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ZONES OF ACCRETION DISK ACTIVITY

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Abstract. In this paper, we consider the accretion disk of a compact object. In the process of evolution, zones of activity are formed, which is developed into two types - internal and adjacent. We analyse the causes of occurrence and investigate the construction, location and characteristic features of each of them. We looking for the connections of the disc behaviour with energy exchange in these zones.

1. INTRODUCTION

In series of papers (Yankova, (2007-2015)), we created a new magneto-hydrodynamic model of accretion disc, based on a new specific advective hypothesis:

$$\frac{\partial(\rho v_i)}{\partial t} + \frac{\partial(\rho v_i v_j)}{\partial x_j} = \rho(\frac{\partial v_i}{\partial t} + v_j \frac{\partial v_i}{\partial x_j}) = \rho \frac{D v_i}{Dt} \tag{1}$$

Here v is the flux velocity; ρ - mass density; x_i is spatial coordinates. The operator D/Dt defines the advective term as a stream with velocity. This means that there is a displacement of the mean stream with velocity in some direction, preserving its character. The solution as a whole is carried over to smaller radii (Yankova et al. 2014, Yankova 2015). Thus, the advective rings effectively maintain the cooling of the disc.

In the one-temperature, optical thick plasma of the advective Keplerian disc, the different instabilities create the irregular periodicities in variation of the substance features, which should not be neglect and can be used:

$$F_i = F_{i0} R(x = \frac{r}{r_0}) \exp[k_\varphi(x)\varphi + \omega(x)t] = F_{i0} f_i(x) \tag{2}$$

Functions F_i transformed the physical parameters of the flow, thereby setting the feedback of the instabilities characteristics with the magnitudes of the accreting plasma. Where $f_i(x)$- dimensionless functions of the physical parameters, $R_0 = 10^n R_g$, or R*(the outer radius of the disc and star-accretor/Schwarzschild radii), F_{i0} are the values of the outer edge of the disc.

$K(x) = \frac{warming}{cooling}$ is the directly connection of the instabilities with the accreting flow. K is a dimensionless magnitude obtained in the modelling process, which is a measure of the disc ability to qualitative cooling (Iankova 2009).

2. THE ACTIVE ZONES

Based on our model, we locate the active areas of the disk and analyse the zones state/behaviour in a specific objects. In each of the zones, the activity is the result of the sudden change in the physical parameters in the stream, caused by the interaction of one of the components of the system (accretor magnetosphere, disk corona, etc.) with the disc structure. An energy excess is released in the flow, which generates long-term or short-term observational effects such as flickering, outbursts, non-thermal radiation, annihilation lines, etc.

2. 1. TYPES OF ACTIVE ZONES

We consider five active zones: *The real active zone (AZ):* The real active zone is formed in the inner the disk, where the accretion rate increases by of up to about 15 percent due to the advection action. The active zone can be determined by indicators such as: - Outer radius of the corona, which we obtain from the condition $v_a^2 \leq v_s^2$ (Iankova 2007), where v_s - sound velocity and v_a - Alfven velocity, respectively; - Temperature distribution in the disk; - Luminosity distribution in the disk; - Critical value of the local heating $K>1$.

External contact AZ: The outer contact active zone is formed by the collision of the transfer inflow with the outer regions of the disk and is commonly known as a spot or hot line.

Internal contact AZ: In the destruction radius area of the disk, where the inner layer evaporates and the disk does not reach the star, is the inner contact active zone. In it the activity is caused by arcs collisions in the accretor magnetosphere and/or interaction whit the inner regions of the disk. We obtain the destruction radius of the disk from the condition $<v_a>^2 \leq (9/4)<v_\varphi>^2$ (Iankova 2009), where v_φ is the angular velocity.

Activity in the transfer stream: Activity in the transfer stream is excited by the formation of a shock front upon variation in the plasma velocity due to orbital eccentricity or stellar wind acceleration, e.g.

Activity in the disk corona or activity by the disk wind: The surface boundaries of the disc are especially important because this is where the effects of the heating in the pad become apparent: The variability of the boundary distributions determines whether the disk will maintain a corona or generate wind. The activity in this area is brought in from the disc across the boundary.

2. 2. ZONAL CONNECTIONS

Some internal and adjacent zones are connected to each other by transferring activity or interaction between parameters: The activity in zone 5 (corona/or disk wind) has a migratory character, it arrives ready from the disk and especially from the real active zone-1. On the other hand, the processes in the disk do not contribute to the activity in the transfer stream, but this AZ-4 affects over the processes in zone 2 (spot or hot line).

2. 3. ZONES ENERGY BALANCE

External contact AZ: The disturbance in the heating distribution in the spot is about two-three orders K_{fl} (figs.1a, 1c). The heating K directly controls the pressure (plasma and radiative) in the zone, so it together with the temperature wills changes. The temperature jumps by about two orders of magnitude and $p_g \uparrow$, but with the spot increases the density $\rho \downarrow$ decreases and $p_g \downarrow$ falls. Then $p_r \uparrow$ as $T^4 \uparrow$ and radiative pressure will dominate. It pushes the spot to expand. So in the luminosity the activity is registered like flickering. So the activity is registered like flickering, in the luminosity.

The real active zone and zone 5: The main reason for the disk activity (zone 1) is the presence of advection: the rate of radial accretion increases, increased the released energy. Free energy is kept in the disk in the form of heat, which reduces the radial gradient of entropy towards the center. Negative entropy creates conditions to the energy absorbing by the instabilities and turning them into microstructures in the flow it stimulates feedbacks. So they close the advective cycle and thus keep the advection in the self-induction mode.

Simultaneously, the developing advection is the main reason for the export of activity from the disc to the peripheral component. Also, tool for determining the degree to transfer activity in the zone 5. The transfer is related with the Parker instabilities action that bring MRI into the corona together with buoyant field lines, (Yankova 2014). Boundary corona-disk is especially interesting because there mutability and mobility of boundary distributions of the sound and the magneto-sonic speeds is caused by the overall interaction between the parameters and non - linear effects in the disk. These two types of velocities are the most sensitive to the energy exchange and hence the action of the advection. They create multiple contours of increasing, which combined with fast growing magnetic field ensure the emergence of compacted regions genetically unrelated to the helices. These are precisely the advective rings that provide heating of the pad at the base of the corona/wind. Tightening of advective rings to the center in disk and negative entropy realize a new state. Then, the corona/wind is positioned over the inner regions of the disk.

The corona shows a non-thermal spectrum. And outbursts and flickering can be observed from RAZ-1, as a result of the interaction of different type's structures formed by the instabilities action in the flow.

Internal contact AZ: The activity caused by magnetic arcs collisions or interaction with the high speed plasma is typical coronal activity like a Sun's. Switching of opposite loops leads to the presence of annihilation lines in the object spectrum.

3. RESULTS

We have calculated how the internal active zones are located in the disk for three types of real sources:

3. 1. RS OPH - SYMBIOTIC NOVA

RS Oph is a member of the recurrent novae group (Ilkiewicz et al. 2019, Merc et al. 2023). RS Ophiuchus is a binary system consisting of a red giant and a white dwarf. The masses of the two components are estimated as $0.68 - 0.80\mathrm{M}_\odot$ for the red giant (Brandi et al. 2009) and for the white dwarf it is $1.2 - 1.4\mathrm{M}_\odot$ (Mikolajewska and Shara 2017). The orbital period of the system found to be 453.6 days (Brandi et al. 2009), and white dwarf has an accretion disk.

The recurrent nova outbursts of RS Oph happen in approximately every 15-20 years, with a brightness variability of ≈ 11 to 6 magnitudes in the V band. Between out-

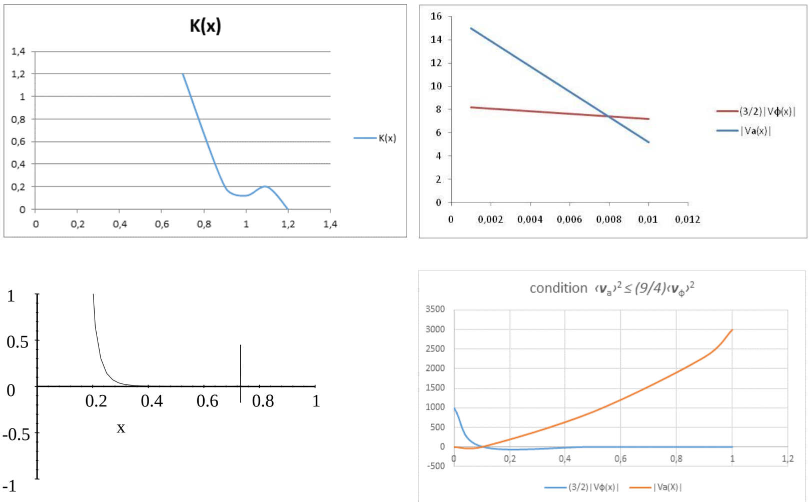

Figure 1: (1a)Distribution of the local heating of the RS Oph disk. (1b) Distribution of the condition $v_a^2 \leq (9/4)v_\varphi^2$ of the RS Oph disk (upper panels). (1c) Distribution of the local heating of the Cyg X-1 disk. (1d) Distribution of the condition $v_a^2 \leq (9/4)v_\varphi^2$ of the Cyg X-1 disk (lower panels).

bursts, the system has a stellar magnitude of 12.5^m. The novae outbursts could be the result of thermonuclear processes on the white dwarf's surface (Starrfield 2008) or by accretion disk instabilities as in the dwarf-nova-like objects (King and Pringle 2009, Alexander et al.2011).

We found out that the inner active zones in the RS Oph disc are distributed as follows: $(AZ-3) < R_{dstr} \sim 0.007R_0$; $(AZ-1) \sim (0.008; 0.5)R_0$ (as we showed in Yankova 2023); $(AZ-2) \sim (0.9; 1.2)R_0$. We show that the perturbation in K(x) develops in the region $(0.9; 1.2)R_0$ (see Fig.1a), it is an indicator to localization the external contact AZ. We obtain R_{dstr} in interval $(0.007; 0.01)R_0$, (see Fig.1b).

3. 2. CYG X-1 MICROQUASAR

Cyg X-1 represents TDS - a spectroscopic binary of a supergiant $\sim 20\mathrm{M}_\odot$ of 9^m, spectral class $9.7Iab$, and a compact object $\sim 10-15\mathrm{M}_\odot$ (Ninkov et al. 1987, Orosz et al. 2011), with orbital period of ≈ 5.6 days. Variations in the optical range with the same period are observed, related to the mass transfer between the system components and the formed accretion disk. The observations also show a variable circular polarization. It requires a magnetic field source. The characteristic size of the field coincides with the ergo-sphere.

Cyg X-1 is highly variable in the X-ray spectrum, with periods ranging from millisec-

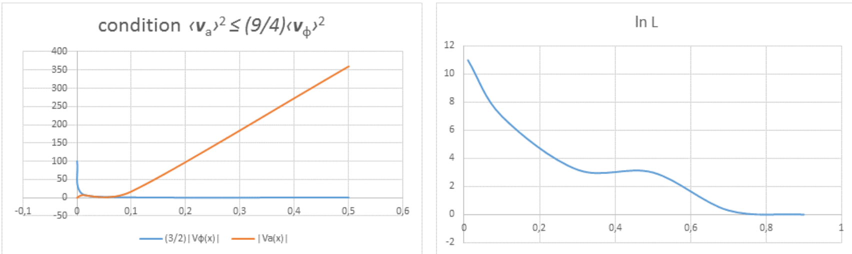

Figure 2: (2a) Distribution of the condition $v_a^2 \leq (9/4)v_\varphi^2$ of the SgrA* disk. (2b) Distribution of the Luminosity of the SgrA* disk.

onds to years. The X-ray luminosity is of the order of $\approx 2-8\times10^{27}ergs^{-1}$, from (soft X-ray $\sim 2-20$ keV) to (hard X-ray $\sim 40-450$ keV), low-energy X-ray (1.3-12 keV) and high-energy X-ray (20-200 keV)(Nayakshin and Dove 1998, Zhang et al. 1997). In spectrum registers the K_α line of iron; reflection of EMR from the inner regions to the outer regions of the disc is observed; and γ-radiation is captured, which are associated with the behavior of the AGN microquasar.
We found out that the inner active zones in the Cyg X-1 disc are distributed as follows: $(AZ-3){<}R_{dstr}0.1R_0$ (see Fig.1c);$(AZ-1)\sim(0.1;0.4)R_0$ (as we showed in Yankova 2023); $(AZ-2)\sim(0.7;0.75)R_0$ (see Fig.1d).

3. 3. SGR A* DORMANT GALACTIC CORE

The Milky Way is a weakly active galaxy with $L\approx1.5\times10^{39}$ erg/s in the range 2-200 keV (Revnivtsev et al. 2004) and magnetic field $\sim 3.5\times10^{-6}G$. Its center is located in the constellation Sagittarius. The emission from the region is diverse in nature, but specifically the soft -rays and X-rays (soft and hard X-rays) come from the non-thermal synchrotron radio source SgrA*, which is associated with a compact object and matches within ±0.1 with the dynamical center of the Galaxy. In its spectrum, γ-emission of Brom is registered, which is associated with minispirals (the accretion disk spirals), the K_α-lines of various highly ionized elements from the outer edge of the disk and the annihilation line 511 keV (Cesare 2011) from the interior of the disk, as well as emission at 10 keV and from his envelope (? corona).
We found out that the inner active zones in the SgrA* disc are distributed as follows: $(AZ-3){<}R_{dstr}\sim0.03R_0$ (see Fig.2a); $(AZ-1)\sim(0,05;0,6)R_0$(see Fig.2a, 2b). For obvious reasons, the object does not have zone 2.
We showed that the condition for the outer radius of the corona $v_a^2\leq v_s^2$, is drawn outwards as it approaches to the equatorial plane, but outwards and the thickness of the disc decreases. This gives grounds for asserting that the corona covers the entire disc and flows into the torus at $\sim$ 60 Rg, Yankova 2014. We obtain that the luminosity decreases smoothly and drops sharply at 0.6Ro (see Fig.a1), which is a convenient indicator of the beginning of active zone-1.
From the condition $v_a^2\leq(9/4)v_\varphi^2$ we find that disk in the core does not destroy in the corona. It evaporates $\sim3R_g$, but the reasons are of a completely different nature - the angular velocity of the flow Ω is already relativistic. In fig.a2 one can see how the velocities overlap in some interval. The reason is the relativistic entrainment near SMBH.

4. SUMMARY

In this paper, we considered some processes in the accretion disk of a compact object, which lead to simultaneous or sequential activation of areas of the disc or its surroundings. We presented the possible types of disk activity zones that arise in the process of evolution in different types of compact objects. We have calculated how the internal active zones are located in the disk for three types of real sources: RS Oph - symbiotic nova; Cyg X-1 microquasar; Sgr A* - dormant galactic core.

We discussed the activating mechanisms and energy balance in each zone. And we found that RAZ-1 is concentrated in the inner disc areas due to the advective shift. This affects the zone-5 due to the connection between the two zones and it also forms over the inner regions of the disk. Such evolutionary mobility could also manifest in AZ-2 in case of increased activity in AZ-4.

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