

ASTR 1120: Stars & Galaxies



Crab
Nebula --
Supernova
Remnant

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Lecture 21 Mon 28 Feb 05
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Today's Stellar Events

- Look at *supergiants*, *planetary nebulae* and *white dwarfs* formed at end of evolution of low-mass stars
- *To come in next lecture*: Evolution of *massive stars* through *giant and supergiant phases*: fusion occurs in 'successive layers of onion'
- End life as *supernova explosion*, leaving behind either *neutron star* or *black hole*
- *Observatory Night 5* tonight – by sign-up
- "Overview of stellar evolution" summary still available + new *Homework Set #6* (due Mon)
- Read 18.2 *white dwarfs* & 18.3 *neutron stars*

Clicker Poll of Advice

- How do you take notes (or listen) during lectures?
- A. I get most of it by just listening
- B. I write down some notes, then go back to book to look things up
- C. I listen, some notes, then get copies of lecture slides from course website
- D. I enjoy talking with my buddies, and they tell me later if I missed anything

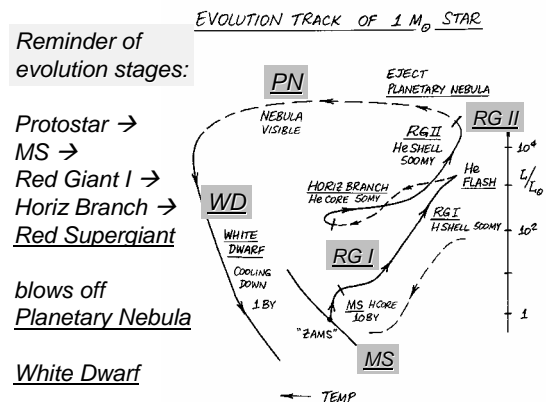
Clicker break – what has stuck?

- The vast majority of stars in a newly formed star cluster are _____ ?
- **A.**
- A. less massive than the Sun
- B. very high-mass, type O and B stars
- C. red giants
- D. about the same mass as Sun



Star Birth
Cauldron

NGC 604
in M33
Triangulum



REMINDER

4: Horizontal branch star

He core burning, H shell burning

Short phase, lasts ~50 MY

Triple-alpha fusion:
 $3 \text{ He} \rightarrow \text{C}$

STEP 4. HORIZONTAL BRANCH STAR
 (ANALOGOUS TO M.S.)
 He CORE BURNING LASTS 50 MY

He TOO COOL TO BURN
 He CORE BURNING
 $3 \text{ He} \rightarrow \text{C}$
 (TEMP ~ $2 \times 10^8 \text{ K}$)
 H SHELL BURNING
 H (NOT BURNING)

$L \sim 100 - 1000 L_{\odot}$
 $T \sim 5000 \text{ K}$

TRIPLE-ALPHA REACTION ($3 \text{ He} \rightarrow \text{C}$)
 $4 \text{ He}_2 (2p+2n) + 4 \text{ He}_2 \rightarrow 8 \text{ Be}_4 (4p+4n)$
 BERYLLIUM
 $8 \text{ Be}_4 + 4 \text{ He}_2 \rightarrow 12 \text{ C}_6 (6p+6n) + 8 \text{ }^1_0\text{n}$
 CARBON + ENERGY

- RADIUS & LUMINOSITY DECREASE SLOWLY
- QUIETLY BURNING He IN CORE, H IN SHELL
- CENTRAL CORE CONVERTED TO CARBON

Helium flash \rightarrow He fusion to C in core (horizontal branch)

Helium flash
 He fusion into carbon in core
 hydrogen-burning shell

Life track of star that lost considerable mass during red giant phase
 helium flash
 Life track of star that lost less mass during red giant phase
 Sun

Luminosity (solar units)
 10^5
 10^4
 10^3
 10^2
 10^1
 10^0
 10^{-1}
 10^{-2}
 10^{-3}

Temperature (Kelvin)
 10,000 6,500 3,000

5. Red Supergiant

Double-shell burning of H and He

Phase could be very short if He burning is erratic (unstable) -- then lasts only a few MY, and blows off outer shells

STEP 5. RED SUPERGIANT (ASYMPTOTIC GIANT)
 He AND H SHELL BURNING LASTS 500 MY

HUGE CONVECTIVE ENVELOPE (NOT TO SCALE)
 $L \sim 1000 - 10^4 L_{\odot}$
 $T \sim 3000 - 4000 \text{ K}$
 $R \sim 100 - 500 R_{\odot}$

DEGENERATE INERT CARBON CORE
 He BURNING SHELL
 H BURNING SHELL

→ EARTH →

- SECOND VISIT TO RED GIANT STAGE ENDS WITH EVENTUALLY BLOWING OFF ENVELOPE

6. Planetary Nebula

RED SUPERGIANT EJECTS ENVELOPE IN SERIES OF "GENTLE PUFFS"

EJECTION NOT EXPLOSIVE, TAKES YEARS LASTS 0.1 MY

Outer shells of red supergiant "puffed off"

Great pictures !

"Naked" white dwarf emerges

EXPANDING NEBULA SHELL
 HOT CENTRAL STAR ILLUMINATES NEBULA

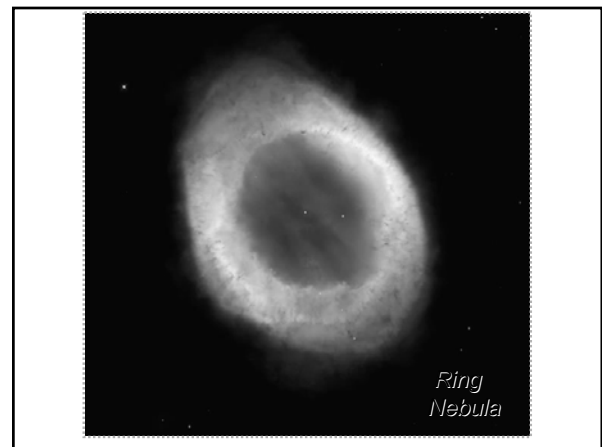
HOT "NAKED" DWARF LEFT BEHIND SLOWLY COOLS DOWN
 \Rightarrow WHITE DWARF

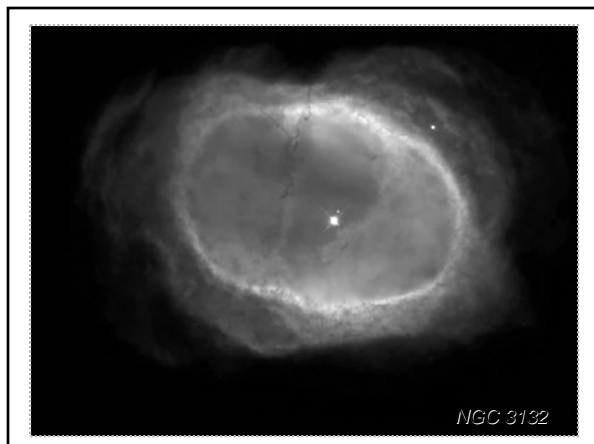
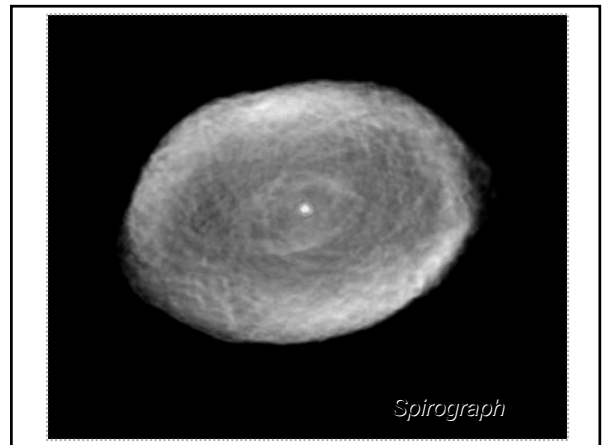
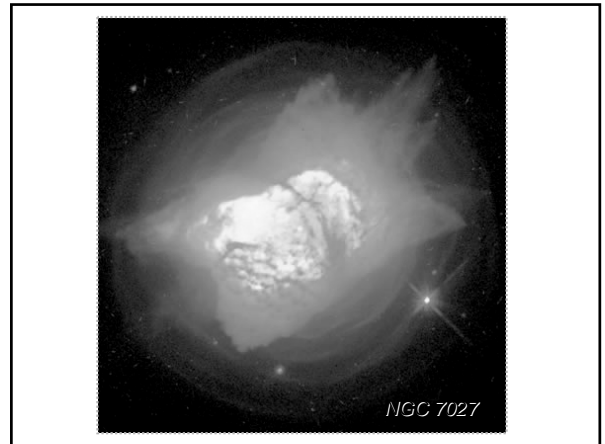
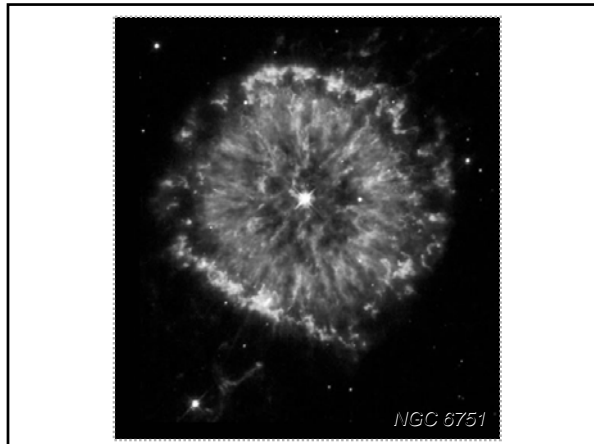
Sun in its "far future" ~5+ BY

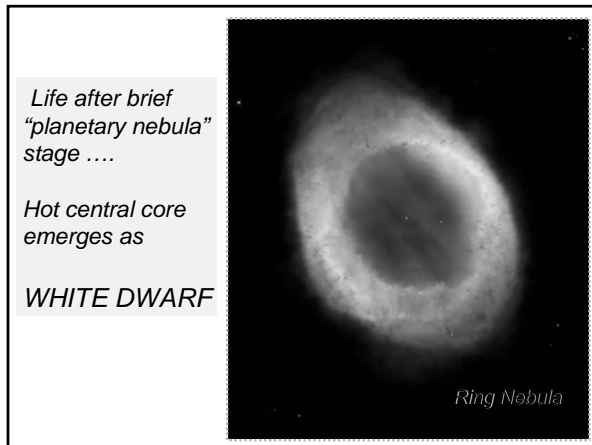
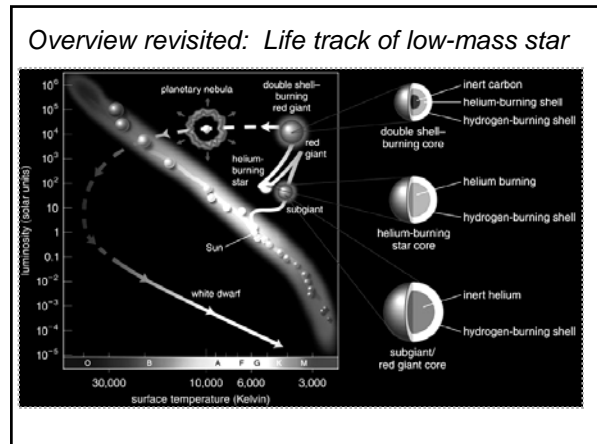
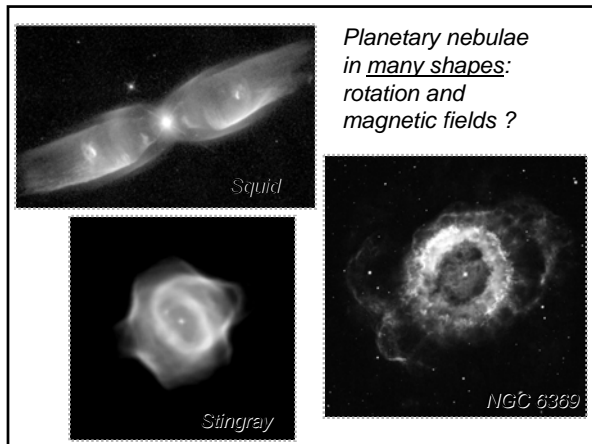
The Sun's Luminosity
 Luminosity (times present value)
 10,000
 1,000
 100
 10
 1
 now
 contraction of protostar
 leaves main sequence
 helium flash
 thermal pulses
 transition to white dwarf
 ejection of planetary nebula

The Sun's Radius
 radius (times present value)
 100
 10
 1
 now
 contraction of protostar
 leaves main sequence
 helium flash
 thermal pulses
 transition to white dwarf
 ejection of planetary nebula

Thermal pulses in red supergiant blow off outer shells







STEP 7. WHITE DWARF

FOR $1 M_{\odot}$ STAR, CARBON CORE NEVER HOT ENOUGH TO BURN

\Rightarrow HOT DWARF SITS & COOLS VISIBLE ~ 1 BY

Inert C core, He & H shells

electron degeneracy pressure holds it up

Very dense, size of Earth

max mass of $1.4 M_{\text{SUN}}$

LESS MASSIVE STARS MAY NOT BURN BEYOND HE

INERT H (SOMETIMES MIXING)

INERT He

INERT C

~ 10^4 km

~ EARTH RADIUS

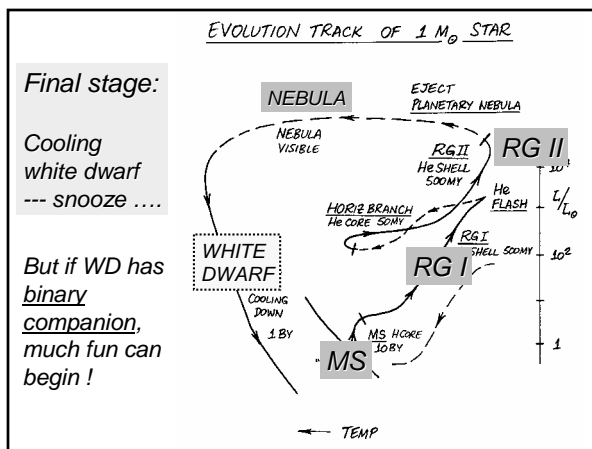
DENSITY ~ MILLION x WATER!

HYDROSTATIC EQUILIBRIUM: ELECTRON DEGENERACY PRESSURE VS. GRAVITY

ENERGY SOURCE: NONE REQUIRED

MAY NOT EXCEED $1.4 M_{\odot}$ "CHANDRASEKHAR LIMIT"

... OR ELSE COLLAPSE FURTHER



Clicker -- Paths in H-R Diagram

- A star moves upwards and to the right on the H-R diagram. What is probably happening in the core?

B.

A. The core has just started to burn a new element

B. The inner core is collapsing and heating up; shell burning is increasing

C. All nuclear burning is slowing down

D. The inner core temperature is cooling

HR diagram shifts

- **B.** The core is collapsing and heating; shell burning is increasing
- Moving upwards on HR diagram means more luminosity \rightarrow more nuclear fusion
- This is usually due to the inner core heating due to gravitational collapse potential \rightarrow thermal \rightarrow faster burning

Overview revisited: Life track of low-mass star

