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# THE 3.3 $\mu m$ PAH FEATURE AS A SFR INDICATOR: PROBING THE INTERPLAY BETWEEN SF AND AGN ACTIVITIES

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## ABSTRACT

We utilize AKARI's slitless spectroscopic capability to detect the 3.3 $\mu m$ polycyclic aromatic hydrocarbons (PAHs) emission and measure star formation (SF) activity for various AKARI programs. First, we obtain 2∼5 $\mu m$ spectra of 20 flux-limited galaxies with mixed SED classes in order to calibrate the 3.3 $\mu m$ PAH luminosity ($L_{PAH3.3}$) as a star formation rate (SFR) indicator. We find that $L_{PAH3.3}$ correlates with $L_{IR}$ as well as with the 6.2 $\mu m$ PAH luminosity ($L_{PAH6.2}$). The correlations does not depend on SED classes. We find that ULIRGs deviate from the correlation between PAH luminosities and $L_{IR}$, while they do not for the correlation between PAH luminosities. We suggest possible effects to cause this deviation. On the other hand, how AGN activity is linked to SB activity is one of the most intriguing questions. While it is suggested that AGN luminosity of quasars correlates with starburst (SB) luminosity, it is still unclear how AGN activity is connected to SF activity based on host galaxy properties. We are measuring SFRs for the LQSONG sample consisting of reverberation mapped AGNs and PG-QSOs. This is an extension of the ASCSG program by which we investigated the connection between SB and AGN activities for Seyferts type 1s at z $\sim$ 0.36. While we found no strong correlation between $L_{PAH3.3}$ and AGN luminosity for these Seyferts 1s, $L_{PAH3.3}$ measured from the central part of galaxies correlates with AGN luminosity, implying that SB and AGN activities are directly connected in the nuclear region.

*Key words:* infrared: telescope; conferences: proceedings

## 1. INTRODUCTION

Understanding how black holes (BHs) form and grow with their host galaxies is one of the key questions regarding galaxy formation and evolution. Supermassive BHs (SMBHs) are ubiquitous at the centers of bulge-dominated galaxies within the local Universe (Kormendy & Richstone, 1995) and the mass of the BHs ($M_{BH}$) presents tight correlations with the properties of the spheroids, such as stellar-velocity dispersion ($\sigma_*$) (Gültekin et al., 2009 and references therein), and luminosity (Haring & Rix, 2004). These tight correlations are believed to indicate that the growth of the central BHs and the formation and evolution of galaxies are closely linked. However, it is still unknown how the BH accretion, or active galactic nucleus (AGN) activity, is linked to the starburst (SB) activity. Recently, it has been suggested that the AGN luminosity of quasars (QSOs) at low and high redshifts correlates with the SB luminosity, indicating an AGN-SB connection in luminous AGNs (Netzer et al., 2007; Lutz et al., 2008). For lower luminosity AGNs it is not clear how strongly AGN activity is connected to global star formation (SF). There have been, however, several studies showing a positive correlation between nuclear SB and AGN activities in local Seyfert galaxies (e.g., Imanishi & Wada, 2004).

In this proceedings, we present three AKARI programs utilizing the unique capability of slitless spectroscopy in order to detect the 3.3 $\mu m$ PAH emission feature and calibrate it as a SF rate (SFR) indicator. While PAH emission features are abundant and can be useful to measure SFR, the 3.3 $\mu m$ PAH feature has not been studied much since it is weaker than others and resides outside of Spitzer's frequency coverage. With IRC onboard AKARI, we can detect and measure the 3.3 $\mu m$ PAH emission and measure SFR of the host galaxies of various AGNs.

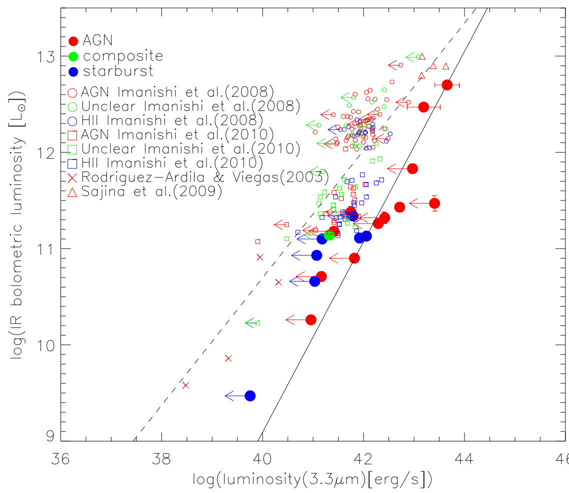


**Fig. 1.** Correlation between $L_{PAH3.3}$ and $L_{IR}$. The symbols with leftward arrows represent upper limits.

## 2. THE 3.3 $\mu m$ PAH EMISSION AS A SFR INDICATOR

### 2.1. *Introduction to AMUSES*

In order to detect and calibrate the 3.3 $\mu m$ PAH emission and investigate its potential as SFR indicator, we carried out an AKARI mission program, the AKARI mJy Unbiased Survey of Extragalactic Sources (AMUSES). We selected 60 galaxies from the 5 mJy Unbiased *Spitzer* Extragalactic Survey (Wu et al., 2010) based on their fluxes at 3.6 $\mu m$ ($>$ 0.7 mJy). Only 20 target galaxies were observed until the shutdown of AKARI. These 20 galaxies have a redshift range between 0.01 and 0.9. Of these 20 galaxies, seven galaxies are of SB SED class and 12 galaxies are of AGN SED classes based on optical SED classification (Wu et al., 2010). The remaining one galaxy has a composite SED. We obtained 2 $\sim$ 5 $\mu m$ low resolution spectra with IRC for the sample. Data reduction was carried out with the IRC spectroscopy pipeline.

### 2.2. *The 3.3 $\mu m$ PAH Emission as a SF Indicator*

Our AKARI observations yield the 3.3 $\mu m$ PAH feature from three galaxies out of 20 target galaxies (15%). Among these three galaxies, two galaxies have SB SEDs while one galaxy has AGN SEDs. Hence, the detection rates are 29% (2/7) and 8% (1/12), respectively.

The three targets of our sample that have detections of the 3.3 $\mu m$ PAH emission feature along with literature samples (Rodríguez-Ardila & Viegas, 2003; Imanishi et al., 2008, 2010; Sajina et al., 2009), show that the 3.3 $\mu m$ PAH luminosity ($L_{PAH3.3}$) and the infrared luminosity ($L_{IR}$) have a positive correlation (Fig. 1). A linear fit to the detections of the combined sample gives a least $\chi^2$ fit as in Eq. (1);

$$log(L_{IR}) = (0.73 \pm 0.06) \times log(L_{PAH3.3}) - (18.68 \pm 0.36), \quad (1)$$

where $L_{IR}$ is in units of $L_\odot$ and $L_{PAH3.3}$ is in units of erg sec$^{-1}$ with the correlation coefficient of 0.70. This fit is shown in Fig. 1 with a solid line. However, we get a better linear correlation for the detections with SB SEDs (see the legend of Fig. 1). The fit to these SB SED detections is given by Eq. (2);

$$log(L_{IR}) = (0.85 \pm 0.13) \times log(L_{PAH3.3}) - (24.04 \pm 0.83), \quad (2)$$

which is shown in Fig. 1 with a dotted line.

Whether our $L_{PAH3.3}$-$L_{IR}$ correlation persists, especially at high $L_{IR}$ remains a subject of further investigation. $L_{IR}$ and $L_{PAH6.2}$ correlate very well within our sample. However, ULIRGs again deviate significantly from the correlation. They have either higher $L_{IR}$, or lower $L_{PAH6.2}$ than lower $L_{IR}$ objects suggest. Therefore, it seems plausible that this is due to the intrinsic properties of ULIRGs. There can be two effects to explain the trend. First, ULIRGs may have larger non-star-forming contribution to their $L_{IR}$. There have been studies showing that AGN contribution to $L_{IR}$ is rather significnat for ULIRGs (Netzer et

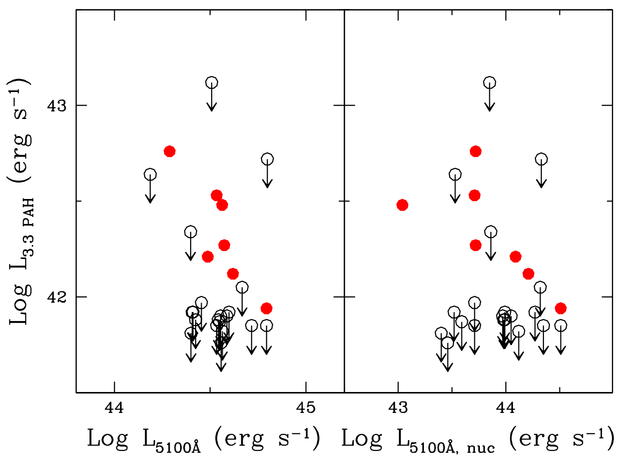


**Fig. 2.** Comparing the 3.3 $\mu m$ PAH luminosity ($L_{PAH3.3}$) with the observed total luminosity at the rest-frame 5,100 Å ($L_{5100}$) (*left*) and nuclear AGN luminosity (*right*). Filled circles represent the PAH detected galaxies while open circles represent upper limits of $L_{PAH3.3}$.

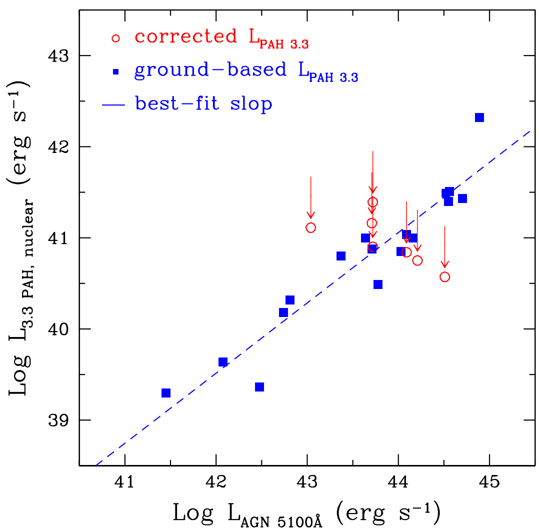


**Fig. 3.** The correlation of nuclear $L_{PAH3.3}$ with AGN optical luminosity. Filled squares represent $L_{PAH3.3}$ measured from ground-based spectroscopy with a narrow-slit while open circles represent the estimated nuclear $L_{PAH3.3}$ of the AKARI sample.

al., 2009, and references therein). Embedded YSOs can be another candidate to contribute to $L_{IR}$ other than AGN activity (Spoon et al., 2007). Second, ULIRGs suppress PAH emission. Both $L_{PAH3.3}$ and $L_{PAH6.2}$ are lower for ULIRGs of a given $L_{IR}$. It is believed that strong UV radiation, such as from an AGN, can destruct PAH molecules. However, it is unclear why AGNs at $L_{IR} < 10^{12}$ $L_{\odot}$ do not reduce the PAH luminosity as much.

## 3. A CASE STUDY OF z ∼ 0.36 SEYFERt 1s

### 3.1. Introduction

We obtained AKARI IRC spectra for 26 moderate-luminosity AGNs at z ∼ 0.36. The sample was initially selected for investigating the evolution of the $M_{BH}$-$\sigma_*$ relation of Seyfert galaxies. Woo et al. (2006) utilized this sample to measure the BH-spheroid relationships beyond the local Universe. They found that Seyferts at z ∼ 0.36 deviate from the local $M_{BH}$-$\sigma_*$ correlation. With this sample, they suggest that scaling relations have evolved significantly in the past 6 billion years, and that black hole growth predates the final galaxy assembly. The observation and data reduction were identical with AMUSES. We carried out IRC spectroscopy on the sample and data reduction by the IRC spectroscopy pipeline.

### 3.2. SB-AGN Connection

The 3.3 $\mu m$ PAH emissions are detected for 7 out of 26 target galaxies. We find no strong correlation between 3.3 $\mu m$ PAH and AGN optical luminosities within the limited AGN luminosity range. The slope of the $L_{PAH3.3}$ correlation with AGN luminosity in Fig. 2 shows that the $L_{PAH3.3}$ to AGN luminosity ratio decreases with higher AGN luminosity. This result may imply that the global SF is not strongly related with AGN activity. Ballantyne (2008) predict that nuclear SB should be associated with lower luminosity AGNs due to the competition between gas and SF. Kawakatu & Umemura (2004), investigating effects of stellar radiation drag on the formation of SMBHs, find that disk galaxies have SMBHs with order of 2 magnitude smaller than elliptical galaxies for a given galaxy mass, due to the effects of geometrical dilution and opacity. A similar trend has been noted by Lutz et al. (2008). In our local sample, the decrease of the SB-to-AGN ratio with increasing AGN lumosity is not as dramatic as in high redshift QSOs, but if confirmed, it implies that for low-luminosity AGNs the growth of galaxy centers is faster than black hole growth in the present-day universe.

On the other hand, when we compare the AGN luminosity of the local Seyfert 1 galaxies and PG QSOs with their nuclear 3.3 $\mu m$ PAH emission luminosity, we detect a strong correlation, suggesting that AGN activity is related to the nuclear SB (Fig. 3). In order to scale the PAH emission measurements from AKARI observations for nuclear SB, we calculated the relation between nuclear and global SFR for a type-I AGN, NGC 7469. The flux ratio between nuclear $L_{PAH3.3}$ and the global $L_{PAH3.3}$ is $\sim$0.04. Thus we took this ratio as a calibration factor and scaled down the AKARI measurements. These results are consistent with the findings of previous studies on the SB-AGN connection (Netzer et al., 2007; Lutz et al., 2008).

## 4. APPLICATION TO LQSONG

In order to investigate the connection between SF and AGN activities across various AGNs, we are carrying out the Low-redshift Quasar Spectroscopic Observation in Near-infrared Grism (LQSONG). The sample consists of two subsamples; 31 bright type-1 AGN and QSOs with BH masses measured by reverberation mapping method and 49 Palomar-Green QSO sample. The observations and data reduction are identical to the previous programs. We detected the 3.3 $\mu m$ PAH emission for $\sim$50% (16/31) of the reverberation-mapped sample and $\sim$20% (10/49) of the PG-QSO sample. We are investigating the dependency of the correlations between SF and AGN activity probes on host galaxy morphology, or the presence of radio jets.

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