Late Stages of Stellar Evolution, Problem Set 1

1 Importance of AGB stars

a) Assume a Salpeter-like Initial Mass Function

$$\frac{\mathrm{d}N}{\mathrm{d}M} \propto M^{-2.35} \tag{1}$$

for a group of stars forming at the same time (you can chose a total mass of $10^4\ M_\odot$ if you find that easier). Calculate the fraction of stars in the mass range 0.8—100 $M_\odot$ that will *not* become supernovae. Assume that the upper mass limit for stars to end their lifes as White Dwarfs is 9 $M_\odot$.
b) If the Main Sequence life time scales as $\tau_{\mathrm{MS}} \propto M^{-2.5}$, with an 8 $M_\odot$ star having $\tau_{\mathrm{MS}} = 50$ Myr, find the percentage of stars that have evolved off the Main Sequence as a function of time between 50 Myr and 10 Gyr (take at least 10 logarithmically spaced time intervals).
c) Use the Initial-Final Mass Relation (approximate it from Fig. 20 in the notes) to find the cumulative fraction of mass returned to the Interstellar Medium for the time intervals from **b)**. Compare this number to the mass returned by the supernova producing stars ($M > 9M_\odot$). To do this assume that those stars leave behind remnants of $\sim 1\ M_\odot$ and have all ended their evolution before 50 Myr.

2 Shell burning stability

a) Review the derivation of the gravothermal specific heat and find the origin of the factor 3 in the expression

$$C_* = C_p \left(1 - \nabla_{\mathrm{ad}} \frac{4\delta}{4\alpha - 3}\right) , \tag{2}$$

(you may need to look at some of the other lecture notes from the set of Robin Ciardullo; the first number in his equation numbering refers to the lecture number; see the course web site for a link to his collection of lecture notes).
b*) From this show that it makes sense to replace this 3 by r/D when considering a thin shell, and that none of the other factors (like the two "4"'s) have to be changed.
c) Check the stability of a H-core flash (start of H-fusion in an electron degenerate core). For the temperature dependence consider both cases: pp-chain and CNO-cycle.
d) Use Fig. 5 in combination with the gravothermal specific heat conditions to argue that we can expect He-shell flashes, but no H-shell flashes in AGB stars[1].

3 Mass evolution

a) Use Fig. 12 from the notes together with the $L-M_{\rm c}$ relation to find the increase of the core mass during the AGB for the three different stellar masses. Express this in $M_\odot$ yr^{-1} and compare this to the average mass loss rates during the AGB (derive these from Figs. 7 and 8 or the IFMR). Why does the answer for the 5 $M_\odot$ does not make sense?

4 On the origin of fluorine in the Milky Way*

Read (at least) Sect. 2.5.7 as well as the last part of Sect. 2.5.13.2 from Lattanzio & Wood's contribution in Asymptotic Giant Branch Stars by Habing & Olofsson. Then read Renda et al. (2004), MNRAS 354, 575.

a) What is the *new* result in this paper?
b) What are the formation and destruction processes of ^{19}F in AGB stars? How is the ^{19}F production related to s-process element nucleosynthesis?
c) Give an overview of the uncertainties in the ^{19}F production.
d) What do you think is meant with *post-processing nucleosynthesis models* (Sect. 3.1)? (Hint: stellar evolution models which calculate the evolution of 100s of different isotopes may be very time consuming). Why is this a reasonable approach to use for ^{19}F?

[1] Note the figure actually only gives you the central positions of the shells, not the actual widths; guestimate a width on the basis of the numbers in the figure.

e) Explain why the AGB stars of spectral type MS, S, and C are not used in finding the ^{19}F abundance of the Milky Way, LMC and ω Cen.
f) Does the O/Fe ratio increase or decrease with time? Explain how you came to your conclusion.
g) What is the problem with the globular cluster ω Cen? What is the solution, and what does this imply for its star formation history?