A fine analysis of stellar and interstellar lines towards four halo B stars

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Summary. High resolution observations of Ca II and Na I interstellar line profiles towards four halo B stars are analysed in terms of multicloud models. Stellar CNO lines present in the spectra have been used in conjunction with an LTE model atmosphere programme to derive values of effective temperature and microturbulence. Using these atmospheric parameters, stellar contributions to the interstellar Ca II and Na I profiles have been calculated and removed. The subsequent renormalized interstellar line profiles were analysed to derive information on the radial velocities, internal velocity dispersions and column densities within individual interstellar clouds. The Na I/Ca II ratio decreases from a value of ~2 to ~0.02 with increasing radial velocity; this range is smaller than that found by previous workers using the doublet ratio method. Additionally the stellar CNO lines in the halo stars imply a composition similar to that found for unevolved B stars in the galactic plane.

Introduction

The nature of interstellar material in the solar neighbourhhood has been extensively investigated with high resolution in the visible lines of Na I and Ca II (Adams 1949; Spitzer 1954; Münch 1957; Hobbs 1969; Marshall & Hobbs 1972). In contrast, there are few equivalent observations of possible material at high galactic latitudes. Münch & Zirin (1961) undertook a survey of the interstellar Ca K absorption lines in stars at large distances (z) from the galactic plane, with dispersions between 2.7 and 10 Åmm⁻¹, and investigated the number of components and their radial velocities in the line of sight to each star. By considering groups of stars at varying z-distances from the plane, they showed that the mean number of components per star increased with z, from which they inferred that some interstellar clouds...
probably exist at $z \sim 1 \text{ kpc}$. Münch & Zirin (1961) pointed out that such clouds would need to be in pressure equilibrium with some intercloud medium in order to maintain their identities, possibly with a hot, low density corona as postulated by Spitzer (1956). They also noted that high velocity clouds occur at large distances from the galactic plane with greater frequency than they do in the plane, which, they suggested, could be due to the fact that either (i) clouds moving at high velocities above the galactic plane would suffer fewer collisions than those moving in the plane, and hence would preserve their identities longer or (ii) the mechanism accelerating the clouds may be intrinsically anisotropic, as has been discussed by Münch & Zirin (1961), Oort (1967) and Siluk & Silk (1974).

Habing (1969) and Rickard (1972) have made a comparison of Ca$^+$ and 21-cm HI interstellar line profiles for several low and high galactic latitude stars. They found good correlation between the profiles for stars close to the galactic plane, but those at large $z$-distances contained many high velocity Ca$^+$ components (as noted by Münch & Zirin 1961) without HI counterparts, implying that the clouds far from the plane are either HII regions or small, dense HI regions.

At lower dispersions Cohen (1974) has measured the equivalent widths of the Ca II $H$ and $K$ and the Na I $D_1$ and $D_2$ interstellar lines in several stars at large distances from the galactic plane, and calculated Ca II and Na I column densities using the doublet ratio method, which has its attendant limitations (Nachman & Hobbs 1973). The interstellar components in high $z$ stars showed a definite peculiarity (strong Ca II relative to Na I) compared with those at low $z$. In a survey of the Feige stars (Feige 1958) at larger average $z$-distances than those previously considered (assuming that the stars are not subluminous and hence actually close to the plane), Cohen & Meloy (1975) noted that this Ca II/Na I peculiarity was strengthened, implying the existence of material at large distances from the plane, between the mean $z$ of the bright stars observed by Cohen (1974) and that of the Feige stars (i.e. up to about $z = 1 \text{ kpc}$).

The above authors have, however, not quantitively accounted for the possible stellar contributions to the observed profiles (particularly in the wings), especially for the Ca II $H$ and $K$ lines, and sometimes were forced to assume doublet ratio values for equivalent widths (Cohen 1974) in order to calculate Ca II column densities, because of the low dispersion employed and the inability to fully resolve the Ca$^+$ interstellar line located in the wing of the strong He stellar line.

More recently, material has been observed at large distances from the galactic plane in the UV region of the spectrum. Savage & de Boer (1979) have obtained evidence for the existence of a hot, low density corona surrounding the galaxy from an analysis of C IV and Si IV lines in the UV spectra of two stars in the Large Magellanic Cloud (LMC). Their results are in accord with the theoretical predictions of Spitzer (1956) and Chevalier & Oegerle (1979). De Boer, Koorneef & Savage (1980) have pointed out that an analysis of the same spectra indicate the possible presence of a halo of ionized gas around the LMC, in addition to the galactic corona discovered by Savage & De Boer (1979). Such a halo had also been postulated by Blades & Meaburn (1980) to explain the presence of an unusually broad interstellar Ca II $K$ absorption feature observed in the spectrum of one of the LMC stars (HD 38268) observed by Savage & de Boer (1979).

It has been suggested (Bahcall & Spitzer 1969), and often contended, that many of the absorption lines in quasi-stellar objects are caused by material in the haloes of intervening galaxies. This has been supported by Boksenberg & Sargent (1978), who discovered Ca II $H$ and $K$ absorption lines in the spectrum of the quasar 3C 232 at the same redshift as that of the galaxy NGC 3067 (which lies 16.5 kpc away from the line of sight of 3C 232 at its closest point), and more recently by Blades, Hunstead & Murdoch (1981) after an analysis.
of the spectrum of the quasar 0446−208. Ulrich et al. (1980) have found eight absorption lines at zero redshift in the ultraviolet spectrum of 3C273, due to the intervening material in our Galaxy, and their analysis of one of these lines (CIV 1550Å) points to the existence of a hot, ionized region of gas lying at z-distances from the galactic plane in excess of 650 pc, and extending well beyond 2 kpc, in accord with the coronal model of Weisheit & Collins (1976).

Interstellar absorption has also been observed in the spectra of other extragalactic objects, for example by Richstone & Morton (1975) who pointed out that most of the CaII toward the Seyfert galaxy NGC1068 probably lies in the halo of our Galaxy. Penston & Blades (1980) have found CaII and NaI interstellar lines in the spectra of a supernova at the same redshift as that of its parent galaxy NGC4321. As the line of sight to the supernova is perpendicular to the plane of NGC4321, the absorbing material may well lie in the halo of this galaxy, although the low CaII/NaI ratio (~1.7) suggests that this is not the case.

Although (as indicated by the above discussion) there is compelling evidence for CaII and NaI absorption in the galactic halo, it is important that its extent and density be accurately established. Accordingly we have embarked on an extensive programme of high dispersion spectroscopy of the interstellar medium in the line of sight to halo stars. In this paper we describe our procedures and first results for four early-type southern stars at large distances below the galactic plane. In particular the results have been corrected where necessary for the influence of stellar components, whose strengths have been estimated from LTE model atmospheres. Moreover the corrected interstellar line profiles have been analysed in terms of multi-component curve of growth models to derive CaII and NaI column densities within individual clouds along the line of sight to each star. Both considerations can also apply to lines observed towards Seyfert galaxies and other extended sources with possible early-type stellar components. The determination of the column densities in individual clouds allows us to investigate with greater confidence the variation in the CaII/NaI ratio with cloud velocity, previously discussed by Routly & Spitzer (1952), Siluk & Silk (1974) and Cohen & Meloy (1975). The method employed in deriving stellar parameters also requires the possible abundances of C, N and O in the atmospheres, and is important for investigating the nature and origin of high galactic latitude early-type stars at large distances from the galactic plane.

Observations

Interstellar CaII and NaI observations were obtained for the four stars using the RGO spectrograph, 82-cm camera and the 1200 R grating of the 3.9-m Anglo-Australian telescope during an observing session in 1979 September. The image photon counting system (Boksenberg & Burgess 1973) was the detector. This instrumental combination gave a nominal dispersion of 5 Å mm⁻¹ and covered the wavelengths from 3800 to 4000 Å for CaII (second order blue), and 10 Å mm⁻¹ from 5670 to 6040 Å for NaI (first order red). The resulting spectroscopic resolutions were measured to be 16.0 km s⁻¹ for calcium and 22.4 km s⁻¹ for sodium (FWHM) from argon comparison lines. All the spectra were recorded in the form of photon counts versus channel number. A minimum count per channel of 1000 was aimed for giving a single-to-noise ratio of ~ 30. However, for the brighter stars (viz. HD 214080 and HD 220787) higher counts of up to 3000 per channel were achieved corresponding in this case to a signal-to-noise ratio of ~ 55. The observing procedure and subsequent reduction are essentially as described by Blades (1980).

In Table 1 we list the programme stars with their galactic coordinates and photometrical properties, as well as their distances and scale heights (z) below the galactic plane. All data has been taken from Kilkenny & Hill (1975) except the measurement of the reddening free 26
Table 1. Basic parameters of programme stars.

| HD No. | $I$ (°) | $b$ (°) | $E_{B-V}$ | $M_v$ | MK type | $r$ (kpc) | $z$ (kpc) | $H_\beta$ | $|C_1|$ |
|--------|---------|----------|-----------|-------|---------|-----------|-----------|---------|-------|
| 173502 | 5.34    | -12.27   | 0.11      | -5.85 | B1.5Ib  | 11.11     | -2.36     | 2.564   | -     |
| 179407 | 24.03   | -10.40   | 0.28      | -6.30 | B0.5Ib  | 9.18      | -1.66     | 2.547   | -     |
| 214080 | 44.80   | -56.91   | 0.13      | -5.40 | B1If    | 2.40      | -2.00     | 2.583   | -     |
| 220787 | 67.78   | -64.39   | 0.04      | -3.20 | B3III   | 2.00      | -1.80     | 2.633   | 0.276 |

colour index $|C_1| = C_1 - 0.2(b-y)$ from Hauck & Meimilliod (1979), and the magnitudes and distances of HD 214080 and HD 220787 from Kilkenny (1980).

Method of analysis

REMOVAL OF STELLAR COMPONENTS

Stellar contributions to the CaK and CaH line profiles were calculated using an LTE model atmosphere programme (for details see Dufton 1972; Kane 1980). Ideally for this it is necessary to know the effective temperatures, $T_{\text{eff}}$, surface gravities, $\log g$, and surface microturbulences, $V_T$, for the stars concerned.

The effective temperature and surface gravity of a star may be found (using the model atmosphere programme) from its $|C_1|$ and $H_\beta$ indices. Unfortunately we only had a $|C_1|$ index for one star (HD 220787) and hence the following method was adopted to derive the temperatures of the other stars.

The strengths of the NiI 3995 Å, OII 3945, 3954, 3983 Å and CII 3918, 3920 Å stellar lines were measured from the spectra. An initial estimate was made of the effective temperature of the star from its spectral type. From the model atmosphere programme the equivalent widths of the stellar lines were calculated for the adopted effective temperature and known $\log g$ for a range of microturbulence velocities. The solar abundance values of nitrogen and oxygen were used in the calculations, and a value of 8.20 was adopted for the logarithmic carbon abundance (on the scale hydrogen = 12.0) following the work of Kane (1980) on CNO abundances in B-type stars in the galactic plane (we assumed that the CNO abundances in B-type stars at large distances from the plane were the same as those of stars in the plane). The calculations were then repeated for different effective temperatures until an effective temperature, $\log g$ and reasonable microturbulence (Kane 1980) were found for which the model atmosphere programme produced equivalent widths in agreement with the measured ones.

Using these atmospheric parameters the equivalent widths of the CaH and CaK stellar components were computed. The profile shapes of the CaII stellar lines were assumed to be identical to those found for the CNO lines (as the profiles are dominated by rotational or macroturbulent broadening this assumption should be valid) and so using the velocity shift derived from the CNO lines the theoretical CaK and CaH stellar lines were superimposed (where necessary) on the observed spectra and the interstellar calcium line profiles normalized. In the case of the CaH line (which occurs on the shorter wavelength wing of the stellar He line at (3970 Å) the uncontaminated longer wavelength wing of the He line was extended into a symmetrical profile and the interstellar line normalized with respect to this.

The stellar equivalent widths of Na $D_1$ and Na $D_2$ were also calculated for a range of effective temperatures (18000—32000 K) but were found never to exceed ~12 mÅ, a value much less than our detection limit of ~40 mÅ for broadened lines. Therefore the stellar contribution to the NaI interstellar line profiles was not a significant problem.
The observed interstellar line profiles have been fitted to theoretical multicloud model calculations using an interactive curve of growth programme (Dufton 1981). The procedure is similar to that used previously by, for example, Bates et al. (1976), Pettini et al. (1977), Wayte, Wynne-Jones & Blades (1978) and Blades, Wynne-Jones & Wayte (1980).

The method assumes that the velocity structure within an individual cloud has a Gaussian profile (resulting in a Voigt function for the line opacity) and did not include contributions from the intercloud medium. The relevant atomic data is taken from Morton & Smith (1973).

In order to perform a multicloud analysis it is necessary to adopt preliminary estimates of the number of components, their weights and internal velocity dispersions. The stronger components were usually easily identifiable in a CaK profile. Weaker components could be either unambiguously identified from the NaD1 and D2 profiles or were required to improve the fit in the wings of strong components. For the latter the inclusion of additional components is to some extent a subjective process guided by the signal-to-noise ratio in the spectrum, and it is possible that, in some cases, spurious components may have been included. We return to this point in the results section, where the components are classified according to the probability of their existence.

The total equivalent widths of the CaII H and K and NaI D1 and D2 interstellar lines were measured by digitization of the normalized line profiles, using an interactive computer procedure. After convolving with the instrumental profile the composite theoretical profile was compared with observation and the model changed until an optimal fit was obtained. In this way a CaII model which fitted the H and K lines, and an NaI model which fitted the D1 and D2 lines, were obtained for each star. In deriving the models equal quality weights were normally assigned to the D1 and D2 lines but greater weight was given to the CaK line observations because of the blending of the CaH line with the He stellar line.

The individual column densities found from the two CaII or NaI components were normally in excellent agreement with differences of typically 0.02 dex. This provides indirect evidence both for the high quality of the observational data (a change of 0.02 dex corresponds to typically 3 per cent in equivalent width) and for the validity of the multicloud models adopted.

Results

Table 2(a) gives a summary of derived stellar data for the programme stars. Column 1 gives the HD numbers; columns 2 and 3 the rotational and heliocentric radial velocities of the stars (found from measurements of the half widths and wavelength shifts of the CNO lines);

<table>
<thead>
<tr>
<th>HD No.</th>
<th>$v \sin i$ (km s$^{-1}$)</th>
<th>$V_T$ (km s$^{-1}$)</th>
<th>$\Delta V$ (km s$^{-1}$)</th>
<th>$T_{\text{eff}}$ (K)</th>
<th>$\log g$ (g in cm s$^{-2}$)</th>
<th>$V_T$ (km s$^{-1}$)</th>
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</thead>
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<tr>
<td>173502</td>
<td>39</td>
<td>+63</td>
<td>+10</td>
<td>28500</td>
<td>3.4</td>
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<td>156</td>
<td>-93</td>
<td>+14</td>
<td>26500</td>
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<td>15 - 20</td>
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<td>105</td>
<td>+38</td>
<td>+3</td>
<td>25000</td>
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<td>20 - 25</td>
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<td>220787</td>
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<td>+1</td>
<td>19100</td>
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</table>

*Assumed value – see text for details.
Table 2. (b) Derived stellar data of Tobin & Kilkenny (1981).

<table>
<thead>
<tr>
<th>HD No.</th>
<th>$v \sin i$ (km s$^{-1}$)</th>
<th>$V_r$ (km s$^{-1}$)</th>
<th>$T_{\text{eff}}$ (K)</th>
<th>log $g$ (g in cm s$^{-2}$)</th>
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<td>29 302</td>
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<td>26 114</td>
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<td>17 561</td>
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Table 2. (c) Stellar distances.

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<th>HD No.</th>
<th>$M_{\text{bol}}$</th>
<th>$M_V$</th>
<th>$r$ (kpc)</th>
<th>$z$ (kpc)</th>
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<td>−4.13</td>
<td>2.89</td>
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Table 3. Equivalent widths and column densities of interstellar lines.

<table>
<thead>
<tr>
<th>HD No.</th>
<th>Ca $H$</th>
<th>Ca $K$</th>
<th>Equivalent widths (mA)</th>
<th>$N$ (Ca II)</th>
<th>$N$ (Na I)</th>
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</thead>
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<tr>
<td>173502</td>
<td>281b</td>
<td>449a</td>
<td>Na $D_1$</td>
<td>357b</td>
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<tr>
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<td>381a</td>
<td>573a</td>
<td>Na $D_1$</td>
<td>615a</td>
<td>803a</td>
</tr>
<tr>
<td>214080</td>
<td>89c</td>
<td>160a</td>
<td>Na $D_1$</td>
<td>163a</td>
<td>244a</td>
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<td>220787</td>
<td>70c</td>
<td>98b</td>
<td>Na $D_1$</td>
<td>50c</td>
<td>94b</td>
</tr>
</tbody>
</table>

Table 4. Cloud models for interstellar line profiles.

<table>
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<tr>
<th>HD No.</th>
<th>Radial velocity (km s$^{-1}$ wrt LSR)</th>
<th>$b$-value (km s$^{-1}$)</th>
<th>Ca II model</th>
<th>Na I model</th>
<th>Weights Ca II model</th>
<th>Weights Na I model</th>
<th>Component quality</th>
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<td>B</td>
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<td>0.0039</td>
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<td>A</td>
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<td>8</td>
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<td>0.8320</td>
<td>0.8800</td>
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</table>

Column 4 gives the correction $\Delta V$ to reduce the heliocentric radial velocities to the local standard of rest; columns 5, 6 and 7 give the effective temperatures, surface gravities and microturbulences derived in the manner described earlier.

In Table 3 we summarize the equivalent widths of the interstellar Ca II and Na I lines, and the resulting mean column densities. The letters a, b and c refer to error estimates in the
equivalent widths (based on signal-to-noise in the continuum and blending effects) with:
a < 10 per cent error, b < 20 per cent and c > 20 per cent.

In Table 4 the cloud models adopted in the analysis are tabulated. For both Na I and
Ca II the same number of clouds were included with the same radial velocities and internal
velocity dispersions (b-values). However, to produce optimal fits the weights had to be
varied from the Ca II to the Na I models.

The validity of the cloud identification is designated by the letters A, B and C, where we
have: A — component identified in all four profiles i.e. a definite component; B — com-
ponent seen clearly in at least one Na I and one Ca II profile i.e. a probable component; and
C — component may exist but its strength is comparable with the noise level i.e. a possible
component.

The experimental and convolved theoretical profiles are presented in Figs 1–4. The
arrows refer to the position of the local standard of rest.

Below the programme stars are discussed individually in detail.

Discussion

INDIVIDUAL STARS

HD 173502

Due to the high effective temperature derived for this star (28 500 K) the predicted stellar
Ca II H and K equivalent widths were only 8 and 31 mÅ, respectively. These values are very
much smaller than the observed equivalent widths and therefore have been ignored when
normalizing the line profiles. However, the heliocentric stellar velocity is +65 km s⁻¹ and we
cannot entirely rule out the possibility that some of the absorption in the redward wing of Ca II has a stellar origin. In our treatment of the results we have ignored this possibility.

As can be seen in Fig. 1, the Ca II model is chosen to give good agreement with the Ca K line, the Ca H line being given a lower weight for reasons discussed previously. This criterion also holds for the Ca II profiles of the other three stars.

For the Na I case, however, any model should fit the D1 and D2 line profiles equally well. This was not found to be so in this instance, however, it being necessary to fit either to the D1 or D2 profiles (in which case the agreement for the other profile was less good). The model that fitted the D1 profile was finally decided upon (as shown in Fig. 1) due to the possible presence of telluric H2O absorption lines in the D2 profile. The wavelengths of these lines are given in McNutt (1963).

**HD 179407**

The Hβ index for this star gives a surface gravity of 2.8, a value which would lead to instability of the star against radiation pressure (Mihalas 1965). The most likely explanation of this is Hβ emission in the core of the line, which reduces the Hβ index, hence leading to an erroneous value of log g. Tobin & Kilkenny (1981), in an investigation of the nature and possible subluminosity of O and B stars far from the galactic plane have also advanced this explanation to explain why an absolute magnitude versus equivalent width (Hy) relation (Balona & Crampton 1974) gave an absolute magnitude for HD 179407 about 3 mag larger than that derived from a similar relationship involving the Hβ index (Crawford 1978).

We adopted for this star a value of log g = 3.0, which is not unreasonable for early-type supergiants (Van Helden 1972; Dufton 1979; Kane 1980).

The equivalent widths of the stellar Ca II H and K lines were calculated to be 18 and 53 mÅ respectively. It was not necessary to separate these from the interstellar line profiles due to the high rotational velocity of the star, which blends these weak stellar lines with the continuum.

The experimental and convolved theoretical Na I and Ca II profiles are shown in Fig. 2. For this star the Ca H profile could be quite well determined due to the large negative radial velocity of the star, which lead to the Ca H line being shifted into the core of the He line. As the wings of the He line were therefore uncontaminated by interstellar features, its profile in these regions could be drawn precisely and extrapolated to find the line shape in the region of the core with reasonable accuracy, which then acted as the continuum for the Ca H interstellar line profile.

**HD 214080**

Due to the high value of the stellar equivalent width and the large rotational velocity of this star, the stellar Ca K line could clearly be separated from the interstellar components. The measured equivalent width of this line (133 mÅ) was in excellent agreement with the calculated value of 132 mÅ. The calculated equivalent width of the stellar Ca H line was only 34 mÅ so it was of less importance during the normalization of the interstellar line profiles. The normalized interstellar line profiles are shown in Fig. 3.

**HD 220787**

For this star the calculated stellar Ca K and Ca H equivalent widths were 100 and 48 mÅ respectively. Unfortunately these lines could not clearly be distinguished from the inter-
Figure 2. HD 179407: Comparison of theoretical and observed (solid points) interstellar Ca II and Na I line profiles.

Figure 3. HD 214080: Comparison of theoretical and observed (solid points) interstellar Ca II and Na I line profiles.
stellar components (due to the small rotational velocity of the star) and hence it was necessary to profile fit the stellar lines as described in the method of analysis. This was easily accomplished for the Ca$K$ line, but was not possible for the Ca$H$ line, due to the poor signal-to-noise ratio in the spectrum. As a result of this the Ca$II$ column densities derived from the Ca$K$ and Ca$H$ lines differed by 0.11 dex (a much larger difference than normal), so it was decided to give the Ca$K$ column density a much greater weight than the Ca$H$ one.

Both the Ca$II$ and the Na$I$ profiles are shown in Fig. 4. When choosing the Na$I$ model greater weight was given to the $D_2$ profile as the $D_1$ profile was very uncertain, its strength (50 mÅ) being close to our detection limit (~ 40 mÅ for a sodium line).

**GENERAL**

*Comparison of stellar results with those of Tobin & Kilkenny (1981)*

Tobin & Kilkenny (1981) have also analysed the four stars discussed in this paper. They derived values for the effective temperatures of the stars by use of a $(u-b)$ versus $\theta (=5040/T_{\text{eff}})$ relation (Philip & Newell 1975), and calculated surface gravities from the width of the H$\beta$ line (Greenstein & Sargent 1974). In general the agreement is poor. Discrepancies in log $g$ may be due to emission in the H$\beta$ line which would effect the observed H$\beta$ index. However a comparison of gravities derived from the H$\beta$ index and from the profile of the H$\gamma$ line in main sequence and supergiant B-type stars indicated that the H$\beta$ index should give gravities accurate to ±0.2 dex (Ella 1980, private communication). In the case of the effective temperatures, the good agreement achieved in the fitting of the CNO equivalent widths indicates that our values should be accurate to ±1000 K.

The derived values of stellar rotational and radial velocities also differ, but our use of relatively high dispersion (5 Å mm$^{-1}$ compared with Tobin & Kilkenny’s value of 49 Å mm$^{-1}$)
leads to error estimates of ±10 km s\(^{-1}\) and ±7 km s\(^{-1}\) for rotational and radial velocities respectively. A summary of the results of Tobin & Kilkenny (1981) is given in Table 2(b).

**Stellar distances**

For all four stars the high dispersion spectra appear normal and confirm their spectral type. In addition, the model atmosphere program yields \(T_{\text{eff}}\) and \(\log g\) values appropriate to their spectral types together with normal CNO abundances. From the atmospheric parameters we may deduce a stellar mass (Allen 1973) on the assumption that these stars have evolved normally, and using this it is possible to derive the bolometric magnitudes of the stars from the formula:

\[
M_{\text{bol}} = 4.75 - 2.5 \log \left( \frac{g_\odot}{g} \left( \frac{T_{\text{eff}}}{T_{\text{eff}}^\odot} \right)^4 \frac{M}{M_\odot} \right)
\]

where the subscript \(\odot\) refers to the Sun and the other symbols have their usual meanings. Hence using the bolometric corrections of Morton and his co-workers (Mihalas & Morton 1965; Hickock & Morton 1968; Bradley & Morton 1969; Van Citters & Morton 1970), coupled with the reddening \(E_B - V\) and assuming a value of 3.2 for the ratio of total-to-selective absorption (Olson 1975) we can derive distances to the stars. These distances, summarized in Table 2(c), are similar to those found by Kilkenny (1980) and Kilkenny & Hill (1975). Although we are not able to totally exclude the possibility of the stars being submassive (and also possibly subluminous), previous analyses of low mass early-type stars (Tomley 1970; Peterson 1970; Richter 1971; Dufton 1972; Greenstein & Sargent 1974; Kudritzki & Simon 1978) have yielded atmospheric parameters significantly different from those found for normal main sequence and supergiant stars. Our results therefore indicate that the four halo stars are normal and are at the large distances derived.

**Comparison of profile fitting with doublet ratio method of derivation of column densities**

As previously mentioned we have derived column densities by fitting observed interstellar line profiles to theoretical calculations using multcloud models. Often, however, the doublet ratio method is used.

In Table 5 the single cloud \(b\)-values obtained from this alternative method are given, and the derived column densities are compared with our values. The doublet ratio method, in most cases, gives approximately the correct column densities, however (as can be seen for the example of HD 214080 in Fig. 5), the resultant convolved theoretical profiles are in very poor agreement with the experimental ones. Hence it is impossible to derive column densities for individual clouds, and one is forced to adopt unrealistically high \(b\)-values for the absorbers in the interstellar gas. We also calculated the effect of 10 per cent changes in the \(\text{CaH}\) and \(\text{NaD}_1\) equivalent widths on the column densities derived via the doublet ratio
method. It was found that, on average, the column densities were changed by ~ 0.2 dex, i.e. small changes in equivalent width lead to large changes in column density. Therefore, although the doublet ratio method can give approximately correct column densities (as here) it requires an accurate knowledge of both the equivalent widths involved, which is difficult to achieve (especially for the Ca H line) even at high resolution where separation of the stellar He line is possible. The profile fitting method, on the other hand, is not only more realistic, but requires in the limit an accurate determination of only one equivalent width. Hence problems with, for example, the Ca H line do not arise.

Figure 5. Comparison of the observed interstellar profiles of HD 214080 (solid points) with the theoretical profiles found from the doublet ratio method.

Figure 6. Plot of log N(Na I)/N(Ca II) versus radial velocity wrt the local standard of rest. Filled circles: component quality A; open circles: component quality B; triangles: component quality C.
Velocity dependence on the $N(\text{Na I})/N(\text{Ca II})$ ratio

In Fig. 6 we have plotted the values of $\log N(\text{Na I})/N(\text{Ca II})$ for the interstellar components against their radial velocities relative to the local standard of rest. The figure confirms the general trend of earlier workers (Routly & Spitzer 1952; Siluk & Silk 1974; Cohen 1974; Cohen & Meloy 1975) i.e. a decrease in the $N(\text{Na I})/N(\text{Ca II})$ ratio (from approximately 1.6 to 0.2) as absolute radial velocity increases. Because of the nature of the multicloud analysis there is a possibility of including spurious clouds. These doubtful components have been labelled type C and are shown as triangles in Fig. 6. There is a stronger correlation between $N(\text{Na I})/N(\text{Ca II})$ ratio and $V_{lsr}$ if these components are excluded from the analysis, although the range of ratios remains unchanged. However, our range of $N(\text{Na I})/N(\text{Ca II})$ ratios is not as great as those previously observed (Routly & Spitzer 1952; Siluk & Silk 1974), which is perhaps due to our more rigorous method of analysis, but confirmation of this awaits additional data.

Conclusions

In the calculations of the stellar Ca H and Ca K equivalent widths we assumed solar values for the N and O abundances, and a value of 8.20 for the logarithmic carbon abundance following the work of Kane (1980). With these values a typical effective temperature, surface gravity and microturbulence could be found for each star consistent with its general classification, for which the model atmosphere programme reproduced the measured CNO equivalent widths. In addition, the measured stellar Ca K equivalent width of HD 214080 (the only stellar calcium line which could be clearly identified) was in excellent agreement with the calculated value. Our conclusions from this are that the CNO abundances used are applicable in this instance, and that the CNO abundances in these B-types stars are similar to those of stars in the galactic disc.

Using values of equivalent widths calculated with the LTE model atmosphere programme, a graph of stellar equivalent width (Ca K) versus effective temperature was drawn for different surface gravities and microturbulences, which is presented in Fig. 7. As can be seen even at

![Figure 7](https://example.com/figure7.png)

**Figure 7.** Variation of the equivalent width of the stellar Ca II K line with effective temperature for two values of the surface gravity and microturbulence.
high temperatures the equivalent widths are not negligible, especially for large micro-
turbulences, which are found for giant and supergiant stars. Unfortunately many of the stars
observed at large distances from the galactic plane fall into one or other of these categories
(see, e.g. the lists of Kilkenny & Hill 1975 and Kilkenny 1980). Their stellar calcium lines
may hence badly contaminate any interstellar features, especially if (i) the star is not a rapid
rotator, (ii) it does not have a large radial velocity with respect to the interstellar com-
ponents and (iii) the interstellar line is weak, as is found with many high galactic latitude
halo stars, e.g. HD 214080 and HD 220787 in this paper, and several of those observed by
Cohen (1974) and Cohen & Meloy (1975). Therefore in the cases when conditions (i), (ii)
and (iii) hold any possible stellar contribution to observed interstellar Ca II profiles must be
removed.

By obtaining good agreement between theoretical and observed interstellar line profiles
using the curve of growth program we have derived multicloud models for the interstellar
medium in the line of sight to galactic halo stars. This analysis is more satisfactory than the
doublet ratio method which is normally used for halo observations.

From inspection of Tables 1 and 4 it can be seen that the two stars with the greatest
number of interstellar components (HD 173502 and HD 179407) are at the largest distances
from the galactic plane. However, this cannot be taken as proof that interstellar clouds exist
at such large distances from the plane due to the fact that these stars are at relatively low
galactic latitudes (|b| ~ 11° as opposed to ~ 60° for HD 214080 and HD 220787) which
means that a larger amount of their lines of sight lie within the galactic disc and hence
intercept more interstellar clouds.

We intend to extend the methods of analysis described in this paper to additional high
latitude stars to examine more extensively the velocity dependence of the Na I/Ca II ratio,
and the frequency of occurrence of high velocity interstellar components. These data are
essential for combination with IUE observations of somewhat lower resolution to investigate
the ionization state and element abundances of the possible high z interstellar clouds.

References

Line profiles towards halo B stars

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