AN ULTRAVIOLET LOOK AT THE BLUE EDGE OF THE ZZ CETI INSTABILITY STRIP

R. Lamontagne, F. Wesemael, and G. Fontaine
Département de Physique, Université de Montréal
and
G. Wegner
Department of Physics and Astronomy, Dartmouth College
and
E. P. Nelan
University of Texas / S.T.Sc.I.

It has already been shown that most, and probably all, of the DA white dwarfs become variable in a narrow temperature range as they cool down (Fontaine *et al.* 1982). Optical photometry and spectrophotometry has led to several determinations of the boundaries of this instability strip. The strip has been found to cover the range 10300 – 13600 K (McGraw 1979), 10400 – 12100 K (Greenstein 1982), 10000 – 13000 K (Weidemann and Koester 1984) and 11000 – 13000 K (Fontaine *et al.* 1985). Theoretical calculations show that the location of the blue edge is very sensitive to the efficiency of convection used in the unpertubed models (Winget *et al.* 1982; Winget and Fontaine 1982; Fontaine, Tassoul, and Wesemael 1984). Also, the sharpness of this boundary depends on the range of stellar mass and thickness of the hydrogen envelope found in ZZ Ceti stars. Recently, Wesemael, Lamontagne, and Fontaine (1986) and Lamontagne, Wesemael, and Fontaine (1987) have obtained and compared ultraviolet observations of several DA white dwarfs, in or near the instability strip, with published model calculations from Nelan and Wegner (1985), hereafter NW, and Koester *et al.* (1985), hereafter KWZV. They determined the boundaries of the variability region at 11400 – 12500 K or 11700 – 13000 K depending on which grid was used. We present here a reanalysis of these *IUE* observations with an improved grid of model atmospheres in order to define more precisely the location of the blue edge.

https://doi.org/10.1017/S0252921100099620 Published online by Cambridge University Press

The main change to our earlier analyses is the use of a new grid of model atmospheres for DA stars, calculated by two of us (GW and EPN), which removes minor inconsistencies present in earlier calculations of the emergent fluxes. Our data base includes ten ZZ Ceti stars (half of the known sample) and several other DA white dwarfs near the blue edge of the instability strip. The program stars were either observed by us in November and December 1984 and December 1986, or obtained from the *IUE* archives through the Astronomical Data Center. The standard *IUE* calibration for the SWP camera was used in the reduction (Bohlin and Holm 1980). We included the correction derived by Hackney, Hackney, and Kondo (1982) to account for wavelength- and exposure-dependent continuum distortions near 1600Å, and the absolute recalibration of the *IUE* cameras from Bohlin (1986). We also took into account the sensitivity degradation of the SWP camera over time, as described by Bohlin and Grillmair (1988). All these corrections tend to increase the observed flux at longer wavelengths. This results in a slightly lower estimate for the effective temperature of a star in that temperature domain (typically less than ~ 50 K). Before fitting the observations to the model fluxes, each spectrum was smoothed with a five point box-filter. The spectrum was then averaged in bins of 20Å shortward of 1650Å and 30Å longward of that limit. This procedure provides a sufficient spectral resolution at short wavelengths, while ensuring a less noisy continuum near the end of the spectral region. Each bin was weighted equally in the fitting procedure. Finally, the calculated fluxes were forced to match the observations longward of 1650Å. We performed several numerical experiments in which we either fit unsmoothed observations, assigned different weights to each bin (e.g. proportional to its standard deviation), or matched the continuum at a longer wavelength (e.g. 1800Å). The resulting temperatures derived for each star were similar within ~ 100 K.

Effective temperatures were determined using the three different grids of models discussed above. As expected, the temperature ordering of our sample remains the same within each grid. The average temperature difference between fits with our new models and the earlier NW grid is 370 K. The agreement is now much improved with the KWZV grid; our new fits yield a temperature higher than that of the KWZV fits by less than 100 K. This is illustrated in Figure 1 where we display the three fits for the hottest ZZ Ceti star in our sample, G117-B15A. Note that the fits obtained with the earlier NW grid and the KWZV grid differ slightly (ΔT_e < 200 K) from those presented in Wesemael, Lamontagne, and Fontaine (1986) because of small changes

https://doi.org/10.1017/S0252921100099620 Published online by Cambridge University Press

in the fitting procedure and the inclusion of new calibration and sensitivity degradation information. It is particularly instructive to note that the main uncertainty in the determination of the effective temperature may now well reside not with the *IUE* calibration, but with the model calculations.

Also, despite noticeable differences between the KWZV models and our improved grid (see Figure 1), the effective temperatures we derive for all our stars are consistent. We are led to conclude that the temperature of the blue edge, defined by G117-B15A, the hottest ZZ Ceti star in our sample, is near 12900 K with an uncertainty of about 200 K. This result is in very good agreement with previous determinations based on optical observations. For example, Weidemann and Koester (1984) assign a temperature of 13010 K for G117-B15A; Fontaine *et al.* (1985) locate the blue edge at 13000 K. We note that the Strömgren colors of McGraw (1979) would yield $T_e \simeq 13200$ K for G117-B15A when compared to the predicted colors of more modern model atmospheres than he used. A somewhat discrepant determination is that of Greenstein (1982); he assigns a lower temperature of 12100 K to G117-B15A, based on MCSP data and the AB79 absolute-flux calibration. On the Hayes-Latham scale, his temperature would be $\sim$ 500 K higher. Purely spectroscopic determinations (as opposed to photometric means) may help resolve the remaining discrepancies. Such analysis of spectroscopic data on selected ZZ Ceti stars is now underway (Daou *et al.* 1988).

This work was supported in part by the NSERC Canada, by the NSF Grant AST 85-15219 and by a E.W.R. Steacie Fellowship to one of us (GF).

Bohlin, R. C. 1986, *Astrophys. J.*, **308**, 1001.

Bohlin, R. C. and Grillmair, C. J. 1988, *Astrophys. J. Suppl.*, **66**, 209.

Bohlin, R. C. and Holm, A. V. 1980, *NASA IUE Newsl.*, **10**, 37.

Daou, D., Wesemael, F., Bergeron, P., Fontaine, G., and Holberg, J. B. 1988, these Proceedings.

Fontaine, G., Bergeron, P., Lacombe, P., Lamontagne, R., and Talon, A. 1985, *Astron. J.*, **90**, 1094.

Fontaine, G., McGraw, J. T., Dearborn, D. S. P., Gustafson, J., and Lacombe, P. 1982, *Astrophys. J.*, **258**, 651.

Fontaine, G., Tassoul, M., and Wesemael, F. 1984, in *Proceedings of the 25th Liège Astrophysical Colloquium: Theoretical Problems in Stellar Stability and*

https://doi.org/10.1017/S0252921100099620 Published online by Cambridge University Press

Oscillations, A. Noels and M. Gabriel, eds., Université de Liège, p.328.

Greenstein, J. L. 1982, *Astrophys. J.*, **258**, 661.

Hackney, R. L., Hackney, K. R. H., and Kondo, Y. 1982, in *Advances in Ultraviolet Astronomy: Four Years of IUE Research*, NASA CP-2238 (NASA, Washington, DC), p.335.

Koester, D., Weidemann, V., Zeidler K.-T., E. M., and Vauclair, G. 1985, *Astron. Astrophys.*, **142**, L5.

Lamontagne, R., Wesemael, F., and Fontaine, G. 1987, IAU Colloq. No. 95, *The Second Conference on Faint Blue Stars*, A. G. Davis Philip, D. S. Hayes, and J. W. Liebert, eds., L. Davis Press, p.677.

McGraw, J. T. 1979, *Astrophys. J.*, **229**, 203.

Nelan, E. P. and Wegner, G. 1985, *Astrophys. J.*, **289**, L31.

Weidemann, V. and Koester, D. 1984, *Astron. Astrophys.*, **132**, 195.

Wesemael, F., Lamontagne, R., and Fontaine, G. 1986, *Astron. J.*, **91**, 1376.

Winget, D. E. and Fontaine, G. 1982, in *Pulsations in Classical and Cataclysmic Variable Stars*, J. P. Cox and C. J. Hansen, eds., Joint Institute fo Laboratory Astrophysics, Boulder, p.46.

Winget, D. E., Van Horn, H. M., Tassoul, M., Hansen, C. J., Fontaine, G., and Carroll, B. W. 1982, *Astrophys. J.*, **252**, L65.

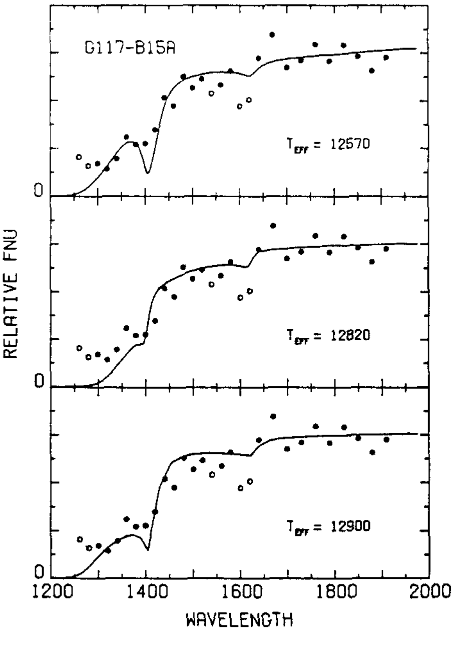

Figure 1. Optimal fits to the spectra of G117-B15A obtained with the Nelan and Wegner (1985) grid (top panel), the Koester *et al.* (1985) grid (middle panel), and our improved grid (bottom panel). Open circles correspond to bins excluded from the fitting procedure.

https://doi.org/10.1017/S0252921100099620 Published online by Cambridge University Press