1. Project overview: Constraining the black hole – galaxy coevolution at high-z

2. Spectroscopic & Imaging observations

3. Initial results for 3 objects with good data quality (FWHM~0.15”)

(Subaru User’s meeting, Jan21—23, 2014)
1. Coevolution of galaxies and supermassive black holes: theory

Various predictions after the discovery of local $M_{\text{BH}}-\sigma_*$ correlation (Kormendy & Richstone 1995).

Formation of Different Hubble Types in Semi-Analytic Models

- Gas cools and forms a rotationally-supported disk
- Galaxies merge on a dynamical friction time-scale
- Major merger leads to formation of bulge; new disk forms when gas cools again
1. observation

\[ \frac{M_{\text{BH}}}{M_{\text{bulge}}} \text{ or } \frac{M_{\text{BH}}}{M_{\text{stellar}}} \text{ ratios} = \text{various}\]

observational results.
(controversial)

(Most data are for bulge--dominated galaxies (E/S0).)
(cf. blue square for disk-dominated galaxies)

Our goal
= accurate measurements
at higher-z. Common IMF (Chabrier) used (M.Schramm+13)
1. Our selection criteria for target quasars from SDSS DR5

0. Higher-z: larger differences in model predictions
1. Hβ width (for BH mass estimation, as low-z studies)
   measurable at K’ band (cf. C IV width suffered from outflow)
   \[3.11 < z < 3.50\] (age of Universe \(\sim\) 2Gyr)
   \(\rightarrow\) J-K’ color measures 4000Å break \(\rightarrow\) M/L ratio

2. Bright (but not too bright)
   \((r < 18)\)

3. >4hr at 50deg or higher elevation

4. Bright tip-tilt guide star within 60”
Distribution of our targets

SDSS DR5 (Shen+08)

Black = all redshift
(0 < z < 4.5)

Blue = 3.11<z<3.50

Red = our targets

not biased to
heaviest BHs
(cf. Lauer+07)
2. Spectroscopic & Imaging observations: Spectroscopy

Observations at 2-4m telescopes (IRTF/SpeX, UKIRT/UIST, WHT/LIRIS) and Subaru/IRCS (backup obs of imaging run) proposed since 2008
- PIs: Y.Minowa, N.Oi, Y.Watabe, T.Morokuma, Y.Saito
- Observers: Y.Minowa, N.Oi, M.Imanishi, T.Morokuma, Y.Saito, T.Kawaguchi

- Band: HK
- Spectral resolution: 375—1000
- Typical exposure time ~ 3600sec

- Measurement of H$\beta$ width
  \[ \rightarrow \text{BH mass} \]

- >30 objects, summarized in
  M-thesis (Y.Saito),
  Y.Saito et al. (in prep)
2. Subaru/IRCS+AO188 Imaging observations

- Observations begun in May 2012
- PIs: T.Kawaguchi, Y.Saito
- Observers: Y.Minowa, M.Imanishi, Y.Saito, T.Kawaguchi, T.Morokuma, T.Minezaki

- Band: K’ and J
- Mode: LGS, NGS, 1pix=52mas
- typical exposure time: ~5000--10000sec
- deconvolve to
  PSF(=nucleus)
  + Sersic profile(=host galaxy)
→ luminosity of host galaxies
→ mass of host galaxies
3. Initial results from this imaging/spectroscopic project: BH mass

- 3 objects with good data quality (exp time, seeing, ..)
- $3.18 < z < 3.48$
- Spectral data (UKIRT, Subaru)
  
  collected in 2009 Jan – 2013 Apr

$\rightarrow$ BH mass via H$\beta$ width

$\Rightarrow \log(M_{BH}) = 8.82 - 8.88$
Distribution of our targets

SDSS DR5 (Shen+08)

Black = all redshift
(0 < z < 4.5)

Blue = 3.11<z<3.50

Red = our targets

The 3 objects

Higher luminosity

J0847

J0725

J1510

log(Eddington ratio = $L_{bol} / L_{Edd}$)

log($M_{BH}(C\ IV) / M_\odot$) or $M_{BH}(H\beta)$
3. Initial results from this imaging/spectroscopic project: images

- Subaru/IRCS+AO188 Imaging data collected in 2013 Jan--Apr
- on-source exposure time: 5560—11160sec
  (3800—7980sec with good quality
  \[\Rightarrow 0.15-0.17''\text{ FWHM}\])
More detailed analysis is in progress, and will be presented elsewhere by Minowa-san.
3. Initial results from this project: host galaxy luminosity

Host galaxy: $M_V(AB) = -(25 - 26.1) \text{mag}$

AGN:
+0.3 -- -1.7mag
w.r.t. host

(Y.Minowa)
3. Initial results from this project: host galaxy mass

- For J1510 (with J & K’ data), we take $(M_{\text{Stellar}}/L_V)_{\text{sun}} = 0.28$ based on the observed J-K’ color (1.47mag).

- For other 2 objects (K’ data), we take the same $(M_{\text{Stellar}}/L_V)_{\text{sun}}$ (0.005—1.26).

(similar M/L ratio for LBGs at similar z and L; Akiyama+08)

![Mass-to-Luminosity Ratio based on Bruzual+Charlot 03) Passive]

![Constant star formation]

(T.Kawaguchi)  Age [yr]
3. Initial results from this project: BH--host galaxy relation

Local:
- Galaxies (Haering+Rix04)
- AGNs (Bennert+11)

Z~1: Schramm+
   Silverman13

Z~2.8: Schramm+08

Preliminary
At z~3.3 (our data),
No evolution (or slightly lower) is indicated.
(No color info → large error)
3. Initial results from this project: BH--host galaxy relation

We obtained the highest-z record for the BH-galaxy relation with Hβ-based BH masses.

**Preliminary**

At z~3.3 (our data), no evolution is indicated.

→ Outflow-regulated BH growth disfavored.
1. **NIR spectroscopy (K’) + Subaru/IRCS AO188 imaging (J & K’)**
   
   K’ spectra: H$\beta$ width measurement for BH mass
   
   (i.e., the same method as the local studies
   → minimize the uncertainty)

2. **Aim = Constraining BH—galaxy coevolution back to higher-z**

3. **Initial results for 3 objects with good data quality (FWHM~0.15”),**
   
   = indicating no evolution up to $z = 3.5$.
   
   = highest-z record for BH-galaxy mass ratio
     
     with H$\beta$-based BH masses.

4. **Color (J – K’) measurement is crucial to reduce the uncertainty.**