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IDENTIFICATION OF THE SOFT X-RAY SOURCE WGA J1802.1+1804 WITH A NEW MAGNETIC CATACLYSMIC VARIABLE

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ABSTRACT

We have discovered a bright ($V \sim 14.5$) cataclysmic variable during observations of the soft X-ray sources in the list of Singh et al. The optical source, which is coincident with the X-ray position of WGA J1802.1+1804, shows all the characteristics of a magnetic AM Herculis–type system: circular polarization, He II strength greater than Hβ, multiple line components, and a consistent photometric, polarimetric, spectroscopic, and X-ray period of 113 minutes. The X-ray spectrum shows a dominant soft blackbody ($kT = 20-45$ eV) and a weaker bremsstrahlung component ($kT > 1$ keV), while the circular polarization is relatively low (4% in the red).

Subject headings: binaries: spectroscopic — novae, cataclysmic variables — stars: individual (WGA J1802.1+1804) — X-rays: stars

1. INTRODUCTION

Singh et al. (1995) have recently compiled a list of the softest sources from the online catalog (WGACAT), which contains all the sources detected from 3 years of pointings with the *ROSAT* satellite (White, Giommi, & Angelini 1994). With their criteria that the softness ratio must be greater than 10, Singh et al. found that virtually all the sources that could be identified with previously known cataclysmic variables (CVs) were magnetic AM Her types. These close binaries (reviewed in Cropper 1990) contain white dwarfs with magnetic field strengths from 15–60 MG. The observed soft X-rays are generated by the heating of the white dwarf surface by the radiation produced in the column of material accreting close to the magnetic poles. At the current time, there are about 50 AM Her systems known (Beuermann 1995), with more than half of them found from X-ray surveys. As the numbers grow, there exist increasing opportunities to understand the variety of physical parameters that affect the magnetic accretion scenario.

With the possibility of finding further magnetic CVs among the remaining unidentified soft sources, we began a program of spectroscopic identification of optical candidates that were located close to the X-ray positions. This paper describes our success in identifying a very bright, strong emission-line object with a previously unknown magnetic CV. After submission of this paper, we became aware that this source has been independently found from the *ROSAT* all-sky survey data (Greiner, Remillard, & Motch 1995).

2. OPTICAL OBSERVATIONS

The first observations were made with the Double Imaging Spectrograph (DIS) on the 3.5 m telescope at Apache Point Observatory (APO) via a remote interface run through the University of Washington on 1995 June 19. The field of WGA J1802.1+1804 was imaged, and a spectrum of the object closest to the X-ray position ($18^h02^m06\overset{s}{.}4$, $+18°04'48''$)(J2000) was obtained. The DIS uses a 512 × 512 UV-coated Tek CCD in the blue ($1\farcs09$ pixel^{-1} in imaging mode) and an 800 × 800 TI CCD in the red ($0\farcs61$ pixel^{-1}). In spectroscopic mode, a $1\farcs5$ slit was used with a pair of gratings with 830.8/1200 lines mm^{-1} giving a resolution of 2–3 Å over the regions 4300–5100 Å in the blue and 5800–6800 Å in the red. The first spectrum revealed a strong emission-line source with He II λ4686 stronger than Hβ. On June 23, a series of 15 blue and red spectra with 5 minute exposures were obtained from 04:46–7:06 UT. The source is identified from a 20 s blue CCD image in Figure 1 (Plate L4). There is a close star about 6$''$ to the northeast. Figure 2 shows a representative blue and red spectrum, and Figure 3 (Plate L4) shows the stacked spectra after reduction with IRAF routines that subtracted the bias, divided by the flat field, extracted the spectrum, subtracted the sky, and calibrated the wavelength and flux from frames of standard stars and arcs.

Follow-up photometry was done at the University of Washington 0.76 m telescope at Manastash Ridge Observatory (MRO) on the nights of 1995 July 18 and 19 and August 26, 27, and 28. Five hours of 30 s integrations were obtained on each night in July, and 2–4 hr in August, using a Ford 1024 × 1024 CCD with a V filter to obtain differential light curves of the variable with respect to field stars in the same frames. The magnitudes were measured by fitting the point-spread function to the bias and flat corrected frames. The light curves from July relative to the $V \sim 15.0$ mag comparison star marked "C" in Figure 1 are shown in Figure 4.

Polarimetry was obtained at the 2.56 m Nordic Optical Telescope on La Palma on 1995 August 20–21 to confirm the magnetic nature. The Low Dispersion Specrograph (LDS;

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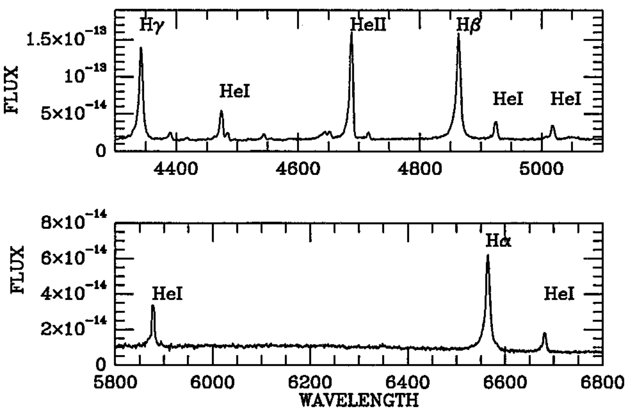

FIG. 2.—A representative 5 minute APO spectrum of the candidate obtained on 1995 June 23. The flux is in units of ergs cm^{-2} s^{-1} $Å^{-1}$.

Thomsen 1990) was used together with a fixed λ/4 plate and a calcite block to enable circular spectropolarimetry. These observations will be discussed in detail elsewhere (Piirola et al. 1995), but we give here preliminary broadband polarization and intensity curves in the red, extracted from ~2000 Å wide spectral region centered at 6700 Å (Fig. 5).

3. RESULTS FROM PHOTOMETRY AND SPECTROSCOPY

Using the positions of stars in the Digitized Sky Survey (DSS), the coordinates of our optical candidate are $18^h02^m06^s.5$, $+18°04'42''.6$ (J2000) with an uncertainty of $2''.0$. Using the blue side of the DIS with no filter, and calibrating with other fields obtained on June 19 and 23, we estimate a magnitude range of 14.3–15.0 for the candidate. There are overall mean brightness changes (from 0.2 mag brighter than the comparison star for the July data in Fig. 4 to 0.4–0.6 mag brighter for the August data), as well as a shorter periodic modulation of 0.4 mag amplitude that is visible on all nights, although it is less pronounced on July 18. Using a periodogram analysis on each night and the combined nights of photometry results in a minimum at 113.21 ± 0.18 minutes with possible aliases at 105.01 and 122.81 minutes for the combined July data and 113.13 ± 0.08 minutes with aliases at 104.66 and 122.60 for the combined August data.

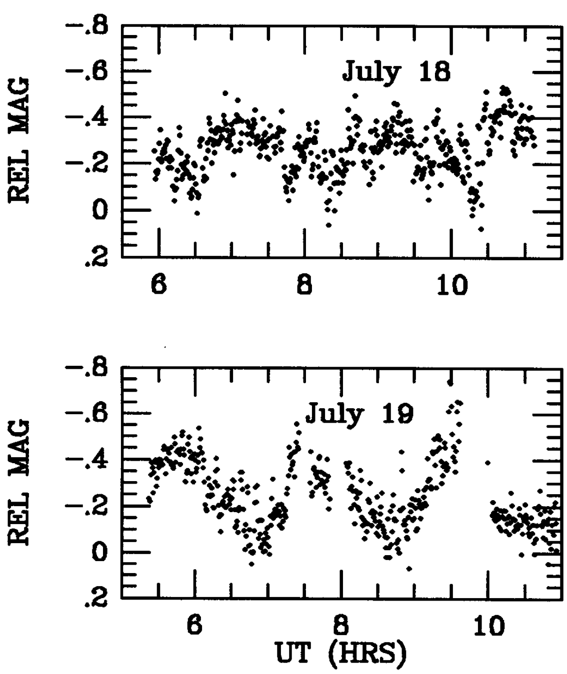

FIG. 4.—*V*-band CCD light curve of the candidate, relative to the 15th magnitude comparison star marked in Fig. 1, obtained at MRO on the nights of 1995 July 18 and 19. Each point is a 30 s integration with statistical uncertainty of 0.02 mag.

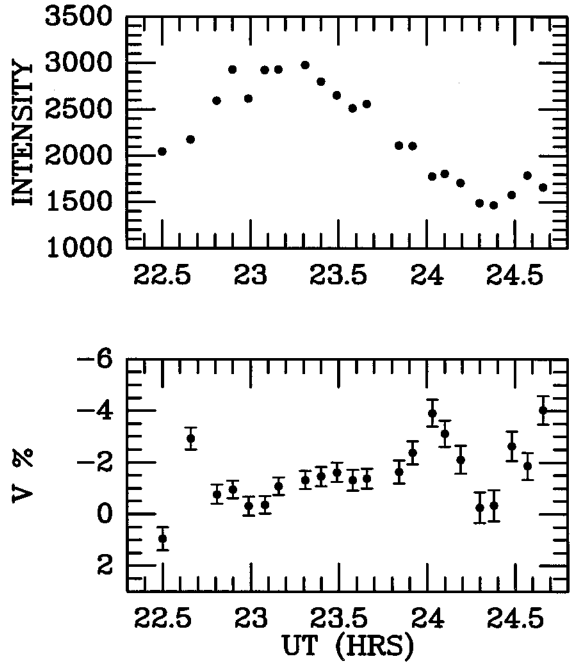

FIG. 5.—The intensity and circular polarization of the source on 1995 August 20–21 in a broad (~2000 Å) red spectral band centered at 6700 Å. Each dot corresponds to a 5 minute integration.

The spectra of this star have very similar properties to other AM Her systems (Mukai 1988), e.g., the extreme strength of He II λ4686, and narrow line components with broad, asymmetric wings in individual spectra (Fig. 2). The gray-scale stack of the spectra (Fig. 3) shows a sine wave modulation during the 140 minutes of observation, as well as a prominent narrow component. The radial velocities were determined from the wings of the emission lines of Hα, Hβ, and He II λ4686 by using a procedure described by Shafter, Szkody, & Thorstensen (1986), which convolves the line with a template consisting of a positive and negative Gaussian and determines the line center from the zero of the convolution. The errors introduced by low-velocity components can be minimized by setting the width of the Gaussians close to the instrumental resolution and adjusting the separation to measure the high-velocity line wings. The resulting best least-squares fit of the velocities to a sine curve was obtained with a width of the Gaussians of 3 Å and a separation of 28 Å for Hα and 14 Å for He II. The resulting parameters of the sine fit for four free parameters of γ, K, P, and T_0 are listed in Table 1, along with the 1 σ errors of the overall fit for each line. All periods are consistent with the photometric period of 113 minutes, although the length of the spectroscopic data is too short to provide a tight constraint on the orbital period. Figure 6 shows the radial velocity measurements for Hα with a sine wave superposed with the period fixed at 113.33 minutes (the fit is identical to that with the period as a free parameter). Mea-

TABLE 1

SINE FITS TO VELOCITY DATA

Line	γ (km s^{-1})	K (km s^{-1})	T_0 (minutes)	P (minutes)	σ (km s^{-1})
Hα...............	-36 ± 12	186 ± 17	253 ± 5	114 ± 5	40
Hβ...............	-24 ± 14	231 ± 20	261 ± 5	106 ± 4	47
He II λ4686	-38 ± 7	195 ± 10	262 ± 3	108 ± 3	23

surements of the narrow line components show a complex pattern of behavior, with more than one component visible at times and the second component offset in phase (but less than 0.5 phase from the broad wings). The equivalent width of Hα varies from 45 to 85 Å throughout the orbit.

4. X-RAY LIGHT CURVE AND SPECTRUM

WGA J1802 was observed with the *ROSAT* PSPC (Pfeffermann et al. 1987) as a serendipitous source, located about 50′ off-axis on 1993 September 11–12. The effective exposure time was 13.4 ks out of 100 ks real time. Because the source was positioned outside the main support ring of the PSPC, there is little loss of flux from the window support structure or the wire grid. The relatively large ratio of exposure time to real time, plus the position of the source on the PSPC, allows a search for periodicities in the X-ray data with few aliasing problems. The source counts were extracted using a circular aperture of radius 6.′9, while the background counts were extracted with a circular aperture of 10′ positioned approximately 30′ east of the position of WGA J1802 (to avoid PSPC window ribs). Using a periodogram analysis (specifically, Bayesian parameter estimation; Bretthorst 1990) and IRAF/PROS period folding, we find the presence of a period near 113 minutes. The light curve folded with the 113.5 minute photometric period is shown in Figure 7. Owing to large uncertainty in the period, the phases are relative and sensitive to the assumed period. The light curve in Figure 7 resembles the "normal" X-ray light curve of QQ Vul (Osborne et al. 1986), with the dips near phases 0.70 and 1.1 corresponding to similar dips at phases 0.35 and 0.70, respectively, in QQ Vul, suggesting a dominant, but complex, single pole accretor, although accretion at a second pole may also have some effect in systems of this type (Cropper 1990). The periodogram analysis also shows a strong peak at about 40 minutes which we believe is spurious. We attribute it to the sharp feature in the X-ray light curve near phase 0.70 and the lack of constraint provided by the light curve between dips resulting from gaps in the data.

We fit the X-ray spectrum of WGA J1802, adopting the soft blackbody and hard thermal bremsstrahlung components typical of polars (Cropper 1990). The 90% confidence limits on the spectral parameters are blackbody temperature, 20–45 eV; bremsstrahlung temperature, >1 keV; absorption column density, 1–2.5 × 10^{20} cm^{-2}. Figure 8 shows the fitted spectrum, assuming a bremsstrahlung component fixed at 10 keV. This combined model gives a χ^2_ν value of 1.13 for 72 degrees of freedom. The fit was insensitive to changes in the bremsstrahlung temperature above 1 keV, reflecting the lack of a hard response in the PSPC. The unabsorbed 0.1–2.0 keV flux is 9×10^{-11} ergs s^{-1} cm^{-2} for the blackbody component, and 1.5×10^{-12} ergs s^{-1} cm^{-2} for the bremsstrahlung component. The flux ratio of these two components is ~50–120, with the large uncertainty attributable to the sensitivity of the blackbody flux to the value of the column density.

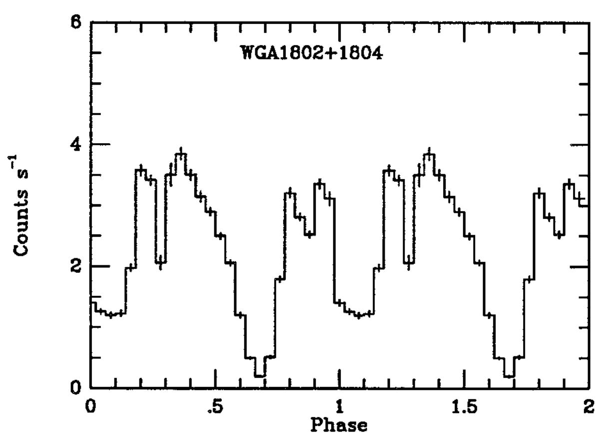

FIG. 7.—X-ray light curve folded at a period of 113.5 minutes.

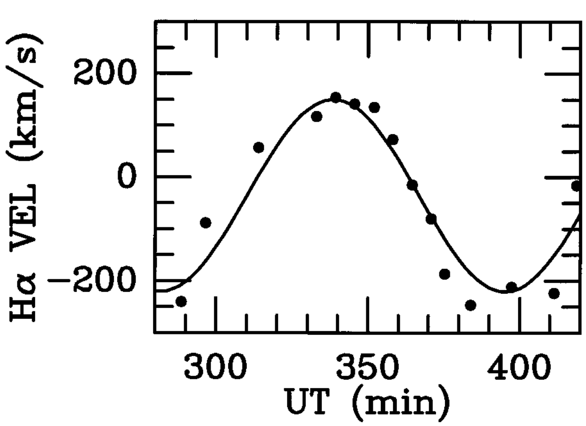

FIG. 6.—Radial velocities of the wings of Hα (using a Gaussian separation of 28 Å) together with the best-fit sine curve with the period fixed at 113 minutes.

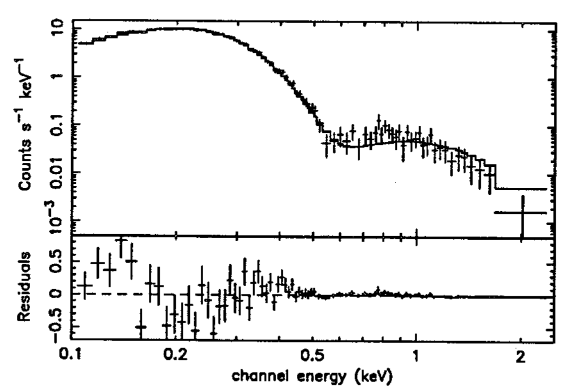

FIG. 8.—*ROSAT* PSPC X-ray spectrum of WGA 1802+1804 and the best-fit two-component (blackbody + 10 keV bremsstrahlung) model (*top*), and the residuals remaining after the fitting (*bottom*).

Ramsey et al. (1994) have recently analyzed the soft to hard ratio in 17 AM Her stars observed with *ROSAT* and concluded that the majority have a soft X-ray excess (defined as a value for the flux ratio of >0.55) and that the excess is correlated with the magnetic field strength. Since the ratio of J1802.1+1804 is so high, the implication is that the magnetic field strength should be large ($\sim$50 MG) and that much of the heating of the white dwarf must occur by blobs penetrating the white dwarf photosphere, rather than from the standard model of irradiation by the accretion column.

5. POLARIMETRY

A comparison of the broadband circular polarization in the red spectral region with the raw intensity (Fig. 5) shows that the polarization reaches a peak value of 4% in two peaks separated by a minimum, at the time of the lowest intensity in the light curve. This behavior is virtually identical (except for the lower polarization) to that seen in V834 Cen (Cropper 1989). The modulation is that theoretically expected from a dominant single pole that is extended in longitude and viewed at different angles during the orbital cycle.

The two circular polarization maxima occur when the field lines are viewed at small angles, while the dip in the center corresponds to viewing directions almost along the field lines, where the cyclotron intensity decreases to zero, and the observed polarization is reduced by dilution effects from other light sources. The predicted linear polarization spike should then occur about 0.5 phase later. The observed light curve (Fig. 5) shows a maximum at the phase of the predicted linear polarization pulse. This is in accordance with the outlined model geometry, as the cyclotron intensity is strongest in directions perpendicular to the field.

The estimated magnitude range of the light curve shown in Figure 5 is $14.0 \leq R \leq 14.8$, indicating that the source was in a high accretion state on 1995 August 20–21. The complications in an extended emission region may be responsible for the relatively low overall degree of the observed circular polarization.

6. CONCLUSIONS

Our observations of a 15th magnitude object at the location of the X-ray position of WGA J1802.1+1804 reveal a strong emission line source with He II stronger than Hβ, a radial velocity variation with an amplitude of 200 km s^{-1} in the Balmer and helium lines, a circular polarization of 4%, and a photometric modulation of 0.4 mag that matches the spectroscopic, polarimetric, and X-ray periods of 113 minutes. These characteristics, along with the two-component X-ray spectrum (20–45 eV blackbody and $>$1 keV bremsstrahlung), all reveal that this object is an AM Herculis–type magnetic CV. The polarization curve implies a magnetic geometry very similar to V834 Cen, while the large blackbody-to-bremsstrahlung ratio implies a strong magnetic field and a large amount of direct energy deposition by the accretion stream to heat the white dwarf. The dissimilarity of the optical light curve on two successive nights is, however, reminiscent of the behavior of slightly asynchronous systems such as BY Cam (Mason, Liebert, & Schmidt 1989). If this is the case, this would be the first closely synchronous system below the period gap. Longer polarimetric and spectroscopic coverage are needed to refine the period determinations to confirm synchronism.

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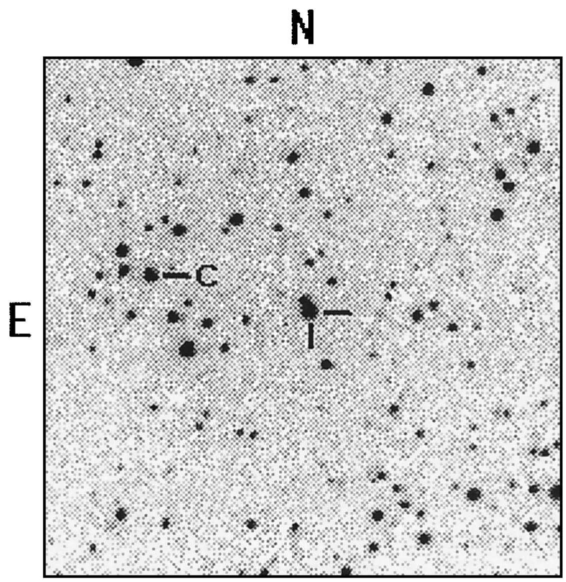

FIG. 1.—An unfiltered blue 20 s CCD frame for the optical identification of WGA J1802.1+1804 as well as the 15th magnitude comparison star used in the light curve. The size of the frame is $4' \times 4'$.

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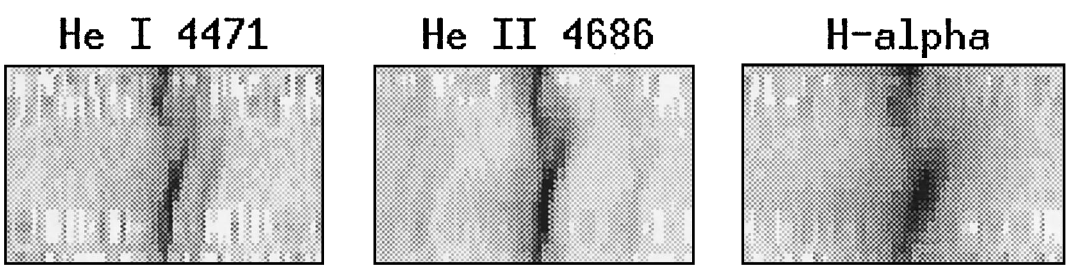

FIG. 3.—Stacked images of He I λ4471, He II λ4686, and Hα from the night of June 23. Time runs from top to bottom in each segment, and wavelength increases in the usual sense from left to right. The total time covered is ∼2.2 hr.

SZKODY et al. (see 455, L43)