Star Formation Rates for Infrared Bright Galaxies

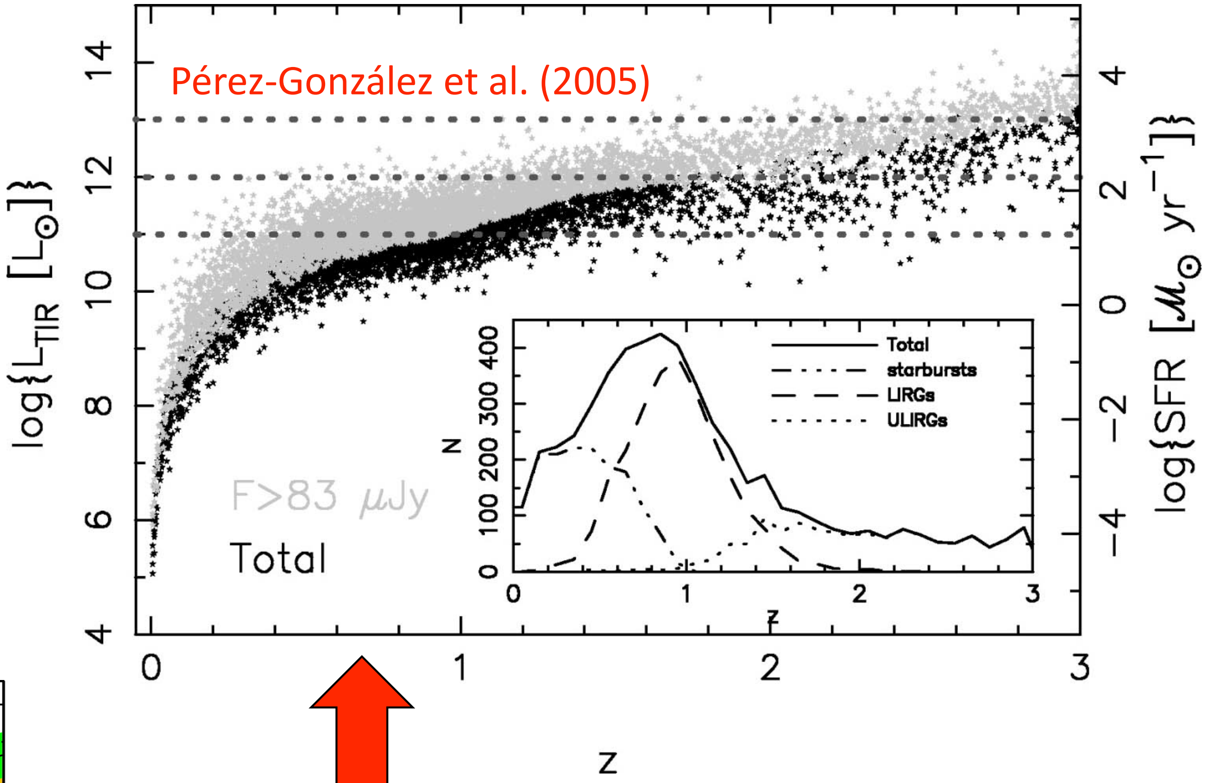
Almudena Alonso-Herrero

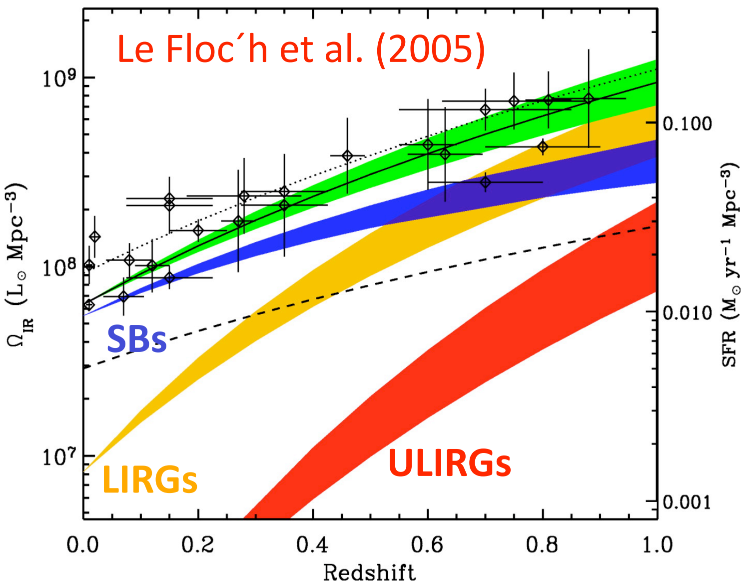
IEM, CSIC, Madrid

G. Rieke, T. Díaz-Santos, M. Pereira-Santaella, L. Colina, P. Pérez-González, C. Packham, B. Weiner, J. Donley, D. Marcillac, M. Blaylock

Infrared Selected Galaxies

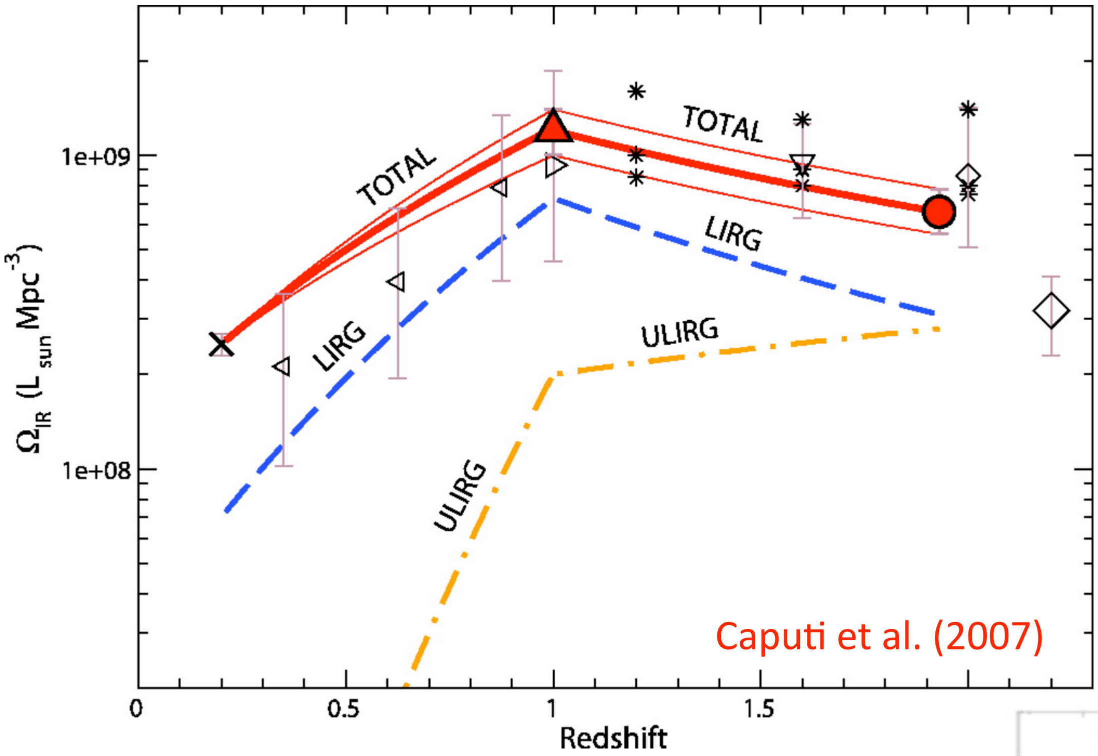
Although the IR-SFR does not take into account the unabsorbed UV SF produced by young stars, at z~1 the total SFR is only underestimated by ~20-30%





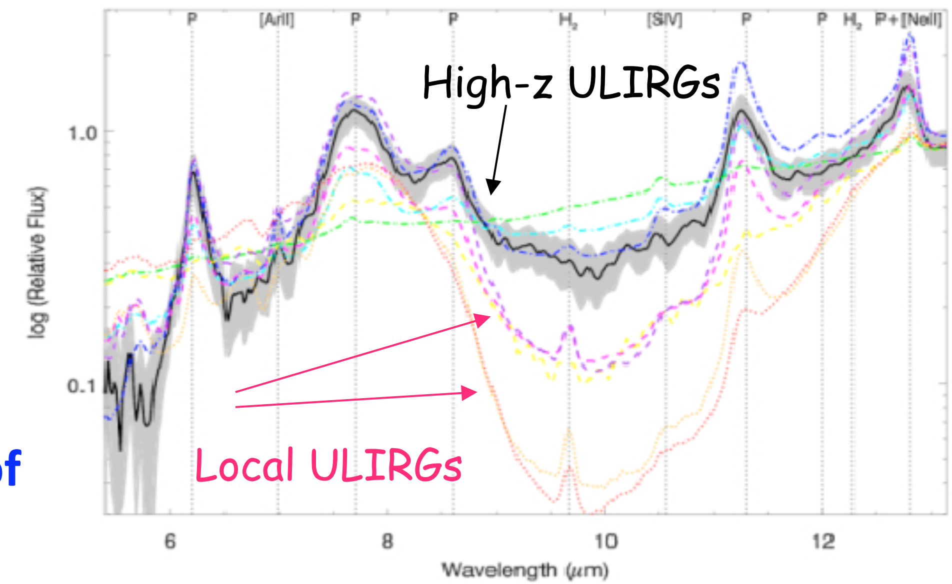
- Galaxies with moderate SFRs detected @ z<1
- Few ULIRGs @ z<1 because of low density
- **1<z<2 ~50% are LIRGs and 50% are ULIRGs**
- **LIRGs dominate the SFR density at z~1**
- z>2 population of HyLIRGs

(U)LIRGs at high redshift (z~0.5-2.5)



LIRGs are major contributors to the comoving IR luminosity density (ie, SFR) at z=1 and have a similar contribution to ULIRGs at z=2 (Le Floc´h et al. 2005; Pérez-González et al. 2005; Caputi et al. 2007).

Farrah et al. (2008)



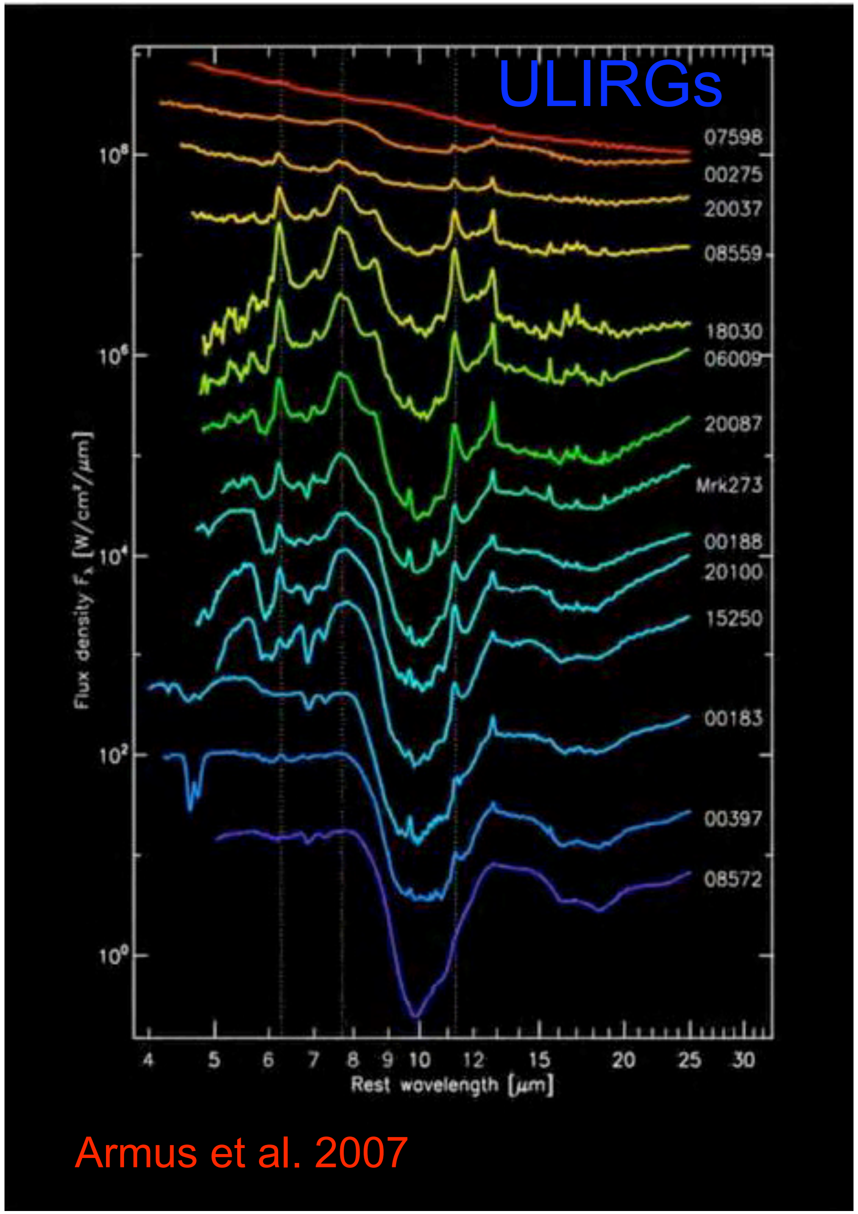
The mid-IR spectra of distant (z~1.7-2) ULIRGs are more similar to those of local starbursts and LIRGs: shallow 9.7μm silicate feature

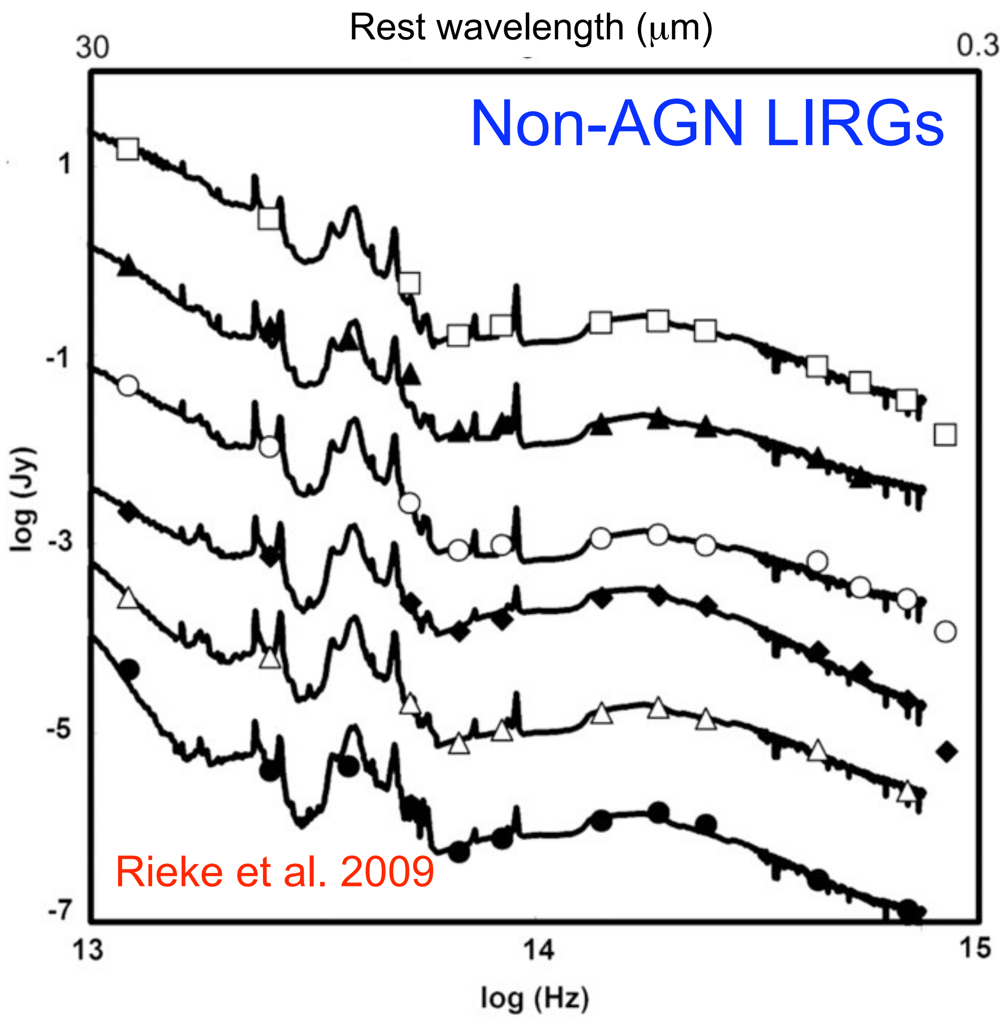
Locally LIRGs and ULIRGs extinctions of a few A_V to ~100A_V

Spitzer Mid-IR integrated spectra of local LIRGs and ULIRGs

LIRGs: $\mathbf{10^{11}L_\odot < L_{IR(8\text{-}1000\mu m)} < 10^{12}L_\odot}$

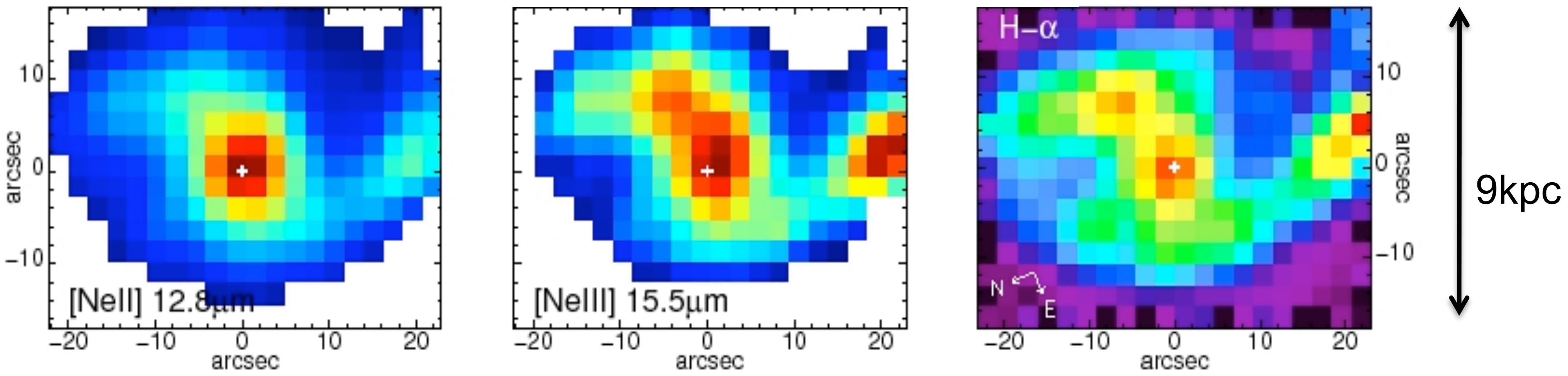
ULIRGs: $\mathbf{10^{12}L_\odot < L_{IR(8\text{-}1000\mu m)} < 10^{13}L_\odot}$





Spatially resolved mid-Infrared emission in local LIRGs

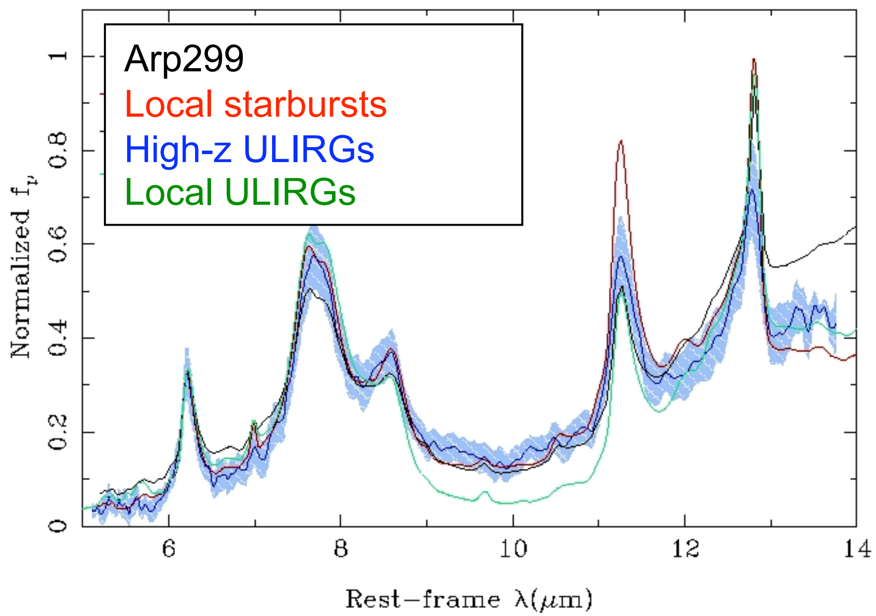
Spitzer [NeII]   Spitzer [NeIII] NGC3110 Hα



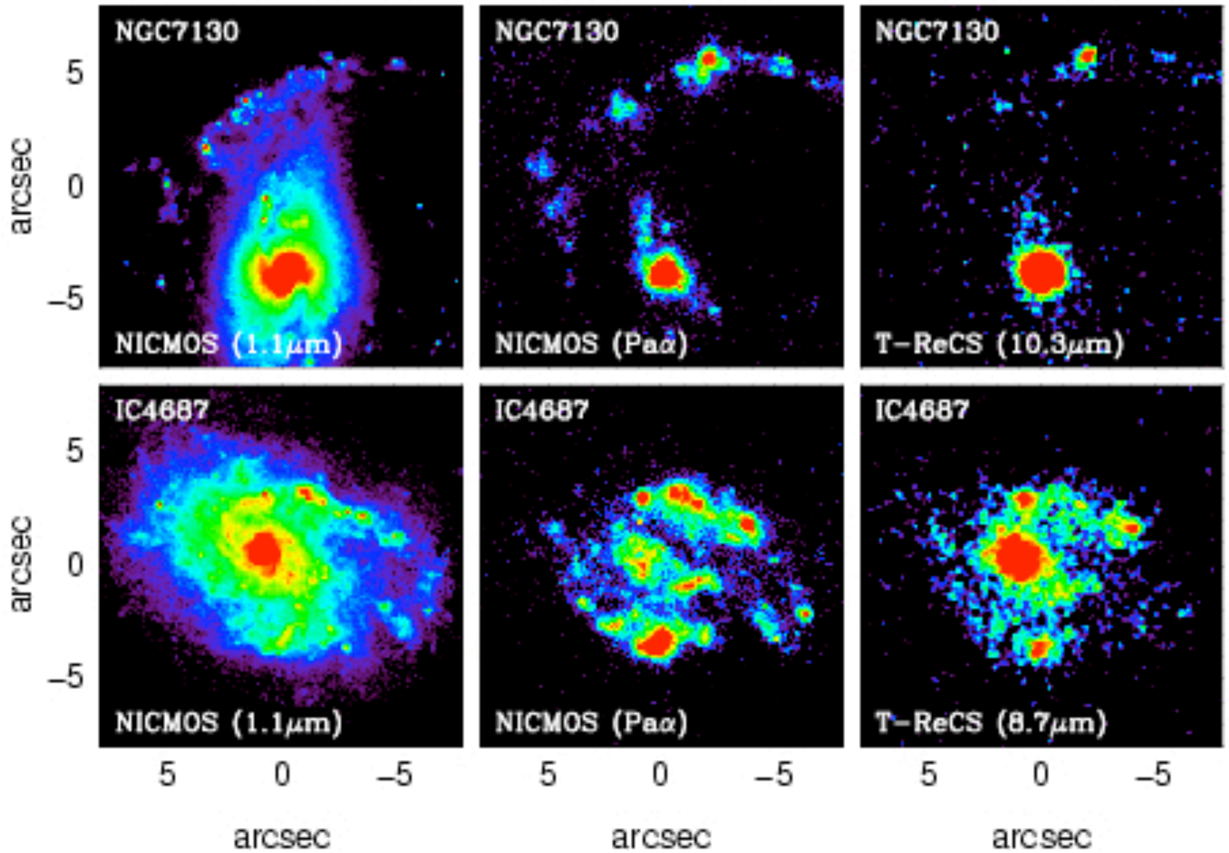
Extended PAH features, mid-IR continuum, Paα, Hα, [NeIII], [NeII] **over several kpc** in at least ~50% local LIRGs

Similar to high-z ULIRGs?

Alonso-Herrero et al. 2006, 2009; Pereira-Santaella et al. 2009



Gemini/T-ReCS 8μm vs HST/NICMOS emission of LIRGs



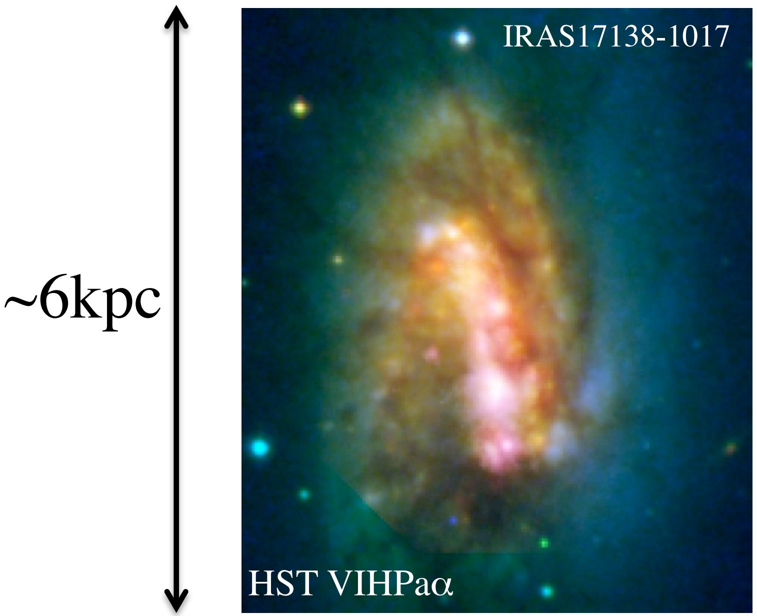
Ground-based mid-IR imaging provides **angular resolutions comparable to HST/ NICMOS**

Near-IR continuum traces mostly evolved stellar populations

Paα emission line and mid-IR continuum are related to the young ionizing stellar populations

Mid-IR emission not necessarily within central kpc

Alonso-Herrero et al. (2006b)
Díaz-Santos et al. (2008)



SURFACE BRIGHTNESSES OF INFRARED STARBURST GALAXIES

Object	Type	Infrared Luminosity (L_{bol} ($L_\odot$))	Surface Brightness ($L_\odot$kpc^{-2})
Orion..........	H II region	1×10^6	2×10^{12}
M 82	Local starburst	3×10^{10}	2×10^{11}
NGC 6090	Starburst	3×10^{11}	2×10^{11}
NGC 1614	Starburst	4×10^{11}	1.5×10^{12}
Mrk 331	Starburst	2.5×10^{11}	$\sim 2 \times 10^{12}$
IC 883.........	Starburst	3×10^{11}	2×10^{12}
VV 114........	Starburst	4×10^{11}	$\sim 5 \times 10^{12}$
NGC 2623	Starburst	3×10^{11}	$\sim 10^{13}$
NGC 3690	Starburst	8×10^{11}	$\sim 10^{13}$
IRAS 17208...	ULIRG	3×10^{12}	1.2×10^{12}
Mrk 273	ULIRG	1.3×10^{12}	$> 2.2 \times 10^{13}$
IRAS 08572...	ULIRG	1.3×10^{12}	$> 2.8 \times 10^{13}$
Arp 220	ULIRG	1.5×10^{12}	6.0×10^{13}

The Mid-IR Emission of Nuclear Regions of LIRGs

SF nuclei: typically 50-200 pc (FWHM)

Nuclear IR emission accounts for 10-50% L_{IR} of the system for LIRGs and almost 100% for ULIRGs

IR surface brightness:
1×10^{11} –$2 \times10^{13} L_\odot$kpc^{-2} and ULIRGs ×10

ORION: $2 \times10^{12} L_\odot$kpc^{-2}

AGN: mostly unresolved, but sometimes with nuclear (<40-80pc) star formation

10-30% of L_{IR} of LIRGs

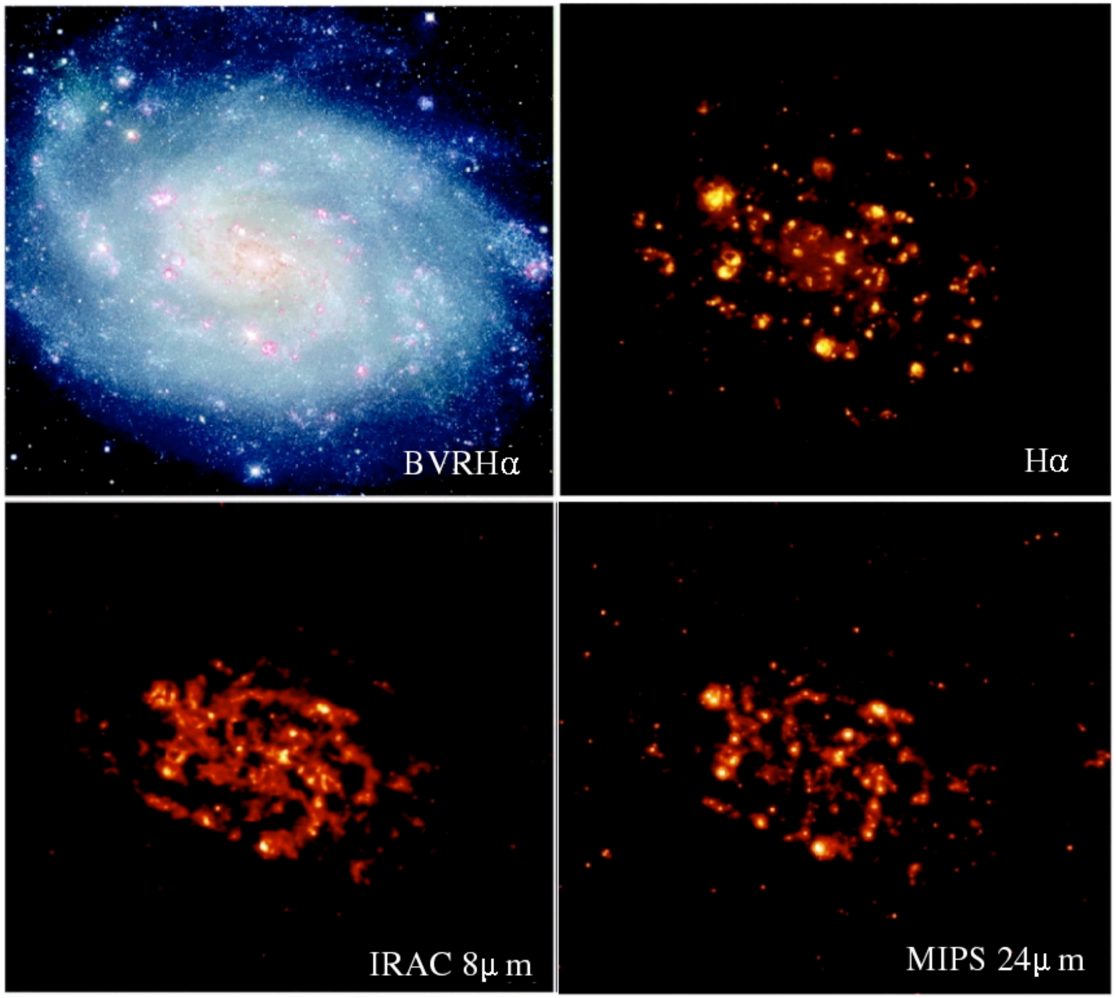
Soifer et al. 2000; 2001; Alonso-Herrero et al. 2006a; Díaz-Santos et al. 2008

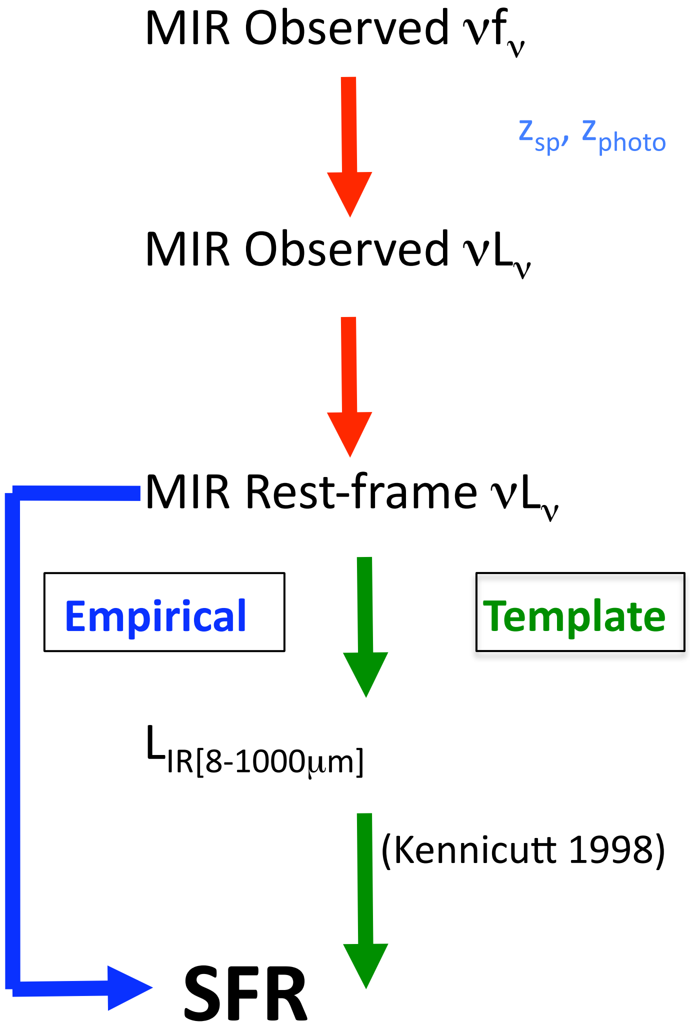
Mid-IR emission as Star Formation Rate (SFR) indicator

SFR Indicators: UV, [OII]3727, Hα, Paα are affected by extinction

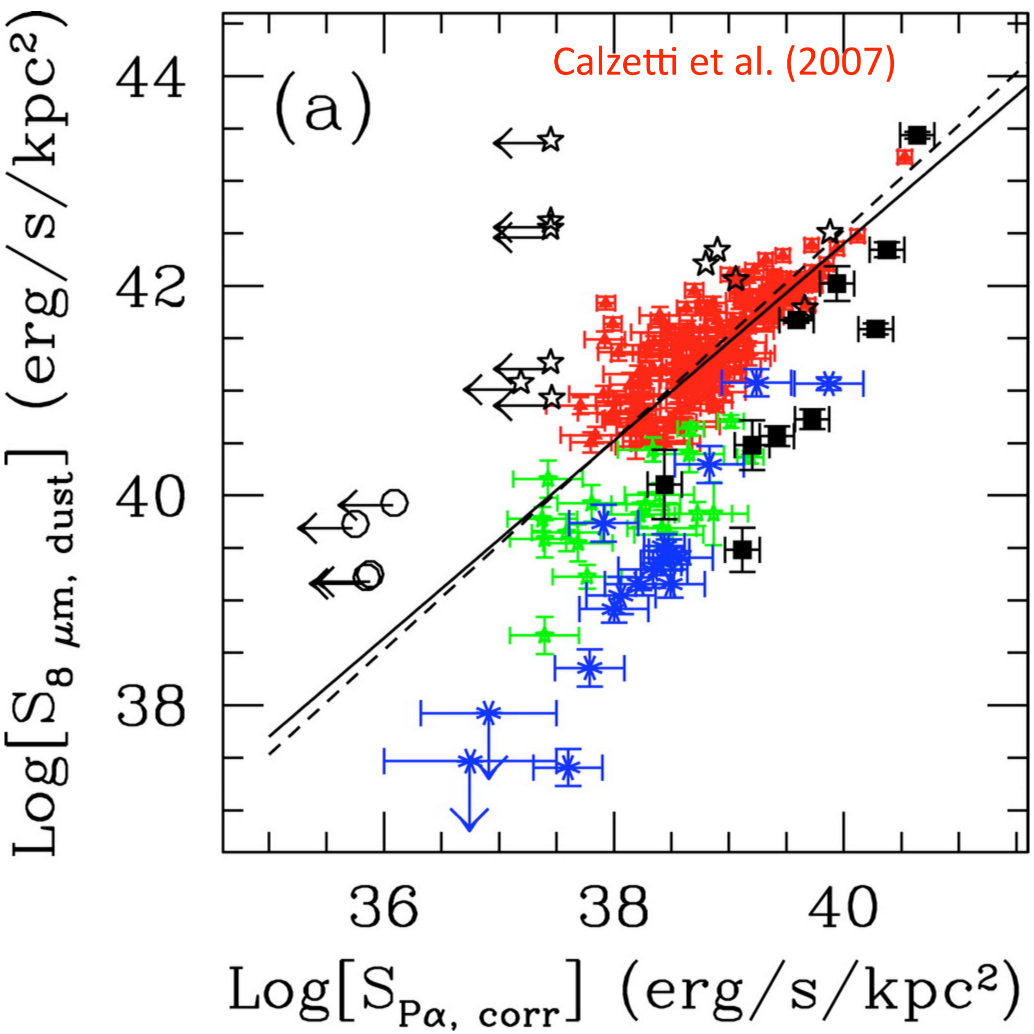
SFR Indicators: IR luminosity, radio NOT affected by extinction

The nearby galaxy NGC300 (Helou et al. 2004)





8μm vs. Paα emission of SINGS HII regions on scales of 500pc



The 8μm vs Paα relation shows a much larger scatter than at 24μm

Strong dependence with metallicity, the size of the emitting region and SF history of galaxy

Range of Metallicities of SINGS galaxies:

High:

12+log(O/H)>8.25

Intermediate:

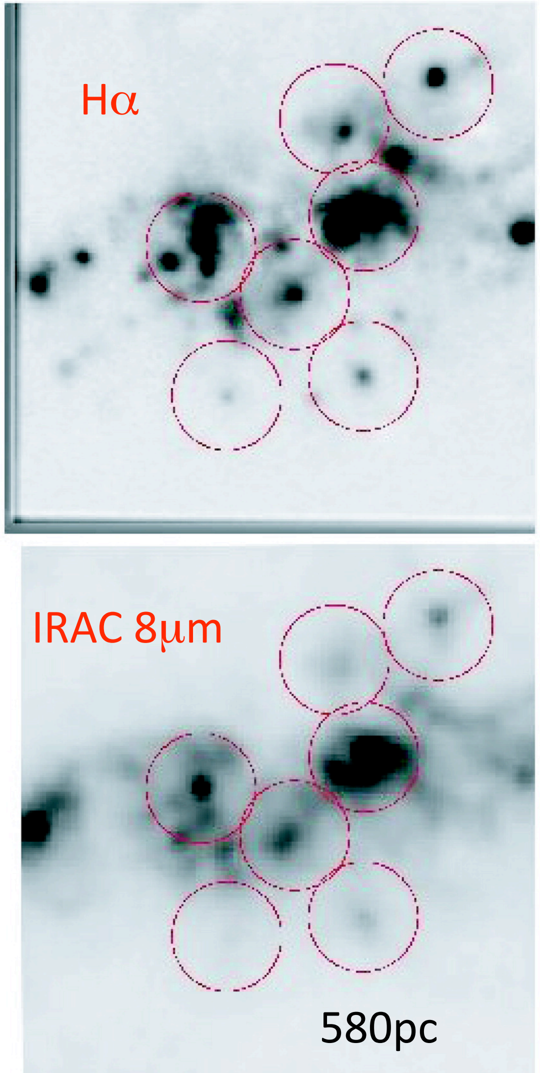
7.90<12+log(O/H)<8.25

Low:

log(O/H)<7.90

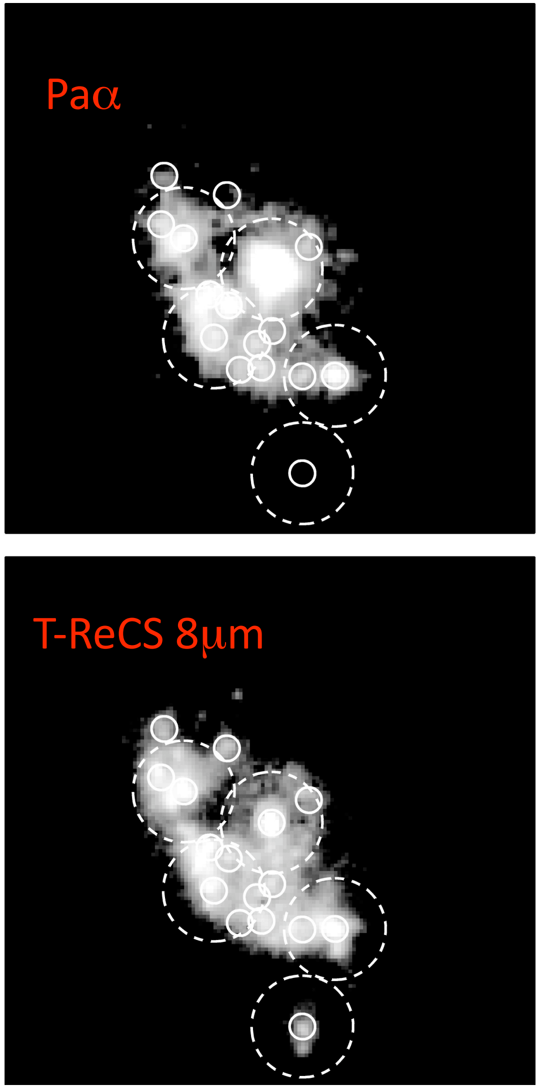
8μm vs. Paα emission of LIRGs HII regions on scales of 500pc

SINGS: NGC925

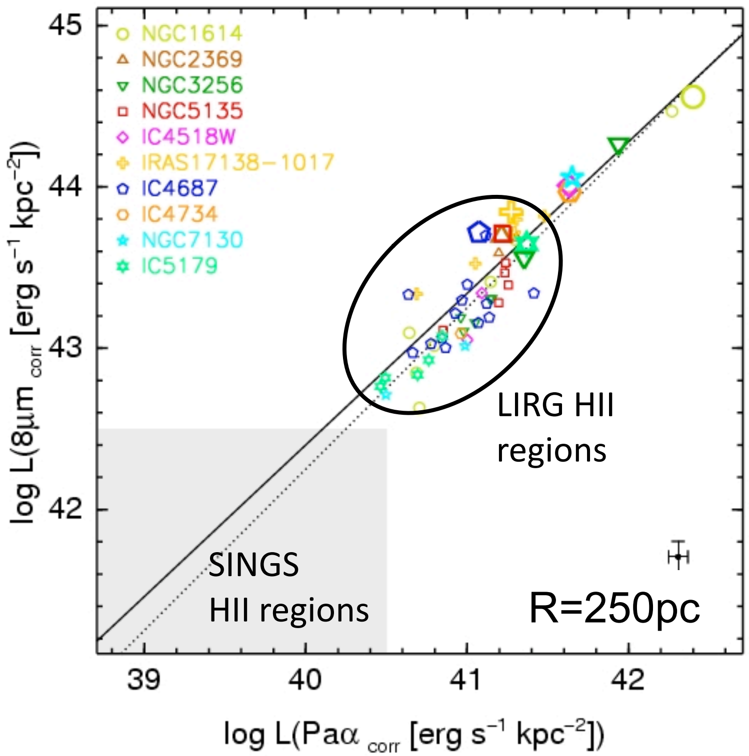


Calzetti et al. (2007)

LIRG: NGC5135



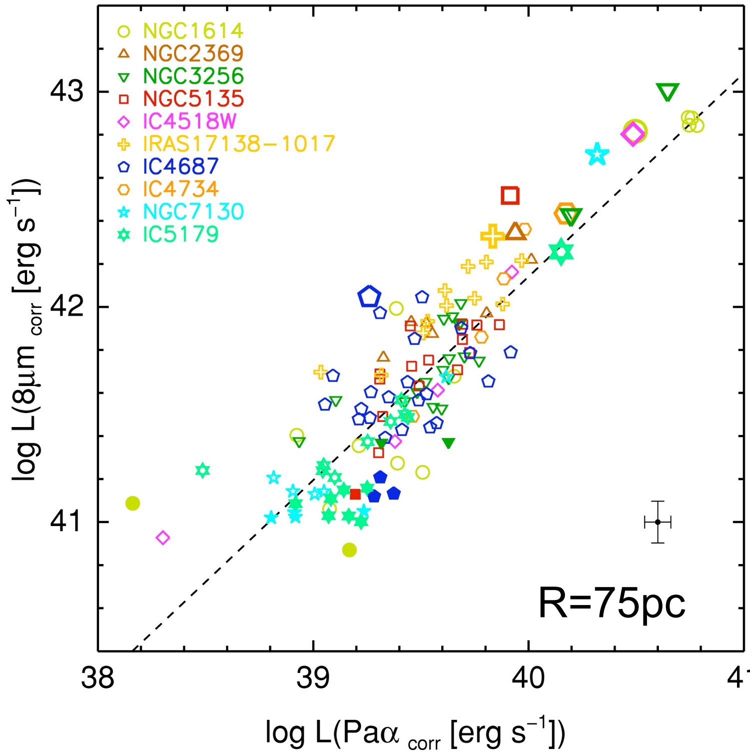
Díaz-Santos et al. (2008)

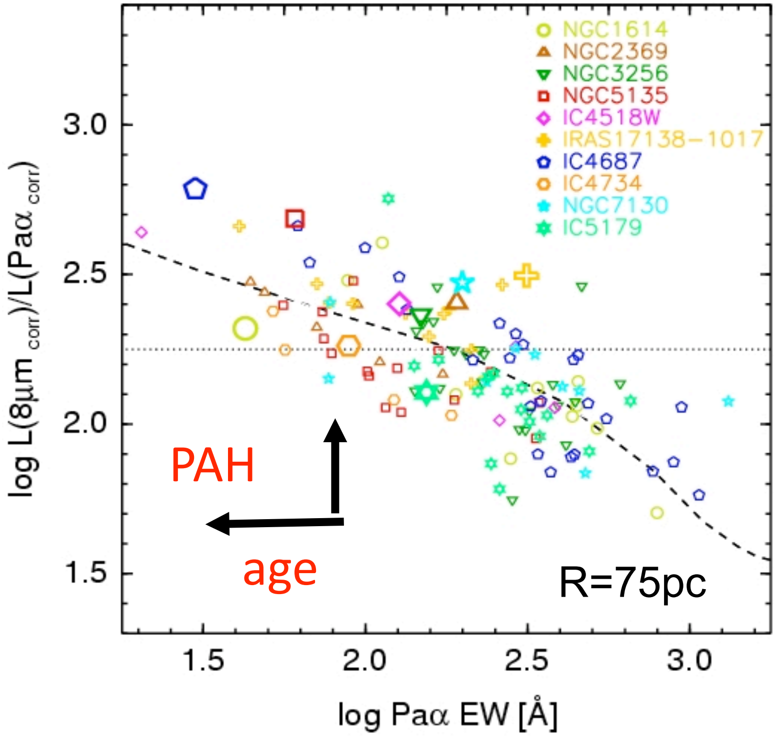


HII regions of LIRGs extend the Paα vs 8μm relation by two orders of magnitude

8μm emission of LIRGs on scales of 100pc

The scatter of the 8μm vs Paα relation increases for smaller physical sizes



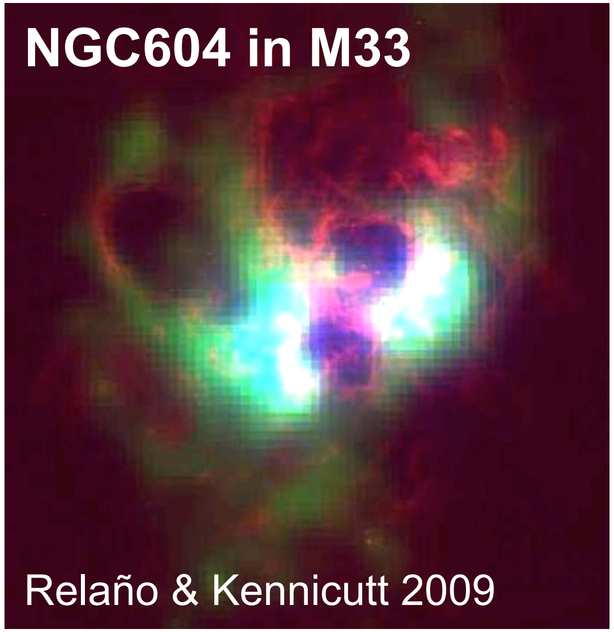


Alonso-Herrero et al. (2006b), Díaz-Santos et al. (2008)

Scatter of 8μm/Paα ratios of HII regions in high metallicity galaxies might be explained as:

- an age effect
- different contribution of the 8.6μm PAH feature to total IR luminosity

SFR in terms of the 8μm emission should be calibrated with integrated emission

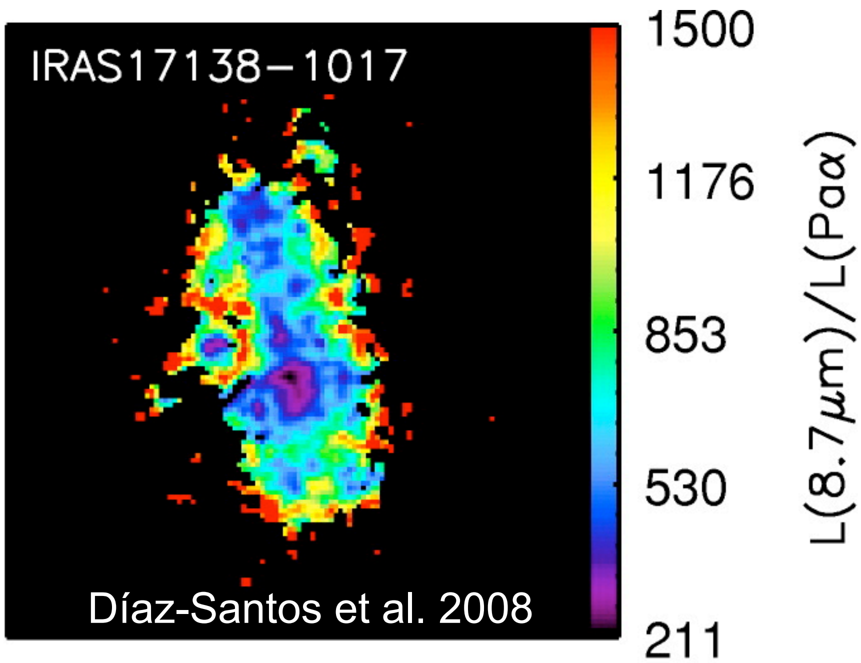


Hα: red, 8μm: green, 24μm: blue

The 24 μm emission is restricted to the central part of the region and correlates with the position of the most intense central Hα knots.

Hα emission are surrounded by the 8 μm emission. The 8 μm maxima is in general displaced from the Hα maxima. The 8 μm emission is more related to the PDR

LIRGs at 8μm: HII regions + an important contribution of diffuse and extended component. This extra emission at 8 μm would be produced not by local, strong ionizing sources, but by the diffuse radiation field.



24μm emission as a SFR tracer

A tight correlation is seen between extinction-corrected Pa-α and 25μm (from IRAS) or 24μm (from Spitzer) flux density for SINGS HII regions, and integrated luminosities of LIRGs, ULIRGs, and normal galaxies.

Alonso-Herrero et al. (2006a)

- 24-70μm emission is powered by young stars
- >70μm emission is diffuse interstellar radiation field powered by modest-age stars

The SFR in terms of the 24μm luminosity for luminous dusty galaxies: (Rieke et al. 2009)

$$SFR(M_\odot\ yr^{-1}) = 7.8 \times 10^{-10} L(24\mu m, L_\odot)$$

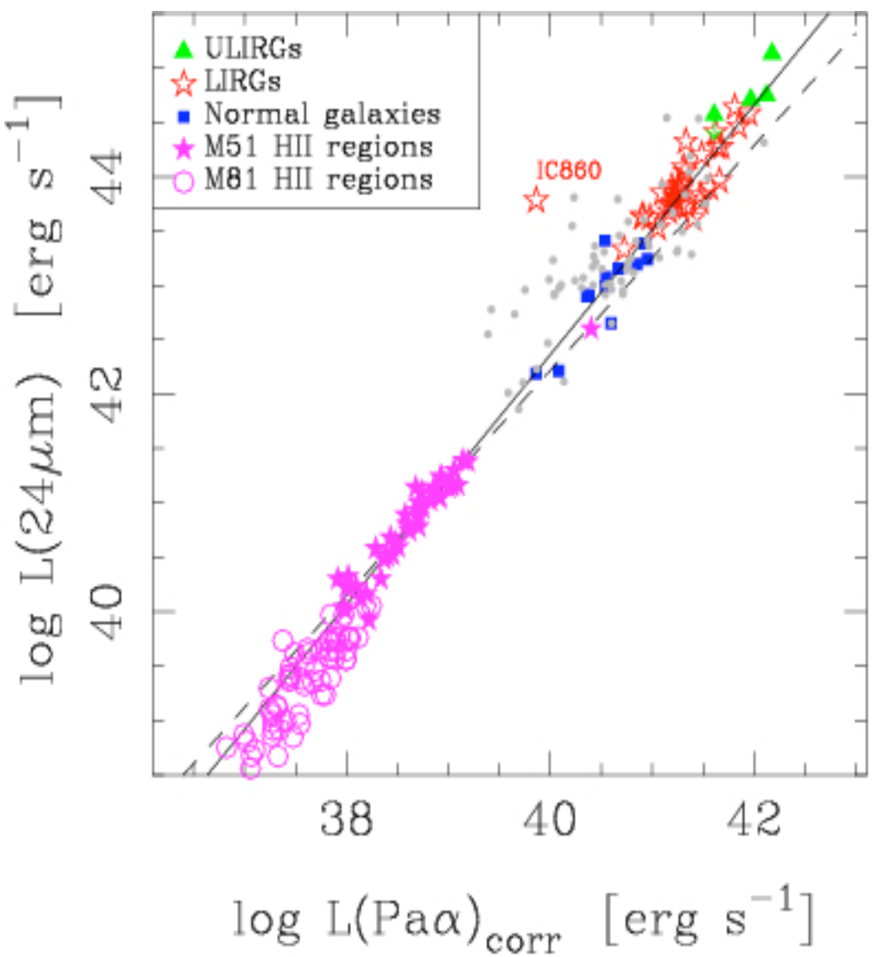
At $L_{IR} > 10^{11} L_\odot$

$$SFR(M_\odot\ yr^{-1}) = 7.8 \times 10^{-10} L(24\mu m, L_\odot) \times (7.76 \times 10^{-11} L(24\mu m, L_\odot))0.048.$$

$L_{IR} = 5\times10^{9}-10^{13} L_\odot$

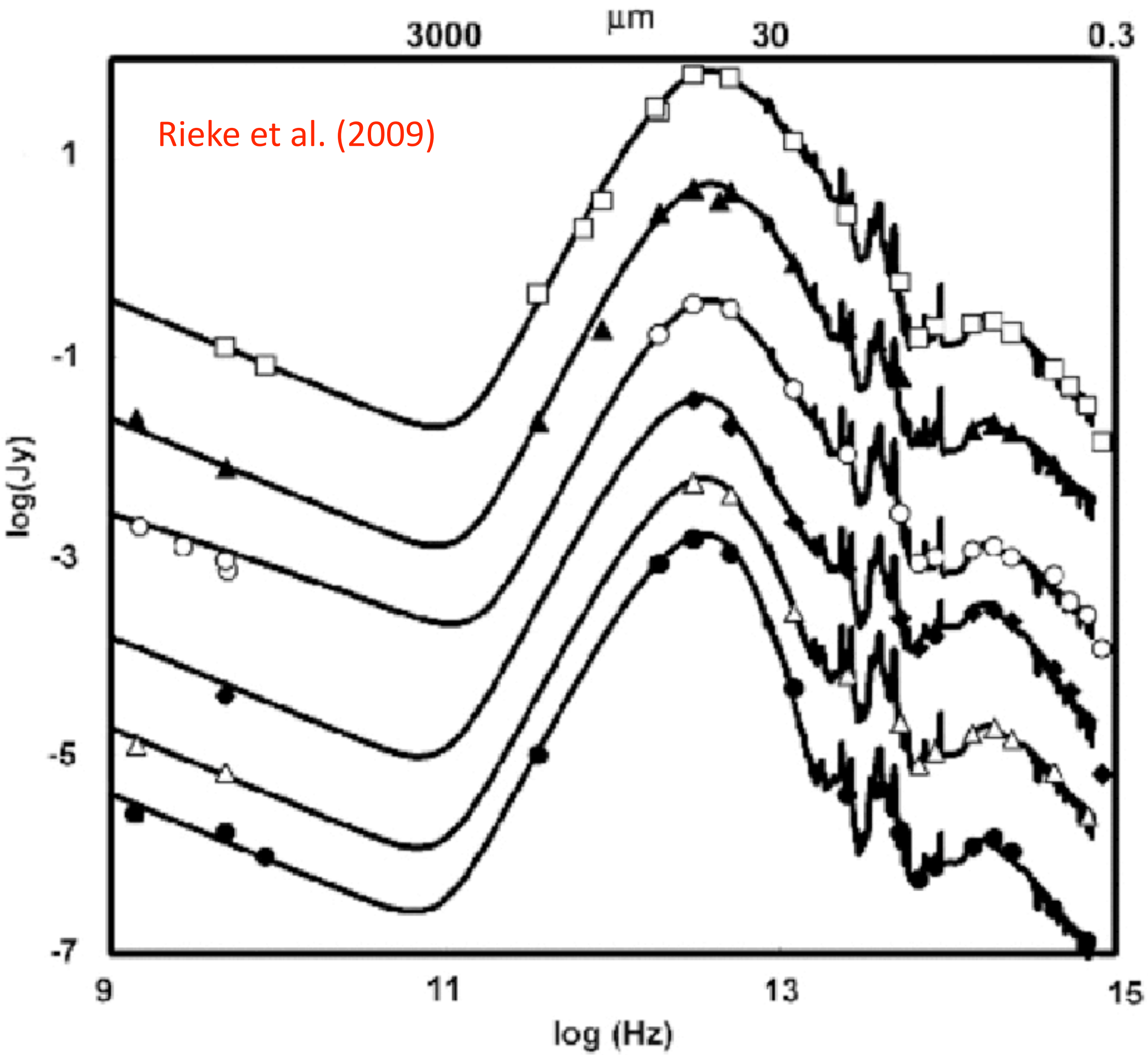
See also Calzetti et al. (2005, 2007), Wu et al. (2005), Alonso-Herrero et al. (2006)

But z=2 MIPS 24μm is λ_{rest}=8μm



Observed (U)LIRG SEDs

UV to Radio Photometric points + 5-40μm spectra



LIRGs

$L_{IR}=10^{11}-10^{12}L_{\odot}$

Only Star Formation

NGC1614

NGC4194

NGC3256

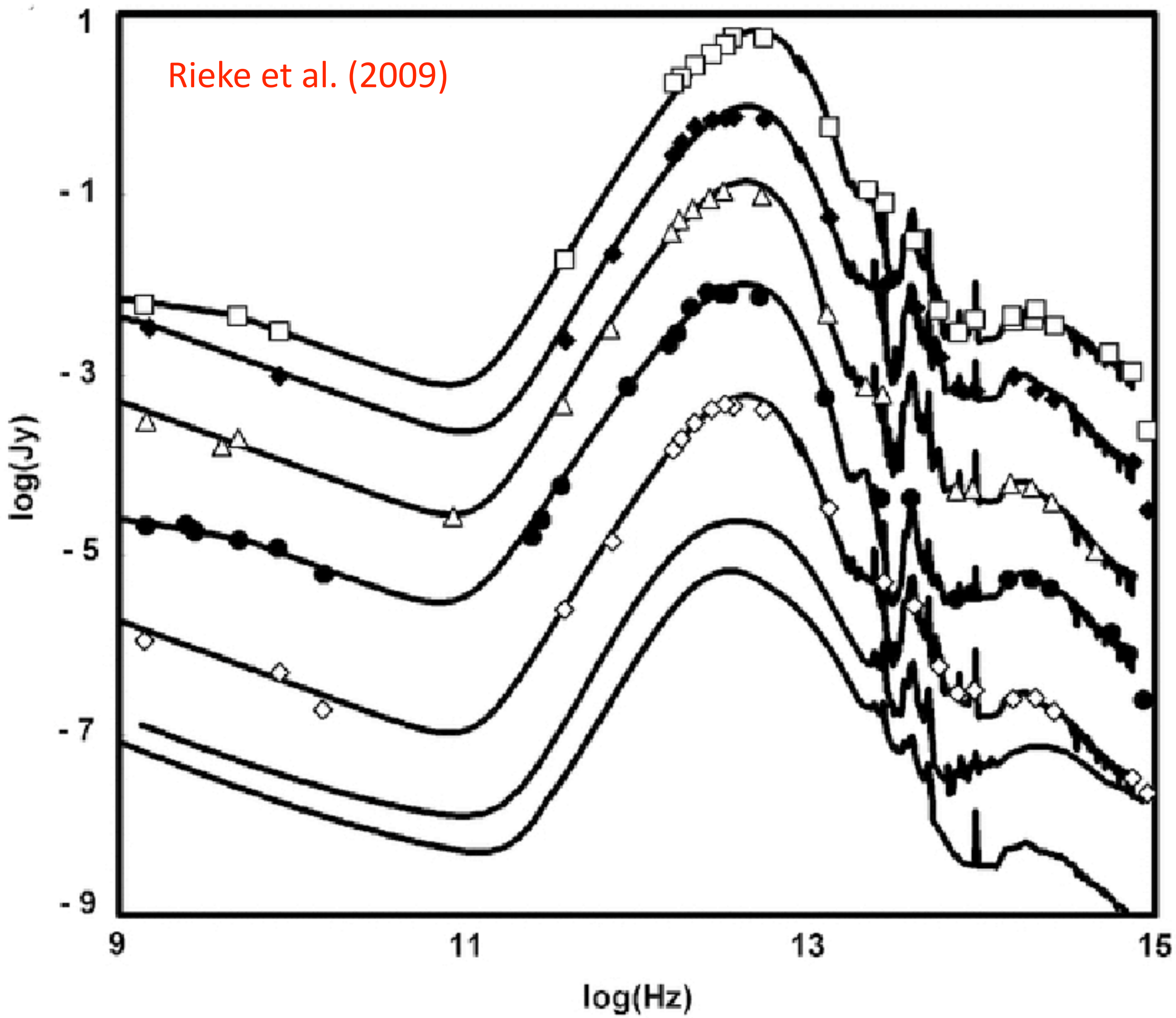
NGC2369

ESO320-G030

Zw049.057

Observed (U)LIRG SEDs

UV to Radio Photometric points + 5-40μm spectra



ULIRGs

$L_{IR}=10^{12}-10^{13}L_{\odot}$

Only Star Formation

IRAS22491

IRAS14348

IRAS17208

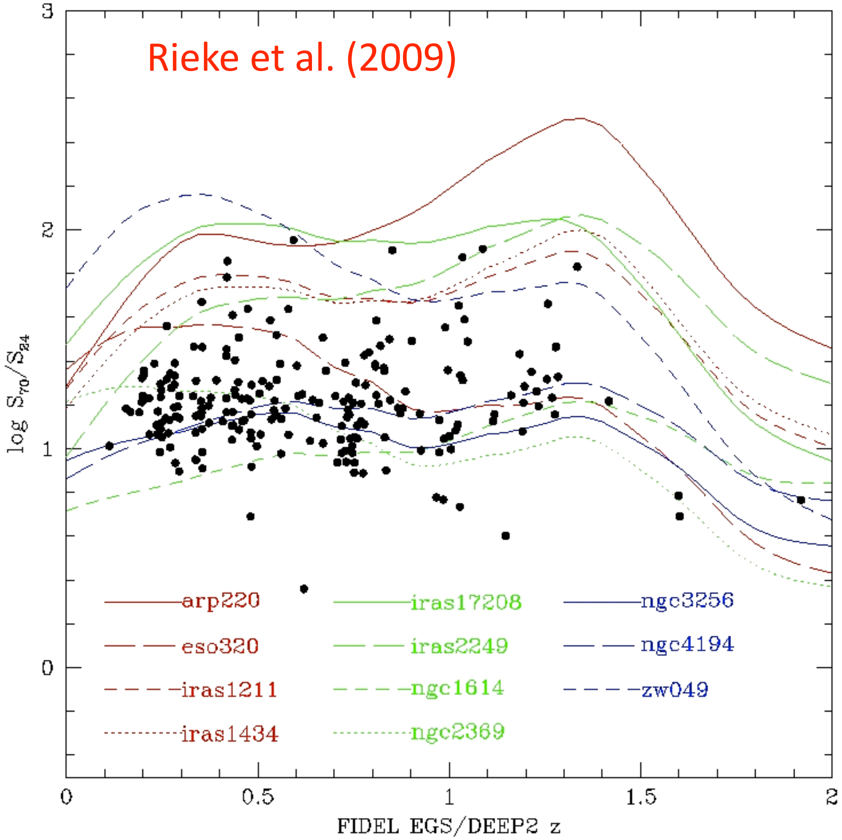
Arp220

IRAS12112

Dale et al. model

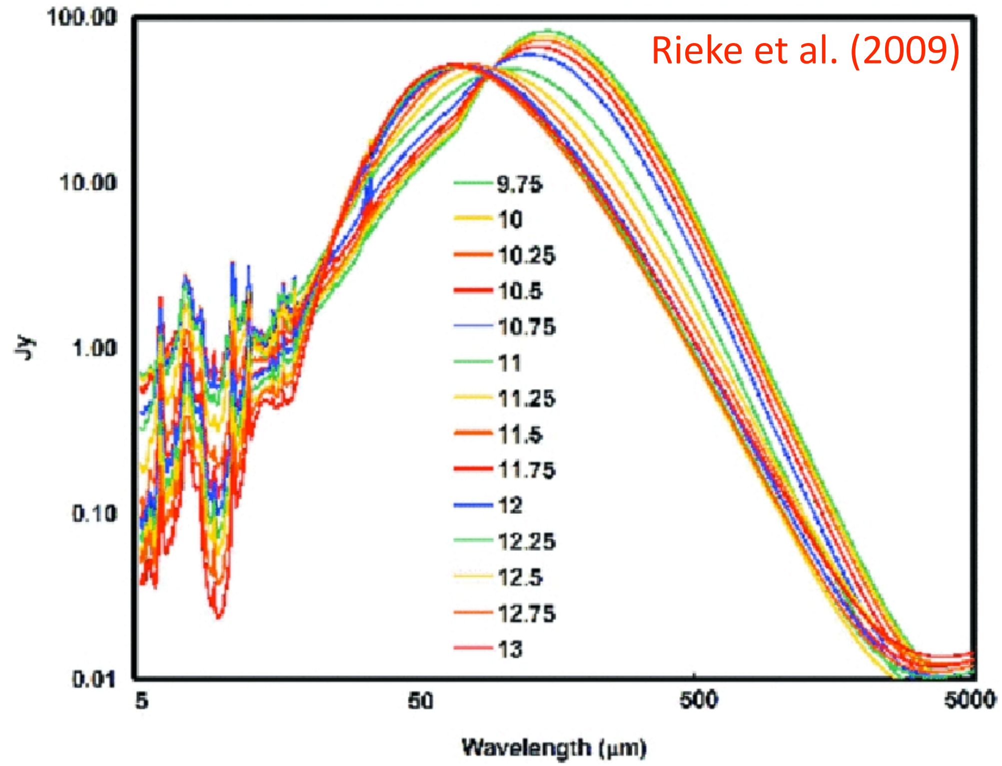
Chary&Elbaz model

Templates based on observed (U)LIRG SEDs



Observed SEDs reproduce well the observed Spitzer 70μm/24μm colors of star-forming galaxies for a large redshift interval

Average templates (available on-line) cover a range in IR luminosities:
$L_{IR}=5x10^9-10^{13}L_{\odot}$



Using local templates to estimate SFR at high-z

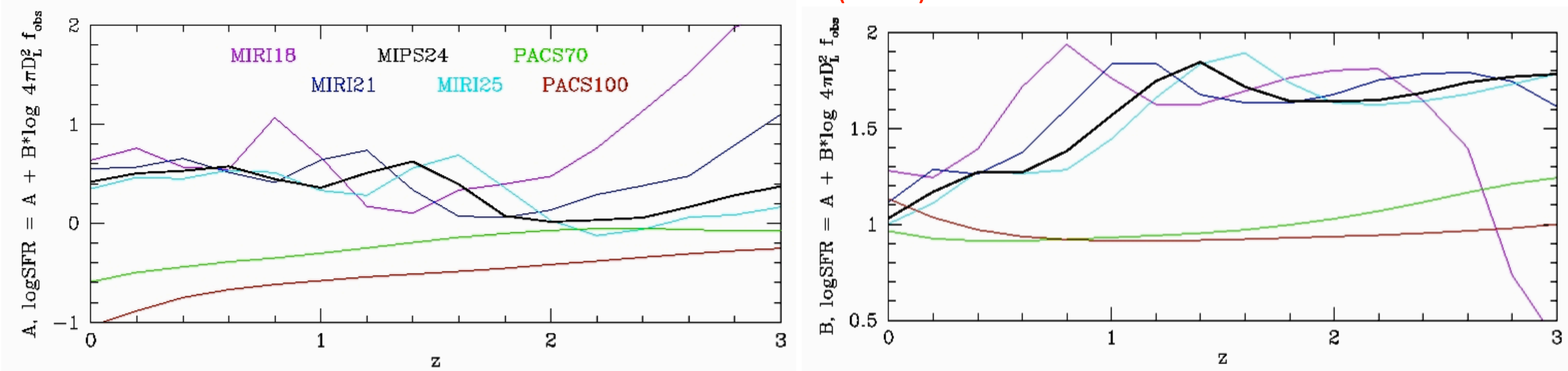
Each template has an associated L_{IR} and $L_{24\mu m}$

For each observational data we convolved the SED the instrumental response curves to estimate the K-correction

The recipe: $\log(SFR) = A(z) + B(z) \times (\log(4\pi D_L^2 f_\nu)-53.)$ in $M_\odot yr^{-1}$

(see Rieke et al. 2009)

Rieke et al. (2009)



Locally these calibrations can be used for: **L_{tot}> $3x10^{10}L_\odot$**

And at high-z to IR-selected galaxies with $L_{IR}=5x10^9-2x10^{12}L_\odot$

CONCLUSION

Empirical calibrations between mid-IR luminosities and SFR should be done using the integrated emission (rather than individual HII regions)

Choose your SFR tracer depending on how your galaxies were selected and their luminosities

For intermediate luminosity galaxies combinations of observed Hα + 24μm luminosities are the best choice (e.g., Calzetti et al. 2007)

For IR-selected galaxies **the 24μm monochromatic luminosity** is a good choice for a SFR tracer (Alonso-Herrero et al. 2006; Calzetti et al. 2007; Rieke et al. 2009). Or similarly use rest-frame 24μm if $\mathbf{L_{tot} > 3x10^{10} L_\odot}$