NLS1 galaxies in the eye of the X-ray excess variance method

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Abstract:

We postulate a universal linear scaling of the X-ray excess variance with the black hole mass. This allows to determine the black hole mass from its X-ray variability. We next compare these values with the black hole mass determination for the same objects obtained independently by reverberation or stellar dispersion methods for a sample of 21 Narrow Line Seyfert 1 (NLS1) galaxies. The excess variance masses are generally too small by a factor ~10-30 while the two values agreed statistically for previously studied Broad Line Seyfert 1 (BLS1) galaxies. However, in a small subset of NLS1s the mass ratio is the same as in BLS1s (~0.5-4). We argue that the enhanced variability in most NLS1 galaxies is likely related to the presence of a second variability mechanism reflected in a change in the soft X-ray slope. The bimodal distribution of the mass ratio in BLS1 + NLS1 sample is rather inconsistent with the continuous dependence of the X-ray excess variance on the bolometric luminosity since the distribution of accretion rates does not show up such bi-modality.

NLS1 sources, in comparison to BLS1 galaxies, generally have smaller black hole masses, show higher accretion rates and indicate soft X-ray excesses in their spectra [1]. The last one translates to a soft X-ray photon indices, $\Gamma_{0.1\text{-}2.4\,\mathrm{keV}}$, which are in the range 2-4 in NLS1s and in the range 1.5-3, with mean ~2, in BLS1 sources [2]. Additionally, the Full Width at Half Maximum of Hβ line, produced in Broad Line Region of NLS1 galaxies, is smaller than 2000 km/s, an intensity ratio [0III]/Hβ< 3 and FeII/Hβ> 0.5 [3,1]. In BLS1s those inequalities are inversed. NLS1 sources show variabilities in short timescales with larger amplitudes variability in comparison to BLS1s [4].

We have considered a sample of 21 NLS1 galaxies and a sample of 15 BLS1 galaxies previously studied by [5]. All sources were monitored both in X-ray and optical band.

The X-ray excess variance method:

We have determined the black hole masses, $M_{BH}^{\sigma^2_{nxs}}$, using the variance method described by [5]. It is based on the scaling of the normalized variance of X-ray light curves, σ^2_{nxs}, measured in the range 2-10 keV with the M_{BH} value:

$$M = C\,\frac{T-\Delta t}{\sigma^2_{nxs}} \qquad (1)$$

where the normalized excess variance is simply calculated from light curves and it is defined as:

$$\sigma^2_{nxs} = \frac{1}{N\langle x\rangle^2}\sum_{i=1}^{N}\left[(x_i-\langle x\rangle)^2-(\delta x_i)^2\right] \qquad (2)$$

In Eq. (1) T is the duration of X-ray light curve, Δt – bin time. In our approach we assume that value C is constant for all sources. To obtain the value of C, we apply Eq. (1) to Cyg X-1 using its light curves in hard state and assuming that the black hole in this system has mass (M) of 20 $M_\odot$[6]. We obtain C=1.92. In Eq. (2) N is the number of data points x_i, δx_i is the error of x_i, $\langle x\rangle$ – arithmetic unweighted mean.

Black hole masses M_{BH}^{lit} from literature:

The independent measurements of the masses of supermassive black hole for all our galaxies were taken from literature. They were obtained with the reverberation mapping method [7], with the relationship between broad line region and optical luminosity (e.g. [8]) or with the stellar velocity dispersion method [9]. Those masses were used to compare with values obtained from X-ray variability.

Results:

We confirm that in case of BLS1 the values of the black hole masses from X-ray excess variance ($M_{BH}^{\sigma^2_{nxs}}$) and reverberation/stellar dispersion ($M_{BH}^{lit.}$) are statistically consistent. In the case of NLS1 $M_{BH}^{\sigma^2_{nxs}}$ are generally smaller than $M_{BH}^{lit.}$ and require multiplying by a factor to obtain equality between them. Such factor lies in the range 10-30. For small subset of NLS1 (e.g MCG -6-30-15, Mrk 507) we do not require such multiplication and the factor is less then 4, like in BLS1s (e.g. Fig. 1, 4). We can say that such galaxy optically belongs to NLS1 but from the point of view of the X-ray variability has the properties of a BLS1.

Dependance on an acrretion rate or an soft X-ray photon index:

What does the value C depend on? [10] have pointed out dependence of variability on an accretion rate, $\dot{m}$ (where $\dot{m}=L_{bol}/L_{Edd}$). We have checked it and found a similar relationship like [10] (Fig 1). We have also pointed out a continuous distribution in acrretion rate values. Our best linear fit to data, which has the correlation coefficient r=0.780, is

$$\log\dot{m} = (1.07+/-0.35)\log M_{BH}^{lit}/M_{BH}^{\sigma} + \mathrm{const} \qquad (3)$$

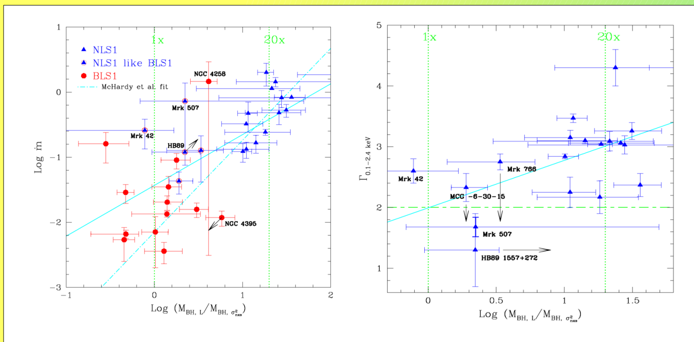

Fig. 1 (left panel): The dimensionless accretion rate, $\dot{m}=L_{bol}/L_{Edd}$, plotted versus the ratio $M_{BH}^{lit}/M_{BH}^{\sigma^2_{nxs}}$. The dotted lines show how many times $M_{BH}^{\sigma^2_{nxs}}$ should be multiplicated in order to obtain M_{BH}^{lit}. The continuous line shows the best fit (Eq. 3) to our sample of galaxies. The dot-short dash line is the McHardy et al. fit [12]. Fig. 2 (right panel) The soft X-ray photon index plotted versus the ratio $M_{BH}^{lit}/M_{BH}^{\sigma^2_{nxs}}$. The dashed line shows arbitrary border $\Gamma_{0.1\text{-}2.4\,\mathrm{keV}}$= 2. Continuous line represents the best fit (Eq. 4) to NLS1s sources. Arrows in both panels show possible directions of changes.

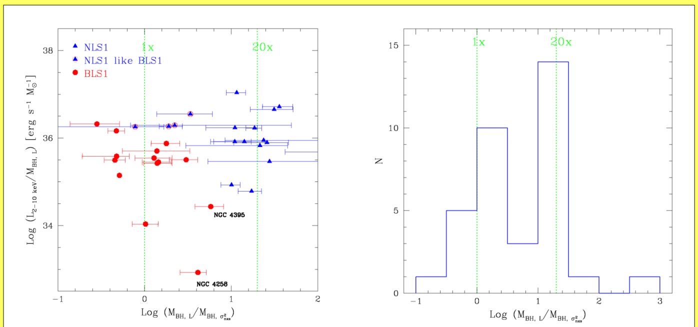

Fig. 3 (left panel): The luminosity in the range 2-10 keV divided by M_{BH}^{lit},plotted versus the $M_{BH}^{lit}/M_{BH}^{\sigma^2_{nxs}}$ ratio. The dotted lines show how many times $M_{BH}^{\sigma^2_{nxs}}$ should be multiplicated in order to obtain M_{BH}^{lit}. In this figure we can see a weak fit if any between $L_{2-10keV}/M_{BH}^{lit}$ and the mass ratio (the correlation coefficient r < 0.19, see text). If we include only NLS1 galaxies plus 'NLS1 like BLS1' sources we will obtain the best linear fit with coefficient r = 0.222. Fig. 4 (right panel) Histogram showing the number of all our sources in a particular bin of logarithm of the mass ratio. We can see bi-modal distribution of the ratio $M_{BH}^{lit}/M_{BH}^{\sigma^2_{nxs}}$.

We have calculated fitted values given in [10] into our relationship and obtained the value 1.41+/- 0.50. Our results of $M_{BH}^{lit}/M_{BH}^{\sigma^2_{nxs}}$ show bi-modal distribution (Fig. 4). Such behaviour shows $\Gamma_{0.1\text{-}2.4\,\mathrm{keV}}$. Therefore, we postulate dependence of Eq. (1) on the soft X-ray indices. Best linear fit obtained by us is:

$$\Gamma_{0.1-2.4\,\mathrm{keV}} = (0.78+/-0.21)\log M_{BH}^{lit}/M_{BH}^{\sigma} + \mathrm{const} \qquad (4)$$

The correlation coefficient is equal to 0.668.

Dependance on X-ray luminosity:

[11] have supposed that X-ray variability depends on luminosity above 2 keV. We have studied that and noticed weak if any relationship between $L_{2-10\,keV}/M_{BH}^{lit}$ ratio and the mass ratio (Fig. 3) [i.e. in the case of taking all sources from our sample the correlation coefficient r is equal to 0.125. When we take only sources with M_{BH}^{lit} obtained by reverberation mapping method then the correlation coefficient r=0.190]. When we take only NLS1s (18 sources) we have relationship:

$$\log L_{2-10\,keV}/M_{BH}^{lit} = (36.26+/-0.28)\log M_{BH}^{lit}/M_{BH}^{\sigma} + \mathrm{const} \qquad (5)$$

with the correlation coefficient r=0.222.

Table 1: Our sample of NLS1 & BLS1 galaxies.

NLS1s:	I Zw1 | Ton S180 | PHL 1092 | 1H 0707-49 | Akr 564 | IC 5063
	Mrk 42,110,142,335,478,507,766 | PG 1211+143, 1244+026, 1404+226
	NGC 4051, 5506 | MCG -6-30-15 | IRAS 17020+45 | HB89 1557+27
BLS1s:	F 9 | Mrk 509 | IC 4329A | Ark 120 | 3C 120, 390.9
	NGC 3227, 3787, 4151, 4258, 4395, 4593, 5548, 7469

Conclusions:

- We calculate the ratios $M_{BH}^{lit}/M_{BH}^{\sigma^2_{nxs}}$ of the black hole masses in NLS1 galaxies obtained by the X-ray variance method and by reverberation/stellar velocity dispersion. The ratios for most sources are of order of 10-30, while they were of order of 1 for BLS1 objects. The overall enhancement of the variability for NLS1 galaxies is consistent with the variability enhancement with bolometric luminosity for a fixed black hole mass described by McHardy et al. (2006).
- For a few NLS1 galaxies $M_{BH}^{lit}/M_{BH}^{\sigma^2_{nxs}}$ ratio is of order of 1, as for BLS1 sources. These sources have hard X-ray spectra, typical for BLS1 galaxies.
- The $M_{BH}^{lit}/M_{BH}^{\sigma^2_{nxs}}$ ratios in a combined NLS1 and BLS1 sample show a bi-modal behaviour. It is related to the bi-modal distribution of the X-ray slope.
- The discontinuous bi-modal behaviour we have found (instead of a continuous dependence on Eddington ratio used by McHardy et al.) points toward the additional soft spectral component as the physical reason for the bolometric luminosity.
- We also find weak if any dependence of $M_{BH}^{lit}/M_{BH}^{\sigma^2_{nxs}}$ ratio on the 2-10 keV luminosity. It is in agreement with result of Gierliński et al. (2008) (for galactic black holes in low/hard state) but our sample is too small. Therefore, such dependence for galaxies might not be ruled out.

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