Photometry of the Dwarf Nova SDSS J094002.56+274942.0 in Outburst

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Abstract Data from the first observed outburst of the dwarf nova SDSS J094002.56+274942.0 show cyclical variations increasing in amplitude when the object fades. These variations are likely due to the ellipsoidal shape of the red dwarf and possibly also eclipses of the accretion disk. An orbital period of 3.92 hours is derived.

1. Introduction

The cataclysmic variable (CV) SDSS J094002.56+274942.0 was discovered by Szkody *et al.* (2007) in spectra from the Fifth Data Release of the Sloan Digital Sky Survey (SDSS; Adelman-McCarthy *et al.* 2007). It was observed only once by SDSS at magnitude $g = 19.10 \pm 0.01$. No further details were provided by Szkody *et al.* (2007).

With $E(B - V) = 0.018$ (Schlegel *et al.* 1998), Galactic extinction is almost negligible in the direction of SDSS J094002.56+274942.0. The SDSS colors $u - g = 0.54 \pm 0.04$ and $g - r = 0.78 \pm 0.01$ therefore make it a fairly red CV, indicating that there is a substantial contribution of the red dwarf to the total light. In this case the orbital period should be fairly large, i.e., above the period gap. This conclusion is further strengthened by the 2MASS colors (Skrutskie *et al.* 2006): $J = 16.1 \pm 0.1$, $J - H = 0.5 \pm 0.2$ and $J - K_s = 0.7 \pm 0.2$ (note that the signal to noise ratio of the 2MASS detections in the H and K_s bands are fairly low). However, there is no immediate evidence for the red dwarf in the SDSS spectrum. The Galaxy Evolution Explorer (GALEX; Martin *et al.* 2005) observed the object twice at $nuv = 19.7 \pm 0.1$, $fuv - nuv = 0.8 \pm 0.3$, and $nuv = 19.3 \pm 0.1$, $fuv - nuv = 0.4 \pm 0.2$, apparently both at quiescence. The spectral energy distribution of SDSS J094002.56+274942.0 is given in Figure 1.

2. Observations

Like many other CVs, SDSS J094002.56+274942.0 is being monitored by the Catalina Real-time Transient Survey (CRTS; Drake *et al.* 2009). Normally it has an unfiltered magnitude around 18. On 18 November 2009, an outburst to magnitude 14.6 was detected by CRTS (http://nesssi.cacr.caltech.edu/catalina/20010319/103191260474100307p.html), and follow-up observations were promptly started at the Astrokolkhoz Observatory.

For the observations a C14 Schmidt-Cassegrain was used, equipped with an ST-10 CCD camera and a Cousins *R* filter (for the first four nights), and a clear filter afterwards (last four nights). The comparison star used was GSC 1965-146, and GSC 1965-893 and GSC 1965-1064 were used as check stars. Using the transformation formulae from Lupton (http://www.sdss.org/dr7/algorithms/sdssUBVRITransform.html#Lupton2005), a magnitude $R = 13.8$ was calculated for GSC 1965-146. The same magnitude was adopted for the unfiltered observations. On each night, except for the short run on the seventh night, standard deviations on the magnitude of the check star were better than 0.01 magnitude. Median standard deviations on five-point averages of the variable gradually deteriorated from 0.013 on the first night to 0.049 on the last night.

The overall light curve of the outburst is given in Figure 2. On 26 November the object was only half a magnitude above its normal brightness, and on 28 November it had effectively returned to its quiescence magnitude.

Near outburst maximum the light curve was fairly featureless. After a couple of days, a double wave became visible with a period of 0.16352 day and growing in amplitude. With the object at quiescence this double wave had an amplitude of around 0.3 magnitude and was clearly visible in the light curve. We interpret these periodic variations at the later stages of the outburst and at quiescence as due to the changing aspect angle of the ellipsoidal shape of the red dwarf, for which the contribution to the total light is increasing when the system fades. These variations can be seen when the inclination of the orbit is high enough. The period of 0.16352 day (3.92 hours) is then the orbital period of the system. Further proof of this scenario can be obtained by observing variations in the color of the object during all stages of an outburst. A phased light curve is given in Figure 3. The dwarf nova HS 0218+3229 shows similar variations due to the ellipsoidal shape of the secondary (Rodríguez-Gil *et al.* 2009), although in that case the orbital period is much longer (7.13 hours).

During the brightest stages of the outburst of SDSS J094002.56+274942.0, there is a small dip corresponding to the phase of one of the minima of the ellipsoidal variations. This may be due to the red dwarf (partially) eclipsing the accretion disk or hot spot. Unfortunately, the phase coverage was not complete on the first nights, missing the time at which the eclipse was expected. It would be especially worthwhile to observe a full orbital cycle close to maximum to verify the possible eclipse at that stage. The minimum at phase zero is sometimes fairly sharp, even near quiescence, so that it actually may be the result of an eclipse as well.

The SDSS spectrum published by Szkody *et al.* (2007) is fairly flat in the near-infrared, with no sign of TiO bands. As most CVs with an orbital period near 4 hours have M4-5 type secondaries, the lack of TiO bands in the spectrum would indicate that the contribution of the red dwarf to the total light is small. However, this seems to be in contradiction with the observed colors and rules out that the observed 0.3-magnitude variations are due to the secondary. Another possibility is that the red dwarf has an early M-type spectrum with little TiO present. A detailed spectral analysis and a radial velocity study is needed to settle the case.

3. Outburst frequency

After the recent outburst archival images of the dwarf nova were investigated, and a further outburst was found on images of the Near Earth Asteroid Tracking survey (NEAT) (http://skyview.gsfc.nasa.gov/skymorph/skymorph.html) in November 2002. The unfiltered magnitude of the object was 14.57 ± 0.02 on 22 November and 14.72 ± 0.03 on 23 November, again adopting magnitude 13.8 for GSC 1965-146.

Following Southworth *et al.* (2009), an estimate can be made of the outburst frequency of SDSS J094002.56+274942.0, based on the dates at which the object was observed by NEAT (three images on one night in December 1997 and forty-one images from sixteen nights between June 2001 and February 2003) and CRTS (282 observations on seventy-two nights between January 2005 and November 2009). Because the latest CRTS observation prior to the outburst detection dates from October 2009, it is not possible to fix the exact start of the outburst. From our data it follows that the outburst lasted at least eight days. A duration of eight days agrees with the empirical relation derived by (Ak *et al.* 2002) for a dwarf nova with the orbital period of SDSS J094002.56+274942.0. In the following an outburst duration of eight days will therefore be assumed. Using Monte Carlo simulations, the efficiency to detect an outburst during the observation interval can be estimated to be 5% for NEAT (or 16% for an outburst between June 2001 and February 2003) and 30% for CRTS.

Further assuming periodic outbursts, the number of observed outbursts in the given observing interval can be calculated. On average a single outburst will have been detected by NEAT if the outburst cycle is around 100 days, and by CRTS if it is around 500 days. If the outburst cycle would be less than 250 days, CRTS would have detected two outbursts or more on average. These discrepant values are of course a result of small number statistics, but an outburst cycle of about one year or longer can be assumed. Southworth *et al.* (2009) found a similar value for SDSS J100658.40+233724.4, another dwarf nova with a 4-hour orbital period. This outburst cycle is much longer than the average cycle found by Ak *et al.* (2002) for historically known and frequently observed dwarf novae with a similar orbital period. This suggests that the sample of previously known dwarf novae, mostly detected because of their variability, was biased towards objects with a high outburst frequency.

4. Conclusion

SDSS J094002.56+274942.0 has been found to be a dwarf nova with an orbital period of 3.92 hours, with a 0.3-magnitude variability at quiescence due to the ellipsoidal shape of the secondary. Possibly also eclipses of the accretion disk may be observed. Unlike the majority of CVs discovered through SDSS spectroscopy (Gänsicke *et al.* 2009), it has an orbital period above the period gap. The outburst frequency is estimated to be about once per year or less, but this has to be confirmed by further observations.

5. Acknowledgements

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References

Adelman-McCarthy, J. K., *et al.* 2007, *Astrophys. J., Suppl. Ser.*, **172**, 634.
Ak, T., Ozkan, M. T., and Mattei, J. A. 2002, *Astron. Astrophys.*, **389**, 478.
Drake, A. J., *et al.* 2009, *Astrophys. J.*, **696**, 870.
Gänsicke, B. T., *et al.* 2009, *Mon. Not. Roy. Astron. Soc.*, **397**, 2170.
Martin, D. C., *et al.*, 2005, *Astrophys. J., Lett. Ed.*, **619**, L1.
Rodríguez-Gil, P., Torres, M. A. P., Gänsicke, B. T., Muñoz-Darias, T., Steeghs, D., Schwarz, R., Rau, A., and Hagen, H.-J. 2009, *Astron. Astrophys.*, **496**, 805.
Schlegel, D. J., Finkbeiner, D. P., and Davis, M. 1998, *Astrophys. J.*, **500**, 525.
Skrutskie, M. F., *et al.* 2006, *Astron. J.*, **131**, 1163.
Southworth, J., Hickman, R. D. G., Marsh, T. R., Rebassa-Mansergas, A., Gänsicke, B. T., Copperwheat, C. M., and Rodríguez-Gil, P. 2009, *Astron. Astrophys.*, **507**, 929.
Szkody, P., *et al.* 2007, *Astron. J.*, **134**, 185.

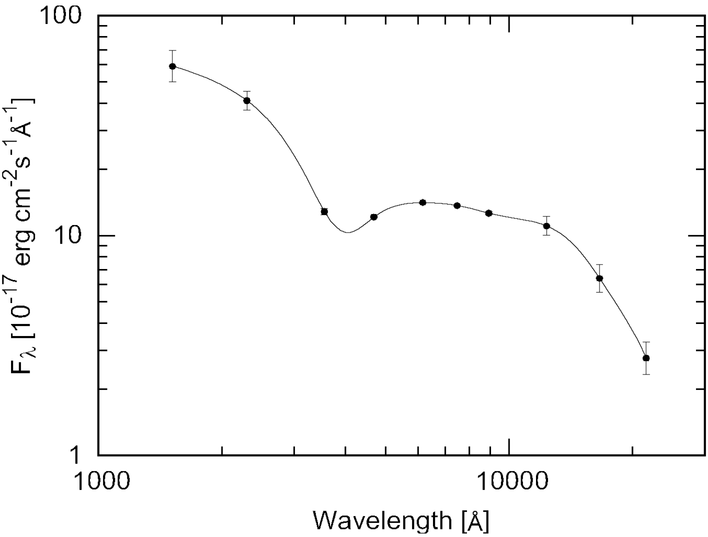

Figure 1. Spectral energy distribution of SDSS J094002.56+274942.0, based on photometry from GALEX, SDSS, and 2MASS. Both axes have logarithmic scales.

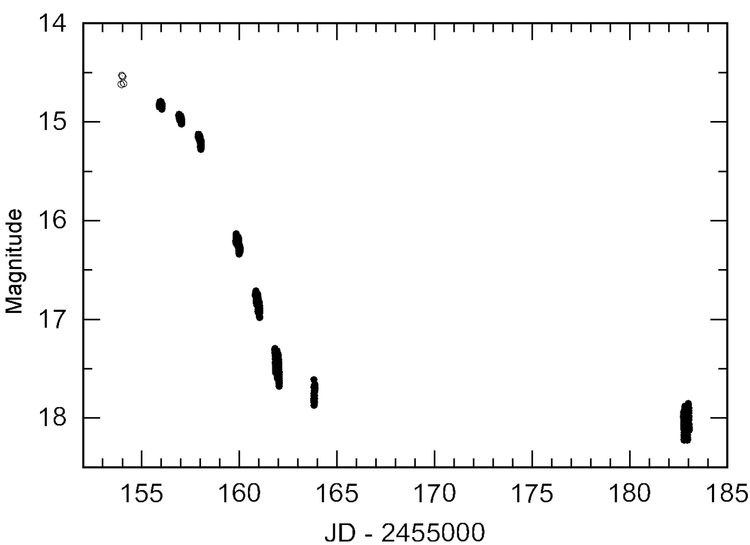

Figure 2. Light curve of the November 2009 outburst of SDSS J094002.56+274942.0. Open circles represent unfiltered CRTS data, filled circles represent *R* and (for the last four nights) unfiltered data from Astrokolkhoz Observatory.

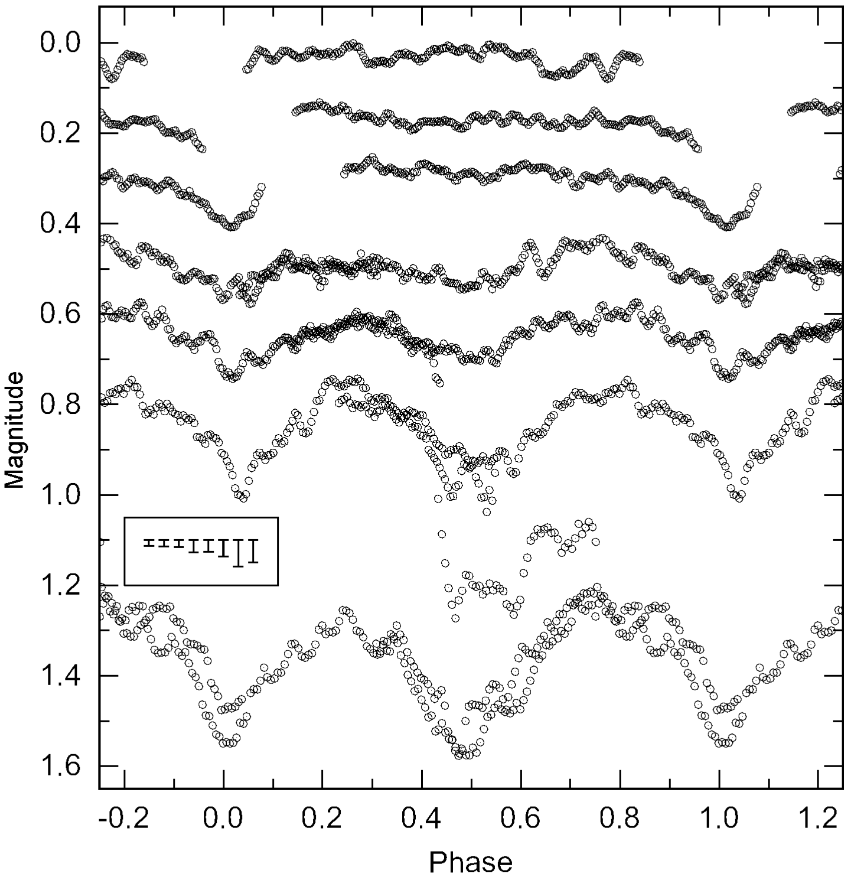

Figure 3. Light curve of five-point moving averages of Astrokolkhoz Observatory data for SDSS J094002.56+274942.0, phased with a period of 0.16352 day. The magnitudes have been arbitrarily shifted for clarity, with the night the object was brightest on top. For the fourth, fifth, and sixth nights a linear fading trend was subtracted from the data. JD = 2455156.06 was taken for the zeropoint of the phase. The vertical lines at bottom left indicate the median standard deviation on the five-point averages for each of the nights.