Strongly Variable AGNs Found in the Second *XMM-Newton* Serendipitous Source Catalogue

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Abstract

We present results of X-ray variability analysis of 53 active galactic nuclei (AGNs) selected from the Second *XMM-Newton* Serendipitous Source Catalogue. We estimate their supermassive black hole (BH) masses by using a correlation between variability root mean square and BH mass, and calculate the Eddington ratios. 12 among 53 AGNs contain relatively low-mass BHs ($< 10^7\ M_\odot$) with super-Eddington luminosities. This result indicates that our sample selection method is effective in searching for candidates of growing BHs that are expected to have relatively low-mass BHs with high accretion rates.

Key words: X-rays: variability — galaxies: active — galaxies: Seyfert

1. Introduction

The evolution of active galactic nuclei (AGNs) is thought to be closely connected to their host galaxies (e.g., Magorrian et al 1998; Marconi & Hunt 2003). It is, however, still to be understood how such a relation has been established. One way to approach this issue is to study growing central black holes (BHs). Assuming that BH growth is mainly governed by accretion, growing BHs are expected to have a combination of relatively low masses and high accretion rates.

X-ray variability of AGNs can be used to estimate BH masses; variability on short timescales implies the presence of a relatively low-mass BH. The advantage of utilizing X-ray variability is that BH masses can be measured even for obscured AGN. In this paper, we describe results of X-ray variability analysis of a large number of AGNs and a new sample of AGNs with relatively low-mass BHs.

2. Sample Selection

We used the Second *XMM-Newton* Serendipitous Source Catalogue (2XMMi-DR3) to derive our sample. In 2XMMi-DR3, probabilities that the source is constant are listed, and they can be used to select AGNs with relatively low-mass BHs. The selected sources satisfy the following conditions: (1) the probability calculated by using EPIC-pn data $< 10^{-5}$, (2) count rate for EPIC-pn in 0.2-12 keV ≥ 0.1 cts/s, and (3) Galactic latitude $|b| \geq 10°$. 718 sources fulfilled these criteria, and 53 among them were regarded as AGN based on object types shown in NED or SIMBAD, and properties of X-ray light curves and X-ray spectra.

3. Results

Excess variance (Nandra et al. 1997, Turner et al. 1999) defined by

$$\sigma_{\rm XS}^2 = \frac{1}{N-1}\sum_{i=1}^{N}(x_i - \bar{x})^2 - \frac{1}{N}\sum_{i=1}^{N}\sigma_i^2 \quad (1)$$

is often used to quantify X-ray variability, where N and $\bar{x}$ are the number of data points and the mean count rate, and x_i and σ_i are the count rate in the i-th bin and its error, respectively. The normalized excess variance is given by $\sigma_{\rm NXS}^2 = \sigma_{\rm XS}^2/\bar{x}^2$. If we compare $\sigma_{\rm NXS}^2$ values of multiple sources, $\sigma_{\rm NXS}^2$ should be calculated using the same duration. The conversion between the $\sigma_{\rm NXS}^2$ measured from data sets with different lengths is given by Awaki et al. (2006). The conversion factor depends on the duration of observations, bin size of each light curve, and slope of the power spectral density. We used their method to correct $\sigma_{\rm NXS}^2$ of each source to the common duration (50000 s) and a bin size of 256 s and assumed that the power spectral density is proportional to a power-law function of frequency $f^{-1.75}$. The error of $\sigma_{\rm NXS}^2$ was estimated by using the expression of Vaughan et al. (2003).

We calculated $\sigma_{\rm NXS}^2$ and its error by using 2-10 keV light curves binned to 256 s and estimated black hole masses $M_{\rm BH}$ by using the correlation between $M_{\rm BH}$ and $\sigma_{\rm NXS}^2$ given by Zhou et al. (2010)

$$M_{\rm BH} = 10^{4.97\pm0.26}(\sigma_{\rm NXS}^2)^{-1.00\pm0.10}\ M_\odot. \quad (2)$$

Furthermore, we analyzed spectra to estimate 2-10 keV luminosities L_{2-10} and Eddington ratios $L_{\rm bol}/L_{\rm Edd}$. Bolometric luminosities $L_{\rm bol}$ were calculated by $L_{\rm bol} \approx$

$20 \times L_{2-10}$, where 20 is a bolometric correction factor (Vasudevan & Fabian 2007). Fig. 1 shows a scatter plot of $M_{\rm BH}$ based on $\sigma^2_{\rm NXS}$ and L_{2-10}. 12 AGNs have relatively low-mass BHs with super-Eddington luminosities. Note, however, that $M_{\rm BH}$ values based on X-ray variability have uncertainties. For example, the values of $\sigma^2_{\rm NXS}$ from different observations of the same object show non-stationarity and we tend to select a strongly variable state of AGN in our sample selection method. Therefore $M_{\rm BH}$ for our sample may be underestimated. In order to examine this issue, we compared $M_{\rm BH}$ based on the reverberation mapping method with our estimates. Table 1 shows a comparison of the two mass determinations. $M_{\rm BH}$ based on reverberation mapping of PG 1211+143 is a factor of 30 larger than $M_{\rm BH}$ derived from $\sigma^2_{\rm NXS}$, while differences between the two estimates are within a factor of four for NGC 3227, NGC 4051, NGC 4395, and Mrk 335. Thus $M_{\rm BH}$ based on $\sigma^2_{\rm NXS}$ likely to have this level of uncertainties.

2XMMi-DR3 is the largest X-ray source catalogue and is useful for exploring serendipitous sources. Indeed, four of 53 are new AGNs that were not recognized as AGN in the past. This result indicates that our sample selection method is effective in searching for unknown growing BHs.

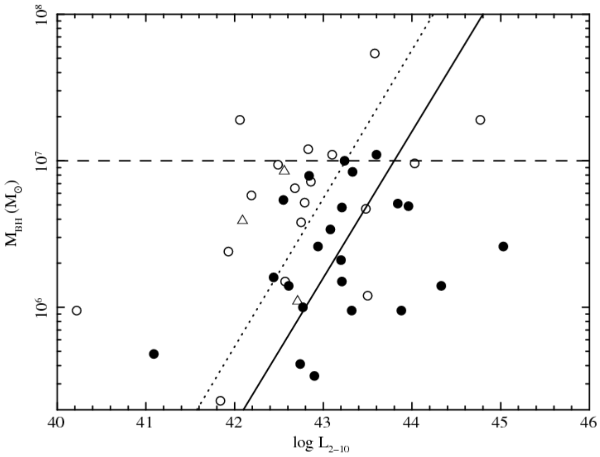

Fig. 1. $M_{\rm BH}$ based on $\sigma^2_{\rm NXS}$ and L_{2-10}. Filled circles and open circles show Sy1/Sy2/QSO, and NLSy1, respectively. Open triangles are AGN with no available optical classifications. Solid line and dotted line are 100% and 30% of Eddington luminosity.

Table 1. The Black hole masses

Name	$M_{\rm BH,NXS}$[a]	$M_{\rm BH,RM}$[b]	$\frac{M_{\rm BH,NXS}}{M_{\rm BH,RM}}$
NGC 3227	18.6	42.2±21.4	0.44
NGC 4051	0.48	1.91±0.78	0.25
NGC 4395	0.95	0.36±0.11	2.6
Mrk 335	4.69	14.2±3.7	0.33
PG 1211+143	4.84	146±44	0.033

[a] BH mass based on $\sigma^2_{\rm NXS}$ in units of $10^6\ M_\odot$.
[b] BH mass based on reverberation mapping in units of $10^6\ M_\odot$ taken from Peterson et al. (2004) and Peterson et al. (2005).

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