Stellar Evolution 2016 Q2

Ugeseddel 8 (week 46)

In the lecture 17 November Günter will conclude the presentation of shell-source homology on the red-giant branch (*Kippenhahn, Weigert & Weiss*, Section 33.2), followed by a few remarks on general aspects of stellar stability (*Kippenhahn, Weigert & Weiss*, Section 25.3). Going back to the beginning he then starts the presentation of star formation and early stellar evolution (*Kippenhahn, Weigert & Weiss*, Chapters 26 and 27). This will be continued on 21 November, including also the final stages before the zero-age main sequence (*Kippenhahn, Weigert & Weiss*, Chapter 28). After this we return to the late evolution stages on the so-called asymptotic giant branch, including shell-source instabilities, thermal pulses and slow neutron-capture nucleosynthesis (*Kippenhahn, Weigert & Weiss*, Chapter 34), and the final stages of the evolution of massive stars, leading up to supernova explosions (*Kippenhahn, Weigert & Weiss*, Chapters 35 and 36).

In the exercise class on 23 November we make a first attempt at using MESA, possibly including completing the installation or getting familiar with the common installation being set up on the servers. Jakob will provide an update of his notes later; I shall put them on the website when they are available, and perhaps they can be handed out on Monday. I suggest the following exercises, as a starting point:

i) Run a $1\,M_\odot$ model until central hydrogen exhaustion, or perhaps, if you can find a way to set this as a stop criterion, at the base of the red-giant branch. If you can figure out how, you can shorten the run by starting the evolution on the ZAMS.

ii) Read the `LOGS/history.data` file into a suitable code for plotting on your laptop (Matlab or Python) and make a simple plot in the HR diagram of the evolution sequence.

iii) Read in selected model structures from the `LOGS/profile` files and follow the evolution of the hydrogen-abundance profile as the star evolves.

iv) Do i) – iii) for a $2\,M_\odot$ model.

In addition, you may consider

v) The extension of the homology analysis, in exercise U8.1 below.

Corrections to ***Kippenhahn, Weigert & Weiss*****:**

- **p. 295, Eq. (25.34)**: Here the first line should be

$$\frac{m_{\rm s}}{l_{\rm s}} = (m_{\rm s} d\varepsilon - dl_{\rm s}) l_{\rm s}^{-1} = \ldots$$

- **The discussion of the red-giant bump, p. 397 – 399; Fig. 33.3**: This discussion is perhaps not completely clear, in particular with regards to the onset of the decrease in luminosity. Perhaps not surprisingly I prefer the analysis provided by Christensen-Dalsgaard (2015; *MNRAS*, **453**, 666). This will also be linked from the website.

- **p. 420, 2 lines below Eq. (34.4)**: Replace 'dt' by 'dT' in $T = T_0 + dT$.

- **p. 428, last paragraph**: Here the description is a little short on the ^{13}C neutron production. The reaction

$$^{12}{\rm C}(p,\gamma)^{13}{\rm N}(\beta^+\nu)^{13}{\rm C}$$

takes place in the intershell region. Subsequently, the reaction

$$^{13}{\rm C}(\alpha,n)^{16}{\rm O}$$

takes place during the helium burning, when ^{13}C is mixed into the helium-burning region. This is described more clearly in the caption to Fig. 34.6.

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Exercise U8.1:

An extended homology analysis. In the treatment of the homology relations (*Kippenhahn, Weigert & Weiss*, Chapter 20), it is of interest to consider also the dependence of the quantities on the *constants* entering in the expressions for the energy generation and the opacity. Hence we write

$$\epsilon = \epsilon_0 \rho^\lambda T^\nu , \qquad \kappa = \kappa_0 P^a T^b ,$$

with similar relations, involving constants ϵ_0' and κ_0', for the primed model, and introduce $\tilde{\epsilon} = \epsilon_0/\epsilon_0'$ and $\tilde{\kappa} = \kappa_0/\kappa_0'$. Also, we replace *Kippenhahn, Weigert & Weiss*, eq. (20.12), by

$$z = x^{z_1} y^{z_2} \tilde{\epsilon}^{z_3} \tilde{\kappa}^{z_4} \; ; \quad p = x^{p_1} y^{p_2} \tilde{\epsilon}^{p_3} \tilde{\kappa}^{p_4} \; ; \quad t = x^{t_1} y^{t_2} \tilde{\epsilon}^{t_3} \tilde{\kappa}^{t_4} \; ; \quad s = x^{s_1} y^{s_2} \tilde{\epsilon}^{s_3} \tilde{\kappa}^{s_4} \; .$$

Find expressions for $z_3, z_4, \ldots, s_3, s_4$. Consider the case $\alpha = \delta = \phi = 1$, $a = b = 0$ (*Kippenhahn, Weigert & Weiss*, section 20.2.2), and calculate the values of the exponents, for $\lambda = 1$ and $\nu = 4$ and 15. What does this correspond to physically? Consider also the case where the opacity is given by Kramers opacity, $a = 1$, $b = -4.5$, for the same values of λ and ν. Why is the luminosity essentially independent of ϵ_0?
