Composition and Mass Loss

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- Two of the major items which can affect stellar evolution are
- Composition: The most important variable is Y – the helium content
- Mass Loss: core evolution is essentially independent of envelope evolution especially during later phases. This means that "lower" mass stars can have a "high" luminosity.

Composition

Y is the more important

- Where this is of greatest impact is in the lifetimes of Pop II/III stars
  - In Pop II (Z ~ 0) t $\propto 10^{2X}$ and since X is somewhat larger than in Pop I one gets a longer lifetime.
  - The converse is that He rich stars leave the MS very quickly.
  - Y changes from 0.3 → 0.2 (at Z = 0.03)
  - At 5 $M_{\odot}$ T_{eff} decreases 10% and L decreases by a factor of 2

Heavy Metal Effects

This is for the Main Sequence

- Changes in Z lead to evolutionary changes essentially opposite to those in Y but are smaller.
  - Z decreases : L and T_{eff} increase
- This means Pop II stars should be more luminous and hotter than Pop I (at the same X,Y)

Post-MS Composition Effects

- Y is more important than Z for fixing the luminosity
- As a star evolves Z becomes more important as the energy generation involves Z (CNO dominates in higher mass stars, if there is CNO)
- The T_{eff} position of the red giant branch is insensitive to Y or Z but the luminosity varies by a factor of 4 according to Y/Z

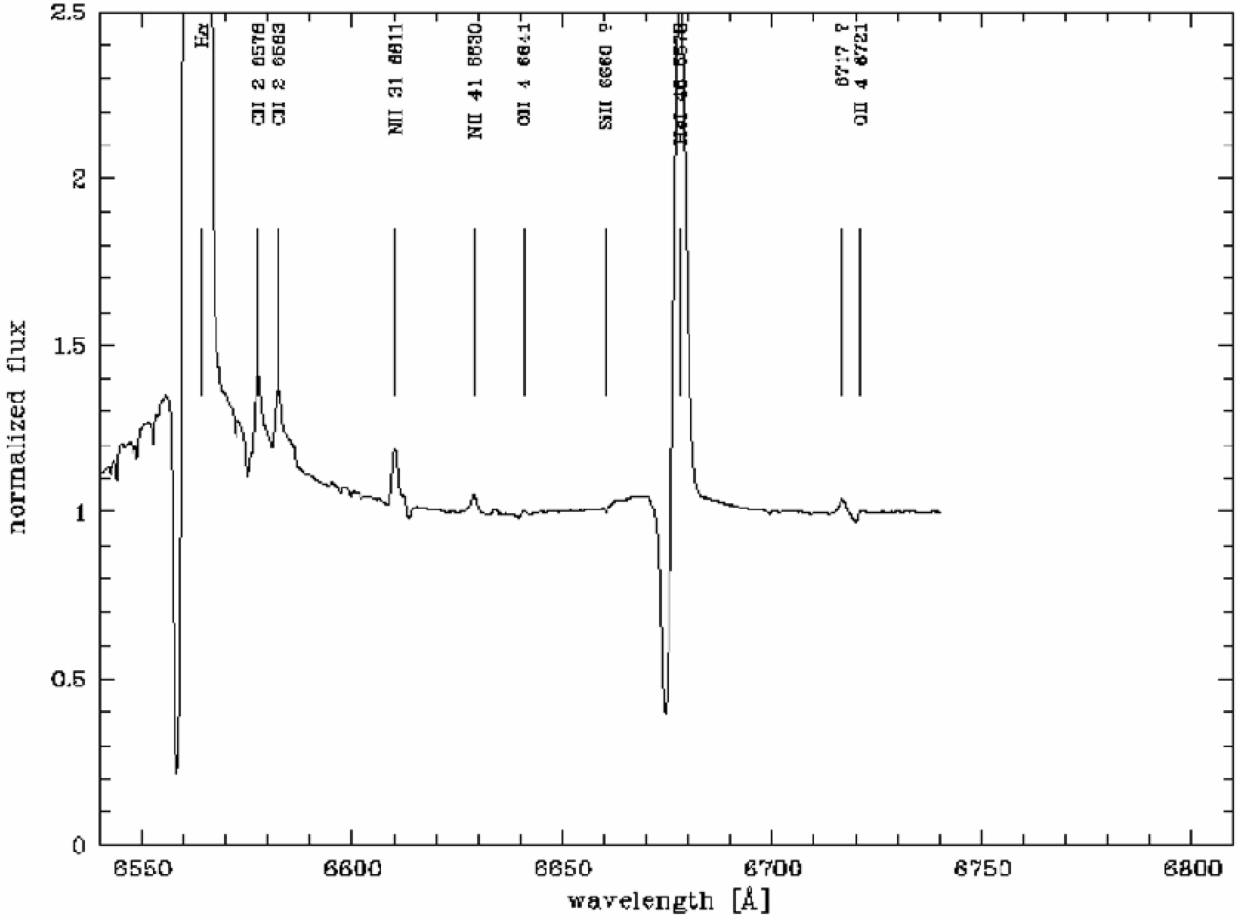
A Problem: Convective Mixing

- There is “no” good *ab initio* theory of convection
- Mixing length: defined as some fraction of the pressure scale height
- General number used is 1.5

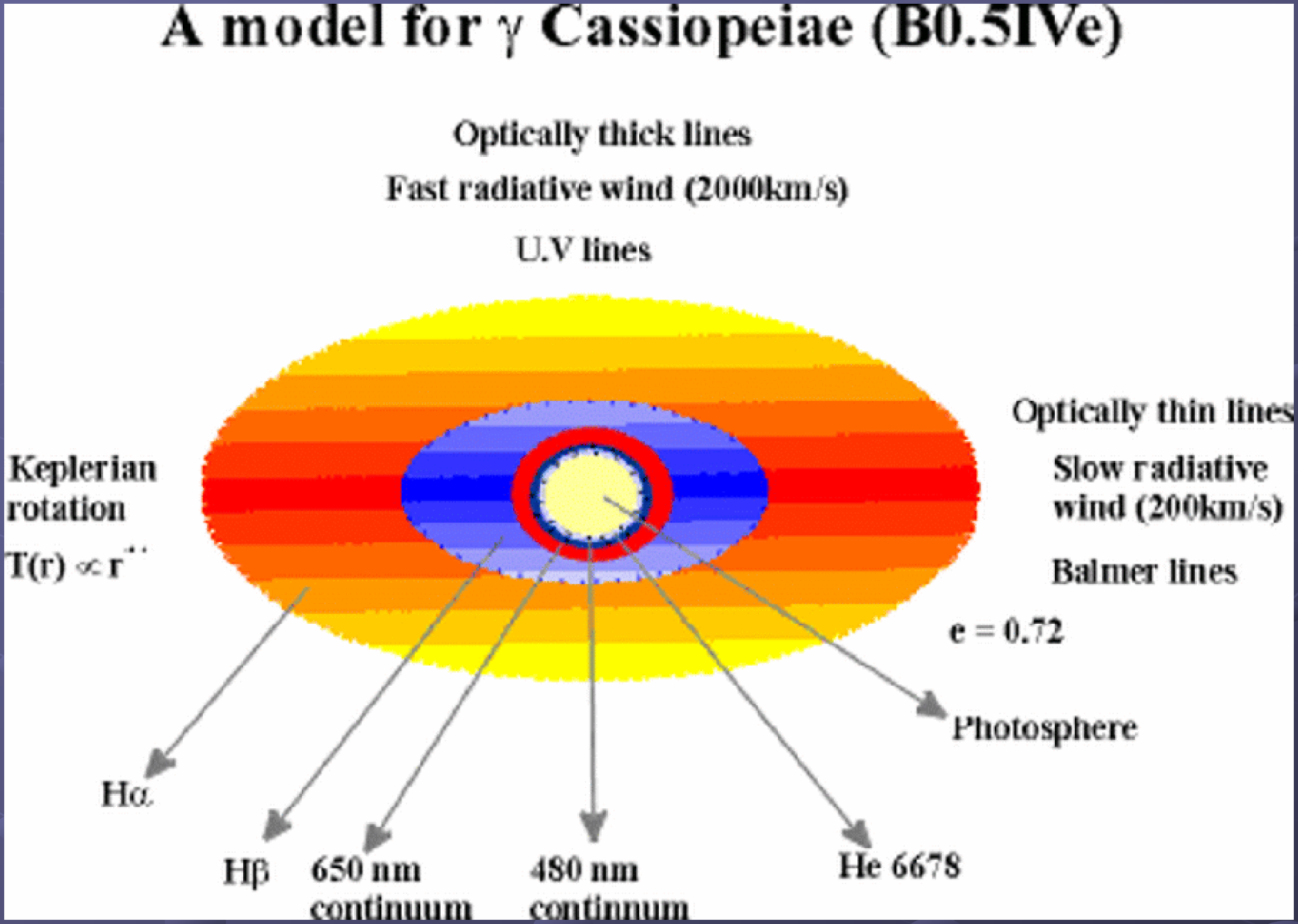
Mass Loss

- Solar Mass Loss – The solar wind
  - Flux = 10 p / cm^3 with V = 400 km/s
  - V must be greater than V_{esc}
- Solar V_{esc} = SQRT(2GM/R) = 620 km/s at $R_{\odot}$ and 42 km/s at 1 AU.
- Current Solar Mass Loss Rate is about 10^{-14} $M_{\odot}$/year
  - Integrated Mass Loss 10^{-4} $M_{\odot}$ if the rate has been constant.
- Observed Rates are up to 10^{-4} $M_{\odot}$ / year and are mass dependent.

P Cygni Stars



Gamma Cas


A model for γ Cassiopeiae (B0.5IVe)
Optically thick lines
Fast radiative wind (2000km/s)
U.V lines
Keplerian rotation
Optically thin lines
Slow radiative wind (200km/s)
Balmer lines
e = 0.72
Photosphere
Hα
Hβ
650 nm continuum
480 nm continuum
He 6678

What Does Mass Loss Do To Stellar Evolution?

- Let us consider two stars with identical composition and the same current mass:
  - Star 1: Constant Mass
  - Star 2: $dM/dt = -a\ M_{\odot}$ / year
- Obviously Star 2 at t = 0 was more massive than Star 1 ➔ It evolved faster.
- Assumptions:
  - Both convert equal H to He
  - Equal amounts of radiation (energy) produced.

How Do We Proceed?

- Assume L ~ M^{α} (This is reasonable – α is about 3 to 3.2)

$$M_2^{\alpha} T = \int_0^{T'} M(t)^{\alpha} dt$$

- Note that $M^{\alpha}T$ is just the total energy produced.
  - T = age of constant mass star
  - T' = age of star with mass loss rate dM/dt
- Assuming the M(t) is known one can solve for T' given M_2, α , and T.

What Happens?

a parameterizes the mass loss

- The sensitivity of the track to the mass loss rate depends on the initial mass:
  - Higher mass stars can sustain a somewhat higher rate without changing the evolution.
  - The integrated mass loss as a fraction of the total mass is comparable.
  - Mass loss of 10^{-12} $M_{\odot}$ or less have little effect on $M \sim 1$ $M_{\odot}$
  - Mass loss of 10^{-9} $M_{\odot}$ or less have little effect on $M \sim 5$ $M_{\odot}$

Rates That Matter

- For a 1 $M_{\odot}$ star 10^{-10} $M_{\odot}$ / year will halve the MS lifetime
  - Original mass of 1.4 $M_{\odot}$
- For a 5 $M_{\odot}$ star 10^{-6} $M_{\odot}$ / year will decimate (10%) the MS lifetime
  - Original mass of 12 $M_{\odot}$
- Note that the lifetime goes with the original mass as it sets the energy generation.

Ramifications

- Globular Clusters: If they are loosing mass then the age estimates are too large
  - Measured mass loss rates are variable
  - The age of the Universe anyone?

Planetary Nebulae

- Stars "blow off" mass in shells – planetary nebulae are the result of these episodes.
- Composition reflects extensive processing.
  - C and O enriched
  - Advanced evolutionary stage (post He burning)
- Thought to be post/during ascent to 2nd Giant Branch. (Detach the shell during an envelope expansion phase)
- Alternate mechanism is the hyperwind model associated with the AGB stars of low mass.

PN

- Typical Shell Mass is 0.01 $M_{\odot}$.
- Lifetime is about 50000 years
  - expansion leads to lowering of density until the material becomes some optically thin it cannot detected
- Core star is usually very blue - probably the core of an ex-red giant – T_{eff} 50000 - 100000K
- PN are binary systems in many cases.

Stellar Mass and the Final Stage of Evolution

- Chandraskhar Limit: 1.41 $M_{\odot}$
  - Electron Degeneracy support
  - Observed white dwarfs in Pleiades and Hyades
    - Turn-off masses are 4 - 6 $M_{\odot}$
    - This means the original masses were in excess of 4 - 6 $M_{\odot}$ they had to lose sufficient mass to get down to the Chandrasekhar limit.

Close Binaries

- Generally stellar evolution does not take into account close binaries:
  - Wide system P > years and the stars evolve without interacting
- Close Systems
  - Mass exchange through the LaGrange points
    - Fill Roche lobe, push mass through and dump on the secondary
    - Secondary then heats up and becomes the primary – these are Algol systems
    - Barium and subgiant CH stars
    - Cataclysmic Variables

Fate of Stars

Category	Mass Limits $M_{\odot}$	Fractional Mass of Galaxy	Fate
a	≤ 1.5	0.6	WD
b	$1.5 \leq M \leq 4$	0.2	WD
c	$4 \leq M \leq 8$	0.06	WD/NS
d	> 8	0.14	SN(NS)