Astronomy 150:

Killer Skies

This Class (Lecture 19):
Death of Massive Stars

Next Class:
Killer Supernova

HW7 due Monday!
No lecture on Monday–
Computer lab opportunity

Music: *We Are All Made of Stars*– Moby

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
- Monday, Oct. 18th
- Tuesday, Oct. 19th

Starts at 8pm until 10pm (expect to spend ~40 mins)

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.

Question

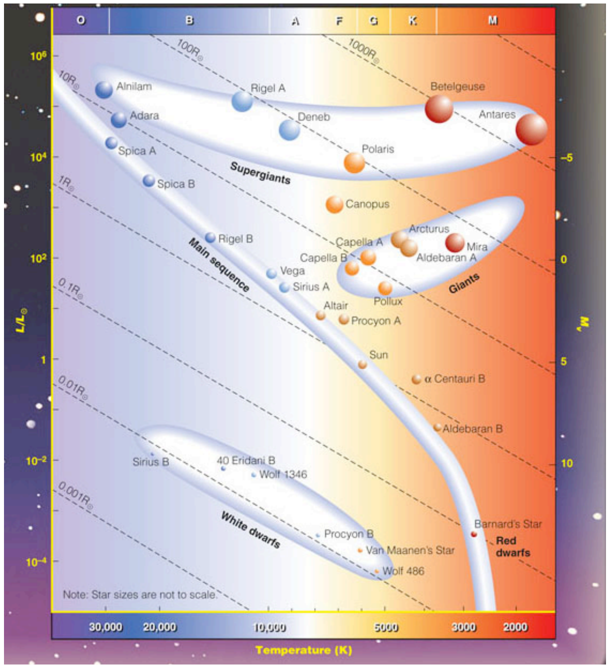
Did you go to the Observatory yet?

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!

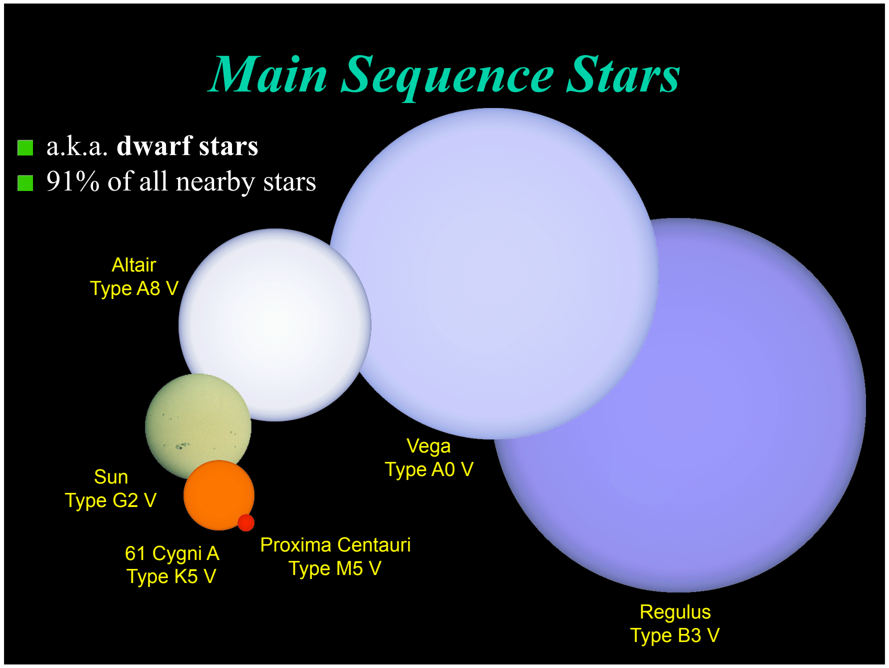
Outline

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

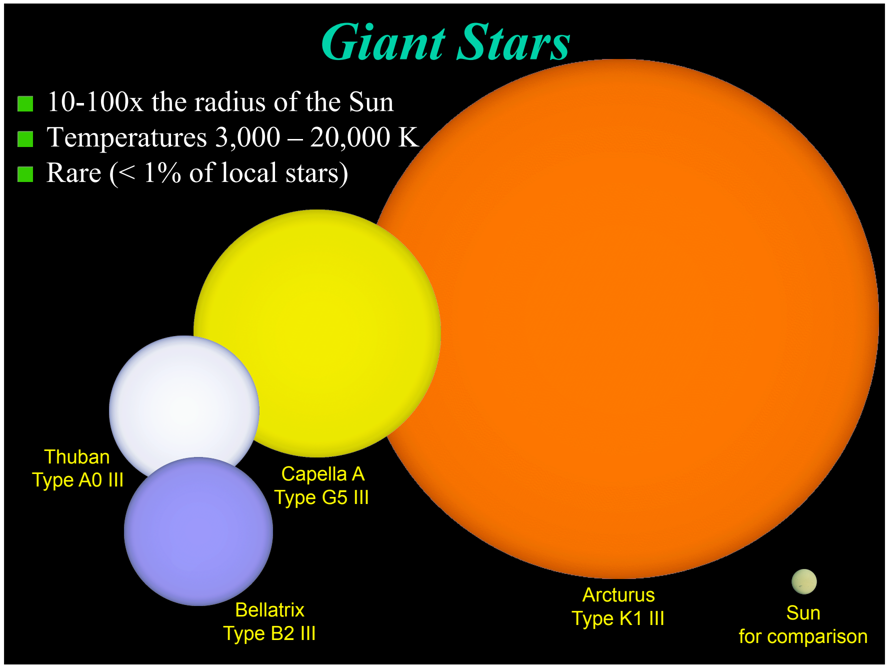
HR Diagram



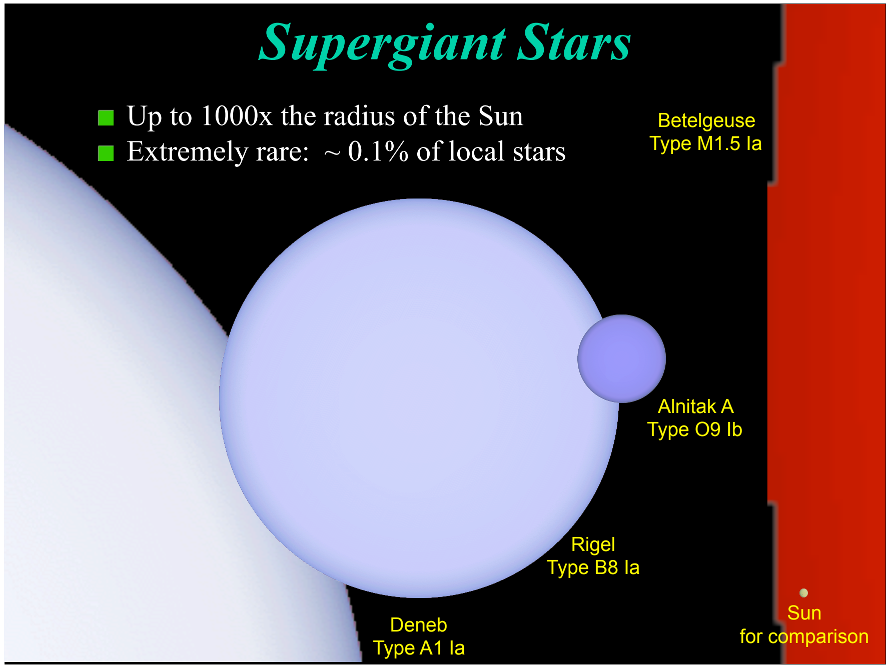
O B A F G K M
100R☉
1000R☉
10R☉
1R☉
0.1R☉
0.01R☉
0.001R☉
Alnilam
Rigel A
Betelgeuse
Adara
Deneb
Antares
Spica A
Polaris
Supergiants
Spica B
Canopus
Rigel B
Capella A
Arcturus
Mira
Capella B
Aldebaran A
Main sequence
Vega
Sirius A
Giants
Altair
Pollux
Procyon A
Sun
α Centauri B
Aldebaran B
Sirius B
40 Eridani B
Wolf 1346
White dwarfs
Procyon B
Barnard's Star
Red dwarfs
Van Maanen's Star
Wolf 486
Note: Star sizes are not to scale.
L/L☉
M_v
Temperature (K)
30,000 20,000 10,000 5000 3000 2000



Main Sequence Stars
a.k.a. dwarf stars
91% of all nearby stars
Altair
Type A8 V
Vega
Type A0 V
Sun
Type G2 V
61 Cygni A
Type K5 V
Proxima Centauri
Type M5 V
Regulus
Type B3 V



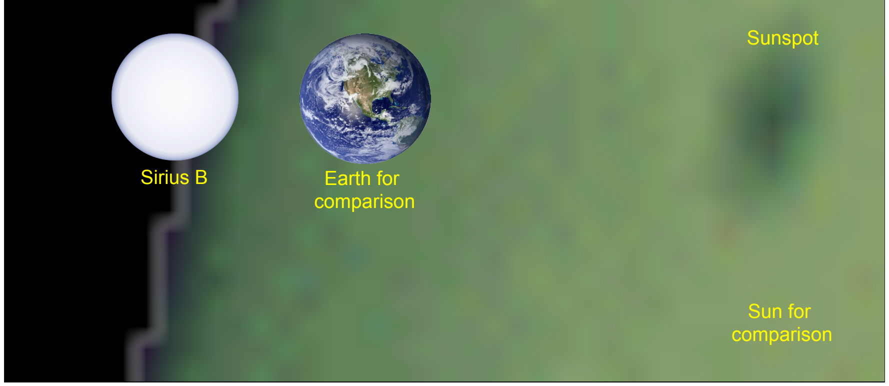
Giant Stars
10-100x the radius of the Sun
Temperatures 3,000 – 20,000 K
Rare (< 1% of local stars)
Thuban
Type A0 III
Capella A
Type G5 III
Bellatrix
Type B2 III
Arcturus
Type K1 III
Sun
for comparison



Supergiant Stars
Up to 1000x the radius of the Sun
Extremely rare: ~ 0.1% of local stars
Betelgeuse
Type M1.5 Ia
Alnitak A
Type O9 Ib
Rigel
Type B8 Ia
Deneb
Type A1 Ia
Sun
for comparison

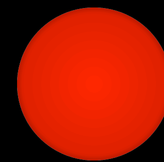
White Dwarf Stars

- 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

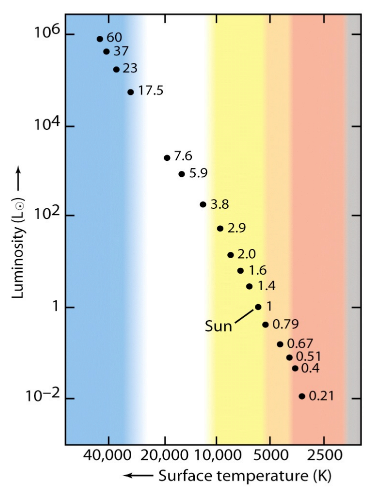
Sirius B

Black dwarf
A very old cooled white dwarf

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

The Mass-Luminosity Relationship

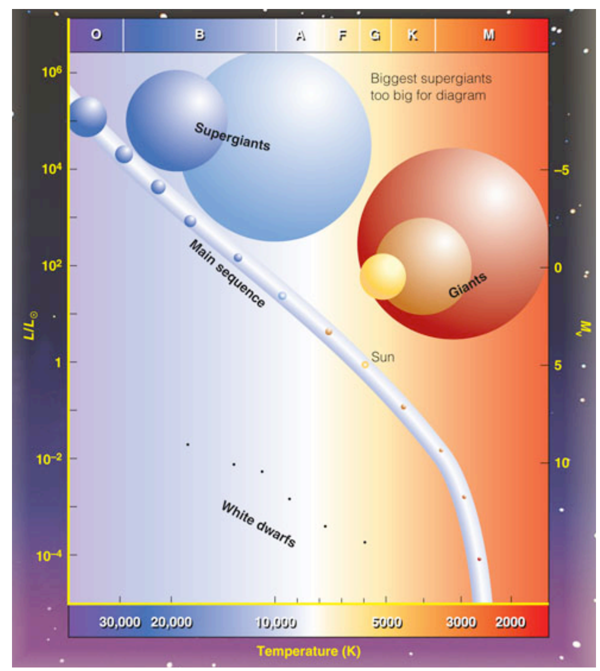
- Luminosity is proportional to Mass
- Larger range in luminosity than mass (10^6 vs. 100)
- Higher mass = higher luminosity, higher temp, and large radius
- Lower mass = lower luminosity, lower temp, and smaller radius
- Only on Main Sequence!



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

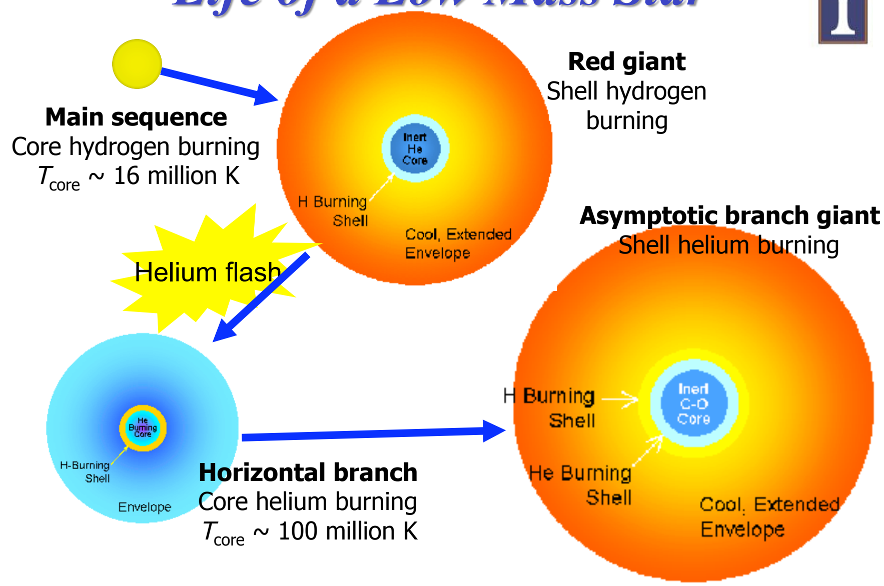
A massive star on the main sequence is where on the HR diagram?

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

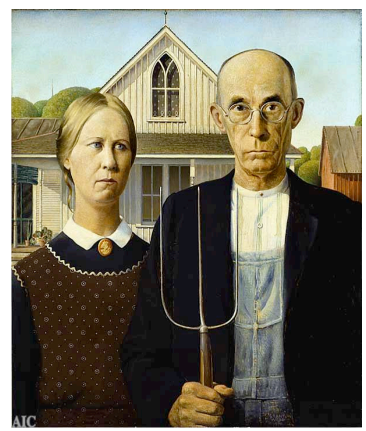
Lifecycle of a Star

- 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

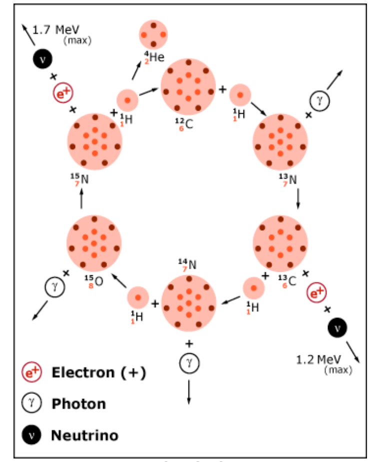
table 21-1 Approximate Main-Sequence Lifetimes

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).

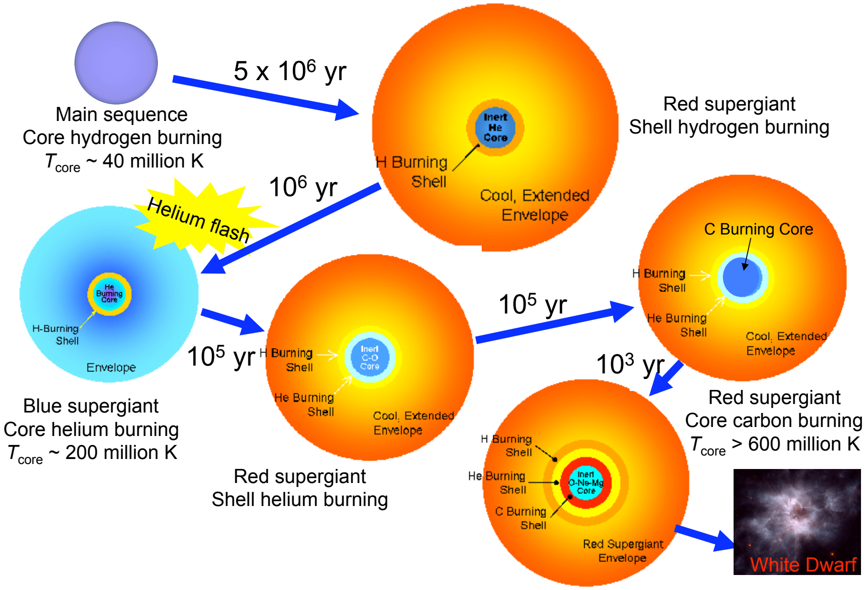
More than one way to fuse

- 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



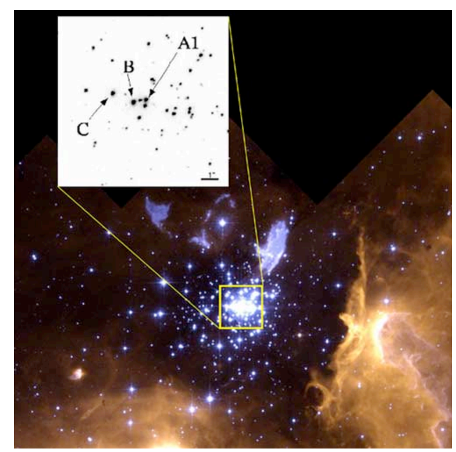
The CNO Cycle

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



For High Mass Stars

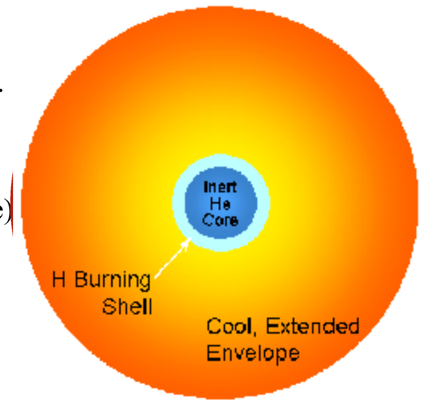
- For stars with an <u>initial mass</u> of more than 10 solar masses
- The final state will no longer be a white dwarf.
- Let's follow more carefully the life path of a high mass star– it's short sweet and ends with a bang!



A1: A 150 solar mass star!

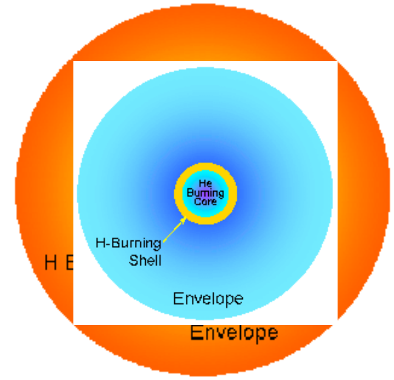
When the Hydrogen Runs out?

- 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**



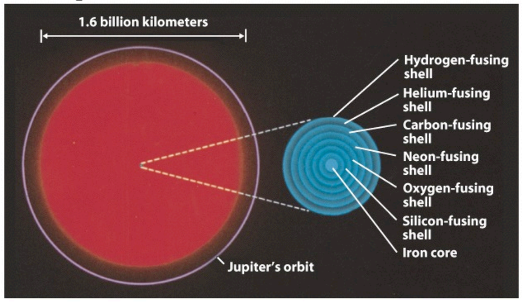
Question

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.

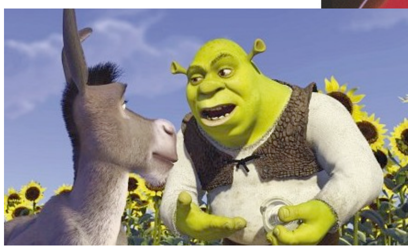
Massive Stars: Cycles of Fusion

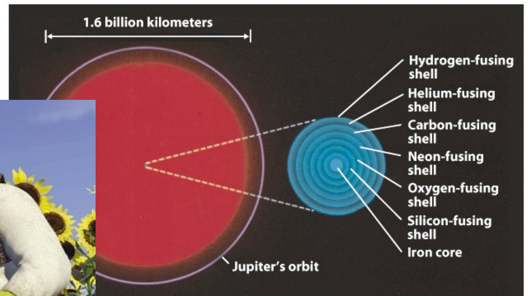
- Helium fusion is not the end for massive stars
- Cycles of core contraction, heating, ignition
- Ash of one cycle becomes fuel for the next
  - hydrogen ⇨ helium
  - helium ⇨ carbon & oxygen
  - carbon ⇨ neon, sodium, & magnesium
  - neon ⇨ oxygen & magnesium
  - oxygen ⇨ silicon & sulfur
  - silicon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



Massive Stars: Cycles of Fusion

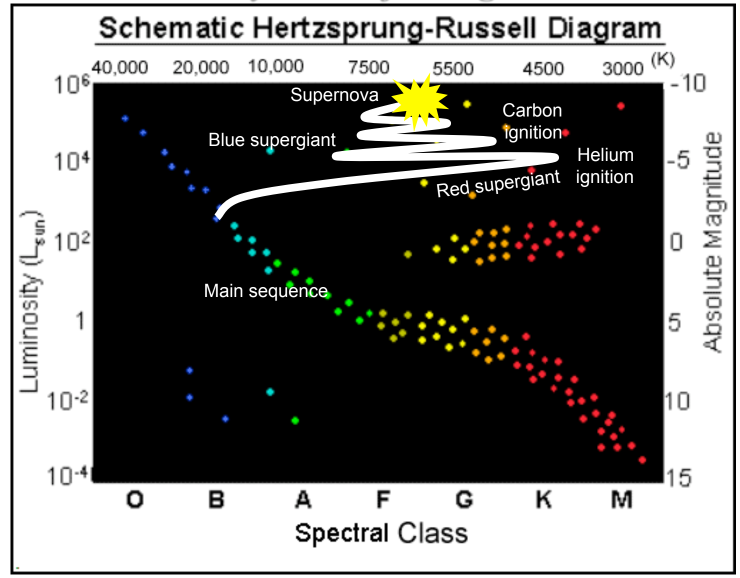
- Onion-skin like structure develops in the core
- Has layers…. like an Ogre..



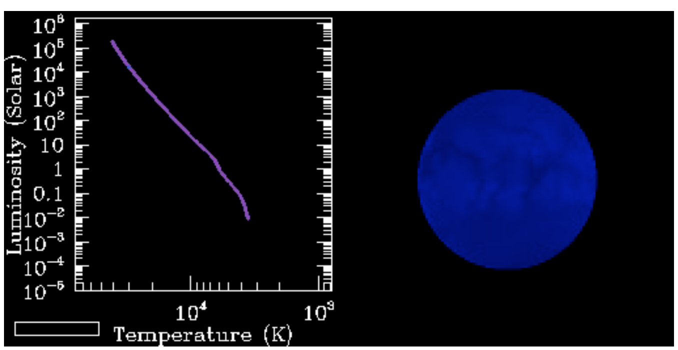


http://servantsthoughts.blogspot.com/2007/08/onion-theory.html

Evolutionary Path of a High-Mass Star



High Mass Stars (15 M_{sun})



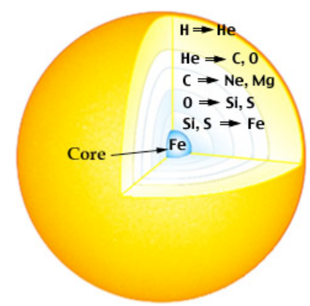
http://rainman.astro.uiuc.edu/ddr/stellar/index.html

Iron – The End of the Road

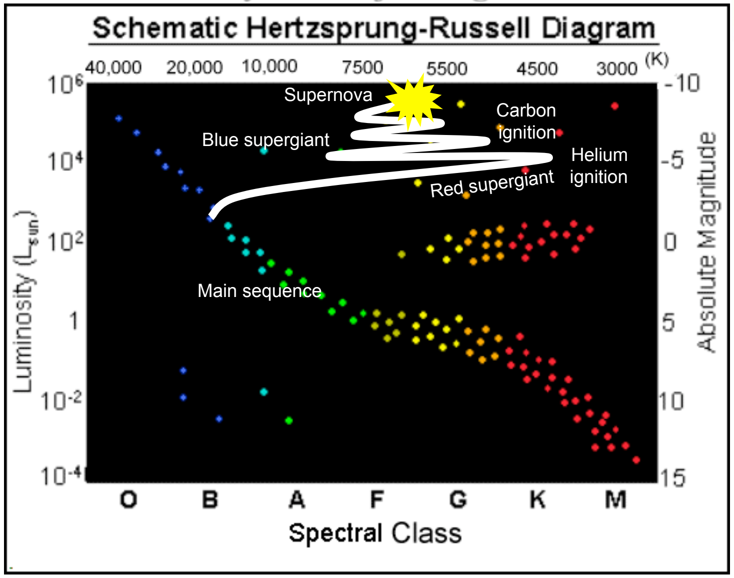
- Supergiants "burn" heavier and heavier atoms in the fusion process
- Each stage faster than the last
- After iron - no fuel left!
  - It requires energy to produce heavier atoms

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 25M_{Sun} star

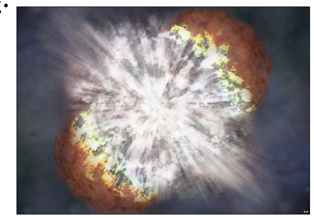


Evolutionary Path of a High-Mass Star

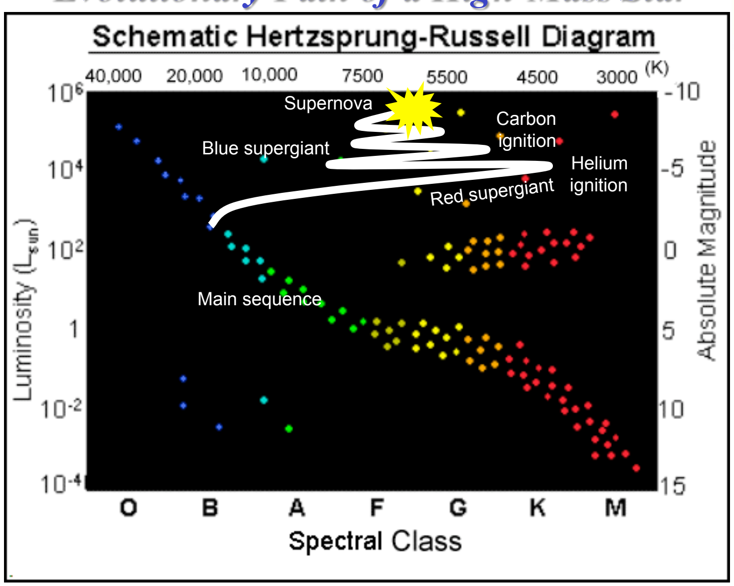


Core Collapse

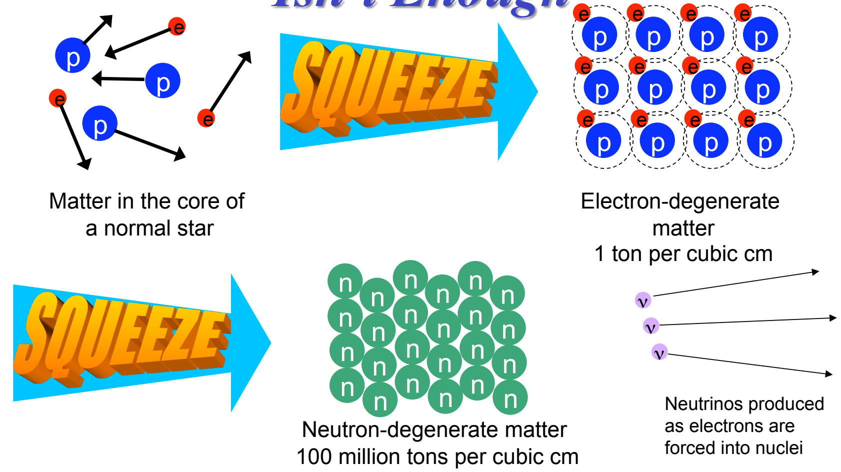
- Completely out of gas!
- Hydrostatic equilibrium is <u>gone</u>.
- The iron core of the star is supported by electron degeneracy pressure
  - Same pressure that supports a white dwarf
- Eventually, gravity wins…
  - This happens when the core is > 1.4 solar masses and no more outward pressure.
  - Remember the Chandrasekhar limit



Evolutionary Path of a High-Mass Star



When Electron Degeneracy Just Isn't Enough



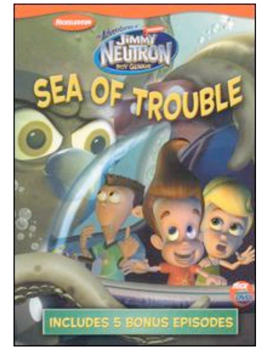
Question

What is the force that supports a white dwarf but can not support a massive stellar core.

a) Pressure from fusion
b) Pressure from CNO fusion
c) Electron degeneracy pressure
d) Gravity pressure
e) Neutron degeneracy pressure

Core Collapse

- When core is greater than 1.4 M_{sun} – **core collapse!**
  - From 1,000 km across to 50 km in *1/10th of a second*
  - ***Nearly 10% speed of light!***
- The core is transformed into a sea of neutrons
  - Electrons are squeezed into protons, neutrinos released
  - High energy gamma rays produced
  - The core has nuclear density!
  - It Earth has same density, it would be 1000 feet in diameter

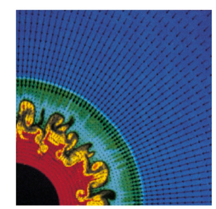


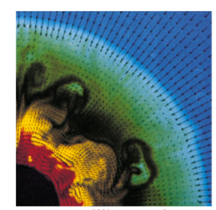
Core Collapse

- Core suddenly collapsed
- Envelope has nothing left to stand on
- Envelope falls at significant fraction of the speed of light, slamming into compressed core

Supernova!

- Hitting the compressed core is like hitting a brick wall and the envelope gas reverses direction– blow-back.
  - But, by itself not enough to destroy star.
  - Material is so dense, that it is slightly opaque to the neutrinos produced
  - And 10^{58} neutrinos!
  - Neutrinos give the shock a “kick”
  - Rips the outer layers of the star apart
- Star explodes in a <u>supernova</u>


10 milliseconds


20 milliseconds

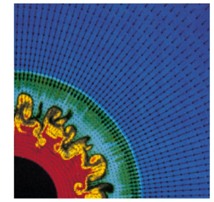
Supernova!

http://www.spacetelescope.org/images/screen/heic0609c.jpg

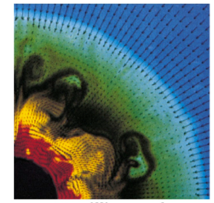
- The lifetime battle against gravity is lost.
- The core collapses under its own weight.
- Much of the mass of the outer region of the star, bounces back into space.

Supernova!

- The energy is enormous! The visible light is around only 1% of the energy output!
  - 99% of the energy in the form of neutrinos
- > 90% of the mass of star is ejected into space!
  - Fast, hot,

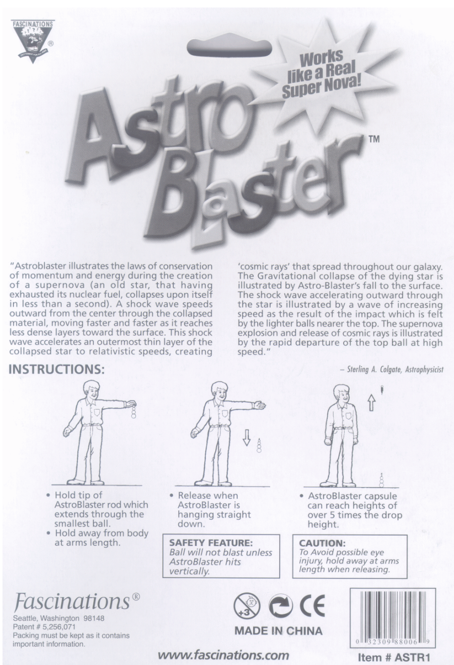


10 milliseconds



20 milliseconds

AstroBlaster!



Question

In the astroblaster demo, what did the little red ball represent?

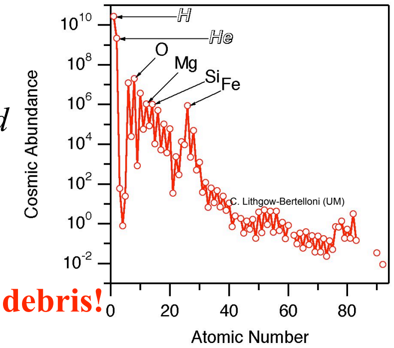
a) The inner core of the massive star
b) The envelope of the massive star
c) A low-mass stellar companion to the high mass star.
d) Iron.

Game Over!

http://www.youtube.com/watch?v=8MHb6_35XJM

Making Heavy Elements

- The star goes **supernova** and explodes. Some of C, O, P, S, Si, and Fe get carried away. At this point, even heavier elements can be made during energy consuming fusion reactions
- These by-products are *blasted* into space (>90% of star)
- Supernovae provide much of the building blocks for planets… and us!
- **We are recycled supernova debris!**
- **We are Star stuff.**

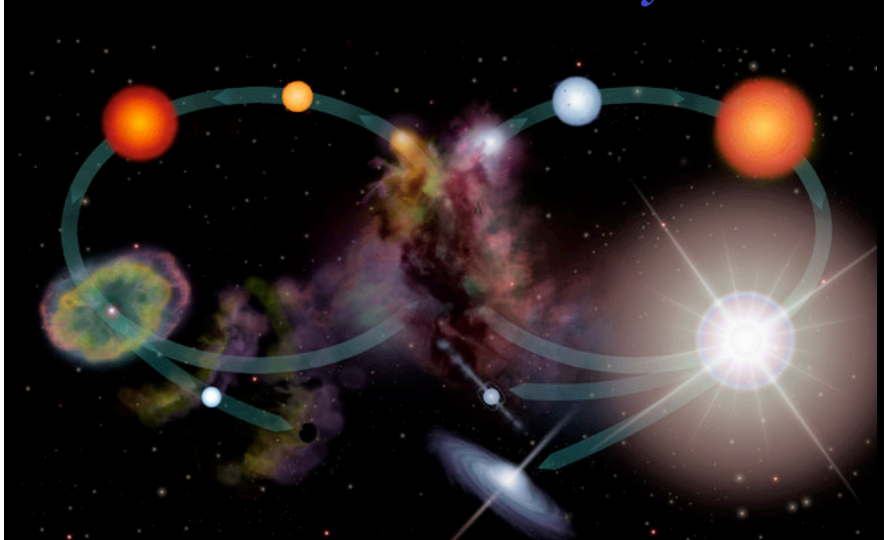


http://www.youtube.com/watch?v=ptwEV0xhTzI&feature=related

Delenn, B5

2:00 - 3:06

Stellar Evolution Re-Cycle



http://www.youtube.com/watch?v=2afotzgrFbE