GENERATION OF MAGNETIC FIELDS IN ACCRETING SYSTEMS AS A BASIS OF NONTHERMAL MODE OF ENERGY RELEASE

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Abstract. Generation of the magnetic field during procces of disc accretion onto black hole or magnetize neutrin star may form current structures in a polar region. The instability and disruption of this currents must lead to effective acceleration of the particles to ultra high energy as it observe by GRO and UHE-astronomy experiments.

Key words: accretion – dynamo – instability – acceleration – gamma astronomy

1. Introduction

Recent observations have been shown that a number of accreting objects - galactic close binaries, as well as extragalactic sources of BL Lac-type (blazars) - release predominant part of energy in the form of particles accelerated up to Ultra High Energy [1,2]. The most striking example to be given is that the latest observations of blazar 3C279, obtained with Gamma Ray Observatory, released its luminosity in the energy range E_γ = 1-20 GeV to exceed almost by order that in the rest spectral regions from radio up to X-rays [2].

This fact is in obvious contradiction with the basic consequence of standard models of accretion - the thermal character of energy release, caused either by the friction of rotating layers in the accretion disc or by heating in the accretion column and upon the front of its shock wave [3,4].

We believe this contradiction to arise because of the processes of accreting plasma interaction with magnetic fields, which leads to rapid increasing of the magnetic field energy up to the value $\frac{H_G^2}{8\pi} \simeq \rho V^2 \simeq \frac{\rho GM}{R}$ with the following flaring dissipation of this energy into particle acceleration and anomalous heating, being ignored in the standard approach. This fundamental property of magnetic fields (and its principal role in energy release) is well known and actively investigated in laboratory plasma experiments and solar physics [5,6]. In the present paper we argue that taking into account the factor mentioned above is necessary in the case of disc accretion onto a black hole as well as in the case of accretion onto a magnetized neutron star, since in both variants it is the basic cause of non-thermal energy release.

2. Disc accretion onto a non-magnetized gravitating centre

The question of necessity of taking into account the generation of intrinsic magnetic field in the disc was raised by Lynden-Bell [7]. Later on this problem was examined

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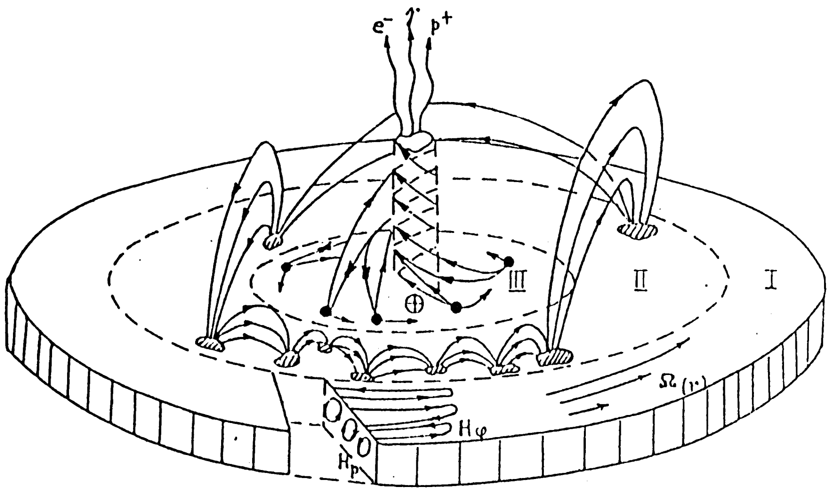

Fig. 1. Structure of a magnetized accretion disc: I—region of α–disc, II—intermediate region of Parker instability, III—central region of the polar Z-pinch

by Pustil'nik and Shvartsman [8], and Galeev et. al. [9]. As it has been shown in these papers, the differential character of Keplerian rotation of the disc matter ($\Omega \propto R^{-3/2}$) results in rapid amplification of initial magnetic field by dynamo-mechanism up to threshold values $H_{cr} = \sqrt{8\pi\delta n_d k T_d}$, with $\delta = 0.2 \div 0.5$, at which the disc is broken by Parker instability, into dense plasma blobs bound up one with another by field lines through the magnetic corona being formed in this process. Anomalous thermal heating of such magnetized corona was examined in detail by Galeev et.al. [9]. However, in this and subsequent papers, devoted to this problem, one principal moment was omitted - the energy release of magnetic corona must be predominantly non-thermal.

Really, after the disc having been disintegrated into the system of blobs, the exchange of rotational momentum between them can take place only via the tension of field lines, which bind them up through the magnetic corona. The blobs rotation being differential, the corresponding magnetic fluxes are getting entangled with current layers formation in the zone of their contact. However, owing to high coronal plasma conductivity, the dissipation of magnetic field via reconnection does not occur at this stage. On the contrary, the process of field amplification is going on, with azimuthal component H_φ generation and corresponding poloidal component amplification, caused by extension of field lines and self-compression of the forming structure by $H_\varphi^2/8\pi$. As a result, on the axis of accretion disc rotation,in the region above and under the gravitating centre the configuration of Z-pinch type is formed, parallel to the disc rotation axis (fig.1), in which the tension of toroidal component is balanced by contrapressure of the disc poloidal field. The Keplerian rotation of the blobs going on leads to further winding magnetic lines of force round axial Z-pinch. The value of magnetic field strength in Z-pinch has the upper limit $H_G = \sqrt{8\pi\rho GM/R}$, at which the tension of field lines becomes equal to gravitational force and the blobs movement becomes radialized. The reliable value of field corresponds to the threshold value, at which plasma turbulization in Z-pinch essentially reduces the effective conductivity σ_{eff} and, therefore, turns on rapid processes of non-thermal dissipation of magnetic energy, concentrated in it. Hence, in the framework of this scheme, basic energy release occurs not in the accretion disc, but in the axial Z-pinch, where under the action of the chain of MHD- and resistive instabilities (sausage and screw modes $\Longrightarrow$ tearing modes $\Longrightarrow$ plasma turbulization with current discontinuity and formation of "double layers") powerful electric fields accelerating the particles are generated [10].

Thus, the consistent account of effects, accompanying generation of magnetic field in the accretion disc leads us to the conclusion that it is possible to realize a non-thermal mode of energy release, with the great bulk of energy being released in the form of anomalous field dissipation in the axial Z-pinch under the action of plasma instabilities. The efficiency of non-thermal energy release in the process of pinch disruption by plasma instabilities was investigated in the numerous plasma experiments and appeared to be high enough [6,10].

3. Disc accretion onto a magnetized gravitating centre

As it has been shown by Ikhsanov and Pustilnik [11], the character of disc accretion onto a magnetosphere (m-sphere) essentially depends on the effective conductivity of disc plasma σ_{eff}. Three different regimes of accretion might be distinguished in accordance with this. In the case of two traditional approximations: $\sigma_{eff} = \infty$ [11] and $\sigma_{eff} \approx \sigma_0 \longrightarrow$ [12], a part of non-thermal energy release is negligibly small. However, in the third intermediate case: $0 \longleftarrow \sigma_0 \ll \sigma_{eff} \neq \infty-$ the case of "squeeze" accretion (s-accretion) [11], in which one takes into account the effect of azimuthal field component generation in a thin skin-layer of the disc, the non-thermal mode of energy release becomes comparable or even predominant in efficiency.

In the regime of s-accretion the disc is screened from magnetic field and squeeze in the process of accretion between the magnetic field lines of a central component, drawing up its lines of force and keeping all principal parameters of α–disc.

At the boundary "disc plasma - magnetic field" a diffusion skin layer (d-layer) of their interpenetration with the thickness δ_m is formed. Plasma, diffusing into the d-layer possesses high rotational momentum $2\pi\rho\delta_m R^2 V_\varphi$, that leads to the magnetic lines stretching in the azimuthal direction and generation of toroidal magnetic winding H_φ . Hence, we get the configuration, analogous to the skined Z-pinch with longitudinal magnetic field [14]. The poloidal field of the central object counteracts the tension of toroidal magnetic winding, providing the equilibrium of the m-sphere. According to [11], the equilibrial configuration in this case is intermediate between a sphere and a dipole, being convex everywhere and stable with respect to insta-

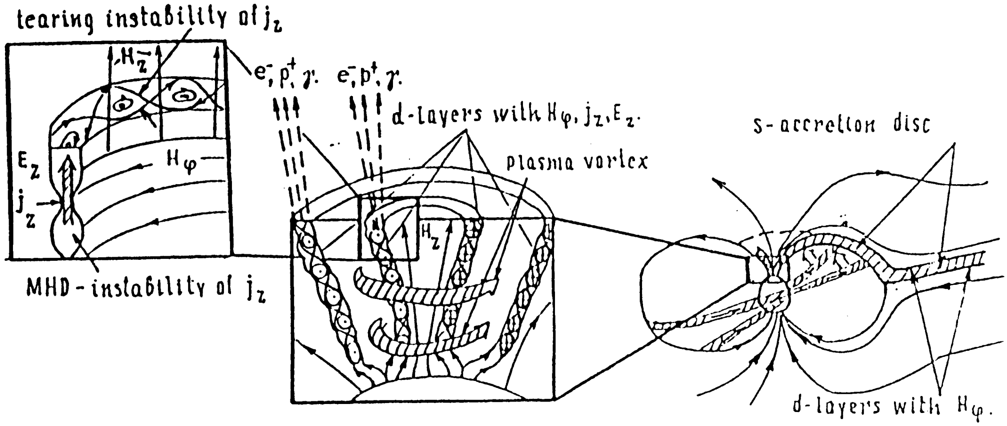

Fig. 2. Structure of the s-accretion onto magnetosphere: I—External region of "squeezing" accretion disc, II—Polar wirlwind structure, III—structure of a currents and fields in the polar d-layer.

bilities of interchange - type (the shear of magnetic field in the d-layer stabilizes long-wavelength perturbations, and "ballooning" of the flute mode stabilizes short-wavelength ones). In the case of non-coaxial rotator, the interaction of accretion disc with the m-sphere leads to the inner part of the disc leaving the Keplerian regime, accretion flow streaming of the m-sphere and a plasma polar vortex being formed in the region of magnetic poles (see fig. 2) [11].

The principal feature of s-accretion is the conservation of a significant part of the rotational momentum of plasma, captured toward the polar vortex, that provides formation of skined Z-pinch-type structure right up to the regions, close to the surface of a central component, or $3r_g$. Plasma, rotating in the polar vortex forms d-layer with azimuthal field

$$H_\varphi = \sqrt{8\pi\rho\, GM_*/3r_*}$$

in the inner magnetosphere and central magnetic tube. This is equivalent to the exciting of a current with the density $|\, j \,|$ in the d-layer:

$$|\, j \,| = (c/4\pi) \mid rotH \mid = cH_\varphi/4\pi\delta$$

The current layer arising is unstable with respect to dissipative tearing-mode on characteristic timescale of instability $\tau \approx \tau_d^{1/2}\tau_A^{1/2} \div \tau_d^{1/3}\tau_A^{2/3}$, that results in the current surface disruption into separate magnetic islands with consequent growth in them the characteristic pinch-modes (m=0 - sausage and m=1 - screw -modes) and formation of "double layers" [15] with extremely high electric fields in the region of current discontinuity:

$E = \frac{c}{4\pi}\frac{\Delta H}{\delta_m}\frac{4\pi\nu_{eff}}{\omega_0 e}$

where ν_{eff} - is the effective frequency of current electrons collision with ions and plasma waves. Under the conditions in the vicinity of a neutron star surface, the cyclotron - electron modes dominate, and therefore $\nu_{eff} = \zeta\omega_{H_e}, (\zeta < 1)$, and the equilibrial electric field has the upper limit, estimated by Dricer [16]:

$E_d = m_e V_{T_e}\nu_{eff}/e$

This corresponds to the maximum energy of particles, accelerated in the current layer, being estimated as

$\epsilon_{max} = eE_d r_* = 10^{19} H_{12} r_6 T_8 \zeta eV$

that coincides with the results of UHE gamma-rays observations [1].

4. Conclusions

From all, mentioned above, it is clear, that taking into account the generation of toroidal component of the magnetic field due to plasma rotation in the process of disc accretion leads to the principal change of the whole picture of energy release, firstly, opening the effective non-thermal channel of magnetic energy dissipation in the current layer, and, secondly, localizing a zone of basic energy release in the region of the disc rotation axis for a gravitating centre without magnetic field and in the region of magnetic poles for a magnetized neutron star. This allows to use the mechanism presented for generation of relativistic and subrelativistic jets, and to explain the cause of non-thermal energy release dominating in a number of galactic and extragalactic accreting systems.

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