A model for the 'outlier' radio/X-ray correlation in black hole X-ray binaries

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Abstract

Observationally, it is found that there is a strong correlation between the radio luminosity and the X-ray luminosity in black hole X-ray binaries. The 'universal' correlation, i.e., $L_R \propto L_X^{\sim 0.6}$ was well explained by the model of the coupling of a radiatively inefficient accretion flow and a jet. Recently a growing number of sources have been found with a complicated radio/X-ray correlation, e.g., $L_R \propto L_X^{\sim 1.4}$ for $L_X/L_{Edd} \gtrsim 10^{-3}$, which is often called 'outlier' correlation. In this paper, we interpreted such a 'outlier' radio/X-ray correlation within the framework of a disk corona-jet model, in which the matter in the accretion flow and the matter in the jet are connected by a parameter, η, describing the fraction of the matter in the accretion flow ejected outward to form the jet. By fitting the spectrum, it is found that the X-ray emission is dominated by the corona and the radio emission is dominated by the jet. Meanwhile, we found that the value of η for the 'outlier' correlation for $L_X/L_{Edd} > 10^{-3}$ is systematically less than that of the 'standard' correlation, which is consistent with the general idea that the jet is often relatively suppressed at the high luminosity phase in black hole X-ray binaries.

Key words: accretion discs — black hole physics — X-rays — radio emission — H1743-322

1. Introduction

Recently, a growing number of black hole X-ray binaries (BHXBs) have been discovered with a 'outlier' radio/X-ray correlation of $L_R \propto L_X^{\sim 1.4}$ for $L_X \gtrsim 10^{-3} L_{Edd}$, which is suggested to be explained within the framework of the coupling of a radiatively efficient accretion flow and a jet (Corbel et al. 2004; Rodriguez et al. 2007; Soleri et al. 2010; Coriat et al. 2011; Corbel et al. 2013). Observationally, there is evidence for the coupling of a disk corona and a jet at a high mass accretion rate and the coupling of a radiatively inefficient accretion flow (RIAF) and a jet at a low mass accretion rates (Wu et al. 2013). Meanwhile, theoretically, for $\dot{M} \gtrsim \alpha^2 \dot{M}_{Edd}$ (with α the viscosity parameter, $\dot{M}_{Edd} = 1.39 \times 10^{18} M/M_\odot\ g\ s^{-1}$), the accretion flow will transit from a RIAF to a disk corona system (Qiao & Liu 2009, 2010, 2013; Narayan & Yi 1995b). In this work, we proposed a disk corona-jet model to explain the 'outlier' radio/X-ray correlation of $L_R \propto L_X^{\sim 1.4}$ for $L_X/L_{Edd} \gtrsim 10^{-3}$. We briefly introduce the disk corona-jet model and the results in Section 2. Section 3 is the conclusion.

2. The model

In the model, the disk and corona are radiatively and dynamically coupled (Liu et al. 2002,2003; Qiao & Liu 2015). Thus, the energy fraction dissipated respectively in the corona and disk, and coronal density and temperature can all be self-consistently determined for given black hole mass and accretion rate. Then the spectrum emitted by the disk and corona can be calculated by Monte Carlo simulation. Assuming a fraction of matter in the accretion flow, $\eta \equiv \dot{M}_{jet}/\dot{M}$, is ejected outward to form the jet, we can also calculate the emergent spectrum from the jet. So far, the theoretical understanding of the jet formation is poor. Specifically, it is difficult to put constraints on the dependence of η on $\dot{M}$ in our model, so we set η as an independent parameter on $\dot{M}$ to fit the observations.

We calculate L_R and L_X at different $\dot{M}$, adjusting η to fit the observed 'outlier' radio/X-ray correlation of the black hole X-ray transient H1743-322 for $L_X/L_{Edd} > 10^{-3}$. It is found that always the X-ray emission is dominated by the corona and the radio emission is dominated by the jet. See Figure 1 for the details. We noted that the value of η for the radio/X-ray correlation of $L_R \propto L_X^{\sim 1.4}$ for $L_X/L_{Edd} > 10^{-3}$, is systematically less than that of the case for $L_X/L_{Edd} < 10^{-3}$, which is consistent with the general idea of jets often relatively suppressed at the high luminosity phase in black hole X-ray binaries.

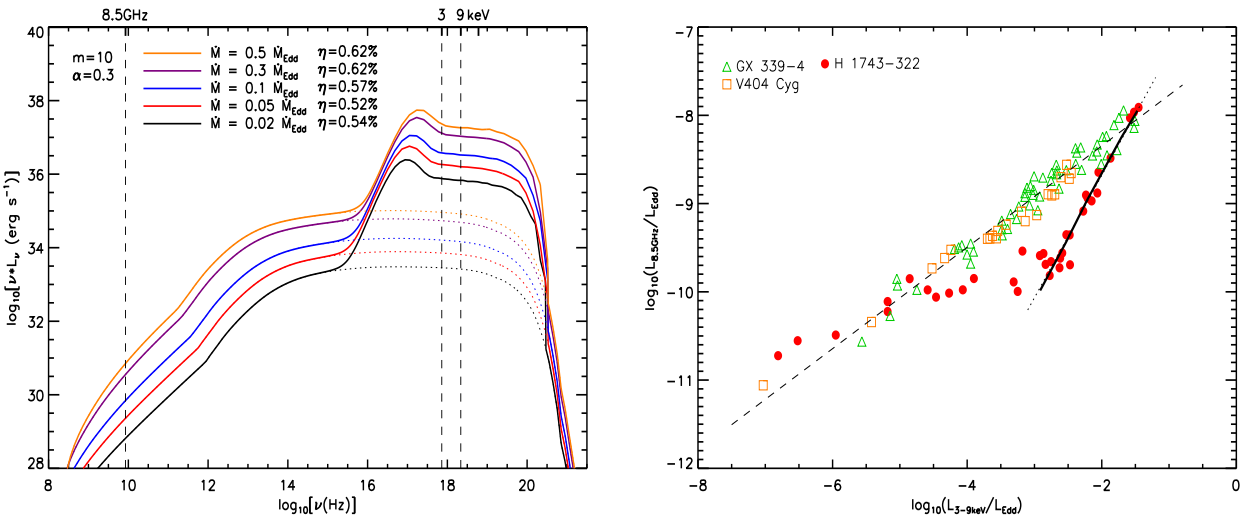

Fig. 1.

Left-hand panel: Emergent spectra of the disc corona-jet model around a black hole with $M = 10M_{\odot}$ assuming $\alpha = 0.3$ for modeling the radio/X-ray correlation of the black hole X-ray transient H1743-322 for $L_{3-9keV}/\ L_{Edd} > 10^{-3}$. From the bottom up, the solid lines are the combined emergent spectra of the disc corona-jet model for $\dot{M} = 0.02, 0.05, 0.1, 0.3$ and $0.5\ \dot{M}_{Edd}$, and the corresponding dotted lines are the emergent spectra from the jet with $\eta = 0.54\%$, 0.52%, 0.57%, 0.62% and 0.62% respectively. Right-hand panel: $L_{8.5GHz}/L_{Edd}$ as a function of L_{3-9keV}/L_{Edd}. The red '•' are the observations for H1743-322, the green △'are the observations for GX 339-4, and orange '□' are the observations for V404 Cyg. The dotted line is the best-fitting linear regression of H1743-322 for $L_{3-9keV}/\ L_{Edd} > 10^{-3}$. The dashed line is the best-fitting linear regression of GX 339-4 and V404 Cyg. The thick solid line is the model line, and the model spectra are shown in the left panel.

3. Conclusions

We investigate the 'outlier' radio/X-ray correlation of $L_R \propto L_X^{\sim 1.4}$ for $L_X/L_{Edd} \gtrsim 10^{-3}$ within the framework of a disk corona-jet model. We note an interesting result, i.e., the fraction of the ejected matter η ($\sim 0.57\%$) for the radio/X-ray correlation of $L_R \propto L_X^{\sim 1.4}$ for $L_X/L_{Edd} \gtrsim 10^{-3}$, is systematically less than that of the case for $L_X/L_{Edd} < 10^{-3}$ (at least $\eta \gtrsim 1\%$), which may put some constraints on the jet formation, i.e., by suggesting that the strength of the jet power is relatively suppressed during the high luminosity phase in BHXBs.

Recently, it is found that there exits a 'outlier' radio/X-ray correlation in luminous active galactic nuclei (AGNs) (Dong et al. 2014; Panessa et al. 2015). We suggested that such a steep radio/X-ray correlation in AGNs can also be explained with the disk corona-jet model, which may imply the similarities of the theory of black hole accretion across the scales of several orders of magnitude. The study of the 'outlier' radio/X-ray correlation in AGNs will be conducted in the future.

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