C IV and Si IV in IUE Spectra of Normal B8-A0 Stars: UV Identified Be/Ae Stars?

Wenhsueh A Chiu
Atholton High School, Columbia MD

Frederick C. Bruhweiler
Department of Physics, Catholic University of America

C.A. Grady
Astronomy Programs, Computer Sciences Corporation
and
IUE Observatory, Goddard Space Flight Center

ABSTRACT

We present the results of a survey of archival IUE high dispersion spectra of 42 B6-A2 stars within 200 pc. Five of the program stars showed significant C IV and Si IV absorption. All of the stars with detected C IV have $v \sin i \geq 190$ km s^{-1}. Sharp absorption cores were present in Si IIλ 1533 in 3 of the objects, indicating that these are previously unrecognized shell stars. Three of the stars have variable or asymmetric C IV profiles which are consistent with the C IV and Si IV being produced in stellar winds. One star had C IV in the form of a shortward-shifted discrete absorption component, similar to those observed in Be stars. The data are compared with similar data for Be and B shell stars.

Keywords: Stellar Winds, Shell Stars, Interstellar Material

1. INTRODUCTION

Recent studies of nearby, apparently normal B8-A0 stars using IUE data have detected C IV and Si IV. The presence of these ions in the spectra of such cool stars has been interpreted as evidence for the presence of C IV and Si IV in the local interstellar medium (Ref. 1, 2), since these stars are clearly too cool to photoionize the surrounding interstellar gas and produce these ions. Although measurable amounts of C IV and Si IV, arising in evaporative interfaces or cloud skins should be observable over large path lengths, the presence of these ions over such short lines-of-sight could pose a significant problem for our current understanding of the physical processes occurring in the interstellar medium (ISM). Alternatively, if C IV and Si IV were to have a stellar origin, it would remove the need to provide an interstellar interpretation. Instead, we would be confronted with explaining how these ions can be present in spectra of stars with only $T_{eff} \cong$10,000 - 12,000 K.

Yet, studies of Be and shell stars with spectral types from B0.5-B9.5 show that C IV and Si IV are common (Ref. 3, 4) and seem to be closely linked to stellar mass loss. The C IV features in the B6-B9 5e stars show shortward-shifted and often asymmetric absorption. Significant line profile variations are known in four of these stars. A further characteristic of the Be stellar winds is that C IV features are detected only in objects with $v \sin i \geq 150$ km s^{-1}. Slettebak and Carpenter (Ref. 5) in a preliminary study of stellar winds in both normal and emission line stars found evidence for C IV and Si IV in the normal stars at later spectral types than would be expected based on simple radiation-pressure driven stellar wind models. Their survey included only single observations of a few stars, precluding evaluation of the source of the highly ionized material.

2. PROGRAM STAR SELECTION CRITERIA

We have restricted our survey to B6 to A2 stars within approximately 200 pc. More distant stars were excluded, both because the lines of sight would have a larger probability of intersecting one or more evaporative interfaces or cloud skins, and because the stellar spectra would require longer exposure times, and hence have lower signal to noise. Our sample includes only stars in luminosity classes V-III, excluding more evolved objects which may retain highly ionized stellar winds as they evolve off the main sequence. We have further restricted the sample to stars with V≤6, since these stars have more reliable stellar data, and higher signal-to-noise ratio IUE spectra. A total of 42 stars with 92 IUE SWP high dispersion spectra met our requirements. Figure 1 shows the distribution of program stars in galactic longitude, latitude, and distance from the Sun.

3. LINE IDENTIFICATION AND ANALYSIS

Two factors limit our ability to detect weak absorption features in the IUE spectra. The first is the finite S/N ratio of the data. Typically, for well-exposed spectral regions a detection limit near 15 mÅ is implied for sharp interstellar-like features in optimally exposed O and early-type B star spectra. Our program stars, covering B7-A2, are cooler and hence have less flux in the vicinity of 1550 Å or 1400 Å, resulting in many cases in detection limits of approximately 30 mÅ. This limit corresponds to $\log(N_{CIV})$=12.86 for the 1548 member of the resonance doublet, and to $\log(N_{SiIV})$=12.52 for the 1393.7 Å line,

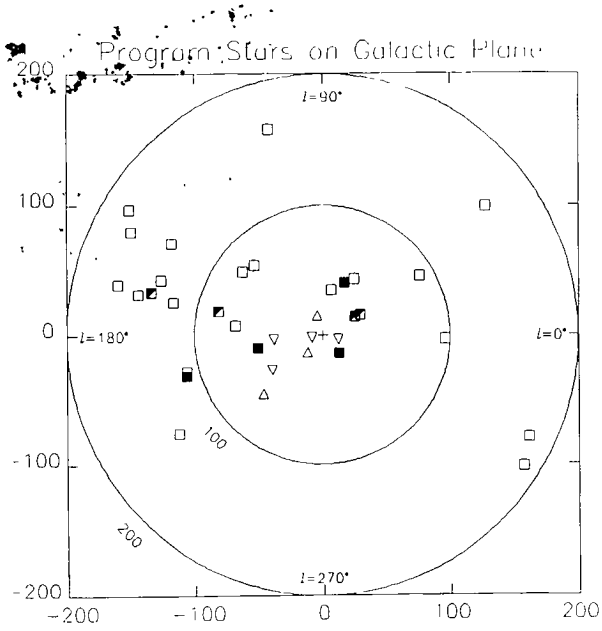

Figure 1. Locations of the stars included in the survey projected onto the galactic plane. Each circle represents a distance of 100 pc. Fully filled symbols indicate the stars with definite C IV and Si IV absorption. Partially filled symbols indicate the five additional stars where some C IV and Si IV absorption is possible, but blending of with other spectral lines is sufficiently strong that a positive identification is not possible. The remaining program stars are plotted with open symbols, with upward pointing triangles indicating stars with $b \geq 45°$ and downward pointing triangles indicating stars with $b \leq -45°$. HD 23383 is not shown in this figure since the distance to the star is uncertain.

under the assumption that the absorption features are on the linear part of the curve of growth. The second, and typically the most important, factor limiting the detectability of weak absorption features is contamination of the region of interest by other lines. The UV spectra of B8-A2 stars are rich in lines due to singly ionized elements. Fe II lines are particularly prominent, especially in the vicinity of the C IV and Si IV resonance lines, and may be sufficiently strong and blended that only large and uncertain upper limits can be placed on the amount of absorption from these highly ionized species. Our criteria for identification of C IV and Si IV absorption in the spectra of these stars rests on the following criteria.

1. Sharp or strong absorption features must be visible at or near the rest wavelengths of the C IV and Si IV resonance doublet transitions. Practically, this corresponds to a requirement that the absorption feature have a depth which is more than 5 percent deeper than the envelope of noise and other weak spectral features in the vicinity.

2. The absorption features in both members of the resonance doublet, and preferably in both the C IV and Si IV doublets must coincide in velocity. In this process we have utilized the reliable relative internal wavelength scale of the SWP camera. Previous studies over the wavelength range 1200-1500 Å have shown that radial velocity measurements of sharp photospheric or interstellar features internal to an IUE image are reproducible to ± 2 km s^{-1}, while measurements of similar features from image to image suggest that one can achieve an accuracy of $\pm 4 - 5$ km s^{-1} with optimally exposed data (Ref. 3).

3. Absorption from the lower f-value member of each doublet should not be stronger than that produced by the higher f-value line. In the case of C IV, Fe II absorption can contaminate the λ 1550 line.

4. RESULTS

Five of the program stars showed definite C IV and Si IV absorption. An additional five stars may have some C IV and Si IV, but the absorption features are highly blended with adjacent absorption lines, predominantly those of Fe II, precluding reliable measurements. The remainder of this section will be devoted to the stars with firm detections.

HR 1147 (HD 23383, B9 Vnn, Ref. 6, $v \sin i$ =440, Ref. 7).— Absorption in C IV and Si IV was first reported in this star's spectrum by Molaro *et al.* (Ref. 1). In addition to C IV and Si IV absorption features which are visible in both members of the resonance doublets, a strong absorption core is present in the Si IIλ 1533.4 line at the same radial velocity as the highly ionized features.

π^2 Ori (HD 30739, A1 Vn, Ref. 6, $v \sin i$ =235, Ref. 7).— Strong (300 mÅ) C IV and Si IV absorption features are present in the IUE spectrum of this spectroscopic binary. The IUE data do not indicate the presenced of a sharp absorption core in Si IIλ 1533.4.

HR 2191 (HD 42477, A0 Vnn, Ref. 6 $v \sin i$ =220, Ref. 7).— The IUE spectrum of this star shows strong C IV (W_λ=270 mÅ) and Si IV features with minimal contamination by adjacent spectral lines. The radial velocities of the highly ionized features coincide with the radial velocities of the absorption cores of the two Si II lines. Both the higher oscillator strength C IV and Si IV profiles show blue asymmetric absorption to -135 and -111 km s^{-1} respectively, suggesting that a stellar wind is present.

Z Cen (HD 119921, A0 V, Ref. 6, $v \sin i$ =137 km s^{-1}, Ref. 6)— The presence of strong C IV and Si IV absorption in the IUE spectra of this star was first reported by Freire Ferrero and Ferlet (Ref. 2). They suggested that the C IV and Si IV were produced in the interstellar medium due to the comparatively late spectral type for this object. Despite the high $v \sin i$, a sharp absorption core is present in Si IIλ 1533. Inspection of the 4 SWP spectra of this star reveals some line profile variability in both C IV and Si IV. In one spectrum, SWP 22668, the higher oscillator strength members of the resonance doublets show two discrete absorption components at -155 and -60 km s^{-1}. This spectrum also has the highest C IV edge velocity detected, -240 km s^{-1}. The other images only showed one absorption component, which is displaced shortward of the Si II absorption core by 50 km s^{-1}. The Si II absorption core is also variable with equivalent widths ranging from 49 to 160 mÅ.

The presence of variablity in both the highly ionized and Si II features rules out an interstellar origin for the C IV and Si IV in this star. The presence of blue-asymetric

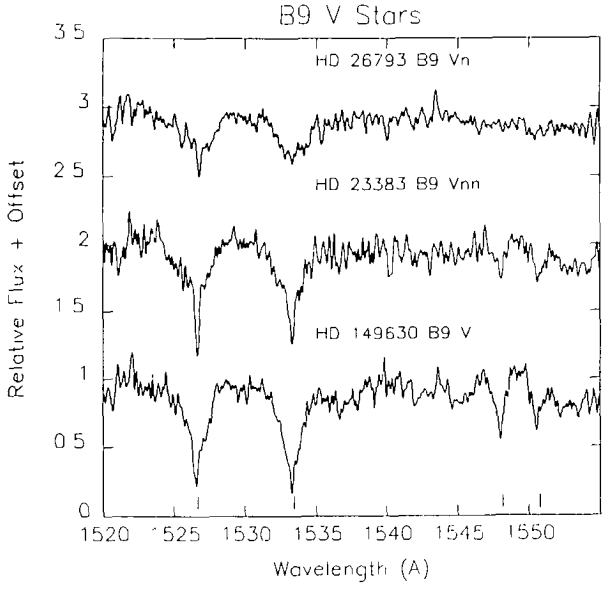

Figure 2 C IV$\lambda\lambda$1548,1550 and Si II (2) $\lambda\lambda$ 1526, 1533 in B9 stars. Each spectrum has been continuum normalized and offset for clarity of presentation The top spectrum is a normal B star, HD 26793, showing no C IV or circumstellar Si II absorption. The circumstellar shell absorption is particularly well developed in the spectrum of HD 23383 σ Her (HD 149630) shows both strong Si II absorption and C IV

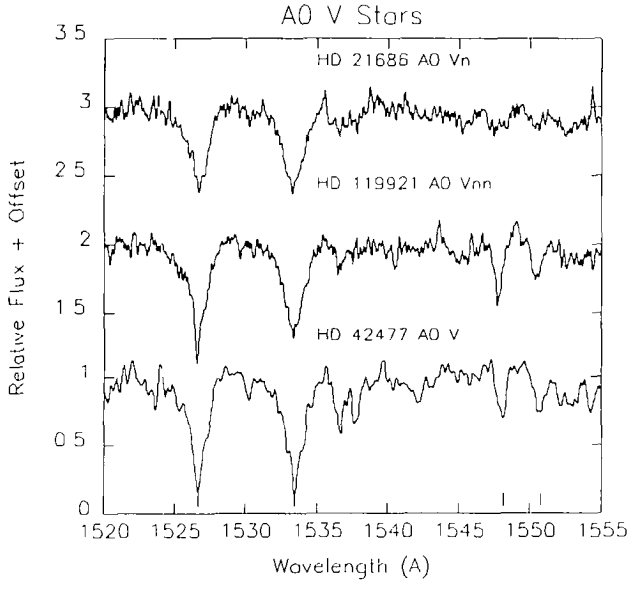

Figure 3 C IV and Si II at A0. The spectra have been normalized and offset as in Figure 2 The top spectrum of HD 21686 shows an A0 star without C IV absorption HD 119921 shows especially strong C IV absorption

absorption profiles and multiple discrete absorption components suggests, together with the detection of the Si II absorption core that this star is a previously unrecognized Ae/shell star.

σ Her (HD 149630, B9 V, Ref. 6 $v \sin i$ =280 Ref. 7).— The UV spectrum of this star is characterized by strong C IV (550 mÅ) and Si IV absorption. The C IV λ1548 profile is blue asymetric, with an edge velocity of -250 km s^{-1}, consistent with the existence of a strong stellar wind. Significant profile variability is observed from SWP 28836 to SWP 29408, when the C IV equivalent width increased by 200 mÅ . A sharp absorption core contributing 100 mÅ is present in Si IIλ1533 This object has a large IRAS 12 micron excess.

5 INTERPRETATION

Four out of the five program stars showing C IV and Si IV in their UV spectra have significant line profile variations in those lines, blue-asymetric absorption profiles, or significant absorption in Si IIλ1533.4 An interstellar origin for the C IV and Si IV can be immediately ruled out for the two program stars Z Cen. and σ Her which show line profile variability similar to that observed in Be stars One star, HD 42477, has been observed too infrequently with the IUE to determine whether it also has variable C IV or Si IV. Interstellar absorption would be expected, especially over the short path lengths to these stars to comprise at most, at IUE's resolution, one essentially Gaussian absorption feature. Absorption profiles which are asymetric on the short-wavelength side of the profile, or variable absorption profiles are characteristic of stellar wind profiles. Thus, the available data for three of the program stars, suggest the production of C IV and Si IV in winds, rather than in the local interstellar medium

Two of the stars with variable wind profiles also show Si II λ 1533.4 absorption, as does one other program star, HD 23383. The detection of a sharp absorption core in Si II in these high $v \sin i$ stars is particularly significant. The λ 1533.4 line arises from a J level 287 cm^{-1} above the 0 Volt level which is responsible for the 1526.7 line, which typically has a strong interstellar contribution to the absorption. As a result of being an excited state line, the population of the 1533.4 line is highly density sensitive and and is produced in the interstellar medium only in high density clouds For the short path lengths to our program stars, and consequent low probability that the line of sight intersects a high-density cloud, any sharp absorption cores to the 1533.4 line are likely to be produced in the immediate circumstellar region rather than in intervening high density clouds.

The only program star without detected profile variability, asymmetric profiles, or evidence for a dense circumstellar shell is HD 30739 This star is noted as a spectroscopic binary, which could potentially account for the presence of highly ionized species

The strength of the C IV absorption, line profile variations, distribution of C IV and Si IV absorption in radial velocity, and the presence of discrete components are similar to the C IV and Si IV profiles observed in the late-type Be stars (Ref. 4). Detection of a dense circumstellar shell via Si IIλ 1533.4 absorption is also common among these stars, and is also seen in high $v \sin i$ A shell stars such as β Pic The available data are consistent with at least 80 percent of the program stars with C IV absorption being hitherto

unrecognized Be or B and A shell stars.

The detetion of previously unrecognized Be or A shell stars is not unexpected, since the optical surveys, upon which identification is usually based, identify only those stars currently showing either Hα emission, or particularly strong circumstellar shell absorption. Long-term monitoring of selected bright Be stars has shown that the optical spectrum can alternate, on timescales of months to years, between an essentially normal B spectrum, to one showing emission lines, or to a spectrum dominated by shell absorption features. In at least one case, UV signatures of mass loss, in the form of C IV absorption, have been observed to be present at a time when no emission was visible in Hα.

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