

V39: An unusual object in the field of IC 1613*

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Abstract. The variable star V39 in the field of IC 1613 is discussed in the light of the available photometric and new spectroscopic data. It has strong emission Balmer lines, and the observed characteristics could be explained by a W Vir pulsating star with a period of 14.341 d, located at more than 115 kpc, that is in the very outer halo of our Galaxy. It should have an apparent companion, a long period (1118 d) red variable, belonging to IC 1613. The main uncertainty in this interpretation is an emission feature at 6684 Å, which we tentatively identified as a He I line.

Key words. stars: emission-line, Be – stars: variables: general – Galaxy: halo – Galaxy: structure

1. Introduction

The variable star V39, $\alpha(2000) = 1^{\text{h}}05^{\text{m}}02^{\text{s}}.1$, $\delta(2000) = 2^{\circ}10'24''$, was discovered by Sandage (1971) in the field of IC 1613. The photographic B observations, with an average apparent magnitude of $B = 19.2$, showed a light curve with the shape of an inverted β Lyr eclipsing variable with a period of 28.72 days. Sandage included it among the possible Cepheids, but in the subsequent works (see e.g. Madore & Freedman 1981) it was never used to derive the PL relation of Cepheids. Hutchinson (1973) re-examined these observations and suggested it could be a W Vir star located very far in the halo of our Galaxy. Van den Bergh (2000) suggested that it could be an isolated star in the intergalactic space. Hutchinson noted also a long term variability of about 1000 d. Antonello et al. (1999) surveyed IC 1613 looking for Cepheids, and added further data points to the time series of V39; the data, taken in unfiltered light, seemed to confirm that this is not a classical pulsating star, however its real nature remained unclear. The new observations indicated a long P of 1123 d and as regards the shorter one it was not possible to select unambiguously between 28.699 d and half this value, 14.350 d. New V and I observations were obtained in the context of the OGLE project (Udalski et al. 2001), but these data alone, due to their short baseline, are insufficient to clarify the matter. In 1999 some spectra

Table 1. Colors of V39.

JD (2400000+)	V	$B - V$	$V - R$	$V - I$
45973.02	18.59	0.56	0.59	1.12
50302.87	18.48	—	0.51	—
51830.	18.85	—	—	1.23

were taken at ESO-LaSilla, in order to throw new light on the nature of this object; in the present note we rediscuss all the photometric data and report on the analysis of the spectra.

2. Photometry

The available photometry includes: 1) the B photographic data published by Sandage (1971, 103 datapoints), which were derived from plates taken by Baade from 1929 to 1937; 2) our unfiltered observations (Wh band, Antonello et al. 1999, 66 datapoints) taken from 1995 to 1998, with further 6 datapoints obtained by E. Poretti with the 1.5 m telescope of San Pedro Martir Observatory in 1999; 3) the OGLE VI observations obtained by Udalski et al. (2001) in 2000 (40 and 42 datapoints, respectively). Another two datapoints were recovered: one $BVRI$ observation obtained by Freedman (1988) and one VR measurement obtained by us with the Dutch telescope (Antonello et al. 1999). These last data are listed in Table 1 along with the mean values of OGLE data. Figure 1 shows the OGLE $V, I, V - I$ data plotted vs.

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* Based in part on observations collected at ESO–La Silla.

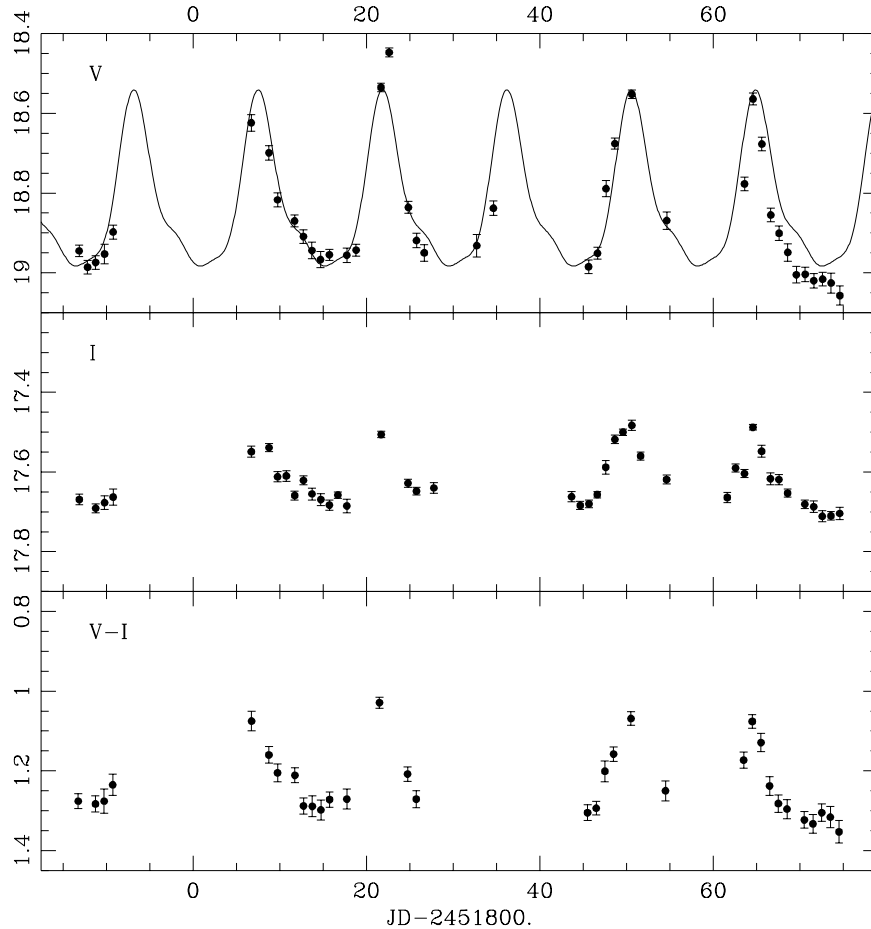


Fig. 1. OGLE V , I , $V - I$ observations. The solid curve in the top panel is the best fitting curve with $P = 14.3411$ d.

the time. We can see that they present a clear variation with a period of about 14 days and a sort of irregularity in the light curve. The three panels have the same scale so that it is possible to appreciate the different amplitudes of the curves ($\Delta V \sim 0.45$, $\Delta I \sim 0.2$ mag).

In order to profit from all the available information we decided to merge all the datasets by transforming them to a common system. Therefore both the B -photographic and Wh data were shifted and rescaled to match the V data (for the transformation of Wh colour to the V one see Antonello et al. 1999 and also Riess et al. 1999; Sandage's B data were transformed assuming that there have not been amplitude variations). When doing this we neglected the small phase shifts between the different color curves, because they are unimportant for the period search. As a result we obtained a dataset of 219 measurements spanning about 26 000 d. If we plot these data vs. time we see that there is a long-period variation. Its presence has been already suggested by Hutchinson (1970) on the basis of Sandage's data alone, and confirmed by Antonello et al. (1999) on the basis of their Wh data.

We frequency-analyzed the data with the least squares power spectrum technique developed to study multi-periodic signals with unequally spaced data (Vanicek 1971; Antonello et al. 1986). We detected 3 periodic components, a long period term with $P_L = 1118$ d

($\nu_L = 8.9 \times 10^{-4} \text{ d}^{-1}$), a short period one with $P_S = 14.3411$ d ($\nu_S = 0.06973 \text{ d}^{-1}$) and its first harmonic. The first two power spectra that show the two dominant periods are shown in the top panel of Fig. 2. The bottom panel of the same figure shows the spectral window, that, beside the presence of the peak at zero frequency with its one reciprocal year sidelobes, shows another peak at $\nu_w = 0.0339 \text{ d}^{-1}$ (reciprocal of the synodic month), flanked by its one reciprocal year sidelobes. The double-wave period of 28.677 d is an artifact generated by this structure of the spectral window, in fact its frequency (0.0348 d^{-1}) corresponds to $\nu_L + \nu_w$ (i.e. it is an alias of the long period). It is a mere coincidence that this value is almost exactly twice the short period. The V amplitude of the short period variation is about 0.45 mag, while that of the long-period one is about 0.40 mag. After removing the long and short period variations, it is apparent that the data dispersion is still large, 0.096 mag, compared to the estimated mean white noise level of 0.068 mag. If we push the analysis further we find another peak at $\nu_4 = 0.07050 \text{ d}^{-1}$, which satisfies the relation $\nu_4 \simeq \nu_S + \nu_L$. This relation could indicate that this is a non-linear coupling term between ν_L and ν_S , suggesting a physical connection between the two periodic variations. However this is a spurious term introduced by the fact that we consider the data in magnitudes; the non-linear transformation

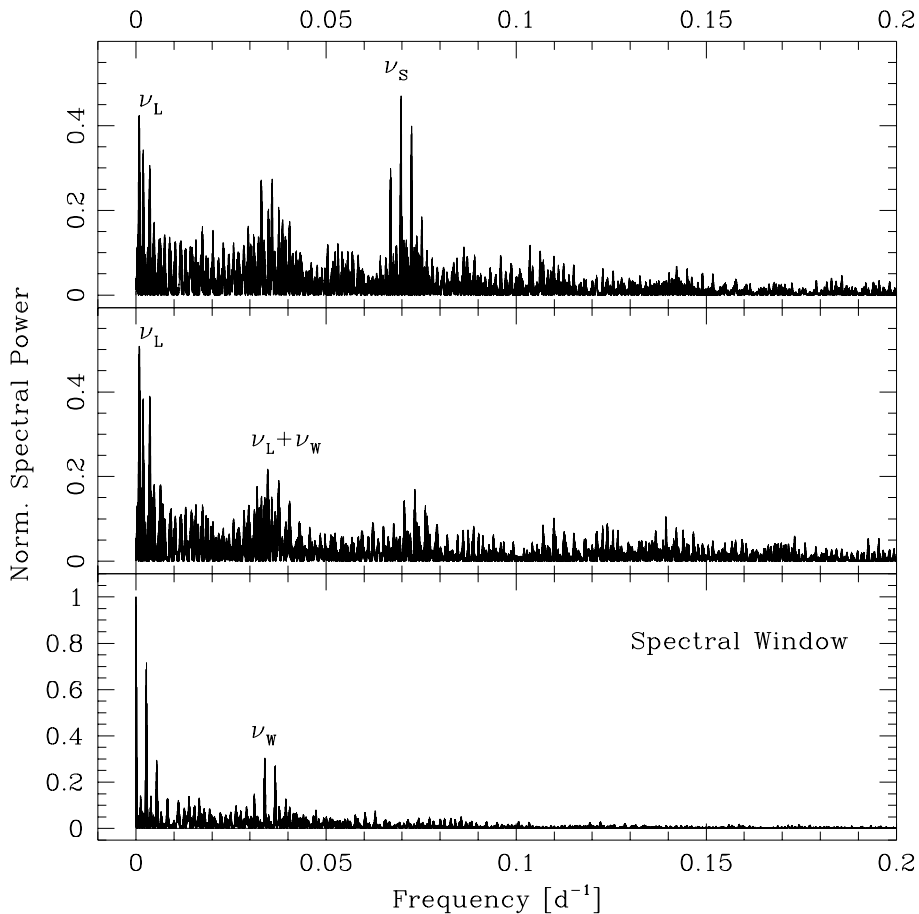


Fig. 2. Upper panel: original least-squares power spectrum; central panel: power spectrum after introducing ν_s as a known constituent, bottom panel: spectral window. The labelled peaks are discussed in the text.

from intensities to magnitudes introduces an apparent modulation of the amplitude of the short-period term. In fact, when analyzing the intensity data, the term at 0.0705 d^{-1} is not present. Figure 3 shows all the available data after removing the long period variation and the amplitude modulation due to it, phased with the period of 14.341 d . The resulting light curve has the typical shape of a pulsating variable, even if the dispersion of the data is still larger than that expected from data errors; probably the light curve does not repeat exactly from cycle to cycle. This can be seen also in the top panel of Fig. 1, which shows the OGLE V data; for comparison the solid line represents the best fit with the period of 14.3411 d . Figure 4 shows the long period variation curve with $P = 1118 \text{ d}$, obtained after removing the short-period variation.

3. Spectroscopy

3.1. Observations

The spectroscopic observations were performed with the the Danish 1.54 m telescope equipped with the DFOSC, and the EFOSC-2 attached to the 3.6 m telescope of the La Silla Astronomical Observatory (ESO) from 12 to 14 September 1999. The observations with the DFOSC

were taken with the grism #4, with a nominal resolution of $\Delta\lambda = 8.3 \text{ \AA}$ and a range from 3500 to 7000 \AA ; whereas the observations with the EFOSC-2 camera were performed with the grism #11 with a nominal resolution of $\Delta\lambda = 13.2 \text{ \AA}$ and a range from 3380 to 7520 \AA . Bias and twilight flat field frames were gathered each night. A helium lamp image was taken soon after the observations. During these three nights we collected a total of 6 images, each with an exposure time of 1200 s . The complete log of observations is reported in Table 2. The table contains for each image the date of the beginning of the night, the heliocentric Julian date of midexposure, the airmass, the slit width in arcsec and the used camera. The phases of the spectra computed according to the ephemeris: $T_{\text{Max}}(JD) = 2451850.6 + 14.3411E$ are: -0.07 (Sep. 12, 1999), 0.01 (Sep. 13), 0.08 (Sep. 14), i.e the observations were performed close to the maximum brightness.

3.2. Data reduction and analysis

The standard corrections and the cosmic-ray removal were performed using the ESO/MIDAS packages. All spectra were wavelength calibrated and extracted by means of the ESO/MIDAS (99NOV) “long” context.

In order to improve the S/N ratio the three spectra of Sep. 13 and the two of Sep. 14 were coadded. At the

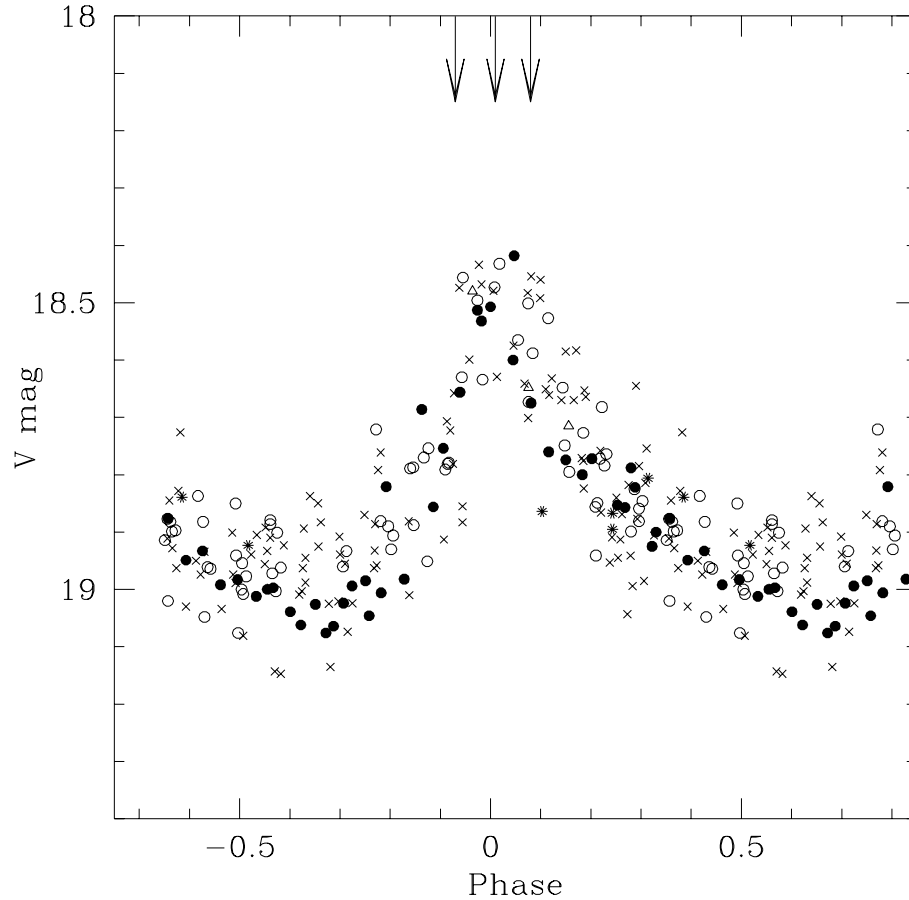


Fig. 3. Photometric data of V39 transformed into V magnitudes and phased with the 14.341 d period after removing the long period variation. Crosses: Sandage (1970); open circles: Antonello et al. (1999); asterisks: data taken at San Pedro Martir; closed circles: OGLE data. Arrows: phases of spectroscopic observations.

Table 2. Characteristics of the spectrograms.

date	JD (2400000+)	Airmass	Slit width (")	Instrument
Sep. 12	51433.75	1.172	2.5	DFOSC
Sep. 13	51434.84	1.389	2.0	DFOSC
	51434.86	1.513	2.0	DFOSC
	51434.88	1.686	2.0	DFOSC
Sep. 14	51435.82	1.377	1.0	EFOSC-2
	51435.84	1.308	1.0	EFOSC-2

continuum level in the region around 6100 Å the mean Danish telescope spectra have a $S/N \sim 30$ and those of the 3.6 m telescope $S/N \sim 50$. The resolutions, as measured from the width of the sky lines, are about 16 Å for the Danish telescope and 13 Å for the 3.6 m telescope. The single Danish spectrum of Sep. 12 has $S/N \sim 23$, however it is slightly defocussed ($FWHM = 23$ Å). The spectra of Sep. 13 and 14 are shown in Fig. 5, where the sky spectrum has been subtracted. We can see four stellar emission lines, $H\alpha$, $H\beta$, $H\gamma$, and a broad feature at 6684 Å ($FWHM \sim 24$ Å, to be compared to that of the adjacent $H\alpha$ of about 13 Å). We tentatively suggest

that it could be the HeI 6678 line; no other strong lines are usually present in the vicinity of this wavelength in stellar spectra. However, in this case the feature is red-shifted by about 180 km s^{-1} , while H lines on the contrary seem rather blue-shifted. The feature is real because it is present in both the 3.6 m telescope spectrograms, while in the Danish telescope spectrograms it is barely detectable. Other weak emissions (in particular in the 3.6 m telescope spectra) seem to be present, but they are not clearly ascribable to well-known spectral features (apart perhaps the $H\delta$) and, at least in part, are spurious features due to the sky subtraction. At the same time, no absorption features are unambiguously detectable.

We tried to verify the membership of V39 to the galaxy IC 1613 by means of the radial velocities. No conclusive results were found because the H lines supply discordant values.

4. Discussion

We can summarize the main observed characteristics of V39 as follows:

- There are light variations with a period of 14.341 d. The corresponding light curve has the typical shape

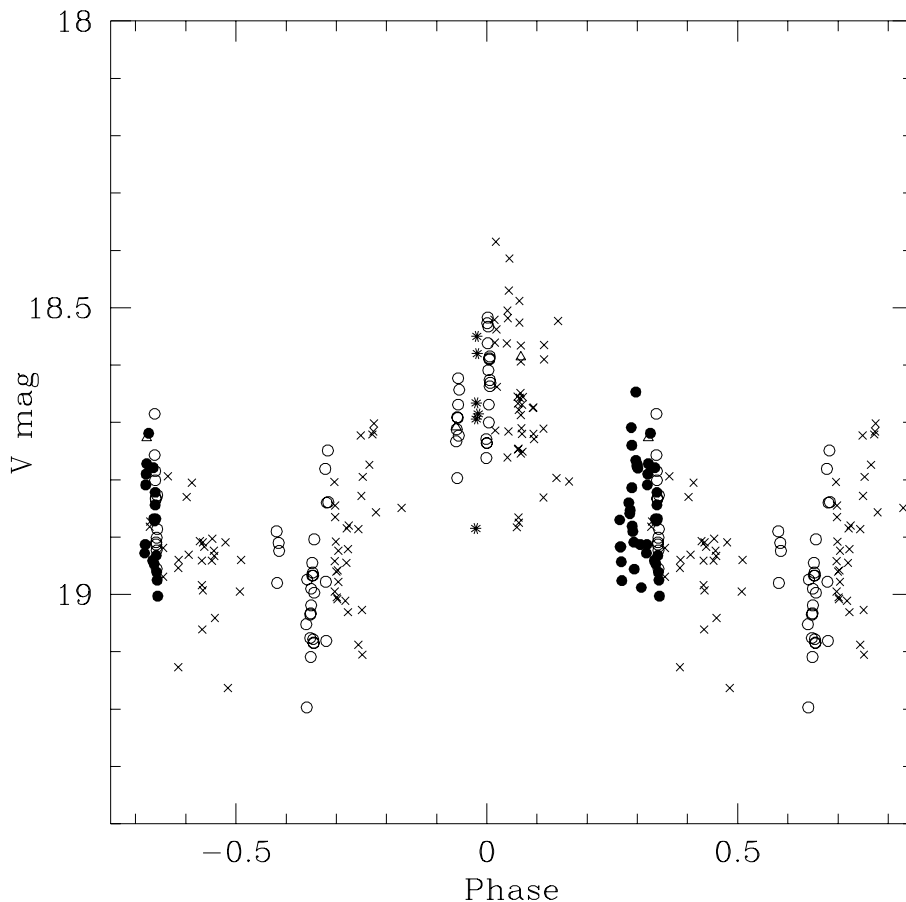


Fig. 4. Photometric data of V39 transformed into V magnitudes and phased with the 1118 d period after removing the short-period variation. Symbols as in Fig. 4.

of a Cepheid-like variable, even if it is not perfectly regular. Its amplitude decreases with increasing wavelength ($\Delta B = 0.9$, $\Delta V = 0.45$, $\Delta I = 0.2$, assuming no significant amplitude change over seventy years). V and I variations are in phase and the star is bluer at maximum luminosity.

- There is a long-period variation with $P = 1118$ d and a V amplitude of about 0.35 mag.
- The spectra at phases close to the maximum brightness show strong H lines emissions. At these phases a feature at 6684 Å (HeI 6678?) is also visible in emission.

4.1. V39 as a pulsating star

While it seems very probable that the star is pulsating with a period of about 14 d, it is an unlikely classical pop I Cepheid. The presence of irregularities in the light curve and of H and HeI(?) emission at maximum light indicate that it could be a pop. II Cepheid (i.e. a W Vir star; Lebre & Gillet 1992). With this interpretation some questions still remain open: a) one should expect also the emission line HeI 5876 Å; however due to the modest resolution of our spectra, this line, if present, should be blended, especially if red-shifted as the 6678 Å one, with the much stronger sky emission line of NaI 5890; b) although the presence of H emission lines at the observed phases is in

agreement with the case of W Vir (Lebre & Gillet 1992), in such a case the HeI emission should be most clearly seen between phases 0.61–0.003, while our best detection is at phase 0.08. Maybe this can be ascribed to the non-perfect regularity of the variations which can affect the accurate estimate of the maximum phase (see Fig. 1), and to the fact that spectroscopic and photometric observations are not simultaneous. If the star were a W Vir variable, its apparent brightness would exclude its membership to IC 1613, and it should be a foreground object.

The long period variations could be ascribed to the presence of a variable red star, a real companion or more plausibly a background star belonging to IC 1613 (a not unlikely case, see the analogous example of the pop. I Cepheid V2942B, Antonello et al. 2000). This is supported by the observed color. The mean $V - I$ is 1.23 while typical values of W Vir (or metal poor population I Cepheids) are around 0.6. We cannot ascribe this discrepancy to the foreground interstellar reddening because it is negligible in the direction of IC 1613 ($\langle E(V - I) \rangle = 0.09$, Macri et al. 2001). A long-period red variable with an apparent V magnitude which is 2 mag fainter than the W Vir star and with $V - I = 2.5$ could approximately explain the observed colour index. Moreover it reduces the ratio between V and I amplitudes of the 14 d period variation from the observed value of about 2.3 to 1.4, which is

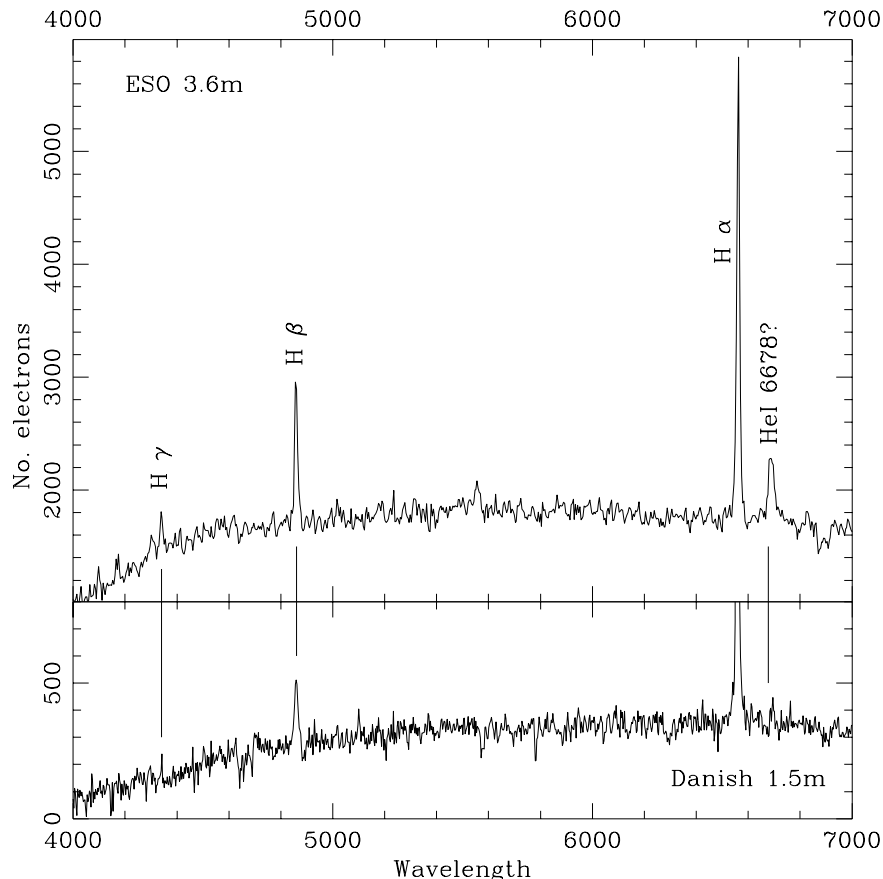


Fig. 5. Spectra of V39 after removal of the sky contribution. The stellar lines are labelled.

similar to that of known W Vir stars. If this were the case, the long-period variation would have a real V amplitude of about 1.4 mag, while the V amplitude of the short-period variation would increase only marginally. The red star should be a supergiant with $V \sim 20.5$ and should belong to IC 1613. Red variable stars with similar period and brightness were found by us in this galaxy (see for instance Table 9 of Antonello et al. 2000).

4.2. V39 as a high energy source?

The strong emission lines and the photometric variations led us to suspect that the star could be an unusual object belonging to the class of cataclysmic variables, that is a relatively nearby star in a binary system with an accreting disk or envelope around a compact object. However the result of the photometric analysis (in particular the ratio of the amplitudes in the different bands and the phase relations between V and I) rules out a geometric origin of the variability. Moreover, other spectral lines should have been observed. The intriguing feature is the line at 6684 Å, which is difficult to explain in the context of the stellar pulsation, and reminded us of the features observed in an unusual object such as SS433. However, no X-ray source has been found in the catalogues at the location of V39. The comparison of the published coordinates of the star suggests the lack of a proper motion during the last

seventy years, and this support the view that it is a far object.

5. Conclusion

The observational data tend to indicate that V39 is a foreground W Vir star of IC 1613. Adopting the PL relation by Nemeč et al. (1994), assuming a $[\text{Fe}/\text{H}] = -1$ and a fundamental mode pulsation we get $M_V = -1.7$, which for $\langle V_0 \rangle = 18.63$ gives a lower limit of distance modulus of 20.3, while the distance modulus of IC 1613 is 24.5 (Macri et al. 2001). We also speculated that the star could have a red companion, but its presence is not sufficient to confirm the membership of V39 to IC 1613. In fact, in this case the companion should be much brighter than the W Vir star, the amplitude of the 14 d period variation would be much smaller than what observed, and the red companion contribution to the spectrum should be dominating. In other words, while the W Vir star belongs to the halo of our Galaxy, the red star should belong to IC 1613. The presence of an isolated W Vir star at a distance of at least 115 kpc (assuming $[\text{Fe}/\text{H}] = -2$, the distance would be about 130 kpc) should raise discussion the open question of the true extent of the galactic halo. If true this would be the farthest known star of our galaxy; known halo field stars and globular clusters are closer than about 100 kpc (e.g. Morrison et al. 2001). Therefore it is

very important to definitively settle the question on the nature of V39. In order to do this, some spectra, at higher resolution than the present ones, should be taken to confirm the reality of the presence of HeI emissions, and to derive accurate radial velocities, which could definitively exclude the membership of IC 1613. The spectra should be taken both at phases in which the emission lines are present in W Vir stars (the ascending branch of the light curve) and at phases of minimum light, where the emission lines should be absent.

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