Astronomical Data Analysis Software and Systems XIX **P65**
ASP Conference Series, Vol. XXX, 2009
Y. Mizumoto, K.-I. Morita, and M. Ohishi, eds.

Environment Study of AGNs at z = 0.3 to 3.0 using the Japanese Virtual Observatory

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Abstract. We present a science use case of Virtual Observatory, which was achieved to examine an environment of AGN up to redshift of 3.0. We used the Japanese Virtual Observatory (JVO) to obtain Subaru Suprime-Cam images around known AGNs. According to the hierarchical galaxy formation model, AGNs are expected to be found in an environment of higher galaxy density than that of typical galaxies. The current observations, however, indicate that AGNs do not reside in a particularly high density environment. We investigated ∼1000 AGNs, which is about ten times larger samples than the other studies covering the redshifts larger than 0.6. We successfully found significant excess of galaxies around AGNs at redshifts of 0.3 to 1.8. If this work was done in a classical manner, that is, raw data were retrieved from the archive through a form-based web interface in an interactive way, and the data were reduced on a low performance computer, it might take several years to finish it. Since the Virtual Observatory system is accessible through a standard interface, it is easy to query and retrieve data in an automatic way. We constructed a pipeline for retrieving the data and calculating the galaxy number density around a given coordinate. This procedure was executed in parallel on ∼10 quad core PCs, and it took only one day for obtaining the final result. Our result implies that the Virtual Observatory can be a powerful tool to do an astronomical research based on large amount of data.

1. Introduction

It has been thought that the origin of AGN activity is accretion of matters into a massive black hole at the center of the galaxy (e.g. Lynden-Bell 1969). One possible mechanism for causing rapid gas inflows into the central region is a major merger between gas-rich galaxies. If this is the case, AGNs are expected to be found in an environment of higher galaxy density than an environment of typical galaxies. Thus the AGN produced at higher redshifts should be observed in a high galaxy density environment.

The previous observations, however, indicated that AGNs did not reside in a particularly high density environment. We must, however, be cautious with the results obtained especially at high redshift ($z > 0.6$). All the high redshift observations were based on the galaxies selected by adapting a color cut, so some kinds of galaxies were missed in their samples. The observations were limited to several specific fields, thus the results were strongly affected by cosmic variance.

We investigated ~1000 AGNs, which were distributed in wide area of the sky, without applying any color selection. The number of AGN examined is about ten times larger than the other studies covering the redshifts larger than 0.6. We successfully found significant excess of galaxies around AGNs at redshifts of 0.3 to 1.8.

If this work was done in a classical manner, that is, raw data were retrieved from the archive through a form-based web interface in an interactive way, and the data were reduced on a low performance computer, it might take several years to finish it. Thus we have developed parallel computing system which can communicates directly with the Subaru data archive in bandwidth of 32 Gbps at maximum (Shirasaki et al. 2007, Shirasaki et al. 2008). All the public Suprime-Cam data were reduced using this system, and the data were provided through the JVO system (Shirasaki et al. 2009). So it is possible to do an environment study for any types of object using the deep image obtained by the Suprime-Cam with very few effort. Our result implies that the Japanese Virtual Observatory can be a powerful tool to investigate the large scale structure of the intermediate redshift Universe.

2. Method

We have constructed a pipeline for calculating the distribution of galaxy number density around a given coordinate. The procedure of the study of QSO environment using the JVO is as follows (see also Figure 1) :

Step 0 (Admin) : Parallel processing of large amount of data
Data reduction of all the Suprime-Cam data were performed on the JVO grid computing system (12 servers, 48 CPU cores). 10 TB of RAW data are reduced through the JVO web interface. The processing time was ~10 days. The metadata of the processed image were registered to database and made public through the VO interface.

Step 1 : Multiple database query
Suprime-Cam image and UKIDSS catalog data (Warren et al. 2007) were searched around known AGNs (Veron-Cetty and Veron 2006, Schneider et al. 2007). The JVO Query Language (JVOQL) shown in the Figure 1 is an example to do a coordinate join between AGN catalog table and Suprime-Cam metadata table.

Step 2 : Workflow for calculating galaxy density around each AGN
We made a script "qso-dataset.sh" which executes the following workflow:

1. Retrieve images and catalog data around a specified coordinate of AGN. The query was directly sent to the SkyNode.

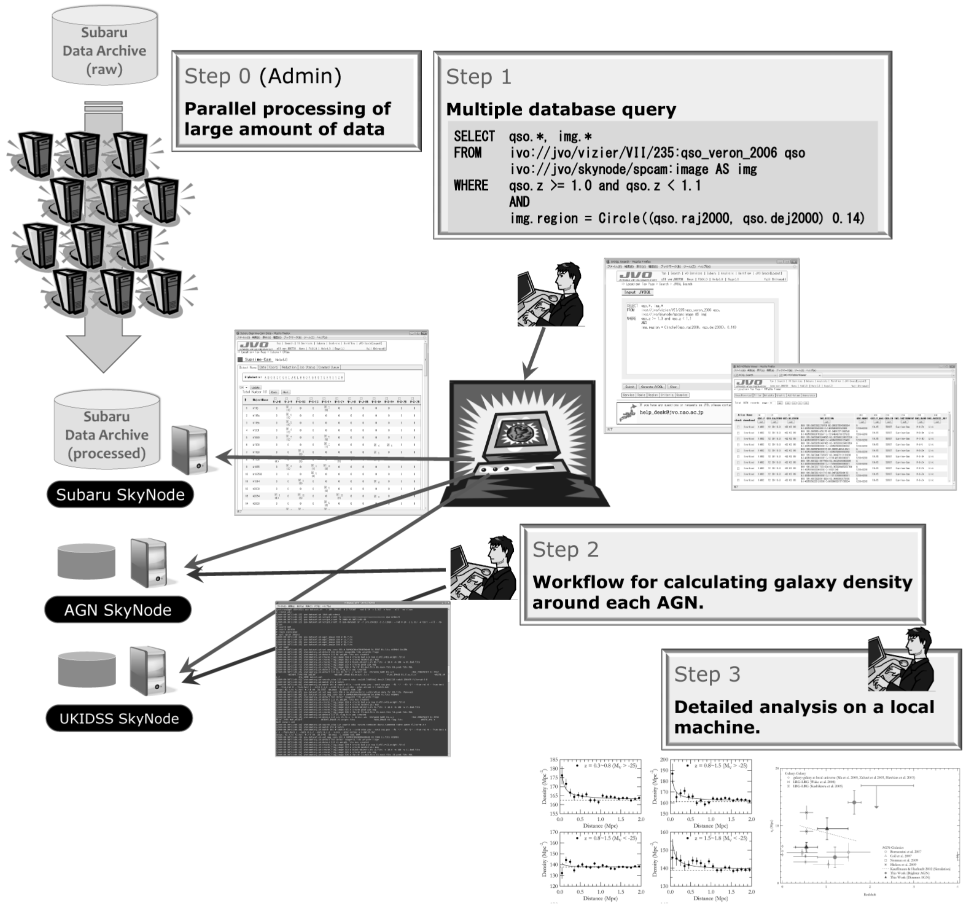

Figure 1. The procedure of the study of QSO environment using the JVO

2. Extract objects from the images, and cross-match to create a multi-bands catalog.
3. Calculate galaxy number density around the AGN coordinate This was executed for every AGN found in the step 1:

Step 3 : Detailed analysis on a local machine

Stack the galaxy density profiles around each AGN, and calculate a correlation length between AGN and galaxies for each AGN's redshift and luminosity range.

The step 2 was executed in parallel on ~10 quad core PCs, and it took only one day for obtaining the final result.

3. Conclusion

Using JVO, we were able to measure the clustering property for ~ 1000 AGNs at redshifts 0.3–3.0 with optical brightness of $M_V = -30$ to -20. It is emphasized that this work uses the largest sample with deep optical images, which are typically deeper than 24 mag. By using the deep optical images, we can also measure the clustering property of faint and blue star forming galaxies around AGNs at high redshift ($z \sim 1 - 2$), which have not been well explored by any other studies. It is also noted that our work would be a bias-free task (free from the cosmic variance), since the AGNs we have used are distributed in a wide area of the sky. The detailed of the result can be found in Shirasaki et al. (2009b).

The functionality of JVO to join the two distributed tables, AGN catalog and the Subaru Suprime-Cam image metadata table, enabled us to easily find Subaru Suprime-Cam images which contained an AGN at the center of the image. Since the data access to the VOs is programmable in a uniform interface, both of the data retrieval and data analysis can be integrated into a single script, and can be executed in an automated way. Just by changing the tables used in the script, we can adapt this script to another science case, which might accelerate astronomical discoveries.

We would like to emphasize that the usefulness to open to public the reduced wide field images like those of Suprime-Cam. Those images might provide room for further studies which were not aimed by the PI observers. The raw data is useful for making detailed analysis on user's local machine, however, it is not appropriate for doing statistical analysis based on large amount of data. It is painful to download all the Suprime-Cam images and reduce them on a low performance PC, which may take over one year to complete. We could finish the workflow to calculate the distributions of galaxy number density around AGNs in about one day, which promises that the VO will be a powerful tool to investigate based on large amount of data.

Acknowledgments. This work was supported by the JSPS Core-to-Core Program and Grant-in-aid for Information Science (15017289, 16016292, 18049074 and 19024070) carried out by the Ministry of Education, Culture, Sports, Science and Technology (MEXT) of Japan. YS is grateful for support under Grant-in-aid for Young Scientists (B) (17700085, 21740143) carried out by the MEXT of Japan.

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