The Cold Dust Content of Optically Luminous Nearby Quasars

Andreea Petric

Science Fellow, Gemini Observatories

Nicolas Flagey (CFHT)
Luis Ho (Kavli Institute for Astronomy, Peking University)
Nick Scoville (Caltech)
Alya Azman (University of Hawaii, Hilo)
Krystal Schlechter (University of Hawaii, Hilo)

Correlations and Coevolution

• All massive galaxies may have a black-hole (BH).

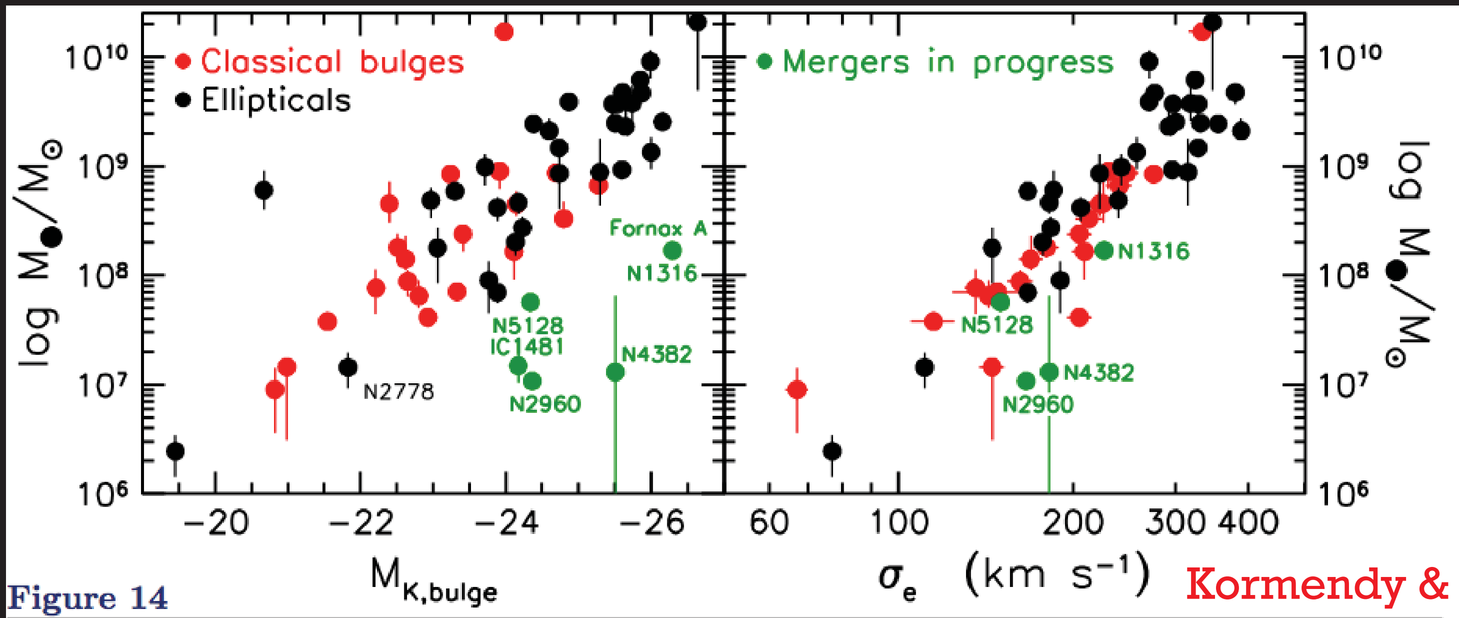


Figure 14

Kormendy & Ho (2013)

• Correlation between mass of BH and stellar velocity dispersion of the bulge suggestive of connection and perhaps co-evolution (e.g. Magorrian et al. 1998, Kormendy 2004, Gebhardt et al. 2000a, Ferrarese & Merrit 2000).

Correlations and Coevolution

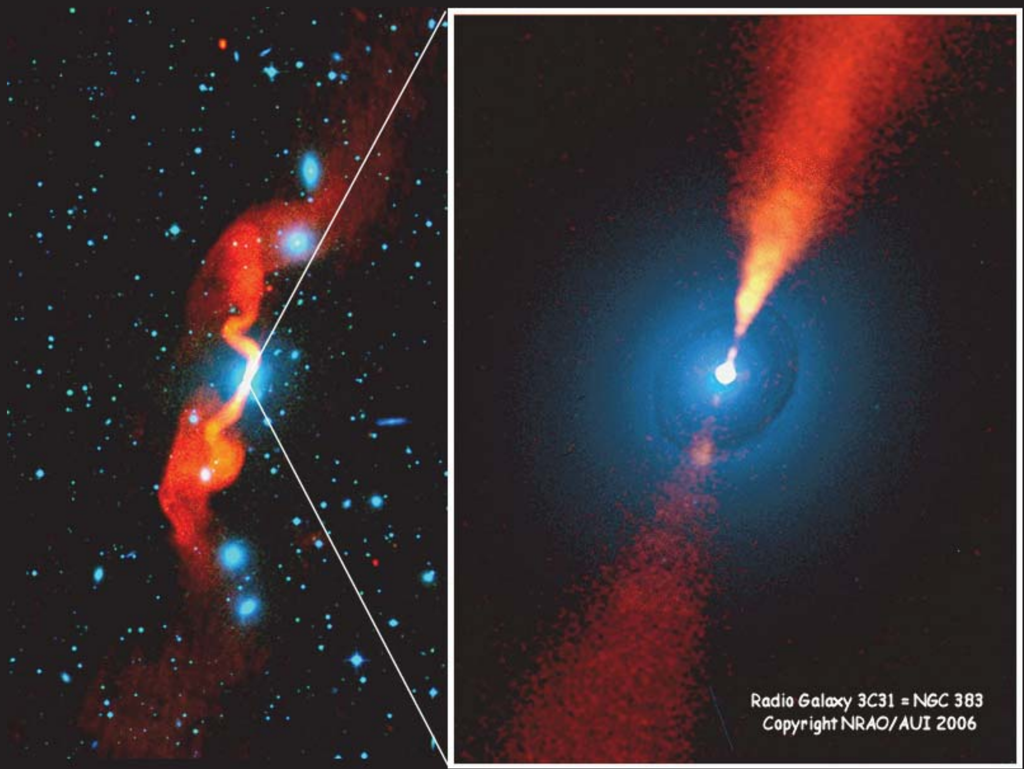
• All massive galaxies may have a black-hole (BH).

• Correlation between mass of BH and stellar velocity dispersion of the bulge suggestive of connection and perhaps co-evolution (e.g. Magorrian et al. 1998, Kormendy 2004, Gebhardt et al. 2000a, Ferrarese & Merrit 2000).

• Complex picture involving different types of mergers and feedback from AGN in the form of radio jets, high velocity winds.

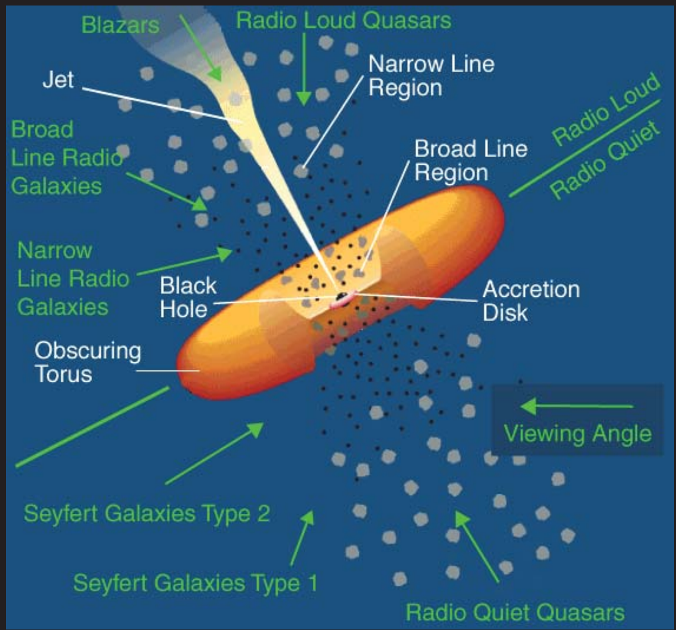
• The cold interstellar medium fuels both the growth of the central BH and that of the host galaxy.

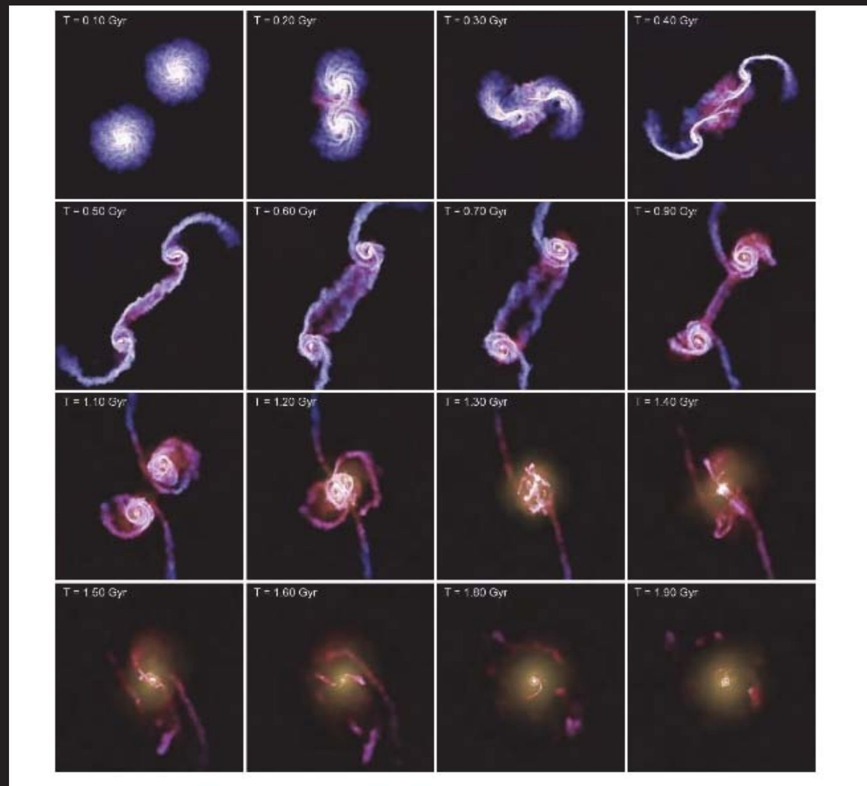
Active Galactic Nuclei



Look at hosts of growing SMBH to look for signs of co-evolution.

Semantics and Geometry
Narrow Line AGN





Do geometry and/or history determine what we see and why we see it?

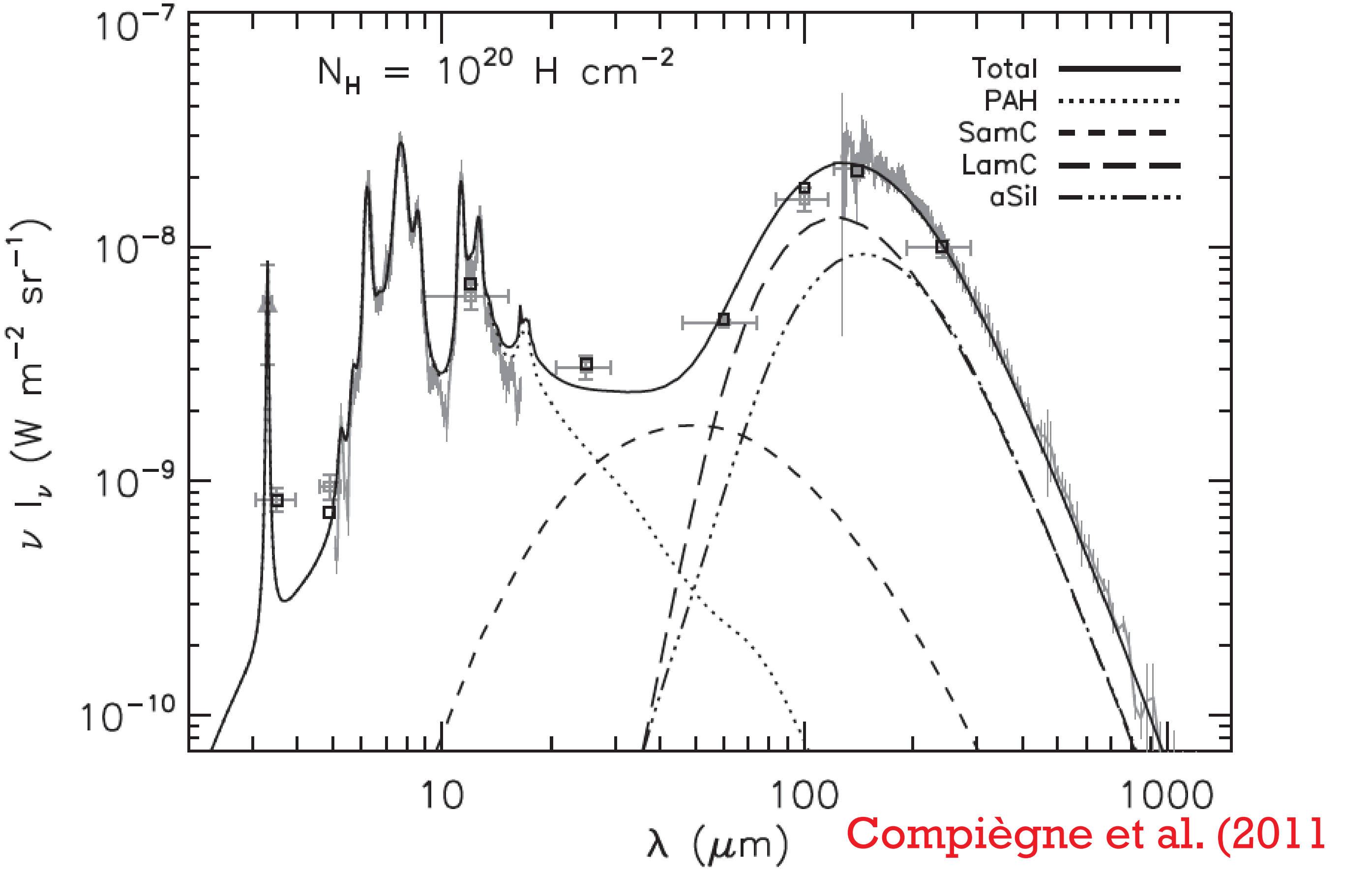
Goals: AGN impact on Host Galaxy

- What:
  - How much fuel for star-formation and BH growth do luminous QSOs have?
  - How do the ISM/cold dust properties change with BH mass and host interaction history?

- How: Follow the energy!
  - Measure "strength of AGN" (e.g. contribution to bolometric luminosity, mass of outflow associated with AGN)
  - Measure host properties (state of molecular gas, SFR, SF histories)

Step 1: the amount of cold ISM available for star-formation.

FIR Emission

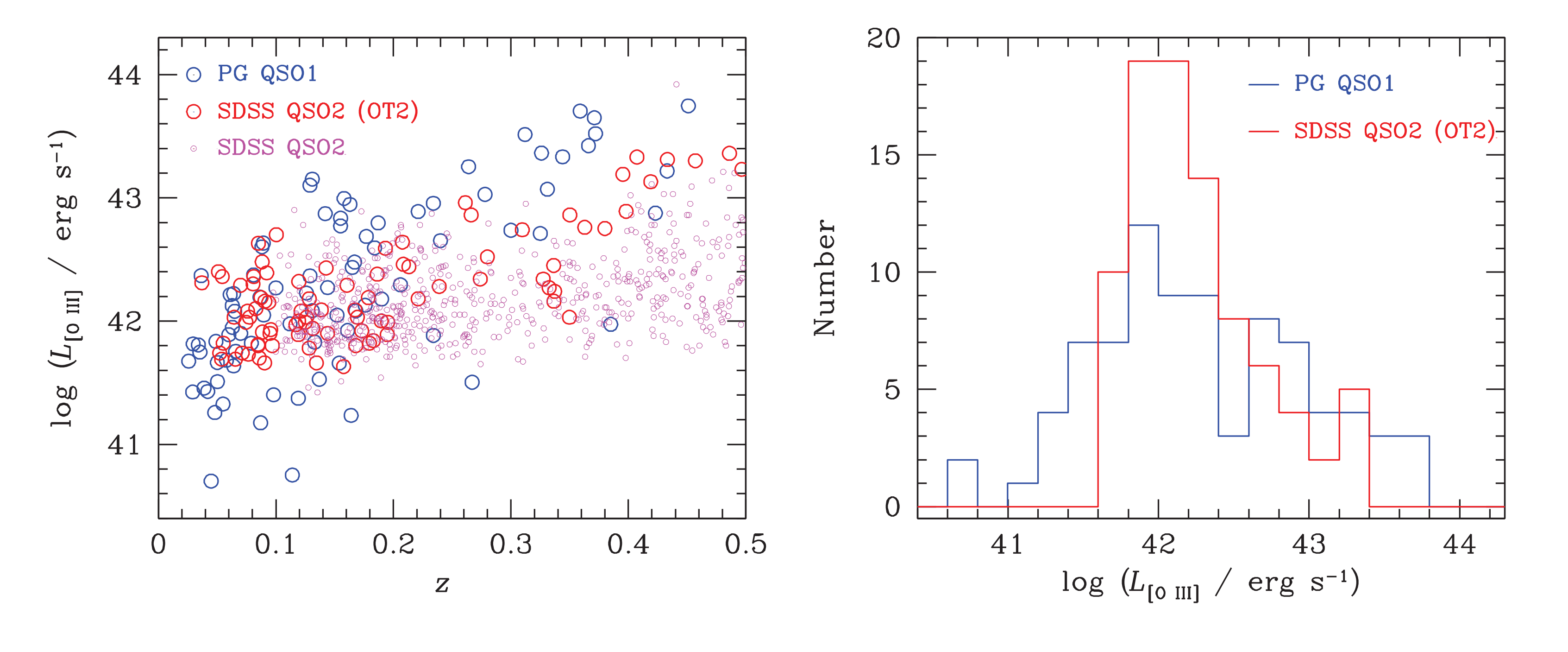


Compiègne et al. (2011

FIR traces Dust.   Dust traces ISM. ISM gives the fuel available for star-formation.

Also, currently analyzing the excitation properties of cold molecular gas (CO lines observed with Herschel) in AGN with UH undergraduate, and UH Space grant fellow Derek Hand

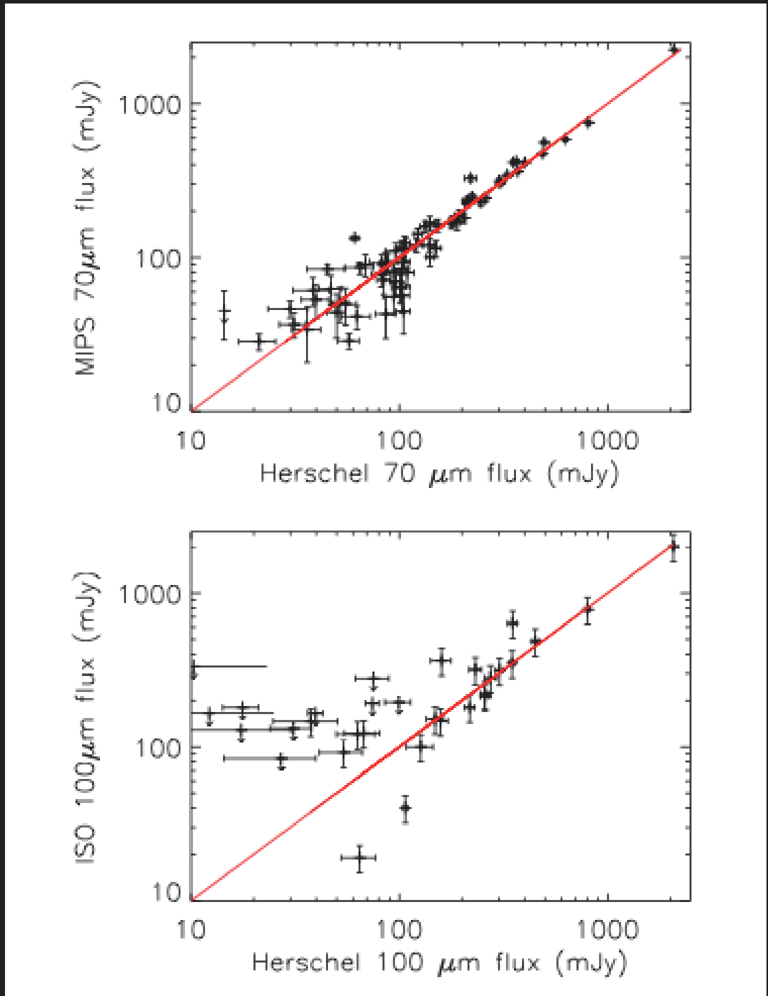
Samples



- Herschel 70 to 500 μm photometry for 85 QSO1s (PI: Ho, Petric et al. 2015,ApJS, arXiv:1505.05273)

- Herschel 70 to 500 μm photometry for 87 QSO2 (PI:Ho, Petric et al. in prep.)

Basic Measurements PG QSOs

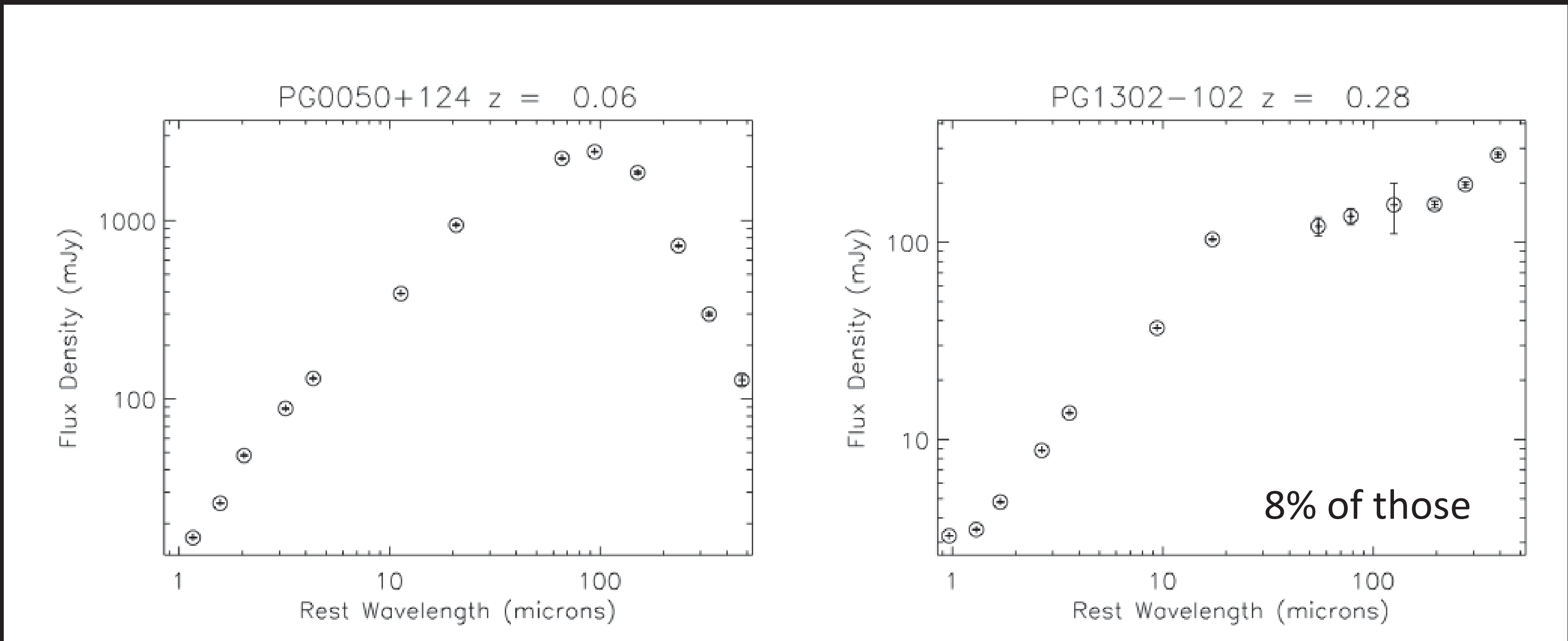


- Herschel data more than an order of magnitude higher spatial resolution than previous IRAS observations and a factor of 8 better than those from ISO
  ➔ less confusion

- We detect sources about 4 times fainter than the faintest PG QSOs detected by ISO.

Petric et al. 2015,ApJS, arXiv:1505.05273

IR SEDs of PG QSOs

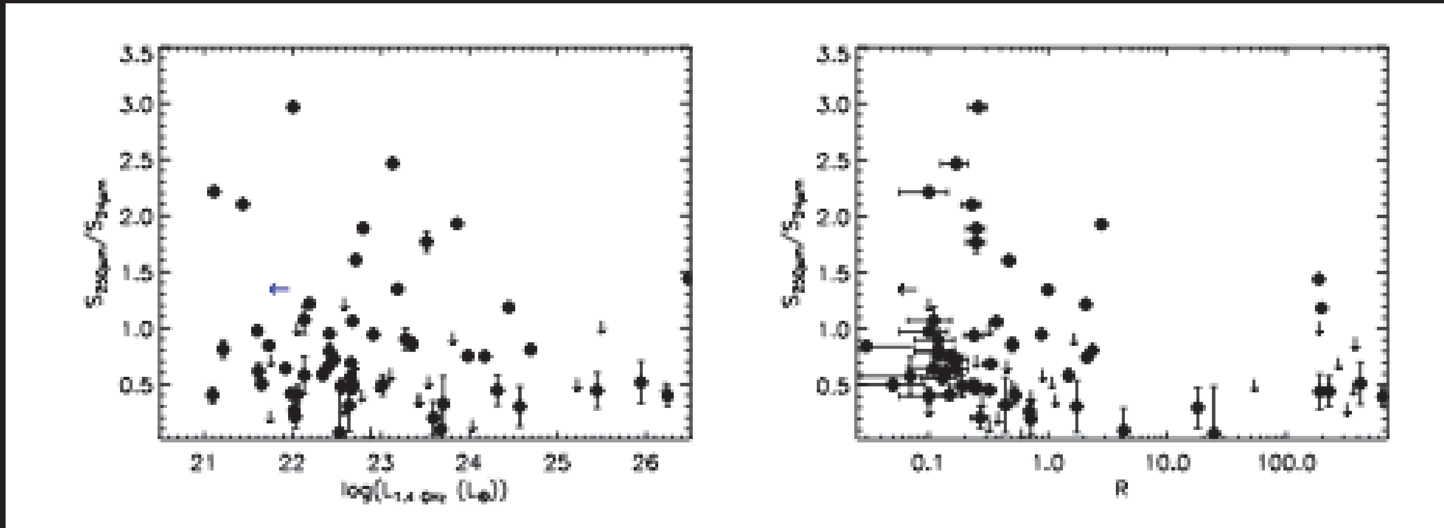


Petric et al. 2015, ApJS

IR SEDs of QSO1s resemble modified black-bodies.

However, 8 % show non-thermal emission at wavelengths longer than 250um.

PG QSOs: Thermal or Synchrotron

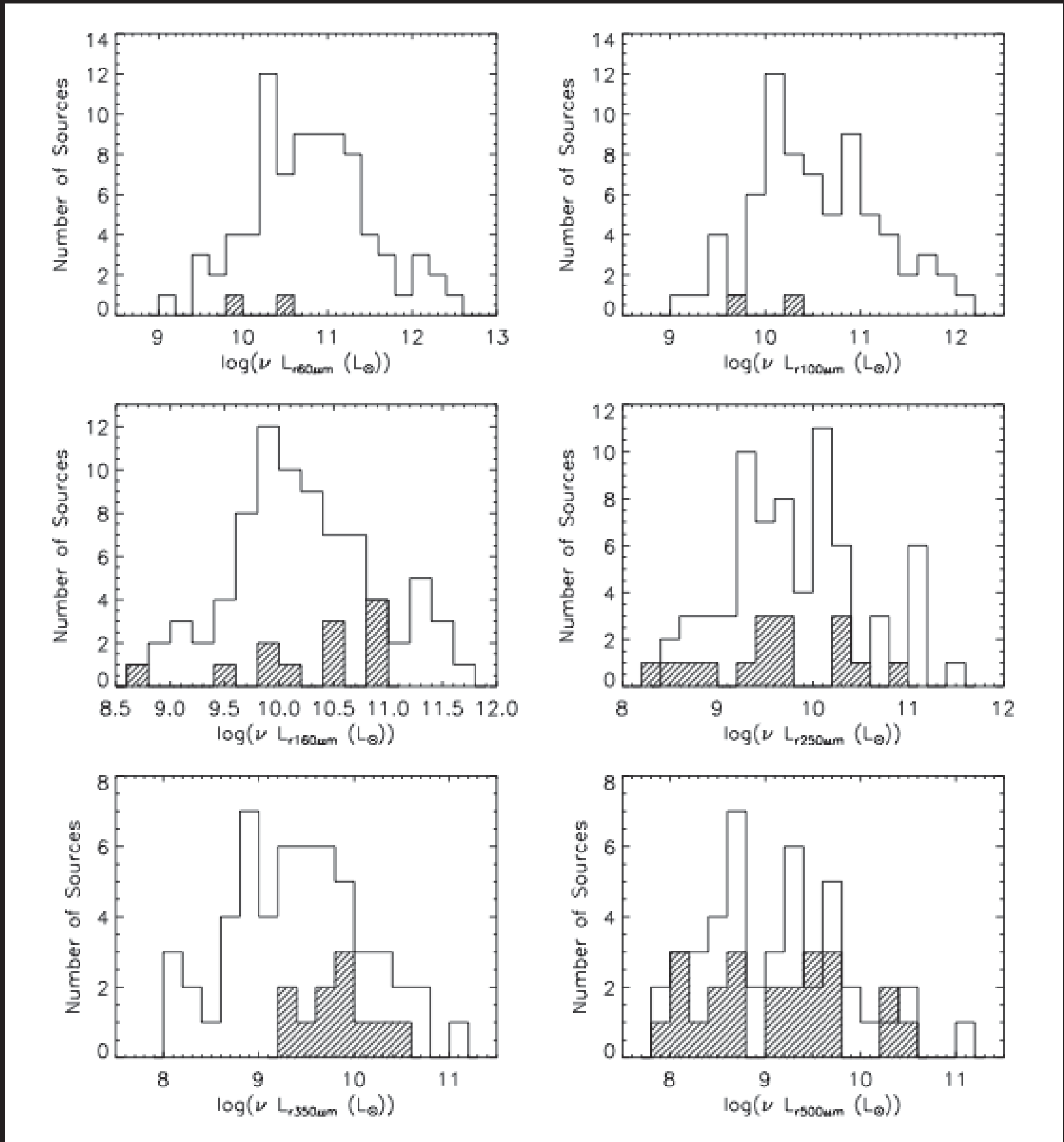


- In 8% of the sources the emission at wavelengths longer than 250 um may contain synchrotron emission associated with radio loud AGN activity.

- We do not find any obvious trends between the FIR color and the radio luminosity, or the radio loudness (R) in agreement with the work of Kalfountzou et al. (2014)

➔ our FIR results are not biased by the radio loud sources

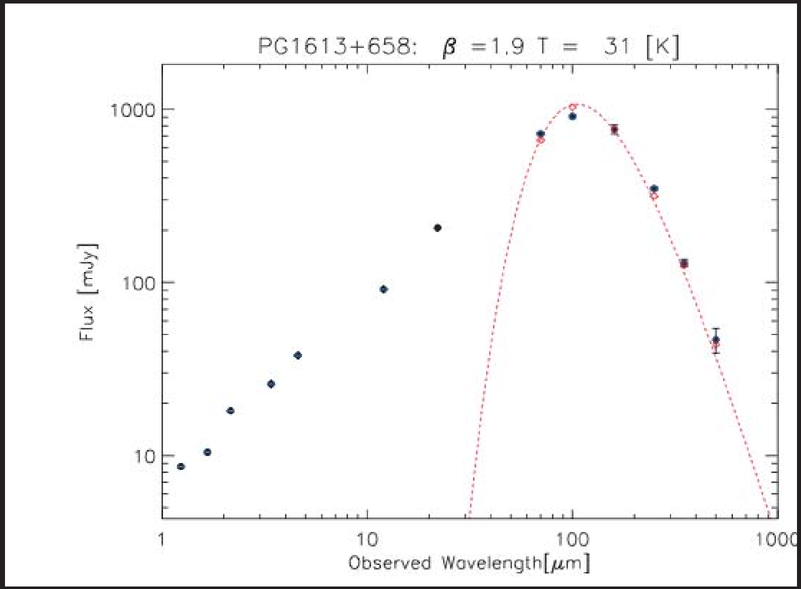
QSO1: Rest frame-Luminosities



The FIR luminosities span four orders of magnitude between $2 \times 10^{9} L_{\odot}$ and $1.65 \times 10^{12} L_{\odot}$

i.e. between the FIR luminosities of normal galaxies and those of Ultra Luminous Infrared Galaxies

Single temperature modified black body fits

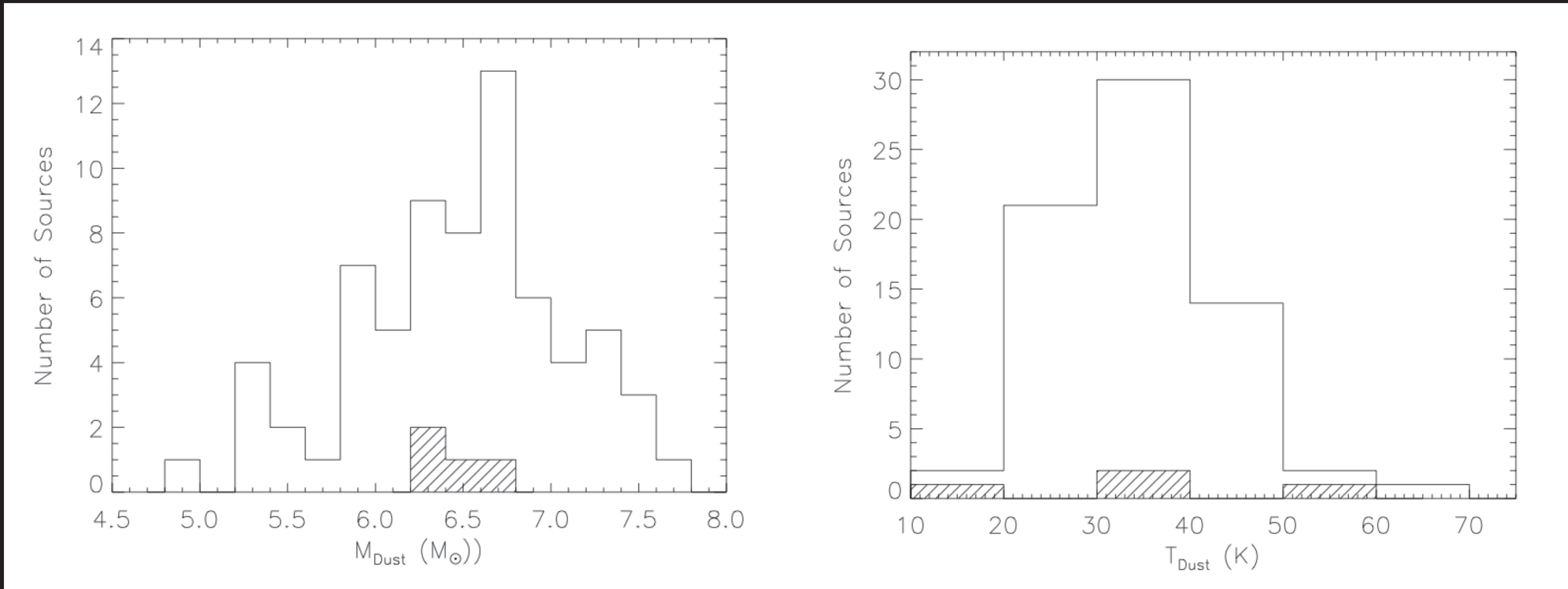


• Fits to the SEDs that use the grain properties (emissivity spectral index and dust absorption coefficient) of Compiègne et al. (2011) or Draine & Li (2007).

• The dust temperatures are almost systematically larger by 1-2 K for the former.

• Dust masses are systematically larger by about 20-40% when using the dust properties from Draine & Li (2007).

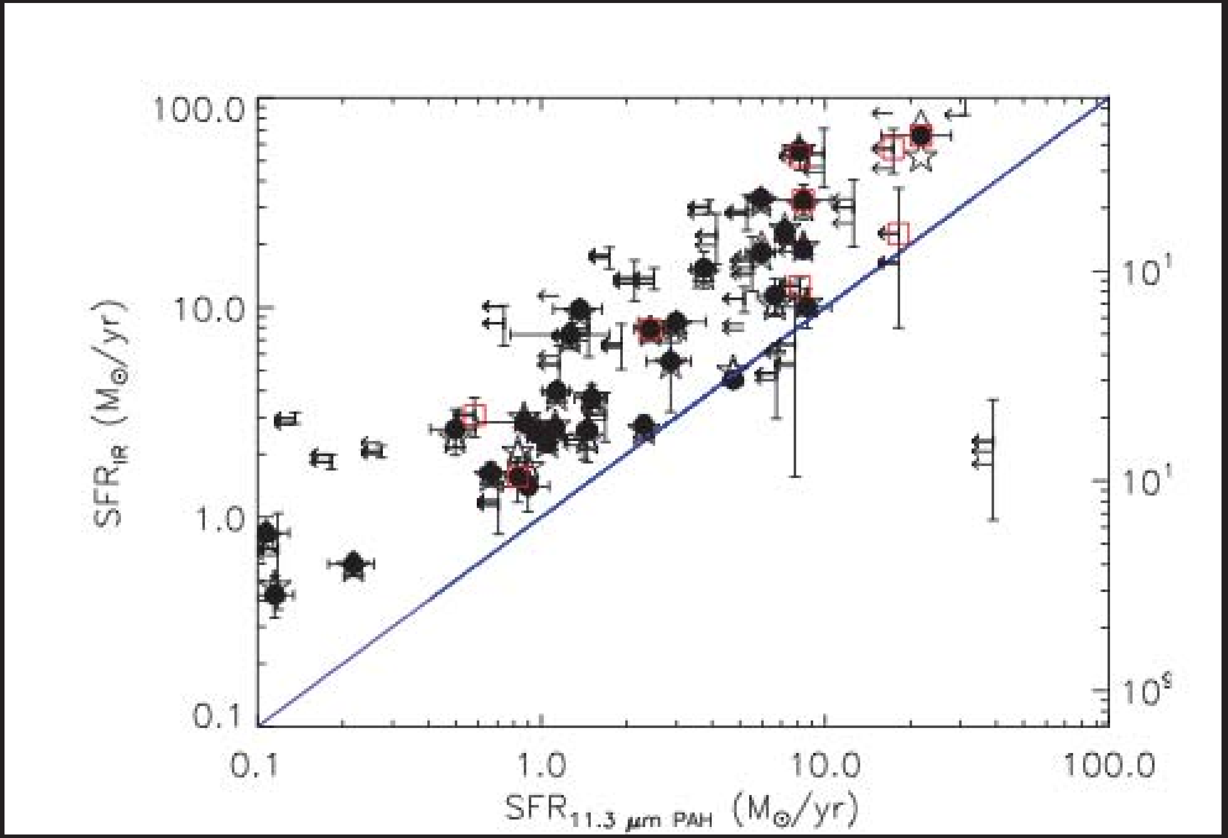
Dust Masses and Temperatures



• Dust temperature mean, median and standard deviation: 33, 35 and 8 K

• Dust masses Md median, mean, and standard deviation: 3×10^6 M⊙, 7×10^6 M⊙, 9×10^6 M⊙ .

Star-Formation Indicators

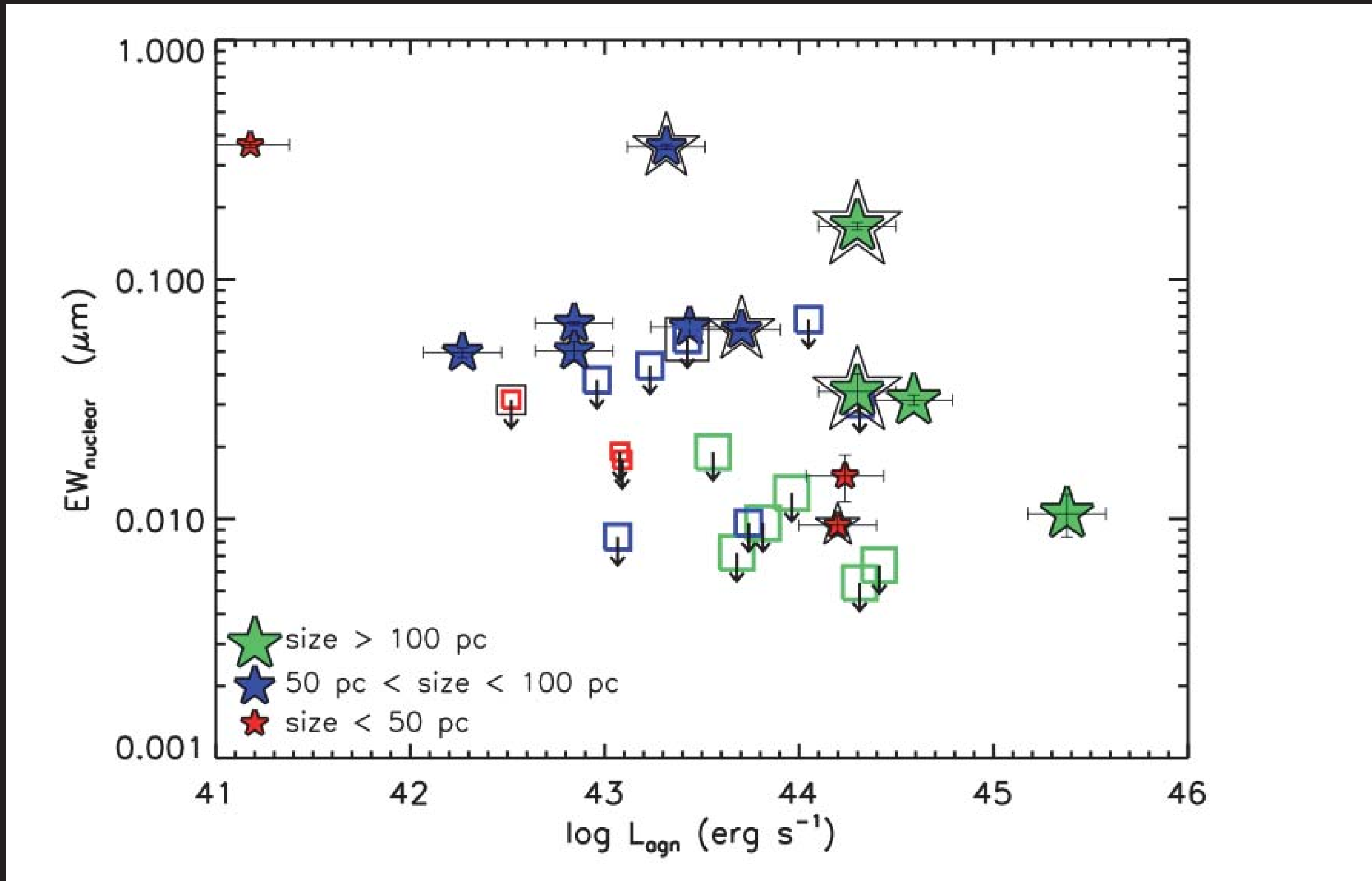


• Estimates of star-formation that are based on the FIR continuum emission correlate with those based on the 11.3 um PAH feature

HOWEVER

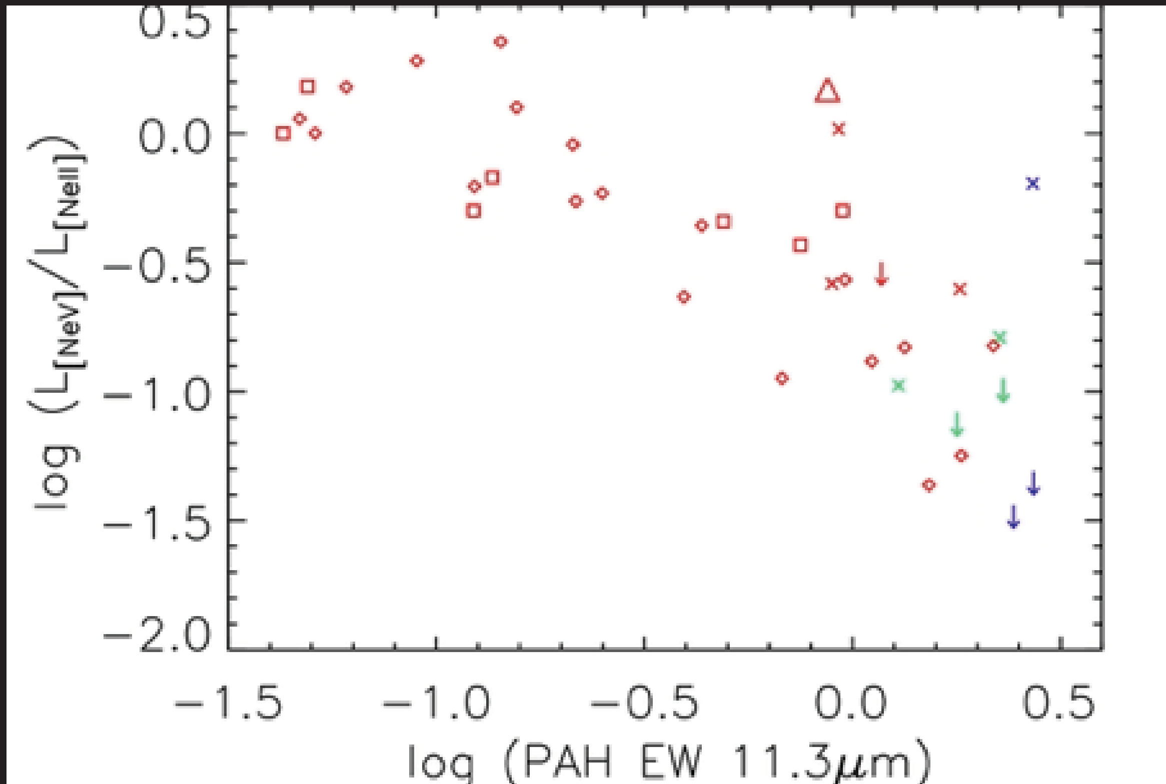
• Star-formation rates estimated from the total FIR luminosities are higher than those estimated from the 11.3 um PAH emission

The 11.3 um PAH as a star-formation tracer in AGN



Esquej et al (2014) => 11.3 um PAH not obviously suppressed in AGN

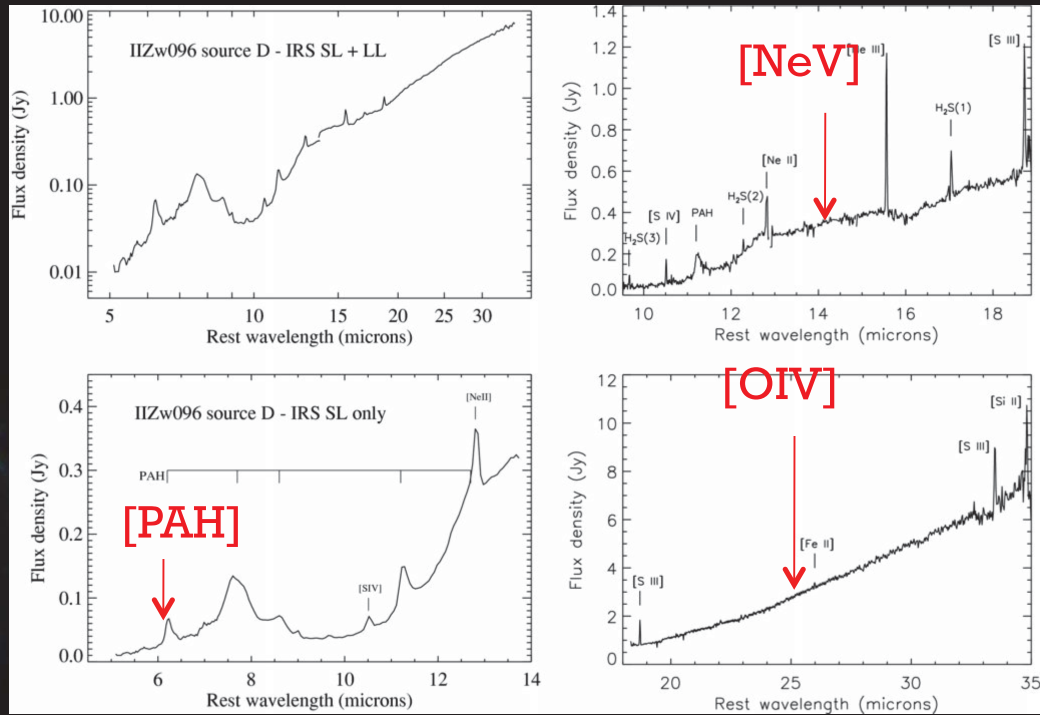
The 11.3 um PAH
as a star-formation tracer in AGN



La Massa et al. (2012) find that the PAH 11.3 um feature is significantly suppressed in the most AGN-dominated systems

PAH as a star-formation tracers
Example: II Zw 96

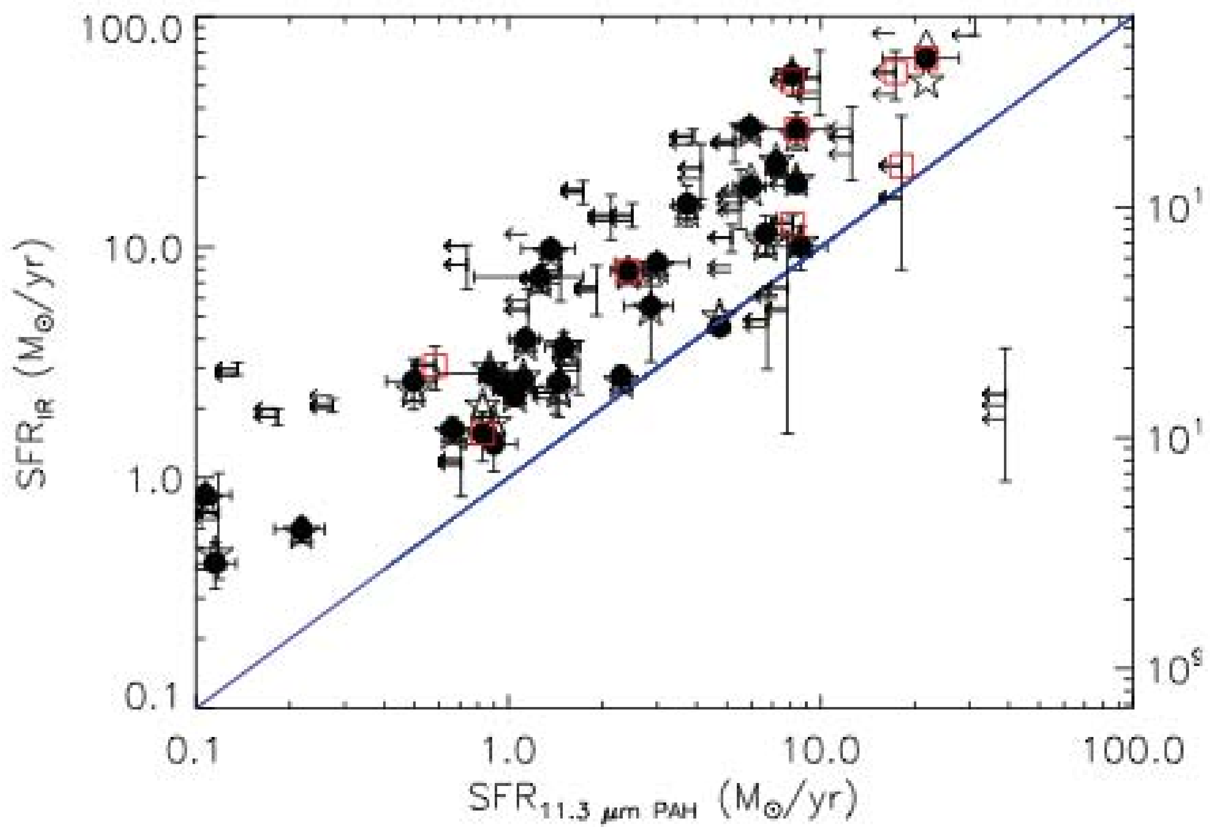
II Zw 96
6.2 μm PAH EW half that of a typical starburst galaxy but no AGN



False-color HST RGB image of II Zw 096 (Inami et al. 2010)

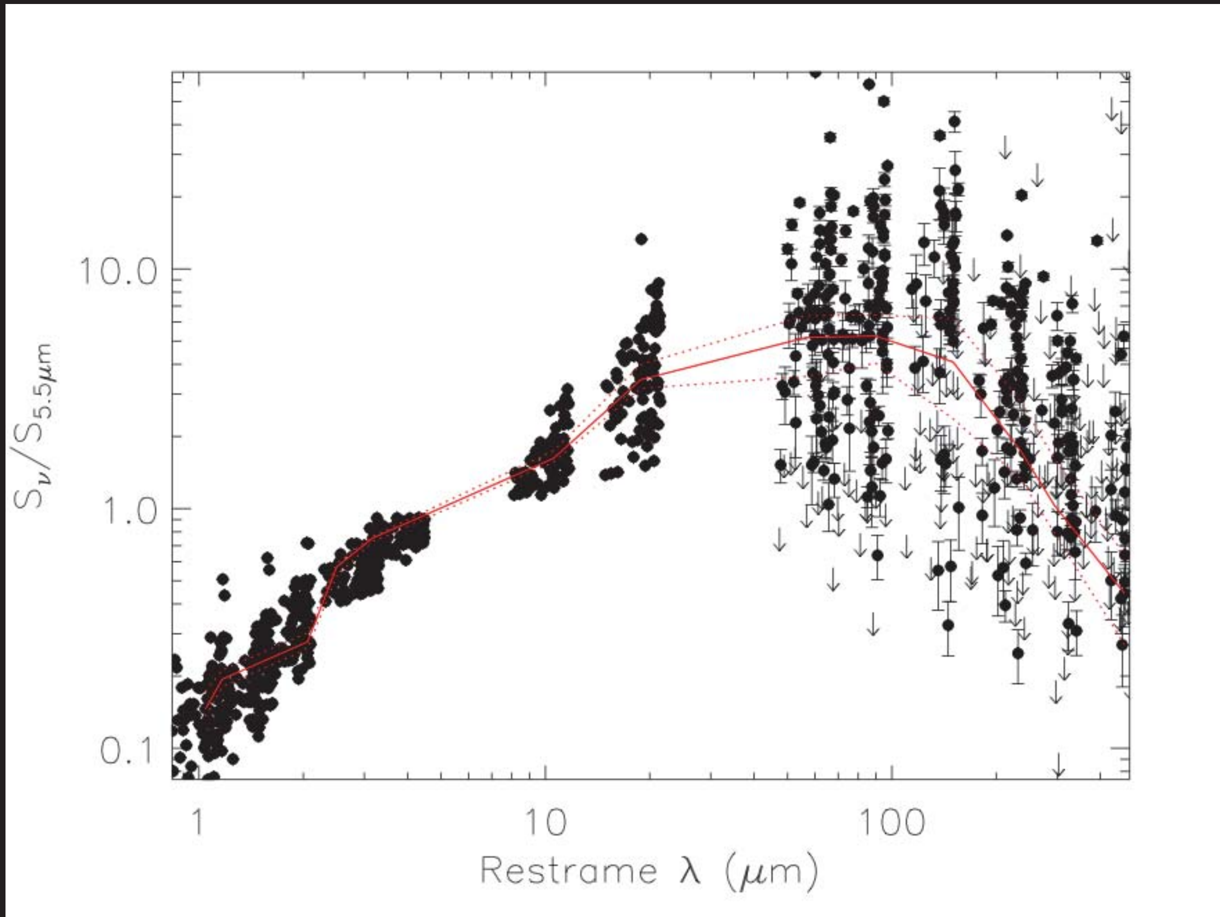
PAHs may also be destroyed by starbursts, and even in regions without an AGN may not provide an ideal way to measure SFR.

Star-Formation Indicators



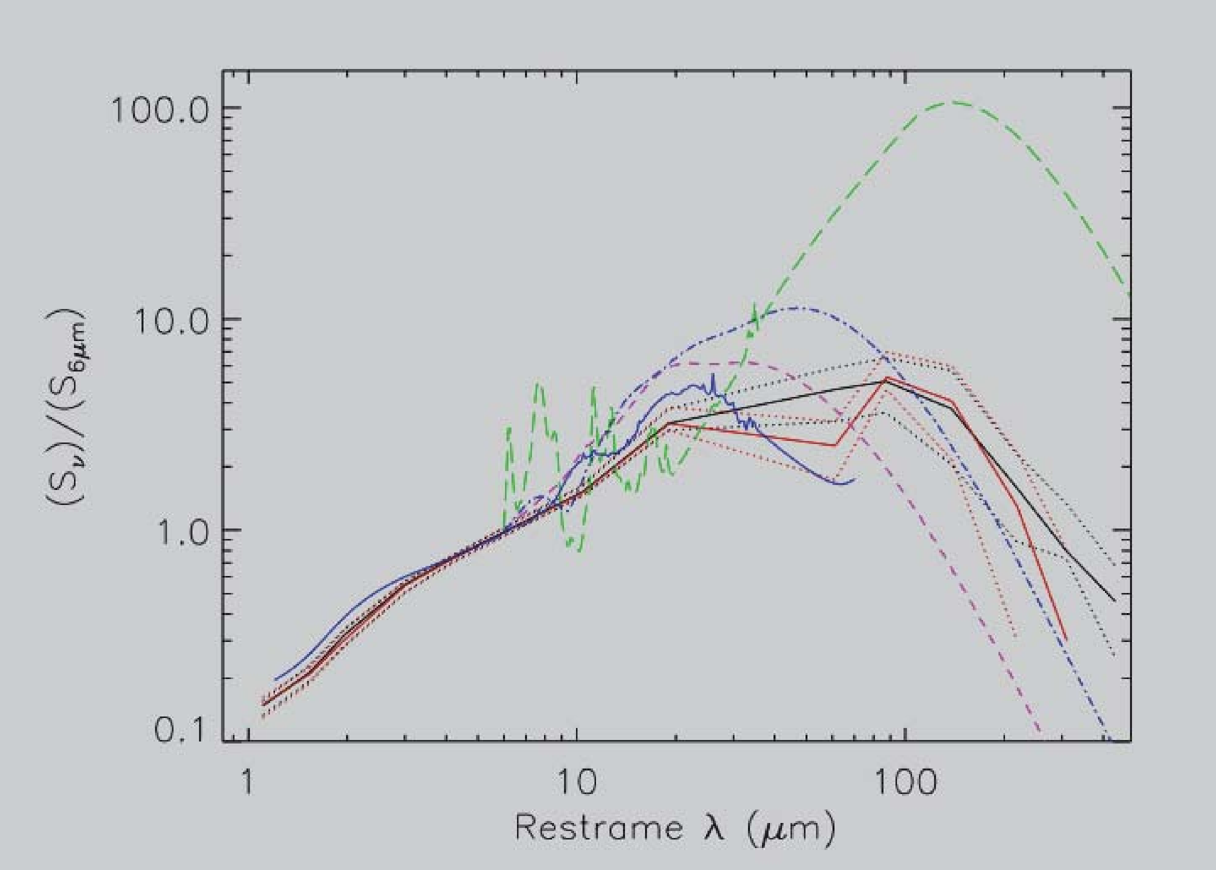
1. High FIR ~ High UV -> destroy PAH
2. FIR may be contributed by clumpy torus
3. FIR may be contributed by old stars

Combined SEDs normalized at 5.5 um



IR SEDs of QSO1s are relatively uniform with the largest scatter in the FIR.

Combined SEDs normalized at 5.5 μm



Black: the entire PG QSOs sample

Red: only the radio quiet sources

Green: starburst template from Mullaney et al. (2011)

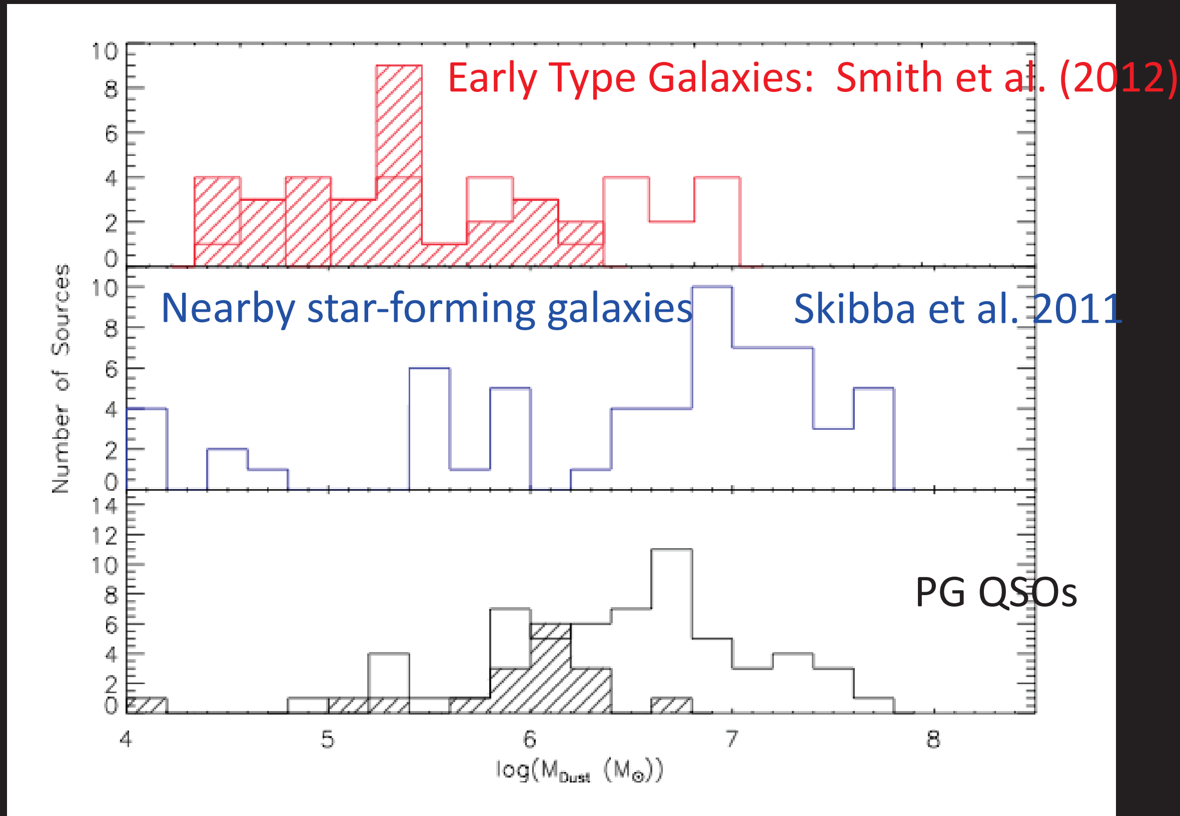
Blue solid: average intrinsic AGN SED of 8 'FIR-weak' PG QSOs, after subtraction of a starburst component from Netzer et al. (2007)

Magenta dashed: average high-luminosity from Mullaney et al. (2011)

Dot-dashed blue: average low-luminosity nearby AGN templates from Mullaney et al. (2011).

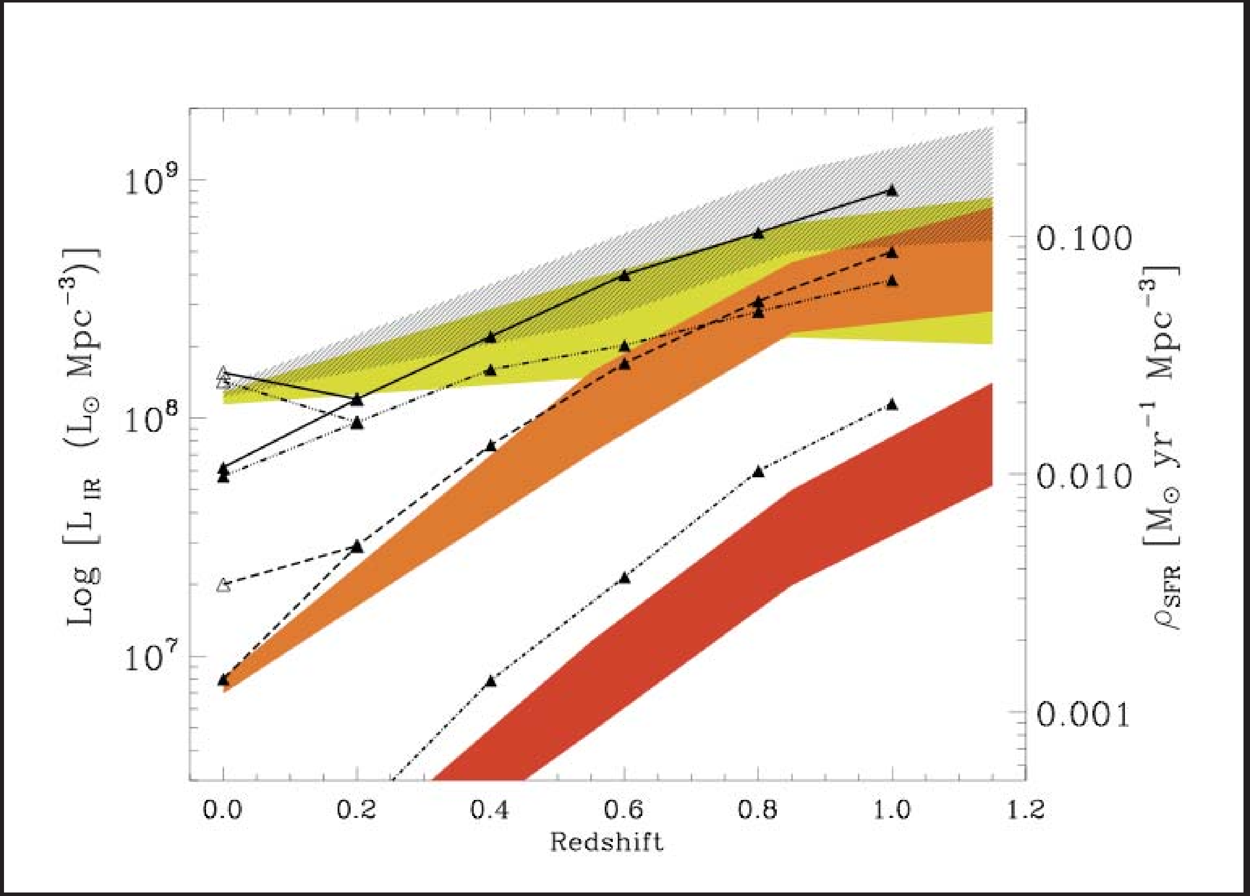
NIR spectroscopy with Gemini's Near-infrared Spectrograph (GNIRS) to measure extinction, warm molecular gas and host SFR properties of MIR selected AGN (with UH undergraduate Krystal Schlechter)

Comparison with Nearby Galaxies



=> Dust masses of nearby galaxies (spirals and ellipticals) are somewhat different than those of PG QSOs, the probability that they are the same is 11-12 %.

70 Micron number counts



Normal galaxies

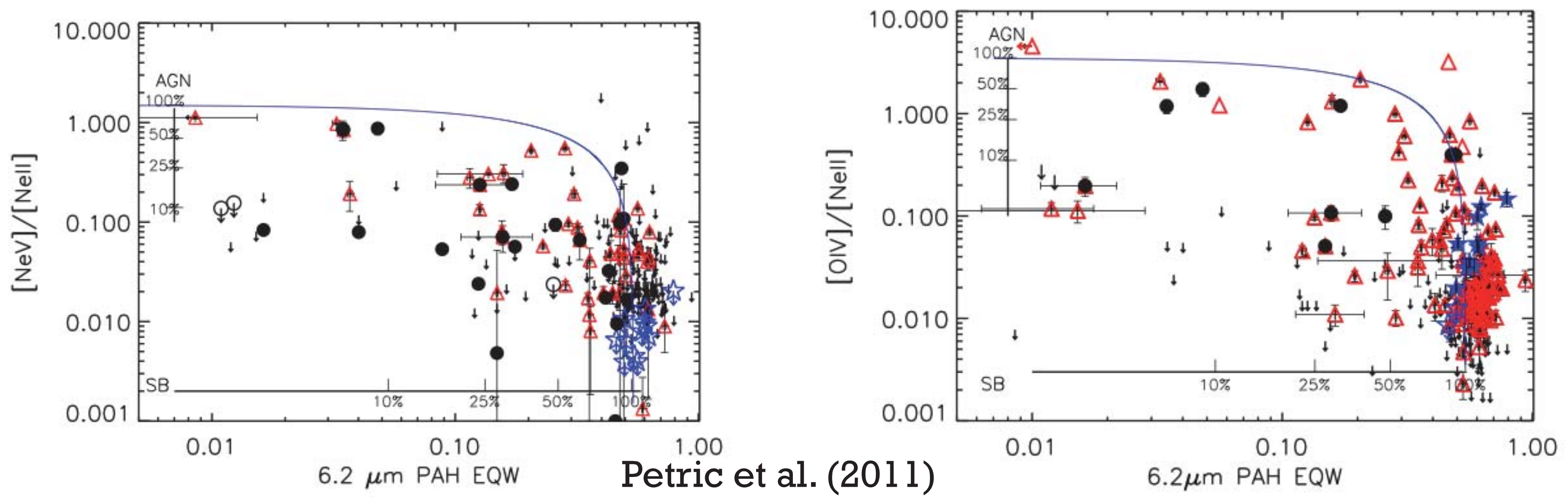
LIRGs $L_{IR} > 10^{11} L_\odot$

ULIRGs $L_{IR} > 10^{12} L_\odot$

IR traces SF => counting up IR sources give SF histories

Unless AGN contaminate the IR number counts

Contribution of SB/AGN to the IR luminosity



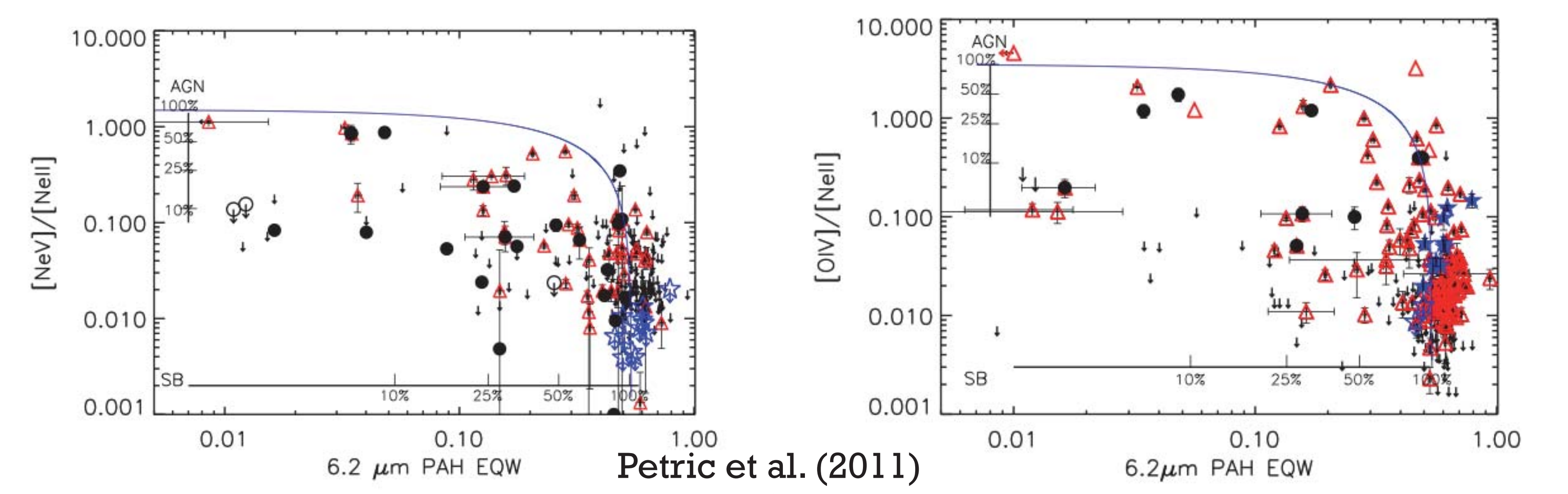
Petric et al. (2011)

Caveat: Eight PG QSOs have been used to represent sources in which AGN contributes 100% of the MIR emission because they were not detected by ISO and IRAS in the FIR (Netzer et al. 2007; Veilleux et al. 2009, e.g.)

Out of these 8 PG QSO, 5 are in our sample: PG 0026+129, PG 1309+355, PG0923+201, PG 1617+175, PG 2251+113.

All five were detected at 70 and 100 um … which indicate they may not be pure AGN

Contribution of SB/AGN to the IR luminosity

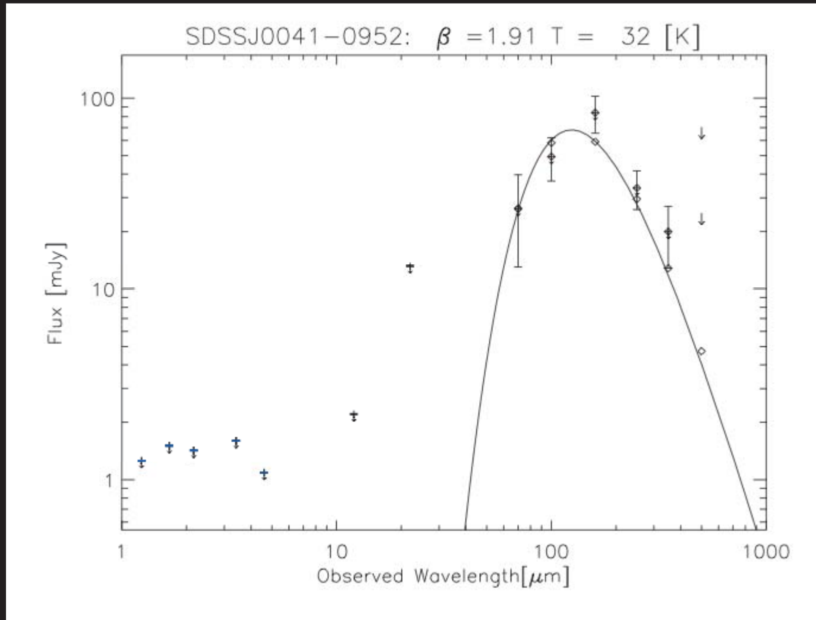


Petric et al. (2011)

Currently investigating mid-IR diagnostics using a sample of ~3000 AGN with IRS spectroscopy, X-ray to radio SEDs

with former Gemini intern Erini Lambrides (JHU), N. Zakamska (JHU), N. Flagey (CFHT) T. Geballe and R. Mason (Gemini Observatories)

Type 2 QSOs

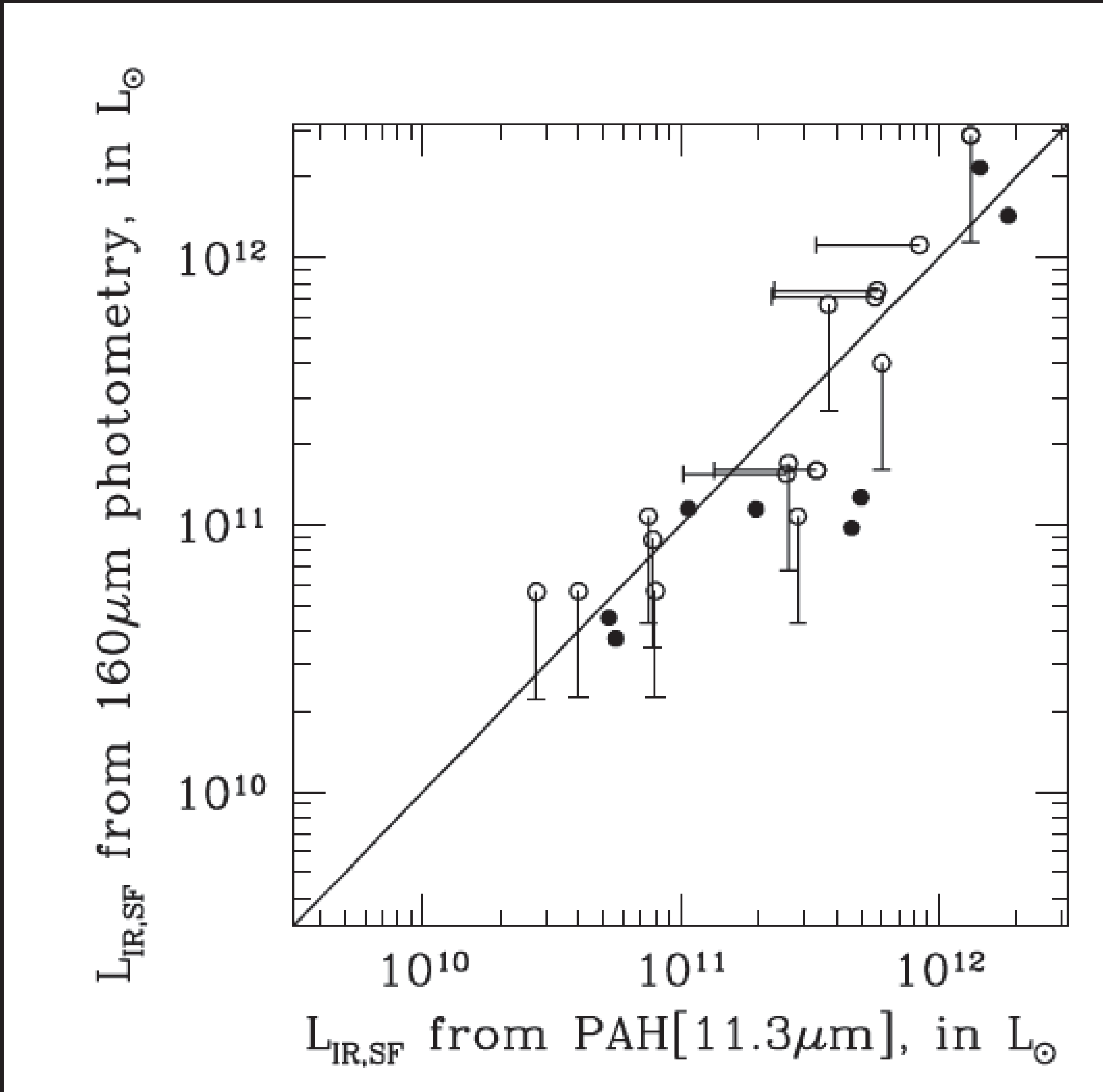


Global dust (mass and temperature) properties of QSO2s and QSO1s are similar when estimated from a single-temperature modified black body.

Dust to gas:

- some QSO1s have already been observed
- IRAM CO 1-0 observations of QSO2s with (UH Undergraduate Alya Azman + Co-I N. Flagey (CFHT), A. Omont (IAP), M. Lacy NRAO, L. Ho (Peking University/Kavli Institute), N. Billot (IRAM)

Star-Formation QSO2s



QSO2s: For the subset of 46 QSO2s with MIR spectroscopy the SFR derived from the 11.3 um PAH match those derived from the 160 um luminosity (Zakamska et al. submitted)

Conclusions I

- QSO1: 93 % detected with PACS (70-160 um), 66% detected at 250 um
- QSO2: 90% detected with PACS (70-160 um), 34% detected at 250 um

- QSO1 and QSO2: Most FIR SEDs well described by single-temperatures modified BB

- QSO1: Largest scatter in 1-500 um SED shapes comes from FIR properties
- QSO2: Scatter in 1-500 um SED shapes comes from NIR/FIR and FIR properties

- QSO1s & QSO2s $L_{FIR} \sim 10^9 L_\odot \sim 10^{12} L_\odot$
- $M_{DUST} \sim 10^{6-7} M_\odot$
- $T_{DUST} \sim 20 – 70$ K

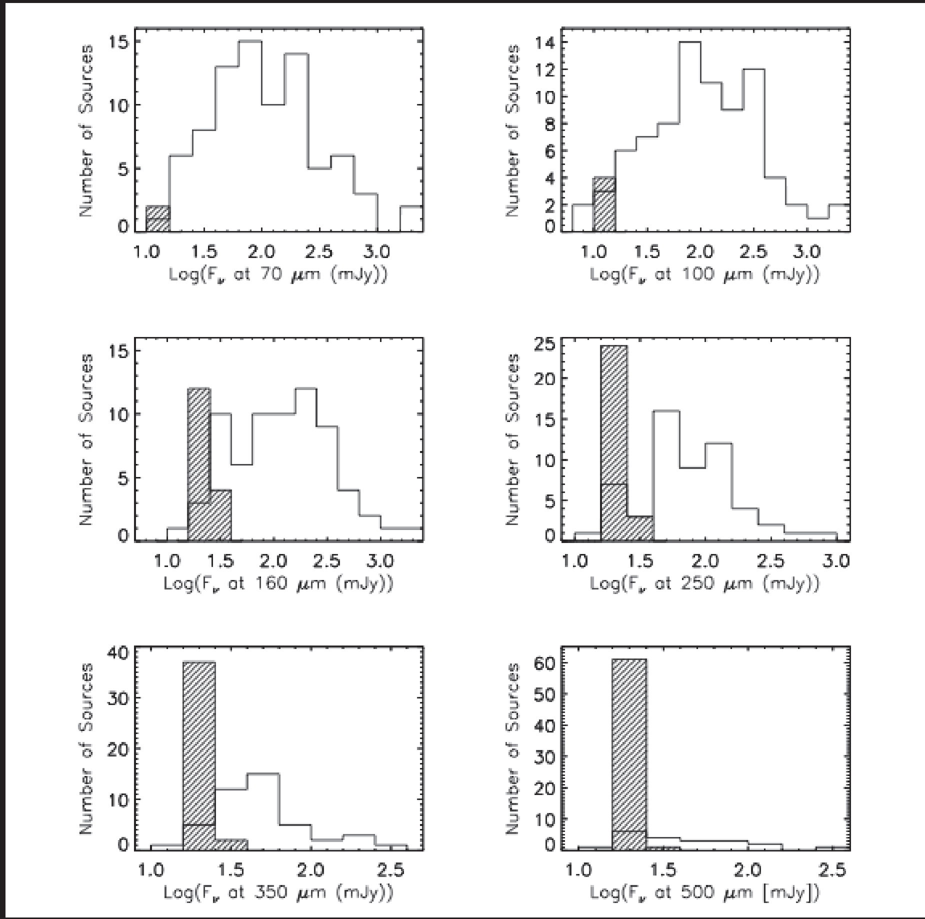
Conclusions II

- For QSO1s and a subset of 46 QSO2s: tight correlation between SFR_{FIR} and $SFR_{11.3\ um\ PAH}$ and also between the luminosity and EW of the 11.3 um PAH feature and M_{DUST}.

- QSO1s: for QSOs with the lowest and highest FIR luminosities the ratio of the 11.3 um PAH to the total FIR decreases in a non-linear fashion
- no 11.3 um PAH features seem to have been detected in sources with T_{DUST}> 50K.

- QSO2s: For the subset of 46 QSO2s with MIR spectroscopy the SFR derived from the 11.3 um PAH match those derived from the 160 um luminosity (Zakamska et al. submitted)

Basic Measurements PG QSOs



• more than an order of magnitude higher spatial resolution than previous IRAS observations and a factor of 8 better than those from ISO

•we are able to detect sources that are about 4 times fainter than the faintest PG QSOs detected by ISO.

Petric et al. 2015,ApJS, arXiv:1505.05273