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The case of the *Kepler* DBAV star J1929+4447

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Abstract. A first pulsating white dwarf has been discovered recently in the *Kepler* field of view[1]. This star, catalogued as GALEX J192904.6+444708 or KIC 8626021, is a He-atmosphere white dwarf of the V777 Her (DBV) type. It appears to be the hottest of its class and, as such, has the potential to be a key object in our understanding of the DB gap problem. We present here a seismological analysis of this star and a look at his previous history.

1. CONSTRAINTS FROM SPECTROSCOPY

A good $S/N \approx 50$ optical spectrum of the rather faint target ($K_p = 18.42$) was kindly obtained by our collaborator Betsy Green at the Steward Observatory. The resulting fit of our detailed analysis of that spectrum is shown in our Fig. 1. Our fit gives values of $T_{\rm eff} = 28,480$ K and $\log g = 7.89$, discrepant in temperature with the original estimates from [1] ($T_{\rm eff} = 24.950$ K and $\log g = 7.91$), but consistent with the expected period-luminosity relationship, given that the observed pulsation periods are the shortest ever found in a pulsating DB star. These estimates make that star the hottest star of the V777 Her type. However, our detection of a trace of hydrogen makes it formally a DBAV star.

2. WHAT DIRECT ASTEROSEISMOLOGICAL METHODS TELL US

We use our standard direct method that consists of searching in parameter space the model with pulsation periods that best fit the observed periods. We define such a model as one that minimizes the goodness-of-fit function given by $\chi^2 = \sum_{i=1}^{N_{obs}} (P_{obs} - P_{th})$, where P_{obs} is an observed period and P_{th} is the corresponding theoretical period obtained from parametrized static models. Our results (see Fig. 2 and Fig. 3) are presented as $T_{\rm eff}$ vs. $\log g$ maps, where the obtained χ^2 values for each given $T_{\rm eff} - \log g$ pair needed to build the map have been optimized independently for the other structural parameters. Such computations are really demanding in terms of computing power: over 60 million stellar models have already been computed during the course of this ongoing investigation. Fortunately, our group has access to a dedicated cluster of 320 processor nodes. We have first taken a look at two hypotheses about the white dwarf structure: A canonical DB white dwarf or a double-layered structure arising from a PG1159 star progenitor.

In the first case, we have looked at the simplest possible structure for our white dwarf model: An onion-like structure composed of a C/O core wrapped by an He layer. Figure 2 gives the results for the entire DBV range of possible values for $T_{\rm eff}$ and $\log g$. All points (2501) used to produce the map have

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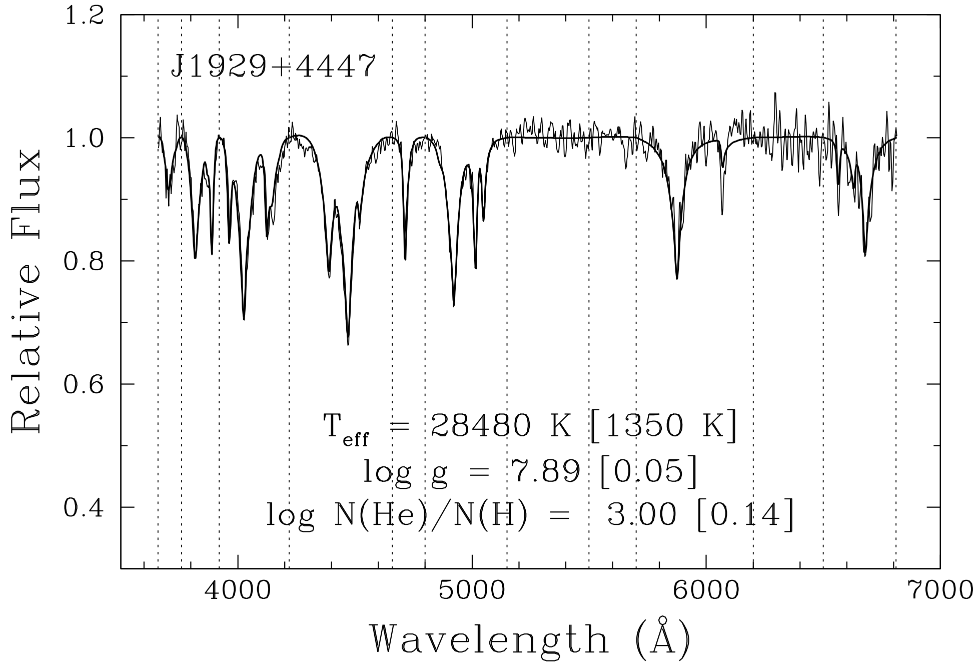

Figure 1. Model fit of the spectrum of J1929+4447.

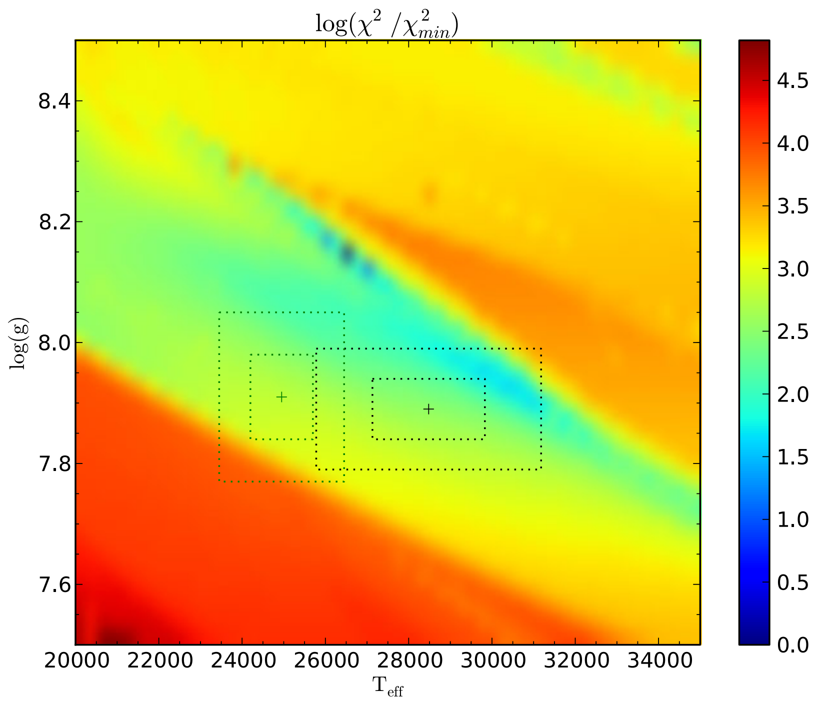

Figure 2. Map of χ^2 values obtained under the hypothesis of a 'classical' DB white dwarf. The cross around 28,000 K corresponds to our determination, while the other one around 25,000 K corresponds to the one from [1]. The two boxes surrounding each point correspond to the 1σ and to the 2σ limits respectively.

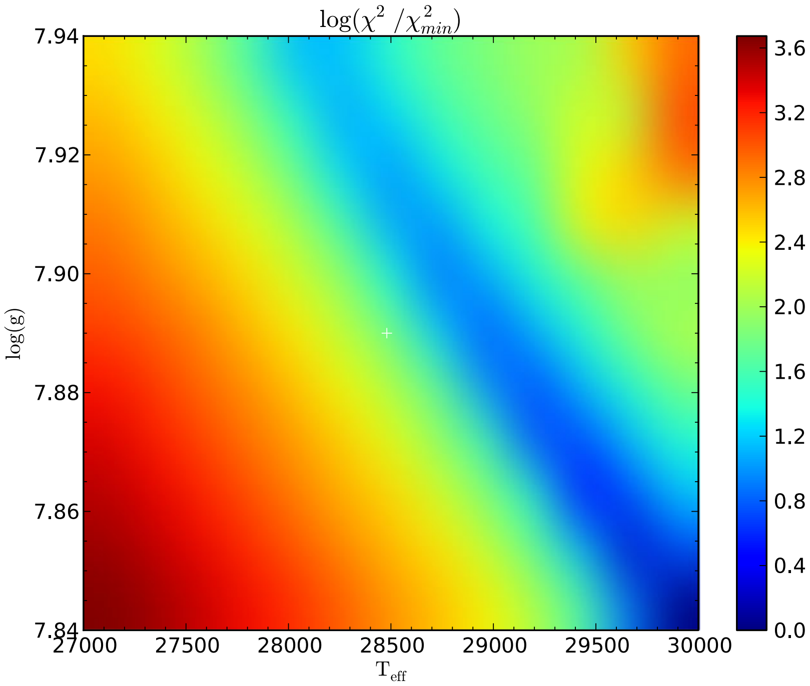

Figure 3. Map of χ^2 values obtained under the hypothesis of a double-layered He white dwarf. The cross at the center correspond to our spectrum-fitted values while the ranges of the axes correspond to 1σ.

been optimized for the He layer thickness along with the shape of the transition zone. In the probable case that all observed modes have the same degree value of $\ell = 1$, we found a unique solution near $T_{\rm eff} = 26,500$ K and $\log g = 8.15$, a solution quite inconsistent with the spectroscopy, however.

For the second case, we took a look at a more complex structure for our models: A double He layer arising from the gravitational separation of He, C, and O after convection and winds have subsided in an evolving model of a hot PG1159 progenitor (see Fig. 4 for such structures). In this case, we do not find a unique solution, but, instead, families of solutions that appear as valleys in a $T_{\rm eff} - \log g$ map. For this reason, we have limited our investigations to the 1σ region around our spectroscopic determination (the smaller dotted box in Fig. 2). Figure 3 gives the solution when all the observed modes have an ℓ index equal to 1. Another solution is possible, when we impose $\ell = 1$ for the three first observed modes (triplets are indeed observed), but we keep the possibility for an ℓ value equal to 1 or 2 for the last two observed modes (two modes observed with smaller amplitudes). In this case, we also find a family of solutions when the fifth mode has an l=2 index. This corresponds to solutions similar (i.e., from the same family) to the one found by [2]. All points (143) of the map have been optimized for six parameters: the first and second He layer position along with the shape of the transition zones, the C/O ratio of the core and the He proportion in the mixed envelope of the progenitor.

3. WHAT EVOLUTION AND DIFFUSION THEORIES TELL US

To test the solutions of our second hypothesis, we next considered the evolution of a canonical PG1159 star and see if we can indeed produce similar stellar configurations. For this task, we used the evolution code that we developed at Montréal. This is a code especially build for the study of white dwarf and hot subdwarf stars. The main characteristic of interest here is the possibility to evolve complete models

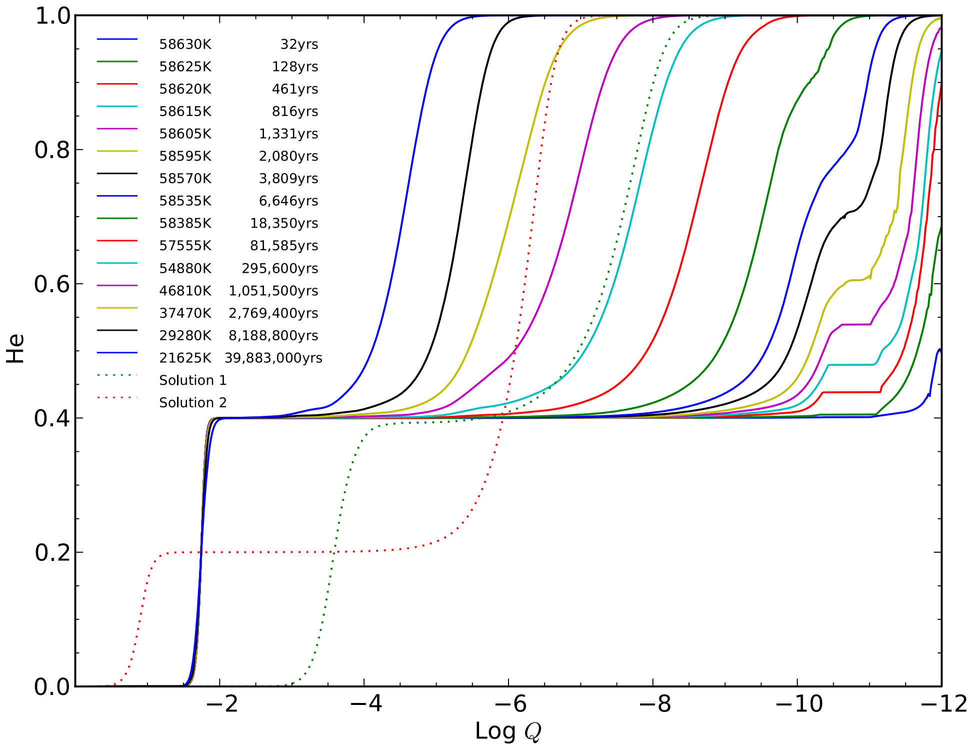

Figure 4. The transformation of a PG1159 star into a DB star.

(including the high-atmosphere layers) while taking into account the simultaneous diffusion of elements along with time-dependent convection.

For a first trial, we used a starting model with "standard" structural parameters: A massive C/O core [X(C)=X(O)=0.50] of about 98% the mass of the star, wrapped by a mixed envelope of a He/C/O mixture [X(He)=0.40, X(C)=0.40 and X(O)=0.20] for the remaining 2% mass. We assume that the physical processes that homogenize the envelope (principally winds, along with some help from convective mixing) stop at a given high temperature. We use here a starting effective temperature near 60, 000 K. The exact temperature is not very important because neutrino cooling is very effective and the effective temperature drops quickly under 50, 000 K. Selected He composition profiles from the resulting sequences are shown in Fig. 4. In our figure the abscissa is given by $\log(Q)$ where $Q = (1 - M(r)/M_\star)$. Such models are characterized by two He transition layers: the first one is the original core/mixed envelope transition zone and the second one is created by the continuous flow of He rising to the surface. In less than 5,000 years X(He)=0.9999 at the surface and the PG-1159 star quickly becomes a DO, and then a DB star.

The dotted lines in Fig 4 shows the He composition profile of the two solutions that we found in our previous asteroseismological investigations. The profile of Solution 1 is very near the one found at 295,600 years (at least for the fast moving part of it). This is way too early, and this solution must be rejected within the hypothesis of a PG1159 progenitor. The case of Solution 2 is less clear; the pure He region ends about at the same place than the model at 37,470 K. This is also too hot for a valid solution, but the starting assumed value of He in the mixed initial region is X(He)=0.40 instead of the asteroseismological determination of X(He)=0.20. This situation can be tricky and will need further investigation.

Then there remains the possibility that such solutions cannot be ruled out after all. Indeed, we have a DBA star! So, maybe the presence of the H traces and the indication of a very short age of $\sim 300,000$ years for the composition transition zone tell us that the star was a DA white dwarf down to $30,000$ K and that the object of our studies is a newborn DBA star that quickly transforms into a DB white dwarf. This brings us into the problem of the DB gap. We are currently working on this new hypothesis.

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