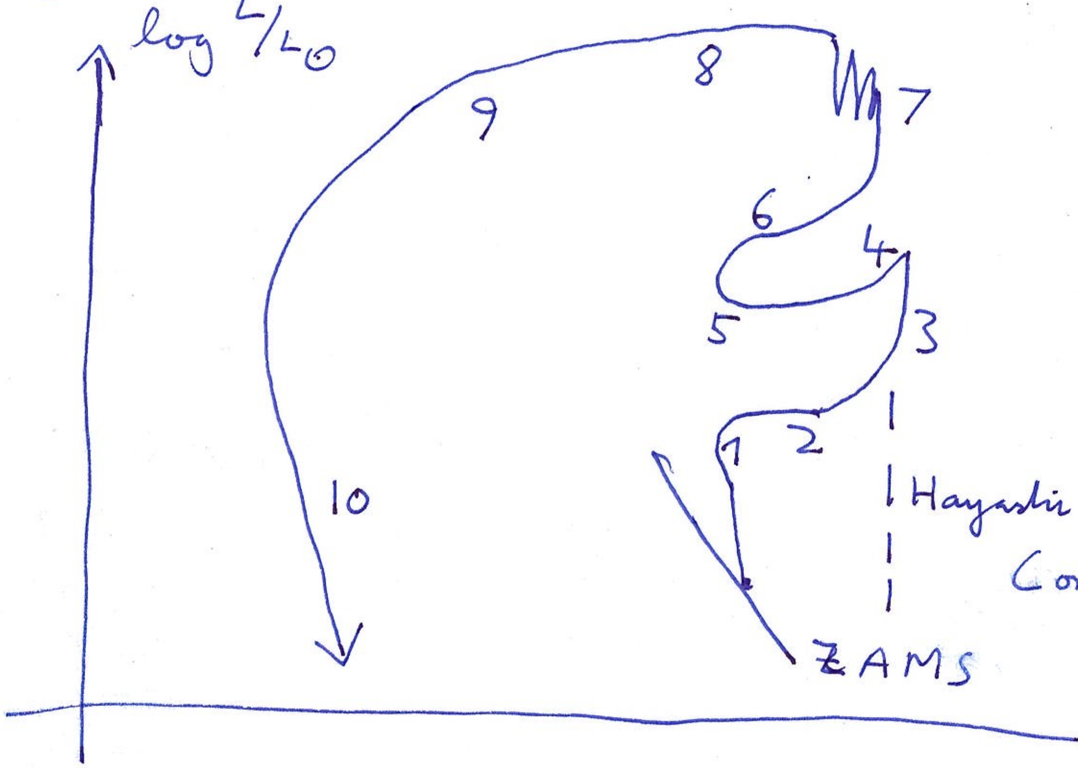
Ay 20 # 22 - Post-main sequence evolution

This lecture is concerned with examining the fates of stars as they leave the main sequence, usally modeled as the ZAMS.



Evolution of a ~1 to ~few solar mass star off the ZAMS.

① The H-core is fully converted to He, and burning in a H-shell surrounding the core also finishes. Once the He core mass exceeds the Schonberg-Chandrasekhar limit,

$$\frac{M_{core}}{M_\star} \sim 0.37 \left(\frac{\mu_{env}}{\mu_{core}} \right)^2 ,$$

the core contracts. Why is this? What is the evolution timescale?

2) As the core temperature increases, residual H is burnt in a shell that generates energy apace, causing the envelope to expand (why?) $\rightarrow$ subgiant branch.

3) Envelope expansion $\rightarrow$ increasing H^- opacity $\rightarrow$ deepening convection zone $\rightarrow$ increasing energy & chemical transport to surface $\rightarrow$ first "dredge up" and evolution along red giant branch (RGB).

This follows the Hayashi track (evolution @ near-constant T_{eff} to higher luminosities).

* Stars to right of Hayashi track have super-adiabatic temperature gradients - recall convection condition!

$$\left(\frac{d \ln T}{d \ln P} > \frac{2}{5} \rightarrow \text{convection} \right)$$

2)

How does the Hayashi track apply to pre-main sequence stars?

4) At the tip of the RGB, He fusion through the triple-alpha process is ignited -> core expansion -> cooling H-burning shell -> net decrease of energy input -> luminosity decreases.

5) This is the horizontal branch. The blue limit is set by when the core mass has increased sufficiently as to drive contraction.

6) This results in a He-burning shell around a CO core, some He, then a H-burning shell. As before, convection is triggered, pushing the star onto the asymptotic giant branch (AGB). Second dredge-up

7) The H-burning shell begins to dominate, and the He-burning shell is periodically turned on and off. Thermal pulse AGB. Some massive stars have a third dredge-up -> carbon stars.

3)

(8) Past the AGB, the star sheds its envelope in a super-wind (mechanisms unknown). The envelope becomes optically thin, revealing an F/G giant.

(9) Once all the envelope is expelled, a planetary nebula surrounds a proto white dwarf.

(10) A white dwarf cools & forms (CO, ONeMg core, maybe with some H and/or He in a thin atmosphere).

Studying mass loss from RGB & AGB stars is an open field of research.

What are the instrument requirements to image a massive star's atmosphere?

What limits the mass of the most massive stars?