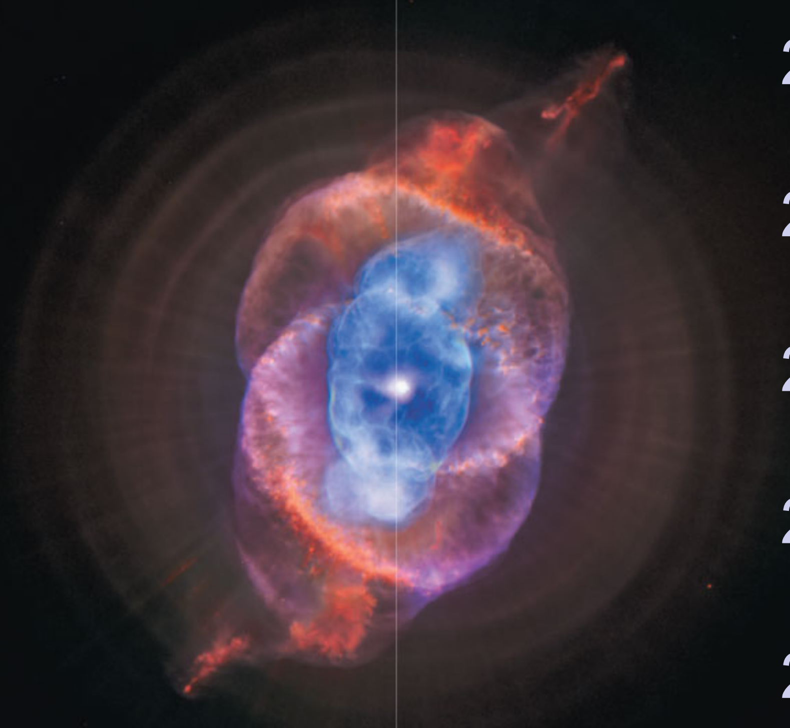
Ch 20 - Stellar Evolution



Death of the Sun Part I

Courtesy of:

The Wright Center,
Science Visualization Lab -
Tufts University/ D.Berry and J. Palmer

Death of the Sun Part II

Courtesy of:
The Wright Center,
Science Visualization Lab -
Tufts University/ D.Berry and J. Palmer

20.1 Main Sequence Evolution

- First … *what is the main sequence?* …
- We cannot observe a single star going through its whole life cycle; even short-lived stars live too long for that.
- Observation of stars in star clusters gives us a look at stars in all stages of evolution; this allows us to construct a complete picture. *[What is it about star clusters that allows this?]*
- During its stay on the Main Sequence, any fluctuations in a star's condition are quickly restored; the star is in hydrostatic equilibrium.

20.1 Leaving the Main Sequence

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

- time on main sequence much shorter for high mass
- A star spends 95-99% of its life on main sequence
- main sequence brightening

20.1 Leaving the Main Sequence

- Evolution from then on depends on mass of star:

  – Lower mass stars ($M < 8\ M_{\odot}$) go quietly, eventually becoming a White Dwarf

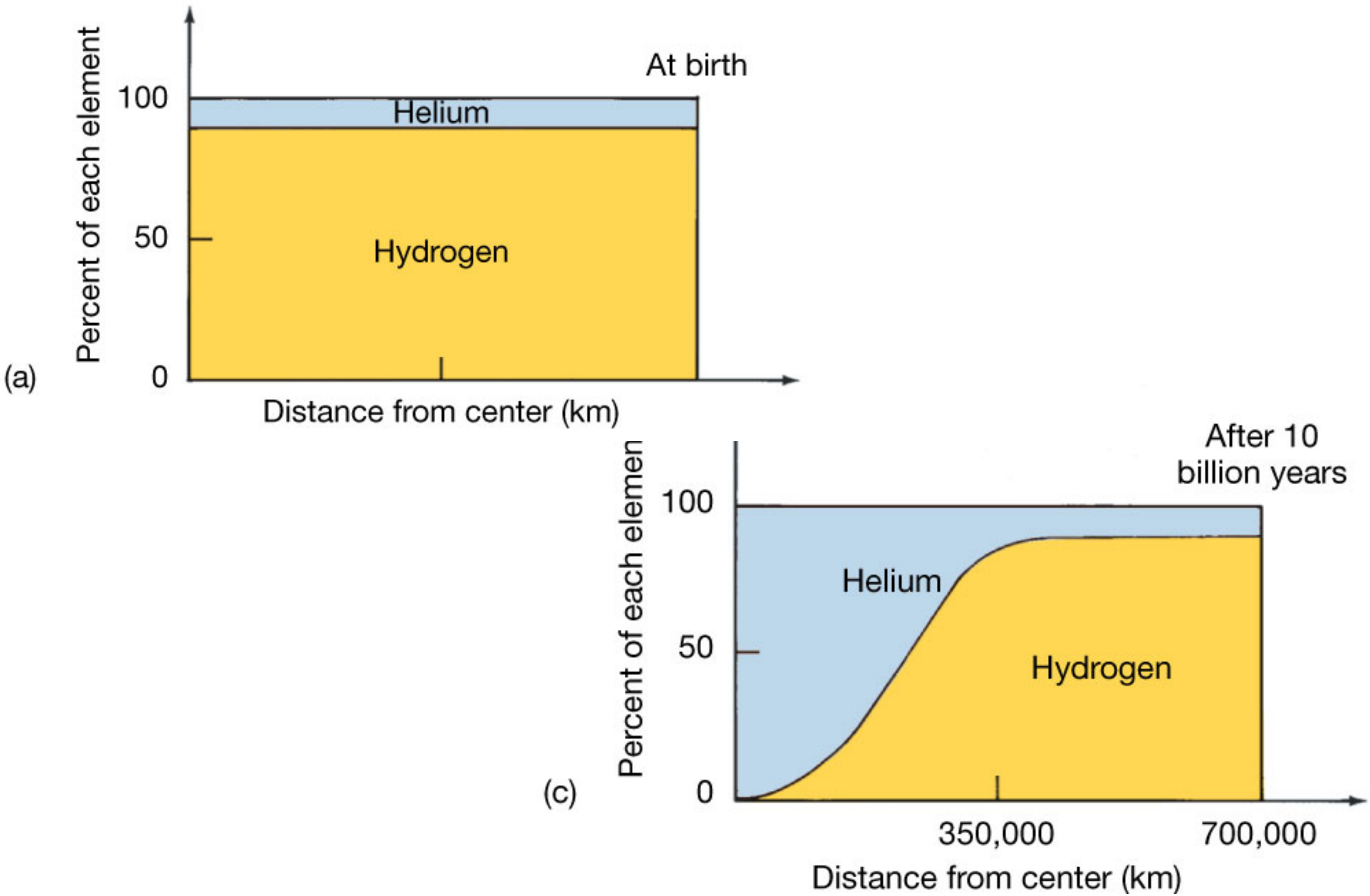
  – Higher mass stars ($M > 8\ M_{\odot}$) go out with a bang – supernova!

But why $8M_\odot$?

We learned that the max mass of a white dwarf was $1.4M_\odot$!

Answer: Mass loss, both as a red giant, and also in final phases of evolution to white dwarf.

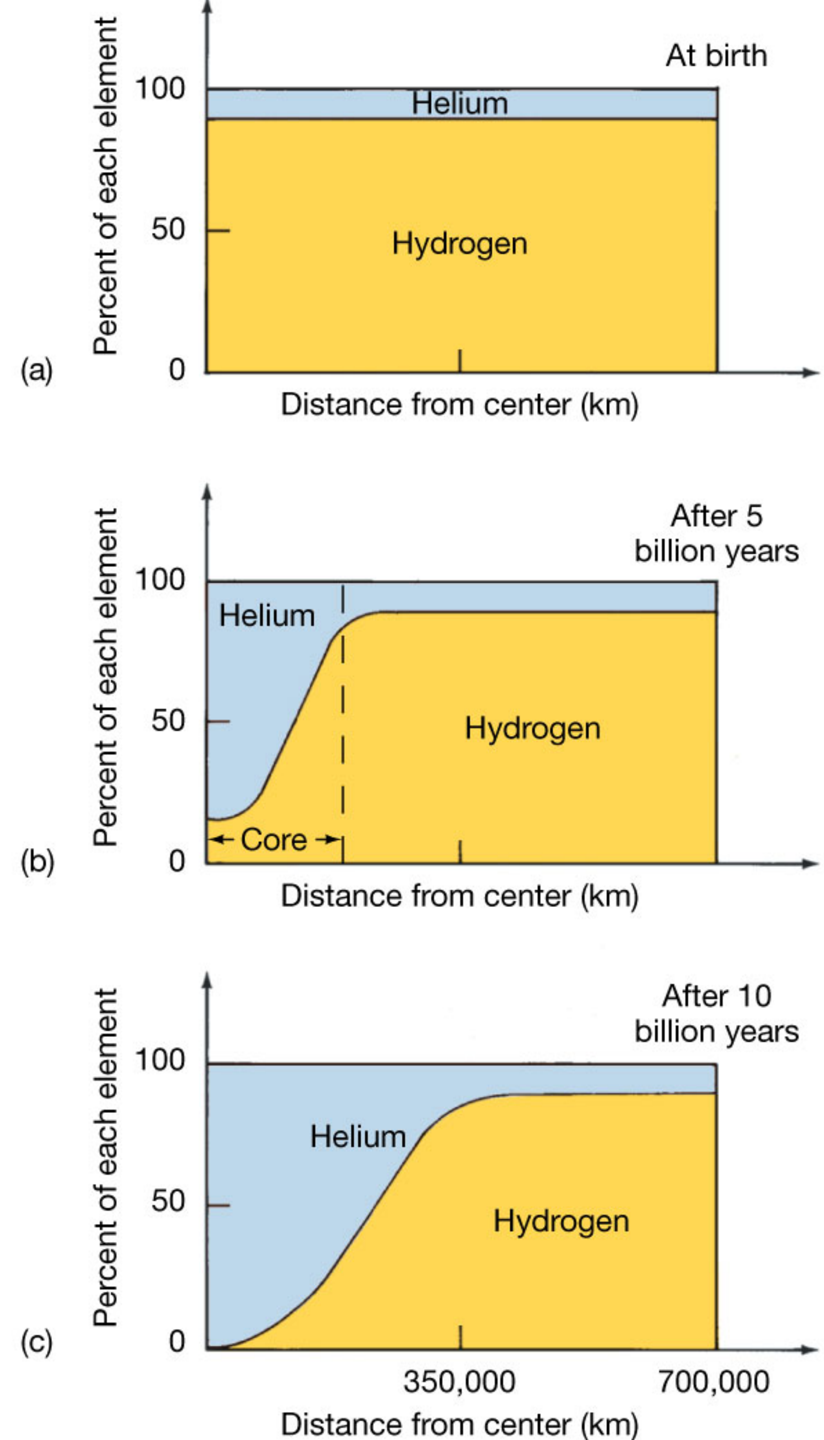
20.2 Evolution of a Sun-like Star



20.2 Evolution of a Sun-like Star

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

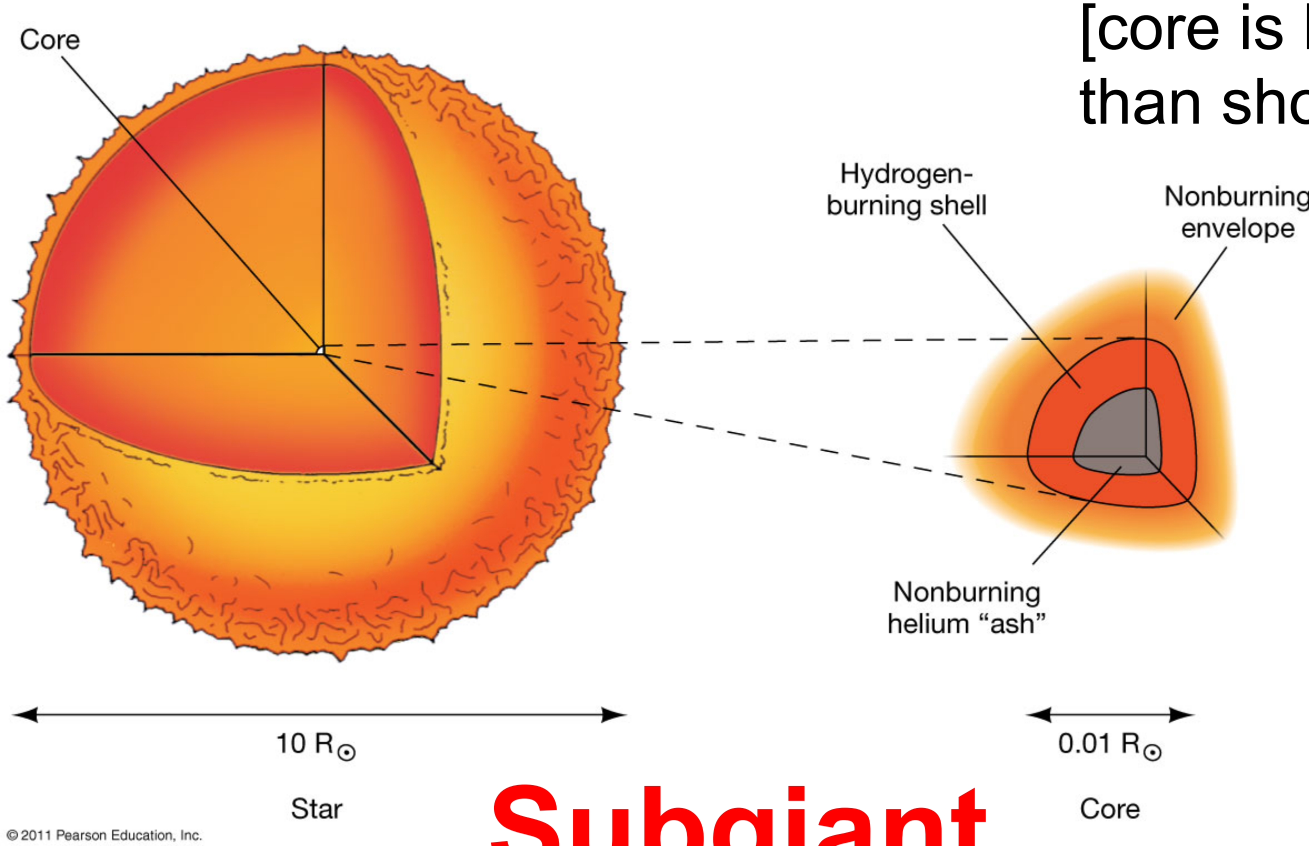
[So why isn't there much more He in the Universe now? And why do we need He from the big bang?]



20.2 Evolution of a Sun-Like Star

As the fuel in the core is used up, the core contracts; when it is used up the ***core begins to collapse and heat up***. ***Hydrogen begins to fuse outside the core:***

[core is bigger than shown!]



Subgiant

Red Giant Evolution

Courtesy of:

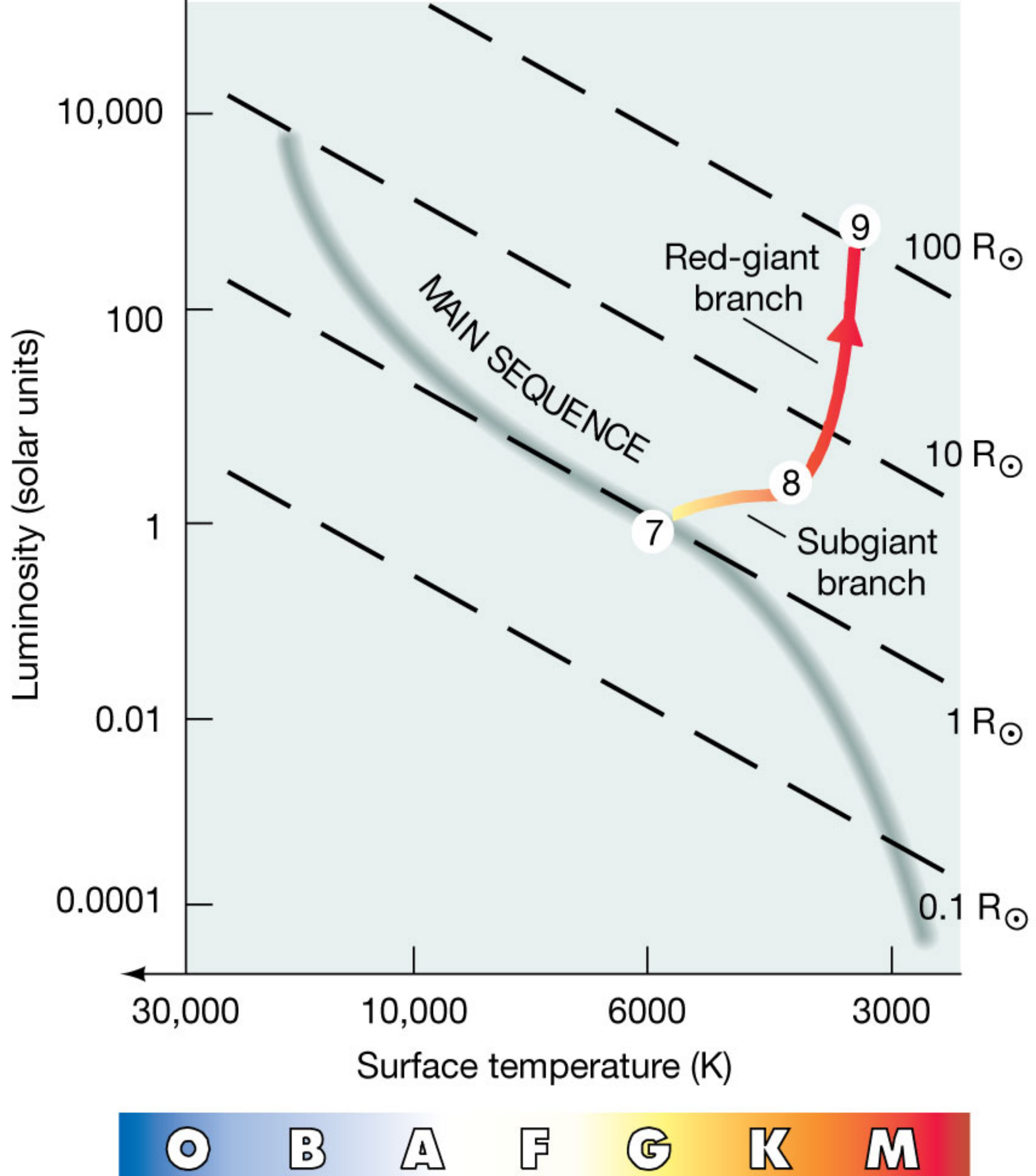
NASA/STScI/G. Bacon

A red giant is much cooler than the sun. So why would the earth be much hotter?

- Answer: a red giant is much more luminous! Hundreds to thousands of times more luminous.

20.2 Evolution of a Sun-like Star

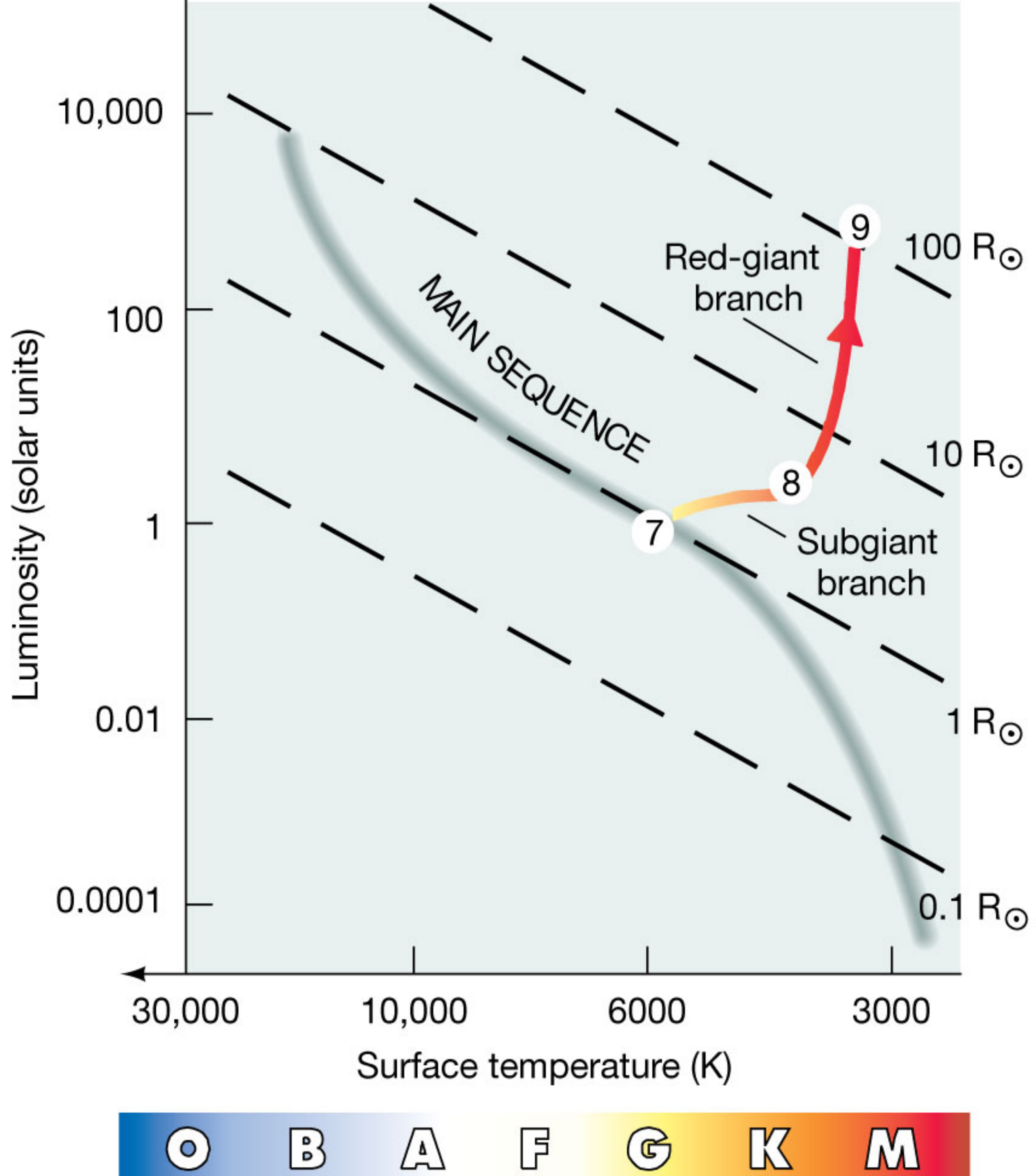
Red Giant Branch



20.2 Evolution of a Sun-like Star

Important:

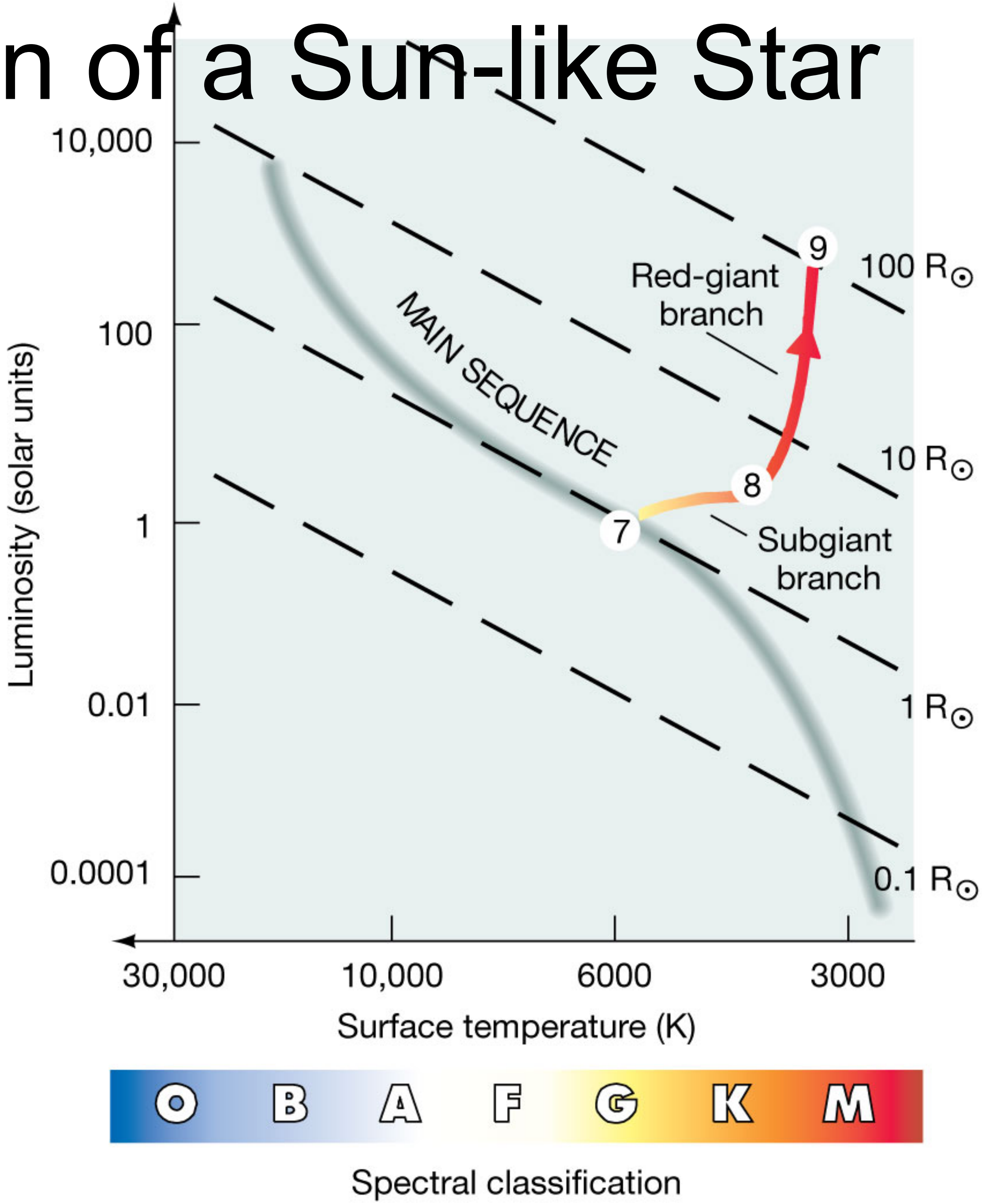
Stars <u>don't</u> evolve along the main sequence. The main sequence is the locus of the starting points of stars of different mass.



20.2 Evolution of a Sun-like Star

Red-Giant Branch

- *Core shrinks and heats*
- ***outer layers expand + cool.***
- **red giant**, size ~ orbit of Mercury.
- cooler temperature, but luminosity increases enormously due to size.
- Still H-shell burning.



20.2 Evolution of a Sun-Like Star

Helium fusion at the tip of red giant branch.

Once core temperature has risen above 10^8 K, the helium in the core starts to fuse, through a three-alpha or triple-alpha process:

- $^4He + {}^4He + {}^4He \rightarrow {}^{12}C + energy$
- high temperatures and densities are necessary. [why?]
- Only for $M > 0.25\ M_\odot$ [why?]

20.2 Evolution of a Sun-Like Star

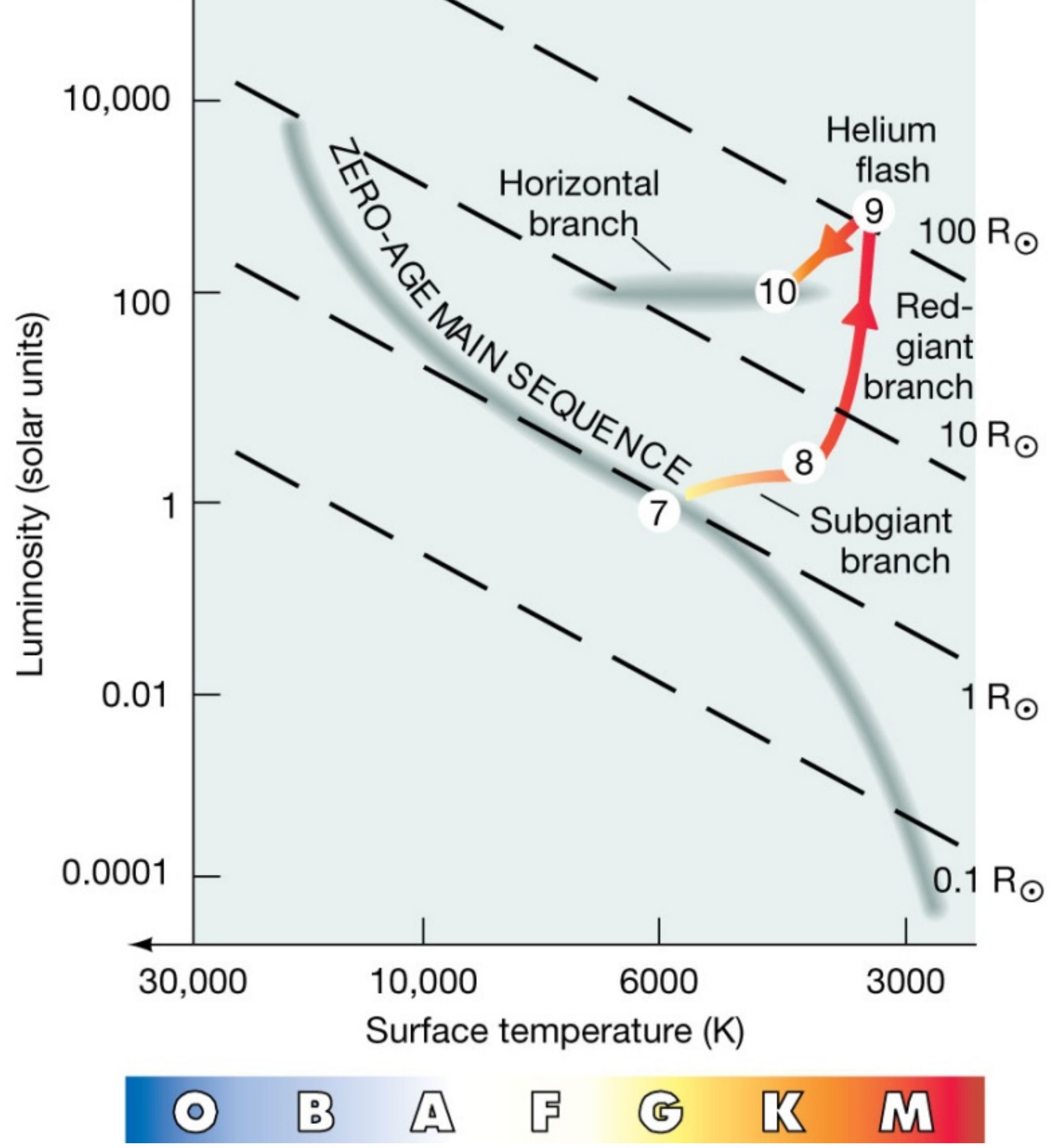
***The helium flash** - background:*

- On the main sequence the star is made of "normal" gases.
- On the RGB the pressure within the helium core is due to "electron degeneracy"—two electrons cannot be in the same quantum state, so the core cannot contract beyond a certain point.
- This pressure is almost independent of temperature—when the helium starts fusing, the pressure cannot adjust.

Red giant branch

20.2 Evolution of a Sun-Like Star

Helium flash

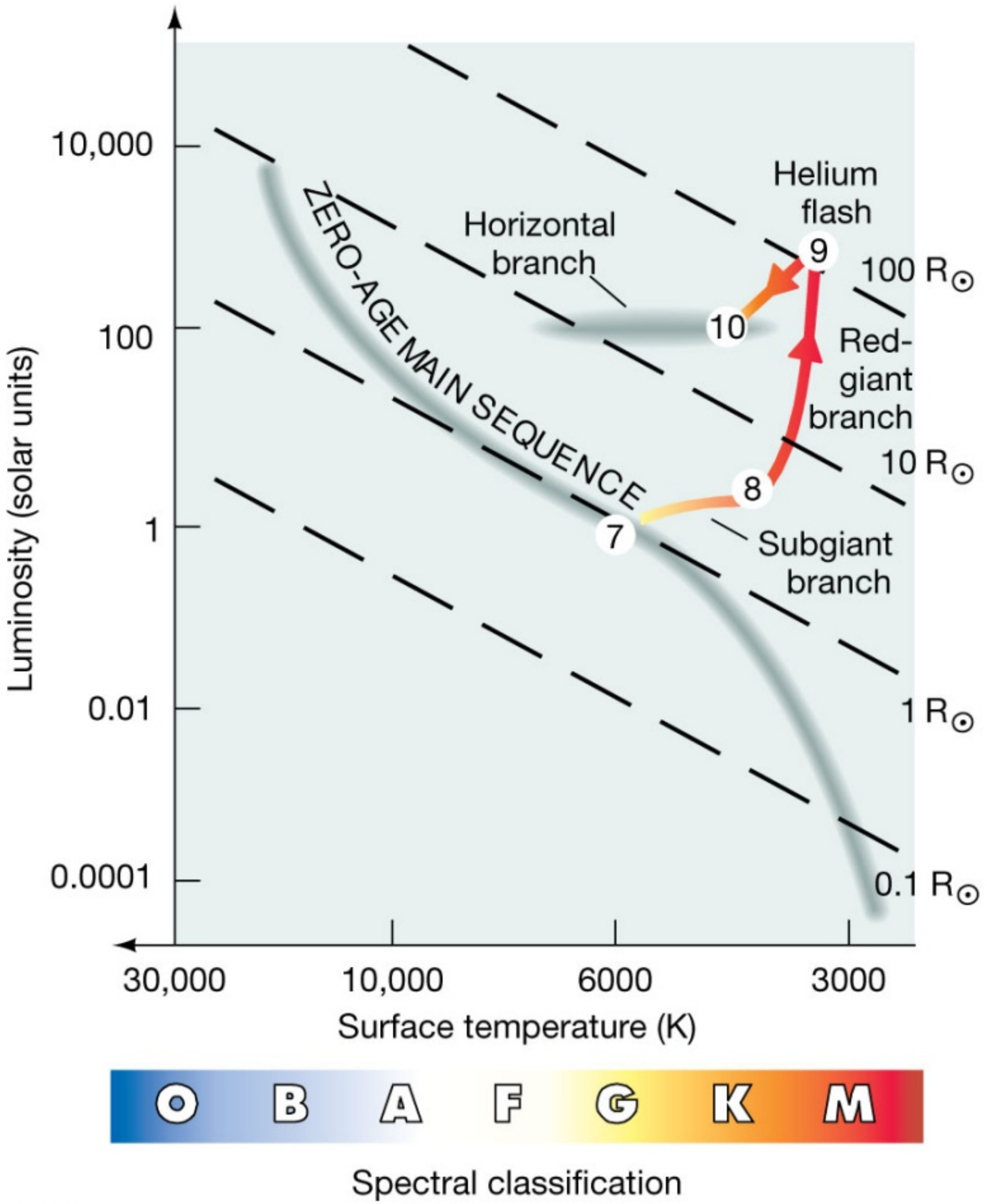


20.2 Evolution of a Sun-Like Star

The helium flash:

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

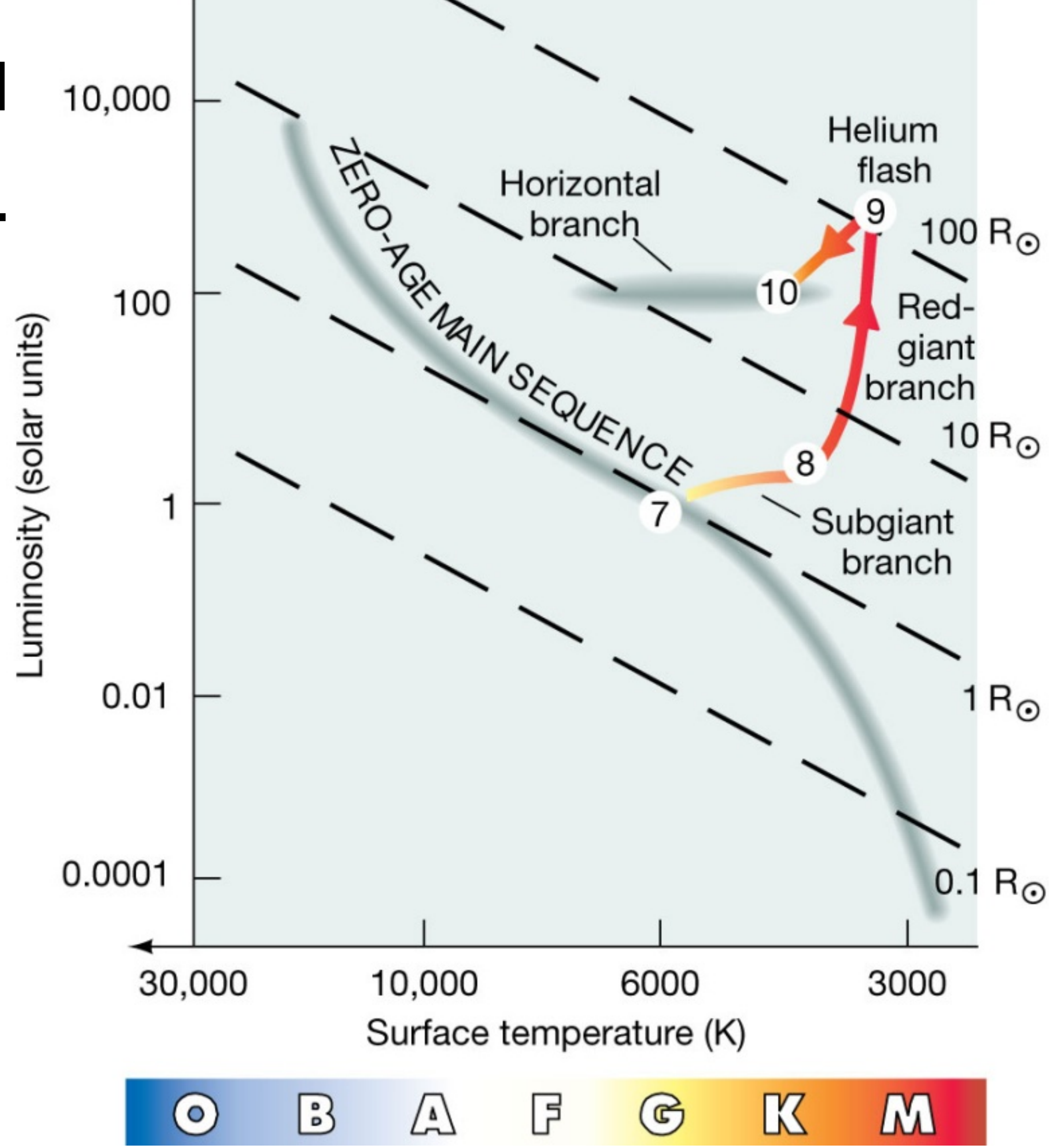
Important: ***not visible at surface!***



20.2 Evolu of a Sun-L Star

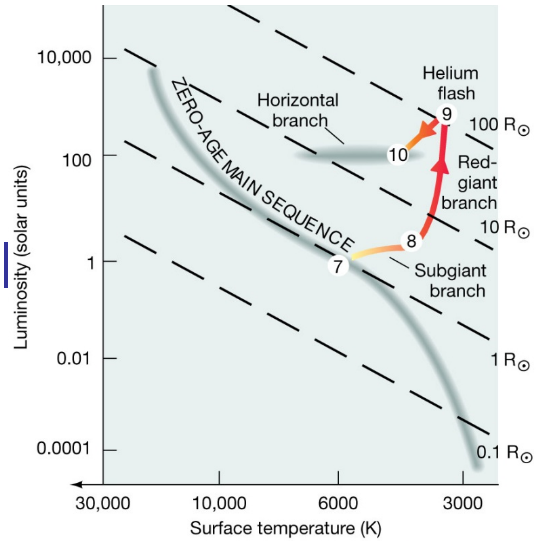
Horizontal branch:

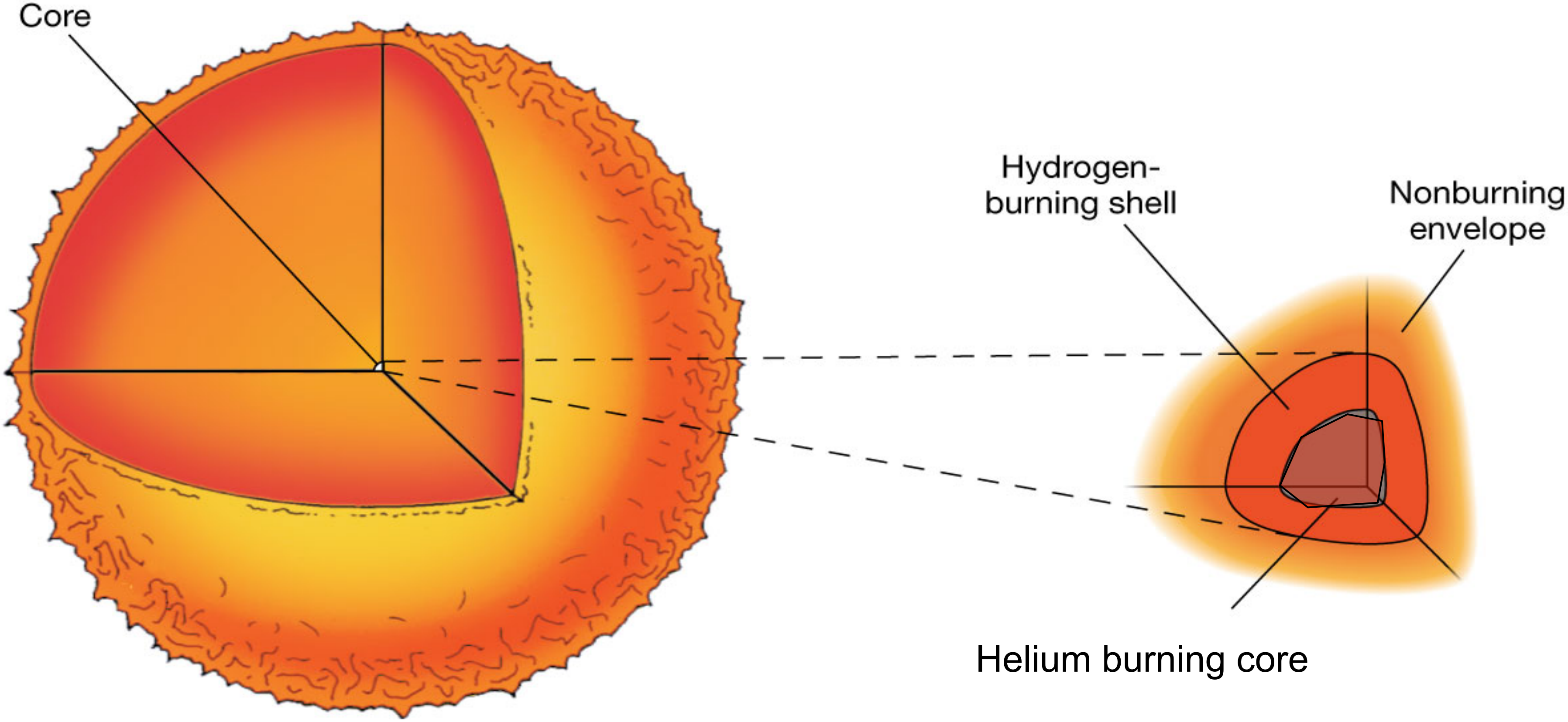
Helium burns stably in the core (with a shell of hydrogen burning outside).



20.2 *Horizontal branch:*

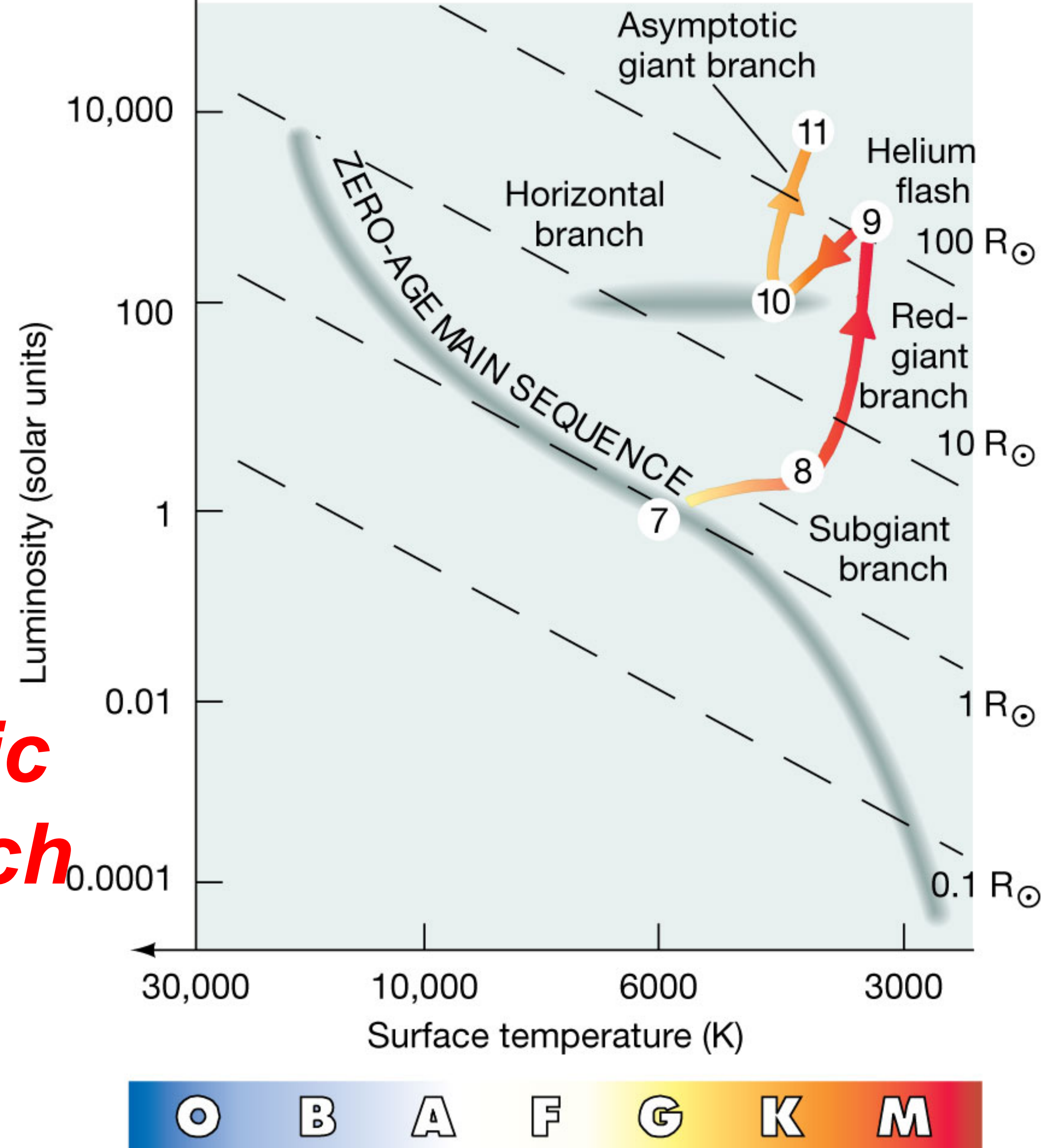
Helium burns stably in the core (with a shell of hydrogen burning outside).





20.2 Evolution of a Sun-Like Star

Asymptotic giant branch (AGB)

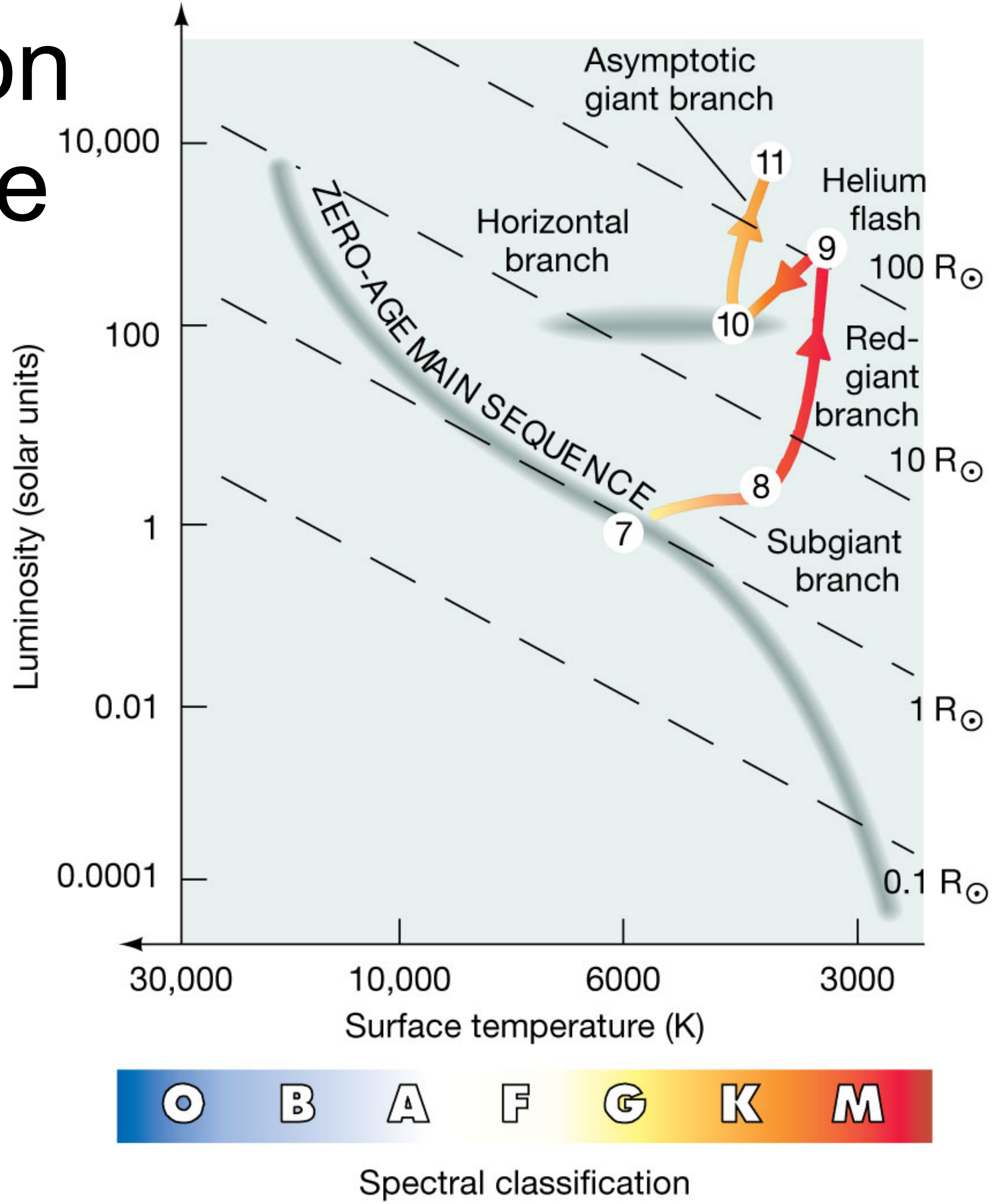


20.2 Evolution of a Sun-Like Star

Asymptotic giant branch:

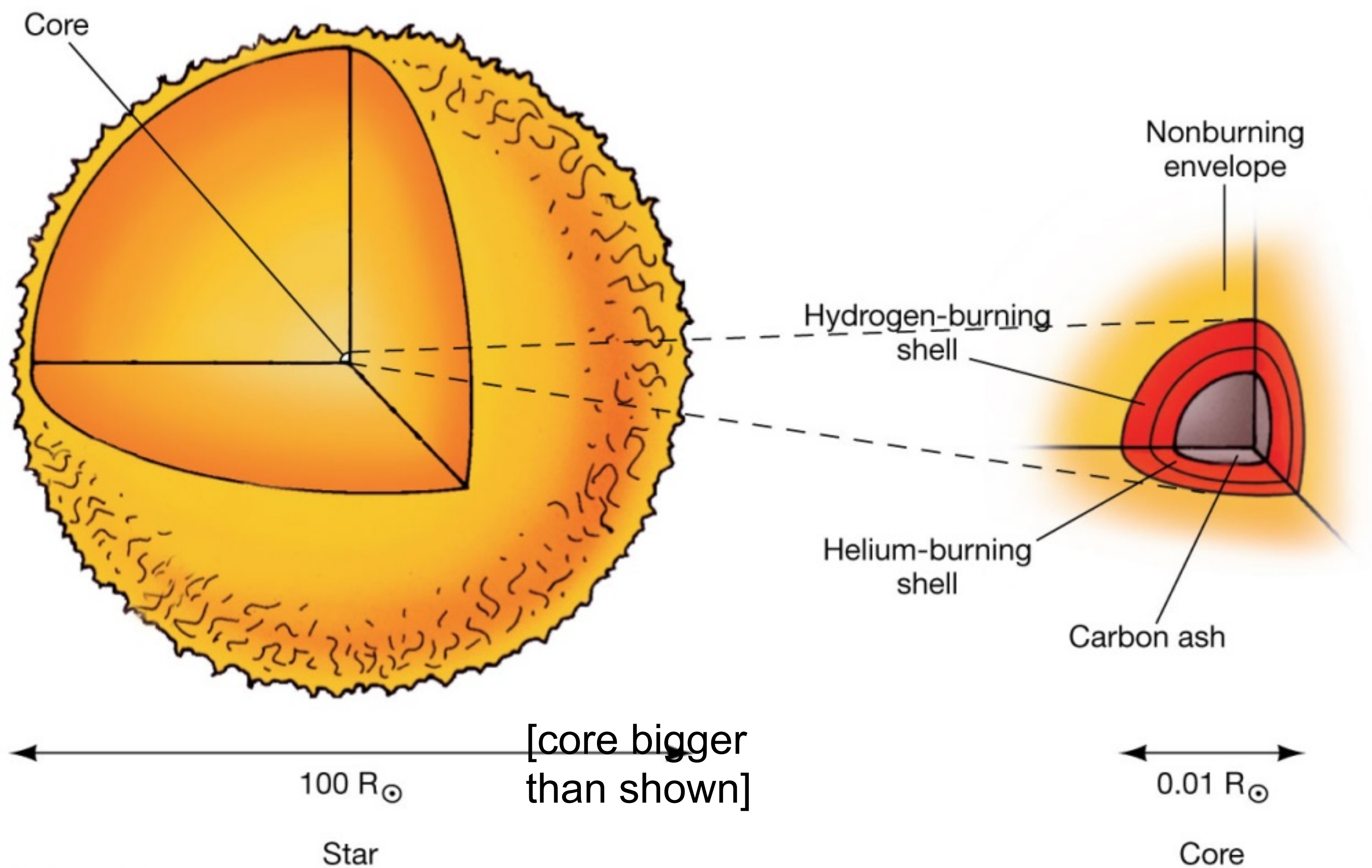
The star has become a red giant for the second time – called an asymptotic giant branch star [AGB star]

- re-ascending the giant branch



20.2 Evolution of a Sun-Like Star

Asymptotic giant branch:

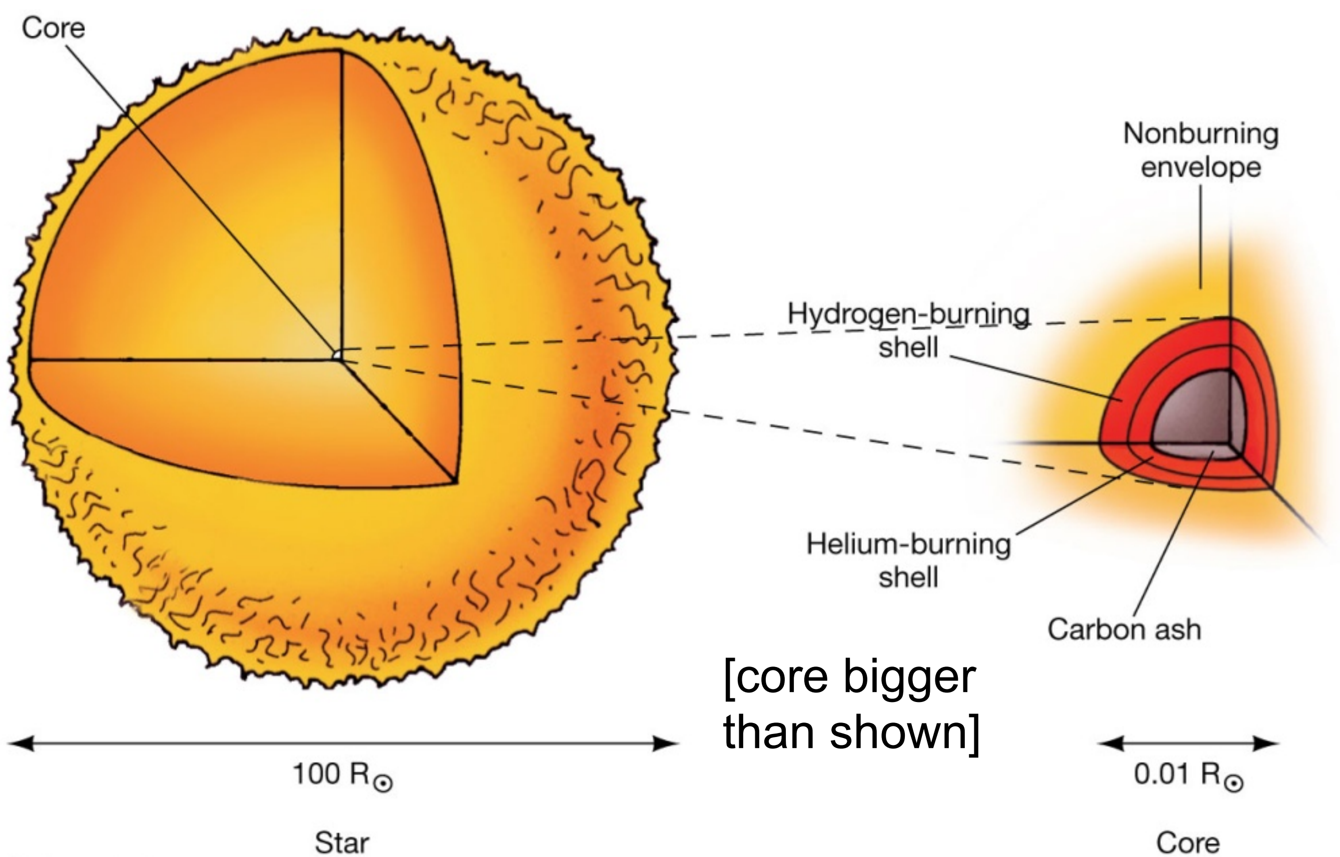


[core bigger than shown]

20.2 Evolution of a Sun-Like Star

Asymptotic giant branch:

Core runs out of Helium since it has all been converted to carbon. The carbon core collapses, becomes hotter and hotter.



[core bigger than shown]

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

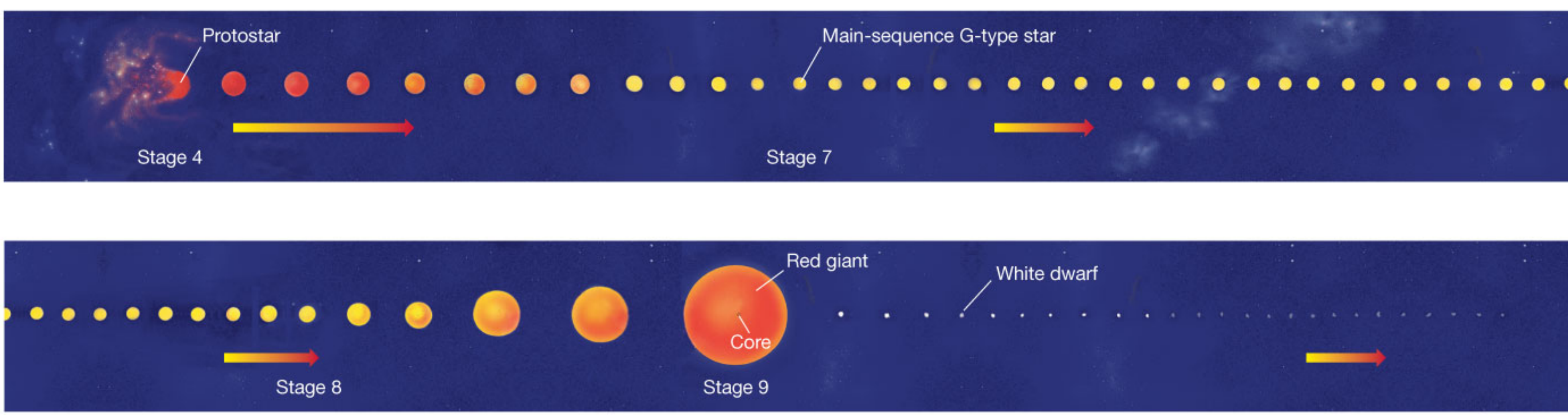
This picture shows the entire evolution of a Sun-like star. Is it accurate?

A. Yes

B. No, missing some evolutionary stages

C. No, size shouldn't change

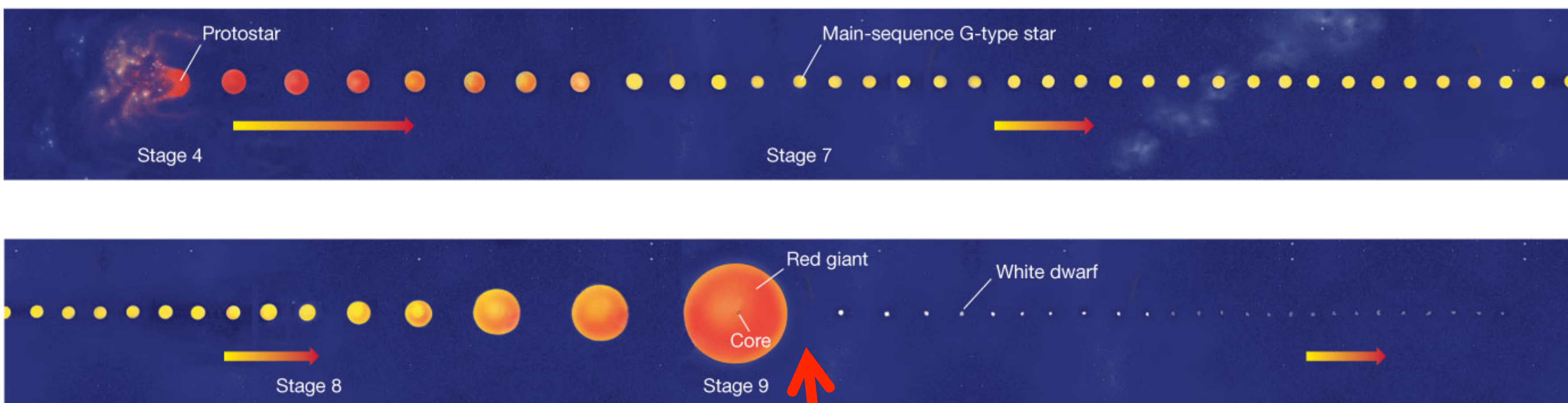
D. No, colour shouldn't change



20.3 Death of Low-Mass Stars

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

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



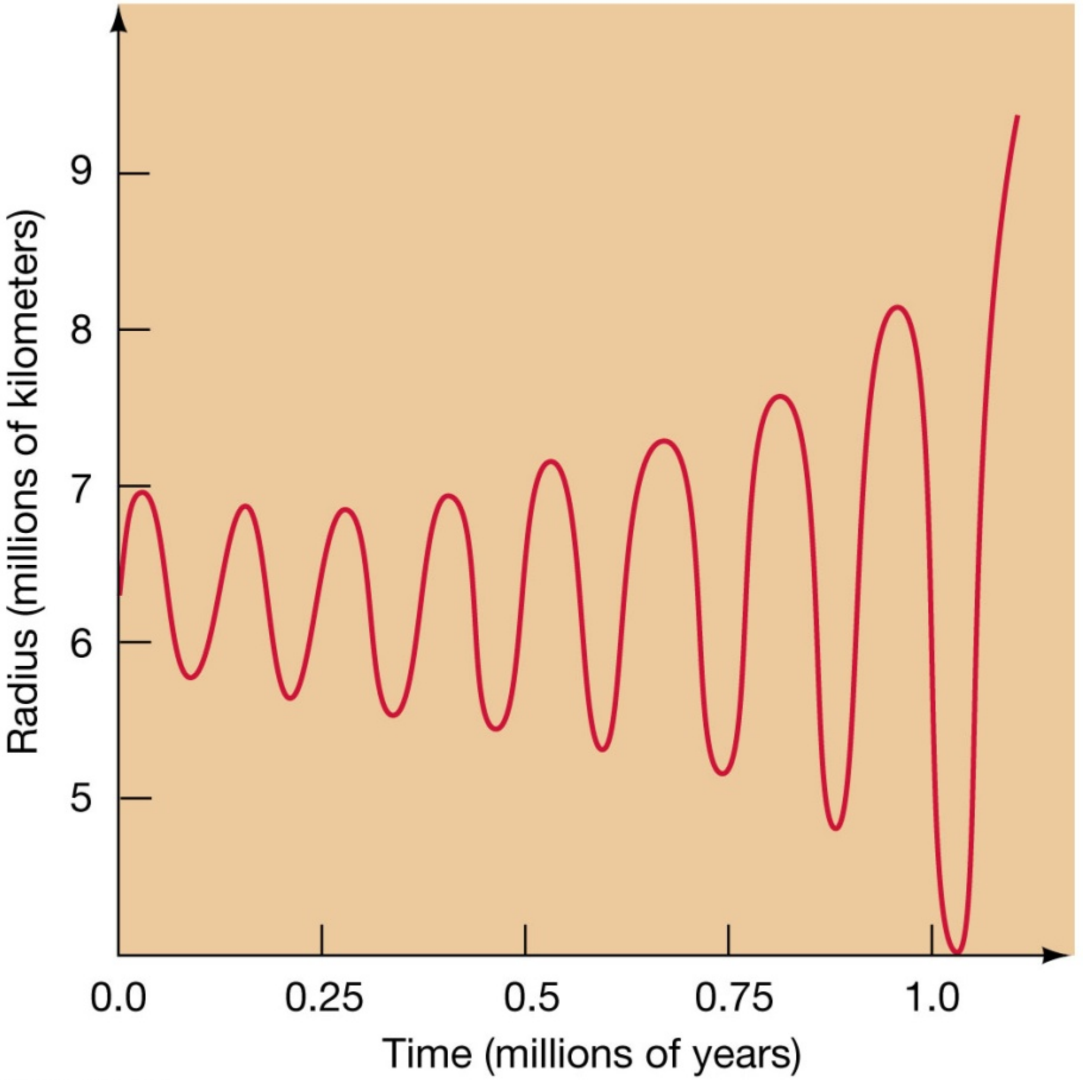
Error: horizontal branch + AGB phase missing

20.3 The Death of a Low-Mass Star

Asymptotic giant branch instability:

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

The outer layers become unstable and are eventually ejected. Lots of mass loss!



Death of a Low-Mass Star

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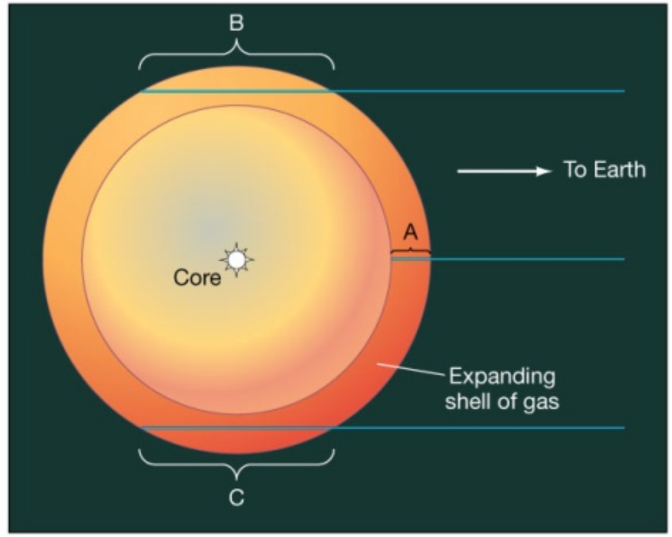

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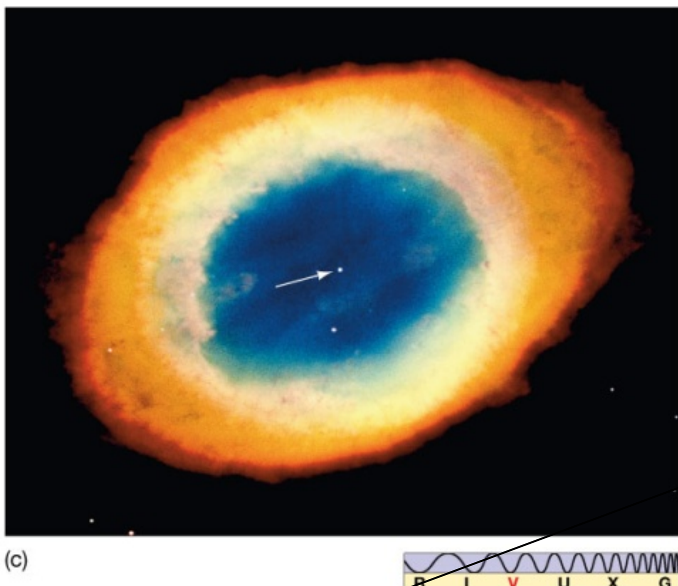


(c)

[why C? why C-O?]

The ejected envelope expands into interstellar space, forming a planetary nebula. The star now has two parts:

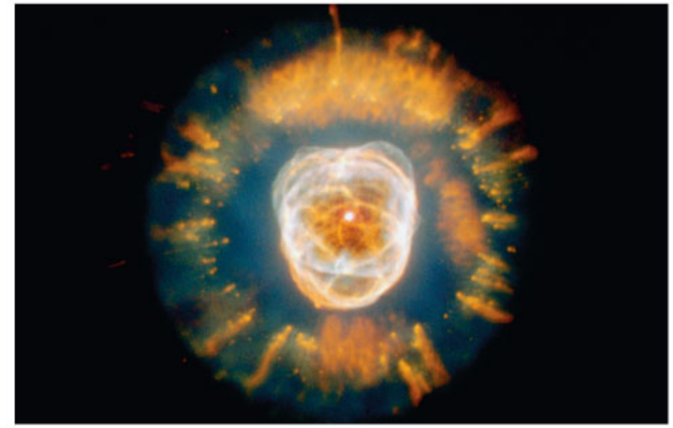
- A small, extremely dense carbon or carbon-oxygen core
- An envelope about the size of our solar system, called a planetary nebula <u>(not related to planets)</u>

20.3 The Death of a Low-Mass Star

Planetary nebulae can have many shapes:

As the dead core of the star cools, the nebula continues to expand and dissipates into the surroundings.

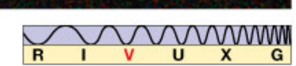
Mass loss!

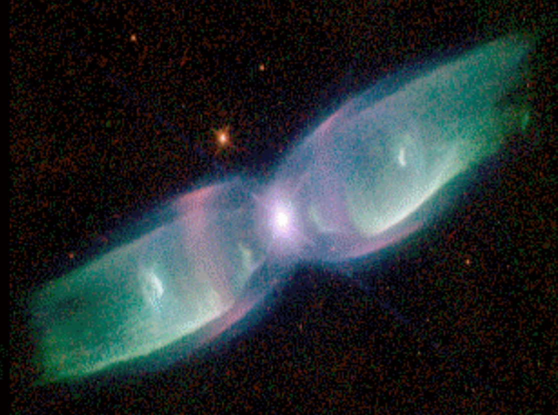
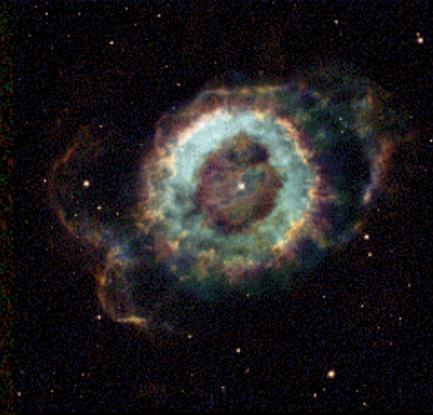


(a)

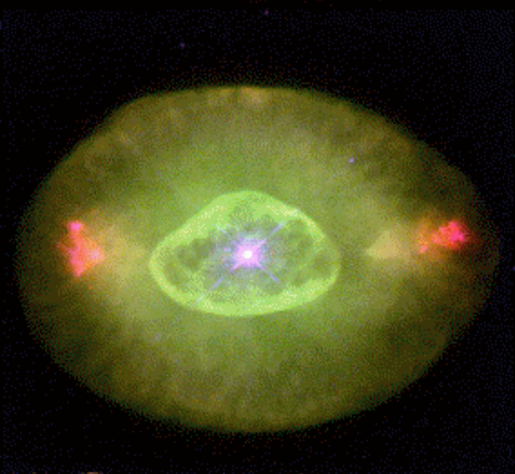
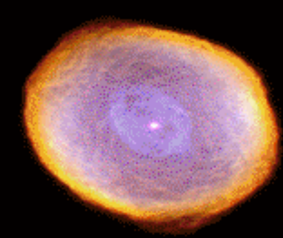
(b)

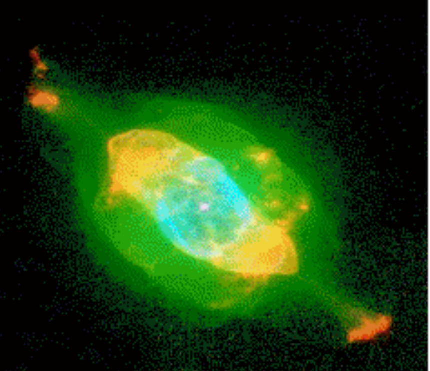
(c)



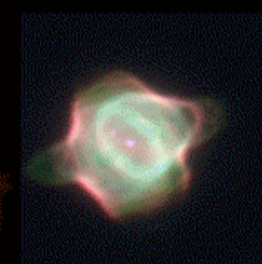





Planetary Nebulae








Hubble Space Telescope photographs of planetary nebulae. In 4.5 billion years, our Sun will become a planetary, and then become a white dwarf star. http://hubblesite.org/

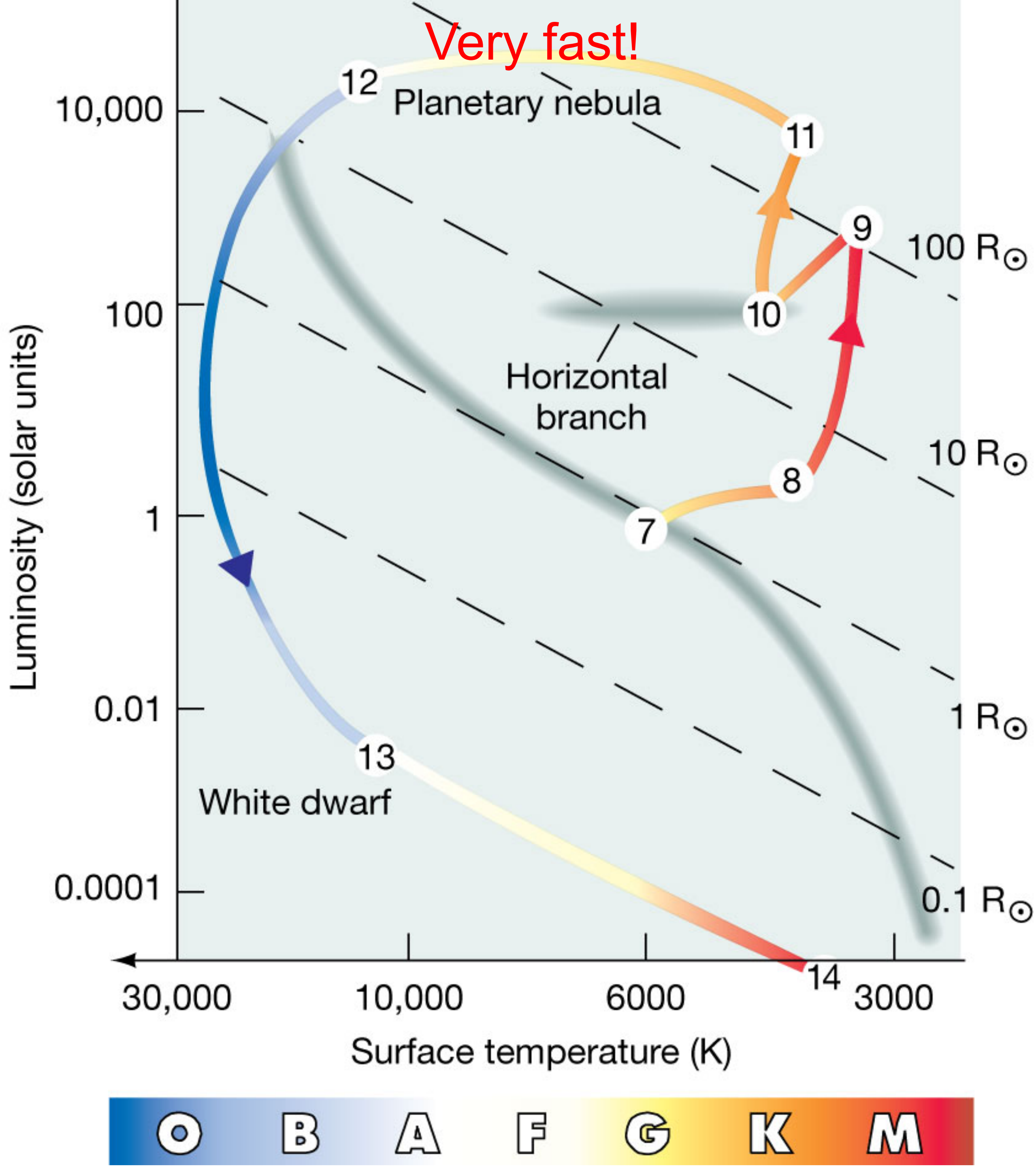
Helix Nebula Animation

Courtesy of:

Astronomy Visualization Lab STScI/NASA

20.3 Death of a Low-Mass Star

White and black dwarfs



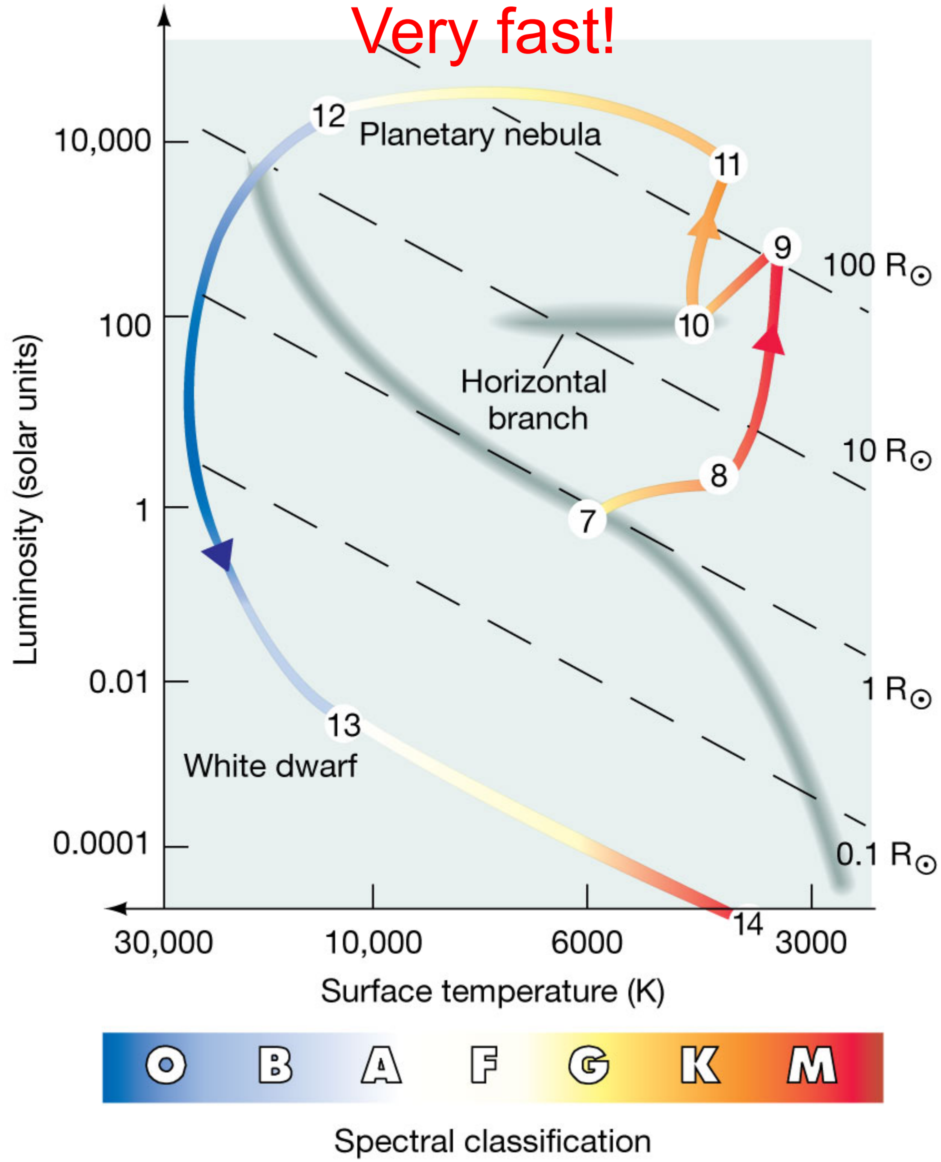
20.3 Death of a Low-Mass Star

White and black dwarfs

Once the nebula has gone, the remaining core is extremely dense and extremely hot, but quite small.

It is luminous only due to its high temperature. **No nuclear burning.**

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



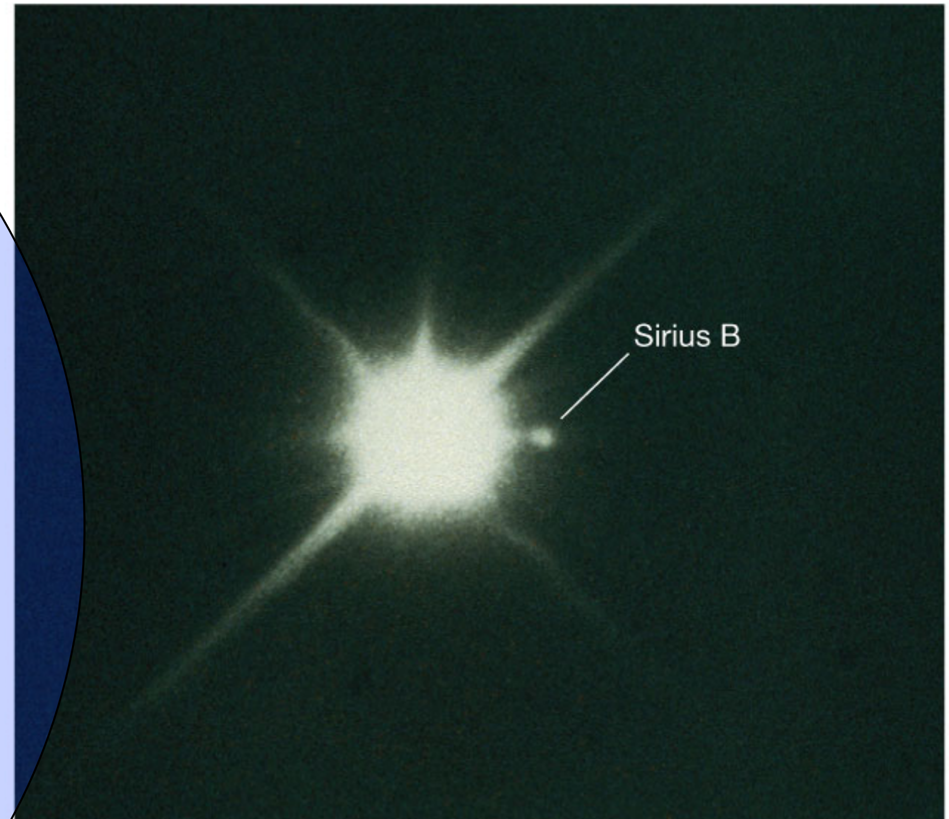
White Dwarf Cooling Sequence

Courtesy of:

NASA/STScI/G. Bacon

20.3 Death of a Low-Mass Star

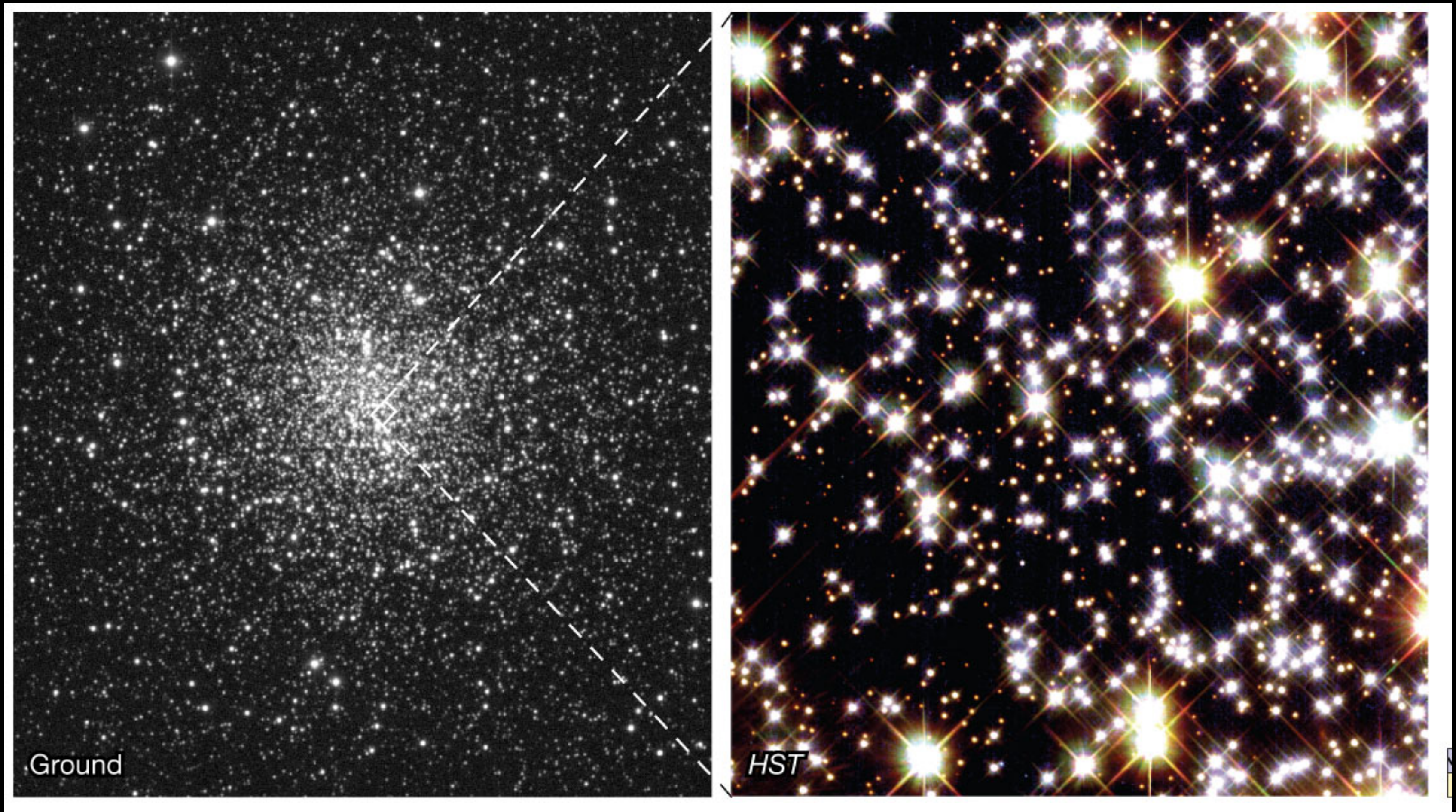
- white dwarf cooling time many billions of years
- white dwarfs are supported by "degenerate electron pressure"
- max white dwarf mass 1.4 $M_{\odot}$



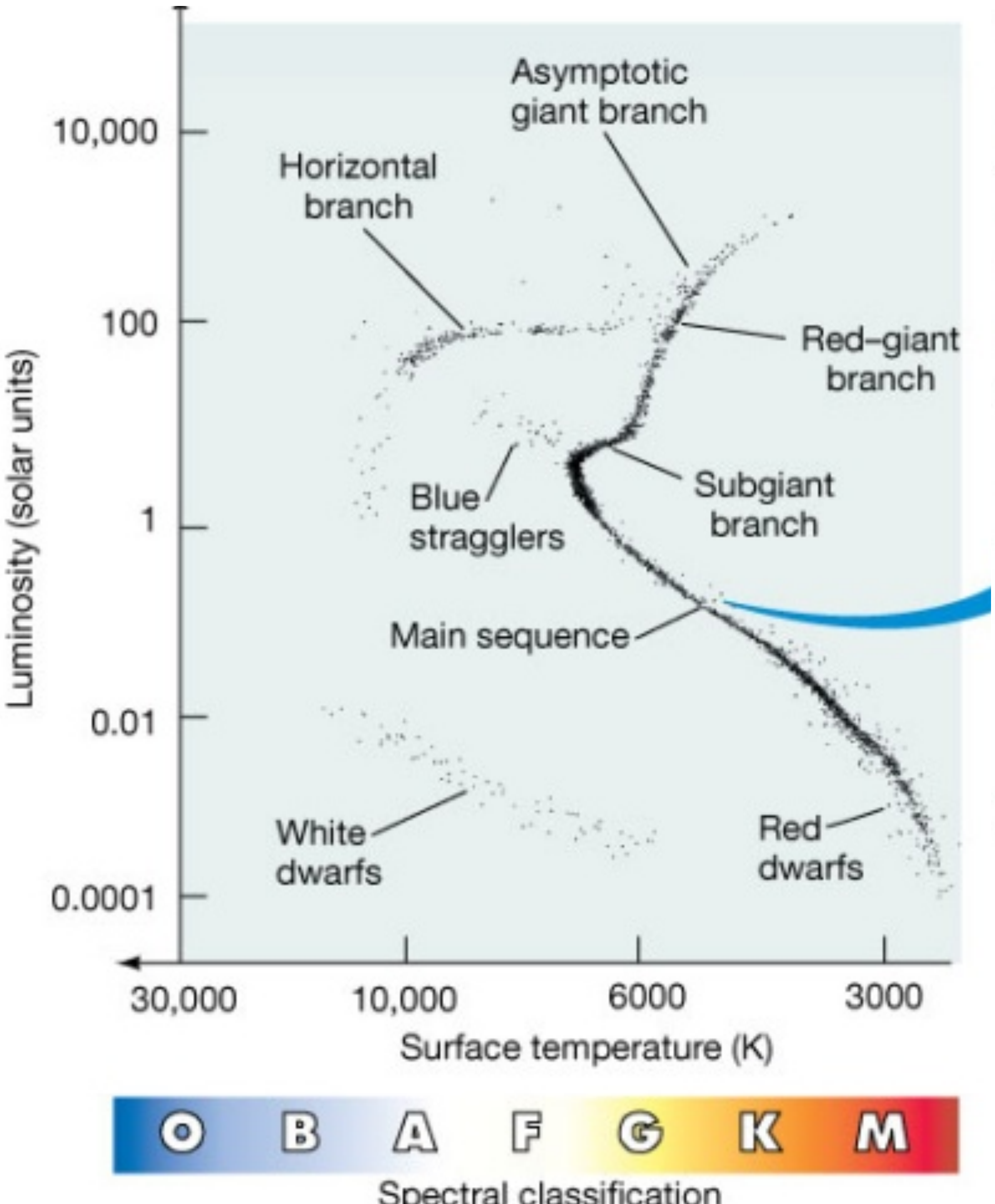
The small star Sirius B is a white-dwarf companion of the much larger and brighter Sirius A:

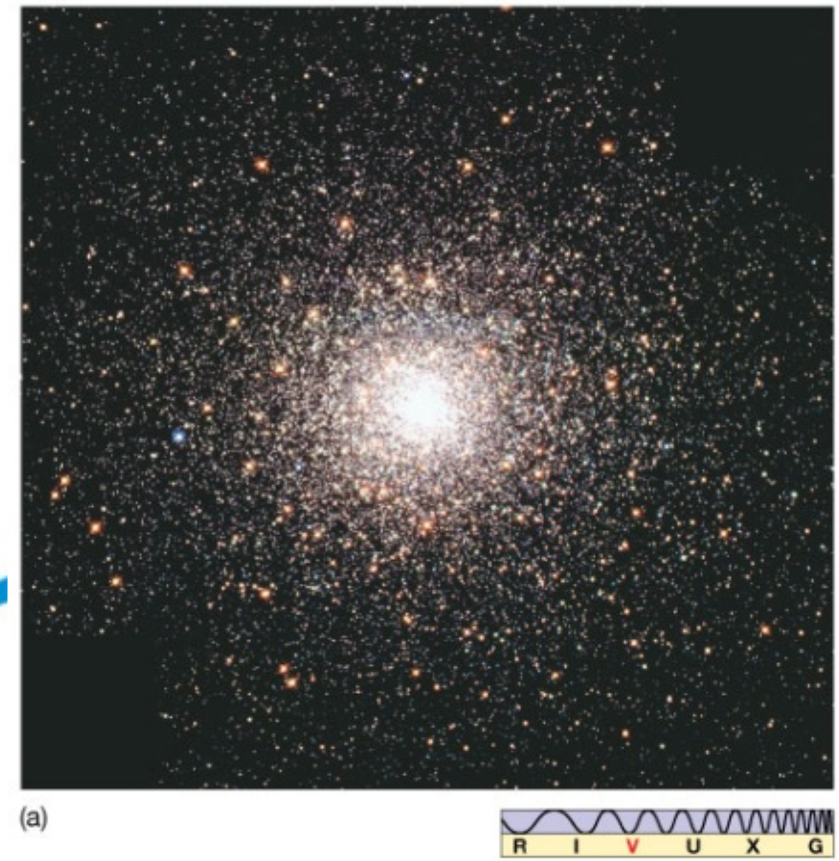
20.3 Death of Low-Mass Stars

The Hubble Space Telescope has detected white dwarf stars in globular clusters:



20.3 Death of a Low-Mass Star

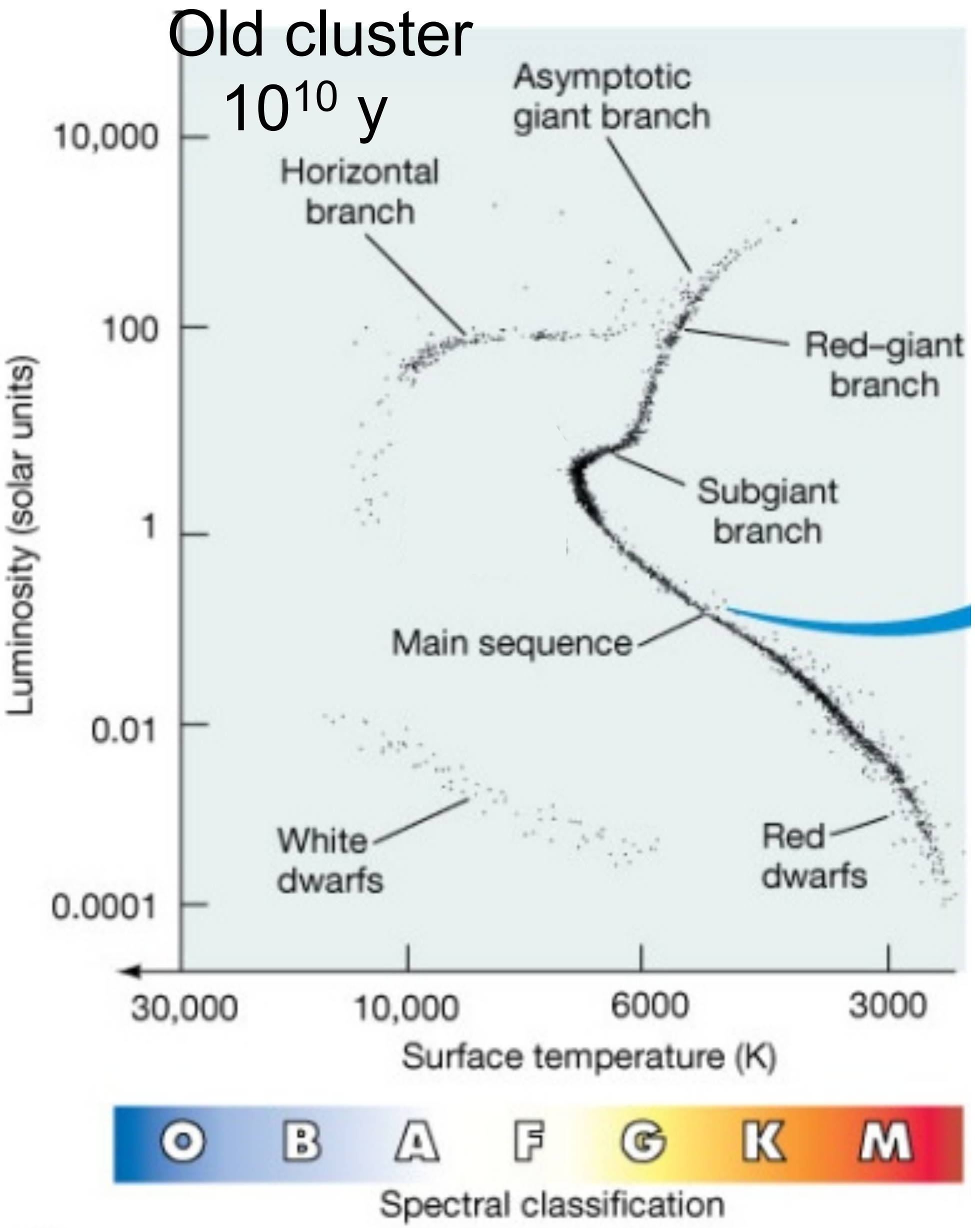




A globular star cluster:

- old – around 10^{10} yr
- all stars the same age

20.3 Death of Low-Mass Stars



- All stars same age
- Ignore blue stragglers

- *Where is upper main sequence (high mass)?*
- *Why haven't low mass stars evolved?*
- *What is varying along the "turnoff", sub-giant, and red giant regions?*

Summary of evolution of low mass stars

Main sequence
Leave main sequence ("subgiant")
Red giant
Horizontal branch
Asymptotic Giant Branch
Planetary nebula ejection
White Dwarf

20.2 Evolution of a Sun-Like Star

Stages of a solar type star leaving the Main Sequence:

TABLE 20.1 Evolution of a Sun-like Star

Stage	Approximate Time to Next Stage (Yr)	Central Temperature (10^6 K)	Surface Temperature (K)	Central Density (kg/m^3)	Radius (km)	Radius (solar radii)	Object
7	10^{10}	15	6000	10^5	7×10^5	1	Main-sequence star
8	10^8	50	4000	10^7	2×10^6	3	Subgiant branch
9	10^5	100	4000	10^8	7×10^7	100	Helium flash
10	5×10^7	200	5000	10^7	7×10^6	10	Horizontal branch
11	10^4	250	4000	10^8	4×10^8	500	Asymptotic-giant branch
12	10^5	300	100,000	10^{10}	10^4	0.01	Carbon core
		—	3000	10^{-17}	7×10^8	1000	Planetary nebula*
13	—	100	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 refer to the envelope.*

H-R Diagram Tracks Stellar Evolution

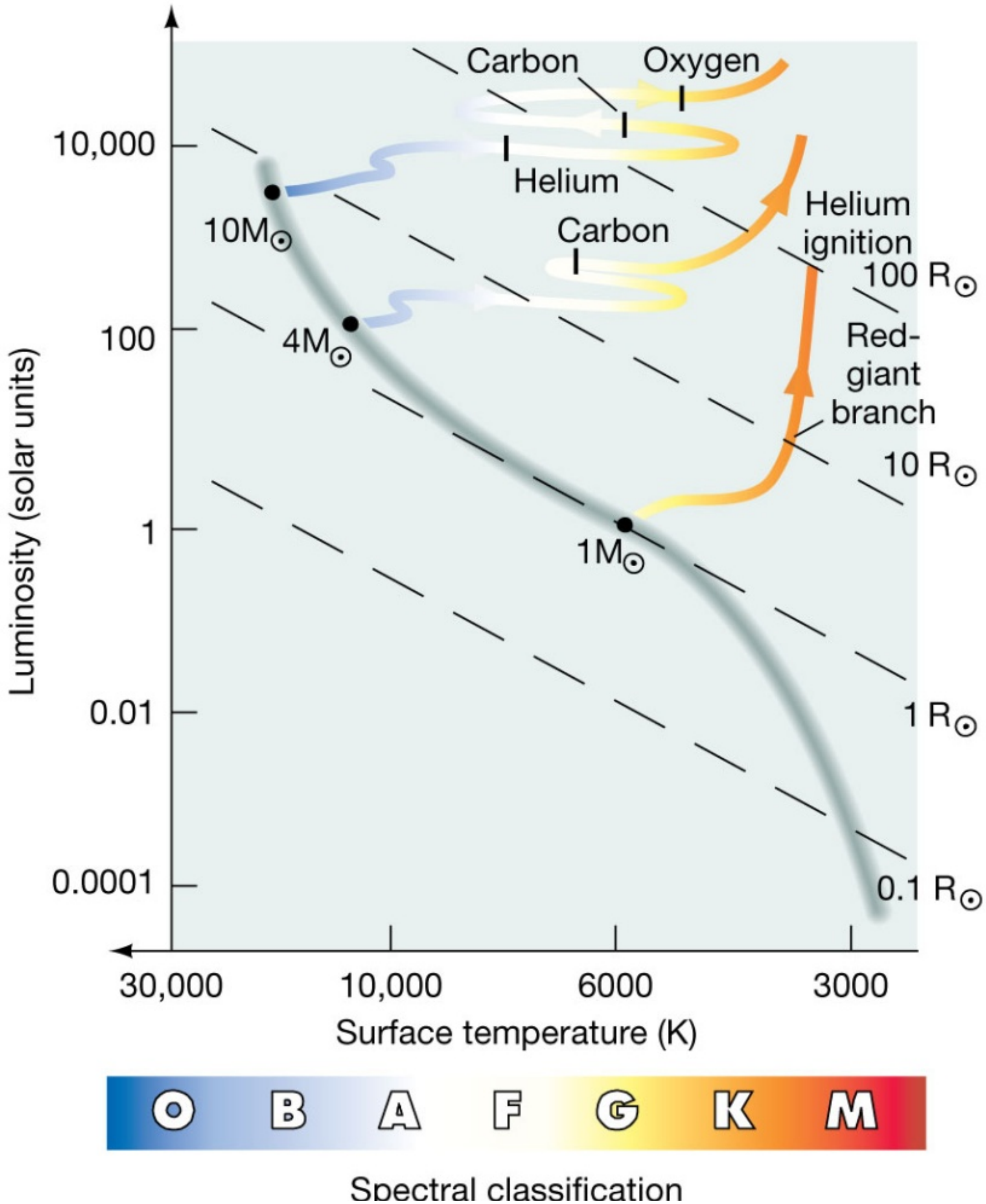
Courtesy of:

The Wright Center,
Science Visualization Lab -
Tufts University/ D.Berry and J. Palmer

http://www.youtube.com/watch?v=mZL7VBmeFxY

20.4 Evolution of Stars More Massive than the Sun

Stars more massive than the Sun follow very different paths when leaving the Main Sequence



20.4 Evolution of Stars More Massive than the Sun

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.

20.4 Evolution of Stars More Massive than the Sun

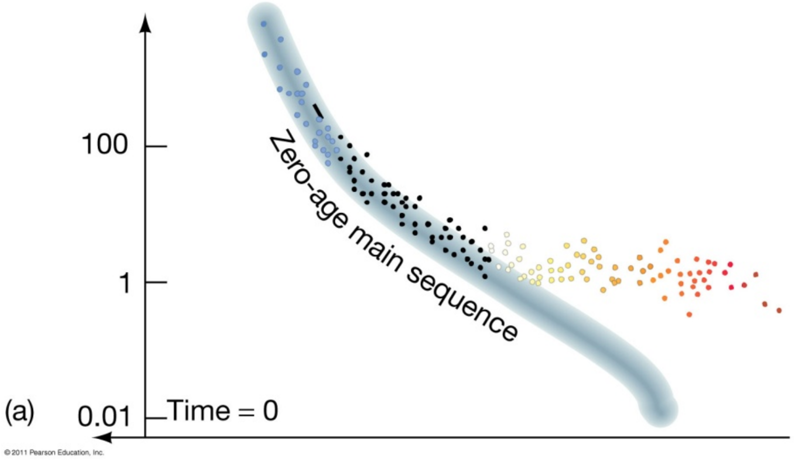
In summary:

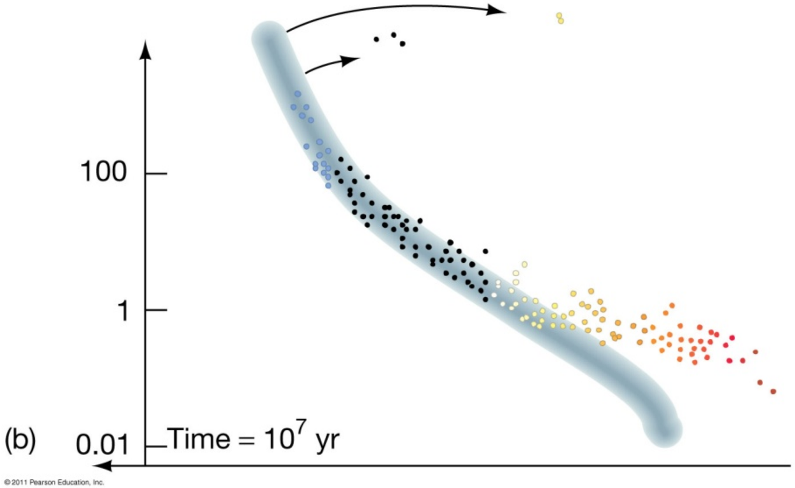
TABLE 20.3 End Points of Evolution for Stars of Different Masses

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~~* 8	supernova (Chapter 21)

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

20.5 Observing Stellar Evolution in Star Clusters

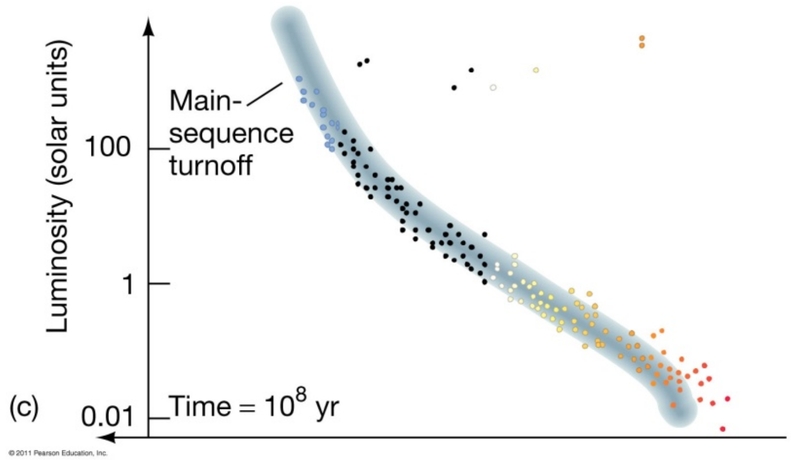


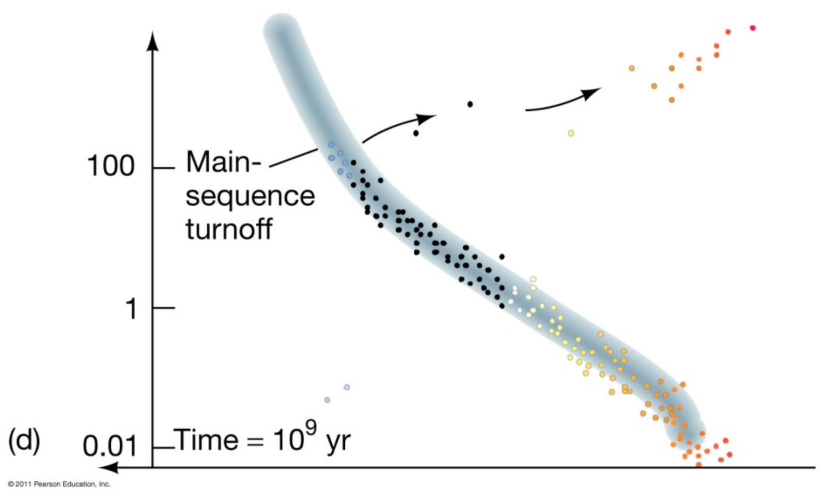


The following series of H-R diagrams shows how stars of the same age, but different masses, appear as the whole cluster ages.

After 10 million years, the most massive stars have already left the Main Sequence, while many of the least massive have not even reached it yet.

20.5 Observing Stellar Evolution in Star Clusters

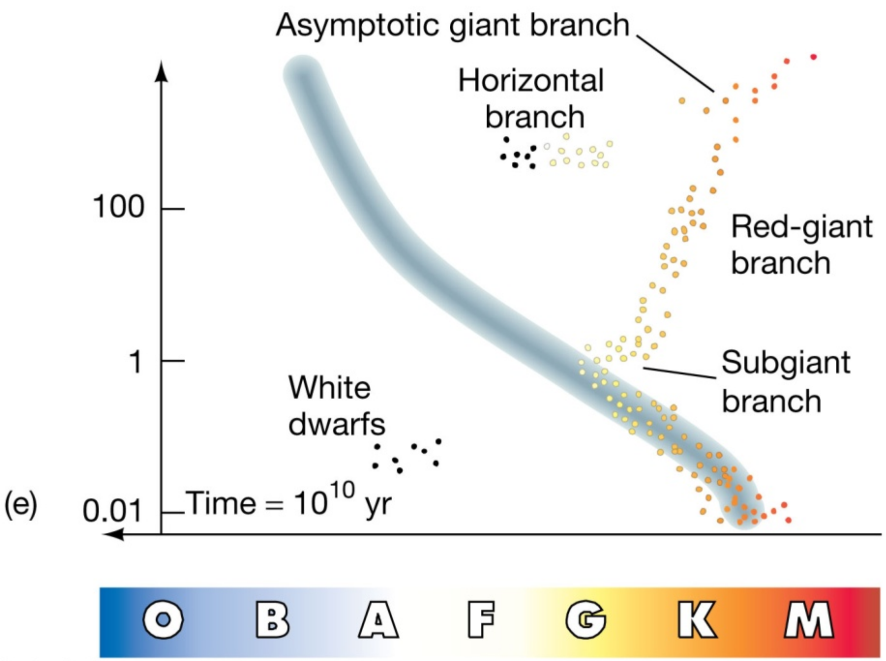




After 100 million years, a distinct main-sequence turnoff begins to develop. This shows the highest-mass stars that are still on the Main Sequence.

After 1 billion years, the main-sequence turnoff is much clearer.

20.5 Observing Stellar Evolution in Star Clusters



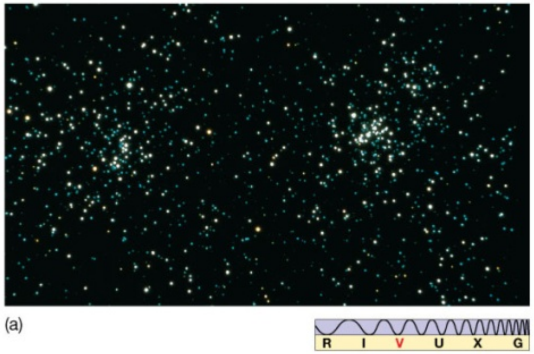
After 10 billion years, a number of features are evident:

The red-giant, subgiant, asymptotic giant, and horizontal branches are all clearly populated.

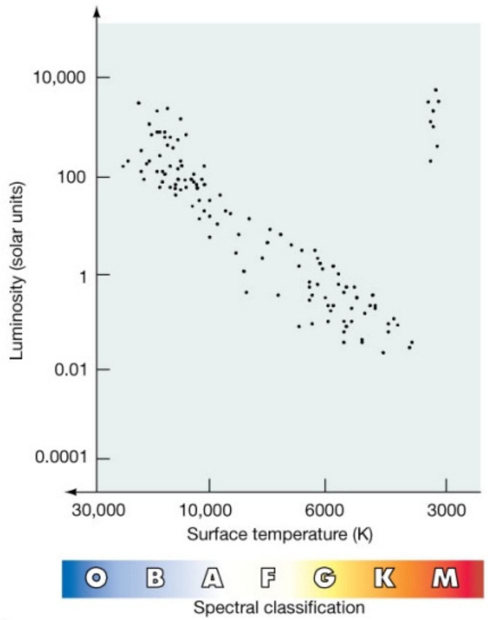
White dwarfs, indicating that solar-mass stars are in their last phases, also appear.

20.5 Observing Stellar Evolution in Star Clusters

This double cluster, h and chi Persei, must be quite young—its H-R diagram is that of a newborn cluster. Its age cannot be more than about 10 million years.



(a)



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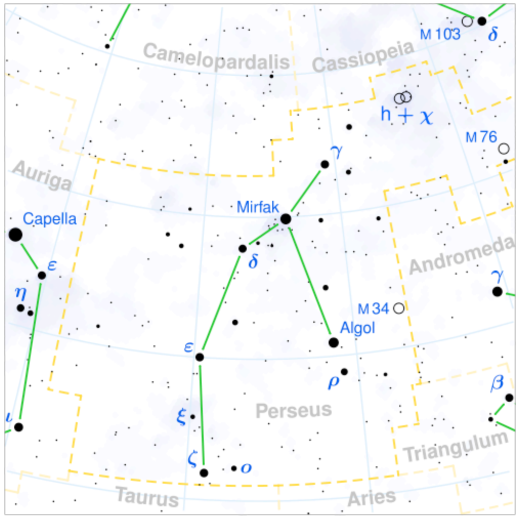
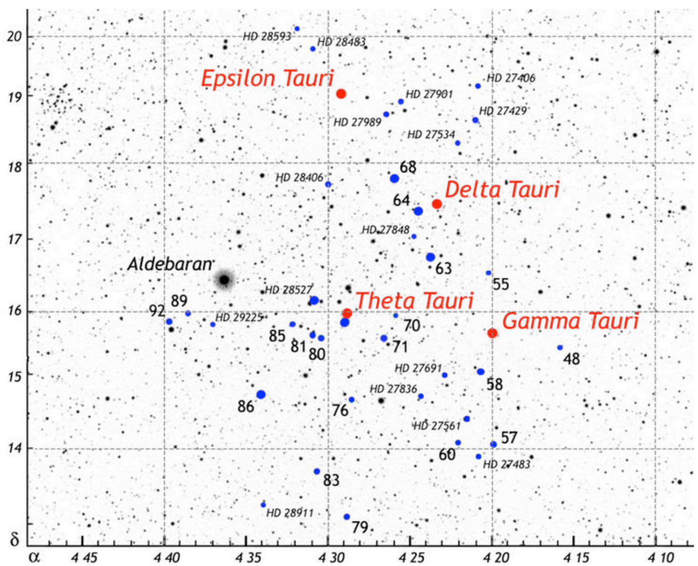
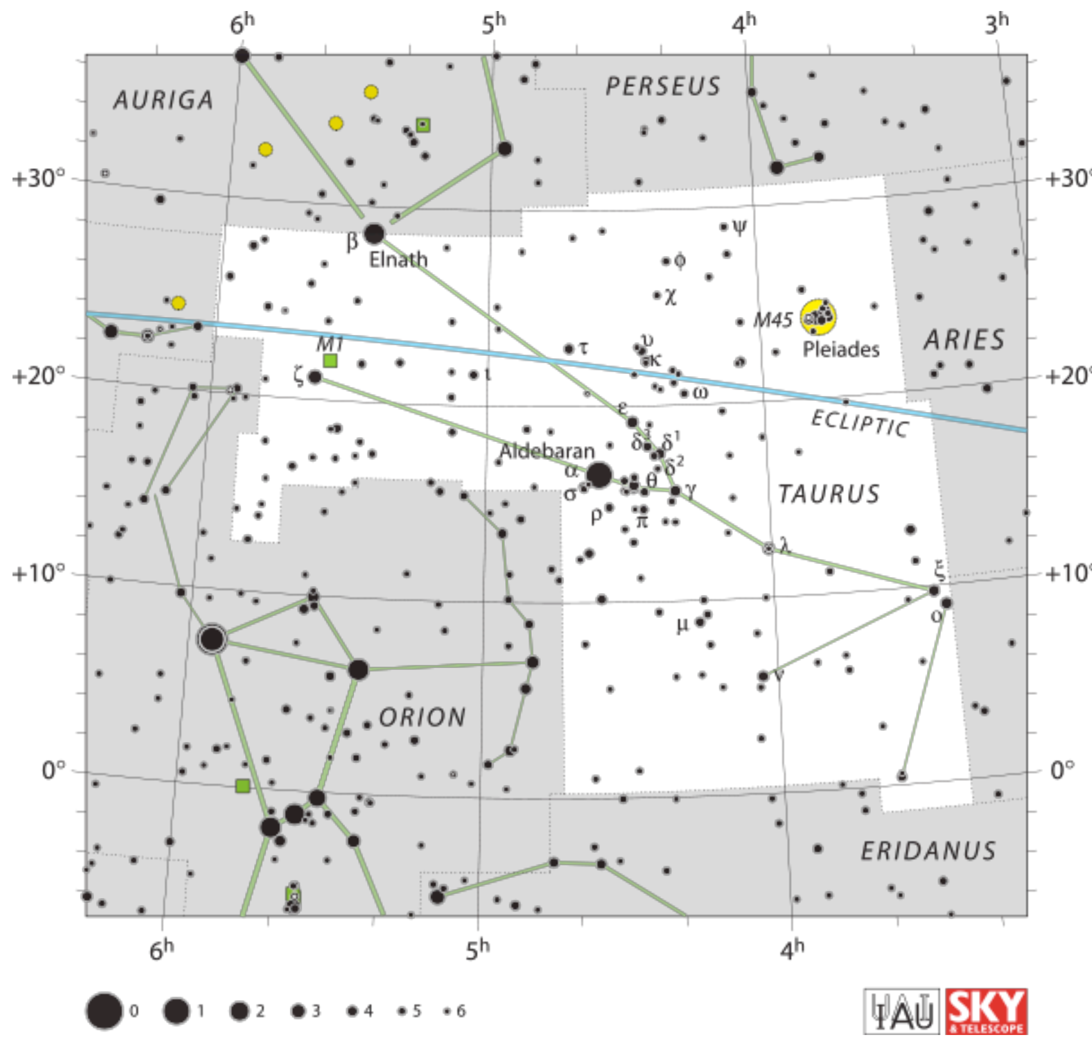


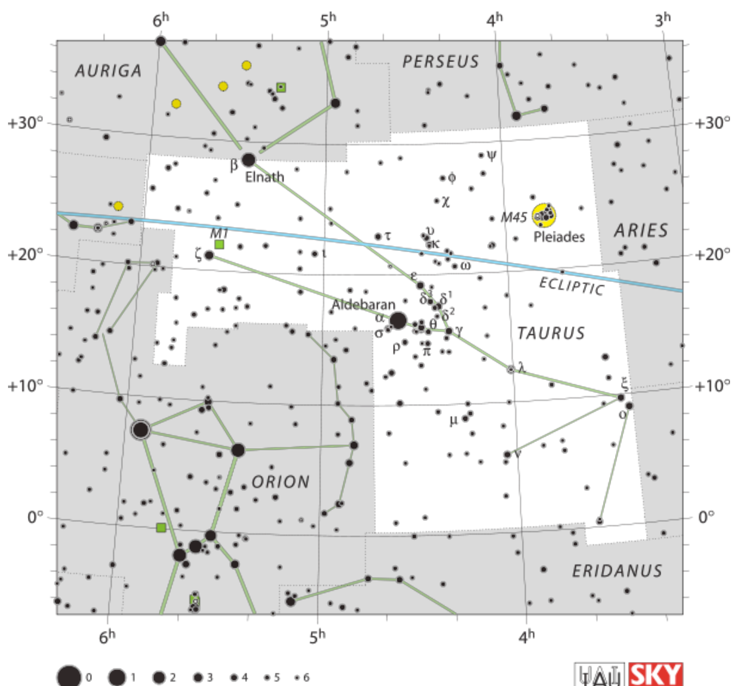
The Hyades Cluster

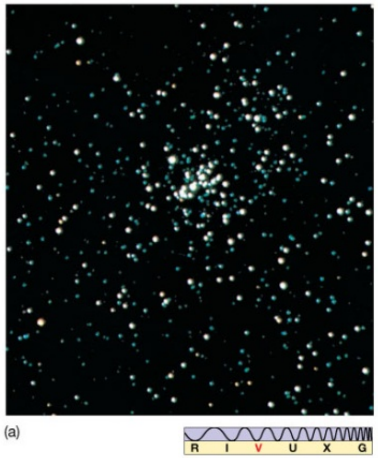




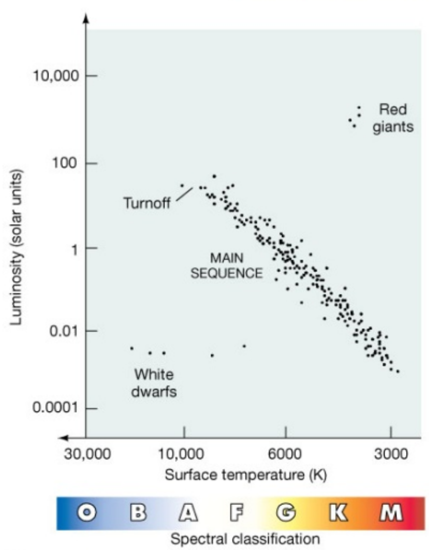
20.5 Observing Stellar Evolution in Star Clusters

The Hyades cluster, shown here, is also rather young; its main-sequence turnoff indicates an age of about 600 million years.





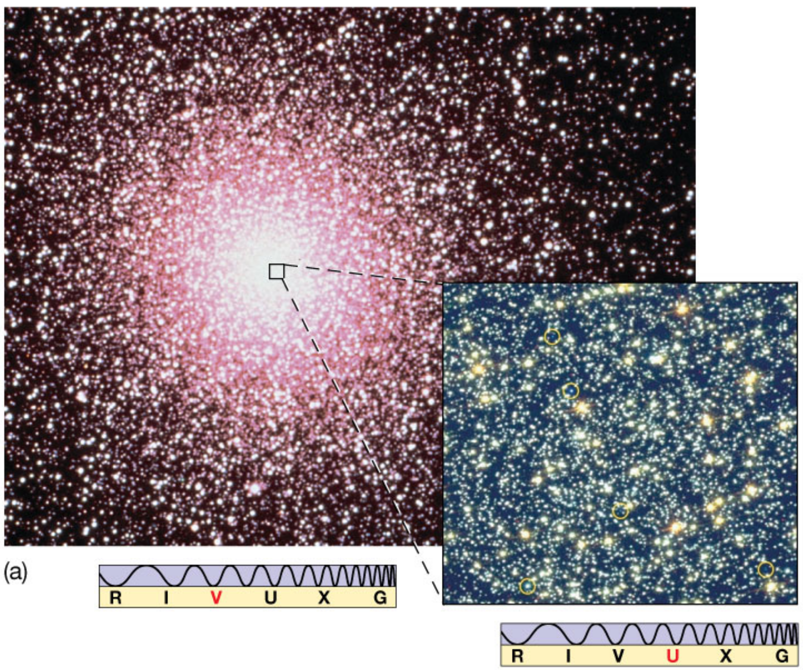
(a)



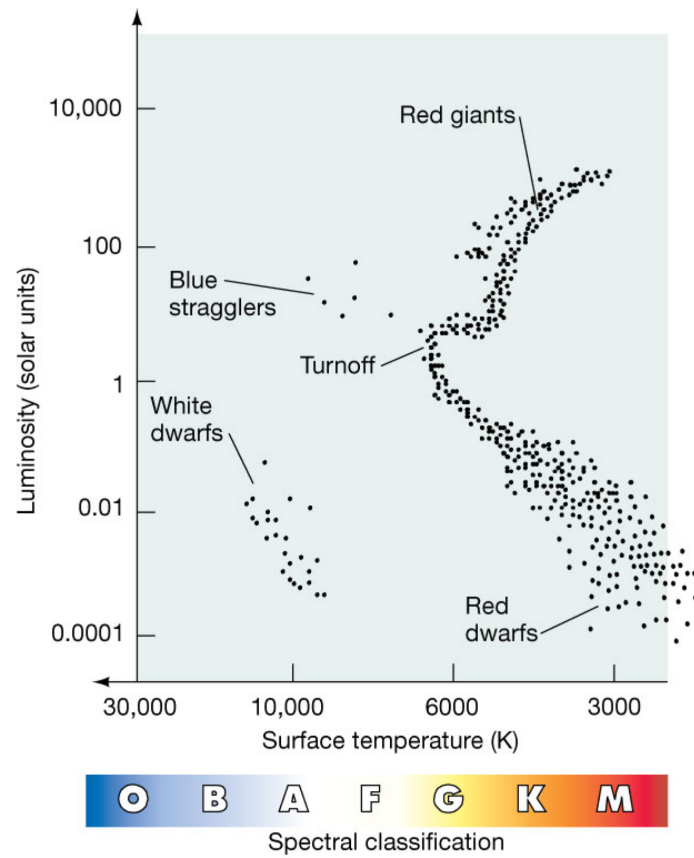
(b)

20.5 Observing Stellar Evolution in Star Clusters

This globular cluster, 47 Tucanae, is about 10–12 billion years old, much older than the previous examples:

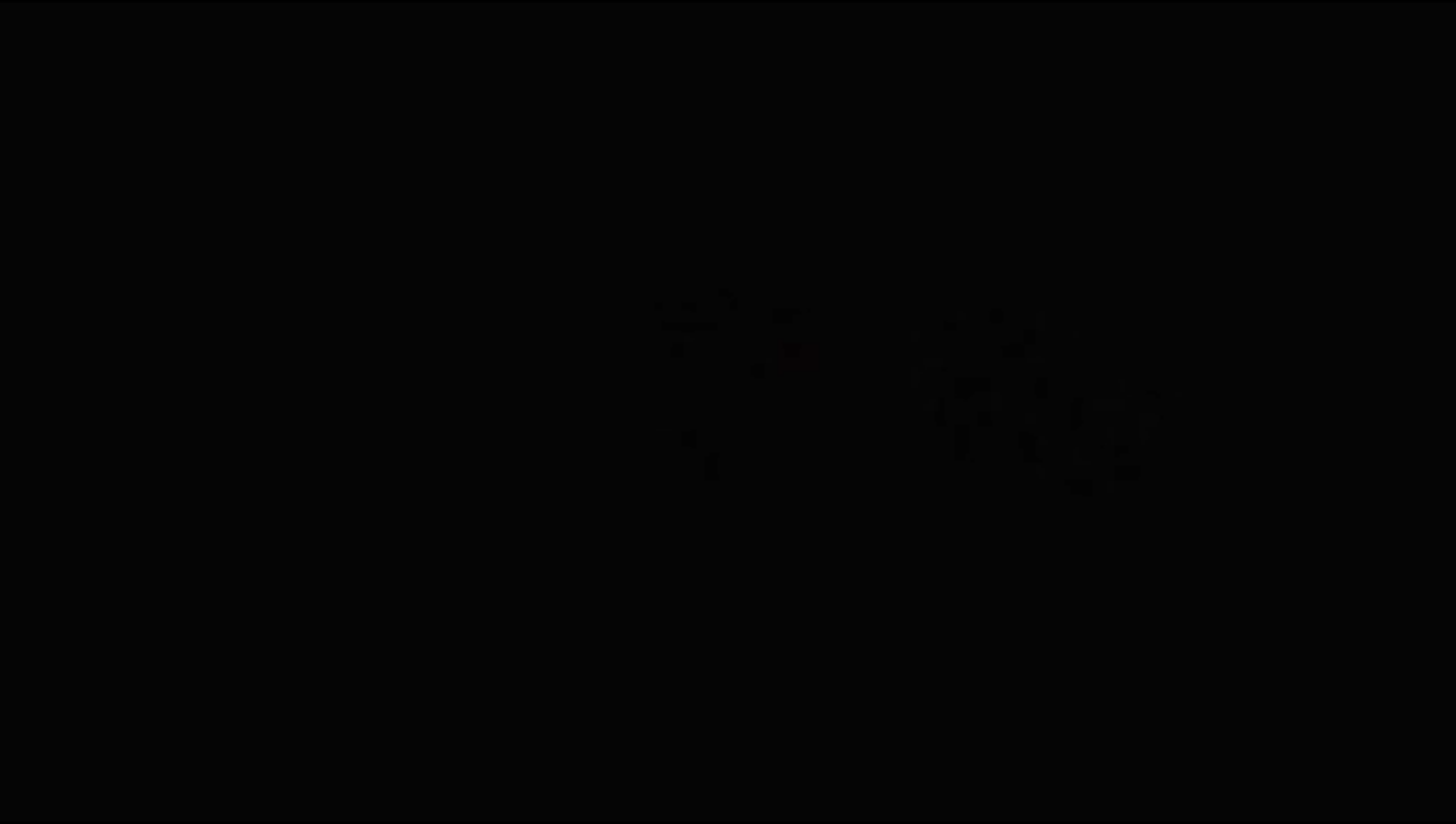


(a)



(b)

http://www.youtube.com/watch?v=PM9CQDIQI0A



Summary – what you need to know about stellar evolution

- What is the main sequence?
- Why does stellar evolution off the main sequence happen?
- Massive stars evolve faster
- Most (like 95-99%) of life of star is on the main sequence.
- Endpoint for stars of different mass – $8M_{\odot}$ dividing point and *importance of mass loss*

Summary – what you need to know about stellar evolution

- For each evolutionary phase:
  - What's happening on HR diagram
  - Why it's happening
  - Approximate time scales
  - Source of nuclear energy
  - Core structure - where burning is happening

- Next – more from ch 20 notes 2012
- Also – show movie http://www.youtube.com/watch?v=PM9CQDlQI0A
- Also look for movie showing evolution on the HR diagram