ASTR 1040: Stars & Galaxies

Blinking Eye Nebula

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Lecture 15 (mid-course!) Tues 3 Mar 2020

zeus.colorado.edu/astr1040-toomre

Topics for Today

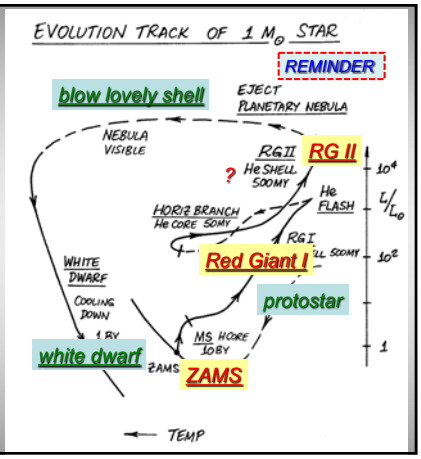
- Life tracks of massive stars: late stages allow fusion like "layers of an onion"
- Massive stars end life with supernova explosion, when iron core exceeds 1.4 M_{sun}
- Pulsars – fast spinning neutron stars with fierce magnetic fields; gradually slow down

Things to do

- Review 17.3 'Life as High-Mass Star'
- Read Chap 18: "Bizarre Stellar Graveyard" and white dwarfs and neutron stars in detail
- Homework #6 now graded (plus answers), outside for pickup
- Observatory Night #5 tonight (signup) looks very good
- Next class in Fiske Planetarium (Thur)

Life track in H-R diagram of solar-mass star

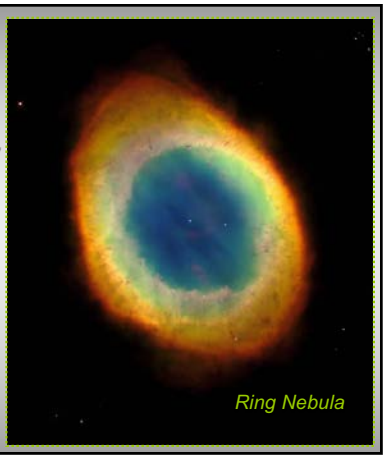
Many meanders, but MS phase longest, red giant phase(s) shorter, finally white dwarf left to cool slowly



Life after brief "planetary nebula" stage ….

Hot central core emerges as

WHITE DWARF



Ring Nebula

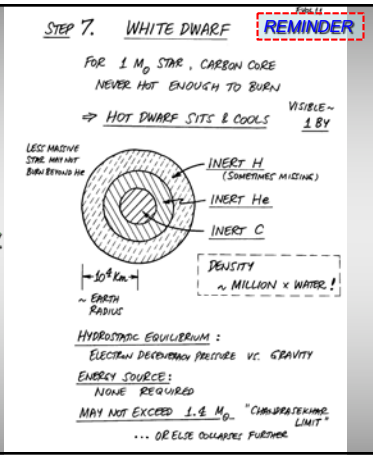
7. White Dwarf

Inert C core, He & H shells

electron degeneracy pressure holds it up

Very dense, size of Earth

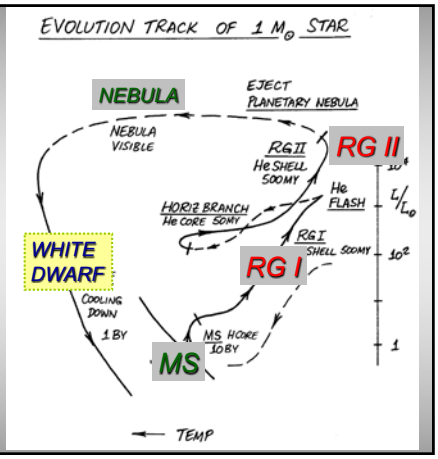
max mass of 1.4 M_{SUN}



Final stage:

Cooling white dwarf --- snooze ….

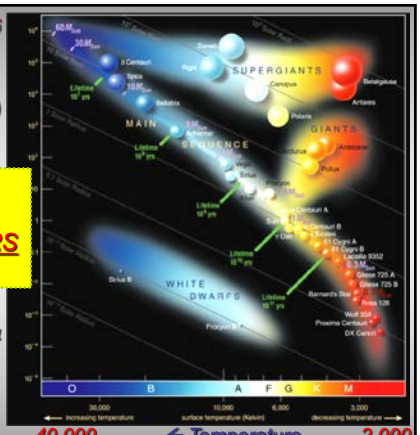
But if WD has binary companion, much fun can begin !



- Hubble Space Telescope spies 12-13 billion year old white dwarfs

Formed less than 1 billion years after creation of the universe

Now consider evolution of MASSIVE STARS after MS



Clicker review – red giants

- The main source of energy for a star as it grows in size to become a red giant is _____ .

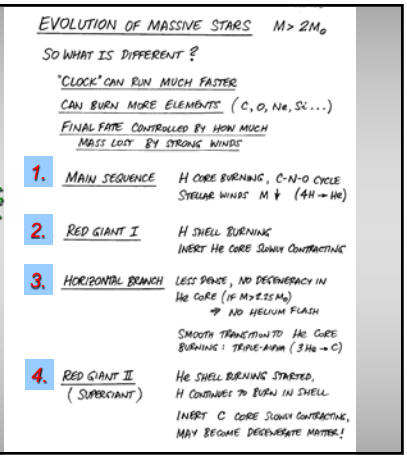
B.

- **A.** gravitational contraction
- **B.** hydrogen fusion in a shell around core
- **C.** helium fusion in the core
- **D.** hydrogen fusion in the core

Evolution of massive stars

Clock runs faster, can burn heavier elements

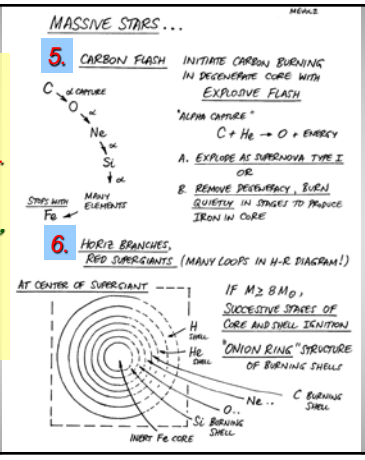
First 4 steps pretty familiar, but no helium flash



Successive core & shell fusion burning of C, O, Ne, Si ..

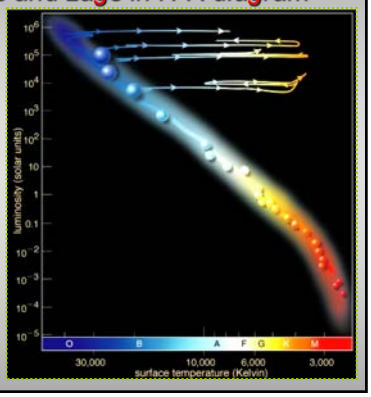
all with "alpha capture" (or He)

stars make many shallow H-R loops

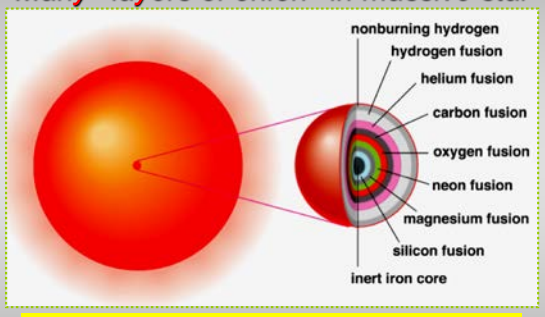


High-mass zigs and zags in H-R diagram

- Elements of higher mass fusion burn successively, releasing energy to support the star against gravity.
- Reactions may change too fast for outer layers to respond, so last zig/zags are small

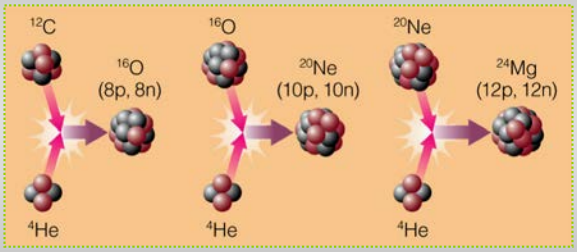


Many "layers of onion" in massive star



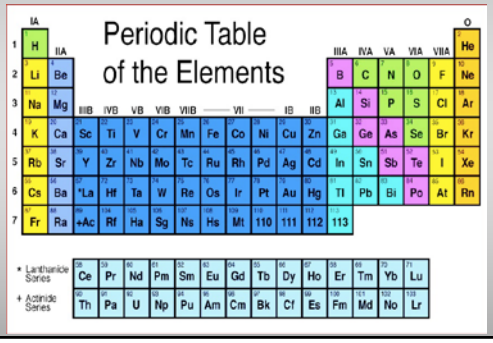
Core structure from successive burning stages: lesser elements on outside, heavier on inside

Fusion by "helium-capture" (alpha-particles) burns C, O, Ne, Mg, Si .. "layers of onion"

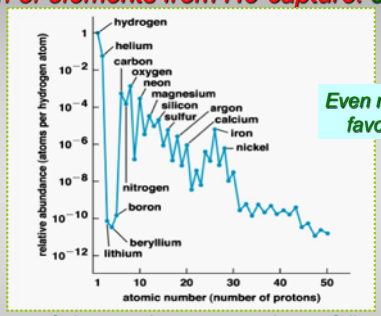


- Helium nucleus (2 protons) is absorbed, energy is released
- Elements are created going up periodic table in steps of 2

Carbon (6), Oxygen (8), Neon (10) Magnesium (12)….



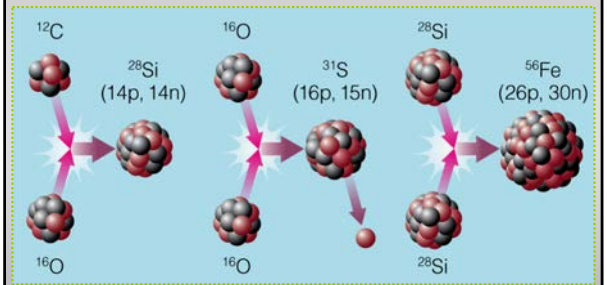
Creation of elements from He-capture: evidence



Even numbers favored !

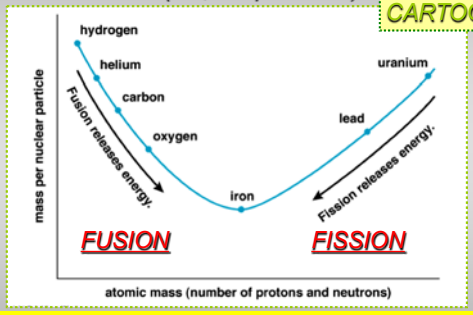
- Mixture of elements in our near universe follows the pattern of He-capture fusion reactions, up to iron
- Even heavier elements are made by nucleosynthesis during supernova explosion

A few of many other fusion reactions also feasible in high-mass stars



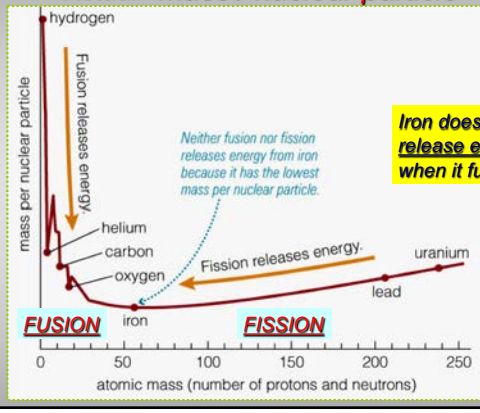
"Onion-shell fusion burning" stops with IRON (Fe, 26 protons)

CARTOON



Iron does NOT release energy when it fuses !

Actual "mass / nuclear particle"



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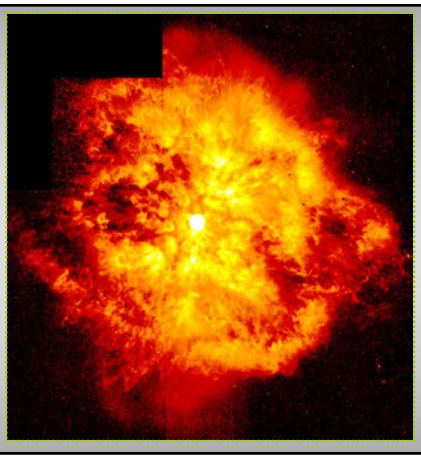


Massive red giant or supergiant:

Fierce hot winds and pulsed ejecta

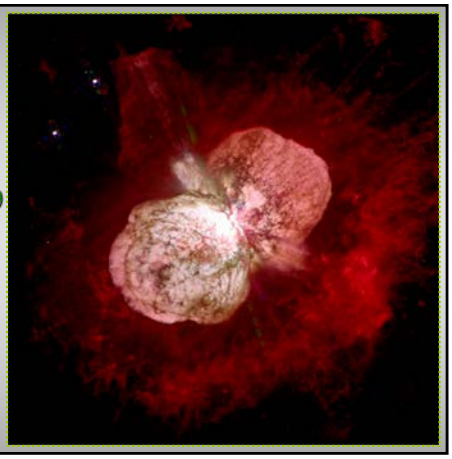
Hubble ST

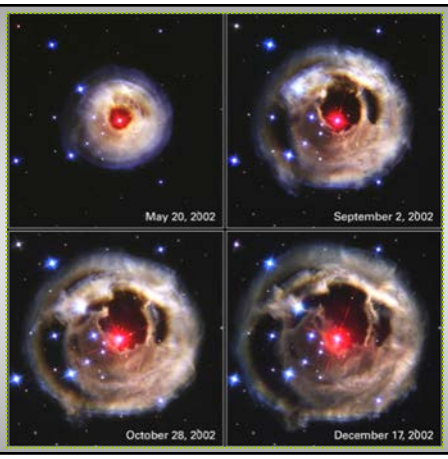
Wildest of all !

ETA CARINAE

Supermassive star (100 M_{SUN}) late in life, giant outburst 150 yr ago

Violent bipolar ejecta + disk at equator





Red Giant or SG with intense brightening

'Light Echo' from pulse

Star V838 Monocerotis HST-ACS

Evolution of V838 Light Echo (HST)

Reading Ahead Clicker Question

After a "core-collapse" supernova event, what is left behind?

A. A white dwarf
B. A neutron star
C. A black hole
D. A white dwarf or a black hole
E. A neutron star or a black hole

Several fates for massive star

1. Strong winds shrink star, may end as WHITE DWARF

2. Or core burns to Fe, eventually sudden CORE COLLAPSE !

⇨ SUPERNOVA

FINAL FATE OF MASSIVE STAR

TWO POSSIBILITIES ....

1. LOSES ENOUGH MASS IN WIND / PLANETARY NEBULA
   $< 1.4\ M_\odot$ LEFT ⇒ WHITE DWARF
   (W.D. COMPOSED OF HEAVIEST ELEMENTS PRODUCED)

2. ENTIRE CORE BURNS TO IRON
   NO MORE NUCLEAR ENERGY CAN BE RELEASED!
   AND $> 1.4\ M_\odot$ LEFT
   COLLAPSE CANNOT BE STOPPED BY ELECTRON DEGENERACY PRESSURE
   ⇒ NEUTRON STAR OR BLACK HOLE

"Core Collapse SUPERNOVA"

- Exploding remnant of massive star disperses heavy elements through the galaxy
- Inside may be a neutron star – a remnant core of pure neutrons!

Crab Nebula (M1), first seen as SUPERNOVA on 4 July 1054 from China -- visible in daytime

"Core collapse" (massive star) SUPERNOVA

"Rapid disassembly" of elements in core
→ neutrons
+ neutrinos

Neutron degeneracy pressure stiffens collapsing core ---
+ push of neutrinos

→envelope `bounces' !
→SHELL BLOWS OFF

STELLAR COLLAPSE (VERY RAPID)

GRAVITY MAKES IT GO ... BUT IRON CANNOT BURN, SO NO RESISTANCE

1. ELEMENTS DISMANTLED
   Fe → .. Si → ... O → Ne → C → He → H
   ⇒ NEUTRONS

2. "INVERSE BETA DECAY"
   PROTONS + ELECTRONS JAMMED TOGETHER → NEUTRONS + NEUTRINOS

3. NEUTRINOS TRY TO ESCAPE
   ⇒ PUSH AGAINST INFALLING GAS
   ENVELOPES "BOUNCES" AGAINST CORE
   ⇒ {EXPLOSION} SUPERNOVA TYPE II
   "DEBRIS" FLIES INTO SPACE

WHAT'S LEFT?
1. NOTHING !
2. NEUTRON STAR (PULSAR)
3. BLACK HOLE

Supernova explosion creates elements heavier than iron:

magic of nucleosynthesis

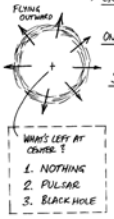
SN shells, and what is left at center ?

SUPERNOVA

AFTER "CORE BOUNCE", OUTER REGIONS OF STAR BLOWN OFF EXPLOSIVELY !

HIGH-ENERGY RADIATION & PARTICLES, NEUTRONS AND NEUTRINOS COME FLOODING OUT

NUCLEOSYNTHESIS : NEUTRONS + VARIOUS NUCLEI
⇒ CREATE HEAVY ELEMENTS BEYOND IRON (LIKE SILVER, GOLD, MERCURY ...)
ONLY PLACE IN UNIVERSE TO MAKE THIS STUFF!



SUPERNOVA SHELLS (OR REMNANT):
DO NOT LAST LONG BEFORE DISPERSING
FIRST ~ 1000 YEARS
SEEN IN VISIBLE, X-RAY
AFTER ~ 10,000 YEARS
SNOWPLOW MATERIAL AHEAD
⇒ RELATIVELY COOL ⇒ RADIO EMISSION

SN REMNANT BECOMES UNDETECTABLE AFTER ABOUT 1 MILLION YEARS

SNR: Crab Nebula M1

4 July 1054

Observing Supernovae

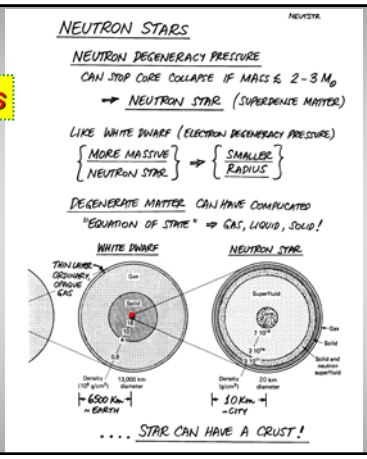
- About 1 per century per galaxy (none in Milky Way since 1604 – Kepler) [1572 – Brahe; 1054 – Crab; 1004 – brightest]
- Bright explosion visible for weeks/months - some visible in daytime!
- Remnant visible for 10,000+ years as huge bubbles and "veils" – longer in radio

Neutron stars

More massive, smaller in size!

Star with a crystal crust !

Idea of neutron stars first suggested in 1930s (Landau, Zwicki, Baade, Oppenheimer) … but seemed like wild dreaming



Favorite Postcard: Size of Neutron Stars

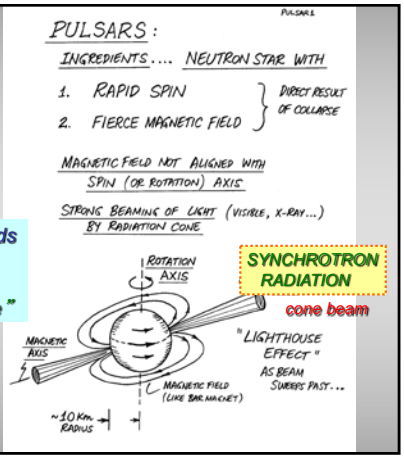
- Structure determined by gravity vs. neutron degeneracy pressure
- Size ~ 10 km. More massive, smaller !!
- Crushing gravity at its surface, so not a nice neighbor …or place to visit …. as tourist – try Big Apple instead.

Neutron star over NYC !

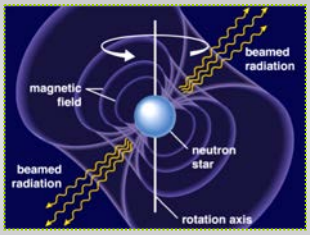
"Pulsar" = rotating neutron star

Fierce magnetic fields + sizzling electrors + fast rotation → finest "lighthouse"

Thomas Gold 1968



Pulsars and Neutron Stars



Neutron Stars on the Web

Listening to Pulsars

- PSR B0329+54 *typical, normal pulsar*: period 0.714 sec (~1.40 rotations/sec)
- PSR B0933-45 *VELA* pulsar: period 89 millisec (0.089 sec) (~11 rot/sec) in SNR ~10,000 yrs ago
- PSR B0531+21 *CRAB* pulsar: ~30 rot/sec youngest known
- PSR J0437-4715 *"millisec"* pulsar, ~174 rot/sec
- PSR B1937+21 *fastest* pulsar, ~642 rot/sec surface of star moving at 1/7 c!