# *Astronomy 150:*
# *Killer Skies*

This Class (Lecture 17):
Supernova: The End of Massive Stars

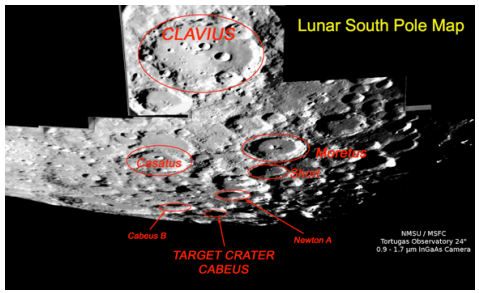
Next Class:
Killer Supernova

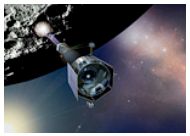
**HW5 due on Sunday!**

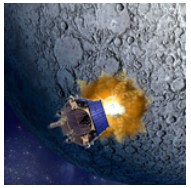
**Music: *Supernova*– Liz Phair**

# *Moon Impact!*

- NASA successfully impacted the moon this morning at 6:30am.
- Main objective was to look for water vapor in the plume of ejected material.
- Water on the Moon?





# *Night Obs*

- Dates:
  - Monday, Sept. 21st ✔
  - Tuesday, Sept. 22nd ✗
  - Wednesday, Sept. 23rd ✗
  - Thursday, Sept. 24th ✗
  - Monday, Sept. 28th ✗
  - Tuesday, Sept. 29th ✔
  - Wednesday, Sept. 30th ✔
  - Thursday, Oct. 1st ✗
  - Monday, Oct 5th ✔
  - Tuesday, Oct 6th ✗
  - Wednesday, Oct 7th ✔
  - Thursday, Oct 8th ✗
  - Next week until 1 more clear night.

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.

Turn in assignment in-class before Oct 26th or so.

# *Question*

Did you go to the Observatory yet?

a) Yes, it was okay.
b) Yes, it was cool!
c) Yes, it was the highlight of my life so far!
d) Yes, but it was boring.
e) No, but I will do so as soon as I can, I promise. I had other things I had to do, but I really, really want to go and I will make it a **top** priority in my life!

# Computer Lab: 15% of Grade!

- Computer labs to look for real killer asteroids.
- Dates:
  - Monday Sept 28th ✔
  - Monday, Oct 5th ✔
  - Monday, Oct 12th
- Places:
  - Nevada Labs
  - Oregon Labs

- Limited space each day, so you ***MUST*** have a reservation for that day and that lab!
- See Assignments webpage for more info and to sign up!
- Lectures are cancelled for those dates.

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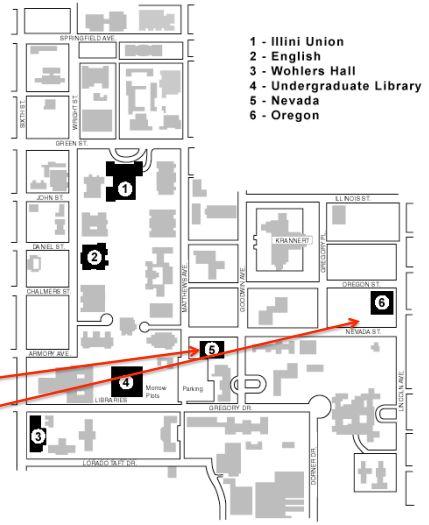



# Don't Forget HW 2

- Orionids are the morning of Oct 21st.
- If you haven't finished HW2, make sure to leave your pan out over that night.
- It doesn't matter if it is cloudy or not.

# Outline

- Massive stars do not live very long.
- Massive stars– making heavy elements.
- Supernova

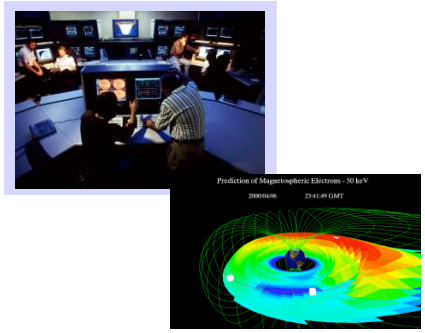
# Mitigation:Monitoring

**Weather**

**NOAA National Weather Service**

**Space Weather**

**NOAA Space Environment Center**



**Accuweather**

http://www.youtube.com/watch?v=DU4hpsistDk

# 2012: End of Mayan Calendar?

- I'm not going to say too much about this, but the concept is bogus, all pseudoscience.
- Except maybe kinda Solar weather, which is sometimes mentioned.
  - Although 2012 is 1 year before solar maximum, the 1859 CME was 1 year before maximum.
  - Still it doesn't mean anything.
  - We have been hit by bad space weather many times in the past and will again in the future.
  - Not the end of the world.
- Science aside though, it should make a fun movie:

http://www.youtube.com/watch?v=Hz86TsGx3fc

# Space Weather on Weather?

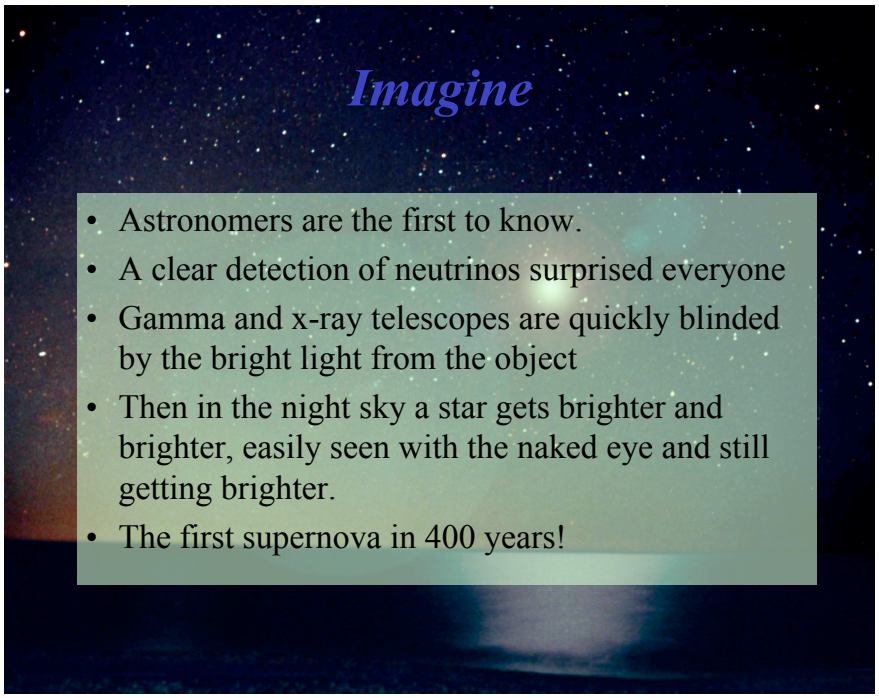
- There is some correlation between the Solar Cycle and weather on Earth.
- Sunspots reduce brightness of Sun, but surrounded by brighter region, so we have a net gain.
- Sun is actually brighter when covered in spots.
- The Maunder minimum: 1645-1715 (hardly any spots)
  - Lower than average temperatures
  - Little Ice Age: river Thames froze over
  - Sun brightness only one factor though, also more than usual volcanism

http://www.youtube.com/watch?v=T1p4GR90lZQ

# Imagine

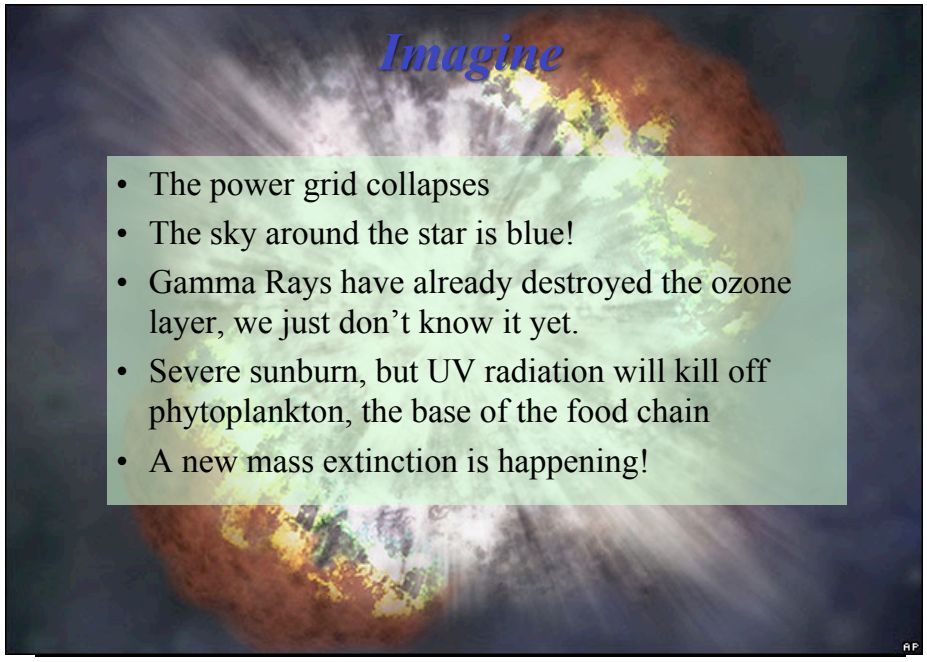
- It's winter. It's cold.
- The Sun is unusually active, and you hear NASA is worried about something called Space Weather.
- A huge batch of new sunspots on the Sun's equator are seen..
- A huge coronal mass ejection from the Sun comes screaming toward the Earth.

Approximate size of earth for


# *Top 10 Ways Astronomy Can Kill you or your Descendents*

1. Impacts!
   Splat.. Boom… Watch out for space rocks!
2. Solar Evolution.
   MS to Red Giant to White Dwarf.
3. Coronal Mass Ejections
   Cold winter days..
4. Supernova in your face!
   Super sunburn.



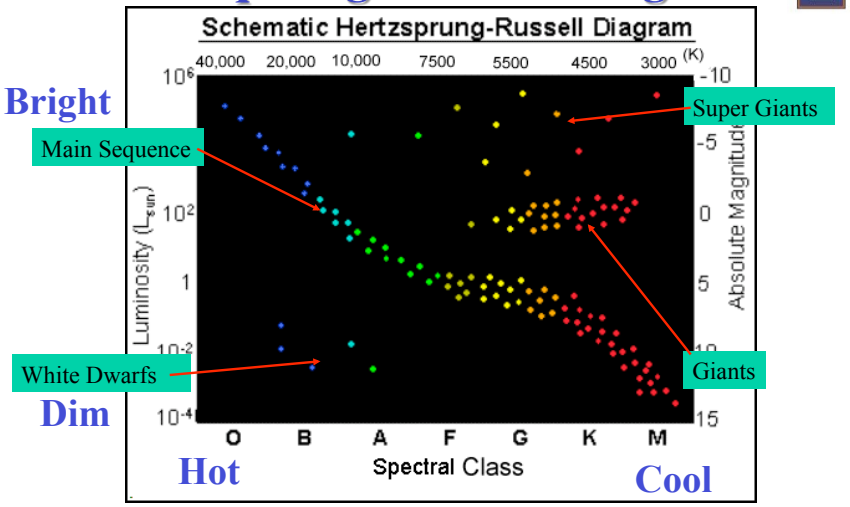
# *Top 10 Ways Astronomy Can Kill you or your Descendents*

4. Supernova in the face!

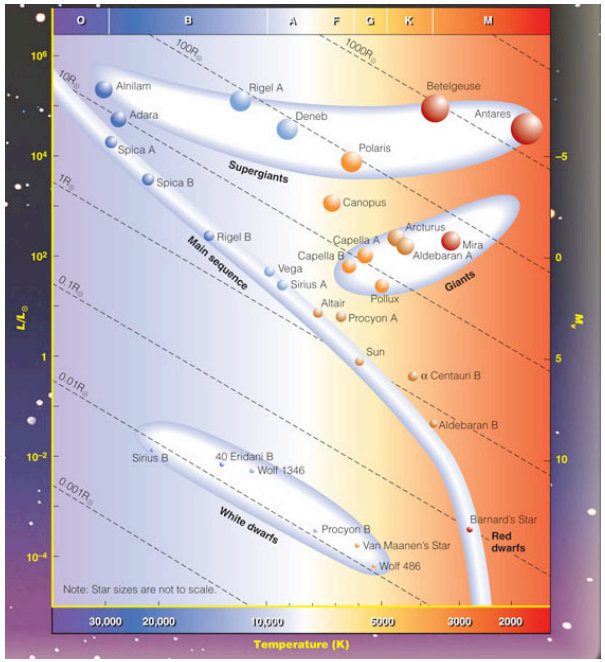
Extreme energy! Can destroy the ozone layer!

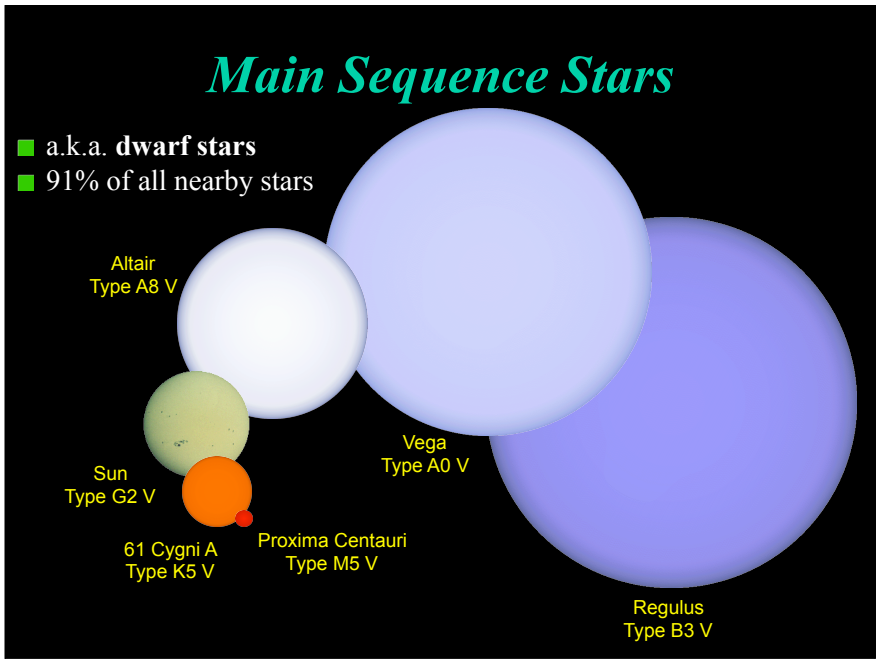
http://www.youtube.com/watch?v=0J8srN24pSQ

# *Hertzsprung-Russell Diagram*



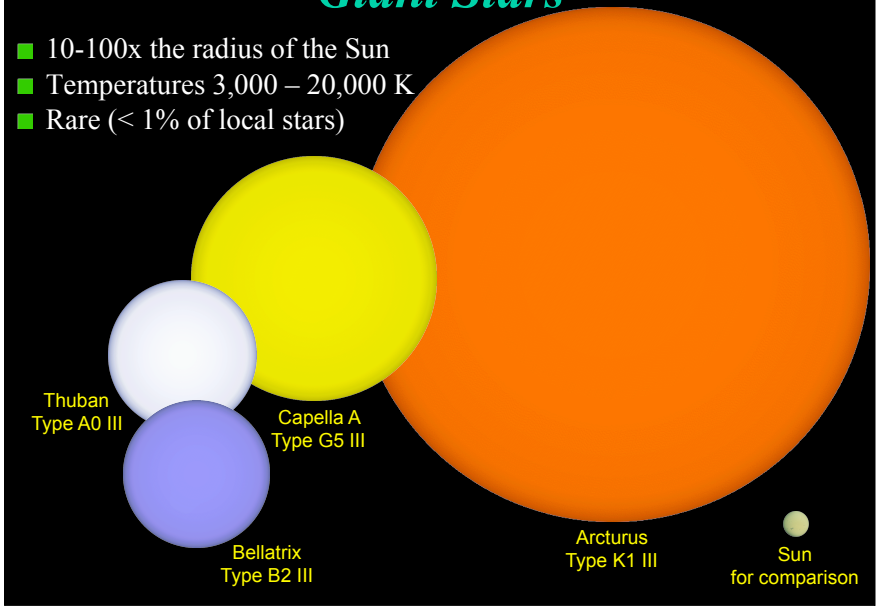

# *HR Diagram*



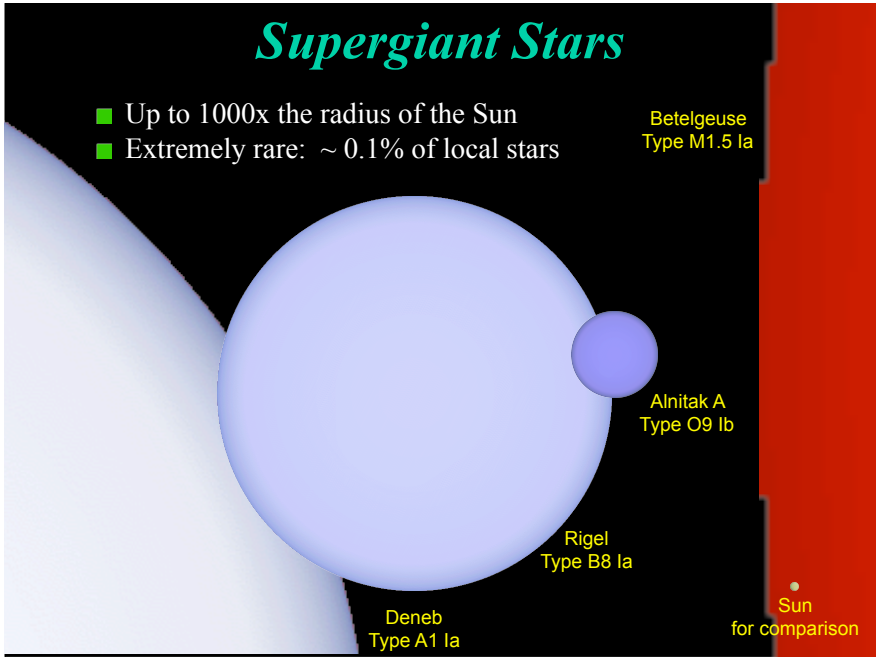
# Giant Stars

- 10-100x the radius of the Sun
- Temperatures 3,000 – 20,000 K
- Rare (< 1% of local stars)



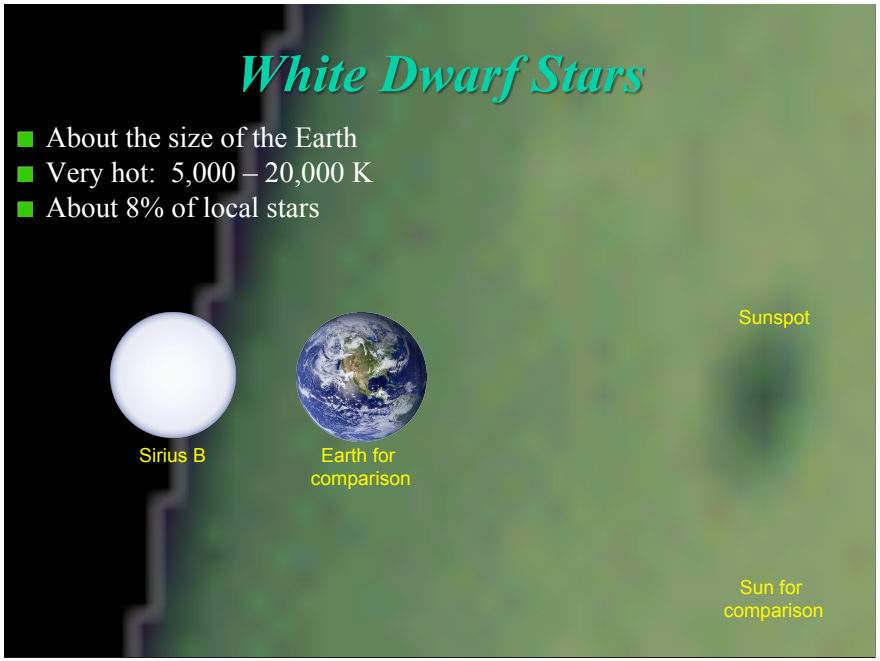

# Supergiant Stars

- Up to 1000x the radius of the Sun
- Extremely rare: ~ 0.1% of local stars



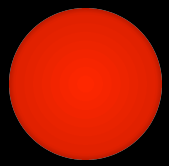

# White Dwarf Stars

- About the size of the Earth
- Very hot: 5,000 – 20,000 K
- About 8% of local stars

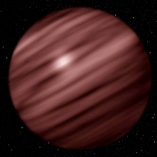



# Kinds of Dwarfs

**Red dwarf**
*Just a very cool main-sequence star*




**White dwarf**
*White-hot burned-out core of a star*

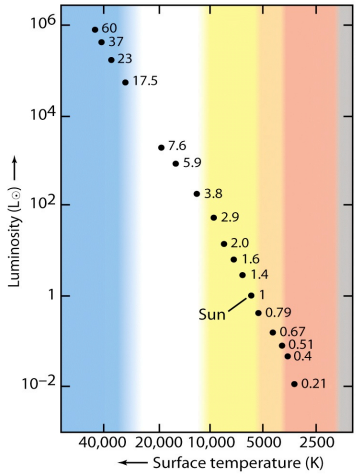

**Black dwarf**
*A very old cooled white dwarf*

**Brown dwarf**
*Not a star at all; wasn't massive enough*

UKIRT/JAC

# The Mass-Luminosity Relationship

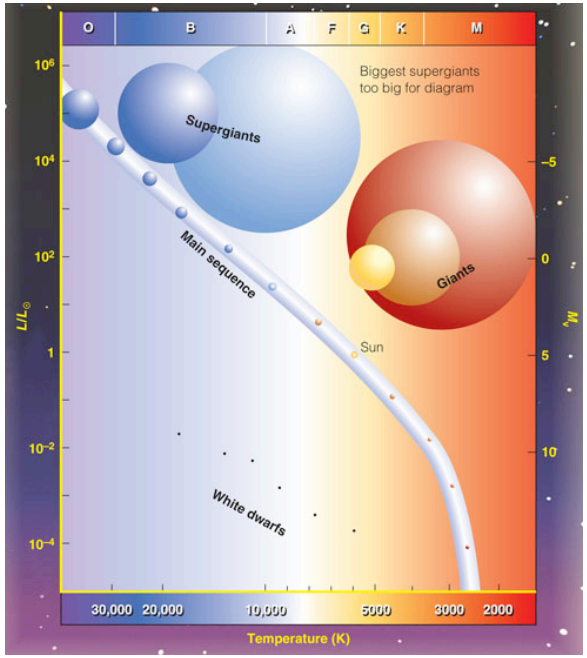
- Luminosity is proportional to Mass
- Larger range in luminosity than mass ($10^6$ vs. 100)
- Higher mass = higher luminosity, higher temp, and large radius
- Lower mass = lower luminosity, lower temp, and smaller radius
- Only on Main Sequence!




# HR Diagram

Sun is converting 700 million tons of H into 695 million tons of He every second!

BUT, a 20 solar mass star is using it's fuel 36,000 times faster!




# Question

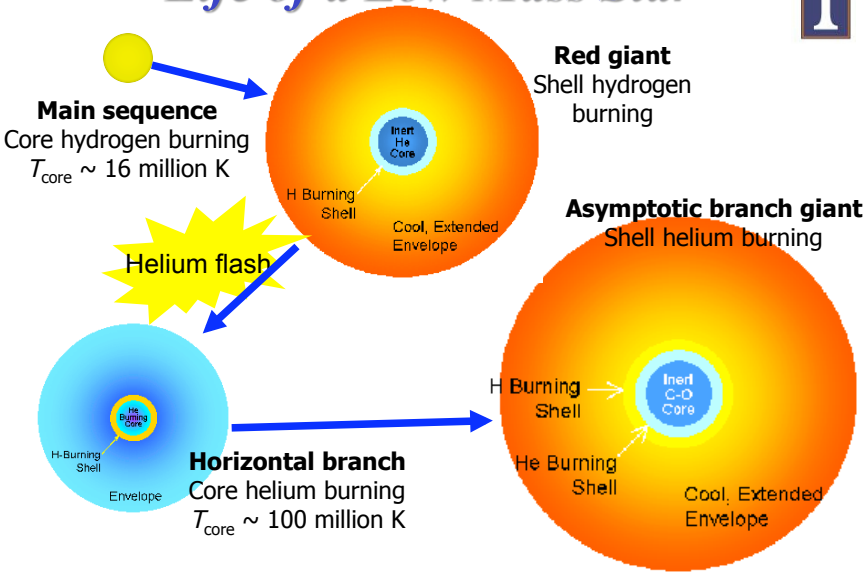
A massive star on the main sequence is where on the HR diagram?

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

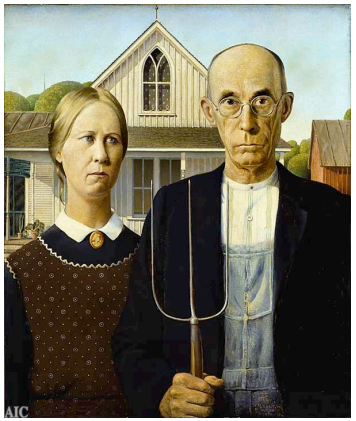
# Lifecycle of a Star

- Star formation
  - Take a giant molecular cloud core with its associated gravity and wait for $10^4$ to $10^7$ years.
- Main sequence life (depends on mass!)
  - Few x $10^6$ years to more than age of Universe
  - Thermonuclear burning of H to He
- Death
  - Exhaust hydrogen
  - Red giant / supergiant
  - White dwarfs, supernova neutron stars, black holes

# Life of a Low Mass Star




# Stellar Lifestyles



*Low-mass stars*

*Massive stars*

# Life Fast, Die Young

- High-mass stars: "gas guzzlers"
  - Very bright
  - Consume hydrogen fuel supply very quickly
  - Only live for millions of years on the main sequence

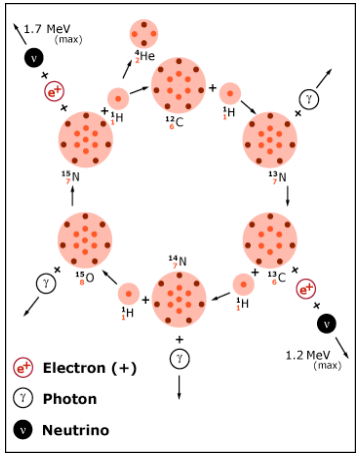
table 21-1 **Approximate Main-Sequence Lifetimes**

| Mass ($M_\odot$) | Surface temperature (K) | Spectral class | Luminosity ($L_\odot$) | Main-sequence lifetime ($10^6$ years) |
|---|---|---|---|---|
| 25 | 35,000 | O | 80,000 | 4 |
| 15 | 30,000 | B | 10,000 | 15 |
| 3 | 11,000 | A | 60 | 800 |
| 1.5 | 7000 | F | 5 | 4500 |
| 1.0 | 6000 | G | 1 | 12,000 |
| 0.75 | 5000 | K | 0.5 | 25,000 |
| 0.50 | 4000 | M | 0.03 | 700,000 |

*The main-sequence lifetimes were estimated using the relationship $t \propto 1/M^{2.5}$ (see Box 21-2).*

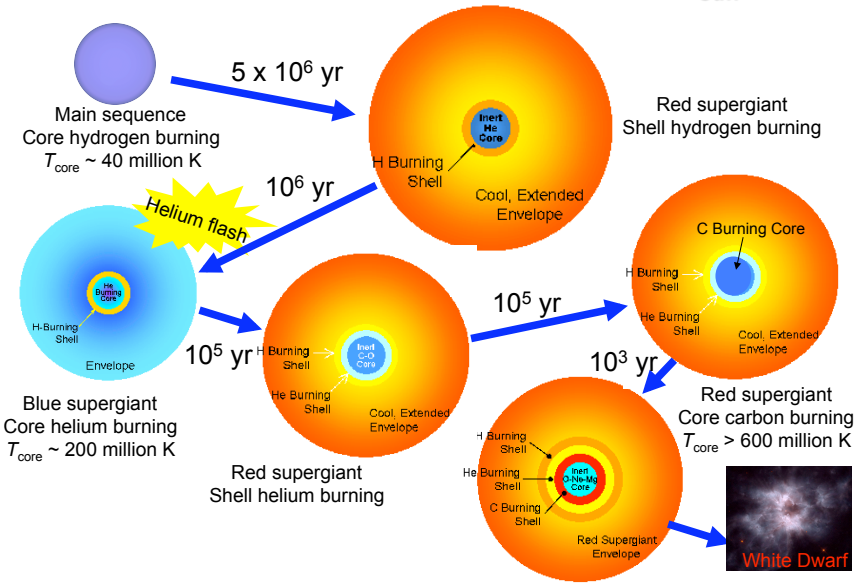
# More than one way to fuse

- High-mass stars do fusion by a different process
- Called the *CNO cycle*
  - Still converts 4 hydrogens into 1 helium
  - Uses a carbon nucleus as a catalyst
- Quicker reaction
- Requires very high temperatures in the core
  - More than low-mass stars (like the Sun) can produce



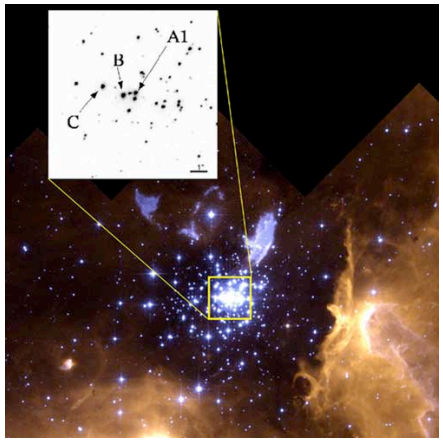

The CNO Cycle

## Evolution of an Intermediate-Mass ( ~4 $M_{Sun}$) Star




## For High Mass Stars

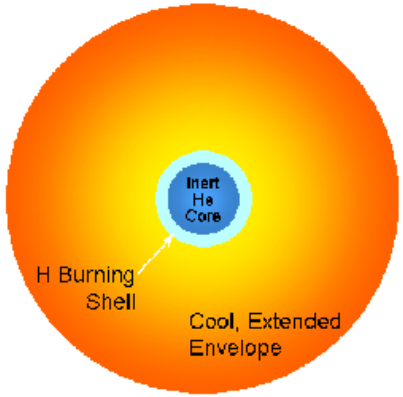
- For stars with an initial mass of more than 10 solar masses
- The final state will no longer be a white dwarf.
- Let's follow more carefully the life path of a high mass star– it's short sweet and ends with a bang!




A1: A 150 solar mass star!

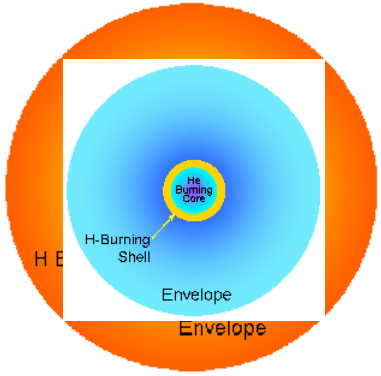
## When the Hydrogen Runs out?

- Similar to lower-mass stars in the first few stages, just quicker.
- When the hydrogen supply runs out the core starts to contract
- Hydrogen shell burning (around the helium core) starts
- The outer envelope expands quickly becoming a **red supergiant**




## The Supergiant Phase

- Outer envelope of the star grows larger and cooler
  - Up to 5 AU in size!
  - Unlike a low mass star, brightness does not increase dramatically
- Eventually, core is hot enough that it can fuse helium atoms together (non-degen gas, so no flash)
  - Star contracts and heats up
  - Now a **blue supergiant**



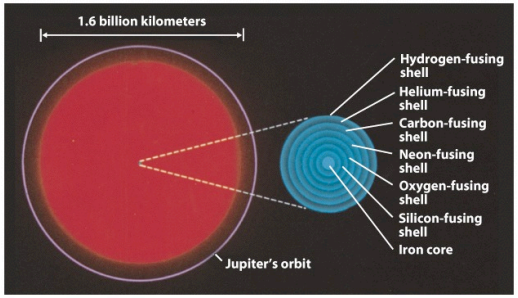
# Question

What causes a high-mass star to leave the main sequence?

a) Just gets tired of the main-stream media and lifestyle.
b) Runs out of hydrogen in the core.
c) Runs out of helium in the core.
d) A shell around the core begins to burn helium.
e) A shell around the core begins to burn hydrogen.

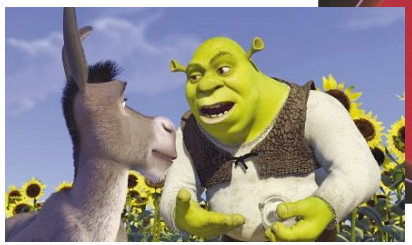
# Massive Stars: Cycles of Fusion

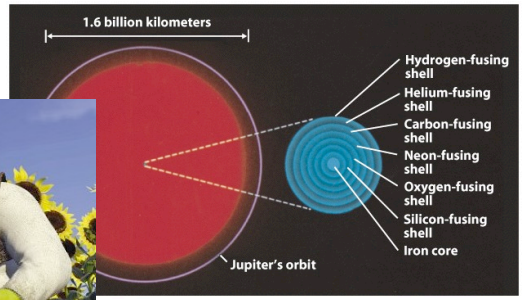
- Helium fusion is not the end for massive stars
- Cycles of core contraction, heating, ignition
- Ash of one cycle becomes fuel for the next
  - hydrogen ⇨ helium
  - helium ⇨ carbon & oxygen
  - carbon ⇨ neon, sodium, & magnesium
  - neon ⇨ oxygen & magnesium
  - oxygen ⇨ silicon & sulfur
  - silicon ⇨ iron




# Massive Stars: Cycles of Fusion

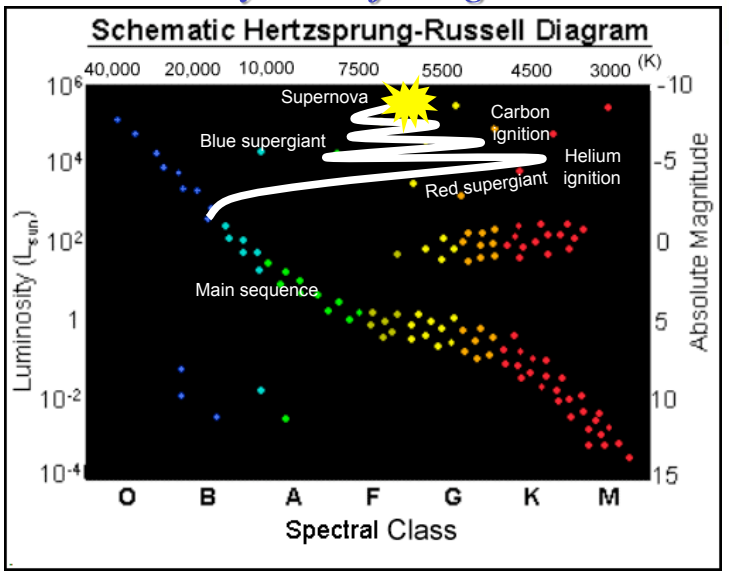
- Onion-skin like structure develops in the core
- Has layers…. like an Ogre..



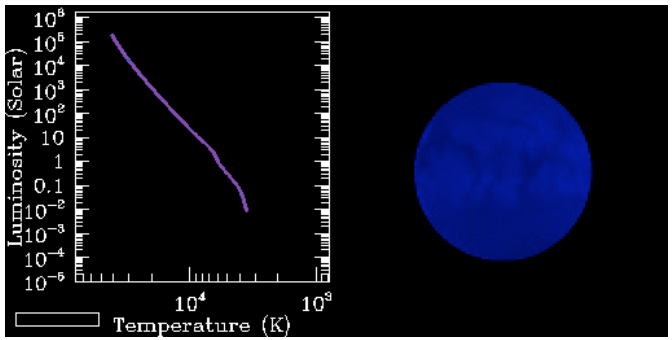



http://servantsthoughts.blogspot.com/2007/08/onion-theory.html

# Evolutionary Path of a High-Mass Star



# High Mass Stars (15 $M_{sun}$)



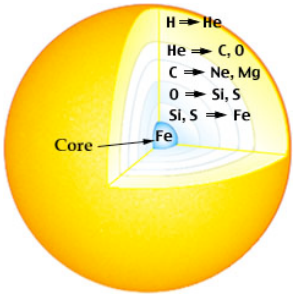

http://rainman.astro.uiuc.edu/ddr/stellar/index.html

# Iron – The End of the Road

- Supergiants "burn" heavier and heavier atoms in the fusion process
- Each stage faster than the last
- After iron - no fuel left!
  - It requires energy to produce heavier atoms

| Stage | Temperature | Duration |
|---|---|---|
| H fusion | 40 million K | 7 million yr |
| He fusion | 200 million K | 500,000 yr |
| C fusion | 600 million K | 600 yr |
| Ne fusion | 1.2 billion K | 1 yr |
| O fusion | 1.5 billion K | 6 mo |
| Si fusion | 2.7 billion K | 1 day |

Values for a 25$M_{Sun}$ star




# Evolutionary Path of a High-Mass Star