SPECTRAL CLASSIFICATION WITH OBJECTIVE-PRISM SPECTRA FROM SKYLAB

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I. INTRODUCTION

During the Skylab I, II and III missions, ultraviolet spectra were obtained in 188 fields with a 15 cm aperture objective-prism spectrograph. The instrument has been described by Henize, Wray, Parsons, Benedict, Bruhweiler, Rybski and O'Callaghan (1975; hereafter referred to as Paper I).

The spectra cover the wavelength region from 1300 to 5000 Å and have a resolution of 2 Å at 1400 Å and 12 Å at 2000 Å. Absorption and/or emission lines of C II λ 1335, Si IV λλ1394, 1403 and C IV λ1549 are visible in more than one hundred stars. The lines of Si IV and C IV are found to be particularly sensitive to stellar temperature and luminosity. Since these lines are visible in spectra of moderate to low resolution it is clear that they should be of special interest in any UV classification system for faint stars. This paper investigates the correlation of the intensities of the C IV and Si IV lines with MK spectral type, and presents a preliminary classification scheme for O4 to B2 stars based on these lines.

II. CORRELATION OF LINE INTENSITIES WITH SPECTRAL TYPE AND LUMINOSITY

The general behavior of the Si IV and C IV lines is illustrated in figure 1. In luminosity classes III and V the rapid changes in both Si IV and C IV intensities between O9 and B3 make the Si IV/C IV ratio an excellent indicator of temperature class. This is particularly true in the interval from B0 to B1 where the ratio changes dramatically from about one-fourth to about 4.

On the other hand, the increase in both C IV and Si IV intensities with luminosity suggests that total intensity of the lines should be a useful luminosity criterion. This is particularly true of Si IV in the O stars where the intensity ranges from zero in the main sequence stars to very strong in the supergiants. C IV is useful at all spectral

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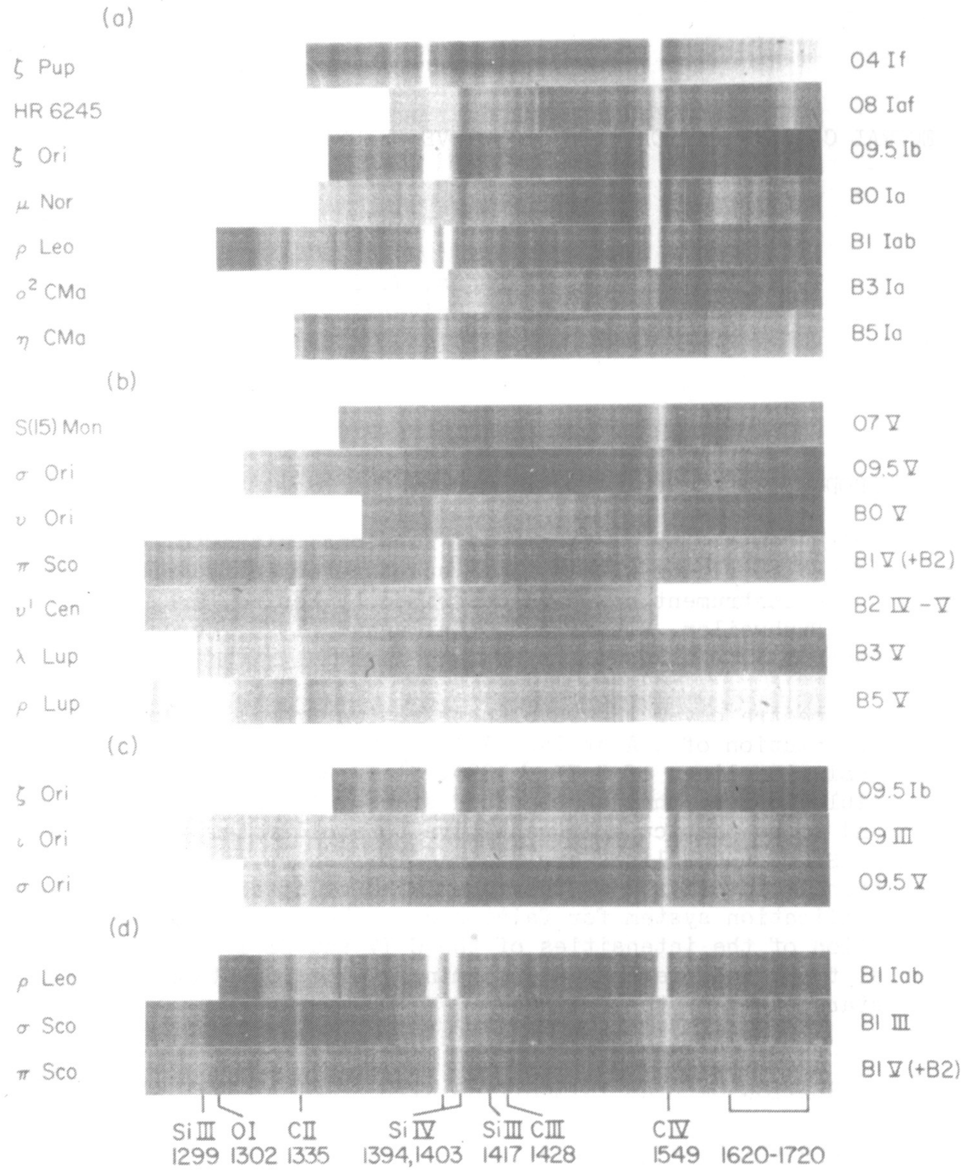

Figure 1. Computer-processed spectra in the region 1300-1800 Å. (a) Temperature effects among supergiants, (b) temperature effects along the main sequence, (c) luminosity effects at O9-O9.5, (d) luminosity effects at B1.

classes, especially at B1. Even though Si IV intensity appears to be a more powerful discriminant of luminosity in the O stars, we will give emphasis to CIV intensity largely because in our prism-dispersed spectra CIV is generally better exposed.

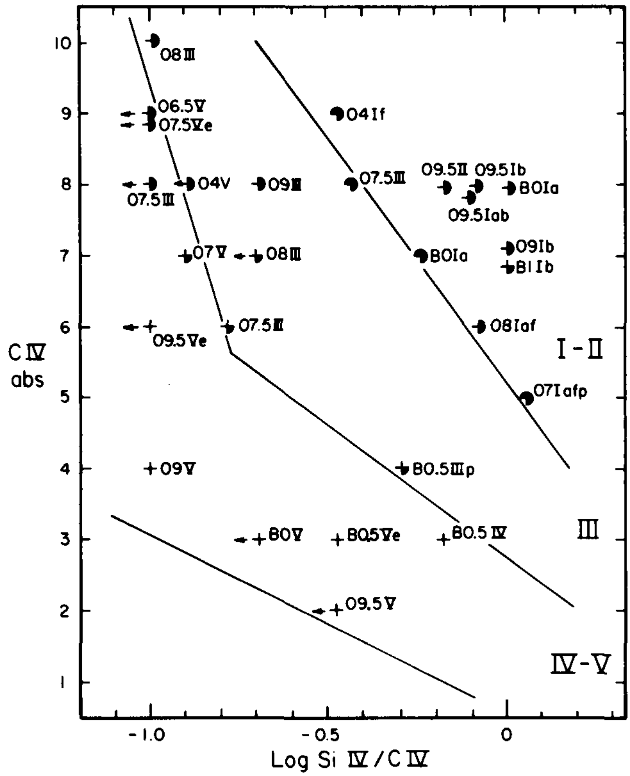

Figure 2. The C IV absorption vs. log Si IV/C IV diagram based on eye estimates of line intensities.

Another useful luminosity criterion is the appearance of a P Cygni emission-absorption profile in the higher luminosity stars. We find that this phenomenon correlates with bolometric luminosity more directly than with MK luminosity class since it varies diagonally across the two-dimensional regime of the MK system (see figure 3).

To further confirm and quantify the above noted trends, a special study has been made of all (a total of 20) O stars plus several B0 and B0.5 stars showing a well-exposed C IV line and reasonably well-exposed Si IV lines. In many cases the exposure in the Si IV region was weak but was sufficient to determine the presence or absence of a strong line. In these stars, eye estimates of the intensities of the C IV and Si IV lines and of the Si IV/C IV ratio were made by Henize from original plates. The results are plotted in figure 2.

In spite of estimated probable errors of ± 1 and ± 0.2 in C IV absorption intensity and log (Si IV/C IV) respectively, it is evident that luminosity classes are well separated in this diagram. A clear separation in temperature class is evident between the B0 stars and the O stars of luminosity classes III and V, but among the O stars the general weakness of Si IV makes the differentiation of temperature class difficult. However, in the class V stars the presence of P Cyg emission in CIV (this is noted by the filled sectors of the crosses in figure 2) clearly separates stars of class O7.5 and earlier from later spectral types. Although the supergiants are confined to a unique region in the upper right corner of the diagram, there is no clear separation of temperature classes.

The spectral types shown are taken from Walborn (1972, 1973), from Morgan and Keenan (1973) and from Hiltner, Garrison and Schild (1969) or Lesh (1968) in that order of priority. It is found that those stars which violate the luminosity regions indicated in figure 2 generally have alternate spectral classes which give better agreement with the UV data. For example, the O9.5 II star in the supergiant region is δ Ori. The class given is from Hiltner et al., but Conti and Leep (1974) give a class of O9.5 I in better agreement with the UV data. Another example is the O7.5 III star, Xi Per, which lies near the supergiant regime. The given class is from Walborn but the Conti class is O7.5 I. The absorption intensities as well as the strength of CIV emission give overwhelming evidence in the UV that this star is a supergiant.

The O7.5 III star in the class IV-V regime (BS 5680) appears to be a peculiar star in which the UV and visible data are truly discrepant. The given class is Walborn's but an alternate class by Hiltner et al., places it as a supergiant. However, there is no doubt on well-exposed UV plates that Si IV is exceedingly weak or absent, thus implying a luminosity class fainter than III.

The emission-line data in figure 2 confirm the conclusion reached in Paper I that the occurrence of the P Cyg profiles is a function of absolute bolometric magnitude (M_{bol}). This is examined in greater detail in figure 3 in which the eye estimates of CIV emission intensity are plotted against absolute bolometric magnitudes derived from the data referenced in Paper I. Three stars, not in figure 2, which show good data at CIV but not at Si IV have been added. This figure clearly illustrates the conclusion drawn in Paper I, that all stars at $M_{bol} = -8.4$ or brighter show emission at CIV while all those fainter do not. The single exception is the peculiar star V819 Cyg, which also shows a somewhat peculiar spectrum in the UV.

For those stars showing emission, the correlation between intensity and M_{bol} is evident but rough. The scatter may be partly cosmic but the majority of it almost certainly arises from errors in the data. The estimated probable error in the emission intensity is at least ± 1 and considerable uncertainty also pertains to the MK spectral class on which the M_{bol} is based. For example, the very low point at intensity 6 is Xi Per which would have $M_{bol} = -10.0$ if the Conti class of O7.5 I were used. The only extreme point for which a favorable revision can not be found is the high point at intensity 2 (λ Cep, O6 Ifp).

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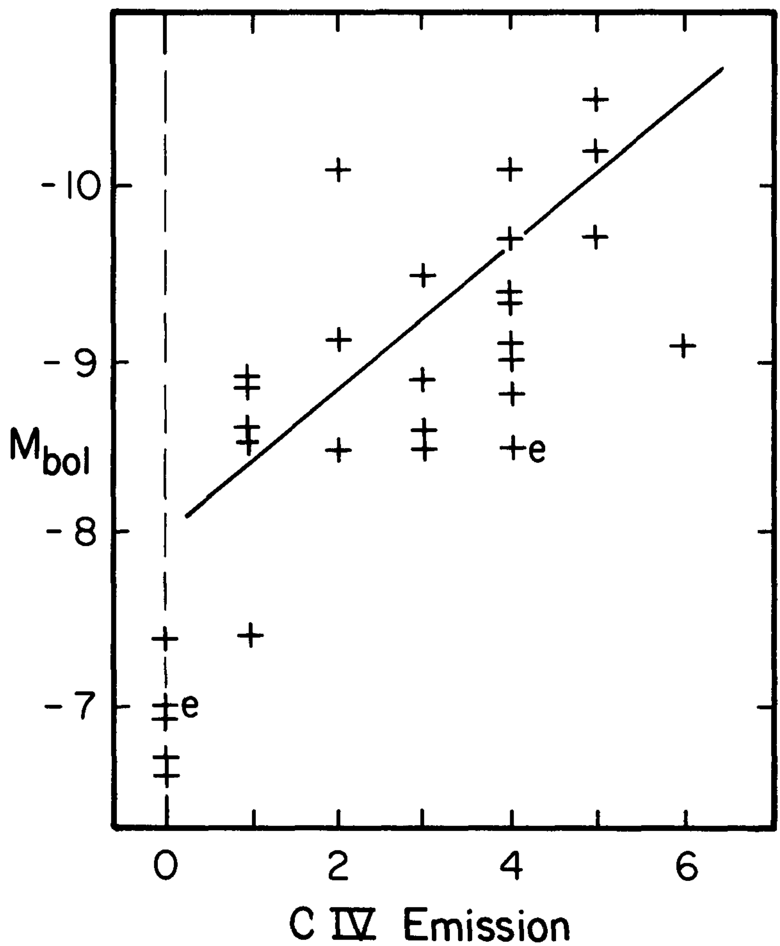

Figure 3. Correlation between CIV emission intensity and bolometric absolute magnitude.

In spite of the evident scatter, these data suggest that the CIV emission intensity in moderate dispersion spectra may be used as a direct indicator of M_{bol}. Such a simple luminosity criterion for the highly luminous stars would be invaluable in guaging the distances of faint O stars within our galaxy (where they serve as spiral arm tracers) or of external galaxies where this measurement might improve estimates of the luminosities of the brightest blue stars which are important distance indicators.

It may be debated whether the CIV emission, or the P Cyg profile in general, should be used as a classification criterion since it probably arises from outward mass flow in an unstable star whereas classical luminosity criteria generally pertain to physical processes within a stable atmosphere. However, the data indicate clearly that the instability itself is directly linked to M_{bol} in at least 90 percent of the

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stars in this sample. Therefore, it is difficult to deny the empirical usefulness of this criterion as an indicator of M_{bol}. More refined measures of emission-line strengths in a greater number of stars would be desirable to confirm this conclusion. Observations of Magellanic Cloud blue supergiants would be especially useful to both confirm and calibrate the relationship.

Further data on the use of the CIV absorption strength vs. log (Si IV/CIV) to indicate spectral type are given in figure 4. These central depth data have been derived by Parsons from tracings of the UV spectra. The eye estimates and central depth data for 14 stars common to the two sets are in good agreement.

Figure 4 confirms the findings of figure 2 and extends them to spectral class B3. Several instances where stars stray from their expected regimes are explainable in terms of available alternate spectral class. In several cases alternate spectral classes are given in parentheses. Three stars remain discrepant. Two of these, τ Sco (B0 V) and ϕ' Ori (B0.5 IV-V), which fall in the region of the supergiants, appear to have unusually strong Si IV. In both cases, comparison with eye estimates suggests that the Si IV central depths may have been exaggerated by uncertainties in the height of the continuum in underexposed regions of the spectrum. The star ζ Cas shows unusually strong CIV for a B2 IV star as was previously noted by Henize, Wray, Parsons and Benedict (1976).

Although the scatter is large, a clear relationship between the Si/C ratio and temperature class for class III-V stars is evident in figure 4. As was previously noted in figure 1, the discrimination at classes earlier than O9 is poor while discrimination between O9 and B2 is much better. Similar data in the B0-B2 spectral range based on eye estimates is shown in figure 1 of Henize et al. (1976). Here we find the Si IV/CIV ratio ranging from 1/4 at B0 to 8 at B2.

Figure 4 also suggests that at spectral classes B1 and B2, the CIV strength is significantly greater in giants than in class V stars. However, the discrimination is small. The strength of CIV is also rapidly increasing with earlier temperature class and the validity of a CIV-based luminosity class depends critically on the accuracy of the temperature class.

III. A PRELIMINARY CLASSIFICATION SYSTEM

It may be concluded that the data presented in figures 2, 3, and 4 generally confirm, for a larger group of stars, the trends which are visually evident in figure 1. It thus appears that the strong lines of Si IV and CIV are useful in the spectral range from O4 to B2 to provide a two-dimensional spectral classification system which correlates reasonably well with the MK system. We propose the following as a preliminary classification system based on the dispersion of the Skylab

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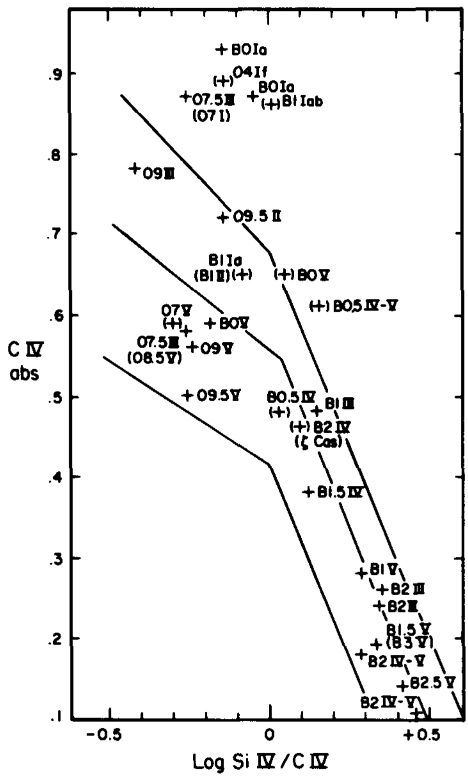

Figure 4. The C IV absorption vs. log Si IV/C IV diagram based on central depth measures.

spectra. Such a system, with appropriate modifications, should also be applicable to other spectra having resolutions between 1 and 6 A in the 1400 to 1600 A range.

A. If P Cyg emission is present in the Si IV or C IV lines, use the Si/C absorption line ratio to discriminate luminosity. If Si/C is very small, the spectral class is O4-O7.5 V. If Si/C is about 1, the spectral class is O4-B1 I. If Si/C is between the above, the spectral class is O4-O9.5 III. In any case, the emission intensity may be used to define a value of M_{bol} for the star.

B. If P Cyg emission is not present, use the Si/C ratio to define temperature class and C IV strength to discriminate luminosity. If the Si/C ratio is one-tenth or less, the spectral class is O8-O9.5 V. If Si/C is about one-fourth the spectral class is B0 III-V. If Si/C is about 1, the spectral class is B0.5 III-V. If Si/C is about 4, the spectral class is B1 III-V. And, if Si/C is about 8, the spectral class is B2 III-V.

This classification system should have significant practical applications inasmuch as it is based on strong lines that can be detected in spectra of moderate to low resolution. Indeed, in spectra of similar quality (most MK classification of early-type stars is currently done with slit spectra) it is to be expected that the UV system may be applied to fainter stars than the MK system since the total strength of the UV lines is significantly greater than the strength of the lines used for classification of visible wavelength spectra. In some areas (e.g., temperature class in the 09-B2 class III-V stars) the UV system has greater discrimination than the MK system, while in other areas (e.g., the temperature class of the O4-B1 supergiants) it has less discrimination. Thus it might be expected that, when UV spectra become more generally available, a hybrid system using the most sensitive data in both the UV and optical regions will evolve.

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