The Impact of Large-Scale Surveys on Pulsating Star Research
ASP Conference Series, Vol. 203, 2000
L. Szabados & D. W. Kurtz, eds.

Driving g-mode Pulsations in γ Doradus Variables

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Abstract. We suggest that the modulation of radiative flux by convection at the base of a deep envelope convection zone during the pulsation cycle is responsible for driving high-order g modes with periods 0.4 to 3 d observed in γ Doradus variables.

1. Introduction

The γ Doradus variables are a new class of pulsating main sequence stars (Kaye et al. 1999, 2000) located near or beyond the cool edge of the δ Scuti instability strip. The observed pulsations, with periods of order one day, are believed to be high-order g modes. To explore possible pulsation driving mechanisms, we calculated nonadiabatic pulsation properties of 1.62-$M_\odot$ evolution models with $Y = 0.28$ and $Z = 0.03$, chosen to lie near the γ Doradus instability region in the HR diagram. We find g-mode pulsation driving consistent with the observations.

2. Results and Conclusions

The models considered have relatively deep envelope convection zones, with a temperature at the convection zone base of 177,000 K on the ZAMS. The convection zone deepens during the evolution, reaching a base temperature of 297,300 K at an age of 0.765 Gyr. These evolution models do not include diffusive element settling or radiative levitation. We use the Pesnell (1990) nonadiabatic pulsation code to calculate the $\ell = 0$, 1, and 2 pulsation frequencies. We find that the models are unstable to high-order g modes with frequencies between 4 and 25 μHz ($\sim$ 0.4 to 3 d), coinciding with the observed range of γ Dor periods. The growth rates (fractional change in mode kinetic energy) for the unstable modes are between 10^{-4} and 10^{-8} per period. The mode kinetic energy varies by three orders of magnitude over this frequency range, and interestingly reaches a minimum at a frequency of $\sim$ 11 μHz, or about one day, near the most commonly observed γ Dor period. The models are stable to pulsations with frequencies between 30 and 150 μHz (0.08 to 0.4 d), but become unstable to δ Scuti-like p modes at frequencies higher than the radial fundamental. When diffusive settling of helium and heavier elements is included, but radiative levitation neglected, both the envelope convection zone and the helium ionization zone rapidly disappear, and the models become pulsationally stable.

For models without diffusion, all of the pulsation driving occurs at the base of the envelope convection zone, where the opacity is increasing rapidly and the transition from fully radiative to fully convective transport is abrupt. The Pesnell code adopts the "frozen-in convection" approximation, in which fluctuations in the convective luminosity are set to zero during the pulsation cycle. Because, in this approximation, convection does not adapt to transport the luminosity, the radiation is periodically blocked by the high opacity at the convection zone base, resulting in pulsation driving.

This mechanism, introduced as "convective blocking" by Pesnell (1987) and further developed by Li (1992), is independent of the classical κ/γ mechanism. This mechanism was first suggested to help explain white dwarf pulsations by Cox et al. (1987) and Cox (1993), but does not work for these stars because the convective time scale of the thin envelope convection zone is much shorter than the pulsation period, so that the frozen-in convection approximation is invalid.

However, for the γ Doradus stars, this mechanism has a chance of operating, especially if the stars have sufficiently deep envelope convection zones. For the models discussed above, the local convective time scale ($\equiv$ local pressure scale height/local convective velocity) at the convection zone base, where pulsation driving occurs, is comparable to or longer than the pulsation period (0.34 d for the ZAMS model, and 1.4 d for the 0.765 Gyr model). Thus, convection does not have time to completely adjust to the changing conditions at the convection zone base during the pulsation cycle, so that the frozen-in convection approximation is not a bad one, and the Pesnell code results may reasonably represent reality. Preliminary results including a time-dependent convection (TDC) treatment in which the convective flux derivatives are not equal to zero, show that TDC slightly reduces, but does not eliminate the pulsation driving.

Work is in progress to assess the effects of diffusive settling and radiative levitation, and to investigate the properties of a wider range of models near the γ Doradus instability region.

Acknowledgments. We are pleased to acknowledge W. Dziembowski, A. Pamyatnykh, Y. Wu, W. Löffler, A. Gautschy, and S. Turcotte for useful discussions.

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