Late Stages of Stellar Evolution, Problem Set 2

1 Variability at different wavelengths

Calculate the amplitude of variability for a pulsating AGB star at the following wave lengths 2.2 μm (K-band), 1.25 μm (J-band), 540 (V-band), 442 nm (B-band). Assume that the star has a black body spectrum with $T_{\rm eff} = 2500$ K, and that its radius varies by 40%.

2 Mass loss recipes

Compare the Reimer's ($\eta = 1$), Blöcker, and Vassiliadis & Wood recipes for mass loss for AGB stars with the following characteristics:

1. $M = 1.5\ M_{\odot}$, $\log_{10} L/L_{\odot} = 3.8$, $\log_{10} T_{\rm eff} = 3.5$ (in K)
2. $M = 3.5\ M_{\odot}$, $\log_{10} L/L_{\odot} = 4.2$, $\log_{10} T_{\rm eff} = 3.5$ (in K)
3. $M = 5.0\ M_{\odot}$, $\log_{10} L/L_{\odot} = 4.4$, $\log_{10} T_{\rm eff} = 3.5$ (in K)

Assume pulsations in the fundamental mode. What η is needed to get closer to the Blöcker, and Vassiliadis & Wood mass loss rates?

3 Force near the critical point

Calculate the relative increase of the mass loss rate (compared to $\Gamma = 0$) for the cases when the external force can be expressed as Γ=0.1, 0.3, 0.5, 0.9. Do this both for a power law atmosphere similar to the ones from Fig. 27, as well as for an exponential atmosphere with scale height $H/R_{*} = 0.04$. For the latter assume that the critical point lies at $r_{\rm c} = 2R_{*}$. Why do the answers for $\Gamma > 0.5$ not make sense for the exponential atmosphere?

You will find a much more substantial relative increase for the exponential atmosphere than for the power law one. Why is it still hard to drive a high mass loss rate from an exponential atmosphere? (assume that the density at the stellar surface is equal for both atmosphere models).

4 Simple AGB evolution*

Construct a simple TP-AGB evolution model and test the various mass loss recipes. Assume that the luminosity is always given by the luminosity-core mass relation. Take the effective temperature to be constant at $T_{\rm eff} = 2500$ K. The growth of the core mass ($M_{\rm c}$) can be taken to be entirely due to H-burning (i.e. neglect the effects of thermal pulses). Mass loss reduces the envelope mass ($M_{\rm env} = M - M_{\rm c}$). Take as a starting point the core mass implied by the luminosity in Fig. 12 of the notes (for initial (ZAMS) masses 1, 2.5, 5 $M_\odot$). Assume also that the pulsation period is the fundamental mode period.
Use the Reimer's ($\eta = 1$), Blöcker, and Vassiliadis & Wood recipes, and for each of these find the length of the TP-AGB phase (take the end of the AGB to be when $M_{\rm env} = 10^{-3}\ M_\odot$), as well as the initial-final mass relation. Can you find a value for η in the Reimer's recipe that will give an IFMR which fits better with the observations? Show a few plots of the luminosity, mass loss rate, and mass against time.

5 Driving the winds of oxygen-rich AGB stars*

Read

- **Too little radiation pressure on dust in the winds of oxygen-rich AGB stars** by P. Woitke, (2006), A&A 460, L9
- **Winds of M- and S-type AGB stars: an unorthodox suggestion for the driving mechanism** by S. Höfner and A. C. Andersen (2007), A&A 465, L39.

You may not understand every detail in the papers, but this is often true when reading scientific papers if they are not in your field. The point is to try to understand the main points. For more background you can also look at Sect. 5.2 (up to 5.2.4) by T. J. Millar in Asymptotic Giant Branch Stars by Habing & Olofsson. It discusses the concepts of LTE chemistry, role of shock waves, and dust formation.

a Write (in your own words!) in one sentence the main conclusion for each of the two papers.
b The Woitke paper shows that silicate grains can form very close to the star. Explain why they are still not able to drive a dense stellar wind.
c Woitke cites previous models (Ferrarottie & Gail 2006; Jeong et al. 2003) that did produce strong winds from O-rich AGB stars. These models used 'grey radiative transfer'. What is 'grey radiative transfer', and why does it give the wrong result for this problem?
d If the glassy silicates are too transparent to drive the wind, why does it not help to add some 'darker' material such as iron to the grains to get the wind going?
e Compare Fig. 3 from Woitke with Fig. 1 from Höfner & Andersen (concentrate on the density, velocity and temperature plots). What are the differences? Some of these differences are due to the different parameters of their models, some are due to the different types of grains they use. Can explain which differences are mainly due to the different parameters, and which due to the differences in grains (qualitatively!).
f Höfner & Andersen keep stressing that it is hard to form Si-based grains, which are nevertheless abundantly found around O-rich AGB stars. Explain how they get around this.
g Both papers refer to observational results that may support their calculations. Summarize these for each paper, and then compare the lists. Please comment on both lists.