Component separation in CMB observations

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The component separation problem

- Point sources
- Galactic emission
- CMB Anisotropies
- Noise
- SZ clusters?

WMAP Observation at 30 GHz
Multifrequency observations

- 20 GHz
- 70 GHz
- 30 GHz
- 90 GHz
- 40 GHz
• 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


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

\[ y_d(x) = \alpha_d s(x) + n_d(x) \]

Solution:

\[ w_d = f(\alpha_d, R) \]
How to "weigh" WMAP channels?

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

If there were no foregrounds

Galactic Latitude

high

low

large

Scale

small

K Kα Q V W

K Kα Q V W

K Kα Q V W

K Kα Q V W

Channel weights (noise level based)

K

Kα

Q

V

W
Localisation ?

WMAP: 11 zones

Tegmark et al.: 9 zones

Park et al.: 400 zones
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

Map synthetised from the filtered needlet coefficients

All sky power spectrum
This is not (not only) a residual of galactic emission ...

All sky power spectrum
Comparison with other maps

WMAP Y channel (foreground reduced)

5 year Needlet ILC

TILC3

Tegmark et al. ILC (3 year)
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. \((2.6 \times 10^{-4})\)

Massardi et al. arXiv:1001.1069
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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 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.

• No individual detection, but we can stack...
**SZ from 893 NORAS+REFLEX clusters**

Fig. 2. Left: Estimated SZ flux from a cylinder of aperture $5 \times r_{500}$ ($Y_{500}^{\text{cyl}}$) 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.

Measurements vs. model

Model:

\[ L_x \rightarrow M_{500} \] from \( \text{Pratt et al. (2009)} \)

\[ M_{500} \rightarrow Y_{500} \] from \( \text{Arnaud et al. (2009)} \)
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