Draft version March 10, 2021
Typeset using LaTeX **twocolumn** style in AASTeX63

Ay 215: Galactic Black Holes on the Radio/X-Ray Fundamental Plane

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1. BLACK HOLE X-RAY BINARIES AND THE LOW/HARD STATE

Black hole X-ray binaries (BH XRBs) are systems with a stellar mass black hole accreting material from a companion star. XRBs can be classified as either low-mass or high-mass systems based on the mass of the companion star, with the boundary being around $1M_{\odot}$. BH XRBs can be classified by their X-ray spectral states. The two most significant spectral classifications are the thermal state (formerly referred to as the high/soft state) and the hard state (formerly referred to as the low/hard state). In the thermal state, the X-ray emission is dominated by a thermal spectrum, thought to originate in the accretion disk of the black hole. In the hard state, the X-ray emission is dominated by a power law spectrum with a high photon index of $1.4 < \Gamma < 2.1$. It is accompanied by nearly flat spectrum radio emission thought to originate from a compact jet. XRBs can also be observed in a quiescent state, characterized by a much lower luminosity than either hard or thermal outbursts but with a spectral similarity to the hard state. Remillard & Mcclintock (2006) provides a detailed review on this topic. Here, we focus on the correlation between radio and X-ray emission of BH XRBs and how the correlation changes with spectral state.

2. PROPERTIES OF THE RADIO/X-RAY FUNDAMENTAL PLANE

Some correlation between the radio and X-ray flux in the hard states of BH XRBs was first observed to exist in superluminal sources GRS 1915+105 and GRO J1655−40, though it was not studied in depth. Quantitative evidence for a correlation was first presented by Hannikainen et al. (1998) for low-mass XRB GX 339−4 and was succeeded by studies of similar correlation in high-mass XRB Cygnus X−1. These results motivated Gallo et al. (2003) to conduct a comprehensive study of the correlation between radio and X-ray emission in the hard state as a general characteristic of BH XRBs. In this study, all known archival data of simultaneous radio and X-ray observations of BH XRBs were used to calculation the correlation. The radio observations range from 4.9 to 15 GHz and the authors assume a flat spectral index for these sources. The X-ray observations are scaled into the 2-11 keV band. Figure 1 shows a plot of these scaled observations. Along the top of the plot is an axis representing the luminosity in units of Eddington luminosity assuming all of the black holes in question are $10M_{\odot}$. With these data, Gallo et al. (2003) find that $S_{\rm radio} = kS_X^{+0.7}$, where k is a constant that is source-dependent. As more data became available for more galactic sources and these results were analyzed in conjunction with high mass black holes (Merloni et al. 2003), this relationship was updated to $L_{\rm radio} = kL_X^{+0.6\pm0.11}$. This is still within 1σ of the results of Gallo et al. (2003).

2.1. *Turnover in Trend*

From Figure 1, it can be seen that both GX 339−4 and Cygnus X−1 show a turnover in the correlation, though GX 339−4 appears to turn over at a lower X-ray luminosity than Cygnus X−1. Taking into account that the black hole in GX 339−4 is actually lighter than $10M_{\odot}$, Gallo et al. (2003) infer that this turnover might be taking place at a constant fraction of the Eddington luminosity, presumably near $\sim 1\%$. This is thought to occur as the source transitions from the hard state to the thermal state, evidenced by observations of Cygnus X−1. In the thermal state, some mechanism "quenches" the compact jet and thus causes the radio luminosity to decline.

2.2. *Correlation in Quiescence: The Case of A0620-00*

Until publication of work by Gallo et al. (2006) on low-mass XRB A0620-00, the place of quiescent sources in relation to the fundamental plane was unknown. However, showing that a quiescent source emitting X-rays at merely $10^{-8.5}L_{edd}$ still fell on the fundamental plane provided compelling evidence sources in quiescence behave similarly to sources in the hard state. This implies that quiescent sources still produce radio-emitting outflows.

3. PROSPECTS FOR FUTURE OBSERVATIONS

Placing observations of both previously known and newly discovered XRBs on the fundamental plane requires frequent monitoring of these systems simultaneously in X-ray and radio bands. Given frequent observations of XRBs with a wide-field X-ray instrument such as eROSITA coupled with upcoming wide-field radio surveys such as the SKA or DSA-2000, it should be

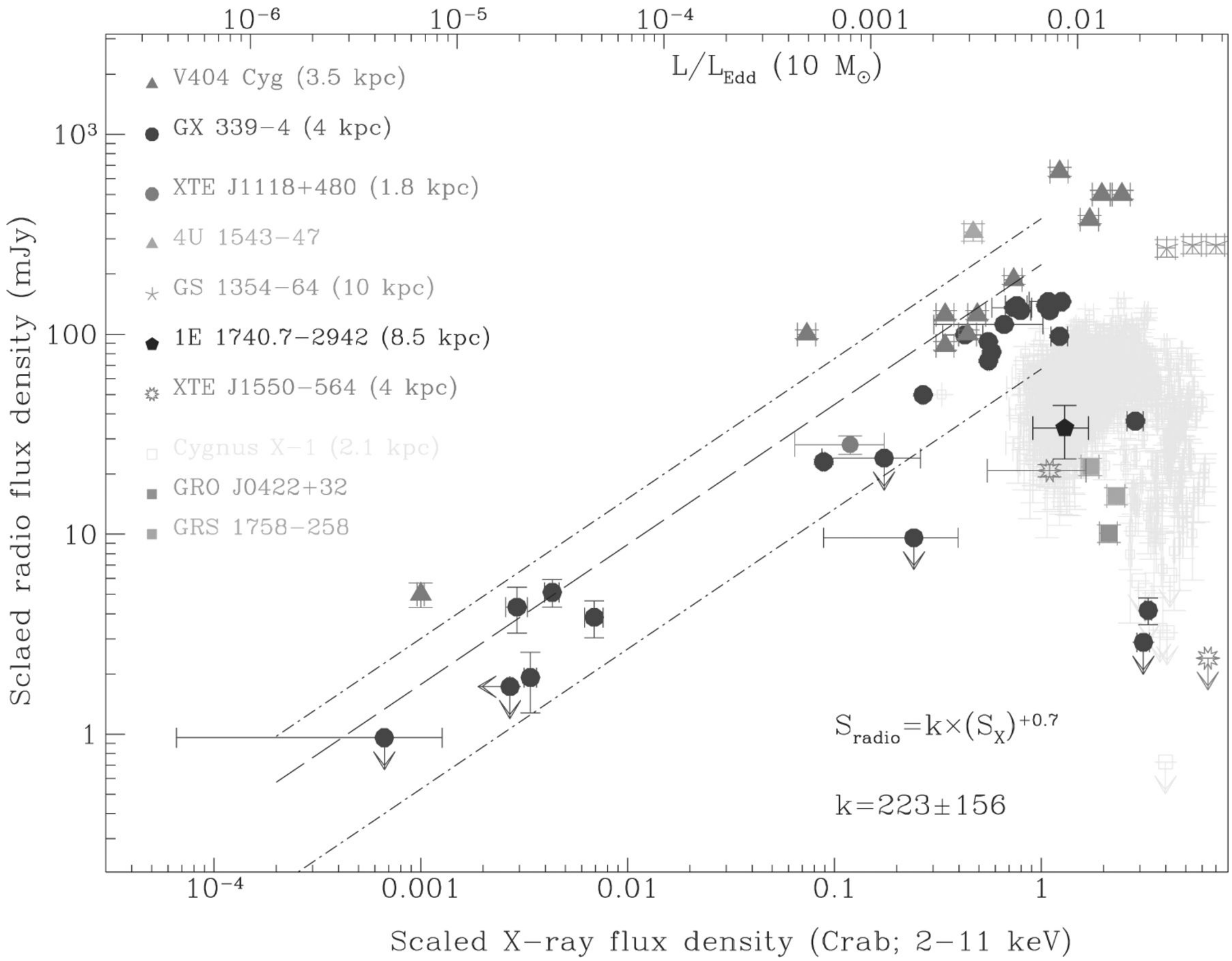

Figure 1.

possible to study the correlation of many more sources. Increasing the population of sources along the fundamental plane is important for more making a more precise estimate of the correlation between radio and X-ray emission, increasing the population of known quiescent sources along the fundamental plane, and perhaps developing a correlation between X-ray turnover luminosity and black hole mass.

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