FULL TITLE
ASP Conference Series, Vol. **VOLUME**, **YEAR OF PUBLICATION**
NAMES OF EDITORS

Does simultaneous solution matter for stellar evolution codes?

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Abstract. A version of the STARS stellar evolution code has been developed that uses a non-simultaneous solution of the equations of stellar structure and evolution. It is therefore possible to test the dependence of the solution on how the equations are solved. Three models of metallicity Z=0.02 are investigated. Prior to the asymptotic giant branch, the models are almost identical. However once thermal pulses start, the two methods of solution yield diverging results with the non-simultaneous technique predicting longer interpulse periods. This is traced to difficulties associated with hydrogen burning caused by the use of a moving mesh. It is shown that, with careful control of the temporal resolution, the results of the simultaneous technique can be recovered.

Calculations of TP-AGB evolution made with different stellar evolution codes show quite different results (Lugaro et al. 2003). The reason for this is not understood. Calculations could be effected by the choice of the method of solution of the equations of stellar structure and evolution. While it is thought that the method of solution will not affect the results obtained (Herwig 2005), this assumption has not been tested until now. To this end a version of the STARS stellar evolution code (Eggelton 1971) has been developed that employs a non-simultaneous solution of the equations of stellar structure and evolution. We can thus test the effect of the method of solution on the evolution obtained. By changing the method of solution employed it is possible to investigate the effect of this alone. We are not hampered by the differences in equation of state, reaction rates, timestep control, differencing scheme, etc. that would exist if a comparison were to be made between two different codes.

Models were evolved from the pre-main sequence to the TP-AGB with both methods of solution. Prior to the TP-AGB no discernable difference is seen in the evolution. The models begin the TP-AGB with core masses within 1% of each other - much less than the differences in core mass seen between different evolution codes. For example, the core masses of a 5-$M_\odot$ Z=0.02 model as calculated by Karakas et al. (2002) and Stancliffe et al. (2004) are different by about 7%. The core mass at which TDUP sets in is also the same to within a percent for both methods of solution. The method of solution does not account for the differences seen between different evolution codes.

Along the TP-AGB, the models are seen to diverge after a few thermal pulses. It is found that the divergence is due to problems associated with H-burning with the non-simultaneous method of solution. The left-hand panel of Fig. 1 shows the evolution of the H-burning luminosity for a 1.5-$M_\odot$ model. If the timestep of the non-simultaneous solution is reduced by over an order of magnitude, the simultaneous solution is recovered.

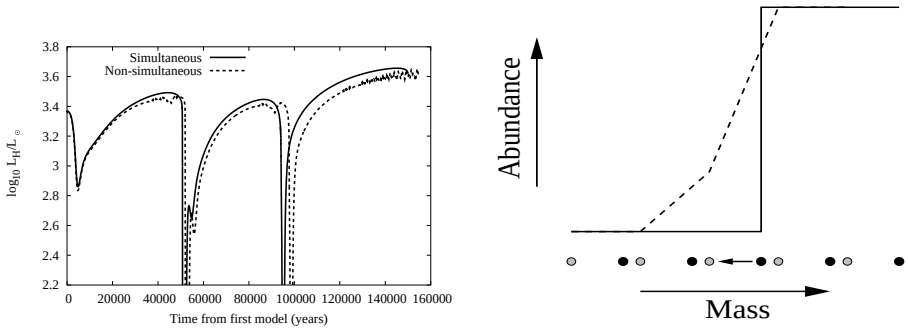

Figure 1. Left panel: The evolution of the hydrogen luminosity of a 1.5-$M_\odot$ model. The solid line is the simultaneous solution while the dashed line is the non-simultaneous solution. Right panel: A schematic depiction of why numerical diffusion occurs. A sharp abundance profile (solid line) is set up over a few mesh points (black dots). If the mesh points then move in mass to the positions indicated by the grey circles, the abundance profile is modified to that indicated by the dashed line.

The H-burning problems are associated with the use of a non-Lagrangian mesh together with a non-simultaneous solution. When a sharp composition profile exists, movement of the mesh leads to numerical diffusion (as depicted in the right-hand panel of Fig. 1). This leads to extra fuel ending up where it should not physically be. The burning rate is enhanced and this feeds back to the structure. In a Lagrangian mesh, this problem does not occur. With a non-Lagrangian mesh the problem can be dealt with if the timesteps are kept small as this limits the extent of the diffusion. This is why the simultaneous solution can be recovered when using a non-simultaneous solution. For further details, the interested reader is referred to the full article by Stancliffe (2006).

The numerical issues associated with using a non-simultaneous method of solution together with a non-Lagrangian mesh make more detailed comparisons problematic. In future work, a version of the STARS code that has a Lagrangian mesh needs to be developed. This would enable a more detailed comparison to be made between the methods of solution. In addition, how the type of mesh used effects the evolution could also be investigated.

Acknowledgments. The author thanks the conference organisers for financial support. He is also grateful to Churchill College for his fellowship.

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