RevMexAA (Serie de Conferencias), **5**, 85–91 (1996)

HD 5980: THE WOLF-RAYET BINARY THAT BECAME A LUMINOUS BLUE VARIABLE

R. H. Barbá[1,6], N. I. Morrell[1,6], V. S. Niemela[1,7], G. L. Bosch[1,5], J. F. González[2,5], E. Lapasset[2,6], O. E. Ferrer[1,6], E. E. Brandi[1,7], S. A. Cellone[1,5], B. E. García[3,6], S. M. Malaroda[3,7], O. H. Levato[3,6], C. Donzelli[2,5], C. Feinstein[1,6], and M. Rich[4]

RESUMEN

La binaria eclipsante Wolf-Rayet HD 5980, en la Nube Menor de Magallanes, ha mostrado un comportamiento peculiar a lo largo de los últimos años, experimentando un gran evento eruptivo durante el año 1994. En el curso del mismo, el espectro de HD 5980 se transformó en uno del tipo conocido como *Variable Luminosa Azul.* En este trabajo presentamos los resultados de espectroscopía óptica realizada antes, durante y después de la erupción, dando énfasis a la evolución de los perfiles de las distintas líneas. Además, el análisis de las curvas de velocidades radiales de líneas de diferentes iones, sugiere que la componente de HD 5980 que ha experimentado el evento eruptivo, es aquélla que se encuentra delante en el sistema durante al eclipse principal.

ABSTRACT

The Wolf-Rayet eclipsing binary HD 5980 in the Small Magellanic Cloud has shown a peculiar behaviour along the past years, developing a sudden eruption during 1994, when the star changed its spectrum to one resembling those of *Luminous Blue Variables.* In this paper, we present the results of optical spectroscopy performed before, during and after the burst, emphasizing the evolution of different line profiles. Furthermore, the analysis of the radial velocity curves of lines from different ions suggests that the component of HD 5980, which underwent the eruptive event, is the one in front of the system during the primary eclipse.

Key words: **BINARIES: CLOSE — STARS: INDIVIDUAL (HD 5980) — STARS: MASS-LOSS — STARS: VARIABLES: OTHER (LUMINOUS BLUE VARIABLES) — STARS: WOLF-RAYET**

1. INTRODUCTION

The Wolf-Rayet (WR) eclipsing binary HD 5980 in our neighbour galaxy, the Small Magellanic Cloud (SMC), experienced a sudden unexpected outburst in 1994 (Barbá & Niemela 1994a; Bateson, Gilmore, & Jones 1994). A visual light-curve of the eruption reported by Bateson & Jones (1994) showed that the maximum

[1]Facultad de Ciencias Astronómicas y Geofísicas, Universidad Nacional de La Plata, Argentina.

[2]Observatorio Astronómico, Córdoba, Argentina.

[3]Complejo Astronómico El Leoncito, San Juan, Argentina.

[4]Department of Astronomy, Columbia University, USA.

[5]Fellow of CONICET, Argentina.

[6]Member of the Carrera del Investigador Científico, CONICET, Argentina.

[7]Member of the Carrera del Investigador Científico, CIC, Provincia de Buenos Aires, Argentina.

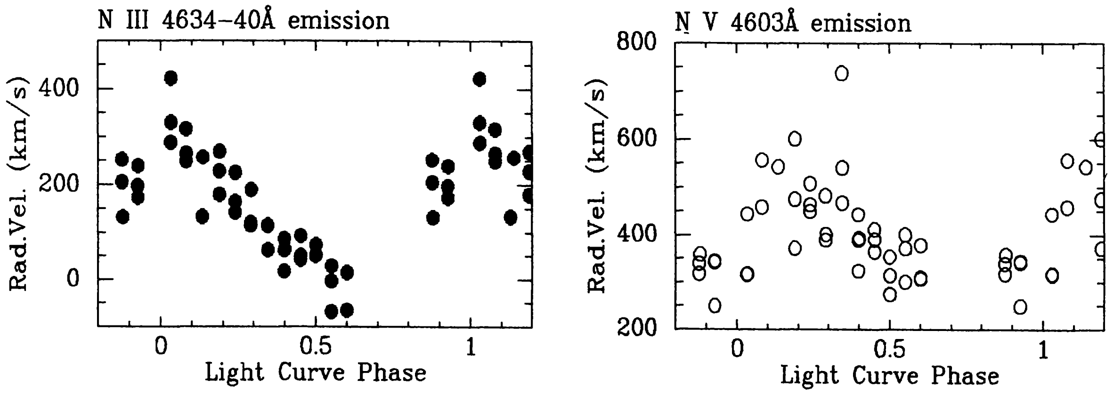

Fig. 1. Radial velocity curves of the emission lines of N III (left) and N V (right) in August 1992.

reached $V \sim 7.9$ in August 1994, when HD 5980 became the visually brightest star in SMC. During the outburst the optical spectrum changed from its former WR type to one similar to those of Luminous Blue Variables (LBV) (Barbá et al. 1995). Subsequent UV spectra from *IUE* have been discussed by Koenigsberger et al. (1995, 1996), and optical CCD photometry and polarimetry by Cellone et al. (1996).

HD 5980 is located near the eastern border of N66, the largest H II region in SMC (Henize 1956), which is excited by the stars of the OB association NGC 346, (Niemela et al. 1986; Massey et al. 1989). This WR eclipsing binary is the brightest star in the close neighbourhood of NGC 346.

A summary of our previous knowledge about HD 5980 can be found in Koenigsberger et al. (1994), Barbá et al. (1995), and references therein.

In this paper we report the results of our optical spectroscopy of HD 5980 obtained before, during and after the 1994 eruption, showing spectral changes from one orbital cycle to the next to be present. The ephemeris for the eclipsing binary are taken from Breysacher & Perrier (1980).

2. OBSERVATIONS

Optical CCD spectra of HD 5980 were secured between 1992 and 1995, with the Cassegrain and échelle spectrographs attached to the 2.15-m telescope of Complejo Astronómico El Leoncito (CASLEO) [8], in San Juan, Argentina. In August 1992 we obtained medium resolution spectra of HD 5980 with the Cassegrain spectrograph during sixteen consecutive nights, almost a complete orbital cycle. The detector used was a Thompson 576 × 384 CCD. Additional spectra with this instrumental configuration were secured in June 1994.

High resolution spectra of HD 5980 were obtained in January 1994 and, starting with the spectroscopic discovery of the outburst in October 1994, an observing campaign was organized; the result was a collection of about 70 spectroscopic images spanning five consecutive (October 1994 – January 1995), and several later orbital cycles. These observations were secured with the REOSC échelle spectrograph and a 1024 × 1024 Tek CCD as detector.

All the observations were processed and analysed using IRAF routines.

3. RESULTS

3.1. Pre-Outburst Spectroscopy of HD5980

Barbá & Niemela (1994b) have summarized the optical spectral variations of HD 5980 over the past decade and they noted the steady change in spectral type, going from WNE to WNL. They also found that the radial velocities of the N IV λ4058Å emission line, for the period 1988–92, do not share the orbital motion of any of the binary components, contrary to the former behaviour of N IV. Previously, this emission line was observed

[8]CASLEO is operated under contract with CONICET, SeCyT, Universities of La Plata, Córdoba and San Juan, Argentina.

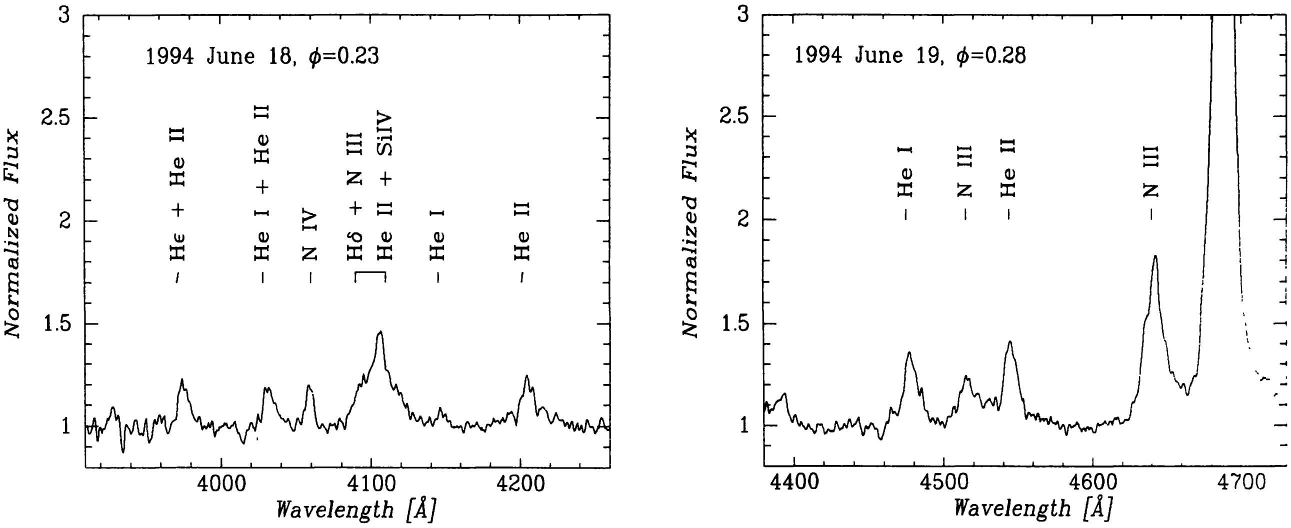

Fig. 2. Spectra of HD 5980 obtained in June 1994, a few days before the beginning of the sudden outburst.

to follow the orbit of the binary component which is eclipsed at phase ϕ=0.0 (Niemela 1988). In what follows we will refer to this star as *component B*, while the star which is in front during phase ϕ=0.0 will be called *component A*.

Barbá & Niemela (1994b) pointed out the outburst-like behaviour of HD 5980, resulting in changes of spectral type, evolving from WN8 to WN6 in only two months.

Koenigsberger et al. (1994) also reported important UV and optical spectroscopic variations noting that the spectral type of HD 5980 changed from WN4 to WN6 over one decade, along with a continuous increase in brightness.

From the analysis of our data obtained in August 1992, when HD 5980 was already slowly brightening, we find that N III $\lambda\lambda$4634-40Å appears stronger than N V $\lambda\lambda$4603-19Å and that the radial velocities of N III and N V emission lines (Figure 1) indicate that both of these lines originate in *component A*. This suggests that the binary component which was brightening (and cooling), was the one earlier classified as WN3 by Niemela (1988).

Spectra of HD 5980 obtained in June 1994, just a few days before the sudden steep rise in brightness, display a spectrum of approximately WN7 type, as N III > N IV, without detection of N V (Figure 2).

3.2. Optical Post-Outburst Spectral Evolution of HD 5980

In October 1994, during one of our periodic observing runs at CASLEO, the spectroscopic discovery of the outburst of HD 5980 was made by one of us (RHB). This was announced to the Central Bureau of IAU (Barbá & Niemela 1994a) in a note describing the event as an η Car type outburst. Two days later, Bateson, Gilmore, & Jones (1994) reported their visual observations obtained all along the evolution of the outburst, which had started four months earlier (Bateson & Jones 1994).

In what follows we will describe the evolution of the optical spectrum of HD 5980 from October 1994, until August 1995. We will label our data with successive *Orbit* numbers for observations obtained in consecutive orbital cycles of the eclipsing binary. Data from October 1994 will thus be referred to as *Orbit 1*. In Figure 3 spectra observed during various *Orbits* are displayed.

The observations obtained during *Orbit 1*, two months after the maximun visual brightness, showing the LBV-like spectrum of HD 5980, have been described and discussed in a previous paper (Barbá et al. 1995).

The spectra obtained in November 1994, during *Orbit 2*, resemble those observed in *Orbit 1*, being dominated by narrow and strong H and HeI lines with P Cyg profiles, as can be seen in Figure 3. These data show an increase in the equivalent width of the HeII λ4686Å emission line from $W_\lambda \sim 2$Å to $W_\lambda \sim 7$Å.

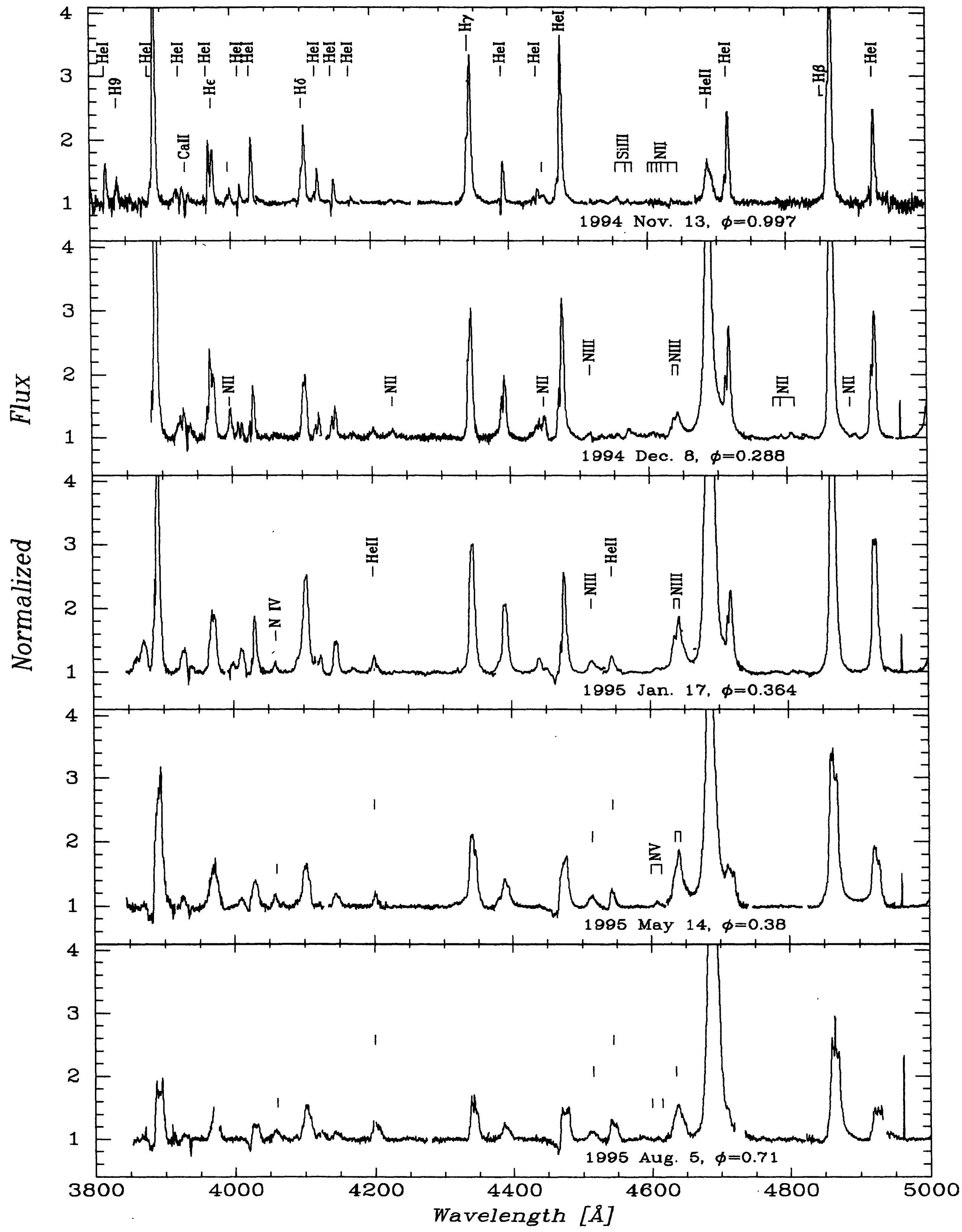

Fig. 3. Normalized spectra of HD 5980 obtained during the year after the outburst.

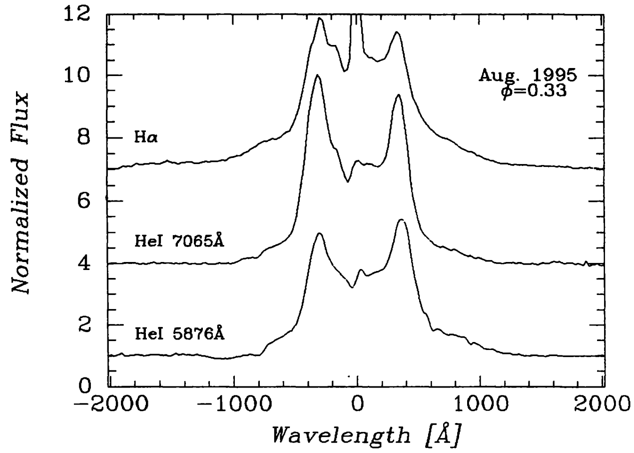

Fig. 4. Profiles of He I 5876Å and 7065Å, and Hα, plotted in velocity scale, showing narrow emissions symmetrically placed on top of the broad features.

This line also presents low amplitude radial velocity variations following the trend of the orbital motion of *component A*.

Figure 3 shows one of the spectra obtained during the first week of December 1994, corresponding to *Orbit 3*. The most remarkable difference between the spectrum observed in this *Orbit* and the previous ones, is the spectacular increase in the strength of He II λ4686Å emission line, reaching now $W_\lambda \sim$ 80Å, a value comparable to the one observed before the outburst. This represents a variation of one order of magnitude in only three weeks. All the emission lines appear wider than in previous *Orbits*. We also note that N III $\lambda\lambda$4634–40Å emission becomes again visible during *Orbit 3*, and that several N II emissions appear in the spectrum.

During *Orbit 4* and *Orbit 5* the WR features in the spectrum of HD 5980 increase. Figure 3 shows a spectrum obtained in January 1995, during *Orbit 5*, when the emissions are observed to be broader, and P Cyg profiles showing strong absorption components are present in He I triplets. In addition, during this *Orbit* Hα and some He I lines display two narrow emissions on top of the broad one, separated by $\sim$ 300 km s^{-1}. Typical WR emission lines, such as N III and N IV, show also variations in their profiles. N II emissions have disappeared suggesting a rise in the temperature of the envelope.

In May 1995, after the period of three months in which HD 5980 was not observable from CASLEO, we obtained spectra corresponding to *Orbit 11*. In these observations, one of which is shown in Figure 3, we can see a reinforcement in the WN type features resembling the spectrum of HD 5980 before the eruption. The emission lines appear even broader and their profiles are variable. As can be seen in Figure 3, N V emission lines appear again in the spectrum of HD 5980. He I triplets continue to display strong P Cyg profiles, with $V_{\rm edge} \sim -1500$ km s^{-1}, and two narrow emission components continue to be observed in some He I and H lines. These narrow emission components, somewhat more separated, are also observed in spectra obtained during June–July 1995, corresponding to *Orbits 13-15* in the red region of the spectrum.

In August 1995, we obtained spectra of HD 5980 over almost one complete orbital cycle corresponding to *Orbit 16*. Figure 3 includes one of these spectra, where we observe that HD 5980 has the spectral appearance of a WN7-8 type star. During *Orbit 16* all the WR type emissions show changes in their line profiles and radial velocities with the orbital phase.

The narrow emission components of He I and H lines now have a separation of $\sim$ 600 km s^{-1}. Figure 4 shows the profiles of He I λ5876Å and λ7065Å and Hα, plotted in a velocity scale. The narrow emission lines do not present radial velocity variations related to the orbital motion of the eclipsing binary. Therefore, they probably originate in a shell expanding at 300 km s^{-1}, which surrounds the binary system.

Plots of radial velocity versus orbital phase for different lines corresponding to our post-outburst observing campaign are shown in Figure 5. Data corresponding to each *orbit* are represented with a different symbol. As can be seen in this Figure, the N III emission continues to follow the same orbital motion as in the spectra obtained before the outburst (cf., Figure 1). Other emission lines, which show radial velocity variations with the orbital phase, all of them seem to move with this same orbit, namely the one corresponding to *component*

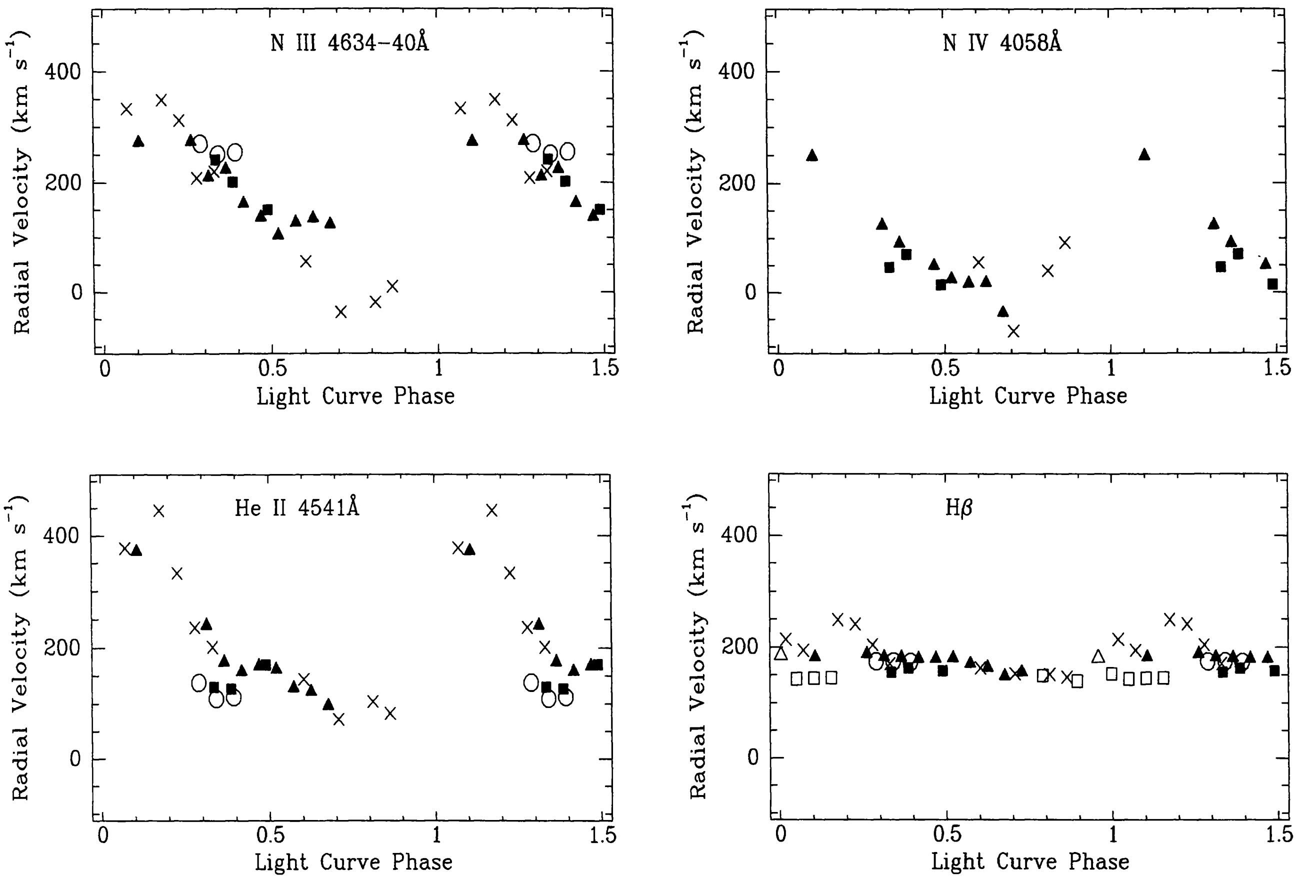

Fig. 5. Post-outburst radial velocities of several emission lines. Different symbols indicate: △ 1994 October; □ 1994 November; ○ 1994 December; ▲ 1995 January; ■ 1995 May; × 1995 August.

A of the binary. Note especially that N IV λ4058Å emission has now a similar radial velocity behaviour as observed for the N III emission line, contrary to the pre-outburst observations (Niemela 1988; Barbá & Niemela 1994). The star which is occulted during the primary eclipse, *component B*, does not show up in our spectra of HD 5980. We also note that the lower ionization emission lines do not have significant radial velocity variations.

4. CONCLUSIONS

The correlation in the spectrum of HD 5980 between the increase of typical WR emission lines during the declining phase of the outburst, and their radial velocity variations, suggests that the outburst was experienced by *component A*, the former WN3 component of the eclipsing binary system. This is the first detection of a WNE star that evolves to a LBV stage.

Humphreys & Davidson 1994 proposed to consider as *giant* LBV outbursts those showing $\Delta V > -2$ magnitudes. The event underwent by HD 5980 reached $\Delta V \sim -3.5$ magnitudes, thus it corresponds to the giant LBV eruptions. However, the observations by Cellone et al. (1996) show a difference from other major outbursts in LBV stars in the faster post-burst evolution of HD 5980, while the star regained its "normal" brightness after 1.2 years from the eruption.

The spectral variations described in this paper, indicate that the spectrum of HD 5980 also returned swiftly to the previous WR type. In January 1995 (*Orbit 5*) the radial velocity variations of the emission lines related to the orbital motion of the eclipsing binary, mostly veiled until that moment as a consequence of the outburst, became again observable. The He II λ4686Å emission line recovered its strength in December 1994, when radial velocity variations of this line following the binary phases, appeared again.

Six months after the maximun in the light-curve of the outburst of HD 5980, a structure consisting of two narrow symmetric emission features observed on the top of the broader emissions, begun to be detectable in some H and He I lines. These narrow emissions are stronger in the red region of the spectrum, and we interpret them as arising in a circumbinary shell, which expands at -300 km s^{-1}.

Regardless the variability observed in H and He emission profiles, the obviously much larger equivalent widths of the H Balmer series emission lines as compared to those of He II Pickering series lines (e.g., the spectrum at the bottom of Figure 3), points to a considerable H/He ratio.

The binary nature of HD 5980 raises once more the question about the role of binary evolution in triggering LBV type eruptions (cf., Gallagher 1989), being this the first case of an LBV within an eclipsing binary system.

Is HD 5980 a peculiar system or is it the the "normal" consequence of binary evolution in a low metallicity medium like SMC?

We are indebted to the director and staff of CASLEO for the use of their facilities during several observing runs. We acknowledge the use, at CASLEO, of the CCD and data acquisition system supported under NSF grant AST-90-15827 to R. M. Rich.

REFERENCES

Barbá, R.H., & Niemela, V. 1994a, IAU Circ. No 6099

__________. 1994b, in IAU Symp. 163, Wolf-Rayet Stars: Binaries, Colliding Winds and Evolution, ed. K.A. van der Hucht & P. Williams, (Dordretch: Kluwer), 254

Barbá, R.H., Niemela, V., Baume, G., & Vázquez, R.A. 1995, ApJ 446, L23

Bateson, F.M., Gilmore, A., & Jones, A.F. 1994, IAU Circ. No 6102

Bateson, F.M., & Jones, A.F. 1994, Pub. RAS New Zealand, 19, 50

Breysacher, J., & Perrier, C. 1980, A&A, 90, 207

Cellone, S.A. et al. 1996, in Colliding Winds in Binary Stars, ed. V. Niemela & N. Morrell, RevMexAASC, 5, 123

Gallagher, J.S. 1989, in IAU Colloq. 113, Physics of Luminous Blue Variables, ed. K. Davidson, A. Moffat & H. Lamers (Dordretch: Kluwer), 125

Henize, K.G. 1956, ApJS, 22, 1

Humphreys, R.M., & Davidson, K. 1994, PASP, 106, 1025

Koenigsberger, G., Moffat, A.F.J., St.-Louis, N., Auer, L.H., Drissen, L., & Seggewiss, W. 1994, ApJ, 436, 301

Koenigsberger, G., Guinan, E., Auer, L., & Georgiev, L. 1995, ApJ, 452, L107

Koenigsberger, G., Shore, S., Guinan, E., & Auer, L. 1996, in Colliding Winds in Binary Stars, ed. V. Niemela & N. Morrell, RevMexAASC, 5, 92

Massey, P., Parker, J.W., & Garmany, C.D. 1989, AJ, 98, 1305

Niemela, V. 1988, in Progress and Opportunities in Southern Hemisphere Optical Astronomy, ed. V.M. Blanco & M.M. Phillips, ASP Conf Ser 1, 381

Niemela, V., Marraco, H.G., & Cabanne, M.L. 1986, PASP, 98, 1133