Connecting CO-to-H_2 Conversion Factors to Molecular Gas Properties in Nearby Barred Galaxy Centers

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Collaborators: Jiayi Sun, Munan Gong, Alberto Bolatto, Adam Leroy, I-Da Chiang, Cliff Johnson, Diederik Kruijssen, Andreas Schruba, Antonio Usero, Ashley Barnes, Frank Bigiel, Guillermo Blanc, Brent Groves, Frank Israel, Daizhong Liu, Erik Rosolowsky, Eva Schinnerer, J.-D. Smith, Fabian Walter, and PHANGS Team

Motivation

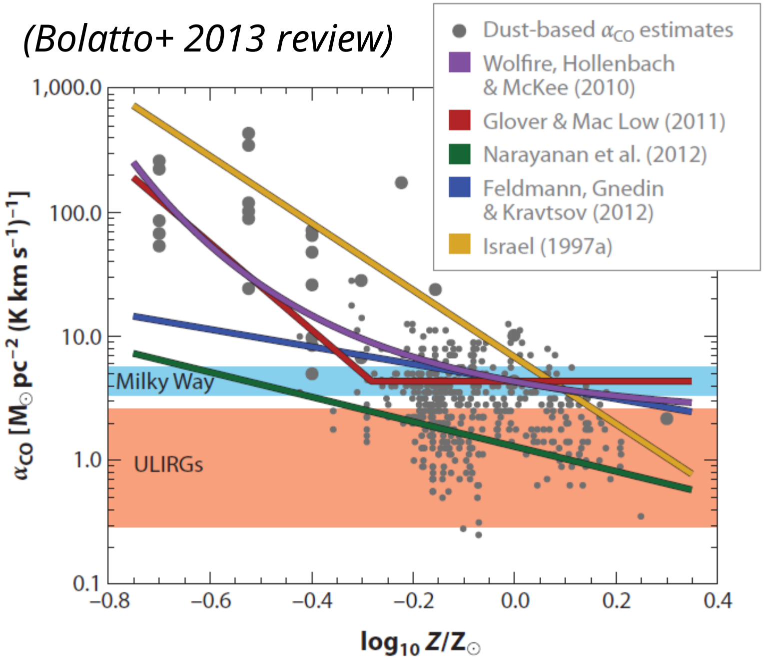
- Tracing molecular gas in galaxies
  → **CO-to-H_2 conversion factor (α_{CO})**

$$\alpha_{\mathrm{CO}} \equiv \frac{M_{H_2}}{L_{\mathrm{CO}(1-0)}} = \frac{\Sigma_{H_2}}{I_{\mathrm{CO}(1-0)}} \left(\frac{\mathrm{M}_\odot}{\mathrm{K\ km\ s^{-1}\ pc^2}}\right)$$

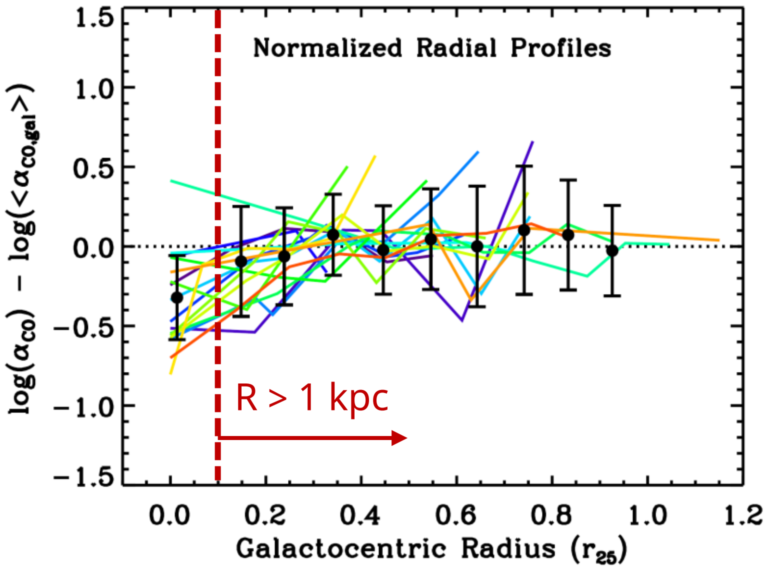
  - direct impacts on inferred star formation properties
- Variation of α_{CO} within and between galaxies
  - Dependence on gas properties
    - metallicity, temperature, density, velocity dispersion…
  - Low α_{CO} observed in star-forming **galaxy centers**
    - gas concentration driven by bars or spiral arms?
    - higher excitation and/or turbulence?

    → **emissivity**-dependent terms are important!

(Bolatto+ 2013 review)



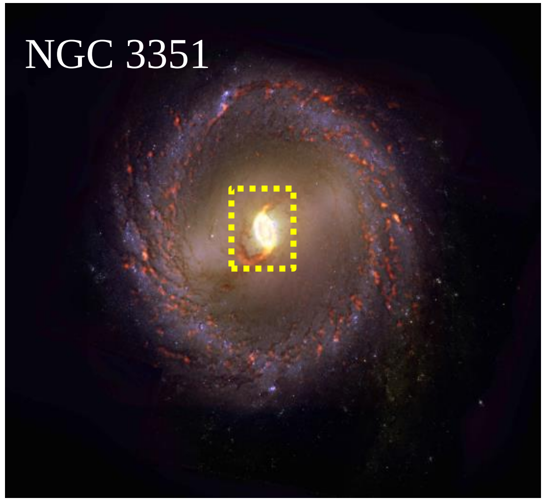
(Sandstrom+ 2013)

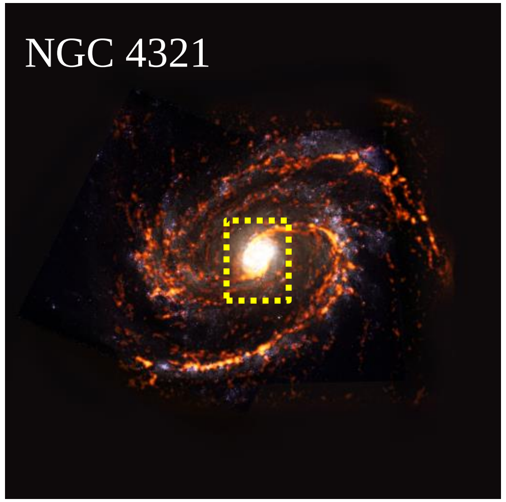


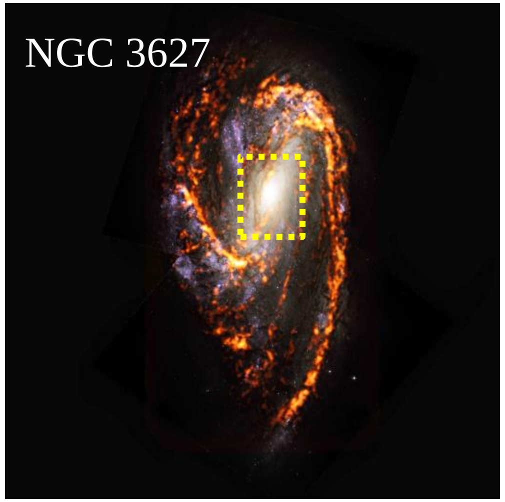
ALMA multi-line observations

- NGC 3351, NGC 3627, NGC 4321
  → nearby **barred spiral galaxies** with **low $\boldsymbol{\alpha_{\mathrm{CO}}}$** in the central kpc
  (e.g., Sandstrom+ 2013, Israel 2020)

- ALMA Band 3, 6, 7
  - Multi-line CO isotopologues
    - ^{12}CO (1-0) and (2-1)
    - ^{13}CO (2-1) and (3-2)
    - C^{18}O (2-1) and (3-2)
  - central ~2 kpc regions
  - angular resolution: 2'' (~100 pc)







(PHANGS–ALMA+HST)

Non-LTE modeling

multi-line radiative transfer + Bayesian likelihoods

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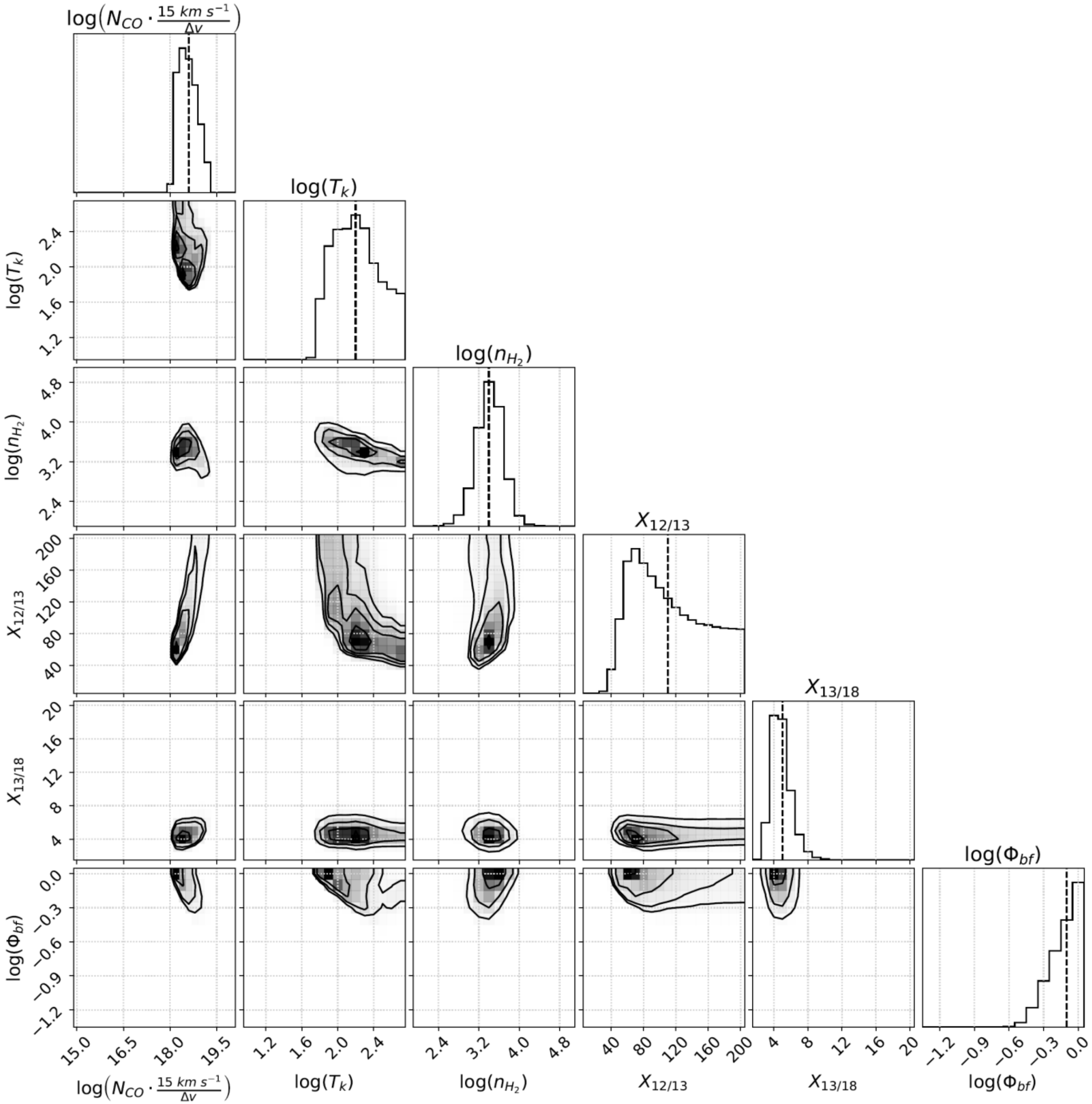

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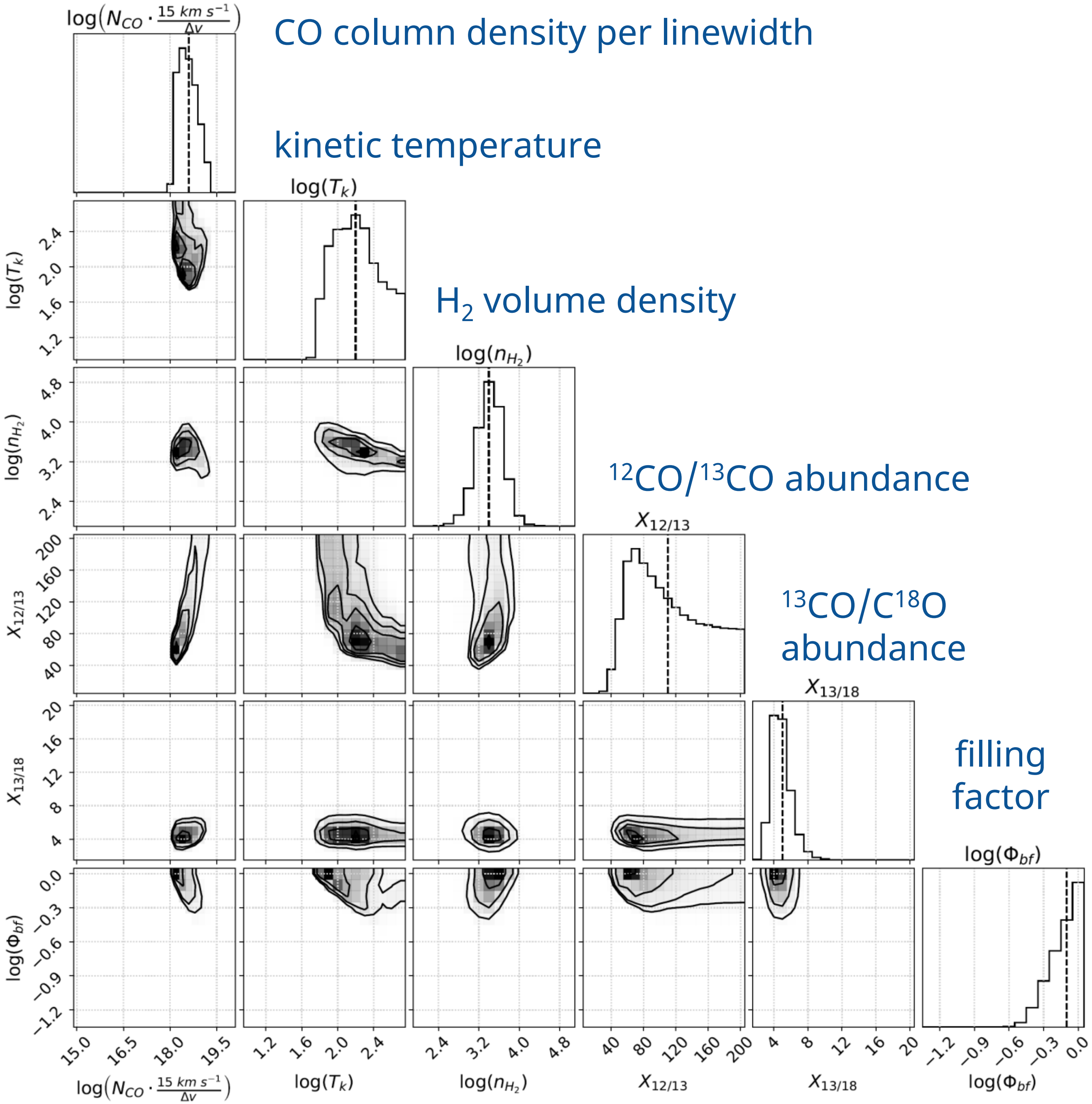
multi-line radiative transfer + Bayesian likelihoods

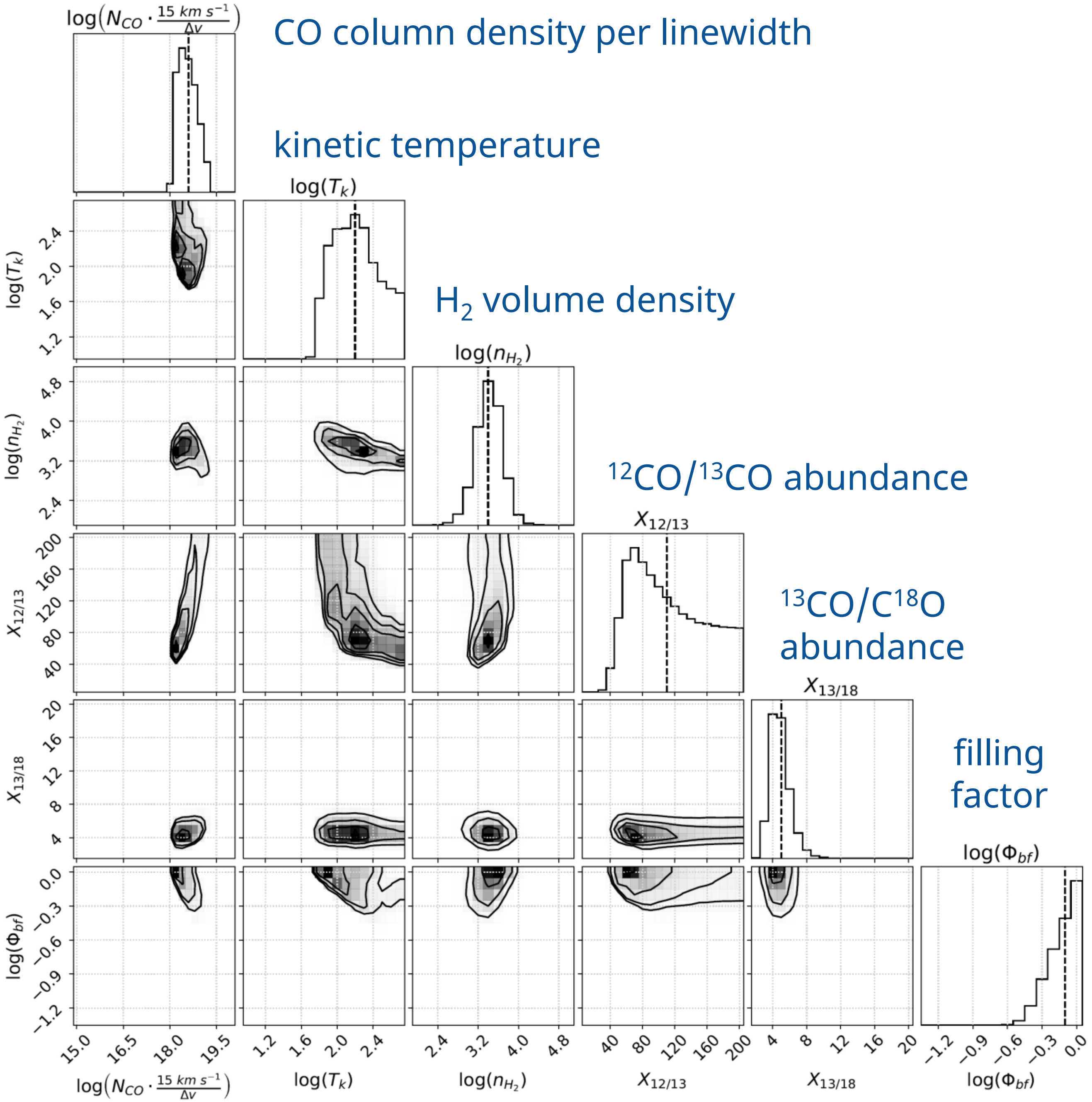


Non-LTE modeling

multi-line radiative transfer + Bayesian likelihoods

$$\boldsymbol{\alpha_{\mathrm{CO}}} = \frac{M_{\mathrm{mol}}}{L_{\mathrm{CO(1-0)}}} \left(\frac{\mathrm{M_\odot}}{\mathrm{K\ km\ s^{-1}\ pc^2}} \right)$$

$$= \frac{1.36\, m_{\mathrm{H_2}} (\mathrm{M_\odot})\, \boldsymbol{N_{\mathrm{CO}}(\mathrm{cm^{-2}})}\, \boldsymbol{\Phi_{\mathrm{bf}}}\, A(\mathrm{cm^2})}{\boldsymbol{I_{\mathrm{CO(1-0)}}(\mathrm{K\ km\ s^{-1}})}\, A\, (\mathrm{pc^2})} \cdot \frac{3 \times 10^{-4}}{x_{\mathrm{CO}}}$$



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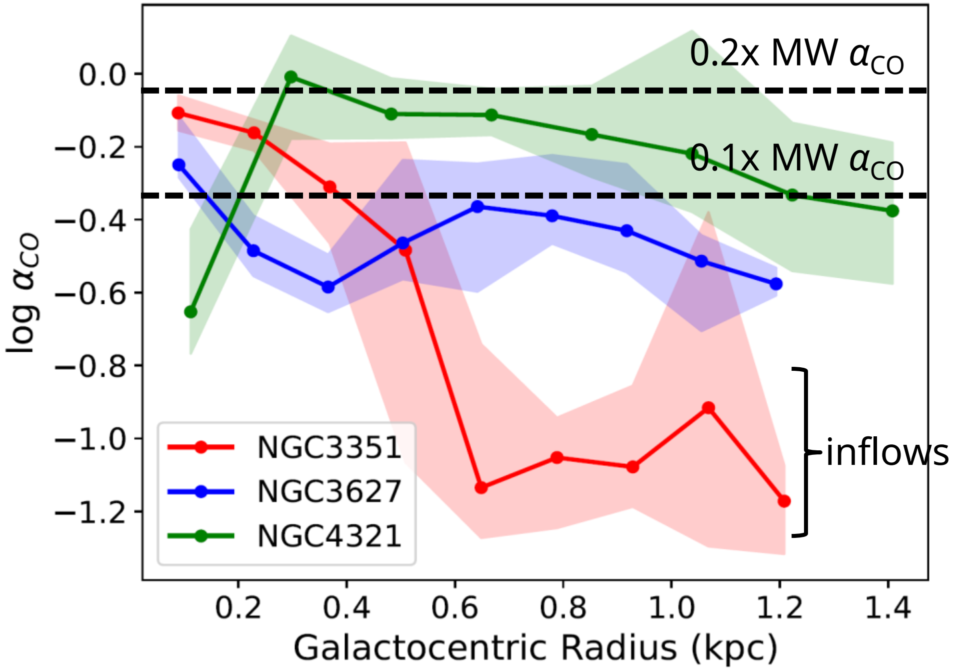
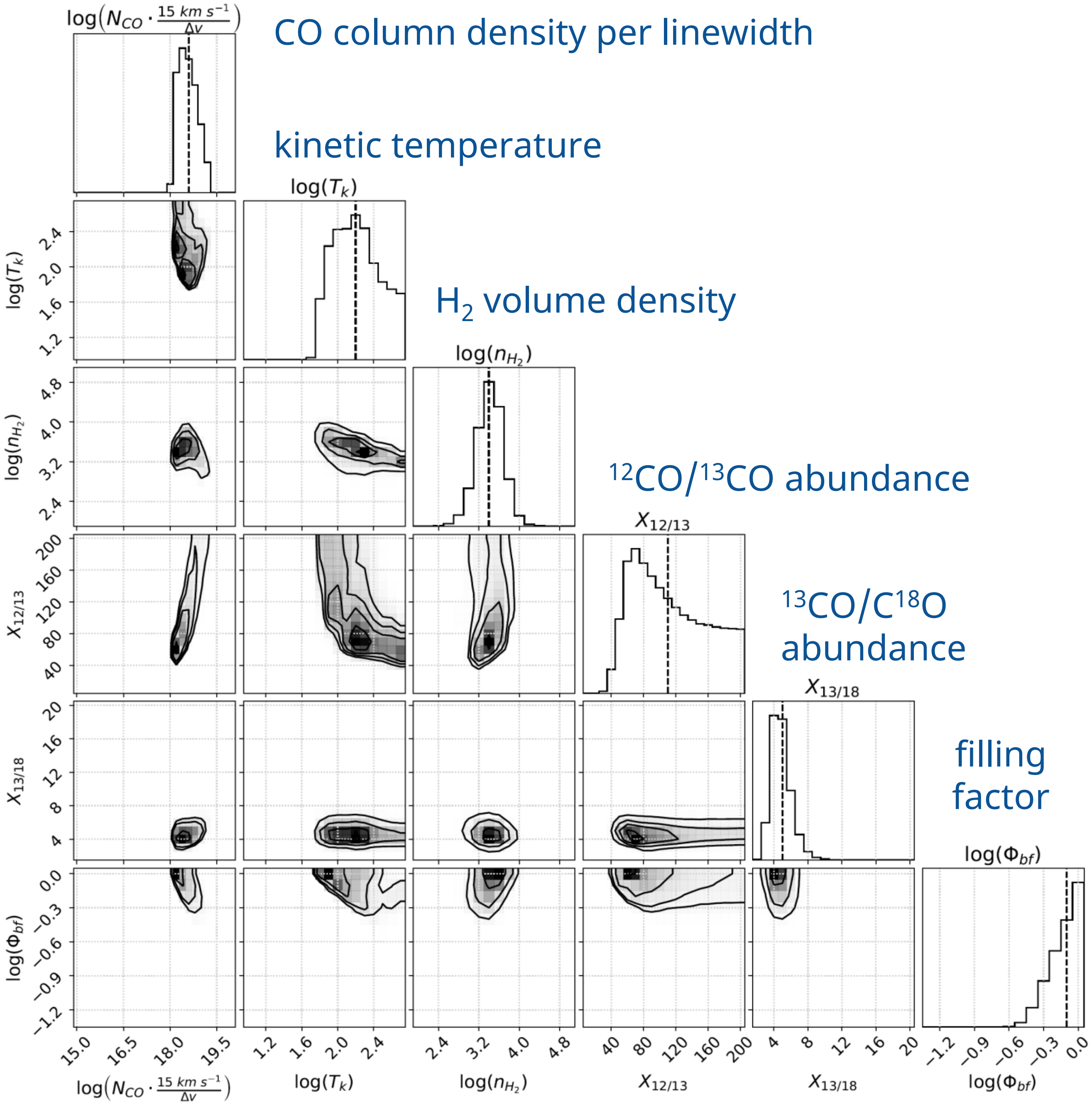


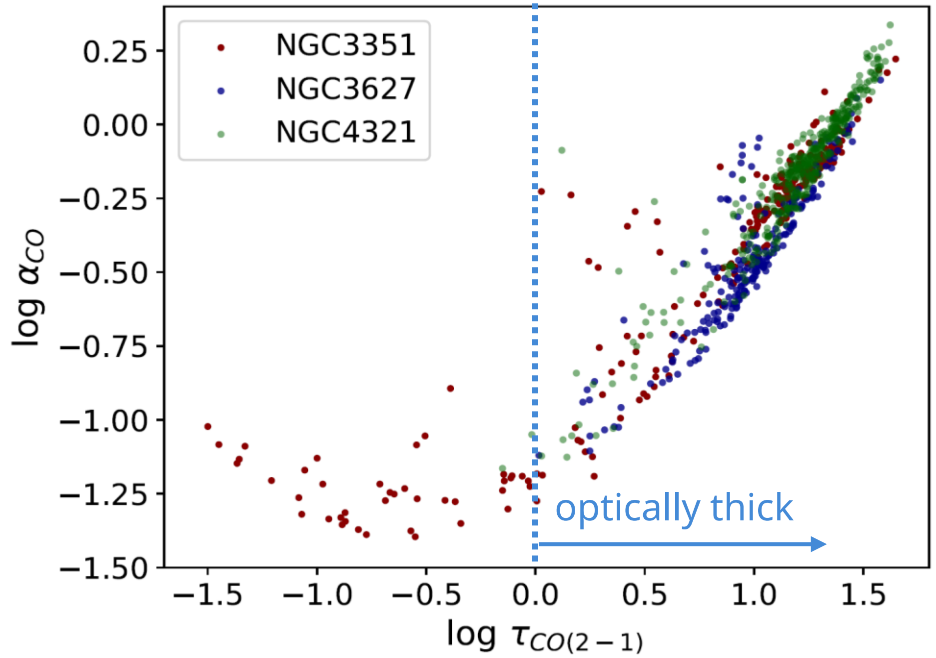


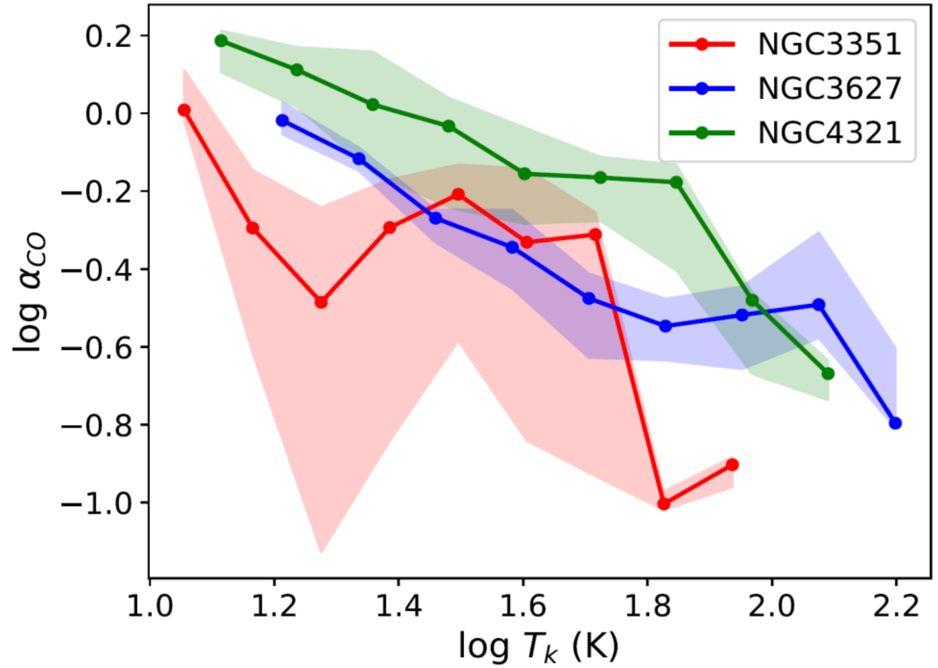
α_{CO} dependence

- Strong correlation between α_{CO} and τ_{CO} in optically thick regions (~80%)
- To the second order, α_{CO} anti-correlates with gas temperature T_k (~20%)

→ $$\log \frac{\alpha_{\rm CO}}{\rm M_\odot\ (K\ km\ s^{-1}\ pc^2)^{-1}} = 0.78\ \log \tau_{\rm CO(2-1)} - 0.18\ \log \frac{T_{\rm k}}{\rm K} - 0.84$$

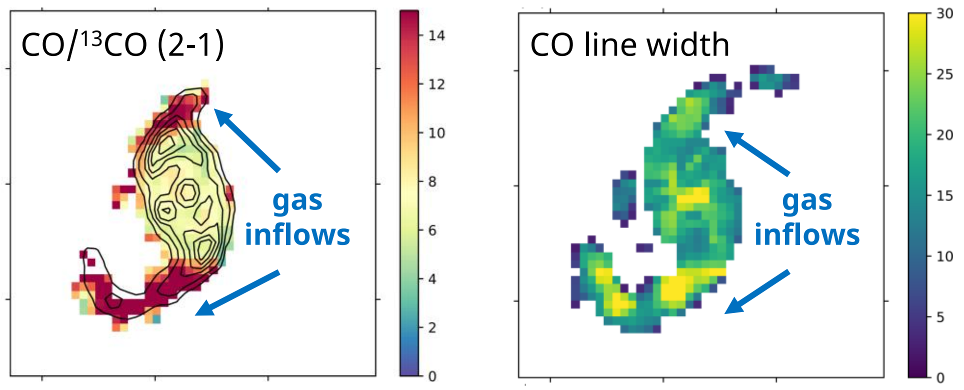
- Next step: observational tracers for α_{CO}?





Potential α_{CO} tracers

- Low α_{CO} and τ_{CO} in NGC 3351 inflows *(Teng+ 2022, ApJ)*
  - escaped CO emission due to very low τ_{CO}
  - increased CO/^{13}CO line ratio and line width



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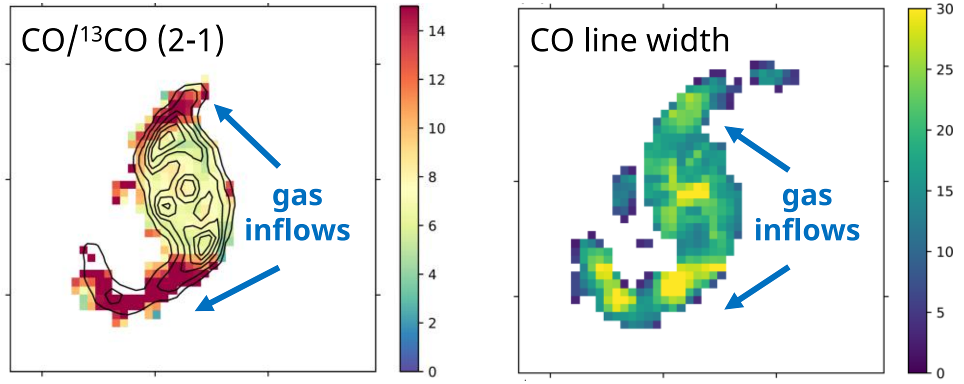
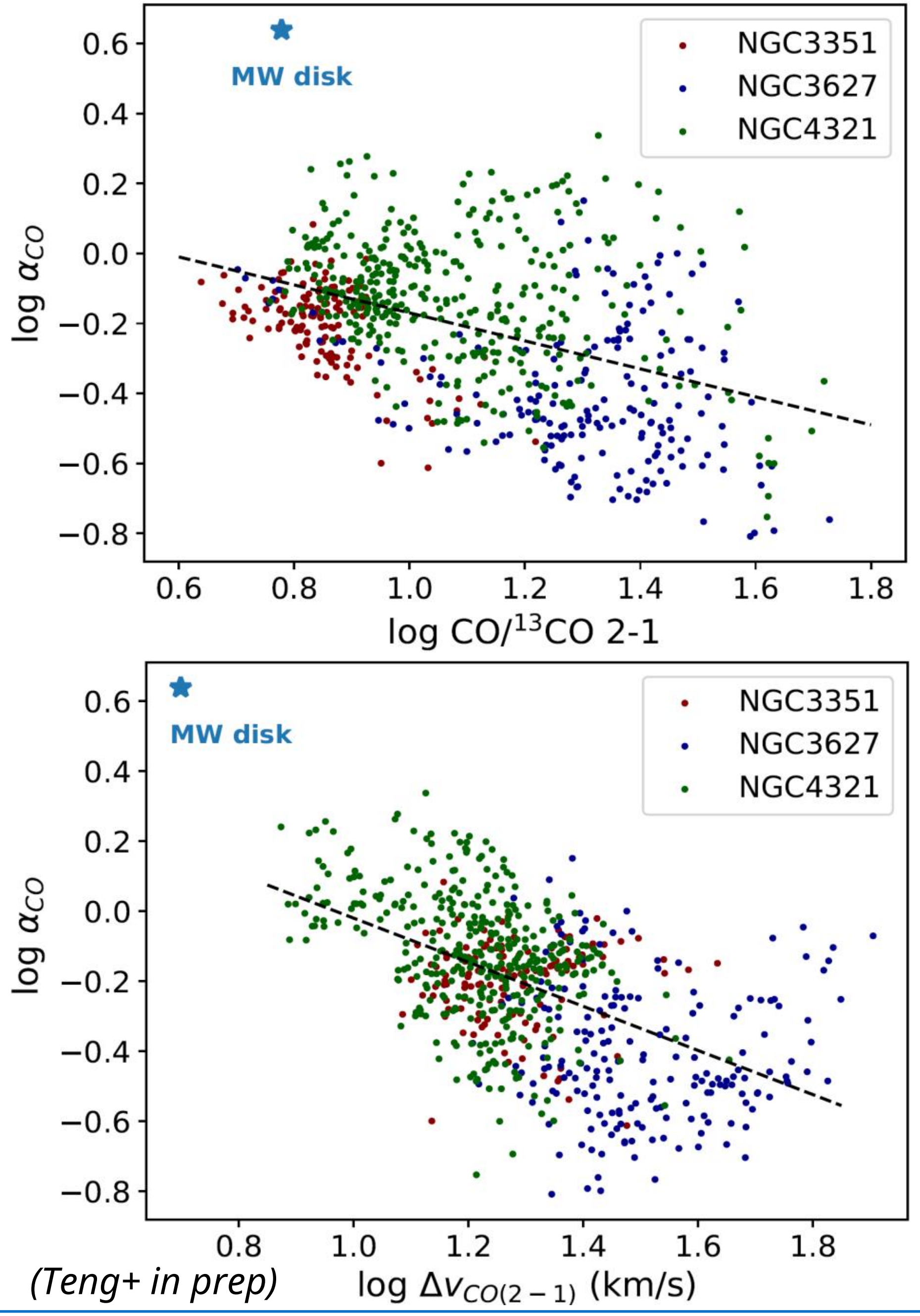


- The CO/^{13}CO (2-1) ratio mainly reflects τ_{CO}
- Higher velocity dispersion in barred galaxy centers decreases τ_{CO} and thus α_{CO}, since $\tau_{CO} \propto N_{CO}/\Delta v$



(Teng+ in prep)

THANK YOU!

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https://elthateng.github.io/

Papers: Y.-H. Teng et al. 2022, *ApJ*, 925, 72

Y.-H. Teng et al. 2023, *in prep*