NON-LTE SPECTRAL ANALYSIS OF PG 1159-035

K. Werner, U. Heber, K. Hunger

Institut für Theoretische Physik und Sternwarte der Universität Kiel

Summary We present first preliminary results from an exploratory spectral analysis of PG1159-035. An effective temperature of 120000 K (±20000 K) and a surface gravity of about log g=7 are derived from optical and ultraviolet profiles of carbon and helium lines. NLTE model atmospheres are used which are composed of H (1%), He (19%), C (40%) and O (40%, mass fractions). The abundances adopted are in accordance with predictions of stellar pulsation theory. A direct spectroscopic determination is under way. The analysis of optical CIV lines is rendered difficult due to the lack of a reliable line broadening theory which would have to account for a gradual change to broadening by linear Stark effect. Due to the complexity of the spectral analysis, reliable abundance ratios can only be derived from a systematic investigation employing a large grid of models.

PG1159-035 is the prototype of a new class of extremely hot hydrogen-deficient pre white dwarfs. The spectra of these stars are characterized by a broad absorption trough at 4670Å, probably caused by HeII and CIV. Some members of this group (including PG1159-035) are known to be non-radial pulsators. The pulsation driving mechanism is probably cyclic ionisation of C and O. Theoretical calculations (Starrfield, 1987) predict that C (and O) must be more abundant than He (by mass), otherwise the stars were stable. In order to determine their atmospheric parameters and chemical composition, spectroscopic analyses are needed. However, due to the lack of adequate model atmospheres no reliable spectral analyses were available yet.

Since the spectral features are weak and broad, spectroscopic observations of high S/N ratios are required. We have obtained optical CCD-spectra of PG1159-035 using the EFOSC (transmission-echelle) spectrograph at the ESO 3.6m telescope, covering the wavelength range from 3900Å to 7600Å at about 3Å spectral resolution. PG1159-035 was also observed at the DSAZ (Calar Alto, Spain) using the B&C spectrograph attached to the 3.5m telescope. These spectra cover the wavelength range from 4000Å to 6000Å at a spectral resolution of 2.5Å. S/N ratios near 100 were achieved for the spectra from both sites. Ultraviolet spectra of low resolution (5Å) were obtained from the IUE data bank.

These spectra allow the detection of following lines: HeII (1640Å,5412Å,4859Å,4686Å), CIV (1550Å,5812Å,5802Å,5022Å,4789Å,4659Å,4646Å,4441Å) and OVI (5290Å). HeII (4686Å), CIV (4659Å) and OVI (5290Å) display central emission reversals, while CIV (5802Å,5812Å) are purely in emission. The spectra were analyzed using non-LTE model atmospheres adapted to the peculiar composition of the PG 1159 stars.

Non-LTE model atmospheres are indispensable for spectral analyses of PG 1159 stars, because large departures from LTE occur at the very high temperatures encountered. The effort to compute non-LTE models for the present analysis is far beyond the limits of the complete linearization technique (Auer and Mihalas, 1969). We therefore use a newly developed code, which is capable of handling many more non-LTE levels and opacities. It is based on operator perturbation techniques which gave way to a new generation of highly sophisticated non-LTE model atmospheres (Werner, 1987, 1988).

With this non-LTE code, a grid of plane parallel, static model atmospheres in the parameter range 75000 K $\leq T_{eff} \leq$ 140000 K and $5 \leq \log g \leq 8$ (cgs units) has been computed. Guided by the results of pulsation theory, we have chosen the following chemical composition for the initial models: H 1%, He 19%, C 40%, O 40% (by mass). We take into account line blanketing effects self-consistently. Altogether, the model atoms consist of 169 levels, 54 of which are explicitly treated in the statistical equilibrium equations. They all contribute to continuous opacities. 88 radiative bound-bound transitions are included into the model atmosphere computations as well. Table I shows in detail the number of non-LTE levels and lines in each ionization stage.

Table I

Non-LTE levels and line transitions in the adopted model atoms

ion		NLTE-levels	lines
hydrogen	I	5	6
	II	1	-
helium	I	1	-
	II	10	36
	III	1	-
carbon	III	1	-
	IV	21	46
	V	1	-
oxygen	IV	1	-
	V	6	-
	VI	5	-
	VII	1	-

A restricted model atom for hydrogen is sufficient, because this species is under-abundant and does not determine the atmospheric structure significantly. On the other hand, the HeII atom has to include many levels, since it is known that the line transitions are responsible for considerable heating of the outer atmospheric layers. Like HeI, CIII is only weakly occupied. CIV is designed as the most detailed model atom, because our present analysis is essentially based on the lines of this ion. Oxygen (represented by 4 ionization stages) has been implemented into our model atmospheres. At the present state, no oxygen lines have been included. We expect that the strong OV and OVI resonance lines influence only the outermost layers. The construction of a model atmosphere is as usual done with pure Doppler broadened line profiles. The emergent line profiles are calculated using fully broadened absorption coefficients. For HeII lines a reliable broadening theory exists (Griem, 1968). For CIV, however, considerable uncertainties in line broadening theory affect our analysis. The resonance doublet at 1550Å is the only observable CIV transition for which reliable line broadening data are available (Sahal-Bréchot and Segre, 1971). The optical transitions arise from highly excited energy levels (n=5-6) which are close to degeneracy, and for which a gradual transition from quadratic to linear Stark broadening occurs. An appropriate theory is still pending. We therefore assume as a first approximation broadening by linear Stark effect. The absorption coefficients are calculated after Unsöld (1968, p.320). The electrical microfield takes into account the mixture of the differently charged ions. As expected, the assumption of the linear Stark effect overestimates the broadening. This becomes evident when the line profiles are compared to those of the central star of NGC 246, whose carbon abundance is known (Husfeld, 1987). In order to reproduce the wings, the broadening parameter has to be reduced by a factor of 3. With this empirical reduction factor, our final CIV line profiles are calculated. The blue part of the characteristic absorption trough is calculated as a blend of 3 lines of CIV, namely 4646Å (transition 5d-6f), 4658Å(5f-6g), 4660Å(5g-6h). The red part is mainly due to HeII 4686Å. The calculations show, that if T_{eff} exceeds some critical value (e.g. 90000 K at log g=7), the line cores of CIV 4658Å and 4660Å develop central emission reversals. At an even higher T_{eff} (100000 K, log g=7) the core of the third CIV component (4647Å) also turns into emission. CIV 4441Å(5p-6d) appears in pure absorption, unless T_{eff} exceeds 120000 K (at log g=7). Varying the atmospheric parameters along a line parallel to the Eddington limit, the wings of these lines hardly change, which means that the cores are sensitive temperature indicators. The same applies to the CIV doublet 5802Å/5812Å (3s-3p), which turns into emission at T_{eff}=100000 K (log g=7). The CIV 1550Å resonance doublet may also be used to constrain T_{eff}, since its equivalent width rapidly decreases with increasing temperature.

From the computed spectra we derive for PG1159-035 as a preliminary result T_{eff}=120000 K and log g=7, but with considerable uncertainty. In Fig.1 we compare the observed absorption trough at 4670Å (EFOSC-spectrum, right panel) and the CIV doublet (5802, 5812Å, DSAZ-spectrum, left panel) to model predictions for T_{eff} = 100000 K, 120000 K and 140000 K at log g=7. As can be seen, the CIV lines in the trough fit best at about 110000 K. In contrary, the HeII 4686Å emission is strong enough only if T_{eff} is as high as 140000 K, in which case the CIV emissions appear too strong. Similarly, the CIV 5802Å,5812Å doublet is reproduced only if T_{eff} exceeds 120000 K. The best fit is obtained for 140000 K (at log g=7). In the UV, HeII 1640Å is reproduced well, but appears to be rather insensitive against variations of T_{eff}. From CIV 1550Å it follows that T_{eff} has to exceed 120000 K, otherwise this line would be too strong.

In order to check how the line profiles depend on the assumed abundances, we computed atmospheres with different compositions. All CIV lines turn out to vary only marginally from model to model, even if the abundance of any given species is decreased by one order of magnitude. It is found, that the atmospheric temperature structure changes the CIV/CV ionization balance in such a way, that the CIV population numbers are hardly changed, when the carbon abundance is varied. The discrepancy between the computed CIV and HeII lines in the absorption trough is milder when the He abundance is decreased, but at present we dare not to give any statement about abundance ratios. Also, on account of the uncertainty in T_{eff} it is premature to give an upper limit for the H abundance. Since we have 5 parameters that determine the structure of the atmosphere (T_{eff}, g, H/He, C/He, O/He), a much larger grid of models is required in order to reach a unique solution.

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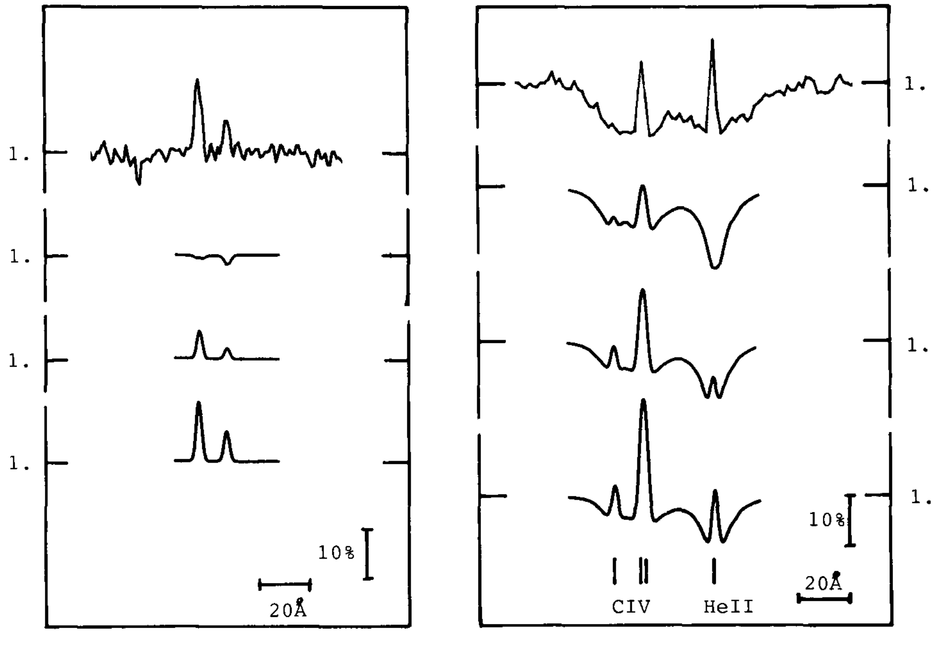

Fig.1 Comparison of the observed spectra of PG1159-035 (top) to model predictions for T_{eff} = 100000 K, 120000 K and 140000 K (bottom), see text.