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ORIGINAL ARTICLE

Topology of magnetic field and polarization in accretion discs of AGN

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Abstract In this paper we demonstrate that the wavelength dependence of polarization degree and position angle allows us to derive the distribution of magnetic field in accretion disc. The polarized radiation arises due to scattering of emission light by electrons in a magnetized optically thick accretion disc. Faraday rotation of polarization plane is taken into consideration. Through wavelength dependence of polarization it is possible to derive the value of the magnetic Prandtl number in the accretion disc plasma. The power law index of the polarization wavelength dependence is related with the radial distribution of magnetic field in an accretion disc. This allows us to test the various models of an accretion disc around the central black hole.

Keywords AGN · Polarization · Magnetic field · Accretion

1 Introduction

The problem of the production of jets in Active Galactic Nuclei (AGN) requires that the accretion disc will be permeated by a large scale magnetic field, so that magnetic field lines are anchored in the disc (Ogilvie and Livio 1998; Lyutikov 2009; Garofalo 2009; Cao 1997; Sadowski and Sikora 2010; Tchekhovskoy et al. 2010). The indication of the field lines on the surface of the disc plays a crucial role on the nature of magnetically driven outflow (Cao 1997).

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For example, the model of Blandford and Payne (1982) established the significance of the angle θ between magnetic field **B** and the normal **N** to the accretion disc. They showed that, when $\theta > 30°$, an outflow is driven spontaneously by the centrifugal force.

Lyutikov (2009) studied this situation for Schwarz-schild and Kerr accretion discs. He found, that for the discs around non-rotating black holes (BHs), the above mentioned condition is the same, as for the Newtonian disc, while for the fast rotating BHs, angle θ depends on radius and the BH spin. For prograde rotating discs around Kerr BH, the angle θ decreases and becomes 0° for footprints anchored to the near the horizon of a critically spinning $a_* = 1$ black hole. Lyutikov (2009) obtained the next relation for this critical angle value, as a function of radial distance R in accretion disc:

$$\tan\theta = \sqrt{1/3 - \frac{4a_* R_g^{3/2}}{3R^{3/2}} + \frac{a_*^2 R_g^2}{R^2}}. \tag{1}$$

Here $R_g = GM_{BH}/c^2 \simeq 1.475 \cdot 10^5 (M_{BH}/M_\odot)$, M_{BH} is mass of black hole, G is gravitation constant, c—the light velocity, and $M_\odot$—the Sun mass. For Schwarzschild metric: $\tan\theta = 1/\sqrt{3}$ and $\theta = 30°$. For $\theta > 30°$ the particle will be flung away from the disc. For prograde rotation ($a_* > 0$) the angle $\theta > 30°$ corresponds to unstable motions. For retrograde disc rotating with $a_* = -1$, $\tan\theta = 4\sqrt{2}/9$ and $\theta = 32.15°$ at the last retrograde stable orbit, corresponding to $R_{ms} = 9R_g$.

According to Lyutikov equation (1), in the limit $a_* \to 1$, for $R = R_g$ the angle $\theta \to 0$, so that the magnetic field lines are directed along the black hole rotation axis. For any $a_* \neq 1$, the condition $\theta = 0$ is satisfied only inside the horizon, so that for $a_* \neq 1$ there is always a set of magnetic field lines around the direction of hole's rotation where a particle is in a state of stable equilibrium.