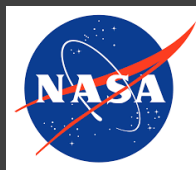


# CO Excitation and Turbulence in High-z Main Sequence Analogues: Resolved CO Line Ratios and Velocity Dispersions in DYNAMO Galaxies

Laura Lenkić • [lilenkic@usra.edu](mailto:lilenkic@usra.edu)

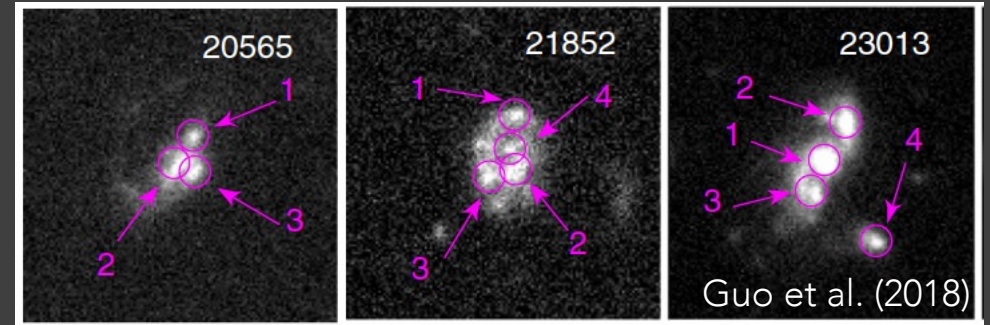
Alberto Bolatto (UMD), Deanne Fisher (SUT), Karl Glazebrook (SUT), Danail Obreschkow (UWA),  
Roberto Herrera-Camus (UDEEC)

Thursday, March 3<sup>rd</sup>, 2022



# Morphologies of $z \sim 1 - 2$ Galaxies

- o Dominated by massive  $\sim$ kpc-sized clumps



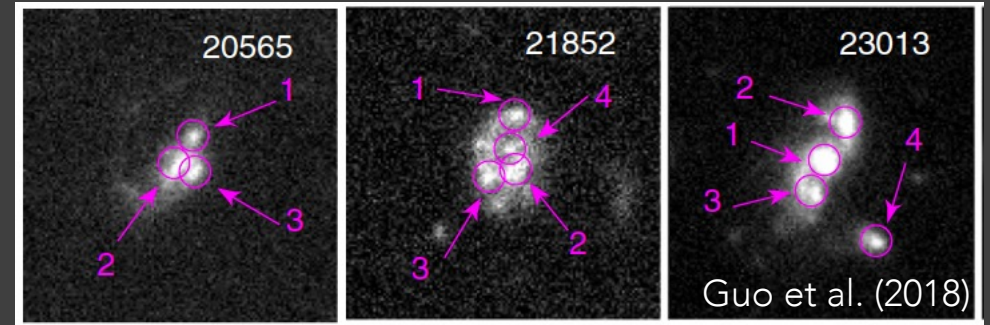
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High Gas  
Fractions  
30 – 80%

High SFRs  
10 – 100 solar  
masses per  
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High Vel.  
Dispersion  
20 – 80 km/s



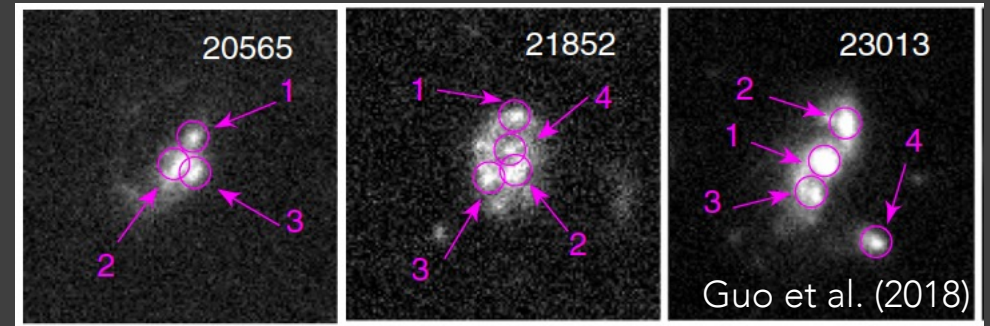
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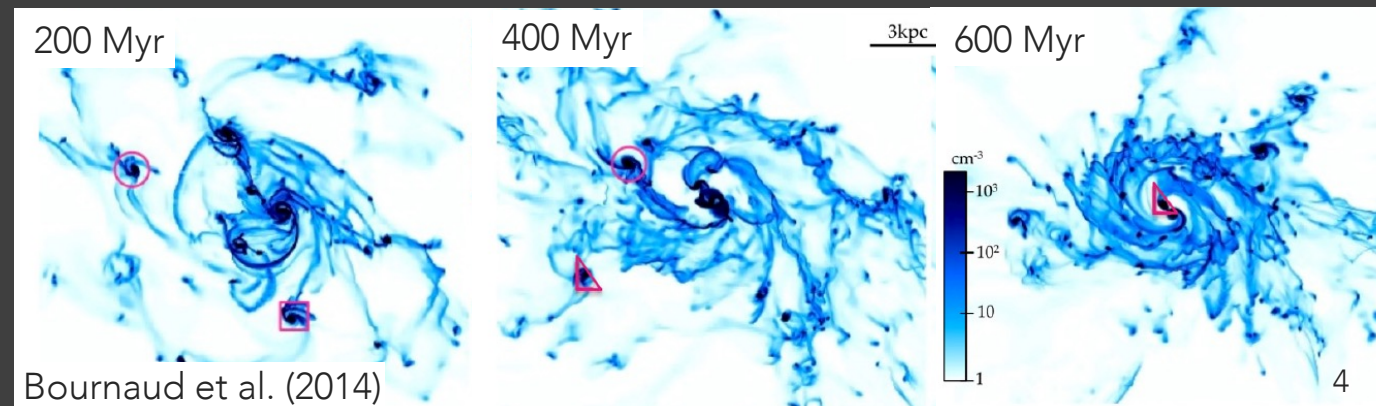
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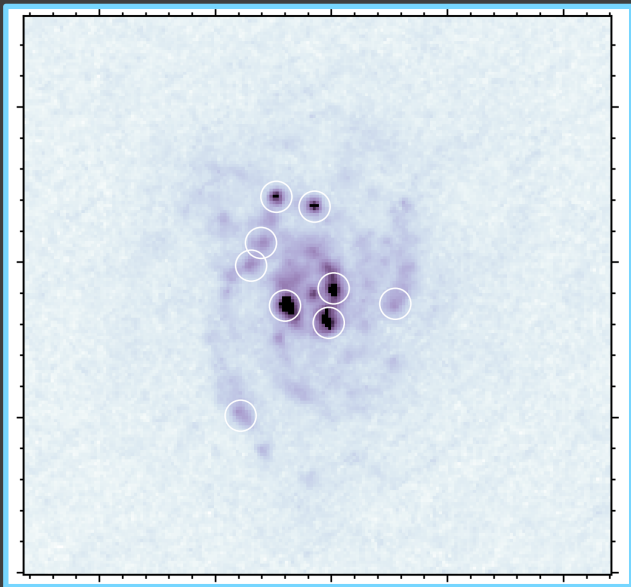
o Formation through *violent disk instability*  $\rightarrow$  migrate inwards and contribute to bulge growth?



# Local Analogues: DYNAMO Galaxies

- *DYnamics of Newly Assembled Objects (DYNAMO; Green+2014)*: 68 very rare local ( $z \sim 0.1$ ) clumpy galaxies selected from SDSS to be H $\alpha$  bright

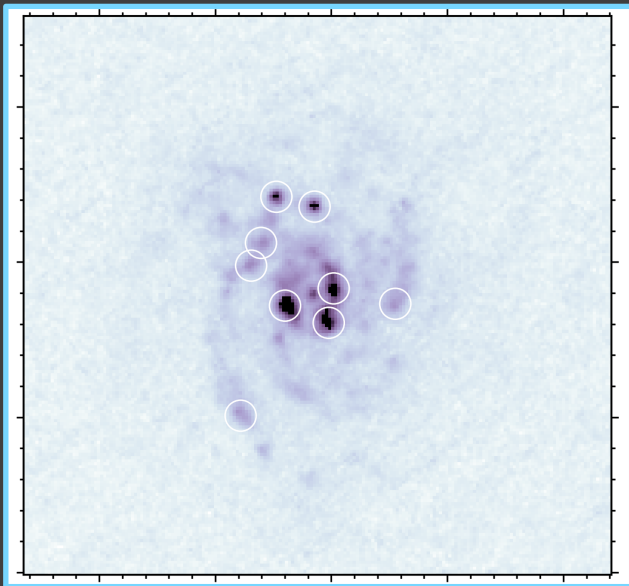
HST F336W (U)



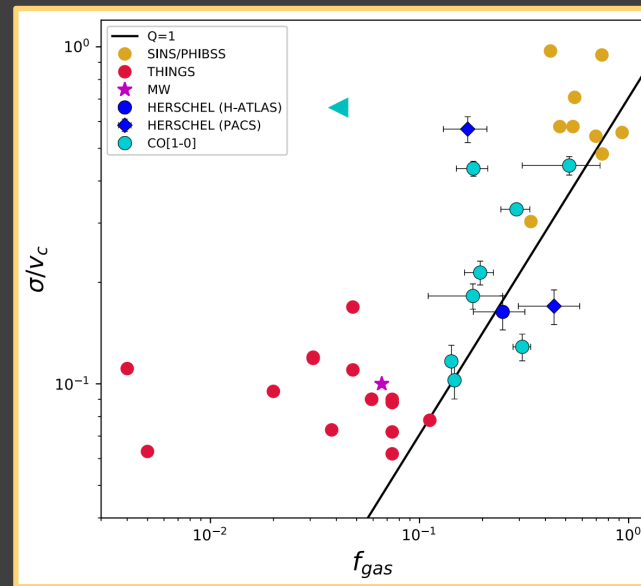
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High gas fractions & velocity dispersions



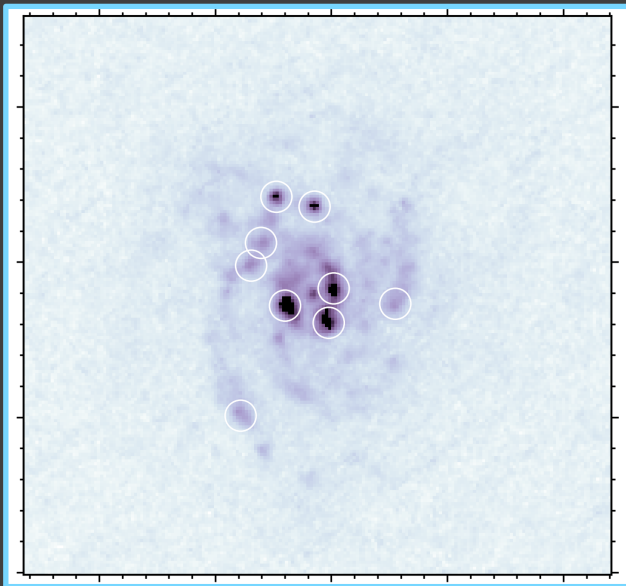
White et al. 2017



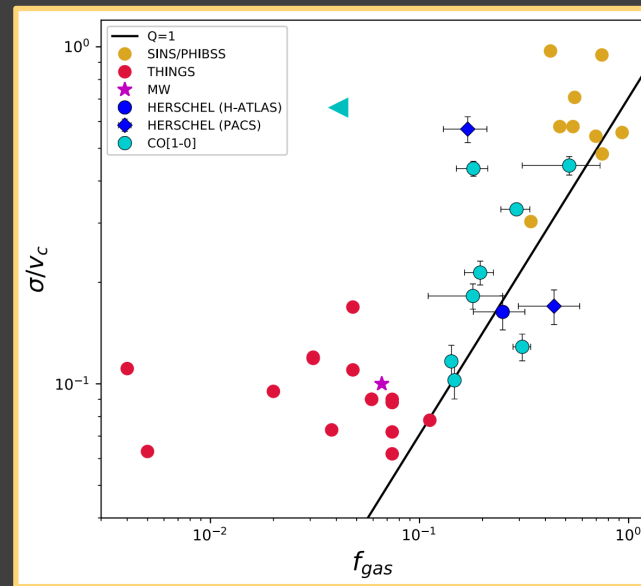
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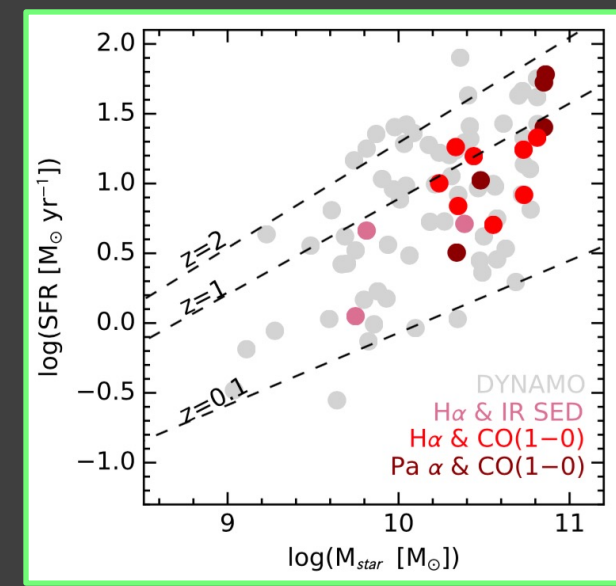


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White et al. 2017

High SFRs



Fisher et al. 2019

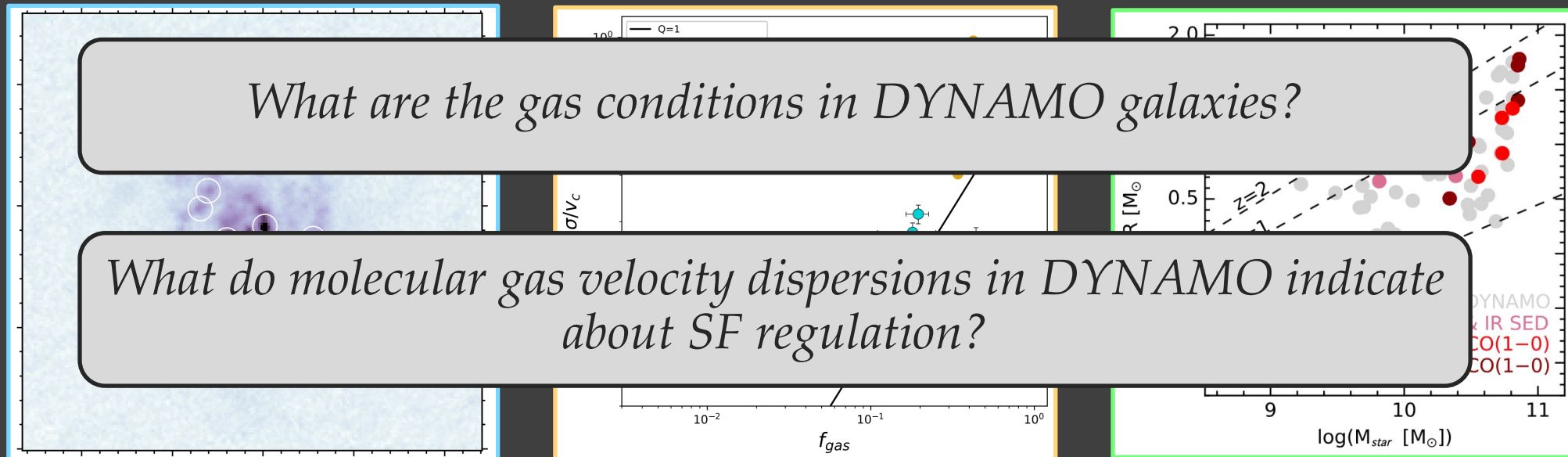
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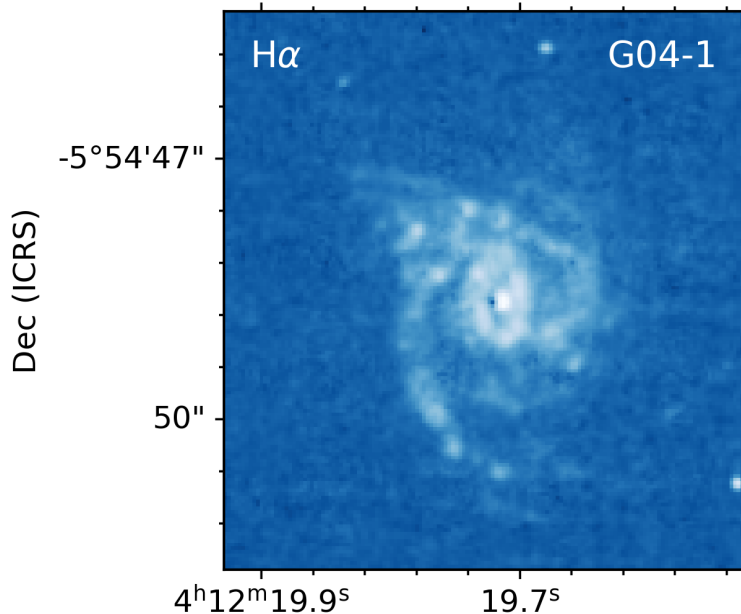


# DYNAMO Observations

- ALMA CO & HST → 1 – 2 kpc scale measurements of  $\sigma_{mol}$ ,  $\Sigma_{mol}$ ,  $\Sigma_{SFR}$
- SOFIA FIFI-LS & HAWC+ → galaxy integrated measurements of  $[CII]/TIR$ ,  $T_{dust}$

Lenkić et al. in prep

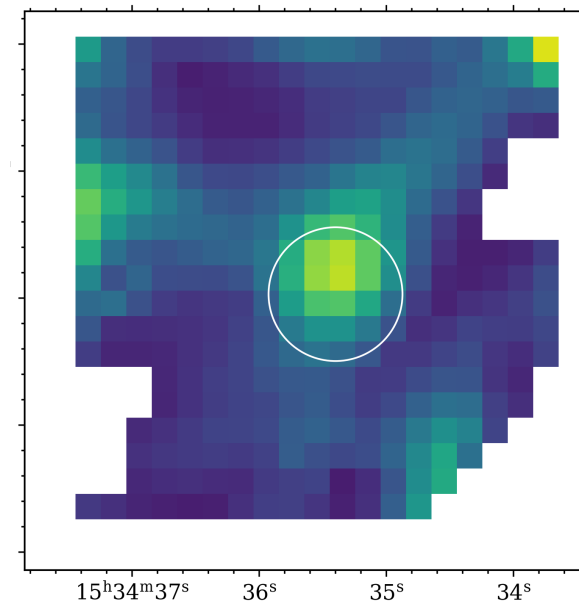
Star Formation Rate



Molecular Hydrogen Gas

measurements of  $\sigma_{mol}$ ,  $\Sigma_{mol}$ ,  $\Sigma_{SFR}$   
integrated measurements of

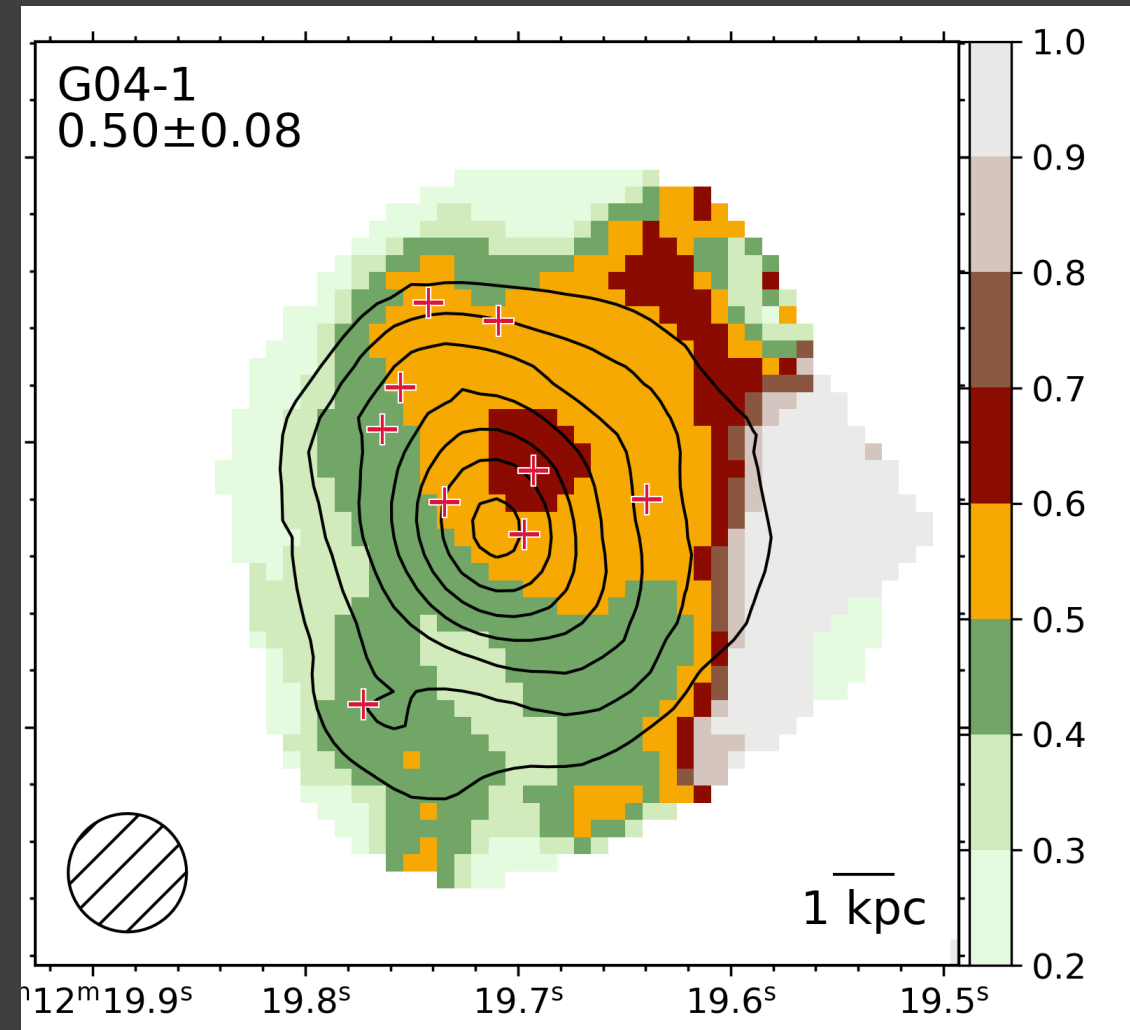
SOFIA [CII]



# Resolved CO Line Ratios

Lenkić et al. in prep

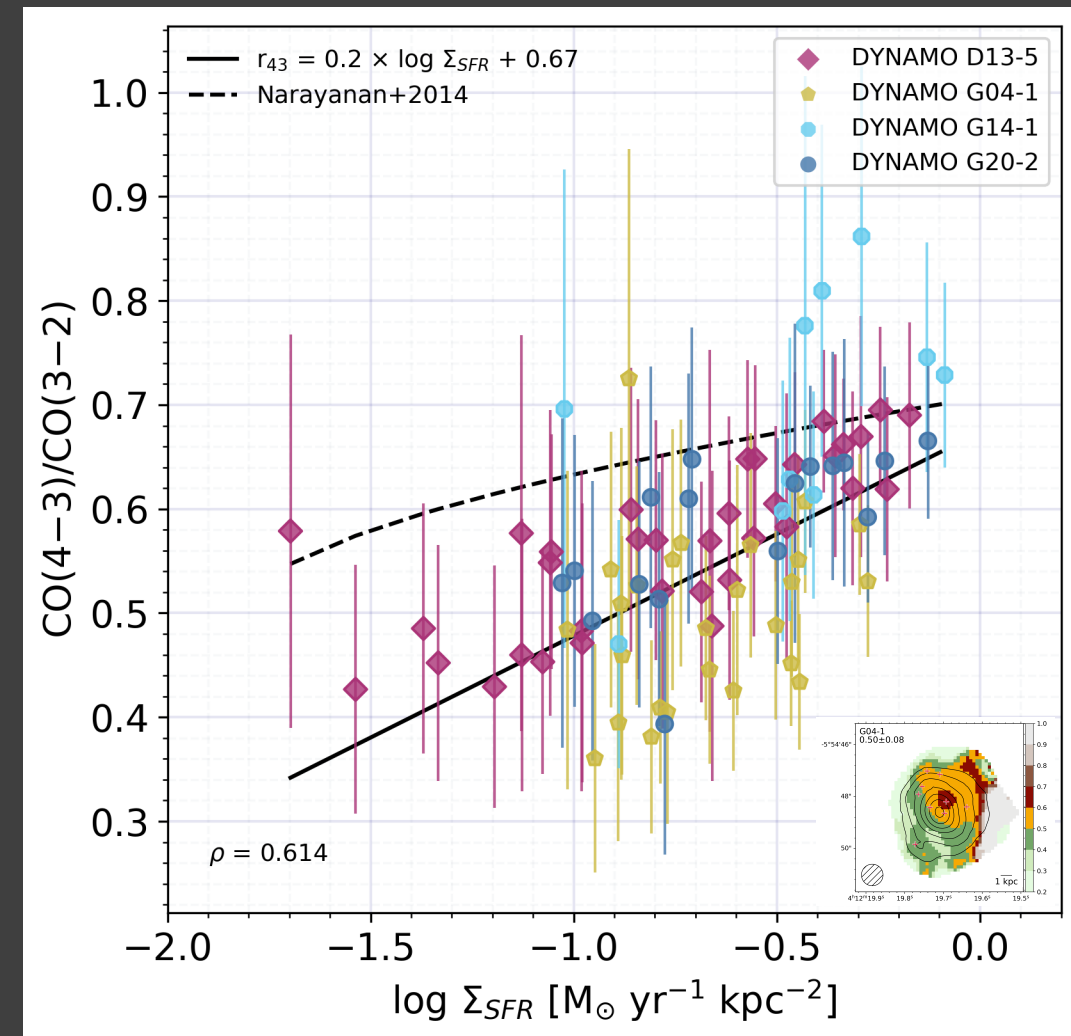
- $\text{CO}(4 - 3)/\text{CO}(3 - 2) = 0.4 - 0.7$
- median:  $0.54 (+0.16 -0.15)$



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Lenkić et al. in prep

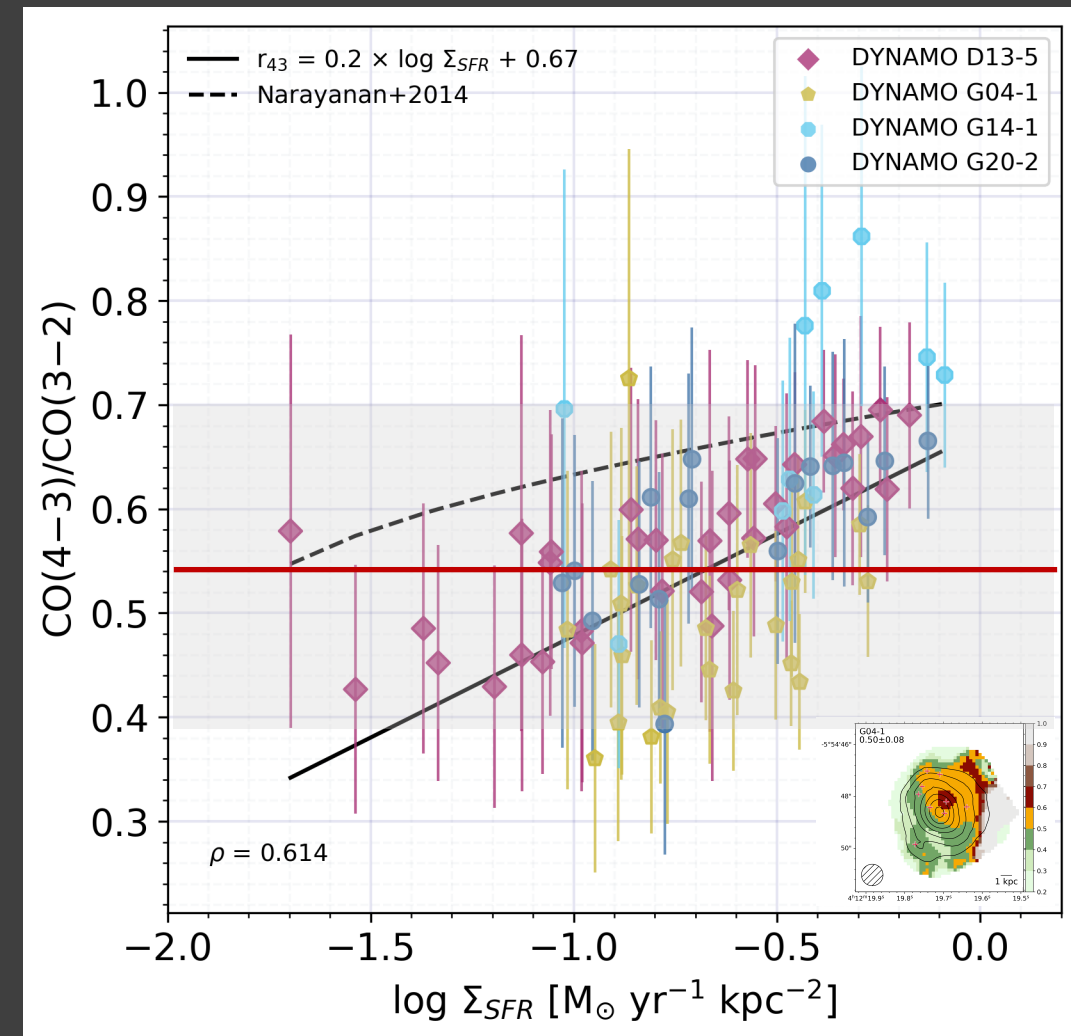
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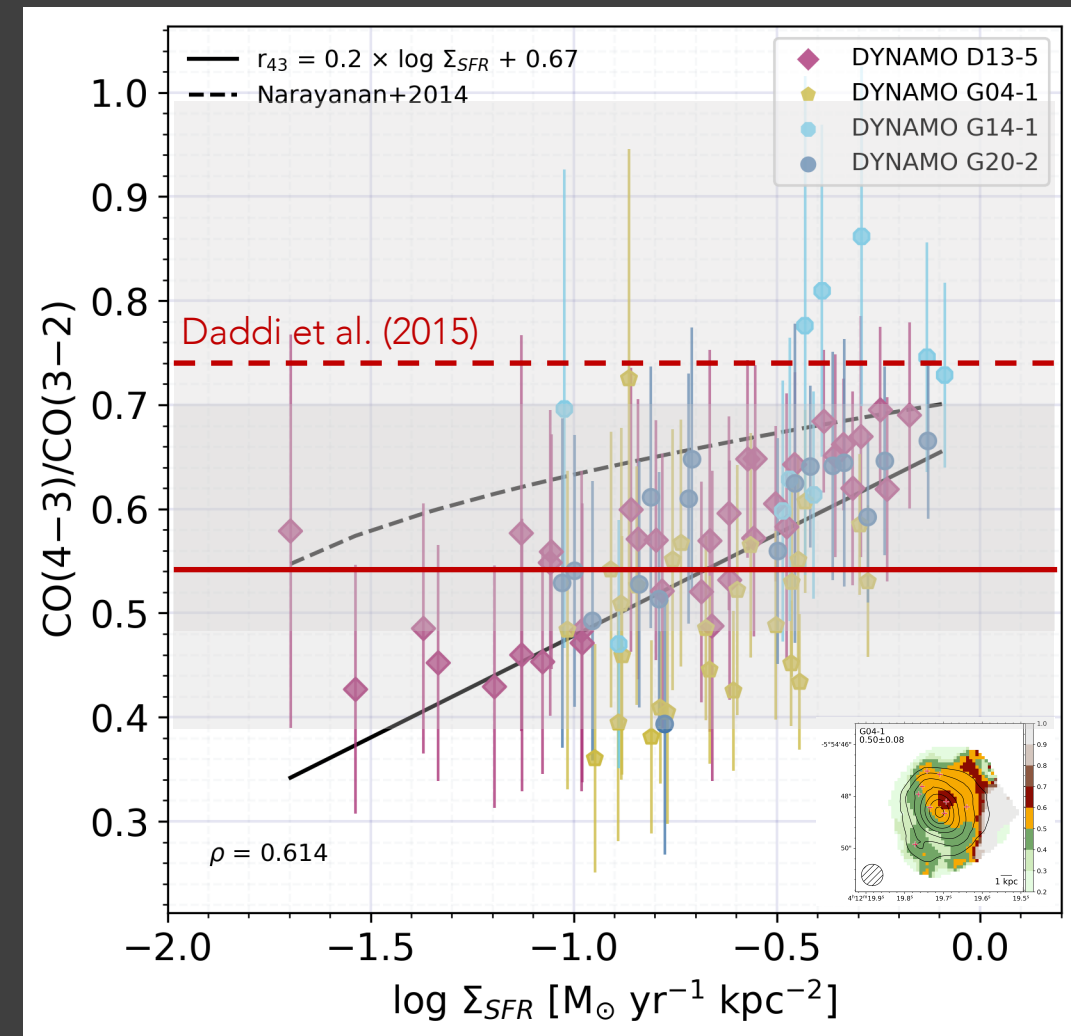
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Lenkić et al. in prep

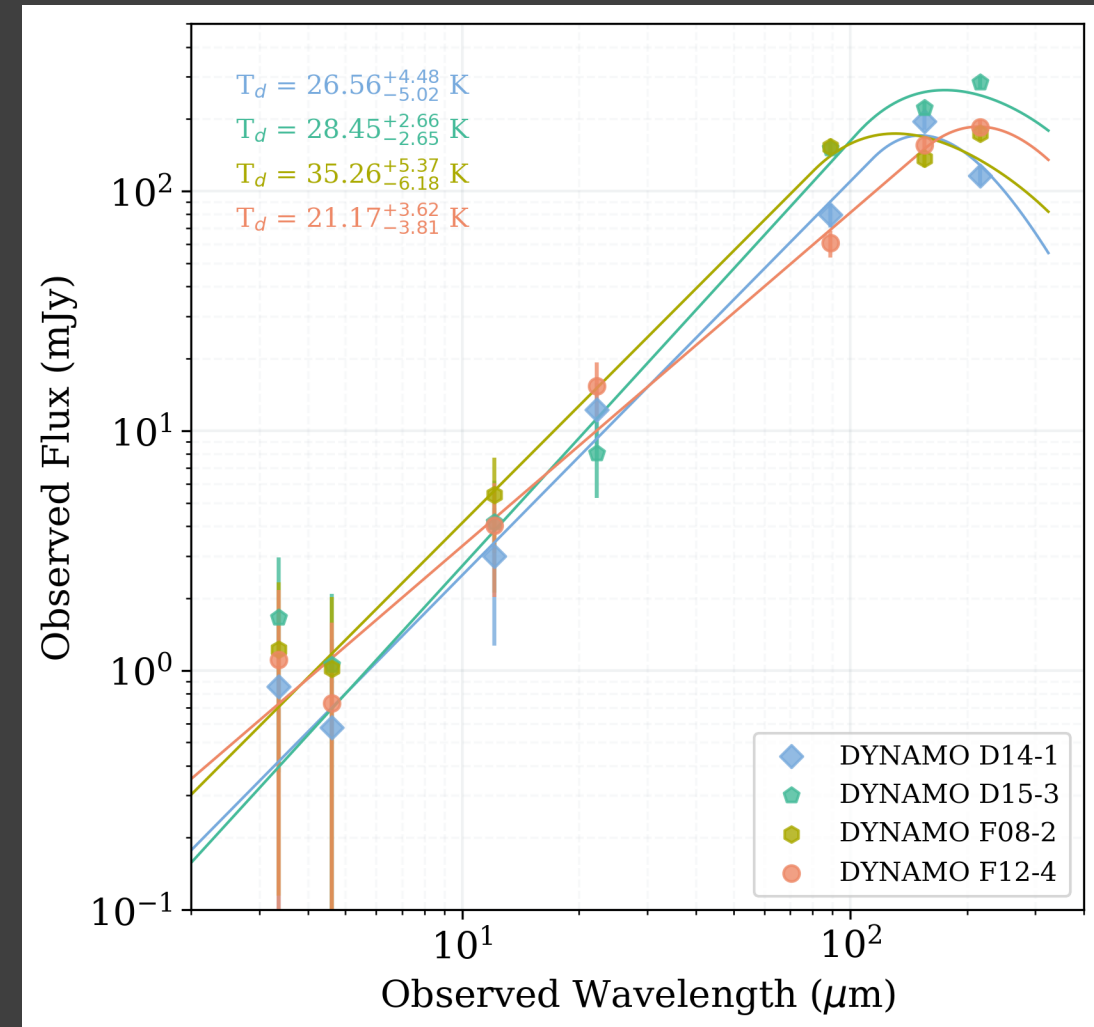
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# Dust Temperatures and [CII] Deficit

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- SOFIA HAWC+ observations constrain peaks of spectral energy distributions
  - Infer low dust temperatures  $\rightarrow$   $\sim 20 - 35$  K
- Low dust temperature – high SFR  $\rightarrow$  no [CII] deficit?

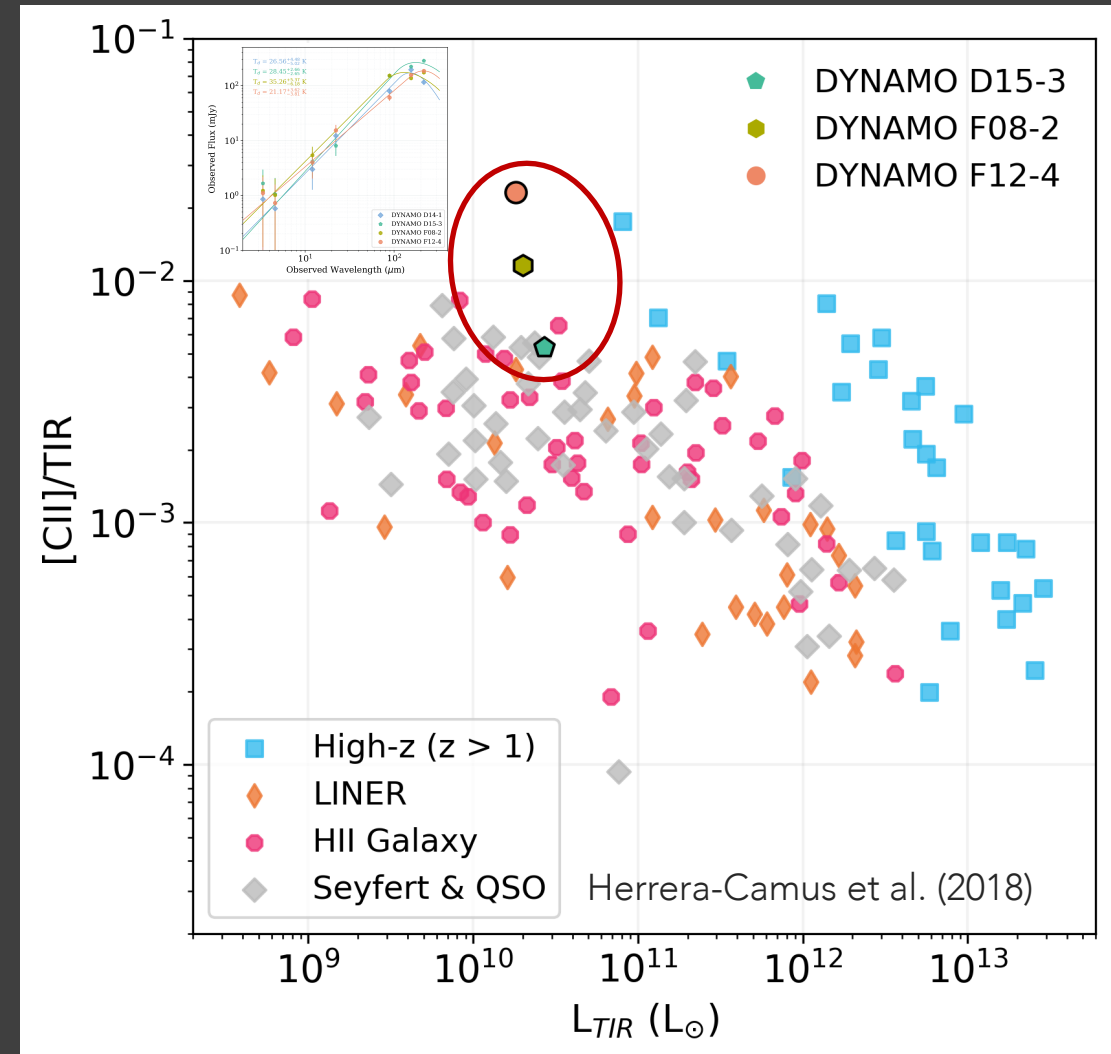




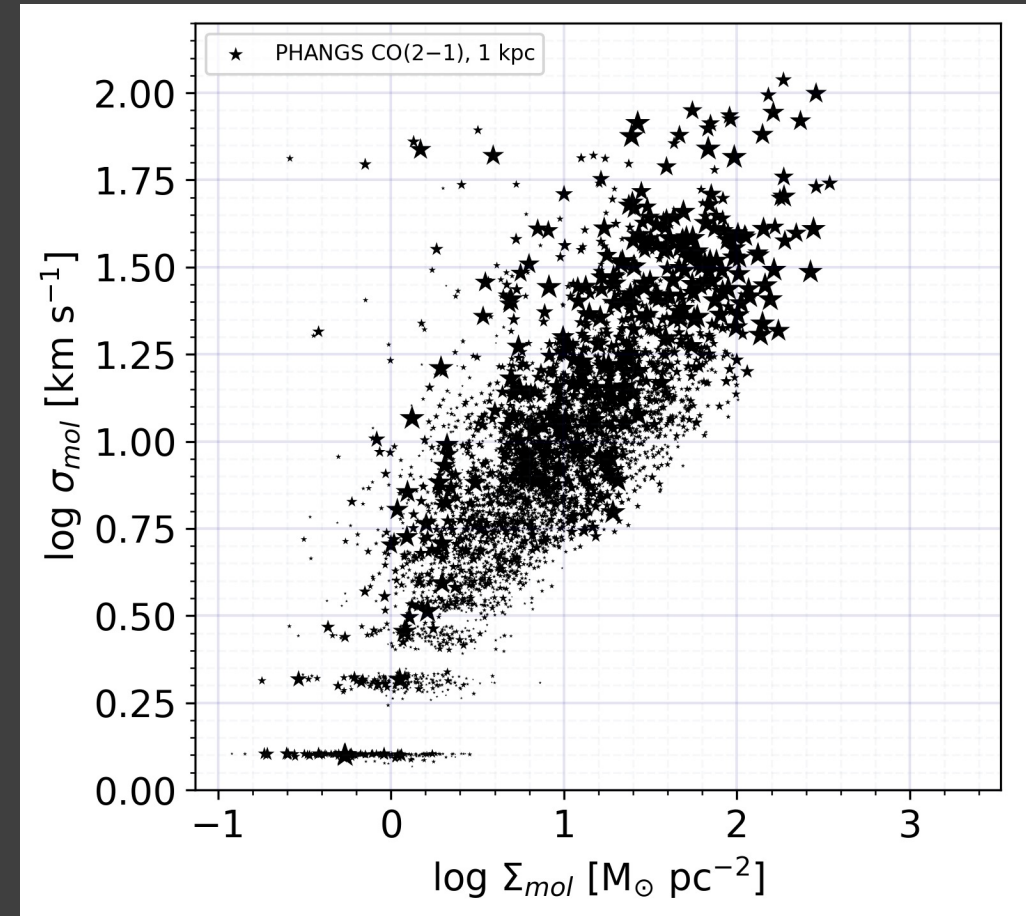
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Lenkić et al. in prep

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- Low dust temperature – high SFR → no [CII] deficit?
- SOFIA FIFI-LS [CII] observations indicate no [CII] deficit in DYNAMO



# Velocity Dispersions in DYNAMO: $\sigma_{mol} - \Sigma_{mol}$

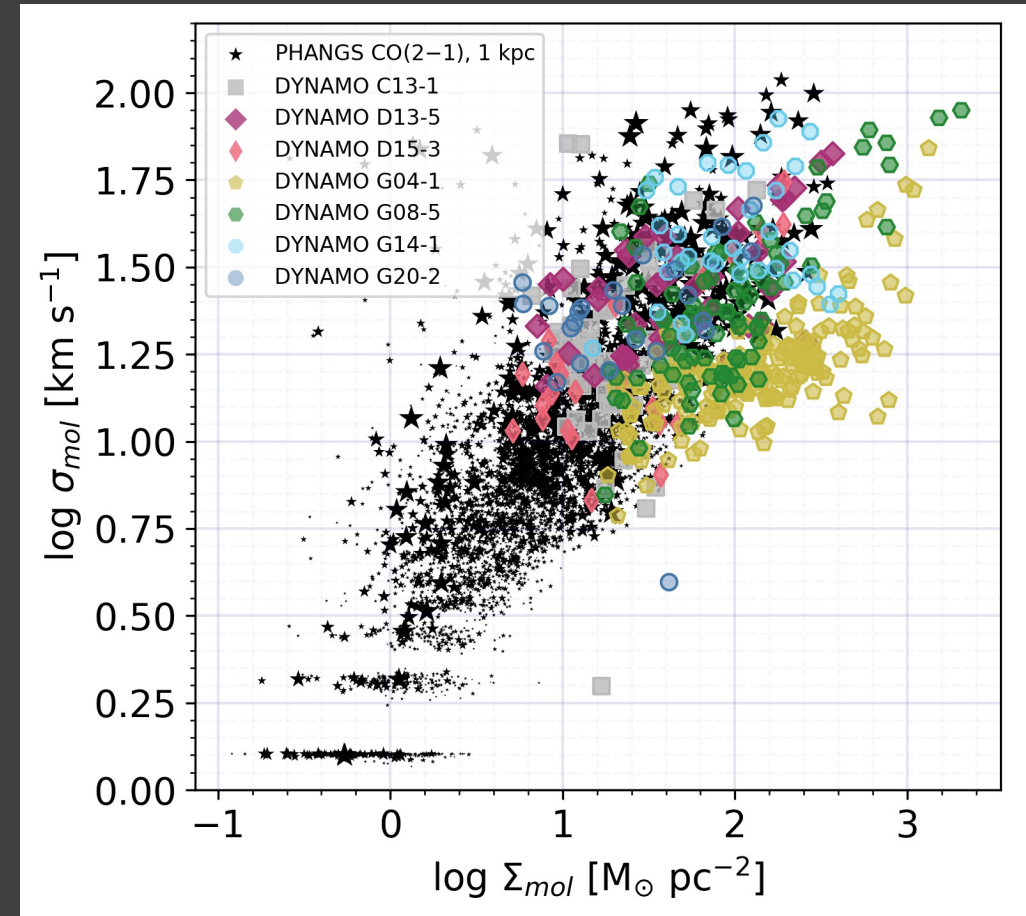


Lenkić et al. in prep

# Velocity Dispersions in DYNAMO: $\sigma_{mol}$ – $\Sigma_{mol}$

o High  $\sigma_{mol}$  and  $\Sigma_{mol}$  in DYNAMO

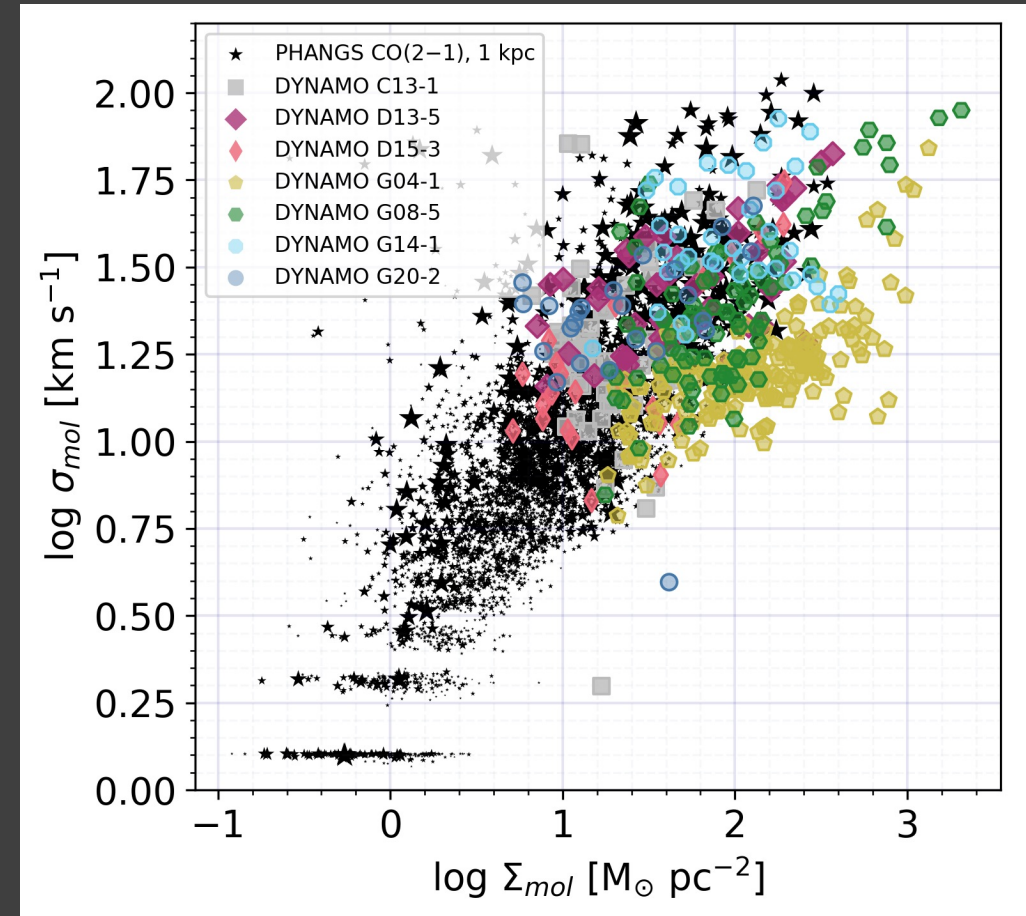
o comparable to centers of other nearby star forming galaxies



Lenkić et al. in prep

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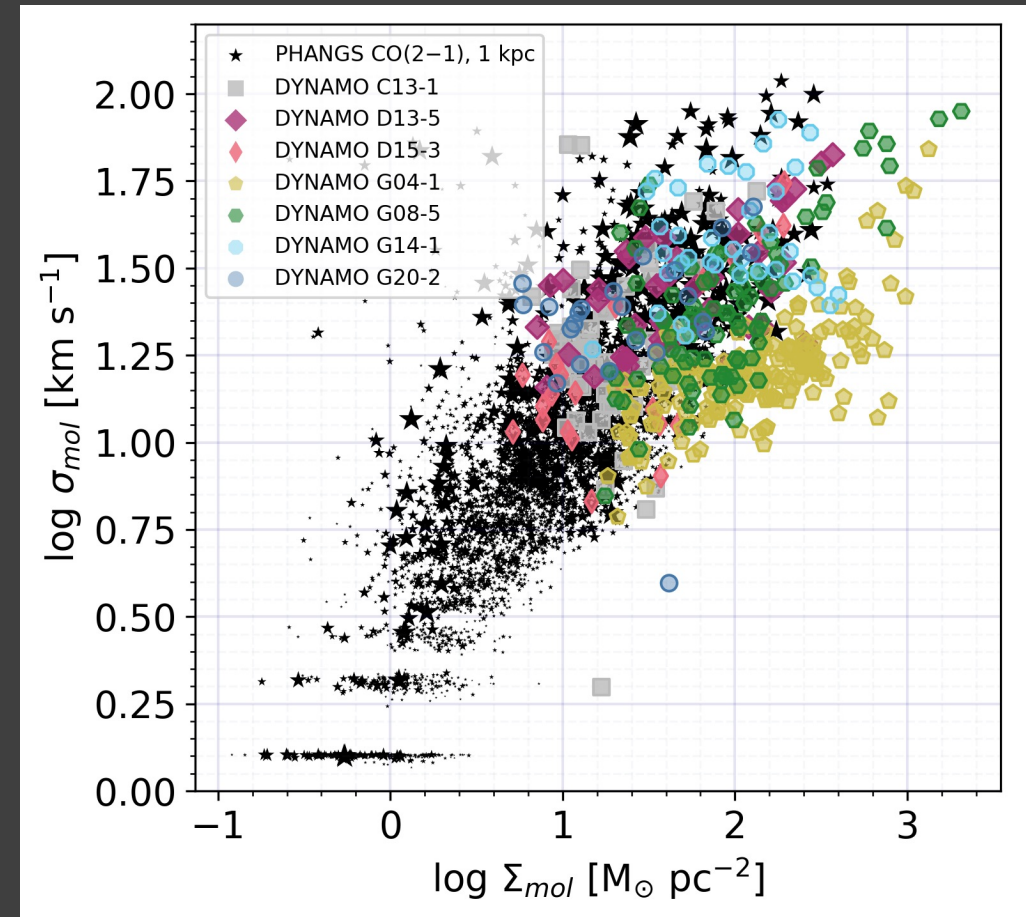
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Lenkić et al. in prep

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- High  $\sigma_{mol}$  and  $\Sigma_{mol}$  in DYNAMO
  - comparable to centers of other nearby star forming galaxies
- What can drive elevated  $\Sigma_{mol}$  and  $\sigma_{mol}$  in the outer disks of DYNAMO?
  - accretion → build up gas
  - radial gas flows → build up dispersion (i.e., turbulence)

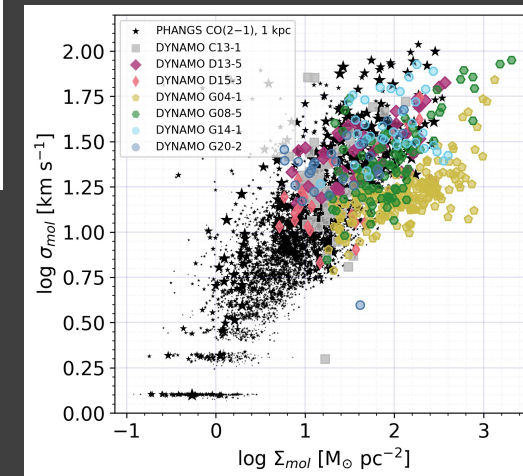
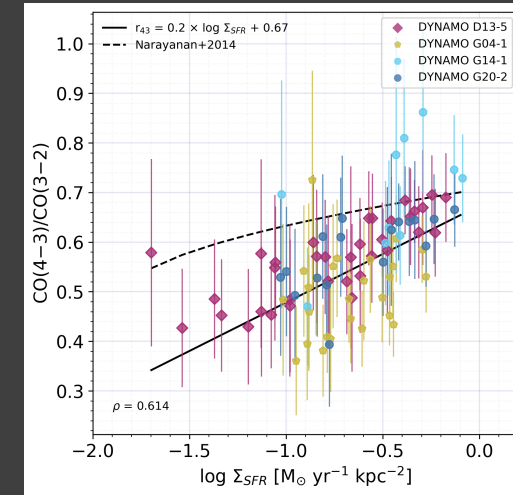
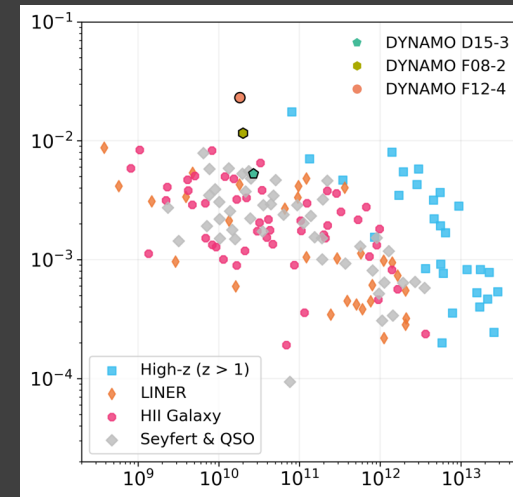


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# Summary

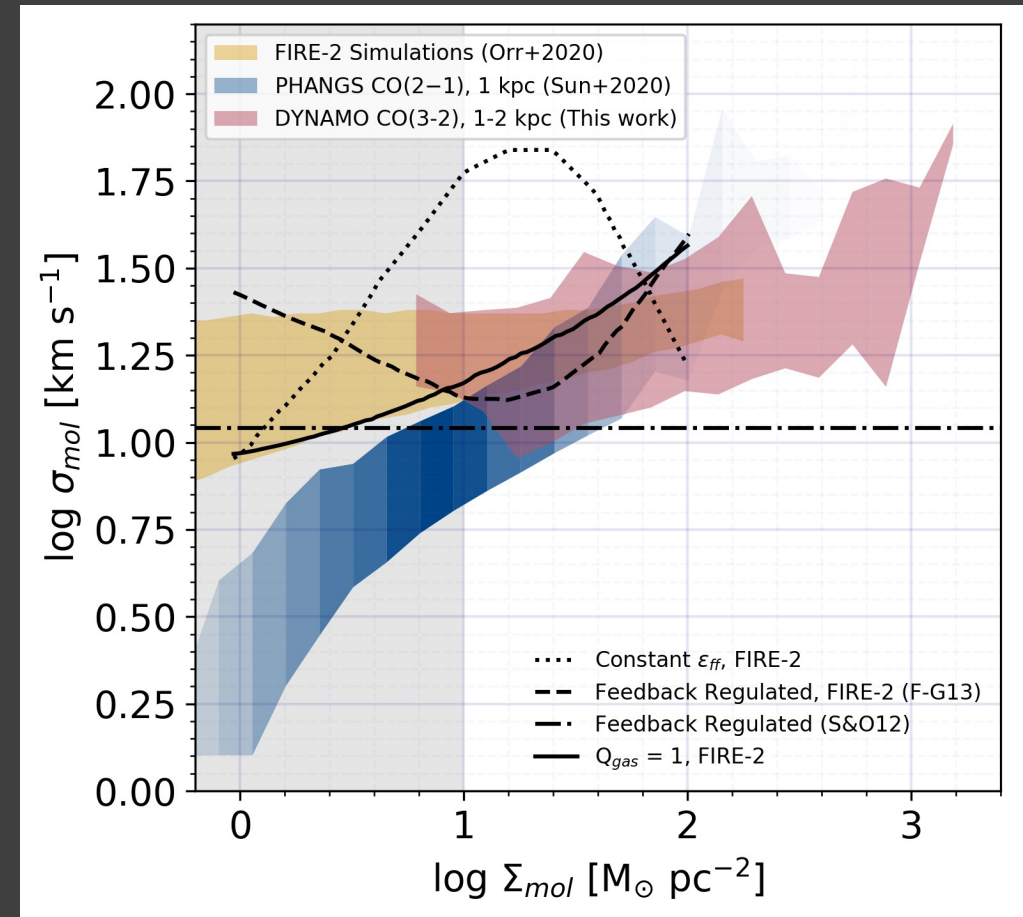
- CO excitation most similar to high-z star forming galaxies
- Models of CO excitation overpredict magnitude and underpredict slope of observations
- Low dust temperatures and no [CII] deficit
- Elevated  $\sigma_{mol}$  &  $\Sigma_{mol}$   $\rightarrow$  evidence for accretion/gas flow powered turbulence?





# Hydrodynamic Models and Theories

- DYNAMO probes  $\Sigma_{mol} > 10$  where gas is expected to be dominated by  $H_2 \rightarrow$  ideal for comparison with simulations
- Numerical simulations capture some but not all behavior of DYNAMO
  - e.g., gas depletion times differ
- Theoretical models simplify  $\sigma_{mol} - \Sigma_{mol}$  in ways that are inconsistent with DYNAMO
  - e.g., angular velocity assumed to be related to turbulence dissipation timescale



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