Why Galaxies Care About AGB Stars:
A Continuing Challenge through Cosmic Time
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Late Thermal Pulse Models and the Rapid Evolution of V839 Ara

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Abstract. We present evolution calculations from the Asymptotic Giant Branch (AGB) to the Planetary Nebula (PNe) phase for models of mass 1.0 to 2.0 $M_\odot$ over a range of metallicities. The understanding of these objects plays an important role in galactic evolution and composition. Here, we particularly focus on Late Thermal Pulse (LTP) models, which are models that experience an intense helium-shell pulse that occurs just following AGB departure and causes a rapid looping evolution between the AGB and PN phases. The transient phases only last decades and centuries while increasing and decreasing in temperature dramatically. We use our models to make comparisons to V839 Ara (SAO 244567). This star has been observed rapidly heating over more than 50 years. Observations have proven difficult to model because the central star has a small radius, high surface gravity, and low temperature compared to our models.

Keywords. stars: AGB and post-AGB, stars: evolution, stars: abundances

1. Late Thermal Pulse Caught in the Act: V839 Ara in the Stingray Nebula

V839 ARA (SAO 244567) appears to have experienced a late thermal pulse (LTP). It has been observed rapidly evolving, becoming hotter and less luminous. According to Parthasarathy (2000) it appeared to be an early type B star in 1971, and has been reported to have a central star mass of approximately 0.6 $M_\odot$. LTP objects are a cousin of Very Late Thermal Pulse (VLTP) objects (e.g. Sakurai's Object) and both undergo a helium shell flash that dredges up helium and other metals, and mixes down hydrogen which is consumed by proton capture. LTP objects experience a helium pulse earlier because they contain comparatively more mass in their helium shell. The star will eventually be hydrogen deficient. We (among others) predicted V839 Ara would ultimately evolve back to the AGB, which has now been confirmed by Reindl *et al.* (2016). We predict the central star will cool rapidly by as much as $15,000$ K in the next 25–50 years and another $10,000$ K in the following 25–50 years. Within 200–300 years, it will appear as a cool AGB star, and will retrace AGB departure over tens of thousands of years. We confirm that an LTP scenario is the most likely explanation for the stars rapid evolution. Another piece of evidence that supports a LTP scenario is that it is the youngest known planetary nebula.

The observations appear to reach a lower luminosity and smaller radius than our models. This is evident in Figure 1 (left side) which shows the evolution of V839 Ara and our models in the $\log(g) - \log(T_{\rm eff})$ plane. Based on the trend of reaching a lower luminosity for a higher Z we predict a better match may be for a model with an initial mass of 1.2 $M_\odot$ and metallicity $Z = 0.030$. Our choice of Z is an estimate based on the stars location in the thin disk of our Galaxy, though the major observed species in Reindl *et al.* imply a metallicity near 0.015. A model that is less massive may lower the

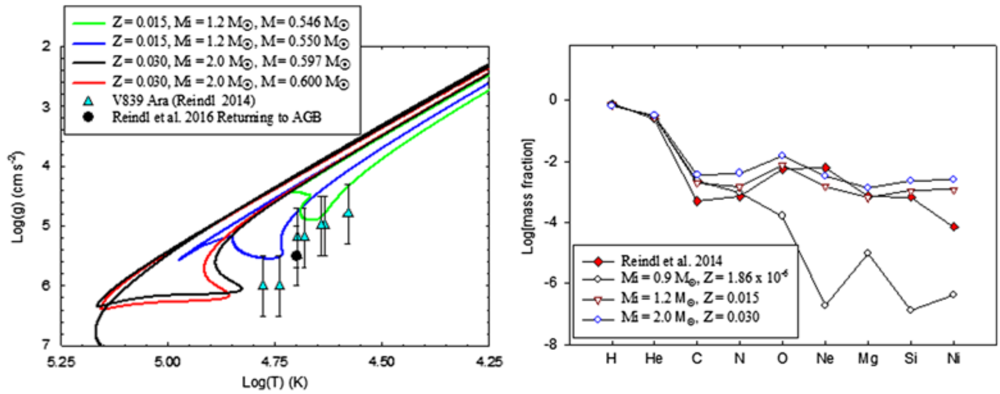

Figure 1. Left: LTP models in the $\log(g) - \log(T_{\rm eff})$ plane compared to V839 Ara from Reindl *et al.* 2014, Reindl *et al.* 2016. Right: log[mass fraction] for LTP models compared to V839 Ara taken from Reindl *et al.* (2014).

temperature, but how much less is limited by the age of the universe. It cannot be less massive than 0.85 $M_\odot$ on the MS.

Figure 1 (right) also shows surface abundances for V839 Ara from Reindl *et al.* (2014) compared to our LTP models taken during the same epoch. The most abundant elements are similar, which supports that the initial Z for this star is between 0.015 and 0.03, and final mass is close to 0.56 $M_\odot$. In general, our models produce too much heavy elements at this stage; however, this may just be due to how we set our initial values and our starting models may begin with too much helium, a crucial parameter in predicting how a LTP will evolve.

2. Take away: Do Galaxies care?

For models that do not undergo a LTP, dredge up is modest and so mass loss on the AGB and during the superwind phase returns mass that is not significantly enriched. However; LTP models experience a period of convective dredge up when it traces its second departure from the AGB. This results in surface abundances of $X = 0.55$ and $Y = 0.40$, and most other abundances enhanced by more than 10 times. VLTP models are similarly enhanced in metals and deficient in hydrogen, but more extremely so. We estimate (Lawlor & MacDonald 2003, Lawlor & MacDonald 2006) that up to 20% of lower mass stars will experience a thermal helium pulse, increasing the metallicity of material returned to the ISM, perhaps earlier than previously thought.

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