

On the relationship between black hole mass and X-ray variability amplitude in the low-mass regime of active galactic nuclei

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Abstract. Recent studies of active galactic nuclei (AGN) found a statistical inverse scaling between the X-ray normalized excess variance σ_{rms}^2 (variability amplitude) and the black hole mass spanning over $M_{\text{BH}} = 10^6 - 10^9 M_{\odot}$. We present a study of this relation by including AGN with $M_{\text{BH}} = 10^5 - 10^6 M_{\odot}$. It is found that the relation is no longer a simple extrapolation of the known inverse proportion, but starts to flatten around $10^6 M_{\odot}$. This behavior can be understood by the shape of the power spectrum density of AGN and its dependence on the black hole mass.

Keywords. galaxies: active, galaxies: nuclei, X-rays: galaxies

1. Introduction

Recent studies suggested an inverse linear correlation between black hole (BH) mass and excess variance (σ_{rms}^2) in logarithmic space for active galactic nuclei (AGN) with $M_{\text{BH}} = 10^6 - 10^9 M_{\odot}$ (Zhou *et al.* 2010; Ponti *et al.* 2012). This scaling relation is tight enough to provide a novel method to estimate the black hole mass of AGN. However, it is not clear if this relation can be extended to lower black hole masses. Our work is to study the relation in the low-mass regime using a sample of low-mass AGN with $M_{\text{BH}} < 2 \times 10^6 M_{\odot}$ observed with *XMM-Newton* and *ROSAT*.

2. Result and discussion

We compiled a sample of 15 low-mass AGN from our sample of low-mass AGN with $M_{\text{BH}} < 2 \times 10^6 M_{\odot}$ (Dong *et al.* 2012). There are 11 objects observed with *XMM-Newton* for a total of 15 observations, and 5 objects observed with *ROSAT* for 6 observations (one object observed with both satellites). The accretion rates in the Eddington units span the range 0.06 – 0.90. We calculate the X-ray excess variances (Nandra *et al.* 1997) and normalize their values on a timescale of 80 ks, using the three power spectrum density (PSD) models in Table 1 (see Papadakis 2004 for the details about the PSD shape of AGN). The relation of the excess variance and black hole mass is plotted in Figure 1. It shows that for almost all the sources with $M_{\text{BH}} < 2 \times 10^6 M_{\odot}$, the excess variances fall systematically below the extrapolation of the $M_{\text{BH}} - \sigma_{\text{rms}}^2$ relation derived from the high-mass sample (Ponti *et al.* 2012). In fact, the $M_{\text{BH}} - \sigma_{\text{rms}}^2$ relation can be derived from the dependence of the break frequency of the PSD, since excess variance is the integral of the PSD over frequency domain (van der Klis 1989, 1997). We fix the observed $\nu_{\text{br}}(M_{\text{BH}}, \dot{m})$ relations as their original form (McHardy *et al.* 2006; González-Martín & Vaughan 2012),

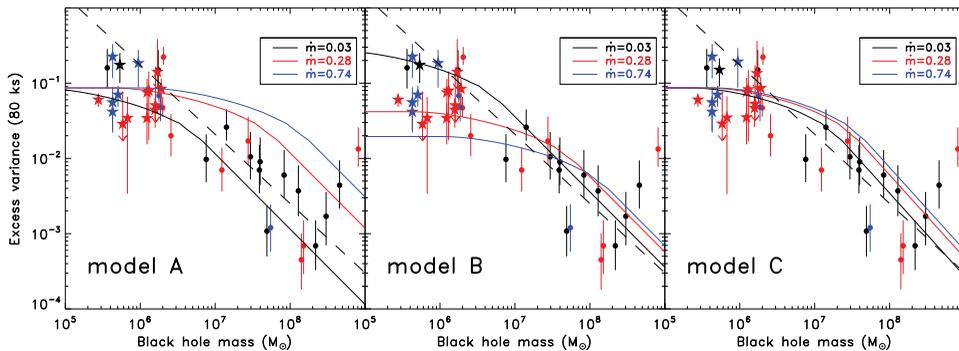


Figure 1. Relationship of the black hole mass and the excess variance for the objects in our sample (stars), together with the sample (dots) and the best-fit relations (dashed lines) from Ponti *et al.* (2012). The objects with \dot{m} in the three \dot{m} bins (0.01-0.1, 0.1-0.5, and 0.5-1.0) are plotted in black, red and blue, respectively. The solid lines represent the relations derived from the best-fit PSD models for three accretion rates.

Table 1. PSD models used

Model	Break Frequency Formalism	PSD Amplitude Suggested in Previous Work	PSD Amplitude Fitted in this Work	χ^2/dof
model A	$\nu_{br} = 0.003\dot{m}(M_{BH}/10^6 M_{\odot})^{-1}$ McHardy <i>et al.</i> (2006)	0.017 ± 0.006 Papadakis (2004)	$C_1 = 0.017 \pm 0.002$	150/36
model B	$\nu_{br} = 0.003\dot{m}(M_{BH}/10^6 M_{\odot})^{-1}$ McHardy <i>et al.</i> (2006)	$\alpha = 0.003^{+0.002}_{-0.001}$ $\beta = 0.8 \pm 0.15$ $C_1 = \alpha\dot{m}^{-\beta}$, Ponti <i>et al.</i> (2012)	$\alpha = 0.010 \pm 0.001$ $\beta = 0.40 \pm 0.04$	106/35
model C	$\nu_{br} = 0.001\dot{m}^{0.24}(M_{BH}/10^6 M_{\odot})^{-1}$ González-Martín & Vaughan (2012)	0.017 ± 0.006 Papadakis (2004)	$C_1 = 0.015 \pm 0.002$	102/36

and obtain the PSD amplitude by fitting the $M_{BH} - \sigma_{rms}^2$ relation. It can be seen that all the three models can reproduce the observed trend of the $M_{BH} - \sigma_{rms}^2$ relation well (Figure 1). In conclusion, the inversely proportional $M_{BH} - \sigma_{rms}^2$ relation established in the high-mass regime fails to extend to M_{BH} below $10^6 M_{\odot}$. Our result is in good agreement with that obtained from a recent similar study by Ludlam *et al.* (2015). This is also consistent with the model prediction from our current understanding of the PSD of AGN and the dependence of the break frequency on M_{BH} .

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