Announcements

- Quiz 7 on Chapters 10 and 11 due next Monday
- Today and Friday: Chapters 11 and 12
- Reminder: extra credit #2 (news summary) due Friday October 24
  - Info on D2L

Astronomy 103

The Evolution of Stars

Star Formation (Chapter 11)

The Lives and Deaths of Stars (Chapter 12)

Star Formation

Star formation is the process of clouds of gas and dust collapsing to form a star. Pretty simple, but we still don't understand all the details.

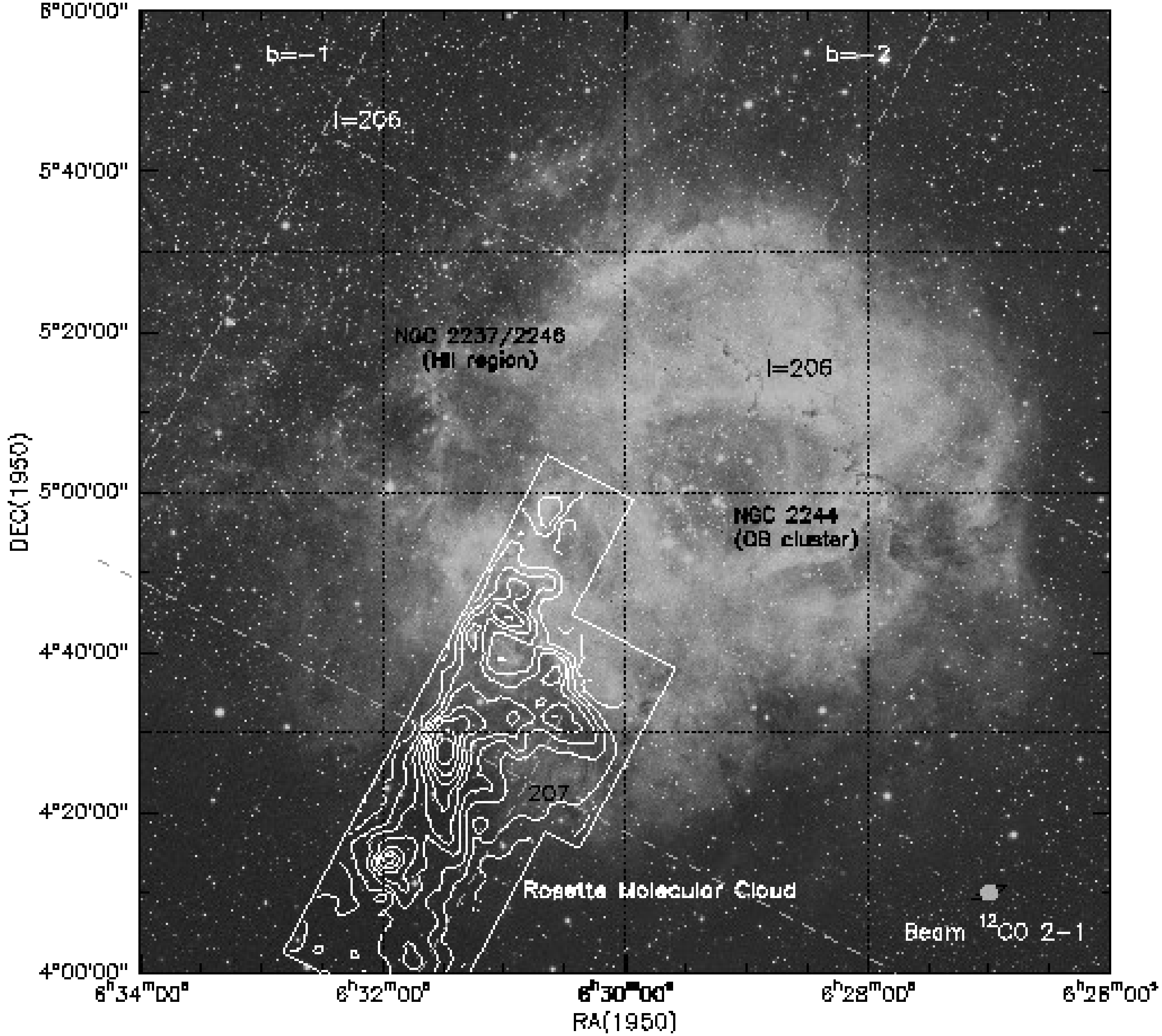
Your book has it broken into 7 stages, which are phases in a single process:

The collapse of molecular gas and formation of stars (textbook stages 1-6)

Stage 1 – A molecular cloud begins to collapse. Usually we see this from spectral lines of molecules. Stars form in cold, dense molecular gas.

Stage 1: Start with a fragment of a molecular cloud

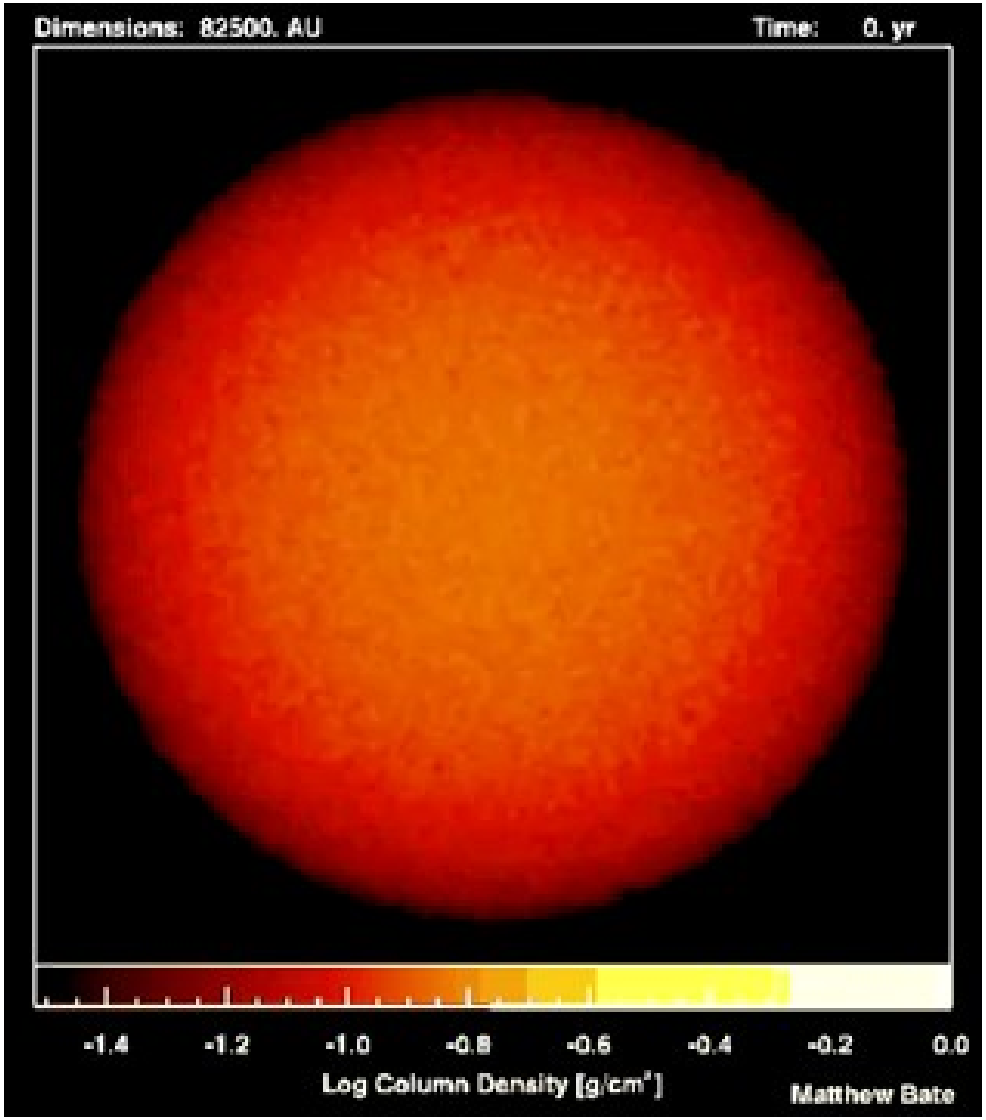
Rosetta Molecular Cloud



Stage 2 and 3: Cloud fragmentation and core collapse

The cloud collapses due to its own gravity

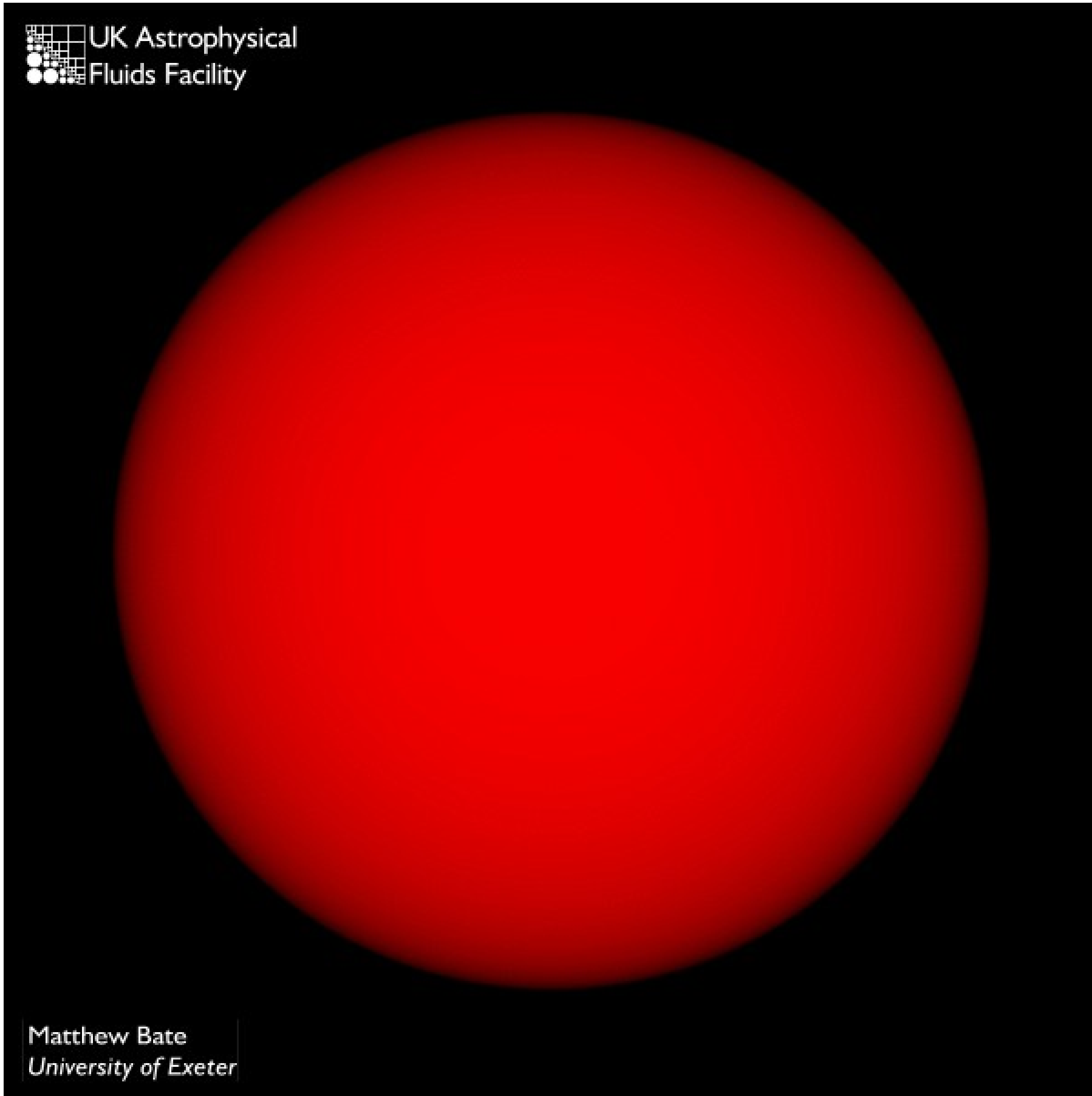
The collapsing cloud fragments into lots of tiny little pieces, called **cores** – all of which continue to contract and build mass from infalling gas.



Movie of collapsing and fragmenting cloud

Molecular Cloud Collapse

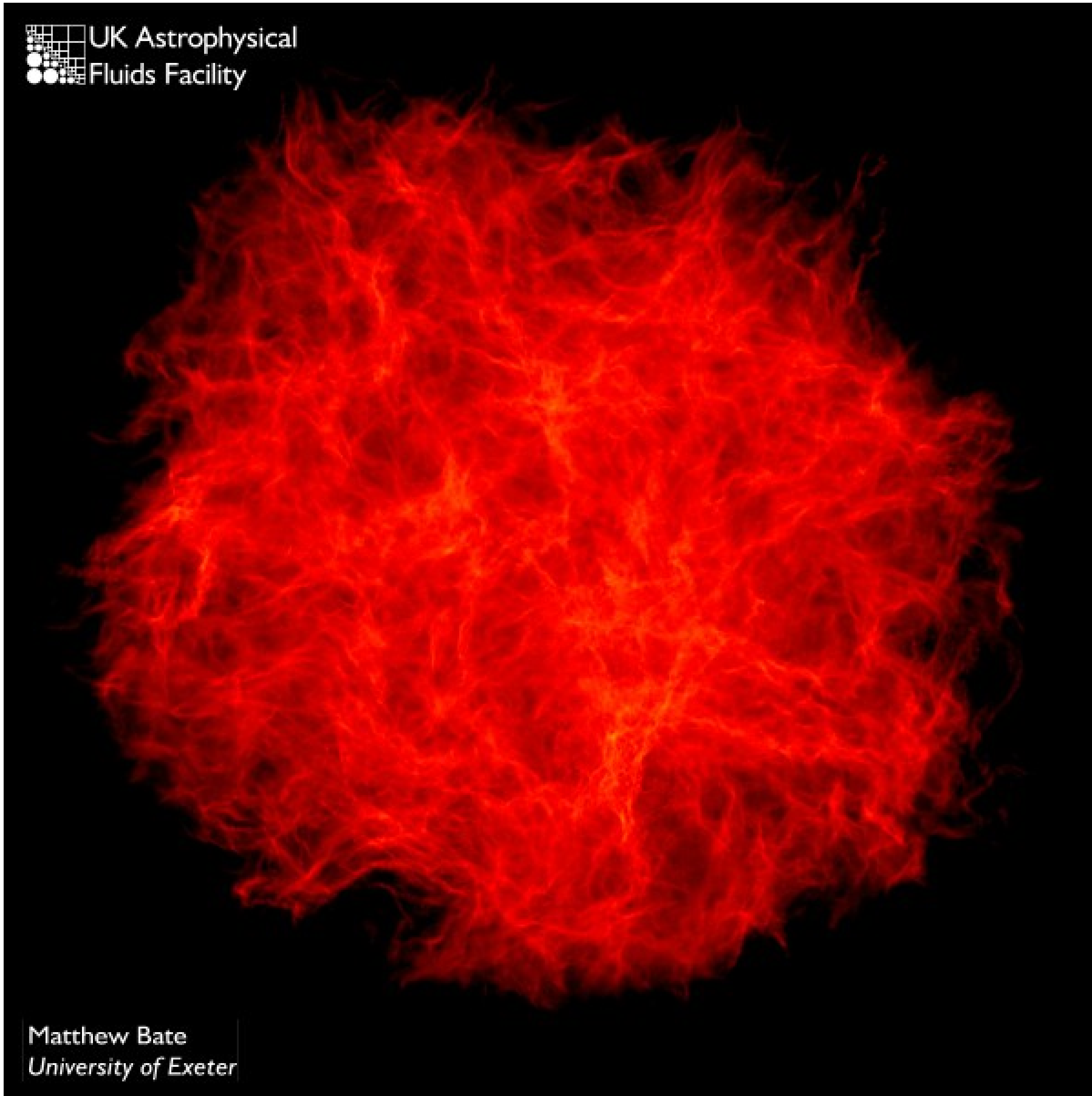
0 yr: We begin with such a gas cloud, 2.6 light-years across, and containing 500 times the mass of the Sun. The images measure 1 pc (3.2 lightyears across).



Source: Matthew Bate, U. Exeter: http://www.astro.ex.ac.uk/people/mbate/Cluster/cluster3d.html

Molecular Cloud Collapse

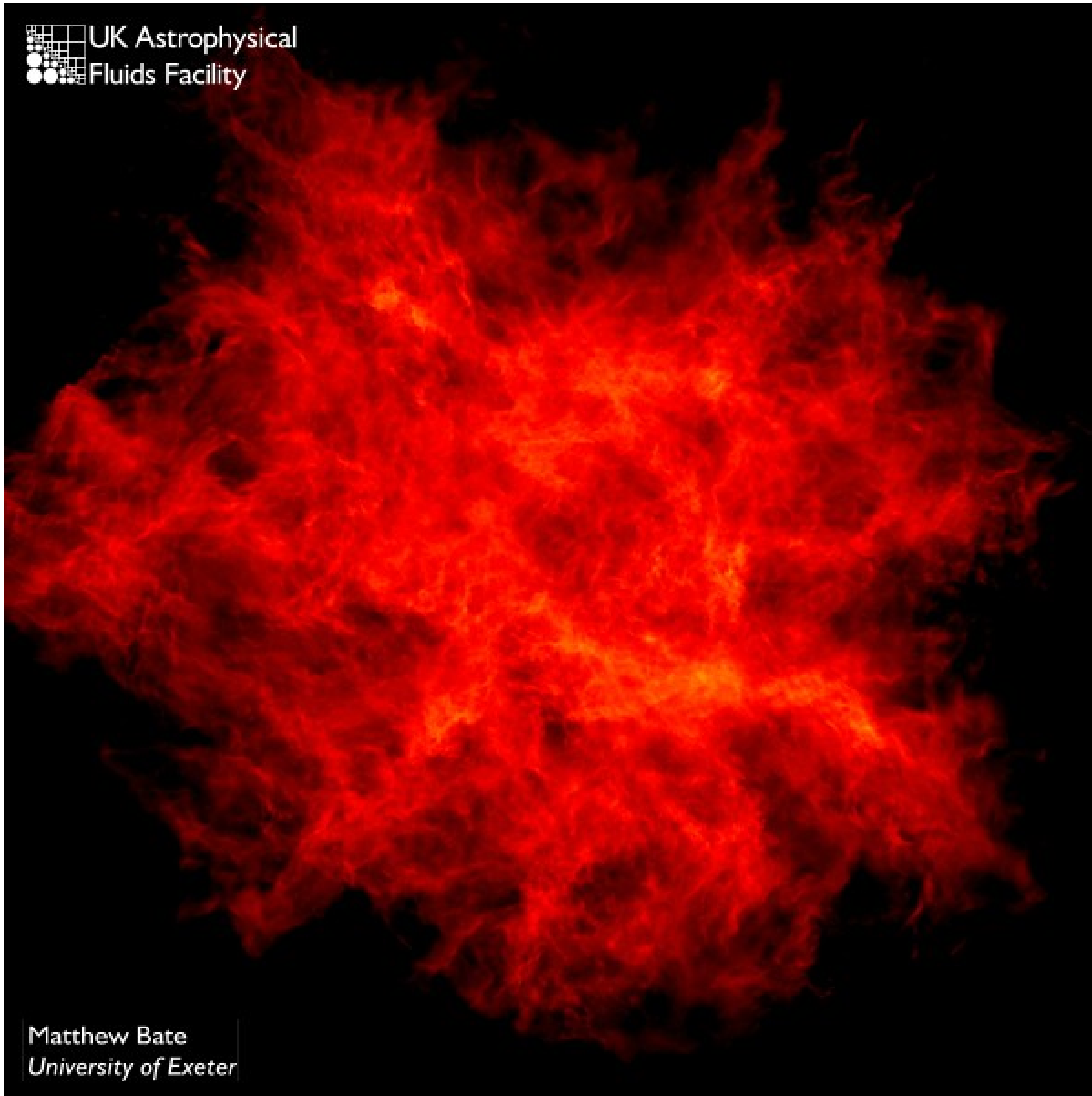
38,000 yr: Clouds of interstellar gas are seen to be very turbulent with supersonic motions.



Source: Matthew Bate, U. Exeter: http://www.astro.ex.ac.uk/people/mbate/Cluster/cluster3d.html

Molecular Cloud Collapse

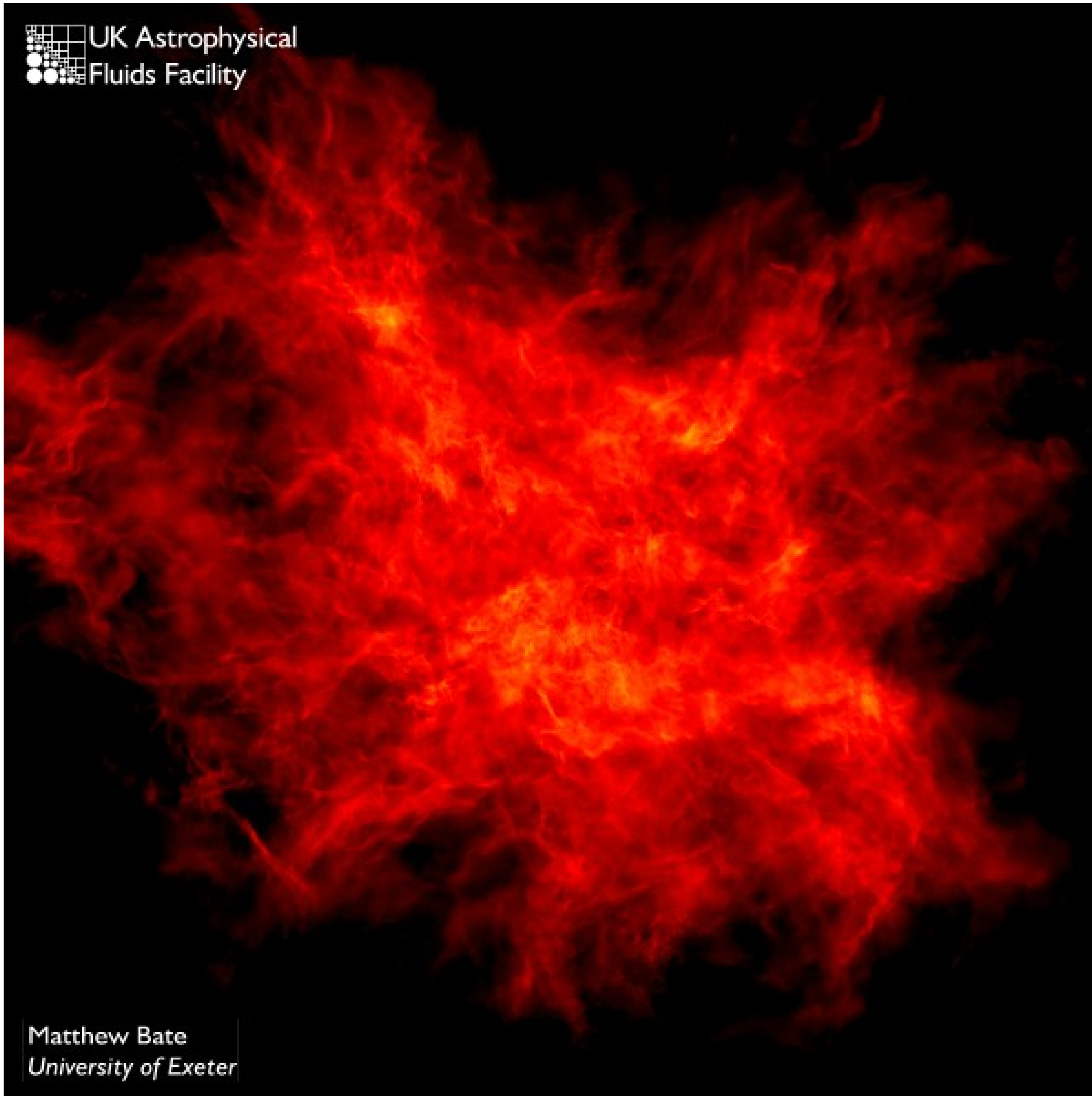
76,000 yr: As the calculation proceeds, the turbulent motions in the cloud form shock waves that slowly damp the supersonic motions.



Source: Matthew Bate, U. Exeter: http://www.astro.ex.ac.uk/people/mbate/Cluster/cluster3d.html

Molecular Cloud Collapse

114,000 yr.



Source: Matthew Bate, U. Exeter:
http://www.astro.ex.ac.uk/people/mbate/Cluster/cluster3d.html

Molecular Cloud Collapse

152,000 yr: When enough energy has been lost in some regions of the simulation, gravity can pull the gas together to form dense "cores".

Source: Matthew Bate, U. Exeter: http://www.astro.ex.ac.uk/people/mbate/Cluster/cluster3d.html

Molecular Cloud Collapse

171,000 yr.

Source: Matthew Bate, U. Exeter: http://www.astro.ex.ac.uk/people/mbate/Cluster/cluster3d.html

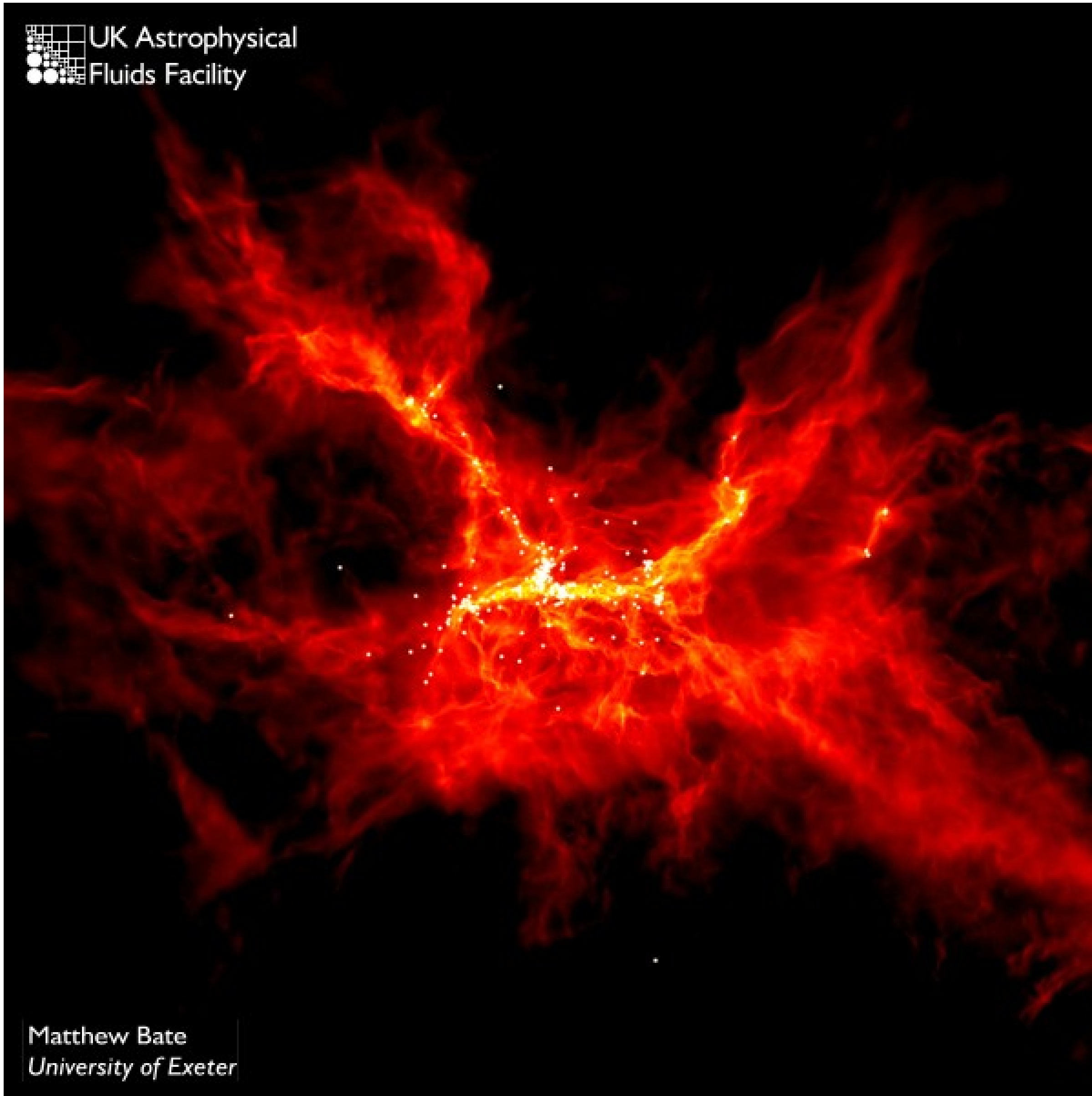
Molecular Cloud Collapse

190,000 yr: The formation of stars and brown dwarfs begins in the dense cores.

Source: Matthew Bate, U. Exeter: http://www.astro.ex.ac.uk/people/mbate/Cluster/cluster3d.html

Molecular Cloud Collapse

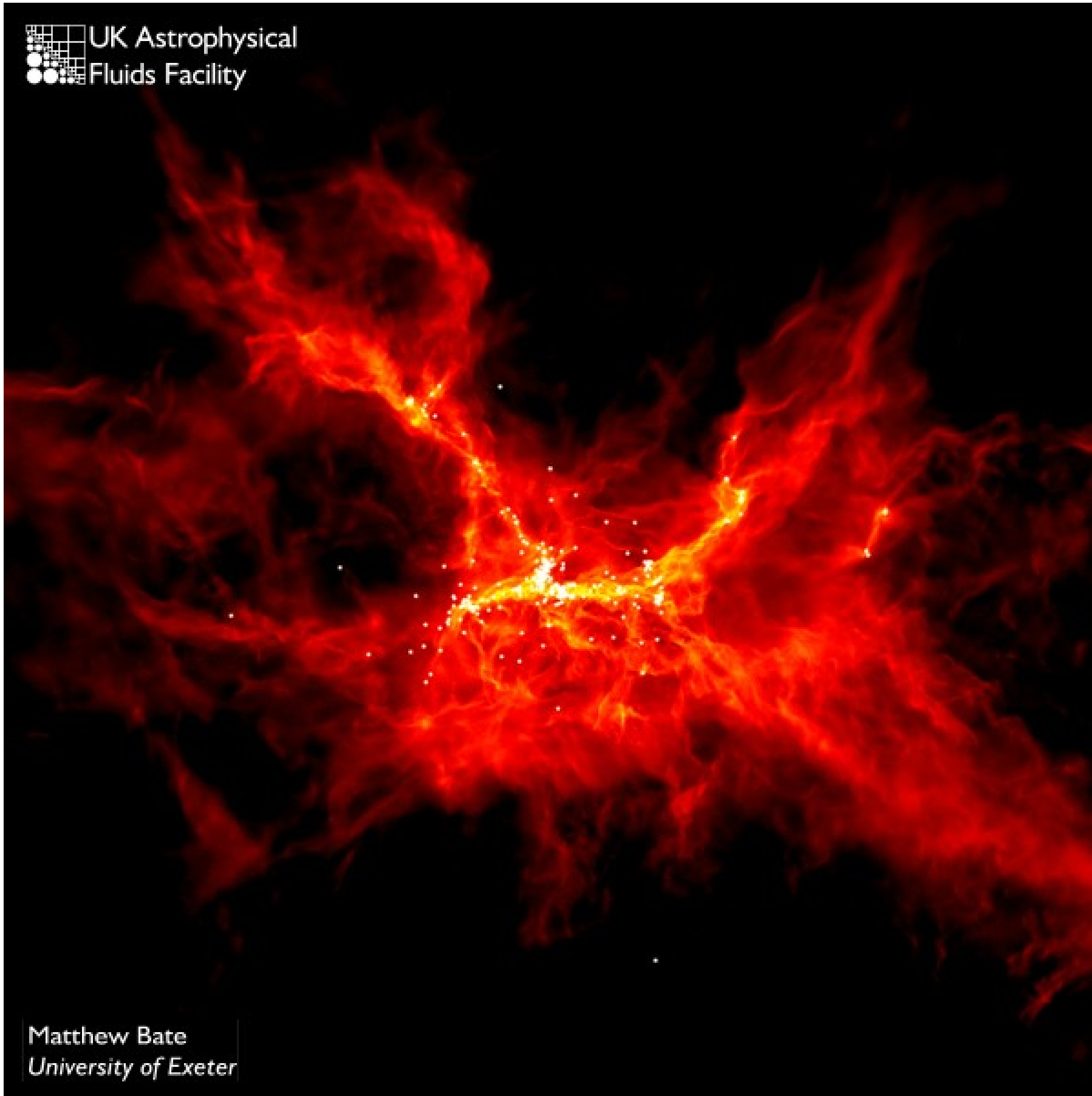
209,000 yr: As the stars and brown dwarfs interact with each other, many are ejected from the cloud.



Source: Matthew Bate, U. Exeter: http://www.astro.ex.ac.uk/people/mbate/Cluster/cluster3d.html

Molecular Cloud Collapse

The cloud and star cluster at the end of simulation (which covers 210,000 years so far). Some stars and brown dwarfs have been ejected to large distances from the regions of dense gas in which the star formation occurs.



Source: Matthew Bate, U. Exeter: http://www.astro.ex.ac.uk/people/mbate/Cluster/cluster3d.html

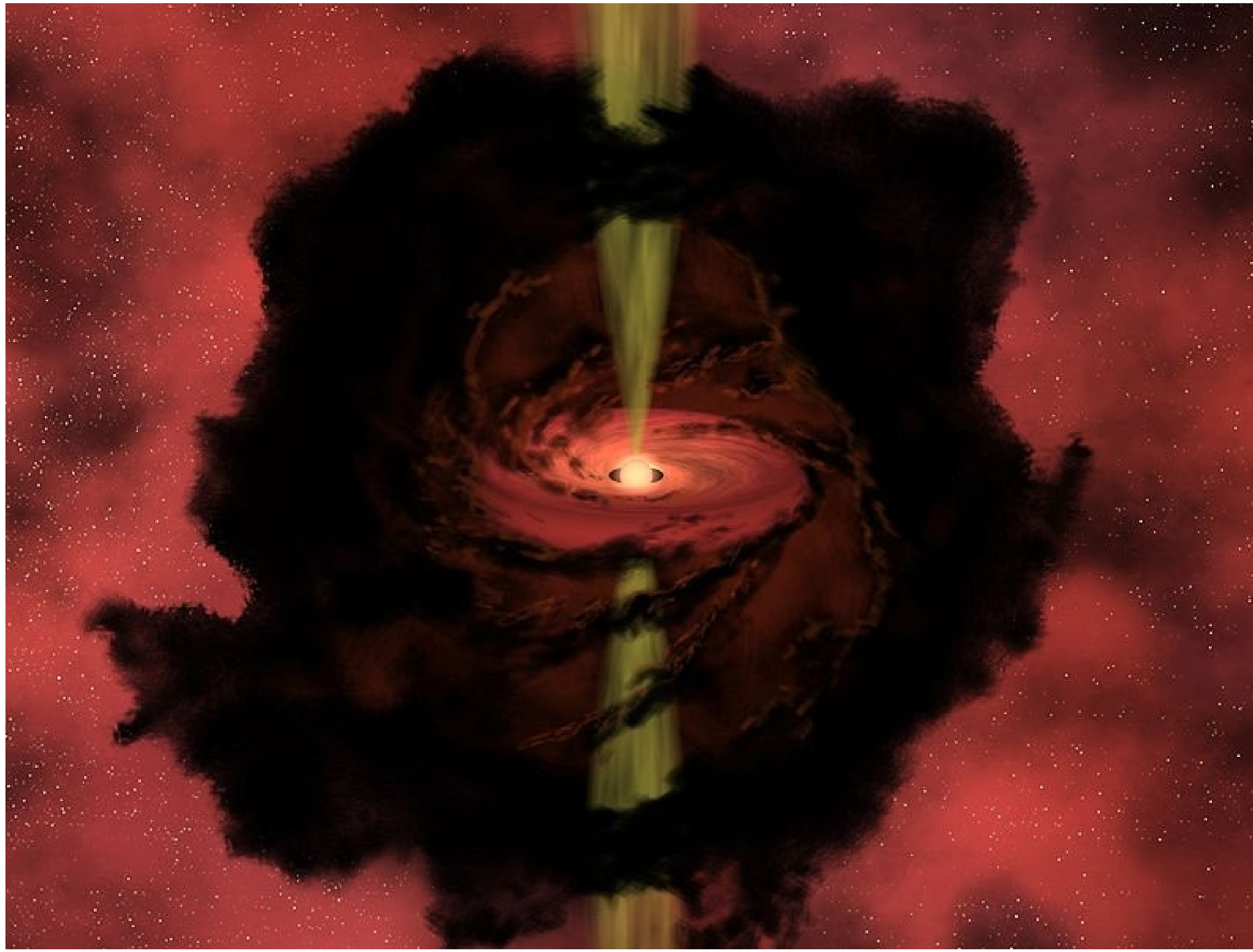
From cloud core to proto-star

Initially these cores stay cold as they collapse. Radiation allows them to cool.

But as they get denser and denser, radiation has a harder and harder time escaping. And eventually they start to heat up.

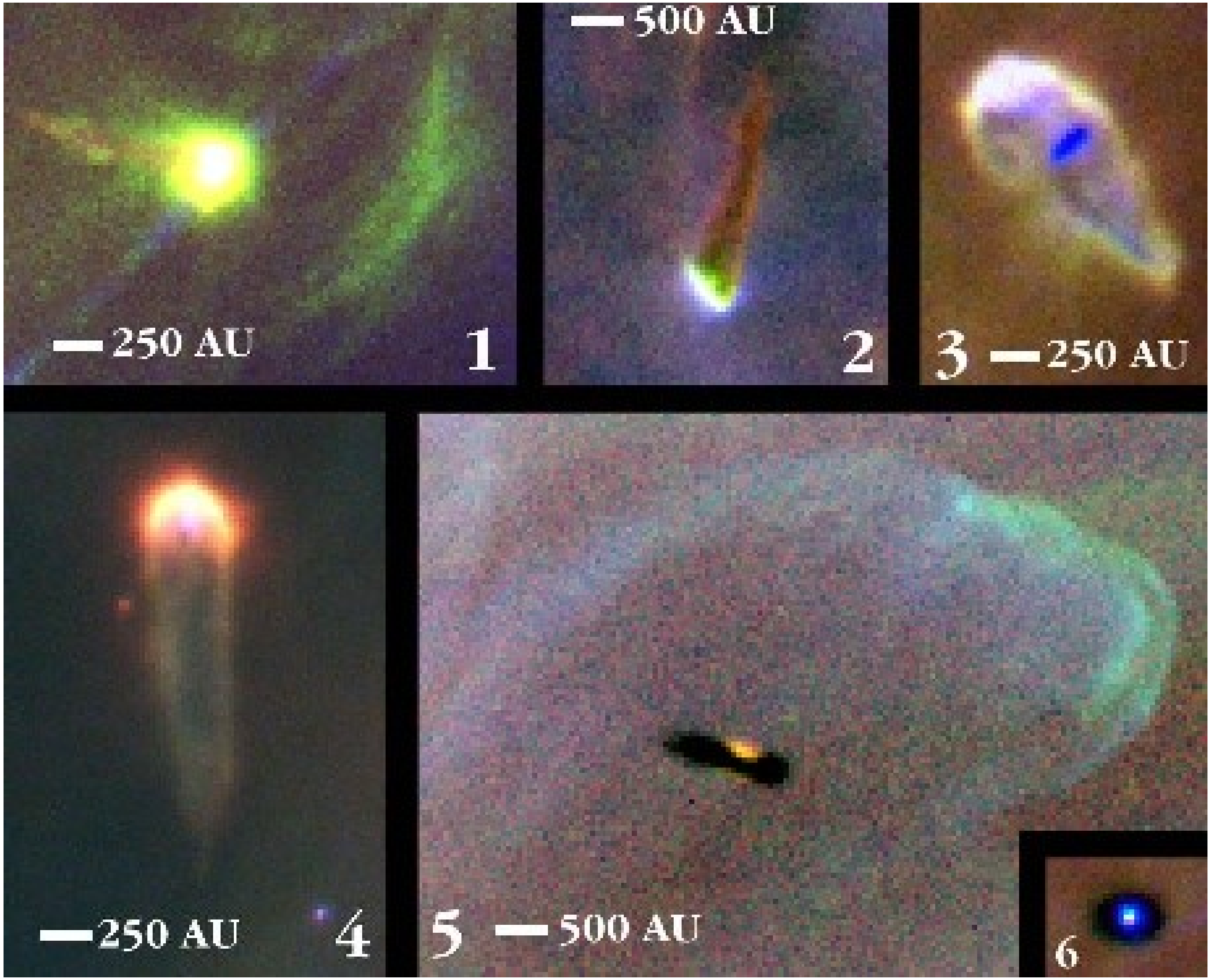
At this point a **protostar** is born.

Stage 4: The protostar



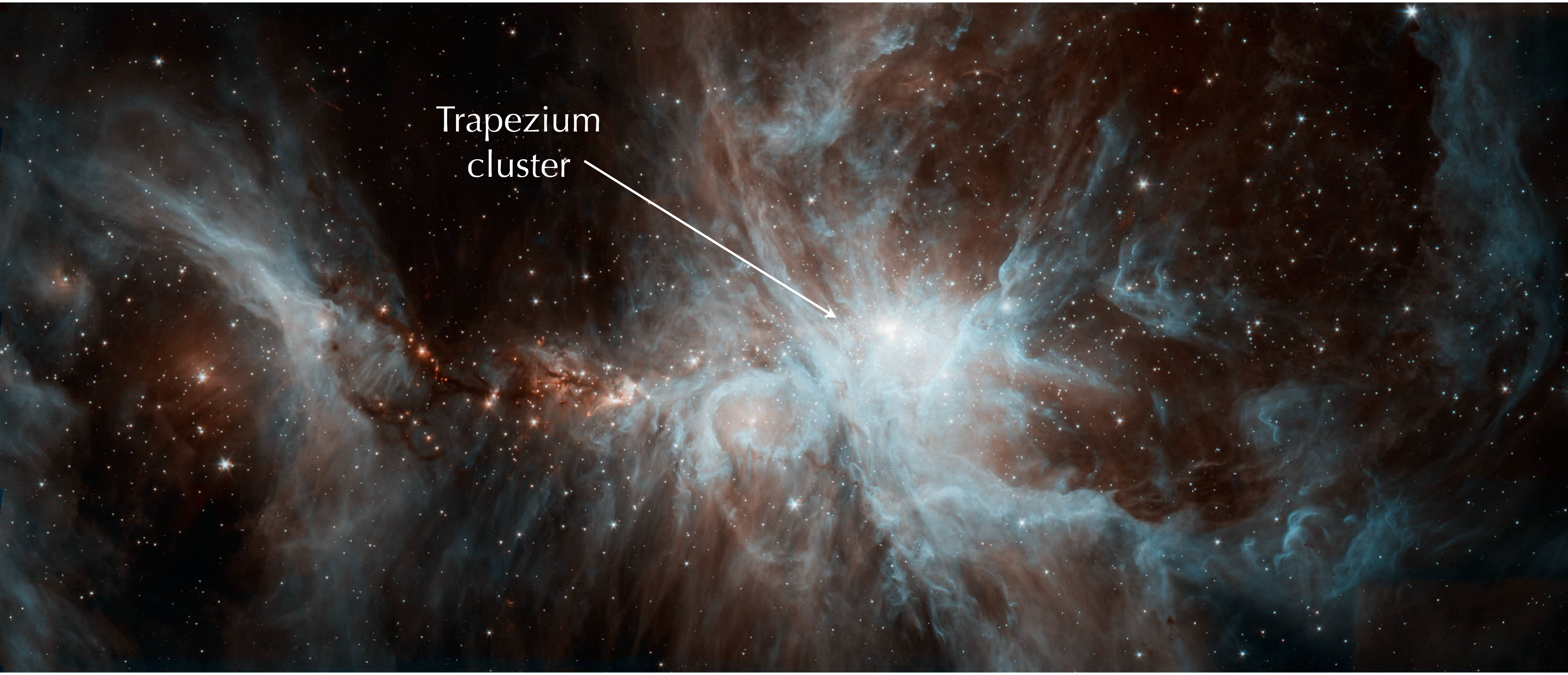
The star is still forming, but the cloud has a hot central thing that can be considered a star already.
It is surrounded by a disk of gas.

Stage 4: The protostar



Some protostars in the Trapezium Nebula, from Hubble

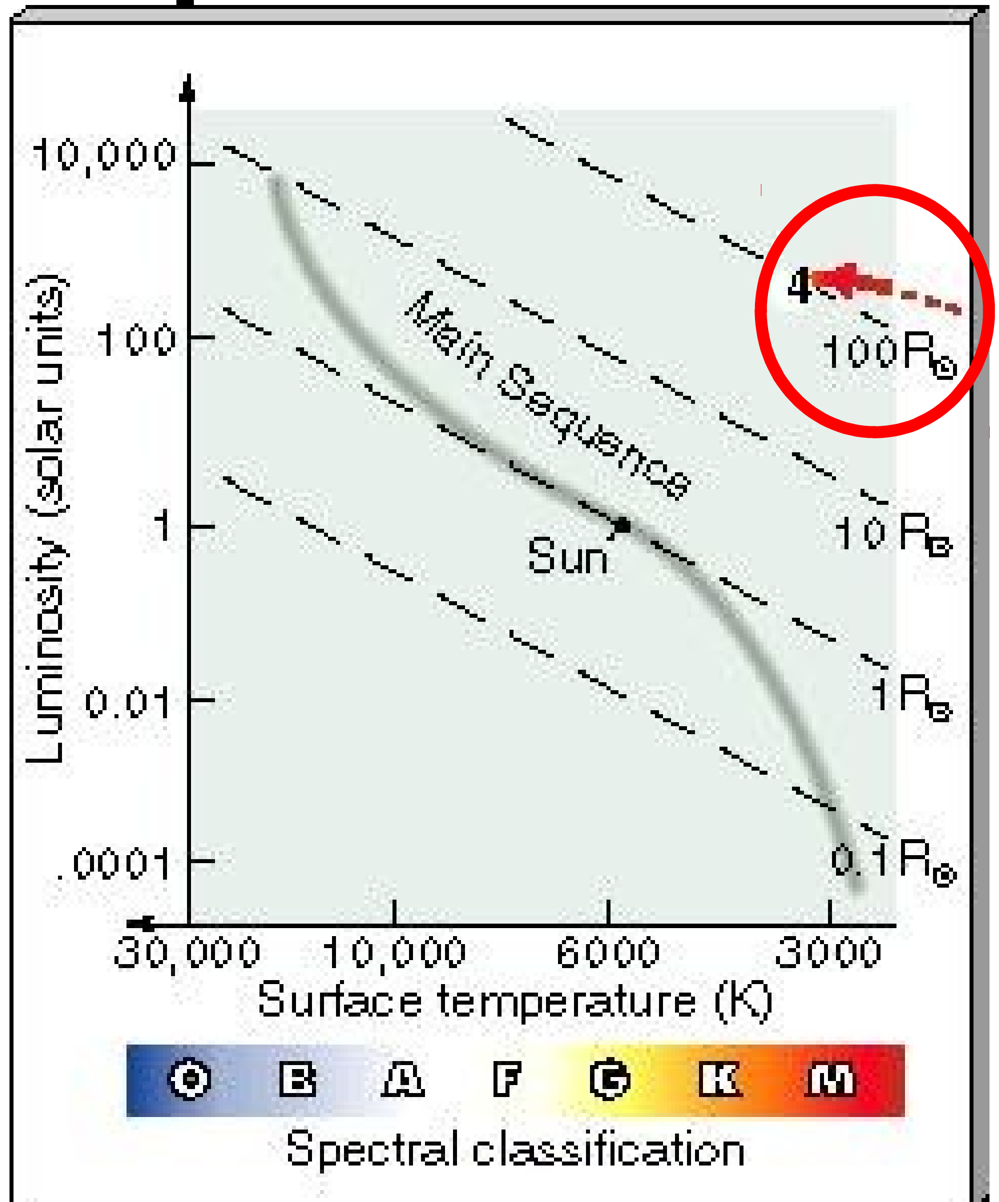
Star Formation in the Trapezium Cluster in the Orion Nebula



Stage 4: The protostar

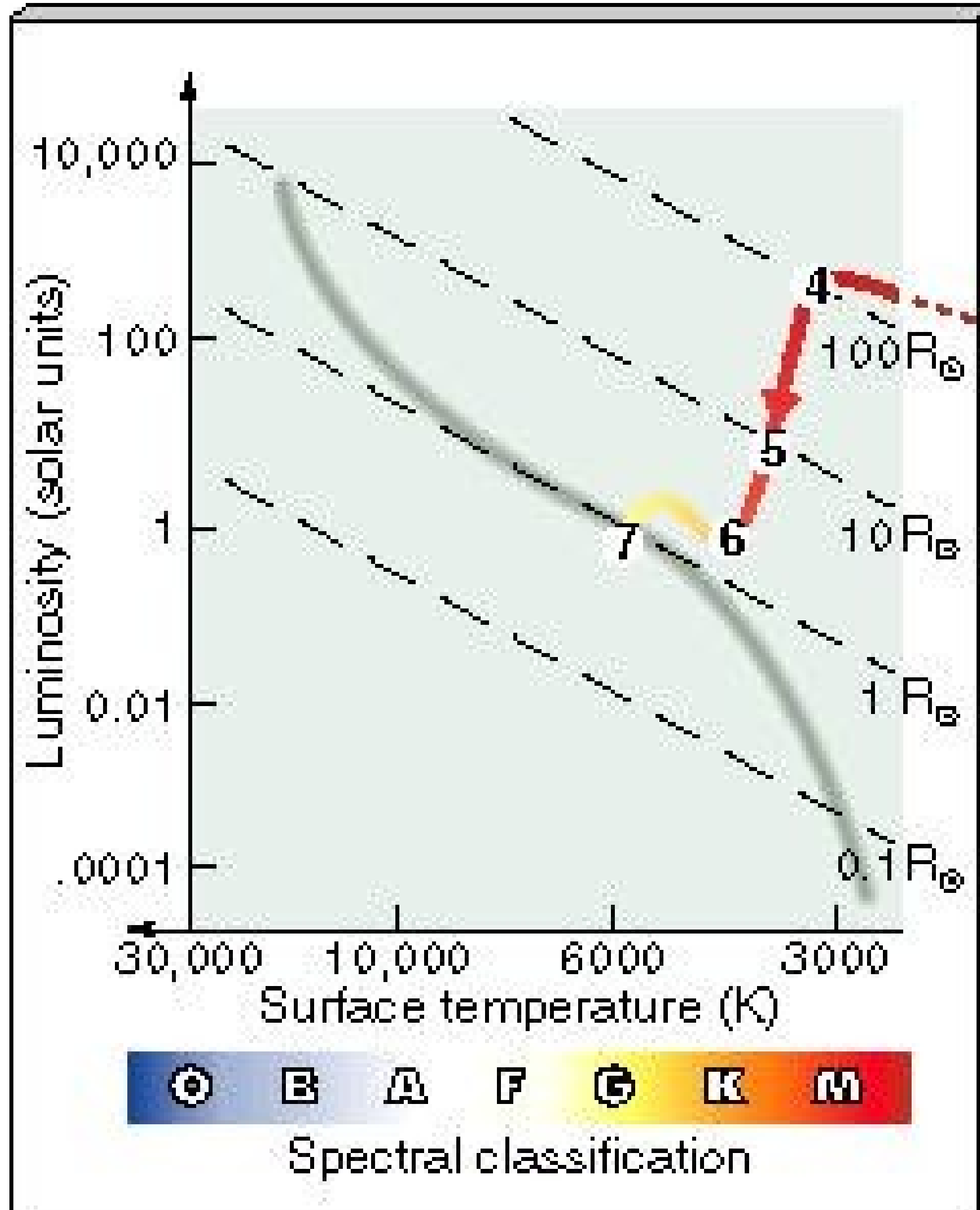
Because a protostar is star-like, we can put it on the HR diagram.

Notice that it is **brighter and cooler** than the sun, which means that it is very, very big at this stage!

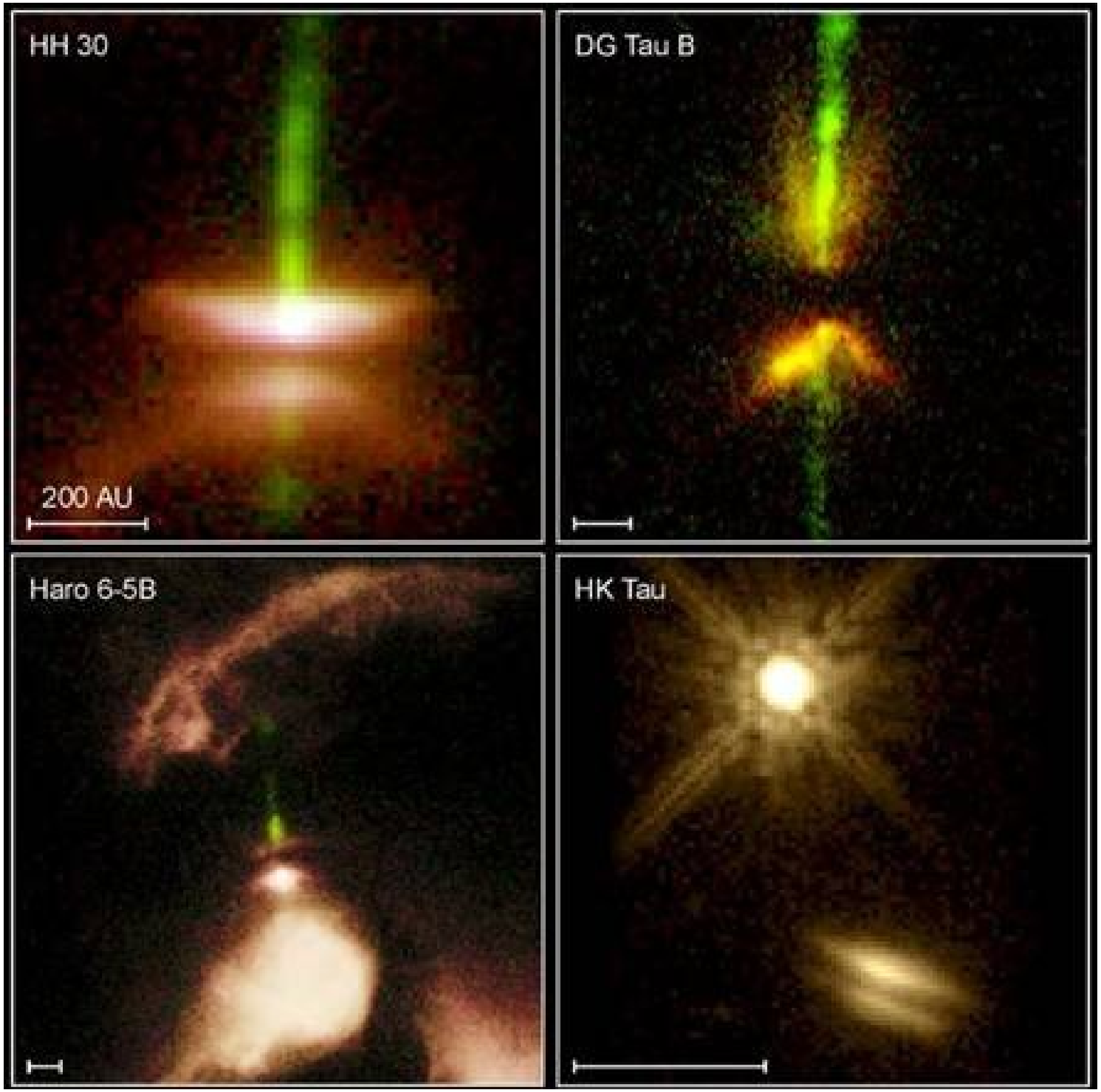


Stage 5: Protostellar evolution

- As the protostar contracts, it heats up, but gets dimmer!! This is because the star is getting smaller
- During this phase, many protostars give off jets of gas – these are called Herbig-Haro objects
- Eventually nuclear fusion starts up and the protostar becomes a star



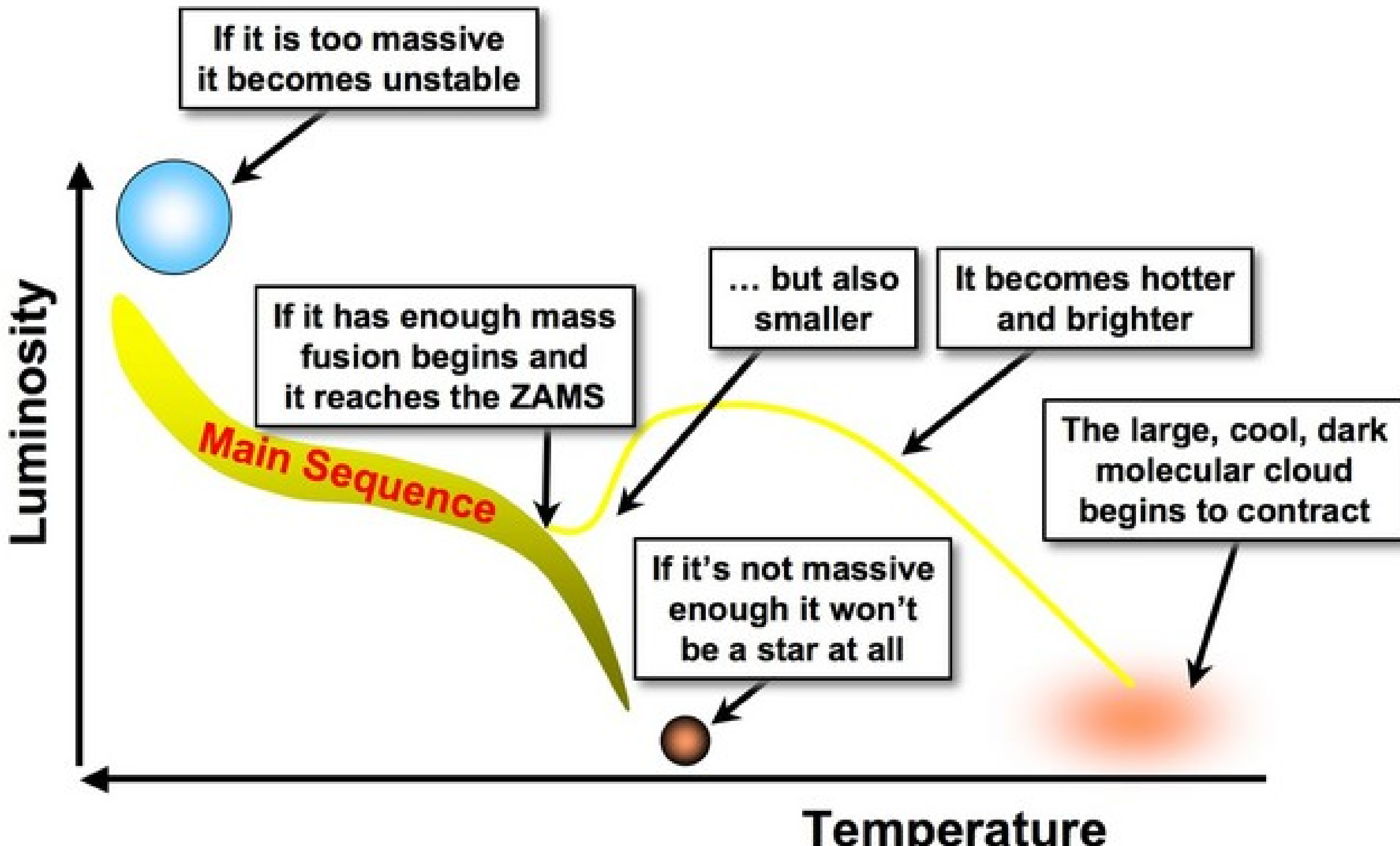
Stage 5: Protostellar evolution



jets of gas from **Herbig-Haro objects**

Stage 6/7: A star is born.

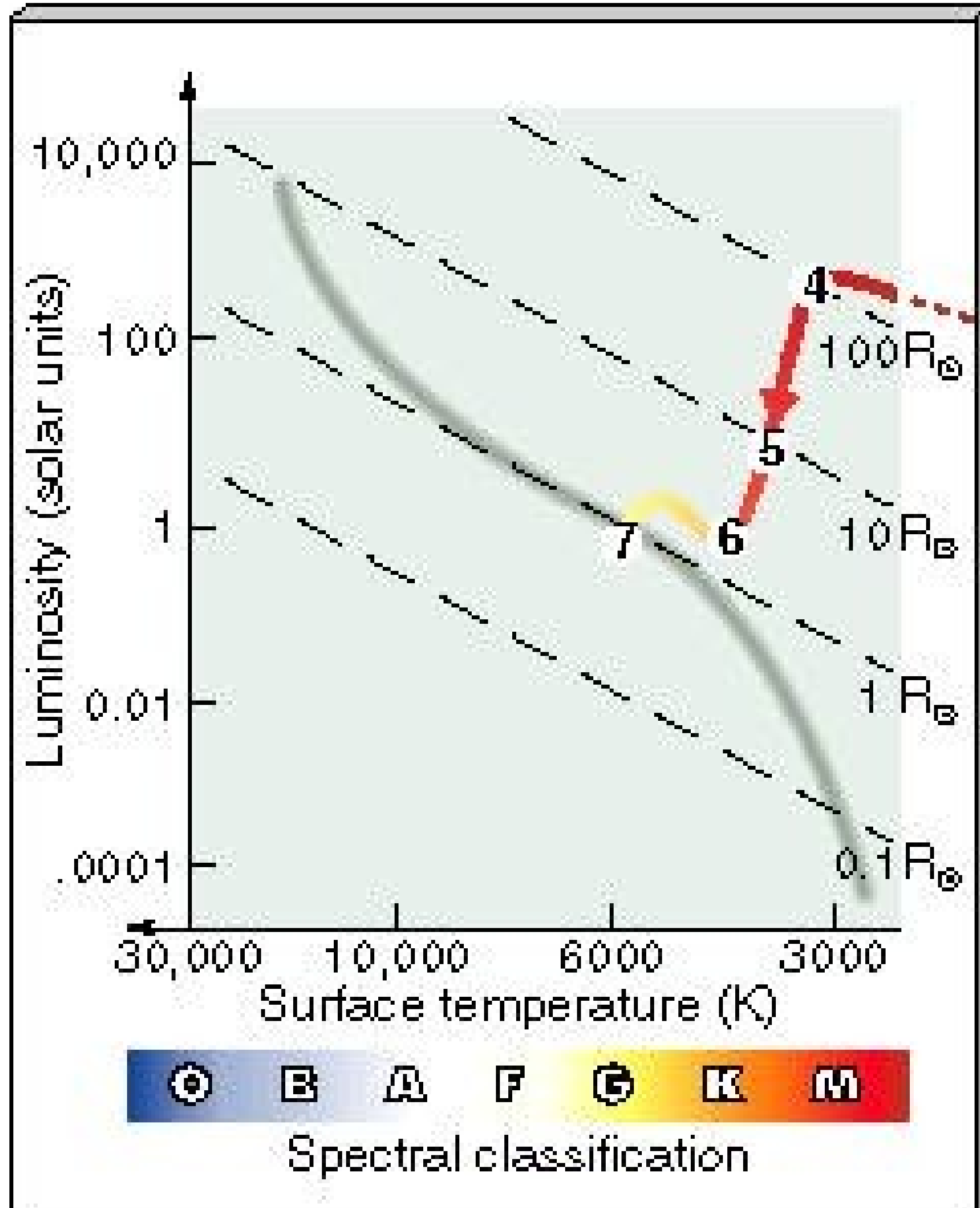
When the star starts burning hydrogen in its core, its collapse is halted and it reaches the zero-age main sequence (ZAMS)



Stage 6/7: A star is born.

Where the star lands on the ZAMS is where it is **stuck**.

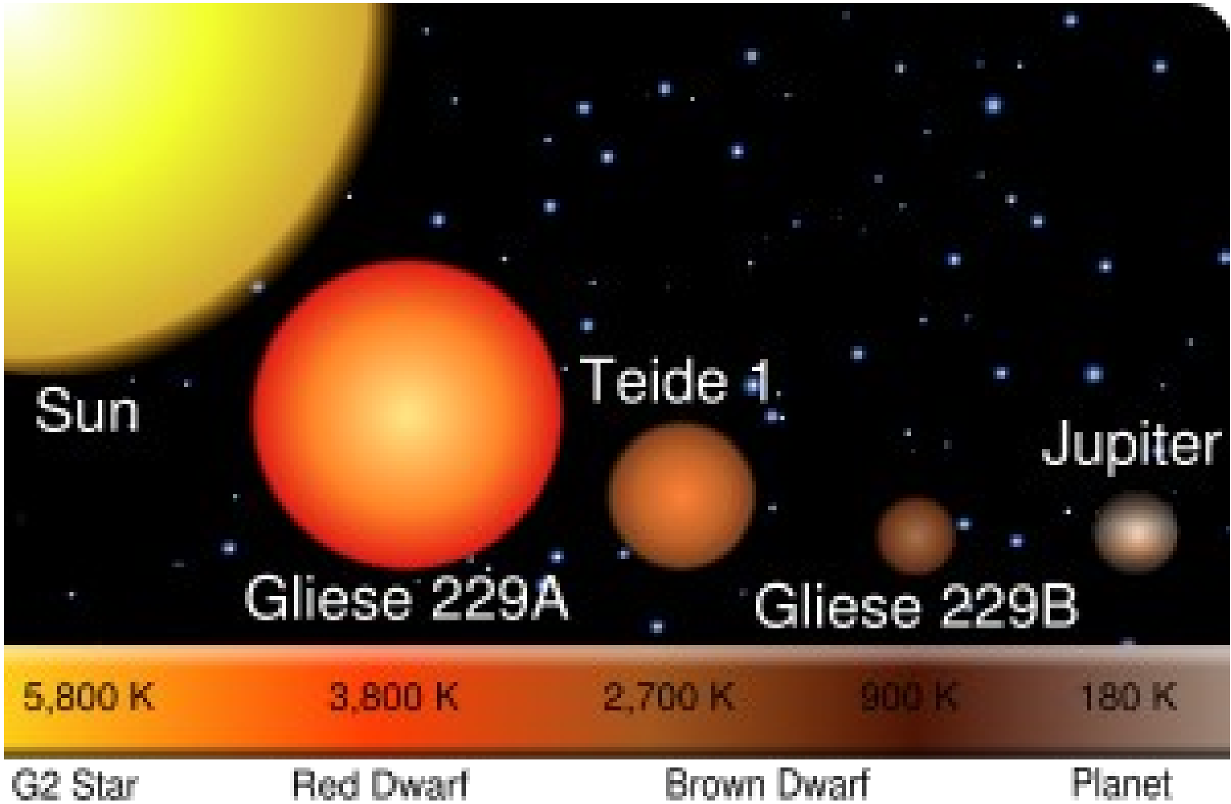
Stars don't move along the main sequence, but they will eventually leave it.



Stage 6/7: Or: a star is not born.

Some stars are not massive enough to burn hydrogen. They are failed stars or **brown dwarfs.**

They range from about the mass of Jupiter up to 80 times Jupiter.



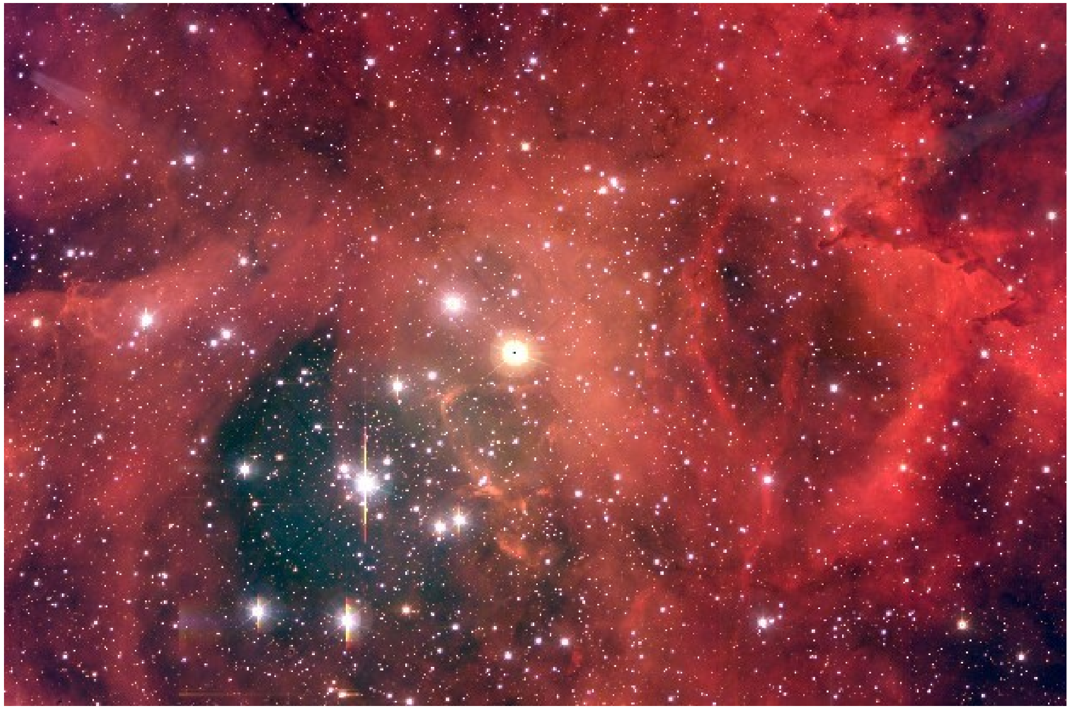
Stars form in groups called **star clusters.** Most of these are called **open clusters,** with 100s to 10,000s of stars.

Examples of open clusters are the Pleiades, the Hyades, and h and χ Persei (χ is the lower-case Greek letter chi). This is a picture of the Pleiades.

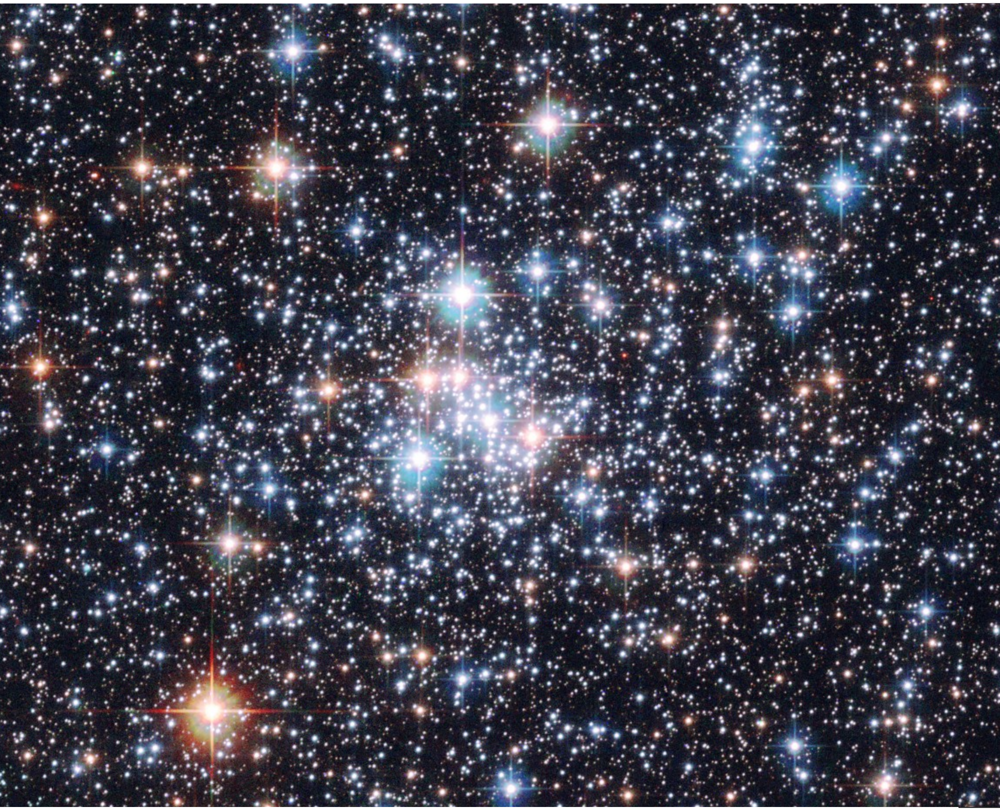
Stars form in groups called star clusters.

More extended, lower-mass versions of open clusters are called associations.

Star form in clusters because they are formed from the original breakup of a single cloud. So we see newborn stars in clusters in molecular clouds.



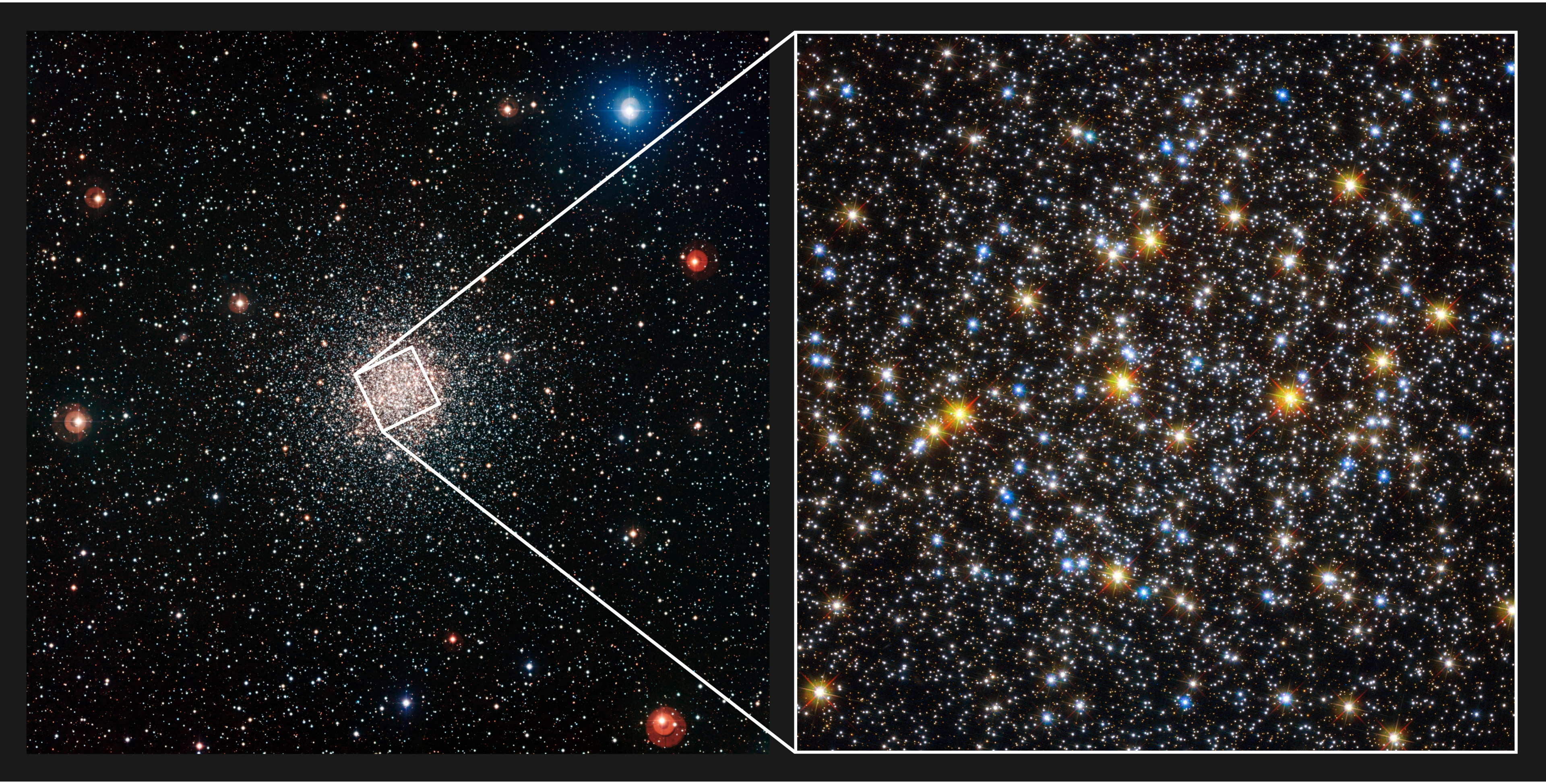
Major types of star clusters



Open clusters – thousands of stars, about 1 to a few parsecs across (recall that a parsec [parallax-arcsecond] is 3.26 light years)

Stellar associations – less massive – extended and not gravitationally bound

Major types of star clusters



Globular clusters – very old, 1-10 pc across and containing up to millions of stars.

Source: http://www.eso.org/public/images/eso1243e/

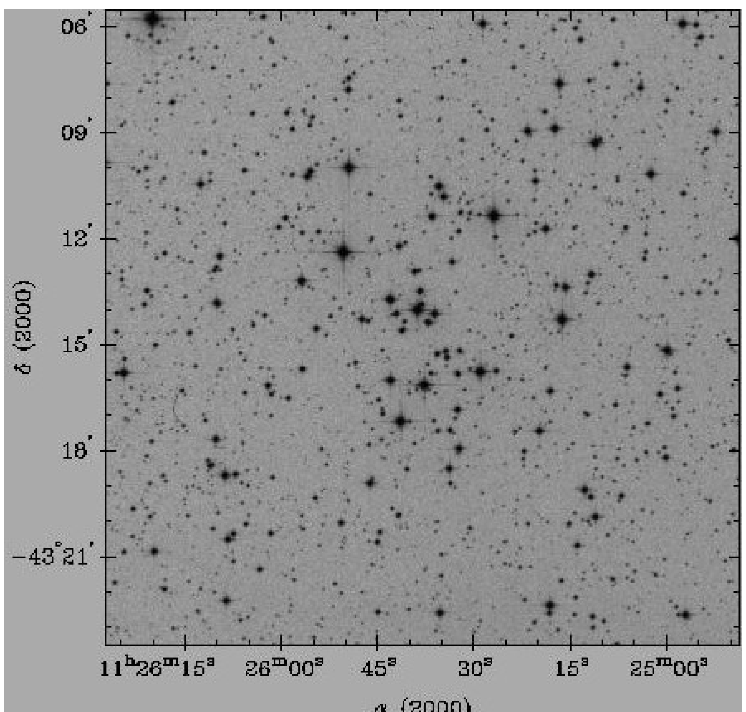
Star Clusters and Nebulae

Massive stars in star clusters tend to break up the stellar nursery. Their ionizing radiation breaks up the molecules in the cloud and their powerful winds blow the cloud apart.

Carinae nebula with Eta Carinae.

Most clusters eventually dissolve. Why?

- Loss of gas – less mass means less gravity, so stars move apart
- Gravity from the galaxy pulls apart the star cluster
- Only the biggest star clusters can stay together – globular clusters



Astronomy 103

The Lives and Deaths of Stars, and the Origin of the Elements

Please read chapter 12

Observing stellar evolution

A star like our sun might live for 10 billion years. Some stars live for 4 million years. So how do we know how stars live and die if humans have only been studying stars for the last 2000 years?

It is because we see many millions of stars and see them at different stages in their life.

It is as if an alien landed in the middle of Milwaukee and saw a baby, a teen, an adult and a senior and tried to put together the life of an average human being.

The textbook breaks down stellar evolution into 13 stages for stars like the sun. We'll talk about a simpler evolution that will be broken into six stages (in Roman numerals)

I. Collapse of a gas cloud to form a star (book stages 1-6)

II. Main Sequence (stage 7)

III. Red Giant

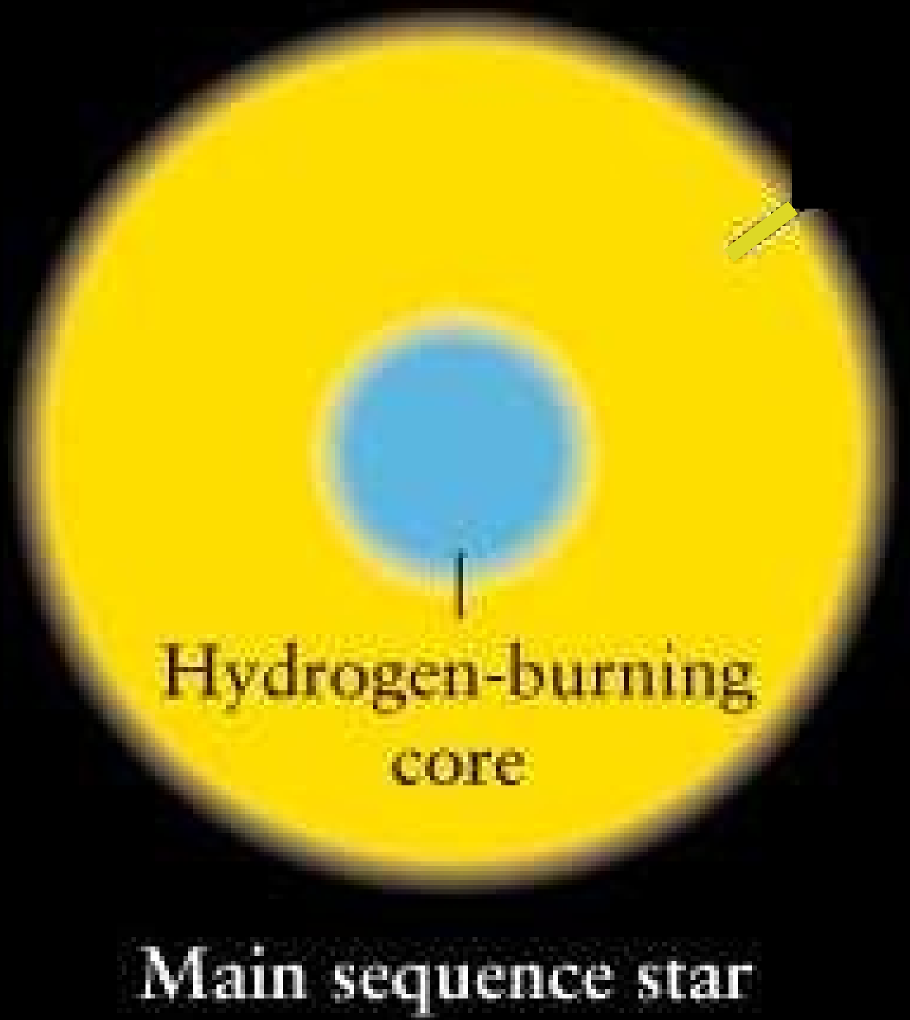
IV. Helium Flash

V. Second Red Giant (Asymptotic Giant Branch [AGB])

VI. Planetary Nebula and formation of White Dwarf

It is helpful to keep in mind that stars are a battle between gravity and nuclear energy. And gravity always wins in the end.

II. Main sequence

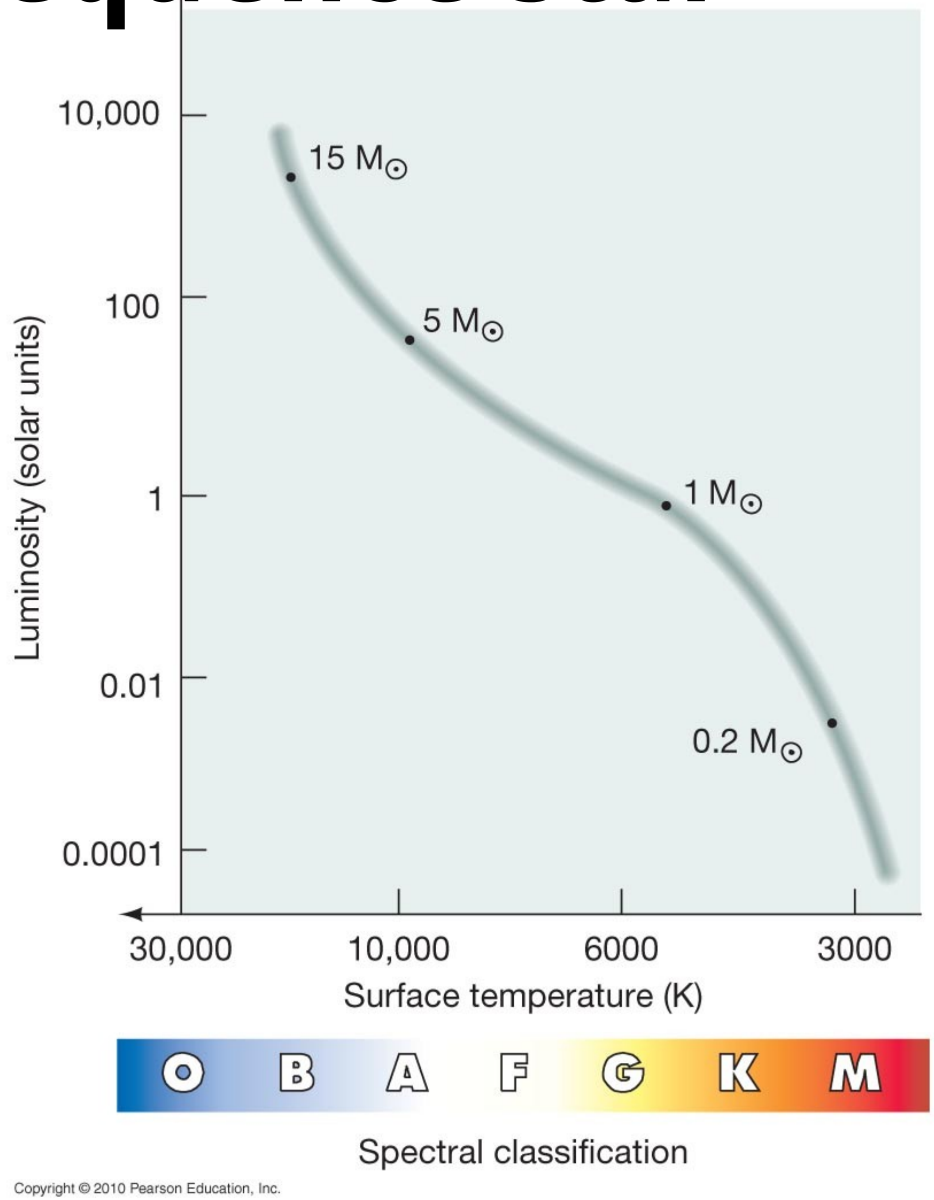


The energy of a main sequence star is produced by fusion of H to He in the star's core

II. Main sequence star

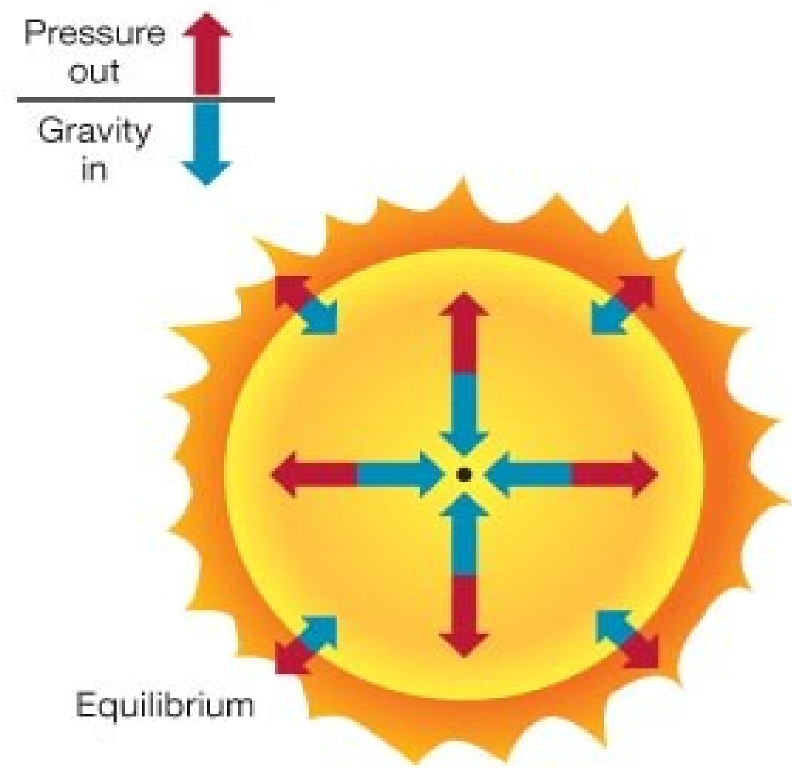
The main sequence is boring – H fuses in the core to make He, but not much else happens

As we have seen, where a star sits on the main sequence depends on its mass

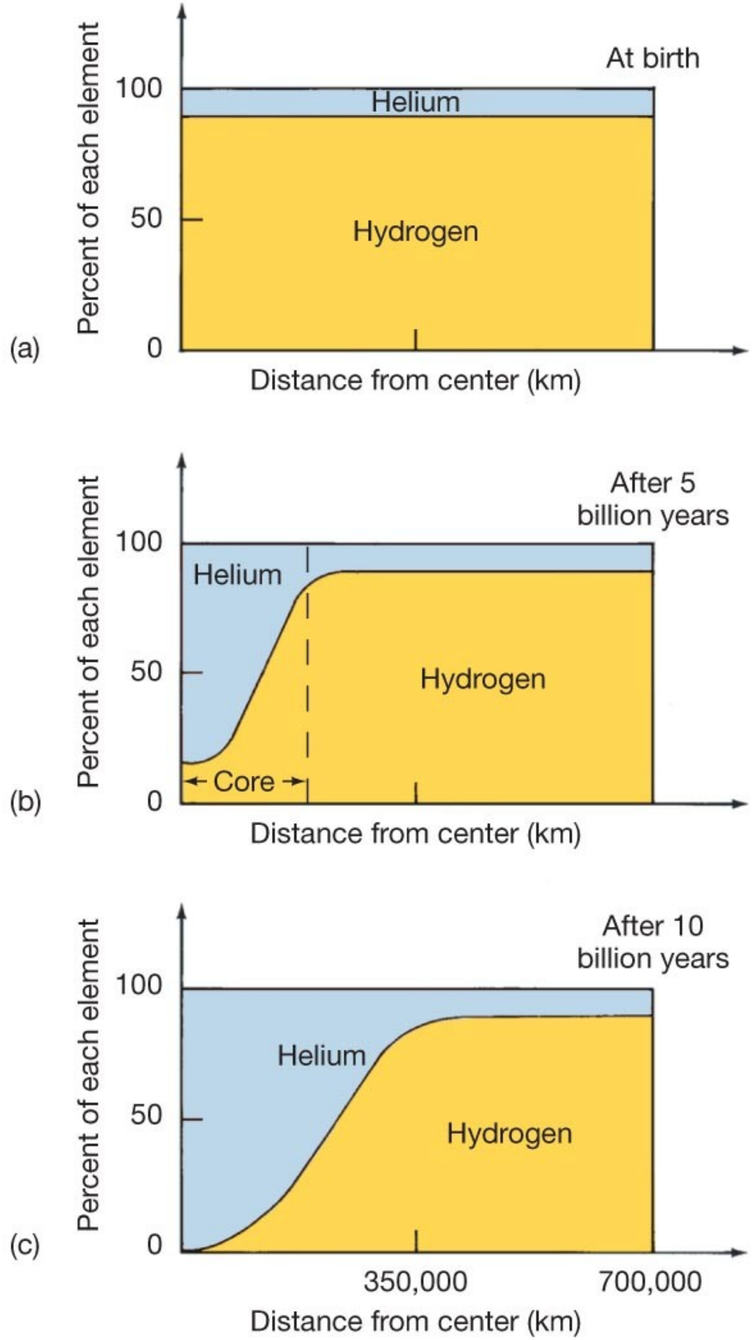


Hydrostatic balance

Recall that stars are a balance between pressure pushing stuff out and gravity pulling stuff in.



Because stars are constantly losing energy, they would contract if it were not for a heat source (nuclear fusion) in the center.



At some point, the star will run out of fuel. At this point it is no longer generating energy to hold itself up. But it will still shine and so gravity takes over: the core again begins to contract.

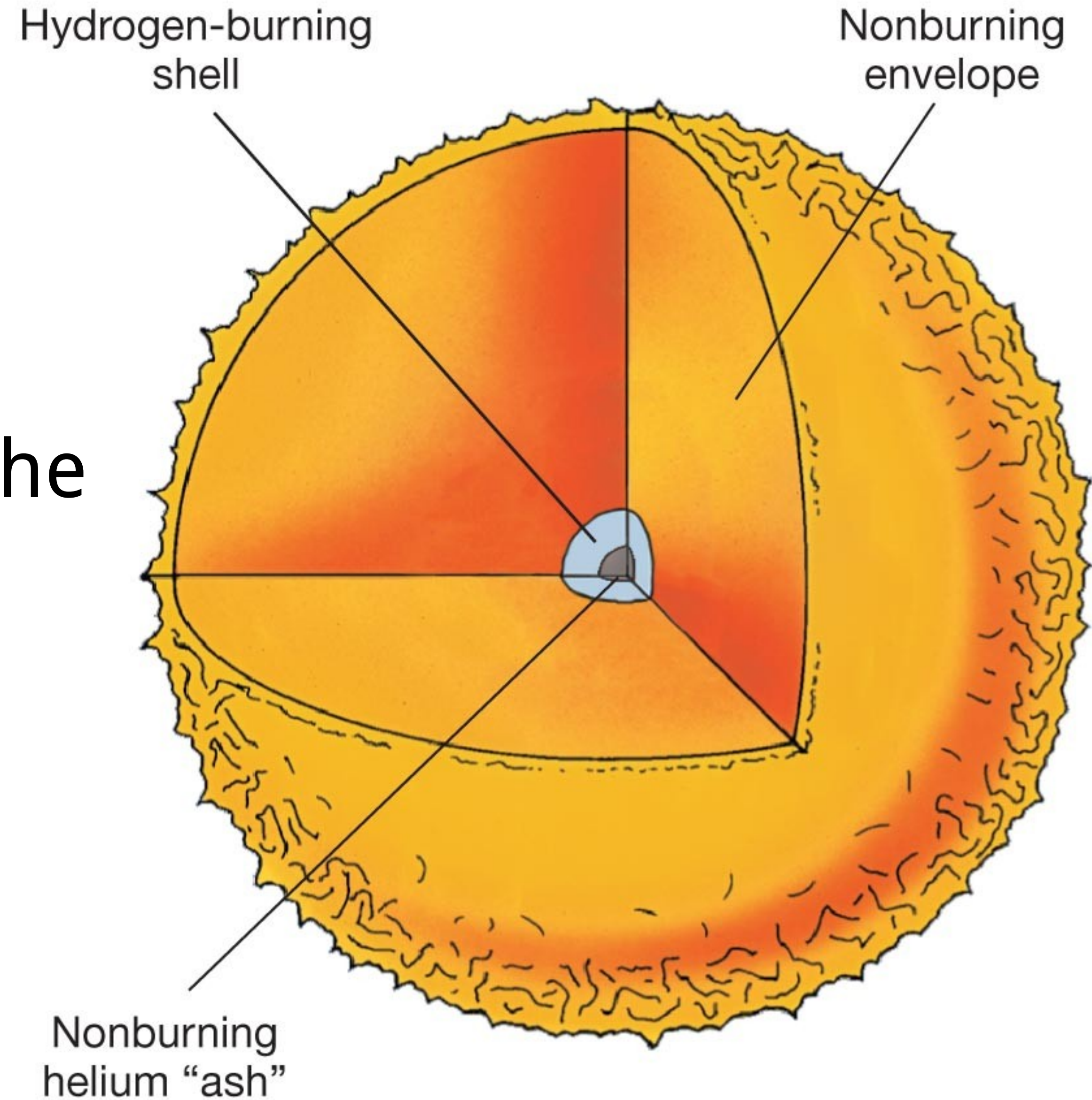
As it contracts, the core heats up.

II. Red Giant

Eventually the star gets hot enough to burn hydrogen in the outer layer around the He core.

This is called *hydrogen shell burning.*

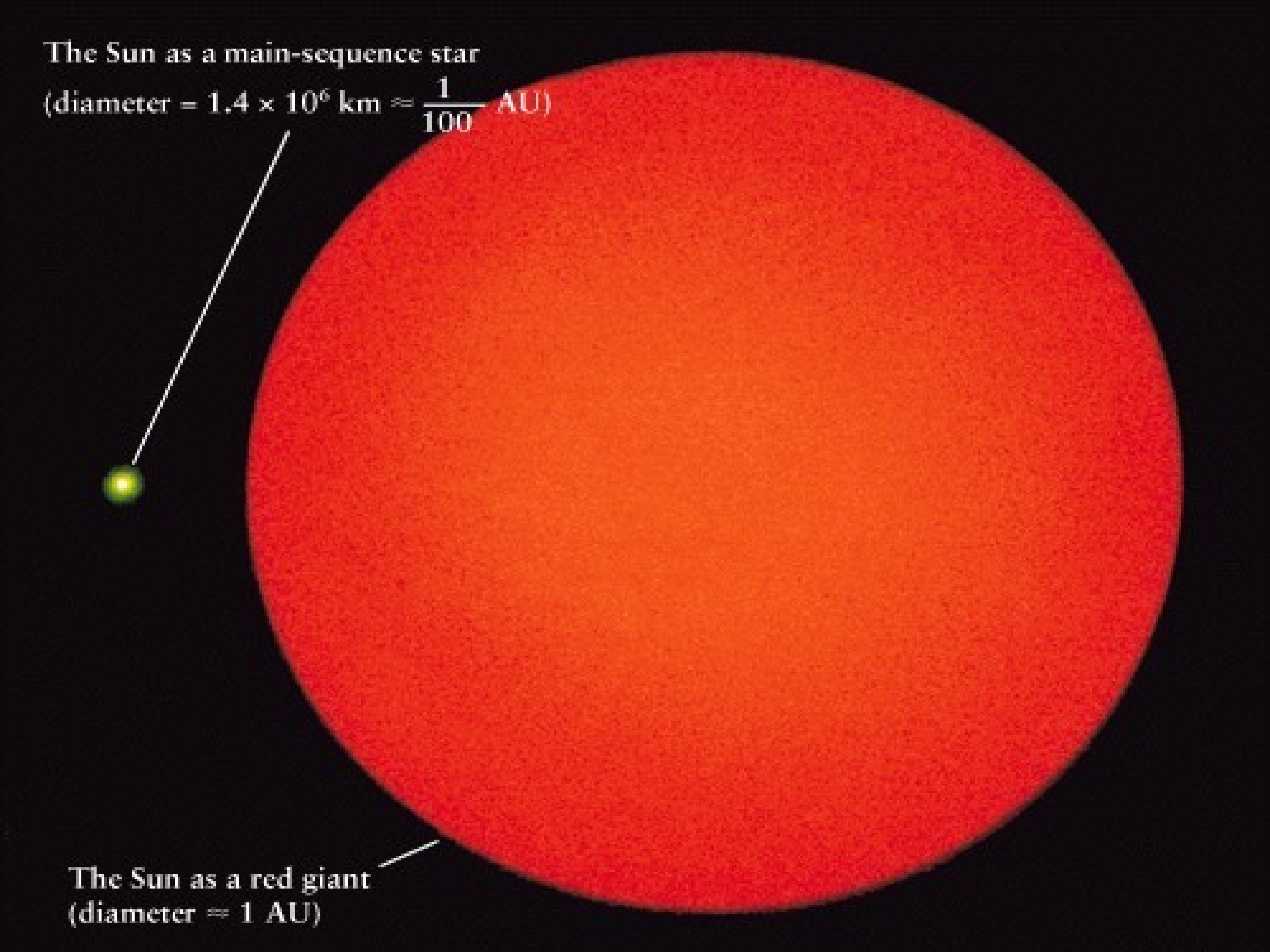
This is the **Red Giant stage.**



II. Red Giant Phase

Because the core is denser and hotter than before, the fusion is much faster in the shell than it had been in the main-sequence star: H fuses furiously to He in the shell and the energy output is much greater than when the star was on the main sequence.

The huge amount of energy pouring out from the central region of the star inflates the outer star like a balloon: When the Sun becomes a red giant its outer envelope will extend past Venus and may engulf the Earth as well.


The Sun as a main-sequence star
(diameter = 1.4 × 10^6 km ≈ 1/100 AU)
The Sun as a red giant
(diameter ≈ 1 AU)

Why is a red giant red?

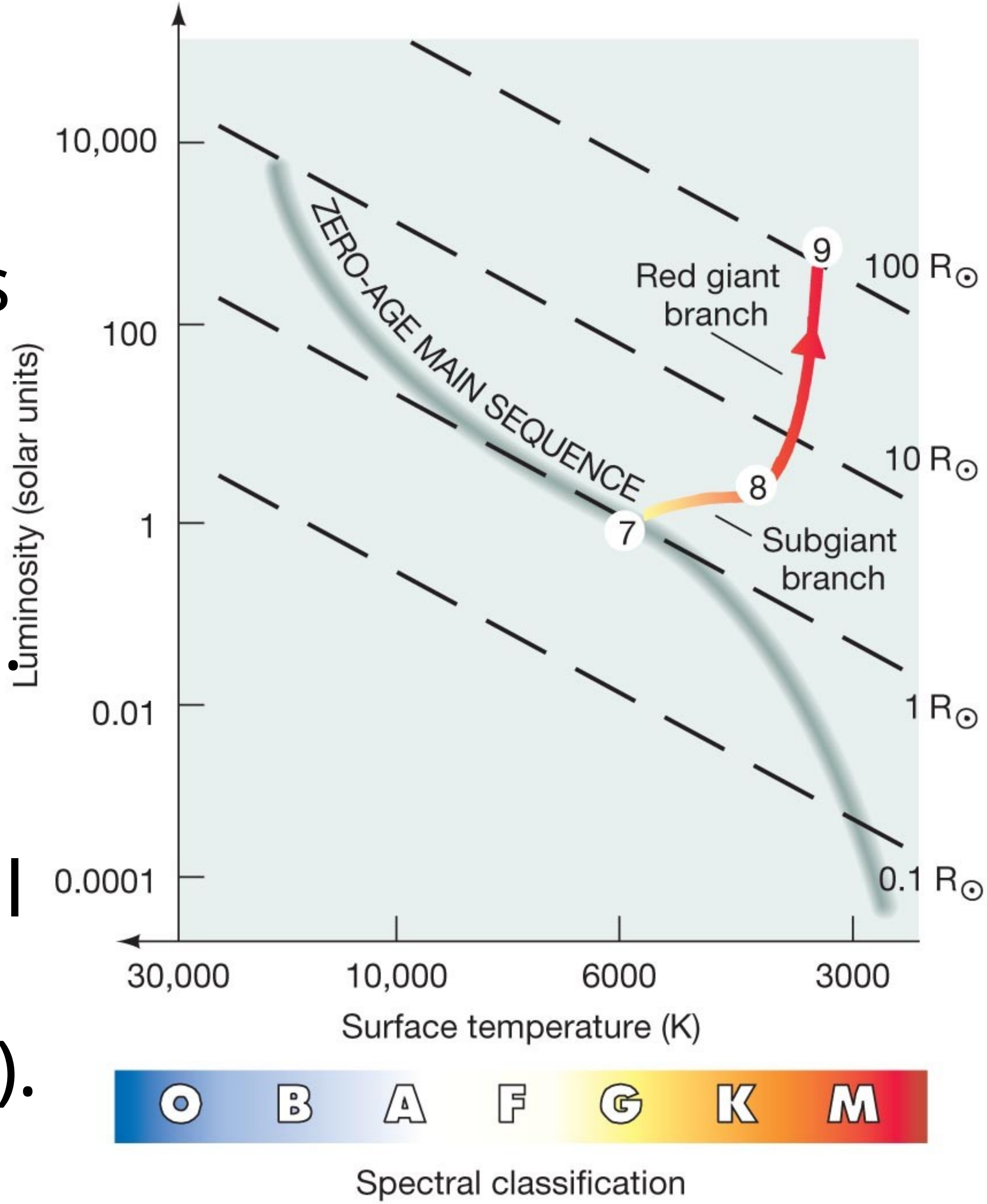
Because of the vast expansion, the photosphere of a red giant is cooler - and therefore redder - than that of the main sequence star from which it evolved.

As the shell around the core burns, more helium is added to the core, which contracts faster and makes the shell still hotter, so the star keeps getting larger and brighter.

II. Red Giant

At first the star cools with the luminosity staying roughly constant—core contraction (stage 8).

Later, hydrogen shell burning makes the star expand (stage 9).



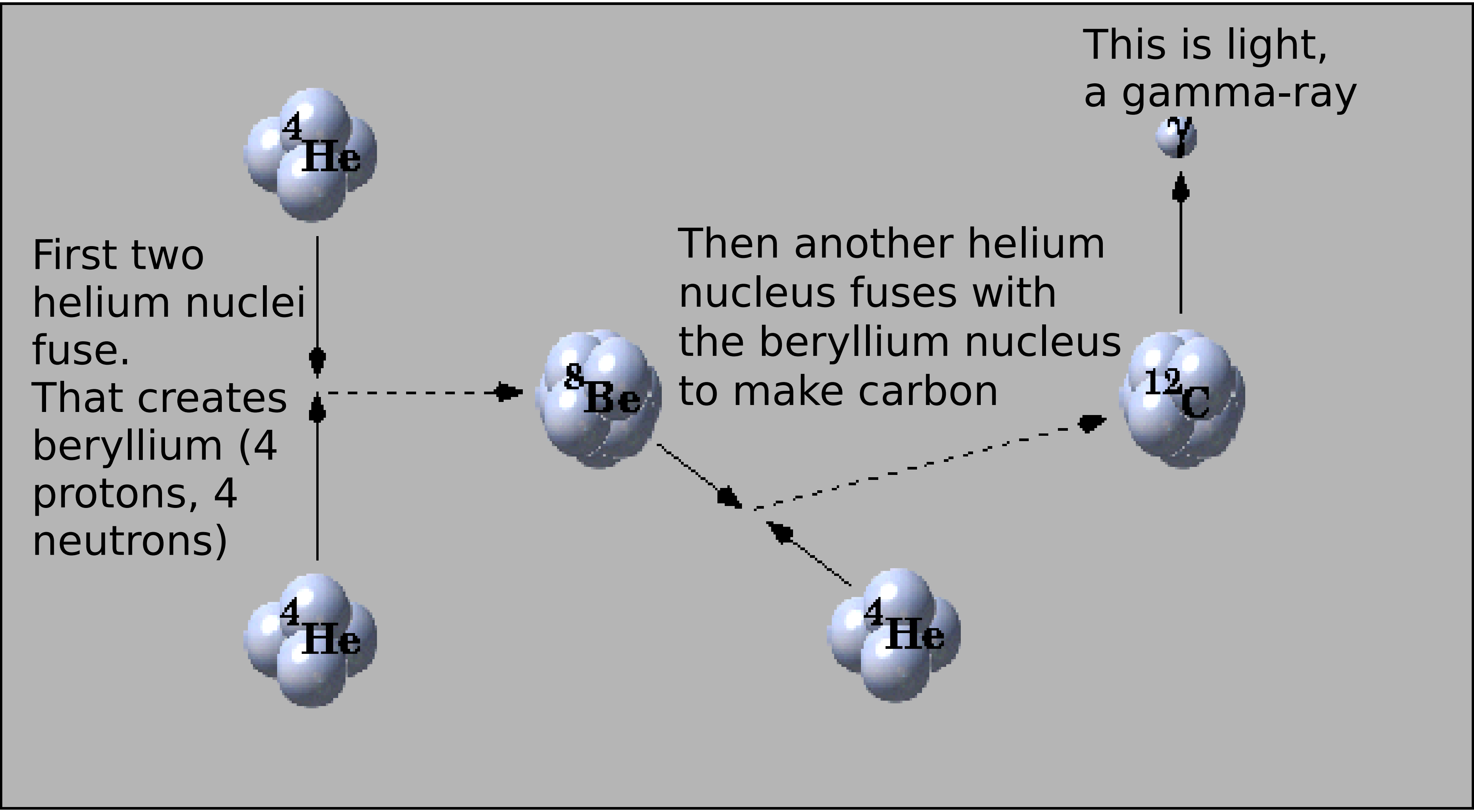
Summary, stages 8 and 9:

8) The inner core has fused to helium and begins to contract and heat up.

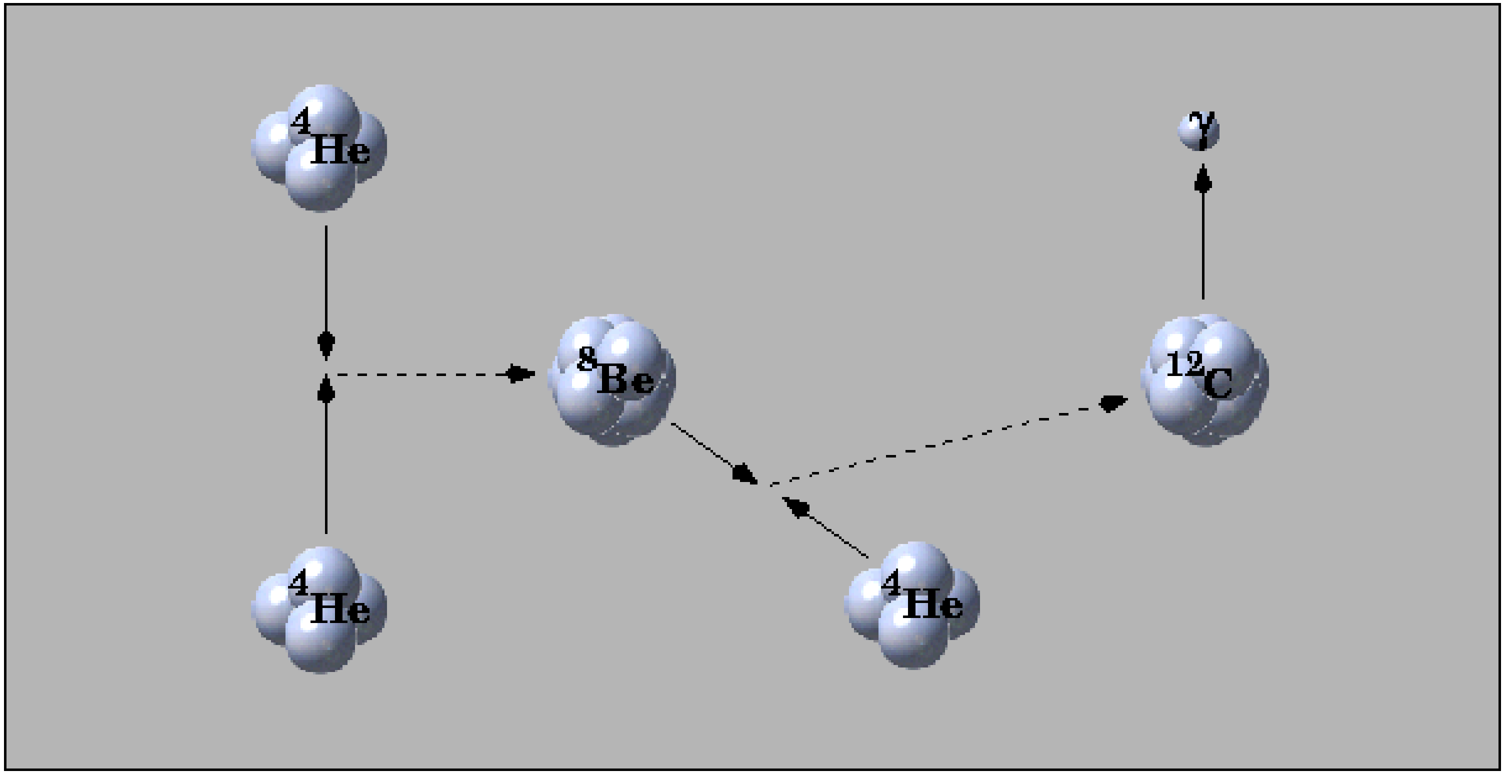
9. The core is now hot enough to drive a furious rate of fusion of H to He in a shell around the core. The outer part of the star vastly expands from the combined energy of contraction and furious shell burning. The core continues to contract and heat up.

The red giant stage ends when the core is finally hot enough at 100 million K to fuse helium to carbon

Helium burning → Carbon



Helium burning → Carbon



The nucleus made from two helium nuclei is beryllium, an element with an unfamiliar name. It's unfamiliar because it is not as tightly bound as helium or carbon. To make carbon you have to stick another helium nucleus to beryllium. This takes a temperature of about 100 million degrees.

IV. Helium flash (stage 10)

For stars with M > 0.4 Msun, the temperature will reach 100 million K, hot enough to ignite the fusion of He in the core to produce C.

Three helium nuclei combine to form a carbon nucleus:

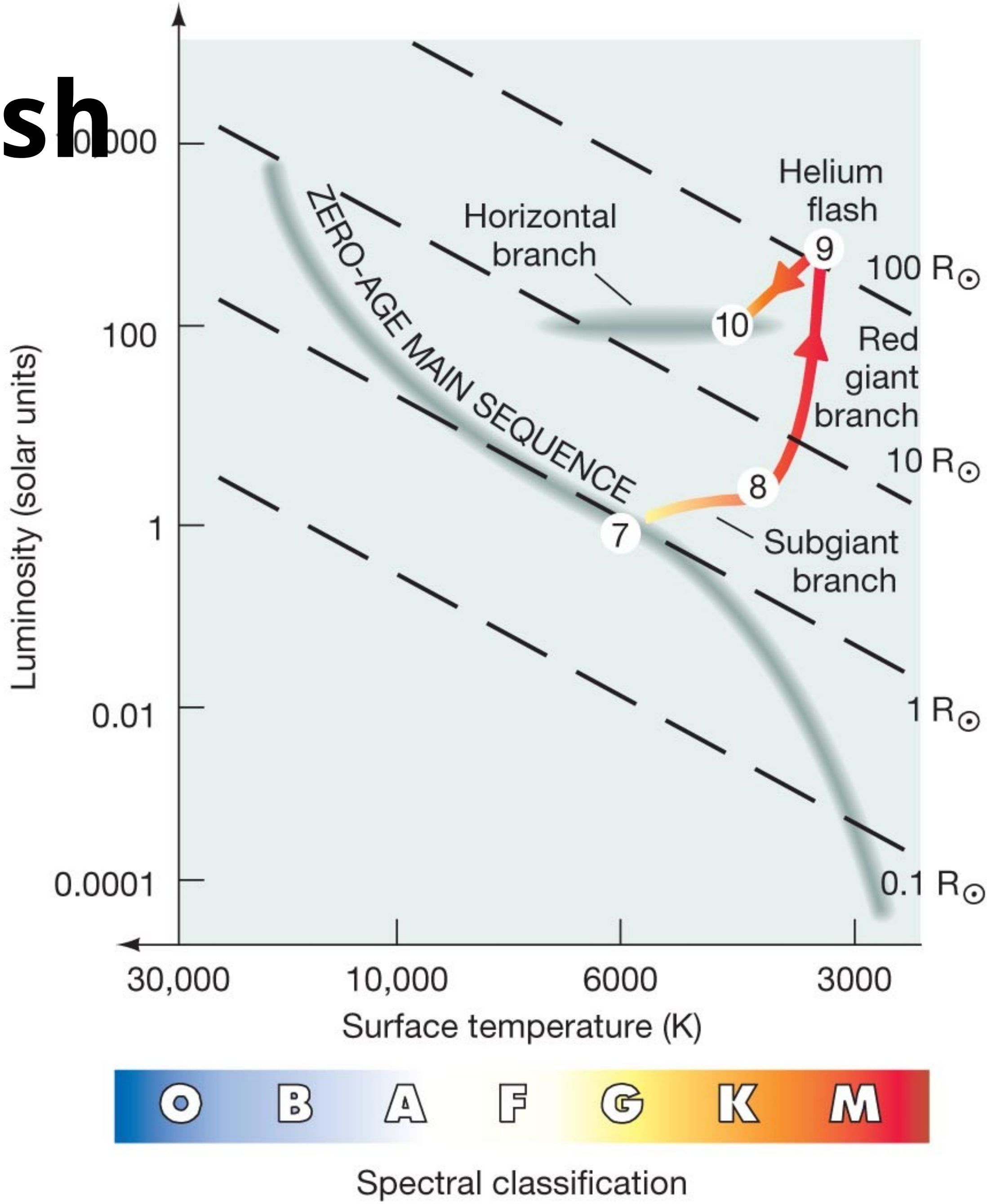
$$^{4}\mathrm{He} + {}^{4}\mathrm{He} + {}^{4}\mathrm{He} \rightarrow {}^{12}\mathrm{C}$$

Fusion of helium to carbon begins explosively throughout the core, and the burst of energy released is called the **helium flash**. The core re-expands, the H burning in the shell slows because the shell is now cooler, and the outer layers of the star contract.

IV. Helium Flash

Helium flash produces an expansion and cooling of the core.

The star settles, fusing helium to carbon in the core (stage 10). This part of the H-R diagram is called the horizontal branch.



V. A second Red Giant Stage (stage 11) or the Asymptotic Giant Branch (AGB)

After the helium flash, a star burns helium to carbon in its core. The fusion continues until all the helium in the core has changed into carbon. Again the fuel in the core is exhausted. And again gravity takes over.

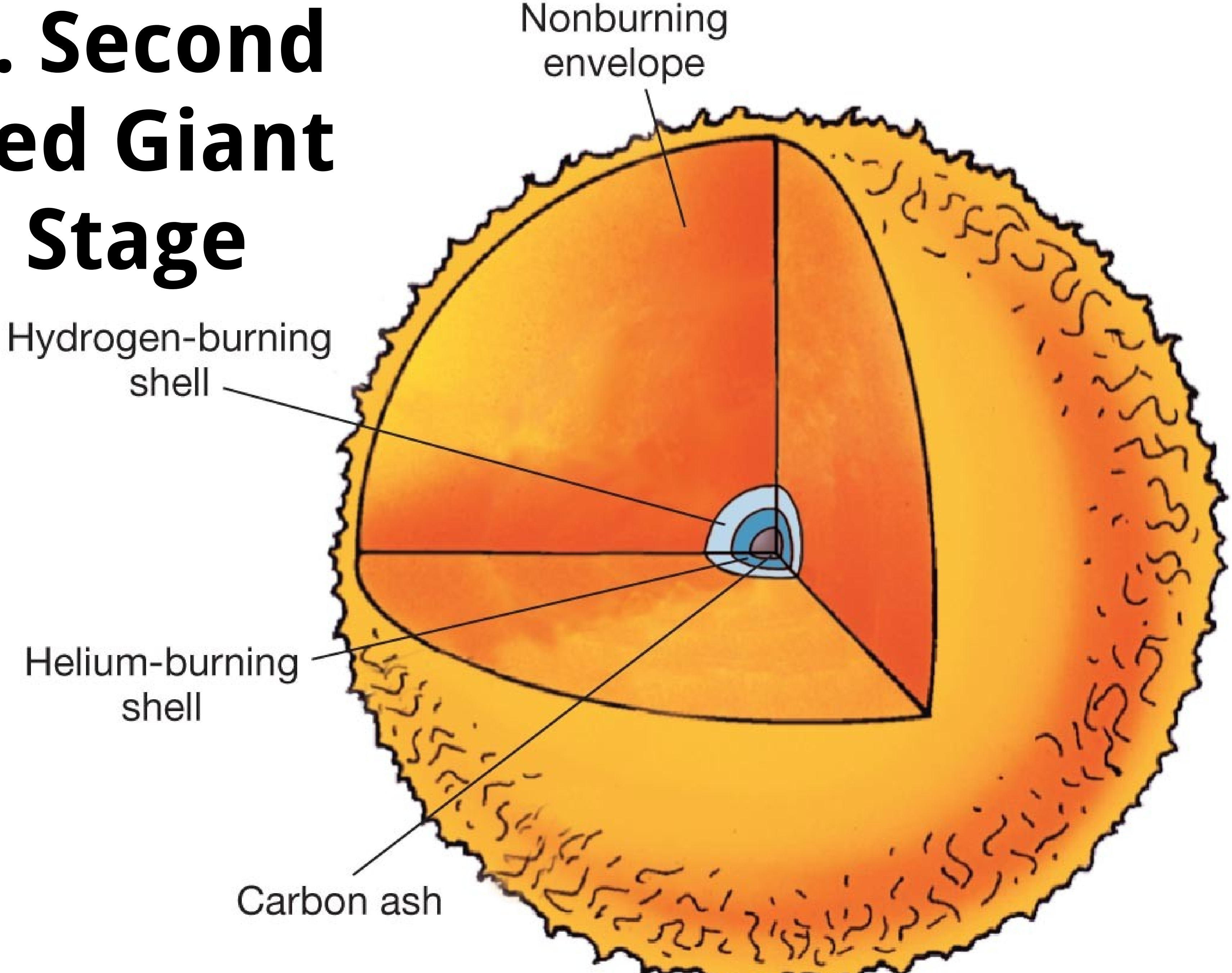
It was this fusion that had halted the contraction of the core, and when the fusion stops, the core once again begins to contract.

V. Second/Asymptotic Giant Branch

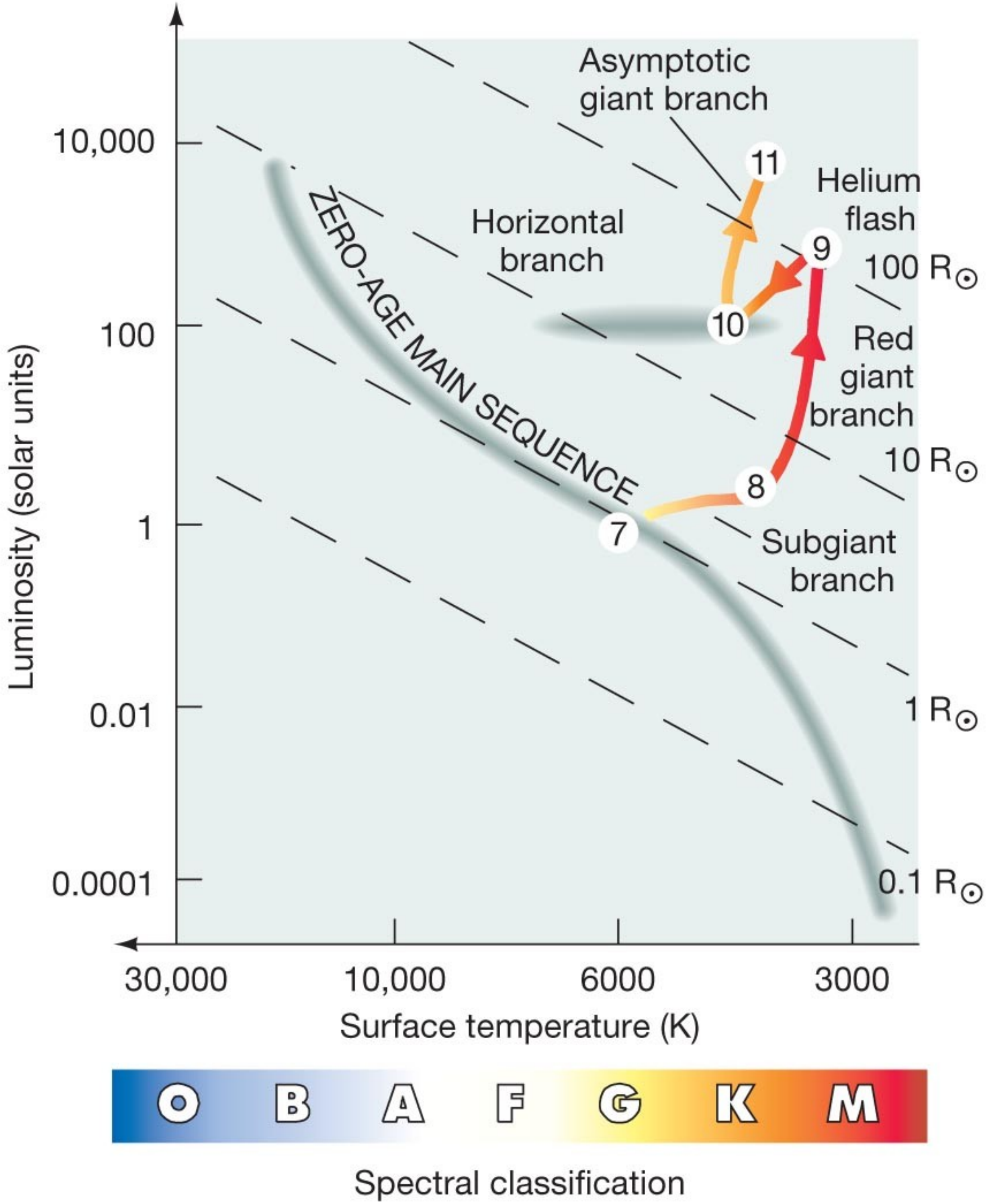
The contracting core heats up and ignites He in the shell around the core.

The intensely hot inner core drives a ferociously rapid burning of helium to carbon in a shell around the core, and a second hydrogen burning shell around the helium shell.

V. Second Red Giant Stage



Similar story as before: Lack of nuclear fusion at the center causes carbon core to contract, releasing energy, the overlaying layers fuse more rapidly, and the star expands again (11).



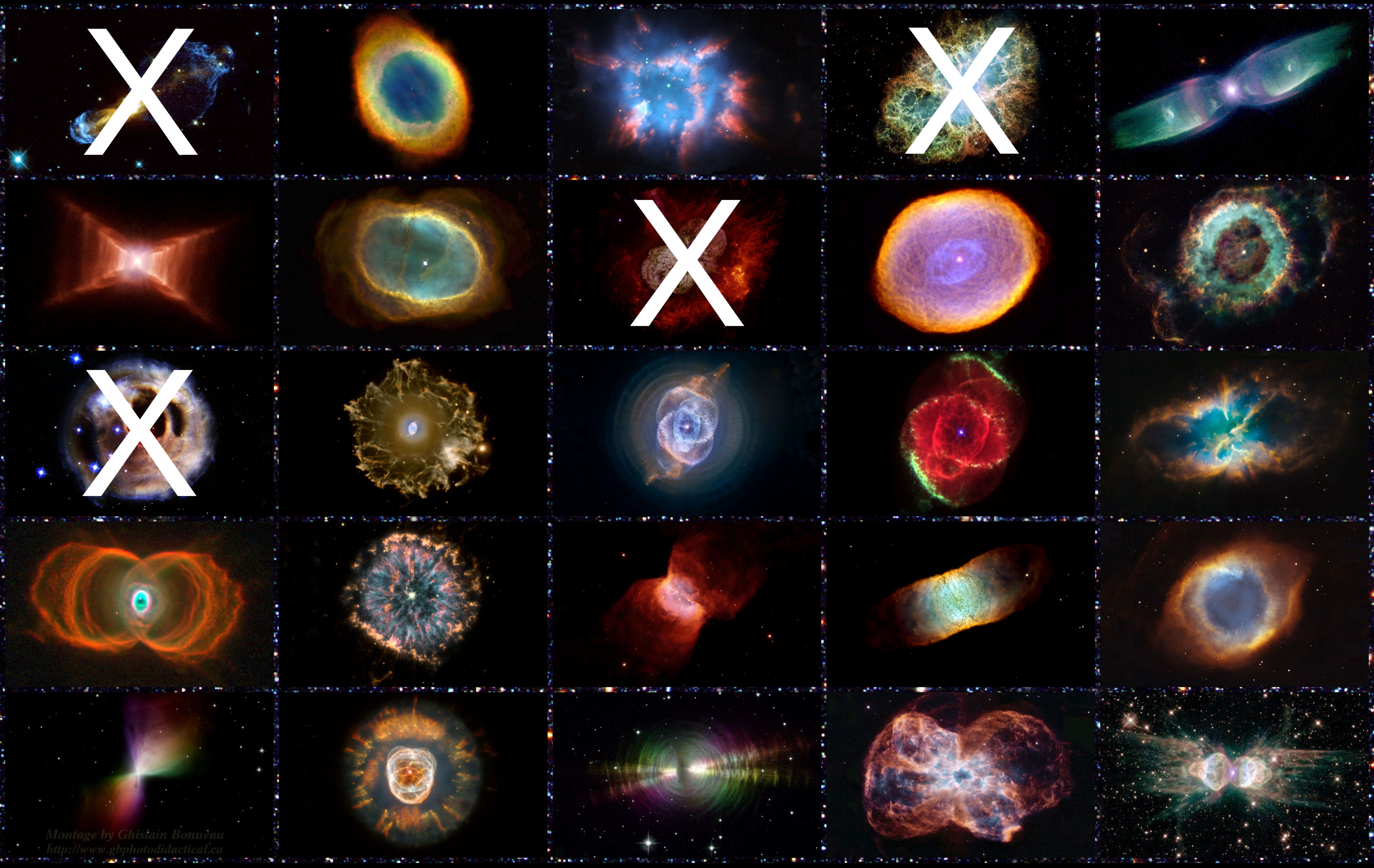
What happens next?

Now we have 3 sources of energy

- Contraction of the core
- Ferocious fusion of helium to carbon in a shell around the core
- Rapid fusion of hydrogen to helium in a second shell

With more energy from these reactions than in its first red giant stage, the star becomes even larger than it did the first time.

Eventually, driven by the increasing temperature of the core and the weak gravitational attraction at the very extended surface, its outer layers are blown entirely off the star, creating a **planetary nebula**.



http://gbphotodidactical.ca/page-free-wallpapers-planetary-nebula-page-3.html