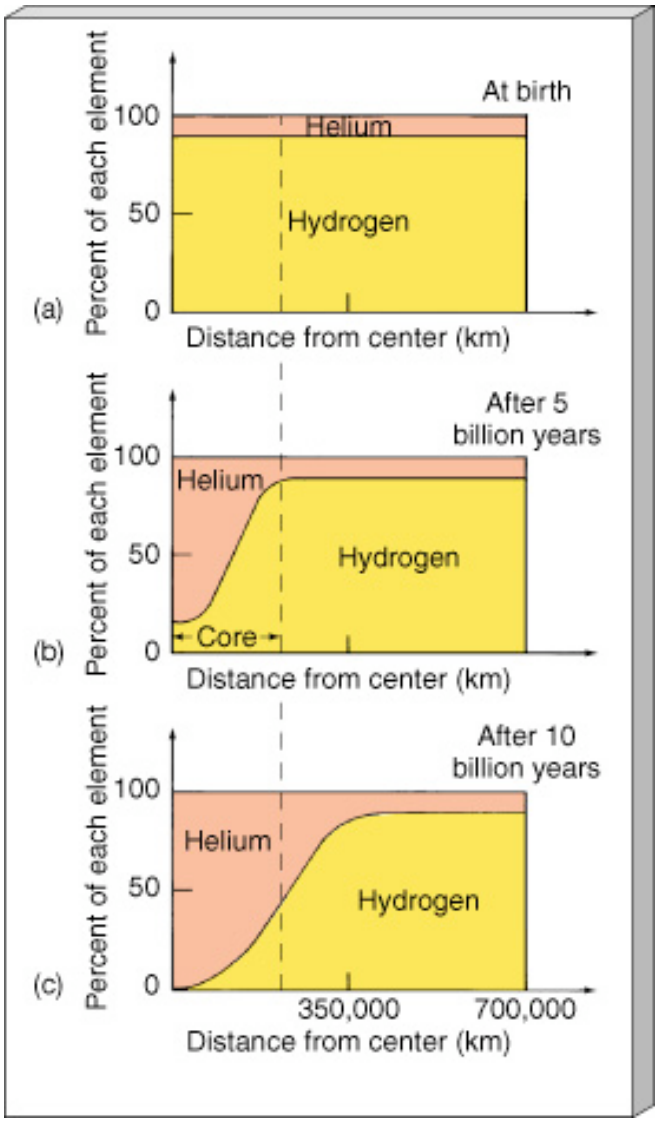
Stellar Evolution

- When hydrogen fusion starts at the end of the protostar stage, a star is born on the `zero-age main sequence'.
- As hydrogen is being converted into helium in the core of a star, its structure changes slowly and stellar evolution begins.

Stellar Evolution



- The structure of the Sun has been changing continuously since it settled in on the main sequence.
- The Hydrogen in the core is being converted into Helium.

Stellar Evolution

- As the helium core grows, it compresses. Helium doesn't fuse to heavier elements for two reasons.

  (1) with 2 p+ per nucleus, the electric repulsion force is higher than was the case for H-fusion. This means that helium fusion requires a higher temperature than hydrogen fusion -- 100 million K

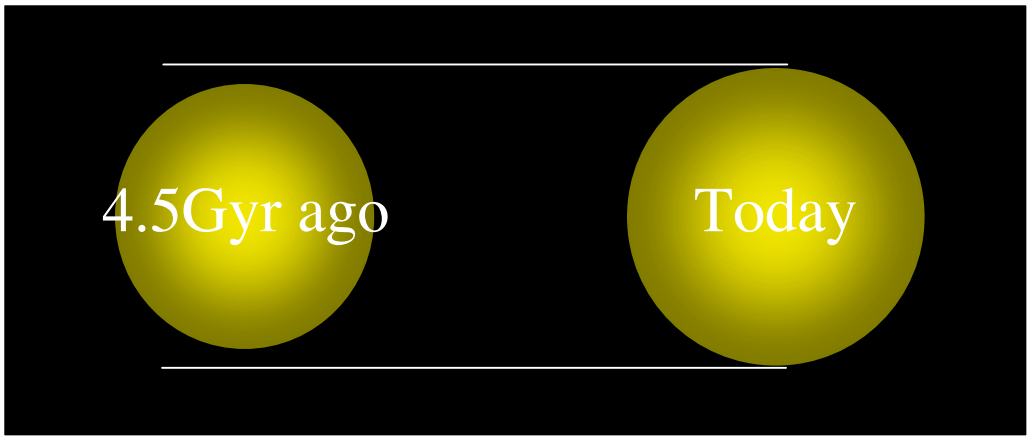
  (2) $He^4 + He^4 = Be^8$. This reaction doesn't release energy, it requires input energy. This particular Be isotope is very unstable.

Stellar Evolution

- As the Helium core contracts, it releases gravitational potential energy and heats up.
- Hydrogen fusion continues in a shell around the helium core.
- Once a significant helium core is built, the star has two energy sources.
- Curiously, as the fuel is being used up in the core of a star, its luminosity is increasing

Stellar Evolution

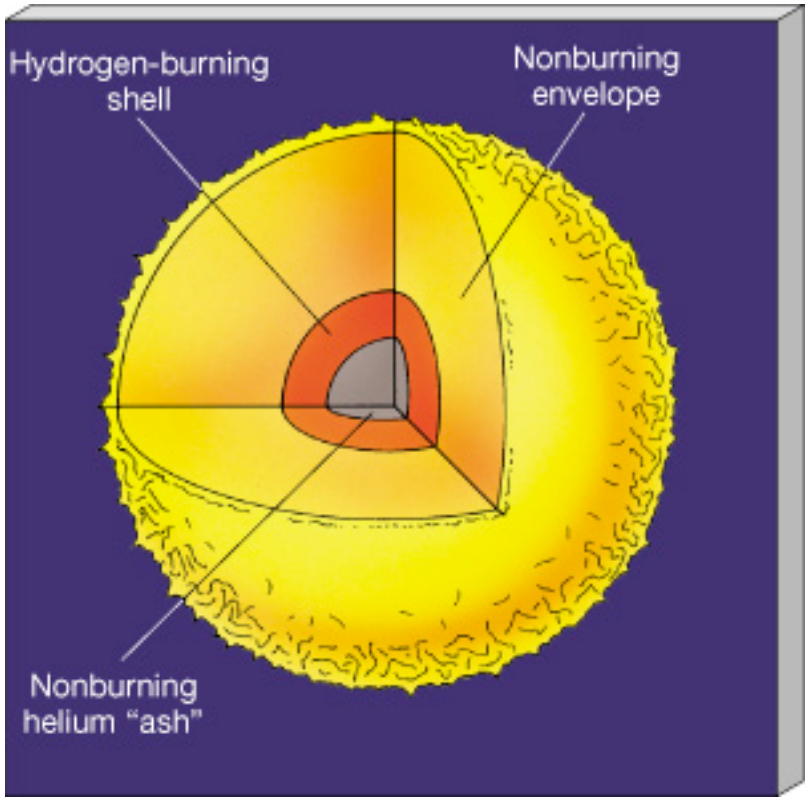
- Stars begin to evolve off the zero-age main sequence from day 1.
- Compared to 4.5 Gyr ago, the radius of the Sun has increased by 6% and the luminosity by 40%.



Stellar Evolution

- In the case of the Sun (or any $1M_o$ star) the gradual increase in radius and luminosity will continue for another 5 billion years.
- While hydrogen fusion is the dominant energy source, there is a useful thermostat operating. If the Sun contracted and heated up, the fusion rates would increase and cause the Sun to re-expand.

Evolution to Red Giant

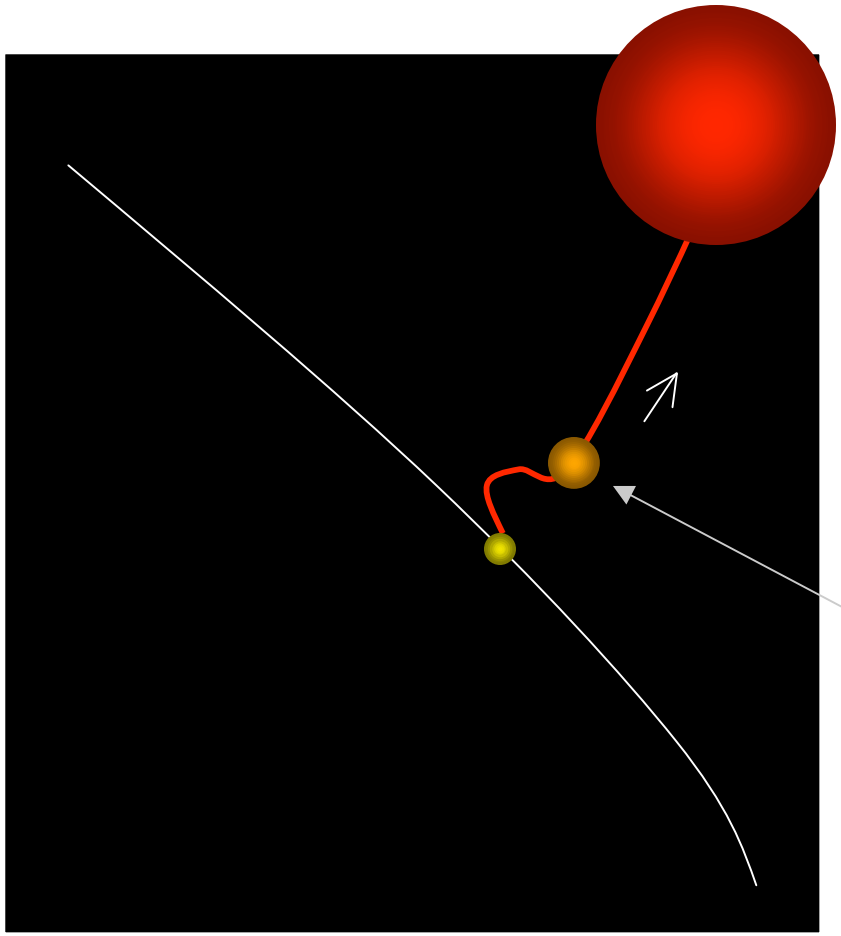


- As the contracting helium core grows and the total energy generated by GPE and the hydrogen fusion shell increases.
- L goes up!
- As L goes up the star also expands.

Red Giants

- Hydrostatic equilibrium is lost and the tendency of the Sun to expand wins a little bit at a time. The Sun is becoming a Red Giant. Will eventually reach:
- L -> $2000L_o$
- R -> 0.5AU
- $T_{surface}$->3500k

Red Giant

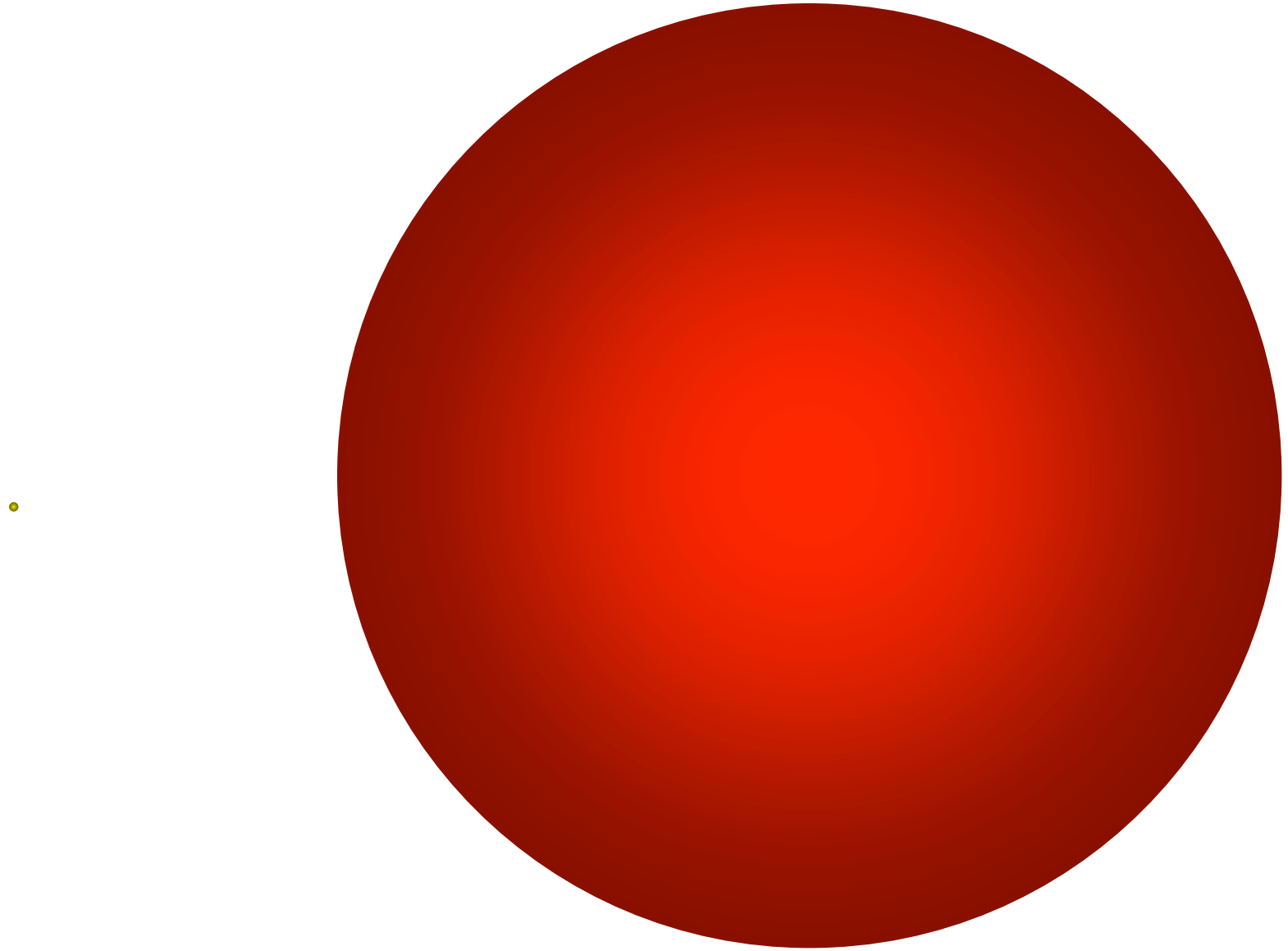


$100R_o$ 10^8years

$3R_o$, 10^{10}years

L

Temperature



Sun as a Red Giant

- When the Sun becomes a Red Giant Mercury and Venus will be vaporized, the Earth burned to a crisp. Long before the Sun reaches the tip of the RGB (red giant branch) the oceans will be boiled away and most life will be gone.
- The most `Earthlike' environment at this point will be Titan, a moon of Saturn.

RGB Evolution

As the Sun approaches the tip of the RGB

	Central T	Central Density
Sun	15×10^6 k	10^2 grams/cm^2
Red Giant	100×10^6k	10^5 grams/cm^2

For stars around $1M_o$, with these conditions in the core a strange quantum mechanical property of e- dominates the pressure.

Electron Degeneracy

- Electrons are particles called `fermions' (rather than `bosons') that obey a law of nature called the Pauli Exclusion Principle.
- This law says that you can only have two electrons per unit *6-D phase-space volume* in a gas.

$$\Delta x \Delta y \Delta z \Delta p_x \Delta p_y \Delta p_z$$

Electron Degeneracy

- When you have two e- per phase-space cell in a gas the gas is said to be degenerate and it has reached a density maximum -- you can't pack it any tighter.
- Such a gas is supported against gravitational collapse by electron degeneracy pressure.
- This is what supports the helium core of a red giant star as it approaches the tip of the RGB.

Review Q3 material

- Stellar Structure
- Stellar energy production
  - Calculation of requirements
  - Forces of nature
  - Nuclear energy
- Sun
  - Stellar wind
  - Neutrinos
- Stellar ages
- Star formation
- Evolution off the main sequence