Sciences with Hyper Suprime-Cam and survey parameters

Version 1

HSC survey design working group

manuscript deadline: 2008 September 30

October 3, 2008

Summary

Summary

Contents

Chapter 1

Science cases and survey parameters

1.1 Subaru Wide-Field AGN Survey

Author(s)

Masayuki Akiyama (Tohoku), Motohiro Enoki (Tokyo Keizai), Tomotsugu Goto (Hawaii), Tetsuya Hashimoto (Kyoto), Masatoshi Imanishi (NAOJ), Nobunari Kashikawa (NAOJ), Nozomu Kawakatu (NAOJ), Yoshiki Matsuoka (Tokyo), Tomoki Morokuma (NAOJ), Takashi Murayama (Tohoku), Tohru Nagao (Ehime), Masahiro Nagashima (Nagasaki), Takao Nakagawa (JAXA/ISAS), Ken Ohsuga (NAOJ), Masahiro Takada (Tohoku), Yoshiaki Taniguchi (Ehime), Yuichi Terashima (Ehime), Yoshihiro Ueda (Kyoto), Masayuki Umemura (Tsukuba), Keiichi Wada (NAOJ), Atsunori Yonehara (Kyoto Sangyo)

Abstract

We propose new AGN surveys, that consist of very-wide 5-band imaging observations and moderately-deep 3-band imaging observations. Through these observations, we identify numerous relatively-faint AGNs at $1 < z < 5$ and bright AGNs at $z > 6$. The former sample ($1 < z < 5$) is used to study the faint end of the AGN luminosity function, the AGN correlation function, and the environment around high-z AGNs. These statistical properties are crucial to constrain the AGN triggering mechanism, the typical lifetime of AGN activities, the growth history of supermassive black holes, and the effects of the AGN feedback onto galaxies. The latter sample ($z > 6$) is used to study detail processes of the cosmic reionization and to extend the cosmic redshift frontier where super-massive black holes are growing rapidly.

1.1.1 Science Goals

Search for AGNs at $z > 6$

In this decade AGNs at $z > 6$ are enthusiastically focused on, because they are crucially important to (1) constrain the formation/evolutionary scenarios of supermassive black holes (SMBHs), (2) prove the physical conditions of the IGM in terms of its neutral fraction, (3) provide a landmark of highest-z (proto-)clusters of galaxies, and (4) trace the earliest stage of the cosmic chemical evolution. While the most distant AGN identified so far has been discovered with CFHT ($z = 6.43$; Willott et al. 2007), most of luminous AGNs at $z > 6$ ever found have been discovered through the SDSS photometric survey with follow-up spectroscopy and/or near-infrared imaging observations (e.g., Fan et al. 2006; Goto 2006; see Figure 1). Consequently the above three issues have been extensively investigated in these years based on mainly the SDSS sample. The mass of SMBHs in some of SDSS AGNs at $z > 6$ has been measured and it turned out to be $> 10^9 M_\odot$ (e.g., Willott et al. 2003; Kurk et al. 2007), that indeed gives strong constraints on some theoretical scenarios for the evolution of SMBHs (e.g., Li et al. 2007; Tanaka & Haiman 2008). The evolution of the Gunn-Peterson optical depth in SDSS high-z AGNs suggests that the end of the cosmic reionization process is at around $z \sim 6$ and the neutral hydrogen fraction at $z > 6$ is significantly more than zero (Fan et al. 2006). Possible overdensity regions around the SDSS high-z AGNs have also identified through follow-up deep multi-color imaging observations (Zheng et al. 2006; Ajiki et al. 2006). The metallicity of SDSS AGNs at $z > 6$ has been examined through FeII/MgII ratio (e.g., Maiolino et al. 2004; Iwamuro et al. 2004; Kurk et al. 2007) and NV/CIV ratio (Jiang et al. 2007); both of which show no chemical evolution, surprisingly. All of these observational progress strongly suggests that AGNs at $z > 6$ are extremely important objects to extend our knowledge on the cosmic frontier toward the so-called the cosmic dark age.

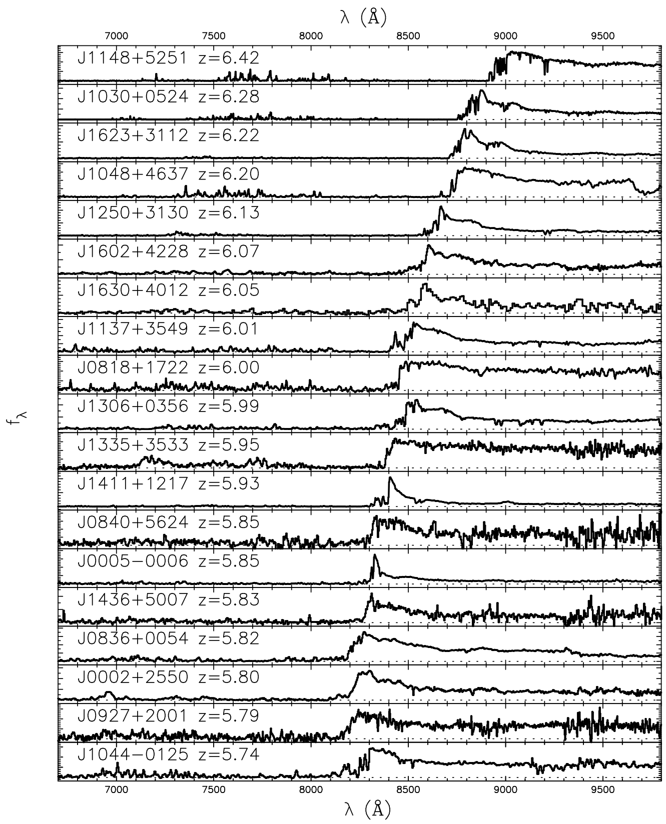

Figure 1.1: Spectra of the SDSS AGNs at $5.7 < z < 6.4$ (Fan et al. 2006). AGNs at the higher redshift (upper panel in this figure) show the weaker (or nearly zero) flux at bluer side of Lyα, suggesting that the fraction of the neutral hydrogen increases significantly at $z > 6$. Note that strong NV emission is also seen at the red side of Lyα. This emission is the crucial metallicity indicator, and the existence of NV suggests that the SDSS AGNs are already metal-enriched even at $z > 6$.

However, there are three fatal drawbacks in the SDSS high-z AGN sample. The first one is that the SDSS sample contains only extremely luminous AGNs due to the shallow limiting magnitude of the SDSS images. This limitation prevents us from investigating the whole shape of the AGN luminosity function, that is important to study the evolution of the UV background and the SMBH mass function. Since the number density of such luminous AGNs is extremely low, currently we cannot investigate the correlation function of AGNs at $z > 6$ and the inhomogeneousness of the cosmic reionization. The lack of observational evidence of the chemical evolution in the SDSS AGNs may be owing to the bias toward the high luminosity. The second problem in the SDSS sample is that the selection method of the SDSS high-z AGNs assumes very red $i' - z'$ colors, that may miss relatively "blue" AGNs; i.e., AGNs whose spectra are less absorbed by the intervenung hydrogen (maybe due to the fractuation of the cosmic reionization or to the relatively low redshift, $z \sim 5.5$). Note that it is difficult to search for such blue high-z AGNs with the SDSS data due to its large photometric errors. The third problem is a very simple one; the current AGN sample discovered so far does not contain any AGNs at $z > 6.5$.

All of these three serious problems in the orevious highest-z AGN surveys are completely solved by a very wide multi-color photometric survey with deeper limiting magnitudes than the SDSS imaging observations. To search for relatively blue and/or lower-luminosity AGNs at $6 < z < 7$, wide y-band imaging data are crucial. By performing $\sim$ 1000 deg^2 survey with limiting magnitudes of $i = 25.8, z = 24.7, y = 23.4$, ∼300 faint AGNs at $6 < z < 7$ are expected. Since the sample size is > 10 times larger than the current SDSS sample, this new survey will bring a breakthrough in this research field. For instance, we will investigate the possible fractuation of the cosmic reionization by investigating the spectra of AGNs at $z > 6$ in various line-of-sights. Also we may give a preliminary constraint on the AGN clustering amplitude at $z > 6$, which is usufut to infer the dark halo mass in which the AGNs (and also their SMBHs, of course) are located. In addition to the "wide" 5-band photometric observation, we also propose relatively deep imaging observations for $\sim$ 50 deg^2 with limiting magnitudes of $i = 26.6, z = 25.9, y = 24.6$ to extend the luminosity function of AGNs at $6 < z < 7$ toward the low-luminosity direction. It is no longer possible to search for AGNs at $z > 7$ with optical photometric surveys since the Lyα wavelength shifts to $\lambda_{\rm obs} > 1\mu$m. However such $z > 7$ AGNs should be moderately bright in the infrared. Therefore, by combining $\sim$ 2000 deg^2 z-band imaging data proposed here with the UKIRT WFCAM large area survey (http://www.ukidss.org/)[1], we will identify ∼10 AGNs at $z > 7$ (see Figure 2).

Search for Low-Luminosity AGNs at $4 < z < 5$

This redshift range is extremely interesting to study the evolution of AGN activities and SMBHs, because this range is just beyond the peak of the number density of bright AGNs (e.g., Richards et al. 2006; see Figure 3) and thus it corresponds to the growing-up phase of SMBHs. To investigate SMBHs in this epoch is also important to study the formation and evolution of galaxies, because galaxies and SMBHs hosted by them experienced "co-evolution" as inferred by the $M_{\rm BH} - M_{\rm bulge}$ relation (e.g., Marconi & Hunt 2003). Note that some theoretical models predict a higher $M_{\rm BH}/M_{\rm bulge}$ ratio at a higher redshift (e.g., Wyithe & Loeb 2003; Croton 2006) while some other models predict no evolution in the $M_{\rm BH}/M_{\rm bulge}$ ratio (e.g., Robertson et al. 2006). Although some observations suggest a constant $M_{\rm BH}/M_{\rm bulge}$ ratio up to $z \sim 3$ (e.g., Shields et al. 2003), some other observations

[1]The UKIRT WFCAM infrared large area survey has started in 2005 and will end in 2012 (http://www.ukidss.org/). A total of 4000 deg^2 will be covered (see Figure 2) with the limiting magnitudes of Y (1.05 μm) = 20.5, J (1.25 μm) = 20.0, H (1.65 μm) = 18.8, and K (2.2 μm) = 18.4. Note that AGNs at $z > 7$ cannot be identified only by using the WFCAM data, because galactic cool stars also display red $optical-infrared$ colors as AGNs at $z > 7$ and their number density is much much larger than that of $z > 7$ AGNs. To effectively separate $z > 7$ AGNs from Galactic cool stars, z-band imaging survey proposed in this program is essential (see Glikman et al. 2008).

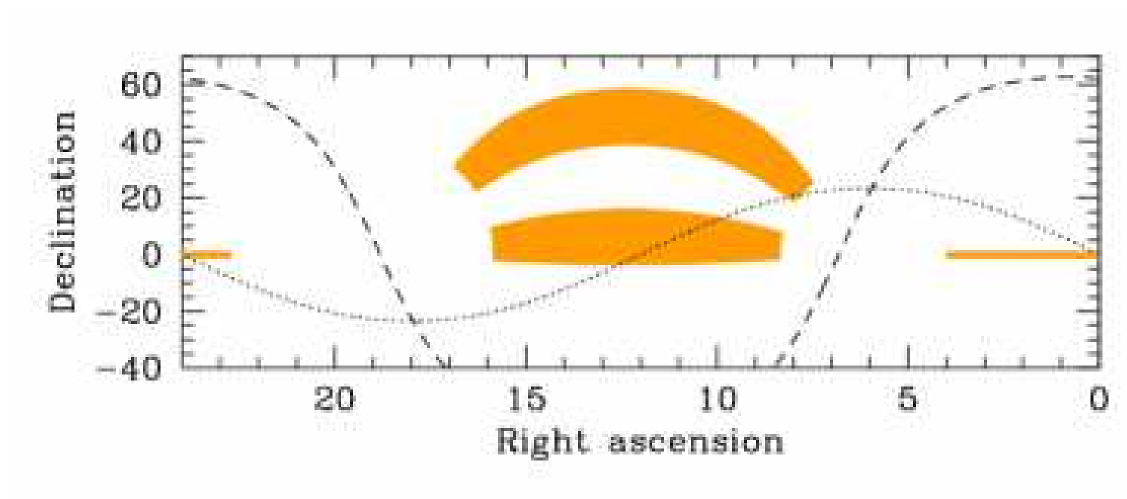

Figure 1.2: The area shown in the orange color is covered with the UKIRT WFCAM large area survey. The northern and equatorial stripe at Right Ascension (R.A.) = 7–18 hr each consists of 1907.6 deg^2. The small area (212.5 deg^2) at R.A. = 22–4 hr is also covered.

report a possible redshift evolution in the $M_{\rm BH}/M_{\rm bulge}$ ratio (e.g., Woo et al. 2008). This problematic situation is largely due to the difficulty in measuring the $M_{\rm BH}/M_{\rm bulge}$ directly at high redshifts. We therefore focus on the following statistical properties of AGNs at $4 < z < 5$ to study the co-evolution of SMBHs and galaxies; "**the environment of AGNs**", "**the spatial correlation of AGNs**", and "**the luminosity function of AGNs**".

The environment of AGNs provides important parameters of the AGN evolution such as the lifetime of the AGN activity, specifically through the number densities of galaxies around AGNs and the biases of AGNs and galaxies. This is because the formation and evolution of AGNs are closely related with the merger process of galaxies, since a major merger carries a large amount of gas in a galaxy disk inward to the central region and then ignite the AGN activity (e.g., Kauffmann & Haehnelt 2000). Therefore some crucial parameters of the AGN evolution such as the AGN lifetime are constrained through observations of the number density of galaxies around AGNs and the biases of AGNs and galaxies. Based on the semi-analytic model of AGN formation by Enoki et al. (2003), the quasar/galaxy number ratio in a dark matter halo depends on the mass of the dark matter halo and the AGN lifetime. Therefore, by measuring the number of galaxies around AGNs, we will constrain the typical timescale of the SMBH growth even at $z > 3$. On the other hand, Kashikawa et al. (2007) reported the habitat segregation between Lyman break galaxies (LBGs) and Lyα-emitting galaxies around a luminous AGN at $z \sim 5$ (Figure 4). This is a strong evidence of the (negative) AGN feedback on the star-formation activity in the neighboring galaxies around AGNs. Such an interplay between AGN activity and galaxy evolution will be directly explored based on new observations of the environments around AGNs.

By measuring the spatial distribution of AGNs and its evolution, we can give strong constraints on some of crucial parameters in the AGN evolutionary scenario such as the

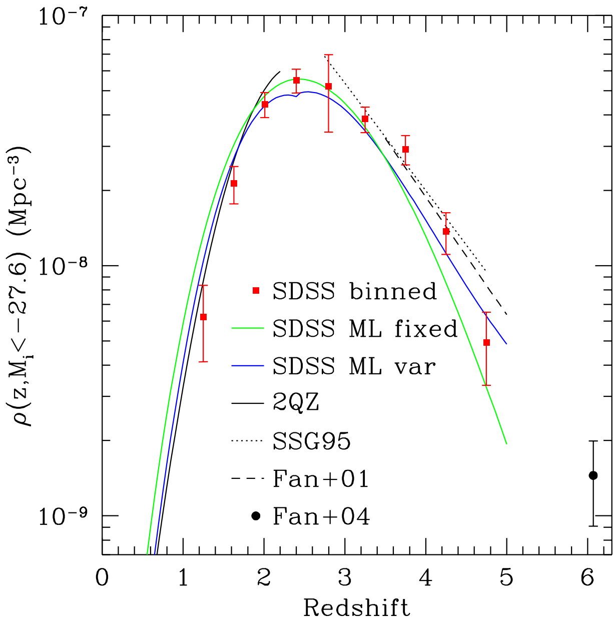

Figure 1.3: Integrated i-band luminosity function of AGNs (with $M_i < -27.6$) as a function of redshift, obtained with the SDSS dataset (Richards et al. 2006) combined with the 2dF quasar survey dataset (Boyle et al. 2000). The number density of luminous AGNs show its peak at $z \sim 2-3$. This suggests that the main growing-up phase of SMBHs should be at $z > 3$, which is the main target of this proposed project.

AGN lifetime, efficiency of the SMBH growth, bias parameters for AGNs and host halo masses. Since the number density of AGNs is quite small, wide surveys are crucial to obtain the AGN auto-correlation function. Croom et al. (2004) found a significant increase in the AGN clustering amplitude and AGN bias parameter in the range of $0.3 < z < 2.2$, based on the 2dF QSO survey. They also claimed that at all redshifts in this range AGNs inhibit approximately the same mass dark matter halos ($\sim 3 \times 10^{12} M_\odot$), and that the AGN lifetime is $t_{\rm Q} \sim 2 \times 10^7$ yr. However, currently there is no statistically relevant data to study the AGN correlation functions beyond $z = 3$ because the SDSS AGNs contains only very luminous object, whose number density is too low for the analysis of their correlation functions. The proposed new survey will find numerous less-luminous AGNs at $4 < z < 5$, which enables us to derive the AGN auto-correlation function accurately in this redshift range.

Another approach to assess the evolution of SMBHs is to utilize the luminosity function (LF) of AGNs, which provides the "average" evolutionary process of AGNs and SMBHs. Recent hard X-ray observations have shown the evolution of AGN LF at $z < 3$; it is found that the number density of luminous AGNs with $L_{\rm X} = 10^{11-13} L_\odot$ decreased rapidly at $z < 2$ while the epoch of the decrease of less-luminous AGNs was delayed, $z \sim 1$ ("downsizing evolution" or "luminosity-dependent density evolution"; e.g., Ueda et al. 2003). The shape and its evolution of AGN LFs are closely related with the evolutionary process of AGNs, especially with the AGN lifetime, as demonstrated by semi-analytic models (e.g., Enoki et al. 2003). However, although the AGN LF has been measured to the low-luminosity range

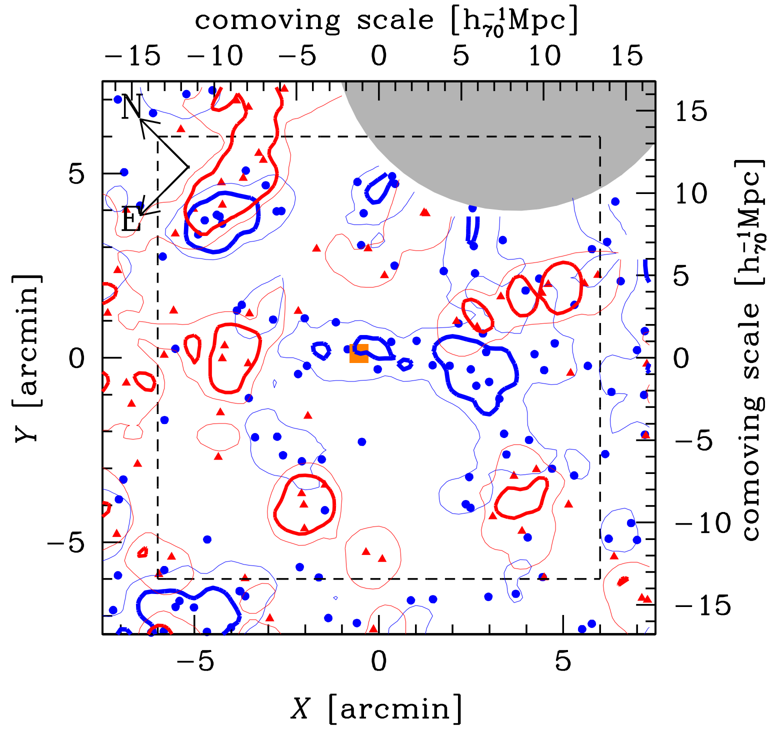

Figure 1.4: Spatial distributions of LBGs (blue circles and contours) and Lyα emitters (red triangles and contours) around a luminous AGN SDSS J0211–0009 (central orange square). Only LBGs are seen at the vicinity of SDSS J0211–0009 (see Kashikawa et al. 2007 for more details).

at up to $z \sim 2$ by previous optical and X-ray surveys, the low-luminosity part of AGN LFs at $z > 3$ have not yet been investigated. This is because previous optical AGN survey such as SDSS were too shallow to select such low-luminosity AGNs and previous deep X-ray surveys were too narrow to find low spatial density objects as AGNs. The proposed new AGN survey with HSC will enable us to measure the faint-side of AGN LFs even at $z > 3$. Note that we will constrain the AGN contribution to the UV background radiation by integrating the obtained AGN LFs. The AGN contribution to the UV background radiation determines its averaged spectral energy distribution, because the UV spectral shape of AGNs is completely different from that of star-forming galaxies. Since the spectral shape of the UV background radiation affects the star-formation activity in forming galaxies significantly, understanding the AGN contribution to the UV background based on the AGN faint-end LFs is crucial also to investigate the galaxy formation.

All of these three statistical properties of AGNs at $4 < z < 5$, i.e., "**the environment of AGNs**", "**the spatial correlation of AGNs**", and "**the luminosity function of AGNs**", will be firmly constrained by this proposed "Subaru Wide-Field AGN Survey", aiming to detect low-luminosity AGNs whose luminosity is ~ 2 mag fainter than the SDSS AGNs. The target AGNs will be identified by color-selection methods that is basically the same as the strategy adopted in the SDSS AGN survey. Specifically, the *gri* selection identifies AGNs at $3.6 < z < 4.4$ and the *riz* selection identifies AGNs at $4.6 < z < 5.1$.

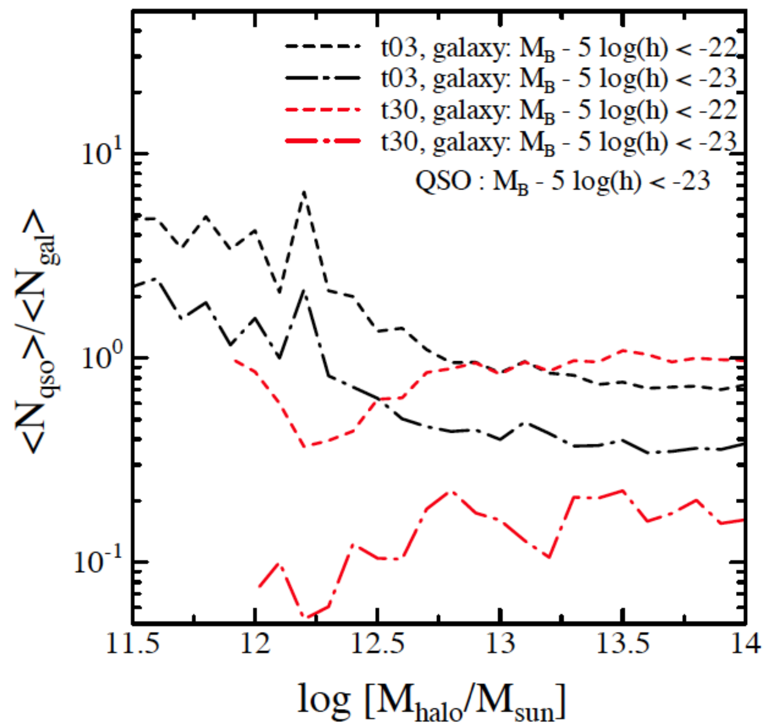

Figure 1.5: Based on a semi-analytic model for AGN formation by Enoki et al. (2003), predictions for number fraction of AGNs to galaxies in a dark matter halo at $z = 4$ are estimated as shown in this figure. In this model, lifetime of AGNs ($t_{\rm Q}$) is assumed to proportional to the dynamical time scale. The $t_{\rm Q}$ value at $z = 0$ is set to be 3×10^7 yr and 3×10^8 yr, and denoted by the labels t03 and t30, respectively.

To reject contaminations of cool stars, y-band data is very useful. In addition to AGNs, we also identify LBGs in the same redshift ranges to examine the AGN environment. We will select at least a few hundreds AGNs at each redshift range, based on $\sim$ 1000 deg^2 multi-band imaging survey. This number is necessary to investigate the AGN correlation function accurately. The limiting magnitudes given in Table 1 is required to select LBGs around the identified AGNs.

In addition to the $\sim$ 1000 deg^2 multi-band imaging survey proposed above, we propose another complementary survey to search for low-luminosity AGNs at $3 < z < 5$. Morokuma (2007) showed that the time-variation selection is very efficient to search for low-luminosity AGNs at $3 < z < 5$. Based on the deep multi-epoch imaging data in the SXDS field, he found a few low-luminosity AGNs at this redshift range, and most of their redshift are confirmed spectroscopically. To construct a large sample of such variability-selected high-z AGNs, we propose deeper imaging observations with HSC. By obtaining $\sim$ 50 deg^2 i and z-band imaging data with the limiting magnitudes of $i = 26.6$ and $z = 25.9$, we will detect $\sim$ 50 variability-selected low-luminosity AGNs at $3 < z < 5$. Note that at least 3 year duration is required to identify such variability-selected AGNs.

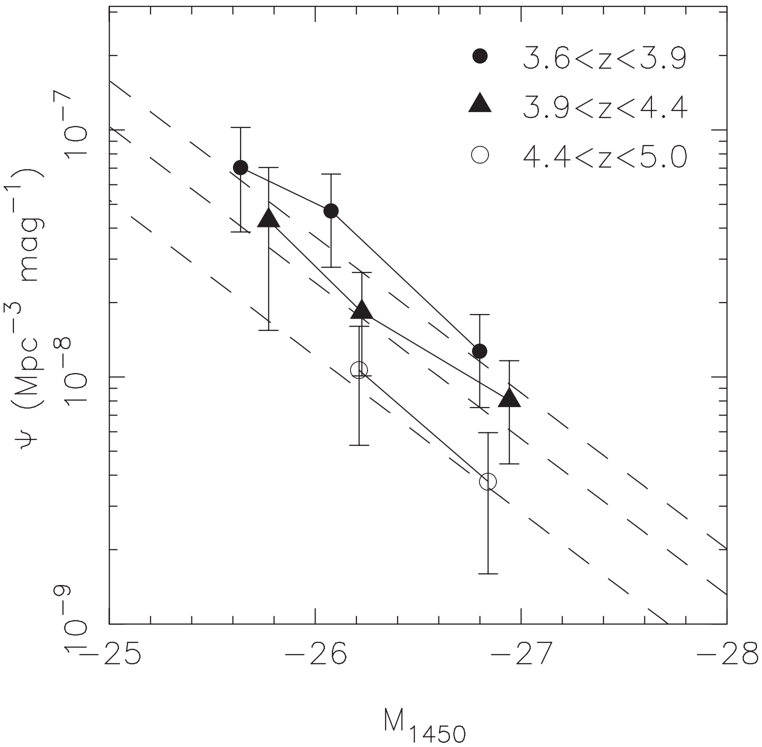

Figure 1.6: UV luminosity functions of SDSS AGNs at $z > 4$ (Fan et al. 2001). Since the SDSS AGNs are limited in extremely luminous AGNs, only the bright end of luminosity functions is seen.

Search for Very Faint AGNs at $1 < z < 3$

As shown in Figure 3, the density evolution of relatively bright AGNs reached its peak at $z \sim 2-3$ and therefore the growing-up phase of SMBHs in such relatively bright AGNs (but still fainter than SDSS high-z AGNs) is at $z > 3$. However, as mentioned above, the density evolution depends on the AGN luminosity (e.g., Ueda et al. 2003). More specifically, the fainter AGNs show their density peak at the lower redshift. This means that the growing-up phase of SMBHs in faint AGNs should be at much lower-z, i.e., $1 < z < 3$. The nature of SMBHs in such very faint AGNs is particularly interesting, because faint AGNs are very "common" objects among galaxies. In the local universe, a large fraction of galaxies show low-level AGN activities (including our Milky Way, although its activity level is extremely low). Therefore, it is crucial to study the evolving stage of SMBHs in very faint AGNs at $1 < z < 3$, in order to understand the co-evolution of SMBHs and galaxies generally.

One difficulty to examine the accreting process in very faint AGNs in moderate-z (but still distant) universe is that their mass-accretion rate normalized by their Eddington accretion limit ($\dot{M}/\dot{M}_{\rm Edd}$) is too uncertain. To solve this issue, it is a good idea to focus on X-ray sources in the fields with previous X-ray surveys. This is because the X-ray spectral slope is a good indicator of $\dot{M}/\dot{M}_{\rm Edd}$ (e.g., Shemmer et al. 2006, 2008). Especially AGNs in a super-critical accretion phase (i.e., $\dot{M}/\dot{M}_{\rm Edd} > 1$ is interesting to study the growing-up phase of SMBHs in faint AGNs. Note that we will identify such faint AGNs at $1 < z < 3$

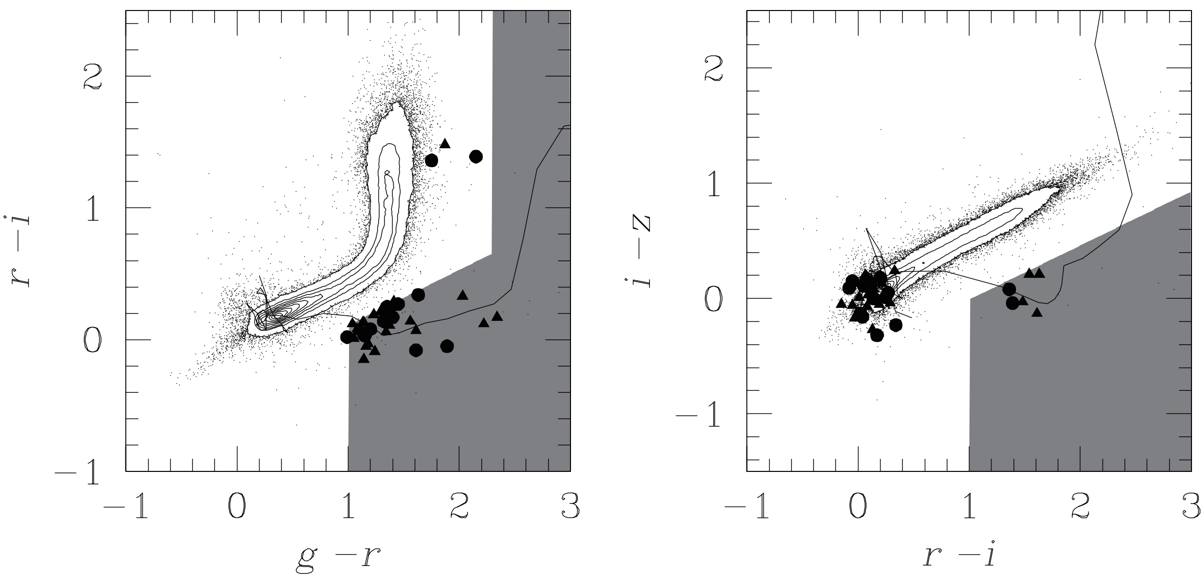

Figure 1.7: Two-color selection diagrams for high-z AGNs. AGNs at $3.6 < z < 4.4$ are selected through the $r - i$ vs $g - r$ diagram (left panel) while AGNs at $4.6 < z < 5.1$ are selected through the $i - z$ vs $r - i$ diagram (right panel). The hatched areas in both panels show the selection criteria for high-z AGNs. Solid line in the panels are the predicted track for high-z AGNs and the filled black symbols denote spectroscopically confirmed SDSS AGNs (Fan et al. 2001).

among the detected objects in ~ 50 deg^2 relatively deep images, basically through the AGN photometric redshift technique (e.g., Richards et al. 2008). Note that AGNs in this redshift range show very blue continuum colors and point-line nuclei.

Another interesting population is variability-selected AGNs in $1 < z < 3$ since the variability-selection method can pick up very low-level AGN activities. Recent observations show that some of such variability-selected AGNs are in a special accretion phase, i.e., harboring a radiation-inefficient accretion flow (RIAF) in their nuclei (e.g., Totani et al. 2005; Morokuma et al. 2008). Their statistical properties are particularly interesting because the feedback processes by AGNs in the RIAF phase are recently focused on as a "radio-mode AGN feedback" (e.g., Sijacki et al. 2007; Okamoto et al. 2008). Observational studies on the interplay between the variability-selected AGNs and star-formation activities in galaxies around the RIAF-mode AGNs will bring us a new insight in this topic.

1.1.2 Survey Parameters

- *Area*:
  - Wide survey: 1,000 [deg^2] for g, r, i, y, and 2,000 [deg^2] for z.
  - Deep survey: 50 [deg^2] for i, z, y.
- *Field(s)*:
  - Wide survey: A part of the UKIRT WFCAM large area survey (see Figure 2).

Table 1.1: Survey parameters. [(a)] Acceptable seeing FWHM [arcsec]

	g_1	r_1	i_1	z_1	y_1	i_2	z_2	y_2
T_{exp}[min]	15	15	15	15	15	60	120	120
depth[AB]	26.5	26.2	25.8	24.7	23.4	26.6	25.9	24.6
lunar phase	d	d	d	d/g	d/g	d	d/g	d/g
seeing[arcsec][(a)]	1.0	1.0	0.7	1.0	1.0	0.7	1.0	1.0
area[deg^2]	1000	1000	1000	2000	1000	50	50	50

  - Deep survey: Including the XMM large sky survey area and other wide X-ray imaging survey areas.

- *Scheduling Requirements*:
  - Wide survey: Each FoV should be completed in the continuous observing run; i.e., all of the 5 bands (g, r, i, z, y) for a certain FoV should be observed without a time interval of a few weeks. This is required to avoid the effects of time variation of AGNs, since the time variation of AGNs makes the color-selection strategy inaccurate and inefficient.
  - Deep survey: Each FoV should be observed at least three times in each band, with a time interval of at least 1 year. This is necessary to identify the AGNs through the time-variation selection. Consequently the observation campaign should continue at least 3 years.

Observing Method and Technical Details

No preferences for the unit exposure time and the dithering pattern. Note that better seeing nights are requested for i-band observations (both in "wide" and "deep" surveys). Sharp images of the target objects is useful to distinguish high-z AGNs and extremely bright galaxies (e.g., gravitationally magnified objects).

1.1.3 Comparison with Other Survey Plan(s)

The most important on-going multi-color optical imaging survey is the CFHT legacy survey (CFHTLS; http://www.cfht.hawaii.edu/Science/CFHLS/). The limiting magnitudes of the CFHTLS are $u = 26.4$, $g = 26.6$, $r = 25.9$, $i = 25.5$, and $z = 24.8$ for "Wide" survey (170 deg^2), and $g = 25.5$, $r = 25.0$, and $z = 24.4$ for "Very Wide" survey (410 deg^2). Our "Wide" survey is $\times 2.5$ wider and ~ 1.0 mag deeper than than "CFHTLS-Very Wide". This difference in the limiting magnitudes is essential to detect not only AGNs but also (relatively bright) LBGs at $z > 3$. Although the limiting magnitudes of our "Wide" survey are similar to those of "CFHTLS-Wide", our survey area is $\times \sim 10$ wider than the CFHTLS. This difference is crucial to study very rare objects such as high-z AGNs. Therefore, although CFHTLS will also find AGNs at $z > 3$, the environment of the detected AGNs is still statistically unclear. To investigate the co-evolution between SMBHs and galaxies, our proposed observations is essencial to provide crucial statistical information. Note that the CFHTLS lacks y data. This is critical to search for AGNs at $z > 6.5$, and thus our project has a significant advantage with respect to the CFHTLS especially in this issue.

The dark energy survey (planned survey period is 2010–2014) will be the most competitive optical project for our survey. Its 5σ limiting magnitudes are $g = 25.4$, $r = 24.9$, $i = 25.1$, $z = 24.7$, and $y = 22.4$ (Banerji et al. 2008). Although its z-band limiting magnitude is comparable to ours, g, r, and y limiting magnitudes are $\sim$1 mag shallower than ours. The deeper blue-side images are crucial to select AGNs at $z > 3$ because the color-color selection technique utilizes the Lyman-break feature in the spectra. The deeper y image is significantly important to search for AGNs at $z > 6.5$. Therefore we would stress that y-band observations with HSC is critically important, not only in terms of the AGN science but also in terms of the survey originality.

There is another powerful future survey based on near-infrared wide-field imaging observations, that is the VISTA/VIKING 1500 deg^2 survey. Its limiting magnitudes are $z = 23.1$, $y = 22.3$, $J = 22.1$, $H = 21.5$, and $K = 21.2$. However, its z and y limiting magnitudes are also $\sim$ 1 mag shallower than ours. This difference is crucial especially to search for extremely rare objects (e.g., $z > 7$ QSOs), since the AGN luminosity function shows basically a power-law shape and thus the fainter AGNs are more numerous. Although the "first discovery" of AGNs at $z > 7$ may be achieved by other survey projects, our AGN survey with HSC will constract the "statistical" sample of AGNs at $z > 7$, for the first time.

1.1.4 Follow-up/Collaborative Survey Plan(s)

To search for AGNs at $z > 7$, we will combine the Subaru HSC z-band data with UKIRT WFCAM LAS infrared data, which will surely be available in 2012. After getting the photometric sample of $z > 7$ AGNs found though this project, we will perform follow-up near-infrared spectroscopy. This will tell us various breakthrough information, including the mass of SMBHs and metallicity in the $z > 7$ universe.

Also for the photometric sample of AGNs at $1 < z < 7$, follow-up optical spectroscopic observations are required. We will select a part of the whole survey area and carry out complete spectroscopic observations for AGNs in the sub-area, because it is unrealistic to perform follow-up observations for all AGNs. Through the optical spectroscopic observations, we will confirm the accuracy, efficiency, and contamination of our color-based AGN selection strategy. The spectra are also used to derive the metallicity, mass of SMBHs, and $\dot{M}/\dot{M}_{\rm Edd}$.

References

Ajiki M. et al. (2006) PASJ, 58, 499
Banerji M. et al. (2008) MNRAS, 386, 1219
Boyle B. J. et al. (2000) MNRAS, 317, 1014
Croom S. M. et al. (2005) MNRAS, 356, 415
Croton D. J. (2006) MNRAS, 369, 1808
Enoki M. et al. (2003) PASJ, 55, 133

Fan X. et al. (2001) AJ, 121, 54
Fan X. et al. (2004) AJ, 128, 515
Fan X. et al. (2006) AJ, 132, 117
Glikman E. et al. (2008) AJ, 136, 954
Goto T. (2006) MNRAS, 371, 769
Iwamuro F. et al. (2004) ApJ, 614, 69
Jiang L. et al. (2007) AJ, 134, 1150
Kashikawa N. et al. (2007) ApJ, 663, 765
Kauffmann G. & Haehnelt M. (2000) MNRAS, 311, 576
Kurk J. et al. (2007) ApJ, 669, 32
Li Y. et al. (2007) ApJ, 665, 187
Maiolino R. et al. (2004) A&A, 420, 889
Marconi A. & Hunt L. K. (2003) ApJ, 589, L21
Morokuma T. (2007) Doctoral Thesis (Univ. of Tokyo)
Morokuma T. et al. (2008) ApJ, 676, 121
Okamoto T. et al. (2008) MNRAS, 385, 161
Richards, G. T. et al. (2006) AJ, 131, 2766
Richards, G. T. et al. (2008) ApJS, in press (arXiv:0809.3952)
Robertoson B. et al. (2006) ApJ, 641, 90
Shemmer O. et al. (2006) ApJ, 646, L29
Shemmer O. et al. (2008) ApJ, 682, 81
Shields G. A. et al. (2003) ApJ, 583, 124
Sijacki D. et al. (2007) MNARS, 380, 877
Tanaka T. & Haiman Z. (2008) ApJ, submitted (arXiv:0807.4702)
Totani T. et al. (2005) ApJ, 621, L9
Ueda Y. et al. (2003) ApJ, 598, 886
Willott C. J. et al. (2003) ApJ, 587, L15
Willott C. J. et al. (2007) AJ, 134, 2435
Woo J. -H. et al. (2008) ApJ, 681, 925
Wyithe J. S. B. & Loeb A. (2003) ApJ, 595, 614
Zheng W. et al. (2006) ApJ, 640, 574