**XMM-Newton and Optical Follow-Up Observations of Three New Polars from the Sloan Digital Sky Survey**

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**ABSTRACT**

We report follow-up XMM-Newton and optical observations of three new polars found in the Sloan Digital Sky Survey. Simple modeling of the X-ray spectra, and consideration of the details of the X-ray and optical light curves corroborate the polar nature of these three systems and provide further insights into their accretion characteristics. During the XMM-Newton observation of SDSS J072910.68+365838.3, X-rays are undetected apart from a probable flare event, during which we find both the typical hard X-ray bremsstrahlung component and a very strong O vii ($E = 0.57$ keV) line, but no evidence of a soft blackbody contribution. In SDSS J075240.45+362823.2 we identify an X-ray eclipse at the beginning of the observation, roughly in phase with the primary minimum of the optical broadband curve. The X-ray spectra require the presence of both hard and soft X-ray components, in a luminosity ratio consistent with that found in other recent XMM-Newton results on polars. SDSS J170053.30+400357.6 appears optically as a very typical polar; however, its large-amplitude optical modulation is 180° out of phase with the variation in our short X-ray light curve.

**Subject headings:** novae, cataclysmic variables — stars: individual (SDSS J072910.68+365838.3, SDSS J075240.45+362823.2, SDSS J170053.30+400357.6) — stars: magnetic fields — X-rays: stars

### 1. INTRODUCTION

Polars (or AM Herculis stars) possess the strongest magnetic fields ($B \sim 10–200$ MG) among cataclysmic variables (CVs). In these systems, the plasma transferred from the secondary does not form an accretion disc, but instead the gas is threaded onto the field lines and accretes at the poles atop the white dwarf (WD) surface. In the simplest picture, a strong shock develops in the accretion column, above the surface, as the flow transitions from its high (approximately free-fall) velocity to a subsonic flow that can settle on the WD. The postshock flow is a strong source of hard X-rays, mostly emitted as a thermal bremsstrahlung continuum (with $kT_{br} = 10–50$ keV), although line emission can also be important. Further cooling occurs via cyclotron emission in the optical/IR, but is typically an order of magnitude smaller. Half of the hard X-ray photons will be incident on the WD photosphere, heating it, so that it is a source of soft blackbody emission (with $kT_{BB} = 20–40$ keV). For an X-ray albedo $\alpha_X = 0.3$ (Williams et al. 1987), and neglecting the cyclotron contribution, the soft/hard energy balance is then expected to be $L_{BB}/L_{br} \sim 0.56$ (King & Watson 1987). However, observations of polars found in some (but not all) cases a large discrepancy, with $L_{BB}/L_{br} \gtrsim 5$ (see Ramsay et al. 1994, and references therein), which was termed the “soft X-ray excess.”

Some of the results presented here were obtained with the MMT Observatory, a facility operated jointly by The University of Arizona and the Smithsonian Institution.

Based on observations obtained with the Sloan Digital Sky Survey and the Apache Point Observatory (APO) 3.5 m telescope, which are owned and operated by the Astrophysical Research Consortium (ARC).

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One of the shortcomings of the accretion flow model is the assumption that the accretion flow is inhomogeneous, consisting of high and low density regions, and likely bulky. The former leads to a hard X-ray deficiency, since the bulk of this emission arises from the highest density region, which may involve a small fraction of the total flow. The latter leads to enhanced blackbody emission. In addition to the irradiation heating of the WD photosphere, if the flow becomes bulky, the longest/most dense blobs of material are able to penetrate deeply before being shocked, and hence the energy released is thermalized before emission. Finally, at the very lowest specific accretion rates, the flow degenerates into a bombardment solution (Kuijpers & Pringle 1982), in which there are no accretion shocks, and the heating of the WD photosphere is also sufficiently weak that we expect no X-ray emission. For a review of the various accretion regimes, see Wickramasinghe & Ferrario (2000).

The Sloan Digital Sky Survey (SDSS) is in its fourth year of a multicolor photometric imaging and spectroscopic survey, which will eventually cover ~25% of the celestial sphere (Abazajian et al. 2003, 2004, 2005; Fukugita et al. 1996; Gunn et al. 1998; Hogg et al. 2001; Lupton et al. 1999, 2001; Pier et al. 2003; Smith et al. 2002; Stoughton et al. 2002; York et al. 2000). Given an imaging limit of $g = 23.3$, SDSS is uncovering an unprecedented number of faint, low accretion rate CVs among the >150 new systems discovered to date (see Szkody et al. 2002, 2003, 2004a). Indeed, this is the very population that is expected to dominate CVs, but owing to selection biases was missed previously (Howell et al. 1997).

Several polars have been identified in the SDSS, among them two of the lowest accretion rate systems known (Szkođy et al. 2003, 2004b) and the shortest period eclipsing system (Schmidt et al. 2005). XMM-Newton observations have helped to identify their accretion characteristics. Here we report follow-up XMM-Newton X-ray and optical observations of three additional sources, SDSS J072910.68+365838.3, J075240.45+362823.2, J170053.30+400357.6 (hereafter SDSS J0729, J0752,
TABLE 1
OBSERVATION SUMMARY

| SDSS J | UT Date       | Observation   | UT Time | Approximate V | Comments                   |
|--------|--------------|---------------|---------|---------------|----------------------------|
| 0729   | 2002 Jan 07  | NOFS          | 05:06–10:49 | 19.8–20.7     | Open filter photometry     |
|        | 2002 Oct 31  | APO: DIS      | 10:40–11:10 | 20.6          | Spectrum                   |
|        | 2002 Oct 31  | XMM-Newton: EPIC pn | 20:39–22:16 | ...           | 5282 s live time\(a\)     |
|        |              | XMM-Newton: EPIC MOS1/2 | 20:16–22:21 | ...           | 7358/7392 s live time      |
|        |              | XMM-Newton: OM | 20:25–22:26 | 20.7          | 5999 s duration, B filter  |
|        | 2003 Sep 22  | SO: SPOL      | ...       | ...           | 1800 s, spectropolarimetry, pol. = \(-0.79\%\) |
|        | 2003 Nov 01  | MMT: SPOL     | ...       | ...           | 1600 s, spectropolarimetry, pol. = \(+0.76\%\) |
|        | 2004 Feb 16  | SO: SPOL      | ...       | ...           | 2880 s, spectropolarimetry, pol. = \(+0.34\%\) |
| 0752   | 2002 Oct 31  | NOFS          | 08:33–13:03 | 17.8–19.1     | Open filter photometry     |
|        | 2002 Oct 31  | APO: DIS      | 11:22–11:37 | 17.5          | Spectrum                   |
|        | 2002 Oct 31 –Nov 01 | XMM-Newton: EPIC pn | 23:40–01:17 | ...           | 4019 s live time           |
|        |              | XMM-Newton: EPIC MOS1/2 | 23:18–01:22 | ...           | 5990 s live time           |
|        |              | XMM-Newton: OM | 23:27–01:28 | ...           | 6002 s duration, UVW2 filter |
|        | 2003 Nov 01  | MMT: SPOL     | ...       | ...           | 2400 s, spectropolarimetry, pol. = \(-0.75\%\) |
| 1700   | 2003 Aug 11  | XMM-Newton: EPIC pn | 16:57–19:29 | 2659 s live time |
|        |              | XMM-Newton: EPIC MOS1/2 | 16:34–17:07 | ...           | 3546/3561 s live time      |
|        |              | XMM-Newton: OM | 17:53–19:34 | ...           | Data lost                  |
|        | 2003 Jul 02  | NOFS          | 03:42–10:48 | 17.9–19.5     | Open filter photometry     |
|        | 2003 Aug 08  | MRO           | 05:09–11:38 | ...           | Open filter photometry     |
|        | 2003 Aug 09  | MRO           | 04:44–11:11 | ...           | Open filter photometry     |
|        | 2003 Aug 10  | MRO           | 04:44–10:57 | 18.5–19.7     | B filter photometry        |

\(a\) The live time of the X-ray CCD detectors refers to the sum of the good-time intervals, less any dead time. It is typically much less than the difference of observation start and stop times.

**2. OBSERVATIONS**

For each *XMM-Newton* observation, data are obtained with all detectors. However, for our targets there were never sufficient counts to render the dispersed spectra from the Reflection Grating Spectrograph (RGS; den Herder et al. 2001) of any use; even for the case of SDSS J0752, our brightest target, the continuum is barely detected and no emission lines stand out. Optical Monitor (OM; Mason et al. 2001) data were successfully obtained for only SDSS J0729 and SDSS J0752. However, in the UVW2 ultraviolet filter (required to avoid field bright- ness limits) SDSS J0729 was not detected; data were obtained for SDSS J0729 using the *B* filter. Low-resolution spectra were available from the EPIC camera, taken with the two MOS detectors (Turner et al. 2001) and the pn (Strüder et al. 2001), where the pn has roughly twice the effective area of each of the MOS. The UT times, length of total observation, and CCD live time are listed in Table 1. These data were reduced, according to the guidelines from the main *XMM-Newton* Web site (Vilspa)\(^9\) and also from the NASA/GSFC *XMM-Newton* Guest Observer Facility ABC guide.\(^{10}\) Using calibration files current to 2004 March 23 and the SAS (ver. 6.0). Given the calibration updates since pipeline processing, as a precaution we used SAS tools to produce new event list files from the observation data files (ODF). To check on variations in the non-X-ray background, we created light curves for each entire detector in the 10–15 keV range, and where appropriate, created new GTIs to exclude intervals of higher background. We also screened these event lists using the standard canned expressions, and we restricted energies to the 0.1–10 keV range. For the two MOS detectors, we used a 320 pixel radius circular aperture size (enclosing \(\leq 70\%\) of the energy, chosen to maximize S/N), with a source-free background annulus surrounding the source; event pattern \(\leq 12\) selection was also applied. For the pn, we extracted source data within a 360 pixel (again encircled energy \(\sim 70\%\)) and background data from adjacent rectangular regions at similar detector \(\gamma\) locations to the target. As advised, a conservative choice of event selection, pattern = 0, was adopted.

We fit simple blackbody (BB) + thermal bremsstrahlung (br) (or MEKAL\(^{11}\) to include line emission) models to the various spectra to obtain estimates of the relative contributions of soft (\(\leq 0.6\) keV) and hard (\(\geq 0.6\) keV) components. Given the lack of counts from SDSS J0729 and the need to time resolve the data from SDSS J0752, we chose to use Cash statistics (Cash 1979), which work better for the case of few counts per bin. For SDSS J1700, the background was a significant contribution (30%–40%), and hence we opted to use background-subtracted spectra and \(\chi^2\) statistics for fitting. In no cases were we able to reliably constrain the absorbing columns. Hence, by default, we adopted the value for the position on the sky given by the HEASARC tool nH, based on dust maps. All our targets are at high Galactic latitude, leading to values \(n_H \sim \) a few \(\times 10^{20}\) cm\(^{-2}\), typical of the values measured in most polars. However, we do caution that our adopted values could be overestimates since these targets are likely within a few hundred parsecs of the Sun, and nH gives the column to the edge of the Galaxy.

Finally, in our fitting, we used two sets of energy ranges (specifically the lower energy cutoffs), since the reliability of the calibrations at the lowest energies is still unclear. The large range (LR) set included energies \(\geq 0.15\) keV for pn and \(\geq 0.2\) keV.

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\(^9\) Available from http://xmm.vilspa.esa.es/external/xmm_sw_cal/sas.shtml.

\(^{10}\) See http://heasarc.gsfc.nasa.gov/docs/xmm/abc/abc.html.

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\(^{11}\) See http://heasarc.gsfc.nasa.gov/xheasoft/xanadu/xspec/ manual/node39.html.
for MOS, potentially useful for constraining any soft blackbody component. The restricted range (RR) had more conservative cutoff limits of $E > 0.3$ keV (pn) and $>0.5$ keV (MOS).

We extracted light curves for both source and background with SAS task *e*vent *s*elect, using the same extraction regions as the spectra, but a less conservative pattern $\leq 4$ for the pn events. Using FTOOLS\(^{12}\) tasks, we subtracted the scaled background and converted the time stamps from JD(TT) to HJD(TT).\(^{13}\)

Contemporaneous optical spectra for SDSS J0729 and SDSS J0752 were obtained on 2002 October 31 using the double-imaging spectrograph (DIS) on the 3.5 m telescope at Apache Point Observatory (APO). These were reduced and flux calibrated within IRAF.\(^{14}\) In addition, differential photometry was obtained for SDSS J0729 (in 2002 January), and SDSS J0752 (contemporaneously), with the US Naval Observatory Flagstaff Station (NOFS) 1 m telescope; see Table 1 for details. These data were taken with no filter to give maximum signal-to-noise ratio, but an approximate zero point for Johnson $V$ was made possible through calibration of the field from all-sky photometry including Landolt standards observed at NOFS. Hence, the light curves are labeled $V$ magnitudes, but actually show broad, white-light results. Finally, optical spectrophotometry and circular spectropolarimetry were obtained for SDSS J0729 and SDSS J0752 in 2003 September, November and 2004 February with either the 2.3 m Steward Observatory (SO) Bok telescope or the 6.5 m MMT atop Mount Hopkins (see Table 1). Both runs made use of the CCD SPOL spectropolarimeter (Schmidt et al. 1992). Neither of the sources was found to be highly polarized (magnitude of polarization $<1.0\%$ is considered a nondetection); only the 2003 September 22 observation of SDSS J0729 made a detection with a polarization of $\approx 2.79\%$. However, we note that SDSS J0752 was in a low state during its only observation on 2003 November 1.

SDSS J1700 was also observed by the NOFS 1 m on 2003 July 2, and then, close to the XMM-Newton observations, by the 0.76 m telescope at Manastash Ridge Observatory (MRO) on 2003 August 8–10. Time resolutions $\approx 200$ s were achieved on all nights using no filter, apart from the final MRO night, which used a $B$ filter. Details of the observations are listed in Table 1. Differential magnitudes were determined relative to at least three local standard stars in the field.

3. RESULTS

From our contemporaneous optical spectra and/or light curves we are able to confirm that each of the targets was in its normal active accretion state at the times of the XMM-Newton X-ray observations. The low-resolution spectra of SDSS J0729 and SDSS J0752 show the characteristic He $\lambda$ 4686 (Fig. 1) and are in general very similar to their SDSS spectra. The NOFS

\[\text{Fig. 1.—} \text{Low-resolution spectra of SDSS J0729 and SDSS J0752. Both show strong He $\lambda$ 4686, which is characteristic of actively accreting polars. However, the emission lines of SDSS J0729 are narrower than those of SDSS J0752 and lack any indication of structure. This indicates that the accretion rate of SDSS J0729 was low at this time. The flux scale is in units of flux density of } \text{ergs cm}^{-2} \text{s}^{-1} \text{Å}^{-1}.\]

\(^{12}\) See http://heasarc.gsfc.nasa.gov/lheasoft/ftools/.

\(^{13}\) The tools actually yield barycentric Julian Date in the barycentric dynamical time system, BJD(TB). However, the offset to heliocentric Julian Date in the geocentric (terrestrial) dynamical time system [HJD(TT)] is less than $\sim 3$ s at any given time, fine for our purposes here.

\(^{14}\) IRAF (Image Reduction and Analysis Facility) is distributed by the National Optical Astronomy Observatories, which are operated by the Association of Universities for Research in Astronomy (AURA) Inc., under cooperative agreement with the National Science Foundation.
photometry of SDSS J0752 also gave a consistent $V = 18.19$. Likewise, SDSS J1700 was observed at $B = 19.33 \pm 0.03$, a flux level similar to all prior optical observations.

3.1. SDSS J0729

In the optical, repeatable variability is apparent, with two full cycles covered. From a PDM analysis, we derive a period of 2.5 ± 0.1 hr. Although of very low S/N, the $V$ light curve from the simultaneous OM observations shows consistent morphology. In Figure 2, we show the folded light curve and also the XMM-Newton light curve for an equivalent time interval. The complex optical morphology is reminiscent of that seen in AM Herculis on occasion (see, e.g., Mazeh et al. 1986). Gänsicke et al. (2001) have recently developed a quantitative model for

![Fig. 2.—Optical and X-ray light curves of SDSS J0729. Top: Orbital phase-folded $V$-band light curve. Bottom: Plot of 100 s binned light curves from EPIC pn. An ephemeris was not available for the X-ray observations, but the scale is chosen to enable direct comparison with the optical curve above. Note HJD(UT) = HJD(TT) – 64.184 s at this epoch.](image)

![Fig. 3.—EPIC spectra of SDSS J0729 for the X-ray flare event (pn, black lines; MOS1, light gray lines; MOS2, dark gray lines). The best-fit bremsstrahlung model is overplotted, and residuals are shown below; the excess at ~0.57 keV is clear. In the inset we show the bremsstrahlung+Gaussian line fit.](image)

### Table 2: Summary of the X-Ray Spectral Fits

| SDSS J       | Energy Range | Model               | Goodness of Fit | $N_H$ ($\times 10^{20}$ cm$^{-2}$) | $kT$ or $E$ | Flux $^c$ |
|--------------|--------------|---------------------|-----------------|-----------------------------------|------------|-----------|
| 0729         | RR          | bremsss             | 54%             | 5.96 (f)                          | $10^{-13}$ keV | 4.2       |
|              |              | BB                  | 47%             |                                   | 40 eV (f)  | 16        |
|              |              | + bremsss           | 8%              |                                   | 30 keV (f) | 3.8       |
|              |              | bremsss + Gaussian line | 8%             |                                   | 30 keV (f) | 0.2       |
|              | LR          | BB                  | 36%$^e$         | 5.11 (f)                          | $66 \pm 3$ eV | 18       |
|              |              | + bremsss           | 74%             | $11.4 \pm 1.9$ keV                | 14 $^{+5}_{-2}$ eV | 18       |
| 1700         | RR          | bremsss             | 1.0             | 2.15 (f)                          | $8^{+3}_{-2}$ keV | 8        |
|              |              | BB                  | 0.97            |                                   | 40 eV (f)  | 14        |
|              |              | + bremsss           | 0.97            |                                   | $12^{+4}_{-3}$ keV | 8        |
|              |              | mekal               |                 |                                   | $7^{+2}_{-1}$ keV | 8        |

$^a$ LR = large range, using 0.15–10 keV for pn and 0.2–10 keV for MOS to make most of low-energy response. RR = restricted range, more conservative lower energy limits imposed: 0.3–10 keV for pn and 0.5–10 keV for MOS.

$^b$ For SDSS J0729 and SDSS J0752, where the fitting utilized Cash statistics, the goodness of fit is found via a Monte Carlo method. Sampling each parameter randomly within its allowed distribution ≥1000 spectra were simulated, and a fit performed. The percentage refers to the incidence of fits with lower C-statistic values than that of the fit to the data. A good fit should have a value around 50%. For SDSS J1700 the reduced $\chi^2$ is quoted.

$^c$ Unabsorbed flux in the 0.01–10 keV range, in units of 10$^{-13}$ ergs cm$^{-2}$ s$^{-1}$, including the correction for the 70% encircled energy fraction.

$^d$ The note (f) indicates that the parameter was frozen at this value.

$^e$ For a single-component bremsstrahlung model the percentage was 100%, clearly indicating the need for the blackbody.
Fig. 4.—Optical and X-ray light curves of SDSS J0752. Top: Orbital phase-folded $V$-band light curve. Bottom: Plot of 100 s binned light curves from EPIC MOS (left) and pn (right). The total energy, soft, and hard bands are shown; note that the egress from the probable eclipse is much more gradual at >0.6 keV, and the post-eclipse hump is most prominent in the soft band. The approximate phase is shown on the top axes; the solid bar represents the uncertainty on $T_0$ at this time. Note HJD(UT) = HJD(TT) − 64.184 s at this epoch.
the $B$ and $V$ light curves of AM Herculis. The accretion column, responsible for the optical cyclotron emission, is always visible, with the primary minimum occurring when the line of sight is along the accretion funnel, and the secondary minimum due to partial self-eclipse by the WD and/or cyclotron beaming effects.

The X-ray flux in SDSS J0729 is undetectable for fully 0.4 in phase, then brightens significantly, possibly for only ~0.2. This is very similar to the X-ray flare behavior seen in a low state of UZ For (Pandel & Córdova 2002), suggesting that the accretion rate is sufficiently low (consistent with the optical spectrum) that any X-ray emitting region is too cool to fall within the XMM-Newton passband most of the time. However, given our incomplete phase coverage, it is also possible that we are simply seeing the X-ray–emitting part of the column coming out of self-eclipse by the WD. Since the X-ray–emitting region is typically smaller and closer to the WD surface than the cyclotron, a much longer X-ray self-eclipse is certainly plausible.

The spectrum from this high X-ray flux interval is also quite unusual. We fit a br+BB model to the restricted range; we constrained the temperatures to 30 keV and 40 eV, respectively, as typical values for polars (Warner 1995). The result indicated that the data do not require any soft blackbody component (see Table 2). However, as seen in Figure 3, the residuals to the bremsstrahlung in the pn data show evidence for a broad line emission feature at 0.57 keV. In the inset, we show a fit to the line (with a linear scale). Given the low S/N, the significance of this feature remains questionable. We did check whether it was an artifact of binning, by trying binning with 4–7 counts per bin instead, but it appeared consistently. A line at this energy could be due to strong O vii emission; we note that a number of strong O vi lines are present in the spectra of AM Herculis in the extreme UV (Mauche & Raymond 1998).
3.2. SDSS J0752

Similar to SDSS J0729, the optical light curve of SDSS J0752 exhibits a large amplitude variation, with a prominent minimum, and additional flux reductions ~0.3 later in phase (Fig. 4). The PDM analysis reveals a period of 2.74 ± 0.05 hr. Although the ephemeris is not well constrained, the optical observation took place only five cycles prior to the X-ray, and we can phase the latter to within 0.1 cycles. We therefore tentatively identify the X-ray and optical minima present at close to our φ = 0.0 as due to self-eclipses. In X-rays there appears to be a short interval of complete occultation, but unfortunately, the eclipse is right at the start of the MOS exposure. In the broadband optical curve, the eclipse is only partial, as expected for the less localized cyclotron and other optical emission sites.

The optical flux dips at φ ~ 0.3, which, again considering the AM Herculis case, could well be caused by the observer looking down along the accretion funnel at this interval. Moreover, immediately following the X-ray eclipse, there is a distinct hump before the source settles into a fairly steady flux level, although we note that a QPO on a 700 s timescale appears toward the end of the observation. Light curves constructed for soft (0.1–0.6 keV) and hard (0.6–8 keV) bands provide further insight. The hump is much more striking in the soft band, with the flux returning to a low (but nonzero) level for the remainder of the observation, whereas the hard band appears to come out of eclipse and remain at a constant high level thereafter.

We also extracted phase-resolved spectra to examine the changes in greater detail (see Fig. 5 and Table 2). For the interval after the hump (HJD > 2452579.495), we fit a basic br+BB model (Fig. 6) and found that in this system, the BB component is very significant; with the F-test giving probabilities >99.99% for either the LR or RR (although the parameters are naturally better constrained for the former). Indeed, the BB contributes half of the unabsorbed flux in the 0.01–10.0 keV range, although we caution that the exact fraction is model dependent and could be a factor of 2 different.

During the hump, we were restricted to the MOS data alone and chose to fix kT_{br} at the value found previously in the combined MOS + pn after-hump data set. The fit yielded kT_{bb} = 65 eV in both cases; hence, the change in the BB flux is not due to a change in temperature but rather to differing normalizations. This suggests that as SDSS J0752 emerges from eclipse, we can see the BB emission region fully before it is once again obscured, most likely by the accretion column, consistent with our model for the optical light curve.

3.3. SDSS J1700

In Figure 7 we present the four nights of optical data, with the best-fit sinusoid overplotted. The morphology of the orbital modulation is indeed close to sinusoidal; although, as illustrated in the phase-folded and binned plots (Fig. 8), the exact shape changes subtly from night to night. Comparison to the 2001 August light curves presented in Szkody et al. (2003) shows more conspicuous differences; at that time, the shape comprised broad maxima and narrow minima, in contrast to the 2003 morphology. To derive an ephemeris, we first used a modified discrete
Fourier transform, the Lomb-Scargle periodogram (Scargle 1982), to determine the approximate best period. This was then refined by cycle counting ($O - C$ method), and finally by fitting a sinusoid model to the entire data set, yielding

$$HJD(TT)_{\text{max}} = 2452859.0103(3) + 0.08080175(8)n,$$

where $HJD(TT)_{\text{max}}$ is the time of maximum light, and the parenthetical values indicate the estimated $1\sigma$ uncertainties in the final digits. With this precision, we are easily able to phase the X-ray light curve (Fig. 9).

Unfortunately, during this XMM-Newton observation, there were technical problems; hence, although we are able to accumulate data from all the small intervals of CCD live time, the MOS data were completely unusable for timing, and only parts of the pn could be used to reliably construct a light curve. However, given the limited coverage, it does seem that the X-ray flux is modulated in antiphase to the optical.

There are at least two alternate explanations for the X-ray and optical light curves. In the first, as for SDSS J0729 and SDSS J0752, a single accretion pole is visible in SDSS J1700. The optical modulation is then a result of our viewing of the cyclotron emission, with the minimum occurring when we view down the accretion funnel. As narrower cyclotron beaming occurs at shorter wavelengths, we then obtain the broader minimum in the $B$ band (see Bonnet-Bidaud et al. 1985). In contrast, the X-ray emission reaches a maximum when the normal to the accretion spot is close to our line of sight. The second model invokes two visible accretion poles, and as is the case during the “reversed” state of AM Herculis, the optical emission is dominated by one, and the X-ray by the other. The X-ray/optical minima are then due to total/partial self-eclipses, respectively.

Only longer contemporaneous observations of SDSS J1700 will be able to resolve this issue.

As a consequence of the limited live time, the X-ray spectrum is of low S/N. We fitted a variety of models to the RR and LR (see Table 2). In no case was a soft BB component (fixed at 40 eV) required. For the br model, we found a very poorly constrained temperature of 8.9 keV. A single temperature MEKAL fit the data equally as well, but with a slightly better constrained $kT = 7.2\pm2$ keV (see Fig. 10). In summary, the spectrum of SDSS J1700 is typical of a polar, with a plasma $T \sim 10$ keV, but no additional soft component is required.

4. CONCLUSIONS

The XMM-Newton and optical observations presented here provide useful constraints on the accretion characteristics of SDSS J0729, SDSS J0752, and SDSS J1700.

In terms of accretion geometries, we find that SDSS J0729 is likely a single-pole accretor, exhibiting a complex optical light curve as a result of the combined effects of cyclotron beaming and partial occultation of the emitting region. The X-ray variation, consisting of a single high-flux interval lasting perhaps only 0.2 in phase, could either be an X-ray flare event due to a sudden, short increase in the mass transfer rate from the secondary, or the X-ray emitting region simply coming out from self-eclipse. In any case, the X-ray spectrum at this time is most unusual, being well modeled by the usual hard bremsstrahlung, but also requiring a strong emission line at 0.57 keV. This line is probably due to O vii emission, and it is interesting to note that similar strong emission lines (of O vi) are seen in the extreme UV spectra of AM Herculis (Mauche & Raymond 1998).

The data on SDSS J0752 also appear to be consistent with a single-pole accretor. Both the X-ray and optical light curves show self-eclipses by the WD. In the optical at $\phi \sim 0.3$, there are additional dips in the flux, possibly due to cyclotron beaming and/or obscuration effects. In the soft X-ray, the eclipse is followed by a short rise in flux, then a long interval at a lower level, perhaps due to obscuration by the accretion column itself. This is the brightest source in X-rays, and we are able to constrain both the BB and br components fairly well. We find a typical $kT_{\text{br}} = 11$ keV, but a somewhat high $kT_{\text{BB}} = 65$ eV, although the latter may relate to the remaining low energy calibration uncertainties of the EPIC instruments. Bearing this,
and the uncertainty in the absorbing column which we could not constrain, in mind, we can derive a value for the soft/hard X-ray energy balance. Taking into account the geometrical effects, the X-ray scattering albedo of the WD photosphere, \( a_X \approx 0.3 \) (Williams et al. 1987), but not the cyclotron term (typically negligible compared to the br), we find

\[
\frac{L_{BB}}{L_{bb}} \approx \frac{\pi f_{BB}(1-a_X) d^2}{2 \pi f_{br}(1+a_X) d^2} = 0.35 - 0.5. 
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This is well within the range found in a recent survey of polars by Ramsay & Cropper (2004) and in agreement with the basic picture of X-ray emission from radial accretion.

For SDSS J1700, the light curves allow two alternate models, either a single- or two-pole accretor, and both are able to explain the antiphasing of the X-ray and optical modulations. In the former, the cyclotron beaming minimum occurs at roughly the same phase that the accretion region appears brightest in X-rays. In the latter, we postulate that the optical and X-ray emission originate at different poles and are principally modulated by the occurrence of self-eclipses.

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