Optical and near-infrared observations of the microquasar V4641 Sgr during the 1999 September outburst

S. Chaty 1,2, P.A. Charles 3, J. Martí 4, I.F. Mirabel 2,5, L.F. Rodríguez 6, T. Shahbaz 7

1 Department of Physics and Astronomy, The Open University, Walton Hall, Milton Keynes, MK7 6AA, United Kingdom
2 Université Paris 7 and Service d’Astrophysique, CEA-Saclay, F-91191 Gif-sur-Yvette, Cedex, France
3 Departamento de Físicas, Escuela Politécnica Superior, Universidad de Jaén, C/ Virgen de la Cabeza, 2, E-23071 Jaén, Spain
4 Departamento de Física, Escuela Politécnica Superior, Universidad de Jaén, C/ Virgen de la Cabeza, 2, E-23071 Jaén, Spain
5 Instituto de Astronomía y Física del Espacio, Conicet, C. C. 67, Suc. 28 (1428), Buenos Aires, Argentina
6 Instituto de Astronomía, Campus UNAM, Morelia, Michoacán, 58190 México
7 Instituto de Astrofísica de Canarias, C/ Vía Láctea, s/n, 38205, La Laguna, Tenerife, Spain

Received date; accepted date

ABSTRACT

We present photometric and spectroscopic optical and near-infrared (NIR) observations taken during the outburst of the microquasar V4641 Sgr = SAX J1819.3-2525 in September 1999. We observed an increase in the J-Ks colour between 5 and 8 days after the outburst, which we interpret as likely evidence for the presence of dust around the source. We also observed an extraordinarily strong, broad and variable Hα line, with a velocity width of 4560 km s$^{-1}$ suggesting the presence of a high-velocity outflow component. We constrain the distance of the system between 3 and 8 kpc, locating it further away than previously derived from radio observations (Hjellming et al. 2000), but consistent with Orosz et al. (2001). We then discuss the nature of this system, showing that the companion star is either a B3-A2 main sequence star, or a B3-A2 sub-giant crossing the Hertzsprung gap. The system is therefore an Intermediate or High Mass X-ray Binary System (IMXB or HMXB). The distance derived by these optical/NIR observations implies that the jets observed by Hjellming et al. (2000) would then exhibit apparent velocities of $\sim 10$ c. We finally discuss the possibility of an interaction between the jets and surroundings of the source, and also of this source being a “microblazar”.

Key words: stars: individual: V4641 Sgr, SAX J1819.3-2525, XTE J1819-254, X-rays: stars, optical: stars, infrared: stars

1 INTRODUCTION

The variable V4641 Sgr attracted considerable attention after the detection of a giant optical outburst on 1999 September 15.7 UT, from V $\sim$ 14.0 to 8.8 (Stubbings 1999). Located in the direction of the galactic bulge (galactic coordinates l, b = 6.77°, −4.79°), V4641 Sgr was initially confused with GM Sgr, and most of the references to this X-ray source are reported under that name. After this confusion was clarified by Williams (1999) and Samus et al. (1999), the source was then designated V4641 Sgr (Kazarovets et al. 2000). The X-ray source XTE J1819-254 flared, from 1.6 to 12.2 Crab on 1999 September 14, as observed by RXTE in the 2-12 keV band, through a brief but dramatic eruption (at its peak it was the brightest X-ray source in the sky), its position being coincident with the optical transient Smith et al. (1999). Less than 10 hours later, the source was fainter than 50 mCrab. It was also identified with the previously detected faint X-ray transient, SAX J1819.3-2525, discovered by Beppo-SAX on 1999 Feb. 20 (flux 0.012 − 0.3 Crab, in’t Zand et al. 1999), and independently detected by RXTE (designated XTE J1819-254) two days earlier (Markwardt et al. 1999), with a flux between 3 and 80 mCrab in the 2-10 keV energy band.

Three other flares followed, each lasting less than two hours in X-rays, some of the fastest events ever seen. The observations by RXTE (Wijnands & van der Klis 2000) allowed the observation of some strong flaring activity: fluctuations by factors of 4 and 500 on timescales of seconds and
The source was resolved, with the presence of an elongation extending 0.25′′ between 0.6-1.2 days after the huge X-ray flare. On Sept. 17.93, 22.00 and 24.1 UT, the elongation was at the same position (Hjellming et al. [1999]), implying a proper motion of 0.5′′ / day, but this is strongly dependent upon the time of the ejection. This allowed the source to be classified as a new microquasar (for a review on jet sources see Mirabel & Rodríguez [1999]). An HI absorption measurement towards the source implied a distance d > 0.4 kpc (Hjellming et al. [2000]), and these authors proposed a likely distance of 0.5 kpc.

Dhondt [1978, 1979] reported a single short outburst of V4641 Sgr in 1978, recorded on Moscow photographic plates, reaching B = 12.4. He also suggested the possible presence of a periodicity of 0.7365 days from analysis of the quiescent data. Another optical outburst occurred in 1999 August [Watanabe [1999]], followed by a period of apparently increasing activity. Kato et al. [1999] reported unusual optical activity 6 days prior to the 1999 Sept. giant optical and X-ray outburst, through a ∼ 1 mag increase combined with a modulation of 2.5 days, which they claimed to correspond to the orbital period. More recently, during 2002 May, V4641 Sgr was active again, exhibiting in the optical chaotic 0.5 magnitude variations on a timescale of a few seconds. In the radio domain, the source was also flaring on timescales of minutes to hours (M. Rupen, VSNET communication). Details of this outburst are reported in [http://vsnet.kusastro.kyoto-u.ac.jp/vsnet/Xray/v4641sgr02.html](http://vsnet.kusastro.kyoto-u.ac.jp/vsnet/Xray/v4641sgr02.html) Oroz et al. [2001] derived from ESO spectroscopic optical observations of the source in quiescence a mass function of 2.74 ± 0.12 M⊙, which, combined with their information on the inclination (60 ≤ i ≤ 70°), Oroz et al. [2001], makes V4641 Sgr a black hole system with a mass of the compact object in the range 8.73 ≤ M1 ≤ 11.70 M⊙. They also found a spectroscopic period of 2.8 ± 0.000056 days, and assuming an extinction E(B-V) = 0.32 ± 0.10, quoted a distance between 7.40 and 12.31 kpc (note that this is larger than previously derived by Oroz et al. [2000]).

Through our on-going ESO Target of Opportunity (ToO) programme aimed at observing new X-ray flaring sources, we quickly obtained near-infrared (NIR) and optical imaging and spectroscopic observations of this new microquasar during the 1999 outburst and we followed it during its decline from 1999 September to 2000 June. We report the observations, including the first near-infrared observations of this source yet published, in Section 2 and the results and a discussion are given in Section 3.

## 2 Observations

All the observations took place at European Southern Observatory (ESO), La Silla, Chile, except the NIR spectroscopy of 1999 September 17, performed at UKIRT, Hawaii, and the optical imaging of 2000 June 24, performed at the 1.23 m telescope of the Centro Astronómico Hispano Alemán at Calar Alto, with the CCD optical camera and exposure times between 30 and 60s (more details on these observations are reported in Marti et al. [2001]). The log of the optical and NIR imaging and spectroscopic observations is reported respectively in Tables 1 and 2.

The optical observations were performed with the 3.58m New Technology Telescope (NTT) equipped with the spectrograph and imaging camera EMMI RILD. We imaged the source in V, R and I filters, and took spectra with grism #1 which gave a resolving power R ~ 270. The exposure times were ~ 5 min with each filter for the imaging and 15 min for the spectroscopy. The ESO NIR observations were performed with the NTT, equipped with the infrared spectrograph and imaging camera Son of ISAAC (SOFT). The imaging was taken through J, H and Ks filters, in combination with the Large Field, giving a 4.9 x 4.9-arcmin² field of view, with a plate scale of 0.292 arc-seconds pixel⁻¹. The spectra were taken with the Grism Red (GR) and V slits. The exposure times were chosen as 9 min for the NIR imaging (10 alternate images of 60s exposure time each offset from the center by nearly 30'' to the East, North, West, South, following the standard procedure) and 15 min for the NIR spectroscopy. The combined magnitudes are the result of these 10 co-added and median filtered 60s exposures, with random offsets and direction between each exposure. The conditions were photometric for most of the observations, the seeing being typically 0.8 arcsec, and the airmass was always between 1.006 and 1.2.

The images were processed using IRAF reduction software. Each of the images were corrected by a normalized dome-flat field, and the NIR images were sky subtracted by a sky image created from combining with a median filter a total of 10 consecutive images. The data were then analysed using the IRAF reduction task “aphot”, taking different apertures depending on the photometric conditions of the night.

Absolute photometry was performed using 2 standard stars from the new system of faint near-infrared standard stars (Persson et al. [1998]): No 9164 (HST P565-C) and 9178 (HST S5808-C). Each exposure of these standard stars is the average of 7x1.2s integration time frames, and this is repeated 5 times by offsetting the images of 1 arcmin to the North-West, North-East, South-East and South-West from the central position, and the final image is the co-add and median filter of those individual frames.

The optical and NIR photometry is plotted in Figure 1. An enlargement during the outburst interval (Sept. 19-24) and also the V-I and J-Ks colours are shown in Figure 2. The flux calibrated optical spectra are shown in Figure 3 and again in normalized form in Figure 4. The flux calibrated
Observations of V4641 Sgr

3 RESULTS AND DISCUSSION

After the big outburst (from V=14 to 8.8), there was still some flaring activity in V, R and I with variations of ~0.5 mag but no significant change in the colours. In the NIR there was also some flaring activity with variation of ~1 mag in J and K\textsubscript{s}, and a significant change in J-K\textsubscript{s} during the post-outburst interval (between 5 and 8 days after the giant burst, see Fig. 2). This change is due to a decrease in J band much faster than in K\textsubscript{s}, and during more than 3 days, the source emits mainly in K\textsubscript{s}. This can be explained either by the emission of a jet, of the appearance of heated dust, or even by the interaction with the interstellar medium, as we will discuss later. We had observed the same phenomenon in GRS 1915+105, which we had interpreted as evidence for an extended cocoon of dust around the source (Mirabel et al. 1996). Later observations by Chandra (Lee et al. 2002) and ISO (Fuchs et al. 2001) confirmed this presence of dust.

The first striking fact is that on a timescale of one day, the optical lines were changing from emission to absorption.

### Table 1. Log of the optical observations.

| Date       | MJD   | Inst   | B          | V          | R          | I          |
|------------|-------|--------|------------|------------|------------|------------|
| 16/09/99   | 51438.1 | EMMI   | -          | 13.60 ± 0.10 | 13.30 ± 0.10 | 13.20 ± 0.09 |
| 17/09/99   | 51439.0 | EMMI   | -          | 13.51 ± 0.06 | -          | 13.04 ± 0.08 |
| 28/09/99   | 51450.0 | EMMI   | -          | 13.65 ± 0.06 | 13.60 ± 0.01 | 13.25 ± 0.02 |
| 29/09/99   | 51451.0 | EMMI   | -          | 13.87 ± 0.06 | -          | 13.41 ± 0.08 |
| 21/03/00   | 51625.4 | EMMI   | -          | 13.89 ± 0.11 | 13.71 ± 0.08 | 13.43 ± 0.04 |
| 24/06/00   | 51719.5 | C.A.   | 14.32 ± 0.05 | 13.98 ± 0.05 | 13.77 ± 0.05 | 13.46 ± 0.05 |

### Table 2. Log of the NIR observations. The K\textsubscript{s} magnitude of Sept. 17 has been estimated from the CGS4 spectrum shown in Figure 5 (Charles et al. 1999).

| Date       | MJD   | Inst   | J          | H          | K\textsubscript{s} | J-K\textsubscript{s} |
|------------|-------|--------|------------|------------|-------------------|-------------------|
| 17/09/99   | 51438.2 | CGS4   | -          | -          | 12.5 ± 0.3        | -                 |
| 19/09/99   | 51441.0 | SOFI   | 13.14 ± 0.11 | -          | 13.10 ± 0.04      | 0.04 ± 0.15       |
| 20/09/99   | 51441.98 | SOFI  | 12.99 ± 0.03 | -          | 12.81 ± 0.06      | 0.18 ± 0.08       |
| 22/09/99   | 51443.97 | SOFI  | 13.93 ± 0.03 | -          | 13.06 ± 0.06      | 0.87 ± 0.09       |
| 24/09/99   | 51445.98 | SOFI  | 14.03 ± 0.03 | -          | 13.72 ± 0.03      | 0.31 ± 0.06       |
| 20/03/00   | 51623.42 | SOFI  | 12.94 ± 0.01 | 12.849 ± 0.01 | 12.72 ± 0.01     | 0.22 ± 0.02       |

Figure 1. Optical and NIR observations of V4641 Sgr from 1999 August to 2000 July. •: VSNET, ☉: B, ✶: V, ×: R, □: I, +: J, ◇: H, △: K\textsubscript{s} magnitudes. We first see a brief optical outburst which occurred in 1999 August, followed by the beginning of a modulation on 1999 Sept. 8 UT (= MJD 51429.5), which leads to the giant outburst of 1999 Sept. 15.7 UT (= MJD 51437). The error bars of our observations are smaller than the size of the symbols used. TJD of 0 corresponds to 1999 August 10.

The NIR spectrum is shown in Figure 5. The strengths of the spectral features are given in Table 3.

Figure 2. Top: Optical lightcurve of V4641 Sgr during the outburst; Middle: V-I colour; Bottom: J-K\textsubscript{s} colour. •: VSNET, ✶: V, □: I, +: J, ◇: H, △: K\textsubscript{s}, ×: V-I, ⋄: J-K\textsubscript{s} magnitudes. The error bars of our observations are smaller than the size of the symbols used. TJD of 0 corresponds to 1999 August 10.
Figure 3. Flux calibrated optical spectra of V4641 Sgr during the outburst. From top to bottom the spectra were taken respectively on 1999 September 17.05, 18.0, 29.0 and 30.0 UT.

Figure 4. Normalized and offset optical spectra of V4641 Sgr during the outburst. Same order as in Figure 3. The unlabelled absorption features are telluric ones.

All the H lines from the Balmer series from Hα to Hκ are detected. The Hα emission line is extraordinarily strong and broad: one day after the outburst, its equivalent width was \( \sim 100\,\text{Å} \), corresponding to a FWZI (Full Width at Zero Intensity) of 4560 km s\(^{-1}\) with a blue wing. This broad Hα emission line suggests the presence of a high velocity outflow component. The single peaked Hα profile suggests a low inclination angle.

There was also a weak He I 5876Å line. The Na-D absorption line equivalent width of 0.45Å gives E(B-V) = 0.25 (following Munari & Zwitter 1997), implying \( N_H = 0.14 \times 10^{22} \text{ cm}^{-2} \) (following Bohlin et al. 1978). This value of E(B-V) is consistent with that derived by Wagner (1999).

The second interesting fact is that there is a strong variability of the lines, as already pointed out by Garcia et al. (1999), particularly in Hα, Hβ and also He I. The He II 4680Å line was claimed to be prominent in emission closer to the outburst time by Ayani et al. (1999). Since we could not detect it, this line was also very variable. We can also note the blue continuum, visible on the flux calibrated spectra, suggesting a contribution from an accretion disk, or from a corona.

In the NIR, the He I (2.06 μm) and Brγ (2.17 μm) lines were observed as broad emission lines by Charles et al. (1999), in a K-band (1.9-2.5-micron) low-resolution (2.5-nm) UKIRT (+ CGS4) spectrum taken on 1999 Sept. 17.22 UT and shown in Figure 5. He I exhibited an equivalent width of 2.1 nm, and Brγ of 1.4 nm, characteristic of LMXBs and with widths of FWZI = 5900 km s\(^{-1}\). The Brγ profile shows a clearly extended blue wing, again suggesting a high velocity outflow component. The continuum of our NIR spectrum taken on 1999 Sept. 19 was also blue. However, our NIR spectrum shows only very faint HeI (equivalent width 6Å), He II and Brγ (equivalent width 1Å) lines, which therefore appear to be also strongly variable.

The broad, strong emission lines and their variability suggest the presence of a high-velocity outflow component (\( \sim 6000 \text{ km s}^{-1} \)) blown off from the accretion of matter onto the compact object (see for example Schulz & Brandt 2002). It is likely that this outflow component forms thereafter an expanding plasma shell or even a cocoon which could have produced the change we observed in the J-K\(_s\) colour.

3.1 Nature of the system: the companion star

We plot on a colour-magnitude diagram (CMD, Figure 6) the optical and NIR absolute magnitudes when the source was faint. In this figure the absolute magnitudes are computed with three different values of absorption and ten different values of distance from 1 – 10 kpc. The values of the absorption cover the range \( N_H = 0.05 \) to \( 0.15 \times 10^{22} \text{ cm}^{-2} \).
Observations of V4641 Sgr

3.2 Interaction with surroundings

If the elongation seen in the radio was a moving component, the proper motion was between 224 < \mu < 788 mas/d depending on the exact time of the ejection. For the sake of discussion, we will take the lower limit, assuming that the approaching (brighter) condensation exhibits \mu = 224 mas/d. Since from our results D > 3 kpc, we conclude that the apparent velocity in the plane of the sky would be strongly superluminal, with v_a greater than 4c. However, no movement of this elongation was detected between Sept. 16.02 and 24.1. This suggests an interaction between matter ejected before the X-ray outburst and its surroundings at 0.25'' \geq 1.5 \times 10^{3} AU from the source at the distance of 6 kpc. This is possible if the ejections began to take place at least 10 days before the radio detection e.g. on September 8, and we can see from Figure 2 that the source was already showing some activity in the optical at this date. This interaction with the surroundings is supported by the increase in J-K_s between 5 and 8 days after the outburst.

It then seems that the source activity was not as sporadic as it appears at first glance. Indeed, a previous optical outburst occurred in 1999 August (Watanabe 1999), and RXTE detected this source \sim 270 days before the giant outburst (in't Zand et al. 2000). Furthermore, at least 5 days before the giant outburst, V4641 Sgr was, in the optical band, continuously 2 magnitudes brighter than immediately after, showing a modulation at the orbital period, and with no X-ray emission (typical upper limit of 12 mCrab, in’t Zand et al. 2000). All these facts, combined with the high X-ray variability, show that, even if the Orosz et al. (2001) results suggest that the accretion in the system is of Roche-lobe overflow type, there is also the possibility that mass transfer in this source is occurring through irregular wind accretion from the companion star. This would not be too surprising in the case of an IMXRB/HMXRB system.

At a distance of 6 kpc, the maximum luminosity of the source is \sim 4 \times 10^{38} \text{ erg s}^{-1}, which is close to the Eddington limit of a \sim 10 M_{\odot} object (1.3 \times 10^{39} \text{ erg s}^{-1}). If the mass transfer rate is highly super-Eddington such a wind could arise. This wind could be the reason why surrounding matter was present, allowing the interaction between further ejections and surrounding matter to take place. In this case, the companion star is more likely to be a main sequence star (U. Kolb, private communication).

Finally, it is interesting to note that Martí et al. (2001) observed V4641 Sgr in order to look for minute to hour variability, discovering 0.05 mag variability on a timescale of hours. Among the different interpretations considered, they suggested that this variability could originate in an extended corona surrounding the jets, by analogy with SS 433 (Zwitter et al. 1991). We mention the possibility that the dust forming this corona could have its origin directly in the jets of X-ray binaries, as in supernova ejecta. If this interaction between the ejections and the surrounding medium is confirmed, this source could therefore be added to the short list of microquasars where such an interaction has been detected (see e.g. Chaty et al. 2001 and Mirabel & Rodríguez 1997).

3.3 A “microblazar”? 

However, V4641 Sgr seems different with respect to other microquasars, since in the latter the outbursts normally fade more slowly, often lasting for weeks. The only similar outburst was that from CI Cam, with an e-fold decay time of \sim 0.5 days (Belloni et al. 1999), its companion star being a symbiotic B star with an irregular wind. Therefore V4641 Sgr resembles several sources in behaviour, but differs from them in other aspects: one possibility to explain this is that it might be a “microblazar”, i.e. a microquasar whose jet is pointing towards the observer (see e.g. Mirabel & Rodríguez 1999, Orosz et al. 2001) already mentioned this possibility, based on the new determination.

Figure 6. Colour-magnitude [V-K_{s_K}K_{s}] diagram. *: Minimum absolute magnitudes of V4641 Sgr. +: typical main sequence stars (Ruelas-Mayorga 1991). 0.28, 0.56 and 0.84 are the visual absorptions corresponding respectively to column densities of 0.05, 0.1 and 0.15 \times 10^{22} \text{ cm}^{-2}. From bottom to top the asterisks correspond respectively to a distance of the source increasing from 1 to 10 kpc. This shows that the distance is constrained to 3 < d < 8 kpc, and that the spectral type is in this case consistent with an early type B3 - A2 main sequence star.

derived by combining our observations and Beppo-SAX results (in’t Zand et al. 2000). If we constrain the companion to be a main sequence star, its location on the CMD, taking into account the uncertainty in the absorption, suggests that the distance is constrained to 3 < d < 8 kpc. Its spectral type is in this case consistent with an early type B3 - A2 V main sequence star.

However, it is interesting to note that the companion star could be crossing the Hertzsprung gap, given the similarities of the system with GRO J1655-40 (Chaty et al. 2002; Kolb et al. 1997 and U. Kolb, private communication), although the mass of the companion star in the case of V4641 Sgr is larger than for GRO J1655-40. In this view, the location on the CMD would be above the main sequence, the distance of the object could then be larger than 3 < d < 8 kpc, this range becoming its minimum distance, and the spectral type would be B3 - A2 IV. In both possibilities the mass is constrained between 2 < M < 10 M_{\odot}, suggesting that it is an IMXB or a HMXB. This is consistent with the A2 V type at 6.1 kpc derived by Orosz et al. (2001).
of the distance of V4641 Sgr. Indeed, assuming that the radio component was moving \cite{Hjellming_2000} implies that the jets would then exhibit apparent velocities of \(\sim 10\) c. These large apparent velocities are consistent with the rapid variability in radio reported during the 2002’s outburst (M. Rupen, VSNET communication), implying either extremely large Lorentz factors or a jet coming from a microblazar. If V4641 Sgr were a microblazar, we also point out that we would not expect to see any Doppler shifted emission lines from the ejecta, which is consistent with our spectra (Fig. 3), as these lines would have a much larger blue/redshift than high-inclination systems. For instance, assuming a plausible jet velocity of 0.95c with \(\leq 10^\circ\) angle to the line of sight (as expected in a microblazar), the Doppler shifted wavelengths of \(\text{H} \alpha\) would appear in the UV (\(\sim 1000\) Å) and NIR (\(\sim 4\) μm) for the approaching and receding jet, respectively.

4 CONCLUSIONS

We have observed the source V4641 Sgr during its 1999 September outburst at optical and NIR wavelengths, deriving \(E(B-V) = 0.25\) and \(N_H = 0.14 \times 10^{22} \text{ cm}^{-2}\). By plotting our optical and NIR colours we have constrained the distance to \(3 < D < 8\) kpc, and the companion star would then be a main sequence star of spectral type B3 - A2 V. If the source is crossing the Hertzsprung gap, this determination of the distance would become its minimum distance, and the spectral type of the companion star would be B3 - A2 IV. The system is therefore an IMXB or a HMXB. From the NIR colours, and the optical spectra, there is a strong suggestion of interaction of the ejecta of the source with its surroundings. This surrounding matter could have originated from an outflow created by fluctuations around the central object, and in this case the companion star would more certainly be a main sequence star. Further observations would be useful to confirm the existence of surrounding matter. The bright X-ray outburst of V4641 Sgr in 1999 could have remained unnoticed, because of its very short duration, if the optical detection had not occurred, and if the source was not located so close. This means that there must be many similar (BH?) objects in our Galaxy, most of them unnoticed when in outburst, because of their short duration and faintest flares. This type of sources will be targets of prime importance for present and future high-energy missions, as for example the INTEGRAL telescope.

5 ACKNOWLEDGEMENTS

SC thanks Rob Hynes for pointing out this new flaring source on September 1999, Bob Hjellming for all the spontaneous communications he gave on the radio observations of this source, and Ulrich Kolb for many stimulating discussions. SC is very grateful to the ESO staff and particularly to the NTT team (Leonardo Vanzi, Olivier Hainaut, Stéphane Brillant and Vanessa Doublier), for their availability and skills to perform service observations for Target of Opportunity programs (63.H-0493 and 64.H-0382, PI S. Chaty). PAC and TS thank Tom Geballe for his assistance in obtaining the UKIRT CGS4 spectrum. The United Kingdom Infrared Telescope is operated by the Joint Astronomy Centre on behalf of the U.K. Particle Physics and Astronomy Research Council. We thank VSNET for all their alerts on V4641 Sgr and their optical data used in Figures 2 and 3. SC and PAC gratefully acknowledge support from grant F/00–180/A from the Leverhulme Trust. JM acknowledges partial support by DGICYT (AYA2001-3092) and by Junta de Andalucía (Spain), he has also been aided in this work by an Henri Chrétién International Research Grant administered by the American Astronomical Society. IFM acknowledges support from grant PIP 0049/98 and Fundacion Antorchas.

REFERENCES

Ayani K., Peiris T.C., Clarke Institute C., Sep. 1999, IAU Circ., 7254, 1+
Belloni T., Dieters S., van den Ancker M.E., et al., Dec. 1999, Astrophys. J., 527, 345
Bohlin R.C., Savage B.D., Drake J.F., Aug. 1978, Astrophys. J., 224, 132
Charles P.A., Shahbaz T., Geballe T., Oct. 1999, IAU Circ., 7267, 2+
Chaty S., Rodríguez L.F., Mirabel I.F., Geballe T., Fuchs Y., 2001, Astron. Astrophys., 366, 1041
Chaty S., Mirabel I.F., Goldoni P., et al., Apr. 2002, Mon. Not. R. astr. Soc., 331, 1065+
Fuchs Y., Mirabel I.F., Ogley R.N., 2001, Astrophysics and Space Science Supplement, 276, 99
Garcia M.R., McClintock J.E., Callanan P.J., Oct. 1999, IAU Circ., 7271, 4+
Hjellming R.M., Rupen M.P., Moduszewski A.J., Sep. 1999a, IAU Circ., 7254, 2+
Hjellming R.M., Rupen M.P., Moduszewski A.J., Sep. 1999b, IAU Circ., 7265, 2+
Hjellming R.M., Rupen M.P., Hunstead R.W., et al., Dec. 2000, Astrophys. J., 544, 977
in’t Zand J., Heise J., Bazzano A., et al., 1999, IAU Circ., 7119
in’t Zand J.J.M., Kuulkers E., Bazzano A., et al., May 2000, Astron. Astrophys., 357, 520
Kato T., Uemura M., Stubbs R., Watanabe T., Monard B., Oct. 1999, Informational Bulletin on Variable Stars, 4777, 1+
Kazarovets E.V., Samus N.N., Durlevich O.V., Mar. 2000, Informational Bulletin on Variable Stars, 4870, 1+
Kolb U., King A., Ritter H., Frank J., 1997, Astrophys. J., 485, L33
Lee J.C., Reynolds C.S., Remillard R., et al., Mar. 2002, Astrophys. J., 567, 1102
Markwardt C., Swank J., Marshall F., 1999, IAU Circ., 7120
Martí J., Zamanov R., Paredes J.M., Ribo M., Feb. 2001, Information Bulletin on Variable Stars, 5036, 1+
Müller J.M., Fabian A.C., in’t Zand J.J.M., et al., Sep. 2002, Astrophys. J., 577, L15
Mirabel I., Rodríguez L., 1999, Annu. Rev. Astron. Astrophys., 37, 409
Mirabel I.F., Rodríguez L.F., Chaty S., et al., 1996, Astrophys. J., 472, L111
Munari U., Zwitter T., Feb. 1997, Astron. Astrophys., 318, 269

\[E(B-V) = 0.25\] and \(N_H = 0.14 \times 10^{22} \text{ cm}^{-2}\). By plotting our optical and NIR colours we have constrained the distance to \(3 < D < 8\) kpc, and the companion star would then be a main sequence star of spectral type B3 - A2 V.
Observations of V4641 Sgr

Table 3. Optical emission and absorption line parameters observed during the outburst of V4641 Sgr. The flux is in W m$^{-2}$μm$^{-1}$. The typical uncertainties are $\sim 0.05$Å for Obs. λ and $\sim 0.1$Å for EW and FWHM.

| Date   | Line Id. (Å) | Obs. λ (Å) | Flux (10$^{-13}$) | EW (Å) | FWHM (Å) |
|--------|-------------|-------------|-------------------|--------|----------|
| 17.05UT| Hα          | 6565.23     | 9.0e-13           | -99.8  | 45.5     |
|        | Hβ          | 4861.13     | -7.4e-14          | 4.6    | 13.1     |
|        | Hγ          | 4340.13     | -1.3e-13          | 6.8    | 14.1     |
|        | Hδ          | 4101.83     | -1.6e-13          | 7.6    | 14.4     |
|        | Hζ          | 3970.16     | -2.1e-13          | 8.1    | 14.2     |
|        | Hη          | 3889.63     | -2.2e-13          | 8.0    | 14.3     |
|        | Hθ          | 3835.78     | -2.0e-13          | 7.5    | 13.4     |
|        | Hι          | 3798.43     | -1.5e-13          | 6.2    | 11.1     |
|        | Hκ          | 3770.67     | -1.2e-13          | 5.6    | 11.5     |
|        | Na-D        | 5780.51     | 8.9e-15           | 4.2    | 9.1      |
|        | Na-D        | 5890.62     | 7.5e-16           | 3.5    | 8.9      |
| 18.05UT| Hα          | 6561.08     | -7.4e-14          | 9.5    | 16.5     |
|        | Hβ          | 4340.82     | -1.3e-13          | 9.2    | 15.0     |
|        | Hγ          | 4101.20     | -1.5e-13          | 8.7    | 13.8     |
|        | Hζ          | 3970.20     | -1.9e-13          | 9.4    | 14.1     |
|        | Hη          | 3889.35     | -2.0e-13          | 9.0    | 14.4     |
|        | Hθ          | 3835.29     | -1.7e-13          | 7.7    | 11.9     |
|        | Hι          | 3798.50     | -1.5e-13          | 6.8    | 10.8     |
|        | Hκ          | 3770.00     | -1.4e-13          | 6.4    | 10.6     |
|        | Na-D        | 5780.49     | -1.0e-13          | 5.6    | 8.4      |
|        | Na-D        | 5889.32     | -2.2e-14          | 1.8    | 10.1     |
| 19.05UT| Hα          | 6560.13     | 2.1e-14           | -6.9   | 30.2     |
|        | Hβ          | 4340.13     | -1.3e-13          | 9.4    | 19.2     |
|        | Hγ          | 4101.30     | -2.1e-13          | 9.9    | 17.6     |
|        | Hζ          | 3970.08     | -2.4e-13          | 9.4    | 17.6     |
|        | Hθ          | 3889.70     | -2.2e-13          | 8.7    | 14.9     |
|        | Hι          | 3835.86     | -1.8e-13          | 8.6    | 14.3     |
|        | Hκ          | 3799.13     | -1.1e-13          | 6.5    | 11.4     |
|        | Na-D        | 5780.29     | -1.0e-13          | 6.4    | 10.6     |
|        | Na-D        | 5881.15     | -8.6e-15          | 2.0    | 11.4     |
| 20.05UT| Hα          | 6560.86     | -6.4e-14          | 7.0    | 20.1     |
|        | Hβ          | 4340.12     | -1.5e-13          | 9.4    | 19.2     |
|        | Hγ          | 4101.30     | -2.1e-13          | 9.9    | 17.6     |
|        | Hζ          | 3970.08     | -2.4e-13          | 9.4    | 17.6     |
|        | Hθ          | 3889.70     | -2.2e-13          | 8.7    | 14.9     |
|        | Hι          | 3835.86     | -1.8e-13          | 8.6    | 14.3     |
|        | Hκ          | 3799.13     | -1.1e-13          | 6.5    | 11.4     |
|        | Na-D        | 5780.49     | -1.0e-13          | 6.4    | 10.6     |
|        | Na-D        | 5881.15     | -8.6e-15          | 2.0    | 11.4     |
| 21.05UT| Hα          | 6562.02     | -5.0e-14          | 7.4    | 19.3     |
|        | Hβ          | 4340.10     | -1.1e-13          | 9.3    | 16.8     |
|        | Hγ          | 4101.53     | -1.1e-13          | 9.3    | 16.1     |
|        | Hζ          | 3969.79     | -1.3e-13          | 9.4    | 14.9     |
|        | Hθ          | 3889.43     | -1.3e-13          | 8.6    | 14.6     |
|        | Hι          | 3835.40     | -1.2e-13          | 8.6    | 14.2     |
|        | Hκ          | 3798.30     | -7.9e-14          | 6.3    | 11.2     |
|        | Na-D        | 5777.52     | -4.0e-15          | 0.5    | 9.1      |
|        | Na-D        | 5890.62     | -2.1e-14          | 2.7    | 14.1     |