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Constraints on convection from pulsating white dwarf stars

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Abstract. We demonstrate how pulsating white dwarfs can be used as an astrophysical laboratory for empirically constraining convection in these stars. We do this using a technique for fitting observed non-sinusoidal light curves which allows us to recover the thermal response timescale of the convection zone (its "depth") as well as how this timescale changes as a function of effective temperature. We also obtain mode identifications for the pulsation modes, allowing us to use asteroseismology to study the interior structure of these stars.

Key words. convection—stars: oscillations—white dwarfs—dense matter

1. The Model

Our approach for deriving information on the depth of the convection zone and its temperature sensitivity is based on the seminal numerical work of Brickhill (1992) and on the complementary analytical treatment of Goldreich & Wu (1999) and Wu (1997, 2001). Essentially, we take a hybrid of these two approaches, and it is this model which we describe below. Our model may also be regarded as a simplification of the approach of Ising & Koester (2001).

The fundamental assumptions of our hybrid model are that:

1. The flux perturbations beneath the convection zone have a sinusoidal time and a spherical harmonic angular dependence.
2. The convection zone is so thin that we may ignore the angular variations and treat the pulsations locally as if they were radial.
3. The convective turnover timescale is very short compared to the pulsation periods ("instantaneous response").
4. We consider only flux and temperature variations in computing light curves, i.e., fluid motions associated with the pulsations are ignored.

The details of the implementation are described in Montgomery (2005a,b), so we omit them here. In terms of a fitting procedure, the parameters to be derived are $\theta_{\rm i}$ (inclination angle), τ_0 (average convective response timescale), N ("convective exponent"), A (intrinsic mode amplitude), and ℓ and m (angular and azimuthal quantum numbers).

Over the limited temperature range of the DAV and DBV instability strips, we may parameterize the instantaneous convective response timescale as $\tau_C = \tau_0 (T_{\rm eff}/T_0)^{-N}$, where τ_0, T_0, and N are constants. From theoretical models using mixing-length theory, we expect that $N \sim 90$ for the DAVs and ~ 25 for the DBVs.

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Table 1. Fits to PG1351+489 and G29-38

θ_i	τ_0	N	A	ℓ	m	Residuals
PG1351+489						
57.8[1] ± 1.6	86.7 ± 8.3	22.7 ± 1.3	0.328 ± 0.018	1	0	4.15 ± 0.65
58.9[2] ± 3.1	89.9 ± 3.6	19.2 ± 2.1	0.257 ± 0.021	1	0	0.95 ± 0.25
0.0[1] ± 5.9	85.1 ± 8.8	18.1 ± 1.4	0.305 ± 0.014	2	0	4.04 ± 0.74
0.0[2] ± 6.1	89.0 ± 6.1	16.0 ± 1.1	0.233 ± 0.011	2	0	0.94 ± 0.15
G29-38						
65.5 ± 3.4	187.4 ± 20.3	95.0 ± 7.7	0.259 ± 0.011	1	1	0.16 ± 0.05
73.9 ± 0.7	150.1 ± 6.5	7.1 ± 0.6	0.417 ± 0.025	1	0	0.18 ± 0.04

[1] 1995 data. [2] 2004 data.

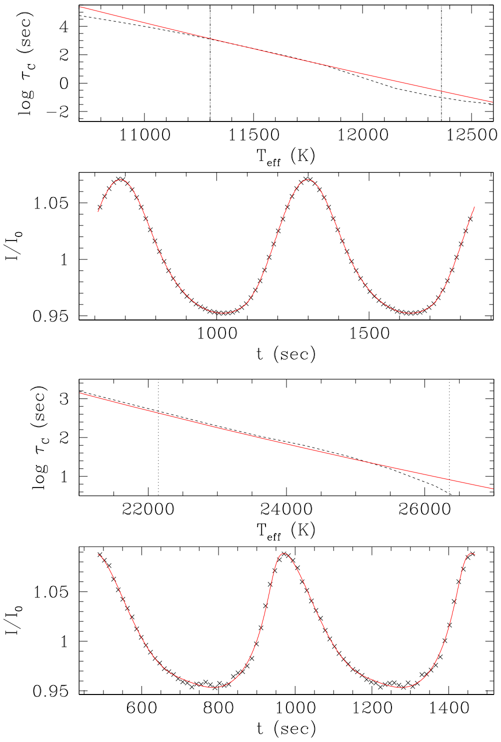

Fig. 1. Fits to the folded light curve of the DAV G29-38 (top) and the DBV PG1351+489 (bottom).

2. Fits to Observed Light Curves and Conclusions

The solutions shown in Fig. 1 and Table 1 provide remarkably good fits to the observed light curves. In addition, the fact that the derived values of N are in the range expected ($N \sim 95$ for the DAVs and $N \sim 25$ for the DBVs) lends further legitimacy to this approach. From a theoretical standpoint, although N is relatively insensitive to the convective prescription and/or the mixing length α, τ_0 is a strong function of α. Using values for $T_{\rm eff}$ and $\log g$ from the literature (Bergeron et al., 2004; Beauchamp et al., 1999), we calculate the value of α which best matches our derived values of τ_0. We find that ML2/α=0.6 is consistent with the results for G29-38 and that ML2/α=0.5 is consistent with the results for PG1351+489. The ultimate goal of this research is to map out the function $\tau(T_{\rm eff}, \log g)$ across the instability strip, which will provide a valuable contact point for future theories of convection.

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