The Life of Stars

Chapter 22


A star expelling some of its mass in a late
stage of its life. Such mass loss is not
uncommon for stars at the end of their lives.

Lifetime on the Main Sequence

- Stars spend most of their lives on the main sequence fusing hydrogen into helium.
- As helium builds up the core gets denser and hotter and the rate of fusion increases. This gives the thickness to the main sequence as stars become a little hotter and brighter during their lives.
- Eventually enough helium builds up in the core that the star will move away from the main sequence.

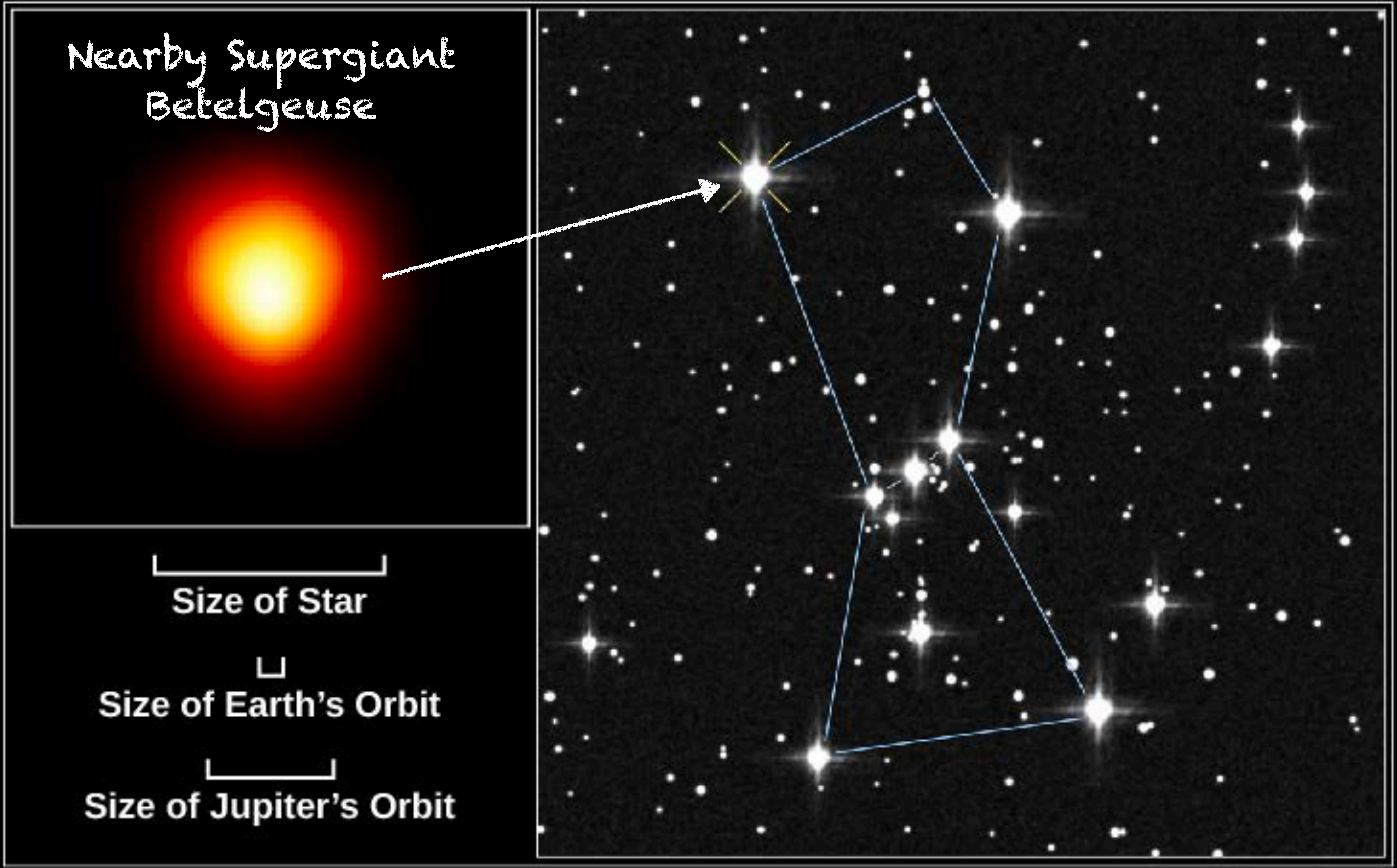
Lifetime on the Main Sequence

- The more massive a star the shorter its life on the main sequence. Even though such a star has more hydrogen to burn, it is much hotter and denser so the rate of fusion is much higher in the core. The star consumes its hydrogen at a much faster rate.

- A star 40 times the mass of the sun will only spend 1 million years on the main sequence. A star twice the mass of the sun will spend 2 billion years burning hydrogen. The sun will take 10 billion years to exhaust its fuel. And a star half the mass of the sun can fuse hydrogen for 100 billion years.

When a star's core becomes helium it is not hot enough to undergo fusion. So the core stops producing energy and shrinks. Denser and hotter it heats the material around it. Now hydrogen that was outside the core is able to fuse in a shell around the core. This greater heat propagates out expanding the star.

These stars become much bigger than the sun. Delta Bootis is a red giant, while Xi Cygni is a supergiants.

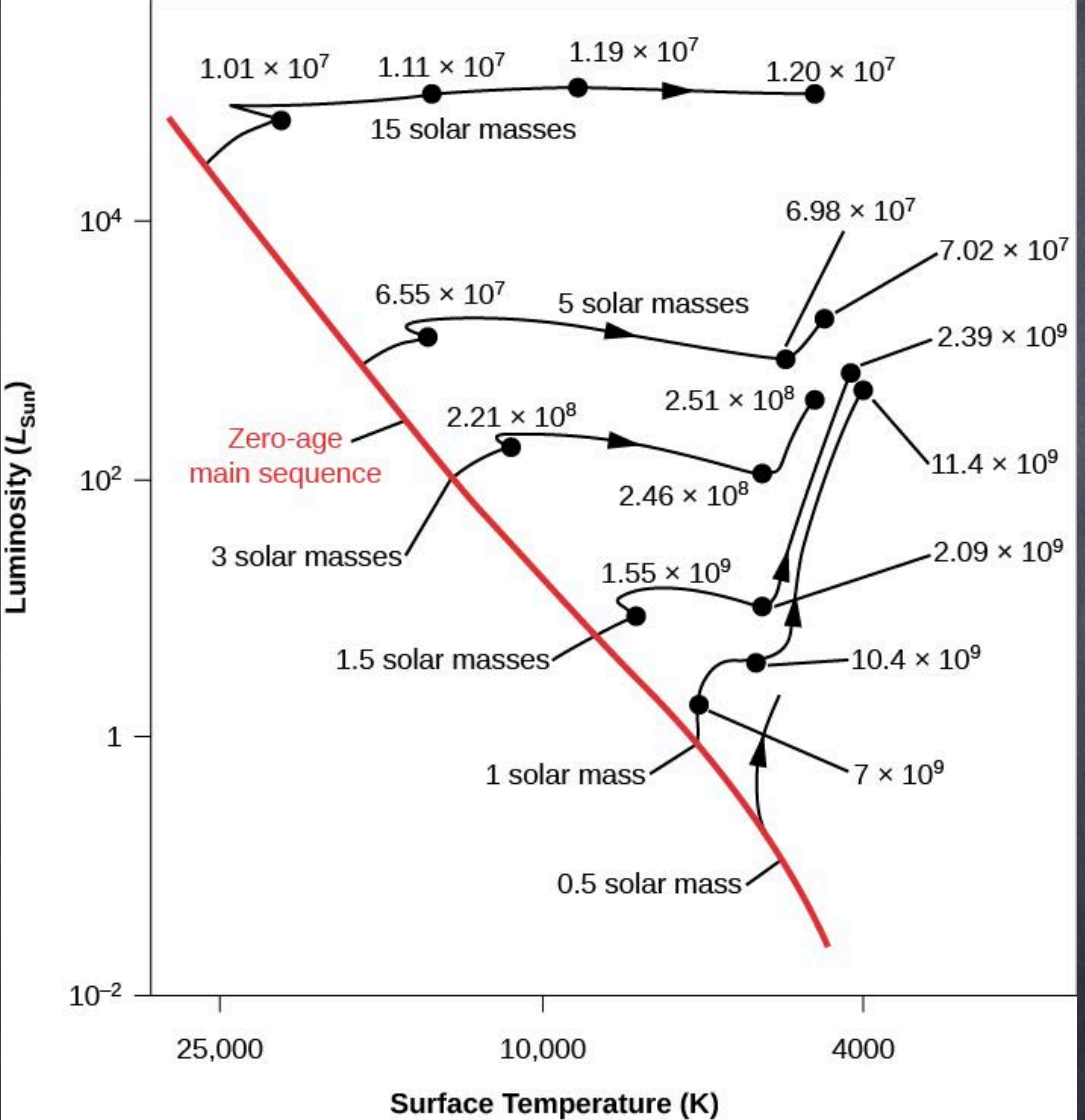

Nearby Supergiant
Betelgeuse
Size of Star
Size of Earth's Orbit
Size of Jupiter's Orbit

Betelgeuse

- To get a sense of these big stars let's compare the super giant Betelgeus to our sun.
- Betelgeuse is 16 times the mass of the sun but its radius is 500 million km compared to the sun's 700 thousand.
- It's surface temperature is only 3600K a bit cooler than the sun's 5800K. The core of Betelgeuse is an outstanding 160 million K compared to the 15 million K of the sun.
- Betelgeuse is 46,000 times as luminous as the sun, but its average density is only a ten millionth that of the sun.
- Finally, Betelgeuse is only 10 million years old compared to the sun's 4.5 billion years.

This figure shows the time it takes for stars of various mass to move off the main sequence. Massive stars move off the main sequence low mass stars take a long time to move off.

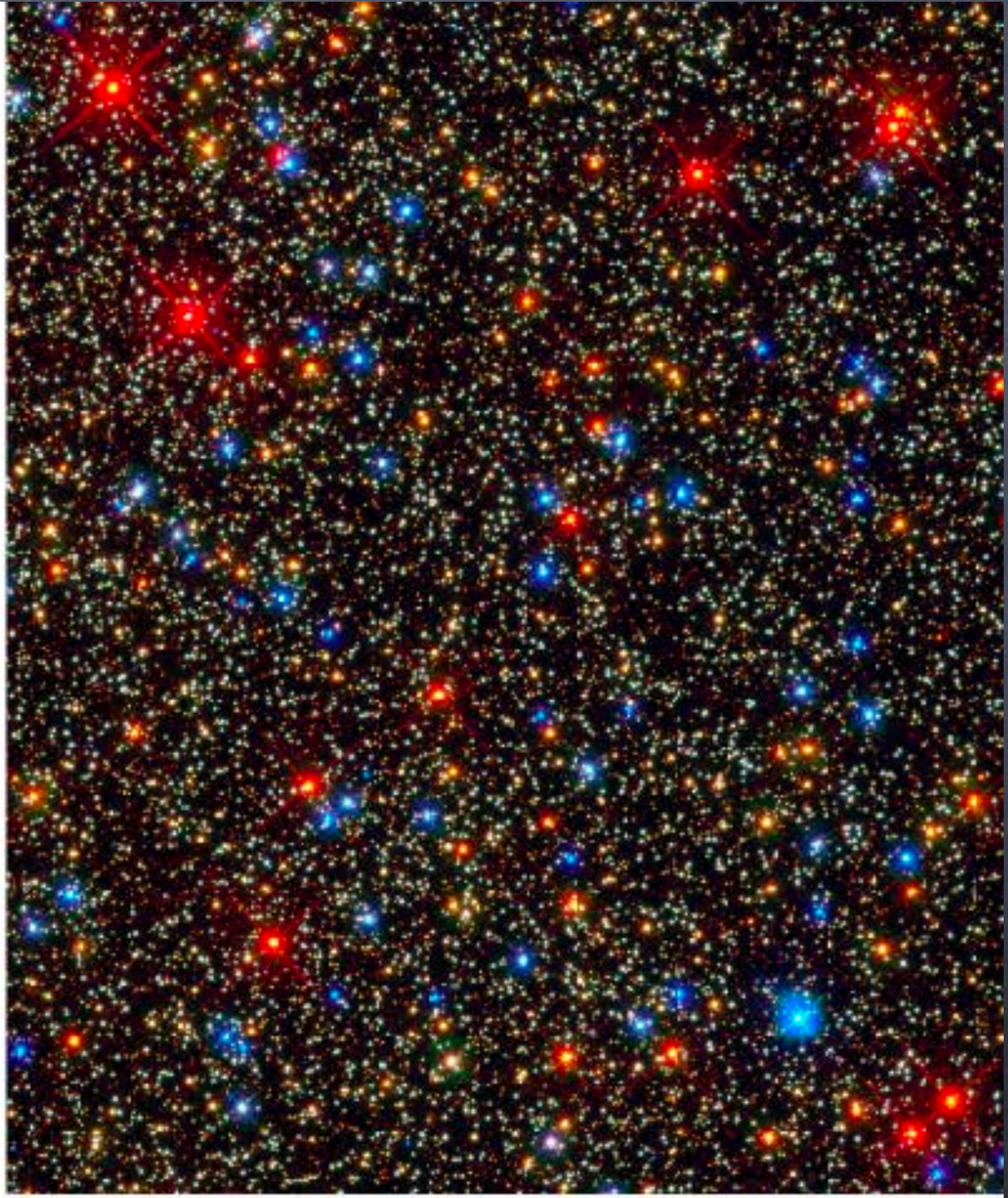
https://www.youtube.com/watch?v=orJQi6oaZfo



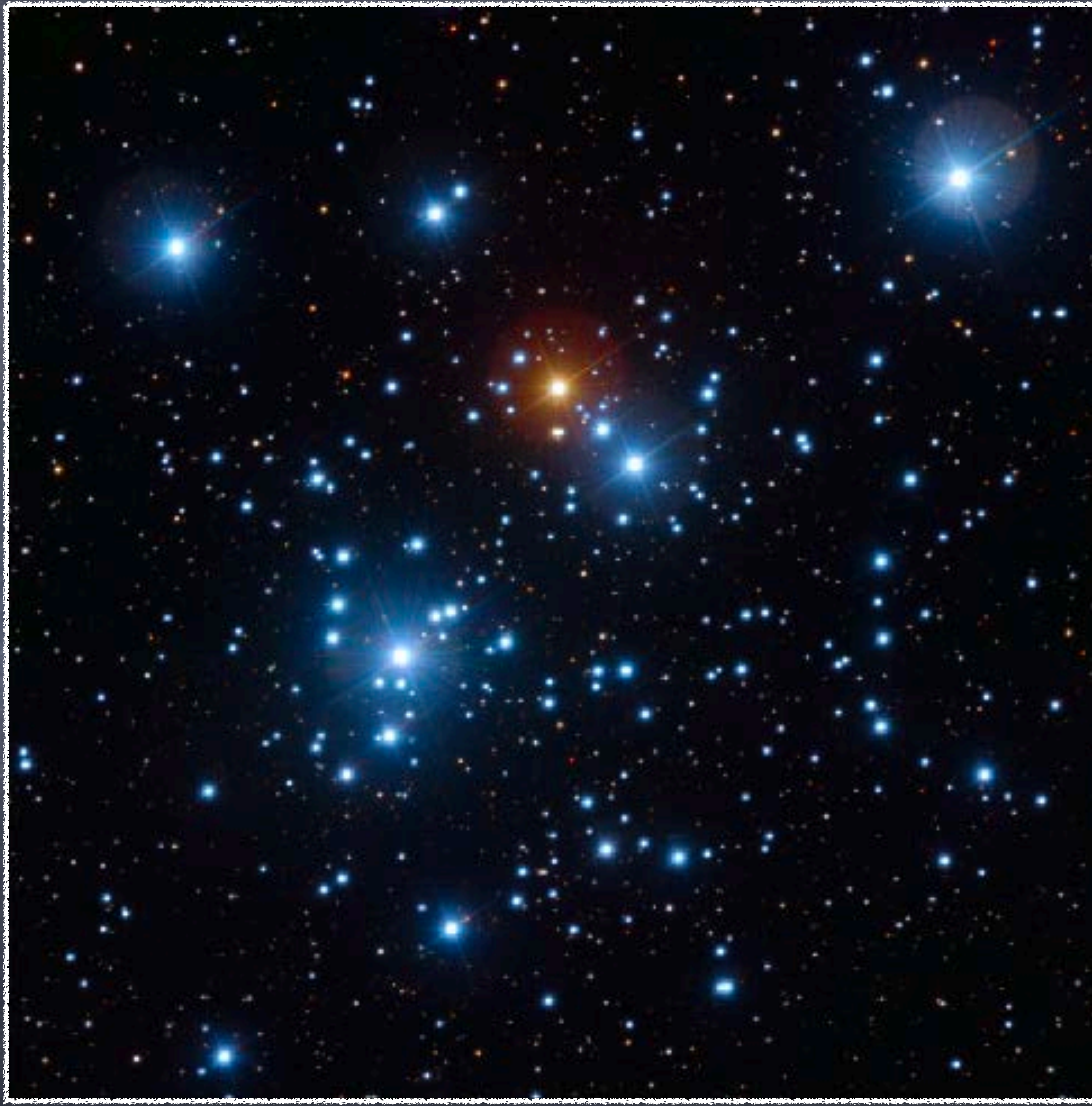
Star Clusters

- The lives of stars are based on models since even the most massive stars live longer than human civilization.
- Luckily we can learn about the evolution of stars by looking at star clusters, regions where many stars are bound together and probably were born at the same time.
- Looking at different star clusters we see snapshots of stellar evolution at different times.
- There are 3 types of star clusters; globular clusters, open clusters, and stellar associations.

This is a massive globular cluster which contain old stars. The Hubble image on the right shows the center.



- Open clusters are found in the disk of our galaxy and can be very young.
- They have less stars than globular clusters and are not as dense.
- Open clusters do not last as a group for that long, usually coming apart in millions or at most 100 million years.



Stellar Association

- A young cluster, still enshrouded in hydrogen gas.
- We see the blue very bright massive stars that only live a short time.

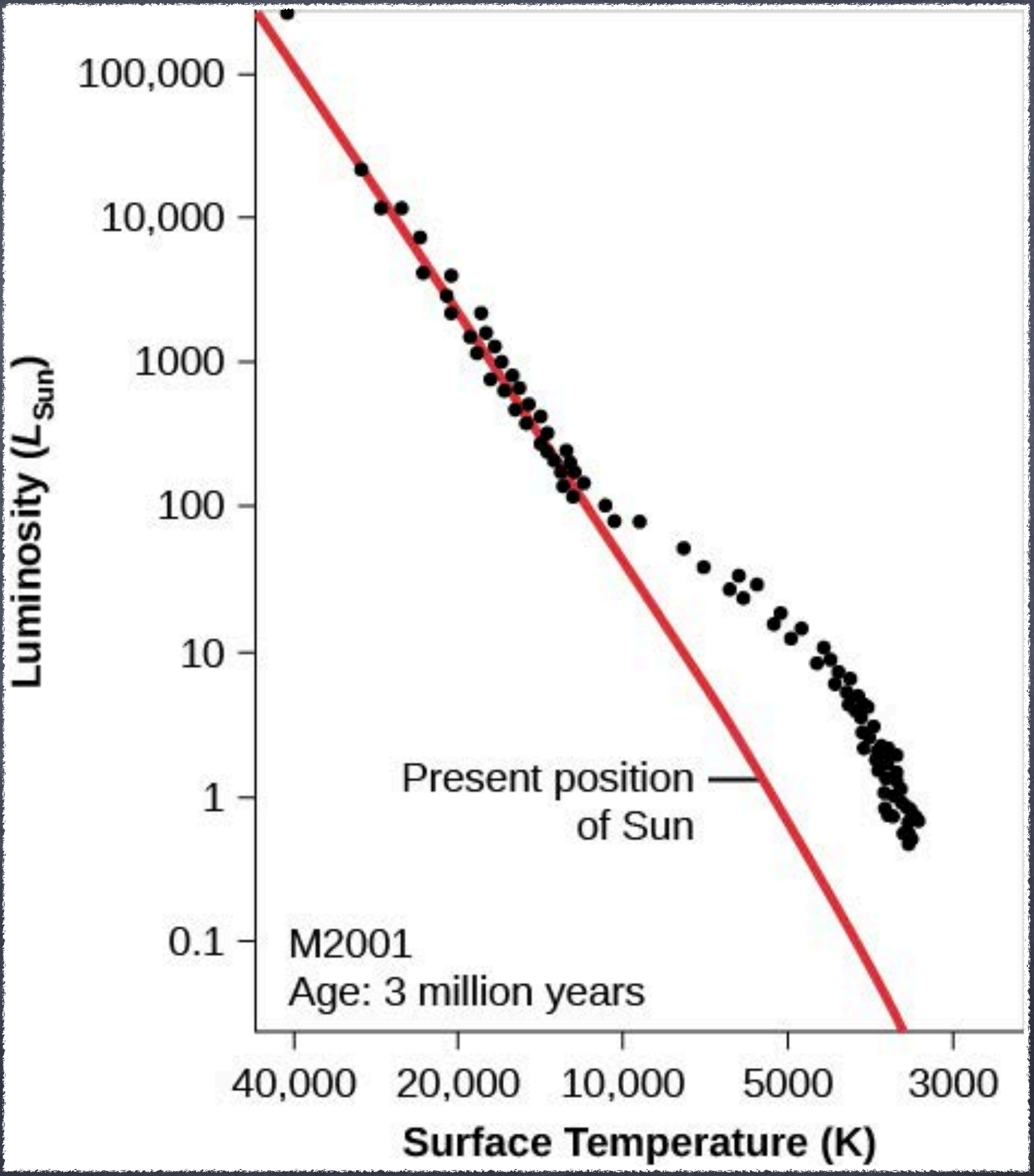
Different Stellar Clusters

- Globular Clusters - Very massive, very dense, up to millions of stars and old.
- Open Clusters - Young, less massive, less dense, only last millions of years.
- Stellar Associations - Extremely young, contain 50-100 really young massive stars.

HR Diagram of Young Cluster

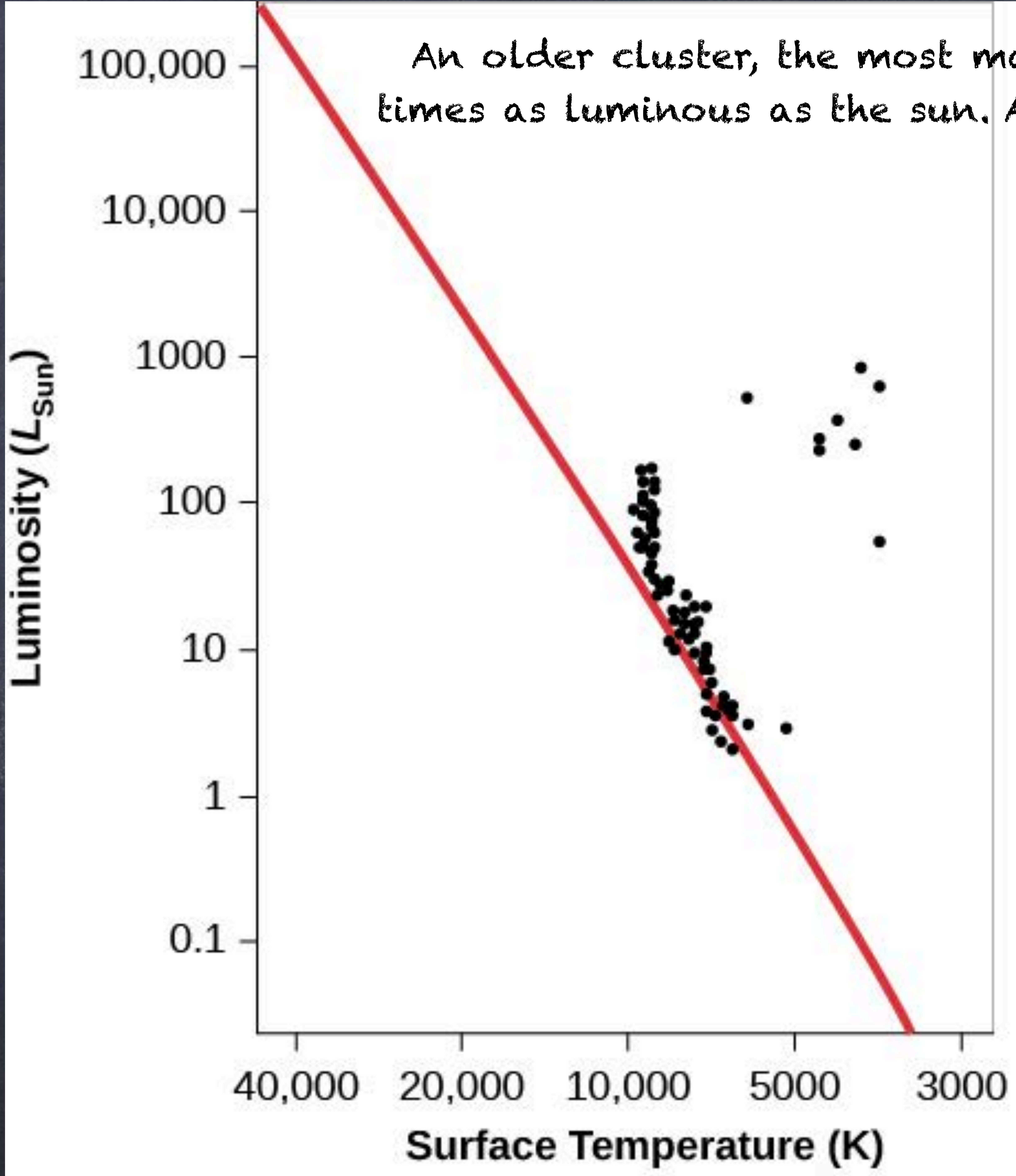
- At only 3 million years the massive stars have reached the main sequence but low mass stars have not.
- Notice that no stars have evolved off the main sequence yet.

https://www.spacetelescope.org/videos/heic1211a/

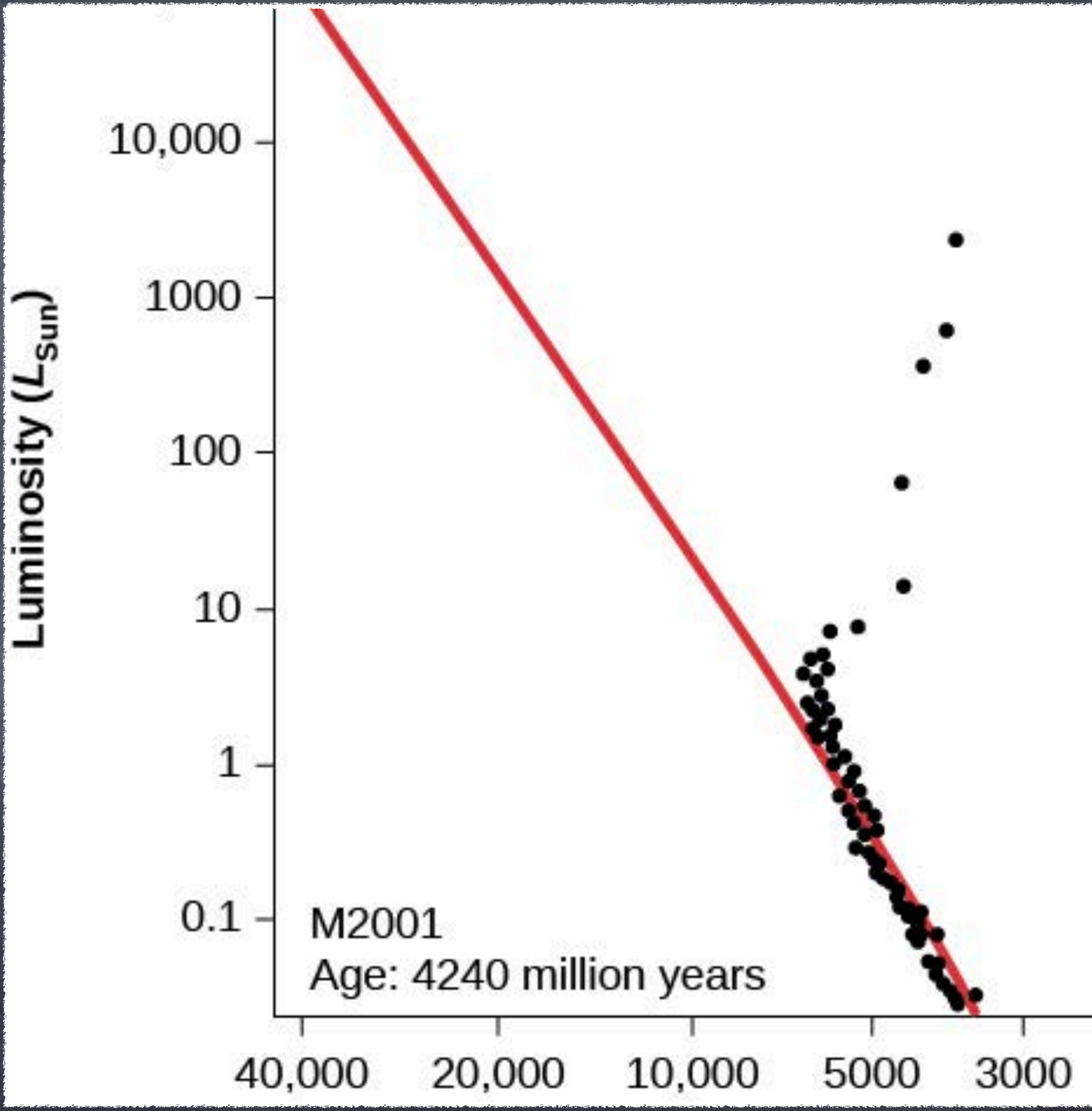


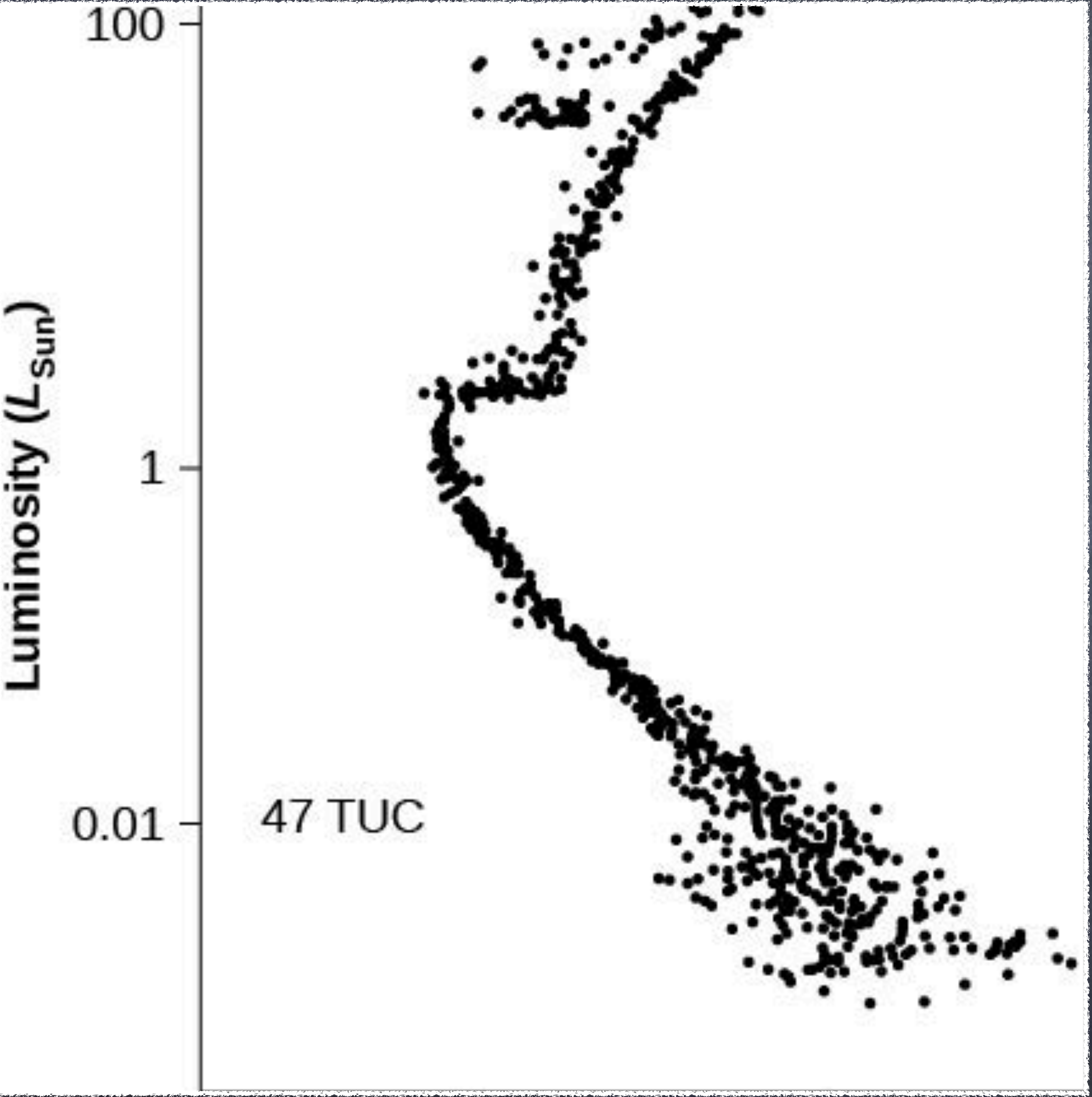
- An open cluster that is a bit older. We can see one star has evolved off the main sequence and become a red giant.

An older cluster, the most massive star on the main sequence is about 20 times as luminous as the sun. Also we see stars have evolved onto red giant.



- An even older cluster at 4.2 billion years old.
- The most massive star on the main sequence is about the mass of our sun.
- We see a number of stars that have evolved off the main sequence onto the red giant branch.





- An even older globular cluster.
- No massive stars, but lots of stars in the red giant branch.
- Now you can see why it is called a branch, because in clusters like this it looks like it branches off from the main sequence.

https://www.spacetelescope.org/videos/heic1017b/

How do we get ages for these clusters?
The ages actually are coming from the HR diagram.
One looks for the most massive stars still on the main sequence and estimate the age based on that.

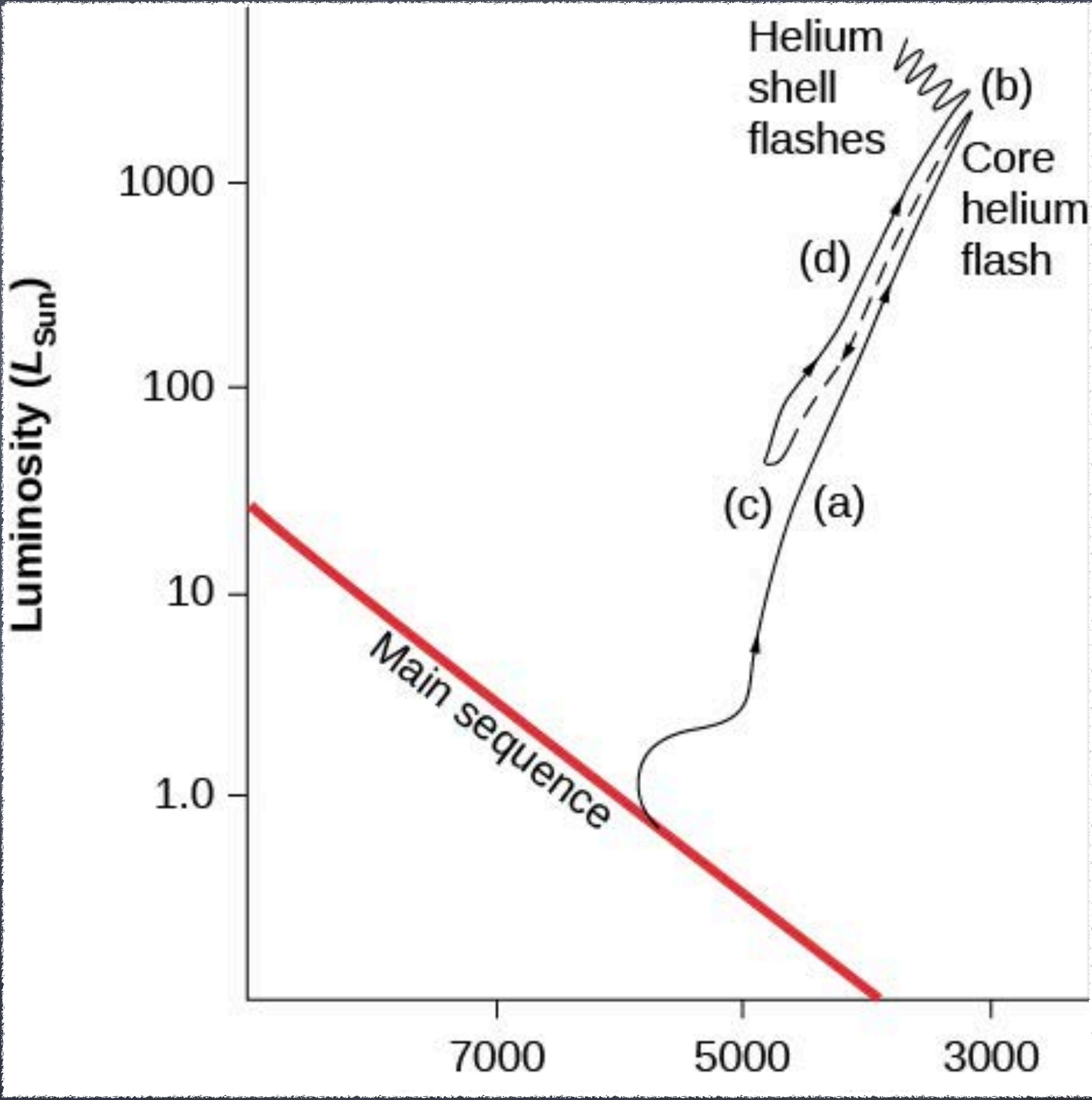
Helium Fusion

- What we have described so far occurs for most stars. Further evolution depends strongly on the mass of the star.
- Let's first consider stars less than twice as massive as our sun. These is the vast majority of stars.
- These stars during the red giant phase the core continues to shrink getter hotter and hotter.
- When the core reaches 100 million K it becomes hot enough for helium to fuse in what is called the triple-alpha process where 3 Helium nuclei fuse to become a carbon atom.

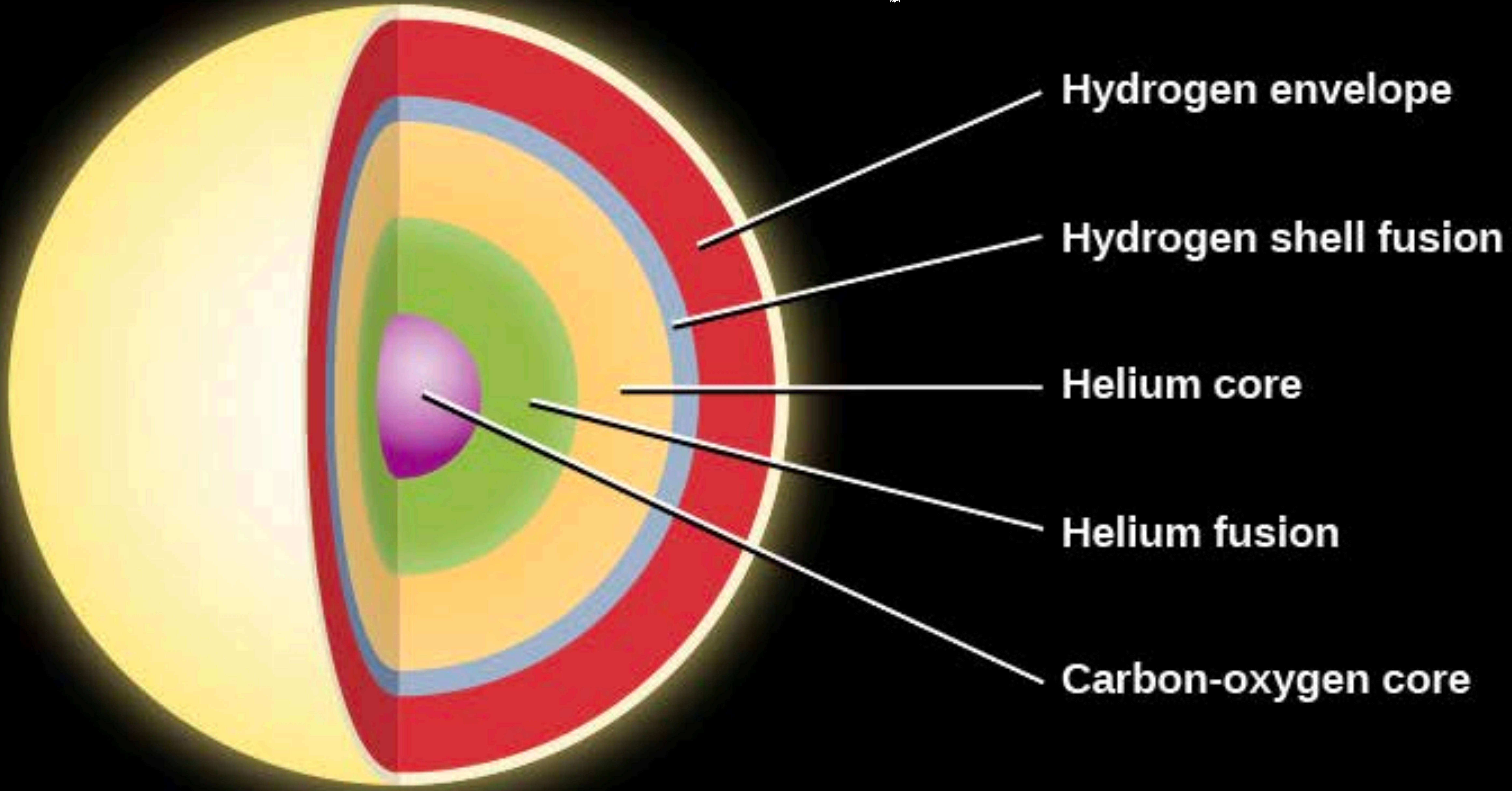
- For these lower mass stars (2.0 -0.8 the mass of our sun), this helium burning turns on in a burst called the helium flash (b).

- The star quickly establishes a new balance between gravity and pressure as the helium fuses into carbon and some oxygen (c).

- The helium is converted rather quickly and we return to a state like before. A carbon-oxygen core not hot enough for fusion that is contracting and heating and shells of fusion that expand the star.



Now there are both a helium and hydrogen burning shells



- For a star like the sun this marks the end of its life as a star. The core will never get hot enough to fuse other elements. Let's recap its life:
  - Main sequence star: hydrogen fusion in the core, 11 billion years, surface temperature of 5800K, luminosity of 1 and size of 1.
  - Red Giant - helium core, hydrogen fusion in a shell, 1.3 billion years, surface temperature min 3100K, luminosity max 2300 and size of 165.
  - Helium Fusion in core, 100 million years, surface temperature of 4800K, luminosity 50 and size of 10.
  - Giant again - carbon/oxygen core, helium and hydrogen fusion in shells, 20 million years, surface temperature 3100K, luminosity 5200 and size of 180.

Mass Loss

- When a star is puffed up as a giant the gas near the photosphere has low escape velocity.
- Radiation pressure, stellar pulsations and events like the helium flash can all lead to gas being driven from the outer atmosphere.
- Astronomers estimate that by the time a star like our sun has reached the helium flash it has already blown off 25% of its mass.
- Aging stars are often surrounded by gas shells containing 10-20% of the sun's mass.

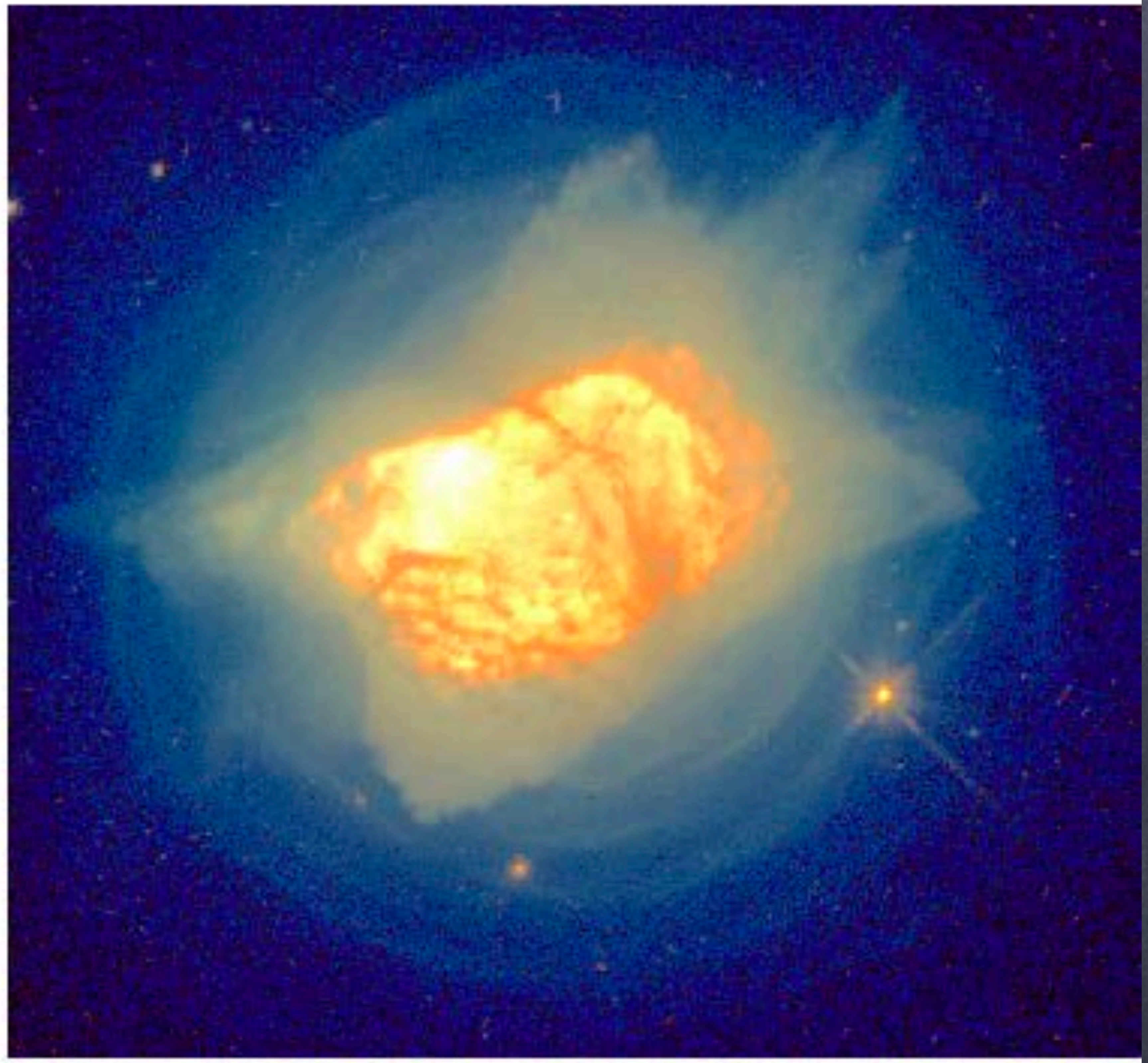
Planetary Nebula

- When fusion in the core ceases the core will shrink again, getting hotter and dumping that energy into the rest of the star and surrounding gas.
- These hot cores with winds and uv radiation can ionize the surrounding gas and cause it glow.
- These glowing rings of gas are called planetary nebula, though they dont have anything to do with planets. They last for about 50,000 years at most.

(a)

(b)

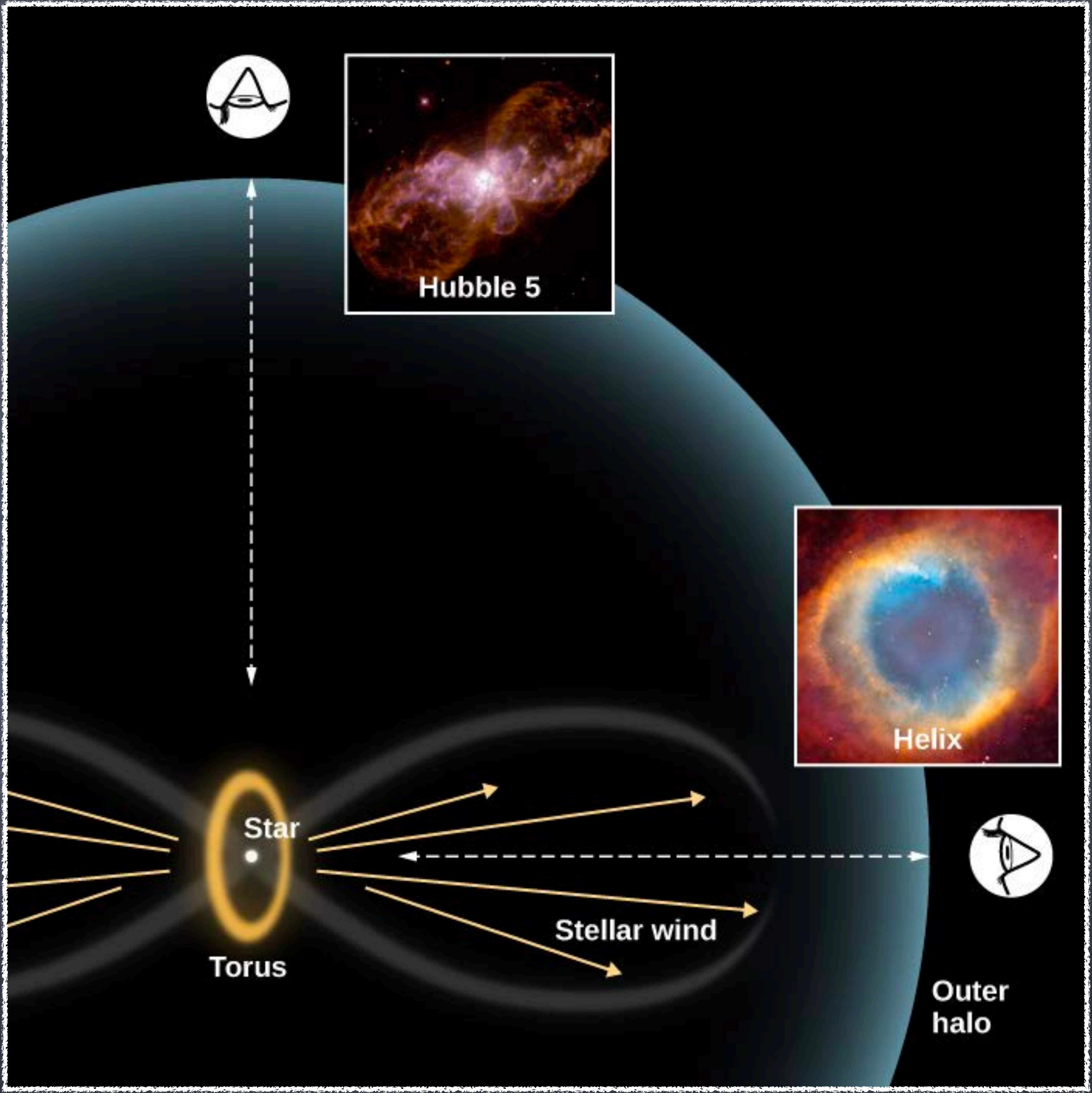
(c)



(d)

These are all planetary nebula though they look very different. In some cases you can see the central star which really isn't a star anymore, just the core of a former star, but vary hot, more than 100,000K

- It's thought the variety of ways planetary nebula appear depends on how we see it.
- From one view we see two rings making an infinity sign.
- But form a view 90° different we see two rings with one in front of the other.
- Clearly there are other differences that may have to do with when we see it, the nature of surrounding gas and if the star has a companion.



Our Sun as a Red Giant

- 4.5 billion years ago the sun was only 70% as bright as now, but we think the oceans were still there so the Earth was probably heated a bit more by having a CO_2 atmosphere.
- As the sun ages it will increase its luminosity, eventually melting the ice caps and then evaporating the oceans. This will cause a runaway greenhouse effect like on Venus.
- When the sun becomes a red giant it will swallow Mercury and Venus. Those planets will spiral in and be vaporized. It is not clear if Earth will follow the same fate.
- You might want to move all life to Mars, but there is a few 100 million year gap between Earth becoming to hot and Mars becoming hot enough to support life.

The Fates of More Massive Stars (>2.0 solar masses)

- Massive stars evolve much the same as the sun, but much quicker.
- They can swell in size to the orbit of Jupiter and they lose mass very effectively.
- The main difference is that these stars do not have a helium flash, instead starting to fuse it slowly and most importantly they are able to fuse elements more massive than helium and carbon.


Eta Carinae, 100 times the mass of the sun.
We see lots of material being blown away at speeds of 1000 km/s.

Massive Stars

- Stars more massive than 8 solar masses can fuse carbon atoms in their core. More massive stars can fuse oxygen, neon, magnesium and finally silicon. In all these situations a new helium nucleus is fused to the element increasing its atomic number by 2.
- Iron, the product of fusing Helium with silicon is the final step in this process, because fusing anything with iron does not produce energy. Iron is the most bound nucleus and going away from iron always takes energy.
- So once a star reaches iron there is no more energy to gain from fusion. The stars life is over.


Hydrogen envelope
Hydrogen, helium fusion
Helium fusion
Carbon, oxygen fusion
Magnesium, neon, oxygen fusion
Silicon, sulfur fusion
Iron ash

Nucleosynthesis

- All of the heavier elements are made in stars. Elements up to iron are made in massive stars.
- Heavier elements than iron are made in supernova where the core of a star explodes.
- These elements are then returned to the interstellar medium where they can be recycled into the next round of star and planet formation.
- Older globular clusters have fewer heavy elements than young open cluster, because being older less stars had gone through their lives and created heavier elements.
- The abundance of these heavier elements is closely related the ages of stellar systems.

End of the Line

- The least massive stars (brown dwarfs) never fuse normal hydrogen. The most massive stars fuse elements up to iron. In all cases the fuel eventually runs out.

- Thus the fate of all stars is to die. For massive stars this can take tens of millions of years while for low mass stars it can take hundreds of billions of years. But in the end the fuel is used up and fusion can no longer occur.