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AN EIGHT-YEAR SPECTROSCOPIC ORBIT FOR THE WC7 + O4 WOLF-RAYET BINARY HD 193793: TOWARD SOLVING THE MYSTERY OF THE INFRARED OUTBURSTS

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ABSTRACT

Some 60 yr of spectroscopic radial velocity data combined from many different sources lead to a 7.9 yr period for this once enigmatic system. The masses and mass ratio derived are compatible with other close systems containing stars of similar type. It is no coincidence that infrared flux enhancement occurs just before periastron passage in the $e = 0.7$ orbit.

Subject headings: infrared: sources — stars: binaries — stars: individual — stars: Wolf-Rayet

I. INTRODUCTION

HD 193793 is a clear case of a Wolf-Rayet (W-R) spectrum with diluted emission lines, superposed on a hot continuum with relatively narrow O-type absorption lines (McDonald 1947). The breadth of the prominent C IV λ4650 line blend corresponds to the hot WC5 class, while the line strength ratio C IV ~5800/C III λ5696 corresponds to WC 7; hence, the W-R component has often been classified as WC7p, with p indicating "peculiar." Despite the obvious spectral duplicity of this bright star (with $v = 7.2$ mag it is the brightest known W-R star in the northern sky), a spectroscopic orbit was obtained only recently by Lamontagne, Moffat, and Seggewiss (1984). These authors derived an orbital period of 2.97 yr, with greater weight being placed on the emission-line radial velocities (RV). Directly thereafter, Conti *et al.* (1984) published more RVs and were not able to confirm the 2.97 yr period, nor were they able to derive any other period. They claimed HD 193793 to be a chance line-of-sight coincidence between a W-R star and an O star.

Since the last-mentioned work above, three new developments have emerged. First, Moffat *et al.* (1986*a*) have shown that HD 193793 has no visual companion of $|\Delta m| \leq 2$ mag down to a separation of $0\farcs05$, thus making the case for a line-of-sight coincidence extremely unlikely. Second, Moffat and Shara (1986) have found low-amplitude (0.01 mag) broad-band light variations with a possible period of 6.25 days over a 2 week period in 1984 June. The source of the variability could be intrinsic to either star (~0.02 mag allowing for mutual dilution of the light) or could be due to a close binary companion of one of the stars. Third, Williams *et al.* (1986) have related the 1985 dust formation episode detected in the infrared to the 1977 outburst and earlier observations. This shows that the IR outbursts occur at intervals of 7.9 yr. They also phased the published absorption-line velocities against the IR variations and argued for the existence of a 7.9 yr orbit of high eccentricity. These results have prompted us to reassess all published as well as newly available RV data together, in order to check the reality of the high-eccentricity binary system from the velocities alone.

II. OBSERVED RADIAL VELOCITIES

The bulk of the RVs available are those published by Lamontagne, Moffat, and Seggewiss (1984) and Conti *et al.* (1984). We supplement these (see Table 1) with several plates and one Reticon observation from other observatories, as

TABLE 1

SOURCES OF THE RADIAL VELOCITIES

Observatory	Years	Number of Plates[a]	Reciprocal Dispersion (Å mm^{-1})
	Lamontagne *et al.* 1984		
DAO	1921–1946	39	30
DAO	1978	14	78
KPNO	1978–1981	31	47
Mont Mégantic	1979–1982	19	45
	Conti *et al.* 1984		
Lick	1969–1970	20	16
Mount Wilson	1972–1973	3	20
Mount Palomar	1973	2	18
KPNO	1973–1979	25	17
DAO	1980–1983	6	20
	This Work		
Hoher List	1975	2	30
Ondrejov	1975–1981	7	17
Ondrejov	1981	1	8.5
DDO	1980	2	43
Calar Alto	1985	1	60

[a] Only the KPNO 1978–1981 and some of the Mégantic plates were obtained using an image tube; the rest are direct plates except for the Calar Alto Reticon datum.

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TABLE 2

New Radial Velocities of HD 193793

Plate No.	JD (2,440,000.+)	Mean Absorption (km s^{-1})	Emission (C IV λ4650) (km s^{-1})
	Ondrejov		
2090	2476.	−21	292
2468	2862.	11	176
2566	2939.	−8	216
2652	3031.	−6	200
2803	3289.	18	232
3024	3716.	−2	231
4146[a]	4831.	0	340
4294	4885.	−11	290
	Hoher List		
C3626	2624.	−6	...
C3628	2629.	+2	...
	DDO		
44947	4477.	−4	217
45125	4523.	−24	190
	Calar Alto		
N2151	6313.	−8	...

[a] Higher dispersion (8.5 Å mm^{-1}).

listed in Table 2. We note that all the Lamontagne *et al.* and the present data were reduced in exactly the same fashion, viz., RVs were obtained by bisecting parabolic fits to the upper (lower) $\sim\frac{2}{3}$ of the emission (absorption) line profile in rectified photographic density mode for the photographic plates (cf. Lamontagne, Moffat, and Seggewiss 1984) and direct intensity using the Reticon. Conti *et al.* reduced their data in a different way, viz., using the cube of intensity; it is therefore not surprising that their RVs for the *asymmetric* line of C IV λ4650 differ from those obtained here and by Lamontagne *et al.*, while the narrower, symmetric absorption lines of the O star show no large differences. A correction of −65 km s^{-1} added to Conti *et al.*'s (1984) RVs of C IV λ4650 brings their velocities into better agreement with the other values. The only absorption-line correction necessary was to add +5 km s^{-1} to the Ondrejov RVs, based on the observed mean shift of the Ca II K line.

III. PERIOD SEARCH

Since short periods are not evident in any of the groups of RV data, we follow the recipe of Lamontagne, Moffat, and Seggewiss (1984) and Conti *et al.* (1984) in grouping spectra into 10 day bins. However, this was only carried out for spectra in the same group as defined in Table 1. This led to a total of 55 absorption-line mean RVs (normally for Hβ, Hγ, Hδ, but also with other fainter absorption lines if measurable), about half of

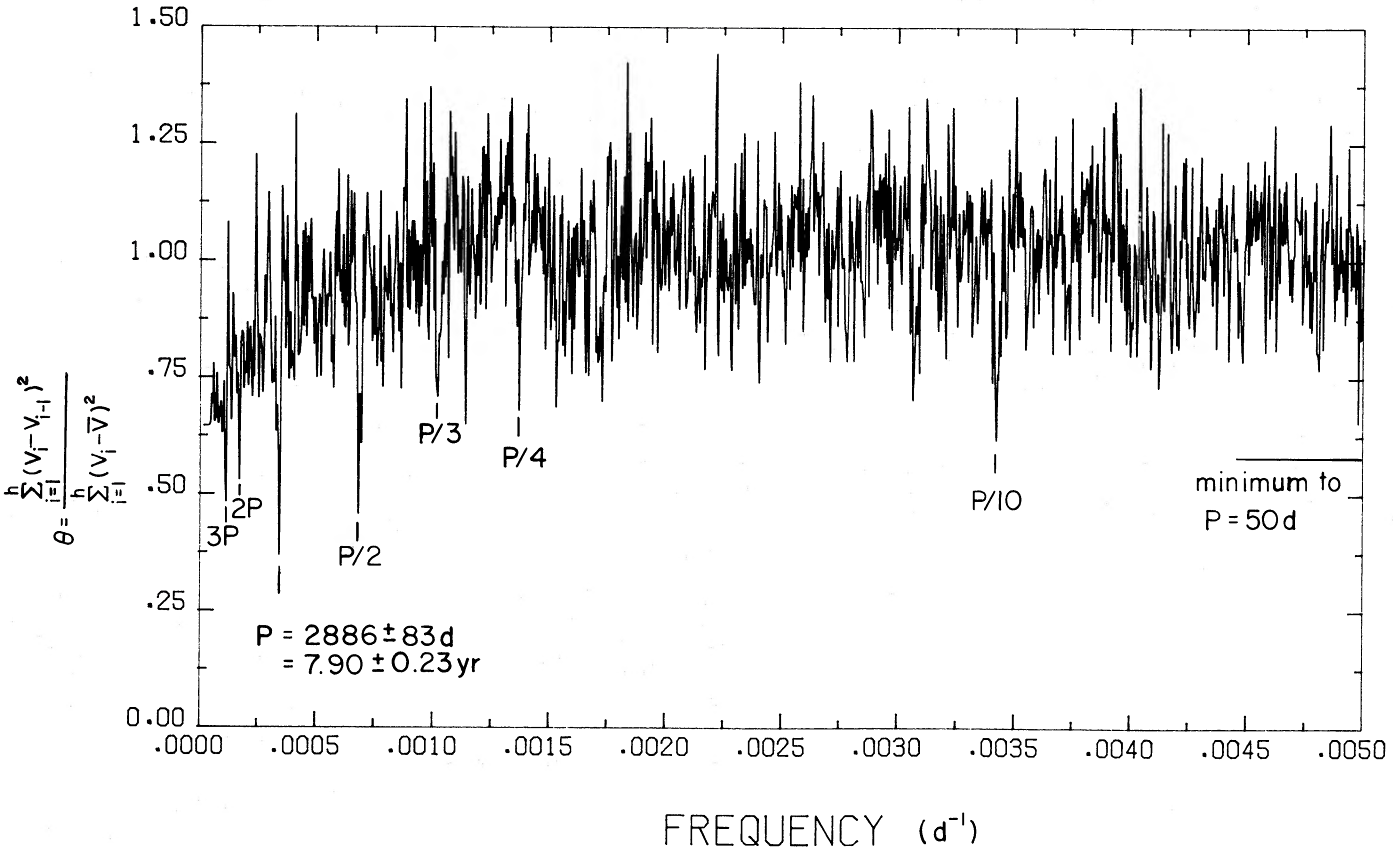

FIG. 1.—Normalized scatter function (cf. Lafler and Kinman 1965) vs. frequency for the mean absorption velocities in 10 day bins

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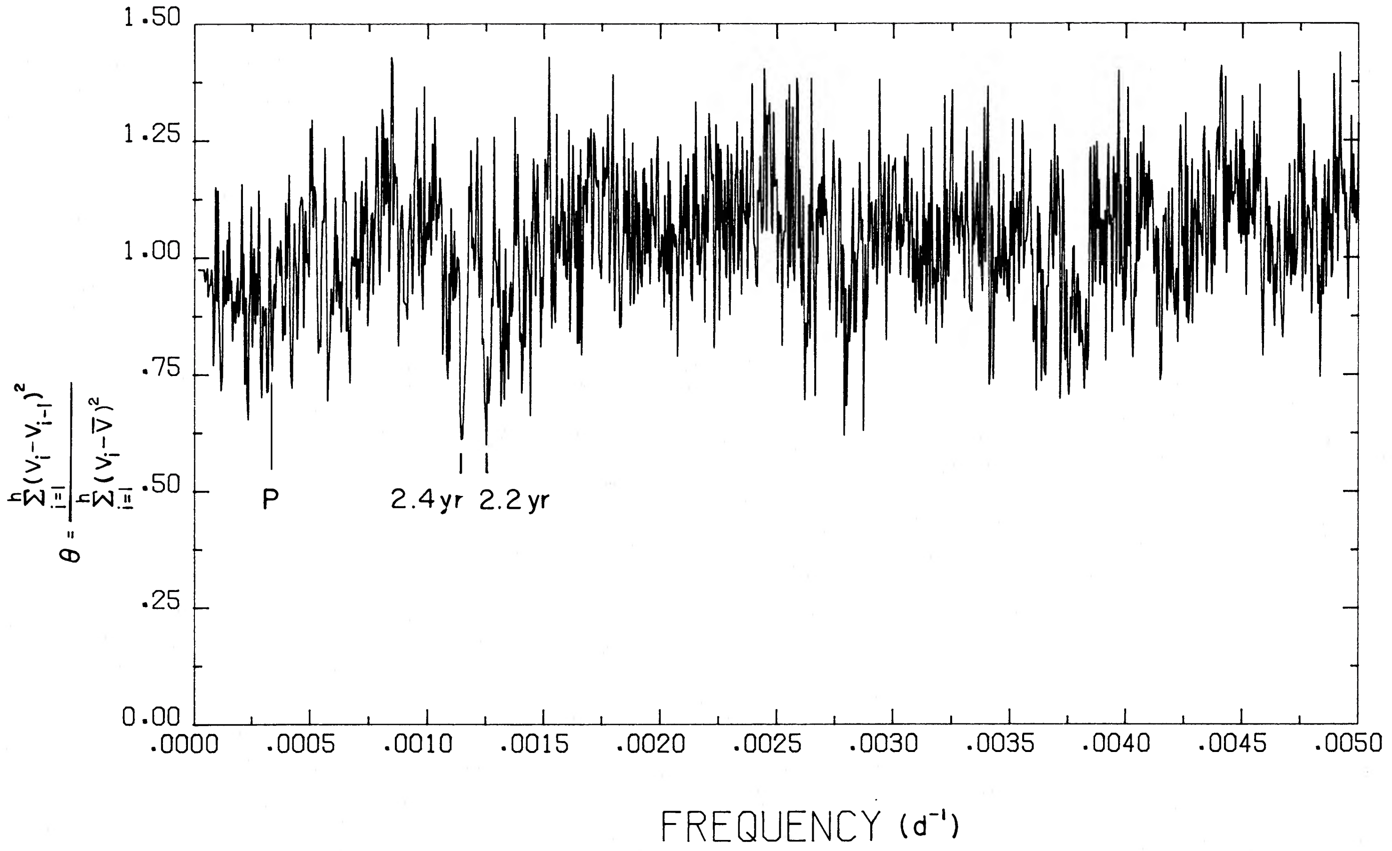

FIG. 2.—Normalized scatter function vs. frequency for the C IV λ4650 emission-line RVs in 10 day bins

which are bins containing at least two points. For the emission line, there are 38 RVs, with about half based on only one plate. If there are intrinsic variations of the order of days (e.g., $P = 6.25$ days from Moffat and Shara 1986), they are not evident below $K_{\mathrm{WR}}(\mathrm{C\ IV}\ \lambda4650) \approx 50$ km s^{-1} or $K_0(\mathrm{abs}) \approx 10$ km s^{-1}, corresponding to the probable noise level in determining the RVs.

In view of the sufficiently large number of RVs and the strong possibility of a noncircular orbit, we submitted the absorption-line mean and the emission-line C IV RVs to a period search using the nonparametric method of Lafler and Kinman (1965). Periods were scanned from $P = 50$ days to $\sim$100 yr in equal frequency ($\nu = 1/P$) steps $\Delta\nu = 1/(30T)$, where $T = 60$ yr, the total time span of the data. This allows adequate resolution in order not to miss any periods in this range. The results are shown in Figures 1 and 2. While the emission-line RVs appear to be too noisy to yield any meaningful estimate of a possible period, the absorption-line RVs yield a best period $P = 7.9 \pm 0.2$ yr. A statistical test (Nemec and Nemec 1985) gives a maximum probability of 1% (in a 95% confidence interval) that the period is spurious. This is based on a period search using the same method as above on 250 random permutations of the original data. As expected, simple multiples or fractions of this value do yield decreased scatter, but never as much as with this period. The agreement between the RV period determined here and the independently determined IR burst period ($P = 7.90 \pm 0.04$ yr; Williams *et al.* 1986) we take to be more than a mere coincidence. In fact, as is discussed in § V, No. 4, IR outbursts tend to occur just before periastron passage, as one would expect in a simple model involving some kind of interaction between the two stars.

IV. ORBITAL PARAMETERS

We begin by fitting the better quality absorption-line RVs, with a fixed period $P = 7.9 \pm 0.2$ yr as obtained above, but with variable eccentricity e, longitude ω and epoch T_0 of periastron passage, amplitude K, and systemic velocity γ. We

TABLE 3

ORBITAL PARAMETERS AND DEDUCED QUANTITIES FOR HD 193793 (WC7 + O4 V)

Quantity	O-Star Absorption (mainly Hβ, Hγ, Hδ)	W-R–Star Emission (C IV λ4650)
γ (km s^{-1})	-3 ± 1	$+242 \pm 8$
K (km s^{-1})	22 ± 3	40 ± 17
P (yr)	7.9 ± 0.2	
e	0.7 ± 0.05:	
ω_0	42 ± 10	$180 + 41 = 221$
T_0 (JD)	$2{,}423{,}069 \pm 35$	
E_0[a] (JD)	$2{,}426{,}065 \pm 42$	$2{,}427{,}508 \pm 42$
$\sigma(O-C)$ (km s^{-1})	10	46
$M \sin^3 i\ (M_\odot)$	17 ± 8	9 ± 4
M(W-R)/M(O)	0.55 ± 0.23	
$a \sin i$ (AU)	11.7 ± 5	
$(1 + e)/(1 - e)$[b]	5.7 ± 1.1	

[a] Time of passage in front toward the observer.

[b] Apastron/periastron.

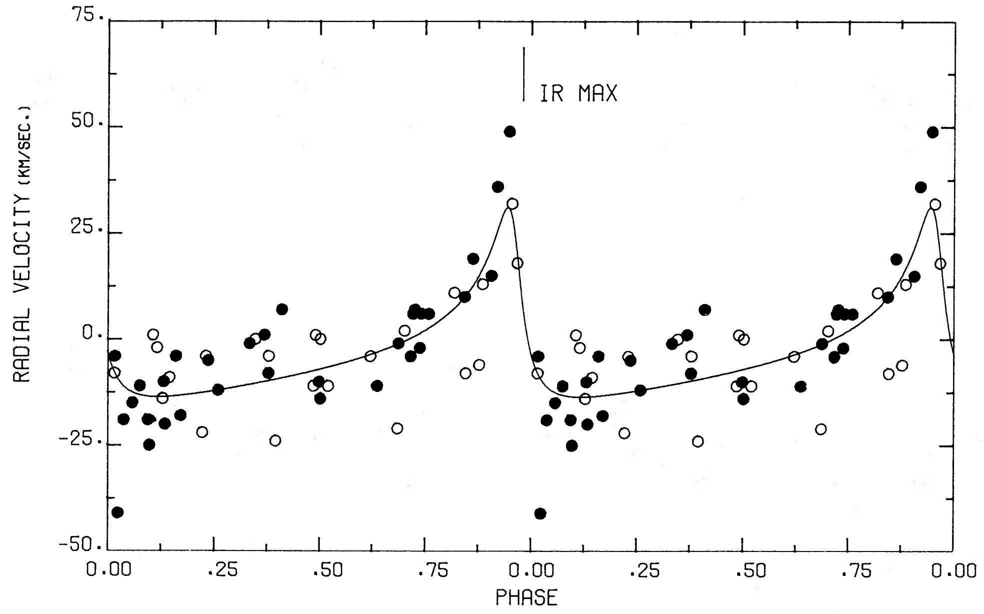

FIG. 3.—Phased plot of the mean absorption RVs with the calculated orbit as in Table 3. Zero phase corresponds to the time of passage E_0 of the O component in front toward the observer. *Open symbols*, bins with only one datum point; *filled symbols*, mean of at least two points. The IR maximum was taken at epoch 1985.40 = JD 2,446,212 from Williams *et al.* (1986), i.e., phase 0.981 here.

find a best eccentricity $e = 0.82 \pm 0.04$. We then inspected RV orbits for fixed $e = 0.6$, 0.7, 0.8, and 0.9 respectively. These showed that $e \approx 0.7$ produces the best overall fit with $O-C$ scatter distributed most uniformly in phase. We thus adopt $P = 7.9$ yr and $e = 0.7$ for the final fit of the presently available absorption-line RVs. For the noisy emission-line RVs, we further constrain the fit with $\omega(\text{emis}) = \omega(\text{abs}) + 180°$ and $T_0(\text{emis}) = T_0(\text{abs})$. This leads to the orbital elements and deduced parameters in Table 3. The phased data with fitted curves are depicted in Figure 3 (mean absorption-line) and Figure 4 (emission-line).

Note that we have assumed the existence of two stars, one W-R, the other O-type, in mutual 7.9 yr orbit, despite the lack of conclusive independent evidence of even a significant period for the emission-line data. While we consider this mutual orbit to be the most likely situation to explain (*a*) the well-established absorption-line orbit, (*b*) the presence of two distinct stars (an O star with an apparently normal Population I abundance and a WC star with enhanced C/N and reduced H/He), and (*c*) the IR outbursts occuring just before periastron passage, it nevertheless remains to be proven beyond a doubt. We will attempt to do this during the next orbit, using RVs from spectra of high signal-to-noise ratio and high dynamic range.

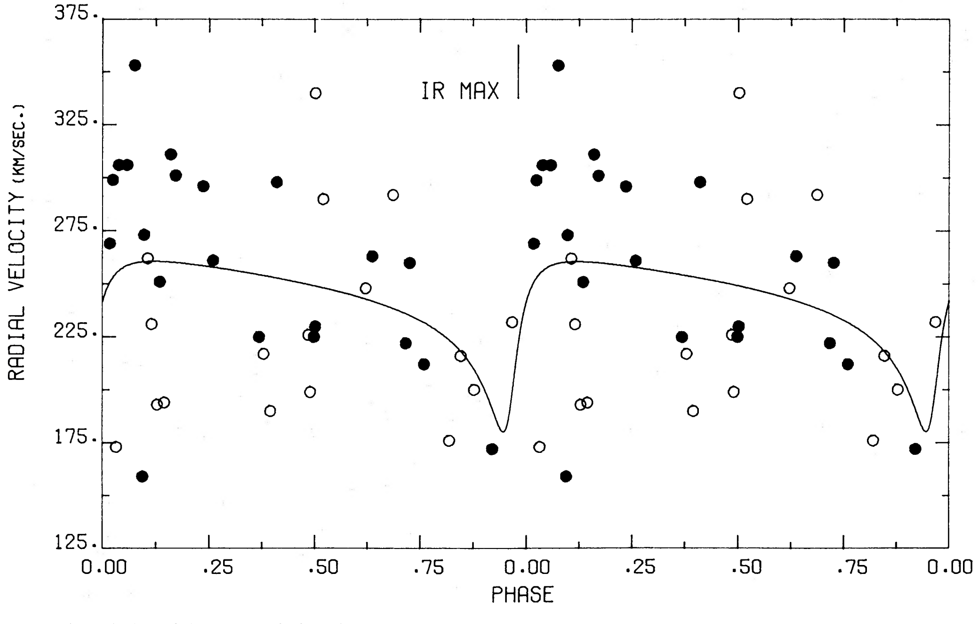

FIG. 4.—Phased plot of the C IV emission-line RVs with the calculated orbit as in Table 3. Symbols and phase as in Fig. 3.

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V. DISCUSSION AND CONCLUSIONS

We note the following:

1. The high eccentricity ($e = 0.7$) is normal for binary systems of long period. A value of e close to 0.5 is typical for stars of $P \gtrsim 100$ days (Batten 1973).

2. Apart from HD 193077 (WN6 + O9), which appears to have a double-line orbit with $P = 4.8$ yr according to Lamontagne *et al.* (1982), the next shortest system, HD 190918 (WN4.5 + O9.5 Ia), has $P = 112.7$ days $= 0.31$ yr, while the shortest known is CQ Cep, with $P = 1.64$ days $= 0.0045$ yr (see compilation of van der Hucht *et al.* 1981). If a significant number of binary stars of long period are yet to be found among the W-R stars, one may have to revise the binary frequency upward. Moffat *et al.* (1986*a*) estimate a 10% increase to ~46% binary frequency if all Galactic W-R + abs stars in the catelog of van der Hucht *et al.* (1981) are in fact binaries. Whether they are close binaries ($P \lesssim$ a few years) with case B mass transfer or not is another matter. If W-R binaries have a Gaussian frequency distribution of mean separation a like that of normal stars with $\langle a \rangle \approx 1$ AU (Shara *et al.* 1986), one would indeed expect to find many more wide W-R binaries.

3. The individual masses, $M \sin^3 i$, are $9 \pm 4\, M_\odot$ and $17 \pm 8\, M_\odot$ for the WC7 and the O4 V component respectively. If $i = 60°$ (mean value in a random sample), one finds $M_{\rm WR} = 14 \pm 6\, M_\odot$ and $M_{\rm O} = 26 \pm 12\, M_\odot$. Both these masses appear to be reasonable (cf. Massey 1981). If the O4 V star has a normal mass for its spectral type of $\sim 50\, M_\odot$, we find $M_{\rm WR} = 28 \pm 12\, M_\odot$, which is also acceptable. The mass ratio $M_{\rm WR}/M_{\rm O} = 0.55 \pm 0.23$ falls in the range of that for other late-type WC stars; Moffat *et al.* (1986*b*) find a mean ratio 0.49 ± 0.09 (σ) for five binaries with WC6–8 components.

4. The occurrence of IR outbursts just before the time of periastron passage suggests some sort of tidal triggering activity (suspected but not found by Lamontagne, Moffat, and Seggewiss 1984, who we now know did not find the right period). Three possible processes come to mind:

a) Wind collisions between the WC 7 and O4 V stars. If the energy released varies as $1/r^2$, where r is the instantaneous separation, one finds an enhancement of a factor $5.7^2 = 32$ during the short interval of periastron passage compared to apastron.

b) Increased accretion of WC7 wind material by a neutron star companion in a 6.25 day orbit around the WC7 star.

c) Enhanced interaction of stellar magnetic fields at periastron.

Williams *et al.* (1986) give reasons for preferring (*a*).

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