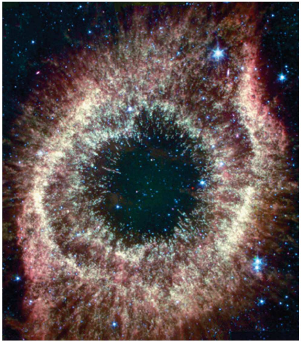
Stellar Evolution

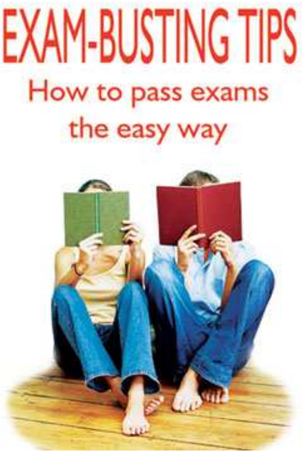
The Lives And Deaths of Stars



10/29/2009

My Office Hours:
Tuesday 3:30 PM - 4:30 PM
206 Keen Building

Test 2: 11/05/2009



Now is a good time to start reviewing.

- Use the study guides!
- Look again at homeworks and miniquizzes!

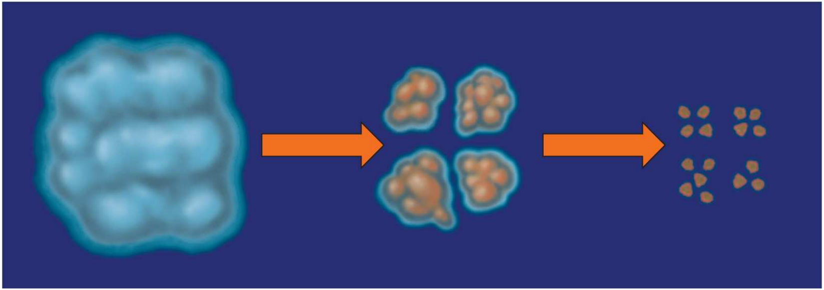
1. Test is mandatory
2. Covers chapters 7-12
3. Consists of 35 questions

Outline

Outline

Stage 1: An Interstellar Cloud

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



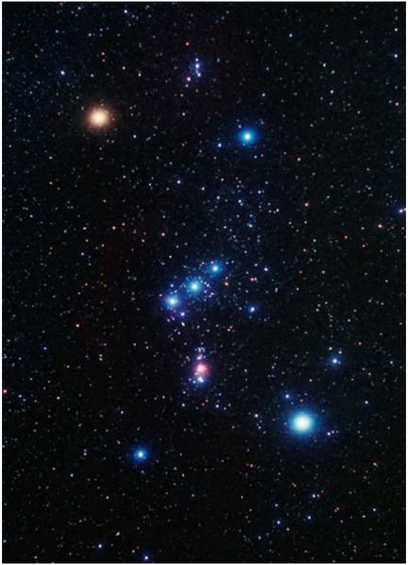
Stages 2 and 3: A Contracting Cloud Fragment

Stage 2

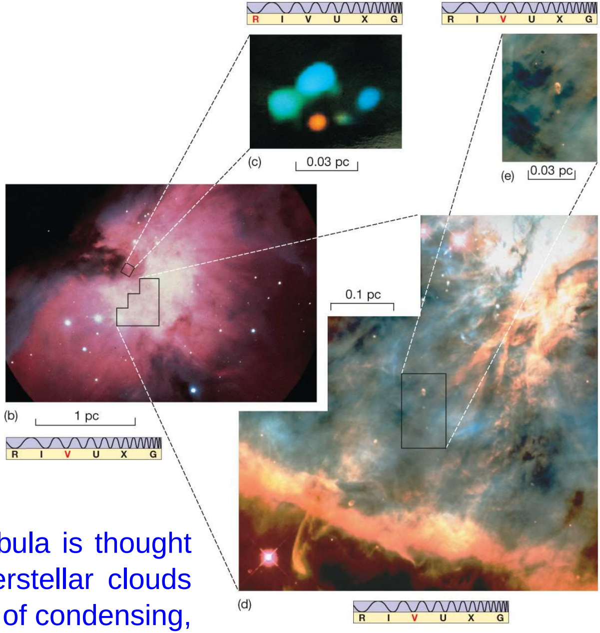
Individual cloud fragments begin to collapse. Once the density is high enough, there is no further fragmentation.

Stage 3

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

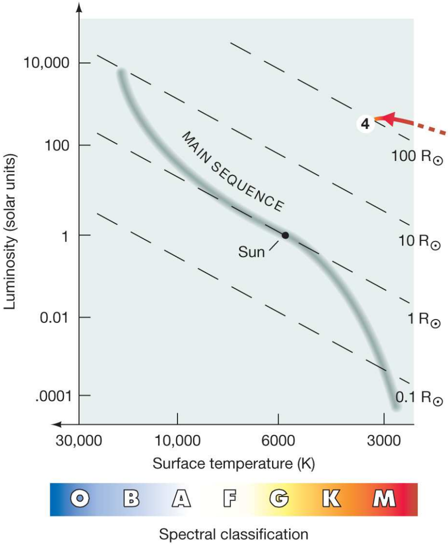


The Orion Nebula is thought to contain interstellar clouds in the process of condensing, as well as protostars.



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

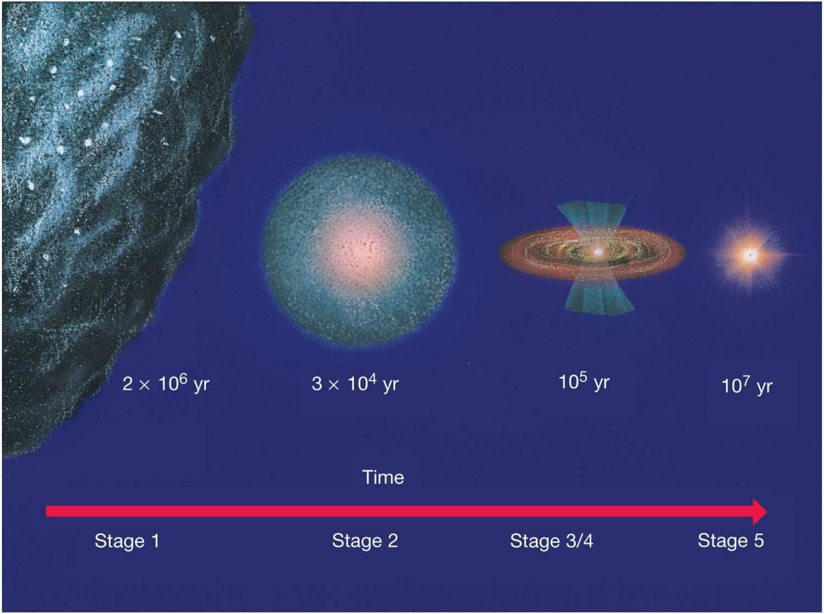
Stage 4: A Protostar



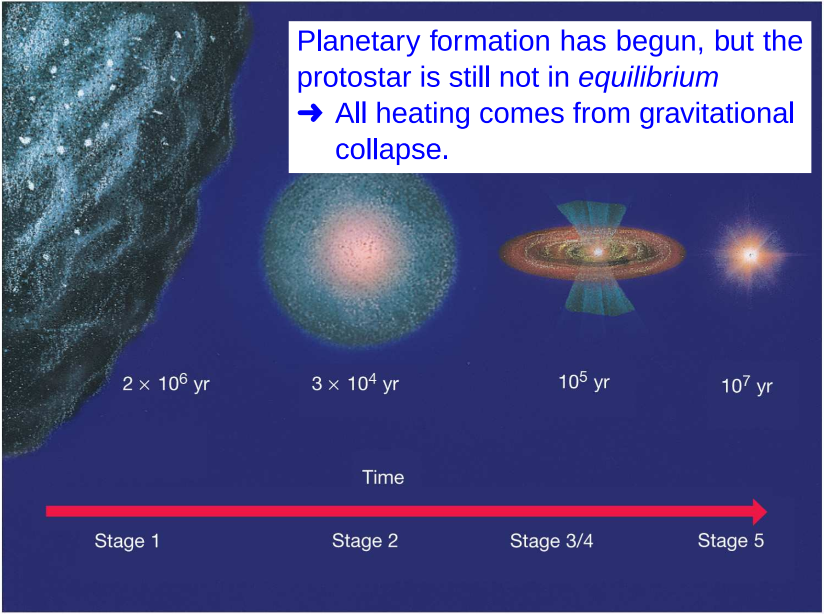
Some 100,000 years after fragment formed, it reaches stage 4:

- Nuclear reactions have not yet begun.

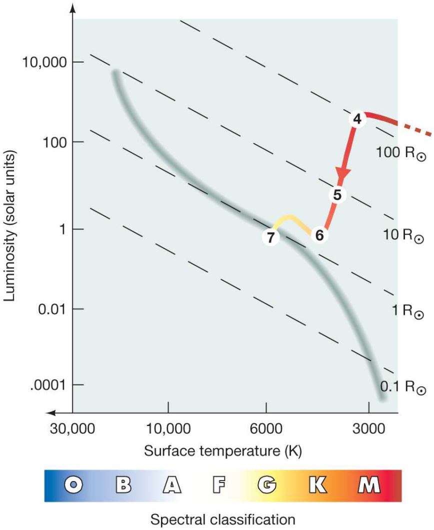
The core of the cloud is now a *protostar*, and makes its first appearance on the *H-R diagram*.


2×10^6 yr
3×10^4 yr
10^5 yr
10^7 yr
Time
Stage 1
Stage 2
Stage 3/4
Stage 5

Planetary formation has begun, but the protostar is still not in *equilibrium*
➜ All heating comes from gravitational collapse.



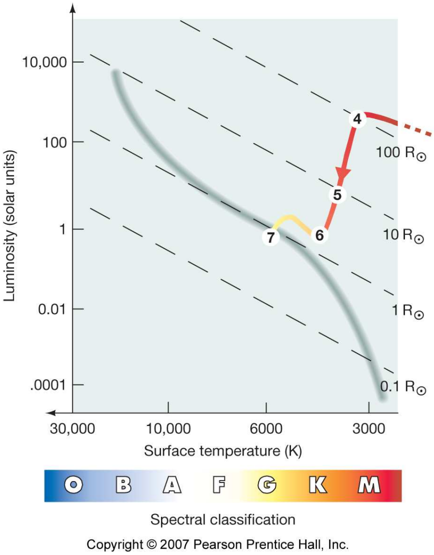
Stage 5: Protostellar Evolution



Last stages can be followed on the H-R diagram:

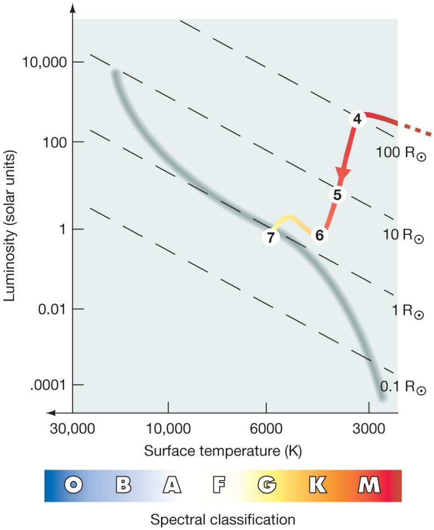
The protostar's luminosity finally decreases even as its temperature rises because it is becoming more compact.

Stage 6: A Newborn Star



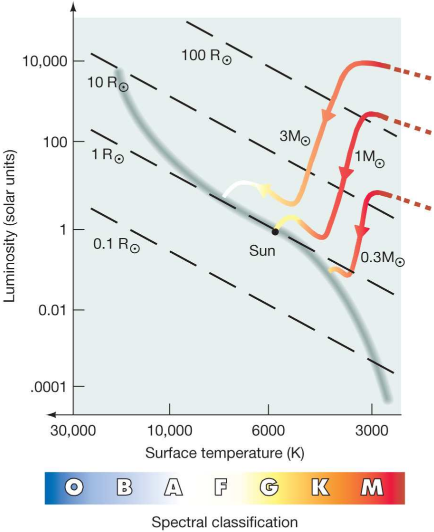
At *stage 6*, the core reaches 10 million K: *nuclear fusion* begins. The protostar has become a star.

Stage 7: A Newborn Star



Star continues to contract and increase in temperature, until it is in *equilibrium:* the star has reached the *Main Sequence* and will remain there as long as it has H to fuse in its core.

Prestellar Evolutionary Tracks

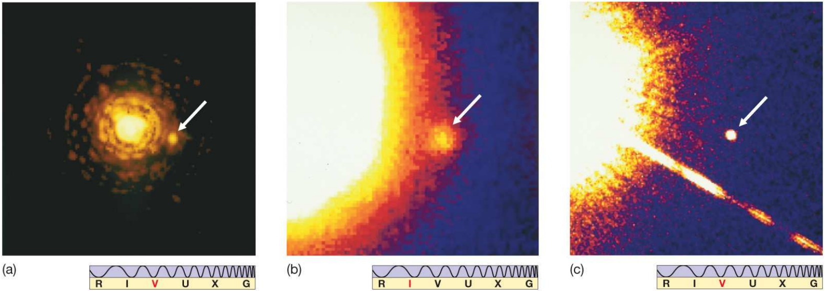


This H-R diagram shows the evolution of stars somewhat more and somewhat less massive than the Sun. The shape of the paths is very similar, but they wind up in different places on the Main Sequence.

Binary Systems: Gliese 623

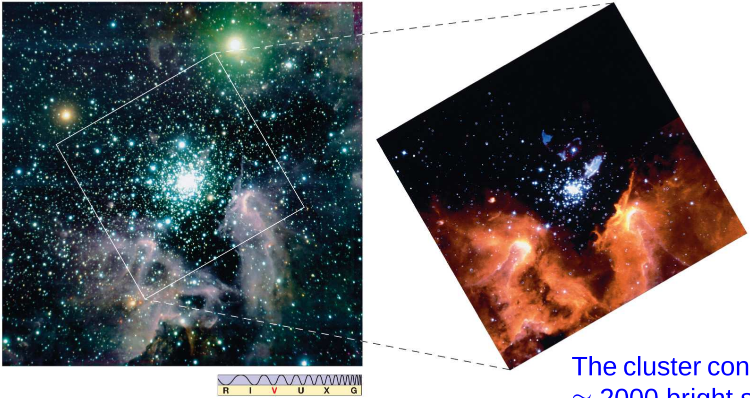
If the mass of the original nebular fragment is too small, nuclear fusion will never begin. These *"failed stars"* are called *brown dwarfs*.

Below: *Hubble* image of *Gliese 623.* This binary system may contain a *brown dwarf.*



Newborn Cluster: NGC 3603

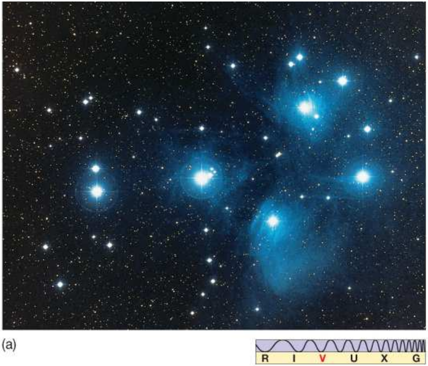
Because a single interstellar cloud can produce many stars of the same *age* and *composition*, star clusters are an excellent way to study the effect of *mass* on stellar evolution.



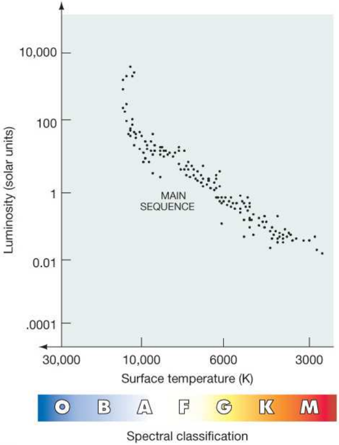
The cluster contains $\approx$ 2000 bright stars.

Open Cluster: Pleiades or M45

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



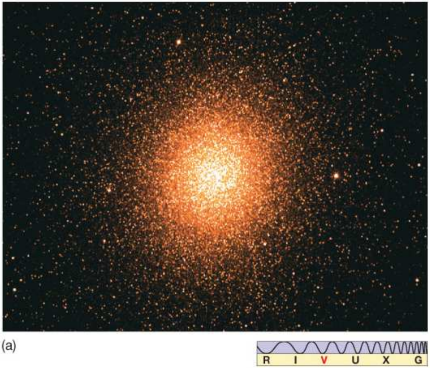
(a)



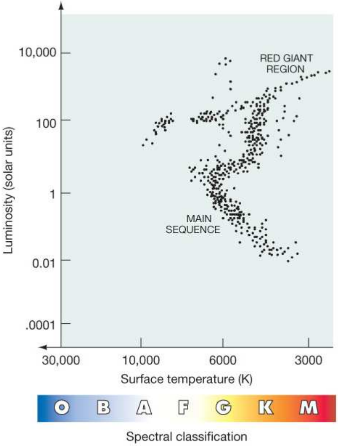
(b)

Globular Cluster: Ω Centauri

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



(a)



(b)

Young Stars in Orion

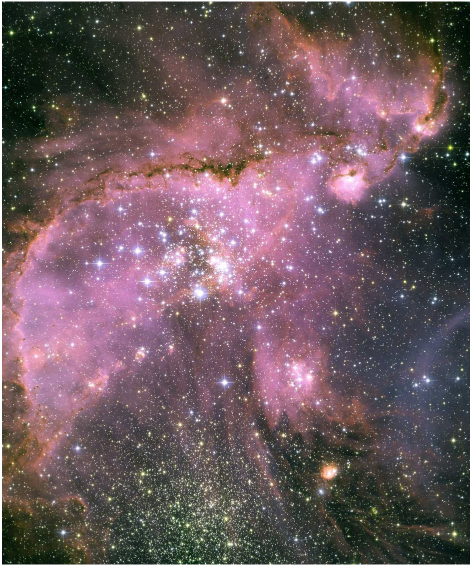
(a)

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

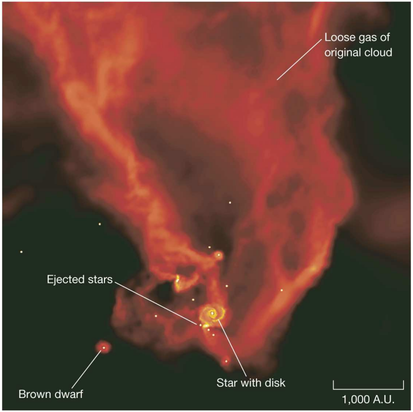
(b)

Visible image dominated by emission nebula. However, IF image shows an extensive star cluster.

Star Cluster NGC 346



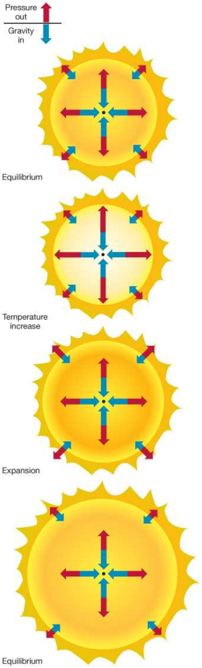
Protostellar Collisions



The presence of massive, short-lived O ($T \approx 30,000$ K) and B ($T \approx 20,000$ K) 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.

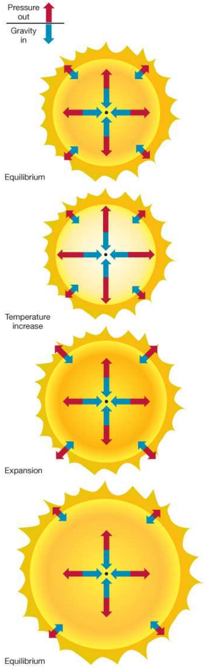
Outline



Equilibrium

During its stay on the Main Sequence (steadily burning), any fluctuations in a star's condition are quickly restored

➜ *Hydrostatic Equilibrium*.



Equilibrium

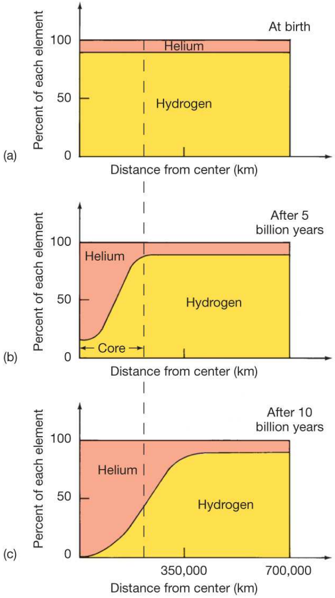
Eventually, as hydrogen in the core is consumed, the star begins to leave the Main Sequence.

Its evolution from then on depends very much on the mass of the star:

1. Low-mass stars leave quietly.
2. High-mass stars go out with a bang!

Outline

Solar Composition Change

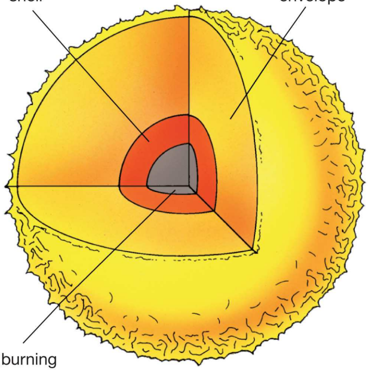


Even while it is on the Main Sequence, the composition of a star's core is changing.

The change speeds up as the nuclear burning rate increases with time.

Hydrogen Shell Burning

As the fuel in the core is used up, the core *contracts*; when it's used up, the core begins to collapse.



The hydrogen begins to fuse *outside* the core:

1. Core has shrunk to a few tens of thousands of kilometers
2. Star's surface is ten times the original size

Evolution of a Sun-like Star

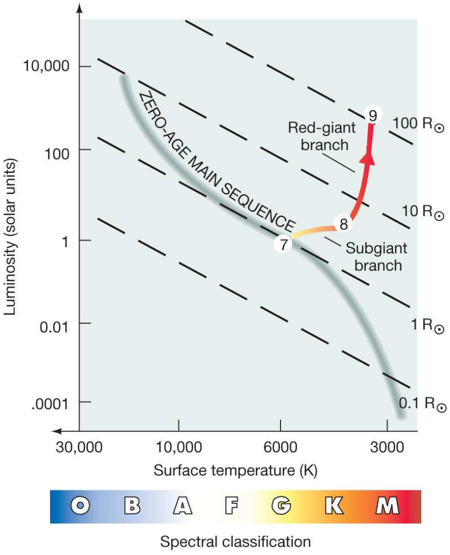
Stages of a star leaving the Main Sequence:

TABLE 12.1 Evolution of a Sun-like Star

STAGE	APPROX. TIME TO NEXT STAGE (yr)	CENTRAL TEMPERATURE (K)	SURFACE TEMPERATURE (K)	CENTRAL DENSITY (kg/m^3)	RADIUS (km)	RADIUS (solar radii)	OBJECT
7	10^{10}	1.5×10^7	6,000	10^5	7×10^5	1	Main-sequence star
8	10^8	5×10^7	4,000	10^7	2×10^6	3	Subgiant
9	10^5	10^8	4,000	10^8	7×10^7	100	Red giant/Helium flash
10	5×10^7	2×10^8	5,000	10^7	7×10^6	10	Horizontal branch
11	10^4	2.5×10^8	4,000	10^8	4×10^8	500	Red giant (AGB)
	10^5	3×10^8	100,000	10^{10}	10^4	0.01	Carbon core
12	—	—	3,000	10^{-17}	7×10^8	1,000	Planetary nebula*
13	—	10^8	50,000	10^{10}	10^4	0.01	White dwarf
14	—	Close to 0	Close to 0	10^{10}	10^4	0.01	Black dwarf

*Values in columns 2–7 refer to the envelope.

Stage 9: The Red-Giant Branch

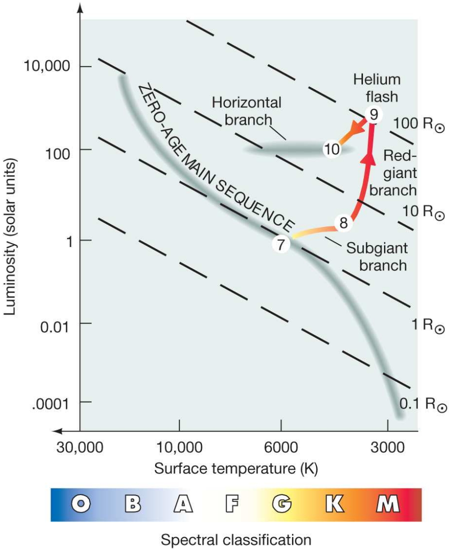


As the core continues to shrink, the outer layers of the star expand and cool.

The star is a *red giant* now, extending out as far as the orbit of Mercury.

Despite its slightly cooler temperature, its luminosity increases enormously due to its large size.

Stage 10: Helium Fusion



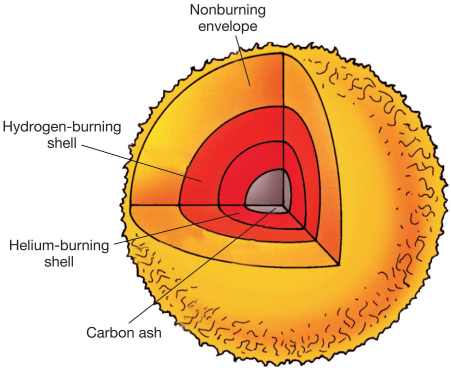
Once the core temperature has risen to 100,000,000 K, the helium in the core starts to fuse.

Helium Flash:

The helium begins to fuse extremely rapidly; within hours the enormous energy output is over, and the star again reaches equilibrium.

Back to the Giant Branch

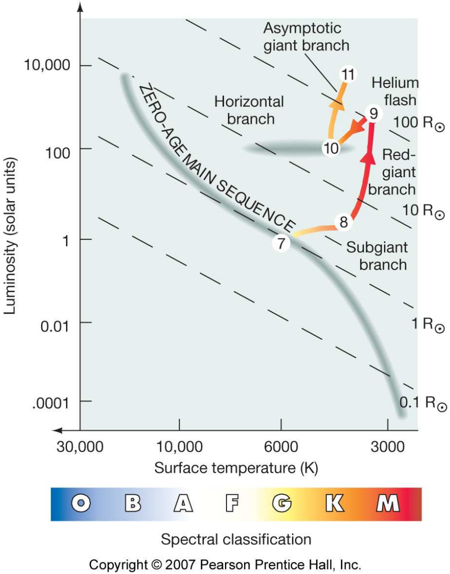
As the helium in the core fuses to carbon, the core becomes hotter and hotter, and the helium burns faster and faster.



Stage 11:

The star is now similar to its condition just as it left the Main Sequence, except now there are two shells.

Stage 11: Reascending the Giant Branch

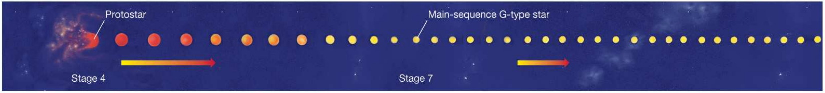


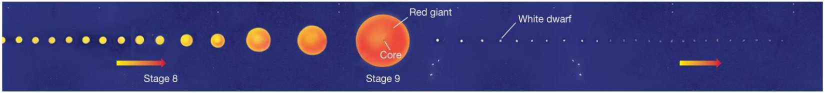
The star has become a red giant for the second time:

Lack of nuclear burning at the center causes the core to contract and overlying layers to expand.

G-type Star Evolution

This graphic shows the entire evolution of a Sun-like star:





Such stars never become hot enough for fusion past carbon to take place.

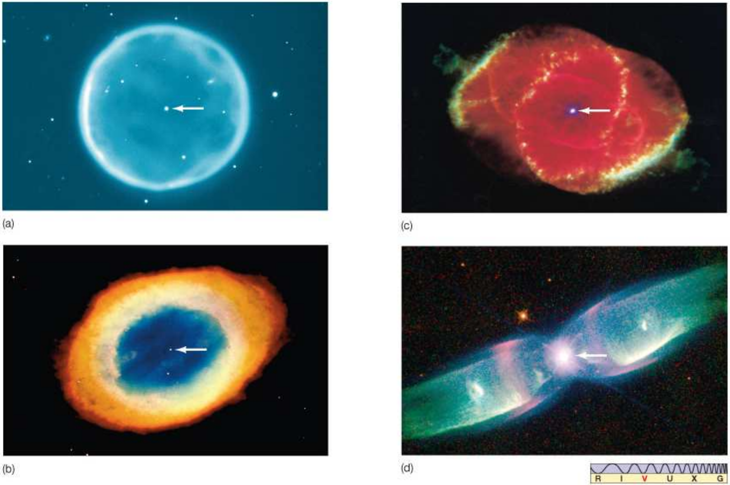
Outline

The Death of a Low-Mass Star

There is no more outward fusion pressure being generated in the core, which continues to contract.

Planetary Nebulae

Meanwhile, the outer layers of the star expand to form a *planetary nebula:*



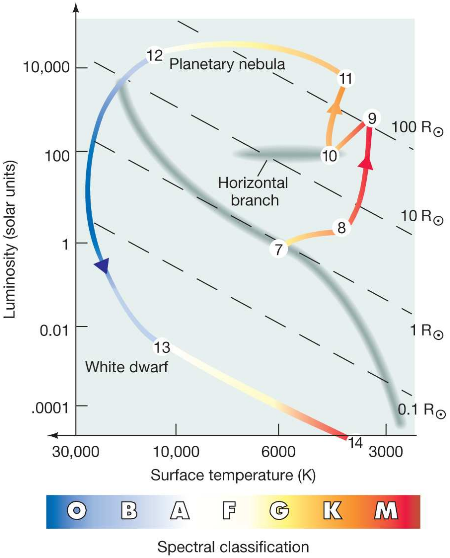
The Death of a Low-Mass Star

The star has now two parts:

1. A small, extremely dense carbon core
2. An envelope about the size of our solar system

The envelope is called a *planetary nebula*, even though it has nothing to do with planets – early astronomers viewing the fuzzy envelope thought that it resembled a planetary system.

White Dwarf on H-R Diagram

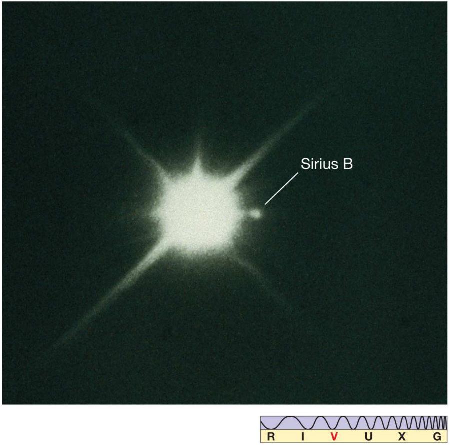


Stages 13 and 14:

Once the nebula has gone, the remaining core is extremely dense and extremely hot, but quite small (size of Earth).

It's luminous only due to its high temperature.

Sirius Binary System

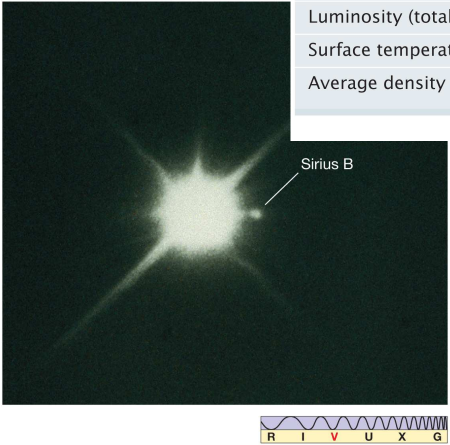


The small star *Sirius B* is a *white-dwarf companion* of the much larger and brighter *Sirius A.*

Sirius Binary System

TABLE 12.2 Sirius B—A Nearby White Dwarf

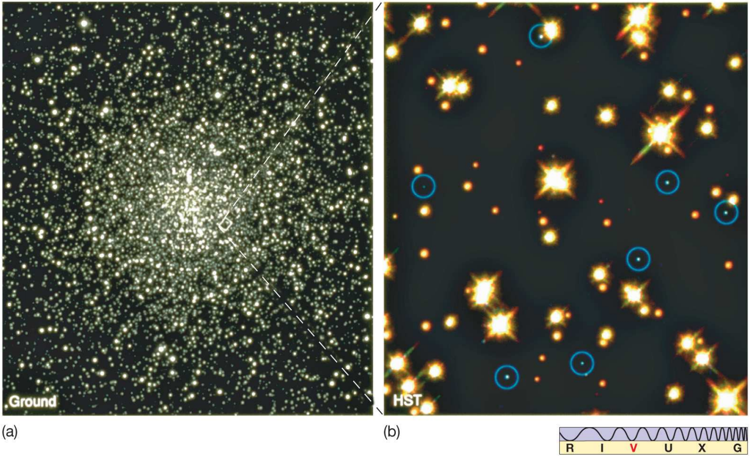
Mass	1.1 Solar masses
Radius	0.008 Solar radii (5500 km)
Luminosity (total)	0.04 Solar luminosities
Surface temperature	24,000 K
Average density	3×10^9 kg/m^3



The small star *Sirius B* is a *white-dwarf companion* of the much larger and brighter *Sirius A.*

Distant White Dwarfs

The *Hubble Space Telescope* has detected white dwarf stars (circled) in globular clusters:



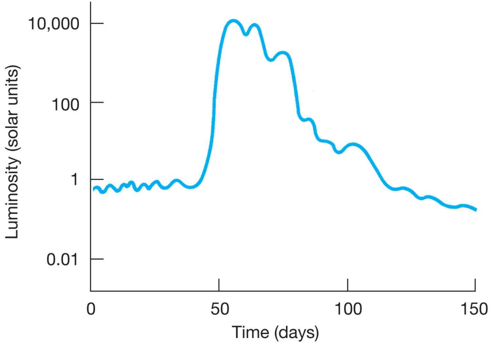
(a) (b)

White Dwarfs

As the white dwarf cools, its size does not change significantly; it simply gets dimmer and dimmer, and finally ceases to glow.

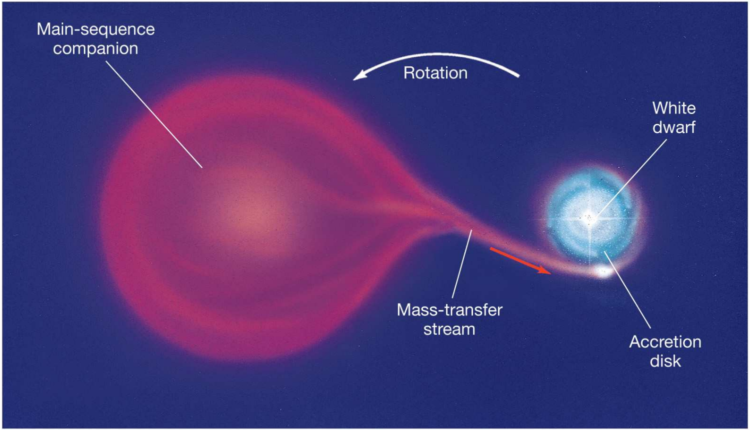
Nova

A nova is a star that flares up very suddenly and then returns slowly to its former luminosity. These novae are the result of explosions on the surface of faint white dwarf stars, caused by matter falling onto their surfaces from the atmosphere of larger binary companions.

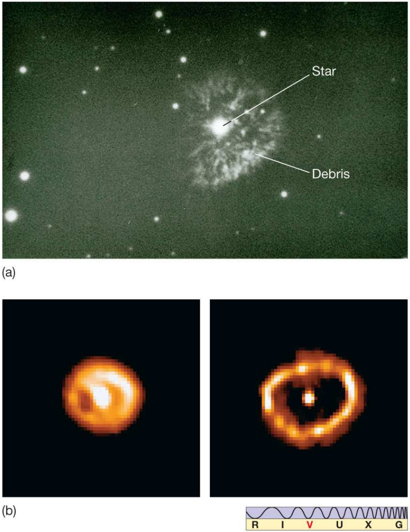


Close Binary System

A white dwarf that is part of a semidetached binary system can undergo repeated novas:



Nova Matter Ejection



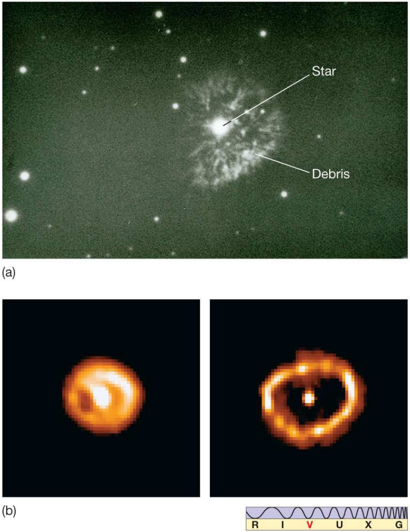
Material falls onto the white dwarf from its main-sequence companion.

When enough material has accreted, fusion can reignite very suddenly, burning off the new material.

Material keeps being transferred to the white dwarf, and the process repeats.

Nova Persei (a) brightened by a factor of 40,000 in 1901.

Nova Matter Ejection



Material falls onto the white dwarf from its main-sequence companion.

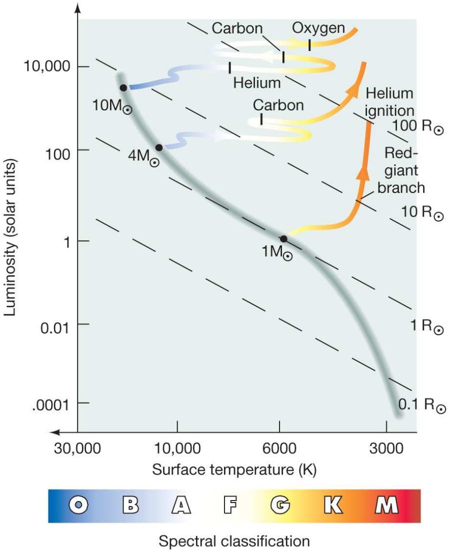
When enough material has accreted, fusion can reignite very suddenly, burning off the new material.

Material keeps being transferred to the white dwarf, and the process repeats.

Nova Cygni (b) is more than 10,000 light-years away (1992).

Outline

High-Mass Evolutionary Tracks

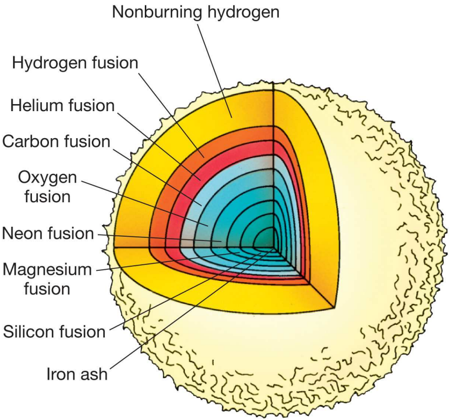


This H-R diagram shows that stars more massive than the Sun follow very different paths when they leave the Main Sequence:

- $M_{\text{star}} > 2.5\, M_\odot$
  ➜ No helium flash, helium burning starts gradually
- $M_{\text{star}} \geq 4\, M_\odot$
  ➜ No sharp moves on H-R diagram; it moves smoothly back and forth

Heavy-Element Fusion

High-mass stars, like all stars, leave the Main Sequence when there is no more hydrogen fuel in the cores.

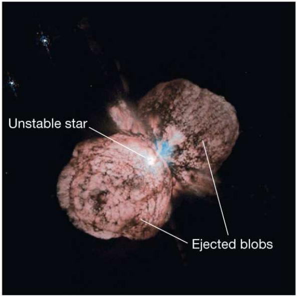


The first few events are very similar to those in lower-mass stars:

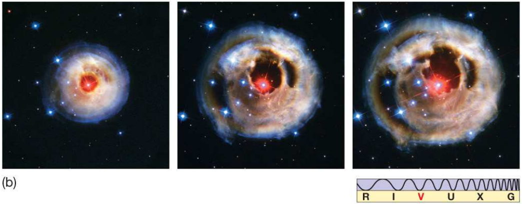
1. First a hydrogen shell
2. Then a core burning helium to carbon, surrounded by helium- and hydrogen-burning shells.

Mass Loss from Supergiants

(a) *Eta Carinae* is one of the most massive and most luminous stars known. An *HST* image shows blobs of ejected material racing away from the star at hundreds of kilometers per sec. (b) Star *V838 Monocerotis* (poorly understood red supergiant) illuminates shells of gas and dust expelled long ago.



(a)



(b)

The End of the Road

TABLE 12.3 End Points of Evolution for Stars of Different Masses

INITIAL MASS (SOLAR MASSES)	FINAL STATE
Less than 0.08	(Hydrogen) brown dwarf
0.08–0.25	Helium white dwarf
0.25–8	Carbon–oxygen white dwarf
8–12 (approx.)*	Neon–oxygen white dwarf
Greater than 12*	Supernova

*Precise numbers depend on the (poorly known) amount of mass lost while the star is on, and after it leaves, the main sequence.

Outline

Supernova

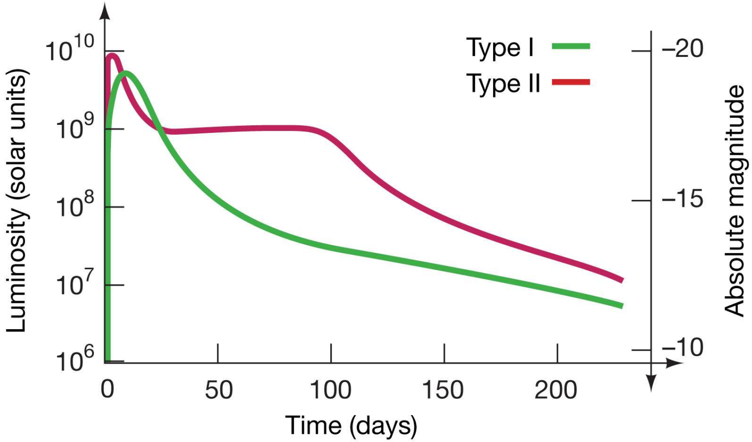
A star of more than 8 solar masses can fuse elements far beyond carbon in its core, leading to a very different fate.

Its path across the H-R diagram is essentially a straight line – it stays at just about the same luminosity as it cools off.

Eventually the star dies in a violent explosion called a *supernova*.

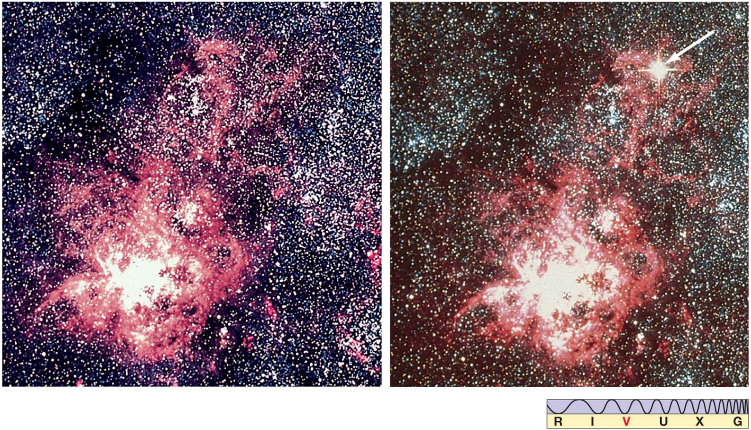
Supernova Light Curves

A supernova is incredibly luminous, as can be seen from these curves – more than a million times as bright a nova.



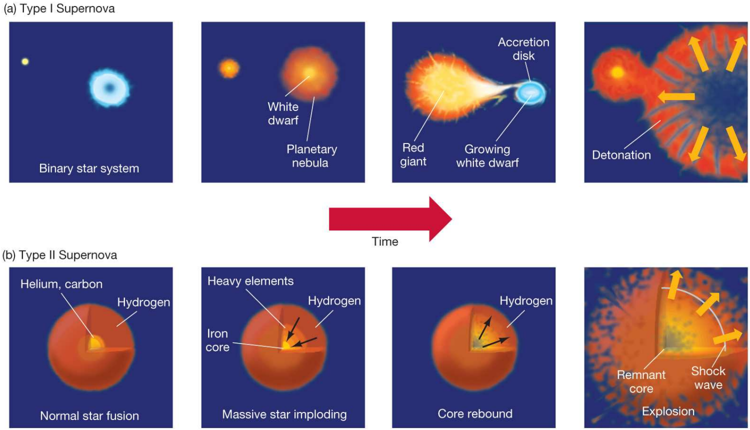
Supernova 1987A

A supernova is a one-time event – once it happens, there is little or nothing left of the progenitor star.



Two Types of Supernova

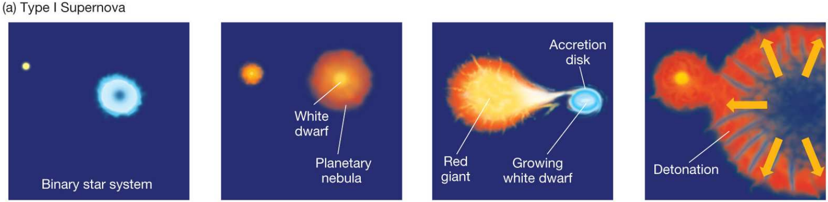
1. Carbon-detonation supernova
2. Death of a high-mass star: core collapses, then rebounds



Carbon-Detonation Supernova

A white dwarf can accumulate too much mass from its binary companion. If the white dwarf's mass exceeds 1.4 solar masses, electron degeneracy can no longer keep the core from collapsing:

Then carbon fusion begins throughout the star almost simultaneously, resulting in a carbon explosion.



Carbon-Detonation Supernova

Supernovae leave *remnants* – the expanding clouds of material from the explosion.

The *Crab nebula* is a remnant from a supernova explosion that occurred in the year 1054.

Stellar Recycling