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The Fundamental Plane of Radio Loud Quasars and X-ray Binaries† ⋆

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Abstract In many X-ray binaries (XRBs) at the low/hard state exists a fairly good correlation between the radio and X-ray luminosities. Dong et al. also found this relation in radio quiet quasars (RQQs), and its expression has a definite similarity with the expression for the fundamental plane of the XRBs in the low/hard state. The collected radio loud quasars (RLQs) are analyzed to see whether such a relation also exists in the RLQs or not, and these sources include 255 RLQs. The analyzed results show that (1) such a correlation exists not only between the black hole mass and radio/X-ray luminosity, but also between the Eddington ratio of radio luminosity and that of X-ray luminosity in the 255 RLQs, which has a definite similarity with the expression for the fundamental plane derived by Dong et al. from the black hole binaries at the bright/hard state and RLQs, but still exists a certain difference; (2) the expressions for the fundamental plane of the XRBs at the low/hard state and that of RLQs can be unified to be $\lg L_R = 0.998^{+0.045}_{-0.045} \lg L_X + 0.592^{+0.049}_{-0.049} \lg M_{BH} - 6.56^{+1.605}_{-1.605}$ (L_R is the radio luminosity, L_X is the X-ray luminosity, and M_{BH} is the black hole mass); (3) the fundamental plane expression composed of the radio and X-ray luminosities and black hole mass has a high universality, it can be used not only for the XRBs at the low/hard state and RQQs, but also for RLQs.

Key words black hole physics—X-rays: binaries—galaxies: jets

1. INTRODUCTION

The black hole accretion and jet formation are considered to be scale-invariant, and the fundamental plane of black hole accretion can be expressed by an empirical expression

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composed of the radio and X-ray luminosities and black hole mass. At present, there are a lot of theory and observational evidence to support the theories of the scale-invariant black hole accretion and relativistic jets. The observational evidence also supports the existence of an expression for the fundamental planes of the black hole activities in the X-ray binary (XRB) and active galactic nucleus (AGN). The expression of fundamental plane is statistically an empirical formula of nonlinear correlation composed of the black hole mass and radio/X-ray luminosities, and in the expression of fundamental plane the radio luminosity is something like a probe of AGN jets, while the X-ray luminosity is something like a measurement of the accretion rate. The XRB system and AGN have a similar central engine: the black hole–accretion disk–jets. The XRB system is always in a quiet state for most of time, but it can erupt suddenly in a very short time, and continuously emits outward the radio and X-ray radiations in the subsequent times from several months to several years. Based on the spectral and periodic characters, such eruptions can be divided into many different states[1]. During the initial period of eruptions, the XRBs are basically in a low state, while they are located in a hard state during the end time of eruptions. The X-ray radiation can be described by a power-law function of the photon spectral index $1.5 \leq \Gamma \leq 2.5$, which can extend from 1 keV to 100 keV. The X-ray spectrum is dominated by a strong black-body radiation, when $\Gamma \geq 2$ the XRBs will stay at the high/soft state with a higher luminosity. However, some XRBs may stay in a very high state when $\Gamma \geq 2.4$, but which is somehow different from the previous high/soft state[2,3]. Through comparative studies of AGNs with the XRBs at different stages, the opinion that many different kinds of AGNs can be uniformly classified has been accepted gradually by people. Generally, we determine the orientation of an AGN based on the horizon and radio noisiness, and the magnitude of noisiness is commonly obtained from the ratio of flux densities at the 5 GHz frequency and B-band 4400 $\mathring{A}$ wavelength[4] ($R_0 = F_{5\mathrm{GHz}}/F_B$). R_0=10 is commonly considered to be a criterion to distinguish the radio quiet and radio loud[5]. On the basis of unified energy theory, different AGNs can be classified by the XRBs corresponding to different stages[6]. The AGNs with a low luminosity (LLAGNs) can be classified as the XRBs in the low/hard state, while the RQQs can be classified as the XRBs in the high/soft state. The radio luminosity of quasars can be deduced from the X-ray luminosity and black hole mass by an empirical formula, and this correlation formula between radio and X-ray luminosities is called the fundamental plane relation. Initially, it was believed that this phenomenon is due to that X-rays are originated from the accretion flows or jets themselves, but it was found very soon that the different sources with the same accretion mechanism may have a difference of mass of about 9 orders of magnitude. Xue et al.[7] found in 2007 that the correlation mechanism of radio and X-ray luminosities is unlike that we thought before. In the later several years, more and more radio binaries were discovered, which do not suit the previous scattering X-ray model. This implies that the radio-X-ray correlation is closely related to the evolution of the radio spectrum. Through analyzing the sample with a higher accuracy,