

THE LIVES OF STARS

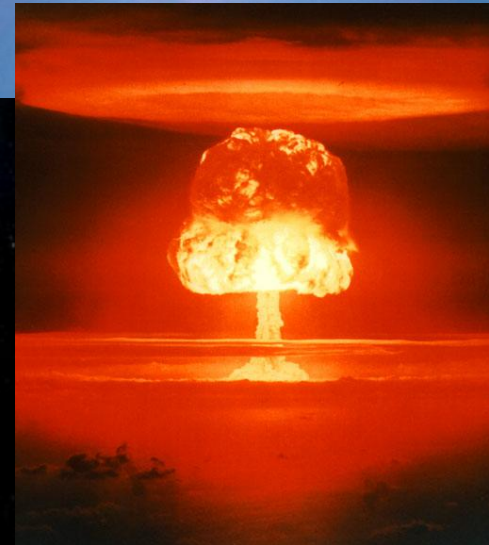
CHARLES ZHU

AST 121 – 4/3/2013

WHAT IS A STAR?

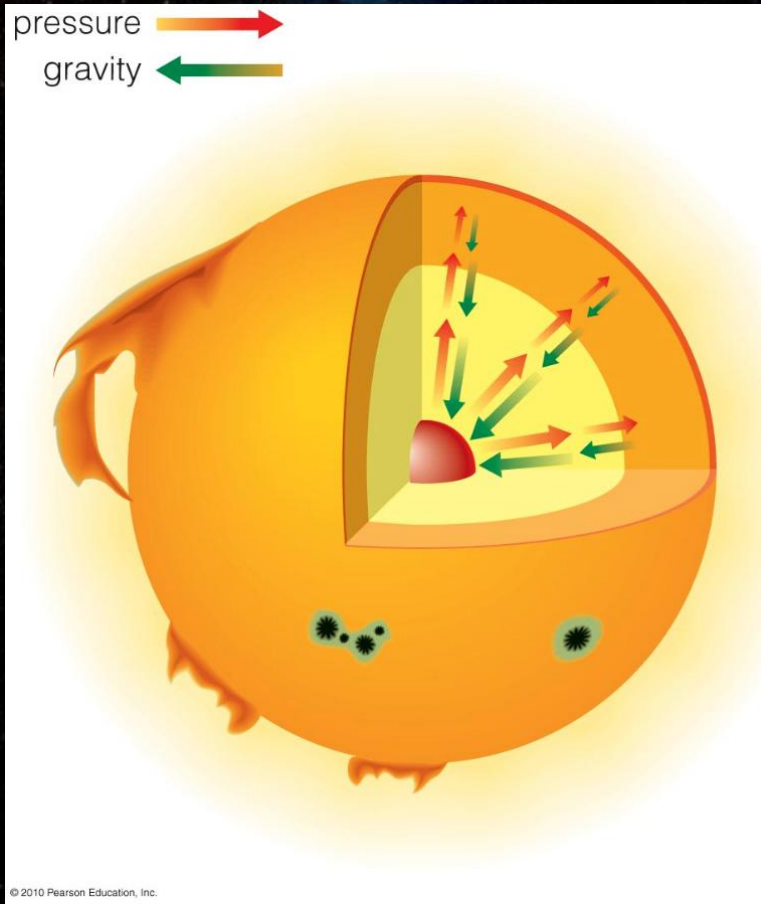
<http://en.wikipedia.org/wiki/Star>

- Massive, luminous, self-gravitating sphere that generates energy through nuclear fusion
- If stars have nuclear fusion, why don't they explode like hydrogen bombs?
- Alternatively, why doesn't everything immediately collapse into a black hole?



http://en.wikipedia.org/wiki/Hydrogen_bomb

A PROTRACTED BATTLE WITH GRAVITY^[1]

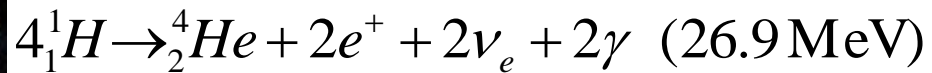


Bennett et al., *The Cosmic Perspective*, 6th ed., 2010

- Objects must support themselves against gravity:
 - Planets (and you!): van der Waals
 - Brown dwarfs, stellar remnants: degeneracy pressure
 - Stars: gas pressure
- Large gas pressure → gas is hot → hot gas radiates → loses energy → bad
- But, gas is hot → nuclear fusion is triggered → star obtains huge reservoir of energy

MEANS OF FUSION

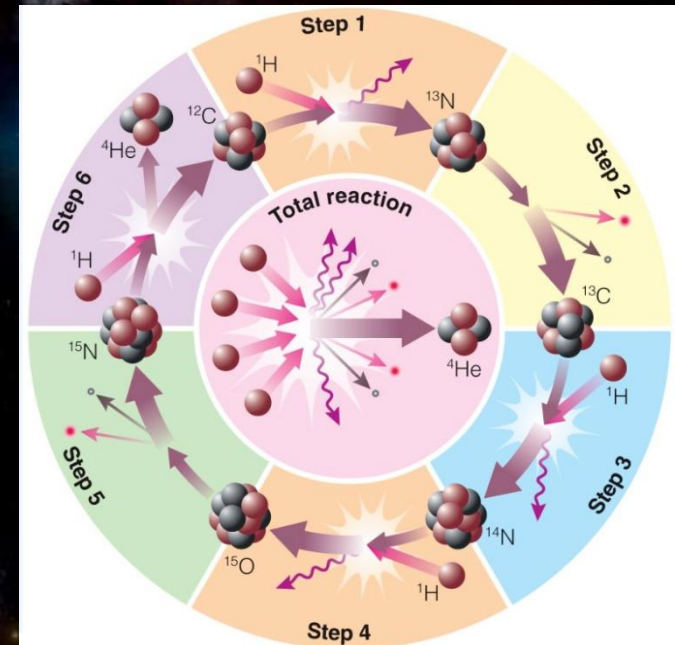
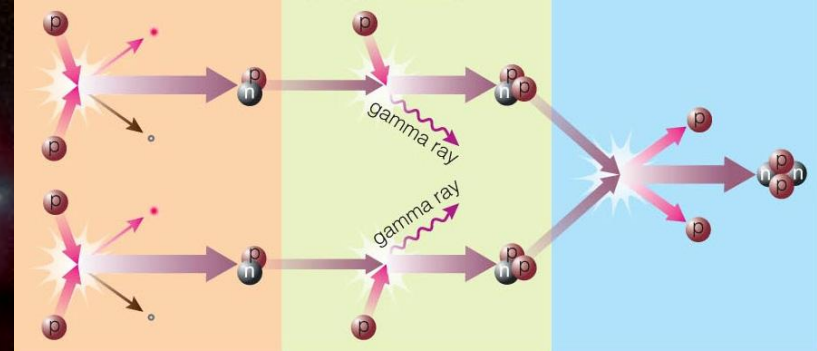
- Reaction:



- Energy generation:

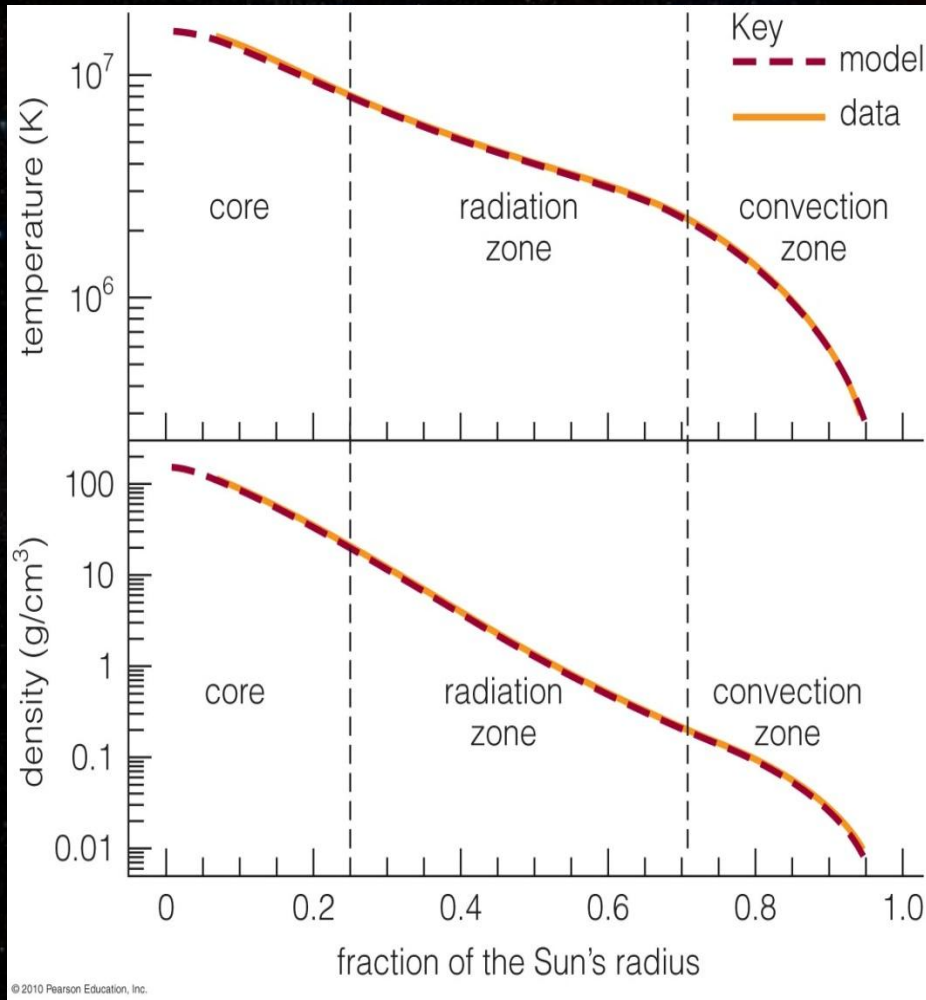
$$E = (\Delta m)c^2 = (m_{4\text{He}} - 4m_{\text{H}})c^2 = fm_{\text{H}}c^2$$

- Proton-proton (p-p) chain:
 - Can occur in pure H environment
 - Dominates for $M < 1.3M_{\odot}$
- Carbon/nitrogen/oxygen (CNO) cycle:
 - Uses ^{12}C , ^{14}N and ^{16}O as catalysts
 - Dominates for $M > 1.3M_{\odot}$



Bennett et al. 2010

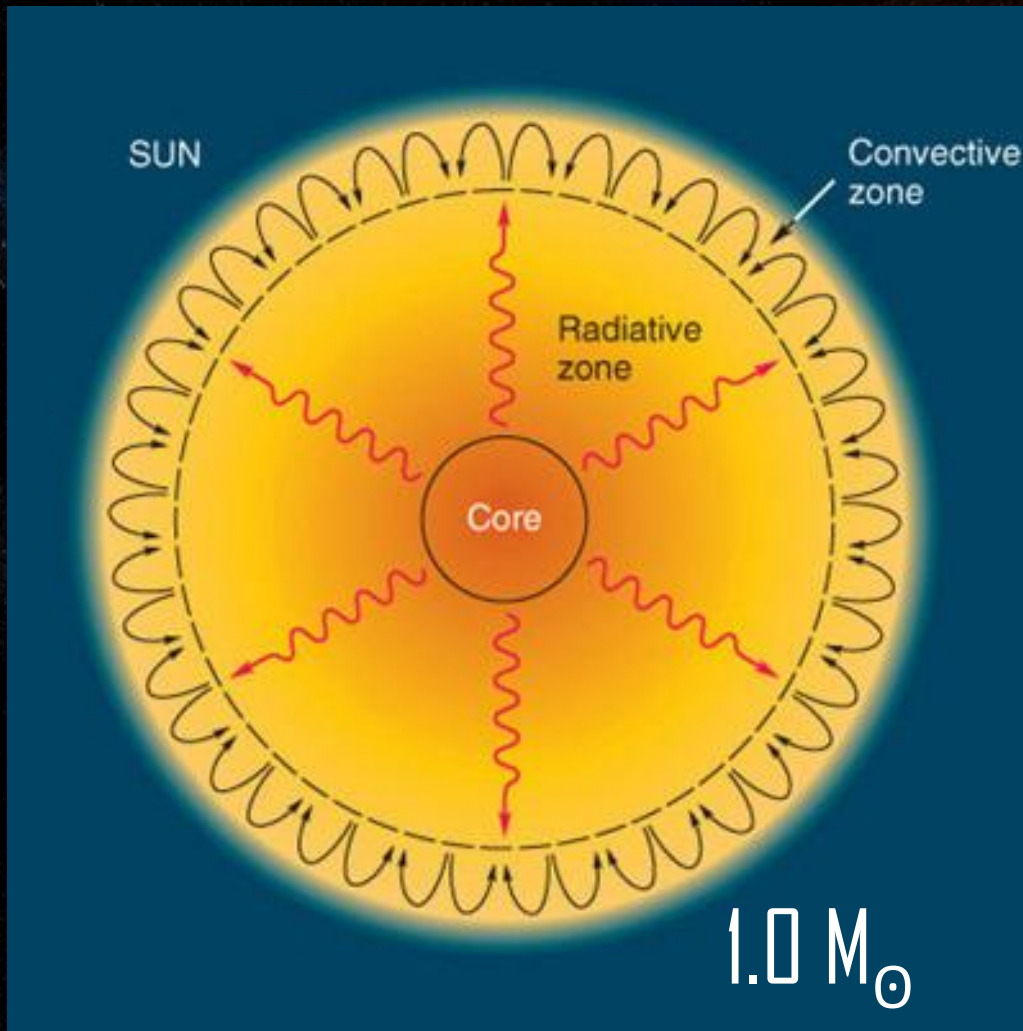
STELLAR STRUCTURE



Bennett et al. 2010

- Can use the equations of hydrostatic equilibrium, temperature, energy transport (includes opacity) and gas equation of state to determine stellar structure
- Observations done using surface observations, neutrinos, asteroseismology

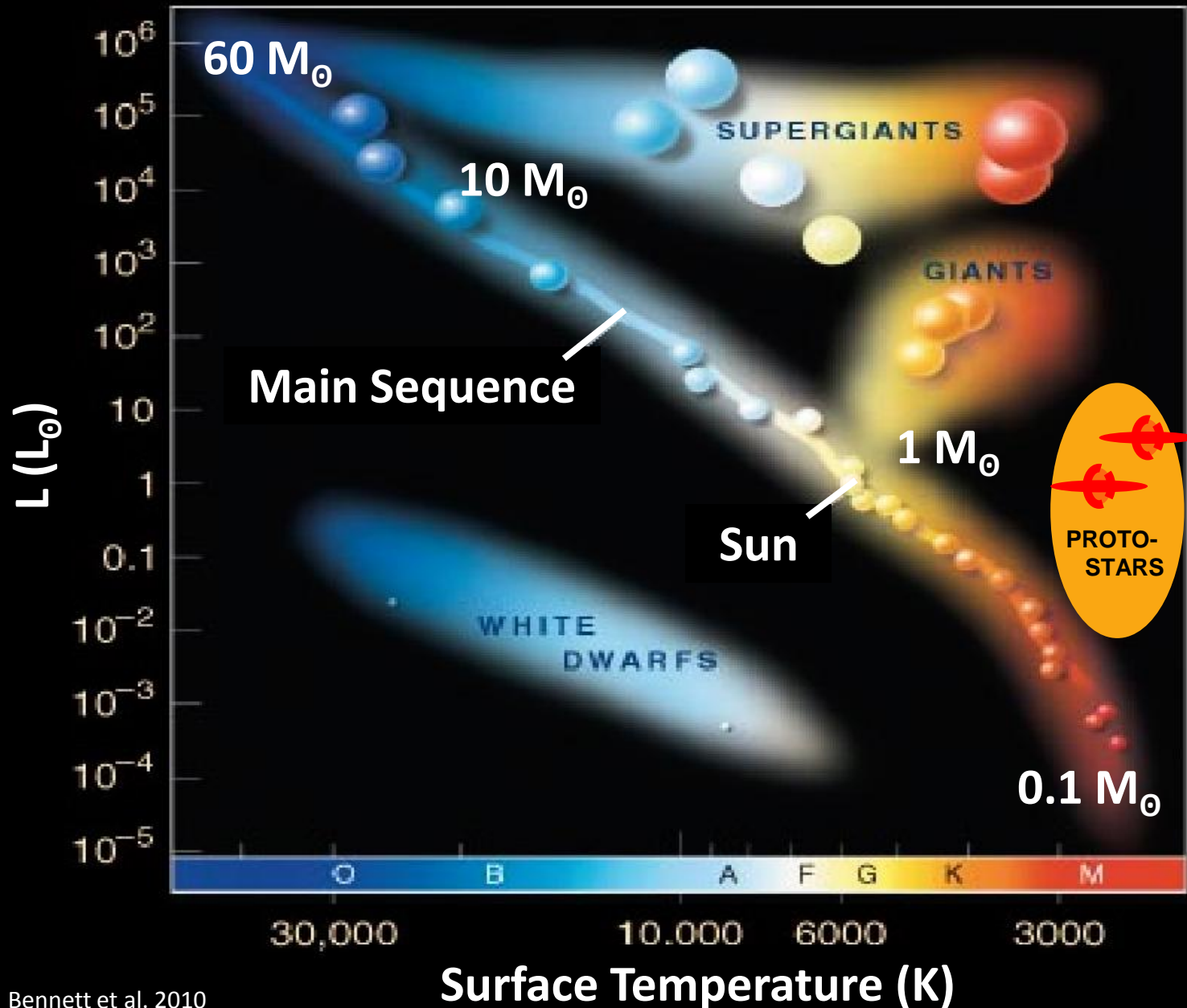
STELLAR STRUCTURE



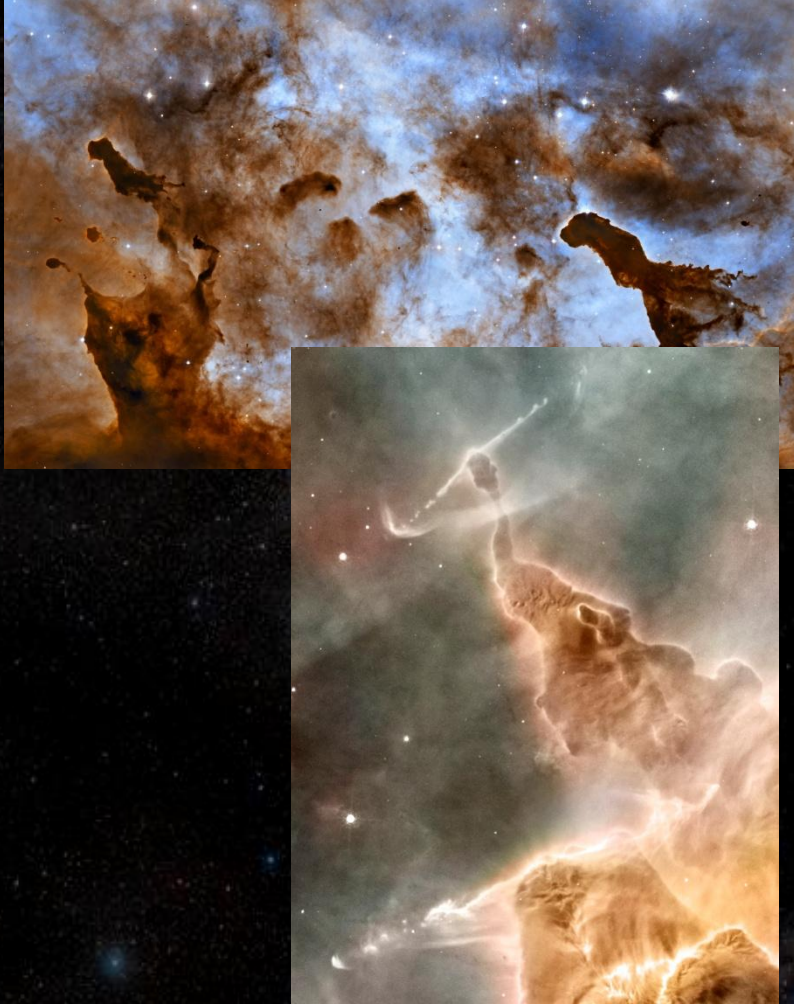
- For stars of differing masses:

- $L \propto M^{3.5}$ (massive stars are much more luminous)
- $R \propto M^{0.5}$ (massive stars are bigger)
- $T_{\text{surface}} \propto M^{0.625}$ (massive stars are hotter)
- $\tau \propto M/L \propto M^{-2.5}$ (massive stars don't live as long)

HERTZSPRUNG-RUSSELL DIAGRAM



WHERE DO BABY STARS COME FROM?

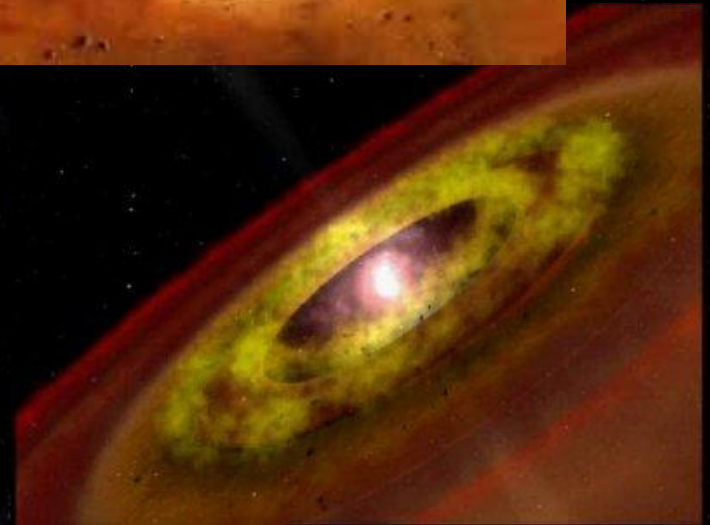


<http://apod.nasa.gov/apod/ap100919.html>
<http://apod.nasa.gov/apod/ap130324.html>

- Clouds of gas and dust supported by gas pressure, radiate and cool
- Cold clouds are “gravitationally unstable”, will begin to collapse under gravity
- Collapse of a cloud continues until it become dense enough to begin heating → forms a **protostar**

WHERE DO BABY STARS COME FROM?

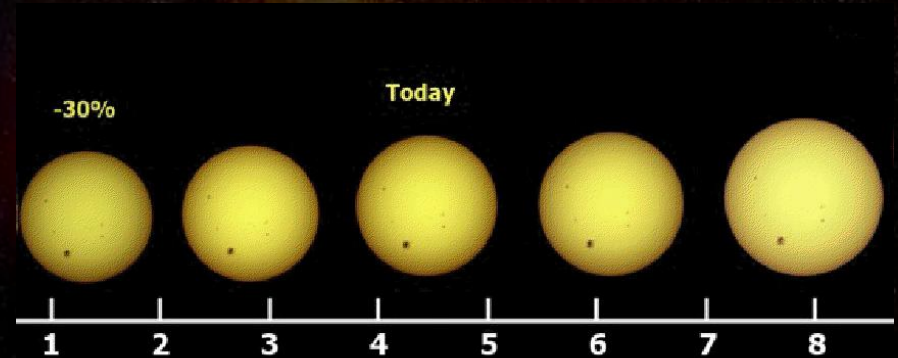
- Protostar accretes material still collapsing due to gravity
- Eventually protostar becomes massive and luminous enough to blow away infalling material → forms a pre-main sequence star
- Pressure balances gravity, but no fusion, so star contracts until its centre ignites fusion



THE MAIN SEQUENCE

- For Sun-like star, core hydrogen burning goes on for 10 Gyr (other star lifetimes scale like $(M/M_{\odot})^{-2.5}$)
- During this time, star is stable (expands and heats slightly)
- This allows planets reasonably stable conditions, essential for development of life

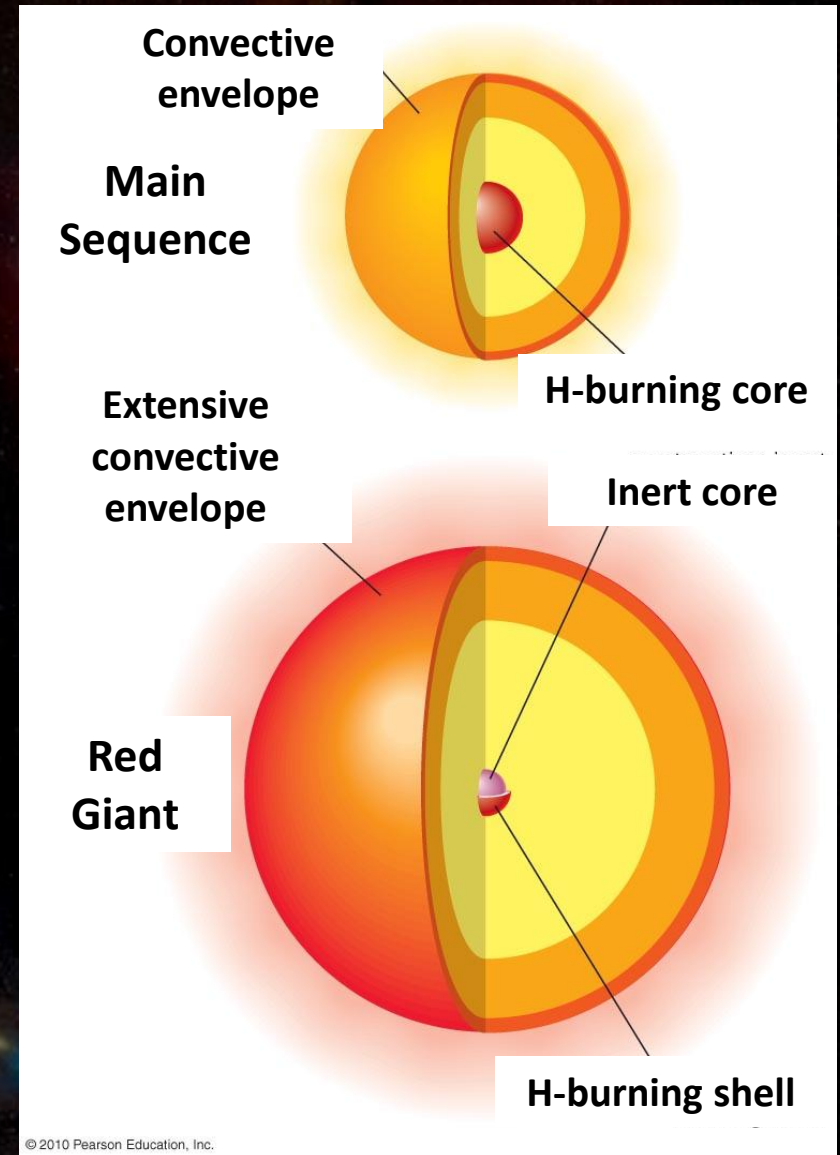
Wu 2011



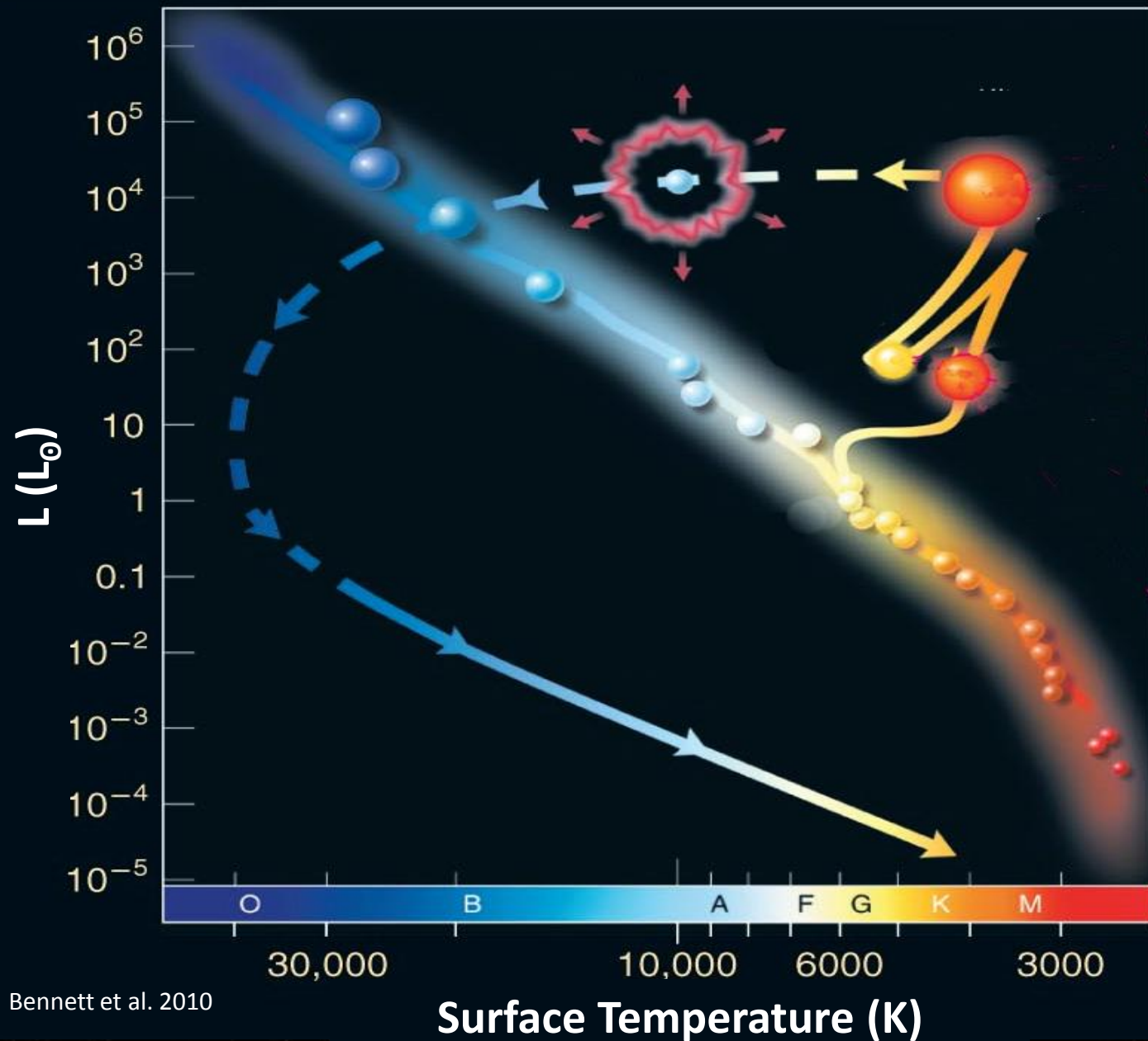
<http://en.wikipedia.org/wiki/Life>

THE END OF THE MAIN SEQUENCE

- Core hydrogen will run out (it's being fused)
- Result: star's core either collapses or contracts until helium fusion ("triple- α " process) can begin
- During collapse/contraction, H-burning continues in shell, and luminosity goes up several orders of magnitude
- Stellar envelope expands and cools; star becomes a **red giant**

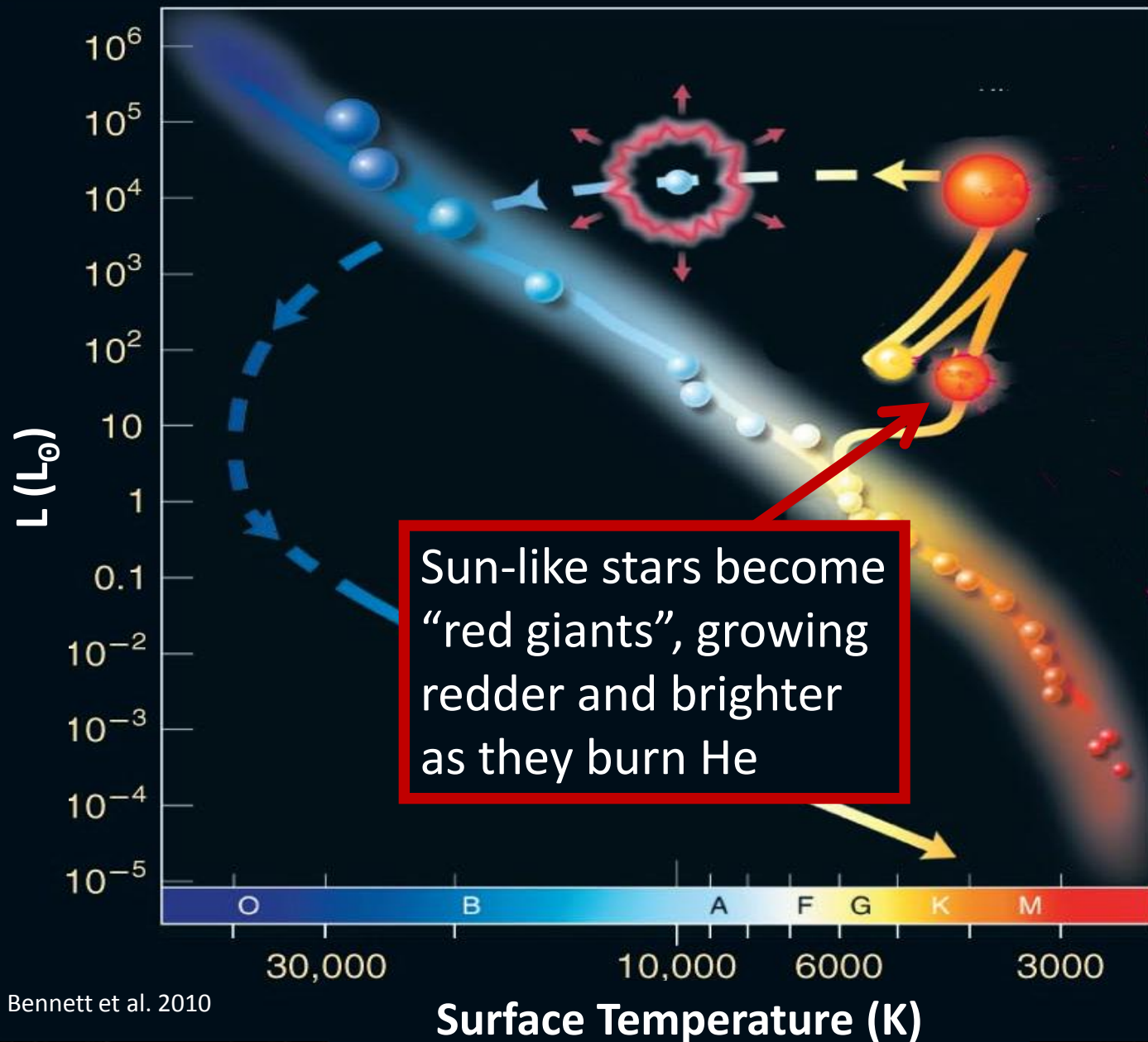


THE END TIMES FOR OUR SUN

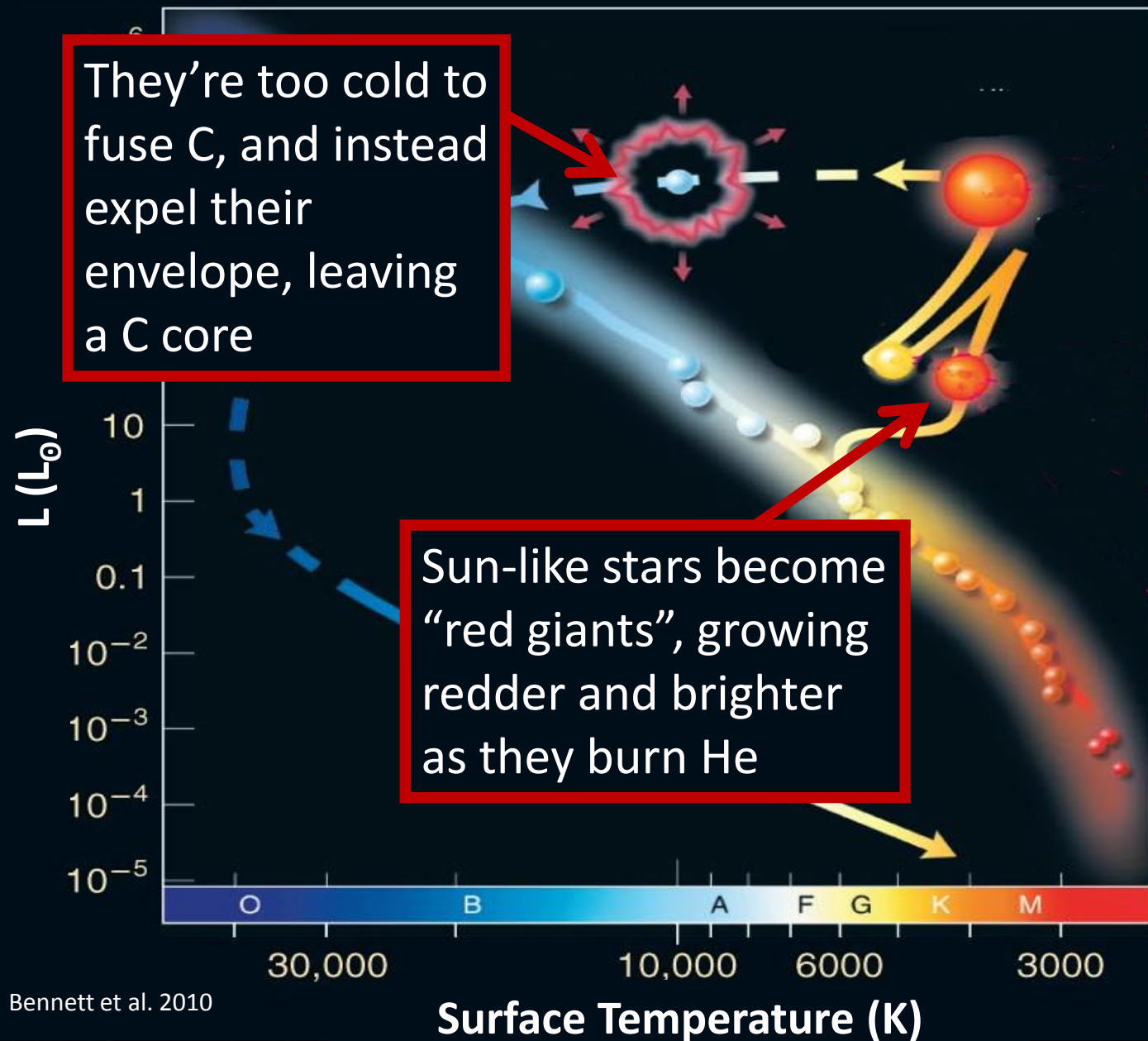


Bennett et al. 2010

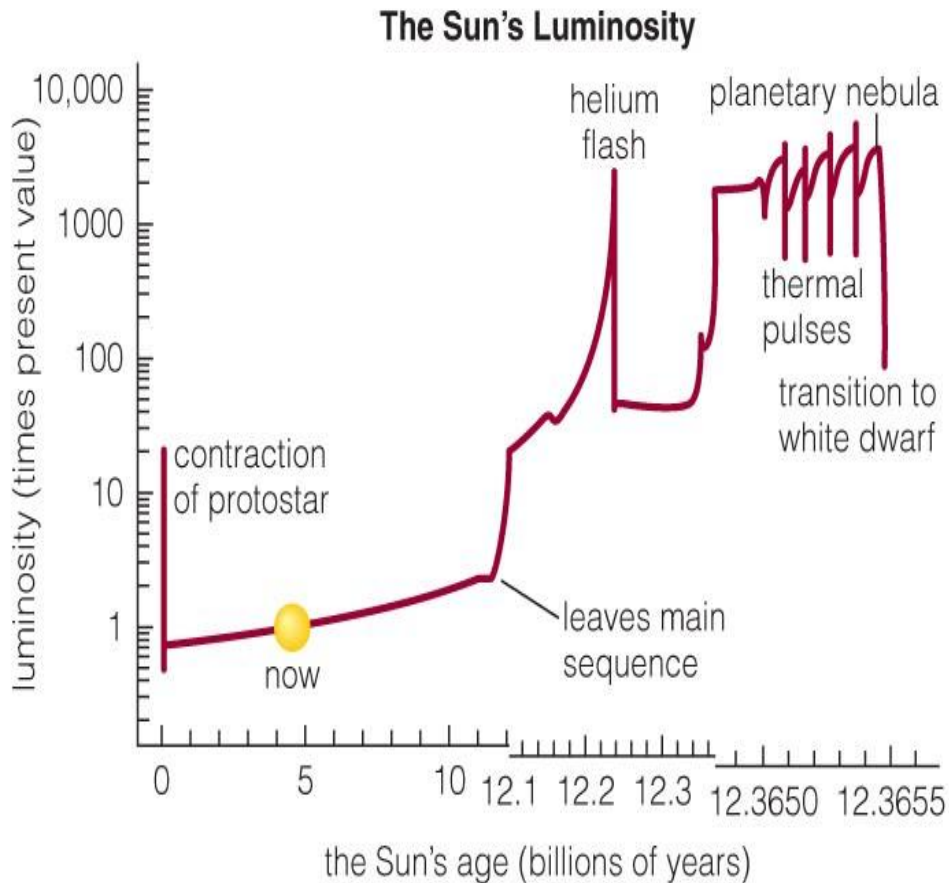
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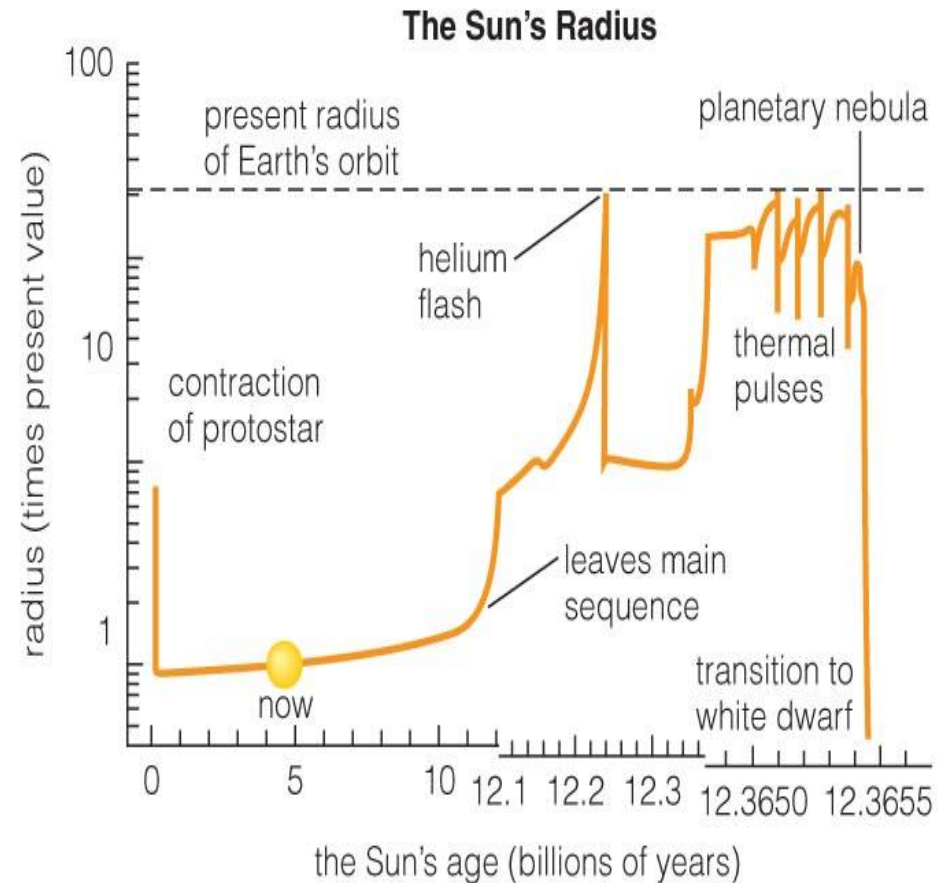
THE END TIMES FOR OUR SUN



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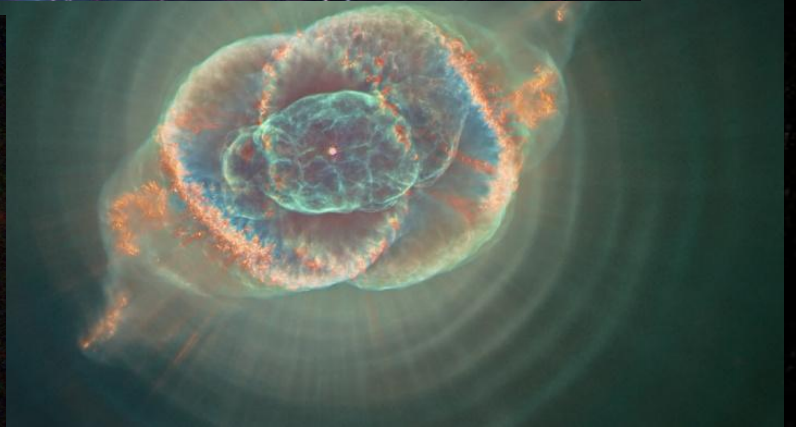
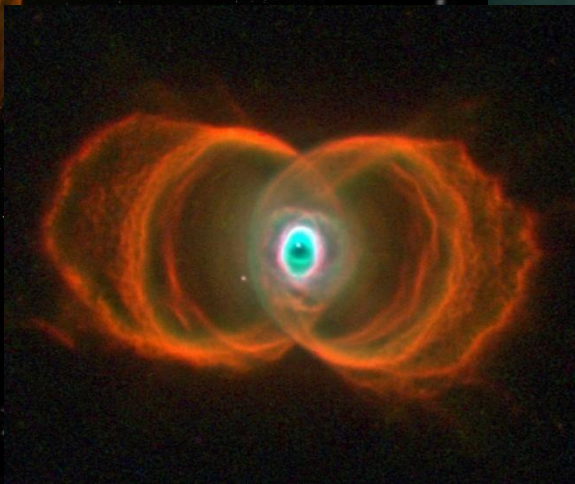


a Changes in the Sun's luminosity over time.

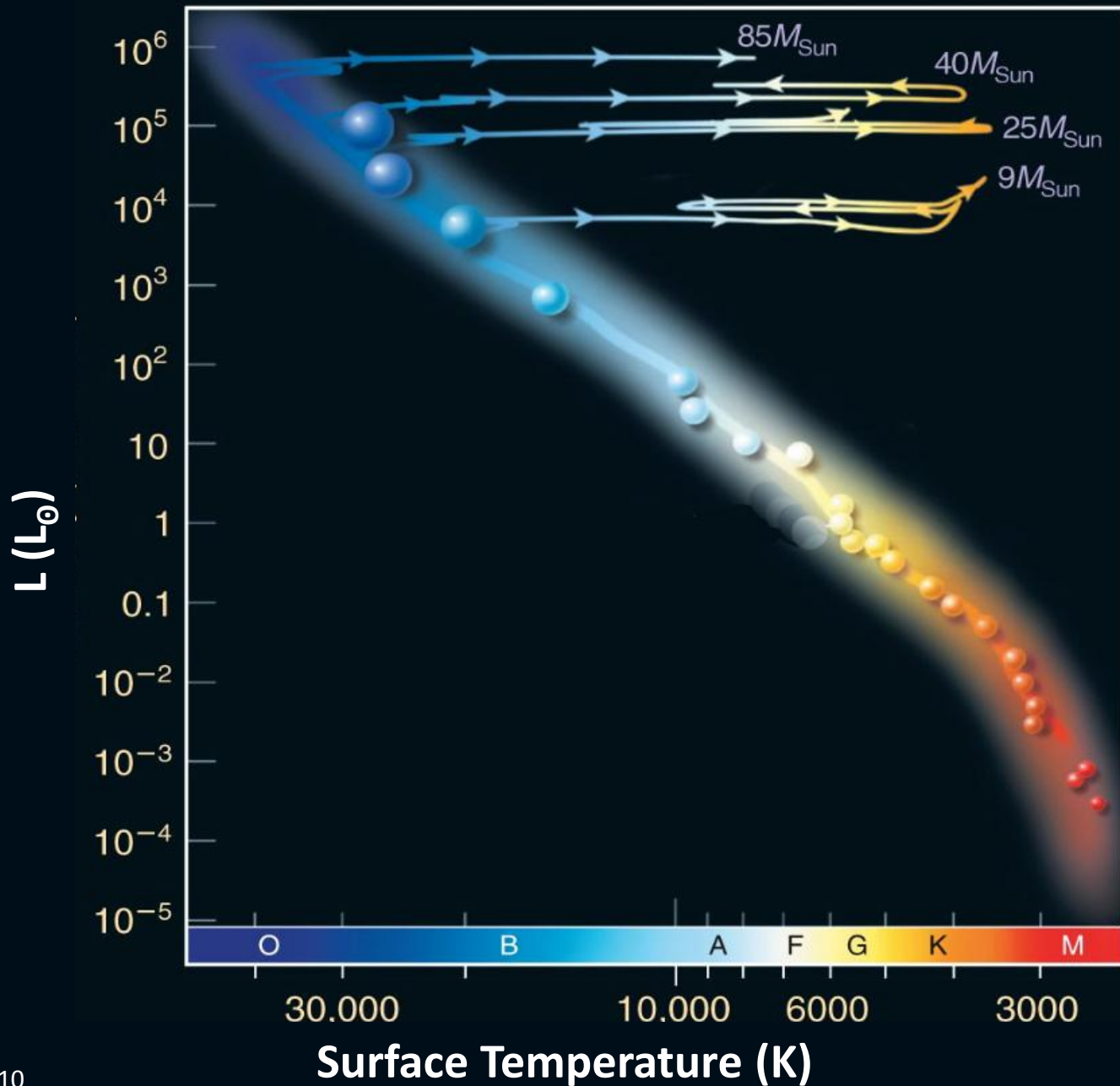


b Changes in the Sun's radius over time.

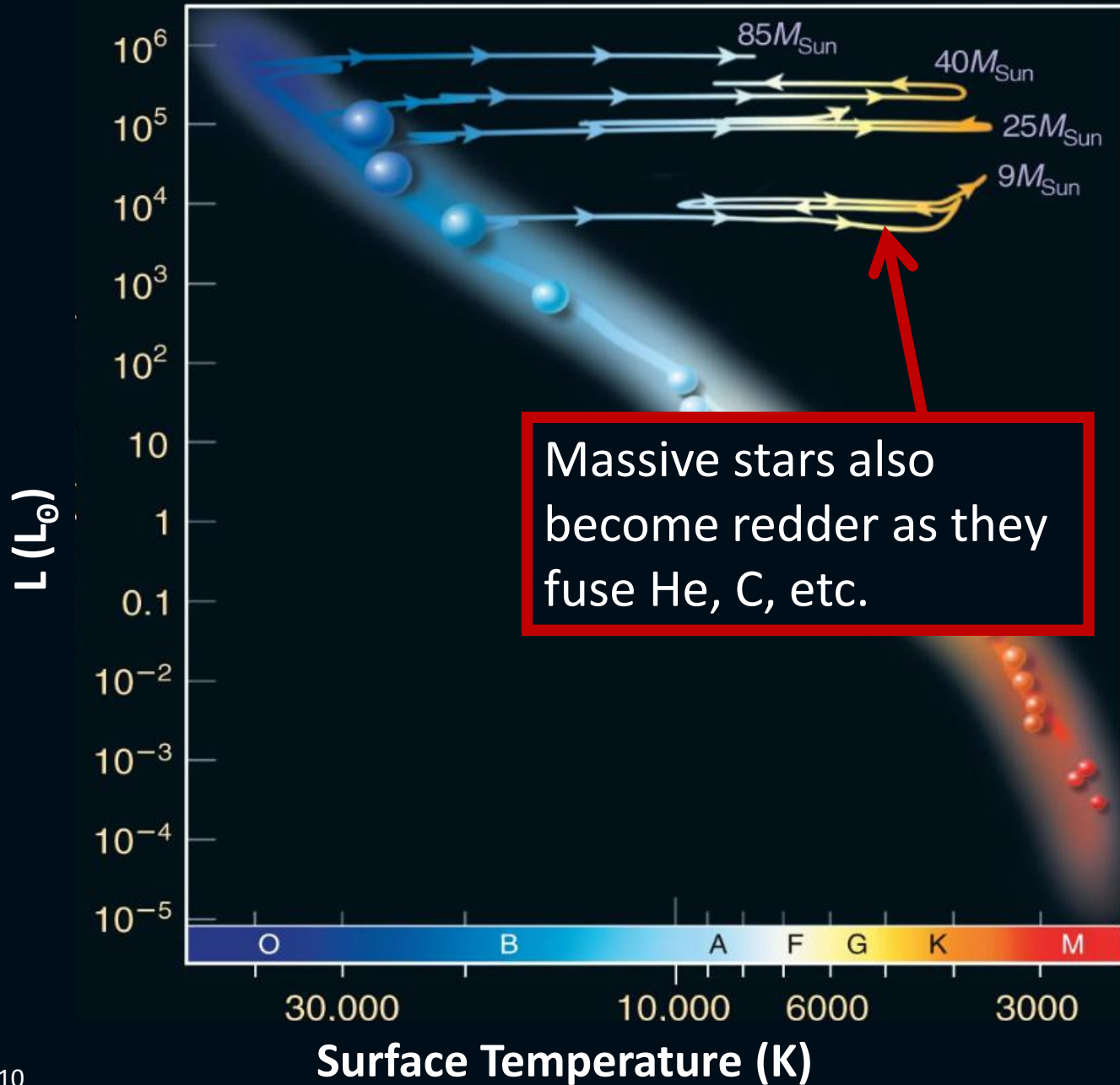
THE END TIMES FOR OUR SUN



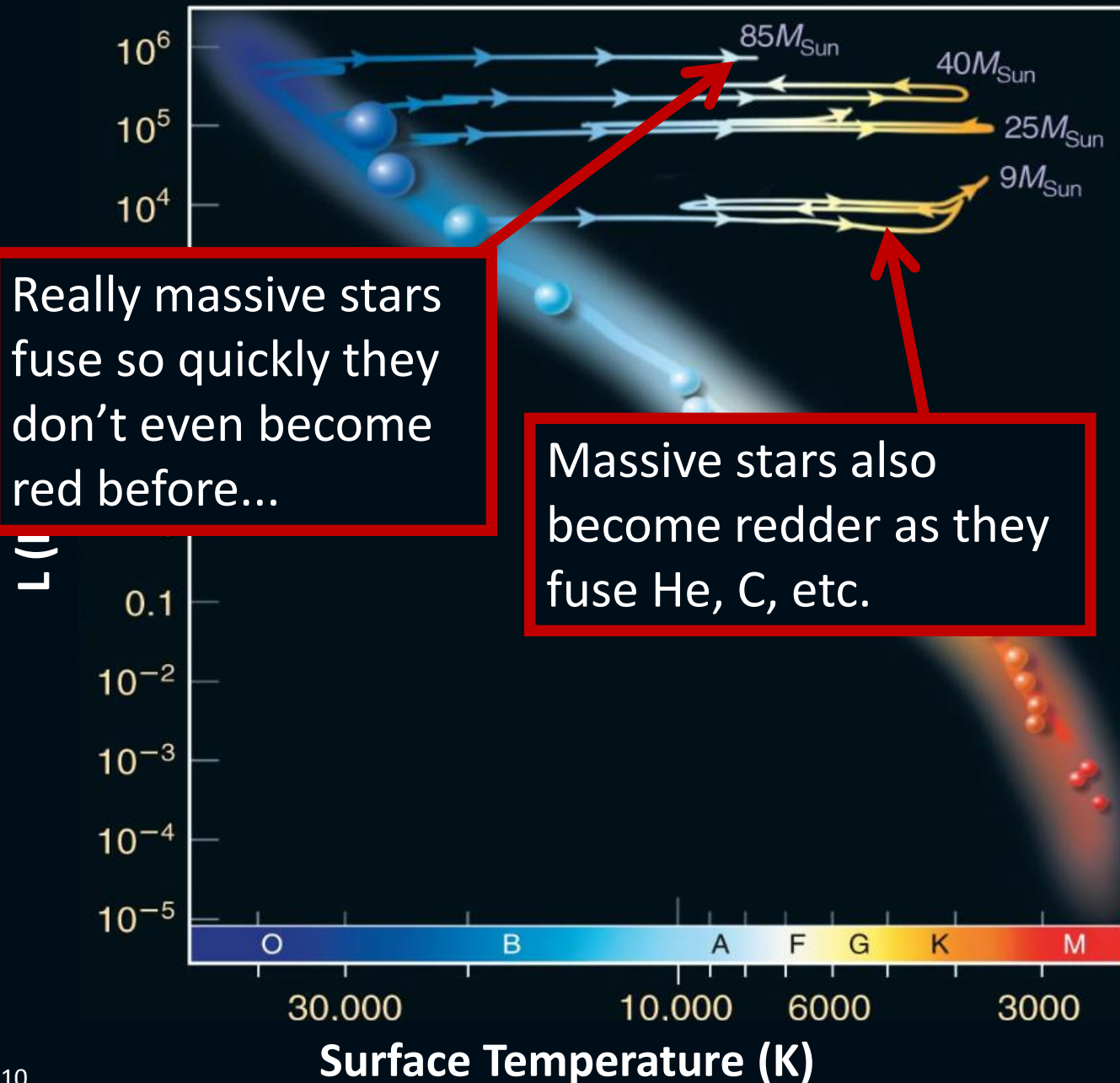
THE END TIMES FOR MASSIVE STARS



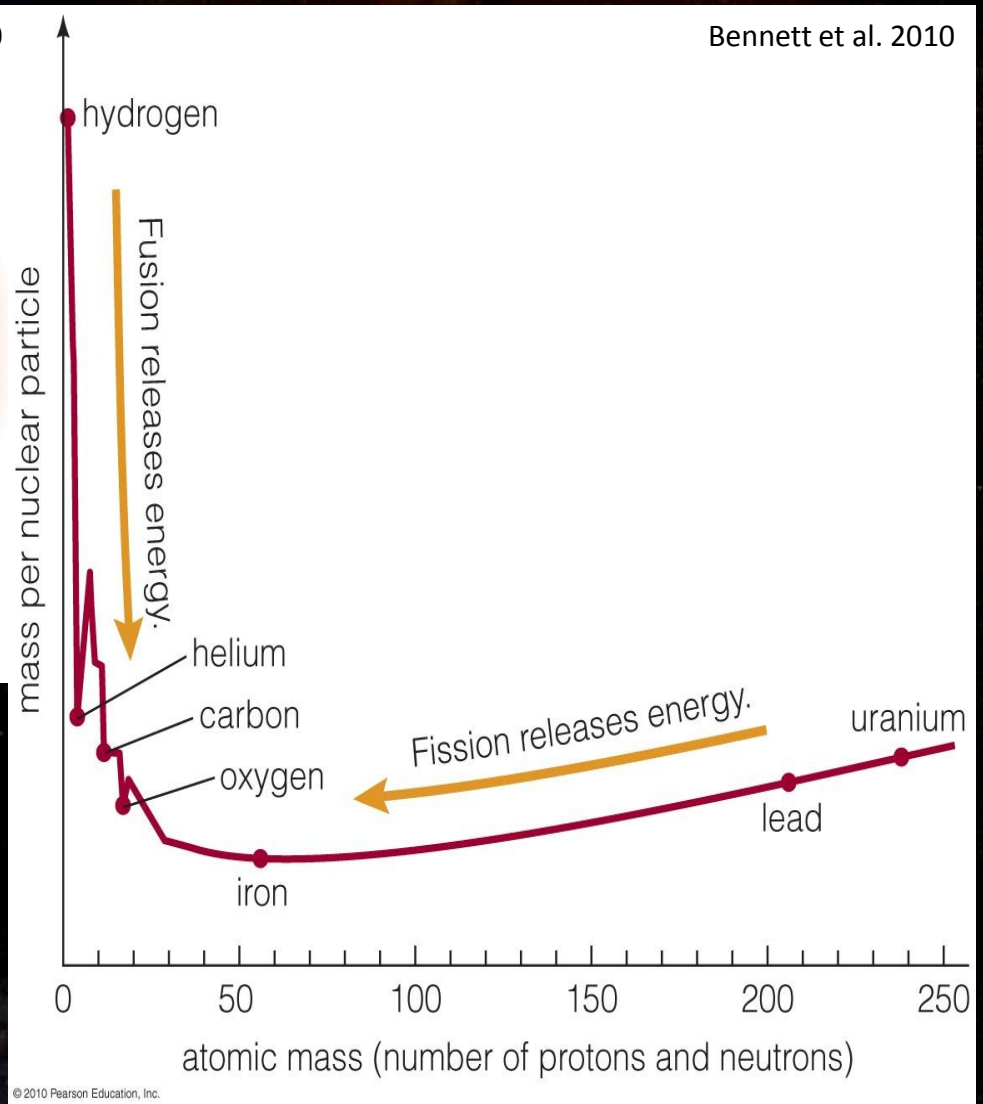
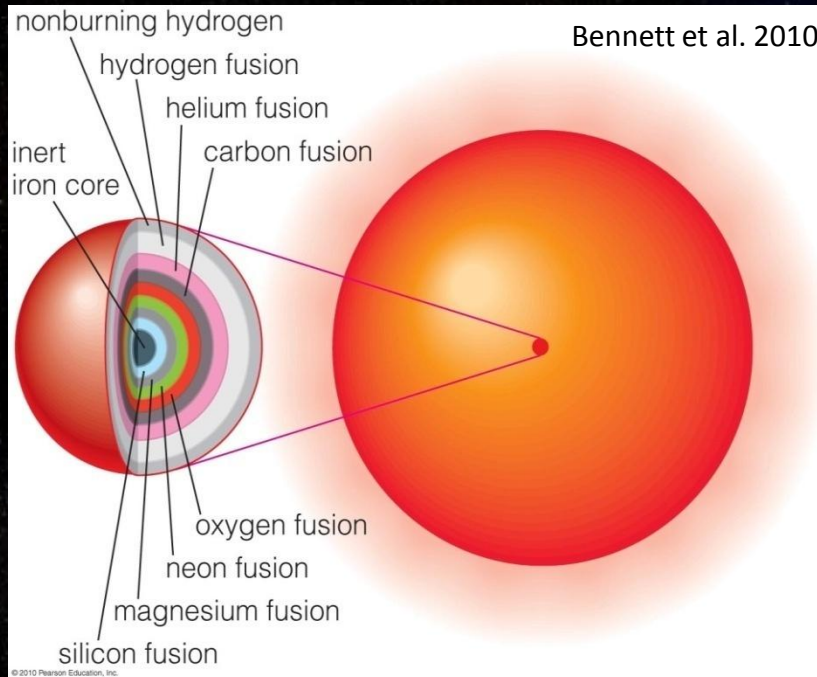
THE END TIMES FOR MASSIVE STARS



THE END TIMES FOR MASSIVE STARS



CORE COLLAPSE SUPERNOVAE



- Eventually $M > \sim 10 M_{\odot}$ stars have multilayered “onion” structure with iron in centre
- Iron fusion is net energy decrease
- Result is catastrophic collapse: “core collapse” supernovae

CORE COLLAPSE SUPERNOVAE

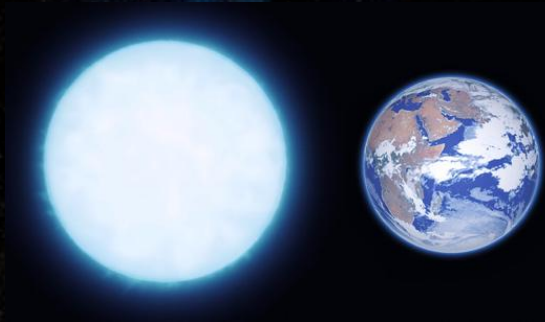


SN 1987a

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THE STELLAR GRAVEYARD

$M < \sim 10 M_{\odot}$ Stars



http://www.bbc.co.uk/schools/gcsebitesize/science/edexcel_pre_2011/space/theoriginsoftheuniverserev3.shtml

- White dwarf
 - Carbon-oxygen
 - Earth-sized
 - Electron degeneracy
 - Inert

$\sim 10 M_{\odot} < M < \sim 25 M_{\odot}$
Stars



http://www.msnbc.msn.com/id/38757238/ns/technology_and_science-space/t/massive-mega-star-challenges-black-hole-theories/

- Neutron stars
 - Neutrons
 - City-sized
 - Neutron degeneracy
 - May emit pulses

$M > \sim 25 M_{\odot}$ Stars



<http://www.nasa.gov/audience/forstudents/k-4/stories/what-is-a-black-hole-k4.html>

- (Stellar) black holes
 - Singularity
 - City-sized
 - Gravity wins
 - Doesn't emit anything

SUMMARY

- Stars balance gravity with gas pressure, which requires high temperatures – these temperatures cause fusion, giving stars the energy they need
- In hydrogen-burning stars fusion occurs (depending on mass) primarily by the proton-proton chain or CNO cycle
- Stars form out of large, cold clouds of gas and dust that get smaller until hydrogen fusion begins
- While burning hydrogen, stars lie on a line called the “Main Sequence” in the Hertzsprung-Russell diagram
- When their cores run out of hydrogen, stars move off main sequence
- Sun-like stars become much redder and much more luminous when they leave the main sequence. Eventually they shed their outer layers and form white dwarfs
- Massive stars become redder and somewhat more luminous. They die in supernovae and become neutron stars or black holes