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METHODS FOR EXPLORING THE DYNAMICAL PROCESSES IN BINARY STARS SYSTEMS

Daniela Boneva

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

Keywords: *Stars: Binary stars; Accretion; gas-dynamical simulations; light curves; polarization;*

Abstract: *We presented theoretical and observational methods on the investigation of the flow dynamics in accreting binary stars.*

We have modeled the dynamical processes in the primary star and in the accretion disc around it on the base of the gas-dynamical calculations.

The results reveal flow structure transformation properties and their relation to the observational events as the quasi-periodic variability in the luminosity.

МЕТОДИ ЗА ИЗСЛЕДВАНЕ НА ДИНАМИЧНИ ПРОЦЕСИ В ДВОЙНИ ЗВЕЗДНИ СИСТЕМИ

Даниела Бонева

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

Introduction

Binary stars are dynamically active systems. It relates to the processes of: flow fluctuations such as density and velocity variations; structural transformations; wave-pattern formations; flickerings and bursts. They could be the result of tidally interacting processes between two stars, as well as the following mass transfer.

Tidal interaction between the out-flowing matters from donor through the point of libration L_1 and the flow around the accretor have been studied by gas-dynamical analysis [7], [3], [9], [14], [15]. Bisikalo et al. [2] have shown that even a small variation in mass transfer rate of the binary system, could disturb the equilibrium state of the hot accretion disc. Hence the conditions of the flow structure transformation in the close binary star system can be generated.

An investigation on the accreting flow morphology is presented in this survey. We consider compact binary stars with accretion disc around the primary. We suggest the flow transformation modeling due to the flow instability.

We show the relationship between the flow fluctuations and the flare-ups activity, which has an effect on the light curve shape's behavior. The accumulation of mass transferred to the surface of the white dwarf from the secondary star through an accretion disc could triggers an outburst. The rotating white dwarf in the system ejects most of the matter transferred from the secondary in a form of fireballs [18]. When they appear in a stochastic way on timescales of a few minutes with amplitude of a few 0.1 magnitudes [17], [1], this variability is called flickering and has been detected in the three main types of binaries that contain white dwarfs accreting material from a companion mass-donor star: cataclysmic variables (CVs), supersoft X-ray binaries, and symbiotic stars.

Variations in the brightness of dwarf nova stars could give an effect to the degree of polarization. The highly polarized emission can also be observed in a hot accretion flow [16]. We investigate the polarized emission properties of accreting binary star systems. Churazov et al. [8] proposed X-ray polarization as a mechanism to probe the flarings and the resulting, reprocessed X-ray should be polarized.

Methods and Results

- **Methods**

- We employ theoretical methods, based on gas-dynamical numerical calculations: Finite-difference scheme – high order; Roe solver; Box-framed scheme [4].
- It is applied the observational data of γCas, SS Syg, GK Per and AE Aqr.
- The polarimetry methods of exploring the brighten-up events in binary stars are also applied: Four Stokes parameters S0, S1, S2, S3 and Poincare vector *P* of polarization - characterize the intensity and polarization of the emission [8], [12], [13].

- **theoretical considerations**

Processes of the binary tidal interaction and high mass transfer rate could give rise to the disturbances of the flow parameters and then to a structure transformation. In the next calculations, we can see that the changes in the mass transfer rate are in a close relation with perturbations in the density. We employ with the theoretical methods, explained in the previous section. We set the initial conditions for the mass transfer rate and for the density, as well: $\dot{M}_0 \sim 10^{-5} M_{\otimes} / year$ and $\rho_0 \sim 10^{-6} \rho_* [gcm^{-3}]$, where $\dot{M}_0$ is the initial mass transfer rate; $M_{\otimes}$ is the solar mass; ρ_0 - initial value of the density; ρ_* - surface density of the star. The boundary conditions define the calculation box frames. We denote the boundary frame with $K(x,y,z)$ and then $K(x,y,z)$ $\sim 10^{-6} \times 10^{-6} \times 10^{-6} \div 10^{-8} \times 10^{-8} \times 10^{-8} AU$ is in the range: In the disturbed regions, where the perturbation function with the variable mode number *m* takes place, the dynamics of the gas flow could be changed.

This way, in the studied regions, fluctuations in the density values are observed (Fig.1). The flow goes through some structure transformation after the mass transfer has been started. Figure 2 shows the initial density wave distribution, as it is received by the box-framed scheme calculations.

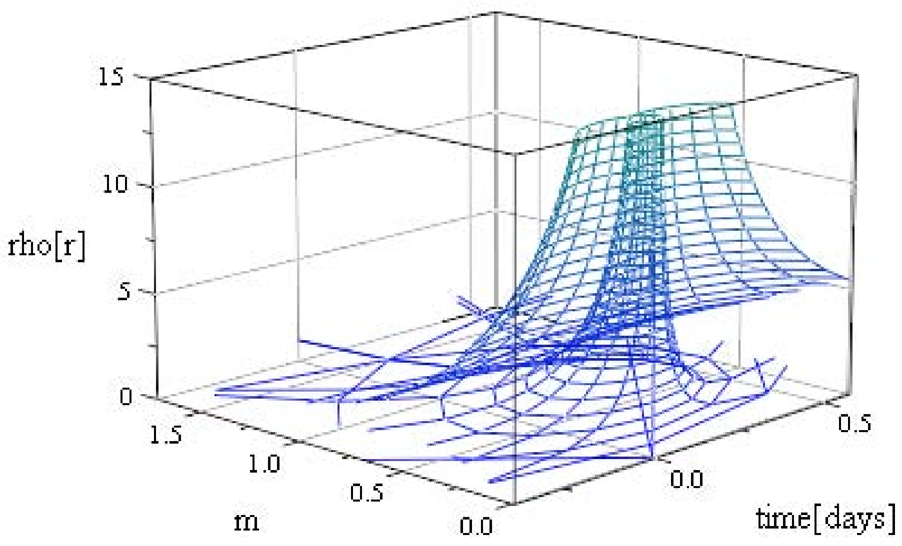


Fig. 1. Fluctuations of the density values $\rho_0 \times 10^n$ in the disturbed mass transfer area. The different values of the mode number *m* have an influence on this result *(m is a term of the perturbation function expression; rho=ρ)* [5]

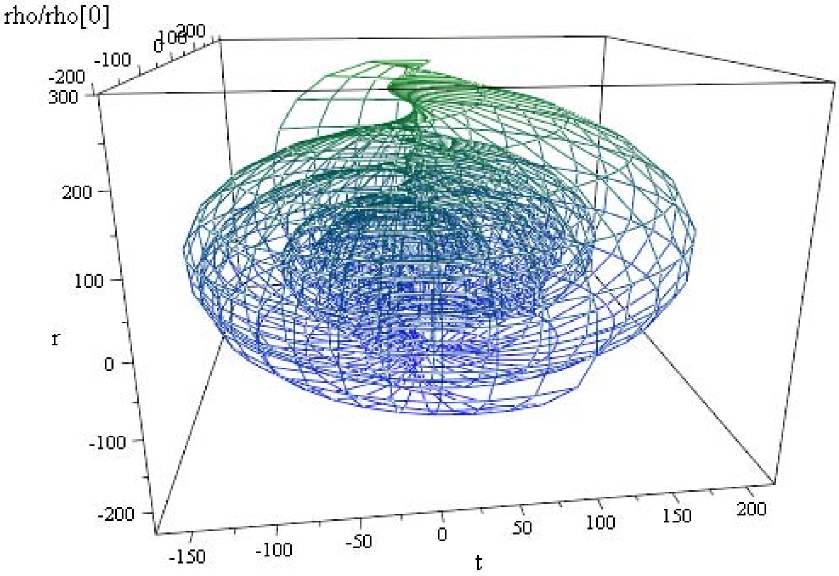


Fig. 2. Fluctuations of the flow during the initial mass transfer in the area close to L1 (*note*: *rho*=ρ)

- **observational and experimental results**

An expression of the flow dynamics could be detected as the brightness variability of some CVs and Be/X stars. A small number of systems, including γCas, SS Syg, GK Per and AE Aqr, exhibit strong optical flickering (stochastic brightness fluctuations on timescales of minutes to hours), The influence of dynamical processes in the flow could be seen on the light curve shape of these binaries.

To show this, we generate the light curve of GK Per (Perseus). GK Per is cataclysmic variable star, DN or classical novae: a compact white dwarf star and expanded cool giant star in a close orbit. The accumulation of mass transferred to the surface of the white dwarf from the giant star through an accretion disc eventually triggers an outburst (Fig. 3).

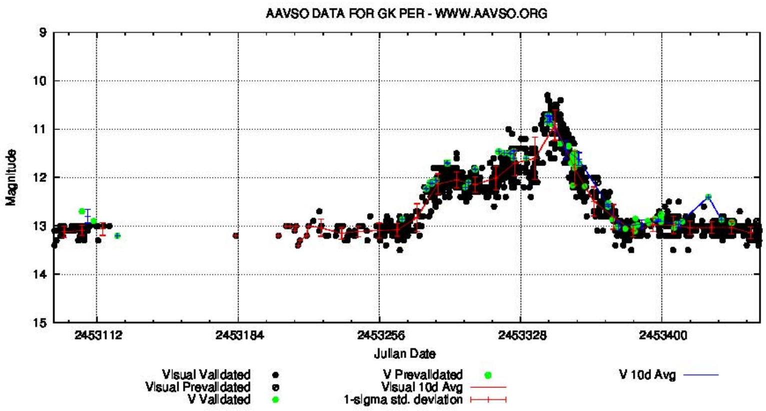


Fig. 3. GK Per (Perseus) light curve for different periods of time. GK Per is a CV star, DN or classical novae: a compact white dwarf star and expanded cool giant star in a close orbit. The image is created on the observational data of AAVSO /www.aavso.org/

Further we follow the research of Zamanov et al. in [18], where they have presented simultaneous multicolor observations of the fireballs of AE Aqr and they estimated the parameters of the blobs that produce the flares. In the current paper we only generate the light curve of AE Aqr to express the observational exhibition of the flow dynamics as the flickerings activity (Fig.4).

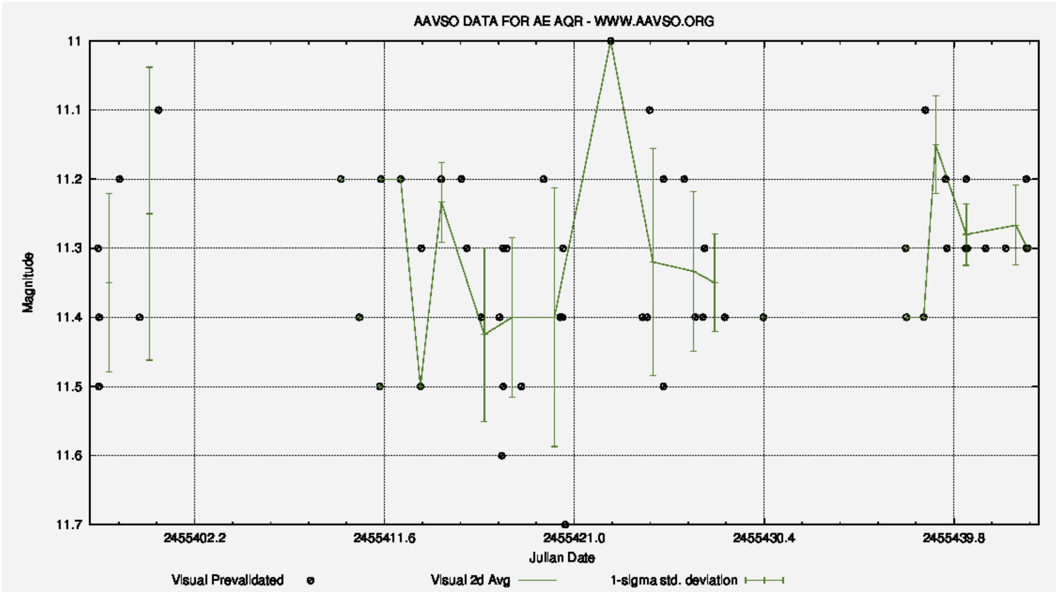


Fig. 4. AE Aqr (CV star) light curve indicates flare-ups. They could be caused by “blobs” that are transferring by the matter in the primary star (or the compact object). The image is created on the observational data of AAVSO /www.aavso.org/

Based on the observations, we apply our modeling in addition to the known models of the X-ray polarization (see Methods). We suggest the variable polarization’s states could be the result of synchrotron radiation from the forming bursts. It is detected a range of degrees of X-ray polarization during the mass transfer period. The modeling prediction gives the polarization degree of the next two binaries, according to their light curves.

First to explore is SS Cyg, which is one of the optically brightest DN (dwarf nova). There is strong evidence in its light curve’s shape for the production of bursts, which could be in the result of dynamically unstable processes in accreting flow around the primary (Fig.5a). During the bursts activity of this binary, the degree of polarization jumps to the higher rate of *P* and this value is normalized to **1** (Fig.5b). The increased level of *P* coincides with the maximum energy value of the burst’s emission.

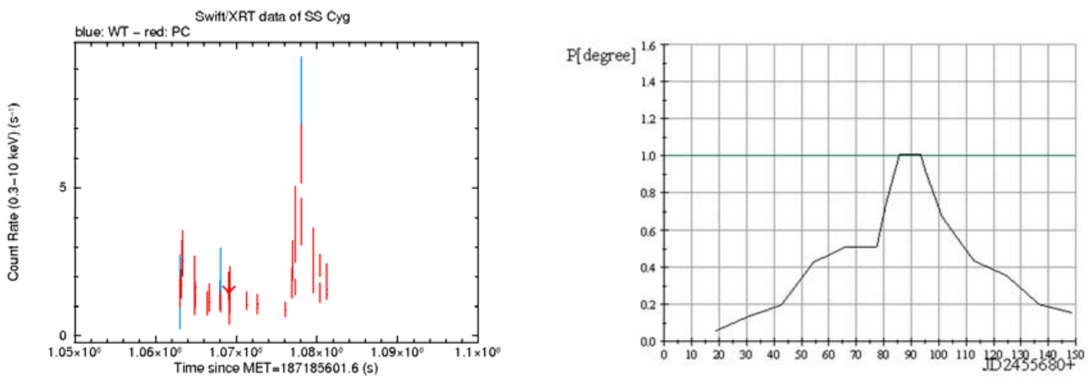
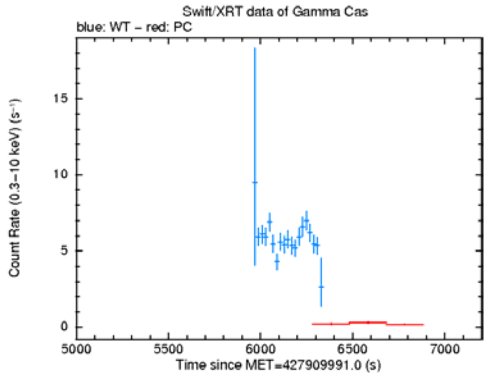


Fig. 5. Swift-XRT light curve of SS Cyg (Swift-XRT generator, Evans et al. 2009)) (5a). Polarization degree (**P**) during the bursts activity of SS Cyg (5b) [6]



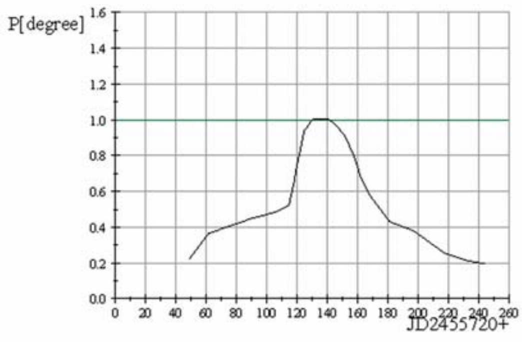


Fig. 6. Swift-XRT light curve of γ Cas (Be/X) (Swift-XRT generator, Evans et al. 2009) (6a). The high accretion rate here could give rise to the X-ray luminosity (10^{34} ÷10^{39} erg/s). The rate of accretion is in a correlation with the level of mass transfer, which depends on density. Polarization degree (P) during the bursts activity of γCas (Be/X) (6b) [6]

The similar situation is observed in another binary star γ Cas (Cassiopeia), which is of Be/X stars type. Typical X-ray luminosities of Be/X-stars are ~ 10^{34}÷10^{39} erg/s. Kaygarodov et al. [11] make an assumption that the X-ray emission is due to the accretion of matter by neutron star with mass ~ $1M_{\circ}$ and they determine the relationship between X-ray luminosity and accretion rate. The higher luminosity rate, in the result of flares could affect on the polarization degree. This suggestion is shown at Figures 6(a,b).

Conclusion

We presented three different methods to investigate the accreting flow dynamics in binary star systems. We employ theoretical methods that include gas-dynamical numerical calculations. The observational data of four binary stars, as well as the light curve generator are applied. We also use the basic polarimetry methods and models to reveal the properties of dynamically active accretion disc.

In this study we showed once again that under the influence of tidal wave, the accretion flow could not remain stable and the conditions of patterns development are generated. In the result of interaction, the shock tidal wave may cause some perturbations in quantities, which could change the dynamics of the gas flow.

We report observations of the flare-ups and burst activity as seen at the light curve's shape of the studied binaries. In these two classes of compact binaries, presented in the section Results, some difference between the flickering is detected. The difference could be caused by physical properties of the accreting flow, as well as by the dominating flickering mechanism or their orbital periods.

The maximum values of the polarization degree ***P*** is reached during the maximum of the bursts.

The results show significant changes in the flow structure during the bursts activity of these binaries.

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