Earth 101
Introduction to Astronomy

Properties of Stars

Instructor:
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OpenStax Ch 18

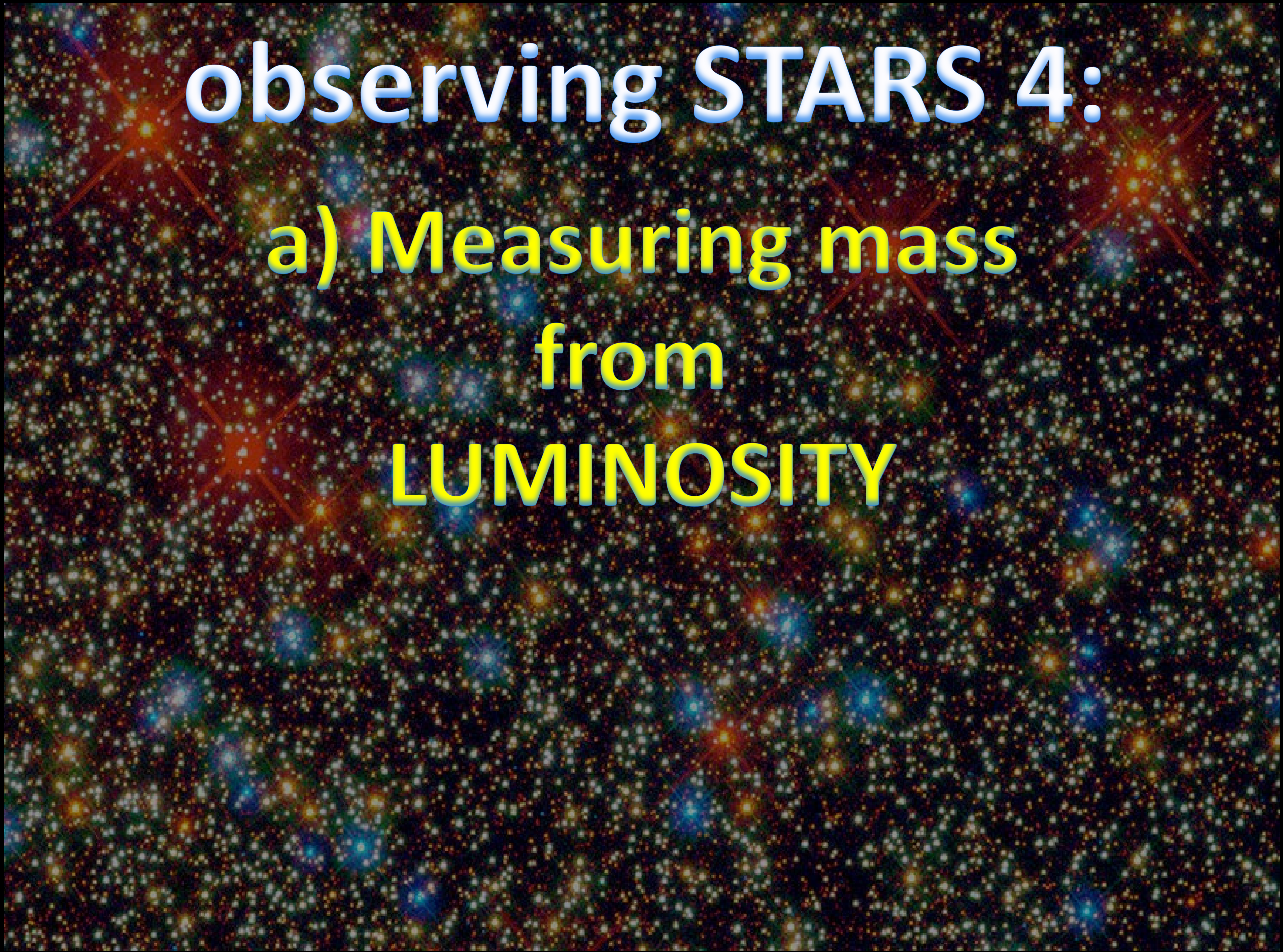
Properties of Stars (from Starlight only)

Measuring Mass from Luminosity

Photo/Material Credit:

- Fred Marschak
- Dr. Jatila van der Veen
- Erin O'Connor + others

HJNP


observing STARS 4:
a) Measuring mass
from
LUMINOSITY

From last time: Interpreting the HR diagram

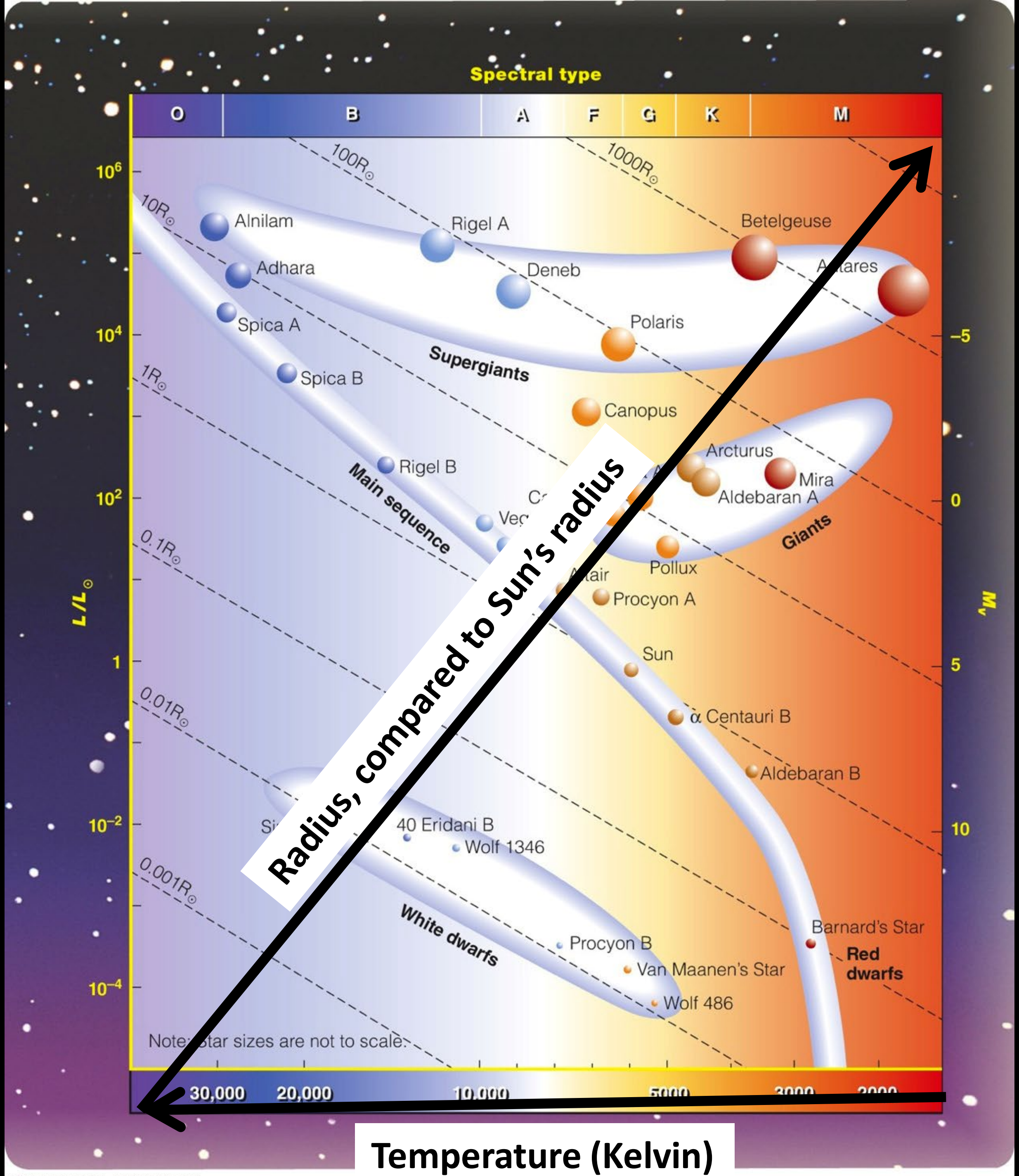
Luminosity increases from bottom to top.

Temperature increases from right to left. Spectral class follows temperature.

Radius increases diagonally, from lower left to upper right.

KNOW HOW TO READ THIS CHART!

Luminosity compared to Sun's luminosity



measuring mass from LUMINOSITY

Why do we care so much about mass and luminosity of stars?

Because MASS and COMPOSITION determine EVERYTHING about a star – how it will live and how it will die! Which stars will live long lives as red dwarfs, and which stars will live short and hot lives, and end up losing it all in a supernova explosion, leaving behind a black hole!

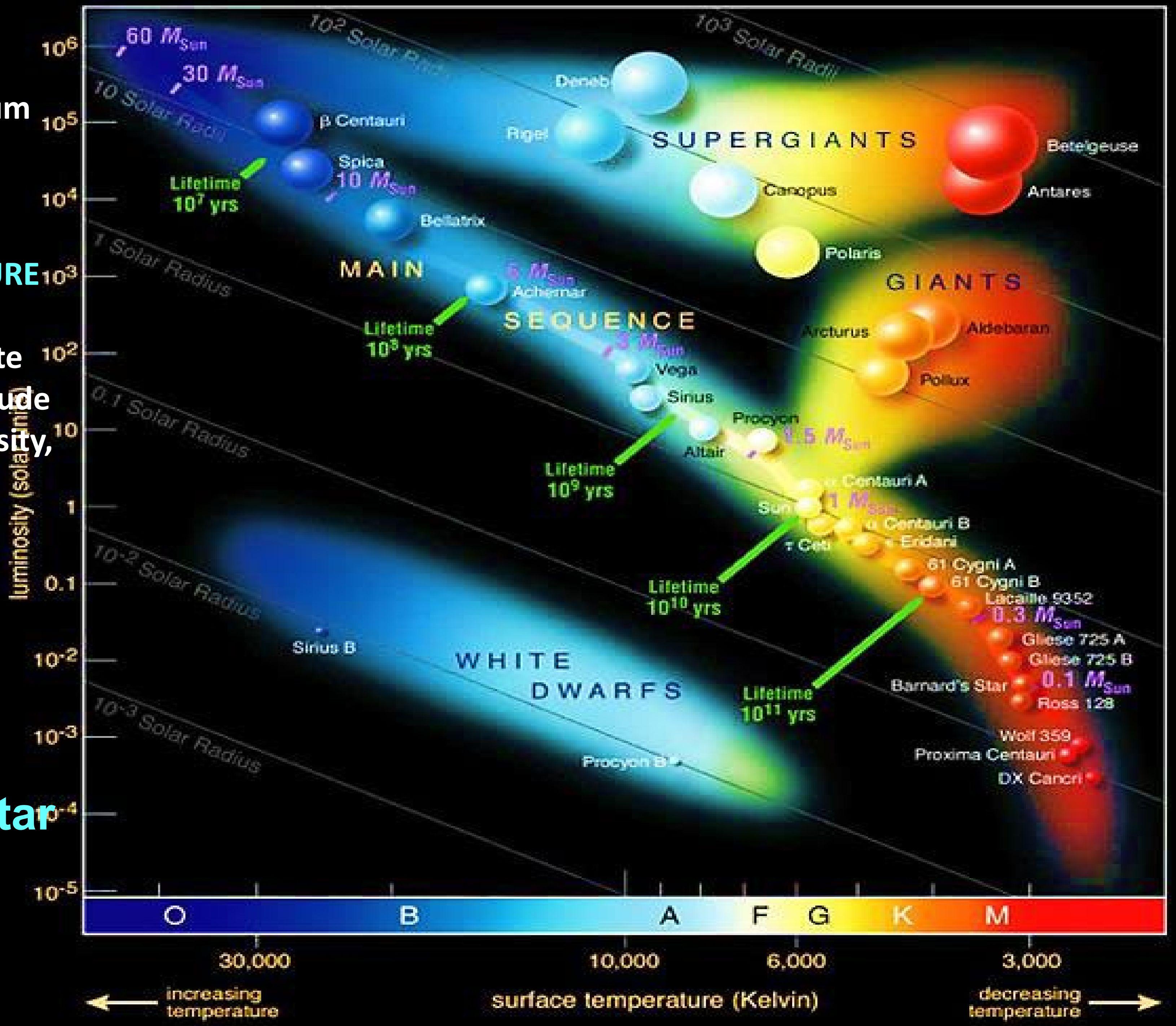
- color &
- spectrum

TEMPERATURE

- Absolute magnitude
- luminosity,

MASS

how a star evolves



$$L = \sigma T^4 (4\pi R^2)$$

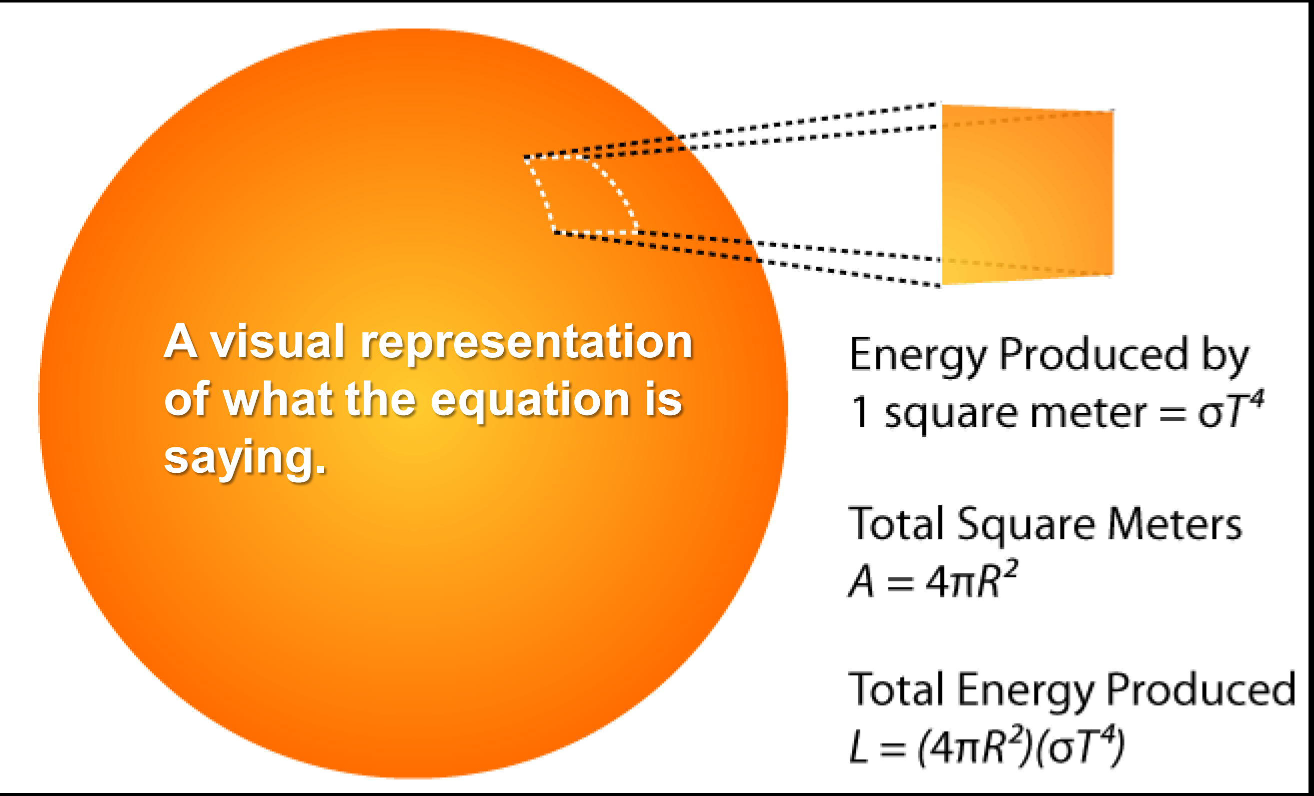
DEFINING LUMINOSITY:

Luminosity is a measure of the total energy output of a star, over its entire surface area.

σ **"Stefan-Boltzman constant" relating luminosity and temperature**

$\sigma = 5.67 \times 10^{-8}\ W \cdot m^{-2} \cdot K^{-4}$ but you do not need to memorize this!

It is the constant of proportionality in the Stefan-Boltzman radiation law, which says that the total intensity radiated at all wavelengths increases in proportion to the surface area and fourth power of temperature.



EXPLAINING LUMINOSITY :

Luminosity is equal to the RATE at which a star uses up its MASS – i.e., converts hydrogen to helium and converts mass to energy via $E = mc^2$!

Thus luminosity is related to the life expectancy of a star – how long it will be a main sequence star, before it runs out of hydrogen in its core and evolves into its next stage of life!

Recall that 90% of a star's mass is contained in the inner 50% of its radius, so this is a fair approximation.

Approximate relationship between Luminosity and Mass:

$$L \cong M^{3.5}$$

mass, not magnitude

for main sequence stars

Invert to get the Approximate relationship between Mass and Luminosity:

$$M \cong L^{1/3.5} \cong L^{0.286}$$

for main sequence stars

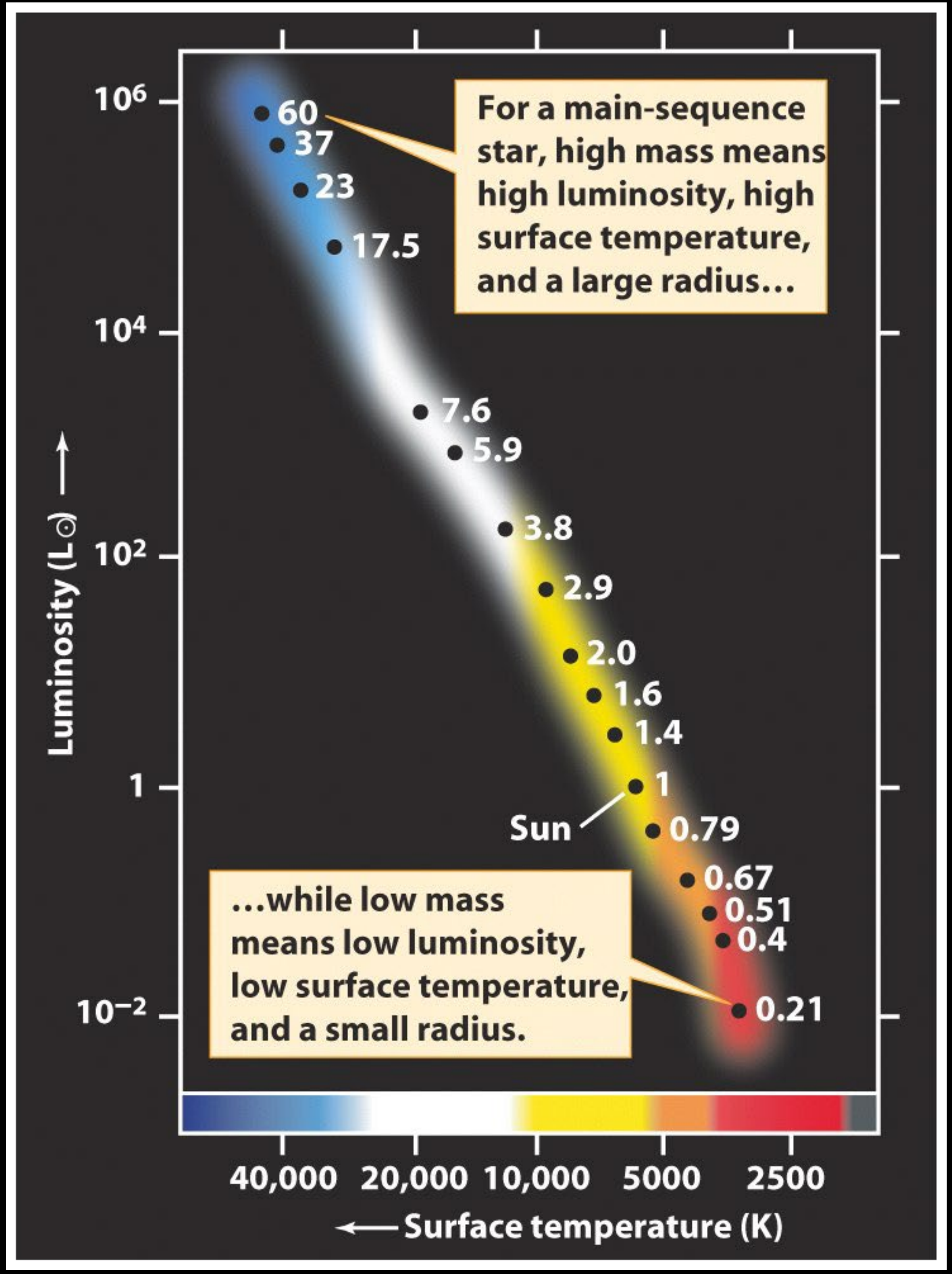
So, from measuring the luminosity, we can calculate a star's MASS!

Greater mass means greater central pressure & temperature

Greater core pressure increases the RATE of nuclear reactions, resulting in greater luminosity.

More massive stars are more luminous!!

Mass and Luminosity



Given: Mass = $L^{.286}$

Where Mass is given in SOLAR MASSES and Luminosity is given in SOLAR LUMINOSITIES

Calculate the Masses of stars with the following luminosities:

$$M \cong L^{0.286}$$

$L = 0.1\ L_{\odot}$

$L = 0.5\ L_{\odot}$

$L = 2\ L_{\odot}$

$L = 5\ L_{\odot}$

$L = 10\ L_{\odot}$

$L = 50\ L_{\odot}$

Example: For the first one:

$M = 0.1^{0.286} = 0.5176$ or $0.518\ M_{\odot}$

(rounding up, using 3 significant figures)

Try to do all of these yourself, before looking at the answers on the next slide.

Given: Mass = $L^{.286}$

Where Mass is given in SOLAR MASSES and Luminosity is given in SOLAR LUMINOSITIES

Answers:

for $L = 0.1\ L_{\odot}$, $M = 0.517\ M_{\odot}$

for $L = 0.5\ L_{\odot}$ $M = 0.82\ M_{\odot}$

for $L = 10\ L_{\odot}$ $M = 1.93\ M_{\odot}$

for $L = 100\ L_{\odot}$ $M = 3.7\ M_{\odot}$

for $L = 1000\ L_{\odot}$ $M = 7.2\ M_{\odot}$

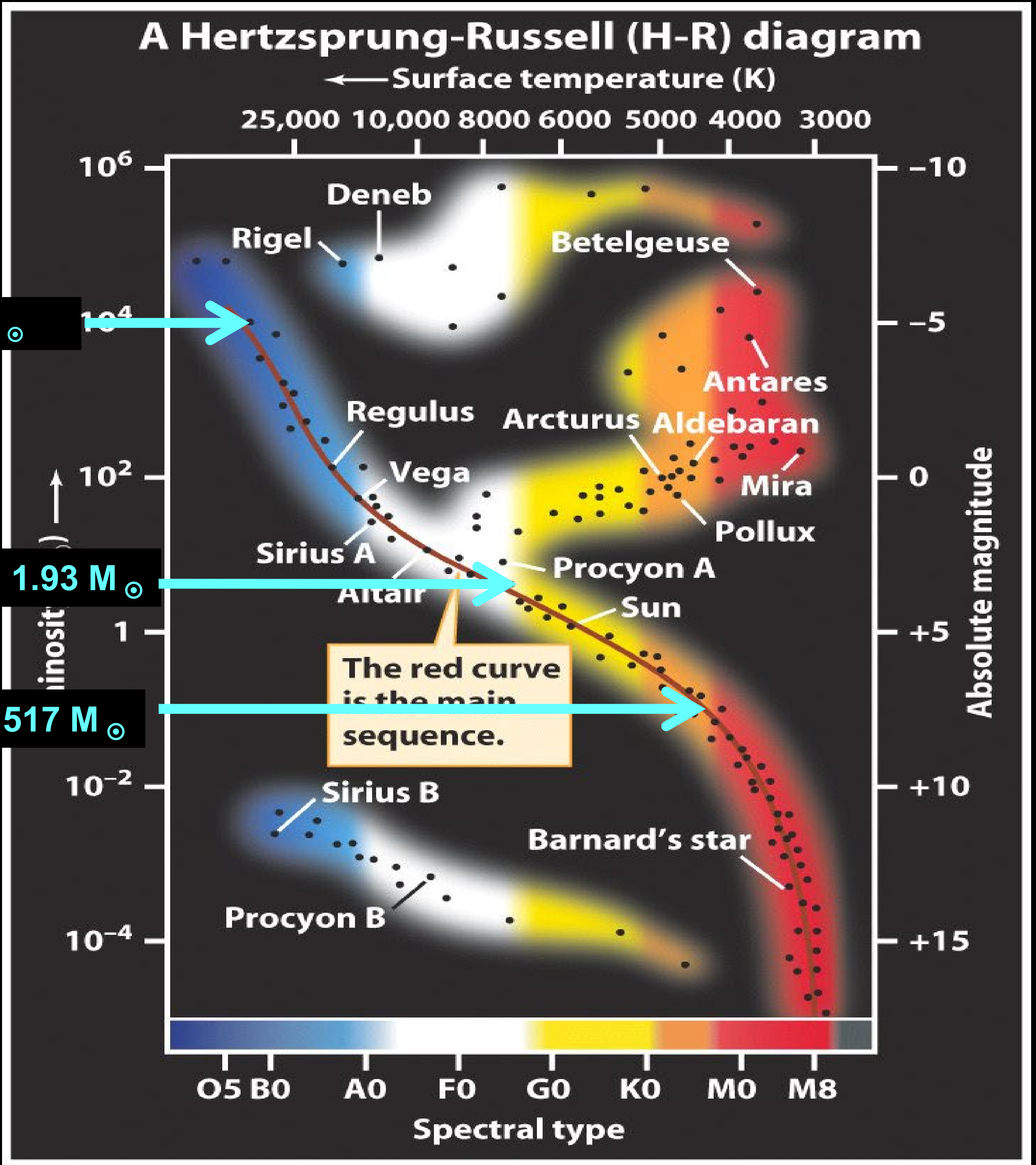
for $L = 10{,}000\ L_{\odot}$ $M = 13.9\ M_{\odot}$

Where do the stars for which we just calculated their masses fit on this diagram?

for L = 10,000 $L_\odot$ M = 13.9 $M_\odot$

for L = 10 $L_\odot$ M = 1.93 $M_\odot$

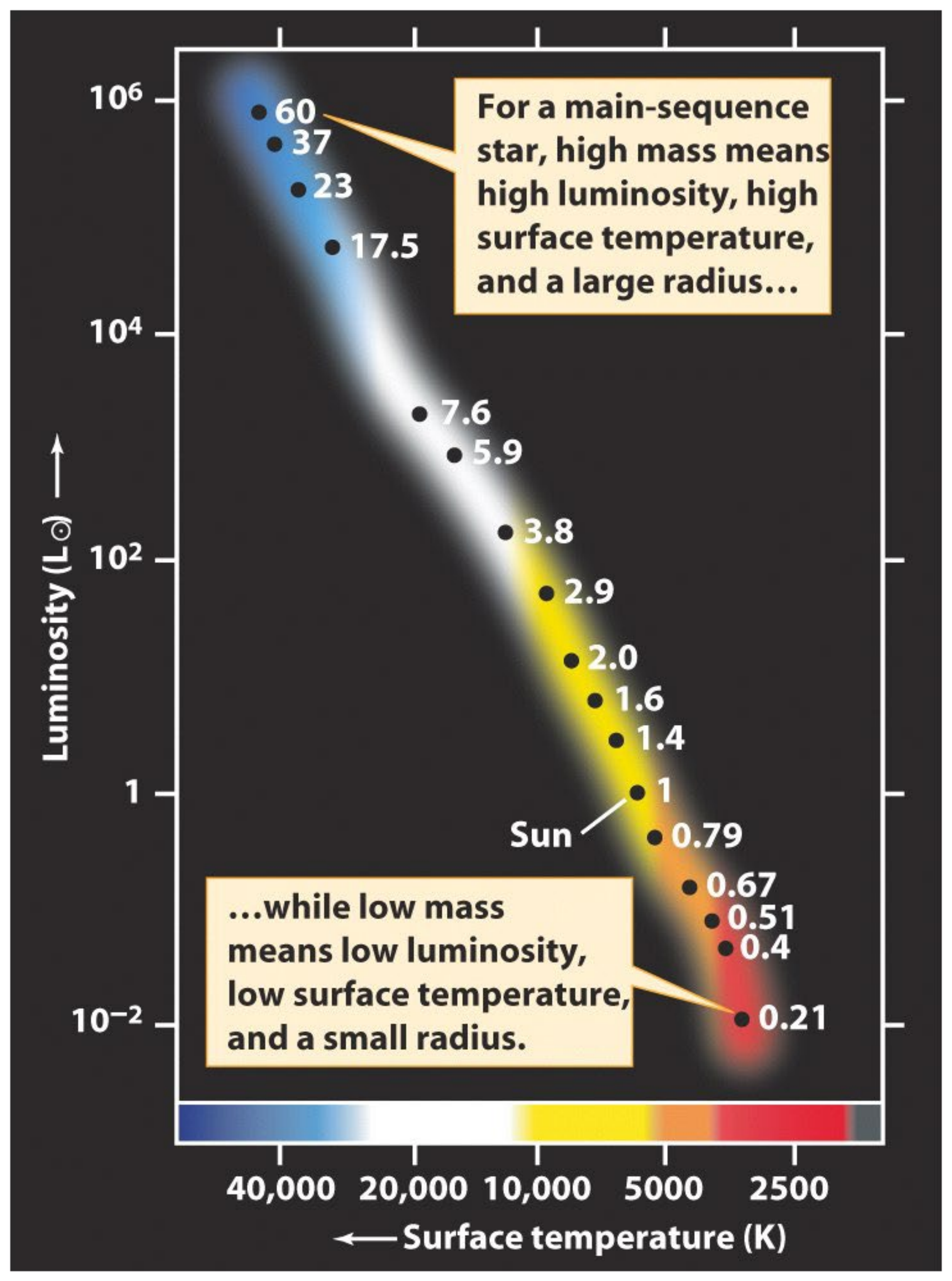
L = 0.1 $L_\odot$, M = 0.517 $M_\odot$



Summary:

High mass =
High Luminosity

Low mass =
Low Luminosity



observing STARS 4:

b) Calculating life expectancy on the Main Sequence from LUMINOSITY, which depends on MASS

RECALL:

The observable properties of main sequence stars, such as their surface temperature, luminosity, and radius, are all dictated by the mass of the star.

Higher mass leads to
Higher compression, which leads to
Higher central density and temperature, which leads to
MUCH faster fusion, which leads to
MUCH higher luminosity.

A theme that will repeat over and over:

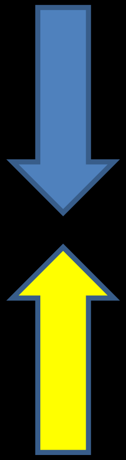
Vogt-Russell Theorem:

The Vogt–Russell theorem states that the structure of a star, in hydrostatic and thermal equilibrium, with all energy derived from nuclear reactions, is uniquely determined by two properties:

mass
and
the distribution of chemical elements throughout its interior.

Hydrostatic Equilibrium

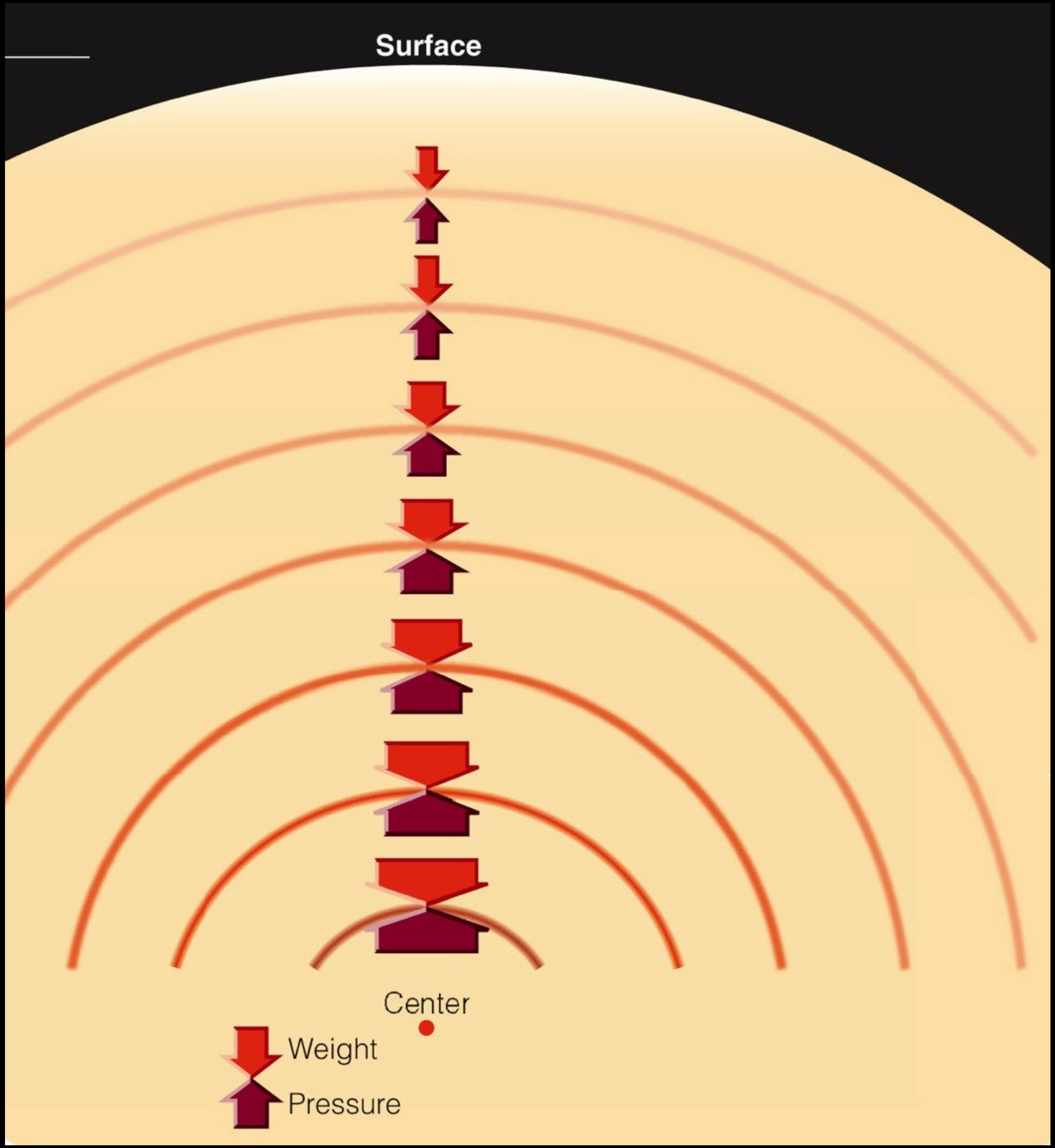
A star's inner life is dictated by the struggle between



gravity

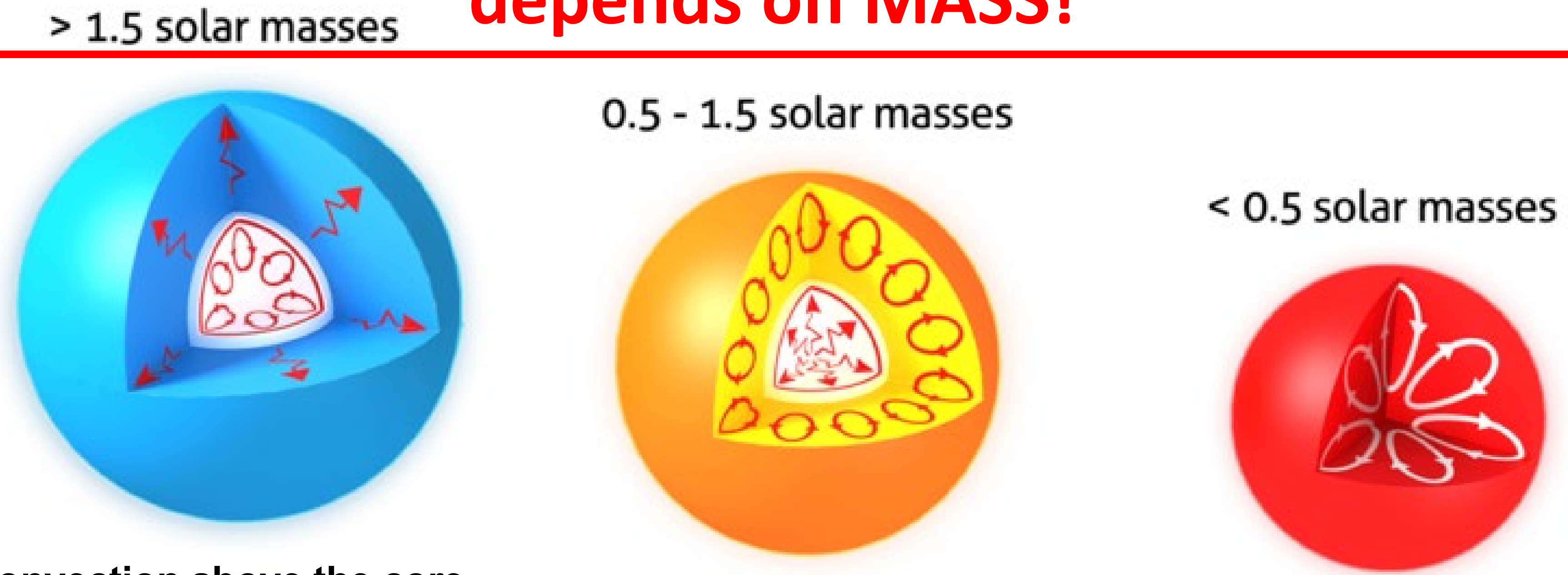
and

radiation pressure



Heat Transfer of Stars

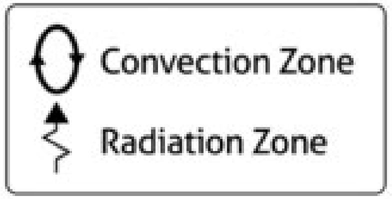
Mechanism of heat transport away from the core depends on MASS!



convection above the core, radiative heat transport to the surface

radiative heat transport above the core, convection to the surface

convective throughout

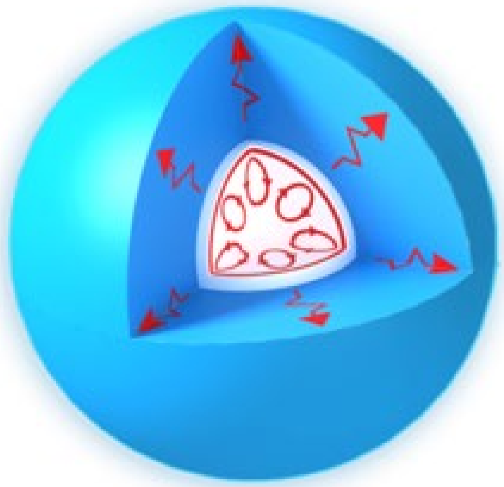


Review The Sun, Part 2 – interior, slides 5 – 9 about radiative and convective heat transport in the Sun.

Heat Transfer of Stars

Biggest stars: shortest lives

> 1.5 solar masses



convection above the core, radiative heat transport to the surface

Medium stars: medium lives

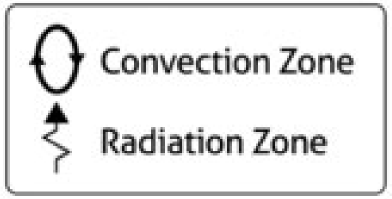
0.5 - 1.5 solar masses

radiative heat transport above the core, convection to the surface

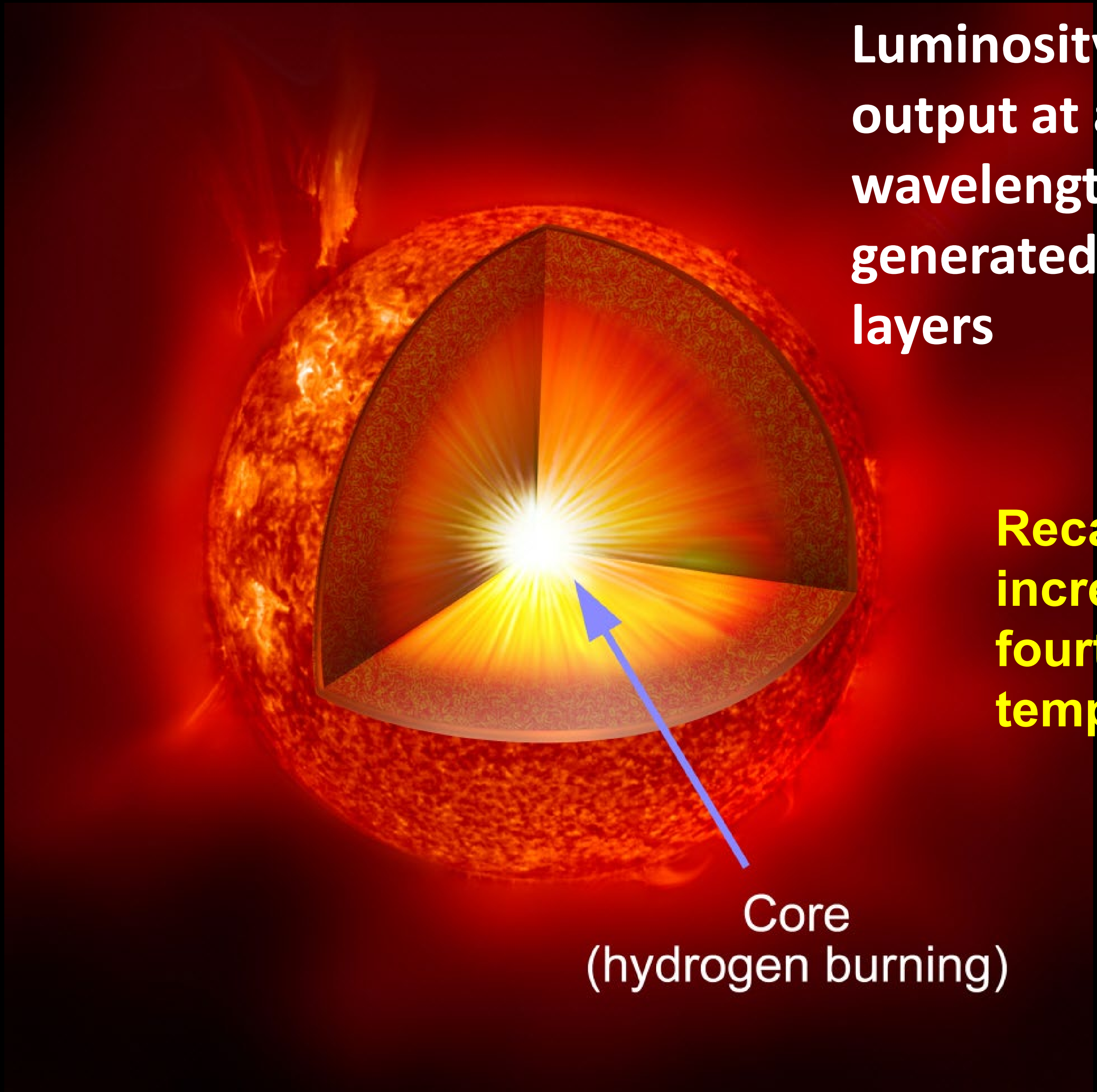
Smallest stars: longest lives

< 0.5 solar masses

convective throughout



Refer to pages 303-305 in Chapter 11.



Luminosity (total light output at all wavelengths) = energy generated in all the layers

Recall: Luminosity increases as the fourth power of the temperature:

$$L \sim T^4$$

Recall:

Approximate relationship between Mass and Luminosity:

$$L \cong M^{3.5}$$

for main sequence stars

Luminosity = rate at which star converts mass to energy = rate at which a star uses up its mass

Mass / (rate at which mass is used up)
= Life expectancy of a star
in terms of solar lifetimes

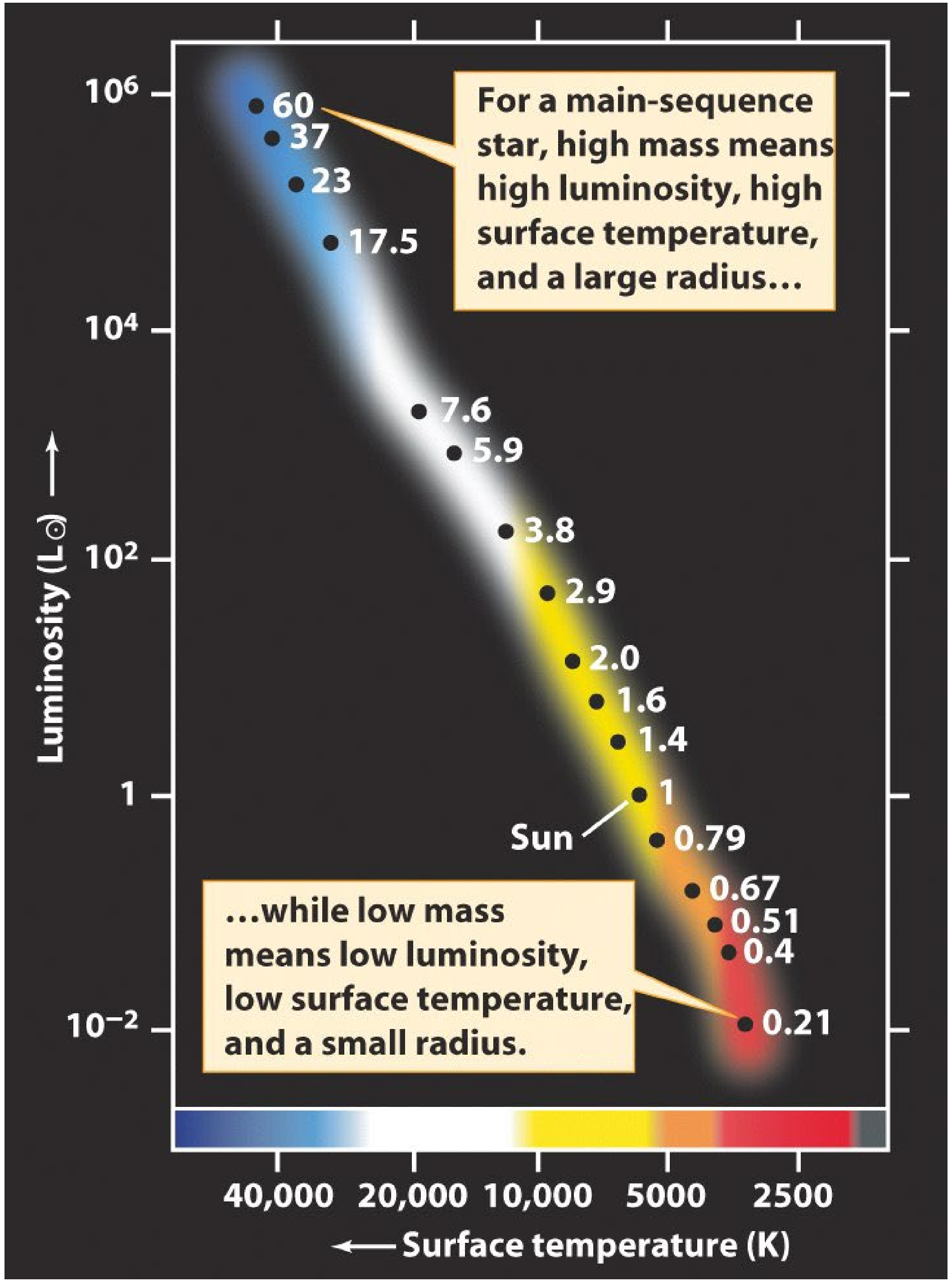
$$\frac{M}{L} = lifetime = \frac{L^{.2857}}{L} = L^{-.7143} = \frac{1}{L^{.7143}}$$

So we can figure out how long a star will be on the Main Sequence from its luminosity, given in terms of solar luminosities…

More mass

faster rate of nuclear fusion

shorter lifetime



$$T = \frac{1}{L^{.7143}}$$

life expectancy of a star

L is in solar luminosities

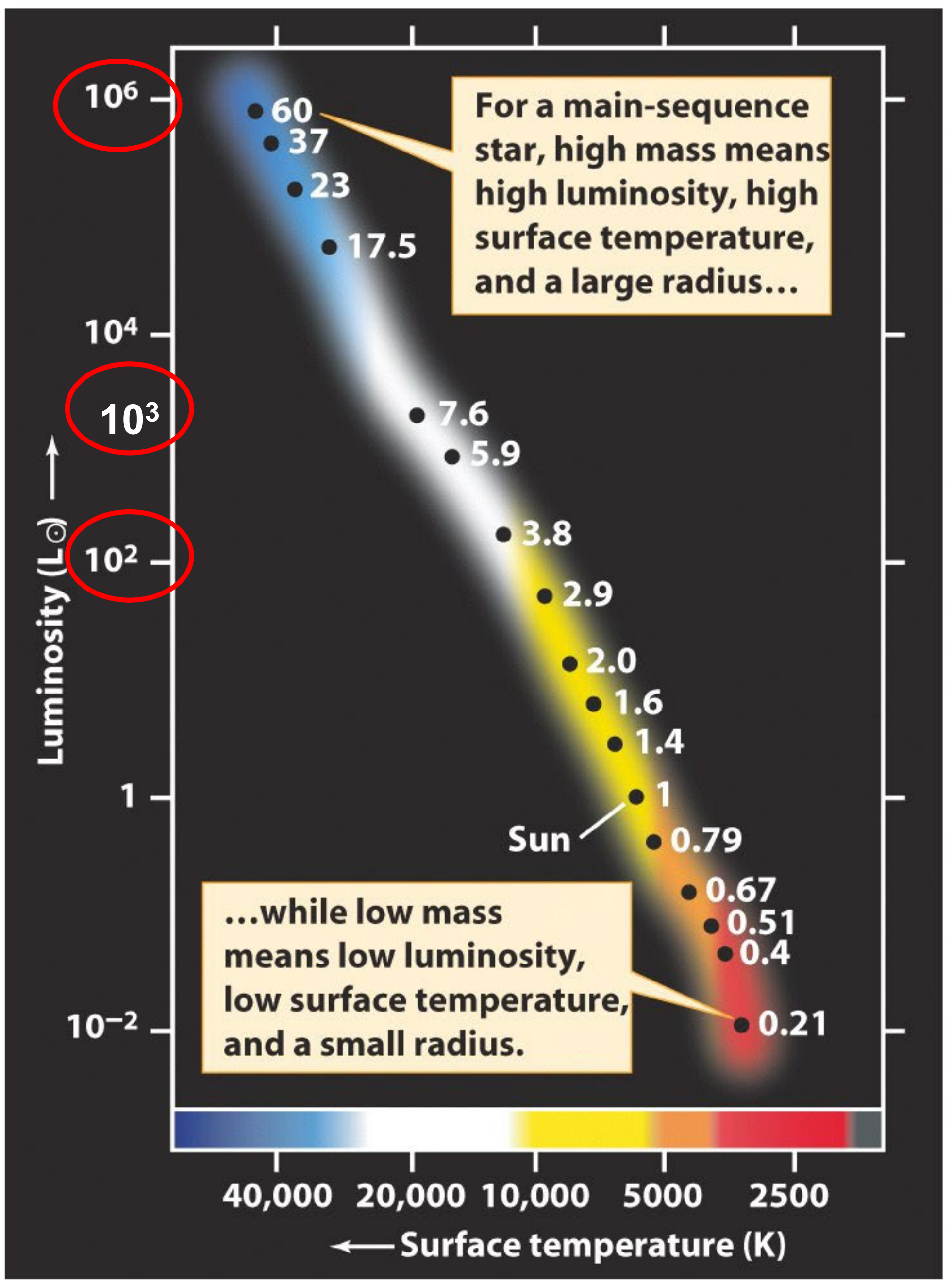
$T_{\odot}$ = 10 billion years

= 10^{10} years

if L = 10^2 $L_{\odot}$ T = ?

if L = $10^3$$L_{\odot}$ T = ?

if L = 10^6 $L_{\odot}$ T = ?



$$T = \frac{1}{L^{.7143}}$$

life expectancy of a star

Example:

$$L = 100 L_{Sun}$$

$$T = \frac{1}{100^{.7143}} = 0.037 T_{Sun}$$

$$T_{Sun} = 10^{10}\ yrs$$

$$T_{Star} = 3.7 \times 10^{-2} \times 10^{10} = 3.7 \times 10^{8}\ yrs$$

370 million years

$$T = \frac{1}{L^{.7143}}$$

life expectancy of a star

L is in solar luminosities

$T_\odot$ = 10 billion years, approx.

= 10^{10} years

if $L = 10^2 L_\odot$ $T = .037T_\odot$

= 3.7×10^8 yrs

= 370 million yrs

if $L = 10^3 L_\odot$ $T = .0072T_\odot$

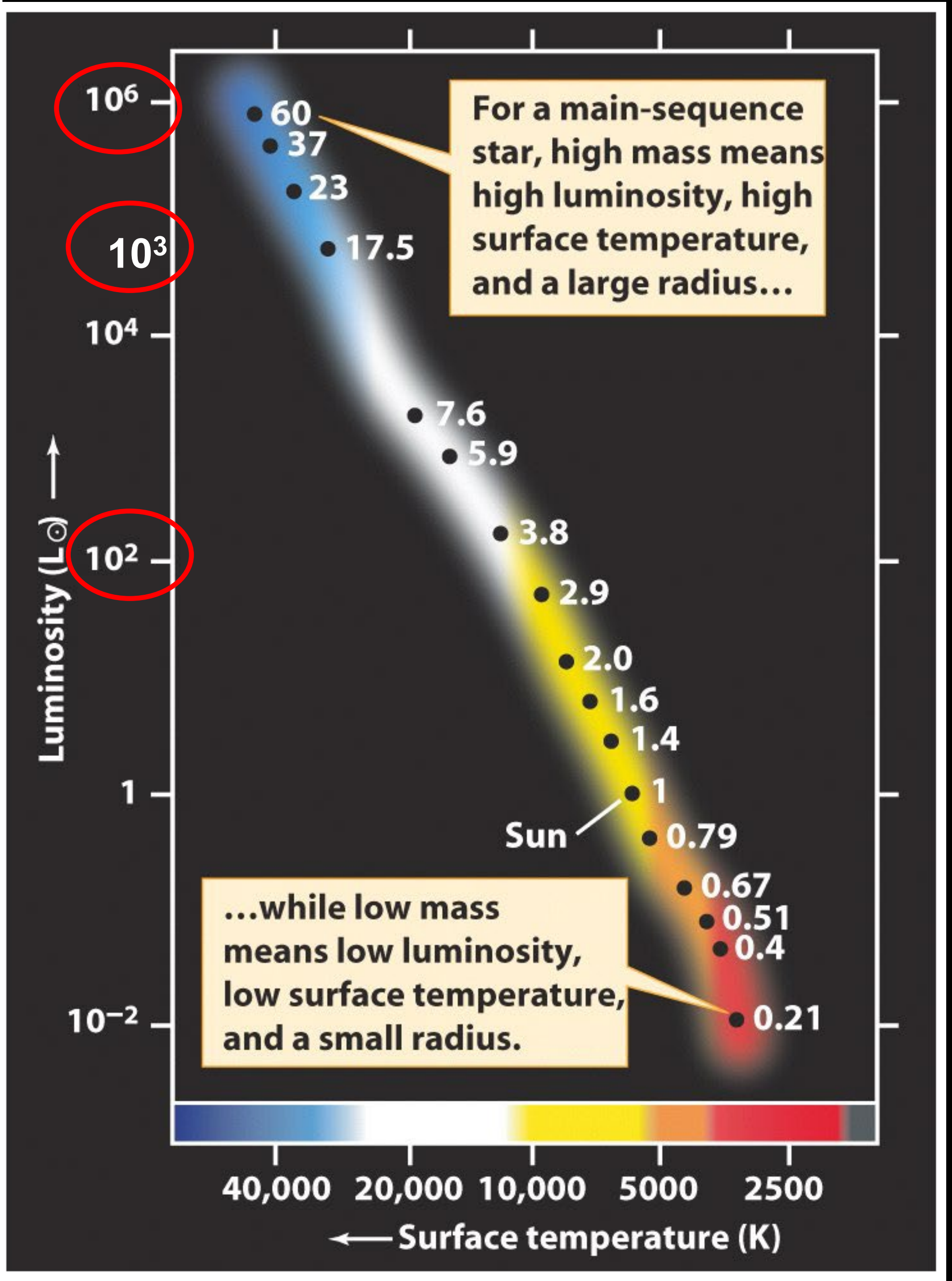
= 7.2×10^7 yrs

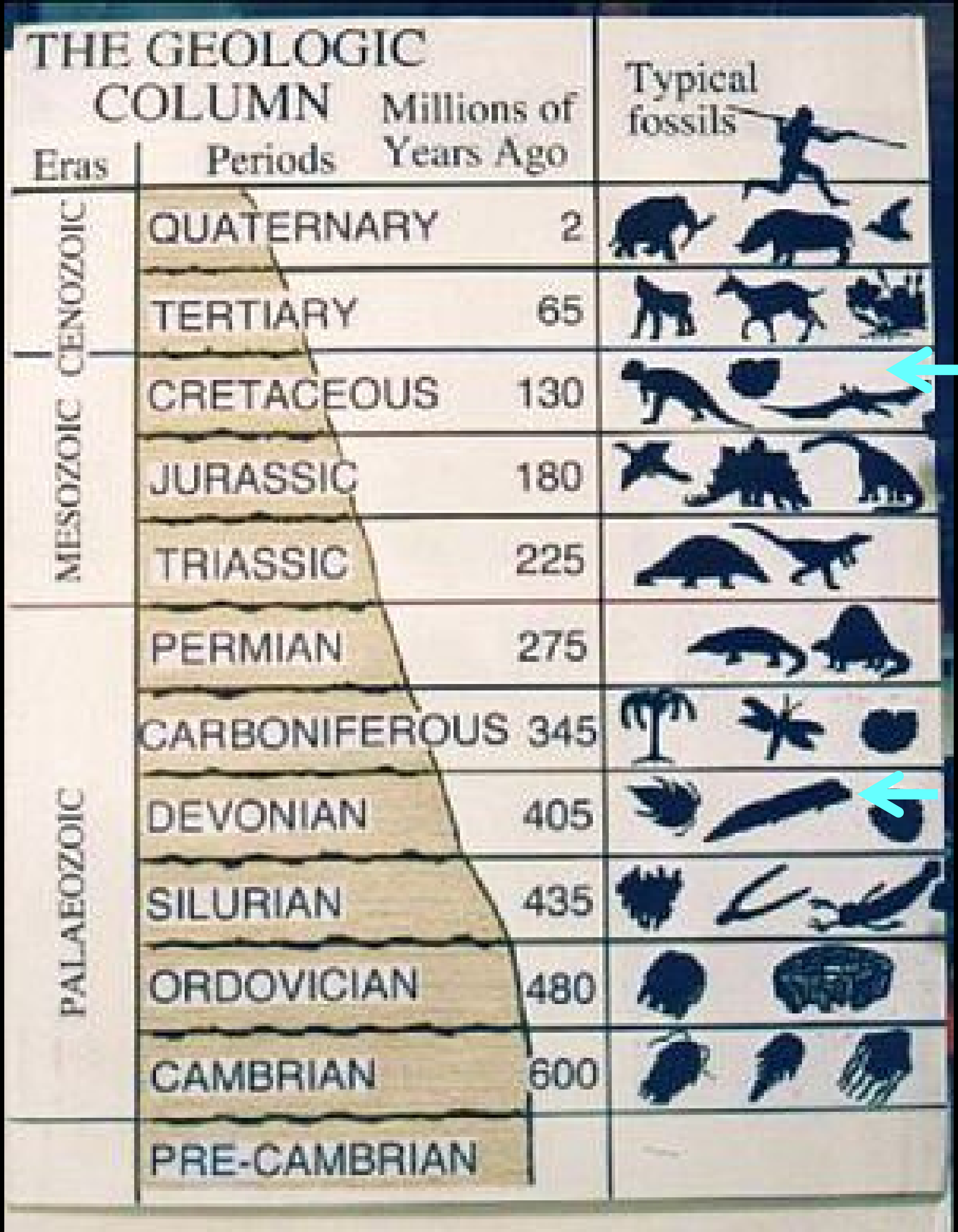
= 72 million yrs

if $L = 10^6 L_\odot$ $T = .000052T_\odot$

= 5.2×10^5 yrs

= 520 thousand yrs



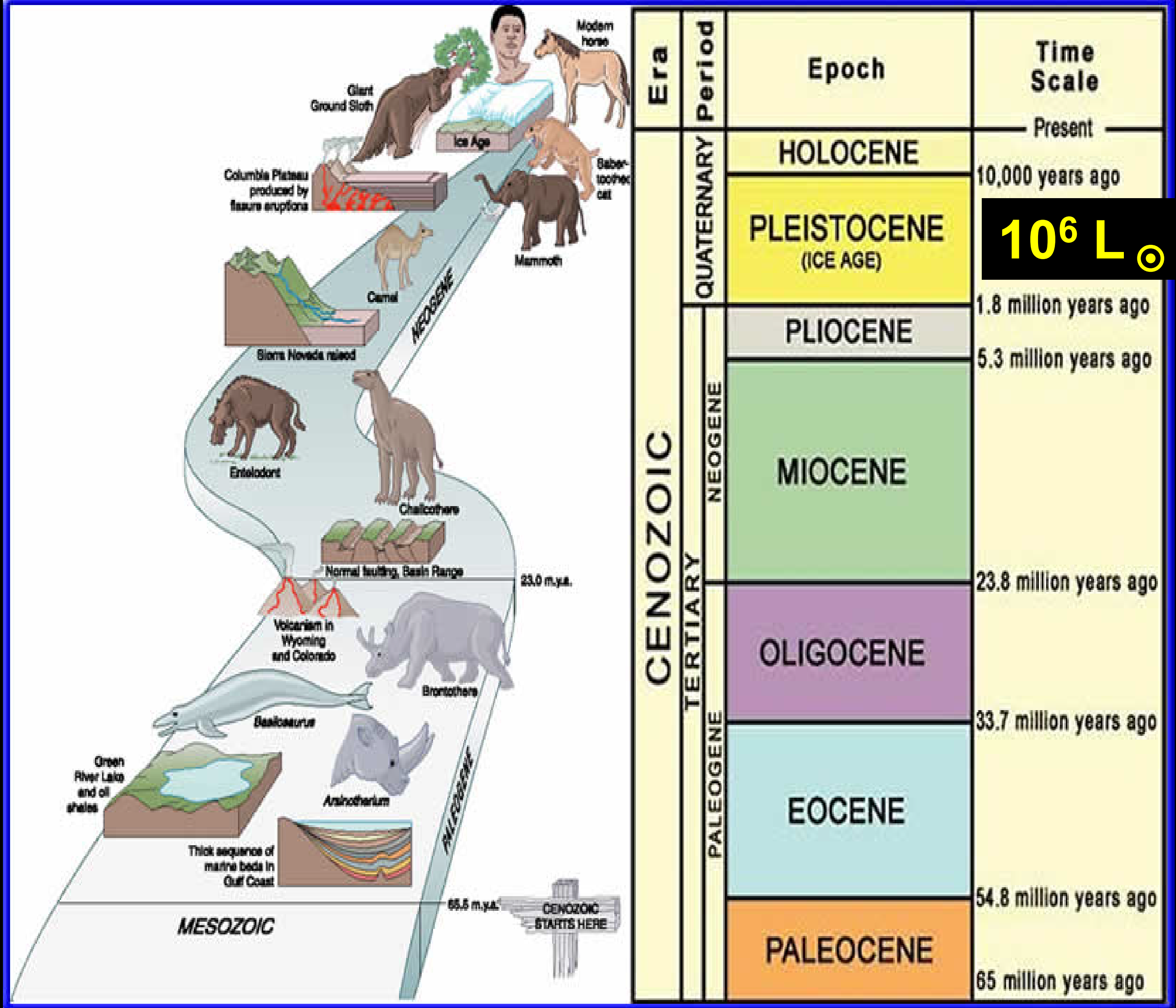


Compare with geologic history:

If these stars would be ending their lives now, what was happening on Earth when they first turned on?

$10^3 L_\odot \sim 72$ Myr

$10^2 L_\odot \sim 370$ Myr



$10^6\ L_\odot \sim 520{,}000$ yr

The Cenozoic Era is the most modern geologic era: the beginning was marked by the K-T extinction, and the era continues to the present. From the earliest to the most recent, the Cenozoic Era is divided into the Tertiary Period, which is subdivided into the Paleocene, Eocene, Oligocene, Miocene, and Pliocene Epochs, and the Quaternary Period, which is subdivided into the Pleistocene and Holocene Epochs (Kazlev 2002).

Summary:

$$L \cong M^{3.5}$$

thus

$$M = L^{1/3.5} = L^{.2857}$$

and since luminosity is the rate at which a star converts mass to energy through the fusion reaction
4H → 1 He + energy,
the life expectancy of a star on the main sequence is defined by its luminosity, which is defined by its mass.:

T is in solar lifetimes of 10^{10} years and L is in solar luminosities.

$$T = \frac{1}{L^{.7143}}$$