The Effect of the Virgo Environment on the Molecular Gas and Star Formation Efficiency in VERTICO Galaxies

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\textbf{Galactic Ecosystem: Opportunities and Diagnostics in the Infrared and Beyond}
Star formation activity plays a key role in driving galaxy evolution.

- Stars form in Giant Molecular Clouds (GMCs) in which the molecular gas is the main constituent (e.g., Sanders et al. 1985).
- We use carbon monoxide molecule (CO) to trace the molecular gas ($\Sigma_{mol}$) through its low-$J$ transitions.
- Increase of stellar mass is quantified through the star formation rate (SFR).
- The Kennicutt (1989, 1998) seminal studies shown a strong correlation between $\Sigma_{SFR}$ and $\Sigma_{gas}$.

Introduction

Bigiel et al. (2008)
Goals

We investigate the Star-Formation Efficiency of the molecular gas, $\text{SFE}_{\text{mol}} = \frac{\Sigma \text{SFR}}{\Sigma \text{mol}}$, in the local universe.

- Almost constant $\text{SFE}_{\text{mol}}$ as a function of galactocentric radius in field galaxies (e.g., Leroy et al. 2013; Villanueva et al. 2021).

In this work, we analyze the environmental effects of the Virgo cluster on:

1. The molecular and stellar exponential scale lengths.
2. $R_{\text{mol}} = \frac{\Sigma \text{mol}}{\Sigma \text{atom}}$ vs galactocentric radius.
3. $\text{SFE}_{\text{mol}}$ vs galactocentric radius
Methods

We focus on the SFE as a function of basic quantities in galaxies selected from the Virgo Environment Traced In CO survey (VERTICO; Brown et al. 2021).

- **VERTICO**: CO(J=2-1) ALMA ACA and TP data.
- **Plenty of ancillary data**: HI (VIVA survey), SFR (GALEX NUV + WISE band 4), and **stellar masses** (WISE band 1).
- **51 VERTICO** late-type galaxies.

- To increase SNR we do **spectral stacking of CO**, in radial bins using HI velocities from VIVA survey.
- Use only galaxies with $i < 75^\circ$ to minimize beam smearing effects.
- **34 galaxies** in total.
Methods

For quantities derived from the CO line emission data:

- We assume $I_{\text{co}(1-0)}/I_{\text{co}(2-1)} = 0.7$ (Brown et al. 2021).
- We obtain radial profiles for $\Sigma_{\text{mol}}$, $\Sigma_{\text{atom}}$, $\Sigma_{\star}$, and $\Sigma_{\text{SFR}}$ ($\alpha_{\text{co}} = 4.3 \, M_\odot \, [K \, \text{km s}^{-1} \, \text{pc}^{-2}]^{-1}$).

We use the classification of the HI-perturbation (based on morpho-kinematics; Yoon et al. 2017), to analyze the 34 selected galaxies:
Results: Exponential Scale Lengths

We compute the exponential scale lengths for the molecular gas and stars:

- We fit exponential profiles, when possible, to the molecular and stellar radial profiles.
- We get the exponential scale lengths, $l_{\text{mol}}$ and $l_{\star}$.
- Close to $1:2$ relation between them.

1. $\text{H}_2$ is noticeably more centrally concentrated than stars when compared to field galaxies (e.g. EDGE-CALIFA)
2. Higher-classes tend to have shorter $l_{\text{mol}}$ than lower-classes.
3. The more perturbed the HI, the more centrally concentrated the $\text{H}_2$. 

![Graph showing exponential scale lengths for molecular gas and stars]
Results: $R_{\text{mol}}$ vs Galactocentric Radius-CLASS

We analyze the molecular-to-atomic gas ratio, $R_{\text{mol}} = \Sigma_{\text{mol}}/\Sigma_{\text{atom}}$, for:

- Annuli (left panel).
- Galaxies by computing the integrated molecular and atomic gas masses within one effective radius, $R_e$ (right panel).

1. $R_{\text{mol}}$, in the aggregate, decreases systematically with radius.
2. Most $R_{\text{mol}}$ are within the range for normal spirals (e.g. HERACLES).
3. Global $R_{\text{mol}}$ systematically increases with class.
4. The more perturbed the HI, the larger the $R_{\text{mol}}$ is.
Results: SFE_{mol} vs Galactocentric Radius-CLASS

We compute the Star-Formation Efficiency of the molecular gas, \( \text{SFE}_{\text{mol}} = \frac{\Sigma \text{SFR}}{\Sigma \text{mol}} \), for the two prior cases.

1. Similarly to \( R_{\text{mol}} \), most of the SFE_{mol} are within the range of normal spirals (e.g. HERACLES).
2. Global SFE_{mol} systematically decreases with class.
3. The more perturbed the HI, the less efficient H\(_2\) is at forming stars.
Summary to date

i) We find a close to **1:2 relation between the molecular and stellar exponential scale lengths**. On average, $\text{H}_2$ in VERTICO galaxies is **more centrally concentrated than stars** when compared to field galaxies.

ii) There is a **systematic increase of the global molecular-to-atomic gas ratio** from lower- to higher-classes. In general, the more perturb in HI a galaxy is, then the larger the $R_{\text{mol}}$ is.

iii) There is also a **systematic decrease** of global $SFE_{\text{mol}}$ from lower- to higher-classes; the more perturb in HI a galaxy is, then the less efficient in forming stars the $\text{H}_2$ is.
Future work

Expand the analysis of VERTICO galaxies by including dynamical indicators:

How does the Virgo cluster environment modify the stability of the gas?

- We will use the CO rotation curves for VERTICO galaxies (Bisaria et al. in prep.) to compute the Toomre-$Q$ by using the Romeo & Falstad (2013), $Q_N$. 
Results: Radial profiles
Results: Molecular and stellar effective radii

1. $\text{H}_2$ is noticeably more centrally concentrated than stars when compared to field galaxies (e.g. EDGE-CALIFA).
2. Higher-classes tend to have shorter $l_{\text{mol}}$ than lower-classes.
3. The more perturbed the HI, the more centrally concentrated the $\text{H}_2$.

As for exponential scale lengths:

1. $\text{H}_2$ is noticeably more centrally concentrated than stars when compared to field galaxies (e.g. EDGE-CALIFA)
2. Higher-classes tend to have shorter $l_{\text{mol}}$ than lower-classes.
3. The more perturbed the HI, the more centrally concentrated the $\text{H}_2$. 
Results: $R_{\text{mol,} \star}$ and $R_{\text{atom,} \star}$ vs Galactocentric Radius

We analyze the molecular-to-stellar, $R_{\text{mol,} \star} = \Sigma_{\text{mol}} / \Sigma_{\star}$, and the atomic-to-stellar, $R_{\text{atom,} \star} = \Sigma_{\text{atom}} / \Sigma_{\star}$.

1. Almost constant global $R_{\text{mol,} \star}$ with HI-Class.
2. $R_{\text{atom,} \star}$ decreases systematically with HI-Class.

Villanueva et al. (in prep.)