

THE SINGLE-LINE WOLF-RAYET STAR EZ CMa REVISITED: ADDITIONAL EVIDENCE FOR A 3.8 DAY BINARY PERIOD

ROBERT LAMONTAGNE,^{a)} ANTHONY F. J. MOFFAT,^{a), b)} AND ANDRE LAMARRE
 Département de Physique, Université de Montréal, C.P. 6128, Succ. A., Montréal, Québec H3C 3J7, Canada

Received 30 October 1985; revised 10 December 1985

ABSTRACT

Precision continuum photometry shows that the variable WN 5 star EZ CMa has exhibited a complex but stably modulated light curve over the past five years, with one and only one period $P = 3.766 \pm 0.001$ days. Together with new spectroscopic data, as well as previously published spectroscopic, photometric, and polarimetric observations, these photometric variations support the hypothesis that EZ CMa is a second-stage Wolf-Rayet binary probably containing a neutron star. Pulsation- and rotation-related phenomena appear unlikely to account for the observed variations. Some peculiarities in the UV and x-ray behavior still remain to be explained.

I. INTRODUCTION

EZ CMa = HD 50896 is an apparently bright, variable Wolf-Rayet (W-R) star of intermediate nitrogen-subclass WN 5. Recent optical investigations (especially those of Firmani *et al.* 1980—hereafter referred to as FKBMI; McLean 1980; Cherepashchuk 1981; and Niemela and Mendez 1982, to all of which the reader is referred for more details) have revealed strong variations in line profiles, radial velocities, light, and polarization—all consistent with a binary orbit of period $P = 3.763 \pm 0.002$ days. If the binary interpretation is correct, the unseen companion would be of low mass ($1.3 \pm 0.4 M_{\odot}$) and would likely be a neutron star (NS). Several other W-R binary candidates may also harbor compact companions (Moffat 1982, 1983).

The evidence for a NS companion in EZ CMa has been apparently weakened recently by three factors: (1) The mean x-ray luminosity L_x ($0.5\text{--}4$ keV) $\approx 10^{33}$ erg s⁻¹ is comparable with that seen from single hot stars (O or other W-R) (Sanders, Cassinelli, and van der Hucht 1982) and significantly less than that seen among massive x-ray binaries (MXRB). (2) Variations in the P Cygni profile of N IV λ 1718 Å show no systematic phase dependency as might be expected on the basis of what one knows from *IUE* observations of MXRBs (Willis *et al.* 1985). (3) On a very speculative vein, Vreux (1984) has claimed that the spectroscopic variations in the lines of EZ CMa (as well as of most of the other W-R + compact (c) system candidates compiled by Moffat 1982, 1983) can be accounted for by the effects of nonradial pulsations.

However, in answer to these points one can say the following: (1) The observed x-ray spectrum at keV energies is relatively soft ($kT \approx 0.5$ keV) as for O stars in general. This implies that these x-rays are likely produced in the outer parts of the wind, where absorption along the line of sight to the observer is minimal. The detectability of the more crucial harder accretion-type x rays associated with the hypothetical NS companion remains an open question (cf. Vanbeveren, van Rensbergen, and de Loore 1982). Nevertheless,

EZ CMa is strongly variable in $0.5\text{--}4$ keV x rays, either with low amplitude on a short, possibly phase-dependent time scale, with minimum flux occurring as the companion passes through the far side of the W-R wind (Moffat *et al.* 1982), or with high amplitude on a long time scale (factor of 3 over 2 yr—cf. Pollock 1985). Among the x-ray data available so far for W-R stars, this appears to be exceptional. (2) Phase-dependent variations of N IV λ 1718 Å may be masked by a high intrinsic noise level. Alternatively, W-R + c systems may behave differently from O + c systems, even though Koenigsberger and Auer (1985) do detect phase-dependent variations of this line in several WN + OB systems. (3) If the variability of EZ CMa is due to nonradial pulsations, it becomes difficult to account for the phase-dependent, *double-wave polarimetric modulation* of this star, as seen in several other well-known W-R binaries (cf. Drissen *et al.* 1986). The binary explanation is clearly the most plausible one for EZ CMa from this point of view (McLean 1980).

In an attempt to settle the question of periodicity and duplicity of EZ CMa, we have recently obtained a relatively large number of precise photometric observations spread over several consecutive cycles. These data strongly support the 3.8 day period (and *only* this period). We also present some new spectral radial velocities (RV) obtained during several optical observing runs over recent years. These latter data, being relatively noisy, are less compelling, but do support the same periodicity.

II. OBSERVATIONS

a) Photoelectric Photometry

We have obtained two sets of precise photometric data since the work of Cherepashchuk (1981). Both of these involved the 61 cm Lowell telescope at CTIO, one run during 1980 December, 8 months after Cherepashchuk obtained his data, and a much more extensive run during 1985 March/April. The 1980 observations employed a blue sensitive (S11) tube and Strömgren *b* and *y* filters, the *b* filter including a substantial contribution from the strong emission features at λ 4600–4700 Å and the *y* filter being dominated by continuous emission. Each data point was derived by simple interpolation from a sequence of several 10 s integrations in the order: sky-c1-WR-c2-sky, where c1, c2 refer to the constant A-type comparison stars HD 50853 and HD 50711, respectively (cf. FKBMI). The 1985 observations employed a red-sensitive (GaAs) tube and broadband *V* and *I* filters,

^{a)} Visiting Astronomer, Cerro Tololo Inter-American Observatory, National Optical Astronomy Observatories, operated by the Association of Universities for Research in Astronomy, Inc., under contract with the National Science Foundation.

^{b)} Visiting Astronomer, Kitt Peak National Observatory, National Optical Astronomy Observatories, operated by the Association of Universities for Research in Astronomy, Inc., under contract with the National Science Foundation.

both dominated by continuum light from the W-R star. Stars were measured in the order sky-c1-WR-c2-WR-c1-sky. With σ_V (c1-c2) = 0.003 mag, the 1985 data are more precise than the 1980 data for which σ_V (c1-c2) = 0.006 mag. Table I lists the times and magnitudes of WR-c1.

b) Image-Tube Spectroscopy

We have obtained some 30 spectra from four runs: one at KPNO—1979 Sept using the #1 0.9 m telescope, and three

at CTIO—1980 Jan, 1980 Dec, and 1982 Jan, using the Yale 1 m telescope. All spectra were secured with a two-stage Carnegie image tube and hypersensitized IIIaJ (KPNO) or IIa O (CTIO) plates, covering the blue part of the spectrum ($\lambda\lambda$ 3700–5000 Å) with an instrumental resolution FWHM $\approx$ 1.5 Å.

Radial velocities were extracted using well-established methods (PDS scanning in density mode—cf. Moffat 1978 and Lamontagne 1983) for the strongest, least-blended emission lines available on these spectra, i.e., He II λ 4686 Å

TABLE I. Photometric observations.

HJD 2 440 000	Phase	WR-C1 Δy	Δb	$\Delta(b-y)$
4590.850	0.035	0.446	-0.374	-0.820
4591.567	0.225	0.541	-0.319	-0.860
4592.577	0.493	0.539	-0.312	-0.851
4592.846	0.564	0.519	-0.334	-0.853
4593.615	0.769	0.513	-0.340	-0.853
4593.840	0.828	0.528	-0.336	-0.864
mean		0.514	-0.336	-0.850
σ		0.035	0.022	0.016
σ (c2-c1)		0.006	0.008	0.008
		ΔV	ΔI	$\Delta(V-I)$
6149.516	0.913	0.613	0.415	0.198
6149.651	0.949	0.587	0.395	0.192
6150.504	0.175	0.649	0.440	0.209
6150.589	0.198	0.655	0.442	0.213
6151.501	0.440	0.644	0.436	0.208
6151.558	0.455	0.644	0.434	0.210
6151.619	0.471	0.641	0.435	0.206
6152.496	0.704	0.623	0.418	0.205
6152.547	0.718	0.629	0.420	0.209
6152.604	0.733	0.628	0.426	0.202
6153.496	0.970	0.579	0.384	0.195
6153.551	0.984	0.572	0.375	0.197
6154.496	0.235	0.649	0.446	0.203
6154.556	0.251	0.648	0.442	0.207
6154.606	0.264	0.645	0.439	0.206
6157.496	0.032	0.583	0.385	0.198
6157.544	0.045	0.586	0.389	0.197
6157.613	0.063	0.598	0.398	0.200
6158.500	0.298	0.640	0.434	0.206
6158.611	0.328	0.636	0.426	0.210
6159.503	0.565	0.645	0.432	0.213
6159.553	0.578	0.638	0.433	0.205
6159.607	0.592	0.638	0.429	0.209
6160.496	0.828	0.652	0.445	0.207
6160.544	0.841	0.652	0.442	0.210
6160.603	0.857	0.650	0.444	0.206
6161.496	0.094	0.616	0.403	0.213
6161.543	0.106	0.619	0.406	0.213
6161.641	0.132	0.637	0.433	0.204
6162.491	0.358	0.627	0.423	0.204
6162.542	0.372	0.627	-	-
6162.600	0.387	0.628	-	-
6163.493	0.624	0.635	-	-
6163.547	0.639	0.628	0.412	0.216
6163.595	0.651	0.623	-	-
6164.491	0.889	0.621	0.419	0.202
6164.540	0.902	0.615	0.413	0.202
6164.606	0.920	0.610	0.415	0.195
6165.493	0.155	0.622	0.415	0.207
6165.578	0.178	0.633	0.424	0.209
6166.511	0.426	0.630	0.422	0.208
6166.578	0.443	0.628	0.429	0.199
mean		0.627	0.421	0.205
σ		0.021	0.019	0.006
σ (c2-c1)		0.003	0.005	0.004

C1 = HD 50853 (A1)

C2 = HD 50711 (A2)

The phase is based on the ephemeris HJD 2 446 153.61 + 3.766 E corresponding to the time of maximum light (1980 - 85).

and the two He II Pickering lines at $\lambda\lambda$ 4199, 4338 Å (cf. FKBMI). The smooth line blend of N IV at λ 3483 Å, which best reflects the W-R orbit (FKBMI), was not available on the present spectra. Table II lists the times and RVs.

III. PERIODICITY

The most precise and complete data subset available to search for periodicity is the present 1985 *V* photometry. It contains 42 data points spread nearly contiguously over an interval of 17 days, with two or three observations at random times per night. The instrumental precision is high, $\sigma(c2-c1) = 0.003$ mag, compared to the W-R intrinsic rms variation of $7 \times \sigma(c2-c1)$.

We thus subjected our 1985 data to a period search using the nonparametric summing technique of Lafler and Kinman (1965). This method is superior to Fourier techniques

in the case of EZ CMA, since its light curve is strongly non-sinusoidal (see below). Periods were searched among the 1985 WR-c1 data in *V* over the interval 0.01 days $\approx$ 15 min $\leq P \leq 35$ days, with frequency step size $\Delta\nu = 0.006$ days $^{-1}$ ($\nu = 1/P$), appropriate for a complete period search of these data. The results are shown in Fig. 1. By far the best period to emerge is $P = 3.8 \pm 0.1$ days, corresponding to $\nu = 0.26$ days $^{-1}$. Other choices of significantly inferior probability occur at the alias frequencies $\nu' = n \pm \nu$, where $n = 1, 2, \dots$ (e.g., $\nu' = 0.76, 1.26, 1.75, 2.25, \dots$, becoming increasingly less probable at higher frequencies) as well as at the simple multiples $\nu/2$ and $\nu'/2$. We interpret this to imply that the aliases are spurious artifacts due to the dominating 1 day sampling interval and that only one period (3.8 days) is evident in this data set. This period is entirely compatible with the previously derived one based mainly on spectroscopic data by FKBMI and on polarimetry by

TABLE II. Spectroscopic radial velocities (km s $^{-1}$).

Plate	JD -2 444 000	Phase	Mean HeIIe 4199/4338 $\pm$ s.e.m.	HeIIe 4686
KPN0 Sept 79				
5133a	129.001	0.806	190	164
5138a	130.004	0.072	126	204
5139e	132.015	0.606	110	-
5143a	133.019	0.873	183	177
			mean: 152 $\pm$ 40 (σ)	182 $\pm$ 20 (σ)
CT10 Jan 80				
3294b	256.535	0.670	263	179
3299b	257.529	0.934	214	167
3303b	258.533	0.201	224	162
3309b	259.531	0.466	294	187
3315b	260.526	0.730	198	205
3321f	261.531	0.997	188	190
3328b	262.531	0.263	232	156
			mean: 230 $\pm$ 37 (σ)	178 $\pm$ 17 (σ)
CT10 Dec 80				
3784b	584.851	0.849	190	121
3788f	585.874	0.121	152	135
3794g	586.875	0.387	139	188
3798f	587.828	0.640	169	121
3803h	588.849	0.911	136	123
3808d	589.818	0.168	202	138
3813f	594.819	0.496	82	126
3817h	595.826	0.764	138	158
3873f	596.820	0.028	102	165
3828h	597.828	0.295	144	188
3834d	598.838	0.563	170	144
3838f	599.821	0.824	116	141
			mean: 145 $\pm$ 35 (σ)	146 $\pm$ 24 (σ)
CT10 Jan 82				
4723h	974.836	0.404	152	146
4724b	974.838	0.404	104	149
4729d	975.844	0.671	234	135
4733g	976.842	0.936	70	137
4738f	977.844	0.202	120	116
4744h	978.841	0.467	136	157
4750d	979.843	0.733	164	153
4756h	980.844	0.999	120	103
4761h	981.847	0.265	138	121
4767d	982.839	0.529	182	154
			mean: 142 $\pm$ 45 (σ)	137 $\pm$ 18 (σ)

Notes: standard error of the mean s.e.m. is the rms error based on the differences between He II 4199 and 4338.

The phase is based on the ephemeris JD 2 443 199.53
(WR star on front: Firmani et al. 1980) + 3.766 E.

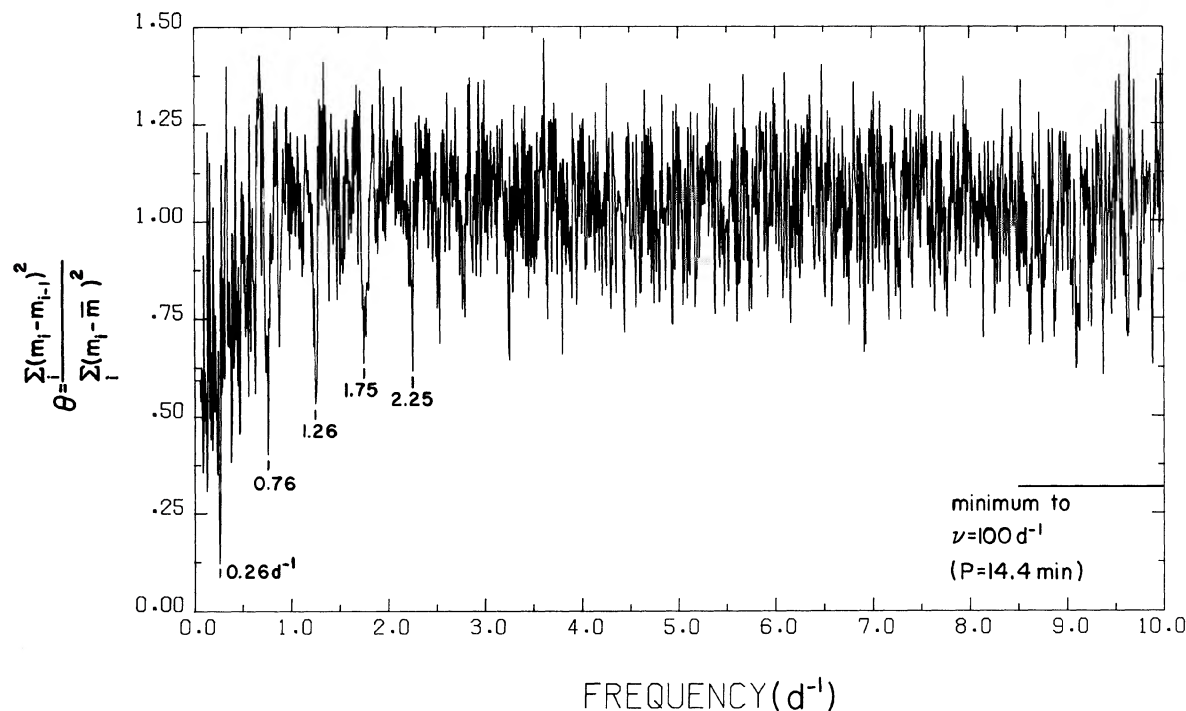


FIG. 1. Period search among the 1985 photometric data in V for WR-c1, according to the method of Lafler and Kinman (1965). The ordinate represents the normalized sum of the squares of the adjacent phase-sorted data points; the abscissa refers to the frequency. The most important minima are indicated with the appropriate frequencies ($\nu = 1/P$ in days $^{-1}$). The horizontal line at the bottom right represents the other deepest minima up to a frequency of 100 days $^{-1}$.

McLean (1980): $P = 3.763 \pm 0.002$ days. In particular we note the complete lack, to within the $\leq 1\%$ noise level, of periods from ~ 2 min to 6 hr in the photometric data for EZ CMa of Moffat and Haupt (1974), Cherepashchuk (1981), and the present 1985 observations. The general decrease of θ in Fig. 1 towards very low frequency is typical for these kind of period-search techniques using finite data strings.

We further draw attention to the fact that a simple curve drawn through the phased 1985 data for WR-c1 leads to a scatter of $\sigma(O - C) \simeq 0.005$ mag, similar to the instrumental scatter based on the comparison stars: $\sigma(c2-c1) \simeq 0.003$ mag. This also supports the hypothesis that one and only one period satisfies these data, with very little if any room left for intrinsic noise or other periodicities.

Application of the same period-searching technique to the Cherepashchuk (1981) V photometry alone yields the best period, $P = 3.77 \pm 0.03$ days. Although the uncertainty of this period estimate is smaller than our 1985 data, due to the longer time base, the elimination of shorter aliases is less convincing, since the 23 data points of Cherepashchuk contain fewer independent measures per night, on average. In any case, both Cherepashchuk's (1981) and the present 1985 data are each extremely coherent and repeatable over their 20 and 5 cycles, respectively.

As discussed below (Fig. 2) the shape of the light curve has varied little over the past ~ 5 yr. Hence, we can combine all the photometric data since 1980 (in V or y), allowing for magnitude zero-point differences between different runs, to give a best overall period $P = 3.766 \pm 0.001$ days, again entirely compatible with the independently determined FKBM period.

IV. THE LIGHT CURVE

In Fig. 2 we show a montage of all the six visual light curves available for HD 50896 (three from 1975, 1976, and 1977 in FKBM, one from Cherepashchuk 1981, and the two present ones), phased using the 1980–1985 light-curve ephemeris such that $\phi_{lc} = 0$ occurs at maximum light, HJD 2446153.61 + 3.766 E. From Fig. 2, we see that while the light curve after ~ 1980 has remained remarkably unchanged (with the exception of two points at $\phi_{lc} \simeq 0.50$ in the data of Cherepashchuk 1981), there is a long-term trend before that to a very small amplitude. For example, the 1977 data show a reduced amplitude (0.05 mag compared to 0.08 mag after 1980), but a much broader maximum centered still approximately at zero light-curve phase. The 1975 and 1976 data show only marginal evidence for variability, even after data binning. Overall, the photometric data imply that EZ CMa is variable with a stable light curve over relatively long time scales (years) but can also become remarkably constant over similar time scales.

Another revealing source of information arises from the phase-dependent color variations. Such variations are very small, as can be seen in Fig. 3, where the 1985 I and $V - I$ photometry are plotted. The same lack of phase-dependent color variations applies to the color indices of Cherepashchuk (1981) and FKBM. However, our 1980 $b - y$ data do show a small phase dependence. This can likely be explained by a lack of coherence between variations in the strength of the strong emission feature that dominates the b filter, and the continuum in that filter and in the y filter.

Finally, we note that the 1980–1985 primary light maxi-

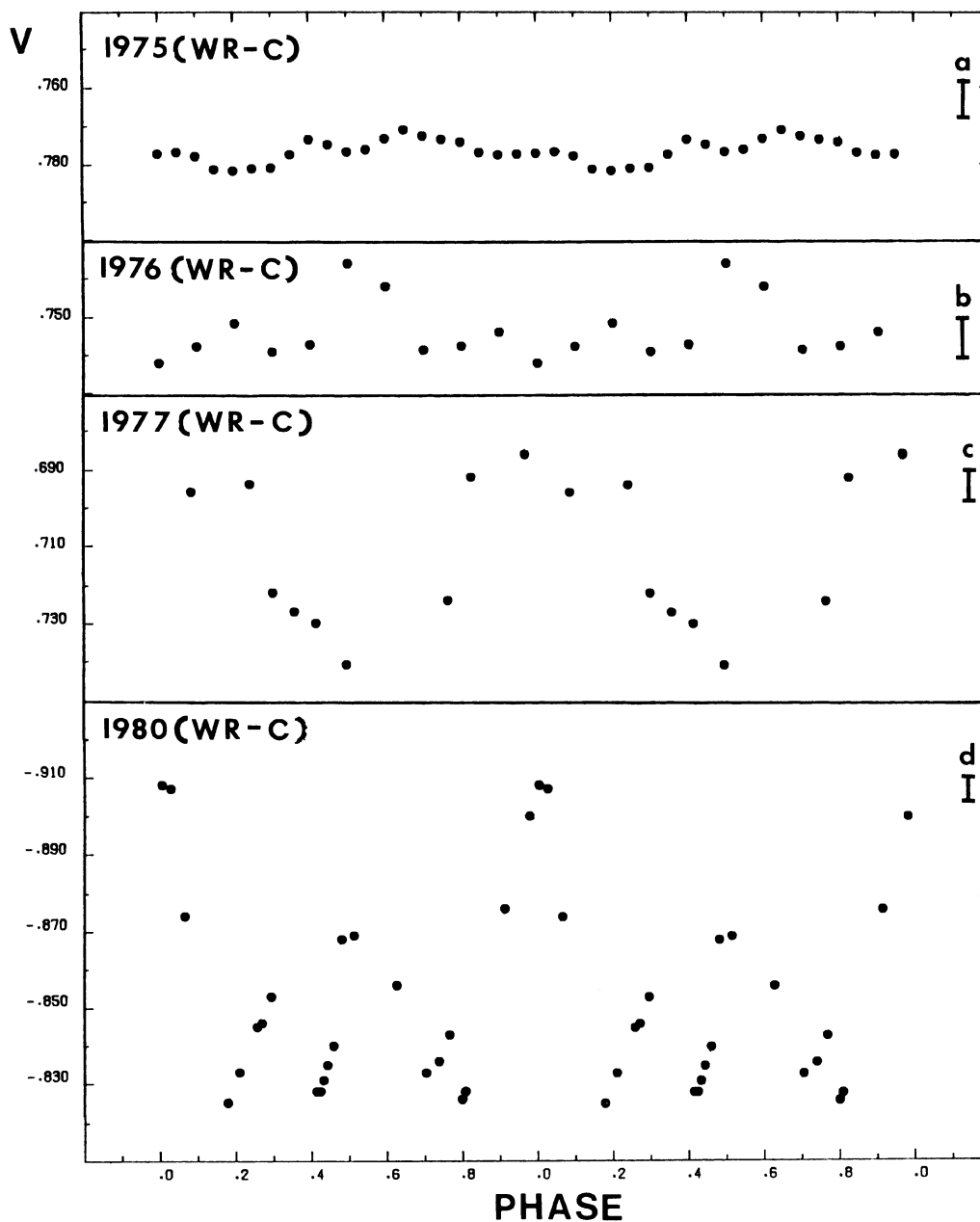


FIG. 2. Visual magnitudes (WR star minus comparison star) versus phase based on the ephemeris for maximum light (1980–1985), $P = 3.766$ days, $E_0 = \text{HJD } 2\,446\,153.61$, for six *independent* data subgroups: (a–c) from Firmani *et al.* (1980) with (a) from 1975 with binning in 0.1 phase intervals and double overlap, (b) from 1976 with binning in 0.2 phase intervals and double overlap, (c) from 1977, (d) from 1980 (Cherepashchuk 1981), (e) from 1980, this paper, (f) from 1985, this paper, and (g) for c1–c2 from 1985, this paper, c–g without binning. The error bar indicates 2σ , where σ is the standard deviation for each point based on binning statistics in (a) and (b), published estimates in (c) and (d), and the scatter in the magnitudes of c2–c1 in (e) and (f). The standard deviation of the points about a simple mean is indicated by s.d. The phase is based on the ephemeris $\text{HJD } 2\,446\,153.61 + 3.766 E$ corresponding to the time of maximum light (1980–1985).

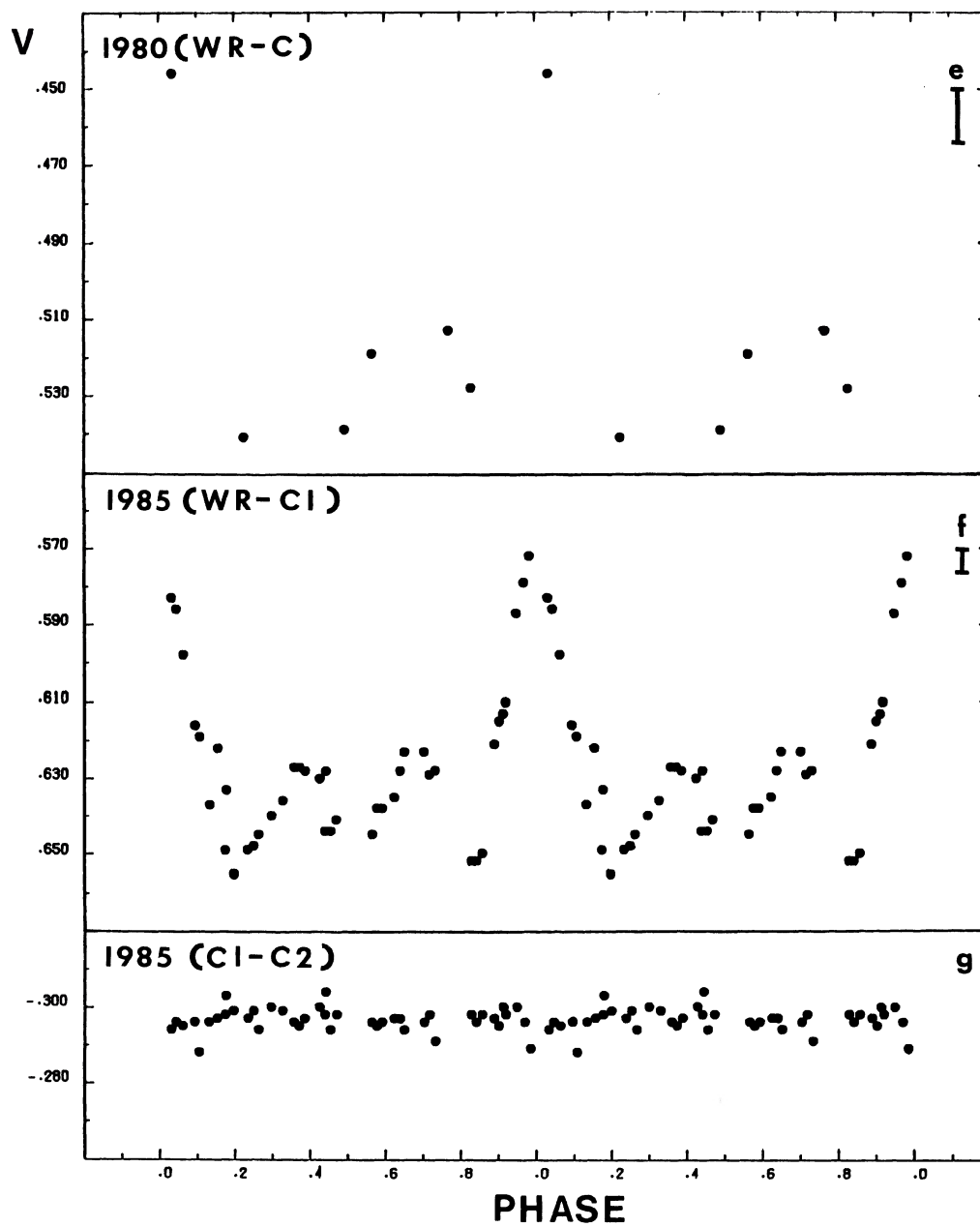


FIG. 2. (continued)

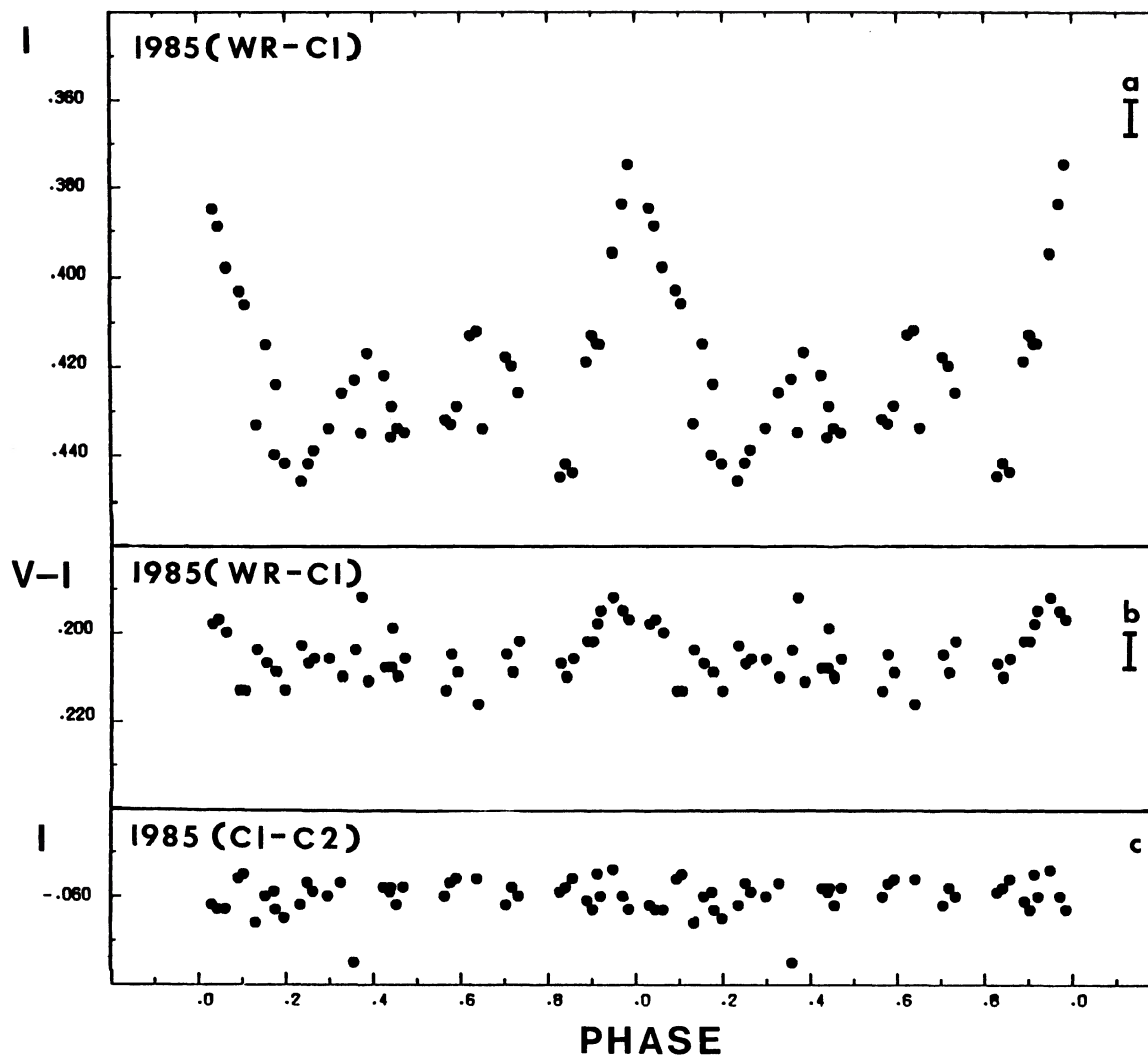


FIG. 3. Near-infrared (I) and $V-I$ data from 1985 (this paper) versus the light-curve phase for WR-c1 [I in (a), $V-I$ in (b)] and c2-c1 [in (c)].

mum, of amplitude ~ 0.08 mag, coincides with the time of passage of the companion in front of the W-R component, in the binary model of FKBM1 (we adopt their orbital-phase origin and the present period).

V. SPECTROSCOPIC ORBIT

Since the work of FKBM1 and Niemela and Mendez (1982) we now have four more epochs of RV data. In Fig. 4 we show each of these plotted versus orbital phase based on the FKBM1 zero point (the W-R star is in front at $\phi_{\text{orb}} = 0$) and the present period, $P = 3.766 \pm 0.001$ days. From Fig. 4 we note that the 1979 data are too few for a useful discussion of the 3.8 day period, while those of 1980 December are very noisy, despite the well-behaved light curve obtained during the middle of the corresponding spectroscopic run. The two other epochs (1980 January and 1982 January) show relatively clear phase-dependent RV variations. The fact that the systemic velocity does not coincide exactly with $\phi_{\text{orb}} = 0$

may be due to a slight imprecision in the period, or to intrinsic noise, which is prominent among these He II lines, as opposed to the smooth phase-dependent N IV λ 3483 Å RV variations on which the adopted FKBM1 orbit is based. The He II 4199/4338 data from 1980 January show a ~ 100 km s $^{-1}$ shift of unknown origin.

Qualitatively, one can state that the present RV variations are of the same amplitude as found by FKBM1 and by Niemela and Mendez (1982), with $K = 30 - 40$ km s $^{-1}$ for the Pickering He II emission lines and $K \approx 20$ km s $^{-1}$ for the He II 4686 emission line.

VI. DISCUSSION AND CONCLUSIONS

The main point of this paper is to draw attention to the relatively high amplitude, continuum light curve of EZ CMa, which remained stable during three epochs from 1980 to 1985. Before that, in 1977, the light curve was reduced in amplitude with a significantly broader primary maximum,

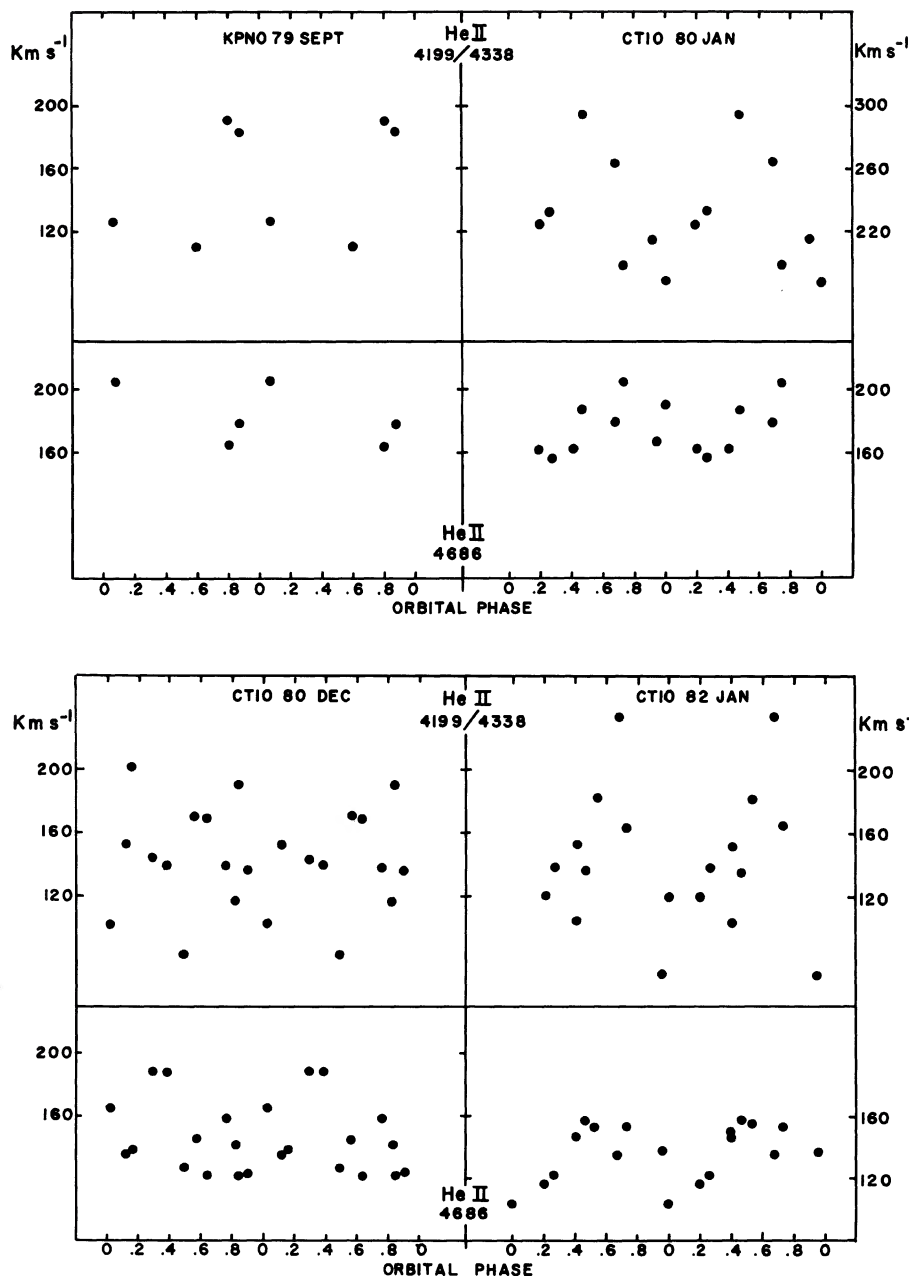


FIG. 4. Radial velocity for the best available emission lines versus orbital phase based on the ephemeris $JD\ 2\ 443\ 199.53 + 3.766\ E$, corresponding to the time of passage of the WR star in front.

but still centered near zero phase (cf. Fig. 2). In 1975 and 1976, variations were virtually absent. Especially important is that, when a period is found in any data subset (photometry, spectroscopy, or polarimetry), it is always compatible with the 3.766 day period based on the 1980–1985 photometry. Among the best-quality data sets, only this period satisfies the variations. In retrospect, the suggestion of a period change by Moffat (1983) was probably premature.

What can be the source of such a periodicity? Three main phenomena come to mind: (a) pulsations, (b) rotation, and (c) binary motion.

(a) Pulsations can be divided into radial and nonradial modes. Although radial pulsations induced by nuclear energizing processes have been predicted among H-poor W-R

stars (cf. Maeder 1985), no observational evidence has yet been found for such pulsations (cf. Moffat and Haupt 1974). Whether or not this is due to damping effects in the wind from which the observable radiation stems is an open question. In any case, for EZ CMa we see a clear 3.8 day periodicity (and only this period, down to a level of $\leq 1\%$ in continuous light), which can have nothing to do with radial pulsations, since they are expected to have periods in the range 15–60 min (Maeder 1985). Similar but less stringent arguments concerning the lengths of periods apply to nonradial pulsations, but are already unlikely in EZ CMa for another reason: a complete lack of evidence for *multiple* periods. It can thus be concluded that pulsations of any kind are not seen above the 1% level in EZ CMa, although the light

curve can vary by up to 8%. We further note that pulsational energy sources are probably no longer needed in any case to explain the high mass-loss rates of W-R stars, as demonstrated for the WN 5 component of the eclipsing binary V444 Cygni (Cherepashchuk, Eaton, and Khaliullin 1984; Pauldrach *et al.* 1985).

(b) Rotation (of a single star) with a stable period must involve an inhomogeneity such as a nearly permanent density perturbation in the wind. No such phenomenon is known to occur in any W-R star, although one *potential* possibility may be related to magnetically confined pockets of plasma (cf. Underhill and Fahey 1984). However, while the photometry and even the photometric variations might be reconcilable with this kind of theory, it is less obvious how to explain the double-wave polarimetric variations (cf. McLean 1980), since any such perturbation would be eclipsed during part of each rotation ($i \simeq 71^\circ$), yielding something more like a single (as opposed to the observed double) polarization wave per rotation. Also, there exists no direct evidence for magnetic fields in W-R stars. MacGregor and Friend (1984) argue on the basis of magnetically coupled wind braking calculations that initial magnetic fields in rotating massive stars must be significantly less than 100 G. The possibility of rotating hot or cold spots is diminished by the absence of phase-dependent color variations.

(c) The remaining mechanism, that of binary modulation, appears to be the most plausible. In particular, this offers the most natural explanation for the double-wave cyclic polarization variations (McLean 1980). Also, the 3.8 day period falls well within the span of known binary periods for W-R stars, which range upwards of 1.6 days and fall off rapidly in frequency above ≈ 20 days. Taking the FKBMI orbit as still valid, the unseen companion would have a mass of $1.3 \pm 0.4 M_\odot$, assuming the W-R star to have a mass of $10 M_\odot$, like that for the same type W-R component in the eclipsing WN 5 + O6 binary V444 Cygni. This makes the hypothesis of a NS companion very attractive, as noted by FKBMI and Cherepashchuk (1981) in particular. If the companion were not a NS, it would have to be a relatively low-mass main-sequence star or a massive white dwarf. While it would be difficult to explain how a low-mass star evolved to the white dwarf stage before a high-mass star became a W-R star, a main-sequence star does not emit enough light to explain the observed light curve, even in the best case of a total eclipse. Also, as pointed out by Garmany *et al.* (1980), most, if not all, massive binaries probably have original mass ratios not drastically different from unity.

Having a NS companion, EZ CMa would fill an important gap in the evolution of massive binaries, from O + O through WR + O, c + O (after a SN explosion: partly spent as an x-ray binary), c + WR, and finally breaking up in most cases as two runaway compact stars (high-velocity pulsars?) c + c. The general trend of the light curve probably has the same origin as the excess line emission from the companion star as it orbits within the W-R wind (cf. FKBMI). Assuming the extreme case of total occultation of this source in going from "in front" to "in back" of the wind, we get a limit for the optical luminosity $L_{v,2} \gtrsim 0.1 L_{v,WR}$. Hence, if the bolometric correction is identical for both sources, and $L_{WR} = 10^{39} \text{ erg s}^{-1}$, we find $L_2 \gtrsim 10^{38} \text{ erg s}^{-1}$, which is roughly compatible with the degraded energy rate expected for an accretion disk emitting close to the Eddington limit around a NS companion. The long-term variations in the light curve may be related to fluctuations in the accretion rate of the compact secondary. Such variations may be induced by a slow change in mass-loss rate from the W-R star, as claimed for the WC 8 component in the W-R + O binary CV Ser (cf. Massey and Niemela 1981). The complex structure of the light curve (secondary minima) may be a consequence of accretion wakes (Cherepashchuk 1981).

However, there remain several questions in the interpretation as WR + c, for which no answers are yet available, for lack of another clear case like EZ CMa. The most severe questions have been mentioned in the Introduction: (1) lack of accretion-type x rays, and (2) lack of phase-dependent modulation of the P Cygni profile in the UV line N IV λ 1718 Å. While both of these points might be dismissed as a consequence of peculiarities in the dense W-R wind itself compared to O + c systems, future work must be aimed at solving this problem definitively. In particular, one needs more precise photometric, spectroscopic, and polarimetric monitoring, as well as a sensitive search for phase-dependent *hard* x rays, which should be able to escape even from a relatively thick accretion disk seen fairly edge-on. A sensitive search in the radio domain for a modulated nonthermal component beyond the very few independent observations of Hogg (1982) may also prove fruitful.

We are grateful to the NOAO for generous allotments of observing time. We also thank A. Pollock and an anonymous referee for useful comments. This project is financially supported by the Conseil National de Recherche en Sciences et en Génie of Canada.

REFERENCES

- Cherepashchuk, A. M. (1981). *Mon. Not. R. Astron. Soc.* **194**, 765.
 Cherepashchuk, A. M., Eaton, J. A., and Khaliullin, Kh. F. (1984). *Astrophys. J.* **281**, 774.
 Drissen, L., Lamontagne, R., Moffat, A. F. J., Bastien, P., and Seguin, M. (1986). *Astrophys. J.* (in press).
 Firmani, C., Koenigsberger, G., Bisiacchi, G. F., Moffat, A. F. J., and Isserstedt, J. (1980). *Astrophys. J.* **239**, 607. (FKBMI).
 Garmany, C. D., Conti, P. S., and Massey, P. (1980). *Astrophys. J.* **242**, 1063.
 Hogg, D. E. (1982). In *Wolf-Rayet Stars: Observations, Physics, and Evolution*, IAU Symposium No. 99, edited by C. W. H. deLoore and A. J. Willis (Reidel, Dordrecht), p. 221.
 Koenigsberger, G., and Auer, L. H. (1985). *Astrophys. J.* **297**, 255.
 Lafler, J., and Kinman, T. D. (1965). *Astrophys. J. Suppl.* **11**, 216.
 Lamontagne, R. (1983). Ph. D. thesis, Université de Montréal.
 MacGregor, K. B., and Friend, D. B. (1984). *Bull. Am. Astron. Soc.* **16**, 996.
 Maeder, A. (1985). *Astron. Astrophys.* **147**, 300.
 Massey, P., and Niemela, V. S. (1981). *Astrophys. J.* **245**, 195.
 McLean, I. S. (1980). *Astrophys. J. Lett.* **236**, L149.
 Moffat, A. F. J. (1978). *Astron. Astrophys.* **68**, 41.
 Moffat, A. F. J. (1982). In *Wolf-Rayet Stars: Observations, Physics, and Evolution*, IAU Symposium No. 99, edited by C. W. H. deLoore and A. J. Willis (Reidel, Dordrecht), p. 263.
 Moffat, A. F. J. (1983). In *WR Stars: Progenitors of Supernovae?*, Paris Workshop, edited by M. C. Lortet and A. Pinault (Observatoire de Paris, Paris), p. III. 13.
 Moffat, A. F. J., and Haupt, W. (1974). *Astron. Astrophys.* **32**, 435.
 Moffat, A. F. J., Firmani, C., McLean, I. S., and Seggewiss, W. (1982). In *Wolf-Rayet Stars: Observations, Physics, and Evolution*, IAU Symposium

- No. 99, edited by C. W. H. deLoore and A. J. Willis (Reidel, Dordrecht), p. 577.
- Niemela, V. S., and Mendez, R. H. (1982). In *Wolf-Rayet Stars: Observations, Physics, and Evolution*, IAU Symposium No. 99, edited by C. W. H. deLoore and A. J. Willis (Reidel, Dordrecht), p. 295.
- Pauldrach, A., Puls, J., Hummer, D. G., and Kudritzki, R. P. (1985). *Astron. Astrophys.* **148**, L1.
- Pollock, A. M. T. (1985). Private communication.
- Sanders, W. I., Cassinelli, J. P., and van der Hucht, K. A. (1982). In *Wolf-Rayet Stars: Observations, Physics, and Evolution*, IAU Symposium No. 99, edited by C. W. H. deLoore and A. J. Willis (Reidel, Dordrecht), p. 589.
- Underhill, A. B., and Fahey, R. P. (1984). *Astrophys. J.* **280**, 712.
- Vanbeveren, D., van Rensbergen, W., and deLoore, C. (1982). *Astron. Astrophys.* **115**, 69.
- Vreux, J. M. (1984). *Publ. Astron. Soc. Pac.* **97**, 274.
- Willis, A. J., Howarth, I. D., Conti, P. S., and Garmany, C. D. (1985). In *Luminous Stars and Associations in Galaxies*, IAU Symposium No. 116, edited by C. W. H. deLoore, A. J. Willis, and P. G. Laskarides (Reidel, Dordrecht) (in press).