Component Separation Methods in Planck

Developments, comparison and validation

Jacques Delabrouille

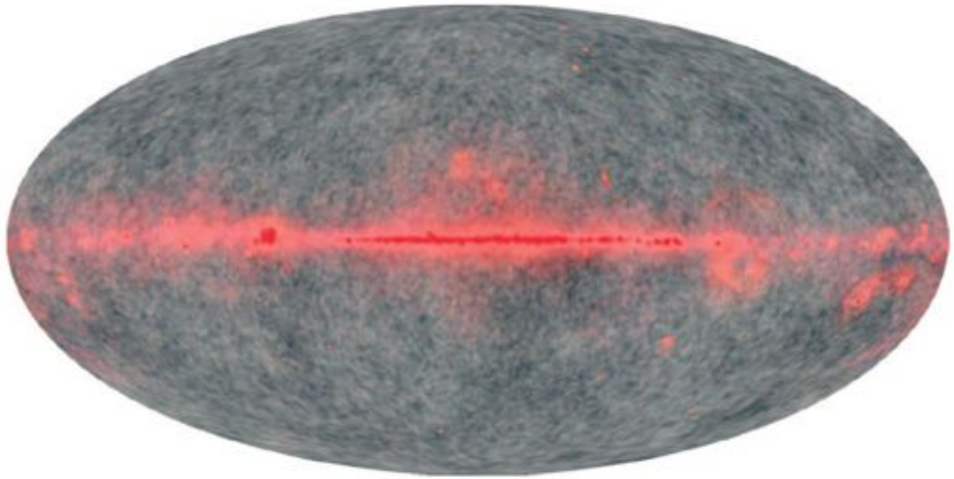
Laboratoire APC, Paris

On behalf of Planck WG2

CMB contamination by foregrounds

- Has always been an issue, since early measurements of CMB anisotropies!

Multi frequency observations allow us to check that observed anisotropies have the correct emission law



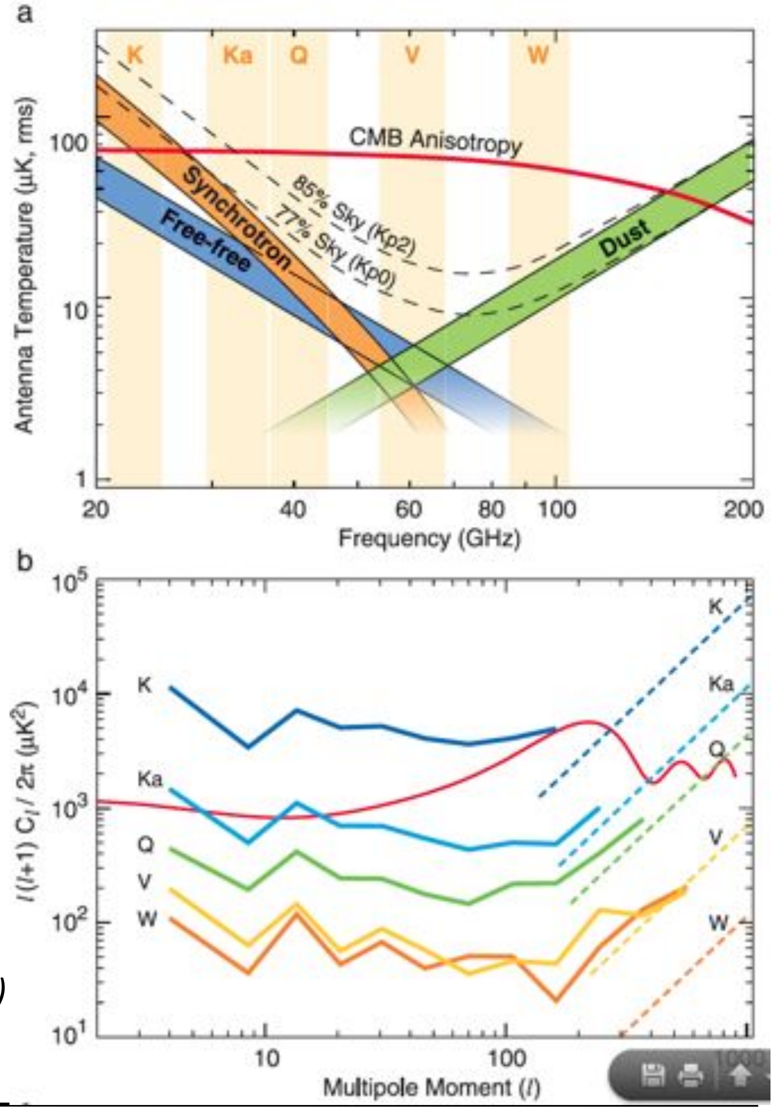
Bennett et al., ApJSS Volume 148, Issue 1, pp.97-117 (2003)

The ultimate frontier

- Astrophysical confusion is the ultimate frontier when instrumental noise becomes vanishingly small…

- Foreground level with WMAP kp2 mask as compared to CMB temperature anisotropies

Bennett et al., ApJSS Volume 148, Issue 1, pp.97-117 (2003)



The Planck working group 2

- Working group for
  - Development, comparison and validation of component separation methods
  - Collection of external data sets for component separation
  - Sky simulation and modelling (development of the Planck Sky Model)

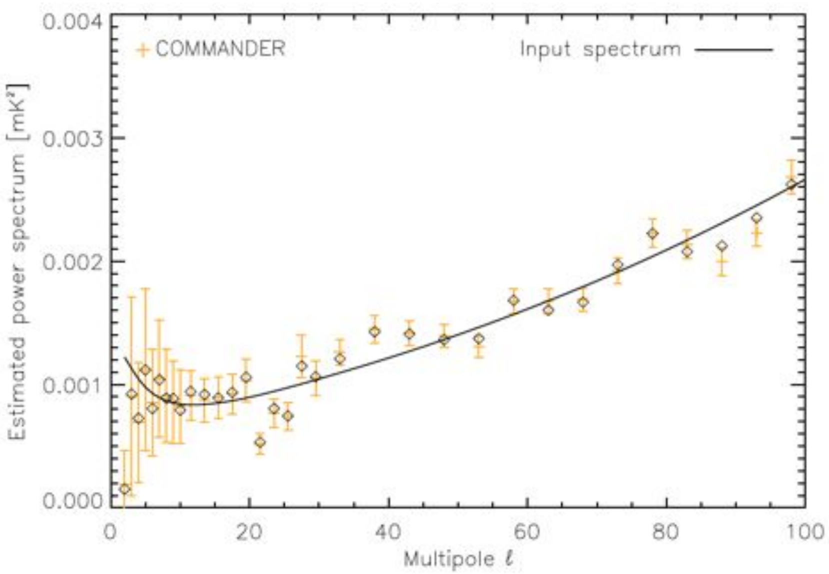
- Organisation of WG2 activities (coord. De Zotti and Delabrouille)
  - Regular meetings to discuss methods and exchange ideas
  - Organisation of data challenges to compare method performance
  - Recommendations given to DPCs for implementing component separation in the DPC pipeline
  - Expertise passed-on to science working groups and projects if needed

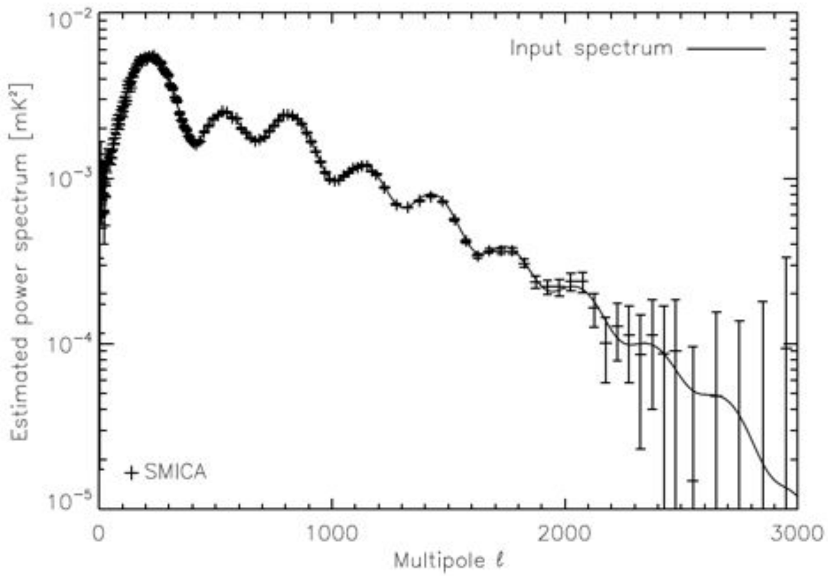
Component separation challenges

- Temperature challenge
  - Objectives: CMB power spectrum and maps
  - Catalogues of point sources and galaxy clusters
  - Maps of diffuse galactic emission
  - Paper by Leach et al. A&A Volume 491, Issue 2, pp 597-615 (2008)
- Polarisation challenge
  - Technically, most methods which work for T can also work for E or B
  - Main uncertainty: the polarised sky model (not representative enough)
  - Next step: improve simulations
    - The polarised Planck Sky Model (using Planck data themselves)!
    - The measurement by the instrument
- SZ challenge
  - organised jointly with WG on secondary anisotropies (WG5)
  - Paper by Melin et al. submitted to A&A

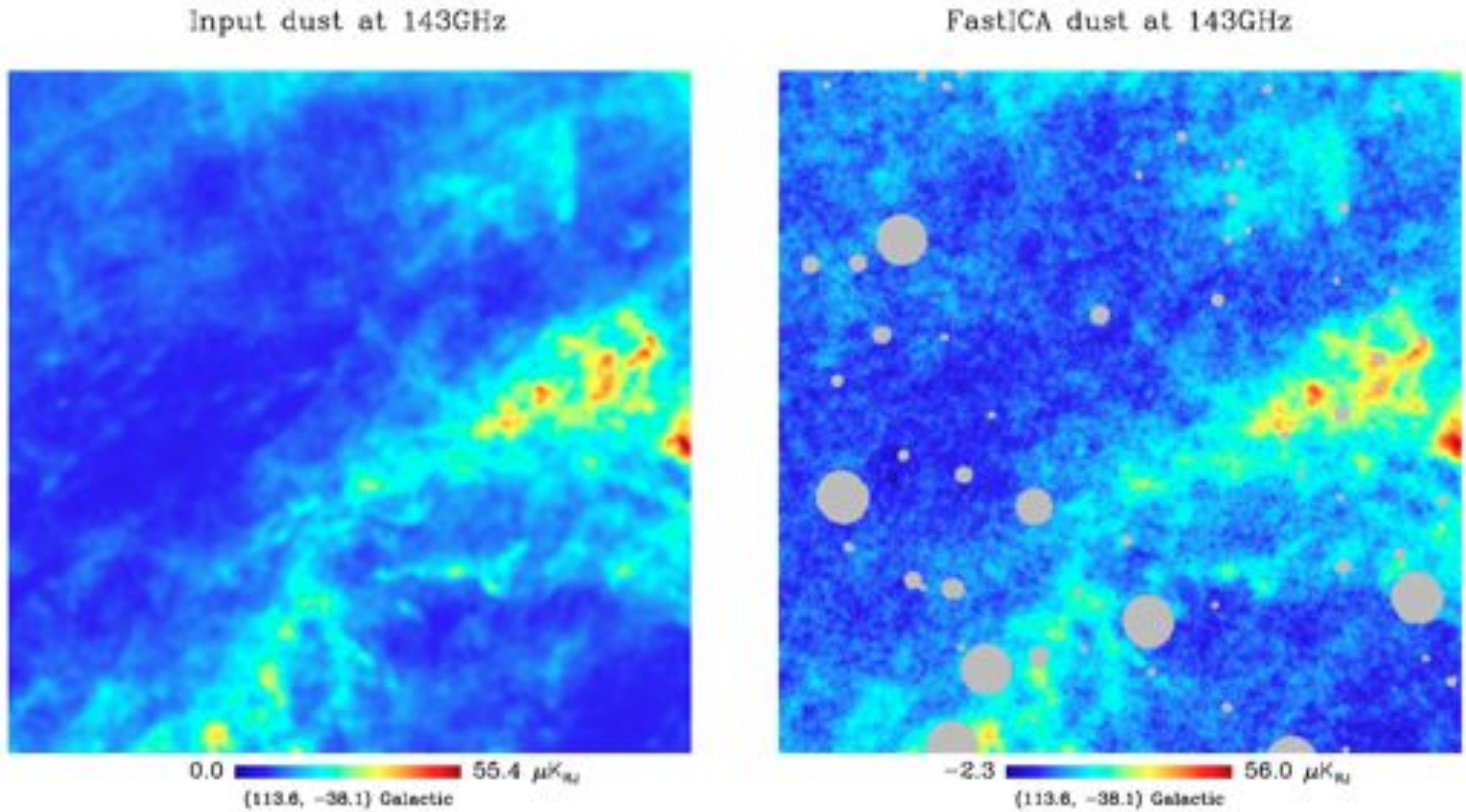
Temperature challenge

- 8 different methods tested and compared (+ one late)
- No single method performs best for all purposes!
- Differences can be fundamental, or due to implementation details
- All methods have been improved during the challenge

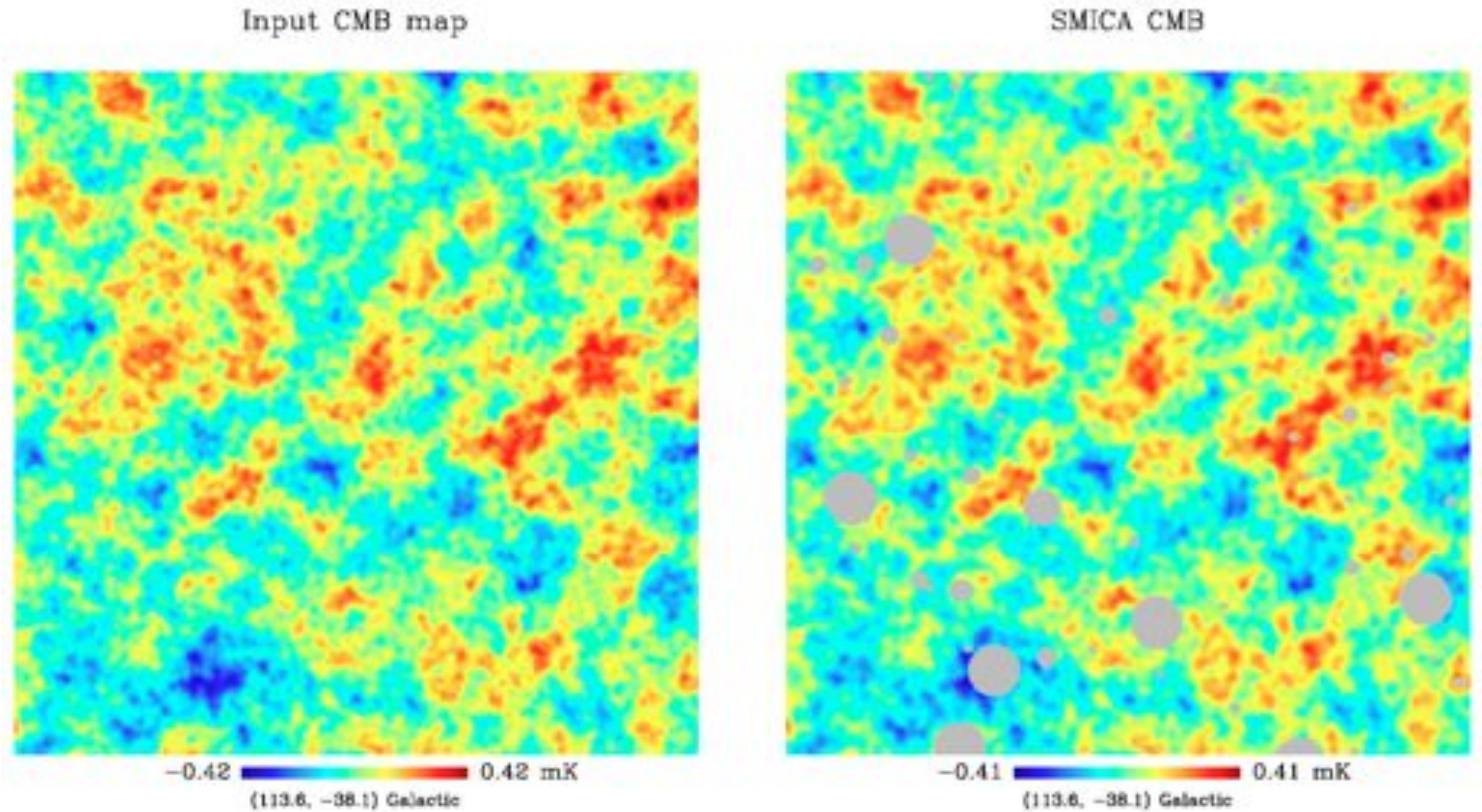




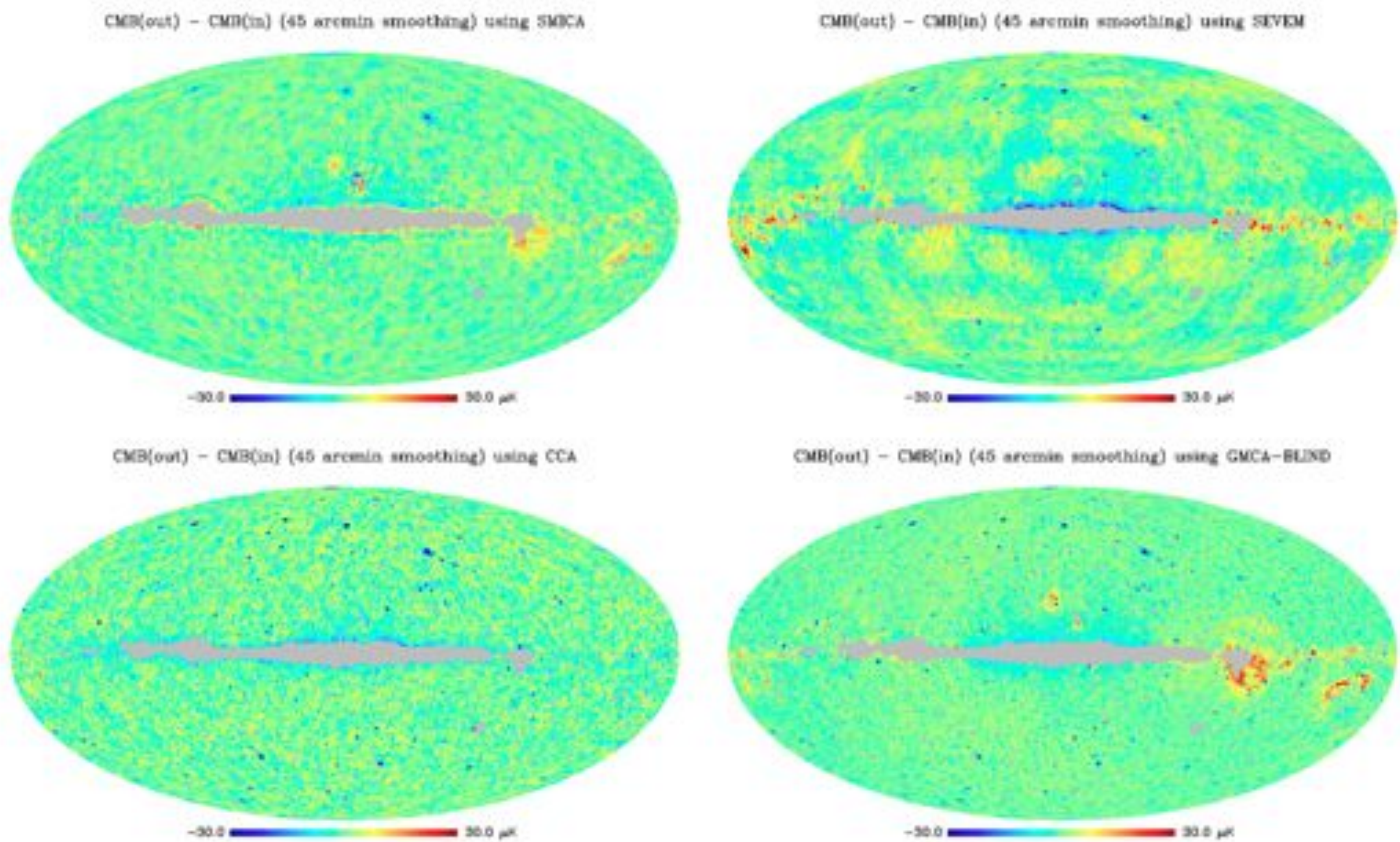
Reconstructed dust map



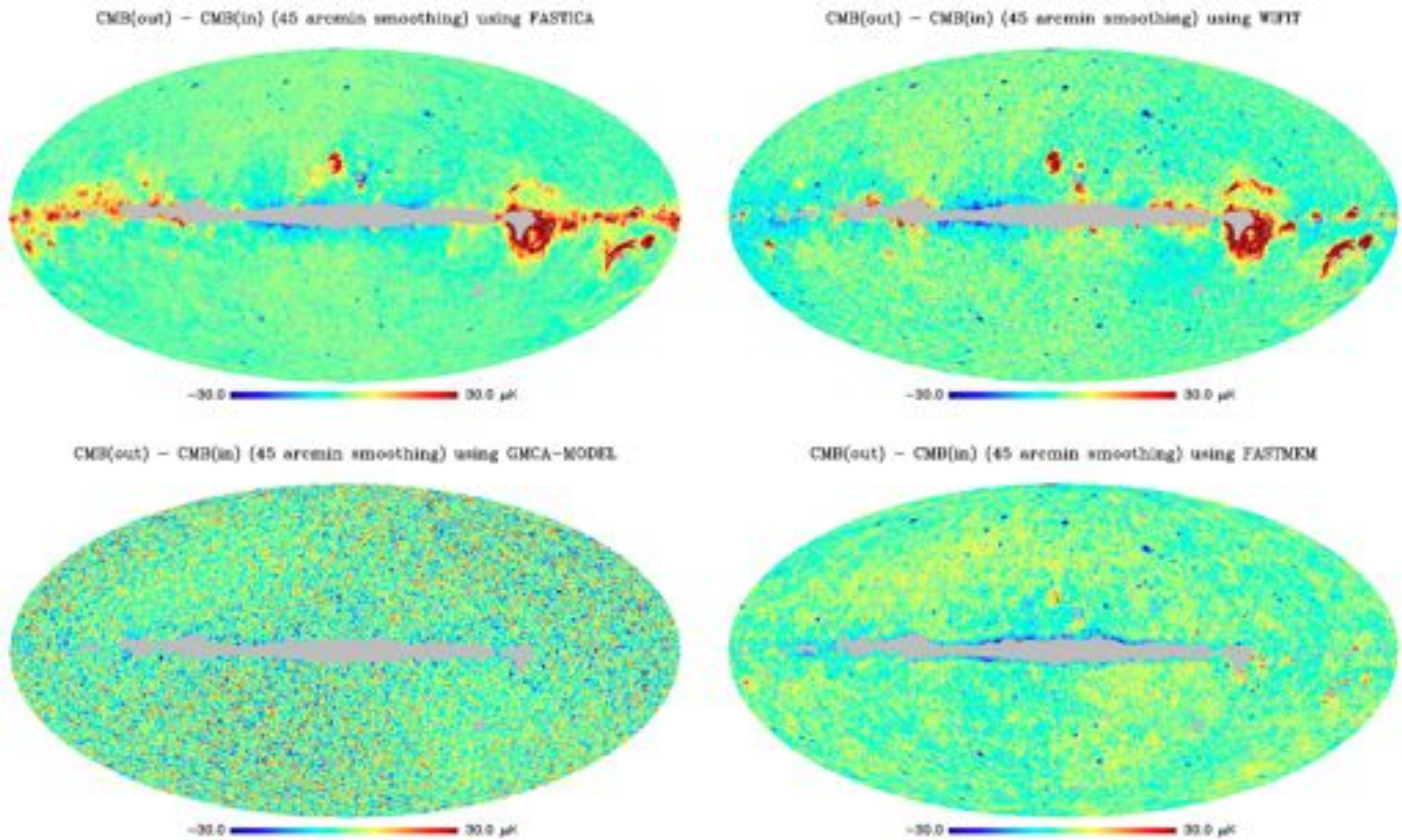
Reconstructed CMB map



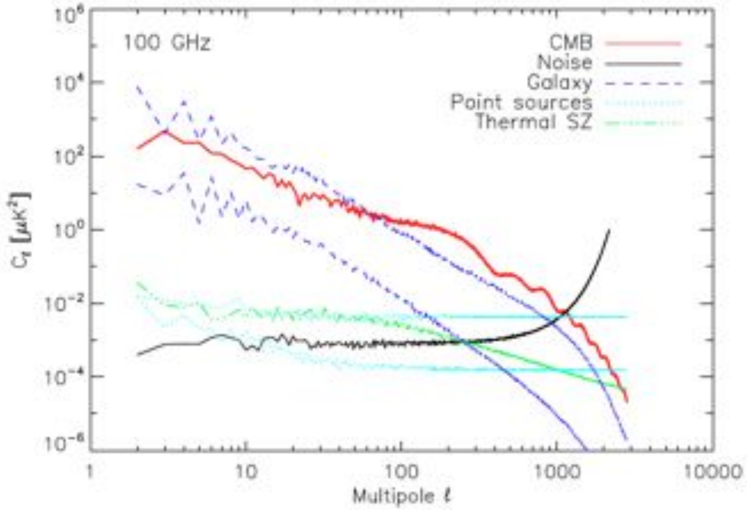
CMB reconstruction error maps

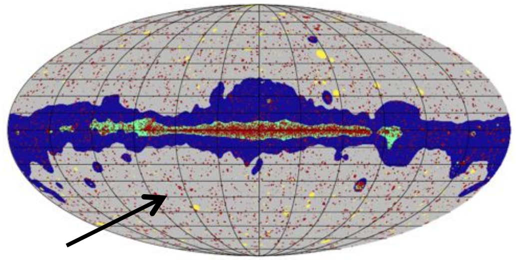


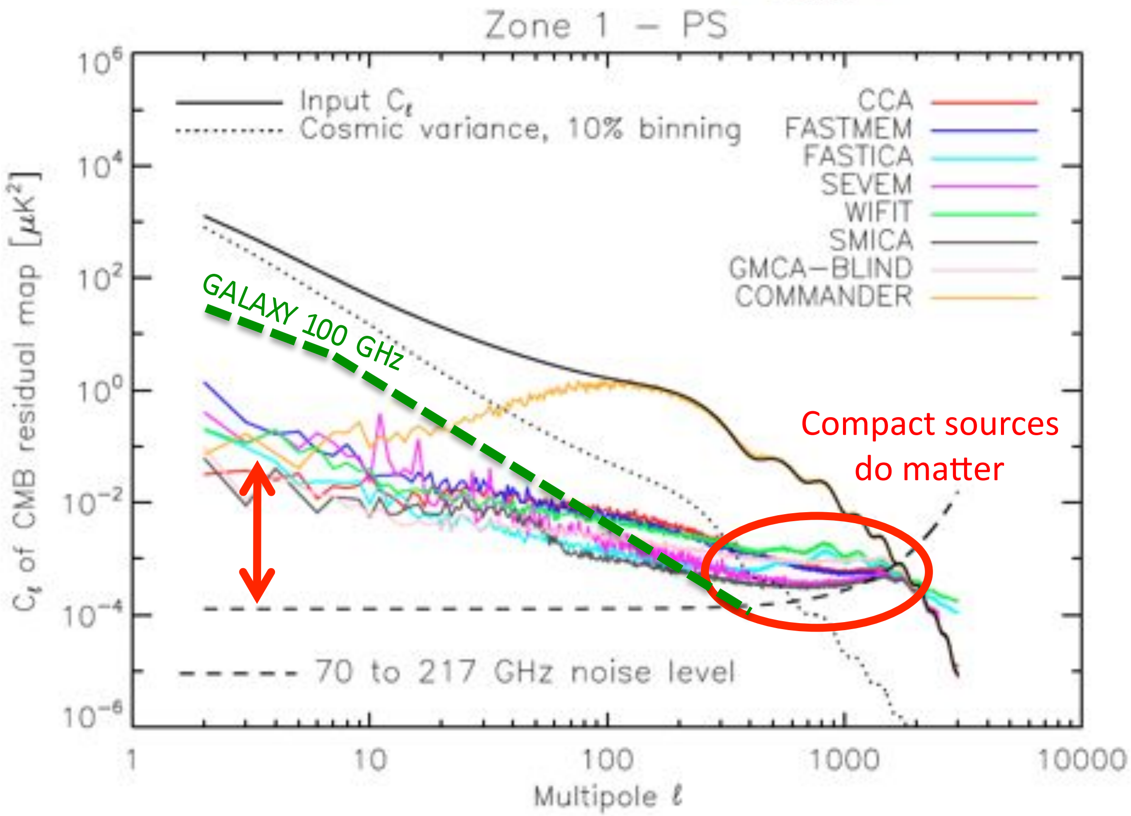
CMB reconstruction error maps



Foreground residuals







Large scale residuals two orders of magnitude above noise

Small scale residuals above noise and cosmic variance

Why do not we get better results?

- Methods are sub-optimal ?
  - Methods performances differ,
  - They certainly can still be optimized
  - but there seems to be a fundamental limit (above the noise level)

- Simulations are pessimistic ?
  - 5 dust templates (two amplitudes, two temperatures, one spinning)
  - 1 free-free template
  - 2 synchrotron templates
  - 2 templates for CMB and SZ
  - Point sources (too many of them) ?
  - Total = 10 templates + point sources (more than Planck channels)

- Does the same limitation hold for polarisation ?
  - Critical for measuring low ell B-modes

Polarisation results for COrE (PSM v1.7)

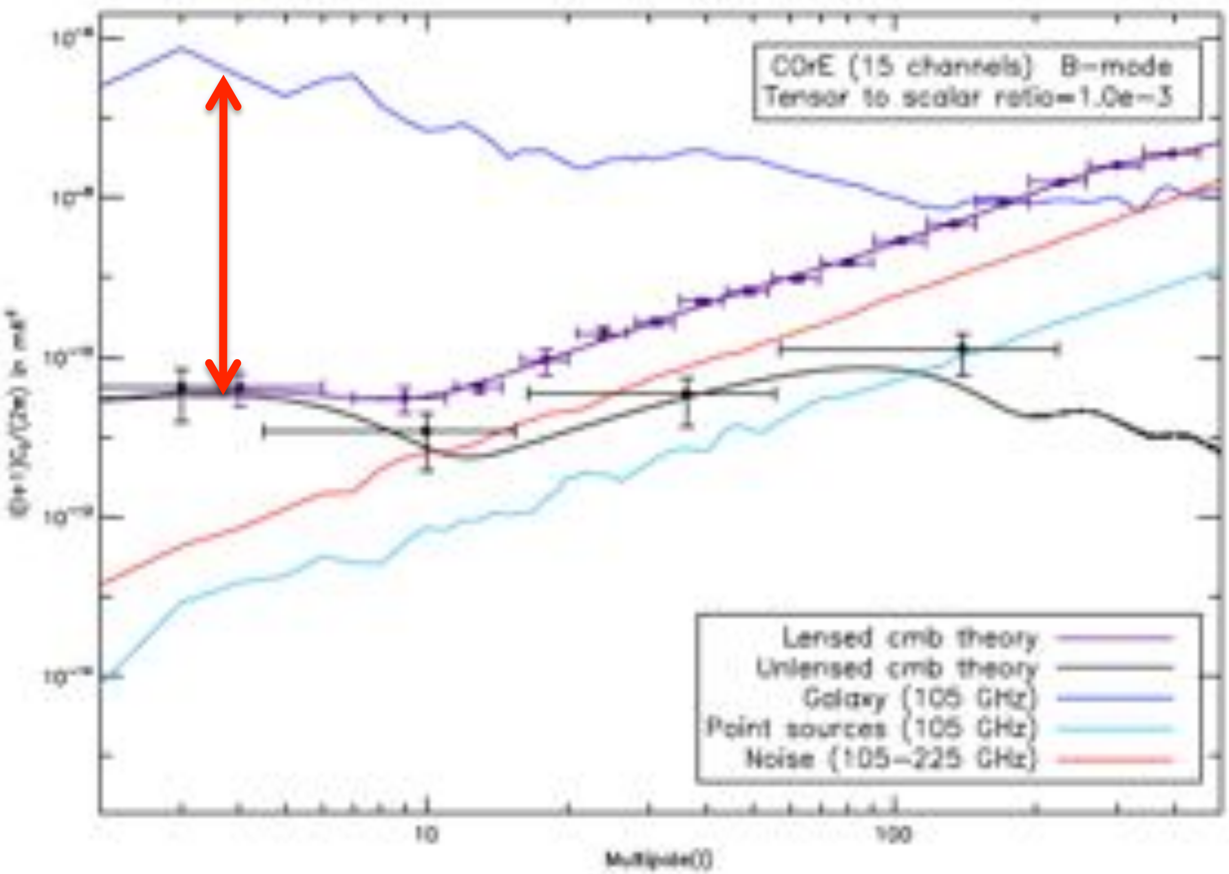
Foregrounds rejected by 4 orders of magnitude !? Why ??

Better method ?

Virtually noiseless data sets ?

Polarisation component separation is easier ?

Importance of number of channels !



See Poster by Basak & Delabrouille for details
Performance similar to Betoule et al. 2009 using SMICA

Linear filters

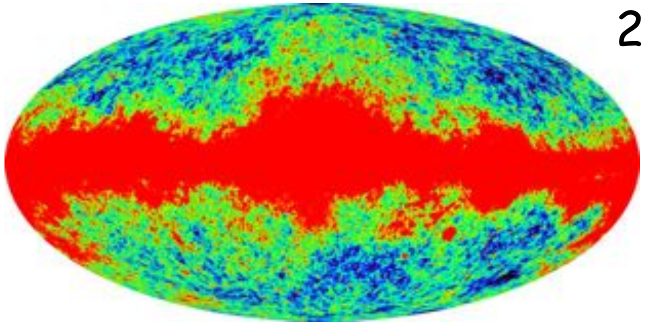
- More than half of the methods evaluated implement CMB separation using linear filters, i.e.

$$CMB = \Sigma\ w_i\ data_i$$

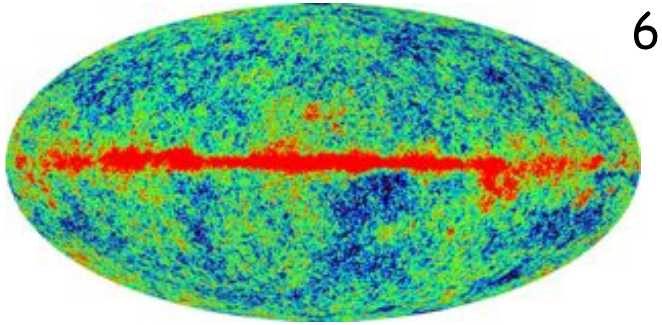
- The weights are determined in a way which depends on the method, and can vary in different regions of the data samples (sky regions, domains of (l,m), wavelet domains…)

- Linear filters allow computing the level of contribution of all input components and noise into the reconstructed CMB – convenient for assessing performances and propagating errors

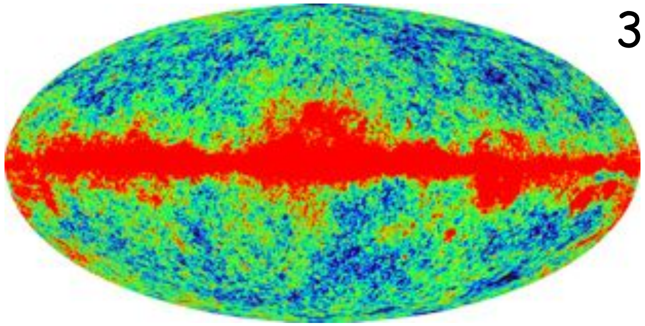
The needlet ILC on real data



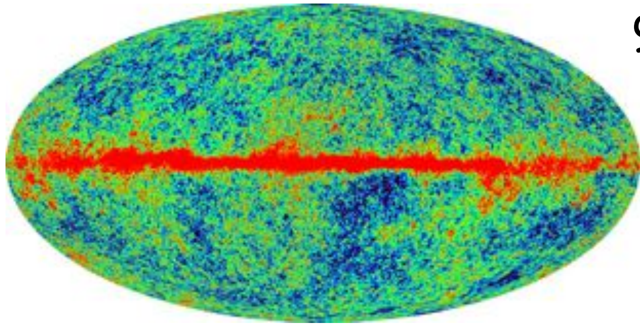
20 GHz



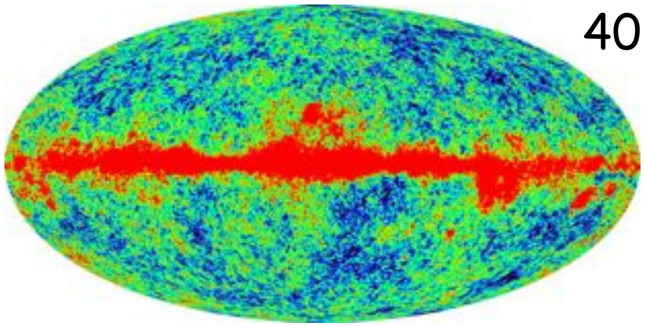
60 GHz



30 GHz



94 GHz



40 GHz

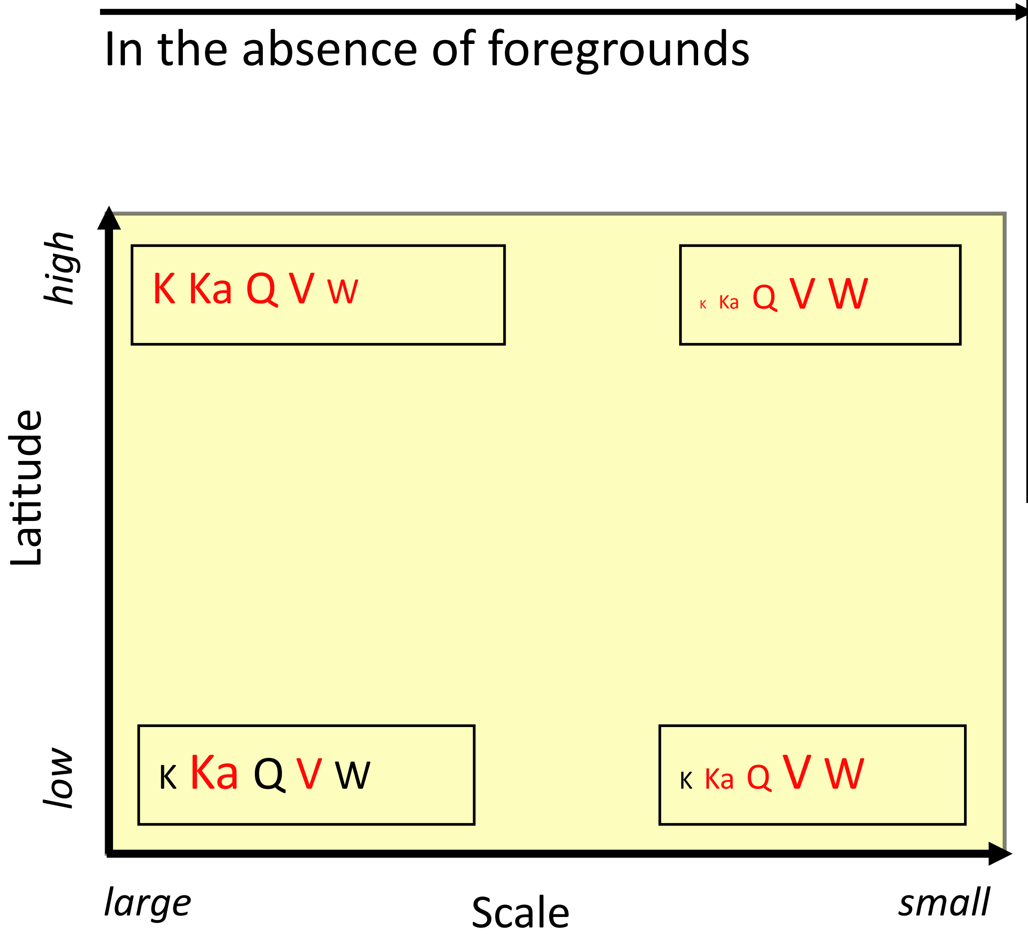
Observed maps are not stationary

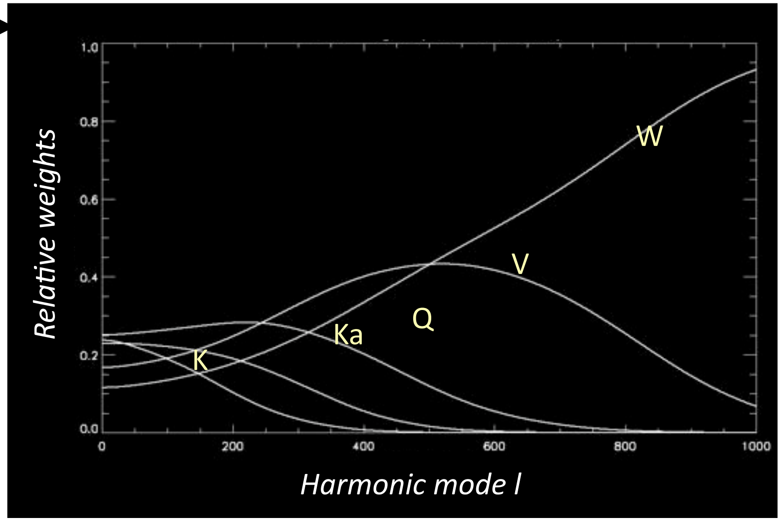
They are not all at the same resolution

The idea is to build sets of linear filters, which vary in space and scale

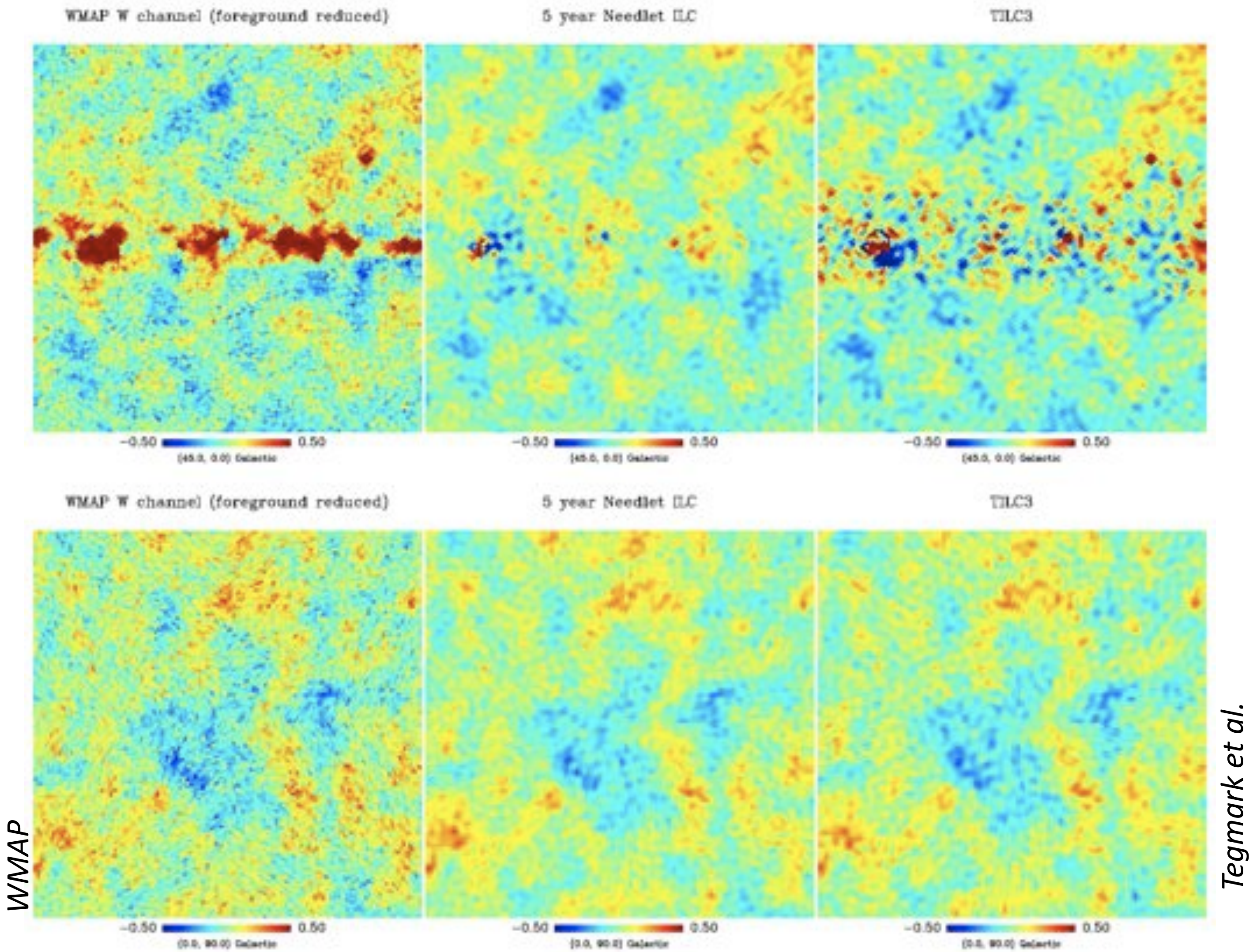
What linear combination ?

Delabrouille, Cardoso, Le Jeune et al. 2009, A&A, 493, 835





Result (and comparison with previous maps)



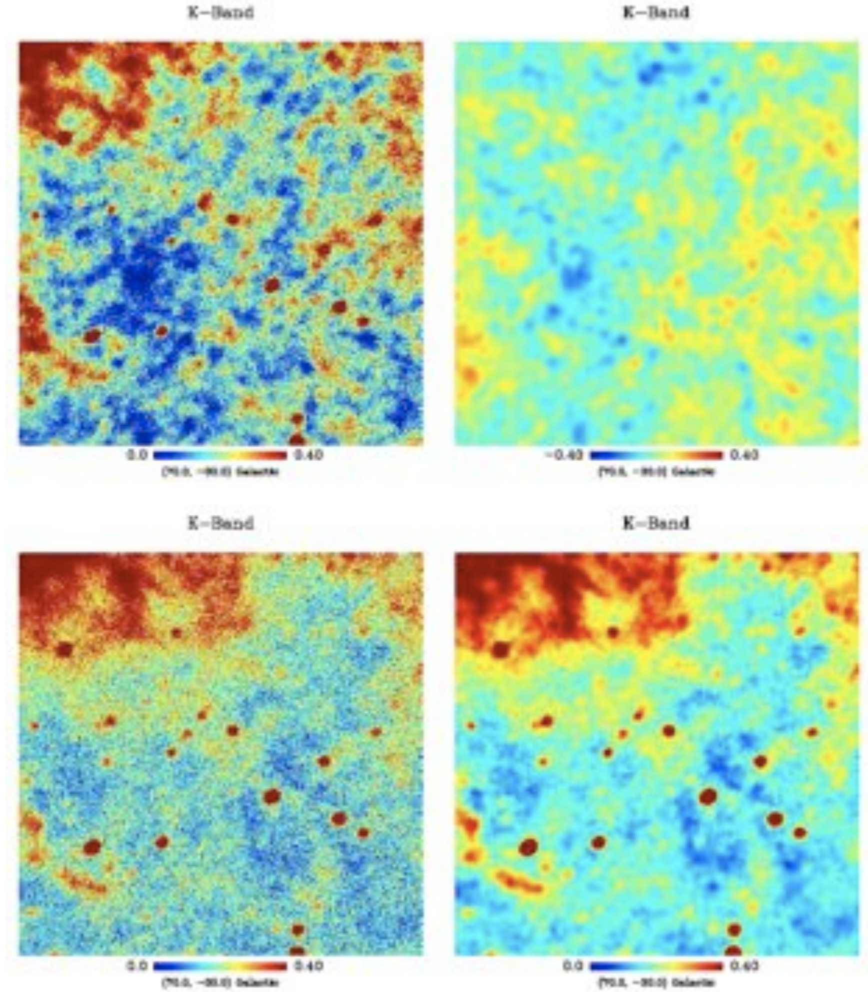
Galactic foregrounds

Ghosh, Delabrouille, Remazeilles et al., 2010

Original maps

CMB from needlet ILC (Wiener Filtered)

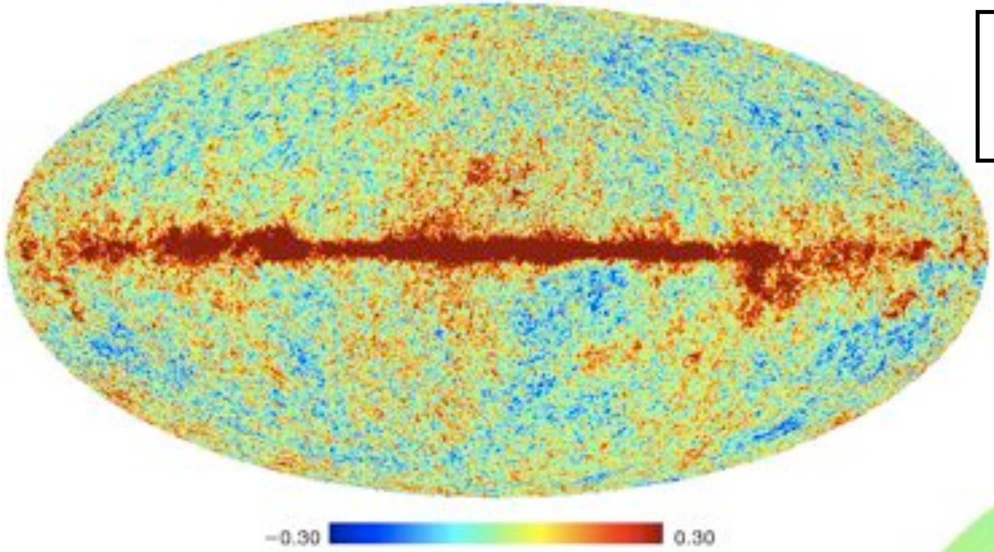
CMB subtraction



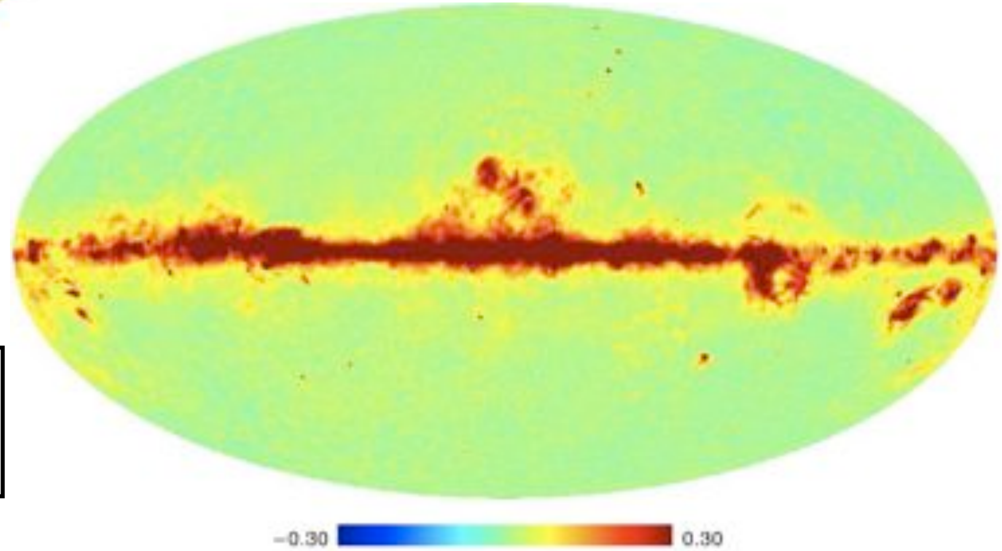
Map without CMB

After localised filtering

Units in mK



V band (61 GHz)
Original map



V band (61 GHz)
Processed map

The CMB subtraction implemented by the DPCs for preparing the data used in the Planck early papers is very similar to this (except for the final localized filtering)
Details in C. Baccigalupi and Mark Ashdown's talks

See also Mathieu Remazeilles's talk and Maude Le Jeune's poster for refinements

But …

- This method is not universal.
- It is not adapted, in particular, for studying faint or very local foregrounds (as mentioned in the Ghosh et al. paper).
- The ILC minimizes the total contamination by foregrounds and noise in the reconstructed CMB, but does not guarantee anything about the rejection of a particular foreground.
- The needlet ILC, for instance, is not adapted for the CIB paper (see G. Lagache's presentation). The linear mixture of all channels which minimizes the variance of the CMB map would contain a mixture of the CIB in all Planck channels !

In summary for the future

- There is no universal "component separation". The method used must be tuned to the problem being addressed. Comparing methods is important, and understanding them even more so!

- Increase number of channels for future experiments
  - COBE-DMR had 3 channels
  - WMAP had 5
  - Planck has 9
  - Better accuracy requires more channels

- Proposed ESA COrE polarization mission
  - 15 channels from 45 to 795 GHz

- Further investigation requires improving the sky model as much as possible !