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EUVE J1429−38.0: A NEW MAGNETIC CATACLYSMIC VARIABLE

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ABSTRACT

The source EUVE J1429−38.0 was discovered serendipitously by the *Extreme Ultraviolet Explorer* (*EUVE*) satellite on 1993 March 5. Optical spectroscopy confirms a cataclysmic variable–type optical counterpart for the source, showing Balmer, He I, and Ca emission, as well as strong He II emission. The optical spectrum, the apparent high/low state behavior, and possible weak cyclotron humps visible in the spectrum indicate that this star is likely to be an AM Herculis system, but the possibility of being a DQ Her, or an unlocked AM Her system, cannot be excluded. Analysis of the highly modulated *EUVE* photometry yields a period of 2 hr 22 minutes, which we conclude is the binary orbital period. In addition, a 57 minute period is also present. An orbital period of 2.5 hr would make EUVE J1429−38.0 only the third known AM Her system within the cataclysmic variable period gap, all three of which were discovered through EUV observations.

Subject headings: novae, cataclysmic variables — stars: individual (EUVE J1429−38.0)

1. INTRODUCTION

Cataclysmic variables (CVs) consist of a white dwarf (WD) primary and a lower main-sequence secondary that fills its Roche lobe and transfers matter toward the more massive primary. In the absence of an external force, this accreted material forms an accretion disk around the primary star. For CVs with orbital periods of 3–10 hr, the secondary star is a K to early-M star; for shorter period systems (2.5–1.2 hr), the secondary is a mid- to late-M star. There are four main types of CV: classical novae, nova-likes, dwarf novae, and magnetic CVs. Warner (1995) has written a detailed treatise covering the entire field of CVs.

Magnetic CVs are divided into two classes: the DQ Herculis stars and the AM Herculis stars. The division between these two classes of magnetic CVs appears to be caused by the strength of the intrinsic magnetic field of the WD primary. When the field strengths are from ∼10 to 80 MG (the AM Her stars), the mass accretion onto the primary occurs from a stream that is magnetically controlled over some length of its travel from the secondary. No accretion disk at all is thought to exist, and the material is funneled onto the WD near one or both of its magnetic poles. A strong shock occurs within the accretion column near the white dwarf surface, producing flux emission in the hard X-ray band and causing large-scale local heating that in turn produces EUV (soft X-ray) photons. Observations in the EUV band are therefore preeminent in their ability to discern the unobstructed accretion impact site.

The magnetic torques produced in the AM Her stars are sufficient to lock the WD spin with that of the binary orbit. As the accretion spot rotates in and out of view, observations of the high-energy emission can be used to determine the binary orbital period (Howell et al. 1995b). At times, these systems show so-called low states that occur when the mass transfer from the secondary drops significantly, resulting in lower overall accretion luminosity and flux output (3–5 mag less). During these low states, the overall high-energy flux can become very weak, and the secondary star can sometimes be seen in the optical bandpass. Consult Cropper (1990) for a detailed discussion of AM Her variables.

For the DQ Her stars with magnetic field strengths near 1–10 MG, the transferred material from the secondary begins to form an accretion disk, but this disk is disrupted at some point near the WD. The material is then accreted onto the WD, mostly near the magnetic poles. The weak magnetic field in DQ Her systems allows the WD to rotate with a spin period, usually much faster than the binary orbital period. Thus, a rotating searchlight effect occurs that can be observed in the output flux at many wavelengths as a pulsed emission. (See Warner 1995 for a review.)

In this Letter we report on a new cataclysmic variable discovered with the *Extreme Ultraviolet Explorer* (*EUVE*) satellite. We present EUV photometric observations as well as the first optical spectroscopy of EUVE J1429−38.0. Section 2 discusses the details of the observations, and § 3 presents a discussion of the results.

2. OBSERVATIONS

2.1. *EUV Photometry*

The source EUVE J1429−38.0 was discovered serendipitously during *EUVE* Right Angle Program (RAP; McDonald et al. 1994) observations. The RAP program uses the survey (imaging) scanners, oriented orthogonally to the Deep Survey telescope, at the same time that the Deep Survey instrument is being used by *EUVE* guest observers (GOs). As a result of the long exposures typical of GO spectrometer and Deep Survey observations, the RAP program is up to 20 times more sensitive than the *EUVE* all-sky survey. The source was observed for 70 hr starting 1993 March 4 and detected at a signal-to-noise ratio (S/N) of 12 in the *EUVE* Lexan/*B* band (58–174 Å or 0.071–0.214 keV). A second *EUVE* RAP observation of *EUVE* J1429−38.0 was obtained between 1995 March 22 and 1995 April 4.

We analyzed the *EUVE* imaging (photometric) data with the latest version of *EUVE*/IRAF software, which reflects

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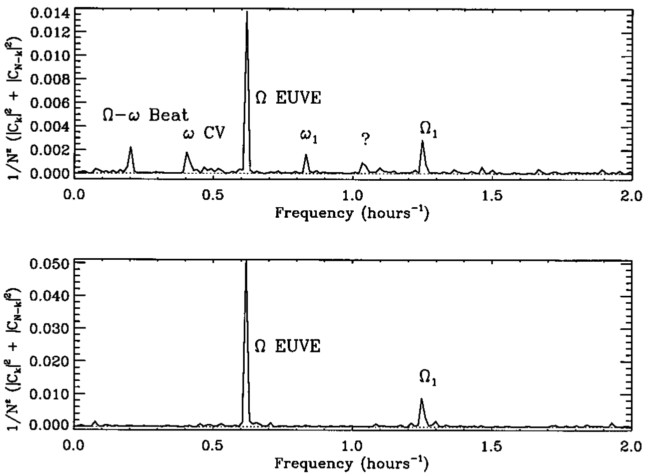

FIG. 1.—Power spectra of EUVE J1429−38.0. Upper panel shows the source aperture; lower panel shows the background annulus region centered on the source. The photon arrival times are divided into $N = 4096$ bins, each of width 69.7 s. The power is the modulus square of the FFT coefficients (C_k) adding negative and positive frequency pairs.

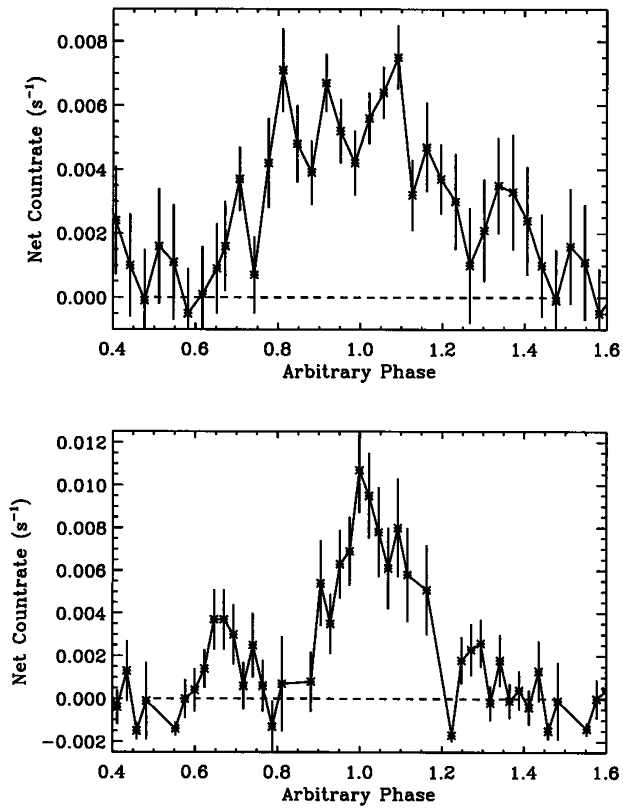

FIG. 2.—(*Top*) The EUV light curve of EUVE J1429−38.0 folded with a period of 3430 s (57 minutes) and binned by 120 s per point. (*Bottom*) The EUV light curve of EUVE J1429−38.0 folded with a period of 8520 s (142 minutes) and binned by 200 s per point.

the most up-to-date vignetting maps and instrument calibrations. In the photometric analysis we defined a region 1'.5 in diameter centered on the source with a background annulus having inner and outer radii of 2'.5 and 5'.5, respectively. The RAP observations yield a corrected count rate of 0.017 ± 0.004 counts s^{-1} for the first RAP detection and an upper limit, caused by a nondetection, of 0.002 counts s^{-1} for the second RAP observation. The large error of 0.004 counts s^{-1} in the first RAP pointing is due to the sharp gradient in the vignetting map near the filter supports. This systematic uncertainty is 4 times greater than the Poisson error in the observed counts. The fact that the source was not detected in the 3 week long second RAP observation indicates that the source is variable in the EUV spectral range.

In order to search for periodicity within the EUV photometry and attempt to determine an orbital period for EUVE J1429−38.0, we performed a Fourier analysis on the 1993 data set. Figure 1 shows the resultant power spectra.

We performed frequency analysis on both the photons within the source aperture and the photons within the background annulus. The background region shows two significant peaks corresponding to the *EUVE* orbital frequency of 0.633 hr^{-1} (period = 94.78 minutes) and its first harmonic (denoted Ω, and Ω_1, respectively). The source region, however, shows four additional peaks.

The spike, denoted ω in Figure 1, at 0.42 hr^{-1} (period = 142 minutes) is the most likely candidate for the orbital period (see § 3). Both its first harmonic (ω_1) and its beat frequency with *EUVE* ($\Omega - \omega$) are clearly seen. The final spike considered at 1.05 hr^{-1} (period = 57 minutes), which has a signal twice that of mean noise of 0.0005, is neither a harmonic nor a beat frequency of any of the other peaks. If this period is the orbital period, then at 57 minutes it would be the shortest period of any known AM Her system (EF Eri presently has the shortest known period: 81 minutes) and below the minimum allowed orbital period for a CV containing a normal main-sequence secondary. If the binary period is not synchronized with the WD spin rate (as in a DQ Her or in an unlocked AM Her system), the 57 minute spike could be attributed to the WD rotation period. Folding the data on a 57 minute period produces a light curve (Fig. 2*a*) that does not preclude the star from being a DQ Her system. Folding the data from the background region on either of these two periods produces a null result (i.e., a flat light curve). We consider the DQ Her classification less likely because of the reasons stated in § 3, but we cannot rule it out completely because of the possibility of the 57 minute period our source data set indicates.

Assuming the determined period of 142 minutes to be the binary orbital period, we construct a phase-folded EUV light curve, shown in Figure 2*b*. The data have a bin width of 200 s, which was used to increase the S/N for the light curve. Since the source was partially imaged on the filter support frame, the background region shows a gradient. Hence, the background subtraction (used to set the zero level in Fig. 2) may introduce a systematic error in the true-zero count-rate baseline of an order of 0.001 s^{-1}.

The phase-folded EUV light curve shows the typical modulation seen in an AM Her star for a single pole accretion region that rotates behind the white dwarf limb for some portion (usually near 50%) of the orbital period (Sirk & Howell 1995). Given the uncertainty in the background subtraction in Figure 2*b*, the observed EUV flux is consistent with zero for ~20%–50% of the orbital phase.

2.2. *Optical Spectroscopy*

As a follow-up to the program of optical identification of previously unidentified *EUVE* all-sky survey sources (Craig et al. 1995), we obtained spectroscopy in 1995 May 19–22 with the 1.5 m telescope at the Cerro Tololo Inter-American

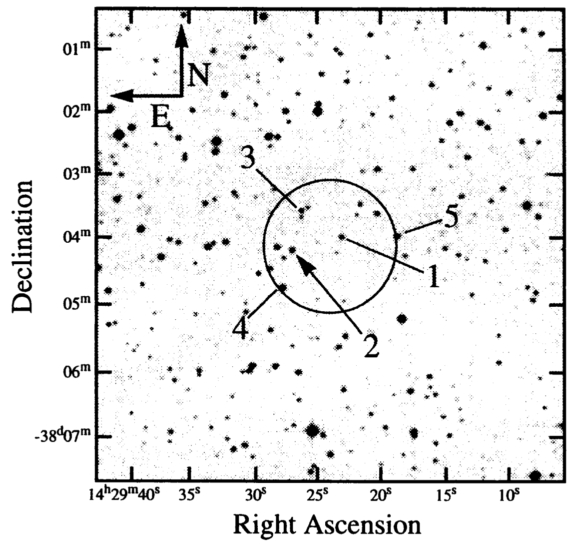

FIG. 3.—STScI finding chart centered on the source EUVE J1429−38.0. The region is 7′ × 7′ with the 1′ radius *EUVE* error circle indicated.

Observatory (CTIO). Spectra were obtained for all candidate counterparts in the field of the previously unidentified source EUVE J1429−038 (*EUVE* source position: $\alpha = 14^h29^m24^s.0$, $\delta = -38°04'5''.2$; Craig 1995) on 1995 May 21 (UT 04:02:45). The Cassegrain spectrograph and CCD detector GEC 10 were used with a 300 line mm^{-1} grating and a 4''.5 entrance slit. This setup gave a spectral resolution of 8.4 Å and covered the wavelength region of 3750–6150 Å.

We reduced the CTIO data using standard IRAF software from the National Optical Astronomy Observatories (NOAO; Tody 1986). The spectra were trimmed, and the bias level was subtracted. We removed pixel-to-pixel gain variations by applying flat-field correction using an internal quartz lamp and extracted one-dimensional spectra. For wavelength calibration, we used He-Ar lamp spectra; the resulting rms wavelength errors were ∼0.1 Å. The standard star LT 7379 was used for flux calibration.

Figure 3 shows the 7′ × 7′ finding chart, supplied by the Space Telescope Institute centered on the *EUVE* source coordinates. The candidate optical counterparts listed in Table 1 are identified, and all positions are given in J2000 coordinates. The 1′ radius positional error circle of *EUVE* for the Lexan sources is shown on the chart. The proposed optical counterpart of EUVE J1429−38.0 is candidate No. 2, which has a position of $14^h29^m27^s.$, $-38°04'10''$ (J2000). The optical position lies 37″ east of the reported *EUVE* source location, well within the source error circle. (The vignetting caused by the *EUVE* scanner-filter support introduces a systematic westward shift in the measured position of about one-third to one-half the expected scanner point-spread function, which corresponds to 30″–50″. Removing this effect places the *EUVE* source within 20″ of candidate No. 2.) We derived spectral types for our observed candidates by comparing the observed spectra with the spectral atlas of Jacoby, Hunter, & Christian (1984) and determined them to within three subclasses. We calculated visual magnitudes to an accuracy of 0.5 mag using bandpass spectrophotometry (the sbands task of IRAF using Johnson's *V*-band response function). Table 1 lists these results as well as the distances of the observed optical counterparts from the original *EUVE* source position.

TABLE 1

OBSERVED OPTICAL COUNTERPARTS OF EUVE J1429−38.0

Candidate	Spectral Classification	m_v	Separation
1	G4 V	16.9	11″ NW
2	CV	16.5	37″ E
3	K5 V	18.1	40″ NE
4	G7 V	15.7	62″ SE
5	G3 V	16.6	72″ NW

The wavelength- and flux-calibrated optical spectrum obtained (Fig. 4) clearly shows the characteristics of a cataclysmic variable. The spectrum contains the typical Balmer emission lines, emission lines of He I and Ca II, strong He II emission, and a rising blue continuum. Note that He II 4686 Å is stronger than Hβ. Table 2 lists measured equivalent widths and line fluxes.

3. DISCUSSION

The source EUVE J1429−38.0 was undetected in the *EUVE* all-sky survey (Bowyer et al. 1995) and in the second RAP

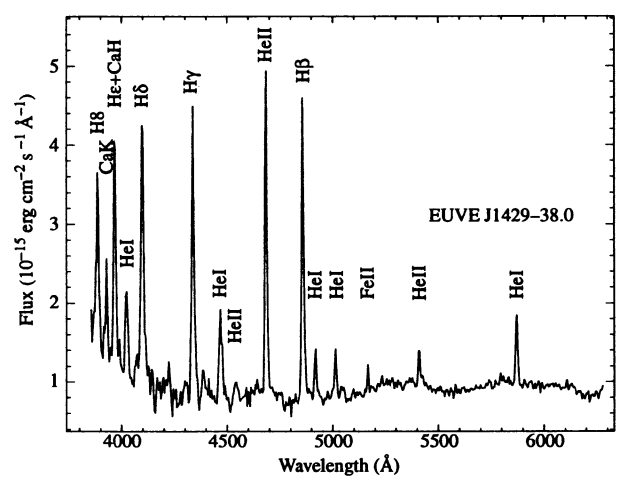

FIG. 4.—Discovery spectrum of EUVE J1429−38.0, observed on 1995 May 20–21. Note the increasing blue continuum, the typical plethora of emission lines, and the very strong high-excitation He II 4686 Å line.

TABLE 2

LINE FLUX AND EQUIVALENT WIDTH MEASUREMENTS

Spectral Line	λ (Å)	EW (Å)	Flux (10^{-15} ergs cm^2 s^{-1} Å^{-1})
H8	3886	22.50	7.10
CaK.............	3933	10.06	1.35
Hε + CaH......	3970	31.33	40.70
He I.............	4026	15.60	17.10
Hδ	4102	47.04	55.53
Hγ	4340	51.91	51.55
He I.............	4471	24.00	19.61
He II	4686	61.41	47.03
Hβ..............	4861	54.71	44.72
He I.............	4922	8.64	7.15
He I.............	5016	6.01	7.88
Fe II............	5170	2.53	2.98
He II	5412	5.54	5.23
He I.............	5876	12.16	11.21

observation of 1995. This nondetection is not completely unexpected if the system is an AM Her star and was in a low state during those observations. Scaling of the (nonsimultaneous) EUV count rate to the discovery optical magnitude suggests that this source is not a strong EUV emitter. This weakness of EUV emission, for the assumed visual magnitude, can be explained if the WD in EUVE J1429−38.0 has a magnetic field strength below ~35 MG, as weak-field AM Her stars are usually strong hard–X-ray emitters and weak EUV sources (Beuermann & Schwope 1994; Howell, Herzog, & Mason 1995a).

For a one-pole emitting AM Her star, high-energy photometric data typically show a hump lasting for ~50% of the binary orbit and essentially zero flux for the remaining part. This phenomenon is explained by the accretion spot being visible to the observer for about half of the binary orbit. The EUV light curve shown in Figure 2*b* looks similar to other EUV data for systems such as RE 1149+28 (Howell et al. 1995b) and VV Pup (cf. Vennes et al. 1995). In fact, if the first bump in Figure 2*b* (phase 0.6–0.75) is real, the light curve of EUVE J1429−38.0 shows a remarkable similarity (minus the eclipse) to that of UZ For (Warren et al. 1995).

An orbital period of 142 minutes would place this new magnetic system within the CV period gap. About 75% of all known AM Her stars have periods below the 2.5–3 hr CV period gap, with UZ For having the longest of these periods ($P_{\rm orb}$ = 126 minutes). Recently, Buckley et al. (1993) discovered the first AM Her within the CV period gap, RE 1938−461. The source RE 0531−462 was the second discovered (Mason et al. 1995). Buckley et al. argue that RE 1938−461 must have been born within the gap as opposed to evolving through it. The same arguments apply to EUVE J1429−38.0, and the reader is referred to Buckley et al. for details. Notably, if this system is indeed an AM Her star, it is only the third known with an orbital period in the gap, all three discovered by EUV observations.

Figure 4 shows an optical spectrum with two additional pieces of evidence we will explore. The first of these is the rising blue continuum indicating a hot source (i.e., the WD and accretion region) and, more important, high-excitation lines of He II. He II (4686 Å) is very strong here and requires a hot component for excitation. This line is stronger than Hβ in a few other magnetic systems and in GK Per during outburst. The likely source of the ionizing photons is the hot, hard X-ray–emitting accretion region, typical in AM Her stars.

The second piece of evidence in the optical spectrum is the presence of what appear to be weak cyclotron humps. These weak features appear at the red end of the spectrum with peaks near 5300 and 5700 Å. If these features are indeed cyclotron humps, a very approximate magnetic field strength of 20–25 MG can be estimated for this source (Ferrario & Wickramasinghe 1990).

4. SUMMARY

We have shown that the source EUVE J1429−38.0 shows EUV variability and photometric light-curve properties consistent with other well-studied AM Her systems. In addition, the optical spectrum has all the characteristics of a highly magnetic cataclysmic variable. The large EUV variability (apparent high/low state behavior) between the RAP pointings, the significant portion of the EUV light curve that shows zero flux, and the possible cyclotron humps in the optical spectrum argue against a DQ Her system. However, the possibility of the 57 minute period should not be ignored and is consistent with an origin cause by a nonsynchronously rotating white dwarf. Thus, we conclude that EUVE J1429−38.0 is a newly discovered magnetic cataclysmic variable with a likely orbital period of 142 minutes. The detection of cyclotron radiation (with optical polarimetry) and phase-resolved optical spectroscopy is needed to establish this star unequivocally as an AM Her system and remove any ambiguity as to its periods.

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