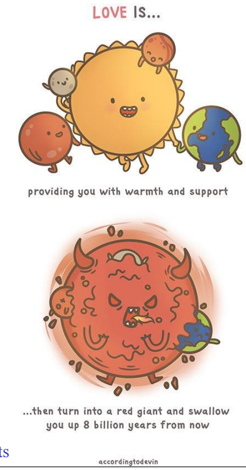
Astronomy 330:

Extraterrestrial Life



This class (Lecture 8):

Death of Stars

Next Class:

Origin of Planets

Jeff Lu

HW #2 due Sunday night.

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

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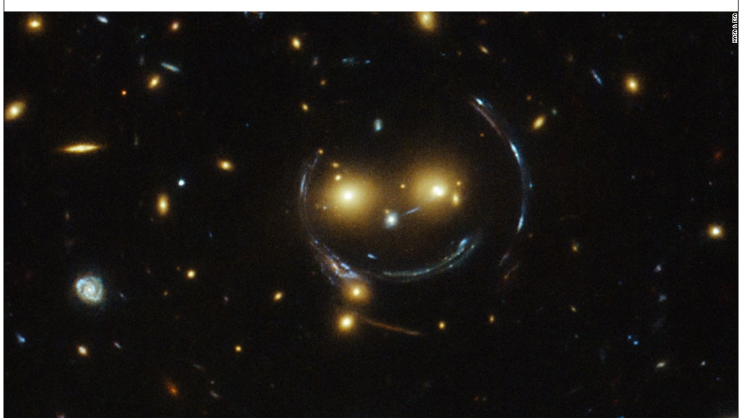
Gravity Lensing

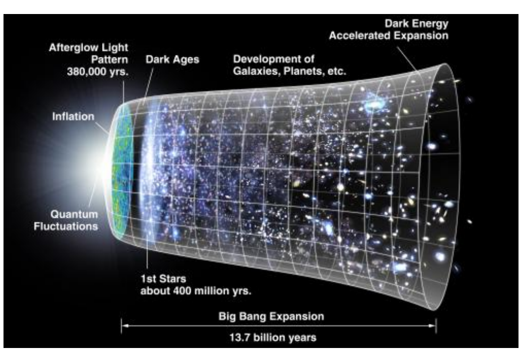


http://www.spacetelescope.org/images/potw1506a/
A smiling lens

A great image from our colloquium speaker this week: Keren Sharon: http://dept.astro.lsa.umich.edu/~kerens/

In the centre of this image, taken with the NASA/ESA Hubble Space Telescope, are two faint galaxies that seem to be smiling. You can make out two orange eyes and a white button nose. In the case of this "happy face", the two eyes are the galaxies SDSSCGB 8842.3 and SDSSCGB 8842.4 and the misleading smile lines are actually arcs caused by an effect known as strong gravitational lensing. Massive structures in the Universe exert such a powerful gravitational pull that they can warp the spacetime around them and act as cosmic lenses which can magnify, distort and bend the light behind them. This phenomenon, crucial to many of Hubble's discoveries, can be explained by Einstein's theory of general relativity. In this special case of gravitational lensing, a ring — known as an Einstein Ring — is produced from this bending of light, a consequence of the exact and symmetrical alignment of the source, lens and observer and resulting in the ring-like structure we see here.

No Big Bang?



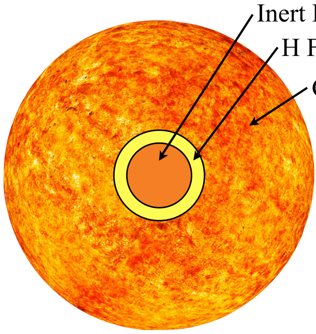
Science in action!

Nice write-up at: http://earthsky.org/space/what-if-the-universe-had-no-beginning

The press has "inflated" this somewhat. The headline really should have been "No Singularity at the Big Bang".

The idea for this paper is a mathematically based speculation of what happened at the time of the Big Bang. Remember I said we don't now too much less than 10^{-43} seconds before, and that is what they are trying to understand. The point isn't that there was not a big bang (hot and dense early time that has expanded ever since), but that there is no mathematical singularity (1/x is a singularity that "blows" up for small x) at the earliest time. In class I stayed away from the idea of a singularity and only used the size of the observable Universe at 10-43 seconds.) That is because it is not really thought to be a singularity anyway— even though the reason is not known. We assume that a theory combining quantum mechanics with general relativity in a mathematically consistent process will solve this at some time. I don't know if this paper's hypothesis will stand the tests, but we will see.

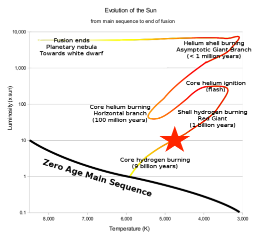
Red Giant Stage



Inert He Core

H Fusing in shell - **Energy released**!

Cool, extended envelope:
Expands and **Cools**!



Expansion takes 100 million years

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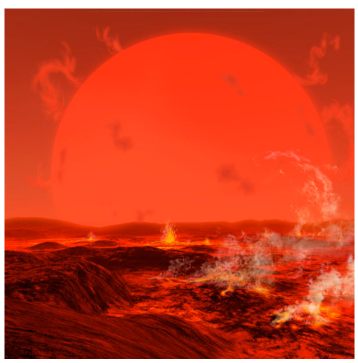
When the hydrogen is gone in the core, fusion stops. Equilibrium is shot. Core starts to contract under its own gravity. This contracting heats the core, and hydrogen fusion starts in a shell around the core. Energy is released, expands envelope ⇒ Lum increases!

Its the end of the world as we know it, and I feel fine!

- Even if Earth not swallowed
  - Evaporate Earth's oceans
  - Drive away its atmosphere
- Earth left a desiccated, dead planet with a surface of molten rock



Sunrise on Earth 5 billion years from now?

Even if the Earth is not swallowed up, conditions on its surface will become impossible for life to exist. The Sun's increased luminosity will heat the Earth's surface so much that the water oceans and atmosphere will evaporate away.

Whether or not the expanding sun becomes large enough to totally engulf Earth, its growing luminosity will certainly: Evaporate Earth's oceans Drive away its atmosphere Even vaporize much of Earth's crust and drive the vapor away into space

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Question

When the Sun goes Red Giant, humans can move where?

a) Nowhere, Earth will be fine.

b) Mars.

c) A moon of Jupiter.

d) A moon of Saturn.

e) Start packing, we should leave the solar system.

iClicker

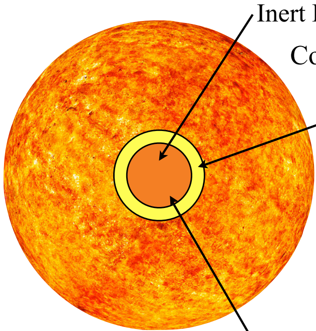
x

D

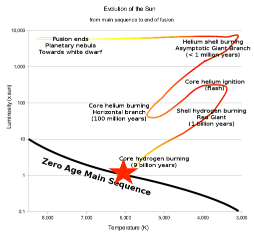
And Core Contraction+

Inert He Core grows

Core density grows and gets hotter.



H
Fusing
in shell



He → C & O

At 100 Million degrees F: Helium fusion beings in the core

Core gets hotter, and hotter, and hotter until…
100 million degrees F
Core heats ⇒ He fusion ignites

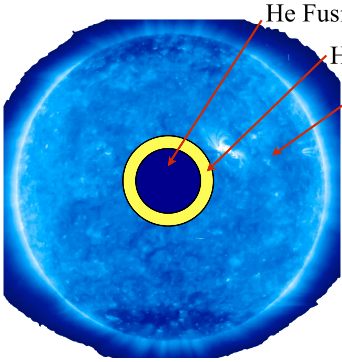
He ⇒ C & O

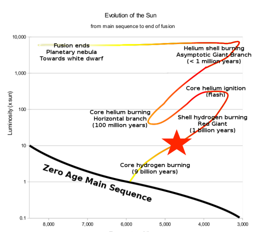
Horizontal Branch

He Fusion in Core

H Fusing in shell

Envelope





Horizontal Branch about 10% of Main Sequence lifetime

Helium burning stabilizes the core. The outer envelope shrinks, heats up, and dims slightly. But helium doesn't last very long as a fuel. Horizontal branch lifetime is only about 10% that of a star's main sequence lifetime. Our Sun will burn helium for about a billion years. Also He burning is unstable

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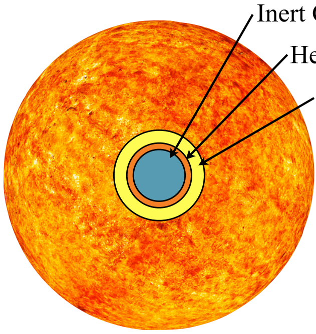
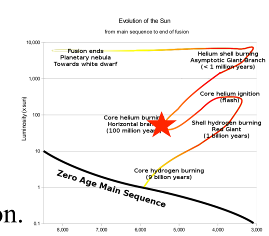
Asymptotic Giant Branch

Inert Carbon and Oxygen Core

He Fusing Shell

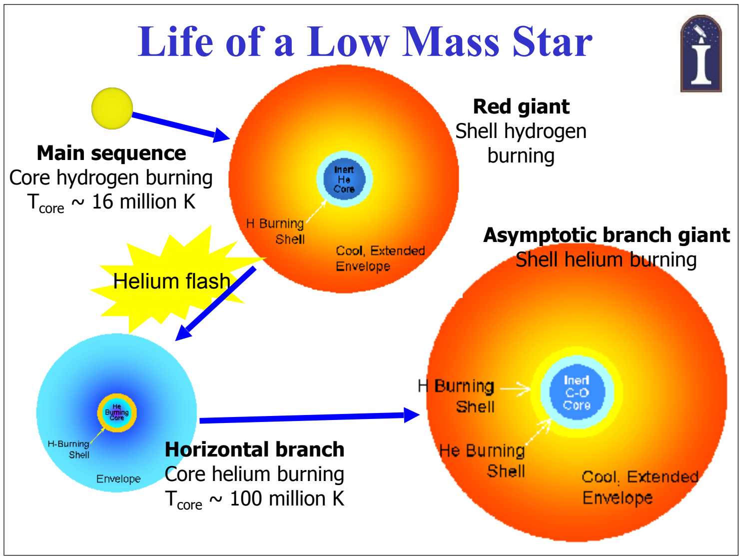
H Fusing in shell

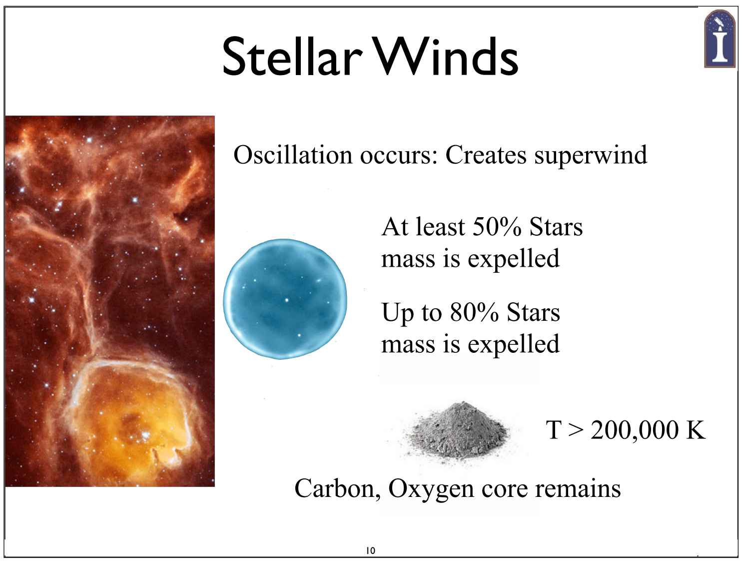




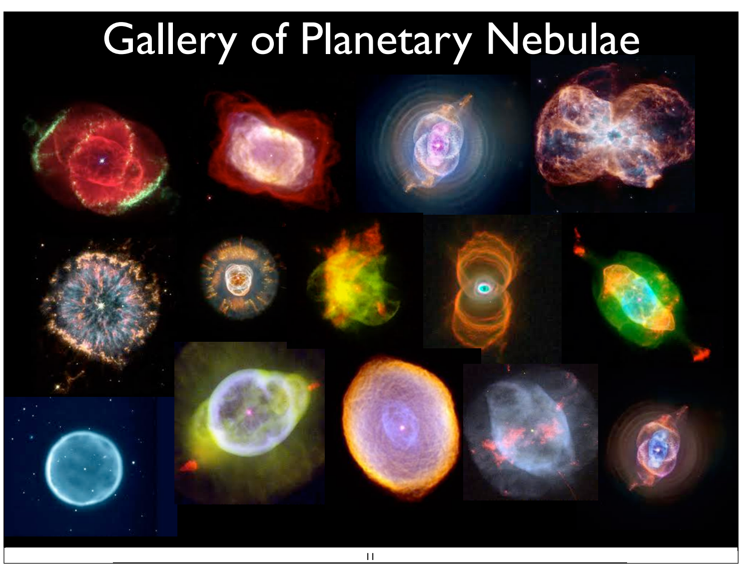
Core collapses, igniting shell He Fusion.
Envelope expands and cools: AGB

Fusion in the core stops – the helium has been converted to carbon and oxygen. Stellar core collapses under its own gravity. Shell starts fusing helium.
Star starts to grow and cool again. Called an asymptotic giant branch star.





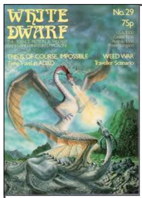
At these last stages, the Sun will likely oscillate in size and temperature. This is messed up and creates a "Superwind". Outer layers of the red giant star are cast off. Up to 80% (at least 50%) of the star's original mass.



Ultraviolet radiation from the core ionizes the cast off outer layers and becomes a planetary nebula. Unfortunate name, but some of the most beautiful objects in the sky.

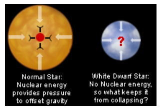
Planetary nebula have nothing to do with planets. Called that because they are round looking like planets.

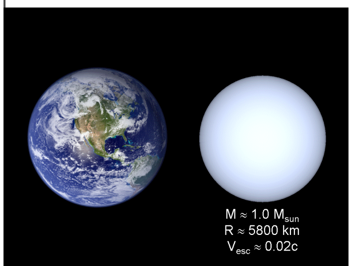
White Dwarf



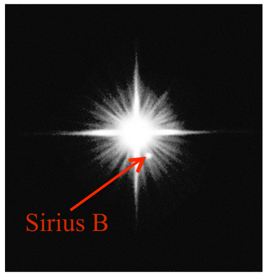
e^{-} degeneracy pressure

Hot body: slowly cools





Life?



"The core remains, made of carbon/oxygen "ash" from helium fusion. The core is very hot, above 200,000 K

Final fate – White dwarf. Slowly cools off over billions of years. Just a hot body. No fusion. Not really a star in some ways. Size of the Earth. Gravity crushes E/M forces, but electron degeneracy pressue— they can only occupy certain energy states— stops gravity for low mass stars. It won't be enough for more massive corpses.

We have detected planets around white dwarfs, but they have presumably had a hard time. If you were to visit the wasteland of Earth, the Sun would only be a very bright point of light. Not sufficient for life.

Question

When the Sun becomes a White Dwarf, we can

a) Live on Earth.

b) Live on Venus.

c) Live on Mars.

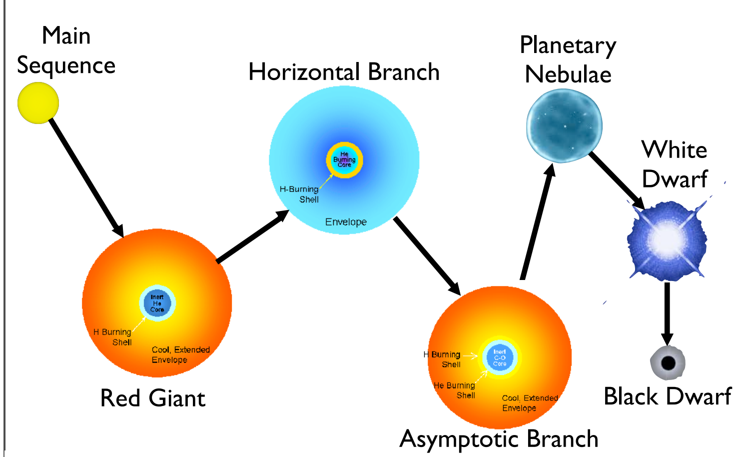
d) Stay in our new home far away.

e) Live on moons of Jupiter.

iClicker

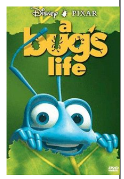
D

Stellar Lifecycle



Group Think

Low Mass Stars & Life

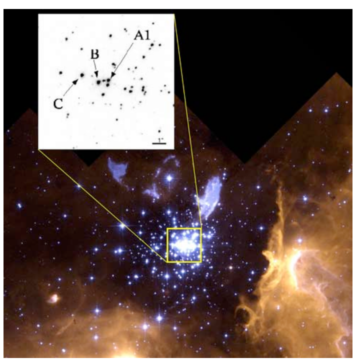


As a group, contemplate and share your thoughts about the impacts of the different stages of a low mass star's life

What do you think?

Why?

High Mass Stars

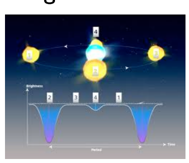


A1 = 114 times Solar Mass

B = 84 times Solar Mass

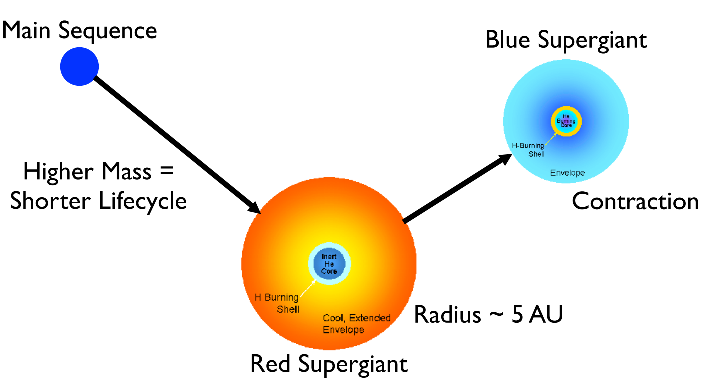
How?

Eclipsing binary
Edge-on orbit



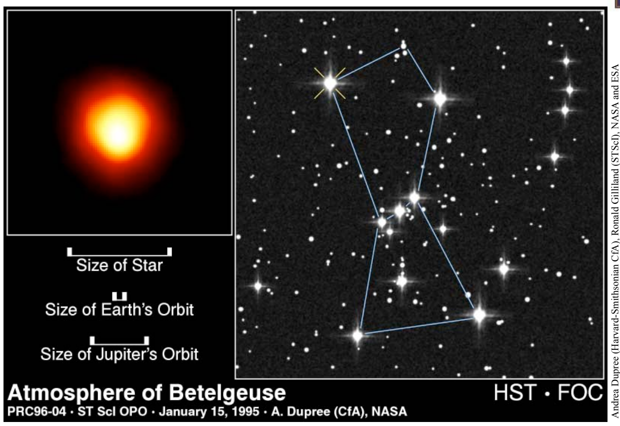
For stars with an initial mass of more than 10 solar masses
The final state will no longer be a white dwarf.
Let's follow more carefully the life path of a high mass star- it's short sweet and ends with a bang!

High Mass Stars



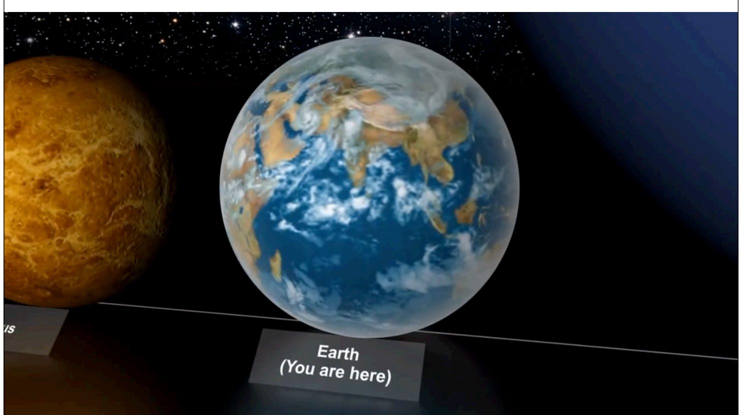
They consume the hydrogen in their cores, ignite hydrogen shells, and become giants or, for the most massive stars, supergiants. Their cores contract and fuse helium first in the core and then in a shell, producing a carbon-oxygen core.

Truly Supergiant Stars...



Big Betelgeuse! Red Supergiant.

Truly Supergiant Stars...

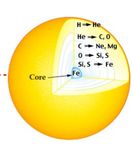


http://www.youtube.com/watch?v=HEheh1BH34Q

High Mass Stars

H → He
He → C O
C → Ne Na Mg
Ne → O Mg
O → Si S
Si → Fe

Contract → Heating → Ignition



Values for a $25M_{Sun}$ star

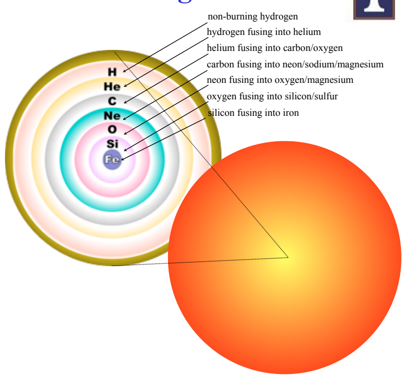
Stage	Temperature	Duration
H fusion	40 million K	7 million yr
He fusion	200 million K	500,000 yr
C fusion	600 million K	600 yr
Ne fusion	1.2 billion K	1 yr
O fusion	1.5 billion K	6 mo
Si fusion	2.7 billion K	1 day

Initial stages are similar to those of Sun-like star:
Main Sequence: H fuses to He in core
Red Supergiant: H fuses to He in shell around contracting He core
Blue Supergiant: He fuses to C in core

The fusion of the nuclear fuels goes faster and faster evolving rapidly. The amount of energy released per fusion reaction decreases as the mass of the types of atoms involved increases. To support its weight, a star must fuse oxygen much faster than it fused hydrogen. Hydrogen fusion can last 7 million years in a 25-solar-mass star. The same star will fuse its oxygen in 6 months and its silicon in just one day

Helium fusion is not the end for high mass stars

- Massive stars can fuse heavier elements--since they are hotter
- Cycles of core fusion, core contraction
  - Shell fusion occurs in layers around the core
  - Ash of one fusion becomes fuel for the next



The onion-like layers inside a supergiant star in the final stages of its life

Unlike medium-mass stars, massive stars finally can get hot enough to ignite carbon fusion at a temperature of about 1 billion Kelvin.

This pattern of core ignition and shell ignition continues with a series of heavier nuclei as fusion fuel.At higher temperatures than carbon fusion, nuclei of oxygen, neon, and magnesium fuse to make silicon and sulfur. At even higher temperatures, silicon can fuse to make iron. Thus, the star develops a layered structure. There is a hydrogen-fusion shell surrounding a helium-fusion shell surrounding a carbon-fusion shell, and so on

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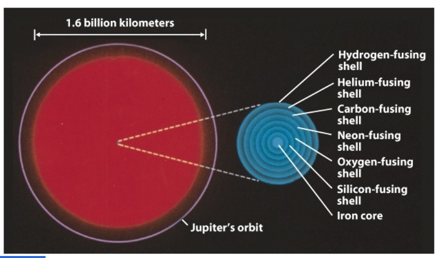
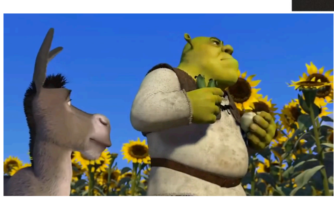
Massive Stars: Cycles of Fusion

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





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

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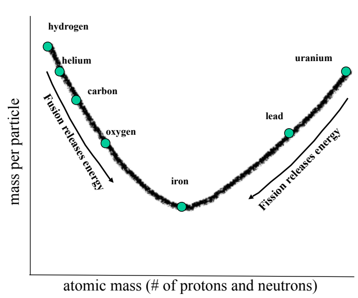
Iron - Dead End

- Final stage of core fusion: Silicon fusion produces iron
- The iron core is a dead end in the evolution of a massive star
- Nuclear reactions involving iron do not release energy
- They consume it!

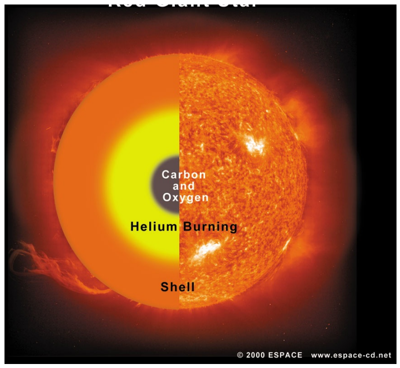


Neither fusion nor fission releases energy from iron

Once the gas in the core of the star has been converted to iron, there are no further nuclear reactions that can release energy. As a star develops an iron core, energy production declines, and the core contracts. Iron builds up in core until degeneracy pressure can no longer resist gravity.

Back to the First Stars

- In the internal furnace of these first stars is where carbon and oxygen are created for the first time in the Universe.
- Leading to the creation of sulfur, phosphorous, silicon, and finally iron.



In the cores of the first stars, it gets hot enough for nuclear fusion. In the internal furnace of these first stars is where carbon and oxygen are created for the first time in the Universe. Higher density and temperature of the red giant phase allows for the creation of sulfur, phosphorous, silicon, and finally iron.

Question

Iron (Fe) is the last element fused in the cores of massive stars, because

a) aliens harvest all heavier elements.

b) it is so heavy, nothing else can be made.

c) fusing heavier elements does not release energy.

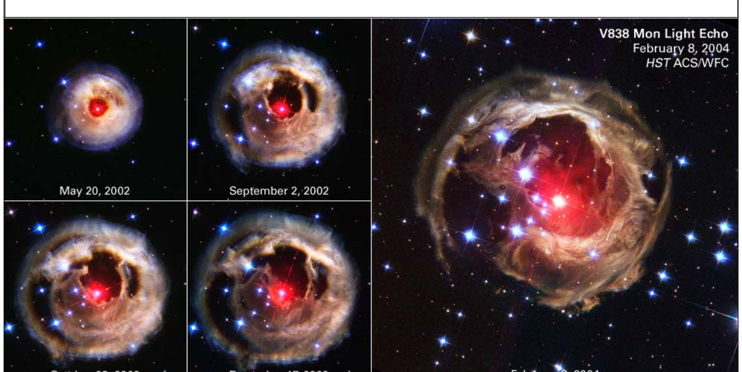
d) Iron does not interact with alpha particles.

e) dark energy prevents further fusion.

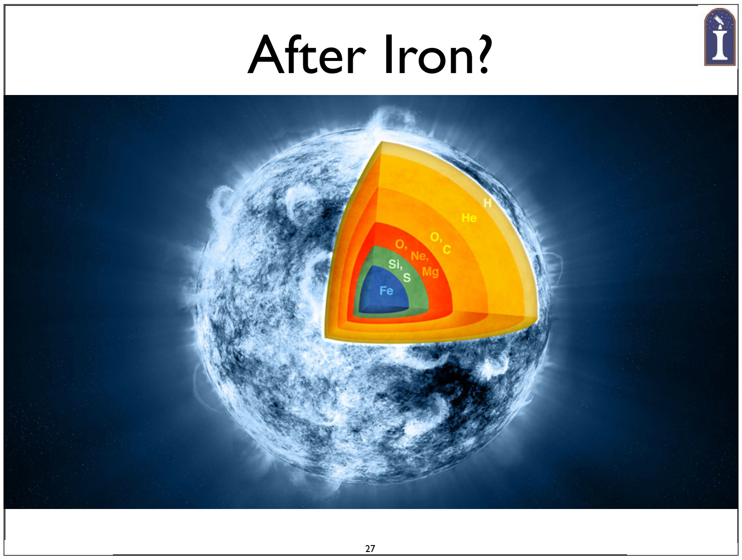
iClicker

C

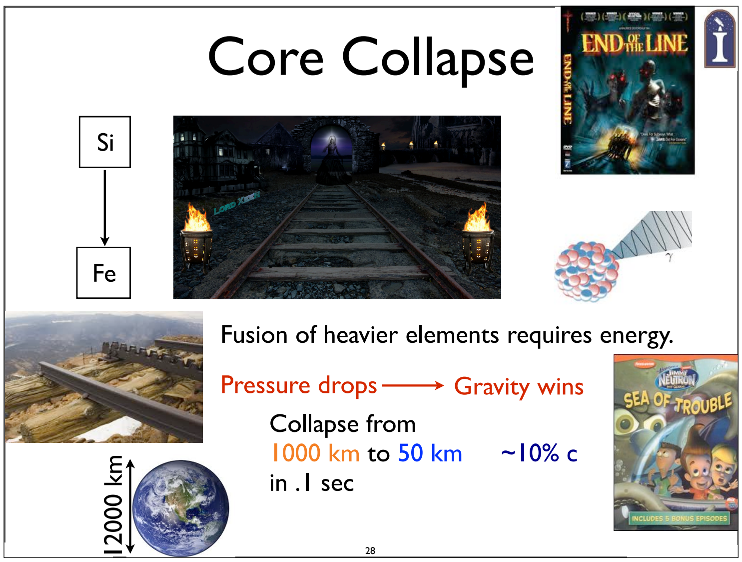
Mass Loss Events



V838 Monocerotis (V838 Mon) is a red variable star in the constellation Monoceros about 20,000 light years (6 kpc)[3] from the Sun, and possibly one of the largest known stars for a short period following the outburst. The previously unknown star was observed in early 2002 experiencing a major outburst. Originally believed to be a typical nova eruption, it was then realized to be something completely different. The reason for the outburst is still uncertain, but several conjectures have been put forward, including an eruption related to stellar death processes and a merger of a binary star or planets.

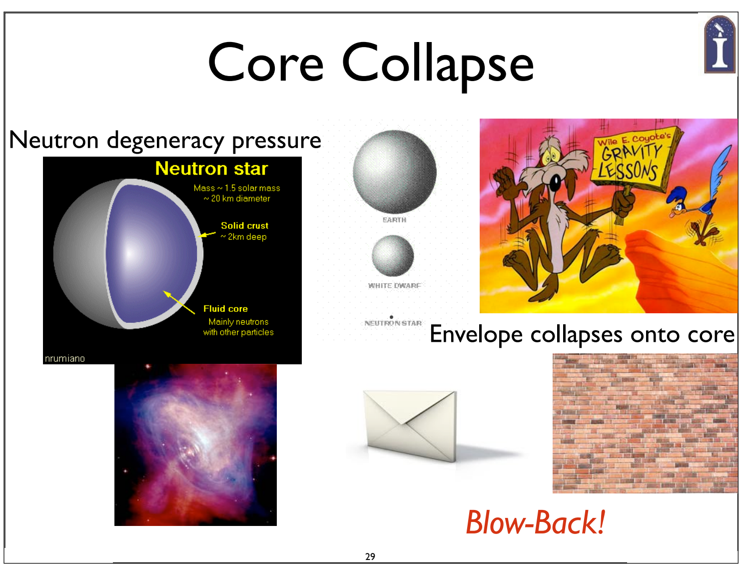


After Iron, there is no possibility of obtaining energy… gravity squeezes again



Completely out of gas! Hydrostatic equilibrium is gone. Eventually, gravity wins…

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

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 supernova.

Nuclear reactions cease at the center of the star's core. Gravity > Pressure. The core collapses in less than 1/10th of a second. Triggers an intensely energetic rebound. Shatters the star in a supernova.

Supernovae!

Gravity Wins!
Core Collapses
Envelope Expelled

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

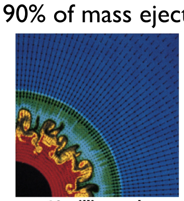
The lifetime battle against gravity is lost. The core collapses under its own weight. Much of the mass of the outer region of the star, bounces back into space.

Supernovae

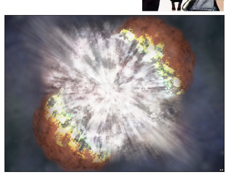
Stellar atmosphere becomes dense: opaque to neutrinos

10^{58} neutrinos

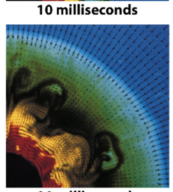
90% of mass ejected



10 milliseconds



1% of energy in visible light



20 milliseconds

Question

Most of the energy of a supernovae is

a) emitted as high energy radiation.

b) is deposited in shock waves that interact with the ISM.

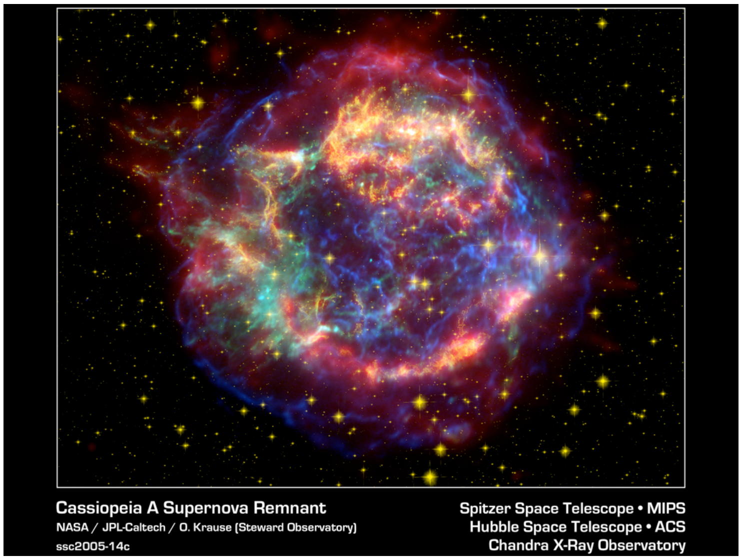
c) is released via neutrinos.

d) is lost into the resulting black hole.

e) is deposited into spacetime as Dark Energy.

iClicker

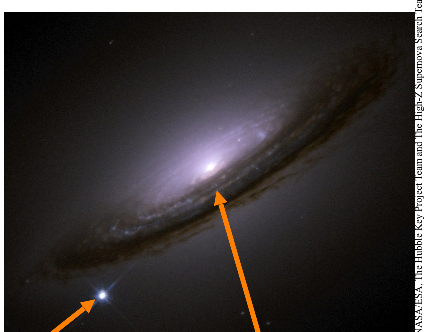
c



Supernova with Light Brights: https://www.youtube.com/watch?v=8MHb6_35XJM

Luminosity of 1 BILLION SUNS!

- Luminosity increases 10,000 times!
- Rivals its galaxy!
- During the supernova, many elements are forged



NASA/ESA, The Hubble Key Project Team and The High-Z Supernova Search Team

Light from a single supernova

Combined light of billions of stars

Supernovae are freaky luminous. Lots of spare energy so even reactions that require energy can occur

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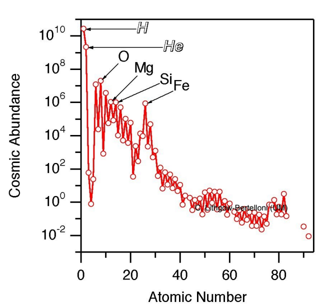
Making Heavy Elements

- Pre- and Post-supernova elements carried away.
- Supernovae provide much of the building blocks for planets… and us!
- **We are recycled supernova debris!**



We are Star stuff.

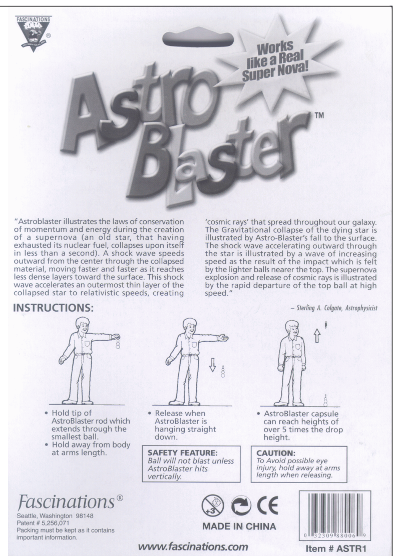
Delenn, B5

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.

Making Heavy Elements

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

AstroBlaster!

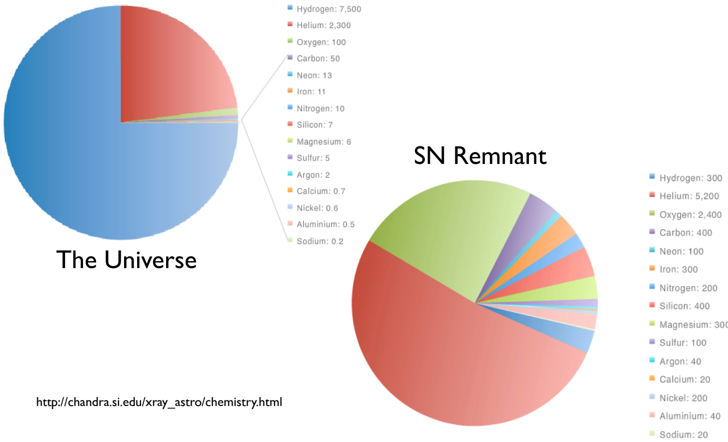


Question

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

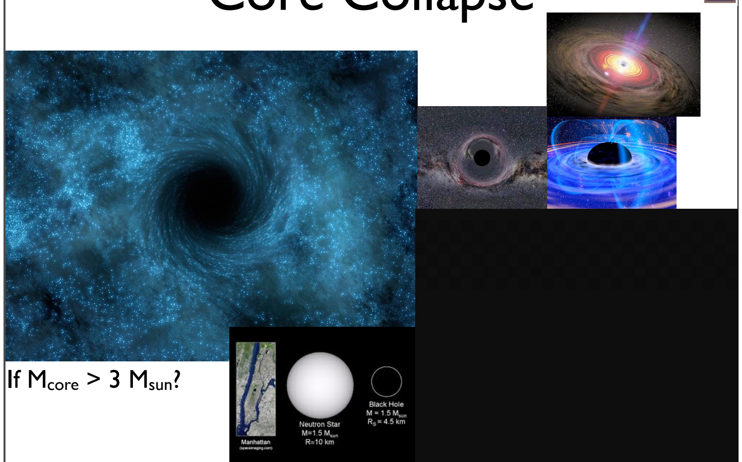
a) The inner core of the massive star
b) The envelope of the massive star
c) A low-mass stellar companion to the high mass star.
d) Iron.

Chemical Enrichment



http://chandra.si.edu/xray_astro/chemistry.html

Core Collapse



If $M_{core} > 3\ M_{sun}$?