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VARIABILITY OF ACTIVE GALACTIC NUCLEI DUE TO FIELD-ACCRETING MODES*

PARK, SEOK JAE
Korea Astronomy Observatory
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ABSTRACT

Variability of the emission-line spectra of active galactic nuclei is now a well-known phenomenon. This remains to be fully explained by a theoretical model of the central engine in an active galactic nucleus. Since the magnetic field lines are anchored on the accreting matter, they continuously fall on the event horizon of the central supermassive black hole and increase the net field strength of the hole magnetosphere. The field strength, however, cannot increase without an upper limit and, therefore, it will be decreased by some unknown processes. In this paper we discuss that these increasing and decreasing modes can be repeated periodically and explain the variability of power output, therefore, variability of active galactic nuclei.

Key Words : black hole, active galactic nuclei, hydromagnetics

I. INTRODUCTION

Variability of the emission-line spectra of active galactic nuclei (hereafter AGNs) is now a well-known phenomenon. Typical time scales of variation seem to range continuously from the black hole time

$$t \approx 100 GM/c^3 \tag{1.1}$$

(hours for supermassive ones) up to months. This remains to be fully explained by a theoretical model of the central engine in an AGN.

An excellent axisymmetric, stationary model has been investigated as the background of the Blandford-Znajek process (Blandford and Znajek 1977), which consists of the supermassive black hole surrounded by a magnetized accretion disk. The model was reformulated and extended by Thorne and Macdonald (1982), Macdonald and Thorne (1982), and Thorne *et al.* (1986) in '3+1'-spacetime formalism.

Based on this axisymmetric, stationary model a time-dependent model was established by Park and Vishniac (1989a, 1989b, hereafter PVa and PVb, respectively). The main point was to add the secular effects of mass accretion to the original axisymmetric, stationary model. PVa and PVb investigate the axisymmetric, non-stationary electrodynamics of a black hole and its accretion disk, respectively.

In PVb we find that the electrodynamic power output from the accretion disk can be variable on time scales associated with secular instabilities. The point was that the local fluctuation in fluid velocities in the accretion disk will cause fluctuations in the nonthermal component of the radiation by the Blandford-Znajek process. The

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time scales for these fluctuations, therefore, will reflect the range of orbital periods in the inner annulus of the disk.

In this paper we introduce another electrodynamic variable analysis to this power fluctuation. Since the magnetic field lines are anchored on the accreting matter, they continuously fall on the event horizon of the central supermassive black hole and increase the net field strength of the hole magnetosphere. The field strength, however, cannot increase without an upper limit and, therefore, it will be decreased by some unknown processes.

Finding the unknown processes seem to be beyond the scope of this analysis, but it is still worth discussing that these increasing and decreasing modes must be repeated periodically due to the continuously-incoming field lines and explain the variability of power output, therefore, variability of AGNs.

II. ANALYSIS AND DISCUSSION

First we will summarize the basic equations of the axisymmetric, nonstationary electrodynamics of a black hole and its magnetosphere. Throughout this paper we define our units such that $c=G\equiv 1$, and the central black hole is assumed to be a Kerr black hole which possesses the total mass M, the angular momentum J, and the angular momentum density a $(\equiv J/M)$.

Axisymmetric, nonstationary conditions can be represented as (PVa eq. [3.1]),

$$\mathbf{m}\cdot\nabla f\equiv 0,\ L\mathbf{mf}\equiv 0 \tag{2.1a}$$

and

$$\frac{\partial f}{\partial t}\equiv \dot{f}\neq 0,\ \frac{\partial \mathbf{f}}{\partial t}\equiv\dot{\mathbf{f}}\neq 0, \tag{2.1b}$$

where $\mathbf{m}$ is a Killing vector of the axisymmety, L means the Lie derivative, and f and $\mathbf{f}$ are any scalar and vector, respectively.

To describe the spherically symmetric spacetime we use the spherical coordinate system $(r,\ \theta,\ \varphi)$ whose unit vectors are expressed as $\mathbf{e}_{\hat{r}}$, $\mathbf{e}_{\hat{\theta}}$, and $\mathbf{e}_{\hat{\varphi}}$, respectively $(\mathbf{e}_{\hat{r}}\times\mathbf{e}_{\hat{\theta}}=\mathbf{e}_{\hat{\varphi}})$.

Throughout this paper $\mathbf{m}$ has the same magnitude as $\tilde{\varpi}$, the separation between the symmetric axis of the black hole and a Fiducial Observer (hereafter FIDO; see Thorne *et al.* 1986),

$$\tilde{\varpi}\equiv\frac{\Sigma}{\rho}\sin\theta, \tag{2.2a}$$

where

$$\rho^2\equiv r^2+a^2\cos^2\theta \tag{2.2b}$$

$$\Sigma^2\equiv(r^2+a^2)^2-a^2\Delta\sin^2\theta \tag{2.2c}$$

and

$$\Delta\equiv r^2+a^2-2Mr. \tag{2.2d}$$

Let ∂A be an $\mathbf{m}$-loop, A be any surface bounded by ∂A but not intersecting the event horizon of the black hole, and $d\mathbf{A}$ be the normal vector on an infinitesimal area on A. Then we can define the total electric current passing downward through A, I $(\mathbf{x},\ t)$, the total magnetic flux passing upward through A, Ψ $(\mathbf{x}$, t), and the total electric flux passing upward through A, Φ $(\mathbf{x}$, t), as (PVa, eq. [3.2]),

$$I\ (\mathbf{x},\ t)\equiv-\int_A \alpha\mathbf{j}\cdot d\mathbf{A}, \tag{2.3a}$$

$$\Psi\ (\mathbf{x},\ t)\equiv\int_A \mathbf{B}\cdot d\mathbf{A}, \tag{2.3b}$$

and

$$\Phi(\mathbf{x}, t) \equiv \int_A \mathbf{E} \cdot d\mathbf{A}, \tag{2.3c}$$

where **j** is the current vector, and α is the lapse function of the FIDO. The value of α is given by

$$\alpha = \frac{\rho}{\Sigma} \sqrt{\Delta}. \tag{2.4}$$

In terms of these the electromagnetic fields described by the FIDO are given by (PVa, eqs. [3.3], [3.5], and [3.6])

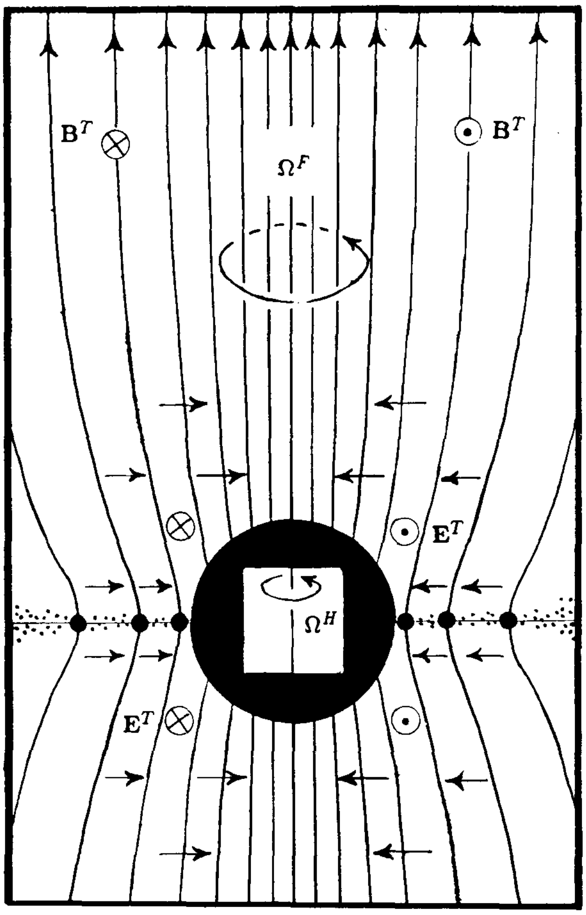
$$\mathbf{E}^T = -\frac{2}{\alpha \tilde{w}} \left(\frac{\dot{\Psi}}{4\pi} \right) \mathbf{e}_{\hat{\varphi}}, \tag{2.5a}$$

$$\mathbf{E}^P = \mathbf{E} - \mathbf{E}^T, \tag{2.5b}$$

$$\mathbf{B}^T = -\frac{2}{\alpha \tilde{w}} \left(I - \frac{\dot{\Phi}}{4\pi} \right) \mathbf{e}_{\hat{\varphi}}, \tag{2.5c}$$

and

$$\mathbf{B}^P = -\frac{\mathbf{e}_{\hat{\varphi}} \times \nabla \Psi}{2\pi \tilde{w}}, \tag{2.5d}$$



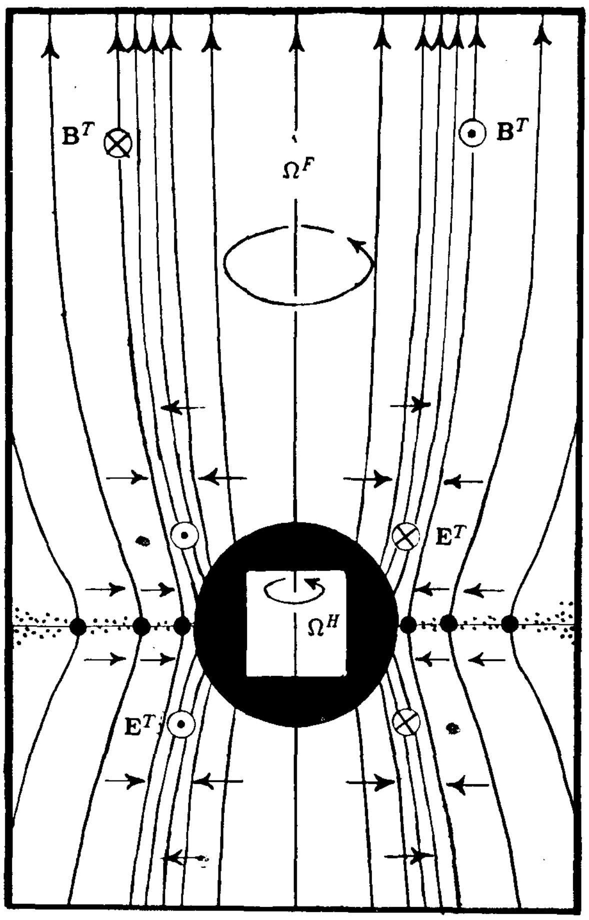


Fig. 1. (left) The strength-increasing mode.
Fig. 2. (right) The strength-decreasing mode.

where T, P denote the toriodal and poloidal components respectively.

Using these definitions Fig. 1 shows the case of the strength-increasing mode. Here Ω^F and Ω^H are the angular velocities of the magnetic field lines and the hole, respectively.

Fig. 2 shows the other, the case of the strength-decreasing mode. The unknown processes react to decrease the field strength and the field lines on the event horizon are pushed out toward the equator. Here we find one interesting fact that the direction of the toroidal electric field can also be varied periodically. This implies that the description of the modes will be much more complicated.

As mentioned in introduction, finding the unknown processes seems to be beyond the scope of this paper. We may be able to estimate it rigorously only if we figure out whole the mechanism. The period, however, may not be very different from Eq. (1.1).

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