Lec #39: 28 NOV 11 Chap. 6; Chap. 2

Today: Stellar Remnants; Star Formation
- Neutron Stars, Pulsars, Black Holes
- Post-Main Sequence Evolution of Close Binaries
- Begin: Star Formation

Wednesday: Star Formation and Pre Main Sequence

Friday: Exam #3

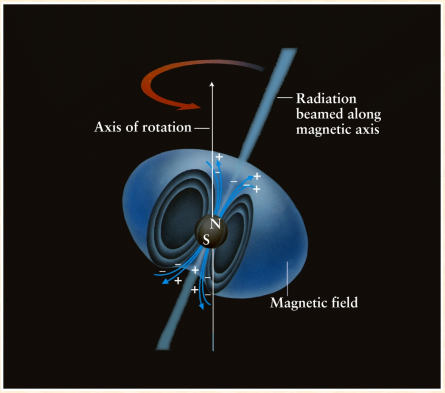
Monday: Odds and Ends/Wrap Up

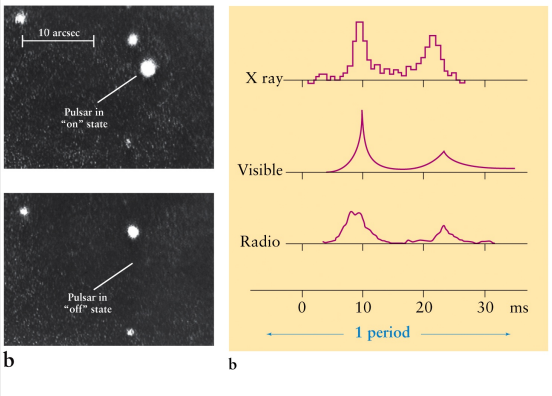
Neutron Stars

- produced in final stage of massive star evolution
  - collapse of iron core: p + e --> n + neutrinos
- not destroyed in SN explosion
- extremely small (30 km) and dense
- must rotate extremely rapidly
  - 100's of times per second
  - but they can slow down...
- extremely strong magnetic field (10^{12} Gauss)
- do not emit light, so how do we see them?
  - emission from accretion disk (if in binary system)
  - emission from magnetic field (even if single)

Pulsars

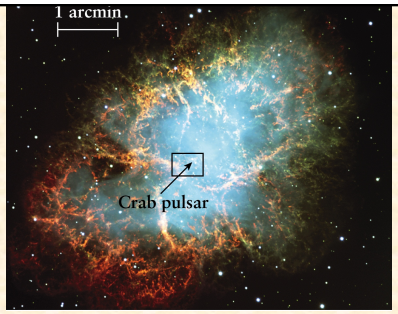
- periodic radio pulses discovered in 1967
  - 0.01 second pulses every 1.34 seconds
- concluded that they must come from small, rapidly rotating object: neutron stars?
  - some thought they could be signals of extraterrestrial intelligence :-)
- Crab Nebula produced by SN in 1054 has pulsar
  - other pulsars linked with SN remnants
  - but remnants don't last forever, so we don't always see the link
  - but all pulsars must be neutron stars





Crab Nebula

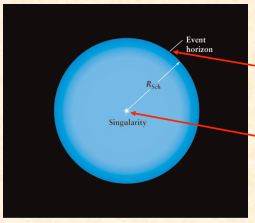
$L \sim 10^5 L_\odot$!!!



- neutron capture in SN performs nucleosynthesis ("R process) all the way up the periodic table
- synchrotron emission, radioactive decay can heat expanding SNR

- pulsars spin down fairly quickly
  - rotational energy radiated away in pulsar beam
  - energy source for remnant nebula!
- for example, Crab Nebula 75,000 times more luminous than our sun!
  - Crab pulsar period 1/30 second
  - change in period 3 x 10^{-8} seconds per day
- fastest pulsars are the youngest
- fastest are "millisecond pulsars", which are probably in close binary systems
  - so we can measure their masses !!!
  - can coalesce to produce gamma ray bursts !!!

Black Holes



$R_S = 2GM / c^2$

what's really going on in here?

impossible to say!?

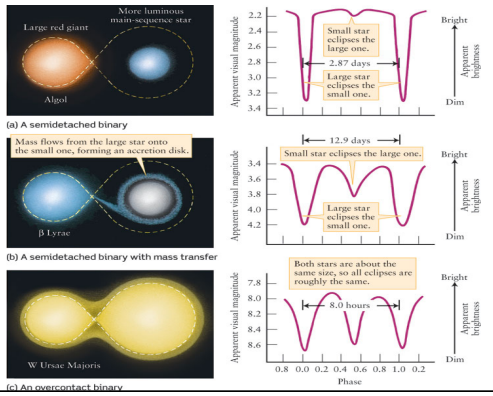
- nothing can escape from within event horizon
- laws of physics break down at singularity
- black hole still has mass, charge, rotation

Life After Death: Close Binaries

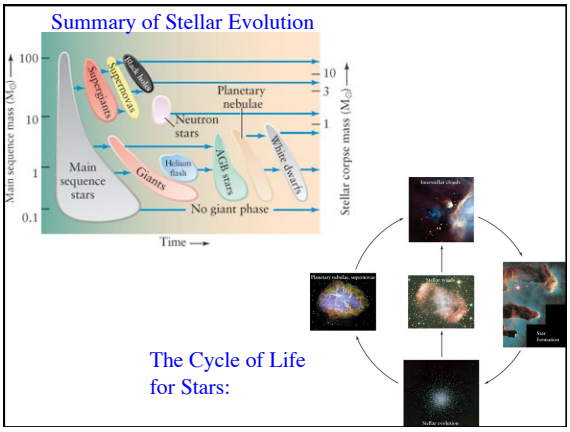
- maximum mass for WD ~ 1.4 $M_\odot$
- maximum mass for NS ~ 3 $M_\odot$
- progenitor mass ranges a bit uncertain, but these give lower limits

- mass transfer in binaries can cause a sub-critical WD to exceed Chandrasekhar limit and explode as Type Ia supernova
- can also cause NS to become BH
- classical novae; x-ray bursters

Close Binaries and Stellar Evolution



Summary of Stellar Evolution



The Cycle of Life for Stars:

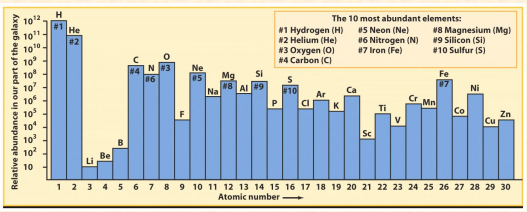
I. Observational Considerations

- Molecular clouds populate arms of spiral galaxies
- Massive stars never very far from these areas
- Also see small, dark dusty clouds
- Stars do form (rather easily, it seems)
- Prefer to form in clusters and multiple systems
- Star counts --> "Initial Mass Function"
  - lots of low mass; few high mass
  - upper limit?
  - lower limit?
- Brown Dwarfs

Interstellar Material: What is it Made Out of?

- **GAS**
  - Hydrogen, Helium
  - other "metals"; varying "enrichment", but typically > solar
- **DUST**
  - solid particles
  - tiny grains (10^{-7} m) ~ wavelength of light but 1000 times bigger than atoms
  - million times more atoms than dust particles
- **PLASMA**
  - ionized gas
- How "hot" is it?
  - not very (T~100 K), but there are hot regions, especially near supernovae and hot stars

"Cosmic" Abundances of the Elements



- The vast majority of the atoms in the universe are Hydrogen and Helium produced in the *Big Bang*
- Everything else is made in stars (We are "star dust")
- Mostly Oxygen, Carbon, and Nitrogen made in stars then returned to the "Interstellar Medium"

II. Theoretical Considerations

- Stability against collapse
- Fragmentation
- The role of dust
- Angular Momentum
- Magnetic Field

Stability Against Collapse

- Gravitationally bound: satisfies Virial Theorem

  $2 * KE = -PE$
- $PE \sim -0.6\, GM_c^2 / R_c$
- $KE \sim 3/2\, NkT$; $N=M_c/\mu m_H$
- if T<-U/2, collapse; T>-U/2, expand
- *Unstable* against collapse if

  $3M_c kT/ \mu m_H < 0.6\, GM_c^2 / R_c$
- $R_c=(3M_c/4\pi\rho)^{1/3}$ if ρ is constant
- with this, we can recast the condition as...