Extended IR Emission from (U)LIRGs

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Papers:
Diaz-Santos et al. 2010 ApJ, 723, 993
Diaz-Santos et al. 2011 ApJ, (in press - @arXiv/1107.5958)

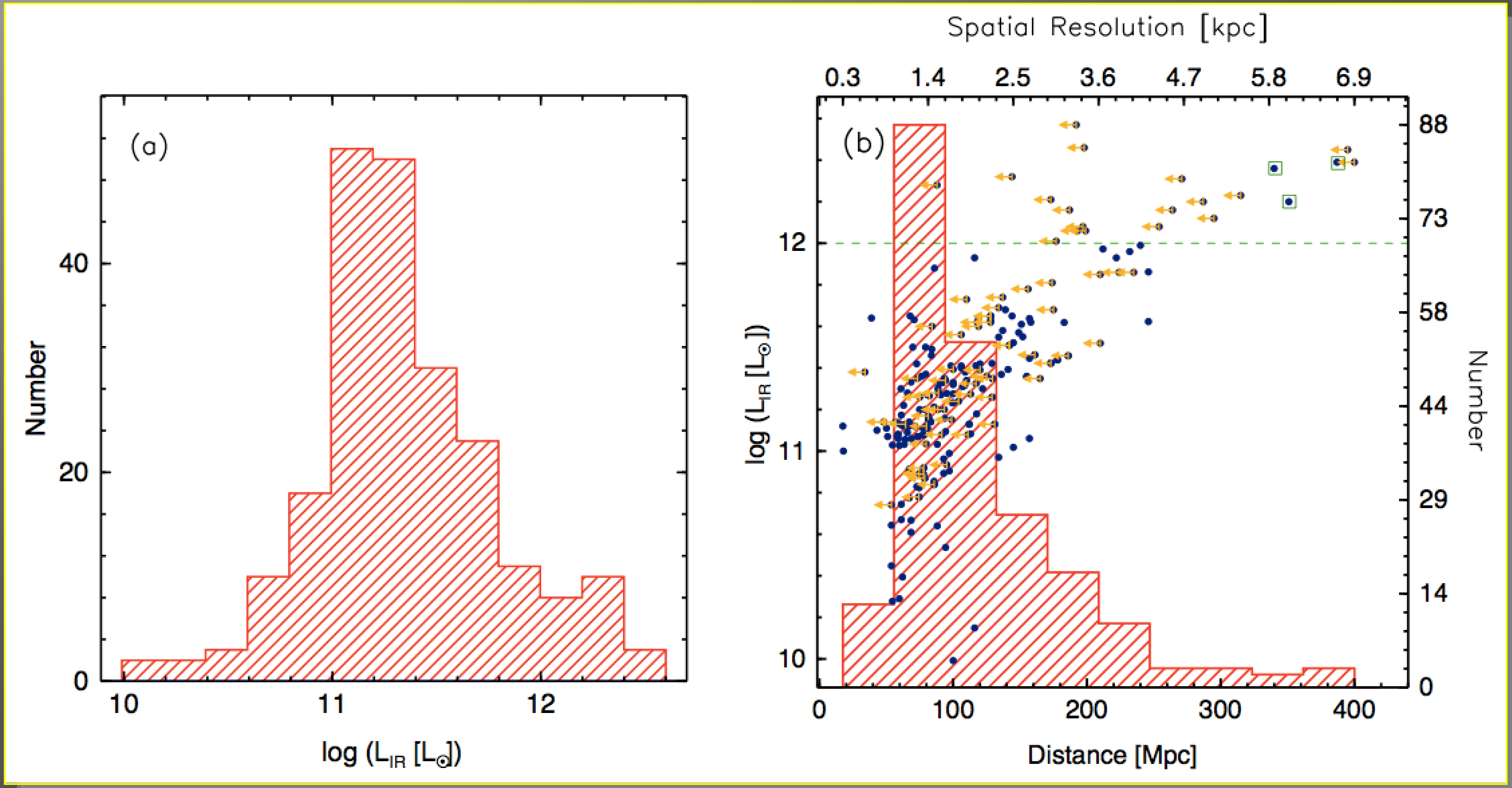
Motivation

- A number of the observational properties of galaxies detected at sub-mm at z~2 with $L_{IR}>10^{12} L_{\odot}$ (SMG) such as:
  - *cold infrared colors*
  - *energy production dominated by star formation* (> 100 $M_{\odot}$/yr)
  - *mid-IR spectral features (ie PAH strength*

  … resemble those of local LIRGs rather than ULIRGs.
- Kinematical evidence from ionized (Hα) and molecular (CO) gas are often consistent the presence of extended (~5kpc) star forming disks
- There is a "broad" connection between mid-IR emission and star formation rate (with some caveats - main sequence/compact starbursts Elbaz et al. 2011)
- We wish to quantify the extended extranuclear emission in local LIRGs in the 5-15μm range to contribute additional evidence in the analogy between the physics of the ISM excitation in LIRGs and the conditions seen in SMGs and ULIRGs at z>1.

The Sample

- The sample is based on the Great Observatory Allsky LIRG Survey (GOALS; Armus et al. 2009) of 202 systems (181 of which are LIRGs)
- All systems are observed with all four Spitzer/IRS modules (~5-37μm)
- Additional Spitzer data with IRAC/MIPS, as well as HST, GALEX, VLA, CO

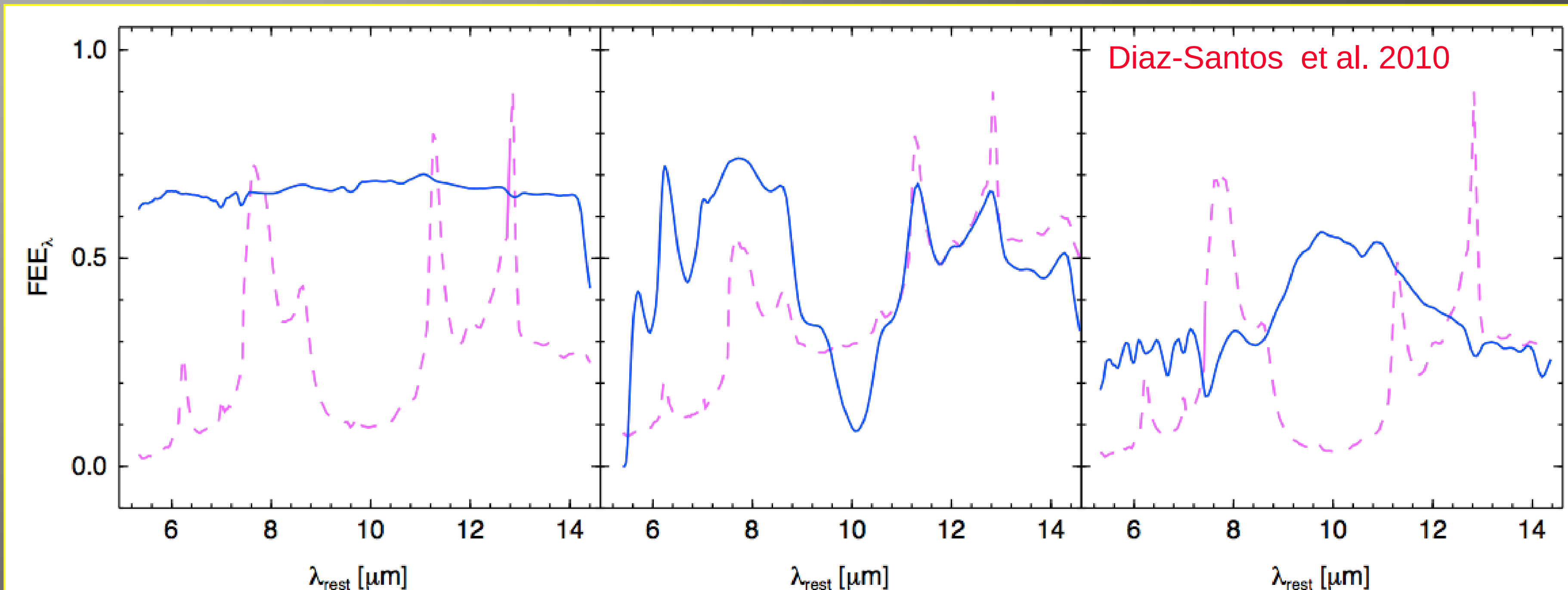


The Method

- Use the 2D IRS longslit images of all sources and re-extract total 5-15μm spectrum using the same algorithms of the Spitzer pipeline
- Use a standard star (HR7341) as our unresolved point source (PSF)
- Scale the spatial profile of the standard star along the slit at every wavelength and subtract it from the corresponding profile of each source.
- Define as Fraction of Extended Emission (FEE):

$$\text{Fraction of EE}(\lambda) = \frac{\text{Total (U)LIRG flux}(\lambda) - \text{PSF}(\lambda)}{\text{Total (U)LIRG flux}(\lambda)}$$

Types of mid-IR spatial profiles



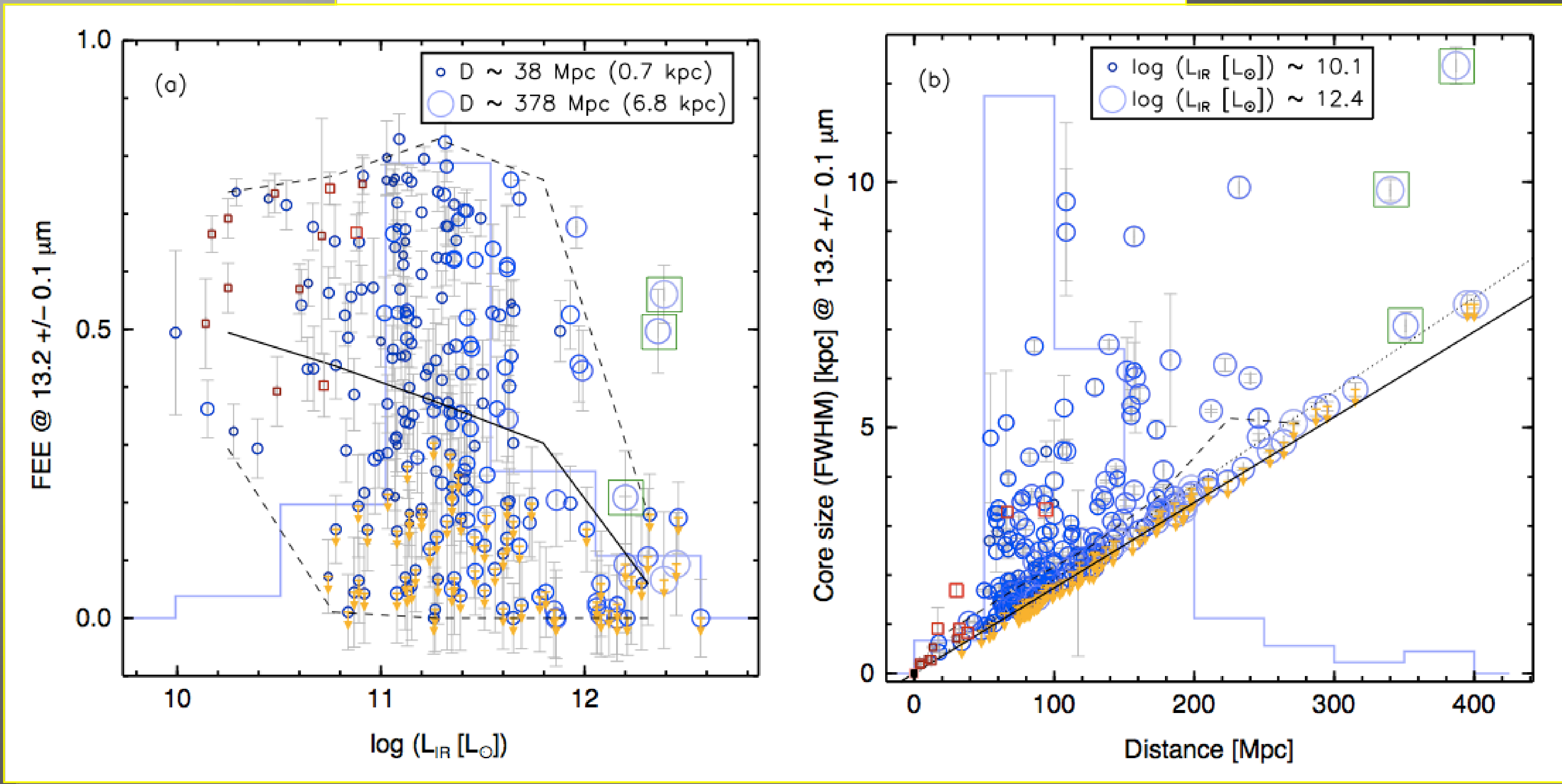
- Three spatial profiles are visually identified:

  Constant: no variation as a function of λ (~50% of sample),

  PAH/line extended: 20-70% of PAH flux is extended (~17% of sample),

  Si "extended": Si at 9.7μm appears extended (~24% of sample) -> suggests that integrated spectrum underestimates nuclear extinction.

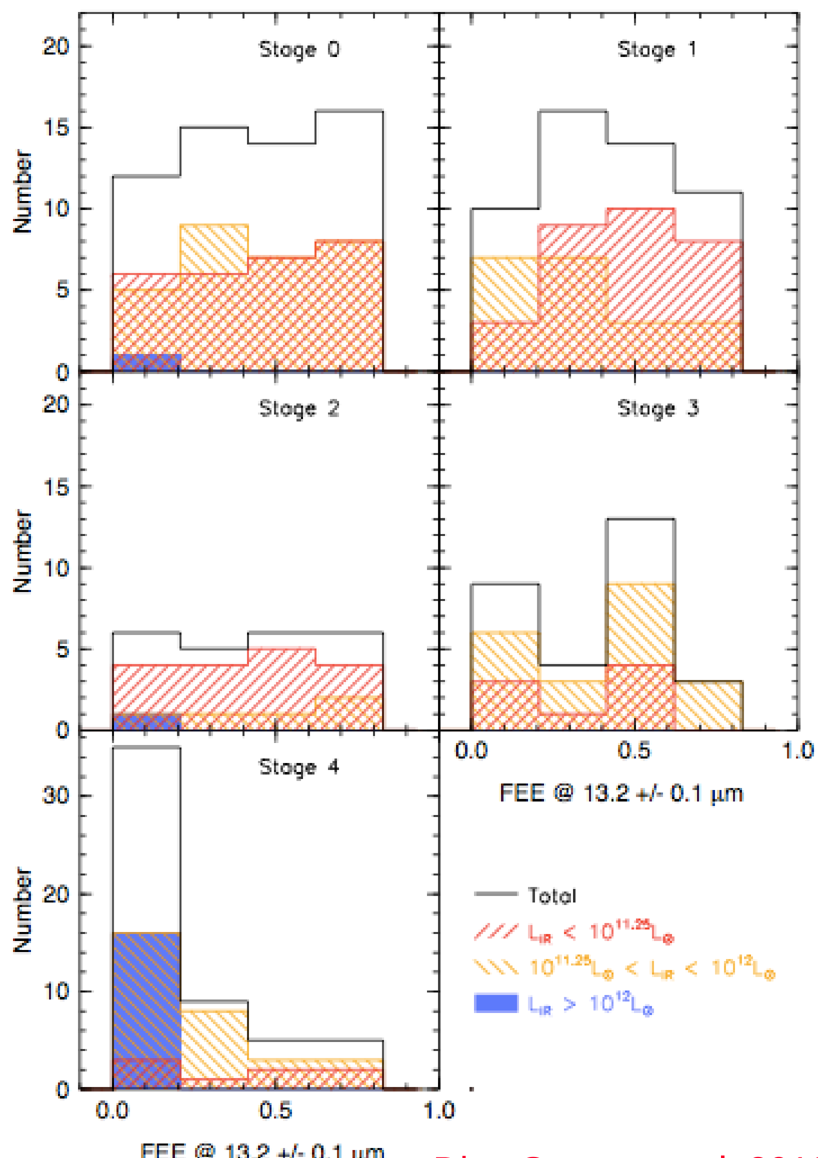
Extended Emission and L(IR)



The median fraction of extended emission decreases when L_{IR} increases.

Similarly for the 13.2µm continuum emission

Extended Emission and Interaction stage

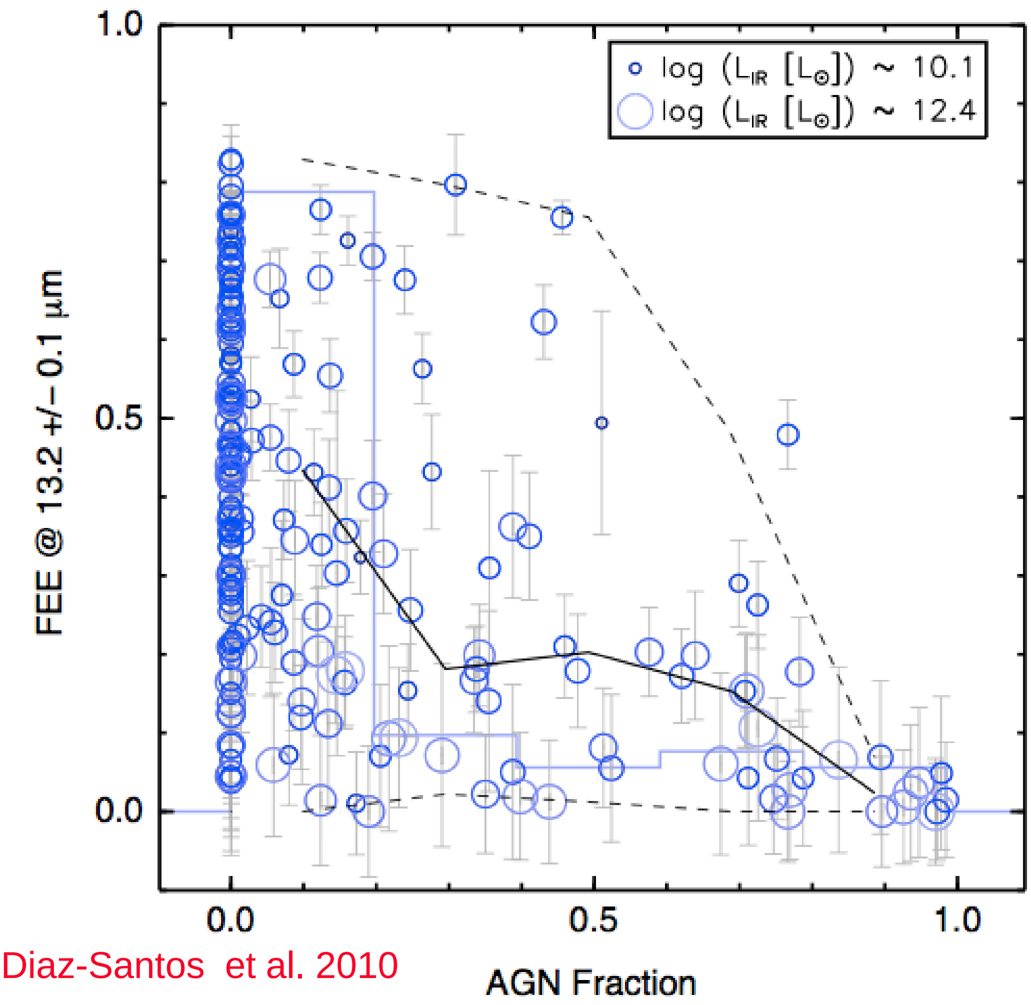


Diaz-Santos et al. 2010

- ❑ Use merger stage classification relying on optical/near-IR morphology from Petric et al. (2011 ApJ, 730,28)
- ❑ 0: non interacting -> 5: mergers
- ❑ More advanced mergers are more luminous and also more compact in their mid-IR continuum

(Similar to what has been shown in other wavelengths)

Extended Emission and AGN



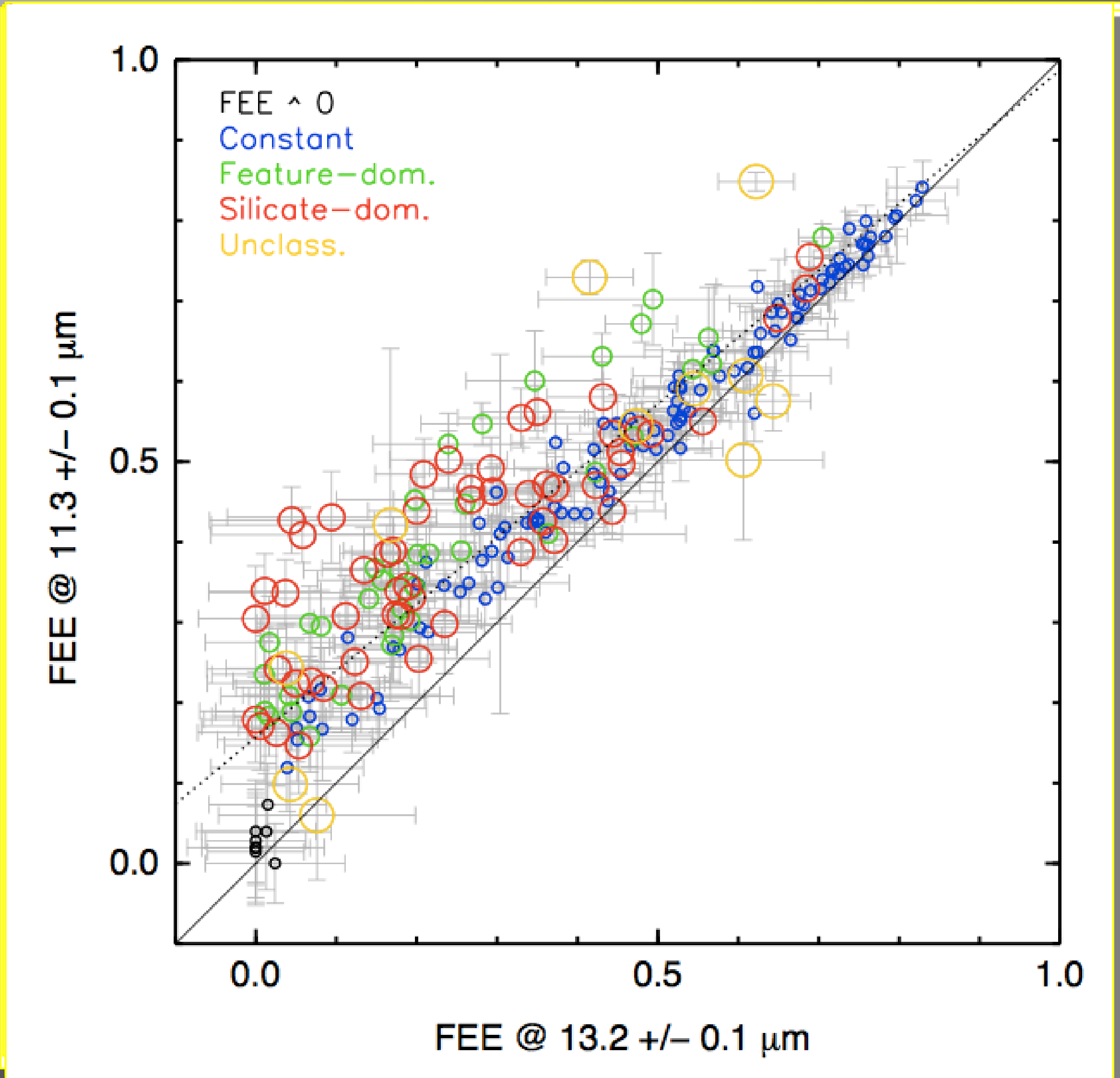
Diaz-Santos et al. 2010

- Use mid-IR AGN classification (Petric et al. 2011) based on the s “Laurent diagram” which probes the presence of at hot dust component (Laurent et al. 2000)

- AGN dominated sources also more compact in their mid-IR continuum

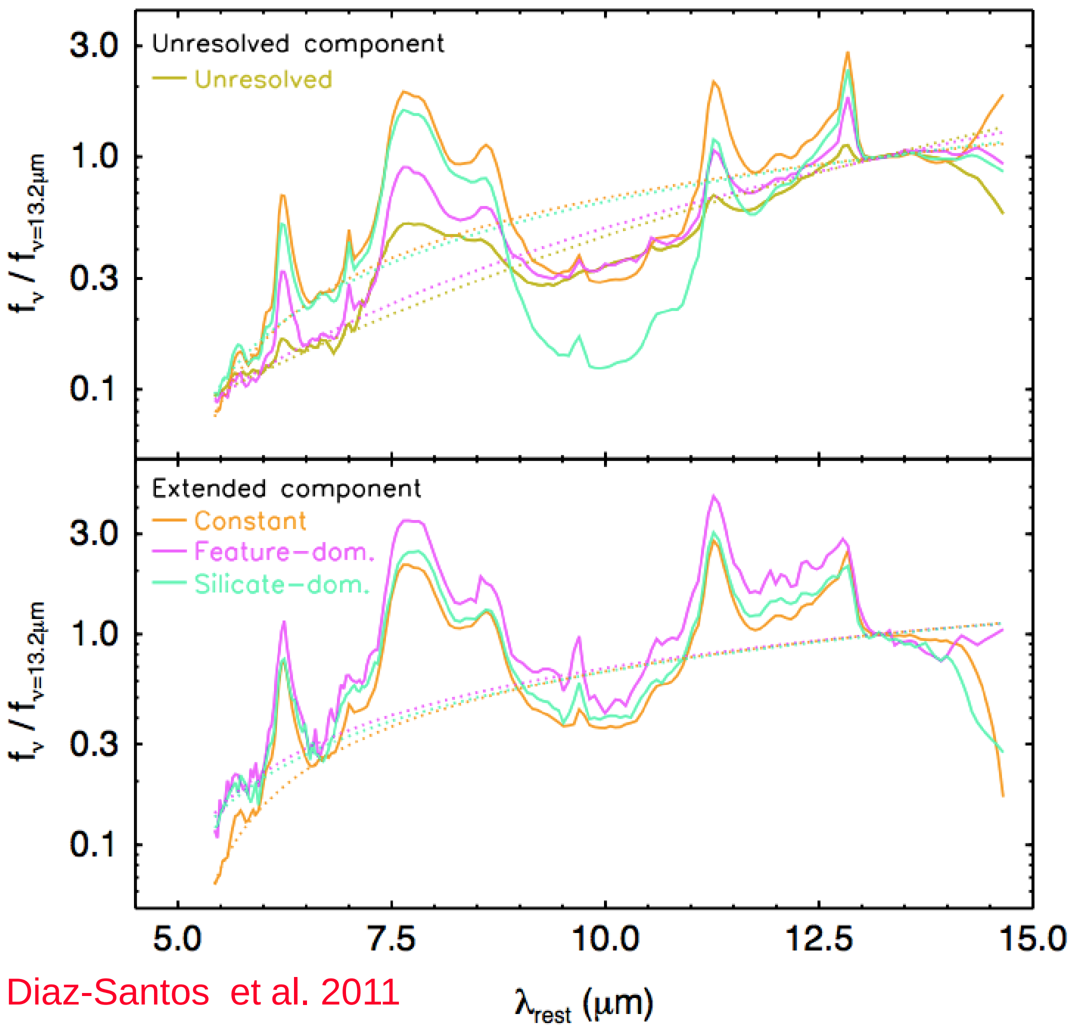
Note that we refer to mid-IR dominant AGN, not bolometricaly

Comparing the extent of various features



- Continuum at 13.2µm and 6.6µm as well as is [NeII] @12.8µm are equally extended.
- The 6.2µm and 7.7µm PAHs are as extended as the 13.2µm continuum
- The 11.3µm PAH is more extended as the 13.2µm continuum.
- Variation likely due to the ionized (6.2, 7.7µm) vs neutral (11.3µm) nature of PAHs. Ionized PAHs need harder radiation field to be excited (Galliano et al 2008)

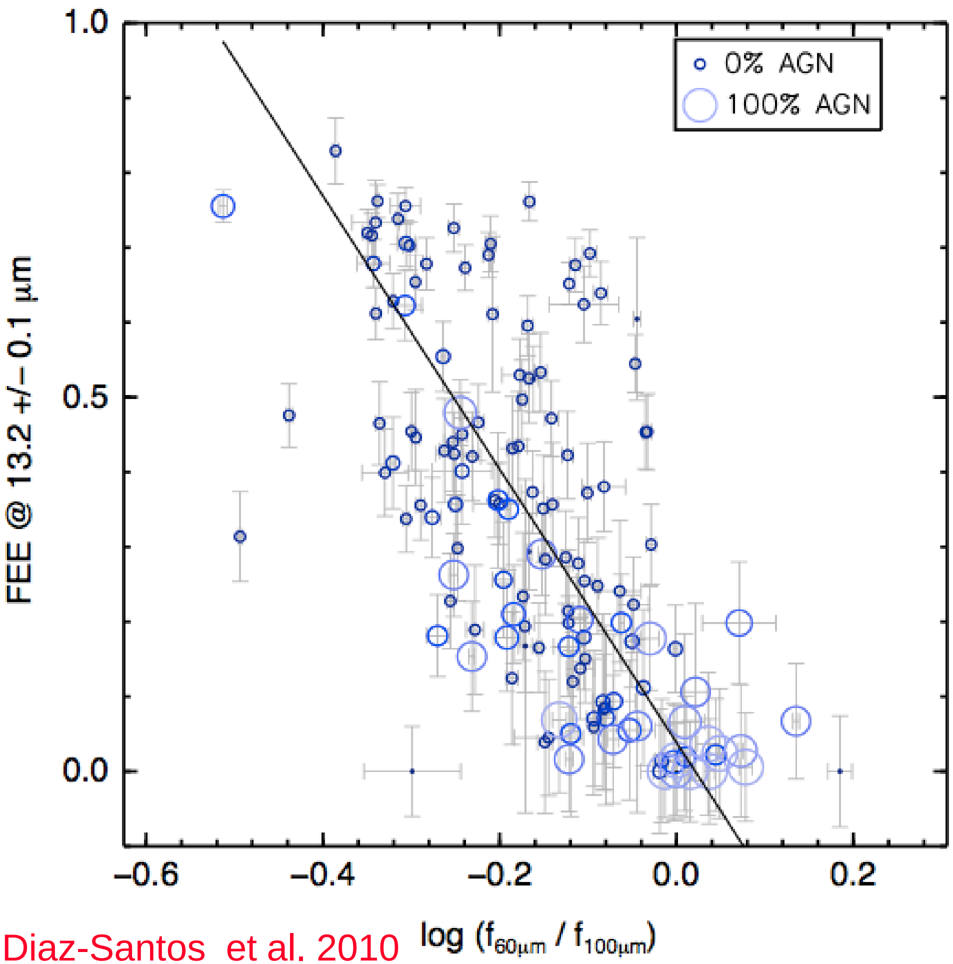
The spectrum of extended & compact components



Diaz-Santos et al. 2011

- The 5-15μm spectrum of the nuclear component varies depending on spectral type.
- The 5-15μm spectrum of the extended component is similar for all three spectral types.
- Suggests common mechanism in the excitation (ie star formation) and dust properties

Extended Emission and far-IR Colors



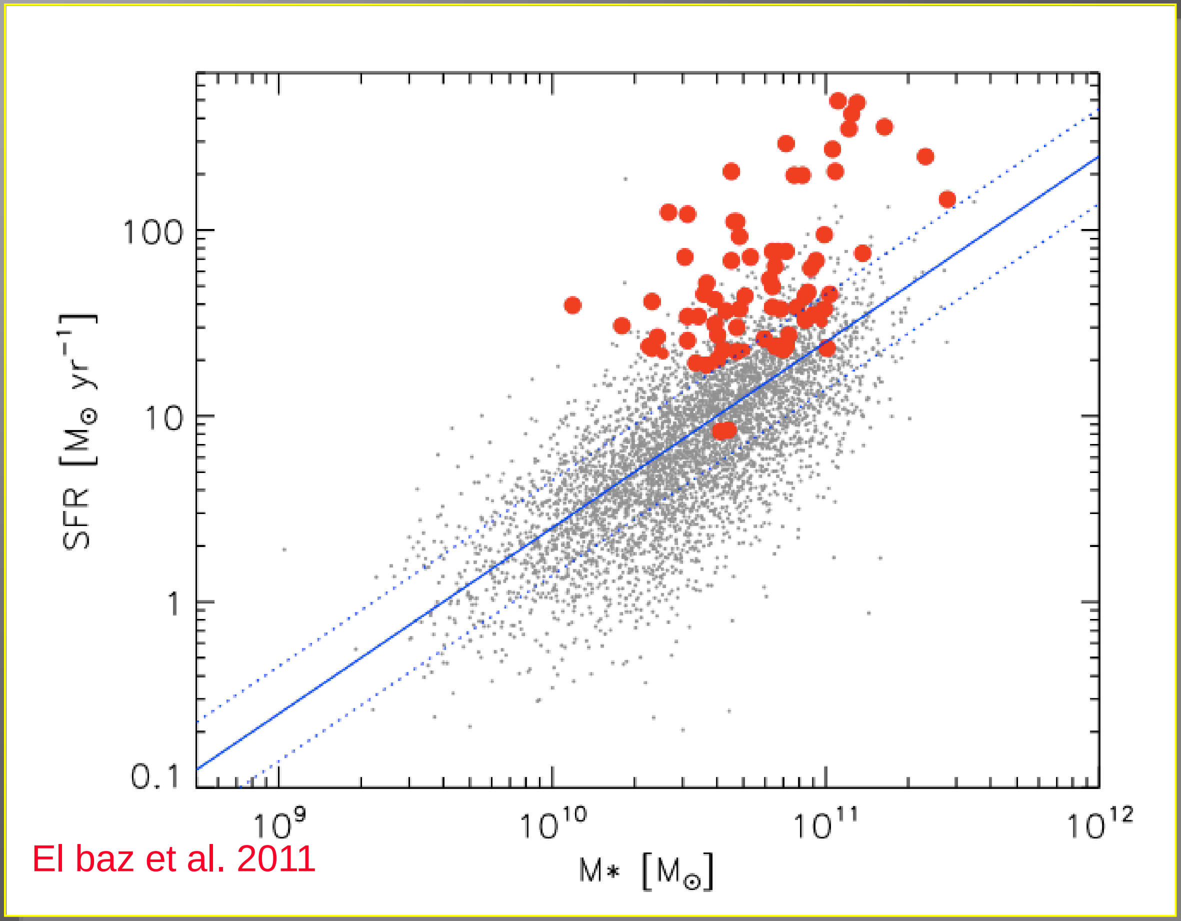
Diaz-Santos et al. 2010

- Use IRAS colors as a probe of the global ISM "temperature"
- Sources which are more compact in their mid-IR continuum have warmer far-IR colors
- This suggests that when nuclear emission is compact in the mid-IR it may dominate the energy production in the galaxy

Can be tested with Herschel Key Project: Hercules (PI P. van der Werf)

$$FEE_{13.2\mu m} = 0.04 \pm 0.02 - (1.83 \pm 0.11) \times \log(\frac{f_{60\,\mu m}}{f_{100\,\mu m}})$$

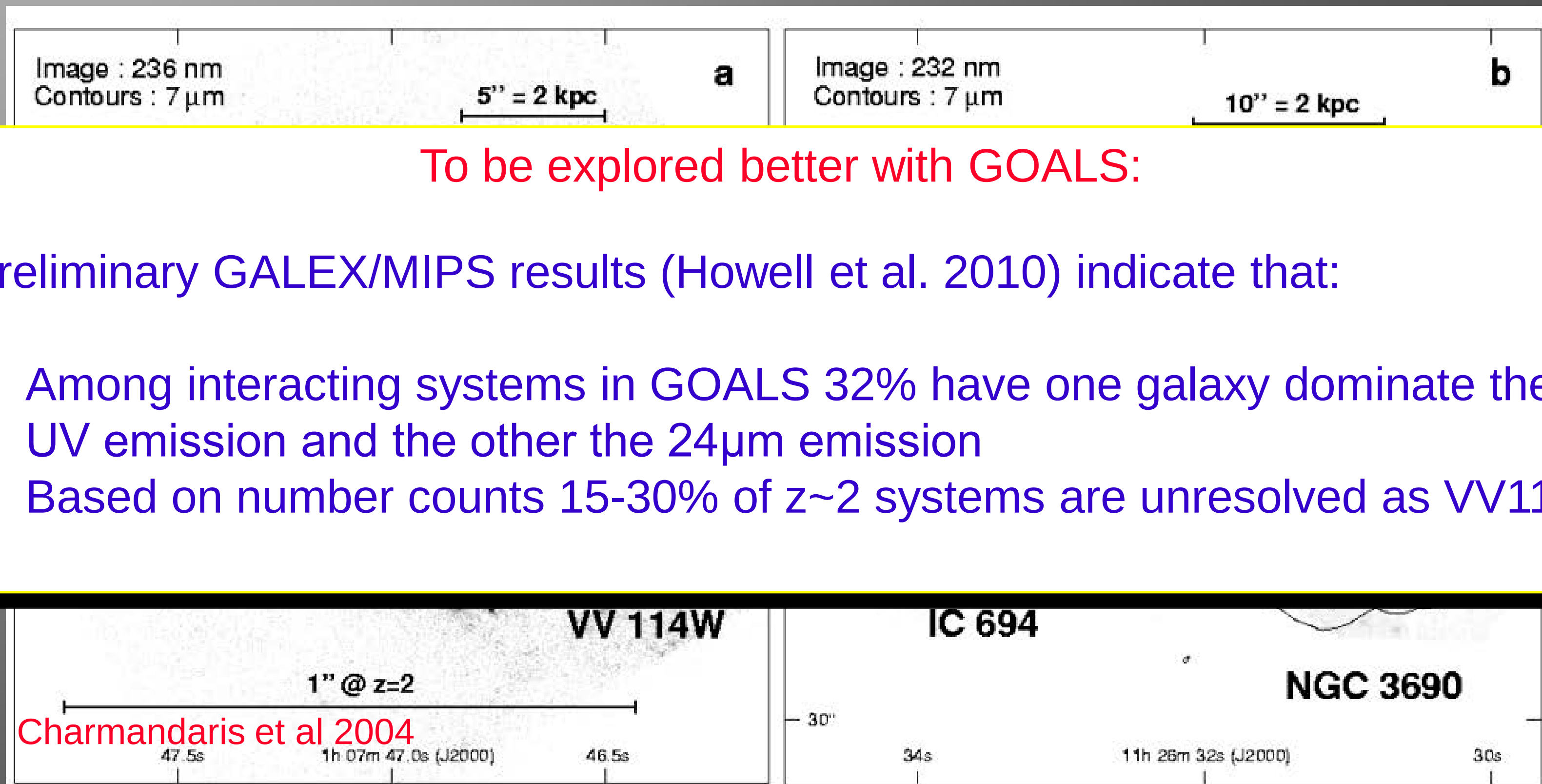
SFR and compactness



Compact galaxies (both local and at high-z) deviate from the SFR/M* relation.

UV/mid-IR comparison of two LIRGs

Images: HST/STIS UV - Contours: ISO/CAM 7um



Charmandaris et al 2004

To be explored better with GOALS:

Preliminary GALEX/MIPS results (Howell et al. 2010) indicate that:

- Among interacting systems in GOALS 32% have one galaxy dominate the UV emission and the other the 24µm emission
- Based on number counts 15-30% of z~2 systems are unresolved as VV114

7µm/UV ~ 800:10:35□ **7µm/UV ~ 330:160:190□**

The spatial resolution of ground & Spitzer/MIPS24 surveys of LIRGs at z~2 will result in blending of the emission from the unresolved interacting components leading to a systematic underestimation of their dust content.

Conclusions / Perspectives

Even though the angular resolution of Spitzer/IRS is ~3.6arcsecs..

- LIRGs display large fraction of extended mid-IR emission in both continuum and 5-15μm features
- For at least 90% of the sample more than 20% of the mid-IR flux originates outside the nuclear unresolved region.
- For at least 35% of the sample more than 50% of the mid-IR flux is extranuclear (probably also their star formation?)
- Systems with $\log(L_{IR})>11.8\ L_{\odot}$ display mid-IR extent of less than 20%
- The 13.2μm size of LIRGs is ~3.5kpc, while ULIRGs are less than 1.5kpc
- The 11.3μm PAH emission is more extended, consistent with it being a "neutral" PAH.
- Spatial extent decrease with mid-IR AGN activity and merger stage.
- Compact sources have warmer far-IR colors

- To do:

  Explore the implications of the mid-IR,UV, and radio continuum (E. Vardoulaki) spatial extent of local (U)LIRGS in unresolved sources of deep high-z surveys