The symbiotic nature of AGN and SF activities of AGNs probed by the PAH 3.3 micron emission feature

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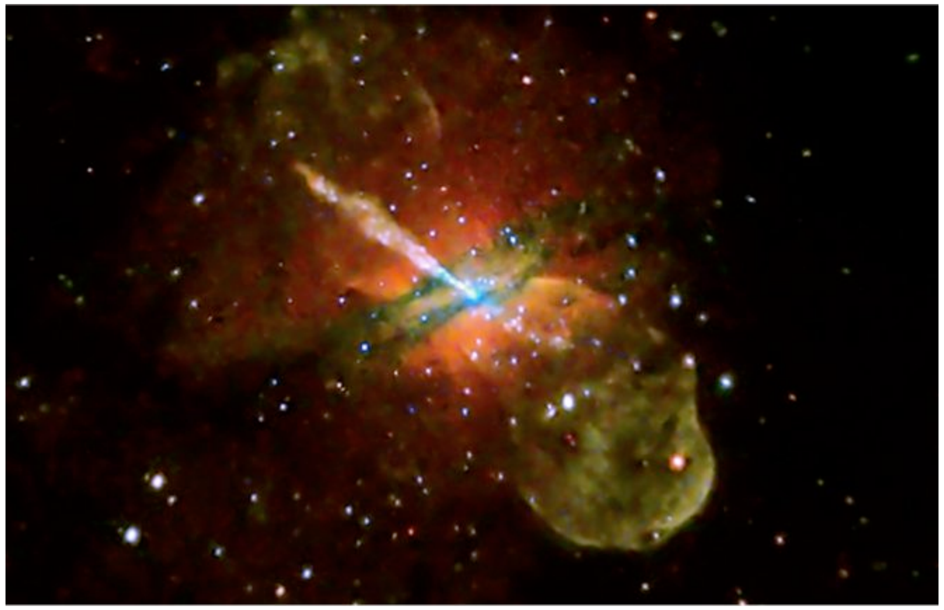
Along with Myungshin Im, Dohyeong Kim, Jong-Hak Woo, Marios Karouzos, Hyung Mok Lee, Myung Gyoon Lee, Hyunsung D. Jun, Dawoo Park (SNU), Masatoshi Imanishi (NAOJ), Takao Nakagawa, Hideo Matsuhara, Takehiko Wada, Toshinobu Takagi (ISAS/JAXA), Shinki Oyabu, Rika Yamada (Nagoya University), George Helou, Yong shi (IPAC/Caltech), Lee Armus, Hanae Inami (SSC/Caltech), and Youichi Ohyama (ASIAA)

June 3 2014 Seminar @

Super Massive Black Holes



- SMBHs are believed to exist in every bulge (Kormendy & Richstone1995; Ferrarese & Ford 2005).
- a tight correlation between black hole masses with host galaxy properties (Gebhardt et al. 2000; Marconi & Hunt 2003; Häring & Rix 2004; Gültekin et al. 2009)
- the co-evolution of black holes and their host galaxies
- AGN feedback within hierarchical galaxy merging scenarios regulates the co-evolution of SMBHs and their host galaxies (Volonteri et al. 2003; Springel et al. 2005; Croton et al. 2006; Hopkins et al. 2007, 2009).

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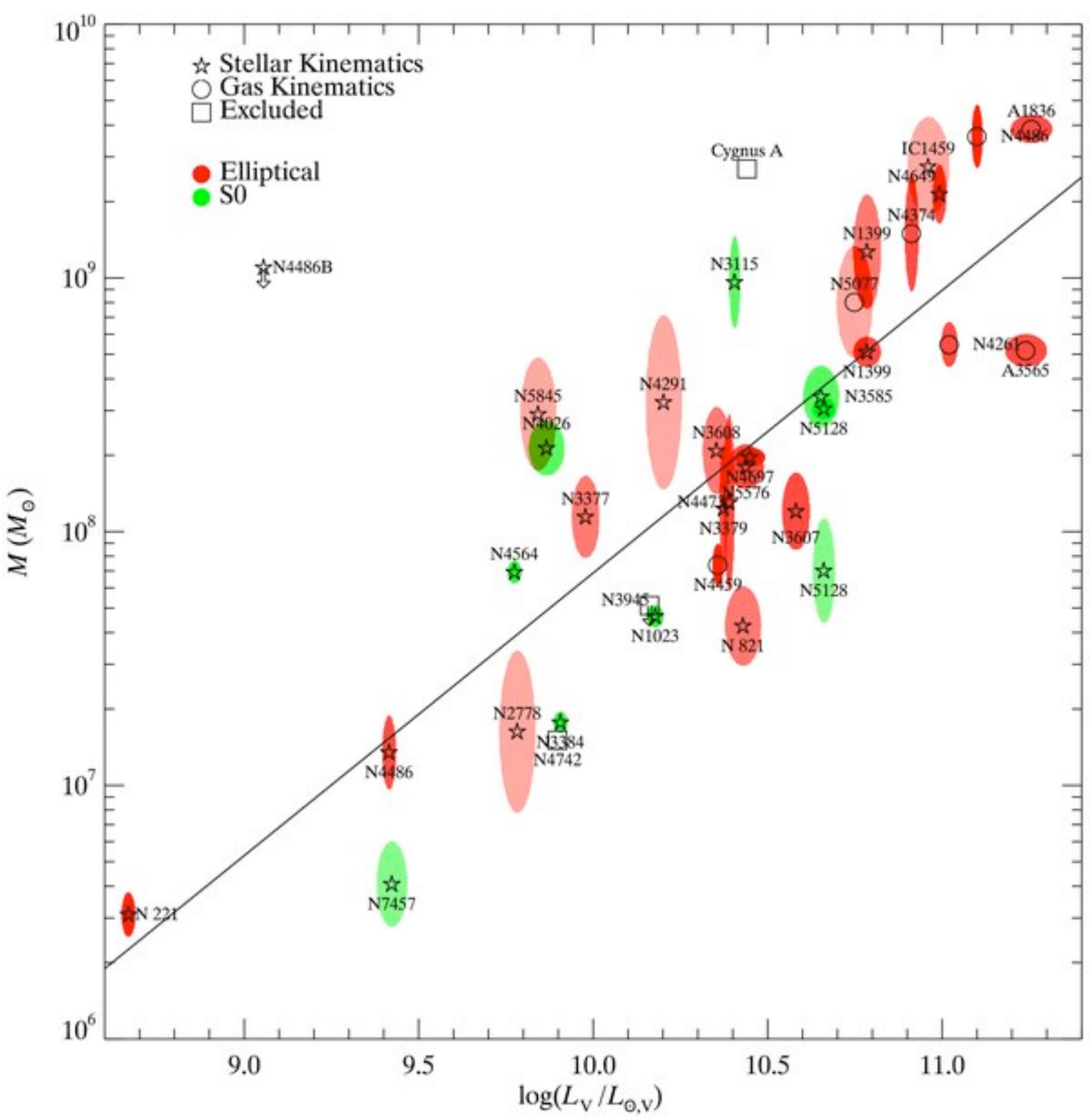

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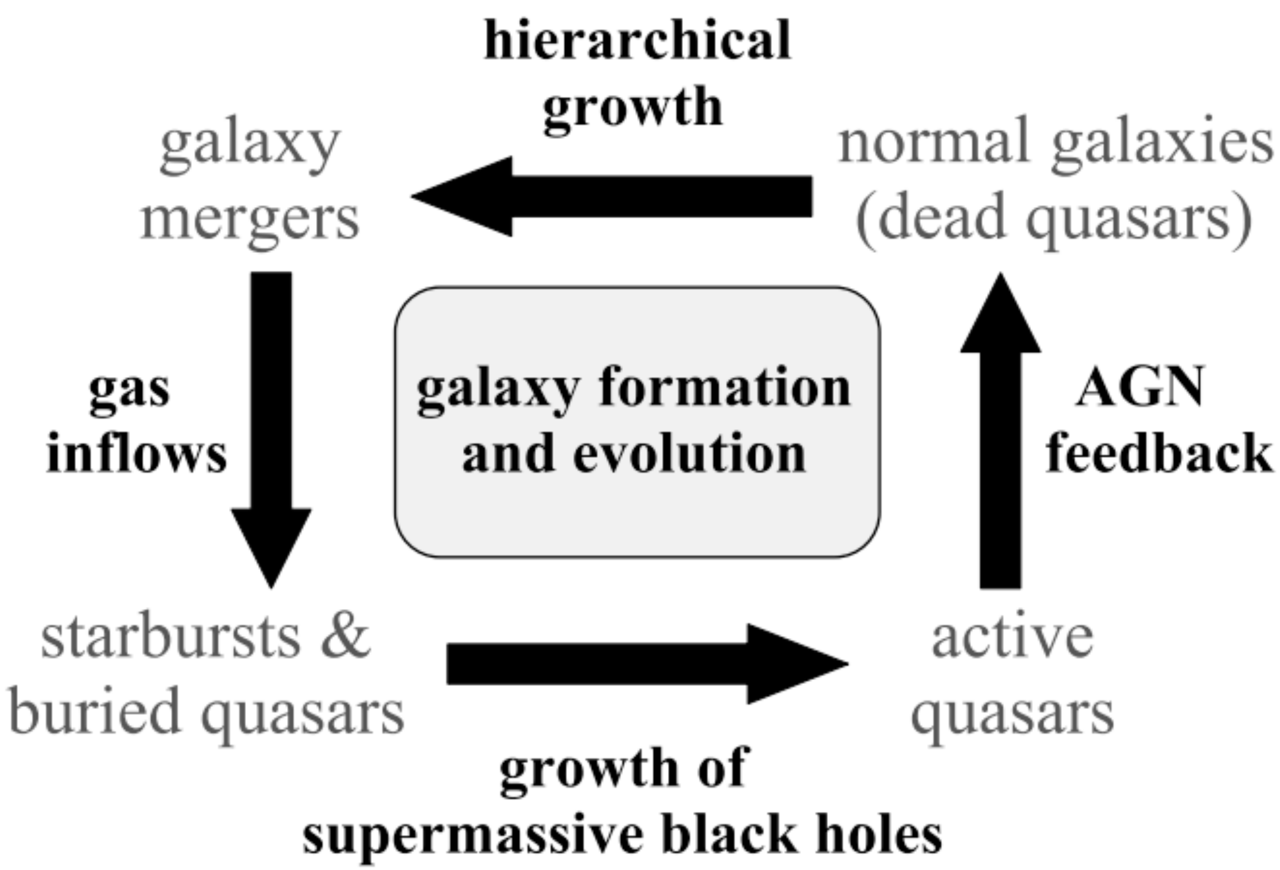
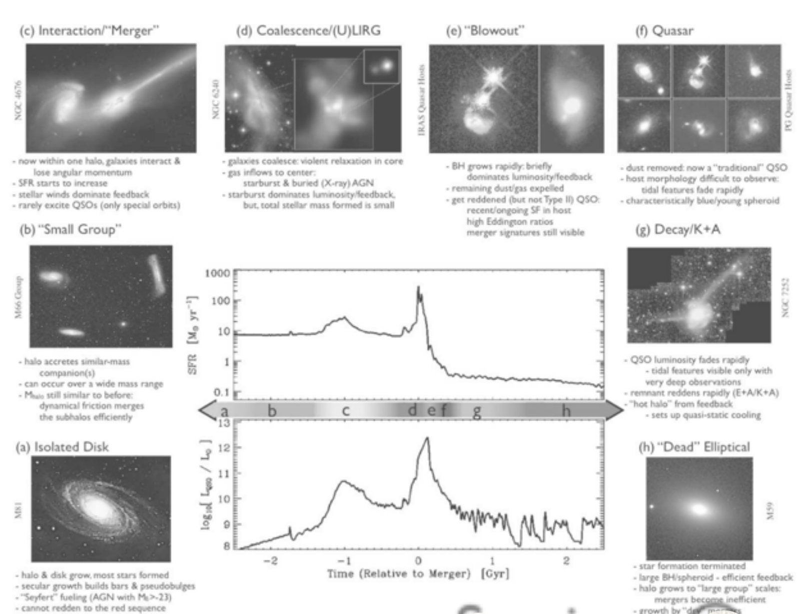


Hopkins et al. (2006)



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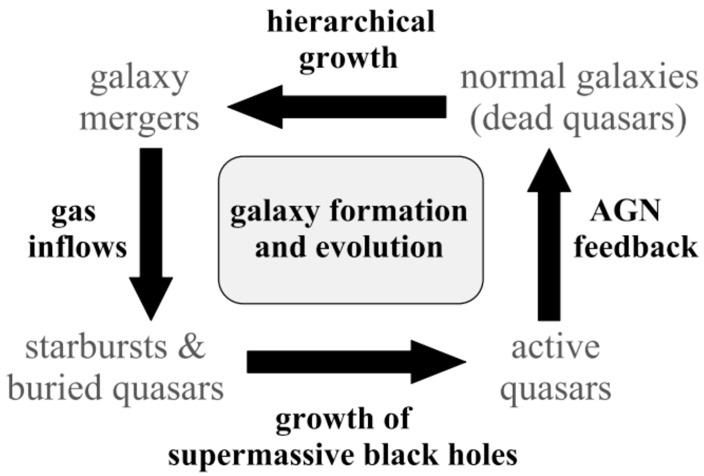

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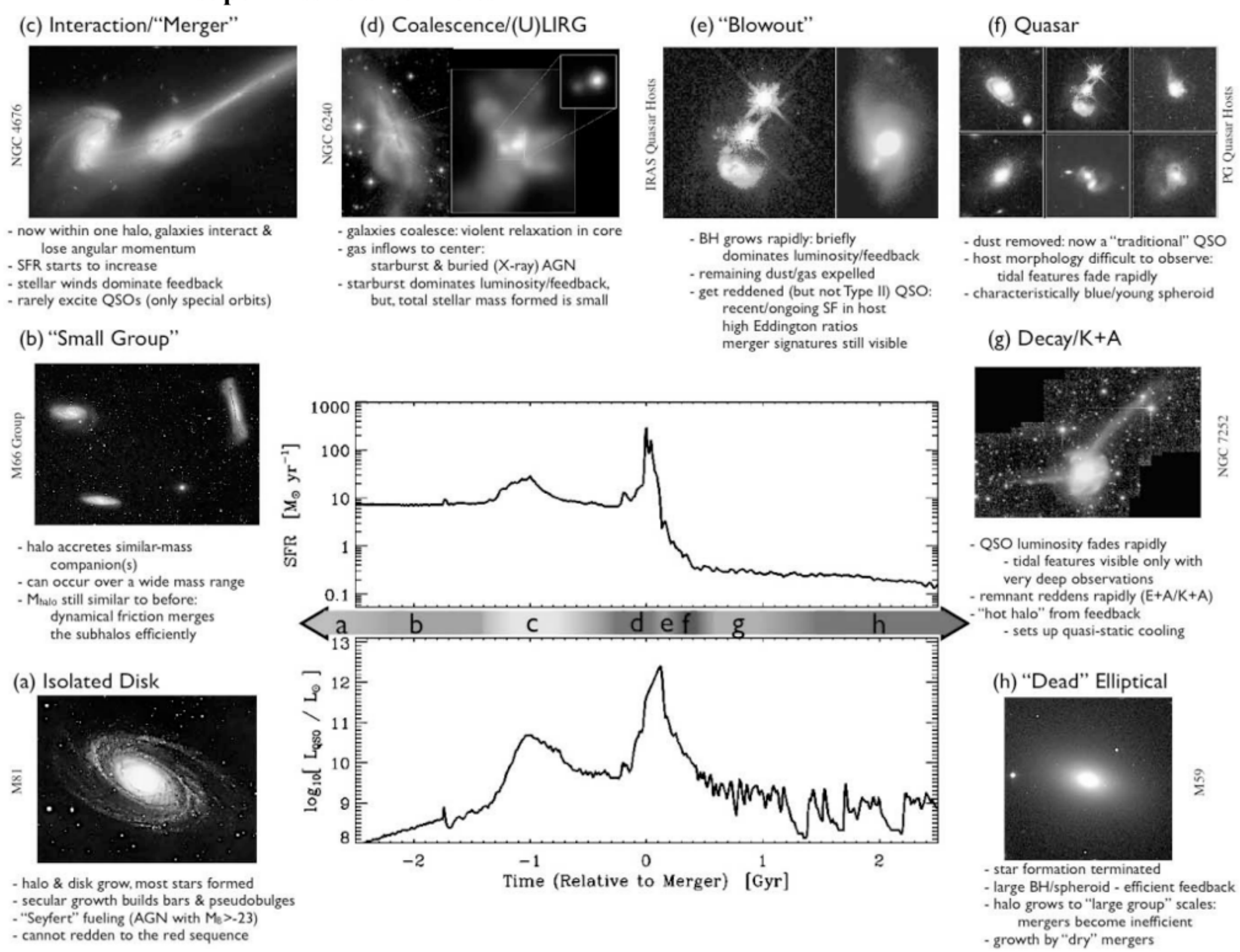
2. time offset : Star formation occurs in the early stages of a merger, while BH growth occurs in the later stage.

3. regulated growth : SF and AGN occur in different events, but one regulates the other.



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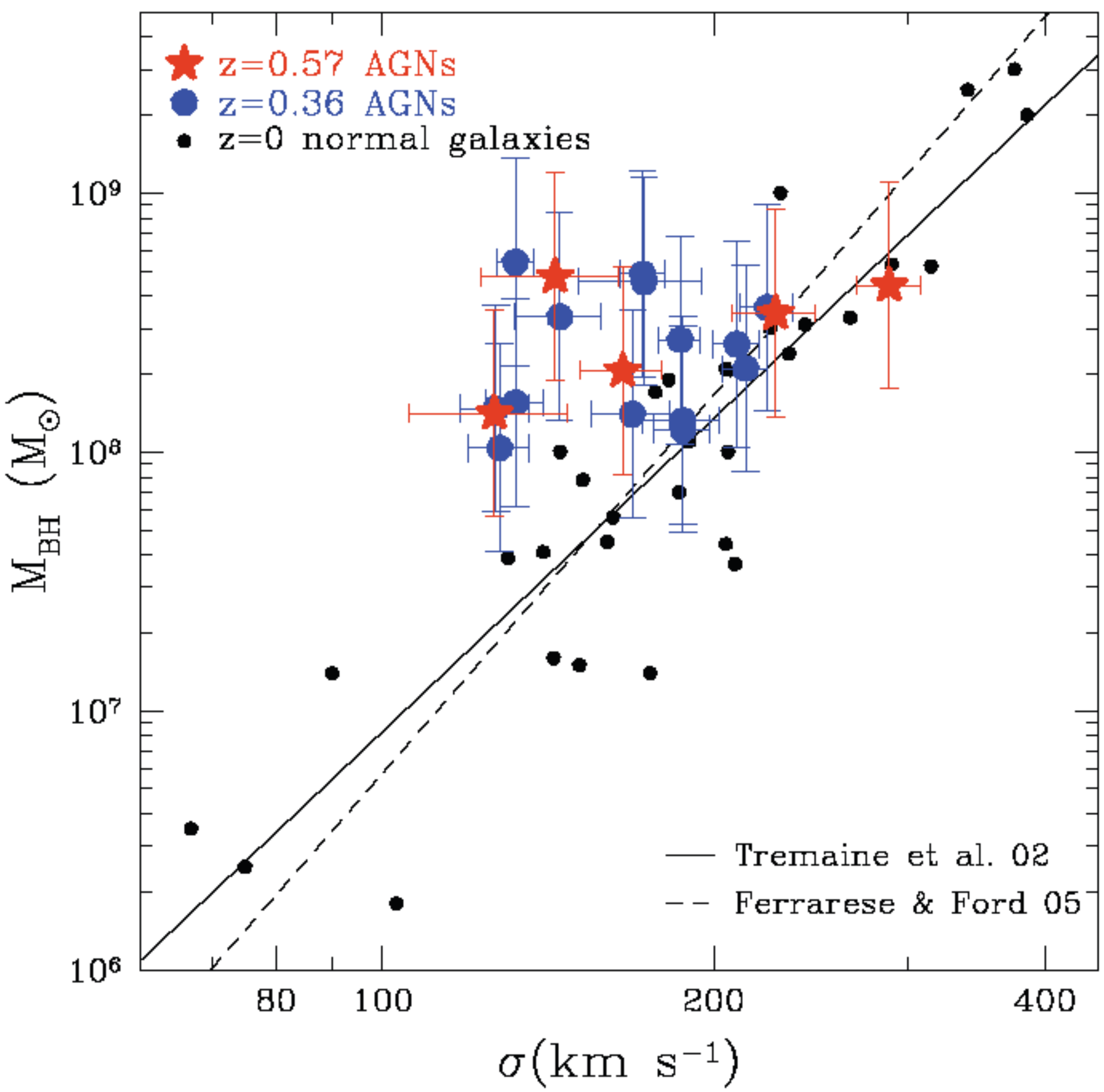
Hopkins et al. (2008)

Super Massive Black Holes



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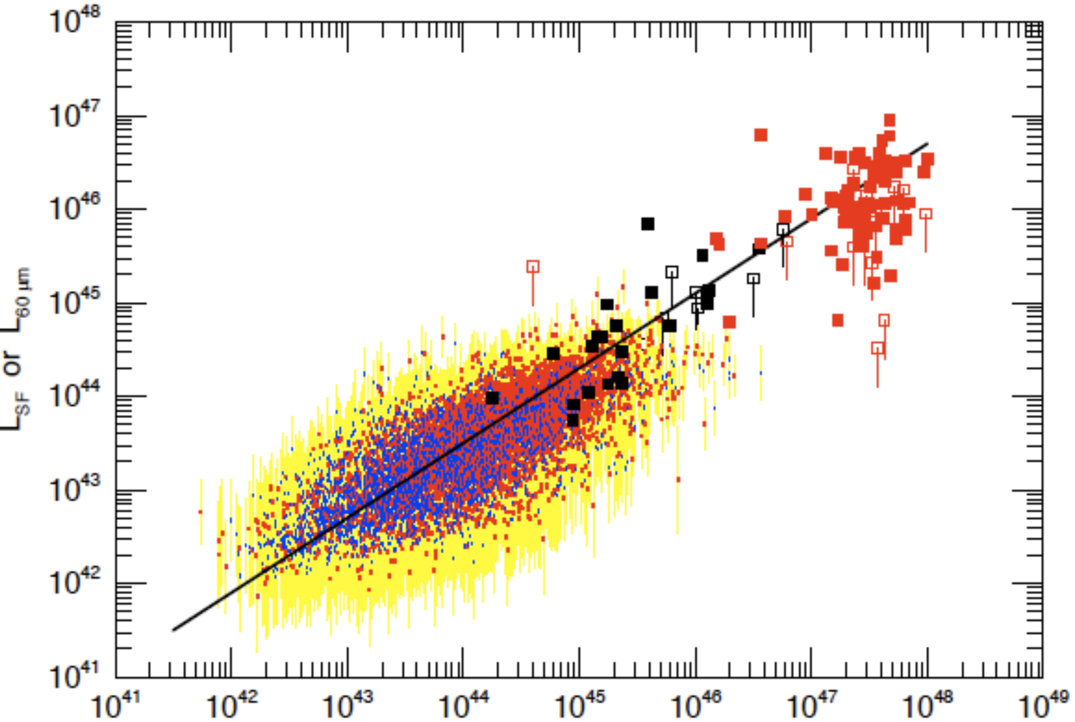
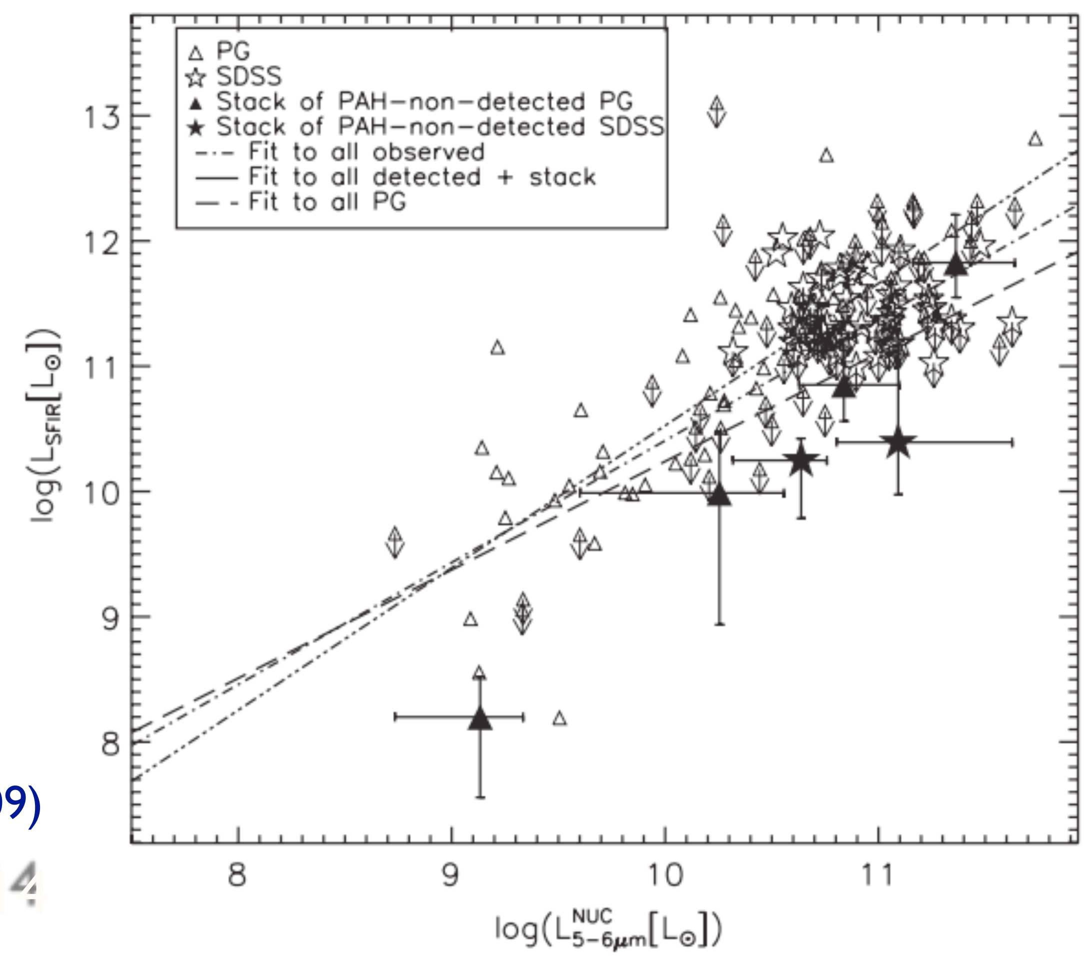
Star Formation vs Active Galactic Nuclei



Netzer et al. (2009)



Shi et al. (2009)

- It is observationally challenging due to their hugely different size scales and the domination of the UV emission and hydrogen recombination lines by UV flux from AGN.
- In general, most studies based on PAH measurement, especially space telescopes show a strong positive correlation between SF and AGN activities (Imanishi & Wada 2004; Schweitzer et al. 2006; Maiolino et al. 2007; Netzer et al. 2007, 2009; Lutz et al. 2008; Shi et al. 2009; Oi et al. 2010; Sani et al. 2010).
- No AGN feedback working? Or is positive feedback working?

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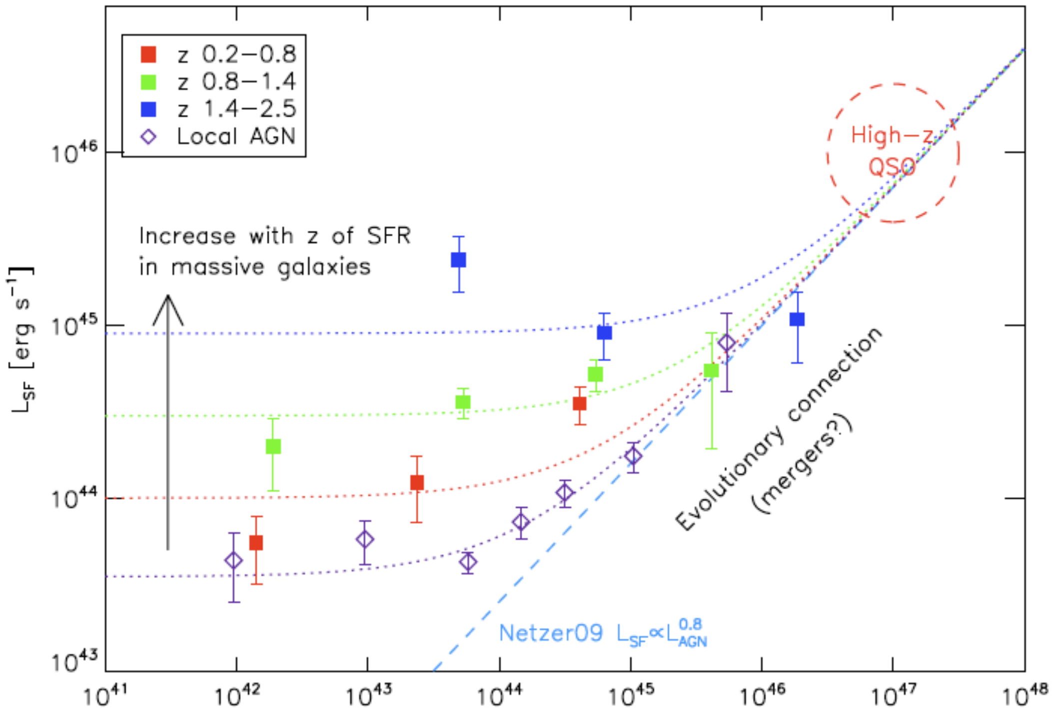
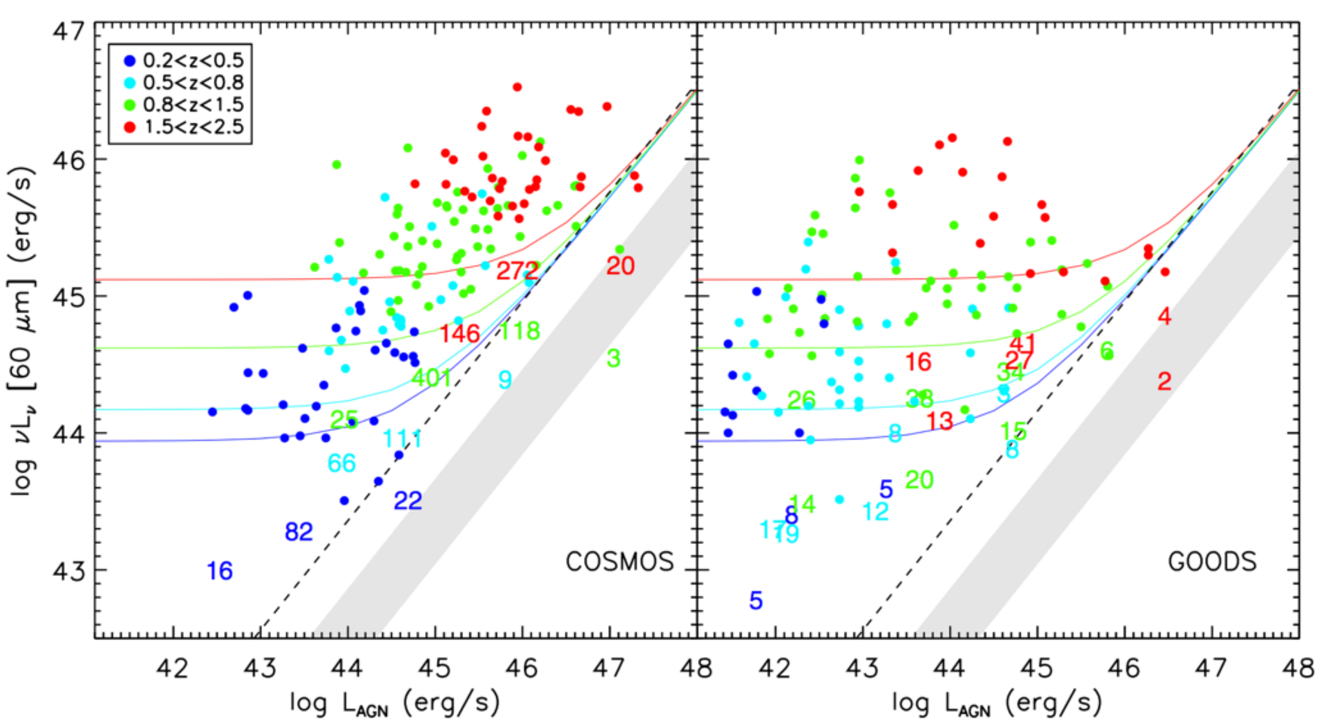


Shao et al. (2010)

D. J. Rosario et al.: SFR of X-ray selected active galaxies



Rosario et al. (2012)

- In general, most studies based on PAH measurement, especially space telescopes show a strong positive correlation between SF and AGN activities.
- No AGN feedback working? Or, is it working?
- Most X-ray based surveys show a correlation between SF and AGN activities for most luminous AGN at low- and intermediate-z, while indicate no correlation for low luminous AGNs (Lutz et al. 2010; Shao et al. 2010; Mullaney et al. 2012; Rosario et al. 2012).

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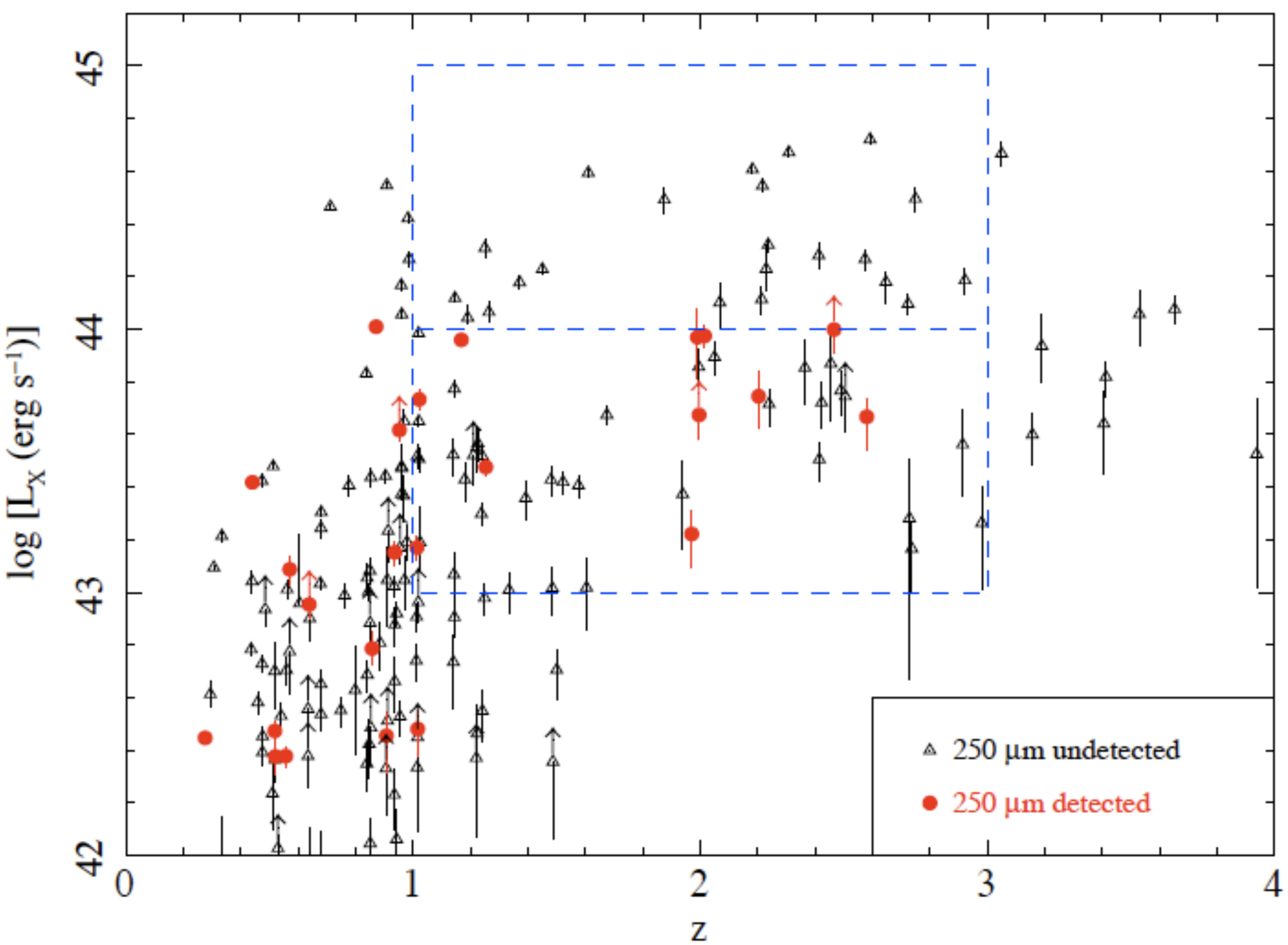

Page et al. (2012)

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- No AGN feedback working? Or, is it working?
- Page et al. (2012) is the strongest example of negative feedback.
- Based on *Chandra* and *Herschel*-SPIRE of CDF-N, Page claims t the mean SFRs of luminous AGNs at z ≈1–3 are significantly lower than those of moderate-luminosity AGNs.

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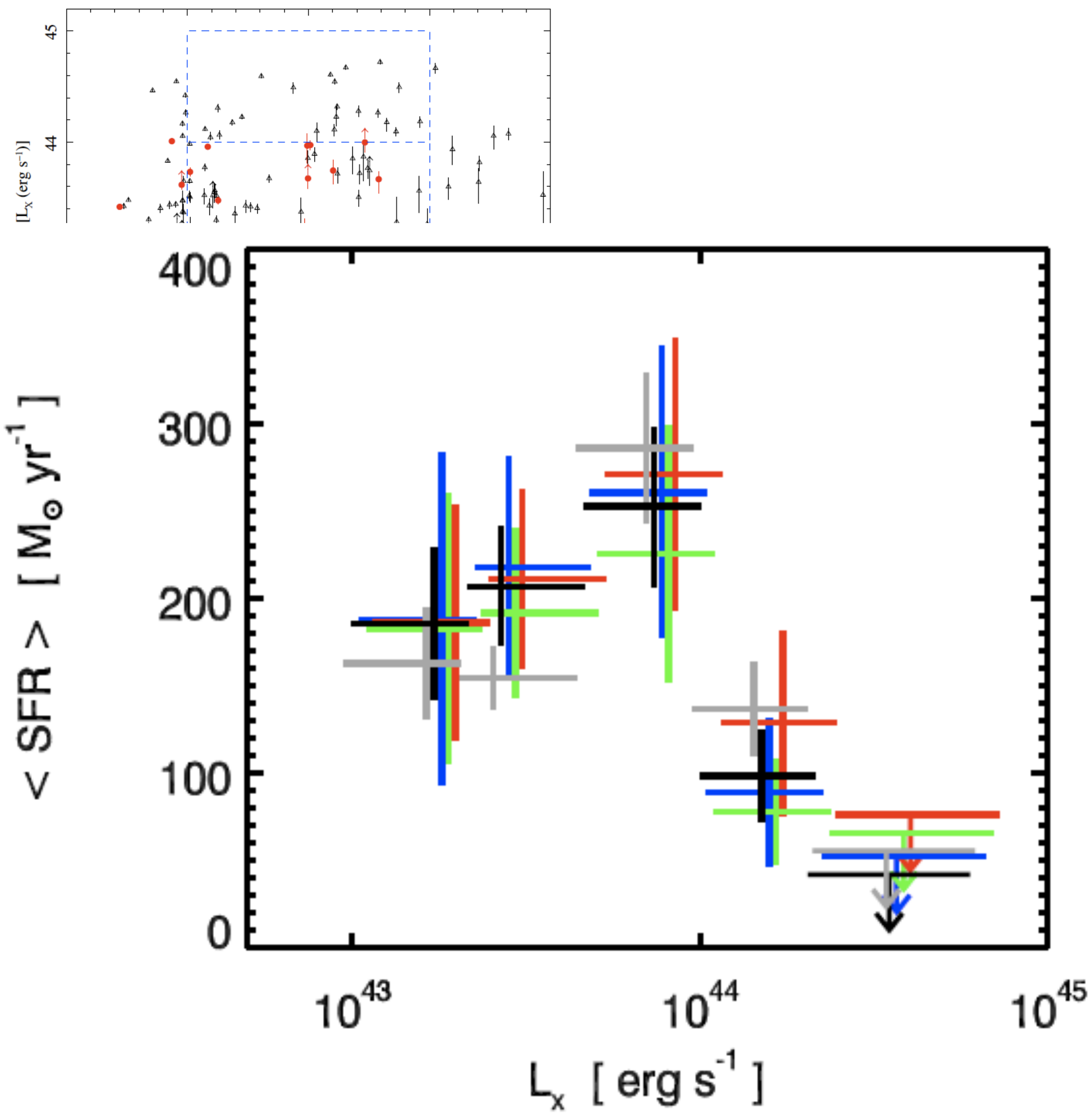

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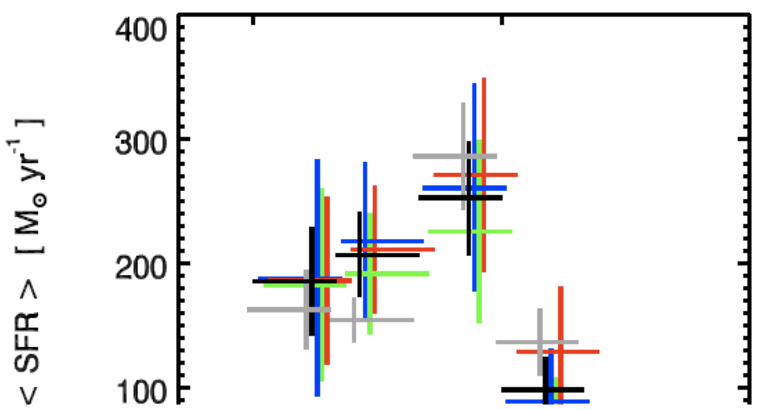

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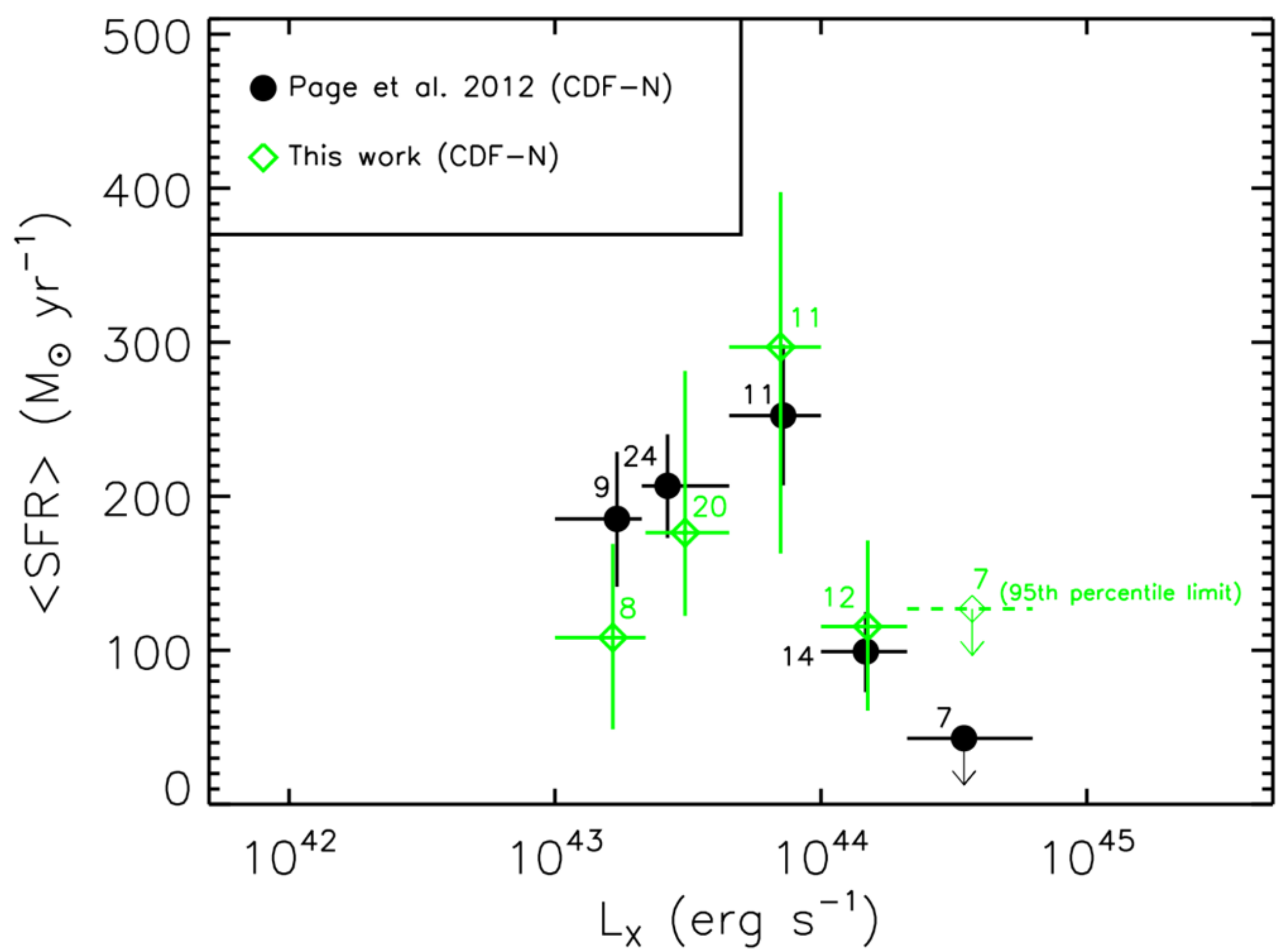


Harrison et al. (2012)

- Probing the direct connection between star formation and AGN is crucial to understand the coevolution of BHs and their hosts.
- No AGN feedback working? Or, is it working?
- Page et al. (2012) is the strongest example of negative feedback.
- Or, is it really?
- Harrison et al. (2012) claims that they do not see it from a wide area which include CDF-N & S, and COSMOS.

Issues on SF vs AGN activities

- Regarding the co-evolution of SMBHs and their host galaxies, what is the correlation between SF and AGN activities, i.e. if it is really positive, or not? Or does it matter?
- In terms of SF activity, are we looking at nuclear SF activity, or global SF activity, i.e SF within entire host galaxies?
- Are SFR indicators reliable? Or, can we believe in monochromatic infrared luminosities as robust SFR indicator?
- Any dependency of the correlation on morphological types of host galaxies, and the presence of radio jets ?

Infrared Star Formation Rate (SFR) indicator

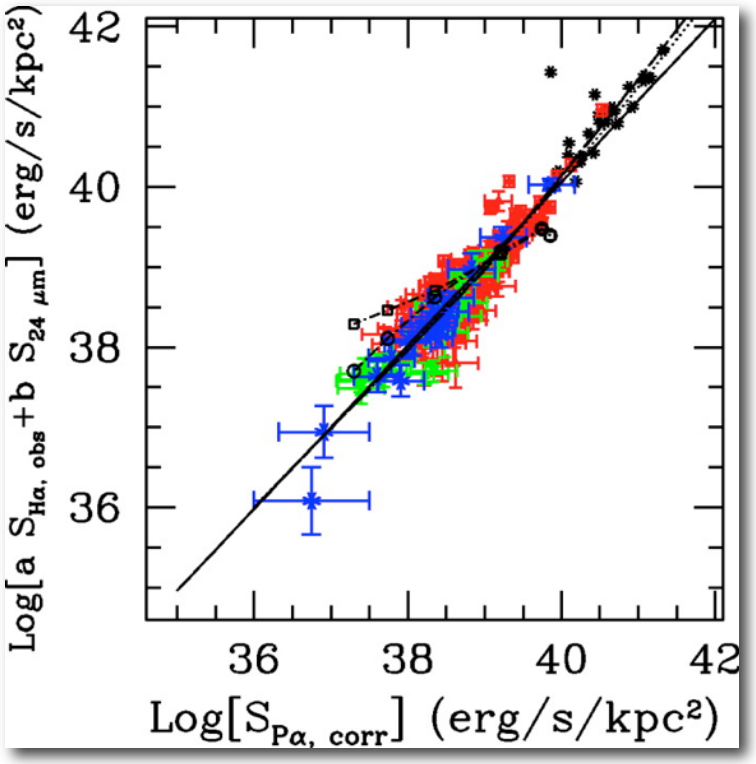
1. The bolometric IR luminosity with in 5 μm < λ < 1000 μm, L_{IR} is attributed to the dust obscured star formation in a galaxy.

2. SFR(TIR) = 2.8×10^{-44}L(TIR) for a stellar population undergoing constant star formation over τ=100 Myr (Kennicutt 1998).

3. Two issues

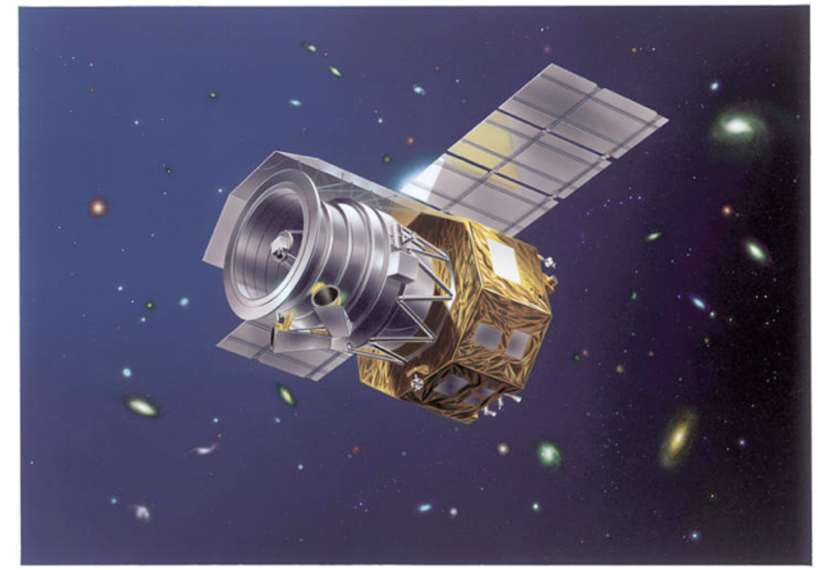
i. sparse sampling of SED, especially for high-z galaxies

ii. dust heating from evolved stellar populations : stochastically-heated dust from both young and evolved stellar populations for monochromatic indicators shortward of 15 ~ 20 μm (e.g., Boselli et al. 2004; Calzetti et al. 2007; Bendo et al. 2008) and increased contribution from low-mass and long-lived stellar populations to longward of around 70 μm



Calzetti et al. (2007)

The 3.3 µm PAH as SFR Indicators

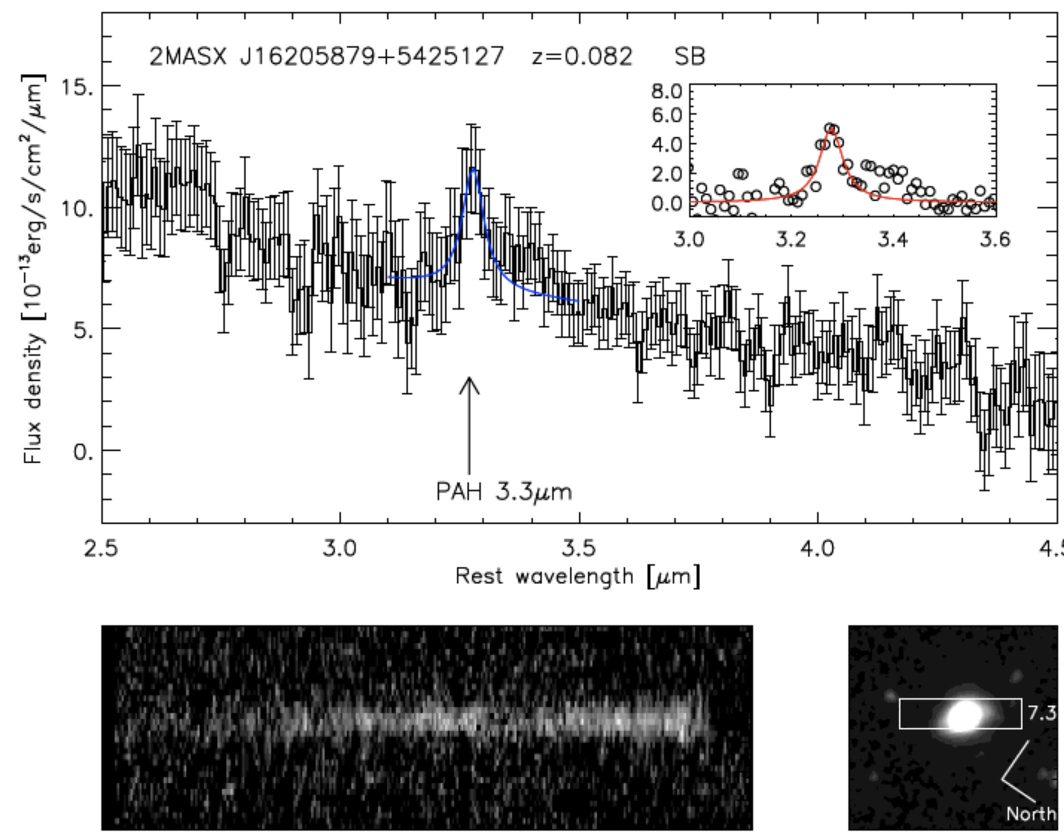


1. AKARI mJy Unbiased Survey of Extragalactic Sources in 5MUSES (AMUSES)

2. Its scientific goal is to construct a continuous infrared spectral library of 5MUSES sample over 2.5 ~ 40 µm utilizing slit-less spectroscopy capability of AKARI telescope.

3. The 3.3 µm PAH is the weakest amongst the various PAH emission features, but the only dust emission feature accessible to JWST at high-redshifts (z > 4.5) galaxies.

4. We detect the 3.3µm PAH emission feature from three (!) out of 20 sources.



Kim et al. (2012)

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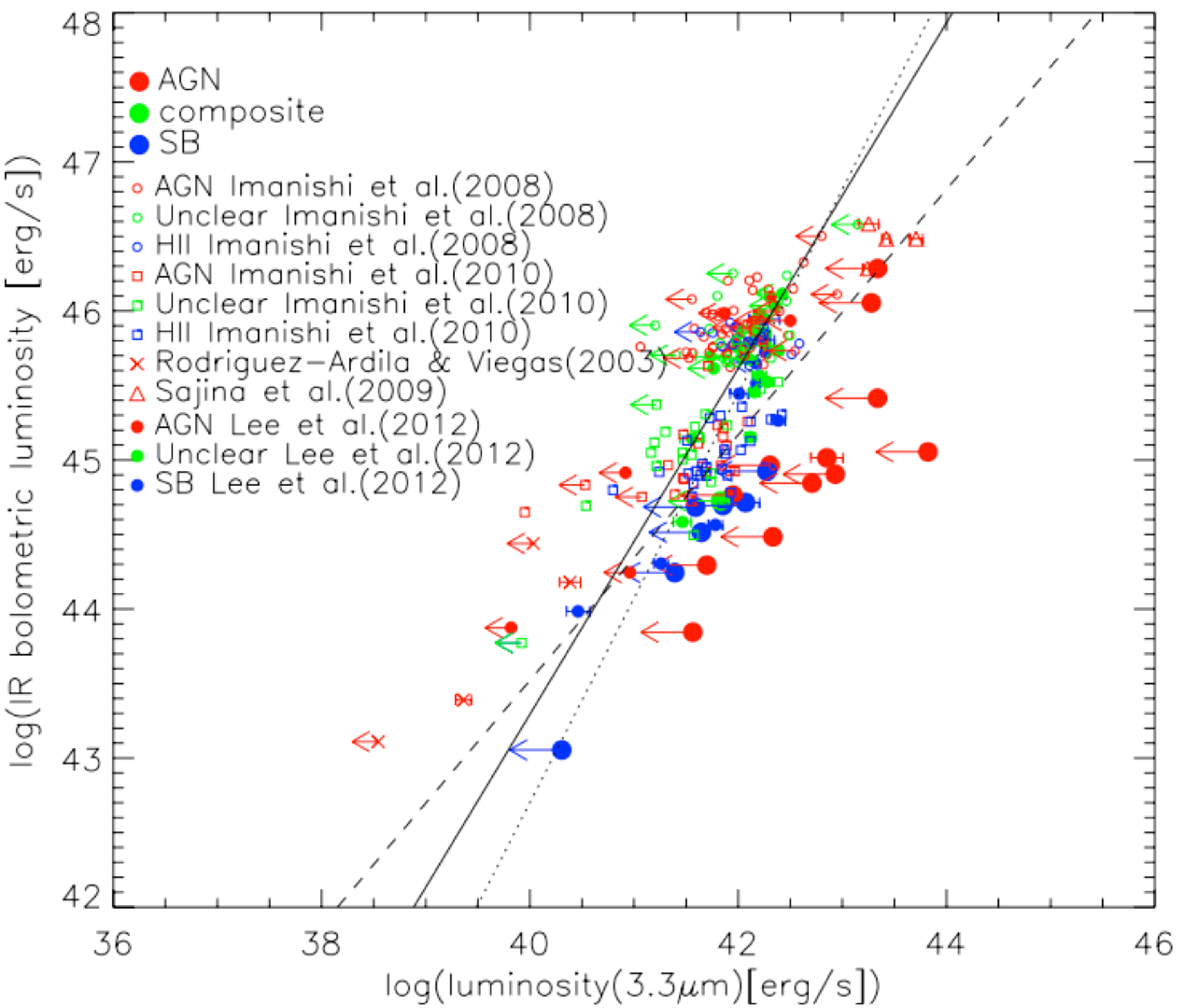

$\log(L_{IR}) = (1.16 \pm 0.30) \times \log(L_{PAH3.3}) - (3.11 \pm 0.34)$ for the detections of the combined sample

the deviation of ULIRGs ?

1. non-star-forming contribution to LIR, such as AGN activity and heavily obscured YSOs

2. destruction of PAH molecules by ULIRGs

Kim et al. (2012)

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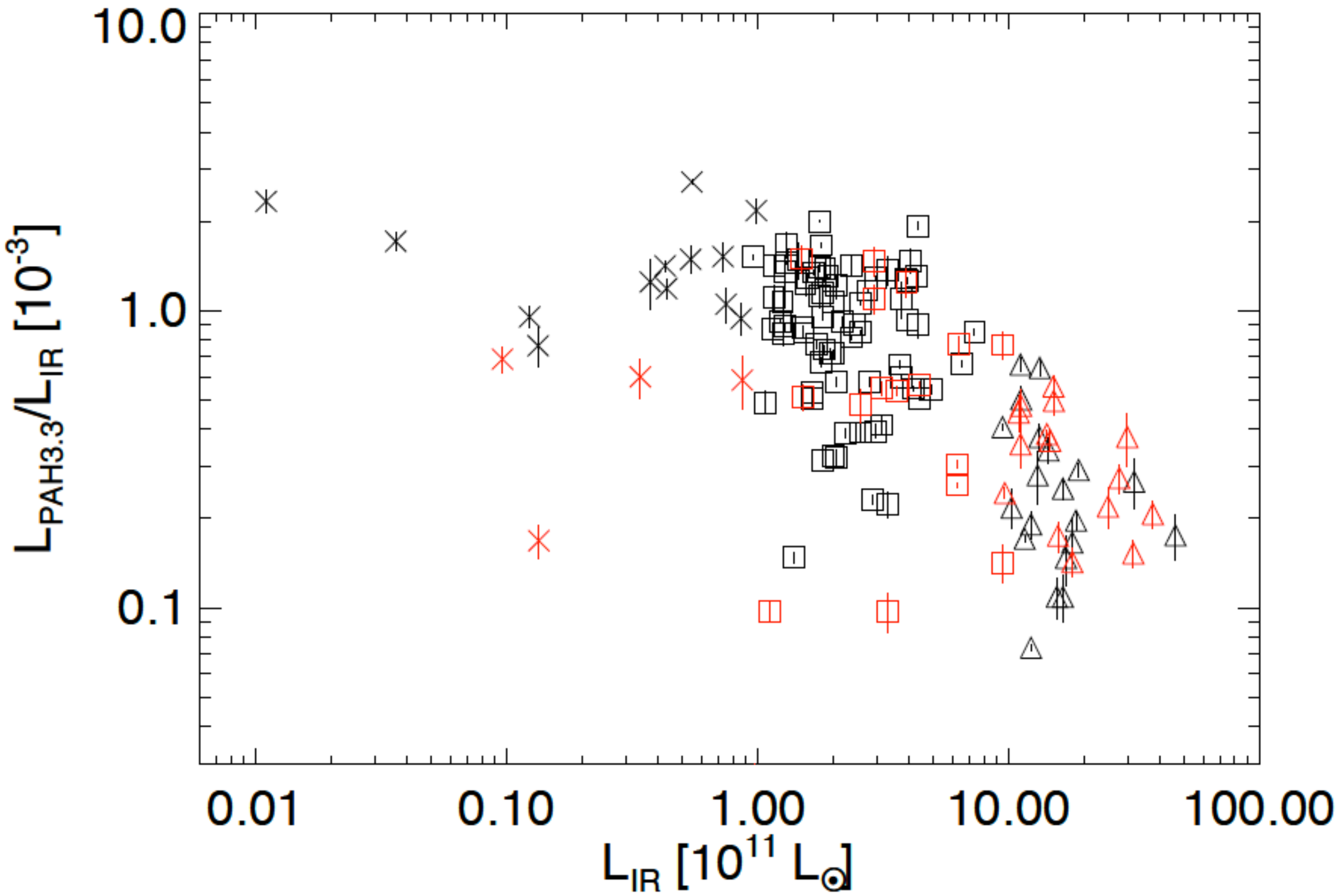

Yamada et al. (2013)

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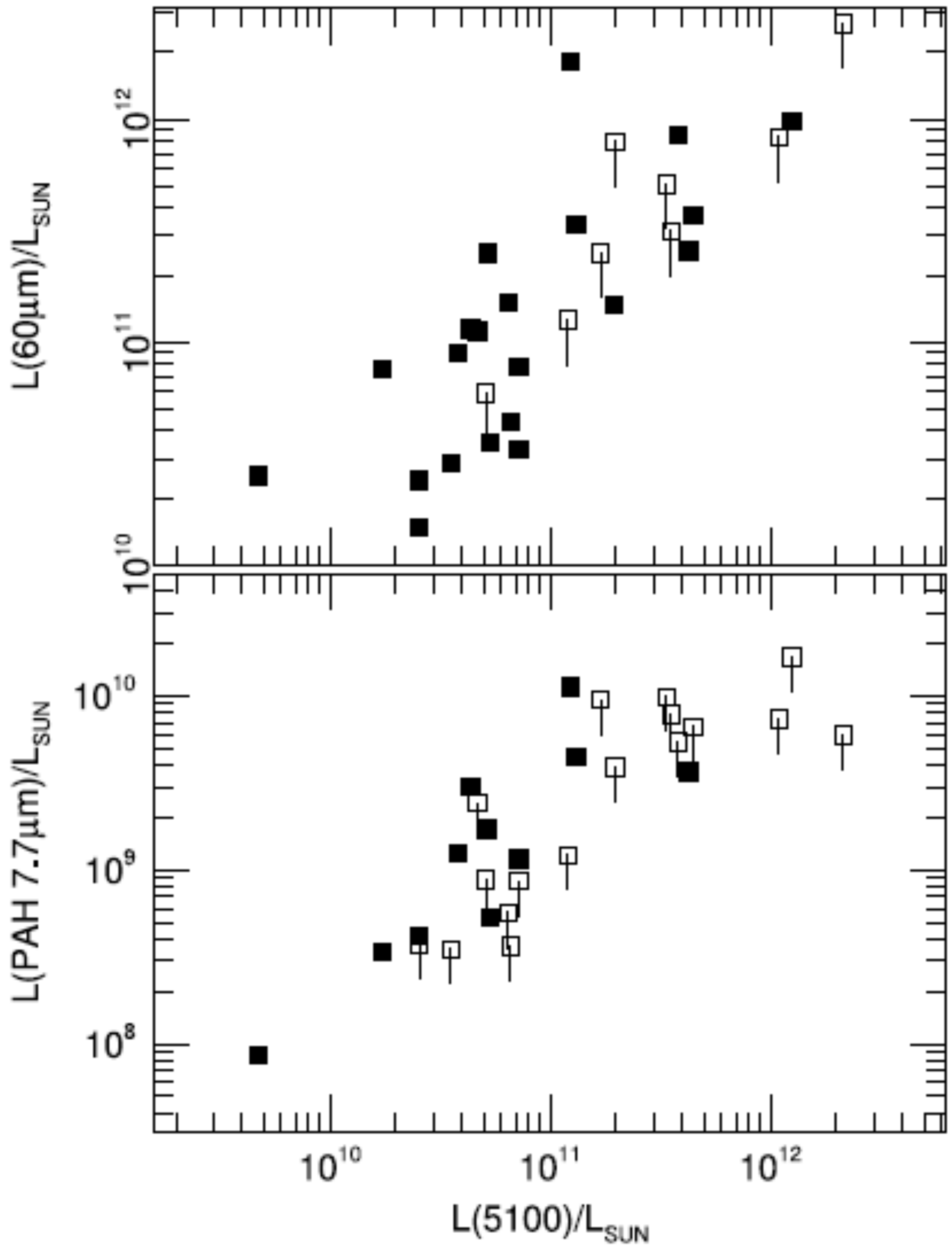

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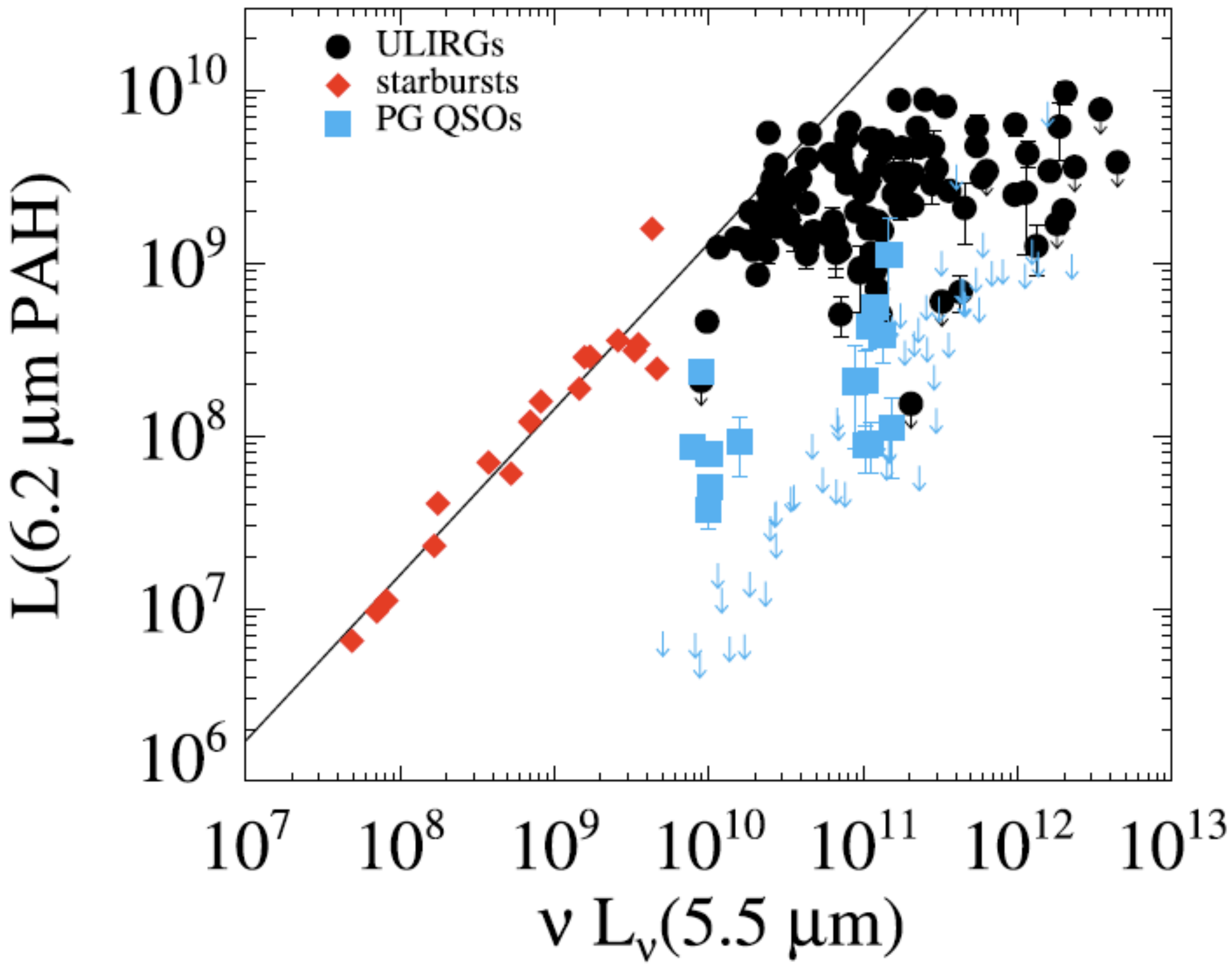

Desai et al. (2007)

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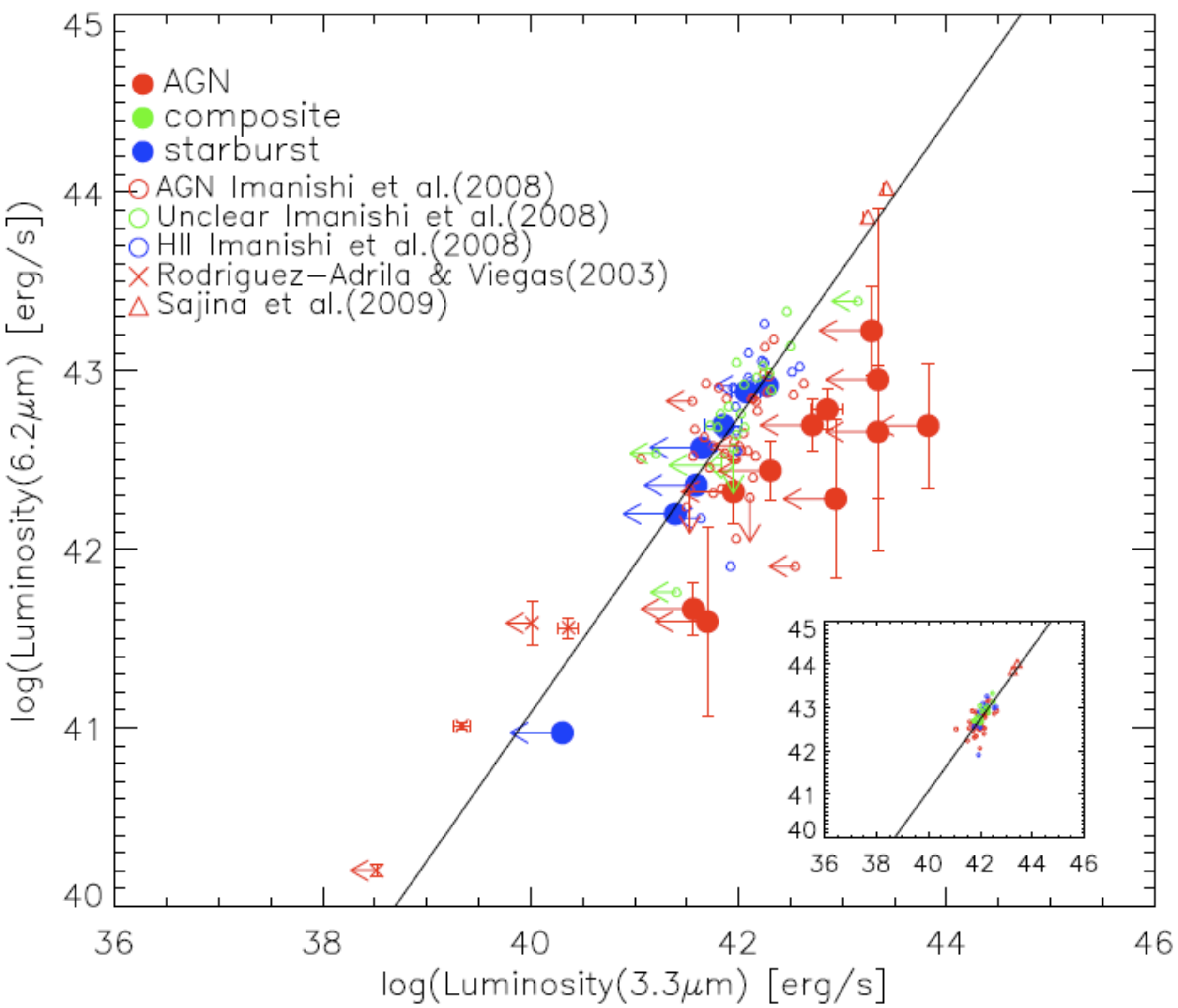


Kim et al. (2012)

$\log(L_{PAH6.2}) = (0.83 \pm 0.06) \times \log(L_{PAH3.3}) + (7.88 \pm 0.41)$ for the detections of the combined sample

No deviation of ULIRGs

Still not a unity. Different origins of PAH features (van Diedenhoven et al. 2004) ?

1. The 6.2 μm and 7.7 μm PAH emission features are originated from PAH cations.

2. The 3.3 μm PAH feature is attributed to neutral and/or negatively charged PAH molecules like the 11.3 μm PAH feature.

Application to LQSONG

- The Low-redshift Quasar Spectroscopic Observation in Near-infrared Grism : a mission program of AKARI
- Two subsamples

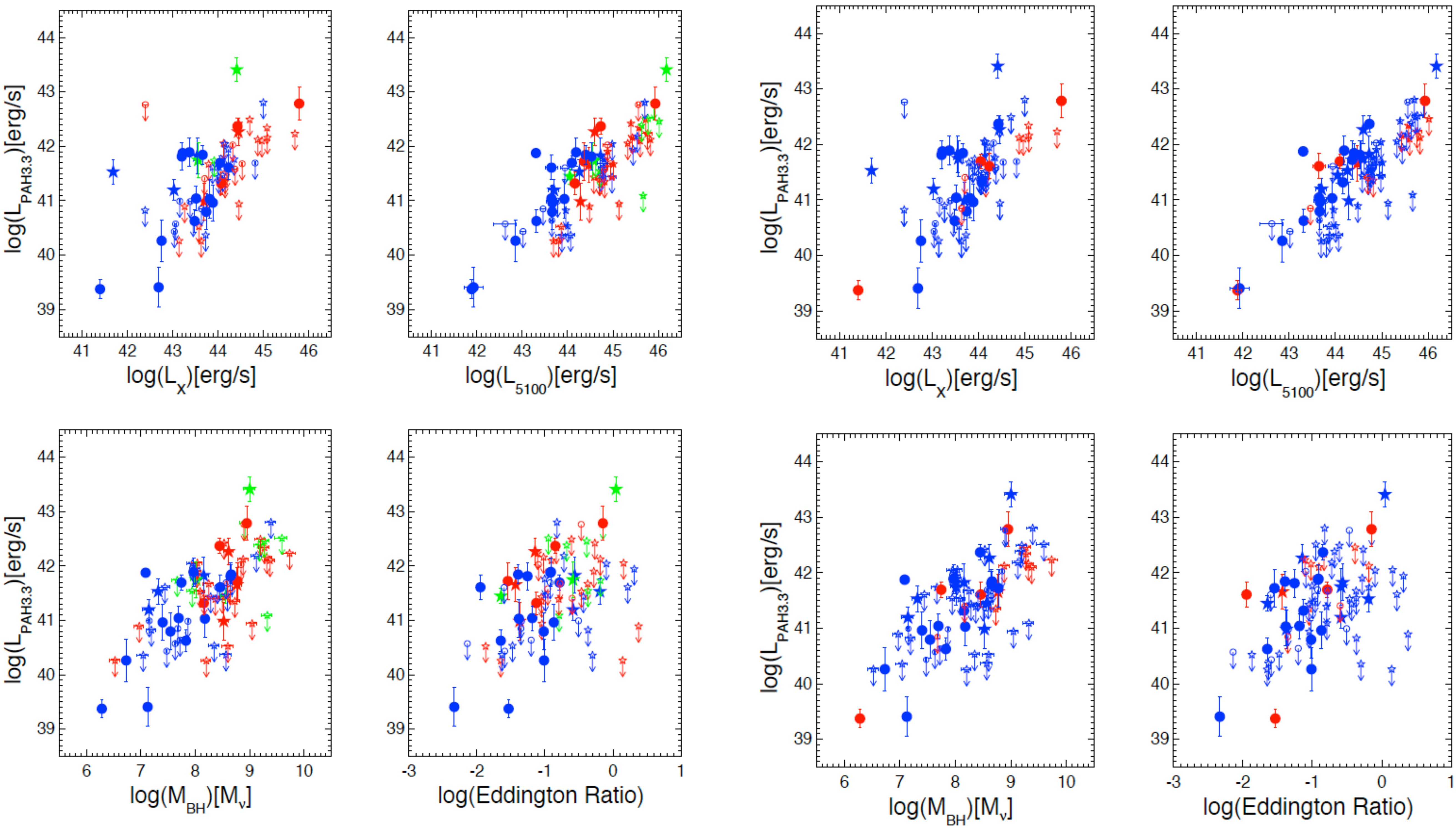
1. bright type-1 AGN and QSOs with BH masses measured by reverberation mapping method - 31 objects
2. Palomar-Green QSO sample - 49 objects

- Even higher detection rates than AMUSES

3. ~60% (18 out of 31) for the reverberation-mapped sample
4. ~20% (9 out of 49) for the PG-QSO sample

- The detection rate is higher than the previous studies of AMUSES (Kim et al. 2012), or Woo et al. (2012), but lower than other studies targeting hidden AGN populations (Imanishi et al. 2008, 2010).

AGN probes versus PAH 3.3 μm



Kim et al. (*in prep*)

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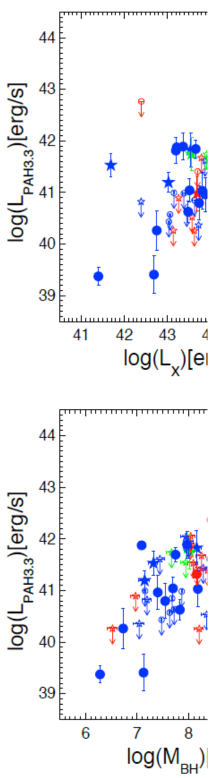

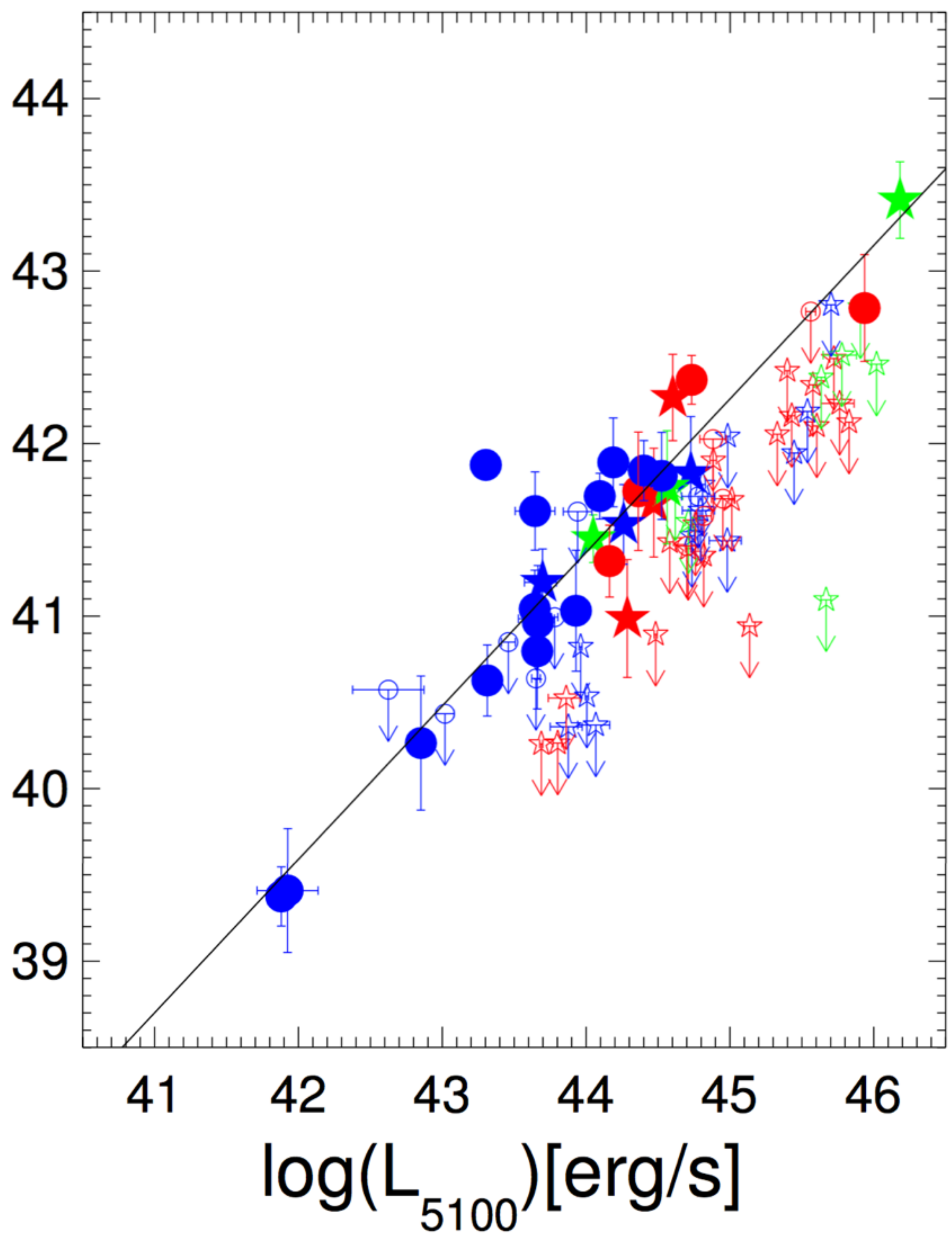

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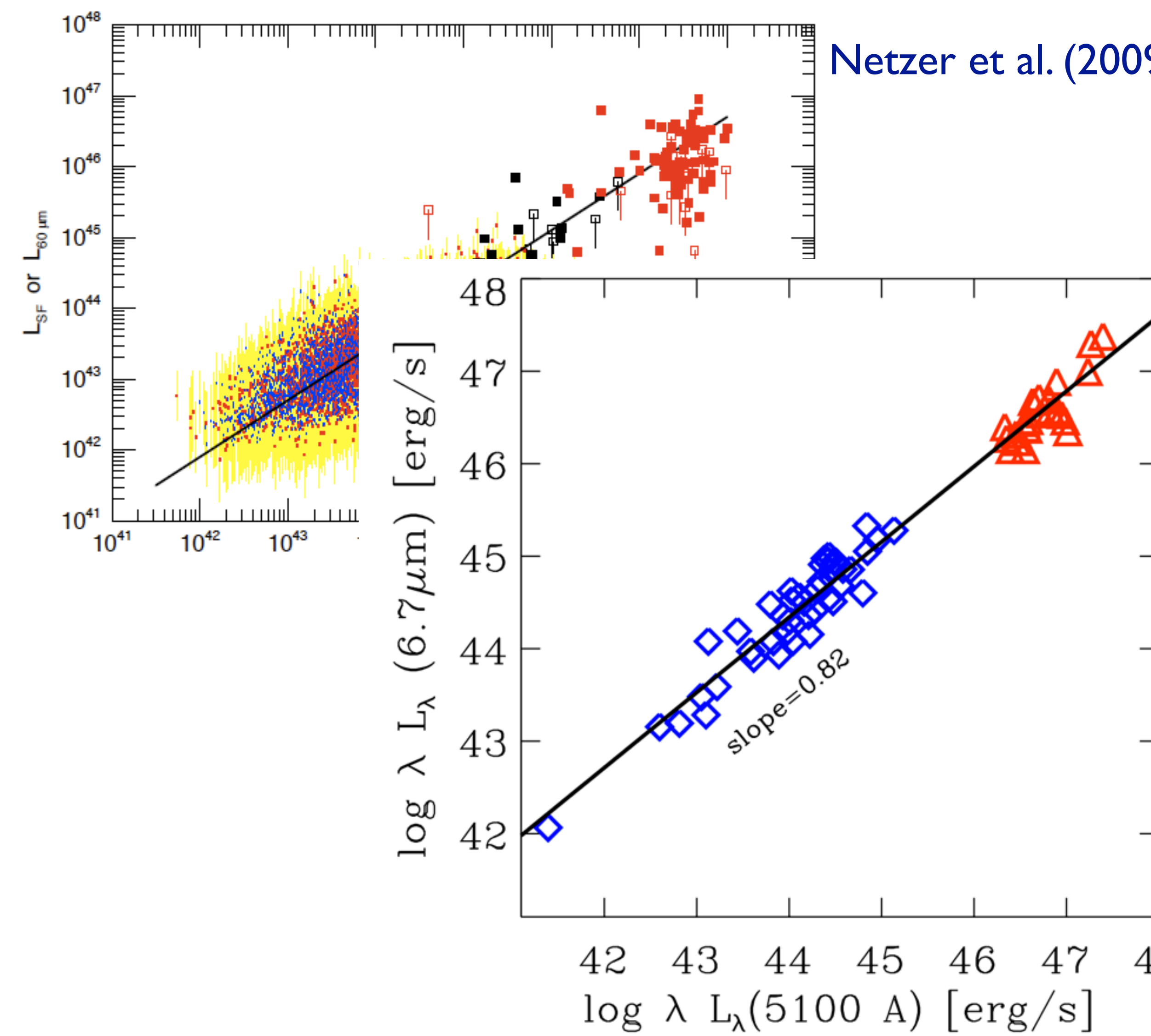


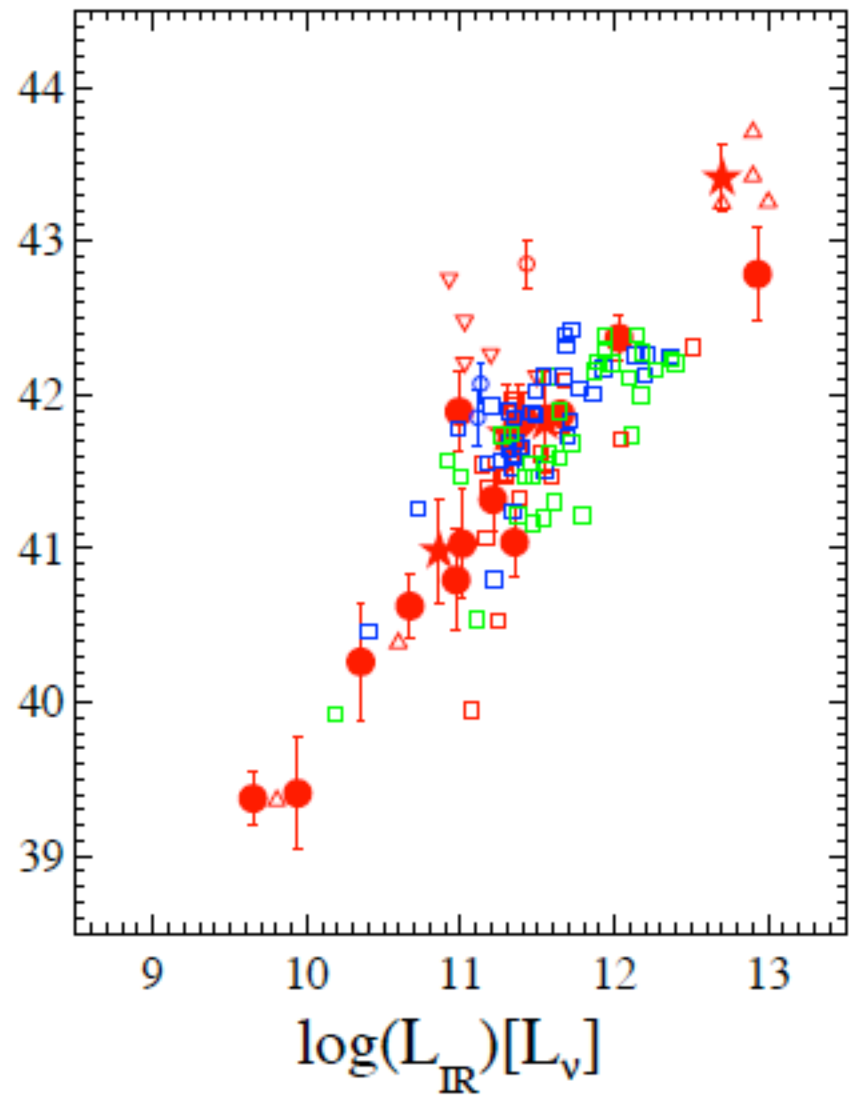
Netzer et al. (2009)

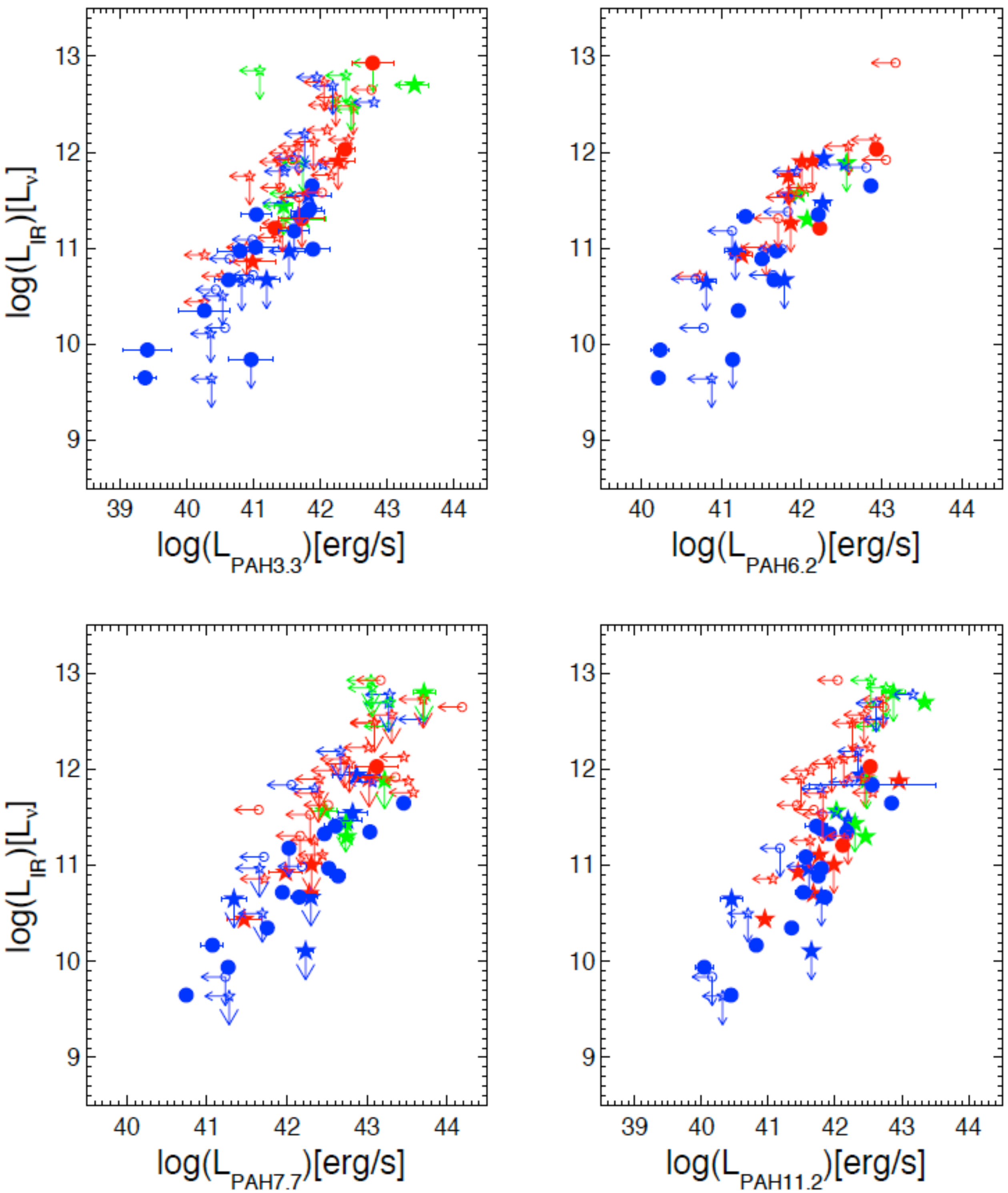
Maiolino et al. (2007)

- $L_{SF} \propto L_{AGN}^{0.89}$

- Slope values from previous studies range between 0.8 and 0.84 (Maiolino et al. 2007; Netzer et al. 2009; Zubovas et al. 2013).

Infrared luminosity versus PAHs





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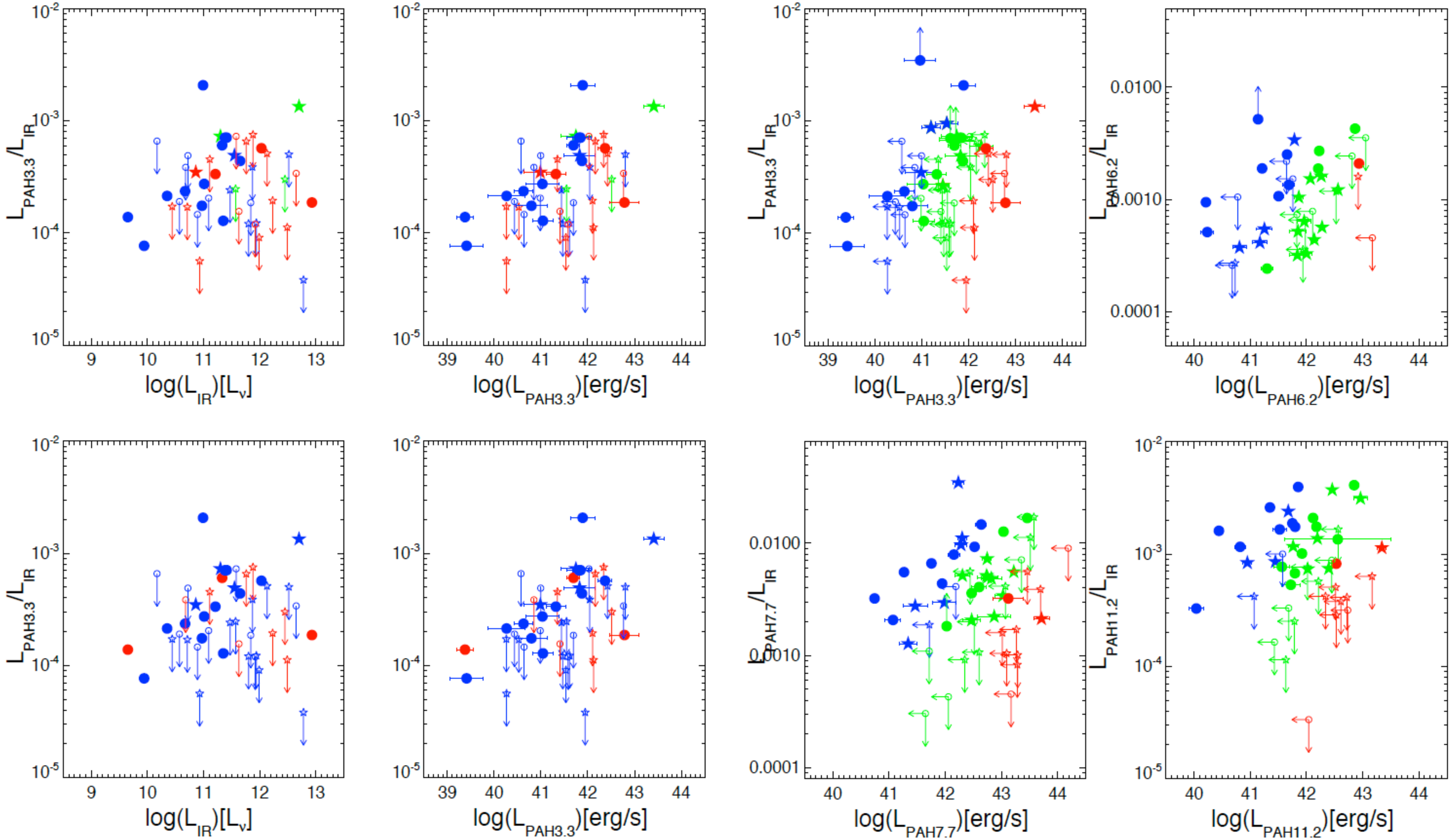
IR to PAH revisited



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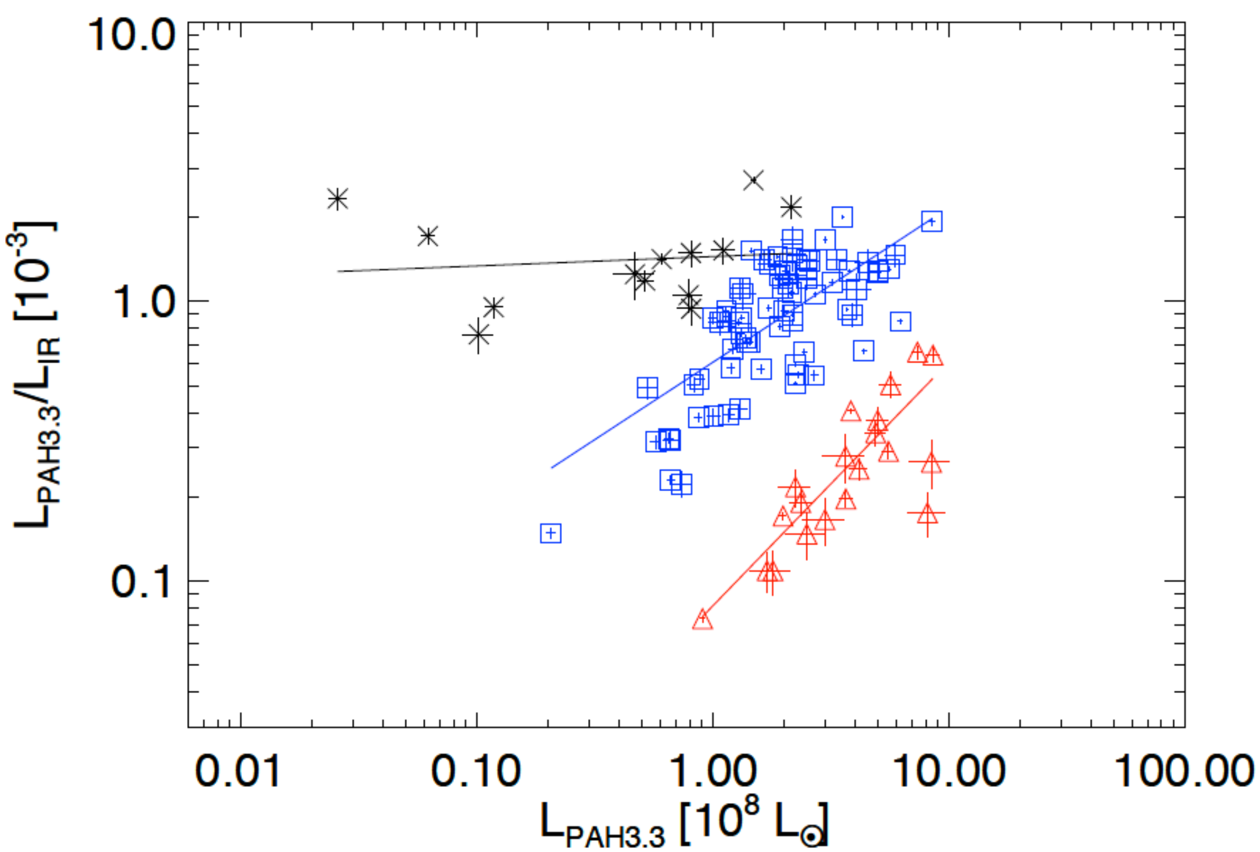
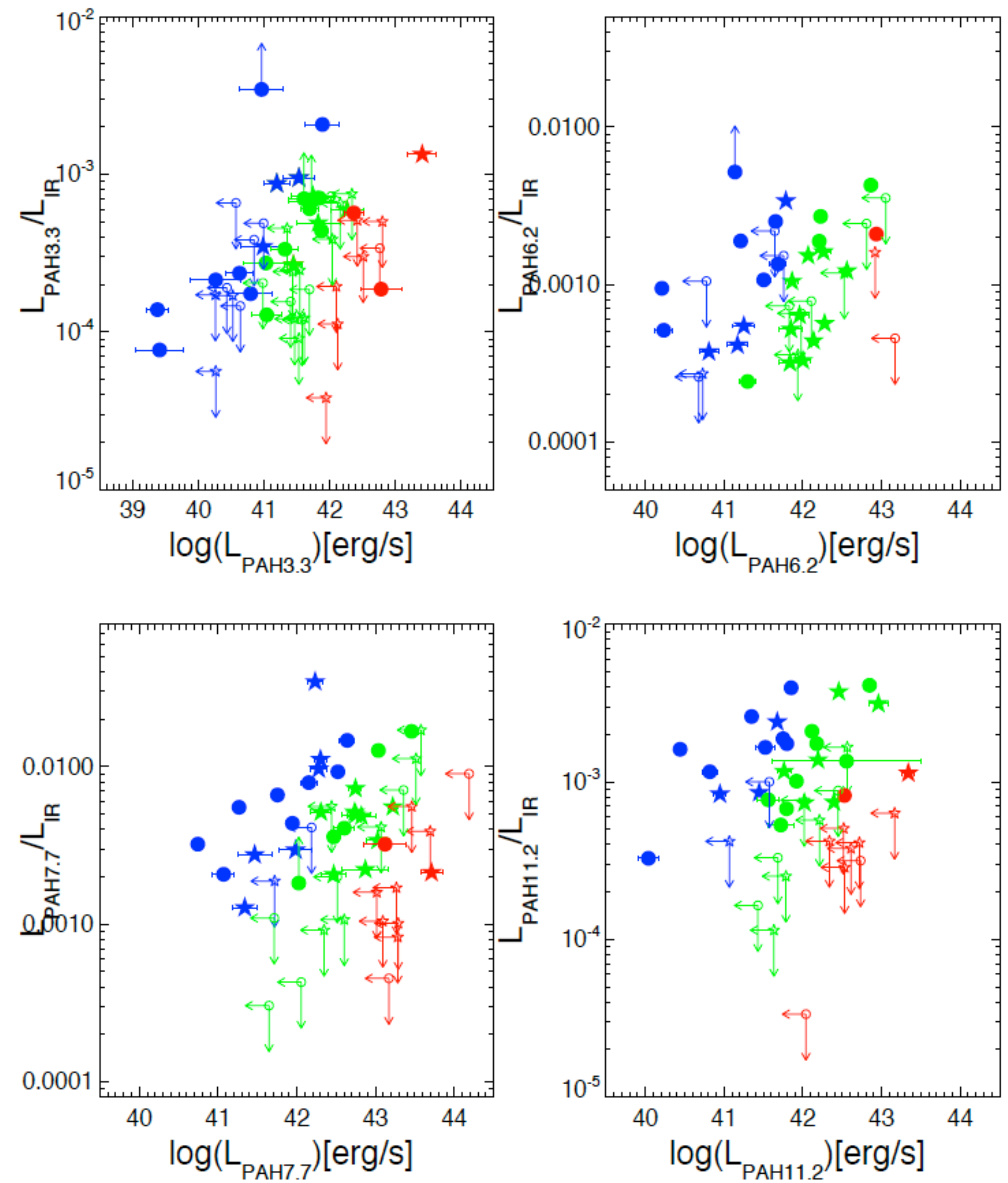


Yamada et al. (2013)

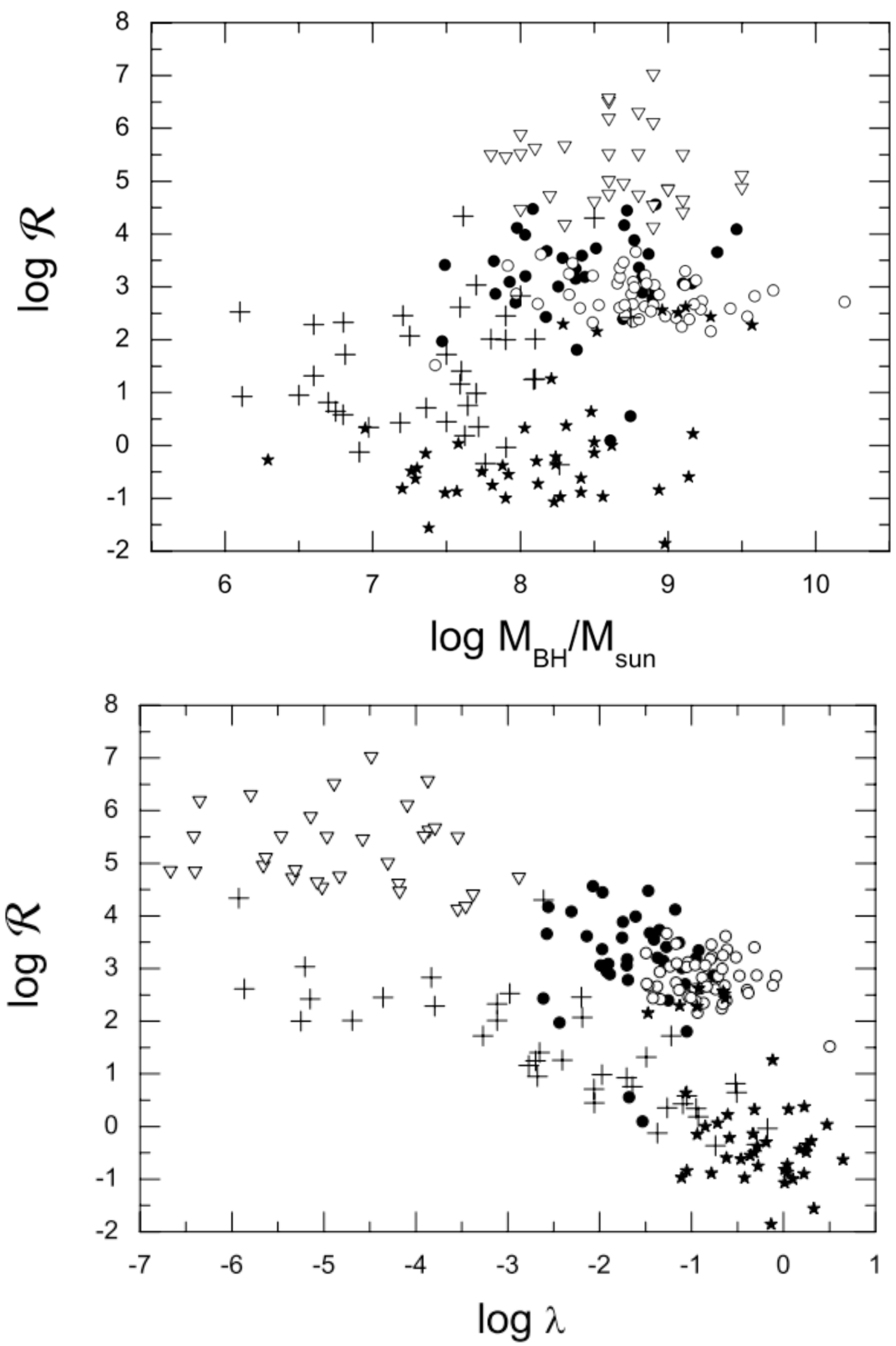


Is it only ULIRGs?

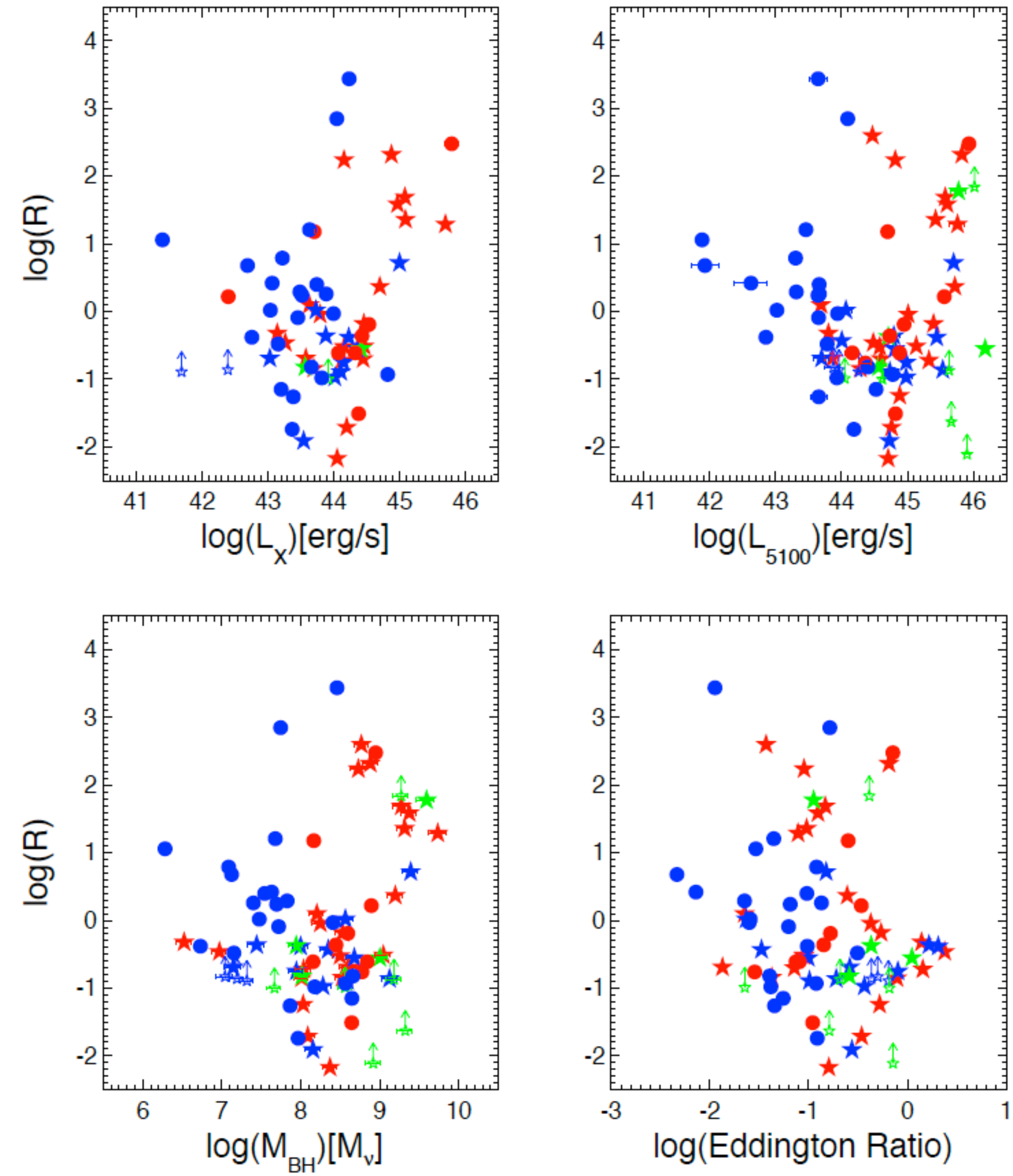
-Yamada et al. rules out photo-dissociation by UV radiation, dust extinction for 3.3 μm emission, hidden AGN and YSOs, low abundance ratio of PAHs to dust for the origin of PAH3.3 to LIR ratio.

Kim et al. (*in prep*)

AGN probes versus Radio loudness

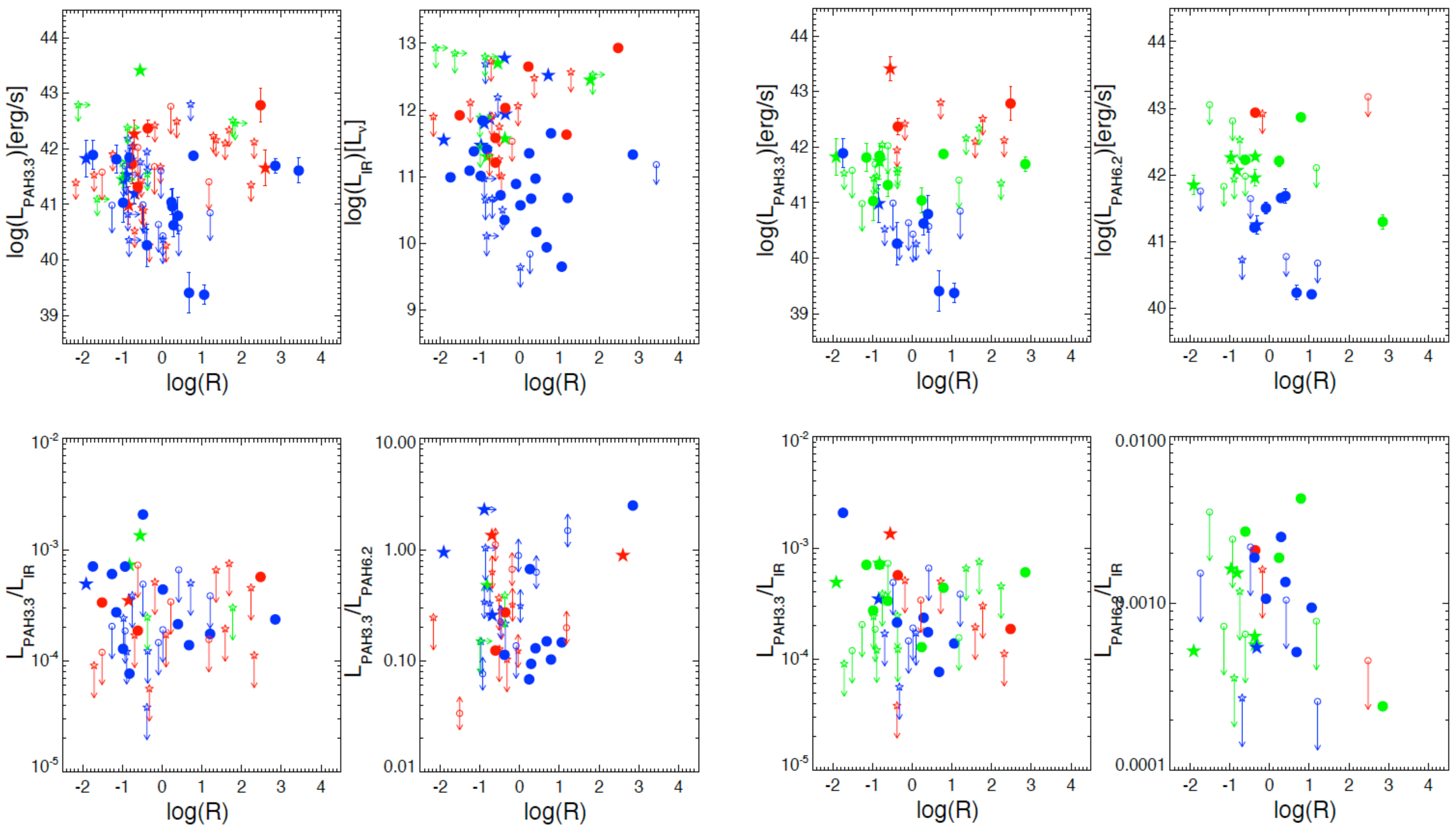


Sikora et al. (2007)



Kim et al. (*in prep*)

PAHs versus Radio loudness



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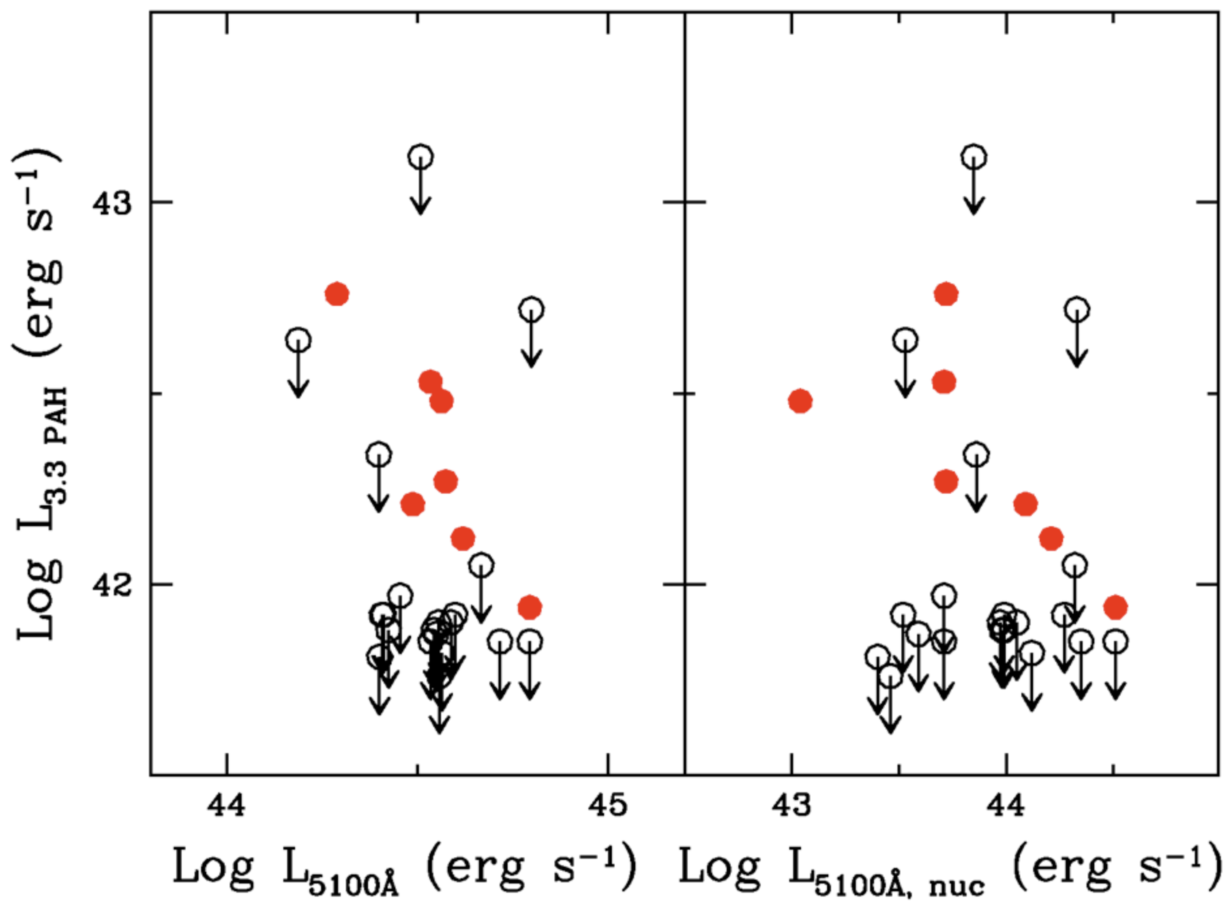
A Case Study of Seyfert 1s at z~0.36



Woo et al. (2012)

- 27 Seyfert 1 at z~0.36
- a very unique sample at a cosmologically significant distance
- This sample deviates from the local Mbh-σ relation, meaning black holes proceed host galaxies.
- 7 targets are detected with the PAH 3.3 μm emission feature.
- Within the sample, the correlation b/w SF and nuclear activities appears to be not significant, or even negative.
- Compared to local type 1 AGN, they appears to follow the overall trend.

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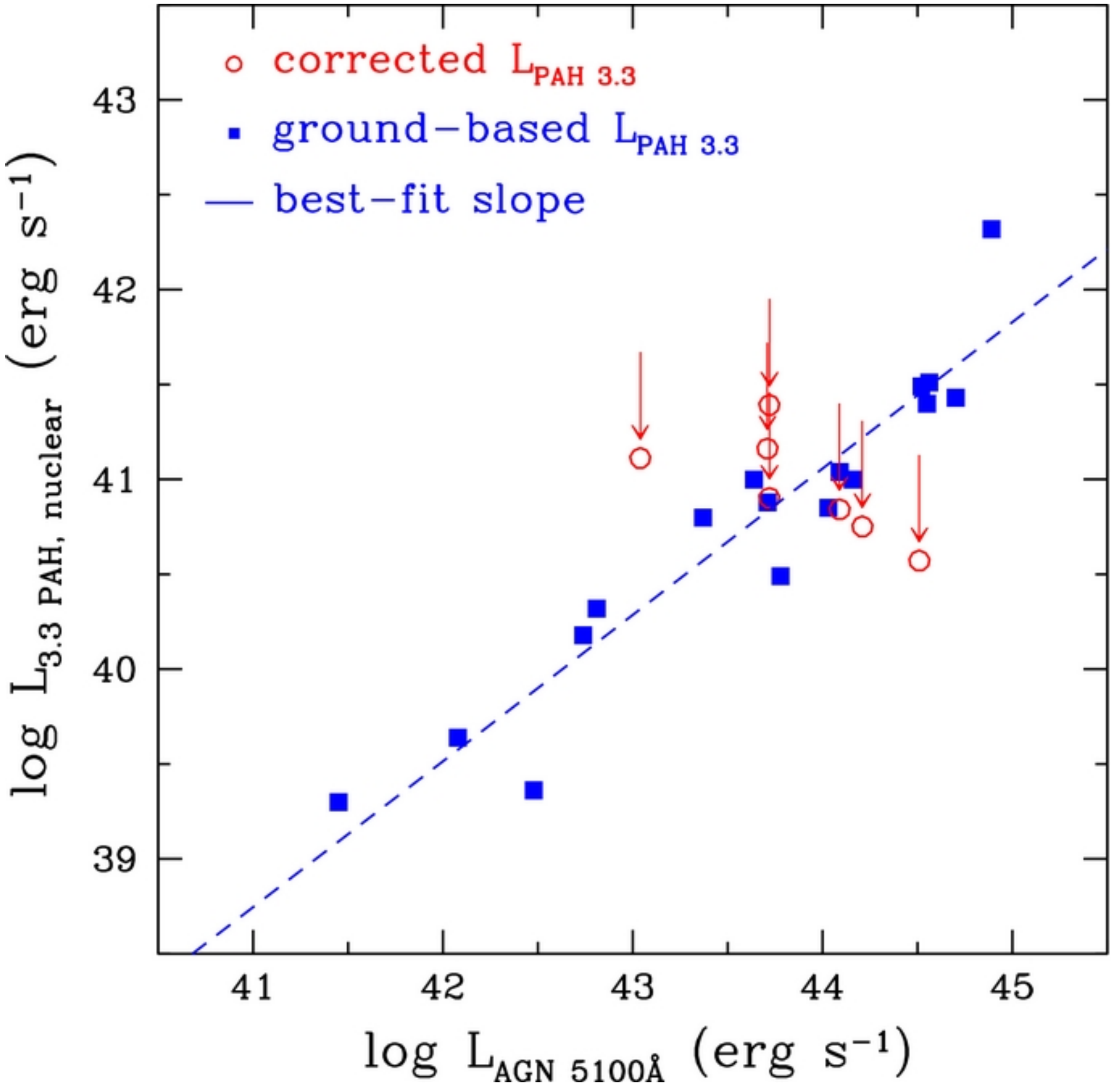

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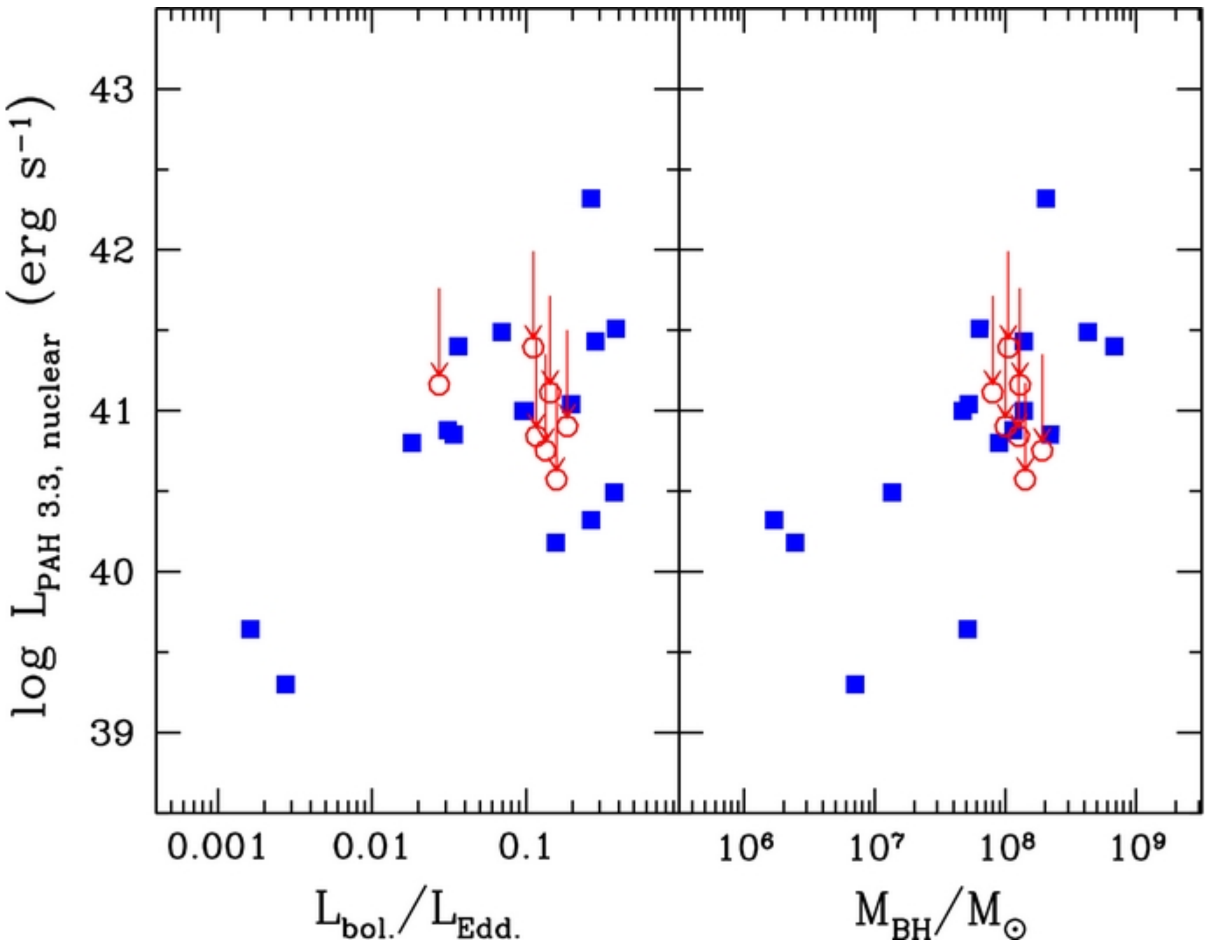

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Summary

- The co-evolution of SMBHs and their host galaxies is one of key astrophysical phenomena to provide important informations on the formation and evolution of galaxies.
- It is very challenging to extract precise SFR of AGN host galaxies due to different size scales, dominant emission from AGN, and the nature of SFR indicators.
- ULIRGs at $L_{IR} > 10^{12} L_\odot$ may deviate from the correlation between $L_{PAH3.3}$ and L_{IR} of the lower luminous objects due to non-star-forming contribution on L_{IR}, such as AGN activity and heavily obscured YSOs, or destruction of PAH molecules by AGN activity. $L_{PAH6.2}$ shows a similar trend with L_{IR}.
- The PAH emission features including 3.3 μm feature can be a good SFR indicator, although the dependence on the metal abundance of the system must be calibrated (Engelbracht et al. 2005, 2008; Draine et al. 2007; Smith et al. 2007; Galliano et al. 2008).
- Type-1 AGNs show that SF activity probed by PAH 3.3 μm correlates well with AGN activity over a wide range of host morphology and radio loudness. Seyfert 1s at z~ 0.36 also show a similar trend.
- However, based on PAH/LIR ratio, it still remains unclear how well infrared luminosity represent dust obscured star formation activity and to what extent.