Black hole masses in NLS1 galaxies from the X-ray excess variance method

Marek Nikołajuk[1,*], Paweł Gurynowicz[1], Bożena Czerny[2]
[1] University of Białystok, Institute of Theoretical Physics, Białystok, Poland; [*] mrk@alpha.uwb.edu.pl
[2] Nicolaus Copernicus Astronomical Center, Warsaw, Poland

Abstract:

We estimate black hole masses in Narrow Line Seyfert 1 (NLS1) galaxies at the basis of their X-ray excess variance. We apply the standard approach appropriate for Broad Line Seyfert 1 (BLS1) galaxies. In general, we find that the obtained masses are by a factor about 20 too small to agree with values obtained from other methods (reverberation, stellar dispersion). However, we can see that a small subset of our NLS1 objects do not require that multiplication, or the correction factor is less than 4. We find that this subset have got a soft X-ray photon index, $\Gamma_{0.1-2.4\,keV}$, smaller than 2. We thus postulate that this subclass of NLS1 actually belongs to BLS1.

NLS1 sources, in comparison to Broad Line Seyfert 1 (BLS1) galaxies, generally have smaller black hole masses, show higher accretion rate and indicate to have soft X-ray excess [1,2]. This last one translate to a soft X-ray photon index, $\Gamma_{0.1-2.4keV}$. In NLS1s this index is higher than 2, with mean value 3.1. BLS1 sources have smaller values of $\Gamma_{0.1-2.4keV}$ with mean ~2.1 (e.g.[3]). Additionally, in accordance with definition of NLS1sources, the Full Width at Half Maximum (FWHM) of Hβ line, produced in Broad Line Region, in those galaxies is smaller than 2100 km/s. In BLS1s FWHM(Hβ) is > 2100 km/s.

We have considered a sample of 21 NLS1 galaxies (see Table 1) and a sample of BLS1 galaxies (e.g. NGC3227, 3516, 4151, 5548, 7469, 3C120, F9) studied by [4]. The all sources were monitored in both optical and X-ray band.

Black hole mass from literature:

The masses of supermassive black hole for all our galaxies were taken from literature. Those values were obtained from the reverberation method [e.g. 5,6] or from the stellar velocity dispersion method [e.g. 7]. Those masses were used to compare with values obtained from X-ray variability.

Black hole mass from X-ray variability:

We have determined the masses using the variance method described by [4]. It is based on the scaling of the normalized variance of X-ray light curves, σ^2_{nxs}, measured in range 2-10 keV with the M value:

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

T is the duration of X-ray light curve, Δt – bin time. To obtain the value of C, we apply Eq. (1) to Cyg X-1 assuming that the black hole in this system has mass (M) of 20 $M_{\odot}$[8]. Value of C resulting from this procedure is 1.92. We use this value for all galaxies. The normalized excess variance is defined as:

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

where N is the number of data points x_i, δx_i is the error of x_i, $\langle x\rangle$ – arithmetic mean.

Results:

We have calculated the ratio of the black hole mass, $M_{BH}^{lit.}$, taken from literature to mass obtained from the X-ray variance method, $M_{BH}^{\sigma^2_{nxs}}$, for all objects (see Figure 1 and Figure 2, left panel). We have computed errors of $M_{BH}^{\sigma^2_{nxs}}$, as well. In order to calculate errors of the $M_{BH}^{lit.}/M_{BH}^{\sigma^2_{nxs}}$ ratio we assumed that masses of black hole taken from literature are without any errors, in other words they are very precise. Therefore, errors of the ratio (shown in Figure 2; left panel) do not take into account such uncertainty.

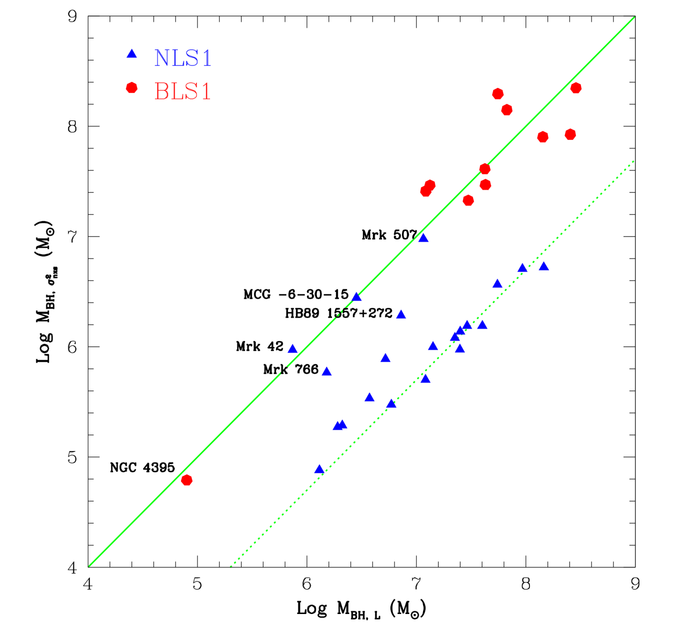

Figure 1: Black hole masses estimated from X-ray variance method, $M_{BH,\sigma^2_{nxs}}$, versus masses taken from literature, $M_{BH,L}$. The continuous line shows the $M_{BH,L}=M_{BH,\sigma^2_{nxs}}$ relation. The dot line shows the $M_{BH,L}=20\,x\,M_{BH,\sigma^2_{nxs}}$ relation. We can see that small subset of NLS1 objects which do not require any rescaling like BLS1 galaxies.

Table 1:

Name	$M_{BH}^{lit.}/M_{BH}^{\sigma^2_{nxs}}$	$\Gamma_{0.1-2.4keV}$	FWHM(Hβ) [km/s]
I Zw 1	18.7 +19.5 -16.1	3.09 ± 0.16	1240
TON S180	18.6 +3.9 -14.7	3.04 ± 0.01	970
PHL 1092	26.4 +29.4 -23.0	4.30 ± 0.30	1790
1H 0707+495	11.0 +5.7 -7.1	2.25 ± 0.25	1050
IC 5063	15.0 +15.9 -7.3		
Ark 564	10.8 +2.7 -8.3	3.47 ± 0.10	950
MCG -6-30-15	1.0 +0.3 -0.7	1.33 ± 0.10	1700
Mrk 42	0.8 +1.0 -0.8	2.60 ± 0.20	770
Mrk 110	18.2 +17.3 -8.3	2.35 ± 0.05	1380
Mrk 142	6.7 +12.2 -2.6	3.15 ± 0.12	1620
Mrk 335	14.2 +9.6 -7.9	3.10 ± 0.05	1370
Mrk 478	25.8 +20.9 -14.2	3.06 ± 0.05	1630
Mrk 507	1.2 +9.4 -0.1	1.68 ± 0.16	1250
Mrk 766	2.6 +1.6 -1.6	1.68 ± 0.10	1150
NGC 4051	10.2 +2.2 -5.7	2.84 ± 0.04	1070
NGC 5506	18.3 +5.9 -12.8		
PG 1211+143	27.7 +130 -22.6	3.03 ± 0.15	1320
PG 1244+026	17.0 +10.8 -7.9	3.26 ± 0.14	830
PG 1404+226	24.0 +160 -15.5	4.30 ± 0.30	880
HB89 1557+272	3.8 +1.9 -1.4	1.30 ± 0.60	1410
IRAS 17020+45	19.7 +8.6 -6.7	2.37 ± 0.20	1040

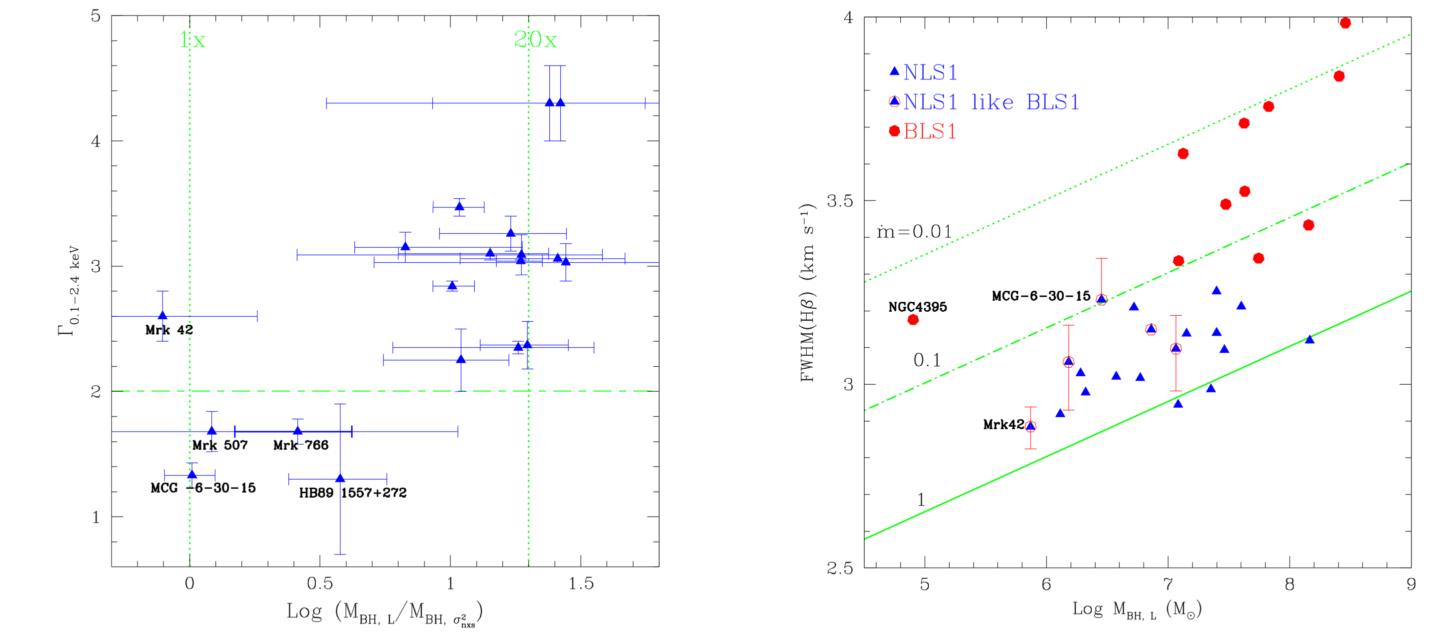

Figure 2. Left panel: The soft X-ray photon index, $\Gamma_{0.1-2.4keV}$, plotted versus the $M_{BH}^{lit.}/M_{BH}^{\sigma^2_{nxs}}$ ratio. The dotted lines shows how many times should be multiplicated $M_{BH}^{\sigma^2_{nxs}}$ in order to obtain $M_{BH}^{lit.}$. The dashed line shows arbitrary border $\Gamma_{0.1-2.4keV}$ = 2. Right panel: The Full Width at Half Maximum of Hβ line produced in Broad Line Region in NLS1 galaxies versus black hole masses $M_{BH}^{lit.}$ (taken from reverberation method, stellar velocity dispersion method). The continuous, dot-short-dash and dot lines represent accretion rate in Eddington units (respectively 1, 0.1 and 0.01).

A small subset of NLS1 galaxies:

Generally, values of the black hole masses, $M_{BH}^{\sigma^2_{nxs}}$, estimated from the X-ray variance method require a multiplication by some factor. Mean value of this factor is 20 (see e.g. [9]). Surprisingly, this factor for four galaxies (Mrk 42, Mrk 507, Mrk 766, MCG -6-30-15) is smaller than 3 and for HB89 1557+272 is smaller than 4. We have to note here that estimation of $M_{BH}^{lit.}$ of HB89 1557+272 has large error and the factor may be in reality much smaller. We suggest that those 5 objects do not require any multiplication like BLS1 galaxies. In other words the variability of X-ray light in the 2-10 keV range of those NLS1 galaxies is very similar to all BLS1 sources.

BLS1 galaxies are sources in which the soft X-ray photon indices (measure in 0.1-2.4 keV range) have values less than or equal to around 2. We can see that the indices, $\Gamma_{0.1-2.4keV}$, for those 5 NLS1 galaxies are in the same range (Figure 2; left panel). Spectra in the soft X-ray range of those 5 NLS1 are similar to spectra of BLS1.

On the other hand when we compare accretion rates, we cannot see difference between those 5 NLS1 and the other NLS1 galaxies (see Figure 2, right panel). Those small subset of NLS1 accrete, like other NLS1, with $\dot{m}$ higher than 0.1 or even close to Eddington limit. This is opposite to BLS1 sources, which accrete mainly with $\dot{m} < 0.1$.

Conclusions:

- We calculate the black hole masses in NLS1 galaxies by applying of the X-ray variance method. This method based on study of variation of the X-ray lightcurves. We compare our results with values obtained from other methods (reverberation, stellar velocity dispersion) and calculate the ratio of estimated masses. Five NLS1 object have this ratio less then factor 4. It is behaviour of BLS1 galaxies.
- We find that this subset have got a soft X-ray photon index, $\Gamma_{0.1-2.4keV}$, smaller or slighlty higher than 2 like BLS1 galaxies.
- By comparison of the Full Width at Half Maximum (FWHM) of Hβ line we do not see that those subset of NLS1 galaxies differ from other NLS1 galaxies in respect of accretion rate.
- We postulate that this subclass of NLS1 actually belongs to BLS1.

References:
1. Mathur, S., Kuraszkiewicz, J., & Czerny, B. 2001, NewA, 6, 321
2. Sobolewska, M., & Done, C. 2006, MNRAS, in press (astro-ph/0609223)
3. Boller, T., Brandt, W., & Fink, H. 1996, A&A, 305, 53
4. Nikołajuk, M., Czerny, B., Ziółkowski, J., & Gierliński, M. 2006, MNRAS, 370, 1534
5. Peterson, B. M.; Ferrarese, L., Gilbert, K. M., et al., 2004, ApJ, 613, 682
6. Bian, W., & Zhao, Y. 2003, MNRAS, 343, 164
7. Woo, J., & Urry, M. 2002, ApJ, 579, 530
8. Ziolkowski, J., 2005, MNRAS, 358, 851
9. Papadakis, I. 2004, MNRAS, 348, 207