**XMM-NEWTON AND OPTICAL OBSERVATIONS OF CATACLYSMIC VARIABLES FROM THE SLOAN DIGITAL SKY SURVEY**

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**ABSTRACT**

We report on *XMM-Newton* and optical results for six cataclysmic variables that were selected from Sloan Digital Sky Survey (SDSS) spectra because they showed strong He II emission lines, indicative of being candidates for containing white dwarfs with strong magnetic fields. While high X-ray background rates prevented optimum results, we are able to confirm SDSS J233325.92+152222.1 as an intermediate polar from its strong pulse signature at 21 minutes and its obscured hard X-ray spectrum. Ground-based circular polarization and photometric observations were also able to confirm SDSS J142256.31−022108.1 as a polar with a period near 4 hr. Photometry of SDSS J083751.00+383012.5 and SDSS J093214.82+495054.7 solidifies the orbital period of the former as 3.18 hr and confirms the latter as a high-inclination system with deep eclipses.

**Key words:** novae, cataclysmic variables – stars: individual (SDSS J233325.92+152222.1, SDSS J093214.82+495054.7, SDSS J083751.00+383012.5, SDSS J142256.31−022108.1, SDSS J154104.67+360252.9, SDSS J204827.91+005008.9) – X-rays: stars

1. INTRODUCTION

While the Sloan Digital Sky Survey (SDSS; York et al. 2000) reveals new cataclysmic variables (CVs) from its spectral database (Szkody et al. 2007 and prior references), the correct identification of the type of close binary often requires followup observations utilizing time series and multiple wavelengths. Optical photometry, polarimetry, and spectroscopy can identify the orbital period, the spin period of the white dwarf, and whether the object has a magnetic field. The X-ray light curve, flux, and spectrum can distinguish a system with an accretion disk (dwarf nova or novalike) from those systems containing a white dwarf with a strong magnetic field (polar, which has the white dwarf spin synchronized to the orbit) or a lesser magnetic field (intermediate polar (IP) with a white dwarf spin shorter than the orbital period). For these magnetic systems, in particular, the funneling of the accretion to the magnetic pole or poles creates a strong modulation of the X-ray fluxes (see Warner 1995 for a thorough review of the different types of CVs and their multilight wavelength curves).

The high sensitivity and wide energy bandpass of *XMM-Newton* have shown this satellite to be ideal for measuring the X-ray fluxes and characterizing the X-ray source in the new CVs found in the SDSS. The spin pulse and spectral temperature can be identified in systems with moderate accretion rates, while flares and softer spectral temperatures can be found in systems with extremely low accretion rates (Szkody et al. 2004b; Schmidt et al. 2005; Homer et al. 2005, 2006). In 2005–2006, we were granted *XMM-Newton* time to observe six CVs with strong He II emission lines that were recently found from SDSS spectra as good candidates for containing magnetic white dwarfs. Unfortunately, except for SDSS J233325.92+152222.2, the majority of the observations were conducted during times of high X-ray background, with the result that only portions of the total times on the sources could be used and only upper limits on the count rates could be obtained for the other five systems: SDSS J083751.00+383012.5, SDSS J093214.82+495054.7, SDSS J154104.67+360252.9, SDSS J142256.31−022108.1, and SDSS J204827.91+005008.9. A request for re-observation was denied. We include here the results for all systems, together with some ground-based observations conducted along with X-ray observations that help elucidate the nature of several of the objects. For the rest of the paper, we will use abbreviations for the object names as SDSS Jhhmm (hours and minutes of right ascension). Table 1 provides a summary of the properties of the six systems that were under study.

2. OBSERVATIONS AND DATA REDUCTION

2.1. X-Ray

The two MOS detectors (Turner et al. 2001) and the EPIC pn detector (Strüder et al. 2001) on *XMM-Newton* were used to obtain X-ray observations of the six CVs. In addition, the Optical Monitor (OM; Mason et al. 2001) obtained simultaneous optical observations, using the B filter (centered around 4500 Å). The pipeline products were used to create light curves and determine B magnitudes. The data from the Reflection Grating Spectrograph were not useful due to low count rates. The details of the X-ray and OM observations, including dates, UT times, observation times (total time (TOT) and good time intervals (GTI) with background flaring times removed), and average count rates are listed in Table 2.

The data were reduced using the Science Analysis System (SAS), version 7.0.0 with calibration files current to 2006 August 15. The data reduction followed the standard guidelines from the *XMM-Newton* Web site (VILSPA) and from the NASA/GSFC *XMM-Newton* Guest Observer Facility ABC Guide (version 2.01). The total observation data were used to identify the source visibility and background levels and then the data were screened to eliminate the high background where possible in order to increase the signal-to-noise ratio (S/N). New event list files were created directly from the observation

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4 [http://xmm.esac.esa.int/sas/](http://xmm.esac.esa.int/sas/)
data files using the SAS tools. From these event list files, light curves were created in the 10–18 keV range using the entire chip for each detector and these files were used to identify and remove background flaring events. Each of the targets had different criteria for selecting good data intervals, depending on their individual light curves. For SDSS J2333, SDSS J2048, and SDSS J1541, the high background count rates were most easily identified by using a count rate cutoff. For SDSS J2333, data were ignored when the count rate exceeded 3.0 counts s\(^{-1}\) for the pn and 0.6 counts s\(^{-1}\) for both MOS detectors. For SDSS J2048, we used limiting values of 12.0 counts s\(^{-1}\) for the pn and 5.0 counts s\(^{-1}\) for both MOS detectors as the background counts were higher throughout the observation. The limit used for SDSS J1541 was 5 counts s\(^{-1}\) for both pn and MOS detectors. For the other three targets, SDSS J0837, SDSS J0932, and SDSS J1422, the background rate was stable throughout most of the observation, but increased significantly at either the beginning or the end of the observation. It was, therefore, easier to trim the data so that only data during the stable background times were used.

Five of our observations (SDSS J0837, SDSS J0932, SDSS J1422, SDSS J1541, and SDSS J2048) had no obvious visible source. We note that in the case of SDSS J1541 several bright pixels appear in the pn image somewhat near the expected location of the source. This is not apparent in the MOS, even though background sources that are fainter in the pn image than these bright pixels do appear in the MOS images. Additionally, the bright pixels do not show the point spread function (PSF) of other sources visible in both detectors so we concluded that this was not the target. For these objects, we employed the following method to place an upper limit on the count rate. Using the pn detector images because of their increased sensitivity over the MOS, we used the target R.A. and decl. to place an aperture (360 pixel radius), and then found the number of counts inside this target aperture, using an energy range of 0.1–15 keV. We then found the number of counts inside four circular background apertures of the same size, one in each quadrant. Each background aperture was a large area free of point sources located at a similar distance from the midplane of the detector. For our observations, the exposure time on the 12 pn chips varied slightly, so a count rate was determined for each aperture. We then calculated the count rate needed to have a 3\(\sigma\) detection, added this to the background, and compared to the count rate for the target aperture. In other words, given a measured background, we calculated the count rate needed to reach a given S/N, using
\[
\sigma = \frac{n\sqrt{r}}{\sqrt{n+b}}
\] where \(\sigma\) is the S/N, \(n\) is the count rate needed to reach that S/N, \(r\) is the time, and \(b\) is the background count rate. We used the average of the count rate needed for a 3\(\sigma\) detection in the four background apertures as our limit. As a consistency check, this analysis was carried out on a field source that appeared by eye to be very faint. The field source was a 5\(\sigma\) detection.

In order to ensure that real signal had not been removed when the flaring background sections were discarded, we also repeated this analysis keeping all of the exposure and limiting the energy range to 0.5–2.0 keV. In this analysis, no target was visible by eye in the image, and no target was above 3\(\sigma\).

For the source that was successfully detected, SDSS J2333, the event list files were filtered with the standard canned expressions, and were restricted to the well-calibrated regions of 0.2–15 keV for spectral analysis and 0.1–12.5 keV for light-curve analysis. With the pn detector, only single events (pattern = 0) were accepted for spectral analysis, and singles and doubles (pattern \(\leq 4\)) for light-curve analysis. For the MOS detectors, quadruples and lower (pattern \(\leq 12\)) were permitted for both the spectral analysis and the light-curve analysis. The data were binned to 20 counts per bin to increase the S/N for the spectral analysis. The source region was taken to be a circular aperture with a radius of 360 pixels for both detectors. The background region for the MOS detectors was determined from an annulus centered on the target and free of other sources, while the pn background was determined using four rectangular regions, each on adjacent CCD chips, with similar Y locations as the target.

The resulting light curve is background-subtracted, and the times have been corrected to the solar system barycenter using FTOOLS (Blackburn 1995).\(^5\) The pn light-curve data as well as the OM data were binned at 200 s to increase the S/N.

SDSS J0932 was the only other source to have sufficient counts in the OM to show variability on the orbital period. For this object, the OM data were binned at 60 s to increase the S/N.

2.2. Ground-Based Data

Optical observations on SDSS J0837, SDSS J0932, SDSS J1422, and SDSS J2048 were conducted at the US Naval Observatory Flagstaff Station (NOFS), as well as at the George Observatory. The optical photometry summary can be found in Table 3.

For SDSS J0932, the NOFS observations were made with the automated 1.3 m wide-field telescope and a single 2048 × 4096 E2V back-illuminated CCD without any filter. This combination gives a pixel scale of 0.60 arcsec pix\(^{-1}\) and a field of view of 20 × 40 arcmin. The exposure times were 90 s, with 50 s of dead time between exposure. For the other NOFS targets, the 1.0 m telescope and a SITe/Tektronix 102 × 1024 back-illuminated CCD without filter were used. This combination gives a pixel scale of 0.67 arcsec pix\(^{-1}\) and a field of view of 11.3 × 11.3 arcmin. Exposure times averaging 200 s were used; dead time at the 1.0 m was always 40 s. In all cases, images were processed using standard techniques, and aperture photometry was performed using DAOPHOT (Stetson 1987) as implemented in IRAF. The exception was for SDSS J2048, where the conditions were poor and DAOPHOT PSF-fitting was used to obtain the highest S/N.

Once instrumental magnitudes were obtained, inhomogeneous ensemble photometry techniques following the guidelines of Honeycutt (1992) were used to obtain the final photometry. At least 10 stars in each field were used for the ensemble. Each

\(^5\) Tools available at [http://heasarc.gsfc.nasa.gov/lheasoft/ftools/](http://heasarc.gsfc.nasa.gov/lheasoft/ftools/).
error estimate is the quadrature sum of the Poisson and the ensemble errors.

All four optical targets have SDSS calibration photometry, but we also obtained $B$ and $V$ optical calibration at NOFS on photometric nights, using standards from Landolt (1983, 1992). The $V$-band calibration was used for the photometry shown in the figures and analysis, as the CCD response was closest to this passband. The calibration photometry is available on the AAVSO Web site\(^6\) and through their online comparison star database.

The George Observatory measurements were made with a 0.46 cm telescope and SBIG CCD in cirrus sky conditions. The images were stacked in 5 minute bins and magnitudes were measured in comparison to other stars in the field to determine a differential light curve.

Circular polarization was also measured for SDSS J1422 using the CCD Spectropolarimeter SPOL on the 2.3 m Bok Telescope on Kitt Peak on the nights of 2005 March 16 and April 14. The instrument configuration and data acquisition was as described in Schmidt et al. (1992), with the exceptions of an improved quality camera lens and state-of-the-art 1200 × 800 pixel cosmetically perfect SiTe CCD with 2.2e$^-$ read noise that was thinned, back-illuminated, and anti-reflection coated by the University of Arizona’s Imaging Technology Laboratory.

This object was discovered and identified as a likely IP (Szkody et al. 2005; Sz05) from 9 hr of photometry in 2004 that showed a 21 minutes period high amplitude modulation in its light curve, while an orbital period of 1.4 hr was determined from a radial velocity curve obtained from 3.5 hr of spectra. Southworth et al. (2007; Sw07) recently reported 4 hr of photometry and spectroscopy covering 6 hr over two nights in 2006. While their spectra confirmed and refined the period to 83.12 minutes, the photometry was consistent with a double-sinusoid variation indicating a spin period of 41.66 minutes and its harmonic at 21 minutes. This result implies two accreting poles causing the variation. The confirmation of an IP generally consists of a large amplitude variation at the spin period in X-ray, combined with a hard, absorbed X-ray spectrum. Fortunately, the best XMM-Newton data among the six objects were obtained for this source.

The object was detected above the 3σ upper limit at the October 7th observation.

\(^6\) http://www.aavso.org/.

### 3. RESULTS

#### 3.1. SDSS J2333

The object was discovered and identified as a likely IP (Sz05) from 9 hr of photometry in 2004 that showed a 21 minutes period high amplitude modulation in its light curve, while an orbital period of 1.4 hr was determined from a radial velocity curve obtained from 3.5 hr of spectra. Southworth et al. (2007; Sw07) recently reported 4 hr of photometry and spectroscopy covering 6 hr over two nights in 2006. While their spectra confirmed and refined the period to 83.12 minutes, the photometry was consistent with a double-sinusoid variation indicating a spin period of 41.66 minutes and its harmonic at 21 minutes. This result implies two accreting poles causing the variation. The confirmation of an IP generally consists of a large amplitude variation at the spin period in X-ray, combined with a hard, absorbed X-ray spectrum. Fortunately, the best XMM-Newton data among the six objects were obtained for this source.

Figure 1 shows the light curve in both the optical OM (top panel) and X-ray pn (bottom panel). A prominent modulation is obvious in both light curves. The discrete Fourier transform (DFT) of these data, shown in Figure 2, reveals a period of 21 minutes ($760 \mu$Hz), consistent with that found in the previous optical observations by Sz05. The period of 41.66 minutes ($400 \mu$Hz) found by Sw07 is not evident. It is not clear if these differences are due to changes in the two accreting poles. The Sz05 optical data set was obtained with a 1 m telescope, using 140 s integrations but was 9 hr long (encompassing about 13 cycles if the period is 42 minutes). The Sw07 data set was obtained with a larger (2.2 m) telescope and 40 s integrations but was only about 4 hr long (somewhat less than 6 cycles of 42 minutes). Their unfolded light curve shows large variations in the depths of the minima so a few cycles could influence the resulting pattern. Our XMM data are even shorter (about 3 hr or only 4 cycles of 42 minutes) and the peaks and troughs are highly variable. Figure 3 shows the XMM-Newton data folded on the 41.66 minutes period. Due to the scatter, any difference in the two peaks in each cycle is not obvious.

We did fold the Sz05 optical data set on 41.66 minutes and the resulting light curve shows two similar humps per cycle.
Figure 1. OM and pn light curves of SDSS J2333 showing the strong modulation in both optical and especially X-ray.

Figure 2. DFT of SDSS J2333 showing the prominent period at 21 minutes and its large amplitude of modulation. Note that there is no peak evident at the 41.66 minutes period (400 $\mu$Hz) found by Southworth et al. (2007).

Figure 3. XMM-Newton pn and pn+mos data on SDSS J2333 folded on the 41.66 minutes period.

Figure 4. Optical data of SDSS J2333 from Sz05 phased on the 41.66 minutes spin period.

The DFT of the Sz05 data (Figure 5) shows the orbital period (0.0002 Hz) and the prominent 21 minutes period but only a small insignificant peak that would be consistent with the 41.66 minutes period, in contrast to the Sw07 data which have a narrower and higher amplitude peak for the 42 minutes than the 21 minutes period. While the XMM-Newton data only show a 21 minutes period, the larger X-ray amplitude (2–3 times larger than the optical) confirms the IP nature of this source. Compared to the XMM results on the IP SDSS J1446+02, where the X-ray spin pulse maximum occurs 0.3 phase before the optical (Homer et al. 2006), the X-ray and optical pulses in SDSS J2333 appear to be in phase.

As further confirmation of the IP nature, we folded the data on the 41.66 minutes period using different energies (Figure 6 shows the resulting light curves). As is typical for IPs, the amplitude of the variability increases for lower energies, likely due to a local absorber in the system.

The pn spectrum of SDSS J2333 is shown in Figures 7 and 8, binned at 20 counts per bin to increase the S/N. The best-fit XSPEC$^7$ simple absorbed bremsstrahlung model gave a reduced $\chi^2 = 1.07$, with a hydrogen column density of the absorbing gas of $9.2 \times 10^{20}$ cm$^{-2}$ and a temperature of $5.1 \pm 1.4$ keV (Table 4). While this simple model provided a reasonable fit with a low reduced $\chi^2$, there was excess emission near 1 keV that could be due to a complex of Fe, Ne, O emission lines that is present in IPs (Mukai et al. 2003) and unresolved in our data. However, the fit with a mekal model (which includes emission lines) produced similar values (see Table 4) of temperature and column but does not fit the excess (Figure 7) either.

While the spectrum is typical of IPs in showing a large absorption, the spectrum is not as hard as usual (10–20 keV), although it does not show a prominent soft X-ray component as evident

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$^7$ Available at http://heasarc.gsfc.nasa.gov/docs/xanadu/xspec/index.html.
in increasing numbers of IPs (Haberl et al. 2002; de Martino et al. 2006). We next tried partial covering absorbers (pcf) and cooling flow models (mkcflow). There was little improvement in the pcf model but the cooling flow seemed to fit the spectrum best (Table 4 and Figure 8). This type of model was used by Mukai et al. (2003) to fit the IP EX Hya.

### 3.2. SDSS J0837

SDSS J0837 identified SDSS J0837 as a polar candidate showing a cyclotron hump in the blue and TiO bands from the secondary star in the red. Followup polarimetry and spectroscopy (Schmidt et al. 2005) confirmed the polar nature, determined a spectral type of M5V, a distance of 330 pc, and an orbital period of either 3.18 or 3.65 hr. Analysis of the spectrum showed this object has a very low accretion rate, similar to systems like MQ Dra (SDSS J1553+5516) and SDSS J1324+0320 (Szkody et al. 2005). XMM-Newton observations of these latter two systems (Szkody et al. 2004a) showed very low X-ray fluxes ($10^{-14}$ erg cm$^{-2}$ s$^{-1}$) and luminosities ($<10^{29}$ erg s$^{-1}$), and soft spectra (0.2–0.8 keV) characteristic of the secondary M star rather than a shock from accretion onto the white dwarf. While the high background rates combined with low source counts prevented a detection of SDSS J0837 in our observations, the upper limit gives us a clue as to the nature of the X-ray flux. Table 5 compares the secondary spectral types, distance, and pn count rates for the three sources. If the X-ray spectrum is similar to MQ Dra ($kT = 0.8$ keV), then scaling by the distance squared predicts a count rate of 0.003 for SDSS J0837, which is below the limit from our observation. The limit of 0.0042 for SDSS J0837 would correspond to a 0.2–10 keV flux of $<8 \times 10^{-15}$ erg cm$^{-2}$ s$^{-1}$ and an X-ray luminosity of $<10^{29}$ erg s$^{-1}$. Thus, it appears that there is also no active X-ray shock in SDSS J0837 and this system is indeed in the regime of extremely low accretion rate.

The count rate from the OM B filter gives a magnitude of 19.4, at the time of the X-ray observation, but there is no obvious variability in the OM light curve. Our optical photometry spans times a year prior to the X-ray data and three months after (Tables 2 and 3). Both data sets show the object at the same faint magnitude as evident in the SDSS photometry and that of Schmidt et al. (2005). Our light curves (Figure 9) show a repetitive structure (typical of polars) but with a low amplitude of modulation (as noted by Schmidt et al. 2005 and suggested

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**Table 4**

| Model       | Reduced $\chi^2$ | $N_H \times 10^{20}$ cm$^{-2}$ | $kT$ (keV) | Norm |
|-------------|------------------|---------------------------------|------------|------|
| brems       | 1.07             | 9.2 $\pm$ 1.6                   | 5.1 $\pm$ 1.4 | 2.2 $\times$ 10$^{-4}$ |
| mekal       | 1.03             | 8.1 $\pm$ 1.6                   | 5.2 $\pm$ 1.0 | 5.5 $\times$ 10$^{-4}$ |
| pcf+mekal*  | 1.05             | 8.1 $\pm$ 1.6                   | 4.9 $\pm$ 1.4 | 6.2 $\times$ 10$^{-4}$ |
| mkcflow     | 0.81             | 8.8 $\pm$ 1.6                   | 0.4–17$^b$  | 7.9 $\times$ 10$^{-16}$ |

**Notes.**

* pcfabs fixed at $2 \times 10^{23}$; resulting covering fraction of 13%.

$^b$ Low and high temperatures of cooling flow.

**Table 5**

| Object      | Sec  | $d$ (pc) | pn (counts s$^{-1}$) |
|-------------|------|----------|----------------------|
| MQ Dra      | M5   | 130      | 0.020                |
| SDSS J1324  | M6   | 450      | 0.0012               |
| SDSS J0837  | M5   | 330      | $<0.0042$            |
| SDSS J2048  | M3   | 260      | $<0.0138$            |

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**Figure 5.** DFT of the optical data from Sz05. The 21 minutes period is evident but the 42 minutes period is not significantly detected above the noise. Amplitude units are milli modulation amplitudes. The top panel is the light curve divided by its mean (in intensity units) minus 1. The bottom panel is the transform of a noiseless frequency with the same time sampling as the data in order to show the alias pattern due to the finite length and gaps in the data.

**Figure 6.** PN data of SDSS J2333 at different energies and phased on the 41.66 minutes period.
to be due to a low inclination of the system). The spacing of the lowest points of the light curve are 3.14±0.10 and 3.00±0.10 hr for the two nights (Figure 9). Running a DFT on the data reveals periods of 2.98±0.08 for 2004 December 15 and 3.06±0.06 for 2006 January 27. Both of these methods show that the shorter period is the correct orbital period for this system.

3.3. SDSS J0932

The SDSS spectrum of SDSS J0932 is highly unusual (Szkody et al. 2006) with a very strong, asymmetric He II 4686 emission line superposed on a blue continuum with only weak Balmer emission. Little information on this object exists in the literature, other than a discovery spectrum by Munari et al. (1997) showing stronger Balmer emission and an abstract report (Holcomb et al. 1994) reporting weak ROSAT sources. The Center for Backyard Astrophysics Web site contains a light curve made by Robert Fried8 that shows an eclipse and gives a period of 10.04 hr, which is very long for a CV. Our XMM-Newton observation provided an upper limit of 0.014 counts s$^{-1}$, confirming a low X-ray flux from this object, despite the strong He II presence and its relatively bright optical mag ($g \sim 17.5$).

The OM data in the $B$ filter show that an eclipse took place during the latter half of the pn observations (Figure 10). We also tried filtering the times of the pn data to exclude the eclipse, but still no source was visible. Our optical photometry obtained about two months prior to the X-ray observations is shown in Figure 10.

8 http://cbastro.org/results/highlights/uma6; note that this is a differential light curve that may not be calibrated with known standard stars.
Figure 9. Ground-based data on SDSS J0837. Error bars are 0.03 mag on 2004 December 15 and 0.02 mag on 2006 January 27.

Figure 10. OM data on SDSS J0932 in the $B$ filter. Data are binned into 60 s intervals. The dashed line is when the pn observation started; solid lines are the GTI intervals used for pn.

Figure 11. Ground-based data on SDSS J0932 obtained 2006 February 27 UT. Error bars are 0.01 mag.

Figure 12. Circular polarization (top) and flux (bottom) spectrum of SDSS J1422.

Figure 13. Ground-based data on SDSS J1422. Error bars are 0.03–0.06 mag.

in $B$ appears to be about 0.5 mag deeper than in $V$, as is typical for eclipses of a hot white dwarf and inner disk (Baptista et al. 1994).

3.4. SDSS J1422

This object was first identified in the Two-Degree Field (2dF) QSO survey (Croom et al. 2001) and suggested to contain a magnetic white dwarf by Marsh et al. (2002). The latter authors identified a possible 3.37 hr orbital period (with possible 1 cycle day$^{-1}$ aliases) from spectroscopic data. This object also exists in the SDSS database (Szkody et al. 2004a) and shows similar spectra to those obtained by Marsh et al. The high X-ray background on this source resulted in very limited data so we were only able to place an upper limit on the X-ray flux. In addition, the source was too faint for any detection in the OM. However, our ground-based spectropolarimetry (Figure 12) obtained on two different nights (2005 March 16 for 960 s and 2005 April 14 for 3600 s) show coadded circular polarization...
values of +2.5% and +2.8%, respectively, thus confirming this object as a polar. Polarization is present throughout the duration of the longer observation, which was obtained in three segments, and each segment displays a net circular polarization between +1.5% and +4%, with individual error bars of ~0.5%. From the coadded results shown in Figure 10, it can also be seen that the polarization is approximately uniform over the optical spectrum, suggesting the smeared cyclotron harmonics of a high-temperature shock (characteristic of a bona fide polar), as opposed to the isolated emission features of a low-accretion rate system. While the continuum flux level in 2005 looks similar to the SDSS spectrum from 2002, there is a rise at the blue end and the emission lines are not as strong, especially the He II emission line. Thus, the accretion state may have been slightly different than in the earlier data.

While our optical photometry was obtained several years prior to the X-ray observations, we show the light curve in Figure 13 as there has not been any prior photometry published that we could find. There is a sinusoidal-type modulation with full amplitude of ~0.4 mag on each night and pdm analysis gives a period of 4 hr, but since this period is about the length of the data string on each night and the nights are too far apart to combine the data to obtain a better period, this value must remain as tentative. However, the photometry indicates the period could be longer than the estimate provided by Marsh et al. (2002).

### 3.5. SDSS J2048

SDSS J2048 is very similar to SDSS J0837. Schmidt et al. (2005) provided the discovery information, identifying it as another very low accretion rate polar with an orbital period near 4.2 hr, an M3 secondary, and a distance of 260 pc. The XMM-Newton observations have a high background count over the whole chip, but the top half of the chip has systematically higher counts than the bottom half of the chip. Although we provide an upper limit, researchers should be cautioned that there may have been a problem with the pn detector during this observation. As with SDSS J0837, there was no significant detection of the source, leading to a limit to the count rate of <0.013. Using the same arguments as for SDSS J0837 (Table 5), the expected count rate would be 0.005 counts s⁻¹ for a comparable spectrum as for MQ Dra. This is also consistent with our limit and argues for a lack of shock at the magnetic pole of the accreting white dwarf. The XMM limit would translate into a 0.2–10 keV flux of <3 × 10⁻¹⁴ erg cm⁻² s⁻¹ and an X-ray luminosity of <2 × 10²⁹ erg s⁻¹.

The OM data show a very low count rate (Table 2) that translates into a B magnitude of 19.9. Our optical photometry obtained about six months prior to the X-ray observations appears to be about 1 mag brighter than the SDSS photometry but the observations were made in cirrus and the error bars are large. The light curve (Figure 14) shows variability of 0.3 mag which may be related to the orbital cycle but better photometry is needed to confirm this.

### 3.6. SDSS J1541

This object was identified as a polar in Szt05. While the SDSS spectrum was obtained during a time of low accretion, the followup spectropolarimetry and photometry were obtained during high accretion states. During a high state, the X-ray flux is expected to be large and shows both soft and hard components. The OM data show the object at a low state,
Mukai, K., Kinkhabwala, A., Peterson, J. R., Kahn, S. M., & Paerels, F. B. S. 2003, ApJ, 586, 77
Munari, U., Zwitter, T., & Bragaglia, A. 1997, A&AS, 122, 495
Schmidt, G. D., Stockman, H. S., & Smith, P. S. 1992, ApJ, 398, L5
Schmidt, G. D., et al. 2005, ApJ, 630, 1037
Southworth, J., Gansicke, B. T., Marsh, T. R., de Martino, D., & Aungwerojwit, A. 2007, MNRAS, 378, 635, Sw07
Stetson, P. B. 1987, PASP, 99, 191
Strüder, L., et al. 2001, A&A, 365, L18
Szkody, P., et al. 2003, ApJ, 583, 902
Szkody, P., et al. 2004a, AJ, 128, 1882
Szkody, P., et al. 2004b, AJ, 128, 2443
Szkody, P., et al. 2005, AJ, 129, 2386 (Sz05)
Szkody, P., et al. 2006, AJ, 131, 973
Szkody, P., et al. 2007, AJ, 134, 185
Turner, M. J. L., et al. 2001, A&A, 365, L27
Warner, B. 1995, Cataclysmic Variable Stars (Cambridge: Cambridge Univ. Press)
York, D. G., et al. 2000, AJ, 120, 1579