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SPECTRAL VARIATIONS IN HD 190002: EVIDENCE OF A COMPANION

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RESUMEN

Se analizan ocho espectros de HD 190002, tomados con una dispersión intermedia de (1.1 A canal^{-1}) en el rango espectral λλ4440-4800. El ancho equivalente y el perfil de la línea C III λ4650-He II λ4686 muestran variaciones periódicas con un período de 8.16 días. La variación del ancho equivalente de la línea se interpreta como debida a la presencia de un objeto secundario que introduce una perturbación periódica al continuo de la WC7.

ABSTRACT

Eight medium dispersion (1.1 A channel^{-1}) spectra of HD 190002 have been analyzed in the spectral range λλ4440-4800. The equivalent width and the profile of the C III λ4650-He II λ4686 blend shows periodic variability with a period of 8.16 days. The variation of the equivalent width of the line is interpreted as due to the periodic contribution to the continuum of the WC7 star by a secondary object.

Key words: **STARS-BINARIES – STARS-WOLF RAYET**

I. INTRODUCTION

HD 190002 was first classified as a WC7 star by Stephenson (1960); this classification was confirmed by Hiltner, Schild, and Jackson (1974). Photometry of the star has been done by Hiltner *et al.* and by Pyper (1966). The values of V, $B-V$ and $U-B$ given by these two authors are very similar (12.58, 0.84, 0.38 and 12.67, 0.83, 0.19, respectively); different values have been given by Westerlund (1966) v = 11.48, $b-v$ = 1.12, $u-b$ = 1.34 who mentions the possible variability of this star. It is difficult to determine whether the differences of magnitude and color given in the literature represent real variations in the star or not.

Further information, possibly relevant to understand the nature of this star was presented by Crampton (1971) who detected a very weak nebulosity surrounding the star, possibly connected with the optical region L69.80+1.74 and with the radio source G69.7+1.1.

Recently Bisiacchi, Firmani, and de Lara (1982), in a program to study spectral variability in WR stars, called attention to variations of the profile and of the line to continuum ratio of the C III λ4650-He II λ4686 blend in this star. The purpose of the present work is to analyze in detail the possible periodicity of the variations, and hence the duplicity of the system.

II. OBSERVATIONS

The observations were carried out in two seasons: June 1981 and October 1981 with the 2.1 meter telescope of the Observatorio Astronómico Nacional at San Pedro Mártir, Baja California (México), using a low dispersion spectrograph and a television multi-channel analyzer. The detector consists of a SIT intensified camera coupled to a 500 channel analyzer (Ruíz 1974; Solar 1977).

The observational material consists of five spectra taken between June 11 and June 16, and three spectra taken between October 16 and October 18. All the spectra were taken with a diffraction grating working in the second order in the range λλ4400-4950 with a resolution of 1.1 Å per channel in all the spectra. The signal-to-noise ratio per channel was of the order of 100 in the peak of the λ4650 line, and of 15 in the adjacent continuum; the stability in wavelength was ±0.2 Å. Unfortunately, no standard star was observed to carry out absolute spectrophotometry thus limiting the information obtainable from the spectra.

III. ANALYSIS OF THE DATA

Wavelengths were calibrated using a standard He-Ar source. The WR continuum, defined by windows at λλ 4368-4380, 4406-4419, 4476-4491, 4587-4598, 4727-4734, 4764-4770, 4821-4826, and 4841-4843, was represented at all wavelengths by a fourth order polynomial interpolation. The part of the normalized spectra, relevant to this analysis, is presented in Figures 1*a* and 1*b* for the two observing seasons. The continuum has been arbitrarily defined equal to 1; the distance between the continua in the vertical axis of the figure is only in-

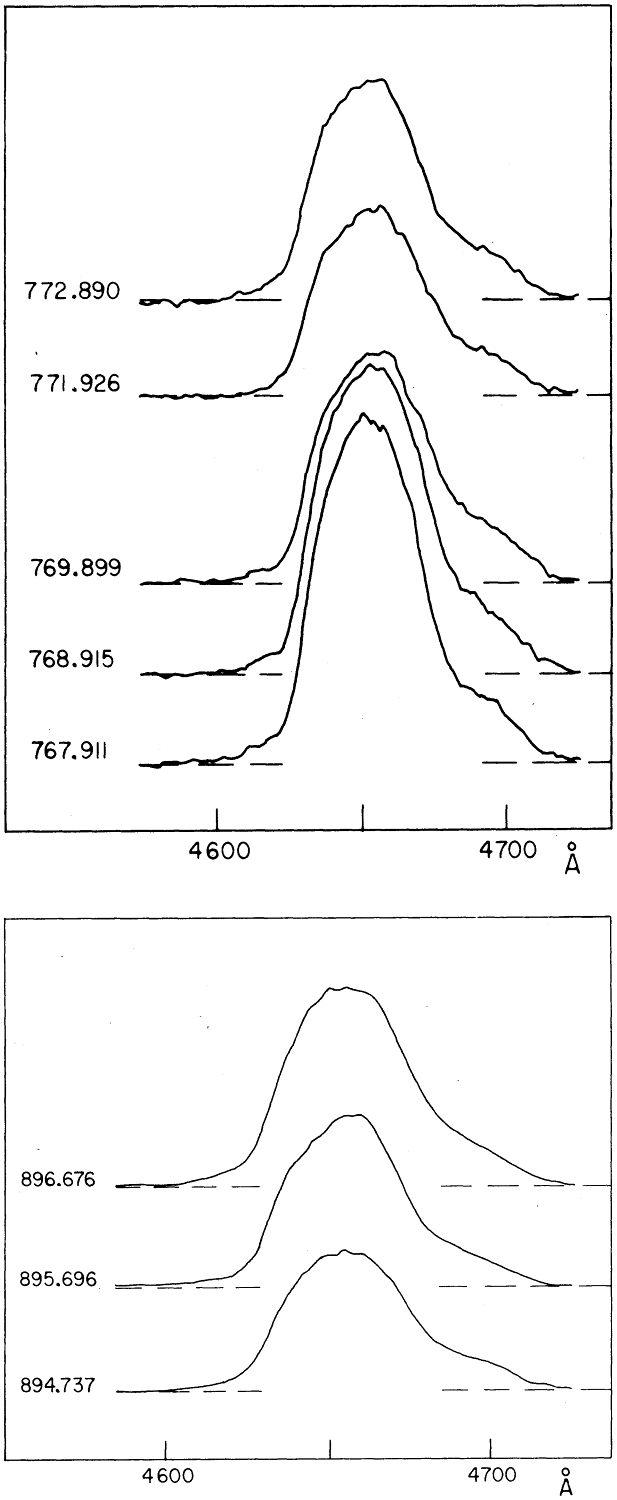

Fig. 1*a,b*. Plot of the relevant part of the spectra for the two observational seasons. The continua are normalized as described in the text. Dashed line represents the fit of the continuum normalized to unity. The difference between the zero and one level is not indicated due to the figure scale. Number at the left gives the Julian Day (JD = 2444000+).

dicative of the epoch at which each spectrum was observed. With this convention, the area under the C III λ4650-He II λ4686 blend represents the equivalent width of the line. It is evident from the figure that the equivalent width varies continuously from day to day; it must be noted that the profile at the top of the line is also changing continuously accompanying the variation of the equivalent width. These continuous and periodic variations of the profiles are known to occur in binary WR stars and have been used to detect duplicity in WR's with an invisible companion (Firmani *et al.* 1980).

From the analysis of the values of the equivalent widths during the two seasons a function of the form

$$\text{Eq. Width} = A \sin\left(\frac{t}{p} + \phi\right) + C$$

was chosen to fit the data. The best fit has been calculated with the least squares method. The absolute minimum is obtained for $P = 8.16$ d, $\phi = 2\pi/p$, $t_0 = 3.47$, $A = 346.4$ Å, $C = 1210$ Å, giving a standard deviation $s = 37.0$ Å.

Due to the large interval of time between the two observational seasons the standard deviation shows many secondary minima as function of the period. A 7.60 d period gives a fit with $s = 37.6$ A; the difference between the two minima is so small that the latter period cannot be excluded. Although the number of observed points is not as large as desired, the correlation coefficient of the fit obtained with the 8.16 d is $r^2 = 0.97$; this gives us confidence in our result. In Figure 2 we plot our data as a function of phase calculated with the 8.16-day period. The phase equal to zero, at which the calculated equivalent width is equal to C, occurred at JD = 2444765.57.

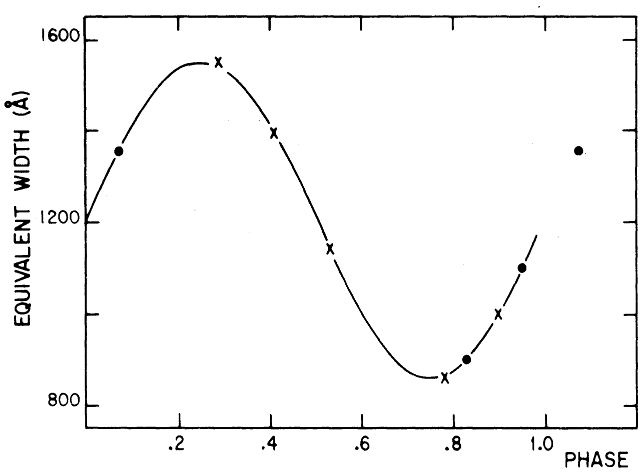

Fig. 2. Plot of the equivalent width of C III λ4650 as function of the phase calculated with the 8.16 d period. Crosses: data obtained in June 1981; open circles: data obtained in October 1981; solid line: the best fit to the data.

The error at each observed point in Figure 2 is difficult to evaluate; it is essentially given by the error in the polynomial fit to the continuum due to the noise in the continuum itself. As we mentioned earlier the uncertainty of signal per channel in the continuum is $\simeq 7\%$. The error in the equivalent width is therefore less than 7 %.

As we said before the observations were planned to search for spectroscopic information and no particular attention was paid to the intrinsic spectrophotometric quality of the spectra. For this reason, we first analyzed the equivalent width of the C III λ4650-He II λ4686 blend which is independent of the instrumental response, the conditions of the sky, seeing, guiding errors, etc. In spite of this it is very important to ascertain as we will discuss later, whether the variation of the equivalent width is determined by the variation in the continuum or by the variation of the line, or both.

In Figures 3*a* and 3*b*, we plot the peak intensity of the line and the intensity of the adjacent continuum divided by the exposure time as a function of the phase. To make the comparison easier these quantities are normalized to the maximum values observed. These correspond to the JD = 2444771.926 for the continuum and to the JD = 2444896.676 for the line. It is evident from the figure that the main contribution to the variation of the equivalent width is the variation of the continuum. The variations of the line are probably real too, but they are not connected with the phase in an obvious way. In Table 1 the relevant quantities are summarized: in column 1 the Julian Day (JD = 2444000); in column 2 the phase; in column 3 the equivalent width of the C III λ4650-He II λ4686 blend in Angstroms; in columns 4 and 5 the maximum intensity of the line and the intensity of the continuum respectively, in counts per channel and in column 6 the exposure time. We must emphasize that, as mentioned before, the results presented in Figures 3*a* and *b*, are affected by observational conditions, while the results in Figures 1 and 2 are not. For this reason the last result is mainly supported by the coherence of the variation of the continuum intensity and of the equivalent width. That the continuum is responsible for the periodic variations of the equivalent width of the line must be regarded only as preliminary evidence to be confirmed. This result must be taken into account when planning future observations and when attempting a first interpretation of this phenomenon.

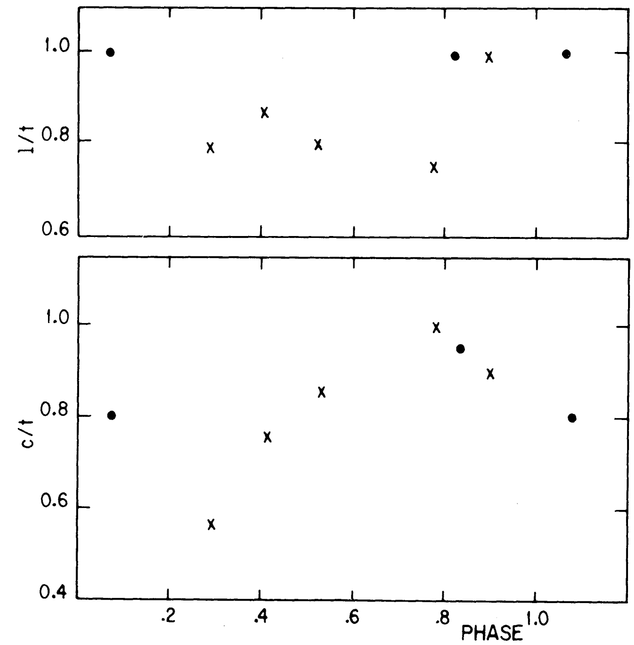

Fig. 3*a,b*. Plot of the maximum line intensity and of the continuum intensity divided by the exposure time. Data are normalized as described in the text. Symbols represent the same as in Figure 2.

Unfortunately no published spectrophotometry or equivalent width were available to improve long term consistence with our results. Further observational work in this direction is currently under progress.

We have attempted to measure a possible displacement of the line due to radial velocity variation but no significant results have been obtained. Our estimated limit of detection of the variations is V = 30 km s^{-1}; velocity changes

TABLE 1

OBSERVATIONAL DATA

J.D. 2444000+	Phase	Equivalent Width (A)	Line Intensity (counts ch^{-1})	Countinuum Intensity (counts ch^{-1})	Exposure Time (s)
767.911	0.29	1577	3800	115	960
768.915	0.41	1423	4200	152	960
769.899	0.53	1088	5750	260	1440
771.926	0.78	856	3590	200	960
772.890	0.90	1028	4756	185	960
894.737	0.83	957	4750	193	960
895.686	0.95	1069	5243	185	...
896.676	0.07	1310	7195	242	1440

due to a possible orbital motion should be less than this limit.

IV. DISCUSSION

It has been shown in the preceding lines that the most plausible evidence of periodic phenomena in HD 190002 is given by the variation of the equivalent width of the C III λ4650-He II λ4686 blend; evidence is also given that the variation is mostly determined by the variation of the continuum adjacent to the line.

It was implicitly assumed that the most probable interpretation of periodic phenomena like that present in HD 190002 is the duplicity of the system. In this hypothesis many facts must be considered in order to understand the origin of the spectral variations.

The lack of evidence for orbital motion in the spectrum and the very high line to continuum ratio exclude the existence of a massive companion. On the other hand, within the limitations of our observational data, C III λ4650 does not show any variability of the total flux in the line related to the periodic variation of the continuum. This excludes the existence of an extended eclipsing body which, if present, would produce an important occultation of the WR atmosphere and hence a strong periodic variation of the line flux. With these limitations in mind we interpret the observational results as due to the continuum emission of the secondary object, which provides in the visual range an energy comparable to the energy emitted in the continuum by the WR star in the same spectral region. As far as we know this is the first WR system, with a low-mass invisible companion, in which the continuum is found to be so strongly variable. The line to continuum ratio in HD 190002 is high as compared to other "single" WR binaries including WC stars. This might be the reason why the perturbation produced by the secondary is so noticeable in this case.

A secondary source of energy in this kind of objects is known to exist. In HD 50896 the existence of a peridic X-ray source has been demonstrated by Moffat *et al.* (1982); to date the contribution of this source to the optical continuum has not been studied in detail but it is expected to be small when compared with the WN continuum. We believe that the most plausible explanation of the periodic phenomena in the spectrum of HD 190002 and HD 50896 is the presence of a low-mass companion orbiting the WR star.

We have mentioned earlier that our data do not yield absolute fluxes from our spectra. On the other hand, the spectral range is too small to make our data comparable to the published *UBV* photometry and thus to obtain the energy contained in the variation of the continuum. New observations in a wider spectral range, with high spectrophotometric quality are needed to obtain the energy and the colors of the variable component.

With the information available at present, it is difficult to determine uniquely the nature of the companion. We can only advance a working hypothesis to explain the observations: that a WR star with a collapsed companion is embedded in the atmosphere of the primary object (spiraling in). The hot spot originated by the interaction is seen at different optical depths as a function of the orbital phase, producing thus a variable contribution to the continuum of the WR star.

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