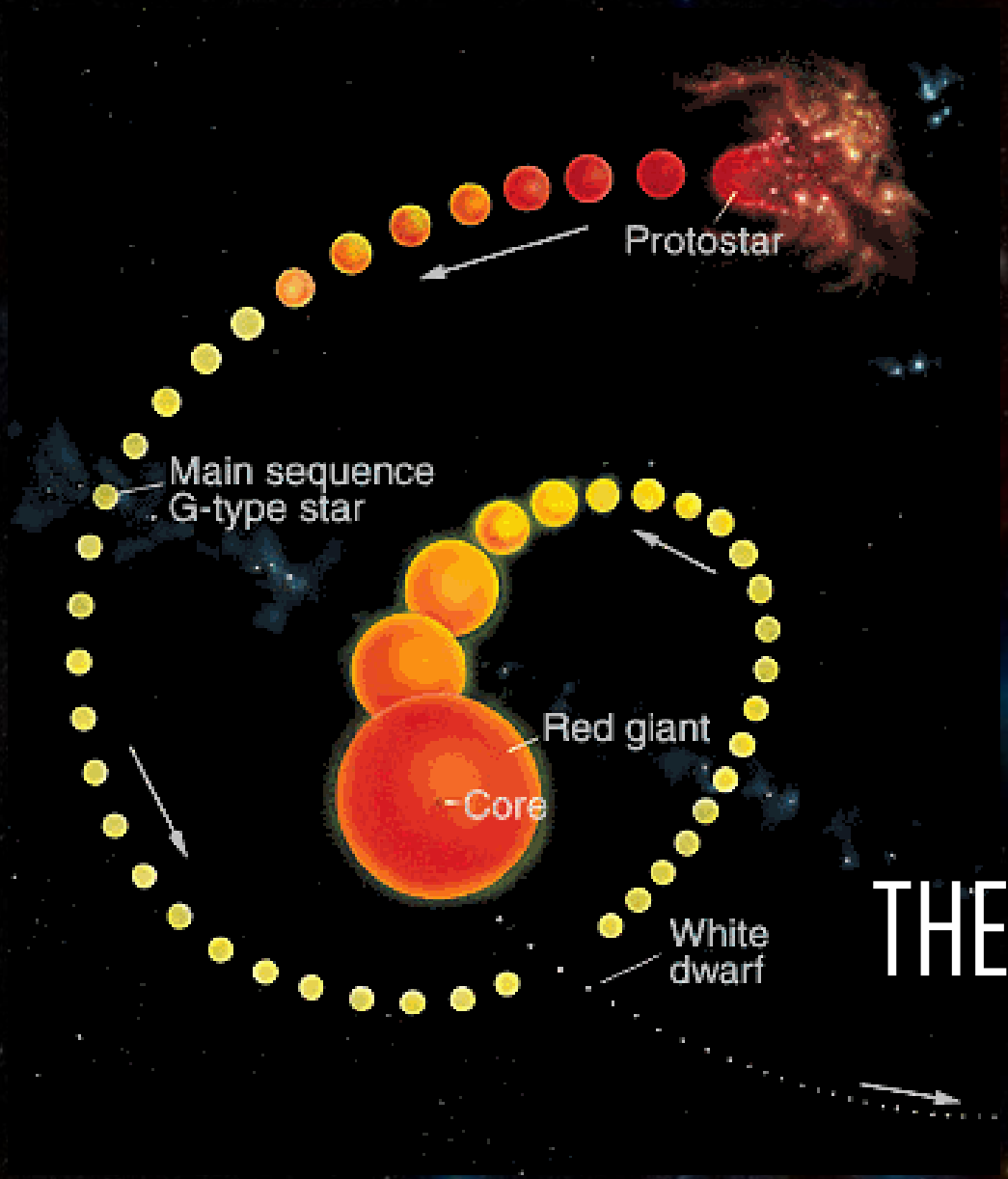


THE LIVES OF STARS

CHARLES ZHU

AST 121 – 4/3/2013

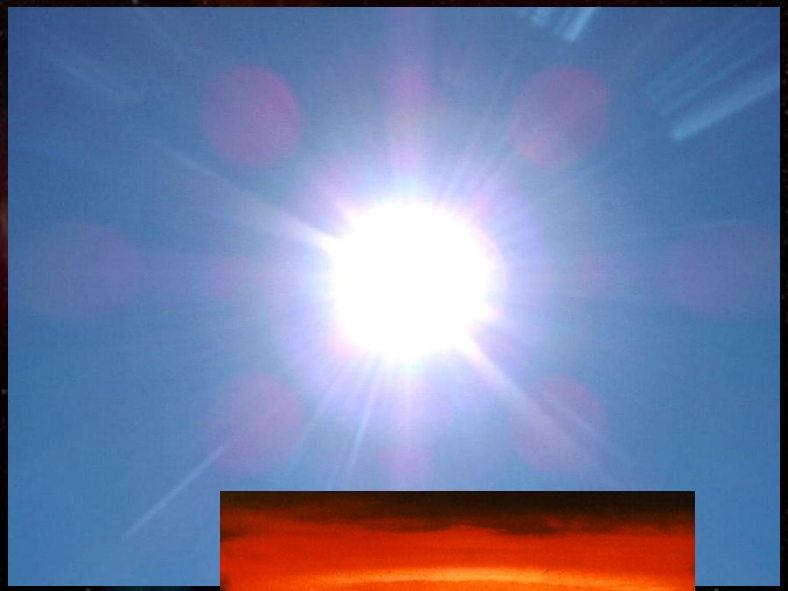
WHAT IS A STAR?

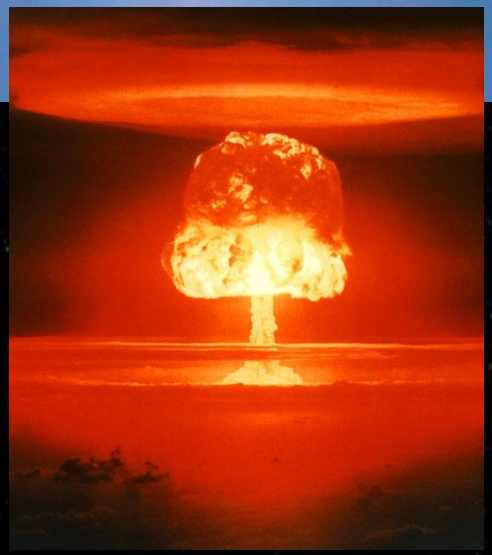
- Massive, luminous, self-gravitating sphere that generates energy through nuclear fusion

- If stars have nuclear fusion, why don't they explode like hydrogen bombs?

- Alternatively, why doesn't everything immediately collapse into a black hole?

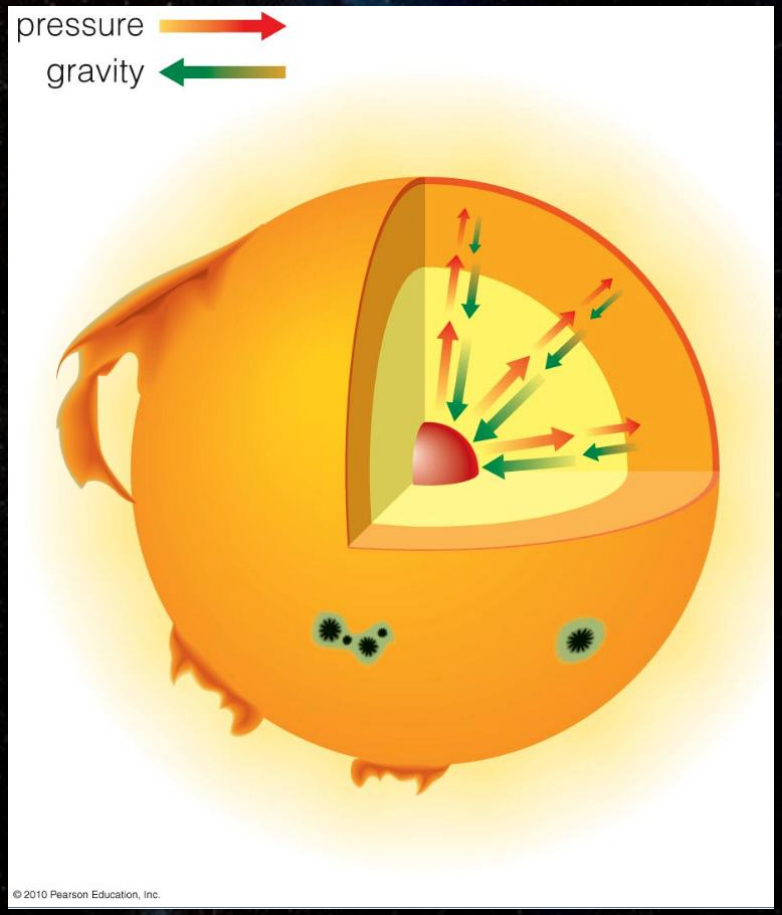
http://en.wikipedia.org/wiki/Star





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!): electrostatic forces
  - 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

[1] Stealing the title from Marten van Kerkwijk

MEANS OF FUSION

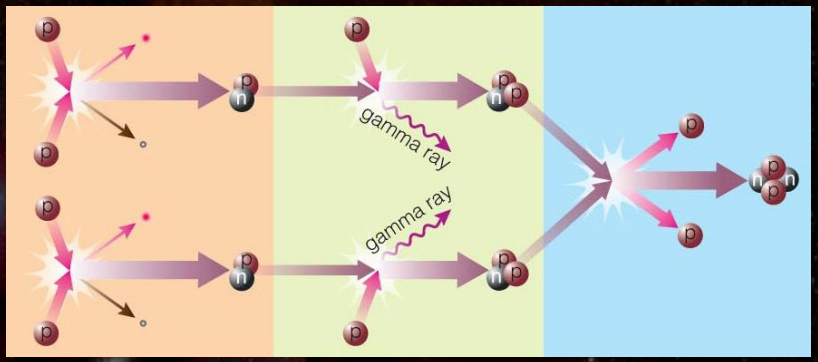
- Reaction:

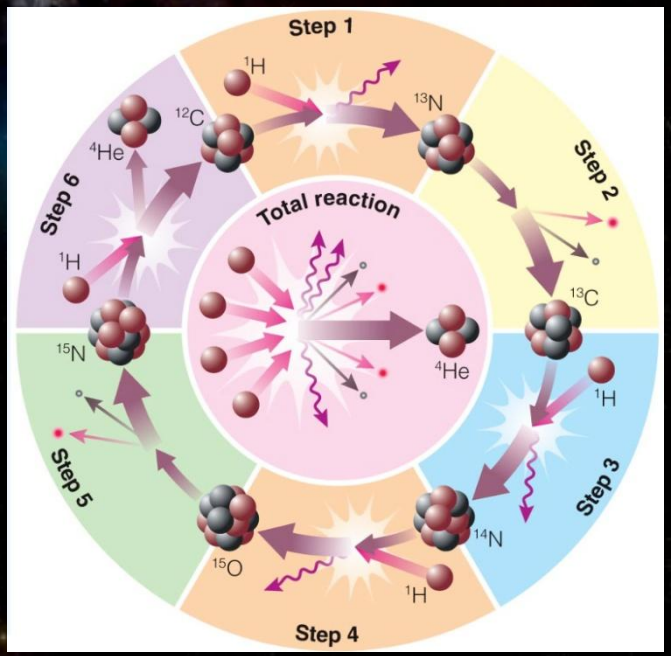
$$4\,{}^{1}_{1}H \rightarrow {}^{4}_{2}He + 2e^{+} + 2\nu_e + 2\gamma \quad (26.9\,\mathrm{MeV})$$

- Energy generation:

$$E = (\Delta m)c^2 = (m_{4He} - 4m_H)c^2 = fm_Hc^2$$

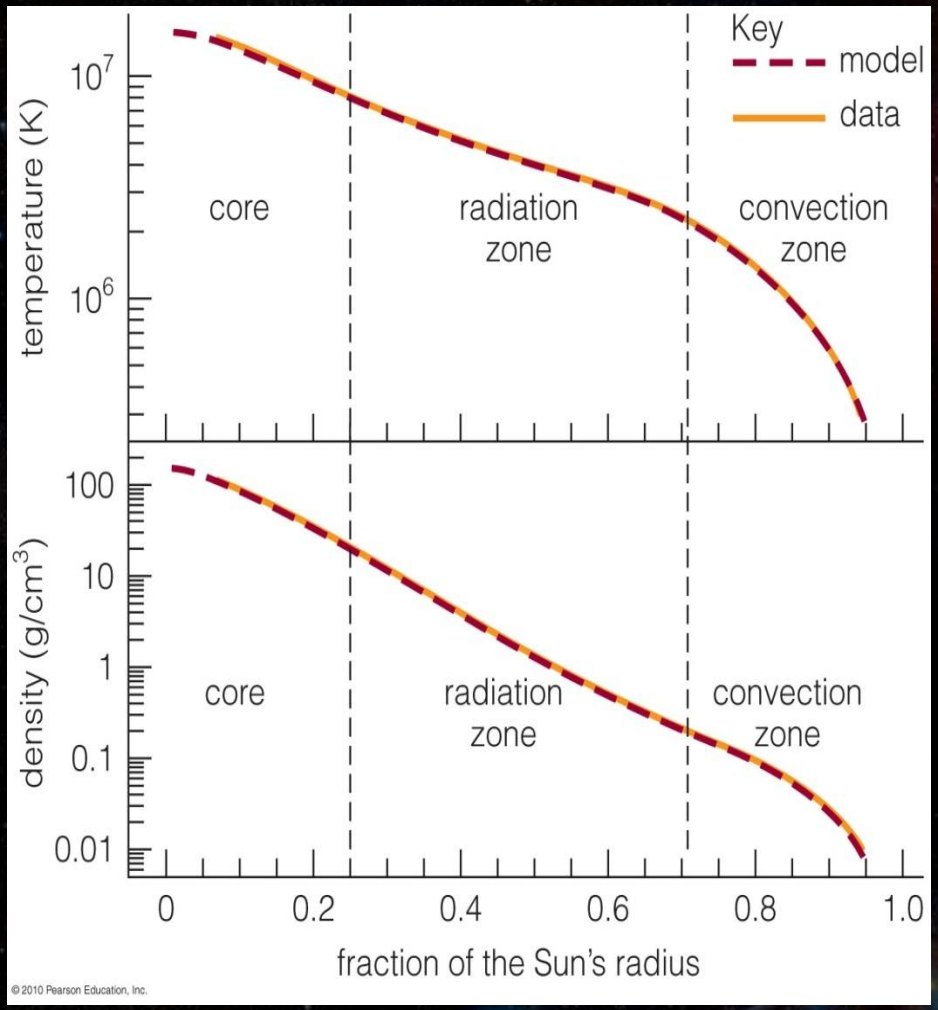
- Proton-proton (p-p) chain:
  - Can occur in pure H environment
  - Dominates for M < $1.3M_{\odot}$
- Carbon/nitrogen/oxygen (CNO) cycle:
  - Uses ^{12}C, ^{14}N and ^{16}O as catalysts
  - Dominates for M > $1.3M_{\odot}$





Bennett et al. 2010

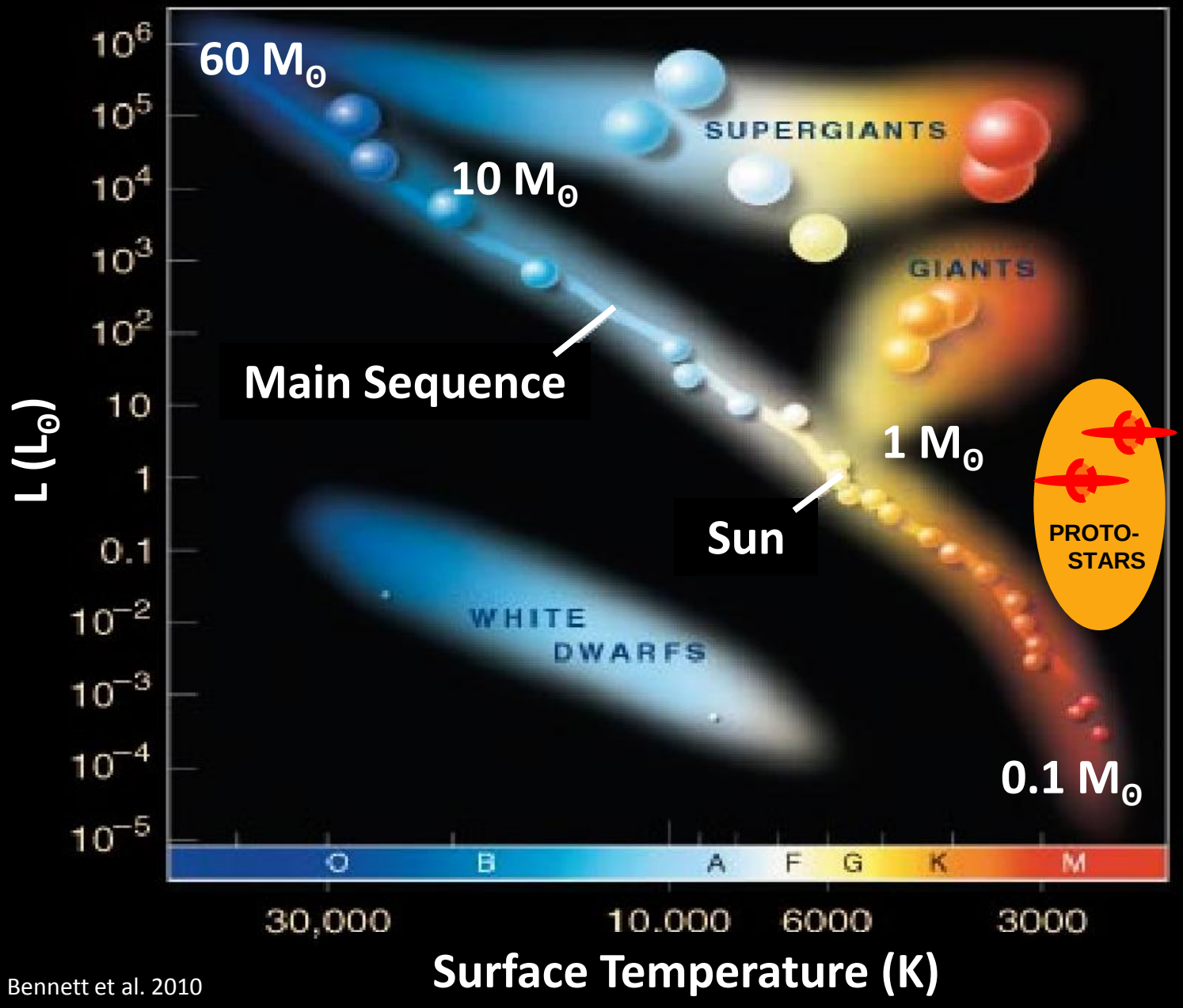
STELLAR STRUCTURE



Bennett et al. 2010

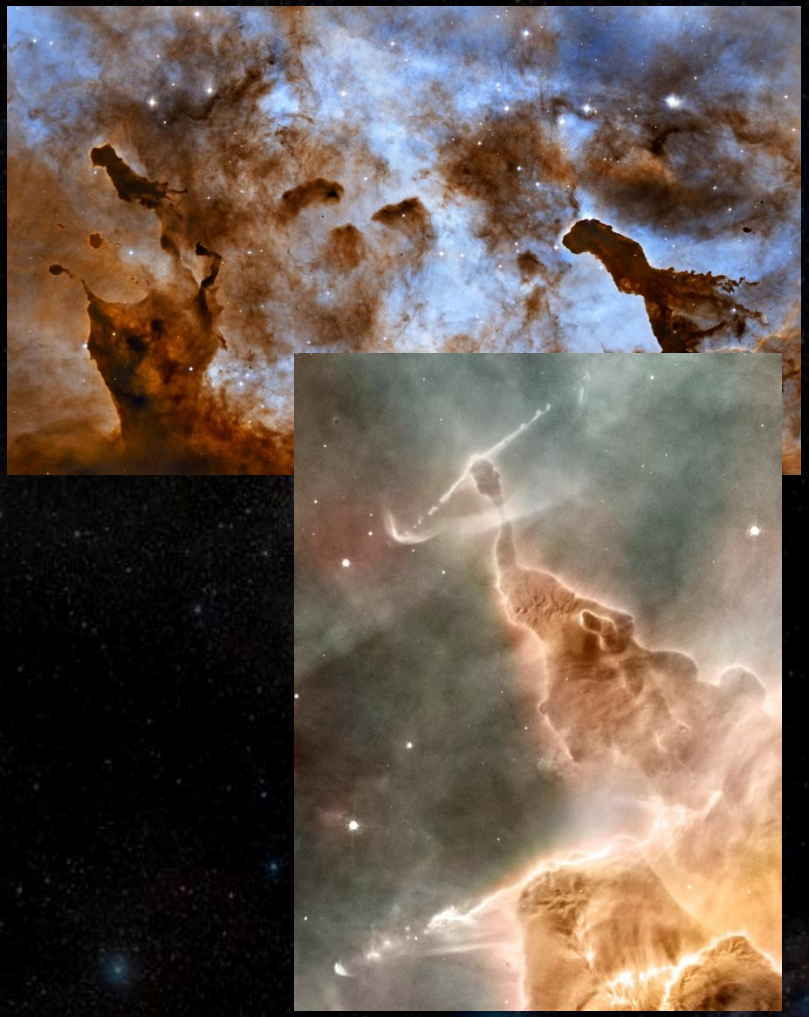
- Can use the equations of hydrostatic equilibrium, temperature, energy transport (includes opacity) and gas equation of state to determine stellar structure
- Observations done using surface observations, neutrinos, asteroseismology

HERTZSPRUNG-RUSSELL (HR) DIAGRAM



Bennett et al. 2010

WHERE DO BABY STARS COME FROM?



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

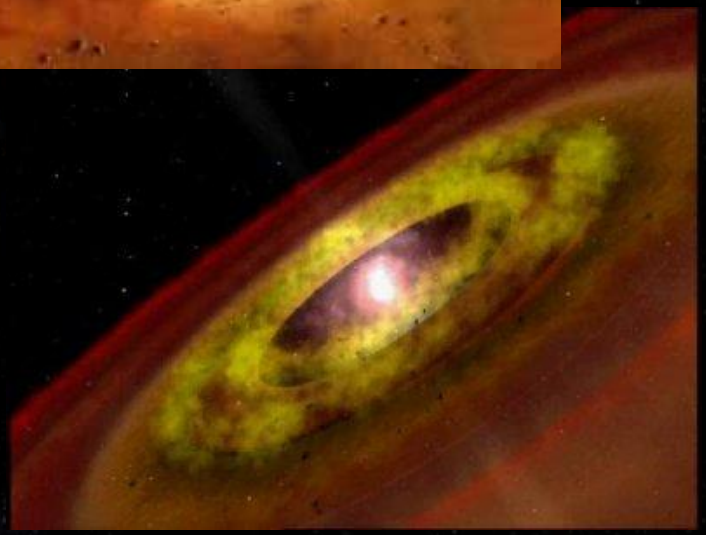
- Clouds of gas and dust supported by gas pressure, magnetic fields, turbulence
- Cold clouds become "gravitationally unstable", will begin to collapse under gravity
- Collapse of a cloud continues until it become dense enough to begin heating → forms a protostar

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 → a pre-main sequence star

- Pressure balances gravity, but no fusion, so star contracts until its centre ignites fusion



http://www.daviddarling.info/encyclopedia/P/protostar.html
http://en.wikipedia.org/wiki/T_Tauri_star

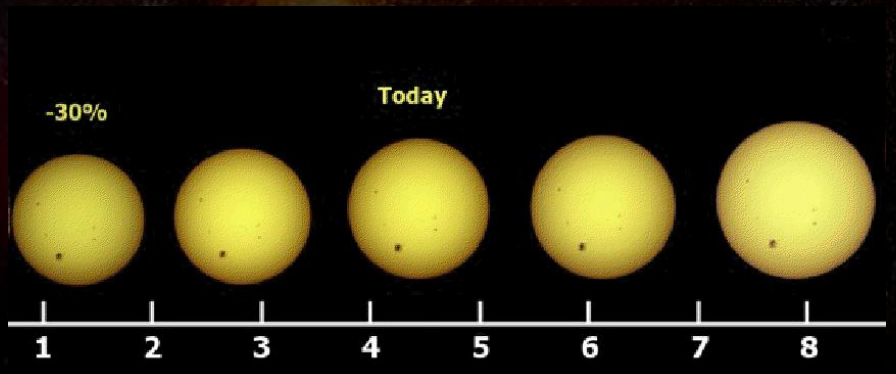
THE MAIN SEQUENCE

- For Sun-like star, core hydrogen burning goes on for 10 Gyr (other star lifetimes scale like $(M/M_0)^{-2.5}$)

- During this time, star is stable (expands and heats slightly)

- This allows planets reasonably stable conditions, essential for development of life

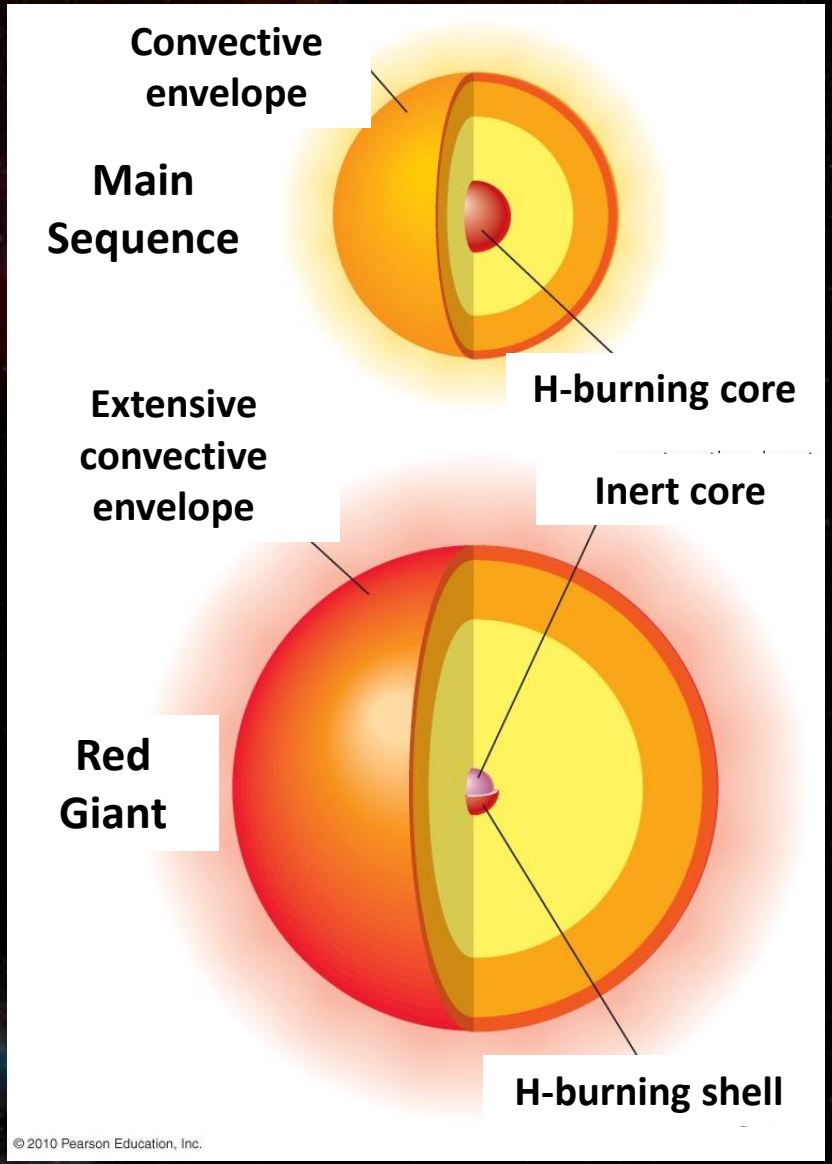
Wu 2011



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

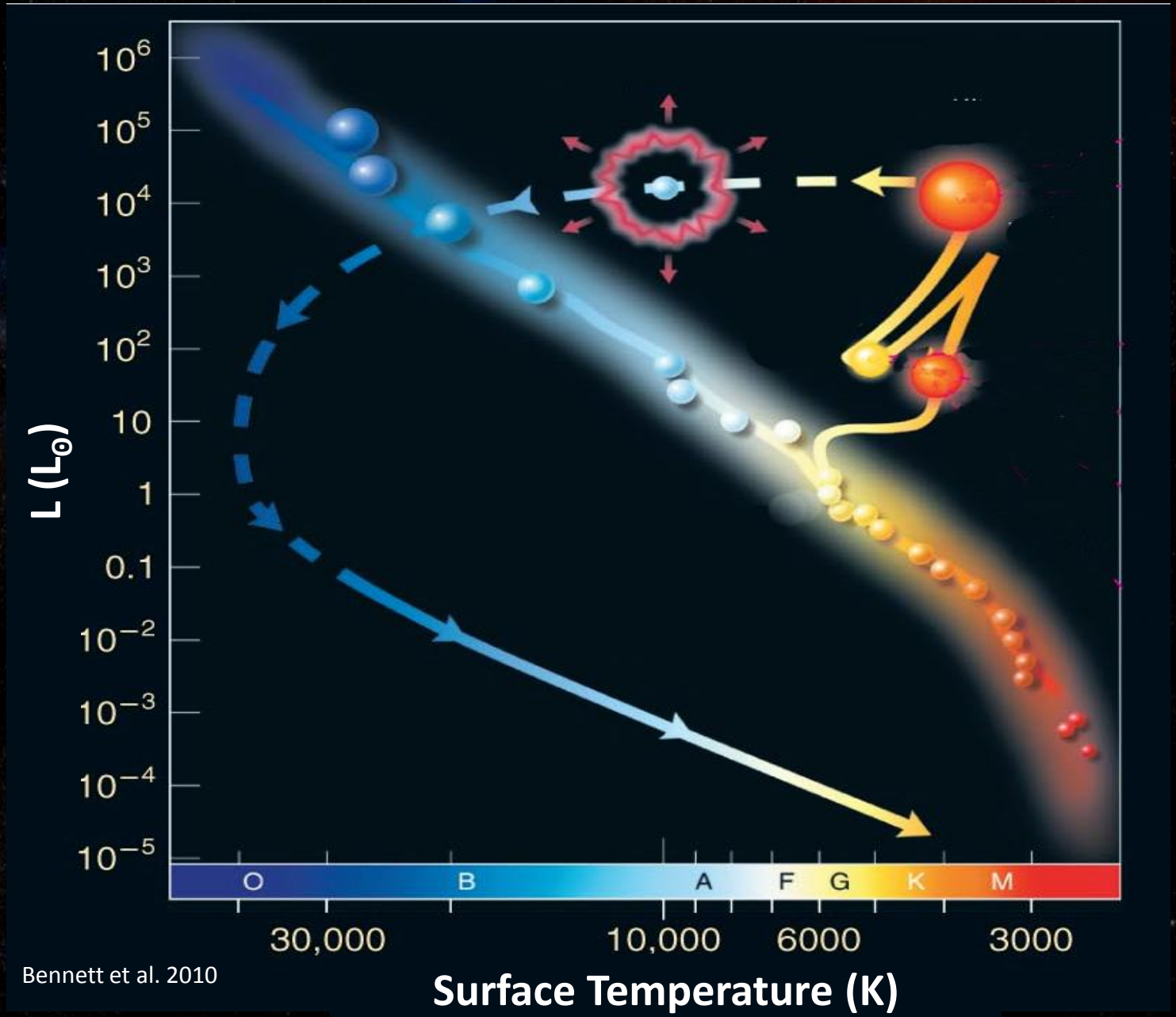
THE END OF THE MAIN SEQUENCE

- 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



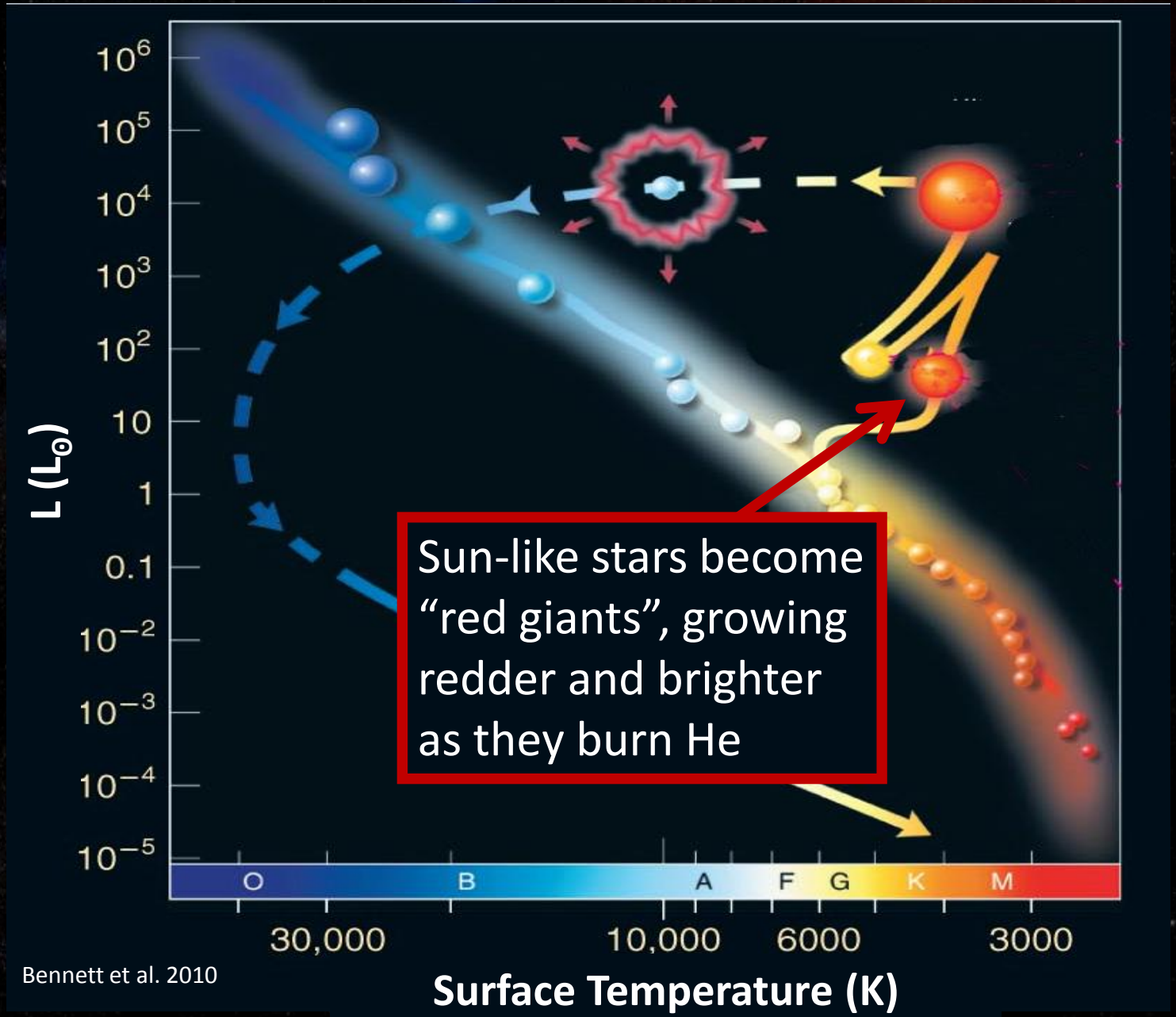
Bennett et al. 2010

THE END TIMES FOR OUR SUN



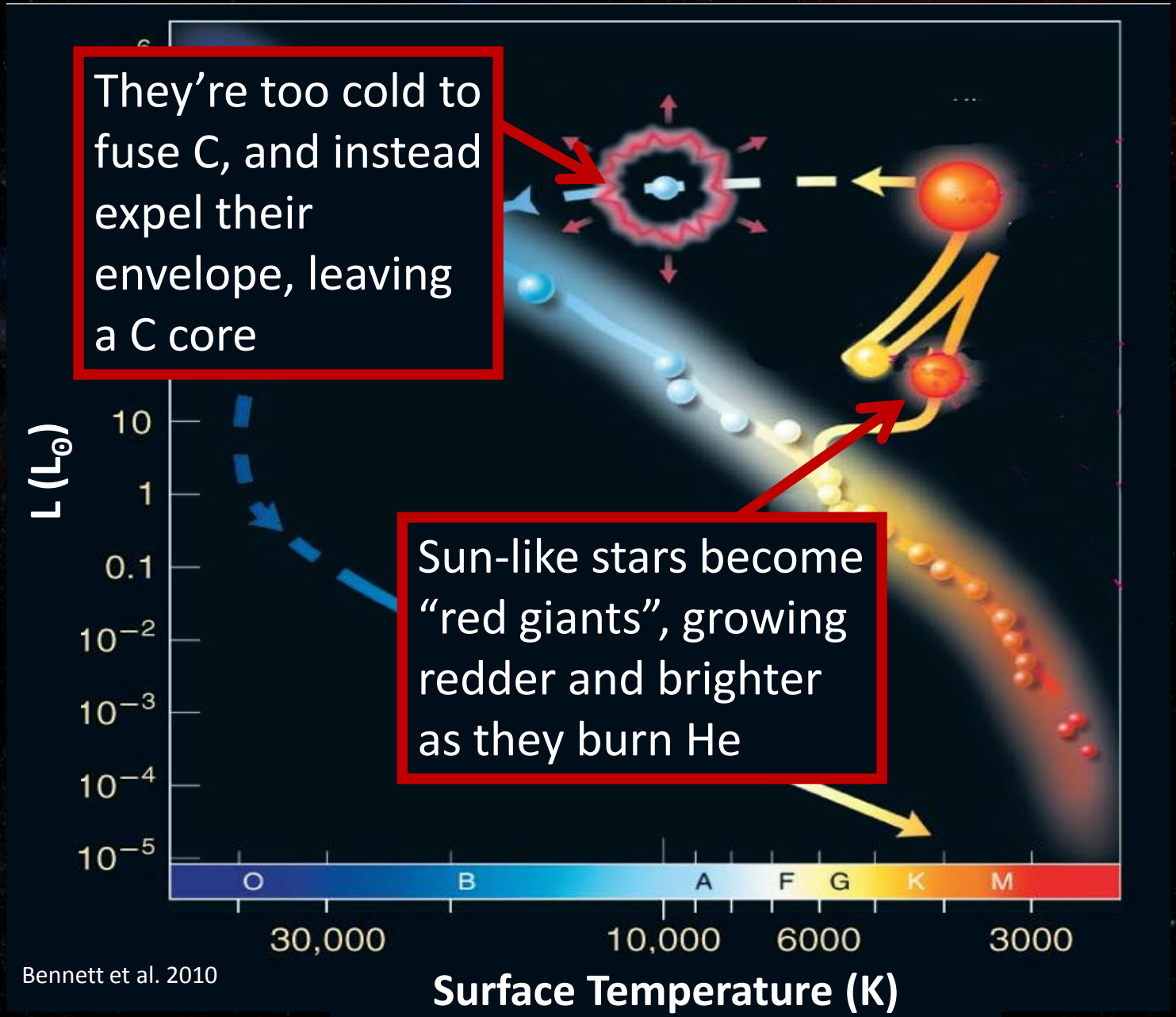
Bennett et al. 2010

THE END TIMES FOR OUR SUN

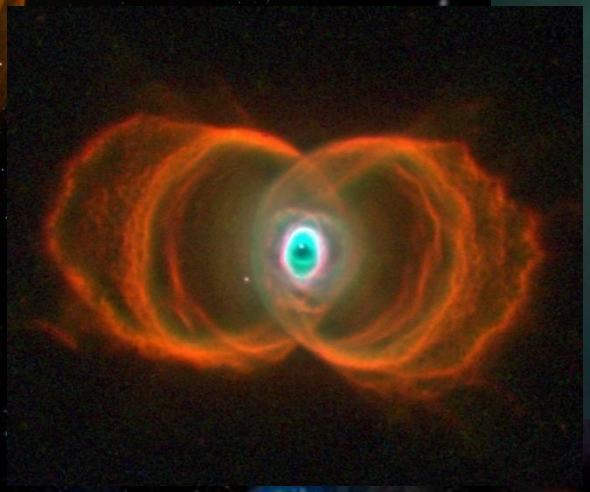


Bennett et al. 2010

THE END TIMES FOR OUR SUN

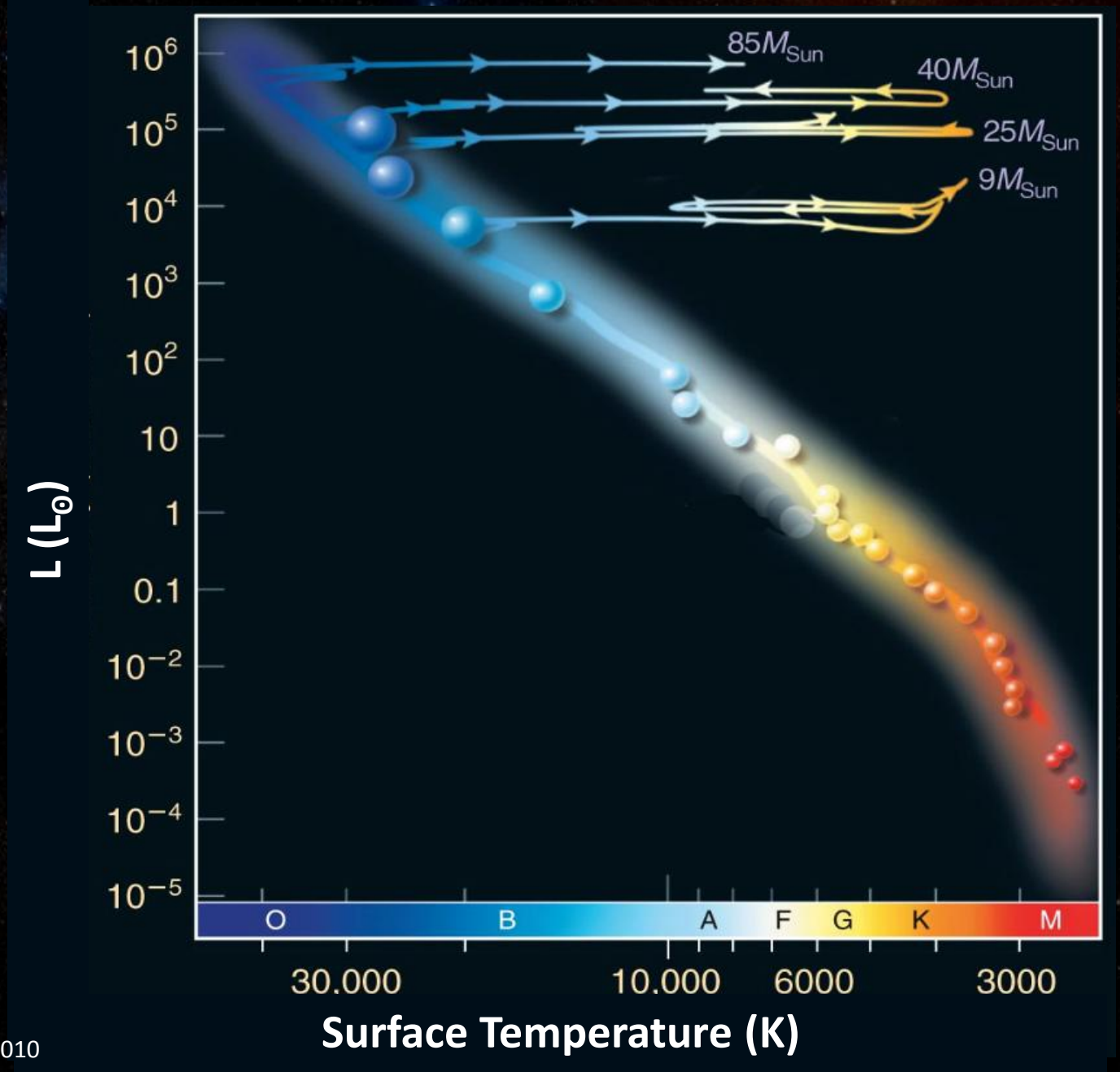


THE END TIMES FOR OUR SUN



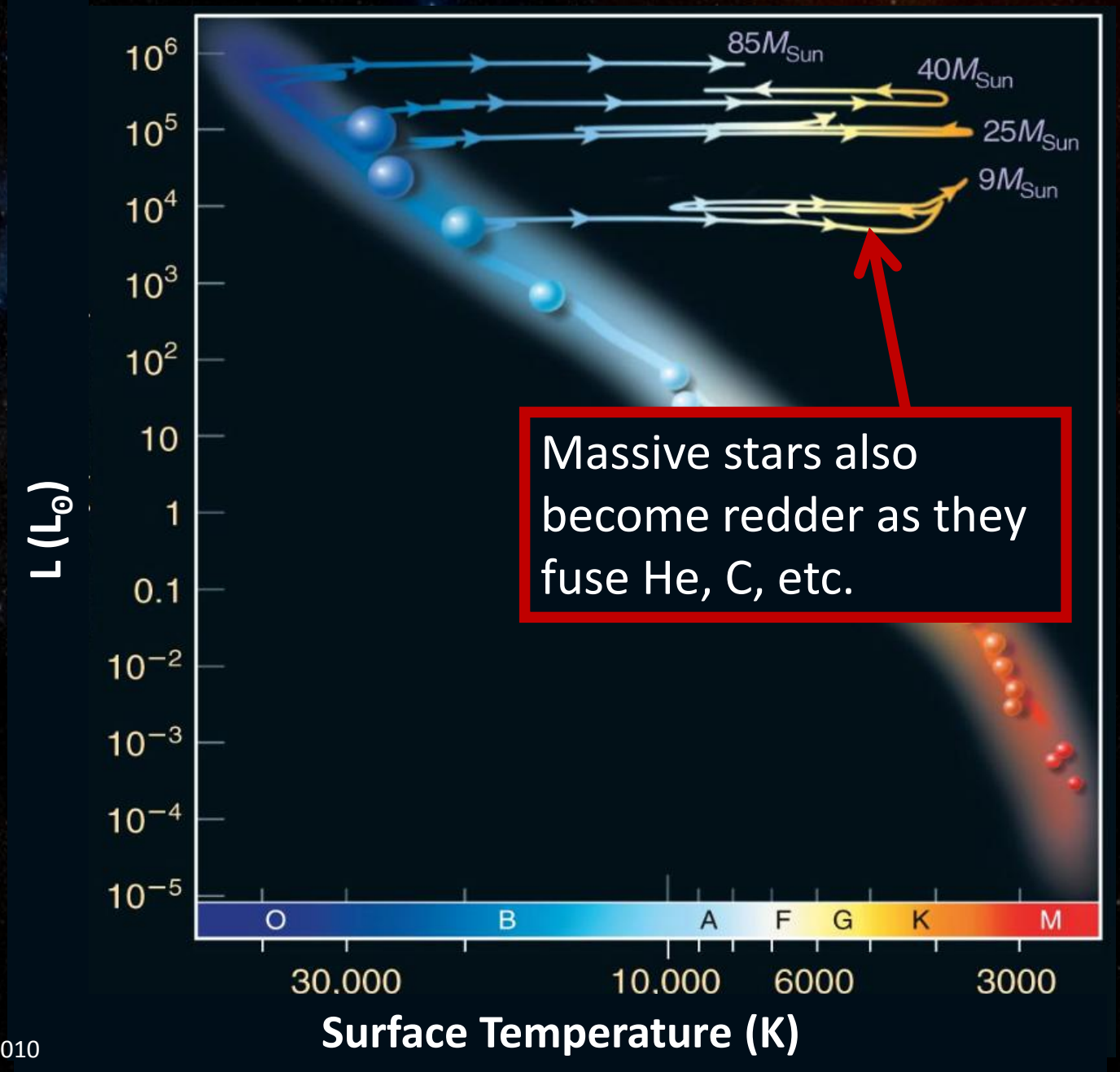
http://apod.nasa.gov/apod/ap090910.html, http://apod.nasa.gov/apod/ap111227.html,
http://apod.nasa.gov/apod/ap110807.html, http://apod.nasa.gov/apod/ap080322.html

THE END TIMES FOR MASSIVE STARS



Bennett et al. 2010

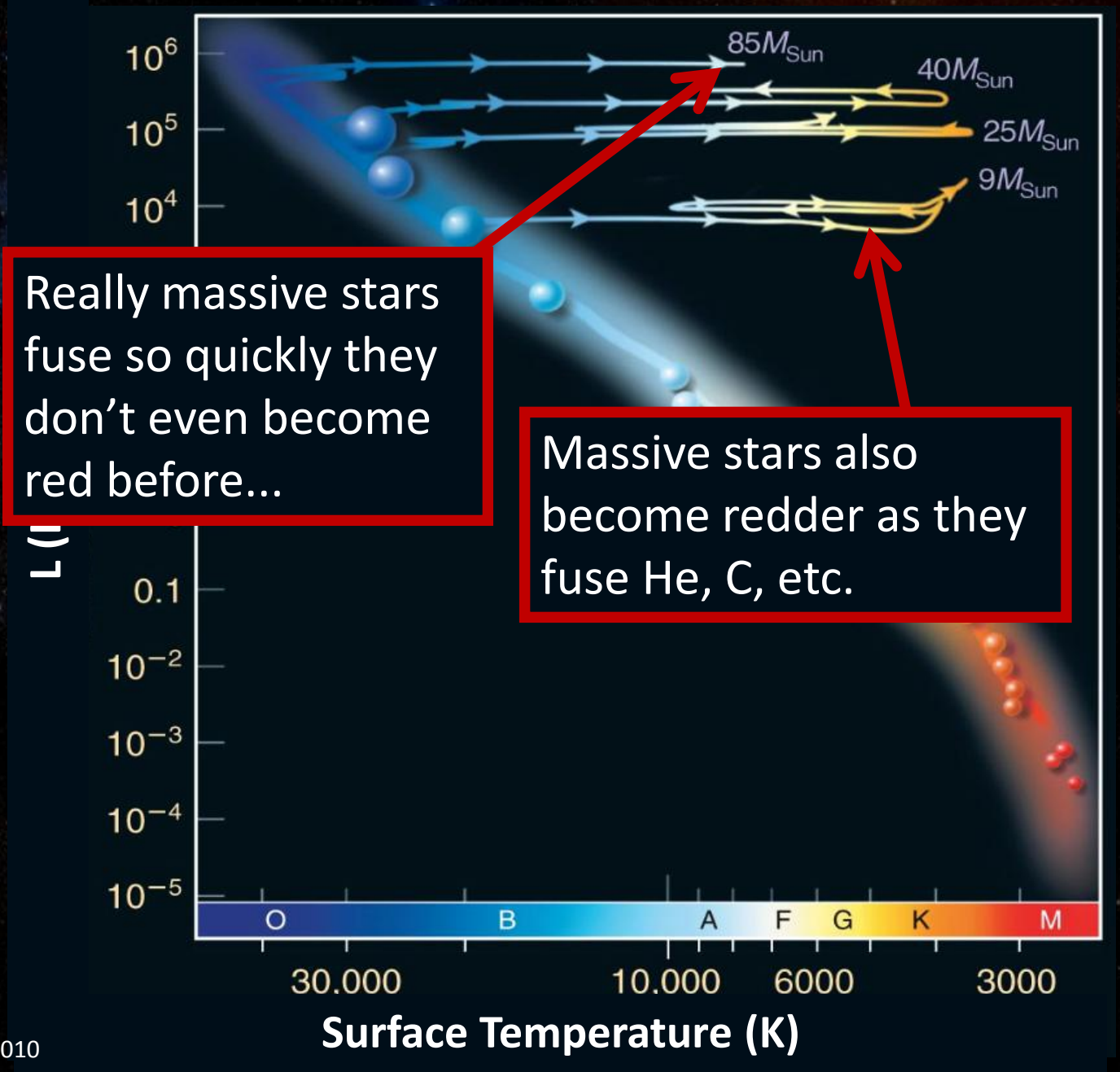
THE END TIMES FOR MASSIVE STARS



Massive stars also become redder as they fuse He, C, etc.

Bennett et al. 2010

THE END TIMES FOR MASSIVE STARS

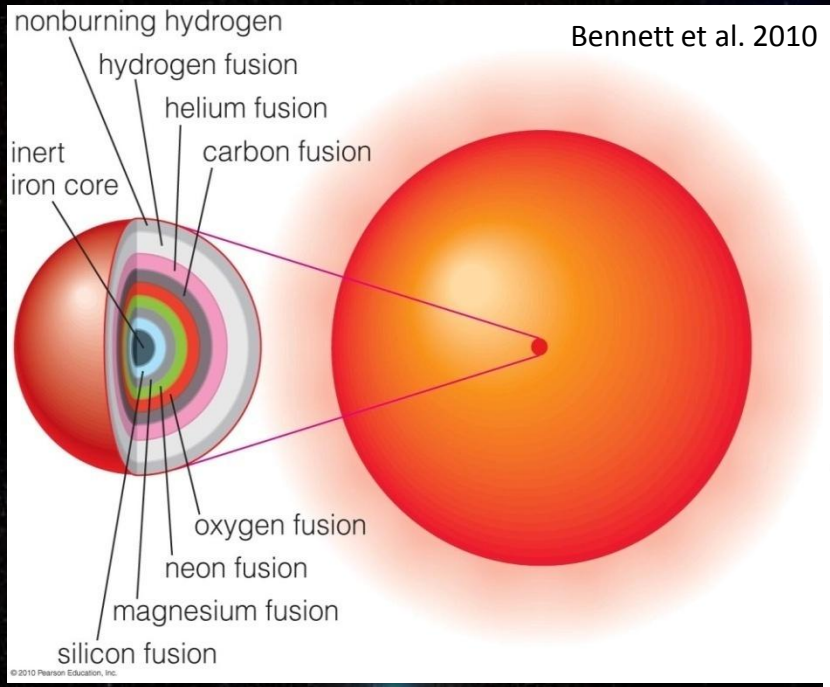


Really massive stars fuse so quickly they don't even become red before...

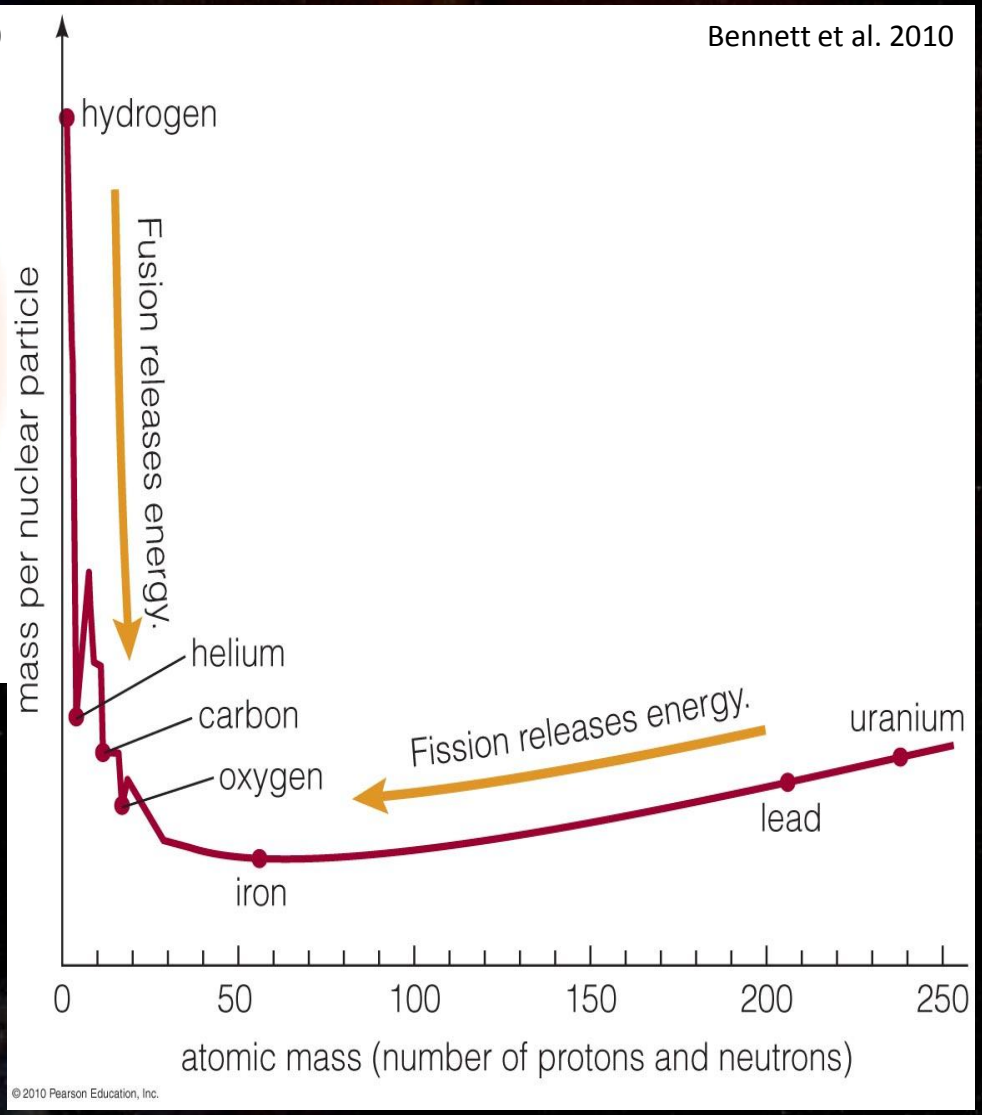
Massive stars also become redder as they fuse He, C, etc.

Bennett et al. 2010

CORE COLLAPSE SUPERNOVAE



Bennett et al. 2010



Bennett et al. 2010

- Eventually M > ~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

Wu 2011

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