Astronomy 122

This Class (Lecture 18):

Explosions to Neutron Stars

Next Class:

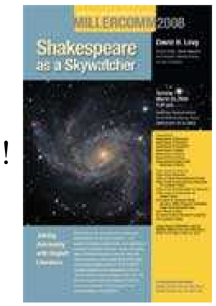
Black Holes Don't Suck

HW #7 due on Sunday

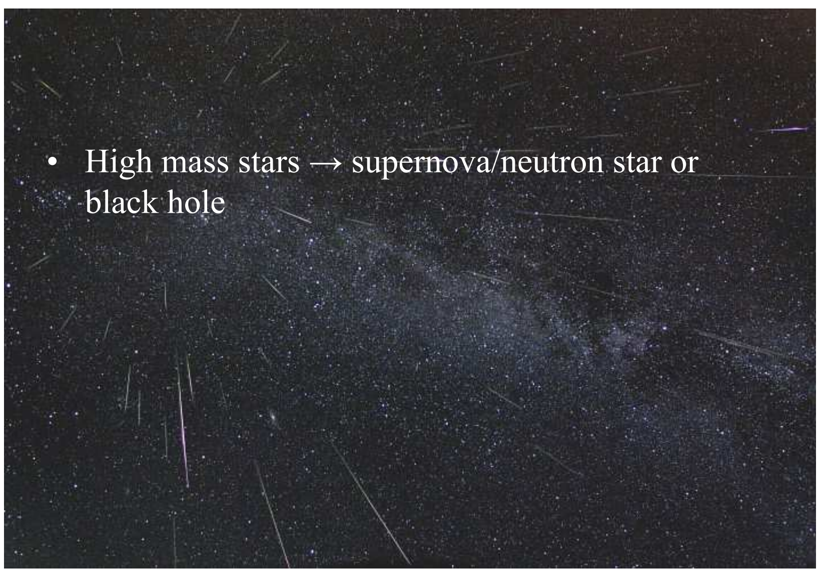
Music: *Supernova* – Liz Phair

Extra-Credit

- The famous amateur astronomer David Levy (ever heard of the Shoemaker-Levy comet?) will be giving a talk on campus tonight.
  - Shakespeare as a Skywatcher: Joining Astronomy with English Literature (Beckman at 7:30pm)
- Go and write a 1-2 page **typed** report that includes:
  1) Summary of the cool ideas
  2) What aspect did you find really interesting?
  3) Relate somehow to class topics.
- Turn in to your discussion section by April 2nd, then you can earn up to 0.5% on your final grade!

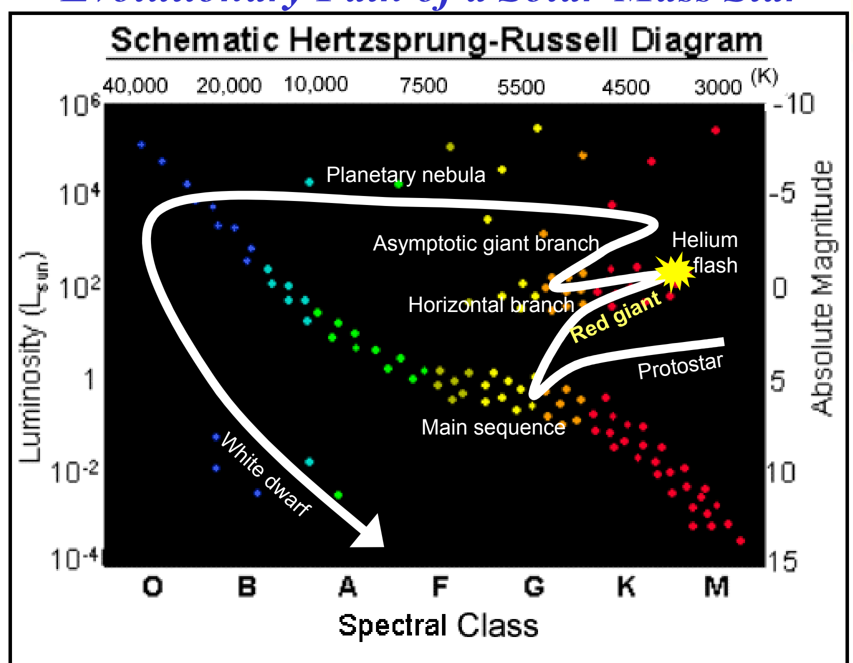


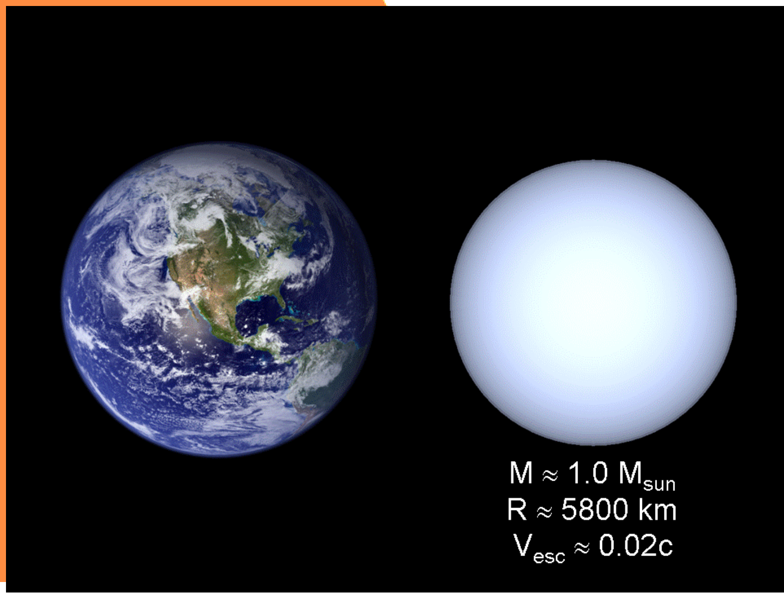
Outline



- High mass stars → supernova/neutron star or black hole

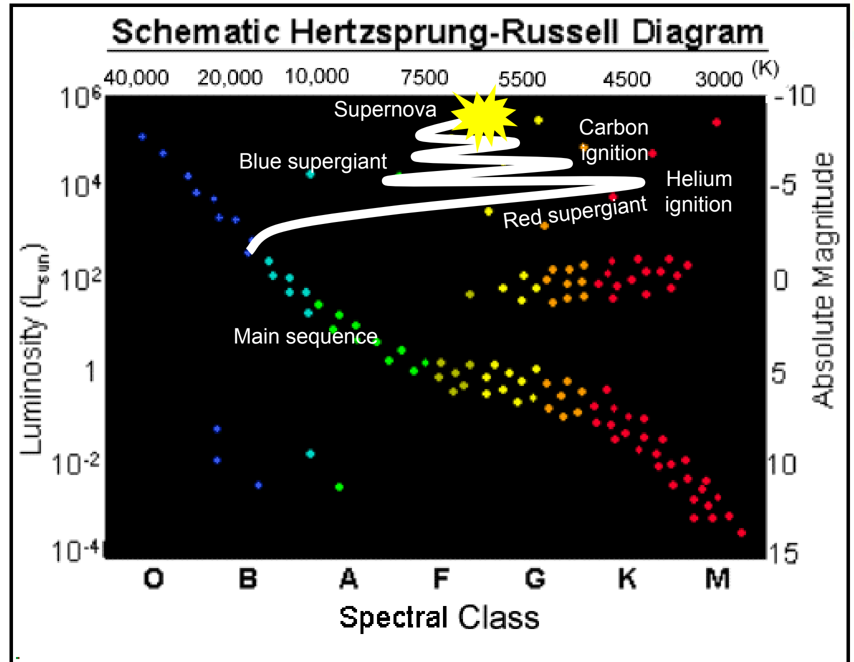
Evolutionary Path of a Solar-Mass Star





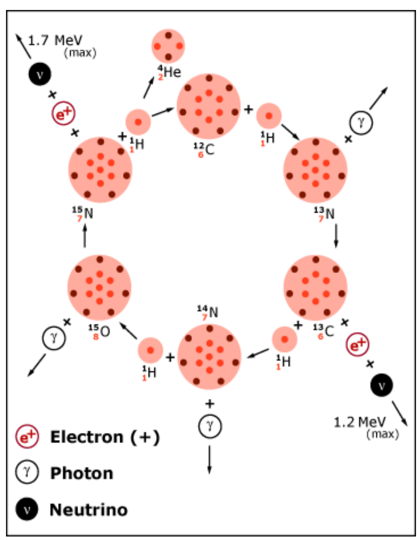
In 5 Billion years…

Evolutionary Path of a High-Mass Star



More than one way to fuse

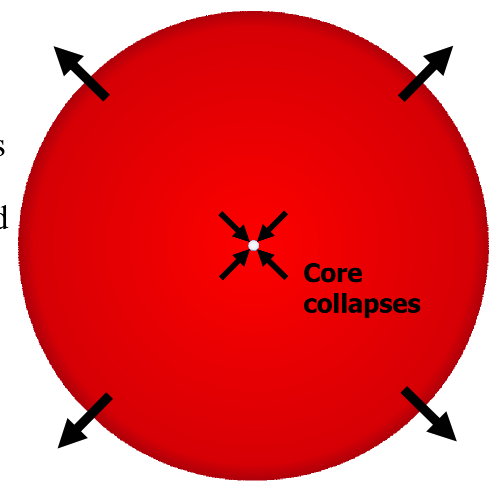
- High-mass stars do fusion by a second process
- Called the *CNO cycle*
  - Still converts 4 hydrogens into 1 helium
  - Uses a carbon nucleus as a catalyst
- Requires very high temperatures in the core
  - More than low-mass stars (like the Sun) can produce



The CNO Cycle

When the Hydrogen Runs out?

- Similar to lower-mass stars in the first few stages
- 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**



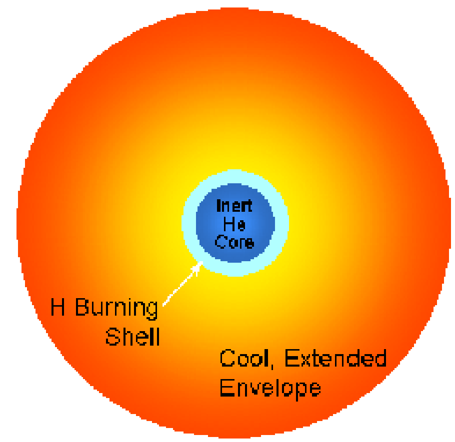
Question

What causes any star to leave the main sequence?

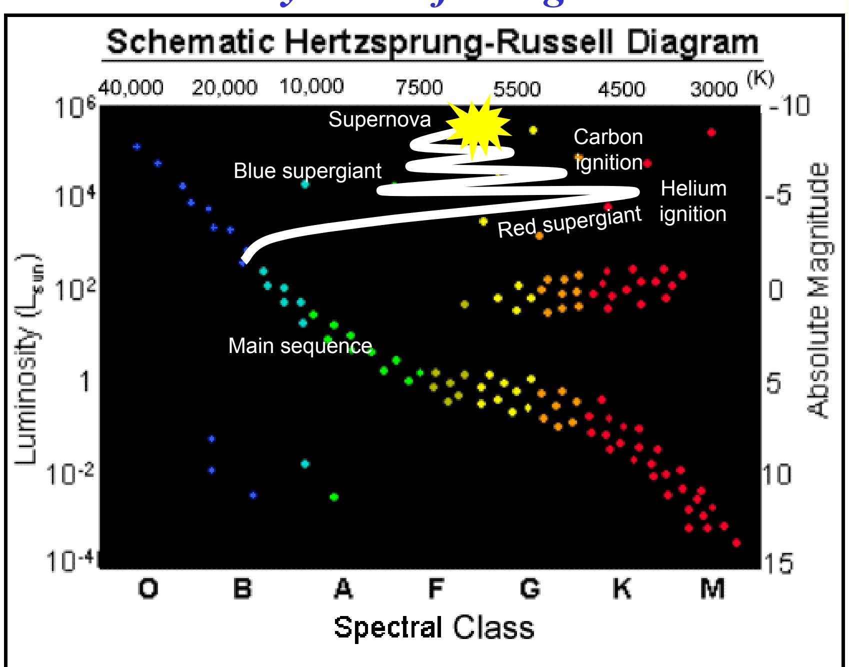
a) Just gets tired of the main-stream lifestyle.
b) Runs out of hydrogen in the core.
c) Runs out of helium in the core.
d) A shell around the core begins to burn helium.
e) A shell around the core begins to burn hydrogen.

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**

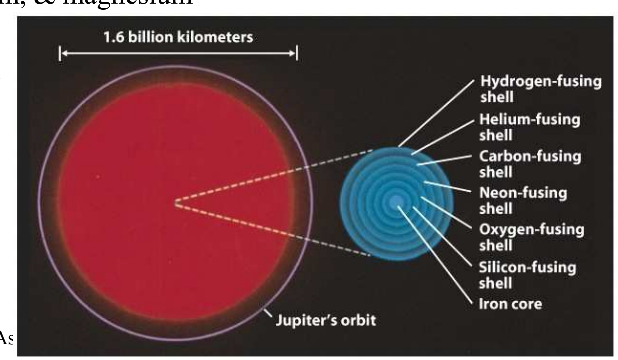


Evolutionary Path of a High-Mass Star



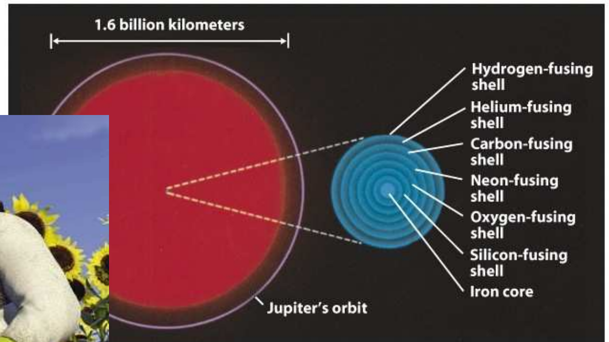
Massive Stars: Cycles of Fusion

- 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



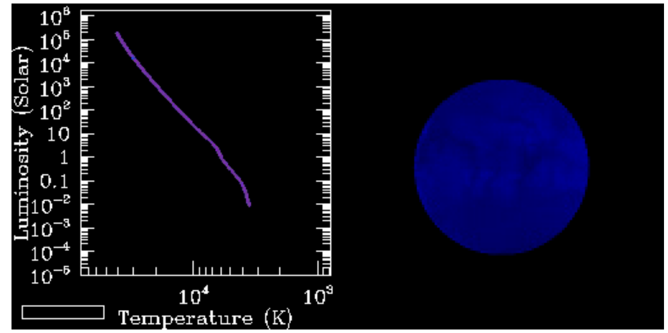
Massive Stars: Cycles of Fusion

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



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

High Mass Stars (> 8 M_{sun})

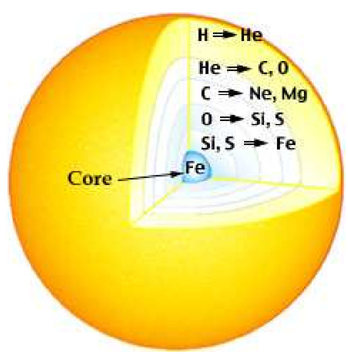


Iron – The End of the Road

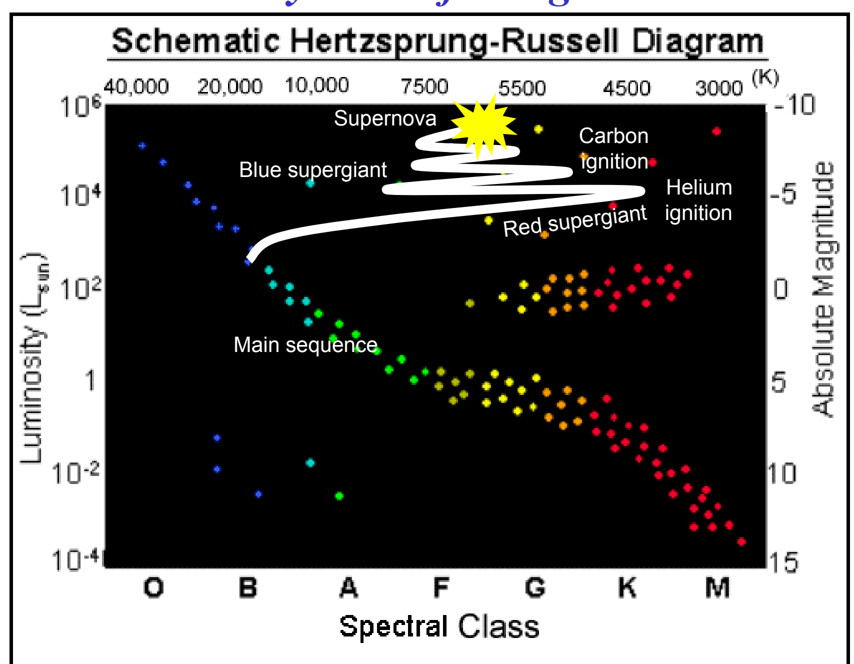
- Supergiants "burn" heavier and heavier atoms in the fusion process
- Each stage faster than the last
- After iron - no fuel left!
  - It requires energy to produce heavier atoms

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



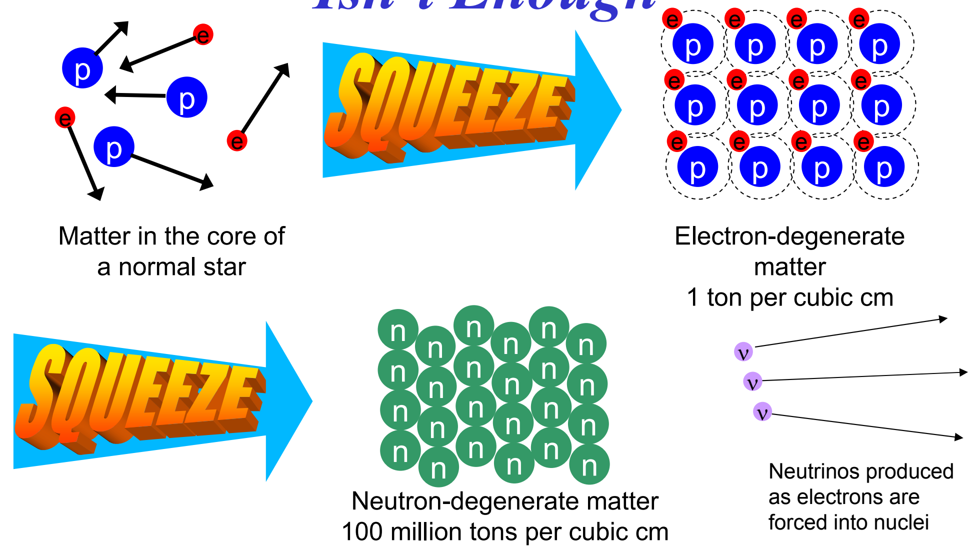
Evolutionary Path of a High-Mass Star



Core Collapse

- Completely out of gas!
- Hydrostatic equilibrium is gone.
- 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 reaches 1.4 solar masses
  - Remember the Chandrasekhar limit

When Electron Degeneracy Just Isn't Enough



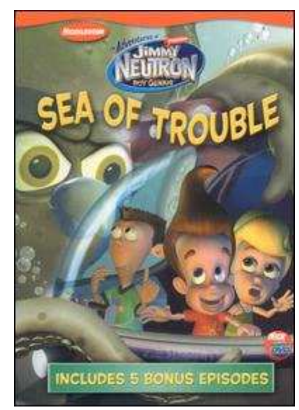
Question

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 decency pressure

Core Collapse

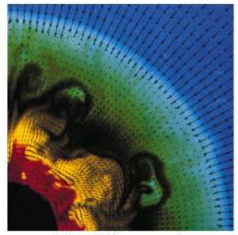
- When core is greater than 1.4 M_{sun} – **core collapse!**
  - From 1,000 km across to 50 km in *1/10th of a second*
  - ***Nearly 10% speed of light!***
- The core is transformed into a sea of neutrons
  - Electrons are squeezed into protons, neutrinos released
  - The core has nuclear density!
 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



Supernova!

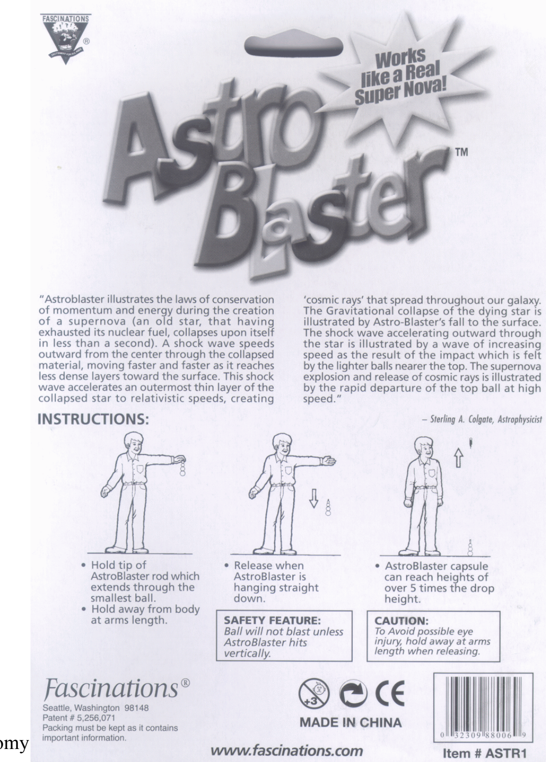
- During collapse, part of the core rebounds and produces a shock wave
  - Material is so dense, that it is opaque to the neutrinos produced
  - Neutrinos give the shock a "kick"
  - Rips the outer layers of the star apart
- Star explodes in a **supernova**
- Releases a tremendous amount of energy
  - 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.
e) Vitamin C

Game Over!

Supernova!

- 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.

Death throes

- What triggers a supernova?
  - Hydrostatic equilibrium is lost, gravity wins
  - Iron core with $M > M_{Chandra}$
- What happens?
  - Quick core collapse overcoming electron degeneracy pressure.
  - Outer layers rebound off the core, explosion of envelope
- What are end products?
  - Enriched ejecta and compact neutron star (if core mass < 3 solar masses)

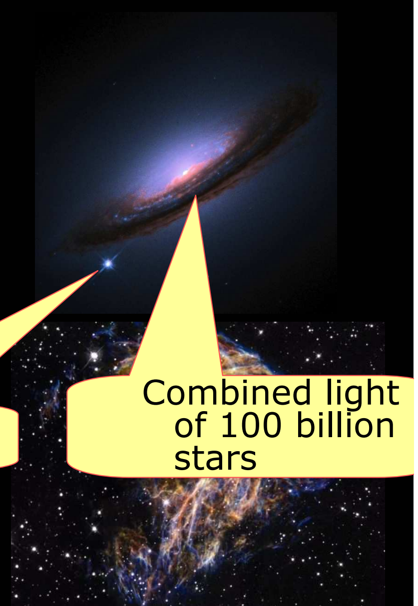
Supernova Explosions

The Death of Massive Stars
>10 M_{sun}

- Spectacular
- Rare
- Crucial for life
  ...but don't get too close...

What do we see?

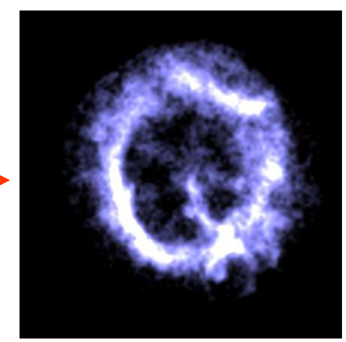
- Bright: can outshine galaxy
- Rapid changes in time:
  max in days
  dims over w
- Shock wa
  Fast, ultra-hot gas



How Close is Too Close?

Minimum safe distance:
About 30 light years
Note: nearest star is 4 light years

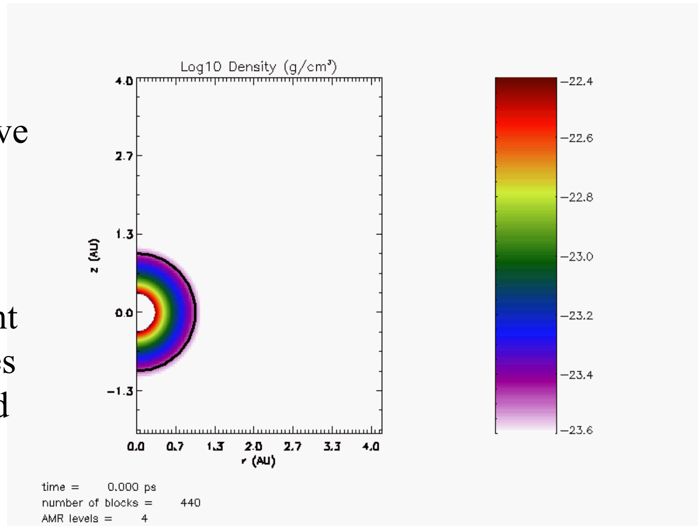
30 light years



Q: ill effects of cosmic WMD?

Cosmic WMDs

- Death of a nearby massive star would be bad news.
- Explosion within 30 light years modifies the solar wind

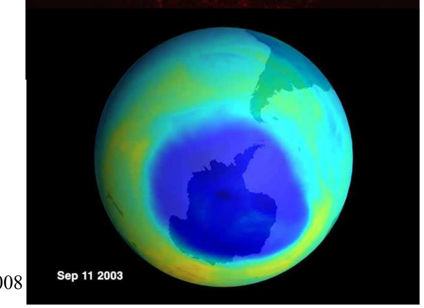


Surgeon General's Warning:
Supernovae are Dangerous to Your Health!

mass extinction due to SN

DNA damage due to high-energy particles (neutrinos)

Radiation damage to atmosphere
- Destruction of ozone layer
  …which is bad because?…
- No protection from ultraviolet (UV) light
- Then Sun's UV unfiltered
- Kills small plants/bacteria at bottom of food chain
- Damage all the way up



Supernova Explosions Near Earth

In our Milky Way galaxy:
- About 1 SN/century
- Most far away: spectacular but harmless

Now: no nearby massive stars

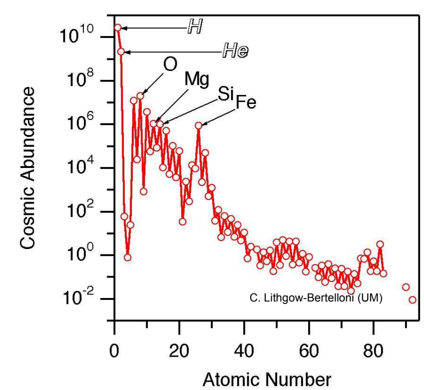
Sleep well tonight!

But over the 4.5 billion year history of Earth:

Many nearby events!

Making Heavy Elements

- During the explosion, energy-consuming fusion reactions are possible
- Heavy elements up to plutonium (& beyond?) are produced
- Dominant product: iron

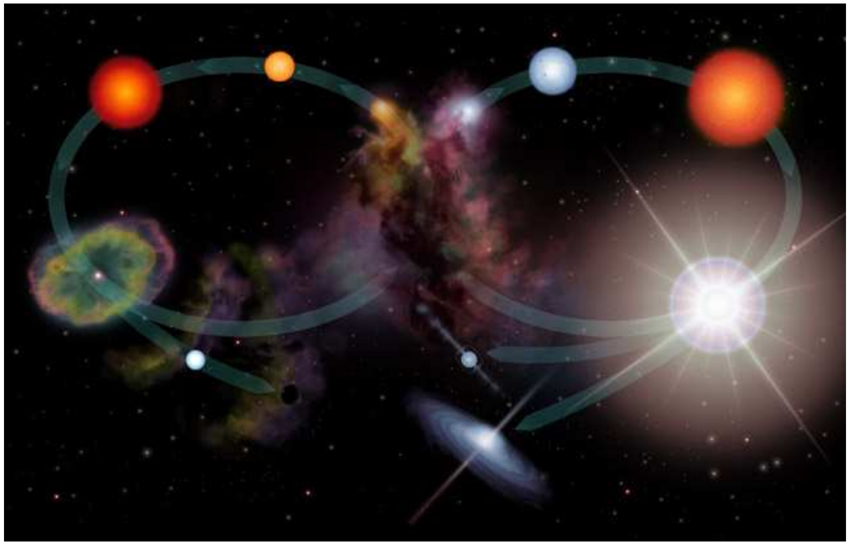


Making Heavy Elements

- These by-products are *blasted* into space (>90% of star)
- Ejection is fast, hot, and enriched.
- Supernovae provide much of the building blocks for planets… and us!
- **We are recycled supernova debris!**
- **Star stuff.**

Delenn, B5

Stellar Evolution Re-Cycle



Question

Why are we star stuff?

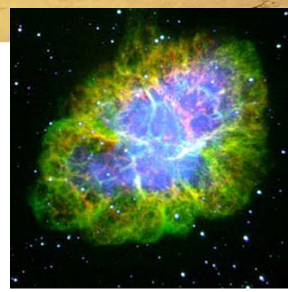
a) We are all going to Hollywood.
b) We are made up of small bits and pieces of stars.
c) We use fusion for power.
d) We have the elements that were forged in the interior of stars.
e) We are just stuff.

Stellar Evolution Cycle

- Stars form out of the interstellar medium
- They manufacture helium, carbon, nitrogen and more in their interiors by nuclear fusion
- Heavier elements (iron, lead, uranium, etc..) are made by supernovae
- Stars give these processed materials back to the interstellar medium when they die
- The processed materials are included in the gas and dust out of which the next generation of stars and planets will form

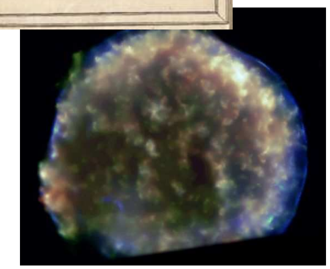
Supernova Explosions in Recorded History

- 1054 AD
- Europe: no record
- China: "guest star"
  - So bright, could see it during the day for most of July.
- Anasazi people
  - Chaco Canyon, NM
  - Rock Paintings
- Modern view of this region of the sky:
  - **Crab Nebula** — a supernova remnant
  - Massive star supernova

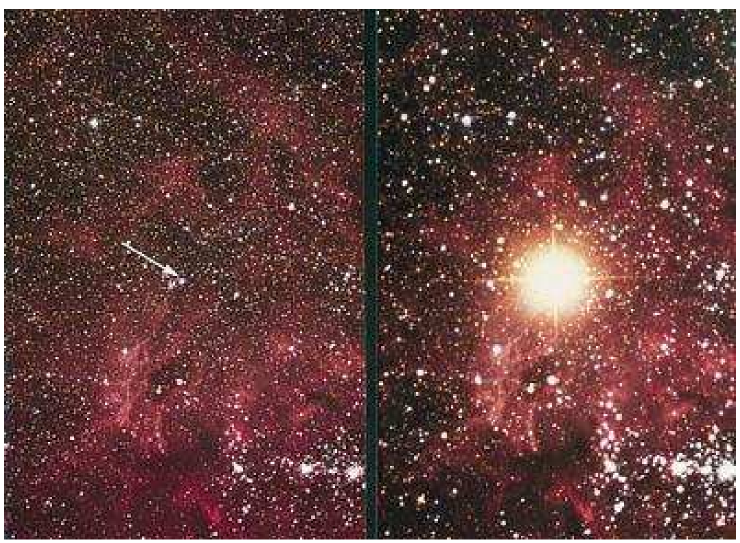


Supernova Explosions in Recorded History

- November 11, 1572
- Recorded by Tycho Brahe
  - Called it a **"nova stella"** (new star)
- For about two weeks the supernova could be seen in the daytime!
- Modern view (X-rays):
  - Tycho's Supernova Remnant
- Probably a white dwarf supernova (Ia)



Supernova 1987A

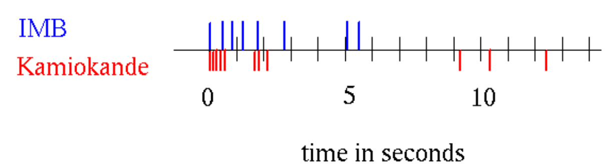


Before Feb. 23, 1987

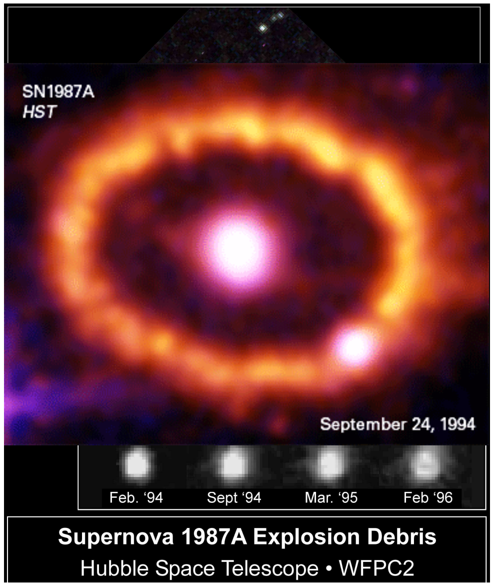
Original star was a B3 blue supergiant

Supernova 1987A

- Supernova are rare
- Only about ~3/century in a galaxy.
- Last was 400 yrs ago (Tycho)
- 1987A happened in the satellite galaxy LMC (150,000 lyrs away)
- Star was about 20 $M_{\odot}$
- Detected neutrinos from the core (most of explosion energy) for 13 secs about 20 detected.



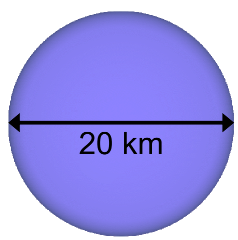
Supernova 1987A - Today



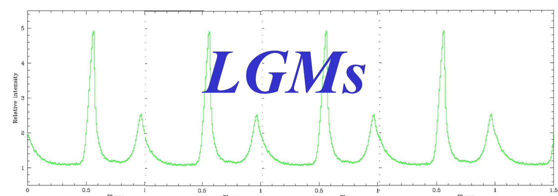
Supernova Leftovers

- What's left of the star's core after a massive star supernova?
- A **neutron star**
  - About 1.4 – 3 solar masses
  - Very small diameter – around 20 km!
  - Composed of a sea of neutrons
    - Supported by *neutron degeneracy pressure!*
    - Teaspoon of neutron star material on Earth would weigh almost 1 billion tons!!!!
  - Surface gravity – 200 billion times that on Earth
  - Escape velocity – half the speed of light

Relative Sizes of Stellar Corpses



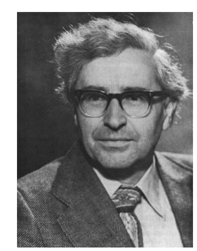
Neutron star



LGMs

- In the late 1960s, Jocelyn Bell discovered radio pulses from the constellation Vulpecula that repeated regularly
  - Every 1.337… seconds
- What could it be?
- Perfect timing, but no real encoding of signal.
- Jokingly called LGMs, then Pulsars.

Jocelyn Bell Burnell

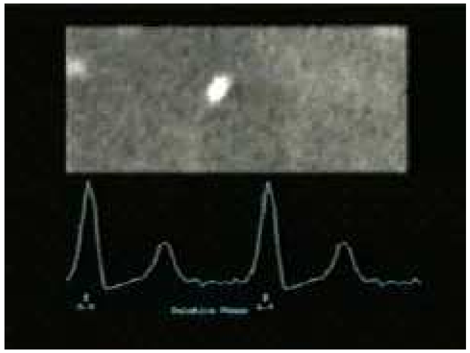


Anthony Hewish

http://www.radiosky.com/rspplsr.html

Pulsars

- What could it be?
  - Pulses were too fast to be a variable star
- A rotating star?



Pulsars

- Very precise, better than atomic clocks.
- Periods from 8.51s to 1.56 ms!
- Could they be something spinning?
  - Would have to be small to be spinning that fast
- They must be spinning neutron stars!