HERM33ES

The
Herschel
M33
Extended
Survey

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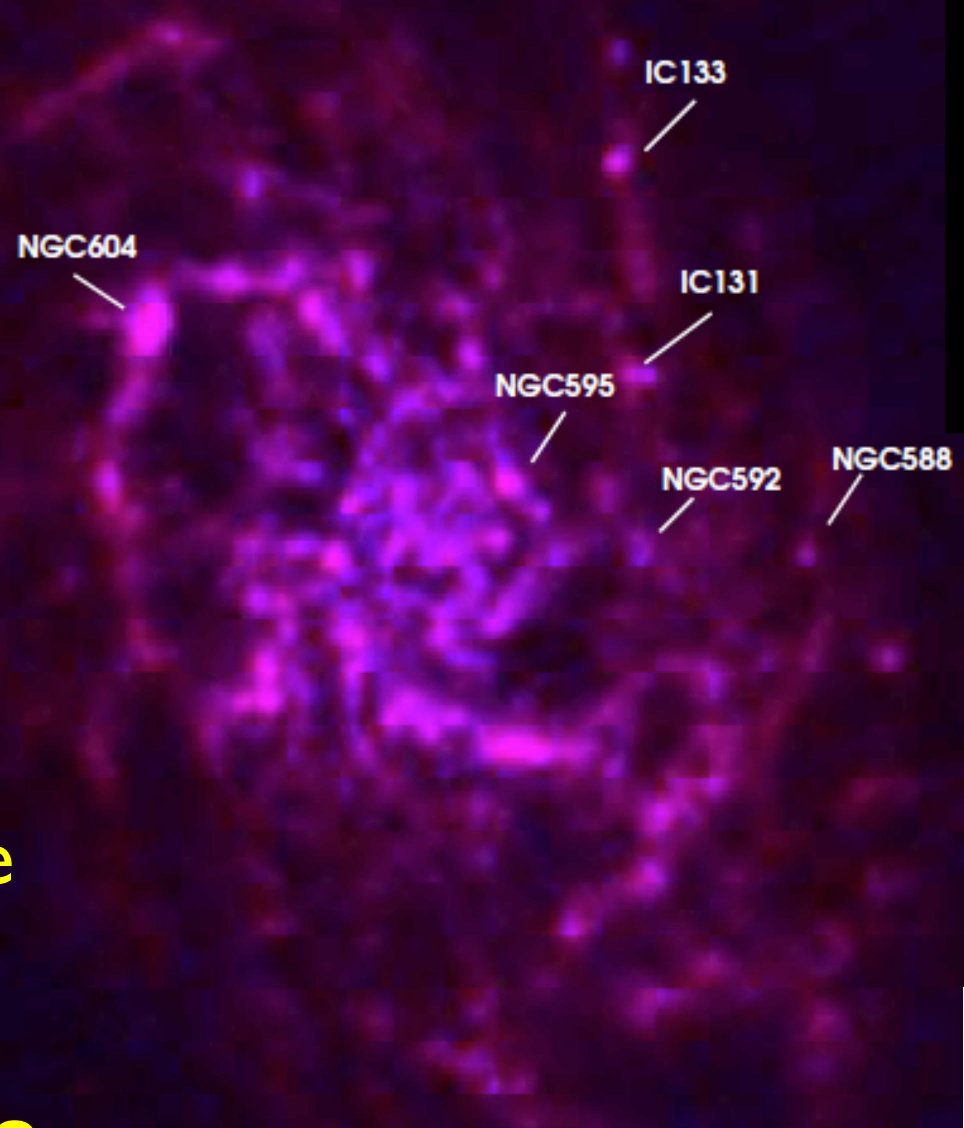
&
The ***HERM33ES***
team



HERM33ES

Gas and
Dust in
M 33

An Open Time Key Project
PI: Carsten Kramer

Herschel M33 extended survey (HERM33ES).★

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Key Topics:

A. Phases of the ISM:
The origin of [CII] emission
CNM, WIM, HII regions, WNM... ?
Line profiles necessary

B. Energy Balance of the ISM

C. Star formation traced by [CII] and [NII]

D. Formation of molecular clouds from the diffuse atomic medium

Strip:

- **[CII] and H_2O with HIFI (150hrs)**
- **[CII], [NII], [OI], [NIII] with PACS (50hrs)**

Entire galaxy:

- **dust continuum between 85μm and 500μm with PACS & SPIRE parallel mode**

Why M33 ?

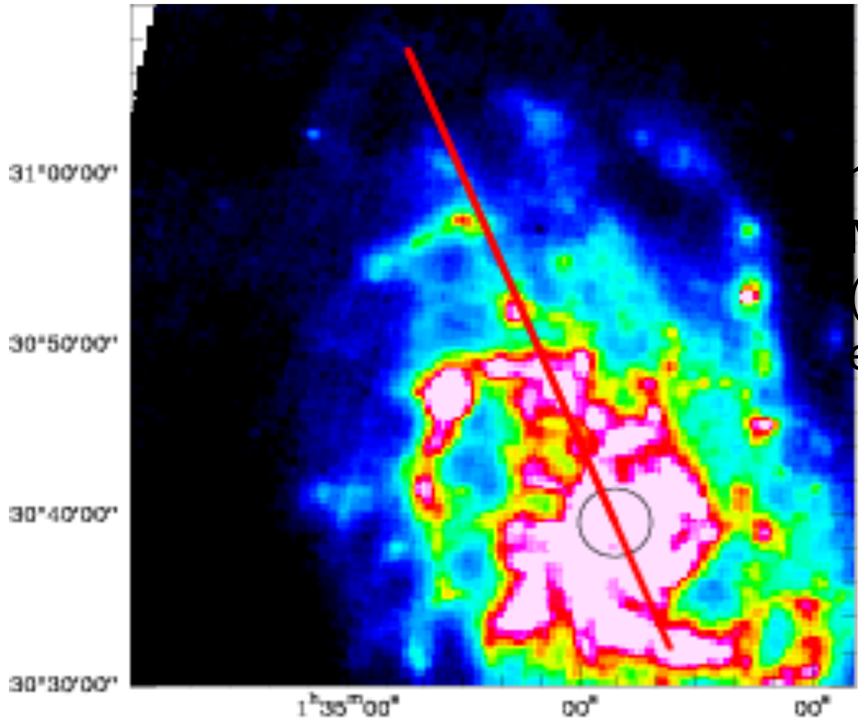
Very nearby (~840 kpc, 1" = 4pc)
==> resolve molecular clouds

True spiral galaxy,
rather average radiation field

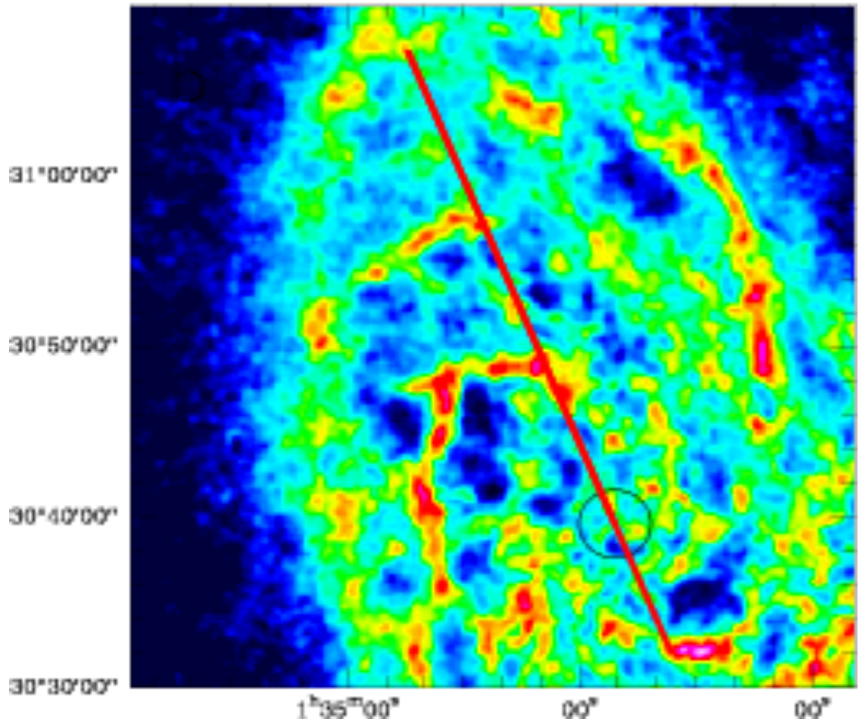
Small, blue, gas-rich, subsolar Z
==> similar to high-z objects?

Stepping-stone towards more extreme objects to understand the ISM and star formation in primitive environments.

Inclination optimal -- dynamics of disk with clear line of sight

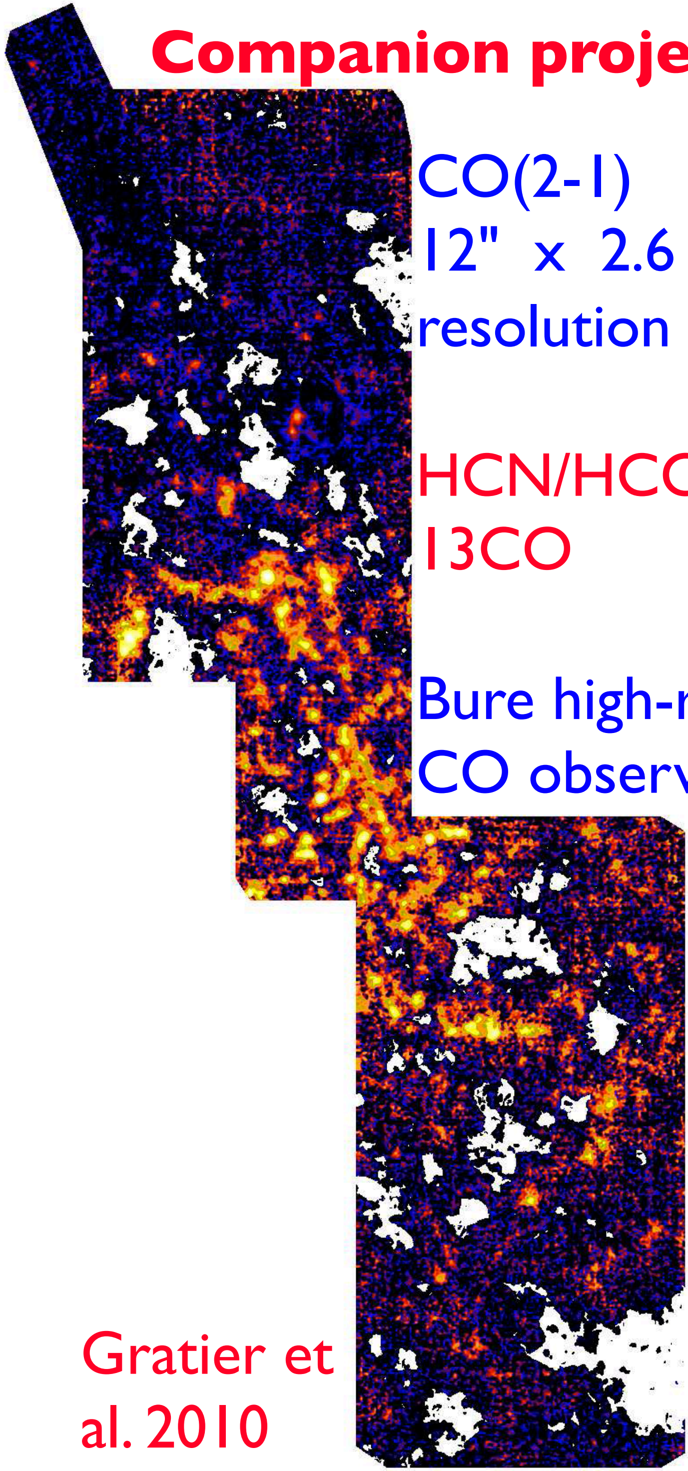


160μm
MIPS/Spitzer
(Tabatabaei et al. 2007)



HI 21cm

Companion projects

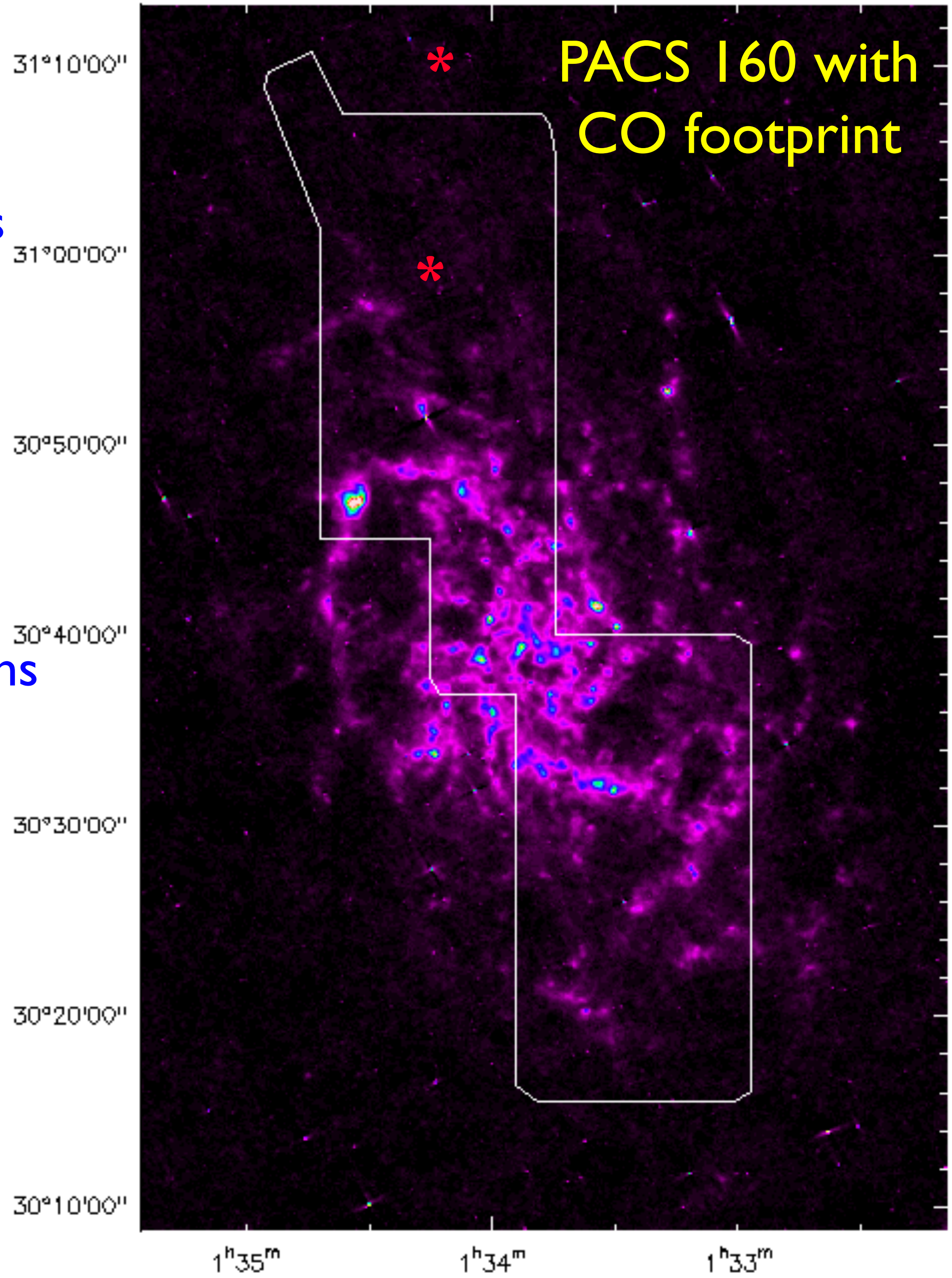


CO(2-1)
12" x 2.6 km/s
resolution

HCN/HCO+/
13CO

Bure high-res
CO observations

Gratier et
al. 2010



Companion projects

HI: Major VLA mosaic in B, C, & D arrays.

Multi-scale clean retrieves ~95% of single-dish flux

==> column densities + dynamics

>> gas mass & star formation

link between dynamics and SF

Bubbles, SN shocks, holes

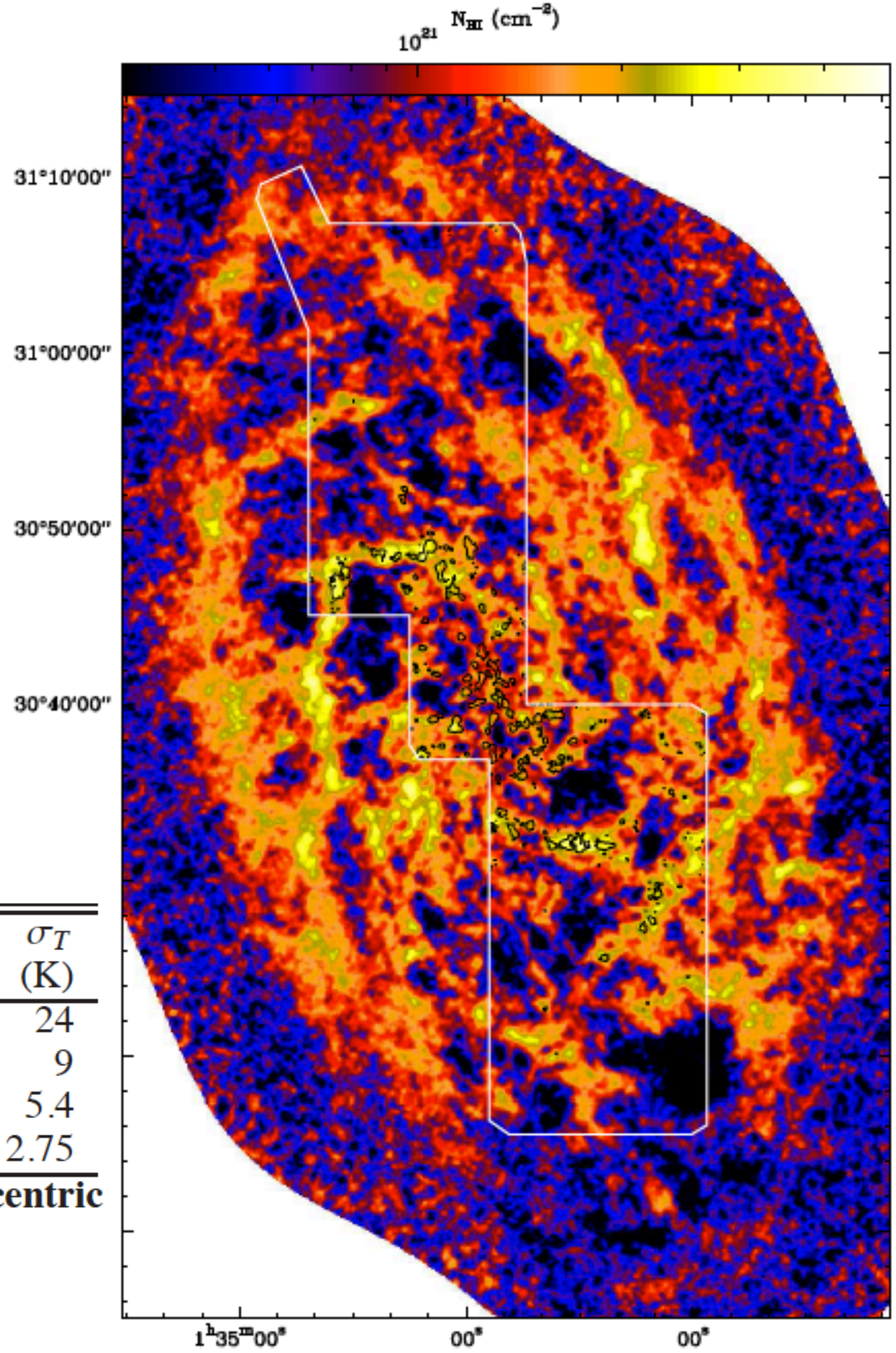
These cubes will be made available

Table 2. Properties of the H I 21cm datacubes

Beam ($'' \times ''$)	PA (°)	σ_S (mJy/beam)	σ_T (K)
5.5×5.2	-95.1	1.1	24
12.0×11.6	-31.8	2.0	9
17.2×17.1	-45.8	2.5	5.4
25.9×24.2	-74.8	2.8	2.75

The *rms* noise was calculated over an ellipse of **galactocentric** radius 8.5 kpc after primary beam correction.

Gratier et al. 2010



General procedure for estimating gas masses

$$S_\nu = B_{\nu,T_d}\,(1 - e^{-\tau}) \approx B_{\nu,T_d}\,\tau$$

$$S_\nu = B_{\nu,T_d}\,N_H\,\sigma$$

dust emission optically thin at submm wavelengths

$$\frac{S_{\nu_1}}{S_{\nu_2}} = \frac{B_{\nu_1,T_d}}{B_{\nu_2,T_d}}\;\frac{\sigma_{\nu_1}}{\sigma_{\nu_2}}$$

A flux ratio enables calculation of a "color temperature" for a given grey body emissivity

$$\sigma_\nu = \sigma_{\nu_0}\,(\tfrac{\nu}{\nu_0})^\beta \text{ with } \beta \sim 1.5 - 2$$

Sigma is dust cross-section per H-atom

Then estimate total H column density and H2 column

Back to reality (some caveats about dust emission)

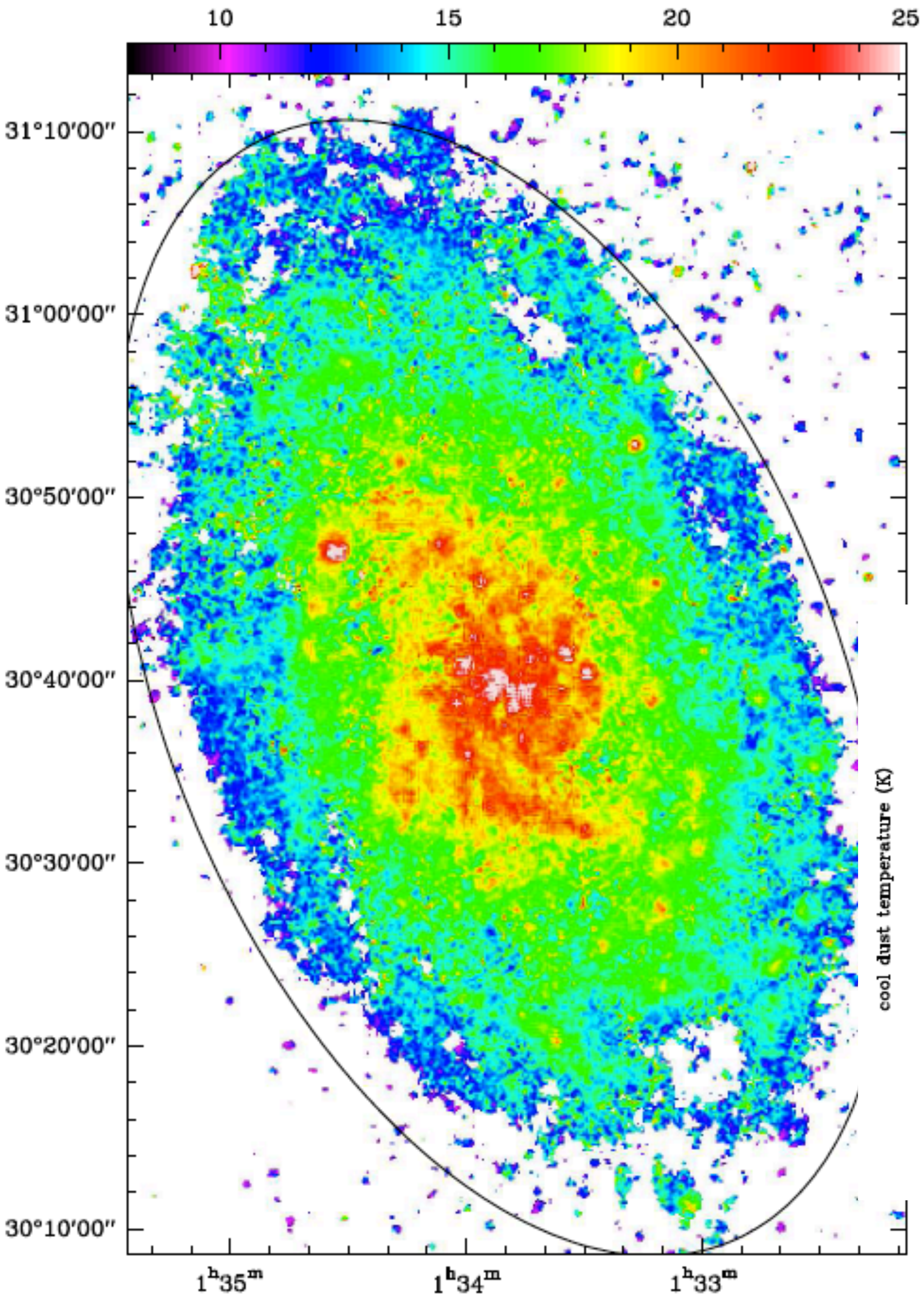
Beta remains unknown, probably 1.5 - 2.

Dust is a mixture of chemical compositions with different behaviors.
Milky Way dust is generally assumed. Correct for M33 ?

Even with a fixed beta, dust temperatures have significant uncertainties.
Distribution of "warm" and "cool" components, calibration.

Dust emission cross-section sigma still not known from theory.
Is it the same for HI and H2 ?
(not for very dense gas: mol depletion and fluffy grains but small mass)

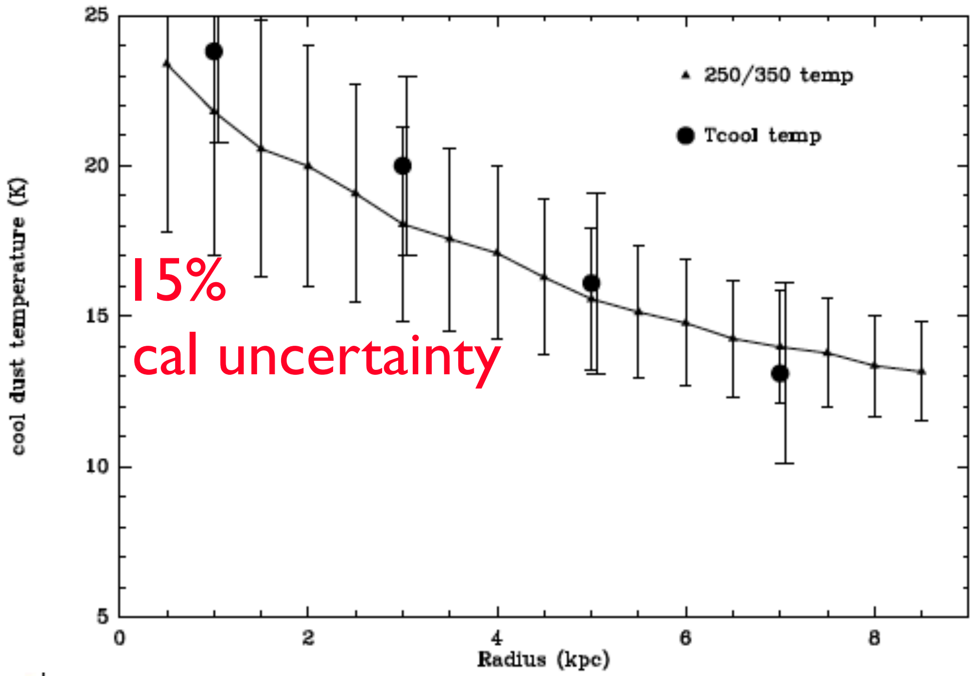
Problem of undetected H2 -- where do we really know the Hydrogen column density? M33 should be similar to the Milky Way (moderate ISRF and only slightly subsolar metallicity) and a first step to low-Z and high-z systems.

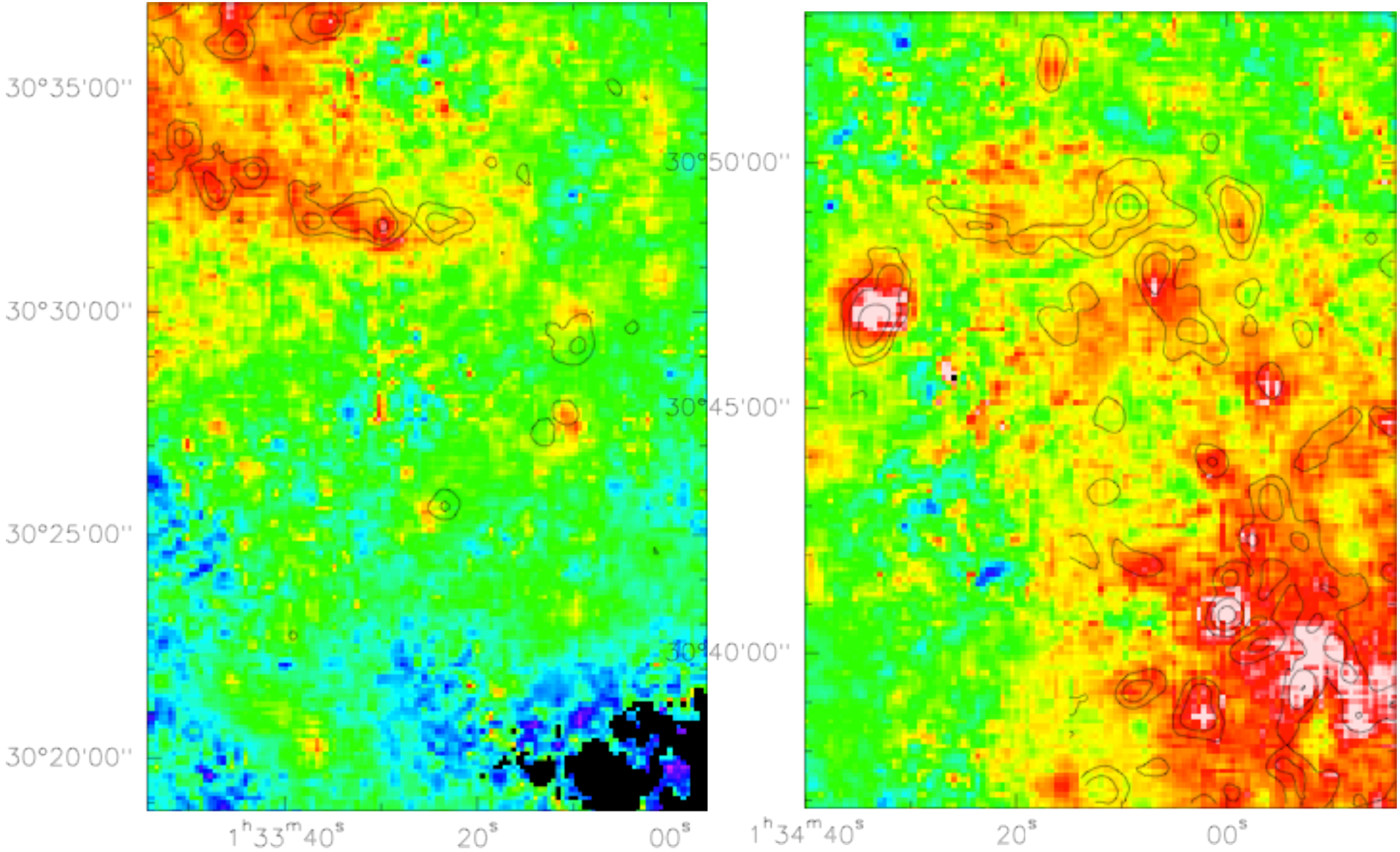


Dust temperature map assuming beta=2 using SPIRE 250 and 350mu.

Temperature well defined out to R25 radius.

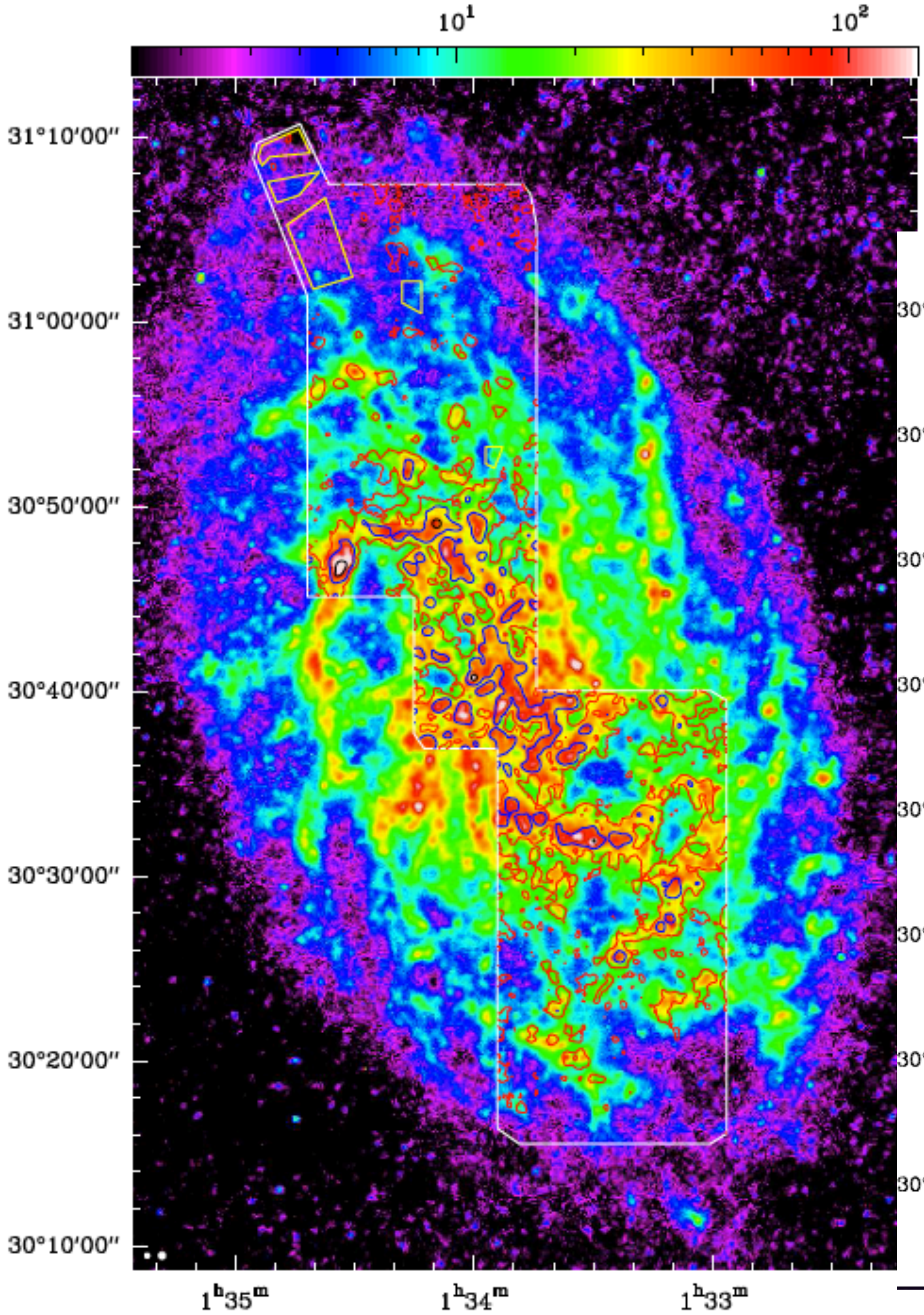
Clear color-mag relation (brighter regions are warmer)

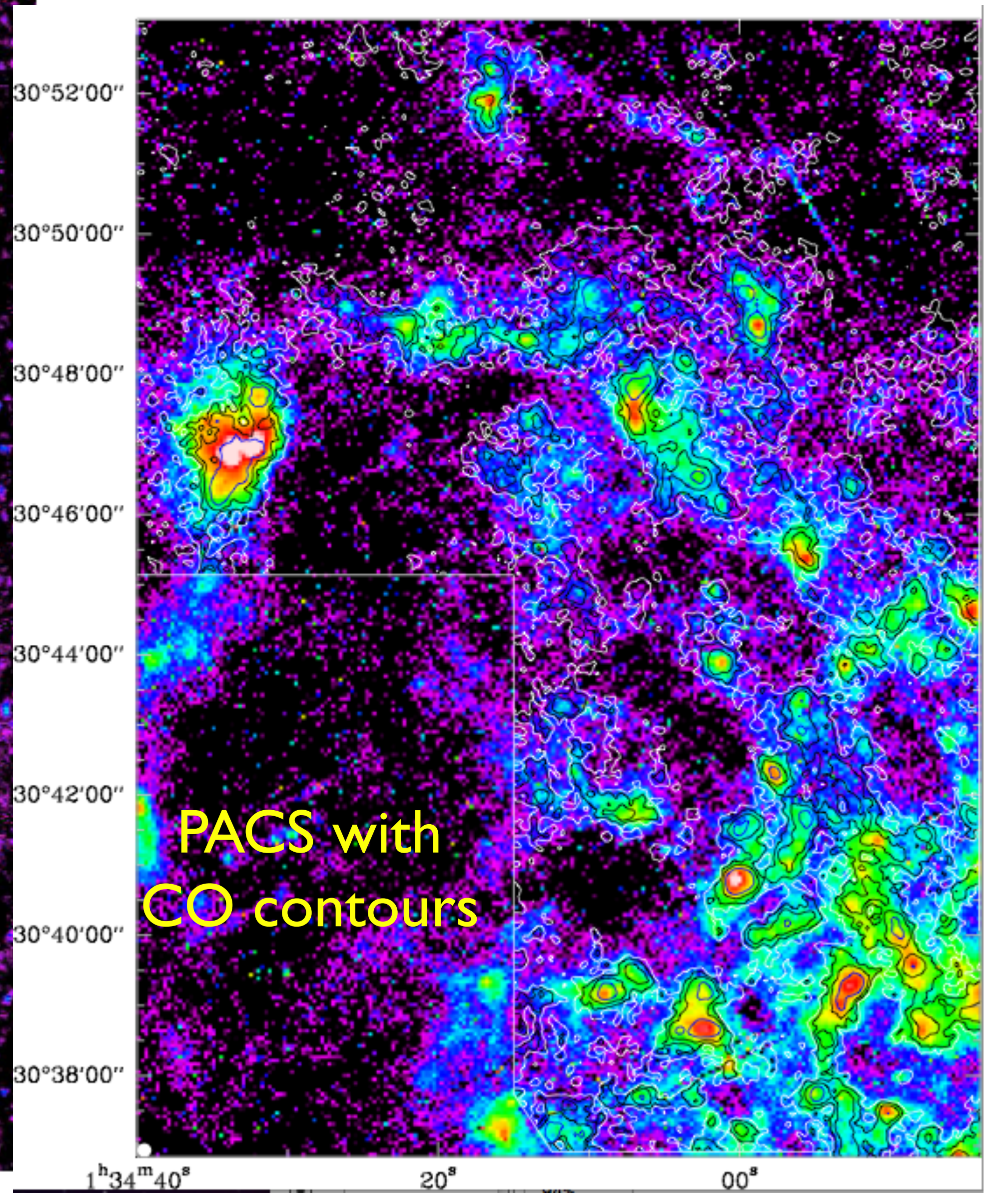




Overlays of dust temp with CO(2-1), both at 25" resolution.
Gain in using 25" instead of 40" (500 micron) important.

CO contours on 250 and 100 (below) micron emission.





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$$\sigma_\nu = \sigma_{\nu_0}\left(\frac{\nu}{\nu_0}\right)^\beta \text{ with } \beta \sim 1.5 - 2$$

Sigma is dust cross-section per H-atom

$$\text{With no H}_2,\ \sigma_\nu = \frac{S_\nu}{B_{\nu,T_d}\,N_{HI}}$$

Measure sigma, then apply it to estimate total H column density

$$N_H = \frac{S_\nu}{B_{\nu,T_d}\,\sigma_\nu}$$

$$N(\mathrm{H_2})/I_{\mathrm{CO}} = 0.5\,\frac{N_H - N_{HI}}{I_{CO}}$$

Dust cross-section measurements

Intrinsic expectation is sigma ~ Z for Z close to solar but metallicity very uncertain in M33.

Surprise: big North-South difference in sigma in addition to general radial decrease.

Two methods: (1) polygons w/o CO emission
(2) max of histograms of sigma values
Goal: avoid contamination by undetected H2

Table 1. Dust cross-section σ at 250μm as a function of radius in M33, expressed in units of 10^{-25}cm^2 per H-atom. The first line gives the values found within the polygons in Fig. 3 and the second and third lines in CO-free beams in the North and South with the histogram method. The last line gives the values used to estimate the total H column density to make Fig. 4.

r (kpc)	4	5	5.5	6	7	7.5
Polygons	1.8	1.02	..	1.07	0.66	0.50
histo-N	0.65	..	0.54	..	..	0.48
histo-S	0.92	..	0.95	0.69	..	..
Model	0.8	..	0.75	..	0.66	0.5

Issue of including undetected H2 is major.

Important NOT to overestimate sigma.

Polygons probably include H2.

Take pixels without detected CO and calculate sigma for each. Take sigma as peak of histo without averaging in large high-sigma tail.

Make symmetric model to estimate total H column density

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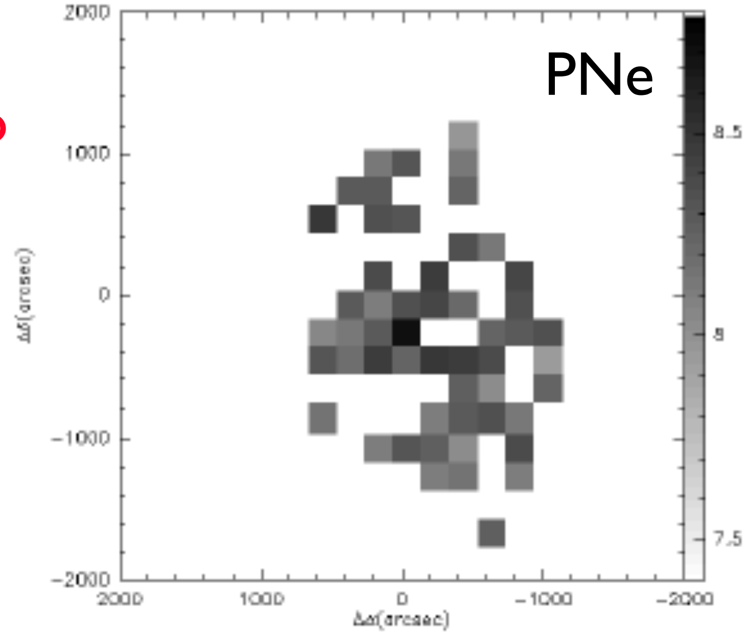
Difficult for polygons, max of histo prob. better



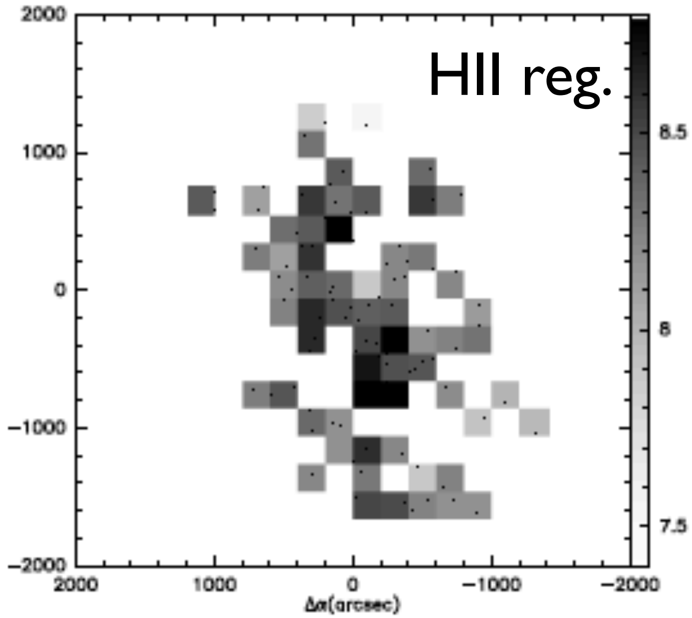


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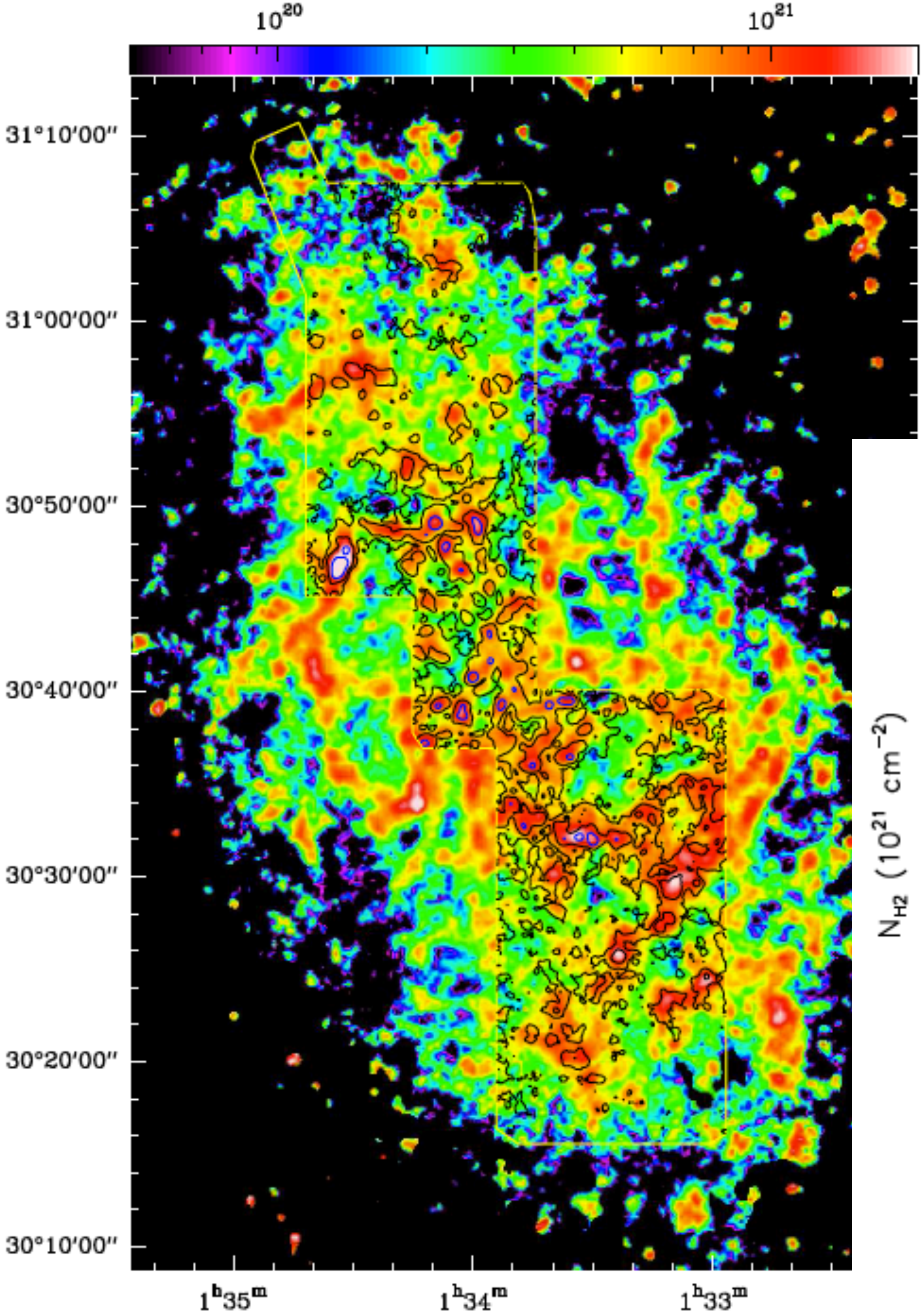
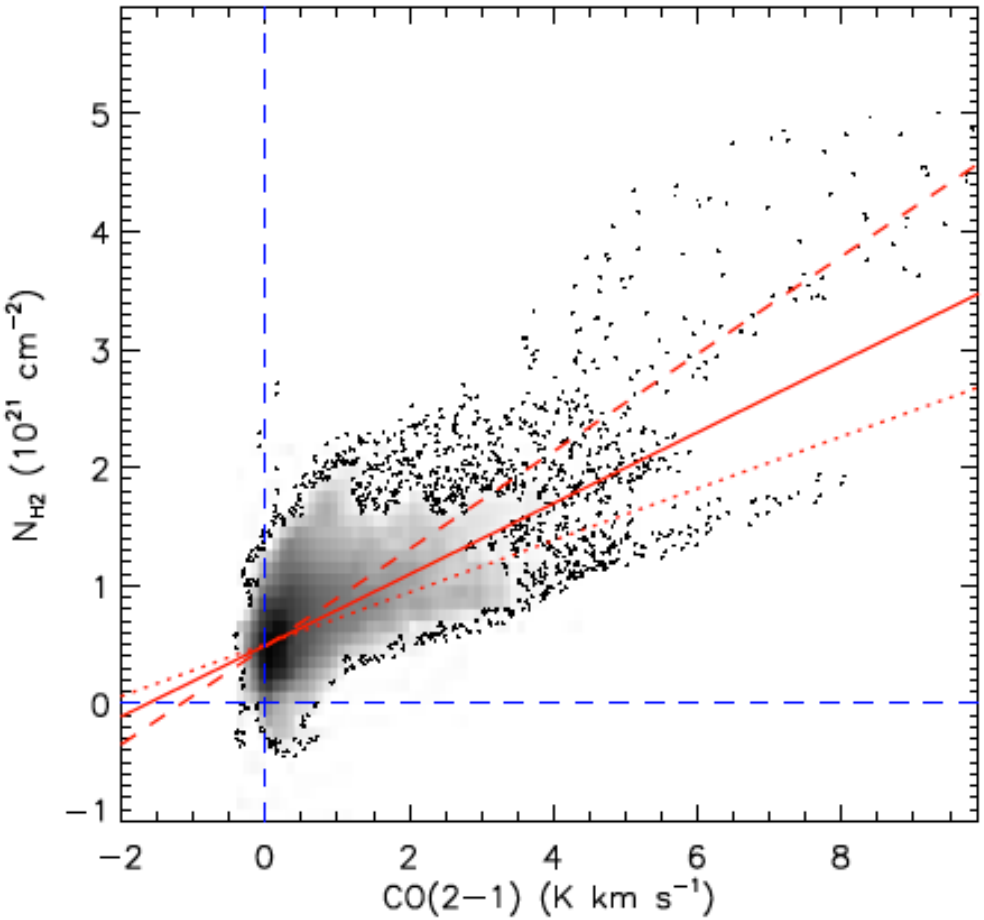
Fig. 1. The metallicity maps: PNe (top) and H
gions (bottom). The 12 + log(O/H) scale is sh



Dust-derived H2 column density with CO contours superposed.

scatter plot of N(H2) vs. Ico with global and inner/outer disk fits $N(H_2)/I_{co} = 3, 2.2, 4.1 \times 10^{20}$



Some Conclusions

Dust-derived gas mass is 1.6 - 1.7 x 10^9 solar masses,
similar to HI + CO derived gas mass with $N(H_2)/I_{CO(2-1)}$ = 5 x 10^{20}

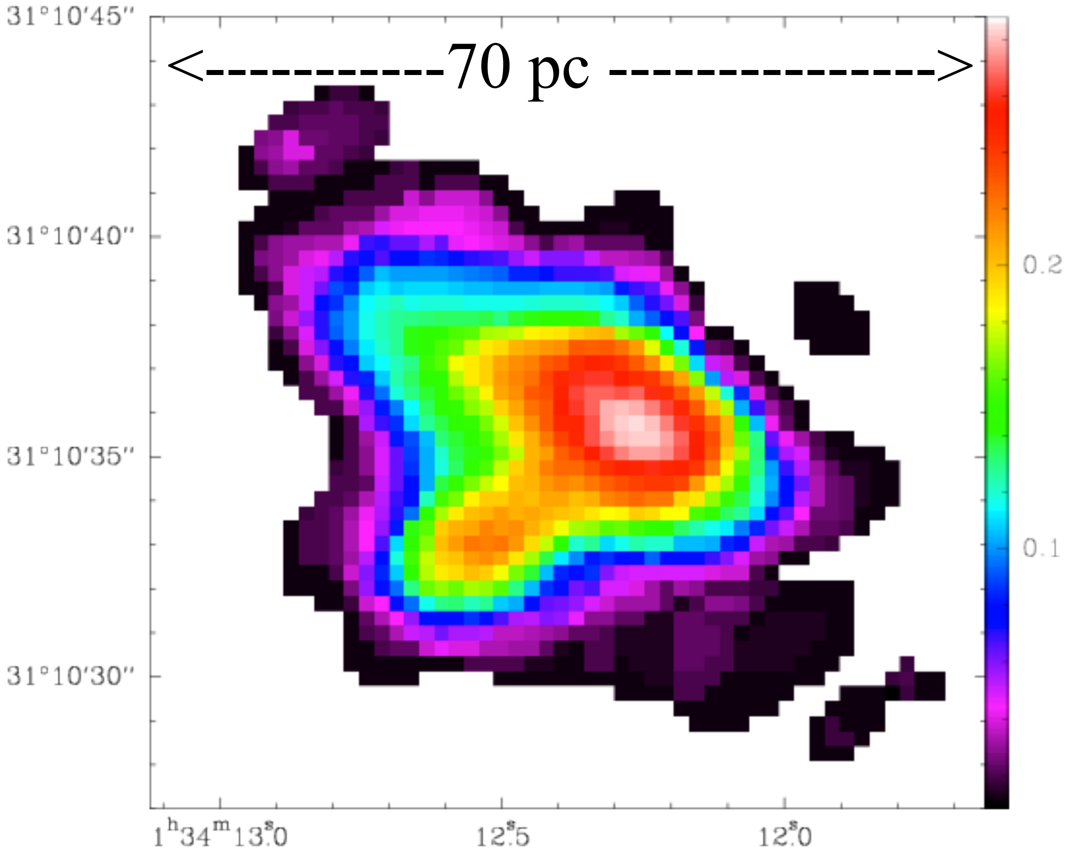
Scatter plot suggests that the outer parts of GMCs are probably not seen in CO -- many points with Ico ~ 0 and $N(H_2)$ ~ 4 x 10^{20} H_2/cm^2. Global ratio similar to that derived from Virial mass of clouds.

Excellent correspondance between dust emission and CO emission. However, also good correspondance between CO and HI, necessary since molecular Hydrogen much less abundant than HI which should be dominant contributor to cool dust emission.

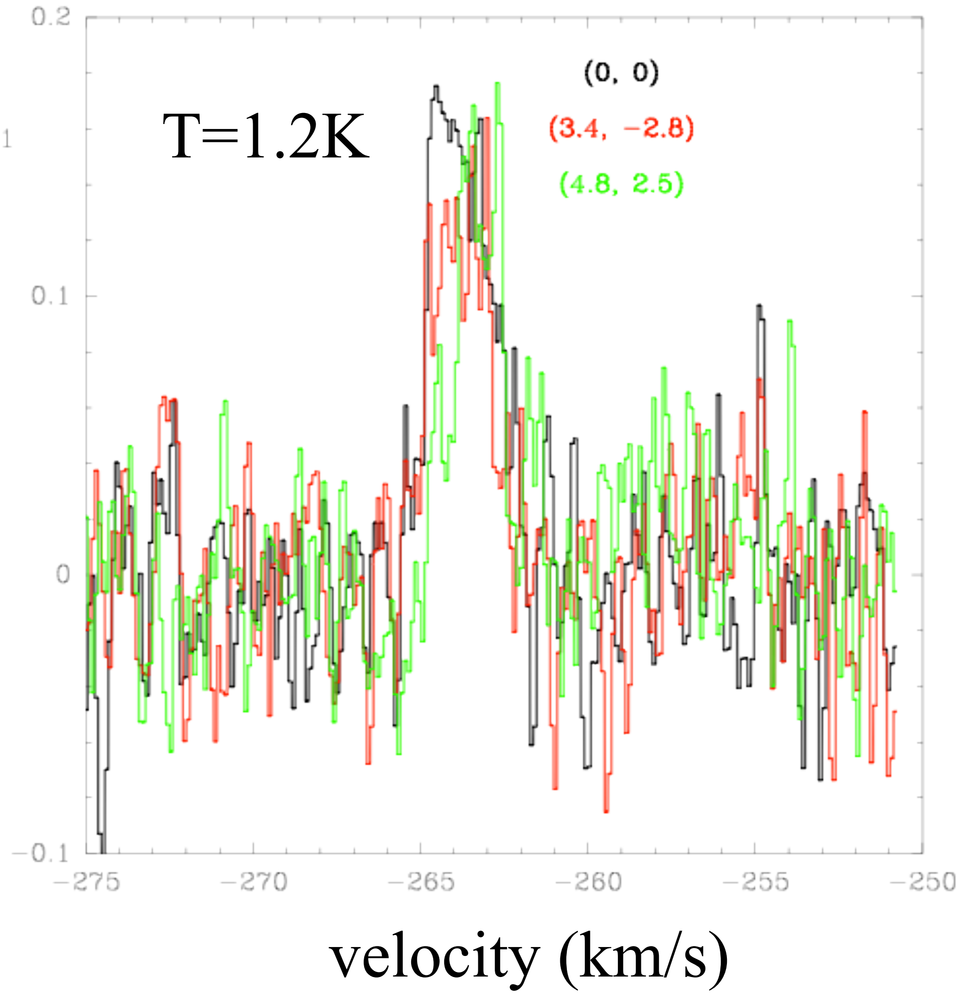
Holes are similar in CO, HI, and dust emission (8-500 micron) so there is no dust-derived molecular gas in HI holes.

Some CO-strong clouds with no detected PACS emission but detected at longer wavelengths.

M33



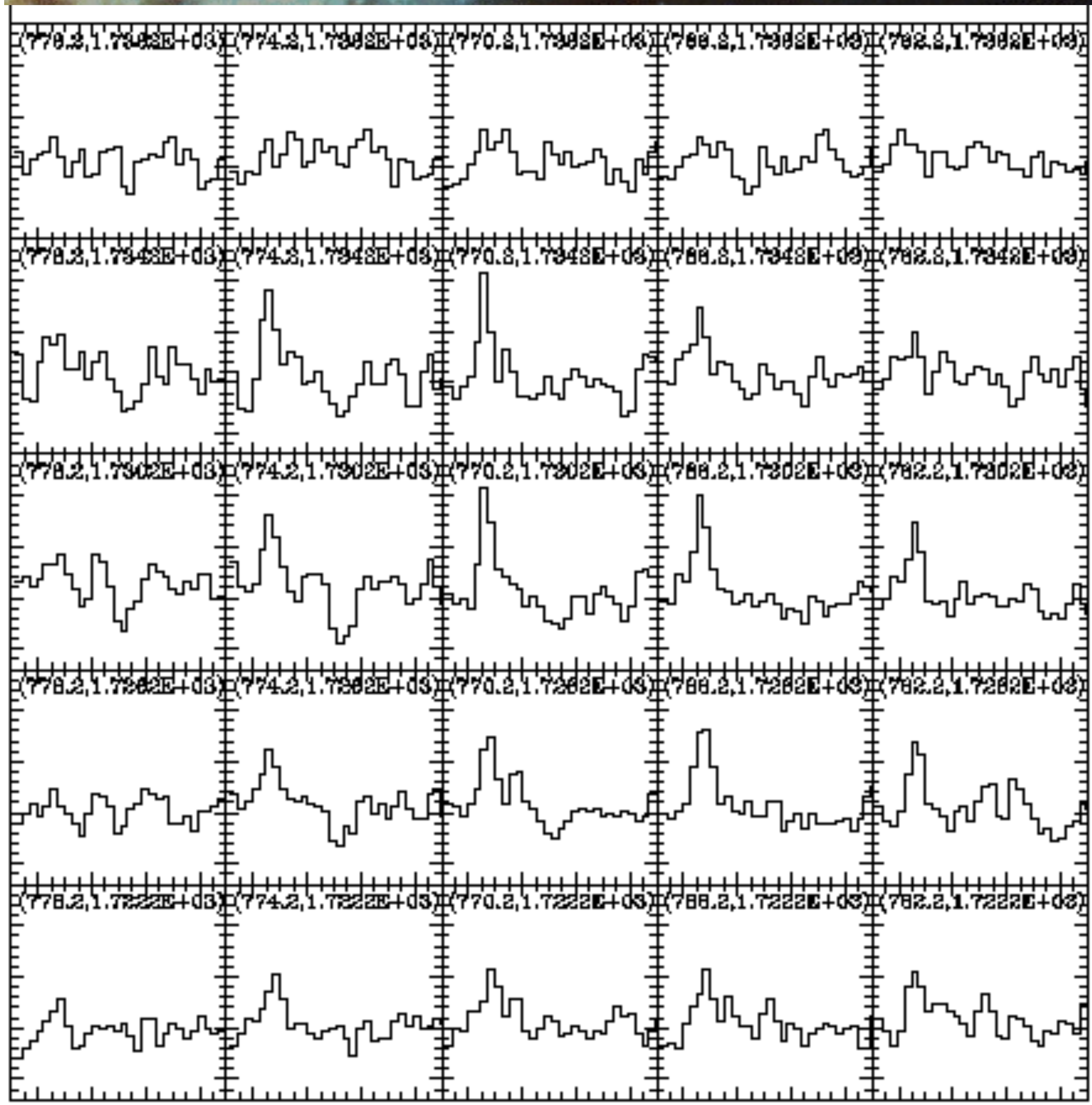
CO(1-0) observations with the Plateau de Bure resolve the outer disk cloud. Narrow line.

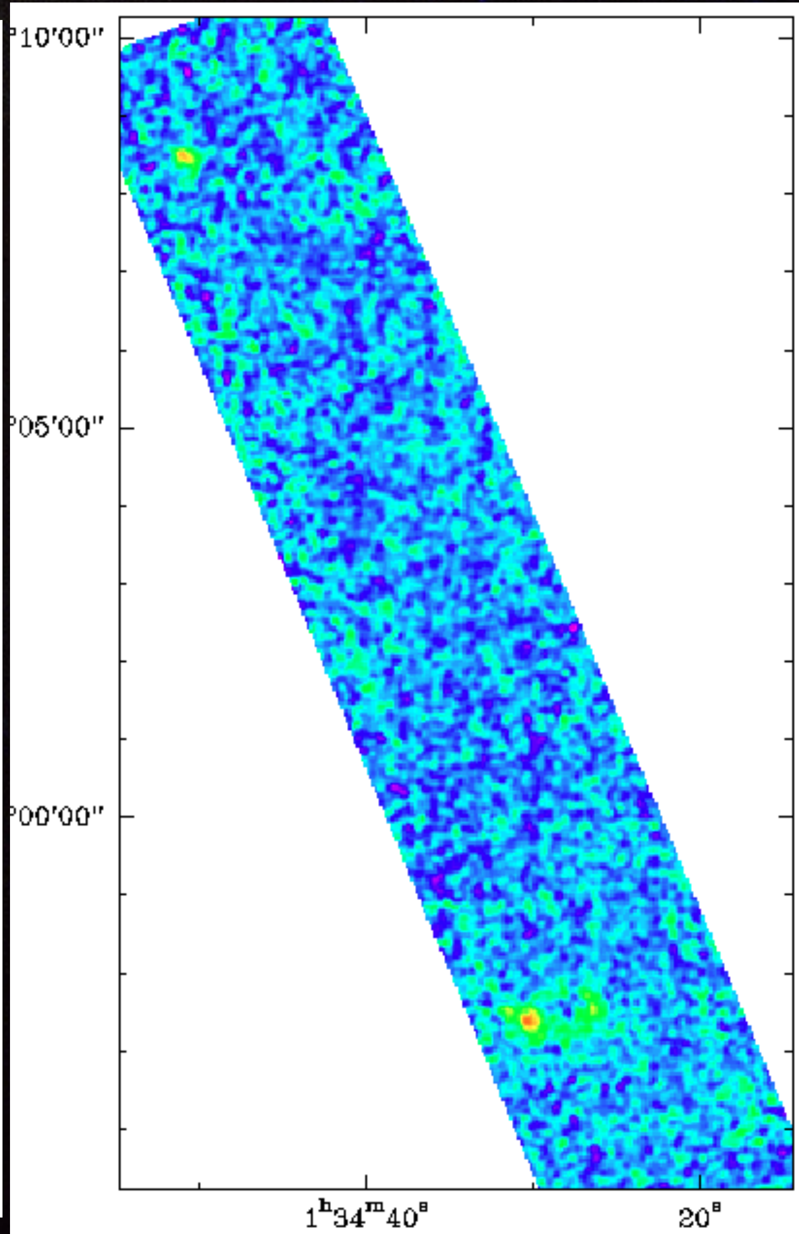


Integrated intensity and spectra at 3 positions in the outer disk GMC of, M33, beyond R_{25}.
Note how strong the CO line is despite the subsolar metallicity and low radiation field: over 1K at 12pc resolution!

en

Northern part of M33 strip at 12" resolution





-290 to -210 km/s and -70 to 140mK


Thank you for your attention