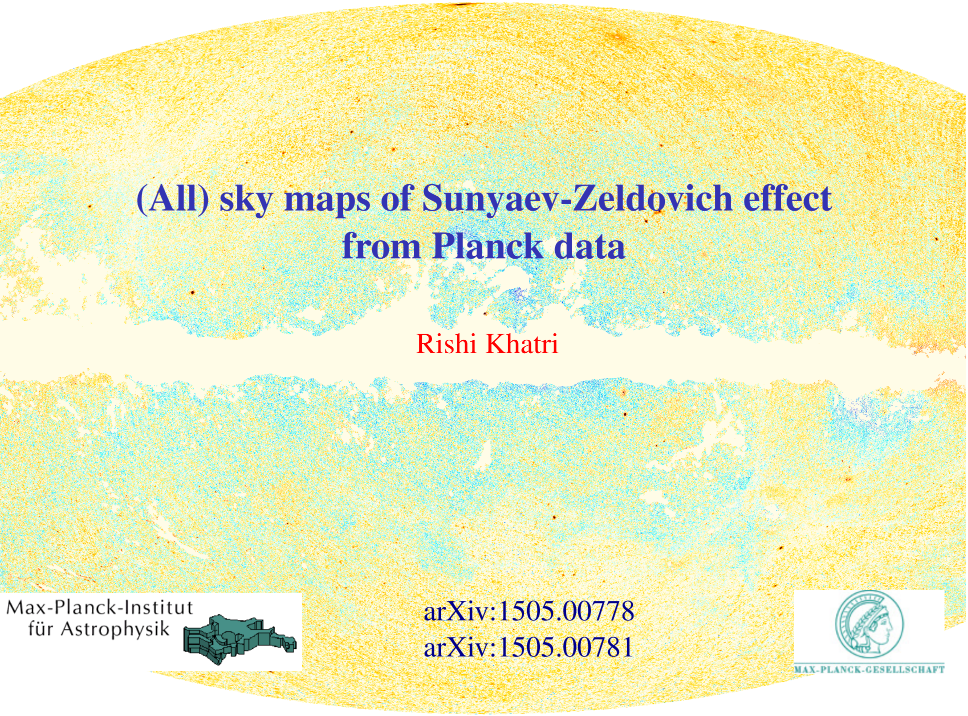


# (All) sky maps of Sunyaev-Zeldovich effect from Planck data

Rishi Khatri

Max-Planck-Institut für Astrophysik

arXiv:1505.00778
arXiv:1505.00781

MAX-PLANCK-GESELLSCHAFT

# *y*-type (Sunyaev-Zeldovich effect) from cluster Abell 2319 seen by Planck

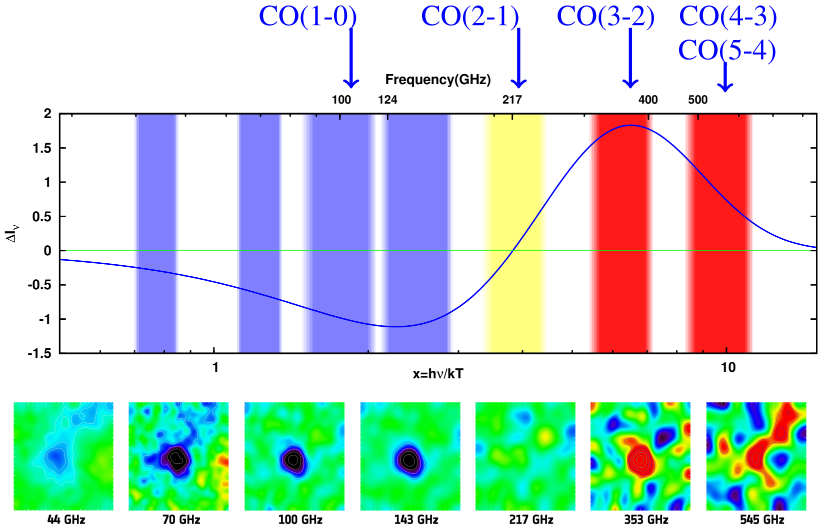
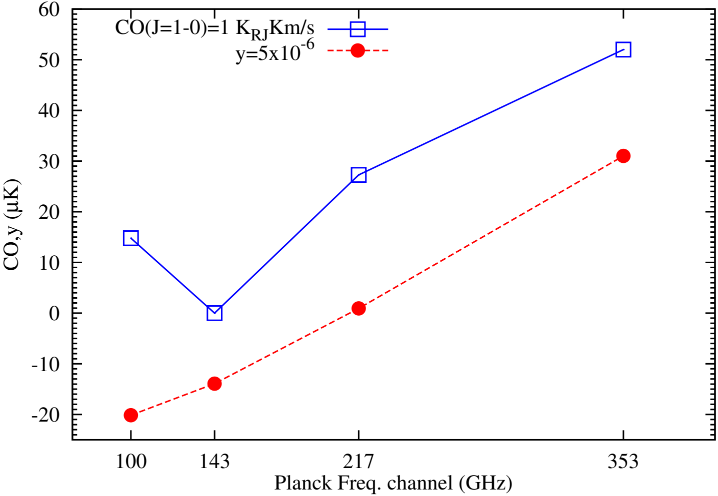



*Image credit: ESA / HFI & LFI Consortia*

# Each Planck frequency channel contains contribution from many components

Sunyaev-Zeldovich or $y$-distortion signal is a weak signal
$\lesssim 100\ \mu$K except in the central part of strong nearby clusters



# Component separation methods: Internal linear combination

y map = linear combination of channel maps

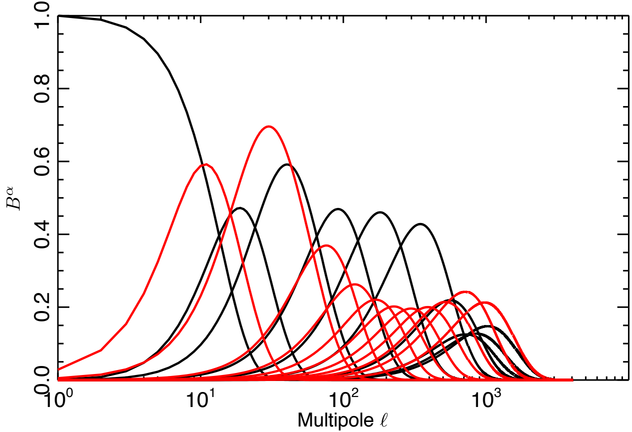
$$y(p) = \sum_i w_i T_i(p)$$

Weights are given by minimizing the variance of $y$.

In principle can be done in any space:
pixel, harmonic, needlet, ....

# MILCA and NILC

Planck collaboration strategy: filter the maps in harmonic space, apply ILC, and combine the maps again to get final y map.




*Planck collaboration (2015)*

# Alternative: parameter fitting (LIL)

- Fit a (non-linear) parametric model
- CMB + y + dust or CMB + CO + dust
- dust: grey body with spectral index as free parameter, temperature fixed to 18 K : 2 parameters
- CO: fixed line ratios : 1 parameter

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Advantages: Can use $\chi^2$ for CO vs y to decide which is the dominant component in a given part of the sky $\Rightarrow$ CO mask, alternative validation of Planck cluster catalog *(see arXiv:1505.00778 for details)*
Map, validation annotation to second Planck cluster catalog publicly available
`http://www.mpa-garching.mpg.de/~khatri/szresults/`

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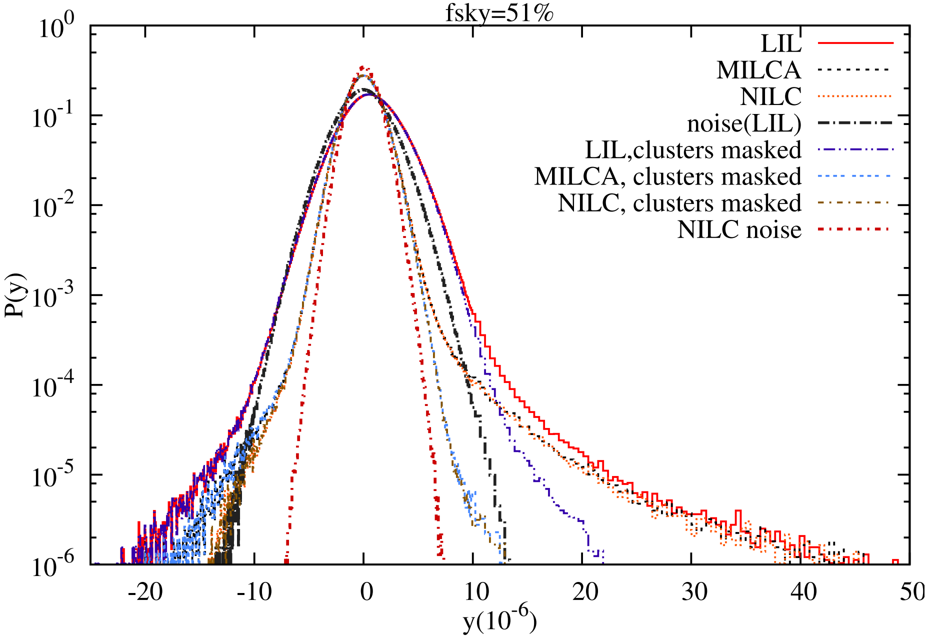
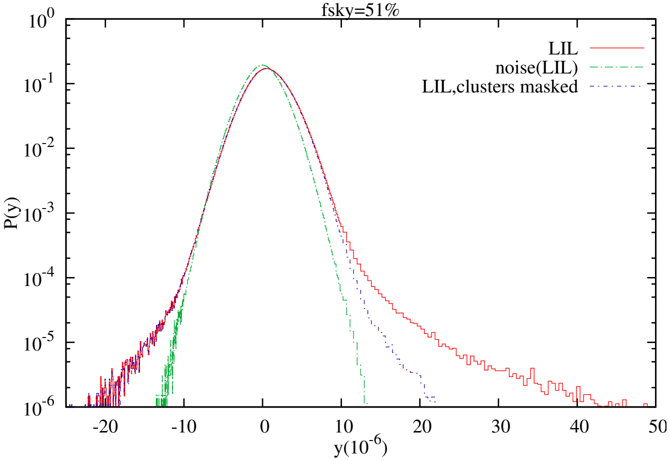
Disdvantage: Have to assume a model

# Map pdfs


fsky=51%
LIL
MILCA
NILC
noise(LIL)
LIL,clusters masked
MILCA, clusters masked
NILC, clusters masked
NILC noise
P(y)
y(10^-6)
10^0
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
-20
-10
0
10
20
30
40
50

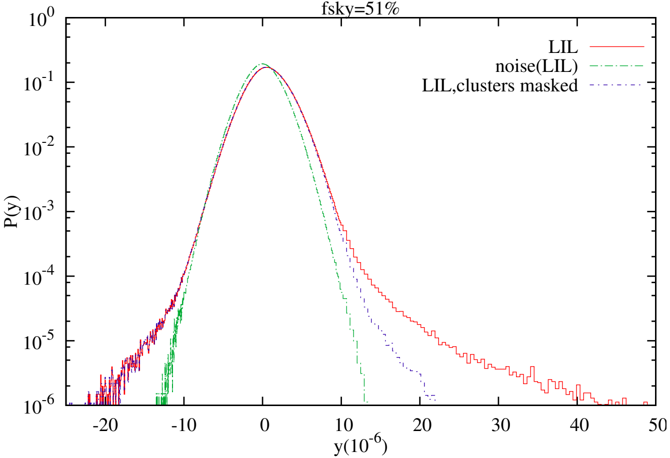
# New upper limit on $\langle y \rangle$ from $y$-map created by combining Planck HFI channels

*(Khatri & Sunyaev 2015)*



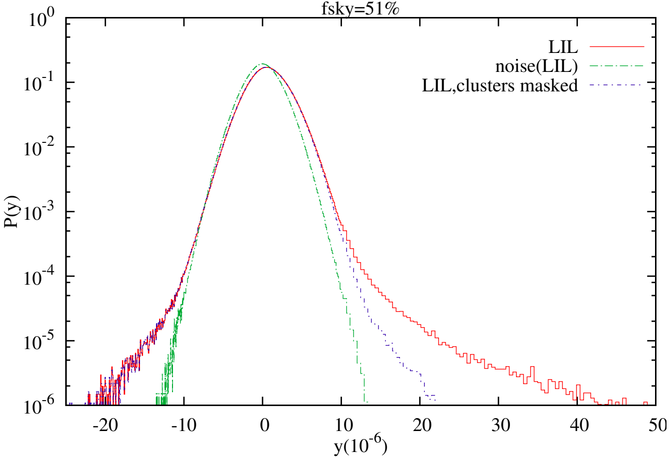
# New upper limit on $\langle y \rangle$ from $y$-map created by combining Planck HFI channels

average the full pdf: $\langle y \rangle \approx 1.0 \times 10^{-6}$ *(Khatri & Sunyaev 2015)*



# New upper limit on $\langle y \rangle$ from $y$-map created by combining Planck HFI channels

average the positive tail: $\langle y \rangle < 2.2 \times 10^{-6}$ *(Khatri & Sunyaev 2015)*



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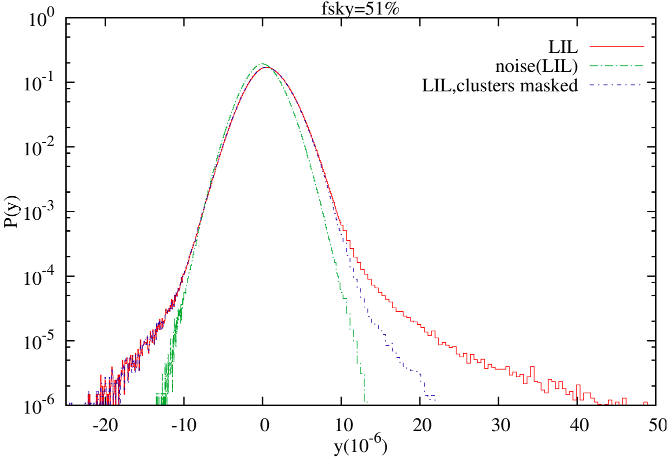
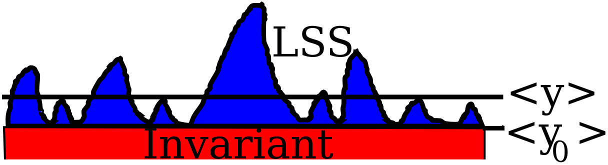


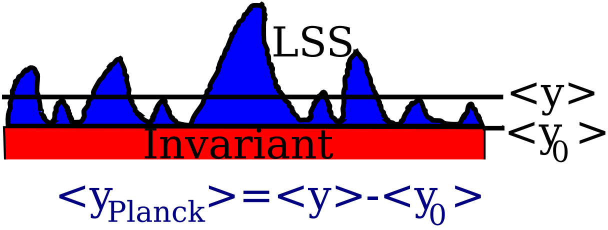

6.8 times stronger compared to the COBE-FIRAS upper limit:
$\langle y \rangle < 15 \times 10^{-6}$ *(Fixsen et al. 1996)*

# Planck is sensitive to only the fluctuations in *y*




$$\langle y_{Planck} \rangle = \langle y \rangle - \langle y_0 \rangle$$

# Planck is sensitive to only the fluctuations in $y$



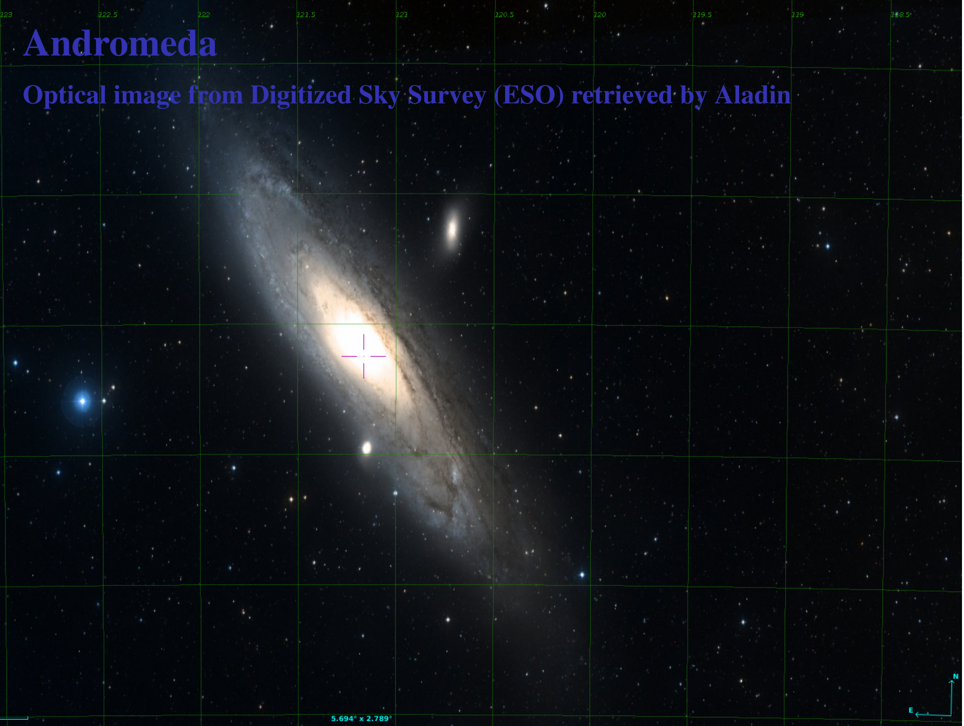

- In the standard model of cosmology the invariant component is smaller, $\langle y \rangle \ll \langle y_0 \rangle$
- This upper limits rules out models involving preheating of the IGM

  *Springel et al. 2001,Munshi et al. 2012*
- Most simulations predict $\langle y \rangle \ll\sim 10^{-6} - 3 \times 10^{-6}$

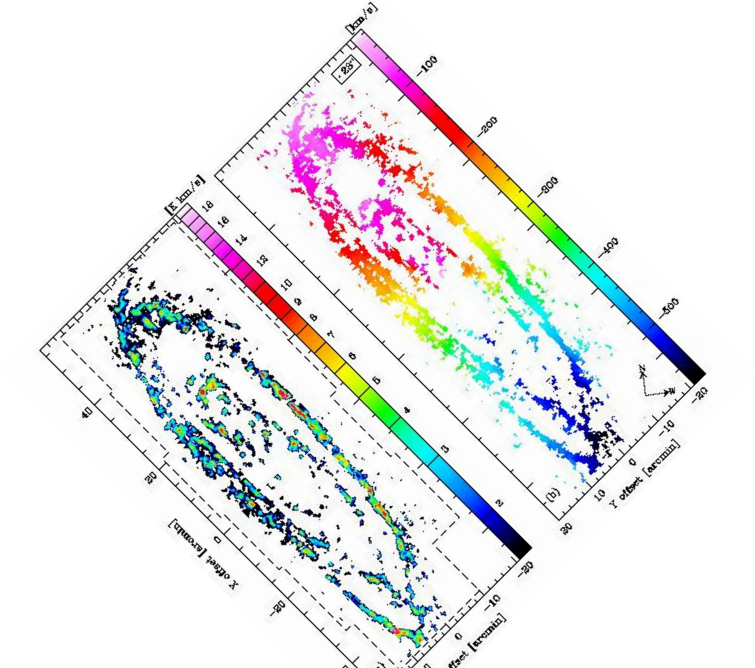
  *Refregier et al. 2000, Nath & Silk 2001, White et al. 2002,Schaefer et al. 2006*
- Indications from our analysis of Planck that true value may be closer to $\approx 10^{-6}$ (*Khatri & Sunyaev 2015*).

# Andromeda

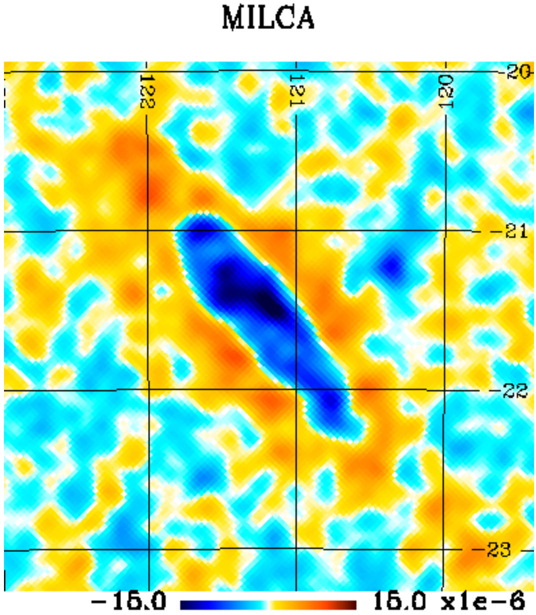
## Optical image from Digitized Sky Survey (ESO) retrieved by Aladin



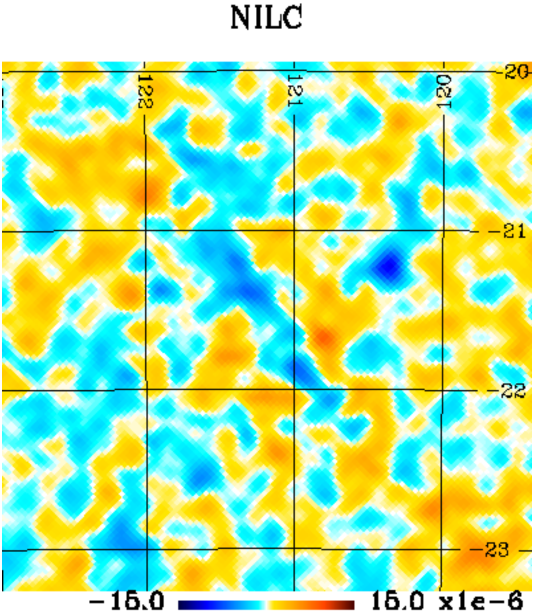
# Andromeda: CO observations from *Nieten et al 2006*



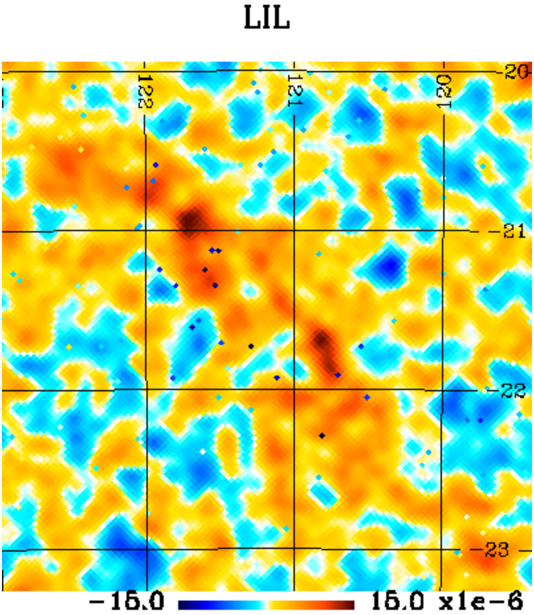
# Andromeda: MILCA



# Andromeda: NILC

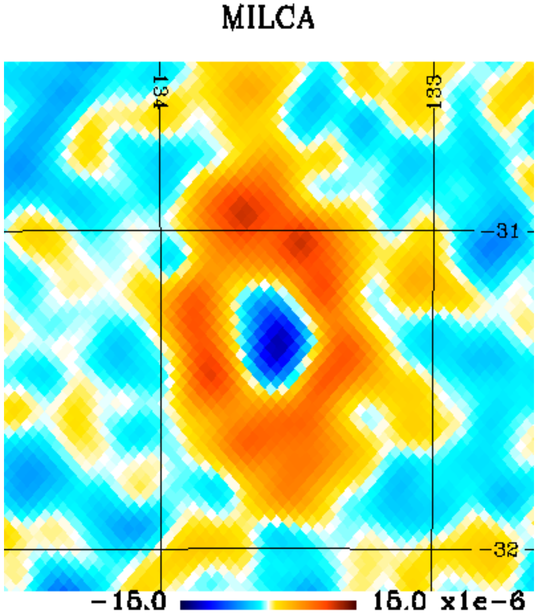


# Andromeda: LIL

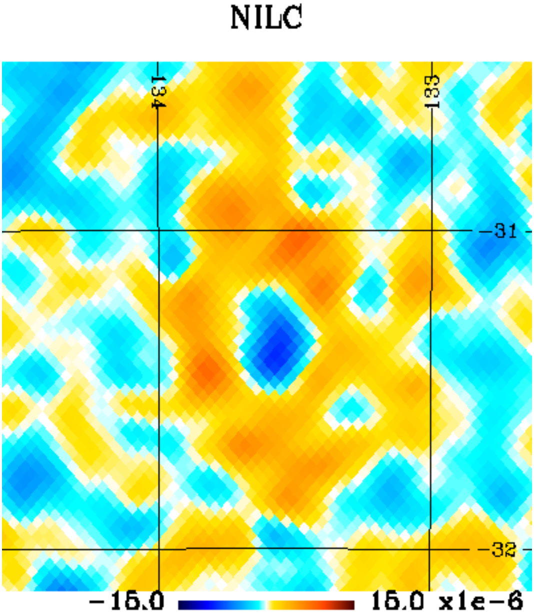


M33
Optical image from Digitized Sky Survey (ESO) retrieved by Aladin
134.25
134
133.75
133.5
133.25
133
132.75
1.925° x 56.05'
E

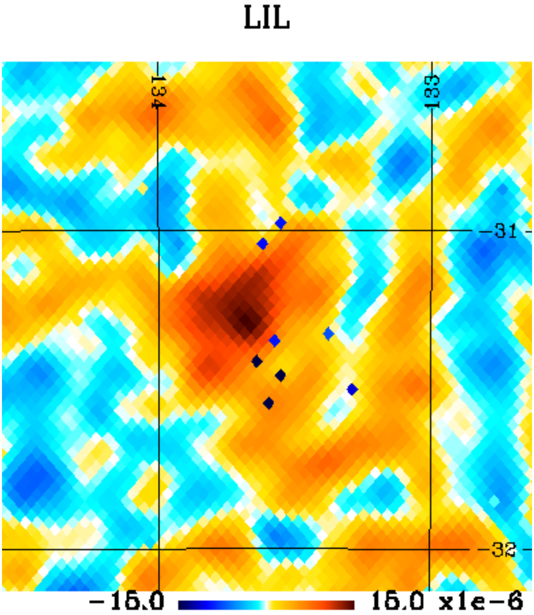
# M33: MILCA



# M33: NILC

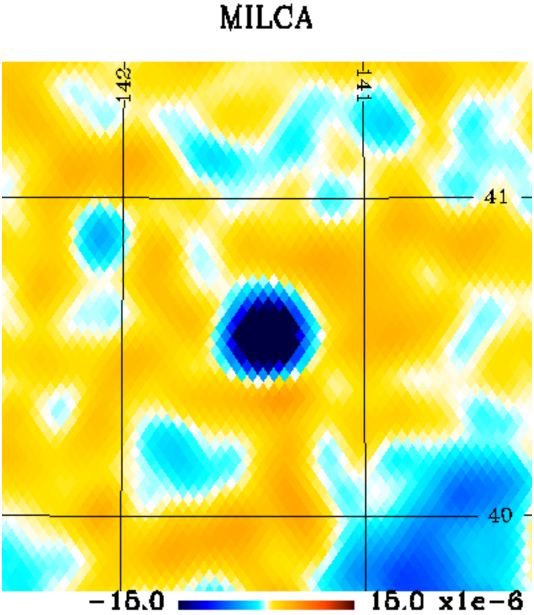


# M33: LIL

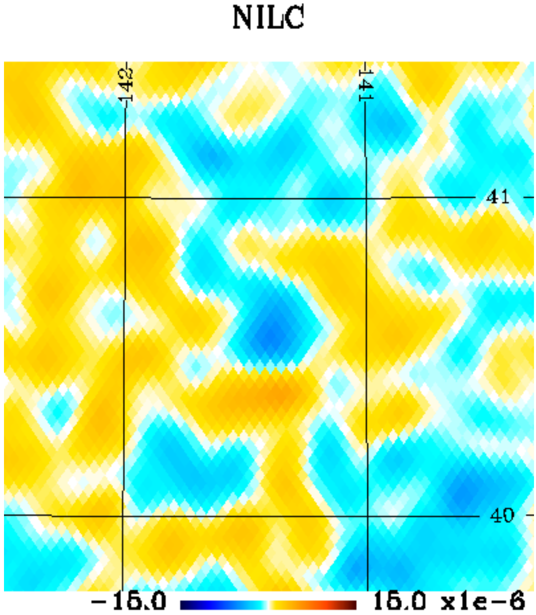



M82
Optical image from Digitized Sky Survey (ESO) retrieved by Aladin
142
141.75
141.5
141.25
141
140.75
140.5
140.25
1.925° x 56.05'
N
E

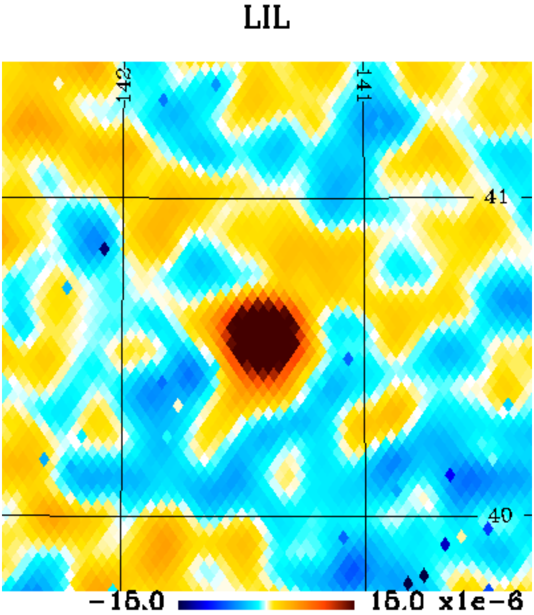
# M82: MILCA



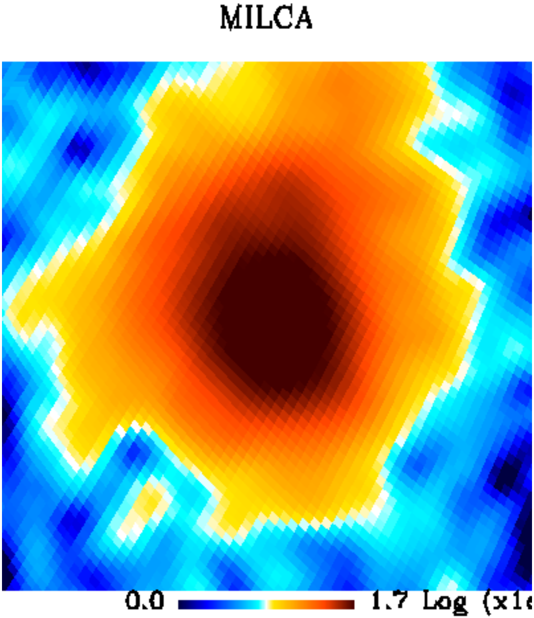
# M82: NILC



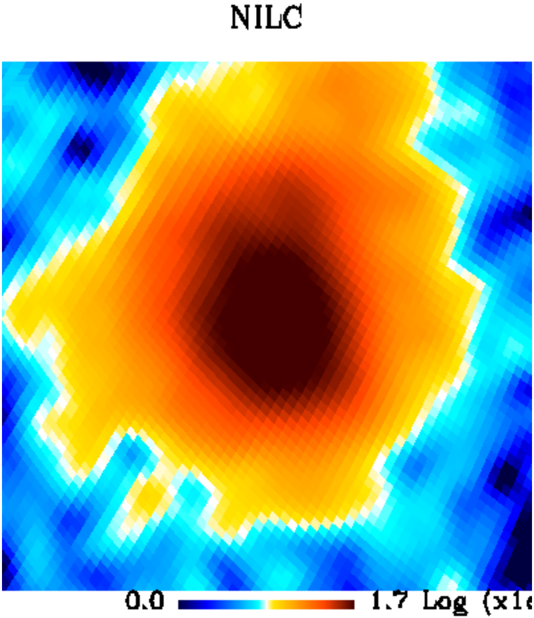
# M82: LIL



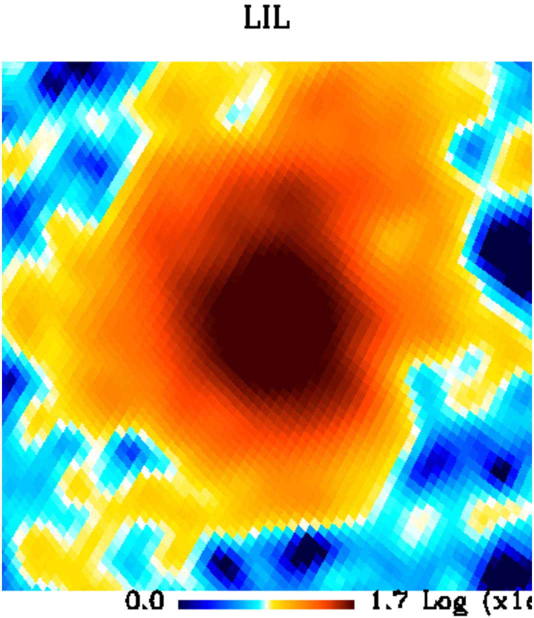
# Coma: MILCA



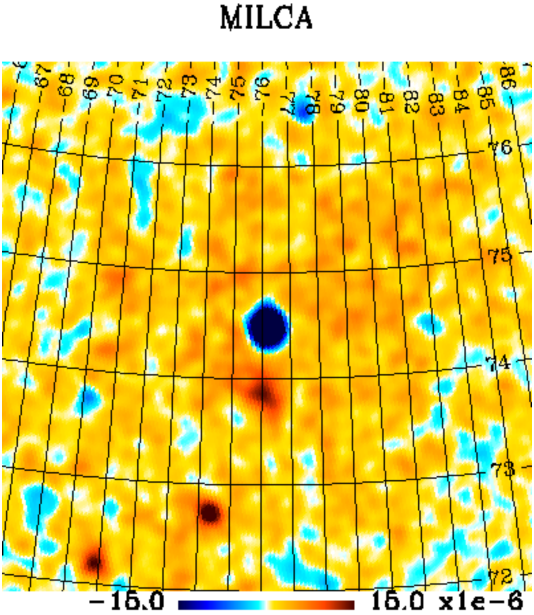
# Coma: NILC



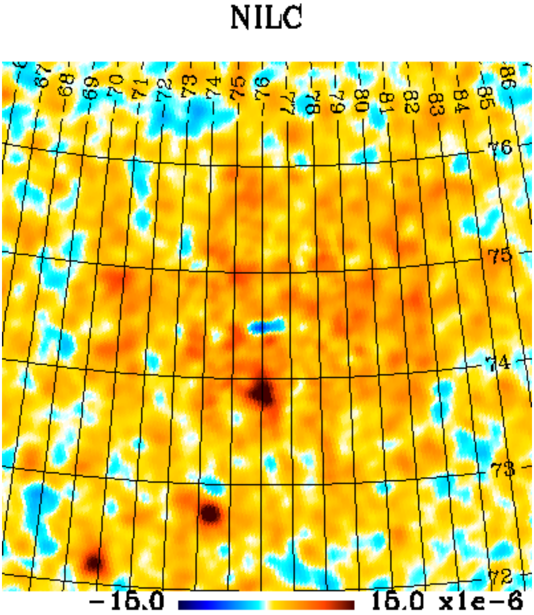
# Coma: LIL



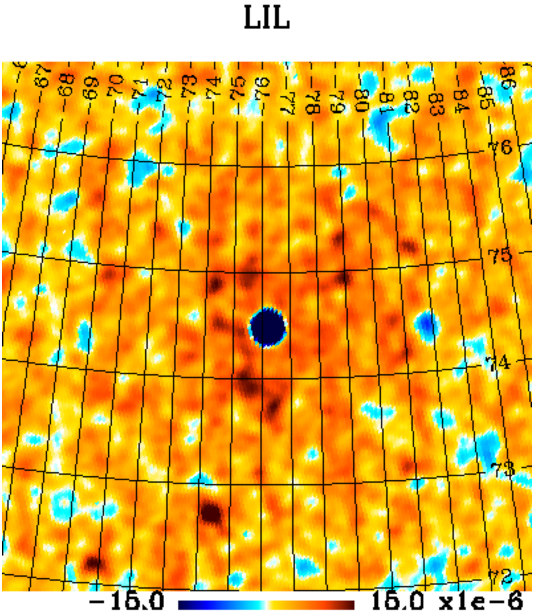
# Virgo: MILCA



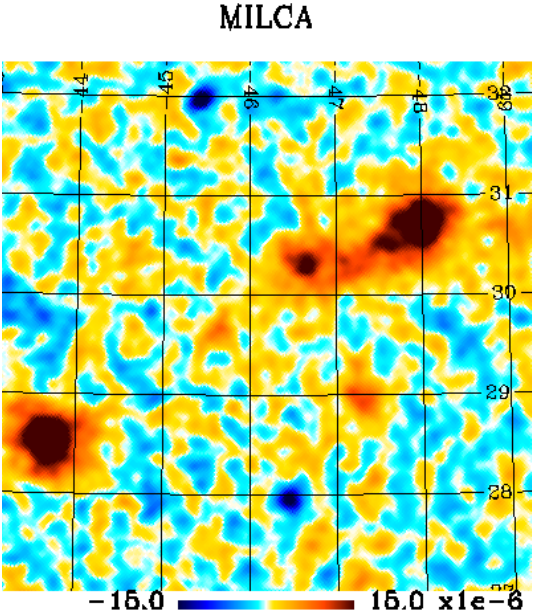
# Virgo: NILC



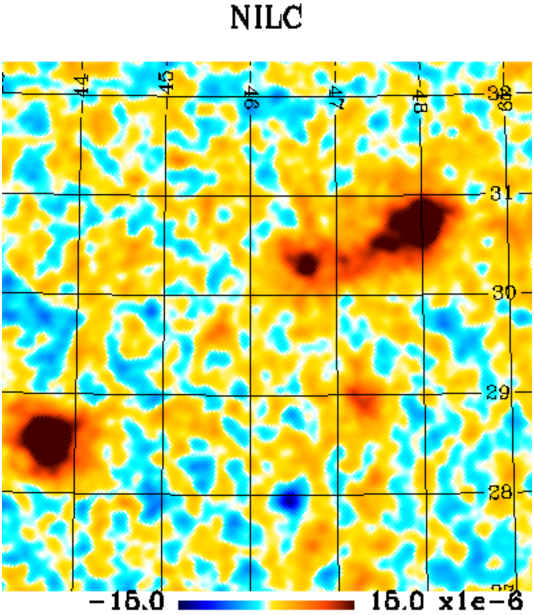
# Virgo: LIL


LIL
67
68
69
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
76
75
74
73
72
-15.0
15.0 x1e-6

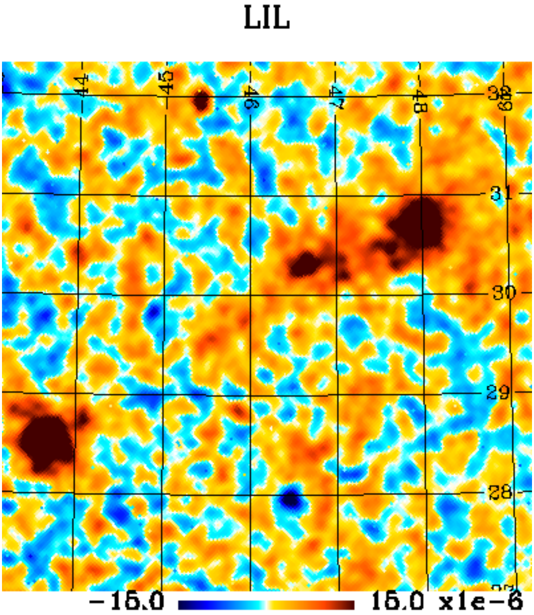
# Shapley: MILCA



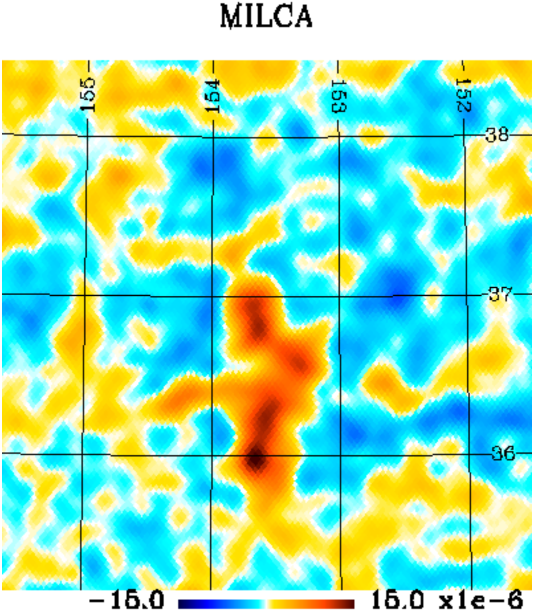
# Shapley: NILC



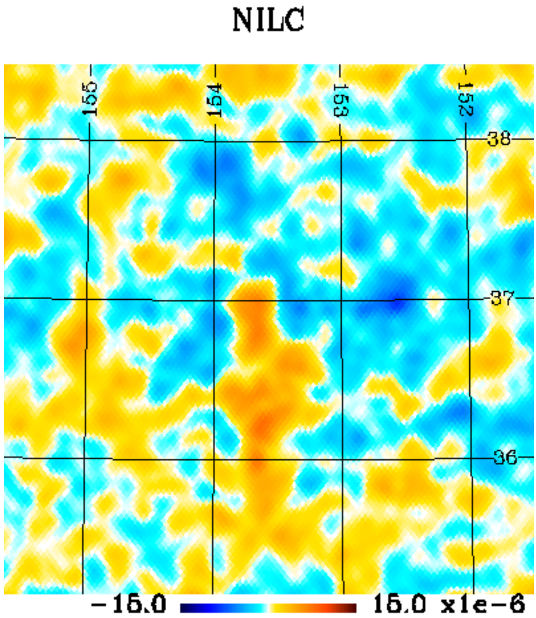
# Shapley: LIL



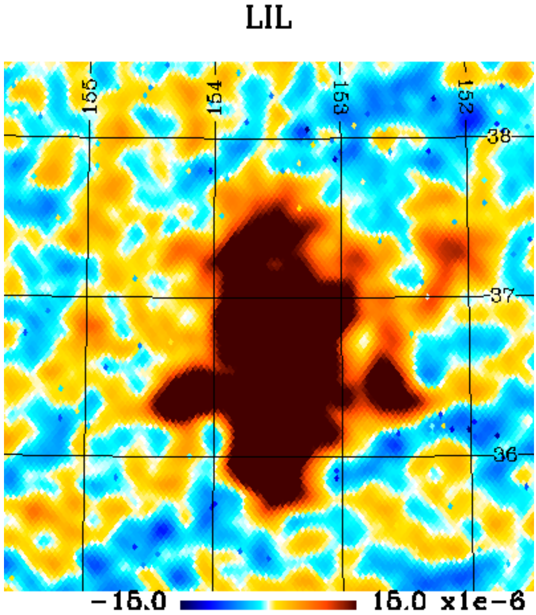
# PSZ2 G153.56+36.82: MILCA



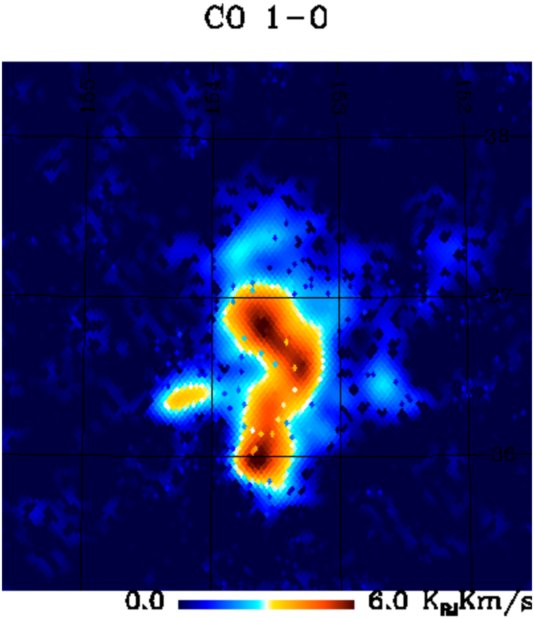
# PSZ2 G153.56+36.82: NILC



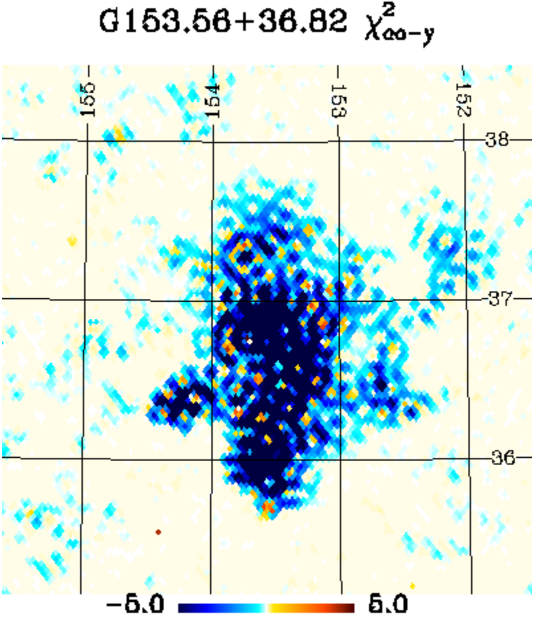
# PSZ2 G153.56+36.82: LIL



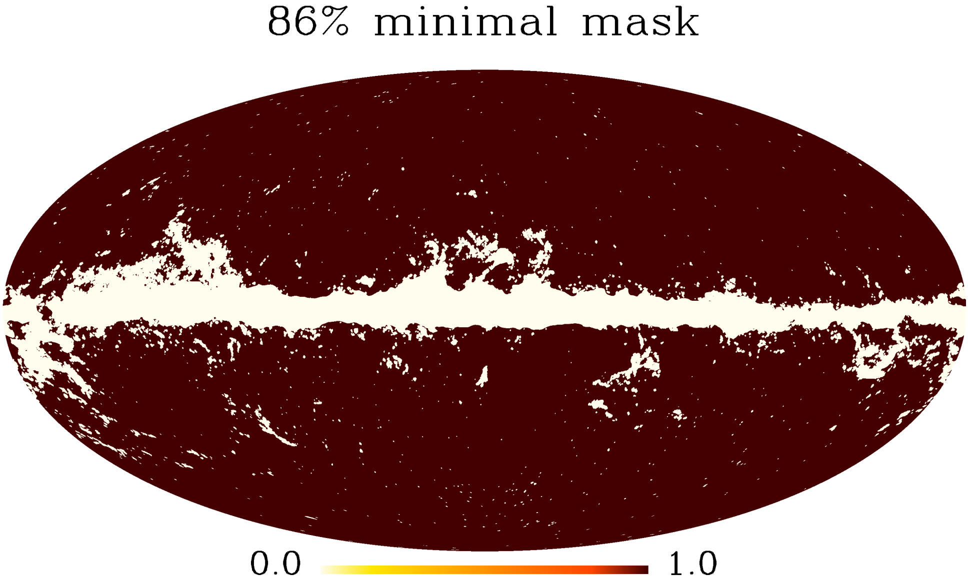
# PSZ2 G153.56+36.82: LIL - CO



# PSZ2 G153.56+36.82: $\Delta\chi^2$



# Use $\Delta\chi^2$ to create a mask (publicly available)



# A relook at second Planck cluster catalog: clusters (publicly available)

| cluster | S/N | z | $\Delta(\sum\chi^2)_{\rm CO-y}$ | valid. | $Q_N$ |
|---|---|---|---|---|---|
| PSZ2 G075.71+13.51 | 48.98511 | 0.05570 | 893.456 | CLG | 0.994 |
| PSZ2 G110.98+31.73 | 40.75489 | 0.05810 | 294.893 | CLG | 0.992 |
| PSZ2 G272.08-40.16 | 39.99466 | 0.05890 | 492.870 | CLG | 0.993 |
| PSZ2 G239.29+24.75 | 36.24374 | 0.05420 | 192.400 | CLG | 0.993 |
| PSZ2 G057.80+88.00 | 35.69822 | 0.02310 | 418.131 | CLG | 0.992 |
| PSZ2 G006.76+30.45 | 35.01054 | 0.20300 | 137.806 | CLG | 0.994 |
| PSZ2 G324.59-11.52 | 32.40285 | 0.05080 | 321.450 | CLG | 0.993 |
| PSZ2 G044.20+48.66 | 28.38608 | 0.08940 | 127.431 | CLG | 0.994 |
| PSZ2 G266.04-21.25 | 28.38260 | 0.29650 | 103.555 | CLG | 0.993 |
| PSZ2 G072.62+41.46 | 27.43035 | 0.22800 | 88.383 | CLG | 0.994 |

# A relook at second Planck cluster catalog: clouds

| cluster | S/N | z | $\Delta(\sum \chi^2)_{\mathrm{CO-y}}$ | validation | $Q_N$ |
|---|---|---|---|---|---|
| PSZ2 G153.56+36.82 | 15.89673 | -1.00000 | -528.090 | MOC | 0.000 |
| PSZ2 G182.42-28.28 | 15.77494 | 0.08820 | -15.384 | MOC | 0.991 |
| PSZ2 G342.45+24.14 | 15.71413 | -1.00000 | -2194.689 | MOC | 0.035 |
| PSZ2 G284.97-23.69 | 15.65867 | 0.39000 | -58.154 | MOC | 0.991 |
| PSZ2 G314.96+10.06 | 15.49399 | 0.09660 | -35.386 | MOC | 0.990 |
| PSZ2 G171.98-40.66 | 13.39432 | 0.27000 | -53.838 | MOC | 0.964 |
| PSZ2 G125.37-08.67 | 12.29307 | 0.10660 | -30.983 | MOC | 0.974 |
| PSZ2 G100.45+16.79 | 11.78533 | -1.00000 | -7597.947 | MOC | 0.024 |
| PSZ2 G105.82-38.36 | 11.51047 | -1.00000 | -342.830 | MOC | 0.000 |
| PSZ2 G340.09+22.89 | 11.35395 | -1.00000 | -2443.363 | MOC | 0.033 |
| PSZ2 G338.04+23.65 | 6.05953 | -1.00000 | -1315.602 | MOC | 0.034 |
| PSZ2 G028.08+10.79 | 6.03667 | 0.08820 | -119.810 | MOC | 0.875 |
| PSZ2 G093.04-32.38 | 6.03185 | -1.00000 | -370.231 | MOC | 0.006 |
| PSZ2 G337.95+22.70 | 6.03163 | -1.00000 | -1959.108 | MOC | 0.047 |
| PSZ2 G278.74-45.26 | 6.03076 | -1.00000 | -67.508 | pMOC | 0.002 |
| PSZ2 G198.73+13.34 | 6.02919 | -1.00000 | -51.949 | MOC | 0.311 |
| PSZ2 G215.24-26.10 | 6.02551 | 0.33600 | -10.723 | MOC | 0.993 |
| PSZ2 G299.54+17.83 | 6.02125 | -1.00000 | -27.199 | MOC | 0.983 |
| PSZ2 G076.44+23.53 | 6.01971 | 0.16900 | -6.638 | pMOC | 0.967 |

# Alternative validation strategy

Use radio telescopes to measure and subtract CO lines from sources which $\Delta\chi^2$ suggests to have CO contamination

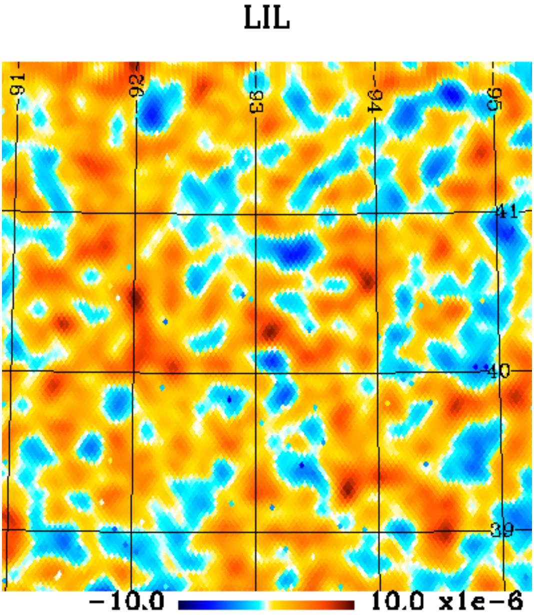
# Alternative validation strategy

Use radio telescopes to measure and subtract CO lines from sources which $\Delta\chi^2$ suggests to have CO contamination

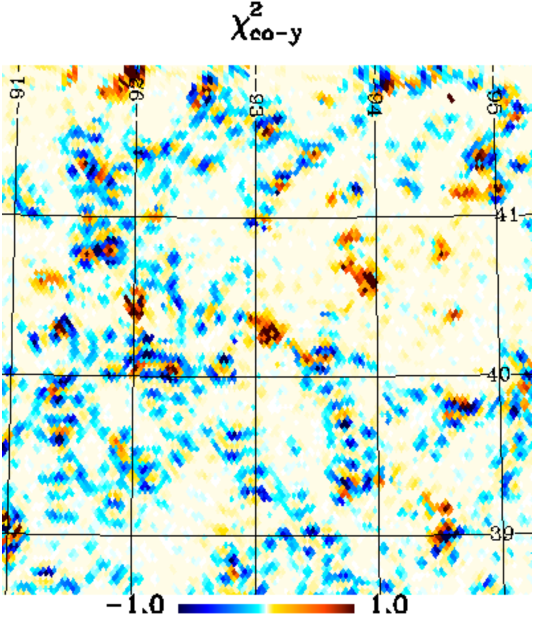
Main difference between ILC and parameter fitting: Identification of the main source contamination to be CO emission

A taste of things to come.

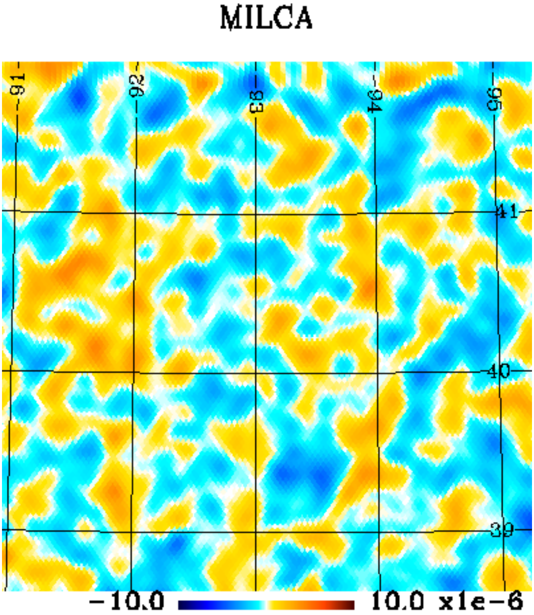
# New SZ clusters and groups?



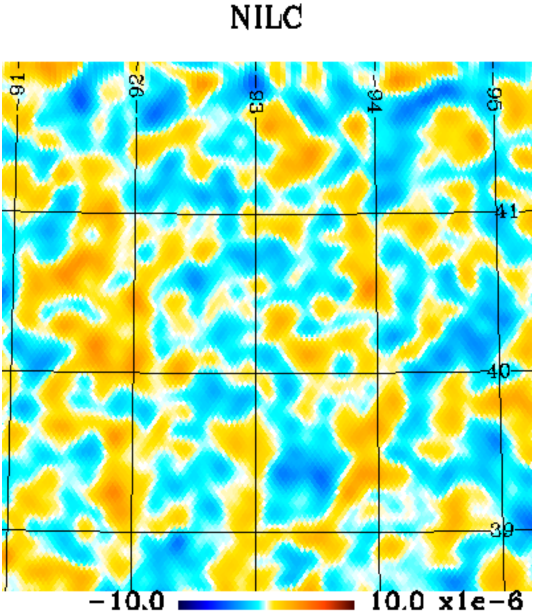
# New SZ clusters and groups?



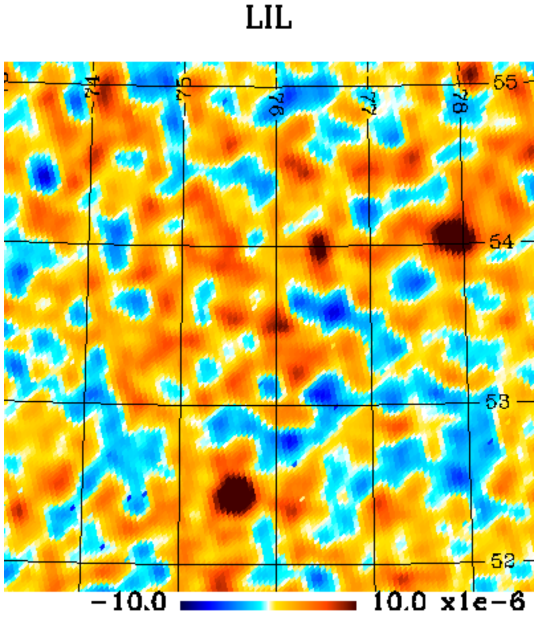
# New SZ clusters and groups?



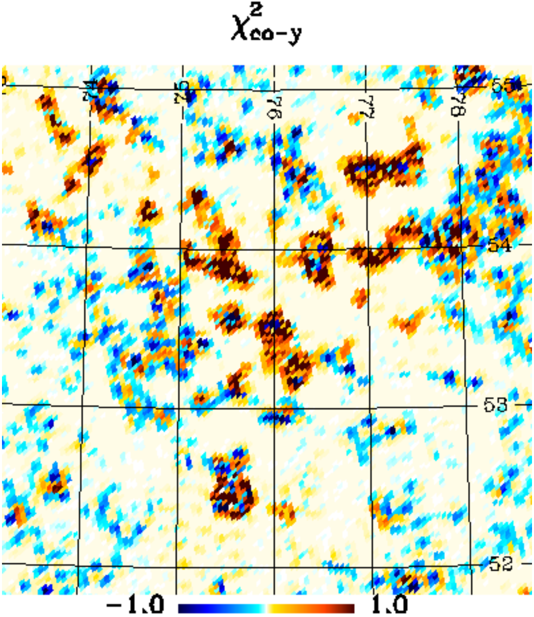
# New SZ clusters and groups?



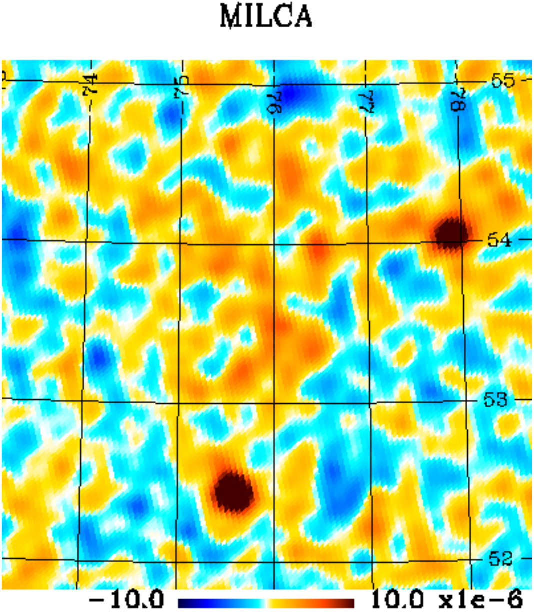
# RXJ1206.5-0744



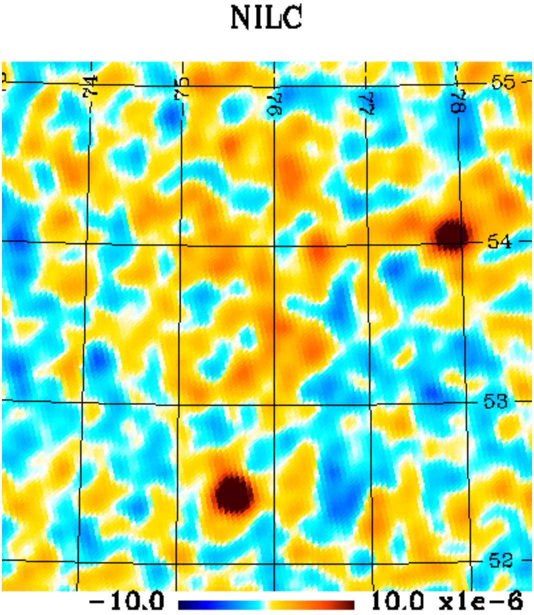
# RXJ1206.5-0744



# RXJ1206.5-0744



# RXJ1206.5-0744



# CO mask, annotations to second Planck cluster catalog publicly available

http://www.mpa-garching.mpg.de/~khatri/szresults/

More results soon.