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A C IV EMISSION FEATURE IN THE NEAR-ULTRAVIOLET SPECTRUM OF THE WOLF-RAYET STAR γ^2 VELORUM

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ABSTRACT

Spectrophotometric satellite observations in the ultraviolet of the binary γ^2 Vel are presented. Spectral features are tentatively identified. An explanation for the strength of the dominating C IV λ2529.97 emission line is suggested. The diffuse red wing of this line suggests mass transfer from the Wolf-Rayet star to the O-type component.

Subject headings: binaries — emission-line stars — line identification — mass loss — spectra, ultraviolet — stars, individual — Wolf-Rayet stars

I. INTRODUCTION

On 1972 May 17, 18, and 19, the Utrecht Orbiting Stellar Spectrophotometer S59 (Hoekstra *et al.* 1972*a*) on board the ESRO TD-1A satellite observed the multiple star γ Velorum. This system consists of a single star γ^1 Vel ($m_v = 4.25$, B1 IV, Hiltner, Garrison, and Schild 1969) separated by 45″ from the double-lined spectroscopic binary γ^2 Vel (WC8 + O8, Baschek and Scholz 1971), which is 2.4 mag brighter in the visible. This Wolf-Rayet star along with ζ Pup probably plays a part in the excitation of the Gum Nebula, the largest H II region known in our Galaxy (Maran, Brandt, and Stecher 1971).

This paper gives a preliminary account of the observations in the 2500 Å channel of S59 (2498–2592 Å).

II. OBSERVATIONS

Of the 35 scans of γ Vel recorded by S59, at this time only three are available for analysis. In order to improve the signal-to-noise ratio, the three scans were averaged; the resulting spectrum is shown in figure 1.

In the measured wavelength region the background radiation is less than 0.5 percent, and the statistical noise is about 0.9 percent of the total counting rate. Judging from the S59 counting rates of similar stars—e.g., η Hya ($m_v = 4.10$, B3 V)—the contribution of γ^1 Vel to the measured continuum counting rate is expected to be less than 6 percent. As the central depth of the absorption lines in the S59 ultraviolet spectrum of η Hya is less than about 15 percent, the noise in the spectrum of γ^2 Vel caused by the presence of γ^1 Vel is expected to be less than 1 percent, which is of the same order as the statistical noise. Hence the contribution of γ^1 Vel to the spectrum can be neglected.

III. PRELIMINARY LINE IDENTIFICATIONS

The identification is complicated by the different radial velocities of the two components of the binary γ^2 Vel. Ganesh and Bappu (1967) measured the radial velocities of the emission lines, attributed to the WC8 component, and the absorption lines assigned to the O8 component. From the given period of 78.5 days and the given radial velocity curves, we calculate that (*a*) S59 observed γ^2 Vel in phase 0.65 of

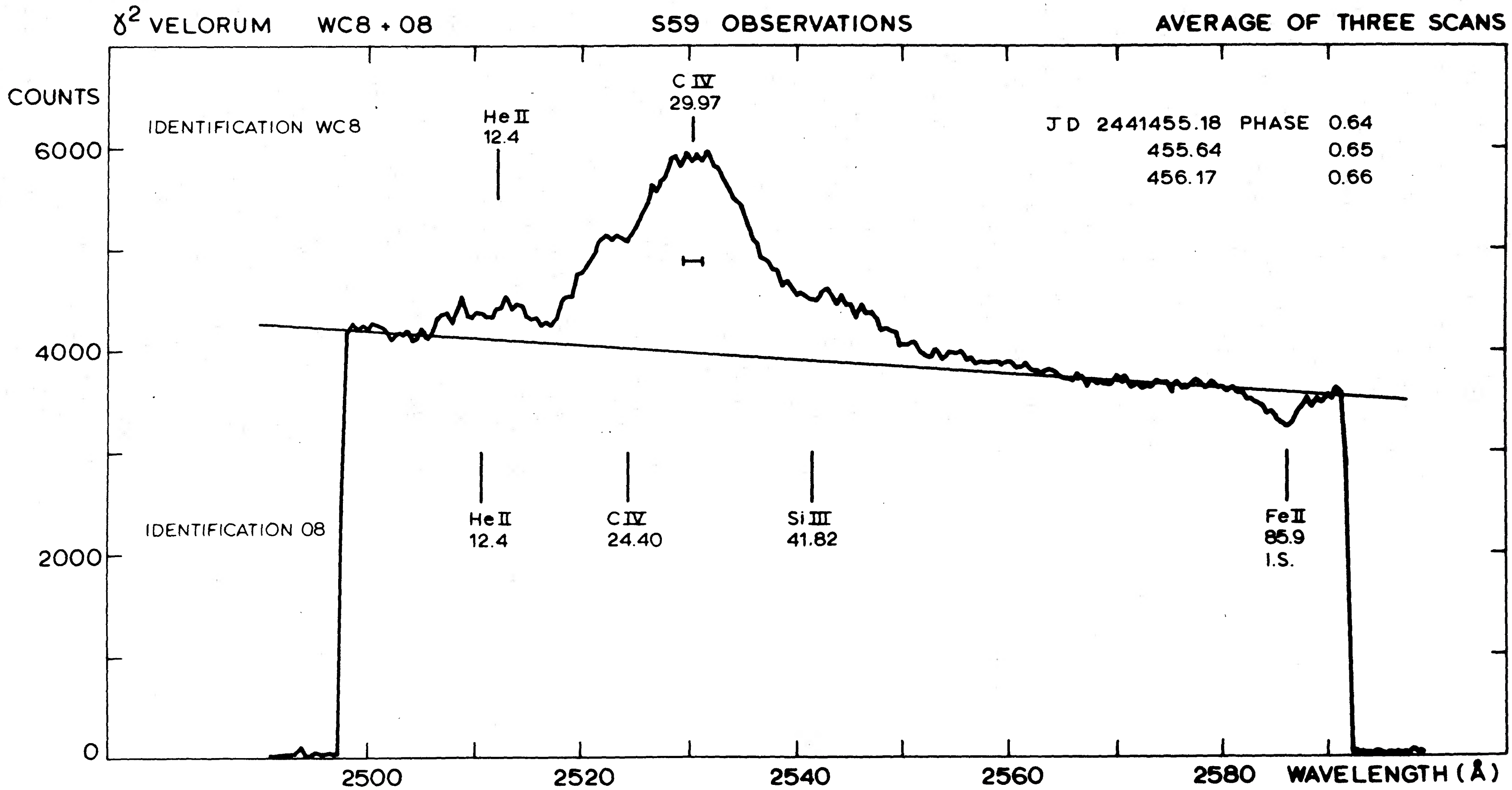

FIG. 1.—The spectrum of γ^2 Vel (WC8 + O8), as observed in the 2500 Å channel of S59. Flux in instrument counts. — indicates the spectral resolution of 1.8 Å.

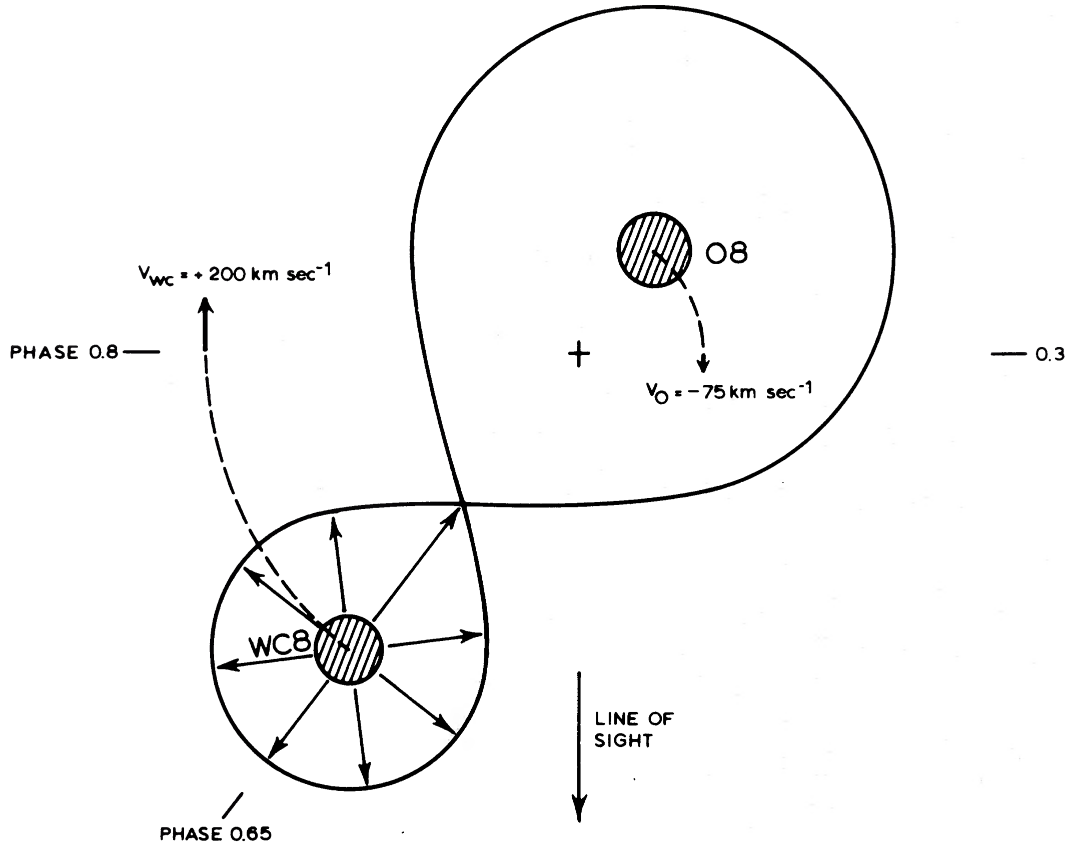

FIG. 2.—The binary configuration of γ^2 Vel at the time of the S59 observations: phase 0.65. The radius of the WC star was taken from Hanbury Brown *et al.* (1970). The plus sign indicates the center of gravity. The phases of maximum radial velocity according to Ganesh and Bappu (1967) are indicated.

the radial-velocity curve (see fig. 2); (*b*) at this phase the expected redshift for the emission lines of the WC component amounts to 1.1 Å, and the expected blueshift for the absorption lines of the O star to 0.5 Å.

After this correction for the orbital velocity and the correction for the system radial velocity, the only remaining uncertainty in wavelength is the 0.5 Å uncertainty of the preliminary wavelength calibration of S59. Using this tolerance of ± 0.5 Å, the following identifications were made (see table 1).

He II λ2512.4 (Pδ). This line was first observed by S59 in absorption in the spectrum of the O5f star ζ Pup (van der Hucht, in preparation). The He II absorption line of the O8 component is probably superposed on the broad He II emission line of the WC8 component, and the wavelength shift between the two lines is assumed to cause the asymmetric profile around 2512 Å. He II emission in the optical spectrum of WC stars was already known (Underhill 1966).

C IV λ2524.40 ($4d\,^2D$–$5f\,^2F^o$). This line we expect to observe in absorption from the O8 component. Indeed, at the expected wavelength a depression in the large emission feature is observed. The corresponding emission line in the spectrum of the WC8 component, if present, cannot be separated from the much stronger emission line C IV 2529.97.

C IV λ2529.97 ($4f\,^2F^o$–$5g\,^2G$). This emission line dominates the presented spectrum (fig. 1). The ultraviolet spectrum of γ^2 Vel from 1200 to 3100 Å has been investigated

TABLE 1

WAVELENGTHS AND PRELIMINARY IDENTIFICATIONS OF FEATURES IN THE SPECTRUM OF γ^2 VELORUM

	PROPOSED IDENTIFICATION			
MEASURED* WAVELENGTH (Å)	Spectrum	$\lambda_{(lab)}$ (Å)	Mult. No. or Name	Origin†
2510.6a	He II	2512.4	Pδ	O
2512.1e	He II	2512.4	Pδ	WC
2524.3a	C IV	2524.40	14	O
2530.3e	C IV	2529.97	15	WC
2541.1a	Si III	2541.82	8	O
2586.2a	Fe II	2585.9	1	IS

* a = absorption; e = emission.

† WC = WC star; O = O8 star; IS = interstellar.

by Stecher (1970) during a rocket flight with a spectral resolution of 10 Å. Probably due to this low resolution he erroneously identified the mentioned emission line as C IV λ2524.40 ($4d$–$5f$). Also Code and Savage (1972) from OAO observations of low resolution (about 20 Å) identified this feature as C IV λ2524.40. The corresponding absorption line in the spectrum of the O8 component may be responsible for the slightly flattened top of the emission feature.

Si III λ2541.82 ($3p\ ^1P^o$–$3d\ ^1D$). Absorption of this line was observed earlier by S59 in the spectrum of β CMa (Hoekstra *et al.* 1972*b*).

Fe II λ2585.9 ($a\ ^6D_{9/2}$–$z\ ^6D^o{}_{7/2}$). This interstellar absorption line was first observed in the S59 spectrum of ζ Pup by De Boer *et al.* (1972).

When in the near future S59 spectra of other O8 stars are available, it may become possible to completely separate the contributions of the O8 star and the WC8 star. Especially the C IV emission and absorption need unraveling.

IV. THE RECOMBINATION SPECTRUM OF C IV

Many C IV lines have been observed in emission in WC8 stars, of which below 7730 Å the strongest per $n \to n-1$ transition are given in table 2. The first four rows of the table suggest a preference for transitions between levels with maximum azimuthal quantum number. These are also the transitions with highest Einstein coefficients at given principal quantum numbers, as is shown in table 3 for 5–4 and 6–5 transitions. This is in agreement with the assumption of a recombination spectrum, i.e., recombination followed by cascade.

TABLE 2

C IV LINES IN WC8 STARS

Multiplet	λ (Å)	Source
$7i$–$6h$	7726	Edlén 1956
$6h$–$5g$	4658	Baschek and Scholz 1971
$5g$–$4f$	2530	This paper
$4f$–$3d$	1169	Morton, Jenkins, and Brooks 1969
$3p$–$3s$	5801	Baschek and Scholz 1971
$2p$–$2s$	1548, 1551	Stecher 1970

TABLE 3

C IV *gf*-VALUES AND EINSTEIN COEFFICIENTS (A) FOR 4–5 AND 5–6 TRANSITIONS, COMPUTED USING THE SCALED THOMAS-FERMI METHOD (cf. Van Rensbergen 1970)

Multiplet	λ (Å)	*gf*	A (10^8 s^{-1})
4*s*–5*p*.	2104	0.429	1.08
4*p*–5*d*.	2405.1	3.067	3.54
4*d*–5*f*.	2524.41	8.859	6.62
4*f*–5*g*.	2529.98	19.731	11.42
5*s*–6*p*.	3936	0.459	0.33
5*p*–6*d*.	4441.8	3.075	1.04
5*d*–6*f*.	4647	8.380	1.85
5*f*–6*g*.	4658.3	16.583	2.83
5*g*–6*h*.	4658.3	30.172	4.22

In such a case the levels with highest azimuthal quantum number are preferably populated, which explains that the line 5*g*–4*f*, λ2529.97 is much stronger than the line 5*f*–4*d*, λ2524.40.

V. LINE PROFILE AND VELOCITY FIELD

The strong C IV λ2529.97 emission line has an estimated equivalent width $W_\lambda = 9$ Å with $(F_\lambda - F_c)/F_c = 0.5$ (c stands for the continuum of the composite spectrum). The total half-width (19 Å) of the line, explained in terms of a differential velocity field, corresponds to a velocity of radial ejected mass of about 1100 km s^{-1}. This is similar to the outstreaming velocities derived from the optical spectrum (Code and Bless 1964).

The C IV emission line shows a diffuse red wing. This is in agreement with observations by Code who reports diffuse red wings of lines such as the C IV λ5801 emission line. Code explains this as a replenishment of mass to the WC8 component. However, we suggest that the red wing indicates mass transfer from the WC star to the O star. From the binary period measured by Ganesh and Bappu we calculate the phase of Code's and our observations to be about the same, i.e., 0.61 and 0.65, respectively (see fig. 2). In this phase the O component is more remote than the WC component.

Hanbury Brown *et al.* (1970), with their stellar intensity interferometer, found the C III/IV λ4650 emission feature to originate near the critical Roche lobe around the Wolf-Rayet star. This makes it very likely that a part of the C IV ions is moving away from the WC component and heads for the O component alongside the Roche equipotential surface, with velocities up to 3500 km s^{-1} according to the extent of the red wing. We expect the diffuse red wing to have disappeared when S59 again observes γ^2 Vel in 1973 May, at which time the phase will be 0.30. At that time the two components will be at equal distances as seen from the solar system.

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Note added in proof.—A contribution to the extensive red wing of the C IV emission line may arise from the effect of electron scattering on the line profile, according to Auer and Van Blerkom (*Ap. J.*, **178**, 175, 1972).