Unveiling HI and Gas-PAH Relations at Sub-kpc Scales: A VLA Perspective

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0. Gas and PAH basics

Gas: Stars form in cold, dense molecular clouds in the interstellar medium (ISM). Neutral gas fuels star formation and is a key to diagnosing star-forming conditions. Therefore, observing neutral gas is essential to understand star formation and galaxy evolution. Two key components of neutral gas are the molecular and atomic phases.

- Molecular gas: could be traced by low-J CO rotational emission lines, e.g. CO (2-1) at 1.3 mm (230 GHz).
- Atomic gas: could be traced by the HI 21 cm (1.42 GHz) spin-flip transition.

PAHs: Polycyclic Aromatic Hydrocarbons (PAHs) are a class of molecules made of aromatic rings. They emit strong C-H and C-C stretch and bending features at 3.3, 6.2, 7.7, 8.6 and 11.3 μm. PAHs take $\sim$ 4% of the interstellar dust mass in star-forming galaxies.

Expectations: We expect the observed PAH intensity ($I_{\rm PAH}$) to scale with gas surface density ($\Sigma_{\rm gas}$), where the scaling relation depends on dust-to-gas mass ratio (D/G), PAH-to-dust mass fraction ($q_{\rm PAH}$), and strength of interstellar radiation field (U). To the first order, we expect:

$$\mathbf{I_{PAH} \propto D/G \times q_{PAH} \times U \times \Sigma_{gas}}$$

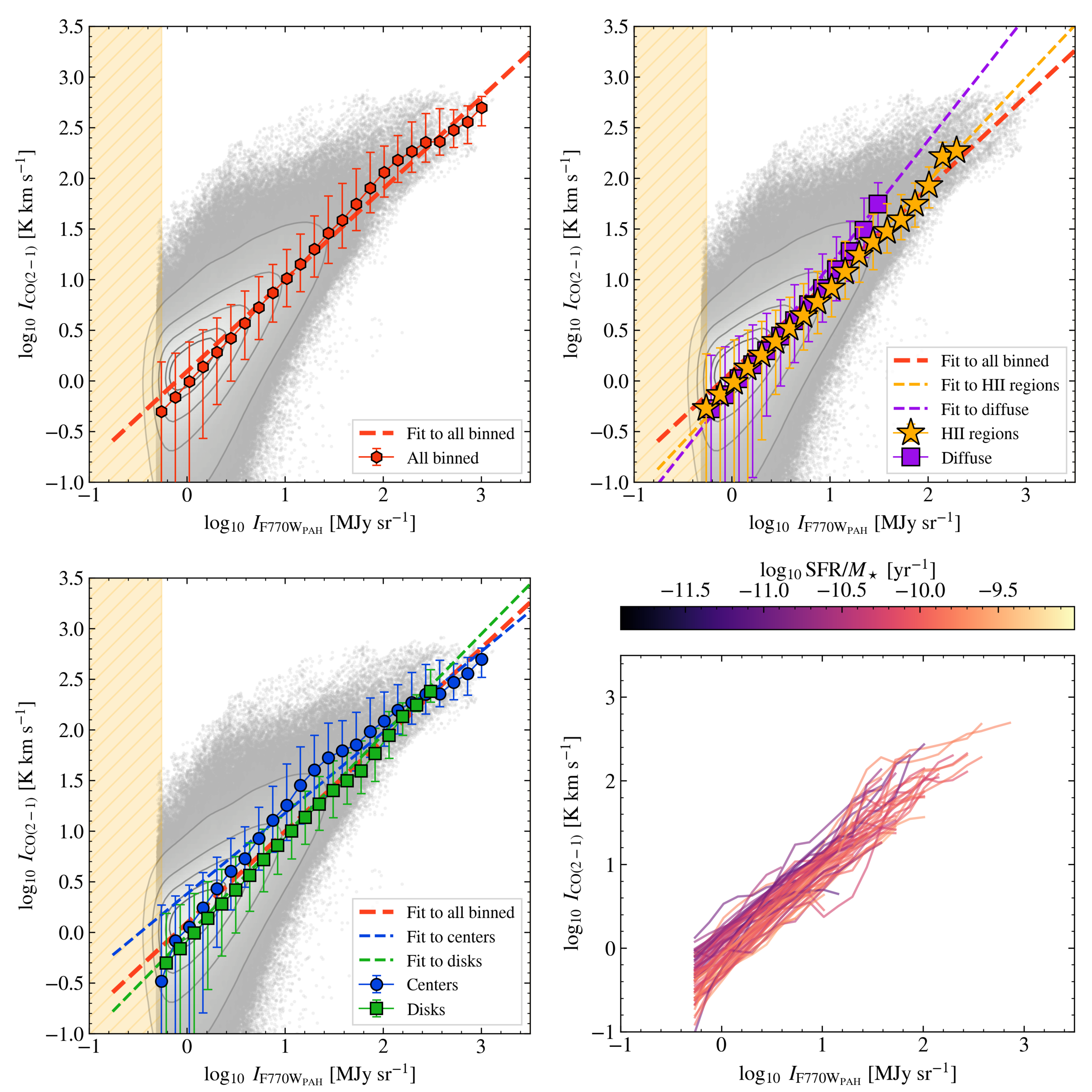
1. Recent Observations with JWST

JWST and PAH: At $z \sim 0$, several JWST filters capture PAH emissions perfectly, e.g. NIRCam F335M for 3.3 μm; MIRI F770W/F1130W for 7.7/11.3 μm. Other filters (e.g. F300M, F360M, and F2100W) also provide information on infrared continuum and stochastic emission. We now have unprecedented resolution and sensitivity for $I_{\rm PAH}$.

The PHANGS Collaboration: The Physics at High Angular Resolution in Nearby Galaxies Survey (PHANGS) collaboration is interested in the baryon cycle in star-forming galaxies at molecular-cloud-scale resolution. Two relevant observations are:

- PHANGS-ALMA: CO (2-1) at 150 pc resolution in the centers of 90+ galaxies (Leroy+21, ApJS, 257, 43).
- PHANGS-JWST: A JWST treasury survey of F335M, F770W, F1130W and ancillary filters, $\sim$ 70 PHANGS galaxies observed as of Cycle 2 (Lee+23, ApJ, 944, 17).

The PHANGS collaboration has found **an almost-linear relation between $I_{\rm PAH}$ and $L_{\rm CO}$** despite various factors that could alter their scaling relation. **Whether this scaling could be extended to atomic-gas-dominated environments remains unclear.**



X	$N_{\rm gal}$	$N_{\rm pix}$	$\log_{10}$ CO/X	r	m	σ
F335M$_{\rm PAH}$	19	296834	1.27 ± 0.38	0.58	1.01 ± 0.10	0.44
F770W$_{\rm PAH}$	70	2090731	0.03 ± 0.35	0.64	0.90 ± 0.07	0.43
F770W	70	2120025	-0.00 ± 0.35	0.64	0.91 ± 0.07	0.43
F1130W	20	972892	-0.12 ± 0.37	0.63	1.02 ± 0.09	0.44

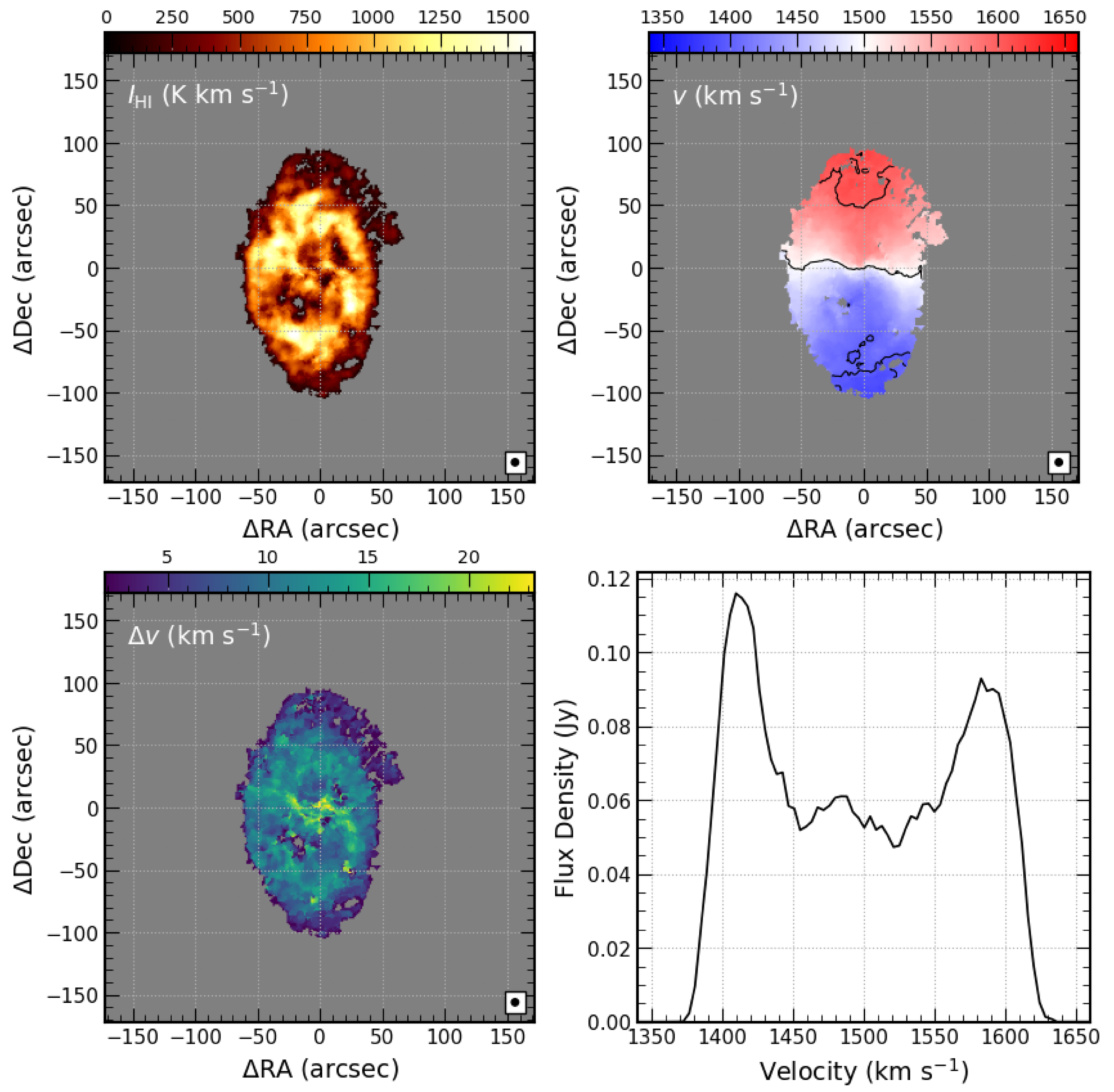
Columns: X – JWST band compared to CO (2-1), where the subscript "PAH" indicates that stellar continuum has been subtracted; $N_{\rm gal}$ – number of galaxies used in this analysis; $N_{\rm pix}$ – number of sightlines included in this analysis; $\log_{10}$ CO/X – log of median ratio of CO (2-1) [K km s^{-1}] to intensity in [MJy sr^{-1}] in X; r – rank correlation relating CO (2-1) and X; m – best-fit power-law index of CO (2-1) to X; σ – rms scatter [dex] from the best fit.

Leroy+23, ApJL, 944, L9; Chown+25, ApJ, 983, 64

2. New HI Observations

Pushing to Atomic ISM: Existing HI 21 cm data lacks the resolution or sensitivity for Gas-PAH analysis. We conducted new observations at $\sim 7''$ resolution, 1-$\sigma \sim 1$ M$_\odot$ pc^{-2} to extend the analysis to atomic ISM. The observations are being done with the VLA B+C+D configurations (4 galaxies) and MeerKAT (10+ galaxies).

Example new VLA observation: NGC1087 (15.8 Mpc, $7'' \sim 542$ pc)



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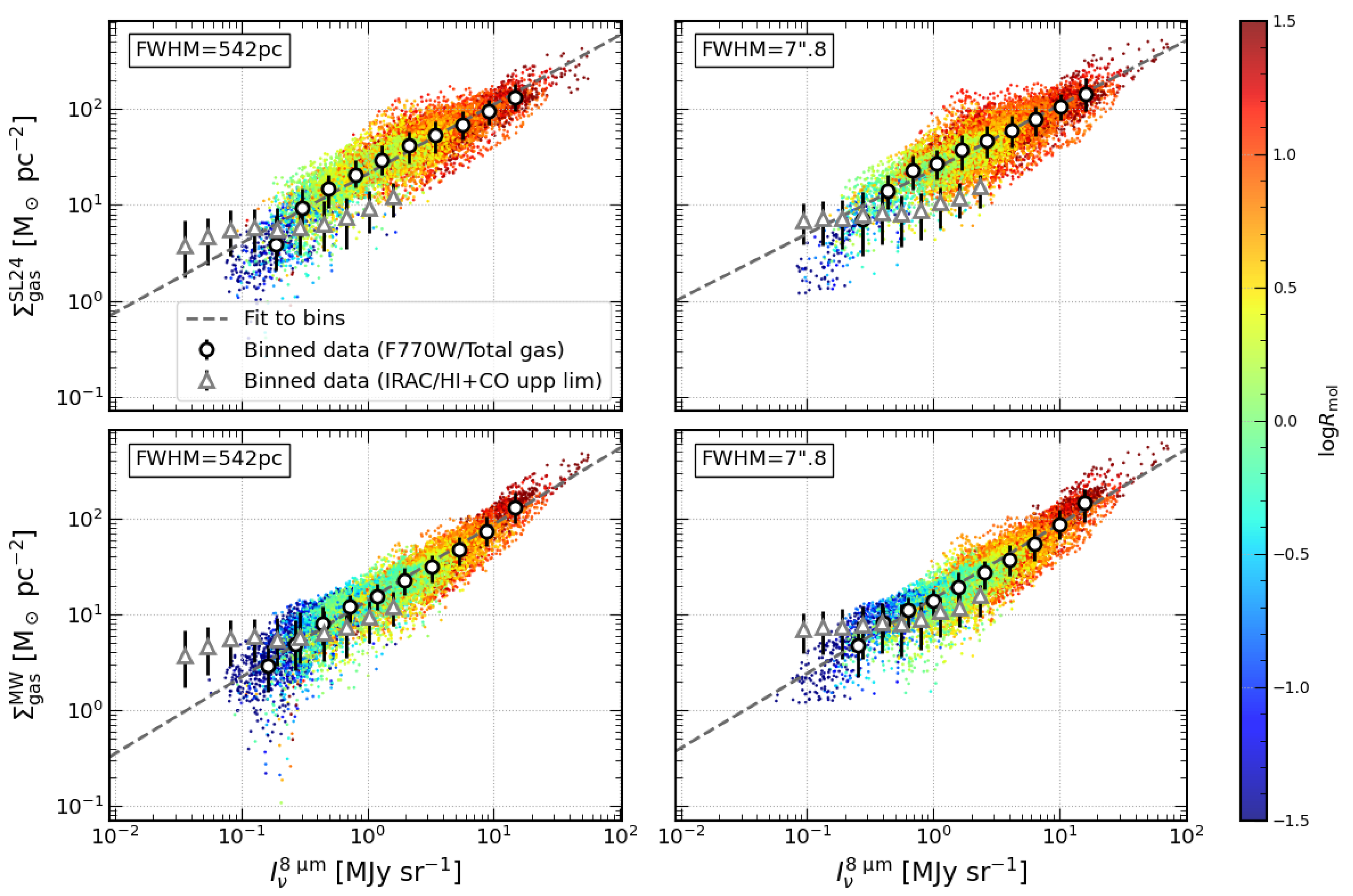
3. Preliminary Analysis



We combine the new VLA, PHANGS-ALMA, PHANGS-JWST, and *Spitzer*/IRAC data (LVL and SINGS)

- After considering the CO-to-H$_2$ conversion factor, the Gas-PAH relation is no longer linear. Instead, it has a power-law index shallower than a linear relation.
- The power law extends to $R_{\rm mol} = $ H$_2$/HI < 1.
- In the outer disk (HI-only & IRAC 8 μm), the Gas-PAH relation is weak or no longer exists.

X	Bin range	m	R^2	ρ
F335M$_{\rm PAH}$	-2.4 to -0.2	0.51±0.06	0.891	0.94
F770W$_{\rm PAH}$	-0.8 to 1.2	0.72±0.02	0.992	1.00
F770W	-0.8 to 1.2	0.72±0.03	0.988	0.99
F1130W	-0.8 to 1.3	0.68±0.03	0.980	0.99

Columns: X – JWST band compared with $\Sigma_{\rm gas}$; Bin range – The range of the JWST band [log(MJy sr^{-1})]; R^2 – R-squared value of the fitting; ρ – Pearson's correlation coefficient of binned data. Using $\alpha_{\rm CO}^{\rm SL24}$ and 542 pc data.

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