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Multi-wavelength observations of the helium dwarf nova KL Dra through its outburst cycle

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ABSTRACT

We present multi-wavelength observations of the helium-dominated accreting binary KL Dra which has an orbital period of 25 mins. Our ground-based optical monitoring programme using the Liverpool Telescope has revealed KL Dra to show frequent outbursts. Although our coverage is not uniform, our observations are consistent with the outbursts recurring on a timescale of ∼60 days. Observations made using *Swift* show that the outbursts occur with a similar amplitude at both UV and optical energies and a duration of 2 weeks. Although KL Dra is a weak X-ray source we find no significant evidence that the X-ray flux varies over the course of an outburst cycle. We can reproduce the main features of the 60 day outburst cycle using the Disc Instability Model and a helium-dominated accretion flow. Although the outbursts of KL Dra are very similar to those of the hydrogen accreting dwarf novae, we cannot exclude that they are the AM CVn equivalent of WZ Sge type outbursts. With outbursts occurring every ∼2 months, KL Dra is an excellent target to study helium-dominated accretion flows in general.

Key words: Physical data and processes: accretion discs; Stars: binary - close; novae - cataclysmic variables; individual: - KL Dra; X-rays: binaries; ultraviolet: stars

1 INTRODUCTION

AM CVn systems are accreting binaries consisting of a white dwarf primary and a degenerate or semi-degenerate secondary star. Their binary orbital periods are extremely short (<70 mins) and are almost entirely hydrogen-deficient (see Nelemans 2005 for a recent review). As such they are the best sources in which to understand hydrogen-deficient accretion flows.

There are currently ∼26 known (or candidate) AM CVn systems (see Rau et al. 2010 for the most recent discoveries) of which around half a dozen have shown optical outbursts with amplitudes of 3–4 mag. These outbursts are assumed to be similar to those observed in the hydrogen-dominated accreting dwarf novae. Although the physics of helium-dominated accretion is poorly understood, outbursts are thought to be due to instabilities in the accretion disc (eg Smak 1983, Tsugawa & Osaki 1997 and Kotko, Lasota & Dubus 2010).

Since many of the more recently discovered AM CVn systems are relatively faint (V ∼19–20) the outburst characteristics of AM CVn systems as a whole are not well understood. To better characterise these properties we have started a monitoring programme using the Liverpool Telescope to obtain images of the northern AM CVn systems once a week over the course of at least one year.

The results of our monitoring programme will be presented in a future paper (Barclay et al. in prep). Here, we concentrate on one individual system, KL Dra, which was initially thought to be a supernova (Jha et al 1998). Subsequent observations showed it was an AM CVn system with an orbital period close to 25 mins (Wood et al. 2002). Our initial observations made using the Liverpool Telescope showed two outbursts from KL Dra within 2 months (Barclay, Ramsay & Steeghs 2009). This makes KL Dra an excellent system with which to gain a better understanding of outbursts in AM CVn binaries.

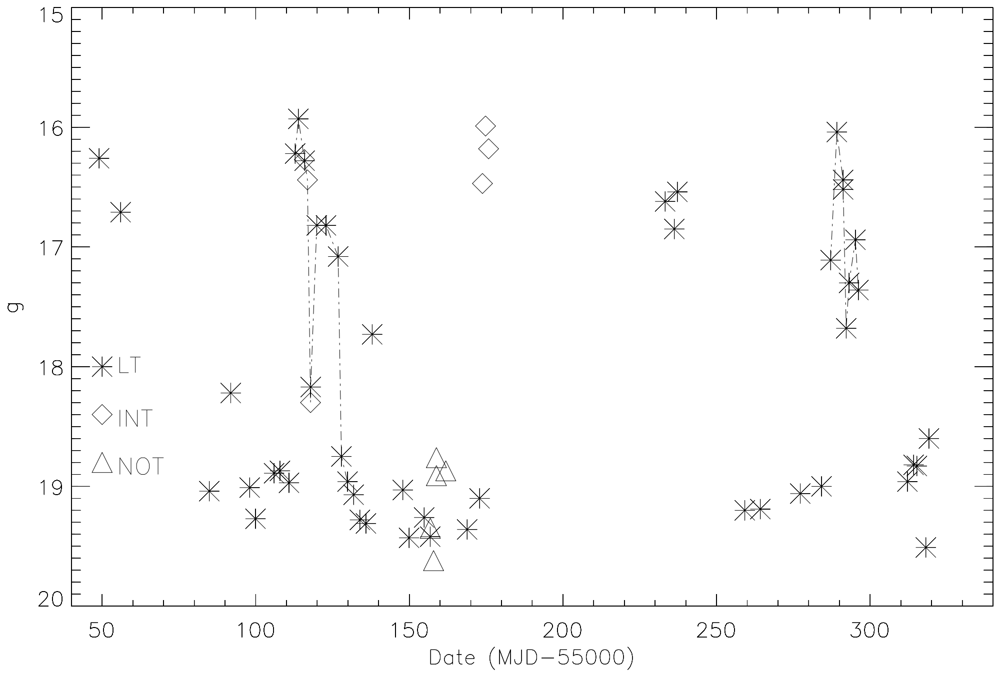

Figure 1. The optical observations of KL Dra made using the Liverpool Telescope (LT), Isaac Newton Telescope (INT) and Nordic Optical Telescope (NOT). The first observation was taken on 2009 July 28th. The dot-dashed line helps guide the eye in the two best sampled outbursts.

In this paper we present results from our recent observing campaign of KL Dra using the *Swift* satellite, the Liverpool Telescope, the Isaac Newton Telescope, the Nordic Optical Telescope, the William Herschel Telescope and the Gemini North Telescope.

2 OPTICAL PHOTOMETRIC OBSERVATIONS

The strategy for our observations made using the 2.0m Liverpool Telescope (LT) was to obtain a single 180 sec image of KL Dra using the RATCAM imager (Steele et al. 2004) in the g band filter approximately once every week. During outbursts we increased the sampling rate to once every few days. Images which had been bias subtracted and flat-fielded using the LT automatic pipeline were typically downloaded the afternoon after the observation had been made. We also obtained supplementary images using the Isaac Newton Telescope (INT) and the Nordic Optical Telescope (NOT).

Since KL Dra is $5.7''$ from the nucleus of an anonymous galaxy (Jha et al. 1998 and Fig 2 of Wood et al. 2002), differential imaging would have been an option for obtaining the photometric light curve of KL Dra. However, since the images were taken using a number of telescopes (giving different image scales etc), we decided to use aperture photometry. Care was taken to exclude as much of the galaxy as possible and to ensure a star/galaxy free background. The difference in magnitude between two comparison stars was constant to within a few 0.01 mag. To place our photometry onto the standard system, we obtained an image of the field and several standard stars in Oct 2009 using the INT. This allowed us to determine the g band magnitude of several local comparison stars.

We show in Figure 1 our optical light curve of KL Dra. Our first observation made on 2009 July 28 showed KL Dra in a bright optical state ($g \sim$16.2). One week later the system had faded by around ∼0.5 mag, after which no observations were obtained for 5 weeks. However, 63 days after our first observation, KL Dra was again observed in a bright optical state ($g \sim$16.0) with an outburst amplitude of ∼3 mag. The rise to peak brightness (maximum) was short (<2 days) with a short duration drop in brightness ∼5 days after maximum. Two weeks after maximum there was another sharp drop in brightness giving an overall duration for the outburst of ∼15 days.

A third burst was detected from KL Dra 61.5±2.0 days after the preceding one. Since KL Dra shortly came too close to the Sun to be observable, we obtained no ground-based optical observations for nearly 9 weeks. However, an outburst was again seen at a time which is consistent with KL Dra showing outbursts on a repeating interval of ∼60 days. Very recently we detected the fifth outburst of KL Dra (2010 Apr 1st) which took place at least 54 days after the start of the previous outburst. Although we find no evidence for other periods in our optical data a more comprehensive dataset is needed to test this more thoroughly.

During its low optical state, KL Dra appears rather variable which is probably associated with its orbital period (Wood et al. 2002). It also shows what appears to be short duration brightenings (up to ∼1.5 mags) on several occasions (ie MJD∼55092).

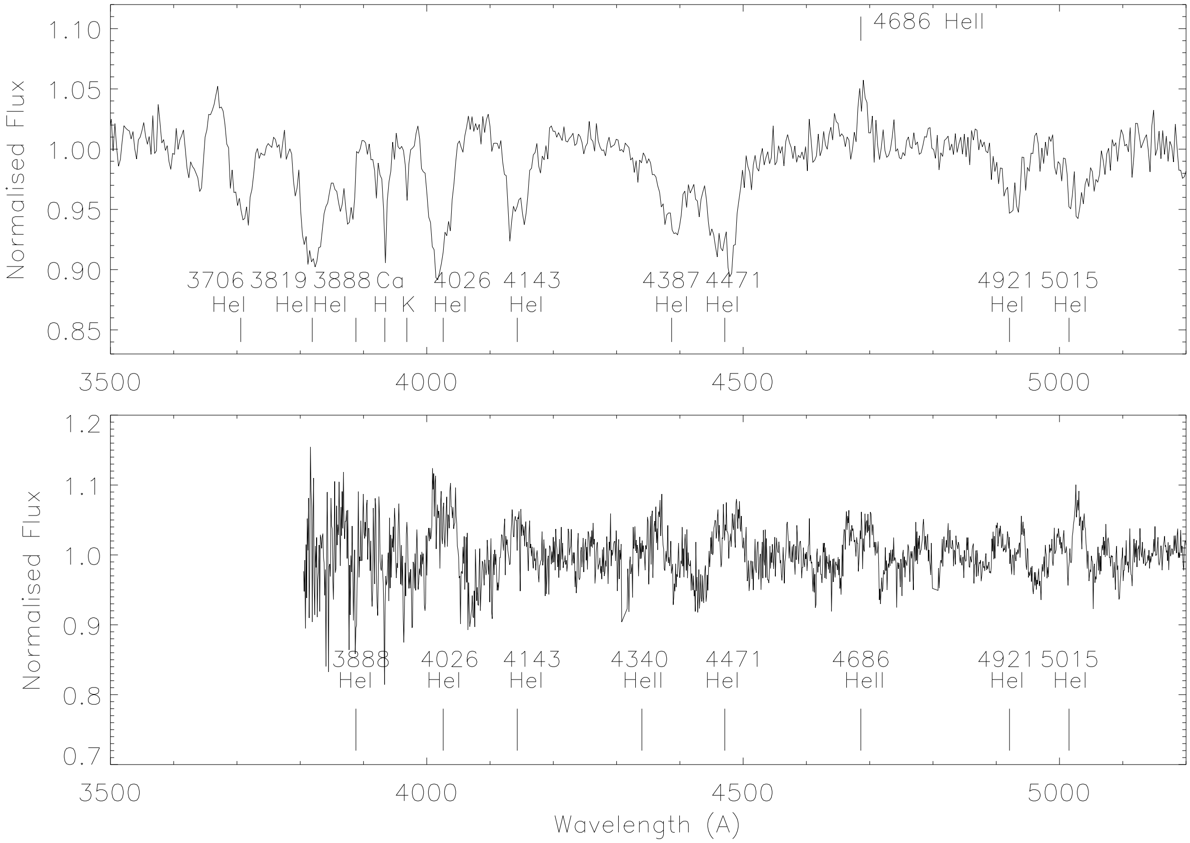

Figure 2. Top panel: the mean optical spectrum of KL Dra obtained using the WHT and the ISIS blue arm when it was in outburst (2009 Oct 10, MJD=55114). Lower Panel: the mean optical spectrum of KL Dra obtained using the Gemini North Telescope when it was in a low state (2007 July 17).

3 OPTICAL SPECTRA

3.1 High state spectra

We were fortunate to be observing on the 4.2m William Herschel Telescope on La Palma when KL Dra was in outburst. We obtained a series of 100 sec exposures using ISIS on the night of 2009 Oct 10 which lasted 67 mins. We used the R300B (giving wavelength coverage between ∼3500–5300Å) and R158R (∼5200–10000Å) gratings together with a 0.8 arcsec slit. Based on the FWHM of the arc lines, the resolution of the spectra was determined to be ∼3 and ∼6 Å for the blue and red spectra respectively.

We reduced these data using optimal extraction (Horne 1986) as implemented in the PAMELA[1] code (Marsh 1989) which also uses the STARLINK[2] packages FIGARO and KAPPA. The wavelength calibration was linearly interpolated from copper-argon arc lamp exposures bracketing our observations.

We show the mean spectrum obtained in the blue arm in the upper panel of Figure 2. Broad absorption lines of He I (FWHM∼30–35Å, corresponding to velocities of ∼2000 km/s) are detected, which is similar to the discovery spectrum of KL Dra (when it was in an outburst) shown in Wood et al. (2002). Unlike the discovery spectrum we detected an emission line at 4686 Å (He II). The red spectra are remarkably featureless with only a possible detection of the He I 5876 Å and He II 7177 Å lines in absorption. We searched for radial velocity shifts in the absorption lines but found none, with an upper limit of ∼40 km/s. This is consistent with a disc origin for the lines and a mass ratio typical for AM CVn systems. We also searched for variability in the flux of the 4686 Å line. However, the low signal-to-noise did not allow us to place any significant constraints on this question.

3.2 Low state spectra

We observed KL Dra on the night of 17 July 2007 with the GMOS instrument in long-slit spectroscopy mode on the Gemini North Telescope at Mauna Kea. The acquisition image allowed us to determine its brightness (g=19.0) using the local comparison stars mentioned in §2 and showed it was in a low optical state.

We obtained 60 consecutive 180 sec exposures and used a 1.0" slit and the B1200 grating with binning factors of 4 (spatial) and 2 (spectral), giving a wavelength range of 3800 − 5300Å with a dispersion of 0.46Å per binned pixel. Weather conditions for these observations were good, with photometric transparency and variable seeing around 1″.

The low-state spectra were reduced in the same manner as the high-state spectra. We combine the results into a

[1] PAMELA was written by T. Marsh and can be found at http://www.warwick.ac.uk/go/trmarsh
[2] The Starlink Software Group homepage can be found at http://starlink.jach.hawaii.edu/starlink

single averaged spectrum which we plot in the lower panel of Figure 2. In contrast to the spectrum taken in the high optical state, the low-state spectrum is dominated by weak emission lines and are typically double-peaked and indicative of emission from optically-thin regions in the helium-dominated accretion disc. Moreover, the widths of the lines are very broad (reaching +/- 1800 km/s in the case of the He 4686 Å line) with the presence of an enhancement at velocities close to zero km/s. This could be connected to the central 'spike' that is seen more prominently in the AM CVn system GP Com which is thought to originate close to the accreting white dwarf (Marsh 1999).

4 SWIFT OBSERVATIONS

We obtained target of opportunity observations of KL Dra using the NASA *Swift* satellite (Gehrels et al. 2004) once every two days for two months. The goal of these observations was to characterise the UV and X-ray flux of KL Dra over the course of an outburst cycle. Because *Swift* is in a low Earth orbit, each observation sequence (which makes up an 'ObservationID') is made up of typically 2–4 separate pointings. The exposure time of each UVOT image is generally 600 sec in duration, while the total exposure time of the X-ray observation in each ObservationID is typically 2–3 ksec. Observations commenced on 2009 Nov 08 (MJD=55146).

4.1 UVOT observations

The Ultra-Violet/Optical Telescope (UVOT) on board the *Swift* satellite has a 30 cm primary mirror and 6 optical/UV filters (Roming et al. 2005). The main goal of our UVOT observations was to determine how the UV flux changed over the course of an outburst. Since *Swift* operates a 'filter of the day', we were not able to pre-define the filter, but images were obtained in either the U (central wavelength 347 nm, and a full width half maximum of 79 nm), UVW1 (251 nm, 70 nm), UVM2 filter (225 nm, 50 nm), or the UVW2 (188nm, 76 nm) filters.

To determine the UV flux of KL Dra we used the *Swift* tool `uvotmaghist` which is part of the HEASoft[3] package of software. This tool takes into account effects such as coincidence loss and converts the count rate to flux based on observations of white dwarfs made as part of the *Swift* calibration process (Poole et al. 2008). As recommended in the UVOT software guide[4] we used a source radius of $3''$. We chose a background region free from stars and galaxies. We note that while the nearby galaxy is much brighter at optical bands compared to KL Dra, in the UVW1 filter KL Dra is much brighter than the galaxy and in the UVW2 filter the galaxy is very faint.

We found that in the low optical state the UV flux was dependent on the UV filter which was used – eg the flux in the UVW2 filter was consistently higher than the other UV filters. This is due to the fact that the filters are sampling different parts of the spectrum of KL Dra. To put the UV flux on a consistent scale (the implied flux in the UVW1 filter) we convolved the effective area curves for the different UVOT filters with white dwarf atmosphere models of different temperatures (Koester, private communication). For a white dwarf with T=16000 K, this implies a correction factor of 0.68 for the UVW2 data, 1.82 for the U data and 1.23 for the UVM2 data (the results were were similar when we used blackbodies). The correction factors for individual filters are comparable within a temperature range of ±4000 K. If the temperature of the UV component changes significantly in the outburst then the fluxes will be more uncertain.

We show the UV light curve in the middle panel of Figure 3. The corrected fluxes in the different UVOT filters now give consistent fluxes during the low optical state. The first point to note is that the optical outburst seen at MJD 55173 (2009 Dec 08) is also seen at UV wavelengths and the increase in flux is very similar (a factor of ∼20). Whilst this result was expected, it is the first time (to our knowledge) that an outburst of an AM CVn system has been seen in both optical and UV wavebands. It gives confidence that an outburst seen at UV wavelengths would also be seen at optical wavelengths. The data is consistent with the UV and optical flux starting to increase at the same time (to within half a day). In contrast, in the case of SS Cyg (which with an orbital period of 6.6 hrs will have a much larger disc than KL Dra) one outburst was observed to be delayed by 1.5–2.0 days at extreme UV energies compared to the optical (Wheatley, Mauche & Mattei 2003).

We also note that the initial rise to maximum brightness is relatively short and there is a significant decrease in the UV flux (which is similar to the drop in the optical flux seen at MJD∼55118, Figure 1), after which there is an increase in the UV flux. We note a brief UV brightening seen at MJD∼55159 which was also marked by a small increase in the optical brightness.

Given that our ground-based optical observations gave some indication that the outbursts repeated on a timescale of ∼60 days, we obtained a further set of *Swift* observations starting on 2010 Feb 09. As expected, KL Dra was in a bright UV state (cf, Figure 3). The data folded on a period of 61.5 days (Figure 4) shows a very similar profile to that of the optical data.

4.2 XRT observations

The X-ray Telescope (XRT) (Burrows et al. 2005) on-board *Swift* has a field of view of 23.6×23.6 arcmin with CCD detectors allowing spectral information of X-ray sources to be determined. It is sensitive over the range 0.2-10keV and has an effective area of ∼70 cm^2 at 1keV (for comparison the *Rosat* XRT had an effective area of ∼400 cm^2 at 1keV).

The XRT has a number of modes of operation (designed to observe gamma-ray bursts at various stages of their evolution) but here we concentrate on the 'photon counting' mode which has full imaging and spectroscopic information. The data are processed using the standard XRT pipeline and it is these higher level products which we use in our analysis [5].

[3] http://heasarc.gsfc.nasa.gov/docs/software/lheasoft/
[4] http://swift.gsfc.nasa.gov/docs/swift/analysis/UVOT_swguide_v2.pdf
[5] http://swift.gsfc.nasa.gov/docs/swift/analysis/xrt_swguide_v1_2.pdf

$N_{\rm H}$	$0.05^{+0.11}_{-0.05} \times 10^{20}$ (cm^{-2})
kT	$2.8^{+4.1}_{-1.0}$ keV
$\rm Flux_o$	$7.7^{+2.1}_{-1.8} \times 10^{-14}$ (ergs s^{-1} cm^{-2}) (0.1-10keV)
$\rm Flux_u$	$10.4^{+2.8}_{-2.5} \times 10^{-14}$ (ergs s^{-1} cm^{-2}) (0.01-100keV)
	χ^2_ν=1.12 (8 dof)

Table 1. The spectral fits to the X-ray spectrum of KL Dra. We used the `tbabs` absorption model and the `vmekal` thermal plasma model in `XSPEC`. $\rm Flux_o$ refers to the observed flux while $\rm Flux_u$ refers to the unabsorbed flux.

To determine the count rate of KL Dra at each epoch we combined the X-ray events from each ObservationID into a corresponding image using `xselect`[6]. This image was input to the HEASoft tool `XIMAGE` and the routine `SOSTA` (which takes into account effects such as vignetting, exposure and the point spread function) to determine the count rate and error at the position of KL Dra. We show the count rates for the individual observations in the lower panel of Figure 3. Since the count rates are low, we created images using more than one observation and determined the count rate from these. We also show these results in the lower panel of Figure 3 as thicker symbols.

In the lower panel of Figure 4 we show the X-ray data folded on a 61.5 day period. We created an image from all the X-ray data taken in the low optical state and also the high optical state. The mean count rates (0.00258±0.00029 ct/s for the low optical state and 0.00190±0.00036 ct/s for the high optical state) are over-plotted as thicker lines in Figure 4. Although the mean X-ray flux during the low optical state is higher than that of the high optical state the difference is not significant: we find no evidence that the X-ray flux changed significantly between the high and low optical states. We also tested whether there was a change in the soft/hard (0.1–1keV/1–10keV) ratio between the low and high optical states – there was none.

Using `XSELECT` we initially extracted an X-ray spectrum of KL Dra over a time interval when it was in a low optical state. In addition, we extracted a background spectrum from a source free region. We used the appropriate response matrix from the *Swift* calibration files and created an auxiliary file using the HEASoft tool `xrtmkarf`.

We fitted the X-ray spectrum of KL Dra in a low optical state using the `vmekal` thermal plasma model and the `tbabs` neutral absorption model. Keeping the metallicity fixed at solar (but with the hydrogen abundance fixed at zero) we found a good fit to the data (χ^2_ν=0.84, 6 degrees of freedom). The hydrogen column density determined from our model fits is consistent with the total hydrogen column density to the edge of the Galaxy in the direction of KL Dra ($\sim 7.4 \times 10^{20}$ cm^{-2}. Dickey & Lockman 1990). Since, we found no evidence that the X-ray flux varied between the low and high optical states we created a second spectrum using all the X-ray data. Using a model in which the metallicity was fixed at solar we obtained a fit with χ^2_ν=1.12, 8 dof. We give the fits with associated errors in Table 1.

[6] http://heasarc.nasa.gov/docs/software/lheasoft/ftools/xselect/xselect.html

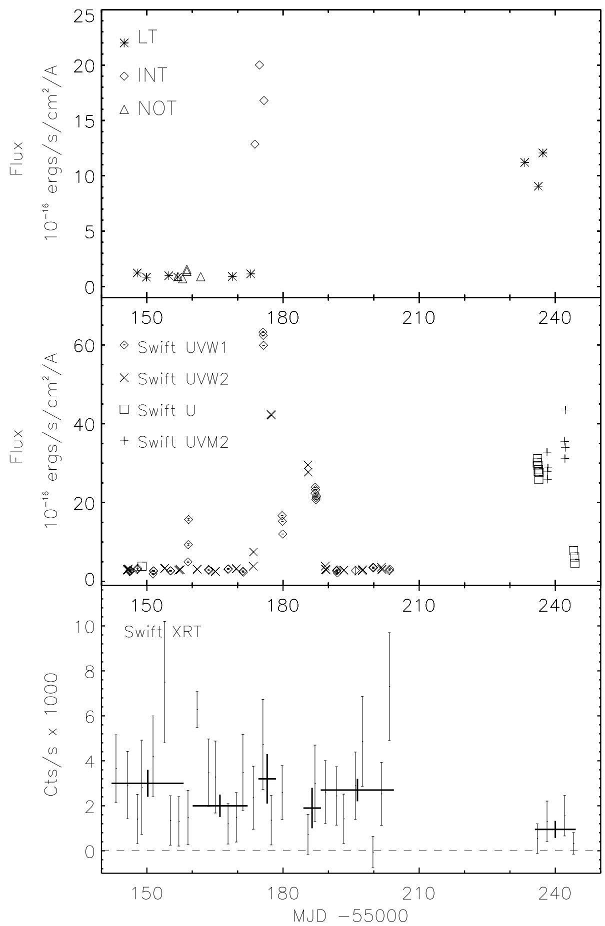

Figure 3. The light curves of KL Dra made over the course of the *Swift* observations. Top panel: Ground-based g band observations made using the LT, INT and NOT. In order to make a suitable comparison with the UV and X-ray data we converted the g band mag to flux using the conversion quoted in Holberg & Bergeron (2006). Middle Panel: The UV flux (in units of 10^{-16} ergs s^{-1} cm^{-2} Å^{-1}) where we have normalised the flux in the different filters to match that expected in the UVW1 filter (see text for details). Bottom Panel: The X-ray count rates as determined using the *Swift* XRT.

5 DISTANCE AND LUMINOSITY

Ramsay et al. (2006) determined the X-ray and UV luminosities for 8 AM CVn systems: of those, 5 had distances determined using parallax measurements. The X-ray luminosity of those 5 systems decreases as the orbital period increases. Based on this trend, we predict that a system with an orbital period of 25 mins should have an X-ray luminosity of $L_{\rm X} \sim 5 \times 10^{30}$ ergs s^{-1}. This is very similar to CR Boo (5.2×10^{30} ergs s^{-1}, Ramsay et al. 2006) with has an orbital period very close to KL Dra. Our findings imply that KL Dra lies at a distance of 550–850pc (using the standard error on the unabsorbed bolometric X-ray flux, Table 1).

The UV luminosity is more uncertain since it is difficult to constrain the temperature of the UV component (which derives from the primary white dwarf plus the accretion disc). However, taking the lead from Ramsay et al. (2006), we fix a single blackbody with a range of temperature

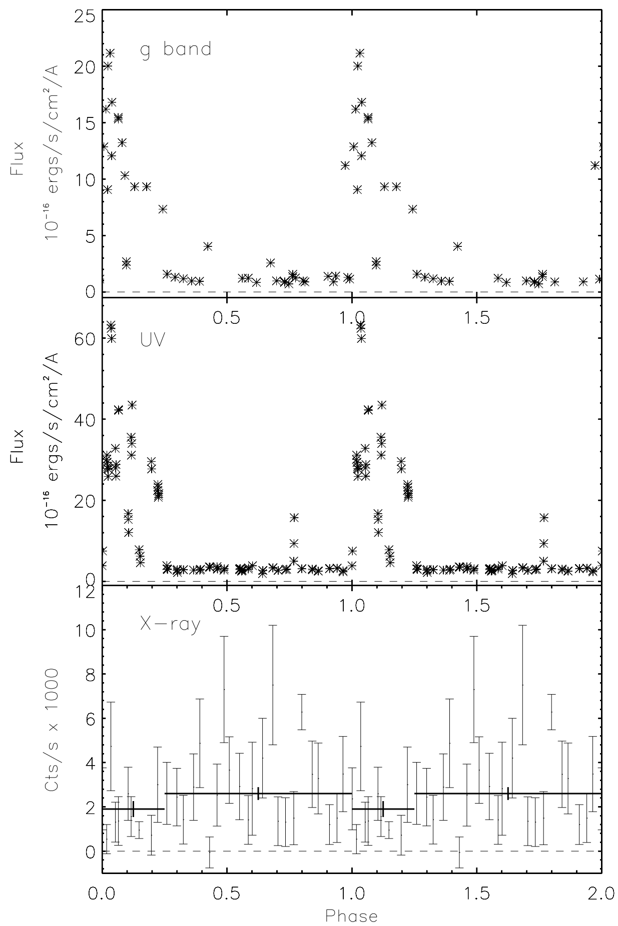

Figure 4. The light curves of KL Dra made at three wavebands folded on a period of 61.5 days with a T_o= MJD 55173.4.

(10000–40000K), and fix the normalisation of the blackbody so that it matches the measured UV flux (we used the `uvred` absorption component in `XSPEC`, Arnaud 1996). Setting the UV flux near the UV maximum (6×10^{-15} ergs s^{-1} cm^{-2}, Figure 3) we find a UV luminosity of 3–10$\times 10^{33}$ ergs s^{-1}for a distance of 700pc and a temperature range 10000–40000K. For a low optical state the UV luminosity reduces by a factor of 20 to $\sim 1 - 5 \times 10^{32}$ ergs s^{-1}, which is still greater than the X-ray luminosity by a factor of 20.

During the low state, the UV flux originates from the accreting white dwarf and the accretion disk. It is therefore difficult to determine the mass accretion rate (which is less than the mass transfer rate, cf. Schoembs & Hartmann 1983) during the low state. However, if we use the high state UV luminosity and $L = GM_1\dot{M}_{\rm acc}/R_1$, we obtain $\dot{M}_{\rm acc} \sim 3 - 10 \times 10^{16}$ g/s ($=4.7 - 15.7 \times 10^{-10}$ $M_{\odot}$/yr, assuming M_1=0.6 $M_{\odot}$, and a distance of 550-850 pc). Deloye et al. (2007) predict the mass accretion rate as a function of the mass and structure of the mass donor star and whether it is irradiated and find $\dot{M}_{\rm acc} \sim 5 - 20 \times 10^{15}$ g/s (which is slightly lower compared with that determined using the high state UV luminosity) for an orbital period of 25 mins. A greater understanding of the origin of the UV emission during the outburst cycle and the nature of the mass donor star is required before the predicted mass accretion rate can be usefully compared with observations.

6 MODELLING THE LIGHT CURVES

We model our optical lightcurve of KL Dra in the framework of the Disc Instability Model (hereafter DIM, e.g. Hameury et al. 1998) which has been adapted for helium discs by Lasota, Dubus & Kruk (2008). (See Lasota 2001 for a review of the DIM). We calculated model lightcurves for several different sets of parameters: $\alpha_{\rm C}$ (the viscosity parameter of the disc in the cold state), $\alpha_{\rm H}$ (the hot state), and the mass transfer rate, $\dot{M}_{\rm tr}$. In our simulations we fixed the mass of the accreting white dwarf at 0.6 $M_{\odot}$. We also allowed the inner radius of the accretion disc, $r_{\rm in}$, to approach the radius of the white dwarf. The outer radius of the disc, $r_{\rm out}$, was allowed to vary around a mean of $r_{\rm out} = 1.2 \times 10^{10}$ cm.

For our initial simulations we took $\dot{M}_{\rm tr} = 3 \times 10^{16}$ g/s and we show a simulated light curve in Figure 5 using $\alpha_{\rm C}$=0.025 and $\alpha_{\rm H}$=0.026. It shows outbursts which repeat on a ~60 day timescale, an amplitude of ~3 mag and bright state lasting ~2 weeks. In the simulations there is an increase in flux of ~0.5 mag between the end of one outburst and the start of the next: this is a known deficiency of the DIM (see comments in Lasota 2001). In contrast, if we assume $\dot{M}_{\rm tr} = 1 \times 10^{17}$ g/s in our simulations then this low-state flux increase is much greater. Further, they give more asymmetric outburst profiles (with the decline being more extended).

We also simulated a set of light curves where we assumed that the secondary star was irradiated by X-rays and UV photons emitted in the accretion region and from the white dwarf. Irradiation of the secondary can cause an enhancement of the mass transfer rate. We found that although this gave values for the viscosity parameters similar to that of hydrogen-dominated accreting dwarf novae (eg $\alpha_{\rm C}$ ~0.02 and $\alpha_{\rm H}$ ~0.1–0.2, Hameury et al. 1998, Smak 1999) the simulated light curves gave a large increase in brightness (over 1 mag) between the end of an outburst and the next. A more detailed investigation can help elucidate how different conditions (different critical values of Σ and T, smaller disc sizes) could affect cold and hot viscosity parameters.

7 DISCUSSION

7.1 KL Dra as a helium dwarf nova

The AM CVn systems CR Boo and V803 Cen have been known for several decades and hence their optical light curves have been well studied – they also have orbital periods close to that of KL Dra. The light curves of all three systems have shown a photometric signal on the 'superhump' period (a signature of the precession period of the accretion disc) when the system is in a high optical state and is a few percent longer than the orbital period.

On longer timescales, both V803 Cen (Patterson et al. 2000) and CR Boo (Patterson et al. 1997) have shown a prominent modulation (~1 mag) on a period of ~19–22 hrs at various epochs: this has been called the 'cycling state'. Patterson et al. (2000) noted that the amplitude and period of these modulations placed these systems on the short

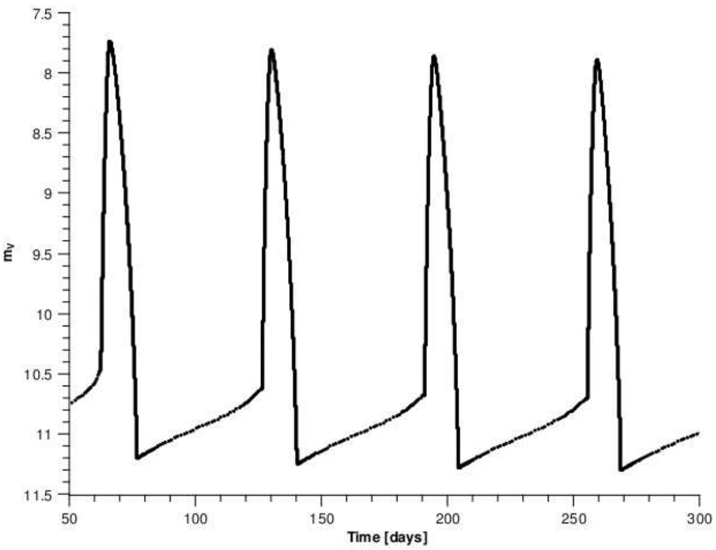

Figure 5. The simulated light curve using the Disc Instability Model which uses a helium accretion flow.

period end of the Kukarkin-Parenago period-amplitude relationship of normal dwarf novae outbursts (Warner 1987). They concluded that these near day-long modulations were similar to hydrogen-rich dwarf novae outbursts (in particular the short-period ER UMa systems). On even longer timescales, evidence has been found for a period of 77 days in V803 Cen (Kato et al. 2000a) and a period of 46 days in CR Boo (Kato et al. 2000b). Both binaries spend around half the time in a bright state.

Whilst our observations of KL Dra are less extensive than those of V803 Cen and CR Boo, they show characteristics which are clearly different to these two AM CVn systems. Indeed, with a possible outburst cycle of ∼60 days and with a duty-cycle of ∼1/5, KL Dra closely resembles the outbursts seen in the SU UMa or U Gem type dwarf novae. However, at this stage we cannot exclude that the outbursts seen in KL Dra are not the AM CVn equivalent of WZ Sge outbursts (dwarf novae which recur on a timescales of years and have outburst amplitudes of 6–9 mag, eg Patterson et al. 2002). As such it makes KL Dra a prime target to investigate the similarities and differences between hydrogen-rich and hydrogen-deficient accretion flows.

7.2 The X-ray flux over the outburst cycle

The hydrogen-accreting dwarf novae have been much studied at various wavelengths over several decades and show regular outbursts on timescales ranging from a few weeks to months or even years. Many systems show characteristics similar to SS Cyg which showed in one outburst that the increase in the extreme UV emission was delayed by 1.5–2.0 days with respect to the optical emission (Wheatley, Mauche & Mattei 2003). In contrast, the hard X-rays, after an initial burst, were suppressed during the remainder of the outburst. To complicate matters, U Gem has shown at least one outburst where the hard X-rays follow the optical and UV flux (Mattei, Mauche & Wheatley 2000). It is not clear if this is due to the relatively high binary inclination of U Gem. More recently GW Lib (which has only had two known outbursts) also shows the enhancement of X-rays at the start of the outburst (Byckling et al. 2009).

One of the key reasons for obtaining *Swift* observations was to determine how the X-ray flux of KL Dra varied over the course of the outburst cycle. It is clear that X-rays are detected from KL Dra both during the low and the high optical states. However, there is no evidence that the X-ray flux changed significantly during the course of the outburst (Figure 3).

8 CONCLUSIONS

Our observations of KL Dra show that it undergoes frequent optical outbursts which are also seen at UV wavelengths. Although our coverage is by no means complete, our data are consistent with KL Dra undergoing outbursts on a period of ∼60 days. The amplitude of the outbursts (∼3 mag) and duration of the outburst (∼2 weeks) are very similar to the typical outbursts that seen in the SU UMa or U Gem sub-class of (hydrogen) accreting dwarf novae. As such we encourage other observers, whether they are amateur astronomers who have suitable equipment or team members of survey telescopes which have suitable spatial resolution (to resolve KL Dra from its 'nearby' galaxy), to obtain a more complete long term coverage and hence verify the ∼60 day outburst period. The fact that KL Dra shows such regular outbursts makes it an ideal system with which to investigate helium accretion flows in detail.

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REFERENCES

Arnaud, K. A., 1996, Astronomical Data Analysis Software and Systems V, ed G. Jacoby & J Barnes, ASP Conf Series, 101, 17

Barclay, T., Ramsay, G., Steeghs, D., 2009, ATel, 2203

Burrows, D. N., et al., 2005, SSRv, 120, 165

Byckling, K., Osborne, J. P., Wheatley, P. J., Wynn, G. A., Beardmore, A., Braito, V., Mukai, K., West, R. G., 2009, MNRAS, 399, 1576

Deloye, C. J., Taam, R. E., Winisdoerffer, C., Charbrier, G., 2007, MNRAS, 381, 525

Dickey, J. M., Lockman, F. J., 1990, ARAA, 28, 215

Gehrels, N., et al., 2004, ApJ, 611, 1005

Hameury, J.-M., Menou, K., Dubus, G., Lasota, J.-P., Hure, J-M., 1998, MNRAS, 298, 1048

Holberg, J. B., Bergeron, P., 2006, AJ, 132, 1221

Horne K., 1986, PASP, 98, 609

Jha, S., Garnavich, P., Challis, P., Kirshner, R., Berlind, P., 1998, IAUC, 6983

Kato, T., Stubbings, R., Monard, B., Pearce, A., 2000a, IBVS, 4915

Kato, T., Nogami, D., Baba, H., Hanson, G., Poyner, G., 2000b, MNRAS, 315, 140

Kotko, I., Lasota, J.-P., Dubus, G., 2010, AN, 331, 231

Lasota, J.-P., 2001, NewAR, 45, 449

Lasota, J.-P., Dubus, G., Kruk, K., 2008, A&A, L523

Marsh, T.R., 1989, PASP, 101, 1032

Marsh, T.R., 1999, MNRAS, 304, 443

Mattei, J., Mauche, C., Wheatley, P., 2000, JAAVSO, 28, 160

Nelemans, G., 2005, The Astrophysics of Cataclysmic Variables and Related Objects, Proceedings of ASP Conference Vol. 330. Edited by J.-M. Hameury and J.-P. Lasota. San Francisco: Astronomical Society of the Pacific, 2005, p.27

Patterson, J., et al., 1997, PASP, 109, 1100

Patterson, J., Walker, S., Kemp, J., O'Donoghue, D., Bos, M., Stubbings, R., 2000, PASP, 112, 625

Patterson, J., et al., 2002, PASP, 114, 721

Poole, T. S., et al., 2008, MNRAS, 683, 627

Ramsay, G., Groot, P. J., Marsh, T., Nelemans, G., Steeghs, D., Hakala, P., 2006, A&A, 457, 623

Rau, A., Roelofs, G. H. A., Groot, P. J., Marsh, T. R., Nelemans, G., Steeghs, D., Salvato, M., Kasliwal, M. M., 2010, ApJ, 708, 456

Roming, P. W. A., 2005, SSRv, 120, 95

Schoembs, R., Hartmann, K., 1983, A&A, 128, 37

Smak, J., 1983, AcA, 33, 333

Smak, J., 1999, AcA, 49, 391

Steele, I., et al., 2004, SPIE, 5496, 679

Tsugawa, M., Osaki, Y., 1997, PASJ, 49, 75

Warner, B., 1987, Ap&SS, 130, 3

Wheatley, P. J., Mauche, C., Mattei, J., 2003, MNRAS, 345 49

Wood, M. A., Casey, M. J., Garnavich, P. M., Haag, B., 2002, MNRAS, 334, 87