Astrophysics I: Stars and Stellar Evolution
AST 4001

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Stars and Stellar Evolution, Fall 2008

Overview

Radiative Transfer in Gray Atmosphere

- distribution of temperature in a gray atmosphere is

$$T^4 = \frac{3}{4} T_{\text{eff}}^4 \left(\tau + \frac{2}{3} \right)$$

Note that $T = T_{\text{eff}}$ at $\tau = 2/3$

- First Eddington-Barbier Relation

$$I_\nu(0, \Theta) = a_\nu + b_\nu \cos \Theta = B_\nu(\tau_\nu = \cos \Theta)$$

- Second Eddington-Barbier Relation

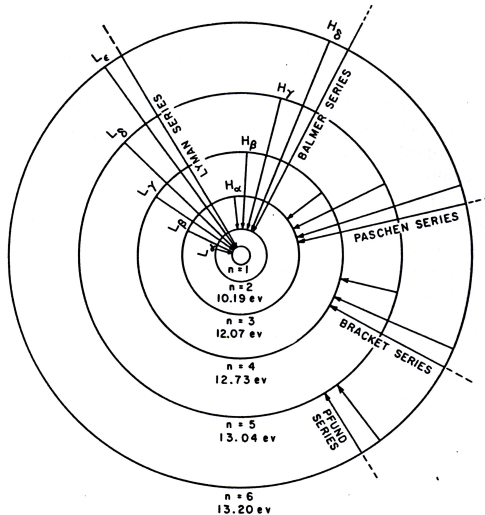$$F_\nu(0) = \pi B_\nu \left(\tau = \frac{2}{3} \right)$$

flux from stellar surface at a particular frequency is determined by Planck function at $T(\tau_\nu = 2/3)$

- Limb Darkening

$$I(0, \Theta) = \frac{F}{4\pi} (2 + 3 \cos \Theta)$$

Hydrogen level scheme

Saha Function - Levels

ratio of occupation N_i of levels $i = n$ and $i = n'$:

$$\frac{N_n}{N_{n'}} = \frac{g_n}{g_{n'}} \exp\left[-(\chi_n - \chi_{n'})/kT\right], \quad g_n = 2J + 1, \quad J = L + S$$

g_n is called the *statistical weight*,
J, L, and S are total and orbital angular momentum and spin of the electron

partition function and total number of atoms:

$$u(T) = \sum g_n \exp\left(-\chi_n/kT\right), \quad N = \sum_{n=1,\dots} N_n$$

Using $\Theta = 5060/T$ in eV we can write:

$$\frac{N_n}{N} = \frac{g_n}{u(T)} 10^{-\Theta \chi_n},$$
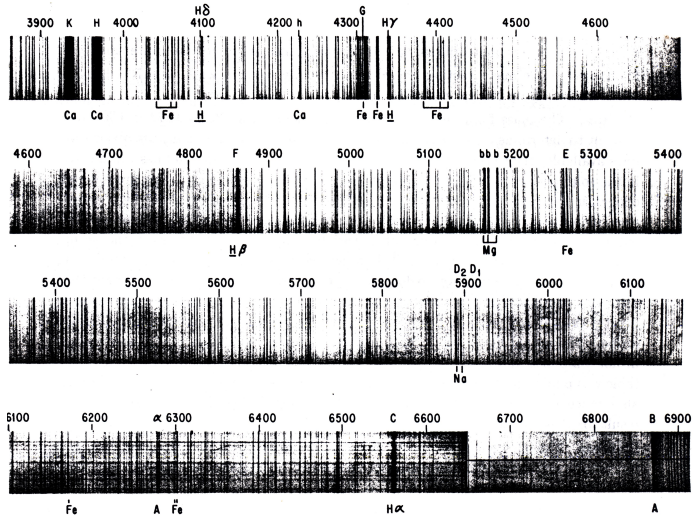
Saha Function - Ionization
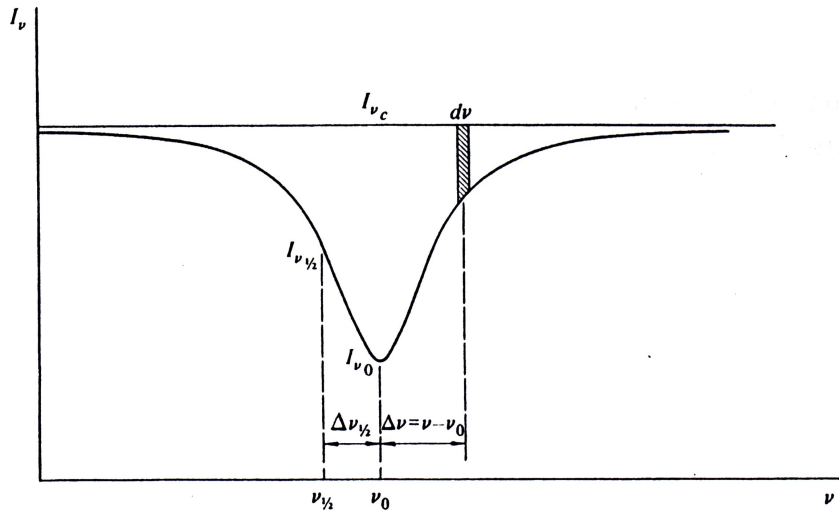
Similarly, using

$$P_e = n_e k_B T$$

we can also write the ratio of ionization levels r as

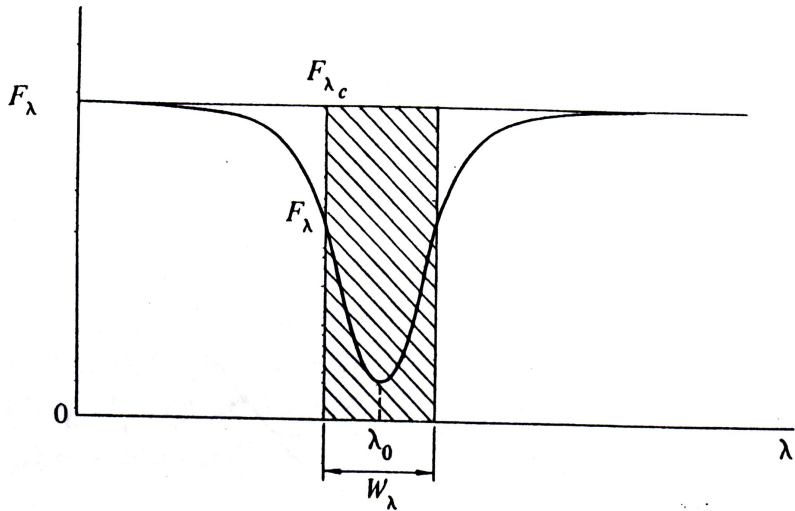$$\log \left(\frac{N_{r+1}}{N_r} P_e \right) = \Theta \chi_r + 2.5 \log T - \log \frac{2u_{r+1}}{u_r} - 1.48$$
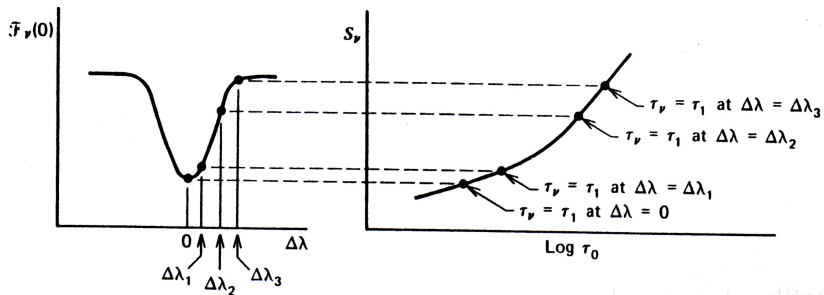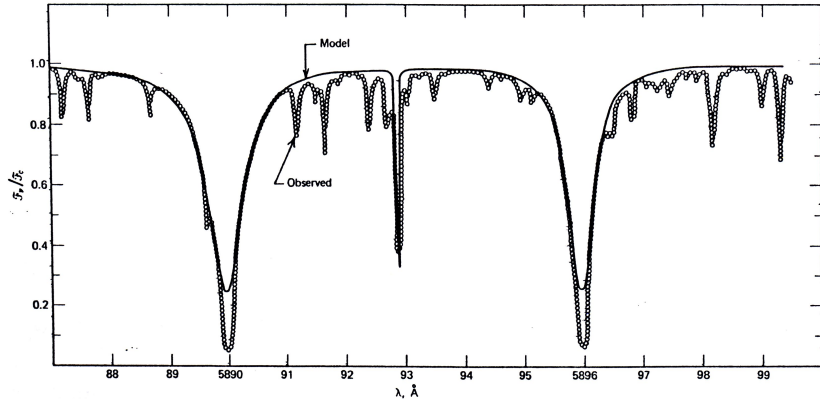
Solar Spectrum
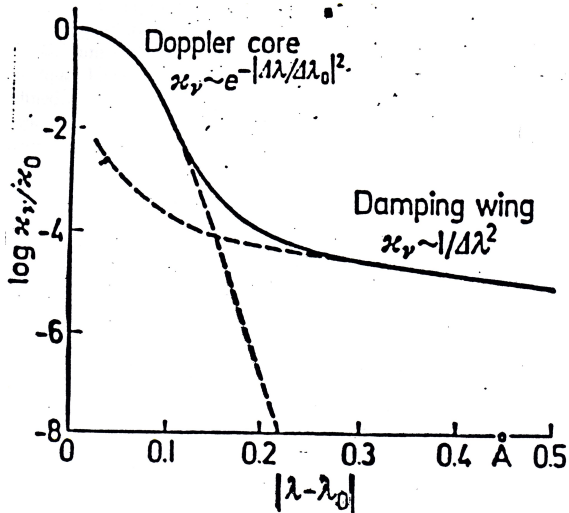
Line Profile

Equivalent Width
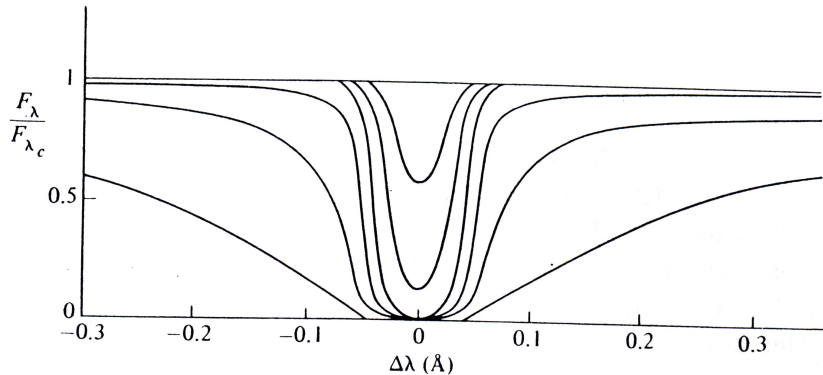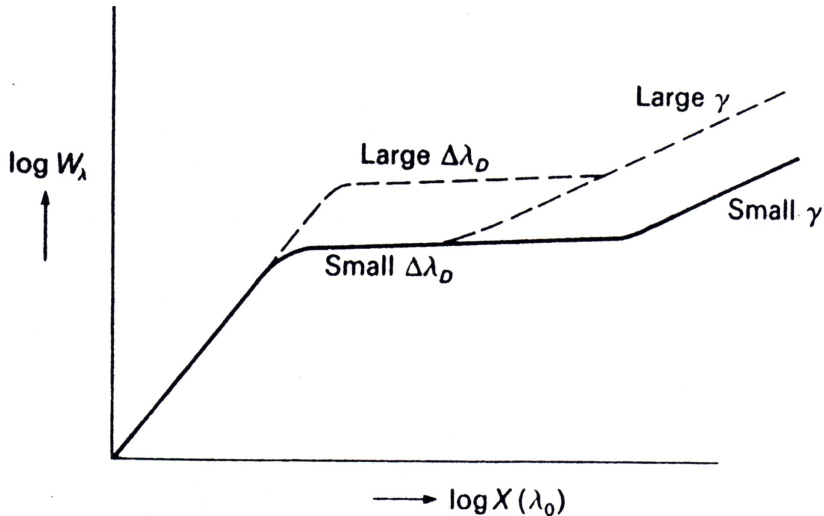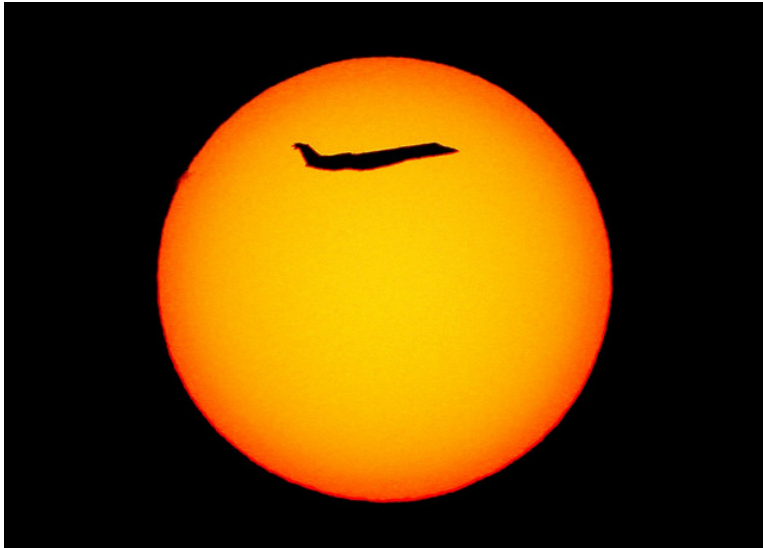
Line Formation

Sodium D Line

Line Broadening

CaII K line, Theoretical Models

Schematic curve of growth

The Sun

Overview

The Guitar Nebula
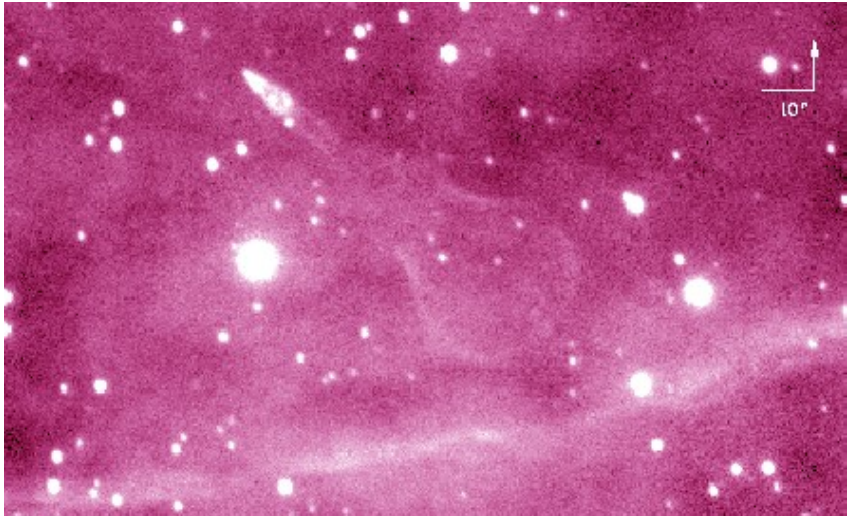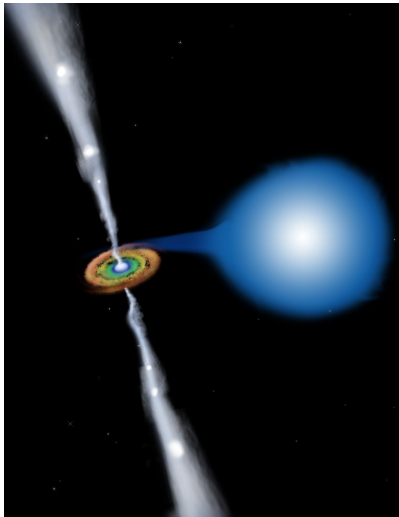
Compact Binaries

- compact remnants
    - white dwarf
    - neutron star
    - black hole
- types of systems
    - compact remnant + ...
        - main sequence star
        - evolved star - (red) (super) giant
    - two compact stars
        - double WD, double NS (double pulsar), double BH
        - WD+NS, WD+BH
        - NS+BH

Accreting Binary

Evolution of Compact Binaries

- mass transfer
  $\Rightarrow$ accretion disk
  $\Rightarrow$ X-ray binary
  What can it tell about the type of the compact star?
- loss of angular momentum (braking)
  - wind
  - magnetic fields
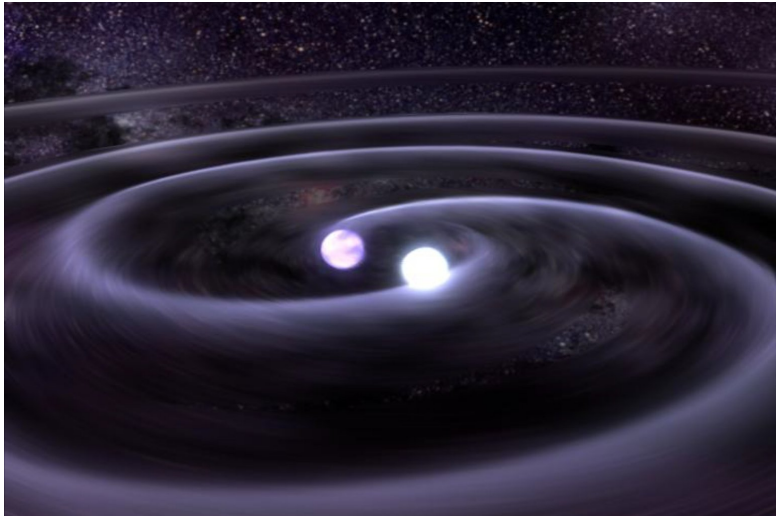 - gravitational waves
  $\Rightarrow$ orbits gets increasingly tighter
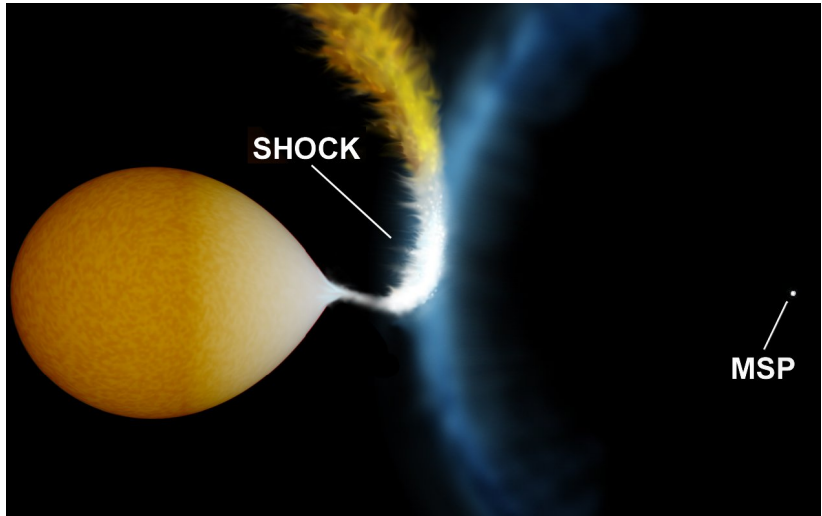 - merger
    $\Rightarrow$ gravitational wave signal
  - disruption of the less compact star
    $\Rightarrow$ accretion disk, . . .

Binary WD

Shock Wave in Millisecond Pulsar

Evolution of Compact Binaries

accumulation of accreted material

- composition of accreted material?
- does accreted material burn?
- burning stable or not?
- thermonuclear runaway?
    - Novae
      how much material is ejected?
      does WD star grow?
    - detonation of "thick" H/He layer on WD surface?
    - supernovae
        - Type Ia - CO WDs
        - AIC - ONeMg WDs
    - (Type I) X-ray bursts
- stability of the accretion disk
    - outbursts from disk instabilities

Neutron Star Merger

Final Fate of Compact Binaries

merger or disruption of one of the stars
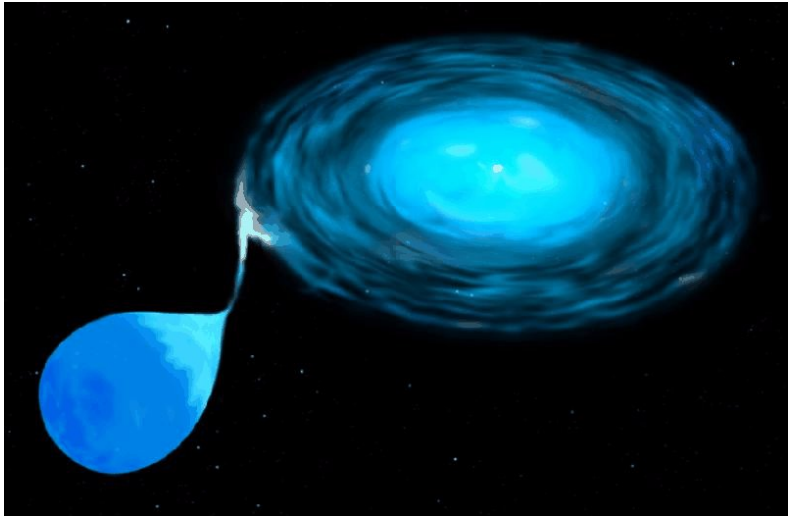
- disruption
    - tidal disruption of less compact star
    - WD + MS/post-MS star: mass transfer
        - CO WD: ignition, Type Ia SN, no remnant
        - ONeMg WD: AIC $\Rightarrow$ NS:
          * "kick" during NS formation $\Rightarrow$ system separates
          * NS + MS/post-MS star

- merger
    - NS+NS $\Rightarrow$ short GRBs
    - WD+WD $\Rightarrow$ supernova?
    - WD+MS/post-MS star $\Rightarrow$ AIC
    - BH+BH $\Rightarrow$ GR wave signal
    - BH+NS $\Rightarrow$ accretion disk, GRB?
    - WD+NS/BH $\Rightarrow$ fast transient form accretion disk...
      NS$\rightarrow$BH collapse?

Accreting Binary

Accretion onto Black Hole