AN ATLAS OF ULTRAVIOLET STELLAR SPECTRA

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Ultraviolet stellar fluxes have been presented for 140 bright stars in the spectral region from 1200 Å to 3600 Å in a graphical and tabular form (A. D. Code and M. R. Meade, 1976). The spectra represent a subset of OAO-2 spectrometer data on file at the National Space Science Data Center. The monochromatic flux is given in units of ergs cm^{-2} sec^{-1} $Å^{-1}$ with a spectral resolution of about 22 Angstroms in the region from 3600 Å to 1850 Å and approximately 12 Angstroms from 1850 Å to 1160 Å.

The monochromatic flux, F_λ, is based upon the absolute calibration described by Bless, Code and Fairchild (1976).

Figure 1a and 1b shows the digital output for a single scan, with 8 second integration time at each step plotted against step number for spectrometer 2 and spectrometer 1 respectively. These counts have been corrected for digital data overflows, based upon the analog output. A background count has been subtracted. The background count determination for spectrometer 2 is relatively straight forward since shortward of the LiF cutoff at 1050 Å the measured counts are just the background as shown on Figure 1a. The spectrometer 1 background is based on the data from late-type stars and the correlation of the background with total counts at longer wavelengths. Typically background counts correspond to about 5 counts.

Figure 1c and 1d show the superposition of 8 scans and 3 scans respectively where the step position for Lyman α or MgII 2800 respectively, have been determined for each scan before superposition. This assignment is usually good to ±1/2 step.

Figure 2a and 2b show the mean curve fitted to the data of Fig. 1. The wavelength assignment is based on the determination of the step positions for Lyman α and MgII along with the empirical relation between angstroms and steps. The data for each scan has been corrected for the small time dependent system degradation by an algorithm constructed to reduce all scans to the sensitivity at orbit zero. The

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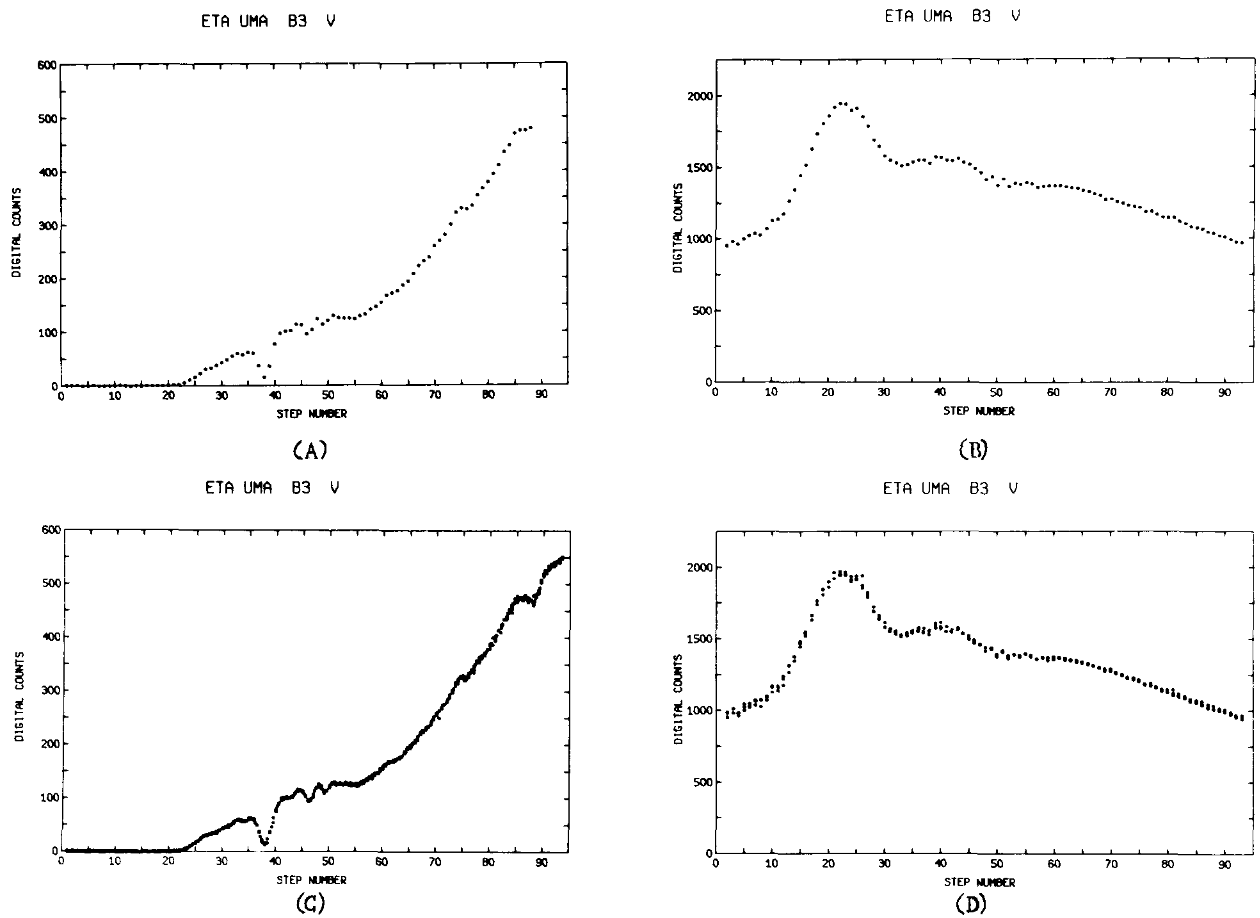

Fig. 1. (a) Digital output for a single spectrometer 2 scan, (b) spectrometer 1, (c) Superposition of 8 spectrometer 2 scans, (d) Superposition of 3 spectrometer 1 scans.

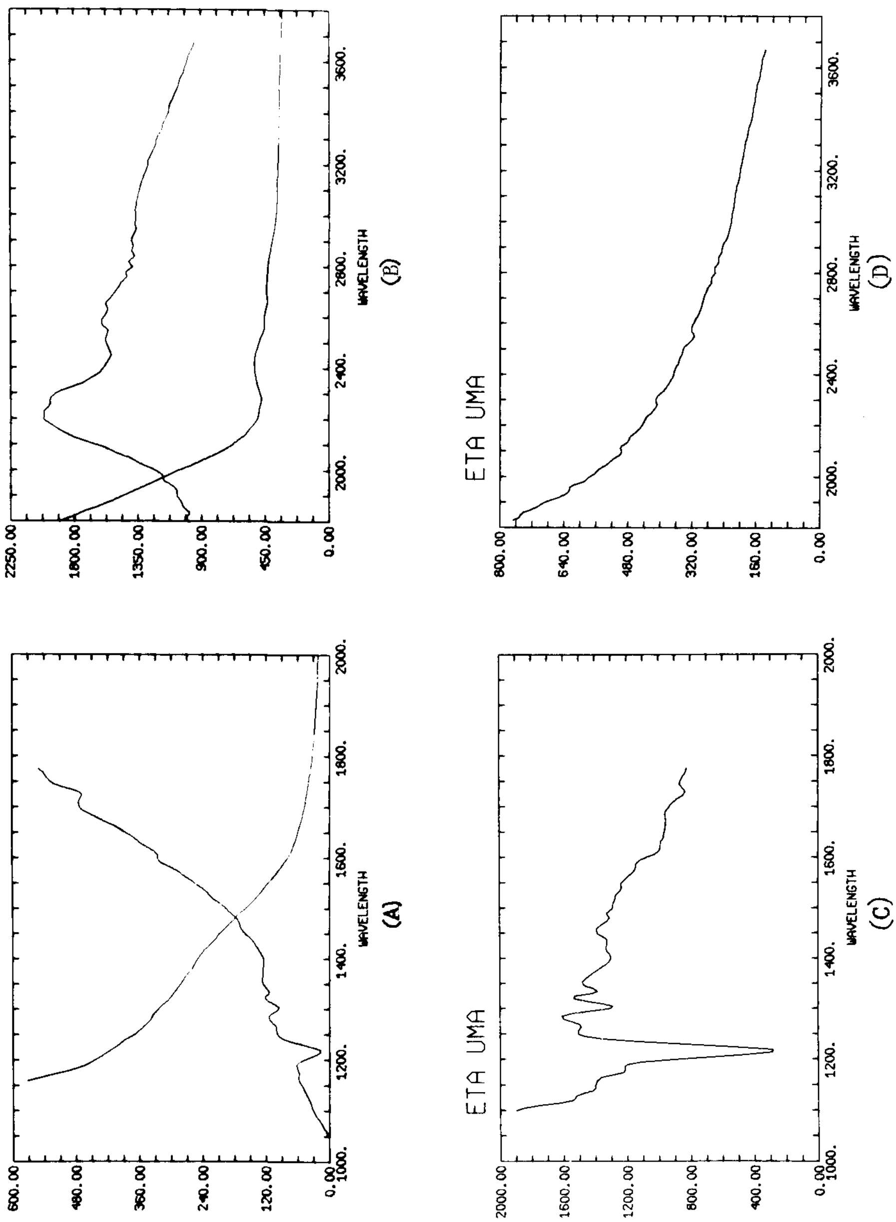

Fig. 2. (a) Mean digital output vs wavelength and relative sensitivity for spectrometer 2, (b) Mean digital output vs wavelength and relative sensitivity for spectrometer 1, (c) & (d) Stellar energy distribution.

investigation of the change of system response over the life time of the satellite for spectrometer 1 is given by C. Navach and M. R. Meade (1976) and for spectrometer 2 by A. Holm and M. R. Meade (1976).

Also plotted on Fig. 2a and 2b are the relative sensitivities of each spectrometer. The product of these two curves yields the stellar energy distribution shown in Figures 2c and 2d. These sensitivity curves are in units of flux per spectrometer count. In the figure the spectrometer 1 data has been normalized to ground based data, on the system of Hayes and Latham (1975), in the neighborhood of 3600 Å. The spectrometer 2 data remains on the OAO-2 calibration system of Bless, Code, and Fairchild.

The general behavior of the ultraviolet stellar spectra at the resolution obtained here is illustrated in Figures 3-8. Most spectral features are a blend of several lines. Underhill _et al._ (1972) have listed possible contributors to twenty absorption features present in early-type stars on OAO-2 spectra. Panek and Savage (1976) have identified the principal contributors to the strongest features present in these spectra in O and B stars. Table 1 reproduces their identifications and comments on the sensitivity of these line features to spectral type and luminosity.

Figure 3 shows the variations in the appearance of the ultraviolet stellar spectra for main sequence stars from O9 through B1. The line at 1215 Å is primarily interstellar Lyman α and shows significant variations from star to star. At O9 the strongest stellar feature is λ1550 C IV which decreases through the sequence as the λ1400 Si IV line grows in strength. The Si III lines at 1300 Å become prominent by B1. The interstellar reddening varies among these early-type stars and is evident in differences in the continuum gradient. Figure 4 shows the luminosity effects at O9.5 and Figure 5 for B0.5. The Si IV 1400 and C IV 1550 resonance lines increase in strength with luminosity. The broad blends at λ1600-1640 and λ1720 are sensitive to luminosity through the B stars and early A stars. Figure 6 shows spectral type variations from B3 V to B7 V. The λ1300 Si III, Si II, blend increases and the ratio of λ1300 to λ1340 is a good spectral type indicator. The luminosity effects at B5 are illustrated in Figure 7. Main sequence A stars at this resolution are characterized by broad blends primarily of Fe II lines that depress the continuum in the 2200-2500 Angstrom region. Figure 9 shows the spectra of later type main sequence stars longward of 2000 Å. The dominant feature at 20 Angstroms resolution is the λ2800 Mg II doublet. The discontinuity at about 2610 Å is present in giant and supergiant stars as well. Inspection of these figures and the Atlas plots show many other systematics with spectral type and luminosity class.

A variety of programs have been carried out or are underway utilizing the data presented here. For 32 early type stars for which angular diameters were available from the Narrabri intensity interferometer Code _et al._ (1976) have determined effective temperature

TABLE 1

STRONGEST FEATURES OBSERVED IN OAO-2 FAR ULTRAVIOLET SPECTRA OF O AND B STARS

λ[Å]	Principal Contributors	Comments
1175	C III (1175-1176, UV4)	Maximum strength near B1, insensitive to luminosity.
1215	H I (1216, Lα) Si III (1207, UV2) N V (1239-1243, UV)	For stars hotter than B2 feature is mostly due to interstellar absorption. For cooler stars the stellar line dominates (see Savage and Panek 1974).
1300	Si III (1295-1303, UV4) Si II (1304-3109, UV3)	Si III dominates in early B stars, Si II dominates in late B stars. The feature increases in strength toward cooler spectral types and increases slightly in strength with increasing luminosity.
1400	Si IV (1394-1403, UV1)	Maximum strength near B1, very sensitive to luminosity. P Cygni profiles are apparent for the very luminous O stars.
1550	C IV (1548-1551, UV1)	Maximum strength occurs for stars earlier than O9, very sensitive to luminosity. P Cygni profiles are apparent for very luminous O stars.
1600-1640	Fe III (1601-1611, UV118) Aℓ III (1600-1612) N II (1627-1630) He II (1640, UV12) and unidentified lines at 1621 and 1632	The strength of this broad blend of lines is relatively insensitive to spectral type but is sensitive to luminosity.
1720	N IV (1719, UV7) C II (1720-1722, UV14.02) Aℓ II (1719-1725, UV6)	The strength of this feature is relatively insensitive to spectral type but is sensitive to luminosity (see Underhill et al. 1972).

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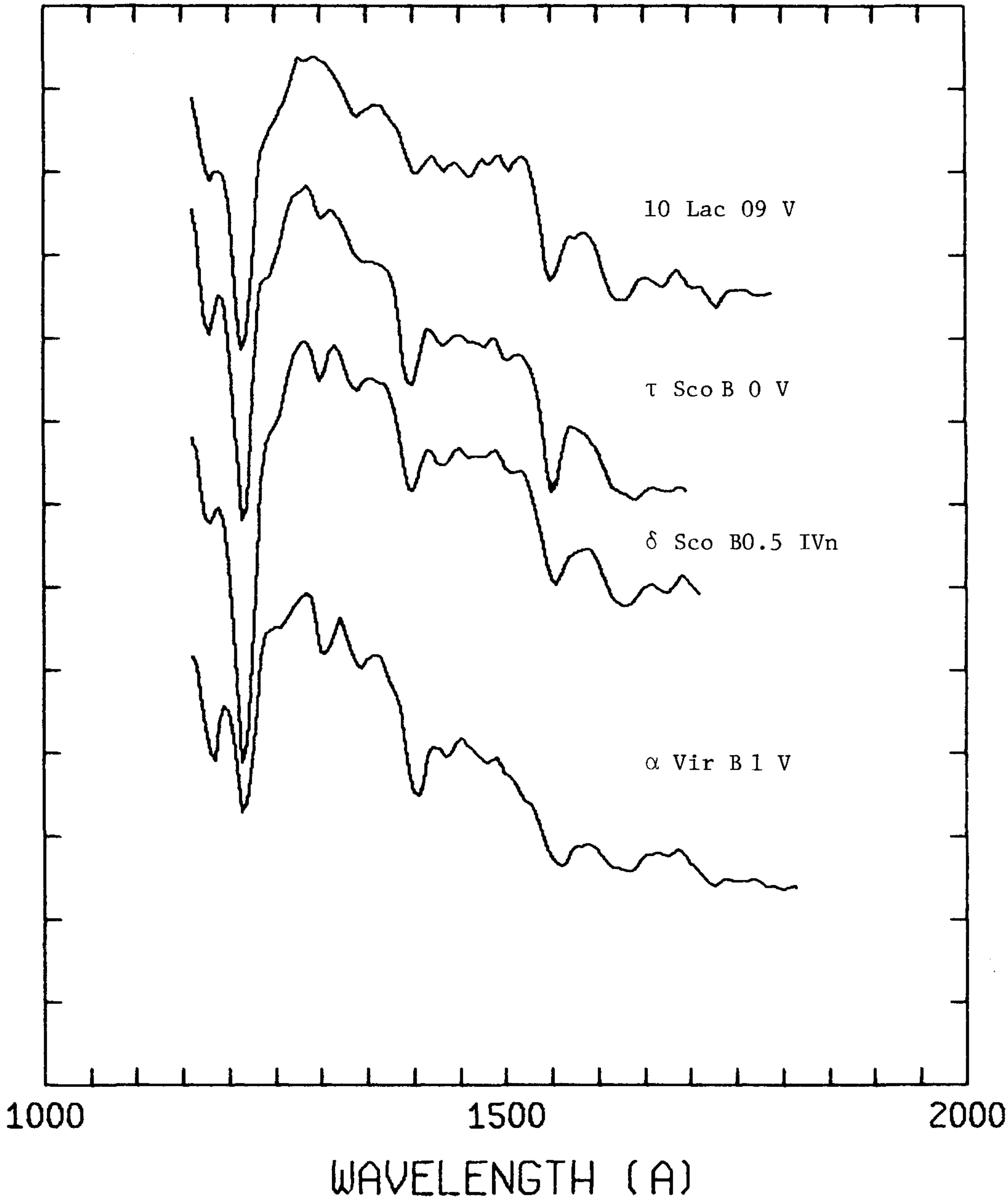

Fig. 3. Spectra of main sequence stars from 09 through B1.

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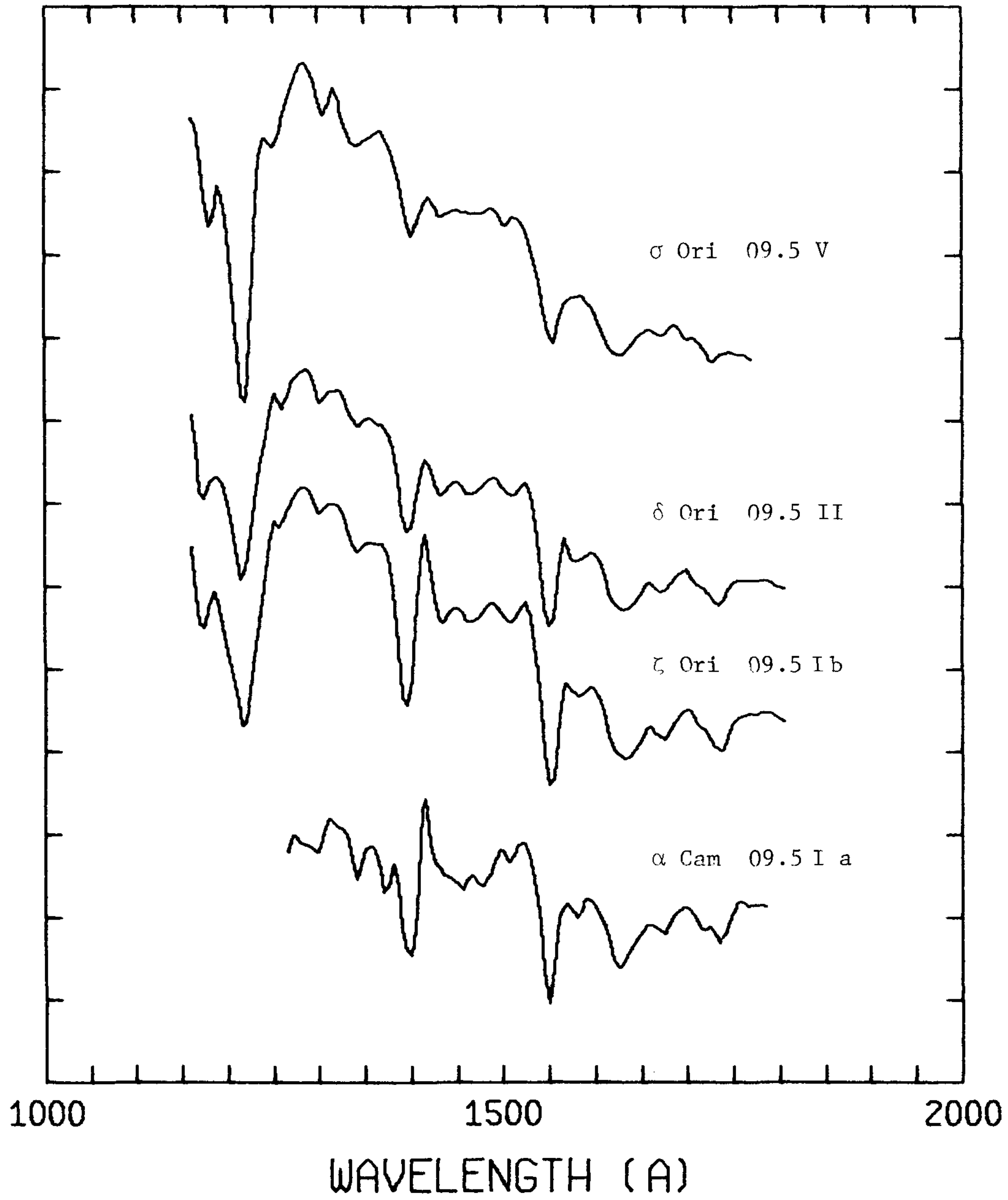

Fig. 4. Luminosity effects at 09.5.

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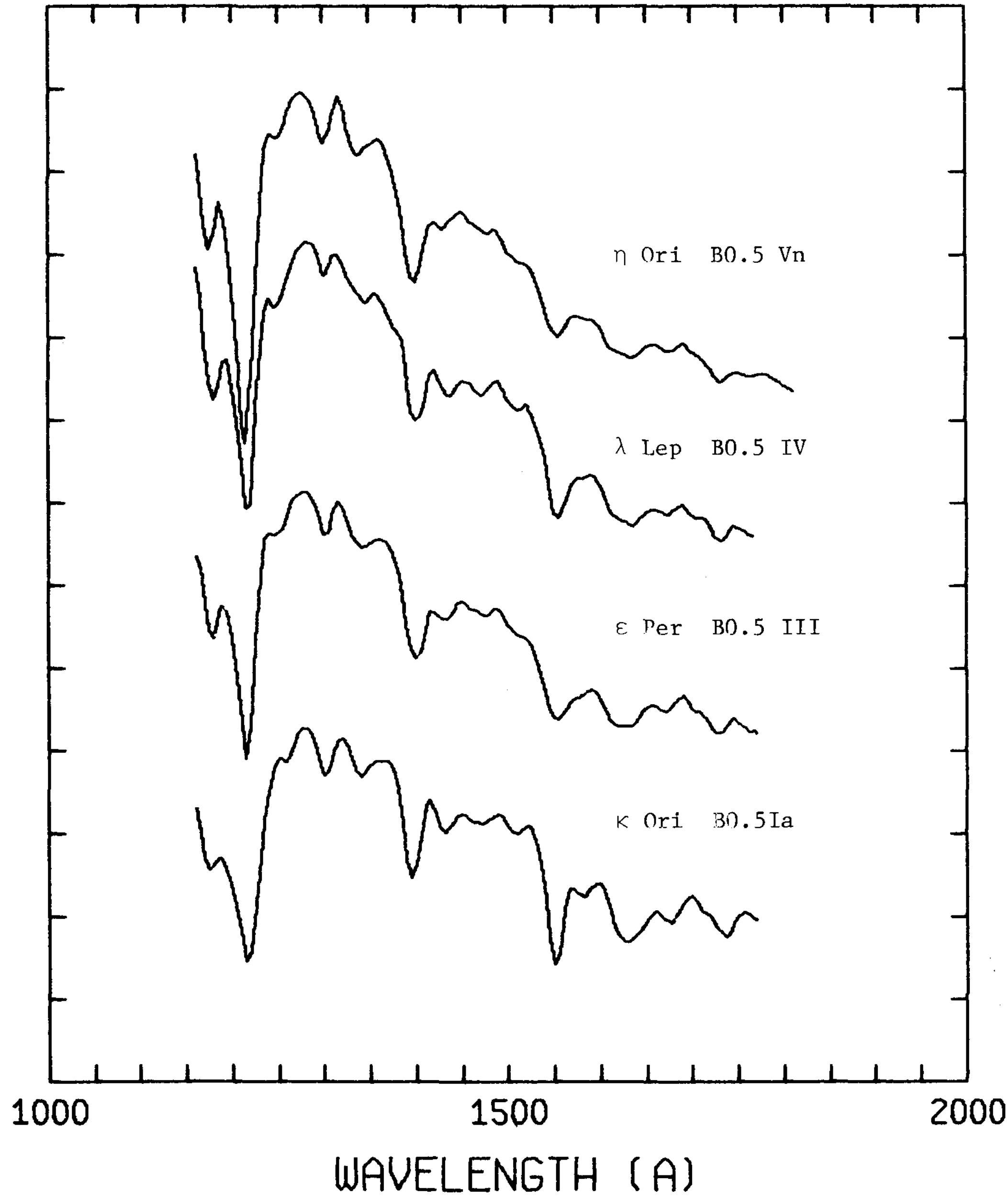

Fig. 5. Luminosity effects at B0.5.

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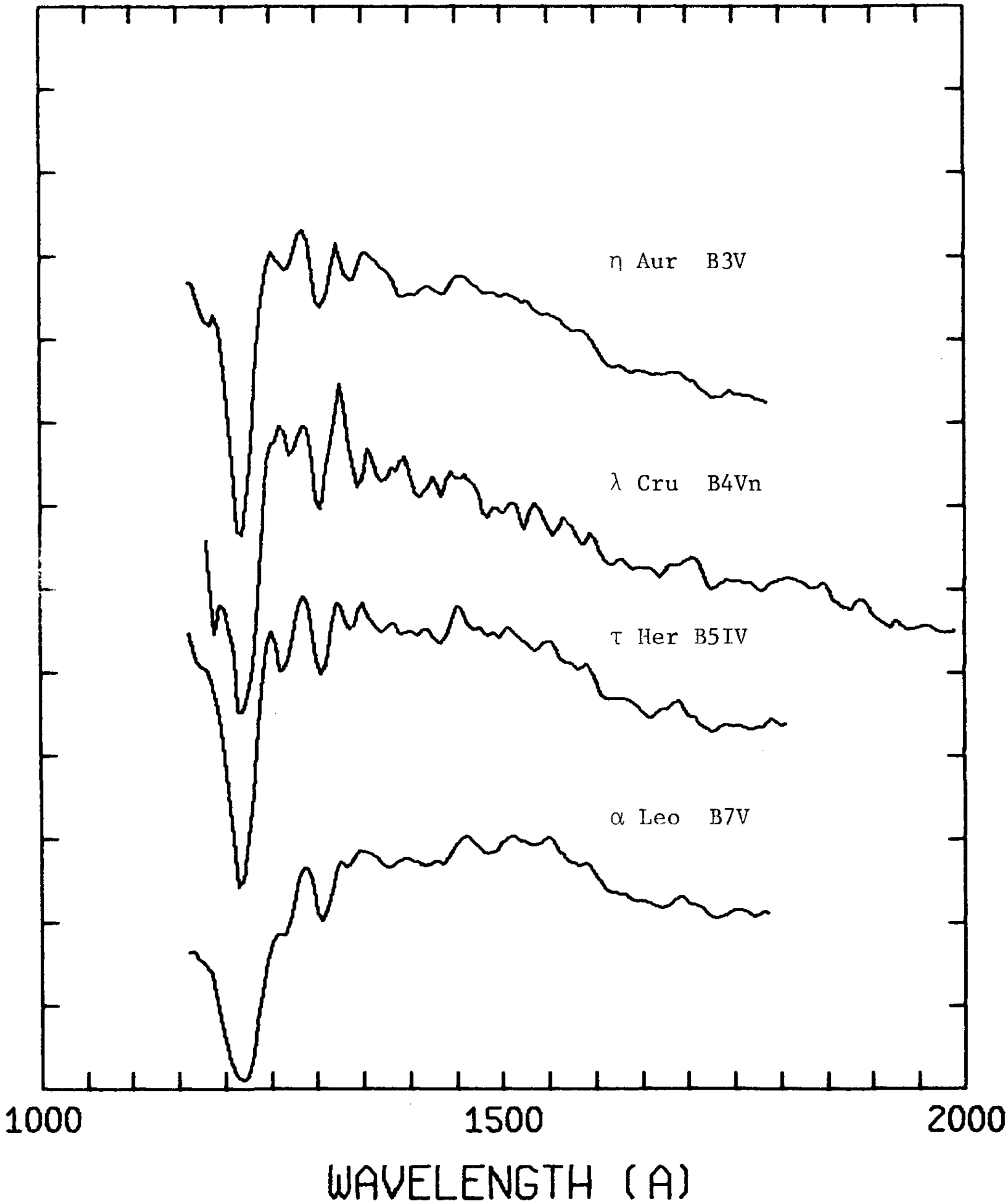

Fig 6. Spectra of main sequence stars B3 through B7.

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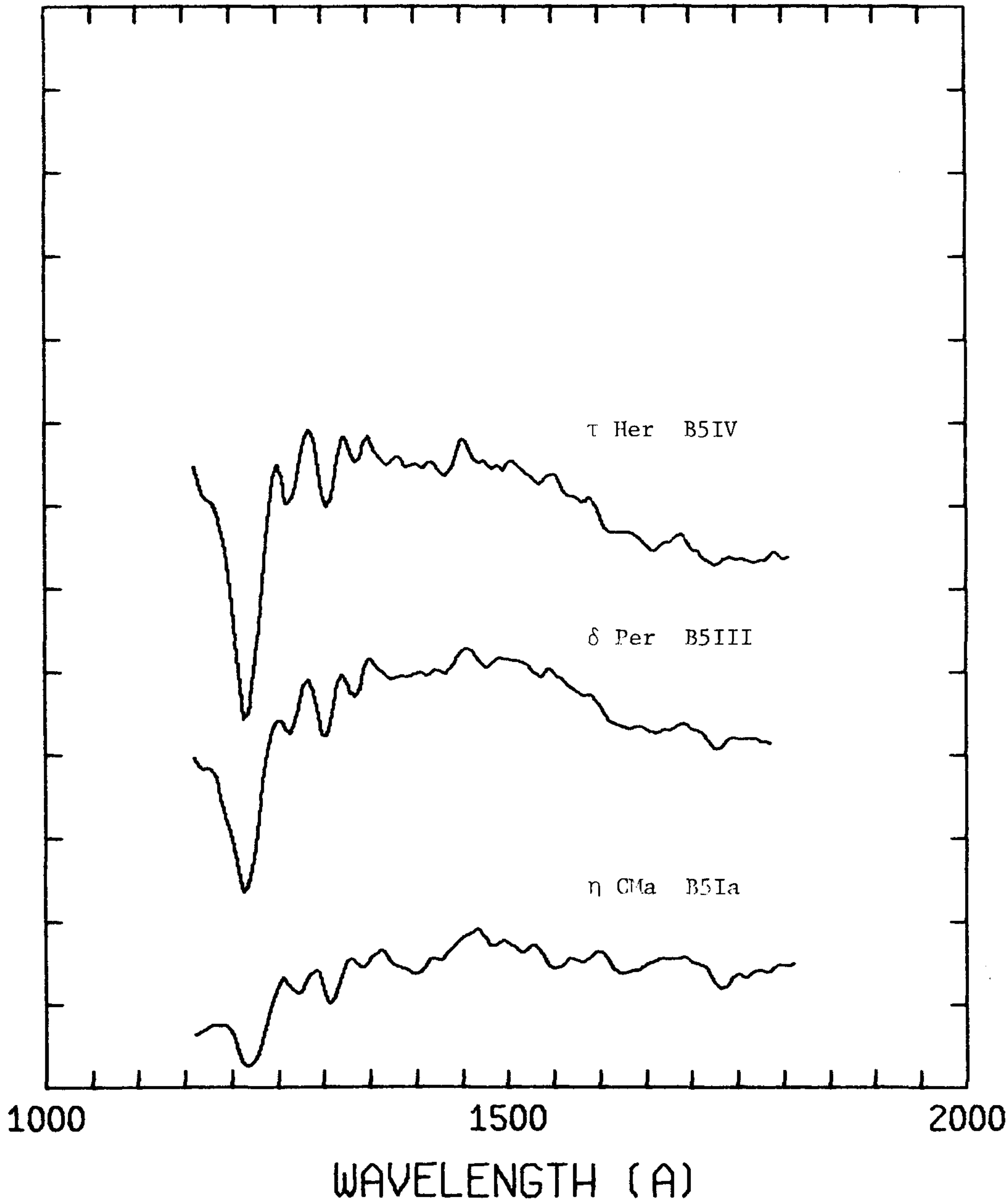

Fig. 7. Luminosity effects at B5.

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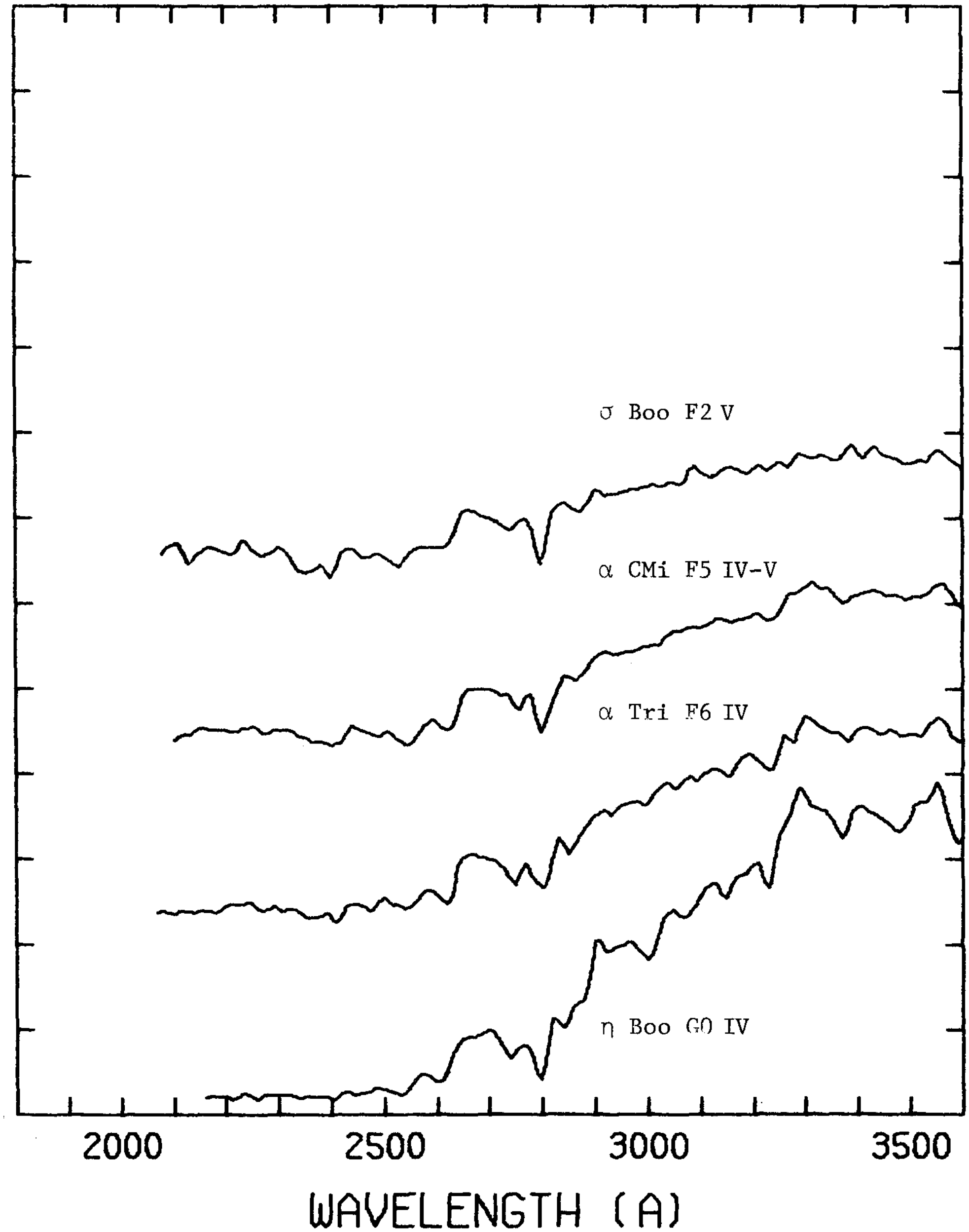

Fig. 8. Spectra of main sequence stars F2 through G0.

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and bolometric corrections. Code and Tobin (1976) have recently determined bolometric corrections for the remainder of the stars appearing in this atlas in order to improve the statistical relation between bolometric correction and spectral type. Among the other investigations currently being carried out are a comparison of these spectral energy distributions with model atmosphere calculations (see Code (1975)), a determination of line blanketing coefficients in the ultraviolet for early-type stars and discussions of the effects of rotation and spectral peculiarities on the observed ultraviolet flux.

Leckrone (1973) has shown that the blue Ap stars are underluminous and cool for their observed UBV colors. Members of these class of stars had already been known to be bluer in B-V than implied by their published MK spectral types. Both the ultraviolet flux and spectral features are more consistent with the MK type than with colors. It is possible that enhanced ultraviolet opacities are responsible for modifying the UBV colors.

Examination of the ultraviolet spectra of Be stars indicates a somewhat earlier spectral type than found in the visual. This may be due to the variation of effective temperature from the pole to the equator in these rapidly rotating B stars.

The effects of interstellar extinction on many of the early type spectra is obvious from inspection, especially the strong extinction bump near 2200 Å. The 2200 Å bump shows a good correlation with B-V color excess and is detectable in stars if the color excess exceeds $0^{m}.02$. For peculiar stars for which there is no basis for an a priori knowledge of the normal color or spectral distribution, a correction for interstellar extinction can be made based upon the appearance of this 2200 Å feature.

An extension of observational material such as presented in the atlas described in this report would provide a powerful tool both for diagnostics of stellar atmospheres and for studies of galactic structure.

References

Bless, R. C., Code, A. D., and Fairchild, E.T.: 1976, Astrophys. J. 203, 410.
Code, A. D.: 1975, in A. G. Davis Philip and D. S. Hayes (eds.), Multicolor Photometry and the Theoretical HR Diagram, Dudley Observatory Report, Albany, No. 9, p. 221.
Code, A. D., Davis, J., Bless, R. C. and Brown, R. H.: 1976, Astrophys. J. 203, 417.
Code, A. D. and Meade, M. R.: 1976, Wisconsin Astrop. No. 30.
Code, A. D. and Tobin, W.: 1976, in preparation.
Hayes, D. S. and Latham, D. W.: 1975, Astrophys. J. 197, 593.
Holm, A. V. and Meade, M. R.: 1976, Wisconsin Astrop. No. 29.

https://doi.org/10.1017/S153929960000352X Published online by Cambridge University Press

Leckrone, D. S.: 1973, Astrophys. J. 185, 577.
Navach, C. and Meade, M. R.: 1976, Wisconsin Astrop. No. 28.
Panek, R. and Savage, B. D.: 1976, Astrophys. J. 206, 167.
Underhill, A. B., Leckrone, D. S., and West, D. K.: 1972, Astrophys. J. 171, 63.

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