THE EFFECTIVE TEMPERATURES OF EARLY WOLF-RAYET STARS

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ABSTRACT

Nussbaumer et al. (1981) (NSSW) have calculated temperatures of 15 Wolf-Rayet stars, which cover most subtypes in the WN and WC sequences. Some Wolf-Rayet stars are found to have a blackbody-like energy distribution and therefore their effective temperature can be well determined, others show deviation from the blackbody shape. This deviation is probably due to an extended continuum emitting region. In view of these later cases NSSW adopted a temperature which they derived from a Zanstra analysis of the He II recombination lines. According to their analysis there should be a continuum jump at 2050 Å. New IUE observations of the WN 5 star HD 50896 however did not show any trace of such an absorption edge. This implies that the effective temperature of this WN 5 star and probably of all WR stars with a non blackbody energy distribution is not yet known accurately. Therefore we started a detailed analysis with a spherically symmetric atmosphere model. Though the model has not yet reached its final shape we have obtained as a first result that the location of HD 50896 in the HR-diagram is to the left of the ZAMS and that the Zanstra analysis is indeed not valid for this star.

INTRODUCTION

The simplest way to determine a stellar temperature is to compare its energy distribution with a blackbody. That is what NSSW did when IUE-spectra became available. Out of the 15 examined Wolf-Rayet stars, they found six stars to have a blackbody energy distribution over the UV and optical wavelength range (for the stars observed by Cohen et al. (1975) from 1200 Å to 8000 Å and from 1200 Å to 5000 Å for the others) and four to have an almost blackbody distribution. Almost means that these stars show in the optical region slight effects of an extended atmosphere as explained by Cassinelli and Hartmann (1977). Because all the temperatures (Table 1) are around 30000 K, which is favourable for a blackbody fitting in the UV and because of the long wavelength baseline for which

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the blackbody distribution is verified, we think that these colour temperatures are for the moment the best representation of the effective temperatures. The remaining five stars either show strong extended atmosphere effects or have a peculiar energy distribution; they all are early type stars, so the effective temperatures of these early type ones still remain to be determined.

Table 1

Star	T (K)	Sp-type	cont. shape
HD 9974	39000	WN 3	b.b
HD 187282		WN 4	f e.d.
HD 50896		WN 5	f e.d.
HD 191765		WN 6	f e.d.
HD 192163	34000	WN 6	a b.b.
HD 92740	30000	WN 7	a b.b.
HD 93131	30000	WN 7	b.b.
HD 151932	24000	WN 7	b.b.
HD 86161	30000	WN 8	b.b.
HD 96548	32000	WN 8	b.b.
HD 165763		WC 5	f e.d.
HD 16523		WC 6	f e.d.
HD 156385	30000	WC 7	a b.b.
HD 192103	26000	WC 8	a b.b.
HD 164270	22000	WC 9	b.b.

UV-optical colour temperatures from NSSW.
Continuum shape description:
b.b. a blackbody curve fits the energy distribution of the star
a b.b. a blackbody almost fits the energy distribution (in NSSW n>8)
f e.d. the energy distribution does not fit a blackbody shape; the spectrum looks flat.

ZANSTRA ANALYSIS

For the non blackbody-like stars NSSW adopted a Zanstra temperature which they calculated assuming photons below 911 Å to be absorbed in the outfowing atmosphere by helium in the quantum state n=2. They pointed out that if their assumptions were correct there should be an observable continuum absorption at 2050 Å. This prediction results from an estimate of the population ratio of He II n=2 to He II n=3. Depending on this ratio the optical thicknes below 2050 Å (controlled by the level n=3) could cause an absorption jump up to 30%. However at the time NSSW wrote there paper there were no well exposed observations of this wavelength region available. A new IUE observation in spring 1981 paying particular attention to this wavelength region did not show any trace (to within an estimated accuracy of 5%) of an absorption edge (figure 1). This observation probably indicates that the Zanstra analysis is not valid.

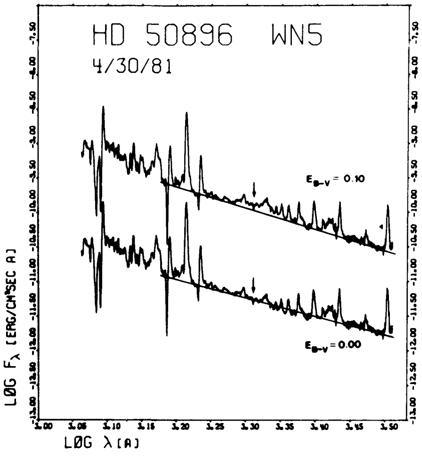

Figure 1

IUE observation of the WN 5 star HD 50896 uncorrected and corrected (E(B-V)=0.1) for interstellar extinction. The arrow indicates 2050 Å where the absorption edge should be, if the assumptions of the Zanstra analysis were correct.

THE MODEL CALCULATIONS

In order to obtain a reliable answer to the problem of effective temperatures of early type stars we began with new model calculations. We assume a blackbody core at the base of the wind and calculate the level populations outwards for a spherically symmetric outflowing atmosphere on Sobolev approximation. With these calculated level populations we solve correctly the transfer equation to find the resulting continuum energy distribution and the line profiles. The model has not yet reached its final shape, the main shortcomings are that up to now only helium is included and that, when calculating the level population, the inward diffuse radiation field is extrapolated from the outward one. Although the calculated numbers will not be of high accuracy the general trends we found should remain valid:

The main parameter that determines the absolute strength of the helium lines is not the number of photons emitted by the core but the mass loss rate. Therefore the equivalent widths of the lines depend not only on the stellar temperature as assumed in the Zanstra analysis.

To obtain a flat continuum as observed for instance in the WN 5 star HD 50896, the free-free opacity has to reach unity in the atmosphere. The density needed is achieved of the velocity law is not too steep and either the mass loss rate is large or the core radius is small. As the mass loss rate is more or less known from Barlow et al. (1981), the stars which show effects of an extended continuum emitting region will have a small core radius. Therefore the effective temperature of these stars is greater than for those with a blackbody distribution as the absolute magnitudes are not very different.

CONCLUSIONS

We found from our observations and model calculations that the Zanstra analysis is not valid in the case of the Wolf-Rayet stars. Therefore the effective temperatures of the early type stars which show effects of an extended continuum emitted region remain ambiguous. We propose that the main parameter that determinates whether the UV and optical continuum emerges from an extended region or not is the radius of the core at the base of the wind. The stars with the most pronounced deviations from the blackbody energy distribution will have the smallest cores and accordingly the hottest effective temperatures. For the WN 5 star HD 50896 we found an effective temperature of about 43000 K and a luminosity of 4.8 (log L/Lo). These numbers would place the WN 5 star to the left of the ZAMS not far from HD 9974, a WN 3 star with an effective temperature of 39000 K and log (L/Lo) = 5.0 (NSSW), which is the hottest star of table 1 with a blackbody-like continuum.

ACKNOWLEDGEMENT

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DISCUSSION

Underhill: It is correct to use resemblance in shape of a stellar spectrum to that of a black-body spectrum over the visible to UV range to determine effective temperatures. This is because black-bodies are "black" - no radiation escapes - over the wavelength range under discussion, while the stars radiate energy. How great the difference in shape is can be found by comparing energy curves from model atmospheres having T_{eff} in the range 20000 to 50000K with energy curves from black-bodies. If T_{eff} is truly of the order of 25000K, one may overestimate T_{eff} by 1000K. The result is rather insensitive to the assumed H/He ratio in the model atmosphere.

Schmutz: As you point out model atmospheres do not look like black-bodies. But we see stars which have a black-body energy distribution from 7000Å down to 1200Å. Therefore we think that in these cases it is appropriate to use a black-body model.

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