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CIRCUMSTELLAR LINES IN THE SPECTRUM OF ETA CANIS MAJORIS

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ABSTRACT

High-resolution scans made with the U1 and V1 scanners of the *Copernicus* satellite covering the centers of lines noted from low-resolution scans as possibly circumstellar in origin have been examined for the presence of sharp components. Three components are found displaced about $-235\ \mathrm{km\ s^{-1}}$ from the line center. They indicate the presence of a cloud moving rapidly out of the star. Other sharp lines due to C II, N I, Mg I, Mg II, Si IV, and Fe II are observed. They originate in a circumstellar shell which is moving with a velocity of about $-25\ \mathrm{km\ s^{-1}}$ with respect to the star.

Subject headings: circumstellar shells — luminous stars — spectra, ultraviolet — stars, individual

I. INTRODUCTION

The presence of a circumstellar shell around Eta Canis Majoris, B5 Ia, is revealed by strong absorption due to the resonance lines of Na I, Mg I, and Mg II (Underhill and Fahey 1973; Underhill 1974, 1975). Other circumstellar lines have been suspected due to N I, O I, Si II, Cl I, and Fe II (Underhill 1974*a*), although the OAO-3 (*Copernicus*) spectrum tracings obtained at 0.2 and 0.4 Å resolution do not indicate conclusively that the observed features are circumstellar rather than interstellar in origin. In order to clarify this question, high-resolution tracings were obtained with the OAO-3 at the positions of some of the suspected sharp features. This note reports on a search for circumstellar features using this material. The U1 scanner (Rogerson *et al.* 1973) provides a resolution of 0.05 Å at wavelengths between 1000 Å and 1400 Å, while the V1 scanner gives a resolution of 0.1 Å between 1800 Å and 3000 Å. A feature is considered to be circumstellar if it is sharper than the average stellar line, and if it comes from a level having an excitation potential of 0 or a few $\mathrm{cm^{-1}}$.

The observations of Marschall and Hobbs (1972) show that the interstellar Ca II lines are very weak in the spectrum of η CMa, and that they are displaced about $-21\ \mathrm{km\ s^{-1}}$ and $-6\ \mathrm{km\ s^{-1}}$ with respect to the star. The strong Na D-lines are displaced $-25\ \mathrm{km\ s^{-1}}$ with respect to the stellar spectrum (Underhill and Fahey 1973), which suggests formation in a slowly expanding shell. The Mg I and Mg II component discussed by Underhill (1975) may belong to this shell, but it is impossible to estimate accurately the displacement of these lines from the low-resolution OAO-3 spectrum scans. The observed strengths of the Na I, Mg I, and Mg II resonance lines on the assumption of solar relative abundances imply a column density of hydrogen in the atmosphere of η CMa which is $6 \times 10^{21}\ \mathrm{cm^{-2}}$ (Underhill 1975). The light reddening of η CMa, $E(B - V) = 0.09$, implies an interstellar column density of $6.7 \times 10^{20}\ \mathrm{cm^{-2}}$ (Jenkins and Savage 1974), while the observed Lα profile implies $7 \times 10^{20}\ \mathrm{cm^{-2}}$ (Bohlin 1975). Since the stellar Lα profile is weak, the hydrogen in the atmosphere of η CMa must be fully ionized.

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II. THE RESULTS

Since most of the regions scanned are in the bottoms of strong stellar lines, the search was for sharp lines at counting levels which are low. The detected components are listed in Table 1, together with their equivalent widths and the column densities estimated using the interstellar curve of growth and a velocity dispersion corresponding to a temperature of 7000 K. In many cases the line is barely visible among the variations due to noise in the detectors and to statistical fluctuations. The velocity displacement with respect to the stellar lines is listed. The absolute value of this displacement depends upon the accuracy with which the wavelength scale was determined. The OAO-C observers have corrected for the motion of the satellite and the radial velocity of the star. We have no evidence that these corrections are systematically in error, but we do not have information to prove they are correct. We assume this is so. Most lines are displaced about as much as the Na D-lines, namely $-25\ \mathrm{km\ s^{-1}}$, while a few seem to be displaced like the interstellar Ca II lines at -21 and $-6\ \mathrm{km\ s^{-1}}$. Those lines for which the excitation potential of the lower level is not $0\ \mathrm{cm^{-1}}$ are probably formed in a circumstellar shell or cloud where the density is sufficient to maintain a low level of excitation, while those which come from a ground level may be circumstellar or interstellar in origin.

There are three components which belong to a cloud which is expanding rapidly from the star, namely N II λ1083.990 at $-232\ \mathrm{km\ s^{-1}}$, C II λ1334.532 at $-239\ \mathrm{km\ s^{-1}}$, and Mg II λ2795.523 at $-231\ \mathrm{km\ s^{-1}}$. Observations were not made at Mg II λ2802.698. The N II line falls at 1083.15 Å. It could be blended with

TABLE 1

SHARP COMPONENTS IN THE SPECTRUM OF η CMa

Spectrum	λ(Å)	E.P. (cm^{-1})	v(km s^{-1})	W(mÅ)	log NH
N II...........	1083.990	0.0	−232	76	16.81
N II...........	1083.990	0.0	−10	130	17.53
N II...........	1084.580	49.1	−30	71	16.84
N II...........	1085.701	131.3	−27	37	14.46
N I............	1134.165	0.0	−20	80	17.78
N I............	1134.415	0.0	−21	120	18.35
N I............	1134.980	0.0	−18	95	17.86
C II...........	1334.532	0.0	−239	91	16.67
C II...........	1335.708	63.42	−28	220	17.75
Si IV..........	1393.755	0.0	−17	50	14.57
Si IV..........	1402.770	0.0	−11	50	14.87
Fe II..........	2585.876	0.0	−21	183	16.76
Fe II..........	2598.369	384.77	−14	61	14.87
Fe II..........	2599.395	0.0	−29	96	15.46
Mg II..........	2795.523	0.0	−231	140	14.73
Mg I...........	2852.120	0.0	−25	207	14.78

stellar Fe III λ1083.176 and Si III λ1082.210, but this seems unlikely because its profile is sharper than that of Fe III λ1082.838, which is clearly visible. The C II line falls at 1333.47 Å, and the Mg II line at 2793.37 Å. No likely blending lines are listed in the tables of Kelly and Palumbo (1973) and of Striganov and Sventitskii (1968) for either of these lines. The rapidly moving cloud was not visible on the low-resolution scans (Underhill 1974*a*).

The spectrum profile near 1335 Å is shown in Figure 1. Here the highly displaced C II λ1334.532 component is clearly visible at 1333.5 Å, as well as the component of C II λ1335.708, which appears at −28 km s^{-1} with respect to the stellar lines. A component of C II λ1335 at −239 km s^{-1} would lie at 1334.64 Å, but no sharp component is visible there. There is a component from the ground-level line (1334.532 Å) at −29 km s^{-1}. The sharp component of C II λ1335.708 comes from a circumstellar shell where the density is sufficient to populate the $^2P_{3/2}$ level, which has an excitation energy of 63.42 cm^{-1}. At the time the low-resolution OAO-3 spectrum scans were made, the strong stellar C II, N II, and Mg II resonance lines were displaced shortward by about 120 km s^{-1}. The weak, sharp components which show the large outward motion in the present scans would not have been visible at the lower resolution. Similar sharp components displaced by about −235 km s^{-1} are not seen for Si IV, which suggests that the level of ionization is lower in the rapidly moving cloud than it is in the main stellar atmosphere.

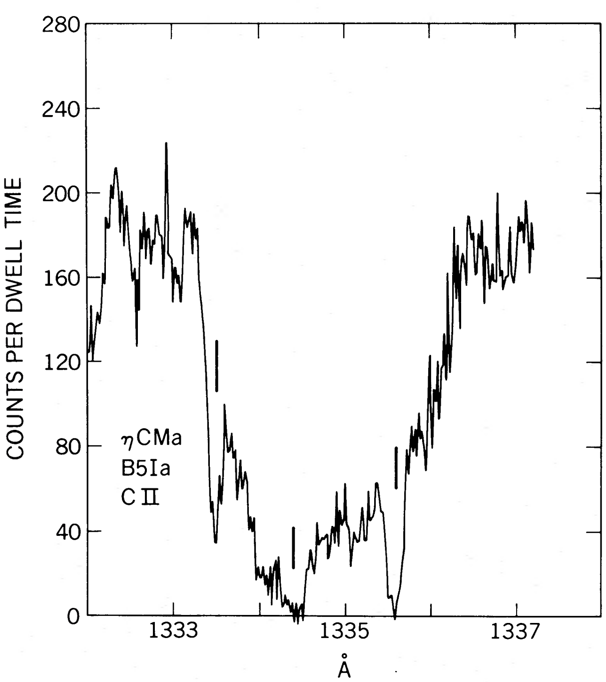

FIG. 1.—High resolution profile of the C II lines at 1334.53 and 1335.71 Å.

Figure 2 shows the central part of the blended N I resonance lines at 1134 Å. The heavy line represents the N I line blend due to the stellar atmosphere. It is estimated from comparison with a profile predicted using Mihalas's (1972) non-LTE model with $T_{\rm eff}$ = 17,500 K and log g = 2.5, which represents the atmosphere of η CMa reasonably well. The prediction assumes that the N I lines are formed in LTE, and that they are broadened by a microturbulence of 15 km s^{-1}, by radiation damping, and by a rotation of 50 km s^{-1}. The rotation is introduced to simulate the broadening which the lines in the visible part of the spectrum show. In the N I lines there is significant absorption due to a circumstellar shell. The circumstellar lines are sharp, there being no blending of N I λ1134.415 and N I λ1134.980 as there would be for a rotation of 50 km s^{-1}. Since the circumstellar shell lines show little or no rotation, the material producing them must lie at a distance of 5 or 10 stellar radii from the photosphere where the broad lines are formed. The average column density for N I, log NH, is 18.0.

The rapidly moving cloud is not visible in N I, nor is it visible in Mg I or Na I, which indicates that the rapidly moving cloud has a higher degree of ionization than the slowly moving circumstellar shell which is

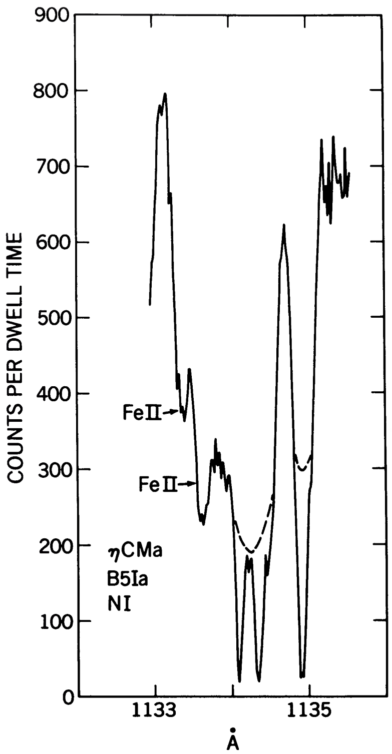

FIG. 2.—High resolution profile of the N I lines at 1134.17, 1134.42, and 1134.98 Å.

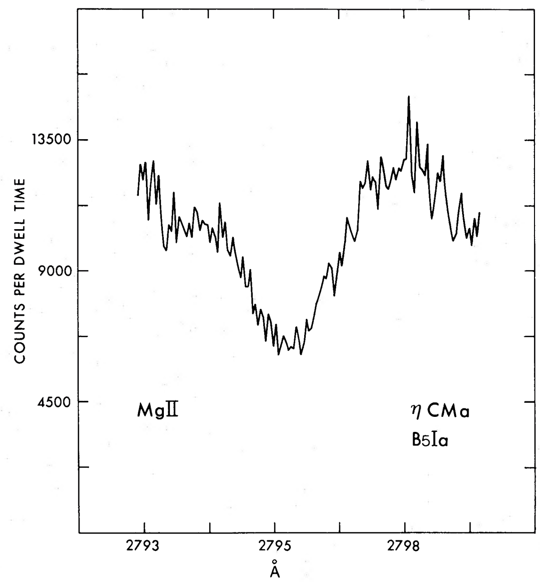

FIG. 3.—High resolution profile of Mg II 2795.523. The noise level lies near 6300 counts.

seen in N I, Mg I, and Na I as well as in C II, N II, Fe II, and possibly Si IV.

The central part of the profile of Mg II λ2795.523 as observed with the *Copernicus* high-resolution V1 scanner is shown in Figure 3. The background noise level lies near 6300 counts per 14-second interval. A strongly displaced component due to a cloud moving at about $-235\ \mathrm{km\ s^{-1}}$ appears at 2793.37 Å. The main line is displaced $-25\ \mathrm{km\ s^{-1}}$ with respect to the velocity of the star. There is no evidence for an absorption line at about $-120\ \mathrm{km\ s^{-1}}$ as there was at the time the low-resolution scans (Underhill 1974, 1975) were obtained. The velocity field in the outer part of the atmosphere of η CMa appears to vary. Such variations are also shown by changes in the shape of the Hα emission (Underhill and Fahey 1973).

The profile of the strong Mg II line, when interpreted by means of the Minnaert-Unsöld empirical formula,

$$\frac{1}{A_\lambda} = \frac{1}{A_c} + \frac{1}{\tau_\lambda} ,$$

where A_λ is the absorption at wavelength λ and A_c is the central absorption, yields an optical depth τ_λ which, at distances greater than 0.1 Å from the line center, indicates an absorption coefficient which varies as $\Delta\lambda^{-2}$. Thus this observed profile is consistent with a damping profile for the line absorption coefficient. The observed Mg II line is much stronger than that predicted using LTE theory and a model with $T_{\mathrm{eff}} = 17{,}500$ K, $\log g = 2.5$, because that line has a residual intensity of 0.39 at its deepest part and it shows no damping wings. It gives a lower limit to the line which may be expected to originate in the stellar atmosphere, for non-LTE effects will result in a stronger line than LTE calculations give (Snijders 1974). The observed strong Mg II line must come in part from the circumstellar shell which produces the Mg I and Na I lines.

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