SPECTROSCOPIC STUDIES AND ATMOSPHERIC PARAMETERS OF ZZ CETI STARS

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The pulsating ZZ Ceti stars cover a narrow range of effective temperatures along the cooling sequence of DA white dwarfs (see, eg., Winget and Fontaine 1982). Fast-photometric searches for pulsating stars in that class have provided strong evidence that the ZZ Ceti phase is an evolutionary phase through which all cooling DA stars will eventually go through (Fontaine *et al.* 1982). Recent investigations, based on optical or ultraviolet photometry and spectrophotometry, have set the boundaries of the instability strip at temperatures near 10,000–11,000 K and 12,000–13,000 K, respectively (McGraw 1979; Greenstein 1982; Weidemann and Koester 1984; Fontaine *et al.* 1985; Wesemael, Lamontagne, and Fontaine 1986; Lamontagne, Wesemael, and Fontaine 1987, 1988).

Our recent endeavours in the study of these variable stars have focused on two specific goals: 1) To investigate theoretically ways to determine, or at the very least constrain, the pulsation properties of ZZ Ceti stars, in particular the ℓ value of the pulsation modes (Brassard, Wesemael, and Fontaine 1987); 2) To improve our knowledge of the time-averaged atmospheric properties of ZZ Ceti stars in order to test specific predictions of the current linear, non-adiabatic g-mode pulsation calculations. Up to now, we have concentrated our efforts in the latter area on narrow-band photometry and ultraviolet spectrophotometry from *IUE* to study, in a consistent manner, reasonably large subsamples of the ZZ Ceti stars.

Relatively high signal-to-noise (S/N>20) optical spectrophotometry at intermediate resolution (~3Å) provides another, independent, means of determining basic atmospheric parameters for the variable DA white dwarfs. Indeed, Schulz and Wegner (1981) have demonstrated that simultaneous spectrophotometry of the lower

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(Hβ or Hγ) and higher (Hδ or Hε) Balmer lines permits reasonably accurate determination of both T_e and log g in the ZZ Ceti range (with typical uncertainties of ±500 K and 0.25 dex in effective temperature and surface gravity, respectively). This technique seems to have been largely overlooked and, indeed, there has not yet been any systematic study of the optical spectrophotometric properties of ZZ Ceti stars at resolution sufficient to render a comparison with detailed synthetic spectra useful. We have thus embarked on a study of the spectroscopic properties of ZZ Ceti stars with the following aims: Firstly, to provide an independent estimate of the temperature of the boundaries of the instability strip, and the ordering of pulsating stars within it. Secondly, to provide the first spectroscopic estimates of the surface gravity in a large sample of ZZ Ceti stars (spectroscopic fits to two ZZ Ceti stars can be found in Weidemann and Koester 1980). Such estimates will permit a better interpretation of the observed variation in strength of the quasi-molecular λ1400 and λ1600 features in ZZ Ceti stars, since current modelling of these features predicts a significant dependence of their strength on log g (Nelan and Wegner 1985). Furthermore, attention has already been drawn to candidates with possible peculiar gravities in the ZZ Ceti sample. Ross 548, for example, is a suspected low-gravity object (log g$\leq$7.5; Fontaine *et al.* 1985 and references therein) on the basis of its Strömgren colors, while current interpretation of the very short period (109 s) of G226-29 requires a large gravity instead (log g $\geq$8.5; Kepler, Robinson, and Nather 1983).

To this end, we have secured optical spectra at 2.5Å resolution of half a dozen ZZ Ceti stars with the Steward 2.3m reflector, Cassegrain spectrograph and intensified, photon-counting Reticon. The spectra span the range 3900-5000Å, and thus provide good coverage of Hγ, Hδ, and Hε, with partial coverage of Hβ or H8 as well. On the theoretical side, we use a grid of recently-developed LTE model atmospheres for DA stars (e.g. Bergeron, Wesemael, and Fontaine 1988) in our analysis of these data.

Our data analysis technique relies on the sensitivity of various Balmer lines to T_e and log g discussed by Schulz and Wegner (1981). We first fit the Hγ and Hδ profiles of each star at various surface gravities [log g= 7.5 (0.25) 8.5] in order to get a gravity-dependent estimate of the effective temperature. This locus of acceptable T_e-log g combinations is then explored in fits to the gravity-sensitive Hε line. We find the latter to be an effective gravity discriminant as its strength

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varies quite dramatically with gravity in the 7.5–8.5 interval. The surface gravity is then fixed by that fit; any other available line (Hβ or H8, depending on the grating tilt for that particular observation) is then checked for consistency.

As an illustrative example, a sample fit to the variable star G226-29 is shown in Figure 1. This is by no means our final fit to this star, as our analysis has been largely exploratory up to this point. And indeed, the indicated temperature, near 11,000 K, is significantly lower than those determined from multichannel spectrophotometry (11,700 K, Greenstein 1982; or 12,470 K, Weidemann and Koester 1984) and ultraviolet spectrophotometry (~12,080 K, an average of estimates given in Wesemael, Lamontagne, and Fontaine 1986).

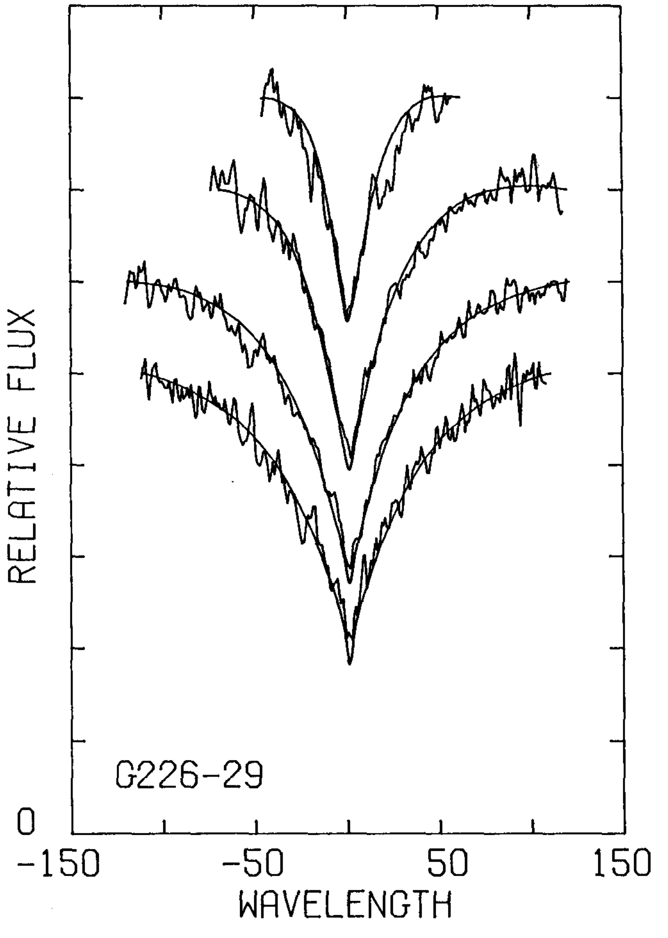

Fig. 1. Sample fits to the spectrum of G226-29. The lines are, from bottom to top, Hβ, Hγ, Hδ, and Hε. The model shown has T_e = 11,000 K, log g = 8.30.

While spectroscopic analysis are essentially free from the calibration problems inherent to optical photometry and ultraviolet spectrophotometry, studies of the high Balmer lines (Hδ and above) seem particularly sensitive to the adopted description of the perturbation of the higher levels of the hydrogen atom. Our current synthetic spectra treat that pressure ionization in terms of a classical Debye model for the last bound level, coupled with an Inglis-Teller cutoff for the last visible level. Some exploratory calculations suggest that the computation of the monochromatic opacity within the framework of the occupation probability formalism developed by Hummer and Mihalas (1988, see also Däppen, Anderson and Mihalas 1987), might lead to noticeable changes in the spectral region under study (see Bergeron, Wesemael, and Fontaine 1988). We note, however, that in contrast to cooler DA stars, where the level perturbation is dominated by interactions with neutral atoms (Bergeron, Wesemael, and Fontaine 1987, 1988), charged particles are here the dominant level perturbers. Clearly these uncertainties, none of which have been explored previously, need to be evaluated in great detail before spectroscopic determinations of effective temperatures and surface gravities of ZZ Ceti stars become trustworthy.

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