The importance of the remnant's mass for VLTP born again times. Implications for V4334 Sgr and V605 Aql.

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Abstract. We present numerical simulations of the very late thermal pulse (VLTP) scenario for a wide range of remnant masses. We show that, by taking into account the different possible remnant masses, the fast outburst evolution of V4334 Sgr (a.k.a. Sakurai's Object) and V605 Aql can be reproduced within standard 1D stellar evolution models. A dichotomy in the born again timescales is found, with lower mass remnants evolving in a few years and higher mass remnants ($M \gtrsim 0.6 M_{\odot}$) failing to expand due to the H-flash and, as a consequence, evolving in timescales typical of He-shell flash driven born agains (~ 100 yr).

1. Introduction and description of the present work

Since the discovery of post-AGB thermal pulses in the early simulations of Paczynski (1970) these events have been object of several studies. Fujimoto (1977) showed that during thermal pulses penetration of the pulse driven convective zone (PDCZ) into the H-rich envelope is possible if the mass of this envelope was small enough. These works were confirmed by Schönberner (1979) who performed calculations of low mass stars with steady mass loss. Schönberner (1979) found that contact between the PDCZ and the H-rich envelope was possible if the thermal pulse happens when the star enters the white dwarf stage (event now termed VLTP). Since the work of Renzini (1979) post-AGB thermal pulses are associated with the formation of H-deficient stars, an idea pushed forward by the simulations of Iben et al. (1983) (who introduced the term "born again AGB stars" for this objects). Due to numerical difficulties in the treatment of the simultaneous mixing and burning of H at high temperatures during a VLTP, early simulations did not follow the evolution during this event. This was first attempted by Iben & MacDonald (1995) who presented the first VLTP simulations that included a time dependent treatment of the convective mixing and burning of H. After the works of Herwig et al. (1997, 1999) it became clear that the abundances of some post-AGB H-deficent stars could be well understood within the born again scenario (see, however, De Marco this proceedings).

The identification of V4334 Sgr as a star undergoing a VLTP event (Duerbeck & Benetti 1996) has renewed the interest in this particular kind of late helium shell flash. V4344 Sgr has showed a very fast evolution of a few years (Duerbeck et al. 1997, Asplund et al. 1999 and van Hoof et al. 2007), not far from the only theoretical value available at the time of its discovery (~ 17 yr, Iben & MacDonald 1995). Since then, the fast evolution of V4334 Sgr has been

| | Iben & | Herwig | Herwig | Lawlor & | Miller Bertolami |
|----------------------|-----------|--------|--------|----------------|------------------|
| | MacDonald | et al. | | MacDonald | et al. |
| | (1995) | (1999) | (2001) | (2002) | (2006) |
| Mass $[M_{\odot}]$ | 0.60 | 0.604 | 0.535 | 0.56 to 0.61 | 0.589 |
| Born Again Time [yr] | 17 | 350 | 21 | 4.5 to 8.5 | 5 to 10 |

Table 1.Born Again timescales of previous simulations of the VLTP withstandard MLT approach that include the violent H-burning event.

the object of several works with results far from showing a consistent picture (see Table 1). The works of Herwig (2001) and Hajduk et al. (2005) introduced a new free parameter in the treatment of convection (the mixing efficiency) and showed that, by fine tuning the velocities of convective mixing during the VLTP (to values different to those predicted by the mixing length theory, MLT), the fast outburst evolution and reheating of V4334 Sgr could be reproduced by a model of 0.604 M_{\odot} . In this context, VLTP evolution was proposed as a tool to test convection theory of reactive convective fluids (Herwig 2001). However, born again timescales of previous simulations of the VLTP episode with standard MLT approach (i.e. no reduction in convective velocities) show a wide range of born again timescales, with differences rising up to a factor 70 (see Table 1). If V4334 Sgr observed evolution and VLTP simulations are to be used to test convection theory, these differences have to be understood first.

As can be seen from third and fourth columns of Table 1 the remnant's mass seems to play an important role in determining the born again timescale. However, most of the existing simulations of the VLTP have been performed in a narrow range in mass. The aim of the present article is the exploration of the (neglected) importance of the remnant mass for the born again timescale.

For the present work we have performed numerical simulations of the VLTP for 10 different remnant masses. All of the remnant models are the result of full evolutionary calculations from the ZAMS, through the AGB phase and to the post-AGB phase for a metallicity of Z=0.02. Overshooting at every convective boundary was considered as in Herwig et al. (1997). Convective mixing was considered as a diffusive process and solved simultaneously with nuclear burning and convective velocities were adopted as given by standard MLT approach. For a more extensive discussion about numerical and physical aspects of the present simulations we refer the reader to Miller Bertolami & Althaus (2007).

2. Discussion of the results and comparison with observations

As can be seen in Fig. 1 (right panel) our sequences show a clear dichotomy in the VLTP born again timescales as a function of mass. While remnants with masses $M \leq 0.6 M_{\odot}$ show a fast born again evolution of a few years, higher mass remnants display born again timescales of the order of centuries, timescales typical of He-flash driven born again evolutions — i.e. when no burning of H takes place (see Blöcker 1995 and Schönberner, this proceedings). The reason for this can be found in the estimation presented in Fig. 1., where the energy available from the burning of the whole H-content of the star ($E_{\rm H}$) is compared with the energy needed to expand the envelope above the point at which such energy is released $(E_{\rm exp})$. As it is shown there, for remnants above a certain value (~ $0.6 {\rm M}_{\odot}$, thick grey line) the energy released by the burning of the H-content of the star is not enough to drive the expansion of the envelope. As a consequence, after burning the H-rich envelope, the expansion back to the AGB of those sequences is driven by the He-shell flash, leading to born again timescales of the order of centuries.

In Fig. 2, left panel, the evolution of our low mass sequences ($M \leq 0.6 M_{\odot}$) is compared with observations of V4334 Sgr. As can be seen, all of them show good agreement with the evolution of the effective temperature of V4334 Sgr. Also the preoutburst location is compared with that inferred in V4334 Sgr (right panel). In particular it is worth mentioning that our $0.561M_{\odot}$ sequence, which nicely reproduces the 1995-1998 evolution of V4334 Sgr also reproduces the outburst lightcurve and preoutburst location for the same distance of ~ 3 - 4 Kpc, consistent with independent distance determinations which place V4334 Sgr below 4.5 Kpc (Kimeswenger 2002). However note that this model is unable to reproduce the rapid reheating reported by van Hoof et al. (2007). Although reheating times can be, in principle, reproduced by increasing the mass loss once the star is back on the AGB (see Fig. 2 left bottom panel) it is also possible that the failure of our models to reproduce the rapid reheating of V4334 Sgr is due to the fact that hydrostatic equilibrium is explicitly broken in the outer layers once the model is back on the AGB.

3. Conclusion

We have shown that post-VLTP born again times can be divided into two groups: low mass remnants that evolve back to the AGB in a few years and high mass remnants in which the energy released by H-burning fails to drive the expansion back to the AGB and, consequently, show born again timescales of the order of a century. We also showed that V4334 Sgr evolution can be understood within the standard MLT as the VLTP evolution of a ~ 0.56 M_{\odot} remnant. However our models fail to reproduce the rapid reheating reported by van Hoof et al. (2007) something that may be pointing to the need of a better treatment of the outer layers of the envelope in our models.

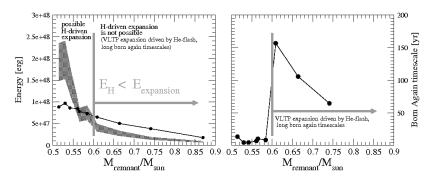


Figure 1. Left: Comparison between the energy available from the burning of the H-content of the star (shaded zone) with the energy needed to expand the envelope (solid line). Right: Born again timescales of the simulations.

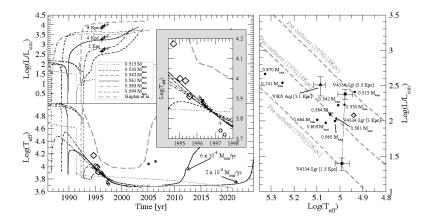


Figure 2. Left: Outburst evolution (top: luminosity, bottom: effective temperature) of our lower mass sequences as compared with observations of V4334 Sgr. Observations are taken from Duerbeck et al. (1997; \diamond and +), Asplund et al. (1999; \times), Pavlenko & Geballe (2002; \circ) and van Hoof et al. (2007; \bullet). For the 0.561M_{\odot} model two different mass loss rates were considered at log($T_{\rm eff}$)< 3.8 leading to different reheating timescales. Inset shows a zoom of the evolution of the effective temperature during the discovery of V4334 Sgr. *Right:* Preoutburst location of our sequences (\bullet). Grey dashed line correspond to possible detection of V4334 Sgr in a ESO/SERC survey (Herwig 2001). V4334 Sgr preoutburst locations are from Kerber et al. (1999; black square) and Hajduk et al. (this proceedings; grey diamond). V605 Aql value is taken from Lechner & Kimeswenger (2004).

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References

Asplund, M., Lambert, D., Pollaco, D., Shetrone, M. 1999, A&A, 343, 507 Blöcker, T. 1995, A&A, 299,755 Duerbeck, H. W., & Benetti, S. 1996, ApJ, 468, L111 Duerbeck, H. W., Benetti, S., Gautschy, A., et al. 1997, AJ, 114, 1657 Fujimoto, M. Y. 1977, PASJ, 29, 331 Herwig, F. 2001, ApJ, 554, L71 Herwig, F., Blöcker, T., Schönberner, D., & El Eid, M. 1997, A&A, 324, L81 Herwig, F., Blöcker, T., Langer, N., & Driebe, T. 1999, A&A, 349, L5 Hajduk, M., Ziljstra, A., Herwig, F., et al. 2005, Science, 308, 231 Iben, I. & MacDonald, J. 1995, Lecture Notes in Physics (Springer Verlag), 443, 48 Iben, I., Kaler, J. B., Truran, J. W. & Renzini, A. 1983, ApJ, 264, 605 Kerber, F., Köppen, J. Roth, M., & Trager, S. 1999, A&A, 344, L79 Kimeswenger, S. 2002, ApSS, 279, 79 Lechner, M. F. M., & Kimeswenger, S. 2004, A&A, 426, 145 Lawlor, T. M., & MacDonald, J. 2002, Ap&SS, 279, 123 Miller Bertolami, M. M., Althaus, L. G., Serenelli, A., Panei, J. 2006, A&A, 449, 313 Miller Bertolami, M. M., & Althaus, L. G. 2007, MNRAS, 380, 763 Paczynski, B. 1970, Acta Astronomica, 20, 47 Renzini, A. 1979, Stars and Star Systems, Bengt Westerlund (ed.), 155 Schönberner, D. 1979, A&A, 79, 108 Van hoof, P. A. M., Hajduk, M., Ziljtra, A. et al. 2007, A&A, 471, L9