Foreground cleaning in CMB experiments

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Outline

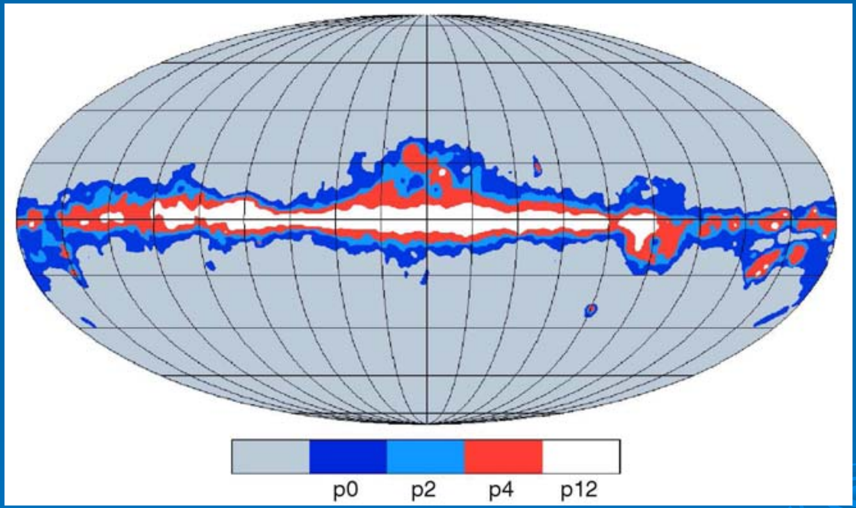
- CMB vs. diffuse foregrounds in total intensity and polarization
- Four concepts for foreground cleaning
- The medal and the back of the medal, beginning 2008
- Conclusion, beginning 2008

Diffuse foregrounds and CMB

- Together with instrumental systematics, foregrounds are the ultimate limitation of CMB observations
- Unlike CMB, the foreground knowledge is mainly empirical, we know the main physical processes activating them, but their emission is calibrated mainly through observations
- Unlike CMB, the Galactic emission is strongly inhomogeneous, concentrated on the Galactic plane
- Unlike CMB, the foregrounds do not possess a black body frequency spectrum
- Unlike CMB, the foregrounds do possess a space varying frequency dependence
- Unlike CMB, the diffuse foreground emission is markedly non-Gaussian

Masking the Galaxy: total intensity

- The sky emission is dominated by the Galaxy at all frequencies
- The contamination is always evaluated after removing its brightest part, together with the main known point sources
- In total intensity, the removal of the brightest part of the sky leaves the sky substantially dominated by the CMB at microwave frequencies
- The quantification of the contamination is usually done by means of the angular power spectrum of the masked sky



Bennett et al. 2006

Masking the Galaxy: polarization

- The sky emission is dominated by the Galaxy at all frequencies
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- In polarization, the removal of the brightest part of the sky leaves the sky substantially dominated by the CMB at microwave frequencies
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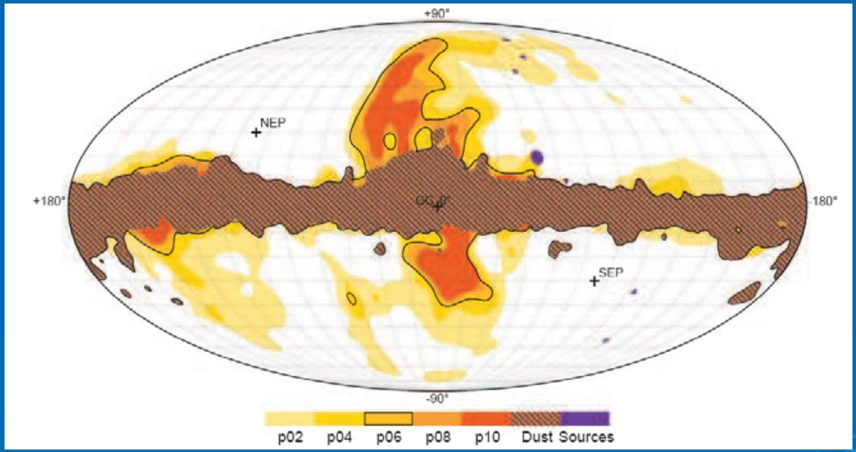

Page et al. 2006

Masking the Galaxy: polarization

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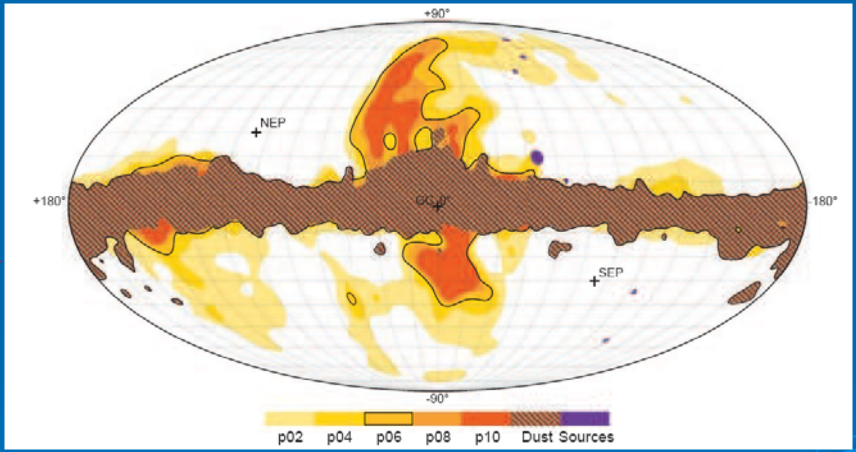
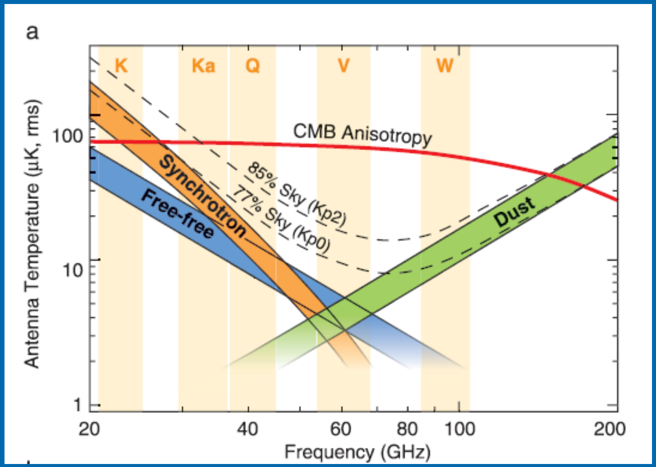
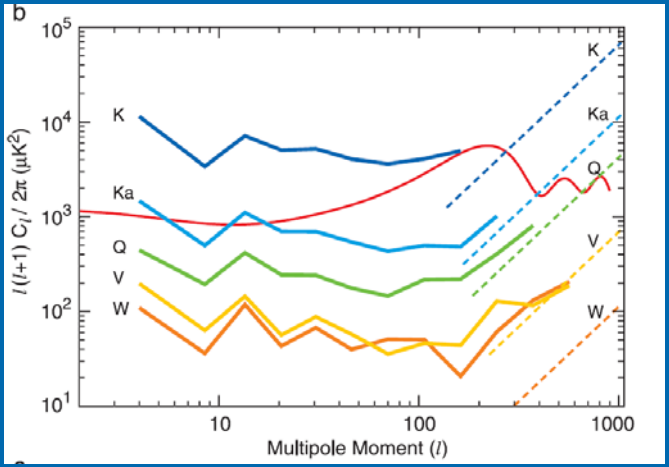
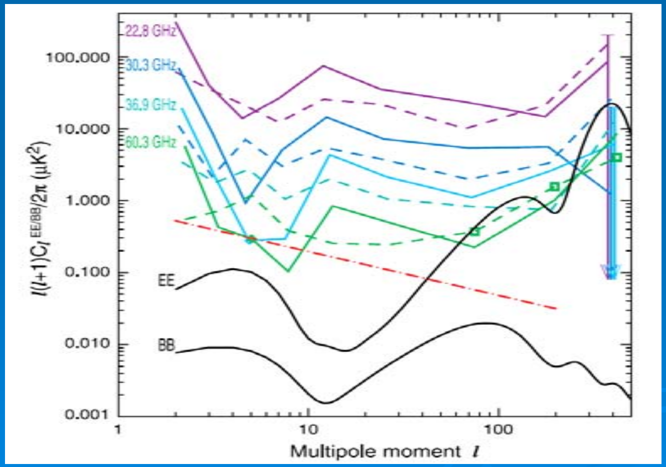


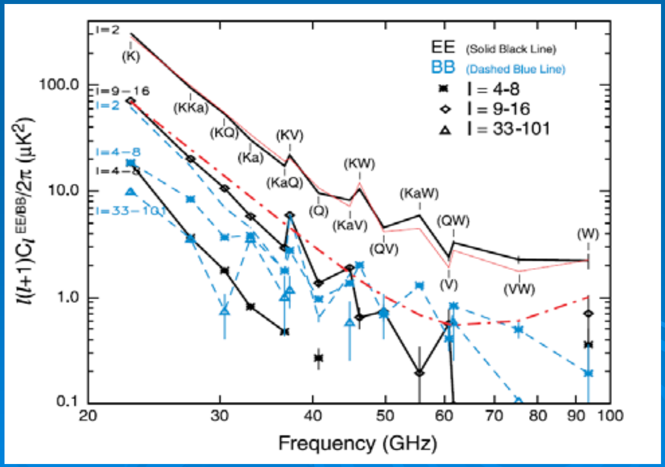
Page et al. 2006

Foreground fundamentals



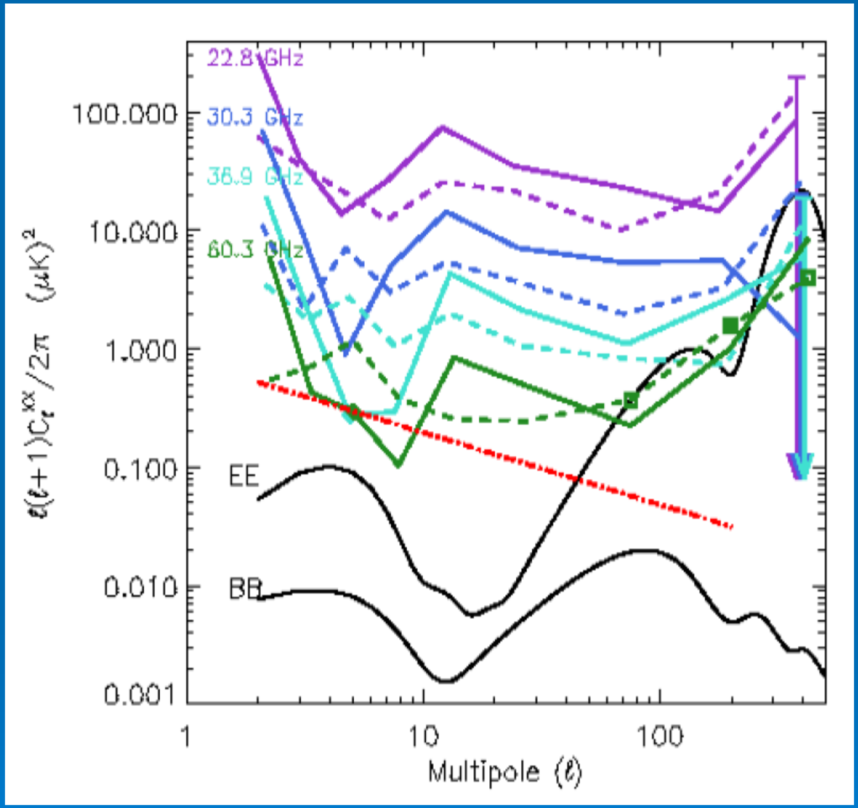




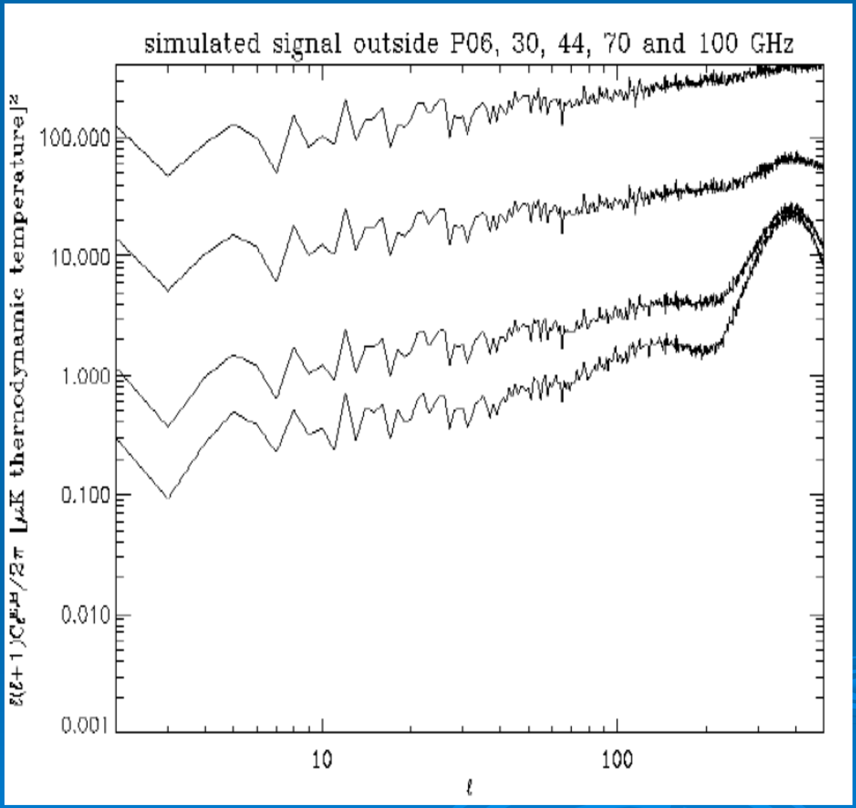


Bennett et al. 2003, Page et al. 2007

Something positive about Planck



Page et al. 2006

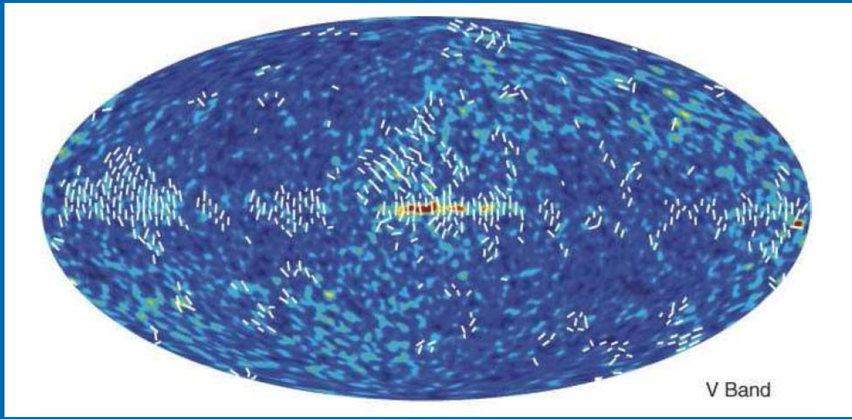


Planck reference sky, 2004

Do we have any hope to see B modes?

- WMAP has no detection in large sky areas in polarization
- Very naive estimates may be attempted in those areas, indicating that the foreground level might be comparable to the cosmological B mode at all frequencies, in all sky regions
- We need to rely on multi-frequency observations as well as robust data analysis techniques which are able to remove at most the foreground emission from polarization CMB data

Page et al. 2006



Are there foreground clean regions at all in polarization?

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- Very naive estimates may be attempted in those areas, indicating that the foreground level might be comparable to the cosmological B mode at all frequencies, in all sky regions
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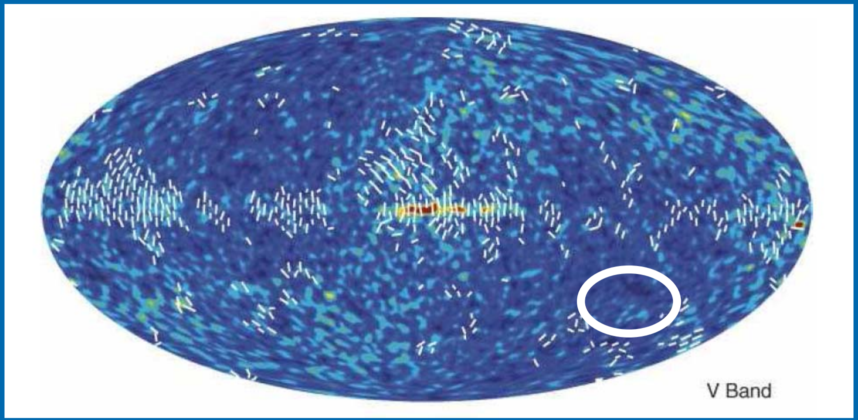
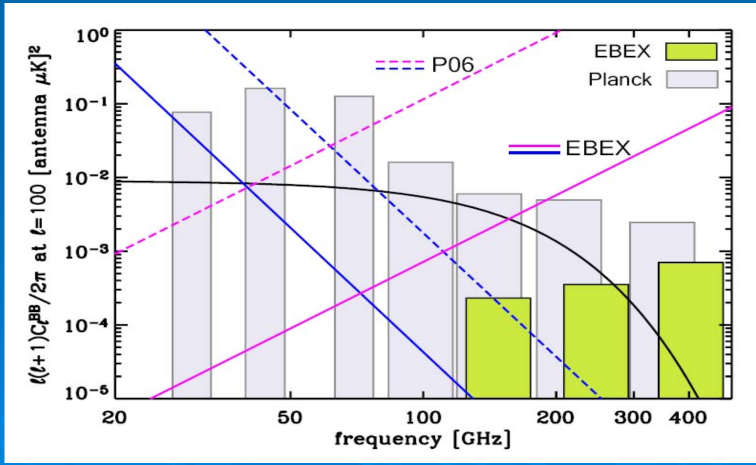
Page et al. 2006

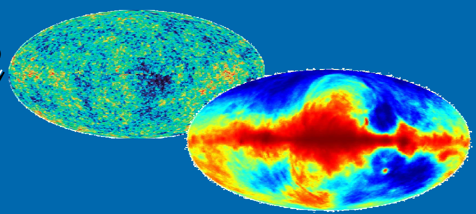




Baccigalupi, Hanany et al. 2007 for the EBEx collaboration

Component separation

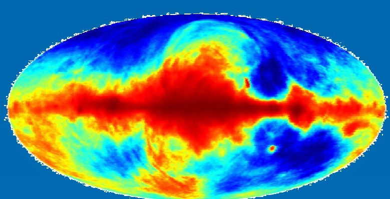
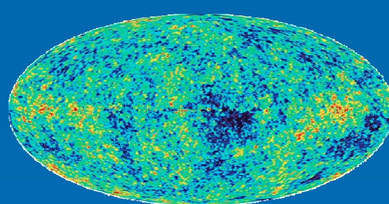
s_2

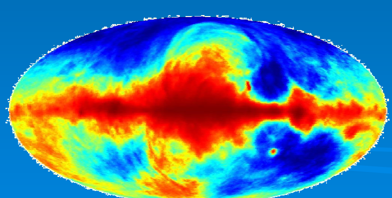
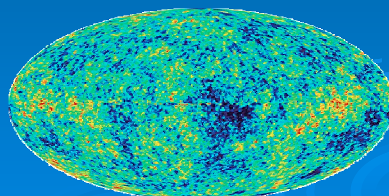


s_1

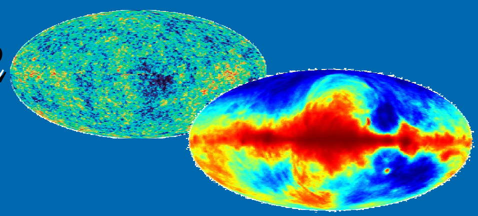
ν_1

ν_2

$x_1 = a_{11}$  $+ \; a_{12}$  $+ \; n_1$

$x_2 = a_{21}$  $+ \; a_{22}$  $+ \; n_2$

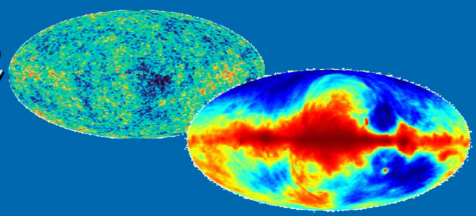
Component separation



$$x_1 = a_{11} \quad s_1 \quad + a_{12} \quad s_2 \quad + n_1$$

$$x_2 = a_{21} \quad s_1 \quad + a_{22} \quad s_2 \quad + n_2$$

Component separation



$$x = As + n$$

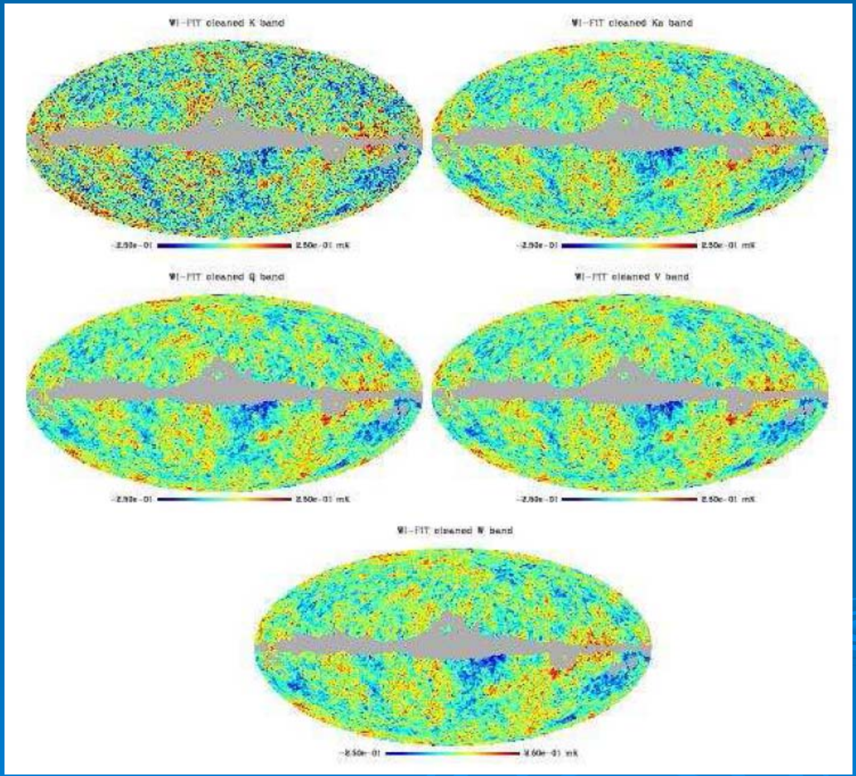
Invert for s!

Four attacking strategies

- Internal combination of multi-frequency data, Hansen et al. (2006)
- Parametrization and fitting of foregrounds, Brandt et al. (1994) - Eriksen et al. (2006)
- Spatial correlations, Tegmark & Efstathiou (1996) – Martinez-Gonzalez et al. (2003), Delabrouille et al. (2003), Stolyarov et al. (2005), Bonaldi et al. (2006)
- Statistics, Baccigalupi et al. (2000) – Maino et al. (2007)

Internal combination

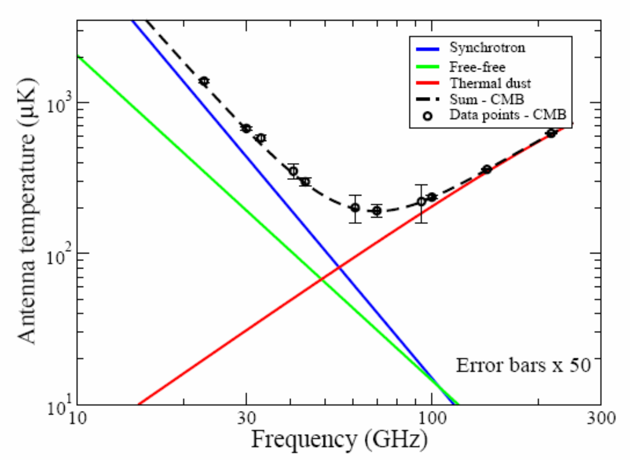
- Linear combinations of the foreground emissions are obtained by subtracting the CMB at all frequencies
- Those combinations are best fitted and subtracted from the CMB dominated channels
- The analysis is conducted in the wavelet space for computational limitations



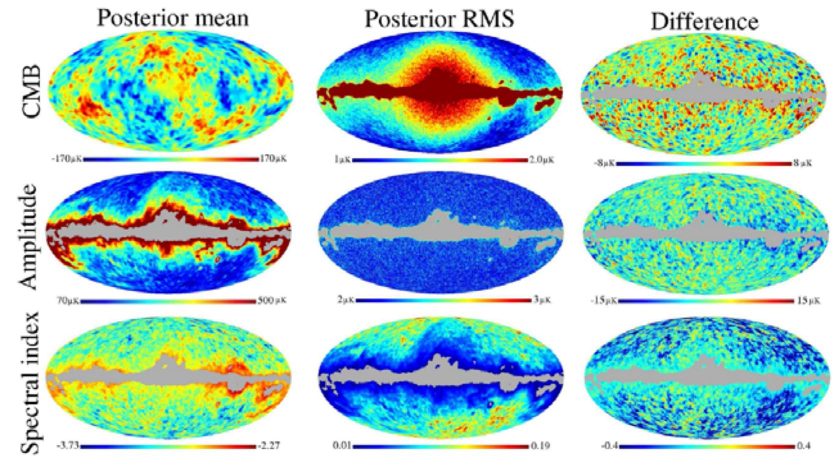
Hansen et al., 2006

Commander

Eriksen et al. 2006



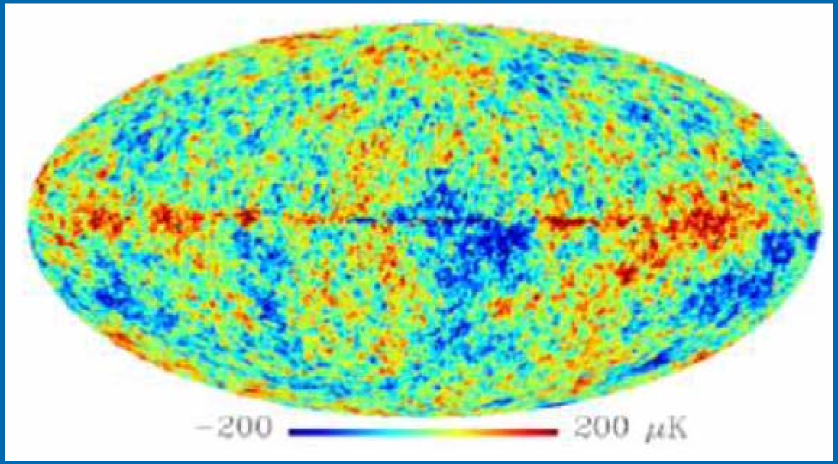
- In each pixel, the foreground emission is parametrized, typically by amplitude and spectral index
- Separation is expressed as a maximum likelihood problem, allowing to retrieve amplitudes, frequency scalings and possibly varying in space, including instrumental parameters with their uncertainties



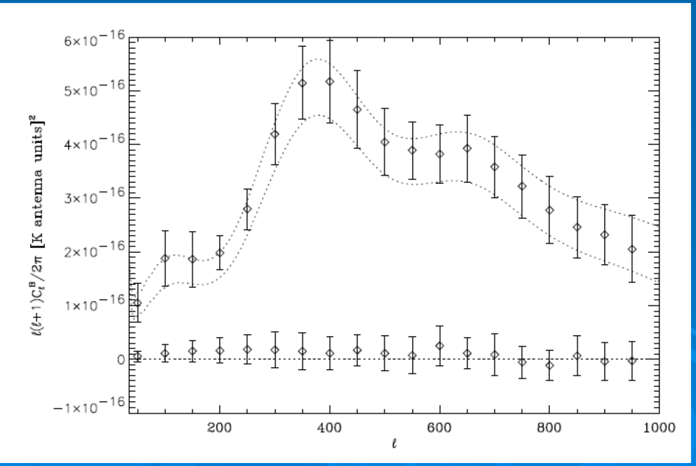
Eriksen et al. 2007

altICA

Maino et al. 2007



- Background and foregrounds are statistically independent
- Their superposition in multi-frequency data tends to be Gaussian
- Reverse the process with linear combinations of the signals at different frequencies, extremizing non-Gaussianity
- Each extremum corresponds to one independent component



Stivoli et al. 2006

Exploiting spatial correlations

- MEM (Stolyarov et al. 2005): prior knowledge of the power of some components in the harmonic domain is used to achieve a solution, which is adjusted iteratively by comparison with the input data
- EM (Martinez-Gonzalez et al. 2003), SMICA (Delabrouille et al. 2003): the power in the harmonic domain and frequency scalings of the different emissions are parametrized, and the parameters found by matching with data
- CCA (Bonaldi et al. 2006): the templates of the different emissions are parameterized, and the parameters found by exploiting the spatial correlations in the real space

The medal, beginning 2008

- All codes performed reasonably well on simulated Planck data in total intensity, residuals at least two orders of magnitude below the signal, exploding at the sixth, seventh acoustic peak, paper in preparation
- Published applications to COBE, BEAST, WMAP total intensity
- Extension to polarization done (Baccigalupi et al. 2004, Aumont et al. 2005, Stivoli et al. 2006) or in progress, ongoing tests on simulated Planck data

The back of the medal, beginning 2008

- Simulations are almost systematics free
- Not clear how realistic the simulated foregrounds are
- Confirmations of known results, but no new discoveries from the applications to real data
- Polarization almost entirely to be done, in particular at the accuracy required for extraction of B modes

Conclusions, beginning 2008

- Foreground cleaning in polarization is a necessary, most important criterium for a convincing detection of B modes
- Foreground cleaning algorithms exist and are promising, although mostly studied on simplified data, total intensity
- A shock into this area of data analysis is expected from the application to the data of suborbital B mode dedicated probes, news in one year timescale