0.1. Super-massive black hole growth and on-set of feedback

With the discovery of super massive black holes (SMBHs) at the center of every massive galaxy, the issue of how these SMBHs formed and evolved over the cosmic history become one of the major unanswerd questions in observational cosmology. The number density of the SMBHs in the local universe can be roughly explained as the relics of accretion activities observed as AGNs. Accretion growth history of SMBHs inferred from the cosmic evolution of number density of AGNs implies major part of the growth happened in the accretion during the violent era of the universe. However, the observational understanding is not complete yet due to the existence of large number of obscured AGNs which can be missed in the current surveys based on optical spectroscopic follow-ups. FMOS SSP can reveal the obscured accretion with the NIR spectroscopic follow-ups of hard X-ray-selected AGNs and mass-selected galaxies in the violent era.

In the local universe, the mass of the SMBHs is directly proportional to the mass of the spheroid of its host. The tight relation implies that galaxies and their central black holes grew concordantly. Galaxy-scale feeding and feedback processes to and from SMBHs should play crucial role in the physical link between the galaxy evolution and SMBH growth. One of such processes is galaxy-scale feedback from low-luminosity radio AGNs, so-called radio mode feedback. The radio mode feedback is thought to heat up the cooling accretion to massive galaxies and suppress their growth further. Following the assembly of massive galaxies and their SMBHs, radio mode feedback starts to play important role in shaping properties of massive galaxies. FMOS SSP NIR spectroscopic suvey of radio-selected AGNs should detect the on-set of radio mode feedback happened during the assembly of massive galaxies in the violent era.

0.1.1. Obscured growth of super-massive black hole during the violent epoch

The growth history of SMBHs with accretion process can be evaluated with the evolution of the comoving space density of AGNs as a function of cosmic time. X-ray surveys provide the most efficient and the cleanest sample of AGNs. Intensive optical spectroscopic follow-ups of X-ray sources revealed broad-/narrow-line AGNs out to $z \sim 5$. Hard X-ray surveys with various depth revealed number density of non-obscured plus mildly-obscured AGNs as a function of redshift for each luminosity bin (e.g., Ueda et al. 2003, ApJ, 598, 886, as shown in the left panel of Figure 1). Using the redshift evolution of the X-ray luminosity functions of AGNs, the average growth history of SMBHs are quantitatively inferred (e.g., Marconi et al. 2004, MNRAS, 351, 169): massive $> 10^8 \mathrm{M}_\odot$ SMBHs gain their mass around $z \sim 2$, on the contrary, less-massive $< 10^8 \mathrm{M}_\odot$ SMBHs increase their mass around $z \sim 1$. During the epoch of violent galaxy evolution, SMBHs grew significantly as well.

However, the understanding on the accretion history is not complete yet, due to the existence of large number of obscured AGNs which are missed in the current optical spectroscopic follow-up observations of X-ray sources. FMOS SSP surveys will overcome the current limits of the understanding of the obscured accretion by 1) NIR spectroscopic follow-ups of optically-faint X-ray sources, and 2) emission line AGN survey of massive galaxies selected with photometric redshift method.

Non-obscured and mildly-obscured accretion revealed with X-ray AGN survey

A significant fraction of the sources in the deep X-ray surveys remain unidentified even with the intensive spectroscopic observations due to the faintness of their optical counterparts. As shown in Figure 2, optical spectroscopic observation reveal the nature of X-ray sources with brighter than i ~23.5mag, but there are large number of sources with fainter optical counterpart. Typically 60% of the CDF-N sample has been spectroscopically unidentified, which

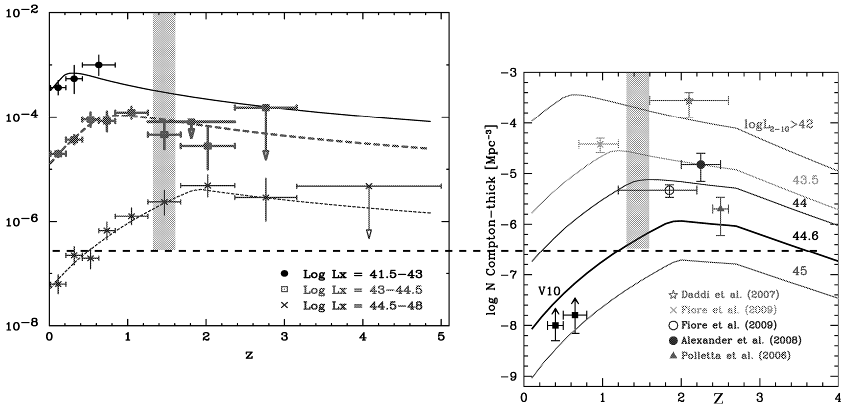

Fig. 1.— Left) Number density of X-ray selected AGNs from Ueda et al. (2003). Almost all of these AGNs are non-Compton-thick AGNs. Right) Estimated number dentisy of Compton-thick AGNs in each luminosity bin as a function of redshift (Vignali et al. 2010). The solid lines are predicted number density by Gilli et al. (2007) model. The proposed spectroscopic survey prove the redshift and number density (=volume) range hatched with orange.

Fig. 2.— SHOWING optically-faint X-ray sources.

drops to ∼50% completeness when only X-ray AGNs are included (i.e., X-ray starbursts are removed).

Photometric redshift estimation suggests that the optically-faint optical-spectroscopically unidentified X-ray sources are located at $z > 1$ (see right panel of Figure 2). Not only the faintness in the optical band but also the fact that the major emission lines of narrow-line AGNs are out of optical wavelength range in the redshift range between $z = 1.3$ and $z = 2.3$ prevent the spectroscopic identification of such population of X-ray sources. Based on the photometric redshift estimation, it is suggested that such obscured population outnumber the non-obscured AGNs in the redshift range 1-3. The obscured fraction of X-ray-selected AGNs at $z > 2$ can be 2 times higher than that in the local universe (Hasinger et al. 2008, A&A, 905, 922).

In the SXDS/UDS region, conducting follow-up observations of X-ray sources, 51 type-1 and 22 type-2 AGNs are spectroscopically identified between $z = 1.3 - 1.6$ and 64 candidates of type-2 AGNs with photometric redshifts in the range (Akiyama et al. 2010, in prep). The 64 objects are primary targets of Sample 3, and ??? X-ray sources without spectroscopic redshifts are also observed as secondary targets of Sample 3. In addition to these obscured AGN candidates, 51 type-1 AGNs will be observed with lower priority, in order to estimate their black hole mass with rest-frame optical broad-emission line. Based on the black hole mass and multiwavelength photometry, typical Eddington ratio of the sample can be estimated. The Eddington ratio of the obscured AGNs may be assumed to be the same as the typical Eddington ratio derived with the non-obscured AGNs with similar luminosity and redshift.

Heavily-obscured accretion revealed with Compton-thick AGN survey

Although X-ray selection is efficient to select mildly-obscured AGNs, still X-ray selection can miss and be biased against heavily-obscured AGNs with obscuration column density of $N_H > 10^{24}\mathrm{cm}^{-2}$, i.e., Compton-thick AGNs, for which the high column density makes the optical depth of Compton-scattering for X-ray photons one. Even very hard

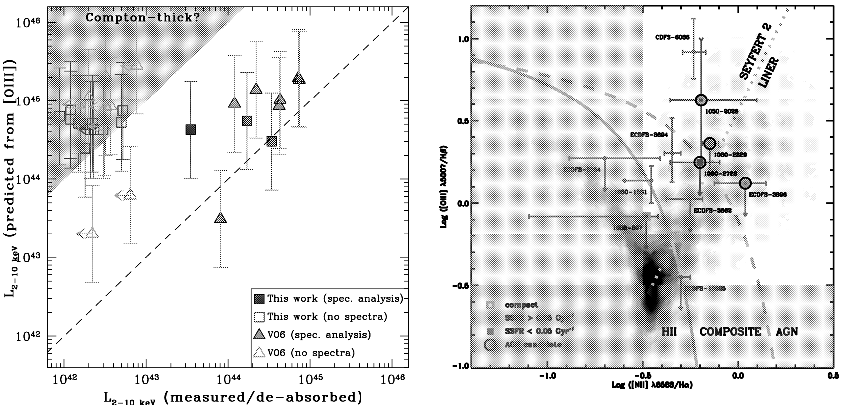

Fig. 3.— Left) Observed unobscured hard X-ray luminosity vs. [OIII] line luminosity (converted to corresponding X-ray luminosity using L[OIII]-Lx relation) of obscured QSOs found in SDSS (Vignali et al. 2010). The thick vertical and horizontal solid lines indicate the [OIII] and 2-10keV detection limits in this survey. Right) Diagnostic diagram of optical emission lines of $z \sim 2$ galaxies (Kriek et al. 2007) overlayed on local SDSS galaxies shown in gray scale. The detection limit of the emission line survey is designed to reject the region hatched with green color.

X-ray 20-40 keV flux of AGNs can be diminished significantly by heavy obscuration and a sample selected in such high-energy band can be biased against Compton-thick AGNs (Malizia et al. 2009, MNRAS, 399, 944).

In the local universe, a significant fraction of [OIII]-line-selected obscured AGNs is possibly Compton-thick AGNs. Candidates of obscured AGNs are selected based on strong [OIII]-line from Sloan Digital Sky Survey (SDSS) spectroscopic database (Zakamska et al. 2003, ApJ, 126,2125). X-ray fluxes of half of them are significantly smaller than that predicted from the strength of the [OIII]-line (see Figure 2, Vignali et al. 2010, MNRAS,). The large $L_{\rm [OIII]}$ / $L_{\rm 2-10keV}$ implies that their active nuclei are heavily-obscured even in the hard X-ray band.

Because summantion of X-ray emission of populations of non-obscured and mildly-obscured AGNs cannot explain the energy density of the Cosmic X-ray Background (CXB) at around its peak energy range (~30 keV), Compton-thick AGNs are expected to contribute significantly to the energy density, and the number density of Compton-thick AGNs needs to be as high as that of mildly-obscured AGNs (Ueda et al. 2003; Gilli et al. 2007). The redshift range of the FMOS SSP survey is especially important because the residual CXB spectrum implies that the contribution from the heavily-obscured AGNs peaked at $z \sim 1.5$ (Worsley et al. 2005).

High number density of Compton-thick AGNs at high-redshifts is inferred from 24μm-excess (Daddi et al. 2007; Fiore et al. 2008; Alexander et al. 2008), MIR plus radio (Martinez-Sansigre et al. 2007), and MIR-SED (Polletta et al. 2006) selections of obscured AGNs. The estimated number density of Compton-thick AGNs is summarized in the right panel of Figure 1. Comparison with that of X-ray-selected AGNs as shown in the left panel implys that Compton-thick AGNs are as numerous as non-obscured and mildly-obscured AGNs, i.e., heavily-obscured accretion can significantly contribute to the accretion growth of SMBHs. However, the current knowledge on the number density of obscured AGNs are rather heterogeneous and not conclusive.

FMOS SSP Sample 1 can constrain the number density of heavily-obscured AGNs similar to [OIII] emission line survey of SDSS in the local universe. The targets are selected based on the photometric redshift and estimated stellar mass. Because almost all of the X-ray selected luminous and low-luminosity AGNs are associated with relatively massive galaxies (M$_* > 10^{10.5} M_\odot$; Yamada et al. 2009, ApJ, 699, 1354), heavily-obscured AGNs are expected to also reside in such massive galaxies. The detection limit of Sample 1 corresponds to $L_{\rm [OIII]}$ of 2.8×10^{43} erg s^{-1} at $z = 1.5$ with SN=10. The luminosity is equivalent to unobscured $L_{2-10\rm keV}$ of 1.4×10^{44} erg s^{-1}. Once Hα and [OIII] emission lines are detected with SN> 10, secondary emission lines, such as [NII] and Hβ are expected to have SN> 3 if they have strength 1/3 of the Hα and [OIII] emission lines. Achieving the detection limit, AGN-like emission lines can be distinguished clearly from HII-region-like lines as shown in right panel of Figure 3. Combining the [OIII]-line selected AGNs with the deep X-ray data in the SXDS/UDS region which reach the detection limit of $L_{2-10\rm keV} = 1 \times 10^{43}$ erg s^{-1}, we can directly identify heavily-obscured AGNs using the ratio $L_{\rm [OIII]}/L_{2-10\rm keV}$ (or lower limit on the ratio) as shown in left panel of Figure 3. Selection with strong [OIII] line may miss obscured AGNs without strong optical emission line, like fully-covered less-luminous AGNs in the local universe (Ueda et al. 2007, ApJ, 664, 79). Such AGNs can be found among radio AGNs in Sample 3 and FIR-selected galaxies in Sample 2-3.

The fraction of AGNs among massive galaxies may be rather high in the high-redshift universe. For example, NIR survey of 26 K-bright galaxies at $2.0 < z_{\rm phot} < 2.7$ by Kriek et al. (2007) found 11 emission line objects and among them there are 4 classical AGNs and 3 possible AGNs (AGN+Starburst) as shown in Figure 3. Among the 7 objects, only 1 object is detected in X-ray. The result indicates that a significant fraction ($\sim$1/3) of the massive galaxies shows AGN activity detectable with rest-frame optical emission lines and most of them are missed in the deep X-ray surveys. The number of the sample is too small to conclude the statistical nature of heavily-obscured AGNs. Assuming similar number of Compton-thick AGNs to X-ray-selected mildly-obscured (type-2) AGNs as mentioned above, it is expcted that about 50 Compton-thick AGNs in the SXDS/UDS region above the [OIII] detection limit.

Finally, combining the X-ray-selected non-obscured/mildly-obscured AGNs mentioned above and the [OIII]-selected heavily-obscured AGNs, the entire population of AGNs among galaxies in the violent era can be revealed.

0.2. Massive galaxy formation and the onset of radio-mode feedback

It is now generally accepted that AGNs play a major role in shaping the evolution of their host galaxies, via a process known as ‘AGN feedback’. This feedback can take one of two forms, for which Croton et al. (2006, MNRAS, 365, 11) coined the terms ‘quasar mode’ and ‘radio mode’. Quasar mode feedback occurs when the central supermassive black hole is accreting close to its Eddington limit, and the infalling material forms a hot accretion disk that, in turn, ionizes the surrounding gas to produce a rich emission-line spectrum. This mode is associated with mergers and interactions which also promote star formation, although the precise relationship between the accretion and star formation activities is not fully understood.

In contrast, the physics and energetics of radio mode feedback are far clearer. This mode occurs when hot gas accretes directly onto the black hole at a low rate, eliminating the need for an accretion disk, and hence not producing strong emission lines (note that classical powerful radio galaxies such as Cygnus A are actually ‘quasar mode’ systems). Best et al. (2005, MNRAS, 362, 25) demonstrated that the fraction of galaxies hosting a low-luminosity radio-loud AGN was a strong function of stellar mass. Inferring this to be a duty cycle of activity, Best et al. (2006, MNRAS, 368, L67) showed that the energy output (making plausible assumptions about the relationship between radio luminosity and kinetic power) precisely balanced the observed X-ray cooling. This mechanism, whereby radio ‘bubbles’ inflate cavities in the surrounding hot X-ray halo (as clearly seen in, e.g., the Perseus cluster; Fabian et al. 2003, MNRAS 344, L43; Fabian et al. 2006, MNRAS, 366, 417) is therefore responsible for the curtailment of baryonic cooling and hence star formation in massive galaxies, and explains the steep cut-off at the bright end of the galaxy luminosity function.

Radio mode feedback only becomes important once massive elliptical galaxies have formed, and it therefore can be used to locate the epoch of massive galaxy assembly. This is still a major problem in modern cosmology, as the existence of massive galaxies at high redshift continues to present difficulties for models of galaxy formation (e.g., Collins et al. 2009 Nature, 458, 603; Stott et al. 2010, ApJ, 718, 23). Blank-field surveys for massive galaxies are hampered by the reliance on photometric redshifts and stellar mass estimates and hence their results are open to debate without extensive confirmational spectroscopic follow-up (see, e.g., van Dokkum et al. 2006, ApJ, 638, L59). By comparison, an observed decline in the number of low-luminosity radio sources would pinpoint the time at which the most massive galaxies have completed their stellar build-up and found equilibrium between gas cooling and radio-source heating. Locating this epoch provides an essential constraint for models of galaxy formation. Detecting such a decline requires far less follow-up and, indeed, has been tentatively seen in the SXDF/UDS sample of 505 radio sources (Simpson et al. 2011, in prep.; Fig. 4). However, this result also hinges on the reliability of photometric redshifts, and is also made slightly ambiguous by the overlap between low-luminosity radio-loud AGN and high-luminosity radio-quiet (quasar mode) sources, although these evolve like the luminous AGN population and so are expected to peak at $z \sim 2.5$.

FMOS is the ideal instrument to tackle this problem, since it is able to detect the strong 4000-Å break in massive galaxies at $z \sim 2$ with little or no line emission, and also detect the strong emission lines of [O II] and/or [O III] at this redshift to eliminate contaminating quasar-mode radio-quiet objects. Since the population we are interested in does not have strong accretion, there is no hot dust emission longward of 1 μm and the *Spitzer*/IRAC colours provide robust (if rather uncertain) photometric redshift estimates (Simpson & Eisenhardt 1999, PASP, 111, 691). By selecting radio sources with appropriate colours from the deep IRAC observations in the SXDS/UDS and COSMOS fields, we will reliably and efficiently measure the evolution of the radio-mode galaxy population and hence determine when the most massive galaxies have fully assembled.

Sample selection bit

From Chris, this should be in the sample section.

We have selected radio sources in the SXDF/UDS (from a new radio map; Ivison et al., in prep) and COSMOS (Schinnerer et al. 2010, ApJS, 188, 384) fields which are believed to lie at $z > 1.5$, based on their *Spitzer* [3.6]−[4.5] colours. This colour cut will also include lower redshift ‘quasar mode’ AGN (due to the hot dust emission from the inner walls of the torus) and these objects have been excluded based on their optical magnitudes. There are **XXX** sources, with a range of J-band magnitudes, that therefore require different exposure times. We aim to achieve S/N=5 in the continuum, which will be sufficient to detect the strong 4000-Å break.

Fig. 4.— Figure from my new paper demonstrating the decline in low-luminosity radio sources.