*Nuclear Activity in Galaxies Across Cosmic Time*
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# The origin of X-ray emission in Low-Excitation Radio Galaxies

**Shuang-Liang Li**

Key Laboratory for Research in Galaxies and Cosmology, Shanghai Astronomical Observatory, Chinese Academy of Sciences, 80 Nandan Road, Shanghai 200030, China
email: lisl@shao.ac.cn

**Abstract.** In previous works, the radio-X-ray slope in FRI radio galaxies is found to be steeper compared with that in low-luminosity AGNs, indicating different origin of the X-ray emission. Here we reinvestigate this point by compiling a sample of 13 low-excitation radio galaxies (LERG) from 3CR radio catalog of galaxies, where the central engine in LERG is accepted to be a radiatively inefficient accretion flow (RIAF). The core radio and X-ray emissions in all the objects of our sample are detected by VLA/VLBI/VLBA and Chandra/XMM-Newton, respectively. Surprisingly, a shallower slope of $L_{\rm R} - L_{\rm X}$ relation ($L_{\rm R} \sim L_{\rm X}^{0.63}$) is given by our sample, which demonstrates that the X-ray emission in LERG may come from accretion disk rather than a jet as suggested by previous works. In addition, the slope in the fundamental plane ($\log L_{\rm R} = 0.52 \log L_{\rm X} + 0.84 \log M_{\rm BH} + 10.84$) of LERG is found to be well consistent with that reported by Merloni *et al.* (2003).

**Keywords.** accretion, accretion disks - black hole physics - galaxies: active

## 1. Introduction

In black hole systems with relativistic jets, a tight correlation between the X-ray and radio emissions ($L_{\rm R} \propto L_{\rm X}^{0.7}$) has been reported by numerous authors, with the X-ray and radio emissions believed to come from accretion disk and jet, respectively. Coupled with black hole mass, a so-called fundamental plane ($\log L_{\rm R} = 0.6 \log L_{\rm X} + 0.78 \log M_{\rm BH} + 7.33$, where $\log L_{\rm R}$ and $\log L_{\rm X}$ are the nuclear luminosity at 5 GHz and the intrinsic rest-frame luminosity in 2−10 keV band, respectively.) was developed by Merloni *et al.* (2003) (hereinafter M03). However, it is found that the slope between the radio and X-ray in radio-loud AGNs appears to be much steeper compared with that of low-luminosity AGNs (e.g., de Gasperin *et al.* 2011), possibly owing to the domination of strong jet emissions in the radio and/or X-ray bands.

In this work, we reinvestigate the origin of X-ray in LERG by constructing a sample satisfying the following conditions: (1) All the sources in the sample should be LERG in order to ensure that the accretion flow is a RIAF; (2) Radio emission comes mainly from the jet in LERG, where both the core and lobe can play important roles. In order to avoid the influence of the surrounding medium, we require that sources must be core-dominated only.

## 2. The LLAGN sample

Our parent sample comprises 113 3CR radio sources with redshift $z < 0.3$, in which all the emission lines necessary to identify LERG are detected in 83 sources (Buttiglione *et al.* 2009). We first exclude 43 HERG with excitation index (EI) larger than 0.95 (see Buttiglione *et al.* 2009 for details) because their accretion flows may be radiatively efficient, leaving us with 40 LERG. Radio flux in LERG is dominated by the jet synchrotron

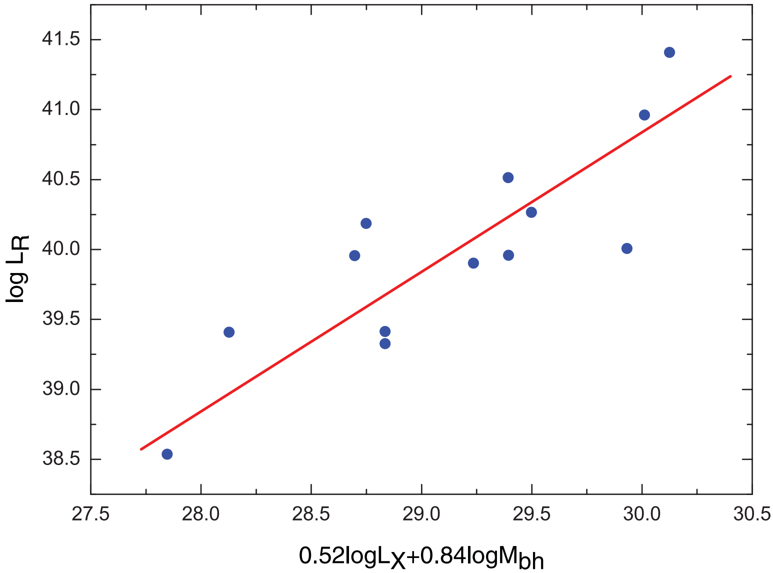


**Figure 1.** The fundamental plane of black hole activity in LERG, where the solid line shows the best fitting function 3.1.

emission, based on the truncated disk-jet model (Narayan & Yi 1994, 1995), which has been successfully applied to the M03 fundamental plane. In order to prevent contamination from the lobe, only sources with radio core emission detected by VLBA/VLBE/VLA are included in this work. For the X-ray, we consider only the sources with X-ray core flux detected by Chandra/XMM-Newton only, in order to maintain a high precision. The final sample includes 13 LERG (see Li & Gu 2018 for details).

## 3. Results

Following M03, we adopt a least $\chi^2$ method to fit the multivariate relation coefficients in black hole fundamental plane. The best fitting result reads,

$$\log L_{\rm R} = 0.52^{+0.16}_{-0.16} \log L_{\rm X} + 0.84^{+0.50}_{-0.50} \log M_{\rm BH} + 10.84^{+5.95}_{-5.95}, \tag{3.1}$$

with an intrinsic scatter of $\sigma_{\rm int} = 0.38$ dex (Figure 1). While the radio-X-ray slope is consistent with M03, it is found that the normalization of our sample is larger than that in M03 by about 0.7 dex (Figure 2). We suggest that this shift can be due to the difference in magnetic field strength (see Li & Gu 2018 for details) because X-ray emission in RIAF has a complicated relationship with the magnetic field strength (e.g., Bu *et al.* 2013, 2016).

We also reinvestigate the slope of $L_R$ and $L_X$ relation in our LERG sample (Figure 3). A linear fit we found can be written as,

$$\log L_{\rm R} = (0.63 \pm 0.11) \log L_{\rm X} + 13.78 \pm 4.71, \tag{3.2}$$

with a strong confidence level larger than 99.9% based on a Pearson test. This slope is considerably flatter than the one found by de Gasperin *et al.* (2011).

## 4. Discussion

In this work, we compiled a sample of 13 LERG from 3CR catalog with optical spectroscopic information (Buttiglione *et al.* 2009). Surprisingly, we discovered a radio-X-ray slope similar to that of the M03 fundamental plane, which suggests that LERG still follow the original M03 fundamental plane. We note that de Gasperin *et al.* (2011) investigated

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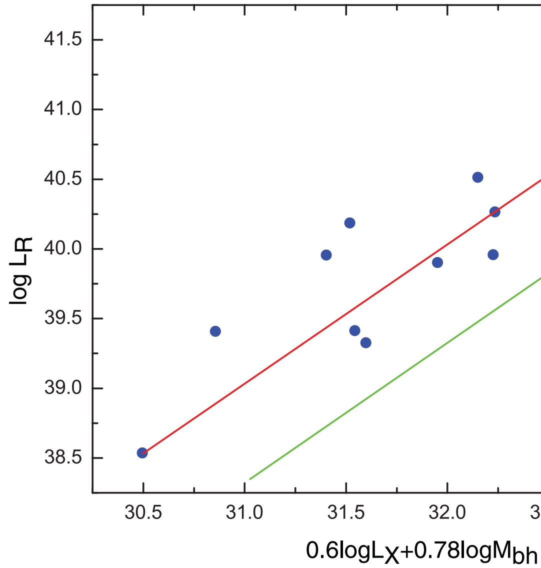


**Figure 2.** The fundamental plane of black hole activity in LERG, where the green line shows the M03 fundamental plane relation. The red line indicates the movement of red line by 0.7 dex.

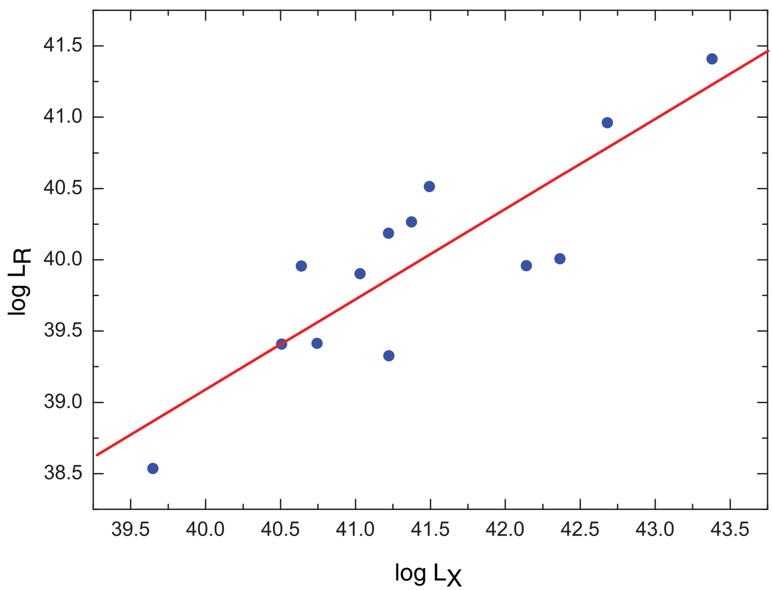


**Figure 3.** The relationship between the radio luminosity $L_{\rm R}$ and X-ray luminosity $L_{\rm X}$ in the present LERG sample.

the fundamental plane in a LERG sample too. They discovered a steeper radio-X-ray slope and suggested that the X-ray emission in LERG may originate from jets. The reason for this discrepancy may be that their sample included some steep-spectrum LERG in addition to the core-dominated flat-spectrum LERG. The shallower radio-X-ray slope in LERG found here suggests that the X-ray probably originate in an accretion disk rather than jet.

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