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A LONG-PERIOD ORBIT FOR THE BINARY WOLF-RAYET STAR HD 193793, WC7 + O4–5

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ABSTRACT

HD 193793 is shown to be a WC7 + O4–5 binary with an orbital period of 1085 days (2.97 yr) and a mass ratio of $M_{\text{W-R}}/M_{\text{O}} = 0.22 \pm 0.09$. The orbital parameters yield a mass of approximately 13 $M_\odot$ for the WC7 component assuming a mass of approximately 60 $M_\odot$ for the O star. HD 193793 has the second longest period of any known W-R binary. No correlation of the orbit (e.g., periastron passage) with the two recently observed IR outbursts is apparent.

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

I. INTRODUCTION

The Wolf-Rayet (W-R) star HD 193793, W-R no. 140 in the Sixth Catalogue of Galactic Wolf-Rayet Stars (van der Hucht *et al.* 1981), is one of a group of eight bright ($v \leq 8.5$) W-R stars in the Cygnus region of the Milky Way. Five of these stars are already known or suspected binaries: HD 190918 and HD 193576 = V444 Cygni are "classical" WR + OB systems (Fraquelli 1977; Ganesh, Bappu, and Natarajan 1967); HD 192163 and HD 191765 are probable W-R + collapsed star systems (Koenigsberger, Firmani, and Bisiacchi 1980; Aslanov and Cherepashchuk 1981; Antokhin, Aslanov, and Cherepashchuk 1982); and HD 193077 might be a triple system consisting of a W-R star, a collapsed star, and an O star (Lamontagne *et al.* 1982).

As early as 1947, HD 193793 was suspected to be a binary system (McDonald 1947) because of its two distinct sets of lines: broad emission (and violet displaced absorption; see Underhill 1962) from the W-R component and O type absorption. However, no periodic radial velocity variations were found. Later, Conti (1971) noted a possible period of one or several years, based on spectra collected over a span of approximately 10 years. More recently, Conti and Roussel-Dupree (1984) claimed HD 193793 to be a single WC7 star with absorption lines. Cherepashchuk (1976) also suggested a possible period of 326 days for this star.

The spectral classification in the catalog of van der Hucht *et al.* (1981) is: WC7 + absorption. Our new spectroscopic data combined with a more precise reduction of old plates from the Dominion Astrophysical Observatory (partly those of McDonald 1947) do not confirm HD 193793 to be a *single* WC7 star with absorption lines. These observations are presented and discussed.

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II. OBSERVATIONS

The new spectroscopic observations were obtained at the Dominion Astrophysical Observatory (DAO), Kitt Peak National Observatory (KPNO), and at the Observatoire du mont Mégantic (OMM). We also analyzed spectroscopic plates from DAO archives spanning more than 25 years. All these observations are described in Table 1. All plates were scanned on the PDS at the David Dunlap Observatory in the photographic density mode with a 10 μm wide slit and a 5 μm sampling interval. The scans were then smoothed with a Gaussian filter of FWHM 30 μm.

Radial velocities for the best lines (see Fig. 1) were derived by fitting a parabola to the emission (comparison and stellar) and absorption (stellar) lines of each spectrum. The parabola was always fitted over the same wavelength range for a given line on all plates, regardless of the source. In the case of the emission spectrum, only the blend C III/IV λ4650 + He II λ4686 was measurable; for the absorption, we measured the velocities of Hβ, Hγ, Hδ, and the interstellar Ca II lines (K and H). We obtained -15 ± 2 km s^{-1} for the K line and 53 ± 3 km s^{-1} for the H line, the latter being blended with Hϵ. In Table 2 we present the mean radial velocities of the emission line C III/IV λ4650 as well as the mean of Hβ, Hγ, and Hδ for subgroups of observations with little spread in time (see below).

III. ANALYSIS OF THE DATA

a) *Spectral Type*

If the absorption spectrum of HD 193793 results from a companion star, as we suggest (see below), the question of the correct spectral type arises. For O type stars, the MK spectral class is determined by the line ratio He I λ4471/He II λ4541. Taking into account that, in the vicinity of the lines, the contribution from the emission spectrum is relatively small (see Conti and Smith 1972), a close inspection of Figure 1 shows that this ratio is very small. We therefore conclude that the spectral class of the absorption component of

TABLE 1

SPECTROSCOPIC OBSERVATIONS OF HD 193793

Description of Observation	Dominion Astrophysical Observatory	Kitt Peak National Observatory	Observatoire du mont Mégantic
Dates	1921–1946/1978 May	1978 Sep/1979 Sep/1981 Aug	1979 Jun–Sep/1980 Jun–Sep/1982 Jun–Sep
No. plates	21, 18[a]/14	6/6/19	5/11/3
Telescope (m)	1.88	No. 1, 0.9	1.6
Inverse disp. (Å mm^{-1})	30, 50/78	45	43
$\lambda\lambda$ (Å)	3800–4900/3700–4800	3600–5000	3800–4900
Image tube?	no/no	yes	no/no/yes
Image slicer?	no/yes	no	no
Emulsion	[b]/IIa-O	IIIa-J baked (N_2, $N_2 + H_2$)	IIa-O/IIa-O/IIIa-J baked (N_2, $N_2 + H_2$)
Width of sp. (mm)	0.5	0.5	0.5
Comparison	Fe/Fe–Ar Hollow Cathode	He–Ar	Fe–Ar Hollow Cathode
Mean exp. (min)	[b]/1	0.5	15/15/5

[a] Prism plates with two different dispersions: 30 Å mm^{-1} and 50 Å mm^{-1} at Hγ respectively.
[b] Unknown.

HD 193793 is O4–O5. This is consistent with the spectral type O5 given for the absorption component by Smith (1968).

From line *ratios*, the W-R component has spectral type WC7, as noted above. However, it is interesting to note that the only strong line in the spectral region studied is the blend C III/IV λ4650 + He II λ4686. This is in marked contrast with the spectrum of HD 97152 = no. 42 in the catalog of van der Hucht *et al.* (1981), who give a type WC7 + O5–7; Davis, Moffat, and Niemela (1981) give WC7 + O7 V. In HD 97152, one can clearly identify many emission lines of C III, C IV, and He II. Possibly, the continuum from a second, hot, luminous companion star (triple system) or the (undeterminable) supergiant nature of the O4–5 component could explain the increased dilution of the emission lines in HD 193793. An even more extreme case of drowning of the W-R spectrum by an O star light is the suspected triple WC6 + O9.5 Iab system θ Muscae (Moffat and Seggewiss 1977).

For the W-R component of HD 193793, Smith (1968) gives the type WC7p, the peculiarity probably a result of its abnormally broad lines for WC7; the width (FWHM) of the C III/IV λ4650 blend is approximately 80 Å, corresponding to WC5. Hiltner and Schild (1966) give (WC6), based on the ratio C III λ5696/C IV λ5812. According to Fitzpatrick,

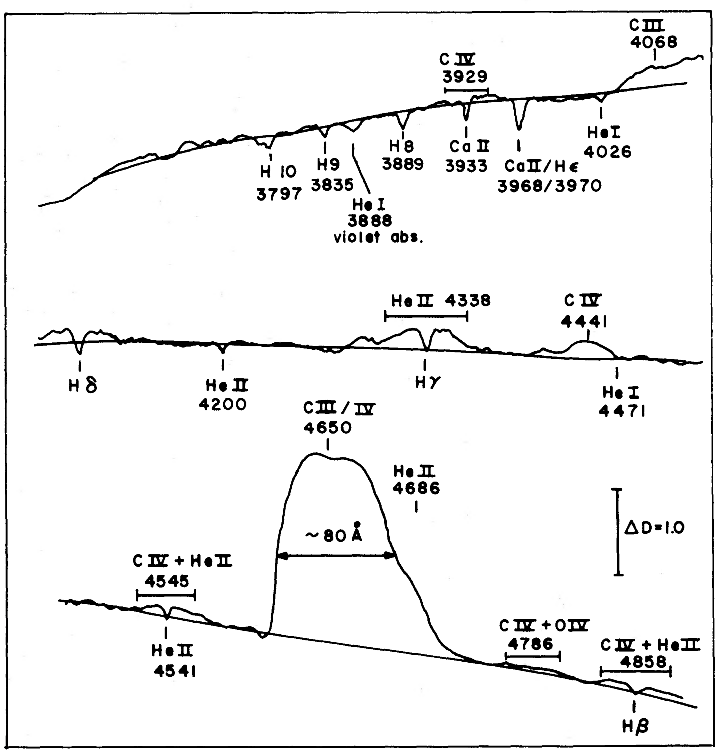

FIG. 1.—Photographic density tracing based on the mean of 31 spectra on IIIa-J image-tube plates taken at KPNO. The smooth line represents an estimate of the continuum.

TABLE 2

MEAN RADIAL VELOCITIES OF HD 193793 FOR EACH SUBGROUP ($km\ s^{-1}$)

Mean Julian Date[a] 2,400,000+	Phase[b]	C III/IV λ4650	Mean Absorption Hδ, Hγ, Hβ
23250. (5)	0.099	299 ± 17[c]	−41 ± 16
23348. (2)	0.189	306 ± 12	−15 ± 21
26160. (1)	0.781	173 ...	... ...
26560. (3)	0.149	301 ± 10	−18 ± 20
28051. (2)	0.524	... ...	−1 ± 16
31610. (3)	0.804	172 ± 9	36 ± 7
31947. (2)	0.114	306 ± 3	−19 ± 9
32055. (8)	0.214	353 ± 10	−11 ± 11
32120. (13)	0.274	273 ± 8	−25 ± 11
43655. (14)	0.905	159 ± 8	−19 ± 14
43770. (6)	0.011	251 ± 7	−20 ± 9
44062. (5)	0.280	296 ± 9	−5 ± 16
44130. (6)	0.343	261 ± 7	−12 ± 22
44447. (11)	0.635	225 ± 11	1 ± 8
44830. (19)	0.988	230 ± 6	−14 ± 7
45221. (3)	0.348	263 ± 10	−11 ± 11
Mean (σ)............	...	258 (57) 10[d]	−13 (17) 14[d]

[a] The number of plates used is in parentheses.
[b] Phase calculated with the elements of Table 3.
[c] Standard error of the mean.
[d] RMS value.

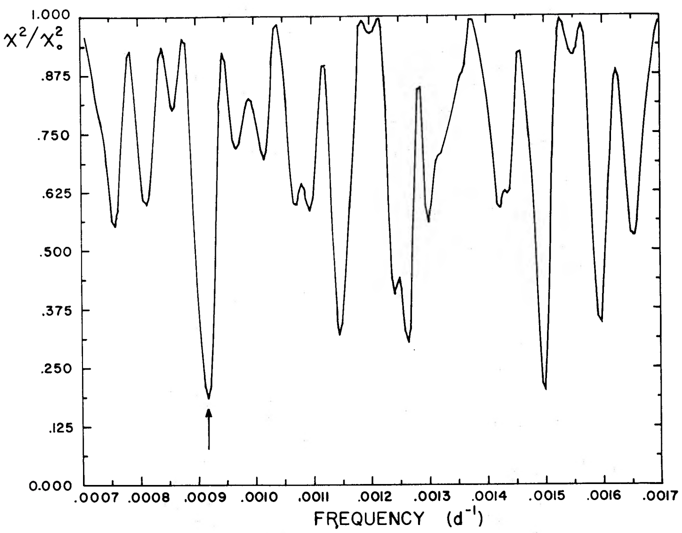

FIG. 2.—Mean square deviation $\chi^2 = \Sigma(O-C)^2/n$ for the C III/IV λ4650 data in Table 2 fit to a sine wave vs. the frequency ($\nu = 1/P$) of the wave for steps of $\Delta\nu = 4.55 \times 10^{-6}$ days^{-1}. The term χ_0^2 is the value of χ^2 at $\nu = 0$. The arrow indicates the best period.

Savage, and Sitko (1982), the UV spectrum indicates a normal WC7 type. We tentatively adopt WC7 for the W-R component of HD 193793.

In a recent paper, Fitzpatrick (1982) suggests that the Fe V absorption lines he observes in the spectra of HD 93162 (WN7) and HD 193793 may be intrinsic to the W-R stars. Willis *et al.* (1984) have studied *International Ultraviolet Explorer* (*IUE*) spectra of a sample of single WC5, WC6, WC7, WC8, and WC9 stars: none show these Fe V lines. Therefore, it is likely that these absorption lines originate in an O type companion and that HD 193793 has a companion similar to Fitzpatrick's comparison star, θ^1 Ori C.

b) *Period*

We first looked for relatively short periodic variations (< 50 days) among the C III/IV λ4650 data of each subgroup separately using a single sine-wave fit. This method has already been described by Lamontagne *et al.* (1982) and Lamontagne, Moffat, and Seggewiss (1983). No clear period resulted from the calculations for any subgroup; the probability of a real variation within any of the subgroups was always inferior to 60%. We then averaged the velocities within each subgroup, and again, using the same technique, we looked for variations, but this time of long period (50 days < P < 30,000 days). Several periods emerged, the best one being $P = 1090 \pm 20$ days, followed by periods of lower quality: 627 days, 667 days, 792 days, and 874 days (see Fig. 2).

In order to decide among these, we applied the same analysis to the mean Balmer absorption velocities. Among the periods that we obtained, the best was 1855 ± 20 days, followed by: 1080 days, 1148 days, and 1289 days, all with estimated uncertainties of ± 20 days. Although the absorption data are noisier, only one period occurs simultaneously within the observational errors in both the absorption and emission components. HD 193793 appears to be a binary W-R star with a period of approximately 1085 ± 14 days.

An orbital fit was calculated for the mean radial velocities of the emission line using the period derived above. The results are presented in Table 3. Then, because the absorption data are noisier, we calculated a fit of these velocities with only the γ and K parameters free to vary. The two solutions are shown in Figures 3*a* and 3*b*. Although the absorption velocity variations are of lower amplitude, their general trend is in antiphase with the emission data. Also, the dispersions (O − C) around the fitted curves are reduced to values closer to the mean internal deviation of one subgroup in each case (see Table 2); this fact adds support to the reality of the orbital fit. In order to make another check, a circular fit was forced to both sets of data; the resulting (O − C) values were about 1.5 times greater than for the elliptical fit. Lack of apparent profile changes in C III/IV λ4650 in our photographic spectra also support the fact that its radial velocity variations are orbital in nature.

TABLE 3

ORBITAL PARAMETERS FOR HD 193793

Parameters	C III/IV λ4650	Mean Absorption Hβ, Hγ, Hδ
P (days)	1085 ± 14	1085 ± 14
γ ($km\ s^{-1}$)	239 ± 9	−6 ± 5
K ($km\ s^{-1}$)	74 ± 9	16 ± 6
T_0 (2,400,000+)	31807 ± 50	31807 (forced)
e	0.39 ± 0.13	0.39 (forced)
ω (°)	261 ± 27	81 (forced)
$\sigma_{(O-C)}$ ($km\ s^{-1}$)	16	13

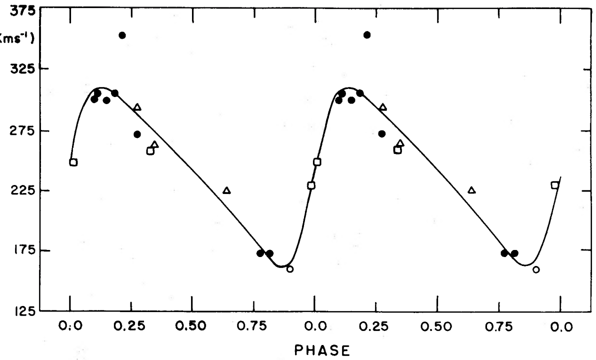

FIG. 3*a*

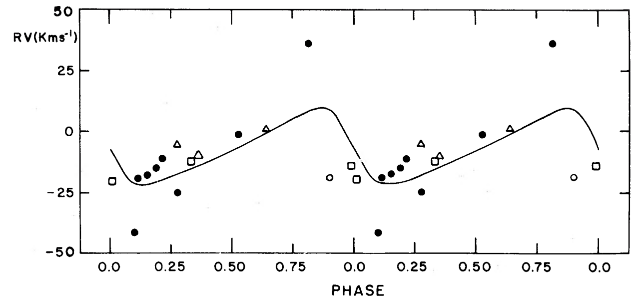

FIG. 3*b*

FIG. 3.—(*a*) Orbit of C III/IV λ4650 emission based on parameters in Table 3. *Filled circles* DAO archives; *open circles* DAO 1978; *squares* KPNO; *triangles* OMM. (*b*) As in Fig. 3*a*, but for the mean absorption Hβ, Hγ, and Hδ.

IV. DISCUSSION

a) *Masses*

Using the parameters of Table 3 we have evaluated the masses and orbital separations of both components of HD 193793: We obtain:

$$M_{\text{W-R}} \sin^3 i = 11 \pm 6\, M_\odot\,, \quad a_{\text{W-R}} \sin i = 6.8 \pm 0.9 \text{ AU}\,,$$

$$M_0 \sin^3 i = 53 \pm 16\, M_\odot\,, \quad a_0 \sin i = 1.5 \pm 0.6 \text{ AU}\,.$$

The mass ratio is $M_{\text{W-R}}/M_0 = 0.22 \pm 0.09$, similar to other W-R + O systems. No estimate of the inclination is possible unless one assumes a mass for one of the components. Adopting $M_0 = 60\, M_\odot$ from the spectrum of the O star (Conti and Burnichon 1975) leads to $i = 74°$, and $M_{\text{W-R}} = 13\, M_\odot$. This mass is similar to that for the WC7 component in the binary HD 97152, with $M_{\text{W-R}} = 17.5\, M_\odot$ (Davis, Moffat, and Niemela 1981).

b) *Kinematics*

Assuming an absolute magnitude $\mathscr{M}_v$ (W-R) = −4.8 for the W-R component (Hidayat, Supelli, and van der Hucht 1982) and $\mathscr{M}_v$ (O) = −6.4 for an O4–5 supergiant (because the W-R spectrum is drowned out) companion (Allen 1973), one gets a total absolute magnitude for the system of −6.6. This value yields a distance of 2.3 kpc if one uses the extinction law $A_v = 4.1\, E_{b-v}$ (Turner and Smith 1984).

One can then compute the local standard of rest (LSR) velocity of HD 193793 from a flat rotation curve (e.g., with $R_0 = 8.5$ kpc, $\theta_0 = 220$ km s^{-1}, from Gunn, Knapp, and Tremaine 1979) and compare it with the γ velocity of the absorption component. We obtain $V_{\text{LSR}}(\text{exp}) = 1$ km s^{-1}. The observed LSR velocity is given by $V_{\text{LSR}}(\text{obs}) = \gamma + u_0 \sin l + v_0 \cos l = 3$ km s^{-1}, where $u_0 = 7.4$ and $v_0 = 10$ km s^{-1} refers to the basic solar motion obtained from B stars (Balona and Feast 1974). The two results are in good agreement, which is to be expected since no supernova explosion seems to have occurred to accelerate the system.

c) *IR Behavior*

In the last decade, many infrared observations of HD 193793 have been carried out; see Hackwell *et al.* (1976), Williams *et al.* (1978), and Hackwell, Gehrz, and Grasdalen (1979). These authors reported a clear variability and interpreted this as the formation of a dust shell around the W-R star. We have looked at their data to see if there could be some kind of correlation between the formation of the shell and the orbit (e.g., periastron passage).

This does not seem to be the case since our period (~3 yr) does not match the 7 year time difference between the two infrared brightenings of 1970 and 1977. Also, although there is a large uncertainty in the value of T_0 (see Table 3), neither of the two brightenings occurred at periastron. One can thus tentatively rule out any kind of gravitational triggering mechanism of the dust shell formation due to a companion.

V. CONCLUSIONS

From old and new spectroscopic observations, we were able to derive a period of 1085 days for the WC7 + O4–5 binary HD 193793. The mass of the W-R component, approximately 13 $M_\odot$, is similar to that of other WC stars (see Massey 1981). The minimum mass of the O type star, $M_0 \sin^3 i \approx 53\, M_\odot$, also appears to be in the range of other "normal" O stars. The low mass ratio of HD 193793 is still compatible with the trend noted by Moffat (1981, 1982), that mass ratio decreases with hotter W-R subclasses. We also note that there is no clear relation between the recent formation of the dust shell around the W-R star and the presence of a companion. The triggering mechanism seems to be intrinsic to the W-R star itself.

The binary frequency among the eight bright Cygnus W-R stars has now increased to 6/8 = 75%, higher than that found among a complete sample of WNL stars (Lamontagne, Moffat, and Seggewiss 1983).

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REFERENCES

Allen, C. W. 1973, *Astrophysical Quantities* (London: Athlone), p. 204.
Antokhin, I. I., Aslanov, A. A., and Cherepashchuk, A. M. 1982, *Soviet Astr. Letters*, **8**, 156.
Aslanov, A., and Cherepashchuk, A. M. 1981, *Soviet Astr. Letters*, **7**, 482.
Balona, L. A., and Feast, M. W. 1974, *M.N.R.A.S.*, **167**, 621.
Cherepashchuk, A. M. 1976, *Soviet Astr. Letters*, **2**, 138.
Conti, P. S. 1971, in *IAU Symposium 49, Wolf-Rayet and High-Temperature Stars*, ed. M. K. V. Bappu and J. Sahade (Dordrecht: Reidel), p. 225.
Conti, P. S., and Burnichon, M. L. 1975, *Astr. Ap.*, **38**, 467.
Conti, P. S., and Roussel-Dupree, D. 1984, in preparation.
Conti, P. S., and Smith, L. F. 1972, *Ap. J.*, **172**, 623.
Davis, A. B., Moffat, A. F. J., and Niemela, V. S. 1981, *Ap. J.*, **244**, 528.
Fitzpatrick, E. L. 1982, *Ap. J.* (*Letters*), **261**, L91.
Fitzpatrick, E. L., Savage, B. D., and Sitko, M. L. 1982, *Ap. J.*, **256**, 578.
Fraquelli, D. A. 1977, J.R.A.S. *Canada*, **71**, 407.
Ganesh, K. S., Bappu, M. K. V., and Natarajan, V. 1967, *Kodaikanal Obs. Bull.*, ser. A, no. 184.
Gunn, J. E., Knapp, G. R., and Tremaine, S. P. 1979, *A.J.*, **84**, 1181.
Hackwell, J. A., Gehrz, R. D., and Grasdalen, G. L. 1979, *Ap. J.*, **234**, 133.
Hackwell, J. A., Gehrz, R. D., Smith, J. R., and Strecker, D. W. 1976, *Ap. J.*, **210**, 137.
Hidayat, B., Supelli, K., van der Hucht, K. A. 1982, in *IAU Symposium 99, Wolf-Rayet Stars: Observations, Physics, Evolution*, ed. C. W. H. de Loore and A. J. Willis (Dordrecht: Reidel), p. 27.
Hiltner, W. A., and Schild, R. E. 1966, *Ap. J.*, **143**, 770.
Koenigsberger, G., Firmani, C., and Bisiacchi, G. F. 1980, *Rev. Mexicana Astr. Ap.*, **5**, 45.
Lamontagne, R., Moffat, A. F. J., Koenigsberger, G., and Seggewiss, W. 1982, *Ap. J.*, **253**, 230.
Lamontagne, R., Moffat, A. F. J., and Seggewiss, W. 1983, *Ap. J.*, **269**, 596.
Massey, P. 1981, *Ap. J.*, **246**, 153.
McDonald, J. K. 1947, *Pub. Dom. Ap. Obs. Victoria*, **7**, 311.
Moffat, A. F. J. 1981, in *IAU Colloquium 59, Effects of Mass Loss in Stellar Evolution*, ed. C. Chiosi and R. Stalio (Dordrecht: Reidel), p. 301.
———. 1982, in *IAU Symposium 99, Wolf-Rayet Stars: Observations, Physics, Evolution*, ed. C. W. H. de Loore and A. J. Willis (Dordrecht: Reidel), p. 515.
Moffat, A. F. J., and Seggewiss, W. 1977, *Astr. Ap.*, **54**, 607.
Smith, L. F. 1968, *M.N.R.A.S.*, **138**, 109.
Turner, D. G., and Smith, L. F., 1984, in preparation.
Underhill, A. B. 1962, *Ap. J.*, **136**, 14.
van der Hucht, K. A., Conti, P. S., Lundström, I., and Stenholm, B. 1981, *Space Sci. Rev.*, **28**, 227.
Williams, P. M., Beattie, D. H., Lee, J. J., Stewart, J. M., and Antonopoulou, E. 1978, *M.N.R.A.S.*, **185**, 467.
Willis, A. J., van der Hucht, K. A., Conti, P. S., and Garmany, C. D. 1984, "An Atlas of High Resolution IUE Ultraviolet spectra of 14 Wolf-Rayet Stars," in preparation.

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