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PULSATIONS IN FAINT BLUE STARS

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ABSTRACT

Blue Large-Amplitude Pulsators are a newly-discovered category of pulsating variable star, with two different sub-groups being discovered in 2017 and 2019. They show brightness variations over a time periods ranging from 3 minutes to 40 minutes, with an amplitude of a few per cent of their total brightness. The evolutionary status of these stars was uncertain upon their discovery, although one suggestion is that they could be low-mass pre-white dwarfs, stars which have had their outer layers removed by a close binary companion, leaving a nearly naked helium core object which is contracting to become a white dwarf.

In this study I produced a sequence of pre-white dwarf stellar evolution models for a range of masses, to test the hypothesis that BLAPs are low-mass pre-white dwarfs. The models were also used to test whether objects in this phase of evolution are sufficiently unstable for pulsations to occur. These models were produced using the MESA open-source stellar evolution code, and the presence of pulsations was determined using the GYRE stellar oscillation code.

It was found that pre-white dwarf stars with masses between 0.28 and 0.31 times the mass of the Sun can provide a reliable explanation for the evolutionary status of BLAPs. The models also indicate that these stars should pulsate, with periods that match the observations, but only if the process of radiative levitation is taken into account. Radiative levitation causes iron and nickel to accumulate in large amounts providing the opacity bump to drive the pulsations. Preliminary predictions are made for the prospect of further objects being found in the region of parameter space between the two distinct sub-groups of BLAP currently known. The morphology of the pulsation instability region may also provide insight into common envelope evolution, a poorly understood phase of close binary interactions.

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INTRODUCTION

Blue large-amplitude pulsators (BLAPs) were discovered by the OGLE Galactic Bulge survey (Pietrukowicz et al., 2017). 14 objects were identified, with pulsation periods between 20 and 40 minutes and brightness variation amplitudes of up to 0.4 magnitudes. Follow-up measurements determined these objects have surface temperatures between 20,000 and 40,000 K, and surface gravities, log(g), between 4 and 5. Another similar group of stars, dubbed high-gravity BLAPs as they had higher log(g) values, were discovered by the ZTF survey (Kupfer et al., 2019). These high-gravity BLAPs have pulsation periods between 3 and 8 minutes.

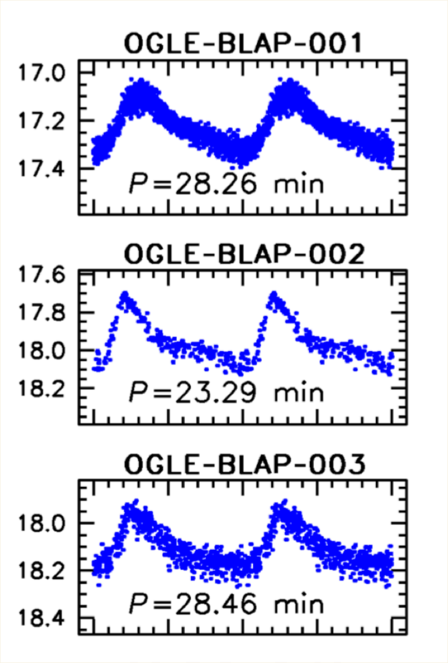

Fig 1: OGLE light-curves of some of the BLAPs discovered in 2017 . From Pietrukowicz et al.(2017)

The evolutionary status of these objects is uncertain, but previous work by Byrne & Jeffery (2018) identified that low-mass pre-white dwarfs are a likely candidate. Low-mass white dwarfs are white dwarfs (WDs) with a mass of less than 0.5 $M_\odot$. For these to have formed within the current age of the Universe, binary interactions are required, whereby a companion star removes most of the mass from a red giant, leaving an inert helium-rich core which cools and contracts to become a white dwarf (Althaus et al., 2013). This can be achieved through stable mass transfer (Roche Lobe overflow) or unstable mass transfer (common envelope evolution).

METHODS

The open-source MESA stellar evolution code (Paxton et al., 2011, 2013, 2015, 2018, 2019) was used to create models of low-mass WDs. This was done by evolving a 1 $M_\odot$ star until the red giant phase and then interrupting the evolution with a sudden mass-loss episode, replicating the effect of common envelope evolution. This was done for a number of red giant core masses to produce a sequence of low-mass WDs. Some of the evolution track are shown in Fig 2.

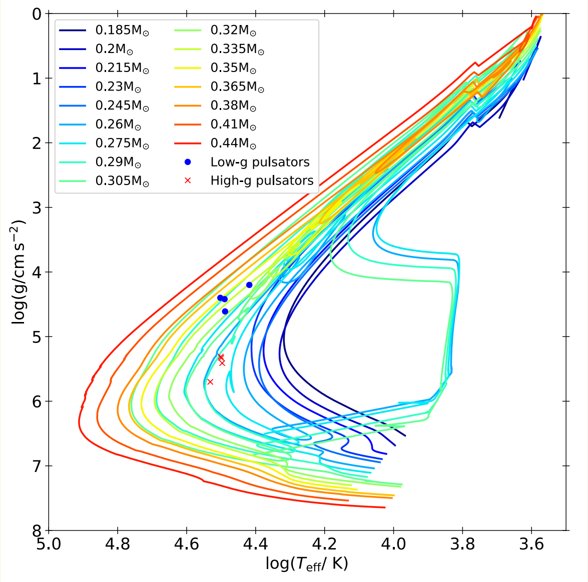

Fig 2: Evolutionary tracks of some of the low-mass pre-white dwarfs, evolving from the RGB to the white dwarf cooling sequence. Some models undergo a hydrogen shell flash, which can be seen in the 'loops' in some of the evolution tracks. The location of the OGLE BLAPs and the ZTF BLAPs are indicated by the blue dots and red crosses respectively. From Byrne & Jeffery (2020)

The effects of atomic diffusion and radiative levitation were considered in these models, as previous work has shown that this is important for driving pulsations in these stars (Byrne & Jeffery 2018). Radiative levitation causes iron and nickel to accumulate in a at a temperature of around 2×10^5 K, which creates an opacity bump to drive the pulsations. The same process causes pulsations in hot subdwarf stars (Charpinet et al., 1997) which are similar to low-mass WDs, but are massive enough to start helium core burning, and sit at the hot end of the Horizontal Branch.

ANALYSIS

Each model was analysed at numerous points along its evolution track using the GYRE stellar oscillation code (Townsend & Teitler, 2013). By carrying out a non-adiabatic analysis, it is possible to determine whether the star is stable or will pulsate. This analysis was restricted to the radial fundamental mode, as this is the mode which is observed to be excited in BLAPs. A number of regions of the parameter space were found to have unstable modes, as can be seen in Fig 3. These include at high luminosity-to-mass ratio, where strange-mode oscillations are present and the low temperature regime where pulsations may be driven by H/He ionisation. The most important region is the large instability region between 25,000 and 60,000 K [$4.4 < \log(T_{\rm eff}) < 4.8$]. Pulsations in this region are driven by the Fe/Ni opacity bump, or Z-bump, which is enhanced by the action of radiative levitation. It is this which provides the driving mechanism for BLAPs.

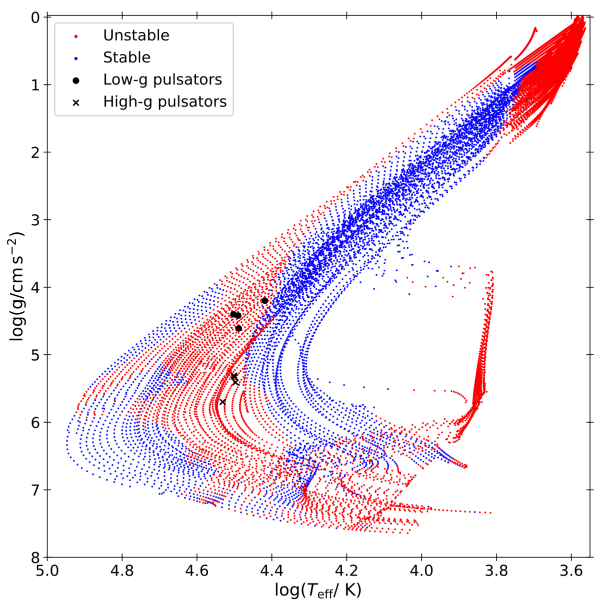

Fig 3: Log(g)-$\log(T_{\rm eff})$ diagram showing models with a stable (blue) or unstable (red) radial fundamental mode. From Byrne & Jeffery (2020)

RESULTS

Fig 4 illustrates the role played by radiative levitation. The colour scale indicates the mass fraction of iron in the pulsation driving region of the stellar envelope. Comparing with the instability regions on Fig 3, it is interesting to note that all of the pulsators lie close the low temperature edge of the instability region, which also coincides with the onset of radiative levitation enhancing the iron in the driving region.

In addition to being unstable to pulsation, the periods of the models agree well with the observations. For example the high-gravity BLAP pulsator known as HG-BLAP-2 has an observed period of 363 sec, while the closest matching model in the log(g)-$\log(T_{\rm eff})$ plane in this data set has a pulsation period of 353 sec. The OGLE BLAPs correspond to pre-WDs with a mass of around 0.31 $M_\odot$, while the ZTF BLAPs correspond to pre-WDs with a mass of 0.28 $M_\odot$.

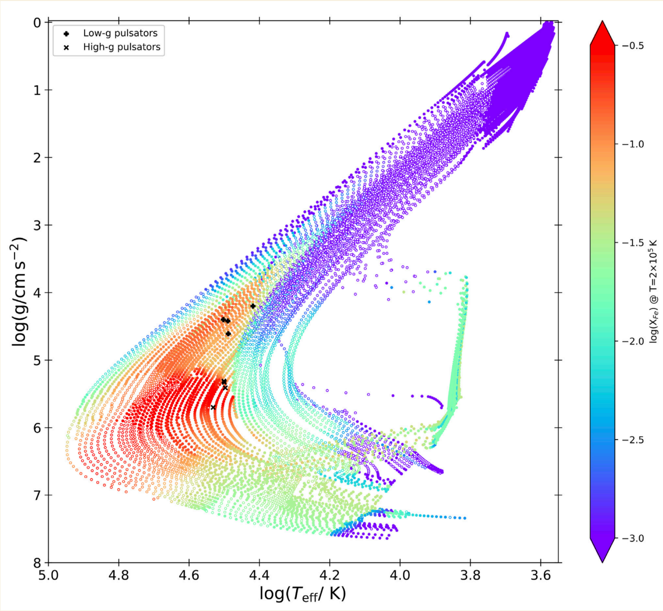

Fig 4: Abundance of iron in the driving region of the stellar envelope, with purple at the bottom of the colour scale corresponding to the solar value. The black symbols indicate the location of the observed BLAPs. From Byrne & Jeffery (2020)

DISCUSSION

The exact location of the low-temperature edge of the instability strip is sensitive to assumptions about the common envelope ejection, such as the remnant envelope mass, so BLAPs may be a useful tool for studying close binary interactions.

The fact that both groups are similar objects; namely, pulsating low-mass pre-white dwarfs of different masses, implies that it is reasonable to expect to find BLAPs at masses intermediate to these two groups. Fig 5 provides a simplified mass distribution that could be expected, based solely on the amount of time each model spends in the instability region, showing that pre-WDs with masses between 0.26 $M_\odot$ and 0.32 $M_\odot$ spend the longest amount of time in the instability region.

To date, only 4 of the 14 BLAPs in the original set of objects discovered by OGLE have had their atmospheric parameters determined. Placing more of these objects on the log(g)-log(T_{eff}) plane would provide a better understanding of how the known population is distributed in terms of mass.

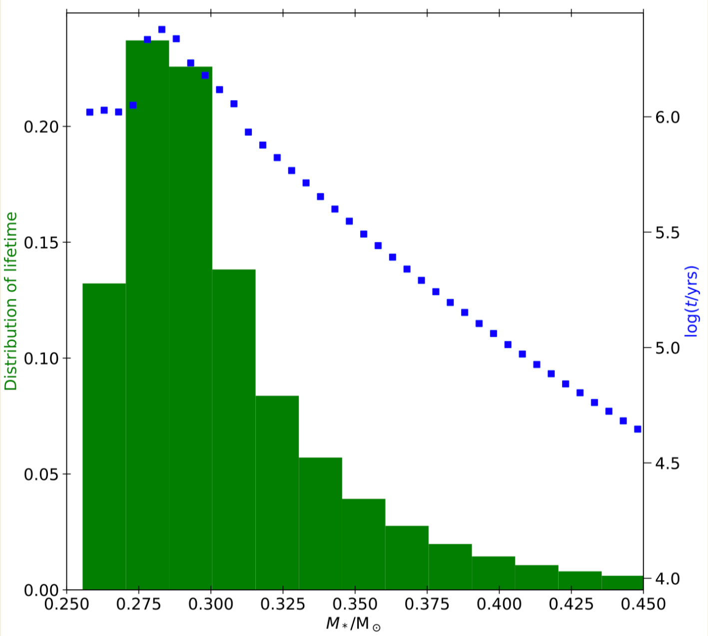

Fig 5: Estimated mass distribution of BLAPs, based on lifetime in the instability region. Note that this distribution assumes a formation rate for low-mass white dwarfs that is uniform. From Byrne & Jeffery (2020)

CONCLUSIONS

- BLAPs and high-gravity BLAPs are identified to be pulsating low-mass pre-white dwarfs, with masses of around 0.31 $M_\odot$ and 0.28 $M_\odot$ respectively.
- The pulsations are a result of Z-bump opacity which provides a significant driving force when the effects of radiative levitation are accounted for, as is the case for hot subdwarf pulsators.
- Further BLAPs should be expected in ongoing and future sky surveys, forming a continuous population, rather than two discrete groups, although binary population synthesis is required to obtain a more accurate expected mass distribution.

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