Molecular Gas in M51: the PAWS View

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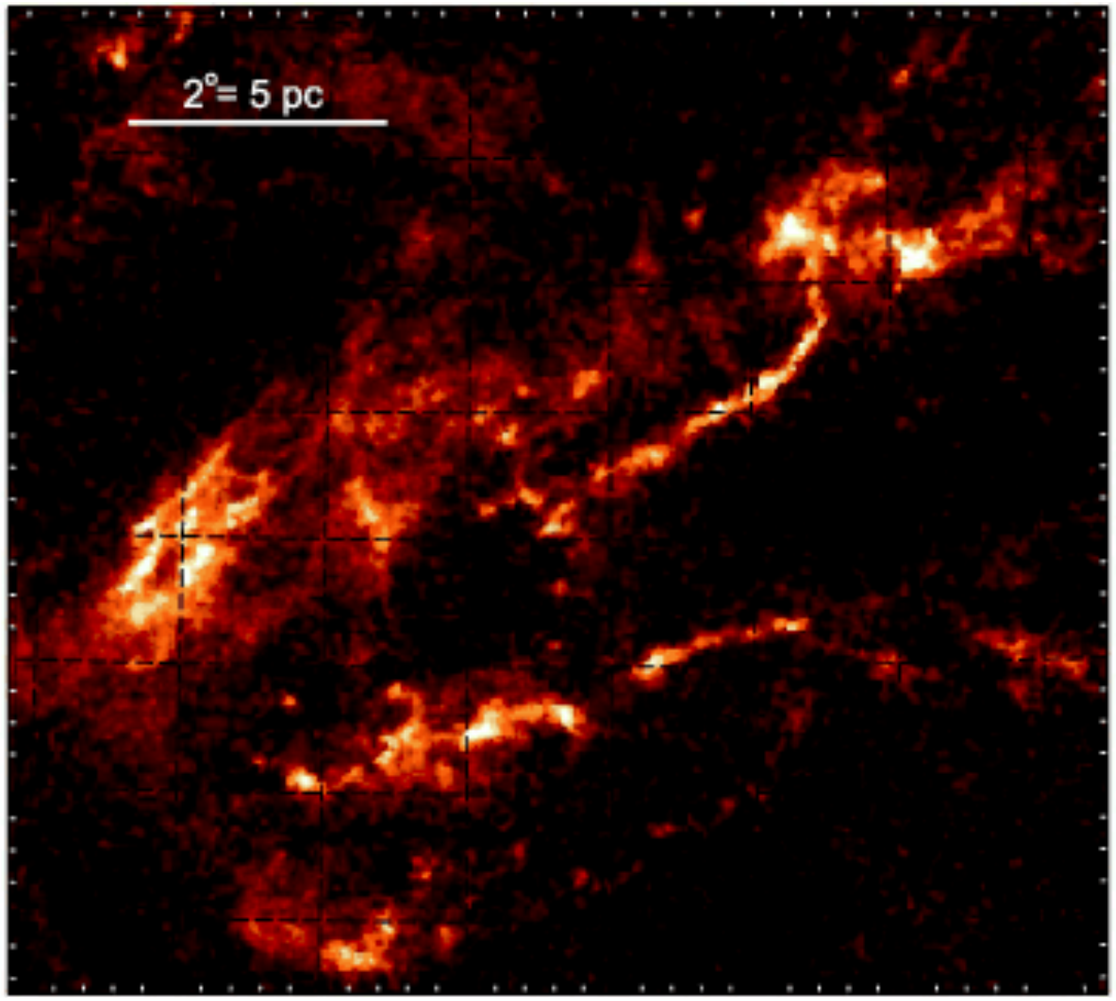
PAWS
PdBI Arcsecond Whirlpool Survey

Talk Outline

I. Distribution of CO emission (PDFs) in different M51 environments

II. Properties of giant molecular clouds (GMCs) in different galaxies and M51 environments

Results for individual clouds

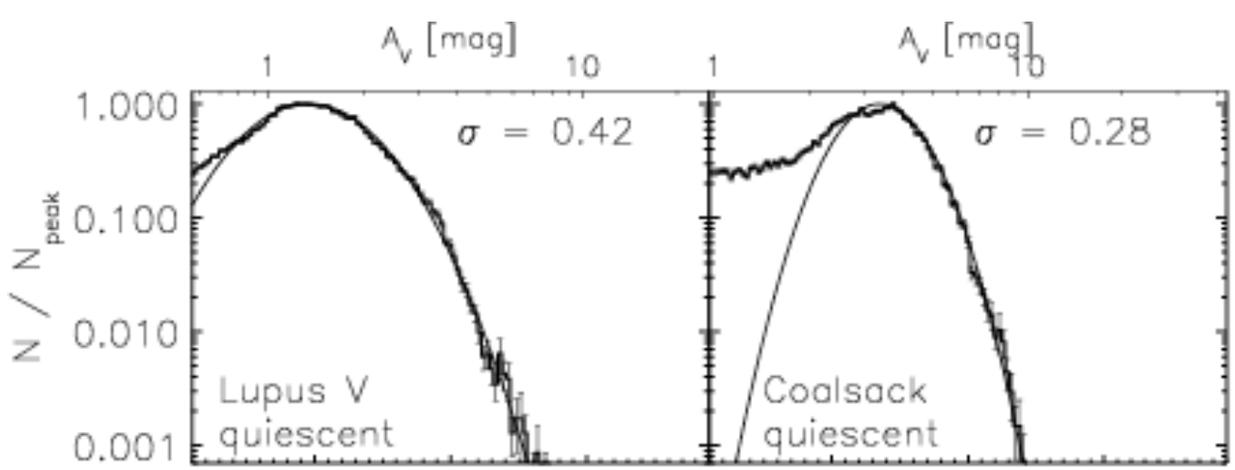


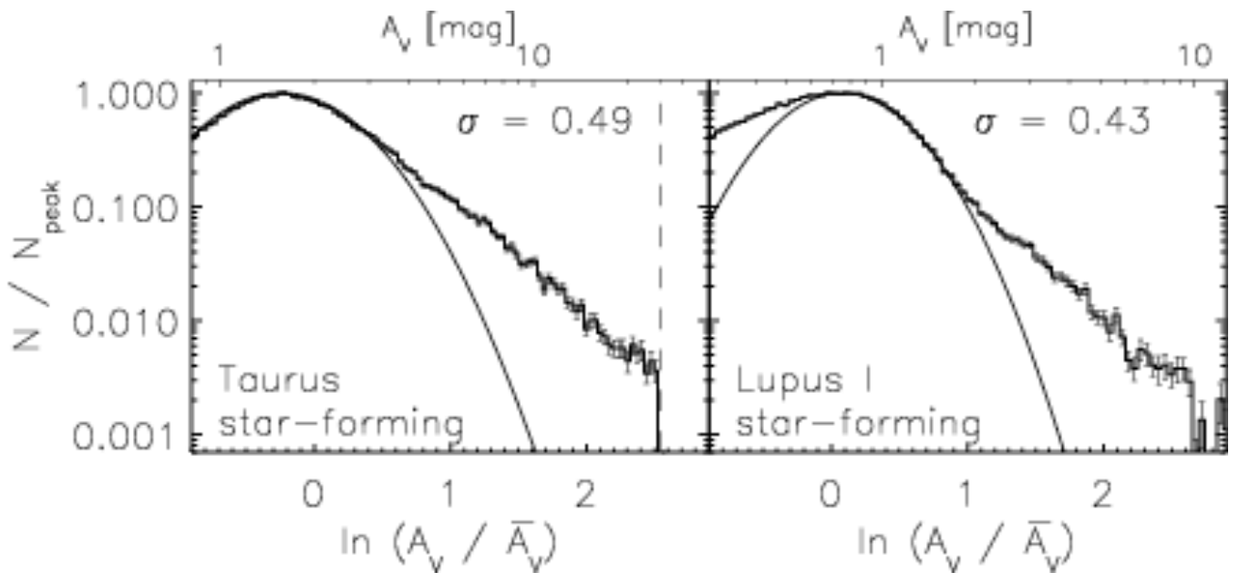
Kainulainen et al 2009

- in isothermal simulations, PDF width depends on Mach number, mode of turbulent forcing and magnetic field

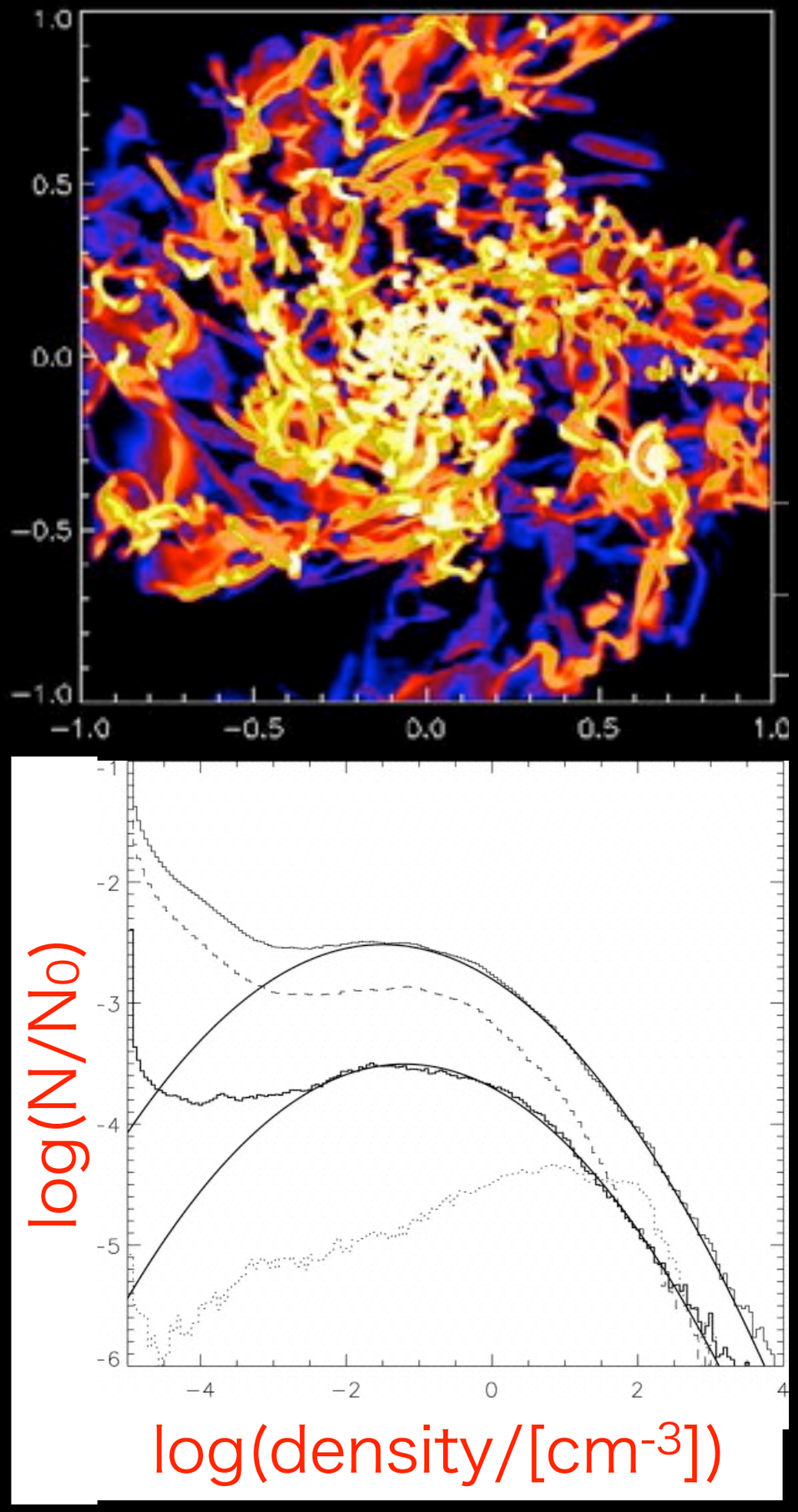
- non-star-forming clouds exhibit lognormal column density PDFs

see also P10 by Adriana Gazol

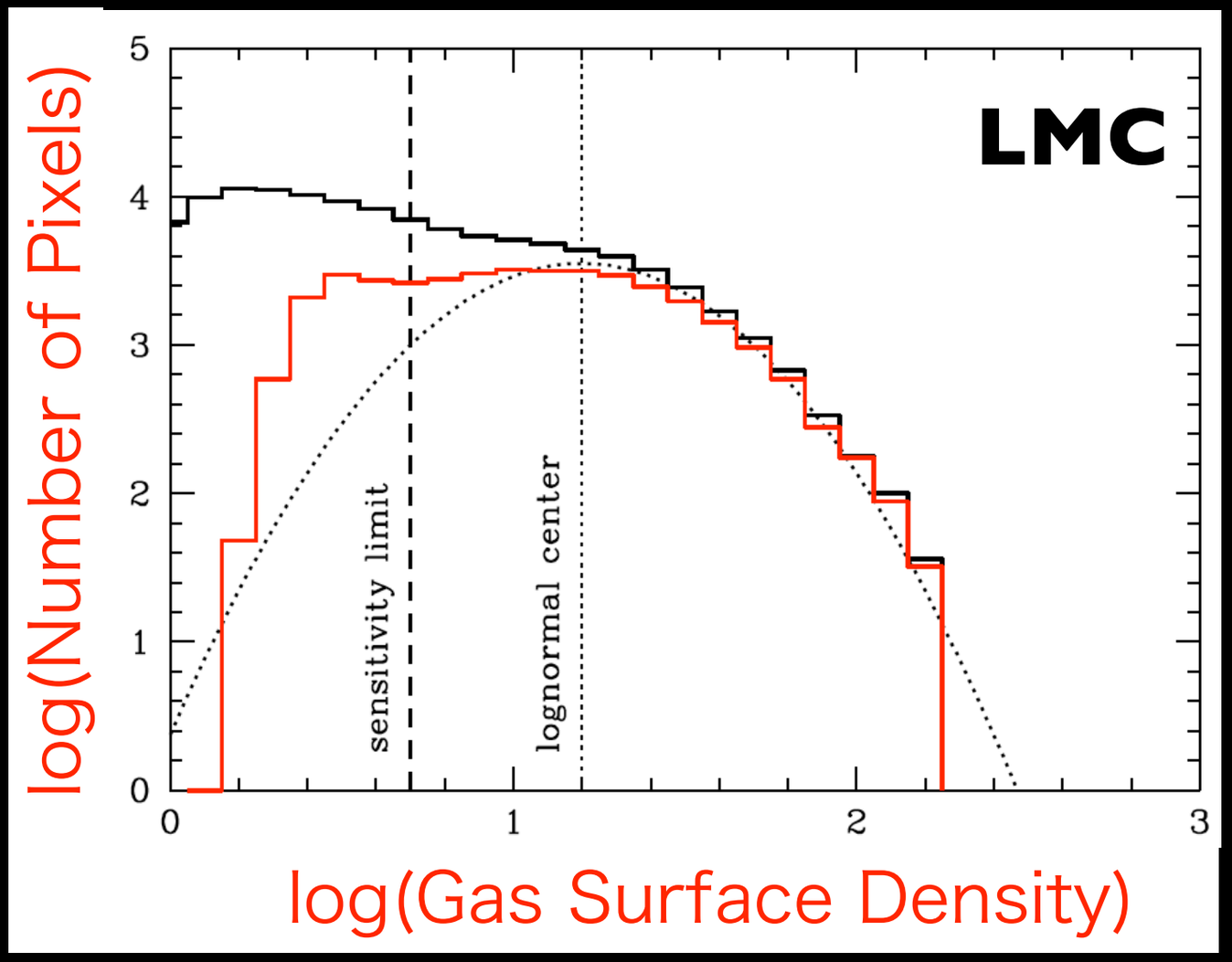




Wada & Norman (2007)

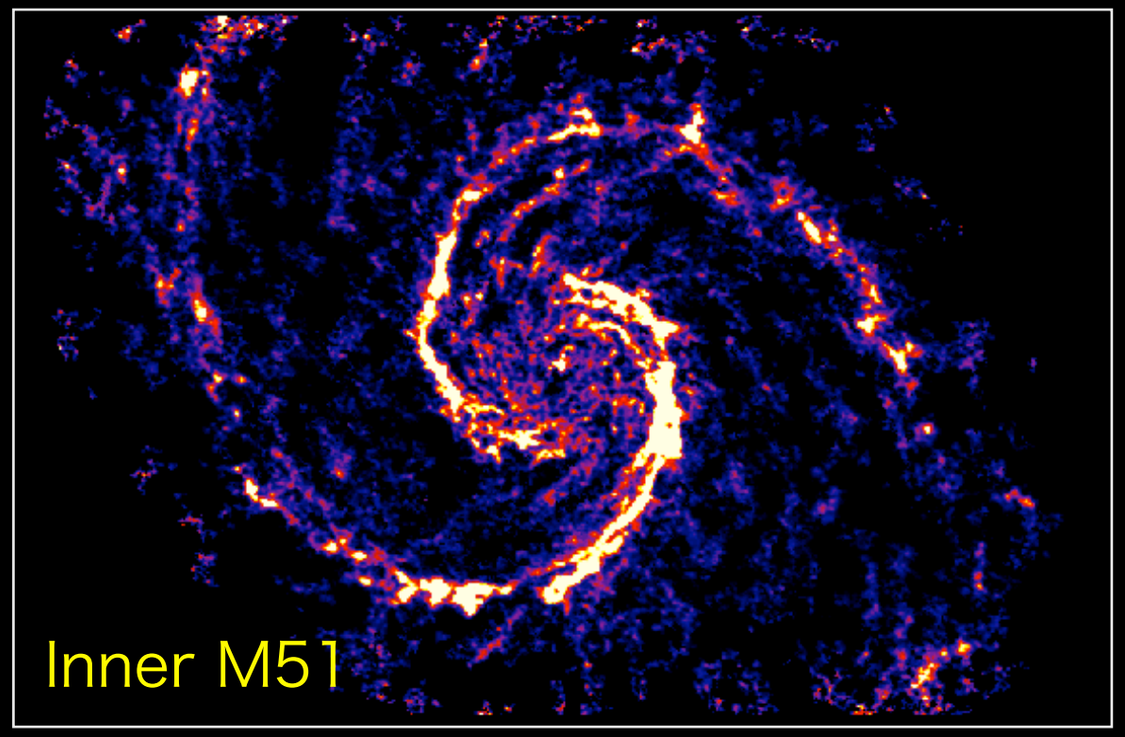


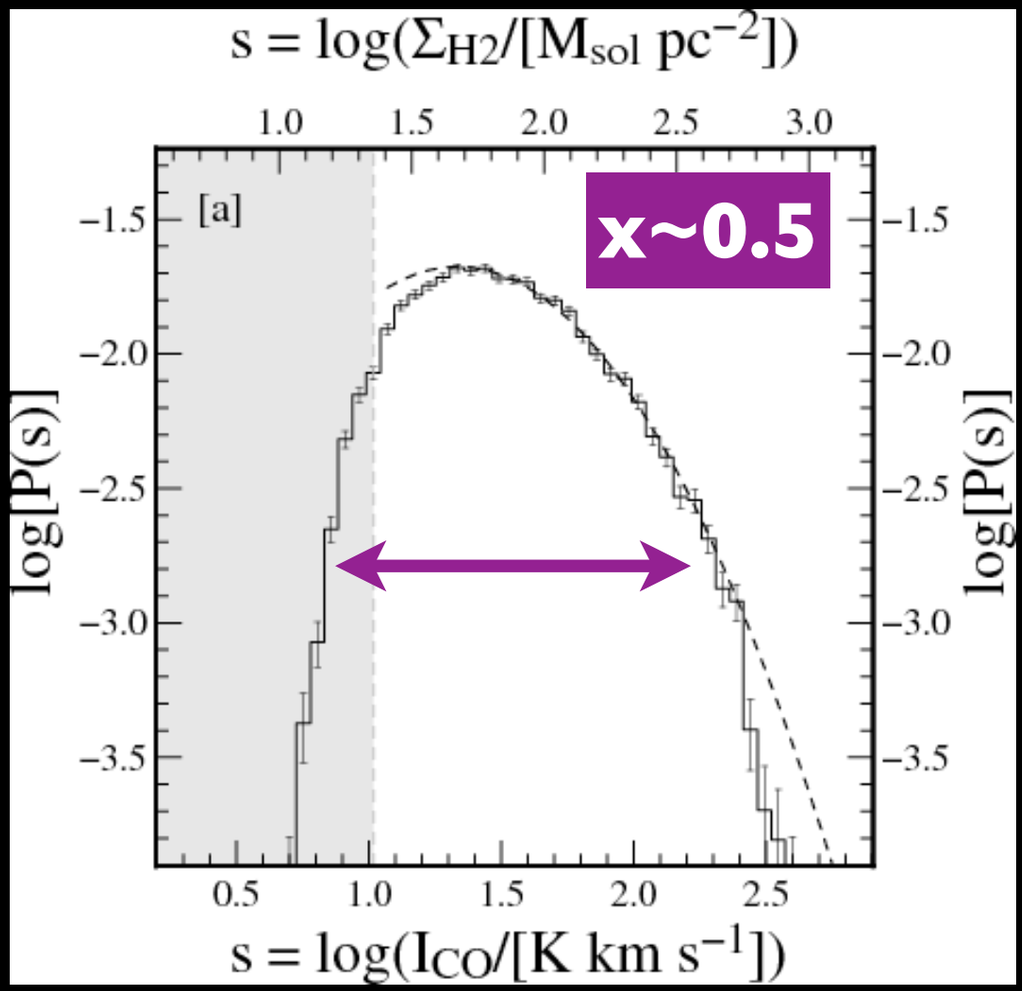
But: universal lognormal PDF for galactic disks not observationally established

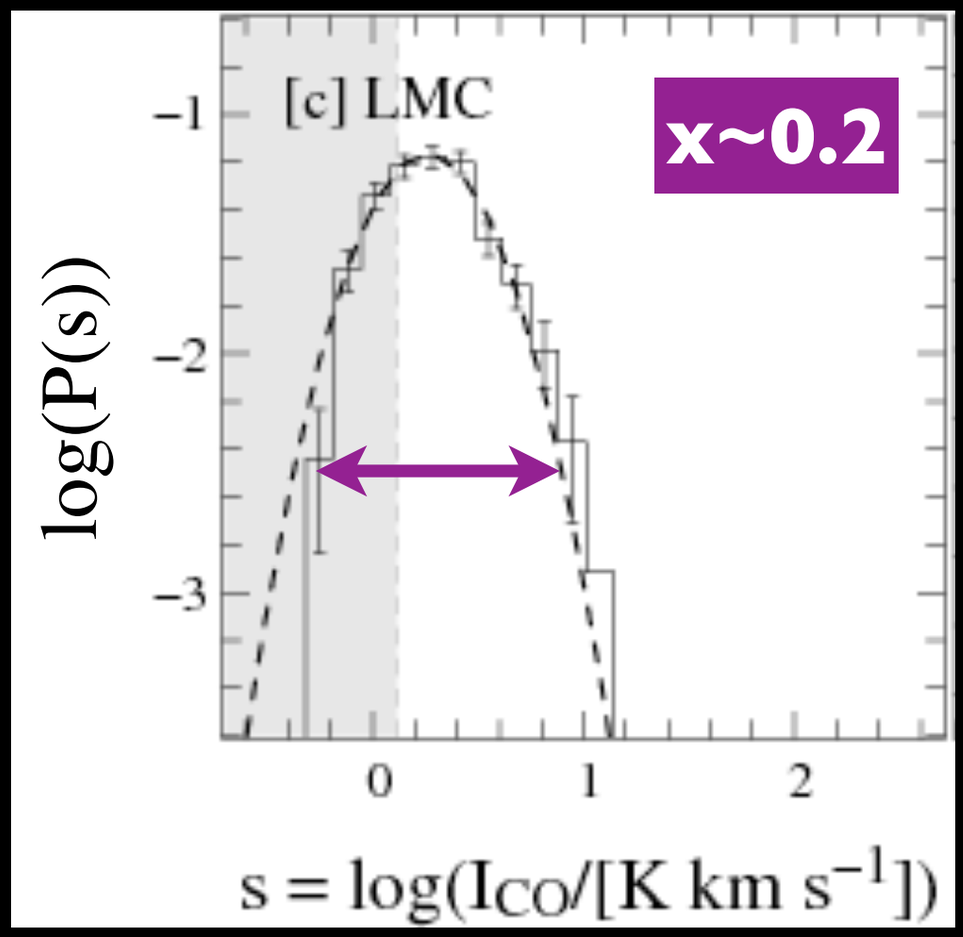


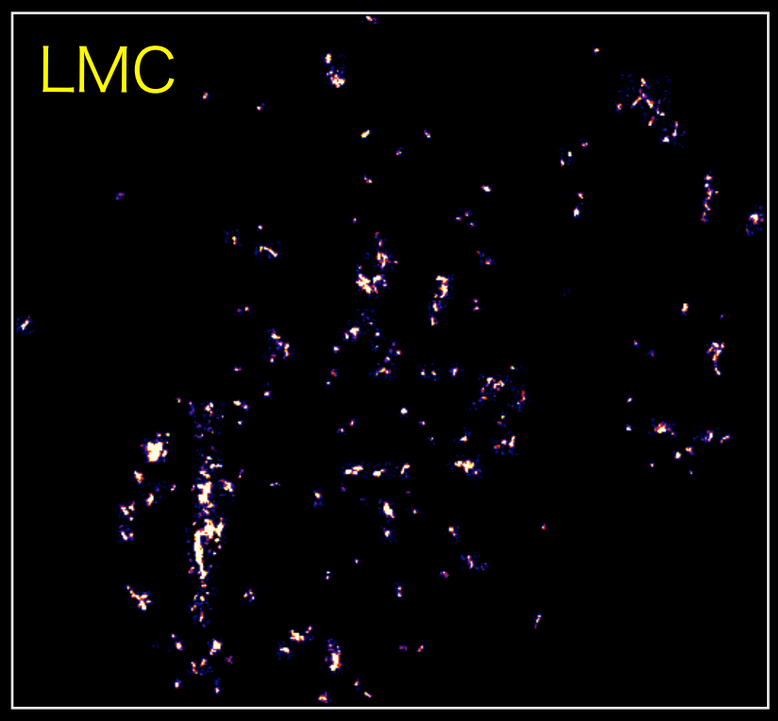
Wong et al. (2011)

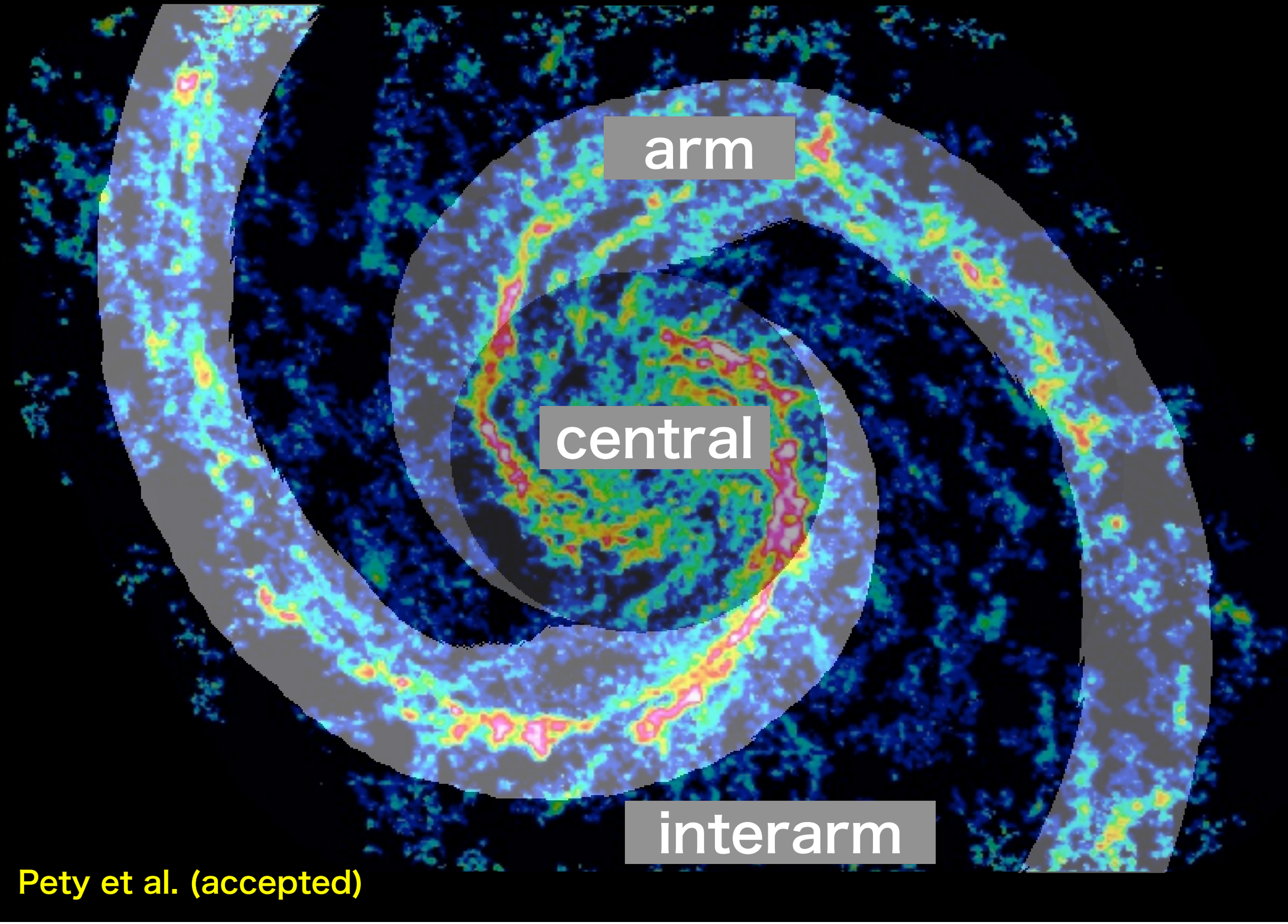
PDF width depends on average gas density


Inner M51

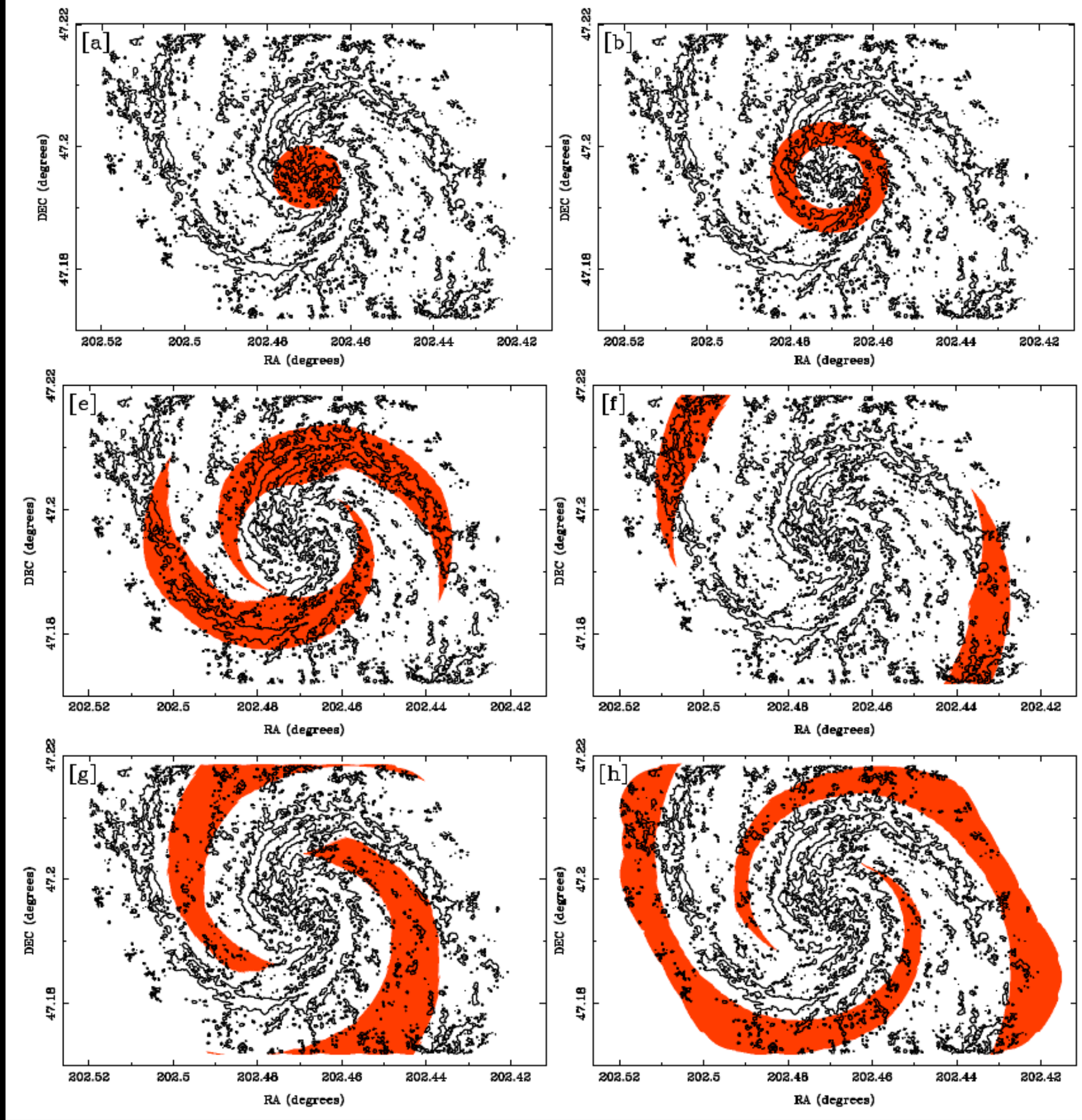

s = log(Σ_H2/[M_sol pc^−2])
[a]
x~0.5
log[P(s)]
s = log(I_CO/[K km s^−1])


[c] LMC
x~0.2
log(P(s))
s = log(I_CO/[K km s^−1])


LMC

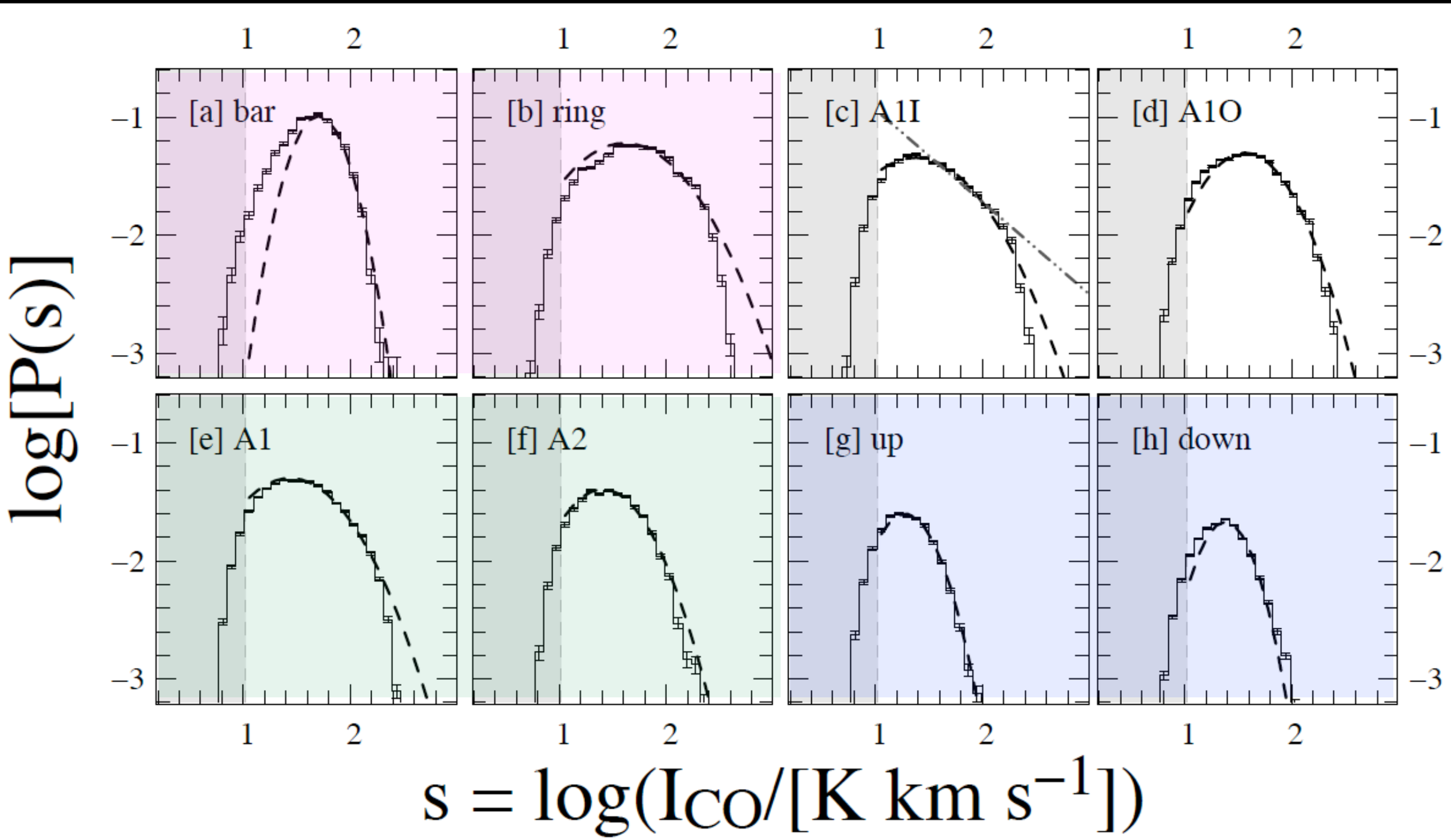


Pety et al. (accepted)


[a]
[b]
[e]
[f]
[g]
[h]
DEC (degrees)
RA (degrees)
47.22
47.2
47.18
202.52
202.5
202.48
202.46
202.44
202.42

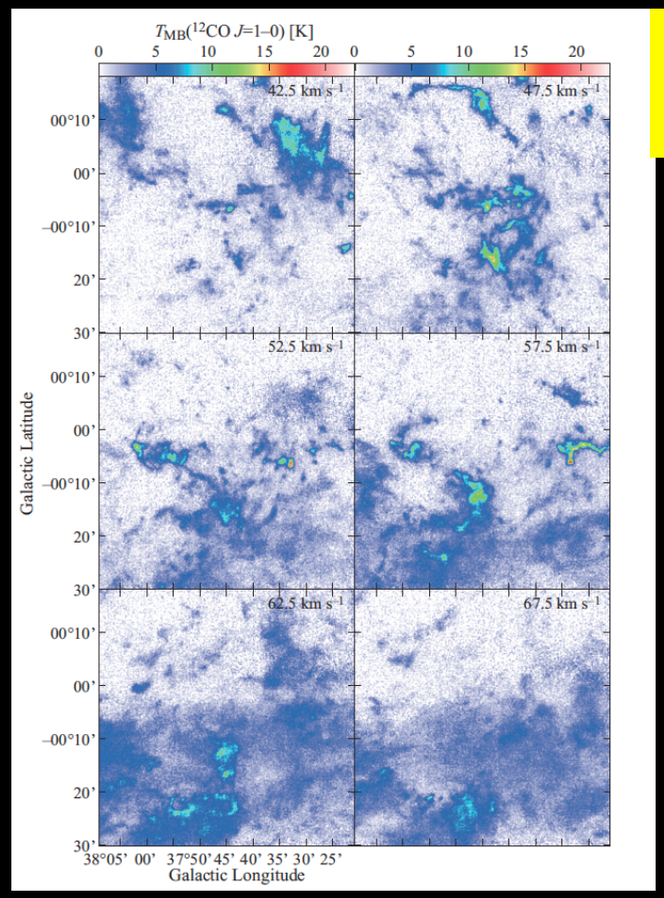
Integrated Intensity PDF

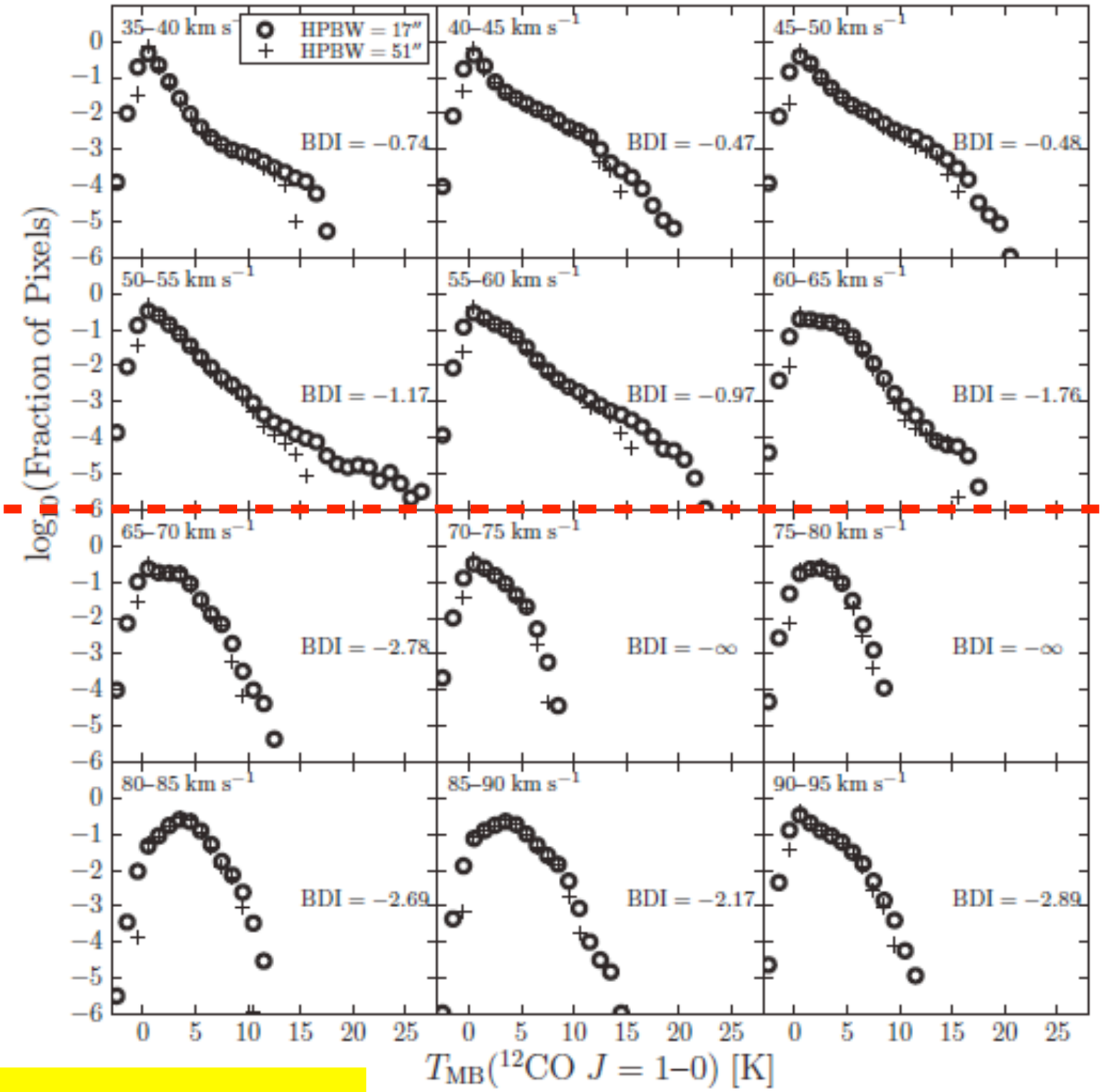
Hughes et al. (accepted)

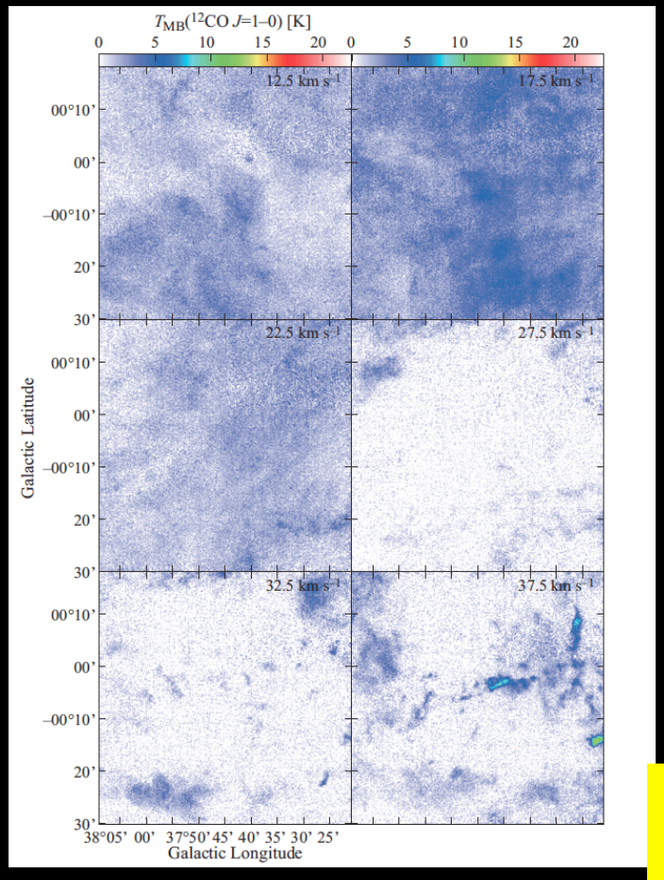


Arm

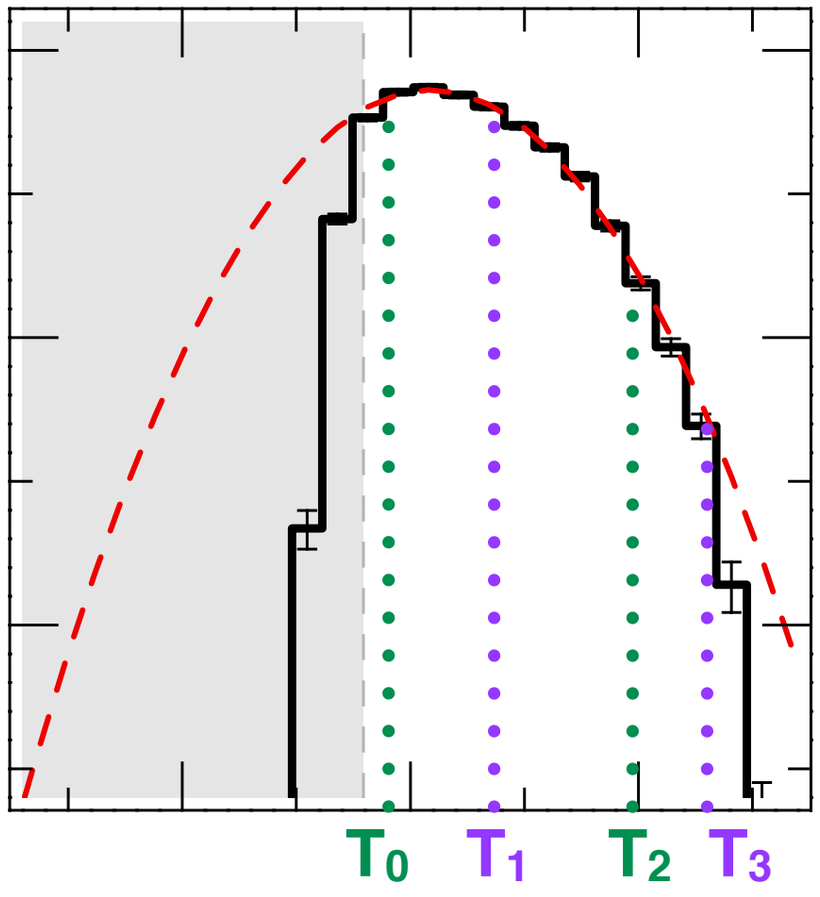
see P26 by Tsuyoshi Sawada







Interarm



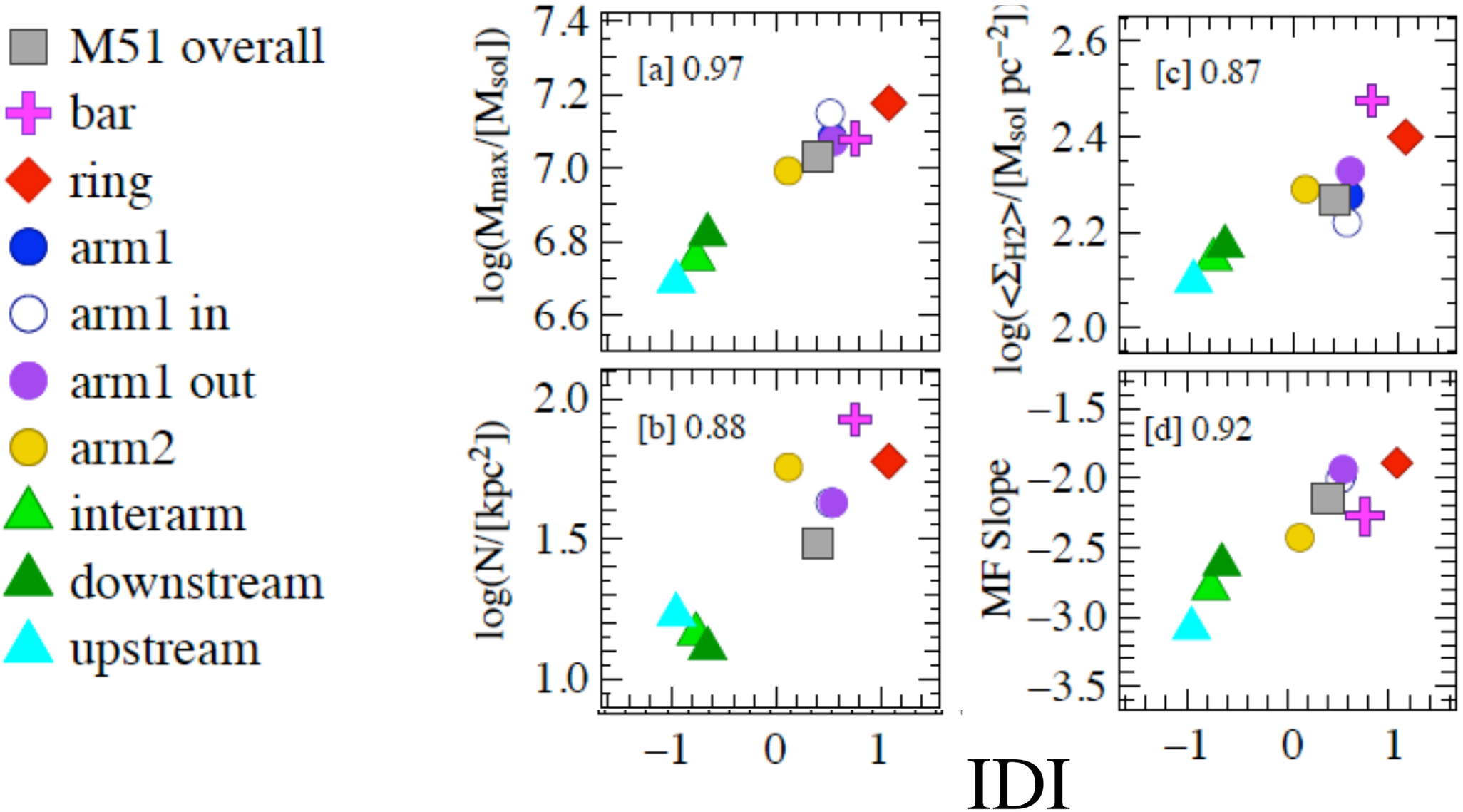
Characterise the shape of a PDF using the BDI, which expresses a ratio between bright and faint CO emission (Sawada et al 2012).

$$BDI = \log \frac{\Sigma T_i \,,\ T_2 < T < T_3}{\Sigma T_i \,,\ T_0 < T < T_1}$$

Region	L_{CO} [10^7 K km s^{-1} pc^2]	BDI	IDI
Global	70.4	-0.66	0.40
Nuclear Bar	6.6	-0.85	0.76
Molecular Ring	16.6	-0.13	1.08
Arm 1 inside corotation (A1I)	11.9	-0.59	0.52
Arm 1 outside corotation (A1O)	17.6	-0.83	0.55
Arm 1 (A1)	29.6	-0.72	0.54
Arm 2 (A2)	6.7	-0.76	0.12
Upstream	4.7	-1.73	-0.95
Downstream	6.2	-1.50	-0.65

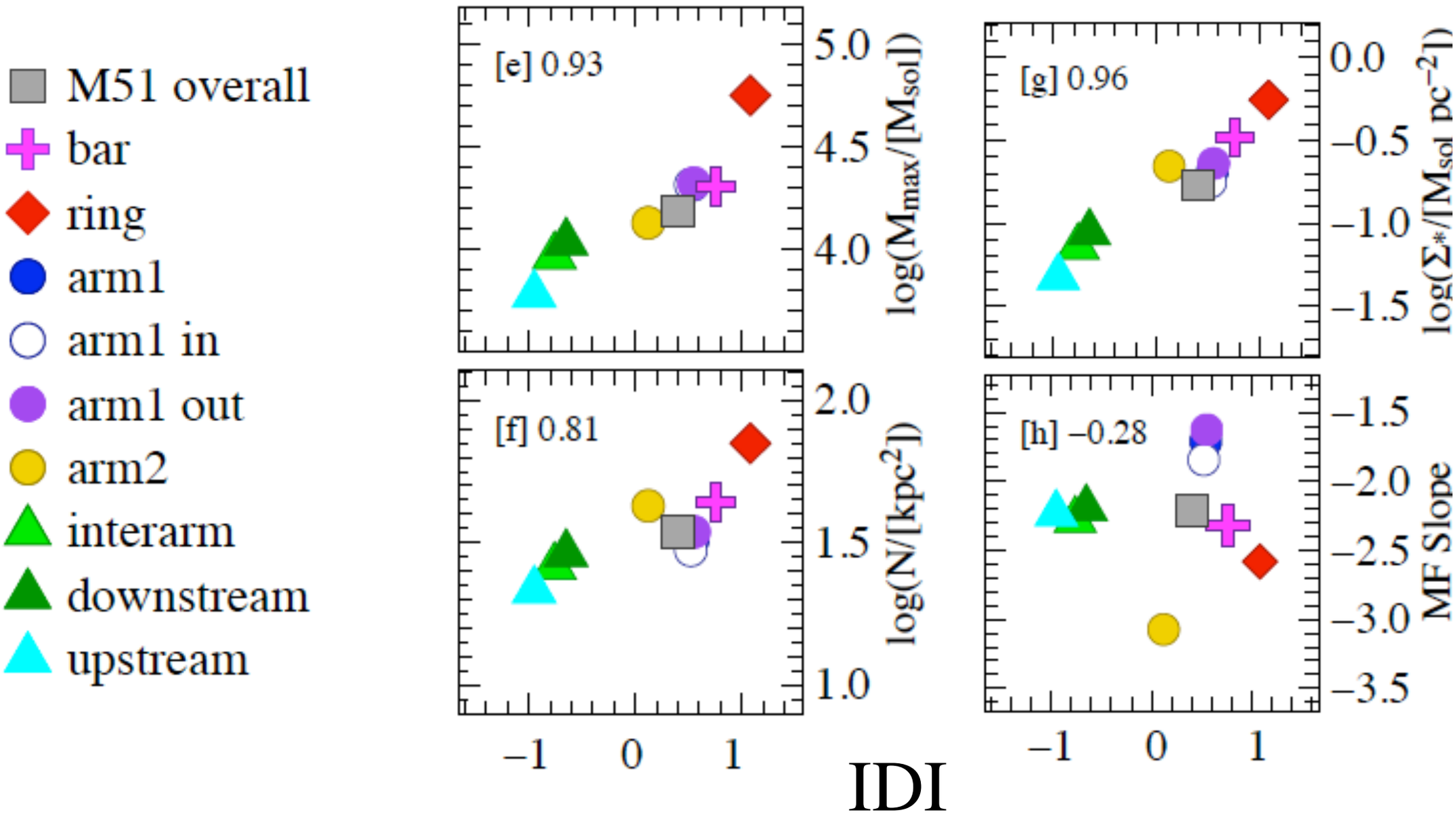
High IDI values associated with:

- higher number density of GMCs
- higher maximum GMC mass
- higher average GMC surface density
- shallower GMC mass spectrum



High IDI values associated with:

- higher number density of clusters
- more massive clusters
- higher maximum cluster mass
- but no correlation with cluster mass spectrum



Part I: Summary

• Width of CO PDFs increases with increasing average gas surface density, as predicted by simulations of galactic disks

• Observed shapes of CO PDFs are diverse ➡ spiral arm phenomena (shocks/streaming motions/stellar feedback) produce observable departures from lognormal gas density distribution on 50 pc to kiloparsec scales

• Shape of CO PDF is connected to properties of both the GMC and young stellar cluster populations.

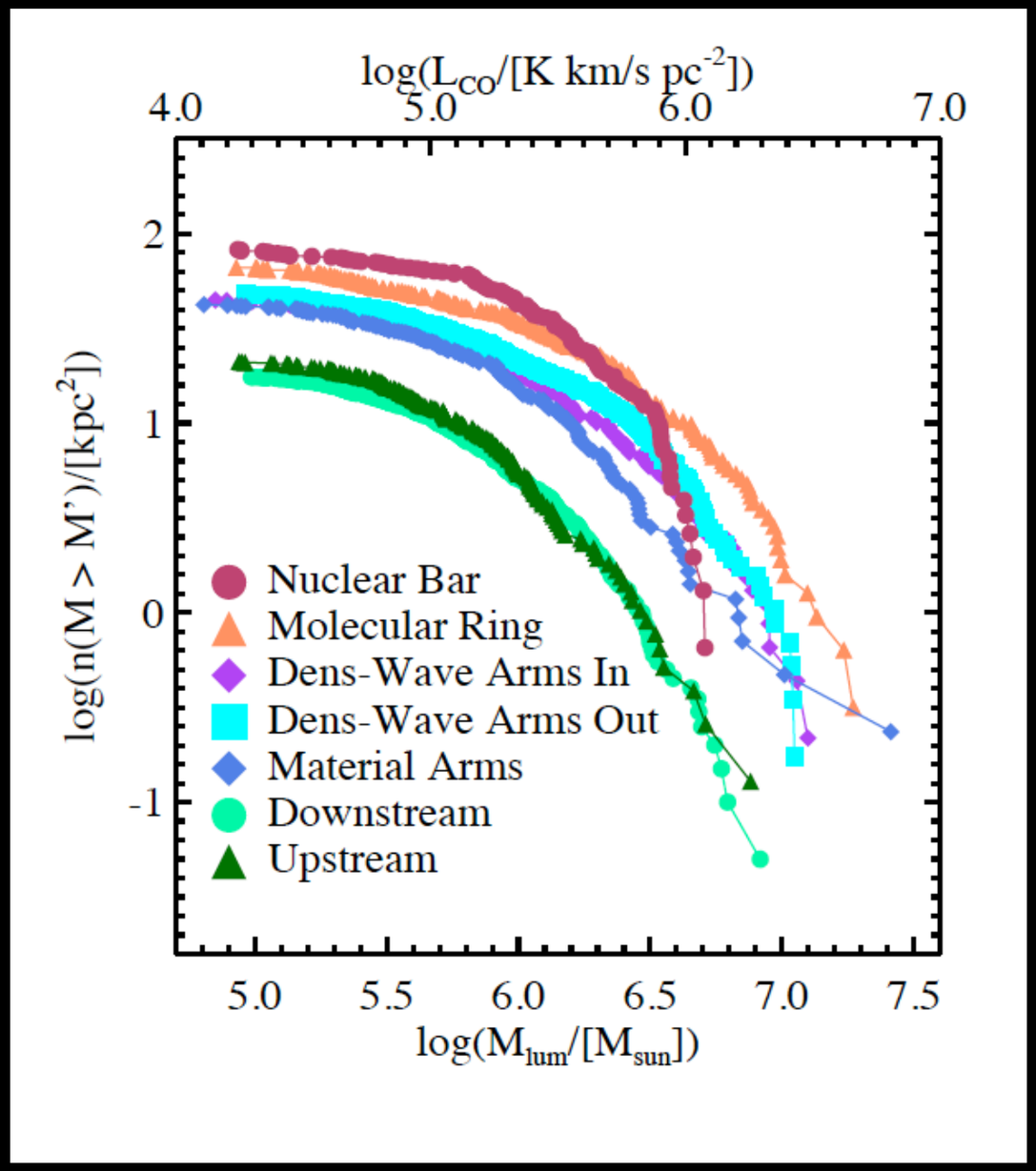
Talk Outline

I. Distribution of CO emission (PDFs) in different M51 environments

II. Properties of giant molecular clouds (GMCs) in different galaxies and M51 environments

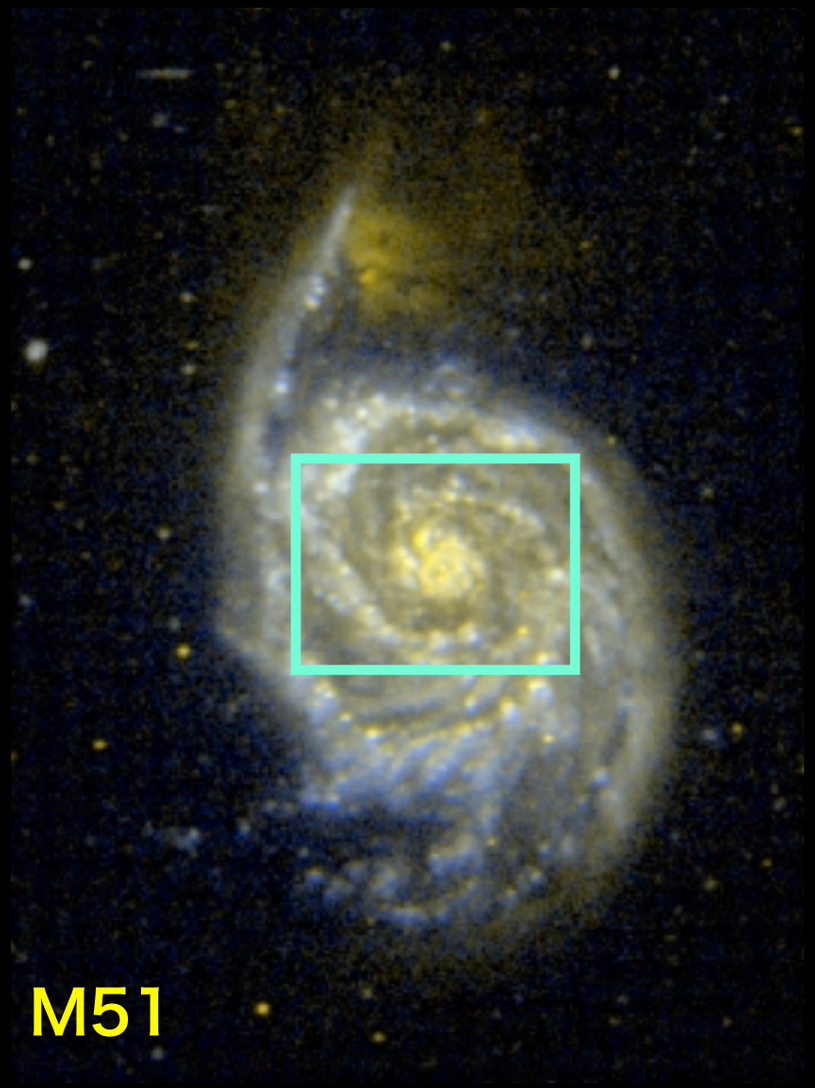
M51 GMC Mass Spectra

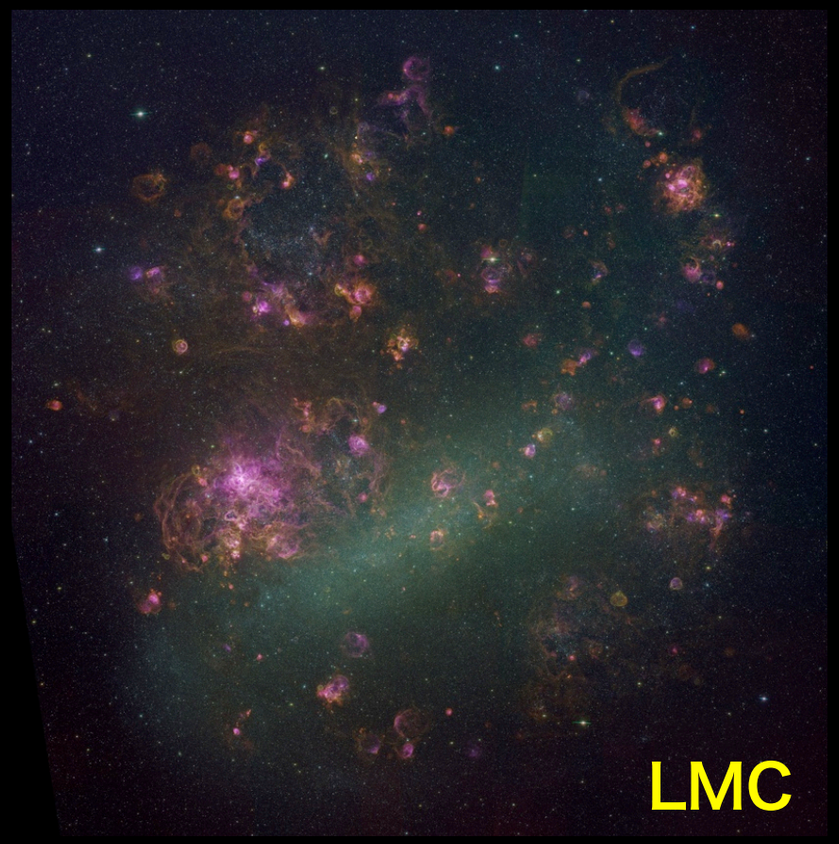
Colombo et al. (submitted)



- Number density of GMCs varies with environment
- Cloud mass spectra in the arms and ring have similar slope to MW GMCs (-1.6 to -1.8)
- Interarm mass spectra are steeper (-2.5)
- Nuclear bar shows a strong truncation

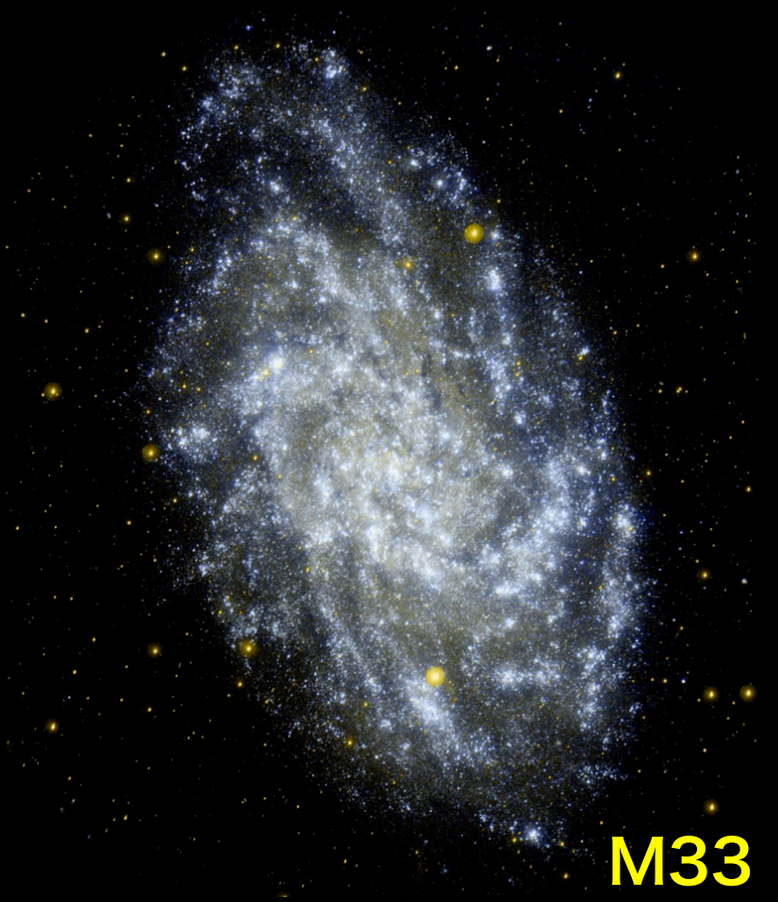
GALEX, Gil de Paz et al 2006





MCELS, Smith et al 1999

GALEX, Gil de Paz et al 2006



massive galaxy
deep stellar potential
molecule-dominated

low mass galaxies
high ratio of gas to stars
HI-dominated
lower dust abundance

GMC Properties

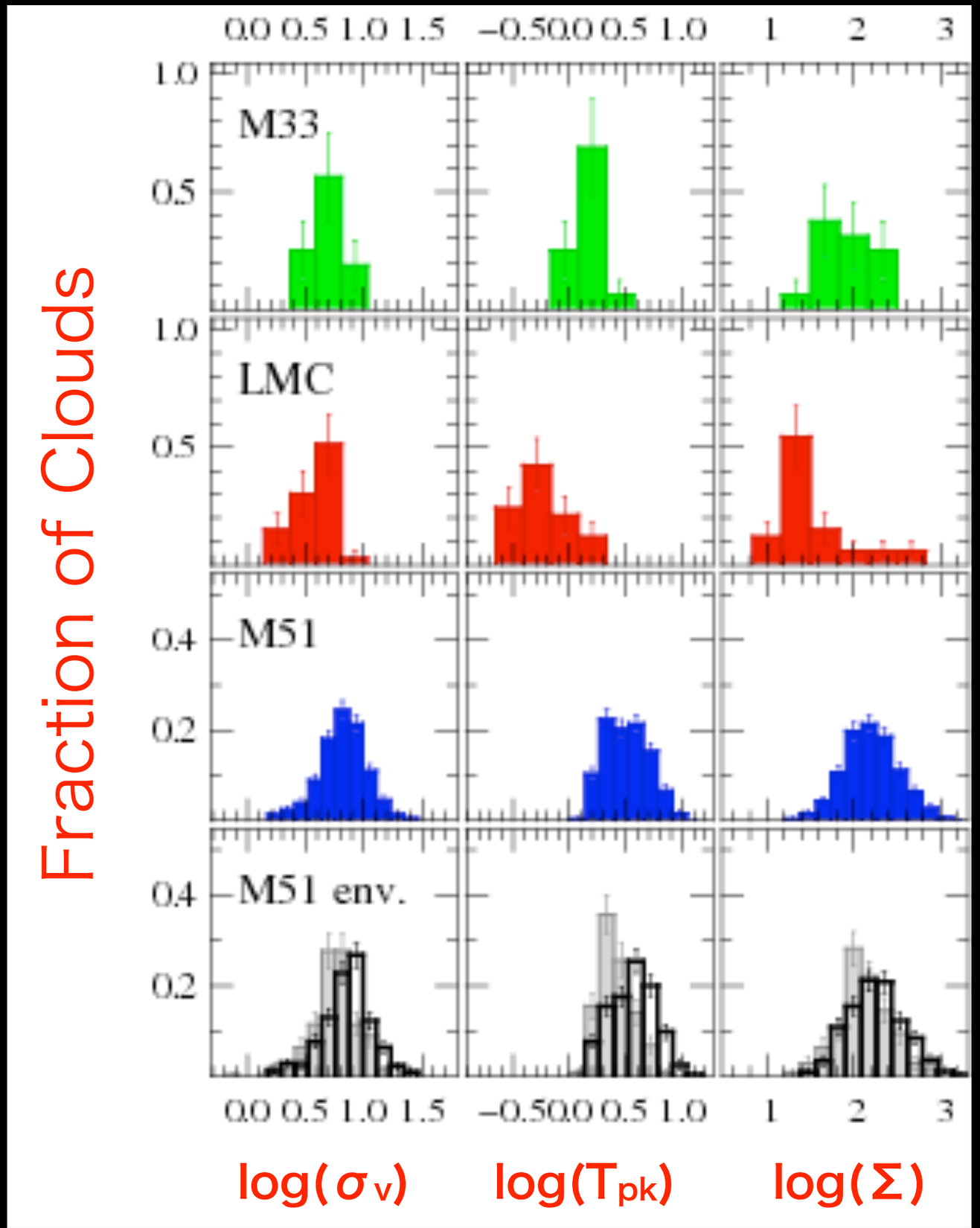
After homogenizing the datasets, M51 GMCs:

➡ are larger

➡ are brighter (peak T and CO surface brightness)

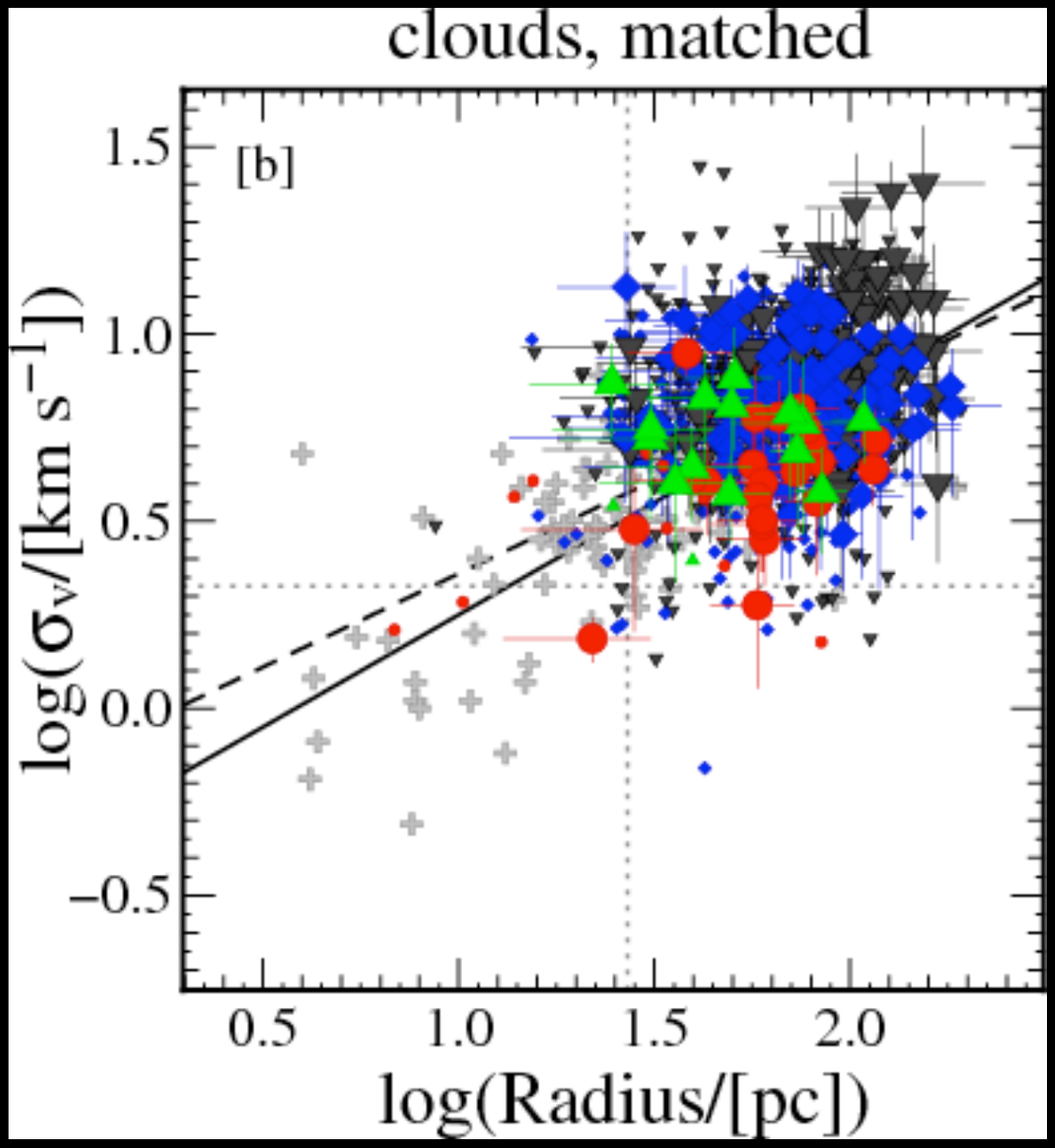
➡ have larger linewidths (especially relative to size) than GMCs in M33 and LMC

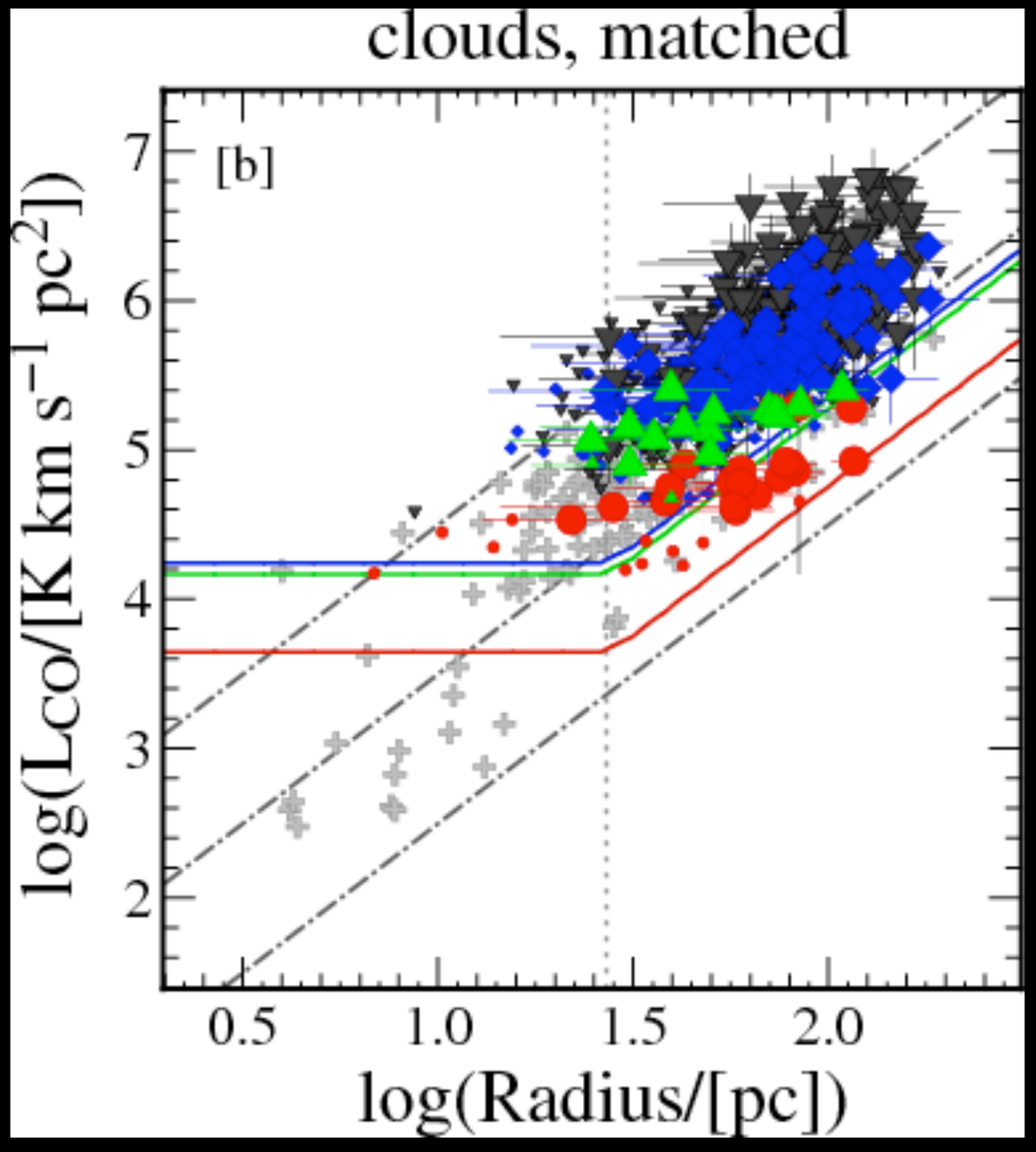
Hughes et al. (submitted)



Scaling relations

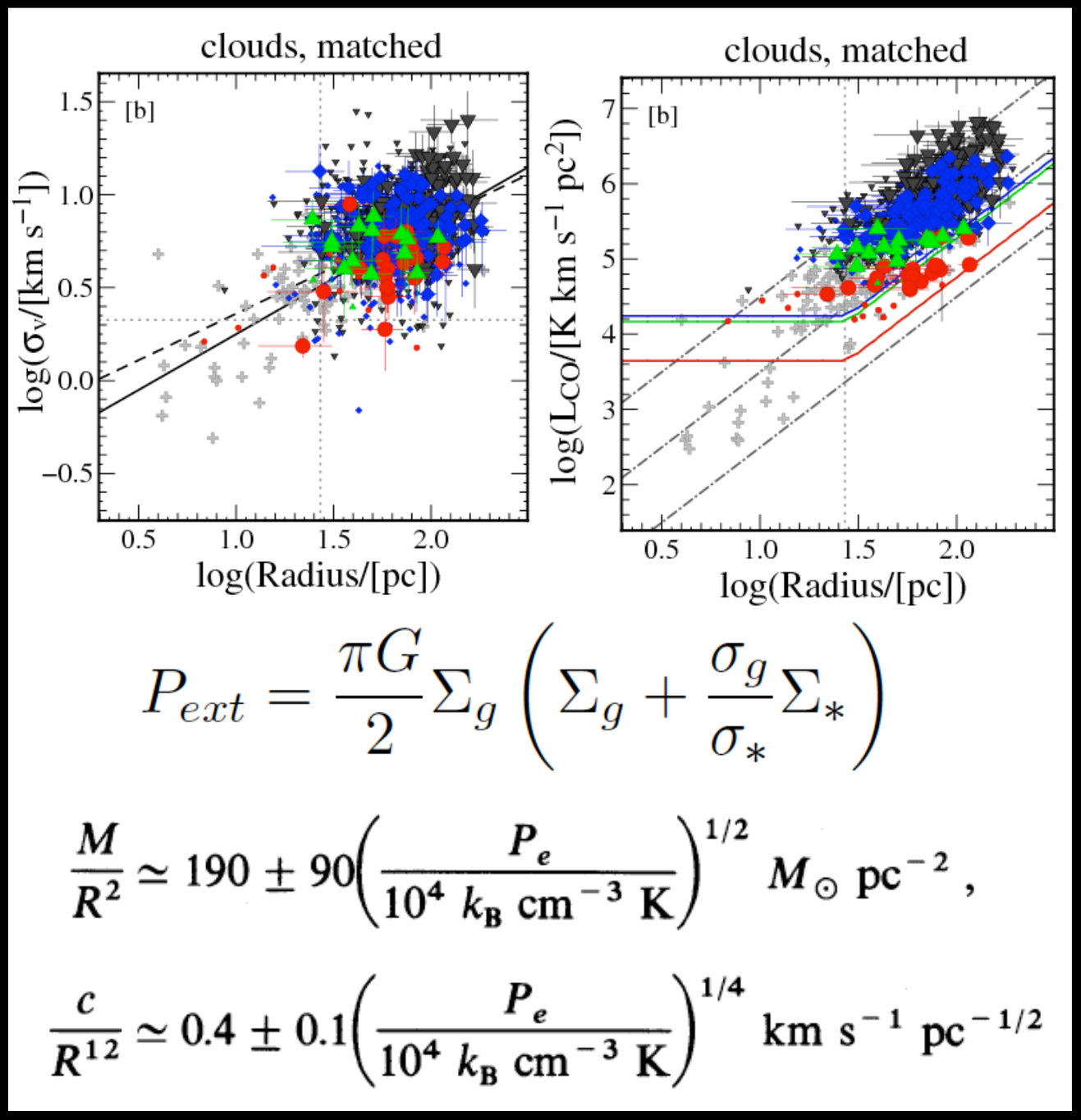
Hughes et al. (submitted)





▼M51 arm + centre ◆M51 i-arm ▲M33 ●LMC

A consequence of P_{ext}?



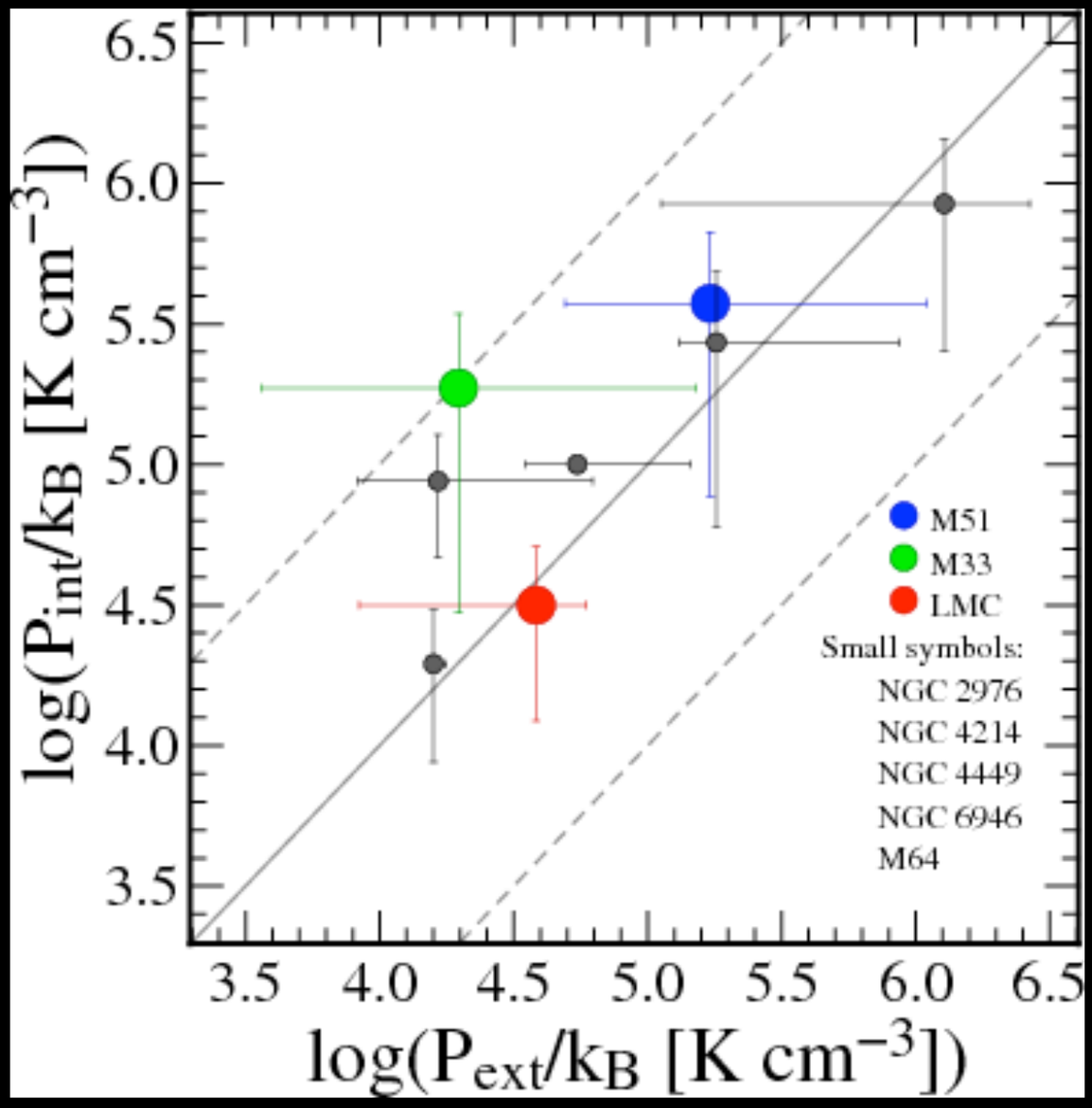
$$P_{ext} = \frac{\pi G}{2}\Sigma_g\left(\Sigma_g + \frac{\sigma_g}{\sigma_*}\Sigma_*\right)$$

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

$$\frac{c}{R^{12}} \simeq 0.4 \pm 0.1\left(\frac{P_e}{10^4\ k_B\ \mathrm{cm^{-3}\ K}}\right)^{1/4} \mathrm{km\ s^{-1}\ pc^{-1/2}}$$

e.g. Elmegreen (1989)

Hughes et al, submitted



▼M51 arm + centre ◆M51 i-arm ▲M33 ●LMC

Part II: Summary

- Basic physical properties of GMCs (e.g. T_{pk}, R, σ_v) and GMC mass functions vary with galactic environment

- No compelling evidence of size-linewidth relationship, but M51 clouds have larger linewidths and higher CO luminosity at a fixed size scale than clouds in the dwarf galaxies

- σ_v and Σ_{H2} of GMCs regulated -- or at least influenced -- by kinetic ISM pressure?