AGN accretion, obscuration and star formation in luminous galaxies

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My thesis explores the connection between galaxies and their central supermassive black holes (SMBHs) through studying multiwavelength datasets in the Boötes survey region. Motivated by the observed correlation between SMBH mass and galaxy bulge mass, many studies have attempted to look for the apparent connection between the growth rates of SMBHs and their host galaxies. With the recent advent of the *Herschel Space Observatory*, the galaxy star formation rate (SFR) can be constrained even in bright active galactic nuclei (AGN), which has greatly advanced our ability of constraining SFR for AGNs host galaxies. However, current studies for AGNs selected with various criteria sill have no conclusive results in the observed connections between the AGN accretion rates and SFR.

To date, a number studies have indicated that black hole accretion rate (BHAR) and SFR are correlated in luminous quasars. However, such trends were not observed for AGNs with lower luminosities. Moreover, the close link between BHAR and SFR is only observed for local QSOs. At higher redshift ($z = 1 \sim 2$) where both cosmic BH accretion density and cosmic SF density peaks, the BHAR-SFR correlation is either less significant or non-existent. Some of the studies have also reported no apparent BHAR-SFR correlations even in local QSOs. These controversial results pose difficulties when reconciling the growth of high redshift galaxies and the tight SMBH and galaxy mass correlation in the local universe. The bulk of my thesis addresses the current issues on the origin of the correlations between the SFR and AGN accretion rate in AGN host galaxies. In deep multiwavelength surveys, the study of AGN-host galaxy connection often suffers from two different observational constraints. The first is the much shorter variability time scale of the SMBH accretion relative to SF. As demonstrated by recent simulations, SMBH accretion rate can vary over 7 orders of magnitudes in a time scale shorter than 10^6 year. Another bias that might limit our understanding of AGN-galaxy co-evolution is that the existence of the heavily obscured AGNs that are often missed in current AGN samples selected using X-ray or optical spectroscopy.

To address the issue with the shorter time scale of AGN variability relativ to SF, we investigated a large sample of *Herschel* selected star-forming (SF) galaxies in Boötes . We measure the SFR for these SF galaxies using far-IR photometry which probes the peak of the thermal emission from cold dust heated by the hot stars in galaxies. We divide the SF galaxies into bins of SFR and measure the average SMBH accretion rate with an X-ray stacking analysis. We find a strong correlation between SFR and the average SMBH accretion rate. This result, published at Chen et al. (2013), highlights that even though the growth rates of the SMBHs and the host galaxies in individual galaxies hosting AGN are not directly correlated due to the short variability timescale of AGN relative to SF, averaging over the full AGN population still yields a strong linear correlation between AGN and and star formation.

My thesis has also presented evidence for a link between nuclear obscuration and host galaxy star formation in the most luminous AGN: quasars. I developed template-based SED fitting codes spanning near-UV to far-IR wavelengths to decompose galaxy and AGN contributions. In combination with stacking analysis in both far-IR and X-ray wavelengths, we confirm that SFR can still be measured with the inclusion of far-IR photometry even in luminous quasars in which AGN radiation outshine the host galaxy at most wavelengths. We find that obscured quasars have 2 times larger far-IR detection fraction, far-IR flux and SFR than unobscured quasars. The quasar obscured fraction also rises from 0.3 to 0.7 between infrared SF luminosity of $440 \times 10^{11} L_{\odot}$. This suggests that in addition to the orientation-based, pc-scale torus model, the large-scale gas and dust in powerful star-forming galaxies may also be obscuring the AGN radiation. These results support a scenario in which galaxy and SMBH grow from the same gas reservoir that can also obscures the central SMBH during the luminous quasar phase. This result by Chen et al. (2014) was recently submitted.

The ongoing part of my research explores the AGN mid-IR to X-ray spectral shapes in luminous quasars. From the studies of large samples of optically selected AGNs, it is now well-established that the intrinsic AGN spectral shape between the ultraviolet and X-ray wavelengths (characterized by α_{OX}, the spectral index between ultraviolet and X-ray) are strongly dependent to the AGN luminosity (e.g. Steffen et al. 2006; Lusso et al. 2010). Meanwhile, the intrinsic X-ray to mid-IR spectral index have not yet been studied for AGNs with quasar luminosities to the best of our knowledge. An almost linear correlation between AGN mid-IR luminosity and the AGN X-ray luminosity has been reported for a selection of Seyfert galaxies (lower luminosity AGNs) by Gandhi et al. (2009). Intriguingly, Fiore et al. (2009) discovered a different AGN mid-IR luminosity to AGN X-ray luminosity relation for X-ray AGNs at $z \sim 1.5$. In accordance to the widely accepted α_{OX}, we have measured the AGN mid-IR to X-ray spectral shape, α_{IX}, for luminous quasars in Boötes . We confirm that α_{IX} is also dependent to AGN luminosity in a fashion similar to α_{OX}, suggesting that there might be more luminous AGNs with relatively weak X-ray emissions, which is consistent with the recent NuSTAR observations of heavily obscured quasars. We recognize that the intrinsic X-ray weakness in luminous AGNs might be an important factor in the study of AGN-galaxy coevolution, and discovered that AGN mid-IR luminosity has a stronger correlation to SFR than the AGN X-ray luminosity (Chen et al. 2014, in preparation).

In summary, this thesis addresses one of the most important unresolved issue in current studies of galaxy evolution, the origin of the tight relationship between the SMBH mass and the host galaxy mass. We have found that the cosmic evolution of SMBH growth and star formation is strongly correlated and is by and large consistent with today's mass ratio between SMBH and their host galaxies.

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