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Orientation Effects in Active Galactic Nuclei Black Hole Masses

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Black hole masses are estimated for radio-loud quasars using self-consistent scaling relationships based on emission-line widths and continuum luminosities. Two emission lines that are regularly used, Hβ and C IV λ1549, have different dependencies on orientation as estimated by radio core dominance. We show that black hole masses from the single-epoch scaling relationships using Hβ emission line depends on orientation, while the C IV-based masses show no dependence. Accounting for orientation significantly reduces the scatter in black hole mass scaling relationships, and we quantify and offer a correction for this effect cast in terms of radio core dominance.

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1. Introduction

There is an intimate link between galaxies and the supermassive black holes they host that has been revealed by the $M_{BH} - L_{bulge}$ and $M_{BH} - \sigma_*$ relationships (Magorrian et al. 1998; Gebhardt et al. 2000). As a result, in order to understand galaxy evolution, it becomes crucial that one also understand the formation history of supermassive black holes and the effects of active galactic nuclei (AGN) activity. These can be probed, but that requires reliable measurements of fundamental AGN properties, in particular, black hole mass.

The black hole scaling relationships allow black hole mass to be measured for any AGN with a single-epoch spectrum (e.g., Vestergaard et al. 2006) and have been calibrated for multiple emission lines, including H β and C IV, with a factor of $2-3$ scatter. In the scaling relationships, black hole mass is estimated from a line width, which is used to measure velocity in the virialized, line-emitting gas, and a continuum luminosity, a proxy for radius. Wills & Browne (1986) showed that the full width at half maximum (FHWM) of H β depends on radio core dominance, an orientation indicator in radio-loud quasars. This and later investigations suggested that black hole masses estimated from the scaling relationships should depend on orientation.

2. Data

Selected to study orientation, the radio-loud sub-sample from Shang et al. (2011) includes 52 objects with quasi-simultaneous optical/ultraviolet spectrophotometry and measurements of radio core dominance, R, the ratio of the core flux density to the lobe flux density at 5 GHz rest frame. The selection criterion that objects have similar extended radio luminosity, a property that is thought to be isotropic, ensures that sample members are intrinsically similar but viewed at different angles (Figure 1). Black hole mass for this sample is calculated in Tang et al. (2012) and radio core dominance is taken as an orientation indicator.

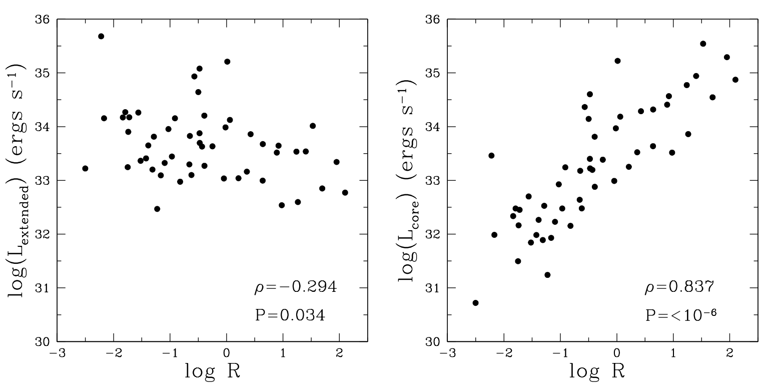

Figure 1: Objects were selected to have similar extended radio luminosity (left), therefore variation in radio core dominance is largely due to variation in the radio core luminosity (right). Spearman rank correlation coefficients and probabilities are given in each panel.

3. Analysis and Results

The radio core dominance dependence of FWHM for H β seen in Figure 2 implies that black hole masses estimated from that line may also have a similar dependence, while the FWHM of C IV is clearly free of any orientation biases.

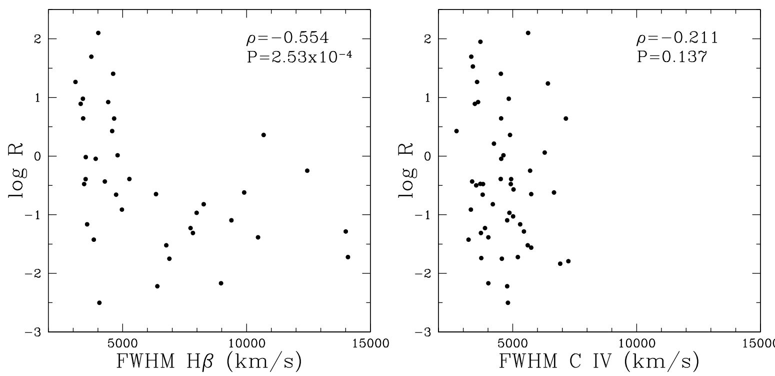

Figure 2: Radio core dominance versus FWHM for Hβ and C IV. The effect is consistent with the Hβ line width being dependent upon orientation in the sense of a axisymmetric velocity field plus a projection effect.

In order to investigate how different black hole mass scaling relationships might depend on radio core dominance, we correlate the difference between the log of black hole masses estimated from different scaling relationships (i.e. the residuals) with radio core dominance (Figure 3). We normalize the masses rather than simply correlating masses derived from Hβ and C IV individually with radio core dominance because we want to isolate the bias in black hole mass from orientation and avoid effects associated with the sample having a range in intrinsic black hole mass, which may mask orientation effects.

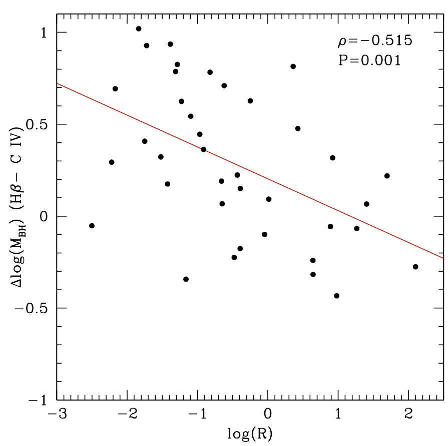

Figure 3: Residuals in the log of black hole mass for Hβ and C IV versus log R for 38 objects where measurements are available for all three quantities. The solid red line shows the linear regression with a nonzero intercept. The relationship is significant at approximately the 3 σ level. This figure shows that an orientation bias of nearly an order of magnitude between the most edge-on and face-on objects is being propagated into black hole mass estimates from Hβ line width measurements.

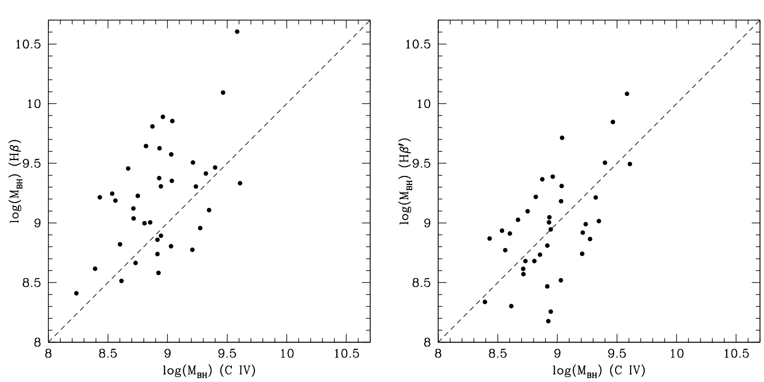

Figure 4: Radio core dominance versus FWHM for H$\beta$and C IV. The effect is consistent with the Hβ line width being dependent upon orientation in the sense of a axisymmetric velocity field plus a projection effect.

We used the C IV FWHM-based mass estimates, unbiased with respect to radio core dominance, to derive the empirical corrections for black hole masses based on Hβ FWHM in terms of log *R*. When these corrections are applied, scatter around the one-to-one relationship is reduced from 0.40 to 0.35 dex between Hβ and C IV-based black hole masses (Figure 4). For the full investigation, including the Mg II emission line, the corrections, luminosity effects, and radio spectral index, see Runnoe et al. (2012c).

This correction is only one among many that will tighten the black hole mass scaling relationships. Tracking down additional sources of scatter will further improve agreement between mass estimates.

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