



Mid-Infrared Spectroscopic Properties of Infrared Ultra-Luminous QSOs (IR QSOs)

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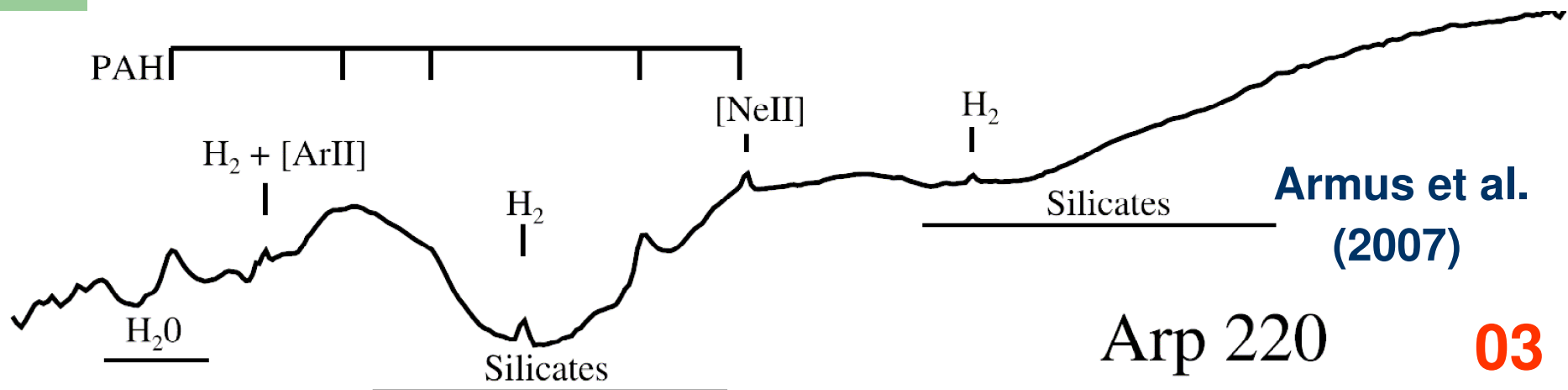
IR QSOs

- Infrared Ultra-Luminous QSOs :
ULIRGs ($L_{\text{IR}} > 10^{12} L_{\odot}$) + **Type 1 AGN**
(optical) \rightarrow **IR QSOs** (Zheng et al. [2002];
Hao, C.N. et al. [2005])
- Transitional Objects from **ULIRGs** to
optically selected QSOs (Canalizo & Stockton
[2000, 2001]; Hao, C.N. et al. [2005])
- **Crucial to understanding the probable
evolutionary link between ULIRGs and
QSOs** (Sanders et al. [1988] etc.)

Background



- **IRS 5-40 μm Probe** \rightarrow
- * **6.2, 7.7, 8.6, 11.3, 12.7 μm PAHs (SFR?!)**
- * **mid-IR fine-structure lines (SFR/AGN)**
- * **9.7, 18 μm broad Silicate features (dust)**
- * **warm-to-hot dust continuum emission (AGN?!)**



Object (1)	Redshift (2)	$\log(L_{\text{IR}}/L_{\odot})$ (3)	$\log(L_{60\mu\text{m}}/L_{\odot})$ (4)	$\log(L_{\text{opt}}/L_{\odot})$ (5)	RFe (6)
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Sample

I Zw 1(PG 0050+124)	0.0511	11.970	11.310	11.050	1.47 ^a
F00275-2859	0.2781	<12.713	12.342	11.568	1.47
F01348+3254(3C 48)	0.3670	<13.018	12.648	11.991	1.19 ^b
F01572+0000(4C 41.01)	0.3420	<13.021	12.824	11.102	1.13
F02054+0835	0.3450	<13.121	12.466	11.819	2.42
F07595+6505(3C 273)	0.4100	<12.876	11.711	11.857	2.75
F11119+3257	0.1890	12.663	12.322	12.089	1.12
F12265+0219(3C 273)	0.1582	12.811	12.262	12.127	0.66
F12540+3705(4C 41.01)	0.0914	12.549	12.236	11.467	1.83
F13218+0552 ^d	0.2051	12.728	12.270	11.467	0.48 ^c
F13342+3902(3C 273)	0.1110	12.711	12.711	11.821	0.73
F14026+4341	0.2233	12.960	12.145	11.930	1.33 ^b
F15439+4853(3C 273)	0.3996	12.784	12.344	11.843	0.86 ^a
F15462-0450	0.0998	<12.250	11.995	10.381	1.32
F16136+6550(PG 1613+658)	0.1290	<12.003	11.533	11.550	0.43
F17002+5153(3C 273)	0.1600	12.600	11.700	11.114	1.56 ^a
F18216+3441	0.1570	<12.415	12.607	12.607	0.39
F20036-1547	0.1919	<12.670	12.359	11.566	2.74
F21117-1711(3C 273)	0.1110	12.110	11.510	11.552	1.52

*** IR QSOs: Hao05 + F14026 (HyLIRG+BALQ)**
→ available: 19 (15 have both low & high -res obs.)

*** ULIRGs (non-S1):**
from IRAS 1-Jy sample and Spitzer GTO #105
+ High-res mid-IR data from Farrah et al. (2007)

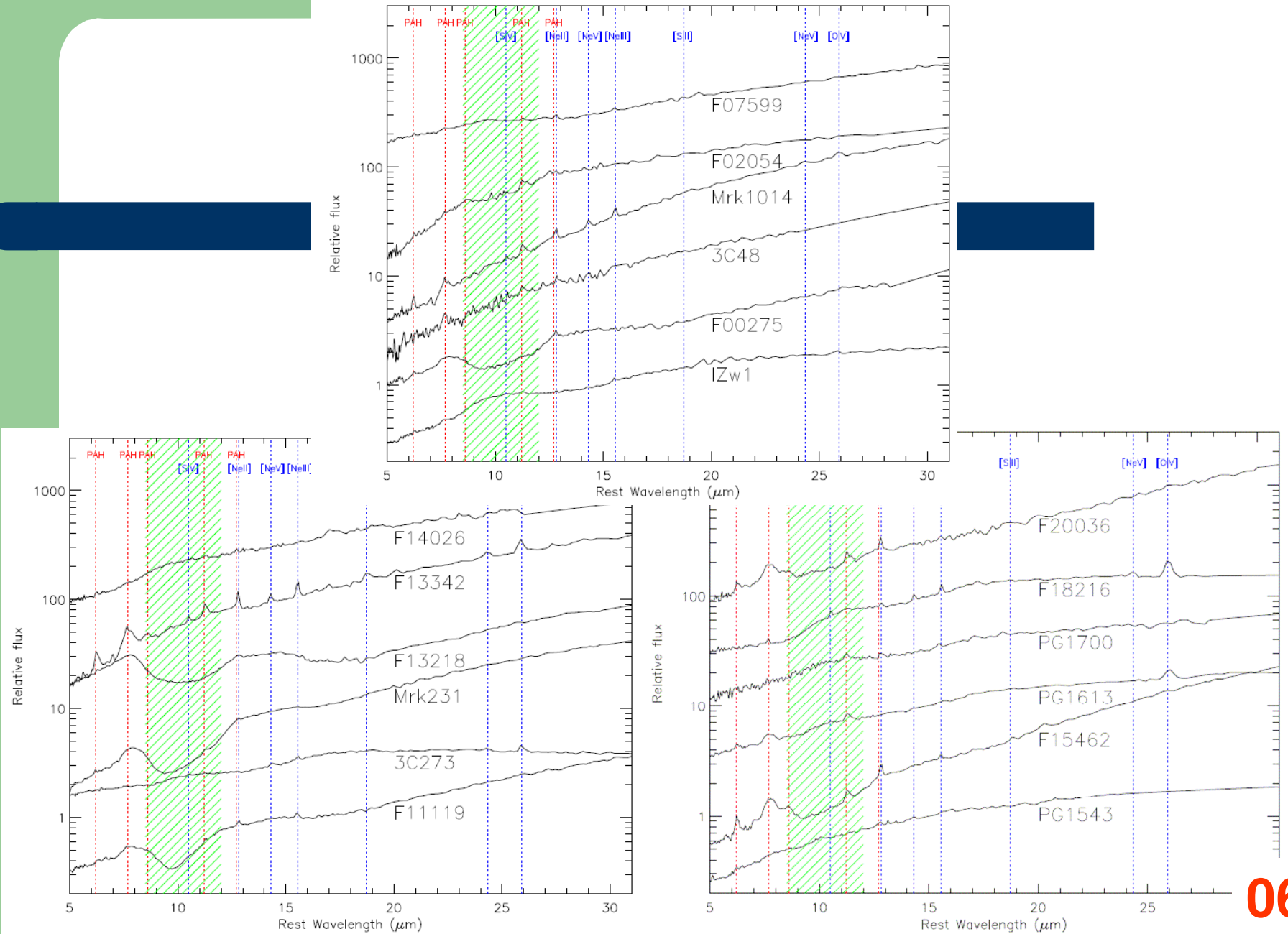
*** PG QSOs: mainly from Spitzer GTO & GO #14,**
3187 & 20142, with enough S/N, z<0.27
+ PG QSOs from QUEST.I (Schweitzer et al. [2006])

Data Reduction

- **Spectral Extraction:** **SMART** software (by IRS team of Cornell Univ.)
- **Scaling** the spectra: use 12 & 25 μ m flux densities from *IRAS* or *ISO*
- Measuring **PAH & fine-structure lines** (following Desai et al. [2007]; Farrah et al. [2007]; Schweitzer et al. [2006])
- Fitting the **continua** & measuring **silicate strengths** (following Spoon et al. [2007])

Results

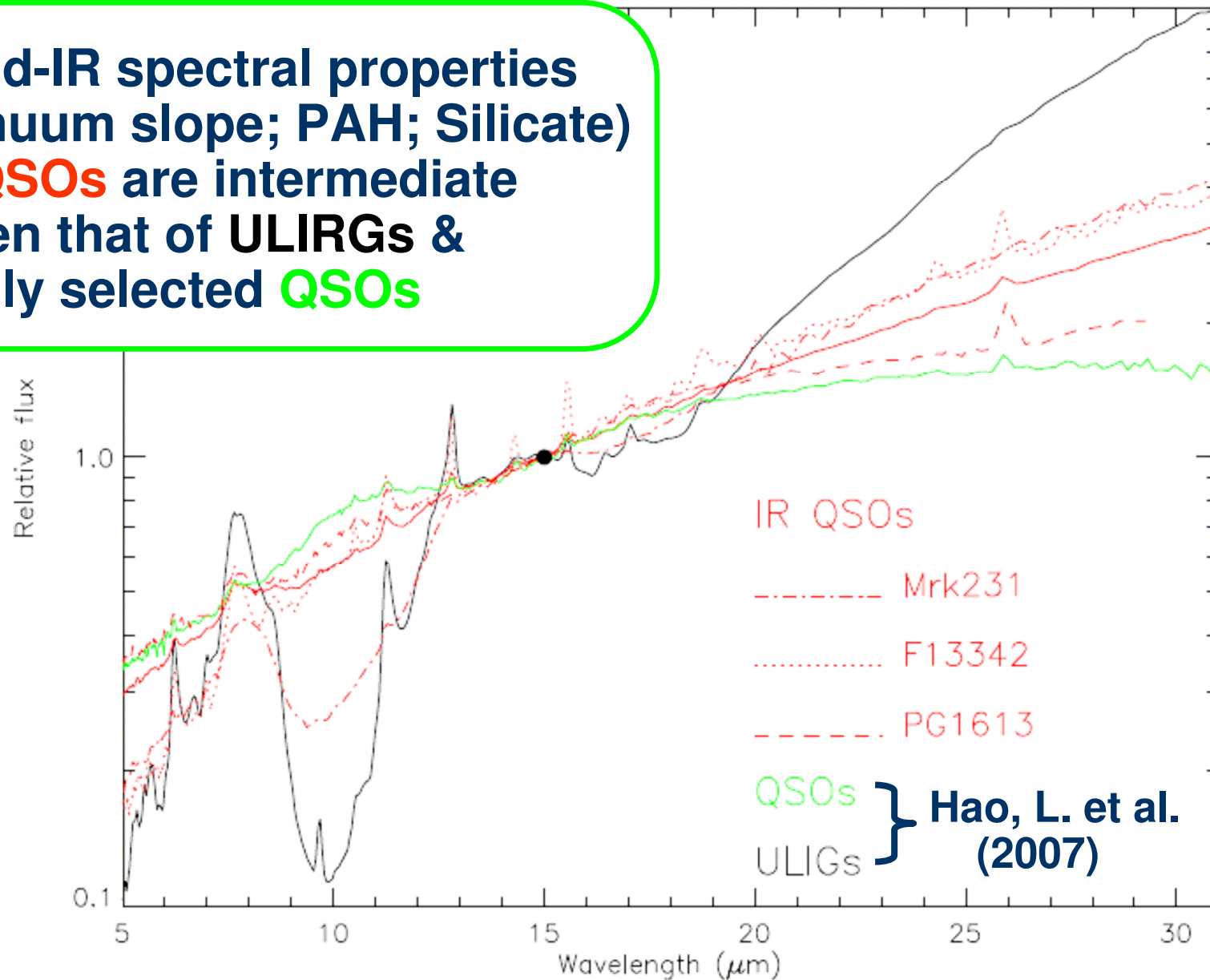
Low-Res Spectra of IR QSOs



Results

Average Spectra

The mid-IR spectral properties (continuum slope; PAH; Silicate) of **IR QSOs** are intermediate between that of **ULIRGs** & optically selected **QSOs**



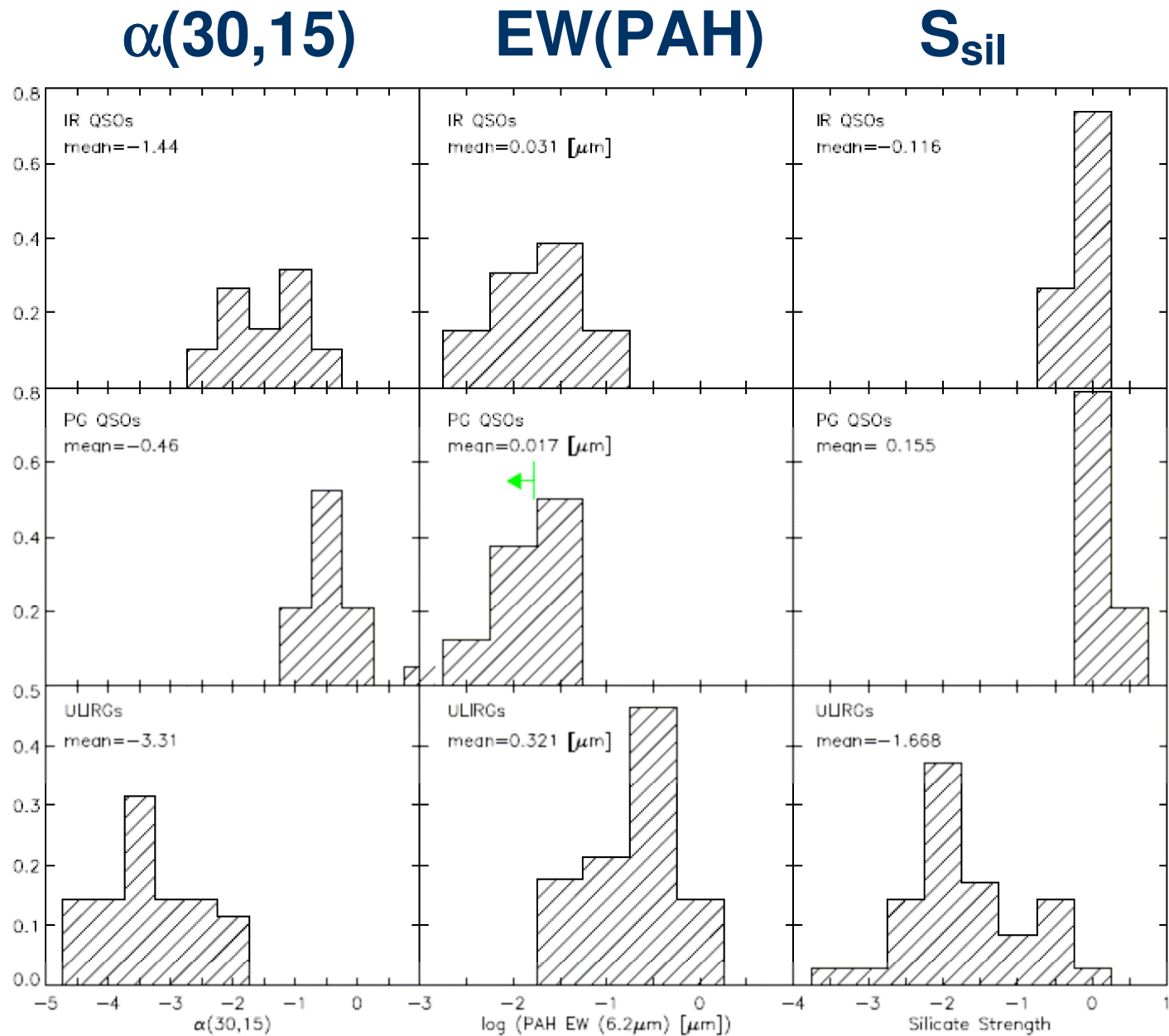
Results

Histograms

IR
QSOs

PG
QSOs

ULIRGs

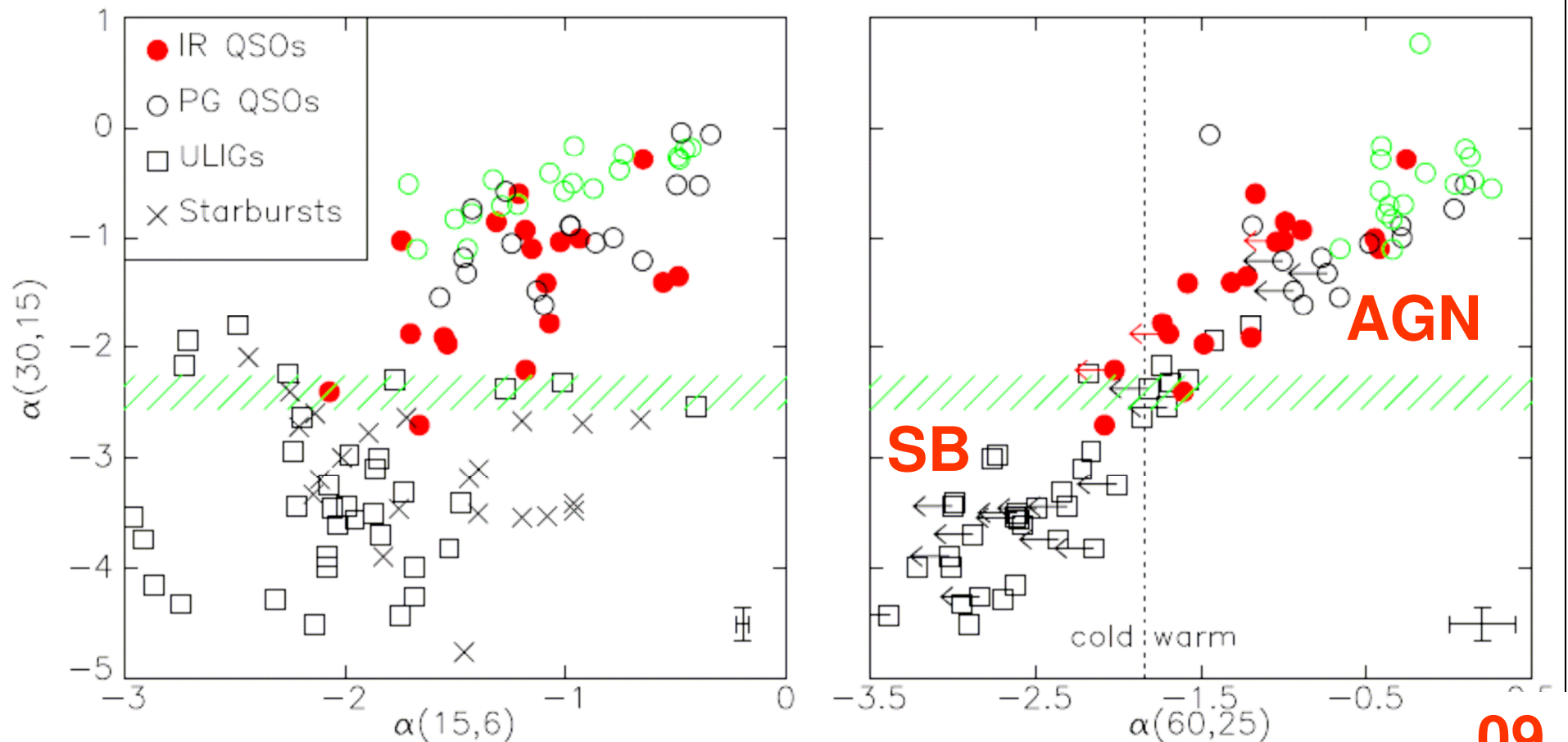


Mid-IR Diagnostics of SB and AGN activities (i)

Mid- and Far-IR color-color diagrams

$\alpha(15,6)$ vs. $\alpha(30,15)$

$\alpha(60,25)$ vs. $\alpha(30,15)$



Mid-IR Diagnostics of SB and AGN activities

(ii)

$\alpha(30,15)$

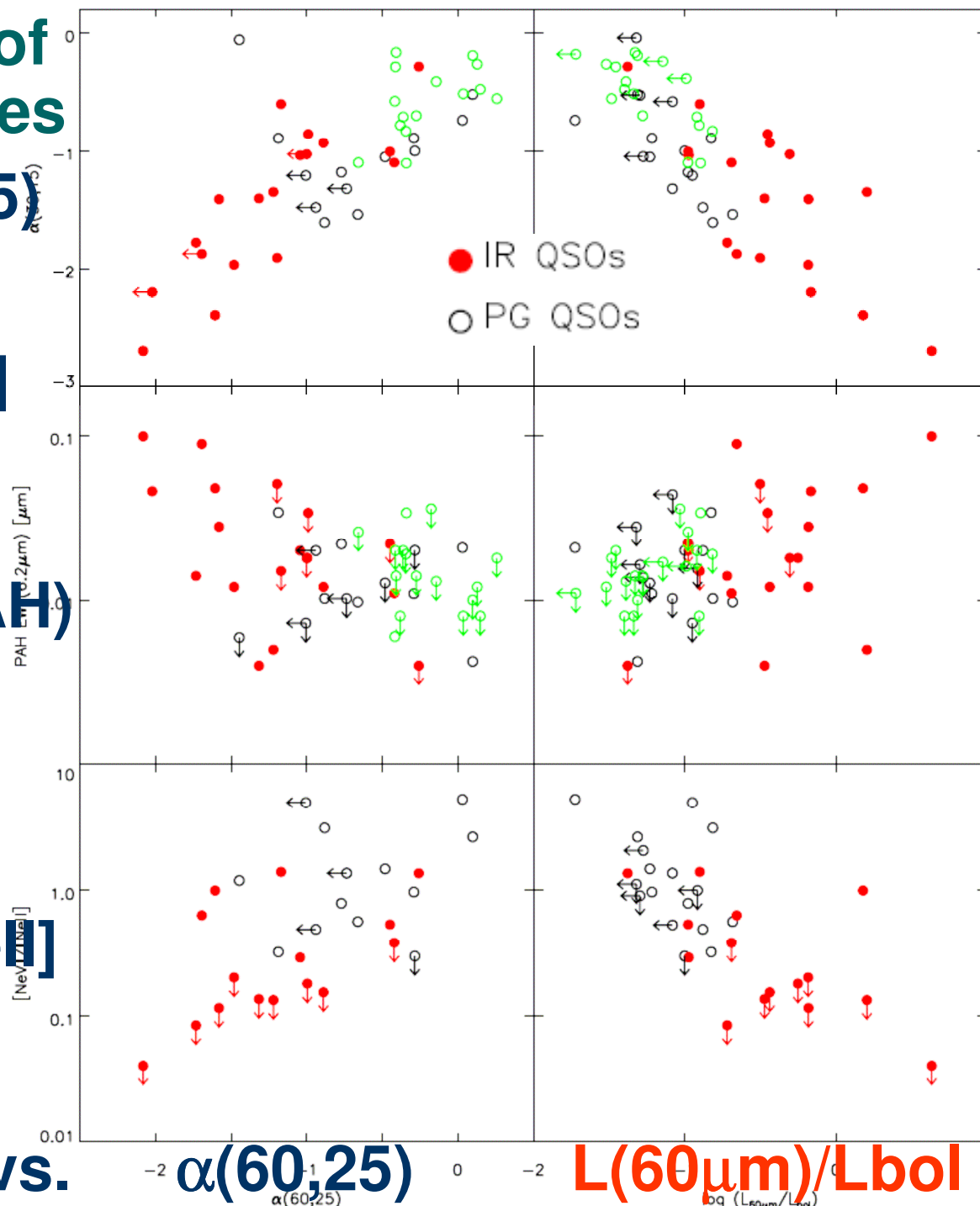
EW
(6.2 μ m PAH)

[NeV]/[NeII]

vs.

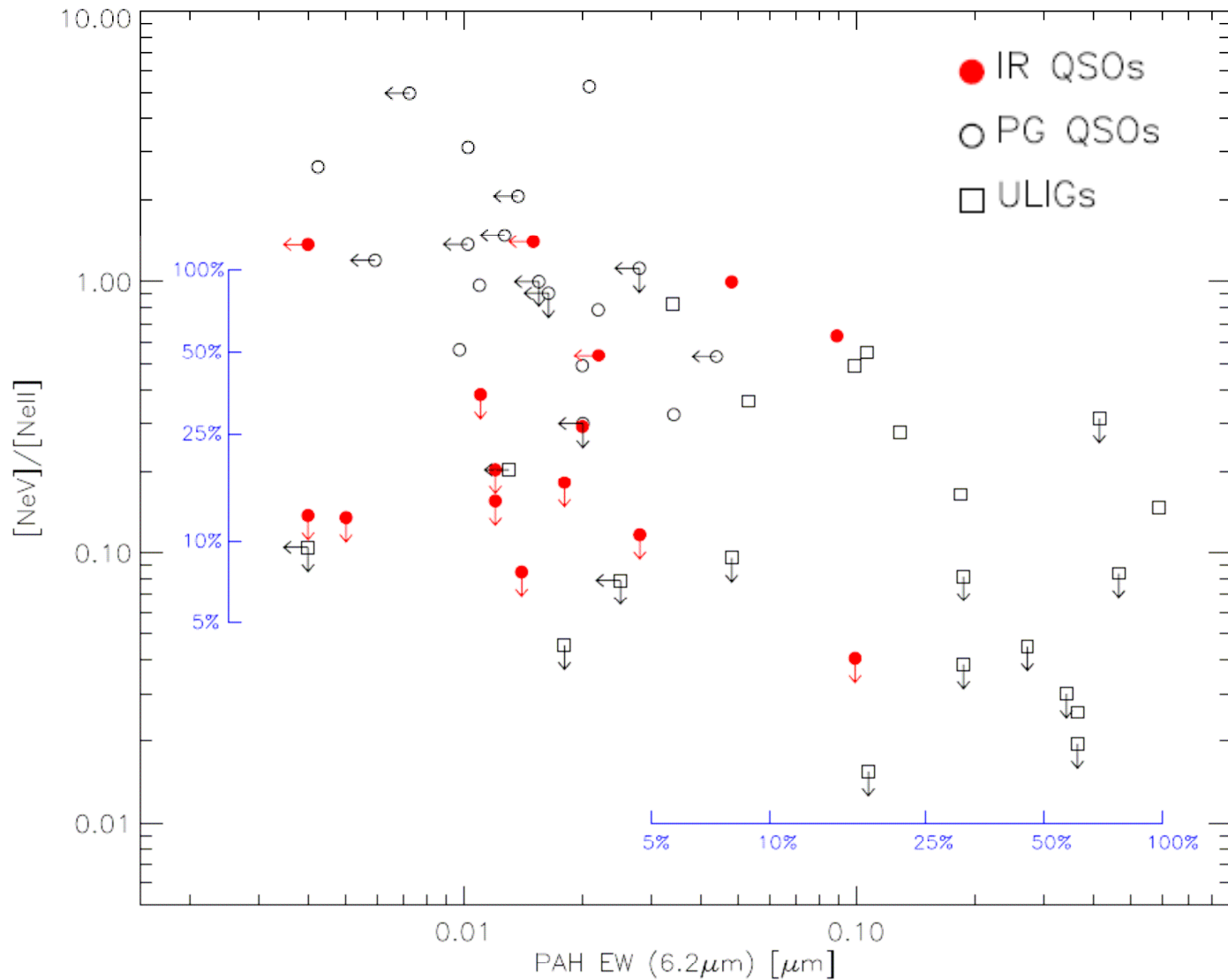
$\alpha(60,25)$

$L(60\mu\text{m})/L_{\text{bol}}$



Mid-IR Diagnostics of SB and AGN activities (iii)

Genzel Diagram -- EW(PAH) vs. $[\text{NeV}]/[\text{NeII}]$



Results

SFRs in QSOs & ULIRGs

-- **Far-IR (60 μ m) : Hao, C.N. et al. (2005, 2007)**

$$SFR = 3.26 M_{\odot} yr^{-1} \frac{L_{60\mu m}}{10^{10} L_{\odot}}$$

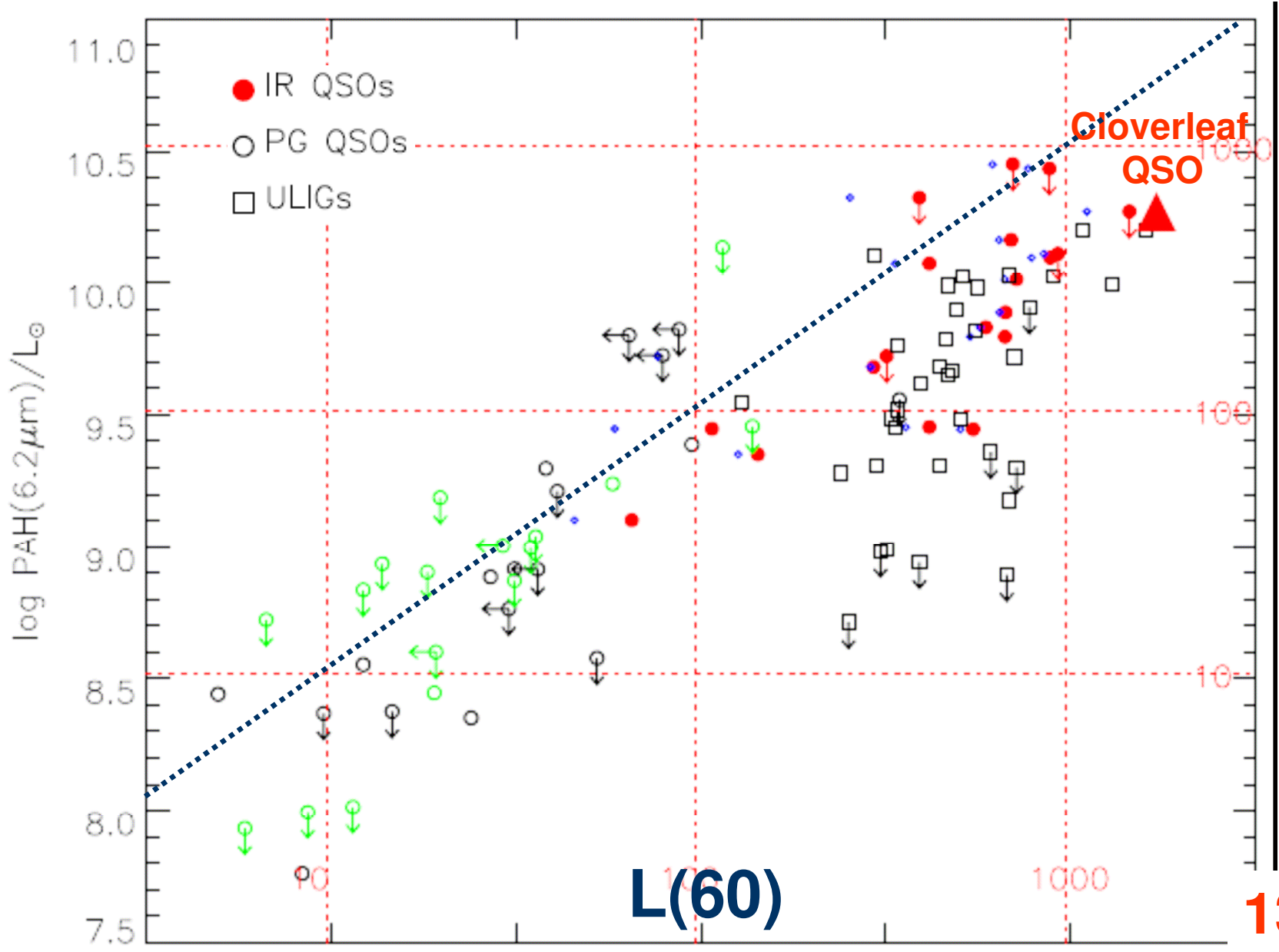
$$\log(L_{60\mu m}(AGN)/L_{\odot}) = 0.794 \log(\lambda L_{\lambda}(5100\text{\AA})/L_{\odot}) + 2.016$$

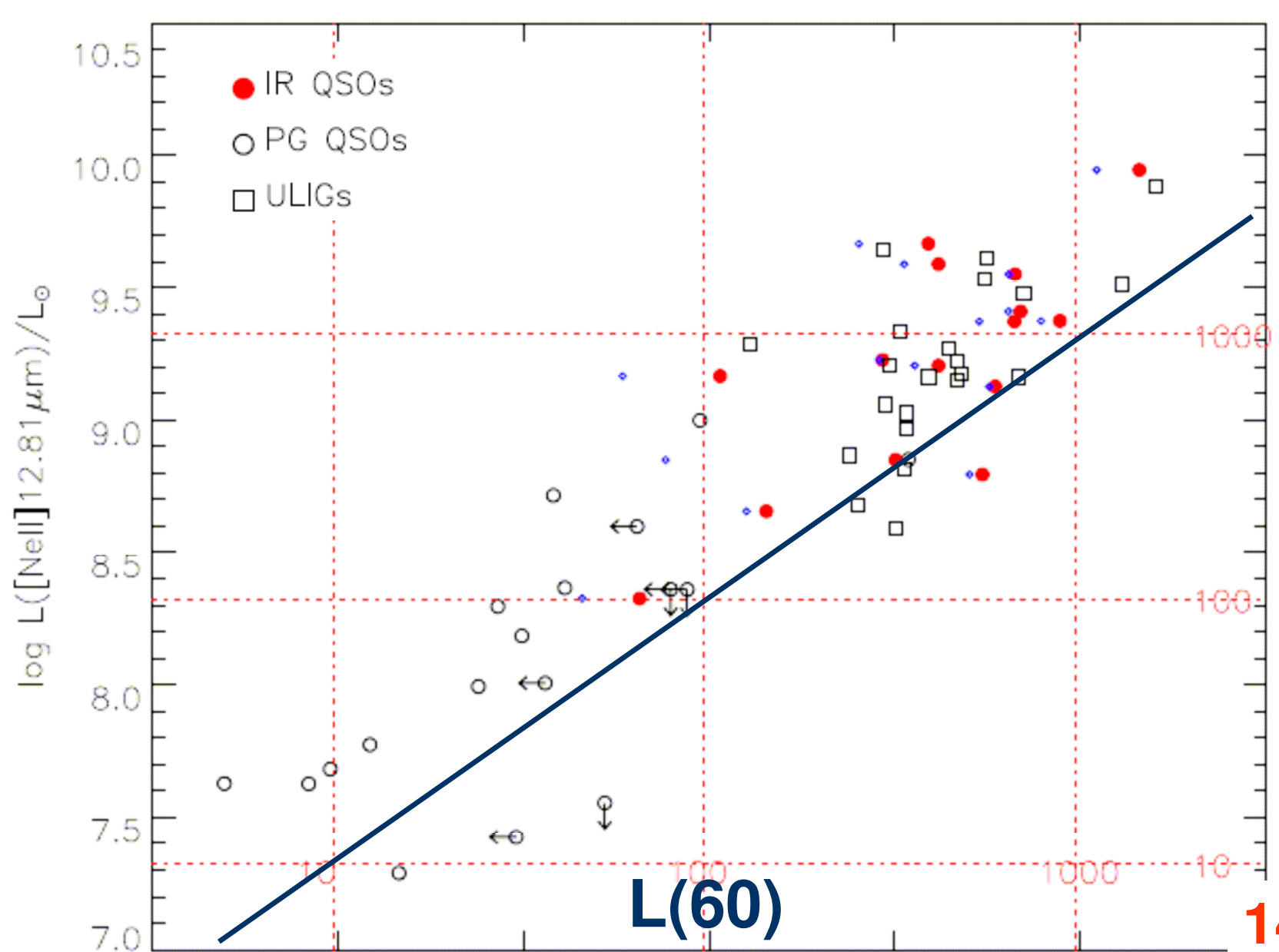
-- **PAH emission (6.2 μ m): Brandl et al. (2006)**

$$\log(L_{IR}^{PAH}) = 1.13 \times \log(F_{6.2\mu m PAH} D^2)$$

-- **[NeII] emission line: Ho & Keto (2006)**

$$\log L_{NeII} = (1.01 \pm 0.054) \log L_{IR} - (3.44 \pm 0.56)$$





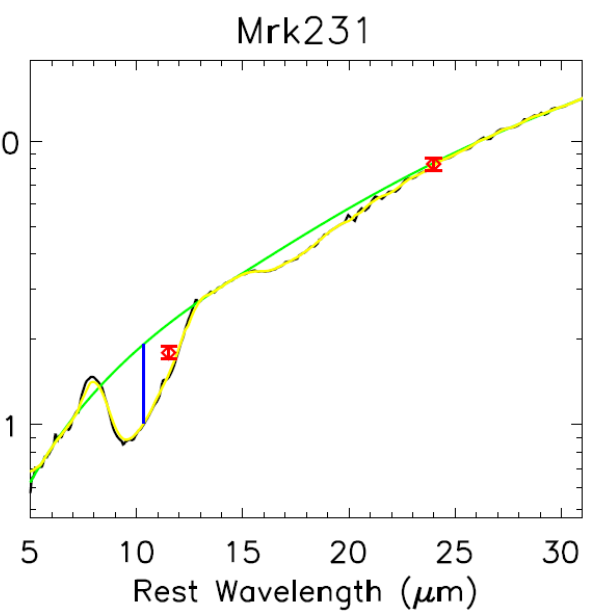
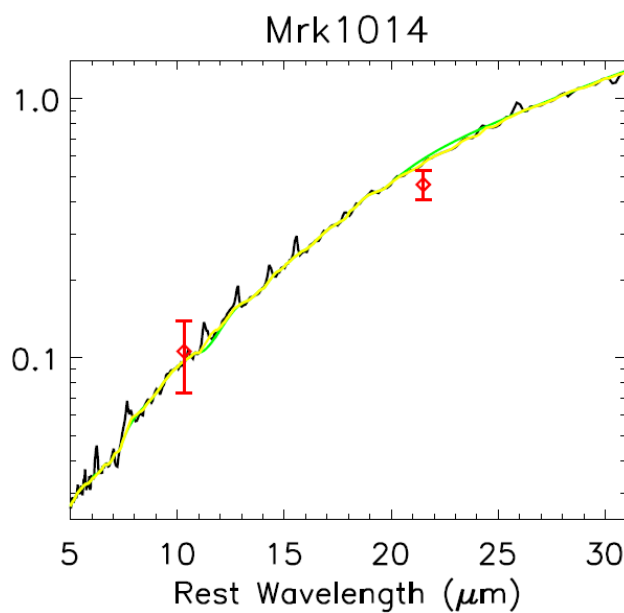
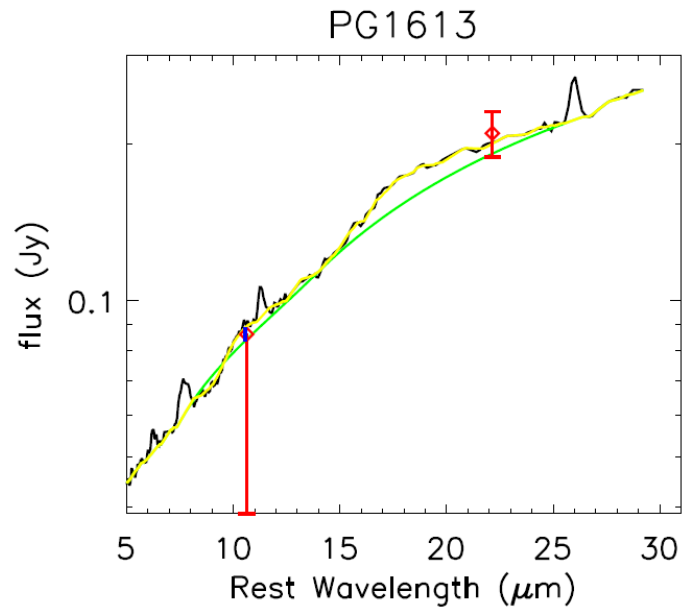
Discussion

Classification of IR QSOs

(pre)-Classical QSO

SB + QSO

ULIRG + QSO



$\langle \alpha(30,15) \rangle$ **-0.83**

-2.29

-1.72

$\langle \text{EW(PAH)} \rangle$ **< 0.017**

0.071

0.018

$\langle S_{\text{sil}} \rangle$ **0.08**

-0.14

-0.53

Discussion

Evolution of dust in IR QSOs

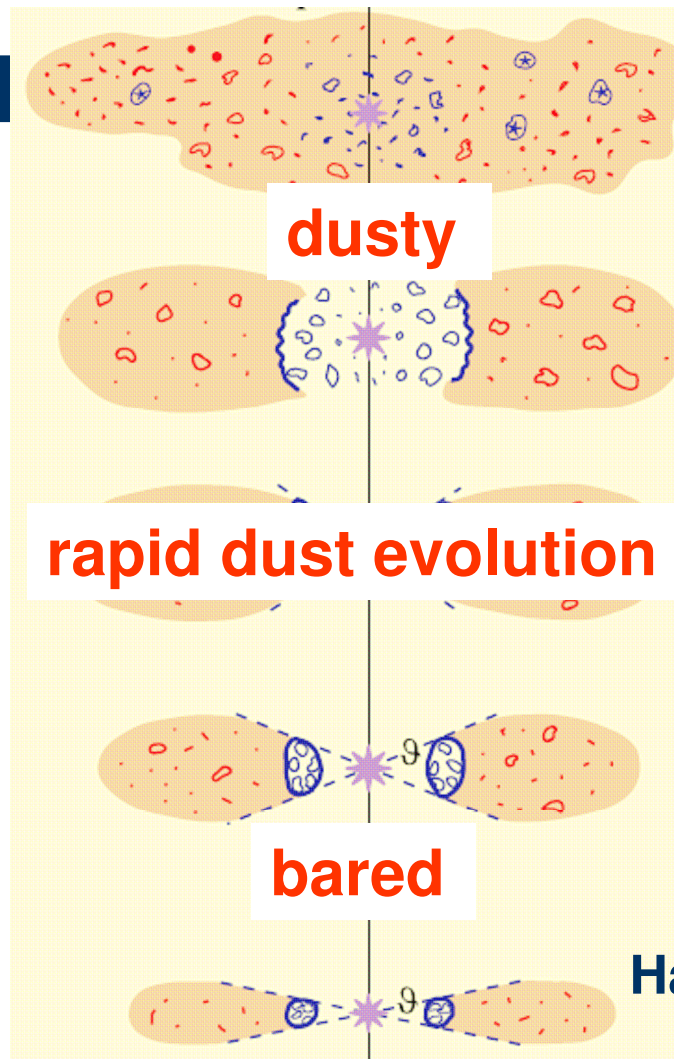
ULIRGs



IR QSOs



PG QSOs



$\langle S_{\text{sil}} \rangle$

-1.67

-0.12

+0.16

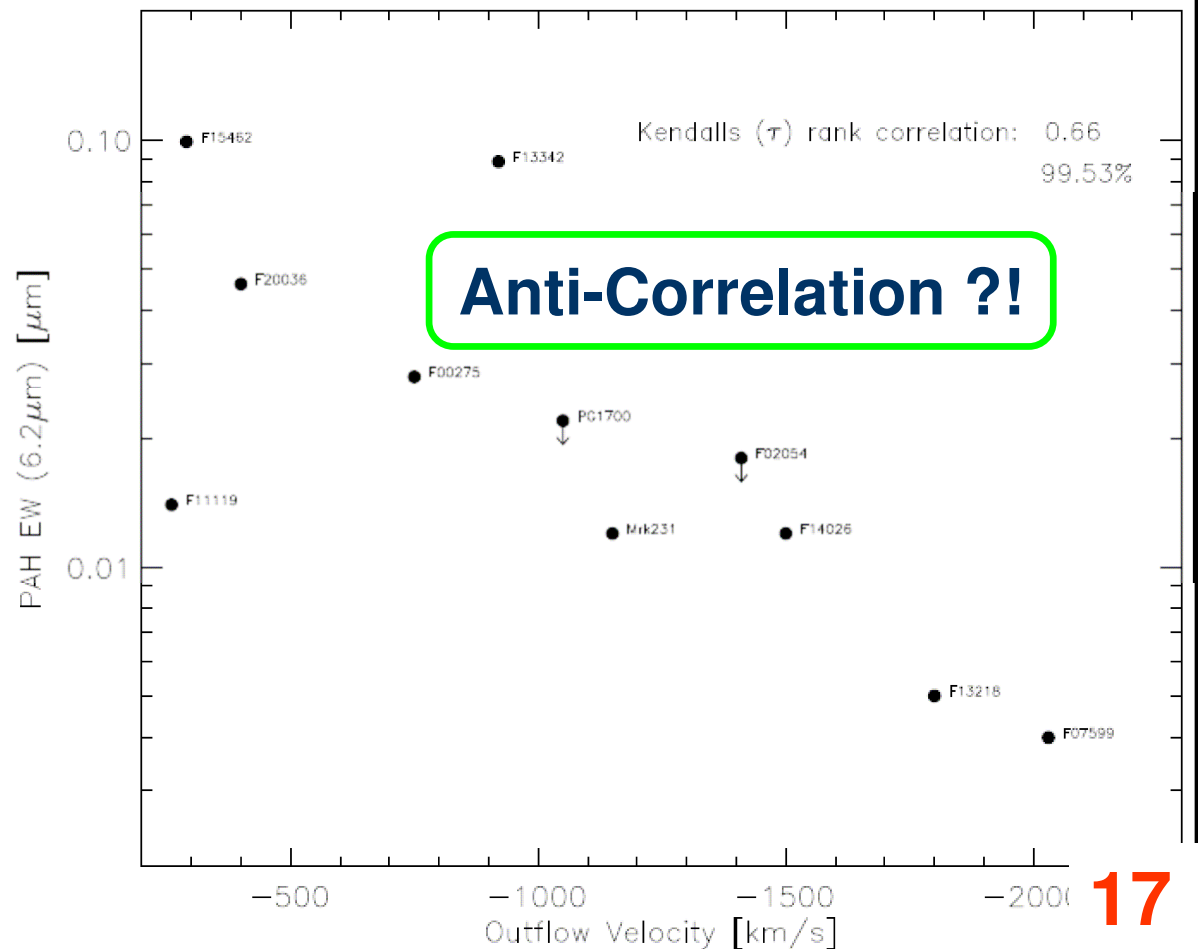
Haas et al.
(2003)

Discussion

Star Formation suppressed caused by AGN feedback ?!

— Outflowing Velocity : the offset broad H β emission (Zheng et al. [2002])

— SFR/Mdot: EW (6.2 μ m PAH)





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