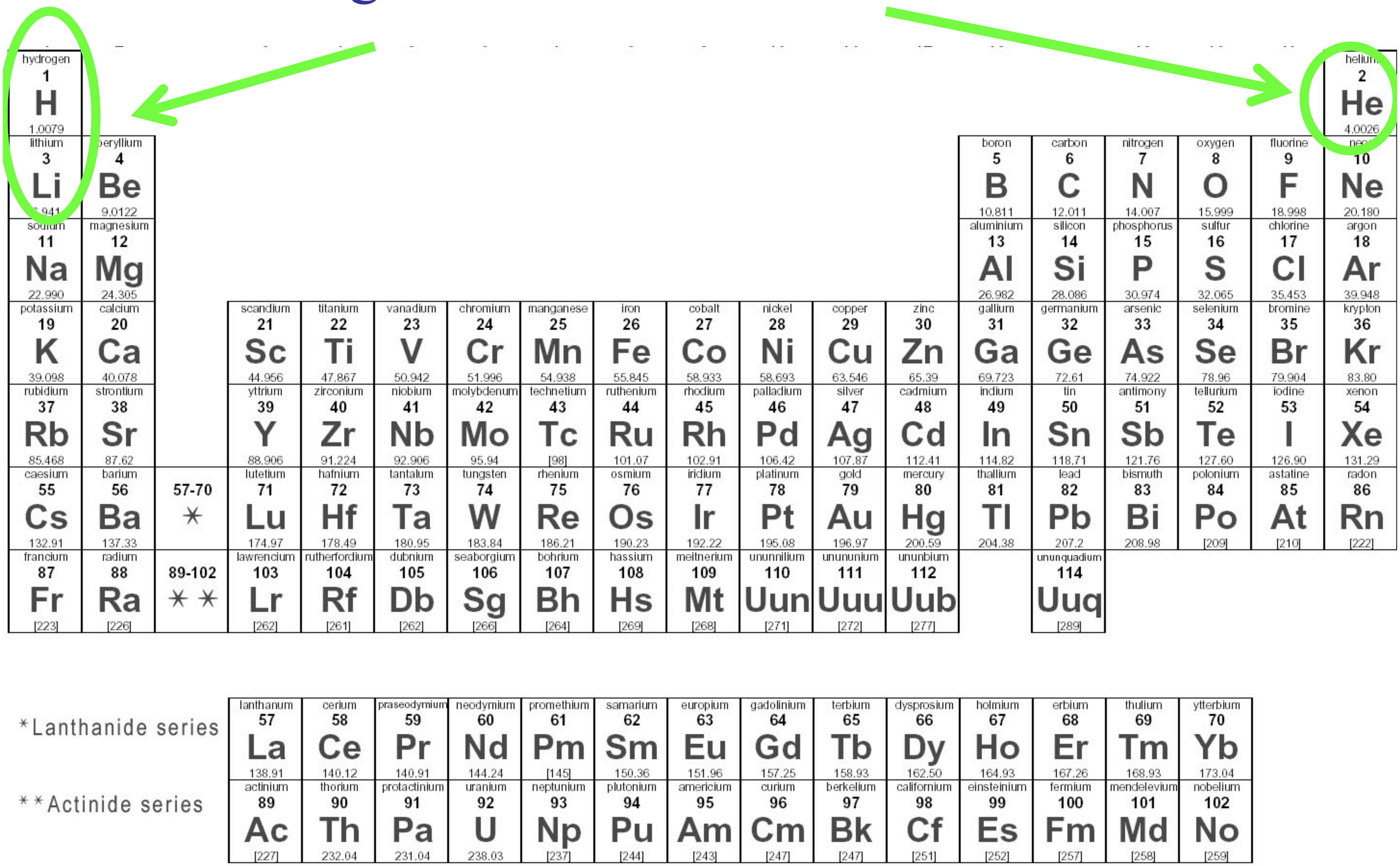
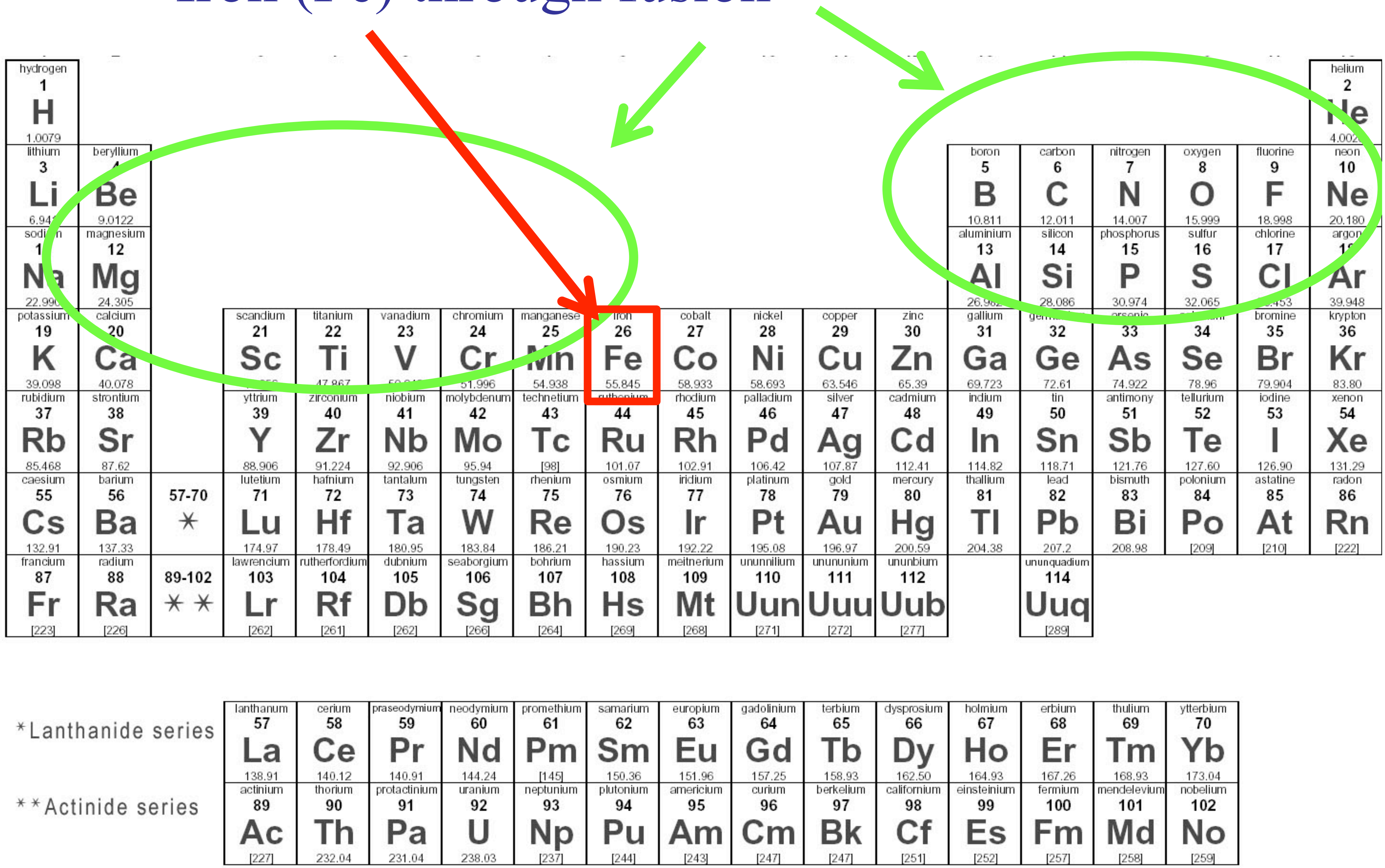
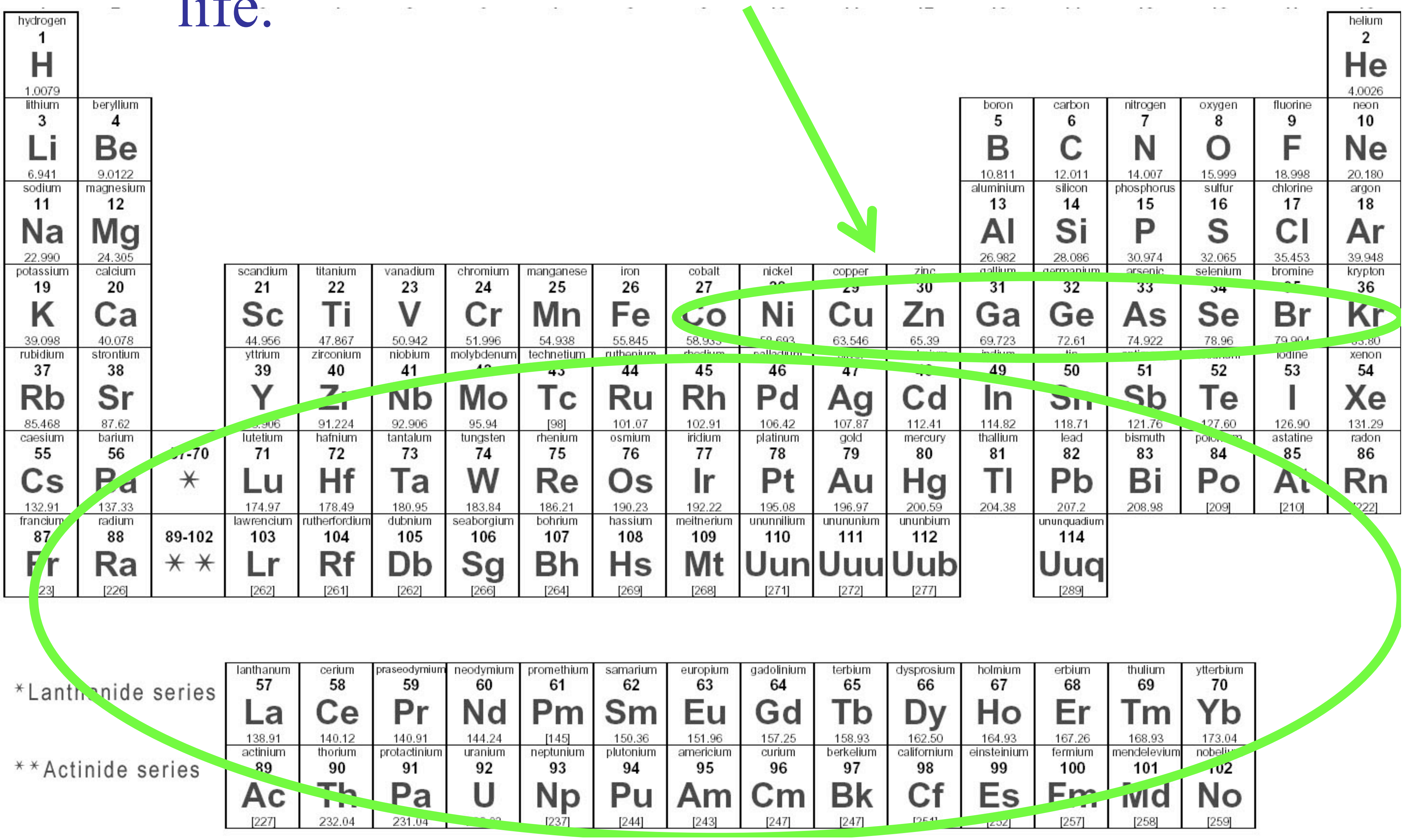
Fusion in first few minutes after Big Bang form lightest elements



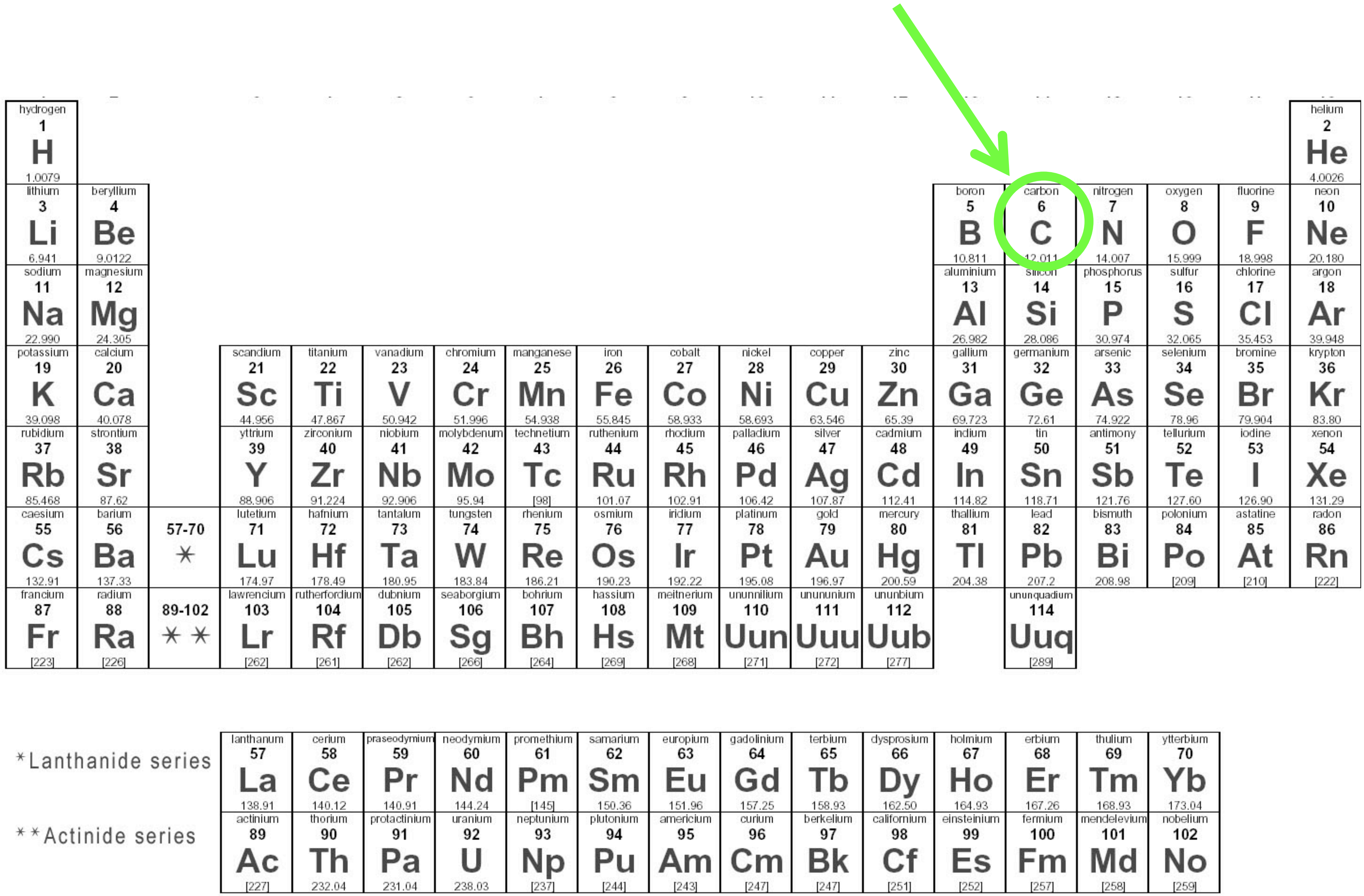
Stars build the rest of the elements up to Iron (Fe) through fusion



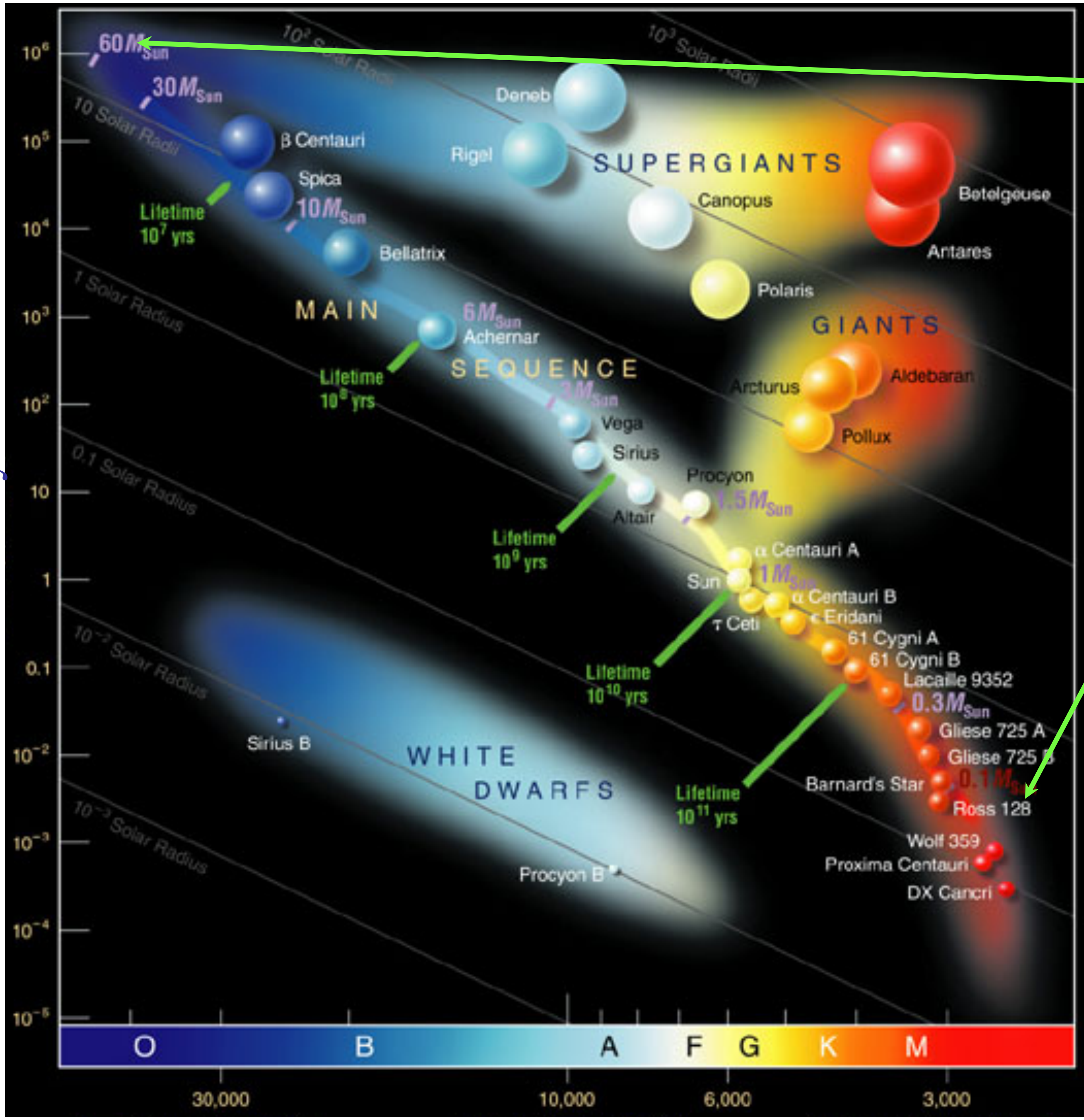
The rest of the elements beyond Iron (Fe) are produced in the dying stages of a stars life.



Example : How do we get Carbon ?

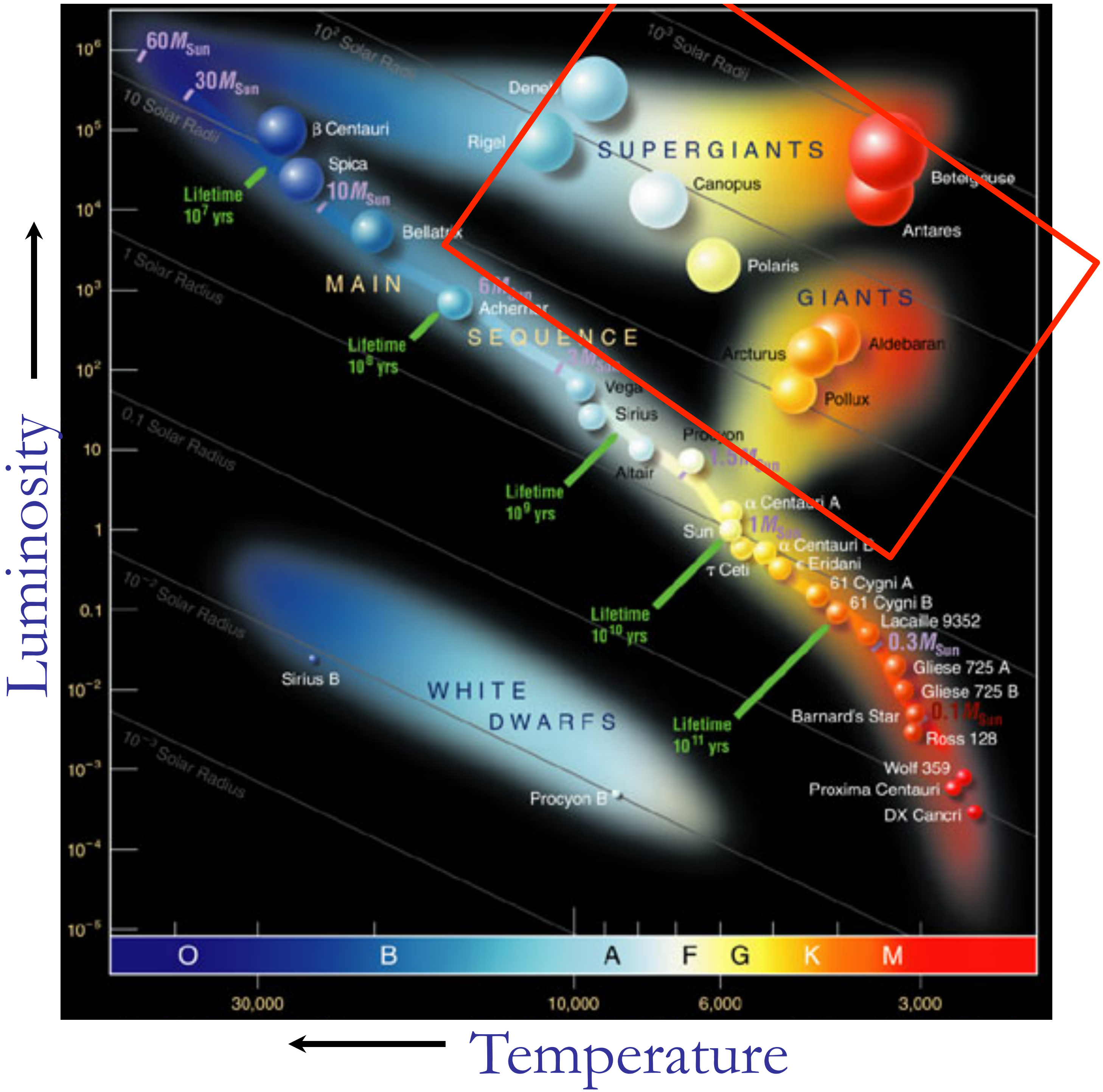


Luminosity

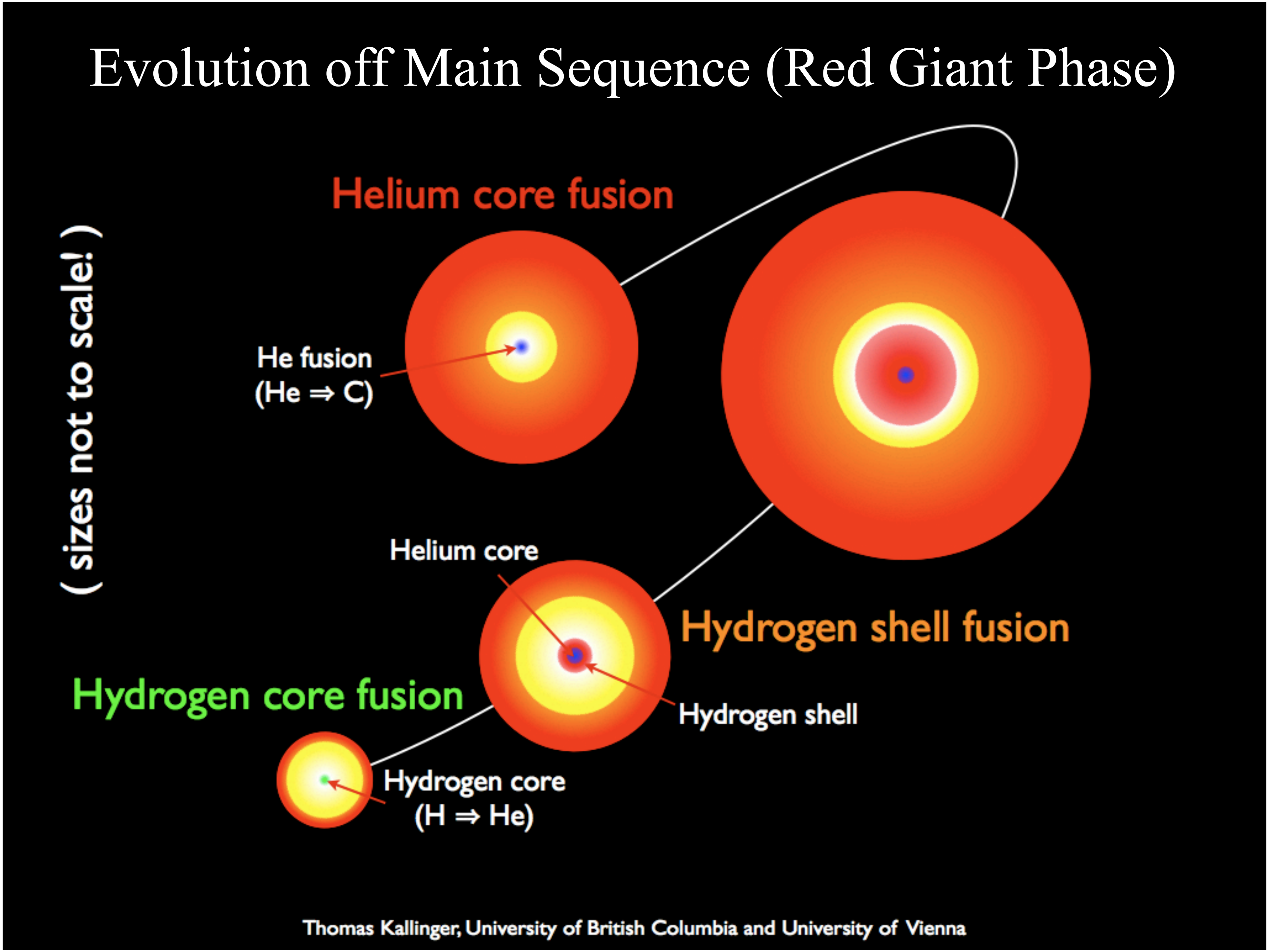


Temperature

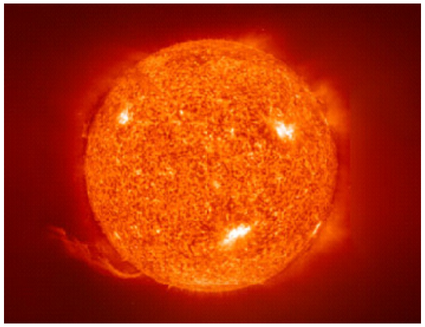
Stars along the main sequence are stably burning H to form He



After stars run out of H in their core, they evolve to the red giant phase and, depending on their mass, can burn He, C, O, Si, etc. up to Fe.

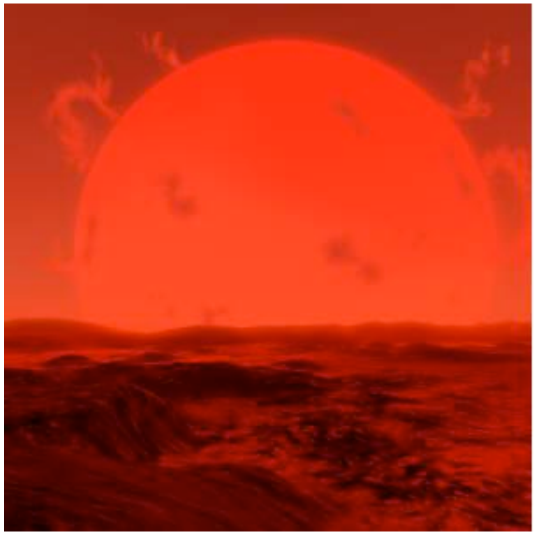

Evolution off Main Sequence (Red Giant Phase)
(sizes not to scale!)
Helium core fusion
He fusion
(He ⇒ C)
Helium core
Hydrogen shell fusion
Hydrogen core fusion
Hydrogen shell
Hydrogen core
(H ⇒ He)
Thomas Kallinger, University of British Columbia and University of Vienna

Review: Where does Carbon Come From ?



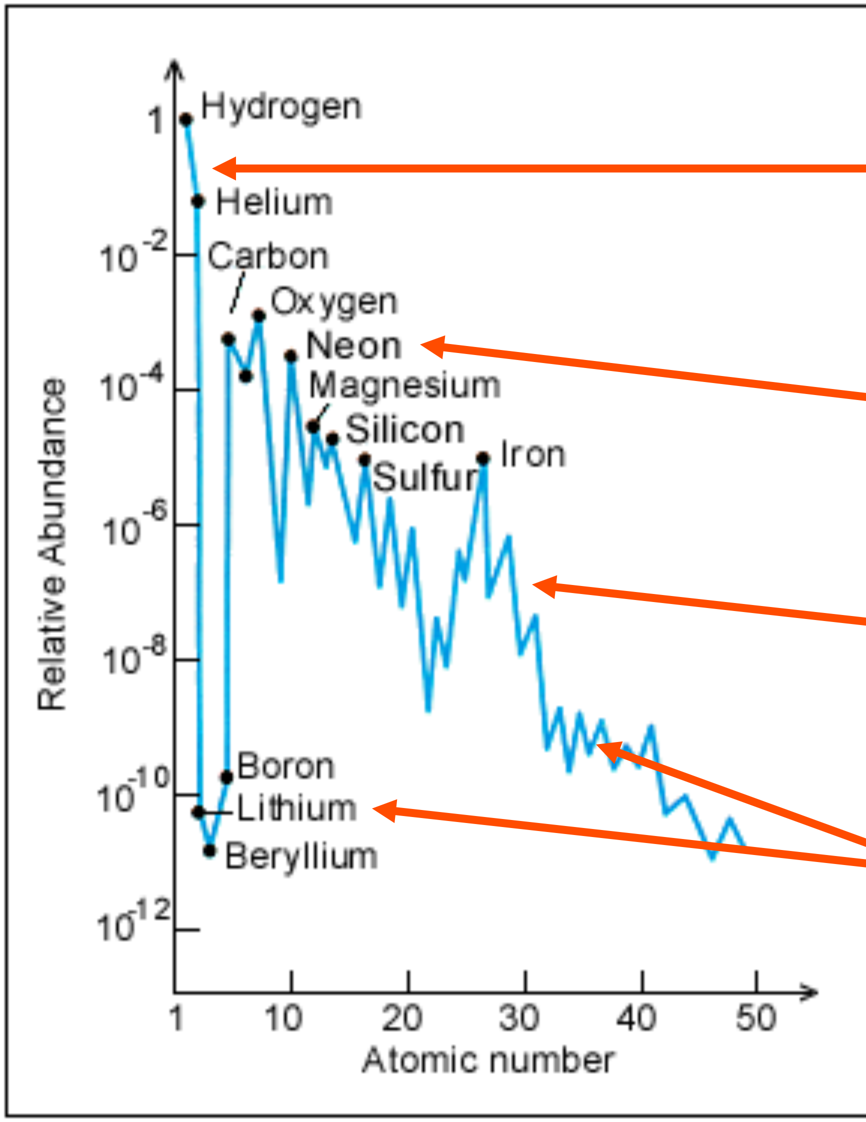
Hydrogen is fused to Helium in a star on the ***main sequence***.

Late in the stars life, it runs out of Hydrogen, contracts and becomes hot enough to burn Helium to form Carbon (Red Giant Phase)



Carbon is ejected into space in the planetary nebula phase at the end of the star's life.

Cosmic Element Abundance



Cosmic chemistry:

H is fundamental and the He is fused in the early hot big bang

Elements from C to Fe fused in moderately massive stars

Elements beyond Fe are mostly fused in supernova blast waves

Sawtooth is He nucleus added, trough due to unstable atoms

Stars are chemical factories. The universe is built for life!

Stellar Properties Summary

Luminosity: from brightness and distance

(0.08 M_{Sun}) 10^{-4} L_{Sun} - 10^{6} L_{Sun} **(100 M_{Sun})**

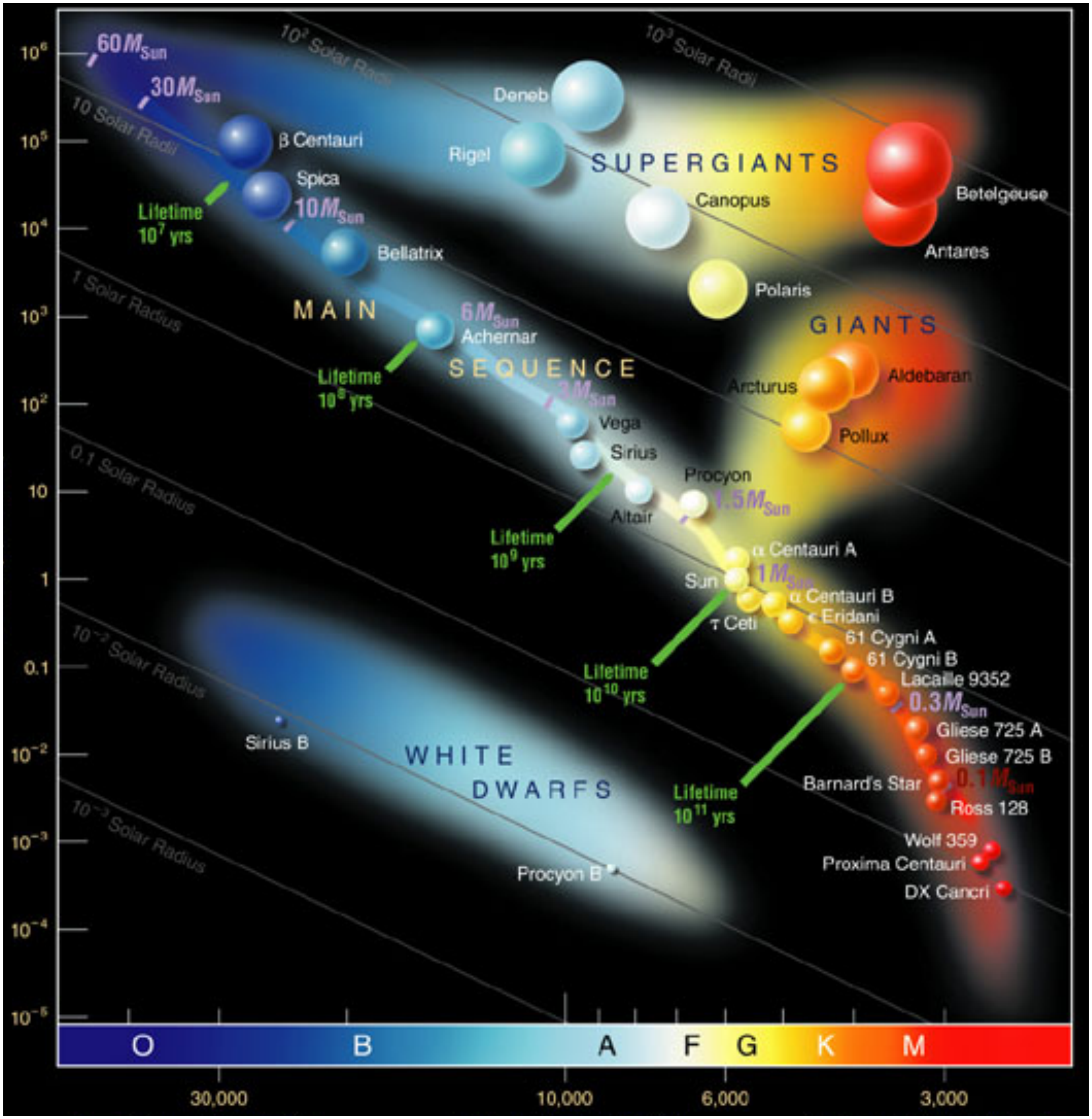
Temperature: from color and spectral type

(0.08 M_{Sun}) 3,000 K - 50,000 K **(100 M_{Sun})**

Mass: calculated from period (p) and average separation (a) of a binary-star orbit

0.08 M_{Sun} - 100 M_{Sun}

Luminosity



Temperature

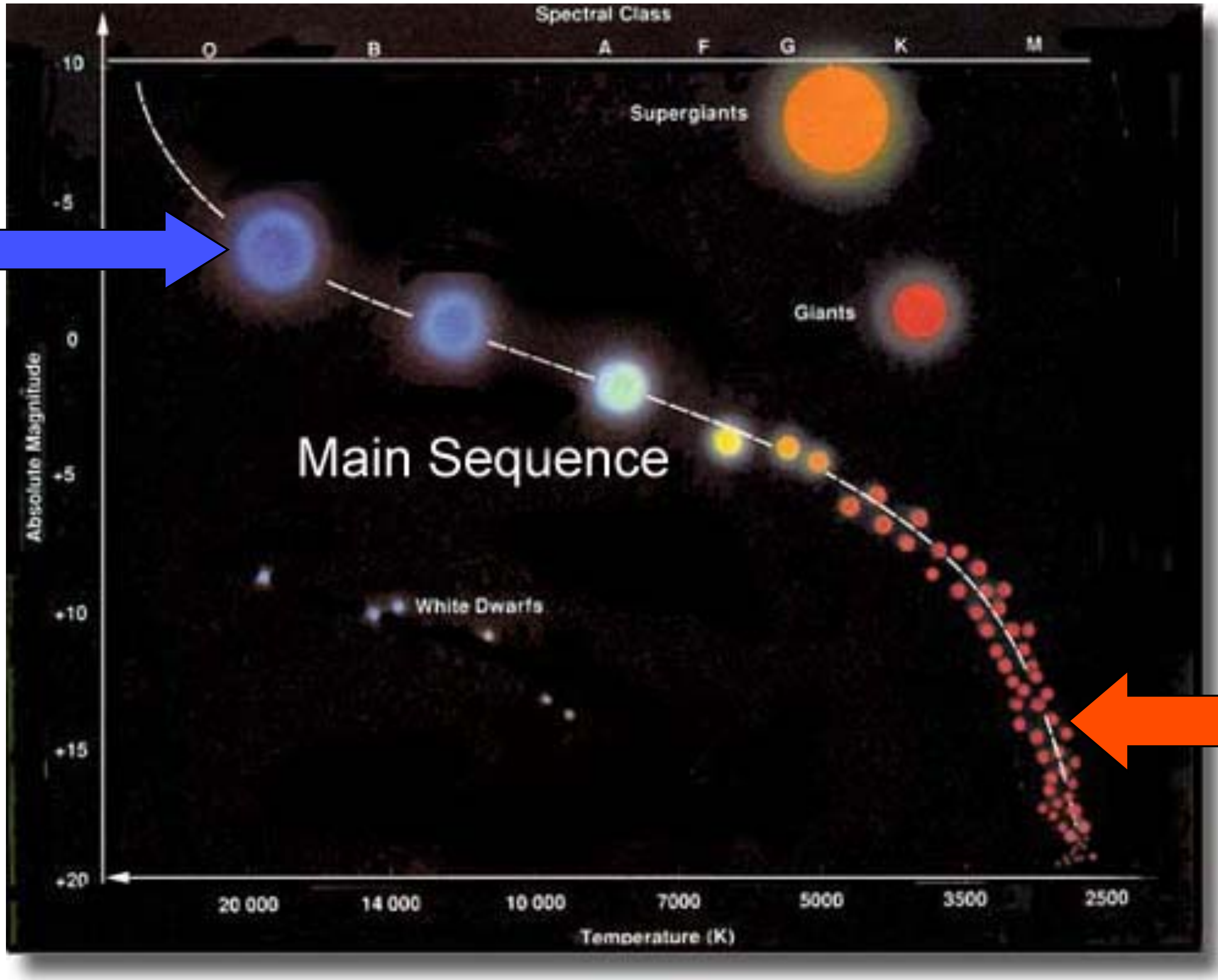
The H-R diagram is the fundamental plot used to describe how a star evolves. It plots luminosity vs. temperature

How Fast Do Different Stars Evolve?

HOT ***COOL***

LUMINOUS

Blue MS stars are massive



DIMMER

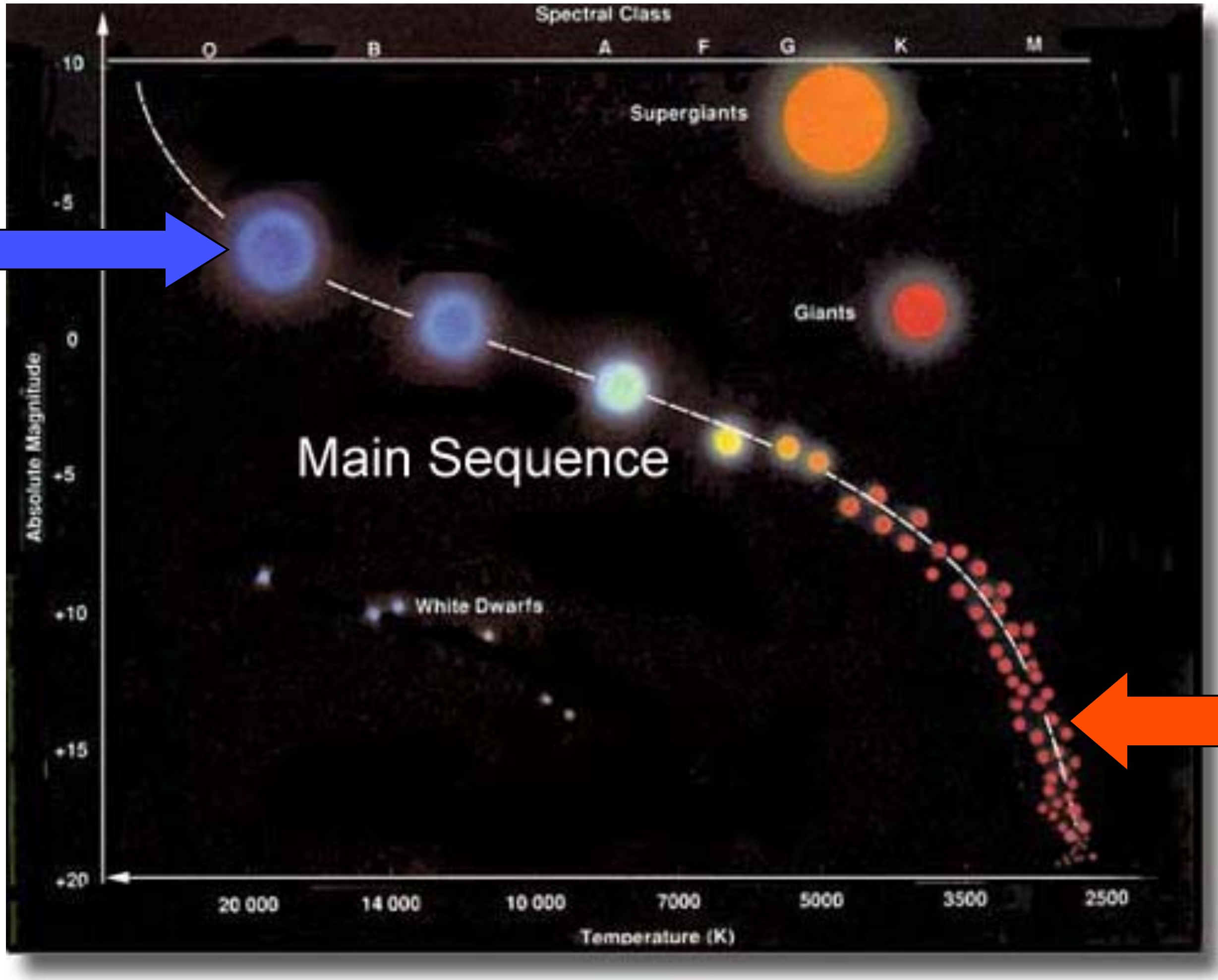
Red MS stars are low mass

Most stars are low mass and relatively cool.

HOT *COOL*

LUMINOUS

There are very few massive MS stars

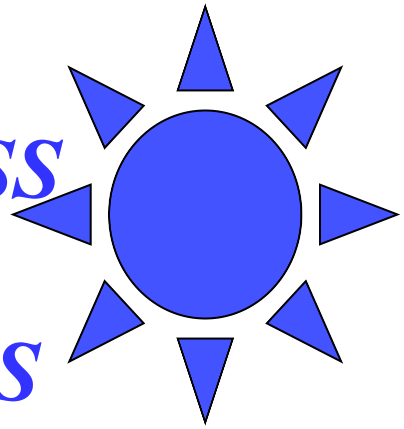


DIMMER

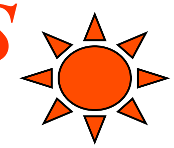
There are a lot of low mass MS stars

Massive stars have the shortest lives.

HIGH MASS
and
LUMINOUS



LOW MASS
and
DIM



Like a gas-guzzling car, big fuel tank but burns fuel fast, so the tank of gas does not last long.

Like a fuel-efficient car, small fuel tank but burns fuel slowly, so the tank lasts a long time.

Mass & Lifetime

Until core hydrogen (10% of total) is used up

Sun's life expectancy: 10 billion years

Life expectancy of 10 M_{Sun} star:

10 times as much fuel, uses it 10^4 times as fast

10 million years ~ 10 billion years x 10 / 10^4

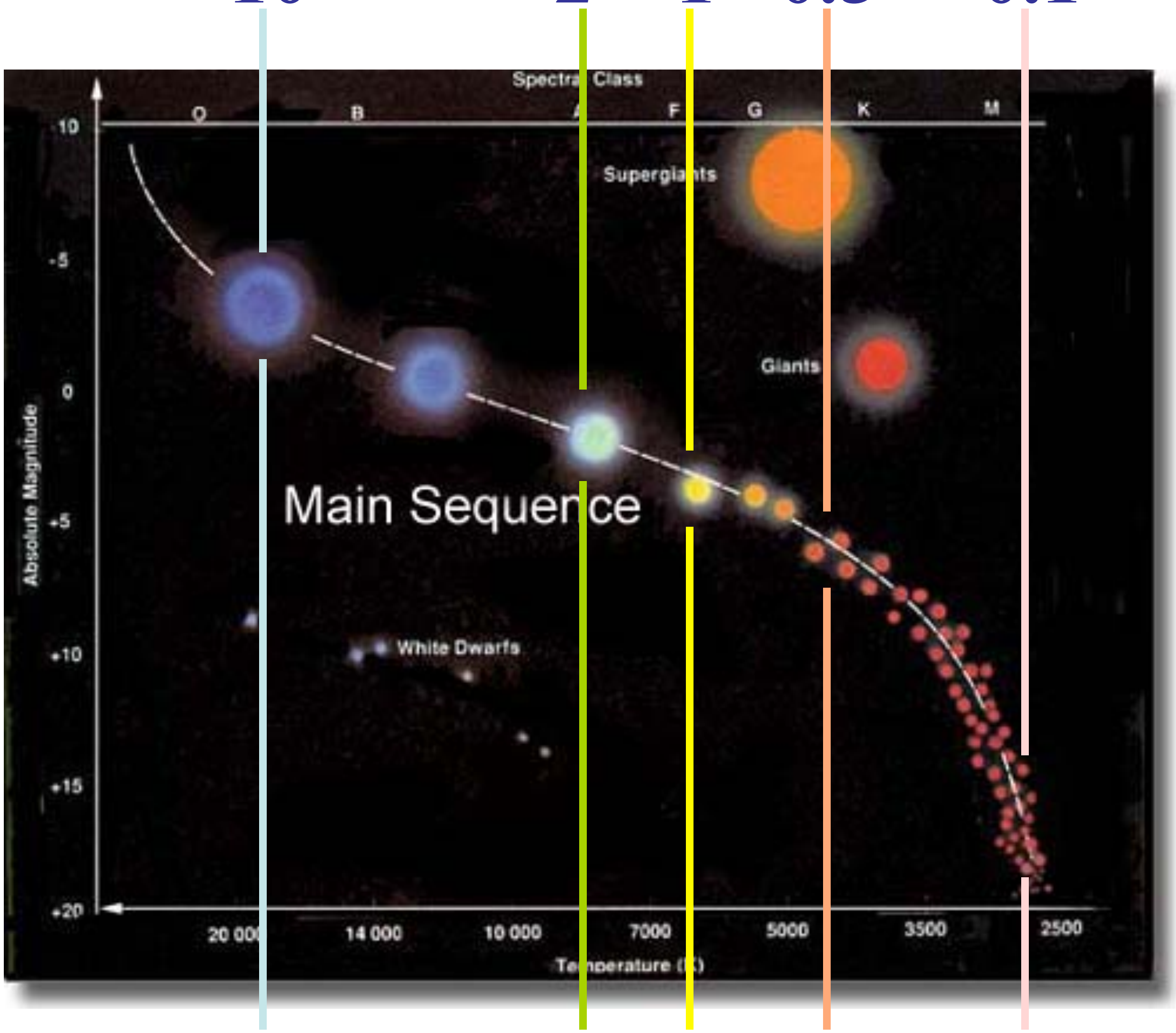
Life expectancy of 0.1 M_{Sun} star:

0.1 times as much fuel, uses it 0.01 times as fast

100 billion years ~ 10 billion years x 0.1 / 0.01

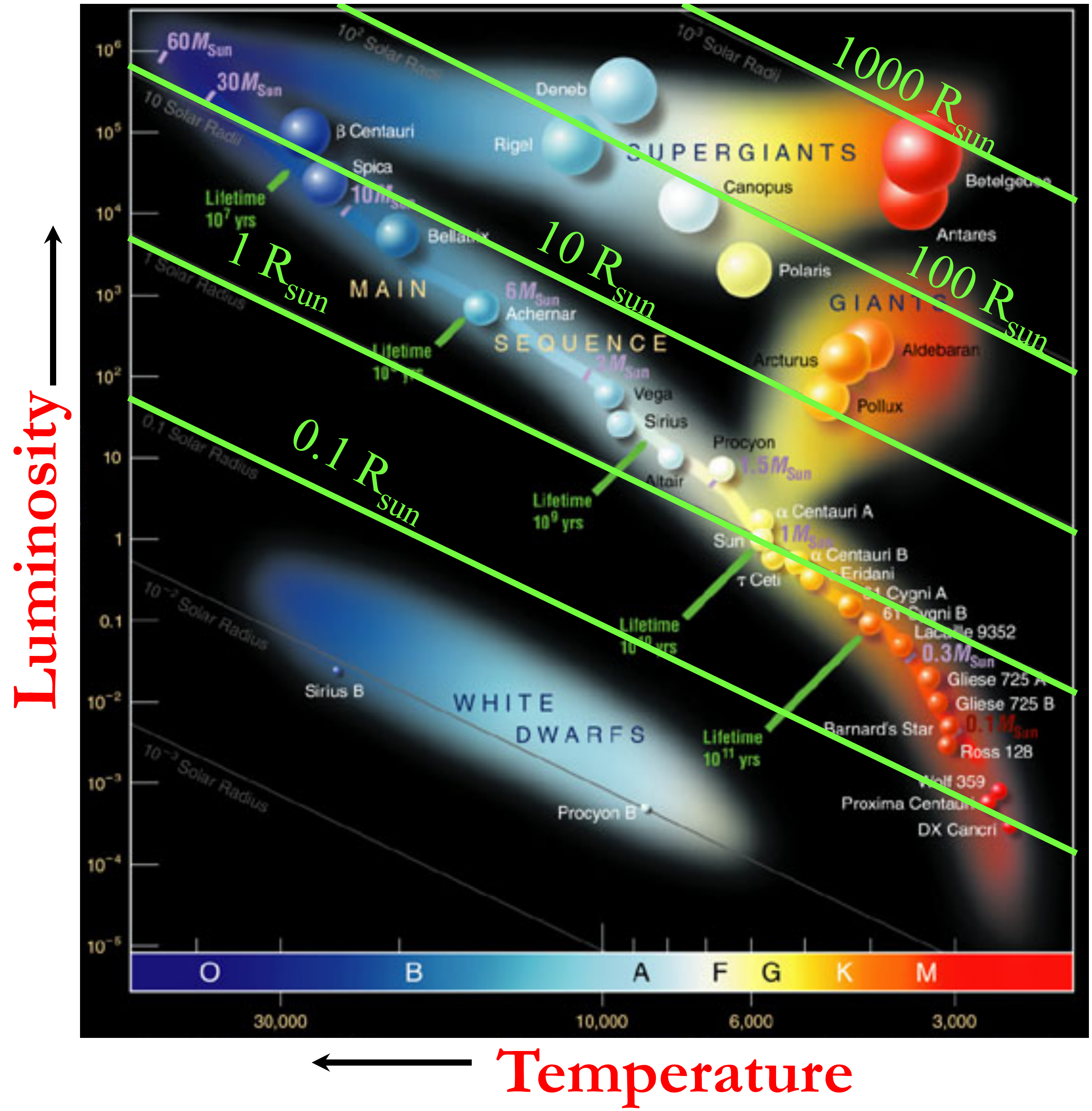
MASS: **10** **2** **1** **0.5** **0.1** *times the mass of the Sun*

LUMINOUS

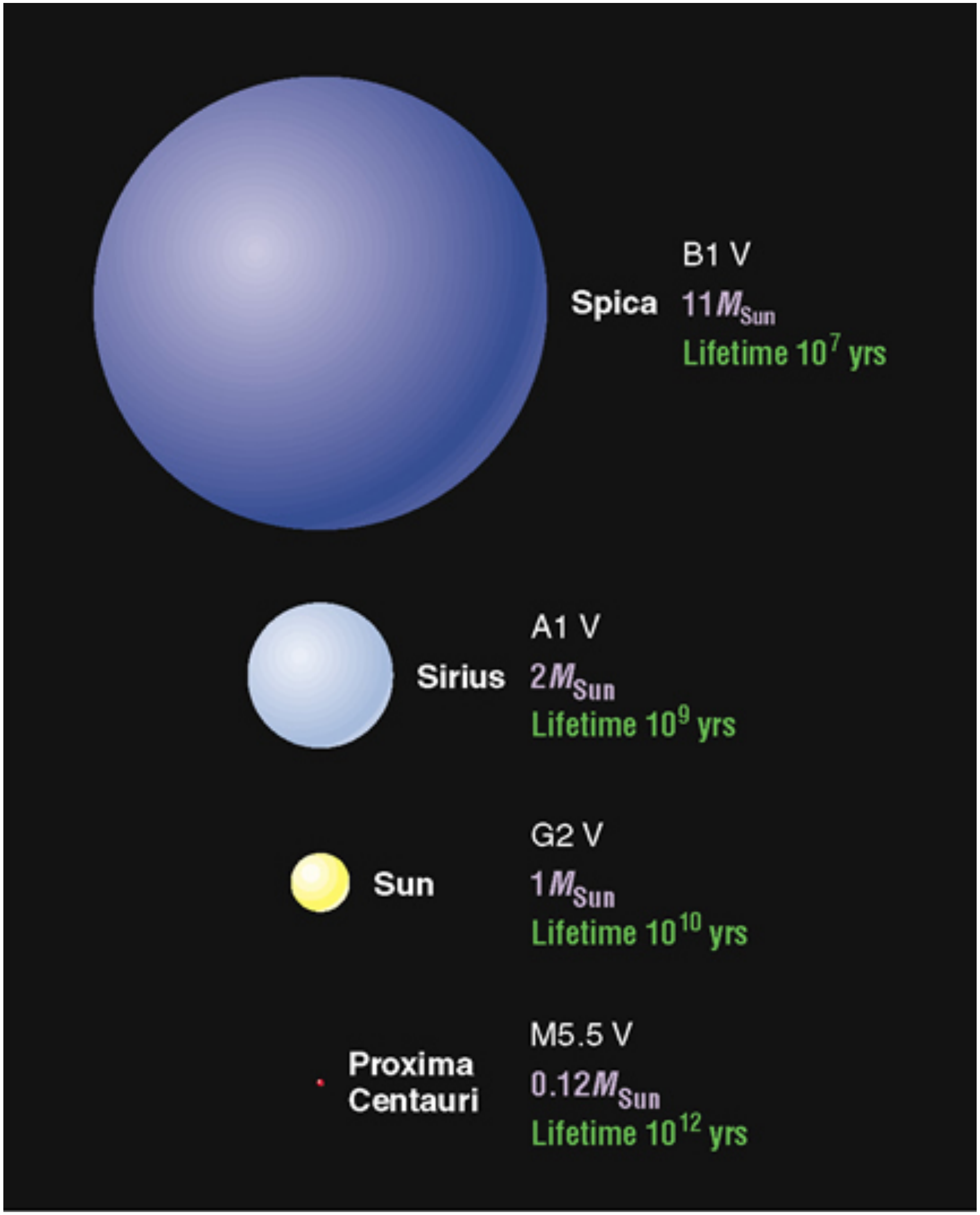


DIMMER

LIFETIME: 10^7 10^9 10^{10} 10^{11} 10^{12} *in years*



Stars in the upper right are bigger than stars in the lower left of the diagram



Star Comparison

High Mass:

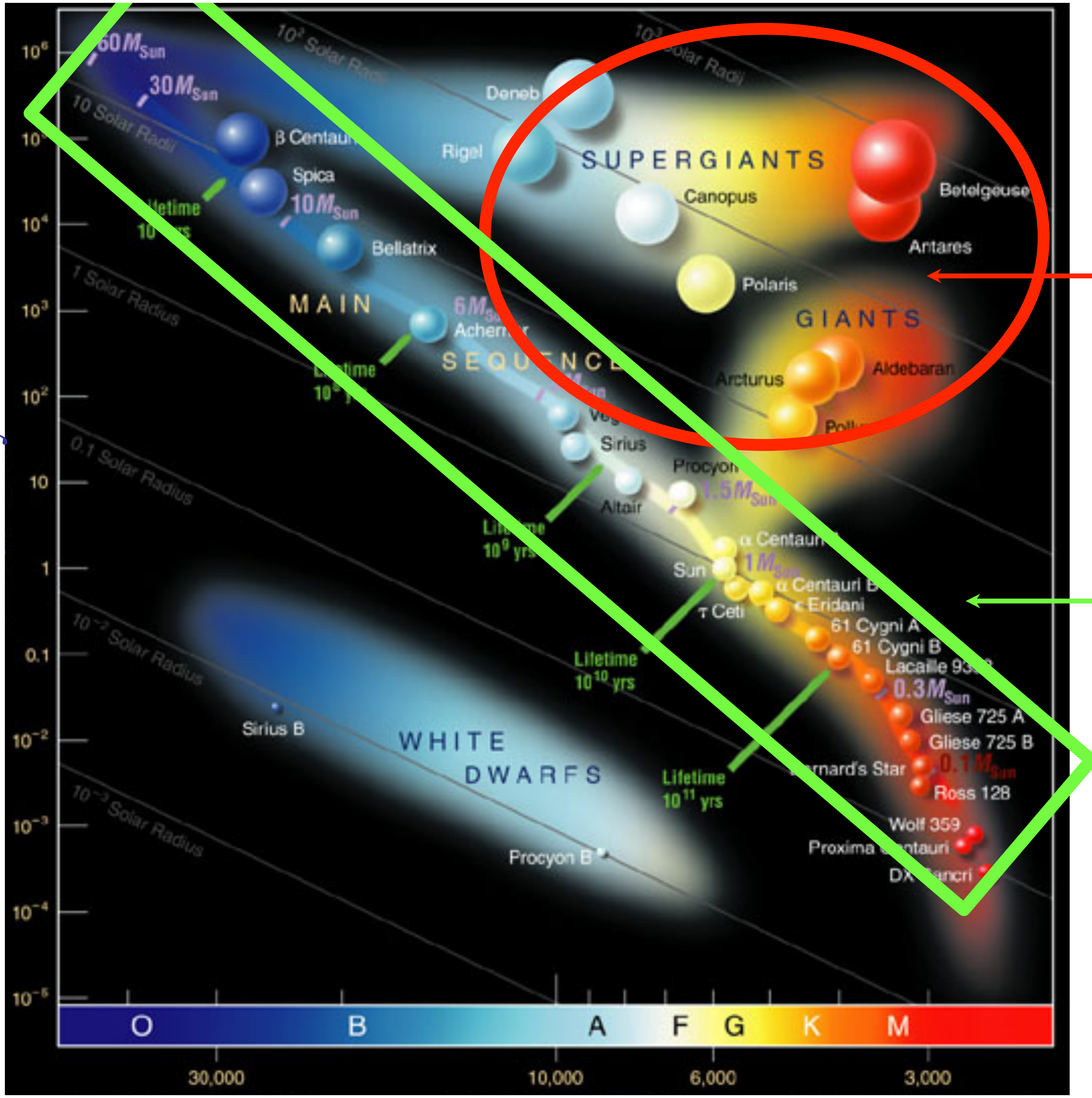
- High Luminosity
- Short-Lived
- Large Radius
- Blue

Low Mass:

- Low Luminosity
- Long-Lived
- Small Radius
- Red

Defining Habitability

- Are habitable planets likely?
- Are Earth-like planets rare or common?
- Habitability depends on luminosity of the star
- Habitability depends on the longevity of the star
- Both are governed by the mass of the star
- There may be a "sweet spot" in mass for habitability.

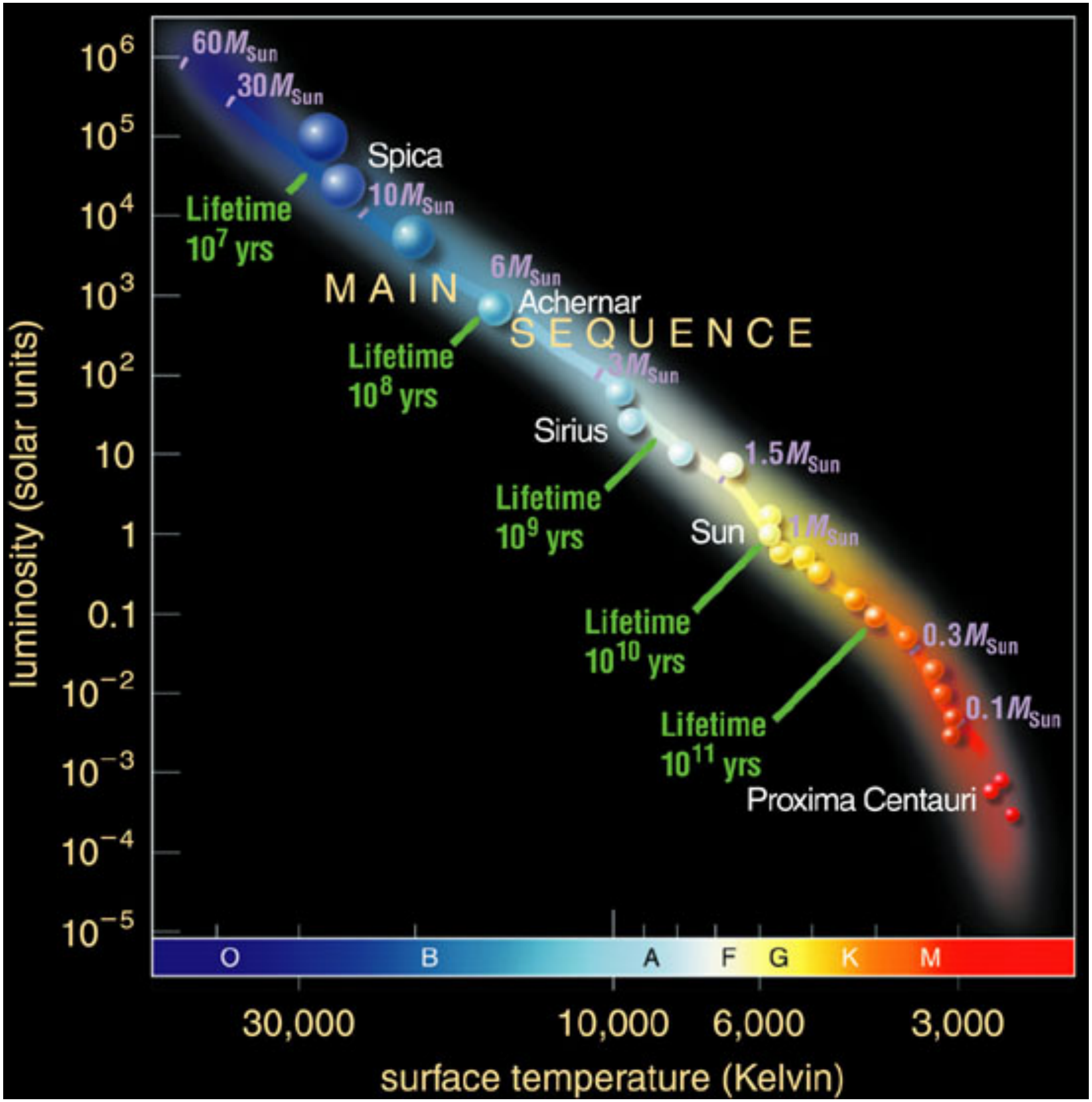


Luminosity

Temperature

Stars off the main sequence have short remaining life!

So, let's focus on the main sequence where stars burn H the longest.



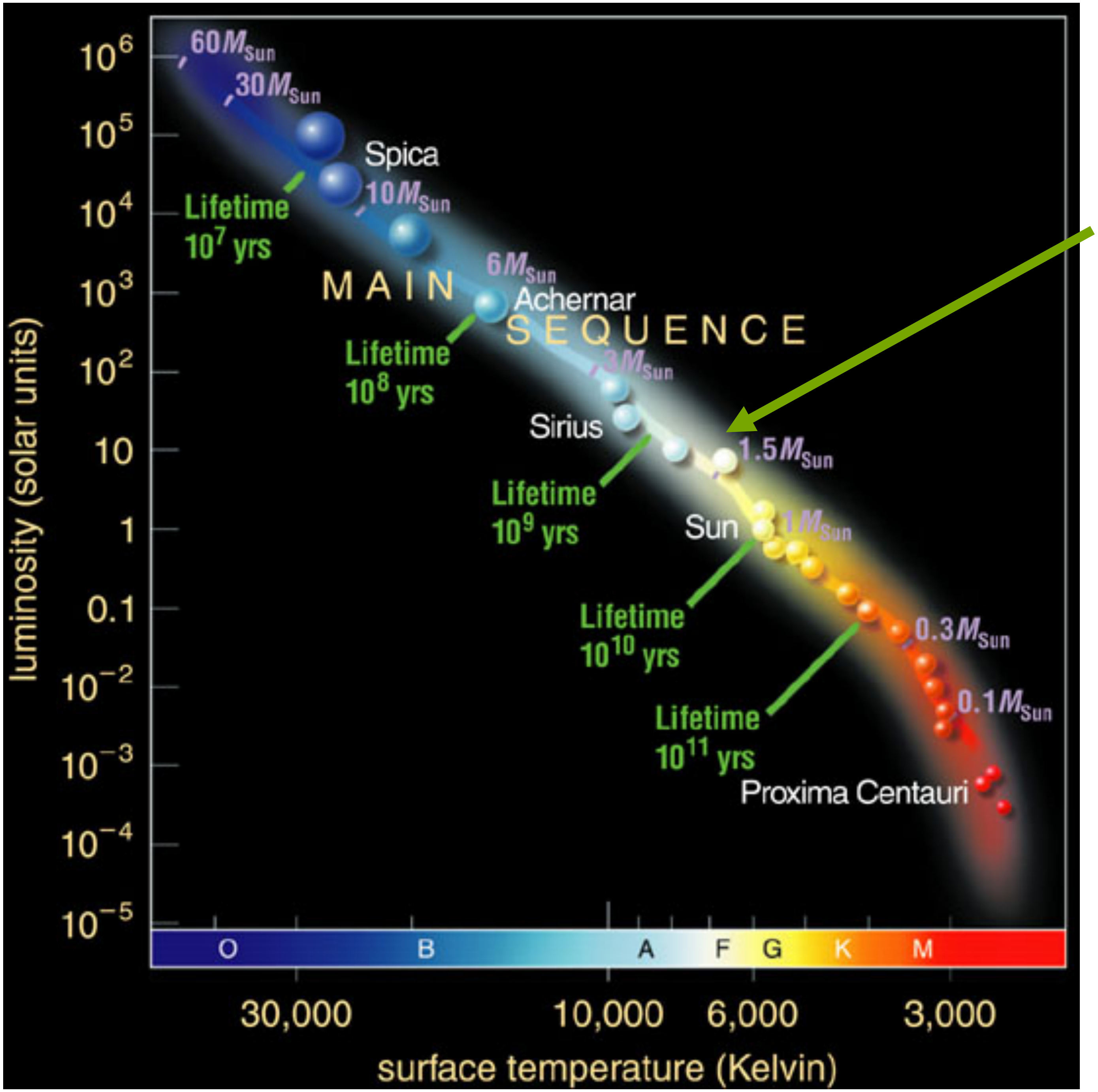
In terms of their suitability to host life, massive stars:

Are rare: bad

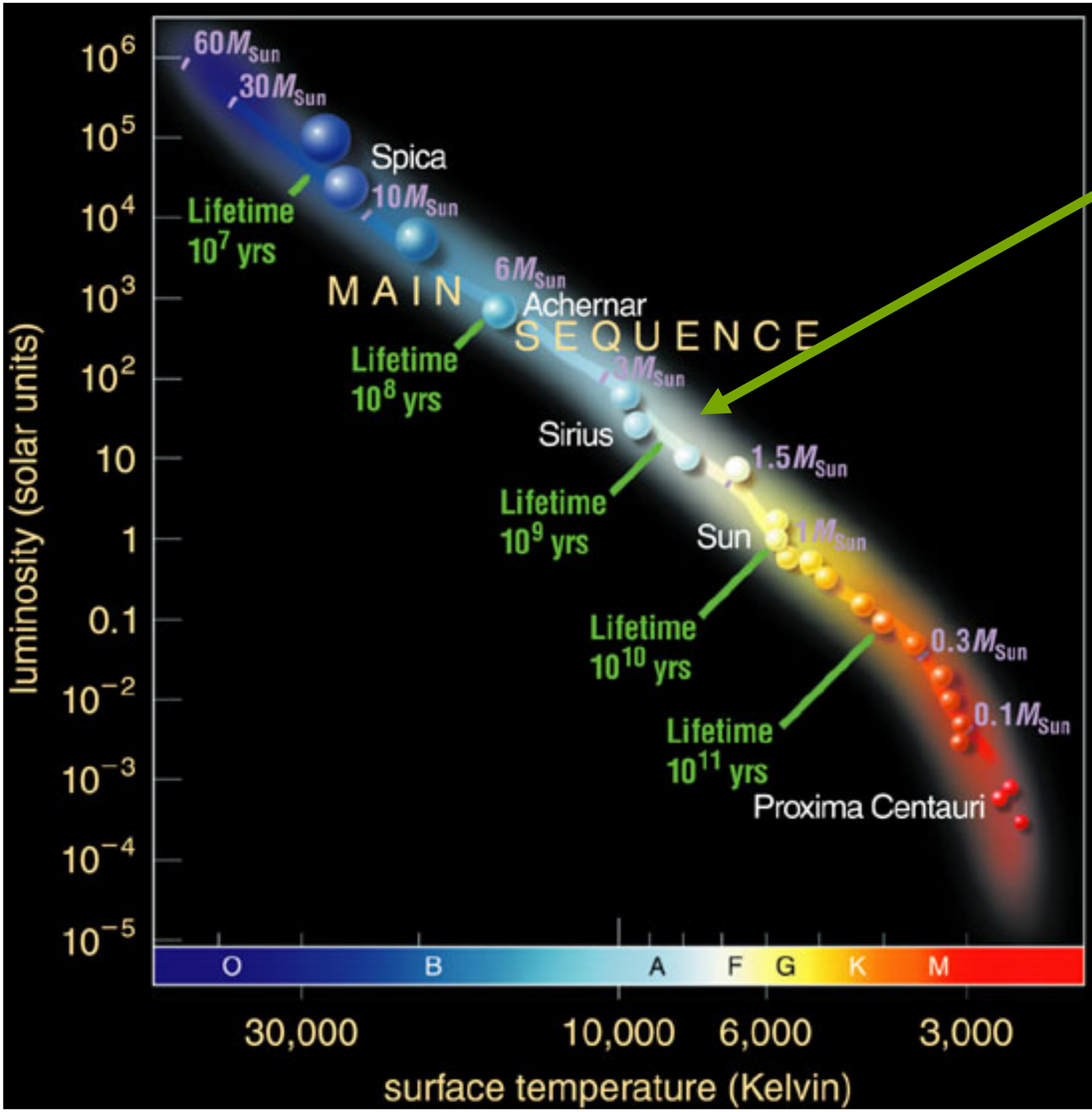
Emit a lot of energy: good

Have short lives: bad

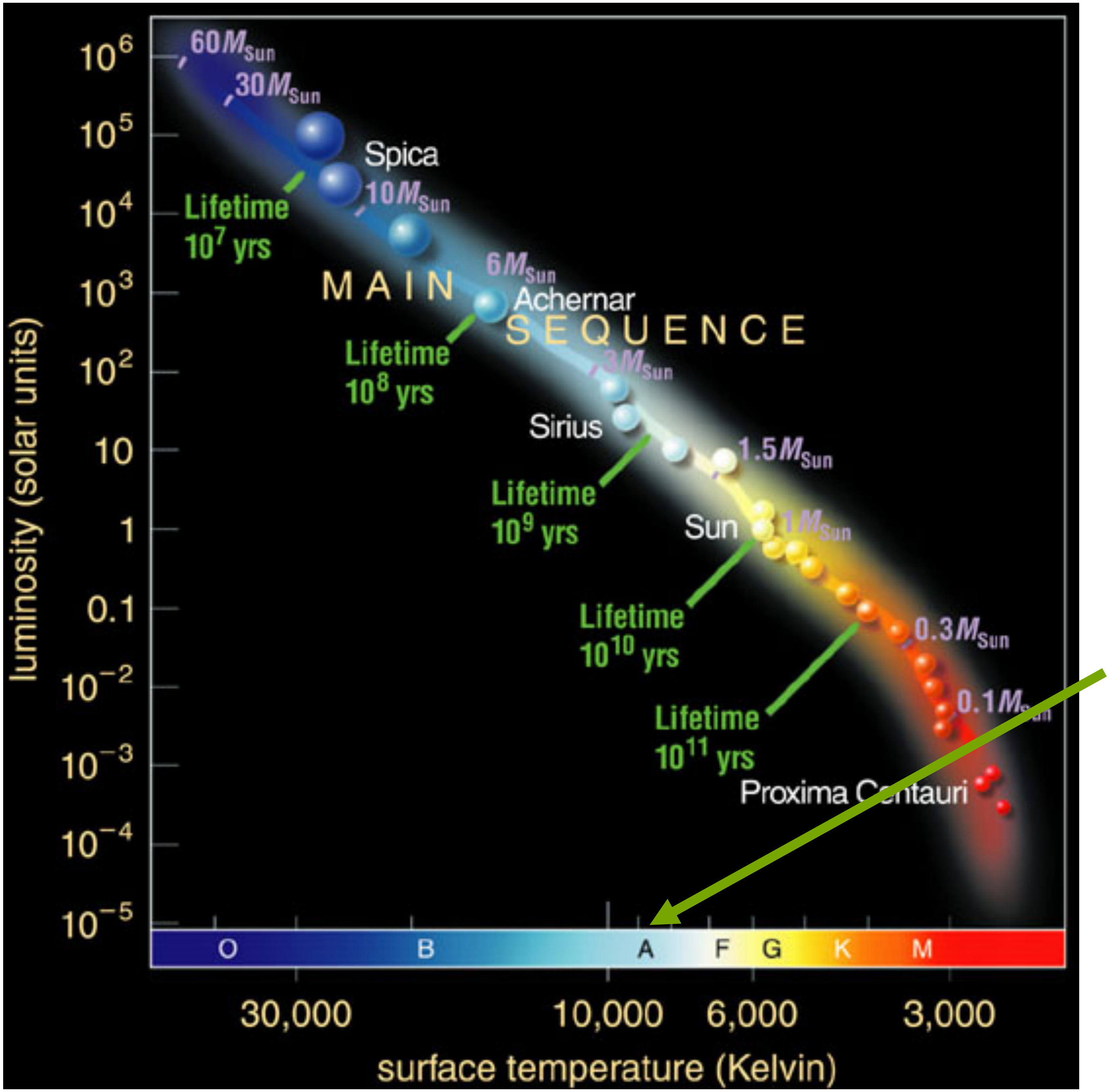
Give off lots of UV: bad



High mass limit of **1.5** times solar mass for lifetime to be at least **4** billion years for development of complex life.



High mass limit of **2** times solar mass for lifetime to be at least **1** billion years for development of life.



High mass stars also put most of their energy out in damaging **UV** radiation — life may not able to tolerate this.

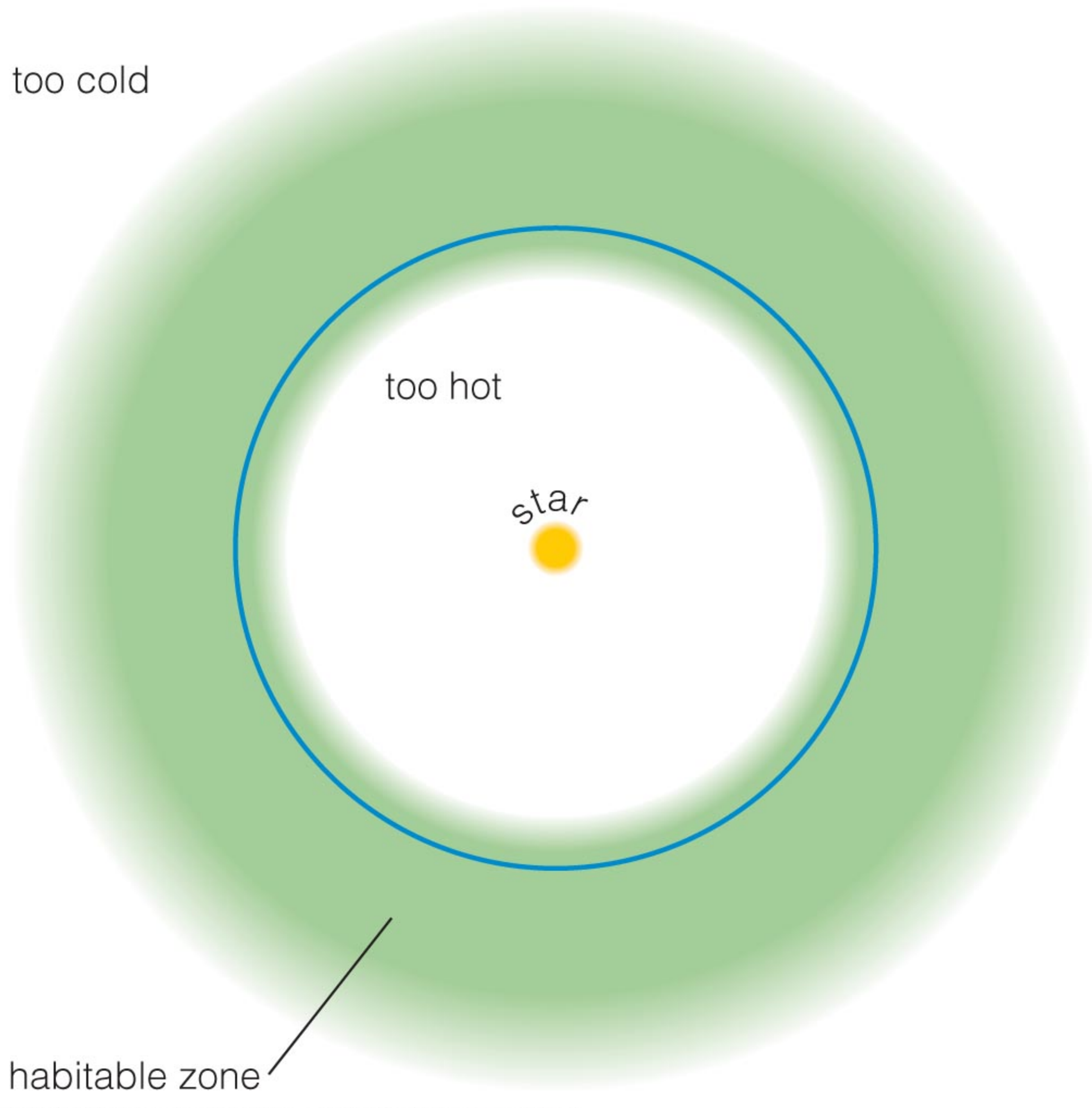
Are habitable planets likely?

Definition:

A **habitable** world contains the necessities for life as we know it: liquid water, a source of energy, and organic (carbon-rich) material.

- It does *not* necessarily have life.

Caveat: Telescopically, we can search only for planets with habitable *surfaces* — not for worlds with Europa-like subsurface oceans.

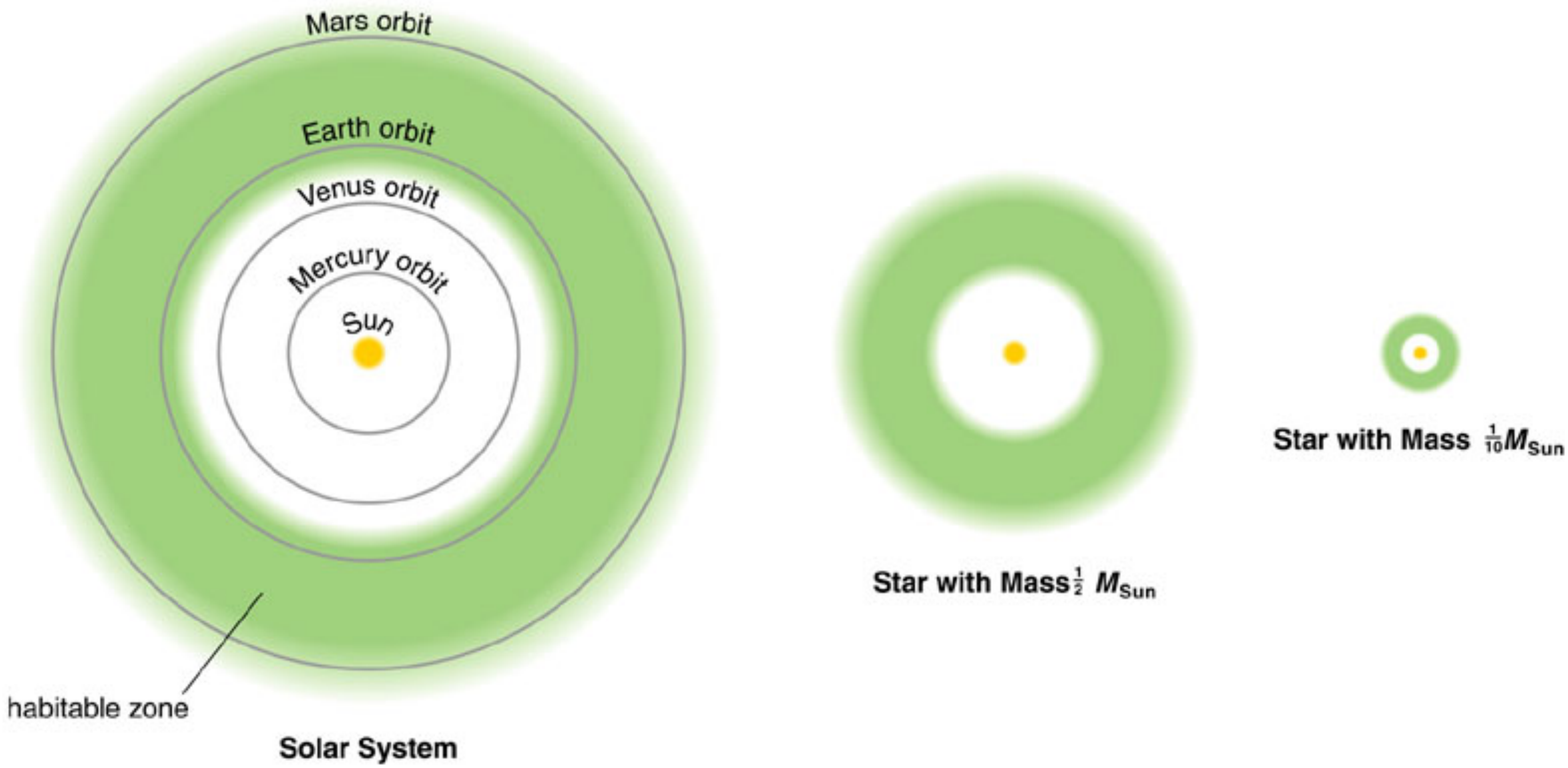


The Goldilocks premise: for a planet to be habitable, it must be within the range of distances from a star where the temperature allows water to be liquid on its surface.

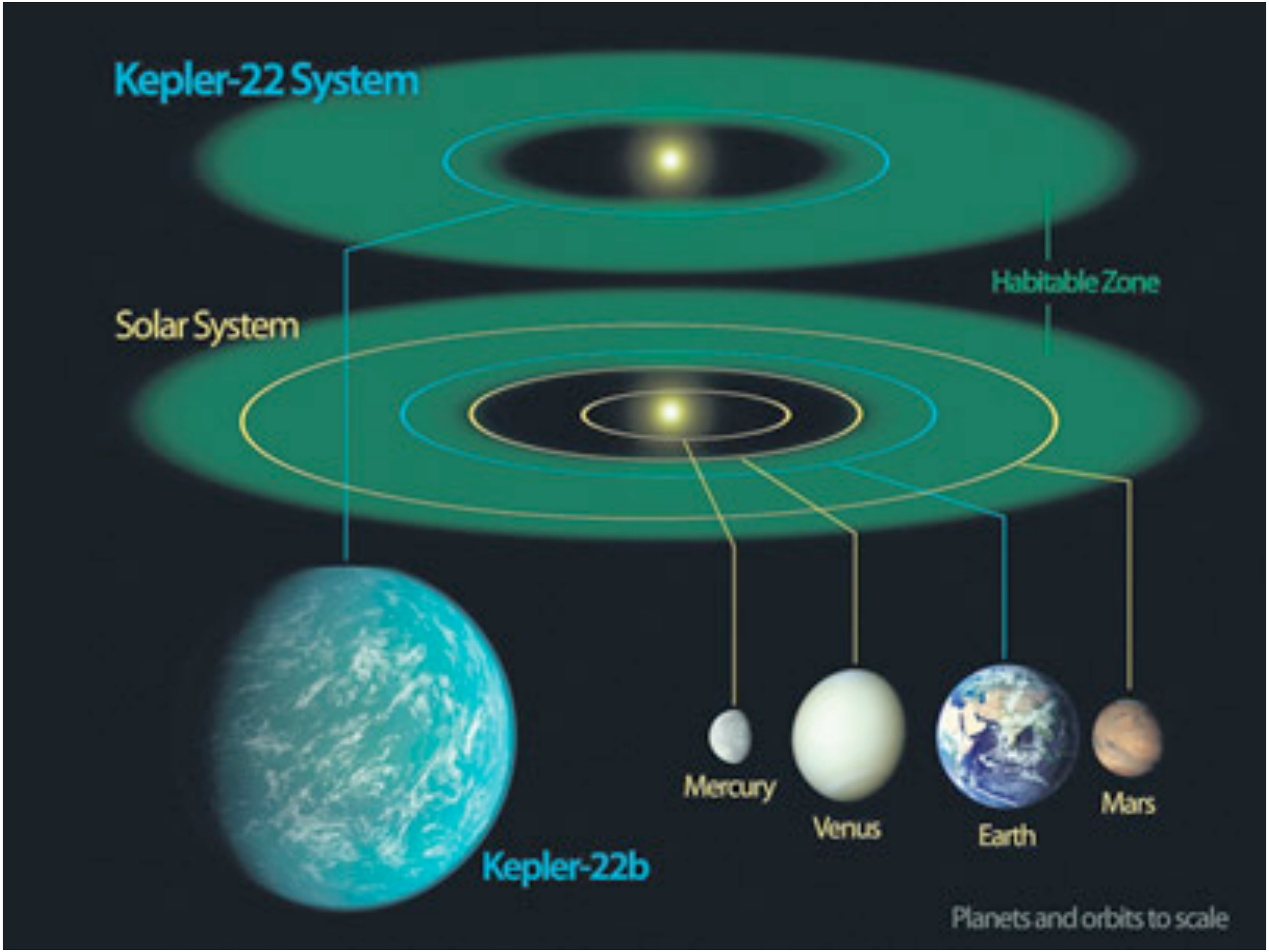
Constraints on star systems:

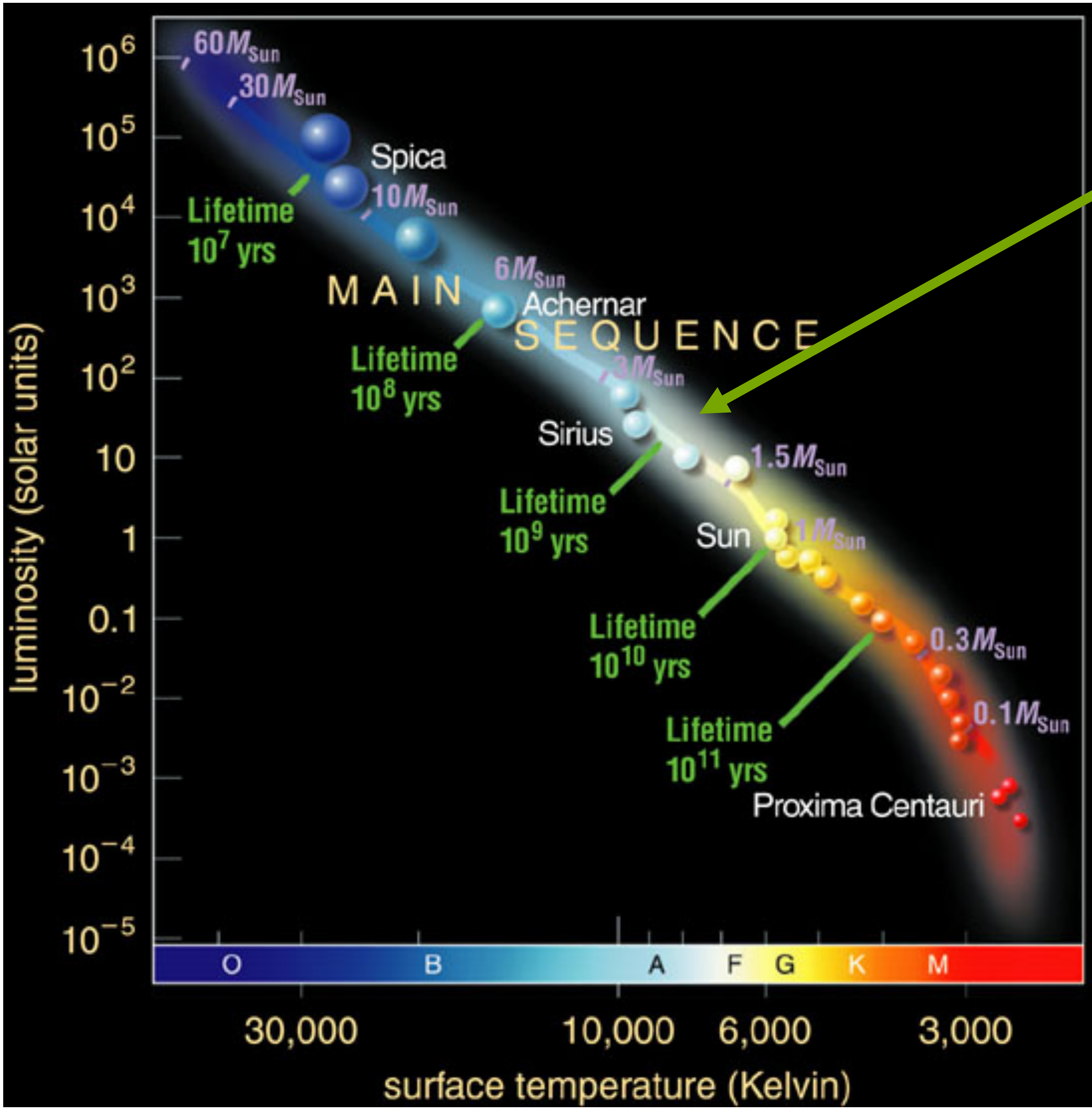
1) Old enough to allow time for evolution (rules out high-mass stars – only a few %)
2) Need to have stable orbits (this *might* rule out binary/multiple star systems – 50%)
3) Size of the "habitable zone": region in which a planet of the *right size* could have liquid water on its surface (this is probably overly stringent)

Even so… the billions of stars in the Milky Way seem to offer the prospect of many habitable worlds.

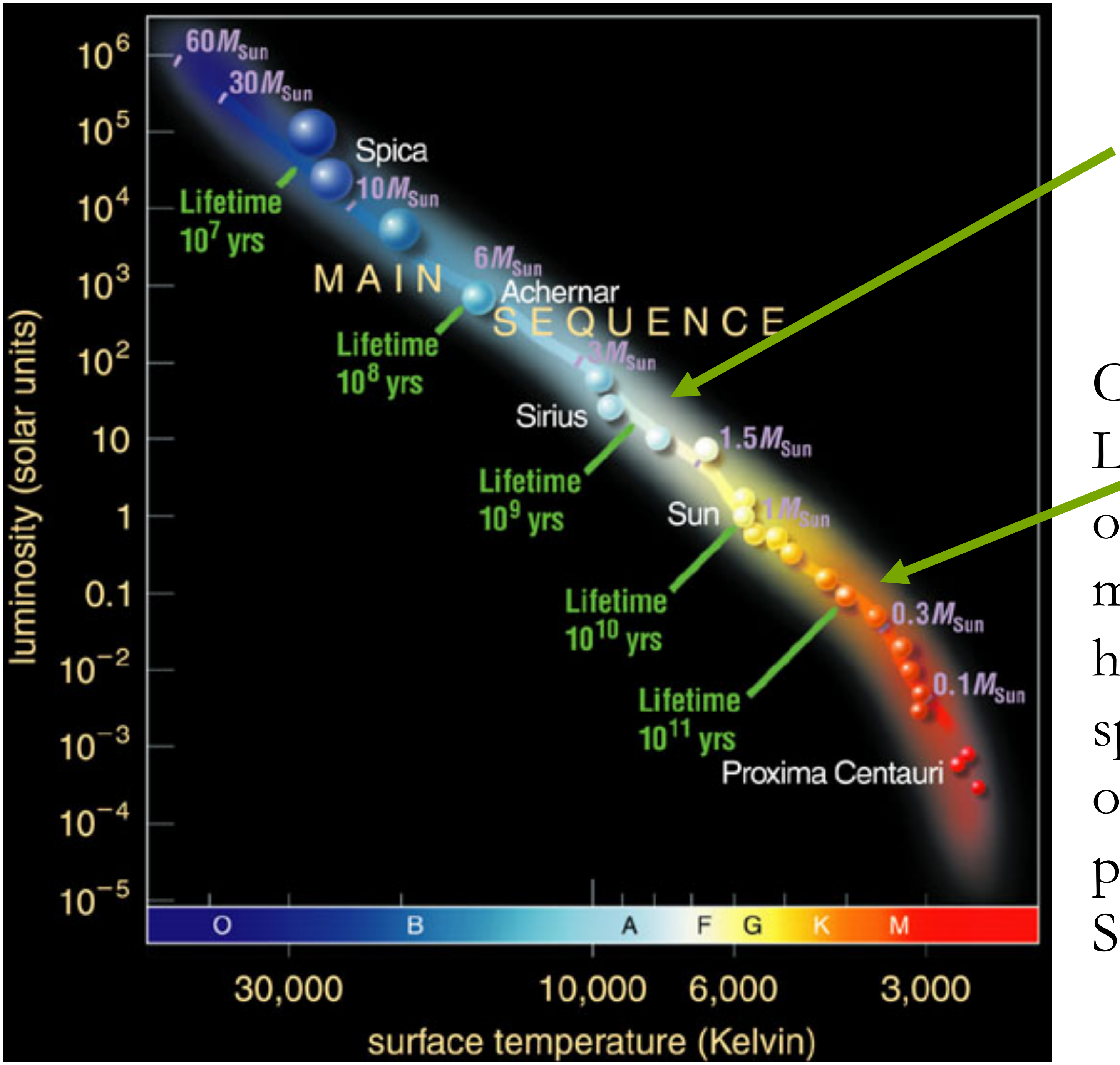


The less massive the star is, the smaller the habitable zone — lower probability of a planet in this zone.

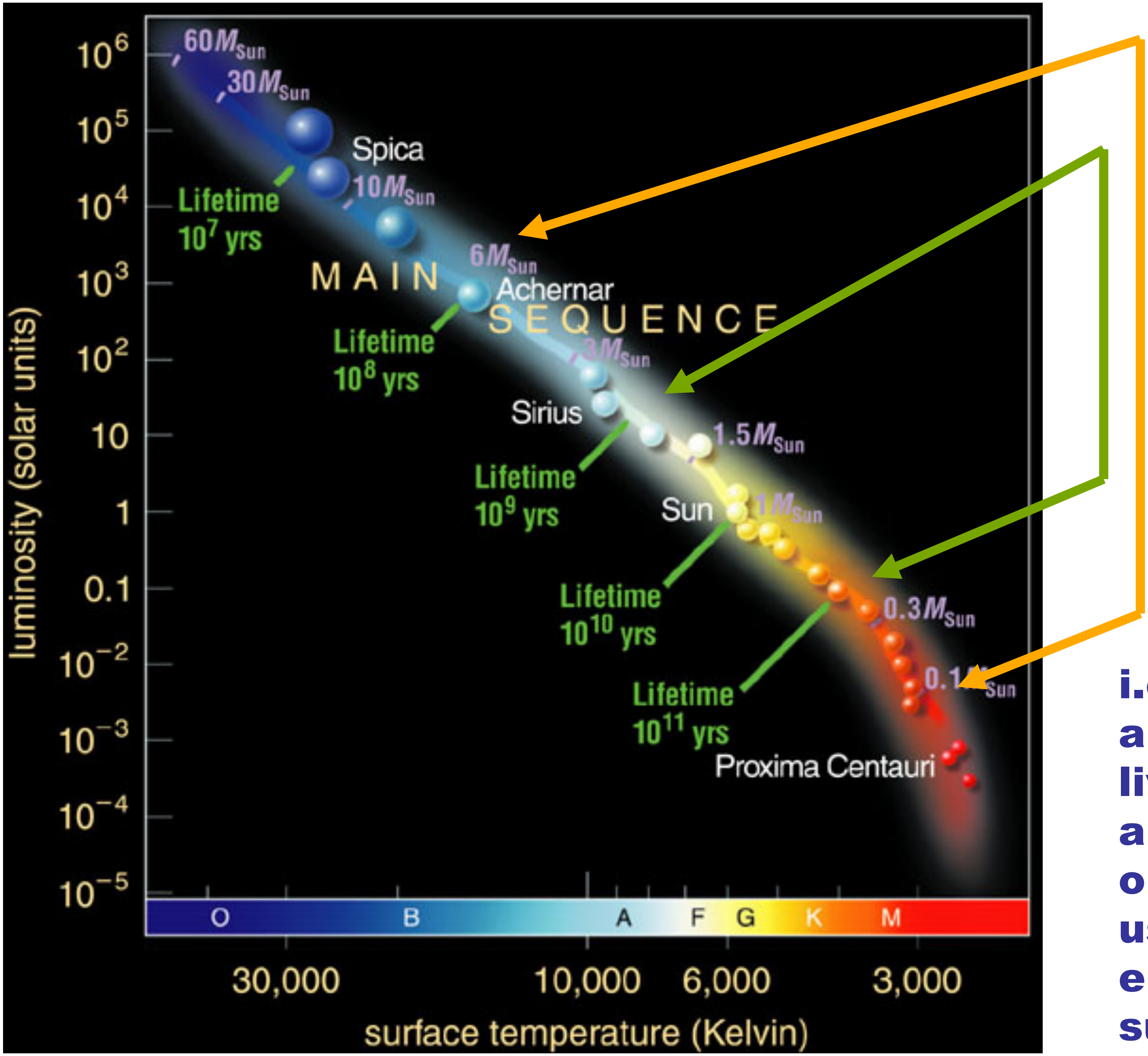

Kepler-22 System
Habitable Zone
Solar System
Mercury
Venus
Earth
Mars
Kepler-22b
Planets and orbits to scale



High mass limit of 2 times solar mass for lifetime to be at least 1 billion years for development of life.



Conservative Low mass limit of 30% of solar mass to have a habitable zone spanning region of the terrestrial planets in our Solar System.



The "sweet spot" for microbial life may be much wider and include many more stars

i.e. planets around short lived stars, and planets or moons that use internal energy for life support

How Many Stars fit these criteria?

- A conservative estimate of the habitable zone gives ~**100 million** potential stars for (possibly advanced) life in the Milky Way.
- A generous estimate based on extremophile properties and a flexible definition of what habitable means gives several billion stars.
- Remember, there are **60 billion** galaxies in the universe beyond the Milky Way.