OBSERVING REQUEST
University of Arizona Observatories

Year: 2015 **Term:** Jan–Jul **Proposal type:** short-term

Investigating the M_{BH}-σ_e relation of the misclassified type 1 AGNs

P.I.: Jong-Hak Woo (SNU; *woo@astro.snu.ac.kr*; +8228804231)
CoI(s): Kooksub Jo⋆ (SNU)

Abstract of Scientific Justification

We propose to obtain spatially resolved spectra for a sample of 21 misclassified type 1 AGNs at $z <\sim 0.04$ from SDSS. Based on our careful multi-component spectral fitting analysis including stellar population models, we detected a broad component of the Hα line (FWHM $> \sim$2000 km s^{-1}) from a large sample of local AGNs, which are typically classified as type 2 AGNs based on the emission line flux ratios. These misclassified type 1 AGNs show large offset from the M_{BH}-σ_e relation of general population of type 1 AGNs when we used the stellar velocity dispersion measurements from the spatially integrated SDSS spectra. To investigate whether these new class of AGNs are truly type 1 AGNs and whether they follow the M_{BH}-σ_e relation, it is necessary to obtain spatially resolved spectra. Based on the proper measurements of the effective stellar velocity dispersion using the rotation curve and velocity dispersion profile, we will investigate the M_{BH}-σ_e relation of these misclassified AGNs.

Text

Summary of observing runs requested for this project

								Scheduling		Sharing	
Run	Telescope	Cage	Instrument	PI	AO	Nights	Moon	Optimal	Acceptable	Poss.	Adv.
1	MMT	f/9	Red			2	Dark	Feb–Apr	Feb–Jun	no	no

Scheduling constraints and unusable dates *(up to 4 lines)*:

no text past this line

A ⋆ appended to the proposal type indicates a continuation proposal; a ⋆ appended to the name of a proposer indicates the proposer is a (graduate) student; a proposer whose name is underlined is certified on the proposed telescope/instrument combination; if a ∗ appears within the PI or AO box in the observations summary table, the instrument is a PI instrument and/or Adaptive Optics are requested – signatures are required on the next page.

Target list (attach list if longer than 26 objects)

#	Object	RA	Dec	mag / color / type / redshift / comment / etc.
1	J075151.88+494851.5	07:51:51.88	+49:48:51.5	z=0.0244, m_r=14.38
2	J093106.75+490447.1	09:31:06.75	+49:04:47.1	z=0.0339, m_r=14.30
3	J094319.15+361452.1	09:43:19.15	+36:14:52.1	z=0.0221, m_r=13.13
4	J094830.01+553822.6	09:48:30.01	+55:38:22.6	z=0.0452, m_r=16.31
5	J104250.27+254616.3	10:42:50.27	+25:46:16.3	z=0.0299, m_r=15.21
6	J104930.92+225752.3	10:49:30.92	+22:57:52.3	z=0.0327, m_r=14.61
7	J105214.95+300328.3	10:52:14.95	+30:03:28.3	z=0.0345, m_r=14.44
8	J105427.88+330943.4	10:54:27.88	+33:09:43.4	z=0.0433, m_r=16.00
9	J110501.98+594103.5	11:05:01.98	+59:41:03.5	z=0.0338, m_r=14.64
10	J111349.74+093510.7	11:13:49.74	+09:35:10.7	z=0.0292, m_r=13.41
11	J112637.73+513423.0	11:26:37.73	+51:34:23.0	z=0.0265, m_r=15.18
12	J120144.91+201941.9	12:01:44.91	+20:19:41.9	z=0.0234, m_r=14.14
13	J124054.96+080323.1	12:40:54.96	+08:03:23.1	z=0.0477, m_r=16.33
14	J130340.81+534323.6	13:03:40.81	+53:43:23.6	z=0.0276, m_r=14.85
15	J141057.23+252950.0	14:10:57.23	+25:29:50.0	z=0.031, m_r=13.70
16	J142307.51+283542.3	14:23:07.51	+28:35:42.3	z=0.0293, m_r=14.68
17	J143318.47+344404.4	14:33:18.47	+34:44:04.4	z=0.0343, m_r=13.97
18	J143727.85+254556.0	14:37:27.85	+25:45:56.0	z=0.0328, m_r=14.08
19	J150653.38+125131.2	15:06:53.38	+12:51:31.2	z=0.0216, m_r=13.94
20	J151512.25+152412.3	15:15:12.25	+15:24:12.3	z=0.0457, m_r=16.56
21	J154357.33+283126.4	15:43:57.33	+28:31:26.4	z=0.0323, m_r=15.05

Approval for Instrument Use from PI: ____________________

*(have instrument PI signature appear on, or attach PI e-mail to, **all** copies)*

Graduate students *(provide the following information for **each** student named as PI or CoI on the cover page. Have the advisor's signature(s) appear on **all** submitted copies)*

Student's Name	Advisor's Name	Advisor's Signature	2nd-yr	Thesis
Kooksup Jo	Jong-Hak Woo		no	no

Scientific Justification

Scientific Rationale: The correlation of the mass of the central black hole (M_{BH}) with the stellar velocity dispersion (σ_e) indicates a strong connection between galaxy evolution and black hole growth, inspiring various unified formation scenarios (see Kormendy & Ho 2013). In the present-day, both inactive and active galaxies seem to follow the same M_{BH}-σ_e relation regardless of the BH activity (Woo et al. 2010, 2013; Park et al. 2012), while cosmic evolution of the M_{BH}-σ_e relation has been suggested by Seyfert galaxies at z$\sim$0.4-0.6 (lookback time 4-6 Gyr), which show an offset from the local M_{BH}-σ_e relation, implying that black hole growth predates the final galaxy assembly (Woo et al. 2006, 2008; Treu et al. 2007; Bennert et al 2010; Park et al. 2014). High redshift QSOs (z$\sim$1-3) also show a consistent picture, with an offset from the local scaling relations (Peng et al. 2006; Merloni et al. 2010; Bennert et al. 2011; Schramm & Silverman).

Although dynamical BH mass measurements have been improved over the last several years to better define the local M_{BH}-σ_e relation (see Kormendy & Ho 2013), not much attention has been paid to stellar velocity dispersion (SVD). Currently, there are two limitations in the SVD measurements, which arguably lead to systematic uncertainties in the local M_{BH}-σ_e relation. First, although SVD has been measured from spatially resolved stellar kinematics for most early-type galaxies based on high quality data (e.g., McConnell & Ma 2013; Kang et al. 2013), the SVD of a number of late-type galaxies have been collected from the old literature. These values were measured from single-aperture spectra extracted with different aperture sizes. The lack of spatially resolved measurements, and inhomogeneous data quality & analysis of these late-type galaxies increase the systematic uncertainties of the M_{BH}-σ_e relation on the lower mass regime, and prevents us from properly constraining the intrinsic scatter of the M_{BH}-σ_e relation. Second, rotation and inclination effect of the stellar disk has not been carefully accounted in measuring SVD. From the spatially resolved stellar kinematics, the effective SVD has been calculated by integrating the luminosity-weighted sum of velocity dispersion and velocity, i.e., $[\sigma(r)^2 + V(r)^2]\, I(r)$, out to the effective radius, to derive the M_{BH}-σ_e relation (Gultekin et al. 2009, McConnell & Ma 2013; Kormendy & Ho 2013). However, this definition of SVD is not a pure velocity dispersion since it includes a contribution from the disk rotation. If BH mass correlates only with bulge properties, but not with disk properties, then we may need to use a SVD corresponding to the bulge potential without a disk contribution. Depending on adding or excluding the disk contribution, the effective SVD will make substantial difference for late-type galaxies, hence in deriving the M_{BH}-σ_e relation. For example, Jardel et al. (2011) showed that the SVD of a Sa galaxy, NGC 4594 changes from 297 $\mathrm{km\,s^{-1}}$ to 200 $\mathrm{km\,s^{-1}}$ if the rotation is excluded in calculating the effective SVD (see their Fig. 9).

In our recent an on-going works, we obtained spatially resolved measurements from Subaru and Palomar telescopes, and investigated the rotation effect, using early-type and pseudo-bulge galaxies in the M_{BH}-σ_e sample (Kang et al. 2013; Woo et al. 2013; Woo et al. in preparation). We found that the rotation correction can significantly reduce the effective SVD, particularly for late-type and pseudo-bulge galaxies since rotation velocity is typically larger than or comparable to velocity dispersion (Jardel et al. 2011; Woo et al. in preparation). By accounting for the rotation effect, we currently btained the best M_{BH}-σ_e relation of normal galaxies, which can be used as the local calibration to study whether active galaxies follow the M_{BH}-σ_e relation.

Recent progress: In our recent study, we searched for misclassified type 1 AGNs among the local AGN sample, which are typically identified as type 2 AGNs based on the emission line flux ratios (Woo et al. 2014). Using 4,113 local type 2 AGNs at $0.02 < z < 0.05$ selected from Sloan Digital Sky Survey Data Release 7, we found a misclassified sample of 142 AGNs, by detecting a broad component of the Hα line with a Full-Width at Half-Maximum (FWHM) ranging from 1700 to 19090 $\mathrm{km\,s^{-1}}$, based on the spectral decomposition analysis with stellar population models and Gaussian modeling of emission line components (see Figure 1). The fraction of the misclassified type 1 AGNs among type 2 AGN sample is $\sim$3.5%, implying that a large number of missing type 1 AGN population may exist. These misclassified AGNs are interesting targets for further study of black hole - galaxy coevolution since they are likely to be low luminosity with relatively weak continuum (the median Eddington ratio is 1%). Thus, their host galaxy properties can be easily studied while the mass of the central black hole can be estimated from the broad component of Hα using various single-epoch mass estimators (Woo & Urry 2002; Park et al. 2012; Bentz et al. 2013).

However, when we used the stellar velocity dispersion measurements available from the SDSS, and investigate the M_{BH}-σ_e relation of the sample, we find a large offset from the relation (see Fig. 2), implying that these black holes are under-massive compared to general population of type 1 AGNs (i.e., reverberation-mapped AGNs; Woo et al. 2013) at fixed stellar velocity dispersion. This finding contradicts to the recent result by Bennert et al. (2014), who showed that $\sim$100 local type 1 AGNs follow the M_{BH}-σ_e relation without any systematic deviation (see their Figure 2). Note that the SVD measurements of Bennert et al. are based on the spatially resolved spectra using the high quality data obtained at the Keck telescope, and the rotation effect is corrected for. Thus, the misclassified type 1 AGNs in our sample appear to be different from typical type 1 AGNs in therms of black hole-galaxy evolution.

There are three possibilities to explain the discrepancy. First, the SVD measurements from the spatially integrated SDSS spectra suffer rotational broadening and possibly overestimated. This overestimation of SVD is also hinted by the fact that the the velocity dispersion of the N II emission line, which should roughly correlate with SVD (Nelson & Whittle 1995), is on average $\sim$14% smaller than SVD. This implies that SVD may be overestimated by $\sim$0.05-0.06 dex, which can explain the M_{BH} offset by 0.2 dex (since $M_{BH} \propto \sigma^4$). Second, the misclassified type 1 AGNs are not true type 1 AGNs. The detected broad component of Hα could be simply caused by the artificial effect (e.g., broad polynomial fit) in the multicomponent fitting process. If this is the case, then the M_{BH} estimates based on the broad Hα component is mistaken. Third, M_{BH} may not be properly estimated since M_{BH} estimators are mainly calibrated by the general type 1 AGN sample. For example, if the strong extinction is present (as implied by the lack of the broad component of Hβ for a majority of objects), then the measured AGN luminosity is a lower limit, hence the M_{BH} could be underestimated.

Thus, to resolve the discrepancy, we need to investigate whether the M_{BH} and SVD are properly measured and whether the broad component of Hα is clearly present. High quality spatially resolved data will enable us to answer whether these newly found type 1 AGNs follow the M_{BH}-σ_e relation of general population of AGNs.

This proposal: We propose to obtain high S/N ratio long-slit spectra along the major axis of each galaxy. We will properly calculate the effective SVD based on the spatially resolved measurements, and investigate the presence of the broad component in the profile of the Hβ and Hα lines. **We request 2 nights in 2015A to measure spatially resolved kinematics from stellar absorption lines and gas emission lines for a sample of 21 objects. Three specific science goals are as follows.**

1. Investigating the M_{BH}-σ_e relation using rotation-free SVDs. Using the long-slit spectroscopy, we will measure velocity and velocity dispersion as a function of radius so that we can calculate the effective SVD with and without adding rotation velocity. We can directly compare the rotation-added and rotation-corrected SVDs and quantify the contribution of disk component. We will explore 1) whether the old SVD measurements from single-aperture SDSS spectra are overestimated due to the rotational broadening, 2) whether rotation and inclination effects are responsible for systematically larger stellar velocity dispersion at fixed BH masses.

2. True nature of the sample. We will investigate the presence or lack of the broad component of Hβ as well as Hα by performing a multicomponent spectral fitting analysis, in order to confirm the nature of the targets as type 1 AGNs. By comparing the stellar population models for the central and outer parts of each galaxy, we can investigate whether the stellar population model + broad polynomial fit can artificially generate the broad component of Hα. The difference of the continuum shape around the Hα line from spatially resolved data can provide a clear answer whether the broad component is intrinsic.

3. Extinction and black hole mass. We will investigate the extinction by comparing narrow components of Hα and Hβ. When the broad component of Hβ is detected, we will also compare the flux ratio between broad Hα and Hβ. By adding an extinction component in the spectral fitting, we will constrain the extinction and calculate the intrinsic luminosity of the AGN, to properly estimate the black hole mass.

References:

Bennert et al. 2010, ApJ, 708, 1507 • Bennert et al. 2011, ApJ, 726, 59 • Bennert et al. 2014, ApJ, submitted (arXiv:1409.4428)• Gultekin et al. 2009, ApJ, 698, 198 • Jardel et al. 2011, ApJ, 739, 21 • Kang et al. 2013, ApJ, 767, 26 • Kormendy & Ho, 2013, ARA&A, 51, 511 • McConnell & Ma, 2013, ApJ, 764, 184 • Merloni et al, 2010, ApJ, 708, 137 • Nelson, C. H. & Whittle, M. 1995, ApJS, 99, 67 • Park et al. 2012, ApJ, 747, 30 • Peng et al. 2006, ApJ, 649, 616 • Schramm & Silverman 2013, ApJ, 767, 13 • Treu et al. 2007, ApJ, 667, 117 • Woo et al. 2006, ApJ, 645, 900 • Woo et al. 2008, ApJ, 681, 925 • Woo et al. 2010, ApJ, 716, 269 • Woo et al. 2013, ApJ, 772, 49 • Woo et al. 2014, JKAS, in press

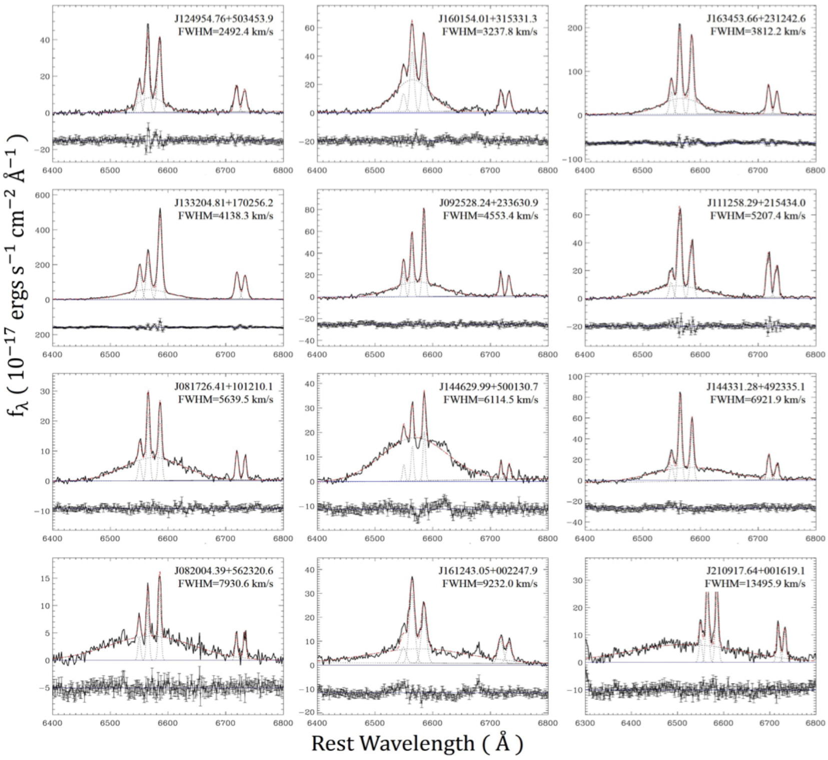

Figure 1. Examples of the best-fit emission line models in the Hα region for 15 objects from Woo et al. (2014). The continuum-subtracted spectra (black line) is overploted with the best-fit model (red line), which is composed of narrow lines (N II, Hα, and S II) and a broad Hα component. At the bottom of each panel the residual is presented (black lines). The object name and the FWHM of the broad Hα component are labeled in each panel.

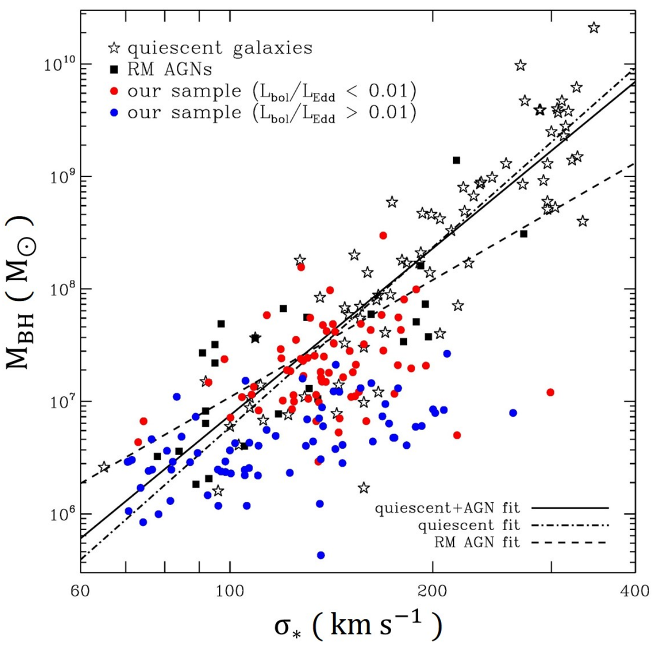

Figure 2. The M_{BH}-σ_e relation of the 142 misclassified Type 1 AGNs compared to the best-fit relation of the reverberation-mapped type 1 AGNs (black filed squares; Woo et al. 2013) and quiescent galaxies (open stars; McConnell & Ma 2013). Our sample was divided near the median Eddington ratio, with lower Eddington ratio objects in red and higher Eddington ratio objects in blue. The average offset of the misclassified type 1 AGN sample from the bset-fit $M_{BH} - \sigma_*$ relation (black solid line) is -0.45 dex.

Experimental Design & Technical Description *Describe your overall observational program. How will these observations contribute toward the accomplishment of the goals outlined in the science justification? If you've requested long-term status, justify why this is necessary for successful completion of the science. (**up to one page**)*

For given the high sensitivity and spatial resolution, the MMT spectrograph provides an ideal setup to measure spatially resolved stellar and gas kinematics along the semi major/minor axis of each galaxy in our sample. We will use the Red Channel Echellette, which provides the spectral range 4300-8900 Å, covering strong stellar lines, i.e., the Mgb triplet and Fe lines around 5200 Åand the CaII triplet region (∼8500 Å), which are typically used for measuring velocity dispersions. Thus, we can have SVD measurements from two different spectral regions and compare them for consistency. The spectral resolution $\sim$ 90 km s^{-1}is good enough to measure velocity dispersion of most of our targets except the low-mass galaxies with SVD $< \sim$90 km s^{-1}. At the same time, we will fit all AGN narrow and broad emission lines in the spectral range, in order to measure gas kinematics and photoionization along the major axis. During the twilight we will observe velocity template stars with various spectral types (including K giants) to minimize the uncertainty due to the difference in the spectral resolution, but we will also use the library of kinematic templates observed with high spectral resolution for measuring velocity dispersion as done for our previous studies.

To obtain spatially resolved measurements of stellar velocity dispersion out to the effective radius, we need to have S/N∼20 per resolution element for each spatial bin along the major/minor axis. Note that S/N∼20 can be easily obtained at the central part of the galaxy, while longer exposure is required for the outer part due to the much lower surface brightness.

Sample Selection. The parent sample of the misclassified type 1 AGN is composed of 142 objects at $0.02 < z < 0.05$ (Woo et al. 2014). First, we selected 121 AGNs with SDSS-based SVD larger than 90 km s^{-1}, in order to match the spectral resolution for properly measuring SVDs. Then, we selected 52 AGNs with higher Eddington ratios ($> 1\%$), since these objects are on average more deviating from the $M_{\rm BH}$-σ_e relation. Among the selected objects, we propose long-slit observations for 21 AGNs, which are optimally observable in 2015A ($7h < RA < 18h$). The final sample of AGNs are typically extended over 20" in the SDSS images. Thus, we can measure the stellar kinematics along the major axis.

We estimate the exposure time 0.5, 1.0, and 1.5 hours for bright ($m_r < 14$), intermediate ($14 < m_r < 16$), and faint ($m_r > 16$) targets. Including a 15-min overhead (slew, acquisition, slit centering, arc, etc) for each target, a total of $\sim$ 20 hour is required. Thus, we request 2 nights for this program. If the weather condition is not optimal, we will further select smaller number of targets and increase the exposure time to obtain high quality spectra.

Summary of Time Requested and Awarded *The TAC needs to understand the scope of this project — (1) tell us how many UAO nights you've already had for this project, how many you request this time, and (a good guess of) how many you need to complete the project; (2) if a substantial amount of observing for this project comes from non-UAO telescopes, tell us about that observing, and how the UAO part fits in; (3) if you are collaborating with people who have telescopes, especially if you are part of a large collaboration, tell us who is leading the project, and how UAO time and your participation fit in.* (***up to one page***)

Previous Use of Steward Facilities *List **all** allocations of telescope time for the present project and allocations for other projects on facilities available through UAO during the past 2 years, together with the current status of the data (cite publications where appropriate). Mark those allocations related to the present proposal (i.e, precede text with* `\related` *command). (**up to one page**)*