T. Diaz-Santos

The Extended MID-IR Emission in (U)LIRGs

We present our analysis of the extended mid-Infrared (IR) emission of the local Luminous and Ultraluminous Infrared Galaxies (U)LIRGs comprised in the Great Observatory All-sky LIRG Survey (GOALS) sample. We use Spitzer IRS spectra to determine the fraction of extra-nuclear emission in these (U)LIRGs as a function of wavelength which allow us to compare among different spectral features. We find that in more than 30% of LIRGs, at least ∼50% of their mid-IR emission stems from the extended component, which may contribute even up to ∼80%. As a whole, the mid-IR emission of local LIRGs is 2.5-3 times more extended than that of ULIRGs, suggesting that mid-IR emission of LIRGs is rather distributed across their disks on a scale of several kpcs. We find that the compactness of the mid-IR continuum emission at 13.2-micron of the LIRGs/ULIRGs in our sample does not depend on their merging stage, but in turn it is related to the AGN contribution to the mid-IR emission. The more AGN-dominated a system is the less extended appears in the mid-IR. The compactness of the LIRGs/ULIRGs is related with the IRAS 60/100-micron color. Colder galaxies are more extended. This places a lower limit, depending on the far-IR color, to the physical size of the region responsible for the fir-IR continuum emission of these systems, which will soon to be probed by Herschel.

THE EXTENDED MID-IR EMISSION IN (U)LIRGs

Tanio Diaz-Santos (Univ. of Crete)

In collaboration with
V. Charmandaris, A. Petric, L. Armus,
and members of the GOALS/IRS team

Motivation

• There is evidence that local LIRGs could be the local analogs of high redshift SMGs (@ z~2), which have:

- cold FIR colors, PAH EQWs *(Desai et al. 2007)*
- very high star formation rates (SFR > 100 Msol yr-1)
- CO and H-alpha kinematics showing a variety of morphologies: from organized, rotating disks to very perturbed systems *(Taconni et al. 2008)*

• It is important to disentangle, quantify and determine the physical properties of the nuclear and extended emission of galaxies.

Aim

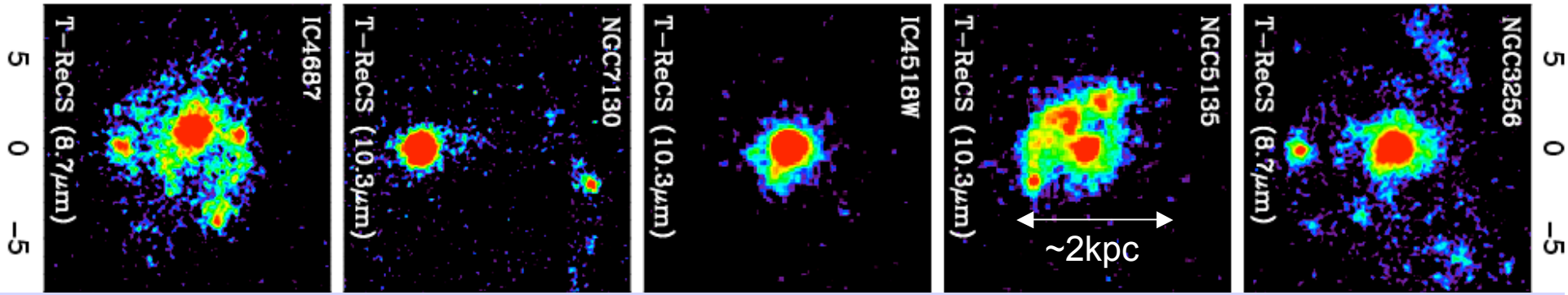
• Quantify and characterize the extended extra-nuclear emission of local LIRGs in the 5-15μm range:

➢ To contribute with additional evidence in the analogy between the processes and modes of star formation taking place in local LIRGs and the conditions seen in SMGs at z>1

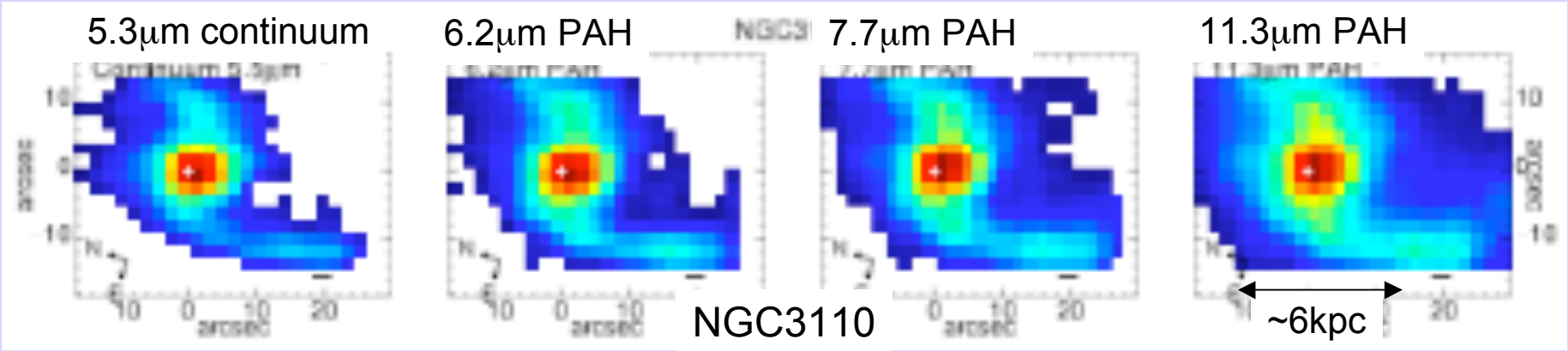
➢ To provide the highest spatial resolution mid-IR spectra of the unresolved nuclear regions for a large number of local LIRGs/ULIRGs. Essential for modeling the physics of their dense nuclear gas with Herschel.

Previous Works

- Ground based high spatial resolution MIR (<1arcsec) imaging and spectroscopy of a handful of local (U)LIRGs *(Diaz-Santos et al. 2008, 2010).*

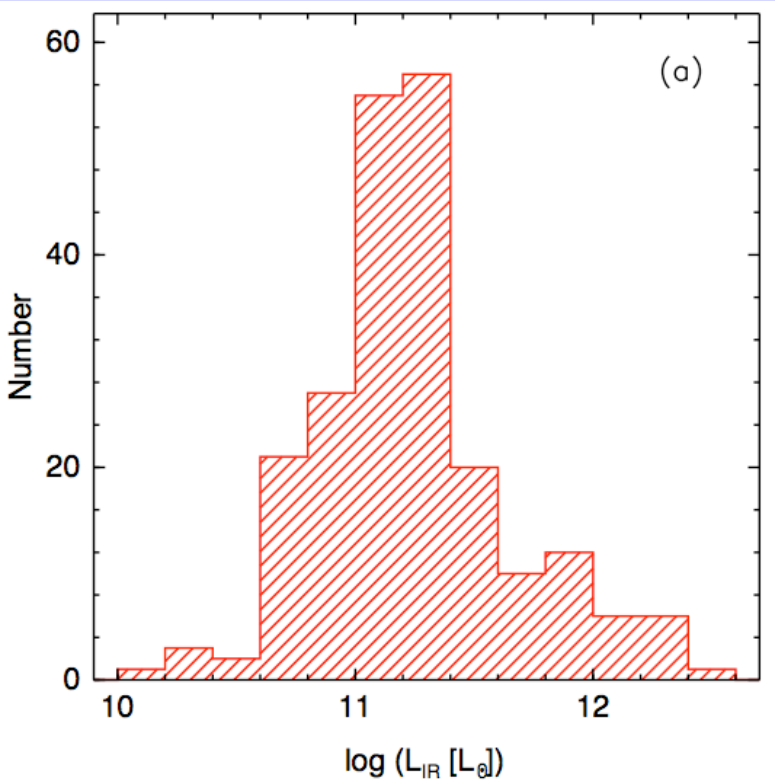


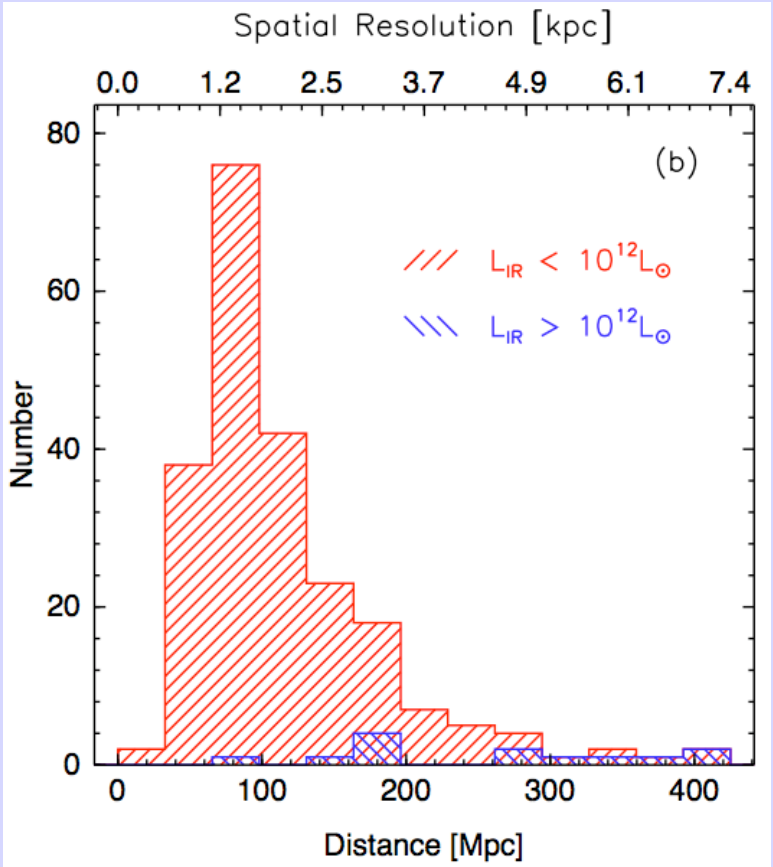
- Spitzer IRS spectral maps of a limited number of nearby (d<75Mpc) LIRGs *(Pereira-Santaella et al. 2010).*



Our Sample

- The Great Observatories All-sky LIRG survey (GOALS; *Armus et al. 2009*) comprises 202 systems (more than 280 individual galaxies) of which 180 are LIRGs, and it is the most complete sample of LIRGs observed with Spitzer in the local universe.
- All systems are observed with all four Spitzer/IRS modules (5-35μm)





Ancillary Data

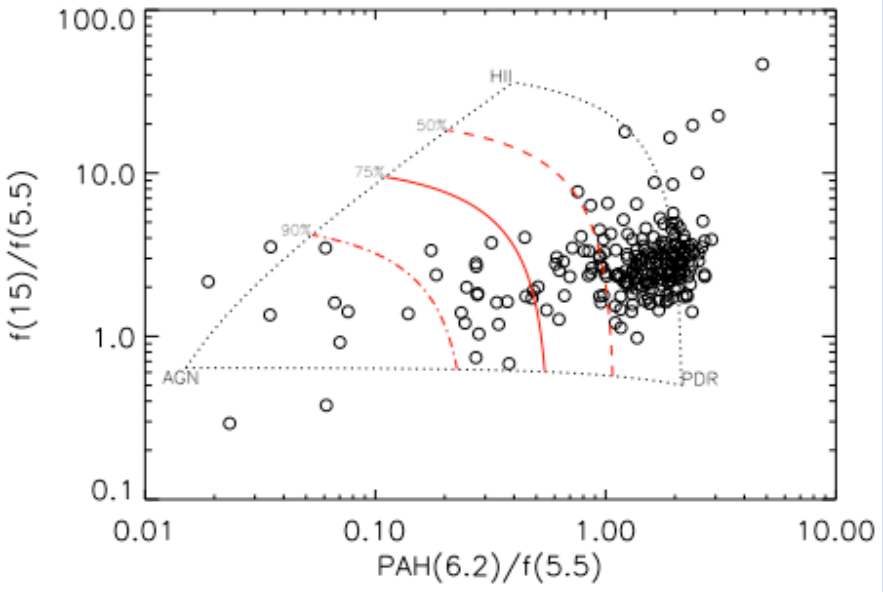
• The GOALS galaxy sample has devoted UV (Galex), optical, and near infrared (HST) observations.

• UV data has been released in *Howell et al. (2010)*
• The first MIR analyses will be soon published in *Petric et al. (2010, sub.)*

Morphological Classification:

Stage 0: No obvious sign of disturbance
Stage 1: Early stage, little morphological disturbance
Stage 2: Strong disturbance (bridges)
Stage 3: Optical disks destroyed but nuclei separated
Stage 4: Interacting nuclei are merged but structure around the remaining disk
(Petric et al. 2010)

AGN-fraction (*Petric et al. 2010*):



The Method

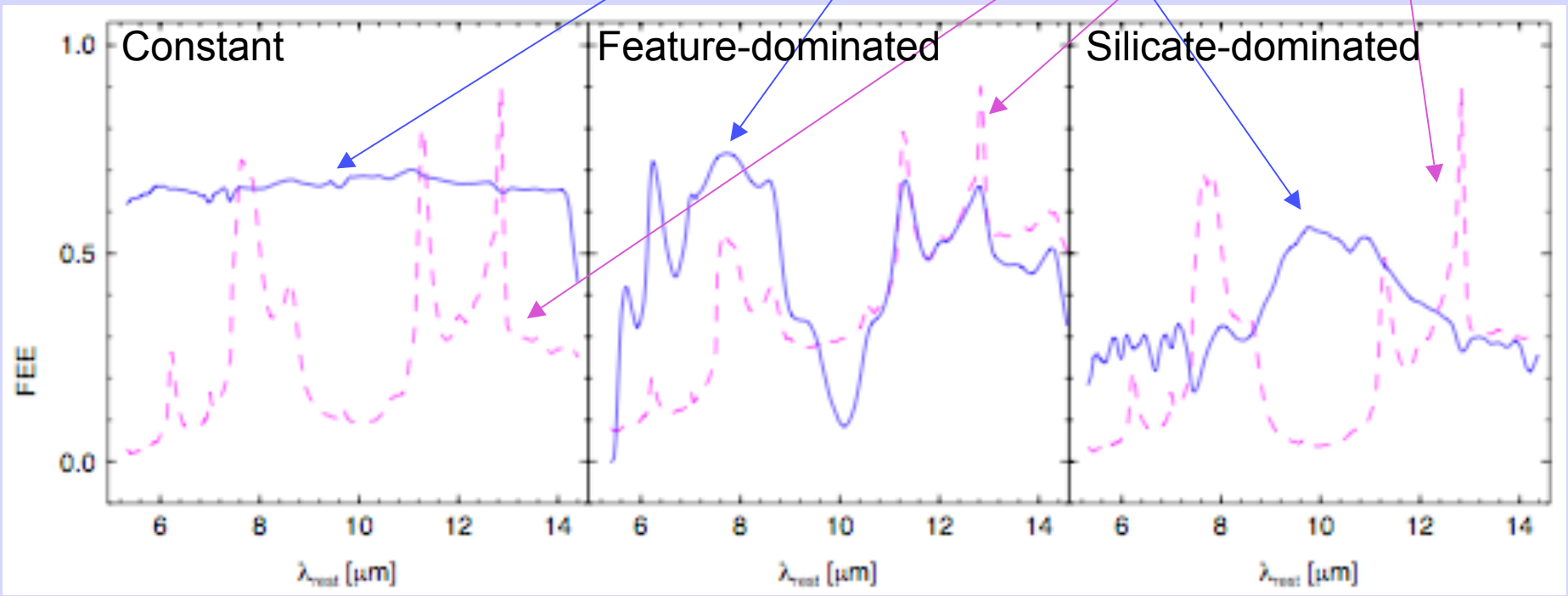
a) We use the 2D images of the IRS SL module (5-15μm) available for 221 LIRGs.
b) We access the spatial profiles of the spectra at each wavelength using the standard SSC pipeline algorithms.
c) We use a reference star (HD7341) as our unresolved point source (PSF)
d) We scale the star spatial profile of the PSF to that of the given galaxy at each wavelength and subtract it.
e) We define the fraction of extended emission, FEE_{λ}, as:

$$FEE(\lambda) = \frac{\text{Total LIRG flux}(\lambda) - \text{scaled PSF}(\lambda)}{\text{Total LIRG flux}(\lambda)}$$

f) We have information not only of the average FEE over the 5-15μm range but also of the FEE at each wavelength -> of each feature.

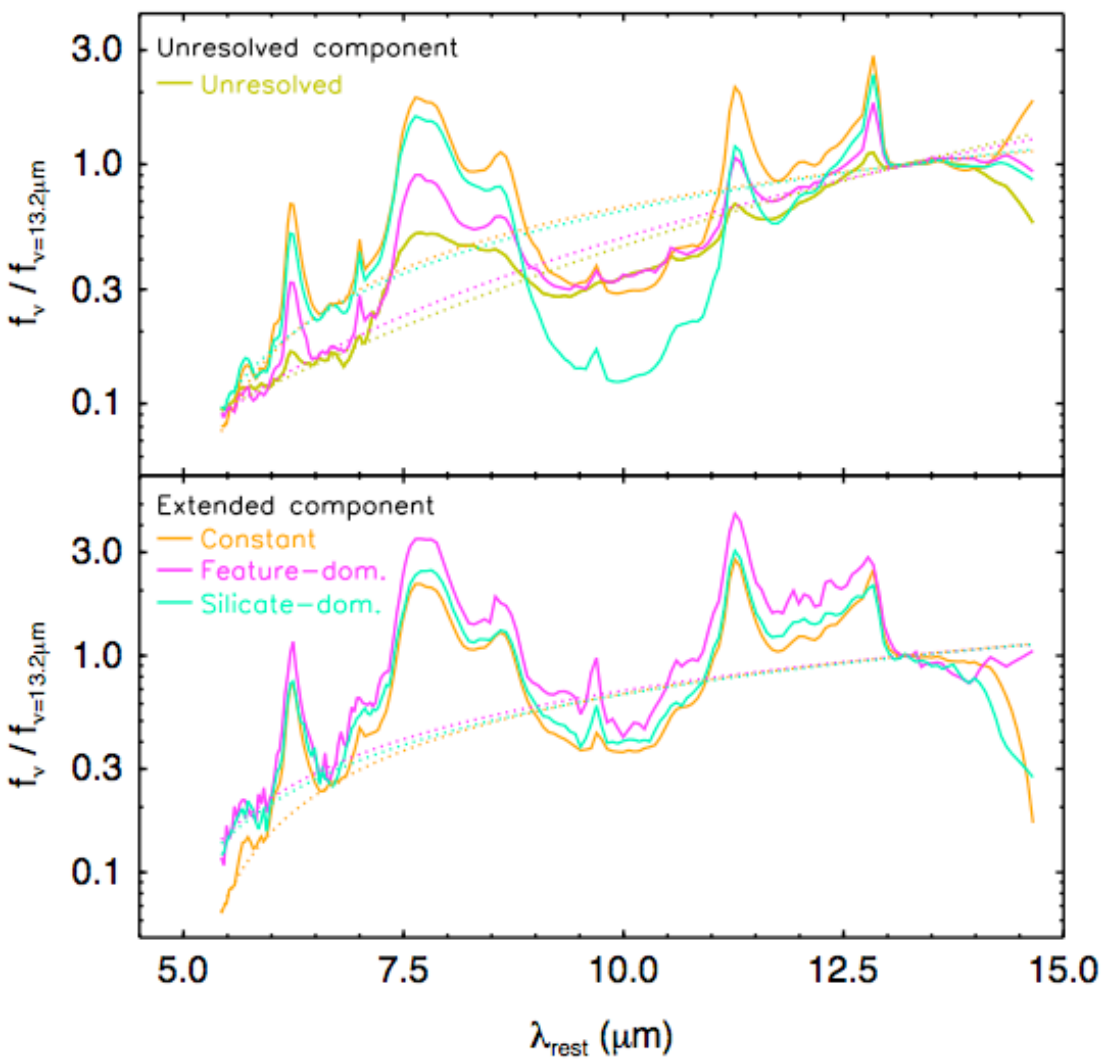
Types of FEE_λ

- Unresolved and unclassified
- Constant/featureless continuum
- PAH-, line-dominated
- Silicate-dominated



(Diaz-Santos et al. 2010a, submitted)

Spectra of the nuclear and extended components for the different FEE types



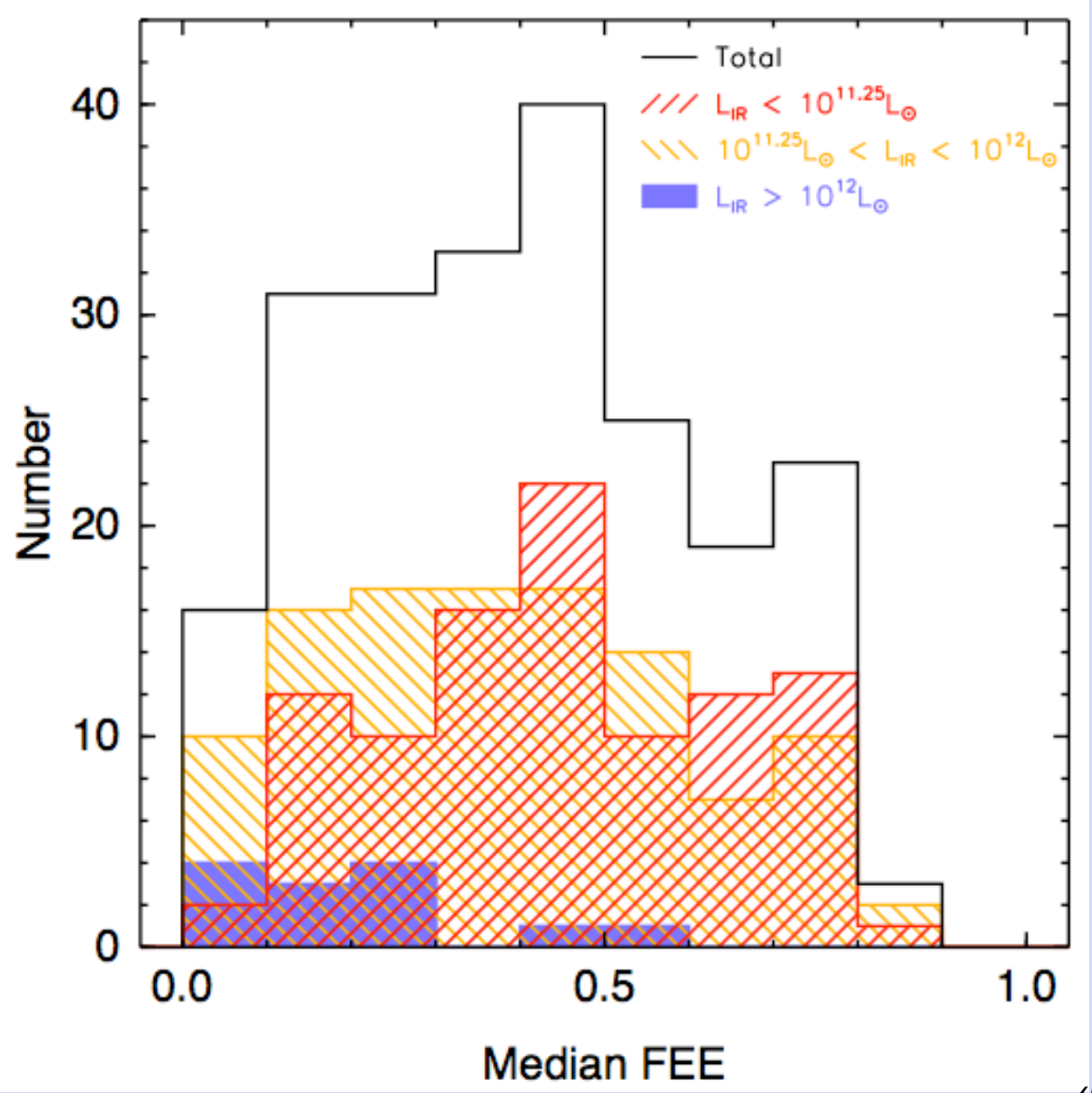
- The spectra of the extended emission are similar -> properties of the extended star formation common to all galaxies.

- The nuclei of the silicate-dominated FEE class are more extinguished.

- From: constant -> feature-dominated -> unresolved FEE types, the PAH EQWs decrease and the silicate absorption is not very deep -> dilution?

(Diaz-Santos et al. 2010b, in preparation)

Median FEE value in the 5-15μm range



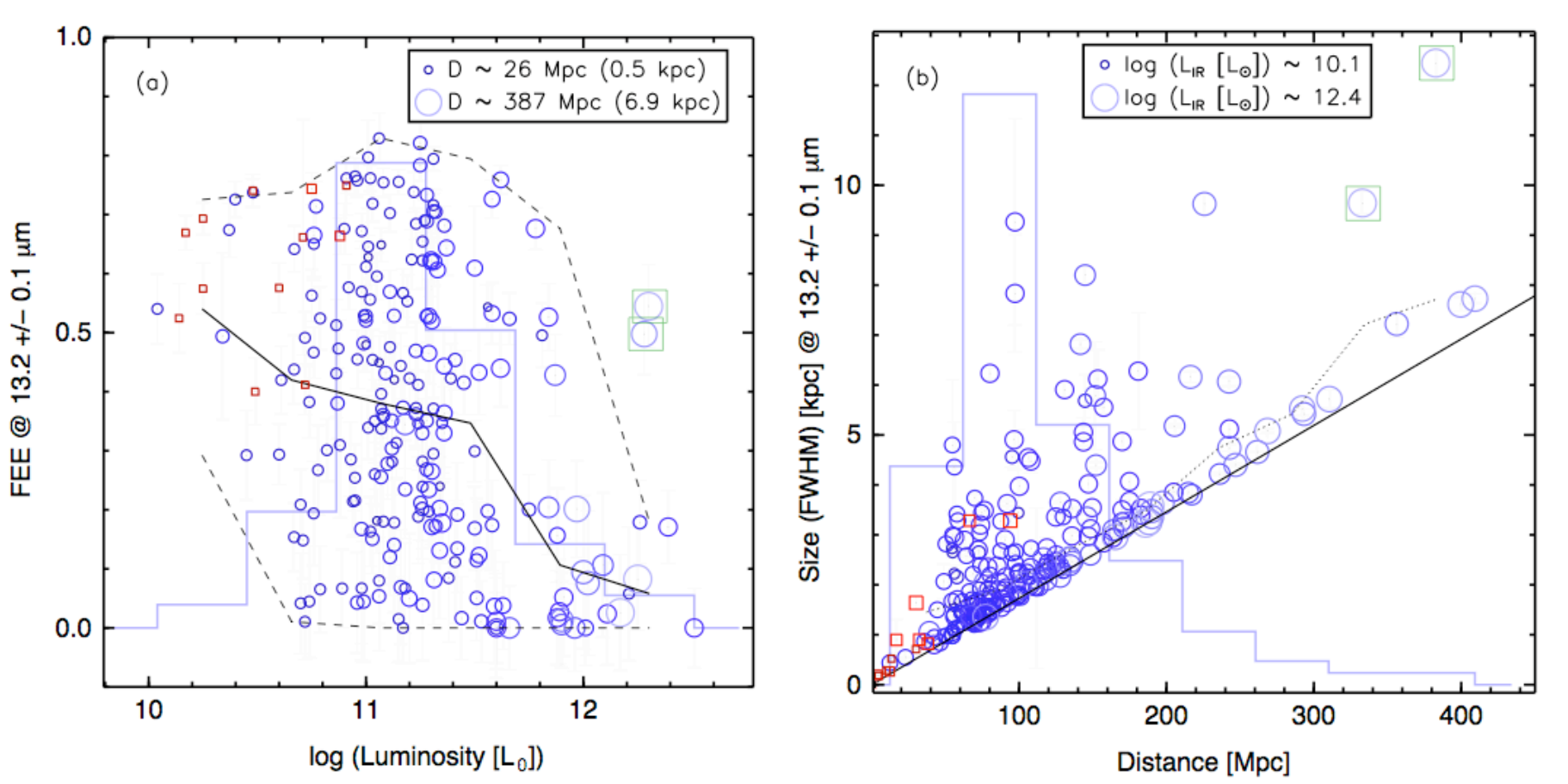
- More than 30% of the galaxies in the sample have median FEEs larger than 0.5. That is, at least 50% of their emission comes from the extended component.

- The median FEE is larger than 0.1 for 90% of the galaxies.

- K-S tests imply that ULIRGs are not drawn from the same parent population as LIRGs.

(Diaz-Santos et al. 2010a, submitted)

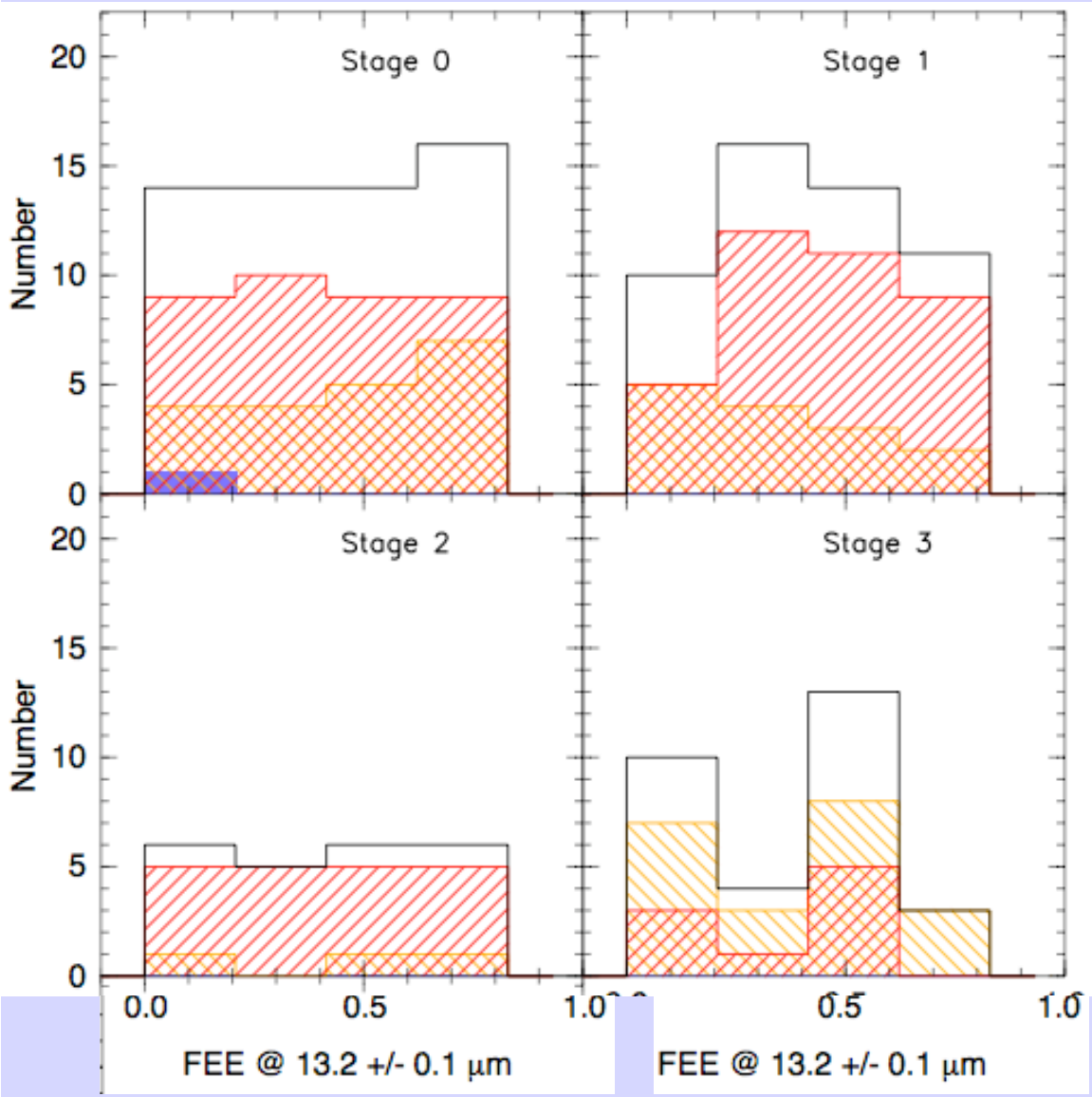
$FEE_{13.2\mu m}$ as a function of L_{IR}



- The $FEE_{13.2\mu m}$ (continuum) decreases with increasing L_{IR}
- ULIRGs are more compact ($FEE_{13.2\mu m}$ <0.2) than LIRGs (0<$FEE_{13.2\mu m}$<0.85)
- Core sizes of LIRGs are up to 6-10kpc

(Diaz-Santos et al. 2010a, submitted)

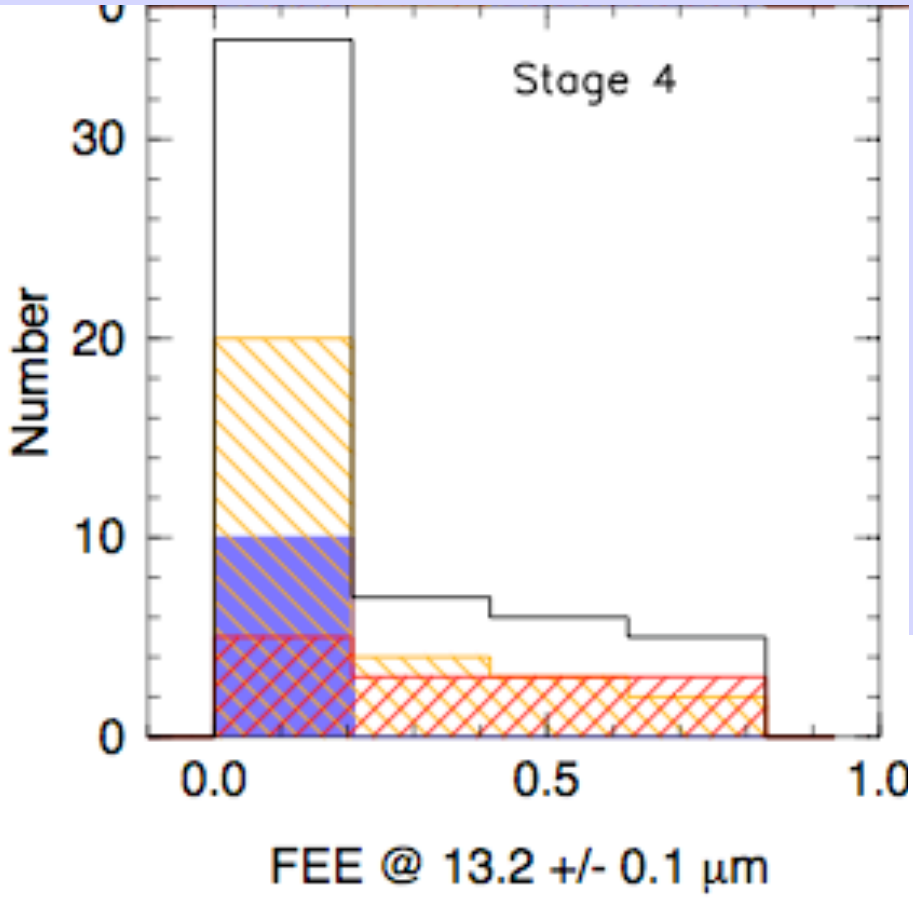
$FEE_{13.2\mu m}$ as a function of the stage of interaction



- Independently of their L_{IR}, the FEE of the galaxies does not depend on their stage of interaction but….

(Diaz-Santos et al. 2010a, submitted)

$FEE_{13.2\mu m}$ as a function of the stage of interaction

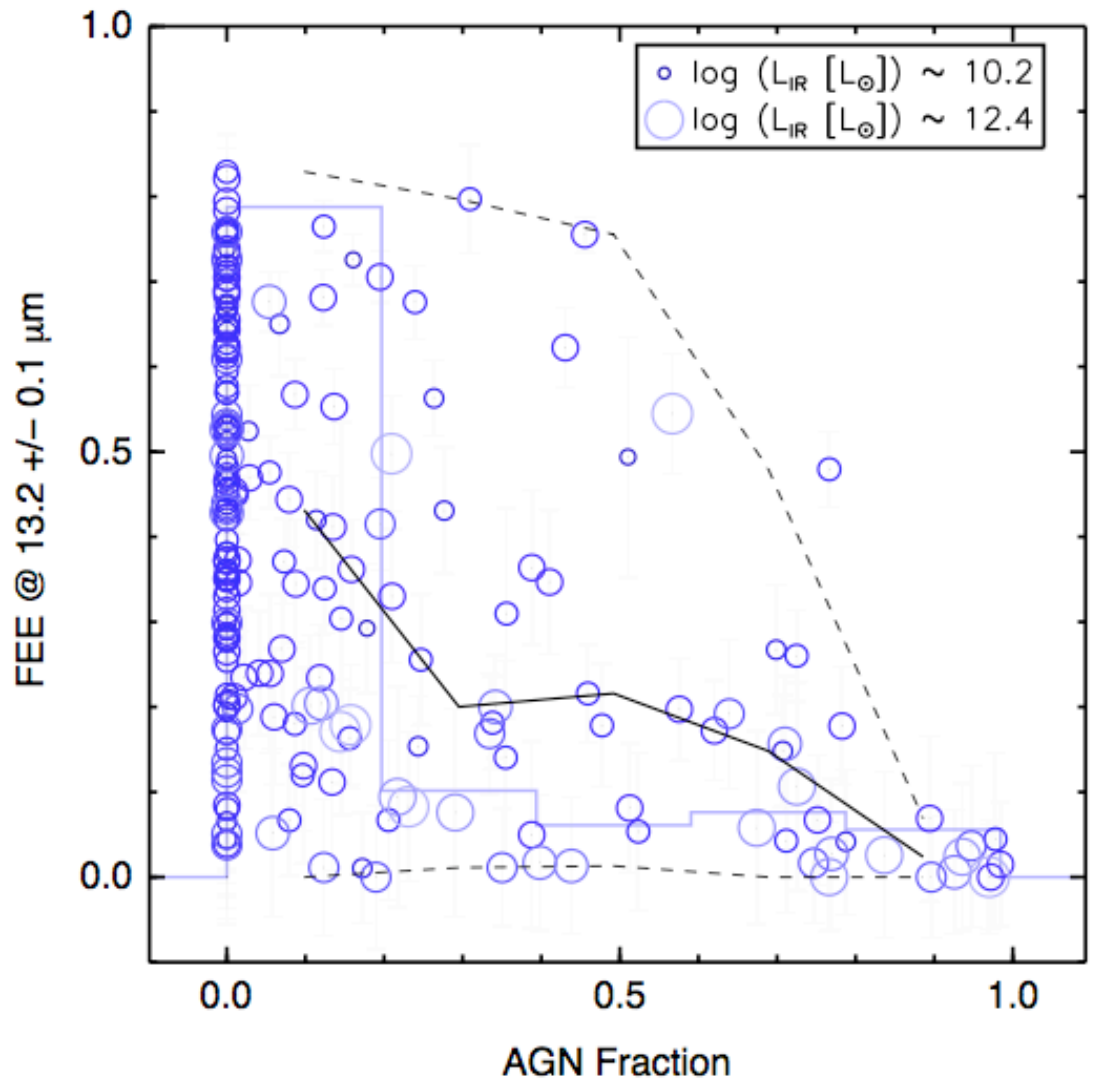


- K-S test indicates that galaxies in the merger stage 4 are more compact.

- In fact, all ULIRGs (except one) are classified in the merger stage 4 but not all galaxies at that stage are ULIRGs.

(Diaz-Santos et al. 2010a, submitted)

$FEE_{13.2\mu m}$ as a function of the AGN-fraction

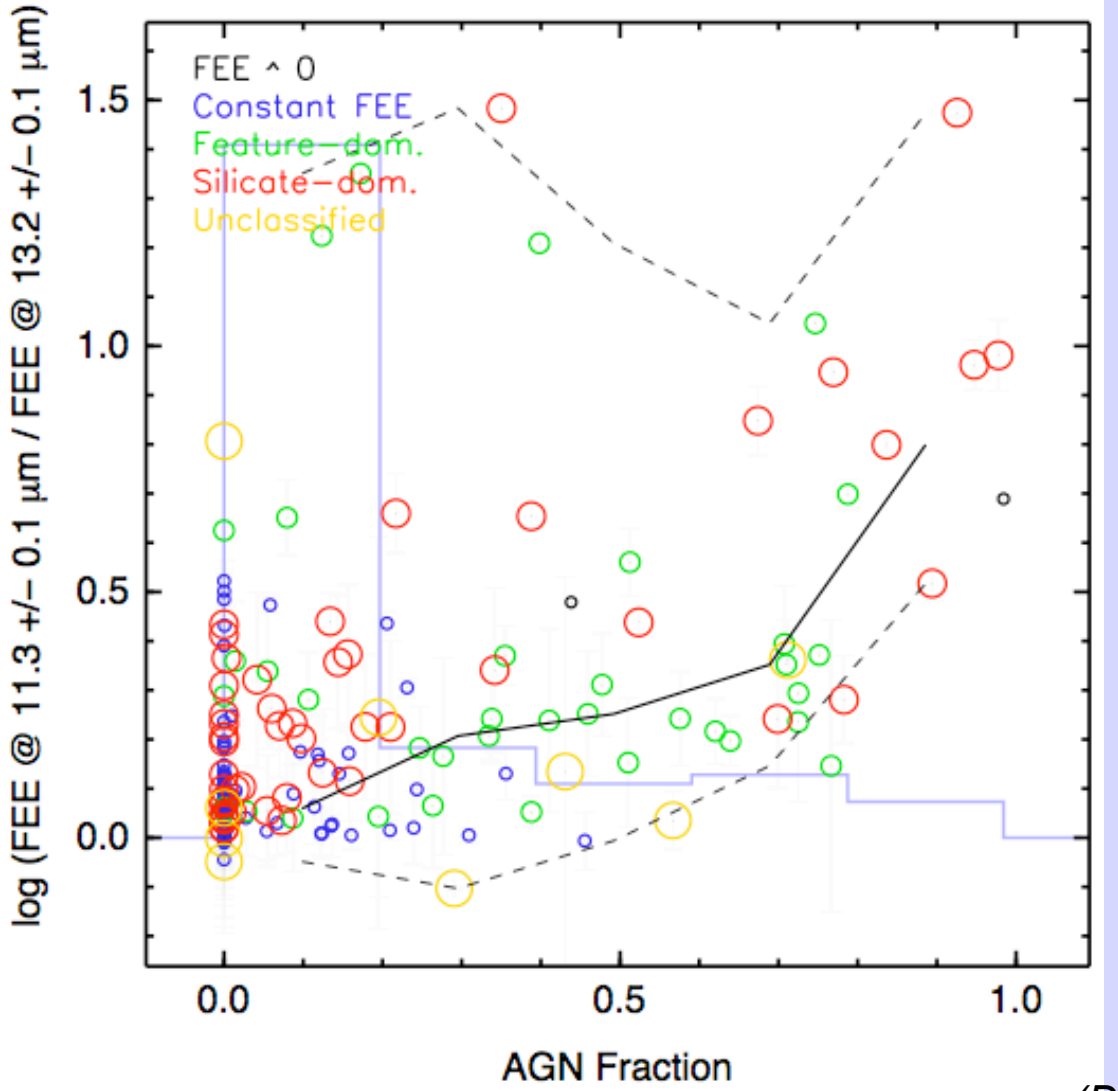


• The FEE of the continuum decreases with increasing of the AGN contribution to the MIR (independantly of the L_{IR}).

I.e., the continuum becomes more and more compact.

(Diaz-Santos et al. 2010a, submitted)

$FEE_{11.3\mu m}/FEE_{13.2\mu m}$ as a function of the AGN-fraction

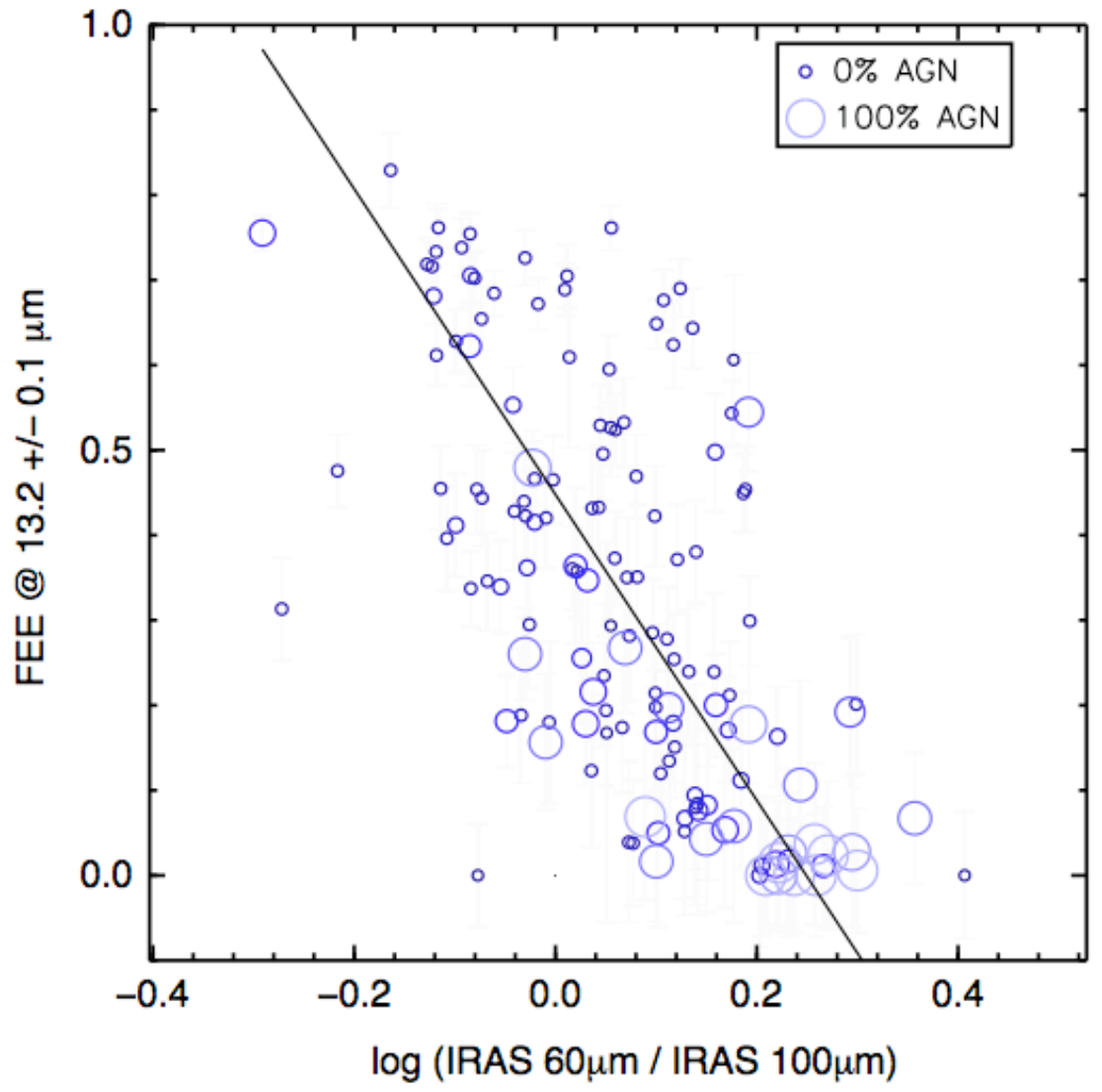


- The $FEE_{11.3\mu m}/FEE_{13.2\mu m}$ ratio increases as the AGN dominates the emission.

- While the continuum becomes more compact, the extension of the PAH emission remain almost unaffected.

(Diaz-Santos et al. 2010b, in preparation)

$FEE_{13.2\mu m}$ as a function of the FIR colors



- We find a tentative correlation between the $FEE_{13.2\mu m}$ and the IRAS log(S60mm/S100mm) FIR color.
- Colder galaxies appear more extended.
- Most of the AGN-dominated (U)LIRGs are warm and compact.
- The $FEE_{13.2\mu m}$ puts a lower limit on the extent of the FIR emission.

(Diaz-Santos et al. 2010a, submitted)

Conclusions

• We present the MIR spectrum of the extended emission in LIRGs. The extended star formation has the same MIR properties in all galaxy types.

• LIRGs display a large FEE in the MIR continuum. In more than 30% of the sample the extended emission accounts for at least 50% of the total MIR emission of the galaxies. ULIRGs have $FEE_{13.2\mu m} < 0.2$.

• Only galaxies in the final stage of interaction show more compact continuum emission.

• $FEE_{13.2\mu m}$ decreases with increasing the AGN-fraction and $FEE_{11.3\mu m}/FEE_{13.2\mu m}$ ratio increases.

• The $FEE_{13.2\mu m}$ is roughly correlated with the IRAS (60μm/100μm) FIR color. MIR places a lower limit for the extension of the FIR emission to be confirmed with Herschel.

• High-z SMGs are similar to local LIRGs rather than local ULIRGs in terms of their sizes.