OBSERVING REQUEST
University of Arizona Observatories

Year: 2015 **Term:** Jan–Jul **Proposal type:** short-term

High Signal-to-Noise Circular Polarimetry of Magnetic CVs: Testing and Development of Cyclotron Emission Models

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CoI(s): Paul Smith (SO), Varol Keskin (Ege University)

Abstract of Scientific Justification

Magnetic cataclysmic variables (mCVs) are mass transferring binary systems. A magnetic white dwarf (WD, as primary) and a red dwarf with a filled Roche-Lobe (as secondary) forms a typical mCV. The transferred mass from the secondary star follows a helical orbit around magnetic field lines of the WD and moves towards to magnetic pole caps and finally falls onto the surface of the WD. Transferred mass (i.e. charged particles) emit cyclotron radiation during their helical motion, which polarizes the observed continuum from the system. By observing polarized light, one can extract information on magnetic field strength of the WD and investigate the effects of the field on the binary system. In this study, a sample of mCVs with a large range in magnetic field strength will be observed with the SPOL Spectropolarimeter at the 90″ Bok Telescope and 61″ Kuiper Telescope. The target systems are all variously identified (X-ray emission, optical emission-line spectra, etc.) as mCVs, but have not been observed for circular polarization. We will obtain full orbital phase coverage circular polarization spectropolarimetry of the sample to investigate the dependence of polarization on orbital phase. Furthermore, the observed polarization signal for each target will be determined and modeled following Tutar (Özdarcan) & Pekünlü (2013).

Summary of observing runs requested for this project

Run	Telescope	Cage	Instrument	PI	AO	Nights	Moon	Scheduling Optimal	Scheduling Acceptable	Sharing Poss.	Sharing Adv.
1	90” or 61”	f/9	SPOL	*		1	grey	Jan	Jan-Feb	yes	no
2	90” or 61”	f/9	SPOL	*		1	grey	Feb	Jan-Feb	yes	no
3	90” or 61”	f/9	SPOL	*		1	grey	Mar	Mar-Apr	yes	no
4	90” or 61”	f/9	SPOL	*		1	grey	Apr	Mar-Apr	yes	no
5	90” or 61”	f/9	SPOL	*		1	grey	May	Apr-May	yes	no
6	90” or 61”	f/9	SPOL	*		1	grey	Jun	May-Jun	yes	no
7	90” or 61”	f/9	SPOL	*		1	grey	Jul	Jun-Jul	yes	no

Scheduling constraints and unusable dates *(up to 4 lines)*: **Either 90″ or 61″ telescopes can be used for any given observing run**, but the 90″ is preferred to allow better time resolution during the orbital period of the target CVs. It is highly desirable to schedule this program along with other SPOL programs to minimize instrument changes. Observations will be made 1 night per month at the telescope used for other SPOL programs.

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A ⋆ appended to the proposal type indicates a continuation proposal; a ⋆ appended to the name of a proposer indicates the proposer is a (graduate) student; a proposer whose name is underlined is certified on the proposed telescope/instrument combination; if a ∗ appears within the PI or AO box in the observations summary table, the instrument is a PI instrument and/or Adaptive Optics are requested – signatures are required on the next page.

Target list (attach list if longer than 26 objects)

#	Object	RA	Dec	mag / color / type / redshift / comment / etc.
1	MR Ser	15:52:47.20	+18:56:28.9	AM Her; V=15.0
2	V1007 Her	17:24:06.32	+41:14:10.1	AM Her; V=17.0
3	UZ For	03:35:28.64	−25:44:21.8	AM Her; V=18.0
4	EU UMa	11:49:55.72	+28:45:07.2	Polar; B=16.5
5	BY Cam	05:42:28.77	+60:51:31.5	Polar; B=16.6
6	GG Leo	10:15:34.67	+09:04:41.8	Polar; V=15.8
7	WX LMi	10:26:27.52	+38:45:04.2	AM Her; V=18.0
8	V1223 Sgr	18:55:02.31	−31:09:49.6	DQ Her; B=13.0
9	IGR J18173	18:17:22.30	−25:08:43.0	DQ Her; V=16.9
10	IGR J16547	16:54:43.76	−19:16:30.82	Intermediate Polar?; B=15.0
11	1RXS J052430	05:24:30.52	+42:44:50.4	Intermediate Polar?; B=17.7
12	EI UMa	08:38:21.99	+48:38:02.1	Dwarf Nova; V=14.7
13	V1062 Tau	05:02:27.48	+24:45:23.2	Nova; B=17.0
14	FS Aur	05:47:48.34	+28:35:11.1	Dwarf Nova; B=14.4
15	V2301 Oph	18:00:35.53	+08:10:13.9	Nova like; V=16.0
16	1RXS J062518	06:25:16.23	+73:34:39.1	X-ray binary; B=14.0
17	YY Dra	11:43:38.51	+71:41:19.2	Intermediate Polar?; B=12.0
18	Swift J0732	07:32:37.64	−13:31:09.4	X-ray binary; V=15.7

Approval for Instrument Use from PI: ______________________

(have instrument PI signature appear on, or attach PI e-mail to, ***all*** *copies)*

Graduate students *(provide the following information for* ***each*** *student named as PI or CoI on the cover page. Have the advisor's signature(s) appear on* ***all*** *submitted copies)*

Student's Name	Advisor's Name	Advisor's Signature	2nd-yr	Thesis
Demet Tutar Özdarcan	Paul Smith		no	yes

Scientific Justification

Magnetic cataclysmic variables (mCVs) have very high magnetic field strength (1–100 MG). These systems are close binary systems, with orbital periods of around three hours. In these systems, the primary star is a white dwarf, while the secondary is a late-type main sequence star. Given the strength of the magnetic field in mCVs, a considerable amount of non-thermal emission is produced in addition to the contribution made by thermal processes to the observed spectrum (Cropper 1990).

Magnetic CVs, of course, are also mass transferring systems. Mass transfer occurs from secondary star to primary star at inner Lagrange point (L1). When the transferred material (i.e., charged particles) accretes onto the white dwarf, it moves in a circular orbit around the magnetic field lines. The charged particles produce cyclotron radiation while accreting onto the primary. This radiation can be seen in both the optical flux and circularly polarized spectrum. Polarization detected in the optical spectrum unambiguously identifies the presence of cyclotron radiation. In turn, the magnetic field strength can be determined from the observed polarization spectrum (Cropper et al.1990a).

In this study, a sample of mCVs will be observed with the SPOL Spectropolarimeter. In Cropper et al. (1990b) circular polarization of mCVs detected cyclotron "humps," indicating separate cyclotron harmonic frequencies. In the scope of this study, optical circular polarization measurements will also be used to identify and model cyclotron emission over a large range of expected field strengths.

As the stars orbit one another, the strength of the cyclotron humps in the spectrum will be observed to vary in flux, since the observed strength of the humps depend on the angle between magnetic field axis and the observer's line of sight, as well as field strength, electron number density, and the kinetic temperature of the radiating column. If the angle is 90°, the magnetic field axis is perpendicular to observer's line of sight, hence, we see the maximum contribution of the cyclotron radiation and the maximum polarization percentage. The amount of the cyclotron radiation is given as energy per unit solid angle per frequency (Eq. 1).

$$\frac{d^2W(\omega)}{d\Omega d\omega} = \frac{c}{4\pi^2} \left| \times \left\{ \begin{array}{c} 2\pi \sum gcis(-\omega\delta t) \\ f\left[cos(0.1\alpha) - cos(0.4\alpha)\right] - \\ \frac{U}{R}\left(cos\left(\frac{\alpha}{\sqrt{6}}\right) - cos\left(0.003\frac{\alpha}{\sqrt{3}}\right)\right) \end{array} \right\} \right|^2 \tag{1}$$

where $\sum = \sum_{l=1}^{10} J_l\left(\frac{\omega}{\omega_{ce}}\beta_{\perp} sin\theta\right)\delta[(l\omega_{ce} - \omega(1-\beta_{\parallel}cos\theta)]$; θ is the viewing angle; $\alpha = R\omega_{ce}/V_{\perp}$; $f = -\omega - (\frac{1}{i\delta t}) + (-\frac{\omega_{ce}}{\gamma})$; $cis(-\omega\delta t) = cos(\omega\delta t) - isin(\omega\delta t)$; $R = r - r'$ is the distance between particles and observer; U is the streaming velocity of the electrons in the accretion column; $\delta t = t - t' = L/c$, L is the thickness of a single radiation source; $g = (4\pi^2 ec^2\omega_{ce}/3V_{\perp}^2\omega_{pe}^2 L)$ and $\omega_{ce} = |e|B_0/m_e c$ is the electron cyclotron frequency; m_e is the mass of an electron; e is the elementary charge, ω is the frequency, $\omega_{pe} = \left(4\pi n_e^2/m_e\right)^{1/2}$ is the electron plasma frequency, $V_{\perp}$ is the perpendicular (to the local magnetic field) temperature of electrons, J_l is the Bessel Function, γ is the Lorentz factor, $\beta_{\perp}$ and $\beta_{\parallel}$ comes from time derivative of velocity normalized to the speed of light and c is speed of light.

The aim of this study is to compare the observed cyclotron spectra and theoretical pure cyclotron spectra of mCVs. The model that will be used is from Tutar (Özdarcan) & Pekünlü (2013). An earlier variant of the model assumed a Maxwellian velocity distribution for the electrons (Kalomeni et al. 2005). Schwope et al.(1990) have argued that more realistic models have to assume a non-Maxwellian velocity distribution. In response, Tutar & Pekünlü (2013) developed a model assuming that the velocity distribution is bi-Maxwellian. In addition, the model assumes that the magnetic white dwarfs in mCVs have dipole magnetic field geometry.

An outstanding question for the pure cyclotron model of Tutar & Pekünlü (2013) is its applicability over the subtypes of mCVs already identified. The model assumes that cyclotron harmonics are produced by electrons having a streaming bi-Maxwellian velocity profile in the lower portions of the accretion column near the magnetic poles of the white dwarf. Cyclotron radiation is produced at the Ordinary and Extraordinary wave modes. Tutar & Pekünlü (2013) solve the Green function for the Extraordinary wave mode and derive the pure cyclotron spectra. This function enables one to calculate the energy radiated per unit wavelength per unit solid angle as a function of wavelength and the initial results correspond closely to the observed values for some members of the “Intermediate Polar” subclass of mCVs. The model’s dependence on parameters is seen in Equation (1).

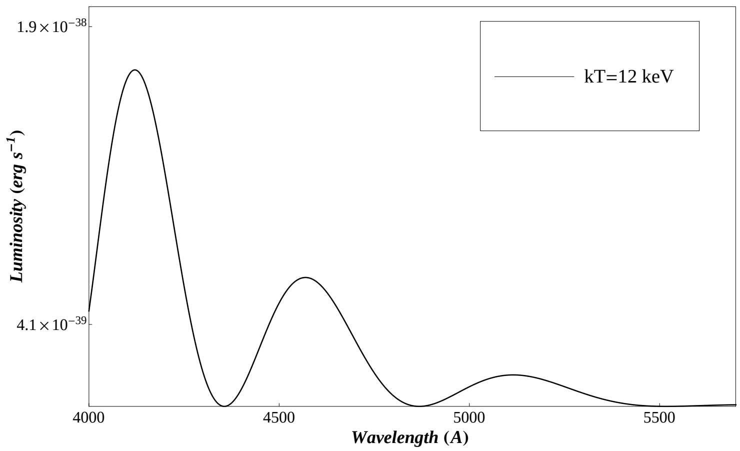

Figure 1: Modeled pure cyclotron spectrum of an IP which has a magnetic field strength of 38 MG (Tutar & Pekünlü 2013).

Some targets in our selected sample are a type of a mCVs known as Polars. Polars are known to have magnetic field strengths at the top of the observed range for mCVs ($\sim$10–100 MG; Butters et al.1990). Thus, these systems are good targets to study polarization with moderate resolution optical spectropolarimetry. The other targets are classified as Intermediate Polars (IPs), which are mCVs that generally have less magnetic field strength than Polars. Their magnetic field strengths are about 1–20 MG (Butters et al.1990), also making them good targets for spectropolarimetric study. The key in the study of IPs is to actually detect the weak polarization expected. Sensitive polarimetry that can be provided by SPOL will be necessary for this portion of the experiment. However, the Tutar & Pekünlü (2013) model was successfully applied to the IP V405 Aur from the broad-band polarimetry of the object published in Piirola et al. (2008).

Wickramasinghe et al. (1991) note that the spread of the magnetic field (i.e., the distribution of opposite polarities) could actually lead to larger values of circular polarization in IPs than expected. Despite this possibility, obtaining high signal-to-noise ratio data will be important to detect weak polarization signals in mCVs with lower field strengths. Since none of the targets in the sample have previously published optical spectropolarimetric observations, this study becomes important in terms of obtaining the observational data and clarifying their nature, testing the model of Tutar & Pekünlü (2013), and finally by investigating the effects of the magnetic field on the evolution of these binary systems.

References

Butters, O.W., et al. 2009, A&A, 496, 891
Cropper, M. 1990, Space Science Reviews, 54, 195
Cropper, M., et al. 1990b, MNRAS, 245, 760
Cropper, M., et al. 1990a, MNRAS, 244, 34
Kalomeni,B., et al. 2005, A&A, 439, 823
Piirola, V., et al. 2008, ApJ, 684, 558
Schwope, A. D., et al. 1990, A&A, 230, 120
Tutar, D., Pekünlü, E.R. 2013, New Astronomy, 19, 42
Wickramasinghe, D. T., et al. 1991, MNRAS, 249, 469

Experimental Design & Technical Description *Describe your overall observational program. How will these observations contribute toward the accomplishment of the goals outlined in the science justification? If you've requested long-term status, justify why this is necessary for successful completion of the science.* ***(up to one page)***

Each magnetic CV, or suspected magnetic system, will be observed over its entire orbital period (some 2–3 hr). For the brightest systems in the sample, SPOL can provide full resolution, high signal-to-noise (S/N) ratio circularly polarized spectra in 5 minutes or less. This will allow >30 measurements over the period of an orbit. The observing cadence will need to be slower for the fainter objects in the sample, but the aim is have to at least 10 polarization measurements during a single orbit. Since the cyclotron features form a broad continuum (see Fig. 1), binning in wavelength can by used to reach reasonable S/N ratios to detect circular polarization at low levels ($\lesssim$1%) for even the faintest targets in the system. Of course, the faintest systems will await opportunities to observe them at the 2.3 m Bok Telescope.

The observational portion of this project is limited to this single semester due to the length of Ms. Tutar Özdarcan's stay as dictated by her funding. Seven full nights spread over six months, along with the fact that the observations will be intermixed with other successful observing proposals that use SPOL on the Bok and Kuiper telescopes should ensure that enough systems are observed in detail to provide a solid basis for the modeling and interpretation portions of the PhD thesis.

Summary of Time Requested and Awarded *The TAC needs to understand the scope of this project — (1) tell us how many UAO nights you've already had for this project, how many you request this time, and (a good guess of) how many you need to complete the project; (2) if a substantial amount of observing for this project comes from non-UAO telescopes, tell us about that observing, and how the UAO part fits in; (3) if you are collaborating with people who have telescopes, especially if you are part of a large collaboration, tell us who is leading the project, and how UAO time and your participation fit in. (**up to one page**)*

One grey night is requested per month on either the Bok or Kuiper telescopes to survey a broad range of magnetic fields in magnetic Cataclysmic Variables. Given the 2–3-hr orbital periods of accreting binary systems, seven total nights will be adequate to obtain full orbital coverage of 20 systems with a temporal resolution of $\sim$10–40 circular spectropolarimetric measurements per orbit, depending on the brightness of the system. This will provide a sufficient range of magnetic field strengths for a sensitive test of the cyclotron-emission model over the various types of mass-transfer systems where the magnetic field plays a significant role in the behavior of the accretion flow.

Although there are observing facilities available to Tutar Özdarcan in Turkey, there are no polarimeters and, therefore, no way to pursue this research topic at her home institution. The only unambiguous technique to identify cyclotron emission in CVs is through circular polarimetry.

Previous Use of Steward Facilities *List **all** allocations of telescope time for the present project and allocations for other projects on facilities available through UAO during the past 2 years, together with the current status of the data (cite publications where appropriate). Mark those allocations related to the present proposal (i.e, precede text with* `\related` *command). (**up to one page**)*

Demet Tutar Özdarcan is a PhD candidate of Ege University, Izmir, Turkey. She is visiting Steward Observatory for 1 year (starting 2014 September) and is funded through a grant from the Turkish government's science agency TUBITAK. She has not used Steward Observatory facilities in the past.

Smith has used Steward Observatory facilities extensively. Please see the proposal for which he is the Principal Investigator (L57) for details on his use of the facilities over the past few years.