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BRACKETT LINE-BASED $M_{\rm BH}$ ESTIMATORS AND HOT DUST TEMPERATURES OF TYPE 1 AGNs FROM *AKARI* SPECTROSCOPIC DATA

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ABSTRACT

We provide results of near-infrared (NIR) spectroscopic observations of 83 nearby (0.002< z <0.48) and bright (K <14 mag) type 1 active galactic nuclei (AGNs). For the observations, we used the Infrared Camera (IRC) on *AKARI* allowing us to obtain the spectrum in the rarely studied spectral range of 2.5–5.0 μm. The 2.5–5.0 μm spectral region suffers less dust extinction than ultra violet (UV) or optical wavelength ranges, and contains several important emission lines such as Brβ (2.63 μm), Brα (4.05 μm), and polycyclic aromatic hydrocarbon (PAH; 3.3 μm). The sample is selected from the bright quasar surveys of Palomar Green and SNUQSO, and AGNs with black hole (BH) masses estimated from reverberation mapping method. We measure the Brackett line properties for 11 AGNs, which enable us to derive BH mass estimators and investigate circum-nuclear environments. Moreover, we perform spectral modeling to fit the hot and warm dust components by adding photometric data from SDSS, 2MASS, *WISE*, and *ISO* to the *AKARI* spectra, and estimate hot and warm dust temperatures of ∼1100 K and ∼220 K, respectively.

Key words: galaxies: active - galaxies: nuclei - quasars: emission lines - quasars: general - infrared: galaxies

1. INTRODUCTION

It has been suggested that galaxies evolve from ultra luminous infrared galaxies (ULIRGs) with merger driven star formation to AGNs with active BHs. In the intermediate stage between ULIRGs and AGNs, the SMBHs are believed to grow quickly and have a dust-enshrouded environment. In recent years, AGNs with very red colors (e.g., $R-K$ >5 mag and $J-K$ >1.3 mag; Glikman et al. 2007; Urrutia et al. 2009) have been found, and they are now thought to be galaxies in an intermediate stage. However, their BH masses and activities are still veiled by their massive dust extinction.

It is common to use UV or optical lines such as CIV, Mg II, Hβ, or Hα emission lines to estimate BH masses, but the usual BH mass estimators suffer from dust extinction and cannot give us correct information for BH masses for the red AGNs. Therefore, previous studies have tried to establish BH mass estimators using NIR spectrum (e.g., Paschen series: Kim et al. 2010). In this study, we derive BH mass estimators using Brackett lines, and expect that the Brackett-based BH mass estimators will give us correct BH masses of the red AGNs even in type 2 AGNs.

In order to use Brackett lines (Brβ: 2.63 μm and Brα: 4.05 μm), we need NIR spectra above 2.5 μm. However, NIR (λ >2.5 μm) spectrum of AGNs are scarce due to observational limitation by atmospheric absorption. In order to get the NIR spectra of AGNs, we used the infrared astronomy satellite *AKARI* with IRC for 83 nearby and bright AGNs. The IRC on *AKARI* provides us spectroscopic observations with a wide wavelength coverage of 2.5–5.0 μm and a low resolution of R∼120 at 3.6 μm.

2. RESULTS

2.1. BH Mass Estimators with Brackett Lines

We derive new BH mass estimators based on the Brβ and Brα lines, with luminosities serving as a BLR size, and σ as a velocity. In order to derive BH mass estimators, we need three parameters, a, b, and c, in the equation $\log(M_{\rm BH}) = a + b\log(L_{\rm Br}) + c\log(\sigma)$. We fix the parameter of the velocity term, c to 2, by the virial theorem. We performed a linear bisector regression fit using the `MPFITEXPR` (Markwardt 2009) code available in IDL. We obtain the following relations:

$$\frac{M_{\rm BH}}{M_\odot} = 10^{5.92\pm0.33}\left(\frac{L_{\rm Br\beta}}{10^{42}\ {\rm erg\ s^{-1}}}\right)^{0.67\pm0.13}\left(\frac{\sigma_{\rm Br\beta}}{10^{3}\ {\rm km\ s^{-1}}}\right)^{2}, \quad (1)$$

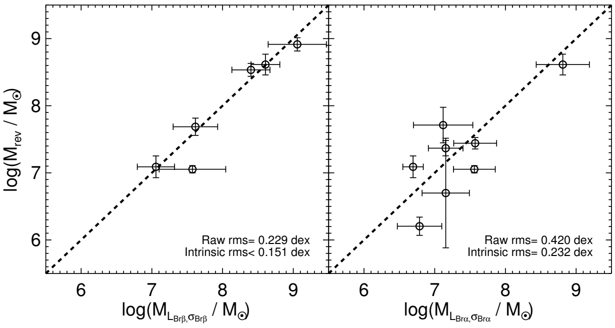

Figure 1. $M_{\rm BH}$ based on Brackett lines vs. $M_{\rm BH}$ derived from the reverberation mapping method. The Brackett-line-based BH masses are derived using $L_{\rm Br}$ and $\sigma_{\rm Br}$ in Equations (1) and (2). The dashed line indicates the line where $M_{\rm BH}$ from Brackett lines and the reverberation mapping methods are identical.

and

$$\frac{M_{\rm BH}}{M_\odot} = 10^{6.15\pm0.27}\left(\frac{L_{\rm Br\alpha}}{10^{42}\ {\rm erg\ s^{-1}}}\right)^{0.59\pm0.16}\left(\frac{\sigma_{\rm Br\alpha}}{10^{3}\ {\rm km\ s^{-1}}}\right)^{2}. \quad (2)$$

2.2. *Dust Component*

In order to estimate temperatures of the dust components, we performed spectral modeling to fit the hot and the warm dust components by adding photometric data from SDSS, 2MASS, *WISE* ($W3$ and $W4$), and *ISO* (7.3 μm: Haas et al. 2003) to the *AKARI* spectra. The spectral energy distribution (SED) model used to fit the dust components is composed of a single power-law and a double black body radiation components: $F_\lambda = C_0\lambda^\alpha + C_1 B_\lambda(T_{\rm HD}) + C_2 B_\lambda(T_{\rm WD})$. C_0, C_1, and C_2 are the normalization parameter of each component, α is the slope of the power-law component, B_λ is the Planck function, and $T_{\rm HD}$ and $T_{\rm WD}$ are the hot and warm dust temperatures. We measured temperatures of the hot and warm dust components for 19 AGNs, and the mean $T_{\rm HD}$ and $T_{\rm WD}$ are 1083 K and 221 K, respectively. The mean $T_{\rm HD}$ is lower than the previous studies (e.g., 1500 K: Barvainis 1987; Elvis et al. 1994 and 1260 K: Glikman et al. 2006). The difference does not arise from the fitting methods.

3. SUMMARY

We obtained 2.5–5.0 μm spectra of 83 nearby and bright type-1 AGNs using the IRC on *AKARI*. We estimated luminosity and σ, of Brackett lines for 11 AGNs, and derived new BH mass estimators. The BH mass estimators will be applied to measure the BH masses of red AGNs, which will enable us to understand galaxy evolution scenarios. Moreover, we derived the temperatures of the hot and the warm dust components for 19 AGNs. The continuum shape of *AKARI* spectra and various photometric data were used for this study. The measure hot dust temperature was ~1100 K, which is lower than the ~1500 K of previous results. A more detailed description of the results will be available in (Kim et al., 2014).

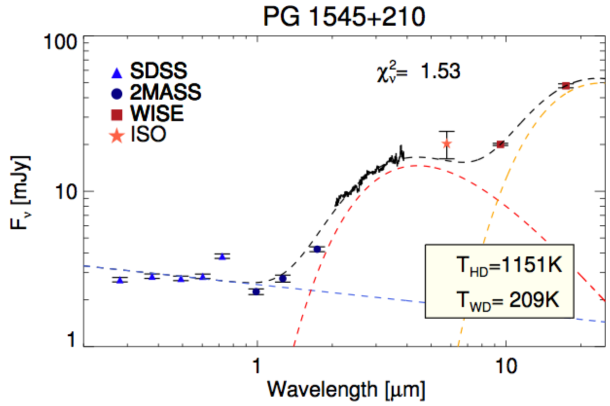

Figure 2. Photometric and spectroscopic SEDs of PG 1545+210. The SEDs are shown in rest-frame. Triangles, circles, squares, and stars indicate photometric data points from SDSS, 2MASS, *WISE* ($W3$ and $W4$), and *ISO* (7.3 μm), respectively. The black solid line denotes the *AKARI* spectrum. The dashed lines are fitted results. The blue, red, and yellow dashed lines indicate power-law, hot, and warm dust components, respectively, and the black dashed line is the sum of all components. The measured hot and warm dust temperatures are indicated at the lower right-hand corner.

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