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VARIABLE MECHANISMS OF MASS TRANSFER IN FOUR BINARY STARS SYSTEMS

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Abstract: *In this paper, we summarize our analysis of accretion properties in four binary stars of different types: AG Dra (Draco), NQ Gem (Gemini), V 592 Cas (Cassiopeia) and 61 Cyg (Cygnus). An accretion efficiency as a useful measure that illustrates the power of accretion as an energy generator is applied. We showed of how the efficiency varies with the three suggested modes of accretion: disc accretion, spherical accretion and two-stream matter feeding. We found that the measured values of accretion efficiency increase in order of the accretion modes development, in the four objects in different ways.*

We discuss on the currently active mass transfer mechanisms between the binary components: via Roche Lobe Overflow and stellar wind. This could be relevant to the type of accretion - wind or disc is dominant for each of the objects.

АКТИВНИ МЕХАНИЗМИ ЗА ПРЕНОС НА МАСА ПРИ ЧЕТИРИ ДВОЙНИ ЗВЕЗДНИ СИСТЕМИ

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

Резюме: *В тази статия, ние представяме обобщен анализ от резултати върху свойствата на акреция при четири двойни звезди: AG Dra (Дракон), NQ Gem (Близнаци), V 592 Cas (Касиопея) и 61 Cyg (Лебед). Величината ефективност на акреция е въведена като мярка, която изразява силата на акретора като генератор на енергия. Показано е как ефективността се променя за трите предложени режима на акреция: дискова акреция, сферична акреция и двупоточно подаване на материя.*

Установихме, че измерените стойности на ефективността нарастват в реда на развитието на режимите на акреция в четирите обекта по различен начин.

Дискутирани са и активните механизми за пренос на маса между компонентите на двойната: през точката на Лагранж и чрез звезден вятър. Това може да е от значение за типа акреция, при който звездният вятър или дискът са доминиращи за всеки от обектите.

Introduction

1. The problem background

At some stage of the evolutionary path, binary stars' components start to interact and transfer matter between them. This could happen in two currently known ways. It depends on types of the studied objects or at which point of an evolutionary stage they are. When one of the stars (usually the secondary) in binary increases the radius enough to fill its Roche lobe and when the binary separation became smaller, the matter overflows through the Roche lobe and L_1 point (Lagrange point) [11].

In some binary stars, one of the components throws out much of its material in a form of a stellar wind, which is attracted by the gravitational field of the primary star. Further, as a product of interaction between the components in binary stars, an accretion flow forms. The accretion processes give possibilities to study the physical properties and conditions of astrophysical objects.

The variable mechanisms of mass transfer through the components could have further contribution to the amplitudes of the brightness variability.

To determine the possible mass-transfer mechanism, we first make a relation to the estimation of accretion efficiency (Section Results). An estimation of accretion efficiency is important, because it has a close relation to the emitted energy and has a further role in binaries evolution. An advantage to know the accretion rate is the possibility to estimate the mode of accretion and the possible transition between them.

2. Targets selection and details

For the purpose of this paper, four binary stars are selected. Two symbiotic binaries AG Dra and NQ Gem, a Nova like V 592 Cas and a visual binary 61 Cyg. Here we present short characteristics of each of them.

AG Dra is a classical type D symbiotic binary. The hot component of AG Dra is considered to be a white dwarf producing a high luminosity in order of $10^3 L_\odot$ and temperature of about $1-2\times10^5$K. The mass of the white dwarf is found to be $M_{wd} = 0.4 - 0.6 M_\odot$ [21] at a distance of 2.5kpc, and $0.5M_\odot$ [27]. Mikolajewska et al. (1995) [21] have obtained for the radius of the white dwarf the values $R_{wd} \approx 0.06 - 0.08 R_\odot$ and they supposed it is a sub-dwarf. The secondary or the cool component of AG Dra is of early spectral type in the range K0-K4 with metal deficiency (Smith et al. 1996) and has also been classified as a Barium star. Its mass was estimated as $1.5M_\odot$ by Kenyon & Fernandez-Castro (1987) and radius ≈ 35 $R_\odot$ [30]. The orbital period of AG Dra is Porb ≈ 550days [25].

NQ Gem is classified as a suspected symbiotic star (catalogue of Belczyński et al. (2000) [2]) and belongs to the family of Symbiotic variables of the Z Andromedae type. They are close binaries that consist of a hot star, a star of a late type, and the existence of extended envelope is very possible, which is influenced by the hot star's radiation.

On the other hand, the Spectral types of those objects are usually C6 or CH3. They are known as "carbon stars" with an excess of carbon in their atmosphere [3], usually red giants. Its SiIII/CIII ratio is similar to that of other symbiotic stars.

The orbital period of NQ Gem is found to be 1308 days [7], and its eccentricity is e = 0.182. The mass of the white dwarf or the object's primary component is estimated as $M_1 \sim 0.6\ M_\odot$.

NQ Gem is a type of Semi-regular variables, which are giants or supergiants of intermediate and late spectral types. The variabilities in its light curves sometimes are interrupted by various irregularities, possible to be detected for a long period of observations. These observational periods could prolong in the range from 20 to more than 2000 days. The object's brightness usually displays irregular variations and the amplitudes may vary with 1-2 mag, and its magnitude range is 7.4−8.18 in V. The light curves of NQ Gem manifest pulsations, with a pulsation period Ppul ~ 58(±1) days [12].

NQ Gem has also been attached to the group of X-Ray symbiotic binaries [20]. In the X-ray spectrum two components, at the soft part with energies below ≈ 1.5keV and at hard part above 2.5 keV, are clearly distinguished.

The Cataclysmic variable V592 Cas consists the late-type main-sequence secondary and white dwarf primary. The components in V592 Cas are interacting by a warped and tilted accretion disc, according to observations of negative and positive superhumps [22, 26, 29].

V592 Cas, is a low-inclination (i =28 ±10−11 degrees, [15]) type CV, with an orbital period of 0.115063(1) d [26], [28] at a distance of 360 pc. Taylor et al. [26] estimate an accretion rate for V592 Cas of about $9 \times 10^{-9}\ M_\odot\ yr^{-1}$.

The visual binary 61 Cyg has two components: V1803 Cyg (hereafter 61 Cyg A) is a primary component and it is a solar-type dwarf of spectral type K5. The secondary component is a K7 dwarf 61 Cyg B. 61 Cyg A is an average active star [9] and its activity cycle was estimated as ~ 7.35(±0.1) yr. [1]. This star was also defined with its solar-type variability [13, 19].

Both components of 61 Cyg are slow rotators and the periods of their rotation are: ~ 35(±1.7) days for the primary and ~ 38(±1.5) days for the secondary, respectively [8, 24]. 61 Cyg A belongs to BY Draconis type variables [16], which are emission-line dwarfs of dKe-dMe spectral type and they usually show quasiperiodic changes in the light curves. 61 Cyg A is also known as a strong X-ray source [14, 23].

Equations

In general, the efficiency η expresses the amount of energy gained from the matter with mass m, in units of its mass energy [17]. It measures how efficiently the rest mass energy, c^2 per unit mass, of the accreted material is converted into radiation. The accretion efficiency η_{acc} is defined by the expression:

(1) $$\eta_{acc} = \frac{GM_1}{R_1 c^2}$$

obtained by the expressions of accretion luminosity:

(2) $$L_{acc} = \frac{GM_1\dot{M}}{R_1} \text{ and } L_{acc} = \eta_{acc}\dot{M}c^2$$

Where M_1 and R_1 are the mass and radius of the central object or the primary star; G is the gravitational constant; c is the speed of light; $\dot{M}$ is the accretion rate.

We can trace the change in efficiency in the three possible modes – disc accretion - η, spherical-like accretion - ξ and a two-stream feeding $\xi+\eta$.

Equation 1 expresses the efficiency of the disc' accretion. Now to obtain such expressions for the other two modes, we will use equations of the related accretion rates.
The accretion rate is different in different type of binary star objects and their stellar components.

Let denote the accretion rate in general case with $\dot{M}$, then $\dot{M}_d$ expresses the disc accretion, by the equation (3), based on[11]:

(3) $$\dot{M}_d = 2\pi R_{R1}\Sigma(-V_r),$$

where V_r is the radial velocity of the stream, Σ is the surface density;

R_{R1} the distance to the central object (sometimes coincides with the radius of the primary or the disc inner radius).

Further, the spherical accretion rate could be expressed as [3, 10]:

(4) $$\dot{M}_{sph} = \pi R_{R1}^2 \rho(-V_r),$$

where ρ is a volume density in this case.

The ratio of the spherical accretion efficiency ξ to the efficiency of the disc accretion - η can be expressed as a relation between the two types of accretion rate:

(5) $$\frac{\xi}{\eta} = \frac{\dot{M}_d}{\dot{M}_{sph}}$$

Then for the efficiency of the spherical accretion we can write:

(6) $$\xi \approx \left(\frac{4H_d}{R_d}\right)\eta$$

Now, the whole disc radius R_d and the full half disc thickness H_d are also included into the calculations.

When using the equation of accretion efficiency, the important relation between the luminosity ***L*** and the effective temperature ***Teff*** should also be applied, by the Stefan-Boltzmann's law:

(7) $$L = 4\pi R_{R1}^2 \sigma {T_{eff}}^4$$

Results

Following the equations from the previous section and the values of the objects' parameters given above, we calculate the accretion efficiency for the four objects.

The obtained value of the disc-accretion efficiency for AG Dra is [4] (Boneva 2020):

η_{accr} [AGDra] = 1.445105 $\times 10^{-5}$.

For NQ Gem and 61 Cyg A we have from Boneva & Yankova (2021) [5]: η [NQ Gem] = 1.28 (±0.12) $\times 10^{-4}$; η [61 Cyg A] = 2.4 (±0.01) $\times 10^{-4}$.

The results of accretion efficiency for V 592 Cas are obtained in Boneva & Yankova (2022) [6]: η [V592Cas] = 1.17 (±0.11) $\times 10^{-4}$.

Table 1. Mean values of accretion efficiency calculated for both objects in the three suggested accretion modes: ξ for spherical accretion, η - for disc accretion, and a sum of both η + ξ expresses the two-stream feed accretion

Object / Mode	1	2	3
X 10^{-4}	ξ	η	ξ+η
AG Dra	0.00578 ± 0.00006	0.145 ± 0.001	0.15 ± 0.001
NQ Gem	0.20 ± 0.02	1.28 ± 0.12	1.50 ± 0.14
V 592 Cas	0.16 ± 0.02	1.17 ± 0.11	1.28 ± 0.13
61 Cyg A	0.4 ± 0.2	2.4 (±0.01)	2.8 ± 0.002

The values in table show that the efficiency for the three modes of AG Dra is almost ten times less than the values of NQ Gem and V 592 Cas. In comparison, 61 Cyg is much more active in disc accretion mode.

The distribution of accretion efficiency throughout the development of accretion modes is clearly seen at the Fig. 1. It is seen from the empirically created figure that the spherical accretion efficiency for all the four objects has lower values than the efficiency in the disc accretion mode.

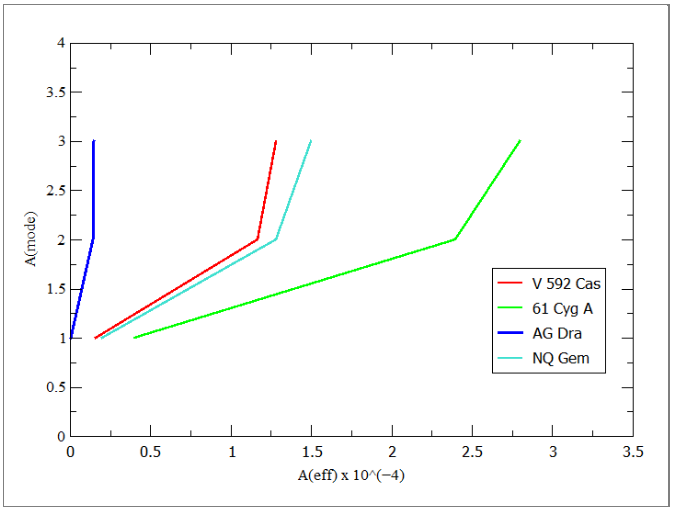

Fig. 1. A growth of accretion efficiency A(eff) against the development of accretion modes 1(ξ), 2(η) and 3(η + ξ) A(mode)

Except for AG Dra, a smoothly growing transition between the modes is observed. It is mostly ++ at the slow rotating accretor of 61 Cyg A.

Discussion and Conclusion

An estimation of accretion efficiency is important, because it has a close relation to the emitted energy and has a further role in binaries' evolution. Its rate is different in different type of binary star objects and their stellar components. One advantage to know the accretion rate gives the possibility to estimate the mode of accretion and the possible transition between them.

Based on the results, we discuss on the type of accretion efficiency dominated for the concrete object. We give a point to an active mass-transfer mechanism for each of the considered binary stars.

In the CV Novae like object V 592 Cas, the primary component has a precessing accretion disc [18]. This could be a reason for the relatively low values of the disc's accretion efficiency. The stream from the secondary is going through the Lagrange point L_1, then a pseudo-spherical inflow contacts the outer parts of the accretion disc. In this way, the Roche lobe overflow together with the wind transfer are most likely possible to be active in this object.

The mass losing and in the same time the matter scattering in 61 Cyg A are possible to be realized by not very high accretion efficiency on the disc surface, but an approximately high accretion rate [5] (Boneva & Yankova 2021). We could suppose about double feeding mass transfer in this object: via the wind and Roche Lobe Overflow.

The symbiotic binary NQ Gem produces an average disc accretion efficiency in comparison to other three objects. The activity of NQ Gem in X-ray luminosity could be contributed by the mass transfer via the stellar wind [5].

As we have seen in the figure, the data for the other symbiotic binary in this survey AG Dra show low rate of accretion efficiency for all three modes.

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