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Nightmare on ′ELM′ Street: MESA Modeling of Low Log (g) Valued Flashing Extremely Low Mass White Dwarf Stars

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Abstract:
Although the average mass of white dwarf (WD) stars is $0.6 \pm 0.1 M_{\odot}$, recent surveys have found a number of extremely low mass (ELM) WDs, with masses less than 0.25 solar masses. Recently, we discovered large-amplitude pulsations in one such supposed ELM WD having effective temperature $T_{\rm eff} \approx 8000$K and a surface gravity described by $\log(g) \approx 4.6$. While this $\log(g)$ value is nominally too high for it to be a main sequence star, it is also quite low to be an ELM WD. Using the open source stellar evolution code MESA, we examine a range of models produced with different final masses and mass loss rates, with the goal of finding the most likely evolutionary scenario that reproduces the parameters of this low - $\log(g)$ star. In addition, we calculate the low-order pulsation modes for these models and show how these change with the evolutionary state of the star. Further work with short-timescale pulsations will better constrain flashing ELM WD candidacy.

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1. MESA Analysis

We used MESA (Modules for Experiments in Stellar Astrophysics) code to test the viability of ELM WD status for the observed candidate. We ran models with a three-step process to approximate how a star would evolve as a flashing ELM WD in a binary system. In addition to using an original mass of 2.0 $M_{\odot}$, from the binary equations we set the absolute mass loss rate of the star as $\log(\dot{M}) \approx 7.4$. We ran 60 models were using varying combinations of a limited set of evolution parameters in mesa. These parameters included final stellar mass (ranging from M_f = (0.15-0.21) $M_{\odot}$), absolute mass loss rate (ranging from $\log(\dot{M})$ = -6 to -8), overshooting (our chosen value of f = 0.014 or off), and the type of stellar atmosphere (either WD Tau 25 Tables, or grey and kap).

2. Results

The outputted MESA data for $\log(g)$ and $T_{\rm eff}$ throughout the star's life produces a curve similar to the looping tracks in Figure 1 if the WD does indeed flash. It is not enough, however, to simply find the point on the evolution curve in respect to $\log(g)$ and $T_{\rm eff}$ that is the closest to the observed data point, as the star spends various amounts of time in different parts of the curve.

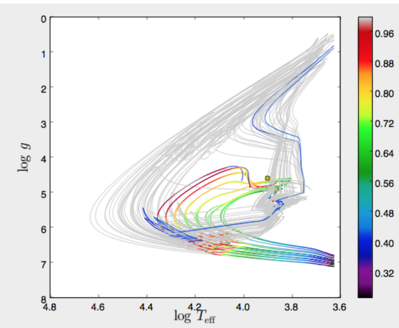

Figure 1: $\log(g)$ vs $T_{\rm eff}$ with the observed stellar parameters in yellow, and evolutionary speed represented by the color bar.

As a result, if the closest point on the evolution track was in a flash phase, we would not expect the observed star to actually be an ELM WD because of how unlikely it would be to observe such a transient evolutionary stage. Drawing from all of the combinations of parameters, the best fit to the observed candidate had an overshoot of $f = 0.014$, the Tau Tables atmosphere, and a final mass of around $M_f = 0.18 M_{\odot}$. There is a probability of approximately 7 orders of magnitude that an ELM WD could be observed in its initial cooling track, compared to when the star was actually flashing.

3. Discussion

While the MESA models do not conclusively support that this observed star is an ELM WD in a binary system, our results show that the possibility is not unlikely given recent surveys describing ELM WDs. Even though our definition of evolutionary speed is not very rigorous, the ballpark probabilities are more than enough to come to the conclusion that the observed star is unlikely to be an ELM WD caught in mid-flash. However, with the data from the revised MESA models, it is reasonable to claim that the observed star is an ELM WD on its initial cooling track before it flashes. Further research will focus on better constraining the evolutionary model of the star by performing short-timescale pulsations on the model and comparing these calculations with observed pulsations of the target star.

References

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[2] Paxton, B., Cantiello, M., Montgomery, M. H., et al., astro-ph.SR, 2009.