ANALYSIS OF DISC'S MODELS AND ACTIVE STATES INDICATIONS OF ACCRETING COMPACT BINARY STARS

Daniela Boneva, Lachezar Filipov

Space Research and Technology Institute – Bulgarian Academy of Sciences
e-mail: danvasan@space.bas.bg, lfilipov@space.bas.bg

Keywords: *Stars: Binary stars; Accretion; polarization;*

Abstract: *We investigate the relationship between brighten-up events, respectively light curve shape's behavior, disc's models and polarization states in accreting compact binary stars. Indications of binary star's activity, by employing theoretical and observational data on their main parameters and conditions are presented.*
Using online data of the base accreting flow parameters, the disc's structure models are created for two types of stars.
We suggest some observational results, which demonstrate the existence of the brightness variability in three binary stars with compact objects: V592 Cas (Cassiopeia), CH Cyg (Cygnus) and V471 Tau (Taurus). The methods of polarimetry to probe the stars conditions during the active states are also applied. The results show variations in the polarization parameters of selected binaries for the flares activity period.

АНАЛИЗ НА МОДЕЛИ НА ДИСКОВЕ И ИНДИКАЦИИ НА АКТИВНИ СЪСТОЯНИЯ В АКРЕТИРАЩИ КОМПАКТНИ ДВОЙНИ ЗВЕЗДИ

Даниела Бонева, Лъчезар Филипов

Институт за космически изследвания и технологии – Българска академия на науките
e-mail: danvasan@space.bas.bg, lfilipov@space.bas.bg

Ключови думи: *Звезди: Двойни звезди; Акреция; Поляризация;*

Резюме: *В тази статия ние изследваме връзката между активност на просветвания, съответните форми на кривите на блясъка, дисковите модели и поляризационното състояние на акретиращи компактни обекти в двойни звездни системи. Представени са индикации за тези активности в двойните чрез теоретични и наблюдателни данни.*
Чрез използване на онлайн данни за основните параметри на акретиращия поток, са конструирани модели на дисковете за два типа звезди.
Използвани са наблюдателни данни, които демонстрират наличието на вариации в светимостта в три двойни звезди с компактни обекти: V592 Cas (Cassiopeia), CH Cyg (Cygnus) and V471 Tau (Taurus). Приложени са и методи на поляриметрията за изучаване на състоянията на тези звезди по време на периоди на активности. Резултатите показват вариации в поляризационните параметри на избраните двойни по време на периодите на промени в светимостта.

Introduction

The main aim of this survey is to show the variations in stars' physical conditions by indications of different models and methods. Active states in astrophysical objects are usually associated with the phenomena like bursts, flickerings, flares or jets (from protoplanets to active galactic nuclei), or the scattering of radiation in highly aspherical distributions of matter. Let's first distinguish the events "bursts", "flares" and "flickerings". In Cataclysmic Variable (CV) stars outbursts can occur when the accretion rate exceeds the upper limit of the steady burning range (Mitsumoto et al. 2005). The bursts' brightness exceeds the value of 1 magnitude and they behave as rapid, sudden and energetic outflows. Bisikalo et al. (2001) have detected significant brightness oscillations in CVs with aperiodic nature in part of them, the so call "flickering". This part is characterized by small magnitude and short timescale. On the other hand they have found that light curves in CVs demonstrate periodic or quasi-periodic photometric modulations with a typical period of ~ 0.1..0.2 P_{orb}. The flickering is stochastic light variations on timescales of a few minutes with amplitude of a few magnitudes (0.01 ÷ 1). This variability is observed in the three main types of binaries that contain white dwarfs accreting material from a companion mass-donor star: cataclysmic variables, supersoft X-ray binaries, and symbiotic stars (Sokoloski 2003).

The flares appear normally 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 ÷ 200s. They found that the light curve of AE Aqr (CV star) exhibits large flares on timescales of about 10 minutes. Bruch and Grutter (1997) found that the strong flares could be also phase dependent.

In this survey we investigate the features of polarization modeling on the emission properties of flares and bursts in binary stars. Churazov et al. (2002) have suggested that a repeated variability in the brightness could affect to the degree of polarization. They proposed X-ray polarization as a mechanism to probe the flarings and the resulting, reprocessed X-ray should be polarized. The result, applicable to this paper's case, is that synchrotrons produce coherent, circularly polarized radiation.
Very little polarization in nearby stars was found by Piirola (1977), Tinbergen (1982) and Leroy (1993a,b, 1999). The mean measured polarization degree 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 in the result of scattering in its dust disc. We apply the observational data of V592 Cas (Cassiopeia), CH Cyg (Cygnus) and V471 Tau. To create the light curves and indicate the existence of flares we used the data from AAVSO (American Association of Variable Star Observers) and SWIFT generator, as well as for their energy spectrum production. The polarization data are taken from PolarBase (A DataBase of high resolution spectropolarimetric stellar observations) (Petit et al. 2014).

Disc's models and basic parameters

We investigate a disc's configuration around the primary star after the mass transfer being started and as a result of interacting processes between the close components. In this case, it is necessary to include physical essence of the flow dynamics. The nature of this interaction allows employment of gas-dynamics equations presented in their applicable vector form, in (Boneva & Filipov 2012, Boneva & Kaygorodov 2016). The equations are as follows: equation of mass conservation; the existence of viscous processes in the accretion flow, as well as influence of forces and rotation could be performed by the following Navier-Stokes equations; energy balance equation for a viscous non-ideal fluid and equation of state for compressible flow.

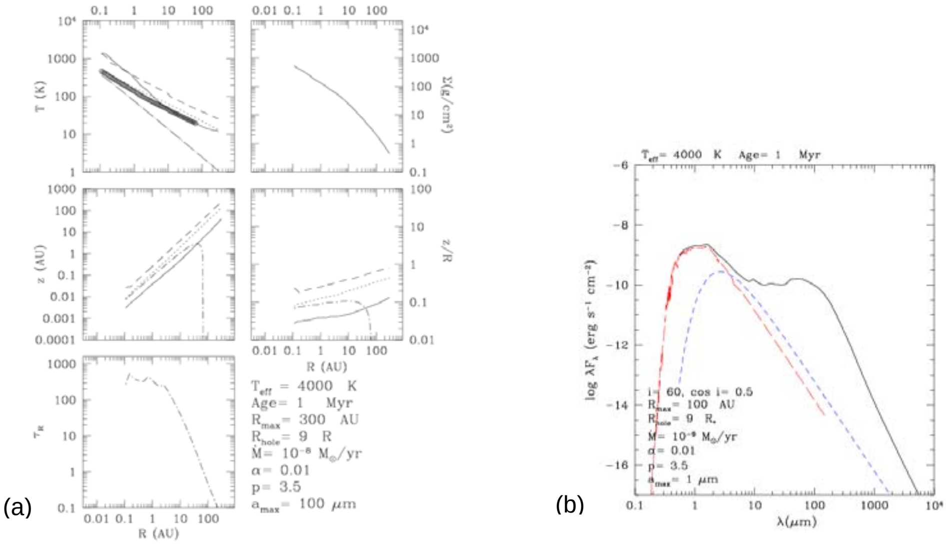

Fig. 1. Disc models for cool objects with values of T_{eff} ~ 4000K and R_{hole} (Inner radius of the disc). The plots show: Disc's model and parameters v/s variations in radius (Fig. 1a); changes in values of temperature, surface density, heights, ratios of heights over radius and the Rosseland mean opacity with variations of disc radius. Spectral Energy Distribution (Fig. 1b); the model flux in ergs/cm^2/s1 against wavelength in micron in thin black line; the model flux for the central star in dashed red line; It illustrates the emission from the star.

To define the conditions for further modeling, it is necessary to create discs structure models for the different stars type. Based on the models of D'Alessio et al. (2004) and Merin B. et al. (2004) we generate sets for K and B types, with different parameters. They are shown at the Figures (1a,b and 2a,b).

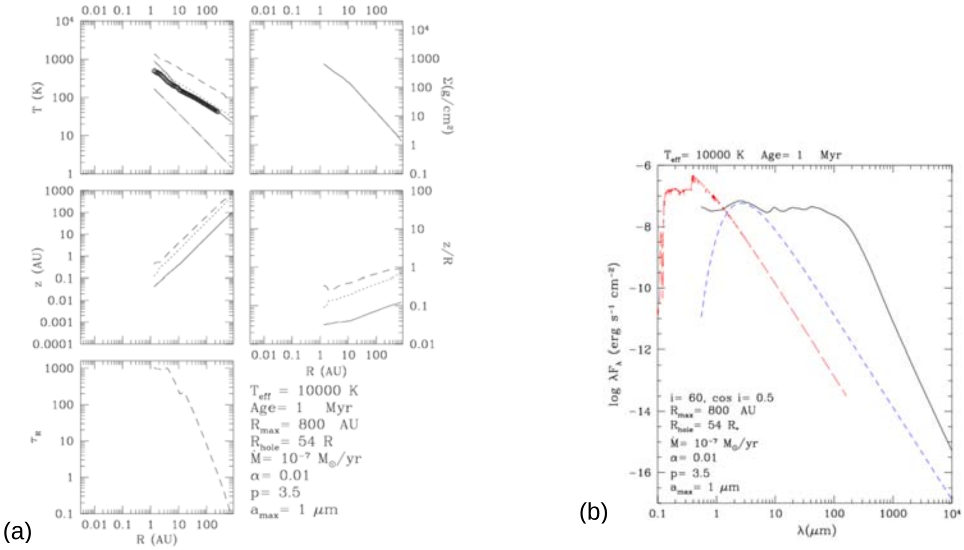

Fig. 2. Disc models for objects with values of T_{eff} ~ 10000K and R_{hole} (Inner radius of the disc). The plots show: Disc's model and parameters v/s variations in radius (Fig. 2a); changes in values of temperature, surface density, heights, ratios of heights over radius and the Rosseland mean opacity with variations of disc radius. Spectral Energy Distribution (Fig. 2b); the model flux in ergs/cm^2/s1 against wavelength in micron in thin black line; the model flux for the central star in dashed red line; It illustrates the emission from the star.

In the cool stars (K type) model we have a different temperature range and density values, compared to the models of B stars, and how it is seen at the Figures 1 and 2. This difference in the flow's parameters has an influence on the physical models of burst activity development (Boneva et al. 2009), as well as of flickerings and flares, suggested in (Boneva & Kaygarodov 2016, Boneva 2016). In the next section we can see the variations in brightness, expressed in the light curves shape behavior, obtained by the observation data of the studied binaries.

Results of observational data and their indications of active states

In this section, the observational exhibition of active states of three binary stars is presented. With the aim of comparing the results between objects, they are chose to be of different classes or types: CV star, Be star and a cool binary star. Let's first give short basic description for each of the targets.

- V592 Cas (Cassiopeia): This OB spectral type CV star is suitable for our recent study, because of its observed flares activity and accretion discs existence, discovered by Greenstein et al. (1970). It behaves as a typical accreting nova like CV, exhibiting a single-peaked Hα 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 is about 0.75 M☼ with a temperature of 45,000K (Hoard et al. 2009) and a mass accretion rate around 1×10^{-8} M☼ yr^{-1} (Taylor et al. 1998; Hoard et al. 2009). We choose this object from the Simbad Astronomical database.

- The next binary is CH Cyg (Cygnus), which is of M7IIIab+Be spectral type. CH Cyg behaves as a Semi-regular variable (SR) star. Those types are usually giants or supergiants of intermediate and late spectral types showing perceivable periodicity in their light changes, accompanied by various irregularities. Periods are in the range from 20 to even more than 2000 days, while the shapes of the light curves are rather different and variable, and the amplitudes may be from several hundredths to several magnitudes (usually 1-2 mag. in V (Visual)). The combined brightness displays irregular variations with amplitudes up to 4 mag. in V.

- V471 Tau is a binary pre-cataclysmic system consisting of a cool white dwarf and main sequence star with an orbital period of 0.52 days. This is an eclipsing binary system and the change in brightness takes only 55 seconds (Hric 2011). The light curves of V471Tau show the typical flares behavior.

Using data from the on-line light curve generators of AAVSO and SWIFT, we created the light curves and received the energy spectrum to detect the existence of flares of those three binaries (see Figures 3-5). The energy spectrum is in pc (photon counter) mode: since 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.

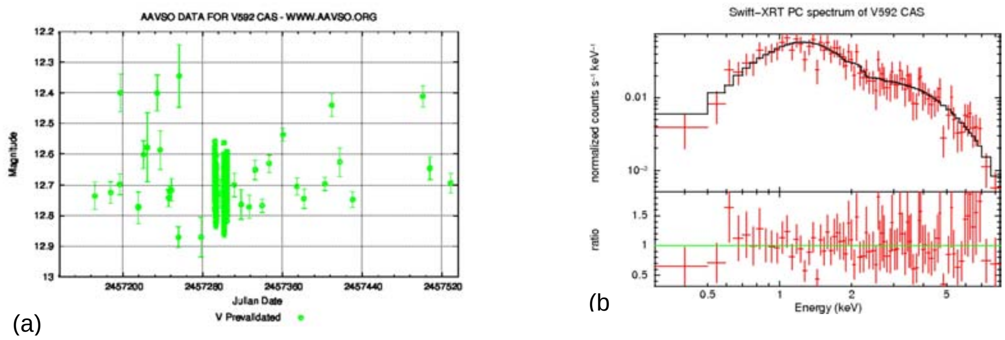

Fig. 3. Active states of the CV star V592 Cas. Indications of flare-ups in V592 Cas light curve (AAVSO data generator)(Fig.3a). Energy spectrum, in PC mode, shows the most active part of the energy range (Fig. 3b).

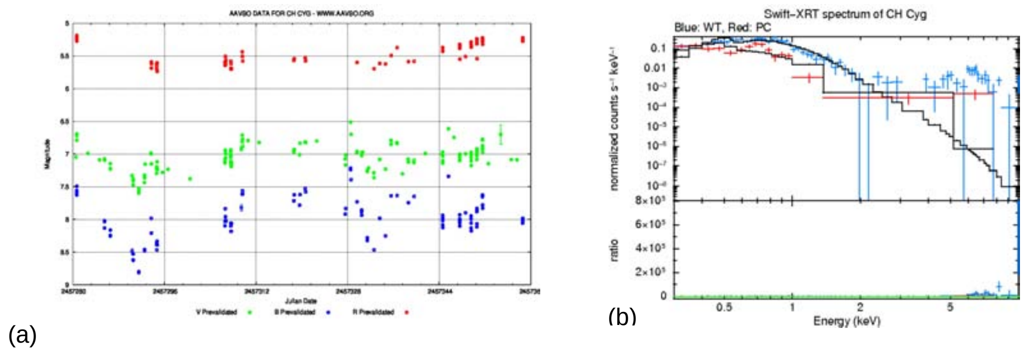

Fig. 4. Indications of active states in CH Cyg. Light curve of CH Cyg shows variations in brightness with amplitude in a range of 1 to 2 magnitudes (VBR observations) and time scales of ~ 10 days. (AAVSO light curve generator).

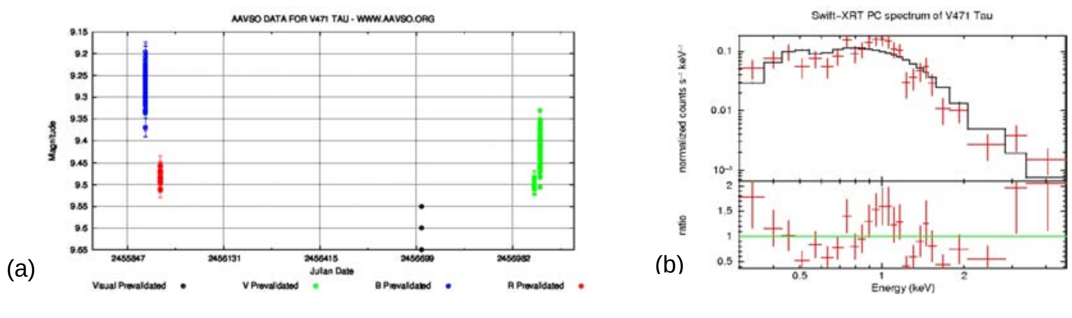

Fig. 5. Light curve of binary with cool white dwarf V471 Tau (Fig. 5a). It is seen flares activity at the time of observations. Fig. 5b shows the count rates in the energy spectrum, in PC and WT modes, are active for the most part at low ranges. (Swift-XRT generator, Evans et al. 2009)

In these three classes of binaries the different behavior of the brighten-up effects is detected. The difference could be caused by physical properties of the accreting flow, as well as by the dominating mechanism or their orbital periods.

The higher luminosity rate, in the result of flares could affect on the polarization degree. The next step is to find any relation between brightness variability and polarization parameters. We reduce the data from PolarBase for our two binaries and we apply them in the calculation of the polarization degree and to create the emission polarization profile. This measurement is in a relation with radial velocity and wavelength in wide broad-bands. The next figures (Figures 6-7) present the polarization profiles of CH Cyg and V592 Cas (Boneva & Filipov 2016, Boneva 2016).

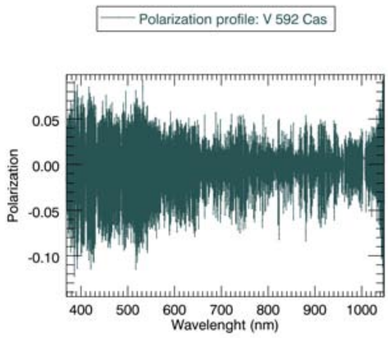

Fig. 6. Polarizations states variations of V592 Cas in a relation to the wavelength. V592 Cas can exhibit variations in rates of polarization degree during the flares periods and at different wavelengths.

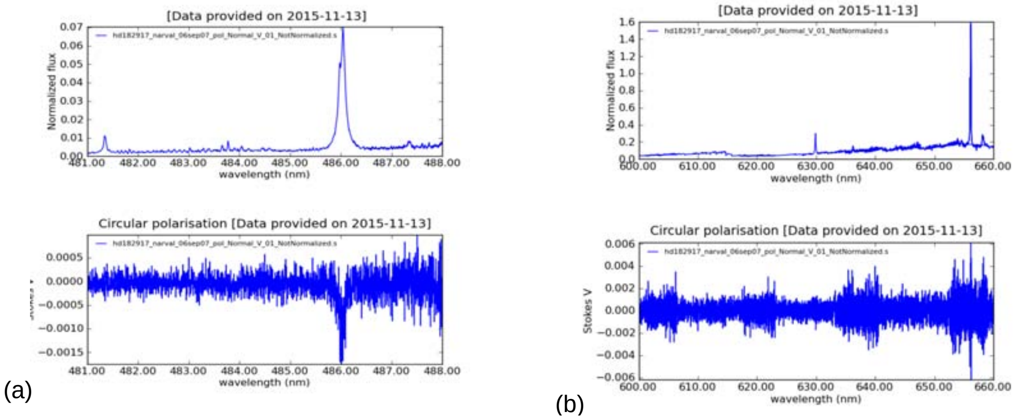

Fig. 7. Polarization profile of CH Cyg for different wavelengths. The figures show variations in values of the V Stokes parameter. The data are taken from PolarBase.

The data of V471 Tau are limited and at the same time, in our calculations, it shows very weak polarization activity to create the meaningful polarization profile. We calculated the polarization profile of CH Cyg in accordance to the observational periods as is used in its energy spectrum (Figure 5b) and the light curve (Figure 5a) that indicates variations in brightness in this binary. This way, to show the relation between the brightness variability and polarization states is possible.

Conclusion

- According to the light curves profiles, the presence of brightness variability and active states are detected at the above three binary stars with compact objects
- We obtained the polarization profiles of those stars against radial velocity and wavelength by applying the data from PolarBase data center. The results show an existence of variations in polarization parameters during the time of outflows activity.
- We know that: The state of polarization of the emitted light in general provides information on various spatial anisotropies of the excited system. After analyzing the polarization parameters and its wavelength dependence we could have an information about the basic properties and structures of the flares material, and the size of the scatterers.

Acknowledgments:

- *This work made use of data supplied by the UK Swift Science Data Centre at the University of Leicester.*

- *Thanks to the AAVSO (American Association of Variable Star Observers) to provide the data of Light Curve Generator*

References:

1. Bisikalo, D. V., Boyarchuk, A.A., Kaigorodov P.V., Kuznetsov O.A. 2003, Astron. Rep. 47, 809
2. Boneva, D. & Kaygorodov, P. 2016, BgAJ, 25, 26.
3. Boneva, D. & Filipov, L. 2012, astro-ph/1210.2767B.
4. Boneva, D. V., Kaigorodov, P. V., Bisikalo, D. V., & Kononov, D. A. 2009, ARep, 53, 1004.
5. Bruch, A., & Grutter, M. 1997, AcA, 47, 30
6. Churazov, E., Sunyaev, R., & Sazonov, S. 2002, MNRAS, 330, 817
7. Evanse, P. A. et al., 2009, MNRAS, 397, 3, p.1177
8. Goosmann, R. W. & Gaskell, C. M. 2007, A&A, 465, 129
9. Greenstein, J. L., Sargent A. I., Haug U. (1970) A&A 7, 1
10. Hric, L. & Kundra, E. 2011, Proceedings IAU Symposium, 282, 121.
11. Hoard, D. W., et al. (2009) ApJ 693, 236
12. Huber, M. E., Howell S. B., Ciardi D. R., Fried R. (1998) PASP 110, 784
13. Kafka, S., D. W. Hoard, R. K. Honeycutt, and C. P. Deliyannis, (2009) AJ 137,197
14. Leroy, J. L., 1999, A&A, 346, 955
15. Leroy, J. L., 1993a, A&AS, 101, 551
16. Leroy, J. L., 1993b, A&A, 274, 203
17. Mitsumoto, M., Jahanara B., Matsuda T., Oka K., Bisikalo D. V., Kilpio E. Yu., Boffin H. M. J., Boyarchuk A. A., Kuznetsov O. A., 2005, Astron. Rep.,49, 884
18. Merin, B., Montesinos, B., Eiroa, C., Solano, E., Mora,A., et al. 2004, A&A, 419, 301.
19. Marin, F., Karas V., Kunneriath D., and Muleri F., 2014, MNRAS, 441, 3170
20. Molinari, S., Bally, J., Noriega-Crespo, A., et al. 2011, ApJL, 735, L33
21. Petit, P., Louge T., Theado S., Paletou F., Manset N., Morin J., Marsden S. C., Jeffers S.V., 2014 PASP V 126 939, 469
22. Piirola, V., 1977, A&AS , 30, 213
23. Sokoloski, J. L., Kenyon S.J., 2003, ApJ 584, 1021
24. Taylor, C. J., et al., 1998 PASP 110, 1148
25. Tinbergen, J., 1982, A&A, 105, 53
26. van Paradijs, J., van Amerongen S., Kraakman H., 1989, AASS, vol. 79, 2, p. 205-215
27. White, N. E., Swank, J., et al. 1982, ApJ, 263, 277W