Resolving the Rise and Fall of Star Formation in Galaxies
Proceedings IAU Symposium No. 373, 2023
T. Wong & W.-T. Kim, eds.
doi:10.1017/S1743921322003842

Tug of War, or Cohabitation? : Star Formation and AGN Activities within Type 1 AGN Host Galaxies

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Abstract. The interplay between star formation (SF) activity and active galactic nuclei (AGN) governs the co-evolution of supermassive black holes (SMBHs) and their host galaxies. AGN feedback has been hailed as the de facto process to suppress, or even shut down SF within the framework of hierarchical galaxy merger based on the current ΛCDM paradigm. However, it is unclear what physical processes regulate the growth of SMBHs and how SMBHs and their evolution are interconnected with their host galaxies when SMBHs and host galaxies are of hugely different physical scales. In fact, there has been no observational evidence to show that AGN feedback works, but rather some evidence to speculate that the more powerful AGNs reside in the more actively star-forming host galaxies. While it is difficult to measure the amount of SF from AGN host galaxies, polycyclic aromatic hydrocarbon (PAH) emission features emerged as good proxies for this purpose. Although having several caveats as SFR indicators, such as metallicity dependency, and non-SF contribution from evolved stellar populations, or AGNs, PAH emissions have been utilized to investigate SF activity of AGN host galaxies with varying results. Utilizing the slitless spectroscopic apability of the AKARI Infrared Camera, we obtained the spectra in the wavelength range of 2∼5 μm from extended regions of 79 type 1 AGN host galaxies to detect and measure the 3.3 μm (PAH) emission feature as star formation rate proxy. Based on 18 sample galaxies, we found that the luminosity of the 3.3 μm PAH emission feature is strongly correlated with AGN luminosity, except for ultra-luminous infrared galaxies (ULIRGs). Therefore, we suggest that host galaxies with stronger AGN activities have stronger star formation activities. However, it is still unclear why ULIRGs deviate from the correlation, not to mention why the detection rate of the 3.3 μm emission feature is so low. High spatial resolution imaging not only for the circumnuclear region of AGN host galaxies, but also for entire galaxies should help the cause. We present the prospective studies to diagnose SF regulation for AGN host galaxies with various space telescope facilities, such as JWST, and SPHEREx.

Keywords. galaxies: star formation, galaxies: ISM, galaxies: Seyfert, infrared: galaxies

1. Introduction

The formation and evolution of supermassive black holes (SMBHs) and their host galaxies are closely linked. While SMBHs reside at the centers of most bulge-dominated galaxies, their masses have tight correlations with the various properties of their host galaxies. While there have been enormous efforts to understand the connection between SMBHs and their host galaxies, it is still uncertain what physical processes govern the growth of SMBHs and their host galaxies, and how their evolutionary phases are interconnected. Numerous theoretical models have been devised to explain the co-evolution of SMBHs and their host galaxies albeit a huge gap in physical scales. Notably, active galactic nucleus (AGN) feedback is a common feature of these models. AGN feedback was originally devised to reconcile the "overcooling" problem of massive halos within the frame work of hierarchical galaxy merger based on the ΛCDM paradigm. While the primary function of AGN feedback is believed to suppress, or to slow down star formation (SF) activity of host galaxies by removing cold gas within them, some recent models suggest that AGN feedback can enhance SF activity by plowing gas into denser clumps. Then, more sophisticated models implement scenarios with a time offset between SF and AGN activities within the same event, or regulated growths of BHs and host galaxies through multiple events of interplays between them.

Therefore, measuring SF and AGN activities to probe the connection between them provides a crucial information on how AGN feedback, either "positive", or "negative", works on the growth of host galaxies. However, it is not trivial to measure SF activity in AGN host galaxies. In general, the radiation from AGN overpowers SF activity of host galaxies. Especially within the ultraviolet and visible wavelength regimes, AGN powers SF rate (SFR) proxies, such as far-ultraviolet emission, and hydrogen recombination lines, more than SF activity. Hence, there have been numerous efforts to measure SF activity using the longer wavelength regimes, such as infrared (IR), and sub-mm wavelength regimes.

Within these longer wavelength regimes, polycyclic aromatic hydrocarbon (PAH) emission features have emerged as good candidates to provide SFR for AGN host galaxies thanks to various space missions, such as *Spitzer* and *AKARI* space telescopes; a handful of studies showed strong correlations between SF and AGN activities by measuring SF activity with various PAH emission features. However, the 3.3 μm PAH emission feature which is the only PAH emission feature accessible for high-z (z $>$ 4) galaxies with *JWST* space-telescope has not been studied due to its weak nature.

2. Data

This study present the results based on the Quasar Spectroscopic Observation with NIR Grism (QSONG). The sample of QSONG consists of two large samples of AGNs; a low redshift (z $<$ 0.5) sample called low redshift QSONG (LQSONG) and high redshift (z $>$ 3.0) sample (HQSONG). Chosen to achievee high S/N with IRC onboard *AKARI* space-telescope, the LQSONG are composed mainly from two differenct sources; 35 bright type 1 AGNS of which BH masses are measured by reverberation mapping method, and 69 PG QSOs. Between them,we observed 31 out of 35 and 48 out of 69 from the reverberation sample and the PG QSO sample, respectively and used for the analysis.

3. Detection of the 3.3 μm PAH Emission

We detected the 3.3 μm PAH emission from 18 out of 79 sample galaxies (34 % detection rate). The detection rates for the subsamples are 42% and 10% for the reverberation sample and the PG QSO sample, respectively. The differences of the detection rates are not be attributed to physical origins, since the only difference is the measurement methods of their SMBH masses.

On the other hand, the detection rates of the 3.3 μm PAH emission feature depend on the strength of AGN activity; the stronger AGN activity means the lower detection rate. However, stronger AGNs are at higher redshifts in general. Therefore, we may not rule out that the decreasing detection rate for stonger AGNs are simply due to the sample selection and/or the detection limit.

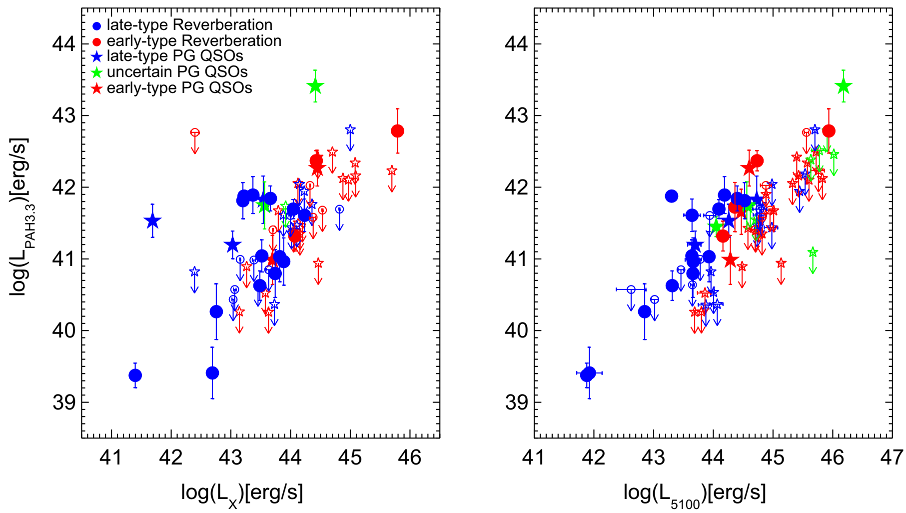

Figure 1. Top two panels of Figure 3 from Kim *et al.* (2019) $L_{\mathrm{PAH3.3}}$ against nuclear activity probes. Symbols represent the subsamples; circles are of the reverberation mapping sample, while stars of the PG QSO sample. Colors represent the host galaxy morphology; red symbols are of early-type, blue symbols are of late-type, and green symbols are of the unclear. All the empty symbols represent upper limits.

4. SF versus AGN

The strength of AGN activity can be probed by various properties; $\lambda L_{5100,\mathrm{AGN}}$ and L_{X} are among the most used ones. Figure 1 shows the correlations of $L_{\mathrm{PAH3.3}}$ with $\lambda L_{5100,\mathrm{AGN}}$ and L_{X}. $L_{\mathrm{PAH3.3}}$ has strong correlations with both L_{X} and $L_{5100,\mathrm{AGN}}$, although there are several outliers against L_{X} more than against $L_{5100,\mathrm{AGN}}$.

Moreover, there is no systematic dependence on the morphology of host galaxies. Regardless of their host galaxy morphology, the correlations between $L_{\mathrm{PAH3.3}}$ and L_{X}, or $L_{5100,\mathrm{AGN}}$ persist for the sample galaxies. Therefore, if $L_{\mathrm{PAH3.3}}$ represents SFR of galaxies, there is a strong positive correlation between star formation activity of AGN host galaxies also correlates with AGN activity. Still, it is hard to rule out that the correlations of $L_{\mathrm{PAH3.3}}$ with L_{X} and $L_{5100,\mathrm{AGN}}$ result from massive objects being luminous.

Several studies suggested that the 3.3 μm PAH emission correlates with various properties of AGN host galaxies. However, the correlations found by Kim *et al.* (2019) are the closet to the unity.

The linear fit between $L_{\mathrm{PAH3.3}}$ and $L_{5100,\mathrm{AGN}}$ follows as;

$$logL_{\mathrm{PAH3.3}} = 0.88 \times logL_{5100,\mathrm{AGN}} + 5.81. \quad (1)$$

The linear fit between $L_{\mathrm{PAH3.3}}$ and L_{X} follow as;

$$logL_{\mathrm{PAH3.3}} = 0.90 \times logL_{\mathrm{X}} + 5.20. \quad (2)$$

5. Discussion

It is clear that there are strong correlations between $L_{\mathrm{PAH3.3}}$ and nuclear activities. There are several caveats, though. First, the PAH emission features are absent for ultra-luminous infrared galaxies (ULIRGs; galaxies with $\mathrm{L_{IR}} > 10^{12}\ \mathrm{L_{\odot}}$) (Kim *et al.* 2012). Although it is well known that not only the 3.3μm PAH emission feature, but also all the longer wavelength PAH emission features are absent for ULIRGs, it is unclear why these PAH emission features absent only for ULIRGs regardless of the presence of AGNs. Secondly, the abundance of PAH molecules are believed to depend on metallicity,

https://doi.org/10.1017/S1743921322003842 Published online by Cambridge University Press

which may impact the overall calibration of luminosity of PAH emission features as SFR proxy. Now that JWST started its operation, there will be more opportunities to measure $L_{PAH3.3}$ from SF regions of AGN host galaxies at various redshift regimes.

References

Kim, J. H., Im, M., Lee, H. M., et al. 2012, ApJ, 760, 120
Kim J. H., Im M., Kim D., Woo J.-H., Karouzos M., Lee H. M., Lee M. G., et al., 2019, PASJ, 71, 25

https://doi.org/10.1017/S1743921322003842 Published online by Cambridge University Press