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Constraints on the ISM of high-z massive dusty galaxies with ALMA

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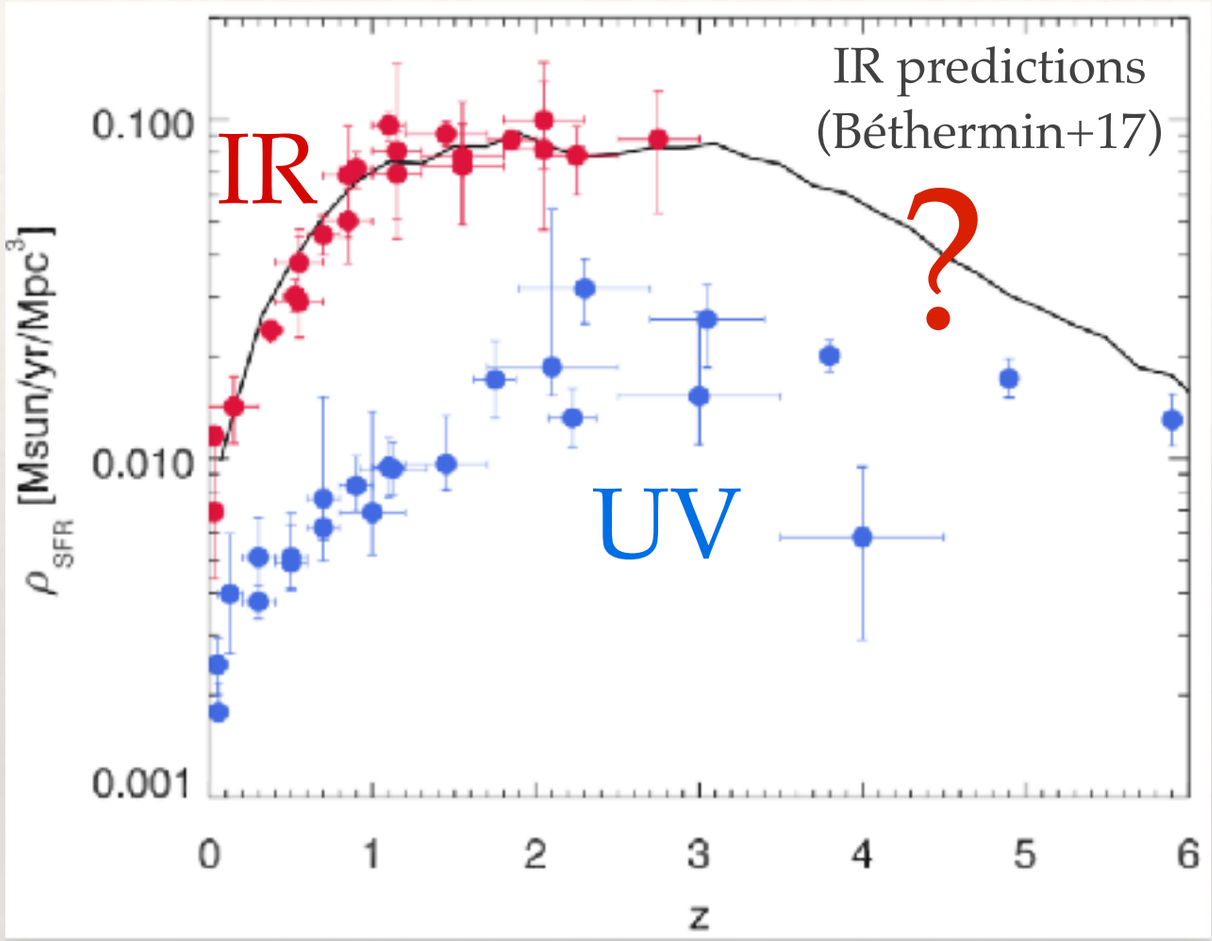
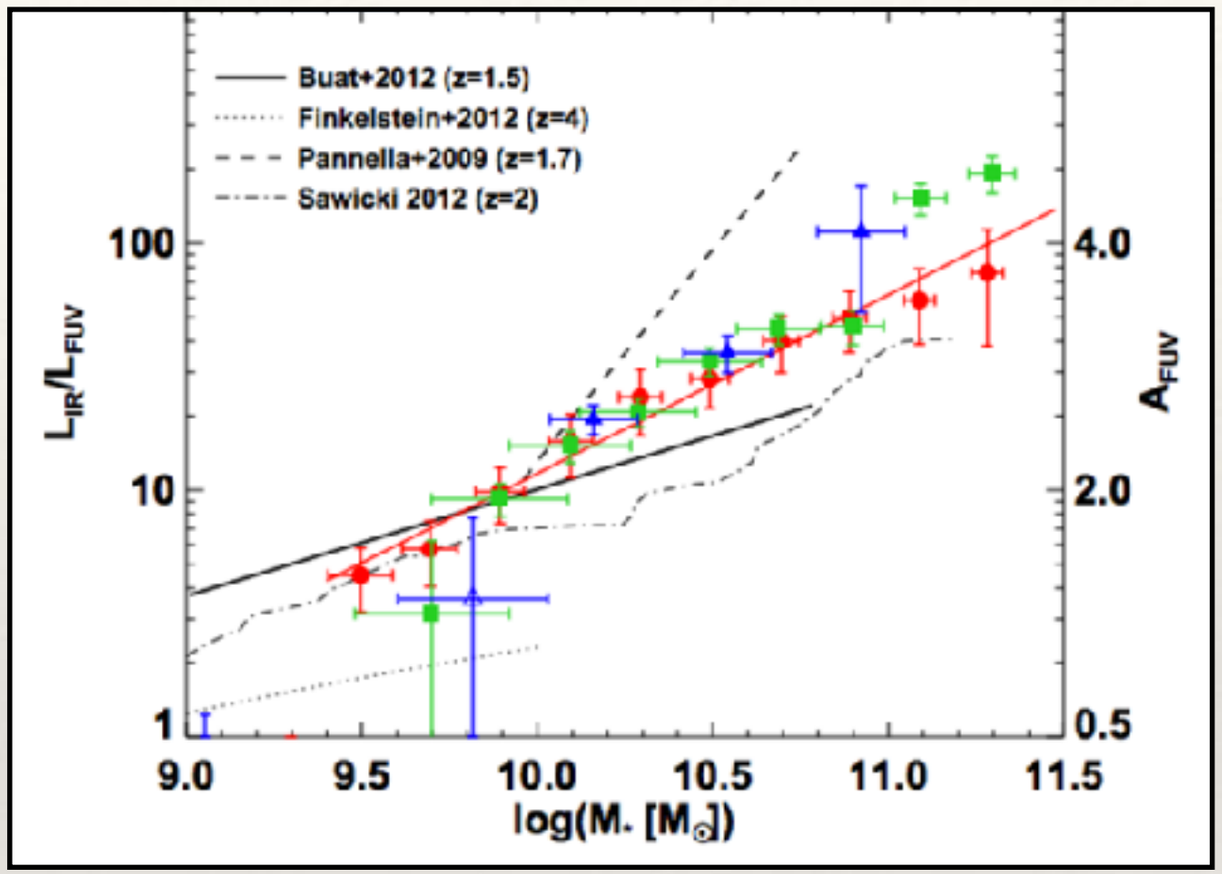
With the SPT SMG collaboration

Why is obscured star formation important?



Star formation history
(adapted from Madau & Dickinson 2014)



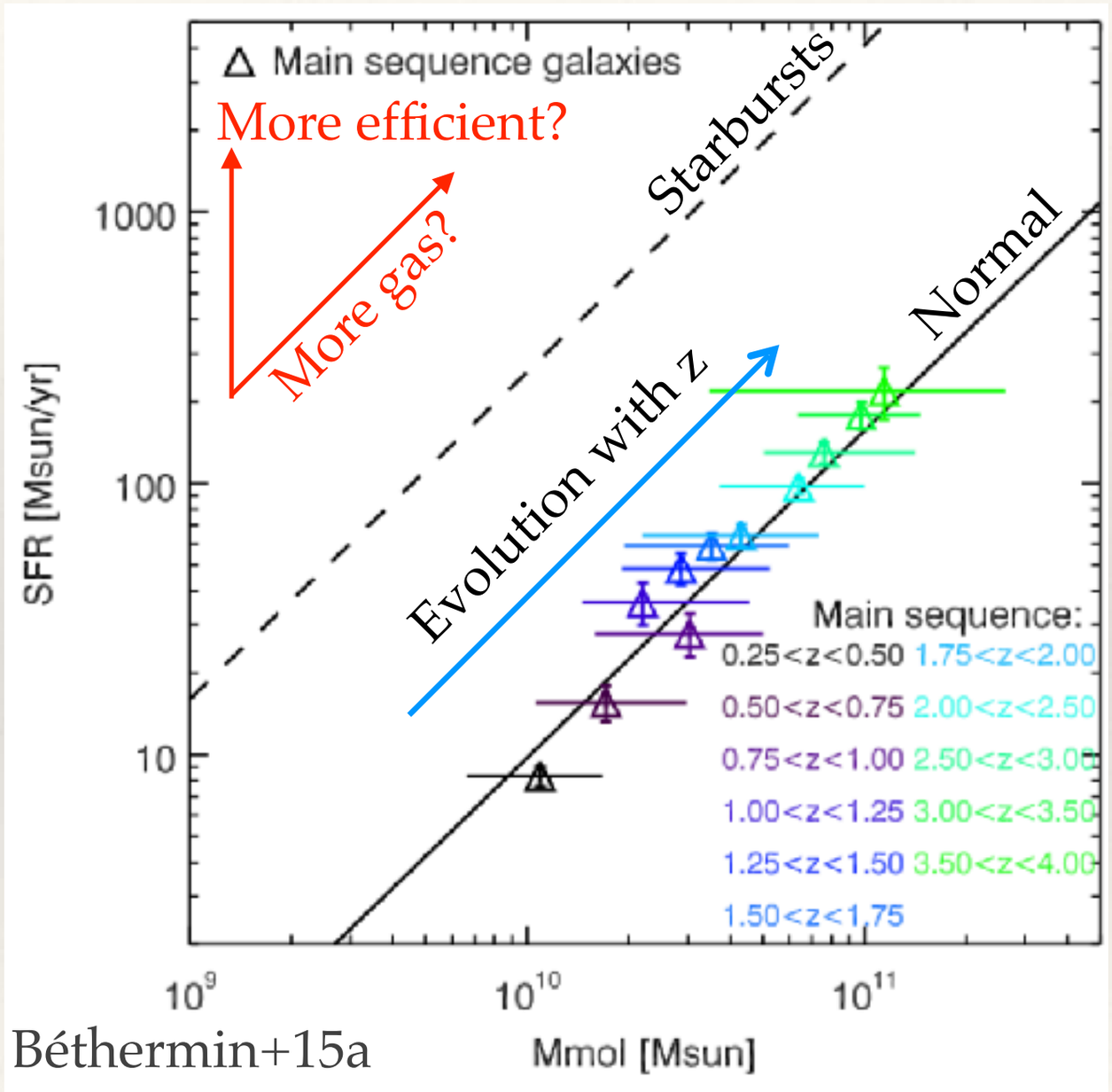
Dust attenuation versus stellar mass
(Heinis et al. 2014)

- Obscured star formation significant up to z~3
- What about higher z?

- Dust attenuation is strong in massive galaxies
- Mstar - IRX relation stable up to z~4

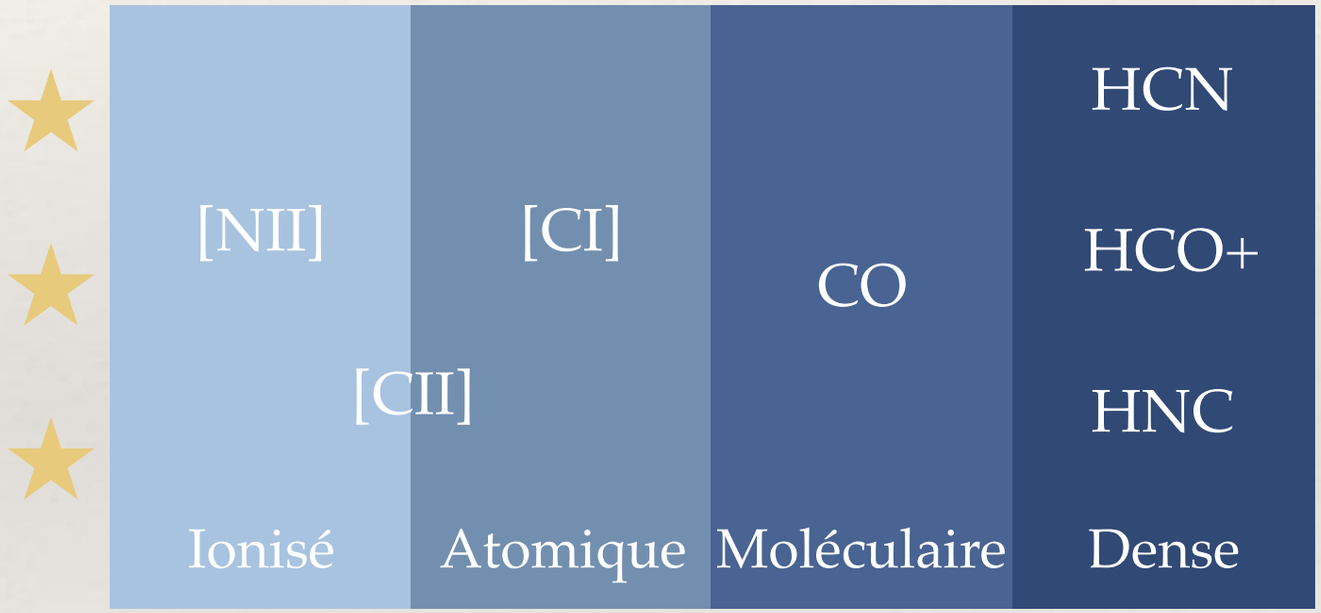
Star formation laws at high redshift

- Two distinct sequences for disks and starbursts (Daddi+10)
- What is the star formation efficiency (SFE) of very high-z massive objects?
- Is the SFE correlated with the dense gas fraction as in the local Universe (Gao+07)



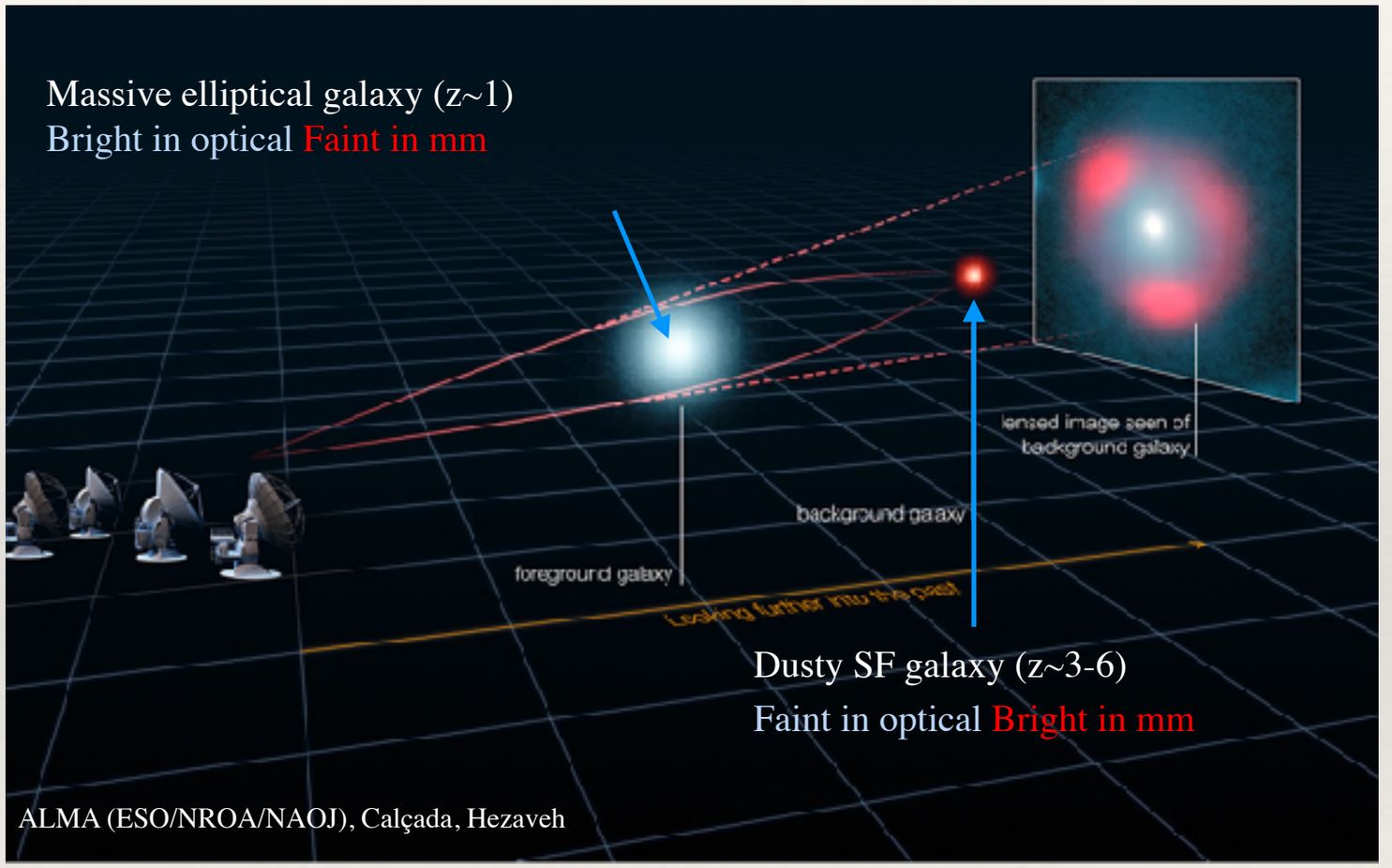
Cold ISM lines

- Far-IR and millimeter lines allow us to probe the cold ISM
- Various lines probe various phases



Detecting faint lines at high z through lensing

- [CII] and CO are very bright, but other lines might be much fainter
- Massive DSFGs are rare = unlikely to find them behind clusters
- Galaxy-galaxy lensing is our best solution
- Magnification ~10 => detection 100x faster



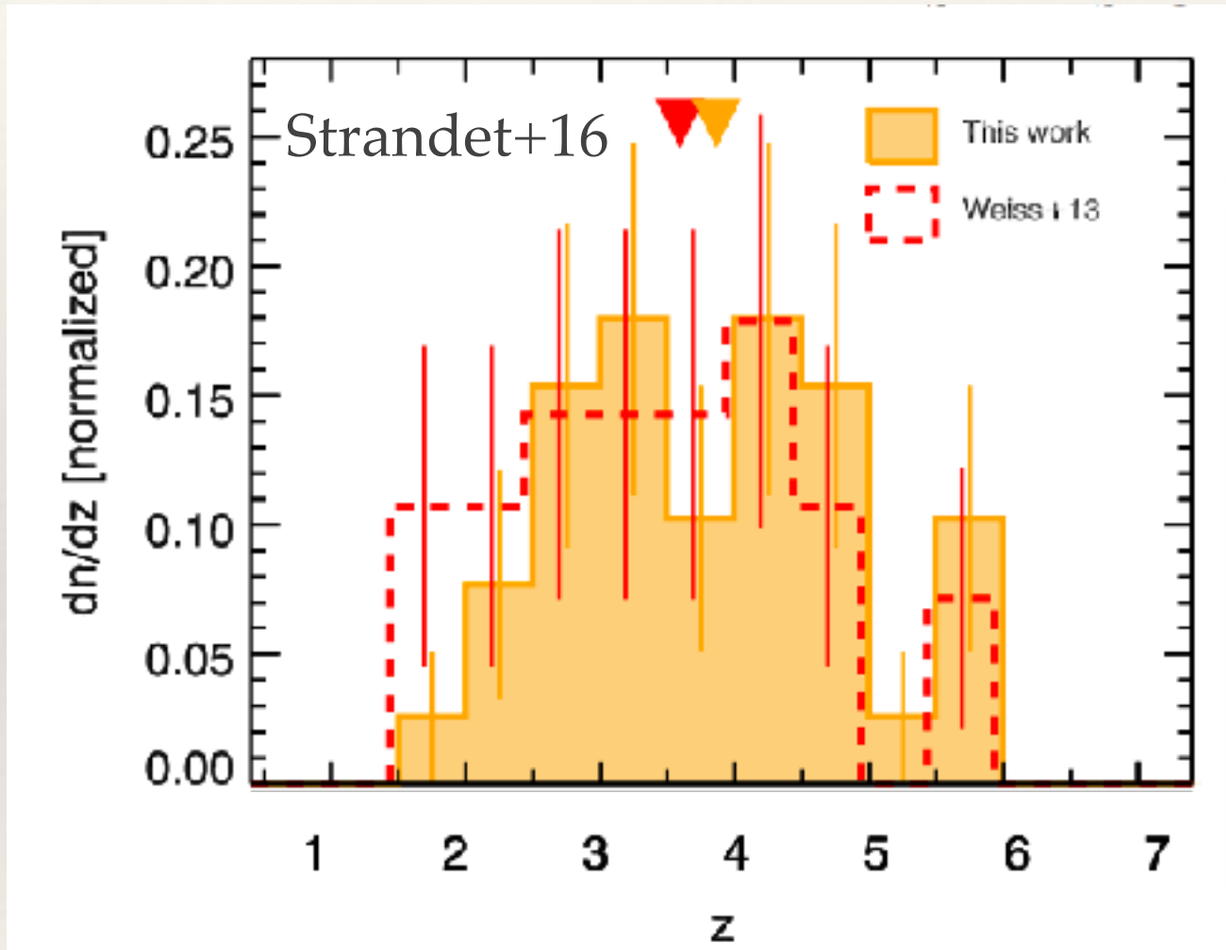
ALMA

Natural telescope (gravitational lensing)

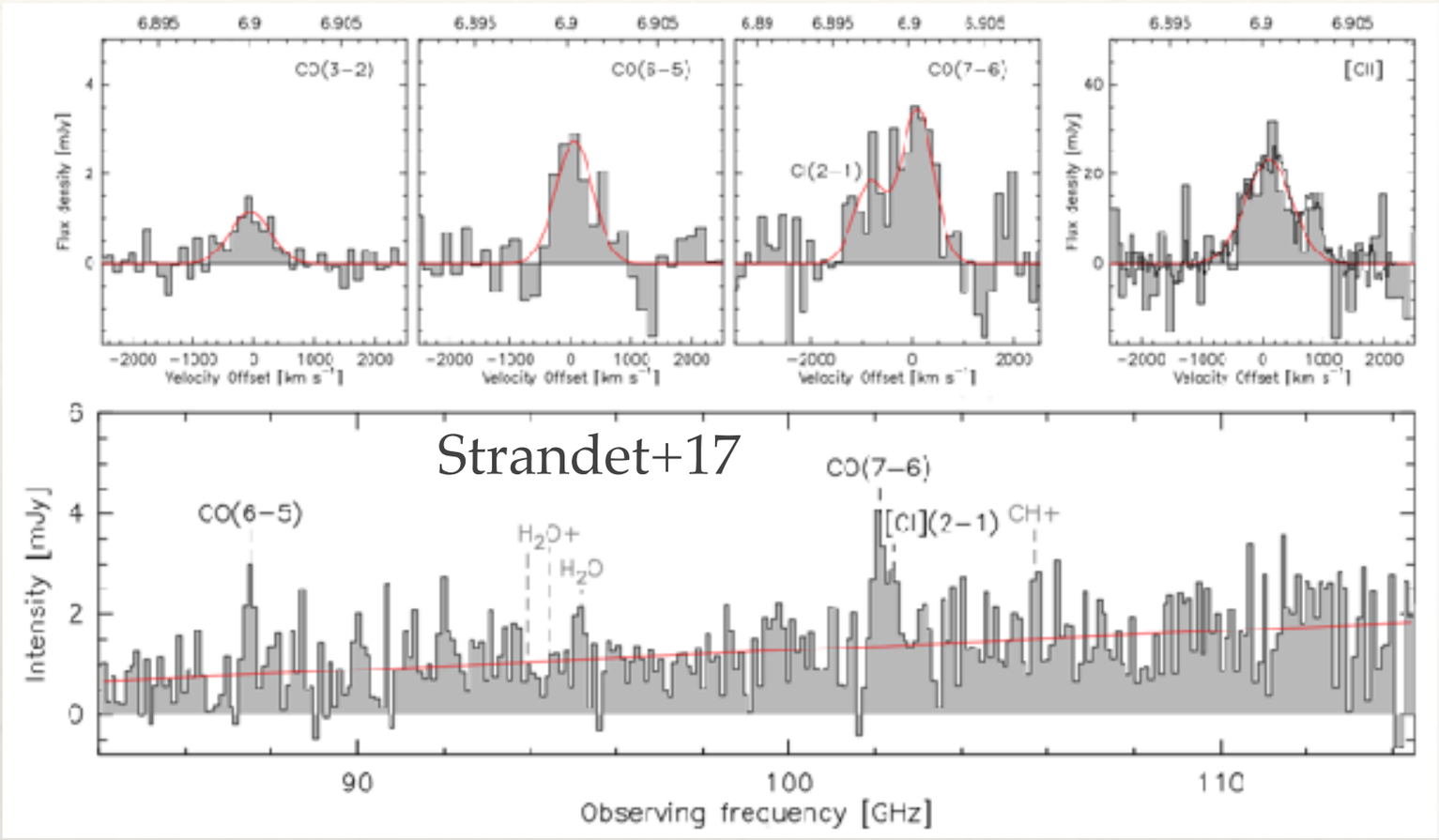
The SPT SMG sample

- Bright millimeter point sources without IRAS counterparts detected by the SPT CMB experiment (Vieira et al. 2010)

- ALMA follow-up:
  - mostly lensed objects
  - median z = 3.9



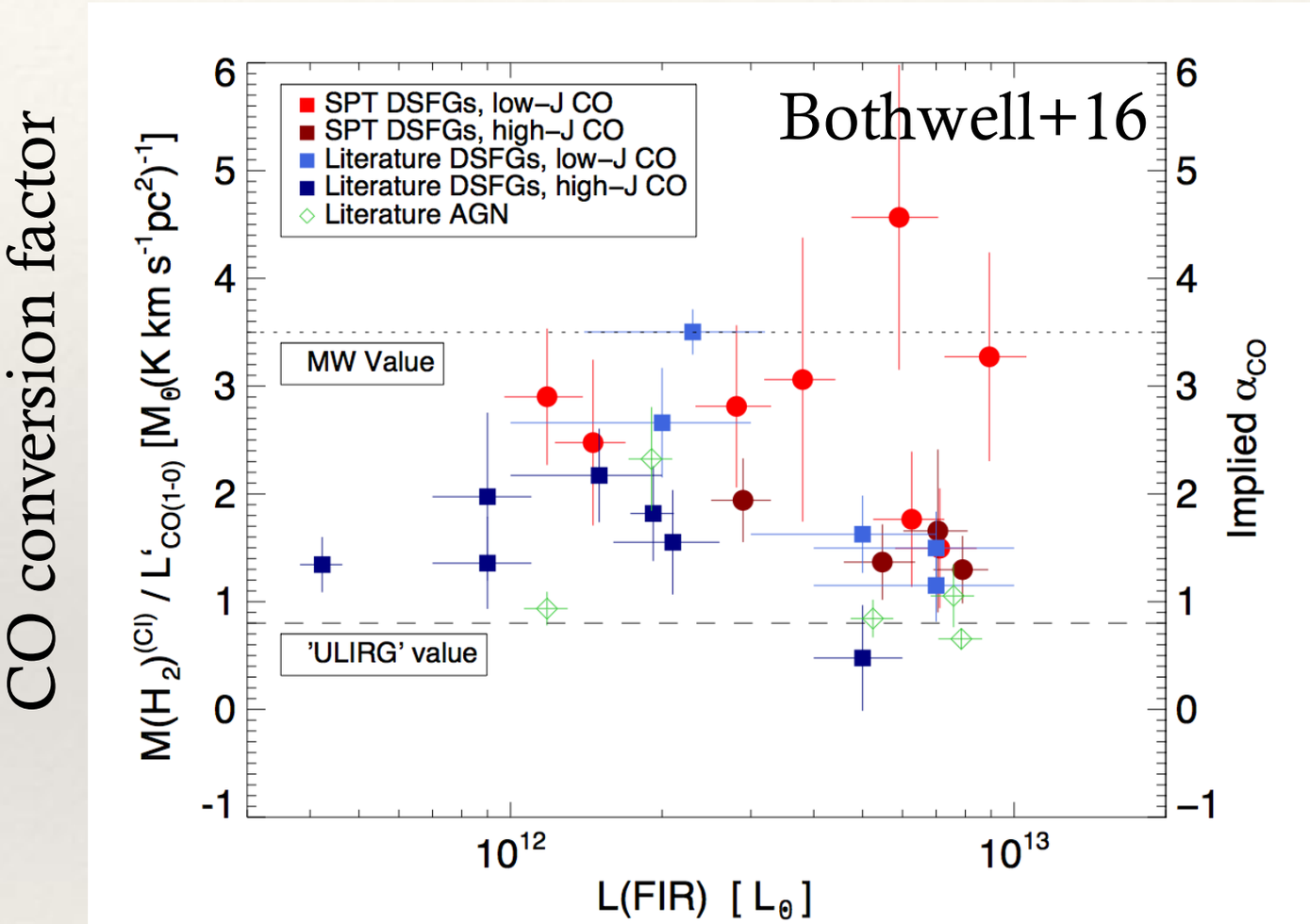
SPT0311-58: the mm redshift record



- Current record for a mm-selected galaxy:
  SPT0311-58, z = 6.9,
  SFR = 4100 Msun/yr
  M_{gas} (LVG modeling) = 3.3 x 10^{11} Msun

Comparison of gas content estimator

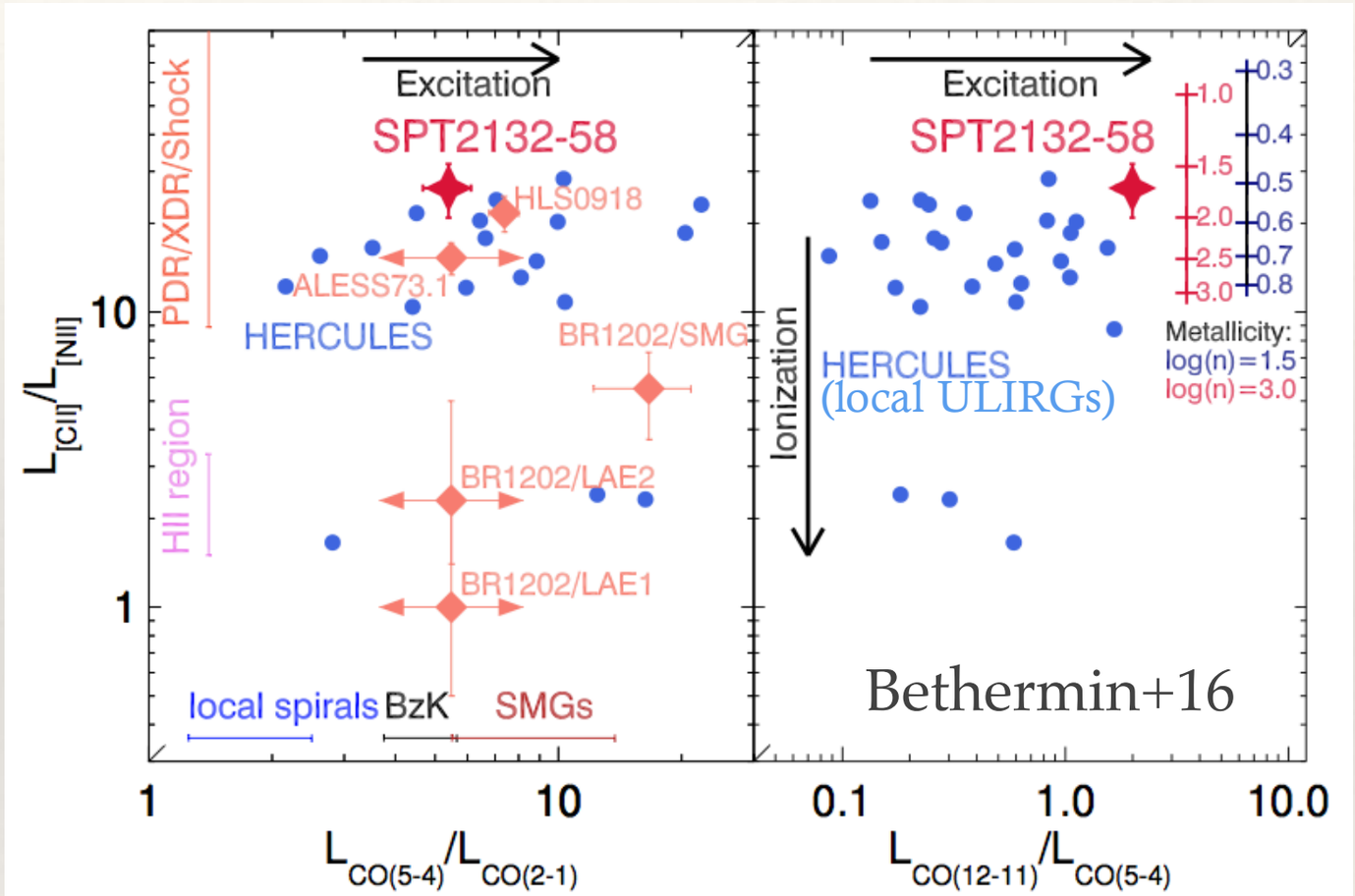
- CO optically thick, [CI] optically thin
  => [CI] less affected by merger effects than CO (Papadopoulos+04)
- Large scatter on the CO conversion factor (Bothwell+16)
- SPT sources, not analogues of local starbursts (line ratios, PDR modeling) (Bothwell+16)



More objects with ALMA and APEX under analysis (Béthermin+ im prep.)

HII versus PDR: [CII]/[NII] ratios

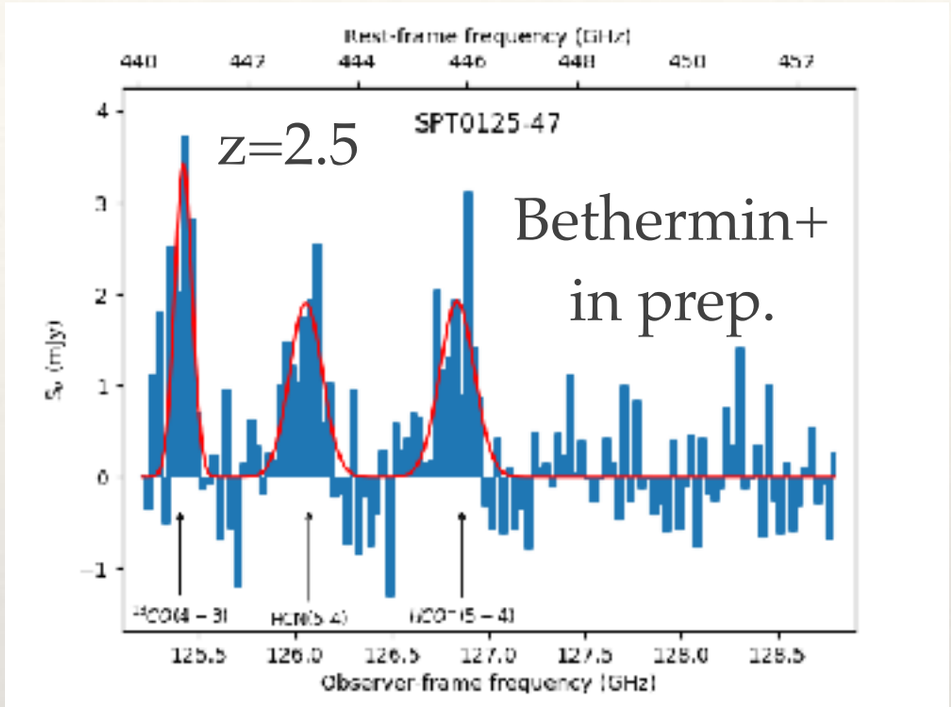
- [NII] in the SPT2132-58 starburst at z=4.7 (pilot obs., full sample being analyzed)
- High [CII]/[NII] => PDR dominated (Decarli+14)
- [CII]/[NII]: rough metallicity diagnostic (Nagao+12)
  => 0.5<Z/Zsun<2
- [CI]: "small" gas reservoir of $3x10^{10}$ Msun
  => $t_{depletion}$= 34 Myr

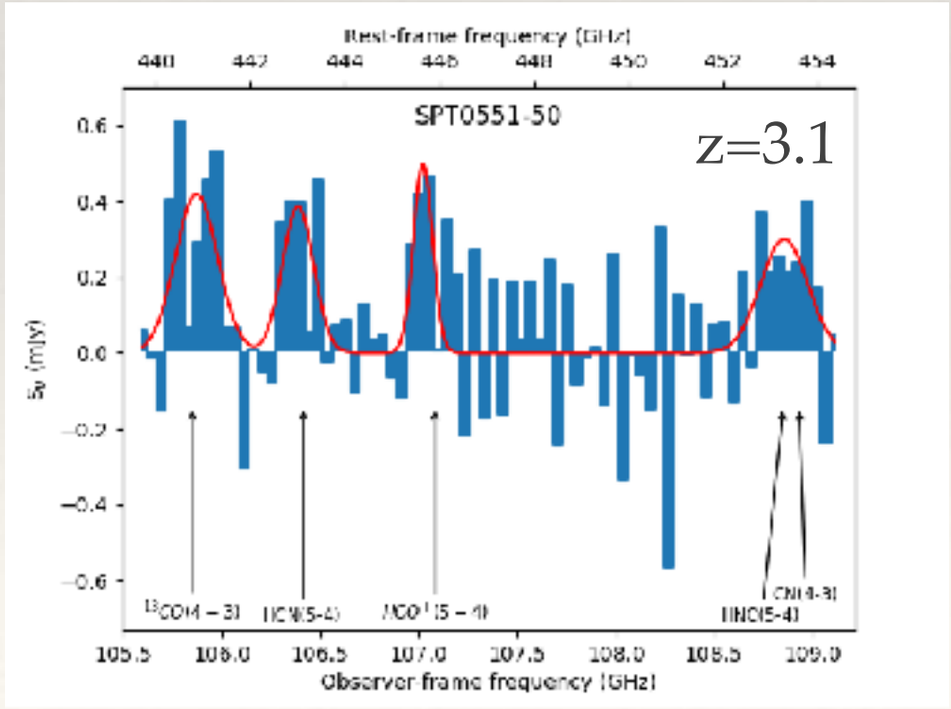


Stay tuned: sample in prep.

A hunt for dense gas tracers at z>2.5

- Pilot study: 5 SPT sources at 2.5<z<4
- Detection of 3 dense gas tracers: HCN(5-4), HCO^+(5-4), and HNC(5-4)
- HCN / HCO^+ ~1 => no evidence for AGN activity
- HNC / HCN ~1 => mid-IR pumping?
- ^{13}CO detected => past star formation in these objects

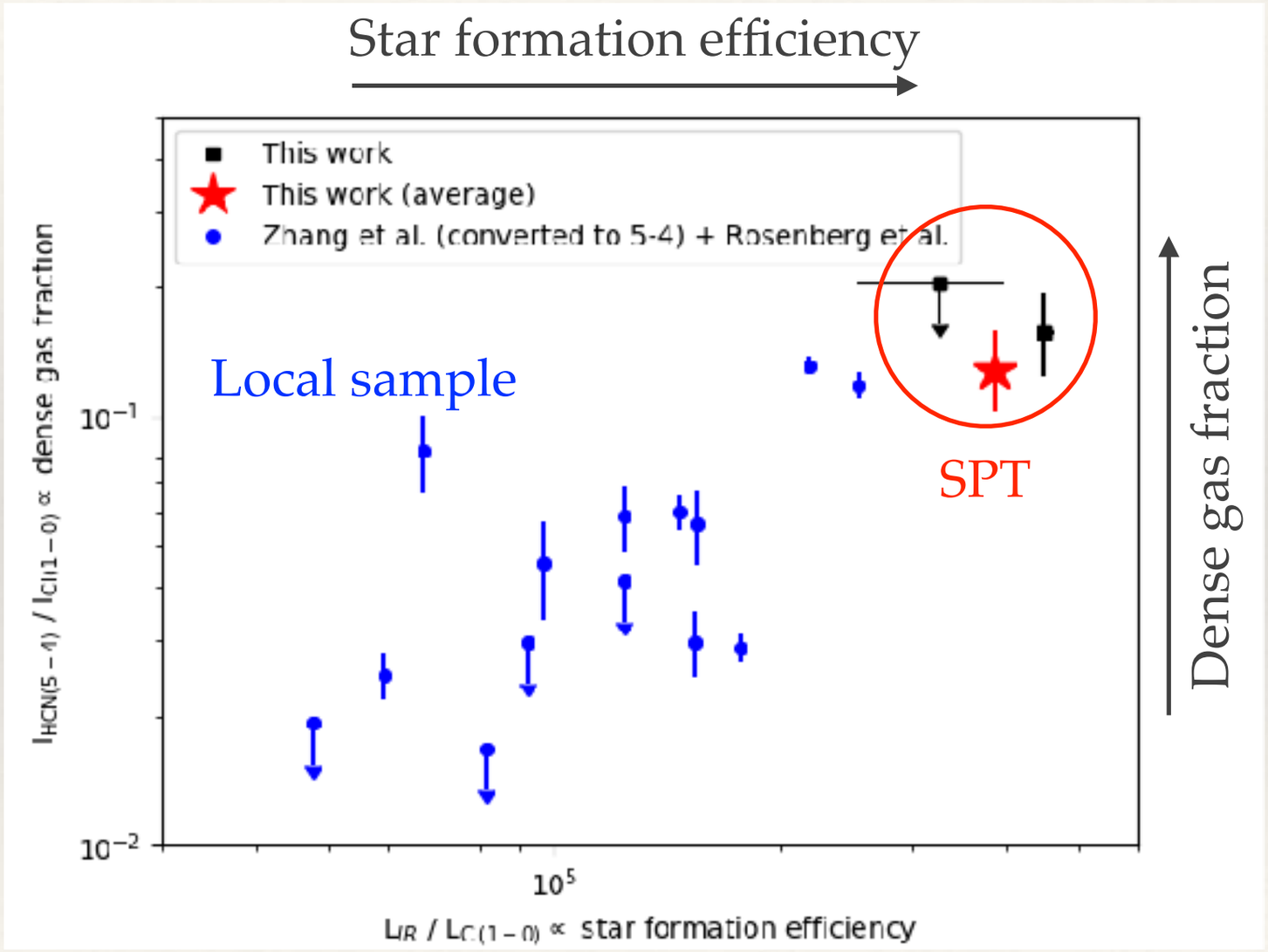




Star formation efficiency vs dense gas fraction

- HCN / [CI] (y-axis)
  ~ dense / atomic gas
  ~ dense gas fraction
- LIR / [CI] (x-axis)
  ~ SFR / gas content
  ~ star formation efficiency
- SPT objects: high dense gas fraction and high SFE
- On the scaling relation of local objects

PRELIMINARY



Bethermin+ in prep.

Conclusion and perspectives

- ALMA is a fantastic machine to probe the high-z cold ISM => much more mature than we could have expected
- Possible to perform statistical studies on lensed samples for many lines
- Many results from SPT coming soon from (stay tuned)!

Acknowledgement to PNCG for funding other projects

- **NIKA2 (Lagache)**: first data are coming and the analysis is starting, the camera works great!
- **CONCERTO (Lagache)**: prototype of Martin-Pupplet interferometer built in Grenoble, simulations developed to clean the CO foregrounds