ASTR 531 - Stellar Interiors and Evolution

Problem Set 3

Tom Wagg

May 7, 2022

12.2 - Early Radii and Timescales

Part a - Radii Estimations

Let's use a couple of different relations from the textbook to get the radii at different times. A protostar becomes ionised and stars the Hayashi concentration phase when it's radius is on the order of (Eq. 12.13)

$$R_{\rm Hayashi,start} \approx 100\,{\rm R}_\odot \left(\frac{M}{{\rm M}_\odot}\right) \tag{1}$$

We find the radius of the protostar once the Hayashi concentration phase comes to an end is approximately a factor of 50 lower (based on assumptions of the temperature and opacity) such that (page 12-8)

$$R_{\rm Hayashi,end} \approx 2\,{\rm R}_\odot \left(\frac{M}{{\rm M}_\odot}\right) \tag{2}$$

The radius at the start of the PMS phase will be the same as the end of the Hayashi concentration phase.

$$R_{\rm PMS,start} = R_{\rm Hayashi,end} \tag{3}$$

Finally, the radius at the end of the PMS phase is the same as the radius at ZAMS and so we can write that (Eq. 12.16)

$$R_{\rm PMS,end} = R_{\rm ZAMS} = {\rm R}_\odot \left(\frac{M}{{\rm M}_\odot}\right)^{0.7} \tag{4}$$

So now we can plug in numbers for the different masses of stars that we considered

$M/\,{\rm M}_\odot$	$R_{\rm Hayashi,start}/\,{\rm R}_\odot$	$R_{\rm Hayashi,end}/\,{\rm R}_\odot$	$R_{\rm PMS,start}/\,{\rm R}_\odot$	$R_{\rm PMS,end}/\,{\rm R}_\odot$
0.3	30	0.6	0.6	0.43
3	300	6	6	2.16
30	3000	60	60	10.8

Part b - Timescale estimations

The duration of the Hayashi concentration phase is given in Eq. 12.15 but we also showed that the timescale scales as $1/M$ such that

$$\tau_{\rm Hayashi} \approx 10^6\,{\rm yr}\left(\frac{M_\odot}{M}\right) \tag{5}$$

The duration of the PMS phase is given by Eq. 12.17 so we have that

$$\tau_{\rm PMS} \approx 6\times10^7\,{\rm yr}\left(\frac{M}{{\rm M}_\odot}\right)^{-2.5} \tag{6}$$

So now we can plug in numbers for the different masses of stars that we considered

$M/\,\mathrm{M}_\odot$	$\tau_{\mathrm{Hayashi}}/\,\mathrm{yr}$	$\tau_{\mathrm{PMS}}/\,\mathrm{yr}$
0.3	3.33×10^6	1.22×10^9
3	3.33×10^5	3.85×10^6
30	3.33×10^4	1.22×10^4

15.4 - Metallicity and Mass Loss Rates

TODO: Need to check code/method with Emily

16.1 - RGB Radii

From inspection of Figure 16.1 we can find values for L and T_{eff} at the start and end of the RGB phase. This phase starts at C and ends at F. We can then use the fact that

$$R = \sqrt{\frac{L}{4\pi\sigma T_{\mathrm{eff}}^4}} \tag{7}$$

to get the radii. Since I'm in a mood for tables today, let's make another!

Stage	$\log(L/\,\mathrm{L}_\odot)$	$\log(T_{\mathrm{eff}}/\,\mathrm{K})$	$R/\,\mathrm{R}_\odot$
C (Start of RGB)	0.4	3.7	2.1
F (End of RGB)	3.4	3.48	183.1

17.1 - Helium Flash Duration
