Disturbances of flow parameters and exceeding luminosity in accretion binaries with compact object

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Abstract. Examinations in the current survey are emphasized to the flow dynamics of accretion disc around compact binaries. As it is known, compact binaries are a special case when one of the stars is a collapsed object, such as a white dwarf, neutron star, or black hole. We analyze base features of the unstable behavior of disc's matter, arisen as an effect of some perturbations of gas-dynamical parameters. We examine temperature springs in the flow's interaction places engendered by non-homogeneities of the accreting material. A graphical view of these abruptly variations of the parameters are presented. It is pointed at the relation of such instable activity to the study of X-ray emissions and sharp variability in luminosities in the studied type of compact objects.Theoretical considerations are followed by an exploration of the observational data of the binaries V 818 Sco, RZ Cas,V 723 Cas, GK Per and MV Lyr.

Key words: accretion disc, Stars: binaries, light curves;

Смущения в параметрите на течението и изменения на светимостта при акреционни дискове с компактни обекти

Даниела В. Бонева

В настоящата работа е изследвана динамиката на течението в акреционни дискове около компактни обекти. Както е известно, компактните обекти са специален клас, при който една от звездите е колапсирал обект, такъв като бяло джудже, неутронна звезда или черна дупка. Анализирали сме основни особености на неустойчиво поведение на дисковата материя, възникващо под влияние на пертурбации върху газо-динамичните параметри. Проследени са температурните скокове в местата на взаимодействие на течението, предизвикани от нееднородността на акретиращата материя. Тези резки промени на параметрите са представени графично. Представена е връзка между тези специфични отклонения от неустойчивото поведение и променливостта в светимостта при изучаваните в този труд компактни обекти. Теоретичните ни изследвания са последвани от проучване на експериментални данни за двойните звезди V 818 Sco, RZ Cas,V 723 Cas, GK Per и MV Lyr.

Introduction

Compact binary systems are among the brightest X-ray sources in the sky. These systems are compact in two senses: one of the stars in the binary is either a compact star, such as a degenerated dwarf or a neutron star or a black-hole candidate, and the distance between the stars is so small that the gravitational pull of the compact object is stripping the companion star of its atmosphere. In this paper we examine neutron stars as a part of low mass X-ray binaries (LMXBs) and white dwarfs (WDs) as cataclysmic variable (CVs).

At the accreting rates of most of the WDs ($M < 10^{-9} M_o yr^{-1}$) the accretion disc is a subject to a thermal instability which causes it to rapidly transfer matter onto WD – for a few days to a week (Townsley & Bildsten 2001). LMXBs are binary systems with a compact object that accretes matter from a low mass optical companion star filling its Roche lobe (Lewin et al. 1995). The presence of an accretion disc in these two types of binaries affects on the light curve in two ways: as a source of light and as a shield of the surface of the part of the companion from the X-ray heating

Analysis of the aperiodic variability in the X-ray flux, coming from the compact object, tells us about processes occurring in the inner accretion flow (van der Klis 2004). In the current survey we stress our view on the study of such processes. Our aim is to find connections between the theoretically obtained warps in flow parameters and based on the experimental data results, visualized in variable behavior of luminosity in selected binaries.

In accordance to the well known fact of perturbations analysis, already used by (Papaloizou & Pringle 1984), we explore in this paper the resulting view of density and velocity variations, as we apply numerical parameterization code, partially on the examined hydrodynamical perturbed equations. These effects are usually associated with some unstable behavior in accretion disc flow: turbulization of the flow layers, creation of vortices locally and globally in accretion discs, and in more cases spiral structures and wave propagation. For the existence of accretion discs, a crucial role is pertained to angular momentum and its transportation.

The vortices and waves are considered to be a main mechanism (Lovelace et al. 1999), also using global 2D hydrodynamical simulation Li et al. (2001) conclude that Rossby wave instability is an efficient purely hydrodynamic mechanism for angular momentum transport in thin disc. He found that individual vortices transport angular momentum outward. It is also suggested from Petersen et al. (2006) that some instabilities or turbulizations in the viscous flow are responsible for the carrying out of angular momentum. Therefore, extending the investigations of this unresolved still problem is so important for us.

In current work we start the exploration with theoretical analysis, which is placed in the Section 1. There we present our theoretical results on the dynamics of the accretion flow. It is showed also that applying of weak consecutive disturbances to velocity, density and pressure turns to appearing of non-periodical and non-uniform variations of such flow parameters, which are presented graphically. Further, in Section 2, we explain the processes, as we base on the observational data and obtain abrupt luminosity increments, probably of the flow instability conditions. It is examined five binary stars with compact object and then light curve of each one is constructed. Their selection is based on the presence of essential properties of the binary star's parameters.

1 Basic equations of gas-dynamics and variations of flow parameters

In this section we present the accretion disc as a hydrodynamical rotating flow with specific physical features, corresponding to an astrophysical object. Additionally, we introduce the terms of instability and fluctuations

1.1 Basic equations

The below system consists of basic equations, which are obtained from the classic hydrodynamical equations and transformed for the current case. We present the first three of them in a vector form. We start with the equation of mass conservation:

$$\frac{\partial \rho}{\partial t} + \nabla.\left(\rho v\right) = 0; \tag{1}$$

We consider viscous, rotating fluid and the Navier – Stokes equation takes the form:

$$\frac{\partial v}{\partial t} + v.\nabla v = -\frac{1}{\rho}\nabla P - \Omega \times \left(\Omega \times r\right) + \nu \nabla^2 v; \tag{2}$$

Where the basic denotations are: ρ is the mass density of the flow; we consider $\rho \neq const$ so that the radial entropy gradient exists; v is the velocity of the flow; P is the pressure; ν is the kinematic viscousity; Ω is the angular velocity; $\Omega \times (\Omega \times r)$ is the centrifugal force of the rotating accretion flow;

The energy balance equation for a viscous non-ideal fluid is:

$$\frac{\partial}{\partial t}\left[\rho\left(\frac{1}{2}v^2 + \varepsilon + \Phi\right)\right] + \nabla.\left[\rho v\left(\frac{1}{2}v^2 + h + \Phi\right) - 2\eta\sigma.v\right] = 0, \tag{3}$$

where in the total energy density change $\frac{\partial}{\partial t}\left[\rho\left(\frac{1}{2}v^2 + \varepsilon + \Phi\right)\right]$ the first term denotes the kinetic energy, the second is the internal energy and the third express the potential of the gravitational field.

The gravitational force here is given by its usual form (Mitsumoto et al. 2005): $\Phi = \frac{GM_1}{|r-r_1|} - \frac{GM_2}{|r-r_2|} - \frac{1}{2}\Omega^2\left(r - r_C\right)^2$, where Ω is again the angular velocity of binary system's rotation, $M_1, M_2$are the masses of the accretor and the donor, $r_1, r_2$are the radiuses of centres of the components,r_c radius of the centre of the binary system.

In the presence of neutron star, it is essential that about half of the gravitational potential energy is released as matter flows through the accretion disk, and the rest is released when the matter falls from the accretion disk into the neutron star's atmosphere. Otherwise, the white dwarfs are very dense, with an enormous gravitational potential and some of it is converted into X-rays during the accretion process.

Then the total energy flux is $\left[\rho v\left(\frac{1}{2}v^2 + h + \Phi\right)\right]$, where $h = \varepsilon + P/\rho$ is the enthalpy. Here η is the shear viscosity of the flow and σ is the rate of shear.

Further we express the equation of the angular momentum conservation as

$$\frac{\partial}{\partial t}\left(\rho r v_\varphi\right) + \nabla . r\rho v_\varphi - \nabla . \frac{1}{3} r v \left(\nabla . v\right) = -\nabla . rP + v r^2 \nabla^2 \frac{v_\varphi}{r}; \qquad (4)$$

In the end, the equation of state for compressible flow is $P = c_s^2 \rho$, where $c_s$is the sound speed.

Gammie (2001) concluded of how important is to consider the compressible flow in providing a significant relation to outward angular momentum transportation. The presented equations (1), (2), (3), (4) and the last equation of state build the necessary system of hydrodynamical equations. We will use the above system for the next considerations.

1.2 Terms of instability and fluctuations

As we mentioned above, it is possible to observe the next situation in most hydrodynamical flows: when some of the parameters characterizing the accretion flow - the velocity, the density or the pressure are perturbed the flow could change its state. Then, a different ways of the flow behavior are possible to be appeared – to remain stable, to become instable, to become turbulent, and to form a vorticity. It is suggested in the current survey of how we consider these perturbations in the quantities. To study these features we choose to explore by the equations of Navier-Stokes, because of the fullness of their form and the possibility of suitable transformations.

Our first step is to insert the perturbation quantities into the parameters and to receive an equation for hydrodynamic instability, such as

$$V = v + u; \rho_0 = \rho + \rho^{'}; p = P + p^{'}, \qquad (5)$$

where in these expressions V, ρ_0, p are the total quantities of velocity, density and pressure, v, ρ, P are the time averaged values and $u, \rho^{'}, p^{'}$ are the perturbations in time.

Balbus (2003) has made a fully and much more detail analysis of disc's stability, using similar expression of perturbation function, but in a different conditions of the disc flow compared to our case. We choose for the perturbations to be in an exponent form with a power of second order and their common view may express for the velocity: $u\left(r, \varphi\right) \approx u \exp\left(ik^2 t - im\varphi\right)$. This form is applied as well to the other quantities. Here k is the wave number and m is the mode number on direction.

For the next considerations, we rewrite the Navier-Stokes equation in cylindrical coordinates (r, φ, z), as we include the newly introduced quantities from (5), transformed over perturbation quantity:

$$\text{(6a)} \quad \frac{\partial V_r}{\partial t} + V_r \frac{\partial V_r}{\partial r} + \frac{V_\varphi}{r}\frac{\partial V_r}{\partial \varphi} - \frac{V_\varphi^2}{r} = -\frac{1}{\rho_0}\frac{\partial p}{\partial r} - \Omega \frac{\partial V_r}{\partial \varphi} + 2\Omega V_\varphi + \nu\left(\frac{\partial^2 V_r}{\partial r^2} + \frac{1}{r^2}\frac{\partial^2 V_r}{\partial \varphi^2} + \frac{1}{r}\frac{\partial V_r}{\partial r} - \frac{2}{r^2}\frac{\partial V_\varphi}{\partial \varphi} - \frac{V_r}{r^2}\right)$$

(6b) $$\frac{\partial V_\varphi}{\partial t} + V_r \frac{\partial V_\varphi}{\partial r} + \frac{V_\varphi}{r}\frac{\partial V_\varphi}{\partial \varphi} - \frac{V_r V_\varphi}{r} = -\frac{1}{\rho_0 r}\frac{\partial p}{\partial \varphi} + \frac{\partial r^2}{\partial r}\Omega \frac{V_r}{r} - \Omega\frac{\partial V_\varphi}{\partial \varphi} + \nu\left(\frac{\partial^2 V_\varphi}{\partial r^2} + \frac{1}{r^2}\frac{\partial^2 V_\varphi}{\partial \varphi^2} + \frac{1}{r}\frac{\partial V_\varphi}{\partial r} - \frac{2}{r^2}\frac{\partial V_r}{\partial \varphi} - \frac{V_\varphi}{r^2}\right)$$

(6c) $$\frac{\partial V_z}{\partial t} + V_r \frac{\partial V_z}{\partial r} + \frac{V_\varphi}{r}\frac{\partial V_z}{\partial \varphi} - V_z\frac{\partial V_z}{\partial z} = -\frac{1}{\rho_0}\frac{\partial p}{\partial z} + \nu\left(\frac{\partial^2 V_z}{\partial r^2} + \frac{1}{r^2}\frac{\partial^2 V_z}{\partial \varphi^2} + \frac{1}{r}\frac{\partial V_z}{\partial r} - \frac{2}{r^2}\frac{\partial V_r}{\partial z} - \frac{V_z}{r^2}\right)$$

The rest denotations are the same as in (2), Because of the time averaging and the presence of perturbations in the quantities, some of the terms in the equations may vanish or reform their expression. As the expression in z-direction brings no new information for us and after averaging over z, we ignore (6c).

Then we obtain from (6a) and (6b) that the second and third term in the right hand site expresses turbulence activity. By the presence of this term we may detect the spring up of instability and we call it "unstable term". This term contains the quantity of angular velocity Ωthat is found to be of importance for studying the differential flow in accretion discs. It is seen from the above equations that the "unstable term" presence only in r and φ directions, which fact is in accordance with our initial conditions for this case.

Now, following the perturbed equations (6a, 6b), where we have extracted the "unstable terms": $\Omega\left(\frac{\partial r^2}{\partial r}\frac{V_r}{r} - \frac{\partial V_\varphi}{\partial \varphi}\right)$ and $2\Omega\left(\frac{1}{2}\frac{\partial V_r}{\partial \varphi} - V_\varphi\right)$, and using the mode number $m$from perturbation expression we consider of how the velocity and density variations develop.

Visualization of the problem requires applying a numerical parameterization code. We used a grid-scale measurement of values [12, 12, 12], which is more suitable to decipher the results. In the result, Fig.1 and Fig. 2 below show the velocity excesses and the density fluctuations distribution over r, during the period of disturbances.

In Figs. 1a, 1b, 1c, 1d we express how the process changes when the different values of m are applied. It is observed that in a range of $(-0.2 \div -0.45)$ the velocity exchange is in a quiet. Further, when the values of $m$are started to decrease ($m \le -1$) the process turns out and it is seen a fission and suddenly exceeds of the velocity values. In our opinion, this may cause some unstable activity locally in the accretion discs zone. The scales of the axes are constrained for the visualization only and there is not a relation to the real values.

The density variations are obtained in the same way. Figure 2 shows that fluctuation's process damps for a period of time, then arises again if the perturbations are still active.

In a presence of white dwarfs we have to include an additional terms. Following the fact that the internal white dwarf luminosity is a large and this indicates for a heating by accretion, we will work with the presence of temperature gradient and entropy. Therefore, it is needed for our calculations to work out an expression and graphical view of such quantities.

We rewrite the energy balance equation in the form with the entropy presence:

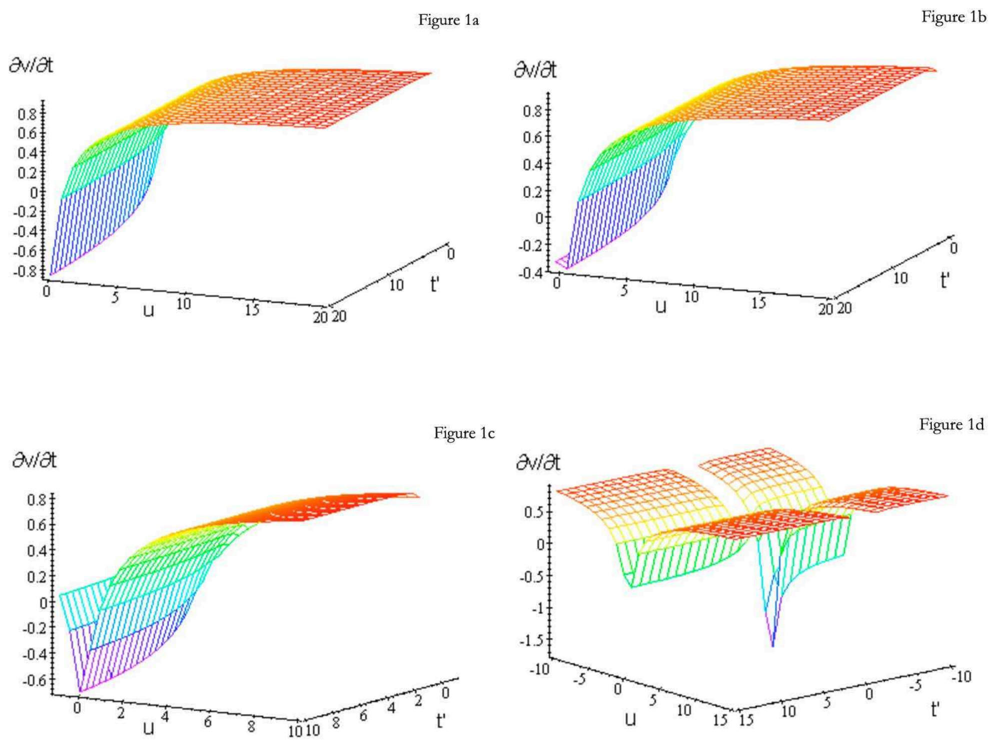

Fig. 1. Velocity exceeding in accretion flow. These graphics are received after applying analytical examinations of the perturbed quantities and using appropriate mathematical software to parameterize the value. In this figure four consecutive phases are expressed to trace out the process in different values of m (1a,1b,1c,1d).

$$\frac{\partial}{\partial t}\left[\rho\left(\frac{1}{2}v^2+\varepsilon+\Phi\right)\right]+\nabla.\left[\rho v\left(\frac{1}{2}v^2+h+\Phi\right)\right]-\rho T\frac{dS}{dt}=0 \qquad (6)$$

Here T is the temperature of the mass flow and S is the entropy function. The rest denotations are the same as above. Now, Eq.(6) is also included in the above system. Then for the temperature evolution we obtained the next expression and the solution shows it is not a constant:

$$\frac{\partial T}{\partial t}=-v.\nabla T-\frac{1}{\rho}\frac{\partial P}{\partial r}+\nu.\Delta T \qquad (7)$$

Friction within the disk heats up the accreting material, and forces the material to gradually spiral down onto the white dwarf surface. One of the

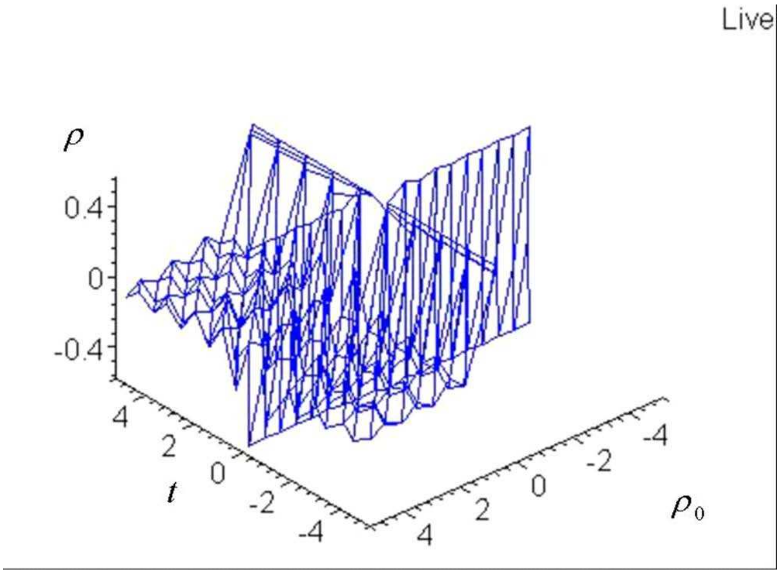

Fig. 2. The image shows distribution of density variations in the disc flow, after applying perturbation function

sources of X-rays luminosity's exchanges in these CVs usually comes from the place, where the accretion disc hits the white dwarf surface.

The infalling matter, rich in hydrogen, forms in most cases an accretion disc around white dwarf. The accretion disc may be prone to an instability leading to outburst, when the portion of disc material falls onto white dwarf. The cataclysmic outbursts occur when the density and temperature rises high enough to ignite nuclear fusion reactions. To verify this, we use last two equations, (7) and (8) and we apply to them a consecutive implicit differentiations, as the perturbation quantities from (5) are also included. Then we put into considerations a numerical parameterization code of the equations' values and it is obtained the evolution exchanges of the relation $\partial T/\partial t$, in the result. The r.h.s. of (8) is found to be most effective term in current analysis and estimation of the temperature's exceeding.

Graphical solution of such result is shown in the Fig.3, where the temperature evolution in the place of interaction of falling material and the white dwarfs surface is traced out.

This sharp growth of temperature of the white dwarfs, which is clearly seen at the Fig.3, could be works in conjunction with the existence of velocity and density fluctuations, such as at the Figs 1 and 2. The above considerations tell us of how unstable effects in accretion discs of these binary stars may be examined in principle. We suggested just one of the recently known methods for detection of such activity. But, even there are quite a few methods, the problem has not fully resolved until now.

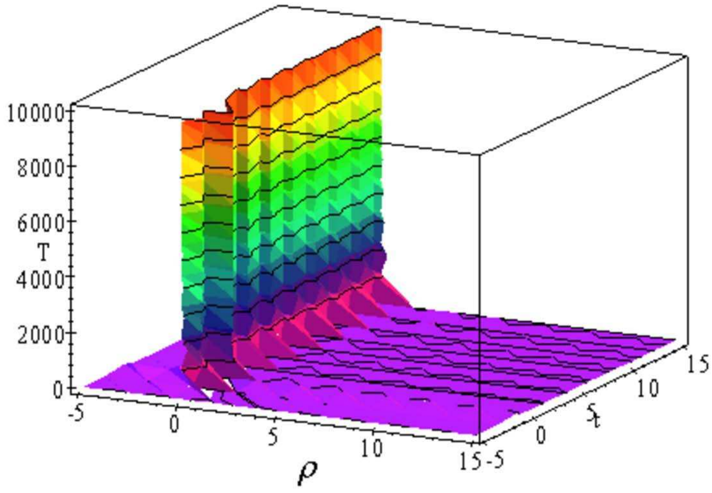

Fig. 3. Temperature evolution of the flow in the presence of white dwarf companion. It is shown the exchange of temperature value and the infalling accreting matter interacts with white dwarf. This increase of the temperature is in a base of the suddenly bursts, which reflects to the shape of light curve of CVs.

2 Effects on the shape of the light curves

In this section we show the observational analysis of some kind of unstable processes, spontaneously or suddenly to be appeared in a flow of accretion binaries.

Measurement of the variation of the X-ray luminosity of an object provides a wealth of information about the dynamics and physical processes in a system. The spin of an object will often appear as a periodic fluctuation in the object's luminosity. The eclipse of an object by an orbiting companion will appear as a periodic dip in the light curves. Instabilities or fluctuations in the flow of material through an accretion disk can appear as random or quasi-periodic fluctuations in the luminosity, which provides information on the physics of fluid flown onto an accreting source. The last relation is the topic of the current paper problem.

The shape of the luminosity of LMXBs may provide important information about their long term evolution. Postnov & Kuranov (2005) noted that the observed shape of the LMXBs luminosity function depends on the distribution of the masses of optical donor star. They assume that the X-ray luminosity of the compact object is directly proportional to the mass transfer rate in the binary system. The coherent kHz oscillations discovering during X-ray bursts from LMXBs strongly suggest (Strohmayer 1996) for the existence of neutron stars in such binaries. Many LMXBs emit X-ray bursts,

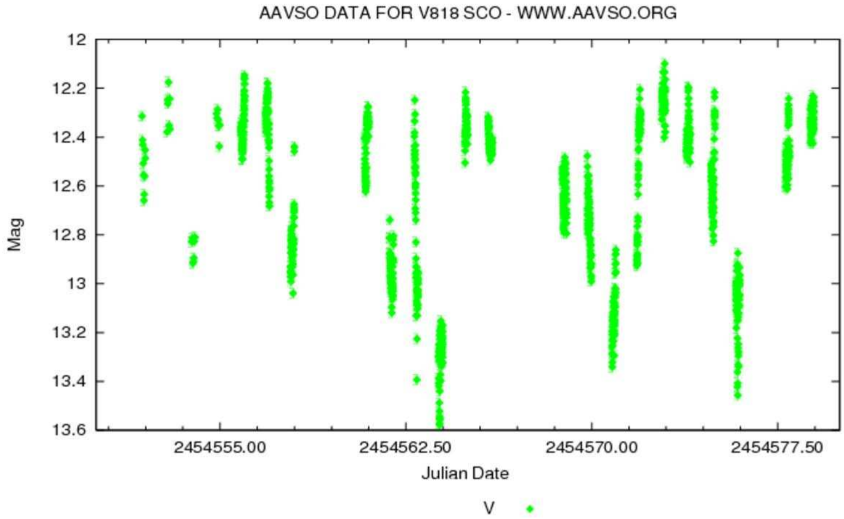

Fig. 4. Light curve of LMXB V818 Sco (RK catalogue of X-ray stars). It is seen the short period oscillations with effect on the shape of light curve. The image is created on the observational data of AAVSO /www.aavso.org/

during which X-ray flux rises by typically at least an order of magnitude, usually within about a second (van Paradijs 1998).

At quasi-periodic intervals, instability that occurs in the accretion disc or in the secondary star triggers an increased amount of matter to accrete onto the primary (white dwarf) (Chakrabarty 2005), creating the explosions (called eruptions or outbursts) that cause the system to brighten up. Most likely, the reason of these bursts is hidden in the flow fluctuations, such as some unstable phenomena: shock waves, turbulization and pattern formation. The optical radiation from an X-ray source arises from a different set of processes, and often from different parts of a system than X-rays, so the ability to make these observations provides much more information about the physical conditions at the objects. When the magnetic field from considering binaries is excluded some of observed results refer to them are weak X-ray sources. Nevertheless, we have received sufficiently amount of data contributed to the next type of considerations.

Some authors have detected that depending of inclination angle the light curve produces the variation in its shape. At small inclination there is a gradual, broad modulation (Tagger & Melia 2006). Whereas, for the high inclination it is begin to see the effects of two-spiral arm emitting region. Moreover, such light curve modulations may associate with Rossby type of instability. The inclination angle of studied in our paper binaries is chosen to be of different values, which give a possibility to analyze and compare this mutuality.

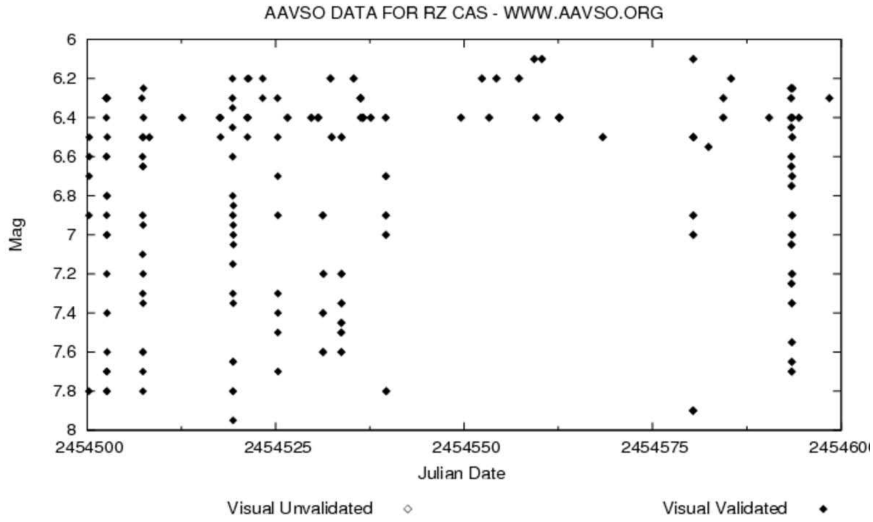

Fig. 5. Light curve of RZ Cas (LMXB). This is semidetached binary systems. It is observed an irregular variation in the light curve shape, caused by some kind of instable behavior in the mass transitions between two objects. The image is created on the observational data of AAVSO /www.aavso.org/

How this look on the light curves shape, which we create for the selected binaries. It is essential for our suggestions the magnitude variations of LMXBs must be elapsed in long period, of about 1 year in quiescent and a month for outbursts. However, this is more optional situation for Soft X-ray Transients. The magnitude variations in the currently studied LMXBs (V818 Sco and RZ Cas) are not so high, but changes sharply. These springs, as well, points to the running of unstable processes, usually in a boundary of accretion disc flow.

In the light curves of GK Per and MV Lyr, which are CVs, the suddenly or rapid luminosity variations are occurred after a period of quiescent and level of similar values (see Fig.7). A period of high magnitude of luminosity is replaced by drop of about six levels, then the value of luminosity restores for a short time and drops fast again (see Fig.8). The aperiodicity of the emission rate can be seen in the Fig.6.

Let's return to the inclination values estimation. We have observed a dependence of the light curve shape on these values, but not in the relation of some instability detection in disc flow. Because of eclipsing of binaries in range of $65° \leq i \leq 90°$, the burst's processes are less possible to reveal and examine by such light curves, correspondingly magnitude variability. In this reason, binaries with $i \leq 60°$would be appropriate for studying of such unstable flare-up processes, or using new methodology.

We have selected currently investigated binaries (LMXBs and CVs) from the General Catalogue of Variable Stars (Kholopov et al 1987) and Catalogue

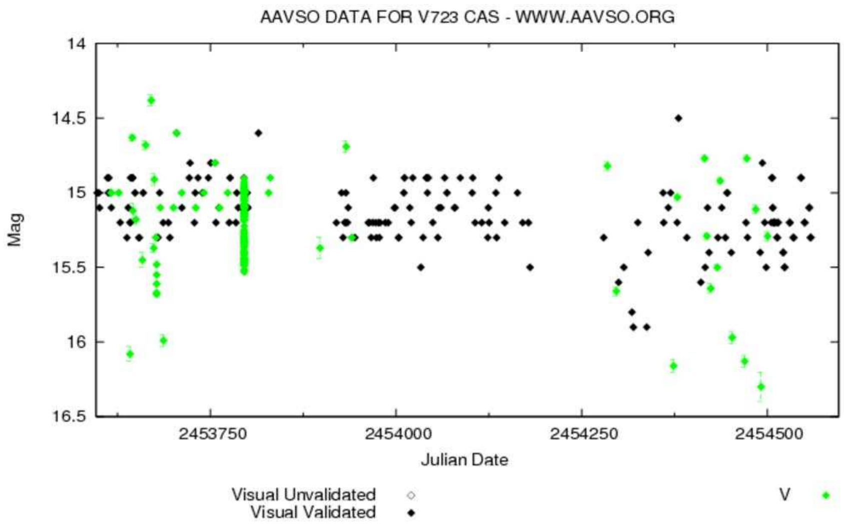

Fig. 6. Light curve of V723 Cas (CV). It is seen aperiodic variability of luminosity during the presented period of observation. The image is created on the observational data of AAVSO /www.aavso.org/

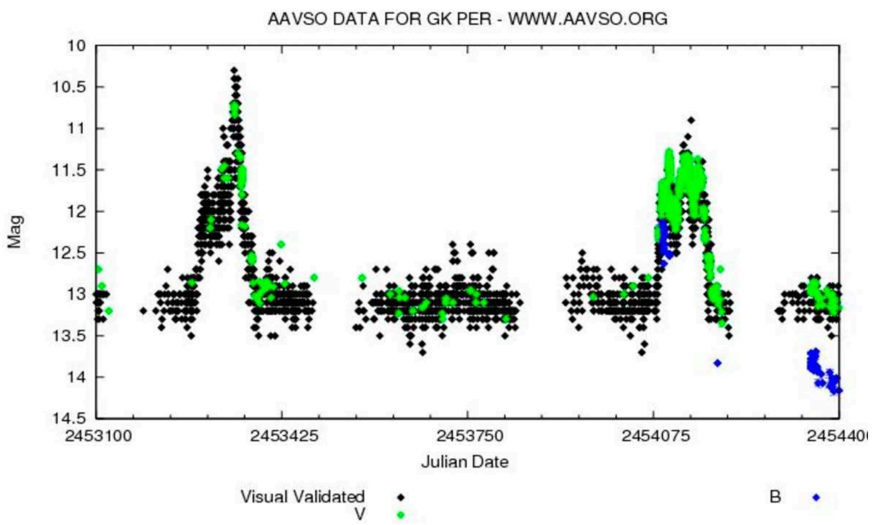

Fig. 7. Light curve of CV GK Per (RK catalogue of X-ray stars). It is observed the X-Ray pulsations with rapid than slow irregular variations in the luminosity. The image is created on the observational data of AAVSO /www.aavso.org/

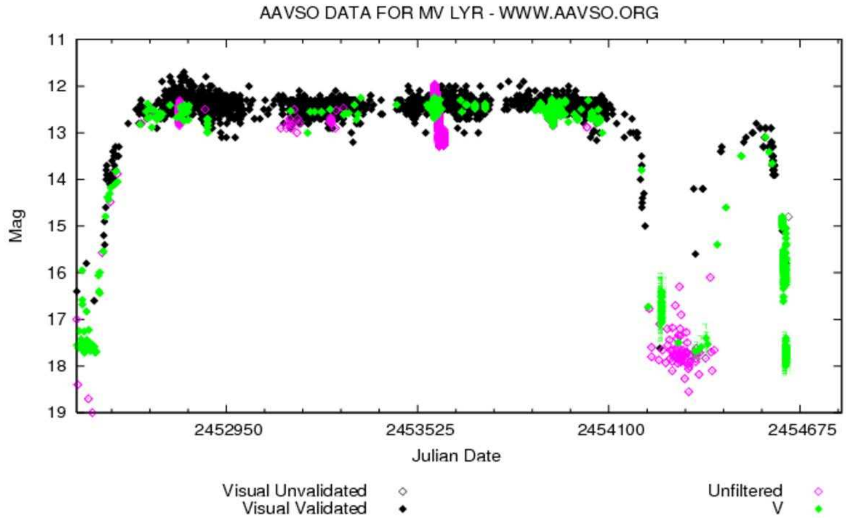

Fig. 8. Light curve of MV Lyr (CV). This is a soft X-Ray source. It is observed quasiperiodic fading at different amplitude. The image is created on the observational data of AAVSO /www.aavso.org/

of CV, LMXBs and related objects (Ritter and Kolb 2003). The data of observations are contributed, as follows, by the observers of AAVSO.

Summary

Gravitational potential of neutron stars provide the most effective mechanism of releasing energy from matter. The viscosity in accretion discs slowly converts gravitational energy into thermal. We have analyzed the conditions of physical processes in LMXBs and CVs compact binaries, contributed to unstable behavior of the accompanying disc flow. We used the well known common assertion of how the instabilities appear. In the theoretical part of this paper we presented the basic equations and we have applied them to show that the disturbances in the parameters of hydrodynamical flow cause some oscillations and bring to the probability of turbulization of the flow. It has applied the Runge-Kutta numerical method, which is implemented to computational program, used in our calculations. According to the different properties of two kind of exploring binaries, It becames obvious that magnetic field in such binaries is possible to neglected in the current considerations.

As a result, we have worked out the expression and have drawn the Fig.3 of temperature evolution in the place of accretion flows' interaction. We have obtained the distribution of density and velocity fluctuation by applying the perturbation function in the equations of motion.

Observationally these disturbances in instability state of the disc flow are expressed as pulsations, bursts, rapidly rotation, quasi-periodic oscillations and etc. It is already known about the influence of such processes on the light curves form. In support of this, we selected to explore the variability of luminosity for the five binary stars.

Finally, based on the above study, we clam that the variations of the shapes of the presented light curves give us information about the conditions inside the accretion flow and give an indication for the existence of some kind of unstable processes. As well, the exceeding of velocity and density in the mass inflow trough the compact binary could be, possible mechanisms that caused some kind of X-Ray radiation variability

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References

Balbus S. A., 2003, Enchanced angular momentum transport in accretion discs, An. Rev. A&A, 41, 555-597.

Castro-Tirado A. J., Pavlenko E. P., Shlyapnikov A. A., Brandt S., Lund N., Ortiz J. L., 1993, Discovery of the optical counterpart of the soft x-ray transient GRO: J0422+32, A&A, 276, 2, L37

Chakrabarty D., 2005, "Millisecond Pulsars in Low-Mass X-Ray Binaries," in Interacting Binaries: Accretion, Evolution, and Outcomes, vol. 797 of American Institute of Physics Conference Series, pp. 71–80

Gammie C. F., 2001, ApJ, 553, 174

Kholopov P.N., Samus N. N., Frolov M.S., Goranskij V.P., Gorynya N.A., et all (13 authors), 1987, General Catalogue of Variable Stars, 4th edition, Volumes I-III, Moskow, Nauka

Lewin W. H. I., van Paradijs J., van den Heuvel E. P. J., 1995, X-Ray binaries, Cambridge Astrophysics Series, p. 73

Li H., Colgate S. A., Wendroff B., Liska R., 2001, ApJ, **551**, 874

Lovelace R.V.E., Li H., Colgate S.A., Nelson A.F., 1999, ApJ, **513**, 805-810

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, 3D gasdynamical modelling of the changes in the flow structure during transition from quiescent to active state in symbiotic stars, arXiv [astro-ph]:0510175

Papaloizou J. C. B., Pringle J. E., 1984,The dynamical stability of differentially rotating discs with constant specific angular momentum, MNRAS, **208**, 721-750,

Petersen M.R., Steward G.R., Julien K., 2006, preprint, astro-ph/0611526v1

Piro A. L., Bildsten L., 2007, Turbulent mixing in the surface layers of accreting neutron stars, Ap. J., accepted for publication, arXiv [astro-ph]: 0704.1278v1,

Podsiadlowski P., Rappaport S., Phahl E. D., 2002, Evolutionary sequences for low- and intermediate- X-ray binaries, ApJ 565, 1107-1133,

Postnov K. A., Kuranov A. G., 2005, The luminosity function of Low-mass X-ray binaries in Galaxies, AstL, 31, 1,

Ritter H., Kolb Ul., 2003, Catalogue of CV, LMXBs and related objects, 7th Edition, A&A, 404, 301-303,

Tagger, M., F. Melia, 2006, A possible Rossby wave instability origin for the flares in Sagittarius A, ApJ, 636, L33

Townsley D. M., Bildsten L., 2001, Faint CVs in Quiescence: Globular Cluster and Field Surveys, submitted to ApJL, astro-ph/0112270v1,

Strohmayer T. E., Zhang W., Swank J. H., Smale A., Titarchuk L., Day C., Lee U., 1996, Millisecond X-ray variability from an accreting neutron star, ApJL, 469, L9,

Van der Klis M., 2004, Rapid X-ray variability, Cambridge University Press "Compact Stellar X-Ray Sources",

Van Paradijs J., 1998, Neutron stars and black holes in X-ray binaries, arXiv: astro-ph/9802177v1