# Component separation
# in CMB observations
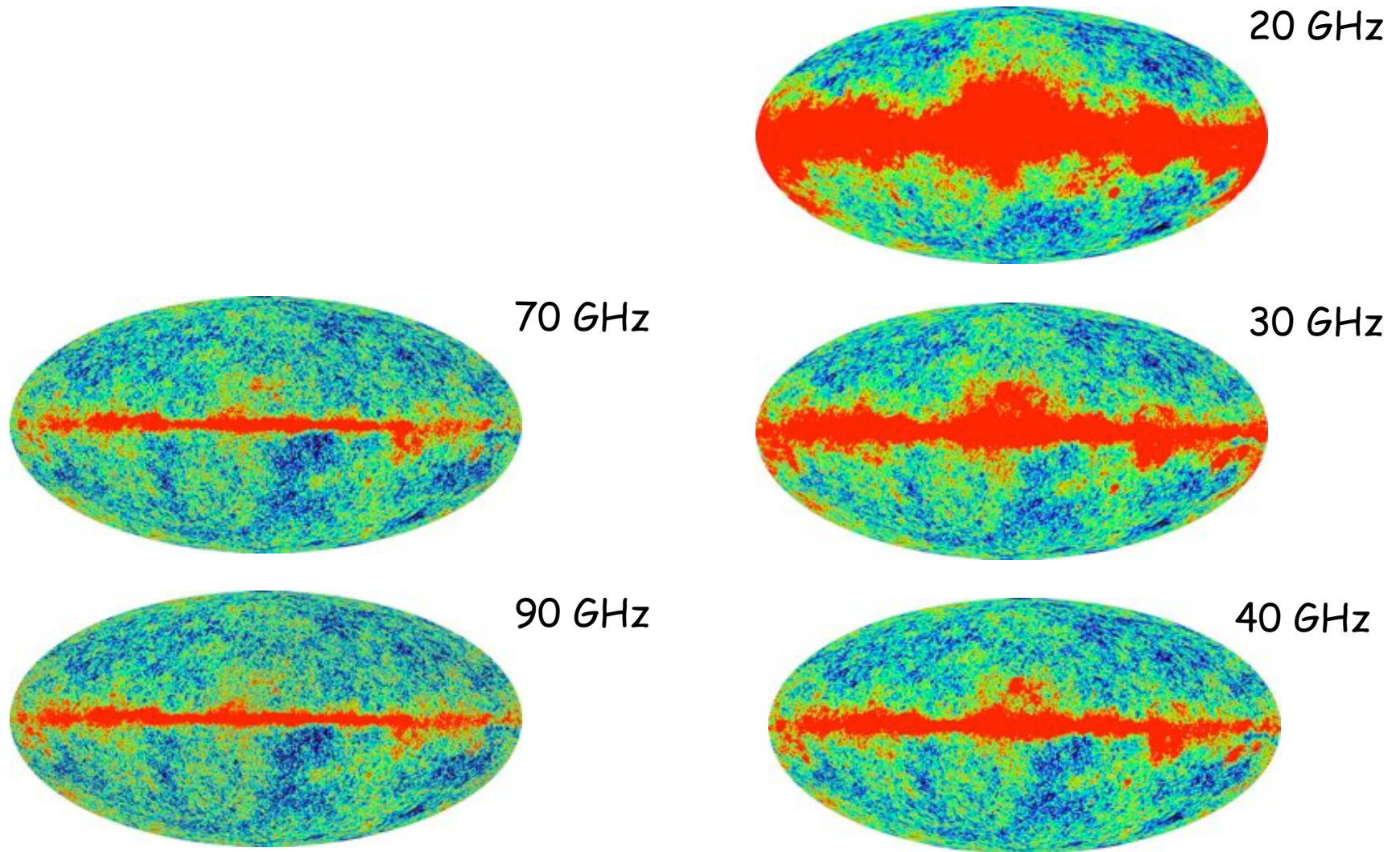
*Jacques Delabrouille*
*APC Paris*

# The component separation problem



Point sources

SZ clusters ?

Noise

Galactic emission

CMB Anisotropies

−6.16e−01        6.16e−01
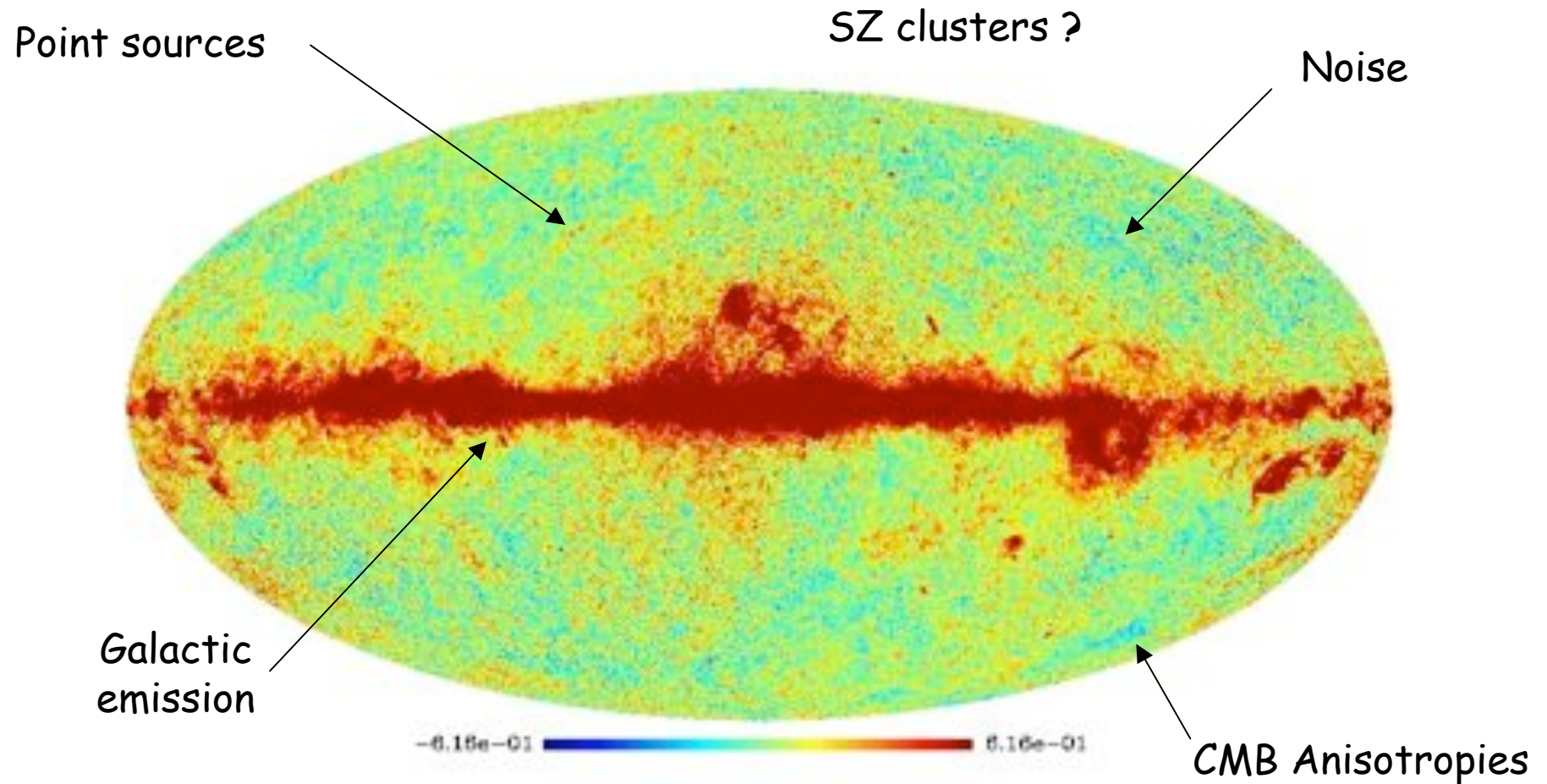
WMAP Observation at 30 GHz

# Multifrequency observations



20 GHz

70 GHz

30 GHz

90 GHz

40 GHz

# Component separation ?

- **Devise methods which exploit**
  - Morphology / shape of components
  - Colour of components
  - Independence of components
  - …

  to separate the emissions due to each individual component, and extract the information of interest about each of them…

# Our objectives

## A clean CMB map

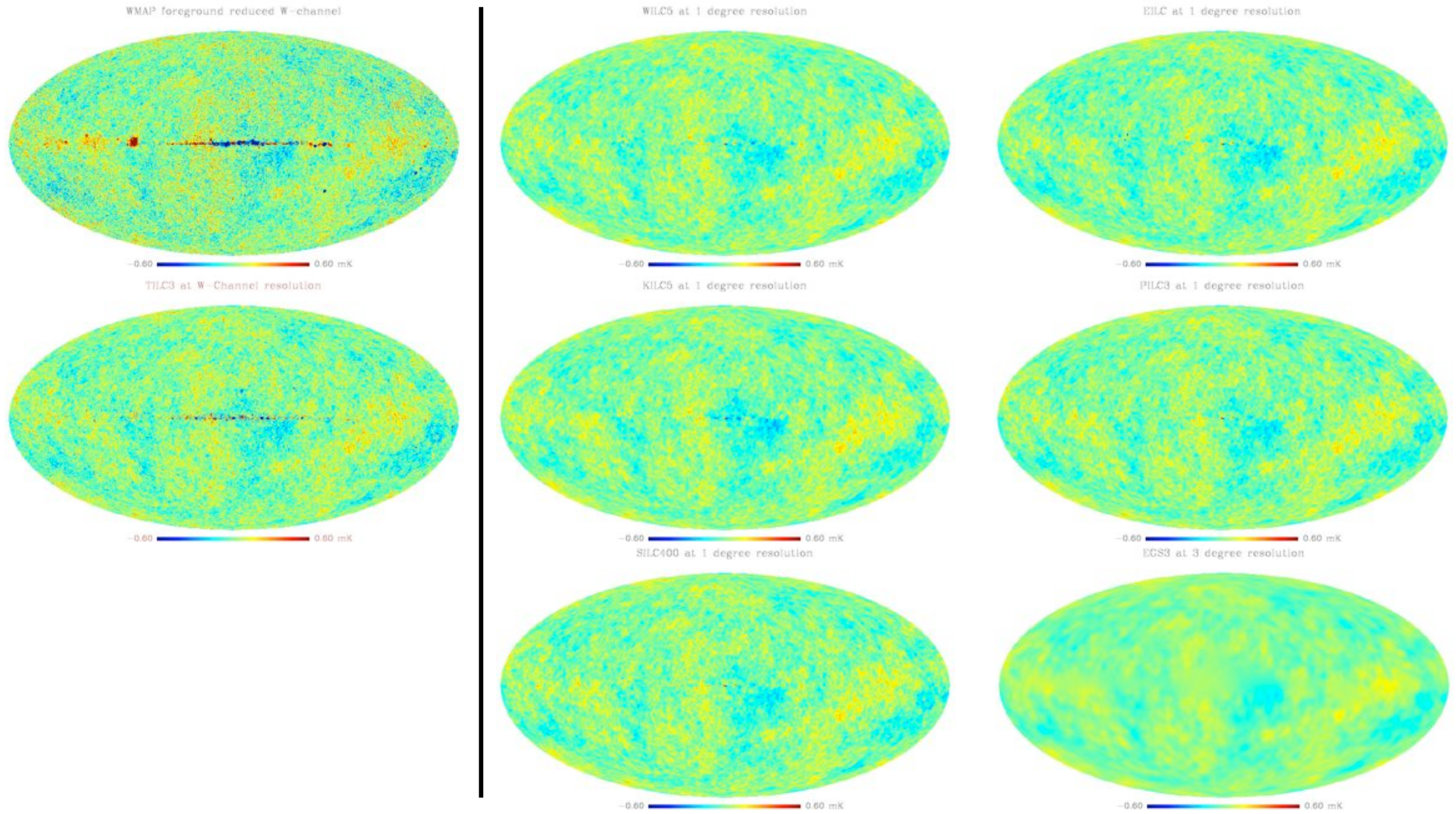*Delabrouille et al. MNRAS (2009) 493, vol.3, p. 835*

## A clean foreground map

*Ghosh et al. in preparation*

## Sunyaev Zel'dovich emission in WMAP data

*Melin et al. submitted to A&A (arXiv/1001.0871)*

# CMB maps have been extracted

# Internal Linear Combination

$$y_d(x) = a_d s(x) + n_d(x)$$

known scaling

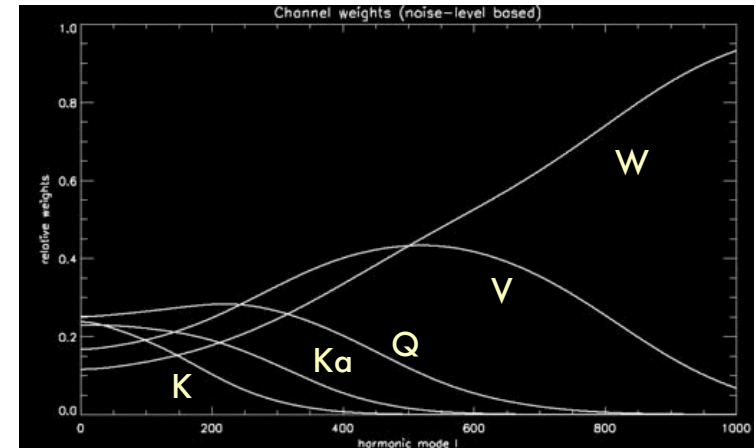one map
of interest

everything
else

Solution :     $w_d = f(a_d, R)$

Empirical covariance matrix
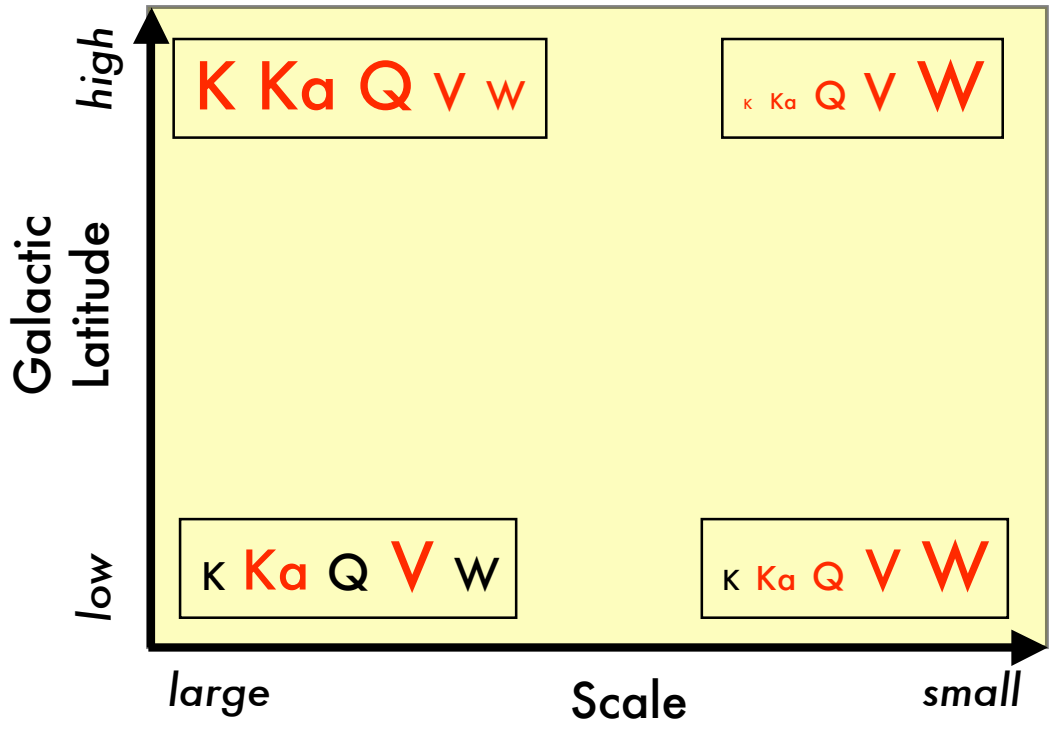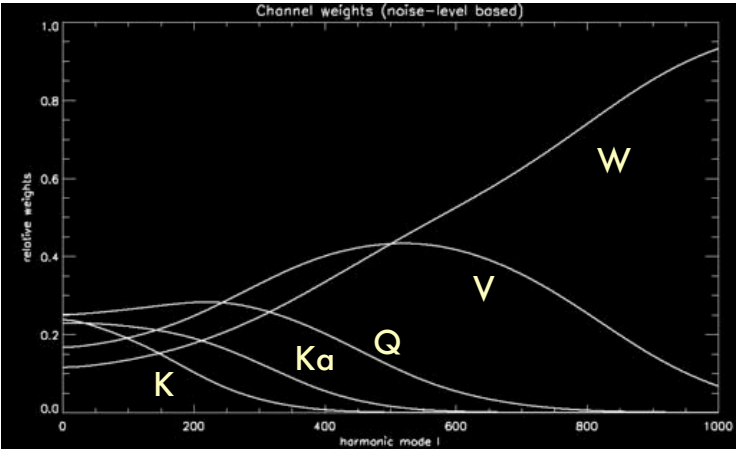of the observations

# How to "weigh" WMAP channels ?

If there were no foregrounds ⟶
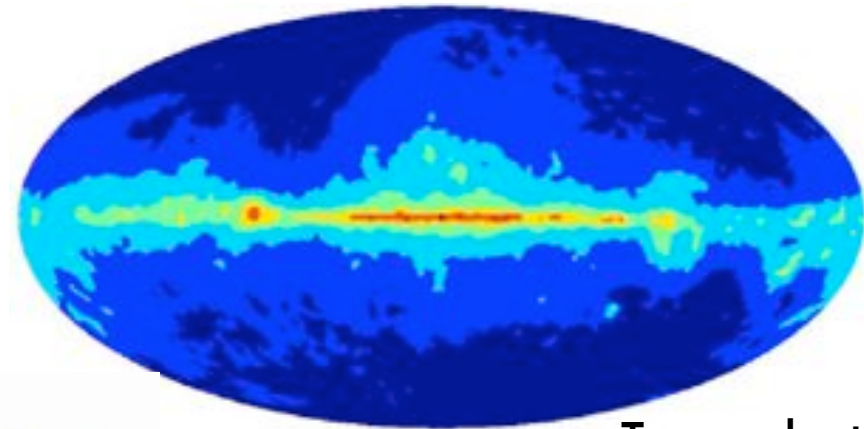
# How to "weigh" WMAP channels ?

If there were no foregrounds →



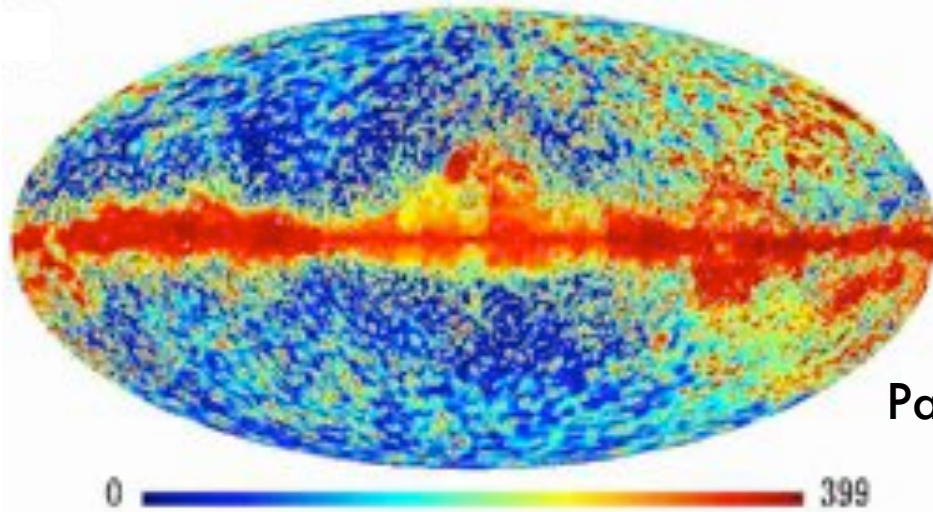Channel weights (noise-level based)

K Ka Q V W

# Localisation ?

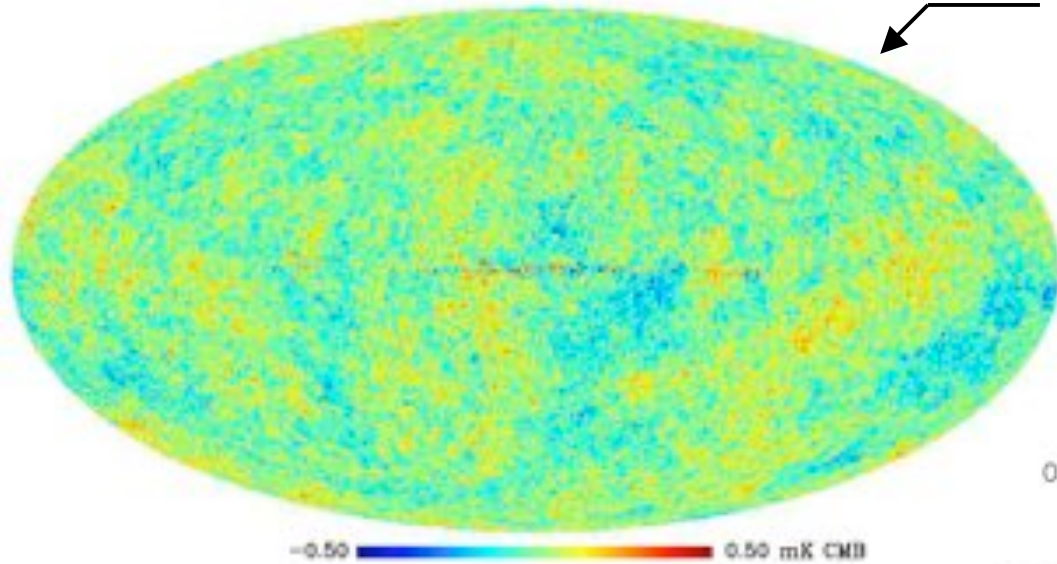WMAP: 11 zones

Tegmark et al.:
9 zones

Park et al.: 400 zones

0     399

# Method

- Basic idea: decompose maps on a set of functions which are localised in space and in scale : spherical needlets

- Spherical needlets form a tight frame (i.e. a redundant basis). One can decompose a map in needlets, work on the needlet coefficients, and then reconstruct a map (here ILC on needlet coefficients)

- Additional tricks in our analysis
  - Special handling of point sources and compact sources
  - Use of 100 micron map (IRIS - *Miville-Deschênes & Lagache*)
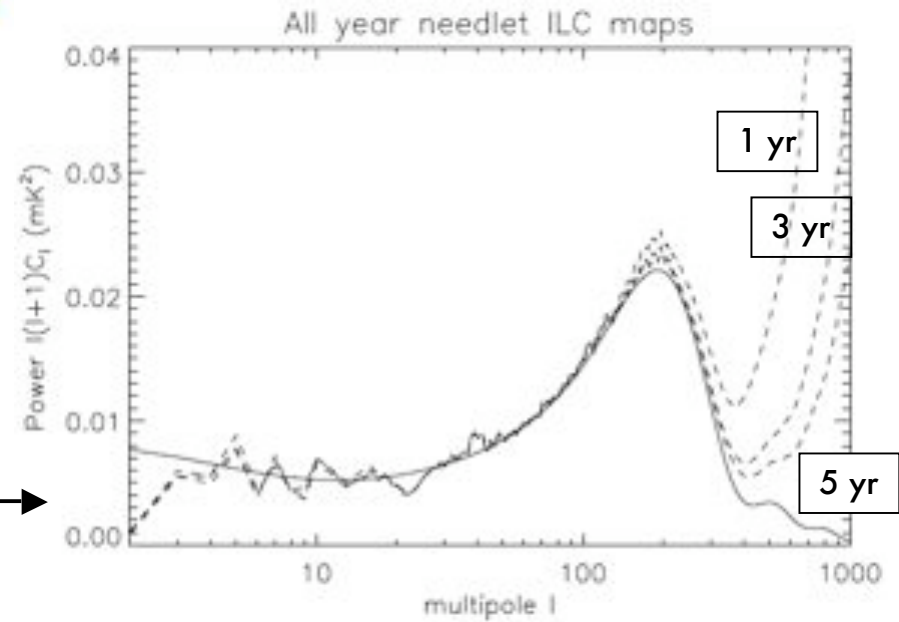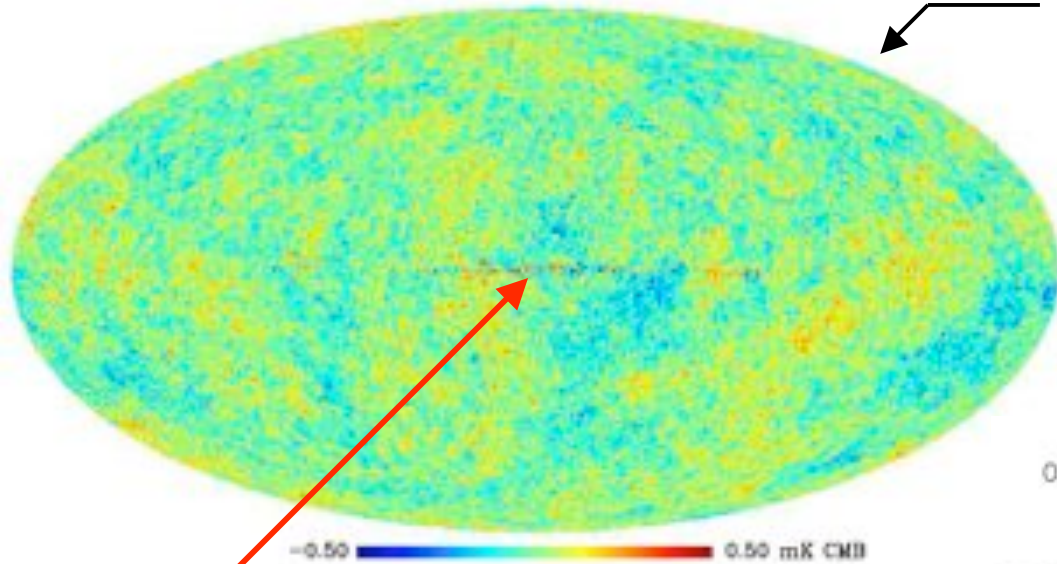
# Result

5 year needlet ILC map

Map synthetised from the
filtered needlet coefficients

−0.50 ▬▬▬▬ 0.50 mK CMB

All sky power spectrum →

All year needlet ILC maps

1 yr

3 yr

5 yr

Power $l(l+1)C_l$ (mK²)

multipole l

# Result

5 year needlet ILC map

Map synthetised from the
filtered needlet coefficients

−0.50 ▮▮▮ 0.50 mK CMB

This is not (not only) a residual
of galactic emission …

All sky power spectrum

All year needlet ILC maps

1 yr

3 yr

5 yr

Power $l(l+1)C_l$ $(mK^2)$

multipole l
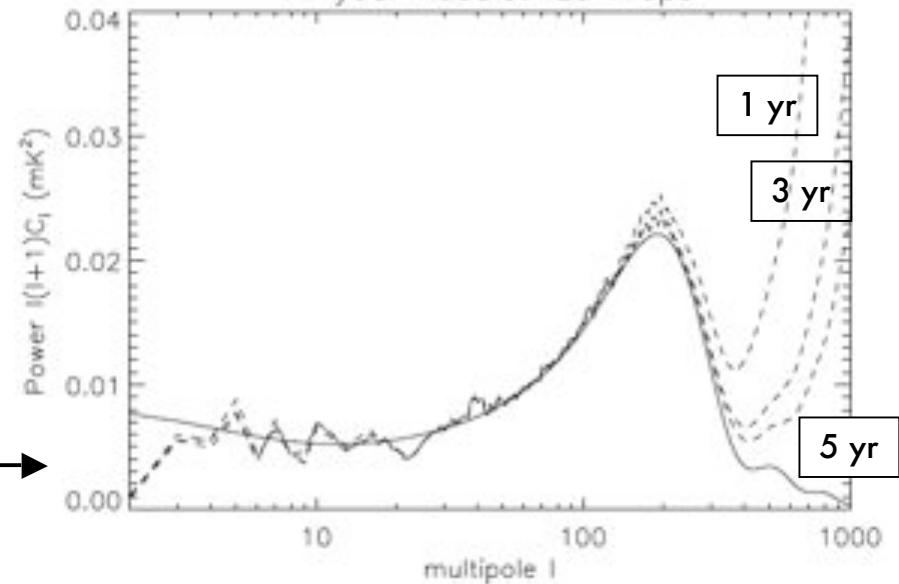
# Comparison with other maps
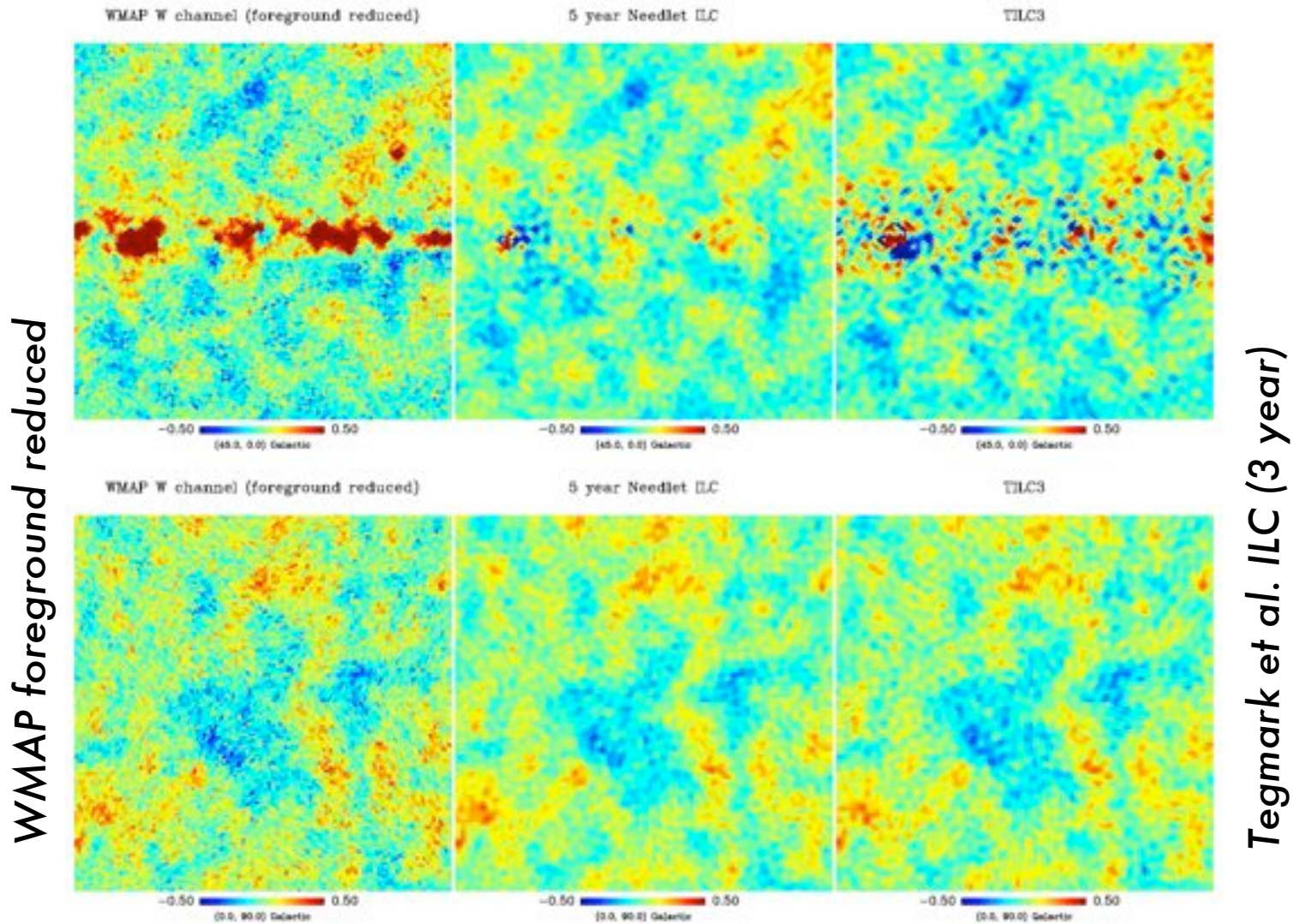
# Quantitatively…
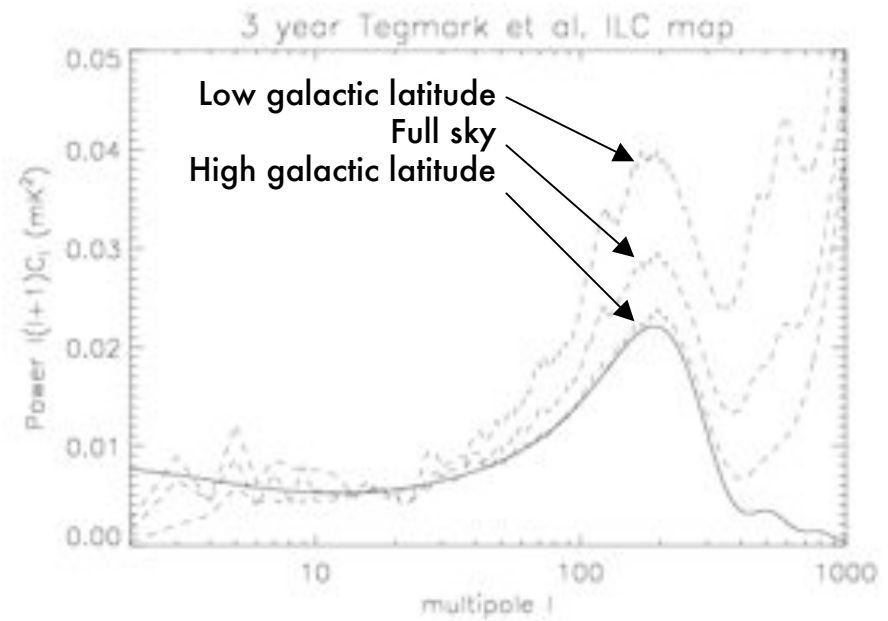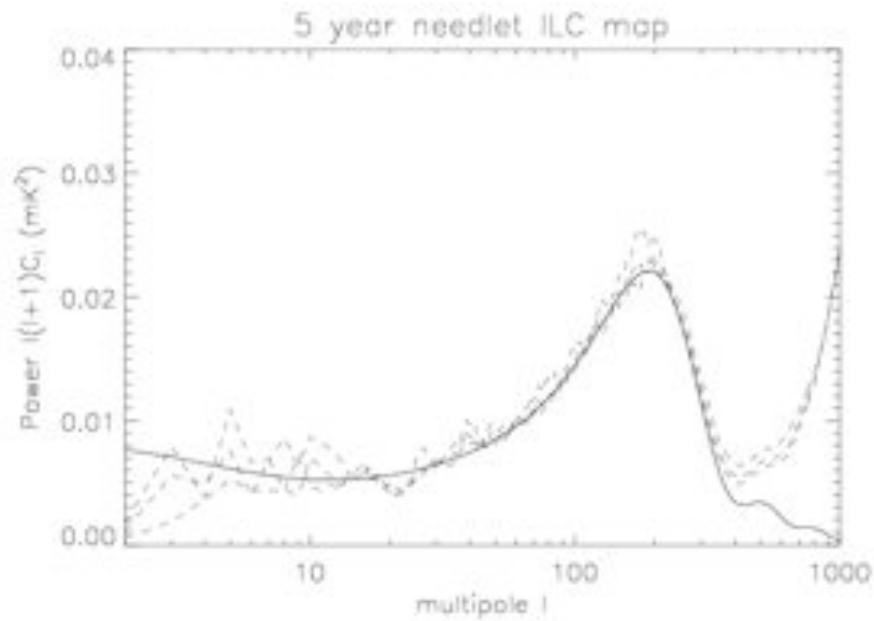


Other maps are significantly more noisy (at least on small scales)

# Uses of the Needlet ILC

- (Non Gaussianity : see C. Räth's talk)

- Looking for ISW : influence of the evolution of potential wells on CMB photons traversing (blueshift for decaying potential wells).

- Assume we have an independent tracer of LSS. Correlation of CMB with the tracer permits to check for the effect.

- Radio sources are a good tracer of LSS: many sources, good sky coverage.

- Massardi et al. use NVSS sources with flux > 10 mJy + the NILC map. They claim significance an order of magnitude better than in previous analyses. (2.6 10⁻⁴)
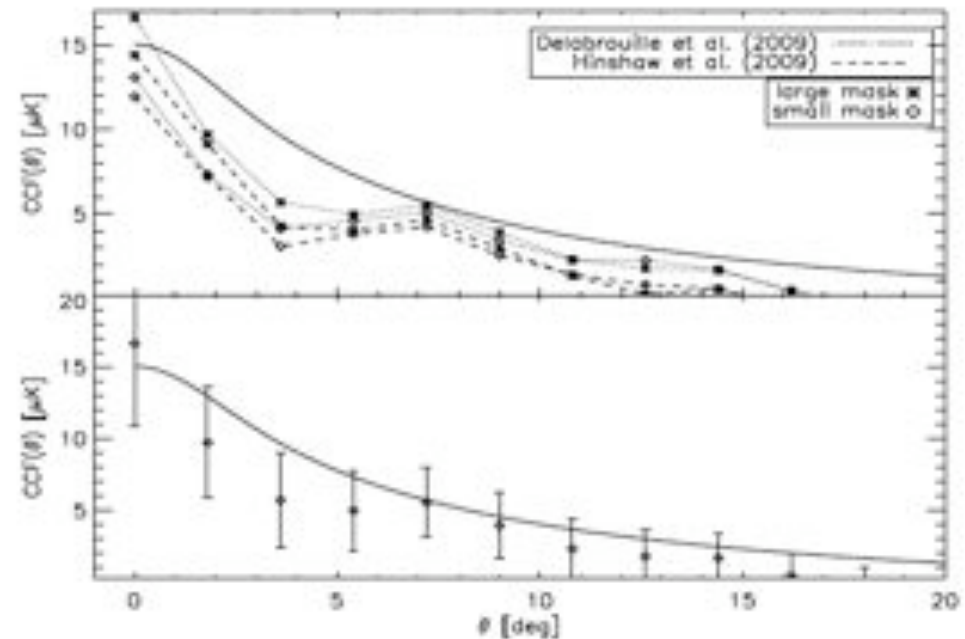


WMAP-NVSS cross-correlation

*Massardi et al. arXiv:1001.1069*

# Our objectives

A clean CMB map
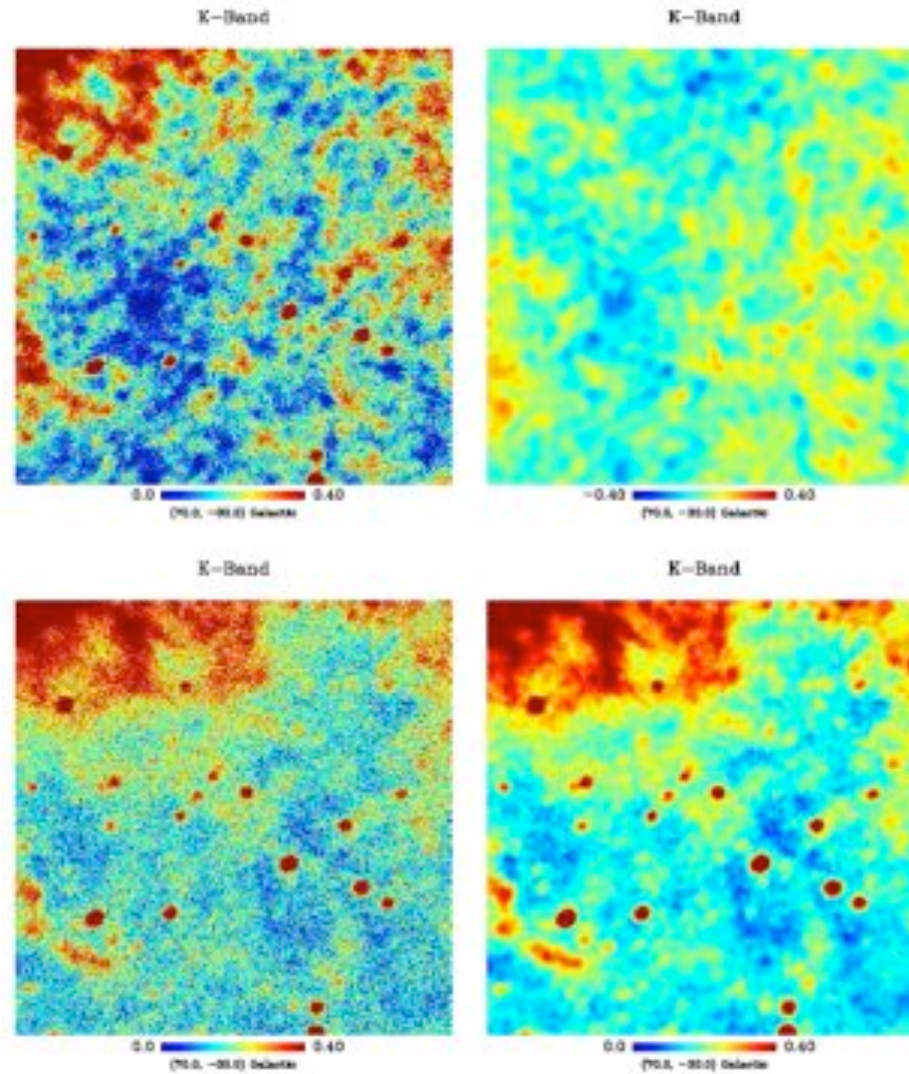
A clean foreground map

Sunyaev Zel'dovich emission in WMAP data

# Subtracting the CMB

- We have a low foreground CMB map
  - Error dominated by noise, not by foregrounds
  - Less noise than in individual channel maps

- This suggests that to get foreground maps, one merely has to subtract the CMB

- However, at small scales, the 'clean' CMB map has still S/N<1: we have to be careful not to add more noise than we subtract CMB

- In each channel, subtract a minimum variance estimate of the CMB at that channel's resolution. Filter out residual noise using a latitude-dependent approximation of a Wiener filter.

*Tuhin Ghosh, JD et al. in preparation*

# Maps...

# Full sky foreground maps

Full sky foreground maps at all WMAP frequencies

# Our objectives

A clean CMB map

A clean foreground map

Sunyaev Zel'dovich emission in WMAP data

# WMAP as an SZ observatory

- WMAP is not a good instrument for detecting SZ
  - Poor resolution (13' to 60')
  - Poor discrimination between thermal SZ and CMB

- Blind detection very hard… (we tried…)

- But it is full sky…

- Look for the signal of ROSAT clusters using a multifrequency matched filter: we look for objects of known emission law and known shape in maps containing correlated contaminants.

  *Melin et al. A&A (2006) 459, p. 351*

- No individual detection, but we can stack…
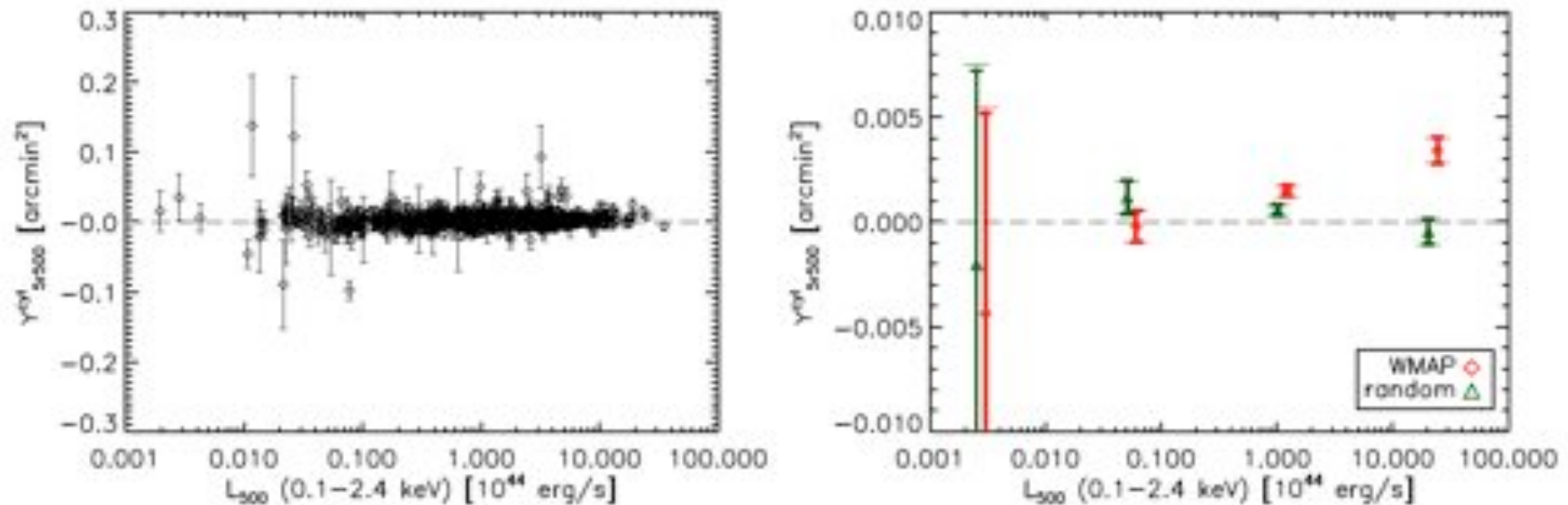
# SZ from 893 NORAS+REFLEX clusters



**Fig. 2.** *Left:* Estimated SZ flux from a cylinder of aperture $5 \times r_{500}$ ($Y^{cyl}_{5 \times 500}$) as a function of the X-ray luminosity in an aperture of $r_{500}$ ($L_{500}$), for the 893 NORAS/REFLEX clusters. The individual clusters are barely detected. The bars give the total 1 $\sigma$ error. *Right:* Red diamonds are the weighted average signal in 4 logarithmically–spaced luminosity bins. The two high luminosity bins exhibit significant SZ cluster flux. Note that we have divided the vertical scale by 30 between Fig. left and right. The thick and thin bars give the 1 $\sigma$ statistical and total errors, respectively. Green triangles (shifted up by 20% with respect to diamonds for clarity) show the result of the same analysis when the fluxes of the clusters are estimated at random positions instead of true cluster positions.

*Melin et al. (2010) submitted to A&A (arXiv/1001.0871)*
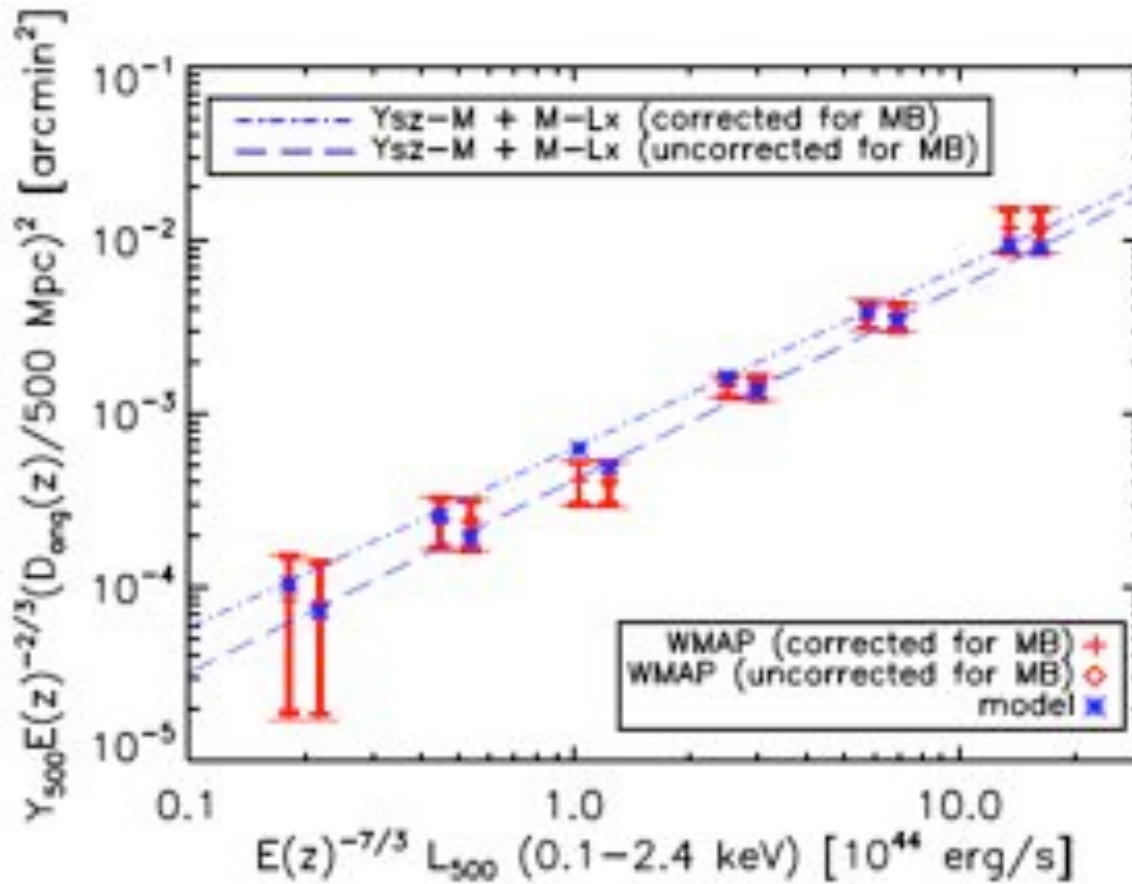
# Measurements vs. model
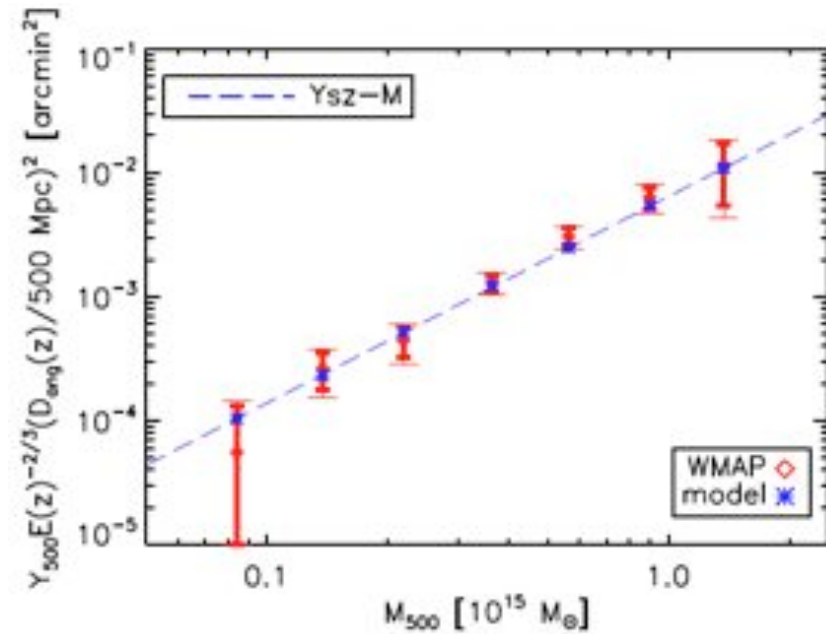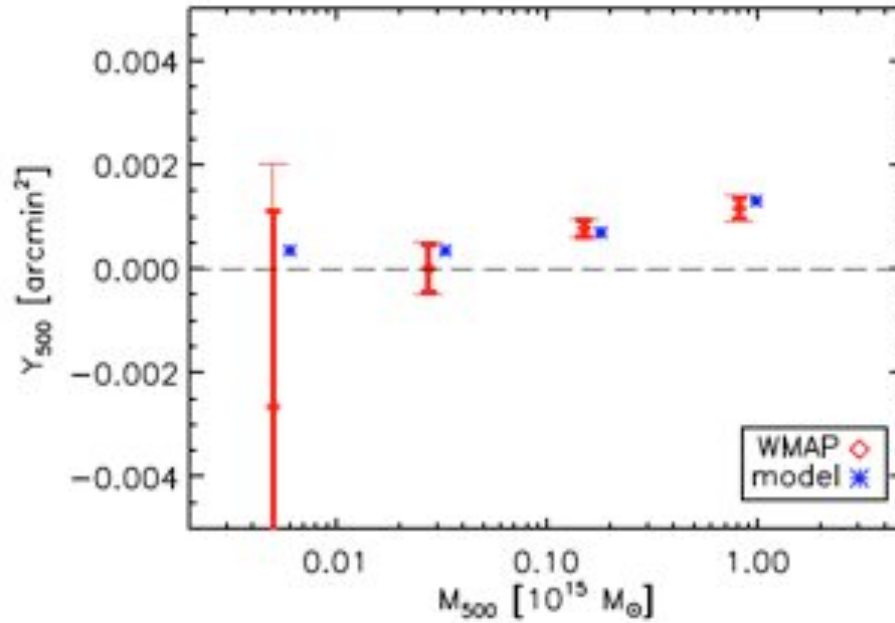


| Model: | $L_x \rightarrow M_{500}$ | from | *Pratt et al. (2009)* |
|--------|---------------------------|------|------------------------|
|        | $M_{500} \rightarrow Y_{500}$ | from | *Arnaud et al. (2009)* |

# $Y_{SZ}$ - $L_X$



**See monday talks by G. Pratt and E. Pointecouteau**

# Conclusion

- Component separation is an important step for the optimised exploitation of CMB observations

- There is no single component separation method which get you all the components. Instead, one has to design methods adapted to the components of interest and the scientific objectives.

- A component separation pipeline should chain several analyses and put them all in a coherent frame.

- This is becoming crucial for upcoming sensitive experiments, for which instrumental noise becomes sub-dominant, and scientific objectives ever more ambitious.
  - Planck : *Leach et al. 2008*
  - Future polarisation experiments : *Betoule et al. 2009*