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# Modeling the red edge of the GW Vir (PG 1159) instability strip : evolutionary calculations taking into account diffusion and mass loss

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**Abstract.** Computations of PG 1159 models show that a red edge for their pulsational instability is naturally reached around $T_{\rm eff} \sim 73,000$ K when we make use of a simple mass loss law in conjunction with diffusion theory.

**Key words.** Stars: oscillations – Stars: diffusion – Stars: white dwarfs

## 1. Introduction

The PG 1159 spectral type is encountered in very hot pre-white dwarfs, and is due to a mixture of He, C and O produced by a violent mixing event during the last He flash. This flash occurs in the so-called "born-again" post-AGB evolutionary phase. About half of the known PG 1159 stars show multiperiodic luminosity variations caused by nonradial pulsational instabilities of the GW Vir type (high-order gravity-modes) and, until quite recently, it has been difficult to explain why variable and nonvariable PG 1159 stars should coexist in the same region of the $\log g - T_{\rm eff}$ plane. However, in a recent publication, we found a natural explanation for this cohabitation. The $\kappa$-mechanism due to the K-shell ionization of carbon and oxygen is responsible for the GW Vir instability domain, and the different PG 1159 configurations (in terms of surface composition and surface parameters) cause the $\kappa$-mechanism to have a different efficiency from star to star.

An equally puzzling fact is that no GW Vir pulsator is found below $T_{\rm eff} = 80,000$ K, and that the PG 1159 spectral type itself ceases to exist below $75,000$ K. It has long been suspected that gravitational settling of C and O would leave behind an increasingly He-rich envelope in evolving PG 1159 stars, but we found that something must slow down this process in order to prevent the quasi-instantaneous transformation of the atmospheric composition of these stars from a He-C-O mixture into a pure He plasma. That "something" is very likely the presence of residual stellar winds. In this context, we summarize detailed evolutionary calculations coupled to nonadiabatic computations showing that the red edge of the GW Vir instability strip can be naturally explained. Our evolutionary calculations take into account diffusion processes competing against mass loss.

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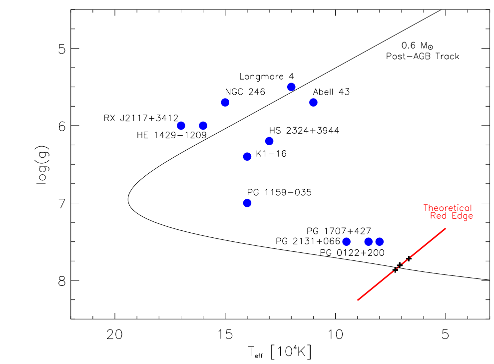


**Fig. 2.** All known GW Vir stars with reliable spectroscopy. The red line draws the theoretical red edge of the class extrapolated from the red edge of three evolutionary tracks marked with crosses. ($0.56 M_\odot$, $0.60 M_\odot$ and $0.62 M_\odot$, respectively, from low $g$ to high $g$)

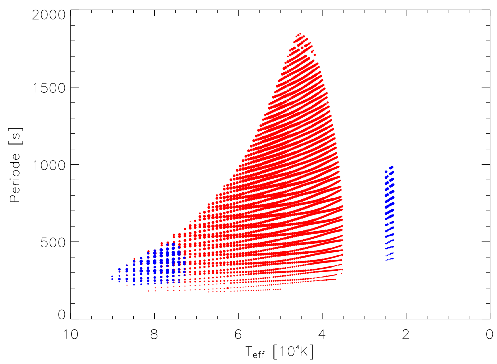


**Fig. 1.** Sample excited period spectra from two evolutionary tracks with and without diffusion/mass loss. The red dots are for an evolutionary track without diffusion/wind and show a red edge of $\sim 35,000$ K. The blue dots on the left side are for a track including diffusion/wind and show a red edge of $\sim 73,000$ K. The additional blue dots region on the right side ($\sim 25,000$ K) comes from the same track and corresponds to the DB white dwarf instability strip. The two instability regions are thus reproduced with success by our model.

## 2. discussion and results

We considered a PG 1159 model with a typical envelope chemical composition of $X(\mathrm{He}) = 0.44$, $X(\mathrm{C}) = 0.42$, $X(\mathrm{O}) = 0.14$ (by mass fraction) and followed its stability behavior during its evolution along the white dwarf cooling track. First, we let the star evolve with no wind or diffusion. From the red dots representing unstable modes in Fig. 1, we see that the model stays unstable until it reaches a low temperature of $\sim 35,000$ K where no PG 1159 has ever been observed. In a more realistic approach, we included diffusion coupled with mass loss in the evolutionary code. Within this approach, the carbon and oxygen present in the envelope settled slowly with time until the star stopped pulsating at some relatively low effective temperature. The blue dots on the left of Fig. 1 show that the red edge is reached at $T_{\mathrm{eff}} \sim 73,000$ K and $\log g \sim 7.87$ for a 0.62 $M_\odot$ model. A model at the red edge shows a significant variation in envelope chemical composition as compared to a starting model. For instance, in the driving layers of the red edge model, defined by the region where the derivative of work integral ($dW/d\log q$) is nonzero (from $\log q = \log(1 - Mr/M_\odot) \sim -6$ to $\log q \sim -11$), we find a chemical composition of $X(\mathrm{He}) = 0.80$, $X(\mathrm{C}) = 0.16$ and $X(\mathrm{O}) = 0.04$. Repeating this evolution process for 0.60 $M_\odot$ and 0.56 $M_\odot$ tracks gave the exact same proportion of elements in the driving layers. The red edge defined by those three models is presented in Fig. 2.

As can be expected, the position of the theoretical red edge is strongly influenced by the mass loss law used in the model. For this illustrative study, we used a simple radiation-driven wind model found in the literature for post-AGB stars: $dM/dt = 1.29 \times 10^{-15} L^{1.86}$. A stronger wind model gives a slightly cooler red edge while a weaker wind pushes the red edge to higher temperatures. This effect is easily understood as wind mass loss slows down the downward diffusion of carbon and oxygen away from the layers where they can trigger the $\kappa$-mechanism.