Observational Perspectives on GMC Formation

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Collaborators

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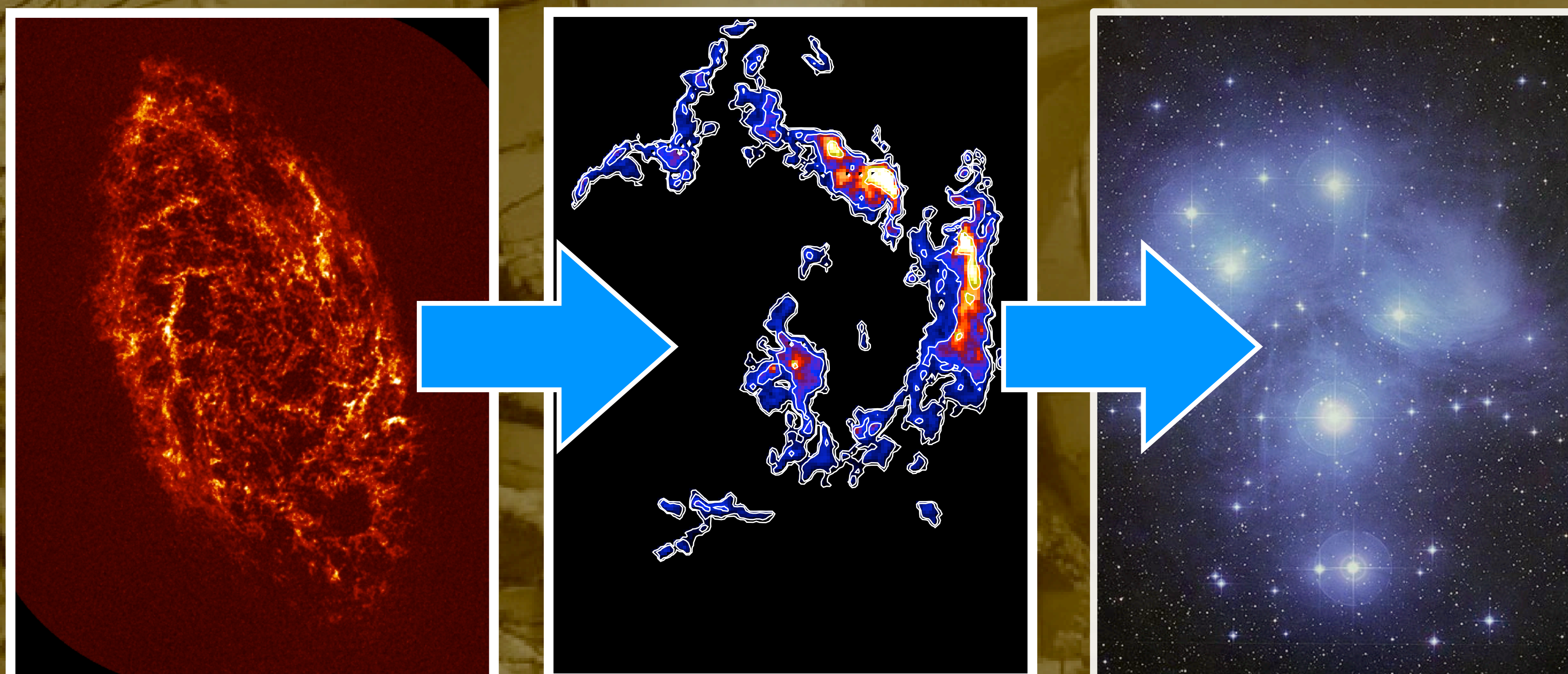
(G)MCs form link between diffuse ISM and stars



Atomic Gas

Molecular Clouds

Stars

Photo Credits: D. Malin, D. Thilker

Basic Formation Problem

- Make a $10^6\ M_\odot$ GMC with D=80 pc
- Start: Σ_{gas}=10 $M_\odot$ pc^{-2} (ISM)
- Finish: Σ_{GMC} = 200 $M_\odot$ pc^{-2}
- Accumulation scale: l >350 pc.
- HI➔H_2 is quick: 3-10 Myr.

Poll: Which of the following are responsible for GMC formation?

A. Accumulation of small molecular clouds

B. Large scale dynamics / instabilities

- Parker, Toomre, MRI, MJI, Swing
- Spiral Arms

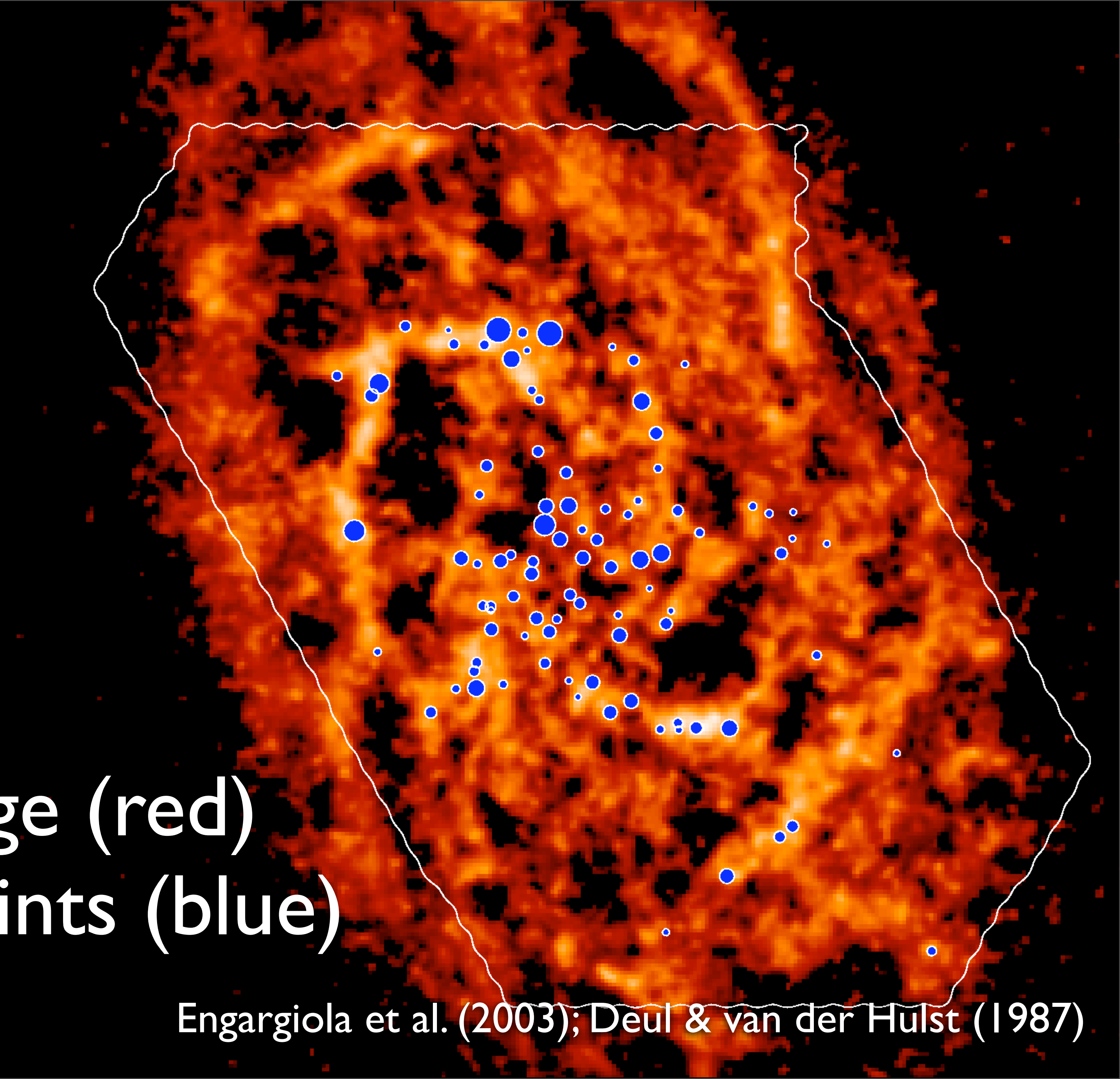
C. Turbulence / Converging Flows

D. Some of the above

E. I am asleep

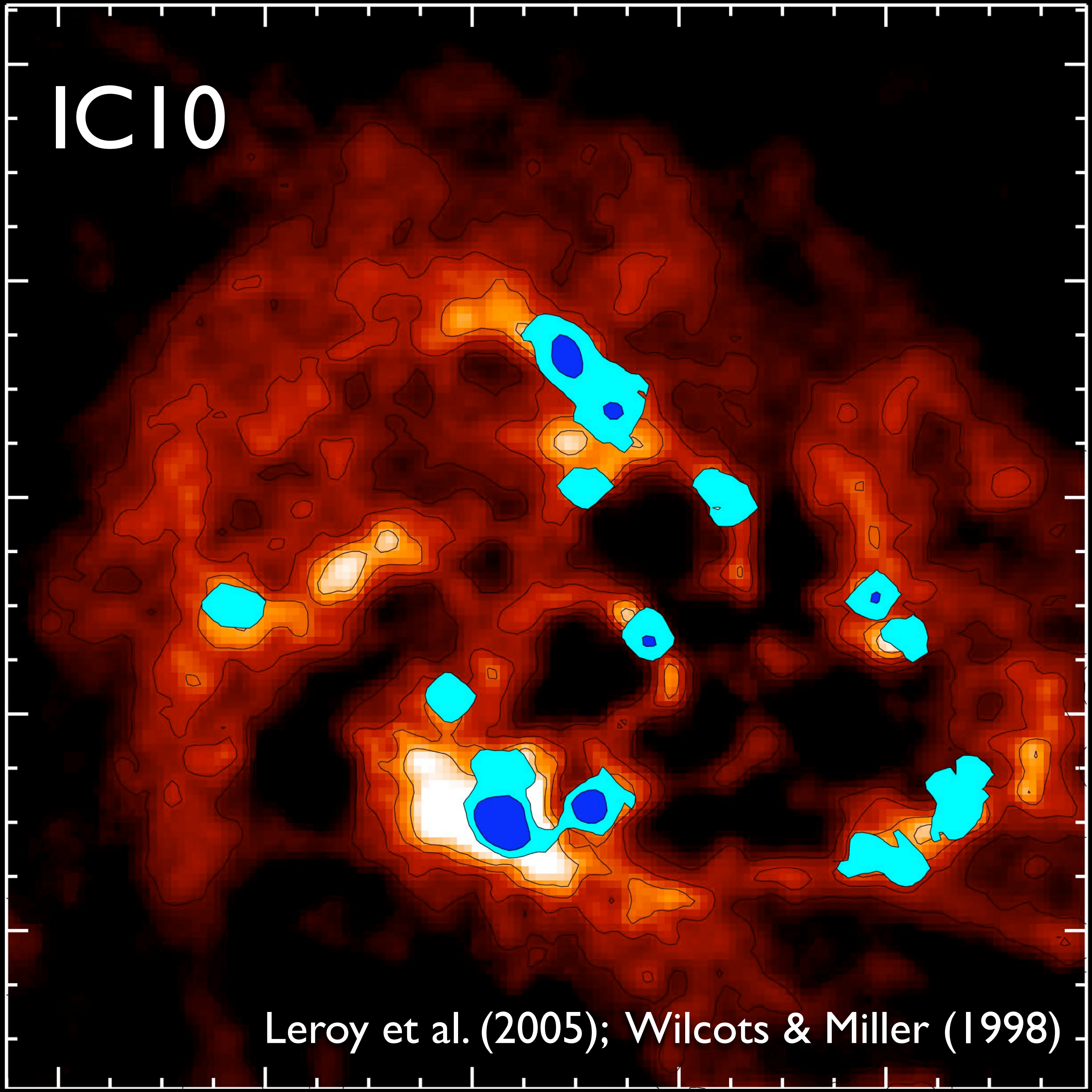
Four Illuminating Observations

- HI and GMC morphology
- Macroscopic GMC properties
- The mass distributions of GMCs
- Angular momentum defects

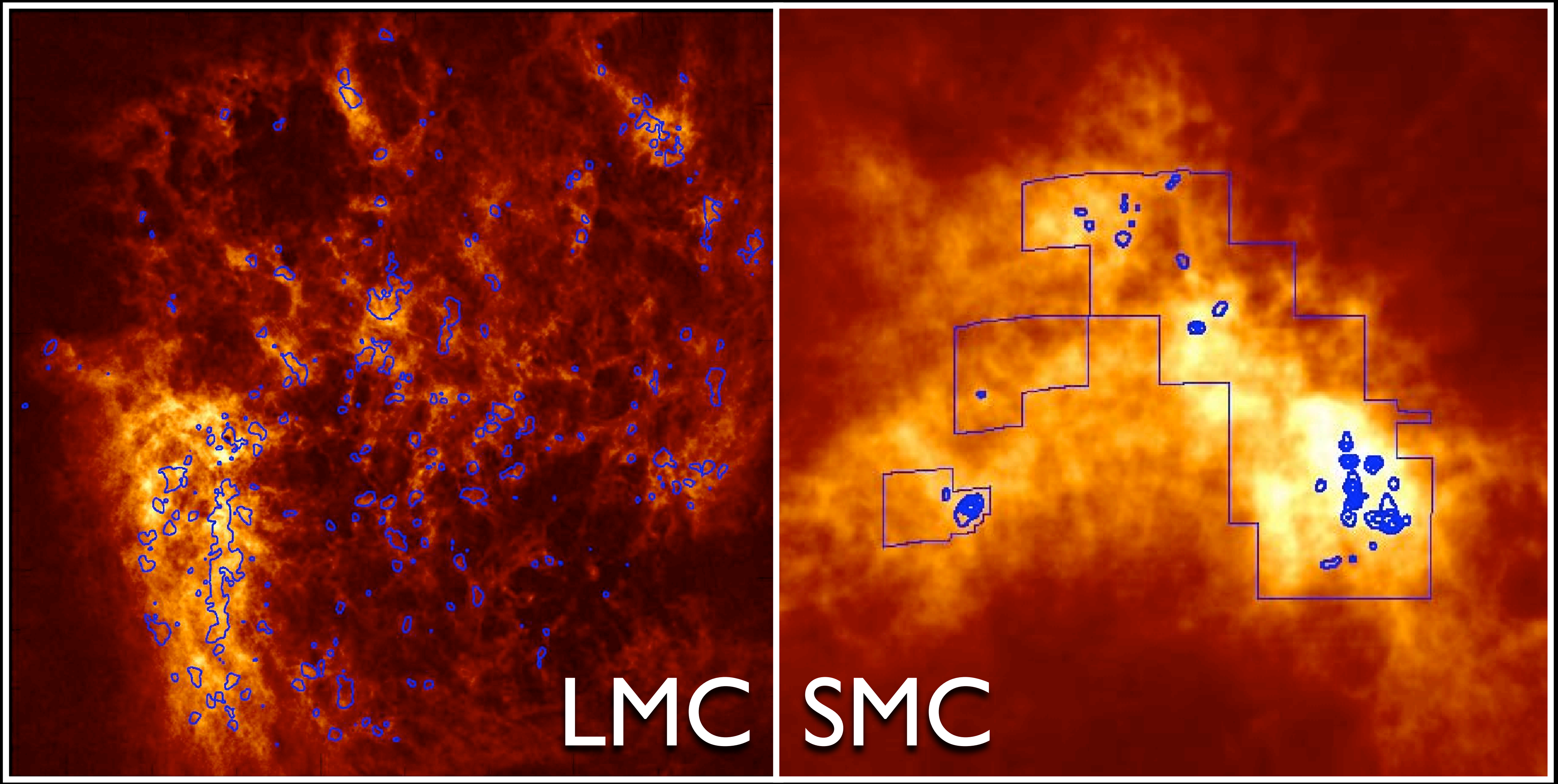


M33
HI Image (red)
CO Points (blue)

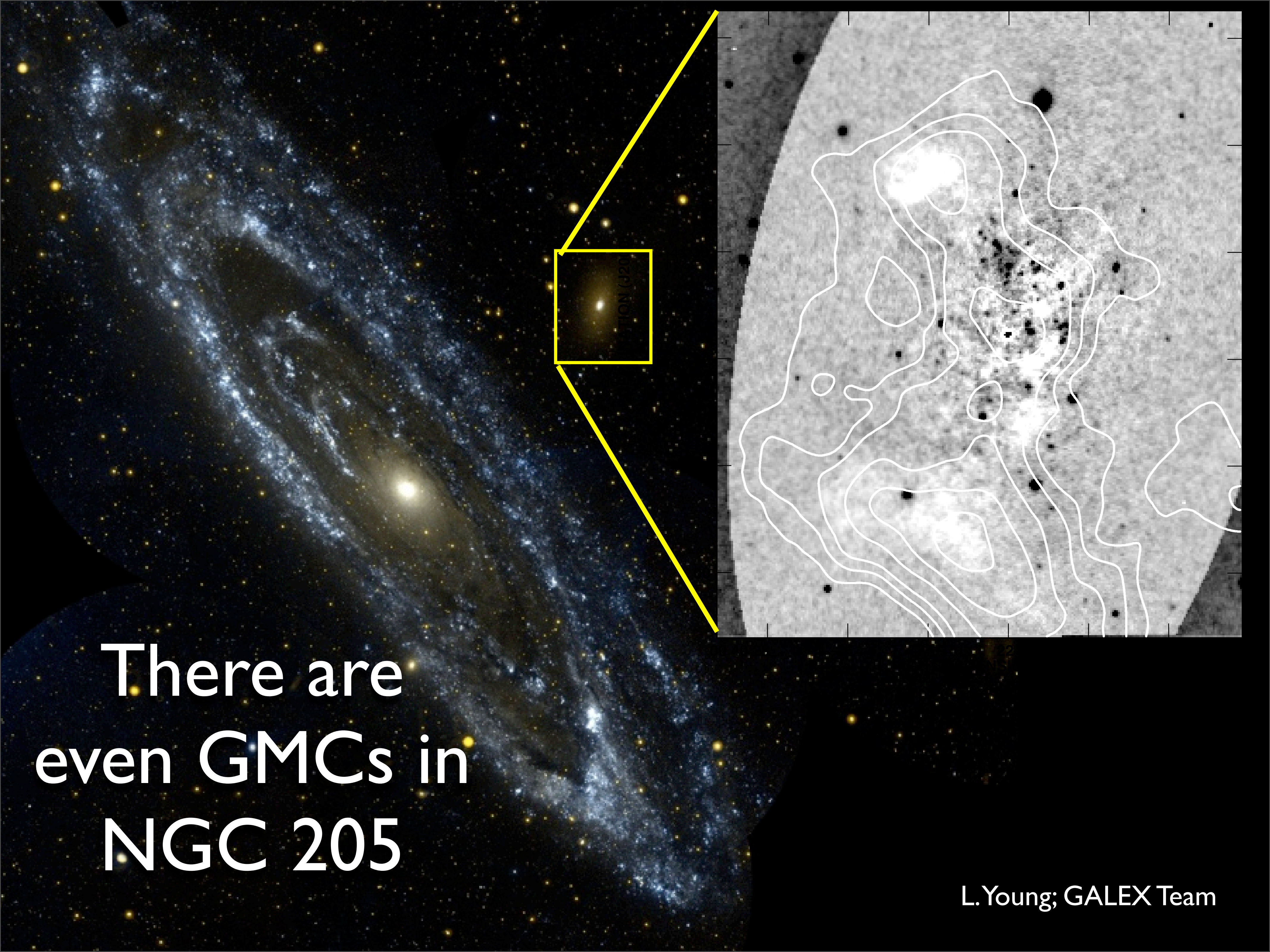
Engargiola et al. (2003); Deul & van der Hulst (1987)



IC10
Leroy et al. (2005); Wilcots & Miller (1998)



From the NANTEN and ATCA Work
(Fukui, Kawamura, Mizuno, Kim, Stanimirovic et al.)


There are even GMCs in NGC 205
L. Young; GALEX Team

Inferences from HI+CO

- GMCs always associated with high column density 21-cm emission
- Origins of 21-cm "filaments" vary
- Radial variation of HI/H_2 fraction implies more parameters.

GMC Properties

Larson (1981) first showed that molecular clouds follow power-law relationships between their macroscopic properties:

$$\sigma_v = \sigma_0 \left(\frac{R}{1 \text{ pc}} \right)^\beta$$

$$\alpha_{\text{VIR}} = \frac{5\sigma_v^2 R}{GM}$$

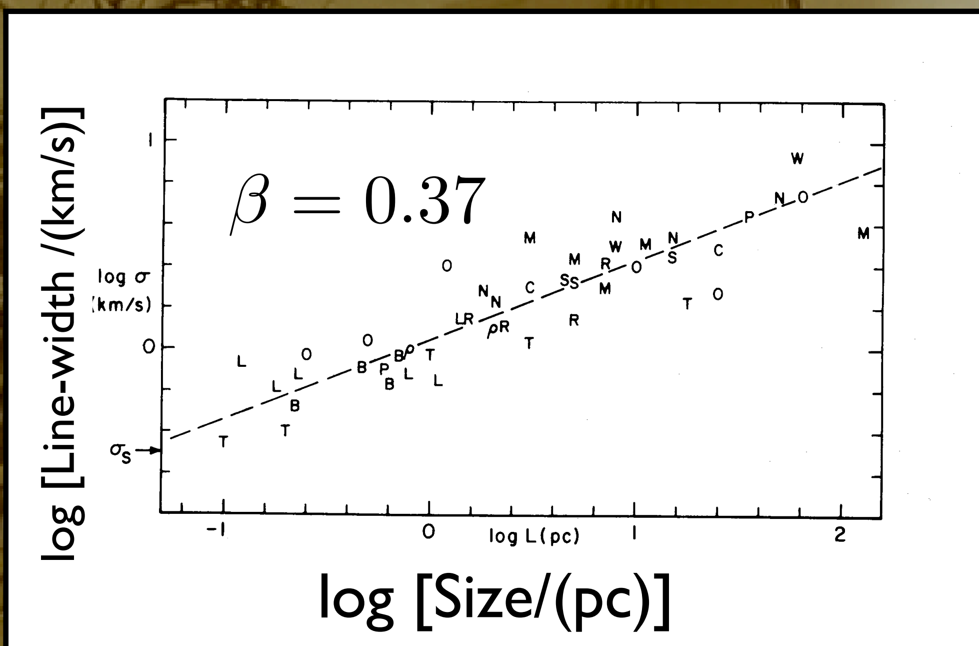
$\sigma_0 = 0.5 \leftrightarrow 0.7 \text{ km s}^{-1}$

$\beta \sim 0.5$

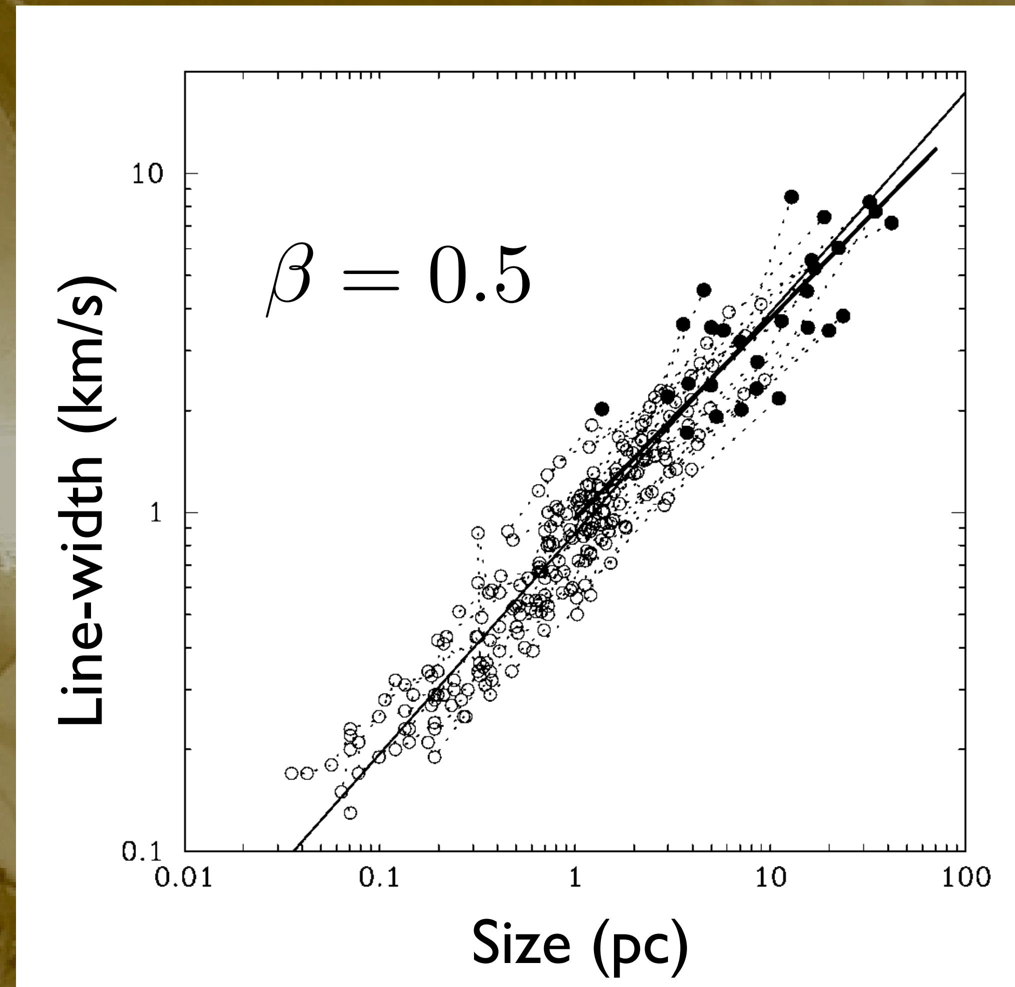
$\alpha_{\text{VIR}} \sim 1.5 \ R^0$

$$M_{\text{GMC}} = \Sigma_0 \pi R^2$$

Size-line width relationship, then and now



Larson (1981)



Heyer & Brunt (2004)

Also: Sanders et al. (1985), Dame et al. (1986), Solomon et al. (1987), Scoville et al. (1987), Leisawitz (1990)

Local Group Studies

- Reanalyze all complete surveys of extragalactic GMCs.
- Use a uniform analysis method to eliminate bias from varying **Sensitivity** & **Resolution.**
- Analysis generates meaningful uncertainties.
- Uniform decomposition method anchored on **physical** rather than **observational** scales.

Rosolowsky & Leroy (2006)

Summary of GMC properties

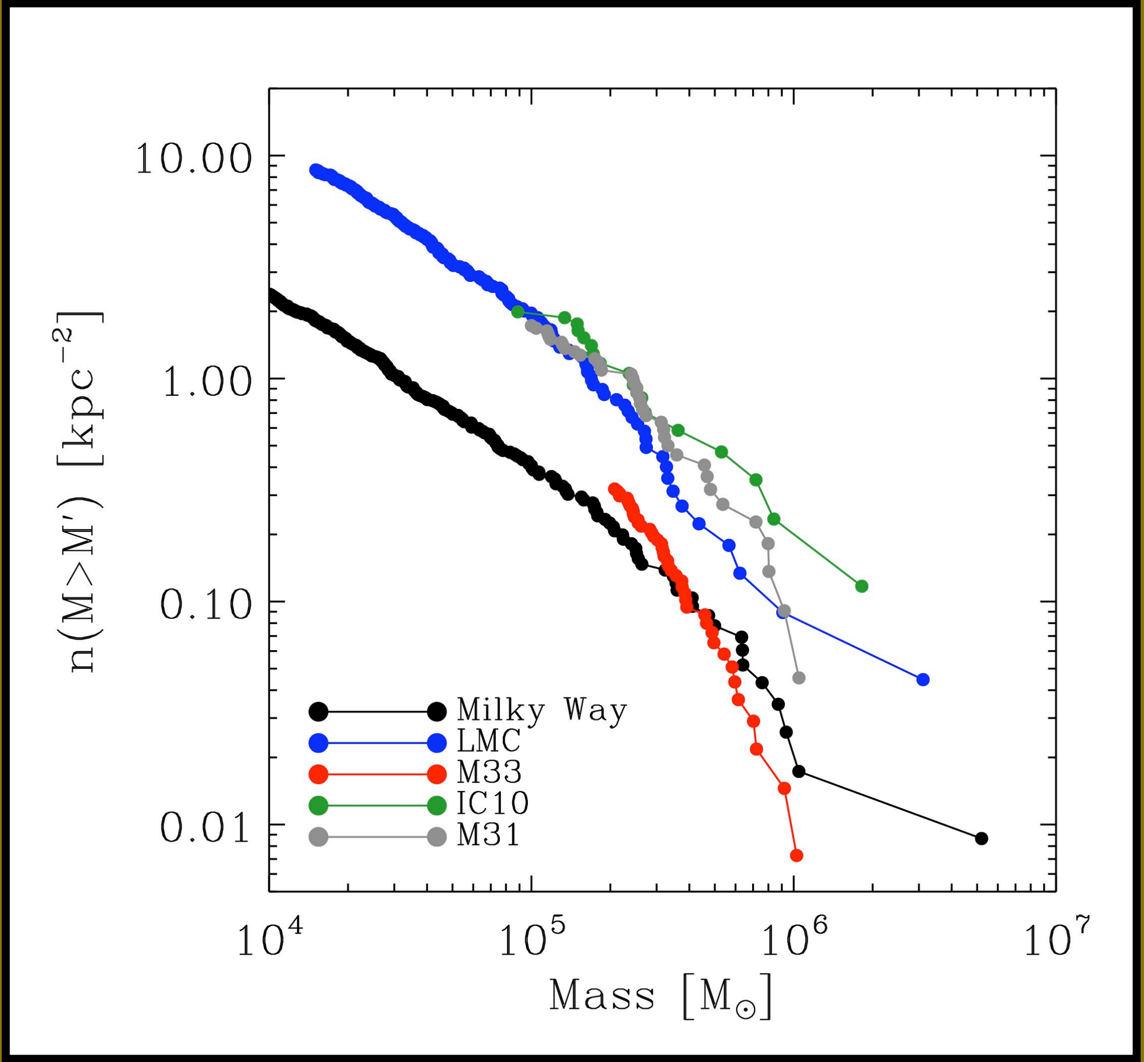
	X_{CO}	σ_0 (km/s)	Σ_0 ($M_\odot$/pc^2)
LMC	2.7	0.39	45
SMC	6.6	0.36	30
M33	2.0	0.61	170
IC10	1.7	0.55	140
M31	2.6	0.72	200
Outer MW	3.0	0.40	50
Errors	0.5	0.05	10
M64	2.0	1.2	300

Blitz et al. in PPV (2007)

Mass Distributions of GMCs

$$N(>M) \propto M^{\alpha+1}$$

Galaxy	α
Inner MW	-1.5
Outer MW	-2.0
IC10	-1.7
M31	-1.6
M33	-2.5
LMC	-1.7
Errors	±0.2

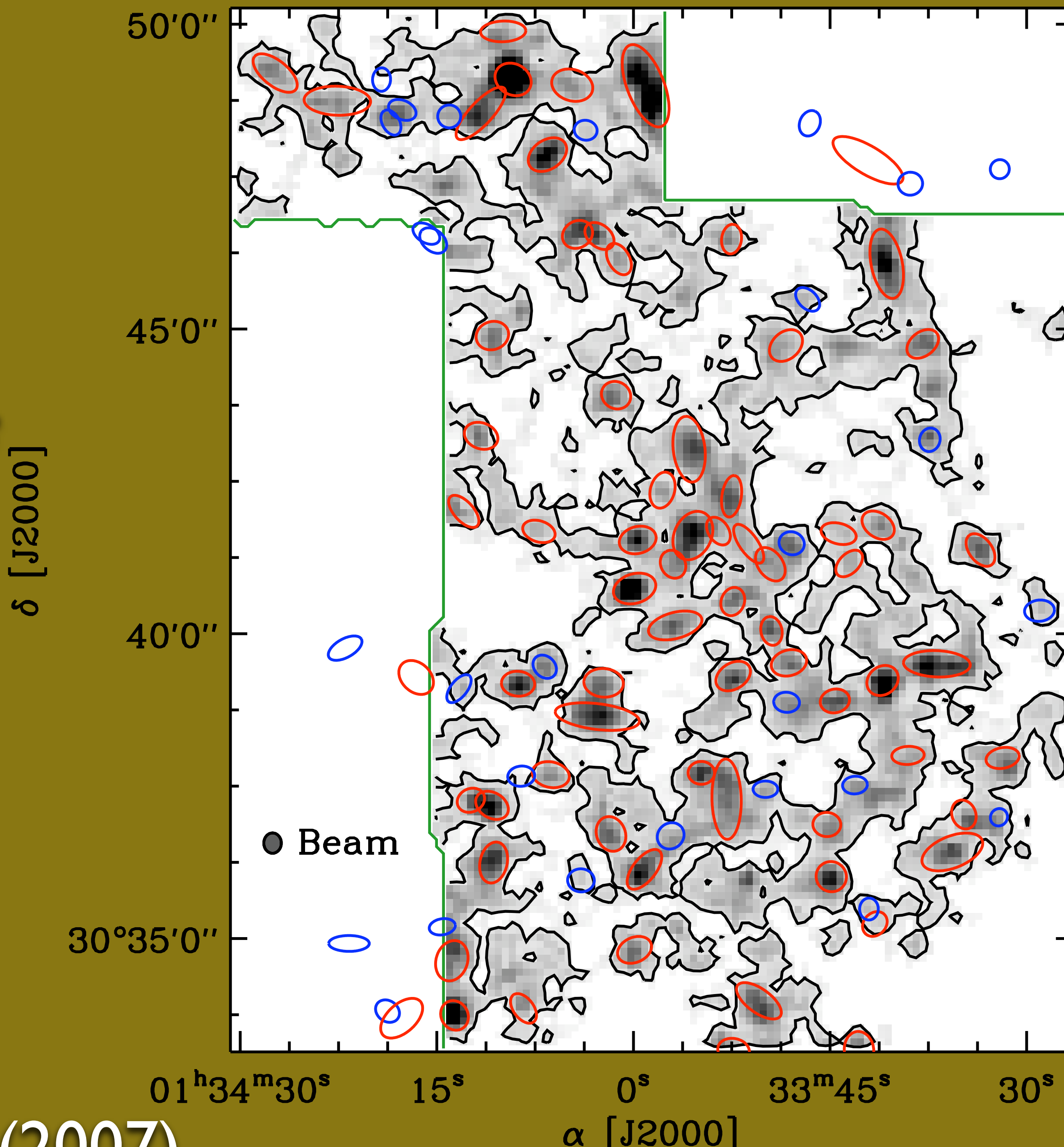


PPV; Rosolowsky et al (2005)

Inferences from GMC properties

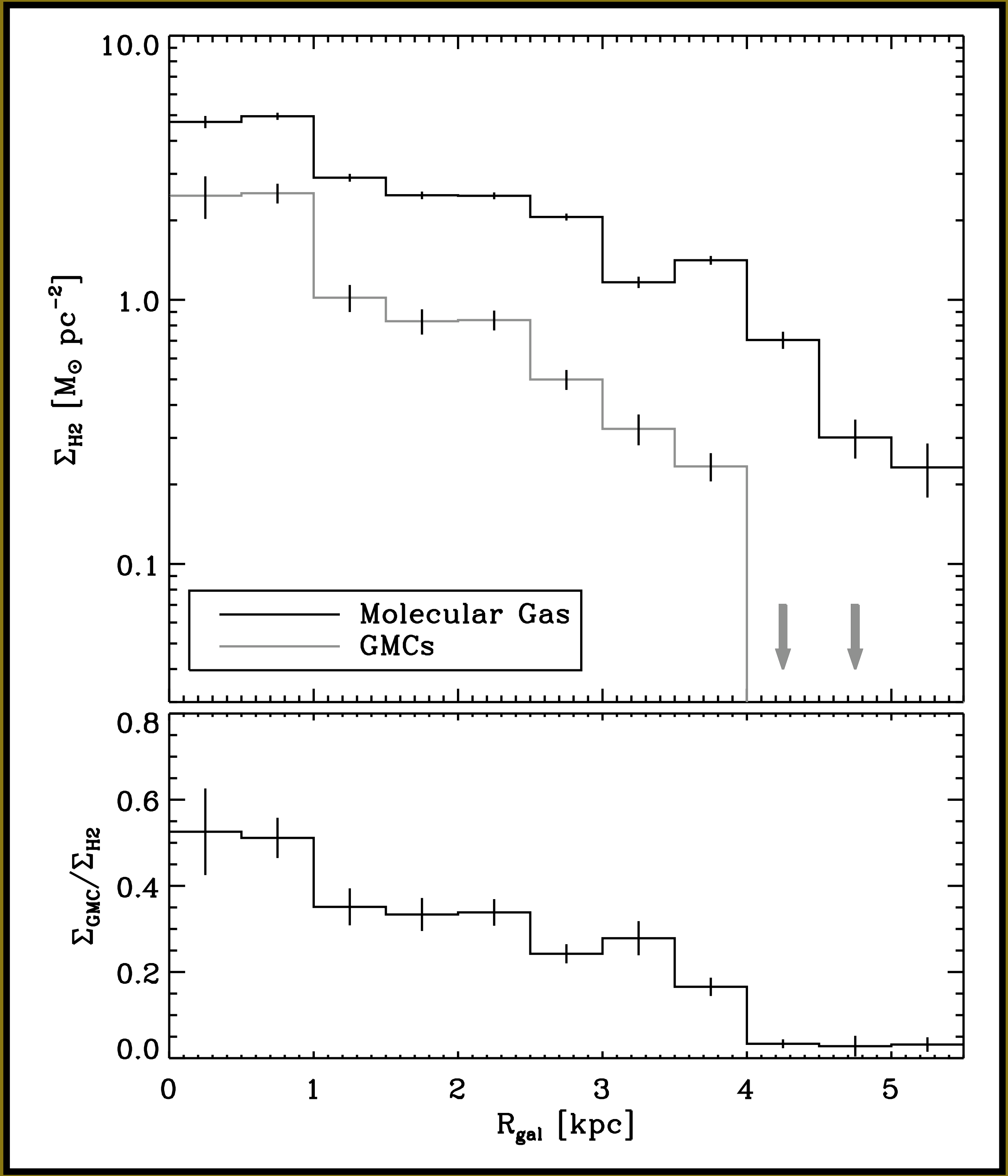
- Significant variation between galaxies
- Similar properties within galaxies
- GMCs are characterized by at least two parameters (e.g. σ_0 & M)

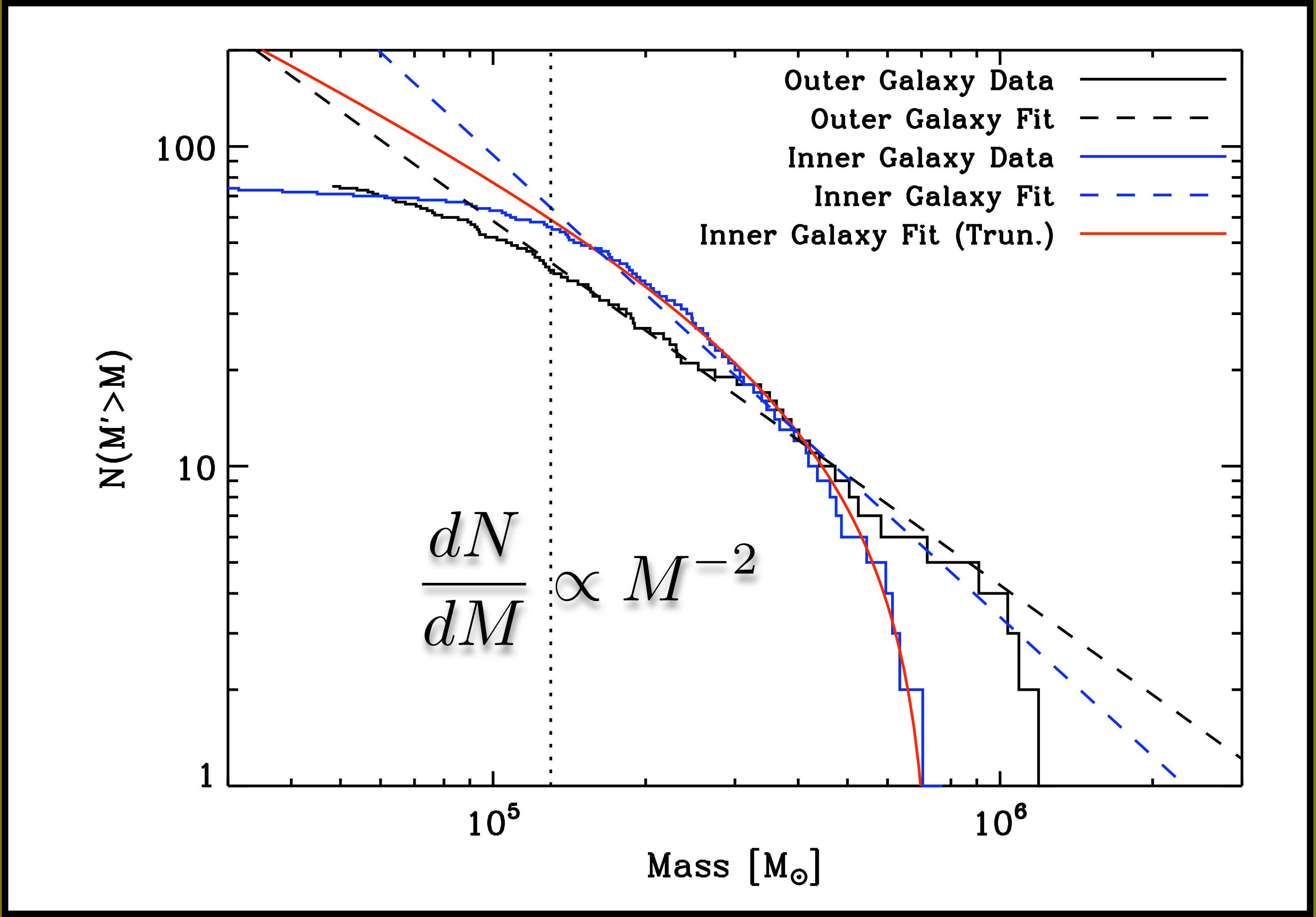
New M33 observations of CO combining BIMA, FCRAO and Nobeyama 45-m



Rosolowsky et al. (2007)

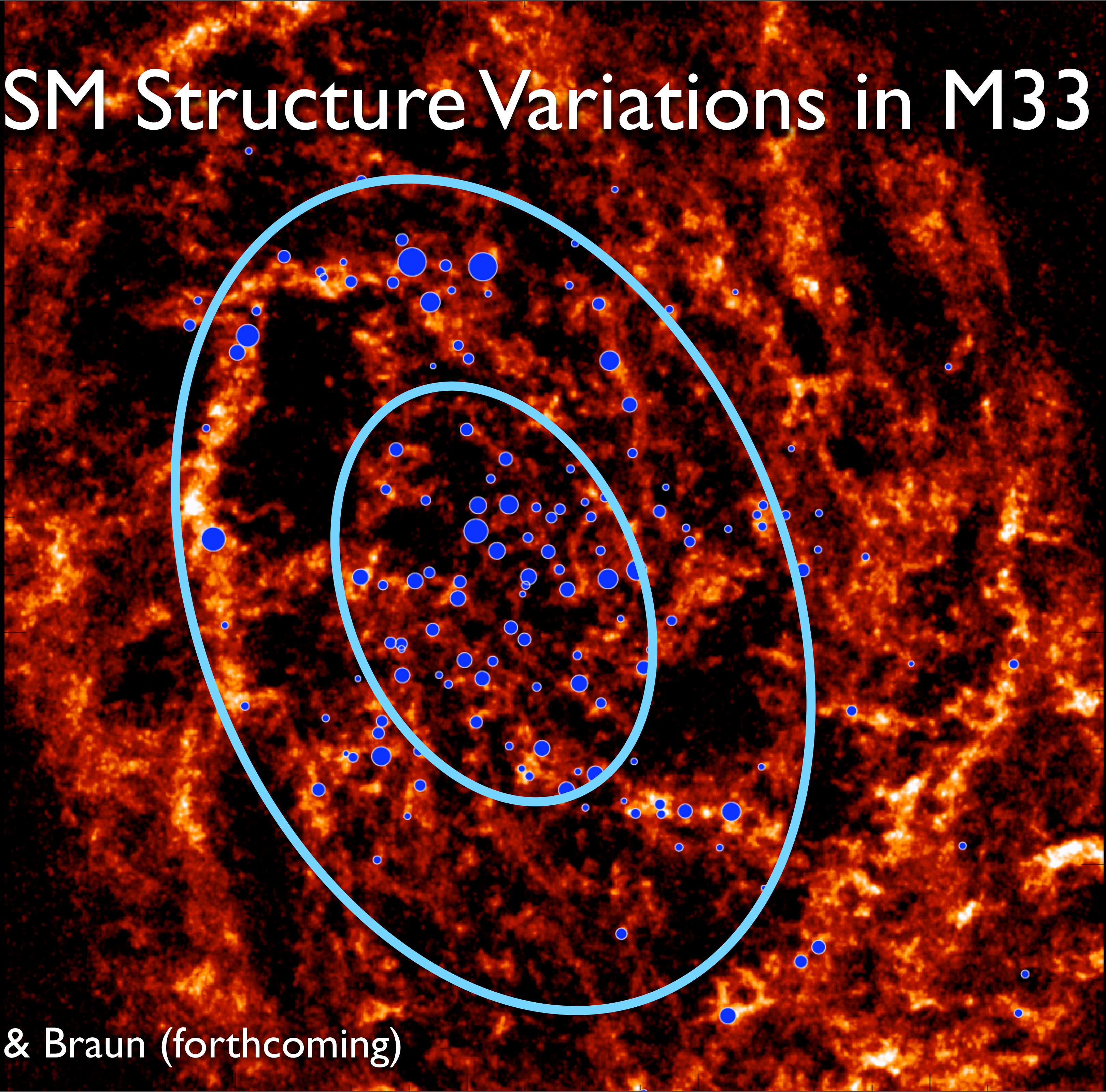
Amount of molecular mass in GMCs drops radially and cuts of sharply at 4 kpc from center





High mass GMCs are suppressed in the center of the galaxy.

ISM Structure Variations in M33



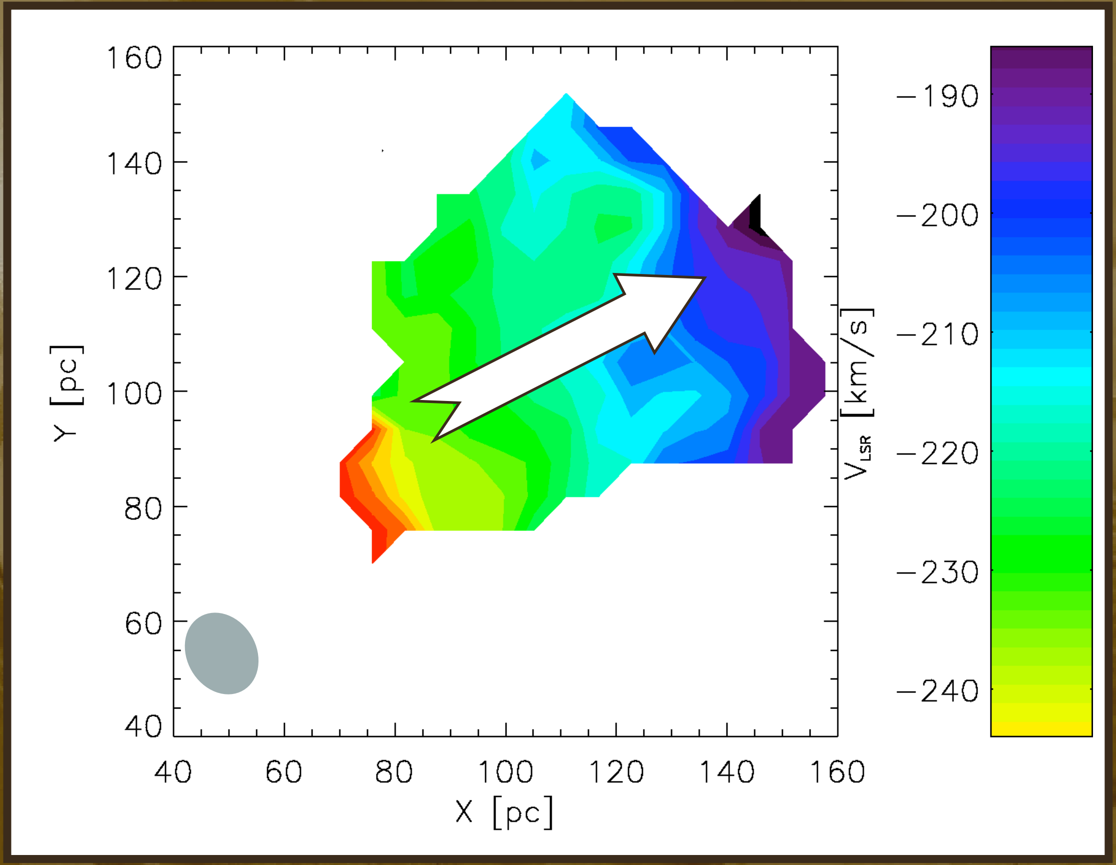
Thilker & Braun (forthcoming)

Angular Momentum Defects

- With resolved GMCs, we observe velocity gradients across the clouds
- Measure specific angular momentum:

$$j = \frac{J}{M} = \beta |\nabla v| R^2$$

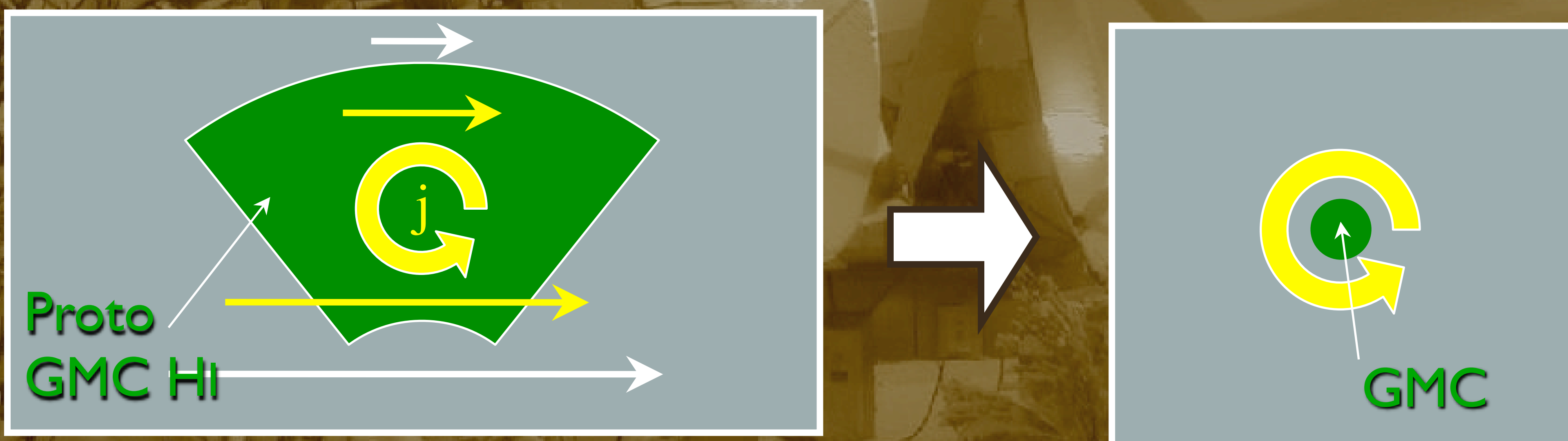
$$\beta \in [0.3, 0.5]$$



Rosolowsky et al. (2003)

Angular Momentum Tests

- Different Theories = Different Collapse geometries = Different angular momentum
- Initial angular momentum from galactic shear



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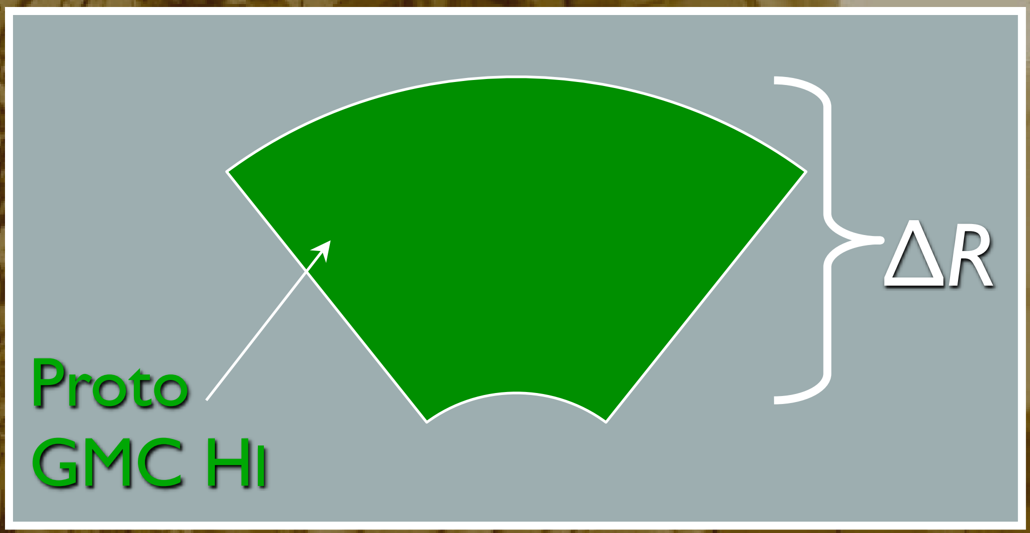
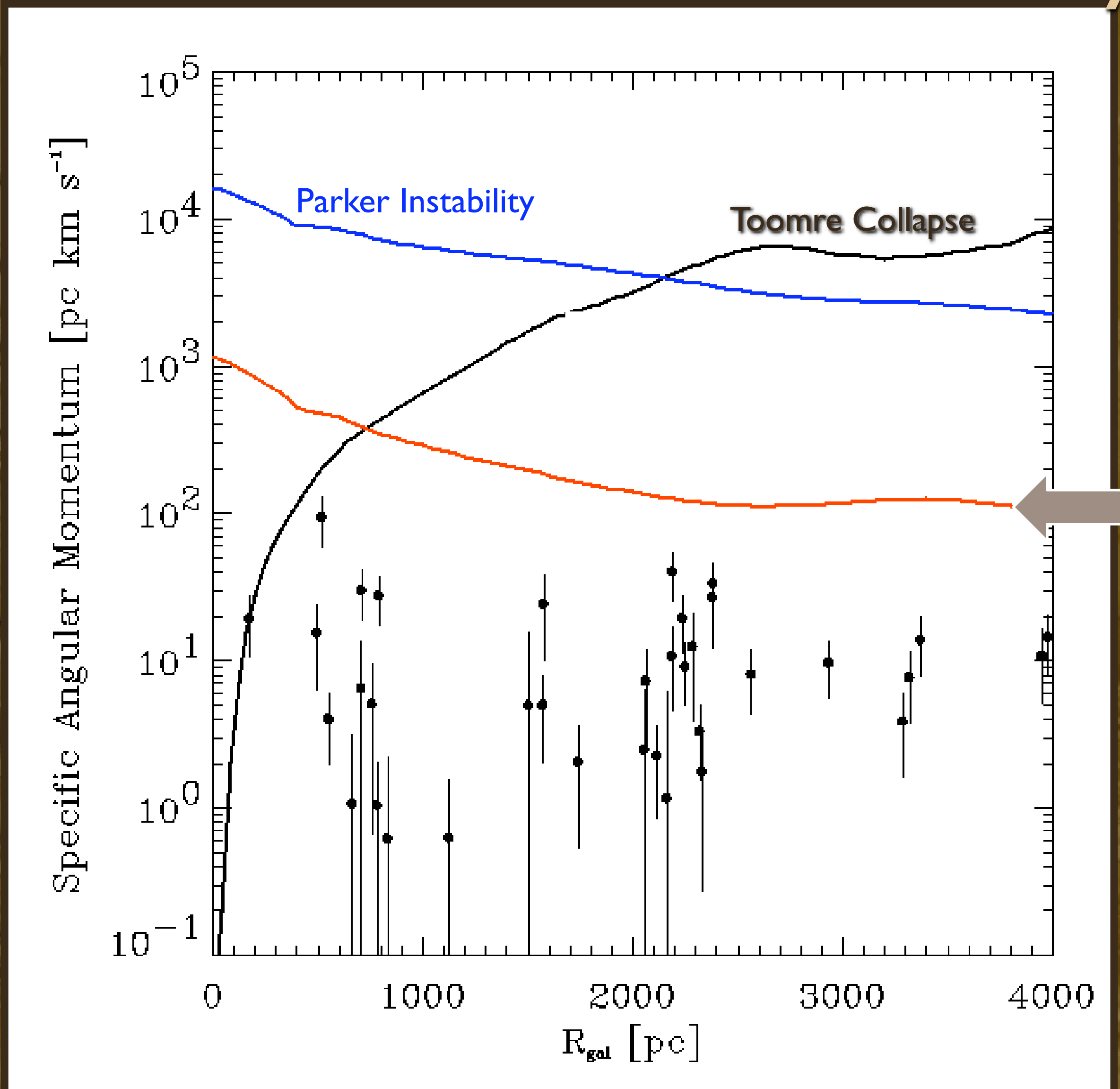


- ΔR is set by the formation mechanism

$$j \geq \eta \, \frac{1}{R}\frac{d}{dR}(RV)\Big|_{R=R_c} \Delta R^2$$

Observed angular momentum is much less than naïve theory predicts



Simple model with ΔR set by how large of a disk is required to get the mass of the observed GMC from HI

$$\Delta R = \sqrt{\frac{M_{\rm GMC}}{\pi \Sigma_{\rm HI}}}$$

Angular Momentum

- Defects also seen in MW (Koda et al. , 2005) and M31 (Rosolowsky 2007).
- *j*(*M*) same across galaxies
- Requires tracking in numerical simulations.

Inferences & Conjectures

- Multiple channels to make GMCs
- Diffuse ISM structure governs GMC formation
- Need connections between ISM structure and GMC variations.