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# A RELATION BETWEEN ACTIVE BLACK HOLES AND STAR FORMATION OF LOCAL ACTIVE GALAXIES

Kenta Matsuoka[1,2], Jong-Hak Woo[2], and Hyun-Jin Bae[3]
[1]Department of Astronomy, Kyoto University, Kitashirakawa-Oiwake-cho, Sakyo-ku, Kyoto 606-8502, Japan
[2]Department of Physics and Astronomy, Seoul National University, 599 Gwanak-ro, Gwanak-gu, Seoul 151-742, Korea
[3]Department of Astronomy and Center for Galaxy Evolution Research, Yonsei University, 50 Yonsei-ro, Seodaemun-gu, Seoul 120-749, Korea
*E-mail: matsuoka@kusastro.kyoto-u.ac.jp*
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## ABSTRACT

We present an analysis of the relation between star-formation (SF) and accretion luminosities of local type-2 active galactic nuclei (AGNs) at $0.01 \leq z < 0.22$. We match type-2 AGNs found in the Sloan Digital Sky Survey to current far-infrared (FIR) survey catalogues based on AKARI and *Herschel*. Estimating AGN luminosities from [O III]λ5007 and [O I]λ6300 emission lines, we find a positive linear trend between FIR and AGN luminosities over a wide dynamical range. This result appears to be inconsistent with recent reports that low-luminosity AGNs show no correlation between FIR and X-ray luminosities; this contradiction is likely due to Malmquist and sample selection biases. Moreover, we also find that pure-AGN candidates, for which the FIR radiation is thought to be AGN-dominated, show significant low-SF activities. These AGNs hosted by low-SF galaxies are rare in our sample. However, it is possible that the low fraction of low-SF AGN is caused by observational limitations, as recent FIR surveys are not sufficient to examine the population of high-luminosity AGNs hosted by low-SF galaxies.

*Key words:* galaxies: active – galaxies: star formation – infrared: galaxies

## 1. INTRODUCTION

In past decades, we have developed the idea that galaxies have evolved with supermassive black holes (SMBHs) located at their center, i.e., the coevolution of galaxies and SMBHs. This idea originated with observational results in the local universe, where there is a tight correlation between BH mass, $M_{\rm BH}$, and galaxy properties, e.g., stellar velocity dispersion and $\sigma$ (e.g., Magorrian et al., 1998; Marconi & Hunt, 2003; Woo et al., 2010, 2013). However, we have not yet revealed the mechanism for the coevolution. It is crucial to resolve this problem in order to understand galaxy evolution. The connection between star formation (SF) and active galactic nuclei (AGNs) is also a key phenomenon to understand the coevolution, since this connection allows us to investigate the ongoing interaction between galaxies and SMBHs instead of the cumulative results. Therefore, we focus on the AGN-SF connection in this study.

The direct comparison between AGN and SF luminosities is one of the simplest ways to investigate the AGN-SF link. Based on the combined sample of local type-2 AGNs and quasars at $0.1 \leq z < 3$, for example, Netzer (2009) found a good correlation between AGN and SF luminosities, albeit with substantial scatter. Recently, using the deep *Herschel* imaging of the X-ray sources at $0.2 < z < 2.5$ in the fields of GOODS and COSMOS, Rosario et al. (2012) reported a characteristic trend between AGN and FIR luminosities. In their study, luminous X-ray AGNs at $z < 1$ show a correlation between AGN and FIR luminosities, as demonstrated in earlier works (e.g., Netzer, 2009), while the correlation flattens or disappears at $z > 1$. In contrast, they claimed that low-luminosity AGNs show essentially no correlation between FIR and AGN luminosities at all redshifts. The enhanced SF for a given AGN luminosity in their low-$z$ X-ray AGNs ($0.2 < z < 0.5$) seems to contrast with the findings of Netzer (2009), who found that local type-2 AGNs ($z \leq 0.2$) show a positive correlation between SF and AGN luminosities. This discrepancy may be caused by observational biases, e.g., the Malmquist bias. Therefore, in order to fully reveal the connection between AGN and SF activities it is crucial to examine potential biases which may impact the $L_{\rm FIR}$-$L_{\rm AGN}$ relation.

## 2. SAMPLE AND DATA

In this study, we focus on the local type-2 AGNs selected from the Sloan Digital Sky Survey (SDSS) based on the BPT diagram. To obtain FIR luminosities of type-2 AGNs, we cross-identified them against the AKARI/FIS all-sky survey bright source catalogue (Yamamura et al., 2010) and the PACS Evolutionary Probe (PEP) survey data conducted with the *Herschel* Space Observatory

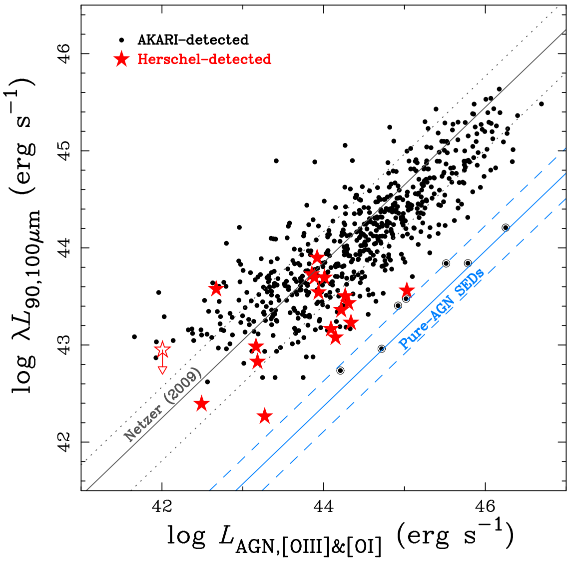


**Figure 1.** Correlation between FIR luminosity and AGN luminosity. The AKARI-detected and *Herschel*-detected objects are denoted with black circles and red-filled stars, respectively. The reference line from Netzer (2009) is represented by grey lines, assuming three different flux ratios, $F_{60\mu m}/F_{100\mu m}$; mean (solid line), minimum and maximum ratio (dotted lines), from Dale & Helou (2002). The pure-AGN sequence with the $1\sigma$ range is calculated from an intrinsic-AGN SED, shown as blue lines. Seven pure-AGN candidates are denoted with large circles.

(Lutz et al., 2011). Here we focus on 90$\mu$m and 100$\mu$m, where the AGN contribution to the FIR is believed to be negligible. Using SDSS spectroscopic data and FIR survey data, we investigate the relation between AGN and FIR luminosities over a wide dynamic range.

## 3. RESULTS AND DISCUSSION

In order to obtain the bolometric AGN luminosities, we adopted a recipe using the [O III]$\lambda$5007 and [O I]$\lambda$6300 line fluxes (Netzer, 2009). In Figure 1, we compare the FIR and AGN luminosities of our sample. We confirm that our result is consistent with that of Netzer (2009). In contrast, we do not find strong evidence of enhanced SF for a given AGN luminosity, as reported by Rosario et al. (2012) for low-luminosity AGNs, particularly at high redshifts, suggesting that low-luminosity AGNs are hosted by low-SF galaxies at the present time. Note that we did not include the composite populations in the BPT selection to avoid uncertainty in the bolometric-luminosity estimation.

We also find seven objects that are located on the pure-AGN sequence, shown as blue lines in Figure 1. Note that it is important to examine these objects as they are likely to be no- or low-SF AGNs. Based on spectral energy distribution (SED) analysis, we confirmed that these pure-AGN candidates are hosted by low-SF galaxies. The fraction of such objects appears to be small, $< 1\%$ in our sample. However, we suggest the possibility that this low fraction is the result of observational limitations. Figure 2 shows simulation results for the AKARI and *Herschel* surveys along with the observations. Our simulations clearly indicate that the flux limit of the AKARI survey is insufficient to explore AGNs hosted by low-SF galaxies, while the limited volume of the *Herschel* survey prevents us from detecting high-$L_{\rm AGN}$ and low-$L_{\rm FIR}$ sources. This means that current FIR surveys are not sufficient to examine whether or not low-SF AGNs at high $L_{\rm AGN}$ are really a rare population in the universe. Therefore, to understand the AGN-SF connection correctly, we require wide and deep next-generation FIR surveys (see Matsuoka & Woo, 2014, for more details).

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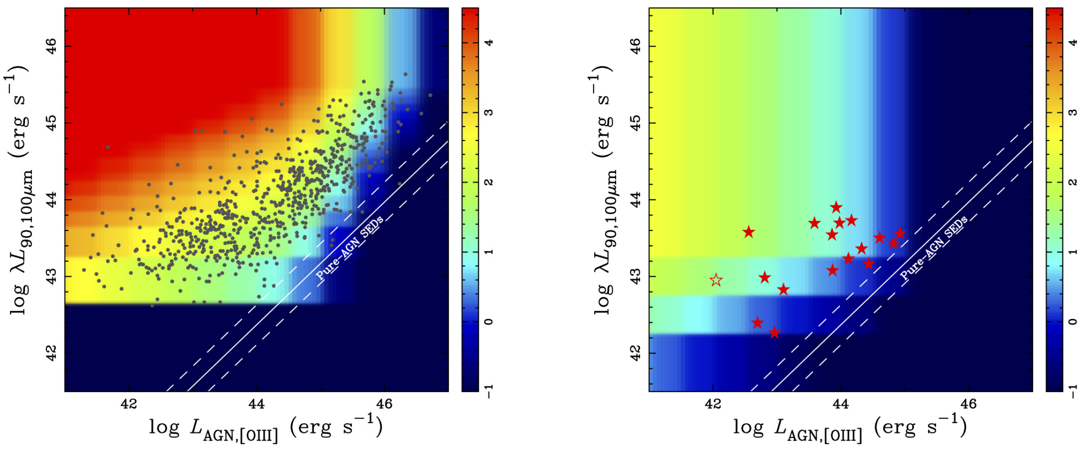


Figure 2. Simulations of the $L_{\mathrm{FIR}}$-$L_{\mathrm{AGN}}$ distribution, demonstrating the effect of the flux limits in the AKARI all sky survey (left-hand panel), and the limited volume of the *Herschel* survey (right-hand panel). The logarithmic number density is calculated for each area bin, and represented with different colours. For comparison, the AKARI and *Herschel* sources are also plotted with gray circles and red stars, respectively, while the pure-AGN sequence is denoted with white lines.