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The Correlations of Jet Power with Black Hole Mass and Spin in Radio Loud Quasars[†] [⋆]

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Abstract The formation of jets is closely related with the black hole mass and black hole spin, to study the correlations of jet power with the black hole mass and black hole spin is of significant importance for understanding the jet formation and structure. We have collected 65 radio loud quasars from the literature. The sample includes 35 Steep Spectrum Radio Quasars (SSRQs) and 30 Flat Spectrum Radio Quasars (FSRQs) with the redshifts ranging from about zero to two. We present here the correlation analysis of jet power with the black hole mass and back hole spin based on the sample data. Our conclusions are as follows: (1) The black hole mass has a strong correlation with the jet power; (2) The black hole spin is also strongly correlated with the jet power, especially for the magnetic field strength $B = B_{EDD}$, where B_{EDD} is the Eddington magnetic field strength, and the correlation coefficient is higher than that between black hole mass and jet power; (3) There are certain differences between the distributions of spin data of SSRQs and FSRQs; (4) This study has further confirmed that the jet energy is related not only with the black hole mass, but also with the spin energy of the black hole. The formation of black hole jet may be very possibly resulted by the joint effect of black hole mass and black hole spin. These results are consistent with the previous results obtained by other methods.

Key words black hole physics—galaxies: active—galaxies: nuclei—galaxies: jets

1. INTRODUCTION

It is generally believed that large-mass black holes will produce strong jets[1,2]. Although there are now a large number of related data and many theoretical models, but until now

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the mechanism how jets are produced from black holes, and their structures are still not yet clear. Commonly, we believe that the jet is produced near the black hole's central horizon, this concept was first proposed by Penrose in 1969, and he suggested that a spinning black hole possesses the spin energy[3]. Blandford et al.[4] suggested that this kind of energy can serve as the energy supply to the jet of the black hole. And they pointed out that the magnetic field will bend due to the black hole's rotation, and therefore favor the production of a collimated jet. The correlation between the black hole spin energy and the jet is very significant in theory, but there is no direct evidence to support this relation. This is due to that previously there was no reliable method to measure the characteristic of black hole spin ($j = cJ/(GM^2)$), where M and J are respectively the black hole mass and angular momentum. However, nowadays we have many methods to measure accurately the black hole spin. For example, using the BZ model[5], in the condition of known black hole mass, magnetic field strength, and flux density, to estimate the magnitude of black hole spin j. This method can be used for the correlation analysis of black hole spin and jet energy, to verify whether a relationship exists between the jet and the black hole spin. Both Narayan et al.[6] and Fender et al.[7] have made the study on the correlation between the black hole spin and the jet energy, but obtained different results. In their studies, the collected samples are rather small, this may cause some errors in their results of correlation analysis. Further more, they have not discussed another important factor in the determination of jet energy—the effect of black hole mass. In this paper, we expand the sample size, and use the angular momentum of black hole spin to make the correlation study between the black hole spin and the jet energy, compared with the spin angular frequency, the spin angular momentum is more representative for the spin characteristic of a black hole. In this paper we will discuss respectively the effects of the black hole mass and black hole spin on the jet energy, and evaluate which one is more important to the jet energy. The formula of black hole spin in the BZ model is used to calculate the spin[6] and spin energy[8] for the collected sample. This paper has discussed respectively the correlations of black hole mass with the spin and jet energy under three kinds of different magnetic field conditions, the obtained result shows that in the radio loud quasars the black hole spin is closely related with the jet energy. This result is consistent with the conclusion obtained by Narayan et al.[6], indicating that very possibly the jet energy is originated from the black hole spin energy. This paper has given a method to estimate the black hole spin in radio loud quasars by using the model formula, which provides a base for the further study of the relation between the spin energy and the jet energy.

2. CALCULATION OF BLACK HOLE SPIN

In this paper the method as same as that of Daly[8] is used to calculate the angular momentum of black hole spin. In the BZ model, the generation of electron beam power L_j and the