Astronomy 150:
Killer Skies

This Class (Lecture 15):
The Dying Sun

Next Class:
Killer Sun

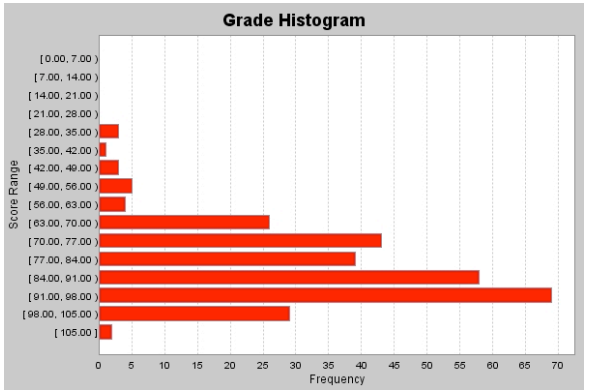
Micro-meteorite lab due tonight!

HW 6 due next Monday.

Music: *Why Does the Sun Really Shine*– They Might Be Giants

Exam 1

- Good job!
- Average = 83.3
- Median = 84



Question

What did you think of Exam 1?

a) Too easy
b) Too hard
c) Just right
d) A little easy
e) A little hard

Night Obs

- Dates:
  - Monday, Oct. 4th
  - Tuesday, Oct. 5th
  - Wednesday, Oct. 6th
  - Thursday, Oct. 7th
  - Monday, Oct. 11th
  - Tuesday, Oct. 12th
  - Wednesday, Oct. 13th
  - Thursday, Oct. 14th

Go to assignment page on class website for more info.

You **MUST** download worksheet before you go.

Can be cloudy, so check webpage before you go.

Outline

- The HR Diagram– learning the secrets of the Stars!
- The Sun gets older and the Earth gets hotter.
- The Sun runs out of fuel
  - Red Giant!
  - Horizontal Branch Star
  - Asymptotic Giant Branch
- The dead Sun— White Dwarf

The Mosquito Dilemma

- It's like a mosquito (lifespan ~2 weeks) trying to understand humans.
- They don't live long enough to watch humans be born and die, so they have to extrapolate.
- How do we understand stars that live for 10 billion+ years?

http://news.uns.purdue.edu/html3month/2004/040823.Williams.fallwnv.html

L and T

- We have the luminosity (brightness) and temperature of stars.
- How do they correlate?
- Think about it.
- If we can have any L for any T, what do we expect?
- If only one L for one T, then what?

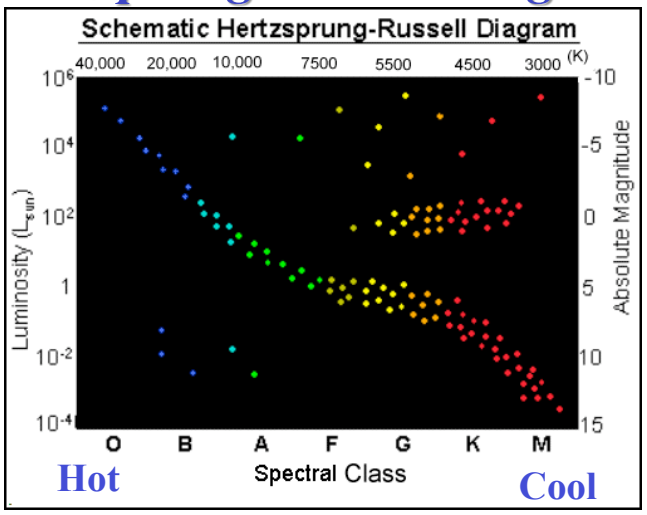
The H-R Diagram

- In the early 20th century, two astronomers plotted luminosity vs. temperature and found an interesting correlation in different regimes.
- It is not a random plot of points!
- The resulting plot is now named for them
- The **Hertzsprung-Russell Diagram**

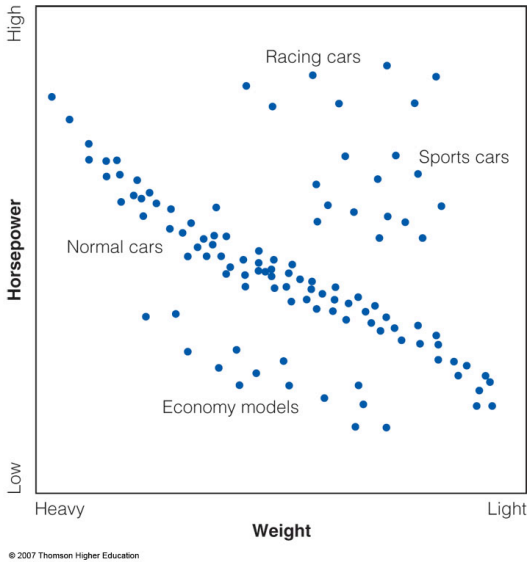
Hertzsprung-Russell Diagram

Bright

Dim



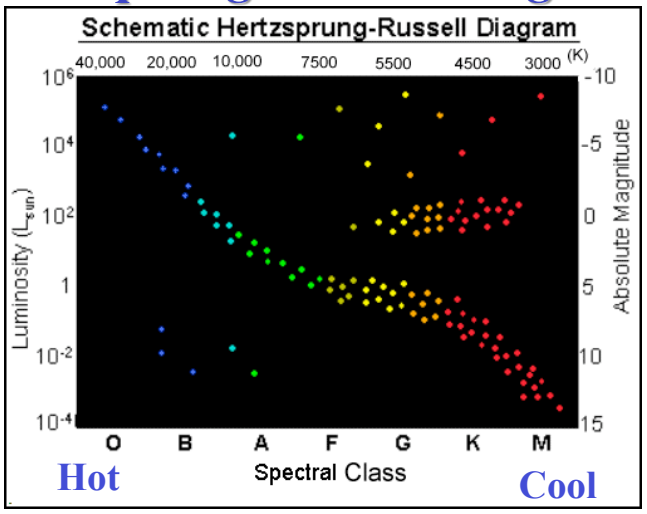
Compare to Cars



Hertzsprung-Russell Diagram

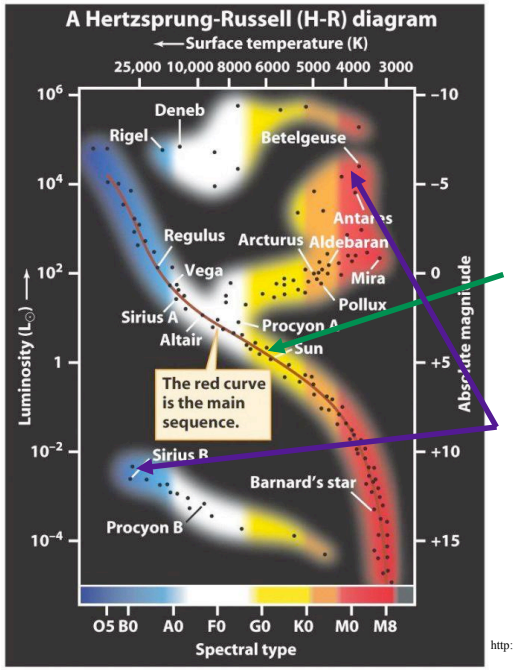
Bright

Dim



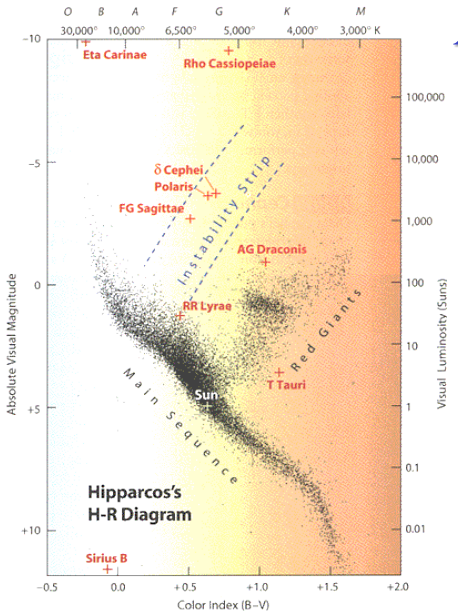
Family Jewels?

- The HR diagram can tell us a lot of information about stars, how they work, and how they die.
- It reveals the family secrets of the stars.



- Stars do not have random temperatures and brightness
- 91% of all stars are on the Main Sequence.
  - Why?
  - Burning H into He
- But, there are also very bright cool stars and very dim hot stars

http://www.kosmologika.net/Stars/HR-fordelning_av_samplade_stjarnor.gif



A Real Example

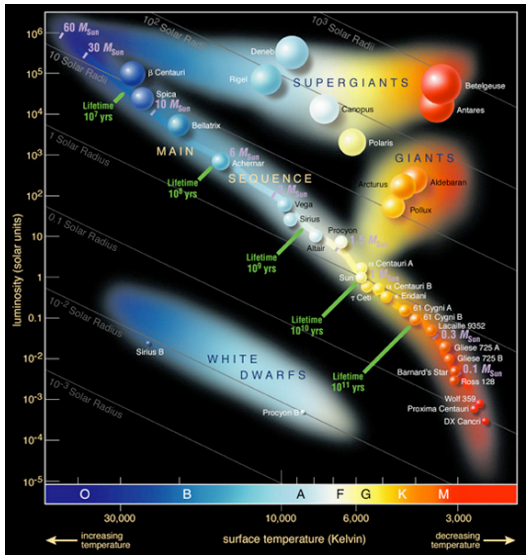
- Notice the large number of stars on the main sequence.
- The Sun is very average.

Question

We can plot stars on the HR diagram. Is there a correlation between luminosity and temperature?

a) Yes
b) No

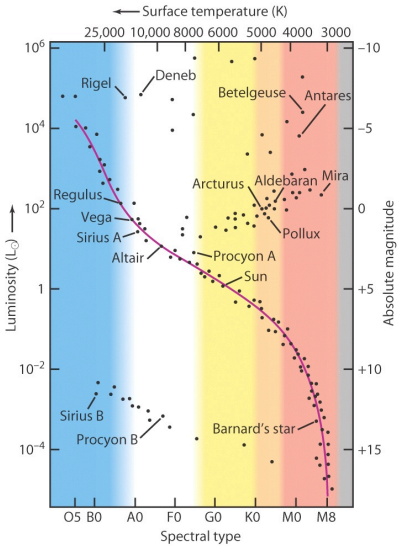
HR-ing It



So the color (temperature) of a Star on the main sequence really tells us about the mass or size of the Star. Warning: only on the main sequence!

Off the main sequence, it depends…

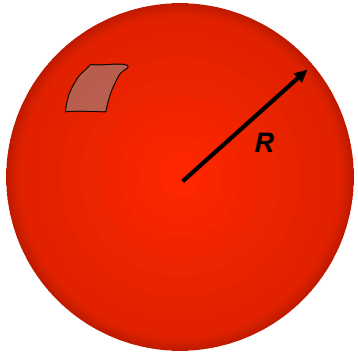
The H-R Diagram



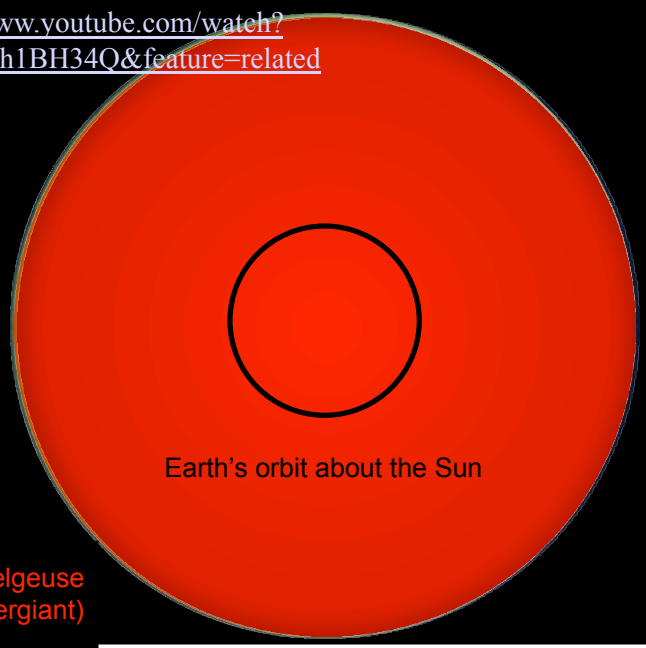
How does the size of a star near the top left of the H-R diagram compare with a star of the same brightness near the top right of the H-R diagram?

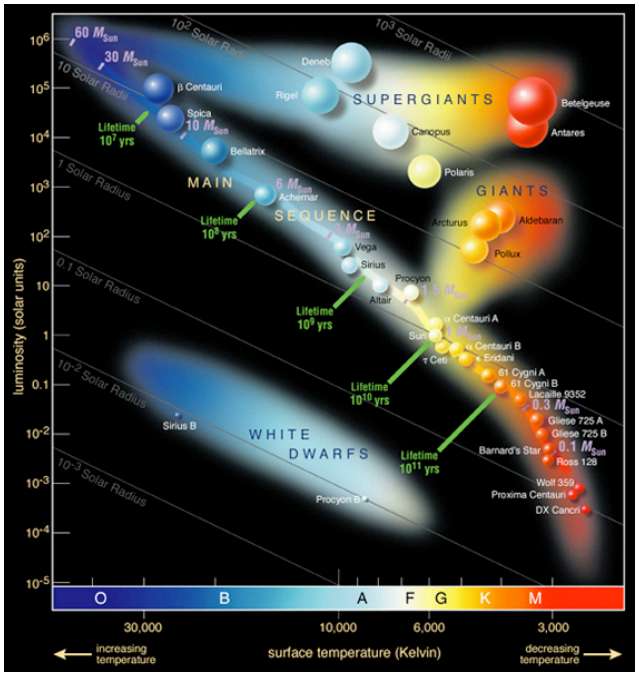
Luminosity

- Bright cool stars must be large (remember $L \sim R^2$)
  - **Giants & Supergiants**
- Dim hot stars must be small
  - **White dwarfs**



http://www.youtube.com/watch?v=HEheh1BH34Q&feature=related





- Bright cool stars must are giants.
- Dim hot stars must be small
- In both cases, they are somewhat rare.

Question

A star is discovered. It is very luminous and red in color. Where is it on the HR diagram?

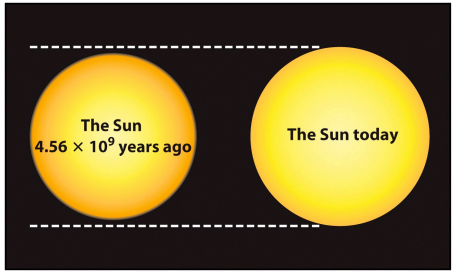
a) Upper right.
b) Upper left.
c) Bottom right.
d) Bottom left.
e) Middle of the graph.

What does the HR Diagram Tell us?

- By observing the number of stars on the main sequence and those off, we have come to understand how stars die.
- Both low-mass and high-mass, but for now, we are interested in only the Sun-like stars.
- As all stories go, it ends when the fuel runs out.
- We the Sun runs out of gas (hydrogen), it will leave the main sequence, but even now it has changed over its 4.6 billion years.

Life of a Low Mass (Sun-like) Star

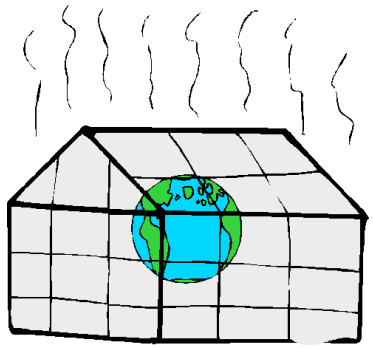
- Most of its life is spent in the happy pursuit of burning H ⇒ He
- With time, luminosity and temperature evolve gradually in response
  - Stays on the Main Sequence, but still evolves..
- The Sun is now 40% brighter and 6% bigger than zero age MS.



http://wings.avkids.com/Book/Myth/Images/ocean_sun.gif

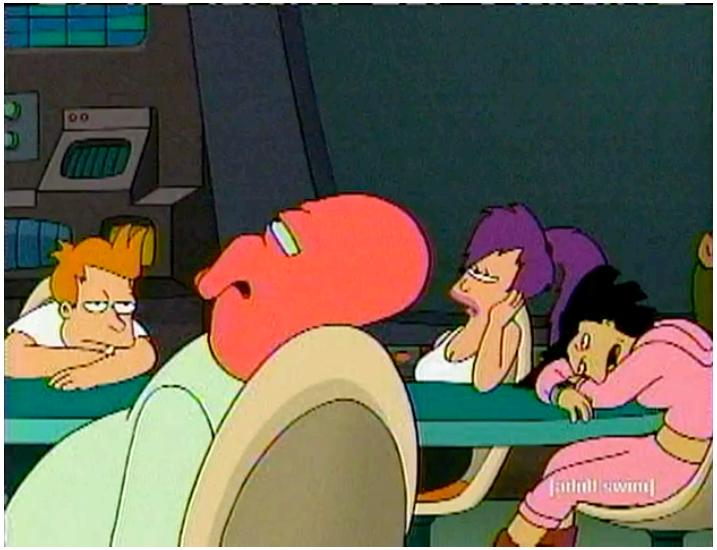
Life of Our Sun

- Over the next billions of years, our Sun will continue to increase in luminosity.
  - Just the aging Sun on the M.S.
- So in 1+ billion years, our Sun will be 10% more luminous.
- This will cause a "moist" greenhouse effect adding 10 degrees F to the average temp.



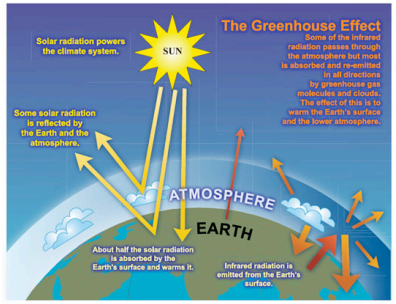
http://www.solcomhouse.com/Greenhouse_Effect.gif

Greenhouse Effect Explained



Converting Light into Heat

- Greenhouse gases (water, CO^2, etc.) trap heat
- Release heat back to Earth, so less heat lost to space
- Without greenhouse gases in our atmosphere, Earth average temperature would only be -14C (0F), instead of 14C (57F)
- But, humans are putting extra greenhouse gases into atmosphere, so Earth is getting warmer, but in aging Sun case, the Sun is adding heat directly!



http://andrian09.files.wordpress.com/2008/12/greenhouseeffectdiagram.jpg

Life of Our Sun

- This increase in total energy will have a major impact on the Earth!
  - Ice caps melt
  - Costal regions flood
  - Equator becomes inhabitable
  - Antarctica becomes warm

http://changeyourways.wordpress.com/2009/06/12/what-on-earth/

Question

As the Sun evolves <u>on the main sequence</u>, it will

a) turn into a Red giant.
b) get brighter
c) get dimmer
d) turn into 100% helium
e) turn into a white dwarf.

Life of Our Sun

- Increased temperature means that the lighter elements, like water molecules in the air, will have enough speed to escape Earth completely.
- The water of Earth begins to pack up and leave!
- In 1.1 billion years, the continents will be deserts and the oceans are beginning to evaporate.

http://www.esquire.com/cm/esquire/images/Gd/desert-1108-lg.jpg

Life of Our Sun

- As the Sun, uses up the hydrogen in the core, the Sun increases by 40% in brightness in 3.5 billion years.
- By that time, all of the oceans are gone!
- The baking sediments at the bottom of the oceans, release CO2
- Earth will become Venus-like!
- Then the heat makes even those heavier molecules leave the Earth.
- The Earth will be a barren rock in about 4 billion years!

http://wings.avkids.com/Book/Myth/Images/ocean_sun.gif

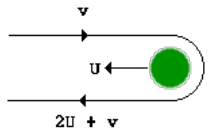
Mitigation: Part 1

1. Move the population
   - I hear that Mars could be a nice place to live.
   - Need to terraform Mars, which could take a while.

http://www-cache.daz3d.com/sections/contests/upload_files/3195.jpg

Mitigation: Part 1

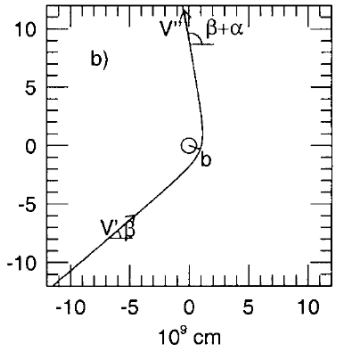
2. Move the Earth
   - There is no place like home, so move it to a nicer place, farther away from the Sun.
   - Use gravity assist or the sling shot technique.



http://upload.wikimedia.org/wikipedia/commons/8/8e/Grav_slingshot_simple_2.gif

Mitigation: Part 1

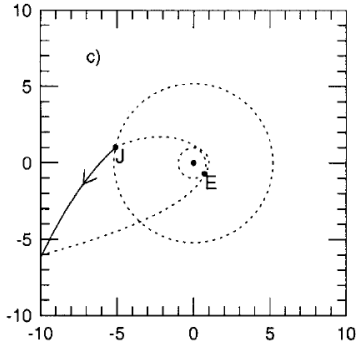
2. Move the Earth
   - Asteroids to the rescue?
   - Move many large asteroids in front of the Earth, sends them toward the Sun and the Earth outwards.
   - Need to do this every 6000 years to make Earth survive until the Sun hits the Red Giant phase.



Korycansky et al. 2001

Mitigation: Part 1

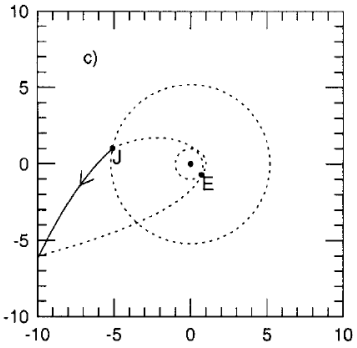
2. Move the Earth
   - For billions of years!
   - We don't have enough large asteroids.
   - We'll have to recycle.
   - The idea is to transfer energy from Jupiter's orbit to Earth's orbit.



Korycansky et al. 2001

Mitigation: Part 1

2. Move the Earth
   - Could keep us safe for a good 6 billion years!



Korycansky et al. 2001

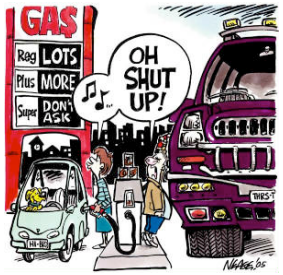
Important Questions

The Sun remains stable and on the main sequence as long as it has hydrogen to fuse in the core… it evolves and will likely kill all life on Earth, but up until now, it has still been on the main sequence.

- **How long will the fuel last?**
- **What happens when the fuel runs out? And how bad will it be for the Earth?**

How much Gas do we have left?

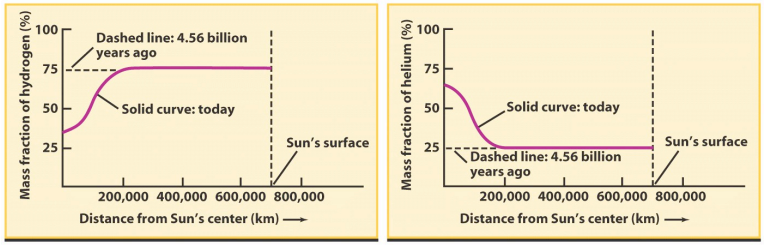
- Total energy available is easily calculated by mass of hydrogen in Sun and energy released by each hydrogen conversion.
- We only have about 6 billion years left!



http://skeptically.org/sitebuildercontent/sitebuilderpictures/.pond/suv-econ-gas-pump.jpg.w300h294.jpg

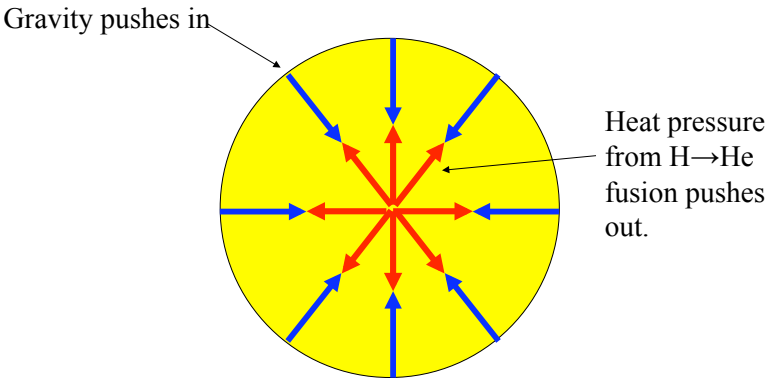
Hungry, Hungry Sun

- On the main sequence for ~11 billion years.
- The core is where fusion occurs- H ⇒ He
- Eventually, runs out of hydrogen in the core.
  - Rest of Sun is mostly hydrogen, but not in the core.
- And it's not hot enough to fuse helium!.....yet



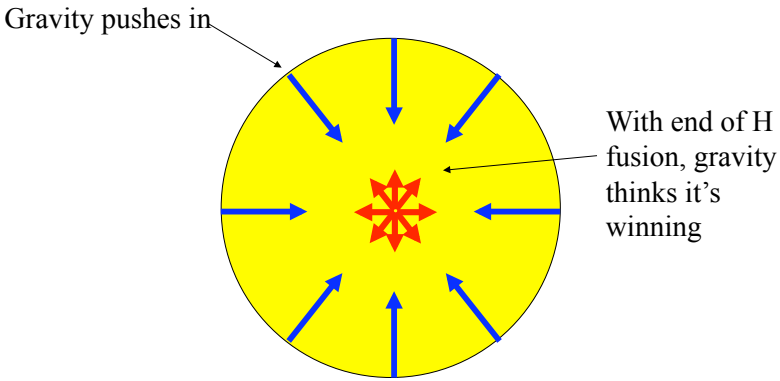
(a) Hydrogen in the Sun's interior (b) Helium in the Sun's interior

The Battle between Gravity and Pressure



Hydrostatic equilibrium: Balanced forces

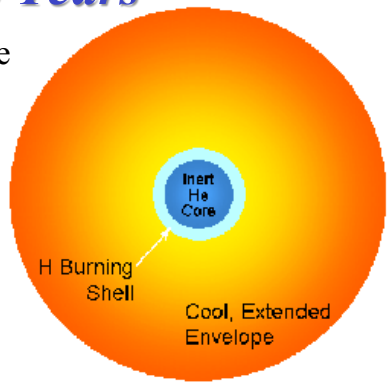
The Battle between Gravity and Pressure



Unbalanced forces

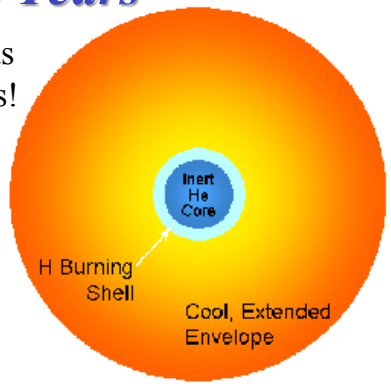
The Red Giant Phase: 6 Billion Years

- When the hydrogen is gone in the core, fusion stops
- Equilibrium is shot.
- Core starts to contract under its own gravity
- This contracting heats the core, and hydrogen fusion starts in a shell around the core



The Red Giant Phase: 6 Billion Years

- Energy is released, expands envelope ⇒ Lum increases!
- As the envelope expands, it cools – so it becomes a **red giant.**
- This process takes 50-100 million years.



http://www.youtube.com/watch?v=fOM7DMxOiAk&feature=related

Evolutionary Path of a Solar-Mass Star