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Wide-Field Variability Surveys: A 21st Century Perspective

A survey of pulsating DA and DB white dwarfs

Observations with the Whole Earth Telescope

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Abstract.
White dwarfs represent the end point of stellar evolution for the majority of stars. As such, they are excellent astrophysical laboratories. They are structurally simple, with electron degenerate cores surrounded by thin surface layers of helium and/or hydrogen. The g-mode pulsations provide a window into their internal structure. The Whole Earth Telescope has been conducting a long-term survey of pulsating white dwarfs with the goal of providing an empirical map of convection parameters across the DA and DB instability strips. We present an overview of white dwarf asteroseismology, and discuss the current status of our survey.

1 White dwarf asteroseismology and diagnostics

Asteroseismology provides us with a window through which to peer into stellar interiors. Through asteroseismology, we can study fundamental problems in stellar evolution such as energy transport, thermodynamics, and magnetism. White dwarfs (WDs) are particularly important targets for asteroseismology. WDs are the most numerous inhabitants of the stellar graveyard. WDs are structurally simple: an electron degenerate carbon/oxygen core surrounded by thin non-degenerate layers of hydrogen and helium. In broad brush strokes, WDs are divided into two classes by their atmospheric compositions. DA white dwarfs have nearly pure hydrogen layers on top of a layer of helium. DAs represent ≈80% of the population ([2]). DB white dwarfs are characterized by a layer of nearly pure helium overlying their carbon/oxygen cores. Lacking substantial nuclear reactions, white dwarfs simply cool as they age, passing through specific temperature ranges (the DBV and DAV instability strips) within which they pulsate. These pulsators are otherwise normal objects, so what we learn about their structure can be applied to the WD entire population to further our understanding of stellar evolution.

WDs are g-mode pulsators, and we assume that each pulsation mode can be described by a spherical harmonic of degree ℓ, radial overtone k, and azimuthal number m, where m takes integer values between $-\ell$ and ℓ. A key diagnostic for g-mode pulsators is the mean period spacing ΔP between modes of the same (ℓ, m) but consecutive radial overtone k (Fig. 1). ΔP depends primarily on stellar mass. Deviations of individual spacings from this mean value provide information on both the

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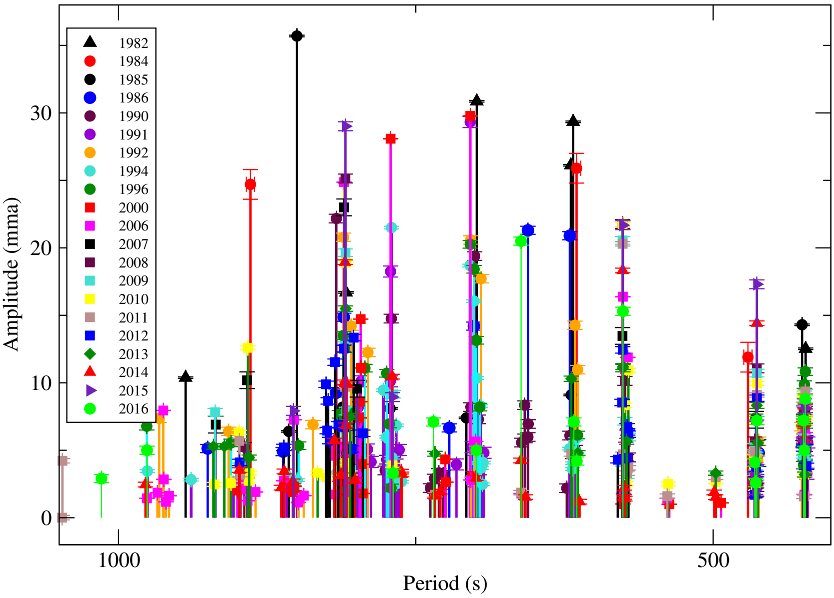

Figure 1. A schematic representation of the distribution of pulsation frequencies for the prototype DBV GD358. The systematic distribution of frequencies into a series of modes is evident.

structure of the surface layers and the degenerate core ([4]). A second diagnostic is the presence of multiplets. The multiplet components have the same (ℓ, k) but different values of the azimuthal index m. In the limit of slow rotation, the frequency difference between multiplet components is an indicator of rotation as sampled by a given mode. Multiplet structure is also a strong indication of a mode's ℓ value. We expect a triplet for $\ell = 1$, a quintuplet for $\ell = 2$, and so on. Deviations from equal frequency splitting within a single multiplet and changes in splittings from one multiplet to the next reveal information about differential rotation and magnetic field strength. Additional details can be found in [6].

2 Convection in white dwarfs

Convection is one of the largest sources of uncertainties in stellar models. The Whole Earth Telescope (WET, [5]) is engaged in a long term survey to provide an empirical map of WD convective parameters across the DA and DB instability strip. The basic premise is that the photospheric flux is delayed and/or attenuated relative to flux at the bottom of the convection zone (CZ) by an amount that depends on the thickness of the CZ. As an additional complication, the depth of the CZ varies during a pulsation cycle. As a pulsation propagates through the star, it interacts with the surface CZ. The CZ acts as a nonlinear mixer, and the result is an observed distortion of the shape of the light curve. Convective light curve fitting utilizes the nonsinusoidal shapes of white dwarf light curves to recover the thermal response timescale at the base of the CZ. Full details can be found in [3] and [6].

Figure 2 shows the current status of the survey for DA WDs. We find two preliminary conclusions. First, the measured parameter τ_0 is the thermal response timescale at the base of the CZ, and is related to the CZ's depth and mass. Theory predicts that a WD convection zone will deepen and increase in mass as the star cools. We should find an increase in τ_0 as we move to lower temperatures, and this is

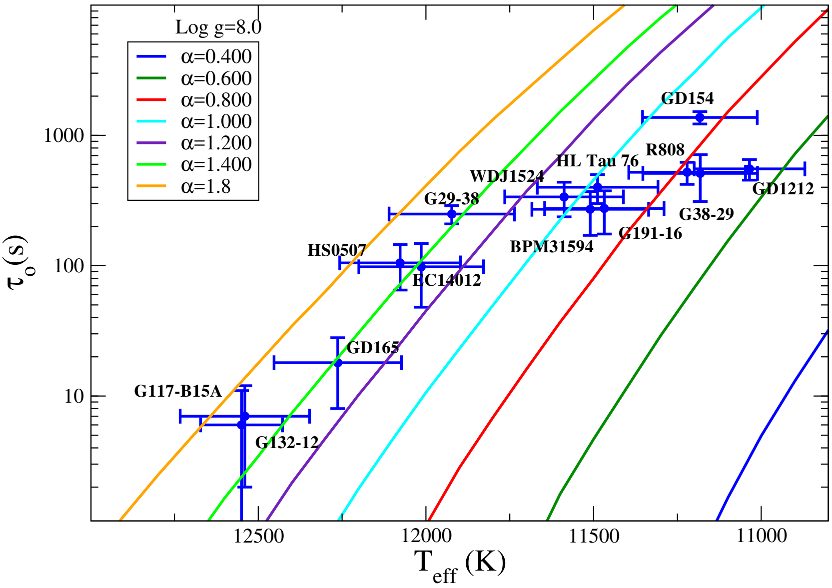

Figure 2. Current empirical map of the thermal response at the base of the convection zone τ_0 as a function of $T_{\rm eff}$ for DA white dwarfs. Predicted values of τ_0 for different values of the MLT parameter α are given.

indeed what we see for WDs with $T_{\rm eff} > 12{,}000$ K. For WDs with $T_{\rm eff} < 12{,}000$ K, τ_0 increases from $\approx$150 s to only $\approx$550 s at $T_{\rm eff} = 11{,}000$ K. τ_0 values for stars below $T_{\rm eff} < 12{,}000$ K do not follow the predictions of any single mixing-length theory (MLT) α parameterization. The behavior of τ_0 is also in rough agreement with the 3D convective simulations of [7]. If one must use MLT in modelling, the proper value of α will depend on the WD temperature. We mention the caveat that τ_0 is the thermal timescale at the base of the CZ. There is no reason to require that the value of α matching the observed τ_0 in this region is also appropriate for representing α at the photosphere.

We find further evidence that the CZ in DAs does not behave as expected when we consider the predicted maximum pulsation periods and the observed longest period pulsations for stars in our sample (Fig. 3). [1] demonstrates that g-mode pulsations should occur when convective driving exceeds radiative damping. This condition is met when the pulsation period $P < P_{\rm max}$, where $P_{\rm max} = 2\pi\tau_0$. In Figure 3, we compare the observed longest period pulsations (points) with the predicted $P_{\rm max}$ (solid line). We find fair agreement for our hottest stars ($T_{\rm eff} > 12{,}000$ K, with low values of τ_0), but diverge rapidly for cooler stars. Some mechanism currently not understood is functioning to both limit τ_0 and prevent observed pulsation periods from increasing as rapidly as predicted in cooler pulsators.

Finally, Figure 4 shows the current status of the survey for DB WDs. Interpreting the behavior of τ_0 for the helium instability strip is hampered by the large uncertainties associated with the optical spectrographic temperature determinations for PG1456, PG1351, KUV05134 and CBS114. The remaining objects have UV temperature determinations with much smaller uncertainties. However, on first look, it does not seem as if τ_0 for helium convection behaves as we see for hydrogen (Fig. 2). We find a general increase in τ_0 with increasing $T_{\rm eff}$.

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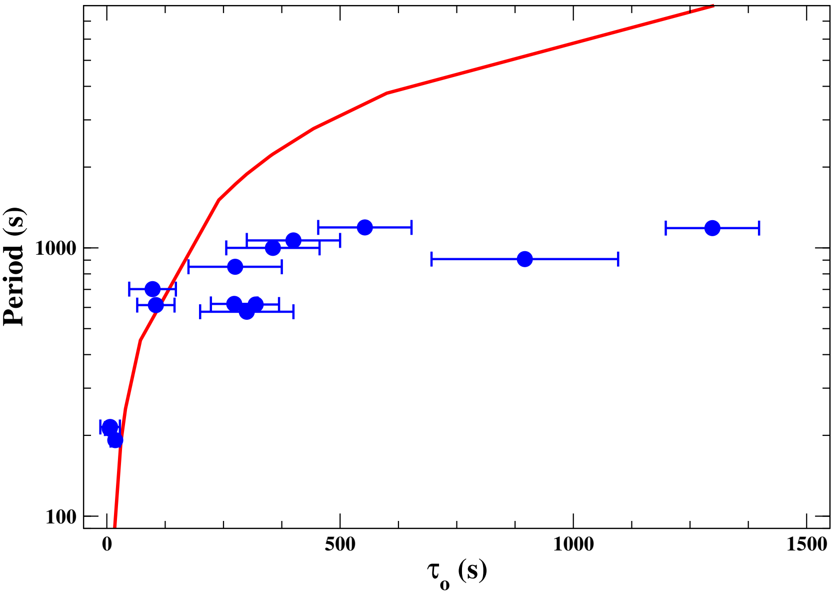

Figure 3. Comparison of the dominant large amplitude observed pulsation period for the stars in Figure 2 (points) with the theoretical value of $P_{\max}$ (solid line).

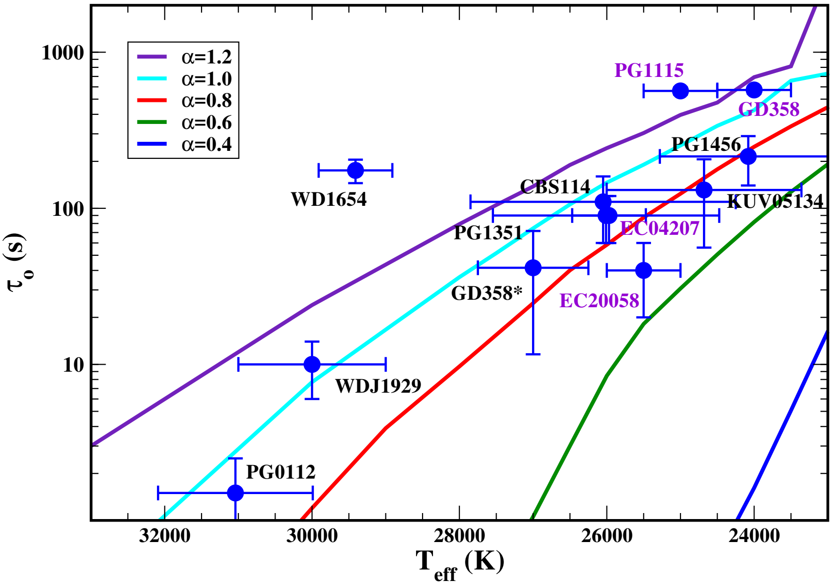

Figure 4. Current empirical map of the thermal response at the base of the convection zone τ_0 as a function of T_{eff} for DB white dwarfs. Predicted values of τ_0 for different values of the MLT parameter α are given.

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