Star Formation and AGN Obscuration in Luminous Quasars

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The challenges in observational studies of galaxy-AGN coevolutions

Observations of direct connections between galaxy star formation and supermassive black (SMBH) accretion are very challenging. In particular, the vastly different physical sizes and time scales of galaxy star formation and SMBH accretion often produce serious selection bias if we focus only on the galaxies hosting SMBHs that are currently ``on''. Another challenge in the search of the direct connection between galaxy and AGN is that rapidly growing systems are often enshrouded by dust. Therefore, a substantial population SMBHs might be growing in an obscured phase that can be missed. To explore the connection between galaxy and AGN, these effects must be treated carefully.

Revealing the correlation between the SFR and the BHAR in star-forming galaxies with *Chandra*

Studies of the typical star formation rates in AGN host galaxies have shown that while there is strong SFR-BHAR correlation in high luminosity AGN (Rosario et al., 2012), at lower luminosity AGN the connection appears to be relatively weak or absent. This difference between the high- and low-luminosity AGN may be attributed to the different time scales of star formation and AGN accretion (Hickox et al. 2014). Since AGN accretion rates vary in time scale much shorter than that of star formation, the *average* BHAR for star-forming galaxies might be a better indicator to study the connection between SFR and accretion.

We select 1,785 star-forming galaxies selected using *Herschel* SPIRE 250 μm filter (Alberts et al. 2013) in Boötes (0.25<z<0.8). The redshift measurements are from AGN and Galaxy Evolution Survey (spectroscopic) and Spitzer Deep Wide Field Survey (photometric). In this sample, there are 140 X-ray or mid-IR selected AGNs for which we can measure their accretion rates directly. For the SF galaxies without individually detected AGNs, we measured the average LX using an X-ray stacking analysis. We find that the average black hole accretion rate (BHAR) is strongly correlated with SFR in SF galaxies, which support a scenario in which galaxy and SMBH grow from a common gas reservoir that can obscure the central SMBH during the luminous quasar phase.

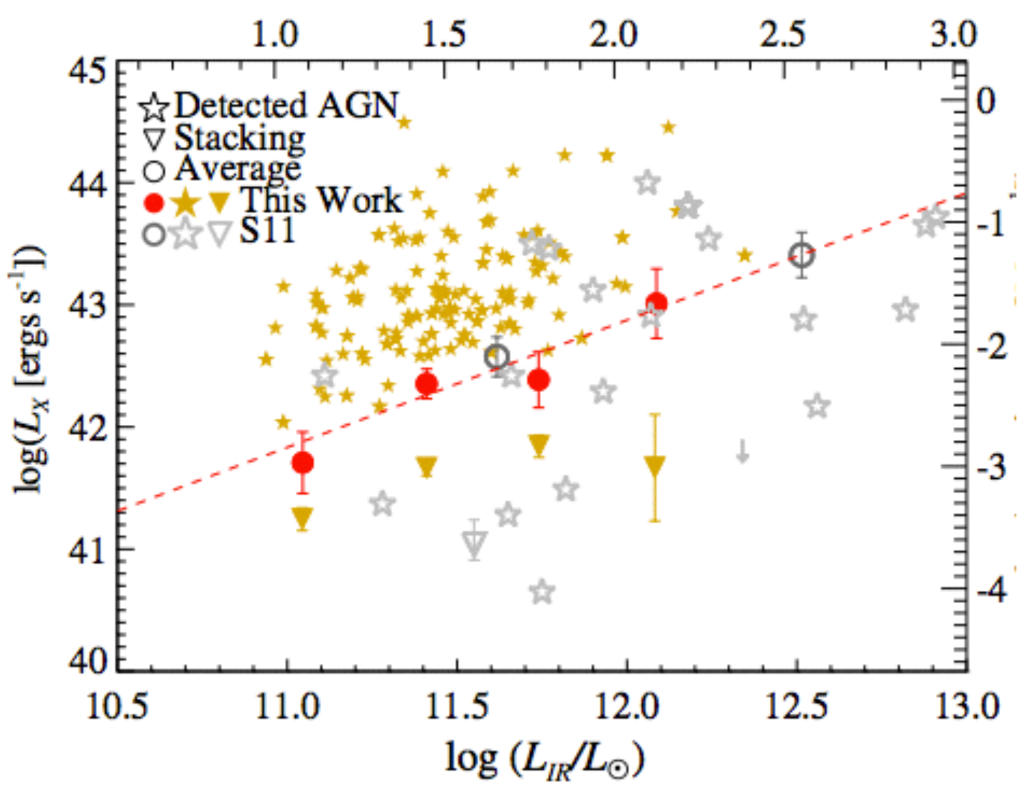


Fig. 2 **SFR and average SMBH accretion rate**
A correlation between star formation and average SMBH accretion is shown here. The observed correlation in our sample is shown as the red circles and the red dashed lines. Individual AGN are plotted as stars, while the X-ray stacking luminosities for galaxies not individually detected in X-ray are shown as downward trangles. For comparison, we also calculate the average SMBH accretion rate for the sample from Symeonidis et al. 2011, which are plotted as open grey circles (Chen et al. 2013)

AGNs hosted by galaxies with stronger SF show signs of nuclear obscuration

To explore the effect of the star-forming gas and dust to the observed AGN properties, we utilize the data from the Chandra Deep Field South (CDFS) 4Ms catalog. We separate these X-ray AGNs into two subsamples with low (log L_{IR}<11) and high (log L_{IR} >11) infrared luminosities. We find that the AGNs hosted by galaxies with more SF have a stronger 6.4 keV iron kα line, which indicates a stronger nuclear obscuration. This implies a connection between the host galaxy SF and AGN obscuration.

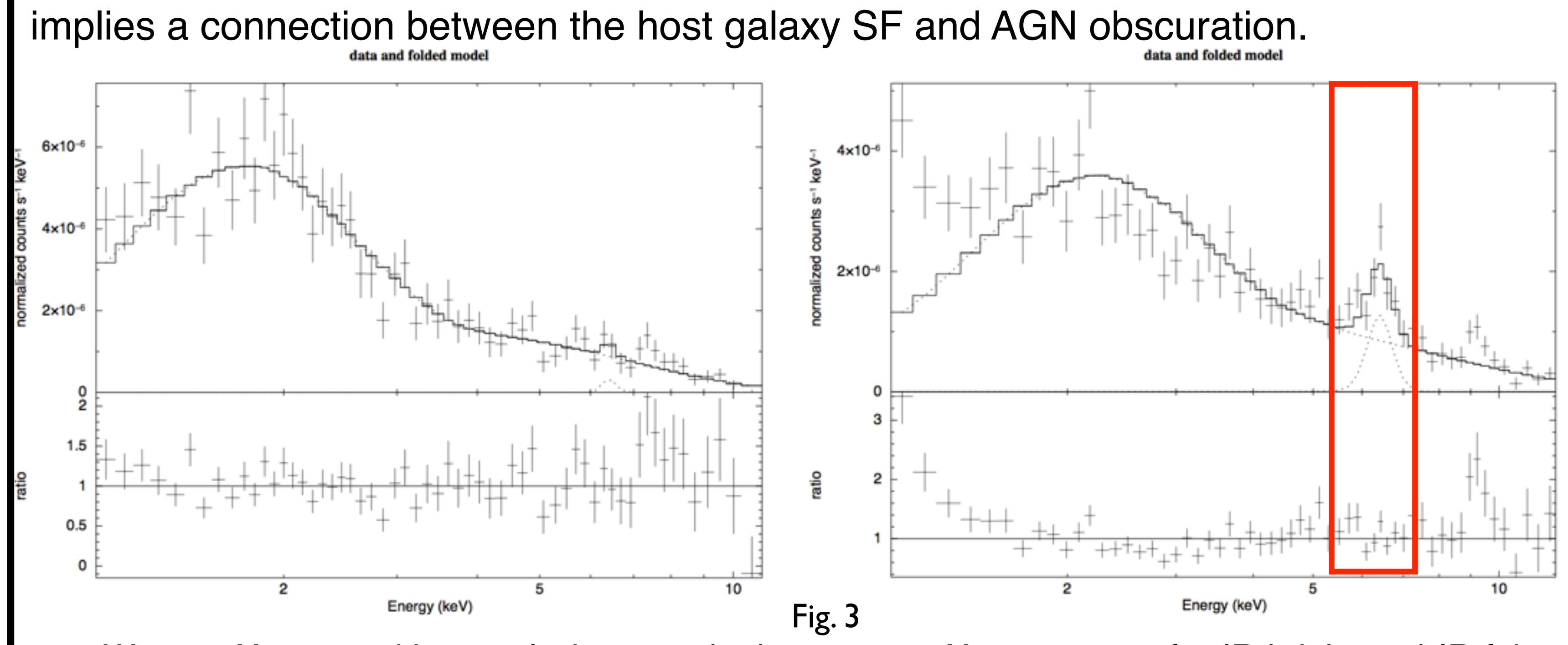


Fig. 3
We use X-ray stacking analysis to study the average X-ray spectra for IR-bright and IR-faint galaxies, we find that for IR-bright galaxies, the average X-ray spectrum show signs of stronger Fe-Kα emission line, which is an indicator of AGN obscuration.

The connection between SF and obscuration in mid-IR selected quasars

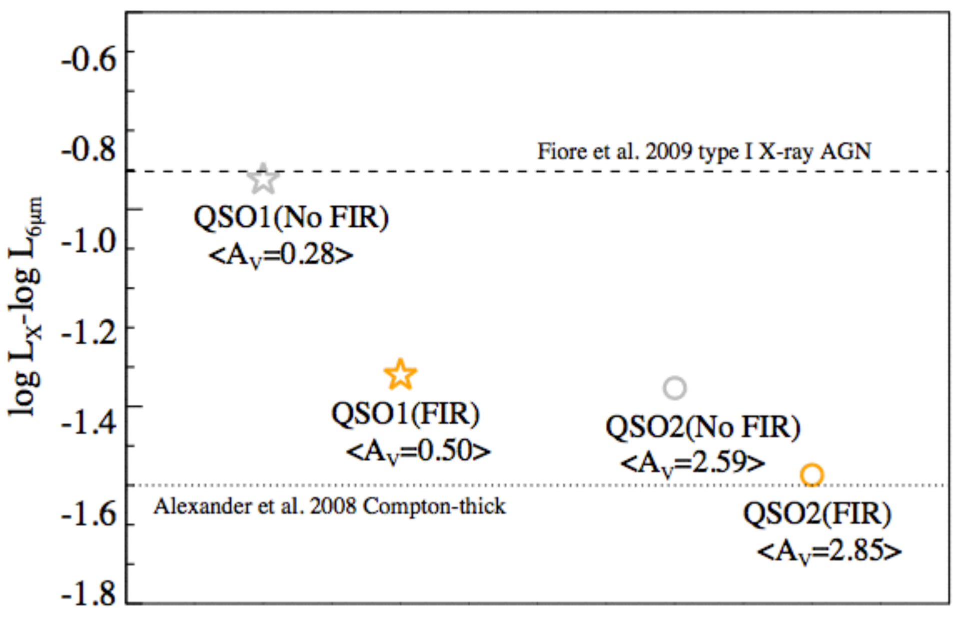


Fig. 4 **The LX/LMIR ratio for different quasar populations**
Since both mid-IR and X-ray are considered a good tracer of AGN accretion and the mid-IR emission is less affected by obscuration, the LX/LMIR ratio is considered to be a good indicator of the presence of obscuration that attenuates the observed X-ray emission in quasars. This figure shows the presence of large-scale far-IR emitting dust also attenuates the AGN X-ray emission, and some of the QSO2s hosted by far-IR luminous galaxies might not be detected in current X-ray surveys.

Far-IR emission in obscured and un-obscured Quasars

There is increasing evidence for the connection between SFR and BHAR in the starburst galaxies and powerful AGNs consistent with a scenario in which AGN and galaxies have gone through a dust-enshroud phase, where the gas-rich major merger drives both active starburst and luminous AGN activity (i.e. quasar) (e.g. Sanders 1988, Hopkins 2008). In this phase, the rich dust and gas in the host galaxy might also be responsible for the obscuration observed in some luminous AGN. However, results current X-ray selected AGN samples do not support this scenario (e.g. Rovilos et al. 2012, Merloni et al. 2014).

To investigate the heavily obscured quasar population, we study an IR-selected quasar sample at 0.7<z<1.8 in Boötes (Hickox et al. 2007) to test whether the obscuration in bright AGN is related to star formation. We separated our sample into obscured AGN and unobscured AGN using a optical/mid-IR color selection criteria (Hickox et al. 2007). We measured the far-IR detection fraction for obscured and un-obscured AGN separately, and found that obscured AGN have a higher far-IR detection fraction and stronger SF luminosity.

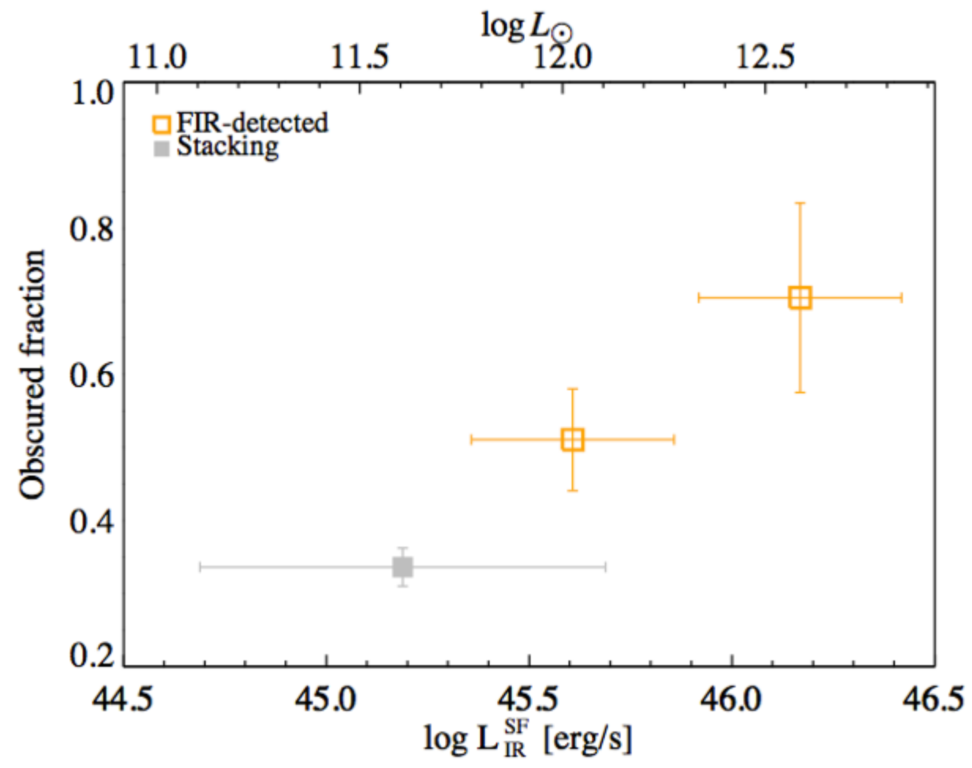
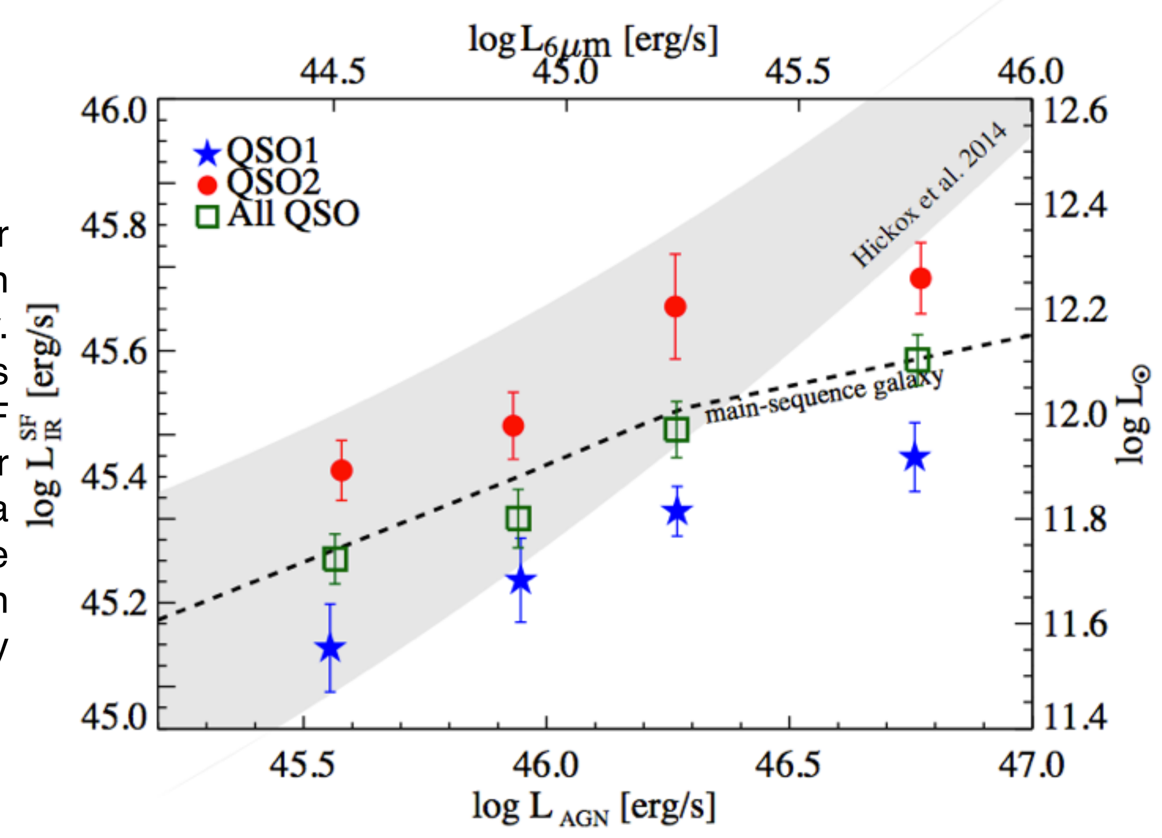


Fig. 5 **Mid-IR quasar obscured fraction**
The obscured fraction as a function of LSF. We separate far-IR detected QSOs into two bins of LSF with equal number of sources in each bin, and plot their obscured fraction as the orange open squares. For the far-IR non-detected QSOs, we show the obscured fraction at the LSF estimated from stacking analysis as the gray filled squares. This plot shows a direct connection between galaxy SF and quasar obscuration.

Fig. 6 **LSF-AGN for different quasar populations**
The average 8-1000 μm star formation luminosity measured in bins of AGN bolometric luminosity. In these luminous mid-IR quasars at 0.7<z<1.8, we find that the LSF for QSO2s is at least 0.3 dex higher than that of QSO1s. As a comparison, we also plot the Hickox et al. (2014) toy model in which LSF is assumed to be tightly correlated with the average LAGN.



Conclusion

In these works, we attempted to 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 average BHAR and SFR are strongly correlated in SF galaxies. This is likely due to a common gas reservoir which fuels both active SF and BH accretion over galaxy evolution time scale. We have also found that the star-forming dust is connected to the obscuration seen in both the optical and the X-ray wavelengths. This suggests that the in addition to a parsec-scale torus, the presence of large-scale star-forming dust might also play obscure the nuclear emission. This work is supported by a Fellowship from the William H. Neukom 1964 Institute for Computational Science.

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