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Intermediate redshift ULIRGs: their ISM properties and evolution

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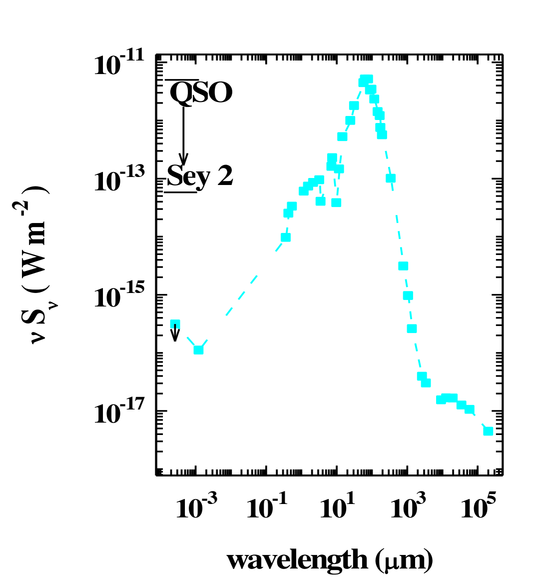
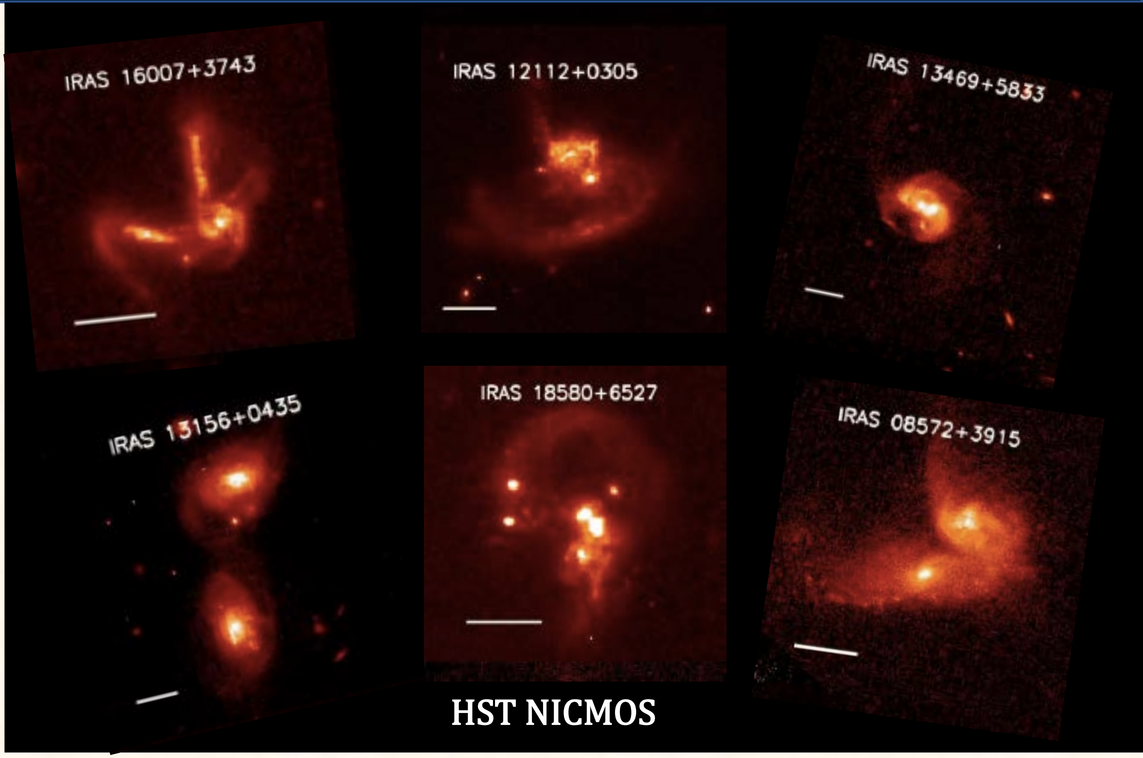
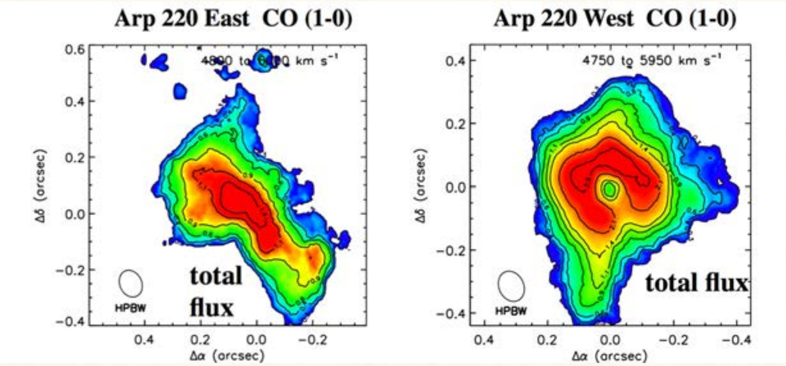
Ultraluminous Infrared Galaxies



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



- Extremely rare
- Nearly always mergers
- Powered predominantly by star formation
- Half contain a detectable AGN
- Templates for high redshift ULIRGs



ALMA : CO(1-0) Scoville+17

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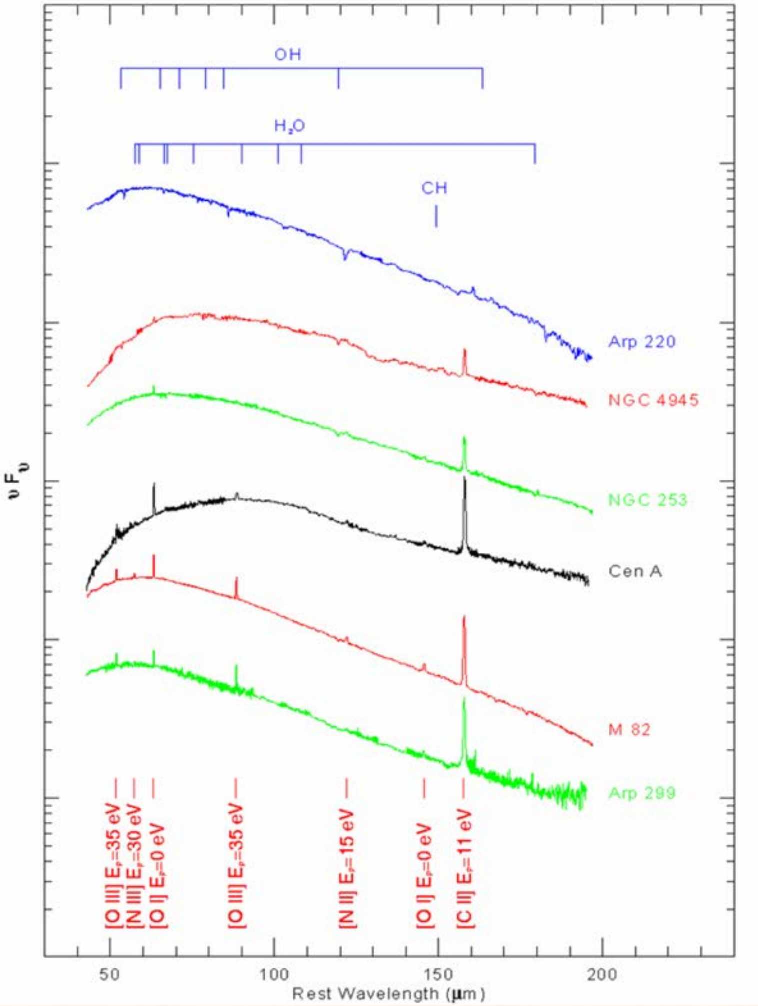
Why study ULIRGs?

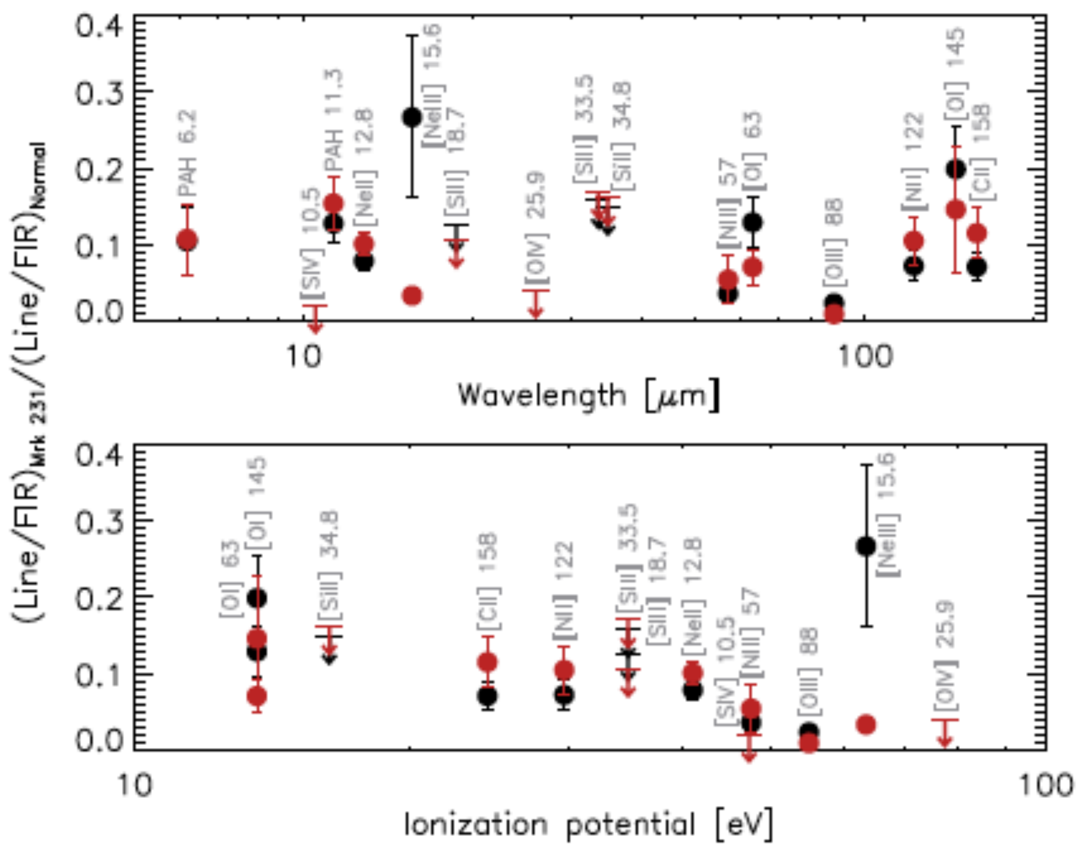
- In the local Universe, ULIRGs signal the merging and morphological transformation of gas rich galaxies: what are their evolutionary precursors, products and how to reach them.
- ULIRGs are major contributors to the IR background
- ULIRGs are often the first galaxies we will learn about at high-z
- In what ways and which high-z ULIRGs are similar/different to local ones and at what z, if any, does a change happen?
- Unique ISM properties (sometimes too complex)

Local ULIRGs are C+ (and other FS lines) deficient



Historic ISO spectra (Fischer +99)
see e.g. Farrah+2013, for Herschel spectra

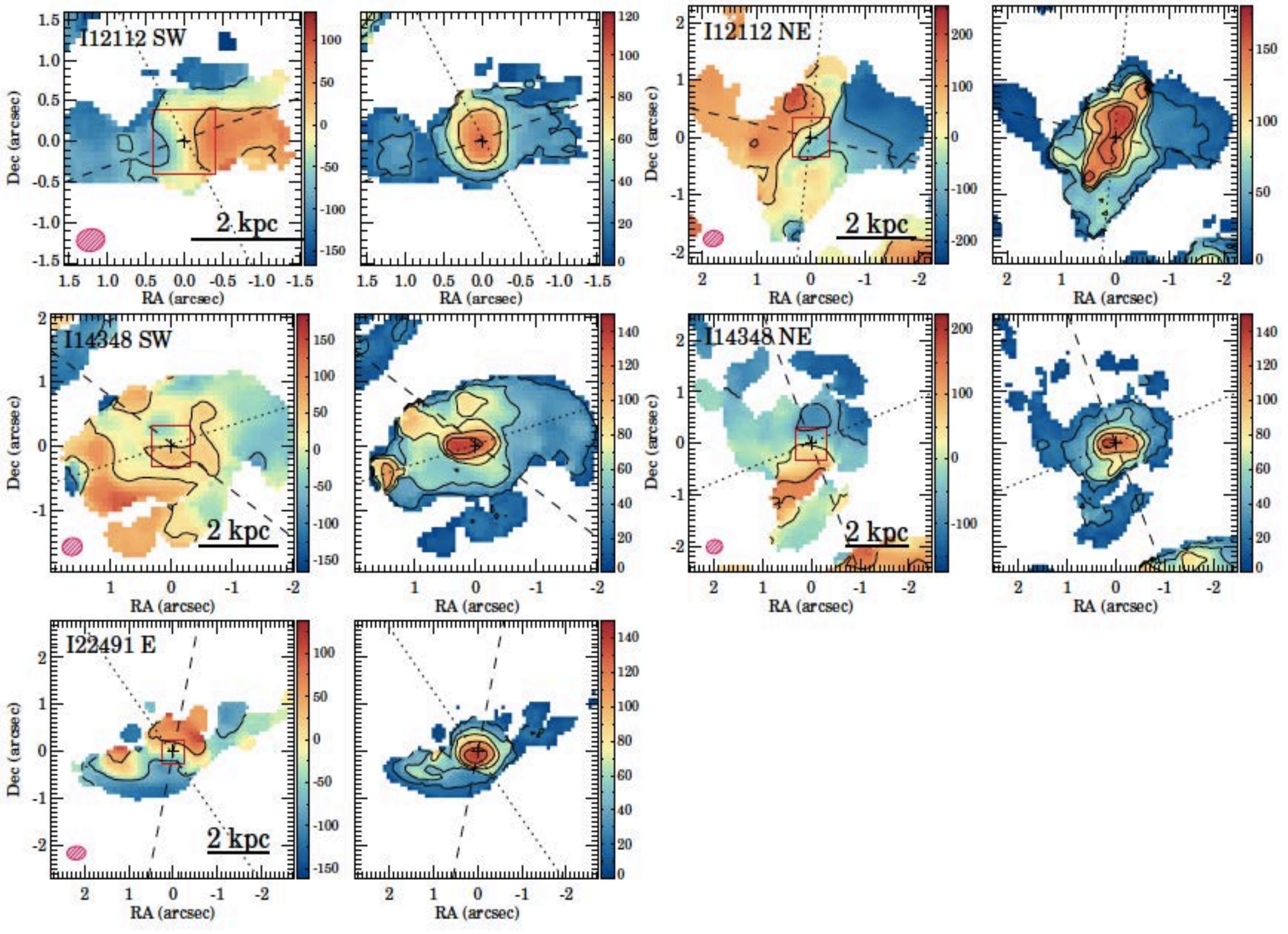
From Fischer et al. /Spitzer lines from Armus et al.



No obvious trend with transition, wavelength or density
Deficit more severe for higher ionization potential
If obscuration is responsible then this is caused by extremely opaque clumps with high covering factor for species with high ionization potential.

The molecular gas content of ULIRGs

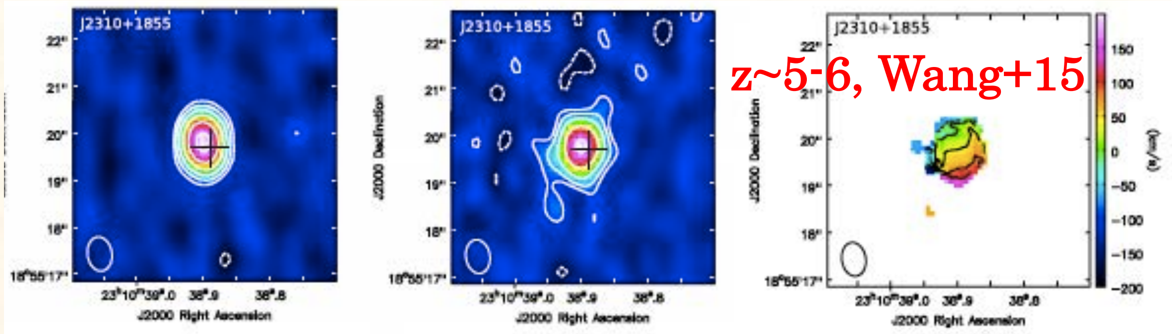
ALMA B6
CO(2-1), 0.”3-0.”4
~400-500 pc
at the distance of these ULIRGs



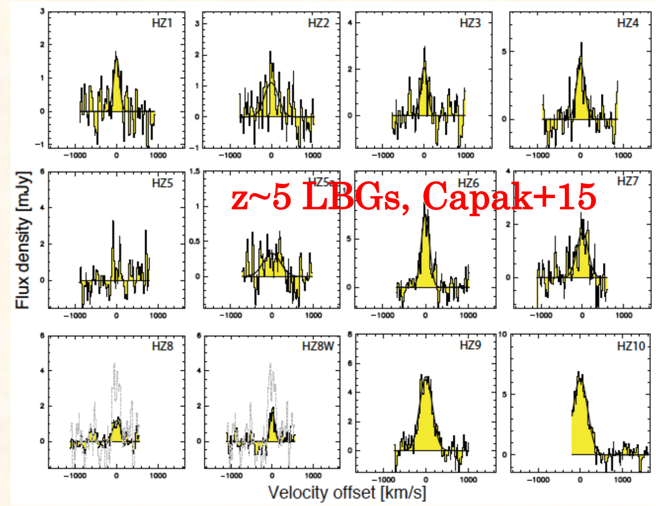
Pereira Santaella+18

[CII] emission at high-z

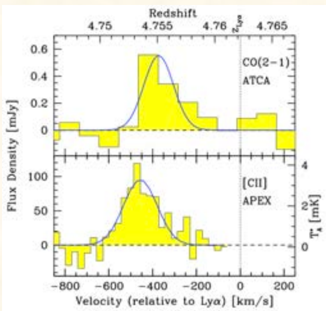
z~5-6, Wang+15



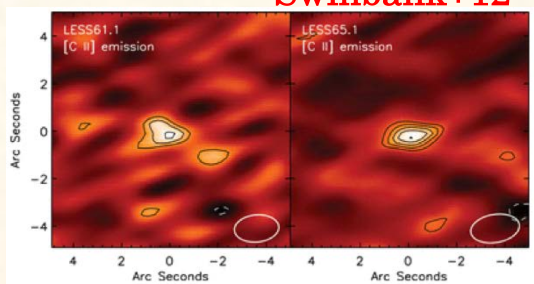
z~5 LBGs, Capak+15



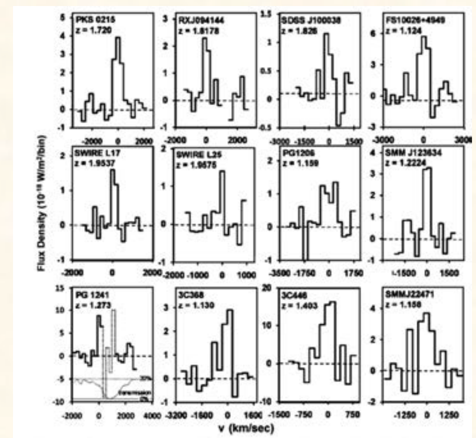
z=4.76, De Breuck+11

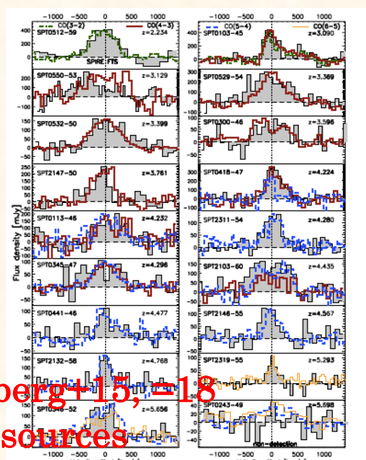


z = 4.4 Swinbank+12

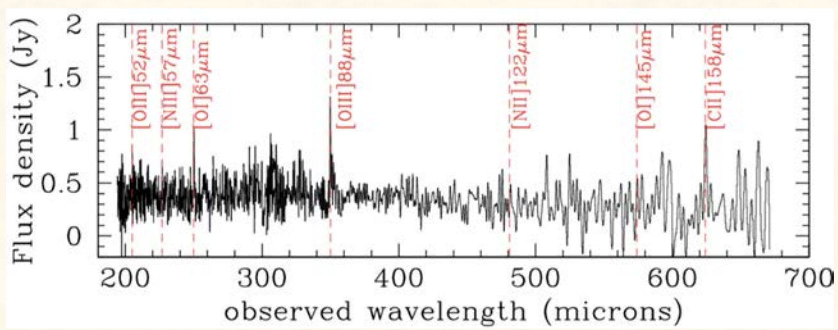


z~1-2 Stacey+10





Gullberg+15, +18
SPT sources



HLock01, z~3, Herschel –detected ULIRG
Rigopoulou+18

The questions:

- Why are local ULIRGs [CII] deficient and high-z luminous infrared galaxies not?
- When does a change in the ISM properties occur?
- Does metallicity play a role?

Herschel survey of intermediate redshift ULIRGs

Selection criteria:

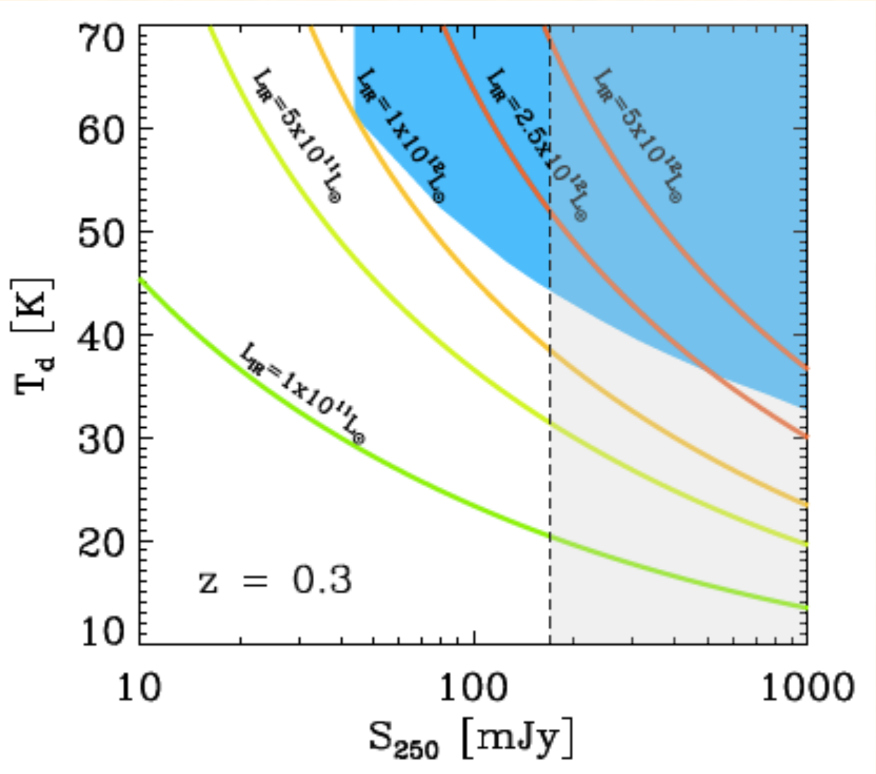
- ❖ S_{250} >150 mJy (appropriate for SPIRE-FTS spectroscopy)
- ❖ 0.23<z<0.8 ([CI],[CII],[OI] accessible to the SPIRE-FTS range)

Target selection: x-match Herschel 250 micron catalogues with 24 micron priors

Targets have excellent ancillary multi-λ data available

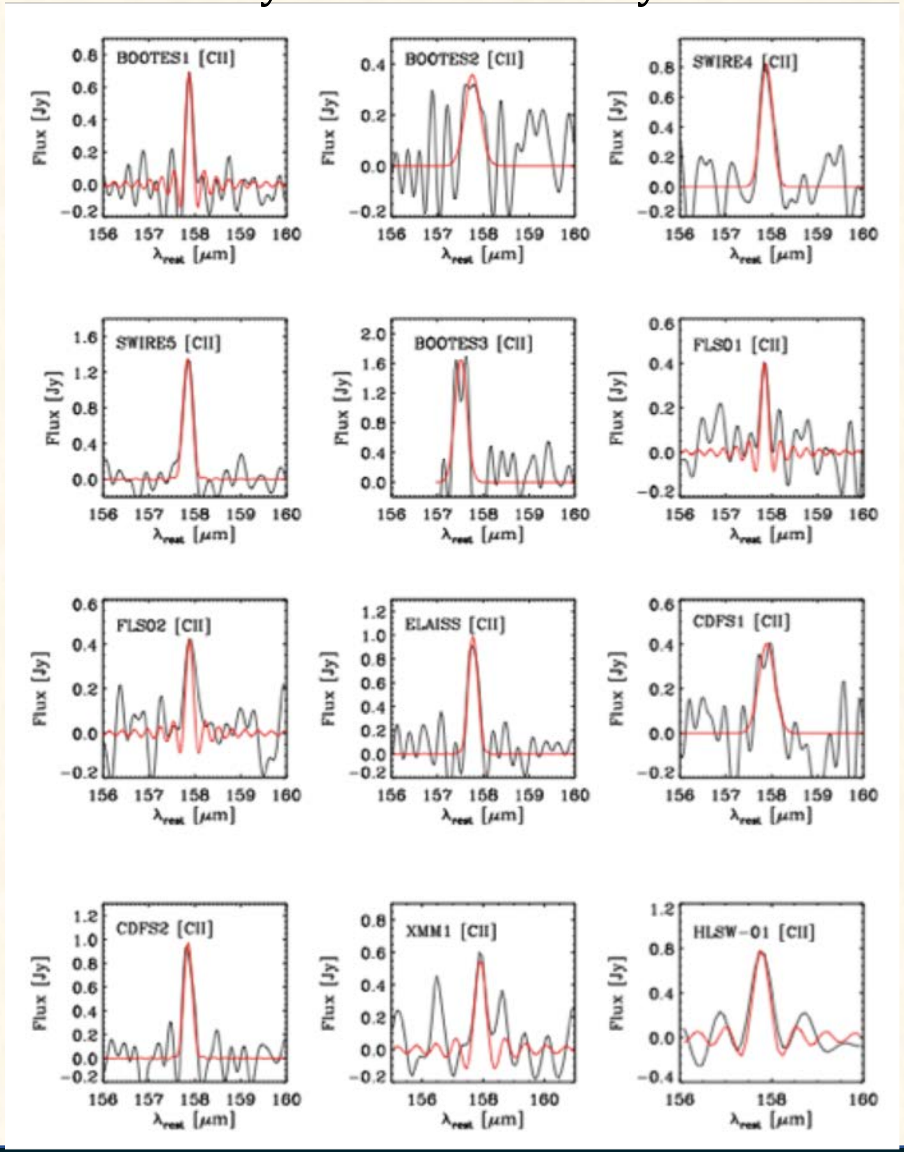
By construction the sample is dominated by U/LIRGs

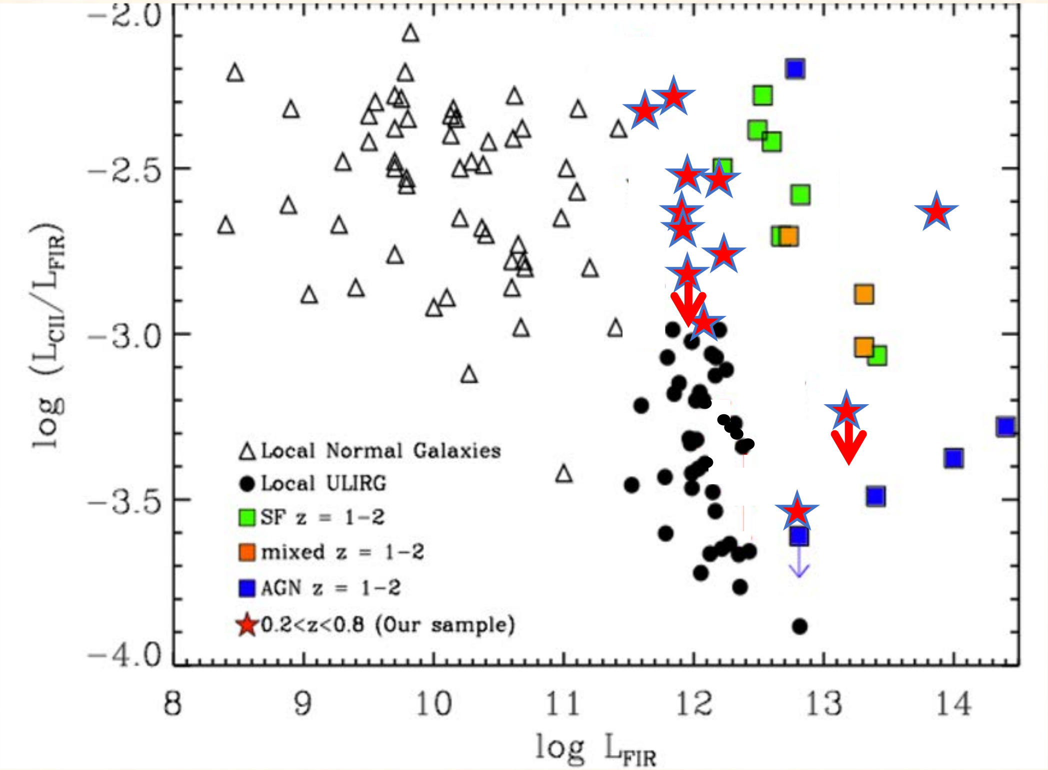
Our selection picks up `colder' sources



Intermediate redshift ULIRGs are not C+ deficient

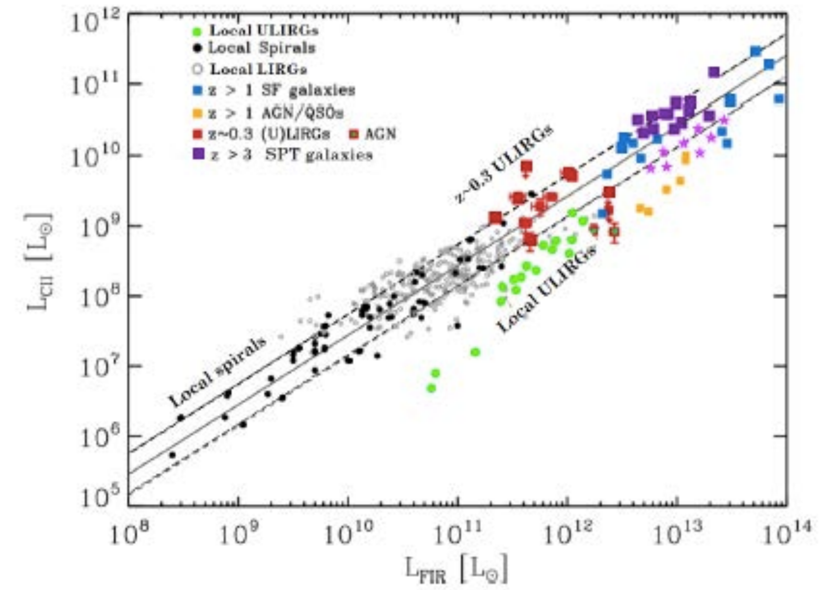
The C+ survey SPIRE-FTS survey of 0.2<z<0.6 ULIRGs (R14, Magdis +14)



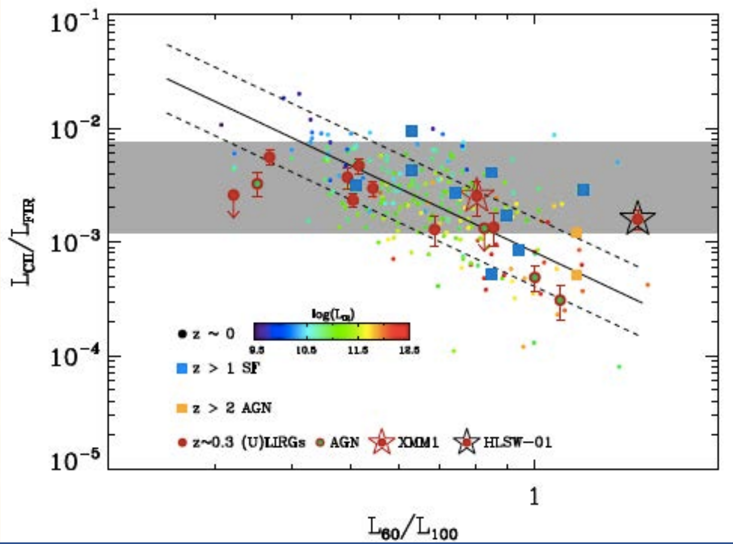


in some galaxies C+ profile much wider than instrumental profile => C+ rotating disk?

$L_{[CII]}$-L_{FIR} relation



Rigopoulou+14, Magdis+14
but also, Diaz-Santos+13,17, deLooze+15 and others

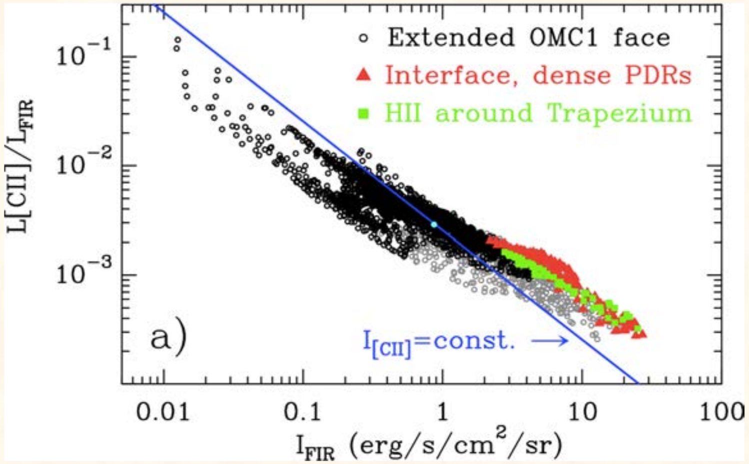


Local ultra-luminous IR galaxies are deficient and this is NOT simply a selection effect!

Complex physics is involved:

- Hard radiation fields
- Compact sizes
- Increased gas-to-dust opacity (UV photons absorbed by dust before they photoionize PDRs (dust-bounded HII regions, see Abel+2009)
- Low metallicities

→ lower gas heating efficiency, warmer T_{dust}



[CII]/FIR ratio in Orion shows deficit as a function of increasing column density (Goicoechea+15)

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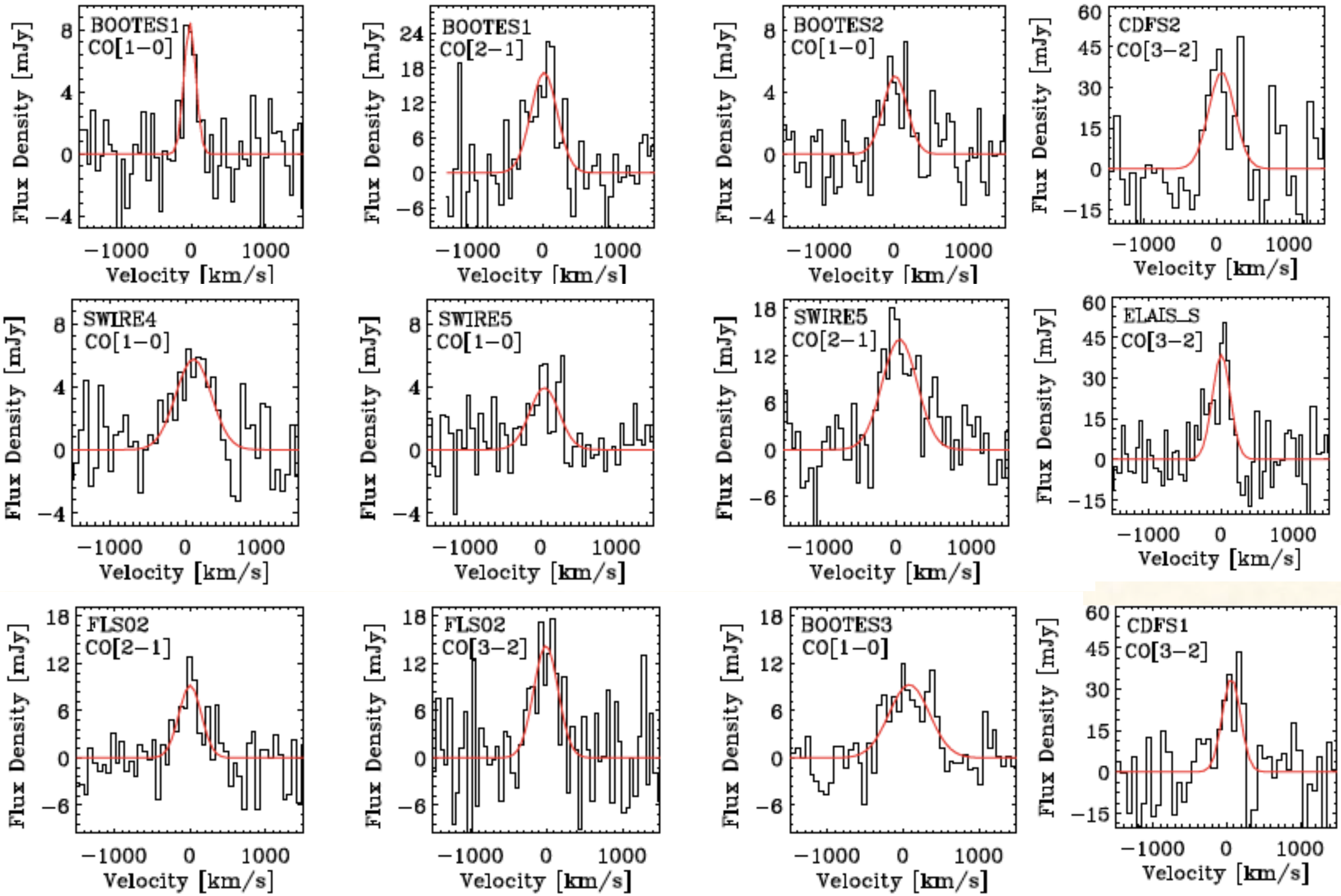
The CO properties of intermediate redshift ULIRGs



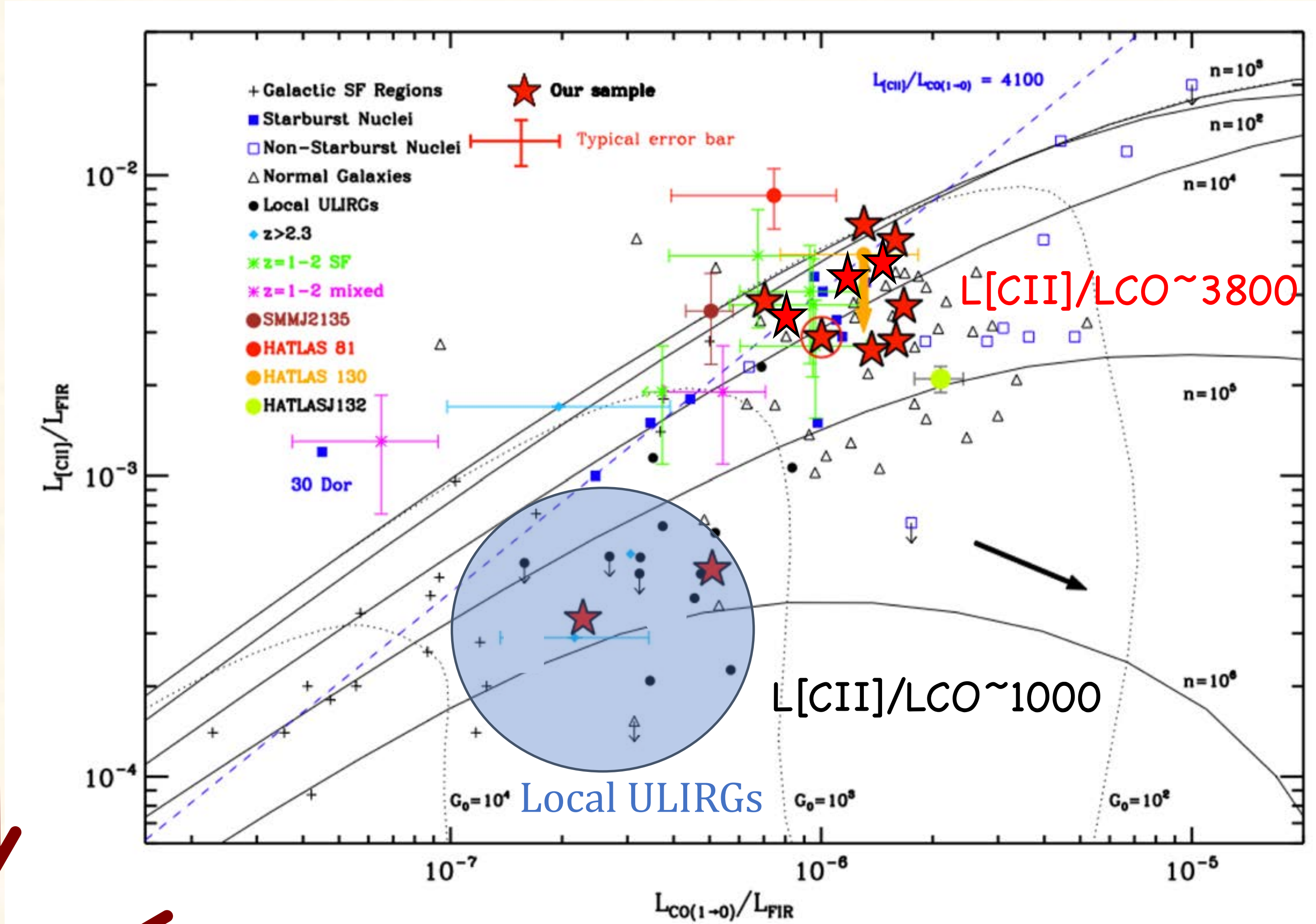
IRAM 30m
APEX
CO(1-0)&CO(2-1)
&CO(3-2)

FWHM=300-500 km/sec

Magdis et al.+14

low-J CO transitions generally broad. Some display double-horn profiles…

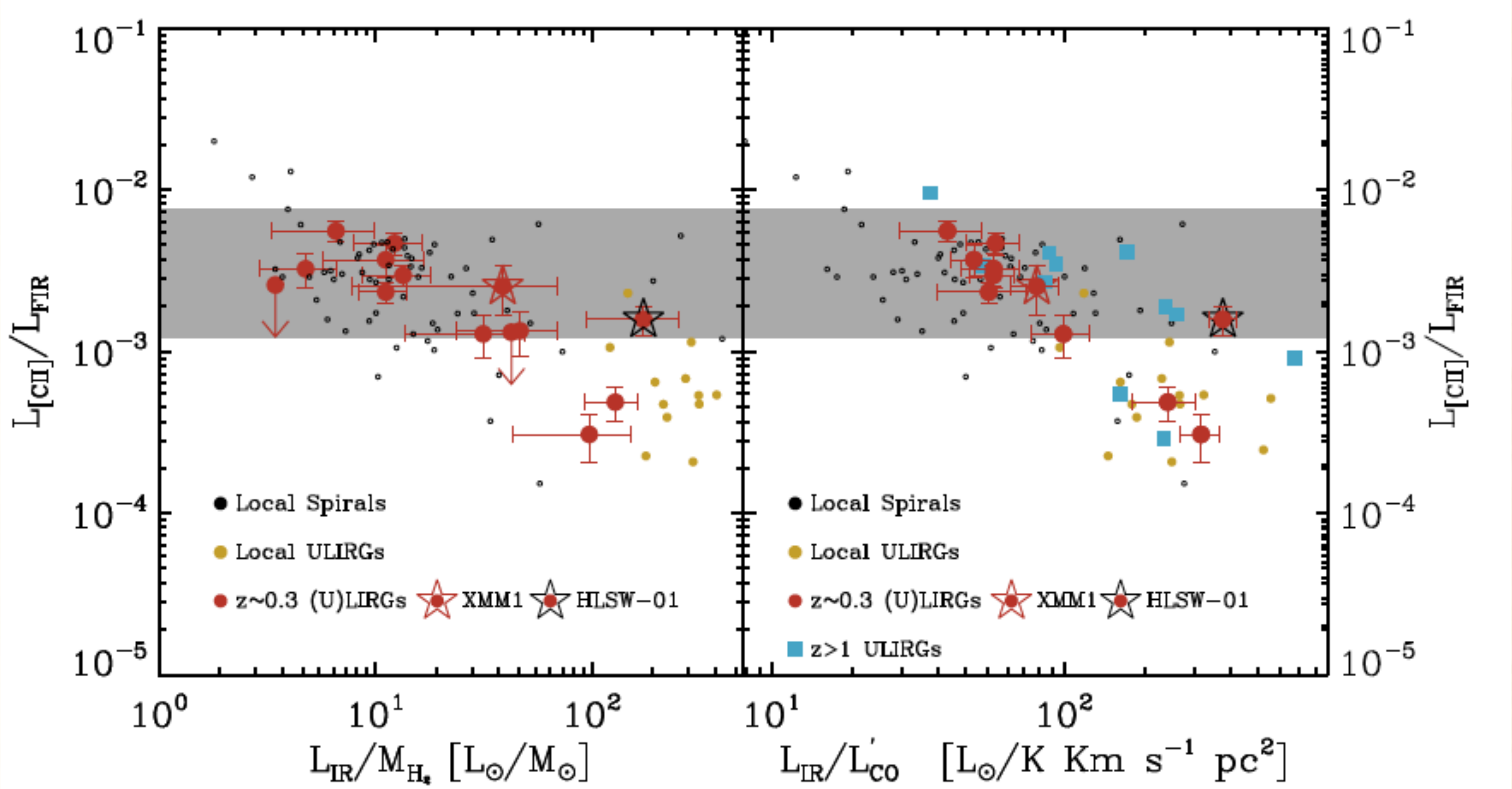
Increase in C+ deficit



Increase in SFE

Rigopoulou+14

Star Formation Efficiencies of intermediate redshift ULIRGs



[CII] deficit pronounced for sources with high SFE =SFR/Mgas

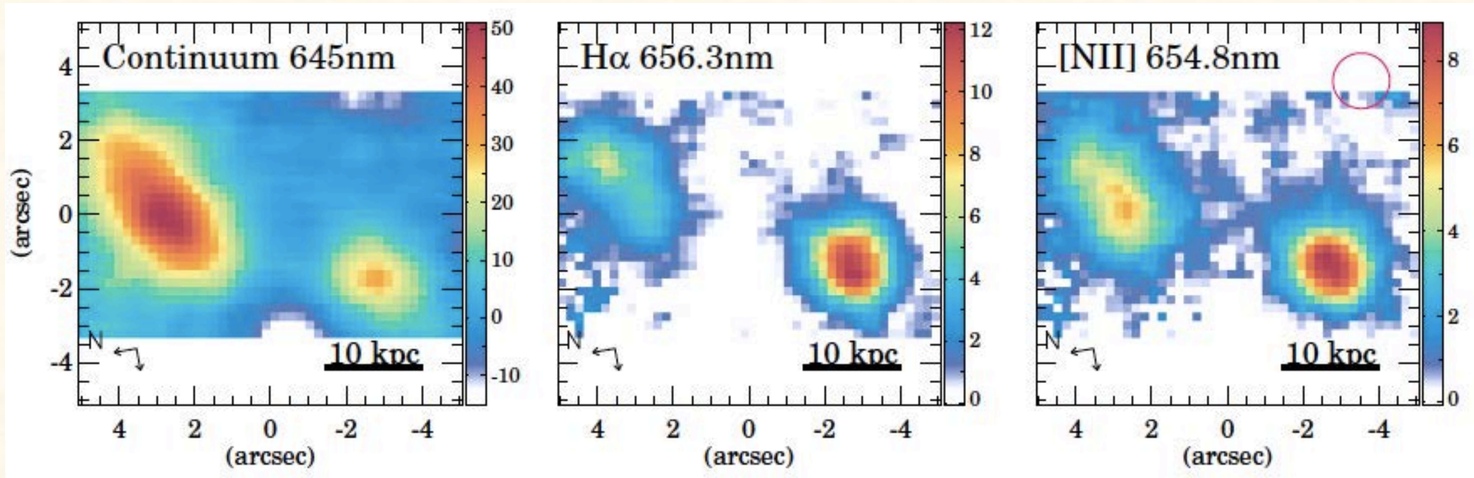
Possible Scenario : High SFE and hard radiation fields due to compressed star formation triggered by mergers.

Need to resolve the star forming regions!

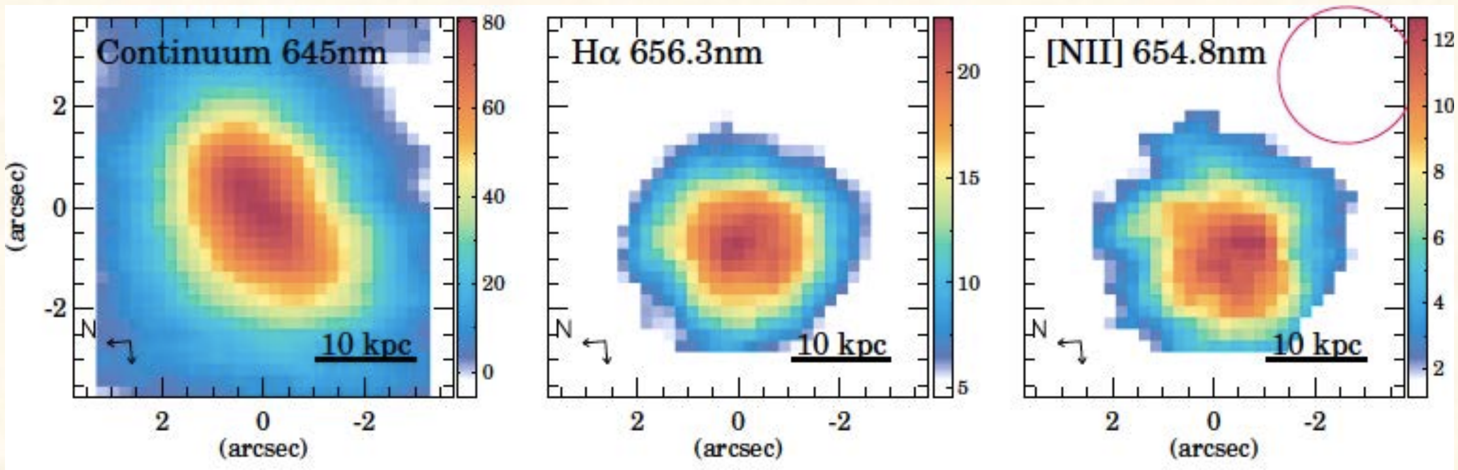
Kinematics of the ionized gas

Spatially resolved Hα &[NII] maps for the majority of our sample

CDFS 01, z=0.3

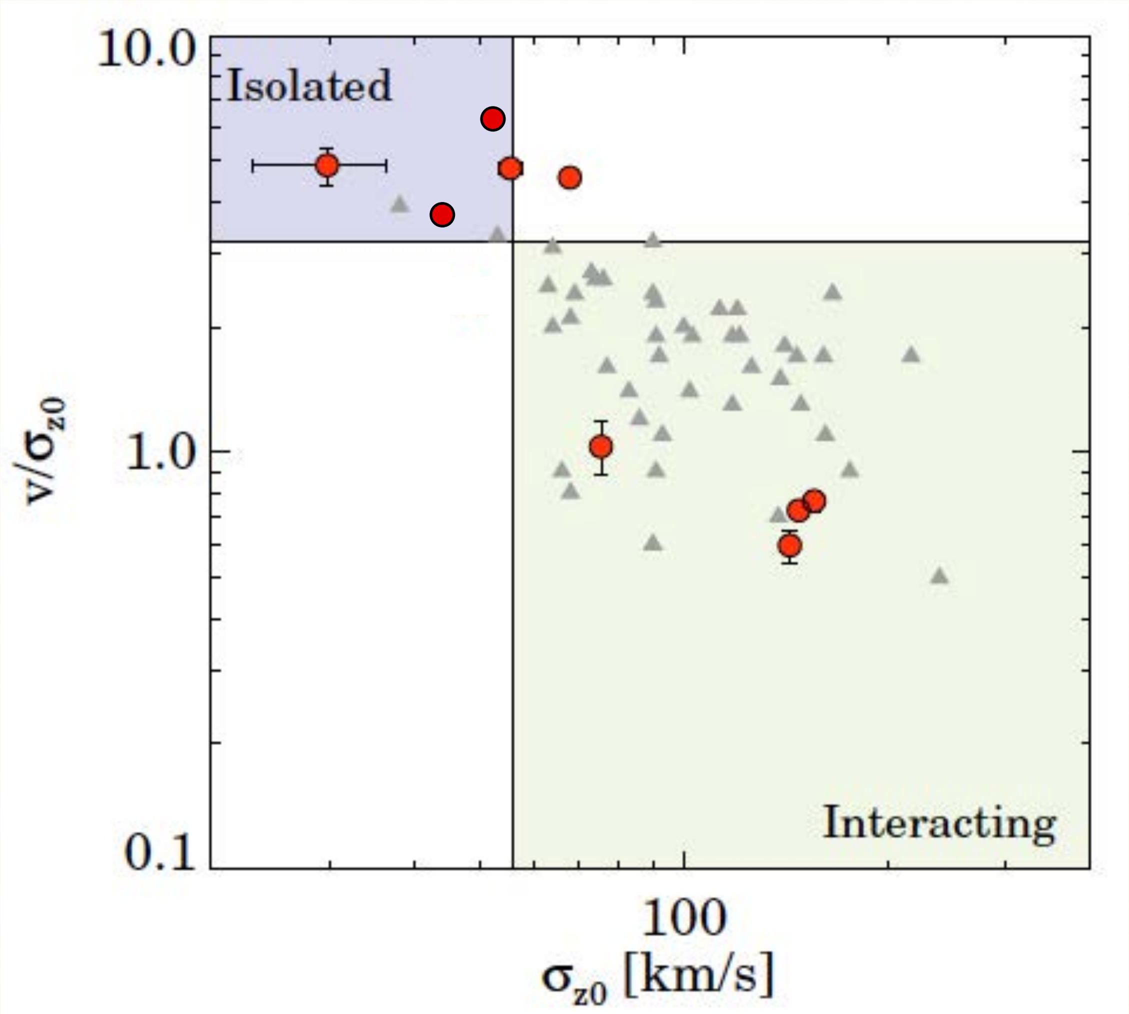


SWIRE 5, z=0.46



Pereira Santaella+19

GalPak ^{3D} models



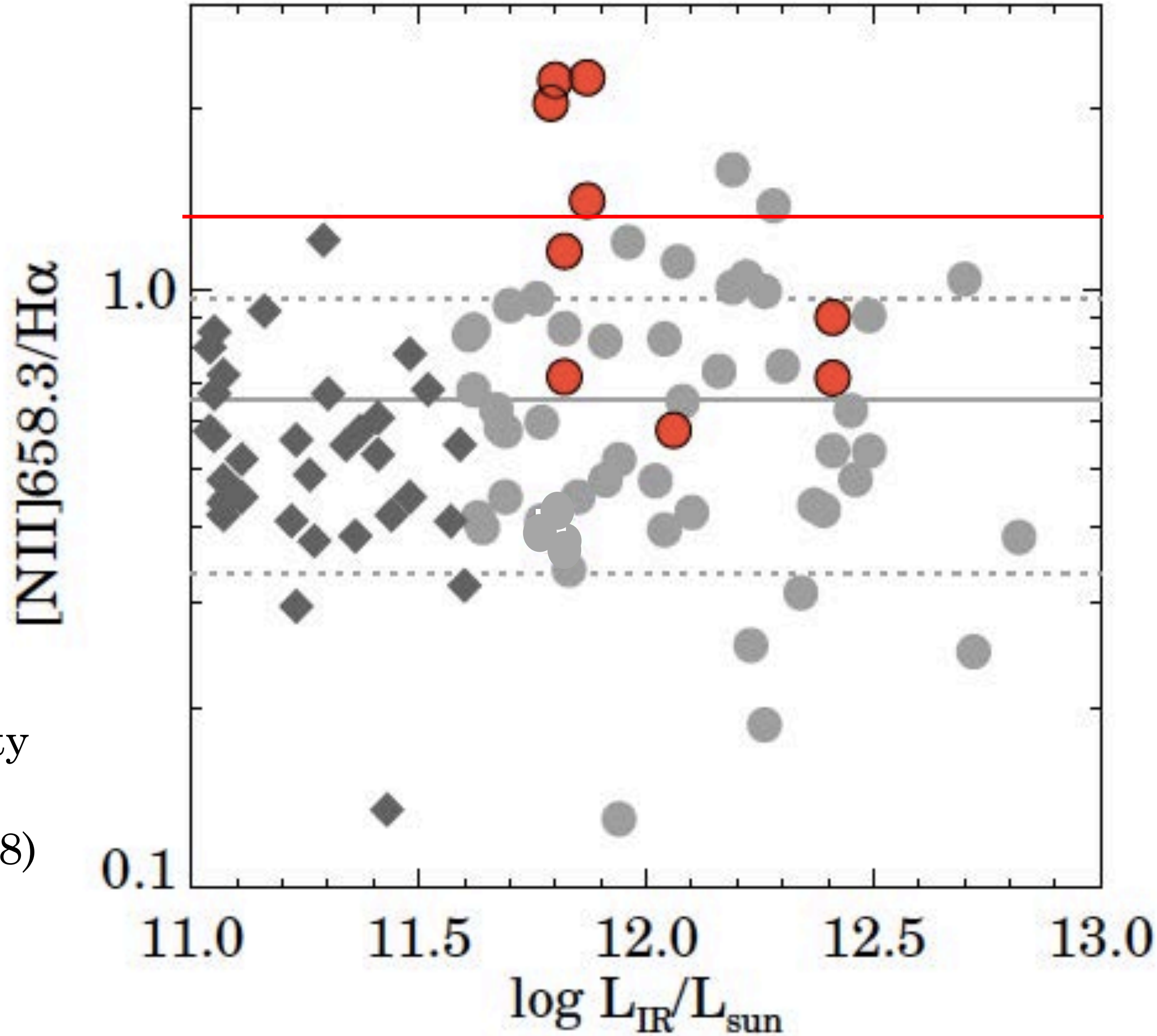
Pereira Santaella+19

N2 metallicity indices

Metallicity estimates based on the N2 index (Pagel+Pettini+02)
Data for local ULIRGs from Rupke+08

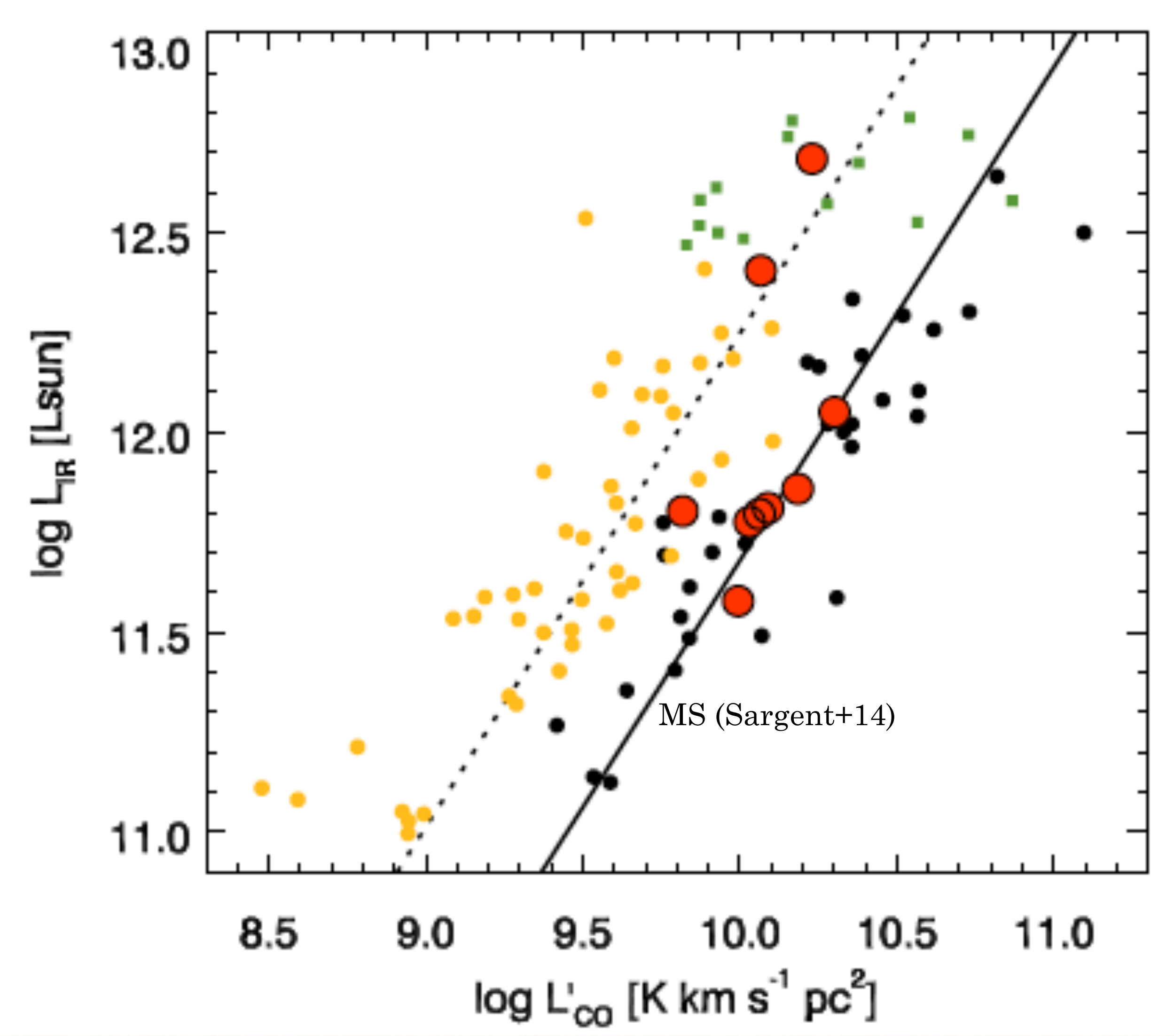
Caution when determining metallicities of dust-obscured objects based on optical ELs.

In Pereira-Santaella+17 we showed that local ULIRGs are offset from the mass-metallicity relation even when we use FIR indicators (Herrera-Camus+18)



Intermediate-z ULIRGs and the MS of galaxies

Proxy for SFR



Proxy for Mgas

Conclusions

- Local ULIRGs have complex physical ISM properties

FIR FS line deficiency likely to be caused by dust obscuration, hard radiation fields and compact sizes

- Intermediate redshift ULIRGs are not C+ deficient

Their L_{CII}/L_{FIR} and L_{CO}/L_{FIR} ratio similar to local star forming galaxies
PDR properties akin to those of local galaxies
They show larger molecular gas reservoirs, lower SFEs (wrt to local ULIRGs)
Analysis of the kinematics finds a fraction of them to be spirals
Gas Phase metallicities are larger compared to those of local ULIRGs

- Intermediate redshift ULIRGs form stars on timescales similar to local spiral galaxies

- Population transitioning between SFGs and SB galaxies

Credit: C. Pearson