

STELLAR EVOLUTION

ASTROPHYSICS

Dr H.T.Sener

CLUSTERS IN HR DIAGRAM

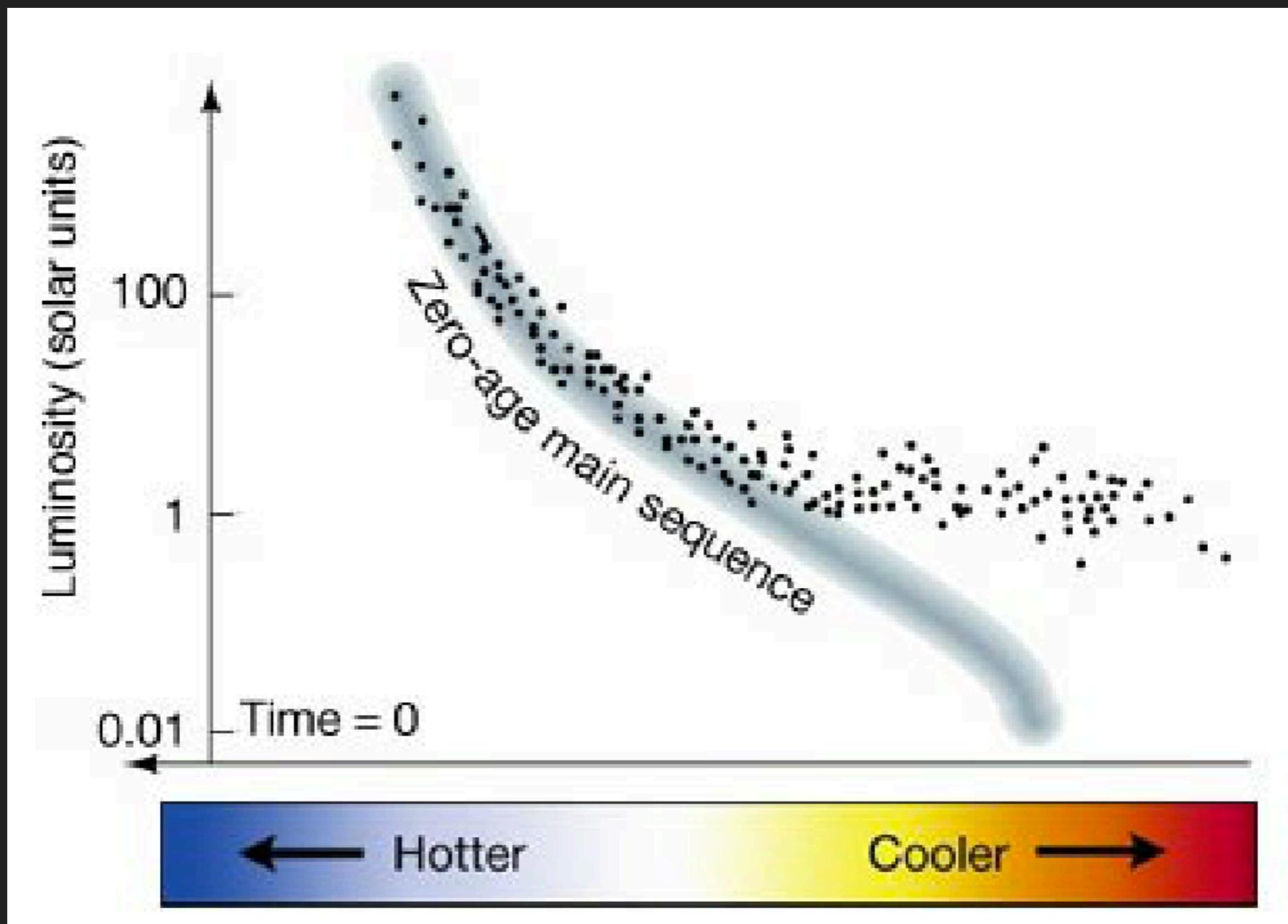


Pleiades

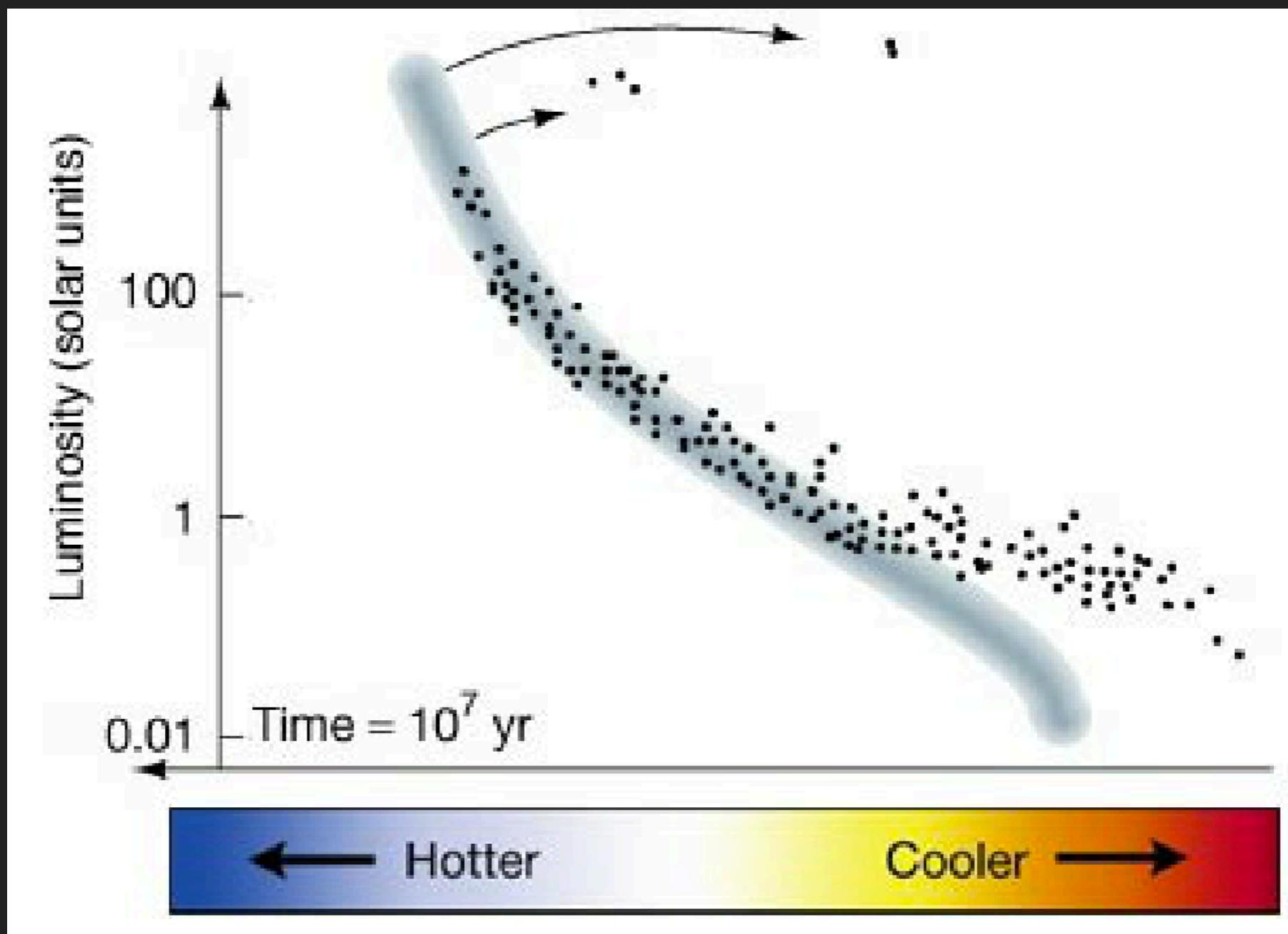


M2

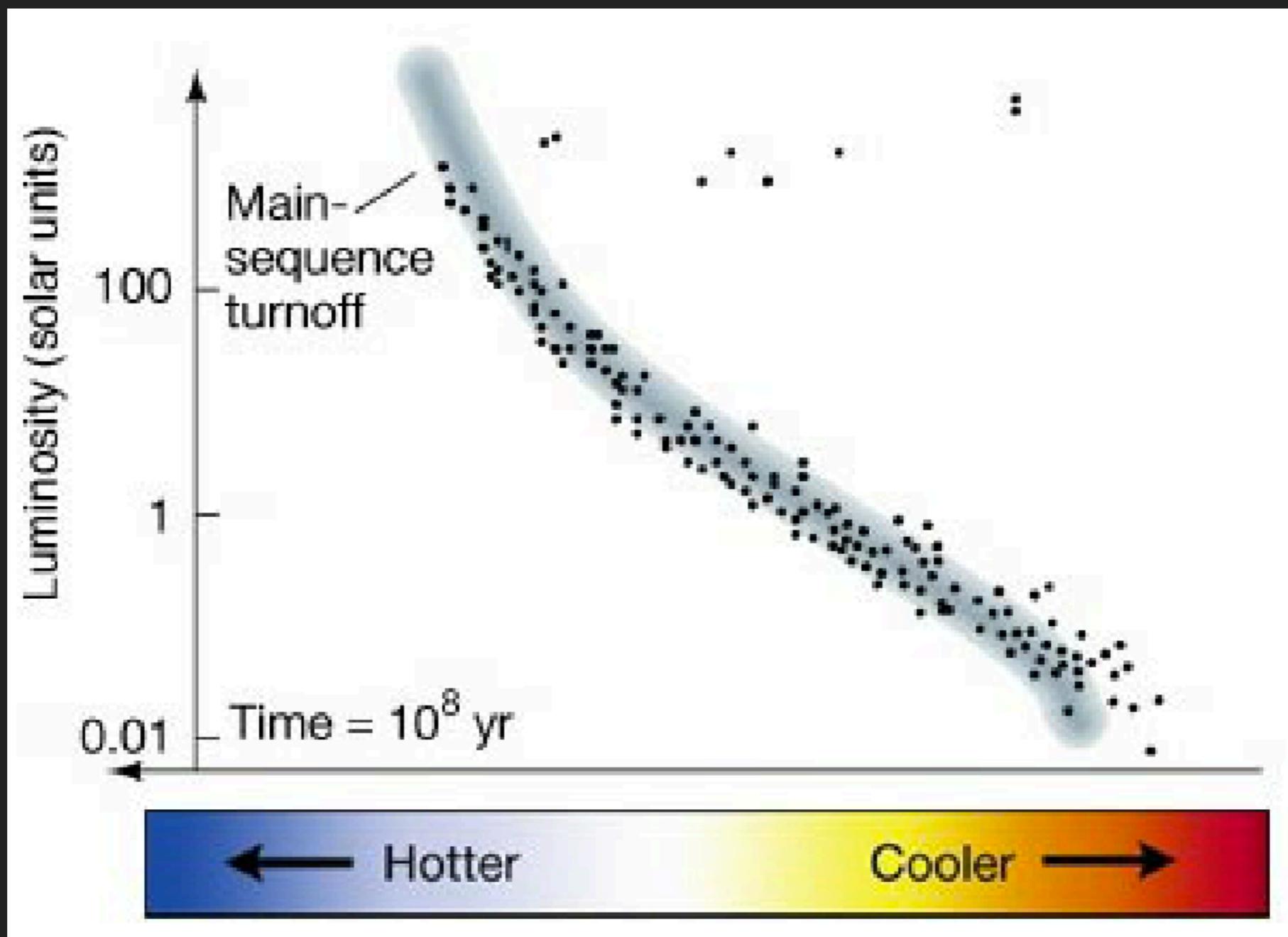
CLUSTERS IN HR DIAGRAM



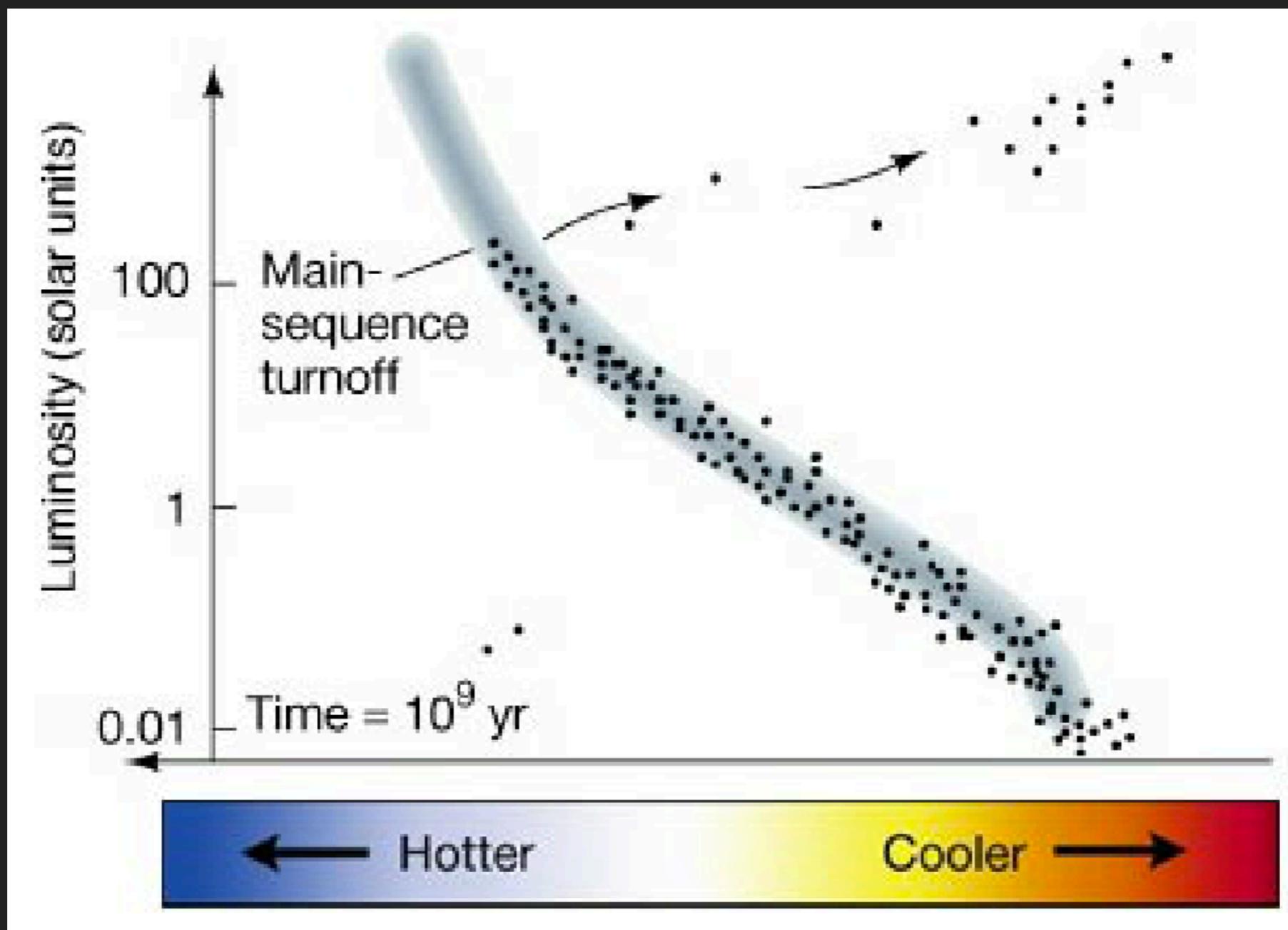
CLUSTERS IN HR DIAGRAM



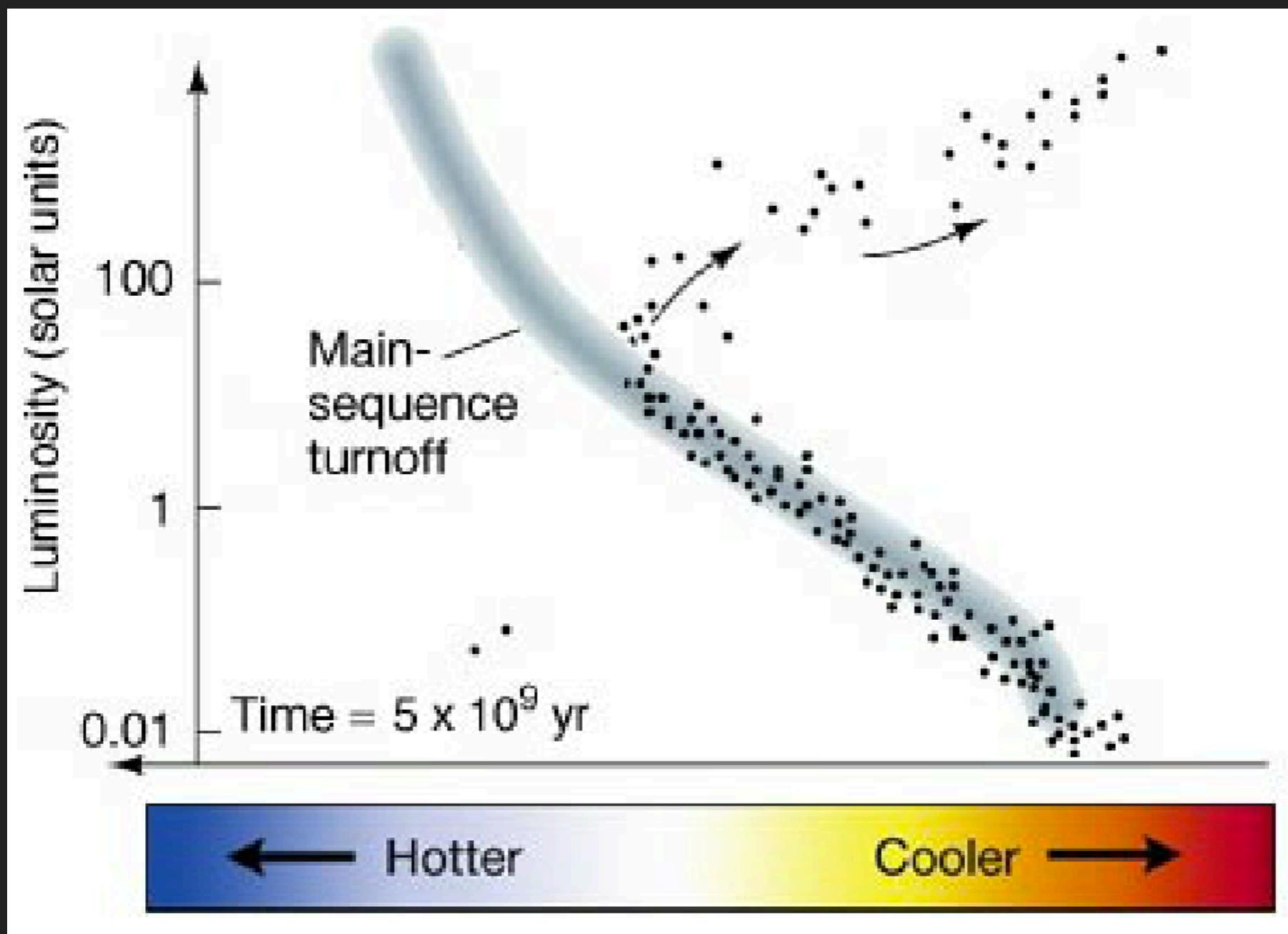
CLUSTERS IN HR DIAGRAM



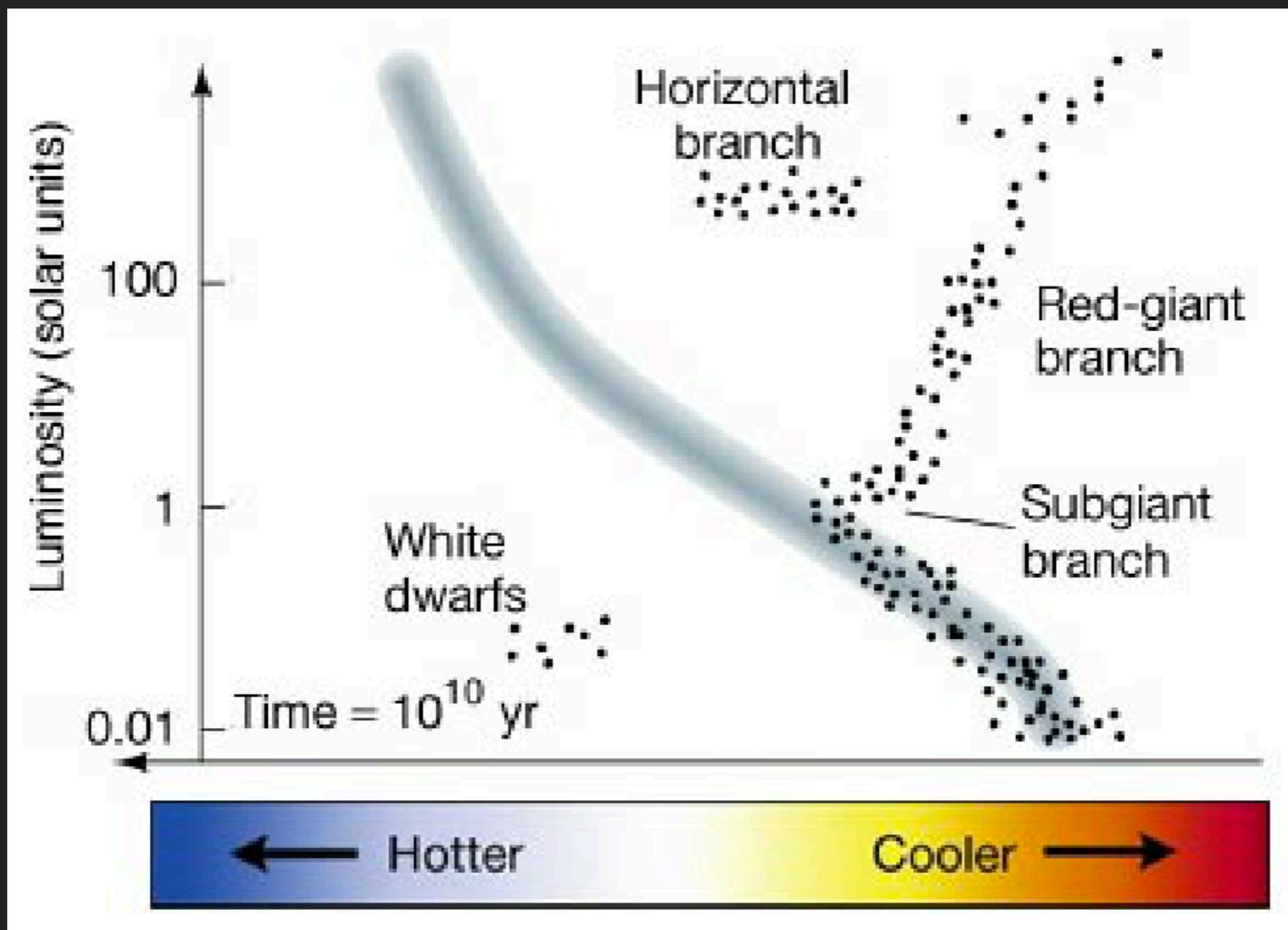
CLUSTERS IN HR DIAGRAM



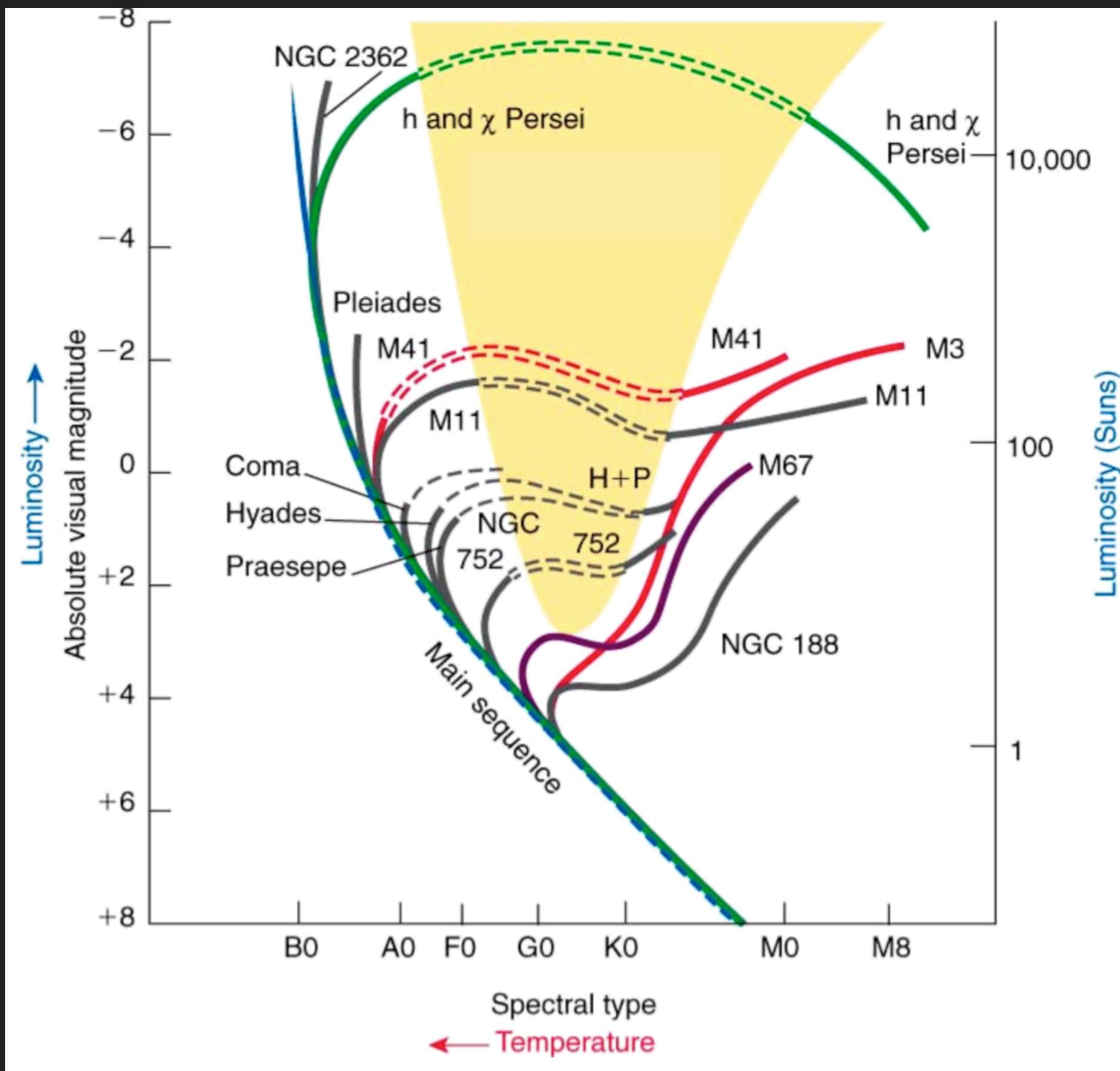
CLUSTERS IN HR DIAGRAM



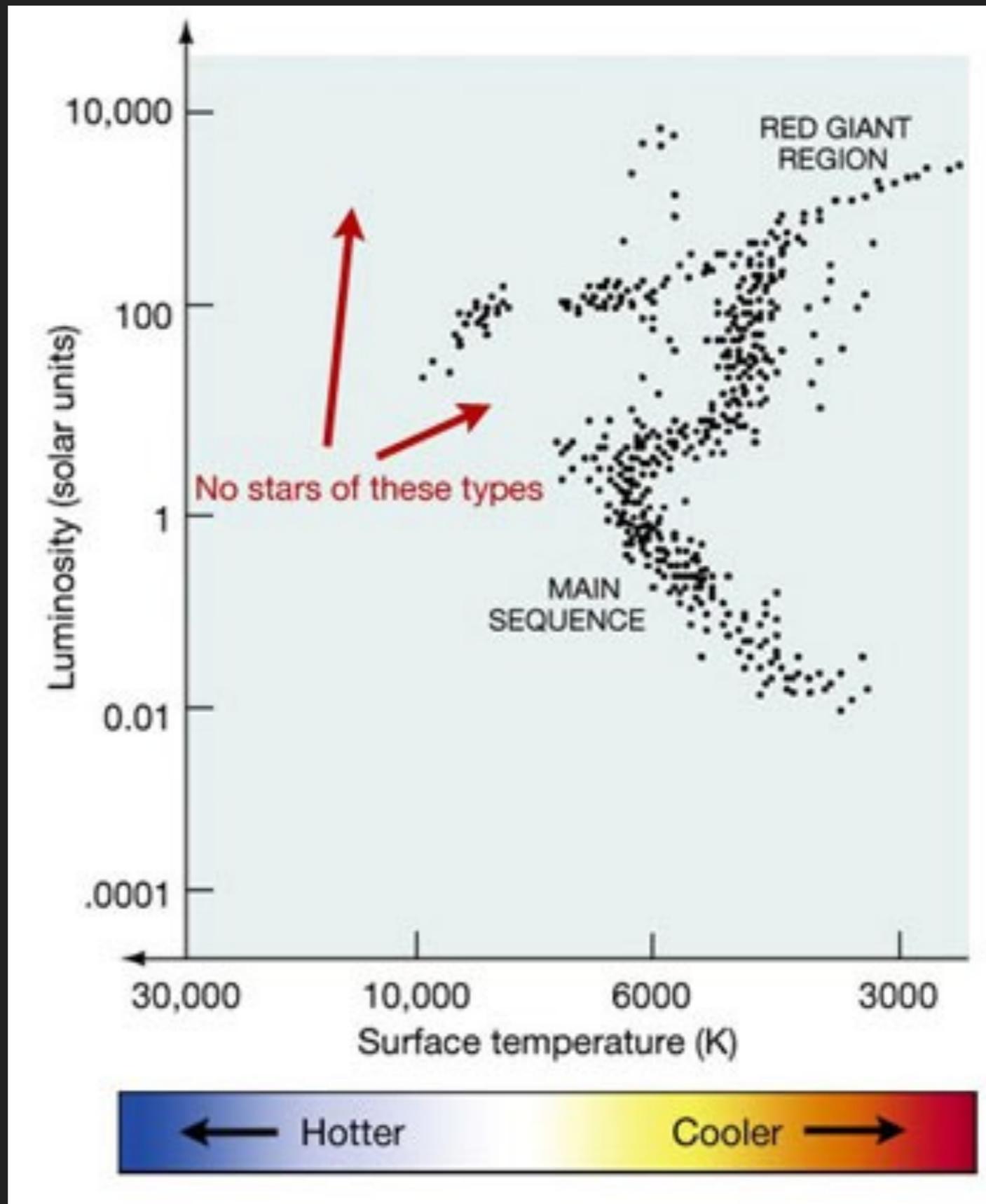
CLUSTERS IN HR DIAGRAM



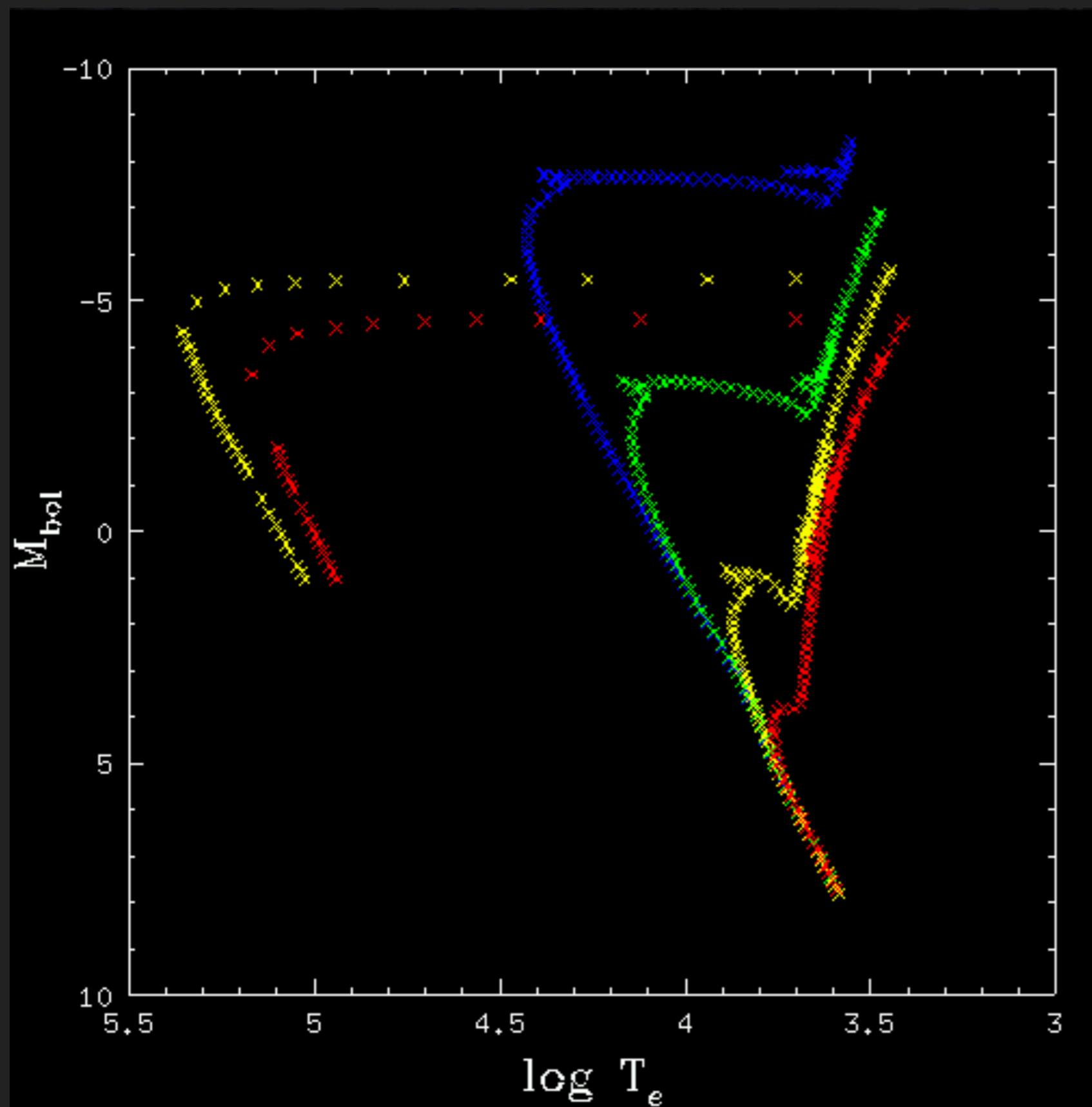
HR DIAGRAM FOR CLUSTERS



HR DIAGRAM FOR CLUSTERS

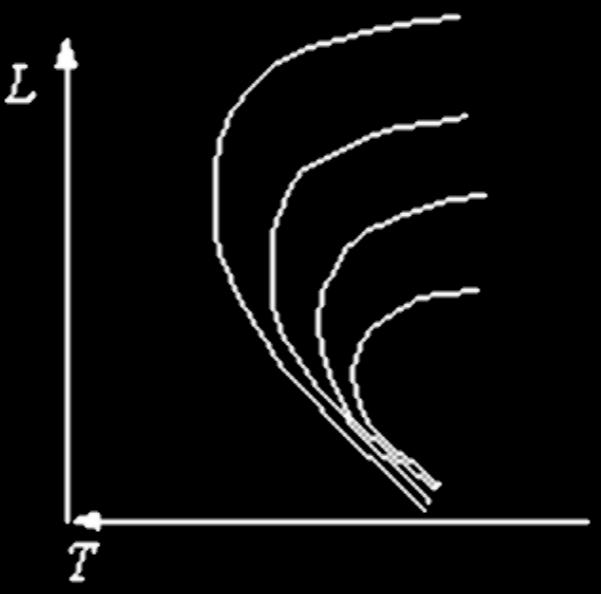
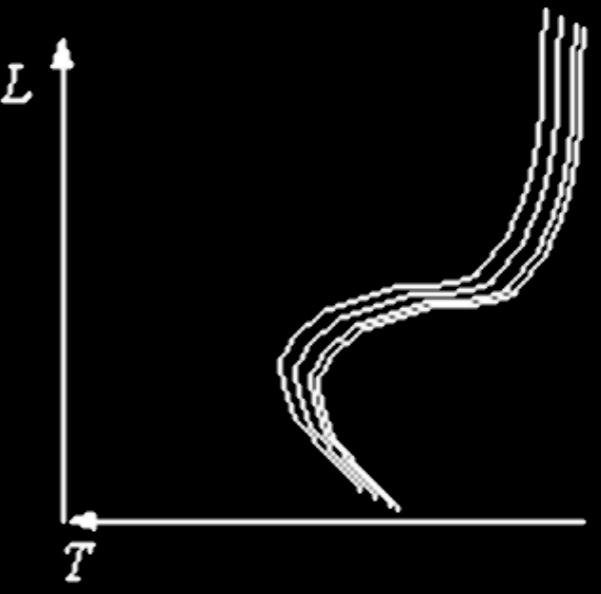


ISOCHRONE

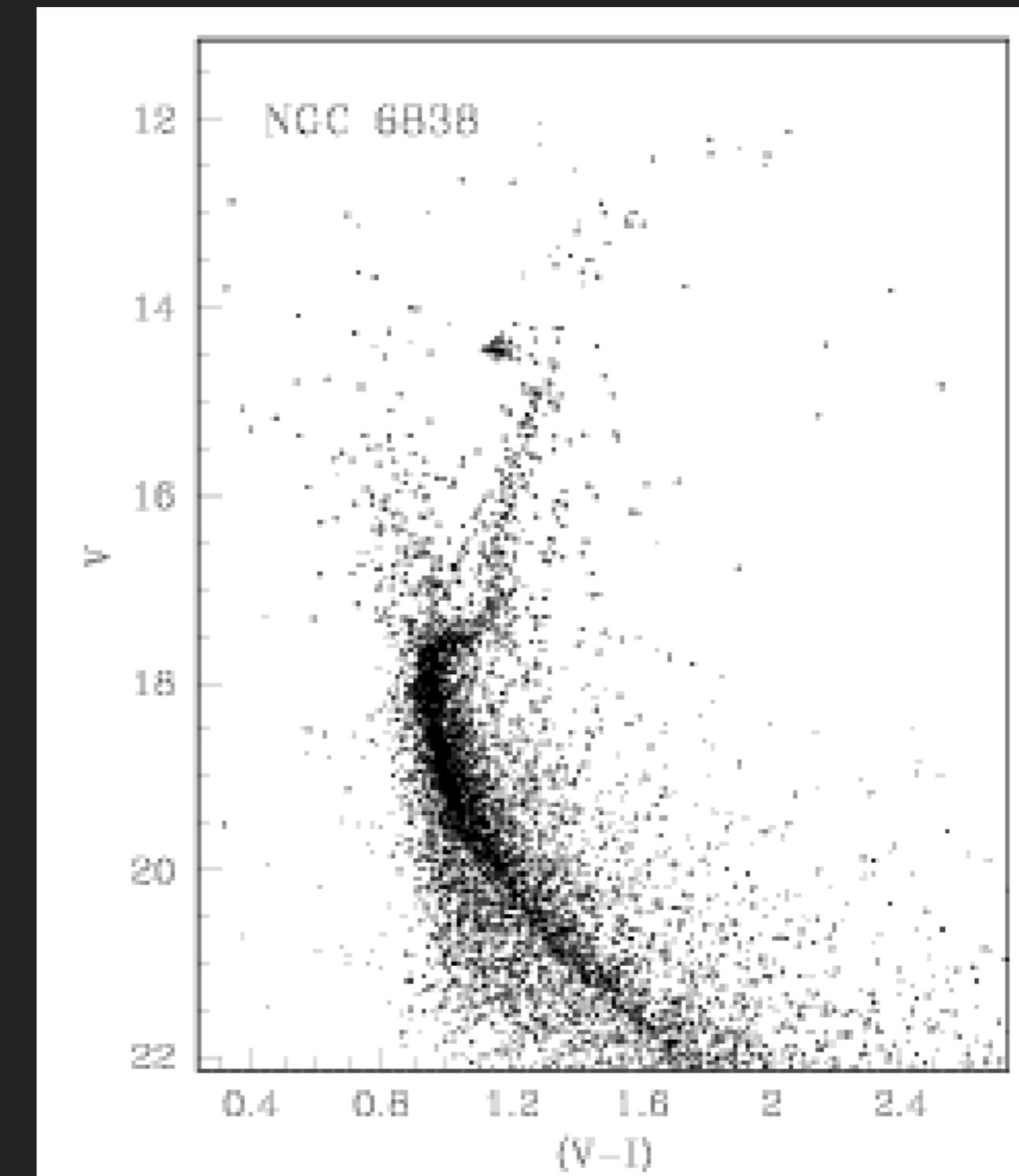
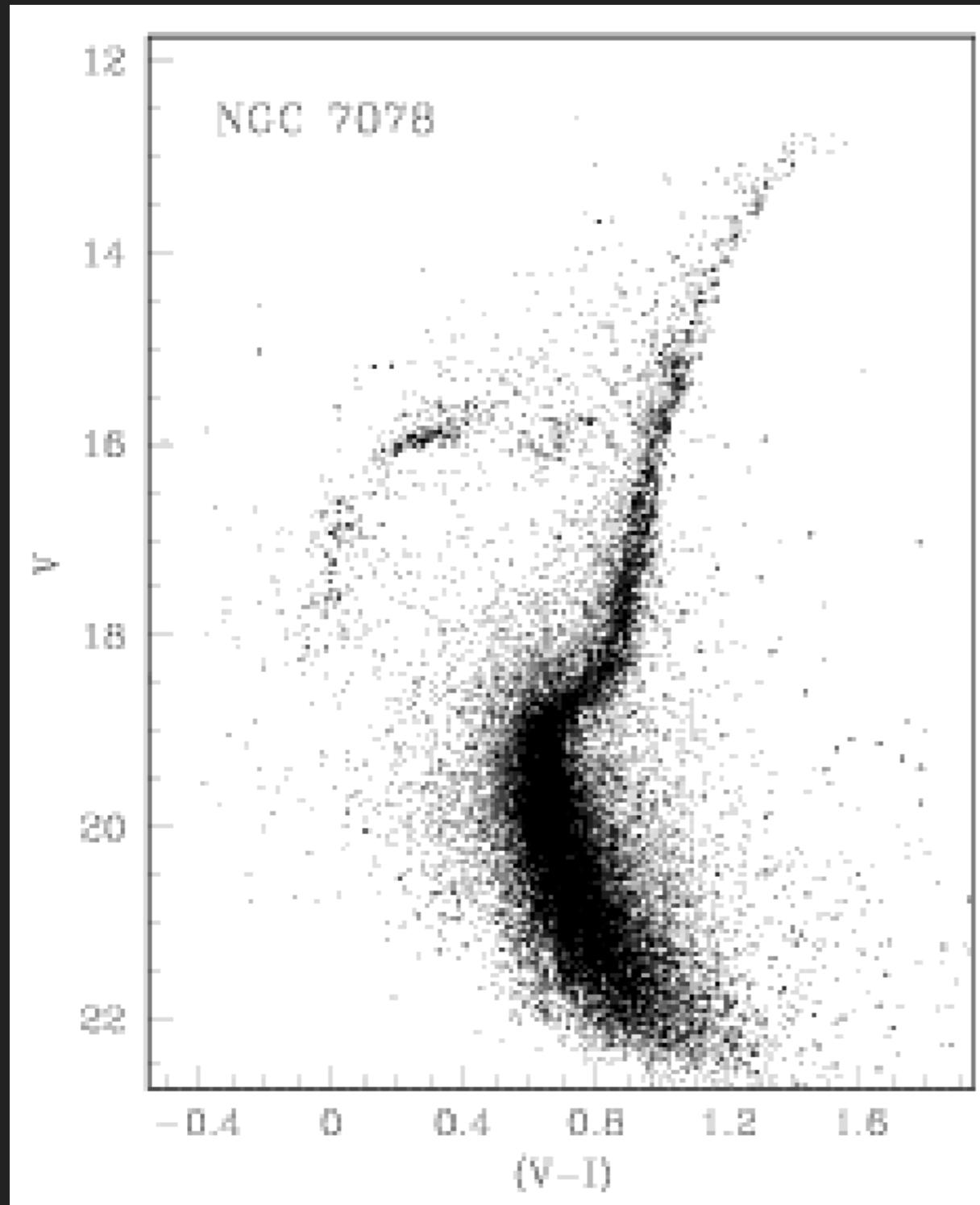


10 million years
100 million years
1 billion years
10 billion years

CLUSTERS IN COMPARISON

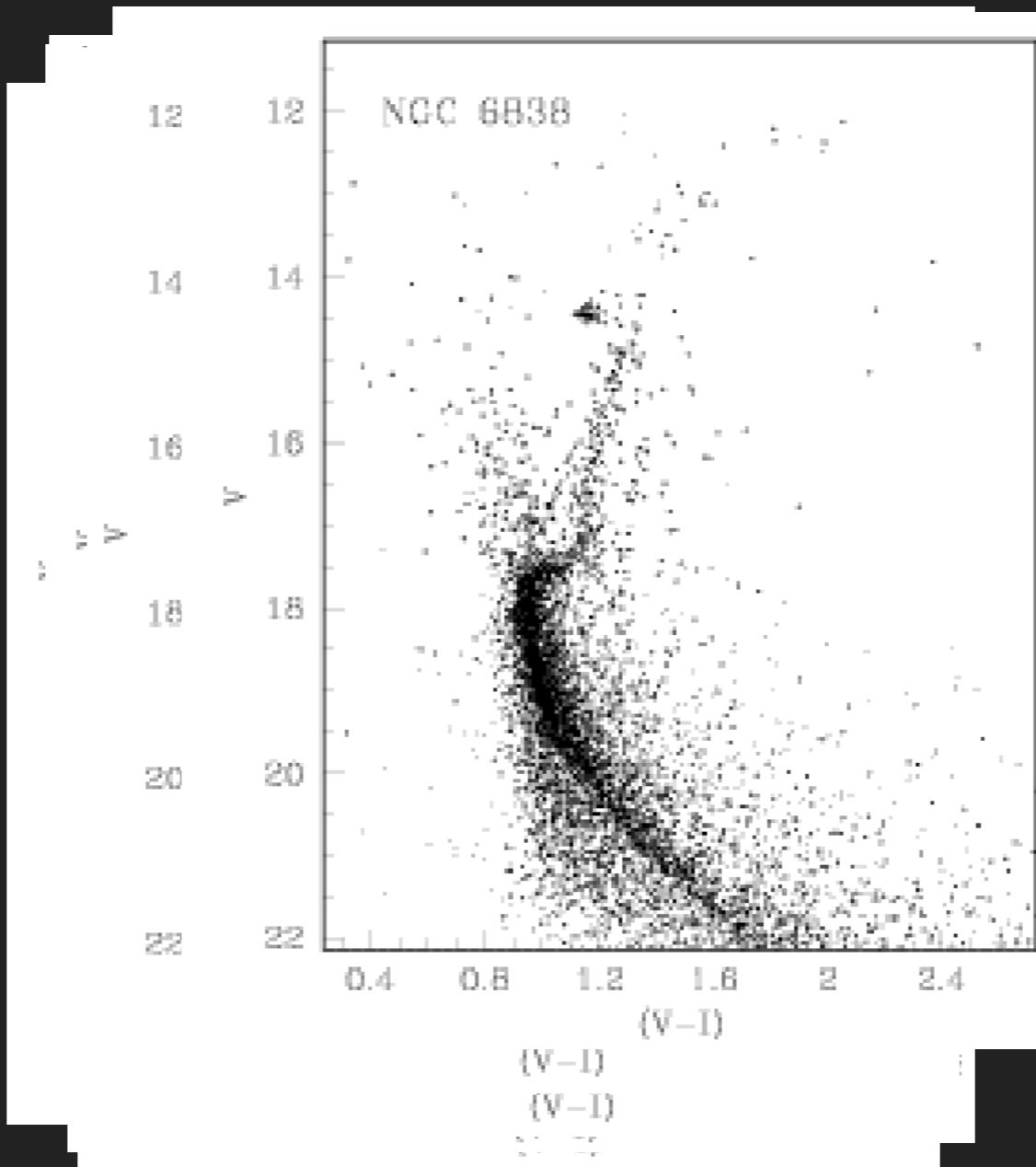
	OPEN (GALACTIC) CLUSTERS	GLOBULAR CLUSTERS
Morphology	Loose, irregular collections of stars	Dense, spherically symmetric distribution of stars
Membership	$\sim 10^2$ stars, plus gas	$\sim 10^5 - 10^6$ stars, no gas
Distribution	restricted to galactic plane	roughly spherical distribution around Milky Way
H-R Diagram	 <p>An H-R diagram with luminosity (L) on the vertical axis and temperature (T) on the horizontal axis. It displays several distinct stellar populations, each represented by a series of points forming a main sequence that curves upwards and then turns off towards higher temperatures. The populations are offset from each other along the temperature axis.</p> <ul style="list-style-type: none">— all show main sequence— wide variety of turn-off points	 <p>An H-R diagram with luminosity (L) on the vertical axis and temperature (T) on the horizontal axis. It shows a single, tightly packed stellar population. The main sequence is relatively short and ends at a very similar turn-off point for all stars in the cluster.</p> <ul style="list-style-type: none">— all show short main sequence— all have very similar turn-off points

HOMEWORK

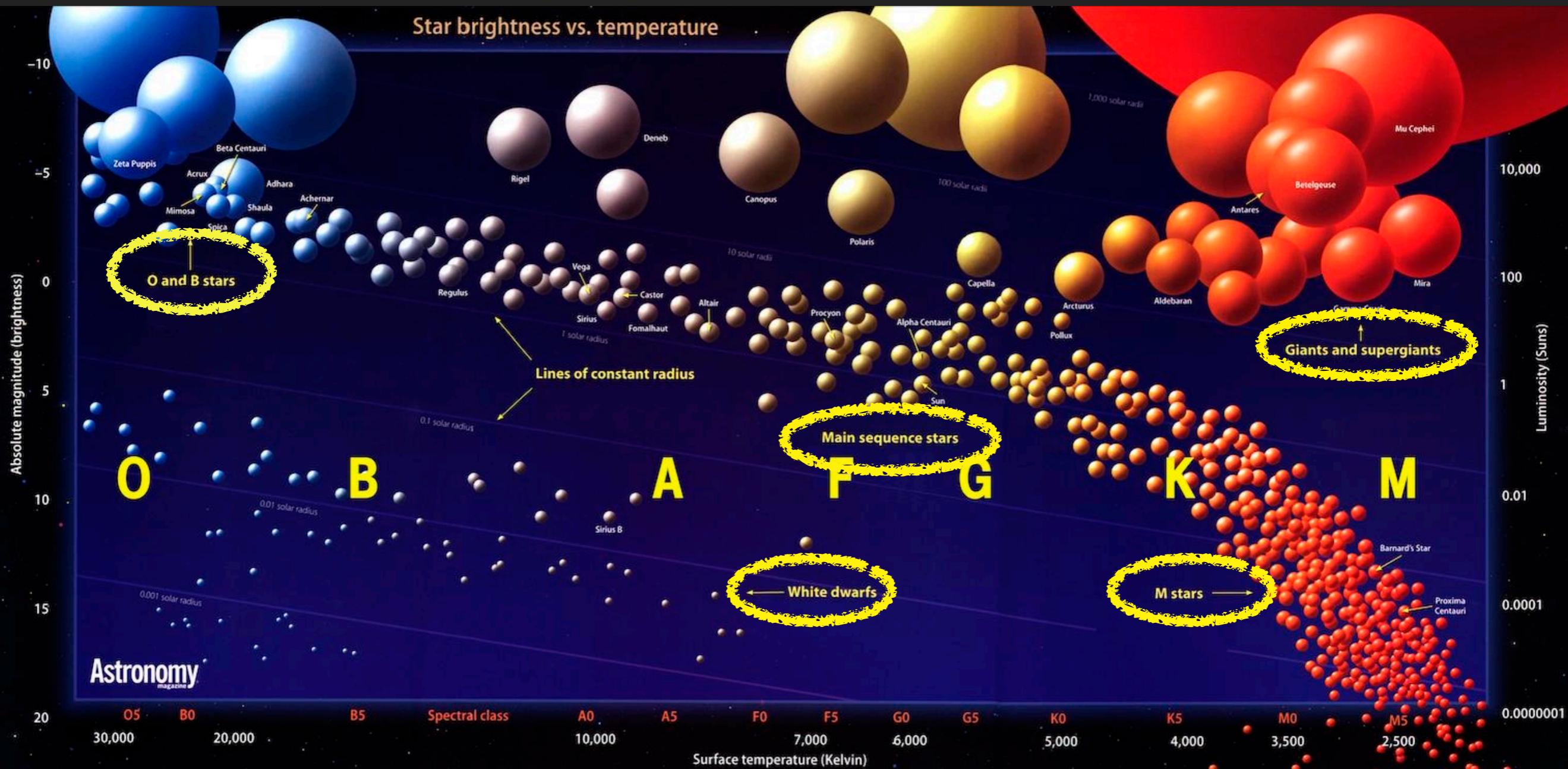


- Try to find the turn off point and put into an age order

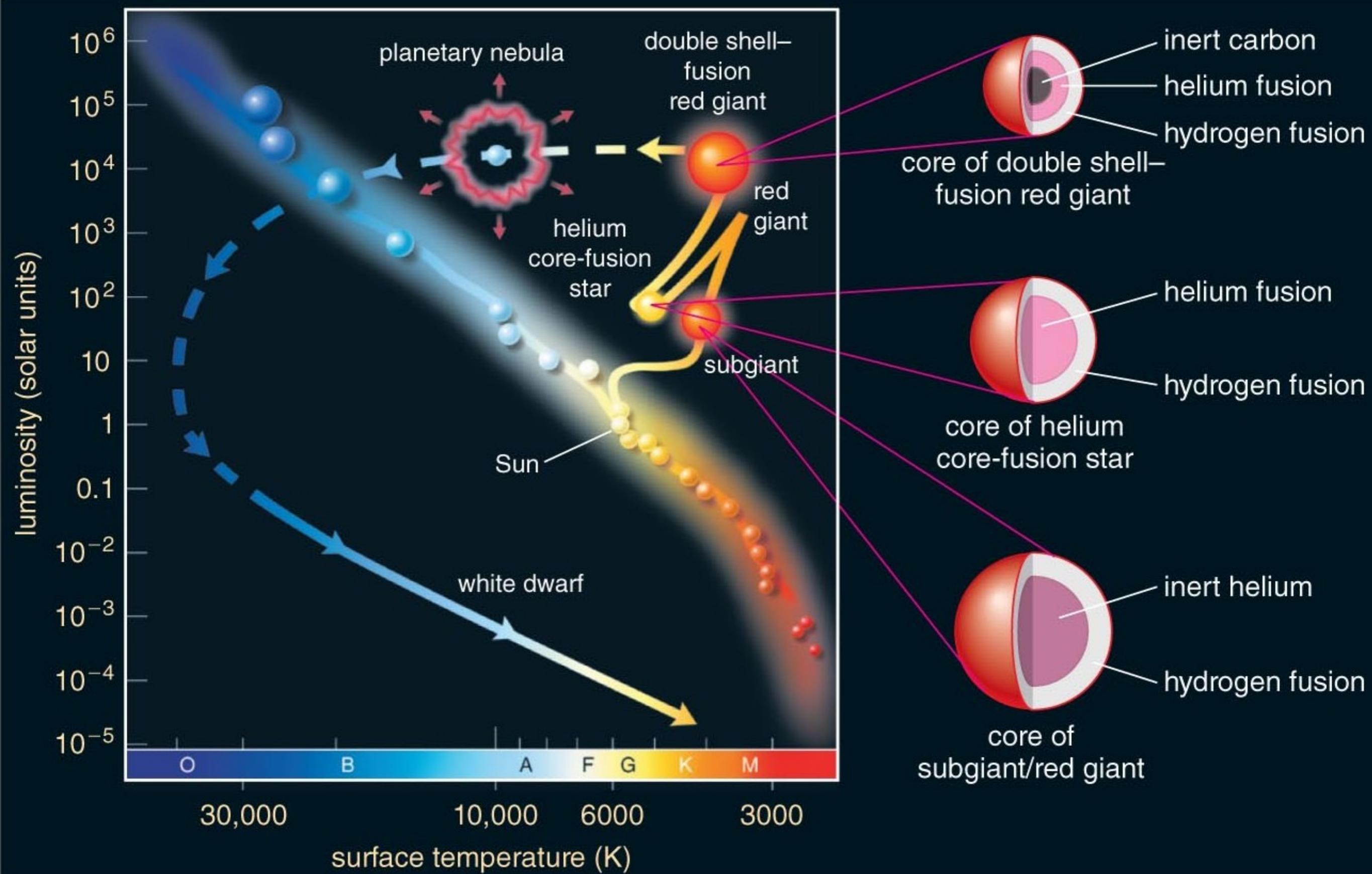
HOMEWORK



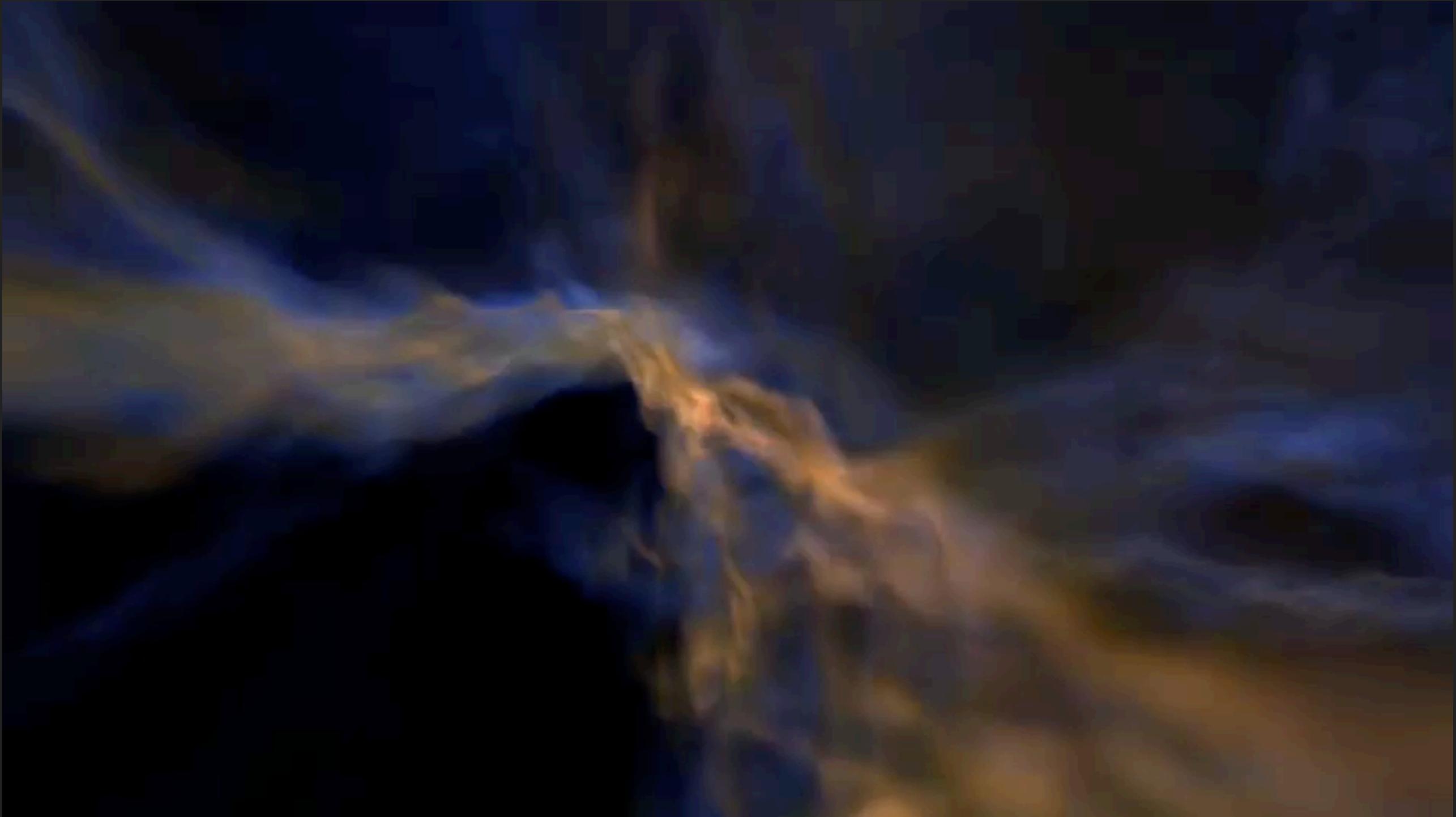
STARS ON HR DIAGRAM



HR DIAGRAM - EVOLUTION



TOWARDS MAIN SEQUENCE

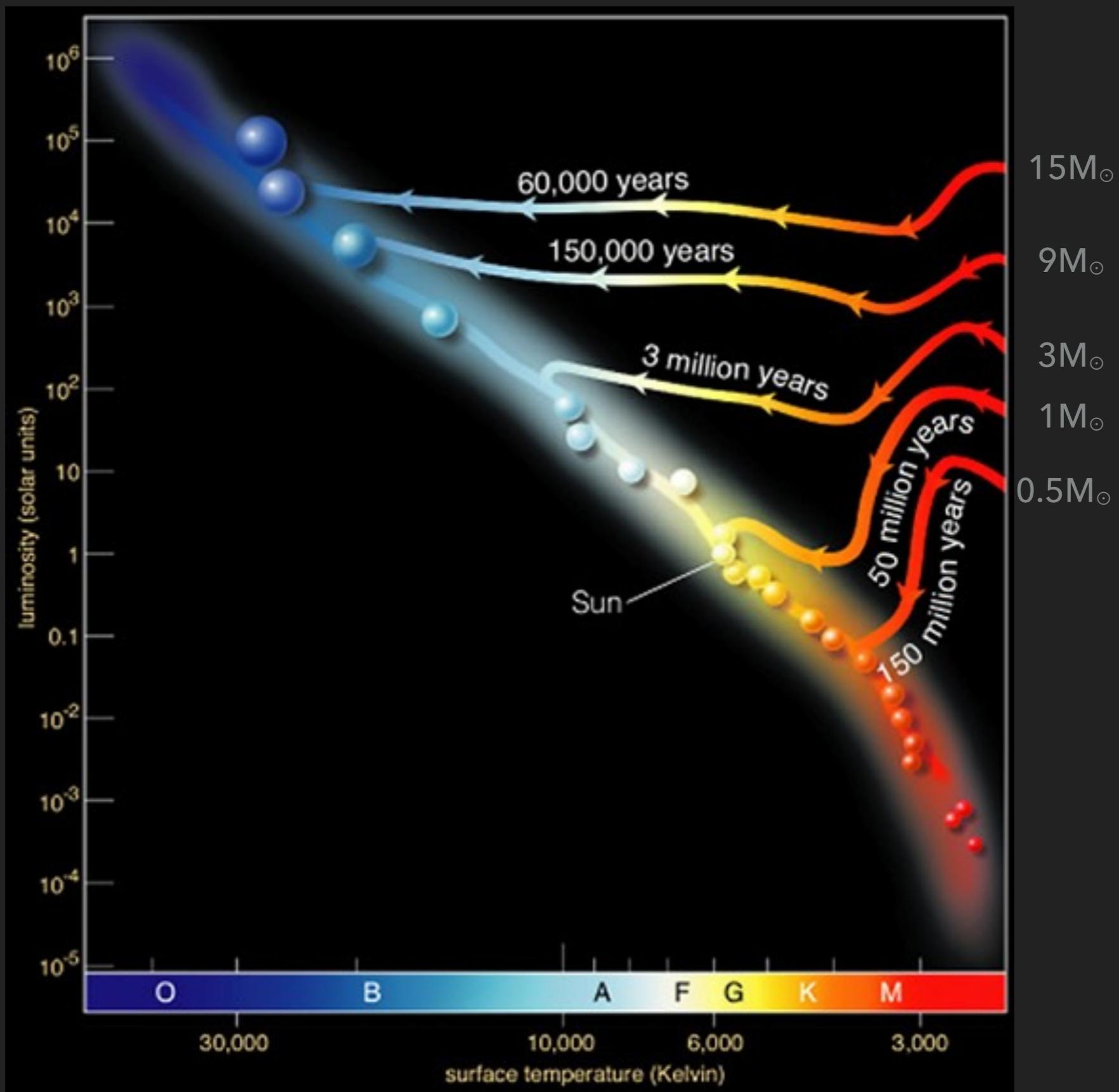


PROTOSTARS

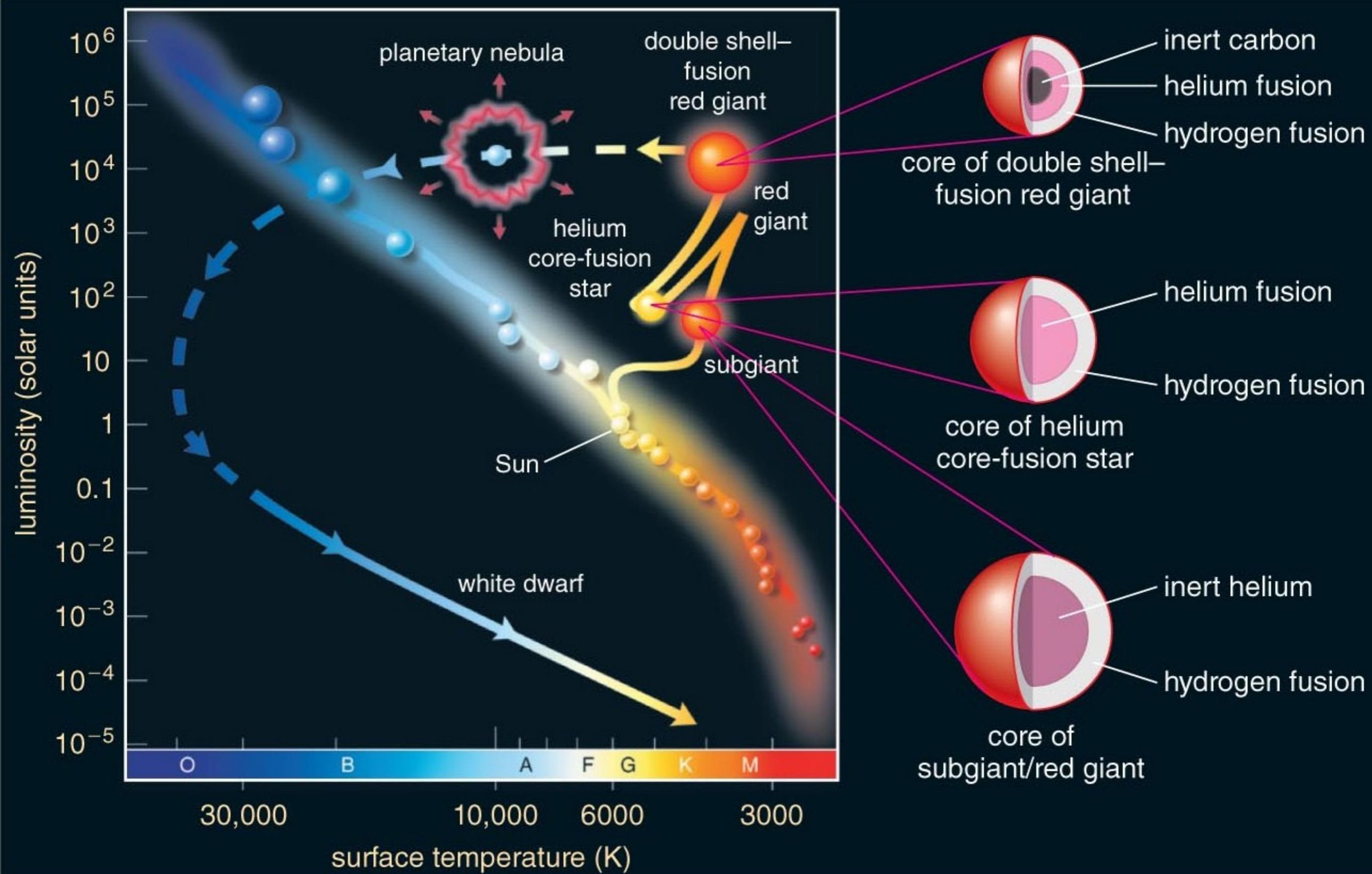
- ▶ Earliest phase of stellar evolution
 - ▶ Molecular clouds
- Stellar nursery
- ▶ Molecular Hydrogen (H_2)
 - ▶ Infrared
- ▶ Pillars of Creation
- @Eagle Nebulae
- ▶ Left: 4 Lightyears long



PROTOSTARS



MAIN SEQUENCE



ZERO AGE MAIN SEQUENCE

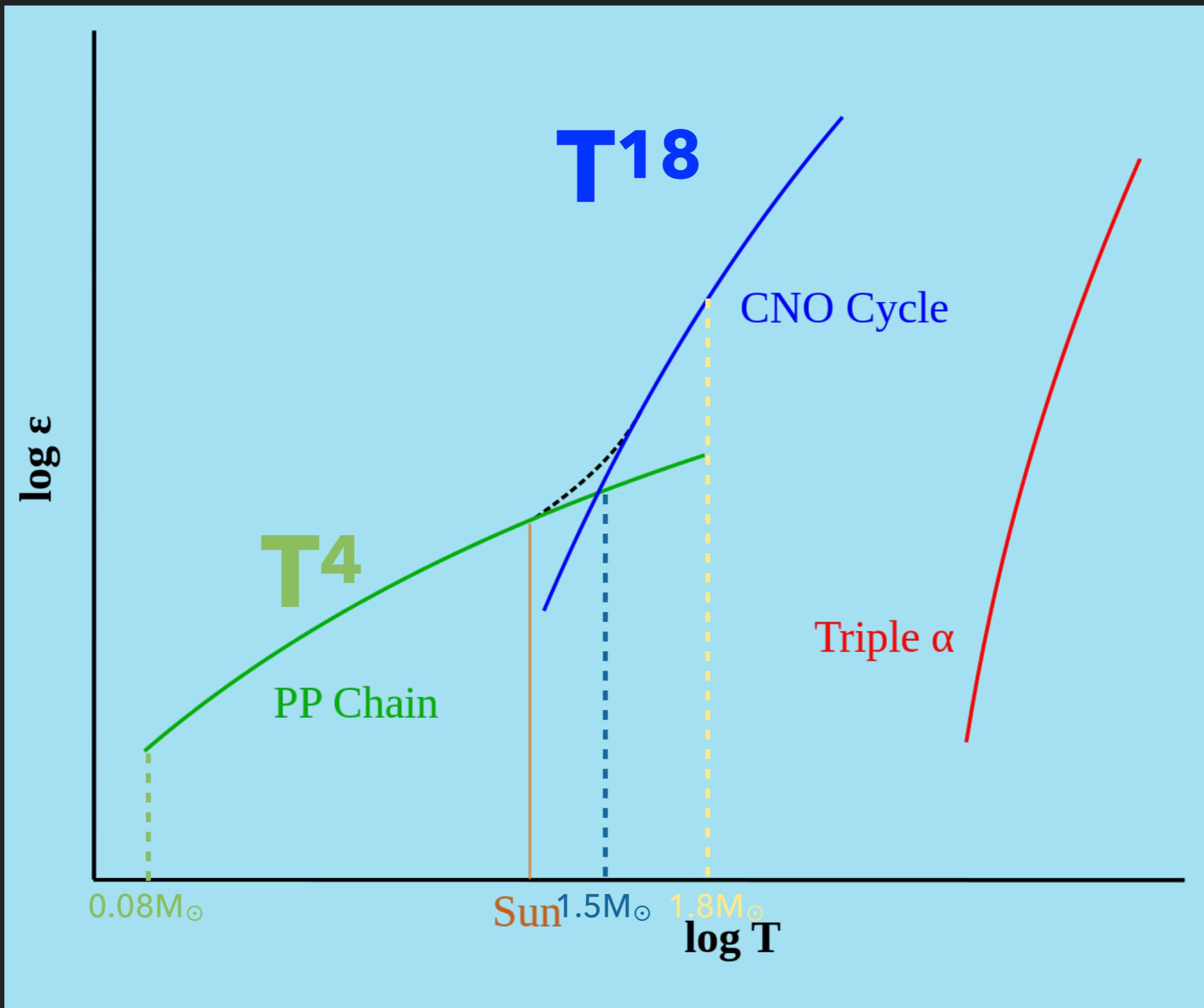
- ▶ Energy Production ↓
- ▶ Mass compress
- ▶ Fusion Rate ↑
- ▶ Energy Production ↑
- ▶ Star expands
- ▶ Core pressure ↓

HYDROSTATIC EQUILIBRIUM

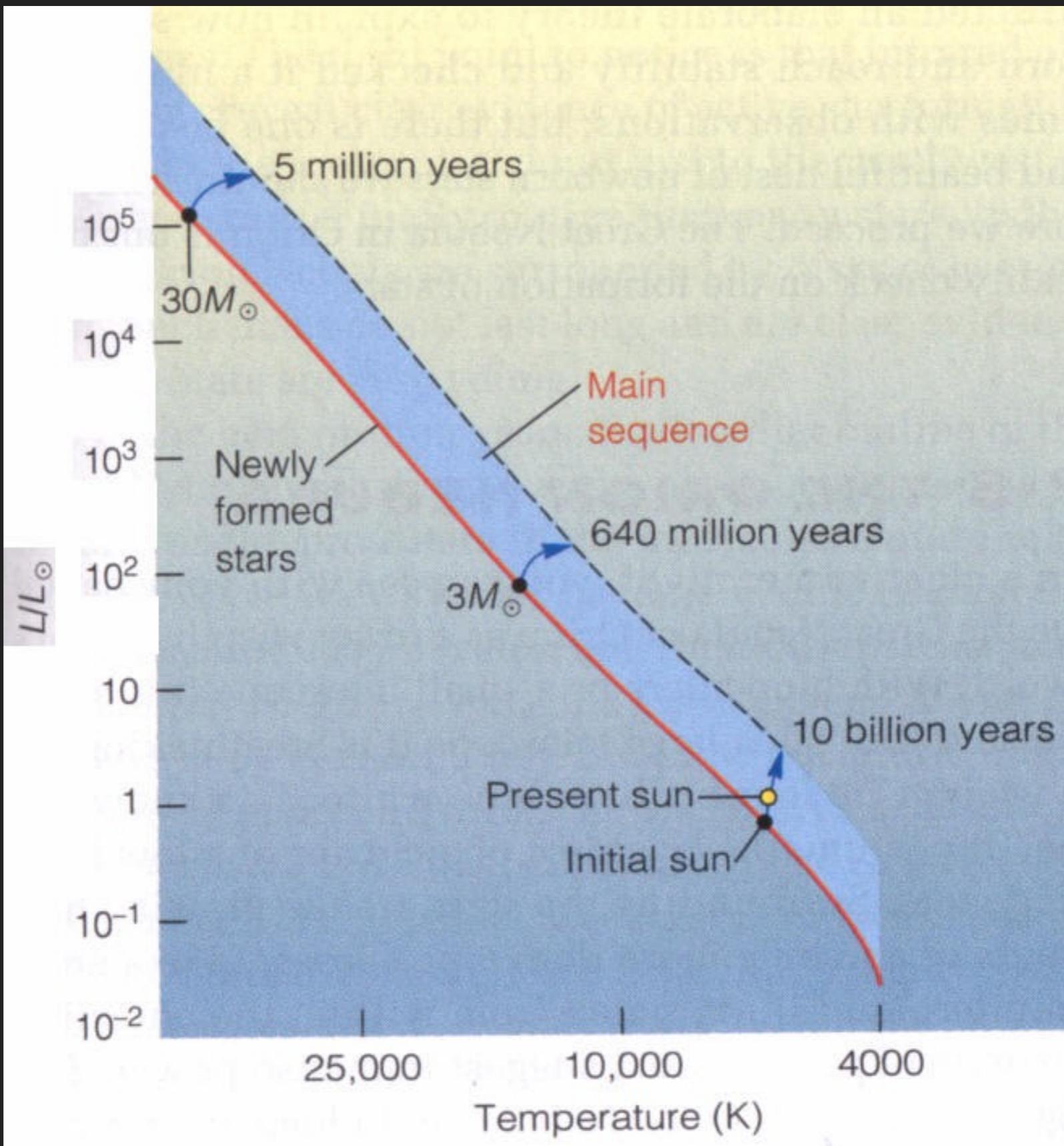
Star is stable during Main Sequence

ENERGY PRODUCTION

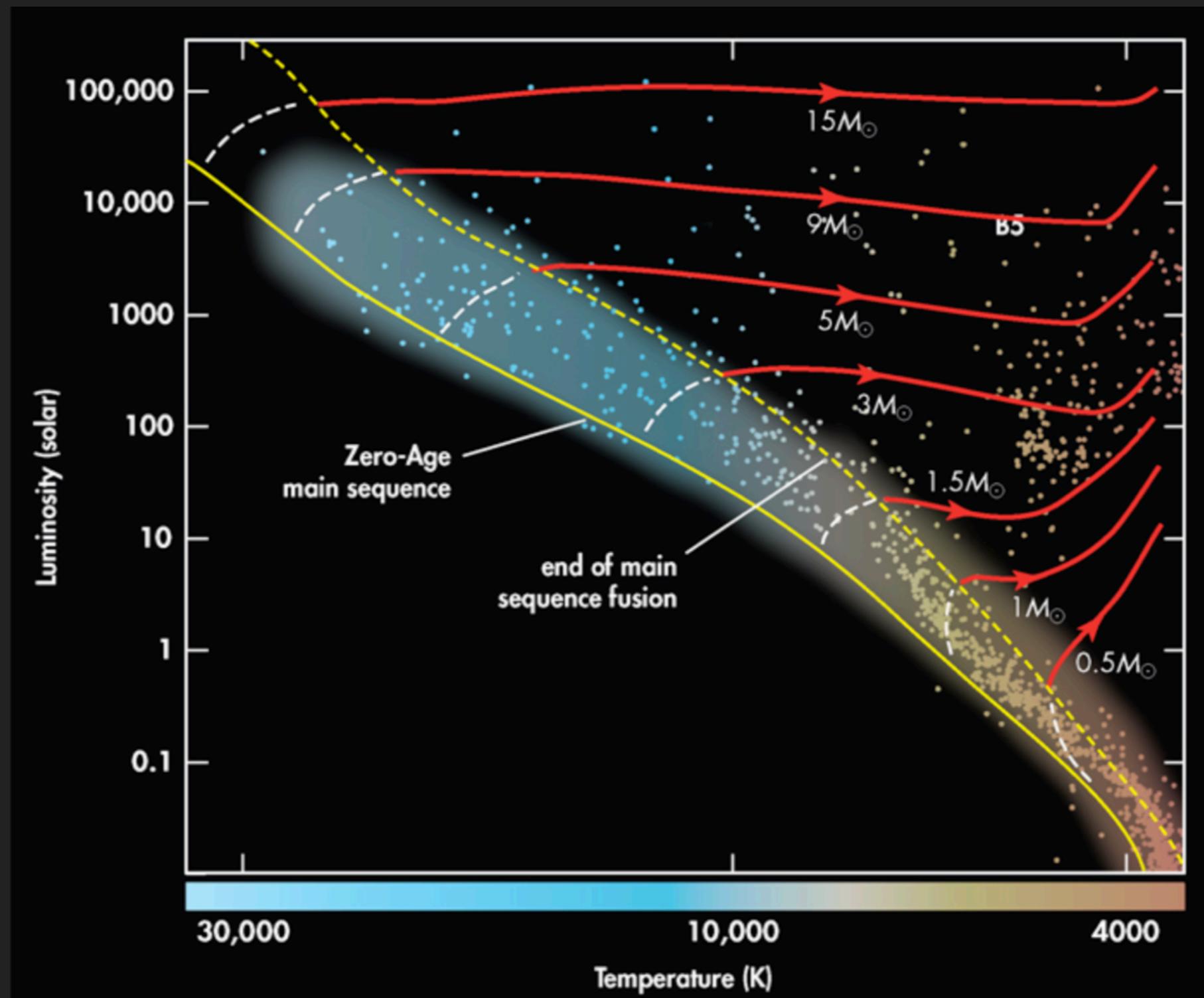
- Nuclear reaction rates are very sensitive to core temperature!



MAIN SEQUENCE



TERMINAL AGE MAIN SEQUENCE



THE EFFECT OF METALLICITY ON MS

Hydrogen mass fraction

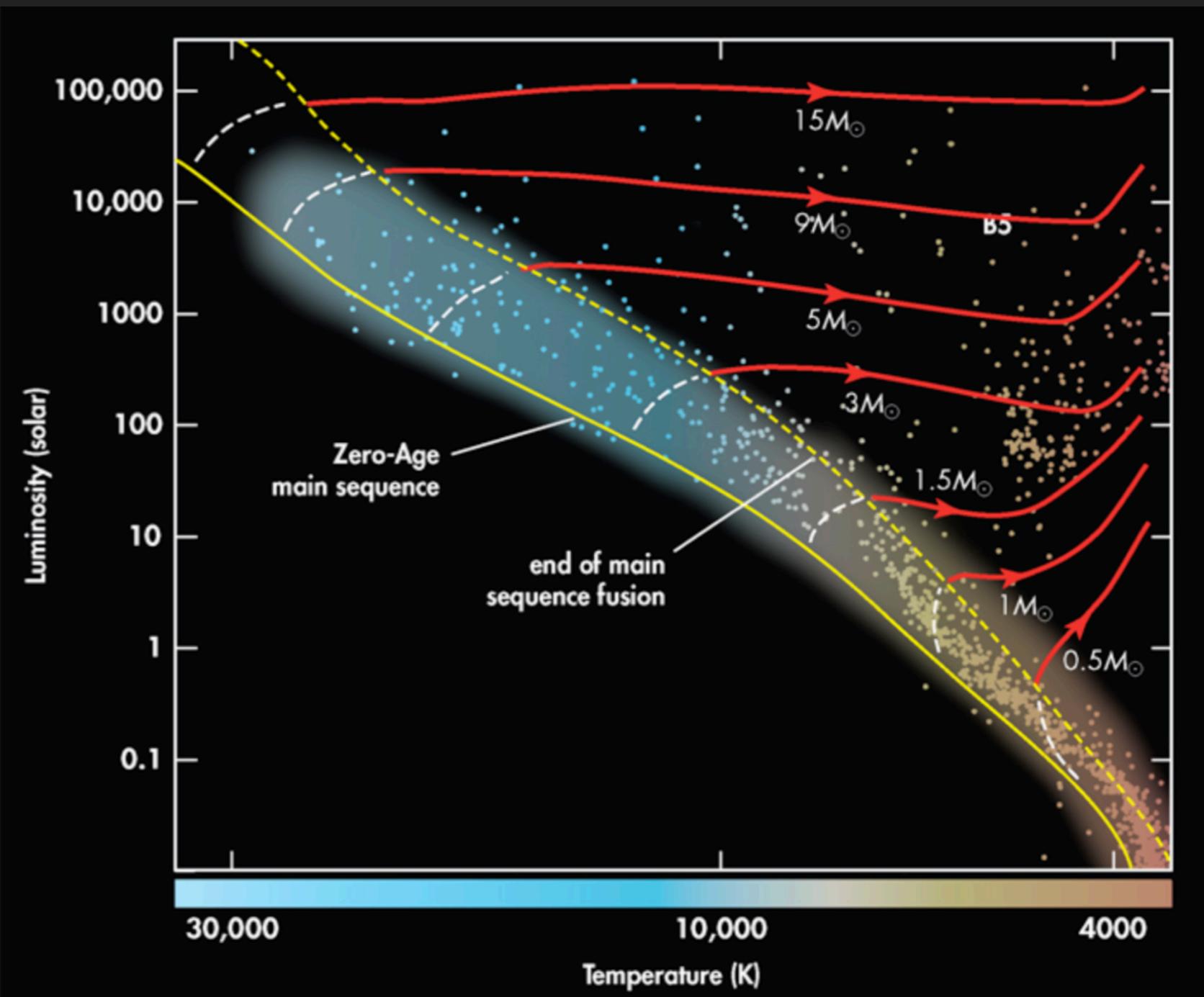
$$X = 0.7381$$

Helium mass fraction

$$Y = 0.2485$$

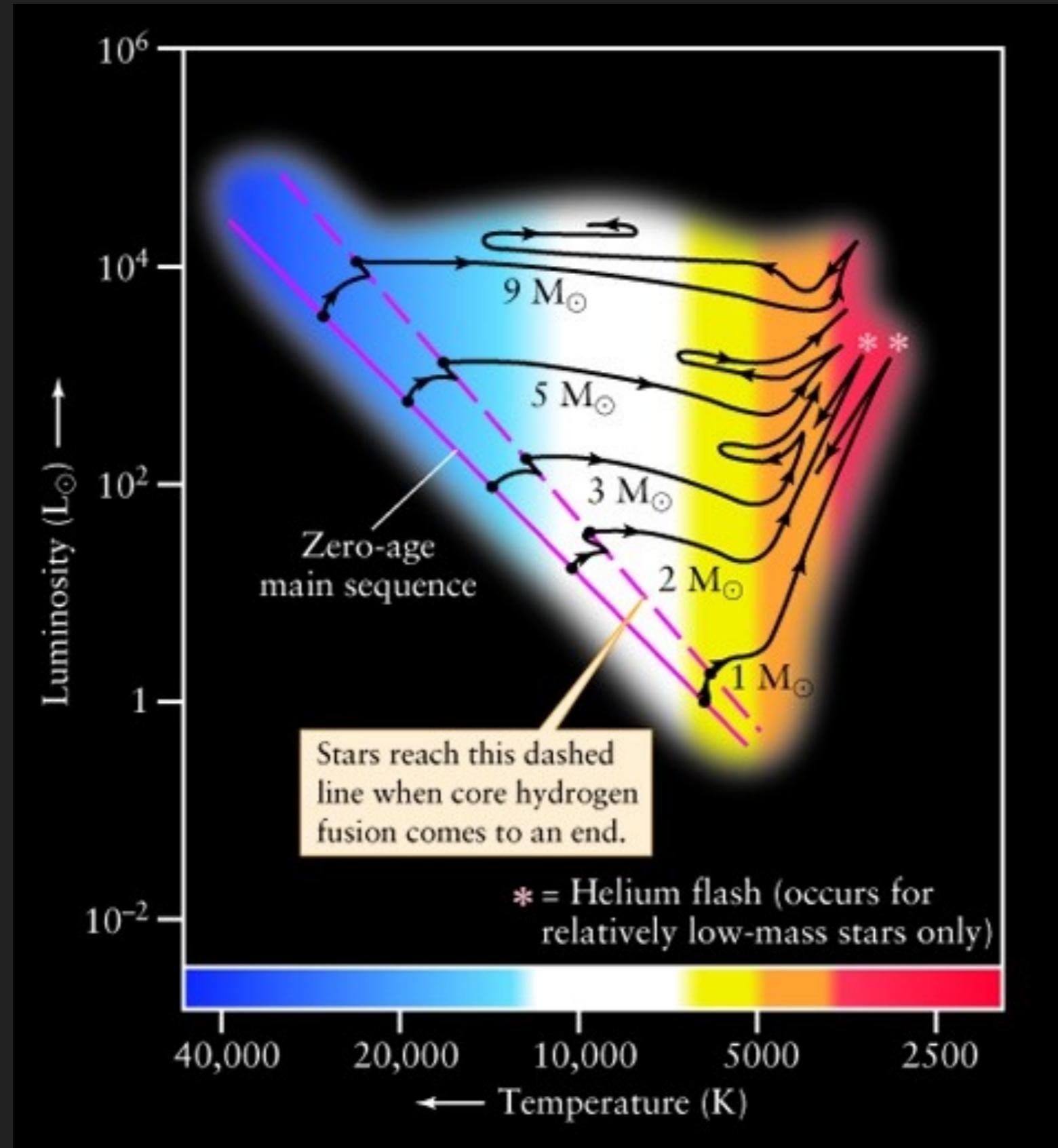
Metallicity

$$Z = 0.0134$$

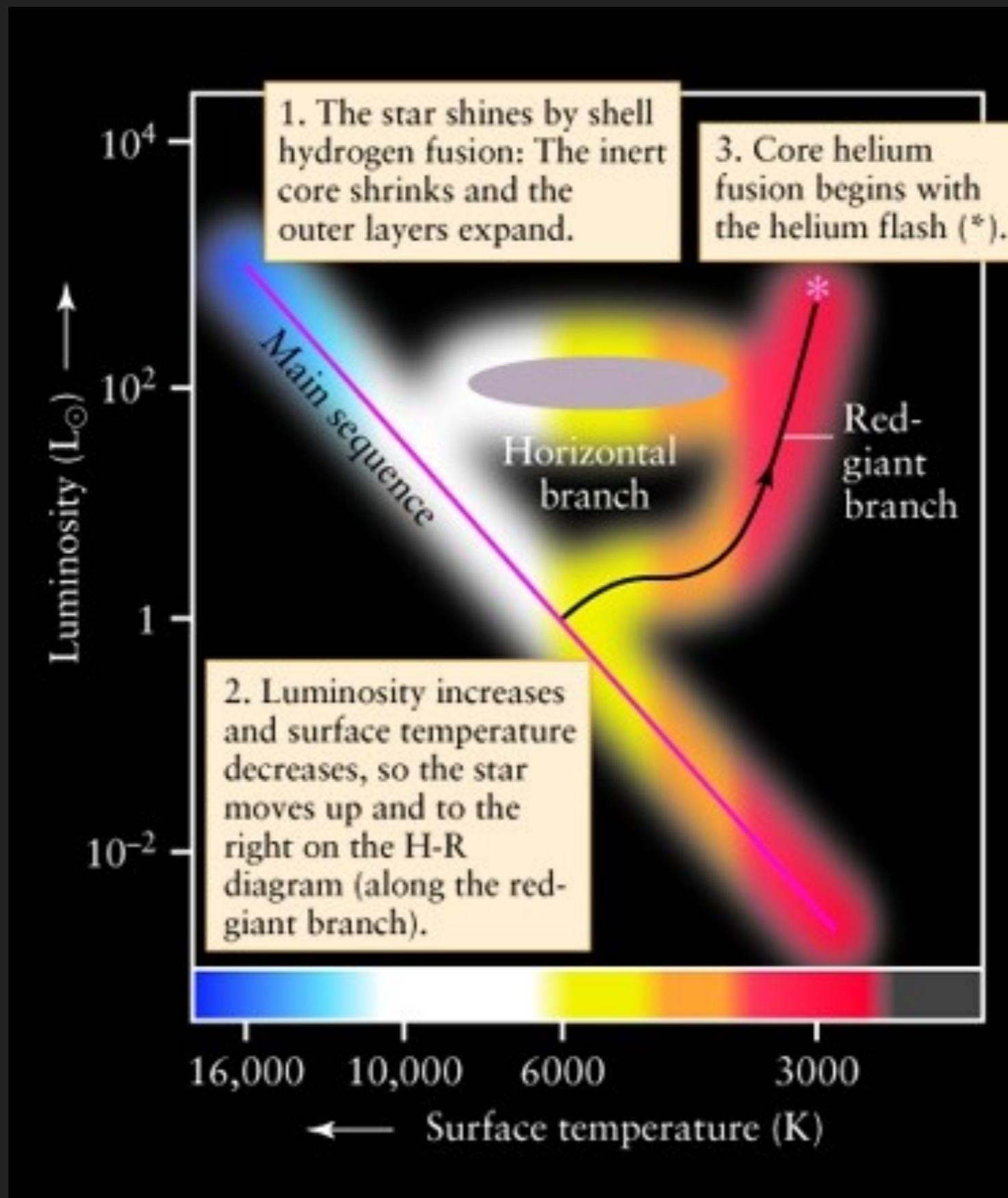


$$X + Y + Z = 1$$

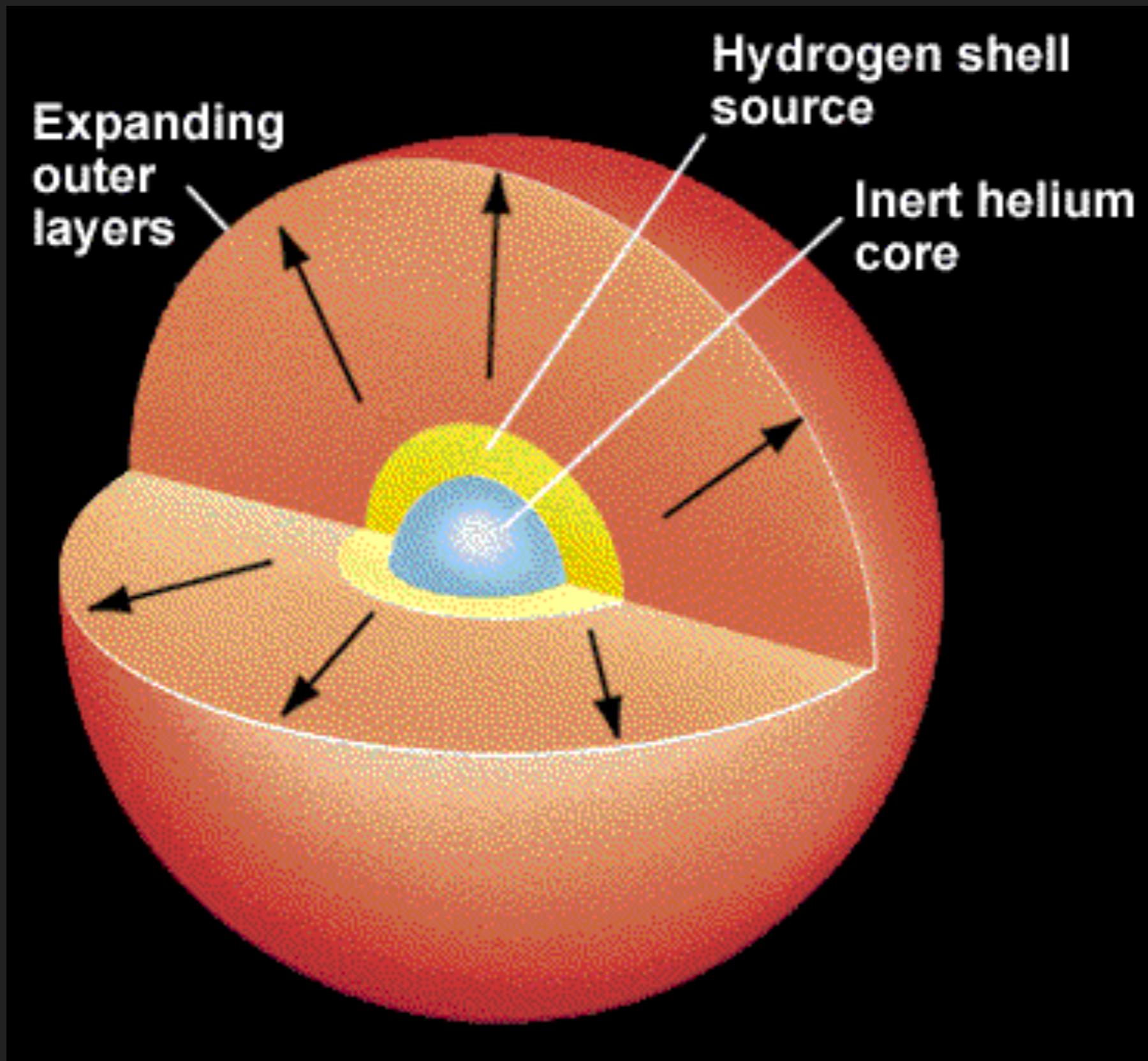
END OF MS



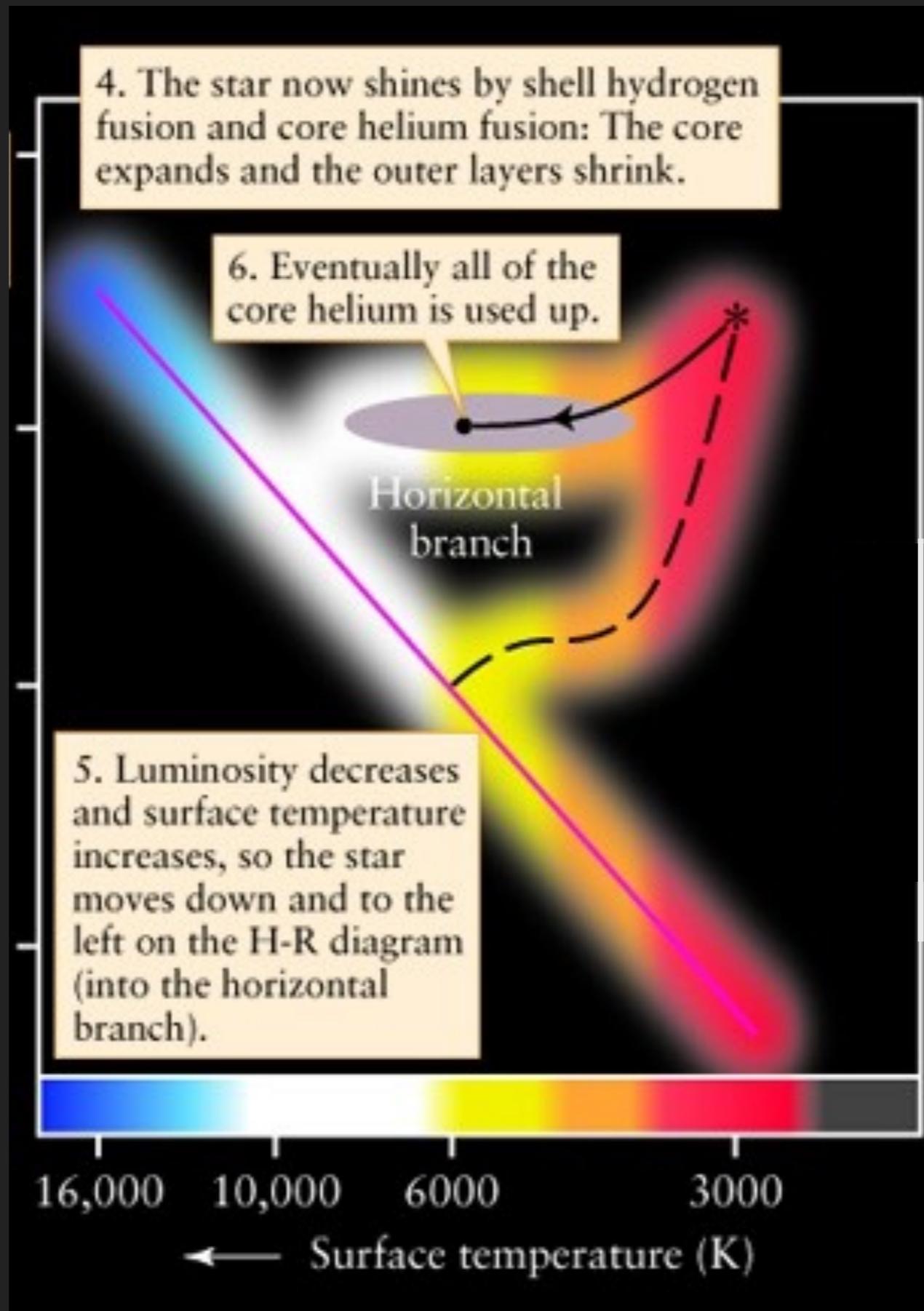
RED GIANT PHASE



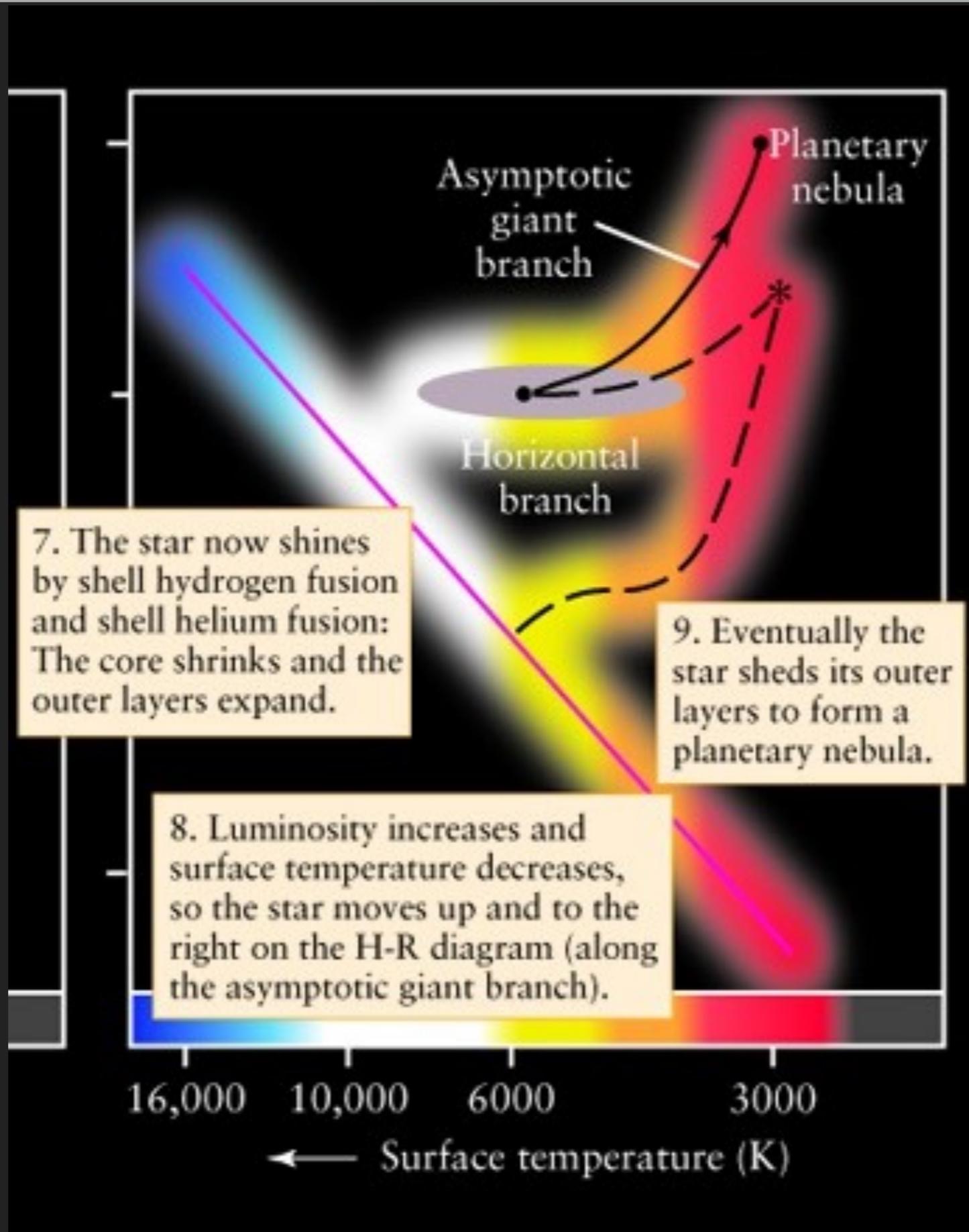
STELLAR INTERIOR



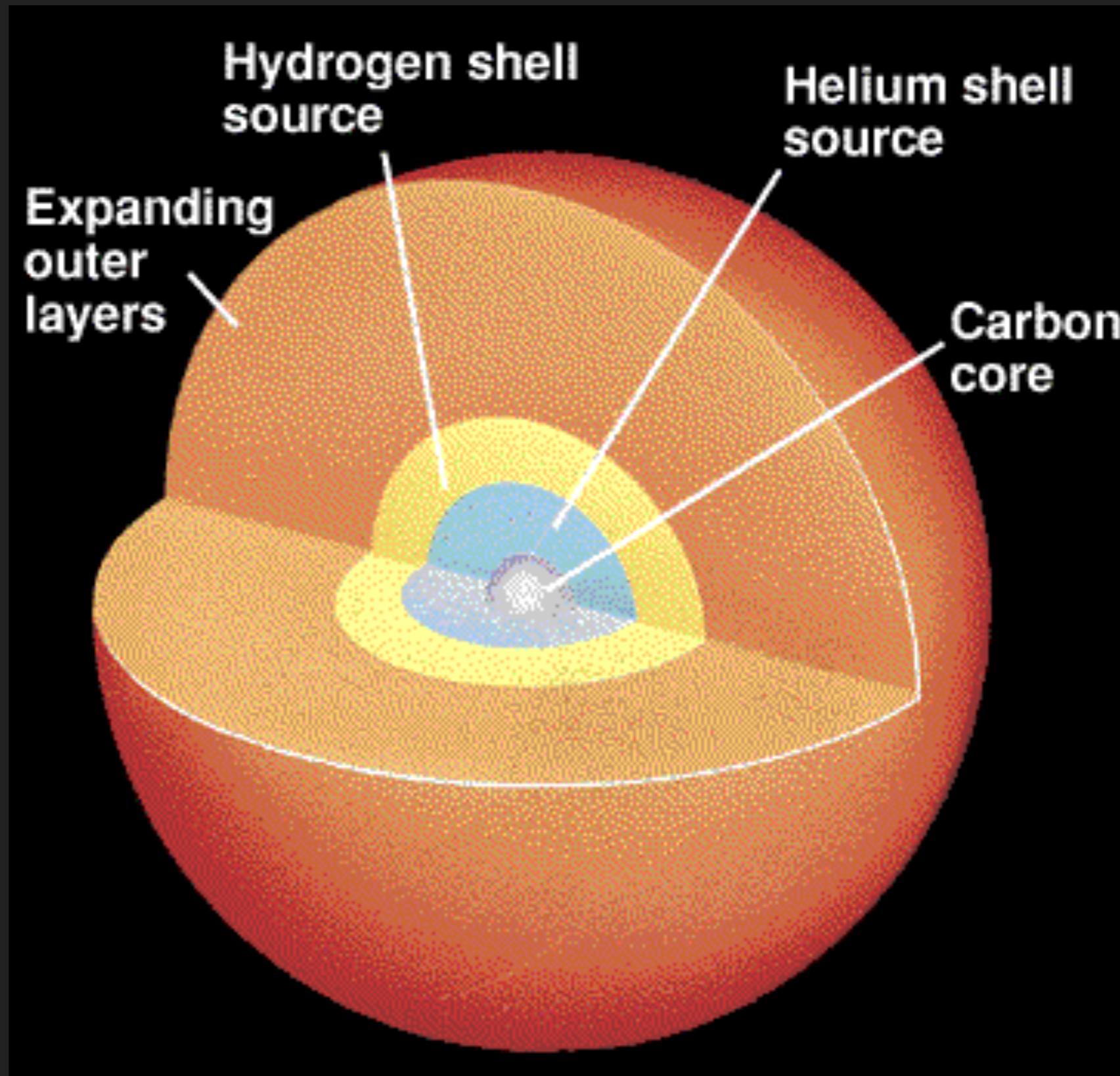
HELIUM FLASH



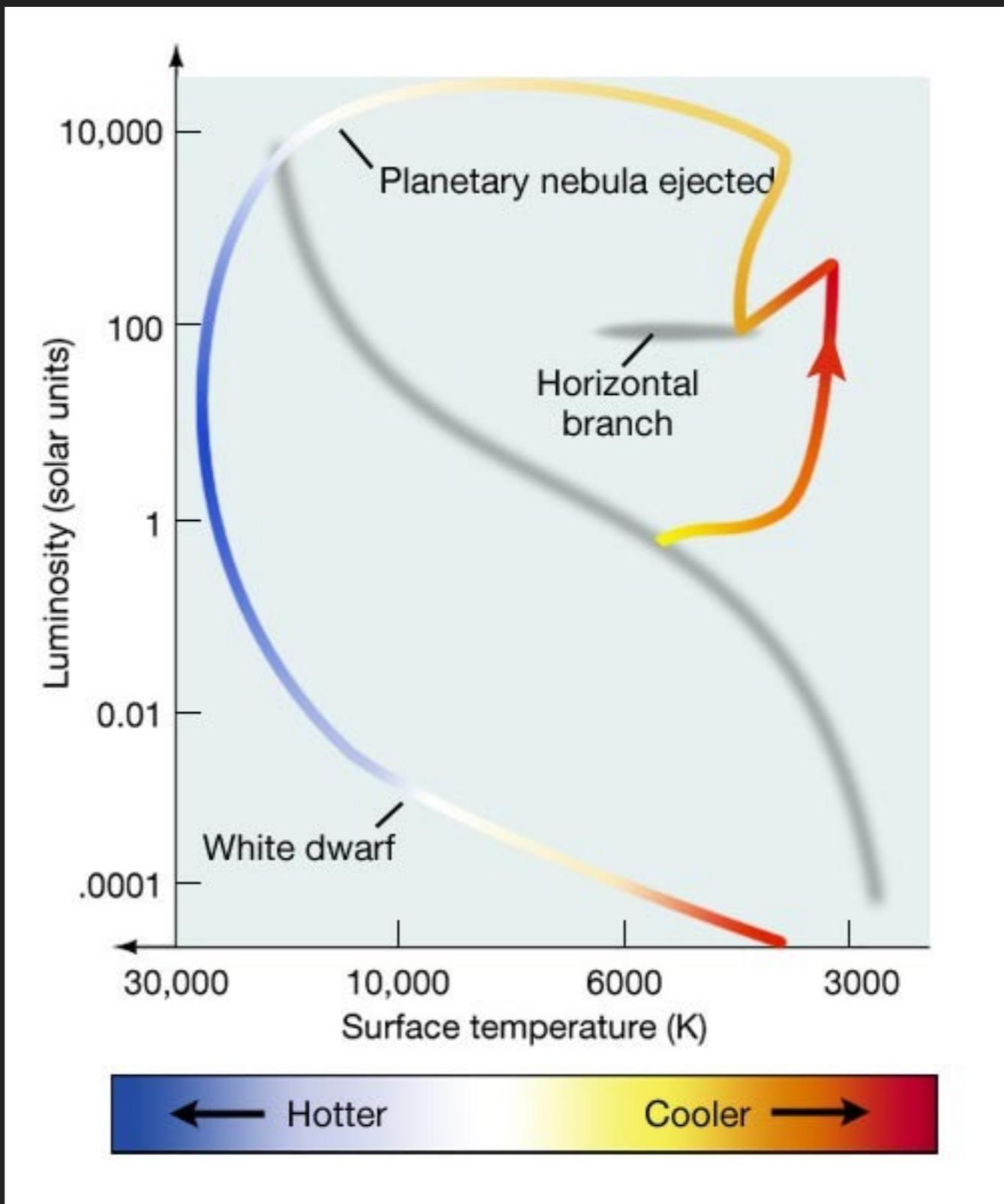
FINAL STAGES - ASYMPTOTIC GIANT BRANCH



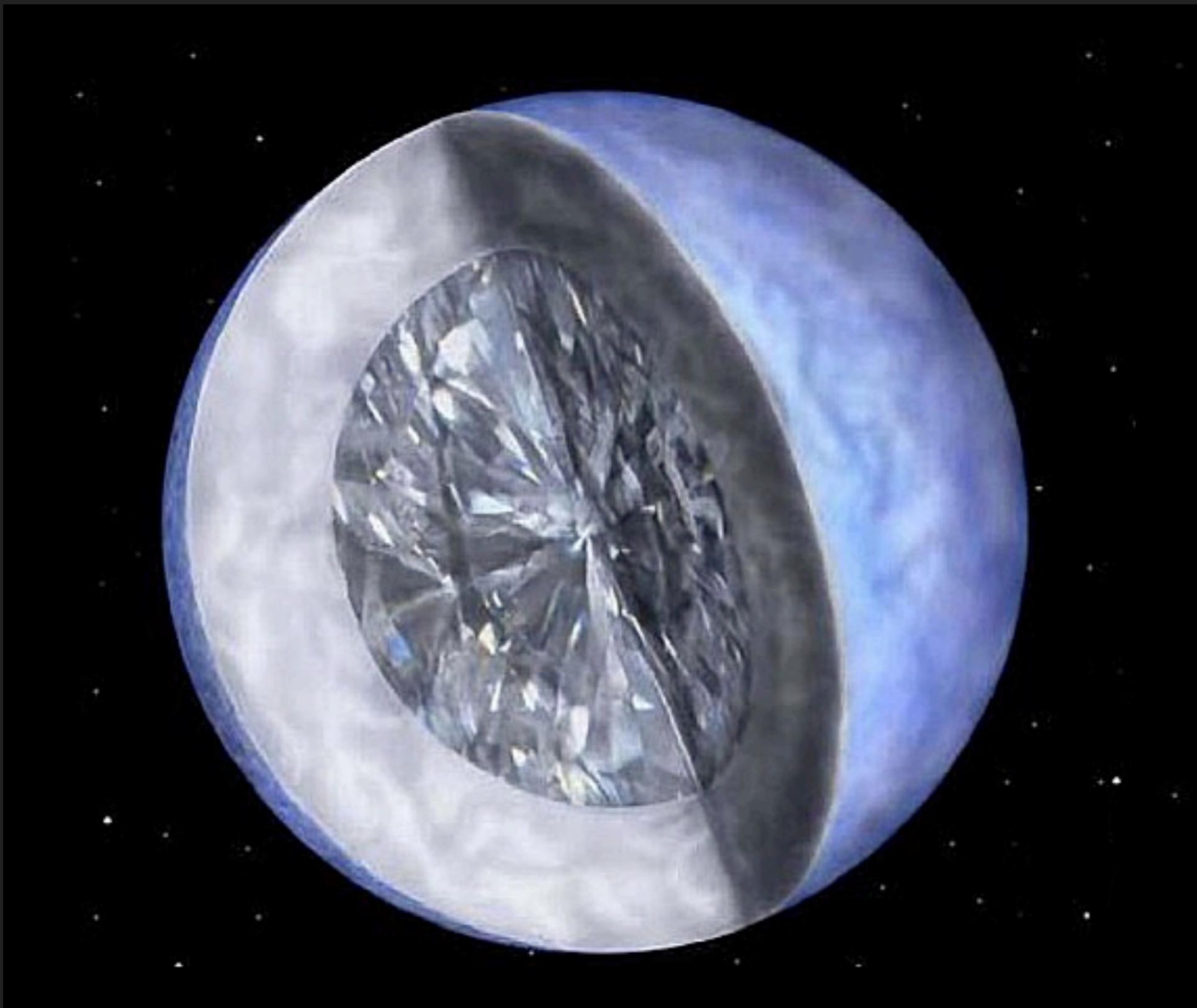
EJECTING OUTER LAYERS



LEFT OVER: WHITE DWARF



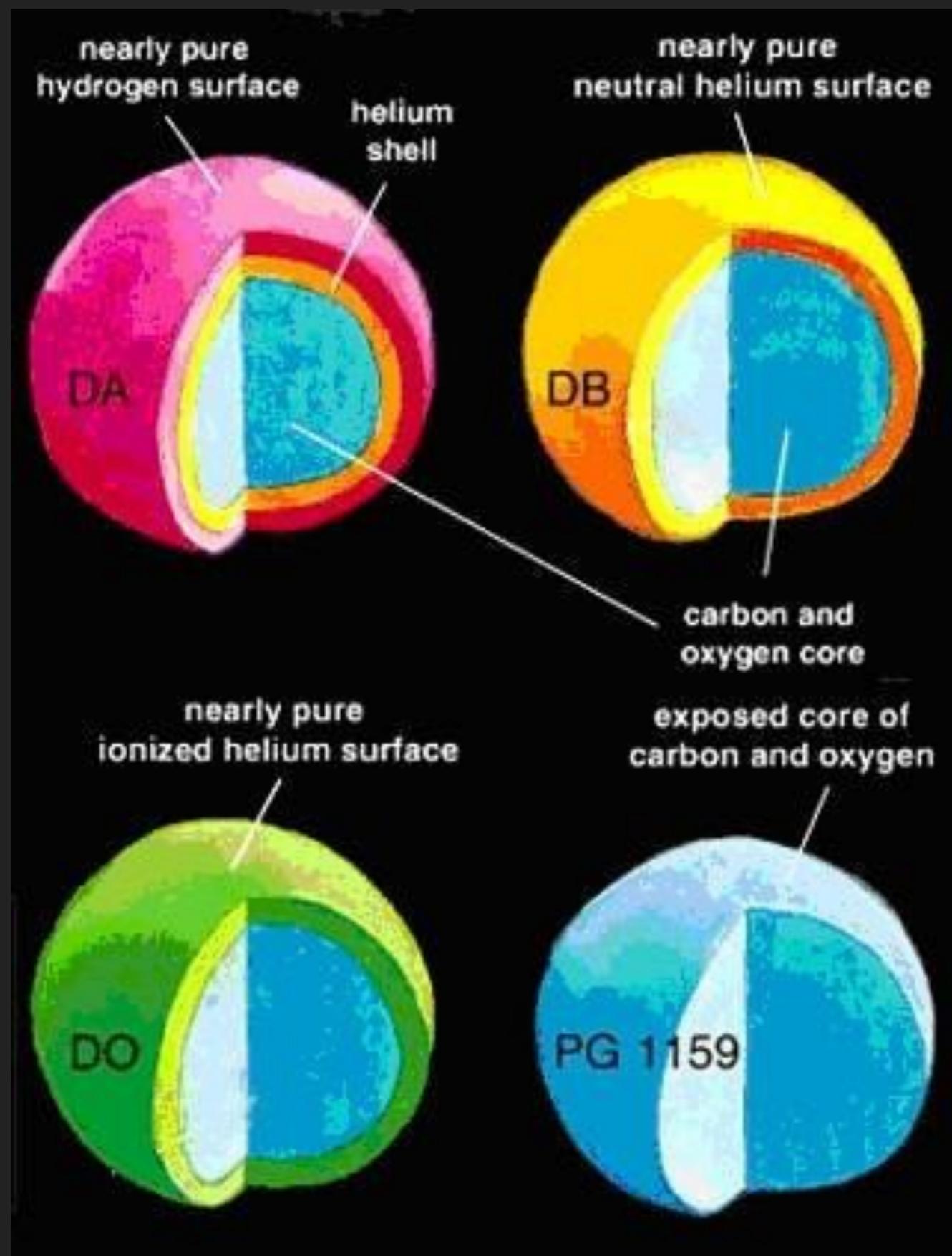
LEFT OVER: WHITE DWARF



LEFT OVER: PLANETARY NEBULAE



WHITE DWARF TYPES



NUCLEAR TIME SCALE

$$\tau_{nuc} = f \varepsilon M c^2 / L$$

f = fraction of nuclear fuel available for fusion

ε = efficiency of matter-energy conversion

M = mass of the star

L = luminosity of the star

NUCLEAR TIME SCALE

$$\frac{t}{t_{\odot}} = \left(\frac{M}{M_{\odot}} \right)^{-2.5}$$

$$M_{\odot} = 1$$

$$t_{\odot} = 10 \text{ billion years}$$

EXERCISE

- ▶ What is the main-sequence lifetime of a $15 M_{\odot}$ star?

- ▶ $t = 1 \times 10^{10} \times (15)^{-2.5}$

- ▶ $t = 11.5 \times 10^6$ years

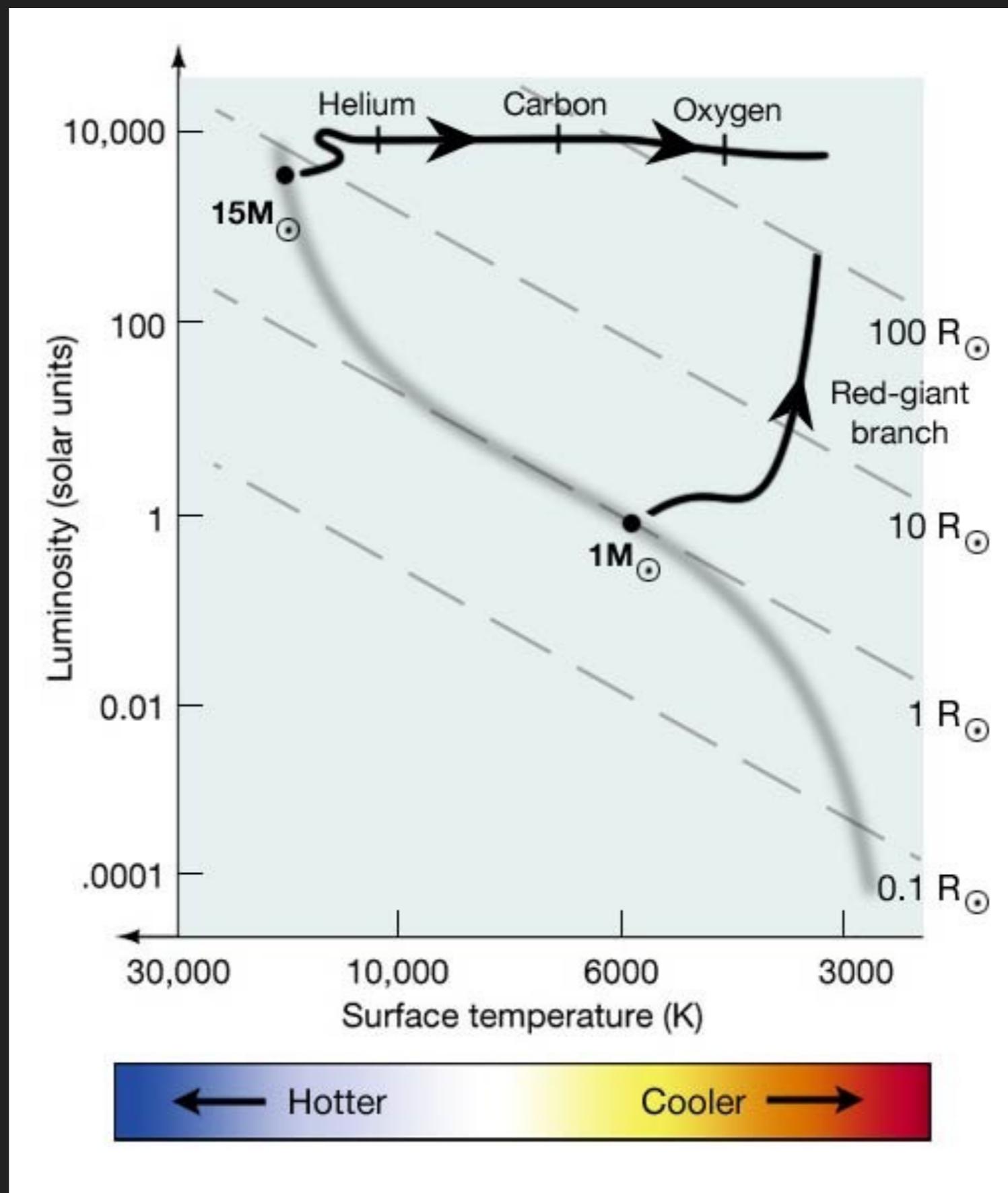
SUMMARY - LOW MASS EVOLUTION



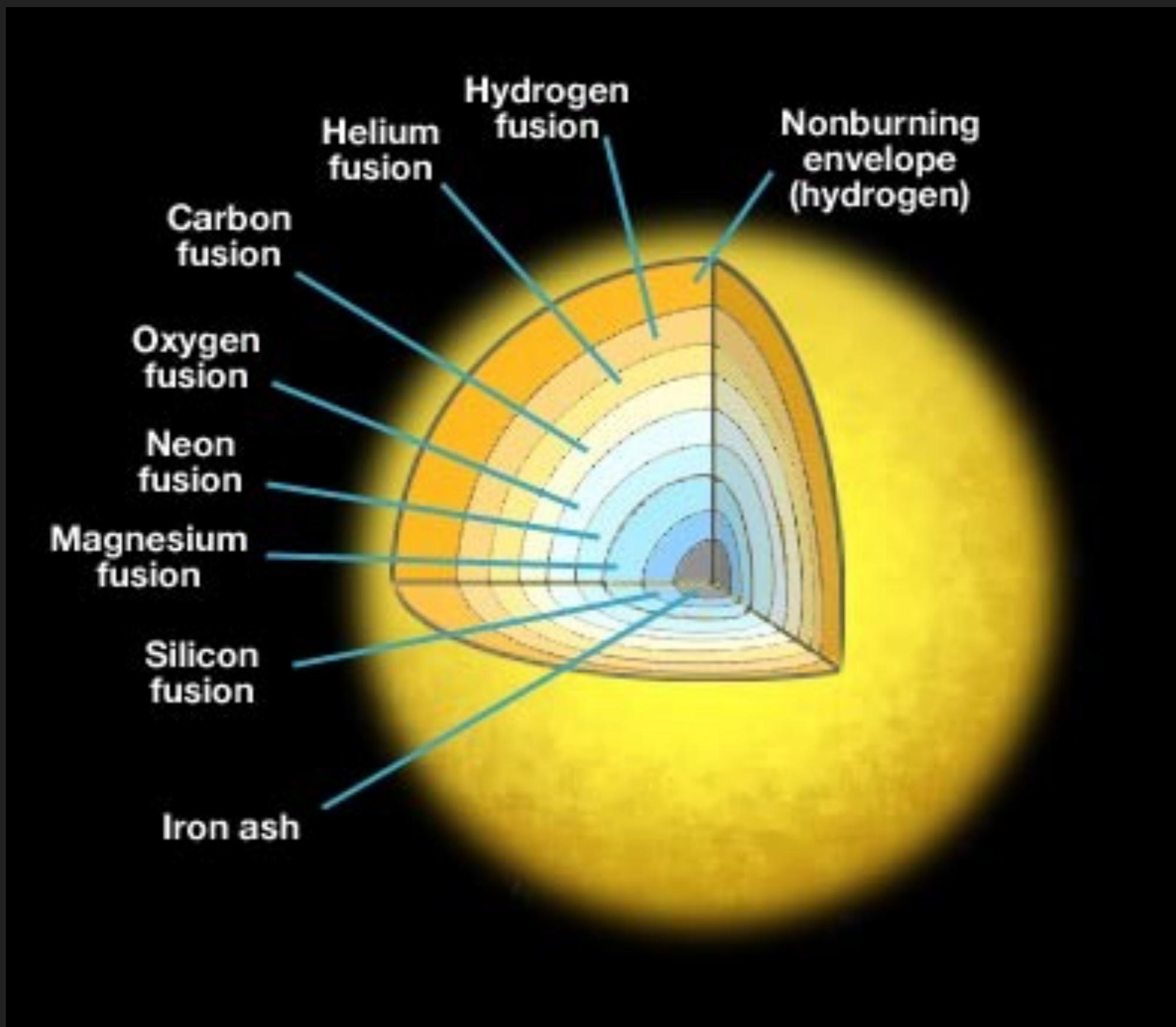
Kurzgesagt – In a Nutshell

11.9M subscribers

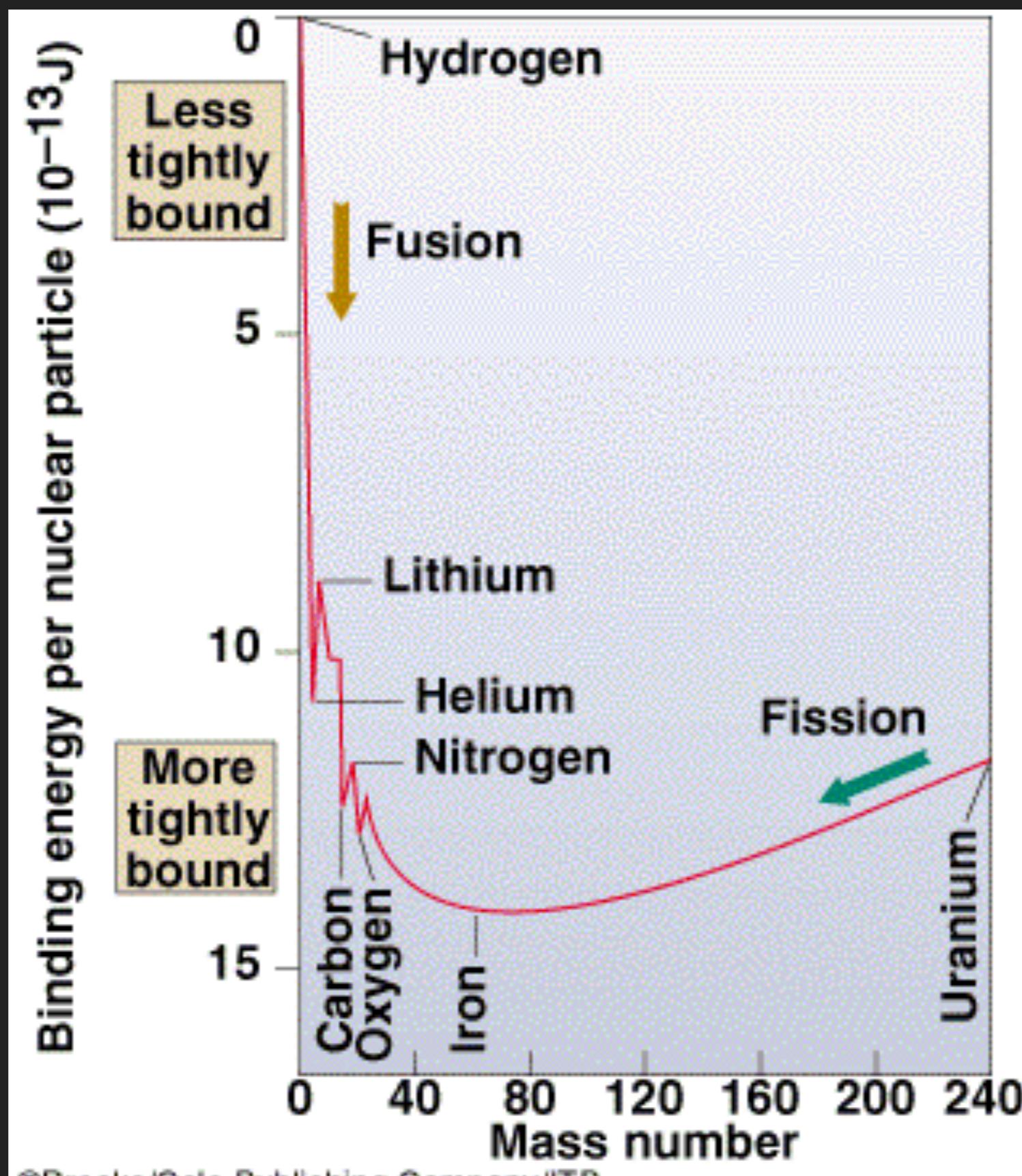
HIGH MASS STARS



ONION SKIN



IRON: LAST STATION



SUPERNova



REFERENCES

- ▶ <https://phys.org/news/2012-03-astronomers-rare-peek-early-stage.html>
- ▶ <https://www.e-education.psu.edu/astro801/>
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- ▶ <http://voyages.sdss.org/expeditions/expedition-to-the-milky-way/star-clusters/hr-diagrams/>
- ▶ <http://www.astronomy.ohio-state.edu/~pogge/Ast162/Unit2/mainseq.html>
- ▶ <http://abyss.uoregon.edu/~js/ast122/lectures/lec15.html>
- ▶ <https://www.britannica.com/science/star-astronomy/Origin-of-the-chemical-elements>
- ▶ <http://ecuip.lib.uchicago.edu/multiwavelength-astronomy/astrophysics/04.html>
- ▶ <http://www.astronomy.ohio-state.edu/~pogge/Ast162/Unit2/lowmass.html>
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- ▶