Cologne-Bonn Symposium

Vz-GAL Dusty Star-Forming Galaxies: Revisiting the CO–H2 Conversion Factor Tension

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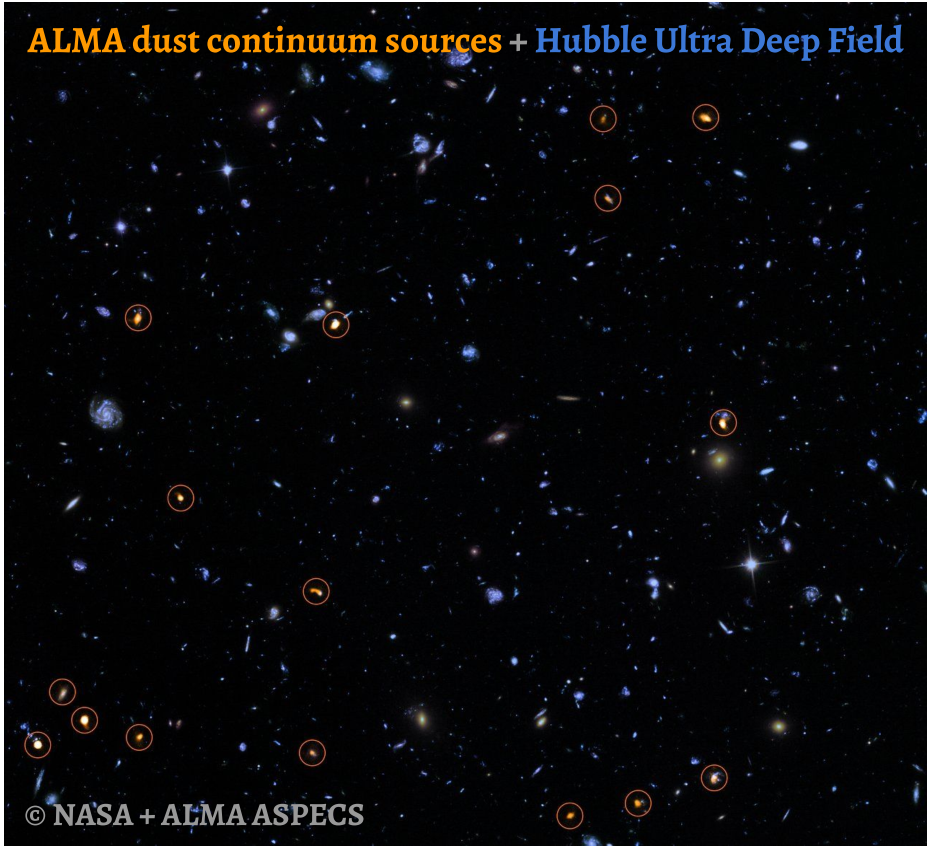
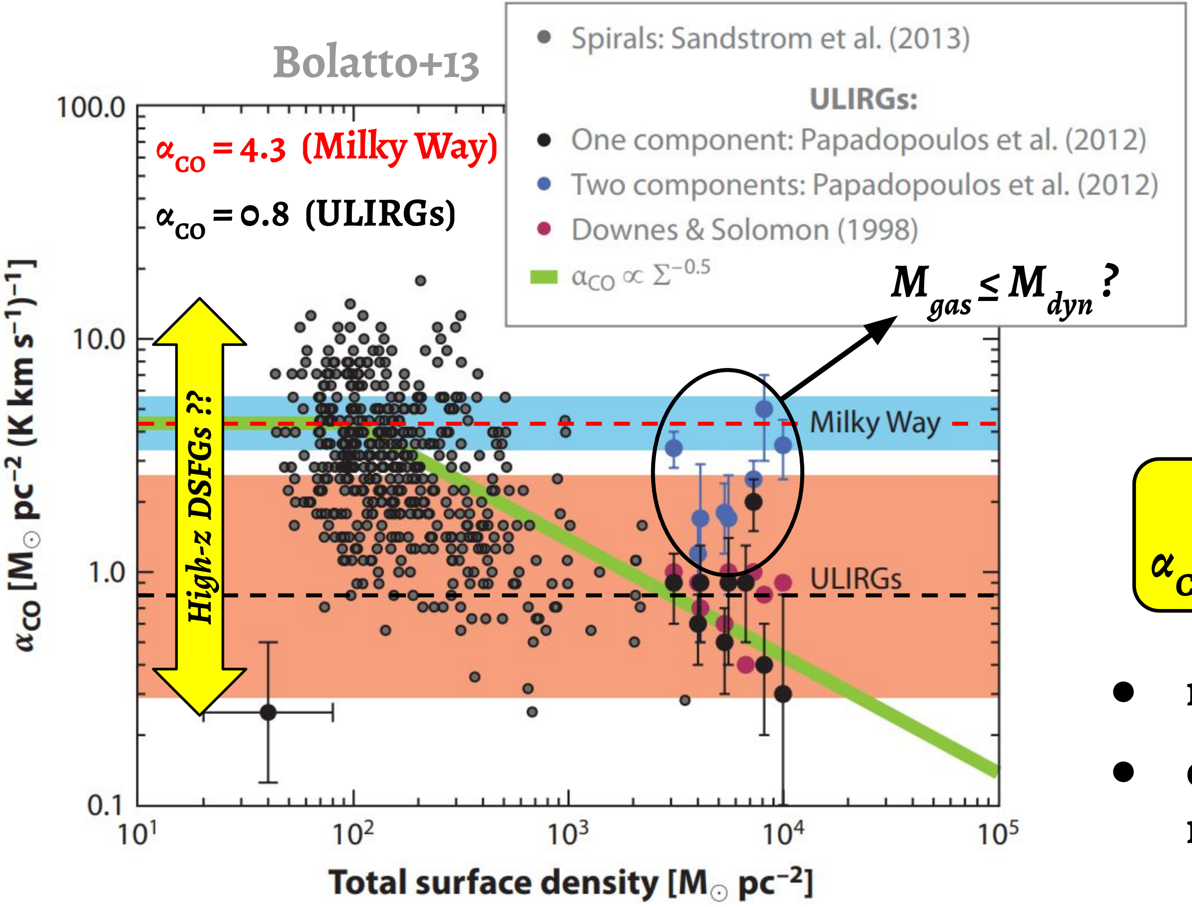
Dusty Star-Forming Galaxies (DSFGs) in the early universe



- $L_{IR} > 10^{12}$–10^{13} $L_{\odot}$, SFR > 100–1000 $M_{\odot}$ yr^{-1}
- dominate obscured star formation across cosmic time
- massive molecular gas reservoirs
- (mostly) unresolved CO measurements available to date

CO luminosity–to–H2 gas mass conversion factor



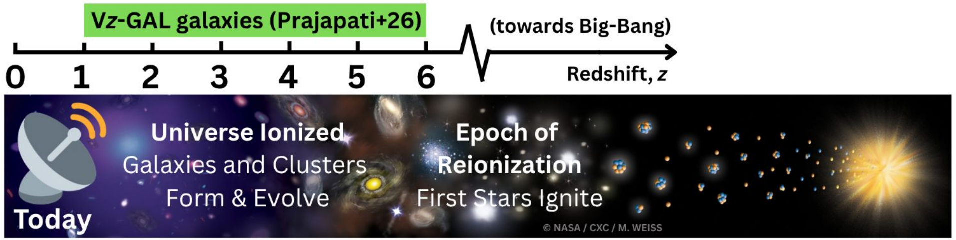
" How much molecular gas mass does the observed CO actually represent? "

$$M_{H_2}\,[M_\odot] = \alpha_{CO} \times L'_{CO(1-0)}\,[\mathrm{K\,km\,s^{-1}\,pc^2}]$$

What could be the "best" α_{CO} value for high-z galaxies ??

- most DSFGs lack CO(1–0) data
- observed using mostly mid-/high-J CO lines

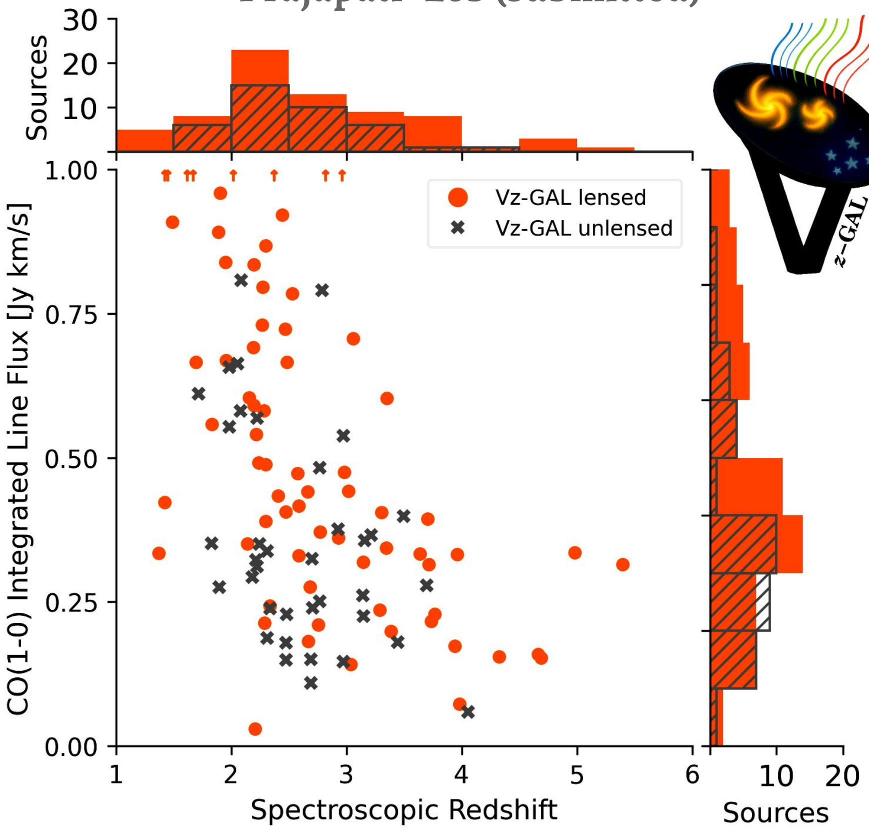
This study: Vz-GAL unlensed DSFGs and α_{CO}



website: vzgal.uni-koeln.de

- VLA Vz-GAL large survey: galaxy-integrated CO(1–0)
- ALMA dust continuum sizes, resolved at 0.1" (PI: T. Bakx)
- 12/106 DSFGs spanning $z = 1$–4, with well-sampled dust and CO line SEDs

Prajapati+26b (submitted)



Testing the "α_{CO} tension" for DSFGs

$$M_{gas} = \alpha_{CO}\, L'_{CO(1-0)} \leq M_{dyn}$$

(available)

for details, see
Prajapati+26b (submitted)
arXiv:2607.18440

molecular gas masses
with assumed G/D ratio = 100
(e.g., Dunne+22)

1. dust SED modeling
   (GMBB approach w/ dust sizes)
2. dust + CO line SED modeling
   (TUNER LVG approach)

dynamical masses with global CO(1–0)

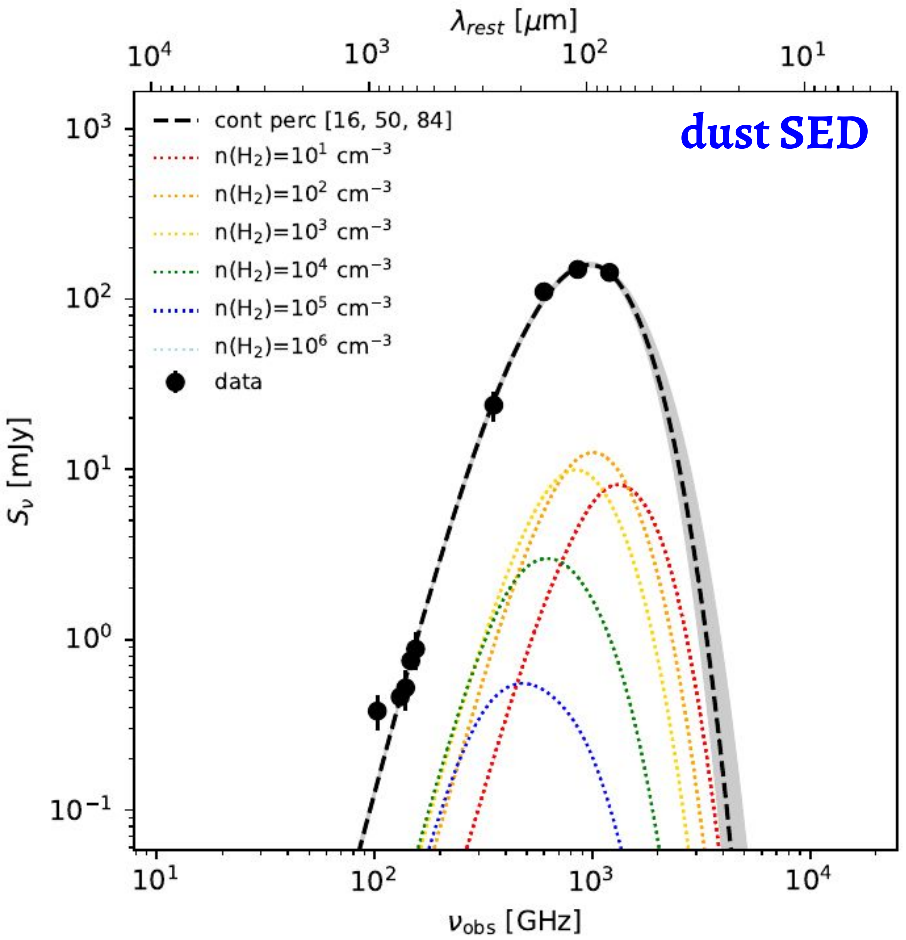
1. isotropic virial estimator
2. rotating, thick disk estimator

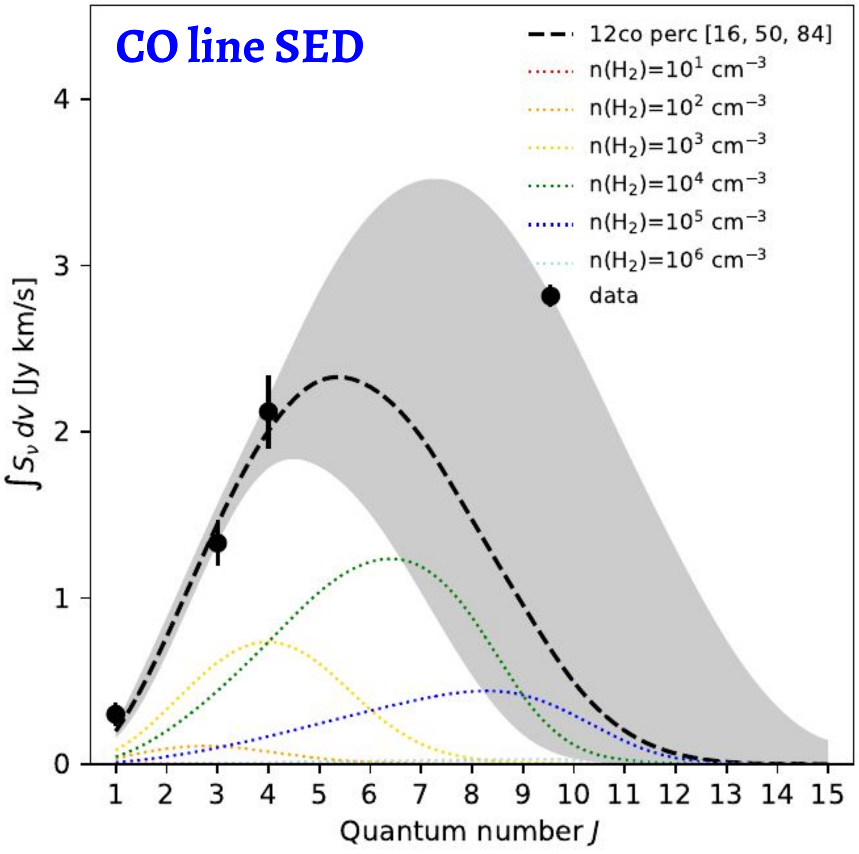
Data: Neri+20, Berta+23, Cox+23, Ismail+23, Stanley+23, Prajapati+26

Modeling: [2]Jarugula+21, [2]Harrington+21, [1]Ismail+23, [2]Boogaard+26a

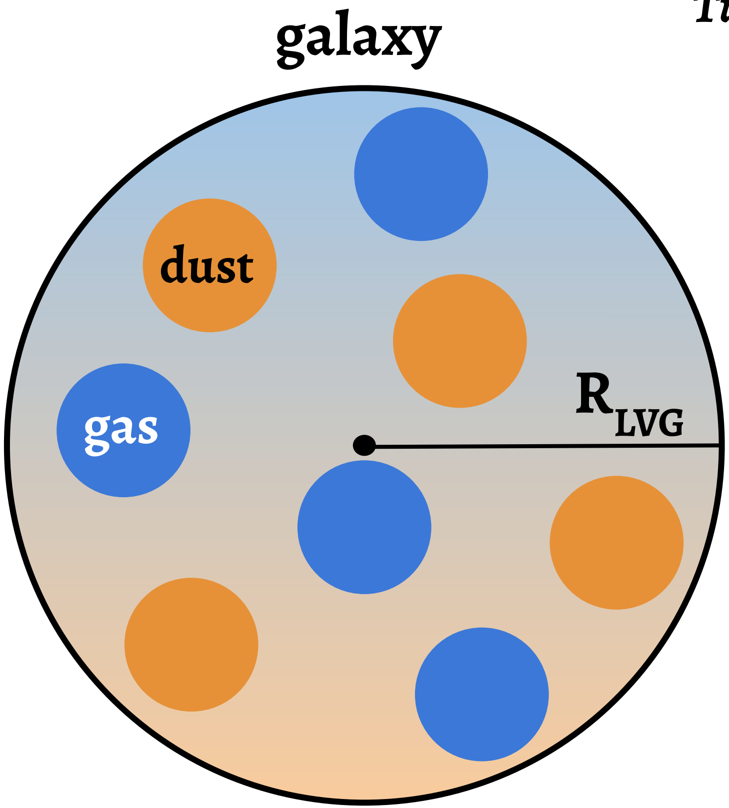
TUNER LVG radiative transfer modeling approach

galaxy HerBS–51 ($z = 2.183$)





TUNER LVG radiative transfer modeling approach



Turbulent Non-Equilibrium Radiative transfer (TUNER) with *Large Velocity Gradient* (LVG) approximation

$$M_{gas,\,LVG}\,[M_\odot] = 0.21\; R^2\, n(H_2)\, \Delta v_{turb}\, (dv/dr)^{-1}$$

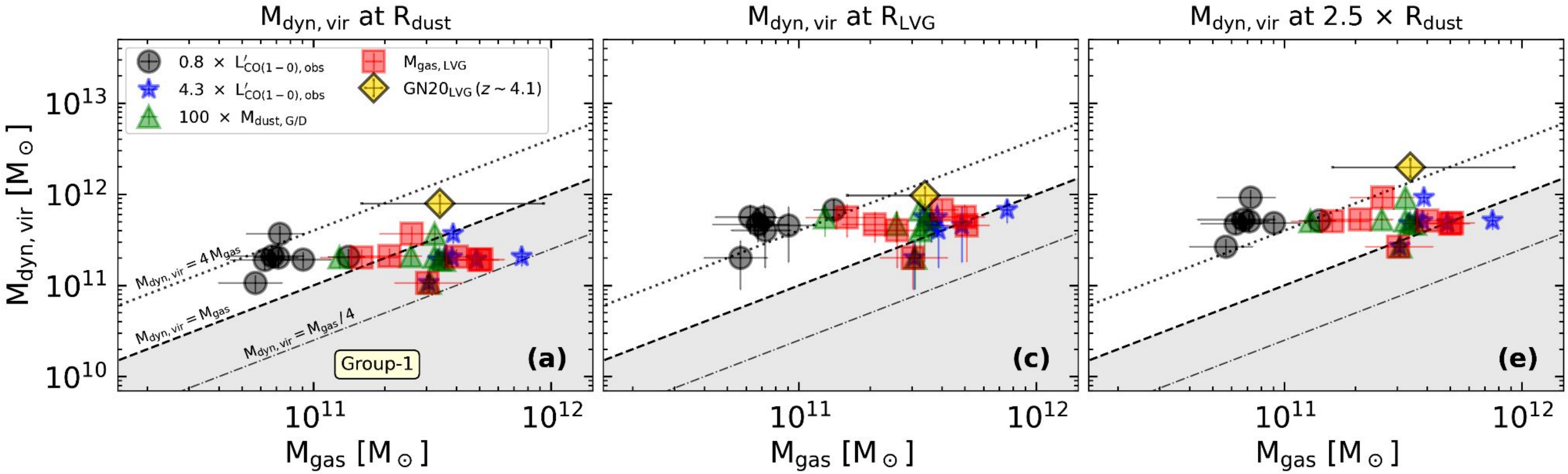
$$R = R_{LVG} = D_A\,(\Omega_{app}/\pi)^{0.5}$$

$$\boxed{M_{gas,\,LVG} = \alpha_{CO,\,LVG}\; L'_{CO(1-0),LVG}}$$

α_{CO} range	median α_{CO}
2.6–11.5	5.1

Dynamical mass – isotropic virial estimator

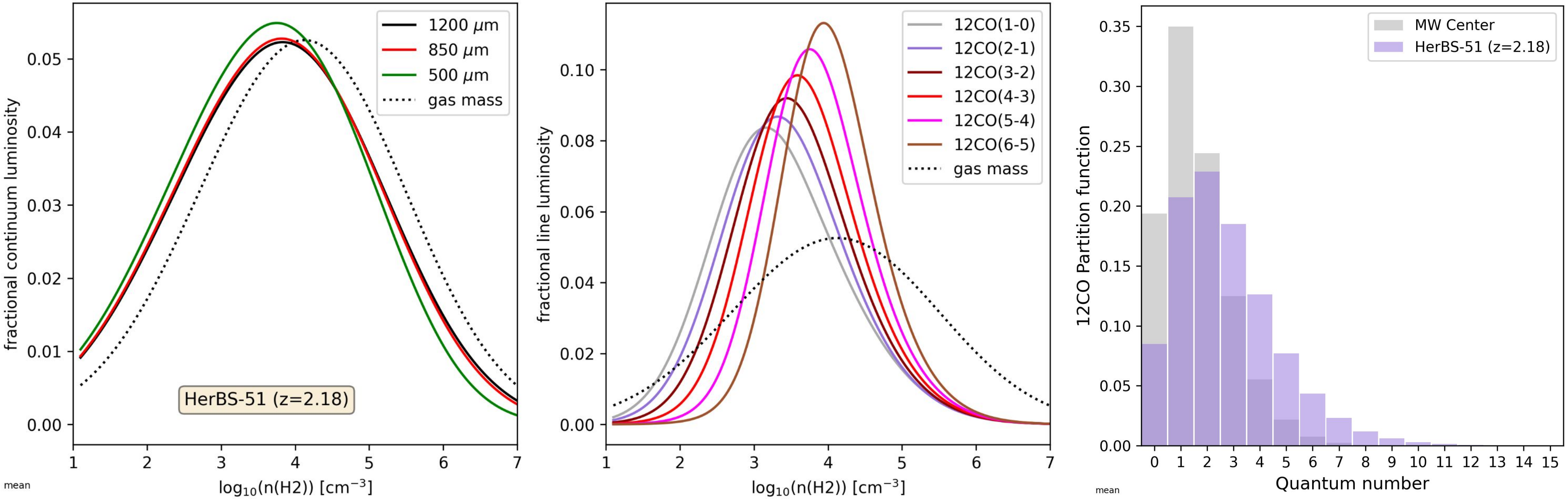
$$M_{dyn,\,vir} = 6.7\ \sigma^2 R_{eff} G^{-1} = 2.82 \times 10^5\ (FWHM_{CO(1-0)})^2 R_{eff}$$ (e.g., Bothwell+13)



- Adopting "realistic" cold-gas sizes may help better compare M_{gas} with $M_{dyn,\,vir}$
- Only conditional need for "ULIRG-like" α_{CO} = 0.8, which may lead to gas mass underestimation for high-*z* DSFGs
- Need for resolved low/mid-J CO dynamics and sizes — alongside dust continuum — for Vz-GAL DSFGs using ALMA upgrades and the upcoming ngVLA.

Understanding $\alpha_{CO} > 0.8$ in DSFGs and local ULIRGs

- **Incorporating dense gas tracers in local mergers/ULIRGs can lead to $\alpha_{CO} \sim 2–6$.**
- **Low α_{CO} only when warm gas is extended and not self gravitating (Papadopoulos+2012).**



median $\alpha_{CO} \sim$ { 5.1 (TUNER LVG approach) ; 3.4 (dust SED approach)

Take Home Messages!

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Dust SED and TUNER LVG modeling for DSFGs leading to $\alpha_{CO} \simeq 2$–11 with a median close to the Galactic α_{CO}

Adopting realistic cold gas sizes may reconcile M_{dyn} and M_{gas}, making the need for $\alpha_{CO} = 0.8$ only "conditional"

Robust α_{CO} calibration requires physically driven ISM modeling and resolved cold gas dynamics with e.g., ngVLA.

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Supplementary Slides

Dust continuum GMBB approach

$$S_\nu \propto (1 - e^{-\tau\nu})\ B_\nu(T_{dust})$$

$$\tau_\nu \propto \nu^\beta M_{dust} (R_{dust})^{-2}$$

$$\boxed{M_{gas} = 100 \times M_{dust} = \alpha_{CO}\ L'_{CO(1-0),obs}}$$

α_{CO} range	median α_{CO}
1.5–8.5	3.4

HerBS–51
($z = 2.183$)