Unveiling obscured black-hole growth phase of massive galaxies

1 Overview

One of the most outstanding astronomical discoveries of the past decade is the finding that every nearby massive galaxy hosts a central super massive black hole (SMBH) with a mass directly proportional to that of its spheroid. The issue of how these SMBHs formed and evolved over the cosmic history is one of the major unanswered questions in observational cosmology. Because the observed black hole mass density in the nearby universe can be explained as a relics of the accretion process observed as the hard X-ray AGNs [1], the major part of the SMBH growth is thought to happen via accretion which is detectable as AGNs. Thus the luminosity function of X-ray AGNs and its cosmic evolution provide quantitative information on when the SMBH growth happened in the universe. Recent studies on the hard X-ray luminosity function of AGNs revealed that the peak redshift of the AGN number density denpends on the luminosity of AGNs: high-luminosity AGNs have a peak at $z = 2$, but the moderate-luminosity AGNs peak at lower redshift ($z < 1$) [2]. The luminosity dependence of the number density evolution implies that more massive black holes stop accreting earlier than less massive black holes, i.e. down-sizing in the accretion history of the universe. However, a significant fraction of the sources in deep X-ray surveys still remain unidentified even with intensive spectroscopic observations due to the faintness of their optical counterparts. Thus, the current understanding on the obscured AGN population is incomplete especially in the high-redshift universe. Spectrum models of the Cosmic X-ray Background (CXB), which is an integrated emission of various AGNs at wide range of redshifts, imply that about 80% of the accretion process happen in obscured AGNs [3], thus complete understanding of the obscured AGN population is critical to reveal the true accretion history in the universe.

To zeroth order, the correlation between the SMBH mass and the spheroid mass implies that galaxies and their black holes grew concordantly. This general hypothesis has found some support from hydrodynamical simulations of major mergers, which show that feedback from AGN winds and outflows can connect the growth of the black hole to that of the host galaxy [4]. In order to reveal the physical origin of the concordance, it is important to reveal when the SMBH growth happen in the history of the galaxy formation and evolution, i.e. to examine the properties of AGN host galaxies, and locate them among the evolution tracks of the non-AGN galaxies. For luminous non-obscured AGNs, due to the bright nuclear stellar component, it is quite difficult to directly examine the properties of their host galaxies, especially in the high-z universe. Even with *Hubble Space Telescope*, the size of the point-spread function (FWHM of $0.10''$) is still comparable to a 1 kpc scale. In addition, the physical size of the high-redshift galaxies are smaller than those of nearby galaxies on average. On the contrary, for obscured AGNs, host galaxy emission significantly contribute to the total light, thus we can examine the properties of the host galaxies directly with the high SN spectra of the obscured AGNs. The sample of the obscured AGNs at $z = 1 - 3$ obtained from the spectroscopic observations of optically-faint X-ray sources can be used for this study. In addition to that, we need to reveal the properties of non-AGN galaxy populations in the same redshift range.

OVERVIEW ON TORUS STUDY, METALLICITY STUDY ?

The goal of the FMOS GTO proposal is to study the spectroscopic properties of obscured AGN populations at high-redshifts by comprehensively investigating a large sample of X-ray selected AGNs in the Subaru/XMM-Newton Deep survey Field (SXDF) and Great Observatories Origins Deep Survey North (GOODS-N). The immediate objectives are 1) Revealing the nature of the optically-faint X-ray sources for which medium-deep optical spectroscopic observation failed to determine their redshifts. Large fraction of them are thought to be obscured AGNs at $z = 1 - 3$ which play a crucial role in the obscured black-hole growth phase of massive galaxies. 2) Constrain the spectroscopic properties of the host galaxies of the obscured AGNs at $z \sim 2$ and reveal the connection between the field galaxy population in the same redshift range. 3) Revealing the structure of obscuring material around the active nucleus. The details of the objectives are shown in Section 2.

In order to accomplish the objectives, we propose to conduct FMOS 8 FOVs (7 in the SXDF and 1 in the GOODS-North) observations of X-ray selected AGNs with several hours integration time. In addition to the observations, we propose to obtain spectroscopic properties of non-AGN galaxies with photometric redshifts between 1.5-1.7. The details of the observation strategies and the target fields are summarized in Section 3. Remaning action items are listed in Section 4.

2 Immediate scientific objectives with FMOS GTO observations

2.1 Revealing the nature of the optically-faint X-ray sources

Intensive optical spectroscopic observation for X-ray sources in the SXDF, CDFS, and CDFN fields have been done so far. The results are shown in Figure **??** for these fields. A large population of $z < 1$ broad-/narrow-line AGNs and luminous broad-line AGNs out to $z \approx 5$ are found, and a large number of narrow-line AGNs at $z > 1$ are revealed. However, a significant fraction of the sources in the deep X-ray surveys remain unidentified even with intensive spectroscopic observations due to the faintness of their optical counterparts ($R > 23.5$mag, shown with cross symbols in Figure **??**. Typically 20% of the SXDF sample and ≈ 30–40% of the CDFN and CDFS samples have been spectroscopically unidentified. If the X-ray detected starbursts are removed, this fraction increases to $\approx 50\%$ in the CDFN and CDFS.

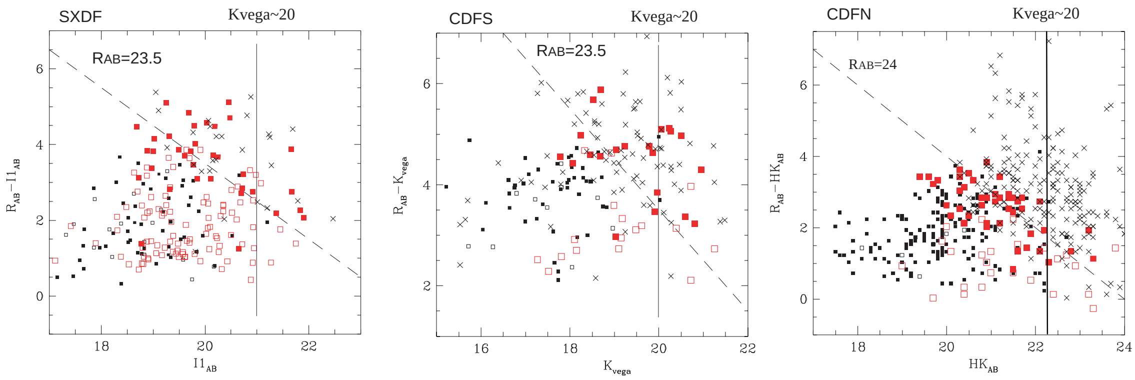

Figure 1: Near-IR (3.6μm, K or HK-band) magnitude versus optical - near-IR colors of optical-spectroscopically observed X-ray sources in the SXDF (left), CDFS (middle, [5]), and CDFN (right, [6]). Intensive spectroscopic observations with optical multi-object spectrographs attached to 8-10m class telescopes identified a large number of AGNs in these fields. Open and filled squares represent spectroscopically-identified broad-line and narrow-line AGNs, respectively. Objects at $z > 1$ are shown with red symbols. Even with the intensive spectroscopic observations, still significant fraction of the X-ray sources are unidentified. They are shown with black crosses. In the SXDF region, K-band observation only covers limited part of the field, thus, we used 3.6μm magnitude obtained from the IRAC/Spitzer observation. Typical $K_{\rm vega} - I1_{\rm AB}$ value is -1.0 for the AGNs, and $I1_{\rm AB} = 21$mag corresponds to $K_{\rm vega} \approx 20$mag.

These spectroscopically unidentified X-ray sources are the most cosmologically interesting AGNs and are the best candidates of obscured AGNs reside in a dusty formation phase of massive galaxies. The lack of the narrow-line obscured AGNs in the redshift range between 1.4 – 2.7 (see left panel of Figure 2) suggests that both of the SXDF, CDFN, and CDFS AGN samples are suffered from the so-called "redshift desert" of optical redshift survey. The photometric properties [7] and the photometric redshifts [8] of the unidentified X-ray sources support that they are obscured AGNs in this redshift range, with a minority at $z \approx 3$–8. In fact, Akiyama et al. (S00-016) conducted NIR single-slit spectroscopic observation of three optically-faint red optical counterpart of X-ray sources found in the Lockman Hole region, and revealed that an object is indeed a narrow-line AGN in the redshift desert (right panel of Figure 2). Similar results also obtained for four very red ($R - K > 6$) optical counterparts found in the HELLAS2XMM survey [9].

If the unidentified X-ray sources are at the predicted redshifts then they will outnumber luminous broad-line AGNs by a factor of > 5 and are the dominant $z > 1$ AGN population in deep X-ray surveys [10]. Their X-ray luminosities are likely to be $L_X \approx 10^{42}$–10^{44} erg s^{-1}, with a fraction having $L_X > 10^{44}$ erg s^{-1}, corresponding to $M_{\rm BH} \approx 10^6$–10^8 M$_\odot$ for accretion at ≈ 10% of the Eddington limit. In addition, the association of these sources with high-redshift ancestors of local massive galaxies (e.g., EROs, radio, and submm (SCUBA) galaxies; [7,11,12]) suggests that they represent the black-hole growth phase of the massive galaxies. Indeed, the X-ray properties of optically faint but spectroscopically identifed SCUBA galaxies in the *Chandra* Deep Field-North imply that these systems are massive star-forming galaxies undergoing a period of obscured black-hole growth prior to an unobscured quasar phase [11,13].

The combined sample of the AGNs from SXDF and CDF-S covers a wide range in the $z - L_X$ plane (left panel of Figure 2). The wide coverage is crucial to quantitatively evaluate the cosmological evolution of obscured/unobscured AGN populations.

2.2 Structure of obscuring material in faint and luminous AGNs

2.3 Host galaxies of the obscured AGNs and their connection to field galaxies

The large sample of high-redshift obscured QSOs will provide us unique opportunity to directly examine the properties of host galaxies of luminous radio-quiet QSOs at high-redshift.

3 Observation strategy and the details of the target fields.

The combination of a medium-deep wide area survey and a deep narrow area survey is important. The SXDF survey covers X-ray flux range around 1×10^{-14} erg s^{-1} cm^{-2} in the 2–10 keV band, where the X-ray number count has a knee and X-ray sources with flux of $10^{-13} \sim 10^{-15}$ erg s^{-1} cm^{-2} have largest contribution to the CXB, i.e. the most important population in the black hole growth history.

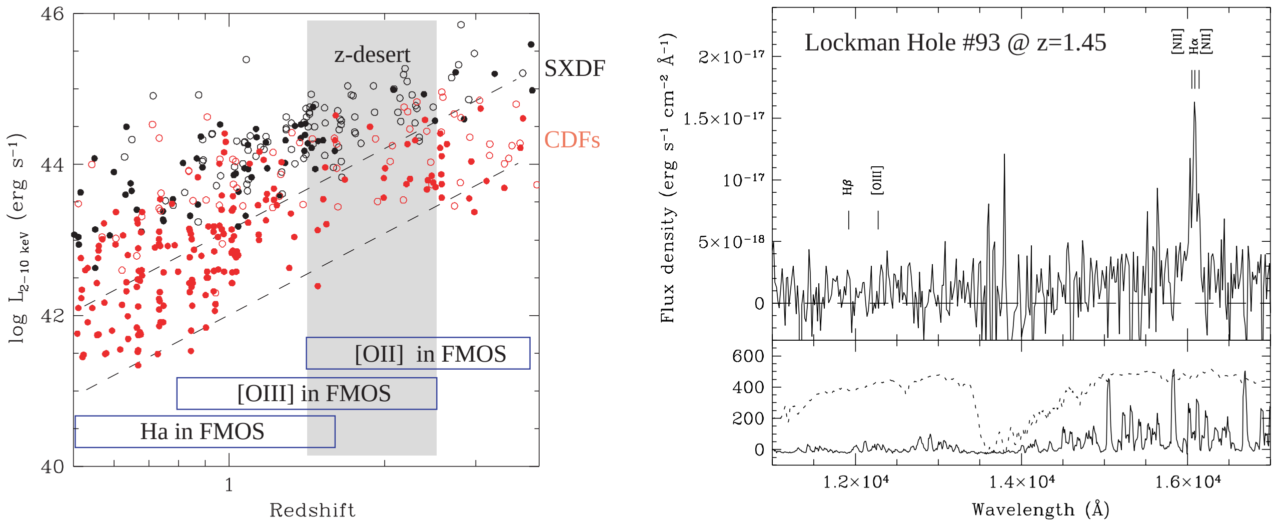

Figure 2: Left) Redshift versus X-ray luminosity for the spectroscopically-identified AGNs in the CDFN/CDFS (red) and SXDF (black) samples. Broad-line and narrow-line AGNs are marked with open and filled symbols, respectively. The dashed lines indicate the detection limits. The so-called "redshift desert" is shown with gray hatch, in the redshift range, strong narrow-emission lines of narrow-line AGNs or normal galaxies are outside of the optical wavelength, and optical spectroscopic observation can only identify broad-line AGNs; NIR MOS observations provide the most efficient route to obtain spectroscopic redshifts for these sources. Right) Sample of a NIR spectrum of an optically-faint red X-ray source found in the Lockman Holoe region ($K_{\rm AB} = 20$mag) obtained by 30 min integration with CISCO JK grism. The emission line detected in the H-band corresponds to the H_α emission line at $z = 1.45$.

3.1 Observation strategy : X-ray follow-ups

3.2 Observation strategy : mini-SDSS @ $z = 1.5 - 1.7$

3.3 SXDF

3.4 GOODS-North

4 Required preparation and planned observations in this fall

4.1 Photometric redshift estimation

4.2 Accurate coordinate of the targets

4.3 Planned additional observation in the field in this fall

VIMOS/VLT observation covering the almost entire area of the SXDF have been done last fall. The observation targets radio and X-ray selected objects. The data reduction is underway by C.Simpson et al.

Refeences: [1] Marconi, A. et al., 2004, MNRAS, 351, 169
[2] Ueda, Y. et al. 2003, ApJ, 598, 886
[3] Gilli, R., Salvati, M. & Hasinger, G., 2001, A&A, 366, 407
[4] Hopkins et al. 2006, ApJS, 163, 1
[5] Szokoly, et al. 2004, ApJS, 155, 281
[6] Barger et al. 2005, AJ, 129, 578
[7] Alexander, et al. 2001, AJ, 122, 2156
[8] Mainieri, et al. 2005, A&A, 437, 805
[9] Maiolino, et al. 2006, A&A, 445, 457
[10] Martinez-Sansigre, et al. 2005, Nature, 436, 666
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[12] Alexander, et al. 2005b, ApJ, 632, 736
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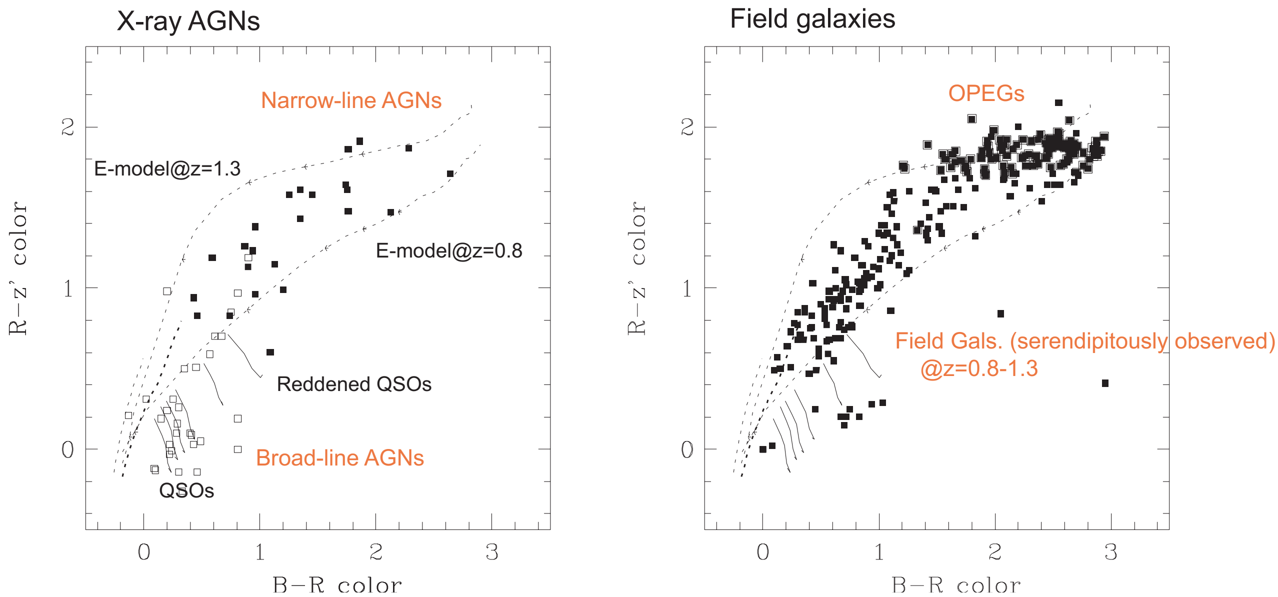

Figure 3: $B - R$ versus $R - z'$ color-color diagrams of X-ray AGNs with spectroscopic redshift at $0.8 < z < 1.3$ (left) and field galaxies in the same redshift range (right) identified in the SXDF. Narrow-line AGNs and broad-line AGNs are plotted with filled and open symbols in the left panel, respectively. The colors of the narrow-line AGNs are consistent with several 100 Myrs old galaxy models in the redshift range. The consistency imply that the optical light of the narrow-line AGNs is dominated by the host galaxy component. The colors are neither as red as the reddest population (OPEGs in the right panel) nor as blue as the bluest population among the field galaxies.

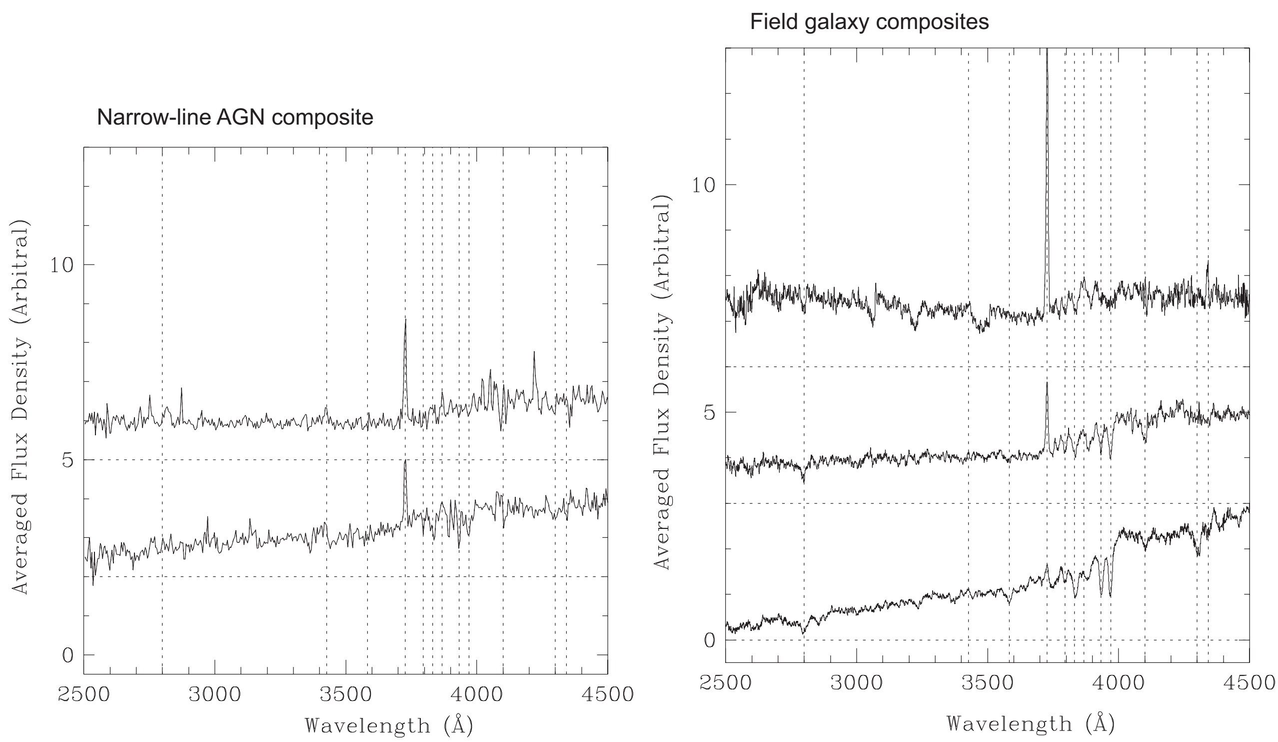

Figure 4: Left) Composite spectra of $z = 0.8 - 1.1$ narrow-line AGNs found in SXDF. The absorption lines around 4000Å break imply that the optical light is dominated by the host galaxy component. Right) Composite spectra of $z = 0.8 - 1.1$ field galaxies. From top to bottom, blue to red galaxies.

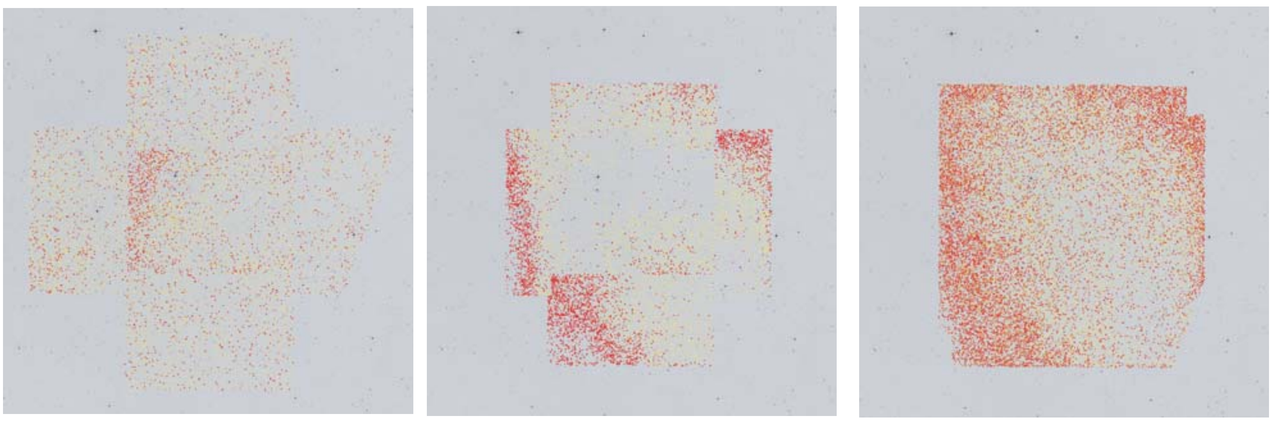

Figure 5: Left) Yellow points show the 1.0″ matched objects in the Scam ver.1 i-band and SWIRE 3.6μm catalogs. Red points indicate matched objects whose distance is larger that 0.8″. Background image is from Digitized Sky Survey. Middle) The same figure for the matched objects in the UDS EDR Ks-band and the Scam ver.1 i-band. Right) The same figure for the matched objects in the UDS EDR Ks-band and the SWIRE 3.6μm band. Red objects concentrate in the edge of the field of view of each image.