A novel black hole mass scaling using coronal lines in active galaxies

Swayamtrupta Panda[1·2·3] and Alberto Rodríguez-Ardila[2·4]

1. Center for Theoretical Physics, Polish Academy of Sciences, Al. Lotników 32/46, 02–668 Warsaw, Poland
2. Laboratório Nacional de Astrofísica - MCTIC, R. dos Estados Unidos, 154 - Nações, Itajubá - MG, 37504–364, Brazil
3. Nicolaus Copernicus Astronomical Center, Polish Academy of Sciences, Bartycka 18, 00–716 Warsaw, Poland
4. Divisão de Astrofísica, INPE, Avenida dos Astronautas 1758, São José dos Campos, 12227-010, SP, Brazil

Using *bona-fide* black hole (BH) mass estimates from reverberation mapping and the line ratio [Si VI] 1.963μm/Br$\gamma_{\rm broad}$ as tracer of the Active Galactic Nuclei (AGN) ionizing continuum, we find a novel BH-mass scaling relation of the form $\log(M_{\rm BH}) = (6.40 \pm 0.17) - (1.99 \pm 0.37)\times$ log ([Si VI]/Br$\gamma_{\rm broad}$), over the BH mass interval, $10^6 - 10^8$ [$M_\odot$]. The analyzed sample consists of 21 Type-1 AGNs with the overall dispersion in our scaling relation at 0.47 dex, one that emulates the well-established M-σ relation, which shows a dispersion ~0.44 dex. The new scaling offers an economically and physically motivated alternative for BH mass estimate using single epoch spectra, avoiding large telescope time (reverberation mapping) or absolute flux calibration (the continuum luminosity method). With the advent of deep infrared surveys in the near future, we aim to reduce the scatter in our novel relation by supplementing with more sources.

1 Introduction

The determination of black hole (BH) masses is one of the major focus studying supermassive black holes and the active galaxies where they reside. Most BH mass estimates are based on correlations between the BH mass and the stellar bulge velocity dispersion, i.e., the M-σ relation (e.g. Ferrarese & Merritt, 2000; Gültekin et al., 2009), or the AGN continuum luminosity, i.e., the mass-luminosity relation by which the optical, UV and X-ray luminosities are found to correlate with the size of the Broad Line Region (BLR) (e.g. Koratkar & Gaskell, 1991; Kaspi et al., 2005; Landt et al., 2013, and references therein). While using the M-σ relation requires the measurement of σ, it is not always easy to determine it, particularly in AGNs wherein the strong continuum from the nuclear region dilutes the stellar absorption lines. To overcome this difficulty, a number of alternative scaling relations using emission lines such as [O III] λ5007 to measure the mass of the bulge (e.g. Nelson & Whittle, 1996), [O II] λ3727 (e.g. Salviander et al., 2006), Hβ or Hα (e.g. Kaspi et al., 2005; Greene & Ho, 2005) to infer on the BLR size, or [Fe II] in the near-infrared regime (e.g. Riffel et al., 2013) to infer on the stellar σ, have been proposed.

Coronal Lines (CLs) are emission lines with high ionisation potentials (IPs range between ~50 eV up to a few hundred eV) making them excellent tracers of the ionising continuum. Although often fainter than the classical medium-ionisation lines used for photoionisation diagnosis, high angular resolution in nearby AGN has shown that CLs, particularly in the near-infrared (NIR) wavelength, are among the most conspicuous features (e.g. Marconi et al., 1994; Müller-Sánchez et al., 2011; Rodríguez-Ardila et al., 2017; Gravity Collaboration et al., 2020). In this work, we highlight the dependence of the BH mass with one such CL, [Si VI] 1.963μm (IP [Si VI] = 167 eV) in the NIR[1] after normalising it to the nearest H I broad line emission (in this case Brγ). A tight correlation between BH mass and the CL ratio [Si VI]/Br$\gamma_{\rm broad}$ is observed.

2 Coronal line diagnostic diagrams

Objects in this work are selected by having BH masses determined by reverberation mapping and single epoch optical and/or near-IR spectra with accurate CL measurements. The first criterion restricts the sample to Type-1 sources only. The second avoids variability issues. The final working sample of objects has 21 AGNs with well-defined [Si VI] 1.963μm/Br$\gamma_{\rm broad}$ estimates (see Tab. 1 in Prieto et al., 2022).

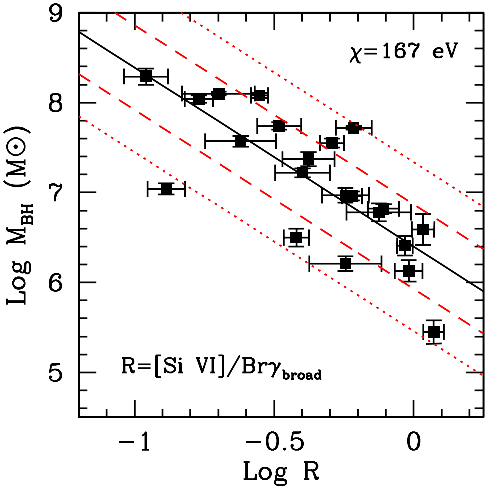

Fig. 1: Observed [Si VI] 1.963μm/Br$\gamma_{\rm broad}$ ratio versus black hole mass for the objects in our sample. The solid line is the linear best-fit to the data and the dashed and dotted lines show the 1σ and 2σ deviation, respectively. Figure courtesy: Prieto et al. (2022).

Fig 1 presents a new diagnostic diagram in which the BH mass for the objects in our sample is plotted against the [Si VI] 1.963μm/Br$\gamma_{\rm broad}$ ratio. It shows a clear trend with $M_{\rm BH}$ over three orders of magnitude in BH mass. A linear regression yields:

$$\log M_{\rm BH} = (6.40 \pm 0.17) - (1.99 \pm 0.37) \times \log\left(\frac{[\rm Si\,VI]}{\rm Br\gamma_{broad}}\right), \quad (1)$$

and a 1σ dispersion of 0.47 dex. The regression analysis follows the LTSFIT package[2] (Cappellari et al., 2013), which accounts for the errors in all variables. The Pearson correlation coefficient for the correlation is r = -0.76, with a p-value = 3.8×10^{-5}.

[1]this CL is among the most common and brightest ones observed in spectra of AGNs (Rodríguez-Ardila et al., 2011; Lamperti et al., 2017). We refer the readers to Prieto et al. (2022) for a broad overview of our presented results.

[2]http://www-astro.physics.ox.ac.uk/mxc/software/lts

3 Concluding remarks

With a final compendium of 21 AGNs, the dispersion in BH mass in the proposed calibration is 0.47 dex (1σ). In comparison, a dispersion of 0.44 dex is inferred from the $M - \sigma$ relation in 49 galactic bulges with direct dynamical BH mass estimate (Gültekin et al., 2009). The intrinsic scatter in the mass - luminosity relations is in the 40% range (Kaspi et al., 2005), driven mainly by differences in optical - UV continuum shape.

The present BH mass scaling relation is restricted to Type-1 AGN, including narrow line Seyfert galaxies. The limitation is driven by the imposition of including *bona-fide* BH masses only, and the need to normalise to broad H I gas. We are nonetheless examining possibilities to extend it to Type 2. The new scaling offers an economic and physically motivated alternative for BH estimate using single epoch spectra, avoiding large telescope time (reverberation mapping) or absolute flux calibration (the continuum luminosity method). With James Webb Space Telescope and extensive surveys in the IR region, large samples of AGNs could be weighted using this approach. We refer the readers to Prieto et al. (2022) for a complete account of the observed spectra for the sources, and detailed photoionisation modelling that confirms the origin of the observed scaling relation.

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