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A common puzzle for Extreme Helium stars and evolved δ Scuti stars

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Abstract. The Extreme Helium stars are hot luminous stars of about one solar mass that are believed to be shell He-burning. We modeled the pulsations of the hottest ExHe star V2076 Oph, for which the 2000 multisite campaign of Wright et al. detected as many as eight pulsation modes with periods of 0.4 to 2.5 days. Our shallower envelope-only models predict such periods for ℓ=0 and 1. However, if the radiative core is included in the models, a large number of closely-spaced modes are predicted that are not observed, since a large number of g-type nodes are present in the eigenfunctions in the deeper interior. This problem occurs also for models of evolved shell H-burning δ Scuti stars such as 4 CVn.

Key words. Stars: evolution – Stars: pulsation – Stars: interior

1. Introduction

The Extreme Helium (ExHe) stars are about one solar mass, with L >10,000 $L_\odot$ and $T_{\rm eff}$ as high as 34,000 K, show little or no hydrogen in their spectra, and are believed to be shell He-burning (Jeffery et al. 2001). Uncertainties remain about their pulsation driving mechanism (κ-effect or strange modes; Jeffery & Saio (1999)) and prior evolution (post AGB or binary white-dwarf merger; Saio & Jeffery (2002)). Here we present pulsation model results for the hottest ExHe star, V2076 Oph, for which a 2000 multisite photometric campaign (Wright et al. 2004, 2005) detected up to eight pulsation modes with periods 0.40, 0.52, 0.72, 0.66, 0.096, 1.06, 1.56, and 2.45 days, with the longest 2.45 and 1.56 day periods being the most robust.

2. Pulsation model results

Based on guidance from Lynas-Gray (2003, private communication), we considered Z=0.011 and Z=0.02 models, with $T_{\rm eff}\sim$30,000 K, and log $g\sim$2.8. We examined models with envelope depths of 1.5 million K, 20 million K, and 200 million K. For our shallow envelope models, we find 15 unstable periods very close to the observed periods considering ℓ=0 (radial) and ℓ=1 only. However, for the deeper models, the shorter periods (<1.4 d) are stabilized due to deep radiative damping, while a large number of closely-spaced long-period modes of 1.4 to 2.4 days are predicted to be unstable, with eigenfunction g-node count ranging from 10 to 100, although the models are still under-resolved.

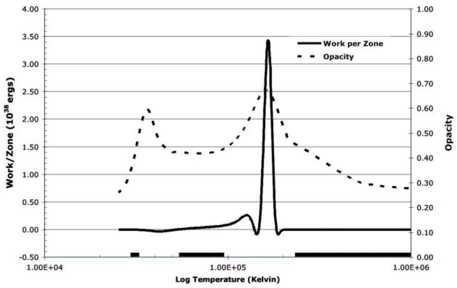

Fig. 1. Opacity, and work per zone versus temperature for 1.58 day mode of V2076 Oph model. The driving occurs where the opacity is high in the Fe ionization region. The heavy lines on the abscissa denote radiative regions, and the gaps show the two convection shells.

For the longer-period modes, the work plots show driving in the Fe-ionization region around 200,000 K, where a convective zone forms that carries up to 36% of the luminosity (Fig. 1). In this region, the convective timescale (mixing length/convective velocity) is comparable to the pulsation period, so convective blocking could play a role in pulsating driving, as found for the γ Dor variables (Guzik et al. 2000; Dupret et al. 2005) There is also an opacity bump in the He-ionization region near 30,000 K, which produces driving for the shorter-period modes. However, for the more realistic deeper envelope models, the driving for these modes is overcome by radiative damping.

To test whether the κ-effect or strange mode behavior is responsible for the pulsation driving, at the suggestion of H. Saio, we turned off the κ-effect for the pulsation analysis only, by setting the opacity derivatives with respect to temperature and density equal to zero. In this calculation, the previously unstable longer-period modes were stabilized, indicating that the κ-mechanism is indeed responsible.

Models for the evolved δ Scuti star 4 CVn discussed by Guzik et al. (2004) have the same problems with a dense spectrum of predicted modes that is not observed. 4 CVn has 18 observed frequencies between 54 and 100 μHz (Breger et al. 1999) Proposed solutions include mode trapping to select modes that become observable (Dziembowski 1997; Breger & Pamyatnykh 2002), or mixing to remove the radiative core and reduce the Brunt-Vaisala frequency and extent of the g-mode cavity (Guzik et al. 2004). A model evolved with forced core mixing that matches observed properties of 4 CVn has about 20 ℓ=0-2 modes, while a model evolved normally has about 200 predicted modes in the observed frequency range.

3. Conclusions

The shell-burning pulsating ExHe variables and δ Sct stars share a common theoretical problem of a dense spectrum of predicted modes that is not observed. This problem is likely pervasive for all stars in a shell-burning phase with radiative cores in which g-modes can propagate. For ExHe stars, the κ-effect due to Fe ionization at about 200,000 K appears to be responsible for driving longer-period modes.

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