# Study of Clustering of Galaxies around AGNs using Japanese Virtual Observatory

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- Cross-correlation analysis between AGNs and galaxies
- 7184 SDSS AGNs for which BH mass is derived
- Obtain observational data using Virtual Observatory
- We found some indication that correlation-length is dependent on the BH mass
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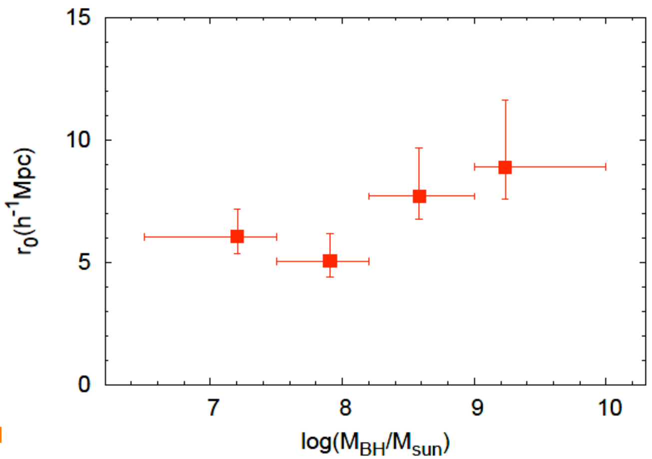

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## Abstract

We present preliminary results of study of galaxy clustering around AGNs at z=0.1-1. For the cross-correlation analysis, we use data of 7,184 SDSS AGNs for which the virial mass ($M_{BH}$) of the central black hole were estimated and galaxy data in the UKIDSS catalog. The observational data is obtained using Virtual Observatory.
We found an indication that the clustering amplitude increases as BH mass increases at $M_{BH} > 10^8 M_{\odot}$. On the other hand, we found no dependence of clustering amplitude on BH mass at $M_{BH} < 10^8 M_{\odot}$.

## 1. Introduction

It is known that most of galaxies have supermassive black holes (SMBHs) in their nuclei and that these black holes (BHs) power active galactic nuclei (AGNs). There are strong observed correlation between BH mass and galaxy properties.
Galaxy merger is thought to play an important role for growth of SMBHs and host galaxies. Measuring the environment and clustering properties of AGNs is key to understand evolution of SMBHs and galaxies.

In this study we present result of cross-correlation analysis between AGNs and galaxies. We investigate dependence of clustering amplitude on virial mass of SMBH ($M_{BH}$).

## 2. Dataset

AGN samples:
- SDSS DR7 quasar catalog (Shen et al. 2011) 6047 AGNs
- Greene & Ho (2007) 1137 AGNs

Galaxy samples:
- UKIDSS DR8 catalog (Large Area Survey)

Figure 1: Distribution of AGNs used in this work in mass-redshift space.

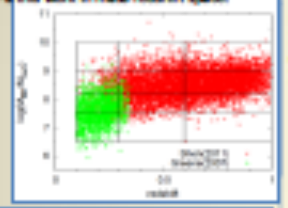
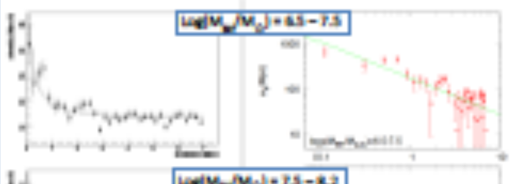


Table 1. Number of AGN samples in each mass and redshift bin.

| $\log(M_{BH}/M_{\odot})$ | redshift range 0.1-0.3 | 0.3-0.6 | 0.6-1.0 | total |
|---|---|---|---|---|
| 9.0-10.0 | 29 | 290 | 577 | 896 |
| 8.2-9.0 | 388 | 1336 | 3334 | 5758 |
| 7.5-8.2 | 633 | [illegible] | 480 | [illegible] |
| 6.5-7.5 | 480 | 67 | 0 | 547 |
| total | [illegible] | [illegible] | [illegible] | 7184 |

Figure 2
Left: Number density of galaxies in UKIDSS catalog as a function of distance from a AGN in the four different mass ranges of SMBH.
Right: Projected number density against projected distance.




## 3. Method

1. Search UKIDSS VO service for each AGN using JVO command line tools.

2. Reject AGN samples which are strongly affected by foreground galaxy.

3. Clustering amplitude of galaxies around an AGN is described by the two point cross-correlation function, $\xi(r)$. As assuming power-law form for $\xi(r)$, we derive correlation length, $r_0$, for the fixed value of power-law index ($\gamma$ =1.8).

$$\xi(r) = \frac{\rho(r) - \rho_0}{\rho_0} = \left(\frac{r_0}{r}\right)^{\gamma}$$

$\xi(r)$: cross-correlation function
$r$: distance from a AGN
$\rho(r)$: number density of galaxy
$\rho_0$: average number density of galaxy at the AGN redshift

We estimate $\rho_0$ from luminosity function of galaxies (Cirasuolo et al. 2007).
From observations, we derive projected cross-correlation function, $\omega(r_p)$. When we assume power-law form for $\xi(r)$, $\omega(r_p)$ is also power-law function.

$$\omega(r_p) = 2\int_{r_p}^{\infty} r dr \xi(r)(r^2 - r_p^2)^{-1/2} = \frac{n(r_p) - n_{bg}}{\rho_0}$$

$\omega(r_p)$: projected correlation function
$r_p$: projected distance from a AGN
$n(r_p)$: observed number density
$n_{bg}$: number density of background galaxies

We derive $\rho_0$, $n(r_p)$, $n_{bg}$ for each AGN samples.

4. We derive projected correlation function from averages of $\rho_0$, $n(r_p)$, $n_{bg}$. Correlation length $r_0$ is computed by power-law fit of $\omega(r_p)$.

$$\omega(r_p) = \frac{\langle n(r_p) \rangle - \langle n_{bg} \rangle}{\langle \rho_0 \rangle}$$

## Japanese Virtual Observatory (JVO)

Virtual Observatory (VO) have been developed for seamless access to many astronomical archives. Today, one can easily access more than 10,000 data archives in the whole world and retrieve data using VO.
Japanese Virtual Observatory (JVO) portal has been developed and operated by Astronomy Data Center, National Astronomical Observatory of Japan (NAOJ).
We have also developed command-line tools to access VO services. It is useful for recurrent access to huge data archives with VO interface in a scripting environment.

http://jvo.nao.ac.jp/portal

## 4. Results

Correlation length for the whole AGN sample is estimated as $r_0 = 6.6^{+1.4}_{-0.9} h^{-1}$Mpc. This is consistent with results of previous cross-correlation studies between AGN and galaxy (5.95±0.90 $h^{-1}$ Mpc, X-ray AGNs at z=0.7-1.4, Coil et al. 2009; 6.98±0.6 $h^{-1}$Mpc, optical AGNs at z<1, Mountrichas et al. 2009).

### Virial mass dependence

### Redshift dependence

We derive correlation length for three redshift ranges. As shown in Figure 4, the clustering amplitude is not dependent on redshift at z = 0.1 – 1.
At $M_{BH}>10^8 M_{\odot}$, we can see the mass dependence for subsamples of z = 0.1 - 0.3 and z = 0.3 – 0.6.
At $M_{BH}<10^8 M_{\odot}$, there are sufficient number of AGNs only for sub-sample of z = 0.1 – 0.3.

## 5. Conclusions & Discussion

- There are some indication of an increasing trend of AGN-galaxy cross-correlation length, $r_0$, as virial mass, $M_{BH}$, increases, at $M_{BH}>10^8 M_{\odot}$.