Non-anomalous diffuse interstellar absorption features in Rho Leonis

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Summary. Photographic spectroscopic observations are presented of ρ Leo (HD 91316), a class B1 supergiant at high galactic latitude which shows little reddening. The interstellar diffuse features λ 4430, λ 5797 and λ 6283 are not detected. There is an indication in the spectra that λ 5780 might be present, with a strength consistent with the amount of reddening. Previous reports of anomalously strong λ 4430 are not confirmed. These were based on low-resolution spectroscopy and the explanation is that the appearance of a wide feature is produced by a combination of several weak atomic absorption lines in the spectrum of the star itself.

1 Introduction

It has been known for more than forty years that the broad absorption features found in the spectra of early-type stars have an interstellar origin, but their physical nature is not yet understood. Various mechanisms have been proposed — most of them are listed by Bromage (1972) and Wu (1972) — and have proved to be more or less unsuccessful. Broadly speaking, they involve formation either by interstellar molecules (or atoms) or by interstellar dust grains. Intensities of the diffuse bands may be expected in general to be correlated either with intensities of absorption lines formed in the gas or with the reddening produced by the dust. It is important to study the correlation of the bands with the lines and with the reddening, as well as with each other, and to examine carefully possible anomalous departures from the normal correlations.

There is now quite good reason (Herbig 1975) to suppose that the diffuse bands are associated with a small-size component of the interstellar dust, grains with radius of order 0.02 μm which appear to be responsible for the ultraviolet extinction (York et al. 1973), as compared with the needle-shaped grains some 0.3 μm long required to produce the optical reddening and associated polarization. Although Bless & Savage (1972) found several stars with unusual ultraviolet extinction, Nandy et al. (1975) have shown that the ultraviolet extinction is very well correlated with the optical reddening, as measured by the visual colour excess $E_{B-V}$, and that there is no sign of dependence on galactic longitude.

The diffuse bands appear to be well correlated in intensity with each other and with the reddening (Herbig 1975) but in certain directions they are clearly weak. In regions in Cygnus...
and Sco-Oph the strength of the diffuse bands per unit colour excess is about 30 per cent below normal. Anomalously weak bands are found also in some stars associated with reflection nebulosity (Herbig 1975), stars seen through dense clouds (Snow & Cohen 1974) and possibly for some emission-line stars (Wu 1972). Such observations suggest that the carrier of the bands is not the grains responsible for the reddening, consistent with it being instead the smaller grains.

Observations of directions where the diffuse bands appear anomalously strong relative to weak reddening are harder to explain. This anomaly would require the carrier of the absorption to be overabundant relative to the grains producing the reddening, by an amount very much larger than the 30 per cent anomaly of the underabundances, suggesting that it could be difficult to explain the bands as produced by dust grains, of any size. Such a direction is that of the B-type supergiant ρ Leonis (HD 91316). It has very little interstellar reddening but strong λ 4430 has been reported there, in low-resolution photographic (Duke 1951) and photoelectric (Stoewly & Dressler 1964; Wampler 1966; Baerentzen et al. 1967) studies. Wampler (1966) and Wu (1972) have reported the probable presence of λ 5780. The star has frequently been cited (e.g. Wampler 1967; Snow, York & Welty 1977) as an outstanding example of one with anomalously strong λ 4430. As discussed below, although interstellar atomic lines have been detected in this star there is reason to suppose that molecular abundances are low in the line of sight; this suggests that any diffuse bands present are not associated with molecules either.

In this paper we present photographic spectroscopic observations of this star. We do not confirm the presence in the spectrum of anomalously strong diffuse bands. Instead, we find that the appearance of a wide feature at 4430 Å in the low-resolution spectra is produced by a combination of several weak atomic absorption lines in the spectrum of the star itself.

2 Previous studies of ρ Leo

The star ρ Leo has $m_V = 3.85$ and MK type B1 Iab (Lesh 1968) and coordinates (2000) RA = 10$^h$ 33$^m$, dec = +9° 18′. The projected rotation is small, $v \sin i = 69$ km/s (Usugi & Fukuda 1970). Extensive UBV photometric data are available (Blanco et al. 1968; Lesh 1968): with $B-V = -0.14$ and using the intrinsic colours of Johnson (1966), the colour excess $E_{B-V} = +0.08$, a very small value. ρ Leo is a high galactic latitude object, with $b = +53°$. From its spectroscopic parallax, using $R = A_V/E_{B-V} = 3.25$ (Moffat & Schmidt-Kaler 1976), its distance is 950 pc and it is 760 pc above the galactic plane. The absence of significant optical obscuration in the general direction of ρ Leo is confirmed by inspection of the relevant Palomar Sky Survey print (number 238) which shows a rich collection of galaxies in the field, one of them only 9 arcmin from the star.

Although the optical extinction is small, ρ Leo shows a complex interstellar gas structure. Adams (1949) found three components of the Ca II K line, at $-11.5$, $-2.0$ and $+17.9$ km/s, after correction (Münch 1957). More recently, the higher-resolution PEPIS studies of interstellar Na I (Hobbs 1969) and Ca II (Marschall & Hobbs 1972) have shown that Adams’ $-11.5$ km/s feature itself consists of at least three components with separations of order 3 km/s, and also that the ratio Ca II/Na I is unusually high (Hobbs 1974). Rickard (1972) included the star in a survey of interstellar gas in objects at high galactic latitude. He found that for stars with $z > 600$ pc a strong negative velocity feature is seen (it is not very strong in ρ Leo) and also that the strong feature observed at zero radial velocity in other directions and presumably produced by local gas is shifted to negative velocities in these stars (the $-11.5$ km/s feature in ρ Leo). He suggested that the explanation could be acceleration of local gas by infalling material, a mechanism which could be related to one proposed.
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exploration of the high-velocity clouds observed in the 21-cm line (see the review by Somerville 1977).

Spitzer, Cochran & Hirshfeld (1974) have observed interstellar molecular hydrogen in the ultraviolet in this star, using the Copernicus satellite. At the resolution of the spectrometer two components are detected, presumably corresponding to the −11.5 and +17.9 km/s features of the optical observations. The total column density of H$_2$ in the line of sight to ρ Leo is $N$(H$_2$) = 4 × 10$^{15}$ cm$^{-2}$. Also from Copernicus observations (Savage & Jenkins 1972), the column density of atomic hydrogen is 4.5 × 10$^{20}$ cm$^{-2}$. The fraction of hydrogen in molecular form is thus very small, only about 2 × 10$^{-5}$. This suggests that the abundance of other molecular species also should be small.

Earlier reports of strong λ4430 thus cannot easily be explained by an origin for the diffuse bands either in the dust or in molecules. It has appeared possible that they could originate in the negative-velocity cloud where the Ca ii/Na i ratio is anomalously high (Snow et al. 1977).

3 Observations and results

Photographic coudé observations of ρ Leo were made by JCB in 1976 April using the 30-in reflector at RGO, Herstmonceux. Two spectrograms were obtained in the first-order red at 20 Å/mm dispersion, on Kodak Eastman 098-01 plates. A third spectrogram, in the second-order blue at 10 Å/mm, on IIaO (baked), was taken and confirms the general results but was not used in the analysis. The spectrograph slit width was set at 150 μm, corresponding to a measured full width at half maximum of 22.7 μm (Fosbury & Harmer 1972); the exposures were tailored to give a width on the plate of 500 μm. The spectrograms were calibrated by exposing on each side of the stellar spectrum a series of intensity strips of known relative intensity; the plates were developed in D19 using bubble burst agitation. Reduction used a Joyce Loebl Mk III microdensitometer.

Density measurements covering the regions of the interstellar features λ 4430, 5780, 5797 and 6283 were converted to intensities using the appropriate calibration curve. These can be compared with Wampler’s photoelectric scan about λ 4430 and with intensity tracings of the diffuse features observed in χ$^2$ Ori (HD41117), a star of similar spectral type (B2 Ia) and rotation ($v \sin i = 29$ km/s; Uesugi & Fukuda 1970) but much more reddened ($E_{B-V} = 0.46$) and with strong diffuse features. The comparison used a 13.6 Å/mm coudé plate of χ$^2$ Ori taken by R. S. Picton (1970, unpublished) at the Radcliffe Observatory. The Herstmonceux and Radcliffe coudé spectroscopes have very similar resolution (Blades & Powell 1976).

3.1. THE λ4430 FEATURE

Spectra of ρ Leo in the region of λ4430 are presented in Fig. 1. The top curve is an intensity tracing from one of the 098-01 spectrograms; below it is a mean intensity trace derived from the two red plates: it has been smoothed with a Gaussian curve of half width compatible with the spectroscopic resolution, to reduce the noise due to photographic grain. Wampler’s photoelectric scan is shown for comparison (Wampler 1966, Fig. 12). The gently sloping continuum evident in the photographic work is caused primarily by the changing spectral response of the photo-emulsion; no attempt has been made to correct for this instrumental effect.

A plausible interpretation of Wampler’s photoelectric scan was that between two stellar absorption lines — the unresolved O ii doublet at 4415 Å and N ii at 4447 Å — there is a
Figure 1. Tracings about the $\lambda$ 4430 position in $\rho$ Leo. The two upper figures are intensity tracings from our RGO spectrograms; the bottom figure is Wampler's (1966, Fig. 12) photoelectric scan, the three horizontal lines indicating the continuum level. The photographic spectra are in intensity units, normalized at the centre of the spectral range. The photoelectric scan is in $A_c$ units which expresses the absorption depth as a percentage of the continuum.

broad absorption feature with central wavelength about 4430 Å, presumably the interstellar band $\lambda$ 4430. The wings of this broad feature merge into the two stellar lines, possibly extending beyond them. The central absorption in the feature is about 3.0 per cent.

Comparison of the spectra in Fig. 1 shows that the appearance of broad absorption around 4430 Å is produced by a collection of weak stellar absorption lines, unresolved in the photoelectric work. There is an excellent correspondence between the photoelectric and photographic spectra: it is possible to explain in detail every feature found in the photoelectric scan, from lines present in the photographic spectrum.

The absorption at 4415 Å is resolved into the two lines of the O II doublet at 4414.91 and 4416.98 Å. The 4447 Å feature also is resolved into two lines, N II at 4447.0 and O II at 4452.4 Å; the O II line causes the extended wing to the red of 4447 Å in Wampler's

Table 1. Identifications and equivalent widths of stellar lines in the spectrum of $\rho$ Leo, from 4385 to 4475 Å.

<table>
<thead>
<tr>
<th>Spectrum</th>
<th>Multiplet number</th>
<th>$\lambda_{\text{lab}}$</th>
<th>$W$(mA)</th>
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</thead>
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<tr>
<td>He I</td>
<td>51</td>
<td>4387.93</td>
<td>559</td>
</tr>
<tr>
<td>Fe III</td>
<td>4</td>
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</tr>
<tr>
<td>O II</td>
<td>26</td>
<td>4395.95</td>
<td>113</td>
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<tr>
<td>O II</td>
<td>5</td>
<td>4414.91</td>
<td>332</td>
</tr>
<tr>
<td>O II</td>
<td>5</td>
<td>4416.98</td>
<td>272</td>
</tr>
<tr>
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<td>112</td>
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<tr>
<td>N II</td>
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</tr>
<tr>
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<td>4</td>
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</tr>
<tr>
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<td>O II</td>
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<td>4452.38</td>
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<tr>
<td>He I</td>
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<td>4471.48, 1.69</td>
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The apparent broad feature at 4430 Å is produced by three stellar absorptions, at 4427.2, 4432.7 and 4437.6 Å, probably produced mainly by N II and He I with contributions from other species listed in Table 1. Inspection of the profiles suggests that most of the weak absorptions are blends of several lines. Identifications of the stellar lines have been made using the Revised Multiplet Table (Moore 1945) and studies of o1 CMa (MK type B3 Ia) by van Helden (1972) and of η CMa (B5 Ia) by Underhill & Fahey (1973). Equivalent widths, measured from the individual intensity tracings using a planimeter, are presented in Table 1.

The stellar continuum appears to be well defined between 4397.3 and 4408.2 Å and at 4422.7, 4435.3, 4450.0 and 4460.9 Å. Observation of these regions with higher resolution could possibly reveal further weak stellar absorptions, altering the level of the continuum. However, the continuum is sufficiently well defined that we may conclude that there is no detectable depression at 4430 Å, apart from the effect of stellar lines, and that the λ 4430 interstellar feature is not present, a result consistent with the observed reddening. Our gross upper limit on the central depth is $A_v < 1$ per cent; from the correlation between equivalent width and colour excess given by Herbig (1975), the equivalent width of λ 4430 in ρ Leo is expected to be 180 mÅ. These numbers are consistent.

3.2 THE λ 5780, λ 5797 AND λ 6283 FEATURES

Wampler (1966) remarked that his photoelectric scans indicate the presence of λ 5780 in the spectrum of ρ Leo, and Wu (1972) measured an equivalent width 10 mÅ for it. Both this and λ 5797 are relatively sharp interstellar bands; Herbig (1975) finds for the FWHM in the heavily-reddened star HD 183143, 2.6 Å for λ 5780 and 1.3 Å for λ 5797, compared with 20 Å for λ 4430. Because the absorption strength lies in the central depth rather than the width, these two features are much easier to detect and measure accurately than many of the other features, particularly λ 4430.

Fig. 2 shows the spectral region between the stellar Si III line at 5739.8 Å and the interstellar Na I D lines. An intensity trace averaged over the two red plates is compared with a tracing of $\chi^2$ Ori from a 13.6 Å/mm Radcliffe plate, on the same scale and positioned so

![Figure 2](https://example.com/figure2.png)

**Figure 2.** Intensity tracings of ρ Leo (upper) and $\chi^2$ Ori (lower). Two separate sections are shown: from 5735 to 5800 Å, to include the interstellar λλ 5780 and 5797 bands, and from 5870 to 5895 Å to include the interstellar Na I D lines. The spectra, which have been aligned using the D lines, also show strong stellar lines of Si III and He I. Note the possible presence of λ 5780 in ρ Leo.
that the D lines are aligned. Both the diffuse features λ 5780 and λ 5797 are clearly present in χ² Ori. Although λ 5797 is not present in ρ Leo, there is a suggestion of a weak feature at 5780 Å; in both spectrograms there is an appearance of absorption at that wavelength, lying at the plate detection limit. We conclude that λ 5780 probably is present. From the correlation of $W$ for this line with $E_{B-V}$ (Herbig 1975), the strength of λ 5780 is expected to be about 54 mÅ. This is slightly larger than the value for the feature in our spectrograms and as measured by Wu. It is clear that, whether λ 5780 is present here or not, it is not anomalously strong.

The diffuse feature λ 6283 is normally conspicuous in spectra of reddened early-type stars. It is difficult to measure its strength and profile accurately because it is superposed on a telluric O₂ absorption band. In a detailed inspection of our two spectrograms, including a comparison with χ² Ori where it is strong, this feature could not be detected in the spectrum of ρ Leo.

3.3 THE ULTRAVIOLET FEATURE λ 2200

The very strong, broad interstellar absorption feature centred near 2180 Å and of FWHM = 360 Å (Nandy et al. 1975) is well correlated with colour excess. It is also correlated strongly with the λ 4430 feature (Nandy & Thompson 1975) although about two orders of magnitude stronger than it. However, in one Wolf–Rayet star Willis & Wilson (1975) found λ 2200 to be anomalously very strong.

The S2/68 telescope on the TDI satellite has conducted an ultraviolet spectroscopic survey; instrumentation is discussed by Boksenberg et al. (1973) and some of the results are presented in an Ultraviolet Bright Star Catalogue (Jamar et al. 1976). Both ρ Leo and χ² Ori are included in the survey and spectra are shown in Fig. 3; the spectrum for χ² Ori is a later one than that given in the Catalogue, being based on more scans, and ρ Leo is not in the Catalogue. Inspection shows that the λ 2200 feature is conspicuous in χ² Ori but absent in ρ Leo, consistent with the optical results. From early S2/68 data using calibration based on an ultraviolet colour excess, Nandy & Thompson (1975) give $W_{2200} = 50$ Å in ρ Leo; this is not confirmed by the more accurate later detailed tracing of the spectrum.

In both stars strong stellar absorption is seen centred on 1920 and 2070 Å, due mainly to Fe III (Thompson, Humphries & Nandy 1974).

![Figure 3](https://academic.oup.com/mnras/article-abstract/181/4/769/964461)

**Figure 3.** Ultraviolet spectra of ρ Leo (upper) and χ² Ori (lower) obtained from the S2/68 telescope aboard the TDI satellite. A number of stellar absorptions are present in the spectra, some being identified here. Between 1800 and 2500 Å the very strong λ 2200 feature dominates the χ² Ori spectrum. There is no evidence of this feature in ρ Leo.
A comparison by eye with spectra in the Ultraviolet Catalogue for 10 stars of similar spectral type and low $E_{B-V}$ indicates that $\rho$ Le is does not have any unusual ultraviolet extinction. In particular, the spectrum of $\gamma$ Ara (HD157246: B1 Ib; $m_V = 3.33$; $E_{B-V} = 0.08$) is almost identical to that of $\rho$ Le.

4 Discussion

This study has shown that anomalously strong interstellar diffuse bands are not present in the direction of $\rho$ Le. Instead, it has demonstrated clearly the effect of weak stellar lines on the measurement of $\lambda$ 4430. Evidently photoelectric – or photographic – studies with low resolution may give unreliable measurements of the equivalent width and central depth of the band, especially if the continuum is sampled only at a few points.

This result supports the conclusion of Deeming & Walker (1967), based on their statistical survey of many separate photographic and photoelectric studies of $\lambda$ 4430, that low-resolution work suffers severely from effects dependent on spectral type, these effects probably being related to spectrum lines. There is some reason to suppose that weak stellar lines could affect $\lambda$ 4430 less strongly for B-type stars rather later than B1, although intensity tracings of B7 and B8 stars do show some evidence for weak stellar lines in that region (Herbig 1966; Bromage 1972). We consider that more systematic observations with high resolution of unreddened stars of low $v \sin i$ are required before a firm conclusion can be drawn.

In their extensive compilation of observations of the diffuse bands, Snow et al. (1977) find that least-squares fits to correlations such as those between central depth $A_c$ and $E_{B-V}$ indicate that for zero colour excess $\lambda$ 4430 and other bands appear still to be present. They suggest (see also Smith, Snow & York 1977) that the small residual absorptions could be produced in low column-density, high-velocity clouds, such as the $-11.5$ km/s cloud in $\rho$ Le. The work reported here does not provide any support for that interpretation. Moreover, in their correlation for $\lambda$ 4430, Snow et al. find a residual $A_c \approx 3$ per cent for $E_{B-V} = 0$. This value is the same as $A_c$ for the spurious absorption feature in $\rho$ Le. An alternative explanation for the non-zero residual value is that it is caused by the contribution of weak stellar lines, suggesting that a correction of this amount should be subtracted from $A_c$ (4430) when it is used in correlation studies. High-resolution work on $\lambda$ 4430 in other directions of low column density clearly is required.

$\rho$ Le has low projected rotational velocity. For larger $v \sin i$ the weak lines observed would merge into the stellar continuum, causing the continuum level to be lowered locally and contributing to the apparent strength of $\lambda$ 4430 in a less discernible way. The problem of spectrum line interference is thus not removed but made more subtle.

In a similar context, it has been shown (Blades 1976) that measurements of interstellar Ca II K line intensities can be affected seriously by stellar absorption in the K line, for B-type stars with low rotational velocity. It appears that in general stellar lines may be stronger in the spectra of early-type stars than has often been supposed in studies of interstellar absorptions, and that care is needed to allow for this effect in the analysis and interpretation of intensities.

Finally, we may remark that no satisfactory profile has yet been obtained for the interstellar feature $\lambda$ 4430. The main points of disagreement between different determinations are in the full extent of the feature, the possible asymmetry of its profile and the possible presence of a blue emission wing. It is probable that weak stellar lines in the region of the feature are responsible for at least some of the disagreements.
Acknowledgments

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References


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