THE SPECTRAL TYPE OF HD 101065

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Abstract. The eighth magnitude star HD 101065 has an extremely peculiar spectrum dominated by numerous lines of the rare earths and lacking the lines of 'normal' elements, such as iron peak elements and lighter elements. For this reason it cannot be fitted into the adopted framework of spectral classification. The spectral type of this star can be defined only by fixing its effective temperature, which is 6040 ± 100 K. However, because of the extremely high blanketing the temperature of the continuum is about 450 K higher. This means that HD 101065 is a late F type star.

1. Introduction

There is probably no other star whose spectral classification has caused as much confusion as that of the eighth magnitude star HD 101065.

In the Henry Draper catalogue it is classified as a B5 star, which certainly it is not. On the basis of its *UBV* colours, it could be classified as a K0 star with an ultraviolet excess. On the other hand, from their six-colour photometry, Kron and Gordon (1961) classified it as an F8 star with the highest known blanketing effect. And finally, Wegner and Petford (1974) assigned the type F0 from their study of equilibria between neutral and singly ionized elements.

The real cause of this confusion ultimately lies in the abnormal chemical composition of the atmosphere of this star. Its spectrum lacks such 'normal' elements as magnesium, silicon, iron, chromium, titanium and other iron peak elements, while only traces of calcium are present. On the other hand the spectrum is entirely dominated by numerous lines of the rare earths. In addition, only the presence of strontium, yttrium, zirconium and barium could be established beyond any doubt.

About 3000 lines were measured in the blue region from λ 3650 to λ 4830 Å. In addition Wegner and Petford recorded about 2000 lines in the red region from λ 4806 Å on.

2. Effective Temperature

In view of the lack of normal elements in the atmosphere, HD 101065 cannot be fitted into the adopted scheme of spectral classification based on selected absorption features. For this reason an appropriate spectral class can be allotted to it only if its temperature is known and the effect of blanketing on the structure of its atmosphere can be evaluated.

The determination of the effective temperature was the subject of a paper now in press

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TABLE I
Six-colour photometry

Star	*U*	*V*	*B*	*G*	*R*	*I*
HD 101065[a]	+0.08	+0.06	−0.04	−0.02	+.07	+0.20
HD 101065[b]	−0.60	−0.30	−0.13	−0.03	+.16	+0.35
β Vir	−0.20	−0.17	−0.06	−0.03	+.09	+0.21
Procyon	−0.43	−0.38	−0.14	−0.03	+.17	+0.39

[a] observed colours
[b] colours corrected for blanketing

(Przybylski, 1975) and therefore only a few details are quoted here. As the six-colour photometry in Table I shows the radiation of HD 101065 between the blue (λ 4880 Å) and the infrared (λ 10300 Å) colours can be approximated quite well to the radiation of β Virginis for which Baschek *et al.* (1967) found an effective temperature of 6120 ± 100 K. In addition, in the far infrared the difference between both stars is still reasonably small. Both stars emit about 75% of their total radiation in the spectral region above the blue band (λ 4880 Å). However, they differ considerably in the amount of energy emitted in the violet and ultraviolet regions. Detailed calculations show that this difference amounts to about 5.7%. This difference is reduced to 5.2% by a small excess in the far infrared in the radiation of HD 101065. A difference of 5.2% in the emission means a difference of 1.3% or about 80 K in the temperature of both stars. Thus for HD 101065 we obtain a temperature of about 6040 K, which makes it an F8 star in full agreement with its classification by Kron and Gordon (1961).

3. Blanketing

In their paper on HD 101065 Kron and Gordon (1961) noticed that this star has the highest known blanketing for any late-type F star. This is obviously due to the numerous absorption lines of the rare earths. In fact, the whole spectrum between λ 3650 and λ 4830 Å can be considered as one large blend.

It is difficult to evaluate the blanketing effect since the position of the undisturbed continuum is problematic. In the present investigations the continuum between λ 3800 and λ 4800 Å was drawn through the highest intensity peaks. Above λ 4800 Å, where lines are weaker and less numerous, it is easier to fix the continuum but unfortunately the two available spectra taken on 130aF Kodak plates are underexposed below λ 5500 Å. The results obtained from both spectra do not agree well, and therefore errors up to about 20% are possible.

The results of the measurements are shown in Figure 1. No evaluation below λ 3800 Å was undertaken since there the 'true' continuum cannot be drawn at all. Only a crude geometrical extrapolation of the blanketing below this limit is possible. Extra-

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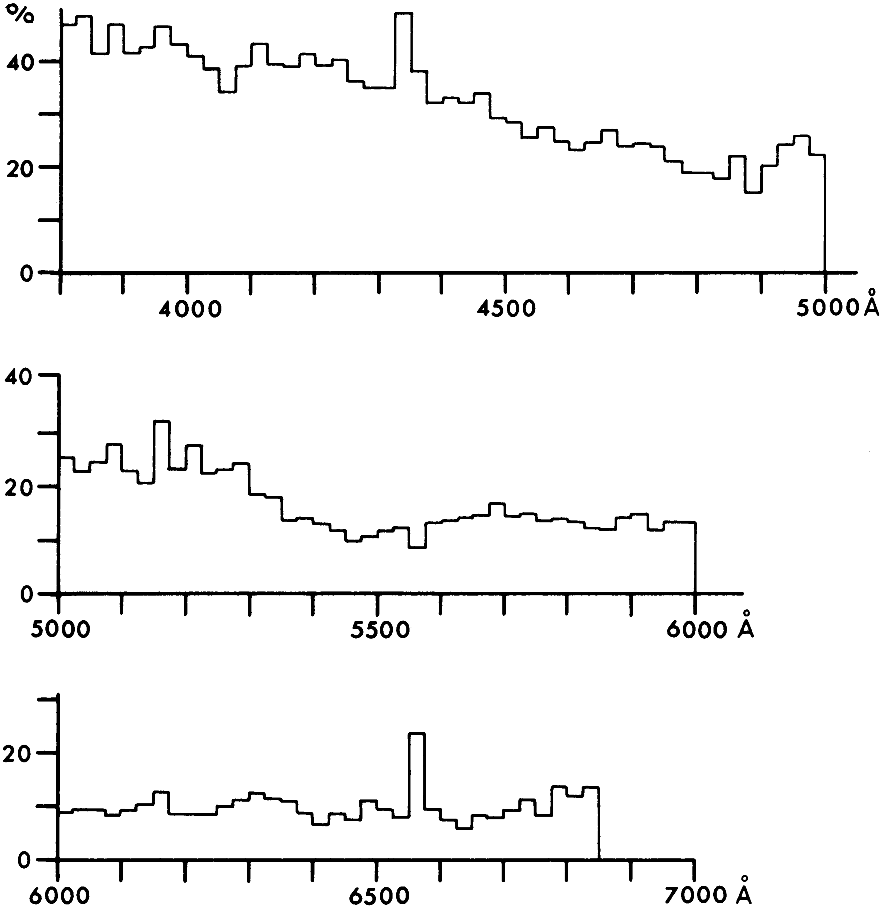

Fig. 1. The blanketing of HD 101065.

polation must also be used above λ 6850 Å since no good quality high-dispersion spectra of this region are available. In the present investigations it was assumed that 54% of the radiation is absorbed in spectral lines at λ 3550 Å, and 75% at λ 2000 Å and below this limit. Further, absorption of 6.8%, 5%, 3.4% and 2% was adopted for λλ 7000, 7500, 8000 and 8500 Å respectively. The assumption was also made that in the infrared band at λ 10300 Å the absorption falls to 1%.

With the help of Figure 1 we easily find that the absorption in *V*, *B* and *G* bands of six-colour photometry is 38.2, 20.3 and 14.6% respectively. For the *U*,*R*,*I* bands the corresponding figures found from the adopted extrapolation are 54, 6 and 1%. In terms of stellar magnitudes the corrections due to blanketing are then 0.84, 0.52, 0.25, 0.17, 0.07 and 0.01 mag. in order of increasing wavelengths. Subtracting those corrections from the observed six-colour photometry and adding uniformly a correction of 0.16 for the sake of normalization we obtain the de-blanketed colours shown in Table I. They agree

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tolerably well with the observed colours of *blanketed* Procyon (HD 61421), which has an effective temperature of 6500 K according to Strom and Kurucz (1969) and also to Carbon and Gingerich (1969). The temperature of deblanketed Procyon is about 150 K higher.

Judging from the data in Table I the temperature of the continuum of HD 101065 should be slightly lower than the effective temperature of Procyon, but the difference is certainly so small that it can be disregarded. A model stellar atmosphere with an effective temperature of 6500° can, therefore, be used for the numerical computation of the blocking coefficient η. The model of Carbon and Gingerich (1969) for a main-sequence star ($\log g = 4.0$) was used for this purpose.

The total energy radiation output for this model is 32.215×10^9 erg cm^{-2} s^{-1}. Detailed computation in the region from λ 3800 – λ 6850 Å based on data from Figure 1 show that 10.86% of radiation is removed from the spectrum by spectral lines in this interval. The absorption below λ 3800 Å (computed with the help of the adopted, extrapolated blanketing down to λ 1683 Å) amounts to 13.65% of the total energy output of the star. The energy absorbed above λ6850 is only 0.78%. Thus the total amount of energy removed from the spectrum is 25.29% or 8.147 erg cm^{-2} s^{-1}. The blocking coefficient η is 0.2529. The effective temperature T_e can now be computed from the temperature T_o of the continuum with the help of the formula

$$(T_e/T_0)^4 = 1 - \eta.$$

Numerically we obtain $T_e = 6043$ K which means that the effective temperature is 457 K lower than the temperature of the continuum. This result agrees well with the temperature obtained from the comparison of HD 101065 with β Virginis but obviously this agreement is coincidental, since the accuracy of our calculations is rather low – more than half of the blanketing had to be computed from extrapolated estimates.

4. Comparison with the Results of Hyland

HD 101065 was recently observed by Hyland *et al.* (1975) in the far infrared colours J (1.25μ), H (1.65 μ) and K (2.2μ). They derived the temperature of the star from deblanketed colours $V-J$, $V-H$ and $V-K$, where $V = 8.02$ is the visual magnitude at λ = 5400 Å. The blanketing correction at λ = 5400 Å derived from Figure 1 is 0.18 mag. From their observations Hyland and his co-workers conclude that the temperature of the continuum of HD 101065 is essentially the same as that of F5 to F6 main-sequence stars with an effective temperature between 6300 and 6500 K. Adopting a differential correction of 120 K due to blanketing effect, they conclude that the effective temperature of HD 101065 is 6300 ± 150 K.

However, their differential correction seems to be too small. For an average F5-F6 star a mean effective temperature of 6400 K can be adopted. From Wildey's *et al.* (1962)

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estimates of blocking coefficients η for several stars we can conclude that the blanketing correction for such a star is about 120 K, and thus we obtain T_0 = 652C K for an average F5-F6 star. Adopting the same temperature of the continuum for HD 101065 and applying a blanketing correction of 457 K from the present investigations, we obtain an effective temperature T_e = 6063°, not much different from comparison of the star with β Virginis and with Procyon. Hyland's observations can, therefore, be well reconciled with the present results.

5. Final Remarks

Objective prism spectra of low dispersion, such as for instance spectra used for the Henry Draper classification, cannot record thousands of narrow spectral lines seen on high-dispersion spectra of HD 101065. For this reason almost all details are lost and only a few broad features can be seen. Among the few visible features are obviously the hydrogen lines. From their strength the star could be classified as a late F or a B5 star. Apparently because of the lack of any visible ionized calcium lines H and K, the B5 type was chosen for the Henry Draper catalogue. Two objective prism spectra of 470 Å mm^{-1} dispersion at Hγ taken in 1961 by B. Westerlund and G. Lyngå with the 26″ Schmidt telescope of the Uppsala Southern Station show that the spectrum of HD 101065 really looks like that of a B5 star with a wrong continuum and without helium lines. Therefore it can be safely assumed that the star is not a spectrum variable in spite of its classification as a B5 star in the Henry Draper catalogue.

In Johnson's three-colour photometry (V = 8.017 ± 0.004, $B-V$ = 0.763 ± 0.003, $U-B$ = 0.241 ± 0.006) HD 101065 seems to be a K0 star with an ultraviolet excess of 0.22 mag. The high $B-V$ value is obviously due to high blanketing in the violet band (λ 4220 Å) which more or less corresponds to Johnson's blue colour. In normal F stars the blanketing amounts to about 15% while in HD 101065 it is 2½ times higher (38.2%). This causes a relative difference of 0.34 mag. in the $B-V$ colour – only partly compensated by increased blanketing in Johnson's visual band.

If we adopt Milne's law of temperature distribution in the atmosphere and assume that spectral lines are formed by true absorption, the maximum limit for blanketing is 50% of the undisturbed radiation. In real stars the boundary temperature drops below the limit imposed by Milne's law and, in addition, spectral lines are formed not only by true absorption but also by the process of scattering and, therefore, more than 50% of energy can be removed in spectral lines. In fact, the present investigations show that at λ 3800 Å almost 50% of the radiation is removed and certainly more than this is removed in the ultraviolet band. Obviously, however, the increase in blanketing is becoming more difficult when already a large amount of energy is removed from the spectrum. In normal late-type F stars about 35% of radiation is removed in the ultraviolet band (λ 3520 Å). In HD 101065 the extrapolated degree of absorption is 54%, or 19% more than in F stars. In terms of stellar magnitudes this difference is equal to 0.37 mag. or only slightly more

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than in Johnson's blue band. Thus the *U–B* difference remains practically unaffected. HD 101065 has, therefore, the *B–V* colour of a K0 star but the *U–B* colour of a late-type F star. This explains the apparent ultraviolet excess of the star in Johnson's system.

An increase of metal abundance in the star would probably increase this ultraviolet excess. It would cause a relatively small increase of blanketing in the visual region, a much larger increase in the blue band and a relatively small increase in the ultraviolet. As a result we would obtain an increase of the *B–V* colour but a decrease of the *U–B* colour. In this way the ultraviolet excess would be increased. In astronomical practice the ultraviolet excess is associated with the underabundance of metals, and conversely the ultraviolet deficiency with the overabundance of metals. HD 101065 is an exception to this general rule because of its enormous blanketing.

The total abundance of metals, whose presence in HD 101065 was established in an analysis of the spectrum (Przybylski, 1966), possibly does not exceed 1/100 of the abundance of iron in normal stars. The star may thus be metal poor in spite of its large blanketing effect. However, this is not a firmly established fact, since additional elements may still be discovered in the spectrum and since the abundance of elements not represented by lines in the spectra of late-type stars is an unknown factor in estimations of the total metal abundance. Recent investigations show that two elements, yttrium and zirconium must be added to the list of elements present in the star. On the other hand the presence of several elements reported by Wegner and Petford (1974) is doubtful. At present this is the subject of a controversy, which will hopefully be resolved in the near future.

The position of the star in the Russel-Herzsprung diagram is unknown. Unfortunately the parallax found by Churms ($\pi = 0\overset{''}{.}004 \pm 0.006$) is small and its probable error exceeds the value of the parallax itself. Hardly any conclusion can be drawn from such results. An eighth magnitude F8 star should have a parallax of $0\overset{''}{.}016$ in order to lie on the main sequence.

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DISCUSSION

Spinrad: Now that you have the temperature, what is the Ho overabundance in the star?

Przybylski: All the rare earths are overabundant by a factor of about 1000 if we assume that the continuous opacity is normal. Unfortunately we cannot be sure of that.

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