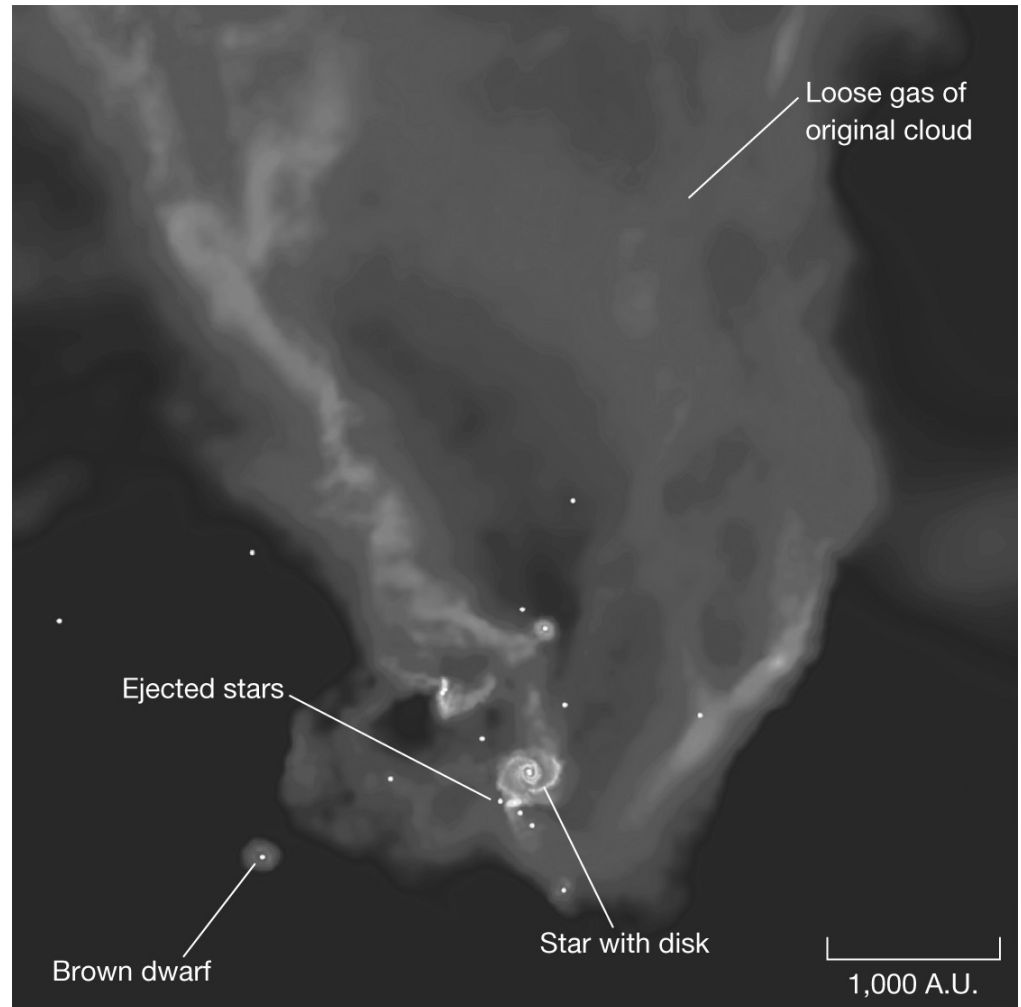
(b)



11.6 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:



Summary of Chapter 11

- **Interstellar medium is made of gas and dust**
- **Emission nebulae are hot, glowing gas associated with the formation of large stars**
- **Dark dust clouds, especially molecular clouds, are very cold. They may seed the beginnings of star formation.**
- **Dark clouds can be studied using the 21-cm emission line of molecular hydrogen.**
- **Star formation begins with fragmenting, collapsing cloud of dust and gas**

Summary of Chapter 11

- **The cloud fragment collapses due to its own gravity, and its temperature and luminosity increase. When the core is sufficiently hot, fusion begins.**
- **Collapsing cloud fragments and protostars have been observed.**
- **Mass determines where a star falls on the main sequence.**
- **One cloud typically forms many stars, as a star cluster.**