THE ASTROPHYSICAL JOURNAL, 446:L23–L26, 1995 June 10

A SUDDEN LUMINOUS BLUE VARIABLE–LIKE BEHAVIOR OF THE WOLF-RAYET BINARY SYSTEM HD 5980 IN THE SMALL MAGELLANIC CLOUD

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Received 1995 February 27; accepted 1995 March 27

ABSTRACT

We report a sudden outburst-like behavior of the WR binary system HD 5980 in the SMC, as disclosed by spectroscopic and photometric observations performed in 1994 October and November. Our spectra show that the WR type spectrum of HD 5980 has changed drastically, now exhibiting a luminous blue variable (LBV) type spectrum with strong emission of H I and He I with P Cyg profiles and weaker emissions of N II, Si II, Si III, and Fe III. The previously dominant He II 4686 Å emission has remarkably weakened and other WR type emission lines have disappeared. Our photometry of HD 5980 reveals a visual brightening of 2.3 mag. The behavior shown by HD 5980, i.e., the transformation of a WNE star in a sort of LBV star, is unprecedented.

Subject headings: binaries: close — stars: individual (HD 5980) — stars: variables: other (luminous blue variables) — stars: Wolf-Rayet

1. INTRODUCTION

HD 5980 is an eclipsing binary system in the Small Magellanic Cloud (SMC) with an orbital period of 19.3 days (Breysacher & Perrier 1980, 1991). It is immersed in the eastern border of N66 (Henize 1956), the largest H II region of the SMC, which also contains NGC 346, the young OB association with the largest concentration of massive O type stars (Niemela, Marraco, & Cabanne 1986; Massey, Parker, & Garmany 1989). HD 5980 was included in the Radcliff Observatory list of the Brightest Stars in the Magellanic Clouds by Feast, Thackeray, & Wesselink (1960), who classified the spectrum as Wp, and noted the spectral lines to be variable. Subsequent spectral classification by various authors agree in that a Wolf-Rayet (WR) spectrum of WN3–4 type is dominant and that absorption lines are observed occasionally. Based on the radial velocity behavior of the emission lines, Niemela (1988) proposed that the system is composed by a WN3+WN4.5 binary, and a line-of-sight OB supergiant.

Recently, remarkable long-term variations have been reported in the spectrum of HD 5980 (Koenigsberger et al. 1994), in the sense that the WR spectrum has become cooler, resembling WN6 type in 1991. Barbá & Niemela (1994a) found that in 1993 November, HD 5980 showed an extraordinary spectral change, when a WN8 type spectrum appeared, but two months later, the WR spectrum had turned again to WN6. Such spectroscopic changes were described as outburst-like behavior. Furthermore, Koenigsberger et al. (1994) have summarized long-term magnitude changes, showing that HD 5980 has increased in V by 0.4 magnitudes during the last decade, with an apparent a posteriori weakening. HD 5980 was also found to have visually brightened about 1 mag by 1994 July (Jones 1994).

In this letter we report our observations of a more extreme outburst of HD 5980 (see Barbá & Niemela 1994b), which we find now to have a spectrum resembling luminous blue variables (LBV). The visual magnitude had increased to $V = 9.4$ on 1994 November 2, thus making HD 5980 (by far) the visually brightest star in the SMC. Although some LBVs at visual minimum resemble Of/WN9 stars (see Bohannan & Walborn 1989; Humphreys & Davidson 1994, and references therein), this is the first discovery when a WR star of WN3–4 type has been observed to become a LBV.

2. OBSERVATIONS AND RESULTS

2.1. *Spectroscopy*

During 1994 October 24 to 27 we obtained spectra of HD 5980 with the 2.15 m reflector at CASLEO, San Juan, Argentina. The spectroscopic observations were made with the REOSC Cassegrain spectrograph in echelle mode, using a Tek 1024 × 1024 CCD with a pixel size of 23 μm as detector. The observations were corrected by bias and flat-fielding, and calibrated in wavelength and flux. HR 9087 was the flux standard star used. All observations were processed with the *echelle* package of IRAF software in a HP-Apollo Workstation at La Plata Observatory. The log of 1994 October observations is summarized in Table 1.

The echelle spectra of HD 5980 revealed a quite unforseen behavior expected by a WR star: its transformation in a sort of LBV star. Figure 1 illustrates the observed spectrum of HD 5980. As seen in this figure, the most striking spectral characteristics are prominent H I and He I P Cyg profiles. The strongest emission line in the current optical spectrum of HD 5980 is Hα, which shows very extended wings (almost 100 Å), the red wing being more extended. Many He I emission lines are observed, by far He I 5876 and 7065 Å appear as the most intense ones. A forest of weaker features due to: N II, Si II, Si III, and Fe III are seen, many of them showing P Cyg profiles. There are two shallow emission features at the infrared region,

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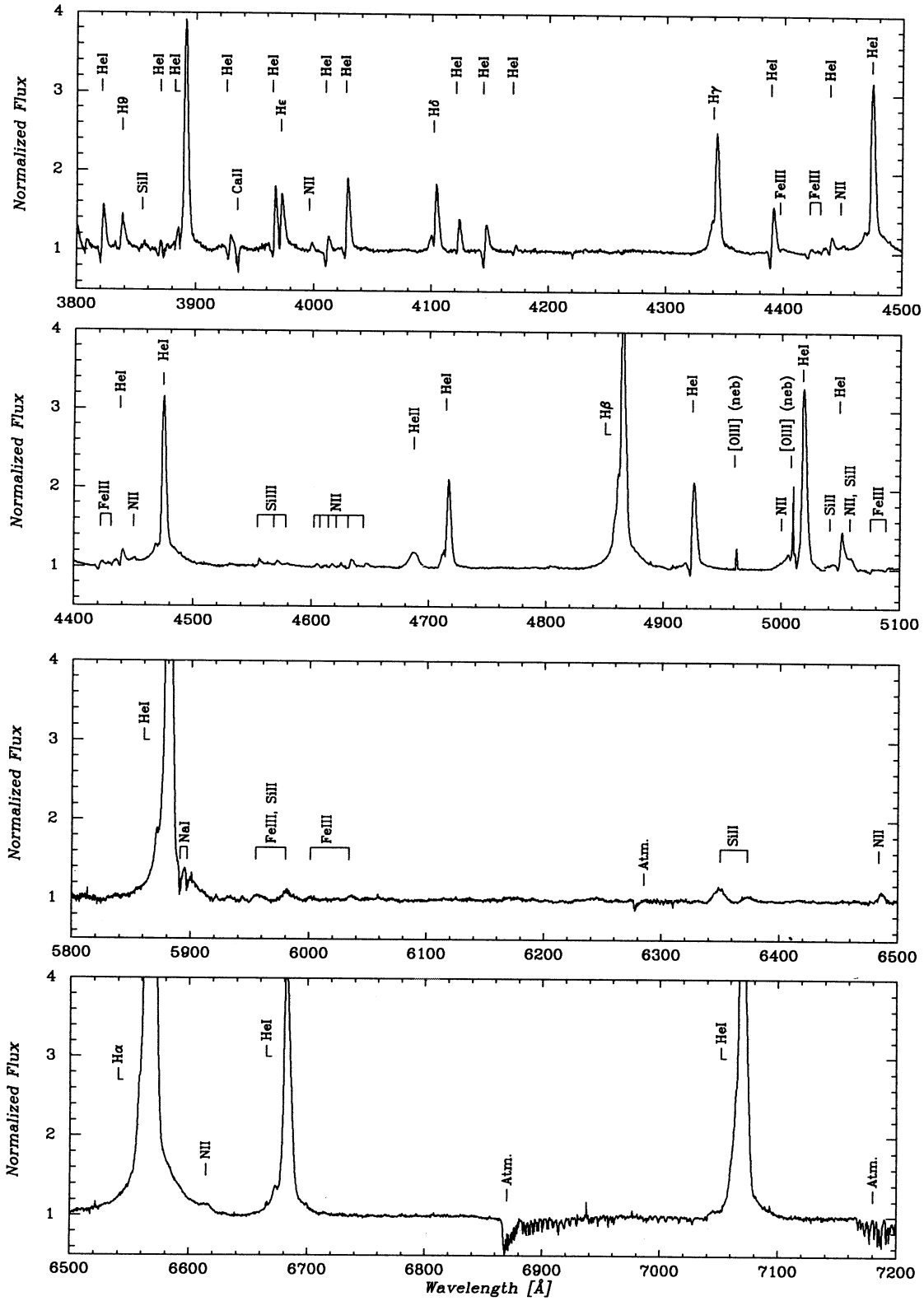

FIG. 1.—Normalized spectrum of HD 5980 in 1994 October, during the LBV stage. Truncated emission lines reach the following normalized intensities: Hα = 10.1, Hβ = 5.1, He I 5876 Å = 7.9, He I 6678 Å = 4.1, and He I 7065 Å = 5.9.

TABLE 1

JOURNAL OF SPECTRAL OBSERVATIONS OF HD 5980 IN 1994 OCTOBER

HJD (2,449,000)	Orbital Phase[a] (P)	Exposure Time (s)	Resolution ($\lambda/\delta\lambda$)
650.53[b].....	0.957	2 × 900	6000
651.54[b].....	0.003	3 × 900	6000
652.54[c].....	0.055	1 × 600	6000
652.59[c].....	0.057	1 × 1200	12000
653.54[c].....	0.102	3 × 900	6000
653.58[c].....	0.104	1 × 1200	12000

[a] Phase is calculated from the emphemeris given by Breysacher & Perrier 1980.
[b] Wavelength range covered: 3600–5900 Å.
[c] Wavelength range covered: 5000–8000 Å.

observable after the subtraction of telluric absorption lines, which may be identified as S II 7165 Å and S II + C II 7231–7236 Å.

We note that the P Cyg profiles of different lines have very distinct shapes, depending not only on the ion, but also the multiplet from which they originate. For example, the He I singlet lines show stronger absorption than the triplets, while these latter show more extended emission wings. In general, the absorption components of P Cyg profiles are observed to be more intense in the ultraviolet-blue spectral region, weakening toward the red, being inappreciable beyond 6000 Å for metallic lines (e.g., Si II 6347–6371 Å, N II 6482 Å).

A weak and broad He II 4686 Å emission line is the only footprint that reminds the previous WR spectrum of HD 5980. This line has decreased its equivalent width to only 2.6 Å, when older spectra typically showed an emission with $W \sim 100$ Å, e.g., Figure 1 in Koenigsberger et al. (1994).

Appreciable variations in radial velocities or in line intensity were not detected during the four nights of 1994 October observations. The absorption components of the P Cyg profiles appear blueshifted by about 200 km s^{-1} with respect to the emissions.

2.2. *Photometry*

CCD photometry through Cousins *U*, *B*, *V*, and *I* filters was performed in 1994 November 2, using the same Tek 1024 × 1024 CCD chip as in spectroscopy. The CCD was binned by 2 × 2, giving a scale of 0".54 $pixel^{-1}$. The exposure times were between 1 (*I*) and 10 seconds (*U*). Twenty of Landolt's (1992) standard stars were also observed during this night for photometric calibration purposes. The observations were processed with the IRAF version of DAOPHOT (Stetson 1987) at La Plata Observatory.

Our CCD photometry of HD 5980, which was obtained a week later than the 1994 October spectra, confirm the sudden brightening as observed visually in the telescope finder during the spectroscopic observations. Our observed *V*-magnitude of 9.4 is 2.3 mag brighter than earlier values (e.g., Massey et al. 1989). In Table 2, we list magnitudes and colors of HD 5980 and the neighbor star Sk 80 obtained during 1994 November 2. A comparison of values for Sk 80 in Table 2 with those published by Massey et al. (1989) show excellent agreement. Thus, Sk 80 seems to have constant light and appears as a suitable comparison star for the ongoing photometry of HD 5980.

We have also measured the *V*- and *I*-magnitudes of HD 5980 relative to Sk 80 in CCD frames obtained at CTIO in 1984 November 5. The instrumental configuration of these observations is described by Niemela et al. (1986) in their study of NGC 346. These CCD frames were processed together with the 1994 November observations. We list the differences corresponding to both data in Table 3. In Figure 2 (Plate L4) we show the *V* frames of HD 5980 region taken in 1984 (at CTIO) and 1994 (at CASLEO), where the remarkable brightening of the WR star can be appreciated.

TABLE 2

CCD PHOTOMETRY OF HD 5980 AND Sk 80, 1994 NOVEMBER 2

Magnitude	HD 5980	Sk 80
V	9.410 ± 0.001	12.350 ± 0.015
B−*V*.....	0.061 ± 0.004	−0.177 ± 0.012
U−*B*.....	−0.899 ± 0.005	−1.006 ± 0.017
V−*I*	0.300 ± 0.005	−0.226 ± 0.003

We note that in our 1994 November CCD photometry, HD 5980 appears *redder*, when compared with previous data (see Massey et al. 1989), but this *reddening* does not mean that the brightening in *U* band is negligible, because its value is $\Delta U \sim 2.4$ mag and the $U-B$ color has remained the same.

3. DISCUSSION AND CONCLUSIONS

This is the first detection of a WR star of WN3–4 type that develops a LBV type behavior, i.e., light variations coupled with spectral variations. Morphologically, the current spectrum of HD 5980 (see Fig. 1) resembles that of the Galactic LBV star AG Car in its lower visual brightness–higher temperature state (e.g., during 1991 June, Viotti, Polcaro, & Rossi 1993), and also the spectrum of the probable Galactic LBV He 3−519 shown by Davidson et al. (1993). However, contrary to AG Car, the LBV spectrum of HD 5980 corresponds to high visual brightness–lower temperature (excitation) state.

The very intense He I emission lines in the spectrum of HD 5980, as compared with the hydrogen Balmer emission lines, point to high values of He/H ratio, indicating an advanced evolutionary state of the component that is undergoing the outburst. This component is the apparently more massive one, i.e., the previously WN3-type (see Niemela 1988), as indicated by the radial velocity behavior of the lower ionization emission lines (e.g., He I, N III) which appeared at later epochs, since these emission lines also follow the orbital motion of the more massive component (Barbá & Niemela 1994a; Niemela et al. 1995, in preparation).

The lack of appreciable radial velocity variations during the 4 days of spectroscopic observations in 1994 October may indicate that material ejected from the binary is forming a pseudo-photosphere surrounding the whole system, i.e., like a circumbinary envelope. In luminous massive binaries, the radiation pressure completely alters the classical equipotential surfaces, giving rise to different forms of mass loss/transfer (see Zorec & Niemela 1980a, b), particularly favoring the formation

TABLE 3

DIFFERENTIAL MAGNITUDES HD 5980–Sk 80

Δ mag	CASLEO 1994 November 2	CTIO 1984 November 5
Δ*V*.....	−2.94 ± 0.010	−0.57 ± 0.002
Δ*I*	−3.47 ± 0.005	−0.61 ± 0.004

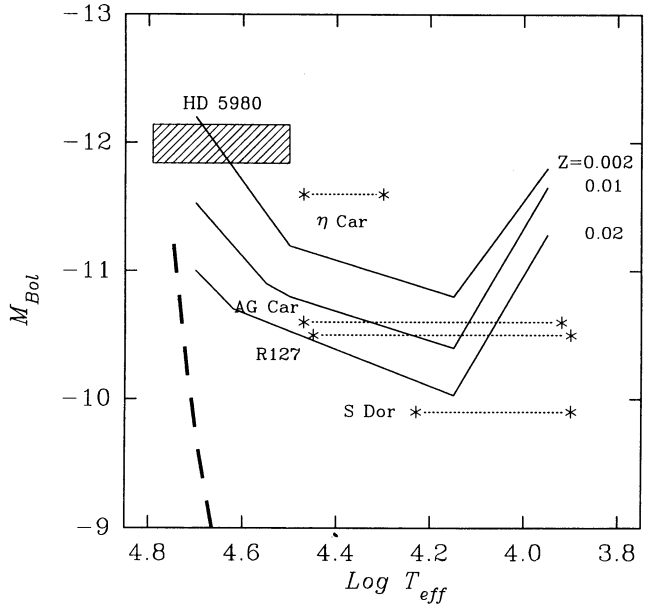

FIG. 3.—Location of HD 5980 in a schematic HR diagram showing the most luminous blue variables: η Car, AG Car, R127, and S Dor. The location of photospheric Eddington limit for different metallicities (Lamers & Noordhoek 1993) is indicated by continuous lines. HD 5980 appears on the top of the diagram (*shadowed rectangle*). The broken line shows the approximate location of the upper main sequence.

of circumbinary structures. Indeed, the bipolar structure of several LBV ejecta has been interpreted as due to binarity (Gallagher 1989).

In Figure 3 we show a comparison of the location of HD 5980 in a schematic HR diagram with brightest LBVs: η Car, AG Car, R127, and S Dor (see Humphreys & Davidson 1994). For the location of HD 5980 we have taken for the system $M_{bol} = -12.8$ published by Massey et al. (1989), assumed similar binary components, and that during the outburst M_{bol} remained constant. The temperature range adopted corresponding to WNE stage is log $T = 4.8$ (e.g., Koesterke et al. 1991), and for the LBV stage log $T = 4.55$, taking into account that the optical spectrum of HD 5980 in 1994 October is very similar to that of He 3−519 (see Fig. 2 in Davidson et al. 1993). It is quite remarkable that the location of HD 5980 in the HR diagram of Figure 3 is even more extreme than that of η Car. This is also consistent with the high temperature of the spectrum of HD 5980 shown at maximum visual light, as compared with other stars which show LBV type behavior. In Figure 3 we have also added the location of Eddington limits for different metallicities $Z = 0.002$ (∼SMC), $Z = 0.01$(∼LMC), and $Z = 0.02$ (solar), as shown by Lamers & Noordhoek (1993). HD 5980 appears to be located at the blue end of the Eddington limit corresponding to SMC.

The present major outburst of HD 5980 has been preceded by at least one previous visual light increase episode of about 1 mag in 1993 November (Bateson & Jones 1994), when the WN8 type spectrum had appeared (Barbá & Niemela 1994a). Probably there have been other light increase episodes, and the absorption lines that occasionally appear in the spectrum of HD 5980 may just come from a residual cooler pseudo-photosphere surrounding the binary. Indeed, these absorption lines appear at more negative radial velocities than the nebular lines, indicating that they may form in a region slowly expanding around the binary system.

Evidently, the unexpected behavior of HD 5980 opens many questions about the evolution of very massive binaries, and deserves intensive further observations.

We are very grateful to A. F. Jones and F. M. Bateson for communicating us their results prior to publication. We thank CASLEO and CTIO for the use of their facilities. The Tek CCD at CASLEO has been generously made available by Michael Rich. We are indebted to Nidia Morrell for help with reductions of the echelle spectra and to Omar Benvenuto for useful comments on stellar evolution theory. V. S. N. would like to thank Hugo Marraco for his help in obtaining the CCD frames at CTIO. This work has been partially supported by PROFOEG (CONICET, Argentina).

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