ESTIMATION OF ACCRETION PARAMETERS IN THE PRESENCE OF MAGNETIC FIELD OF THE BINARY STAR GAMMA CASIOPEIAE

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Abstract: *We explore the flow properties of the binary star gamma Cassiopeiae (hereafter γ Cas and gamma Cas), which is a member of the Be stars group. Gamma Cas is an X-ray binary star and its main activity manifests in hard X-rays. One possible origin of this emission is magnetic disc – stellar atmosphere interaction. To visualize the object's activity, the observational data for two selected days, obtained from an X-ray telescope are presented.*

The main aim is to study of how the parameters of the system with the accreting flow are in a relationship with the presence of magnetic field. We consider, calculate and describe the basic parameters and on the base of the obtained values we give an estimation of this relation. The results confirm the magnetic field existence and the possibility of this interaction to be a source of the X-ray emission.

Following the obtained results, we discuss about the accretion disc formation around the primary component as a most possible scenario in this star's system evolution.

ОЦЕНЯВАНЕ НА АКРЕЦИОННИТЕ ПАРАМЕТРИ ПРИ НАЛИЧИЕ НА МАГНИТНО ПОЛЕ В ДВОЙНАТА ЗВЕЗДНА СИСТЕМА GAMMA CASIOPEIAE

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Ключови думи: *Двойни звезди; Be звезди; рентгеново излъчване; акреционни дискове; магнитно поле*

Резюме: *В тази статия ние изследваме свойствата на потока на двойната звездна система gamma Cassiopeiae (γ Cas and gamma Cas), която принадлежи на Be клас звезди. Gamma Cas е рентгенова двойна и нейната основна активност се проявява в твърдата част на рентгеновия спектър. Един основен произход на това излъчване е взаимодействието между акреционен диск с магнитно поле и магнитна звездна атмосфера. За визуализиране на активността на обекта, са представени наблюдателни данни за два избрани дни от различни години, получени от рентгенов телескоп.*

Основна цел е изучаването на връзката между параметрите на двойната система с акреционно течение и наличието на магнитно поле. Тук представяме, пресмятаме и описваме основните параметри и въз основа на получените стойности даваме оценка на тази връзка. Резултатите потвърждават наличието на магнитно поле и възможността това взаимодействие да е източник на рентгеново излъчване.

Спрямо получените резултати се дискутира формирането на акреционен диск в двойната система около първичната компонента като най-възможен сценарий в еволюцията на системата.

1. Introduction

The research in this paper focuses on the astrophysical object gamma γ Cas, which belongs to the special class binary stars – Be stars. Be stars are of the B spectral type with HeI emission lines in their spectra. They are also known by their rapid rotation - up to 450 km/sec at their equator [15]. Gamma Cas is found by Secchi in 1867, as the first known in Be class [23]. The spectral type of γ Cas is BO.5 IV [15, 28].

The Hα emission lines in its spectra is also observed, whose origin is most likely from a disc or from that part of the disc with a higher density ~ 10^{13} cm^{-3} [25, 31]. The disc's recognition image is received by implication of an interferometer [21, 29]. The optical observations of the star show variability, with magnitudes of 1.9 – 2.5 in V band (according to AAVSO data).

Gamma Cas produces X-rays, dominantly in the hard part of the spectrum (kT ~ 10 - 12 keV) [12, 32], most probably by the hot component [18, 19, 20], which are untypical for this class of objects. The X-ray luminosity of γ Cas is in a range of $\sim 10^{32}-10^{33}$ erg s^{-1}. These values are considered to be larger than the X-ray luminosity of the typical O and B classes of stars [24]. Data of these detections are reported by observations of X-ray instruments on board of the telescopes and satellites, such as: ROSAT, Chandra, XMM – Newton, Rossi X-ray Timing Explorer (RXTE), INTEGRAL, Suzuku, Swift etc.

Two basic suggestions to explain the X-ray emission of γ Cas are commonly accepted. The first one proposes that it is powered by the wind or accretion from Be star to the primary neutron star [32] or even some authors consider it is a white dwarf one [8,18], which is still under discussion.

The second idea gives the model in which the interaction between the magnetic stellar surface and circumstellar disc magnetic field produces the observed X-ray range in γ Cas [12, 22].

It is also supposed that the X-rays generation in γ Cas could be produced by a Balbus-Hawley instability [1], further related to a disc dynamo [22].

The possible existence of magnetic disc in γ Cas provokes the research in the current paper.

To visualize particularly the observational behavior of γ Cas, in Section 2 we present data [4,5] from the X-Ray telescope (XRT), which is loaded at the Swift satellite.

We focus on the measurement of the disc-star parameters, see Section 3. We should note that all the values in the calculations in this paper are in units of: *g (gram); cm (centimeter); s (second); cm / s (centimeter per second)*. In the Discussion, we give an estimation of the existence of magnetic field, according to the resulting values and relations from the calculations.

2. Observational data

As an X-ray binary, the most detectable events of γ Cas activity manifests in the X-ray band. We use observational data from the online generator of the SWIFT – XRT data base.

We include data of registered events from two days: 2458589.3604 JD (Julian Date) and 2456862.5 JD. The whole energy range E in the analysis of XRT data is between 0.3 ÷ 10 KeV, delimited in 3 bands separation [5]: Soft = 0.3 ≤ E < 1 keV; Medium = 1 ≤ E < 2 KeV; Hard 2 ≤ E < 10 keV.

There are two reading-out basic modes at the XRT, included into the preparation processes of light curves and energy spectrum [4]. They are switching automatically depending on the source intensity. The Windowed Timing (WT) mode operates at high count rates. The other one is Photon Counting (PC) mode, which is used at lower count rates. Both can be seen in the resulting light curves and energy spectrum of γ Cas (fig.1 and fig.2). The Modified Julian Date (MJD) is used as a time format of the generated X-ray light curve.

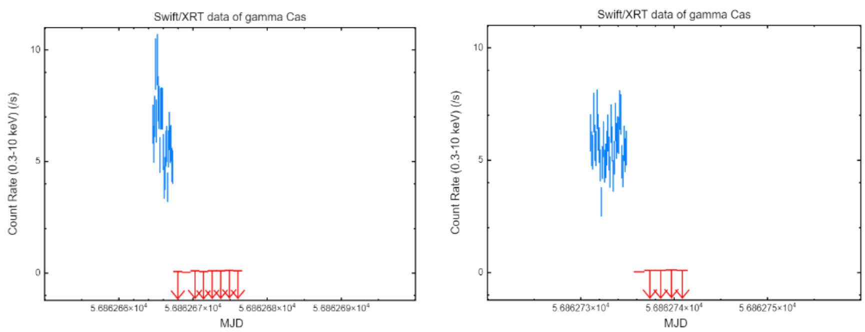

Fig. 1. XRT light curves of γ Cas in the 0.5 - 10 keV energy bands with 3σ certainties. The light curve consists of 100s time bins in PC mode and covers the time period of 2458589.3604 JD. The average count rate for this time period is ~ 6.5 c/s.

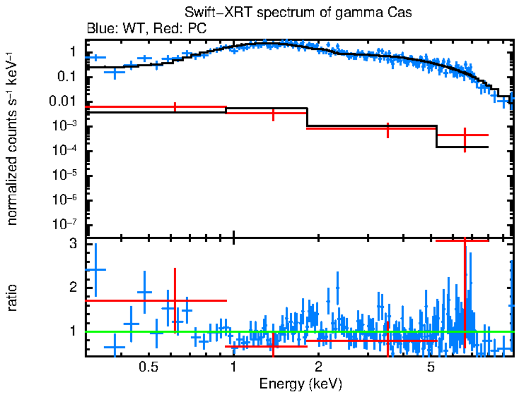

Fig. 2. XRT energy spectrum of γ Cas for day 2456862.5 JD. The normalized counts have their highest values at the hard band of the energy spectrum (2 ÷ 10 keV), in WT mode. (Data from Swift-XRT)

The obtained data for two dates can be summarized, respectively for the energy spectrum and light curves, as follows:

As it is expected, the saturation of the registered events is observed at the hard part of the energy band, mostly at 3 ÷ 10 keV with largely operation of WT mode for both dates.

For day 2458589.36 JD (58588.86 MJD), the counts rate per second are between 4 - 9 c/s in WT and ~ 0.03 c/s in PC. The normalized counts per second reach the maximum value of 2-3 $s^{-1}keV^{-1}$.

For 2456862.5 JD (56862 MJD), the maximum counts rate per second are between 4 ÷ 7 c/s in WT and ~ 0.005 c/s in PC

The obtained observational data could be further used to estimate some of the parameters of the γ Cas binary system.

3. Estimation of the g Cas parameters and magnetic field.

For the purpose of this study, we are taking into account some basic parameters of the binary's components, those related to their interaction. The masses of two components has been estimated and for the primary it is in the range of 13 - 18 M⊙ [7, 10, 28, 33], while the mass of the secondary is between 0.7 and 1.9 M⊙.

An orbital separation of the binary components ***a*** ~ 350 - 400 R⊙ [9, 10]. The γ Cas orbital period is known to be in ~ 203.9 days and its eccentricity ***e*** ~ 0.26 [10, 12]. The estimated distance to the star is of 188 pc [3]. Its optical luminosity is L = 3.51L⊙ and the evaluated effective temperature is 25000 K [26]. Calculations of the radial velocity give the values between 230 km s^{-1} [26] and 430 km s^{-1} [27].

Using the values of these parameters, we further calculate and estimate the radii of two components, orbital momentum, mass transfer and accretion rate.

Assuming the primary star is a main sequent (MS) or close to the MS star, its radius' value can be obtained by the next simple expression:

(1) $$\frac{R_1}{R_\odot} = \left(\frac{M_1}{M_\odot}\right)^{0.75}$$

Where $R_\odot$ and $M_\odot$ are respectively radius and mass of the Sun. For M_1, we accept the value: $M_1 = 15M_\odot$. The calculation then gives: $R_1 = 7.62R_\odot = 5.25 \times 10^{11} cm$.

For the radius of the secondary, we apply the equation of Eggleton [13, 30], which is appropriated for masses less than Chandrasekhar mass $M_{Ch} = 1.4M_\odot$:

(2) $$\frac{R_2}{R_\odot} = 0.0114 \left[\left(\frac{M_2}{M_{Ch}}\right)^{-2/3} - \left(\frac{M_2}{M_{Ch}}\right)^{2/3}\right]^{1/2} \times \left[1 + 3.5\left(\frac{M_2}{M_p}\right)^{-2/3} + \left(\frac{M_2}{M_p}\right)^{-1}\right]^{-2/3}$$

Where for the mass of the secondary, we accept $M_2 = 1.2M_\odot$ and $M_P = 0.00057M_\odot$ is a constant.
We derive for $R_2 = R_\odot = 5.54 \times 10^{-3}R_\odot = 3.82 \times 10^8\ cm$.
Then, for the total mass $M = M_1 + M_2$, we have $M = 16.2M_\odot$ and mass ratio $q = M_2/M_1 = 0.08M_\odot$.

The orbital momentum of the system, J_{orb}, can be calculated by the equation [6]:

(3) $J_{orb} = M_1 M_2 \left(\frac{Ga}{M}\right)^{1/2}$

where G = 6.67 x 10^{-8} cm^3 g^{-1} s^{-2} is the gravitational constant. We derive for J_{orb} = 5.67x10^3 g cm^2 s^{-1} The rate of mass transfer in Be/X-stars [11] is estimated to be ~$10^{-12} \div 10^{-7}$ M⊙ yr^{-1}.

The accepted and measured values of the current parameters are listed in Table 1.

Table 1. The γ Cas parameters, as follows: M_1 - mass of the primary star, M_2 – mass of the secondary star, q – mass ratio, P – orbital period, *i* - inclination angle, R_2 – radius of the primary star, R_1 – radius of the secondary star, a – the orbital separation between the components, J_{orb} – orbital momentum.

M_1 [M⊙]	M_2 [M⊙]	q	M (M_1+M_2)	P [days]	*i* [deg]	R_1 [R⊙]	R_2 [R⊙]	a [R⊙]	J_{orb}
15	1.2	0.08	16.2	203.9	44	7.62	5.54x10^{-3}	350	5.67 x10^3

Recently, there are much more arguments in the investigations that confirm the formation and existence of accretion disc in γ Cas.
One of them is related to the existence of rotational line in Hβ emission [2]. From this line the radial velocity can be estimated and then the Keplerian disc radius $R_K \approx 1.7R_1$. Since in Hα vibrations are found, which are probably coming from the last stable orbit. Then by these vibrations and from their velocity, the radial velocity of this orbit could be found and from there the inner disc radius is derived, R_{in}~$1.5R_1$.

In a difference with these estimations, if we are taking into account the thin disc approximation, from the expression of the radial velocity: $v_R = \alpha c_S \frac{H}{R_d}$, we can measure the ratio of the disc thickness H to the disc radius R_d. For the radial velocity we apply the accepted value: $v_R \approx 230 km/s \approx 2.3 \times 10^7 cm/s$; c_S is the speed of sound; $\alpha \approx 0.01 \to 1$ is the turbulent parameter. The calculated ratio is then: $\frac{H}{R_d} \approx 6.72 \times 10^4 cm$. According to our result, this value is quite lower than the radius of the primary star, which is in contrast to the typical systems with accretion disc onto the compact objects.

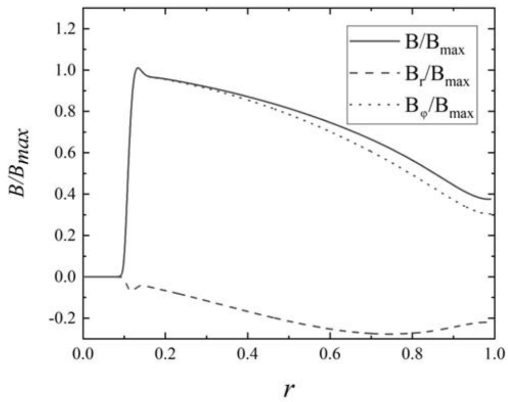

Fig. 3. Magnetic field structure. The field is measured in units of equipartition value *Bmax*, the distances are measured in outer radii of the disc.

In case, when the magnetic field source is coming from the secondary component, the magnetic field evolution for the objects of γ Cas type can be described using so-called no-z approximation [17]. It has been developed for galaxy discs [16], but the principal structure of the magnetohydrodynamical fluids is nearly the same (of course, we should take into account different length-scales). The typical spatial structure of the magnetic field is shown on fig.3. We can see from the simulations that the field has both components an azimuthal and a radial, where the second one is more relevant to our object.

Discussion and conclusion

In this paper, we presented some basic parameters of the special binary star γ Cas, classified as a Be/X star. We calculated the radii of the star's components, orbital momentum, we estimated the disc radii and we described their relation.

From the properties and value of the X-ray luminosity, Lx ~ 10^{33} erg s^{-1}, and the dominantly high values of *kT ~ 14keV*, seen at the spectra of γ Cas, the estimated value of the plasma temperature is *Tpl ~ 10^8 K* [27]. These values are a sign that plasma in the disc, no matter if there is an accretion or decretion, is an optically thin. The disc is still Keplerian, for which has an evident [14]. Estimations of the disc temperature vary of values between 9000K and 10700K, which is much lower than the stellar temperature, see in the previous section above. All these results adopt that the disc has a magnetic field. This could be one more clue in support to the second hypothesis of the X-ray production in γ Cas, related to the magnetic circumstellar disc and stellar surface interaction.

The selected from us observational data for two days, registered by Swift – XRT, presented in Section 2, just confirm the dominant emission of γ Cas in the hard part of the X-ray band. These X-ray data could be used in our next paper to measure the energy released by the emission and the actual accretion efficiency.

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