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Variations in the polarization profile and active states indications of accreting binary stars

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We investigate the emission properties of two accreting binary stars during the active state periods. Our study is based on the polarization methods. The polarization degree is computed according to the light curves and energy spectrum in the time of brighten-up events in those two stars. The results indicate that the polarization parameters show variations in their values during the flares activity and it mainly depends on radiation properties.

Keywords: Accretion, accretion disks; methods: polarization; (stars): binaries: close

1 Introduction

Accreting binary stars are dynamically active systems. Because of the high energetic processes there, they are easily detectable. This merit is sufficient to choose those types of astrophysical objects for an investigation of the flow's physical properties there. Emission processes from astrophysical objects are usually associated with the brighten-up phenomena, which include, for example, bursts, flickerings, flares or jets (from protoplanets to active galactic nuclei), or the scattering of radiation in highly aspherical distributions of matter.

In this survey we investigate the polarization features of two binary stars in the periods of flares and bursts activity. The flares appear ordinarily in systems with accretion discs in time scales of hours to days, with amplitudes in a range of 1–3 magnitudes. On the other hand, van Paradijs et al. (1989) performed five-colour observation and demonstrated that the flares occur throughout the whole orbital period with the rise time ∼100–200 s. They also found that the light curve of the CV star AE Aqr exhibits large flares on timescales of about 10 minutes. Bruch and Grutter (1997) found that the strong flares could be also phase dependent.

In accordance with Churazov et al. (2002), a repeated variability in the brightness could affect the degree of polarization. They proposed X-ray polarization as

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a mechanism to probe the flarings and the resulting, reprocessed X-ray should be polarized.

Very little polarization in nearby stars was found by Piirola (1977), Tinbergen (1982) and Leroy (1993a,b, 1999). Leroy (1993b) found only 25 of 1000 stars with definite polarization within nearby stars (about 50 pc). Further analysis showed that most of these polarized stars are at longer distances. Bailey et al. (2010) has observed the linear polarization of a sample of 49 nearby bright stars. The measured polarization degree for about 75 percent of the stars is less than 2×10^{-5}. As an example, the polarization level of BS 7001 (Vega) has a value of $\sim 17 \times 10^{-6}$ and it is most likely the result of scattering in its dust disc. Correlations of the polarization with distance and position indicate that most of the polarization is of interstellar origin. The polarization could appear as patterns, as it depends mainly on the properties of radiation and geometry of the source. We apply the observational data of V592 Cas (Cassiopeia) and Gamma Cas (γ Cas). We create light curves of the two studied binaries by using observational data from AAVSO (American Association of Variable Star Observers) and Swift data center and generator, as well as for their energy spectrum production. The polarization data are taken from PolarBase (A DataBase of high resolution spectro-polarimetric stellar observations) (Petit et al. 2014).

2 Models and equations

To make a clearer view, we suggest a schematic algorithm of the processes. The flare-ups activity in the selected binary is in relation with variations in the flow density level. The transformed flux structure gives rise to polarization variations in the optical and near-infrared bands, and the polarization degree could change its values, according to the whole system conditions. By the initial conditions the variable polarizations states could be the result of synchrotron radiation from the forming bursts. Then an elliptical or circular polarization is established there. In the high-energy processes the stronger emission intensity is observed. The measurement of this intensity is associated with the calculation of Stokes parameters. In the next step we can define the degree of polarization.

In the mean of polarization parameters in this study, we apply the well known four Stokes parameters. We use the notations: S_0, S_1, S_2, S_3 or I, Q, U, V (Churazov 2002, Marin 2014, Molinar 2011) and they are defined in the next basic equations, obtained in the current form by Stokes (1852), Berry et al. (1977), Trippe (2014) (Eqs. 1–4):

$$I = S_0 = I(0^\circ) + I(90^\circ) = \langle |E_x|^2 \rangle + \langle |E_y|^2 \rangle, \tag{1}$$

$$Q = S_1 = I(0^\circ) - I(90^\circ) = \langle |E_x|^2 \rangle - \langle |E_y|^2 \rangle, \tag{2}$$

$$U = S_2 = I(45^\circ) - I(135^\circ) = 2\langle E_x E_y cos\delta \rangle, \tag{3}$$

$$V = S_3 = I_{RHC} - I_{LHC} = 2\langle E_x E_y sin\delta \rangle. \tag{4}$$

For measurement of Stokes parameters a Cartesian coordinate system (x, y, z) is used, where x and y are perpendicular to the direction of light propagation z. E_x and E_y are the complex amplitude of the electric field components in the x and y directions, and $I(\varphi)$ is the intensity of light polarized in the direction φ to the x axis. The parameter $\delta = \phi_2 - \phi_1$ is the difference between two arbitrary phases ϕ_1 and ϕ_2. Each of the Stokes parameters, by their construction, corresponds to a type of the polarization it defines: I, the total intensity; Q, the difference in the intensities in x and y, and gives information on linear polarization; U, the difference between the two field components at angles of 45° and 135° counted from the positive x axis to the x and y coordinates, probing linear polarization again; V, corresponds to the intensity of circular polarization and represents left-handed or right-handed polarization. The relative Stokes parameters completely determine the polarization state by the three ratios $S_1/S_0, S_2/S_0, S_3/S_0$. Taking into account these simple relations and the results in Trippe (2014) and Bohren & Hufman (1983), we can express the degree of different types of polarization in the next equations (Eqs. 5–7) as follows:

The degree of polarization P, in terms of all Stokes parameters, is given by:

$$P = \sqrt{(S_1^2 + S_2^2 + S_3^2)}/S_0. \tag{5}$$

The degree of linear polarization P_L is:

$$P_L = \sqrt{(S_1^2 + S_2^2)}/S_0. \tag{6}$$

The degree of circular polarization P_C is related to V Stokes parameter:

$$P_C = \frac{S_3}{S_0}, \tag{7}$$

where P_C is positive for right-handed circular polarization and negative for left-handed circular polarization.

On the estimation of polarization profile of the flares emission, we also apply the idea of Goosman and Gaskell (2007), and Marin et al. (2014), implemented in their code. The code is based on the Monte Carlo method for the purpose of polarization modeling, produced by absorption, re-emission and scattering in many astrophysical situations. They have studied the relation between spectral flux, polarization in percentage and the polarization position angle and the photon energy.

3 Results of flare-ups activity indications and polarization state profiles

In this Section we present the behavior of two binary stars, according to their light curves, energy spectrum and polarization conditions. The CV (Cataclysmic Variable) star V592 Cas (Cassiopeia) is suitable for our recent study, because of its observed flares activity and existence of accretion discs discovered by Greenstein et al. (1970). We chose this object from the Simbad Astronomical database. V592 Cas behaves as a typical disc-accreting nova-like CV, exhibiting a single-peaked $H\alpha$ emission line (Kafka et al. 2009). The low inclination angle (Huber et al. 1998) makes possible to take the real emissions from the object. Its WD (white dwarf) is about 0.75 $M_\odot$

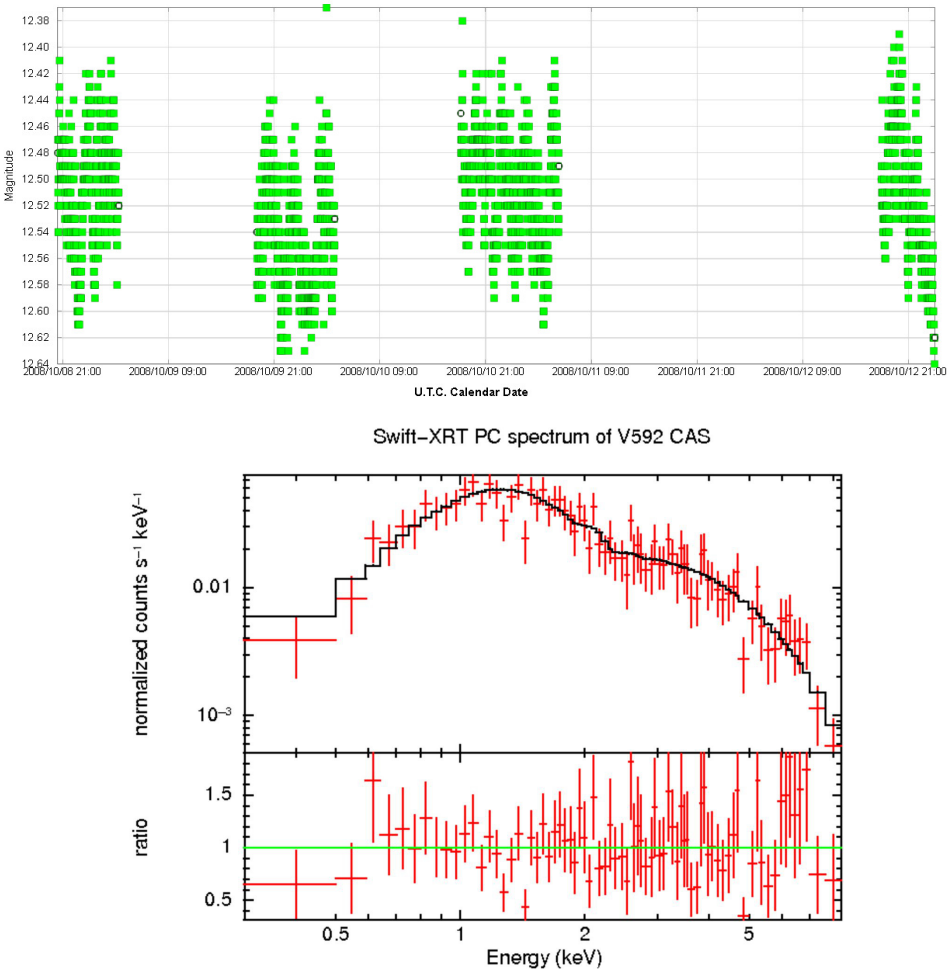


Figure 1 Active states of the CV star V592 Cas. Indications of flare-ups in V592 Cas light curve (AAVSO data) (upper panel). Energy spectrum, in PC (photon counter) mode, shows the most active part of the energy range (lower panel).

with a temperature of 45,000 K (Hoard et al. 2009) and a mass accretion rate around 10^{-8} $M_\odot$ yr^{-1} (Taylor et al. 1998; Hoard et al. 2009).

The second object is a binary star γ Cas (Cassiopeia), which is of Be/X stars type. Typical X-ray luminosities of Be/X-stars are $\sim 10^{34}$–10^{39} erg/s. The most common suggestion is that the emission from the Be star comes from accretion wind or disc (White et al. 1982). In Kaygorodov et al. (2013) we make an assumption that the X-ray emission is due to the accretion of matter by neutron star with mass ~ 1 $M_\odot$. There the relationship between X-ray luminosity and accretion rate is determined. M. Templeton in his AAVSO report (2013) gives an explanation that the γ Cas stars eruptions are possibly related to the formation and destruction of a circumstellar disc of material, and instabilities within the disc.

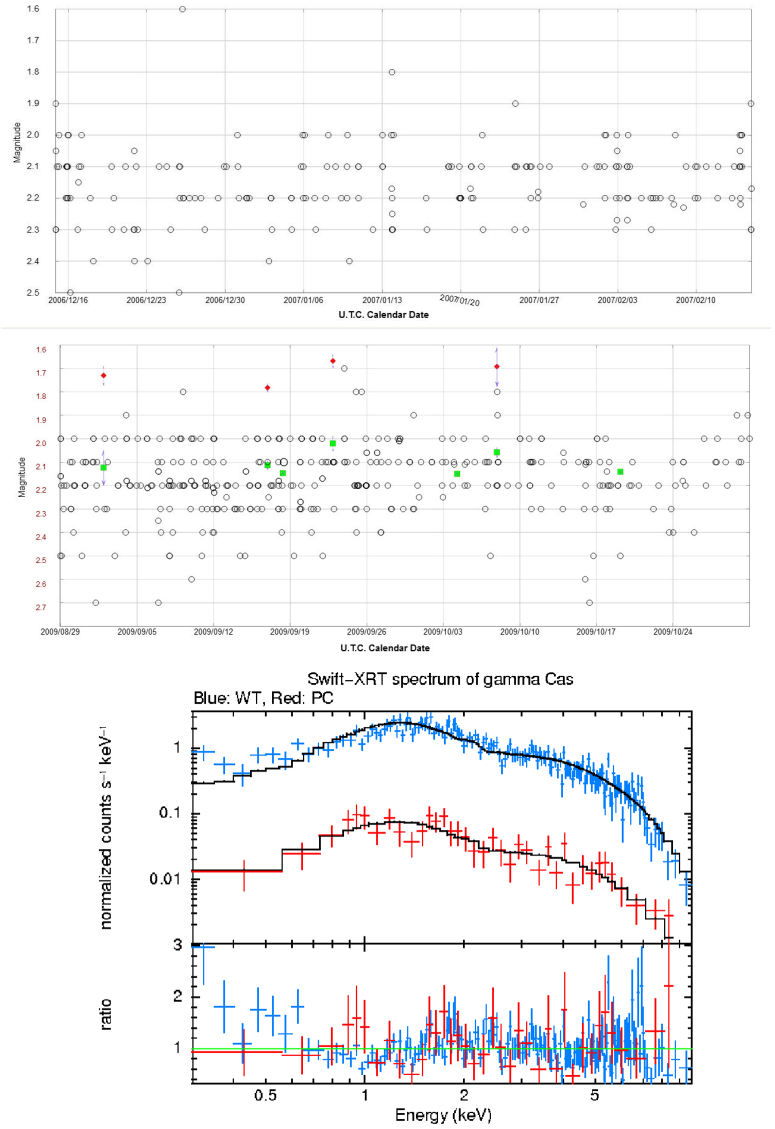


Figure 2 γ Cas light curves (by the AAVSO generator) indicates flare-ups (upper and middle panels). Two figures (upper and middle) are pointed to different periods of time. The count rates in the energy spectrum, in PC mode, are active for the most part at low ranges (lower panel). Swift-XRT light curve of γ Cas (Swift-XRT generator, Evans et al. 2009).

As we have already mentioned in Introduction, the applied observational data in this paper are taken from the on-line light curve generators of AAVSO and Swift. First, we build the light curves and the energy spectrum with an aim to trace the active states arising in the chosen targets. Then we detect the possible existence of flares of those two binaries (see Figs 1–2). The energy spectrum is in PC (photon counter)

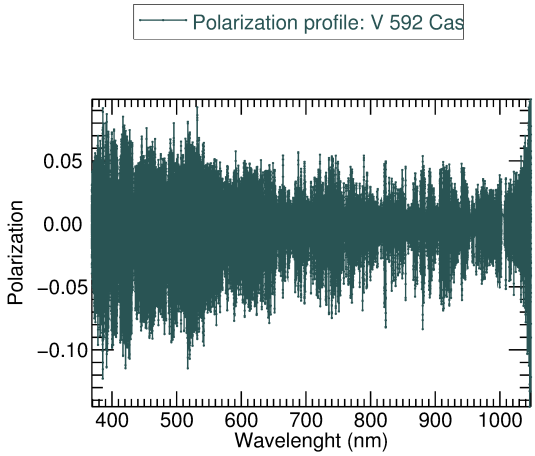


Figure 3 Polarizations states variations of V592 Cas in relation to the wavelength. V592 Cas can exhibit variations in rates of polarization degree P, which is defined by all Stokes parameters, during the flares periods and at different wavelengths. The calculations are made for two dates: 2008-10-09; 2008-10-10. The data are taken from PolarBase.

mode: the high count rate of the photon flux is necessary for the better polarization sensitivity in the calculations. The indications of active states are presented as follows.

The higher luminosity rate, in the result of flares activity, could affect the polarization degree. The next step is to examine the behaviour of polarization parameters during the brightness variability. In order to calculate the polarization degree P and to create the emission polarization profile, we apply the reduced data for our two binaries, taken from PolarBase. The instruments used in this database are a stellar spectro-polarimeter NARVAL installed at the Telescope Bernard Lyot in south-west France, as well as ESPaDOnS – a high resolution spectro-polarimeter designed and constructed at Observatoire Midi-Pyrenees (OMP) in France. The measurement of polarization is in relation with radial velocity and wavelength in wide broad-bands. Figures 3 and 4 present the polarization profiles of V592 Cas and γ Cas. The polarization profile of V592 Cas, in terms of the polarization degree P (see Eqs 1 and 5), is constructed to the whole wavelength range of the visible spectrum, employing the data values of all Stokes parameters and intensity I. This allows us to observe the entire profile picture of the polarization state variations, although there is not enough data to calculate the errors. The dates of observations and polarization calculation are in relation to the light curve epochs: 2008-10-09; 2008-10-10 (the dates format here: yyyy-mm-dd). Therefore, in the future work, to give an estimation of how the polarization changes over different wavelengths for V592 Cas, it is necessary to process the data and to clear the noise signal from them.

In the PolarBase spectra, as it is explained in Petit et al. (2014), to detect polarization signatures below the noise level, the improvement of capability of ESPaDOnS and NARVAL is necessary most of the time. Therefore, to process each normalized PolarBase spectrum (Petit et al. 2014), the Least-Squares Deconvolution method (LSD) is implemented (Donati et al. 1997; Kochukov et al. 2010). In this way a

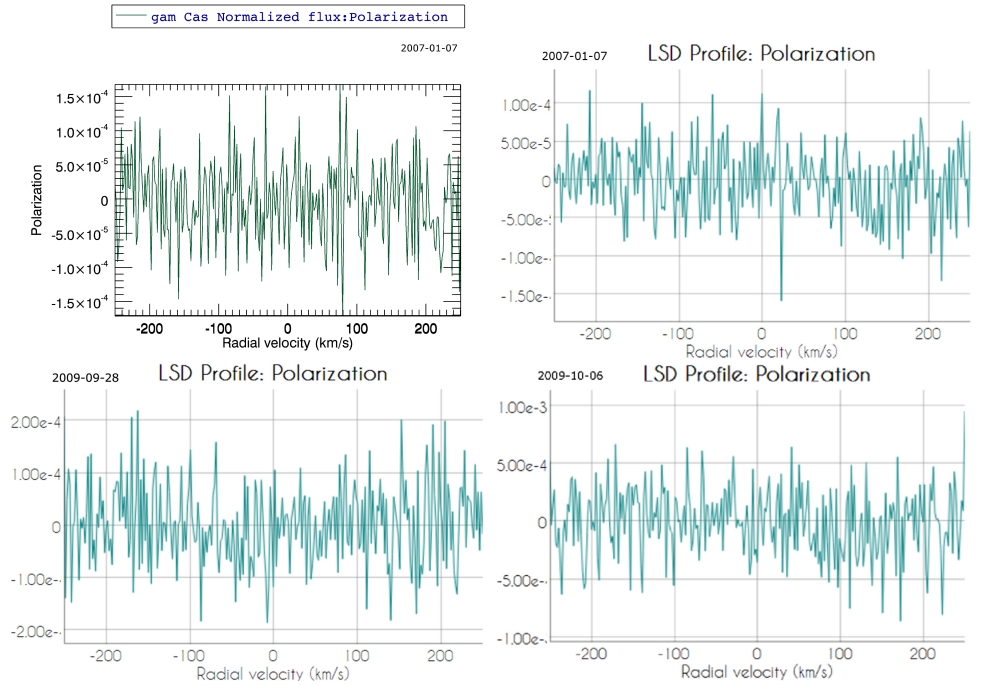


Figure 4 Polarization profile of γ Cas against radial velocity. Variable polarization states of γ Cas are shown for three different observational periods of time: 7-Jan-2007 (upper left and right); 28-Sept-2009 (lower left); 06-Oct-2009 (lower right). The figures show the variations in values of the V Stokes parameter: normalized flux and LSD profile (upper left and right); Q Stokes parameter (lower left) and U Stokes parameter (lower right), both after the LSD processing. The data are taken from PolarBase.

mean pseudo-line profile in all available Stokes parameters can be extracted. The polarization profile of γ Cas is calculated to the V and I Stokes parameters in accordance to the obtained data from PolarBase for an observational period: 7 January 2007 (Fig. 4, upper left and right). The polarization signatures for this star, processed by LSD, according to Q and U Stokes parameters are also detected. They are pointed to two dates: 28 September 2009 and 06 October 2009 (Fig. 4, lower left and right) with SNR (Signal to Noise ratio) (max) = 1166.0 and SNR (max) = 315.0. Radial velocity corrections from telluric lines (km/s) for those two dates are respectively: –0.172 and –0.089. The mean values of *sigma* for the maximum signal of inside stellar lines are as follows:

date: 2007-01-07, V Stokes parameter, $\sigma = 4.799$;
date: 2009-09-28, Q Stokes parameter, $\sigma = 4.454$;
date: 2009-10-06, U Stokes parameter, $\sigma = 6.394$.

These dates are part of the period used to generate the light curve and energy spectrum of the star (depicted by the blue dotted lines in Fig. 2), where the flares were observed. We detected variations in the brightness in the same period of time as the fluctuations in the polarization profile can be observed, for both objects considered

in this paper. If, in the further observational results, the coincidence of some flares activity and polarization fluctuations in time occurs again, then we could work out a suggestion about the type of dependence in the relation between the brightness variability and polarization states.

4 Discussion

We presented activity states of two binary stars (V592 Cas and γ Cas) by indications of flares in their light curves and energy spectrum profiles. We obtained the polarization profiles of those stars against wavelength and radial velocity by applying the data from PolarBase data center. Variations in the polarization V, Q and U Stokes parameters, and in the polarization degree P during the periods of active states are observed. In the current work, as in the paper of Baley et al. (2010), the measured values of the degree of linear polarization are expectantly in order of about 10^{-4}–10^{-6}.

We know that the state of polarization of the emitted light in general provides information on various spatial anisotropies of the accretion system. The wavelength dependence of polarization gives information about the size of the scatterers. Further study of the emitted light by the methods of polarimetry could give us more complete analysis about the basic properties and structures of the flares material, and of the excited system as a whole.

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