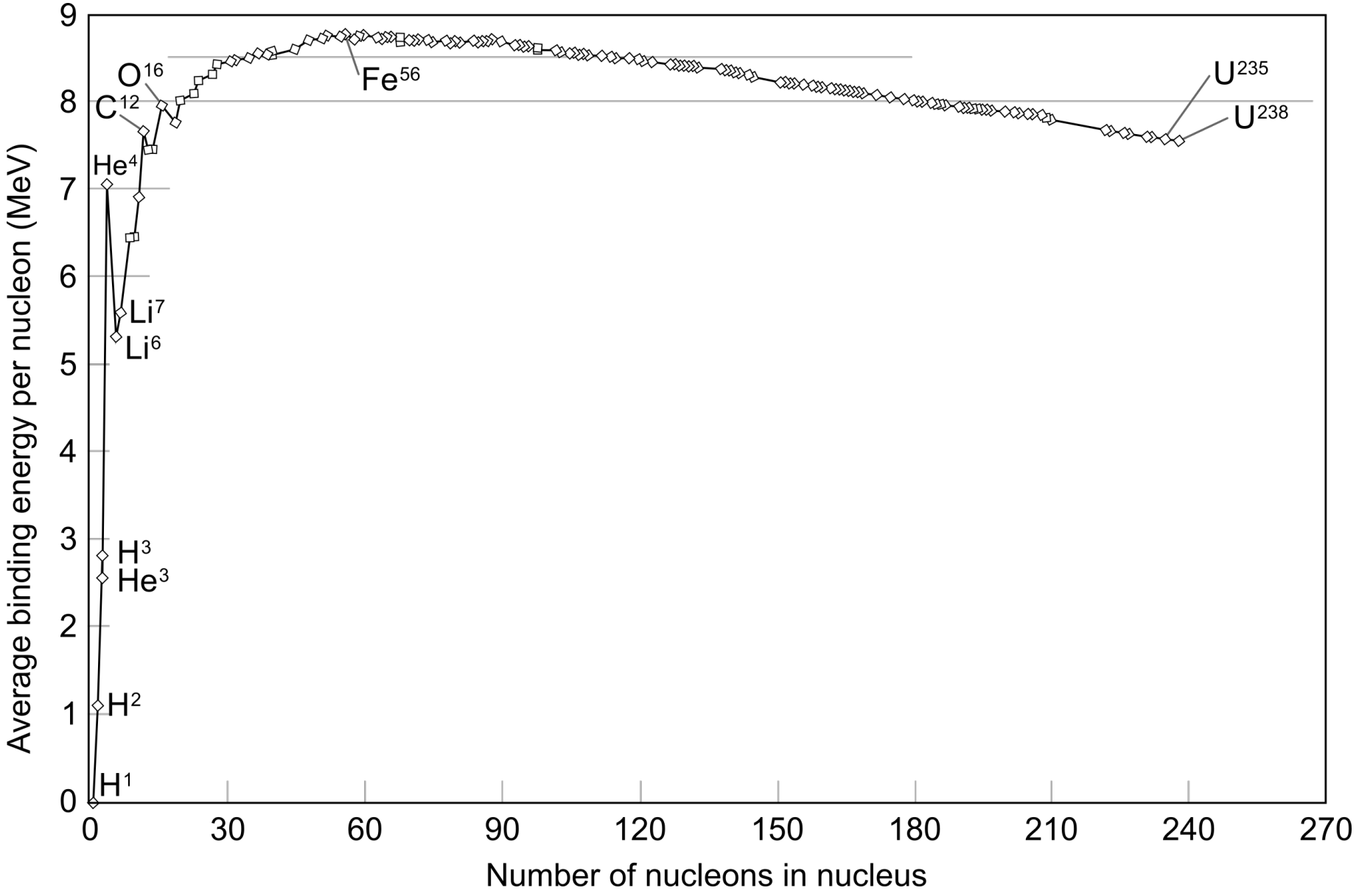
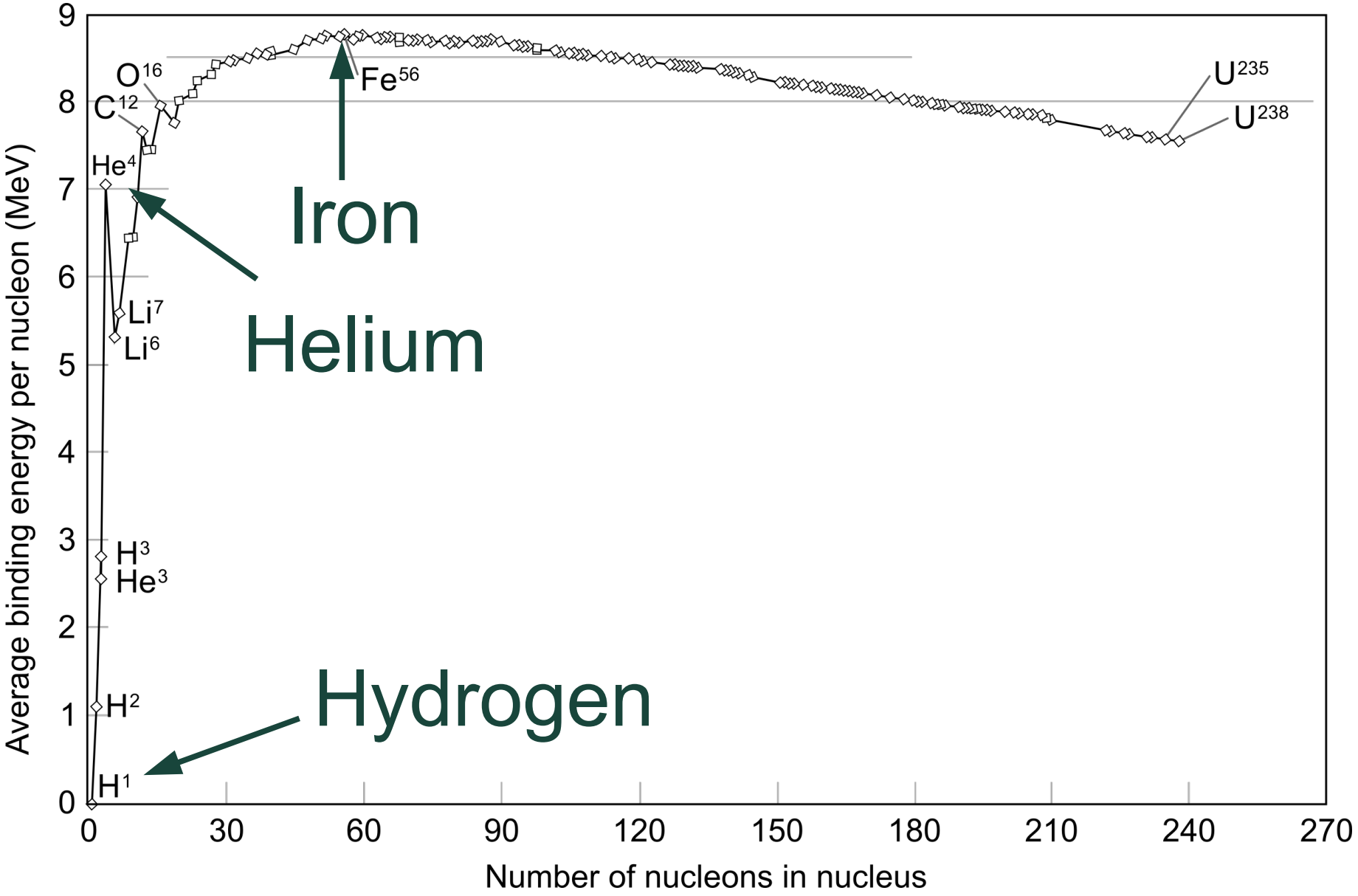
What is the life cycle of stars?

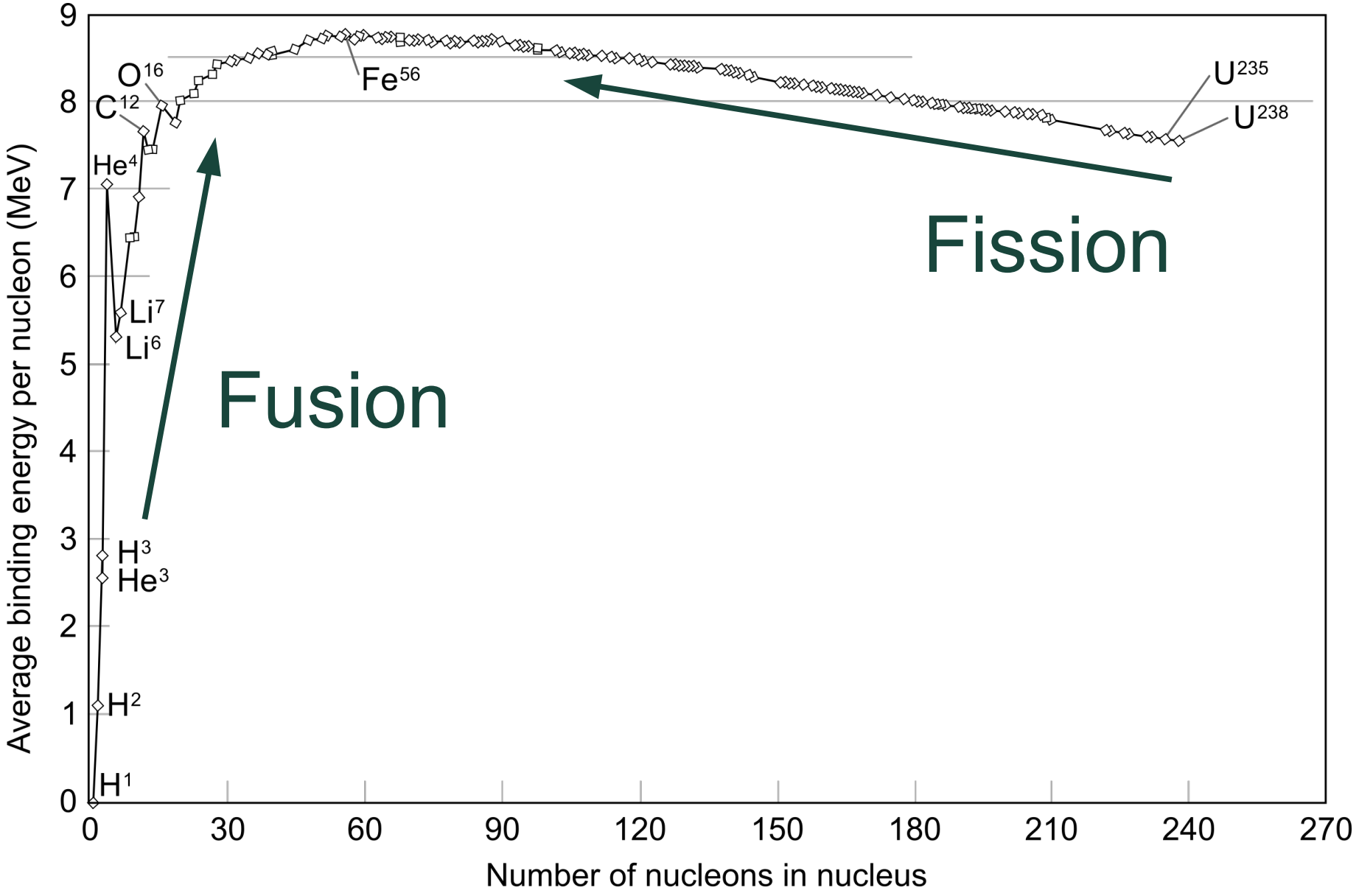
Stars are like nuclear reactors



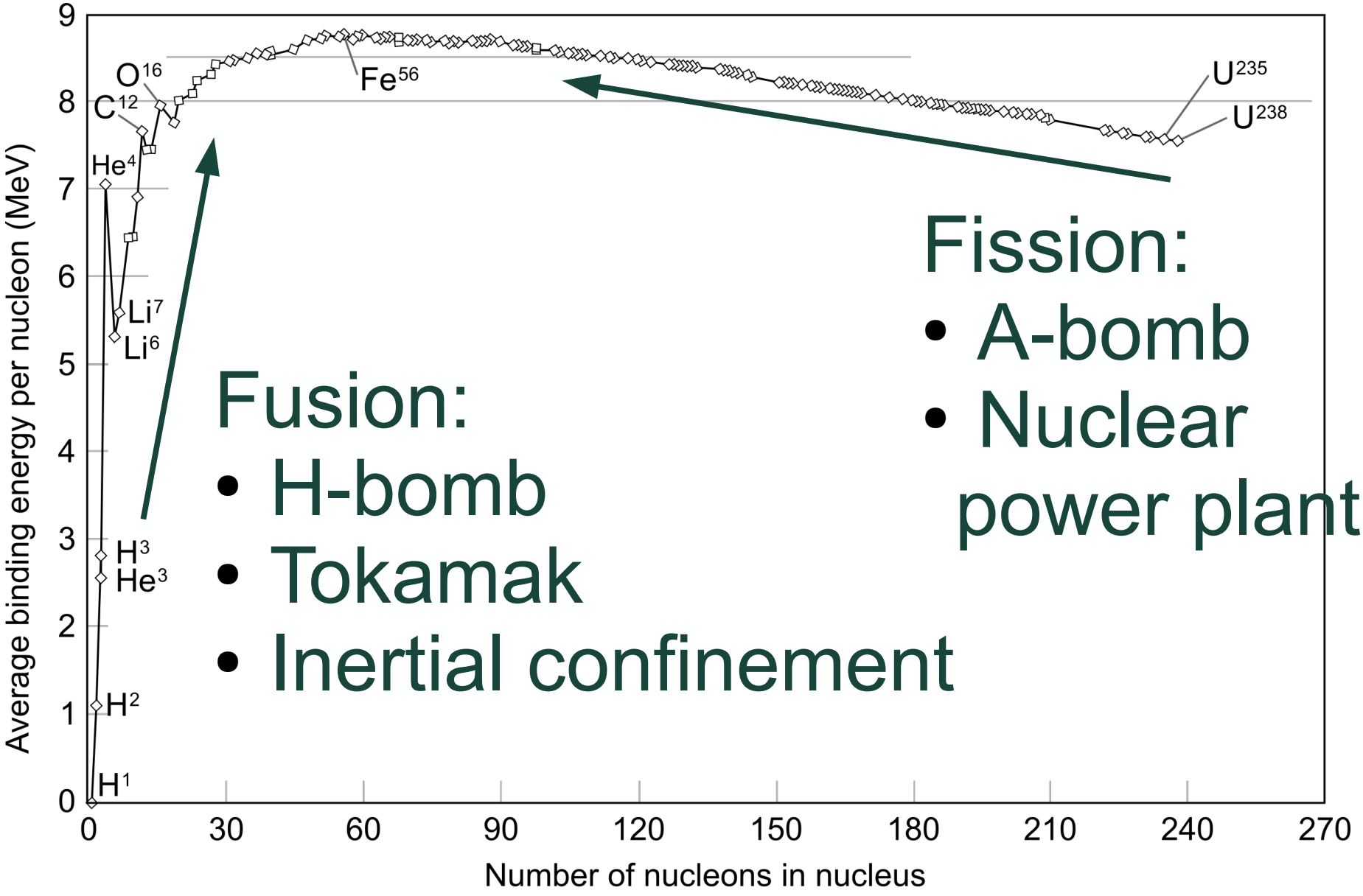
Nuclear vs. EM forces



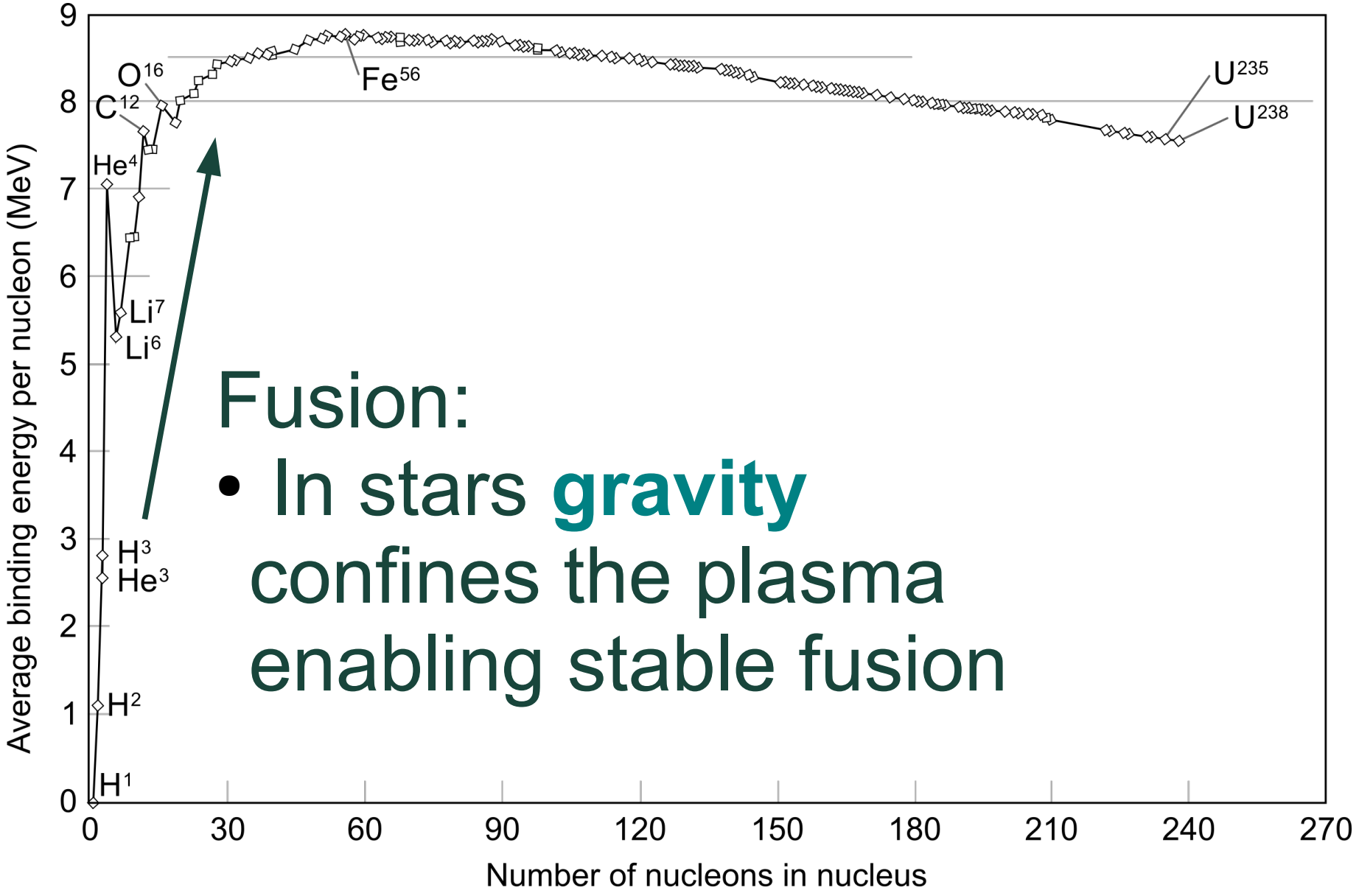
Ways to get energy from nuclei



Ways to get energy from nuclei



Quantum tunneling

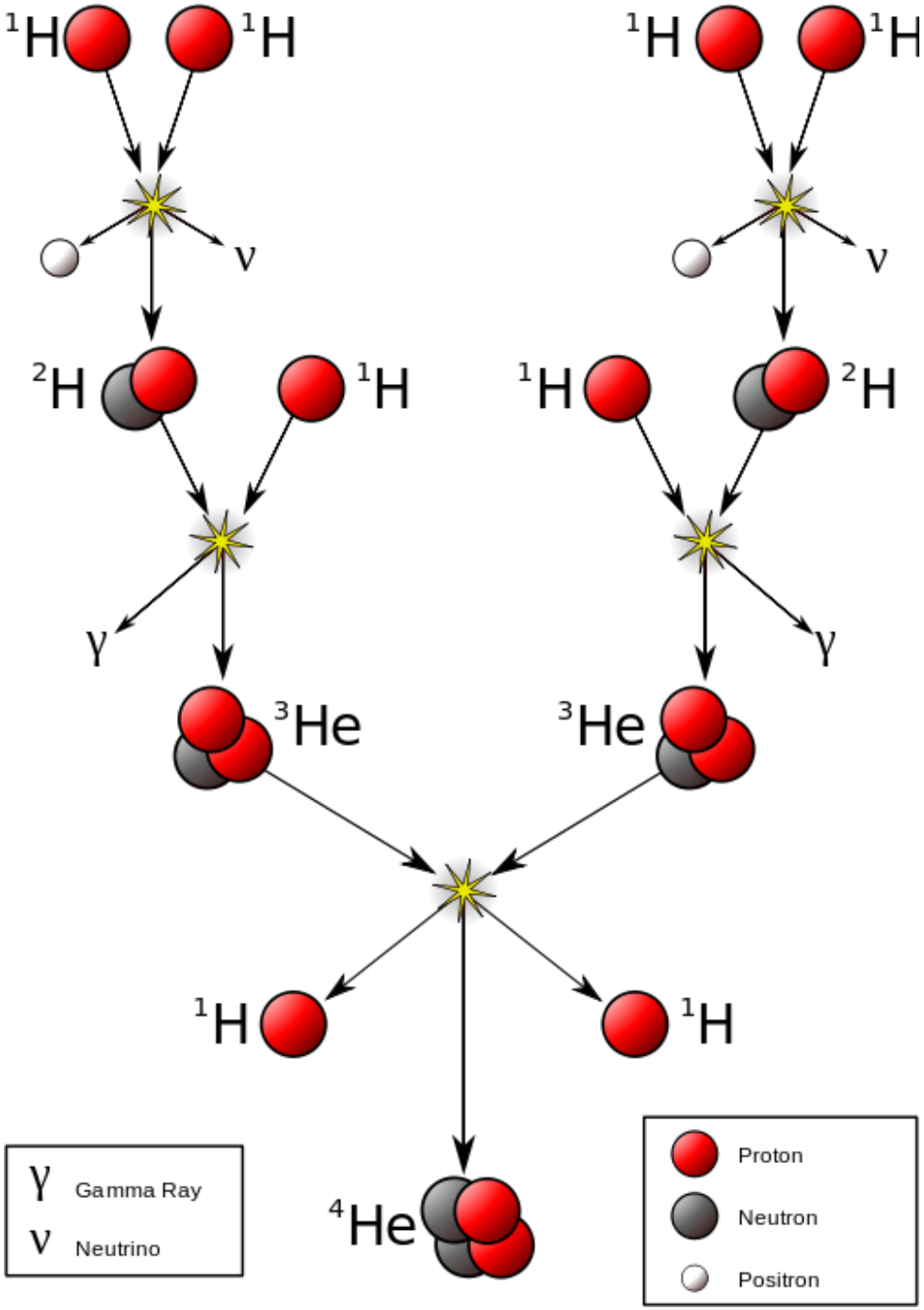


Fusion:

- In stars **gravity** confines the plasma enabling stable fusion

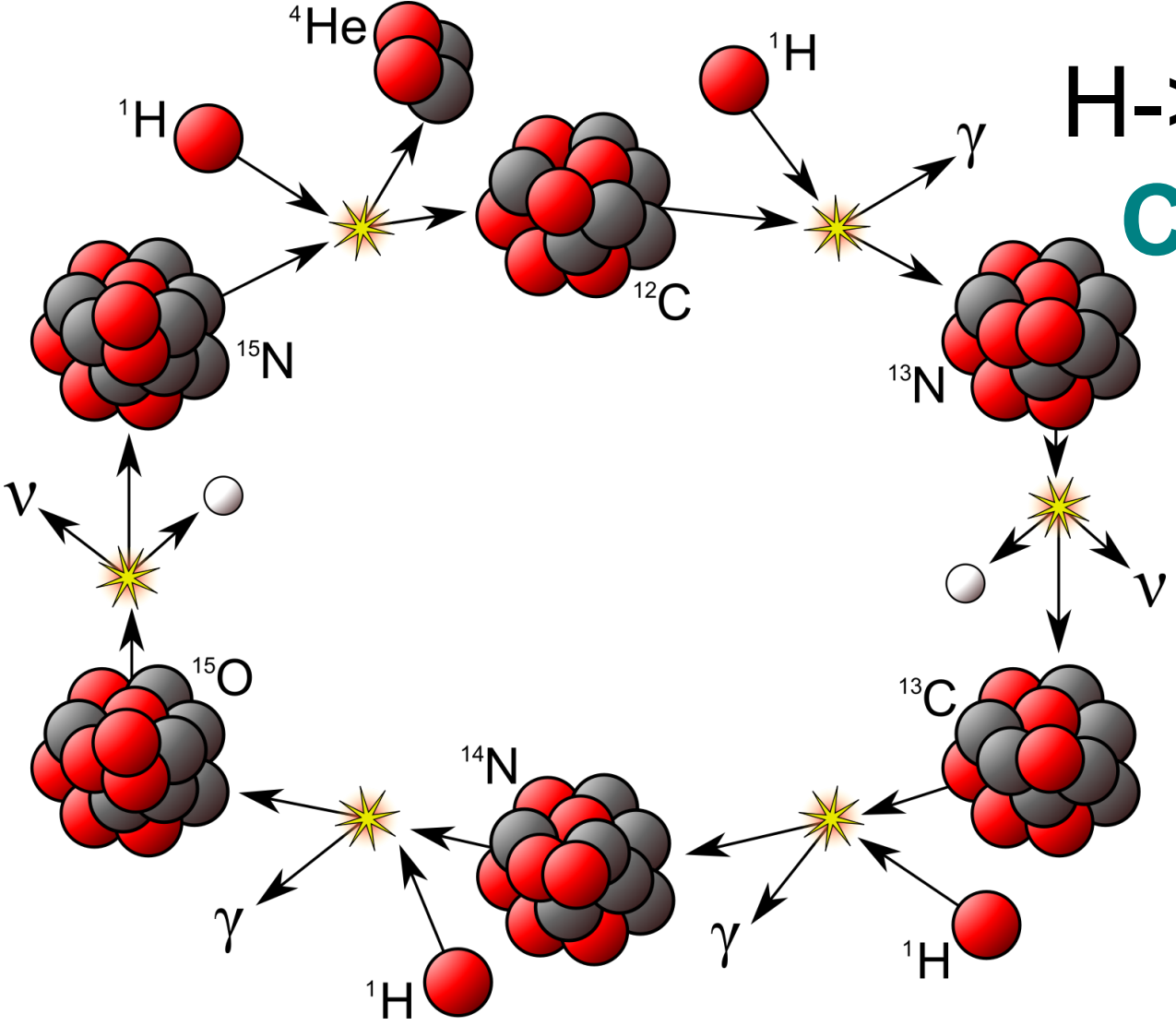
H->He Fusion

p-p reaction



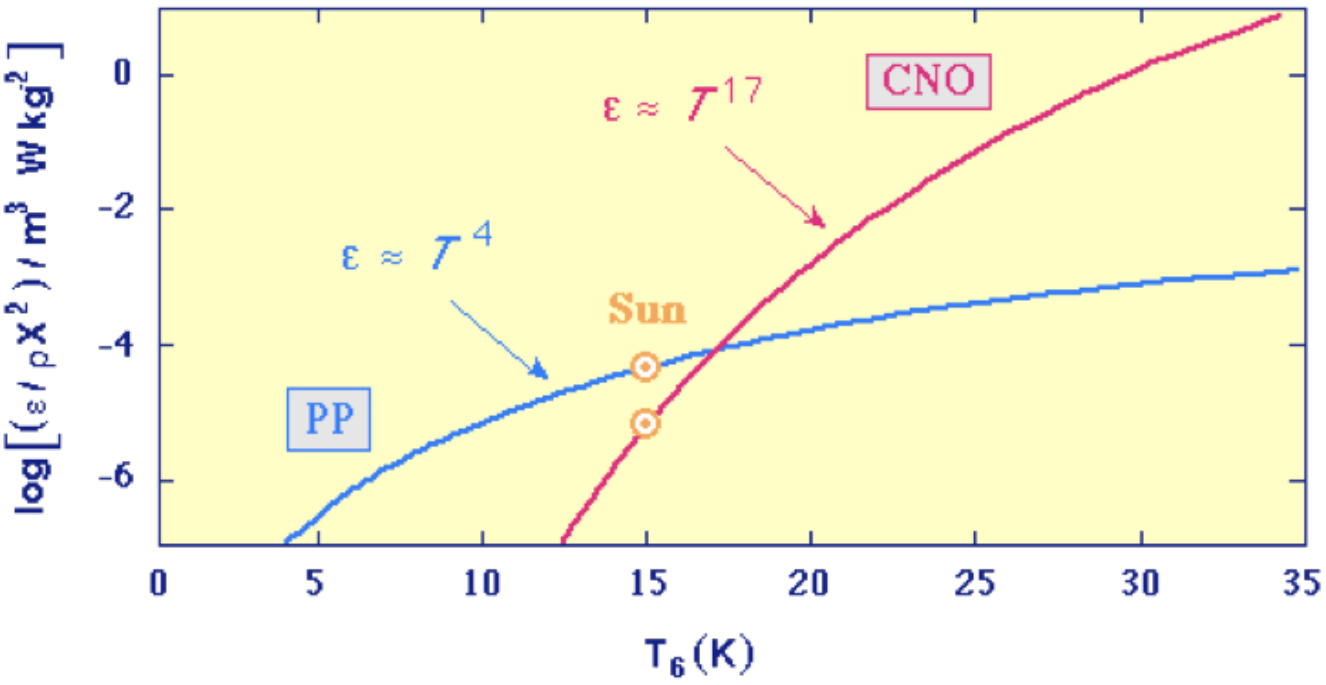
H->He Fusion

CNO cycle

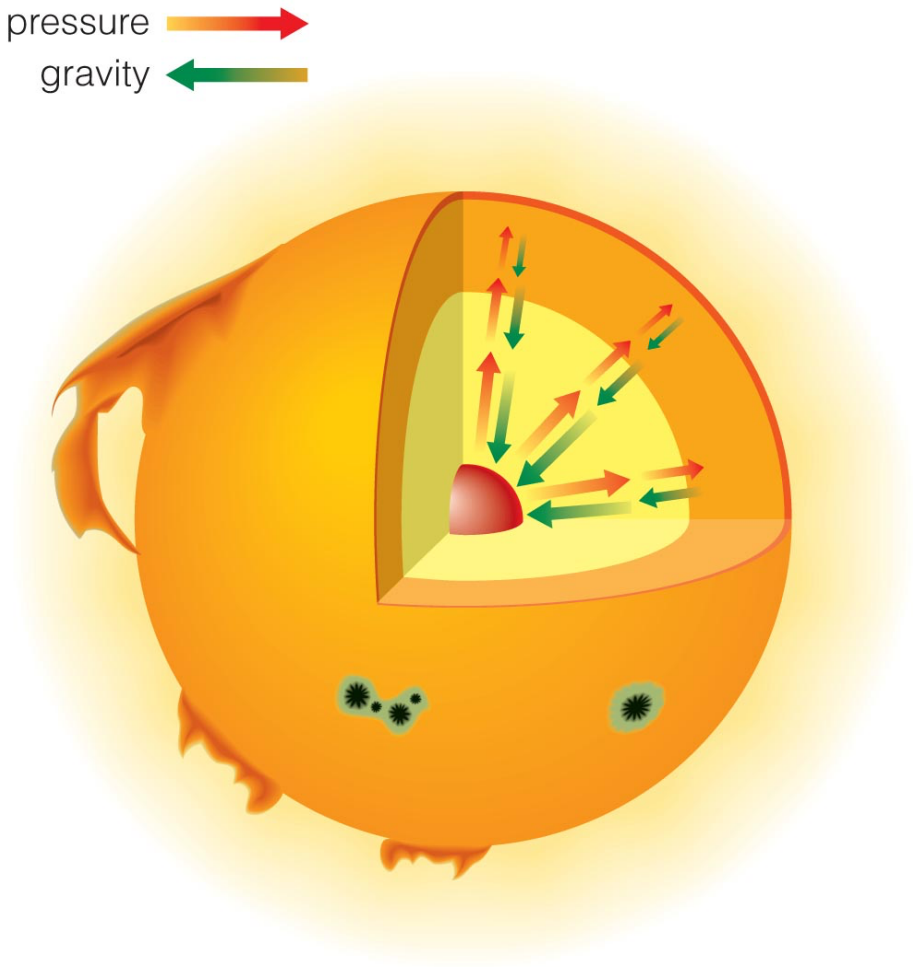


Proton		γ	Gamma Ray
Neutron		ν	Neutrino
Positron			

Why do luminosities vary so much?

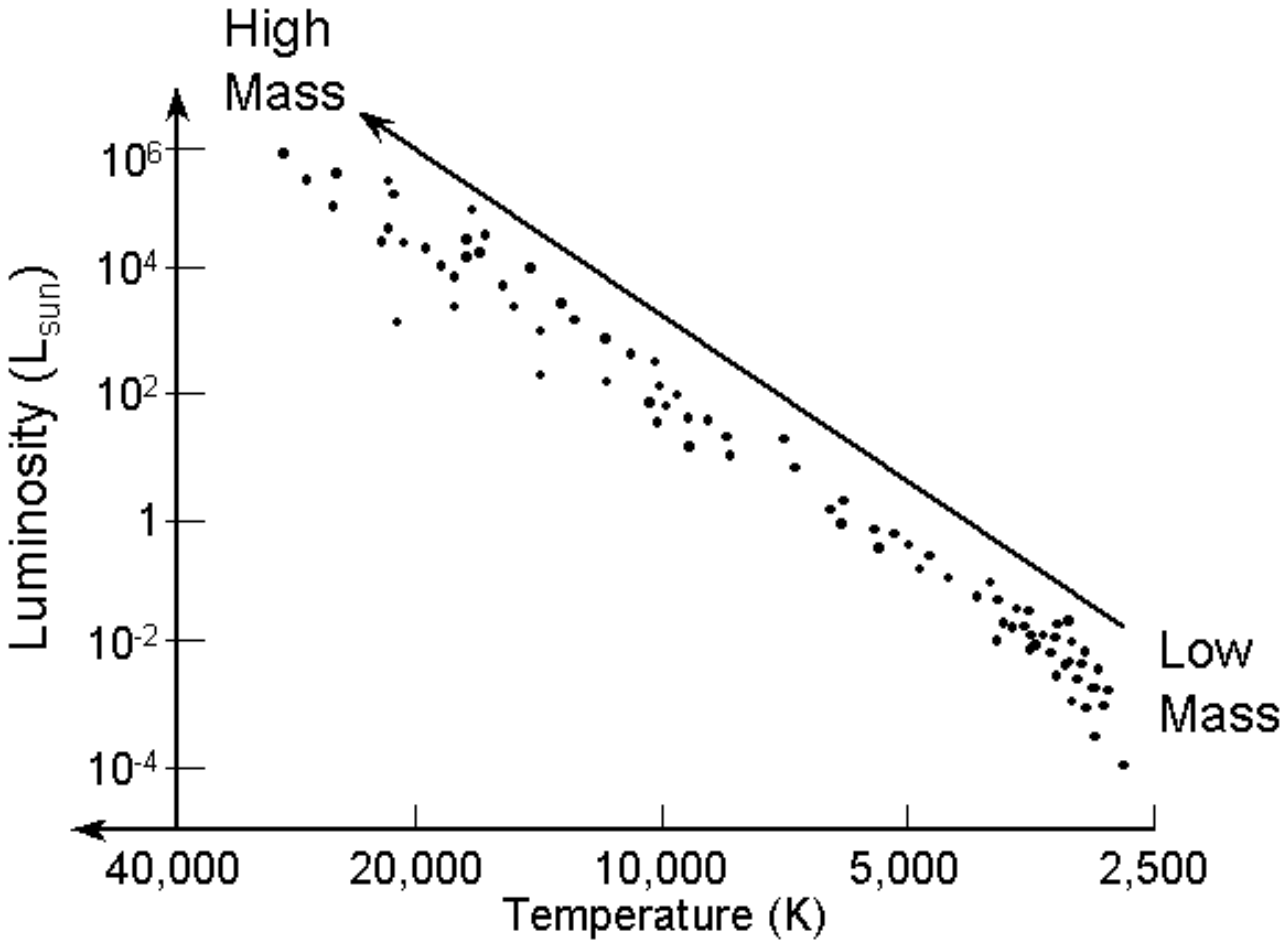


fusion rates are VERY temperature sensitive

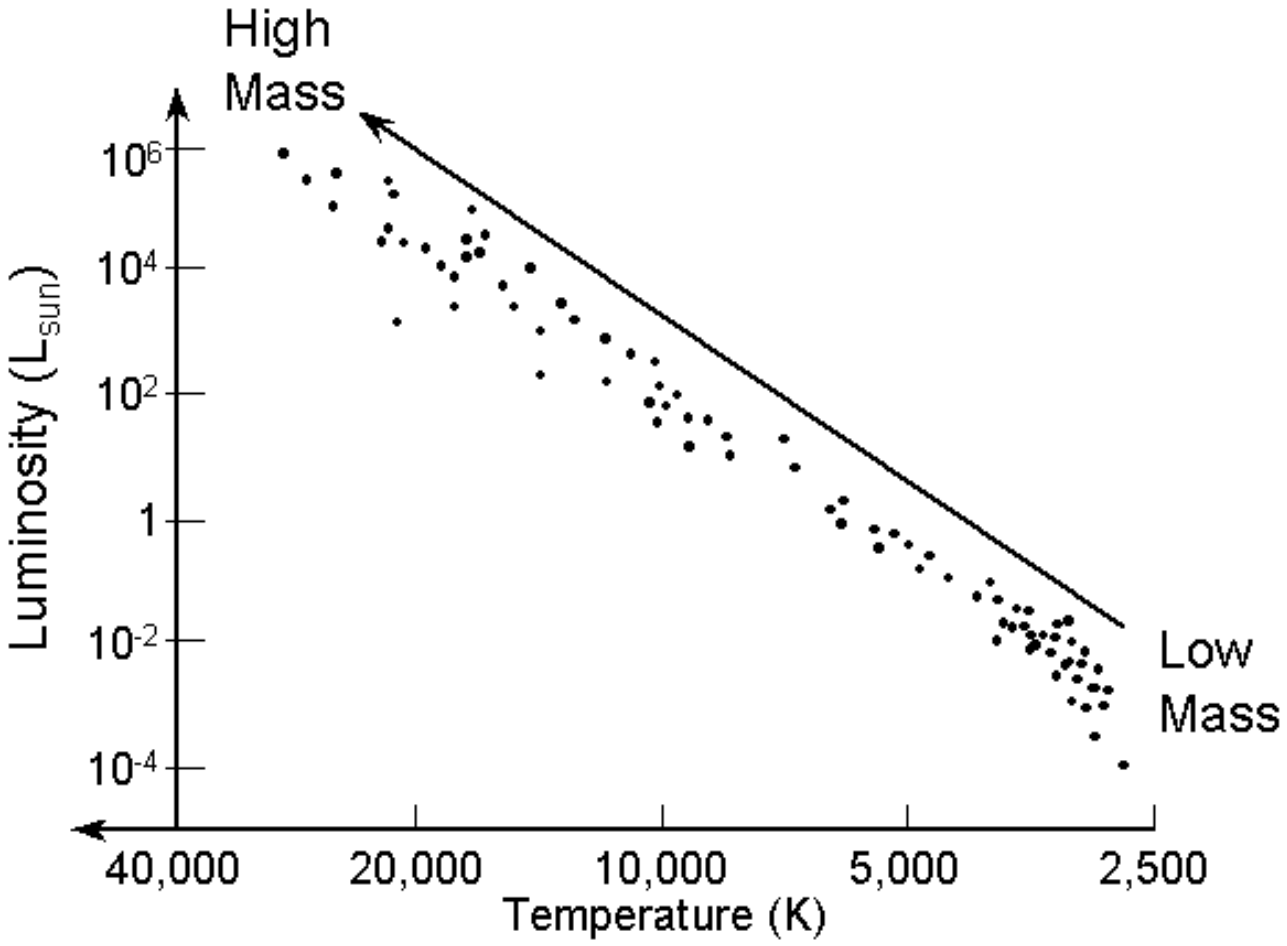


Hydrostatic Equilibrium: Energy supplied by fusion pushes out against the inward crush of gravity

H->He fusing stars form **the Main Sequence!**

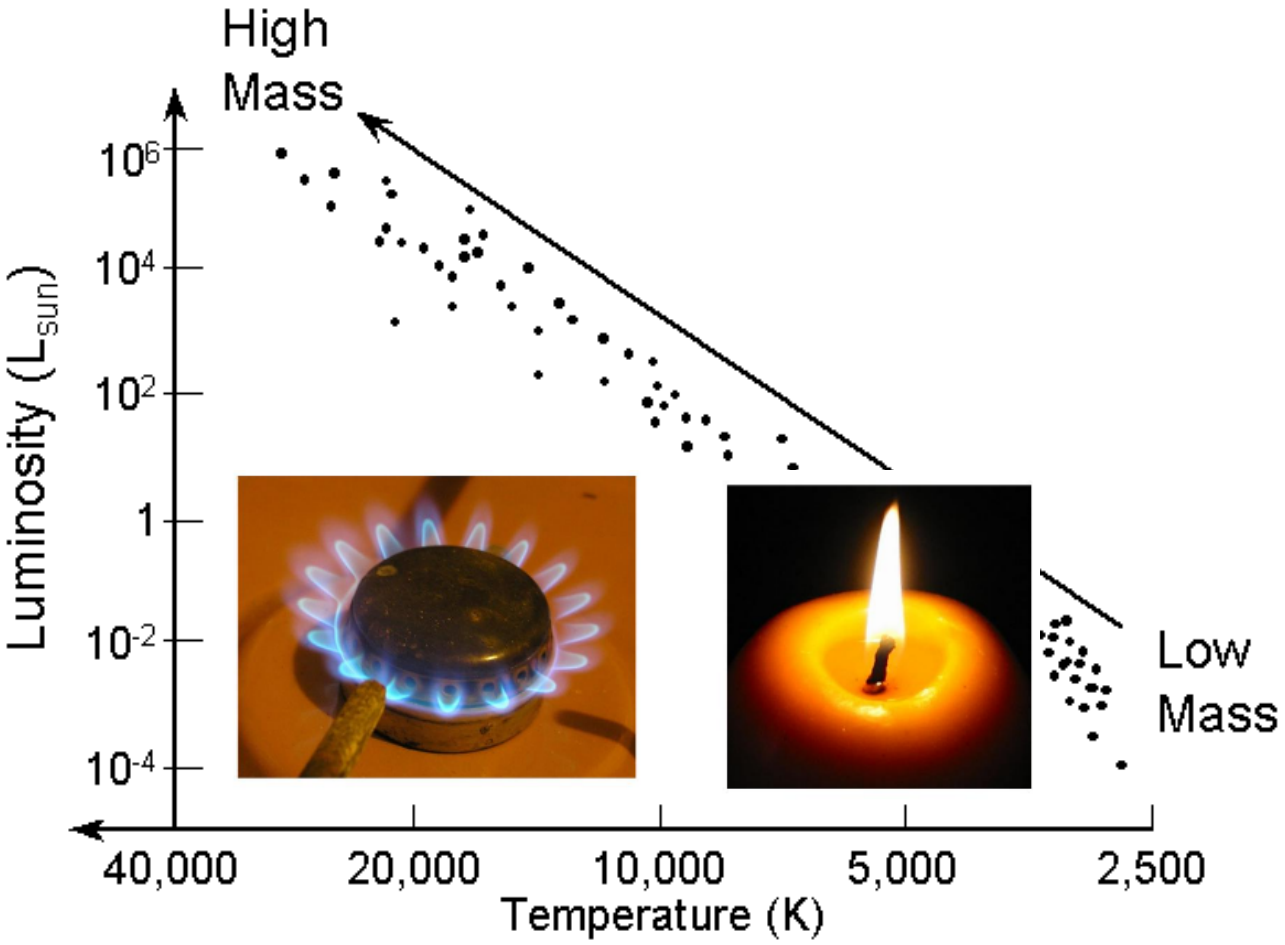


How to put a star on HR diagram?



How to put a star on HR diagram?

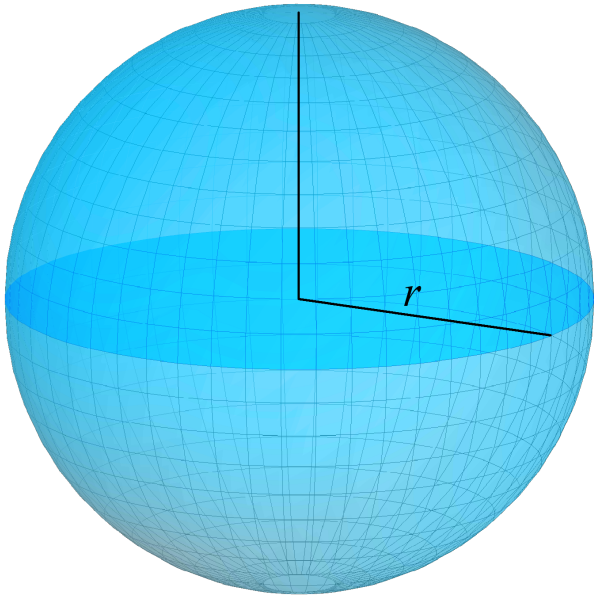
We can guess temperature from the star's **color**

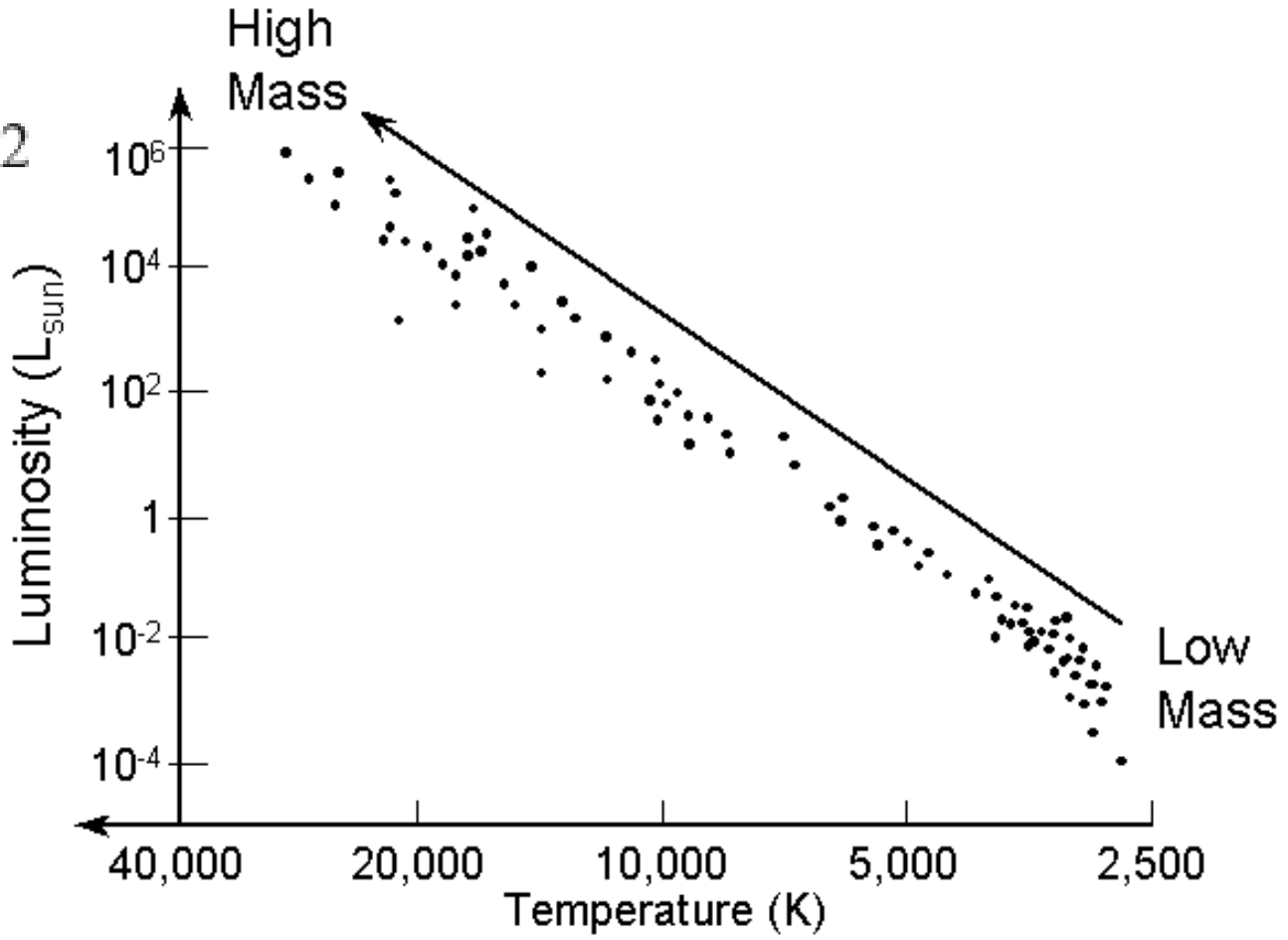


How to put a star on HR diagram?

We can see how bright the star is. Need to know **distance** to compute the star's Luminosity

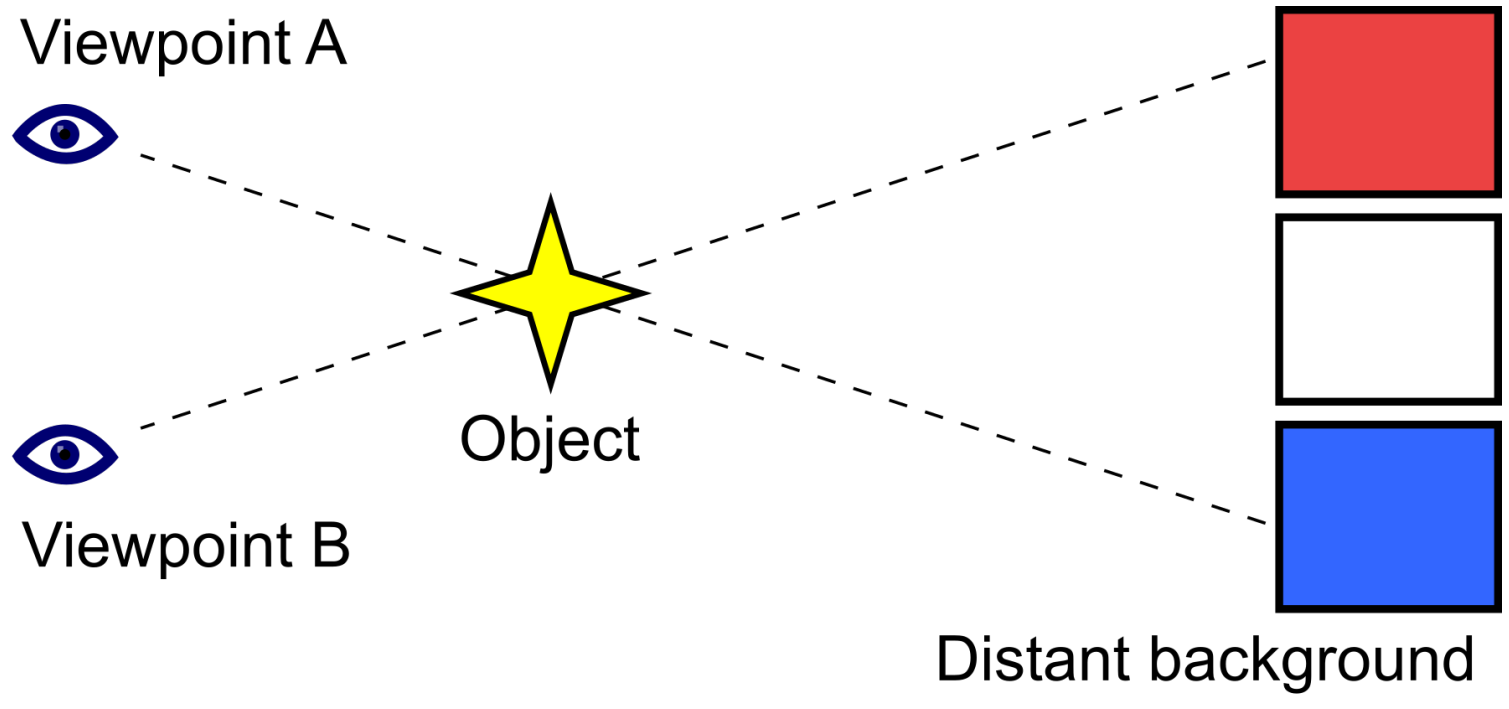
$$A = 4\pi r^2$$

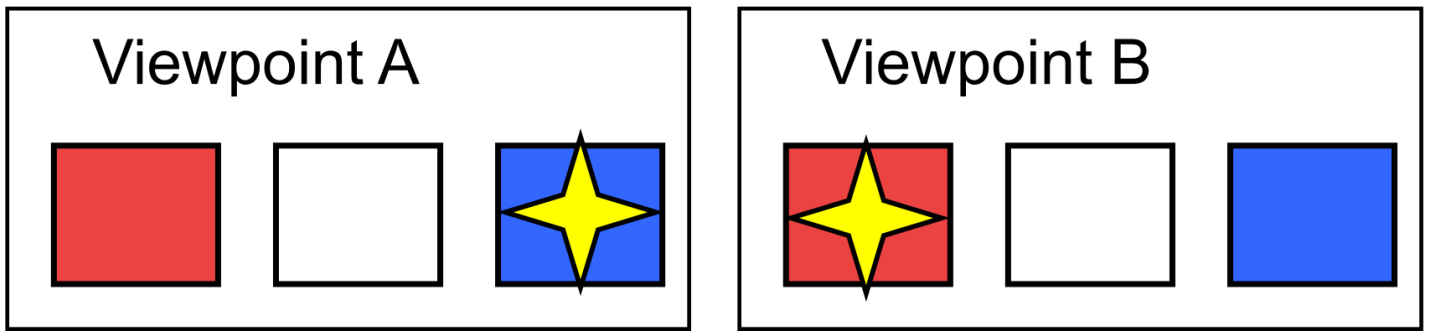




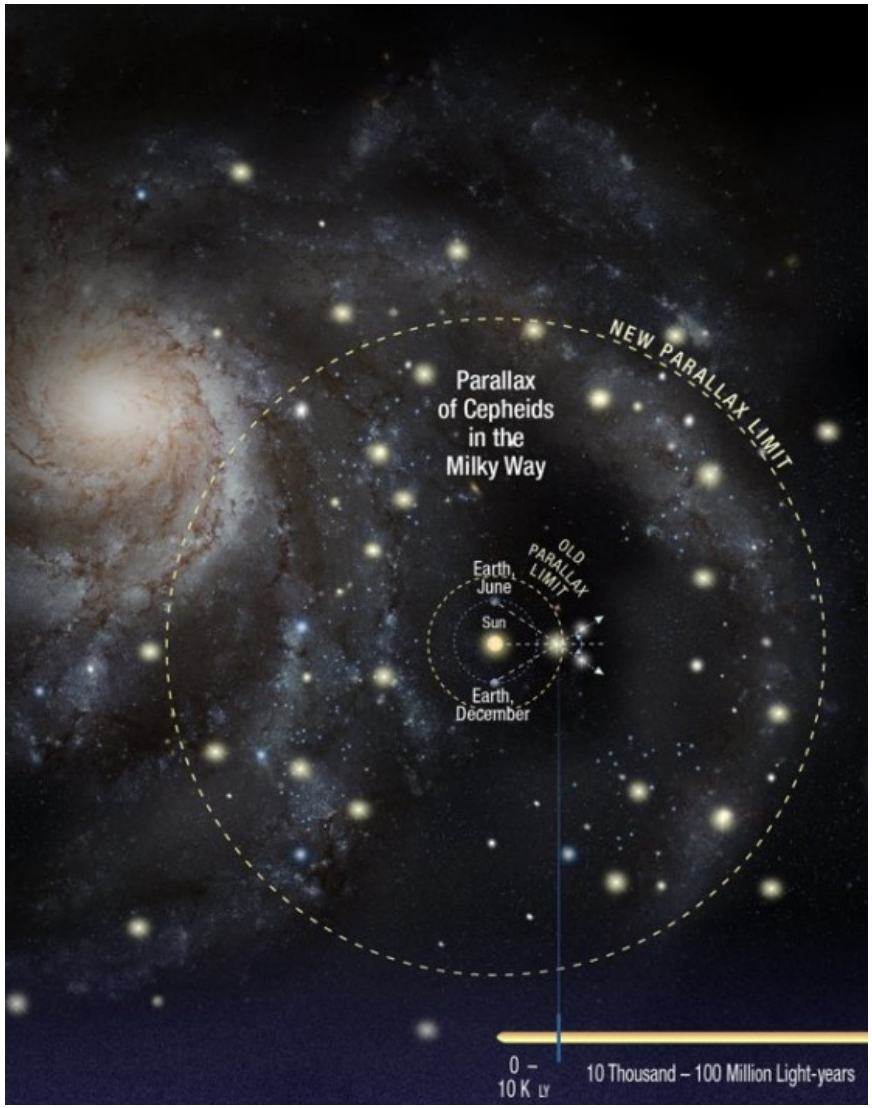
How to put a star on HR diagram?

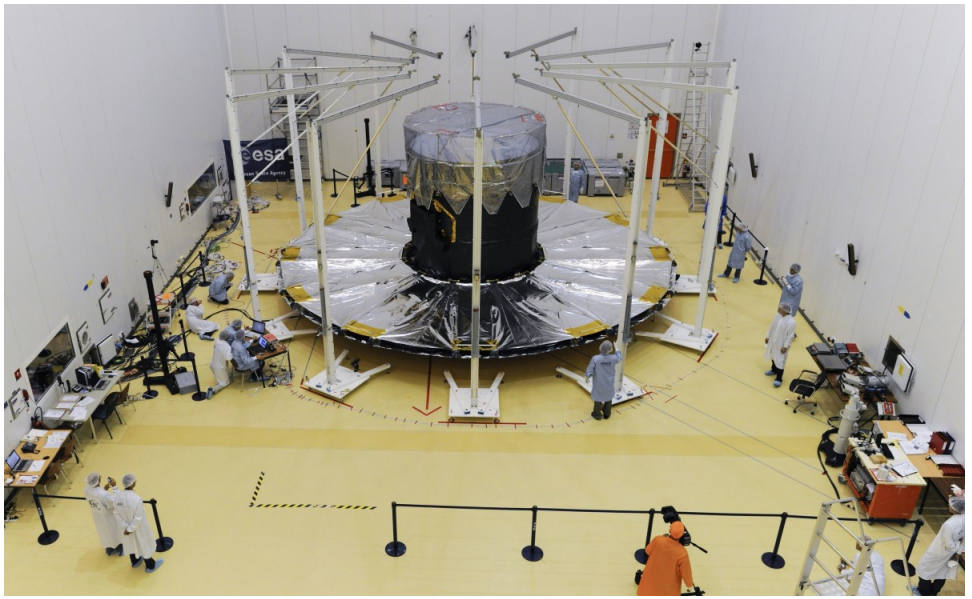
We know **distance** from **parallax**

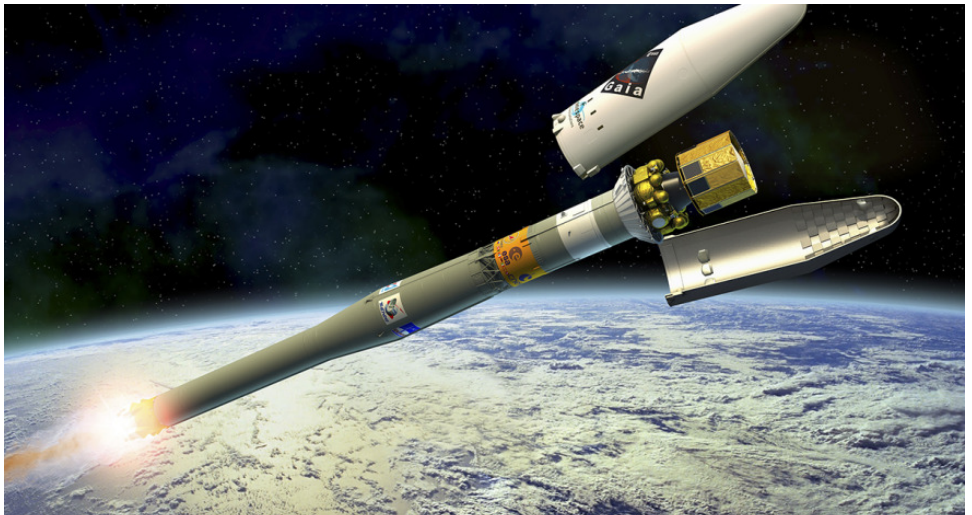




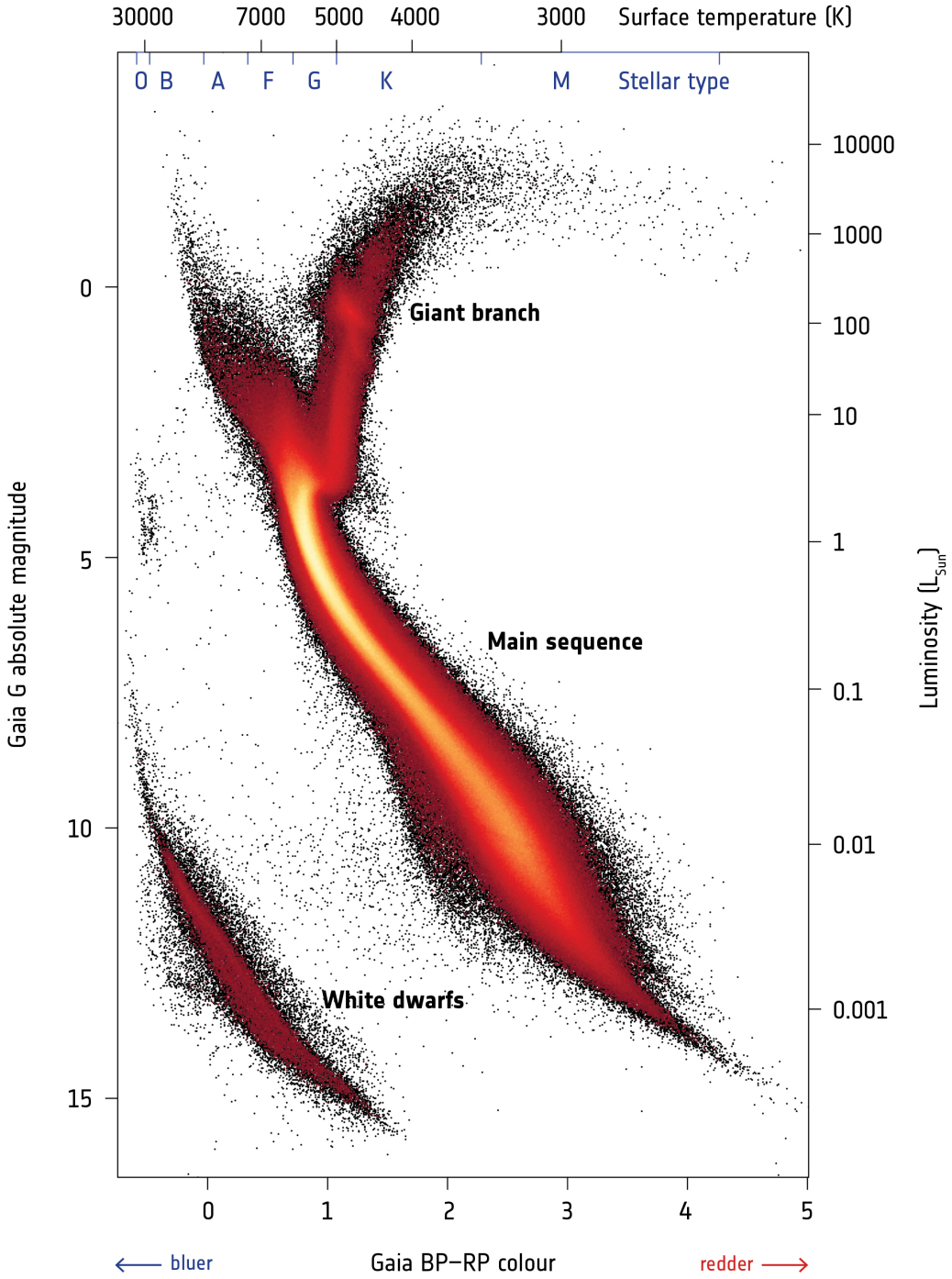
Gaia space probe measures **parallaxes** and **colors** of stars

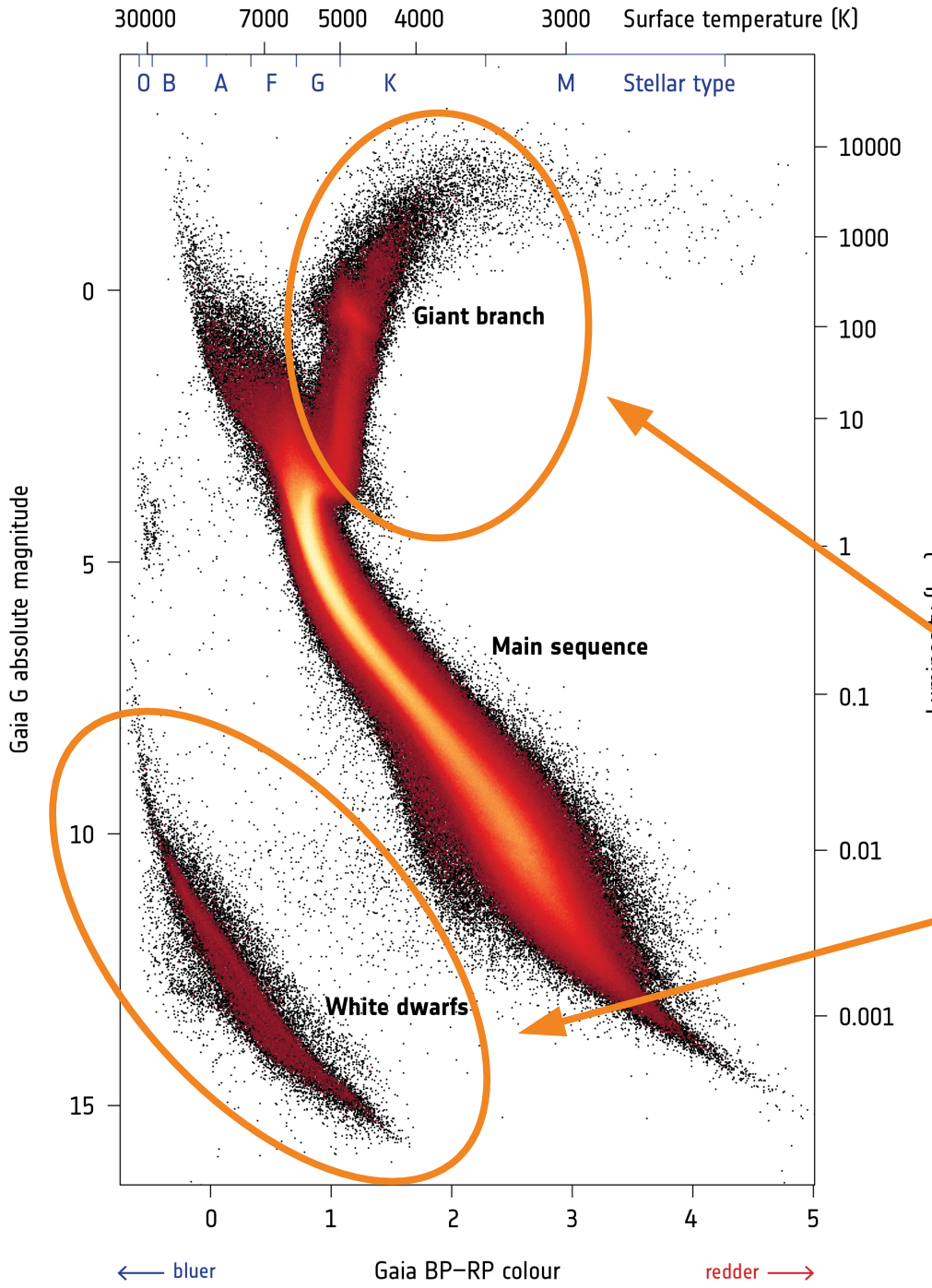






HR diagram from Gaia





HR diagram from Gaia

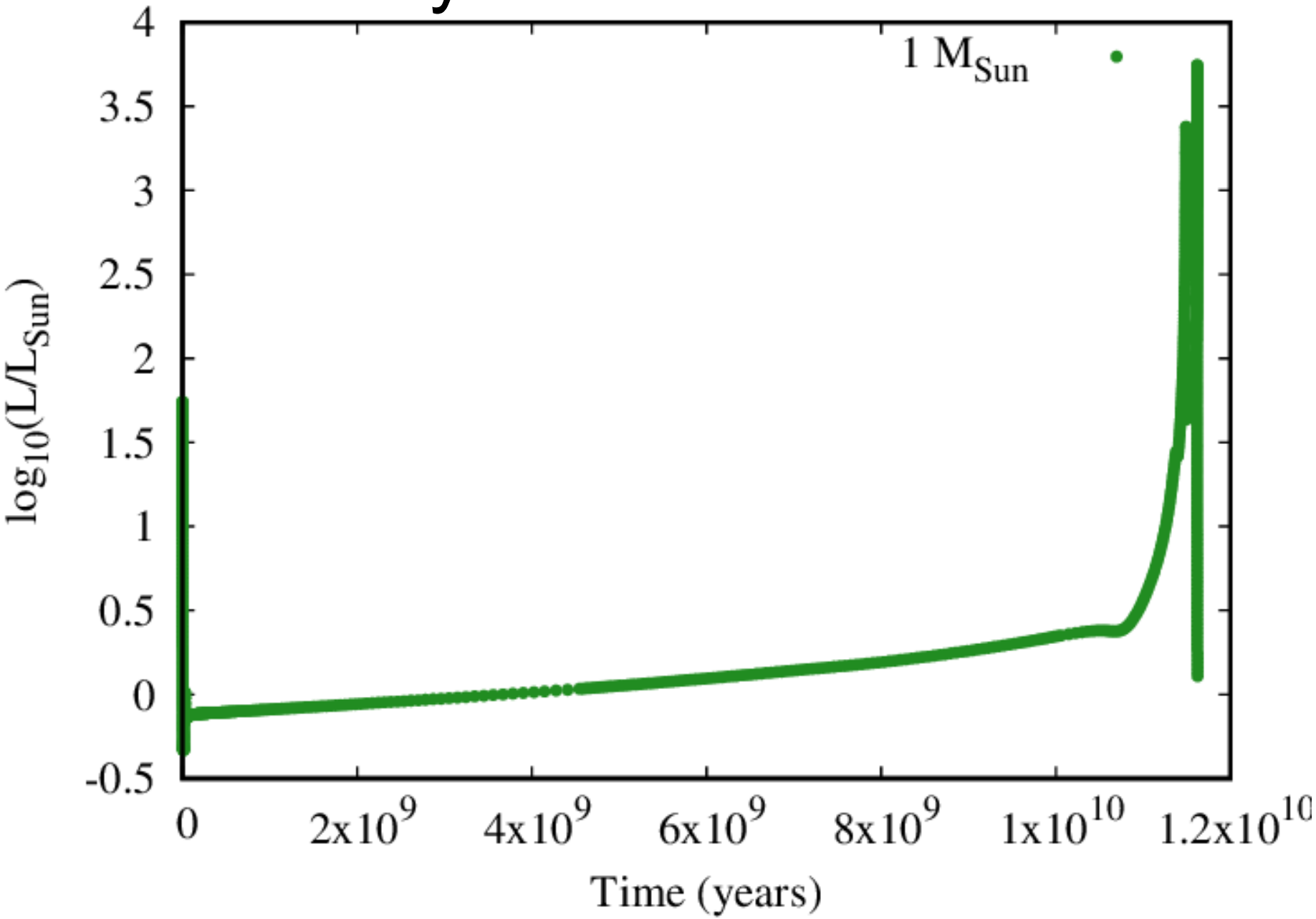
Stars that are out of Hydrogen fuel in their cores

How to put a star on HR diagram?

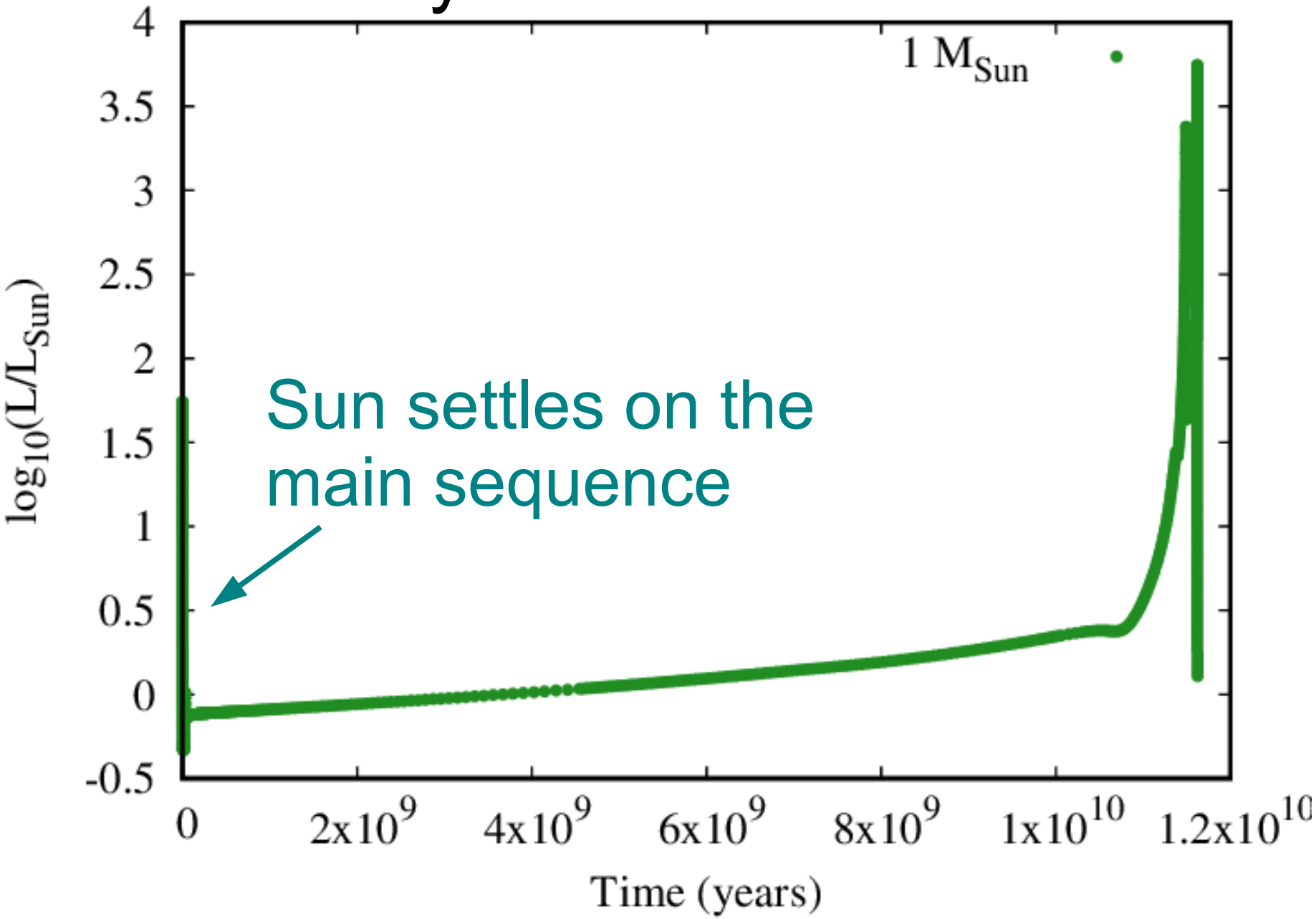
We can model life of a star on a computer

The following plots are made with the MESA/MIST stellar evolution code:
http://waps.cfa.harvard.edu/MIST/

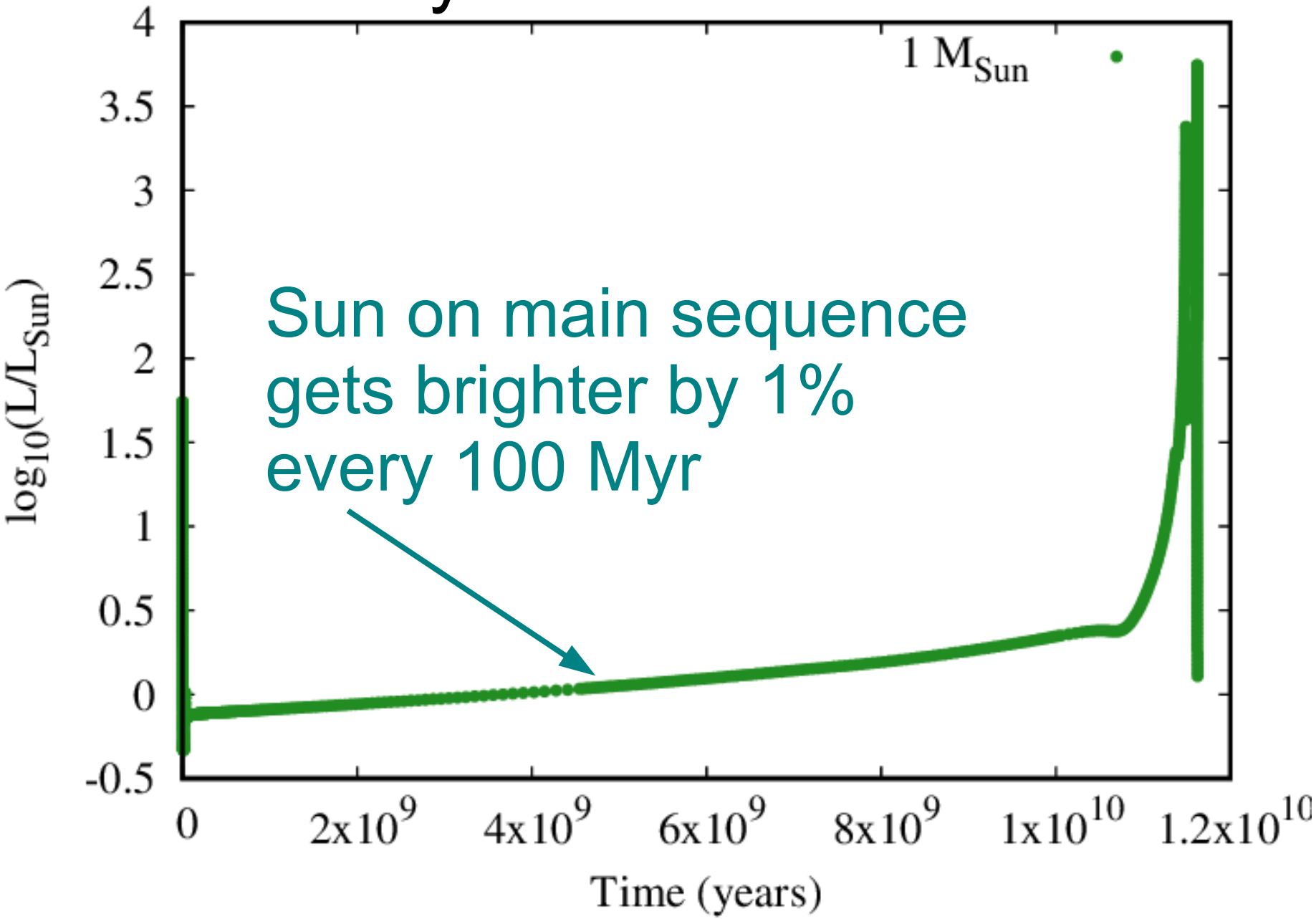
Luminosity as a function of time



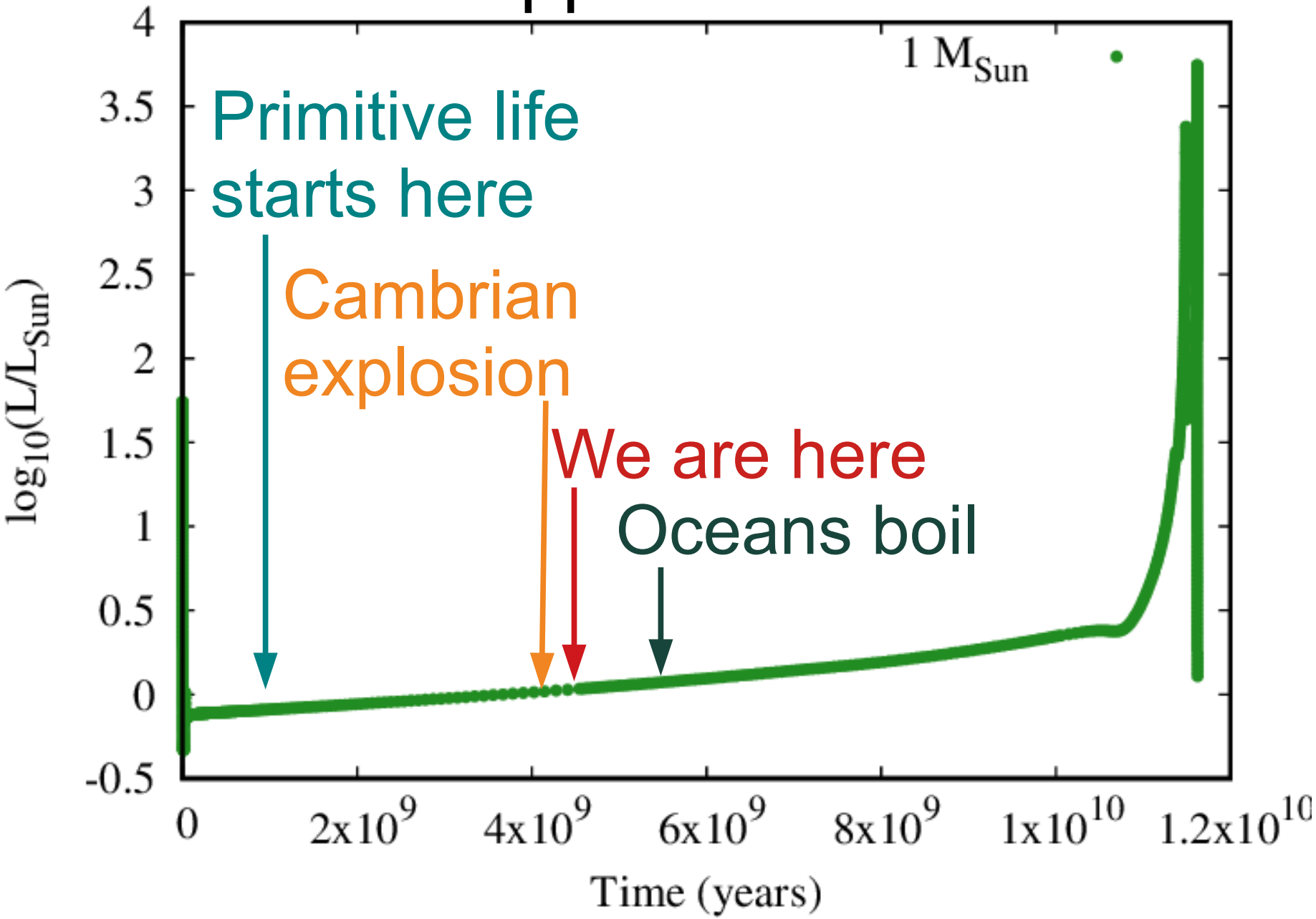
Luminosity as a function of time



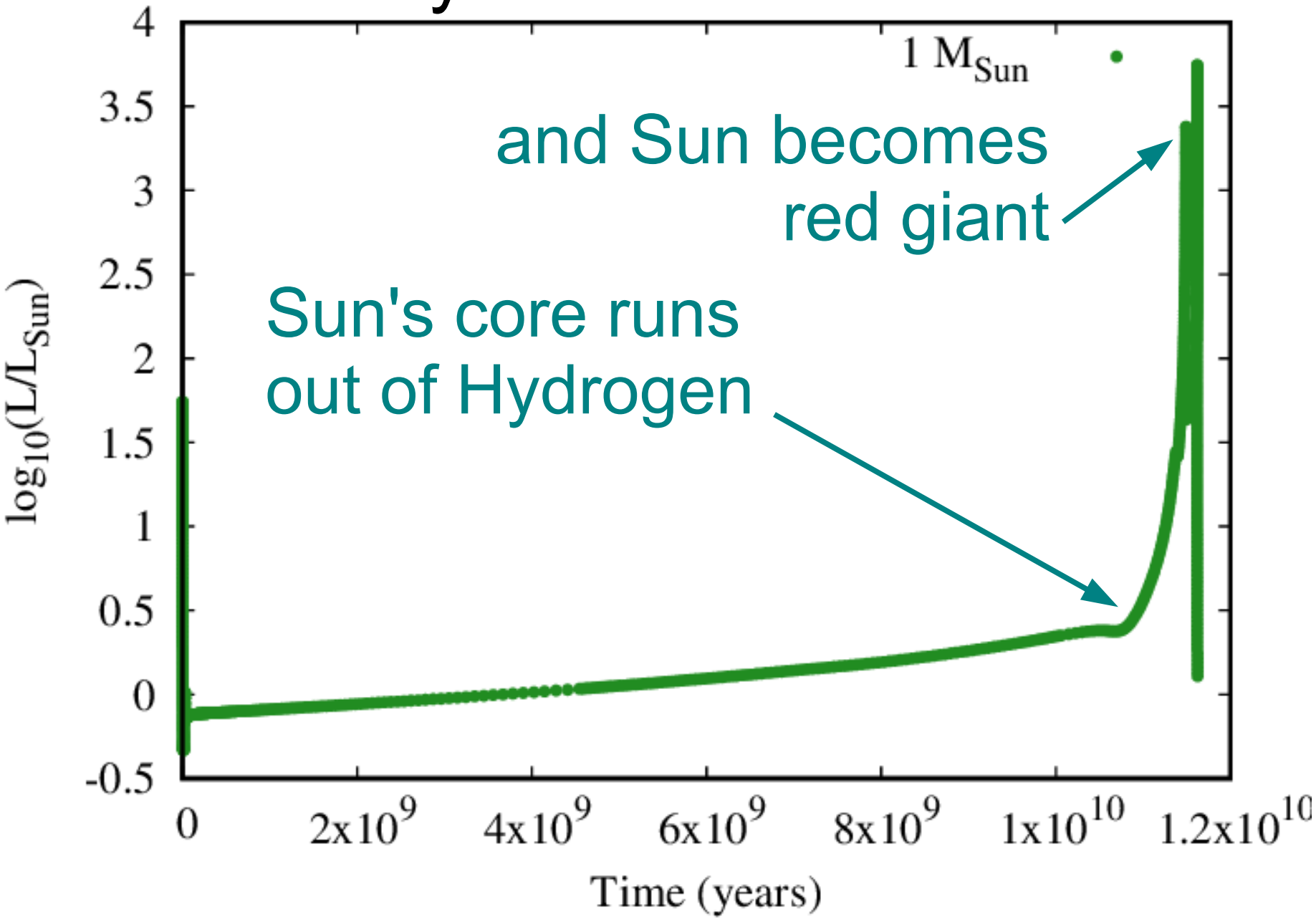
Luminosity as a function of time



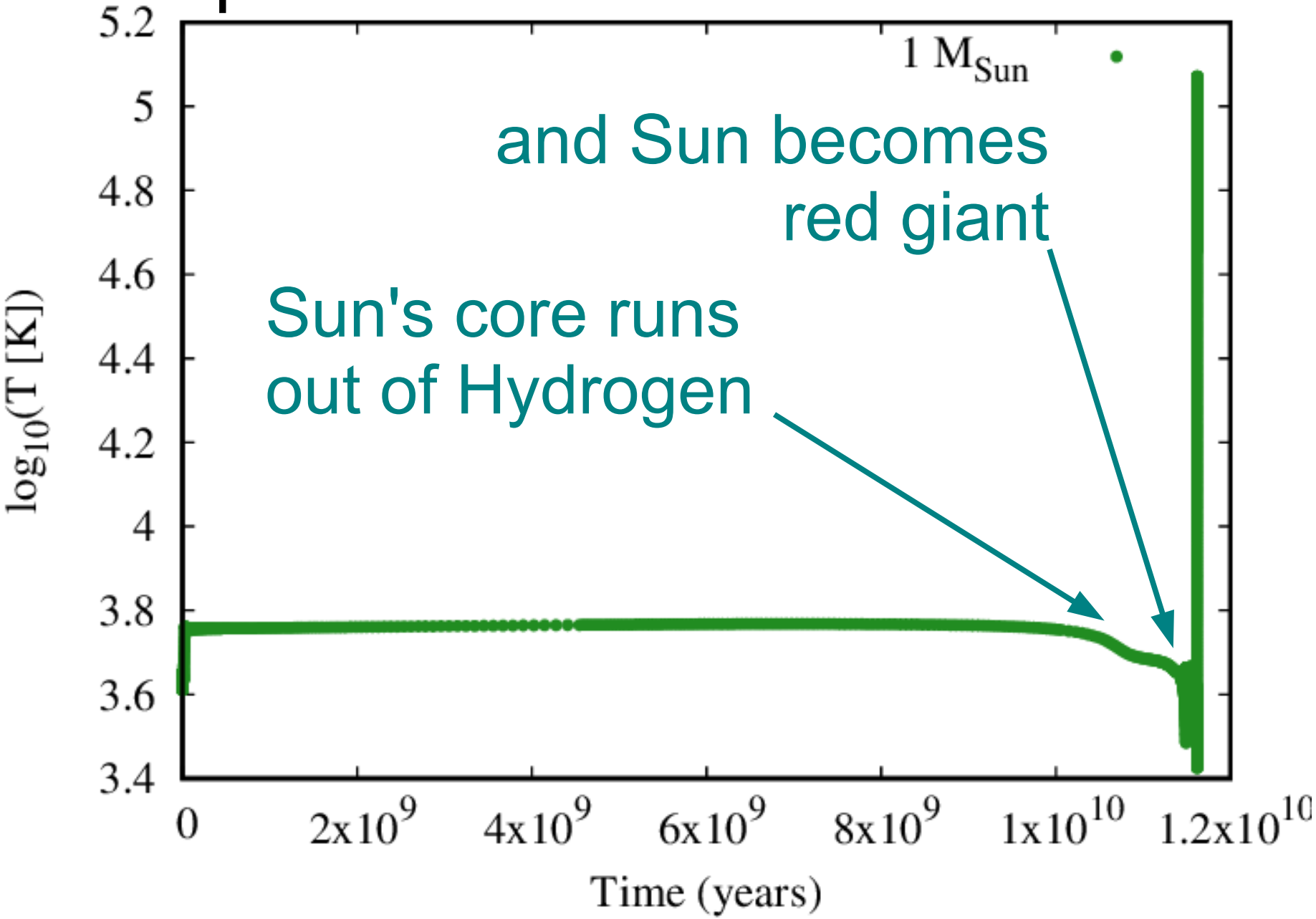
What happens on Earth



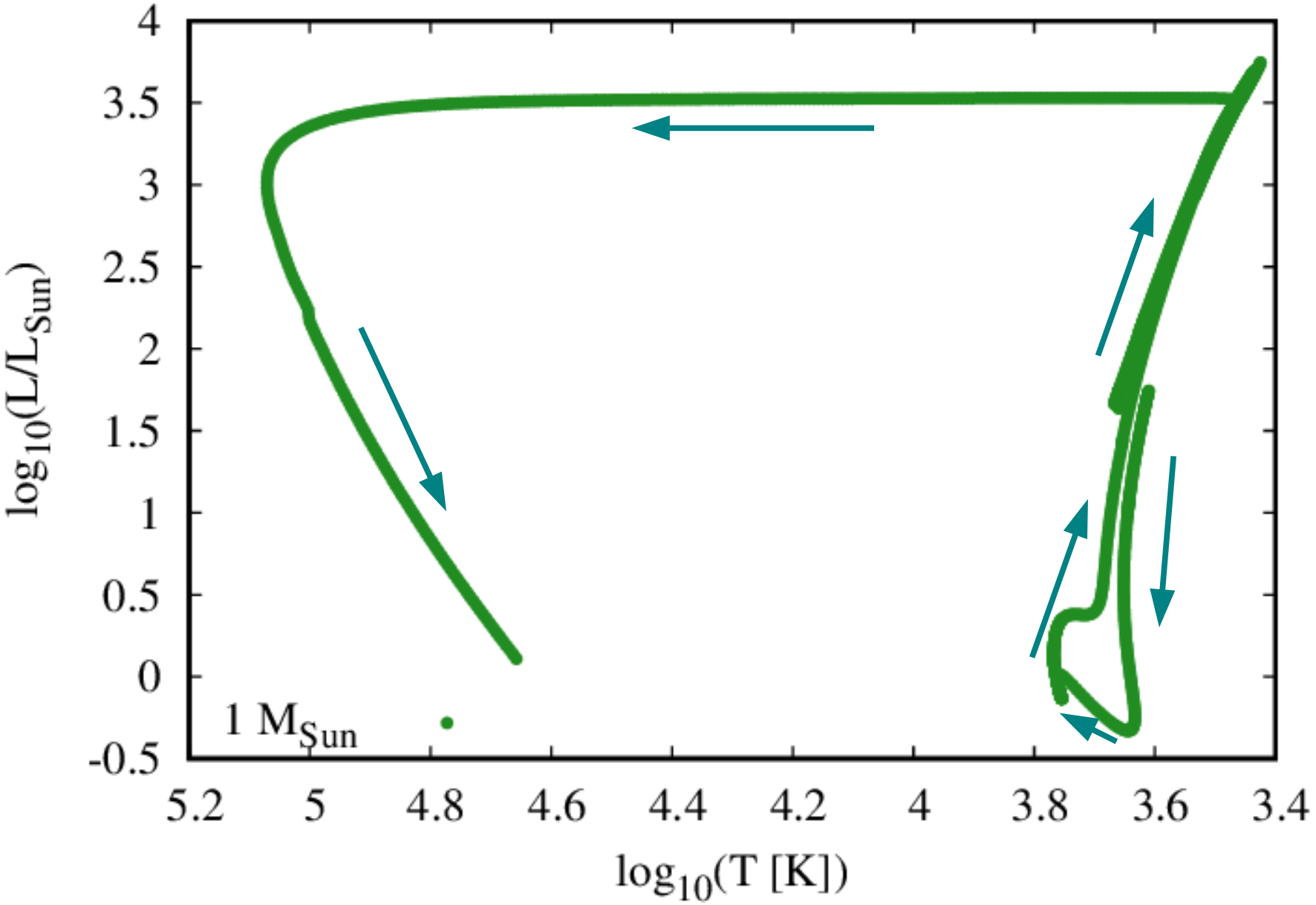
Luminosity as a function of time



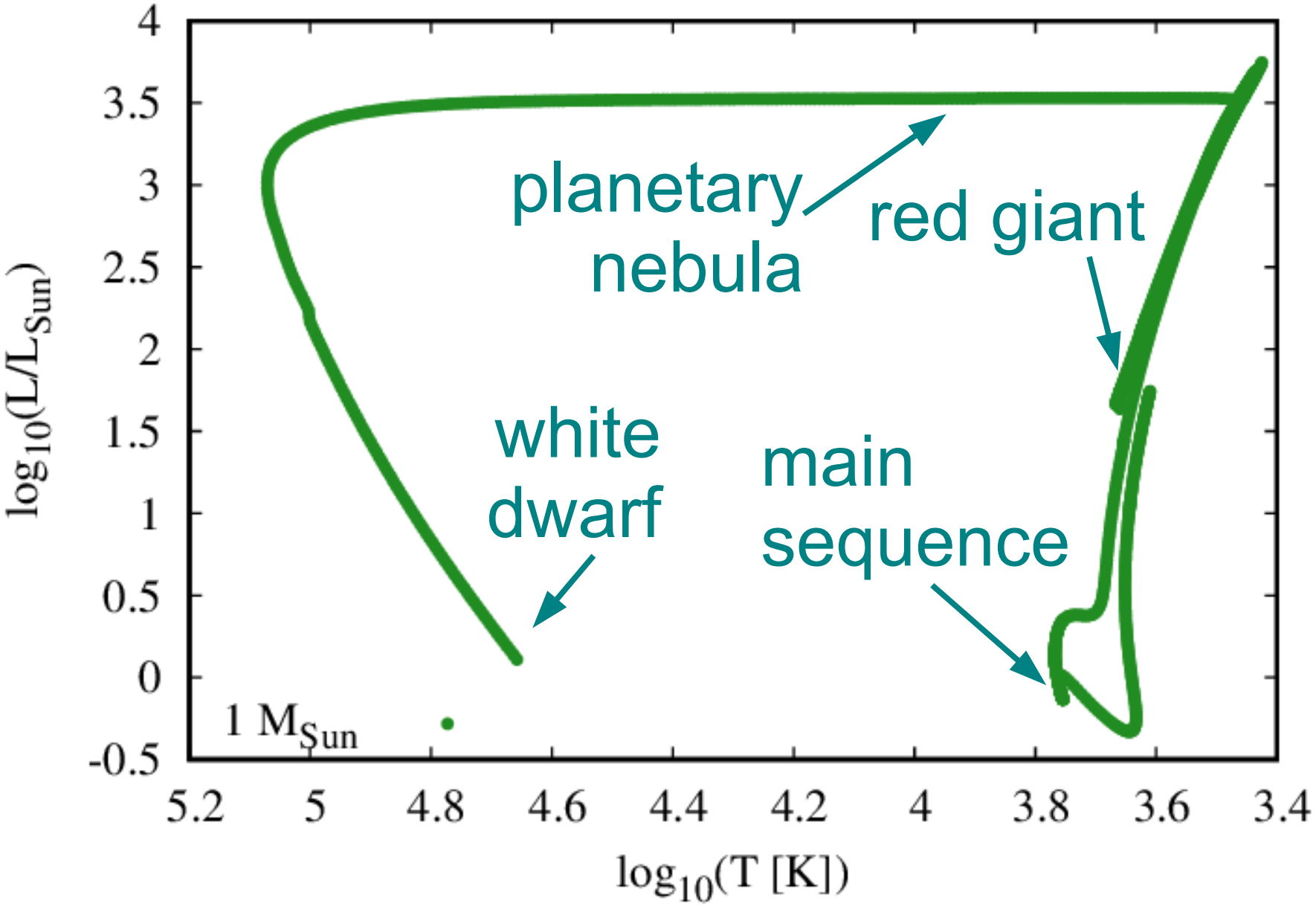
Temperature as a function of time



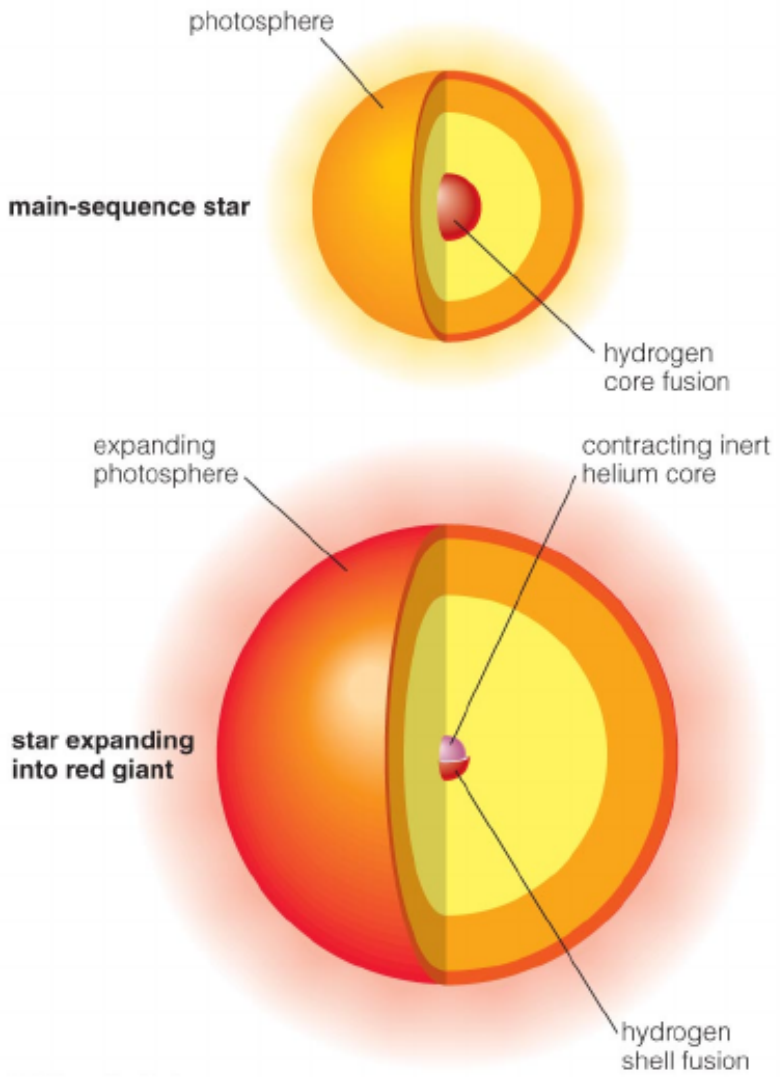
HR track of the Sun



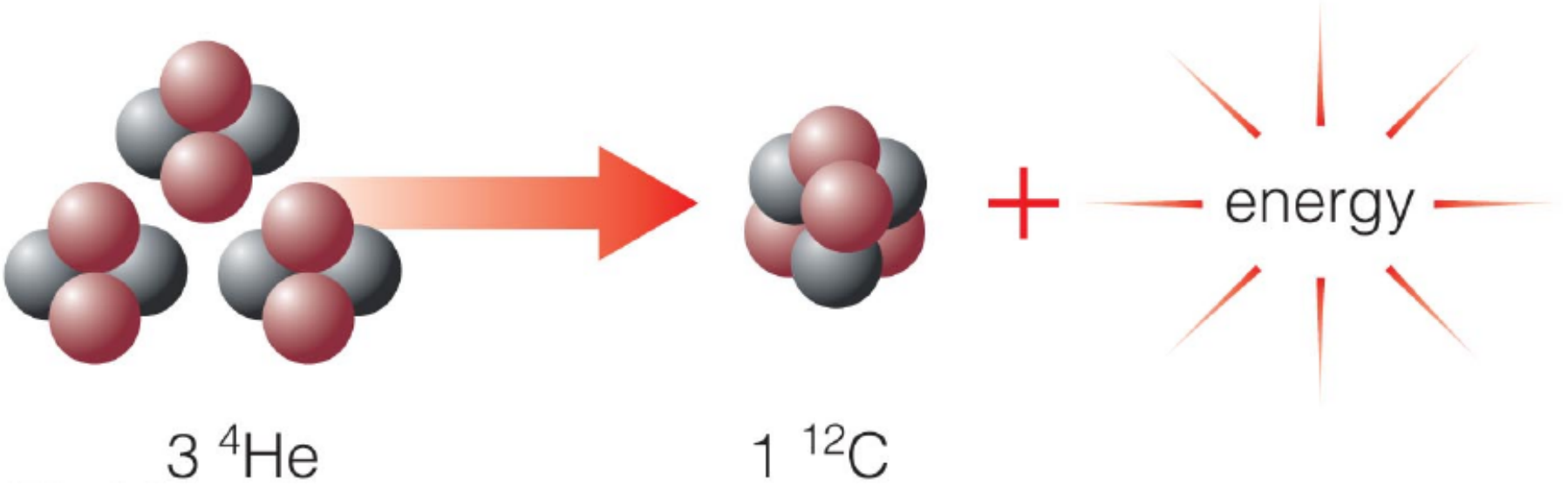
HR track of the Sun



Red Giants: Broken Thermostat

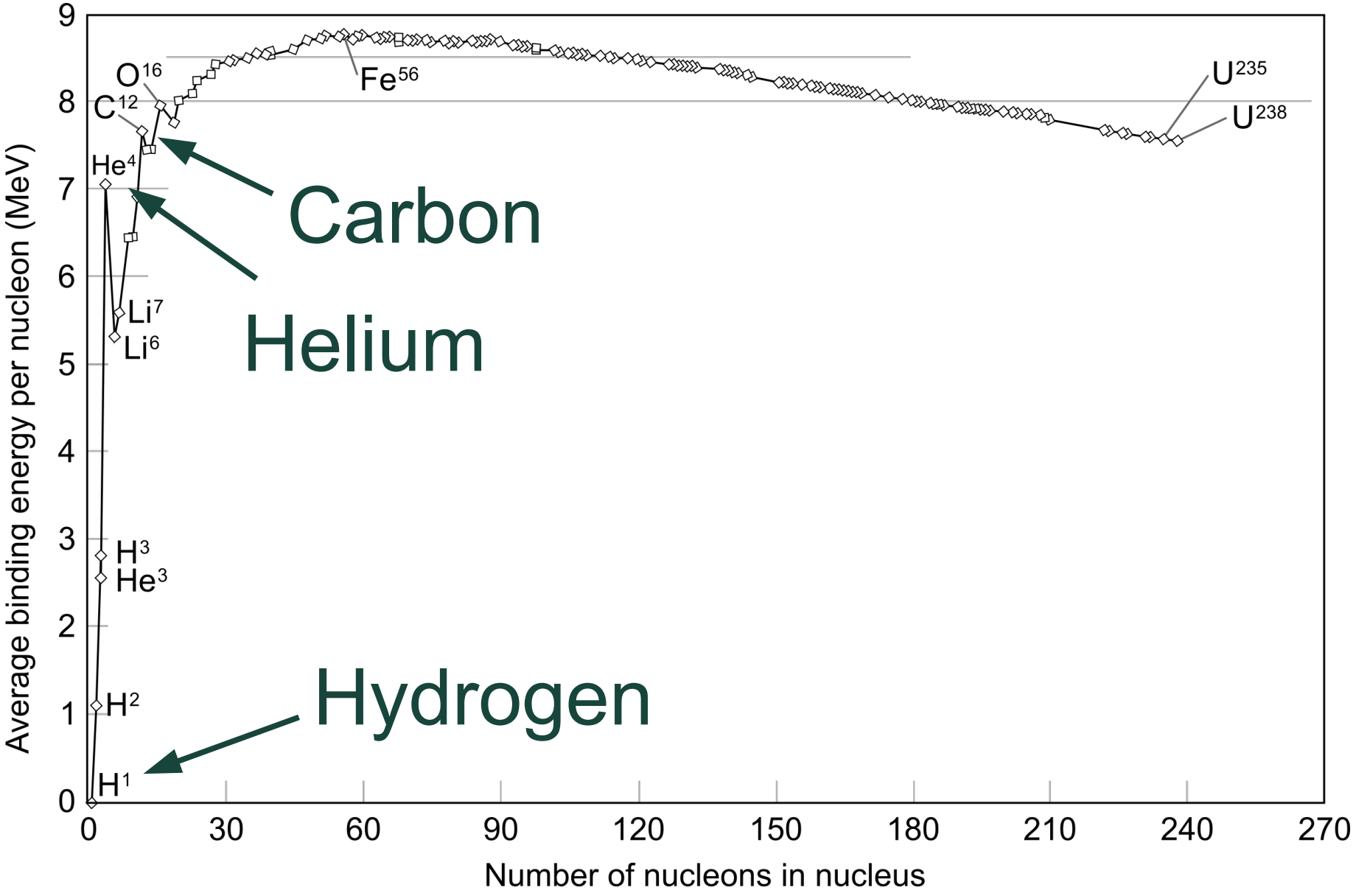


- As the core contracts, H begins fusing to He in a shell around the core.
- Luminosity increases because the core thermostat is broken—the increasing fusion rate in the shell does not stop the core from contracting.

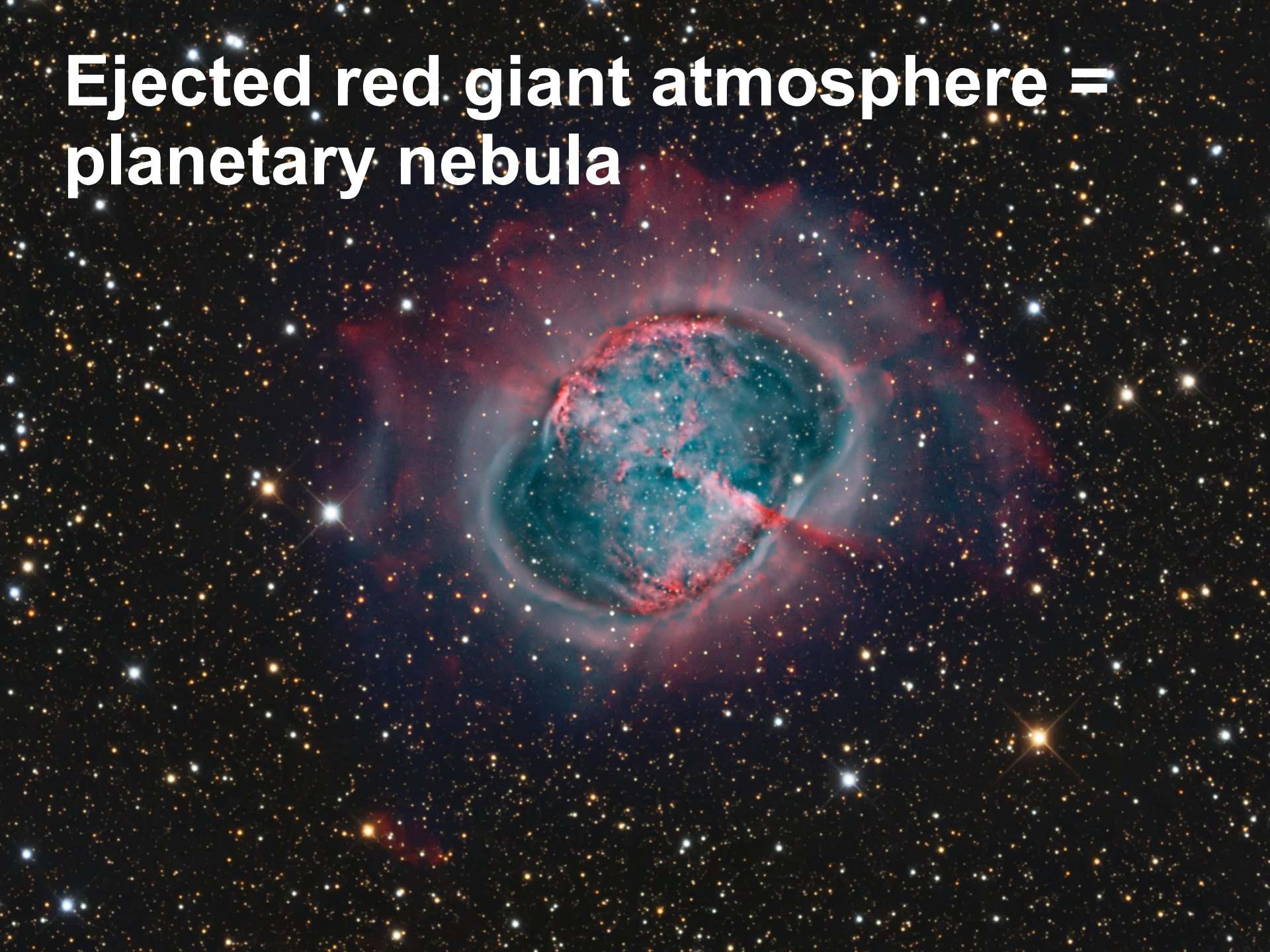


- Helium fusion does not begin right away because it requires higher temperatures than hydrogen fusion—larger charge leads to greater repulsion.
- Fusion of two helium nuclei doesn't work, so helium fusion must combine three helium nuclei to make carbon.

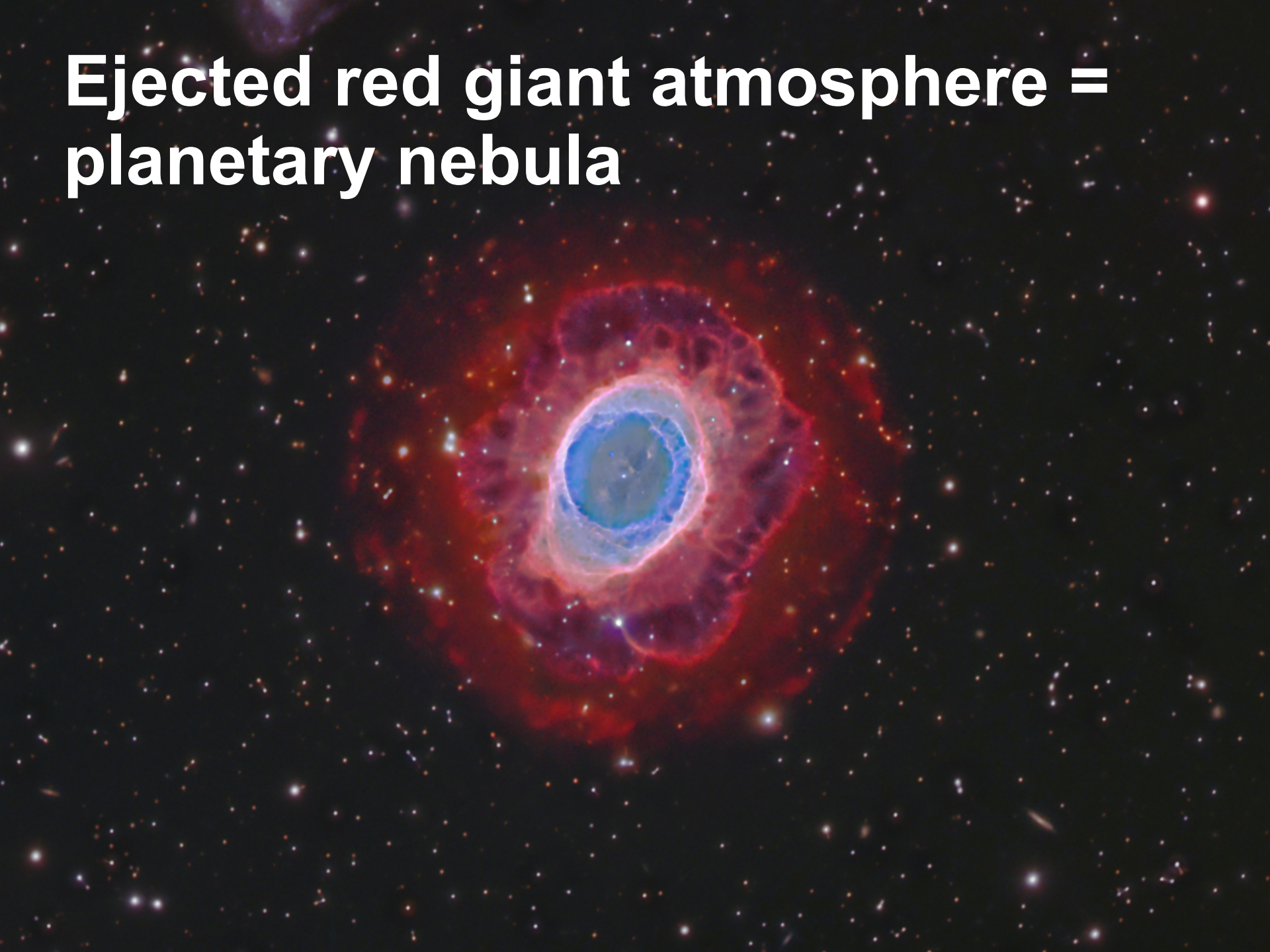
Nuclear vs. EM forces



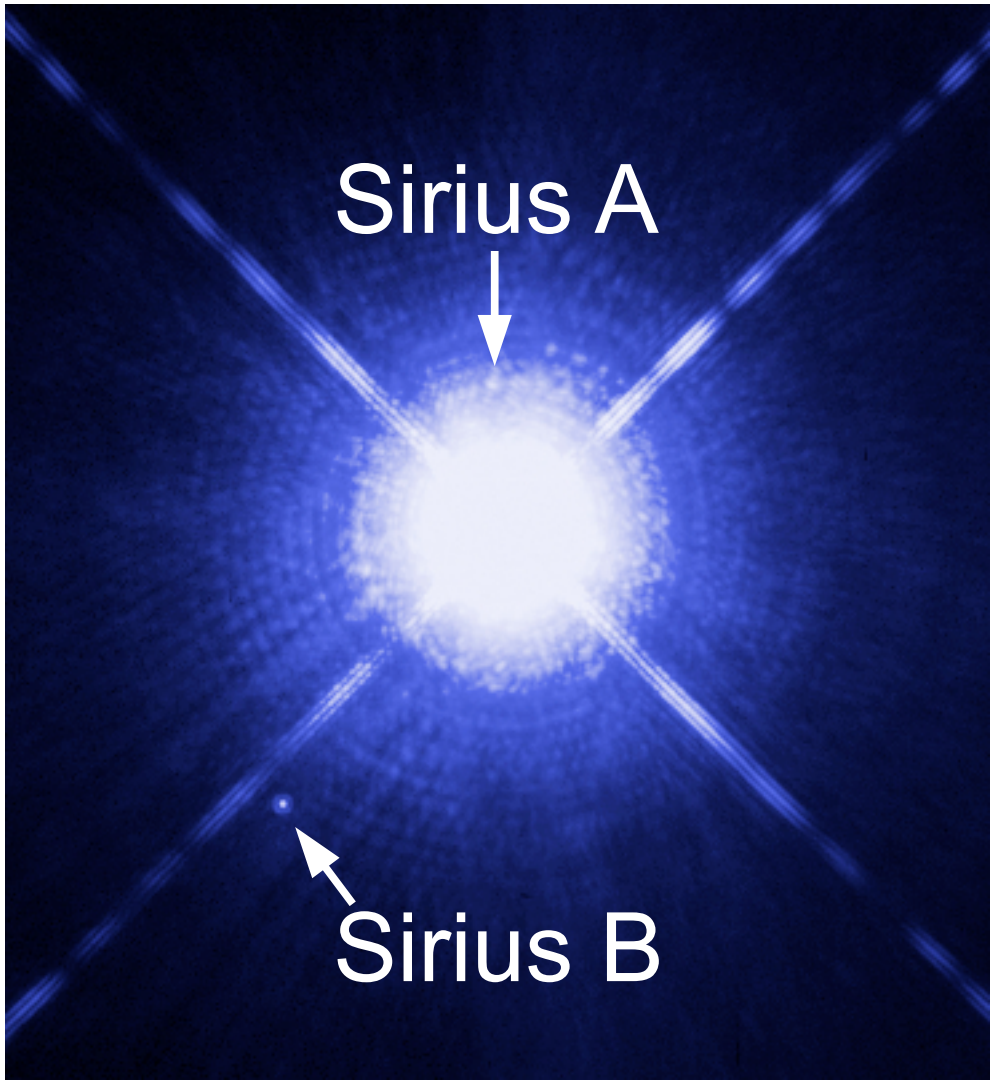
Ejected red giant atmosphere = planetary nebula



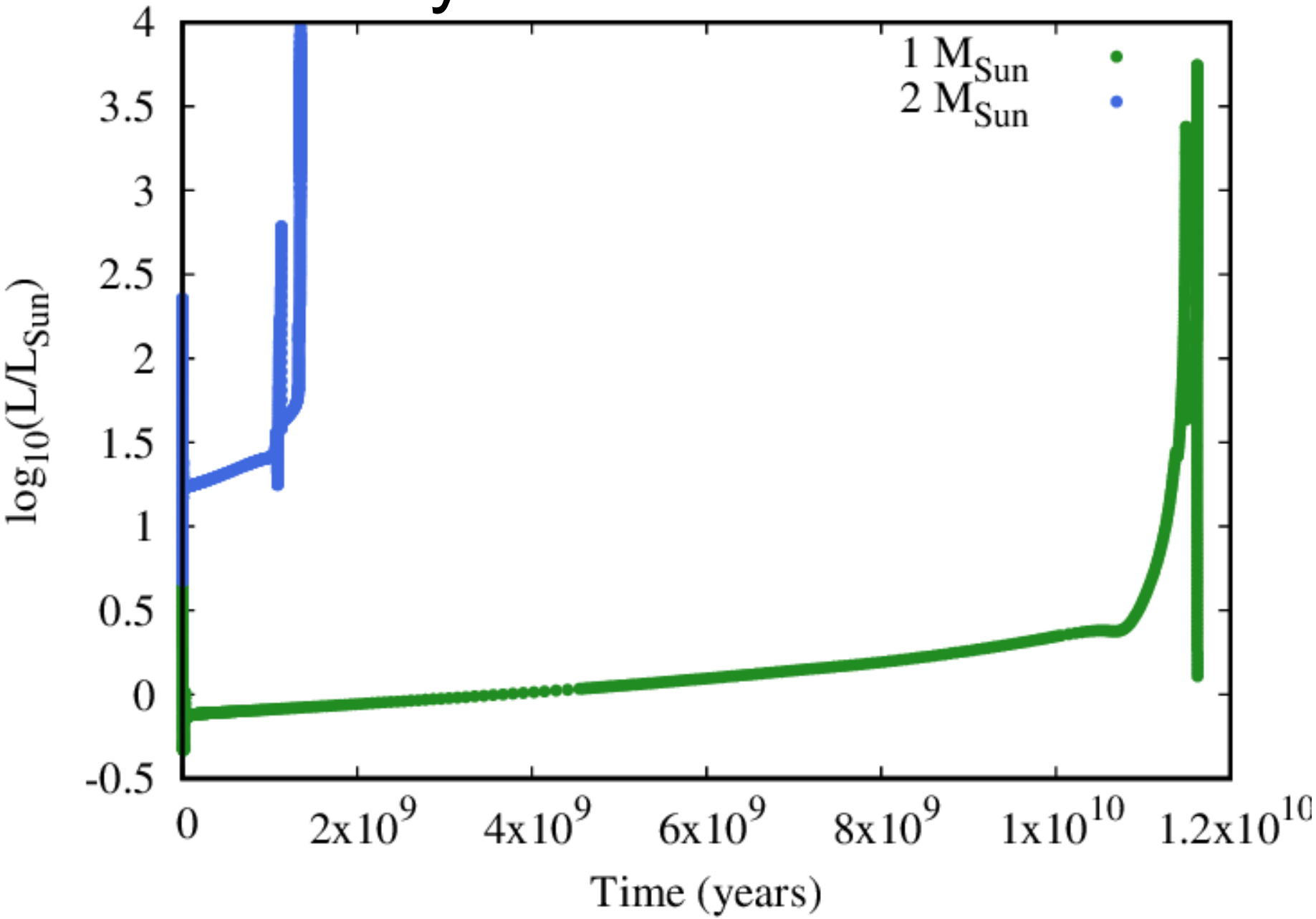
Ejected red giant atmosphere = planetary nebula



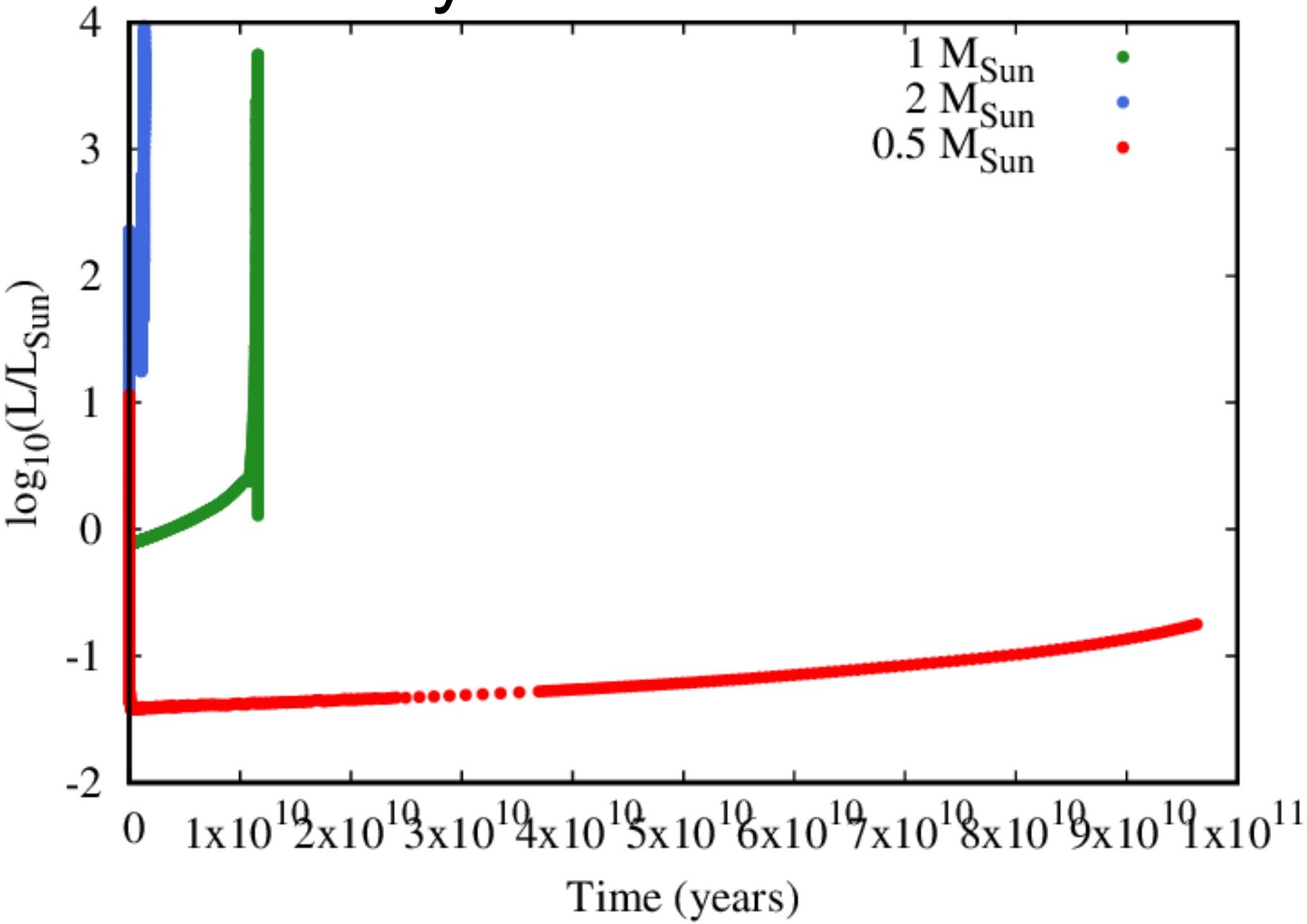
White Dwarf = exposed degenerate core of a solar-type star



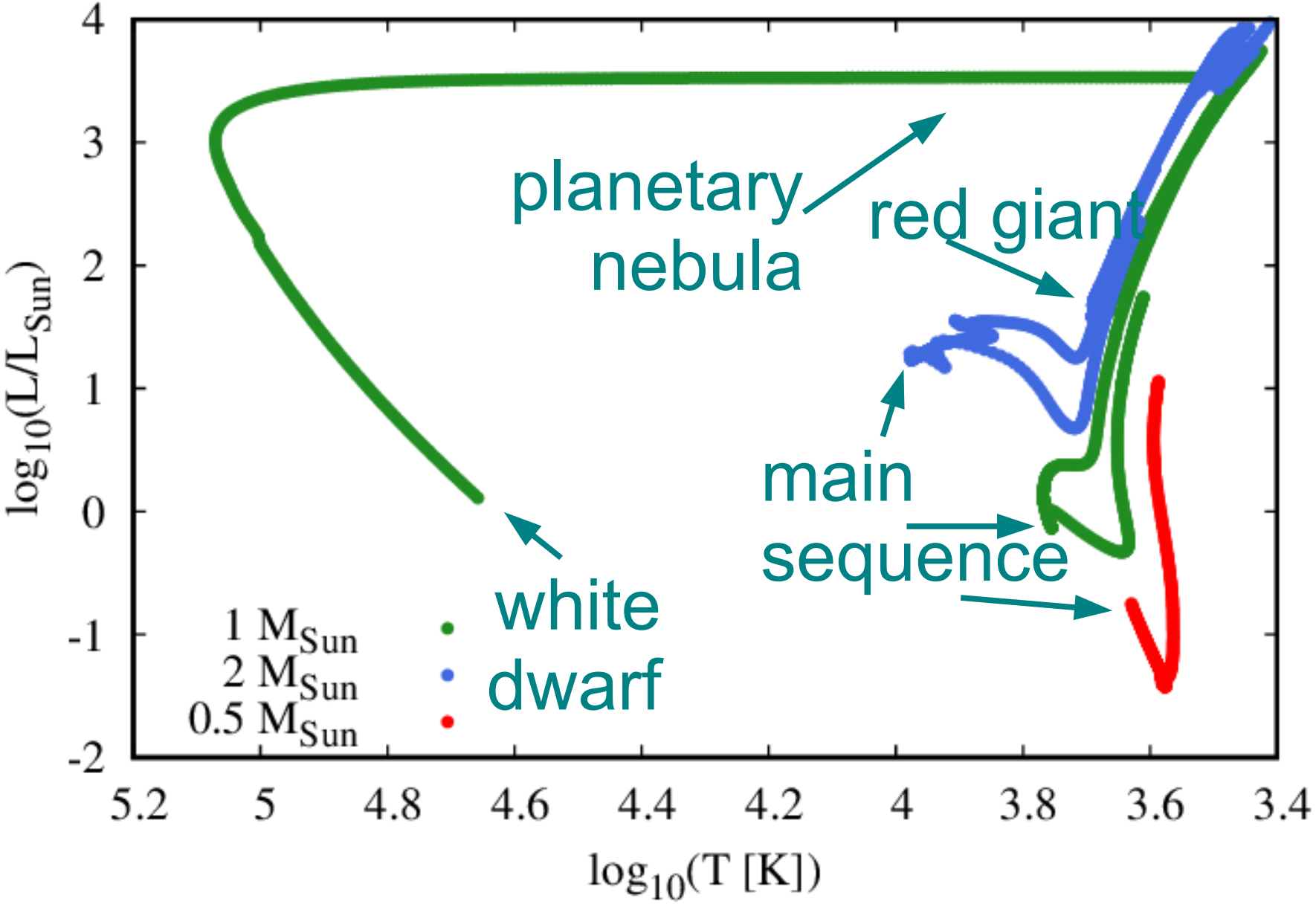
Luminosity as a function of time

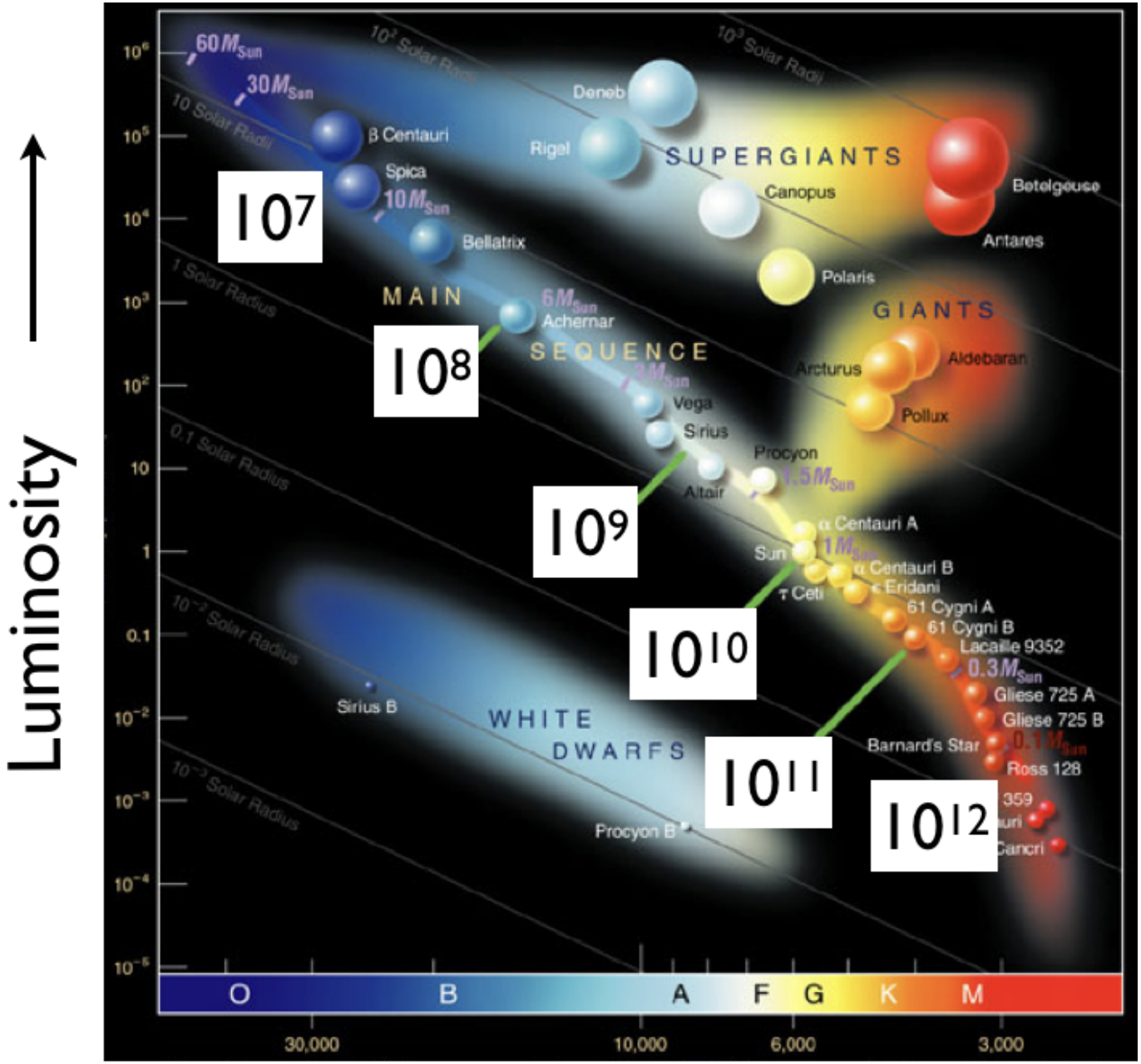


Luminosity as a function of time



HR tracks

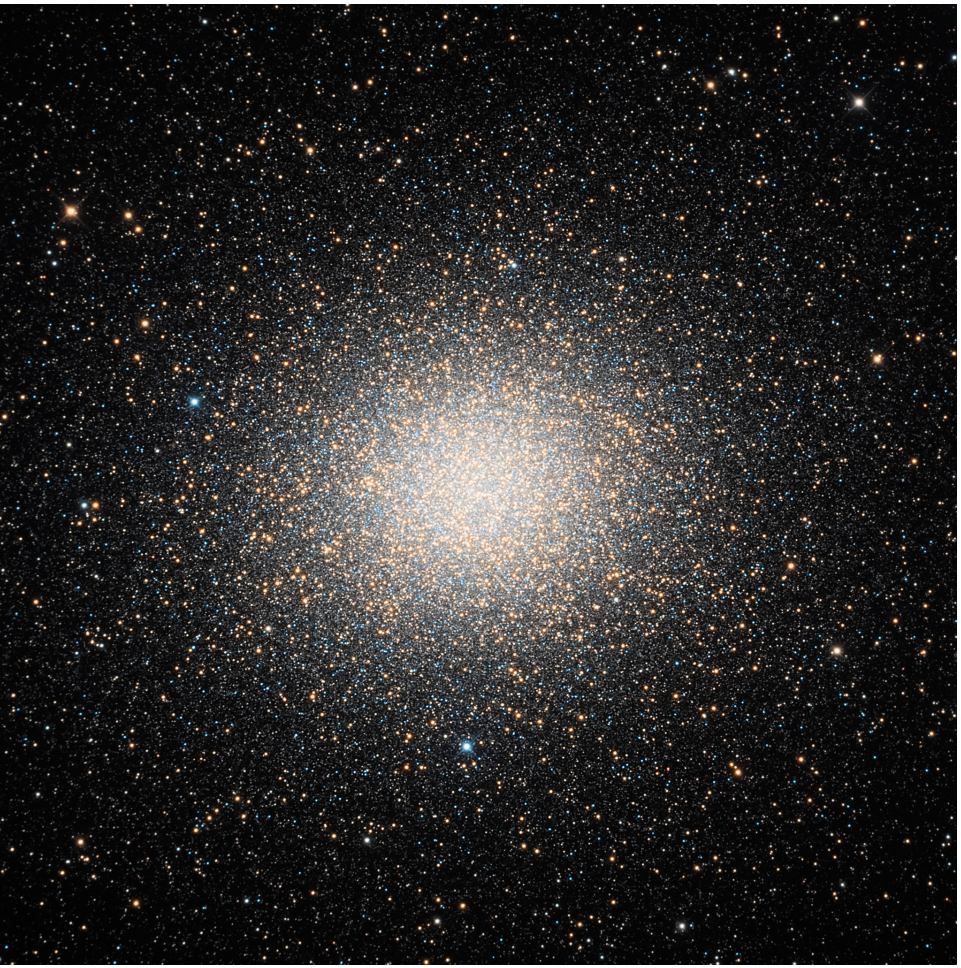

4
3
2
1
0
-1
-2
5.2
5
4.8
4.6
4.4
4.2
4
3.8
3.6
3.4
log10(L/LSun)
log10(T [K])
planetary nebula
red giant
main sequence
white dwarf
1 MSun
2 MSun
0.5 MSun


Luminosity
Temperature
SUPERGIANTS
GIANTS
MAIN SEQUENCE
WHITE DWARFS
Deneb
Rigel
Canopus
Betelgeuse
Antares
Polaris
β Centauri
Spica
Bellatrix
Achernar
Arcturus
Aldebaran
Pollux
Vega
Sirius
Procyon
Altair
α Centauri A
Sun
α Centauri B
τ Ceti
ε Eridani
61 Cygni A
61 Cygni B
Lacaille 9352
Gliese 725 A
Gliese 725 B
Barnard's Star
Ross 128
Sirius B
Procyon B
10^7
10^8
10^9
10^{10}
10^{11}
10^{12}
$60M_{Sun}$
$30M_{Sun}$
$10M_{Sun}$
$6M_{Sun}$
$3M_{Sun}$
$1.5M_{Sun}$
$1M_{Sun}$
$0.3M_{Sun}$
$0.1M_{Sun}$
10^3 Solar Radii
10 Solar Radii
1 Solar Radius
0.1 Solar Radius
10^{-2} Solar Radius
10^{-3} Solar Radius
10^6
10^5
10^4
10^3
10^2
10
1
0.1
10^{-2}
10^{-3}
10^{-4}
10^{-5}
O
B
A
F
G
K
M
30,000
10,000
6,000
3,000

Stars often born in clusters

There are two types: **Globular** and **Open**

Omega Centauri

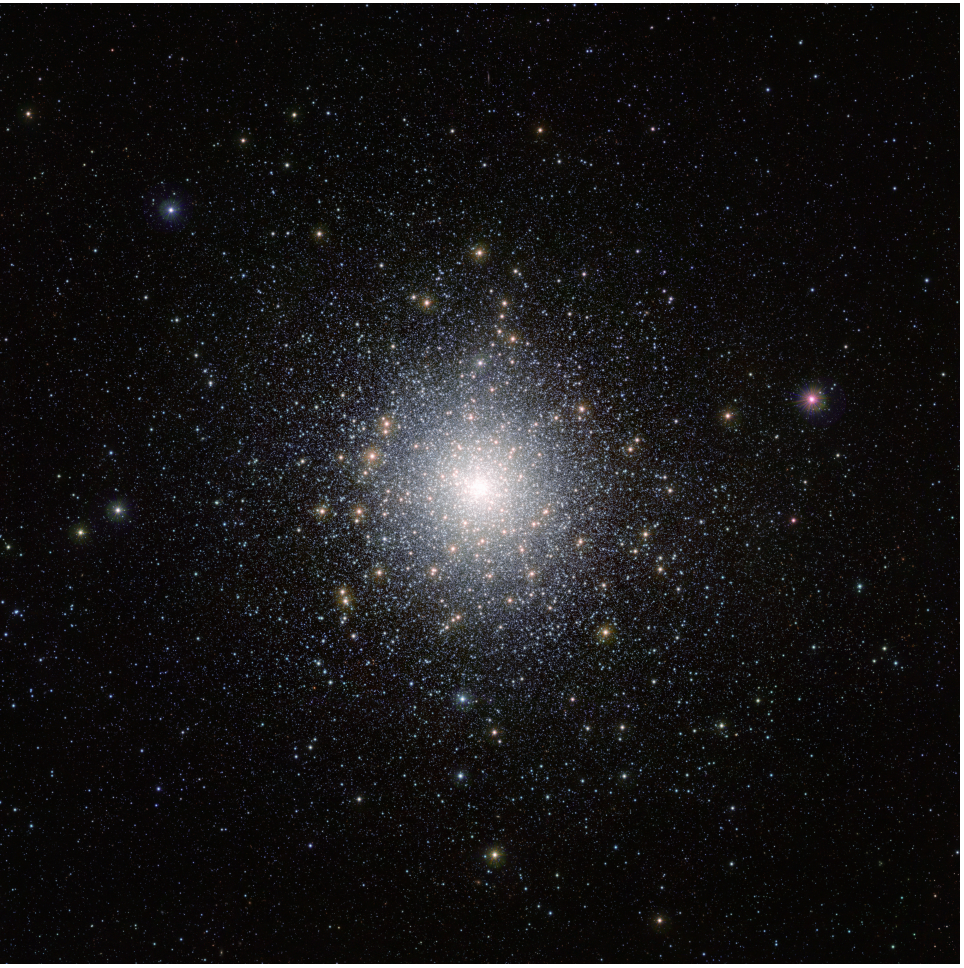


Pleiades

Two other examples of star clusters

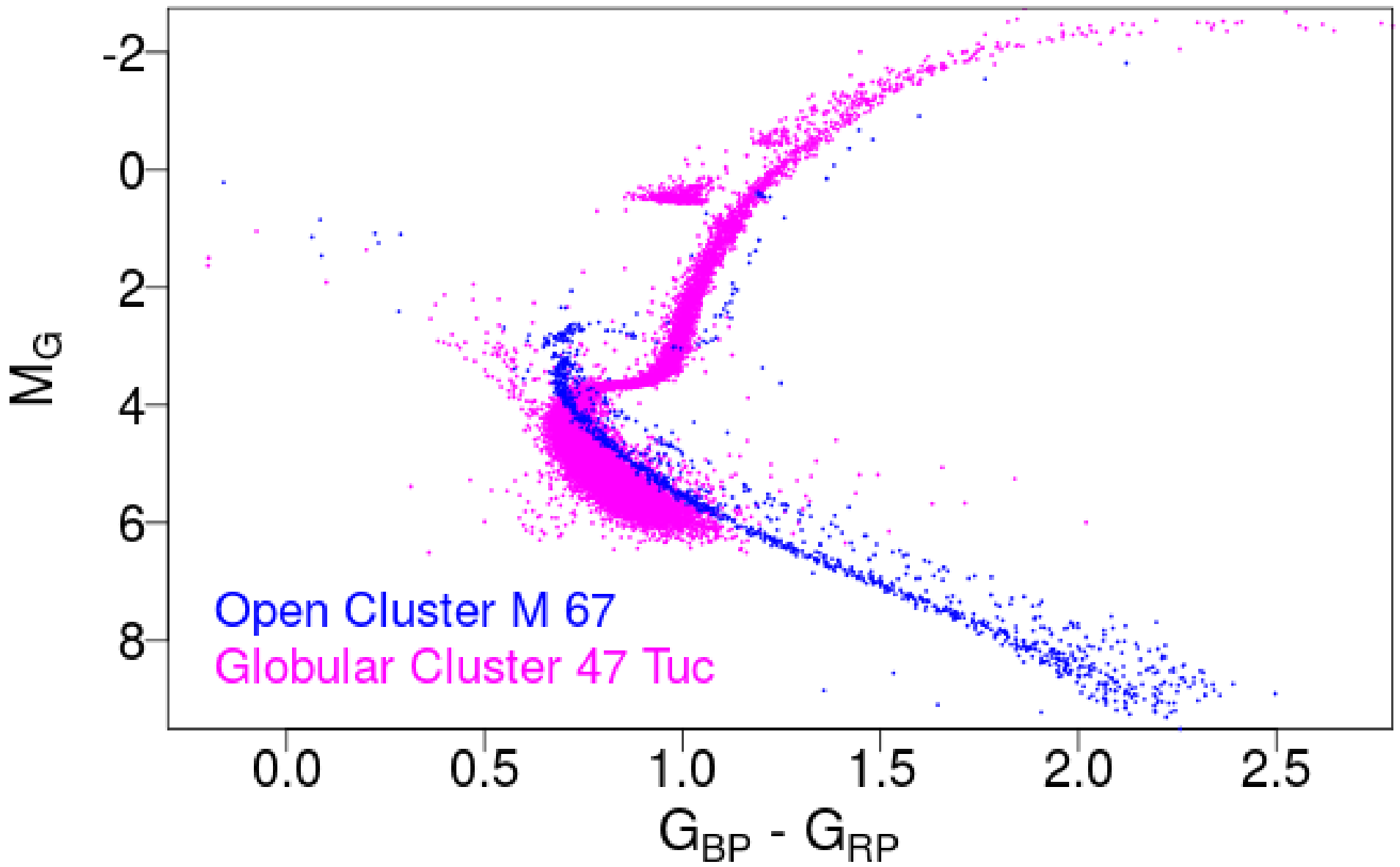
There are two types: **Globular** and **Open**

47 Tucanae

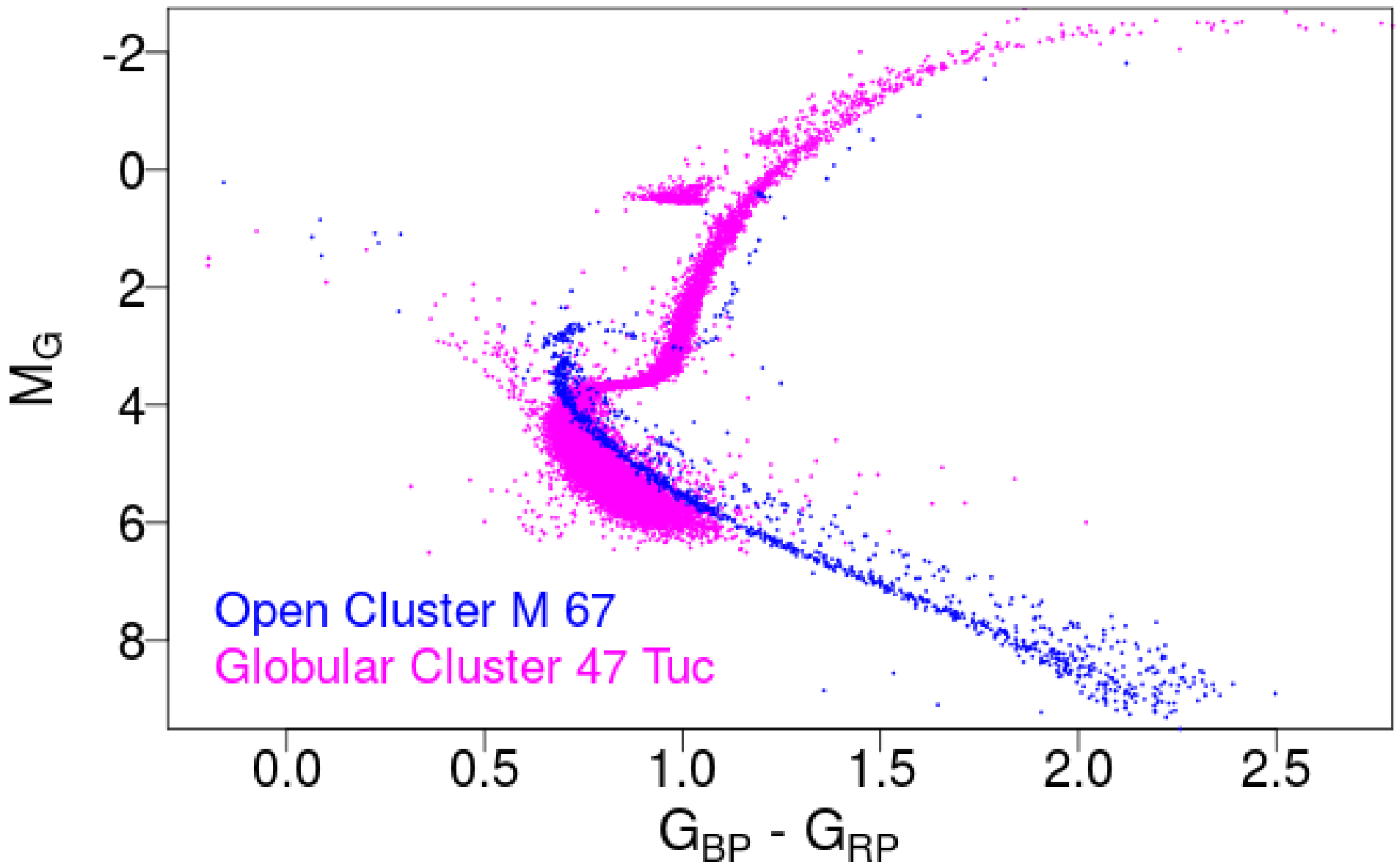


M67

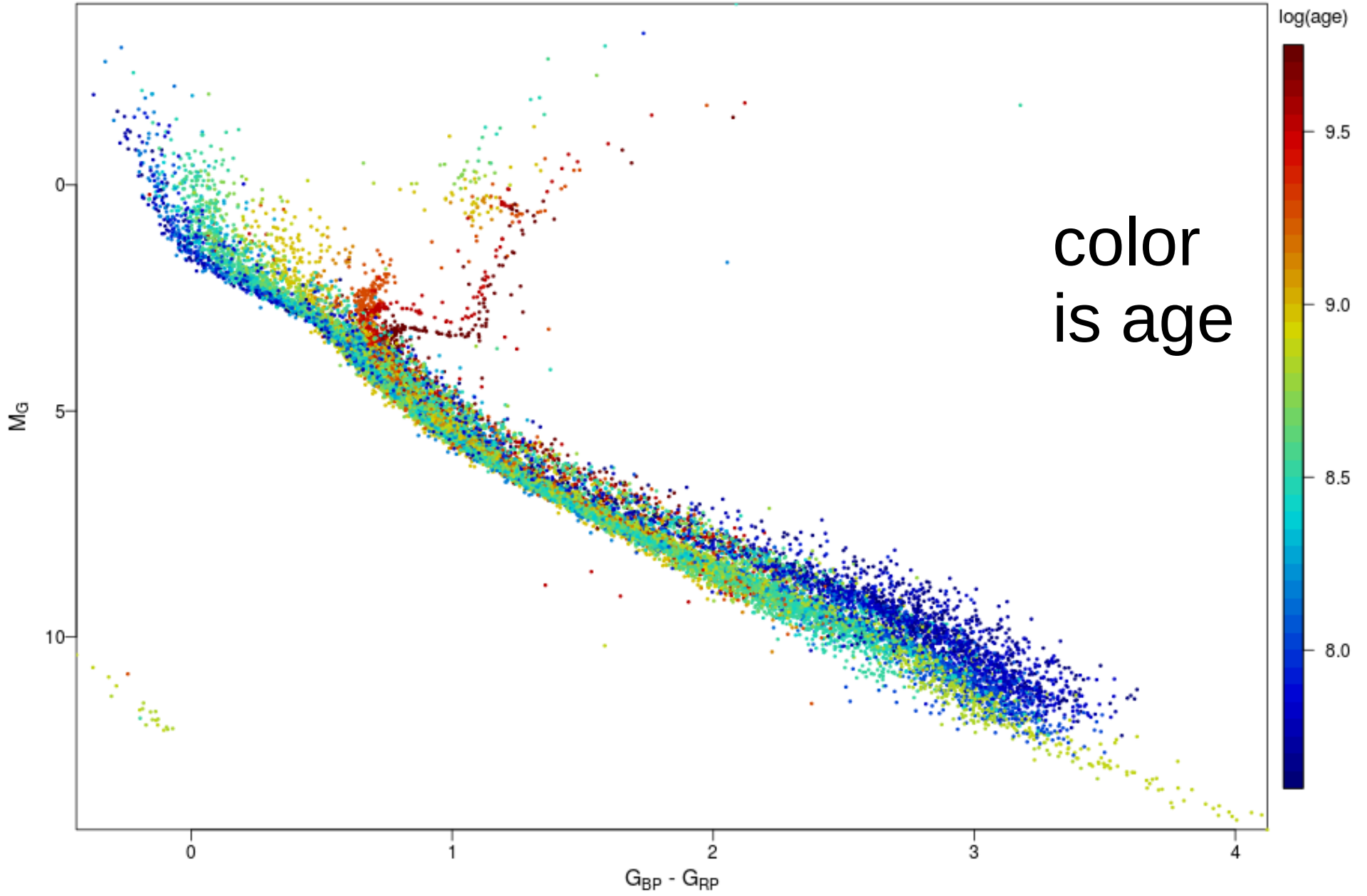
Gaia HR: old OC vs “young” GC



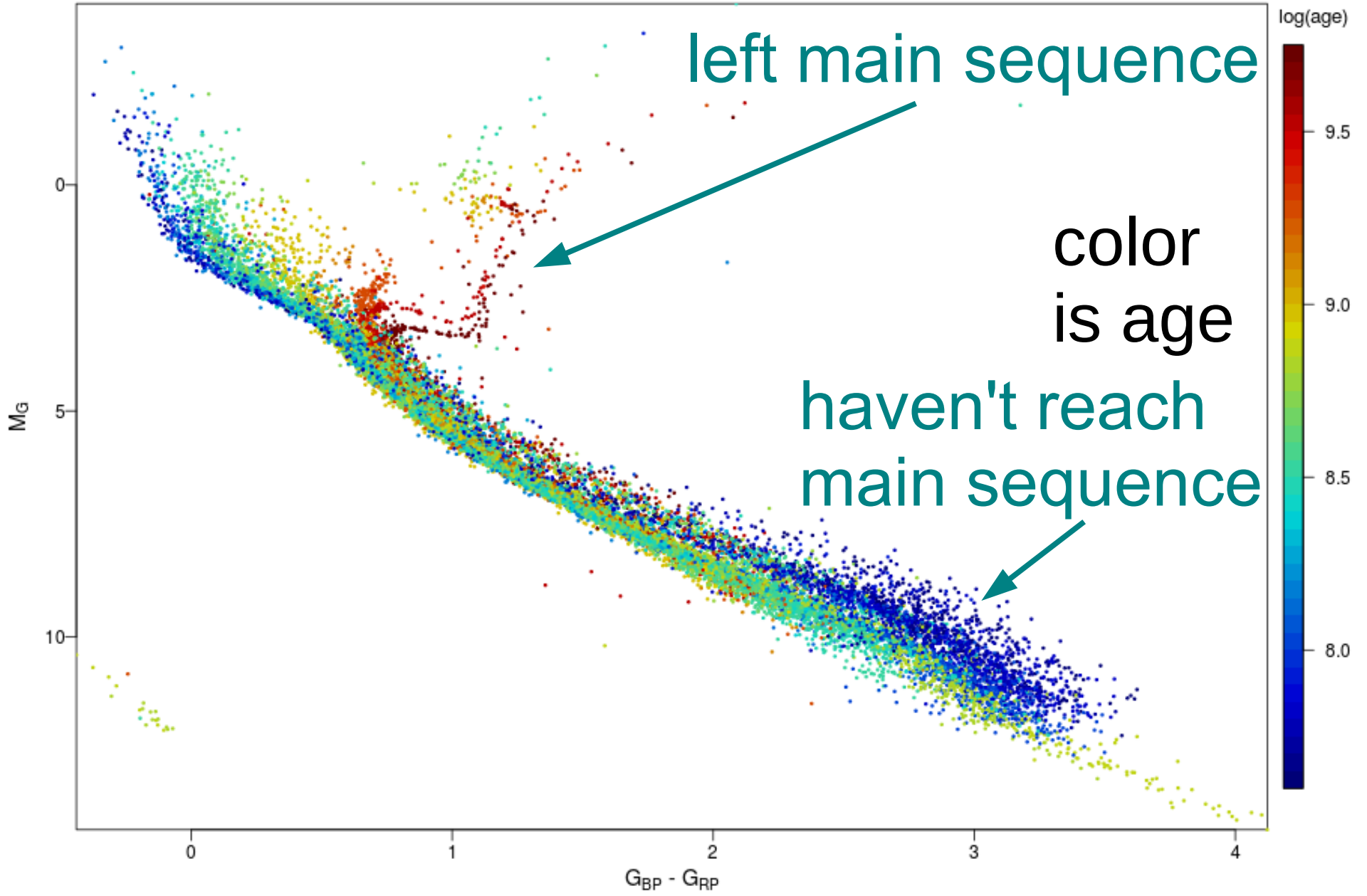
Two factors: age and metallicity



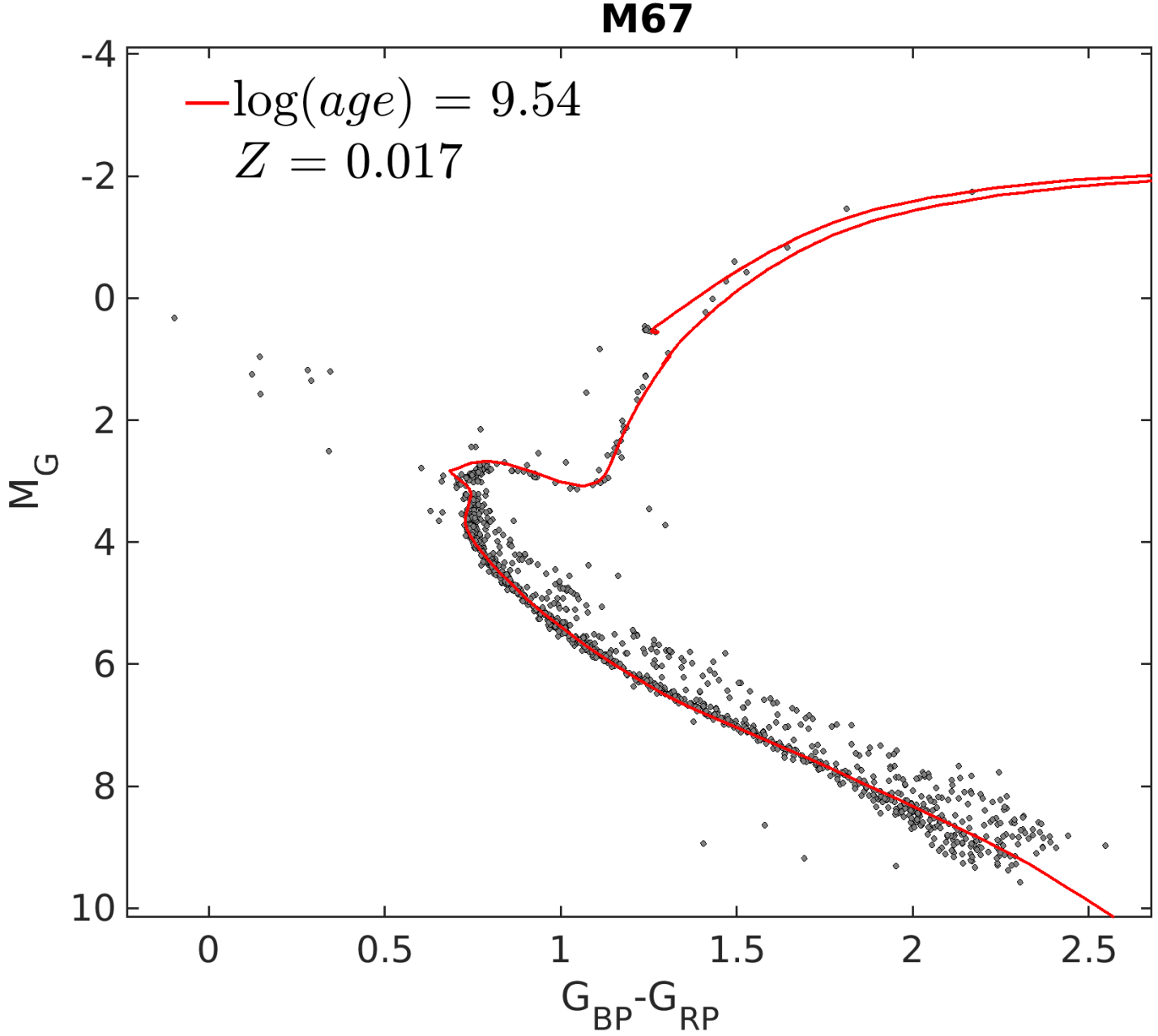
Gaia HR: open clusters



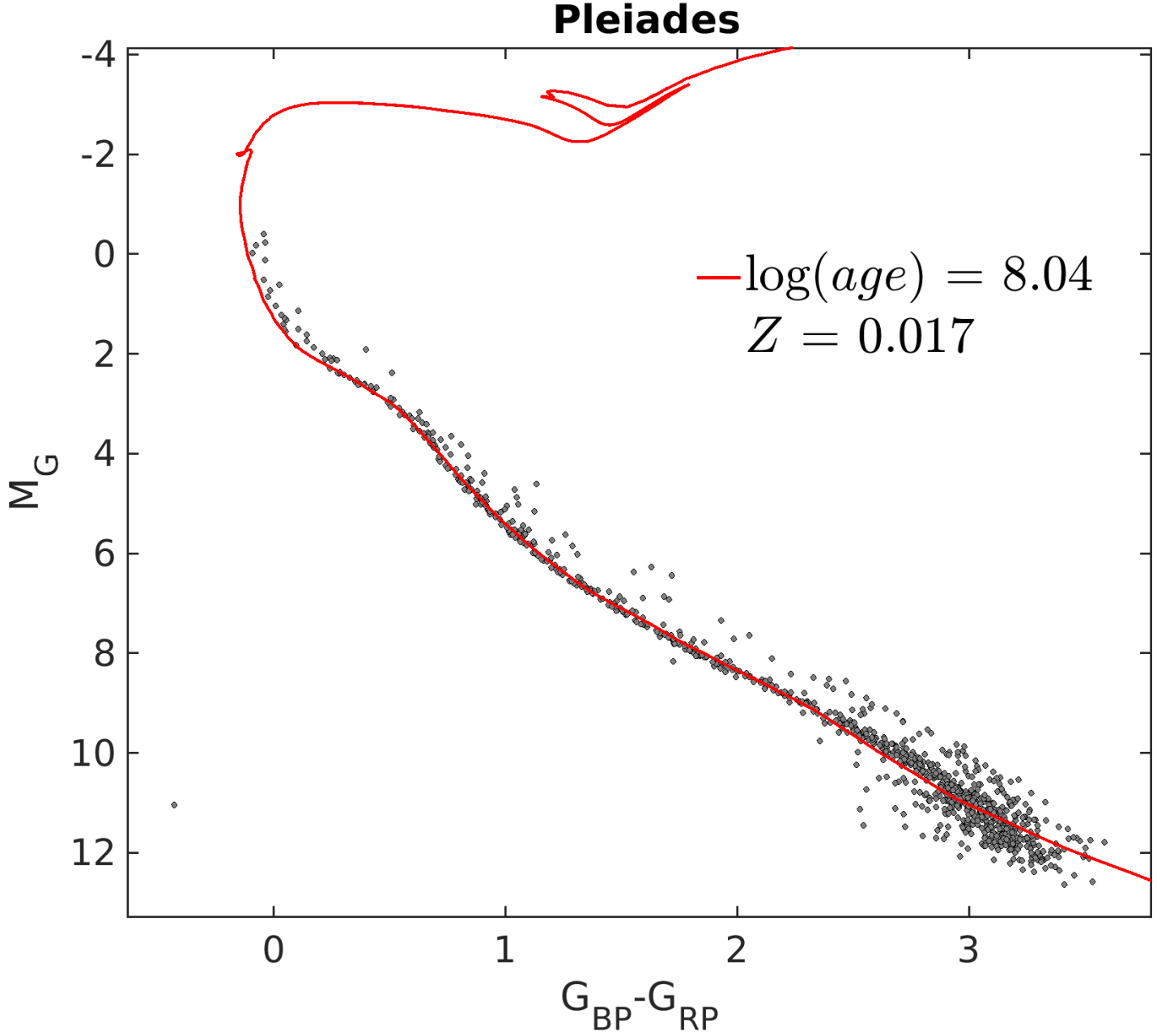
Gaia HR: open clusters



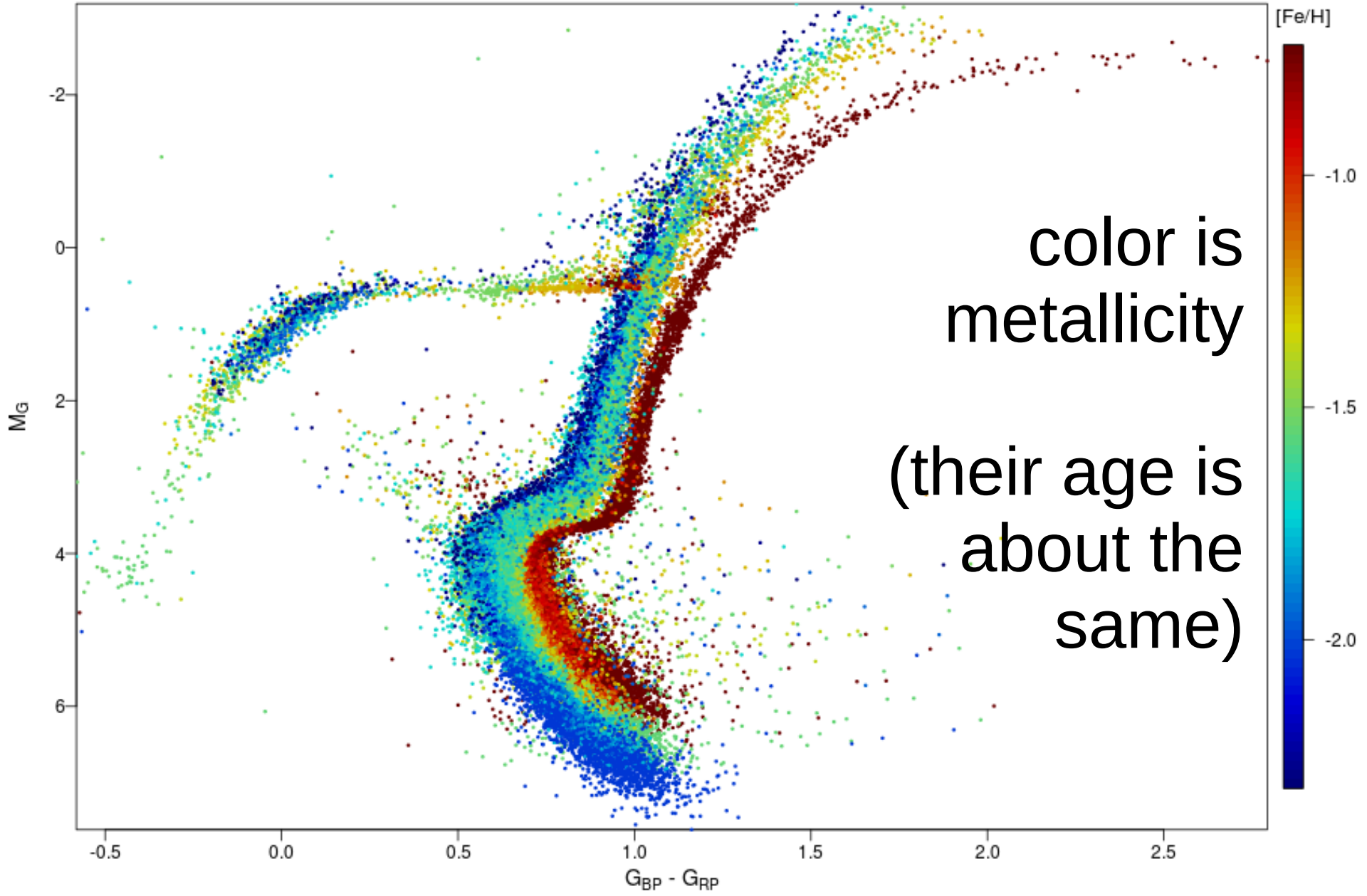
Isochrones: HR positions of same-age stars



Isochrones: HR positions of same-age stars



Gaia HR: globular clusters



Summary

- **Mass**, **age** and **metallicity** determine luminosity and temperature of a star
- Stars in **clusters** are born the same time and are at the same distance from us - useful for comparing with **stellar evolution models**
- **White Dwarf** is the evolutionary end point of a solar-type star