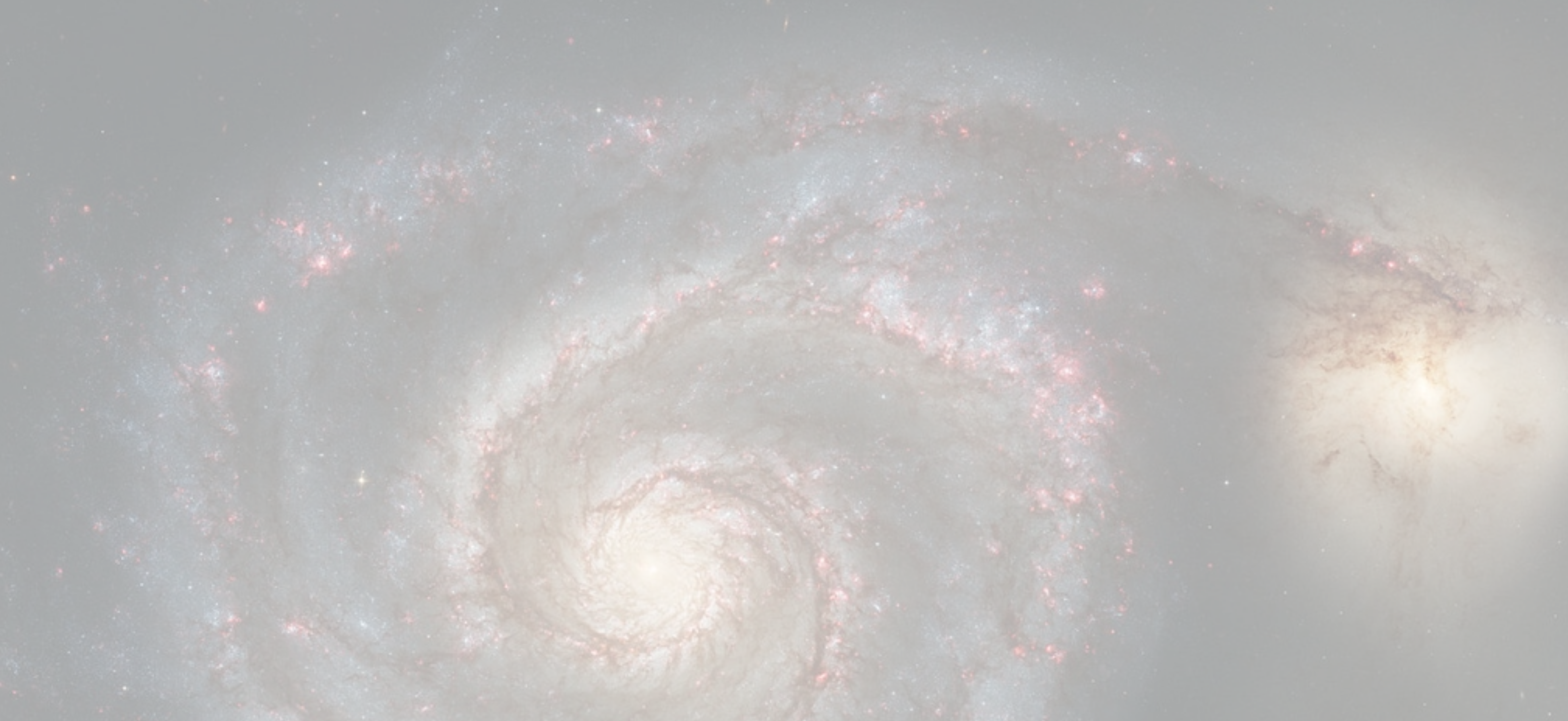


GMC Populations of Nearby Galaxies

Andreas Schruba, MPE for Annie Hughes, IRAP

PAWS: **Adam Leroy**, **Dario Colombo**, Eva Schinnerer, Sharon Meidt, Jerome Pety, Clare Dobbs, Gaelle Dumas, Todd Thompson, Santi Garcia-Burillo, Carsten Kramer, Karl Schuster

CANON: Jin Koda, Jen Donovan-Meyer, M31: Andreas Schruba

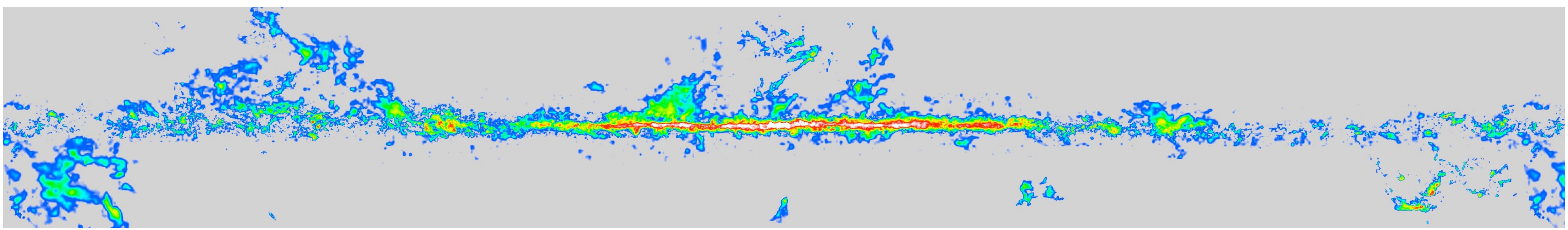
MAGMA: Tony Wong, Juergen Ott

Motivation

Milky Way's molecular mass is ~ 2 x10^9 $M_\odot$

n ~ 100 cm^{-3} ➡ t_{ff} ~ 4 x 10^6 yr ➡ SFR ~ 500 $M_\odot$ yr^{-1}!

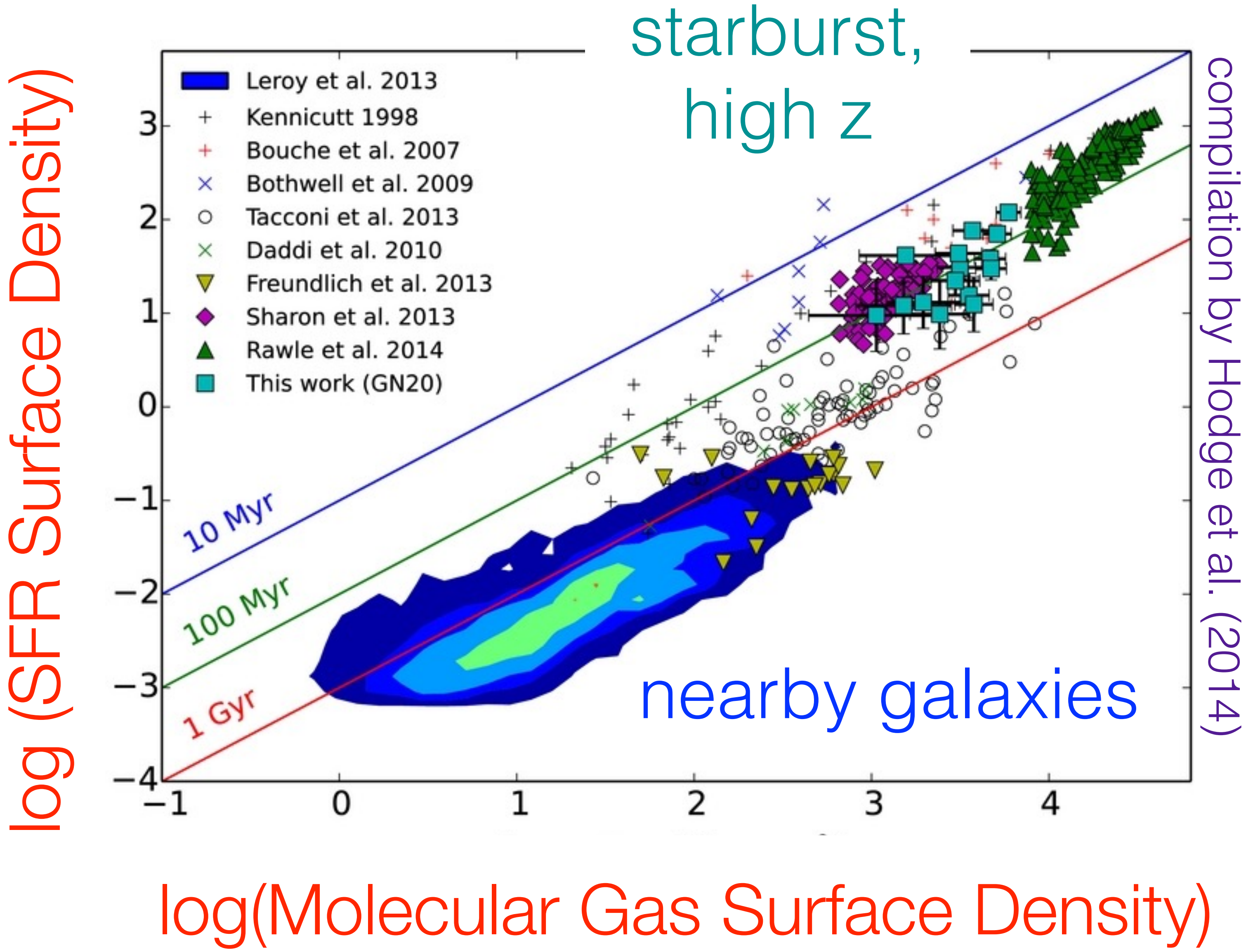
Observed SFR is 0.7 to 1.5 $M_\odot$ yr^{-1}

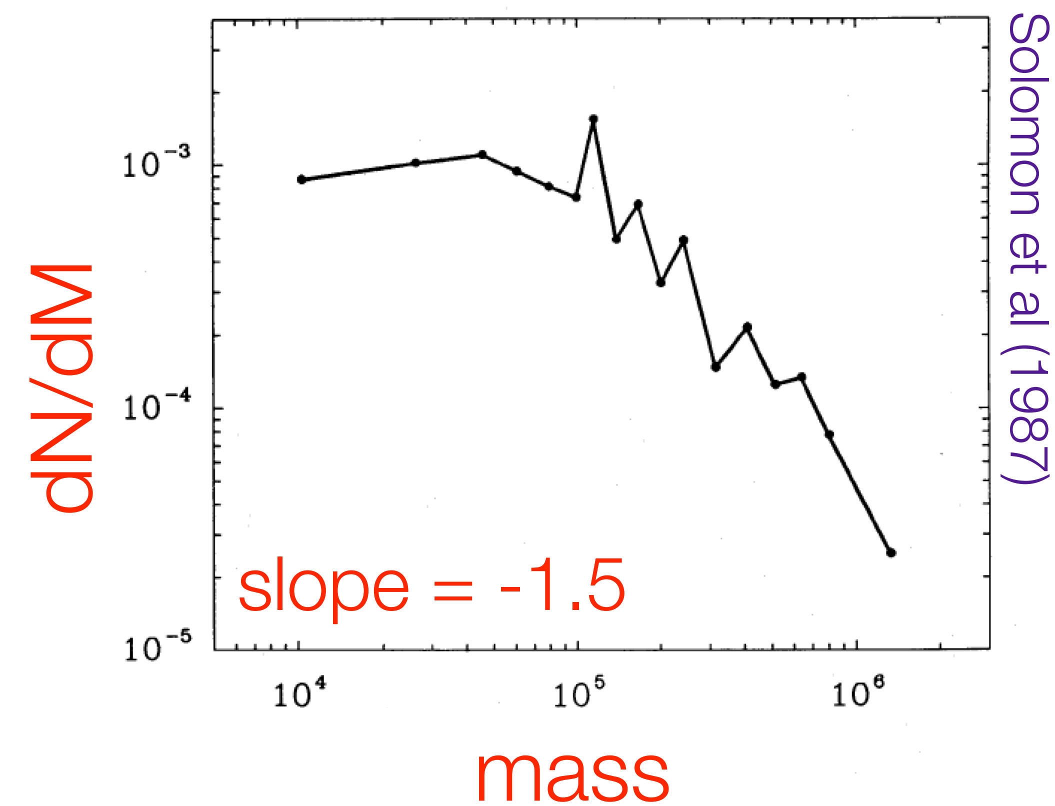


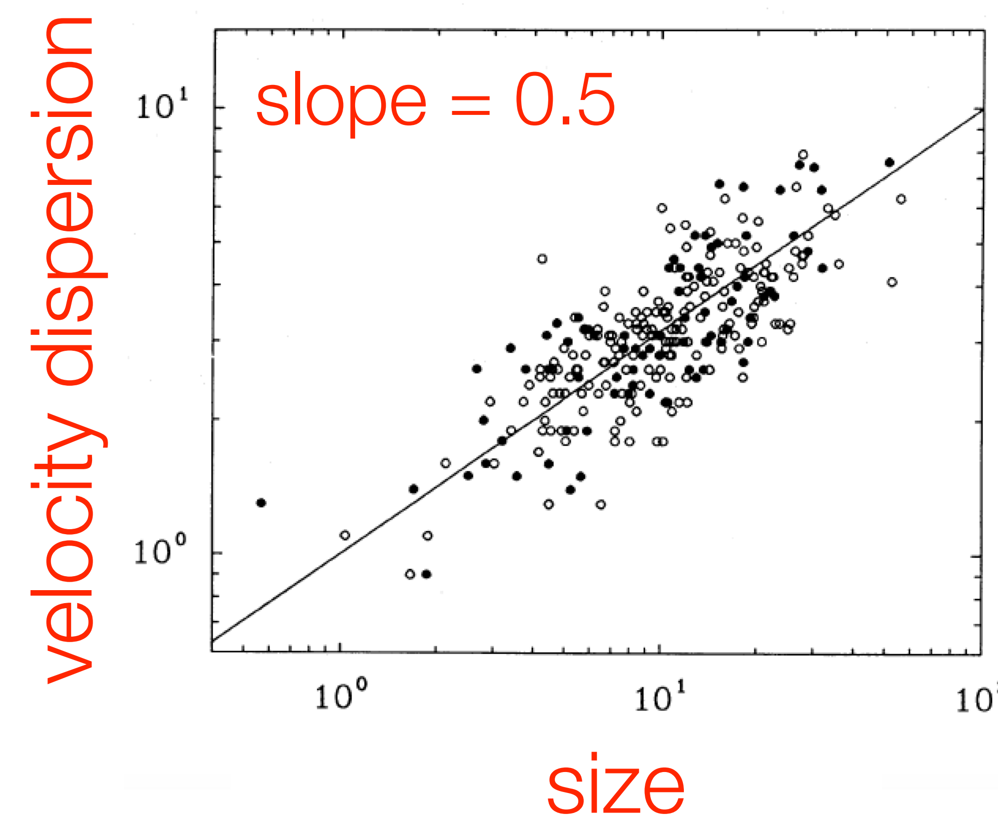
Explanation depends on whether GMCs are:

- bound + long-lived — e.g. Krumholz & McKee (2005)
- unbound + short-lived — e.g. Dobbs et al (2011)
- collapsing + short-lived — e.g. (Ballesteros-Paredes et al. (2011)

A Resolved Extragalactic SF 'Law'







stars form from molecular gas with a constant depletion time of ~2 Gyr in nearby disk galaxies

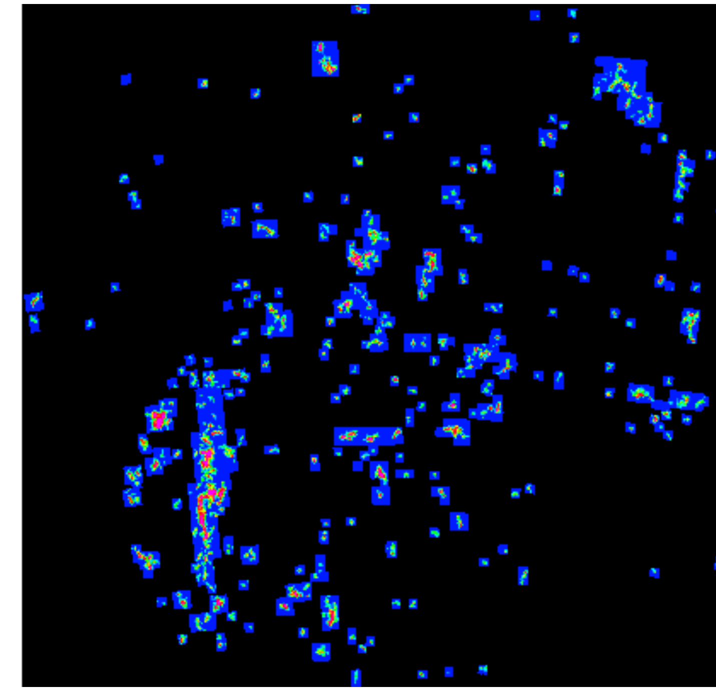
This Talk

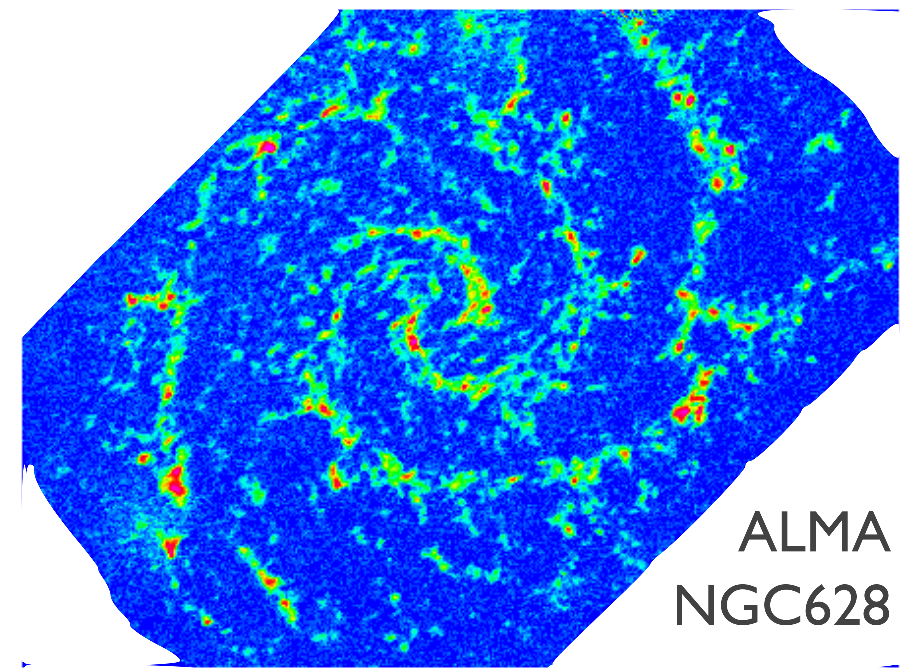
Do the properties of a GMC population depend on host galaxy properties?

Do galaxy properties & processes influence GMC formation and evolution?

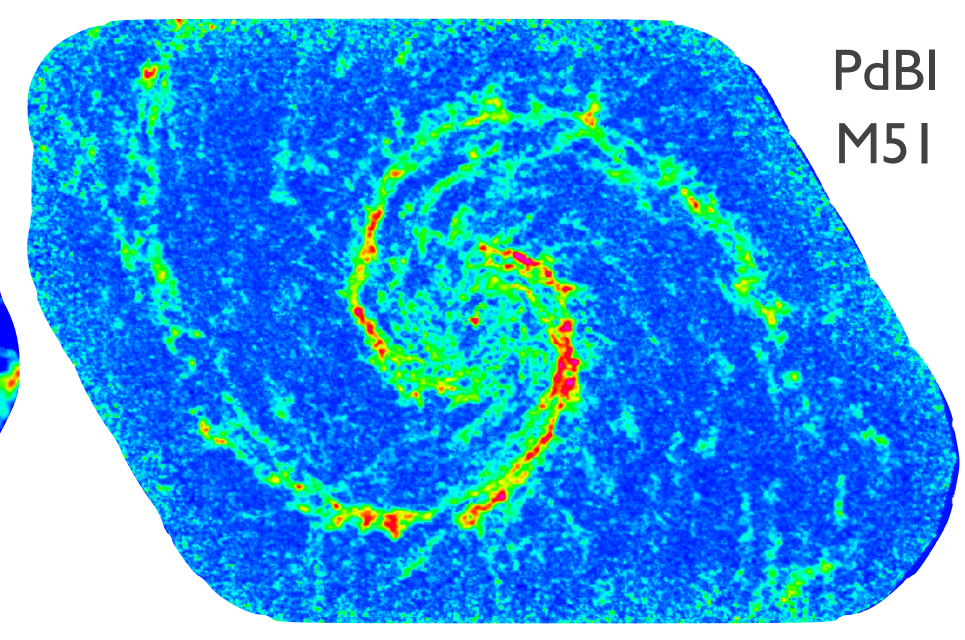
Do GMC properties matter for star formation (on galactic scales)?

MAGMA
LMC

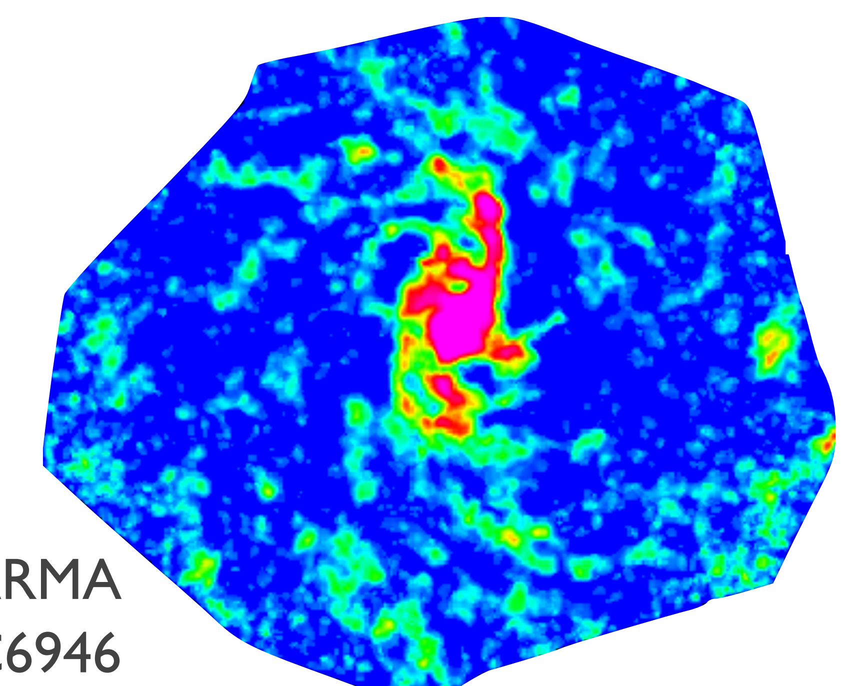




ALMA
NGC628



PdBI
M51

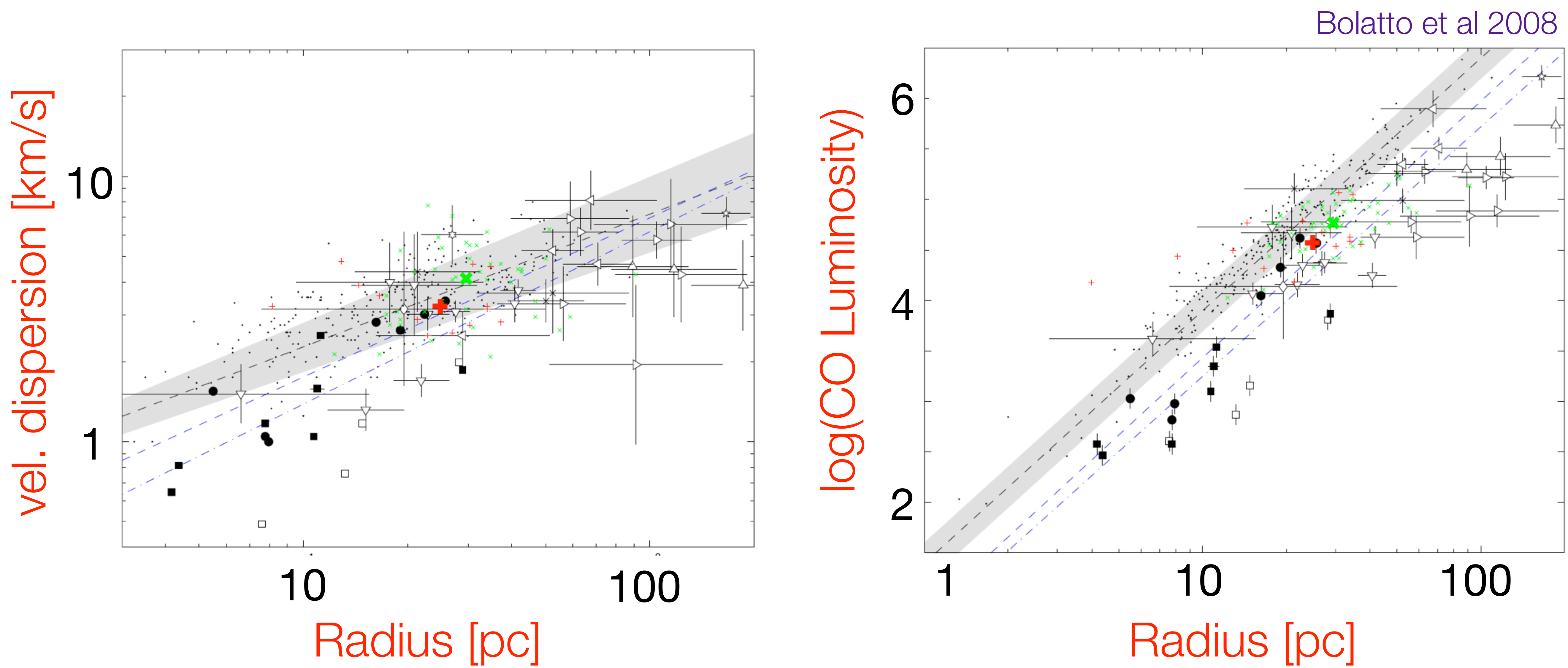


CARMA
NGC6946

NGC253: Leroy
M31: Schruba
NGC4526: Utomo
CANON: Donovan-Meyer
M33: Druard, Gratier, Braine
NGC6822: Gratier
IC342: Hirota
M83: Hirota

Are GMC Properties Universal?

Confirmation from Local Group GMCs?

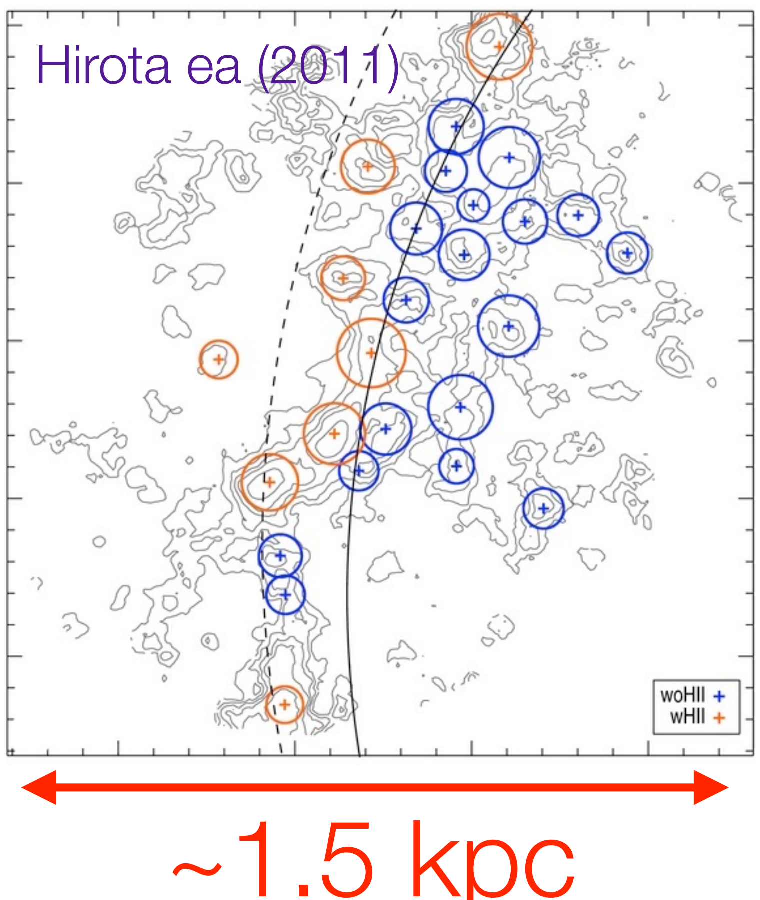


"GMCs identified on the basis of their CO emission exhibit remarkably uniform properties from galaxy to galaxy…"

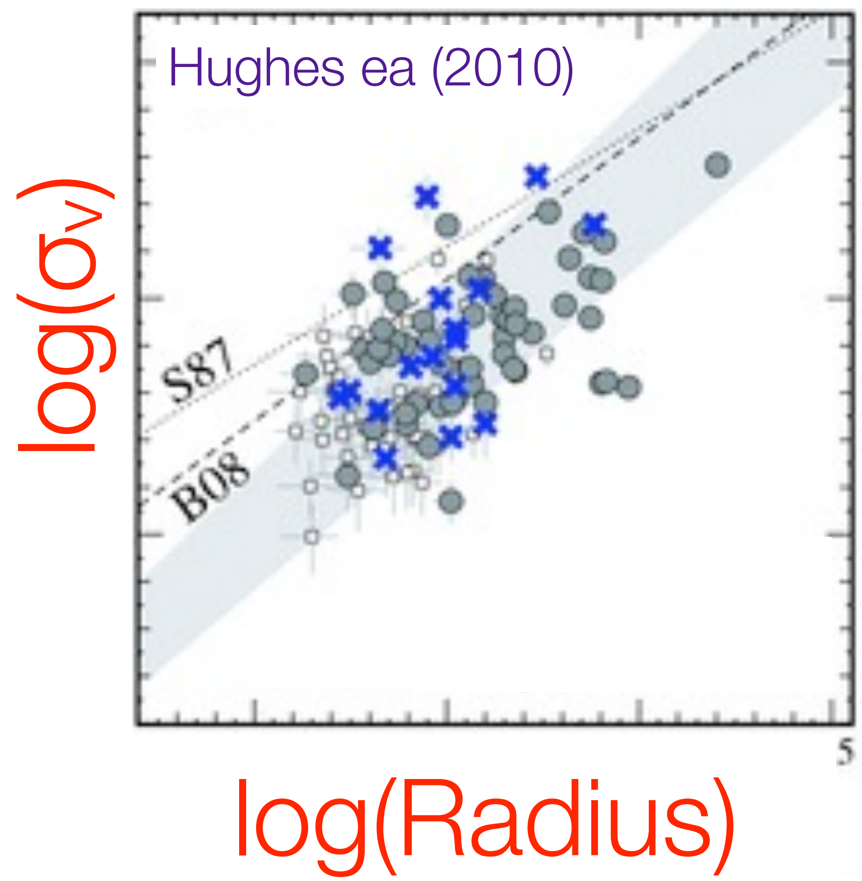
But...

Some observational evidence that GMC dynamical properties (e.g. mass, linewidth) may depend on galactic environment

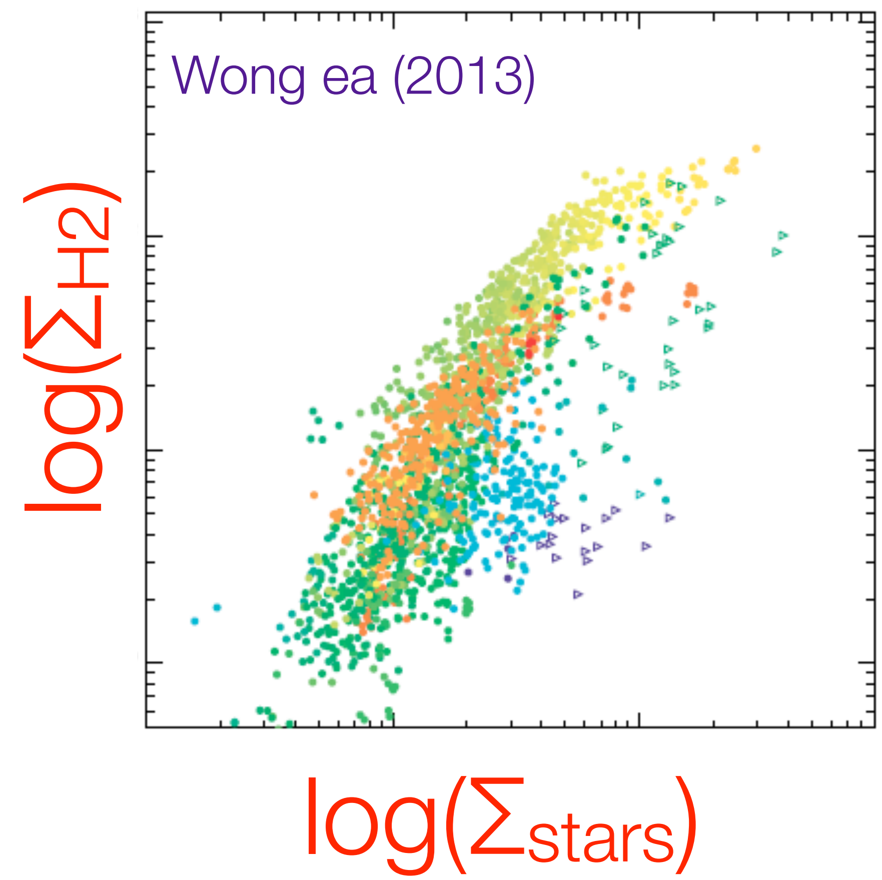
IC342



LMC



CARMA-STING

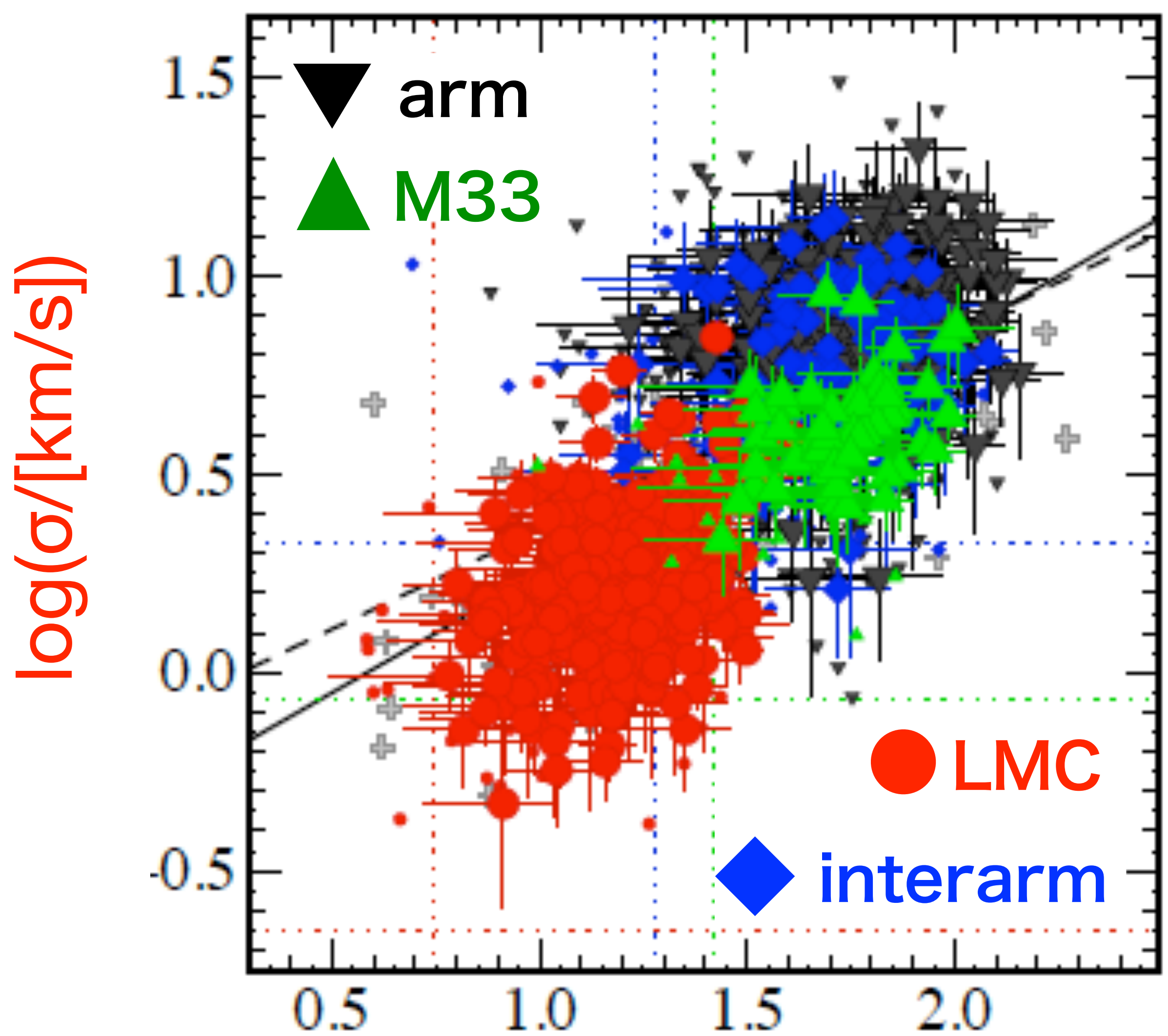


+ clear evidence for mass evolution through spiral arms

e.g. Koda ea (2009), Egusa ea (2011)

Size-linewidth relation: M51, M33, LMC

intrinsic



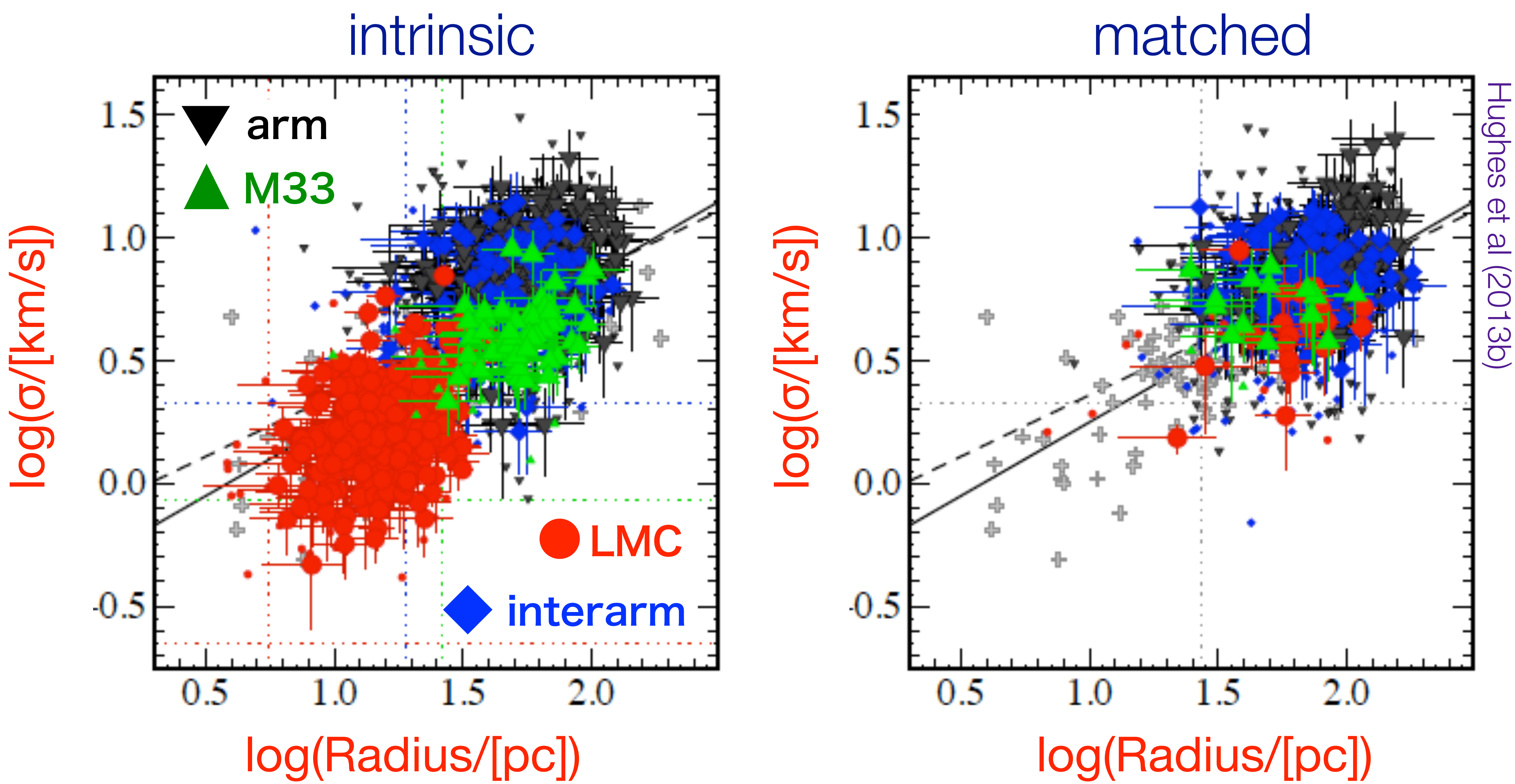
this ‘correlation’ largely due to resolution effects

Decomposition applied to CO data cubes with their original spatial and spectral resolution

Data points cluster around the resolution limits

Scaling relations obtained from composite samples must be interpreted with caution: beware observational bias

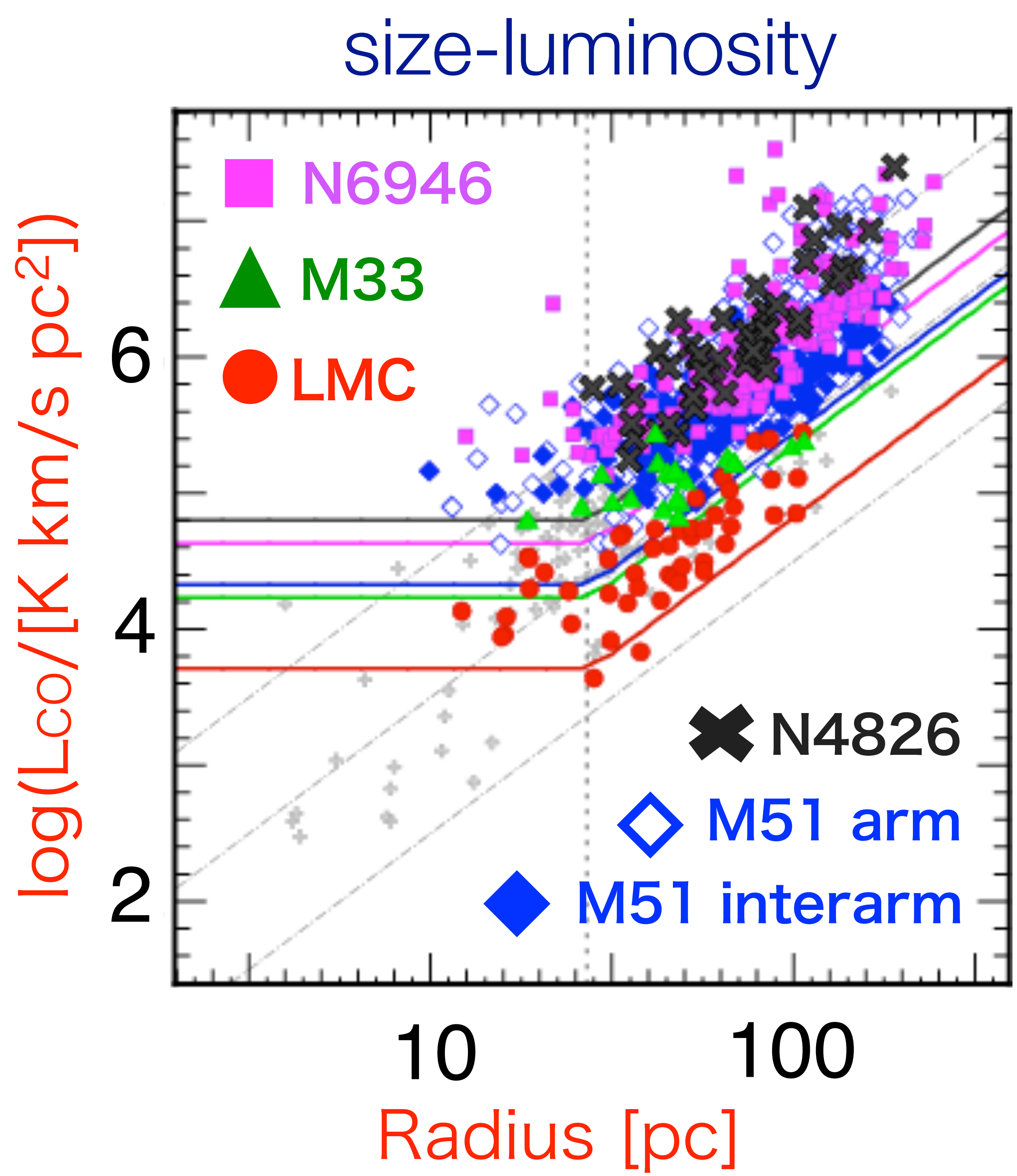
Size-linewidth relation: M51, M33, LMC



this 'correlation' largely due to resolution effects

at fixed size, M51 clouds still have higher σ

R-Lco relation: Nearby Galaxies



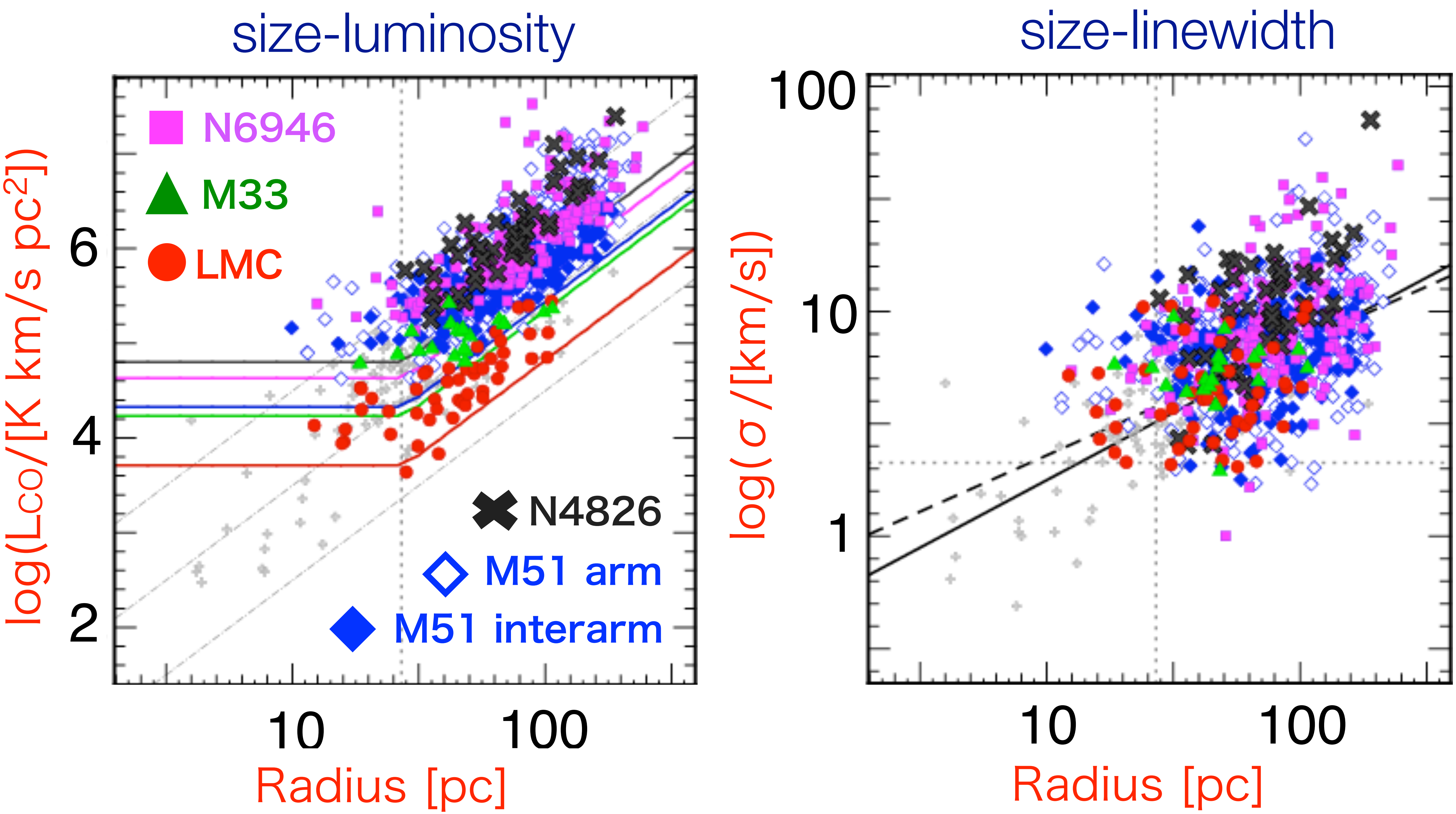
Within M51, slope and normalisation of size-luminosity relationship varies

<Σ> at fixed scale also varies between galaxies

difference in <Σ> between spiral and dwarf galaxies (factor of ~10) exceeds X_{CO} variations (factor of ~2 to 3)

Hughes et al (2013b)

Extragalactic Larson Relations at 50pc



<σ>/R and Σ of GMCs vary with galactic environment

A consequence of external pressure?

$$\frac{M}{R^2} \simeq 190 \pm 90 \left(\frac{P_e}{10^4\, k_B\, \mathrm{cm}^{-3}\, \mathrm{K}} \right)^{1/2} M_\odot\, \mathrm{pc}^{-2}\,,$$

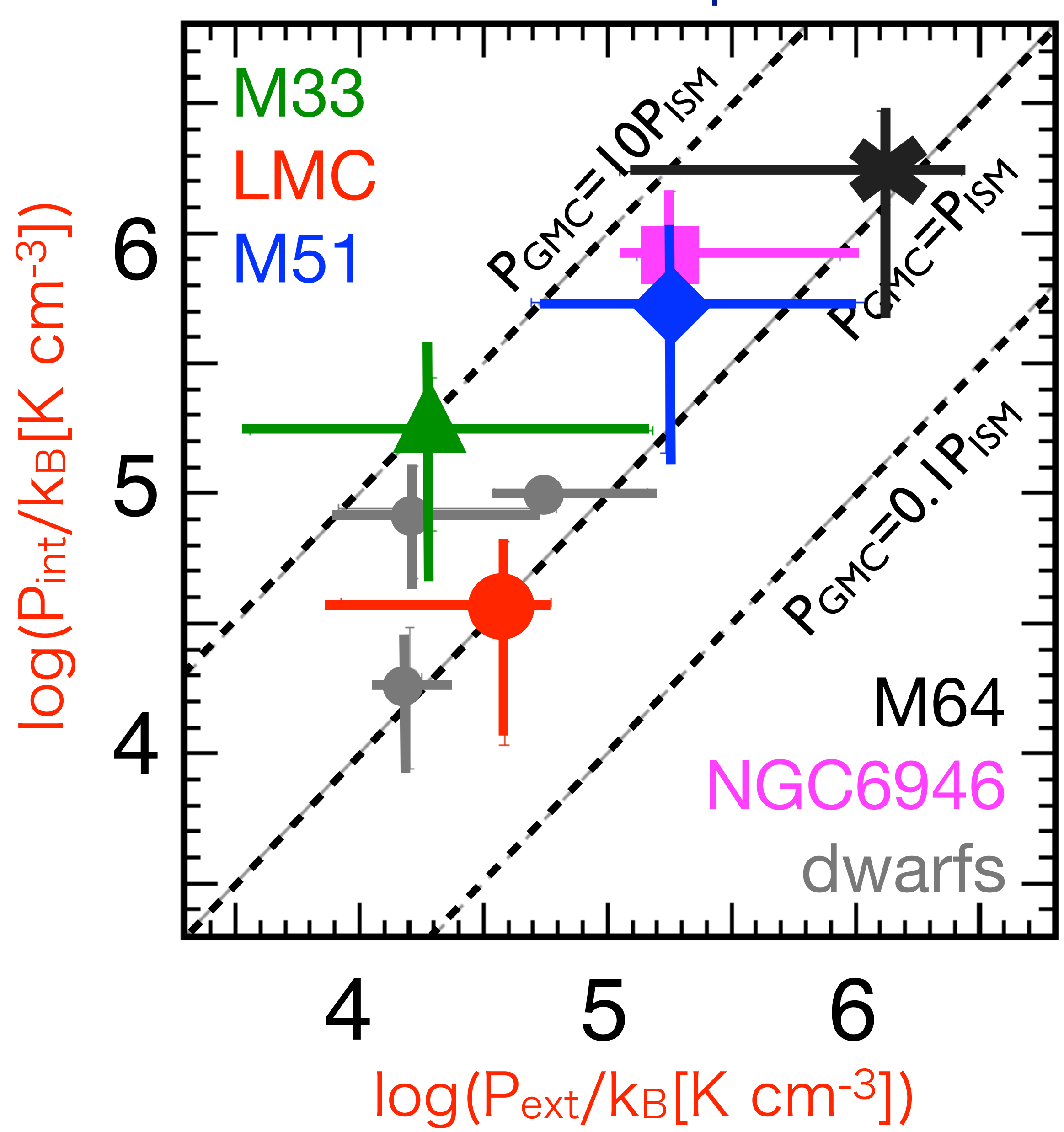
$$\frac{c}{R^{1/2}} \simeq 0.4 \pm 0.1 \left(\frac{P_e}{10^4\, k_B\, \mathrm{cm}^{-3}\, \mathrm{K}} \right)^{1/4} \mathrm{km\ s^{-1}\ pc^{-1/2}}$$

e.g. Elmegreen (1989)

➡ if $P_{int} \sim P_{ext}$, environment more likely to influence cloud stability, dense gas mass function, star formation activity, GMC evolution...

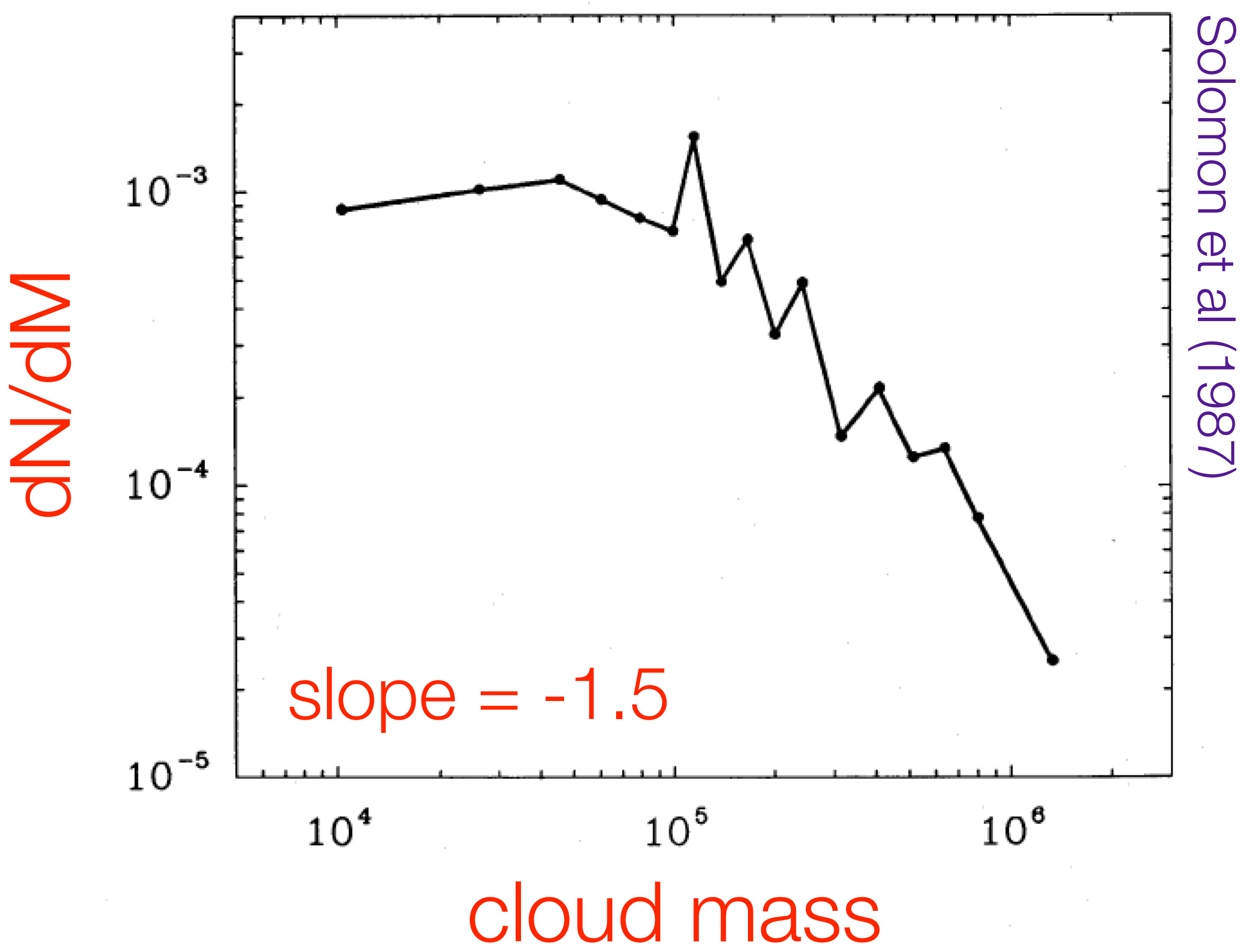
$$P_{ext} = \frac{\pi G}{2} \Sigma_g \left(\Sigma_g + \frac{\sigma_g}{\sigma_*} \Sigma_* \right)$$

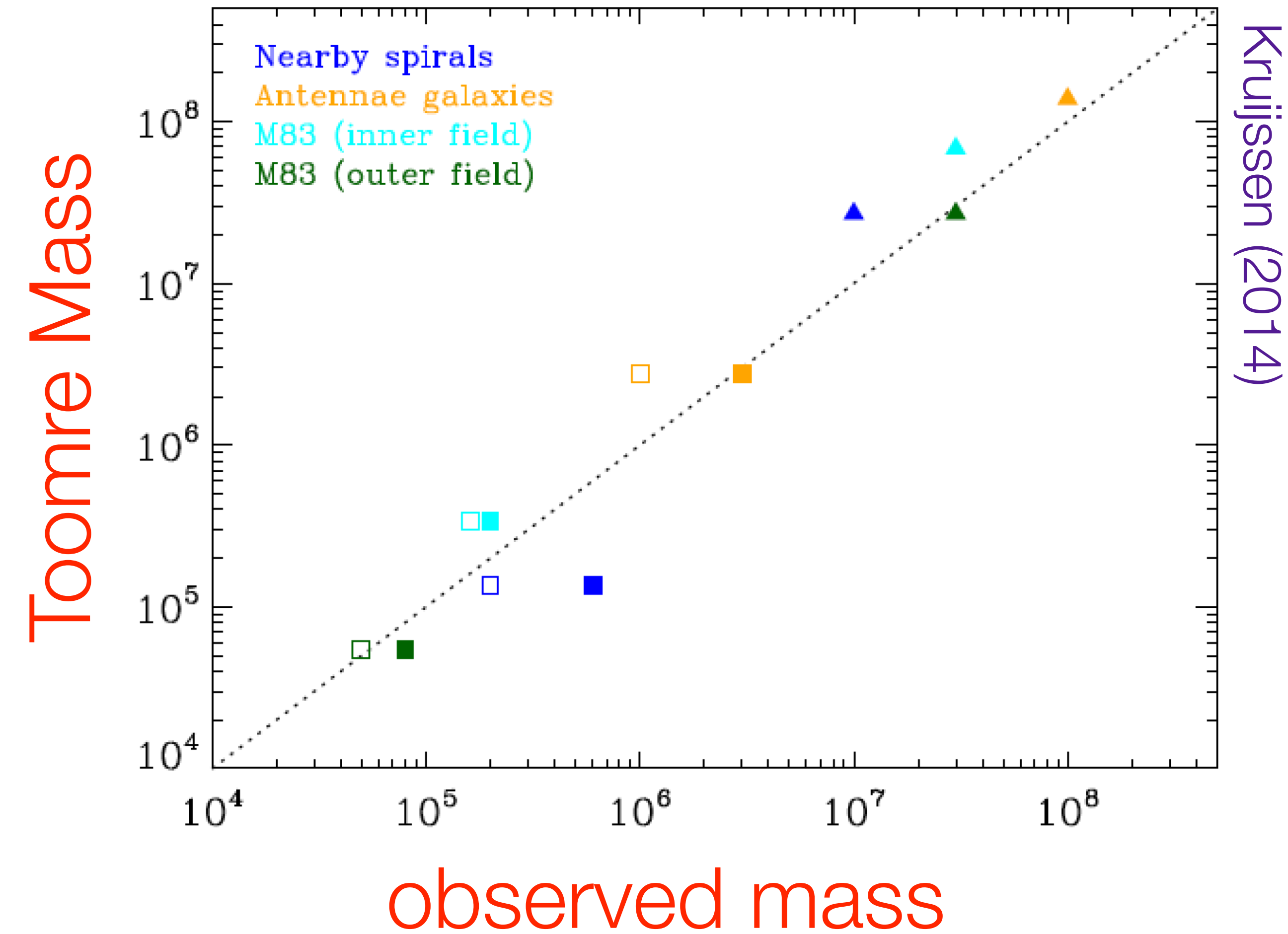
GMC vs ISM pressure



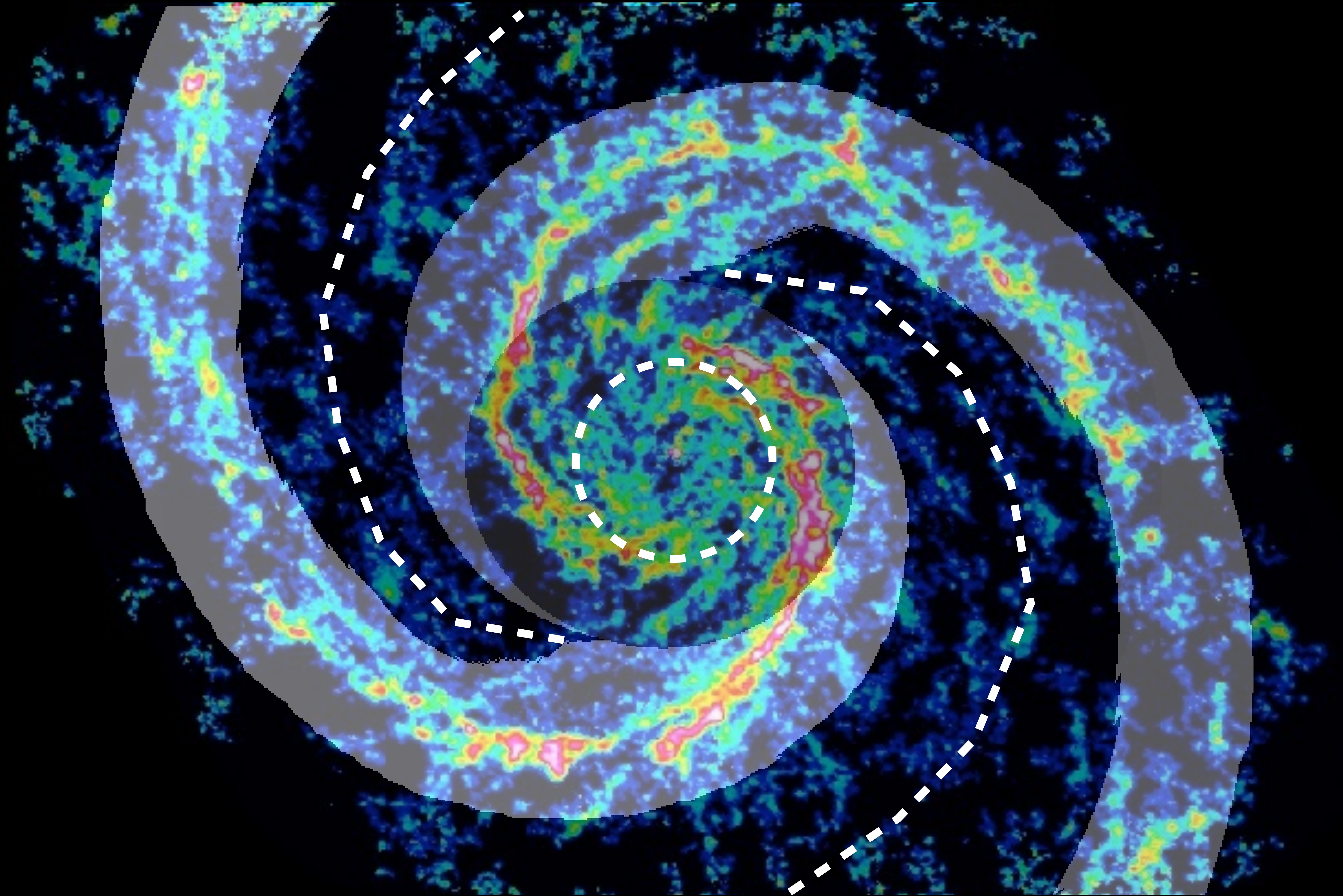
How is Molecular Gas in Galaxies Distributed?

GMC Mass Distributions: Motivations



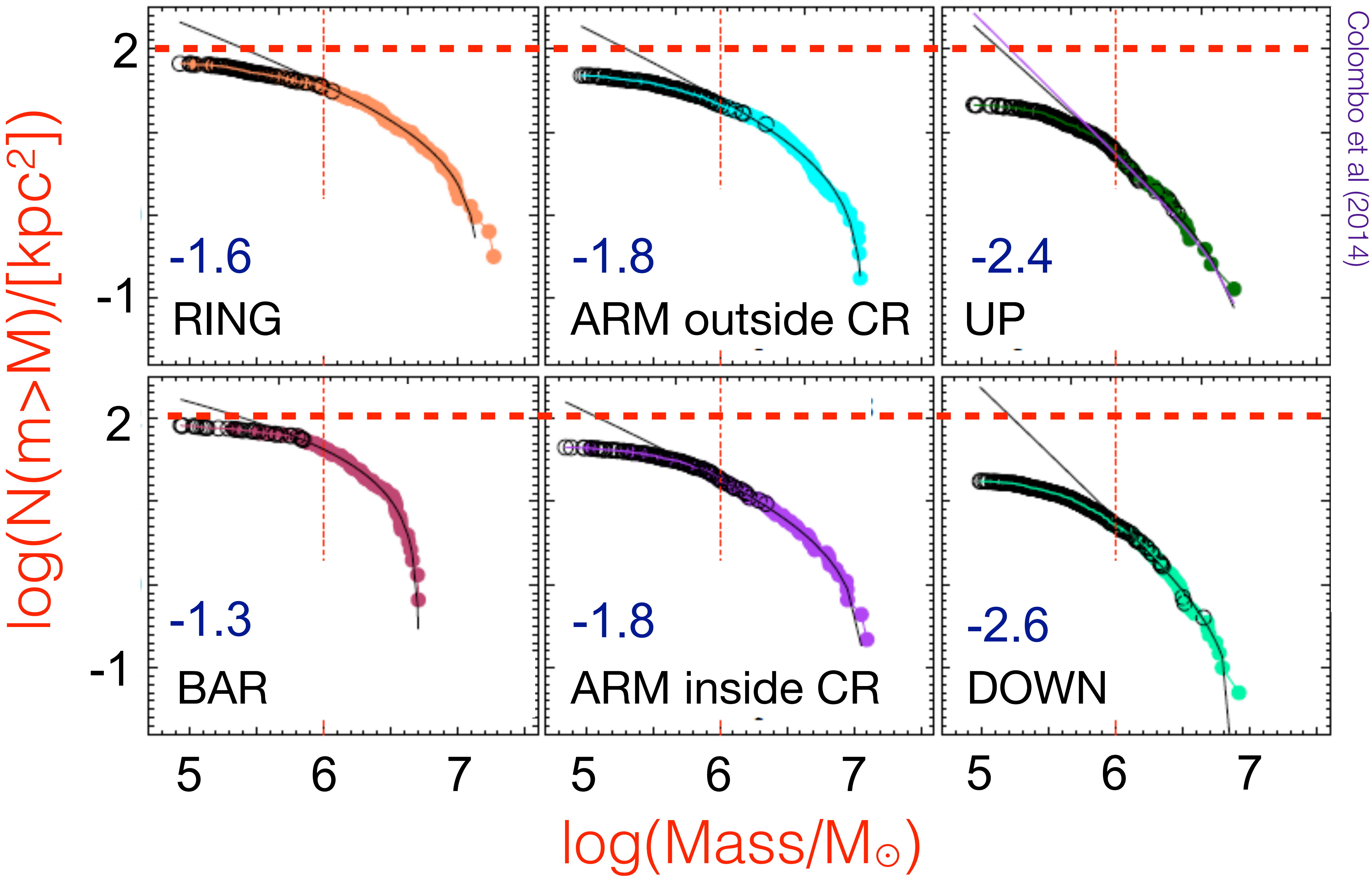


- diagnostic of GMC formation & destruction processes
- potential link to core mass function and cluster IMF
- in inner MW, γ = -1.5 ➡ GMCs dominate total H_2 mass

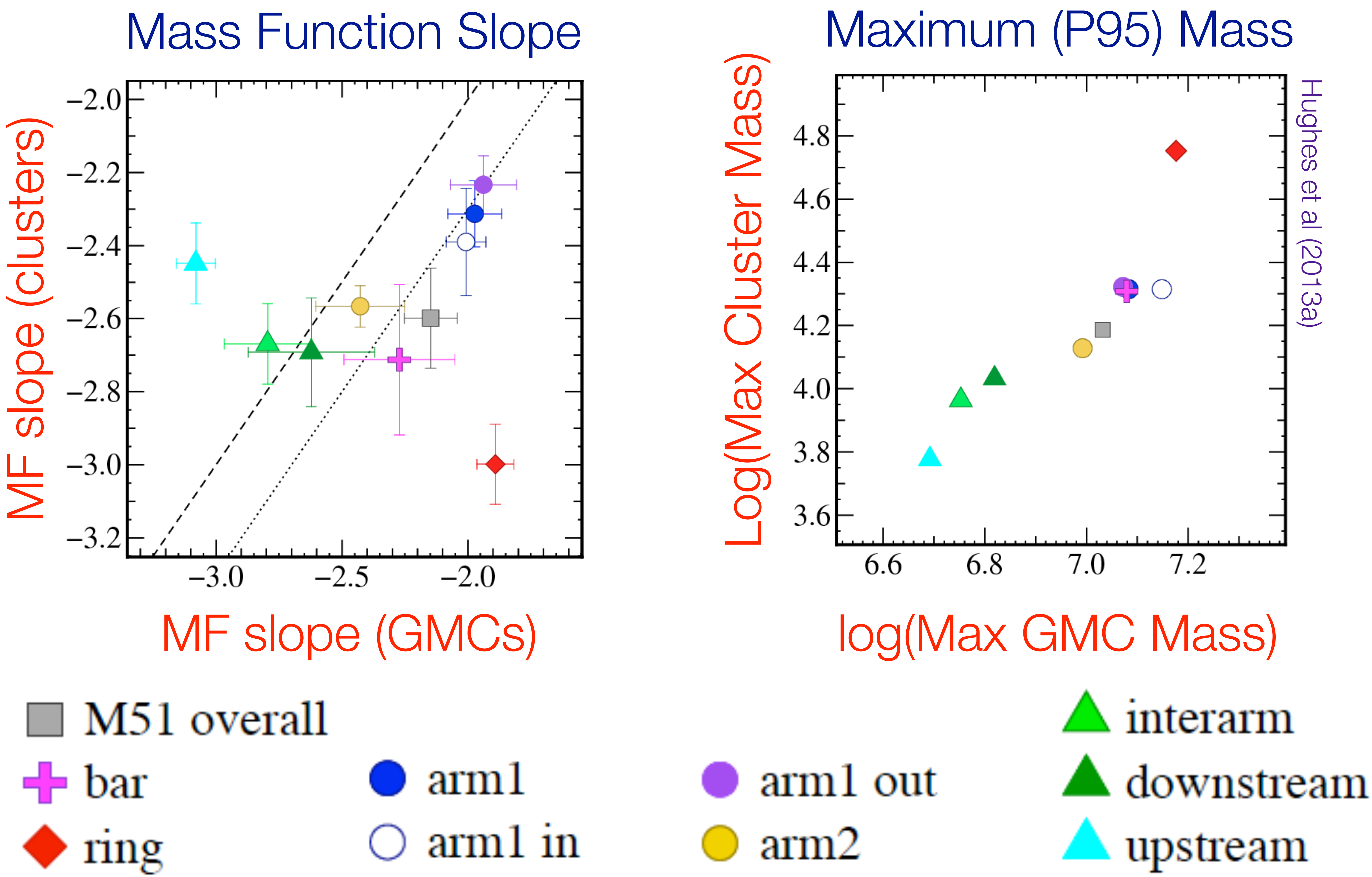


PAWS Survey of M51: Dynamical environments defined in Colombo et al (2014)

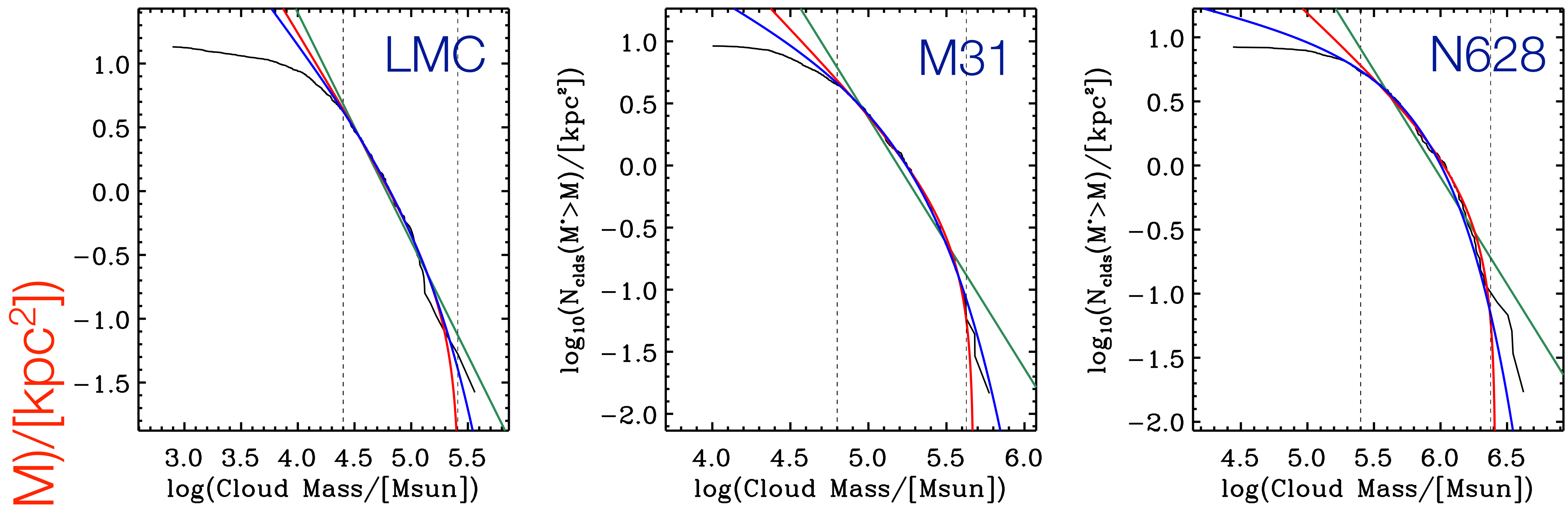
GMC Mass Spectra: M51 environments

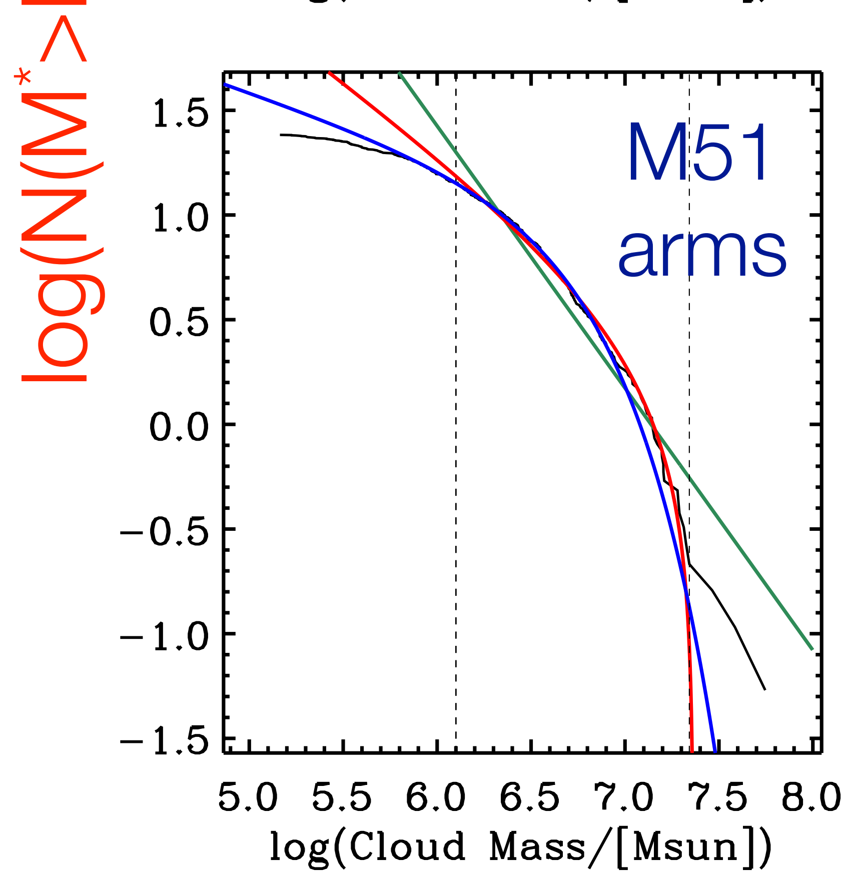


GMC & Young Cluster Properties



GMC Mass Spectra: Nearby Galaxies



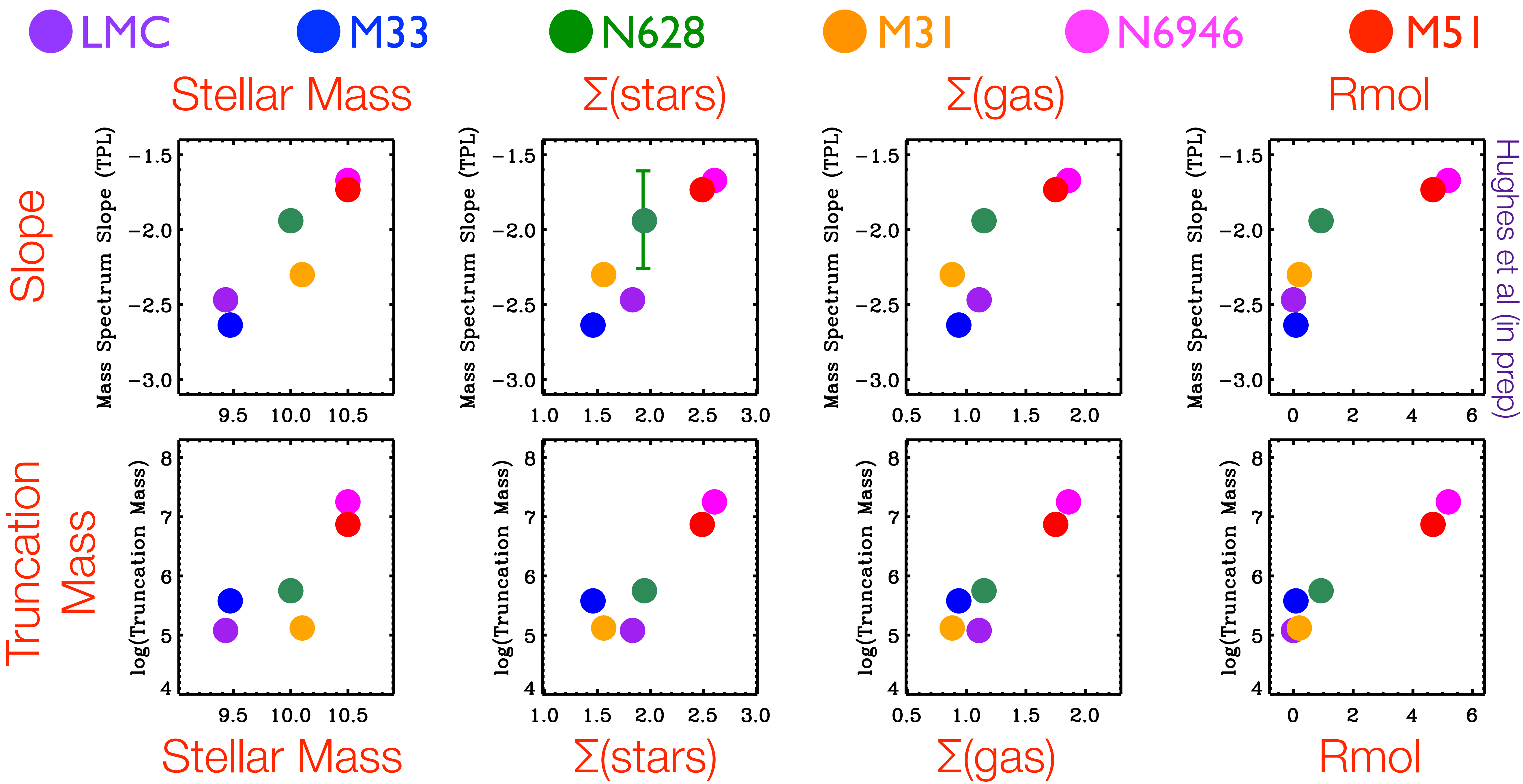


log (GMC Mass/[M⊙])

simple power law is insufficient for most galaxies

GMC mass spectra are steeper in diffuse environments

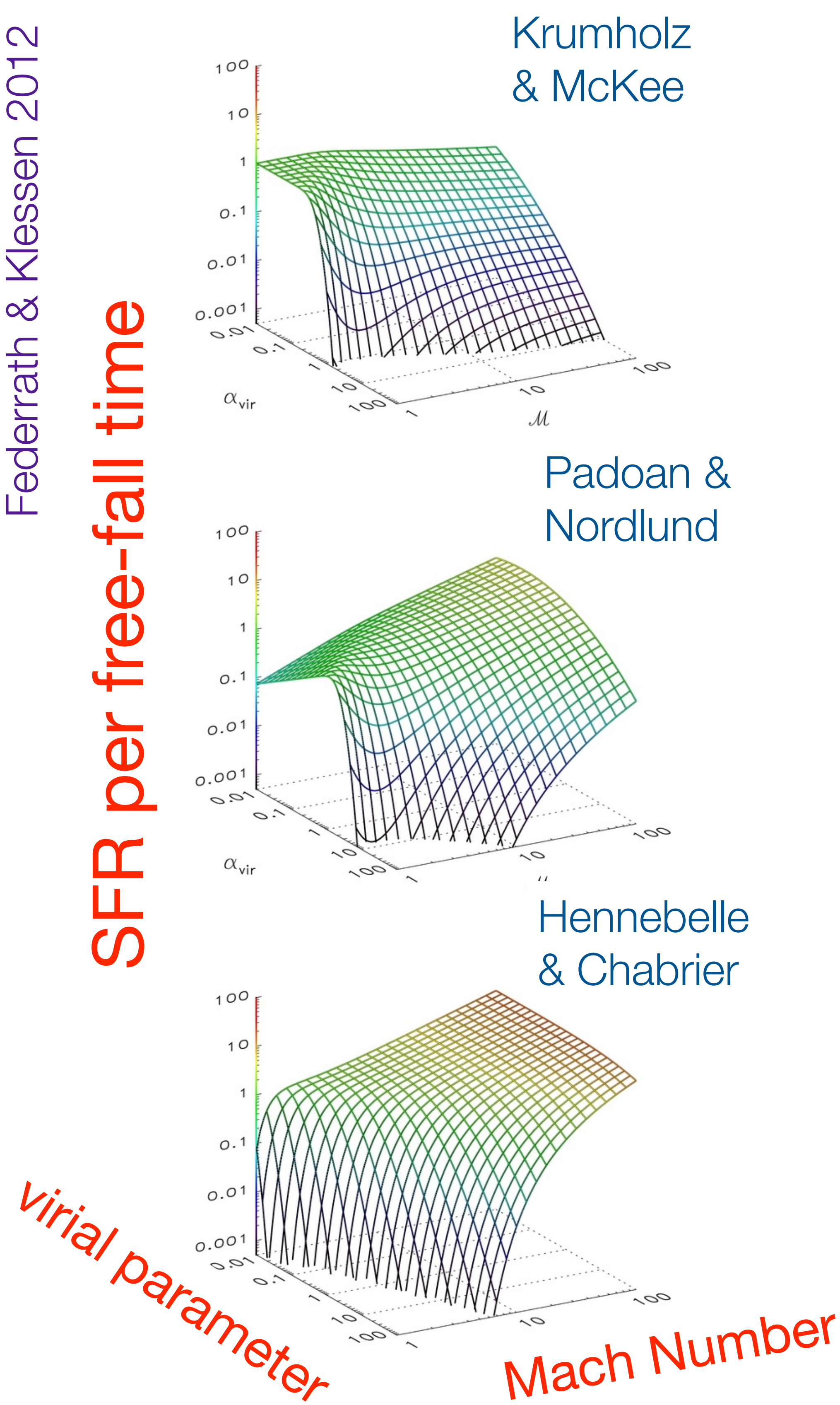
GMC Mass Distributions: Trends



shape of GMC mass distribution is not universal: slope and turnover mass increase in more massive systems

Do GMC properties matter for star formation (on galactic scales)?

Star Formation: Theory



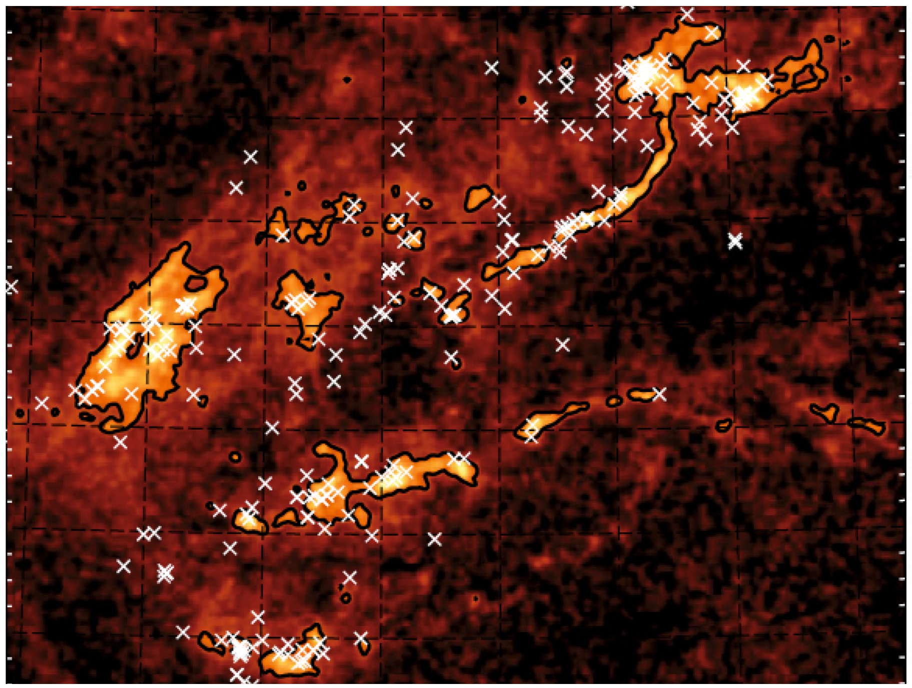
In star formation theory, the SFR depends on the properties of the parent cloud

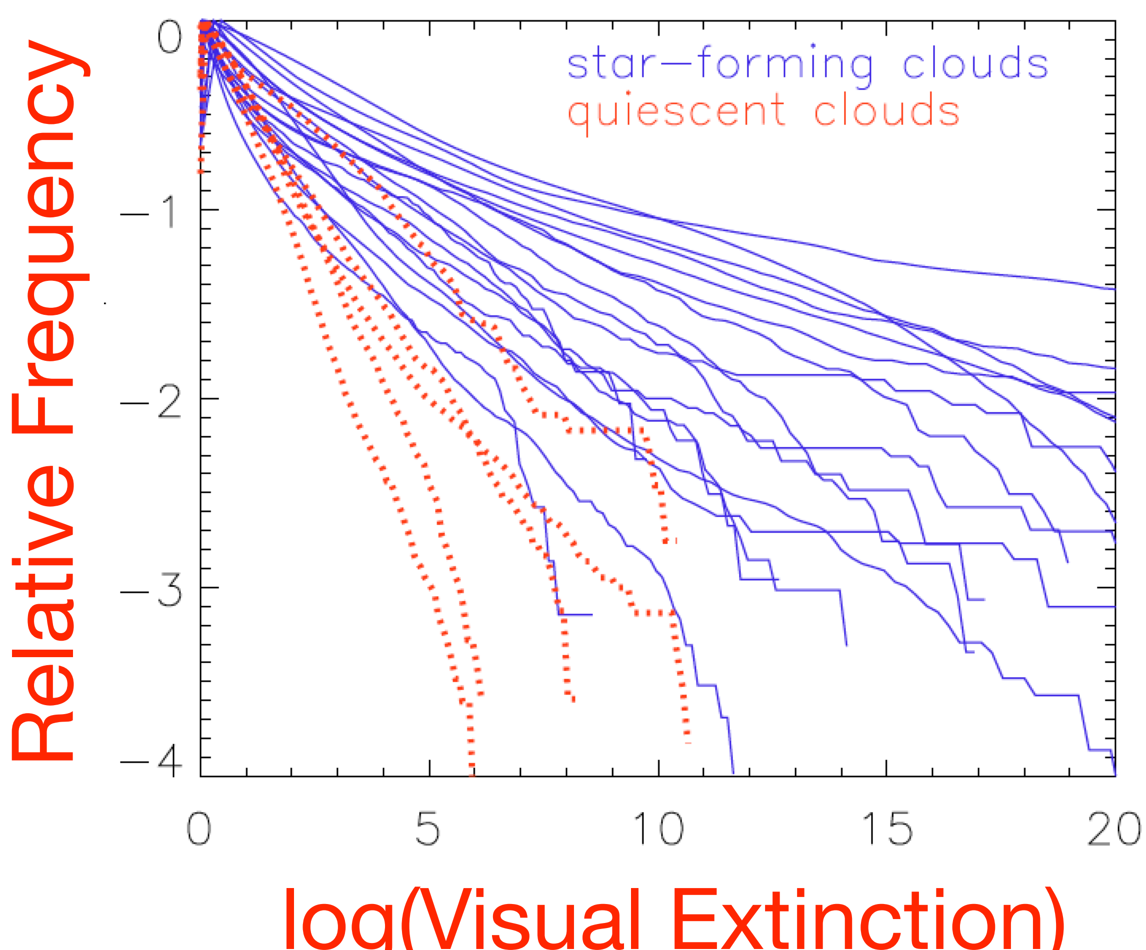
- cloud properties act as the boundary conditions for small scale star formation
- turbulent cloud properties set the density distribution
- Mach number sets the width of density distribution

e.g. Krumholz & McKee 2005, Padoan & Nordlund 2011, Hennebelle & Chabrier 2011, Federrath & Klessen 2012,

Star Formation in Local Clouds

Kainulainen et al (2009)



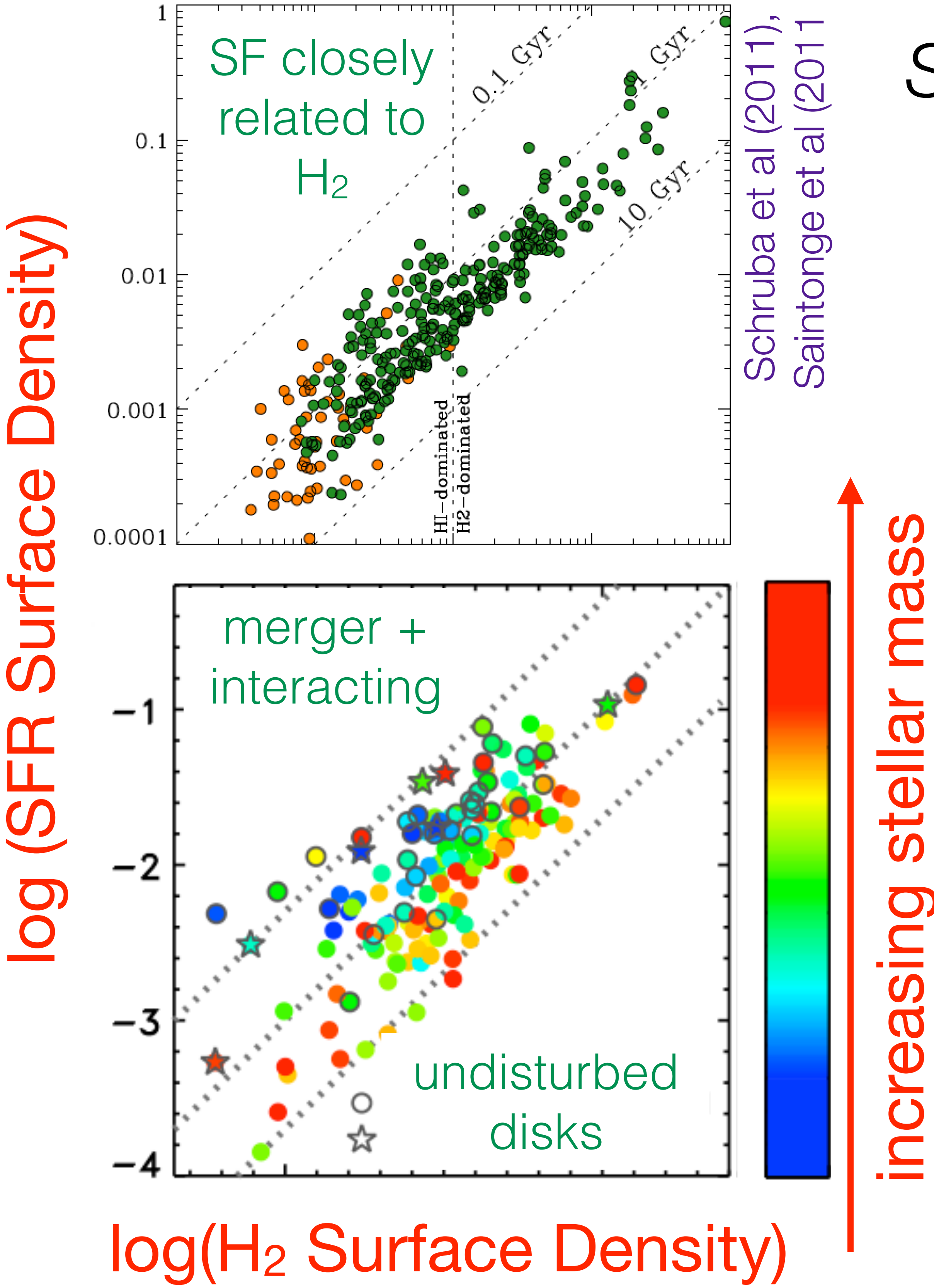


In local clouds, SFR relates to high density gas, not total H_2

- YSOs found in regions of high column density and extinction
- Actively SF clouds show excess amounts of high extinction material
- SF appears closely associated with dense filamentary substructure

Kainulainen et al (2009), Lada et al (2010), Heiderman et al (2010), Arzoumanian et al (2011), Stutz et al (2015)

Extragalactic Star Formation



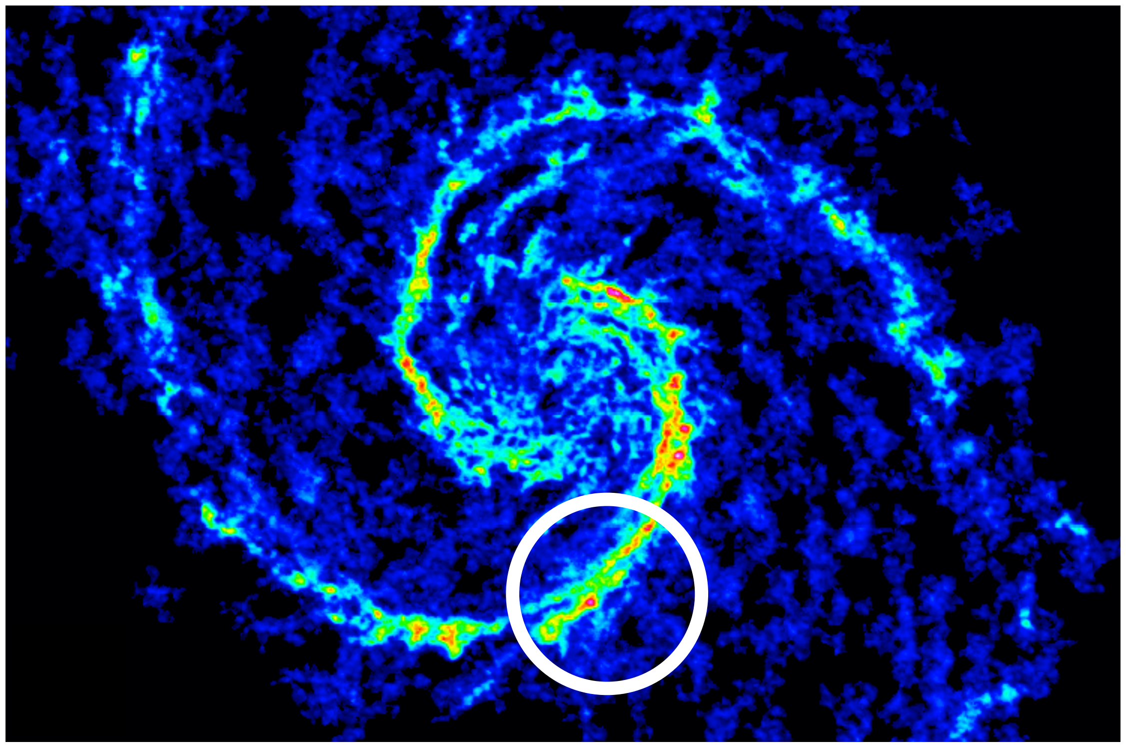
SFR-per-H_2 varies (systematically) on large scales in local galaxies

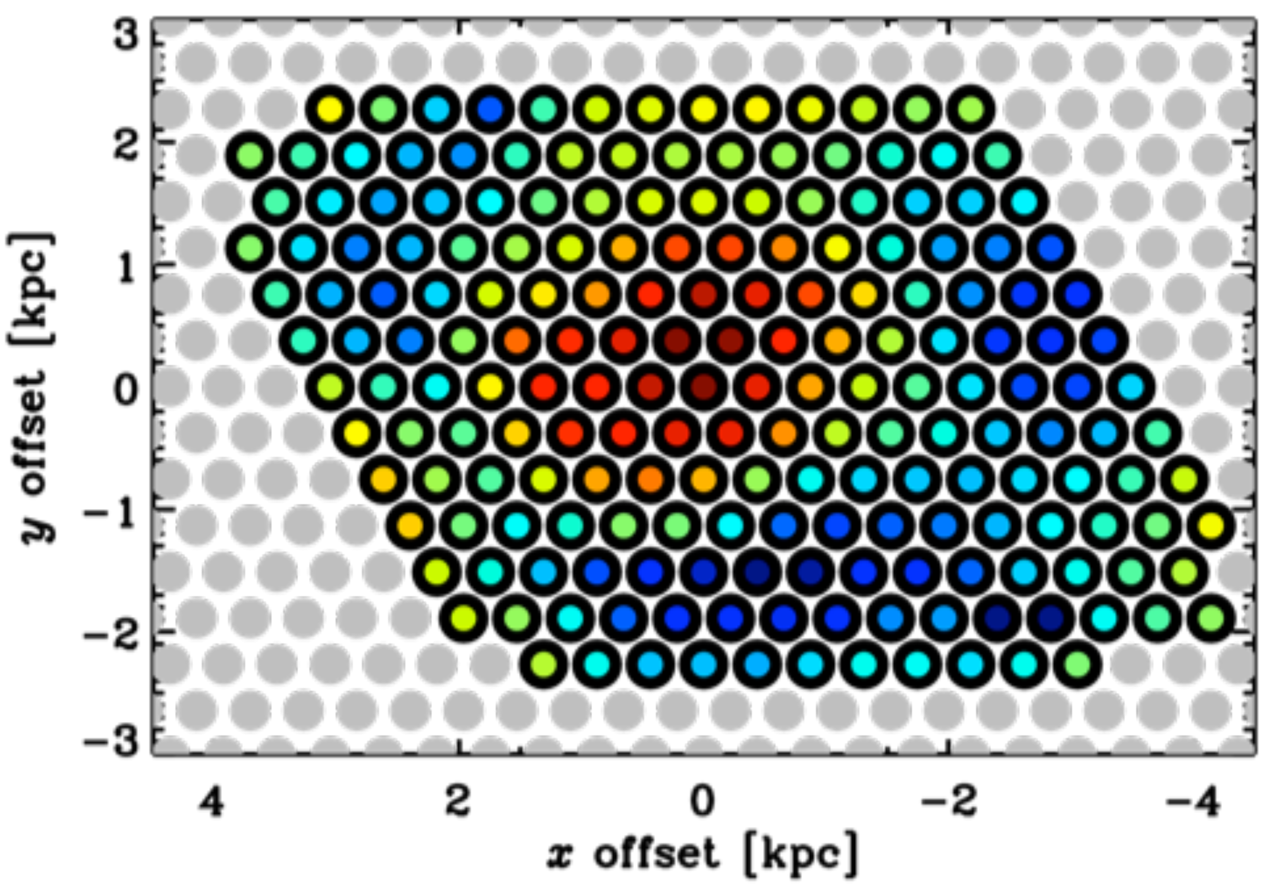
- High SFR/CO in galaxy centres, luminous starbursts, low-metallicity dwarfs
- Low SFR/CO in ETGs
- SFR/CO shows variations with local gas kinematics, galaxy morphology and metallicity

Schruba et al (2011), Saintonge et al (2011), Davis et al (2014), Meidt et al (2013), Koda et al (2009), Leroy et al (2013), Gao & Solomon (2004), Huang et al (2015)

GMC Properties and Star Formation

Schinnerer et al (2013), Pety et al (2013)





For simplicity, we write

TIR/CO: overall SFE in H_2

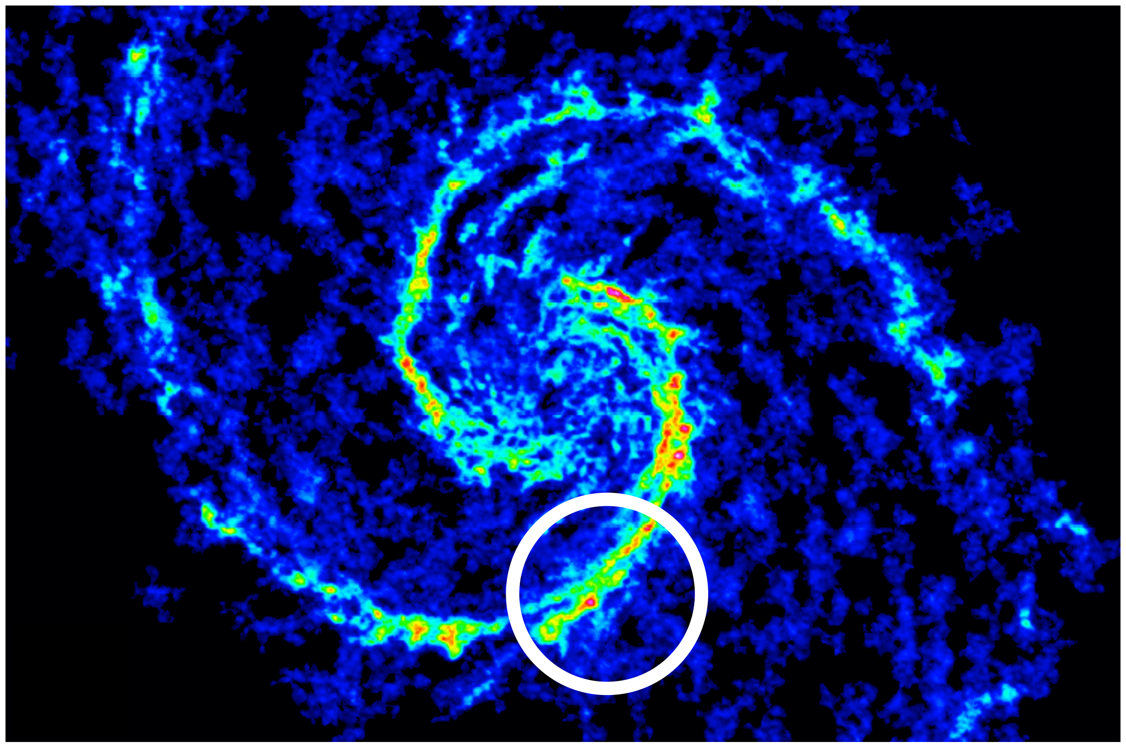
HCN/CO: dense gas fraction

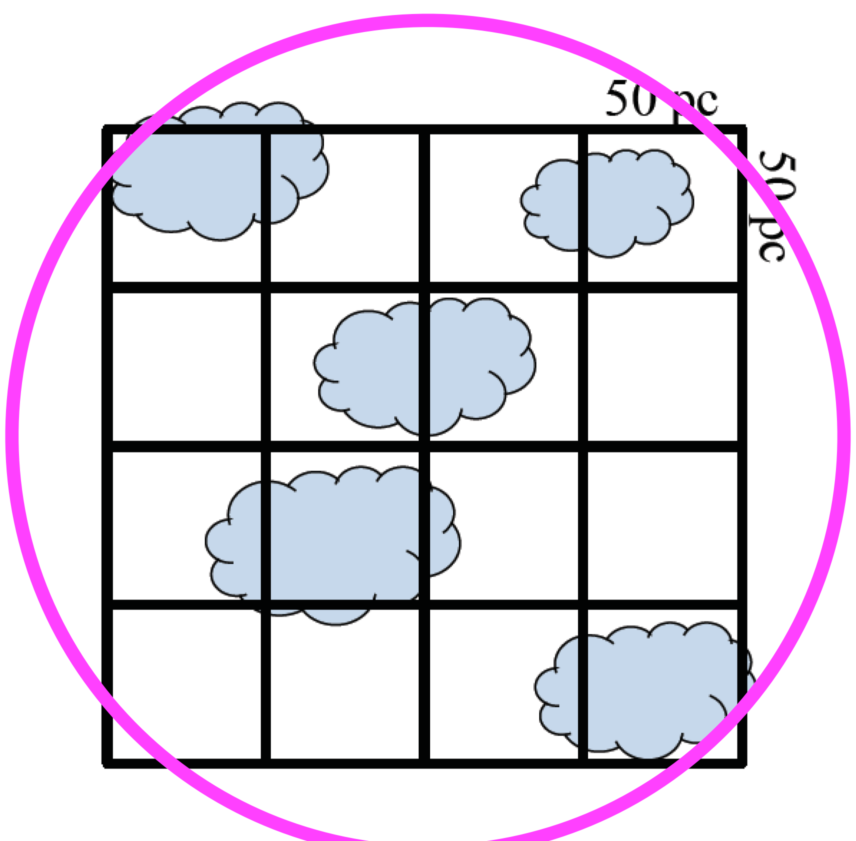
TIR/HCN: SFE of dense gas

Measure TIR/CO, SFR/HCN, or HCN/CO ratio in a ~kpc aperture that is small enough to roughly isolate local conditions.

Integration over a ~kpc area is needed to capture the time-cycling of gas and stars

GMC Properties and Star Formation

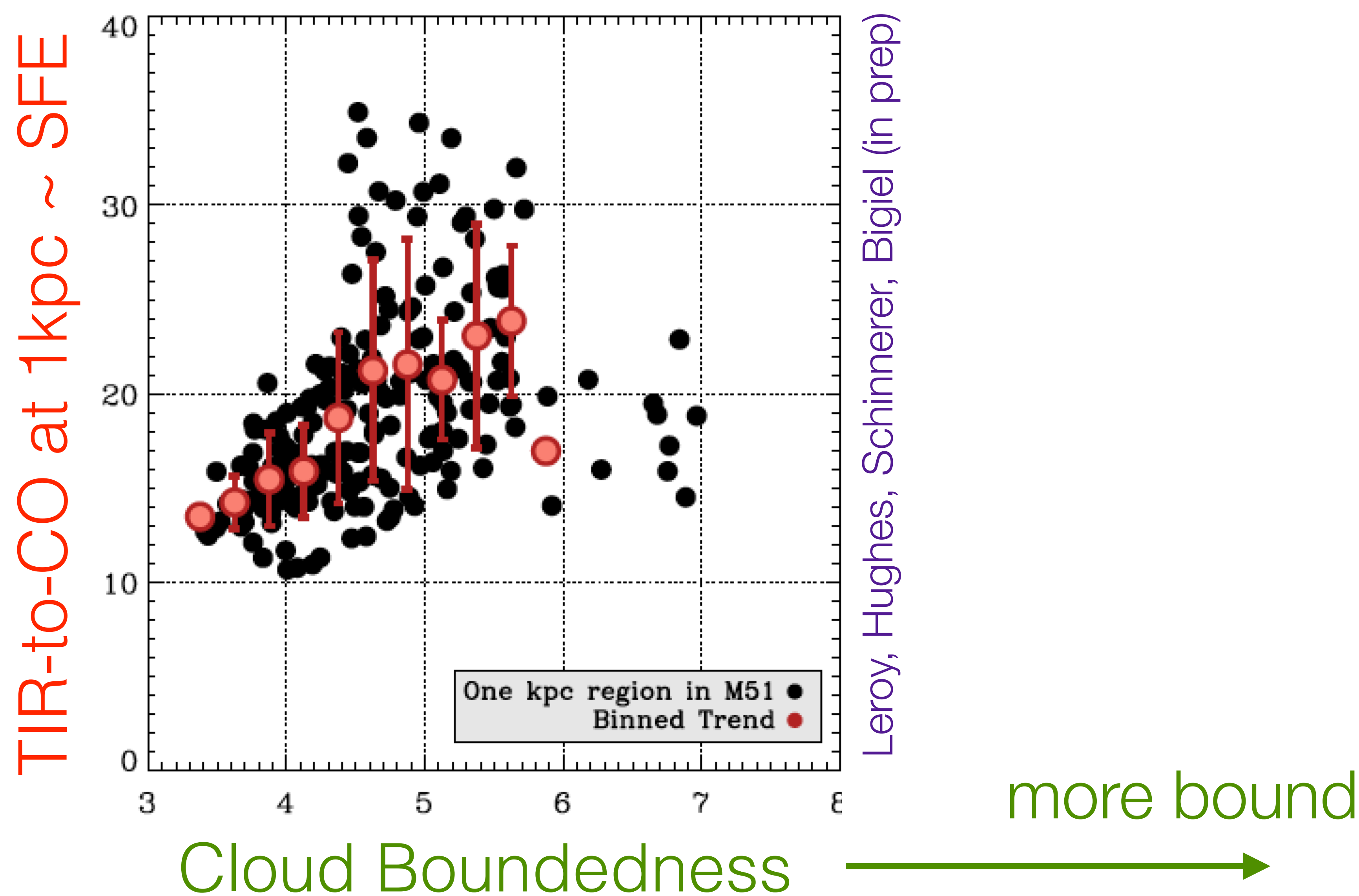




Within the ~kpc aperture, measure the typical cloud-scale properties of the molecular gas, e.g. mass-weighted surface density, velocity dispersion (Mach number), and gravitational boundedness

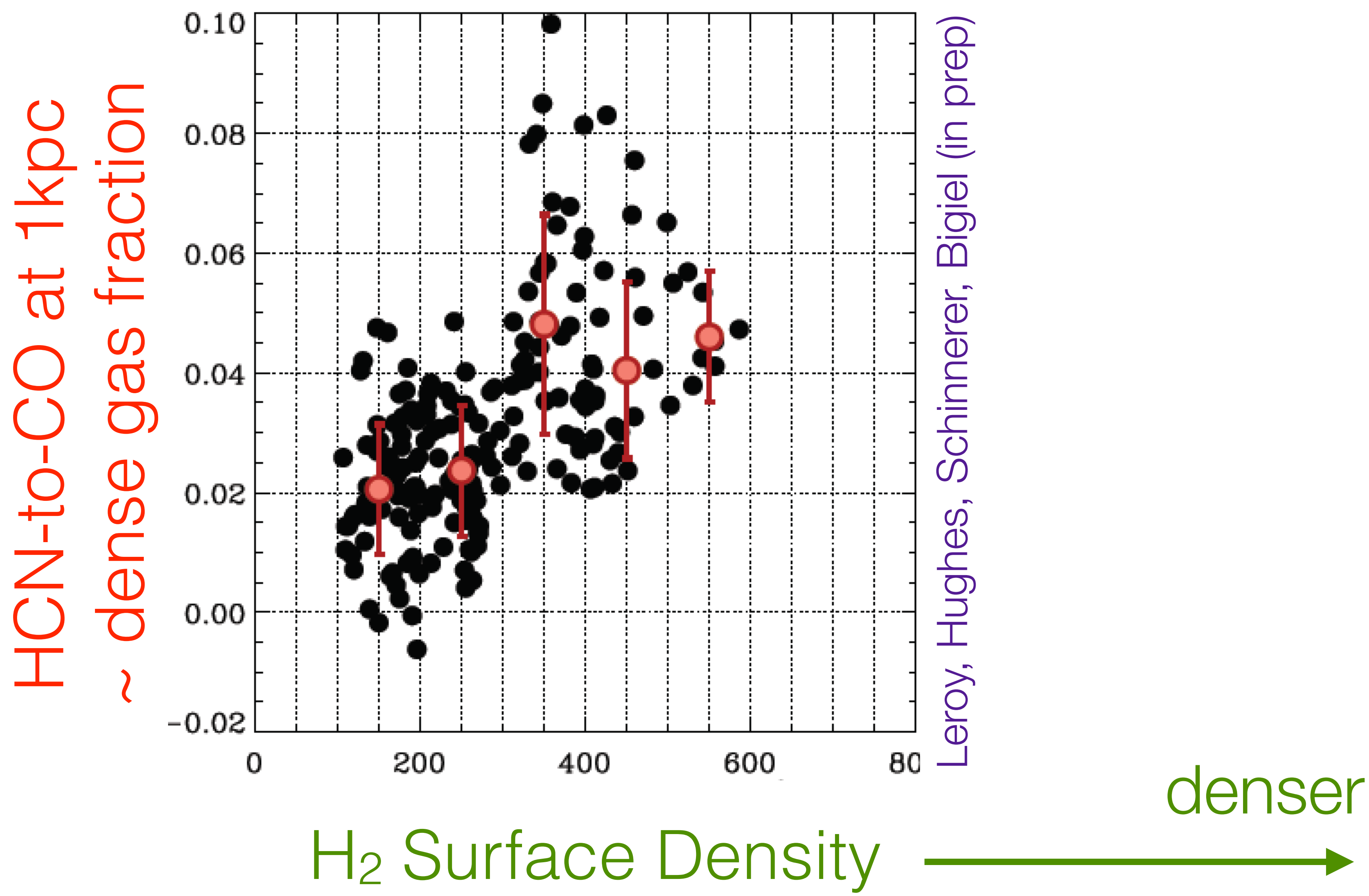
Underlying GMC Properties Matter

Within the PAWS field-of-view, the ability of the ISM to form stars (IR/CO) correlates with the self-gravity of the gas at cloud (50 pc) scales – gas that is more bound appears better at forming stars.



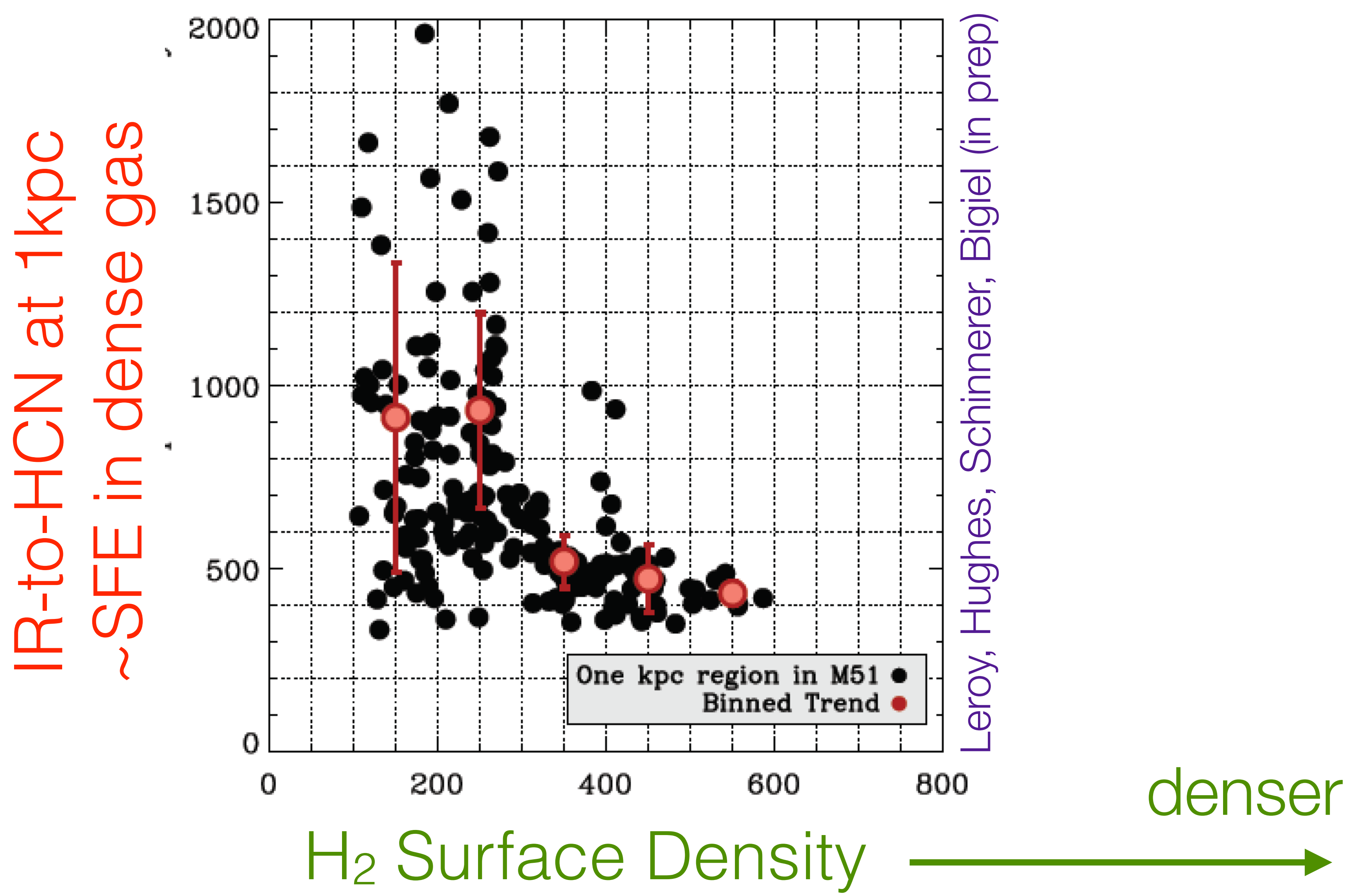
Underlying GMC Properties Matter

Within the PAWS field-of-view, the average small scale surface density within a kpc region correlates with the apparent fraction of the molecular gas mass that is dense.



Underlying GMC Properties Matter

But higher cloud-scale surface densities are associated with lower ratios of star formation per unit dense gas! I.e. dense gas is worse at forming stars as overall ISM density increases



Summary

GMC physical properties and mass distributions vary with environment, both within and among galaxies

More massive systems tend to have denser, more turbulent GMCs, and tend to build more massive GMCs

In M51, relations between star formation, molecular gas and dense gas are qualitatively consistent with a "whole cloud" view in which star formation occurs in local overdensities (rather than a universal density threshold)