Theoretical Prediction of observing jet precession in spinning black hole

Uicheol Jang*  Hongsu Kim† Yi Yu*

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Abstract

Relativistic jets are observed around accreting black holes, from stellar mass to super massive black holes. But Its origin has not been fully understood. Although Blanford-Payne process has been considered as most reliable theory of jet production It has no observational proof or supports. In this problem, We suggested the way to display that Bardeen-Petterson effect can become a supporter as providing observational idea of Blanford-Payne process. And we studied black hole jet production by Blanford-Payne process and Bardeen-Peterson effect. As a result, we could calculate observable timescale of black hole jet precession.

1 Introduction

Accreting blackholes are observed to produce relativistic jets. Although the production of active galactic nuclei(AGN) jets has been known as Blanford-Payne process[6]. Observational evidence or support have been rare. Therefore, we would like to suggest observable cases which can support observational evidence of Blanford-Payne process. Blanford-Payne process described jet production of AGN has been driven by gas(corona) pressure[6]. This interpretation show the jet out flow has closely related with accretion disk. And the accretion disk around spinning black hole has been affected by frame

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* Astronomy &Space science and Geology, Chungnam Natinal Univ.
† Center for Theoretical Astronomy, KASI
dragging, namely, (Einstein) Lense Thirring effect\cite{10}. It is well known as Bardeen Peterson effect\cite{5}. We suggest the coupling of Blanford-Payne process to Bardeen Peterson effect. Because Concurrence of the two theories implies that the Blanford-Payne process is a distinguishable theory through Bardeen-Peterson effect.

2 Production of AGN Jet outflow.

2.1 Blandford-Payne process

As we remarked in the introduction, Blanford-Payne process explain the production of AGN Jet outflow by employing Magneto hydrodynamics(MHD) in 1982. According to the theory, A centrifugally driven outflow of matter from the disc is possible, if the poloidal component of the magnetic field makes an angle of less than $60^\circ$ with the disc surface. At large distances from the disk, the toroidal component of the magnetic field becomes important and collimates the outflow into a pair of anti-parallel jets moving perpendicular to the disk In this way, magnetic stress can extract the energy and angular momentum from an accretion disk independently of the presence of viscosity\cite{6,9}.

2.2 Timescale for Accretion jet flow.

As a simple estimate for $\Delta t_{BP}$, the time scale of the whole outflow process, would be given by;

$$\Delta t_{BP} \sim \frac{l}{c_v} \quad (2.1)$$

where we denote that the $c_v$ is Alvein velocity, and the $l$ is the length scale over which the poloidal magnetic field extends, which are given as

$$c_v = \left(\frac{dp}{d\rho}\right)^{\frac{1}{2}} = \frac{B}{\sqrt{\mu_0 \rho}} \quad (2.2)$$

$$l = 10^3 \frac{GM}{c^2} \quad (2.3)$$

respectively, for radio jet(or accretion disk) length scale of AGN, where we denote that $\rho$ is the plasma density, $B$ is the magnetic flux, $p$ is the
gas pressure of plasma, $\mu_0$ is the vacuum permeability, $G$ is the Newton’s gravitational constant, $c$ is the speed of light, and $M$ is the mass of the black hole.

3 Precession of the accretion disk.

3.1 The Bardeen-Petterson effect

The deformation of the accretion disk has been demonstrated by General relativistic magneto-hydrodynamics(MHD)[7]. Bardeen-Petterson effect presented influence on tilted accretion disks around Kerr black holes as astrophysical evidence for Frame dragging(Lens-Thirring effect)[5]. That develops within the Bardeen-Petterson radius $R_{BP}$ which is given, rough, by;

$$R_{BP} \gtrsim 10^2 \frac{GM}{c^2} \quad (3.1)$$

which reaches far outside the horizon.

3.2 Time scale for accretion disk precession

Since the total torque involved in the Bardeen-Petterson effect consists of three parts: alignment, precession, and spin-down components. Evidently, the precession time scale and the alignment time scale would be of the same order;

$$\Delta t_{LT} \sim \frac{2\pi}{\Omega_{GM}} \quad (3.2)$$

where $\Omega_{GM}$ is the precession angular velocity which due to the Lense-Thirring effect is given by Wilkins [13]

$$\Omega_{GM} = \frac{2GJ}{c^2R_{BP}^2} \lesssim a_* \frac{2G^2M^2}{c^3(100GM/c^2)^3} = 10^{-6} \frac{2c^3a_*}{GM}; \quad (3.3)$$

$J$ is the total angular momentum of the black hole which is given by $J = 2GM^2a_*/c$, and $a_*$ is the angular momentum ratio with $0 \leq a_* < 1$ [11].

3
4 Concurrence of the Blanford-Payne process with the Bardeen-Peterson effect.

Close to the disk, the plasma flow is driven gas pressure in a hot magnetically dominated corona\[^{[6]}\]. And it produce the jet outflow. The disk should be shifted periodically by frame dragging \[^{[5]}\]. Therefore, When the Blanford-Payne process and the Bardeen-Peterson effect work simultaneously, the AGN jet outflow is probably rotating along the time scale(\(T_{LT}\)) like to (FIG 1).

We begin with a requisite condition to take place. And we make sure that the events have to be well resolved in a time sequence. in this context, we demand the following condition.

If \(\Delta t_{BP} \lesssim \Delta t_{LT}\), the concurrence of Blandford-Payne process and Bardeen-Petterson effect could be resolved (FIG 1). This result can be applied to super massive black hole(SMBH) M87 which has been observed directly from the Event Horizon Telescope(EHT) \[^{[8]}\][\[^{[4]}\]. SMBH M87 given \(M \sim (6.5 \pm 0.7) \times 10^9 M_\odot\[^{[12]}\] and \(B = 1 \sim 34 G\[^{[2]}\][\[^{[3]}\]. The calculated time scale are \(\Delta t_{BP} \sim 1.015yr, \Delta t_{LT} \sim 3986.7yr\), which is impossible value for observation. This is a reason that no one detect the Jet precessions of M87. This results imply observable properties can be calculated by selecting smaller black holes. In same manner, Sagittarius A\(^*\) which was directly observed by EHT Given \(M \sim 4 \times 10^6 M_\odot\[^{[1]}\], the time scales are \(\Delta t_{BP} \sim 35.6hours, \Delta t_{LT} \sim 15.9years\). If the mass of the black hole is smaller, the value of the time scales will be a more reliable value to observe. Therefore, we suggest the time series observation of the black hole jet. If the time series continuum of concurrence of two events is actually observed, this shape like to (FIG 2).

5 Discussion

Our motivation to couple the Blanford-Payne mechanism with Bardeen-Peterson effect is to get any circumstantial evidence if the long standing Blanford-Payne mechanism is indeed a presumable working mechanism as given the Blanford-Payne mechanism alone there is literally no way to judged its relevance as a practical working mechanism.
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Figure 1: Cartoon for the concurrence of the Blandford Payne process and the Bardeen Petterson effect. The red arrows indicate the plasma flow direction.
Figure 2: Schematic Light Curve of the coupled Blandford Payne process and the Bardeen Petterson effect.