V4745 Sgr – a nova above the period gap and an intermediate polar candidate

A. Dobrotka1⋆, A. Retter2⋆ and A. Liu3⋆

1Faculty of Materials Science and Technology, Slovak University of Technology in Bratislava, Paulínska 16, 91724 Trnava, The Slovak Republic
2Departement of Astronomy and Astrophysics, Penn State University, 525 Davey Lab, University Park, PA, 16802-6305, USA
3Norcape Observatory, PO Box 300, Exmouth, 6707, Australia

Accepted ???. Received ???; in original form ???

ABSTRACT
A period analysis of CCD unfiltered photometry of V4745 Sgr (Nova Sgr 2003 #1) performed during 23 nights in the years 2003 – 2005 is presented. The photometric data are modulated with a period of 0.20782 ± 0.00003 d (4.97868 ± 0.00072 h). Following the shape of the phased light curve and the presence of the periodicity in all data sets with no apparent change in its value, we interpret this periodicity as orbital in nature and this is consistent with a cataclysmic variable above the period gap. We found a probable short-term periodicity of 0.017238 ± 0.000037 d (24.82272 ± 0.05328 m) which we interpret as the probable spin period of the white dwarf or the beat period between the orbital and spin period. Therefore, we propose that nova V4745 Sgr should be classified as an intermediate polar candidate, supporting the proposed link between transition-oscillation novae and intermediate polars. The mass-period relation for cataclysmic variables yields a secondary mass of about 0.52 ± 0.05 M⊙.

Key words: stars: novae, cataclysmic variables - stars: individual: V4745 Sgr - stars: white dwarfs

1 INTRODUCTION

Novae are a subclass of cataclysmic variable stars. In these binaries, matter from a secondary star is accreted onto the surface of a white dwarf. When this material gets sufficiently hot and dense for the white dwarf to ignite a thermonuclear runaway, it blows off the hot burning layer at the surface. This event, which leads to a rapid increase in the luminosity of the binary system, is called a nova outburst.

V4745 Sgr (Nova Sgr 2003 #1) was discovered independently by Brown and Yamato (2003) on April 25th and 26th 2003. Optical and infrared spectroscopic confirmation was made by Ashok & Banerjee (2003). The optical spectrum showed that it was a Fe II nova (Williams 1992), with strong Balmer lines with P Cyg profiles. After rapid fading the nova rebrightened again and the Balmer lines with Fe II 4176, 4233 Å showed complex P Cyg profiles (Kiss & Jacob 2003). A detailed low and medium resolution spectroscopic study of the transition phase of the nova was presented by Csák et al. (2004). The spectral lines switched back to strong P Cyg profiles during the peaks of oscillations. The authors concluded that the observed repetitive rebrightening events were due to multiple episodes of mass ejection and they proposed that the transition phase in classical novae is driven by repetitive instabilities of the hydrogen shell burning on the surface of the white dwarf. They derived an absolute magnitude of the system $M_V = 8^{m}.3 ± 0^{m}.5$ and the interstellar reddening to be very low ($E(B − V) < 0^{m}.1$) and this leads to a rough distance estimate of V4745 Sgr (between 9 and 19 kpc).

V4745 Sgr is a transient type of nova (Csák et al. 2004) – a nova with oscillations during the transition phase. Several models have been suggested for the transition phase, such as stellar oscillations of the hot white dwarf, oscillations caused by the wind, formation of dust blobs that move in and out of line of sight to the nova, dwarf nova outbursts and oscillations of the common envelope (Bode & Evans 1989, Leibowitz 1993, Warner 1995, Csák et al. 2005). Shaviv (2001) argued that super-Eddington winds can be a natural explanation for the oscillatory behaviour during the transition phase of some novae. Retter (2002) suggested another solution for the transition phase. He noticed that this phase occurs around the time when the accretion disk is re-established and proposed a possible connection between this phase and intermediate polars. Finding rapid oscillations in the light curves of transient novae is required to support this hypothesis.
Currently, there are about 50 novae with known orbital periods (Warner 2002). Typical nova periods range from 2 to 9 hours. Finding the orbital period of a nova yields an estimate of the secondary mass (Smith & Dhillon 1998). In addition, detecting several periodicities in novae can help in classifying the system into different groups of CVs, such as magnetic systems, intermediate Polars, and/or permanent superhump systems (e.g. Diaz & Steiner 1989, Skillman et al. 1997, 1999, Retter et al. 1997, 1998, 1999, 2002, 2003, 2005, Patterson et al. 1997, 2002, Patterson & Warner 1998, Retter & Leibowitz 1998, Retter & Naylor 2000, Patterson 1999, 2001, Ak et al. 2005, Balman et al. 2005, Baptista et al. 1993, Lipkin et al. 2001, Woudt & Warner 2001, 2002, Warner 2002, Kang et al. 2006a, 2006b). This yields valuable information about the magnetic field of the white dwarf and reveals the presence or absence of the accretion disk. The suggestion that the oscillations in the transition phase of novae are connected with intermediate polars motivated us to obtain continuous photometry of the nova V4745 Sgr and to look for short-term periods in its light curve.

In this paper we report the detection of two periodicities in our photometric data ($P_1 = 0.20782 \pm 0.00003 \text{ d}$ and $P_2 = 0.017238 \pm 0.000037 \text{ d}$). In Section 2 we present our observational material. The period analysis of the data is presented in Sec. 3 and the results are discussed in Sec. 4.

## 2 OBSERVATIONS

V4745 Sgr was observed during 3 nights in 2003, 11 nights in 2004 and 9 nights in 2005. The observations included 138.8 hours and 3853 data points in total and the nightly mean length was about 6.0 hours. Table 1 presents a summary of the schedule of the observations. The photometry was carried out with a 0.3-m f/6.3 telescope coupled to a SBIG ST7E CCD camera. The telescope is located in Exmouth, Western Australia. The pixel size of the CCD is 9 x 9 microns. This camera is attached to an Optec f5 focal reducer giving an image field of view of 15 x 10 arcmin. The range of seeing for the data was 2.5 – 3 arcsec. The exposure times were between 30 and 60 sec every 120 sec, and no filter was used. Aperture photometry was used in the reduction, with an aperture size of 12 pixels. As comparison star (check star) we used GSC 7411 1591 – $V = 13.4$ mag (GSC 7411 2719 – $V = 12.7$ mag) for the first night in 2003, GSC 7411 1591 – $V = 13.4$ mag (GSC 7411 1897 – $V = 11.9$ mag) for the rest of the 2003 data and GSC 7411 1591 – $V = 13.4$ mag (not listed in the GSC catalog – $V = 13.8$ mag) for the 2004 and 2005 data. The magnitudes of the stars were derived from the SBIG CCDOPS software.

Figure 1 displays our light curve obtained during the 3 years of coverage. The long-term light curve of the nova from the Variable Stars Network (VSNET) was published by Csáki et al. (2004). The jump in our data at June 30th 2004 ($\text{HJD} = 2453187$) is probably due to a transition oscillation of the nova. We can not confirm this using the VSNET light curve because of the lack of observations after October 2003 in these data. In Fig. 2 we show 4 examples (discussed later in Section 3.4) of our observational runs with the sinusoidal fit to the data using the longer period derived in this paper. The studied variations are clearly seen.

| Date       | HJD (start) | t [h] | N     |
|------------|-------------|-------|-------|
| 26.08.2003 | 2877.98812  | 3.8   | 118   |
| 30.08.2003 | 2882.01453  | 0.6   | 17    |
| 31.08.2003 | 2882.98852  | 4.6   | 138   |
| 28.04.2004 | 3124.19436  | 4.9   | 177   |
| 07.05.2004 | 3133.15835  | 5.6   | 157   |
| 11.05.2004 | 3137.14934  | 6.1   | 170   |
| 12.05.2004 | 3138.14385  | 6.1   | 167   |
| 13.05.2004 | 3139.15116  | 5.9   | 165   |
| 17.05.2004 | 3143.13053  | 6.5   | 172   |
| 18.05.2004 | 3144.12962  | 6.5   | 178   |
| 20.05.2004 | 3146.12197  | 6.5   | 172   |
| 30.06.2004 | 3187.03922  | 7.8   | 211   |
| 01.07.2004 | 3188.05384  | 7.2   | 195   |
| 03.07.2004 | 3190.01182  | 8.2   | 225   |
| 02.07.2005 | 3554.02557  | 6.9   | 194   |
| 03.07.2005 | 3555.03576  | 6.7   | 188   |
| 04.07.2005 | 3556.00550  | 7.5   | 212   |
| 05.07.2005 | 3557.05043  | 6.8   | 180   |
| 27.07.2005 | 3579.01445  | 6.1   | 161   |
| 28.07.2005 | 3580.03659  | 6.3   | 170   |
| 30.07.2005 | 3582.03166  | 6.1   | 164   |
| 31.07.2005 | 3583.02092  | 6.0   | 159   |
| 01.08.2005 | 3584.01752  | 6.1   | 160   |

Figure 1. The unfiltered light curve of our data. The $\sim 1$ mag jump observed during June 30th 2004 can be due to a transition oscillation of the nova.

## 3 PERIOD ANALYSIS

For the period analysis we used the Lomb-Scargle algorithm (Scargle 1982). We tested separately the 2004 and 2005 observations. The 2003 data are too few for a useful separate analysis. The data were at first detrended by substracting the linear fit from each night. Detrending by the substrac-
Figure 2. A selection of our observations. Three detrended runs from 2004 and 1 detrended run from 2005. The solid curve is the sinusoidal fit to the data using the long-term period derived in this paper. The selected runs are discussed later in Section 3.4.

Figure 3. Power spectra of the 2004 data. a – raw data, b – synthetic data. The dotted line at 4.812 $d^{-1}$ shows the periodicity found ($f_1$) and at 9.624 $d^{-1}$ – its harmonic.

Figure 4. Power spectra of the 2005 data. a – raw data, b – synthetic data. The dotted line at 4.812 $d^{-1}$ shows the periodicity found ($f_1$) and at 9.624 $d^{-1}$ – its harmonic.

3.1 2004 data

The results from the period analysis of the 2004 data are depicted in Fig. 3 (top panel). The suspected periodicity ($f_1 = 4.812 \pm 0.007 \, d^{-1}$, which corresponds to the periodicity $P_1 = 0.2078 \pm 0.0003 \, d$ (4.9872 ± 0.0072 h). We calculated the errors in the frequency from the half width at the half maximum of the peaks in the power spectrum.

3.2 2005 Data

The power spectrum of the 2005 light curve of V4745 Sgr is shown in the top panel of Figure 4. The strongest peak in the power spectrum ($f_1 = 4.812 \pm 0.011 \, d^{-1}$, $P_1 = 0.2078 \pm 0.0005 \, d$) is consistent with the periodicity found in 2004. To test its reliability we repeated the tests performed for the 2004 data. The synthetic power spectrum is presented in panel b. The presence of the signal and its harmonic is clear. Once again, the periodogram of the check star did not show any related periodicity.

We can then conclude that all typical features obtained by the period analysis can be explained by the periodicity $f_1 = 4.812 \, d^{-1}$. The same result is obtained when we analyzed different subsamples of the data, so we conclude that this periodicity is real.

3.3 All data

The results of the period analysis up to 80 cycles/day of the 2004 and 2005 data separately are depicted in Fig. 5. We
analyzed each year separately. Combining the two data sets is less meaningful because of the cumulative error between the years which is larger than one full cycle (2005 – 2004; 4.812 d\(^{-1}\) \times 0.0003 d \times 365 d = 0.5269 d > 0.2078 d).

### 3.4 Short-term oscillations

A simple visual inspection of the runs suggests that a short-term periodicity (\(\sim 0.5\) hours) is present in the data (Fig. 4). In Fig. 4 we show the normalised power spectra of the two years separately including the high frequency part. There is a group of peaks near the expected value, but they are very weak in power. To check whether this periodicity is real we selected different subsamples and runs and we analysed them.

The first clear result was obtained using a subsample of 3 chosen runs (June 30\(^{th}\), July 1\(^{st}\) and 3\(^{rd}\)) from 2004. The power spectrum is presented in Fig. 5b. We found a periodic signal of \(f_2 = 58.011 \pm 0.125\) d\(^{-1}\) (\(P_2 = 0.017238 \pm 0.000037\) d, 0.43712 \pm 0.000888 h). After subtracting the period \(P_1\) and its first harmonic this peak survived.

Figure 5 shows the power spectrum of one suitable night in 2005 (July 4\(^{th}\)). We found a periodicity of \(f_2 = 57.84 \pm 1.00\) d\(^{-1}\) which is within the errors of the previously derived value. This peak survived the test of subtracting the period \(P_1\) and its first harmonic. It is surprising that the short-term variation is best seen only on this night in the 2005 observations. Even a simple visual inspection of the data from this night shows the prominent presence of the variation. Adding other nights increased the noise in the power spectrum and provides negative result (Fig. 5, nights – July 2\(^{nd}\), July 3\(^{rd}\) and July 4\(^{th}\) 2005).

Other subsamples produced negatives or very unclear results (Fig. 5a, with dominant \(f_2 + 1\) d\(^{-1}\) alias, nights – May 13\(^{th}\), May 17\(^{th}\), May 18\(^{th}\) and May 26\(^{th}\) 2004 or Fig. 4).

#### Figure 5. Power spectra including the high frequency part (2004 data – top panel, 2005 data – bottom panel). The dashed line shows the short-term periodicity found: \(f_2 = 58.011\) d\(^{-1}\).

#### Figure 6. The power spectra of different subsamples of the data arranged chronologically. Panel a – nights May 13\(^{th}\), May 17\(^{th}\), May 18\(^{th}\) and May 20\(^{th}\) 2004, panel b – June 30\(^{th}\), July 1\(^{st}\) and 3\(^{rd}\) 2004, panel c – July 2\(^{nd}\), July 3\(^{rd}\) and July 4\(^{th}\) 2005, panel d – July 4\(^{th}\) 2005, panel e – July 27\(^{th}\), July 28\(^{th}\), July 30\(^{th}\), July 31\(^{st}\) and August 1\(^{st}\) 2005. The dashed lines are from left to right: \(f_2 \pm 1\) d\(^{-1}\) alias, \(f_2\) and \(f_2 \pm 1\) d\(^{-1}\) alias.

#### 3.5 Structure of the periodicities

In Figure 6 we show the light curve of V4745 Sgr folded on the 0.20782 d period. The points are the average magnitude values in each of the 40 equal bins that cover the 0 – 1 phase interval. The full amplitude of the mean variation is 0.069 \pm 0.006 and 0.175 \pm 0.013 mag for the 2004 and 2005 observations respectively. Using the sinusoidal fit to determine the amplitude is not adequate, because of the non sinusoidal shape of the light curve, we therefore estimated the amplitude by measuring the difference between extrema. In Figure 7 we present the light curve of V4745 Sgr folded on the \(\sim 25\) min period and binned into 10 equal bins. The full amplitude of the mean variation is 0.013 \pm 0.001 and 0.034 \pm 0.001 mag for the 2004 subsample (June 30\(^{th}\), July 1\(^{st}\) and 3\(^{rd}\)) and the one night in 2005 (July 4\(^{th}\)) respectively. The bars are the errors of the mean value. The
amplitudes of the mean variations were derived by fitting a sinusoidal curve to the mean light curve.

We determined the epochs of minima by fitting low-order polynomials to the selected parts of the light curve. The best fitted (using sinusoidal fits) ephemerides of the periodicities are:

\[ T_{1 \text{(min)}}(HJD) = 2453137.33760(53) + 0.20782(3)E \]

\[ T_{2 \text{(min)}}(HJD) = 2453556.20027(10) + 0.01724(3)E \]

Since the error of the periodicity found from the periodogram analysis is larger than the error derived by the fit, we adopt instead the value \( P_1 = 0.20782 \pm 0.00003 \) d determined by the fit to the data. Since the error in the fit determination of the short-term periodicity is larger than the error from the periodogram analysis, we adopt instead the value \( P_2 = 0.017238 \pm 0.000037 \) d.

The light curves folded on the 0.20782 d period show the typical features of an eclipse. Noteworthy is the dip at phase 0.5 with an amplitude of \( \sim 0.02 \) mag which is clearly present in the 2004 data. In the 2005 observations it is not so regular, but the amplitude is higher \( \sim 0.05 \) mag.

4 DISCUSSION

We have identified two periodicities in the light curve of the nova V4745 Sgr. The first one is \( P_1 = 0.20782 \pm 0.00003 \) d (4.98768 \pm 0.00072 h). The period was constant during our observations and the shape of the folded light curve suggests an eclipse. We therefore propose that this periodicity is the orbital period of the binary system. Such a period is typical of orbital periods in novae (Warner 2002) above the period gap. The full amplitude of \( P_1 \) increased from 0.069 mag in 2004 to 0.175 mag in 2005. A similar behaviour was observed in three other novae; V838 Her (Leibowitz et al. 1992), V1494 Aql (Bos et al. 2002) and V4743 Sgr (Richards et al. 2005, Kang et al. 2006b). These authors interpreted the phenomenon as an eclipse of the accretion disk by the secondary star. Similarly, we propose to explain the 4.98768-hour variation in the light curve of V4745 Sgr as an eclipse of the accretion disk by the companion star.

Using the orbital period of the system, we can obtain a rough estimate for the secondary star mass. Smith & Dhillon (1998) derived a mass-period relation for the secondary stars in CVs using a sample of reliable mass estimates. From their equation (9) we obtain a mass of \( 0.52 \pm 0.05 \, M_\odot \) for the secondary star in V4745 Sgr. Using a mean white dwarf mass of \( 0.85 \pm 0.05 \, M_\odot \) given for classical novae (Smith & Dhillon 1998), we find a mass ratio of \( M_2/M_1 = 0.6 \pm 0.1 \). V4745 Sgr was classified as a transient type of nova (Csák et al. 2004). Retter (2002) proposed a possible connection between the transition nature and intermediate polars. A short-term periodicity seems to be seen in the light curve (Fig. 4). We found a very probable signal of \( f_2 = 58.011 \pm 0.125 \, d^{-1} \) \( (P_2 = 0.017238 \pm 0.000037 \, d, 0.413712 \pm 0.000888 \, h) \). Such a signal could presumably be the spin period of the white dwarf or the beat period between the orbital period and the spin period of the white dwarf and confirm the intermediate polar nature of the system. If the \( \sim 1 \) mag jump in the light curve, which was observed during June 30\textsuperscript{th} 2004, indeed represents an oscillation during the transition phase, in the model of Csák et al. (2005), the accretion disk is destroyed. In this case, it should be easier to observe variations caused by the spin period of the exposed white dwarf. This may explain why the short-term periodicity is best seen around this selected night. We still need a confirmation for this period because the signal was only detected in a few subsamples of our light curve. Therefore
we propose that nova V4745 Sgr can be a member in the intermediate polars group and this can supports the previous suggestion that the transition phase of novae may be related to intermediate polars. The best way to confirm our result is to obtain X-ray observations which are crucial in identifying of the spin period of the white dwarf. Such a confirmation was made in the case of a few other systems. No short-term periodicity was found in the optical light curve of the transient nova V1494 Aql, but a \( \sim 40 \) min signal was found in the X-ray data (Drake et al. 2003). A similar detection of an X-ray periodicity of \( \sim 22 \) min was found in the observations of the transient nova V4743 Sgr (Ness et al. 2003). Therefore the intermediate polar nature of the nova V4745 Sgr should be clarified after further X-ray and optical observations. Similar results were obtained by Ak et al. (2005). They analysed photometry of the transient nova V2540 Oph and did not detect any short-term periodicity in their data. Confirmation by X-ray observations is required in this case as well.

5 SUMMARY

We found a periodic signal of 4.98768 hours in \( \sim 130 \) hours of unfiltered photometric observations obtained during 2 years of the nova V4745 Sgr. We interpret this periodicity as orbital and therefore the nova belongs to the numerous systems above the period gap distribution of cataclysmic variables. We found a probable short-term periodicity of \( \sim 25 \) minutes which needs to be confirmed. We tentatively interpret this periodicity as the spin period of the white dwarf or as the beat period between the orbital and spin period of the white dwarf. The nova should then be classified as an intermediate polar candidate.

ACKNOWLEDGMENTS

This work was supported by the Slovak Academy of Sciences Grant No. 4015/4.

REFERENCES

Ak, T., Retter, A., Liu, A., 2005, PASA 22, 298
Ashok, N.M., Banerjee, D.P.K., 2003, IAUCC 8132, 1
Balman, S., Yilmaz, A., Retter, A., Saygac, T., Esenoglu, H., 2005, MNRAS 356, 773
Baptista, R., Jablonski, F.J., Cieslinski, D., Steiner, J.E., 1993, ApJ 406, L67
Bode, M.F., Evans, A., 1989, Classical Novae, Alden Press, Oxford
Bos, M., Retter, A., Cook, L., Novak, R., 2001, IAUC 7665
Brown, J., Yamamoto, M., Nakano, S., et al., 2003, IAUC 8123, 1
Csák, B., Kiss, L.L., Retter, A., Jacob, A., Kaspi, S., 2005, A&A 429, 599
Diaz, M.P., Steiner, J.E., 1989, ApJ 339, L41
Drake, J.J., Wagner, R.M., Starrfield, S., Butt, Y., Krautter, J., et al., 2003, ApJ 584, 448
Kang, T. W., Retter, A., Liu, A., Richards, M. 2006a, AJ 131, 1687
Kiss, L.L., Jacob, A., 2003, IAUC 8132, 1
Leibowitz, E.M., Mendelson, H., Mashal, E., Prialnik, D., Seitter, W.C., 1992, ApJ 385, L49
Leibowitz, E.M., 1993, ApJ 411, L29
Lipkin, Y., Leibowitz, E.M., Retter, A., Shenmer, O., 2001, MNRAS 328, 1169
Ness, J.U., Starrfield, S., Burzitz, V., Wichmann, R., Hauschildt, P., et al., 2003, ApJ 594, L127
Patterson, J., Kemp, J., Saad, J., Shambrook, A., Thomas, G.R., Halpern, J., Skillman, D., 1997, PASP 109, 1100
Patterson, J., Warner, B., 1998, PASP 110, 1026
Patterson, J., 1999, in: “Disk Instabilities in Close Binary Systems”, eds.: Mineshige, S., Wheeler, C., Tokyo: Universal Academy Press
Patterson, J., 2001, PASP 113, 736
Patterson et al., 2002, PASP 114, 65
Retter, A., Leibowitz, E.M., Ofek, E.O., 1997, MNRAS 286, 745
Retter, A., Leibowitz, E.M., 1998, MNRAS 296, L37
Retter, A., Leibowitz, E.M., Kovo-Kariti, O., 1998, MNRAS 293, 145
Retter, A., Leibowitz, E.M., Naylor, T., 1999, MNRAS 308, 140
Retter, A., Naylor, T., 2000, MNRAS 319, 510
Retter, A., Chou, Y., Bedding, T., Naylor, T., 2002, MNRAS 330, L37
Retter, A., 2002, in “Classical Nova Explosions”, eds. Hernanz, M., José, J., AIP Conf. Ser. 637, 279
Retter, A., Hellier, C., Augusteijn, T., Naylor, T., Bedding, T., Bembrick, C., McCormick, J., Velthuis, F., 2003, MNRAS 340, 679
Retter, A., Richards, M.T., Wu, K., 2005, ApJ 621, 417
Richards, M.T., Kang, T.W., Retter, A., Liu, A., 2005, AAS 207, 7020
Scargle, J.D., 1982, ApJ 263, 835
Shaviv, N.J., 2001, MNRAS 326, 126
Skillman D.R., Harvey, D., Patterson, J., Vanmunster, T., 1997, PASP 109, 114
Skillman D.R., Patterson, J., Kemp, J., Harvey, D.A., Fried, R., Retter, A., Lipkin, Y., Vanmunster, T., 1999, PASP 111, 1281
Smith, D.A, Dillon, V.S., 1998, MNRAS 301, 767
Warner, B., 1995, Cataclysmic Variable Stars, Cambridge University Press, Cambridge
Warner, B., 2002, in “Classical Nova Explosions”, eds. Hernanz, M., José, J., AIP Conf. Ser. 637, 3
Williams, R.E., 1992, AJ 104, 72
Woudt, P.A., Warner, B., 2001, MNRAS 328, 159
Woudt, P.A., Warner, B., 2002, MNRAS 335, 44