Astron. Astrophys. 339, 75–86 (1998)

ASTRONOMY
AND
ASTROPHYSICS

V 439 Cyg: the smallest LBV?*

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Received 14 April 1998 / Accepted 22 June 1998

Abstract. The emission line star V 439 Cyg (MWC 1015) dramatically changed its spectrum from late to early type in a few decades with line variability present at various levels. The star is a member of the peculiar young open cluster Berkeley 87 that contains, besides V 439 Cyg, a few peculiar objects in a late stage of stellar evolution. A strong IR source is associated with the region surrounding V 439 Cyg. The star has a peculiar position in the cluster HR diagram possibly due to anomalous reddening. We have analysed a collection of historical observations and collected new spectroscopic and photometric data on this unique object. We find several indications suggesting that the star has passed, in the last decades, through an instability phase with several features of the LBV behaviour. We suggest that its spectral change could be accounted for in the light of recent stellar models.

Key words: stars: evolution – line: formation – line: identification – stars: mass-loss – stars: Wolf Rayet – stars: individual: V 439 Cyg (MWC1015)

1. Introduction

The emission-line star V 439 Cyg (Kukarkin et al., 1969 *[General Catalog of Variable Stars]*) also named MWC 1015 (Merrill & Burwell, 1949) is located in the nearby (950 pc), heavily reddened open cluster Berkeley 87 (=Dolidze 7 =C2019+372). V 439 Cyg is also identified with the strong infrared source IRAS 20198+3716 in the IRAS Point Source Catalog.

The Berkeley 87 cluster is probably part of the starforming region ON2, where many compact H II regions, strong OH masers, CO and ammonia molecular clouds and high energy sources have been detected (Manchanda et al., 1996 and references therein). Most of the cluster members are young, heavily reddened OB stars (Turner & Forbes, 1982, Polcaro et al., 1991), but the red supergiant irregular variable BC Cyg (M3.5I), also associated with an IRAS source, and the WO Wolf-Rayet star Sand 5 (Polcaro et al. 1997 and references therein) are also members of this cluster.

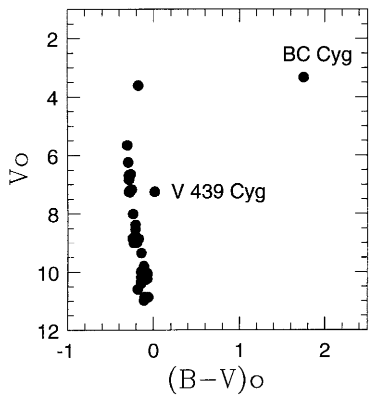

Fig. 1. Berkeley 87 C-M diagram (*from Turner & Forbes, 1982*).The positions of V 439 Cyg and BC Cyg are indicated.

Diffuse far-infrared emission was discovered by the *IRAS* satellite in the whole cluster region.

An early study of V 439 Cyg (Turner & Forbes, 1982) showed already that the position of the star in the cluster CM diagram is anomalous (see Fig. 1) and that the age of BC Cyg could not easily be reconciled with the estimated cluster age of 2 Myr.

In the framework of the present-day models for the high mass stars (e.g. Maeder, 1996), the evolutionary stage of a further cluster member, Sand 5, would be inconsistent with a 2 My cluster age.

An age of 4 My is probably more appropriate for Berkeley 87 (Norci et al, 1988). This age value is compatible with the position in the HR diagram of all cluster members except V 439 Cyg which lies well outside the MS at the red side of it. The possibility that the star could be a pre-MS object can be discarded on the basis of the observed spectrum.

2. Early spectrophotometry of V 439 Cyg (1941–1985)

In Table 1 are summarized the early spectro-photometric observations of V 439 Cyg. They span an interval of about 50 yr during which the star seems to have changed its spectral type

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* Based on data collected at the Bologna Astronomical Observatory, Loiano (Italy); Telescopio InfraRosso Italiano al Gornergrat (TIRGO), Gornergrat (Switzerland); Juan Sanchez Telescope (JST) and INT (Canary Inslands), Sharru Observatory, Covo (Italy) and on archive plates from the OHP

Table 1. Early spectrophotometry of V 439 Cyg (1941–1985)

Obs. date	V Mag	Colour	Sp. Type	References	Comments
1941	12.6–13.0	"red"	"Mira like"?	van Schewick (1941) in Kukarkin et al. (1969)	variable, possible period 260d
1944	11.0		B3e	Merrill, Burwell (1949)	strong H_α emission
1958			C star	Perraud, Pelletier (1958)	objective prism (4000–4900 A)
1982	11.84	B-V=1.54 U-B=0.37	Reddened OB star	Turner, Forbes (1982)	not variable
1982			B0ep	English et al. (1983)	V constant possible variability of (U-B)
1979/ 1985	11.92±0.03	$1.38 < B-V < 1.54$ $0.37 < U-B < 0.43$ $V-R < 1.00$ $R-I < 0.97$		English (1986) (priv. comm.)	V constant possible variability of (U-B), (B-V) R, I constant

from late to early on time scales of a few years. In 1982 the star was reported to have a early type spectrum, compatible with a B0ep classification (English et al., 1983), while in 1958 it had been classified as a carbon star (Perrault & Pelletier, 1958).

We have checked, as far as possible, the historical records in order to exclude misidentifications and performed in August 1989 a complete low dispersion spectroscopic survey of all the members of Berkeley 87 and field stars down to V=16 inside a 16′ circle centered on V 439 Cyg. No object with a spectrum similar to that of a C star was found, giving us confidence that the Perrault & Pelletier (1958) classification was not due to a misidentification (Polcaro et al, 1991).

Nevertheless, the best proof of the spectral variability of V 439 Cyg comes from the recovery of the original plates (18 Kodak IIaO plates) taken by Perraud and Pelletier in August 1958, with the Great Objective Prism spectrometer mounted on the 40 cm OHP telescope with Fehrenbach's double exposure technique, in the range 4000–4900 A. We show in Fig. 2 a detail of a print of the best exposed of these plates (no. 451/1958), overlapped to an enlargement of the red POSS image of the cluster; the numbers refer to the cluster member list by Turner & Forbes (1982). V 439 Cyg is the star no. 15, while no.78 is BC Cyg (very faint in the OHP plates wavelength range). As can be seen, despite the crowding of the field, the spectrogram of V 439 Cyg is well exposed and easy to identify. It is also clear that the much fainter stars No. 14, 16 and 73 do not give any meaningful contribution to the spectrogram. The good quality spectrum of V439 Cyg that we have recovered from the 1958 plates shows the Balmer lines in deep absorption and a very clear G band, as well as other absorption features, which can be identified as CN, CH, C_2 bands (Polcaro et al., 1989; see Fig. 3). On the basis of this, we can confirm a late-type spectrum for V 439 Cyg in 1958, even though a "C star" classification does not fully reflect the detected features (see later discussion).

We were unfortunately unable to recover the original Mount Wilson plate, despite knowing the observing date (July 1944). On the other hand, we would like to stress that the Mount Wilson Emission Line Stars Survey was performed on the basis of red objective prism spectrograms with a cut-off shortward of $\lambda = 5600$ A and only higher resolution spectra in the Hα range were taken in case of dubious classification (Merrill & Burwell, 1949). Thus, the 1944 Mount Wilson spectrum does not overlap (and cannot be directly compared) with the 1958 OHP one. We cannot therefore directly confirm or discard a spectral change between 1944 and 1958.

The *Vatican Observatory Survey for Hα Emission Objects in the Milky Way, "Revised Catalogue of Parts I-V"* (Coyne & Mac Connell, 1983) does not report V439 Cyg as an emission line star, while two other Berkeley 87 members (VES 203 and VES 204, i.e. Berkeley 87 no 9 and no. 38 in the Turner & Forbes, 1982, list) are included in this revision of the *VES* survey. Notice that V 439 Cyg and VES 203 have similar magnitude and that the Hα emission of V 439 Cyg is at the present day by far the strongest (see e.g. Fig. 1 in Polcaro & Viotti, 1997, where an objective prism-like image of the field, taken in June 1997, is shown); thus the only possible explanation is that in 1975, when the Vatican Observatory plate was exposed, V 439 Cyg was not an emission line star.

V 439 Cyg has a far IR excess absolutely anomalous for a Be star. According to the prescriptions reported in the IRAS Explanatory Supplement (Beichman et al., 1985), the corrected fluxes are 87.84, 538.54, 5812.22 Jy at 12, 25, 60 μm, respectively. An upper limit is given for the 100 μm band.

3. Recent (1986–1997) spectroscopy of V439 Cyg

3.1. The spectral changes of V 439 Cyg in the recent years

In Table 2 are summarized the recent spectrophotometric observations of V439 Cyg performed by our group between 1986 and 1997.

The 1986 spectrum is extremely similar to the one reported by English et al. (1983), typical of an early type, emission line

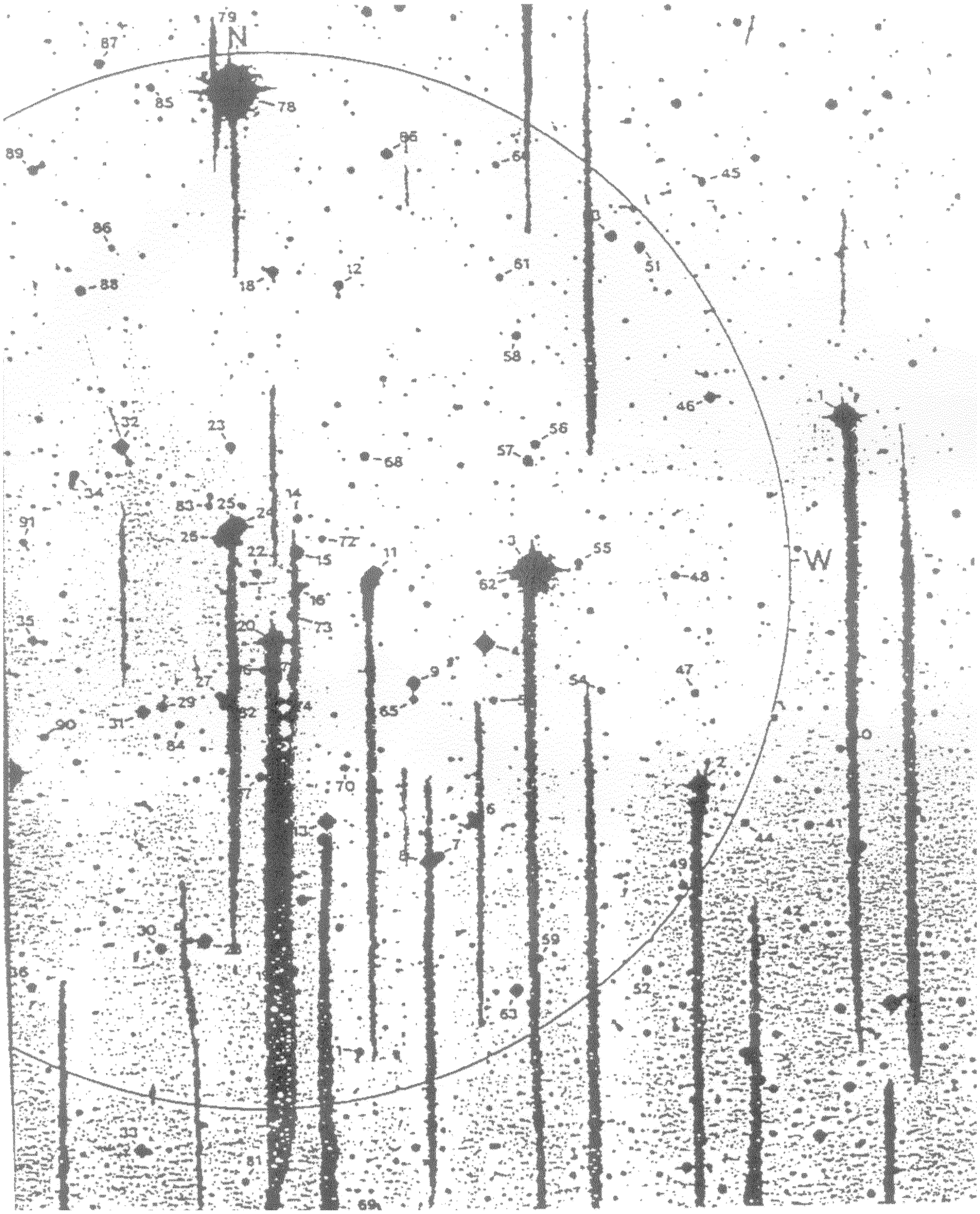

Fig. 2. Detail of the OHP objective prism plate no. 451/1958, overlapped to the Berkeley 87 field (digitized from Fig. 1 of Turner & Forbes, 1982). V 439 Cyg is star n.15, n.78 is the red supergiant BC Cyg.

star. However, the $\lambda\lambda$ 4400–4440 A band and the Merril and Sanford (MS) band in the Hβ region appear much weaker in our 1986 spectrum with respect to the 1982 one.

We also noticed some similarities in position and strength of the lines in the 3700–4800 A range of V439 Cyg and that of the SN 1987A precursor (Norci et al., 1988) but the bad quality of this last spectrum has prevented us to reach firm conclusions in this sense.

The 1987 spectra were obtained from a high S/N 40 min exposure at the 2.5 m INT at intermediate resolution – 1 A in the blue range and 0.5 A in the red one –. The blue region is shown in Fig. 3, compared to the 1958 OHP spectrum. In 1987, the star displays Hα and Hβ in strong emission, Hγ and Hδ in absorption with narrow central emissions, and numerous absorption lines. On the basis of the identified lines, we classified V 439 Cyg as (O9.5–B0)ep. The "peculiar" notation was added because of the unusual intensity and narrowness of the Balmer emission lines (already noted by English et al., 1983), the narrowness of the He line and, mainly, of the unusual intensity of the blends at 4499–502 A, 4515 A and 4517–19 A, to which, in B stars, N III and S II are the main contributors. Moreover, we noticed that the blend at 4634–42 A was stronger than the one at

Table 2. Recent spectroscopic observations of V 439 Cyg

Obs. date	Resolution (A)	Range (A)	Instrument	Comments
Aug 1–7,1986 Sep 20–24,1986	$\Delta\lambda$=3.0	3630–6670	1.52 m Loiano+ $B\&C$+EMI+Kodak IIaO	similar to English et al., 1983
July 8,1987	$\Delta\lambda$=1.0	4020–4950	2.5 m INT+IDS+IPCS	similar to 1986
July 9,1987	$\Delta\lambda$=0.5	H_α region	2.5 m INT+CCD	similar to 1986
Aug 15,1988	$\Delta\lambda$=1.8	4450–7100	1.52 m Loiano+ $B\&C$+CCD	“4500 A blend” and MS ”Hβ region” band disappeared
Aug 6,1989	$\Delta\lambda$=15	4100–7200	1.52 m Loiano+ $B\&C$+CCD	similar to 1988
Sep 18,1992	$\Delta\lambda$=1.8 (B,V) $\Delta\lambda$=3.6 (R)	3900–7200	1.52 m Loiano+ $B\&C$+CCD	Hα profile changed new narrow absorptions
June 2,1994	$\Delta\lambda$=5.5	3300–5800	1.52 m Loiano+ $BFOSC$	poorly exposed
June 24 1997	$\Delta\lambda$=5.5	3300–5800	1.52 m Loiano+ $BFOSC$	similar to 1988
Jun 24 1997	$\Delta\lambda$=8.3	3940–7860	1.52 m Loiano+ $BFOSC$	similar to 1988
Jun 24 1997	$\Delta\lambda$=7.5	5200–9050	1.52 m Loiano+ $BFOSC$	strong emissions in Pashen lines
Jun 25 1997	$\Delta\lambda$=3.0	6200–7850	1.52 m Loiano+ $BFOSC$	Hα emission nebula detected

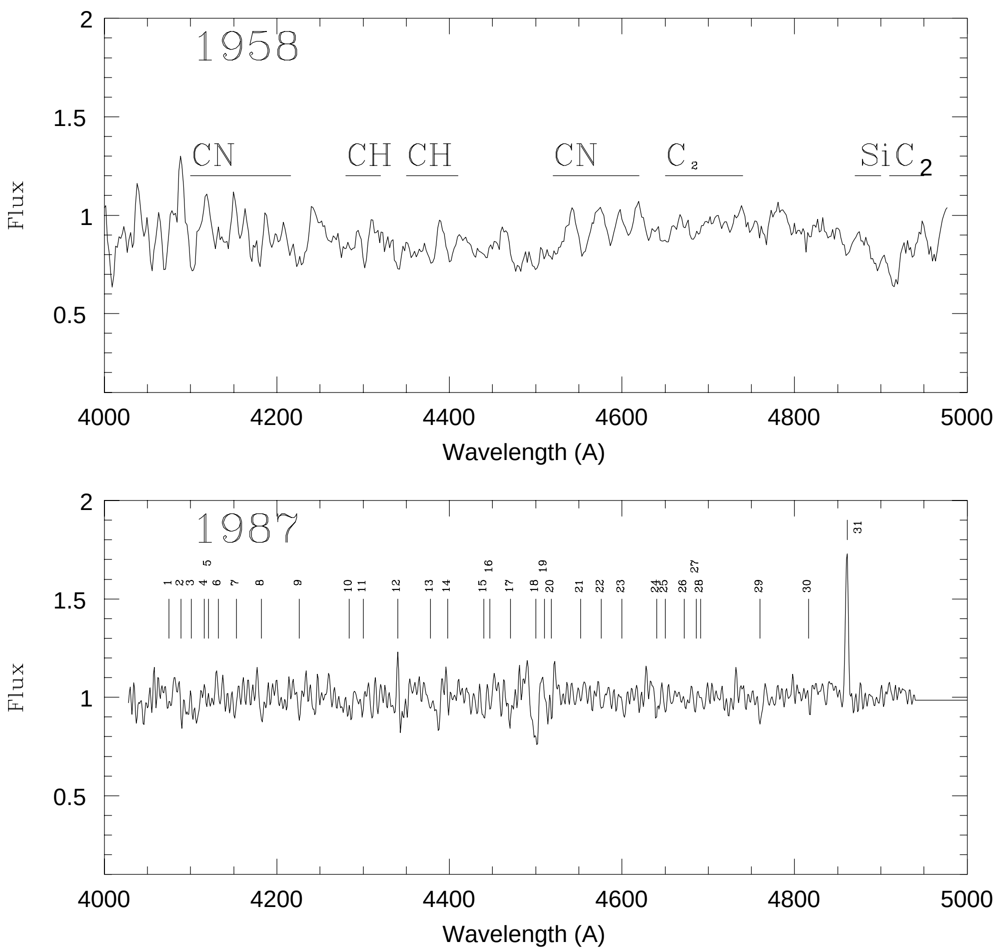

Fig. 3. Comparison between the blue (4000–5000 A) spectra of V 439 Cyg in 1958 and 1987. The molecular bands are indicated in the 1958 spectrum. The line labels superposed to the 1987 spectrum refer to the list reported in Table 4.

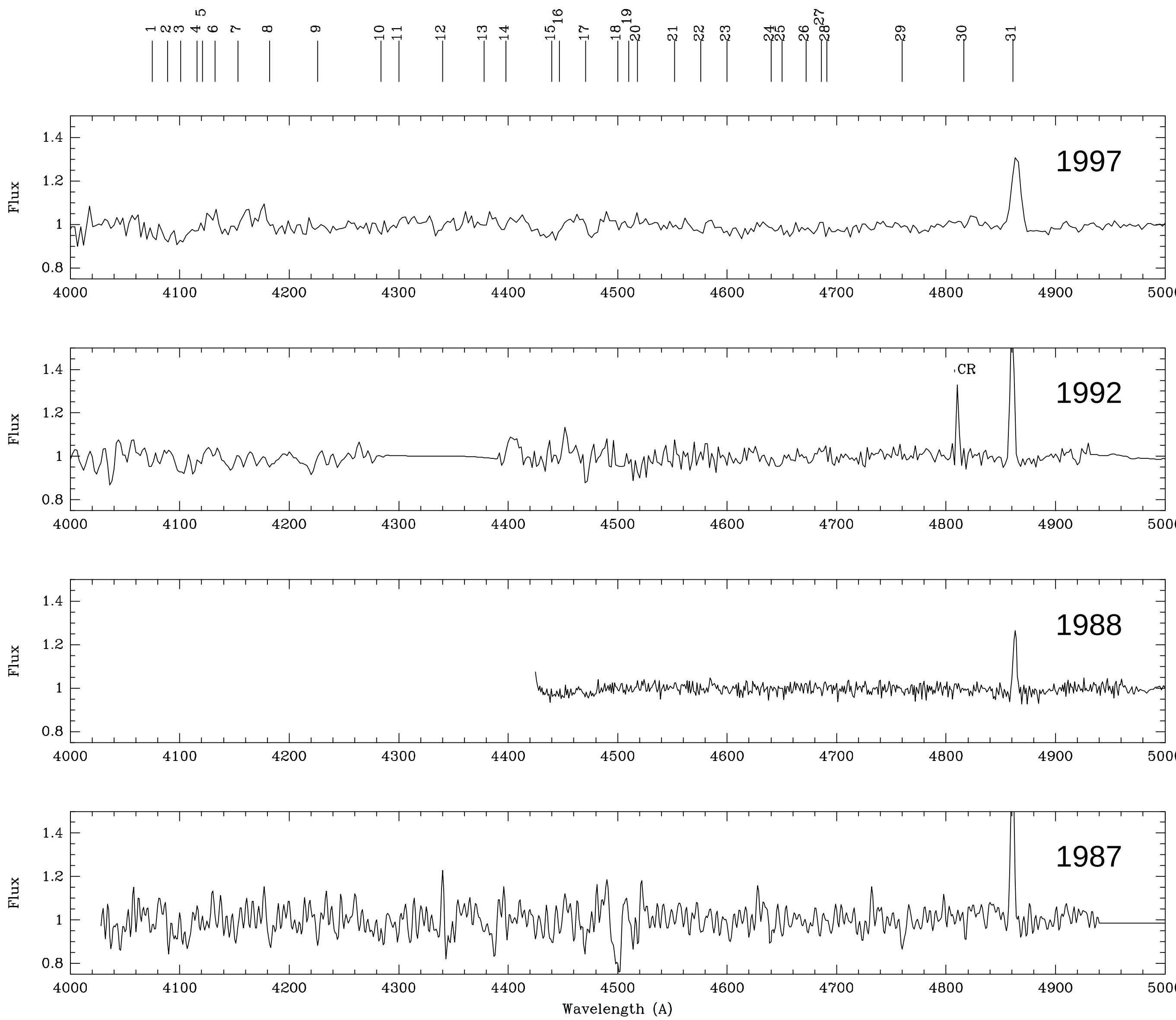

Fig. 4. Comparison between the rectified blue (4000–5000 A) spectra of V 439 Cyg in 1987, 1988, 1992 and 1997; the lines labels refer to those reported in Table 4.

4650 A. This could indicate CNO anomalies in the stellar atmosphere (Walborn, 1971). We have deduced, in a previous paper (Polcaro et al., 1989), a luminosity class II from the intensity ratio SiIV(4089 A)/HeI(4121 A)=1.75, using a diagram from Giangrande et al. (1980) which shows the behaviour of this line ratio versus luminosity class for different spectral types. Nevertheless the disappearance of the line identified as SiIV in the spectrum of 1992 and its change in intensity in the spectrum of 1997 show that these lines cannot, in this case, be used for classification purposes.

We have observed again V439 Cyg in the range 4450–7100 A on August 15, 1988 using the Loiano telescope, the B&C spectrometer and a RCA CCD detector (Polcaro et al., 1990). The 1988 spectrum shows significant differences from the 1986 and 1987 ones (see Fig. 4, where this spectrum is compared with other spectra of the star taken by us at different epochs). The main one is given by the lack of the 4499–502 A blend. The spectral region around Hβ does not show the MS absorption band that was always present since the English et al. (1983) measurement and many of the lines identified in the 1987 spectrum also look changed or have completely disappeared. We also noticed many FeII lines in emission, that were absent or barely visible in the spectrum of 1987, albeit the latter was made at higher resolution and had a S/N ratio similar to that of the other spectra.

In 1989 (August 6) a low resolution spectrum ($\Delta\lambda = 15$ A) was taken in the range 4100–7200 A using the Loiano telescope and the B&C spectrometer. Again, despite the low resolution, it was easy to see that in this spectrum the relative intensities of the absorption lines were different from the previous spectra.

In 1992 (September 18), a spectrum covering the range 3900–7200 A (with a small gap around Hγ), was obtained combining three spectrograms taken with the same telescope and spectrometer, respectively in the B,V ($\Delta\lambda = 1.8$ A) and R ($\Delta\lambda = 3.6$ A) regions. The blue region of the rectified 1992 spectrum is compared in Fig. 4 to the 1987, 1988 and 1997 spectra. The flux calibrated version of the same spectrum is shown in the full range in Fig. 5. The 1992 spectrum, compared to the 1988 one (see Fig. 2 in Polcaro et al., 1990), shows clear differences in the profile of Hα, lower intensity of Hβ and of the FeII emissions. A number of deep, narrow absorption lines are present, as well as the MS band in the Hβ region that was absent one year before.

A further spectrogram, with $\Delta\lambda = 5.5$ A was taken in 1994 at the Loiano Telescope with the new Bologna Faint Objects Spectrometer and Camera (*BFOSC* Merighi et al, 1994) in the 3400–5800 A range, but, due to the short exposure, the S/N ratio was poor and only the spectrum redward of 4400 A was measurable.

Three spectra taken in 1997 (June 24) at the Loiano telescope with the *BFOSC* covered the optical emission of the star from 3300 to 9050 A with a very high signal-to-noise ratio ($>$ 100). A further spectrum with the higher resolution of 3.0 A was taken the following night in the 6200–7800 A range, with a similar S/N ratio. The spectrum looks very similar to the 1988 one, while the absorptions that were detected in 1992 are now very faint or undetectable. The 6500–9000 A range, that was recorded for the first time, shows the complete H Paschen lines in emission (Fig. 6). The Hα line is asymmetric with a clear red wing. The MS band in the Hβ region is again barely detectable at this epoch.

Most noticeable is the presence of an H_α nebula around the star, that is clearly visible in the higher resolution spectrum and that was discovered because of the improved sensitivity of the new instrumental set up. This nebula is 7.9$''$ wide in E–W direction, corresponding to a 1.2×10^{17}cm diameter at 950 pc, and is clearly standing as an enhanced emission centered on V439 Cyg on the diffuse Hα emission of the whole Berkeley 87 region. Unfortunately, our instrumental sensitivity and spectral resolution are not enough to allow the measurements of the physical parameters of the nebula.

We want also to report that Turner (1992), commenting in a private letter on an unpublished spectrum of V 439 Cyg that he took in 1985, classified the star as B0:n (or B0:ne) and stated the presence of "some shallow absorption lines (heavily broadened by rotation from all appearances)". As can be seen from Fig. 3, both this spectral classification and the presence of broad lines are not compatible with the spectrum taken by us in 1987 nor in the one of 1986.

3.2. *The Hα and Hβ emission lines*

We will restrict ourselves to the quantitative analysis of the Hα and Hβ emission lines only, since it is difficult to perform the same study on the other spectral features of V 439 Cyg (see later discussion). Table 3 reports the main parameters of these lines as measured in our spectra since 1986.

Table 3. Parameters of the Hα and Hβ lines of V 439 Cyg

Year	Central Wavel. A	*FWZH* A	intensity erg (cm^2 s A)$^{-1}$	eq.width A	σ_{ew} A
Hα					
1986	6564.0	34.0	uncalibrated	39.1	7.8
1987	6559.9	63.4	0.908E-12	45.4	4.0
1988	6559.9	66.8	0.902E-12	45.2	9.0
1989	6556.3	70.9	0.807E-12	37.8	7.6
1992	6570.0	64.0	0.540E-12	25.6	5.2
1997	6560.9	68.4	0.490E-12	43.8	4.4
Hβ					
1958	4857.7	21.2	absorption	-4.7	20.0
1986	4861.0	19.0	uncalibrated	3.0	4.0
1987	4861.0	14.0	0.246E-13	3.7	3.0
1988	4861.2	14.1	0.954E-14	1.3	4.0
1989	4855.2	34.5	0.203E-13	2.8	15.0
1992	4860.0	14.0	0.418E-14	3.2	4.0
1994	4861.9	25.9	0.141E-13	5.9	4.0
1997	4859.0	27.0	0.138E-13	4.3	4.0

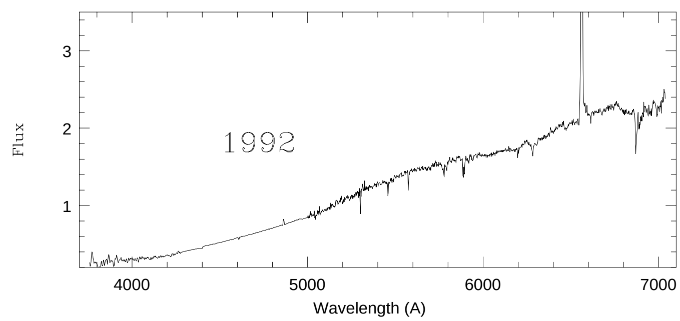

Fig. 5. Flux calibrated spectrum of V 439 Cyg in 1992; fluxes are in $\mathrm{erg\,cm^{-2}s^{-1}\,A^{-1}}$

A possible variability in the Hα equivalent widths (ew) is present, as illustrated in Fig. 7. The statistical uncertainties have been evaluated following the Chalabaev & Maillart (1984) method. Considering the very conservative error evaluation, Fig. 7 suggests that the Hα ew increases from 1986 to 1987, reaching a maximum that remains stable until 1989, then decreases linearly up to 1992 and increases again in 1997. The Hβ ew is essentially constant. The Hα full width at zero intensity (FWZI) has a maximum in 1988–1989, then decreases, reaching in 1997 the same value of 1986.

The Hα/Hβ intensity ratio is much more difficult to measure, since the difficult evaluation of the continuum at the Hβ wavelength strongly affects this figure. Its value is $\sim$100 in 1992 and 1988, otherwise is always $\sim$40. Nevertheless it is difficult to firmly assess the variability of this intensity ratio because of the quite sizeable measurement errors on the line intensities.

The Hα/Hβ ew ratio is always beteen 8 (in 1992) and 13 (in 1987, 1989), except for a value of 35 in 1988. It is unlikely

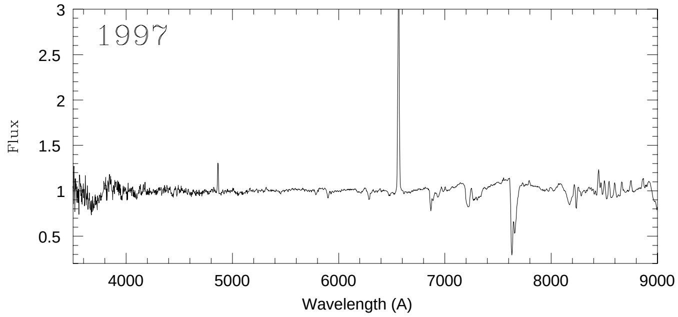

Fig. 6. Normalized 1997 spectrum of V 439 Cyg.

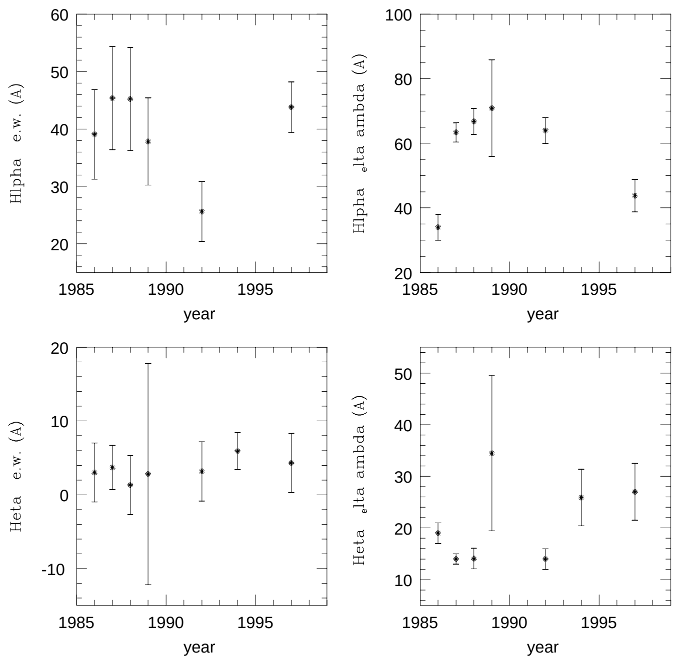

Fig. 7. Variation of the equivalent width and FWZI of the Hα and Hβ lines

that this effect might be due only to the relatively low spectral resolution of the 1988 spectrum.

If, on the other hand, one calculates the ratio intensity/ew for Hα, one finds values around 20, except in 1997, when it is 11. Thus, in this respect there is nothing peculiar about the 1992 spectrum of the star, when the Hα ew varies well outside the statistical uncertainties.

Fig. 8 shows the Hα profiles in 1986, 1987, 1988, 1992 and 1997; the profile in 1989 is also reported for comparison, despite the very low spectral resolution. The line profile appears always asymmetric, with wings up to $\sim$ 500 km/s. A possible shift of the peak wavelength is here difficult to measure due to the limited spectral resolution. The higher resolution spectrum of 1987 seems to suggest the presence of a number of components of Hα, the clearest one at a velocity of $\sim$120 km/s. These peaks could be responsible both for the asymmetry and variability of the line profile.

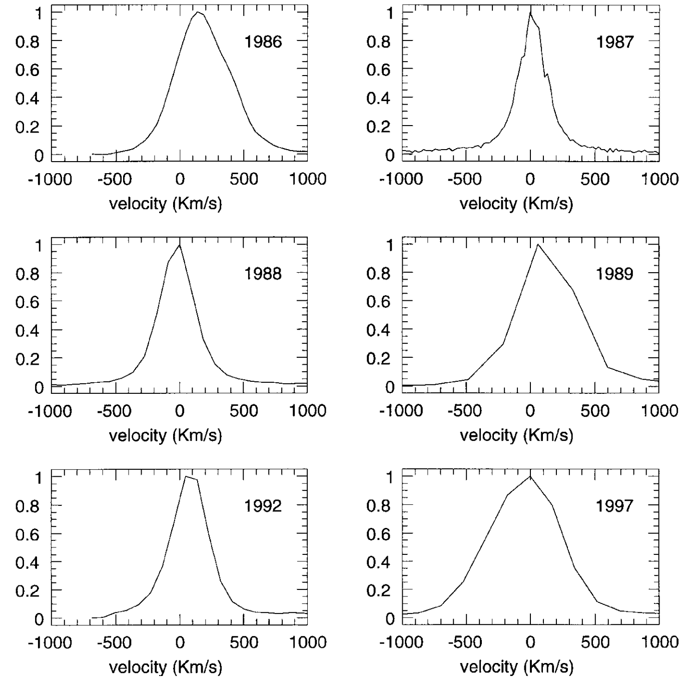

Fig. 8. Hα profiles of V439 Cyg in 1986, 1987, 1988, 1989 and 1992

3.3. *Identification of other lines*

The determination of the line parameters in the hot phase spectra of V 439 Cyg (with the exception of Hα and Hβ) is often made uncertain by the crowd of emission and (mainly) absorption lines, that are difficult to separate even at a resolution of 0.5 A.

A further problem is introduced by the strong variability of most of the lines, that can also mask the permanent spectral features.

Table 4 reports the list of the lines detected in the blue 1987 spectrum of V 439 Cyg. The first column refers to the labels of these lines in Fig. 3, while columns 2 and 3 give the wavelengths and the identifications of these lines as reported in Polcaro et al. (1989). Columns 4–8 schematically describe the line appearence in various years, considering only the best quality spectra, where the S/N ratio rules out the possibility of false detections. The identifications reported in Polcaro et al.(1989) were proposed on the basis of the comparison of the star's spectrum with that of a "standard" Be star. The lack of detection of most of these lines, considered of photospheric origin, in some of the spectra taken in the following years, makes these identifications uncertain. Furthermore, if one excludes H Balmer lines, not a single ion is constantly present in all spectra and the line ratios are often incompatible with their theoretical values. Actually we now doubt the correctness of the line identifications reported in Polcaro et al. (1989). Notwithstanding this, we feel that the presence of FeI and FeII emission lines in 1988, 1992 and 1997 is unmistakable, although in the 1992 and 1997 spectra the iron lines are quite weak. The bad quality of the 1994 spectrum does not allow us to assess the presence of such lines. Other lines that are always present in our spectra are the HeI line (and mainly the 4471, 5015, 5875 and 6678 A features) A number of other absorption lines have appeared (sometimes with clear evidence) and disappeared over the years such as, for example, the “4500 A blend”. Given this variability, we suspect that these lines might not be of photospheric origin and might possibly be due to molecular transitions in the extended atmosphere of the star. Therefore the identification of these lines appears very problematic.

4. The cold spectrum of V 439 Cyg

The list of identified lines in the 1958 spectrum of V 439 Cyg can be found in Polcaro et al. (1989). It would appear from Fig. 3 that the feature at 4500 A is also present in this spectrum but it was at the time associated by us with metal lines. Although the line identification was made difficult by blending and the low resolution, the C_2, CH and CN bands are clearly detected (see Fig. 3). The MS bands, due to the SiC_2 molecule, are also present. On the other hand, the spectrum of the star in 1958, taken as a whole, is definitely different from that of any standard C star reported in the atlas of Barnbaum et al. (1996), mainly because of the intensity ratio between the CH and CN bands and the strength of the Hδ, Hγ and mainly Hβ lines, that are usually very faint in C stars. Furthermore, the mysterious “4500 A blend” seems too strong to be due only to the summed contribution of Fe I, Ti I and Ni I lines commonly present in C stars. A further problem is given by the strength of the line that we associated with the Ba II feature at 4554 A: this line is stronger than in the “Ba stars” themselves. The same can be said for the nearby blend at 4602–07 A, that we (Polcaro et al, 1989) tentatively associated with Cr I, Fe I and Sr I. Notice that absorption features at the same wavelengths are present in the hot spectrum of the star in 1986 and 1987 and were associated by us (Polcaro et al., 1989) in these spectra with N II, N III, S III ions.

Actually, comparing the line spectra of the star in 1958 and 1987 (Fig. 3), we clearly notice that most of the absorption lines are present in both spectra, the main difference being only the lack of the He I lines in 1958 and of the C_2, CH and CN bands in 1987, while the Balmer lines changed from absorption to emission.

Most probably, the absorption lines, that strongly weakened or disappeared in 1988, in the cold (1958) and hot (1986/7) spectra of the star have to be attributed to molecular transitions.

5. Photometry

5.1. Photometric variability of V 439 Cyg

An indication of possible variability of colour indices of V 439 Cyg was first given by English et al. (1983). These authors also clearly stated that the quasi-periodical variability of the star detected by van Schewick (1941) was not present at the epoch of their measurements.

We carried out photometric measurements of V 439 Cyg in 1986, using the Loiano telescope equipped with an RCA CCD (320x512 pixels) at the Cassegrain focus. B,V,R and I images were obtained and the star’s brightness (see Table 5) calculated

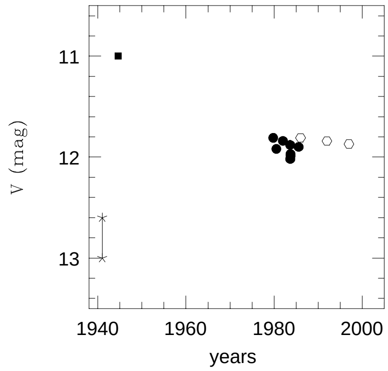

Fig. 9. Photometric variations of V 439 Cyg in the V band. Stars: van Schewick (1941); square: Merrill & Burwell (1949); filled dots: English (1986); open dots: this work

by comparison with field stars (nos. 20 and 28 of the list in Turner & Forbes, 1982) with constant flux.

The J, H, K and L measurements were performed by us on four separate occasions in November ’88 and June/July ’89 using the TIRGO 1.5 m telescope, equipped with the IAS In-Sb detector, and the JST 1.5 m telescope with the IAC IR photometer (Polcaro et al., 1991). The photometric measures in all these bands do not show a variability greater than the estimated uncertainties.

In August 1992, photometry in the V band was performed on our behalf by the amateur astronomer Rinaldo Monella (Sharru Observatory), equipped with a 60 cm (f8) Cassegrain reflector and a 1P21 CCD device: the star was measured each night for the whole month and was found to have a constant V=11.84$\pm$0.05 magnitude.

In June 1997, we took calibrated V and R images of the star using the Loiano telescope equipped with the *BFOSC* camera and derived flux calibrated magnitudes in these two bands.

All these measurements, when compared with the UBV photometry of Turner & Forbes (1982) and the UBVRI data of English (1986, priv. comm.), do not show any substantial variability.

In order to produce a light curve of V 439 Cyg on the widest possible time scale we have chosen the V band. Fig. 9 reports the whole data set since the van Schewick (1941) observation. As can be seen, the star brightened strongly between 1941 and 1944 (Merril & Burwell, 1949), then faded again reaching, before 1982, a V$\simeq$11.85 that remains until now stable with a minor variability of $\Delta V \simeq$0.05.

To our knowledge, the V magnitude in 1958 was not measured by any observer, but the relative intensity, with respect to nearby stars, in the 4000–4900 spectrum on the OHP objective prism plate (see Fig. 2), suggests that at that epoch the star was still brighter than at present in the V band. Unfortunately, it is impossible to obtain a quantitative evaluation of the flux from this kind of plates.

The sparse measurements existing for the other bands, besides the V band, prevent us to confirm the small variability of colour indices suggested by English (1983).

Table 4. List of the classification lines detected in the 1987 spectrum of V 439 Cyg. Column 1: labels of these lines in Fig. 3., column 2: wavelengths, column 3: identifications of the lines as reported in Polcaro et al. (1989), columns 4–8 state of the line in 1987, 1988, 1992, 1994, 1997. (Y: line detected, N: lack of detection, W: possible weak presence, S: strong line, (e): emission line; OR: out of range.). Lines 18,19,20 form the "4500 A blend"

Label	Wavelength	*Polcaro et al. (1989)* identification	1987	1988	1992	1994	1997
1	4075	O II, C III	Y	OR	Y	OR	Y
2	4089	Si IV	Y	OR	N	OR	Y
3	4101	Hδ	Y(e)	OR	Y	OR	Y
4	4116	Si IV	Y	OR	Y	OR	Y
5	4121	He I	Y	OR	Y	OR	Y
6	4132	O II	Y	OR	Y	OR	N
7	4153	O II, C III, S II	Y	OR	Y	OR	Y
8	4182	O II, Ar II, K II	Y	OR	W/N	OR	N
9	4226	N II, Ar II	Y	OR	N	OR	Y
10	4284	S III, O II, S II	Y	OR	OR	OR	Y
11	4300	Ar II	Y	OR	OR	OR	N
12	4340	Hγ	Y(e)	OR	OR	OR	Y
13	4378	N III	Y	OR	OR	OR	Y
14	4398	Ne I	Y	N	N	N	Y
15	4440	He II	Y	N	N	Y	Y
16	4447	Ne II, Ar I	Y	Y	N	Y	Y
17	4471	He I	Y	Y	Y	Y	Y
18	4500	Ne II, N II,					
19	4510	NIII, K II,	Y,S	N/W	N/W	N	N/W
20	4518	SIII					
21	4552	He II, Si III	Y	Y	N	Y	Y
22	4576	Si III	Y	Y	W/N	N	Y
23	4600	Ne II, N II	Y	Y	W/N	N	Y
24	4640	N III, O II	Y	N	Y	N	Y
25	4650	C III, O II	Y	N	Y	Y	N
26	4672	Si IV, OII	Y	N	Y	Y	Y
27	4686	He II	Y	N	N	Y	Y(e?)
28	4691	O II	Y	N	N	Y	Y
29	4760	S II +?	Y,S	Y	Y	N/W	Y,S
30	4816	S II, Si III	Y	Y	Y	Y,S	Y/W
31	4861	Hβ	Y,S,(e)	Y,S,(e)	Y,S,(e)	Y,S,(e)	Y,S,(e)

5.2. *Energy distribution of V 439 Cyg*

In Fig. 10 is shown the energy distribution of V 439 Cyg from near UV to IR wavelengths. The UBVRI photometry is taken from Turner & Forbes (1982). The H, J, K, L points are from Polcaro et al. (1991) and the far IR flux from the IRAS Satellite Point Sources Catalog.

Our monitoring study shows that any variation of the stellar magnitude in the UBVRI bands has been very small (smaller than the symbol size in the figure) in the last decade. Unfortunately, in the HJKL region no other measurement exist besides ours. Therefore, we are unable to assess whether there has been any variation in this spectral region. The same can be said of the IRAS photometry.

Therefore, we have concentrated our efforts on trying to determine the spectral parameters for the UBVRI region only. We have attempted a fit of this spectral region (Polcaro et al. 1989) with a black body curve and a reddening correction E(B-V)=1.53 (deduced from the Turner & Forbes, 1982, isoreddening lines of the cluster) but it was impossible to find any black body temperature that would fit these data. Using E(B-V) = 1.83 mag, suggested by English et al. (1983) in order to bring

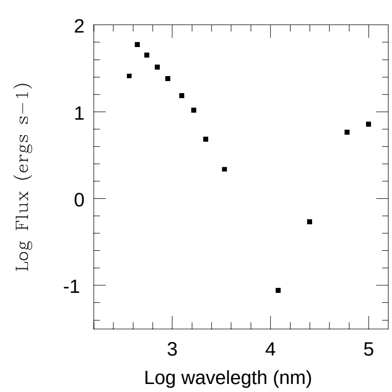

Fig. 10. Energy distribution of V 439 Cyg. The optical photometry is taken from Turner and Forbes (1982). The H, J, K,L points are from Polcaro et al. (1991) and the far IR flux from the IRAS satellite archival data.

Table 5. Recent photometry of V 439 Cyg

Obs. date	Band and Magnitude	σ Magnitude	Telescope and detector	Comments
8 Sept 1986	B=13.25	0.04	Loiano 1.52 cm telescope + RCA CCD	
	V=11.81	0.03		
	R=10.55	0.04		
	I= 9.44	0.03		
26 nov 88	J=8.56	0.1	TIRGO 1.5m+IAS + In-Sb	
	H=8.05	0.1		
	K=7.55	0.1		
	L=6.93	0.1		
15 jun 89	J=8.60	0.23	JST 1.5m + IAC IR Phot.	Bad seeing
	H=8.10	0.23		
	K=7.62	0.23		
	L=7.13	0.23		
5 jul 89	J=8.70	0.23	JST 1.5m + IAC IR Phot.	Bad seeing
	H=8.17	0.23		
	K=7.68	0.23		
	L=6.96	0.23		
15 jul 89	J=8.70	0.04	JST 1.5m + IAC IR Phot.	
	H=8.20	0.04		
	K=7.77	0.04		
1–30 Aug 92	V=11.84	0.05	Sharru Obs. 0.6m + 1P21 CCD	
24 Jul 1997	V=11.87	0.03	Loiano 1.52m + BFOSC	
	R=10.54	0.04		

the star's position on the cluster main sequence assuming an early B spectral type, also gives similarly disappointing results. Even assuming higher reddening values or an uncertainty in the classification of the star, it appears impossible to get a reasonable fit to the spectrum with any single black body temperature.

The presence of anomalous reddening could probably partly account for the difficulties encountered in fitting the energy distribution. This could also account for the anomalous position of V 439 Cyg in the Turner & Forbes CM diagram of Berkeley 87.

For what concerns the far IR region, the angular resolution of the IRAS measurements, about $2'$ for a source of this strength, does not allow to firmly associate this source with V 439 Cyg. In fact because of the complexity of the Berkeley 87 region, several objects (some other cluster members, a compact HII region, a CO emission region) are included in the IRAS error circle. The IRAS fluxes (apart from the 100 μm band upper limit) can be perfectly fitted by a power law, with an exponent of -2.78 which could be an indication of a free-free emission origin of the IRAS source.

A clear indication that V 439 Cyg must be a very hot star comes nevertheless from the strong intensities of the Paschen lines, detected in the 1997 spectrum (Fig. 6), suggesting a strong contrast effect with the continuum distribution and thus a very steep and blue continuum.

6. Discussion

6.1. Interpretation of the observed variability

A star that changes its spectral type from C to Be on a time scale of 50 yr is certainly a very peculiar object. The study that we have performed of V 439 Cyg, monitoring the star over an interval of time of 11 years and recovering more than 50 years of historical records and literature about this object, has convinced us that the red spectrum observed in 1958 was actually to be associated with V 439 Cyg and also that it is far from being a classical spectrum of a C star. Indeed, while the C bands are present in the 1958 spectrum and disappear in later years, some of the other absorption features can still be recognised in later years when the spectrum is definitely a hot one.

Line variability seems to be the main characteristic of this object. A clear example of this is the deep absorption feature at 4500 A, first visible (but not commented by the authors) in the English et al. (1983) spectrum, that remains unidentified. This feature has been varying over the years till its complete disappearence in 1988. One may notice nevertheless that a similar feature is present in the 1958 spectrum.

This variability is present at various levels as has been illustrated in the previous sections. In particular, the variability of the H lines that were in absorption in 1958 and have always been observed in emission since the 1983 observation suggests deep changes in the star's atmosphere over this time interval.

It is of interest to note that, also when the star has a hot spectrum, this appears nevertheless not quite like that of a normal Be star, from which the classification as B0ep.

A possible explanation of the observed changes could be an episode of mass ejection, before 1958 and probably after 1941, that has created a pseudo-photosphere around this star. Such a pseudo-photosphere would be observed as a change in colour towards the red and in spectral lines. The star would probably also have at first an increase in brightness, due to the the larger emitting surface, as is actually suggested by the V band light curve and the strength of the spectrum on the 1958 OHP plate.

This hypothesis would explain the presence of molecular features, as is expected in a cold photosphere, and the indication of a Mira-like behaviour (with a V flux more than 1 mag fainter ratio than the present-day one) mentioned by van Schewick (1941). The 1958 pseudo-photosphere would be in some way similar to the late spectrum of the LBV stars during outburst.

Since 1958 this pseudo-photosphere would have dissipated gradually with the physical conditions in the ejected shell changing accordingly so as to cause the observed progressive disappearence of the molecular features and the emergence of the spectrum of the true stellar photosphere, the observed hot spectrum.

At the present time, the ejected material would still be in the immediate surroundings of the star causing the anomalous reddening, the unusual and possibly variable Hα/Hβ, ratio and contribute to the strong IR emission. Our observation of an Hα nebula around the star (see Sect. 3.1) reinforces this hypothesis.

V 439 Cyg would then be a hot star surrounded by the remnant of a shell ejection. The question, of course, is what evolutionary scenario we could envisage to explain this phenomenon.

6.2. Evolutionary scenario

A B spectral type (and variable subtype), with strong and variable Balmer and Fe II emission during hot phases and a late spectral type during the cool phases is typical of LBVs (e.g. Humphreys & Davidson, 1995 and refs. therein; Smith, 1997). The occurrence of minor eruptions a few years after a major one (that could explain the Balmer lines variability detected in our measurements), the anomalous reddening and the strong IR excess are also typical of the LBV behaviour.

The short time scale of the cool phases, the high wind velocity and the smaller difference in magnitude between the maximum brightness during the outburst and the present brightness level prevent us to classify V 439 Cyg as a “standard” LBV; but these facts can easily be explained by a lower mass of the ejected shell with respect to massive LBVs, as η Car, P Cyg or AG Car. The higher wind velocity with respect to a typical LBV star could be accounted for if a similar energy output is used to accelerate a smaller mass shell.

Present-day evolutionary models for high mass stars ($M_{\rm initial} > 25\,M_\odot$, see Maeder, 1996, for an exhaustive review) could in principle allow such an interpretation of the V 439 Cyg phenomenon. For instance, Crowther et al. (1995) have suggested an evolutionary sequence for massive stars with relatively low luminosities (log $L/L_\odot \sim 5.5$). This would be:

$$\rm O \rightarrow (LBV\ or\ RSG) \rightarrow WN8 \rightarrow WNE \rightarrow WC \rightarrow SN.$$

Such stars would experience either a red supergiant phase (RSG, $25\,M_\odot < M_{\rm initial} < 40\,M_\odot$) or become Luminous Blue Variables (LBV, $40\,M_\odot < M_{\rm initial} < 60\,M_\odot$).

The precise $M_{\rm initial}$ value separating the RSG evolution from the LBV one needs further tuning, but this general evolutionary scenario is now widely accepted.

It is thus conceivable that a star with $M_{\rm initial} \simeq 40 M_\odot$, having the lowest mass in which a LBV phase is expected to be present, could have a quite short period during its evolution when it experiences a variable phase, where some of the typical features of a LBV are present at a very low level.

While the observation of van Schewick (1941), that classified the star as a Mira variable, would suggest that a pulsation period was detected and therefore that a true stellar photosphere was being observed, the subsequent observations point to some kind of dynamical instability such as one could encounter in a LBV-like phenomenon.

The V magnitude of a star with $M_{\rm initial} = 40\,M_\odot$ and an age of 4 My (assuming the corresponding model of Schaerer et al., 1993 with Z=0.04 and a bolometric correction of -2.30 – Landolt, Börnstein 1982 –) at a distance of 0.95 kpc, were $M_v \simeq 2.1$. If V 439 Cyg would be a star of such mass, its total reddening would be $A_V \simeq 8$ mag considering the observed position in the Berkeley 87 *CM* diagram.

Since the local colour excess in the V 439 Cyg cluster region is $E_{(B-V)}$=1.53 (Turner & Forbes,1982), this would account for a reddening of only 4.8 mag. Therefore the circumstellar reddening of V 439 Cyg would be responsible for the residual 3.2 mag reddening. The non-solar (and still poorly known) chemical composition of the ejected shell, and the unknown date and geometry of the eruption, prevent us from a precise determination of the ejected shell mass. However, its order of magnitude is easily calculated if we assume that the nebula that we detected in Hα corresponds to the present day size of the shell and if we consider a spherical shell made by pure H: with these assumptions, a 3.2 mag reddening corresponds to a $N_H \simeq 5\times10^{21}$ cm^{-2} and to a total ejected mass $\simeq 4\times10^{32}$ g. This figure is fully compatible with the value expected from the material ejected in a small LBV-type eruption (e.g. Smith, 1997).

7. Conclusion

We believe we have exhaustively demonstrated that V 439 Cyg is at present a hot star surrounded by an H_α nebula that is probably the remnant of one or more shell ejections. The spectral and photometric variability exhibited by the star in the last decades resembles that of the LBV stars although at a somewhat lower level of activity. The indication that the star had a Mira-like appearence in 1941, meaning that it was at that time of red colour with a measurable pulsation period, could imply that a dynamical instability had already set in possibly culminating in a shell ejection. This created a pseudo-photosphere that was observed in the 1958 spectrum.

The age of the cluster and the spectrum of the star in the present hot phase rule out the possibility that we have observed a post-AGB PN ejection; on the other hand, given the smaller amount of mass apparently ejected in the outburst compared with other LBVs, we have postulated that V 439 Cyg is a star of smaller mass than a classical LBV star.

We have tried to make some hypothesis about the stellar mass in the light of the most recent evolutionary models for massive stars, concluding that the V 439 Cyg scenario is compatible with that of a star having an initial mass $\simeq$40 $M_\odot$.

What we have deduced about V 439 Cyg fits in the general evolutionary scenario of the parent cluster Berkeley 87. Assuming a cluster age up to 4 My (Norci et al., 1988) most of the members of Berkeley 87 are massive main sequence OB stars, still heavily reddened by the protostellar material (as the spectrophotometric data clearly show – e.g. Turner & Forbes, 1982; Polcaro et al., 1991); a $M_{\rm initial} \simeq 30 M_\odot$ should be in a RSG phase, as BC Cyg (M3.5I), a $M_{\rm initial} \simeq 40 M_\odot$ should pass through an unstable phase as V 439 Cyg and a star with $M_{\rm initial} \simeq 80 M_\odot$ (or more) will be in the WO phase, as Sand 5. Star formation should still be active at the cluster boundary, but it is not necessary to invoke a previous star forming burst, as we did in our preliminary study of the cluster (Polcaro et al., 1991)

We have probably observed V 439 Cyg in a possibly rare instability phase with mass ejection. If the estimated mass of $40 M_\odot$ were confirmed (e.g. quantitatively comparing its long term spectral and photometric variability with more detailed evolutionary models), our observations of this star could give a significant contribution towards establishing the limiting mass at which massive stars are supposed to experience a LBV phase.

This study has also shown that Berkeley 87 and similar young open clusters or associations, where high mass objects (Of, RSG, B[e], LBV and WR stars) are present, and where star formation processes are still active or are just ended, are precious experimental testing grounds for evolutionary models of massive stars.

The spectra described in this paper are available on request at the internet address polcaro@saturn.ias.rm.cnr.it

Acknowledgements. We would like to thank D.English and D.Turner who kindly supplied us with their unpublished data on V 439 Cyg, G. Muratorio and R. Duflot who allowed the recovery of the original 1958 OHP plates, R. Monella for the photometry performed on our behalf, R. Viotti, P. Persi, E. Meurs and C. Rossi for useful discussions and the whole Loiano Observatory staff for generous observational time allocation and support during our eleven years long work. This paper has made use of the Simbad data-base, operated at CDS, Strasbourg, France. L.N. was supported, while writing this paper, by a TMR European Fellowship.

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