Proceedings of the 2nd International Conference on Computing Innovation and Applied Physics
DOI: 10.54254/2753-8818/19/20230529

Formation mechanism of blazar jets

Jiaxuan Chen

Institute of Space Sciences, Shandong University, Weihai, No. 180, Wenhua West Road, Yiyuan Street, Huancui District, Weihai City, Shandong Province, the People's Republic of China

lewxam0102@163.com

Abstract. In research of astronomy, cosmology and the basic theoretical physics, the black hole is one of the most concerned celestial bodies. AGN is a kind of observation source with supermassive black hole as the central core, among which Blazar is the key observation subclass of the observer whose jet is facing the Earth. Therefore, the study of the jet has become an crucial subject of black hole research. In this paper, I start with the basic structure model of AGN, briefly describe the characteristics and mechanisms of each structure, especially the jet, and afterward introduce the observed spectral bimodal characteristics, focusing on the analysis of the existing jet formation mechanism from the radio band. Through the existing observations and data fitting, that is, the logarithmic linear fitting of the jet power to the luminosity of the accretion disc and the jet power to the mass and spin parameters of the black hole, corresponding to the Blandford&Payne and the Blandford&Znajek mechanism respectively. Finally, we analyze the conclusion of the two methods and draw the possibility of the two processes and the complementary relationship in theory. Incidentally, the model theory of mixed interpretation of the two mechanisms and processes is obtained.

Keywords: AGNs, Blazar jet, black hole mass, black hole spin, accretion disc luminosity.

1. Introduction

Currently, a special kind of galaxy attracts extraordinary attention regarding to its strenuous activity, called Active Galaxy. The core of it is called Active Galaxy Nuclei (AGNs). AGNs are divided into Blazar, Quasar, Seyfert Galaxy, Radio Galaxy, Markarian Objects, Low Ionization Nuclear Emission-Line Region(LINER) and so on[1]. Among them, we call the most extreme one as the "Blazar". Blazar is a kind of AGNs which is extreme on luminosity, polarization, the speed and amplitude of optical variation, non-thermal continuous radiation and apparent superluminal phenomenon[2], and is defined as having a jet of material in the direction of the earth and perpendicular to accretion disc[1]. According to the strength of emission line, we divide the Blazar into Flat spectrum radio quasars (FSRQs) and BL Lac objects (BL Lacs).

As a kind of AGN, the Blazar also follows the standard model of "black hole accretion and jet". Up to now, we generally consider the origin of the jets are spinning black hole through Blandford&Znajek mechanism[3] or accretion disc through Blandford&Payne mechanism[4]. According to the Blandford&Znajek mechanism and the Blandford&Payne mechanism, the jet is generally considered to originate from the rotating black holes or accretion discs. As an important phenomenon for

DOI: 10.54254/2753-8818/19/20230529

observing AGNs, the study of jets can help us understand the activity of AGNs, so as to have a good way to start research on the accretion of central black holes, the emergence of relativistic high-energy particles and their interaction with the surrounding environment, which is conducive to the study of the evolution and even formation of the universe and internal galaxies, including central black holes. When we did some efforts on studies on the spinning of the black holes, we always assumed that the spinning may provide energy to the AGNs jets and estimate the spinning depending on the theoretical model. Following this line of thought, we naturally started to explore the formation mechanism of the jets of the Blazar along the line of thought. From then on, the previous papers analyzed the relevance between the power of the jets and the mass and spinning of the black hole and the luminosity of the accretion disc[5,6].

The following section establishes the models of the Blazar and the jet. The Blazar part will be divided into 3 smaller parts to have the models of central supermassive black hole, the accretion disc and the process itself.After all these source models have been established, we can focus on the jet formation mechanism from the relationship between the power of the jets and the luminosity of the accretion disc and the spin and mass of the central supermassive black hole.

2. The developments on blazar and its jets

2.1. The basic model of AGNs

In fact, there has never been an exact definition on AGNs and we always divided and described them through their observation characteristics. As we have distinguished them so far, they have several main observation characteristics and here are these[1,7]. First, the nuclei zone has a high luminosity of about $10^{43}\sim10^{48}$ erg s^{-1} strongly distributed in various bands with scales smaller than 0.1 parsec. Second, the typical spectral characteristic is non thermal radiation and polarized. Third, the radiation intensity of continuous spectrum and emission line spectrum, profile and polarization change with time. Fourth, they can radiate higher energy X-rays, gamma rays photon than normal galaxies and strong atomic and ion emission lines. Finally, with the jet phenomenon. Celestial bodies with some of the above observation characteristics are called ans. There has been no unified classification standard to classify ans yet. But according to the perspective of observation characteristics, we divide ans into six different kinds mentioned in the introduction, and the Blazar is the radio-loud AGNs whose angle between the observed line of sight and the jet direction is about zero.

People use "unified model of AGNs" to interpret the observed characteristics of AGNs mentioned before[8,9]. Figure 1.1 shows the unified model of AGNs, basic structure of it. As the framework is used, the center is a supermassive black hole accreting the surrounding material and convert the gravitational potential energy of them into radiant energy so that there is always an accretion disc around and the radiation jet flow out from the black hole perpendicular to the accretion disc.

On the accretion disc distributed a large number of hot electrons move with the rotation of the gas clouds, strong optical and ultraviolet radiation is generated, especially hard x-ray radiation is generated near the black hole. Out of the accretion disc is the broad line region (BLR) which moves also at a high Kepler speed[10], while out of the BLR is the NLR which moves at a lower speed than the BLR. In the BLR, gas accreted by the gravitation and ionized within a high electron number density by radiation from the accretion disc. From this process, wide emission rays are generated[1]. The same principle, the NLR further from the center moves at a lower Kepler speed and the low-density gas clouds results in relatively narrow spectral lines. Between the BLR and the NLR, there is a torus composed of high-column-density interstellar medium and dust[1]. The dust mainly absorbs and scatters light in the optical and ultraviolet bands and then re radiates from the infrared band, thereby extinction and reddening the observation[11].

DOI: 10.54254/2753-8818/19/20230529

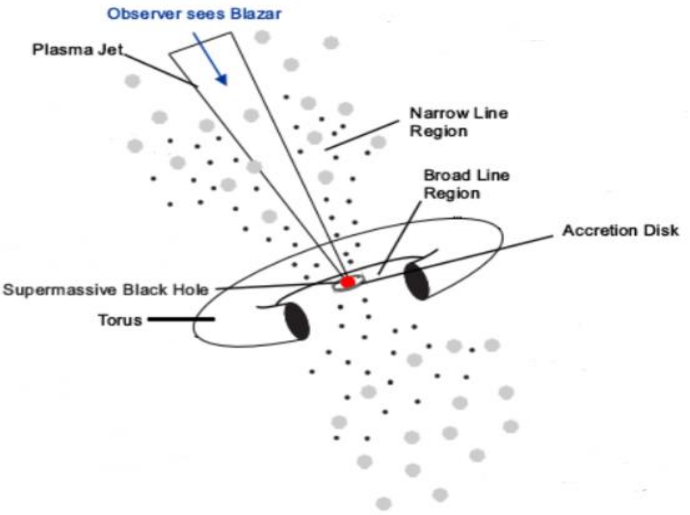

Figure 1. The basic structure of the unified model of AGNs.

2.2. Blazar jets

When considering the radiation mechanism of active galactic nuclei, people have constructed the full band energy spectrum distribution[12]. From the radio band to the gamma band, the energy spectrum of the Blazar presents a typical bimodal structure distribution, which is respectively the low energy peak from the millimeter wave band to the soft x-ray band formed by synchrotron radiation and the high energy peak from the MeV band to the TeV band formed by the inverse Compton scattering of the lepton model[13]. Inverse Compton scattering, that is, the process of quasi light velocity electrons reducing the wavelength of low-energy photons through collisions. And the main part of the radiation of the radio loud AGNs and Blazar is the jet[14].

Very long baseline interferometry (VLBI) is a technology to combine several small telescopes to achieve the observed effect of large telescopes, mainly used for radio band observation. According to VLBI observation, there is a small-scale linear structure nearby the central nuclei zone supposed to be a channel that continuously transports plasma and energy from the center of the galaxy to the radio lobe. And this channel is jet. The jets are always bidirectional from the accretion disc at a relativistic speed and the part linking to the central zone of the AGNs can be extended to ~10^6 pc. In even the x-band, including the lower frequency band, it is almost aligned perpendicular to the accretion disc[4]. The radio lobe linking to the tail of jet forms because the material of the jet interact with the media in galaxy filled with 1~1000 pc[7].

3. Formation mechanism model of the jet and discussions

There are two main models of the formation mechanism of Blazar jet. One is Blandford & Znajek mechanism, in which when the black hole spins under the plasma of the magnetic field, an electric field will be formed in the polar region, thus accelerating the charged particles in the direction of the electric field[3]. Another is Blandford & Payne mechanism, in which under the magnetic freezing effect, the movement of matter on the accretion disc makes the magnetic lines coupled with the accretion disc, and converts the energy and angular momentum of the accretion disc into the kinetic energy of plasma in the magnetic field to form a jet[6].

Under this mechanism, When the Poynting flux is assumed to be the driving energy of the relativistic jet, and the magnetic field energy density near the black hole accounts for a small part of the gravitational energy, we use L_{BZ} to express the power of jet gotten from Blandford & Znajek

DOI: 10.54254/2753-8818/19/20230529

mechanism. The maximum value follows[15]

$$L_{BZ,max} \sim \frac{L_{disk}}{\eta_{acc}}$$

where L_{disk} is accretion disc luminosity and η_{acc} is accretion efficiency which is defined from [16]

$$L_{disk} = \eta_{acc} \dot{M} c^2$$

At present, one of analyzing of the fitting results commonly used for the strong correlation between jet power and accretion disc luminosity are[17]

$$\lg P_{jet} = (11.76 \pm 1.47) + (0.76 \pm 0.03) \lg L_{disk}$$

By the way, researchers found that the jet power of most FSRQ groups (CFs) and all of the BL Lac groups (CBs) are more than the accretion disc luminosity. A theory interprets that for the FR II radio galaxies which are the parent galaxies of FSRQs, the power of the jet is so high-power that it needs only a little part of power to provide energy to the radio lobe causing the jet power to be about the same as accretion disc luminosity, while for the low-power FR I radio galaxies which are the parent galaxies of BL Lacs, there are strong not enough broad transmission rays to show the accretion disc luminosity so that the jet power is much more than the accretion disc luminosity[15]. As this conclusion coming out, there is a new problem that not only the accretion disc contributes to the start up the jet.

To describe the black hole mass and spin contributing to the magnetic field strength to influence the jet start, the empirical relationship[18]

$$L_{j,\ BZ} \approx 2 \times 10^{43} j^2 M_8^2 B_4^2\ erg\ s^{-1}$$

and P_{jet} replacing $L_{j,\ BZ}$, we have[17]

$$\lg P_{jet} \approx 20.78 + 2\lg j + 3\lg M + \lg L_{disk} + \lg \frac{4G}{R^3 c^3 \eta_{acc}}$$

Considering the constant in this empirical formula, there is one example of the strong correlation formula[17,19,20]

$$\lg P_{jet} = (32.37 \pm 0.93) + (0.56 \pm 0.04)(2\lg j + 3\lg M)$$

4. Discussion

Based on checking samples, CBs subclasses and CFs subclasses show similar strong correlation. This result proofs the contribution of the mass and spin of black holes. But in fact, when fitting the correlation between jet power, black hole mass and spin respectively, the mass correlation is weak, while the spin correlation is strong. Similarly, compared with CBs and CFs sample sets, the quality correlation of CFs is slightly larger[17]. However, according to the theory, there should be a quadratic proportional relationship between the jet power and the black hole mass, so it is speculated that this is caused by the overestimation of the black hole mass at the BL Lacs center[21,22]. The reverberation mapping method which uses the wide line photoionization spectrum to obtain the scale and velocity of the broad line region with the light variation delay time of the central region, so as to calculate the mass of the central potential black hole[23-25] is a reliable method to estimate the mass of black holes, but despite this, there is still a large estimation system error. Because except it needs long enough period of observation time, different scholars use different versions of Hβ and Mg II wide emission ray for geodynamic parameter correction. There must be many assumptions about the geometry, the velocity structure of BLR and the ionization source radiation position[26]. And in fact, the velocity of the gas clouds in the BLR is estimated as

DOI: 10.54254/2753-8818/19/20230529

$$v_{BLR} \approx \frac{\sqrt{3}}{2} FWHM$$

In addition, the continuous spectral luminosity will be enhanced by the host galaxy or even obscured by dust due to the synchrotron radiation effect. When the sample black holes are reduced by an order of magnitude on average, a strong correlation is obtained, so it can be preliminarily judged that the correlation between jet power and black hole mass is proved[17]. However, the black hole spins correlation of CBs is stronger than that of CFs, probably because when the mass correlation of CBs decreases, the correlation of the accretion disc luminosity increases, while the estimate of the black hole spin depends on the accretion disc luminosity, which is the opposite for CFs.

Blazar is a kind of radio loud active galactic nuclei. The other kind to is the radio quiet source. If we mainly consider the explanation of radio radiation from jets, there is a radiation pressure driving mechanism for the formation mechanism, as which the material on the accretion disc accelerates and collimates on a funnel like channel in the axial direction in high accretion mode. Although the acceleration semidiameter can reach hundreds of the Schwarzschild semidiameter, the speed is still smaller than the explanation of the strong jets observed by radio loud active galactic nuclei.

According to this, we can see that the formation mechanism of jets of BL Lacs is more inclined to the leading role of Blandford&Znajek process like FSRQs[27]. Of course, we can also see that in addition to the correlation between the mass and spin of black holes, the strong correlation between jet and the luminosity of accretion disc is an influencing factor that we cannot ignore, that is, the contribution of Blandford&Payne process should not be excluded from the scope of consideration. Finally, a mixed theoretical model emerged, which believes that the large-scale magnetic field passing through the black hole generates energy under the joint influence of the black hole spin and the accretion disc, leading to the formation of jet[28].

5. Conclusion

This paper offers a view of the formation mechanism of the Blazar jets to summarize the existing literature and research. To understand this problem, researchers need to analyze the construction of the ANGs especially the jet, the correlation of the accretion disc luminosity, black hole mass and spin. And the two mainly mechanisms are both contributing to the mechanism for Blandford&Znajek with black hole mass and spin and for Blandford&Payne with accretion disc luminosity.

As the contain above, in answering the research question, formation mechanism of the Blazar jets, there are many logarithmic linear fitting of jet power to accretion disc power, jet power to mass and spin of central black hole of sample set. By analyzing the correlation between these three parameters and jet power, we can further understand the measured basis and reasoning support based on data analysis of two formation mechanisms corresponding to accretion discs and black holes respectively. In this article, I have attempted to explain the measured basis and reasoning support based on data analysis of the three parameters to elaborate the two existing formation mechanisms respectively and the system error factors that cause the weak correlation between data are simply analyzed, such as the influence of the estimation accuracy of the black hole mass, etc.

Starting from the correlation between the luminosity of the accretion disc and the power of the jet, the discovery of deficiencies further leads to the correlation between the mass and spin parameters of the black hole, which emphasizes the strong possibility of the contribution of the Blandford&Payne process and the Blandford&Znajek process to the formation of the jet respectively. However, based on the relationship between the physical and theoretical processes between the two, further exploration is needed. Starting from the relationship among the parameters of the black hole and the parameters of the accretion disc, maybe we can find a jet formation process theory compatible with the two processes.

References

[1] Huang Kerong (2005). Quasars and active galactic nuclei. China Science and Technology Press

DOI: 10.54254/2753-8818/19/20230529

[2] Stickel, M. , Fried, J. W. , Kuehr, H. , Padovani, P. , & Urry, C. M. . (1991). The complete sample of 1 jansky bl lacertae objects. i - summary properties. Astrophysical Journal, 374(2).
[3] Blandford, R. D. , & Znajek, R. L. . (1977). Electromagnetic extraction of energy from kerr black holes. Monthly Notices of the Royal Astronomical Society, 179(3), 433-456.
[4] Blandford, R. D. , & Payne, D. G. . (1982). Hydromagnetic flows from accretion discs and the production of radio jets. Monthly Notices of the Royal Astronomical Society, 199(4), 883-903.
[5] Maraschi, L. , & Tavecchio, F. . (2002). The Jet-disc Connection and Blazar Unification. arXiv, 10.1086/342118.
[6] Ghisellini, G. , Tavecchio, F. , Maraschi, L. , Celotti, A. , & Sbarrato, T. . (2014). The power of relativistic jets is larger than the luminosity of their accretion discs. Nature, 515(7527), 376-378.
[7] He Xiangtao (2007). Observational cosmology. Beijing Normal University Press
[8] Urry, C. M. . (1995). Unified schemes for radio-loud active galactic nuclei. publications of the astronomical society of the pacific.
[9] Wills, Beverley, J., Wills, D., & Breger, et al. (1992). A survey for high optical polarization in quasars with core-dominant radio structure - is there a beamed optical continuum?. ApJ, 398(2), 454-454.
[10] Ding Nan. (2020). Research on multi band light variability of active galactic nuclei (doctoral dissertation, Nanjing University). https://kns.cnki.net/KCMS/detail/detail.aspx?dbname=CDFDLAST2021&filename=1021501269.nh
[11] Li Linlin, Shen Shiyin,&Hou Jinliang (2018). Advances in the study of the spatial distribution of intergalactic extinction in the Milky Way Progress in Astronomy , 36(1), 16.
[12] Fossati, G. , Maraschi, L. , Celotti, A. , Comastri, A. , & Ghisellini, G. . (2010). A unifying view of the spectral energy distributions of blazars. Monthly Notices of the Royal Astronomical Society(2), 433-448.
[13] Urry, C. M. . (1998). Multiwavelength properties of blazars. Advances in Space Research, 21(1-2), 89-100.
[14] \bibitem[Dermer \& Schlickeiser(1993)]{1993ApJ...416..458D} Dermer, C.~D. \& Schlickeiser, R.\ 1993, \apj, 416, 458. doi:10.1086/173251
[15] Ghisellini, G. . (2007). Blazars and Gamma Ray Bursts. VI Microquasar Workshop: Microquasars and Beyond.
[16] Calderone, G. , Ghisellini, G. , Colpi, M. , & Dotti, M. . (2013). Black hole mass estimate for a sample of radio-loud narrow-line seyfert 1 galaxies. Monthly Notices of the Royal Astronomical Society(1), 210-239.
[17] Zhang Lixia Jet and accretion of blazing variants
[18] Daly, R. A. . (2009). Bounds on black hole spins. Astrophysical Journal, 696(1), L191.
[19] Ghisellini, G. , & Tavecchio, F. . (2010). The blazar sequence: a new perspective. Monthly Notices of the Royal Astronomical Society, 387(4), 1669-1680.
[20] Thorne, K. S. . (1974). disc-accretion onto a black hole. ii. evolution of the hole. The Astrophysical Journal, 191(2), 507-520.
[21] (1998). The demography of massive dark objects in galaxy centers. The Astronomical Journal.
[22] Ferrarese, L. , & Merritt, D. . (2000). A Fundamental Relation between Supermassive Black Holes and Their Host Galaxies. ApJL, 10.1086/312838.
[23] Blandford, R. D. , & Mckee, C. F. . (1982). Reverberation mapping of the emission line regions of seyfert galaxies and quasars. Astrophysical Journal, 255(2), 419-439.
[24] Bradley, m., & Peterson. (1993). Reverberation mapping of active galactic nuclei. Publications of the Astronomical Society of the Pacific.

DOI: 10.54254/2753-8818/19/20230529

[25] Koratkar, A. P. , & Gaskell, C. M. . (1991). Structure and kinematics of the broad-line regions in active galaxies from iue variability data. Astrophysical Journal Supplement, 75(3), 719-750.
[26] Krolik, & Julian, H. . (2001). Systematic errors in the estimation of black hole masses by reverberation mapping. Astrophysical Journal, 551(1), 72-79.
[27] Liang, C. . (2018). On the jet properties of γ-ray-loud active galactic nuclei. Astrophysical Journal Supplement, 235(2).
[28] Kang Shiju (2017). A study of jet physics of blazing bodies Journal of Astronomy, 58(5), 130-132.