THE NEAR ULTRAVIOLET SPECTRUM OF B AND A TYPE MAIN SEQUENCE STARS

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ABSTRACT

Scans of λ Lep, η UMa, ζ Dra, ε Dor, α Leo, ϕ Dra, ν Dra, β Aur, α Pic and δ Dor have been obtained with scanner No. 1 of OAO-2 over the range 1800-3600 Å on the OAO guest observer program. These scans have been reduced to tracings of F_λ in the 20 Å pass band vs. wavelength using a wavelength conversion scale and a relative spectral sensitivity function kindly communicated by B. D. Savage. The general trend of the relative flux plots compares well with the continua predicted by simple model atmospheres. The line blocking per 100 Å in the region 2000-3000 Å relative to theoretical continuous spectra is tabulated. At type B6 and later the blanketing is due chiefly to the many lines of Fe II and Cr II. In the stars of types B0.5 to B3, the lines from the third spectra of the metals contribute a blanketing similar to that predicted by Elst for a B1 star. The significant line blocking that can occur in early type atmospheres, particularly in stars with extended atmospheres, throughout the range $4.0<\lambda^{-1}<5.5\mu^{-1}$, raises doubts whether the hump in the interstellar extinction curve found in this region by Stecher and by Bless and Savage is solely due to the interstellar medium. The severe line blanketing which occurs in the range 2000-3000 Å for stars of types B6 and later will make the interpretation of broad and narrow band photometry in this range difficult.

The results of a study of spectrum scans requested by the author as an OAO-2 guest observer while she was at the

Utrecht University, Netherlands are reported. The purpose was to obtain OAO observations of a few of the stars that will be observed with the Utrecht scanning spectrometer (experiment S59) which will be on the ESRO astronomical satellite TD1 which is to be launched early in 1972. The satellite will be launched in a circular near polar synchronous orbit and in the course of six months the scanning spectrometer should observe the whole sky. When a sufficiently bright star enters the field of view of the telescope, a scanning mechanism is triggered so that three bands of 100 Å centered at 2085, 2520 and 2800 Å, respectively, are scanned in steps of 1 Å. The resolution is about 1.4 Å per step. By obtaining OAO scans of a few objects which should frequently appear in the field of view of S59, it is hoped to be able to relate the Utrecht results, which will cover only limited spectral regions, to the extensive body of OAO data.

Reliable spectral scans of 10 main sequence B and A stars were kindly made available by the Wisconsin Principle Investigator, Dr. A. D. Code. The scans extend from about 1800 Å to about 3700 Å. The raw data were converted from grating step and number of counts per 20 Å pass band using conversion formulas kindly communicated by B. D. Savage. The wavelength scale is not precise because to establish an accurate zero point one must recognize at what grating step the blended Mg II resonance lines occur. This is not always possible. An uncertainty of one grating step means an uncertainty in wavelength of about 20 Å. The conversion formulas of Savage are strictly valid only for wavelengths longer than 2200 Å. The short wavelength formula was extrapolated shortward in order to obtain a wavelength scale to the end of the data range. The same extrapolated nominal wavelength scale has been used for all the stars using an estimated position for the Mg II resonance lines as zero point.

The stars observed are listed in Table 1 together with their color excesses and some further information. Unless otherwise noted, the spectral types, V magnitudes and B-V colors have been taken from the Bright Star Catalogue (Hoffleit 1964). The intrinsic colors of Johnson (1963) were adopted.

The relative flux distributions over the range 1800-3400 Å for a 20 Å pass band are shown in Figures 1 and 2. (The flux distribution for α Pic is not shown; it is similar to that of δ Dor.) In Figures 1 and 2 each observed flux distribution (solid line) is compared with the relative continuous spectrum from an LTE, hydrogen-line blanketed model atmosphere (Klinglesmith 1971). The composition of the models is $X = 2/3$, $Y = 1/3$; log g is 4.0. Appropriate effective temperatures are adopted for each type. The predicted

Table 1. The Stars Observed

HR No.	Name	Sp. Type	V	B-V	E(B-V)	Remark
1756	λ Lep	B0.5 IV	4.28	-0.28	0.00	
2015	δ Dor	A6 IV	4.34	+0.22	+0.05	
2064	ε Dor	B5	5.10	-0.15	-0.01	1.
2088	β Aur	A2 V	1.90	+0.03	+0.03	2.
2550	α Pic	A5 V	3.26	+0.21	+0.06	
3982	α Leo	B7 V	1.36	-0.11	+0.01	3.
5191	η UMa	B3 V	1.86	-0.20	0.00	4.
6396	ζ Dra	B6 III	3.20	-0.15	-0.01	
6554	ν Dra	Am	4.86	+0.25	+0.08	5.
6555			4.84	+0.28	+0.11	
6920	ϕ Dra	A0p(Si)	4.18	-0.00	0.00	6.

1. According to Hiltner, Garrison and Schild (1969) the MK spectral type is B6 V.
2. This star is a double-lined spectroscopic binary and it appears in the catalogue of rotational velocities of Bernacca and Perinotto (1970).
3. Blanco, Demers, Douglass and Fitzgerald (1968) list V = 1.33 and B-V = -0.12; this star is in Bernacca and Perinotto (1970).
4. Blanco, Demers, Douglass and Fitzgerald (1968) list V from 1.85 to 1.96 and B-V from -0.170 to -0.20; this star is in Bernacca and Perinotto (1970).
5. Both stars are observed together; HR 6555 is a spectroscopic binary; these stars are in Bernacca and Perinotto (1971) who list types A6 V and A4m respectively.
6. This star is a spectroscopic binary listed in Bernacca and Perinotto (1971); Cowley, Cowley, Jaschek and Jaschek give V = 4.22 and B-V = -0.10. It is also a magnetic star.

continuous spectra from these admittedly simple models are used as convenient reference flux distributions with which to compare the observed flux distributions. None of the stars are reddened by a significant amount. Little weight should be placed on the apparent intensity distribution at $\lambda < 2000$ Å because at these wavelengths the sensitivity of the equipment is low, with the result that the observed number of counts has been multiplied by a number of the order of 5 or 6. In fact, comparison with the results of Evans (1971) indicates that the adopted sensitivity function is too low at $\lambda < 2000$ Å.

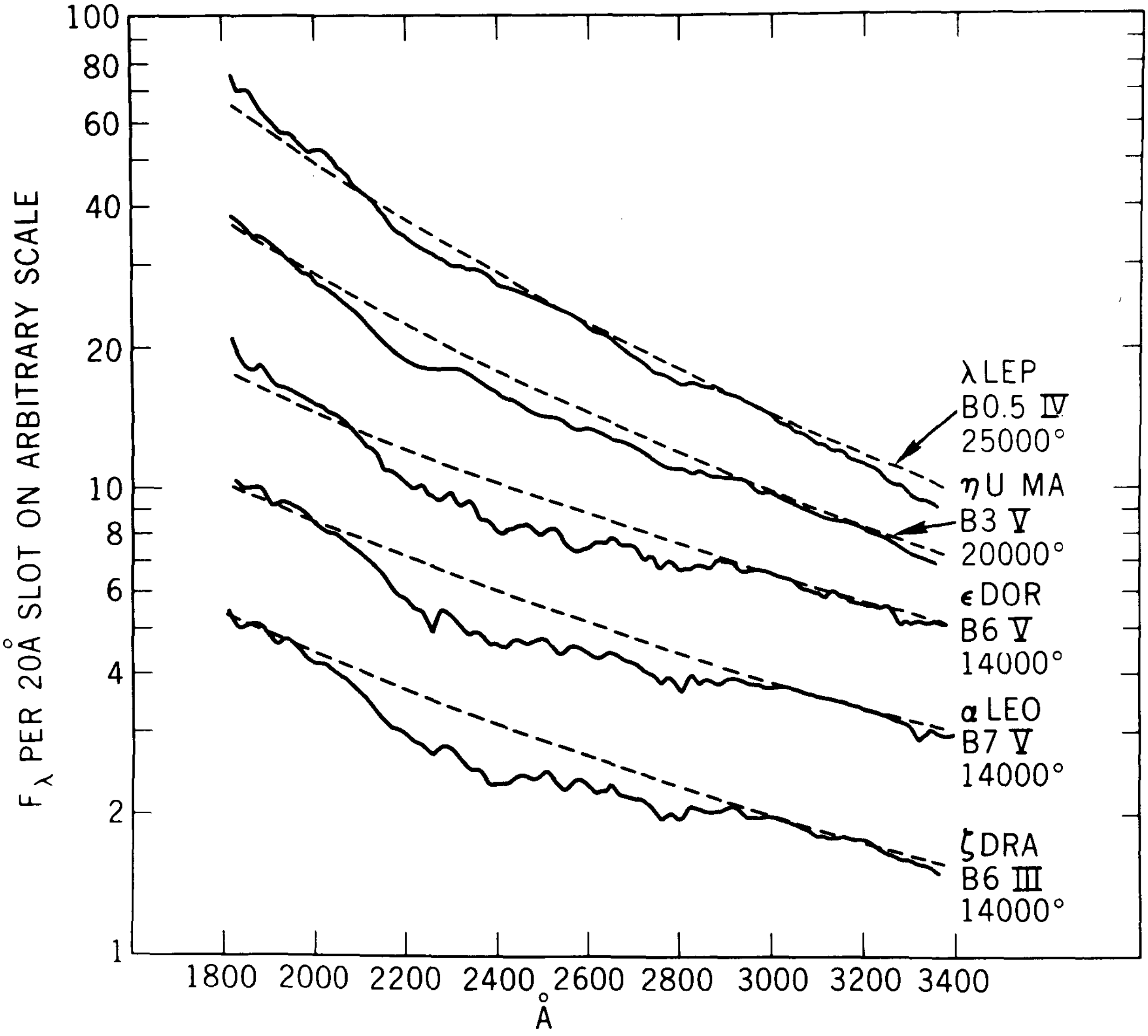

Figure 1.—Relative flux distributions in a 20 Å bandpass for B stars relative to continua predicted from hydrogen line blanketed model stellar atmospheres having log g = 4.0 and the indicated value of effective temperature.

At spectral type B0.5 IV, there is very little line blanketing. However, by type B3 V (η UMa) the blanketing is quite significant. The spectrum from about 2000-2900 Å is depressed from what is predicted when the effects of all lines except those due to hydrogen are ignored. At types B6 and B7 the blanketing is conspicuous. The luminosity class III star ζ Dra seems to have slightly stronger blanketing

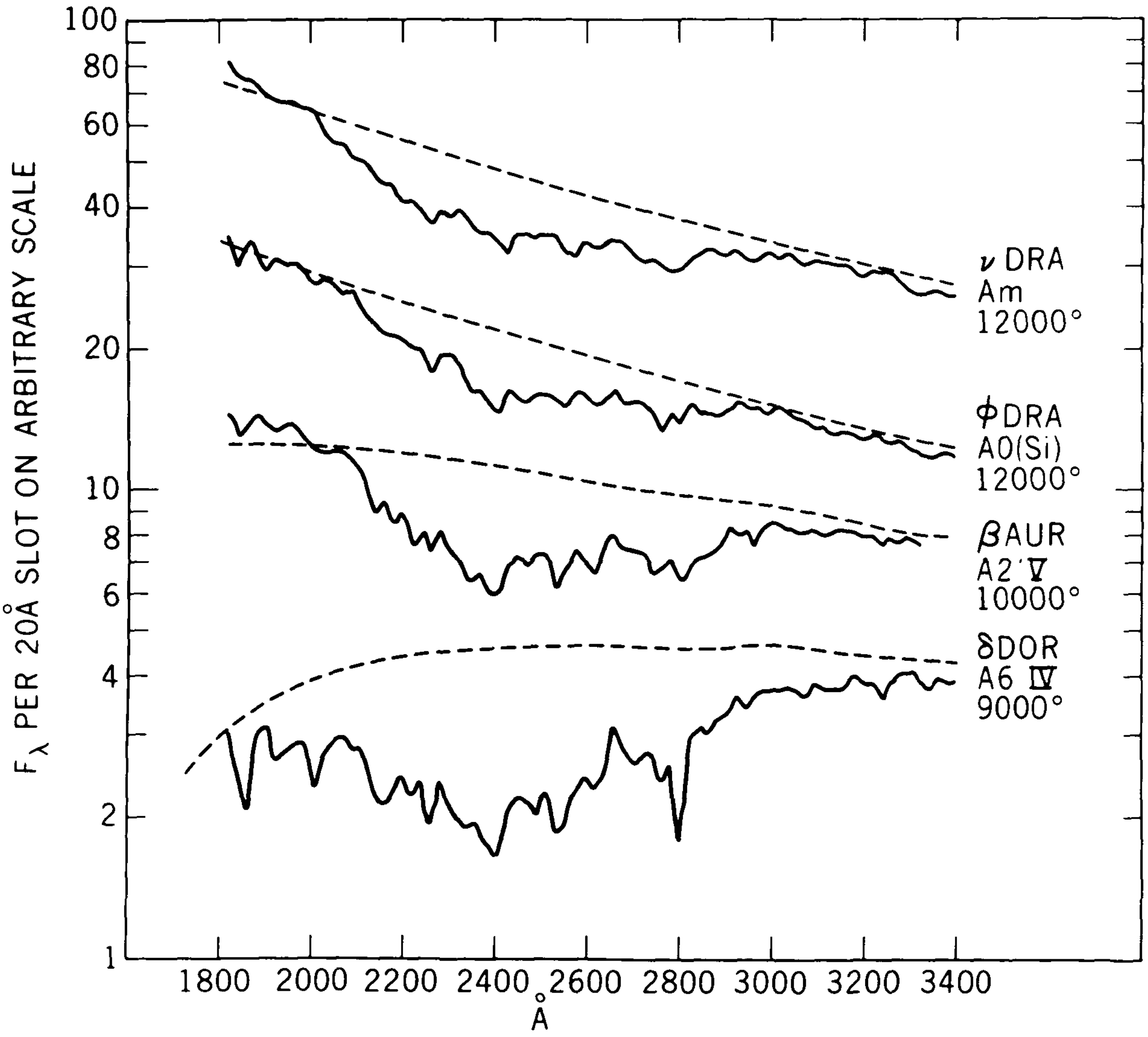

Figure 2.—Relative flux distributions in a 20 Å bandpass for A stars relative to continua predicted from hydrogen line blanketed model stellar atmospheres having log g = 4.0 and the indicated value of effective temperature.

than do the class V stars. One may suspect that the Mg II resonance lines near 2800 Å would be resolved at 10 Å resolution. Scans of some A type main sequence stars are shown in Figure 2 compared with cooler model atmospheres of the same grid. The line blanketing increases rapidly with advancing spectral type and the Mg II lines become prominent by type A5 or A6. The scan for ν Dra records the spectrum of all stars of this composite system. The line blanketing at wavelengths shortward of 2200 Å seems to be stronger for this Am spectrum than it is for normal A stars.

The A type stars are probably quite nearby. Their apparent color excesses must reflect a systematic effect in Johnson's intrinsic colors for types A2 and A5. The reasonable fit of the theoretical continua to the observed spectral distributions at wavelengths between 3000-3700 Å indicates that the sensitivity function communicated by Savage is acceptable.

An attempt was made to identify some of the more prominent dips, but it is impossible to make detailed line assignments because this part of the spectrum is full of lines. A resolution of the order 1 Å rather than 20 Å will be required to make progress with identifications. A measure of the density of lines from the more abundant metals (Ti, Cr, Mn, Fe, Co and Ni) has been obtained by counting all the lines of the second and third spectra of these elements per 100 Å range between 1700-3000 Å. The results are shown in Figure 3. There are very many lines from the second spectra of the metals, in particular from Fe II and Cr II. The density of

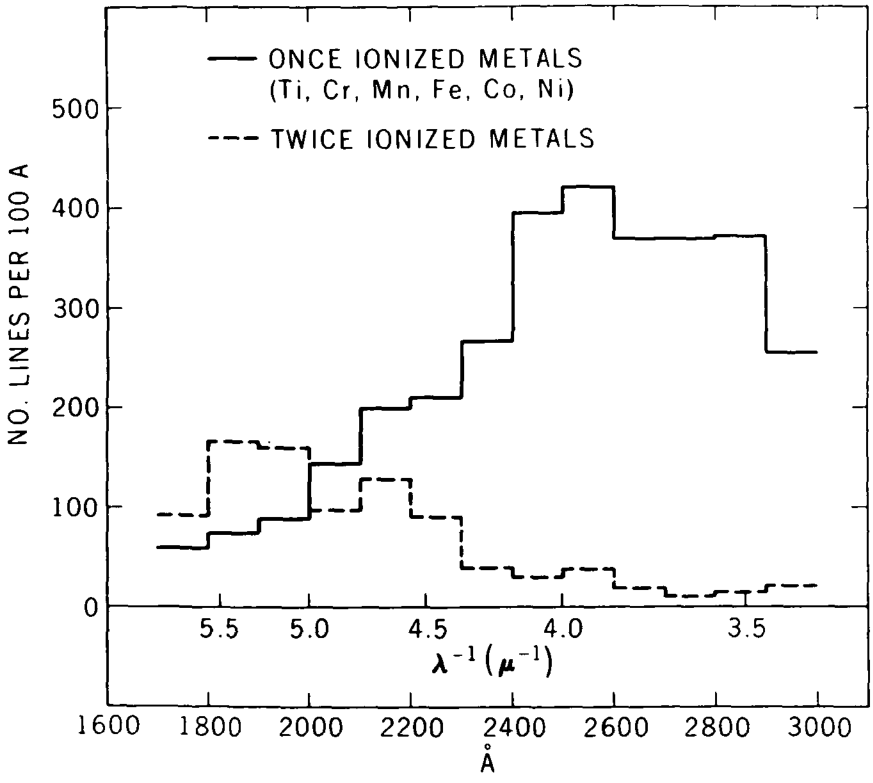

Figure 3.—The relative density of spectral lines per 100 Å of the second and third spectra of the metals.

lines from the second spectra of the metals is particularly large from 2300-2900 Å. The lines of the third spectra of the metals fall mostly in the range 1900-2300 Å; they peak between 1800-2200 Å. Reference to Figures 1 and 2 shows that line blanketing at types B0.5 and B3 is concentrated most strongly near 2200 Å; at types B6 and later, the blanketing is strongest over the range 2300-2900 Å. It is at least as strong as that found in the 3400-4400 Å region of F type spectra (see Melbourne 1960).

The line blocking per 100 Å relative to the adopted nominal continua has been measured and is tabulated in Table 2 as $\Delta m = 2.5 \log (F_\lambda/F_c)$ averaged over a 100 Å range. It is shown in Figure 4. The line blocking for λ Leporis is rather similar to that predicted by Elst (1969) using a model atmosphere of nominal type B1.5 V. The line blocking increases

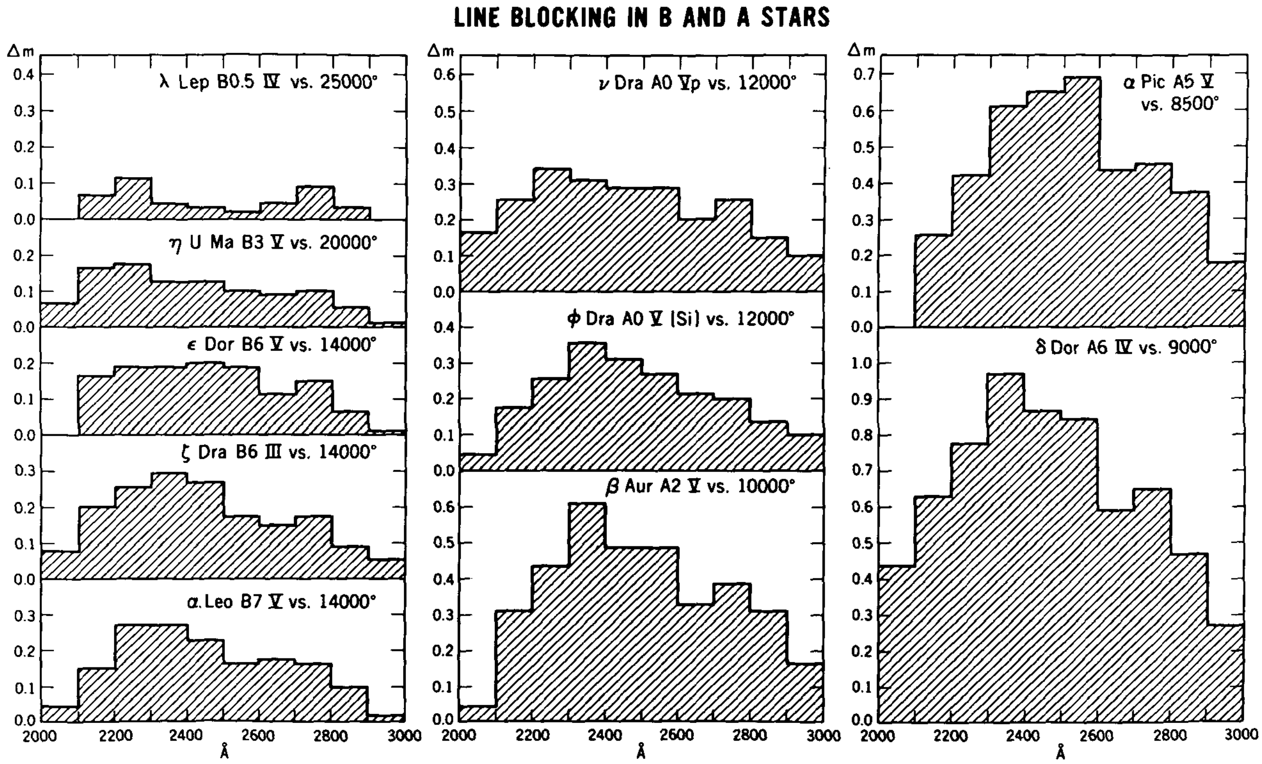

Figure 4.—The line blocking in B and A main sequence stars per 100 Å relative to theoretical continuous spectra. The ordinate, Δm, is the flux per 100 Å of the star relative to the continuous spectrum expressed in magnitude units. The amount of line blocking shortward of 2100 Å is uncertain owing to uncertainties in the adopted sensitivity function at λ < 2100 Å.

Table 2. The Line Blanketing Relative to a Grid of Reference Models Expressed in Magnitudes

Star Sp.Type T_{eff}	λ Lep B0.5 IV 25000	η UMa B3 V 20000	ε Dor B6 V 14000	α Leo B7 V 14000	ζ Dra B6 III 12000	ν Dra Am 12000	φ Dra A0p(Si) 12000	β Aur A2 V 10000	α Pic A5 V 8500	δ Dor A6 IV 9000
20-21	--	0.07	0.00	0.04	0.08	0.16	0.04	0.04	--	0.44
21-22	0.07	0.16	0.16	0.15	0.20	0.26	0.18	0.31	0.26	0.63
22-23	0.11	0.18	0.19	0.27	0.26	0.34	0.26	0.44	0.42	0.78
23-24	0.04	0.13	0.19	0.27	0.30	0.31	0.36	0.61	0.61	0.97
24-25	0.03	0.13	0.20	0.23	0.27	0.28	0.31	0.48	0.65	0.87
25-26	0.02	0.10	0.19	0.16	0.18	0.28	0.27	0.48	0.69	0.84
26-27	0.04	0.09	0.11	0.18	0.15	0.20	0.22	0.33	0.44	0.59
27-28	0.09	0.10	0.15	0.16	0.18	0.26	0.20	0.39	0.45	0.65
28-29	0.03	0.06	0.07	0.10	0.09	0.15	0.14	0.31	0.37	0.47
29-30	0.00	0.01	0.01	0.02	0.06	0.10	0.10	0.16	0.18	0.27

rapidly with advancing spectral type. By type A6 V nearly 1 mag per 100 Å is being removed from the spectrum in the neighborhood of 2300 Å. This is probably chiefly due to the numerous very strong lines of Fe II and Cr II.

The considerable line blocking that occurs in spectral types B6 and later between 2100-2900 Å means that study of this region by broad or narrow band photometry will not result in an accurate approximation to the shape of the continuous spectrum. Because the line blocking is not entirely negligible even at type B0.5, the derivation of the shape of the interstellar reddening curve by comparing spectra of two stars of not precisely the same spectral type is fraught with danger. The principal lines which are causing the line blocking are from low-lying configurations and are of such a spectroscopic character that one may expect them to be enhanced in strength in a star with a somewhat extended atmosphere. It is well known that the lines of the ionized metals are enhanced in the spectra of giants and supergiants. That large numbers of these lines fall in the neighborhood of 2200 Å makes it particularly difficult to establish what part of the apparent blocking of radiation here in a reddened star relative to an unreddened star, is due to the stellar atmosphere and what part is truly due to interstellar reddening.

Stecher (1969) and Bless and Savage (1970) have suggested that there is a hump in the interstellar reddening curve throughout the range $4.0<\lambda^{-1}<5.5\mu^{-1}$. However, to be certain of the reality of this feature, one would have to demonstrate that there is significantly less than 0.1 mag difference in the line blocking for the two stars being compared. In all published cases, the measured difference in the spectrum profiles between the reddened and the unreddened star in the neighborhood of 2200 Å has been magnified by a factor of the order of 5 owing to the normalization procedure adopted.

The significant line blocking shown by the 20 Å resolution scans of B and A stars is a fascinating indication of how rich in lines the spectra of B and A stars will be in the 2000-3000 Å region when viewed at high resolution. The predicted line strength for types near B1 V of Guillaume, van Rensbergen and Underhill (1965), Guillaume (1966), and Elst (1969) and for type A0 by Maran, Kurucz, Strom and Strom (1968), inadequate as they are, give an indication of what is to be expected. The Bp and Ap stars when examined at adequate resolution in the 2000-3000 Å range should reveal many spectral peculiarities because of the great density of spectroscopically significant lines. It may be possible to set up a finely divided spectral classification system for late B and early A stars when spectra of moderate resolution in the 2000-3000 Å region are available. In this way some present anomalies may be resolved.

This survey of the near ultraviolet spectra of B and A stars was made possible by the generosity of the NASA OAO-2 Guest Observer Program. Particular thanks is due to Dr. B. D. Savage of the University of Wisconsin for communicating the scanner data and the wavelength and sensitivity conversion factors in a most convenient form.

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