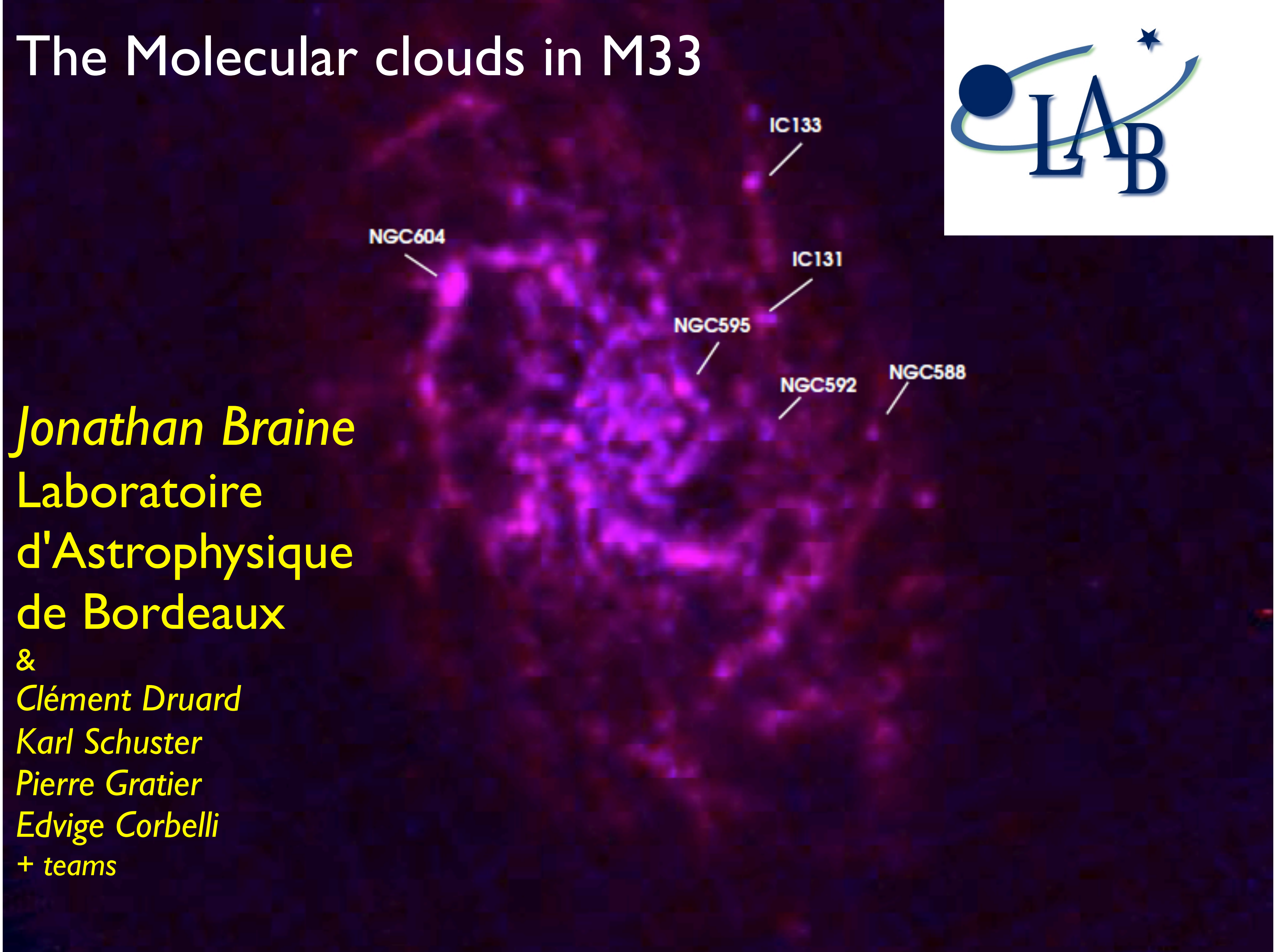
The Molecular clouds in M33



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+ teams

***Why care about molecular cloud properties*?**

Complete CO(2-1) map of M33 (IRAM)

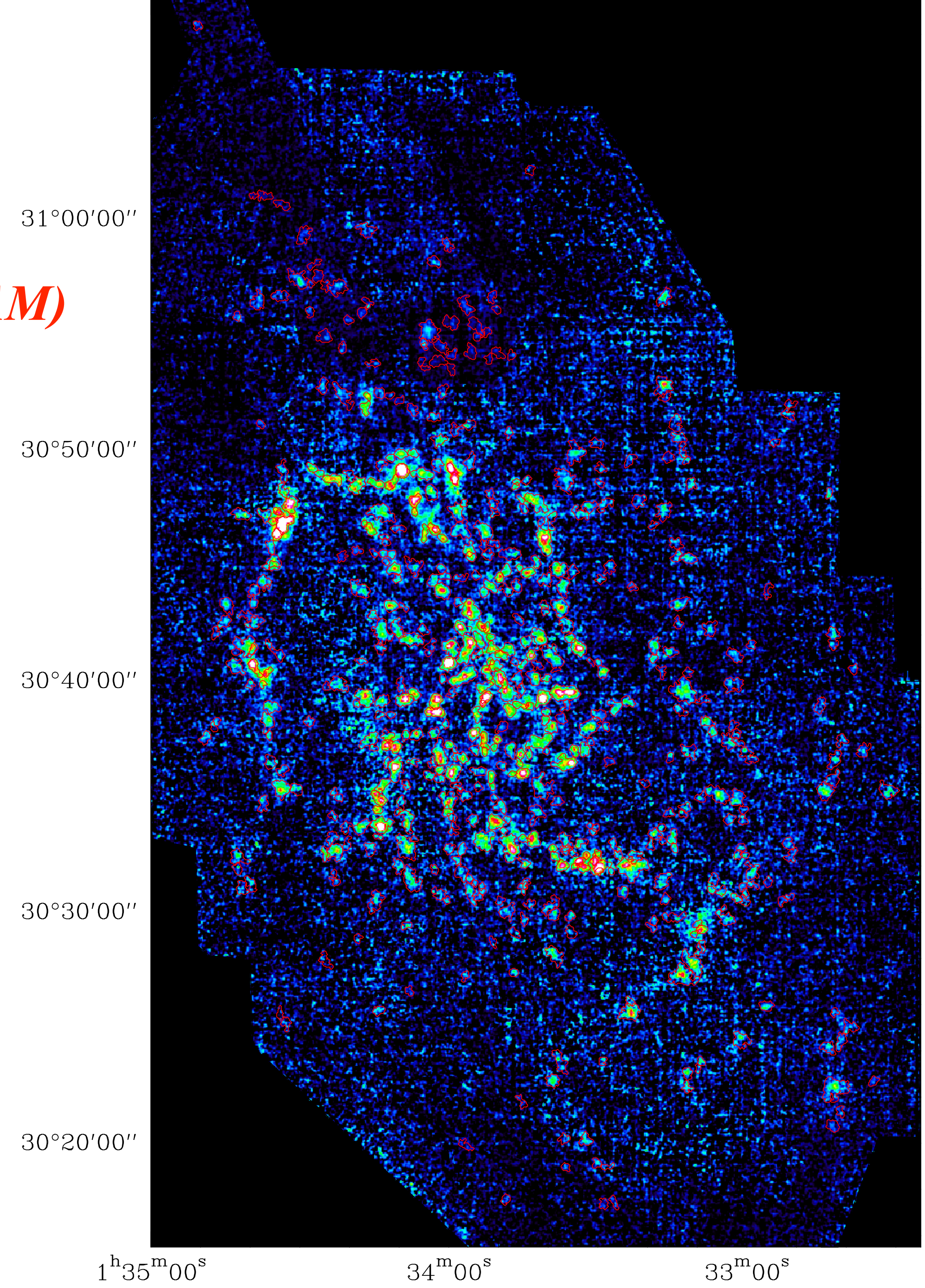
Clues to formation mechanism
probably HI → H2 but how?

Initial conditions for dense core and star formation

Cloud lifetimes (Corbelli+17) and ***forms of support against collapse (rotation)***

Are clouds similar from one environment to another?

Sample of 566 clouds (CPROPS)



size linewidth relation for different galaxies

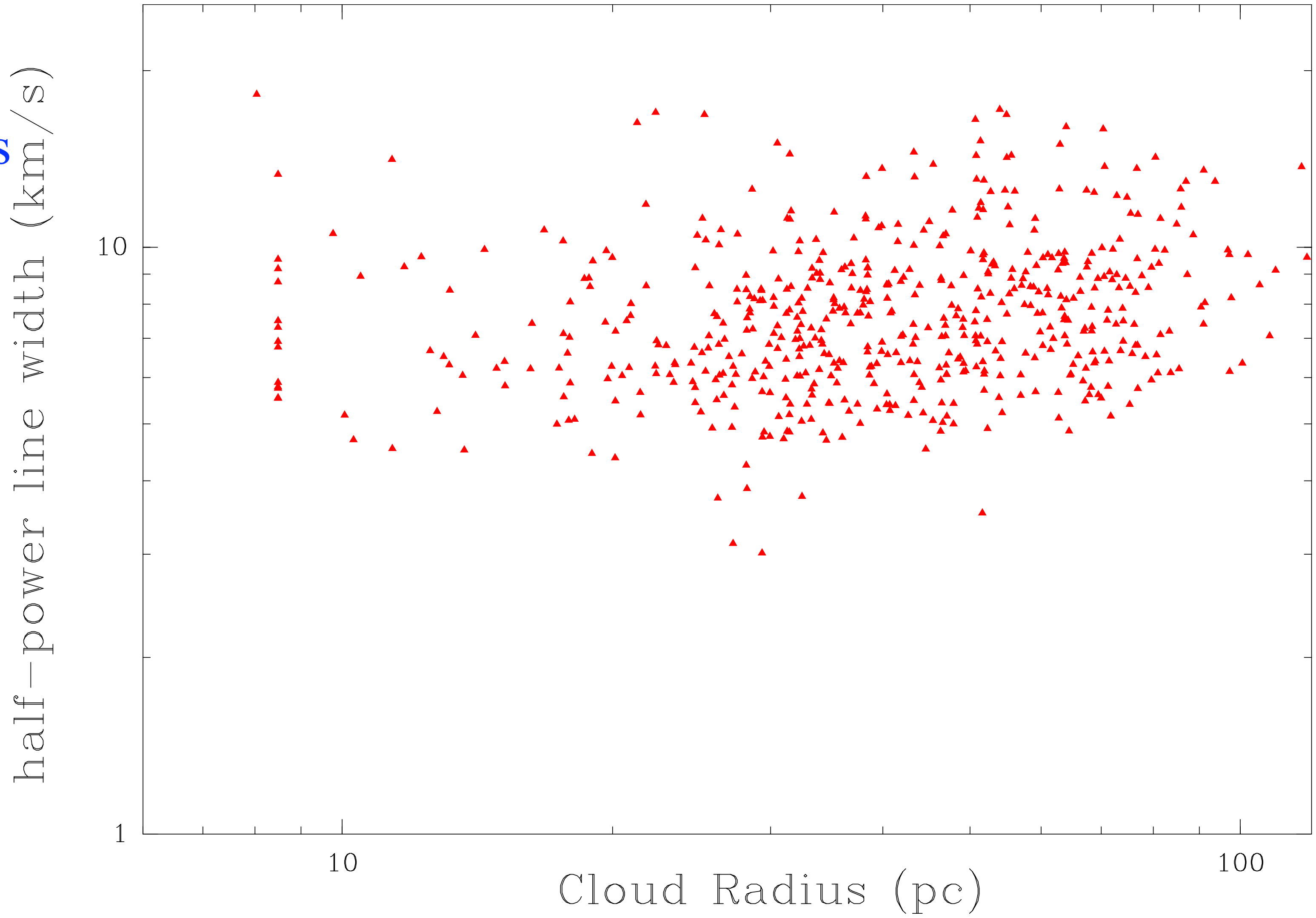
sample of 566 clouds in M33 shown as small triangles and averages as large triangles

M51: Z ≳ Z⊙

M33: Z ≈ 0.5-0.7 Z⊙

LMC: Z ≈ 0.5 Z⊙

N6822: Z ≈ 0.3 Z⊙



refs: Colombo+2014 (M51, 40pc), Gratier+2010 (N6822, 37pc), Solomon+1987 (line), Hughes+2010 (LMC,11pc)
M33: Gratier+2012, Corbelli+2017 and in prep, 48pc

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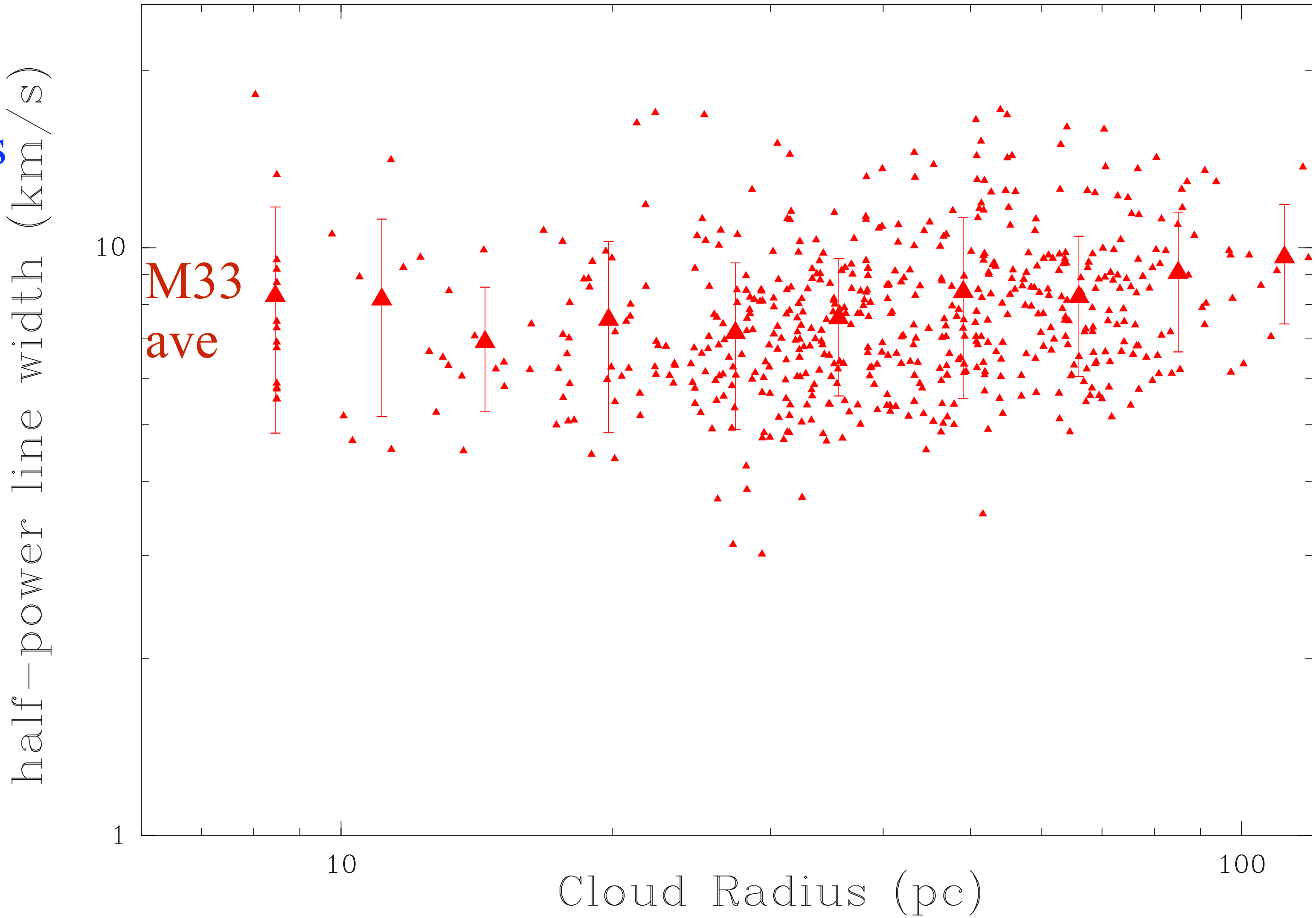

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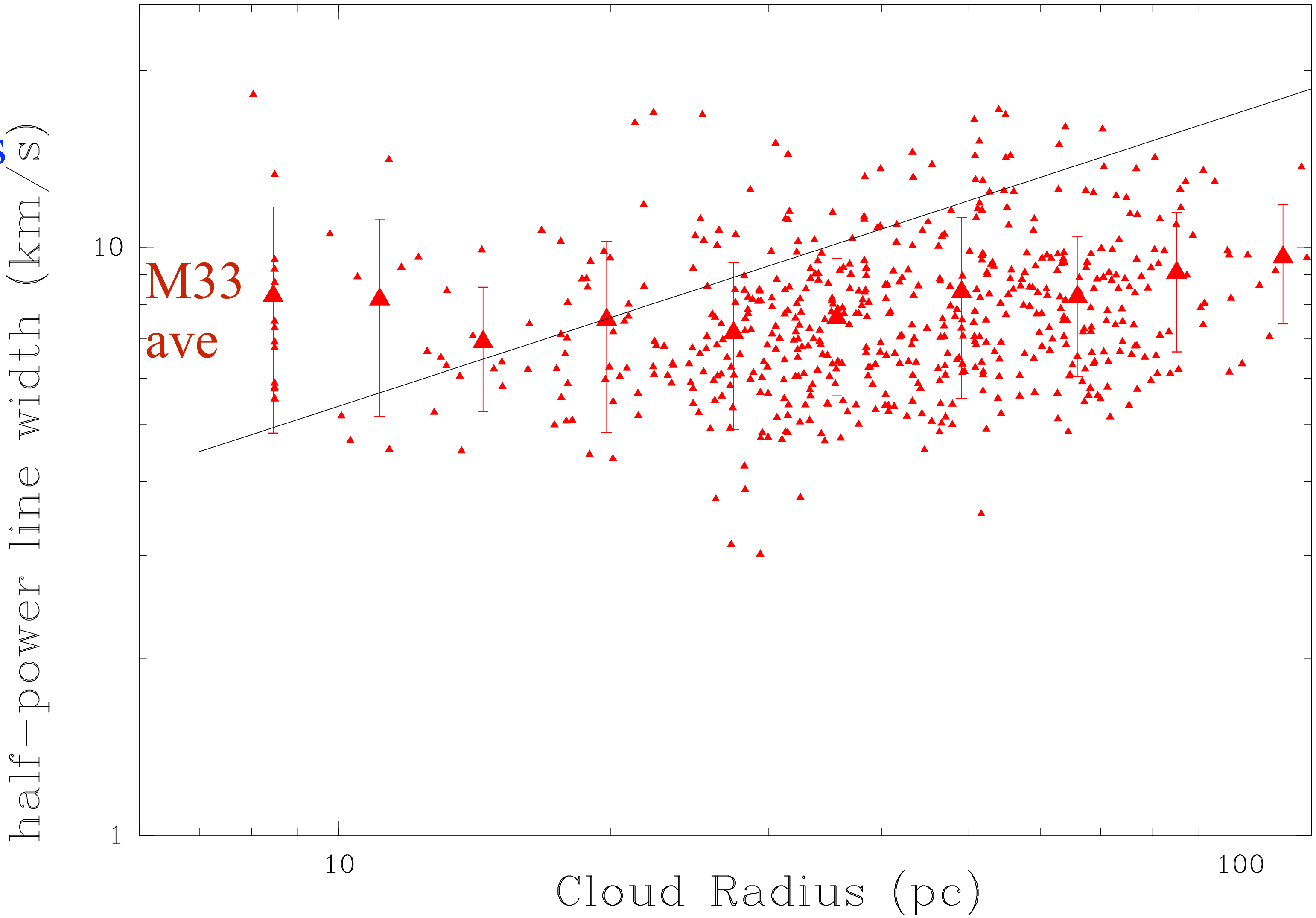

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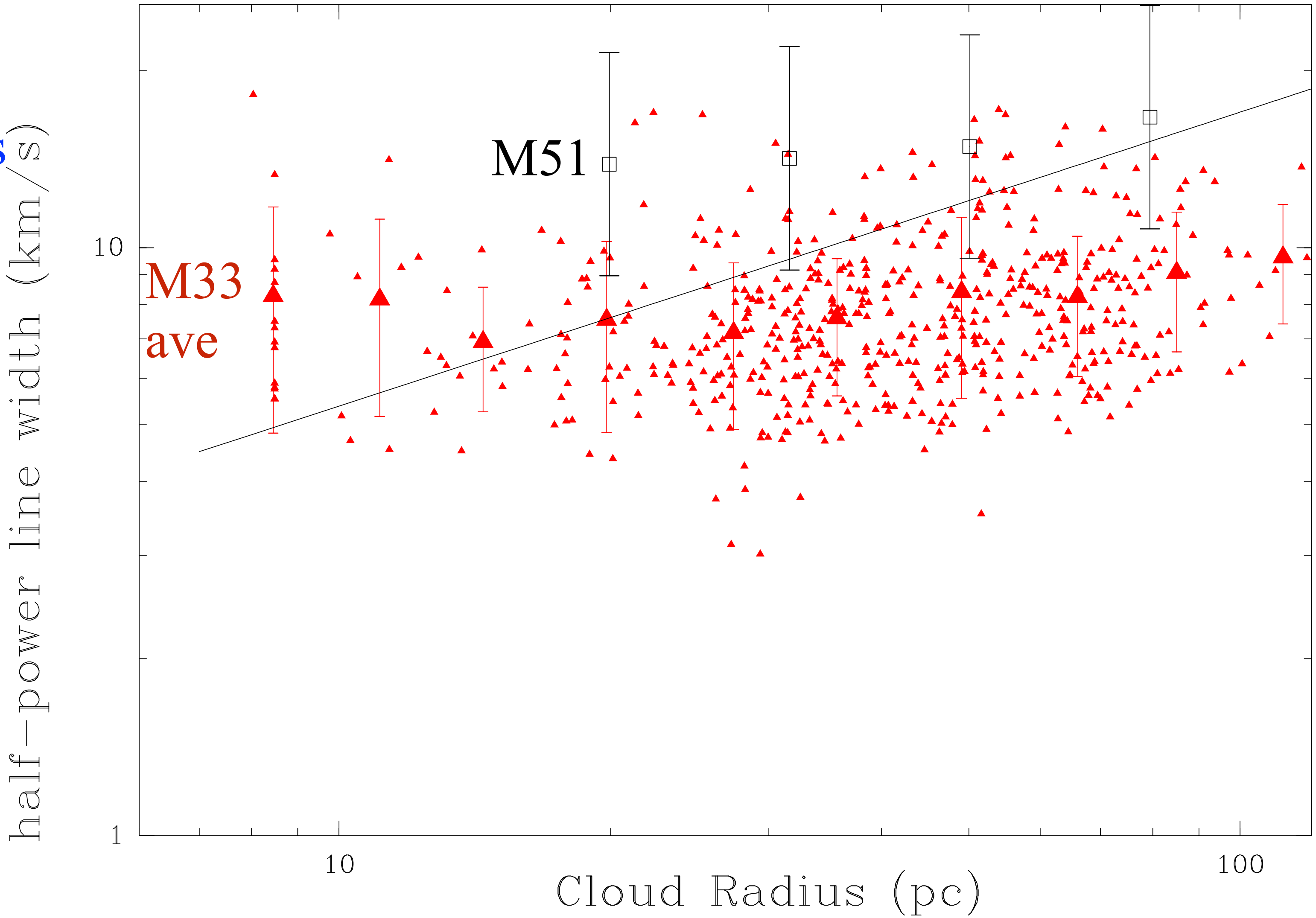

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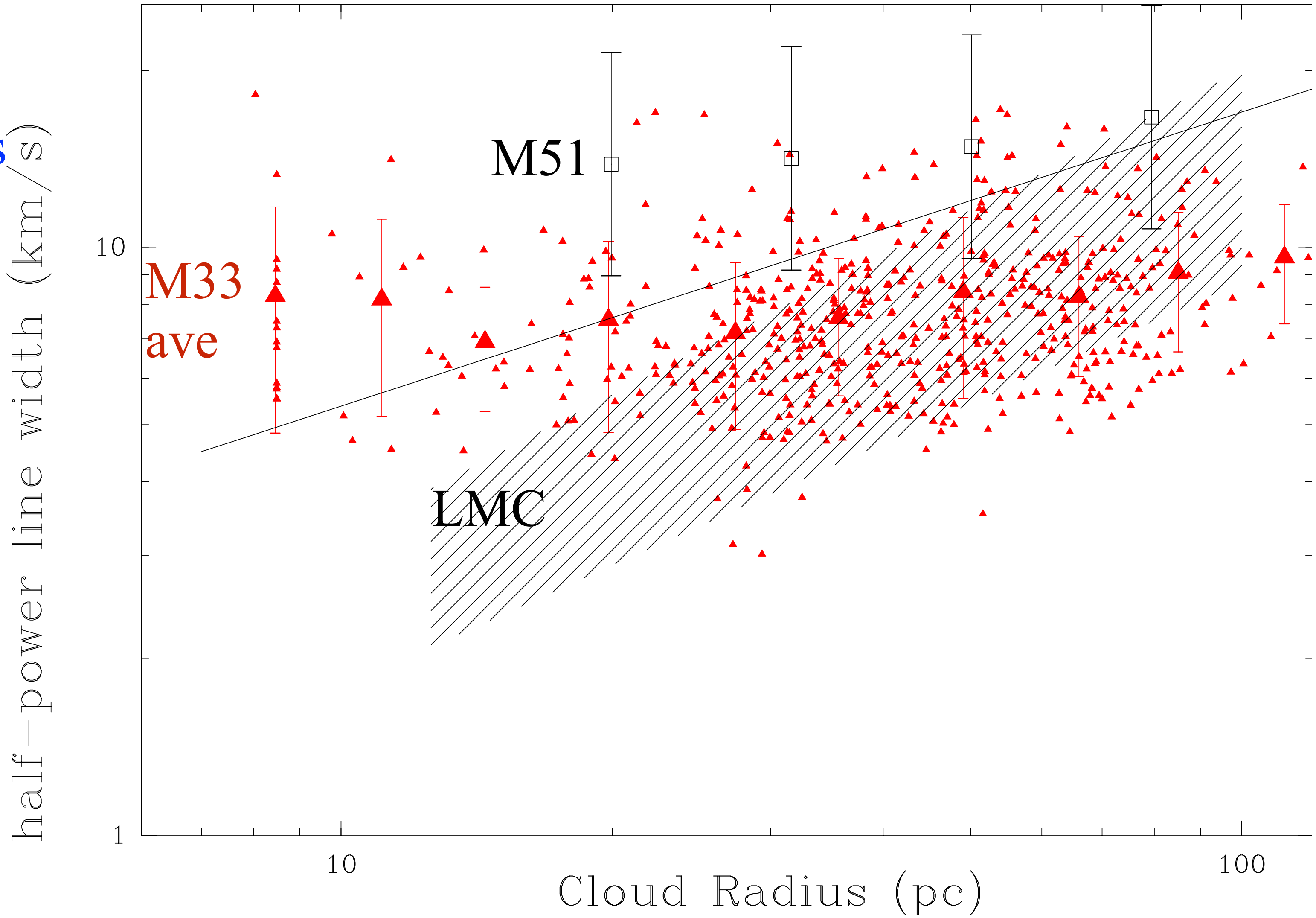

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Linewidths appear to decrease with metallicity at constant size

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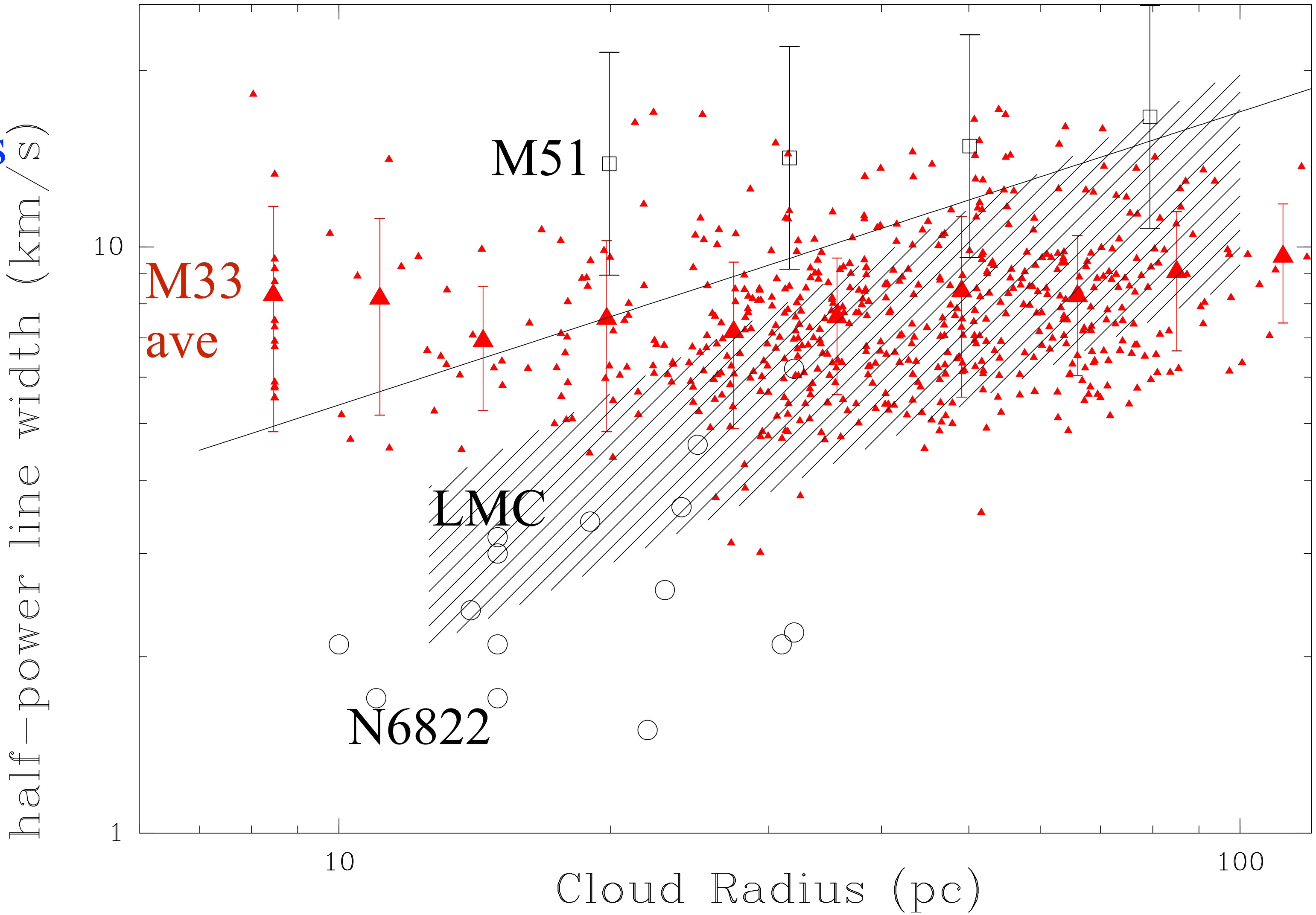

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Linewidths appear to decrease with metallicity at constant size

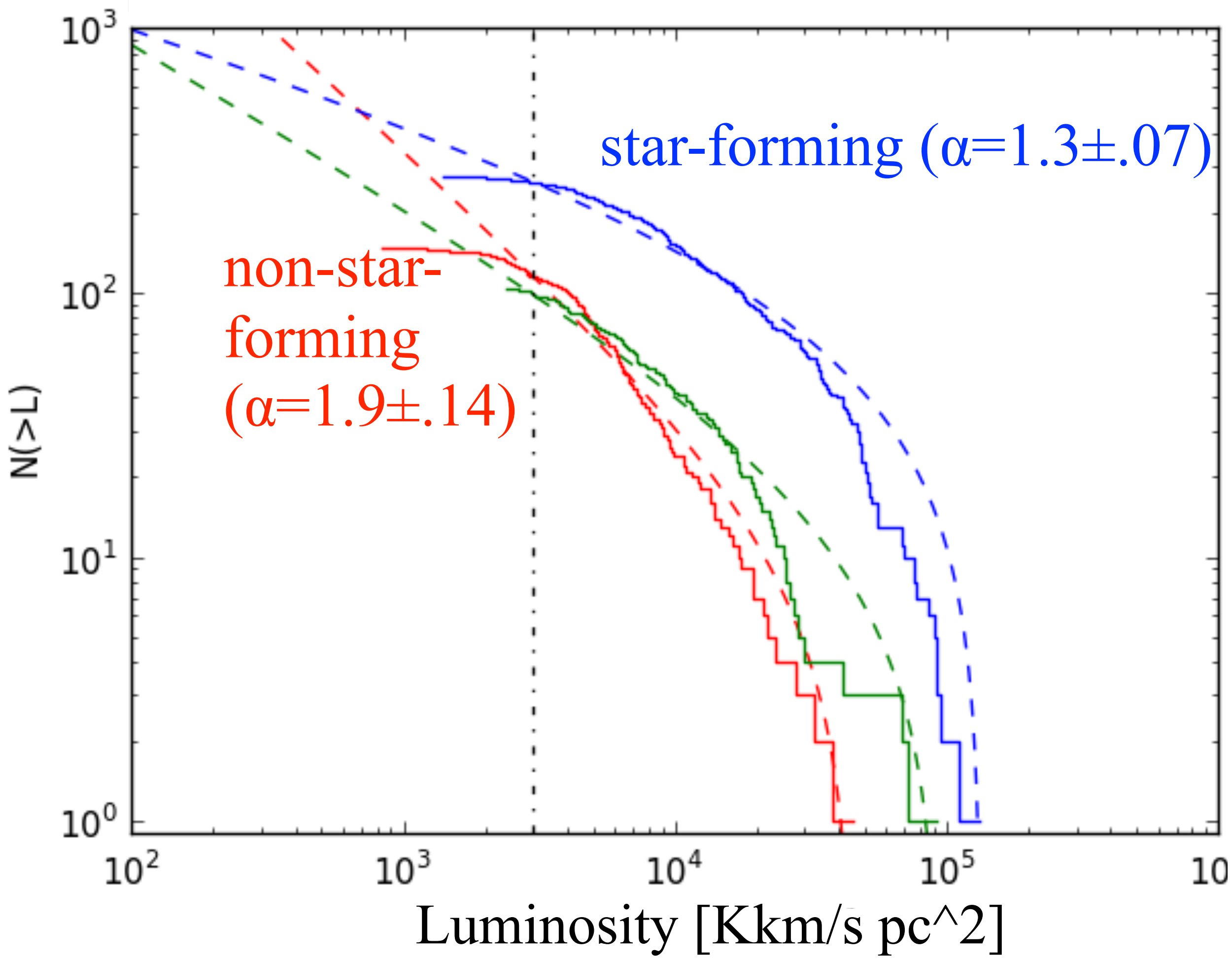
Other results from the sample include:

- sharp decrease in cloud intensity and temperature with galactocentric distance (Gratier+2012)

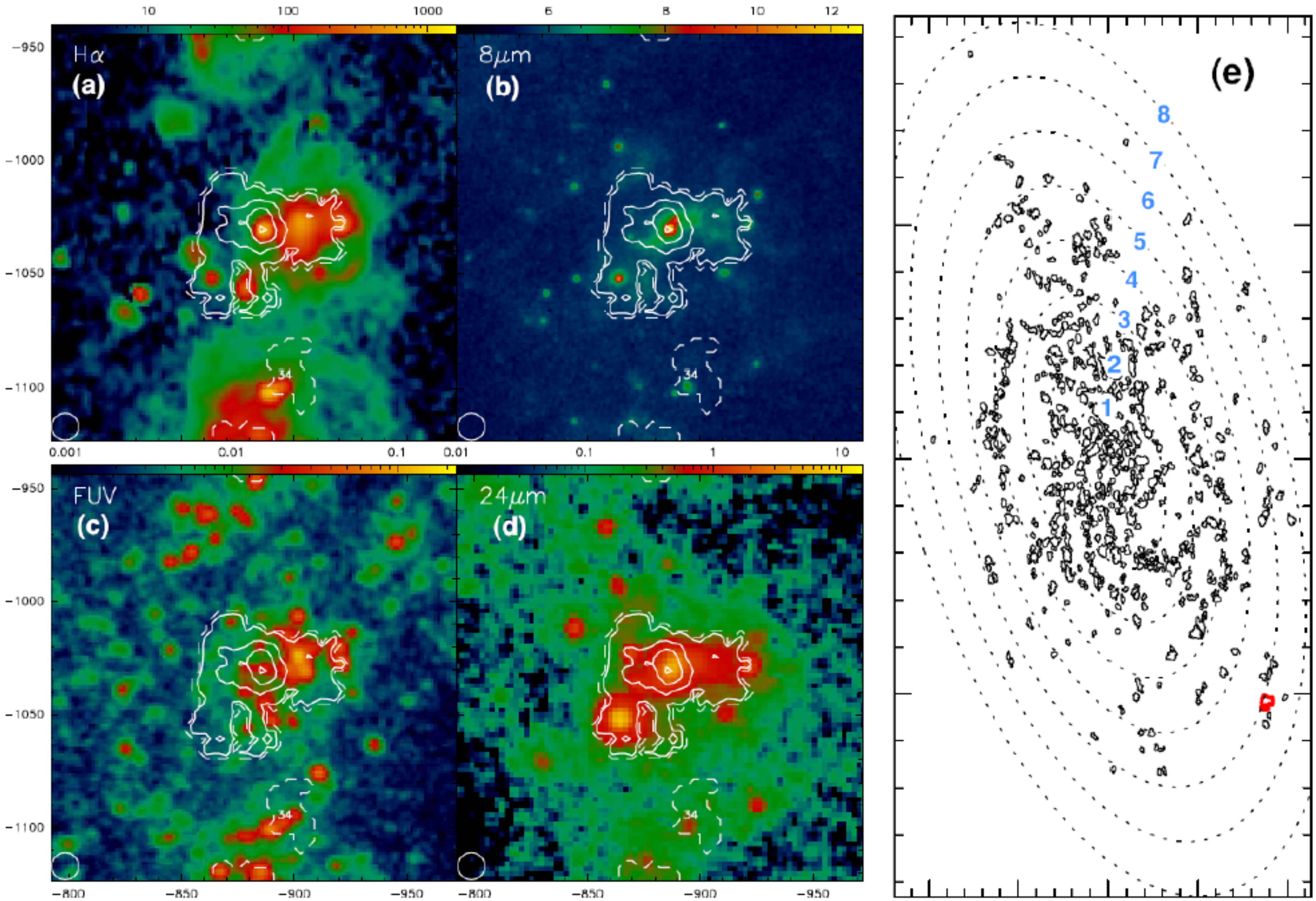
- weak but significant (8σ) decrease in linewidth with galactocentric distance (new result)

- cloud mass (luminosity) function not constant over disk
  (a) steepens with galactocentric distance (Gratier+2012)
  (b) steeper in clouds without star formation (***new***)

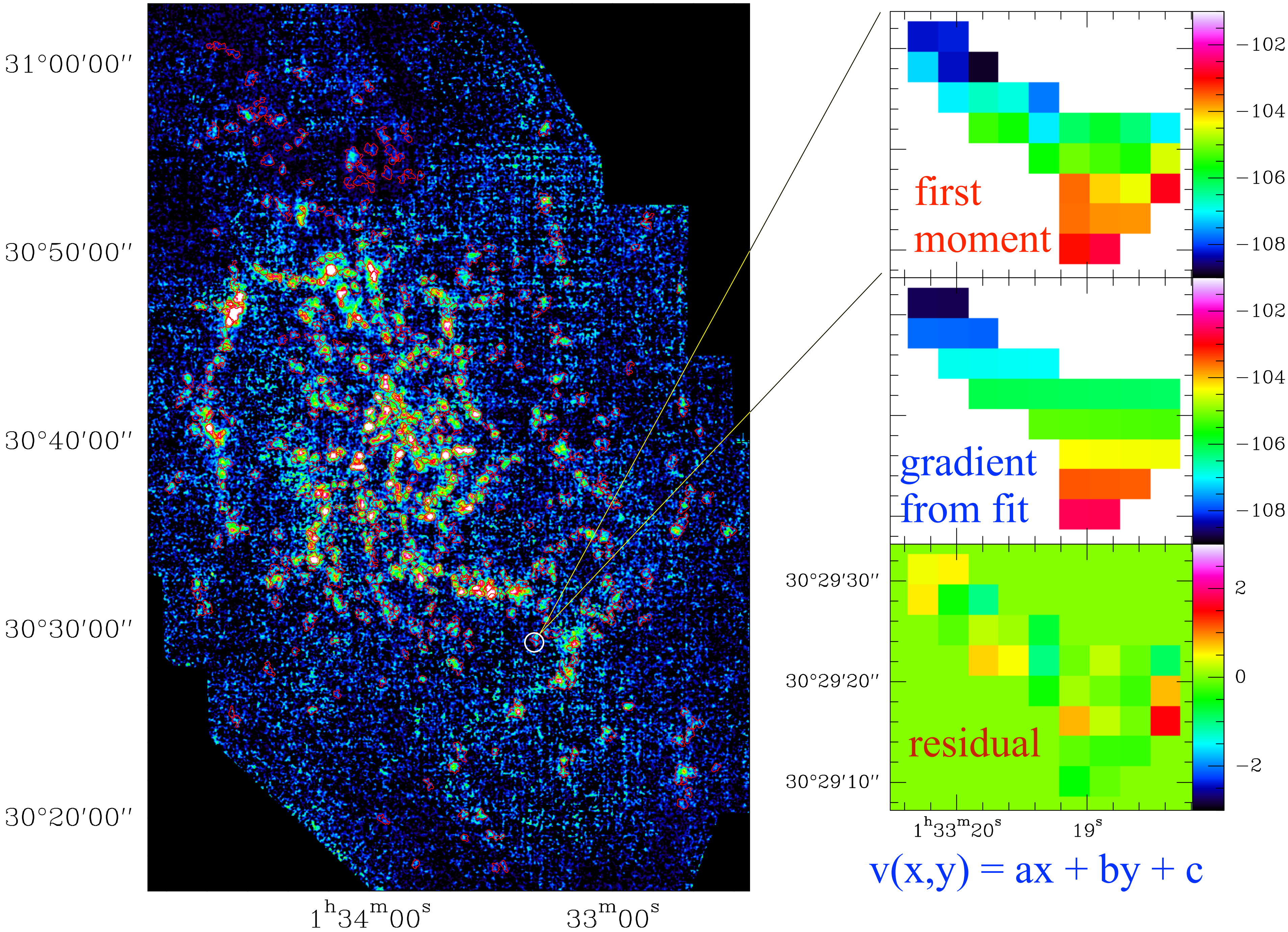
- ***cloud rotation***
  (keep listening!)



Classifying clouds and their star formation

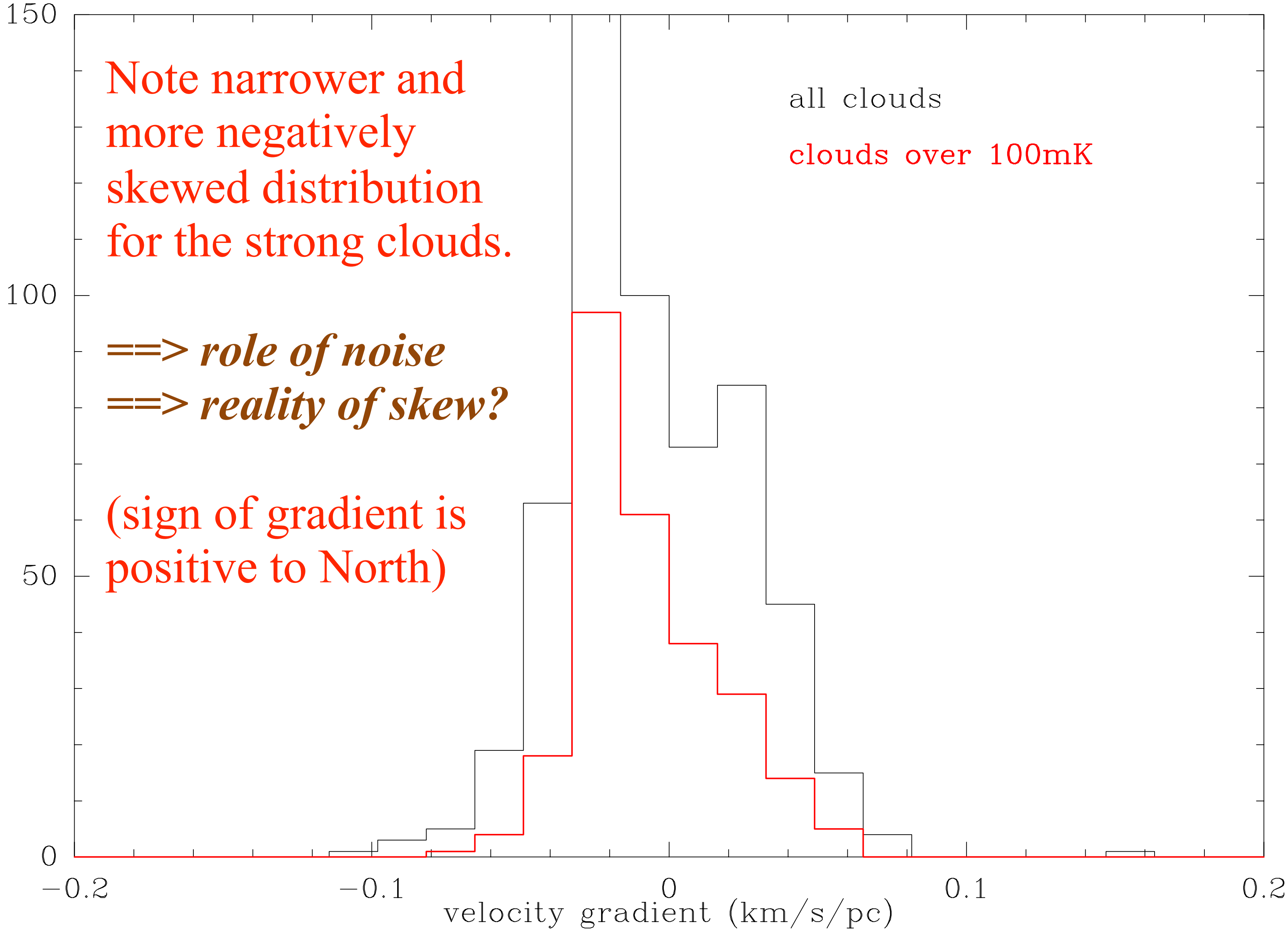


Cloud sample on CO(2-1) emission, focus on cloud 4



So, we are able to identify a velocity gradient (calculate 1st moment and fit a plane, as in previous work by Blitz, Rosolowsky, Imara).

Observed velocity gradients in M33 clouds



Previous work

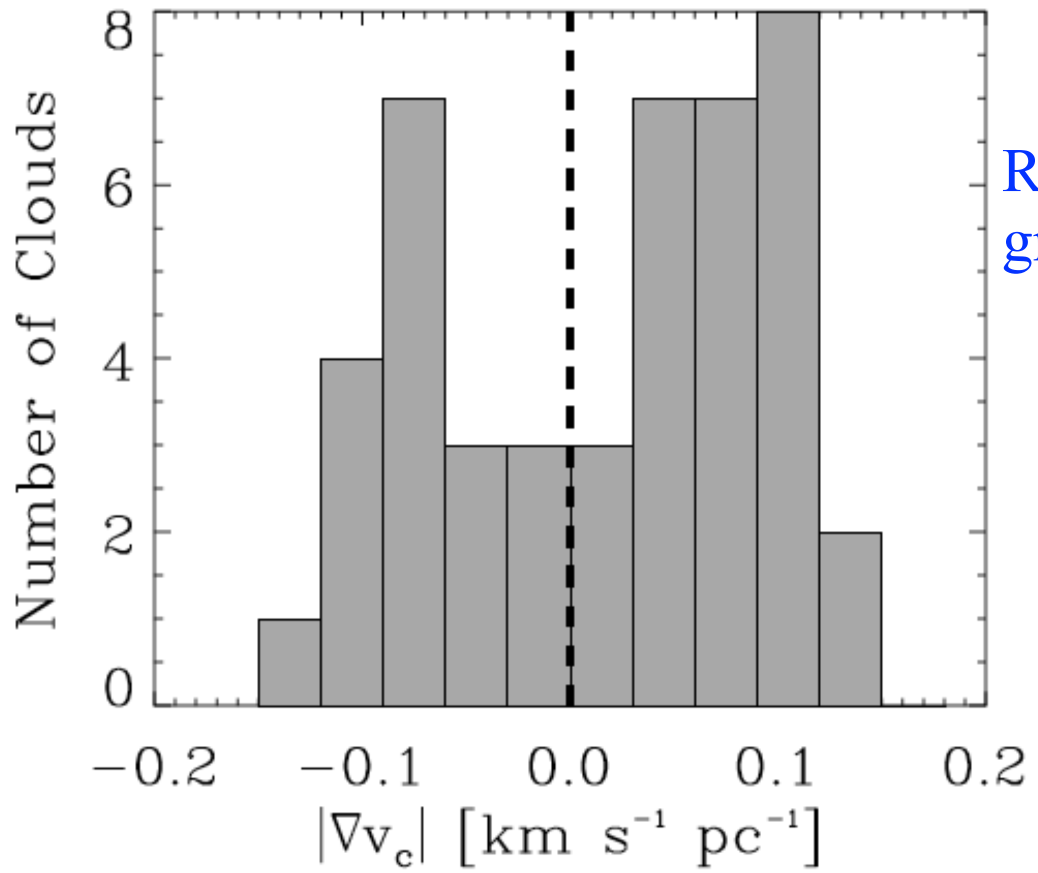


FIG. 7.—Gradient magnitude values for clouds in M33. Negative values are given to those clouds that have a position angle differing from the galaxy by more than 90°. The gradient magnitudes are comparable to typical values found in the Milky Way. Moreover, the magnitudes of the gradients are comparable among clouds, independent of alignment with the galaxy.

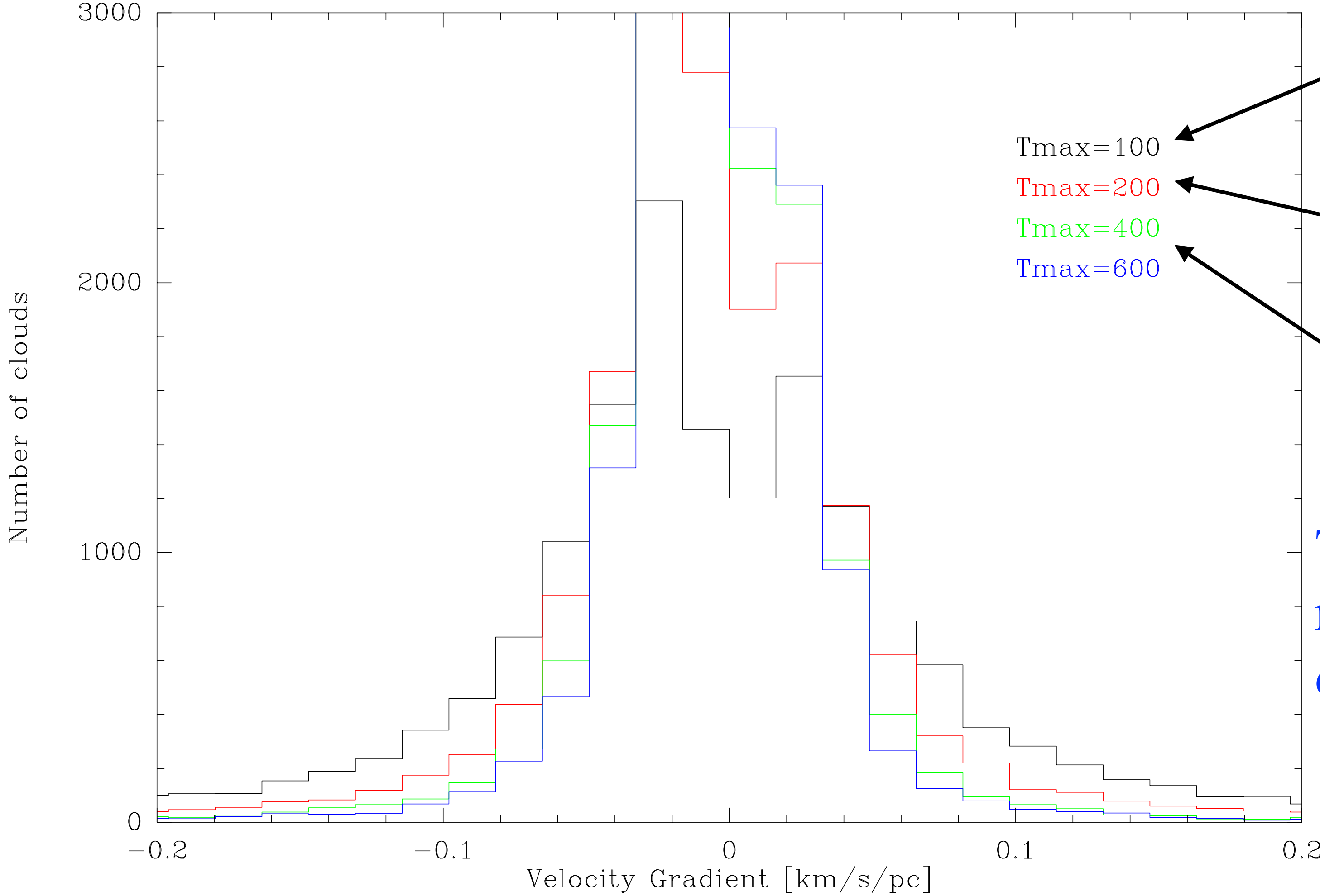
Rosolowsky et al (2003) velocity gradients for 45 clouds in M33

Imara et al (2011) conclusion that GMCs may not be rotating

roughly one order of magnitude lower than what is observed. Based on our observations, we consider the possibility that GMCs may not be rotating. Atomic gas not associated with GMCs has gradients closer to 0.03 km s^{-1} pc^{-1},

The effect of noise

Using observed distribution of cloud sizes, shapes, and gradients, create mock clouds and test the effect of varying noise levels. Since we are adding noise to the measured (i.e. already including the real noise), this necessarily broadens the distribution.



weak clouds

average of strong clouds

strongest clouds

Tmax of 100 roughly doubles dispersion (stdev^2)

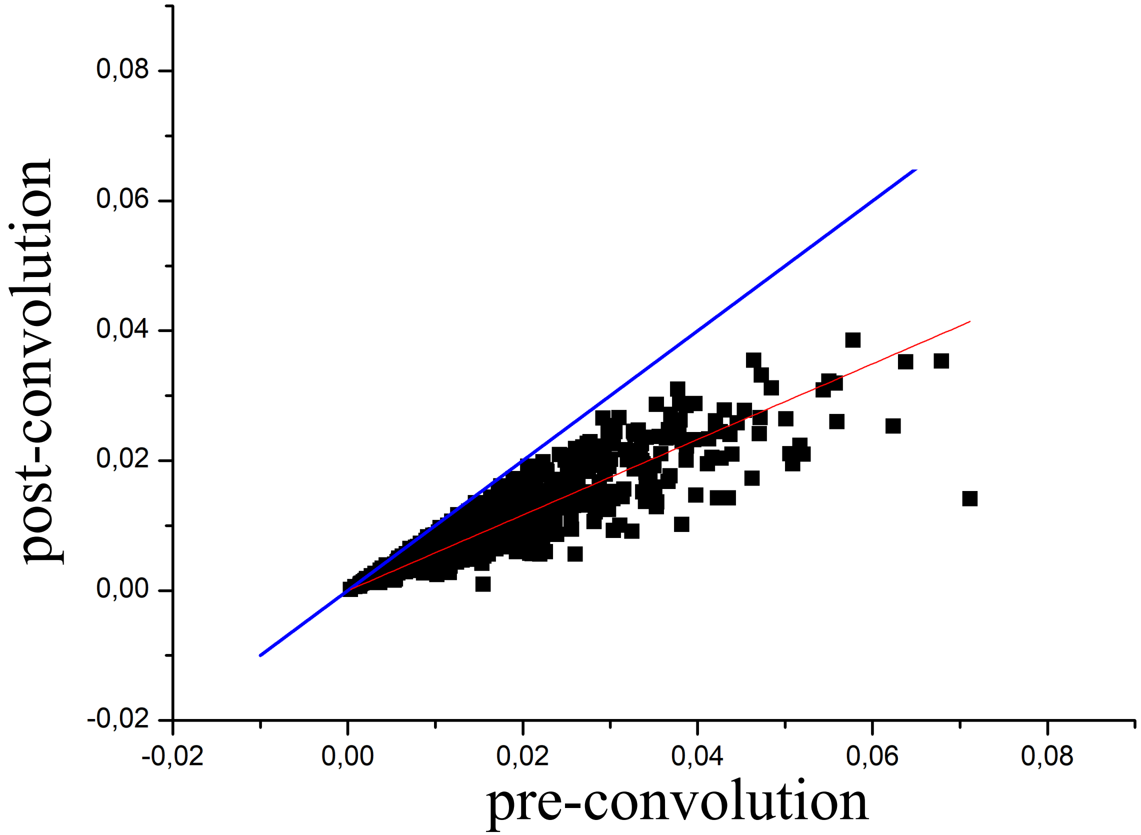
==> noise likely explains dispersion of the weak sources

The effect of beam size on the gradients

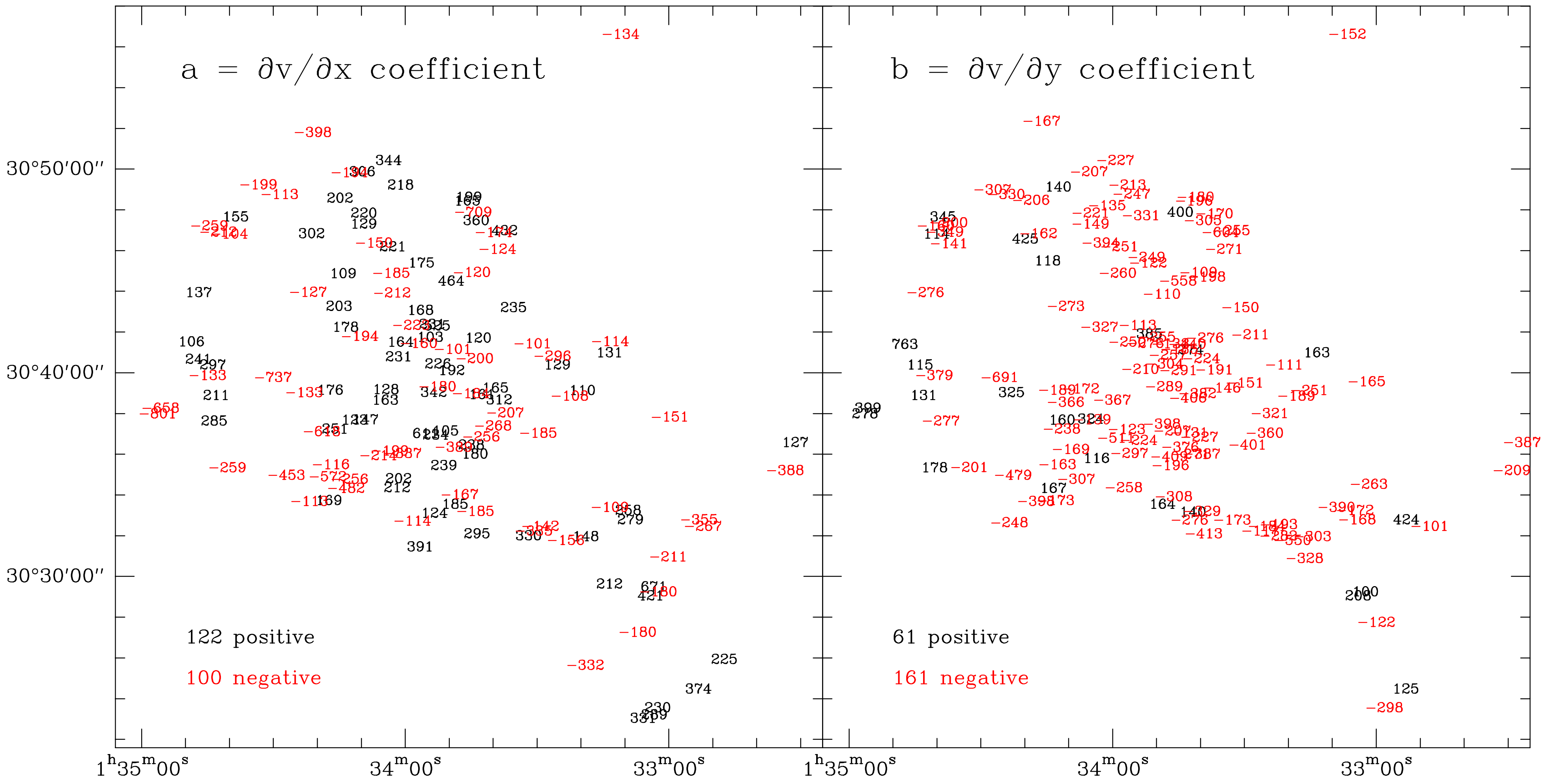
Our 12" beam is comparable to the cloud size in many cases so this could be expected to have an effect on the measured gradient.
One would expect the real gradient to be higher.

We took our mock cloud sample and convolved with the IRAM beam and then measured the gradients.

Conclusion:
on average convolved gradients are 60% of true gradients
==> ***real gradients are 60% higher than what we measured***

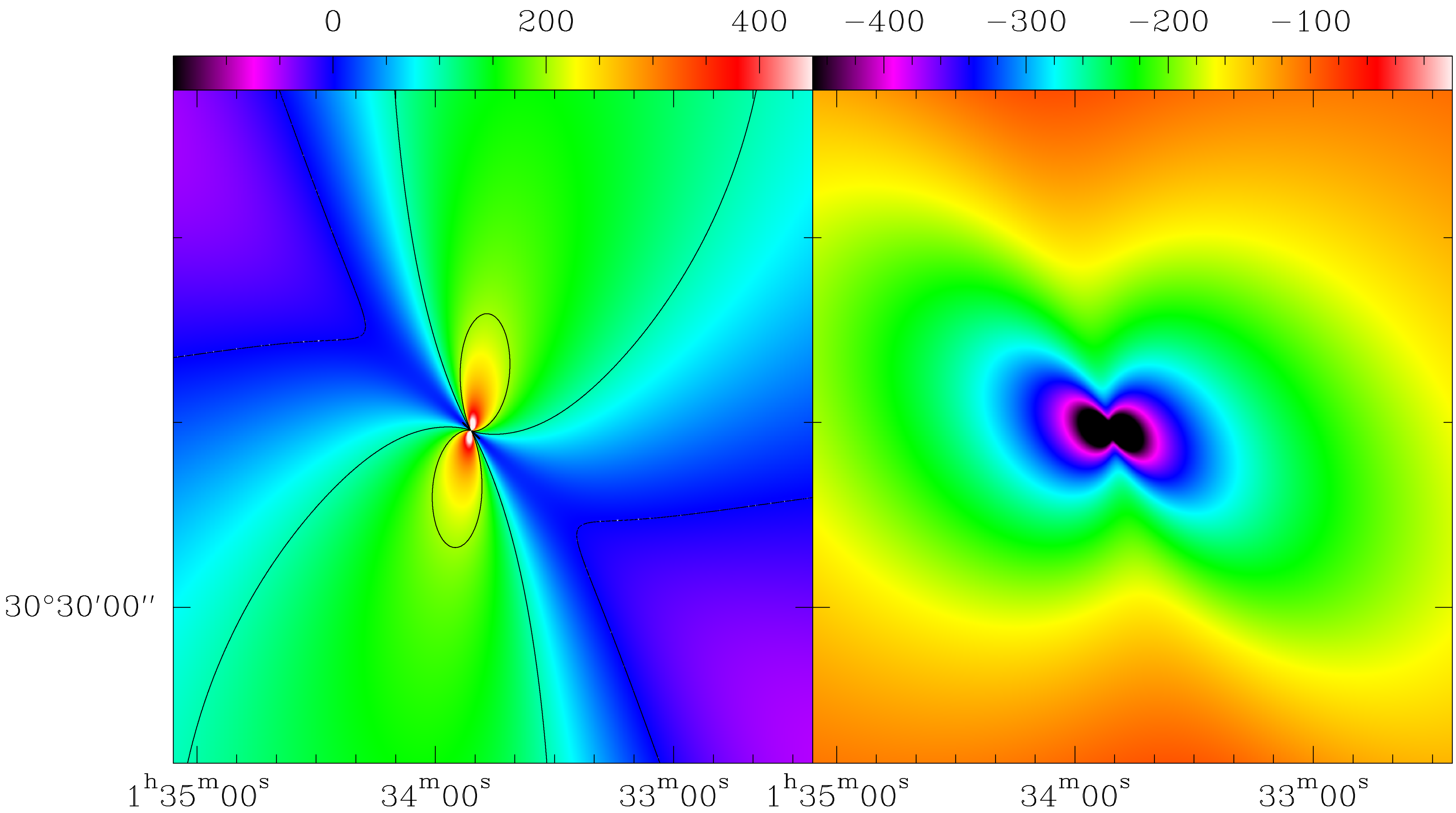


Understanding why gradients are negative



Above we show the ***a*** and ***b*** coefficients fitting v(x,y) = ax + by + c for the 222 strongest clouds and where the values are over 100m/s/pixel (pixelsize=12pc). Since the gradient sign is that of the b coefficient, not surprising that b is dominantly negative -- ***but why*** ?

Understanding why gradients are negative



Calculated, using a "Universal Rotation Curve" with parameters for M33, by taking projected velocity differences between adjacent pixels.

Understanding

1) Systematic velocity gradients are observed and are not due to noise.
2) Direction of gradient follows galactic rotation: ***prograde rotation is dominant***.
Question of whether this is to be considered rotation as period is that of galaxy.

Observed gradients of roughly .03 km/s/pc / 0.6 (deconvolution) yield a rotation period of 120 Myr, comparable to galactic rotation period.
And much longer than free-fall time.
Rotational kinetic energy < 1% of gravitational potential energy.
==> at this scale, angular momentum is not a source of support against collapse.

Plan to do same with outer galaxy CO survey (Sun et al. 2015) although observation angle is different.

Size-linewidth relation appears to vary with metallicity.
Low-Z clouds tend to have narrower lines at similar size.
Some degeneracy between metallicity and (stellar) surface density.

GMC mass function steeper for clouds without star formation and/or at large galactocentric distances. Linewidths decrease with galactocentric distance.