

Bright Extragalactic ALMA Redshift Survey (BEARS) 🐻 : Emission line properties of the bright *Herschel-* selected galaxies in South Galactic Pole

BEARS paper:
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Hagimoto+ in prep.

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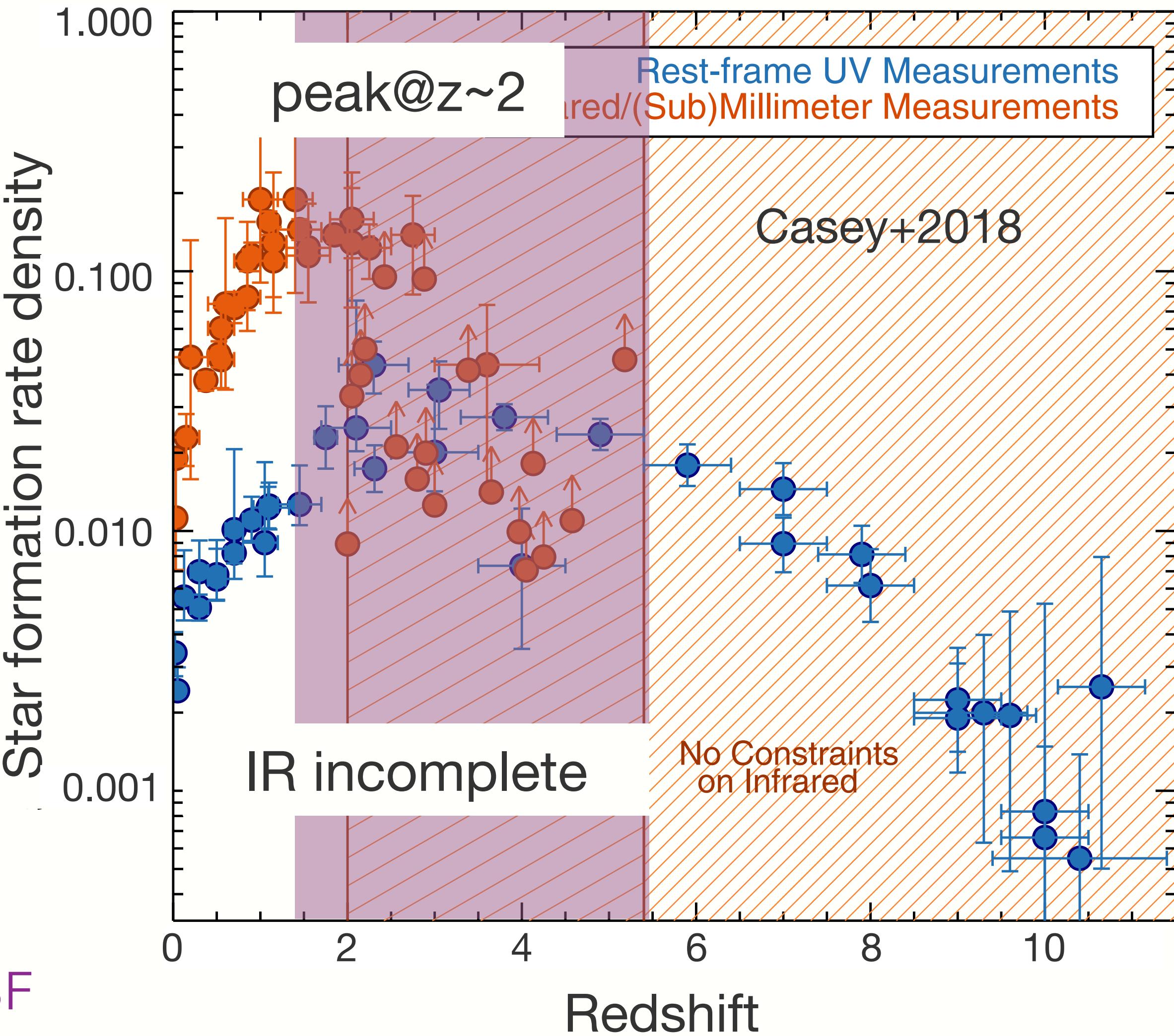
Outline

- ▶ Introduction
 - ▶ Motivations for studying $z \sim 2-4$ & SMGs in sub-mm
 - ▶ CO observations & CO SLEDs
 - ▶ Sample selection
- ▶ Results
 - ▶ Spectra and CO SLEDs for each sources
- ▶ Discussion
 - ▶ Some relationship between 2 line/continuum emissions, comparing with previous works
- ▶ Future works & Summary

Motivations of studying z~1-4 and SMGs in sub-mm

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- ▶ The era of $z \sim 1-4$
 - ▶ Most vigorous star formation activity
 - ▶ Key to understanding the galaxy formation & evolution
- ▶ Lacking in FIR (sub-mm) CSFH understanding
- ▶ Sub-millimeter galaxies (SMGs)
 - ▶ Dominant galaxy population in $z \sim 2-4$
 - ▶ (Apparent) $L_{\text{IR}} \geq 10^{12} L_{\odot}$, $\text{SFR} \sim 10^2 - 10^4 M_{\odot} \text{ yr}^{-1}$
- ▶ Playing critical role in the history of cosmic SF

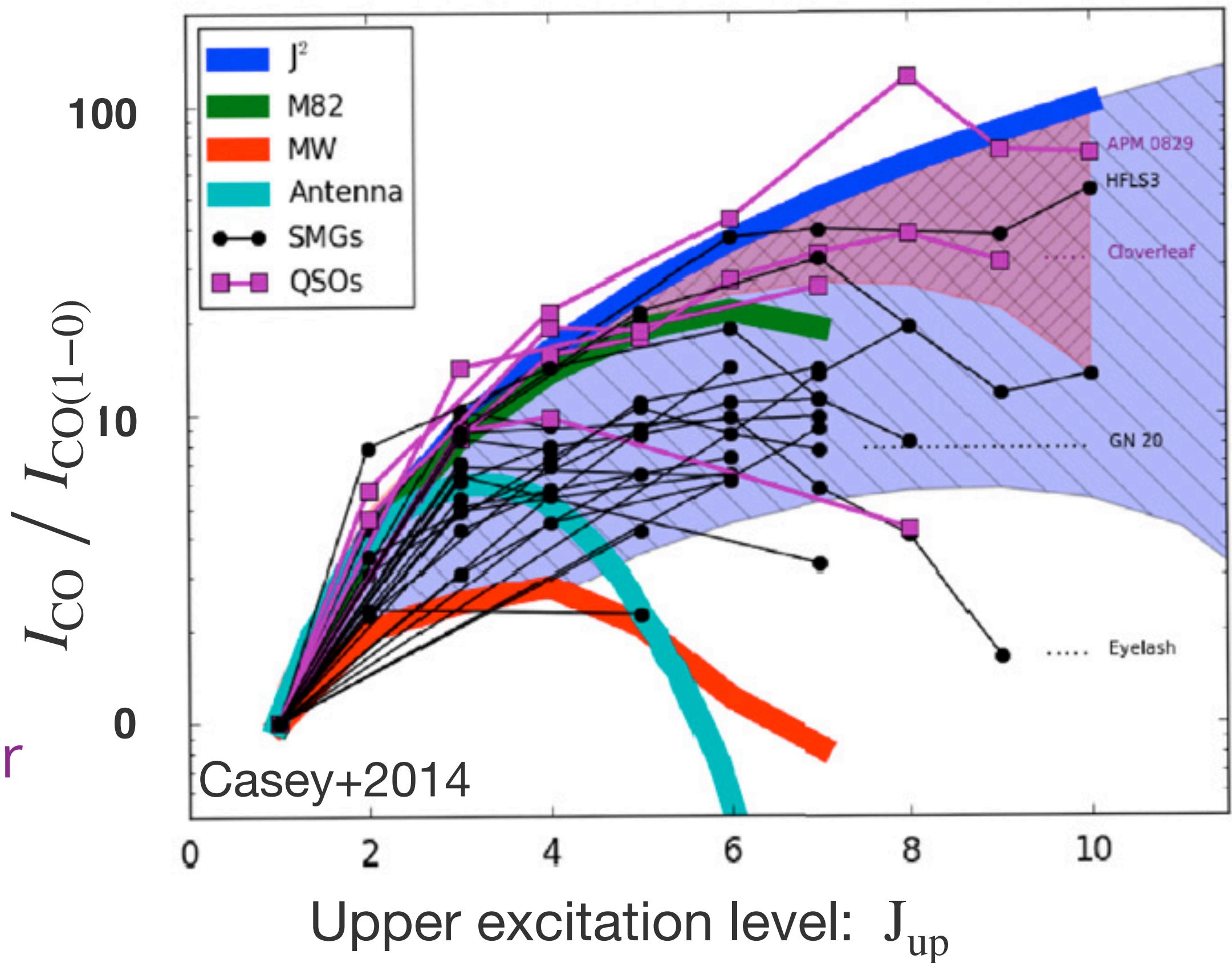


CO Observation & CO SLED

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- ▶ CO: second most abundant molecule
- ▶ Radiate from cold gas & bright
 - ▶ Gas mass indicator
 - ▶ Redshift indicator
- ▶ CO excitation conditions
- ▶ dependent on the molecular gas temperature & density
=> CO SLED is useful diagnostic tool for physical gas properties in galaxies
- ▶ J_{up}^2 : theoretical maximum emission

CO Spectral line energy distribution: CO SLED

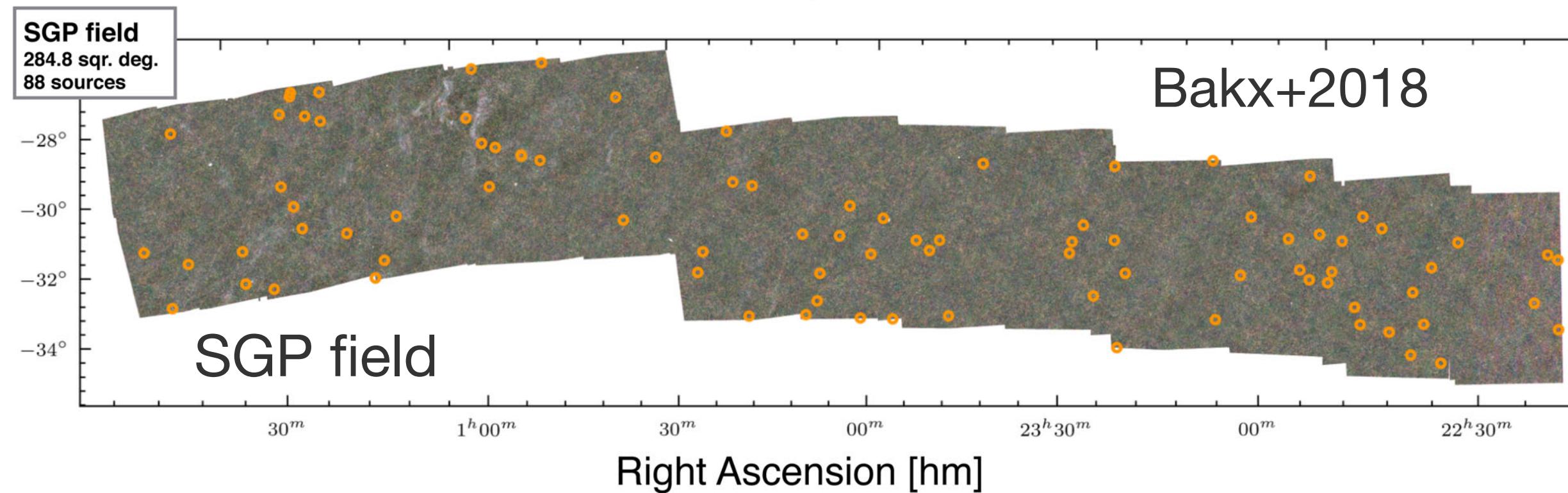


The goal of this project and my work

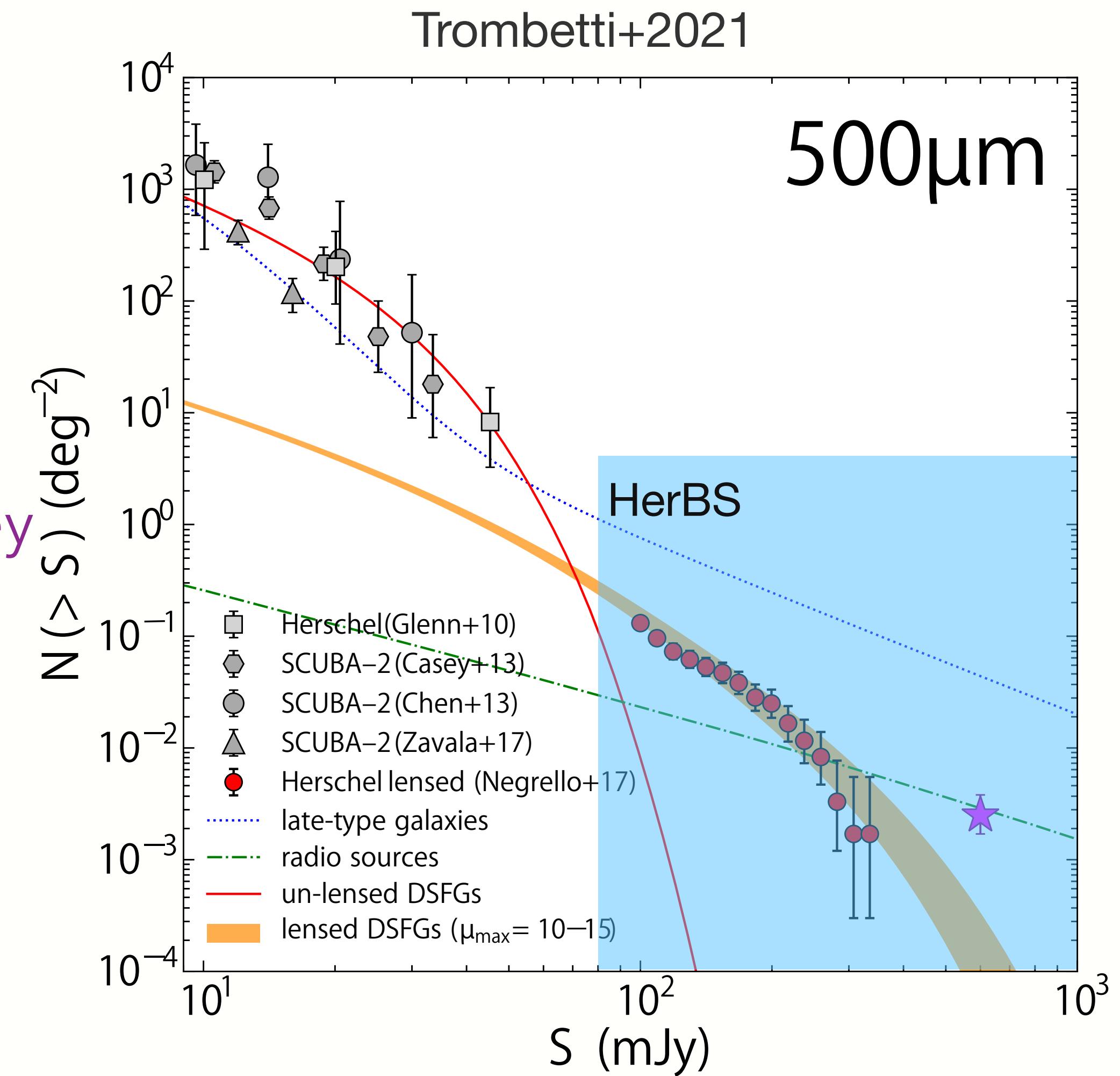
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- ▶ Open questions
 - ▶ What is the nature of obscured star formation in $z=2-4$?
 - ▶ What are the typical ISM conditions (e.g., temperature & density) in SMGs?
 - ▶ What is the characters of bright sources?
- ▶ Goal: Understanding the SMGs from BEARS through emission lines
 - ▶ Physical conditions of each SMG estimated by its CO SLED
 - ▶ Comparing line and luminosity ratios of different galaxy populations

Sample selection

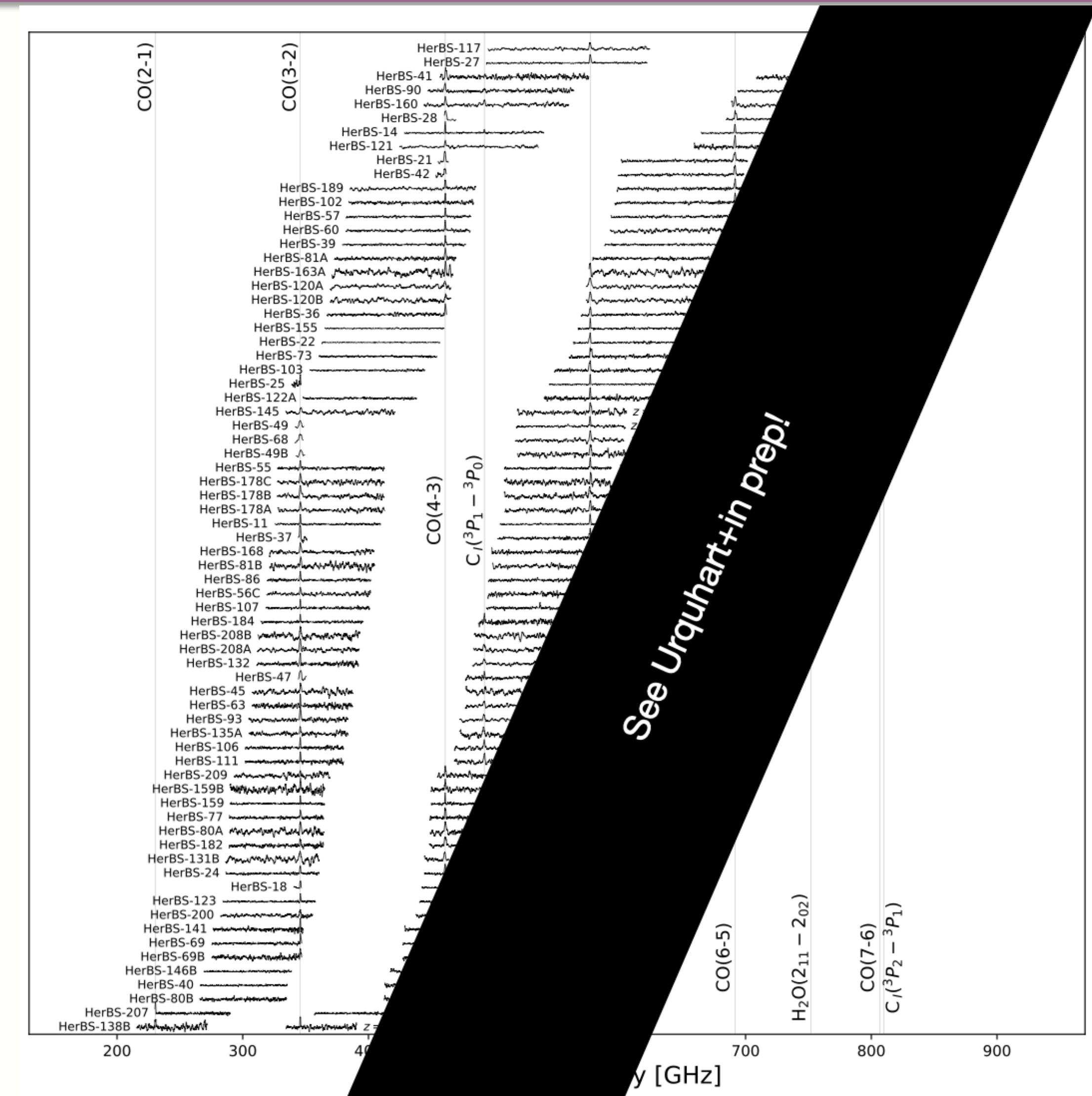


- ▶ Selected from the *Herschel* Bright Sources (HerBS) sample in the 616.4 deg^2 H-ATLAS survey
 - ▶ $S_{500 \mu\text{m}} \geq 80 \text{ mJy}$, $z_{\text{phot}} \geq 2$
 - predominantly strongly gravitationally lensed, but possibly include HyLIRGs
- ▶ Our sample: 85 in South Galactic Pole
- ▶ Unidentified z_{spec}



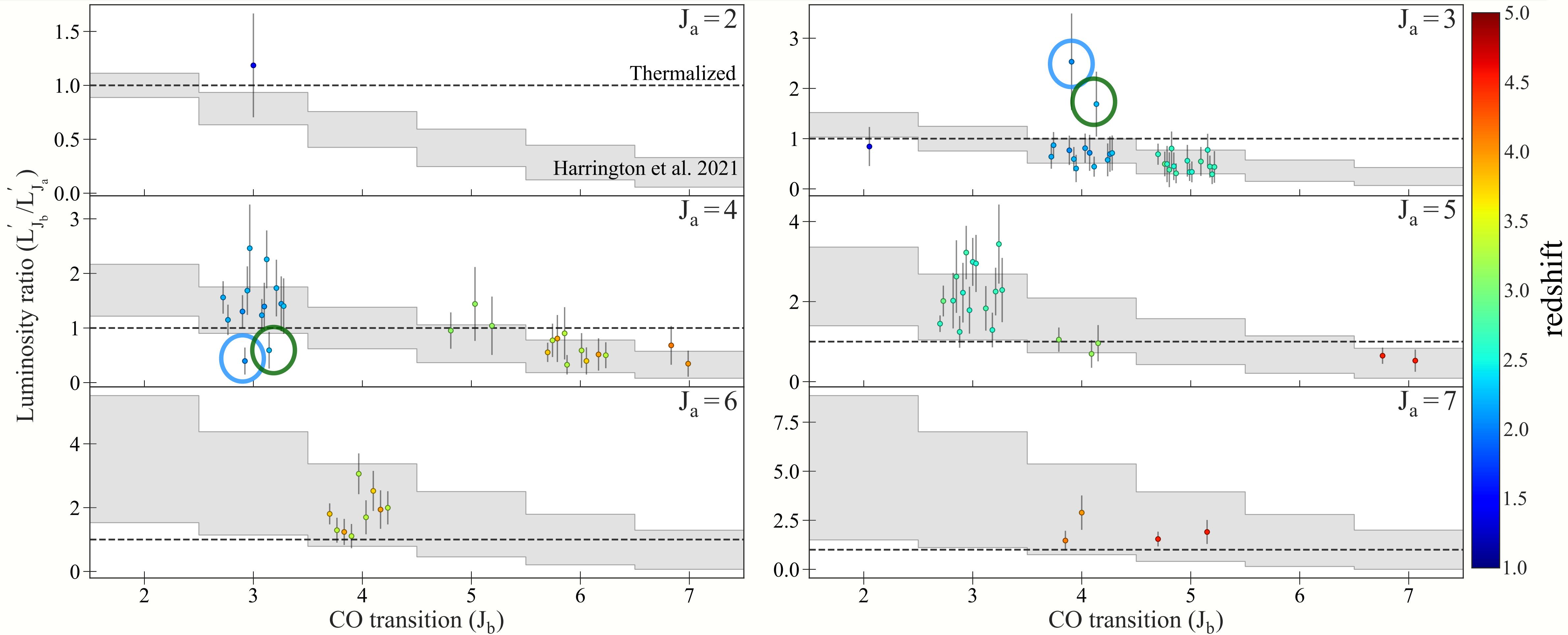
All spectra of our targets with zspec

- ▶ We detected 71 galaxies
(62 / 85 *Herschel* sources)
- ▶ 8 sources consists of 2 or 3 components
- ▶ Various lines
 - ▶ From CO (2 – 1) to CO (7 – 6)
 - ▶ [CI](${}^3P_1 - {}^3P_0$), [CI](${}^3P_2 - {}^3P_1$)
 - ▶ H₂O ($2_{11} - 2_{02}$)
- ▶ Wide redshift range
 - ▶ From z=1.4 to 4.5



CO SLED (divided by each transition)

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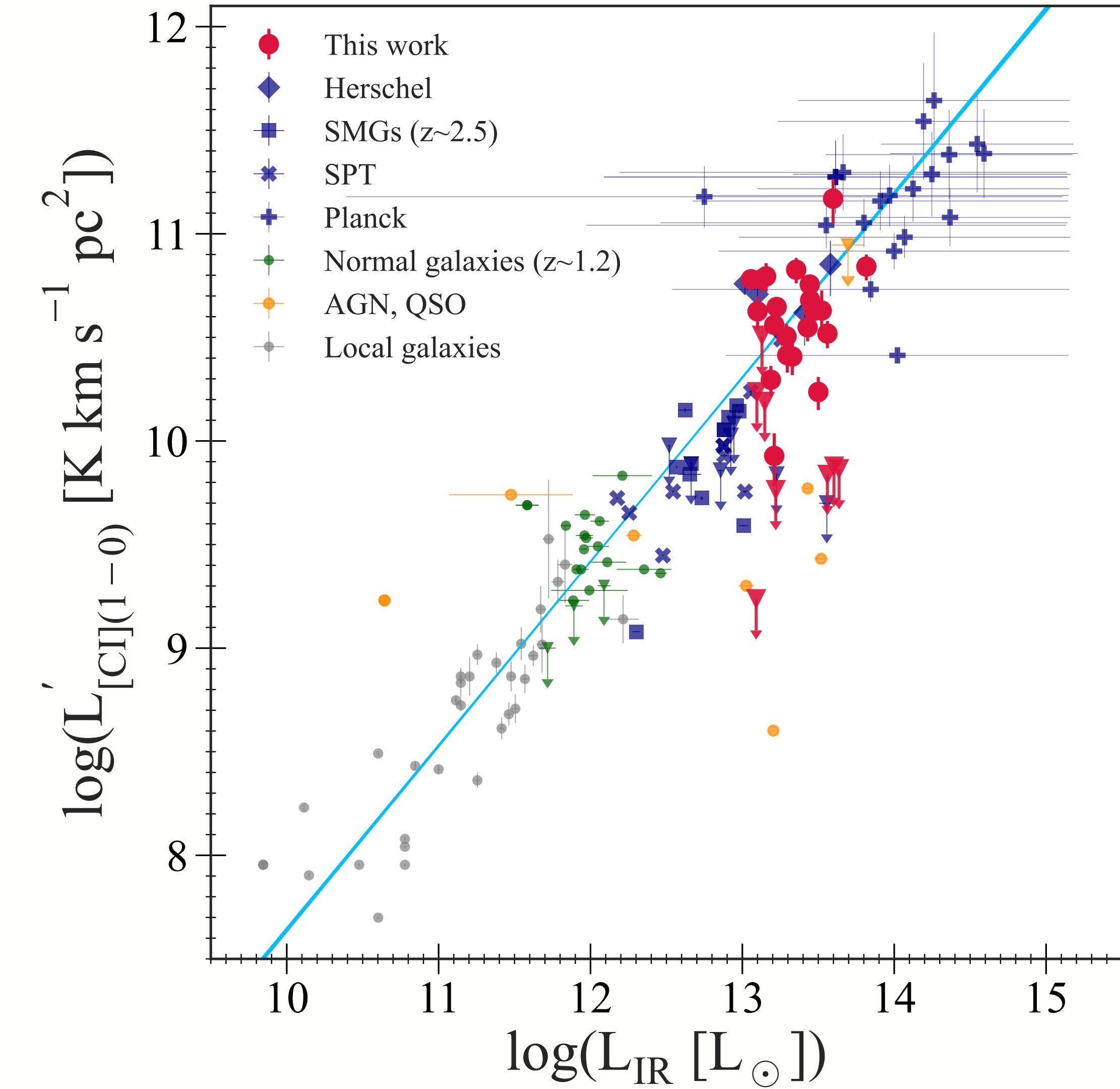


- ▶ Almost all targets follow the typical CO SLED suggested by Harrington+2021
- ▶ 2 strange sources: showing "super thermalized" spectral ratios

Relationship between CI and IR luminosity

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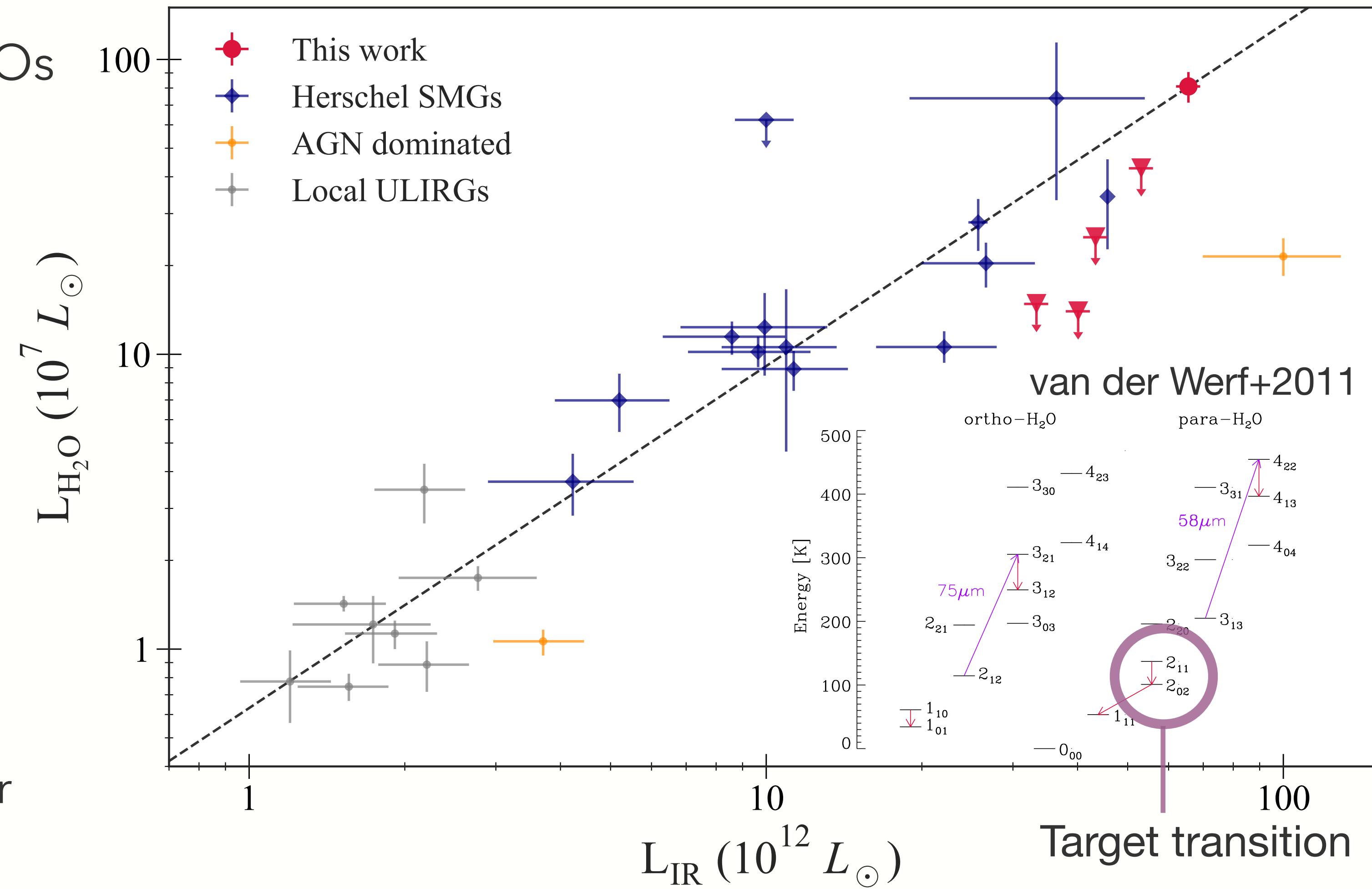
- ▶ IR vs. [CI] (1-0) luminosity relation for local galaxies to high-z SMGs
- ▶ We can see sub-linear (~ 0.88) relation in logarithmic space between 5 order of magnitude in IR luminosity
- ▶ $L_{\text{IR}} \rightarrow \text{SFR}$, $L'_{\text{CI}(1-0)} \rightarrow M_{\text{gas}}$
- ▶ sub-linear relation
=> "proxy of" Kennicutt-Schmidt relation



Relationship between H₂O and IR luminosity

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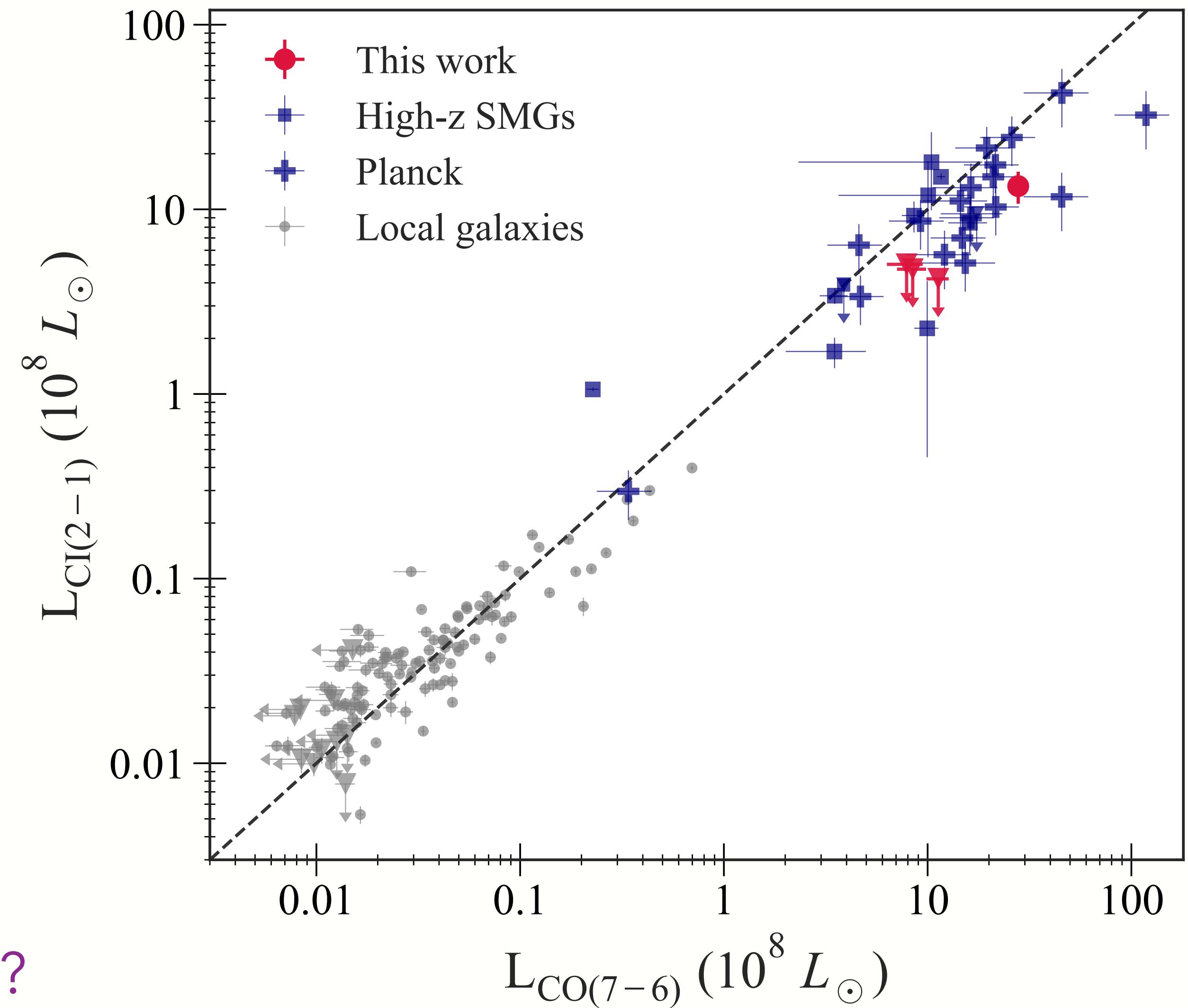
- ▶ H₂O vs. IR luminosity relation for local ULIRGs to high-z SMGs, QSOs
- ▶ ULIRGs and SMGs following super-linear ($L_{H_2O} \propto L_{IR}^{1.16}$; Yang+2016)
 - ▶ QSOs are systematically fainter than this relation
- ▶ Our target:
 - ▶ One: star formation dominated
 - ▶ Upperlimits: possibly an AGN components, but we need deeper observations



Relationship between CI(2-1) and CO(7-6)

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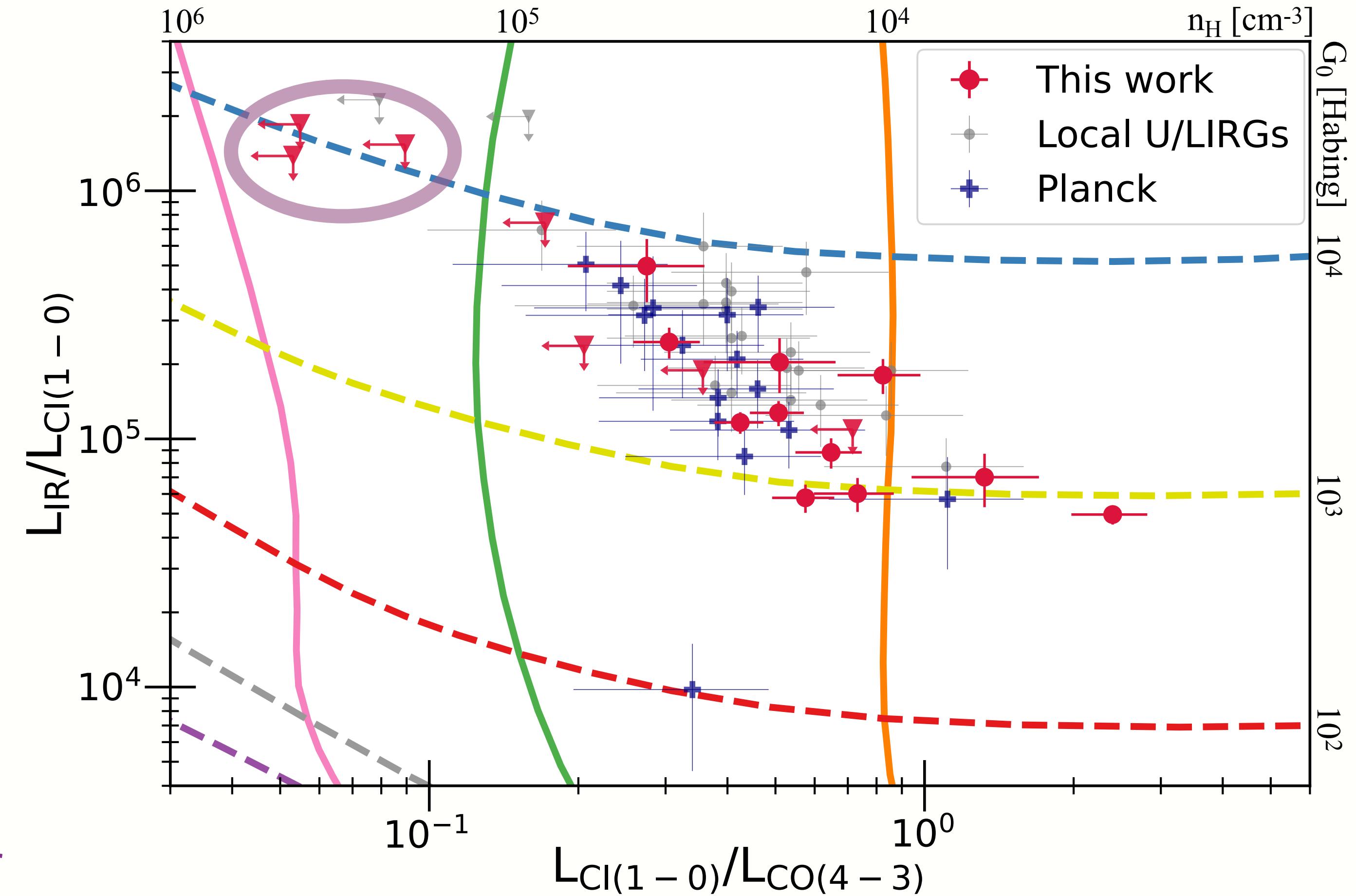
- ▶ [CI] (2-1) vs. CO (7-6) luminosity relation for local galaxies to high-z SMGs
- ▶ We can see a positive correlation between these 2 line luminosities
 - ▶ CO (7-6): dense, highly excited
 - ▶ [CI] (2-1): relatively diffuse, low extinction
- ▶ [CI] (2-1)/CO (7-6) ratio shows relative amounts of different gas phase or differential lensing affects?



CI(1-0)/CO(4-3) comparison with U/LIRGs

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- ▶ IR/[CI] (1-0) and [CI] (1-0)/CO (4-3) luminosity ratio
 - indicator of the far-UV intensity and gas density in PDR
- ▶ most of our targets
 - $10^3 \leq G_0 \leq 10^4$, $10^4 \leq n_{\text{H}} \leq 10^5$
- ▶ Some sources: [CI] (1-0) is faint
 - higher gas density?
- ▶ SMGs and local U/LIRGs appear similar



Future works & Summary

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▶ Future works

- ▶ We need to consider the causes of “super thermalized” galaxies
 - ▶ Differential lensing? Galaxy interactions? Calibration errors?
- ▶ We need deeper observations towards noisy sources

▶ Summary

- ▶ We observed 85 sources selected from HerBS samples in SGP by ALMA
- ▶ We successfully identified the redshift of 71 galaxies (62 / 85 sources ~ 73%)
 - ▶ Includes multiple components in one region defined by *Herschel*
 - ▶ Almost sources are similar to typical CO SLEDs suggested by Harrington+2021
- ▶ We confirm some relations between emission lines and dust continuum suggested in previous works
- ▶ We are preparing 3 BEARS papers: Urquhart+, Bendo+, Hagimoto+

