Optical Version of the Fundamental Plane of Black Hole Activity

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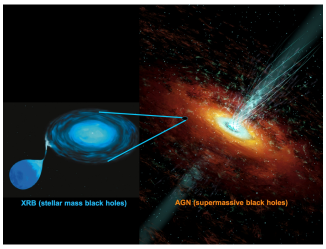
ABSTRACT

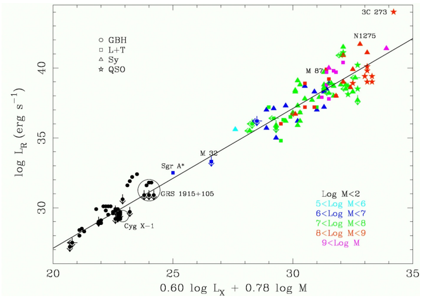
Black Hole accretion and jet formation have long been thought to be scale invariant. One empirical relation suggesting scale invariance is the Fundamental Plane of Black Hole activity, which is a plane in the 3D space given by the black hole mass and the radio/X-ray luminosities. We search for an alternate version of this plane using optical emission instead of X-ray luminosity. We use a complete sample of 39 supermassive black holes selected from the Palomar Spectroscopic Survey with available radio and optical measurements and information on black hole mass. The stellar mass X-ray binary GX339-4 has also been included to examine if physical processes behind accretion is universal across the entire range of black hole mass. We present results of multivariate regression analysis and show that the sample stretches out as a plane in the 3D logarithmic space created by [OIII] or bolometric luminosity, radio luminosity and black hole mass. We also propose a new definition for Radio Loudness $\bar{R}$ in view of the fundamental plane found.

INTRODUCTION

Accretion physics is thought to scale globally across black holes of entire mass range from the supermassive to the stellar-mass black holes.



The fundamental plane of black hole activity - connecting XRBs and AGN is a non-linear empirical correlation in the space given by the M_{BH}, the L_R and the L_X with high statistical significance.

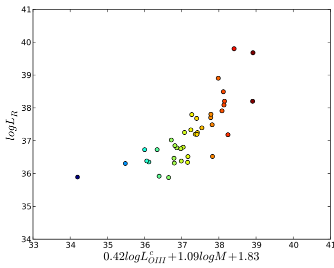


Fundamental Plane of Black Hole Activity : Merloni et al 2003, Falcke et al. 2004

SAMPLE SELECTION

To study the general properties of accretion, it is needed to have a complete and unbiased sample of galaxies covering a broad range of spectral types, luminosities and morphological types.

The SMBH sample used for this study has been extracted from the Palomar Spectroscopic Survey. We have restricted our sample to the galaxies having available data in 15 GHz radio luminosity, [OIII] line luminosity and black hole mass. This gives us a SMBH sample of 39 galaxies, which stretches out as a plane in the 3D log space defined by M_{BH}, L_R and the $L_{[OIII]}$.



We also include the persistent stellar-mass source XRB GX 339-4 as 88 quasi-simultaneous radio and X-ray observations from a long-term campaign of the source in the low/hard state.

ANALYSIS

Multivariate correlation linear regression analysis was performed on the data to estimate the parameters for the plane.

The modified chi-square estimator known as merit function was used as uncertainties were present in all the required measurements. The merit function is defined as

$$\chi^2(a,b) = \sum_i \frac{(y_i - b - \sum_j a_j x_{ij})^2}{\sigma_{yi}^2 + \sum_j (a_j \sigma_{x_{ij}})^2},$$

where $\sigma_{x_{ij}}$ and σ_{yi} are respective uncertainties. Here y_i can denote the $L_{[OIII]}$, x_{1j} can represent the L_R and x_{2j} can denote the M_{BH}.

We use the merit function to estimate the best fit coefficients for the function

$$\log L_R = \xi_{RO} \log L^c_{OIII} + \xi_{RM} \log M + b_R \,,$$

where ξ_{RO} and ξ_{RM} denote the respective correlation indices and b_R is the constant offset.

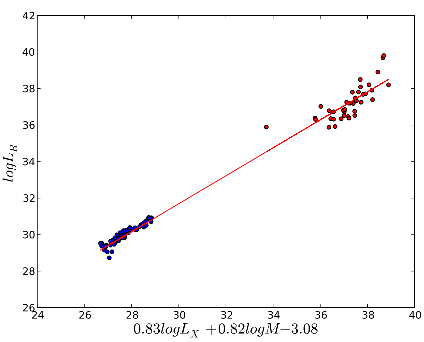
We also performed the Kendall τ Correlation Test on our Supermassive black hole sample to statistically verify the significance of the plane. We obtained a value of 1.20×10^{-7} as the probability for absence of this plane.

RESULTS

REPRODUCING THE FUNDAMENTAL PLANE

We reproduce the Fundamental Plane of black hole activity by converting the [OIII] line luminosities to X-ray luminosities. We show that the stellar mass black holes completely agree to the extrapolation of the fundamental plane independently stretched out by the supermassive black hole sample. A combined fit of the sample gives

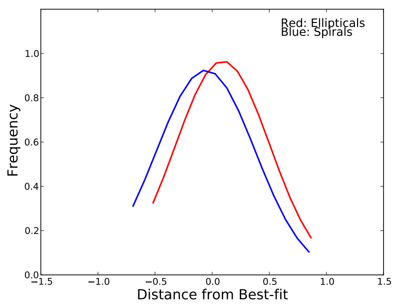
$$\log L_R = 0.66 \log L_X + 0.61 \log M \,.$$



IMPLICATION FOR RADIO LOUDNESS

In view of our Fundamental Plane, we propose a new Radio loudness parameter $\bar{R}$ which takes into account the non-linearity in the radio and optical luminosity correlation and also introduces mass scaling. We define the new parameter as

$$\bar{R} = \frac{L_R}{L_{OIII}^{0.42} M^{1.09}}$$



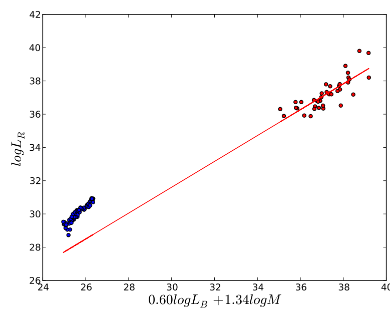
KS tests show that the $\bar{R}$ of ellipticals and spirals may belong to the same underlying distribution.

INTRODUCING THE BOLOMETRIC PLANE

We also introduce a bolometric fundamental plane obtained by converting the corresponding [OIII] line luminosities to Bolometric luminosities. Using a simple linear relation between [OIII] and bolometric luminosities, we obtain a plane for the supermassive sample defined by

$$\log L_R = 0.60 \log L_B + 1.34 \log M \,.$$

Inclusion of the GX 339-4 data does not change the parameters of the plane considerably.



References

Saikia P., Körding E., In prep.; Falcke H., Körding E., Markoff S., 2004, A&A, 414, 895; Merloni A., Heinz S., Matteo T.D., 2003, MNRAS, 345, 1057