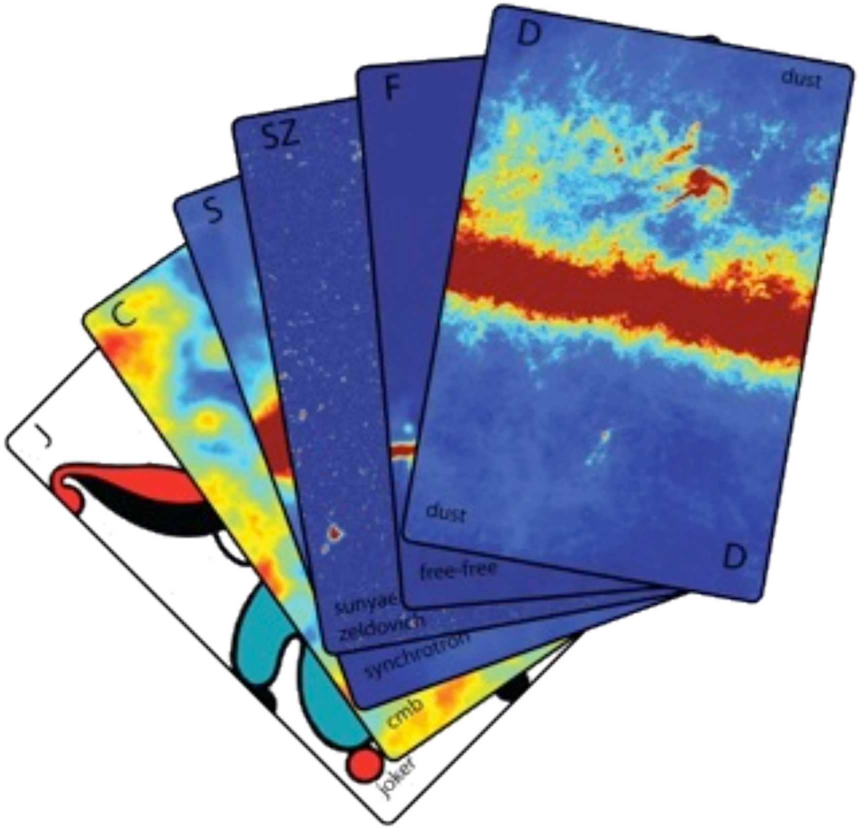
PolEMICA, component separation for polarized CMB observations



Jonathan Aumont, CESR

Toulouse, France

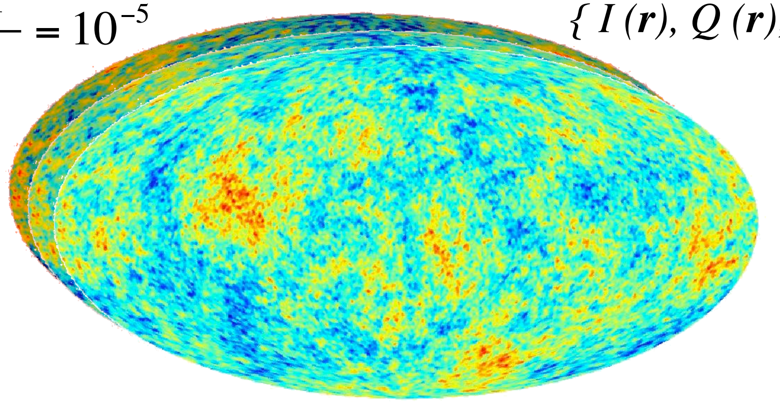
Thursday, May 8th 2008, ADA5

The Cosmic Microwave Background

Jonathan Aumont, CESR

$$\frac{\Delta T}{T} = 10^{-5}$$

$$\{\, I(\mathbf{r}),\, Q(\mathbf{r}),\, U(\mathbf{r}) \,\}$$



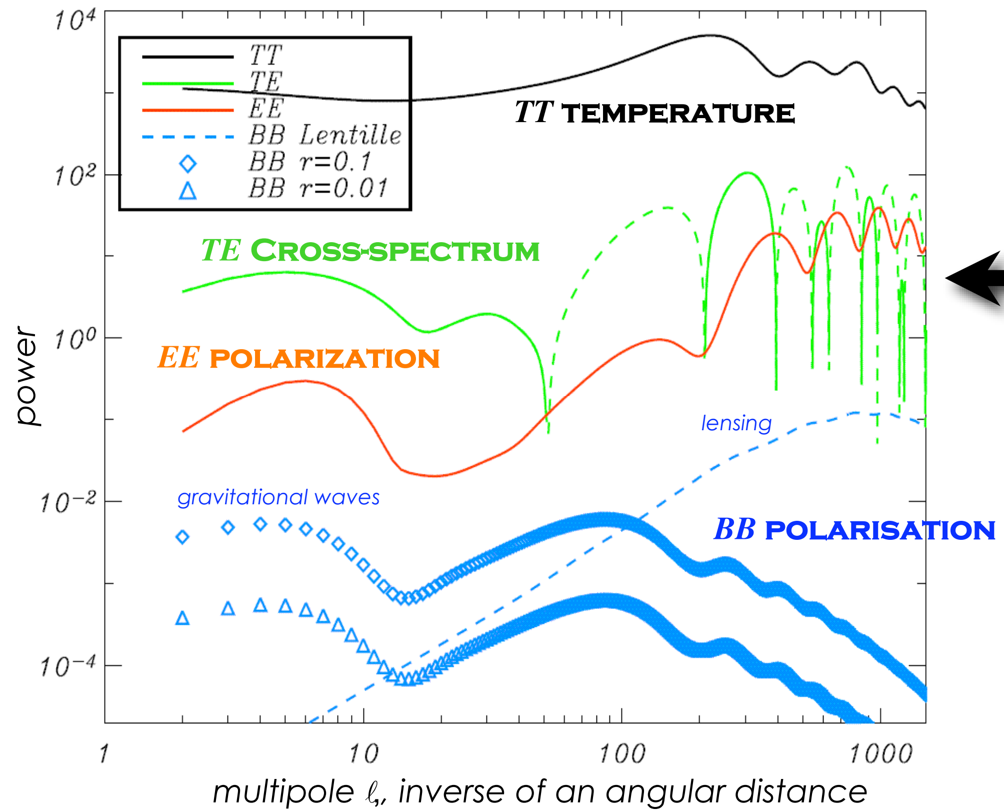
$$\frac{\Delta T(\mathbf{n})}{T_0} = \sum_{\ell=0}^{\infty} \sum_{m=-\ell}^{\ell} a^T_{\ell m} Y_{\ell m}(\mathbf{n})$$

$$(Q \pm iU)(\hat{\mathbf{n}}) = \sum_{\ell,m} a_{\pm 2,\ell m} \cdot {}_{\pm 2}Y_{\ell m}(\hat{\mathbf{n}})$$

$$a^E_{\ell m} \equiv -\frac{a_{2\ell m} + a_{-2\ell m}}{2}$$

$$a^B_{\ell m} \equiv i\frac{a_{2\ell m} - a_{-2\ell m}}{2}$$

$$C_\ell^{XX'} = \langle a^X_{\ell m} \cdot a^{X'\star}_{\ell m} \rangle$$



Components of the microwave sky

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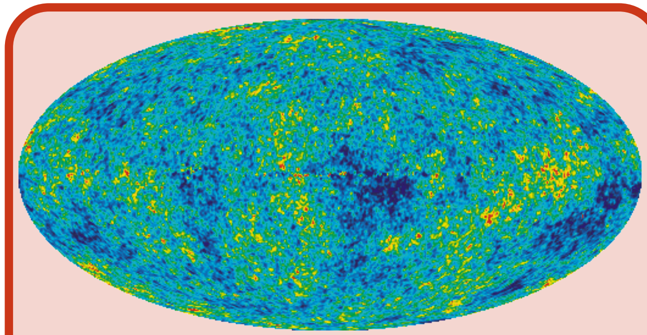
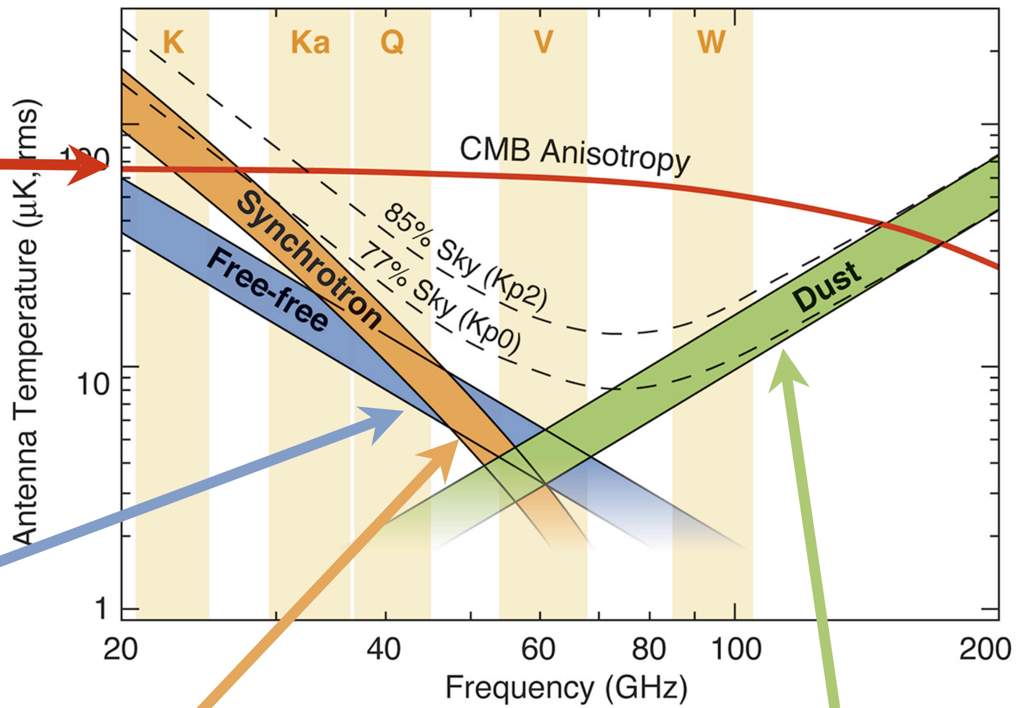


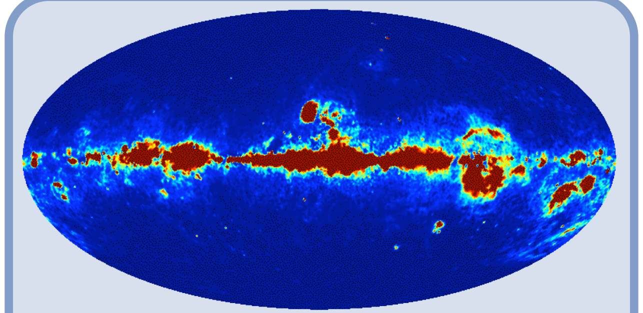
CMB anisotropies

★flat emission law in μK^{CMB}

★$\Delta P \sim 0.05 \cdot \Delta T$

★gaussian distribution on the sky

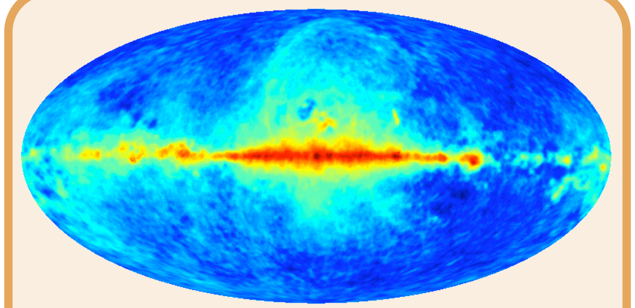




Free-Free emission

★emission in $\nu^{-2.1}$

★not polarized

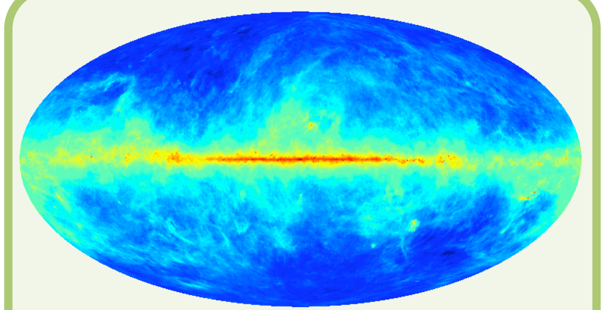


Synchrotron emission

★emission in ~ $\nu^{-3.0}$

★anisotropic spectral index

★polarized up to 75%



Dust emission

★emission in $\nu^{2.0}$

★thermal and anomalous dust

★polarized up to 10%

Modeling of the sky observations

★*Data in the spherical harmonics space for* $X = \{\, T, E, B \,\}$

$$y_{\ell m}^{\nu,X} = \sum_{c=1}^{n_c} A_c^{\nu,XX'} s_{\ell m}^{c,X'} + n_{\ell m}^{\nu,X}$$

Data
for each frequency channel

Mixing matrix
contains emission laws

Components
CMB, synchrotron, dust, free-free

Noise
For each frequency channel

$$\begin{pmatrix} y_{\ell m}^{\nu_1 T} \\ y_{\ell m}^{\nu_1 E} \\ y_{\ell m}^{\nu_1 B} \\ y_{\ell m}^{\nu_2 T} \\ y_{\ell m}^{\nu_2 E} \\ y_{\ell m}^{\nu_2 B} \end{pmatrix} = \begin{pmatrix} f_{\nu_1 c_1}^T & 0 & 0 & f_{\nu_1 c_2}^T & 0 & 0 \\ 0 & f_{\nu_1 c_1}^E & 0 & 0 & f_{\nu_1 c_2}^E & 0 \\ 0 & 0 & f_{\nu_1 c_1}^B & 0 & 0 & f_{\nu_1 c_2}^B \\ f_{\nu_2 c_1}^T & 0 & 0 & f_{\nu_2 c_2}^T & 0 & 0 \\ 0 & f_{\nu_2 c_1}^E & 0 & 0 & f_{\nu_2 c_2}^E & 0 \\ 0 & 0 & f_{\nu_2 c_1}^B & 0 & 0 & f_{\nu_2 c_2}^B \end{pmatrix} \cdot \begin{pmatrix} s_{\ell m}^{c_1 T} \\ s_{\ell m}^{c_1 E} \\ s_{\ell m}^{c_1 B} \\ s_{\ell m}^{c_2 T} \\ s_{\ell m}^{c_2 E} \\ s_{\ell m}^{c_2 B} \end{pmatrix} + \begin{pmatrix} n_{\ell m}^{\nu_1 T} \\ n_{\ell m}^{\nu_1 E} \\ n_{\ell m}^{\nu_1 B} \\ n_{\ell m}^{\nu_2 T} \\ n_{\ell m}^{\nu_2 E} \\ n_{\ell m}^{\nu_2 B} \end{pmatrix}$$

★*Example for* $n_c = 2$ *and* $n_\nu = 2$

[Aumont & Macías-Pérez 2007]

Angular power spectra description

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★*Density matrix construction, containing the angular power spectra*

$$C_\ell^{XX'} = \langle a_{\ell m}^{X} \cdot a_{\ell m}^{X'\star} \rangle$$

$$y_{\ell m}^{\nu,X} = \sum_{c=1}^{n_c} A_c^{\nu,XX'} s_{\ell m}^{c,X'} + n_{\ell m}^{\nu,X} \quad \longrightarrow \quad R_Y = A R_S A^T + R_N$$

Mixing matrix
contains emission laws

$$\begin{pmatrix} & \nu_1 & \nu_2 \\ \nu_1 & \begin{bmatrix} TT & TE & TB \\ TE & EE & EB \\ TB & EB & BB \end{bmatrix} & \begin{bmatrix} TT & TE & TB \\ TE & EE & EB \\ TB & EB & BB \end{bmatrix} \\ \nu_2 & \begin{bmatrix} TT & TE & TB \\ TE & EE & EB \\ TB & EB & BB \end{bmatrix} & \begin{bmatrix} TT & TE & TB \\ TE & EE & EB \\ TB & EB & BB \end{bmatrix} \end{pmatrix} = A \cdot \begin{pmatrix} & c_1 & c_2 \\ c_1 & \begin{bmatrix} TT & TE & TB \\ TE & EE & EB \\ TB & EB & BB \end{bmatrix} & 0 \\ c_2 & 0 & \begin{bmatrix} TT & TE & TB \\ TE & EE & EB \\ TB & EB & BB \end{bmatrix} \end{pmatrix} \cdot A^T + \begin{pmatrix} & \nu_1 & \nu_2 \\ \nu_1 & \begin{matrix} TT & & \\ & EE & \\ & & BB \end{matrix} & 0 \\ \nu_2 & 0 & \begin{matrix} TT & & \\ & EE & \\ & & BB \end{matrix} \end{pmatrix}$$

Data

Components
are not correlated
between each others

Noise
is not correlated
between detectors

[Aumont & Macías-Pérez 2007]

PolEMICA's algorithm

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★*POLarized Expectation-Maximization Independent Component Analysis*
★*adaptation to polarization of the Spectral Matching ICA (SMICA) algorithm* [Delabrouille *et al.* 2003]

$$R_Y = A R_S A^T + R_N$$

★*sets of parameters to extract, several levels of a priori*

BLIND $\theta_{\mathrm{blind}}(b) = \left\{A, R_s(b), \mathrm{diag}\big(R_n(b)\big)\right\}$

CMB-FIXED $\theta_{\mathrm{CMB-fixed}}(b) = \left\{A_{i,j\neq \mathrm{CMB}}, R_s(b), \mathrm{diag}\big(R_n(b)\big)\right\}$

A-FIXED $\theta_{\mathrm{A-fixed}}(b) = \left\{R_s(b), \mathrm{diag}\big(R_n(b)\big)\right\}$

★*Expectation-Maximization (EM) algorithm* [Dempster *et al.* 1977]

E-STEP: *computation of the conditional statistics from* θ_i (gaussian a priori)

M-STEP: *maximization of the likelihood and update of the parameters to compute* θ_{i+1}

MAXIMIZATION OF THE LIKELIHOOD ANALYTICALLY GUARANTEED

iterations

Simulations of the Sky

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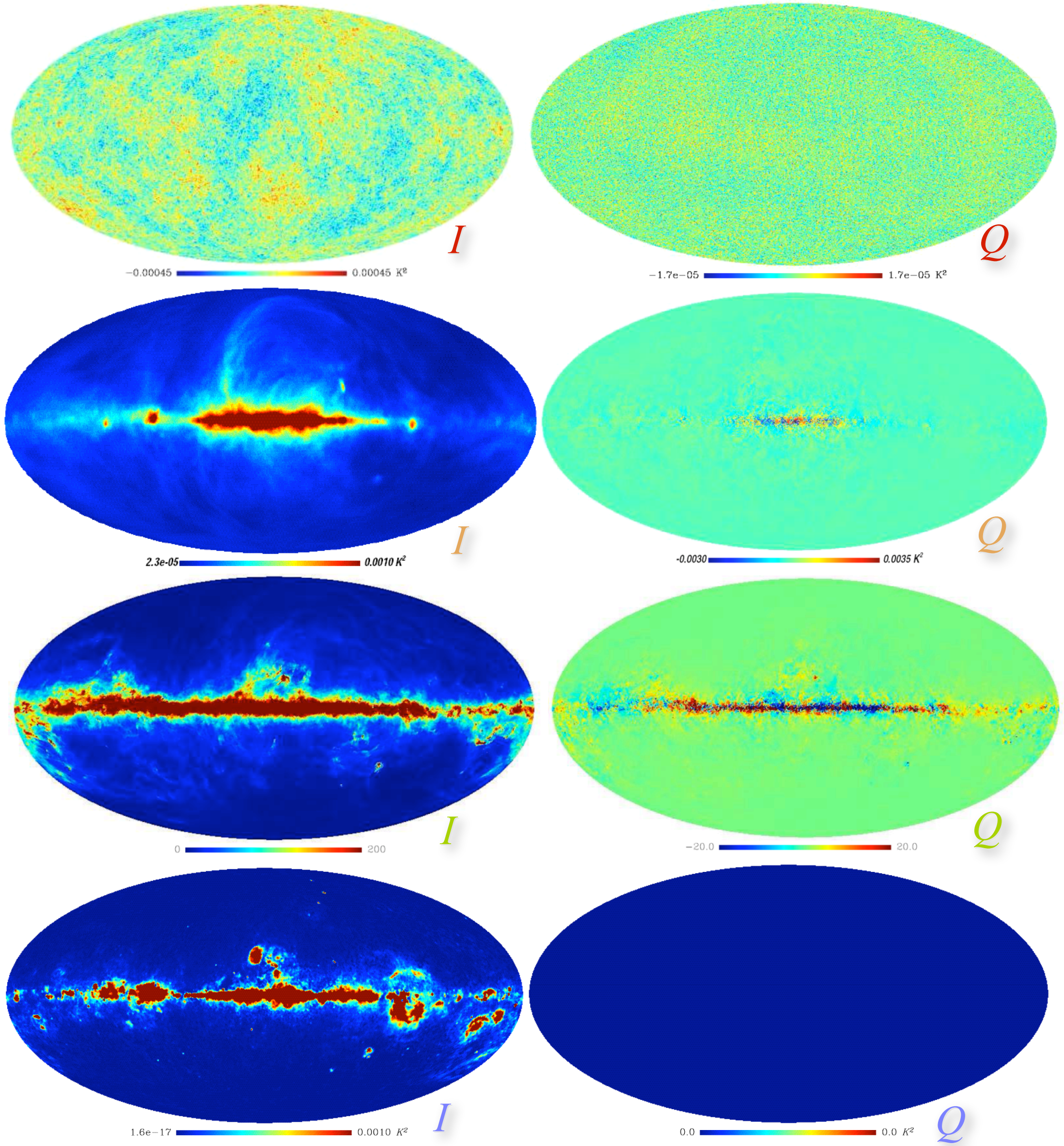


CMB
spectra generated from the WMAP1 concordance model [Bennett *et al.* 2003]

Synchrotron
template of [Giardino *et al.* 2002], *isotropic spectral index* (β = -2.7)

Thermal dust
model #7 from [Finkbeiner *et al.* 1999] *grey-body spectrum with emissivity of* $\beta = 2$

Free-free
template of [Dickinson *et al.* 2003], *with a spectral index of* β = -2.1, *no polarization* [Keating *et al.* 1998]

Instrumental noise
white noise maps normalized to the instrumental sensitivity for each frequency band

PLANCK CMB RECONSTRUCTION

Jonathan Aumont, CESR

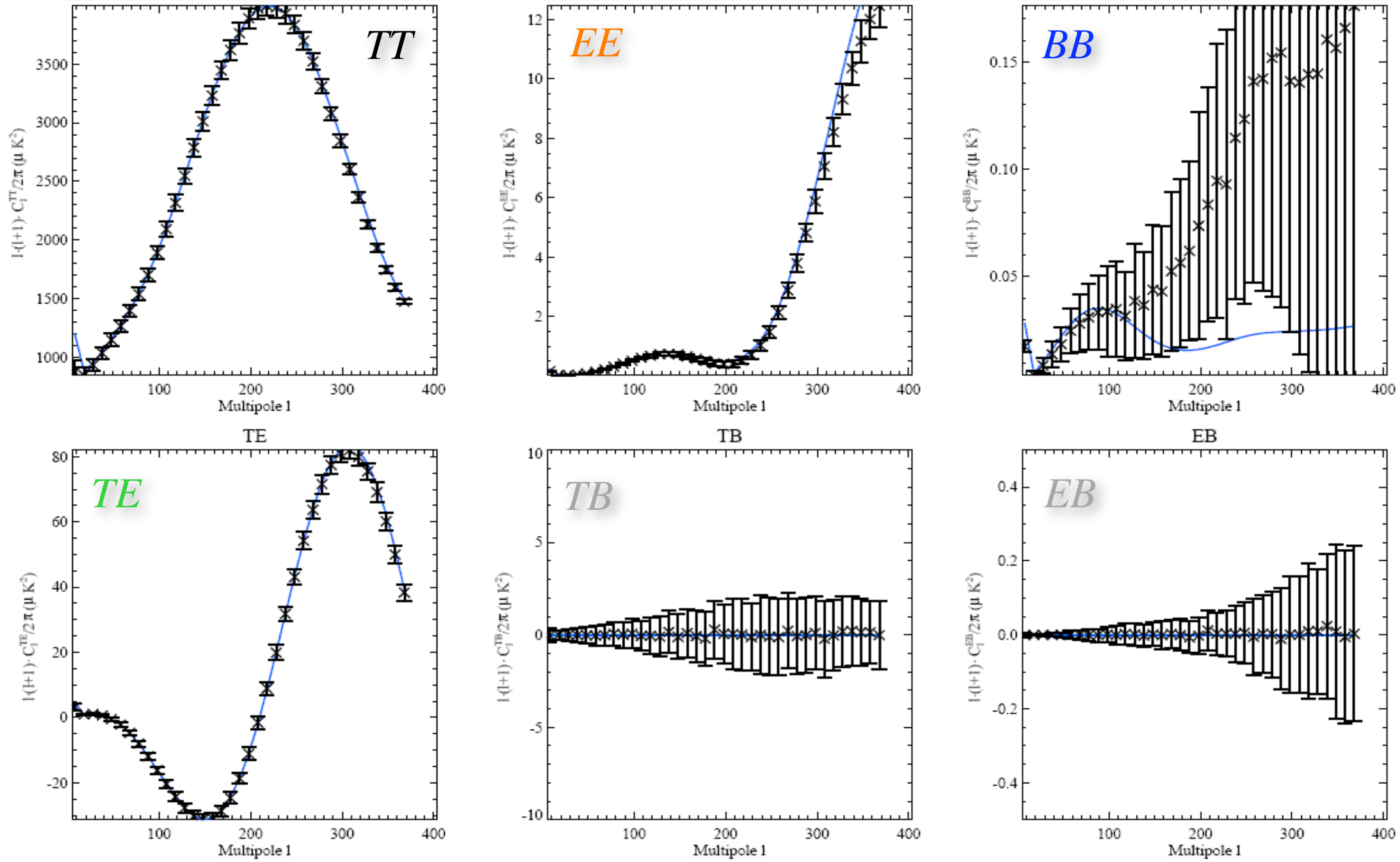
★*simulation of PLANCK maps for polarized channels of LFI and HFI, [30,40,70,100,143,217,353] GHz*

★*nominal mission of 14 months, total sky coverage, infinite resolution, no systematics*

★*maps containing* **CMB**, **SYNCHROTRON**, **DUST**, **FREE-FREE** *and* **INSTRUMENTAL NOISE**

results for I, Q and U simulations, for a **A-FIXED** *separation, 5000 EM iterations*

CMB



[Aumont & Macías-Pérez 2007]

★*simultaneous reconstruction of auto and cross power spectra*

★*accurate reconstruction of* C_ℓ^{TT}, C_ℓ^{TE} *and* C_ℓ^{EE}

★ C_ℓ^{BB} *reconstructed up to* $\ell = 100$

Planck dust reconstruction

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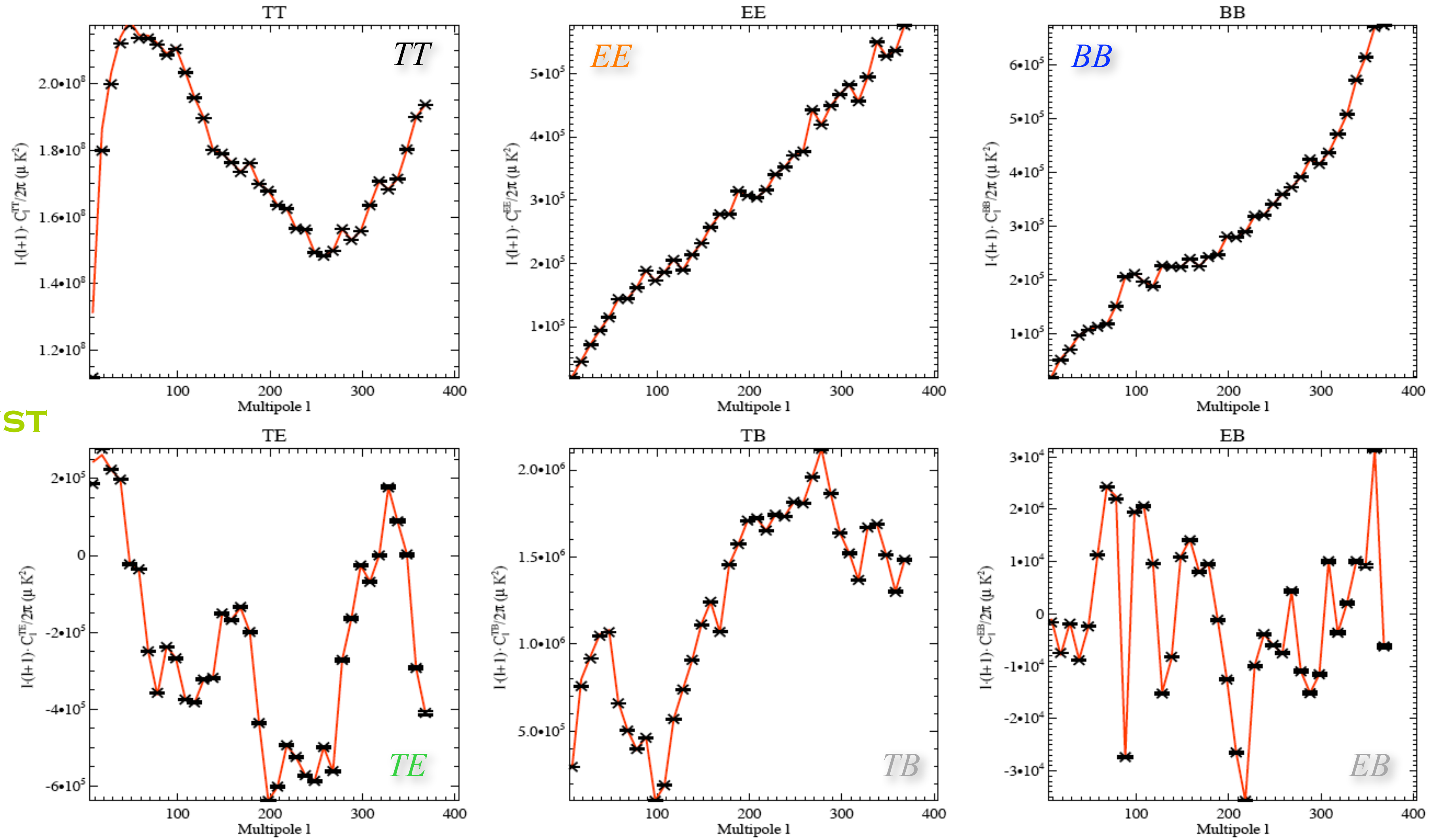
Dust



[Aumont & Macías-Pérez 2007]

★accurate reconstruction of all auto and cross power spectra

Planck free-free reconstruction

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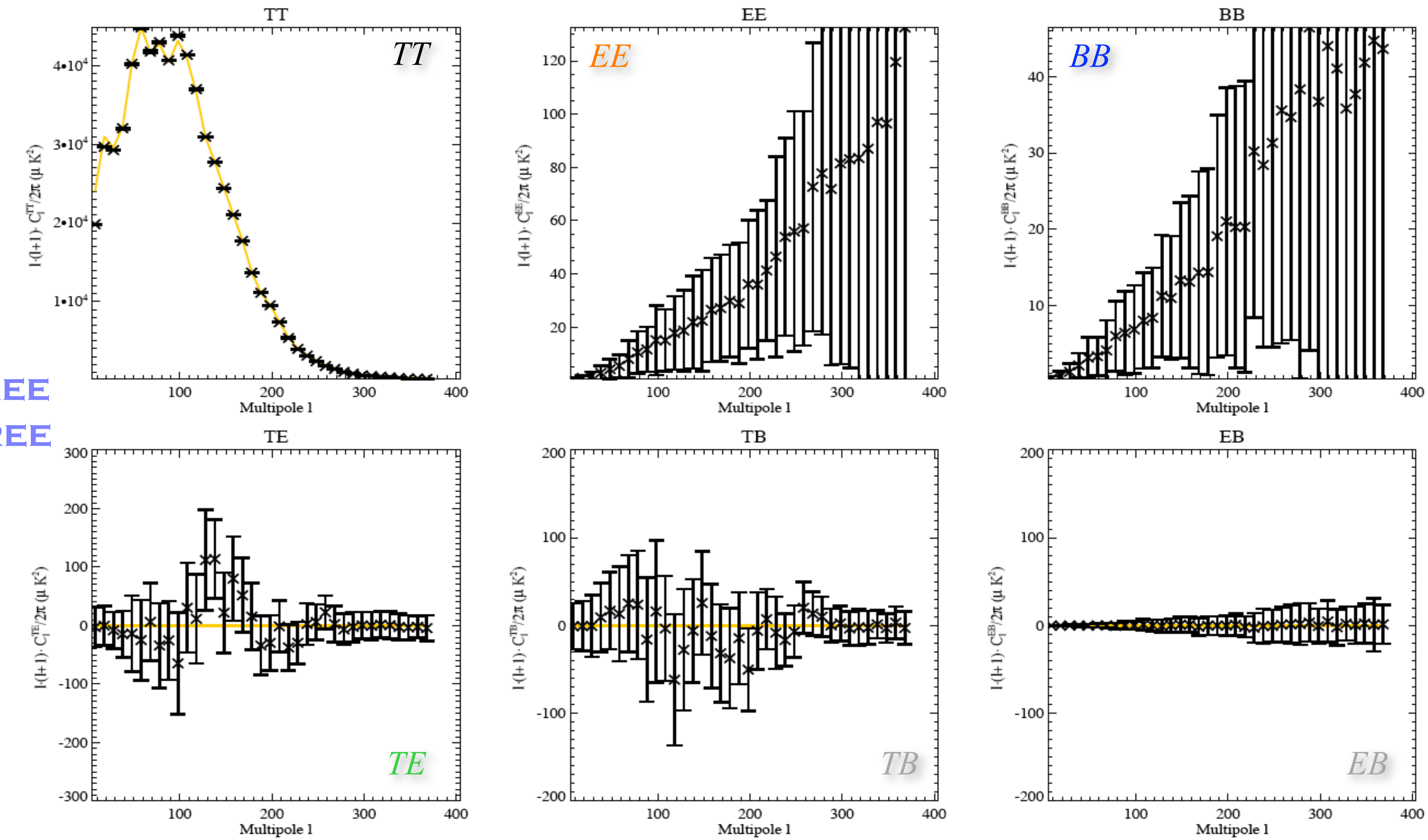
Free -free



[Aumont & Macías-Pérez 2007]

★accurate reconstruction of C_ℓ^{TT}

★biased reconstruction of C_ℓ^{EE} and C_ℓ^{BB} due to the lack of polarized signal

Planck synchrotron reconstruction

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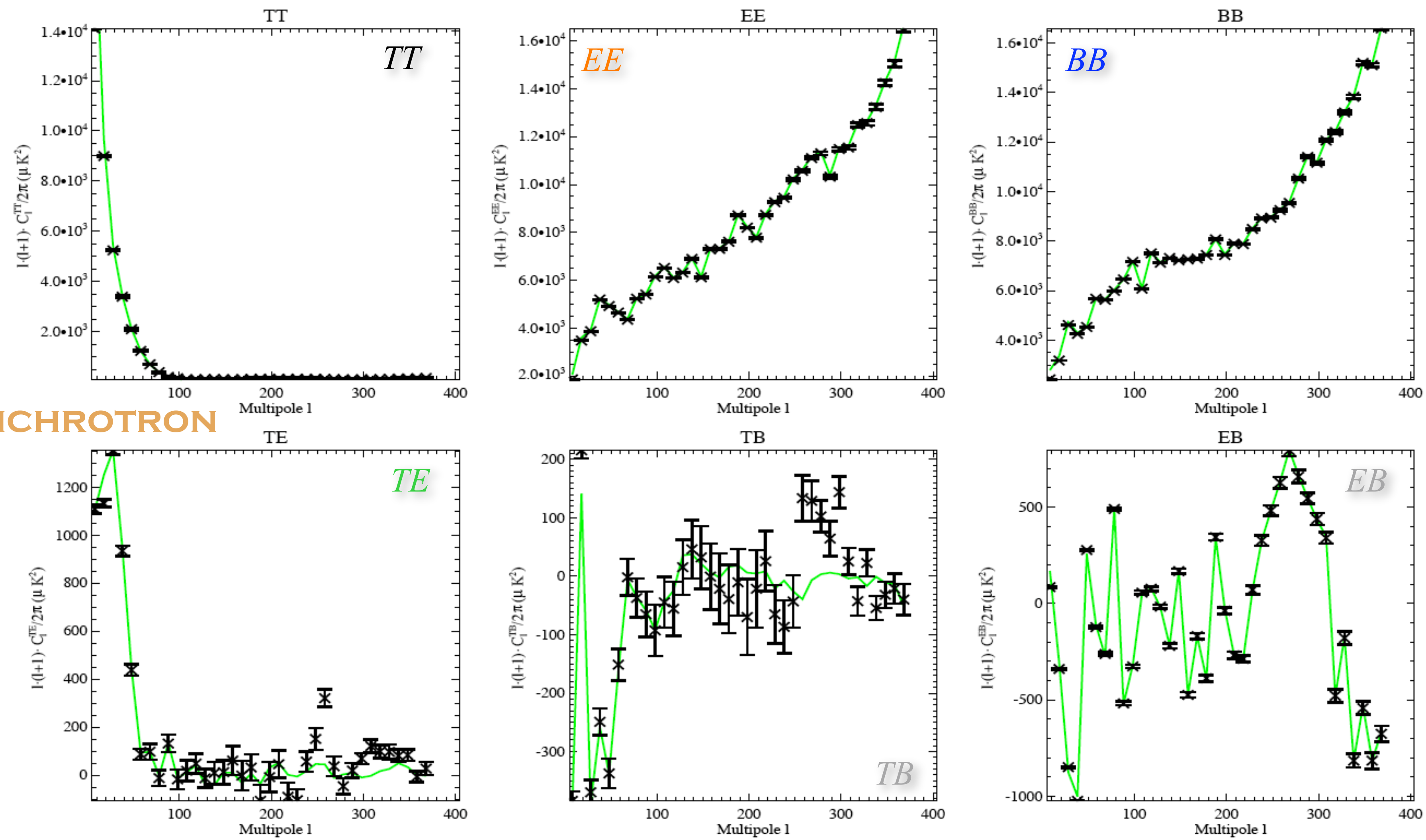
Synchrotron



[Aumont & Macías-Pérez 2007]

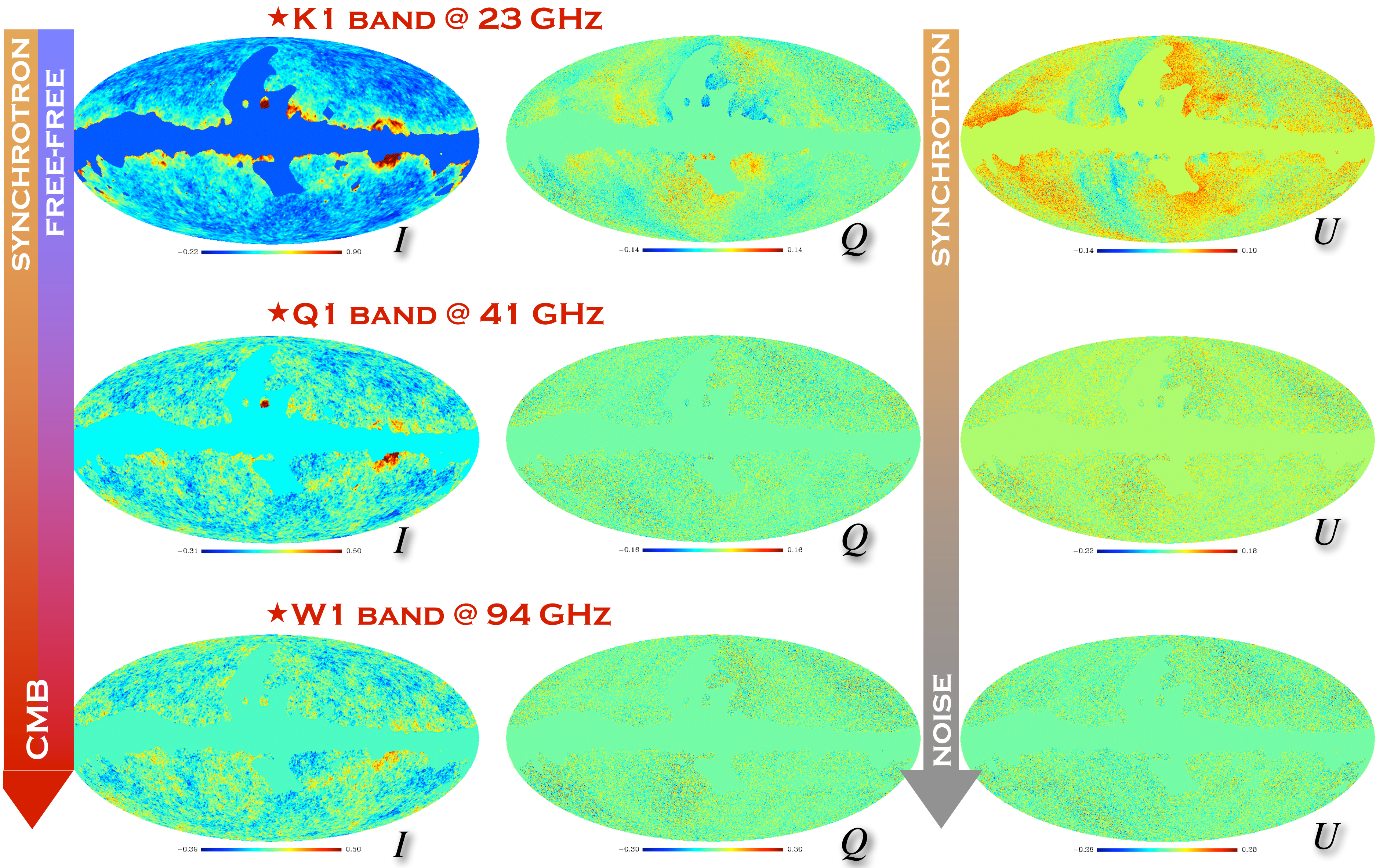
★*accurate reconstruction of only polarization spectra* C_ℓ^{EE}, C_ℓ^{BB} *and* C_ℓ^{EB}

★*bias in the reconstruction of* C_ℓ^{TT}, C_ℓ^{TE} *and* C_ℓ^{TB}

WMAP 5 YEARS MAPS

Jonathan Aumont, CESR

★ 10 sets of I, Q and U maps for WMAP5 channels (1@(23&33GHz), 2@(41&61GHz),4@94GHz)
★ resolution degraded to N_{side} = 128, WMAP5 polarization mask applied

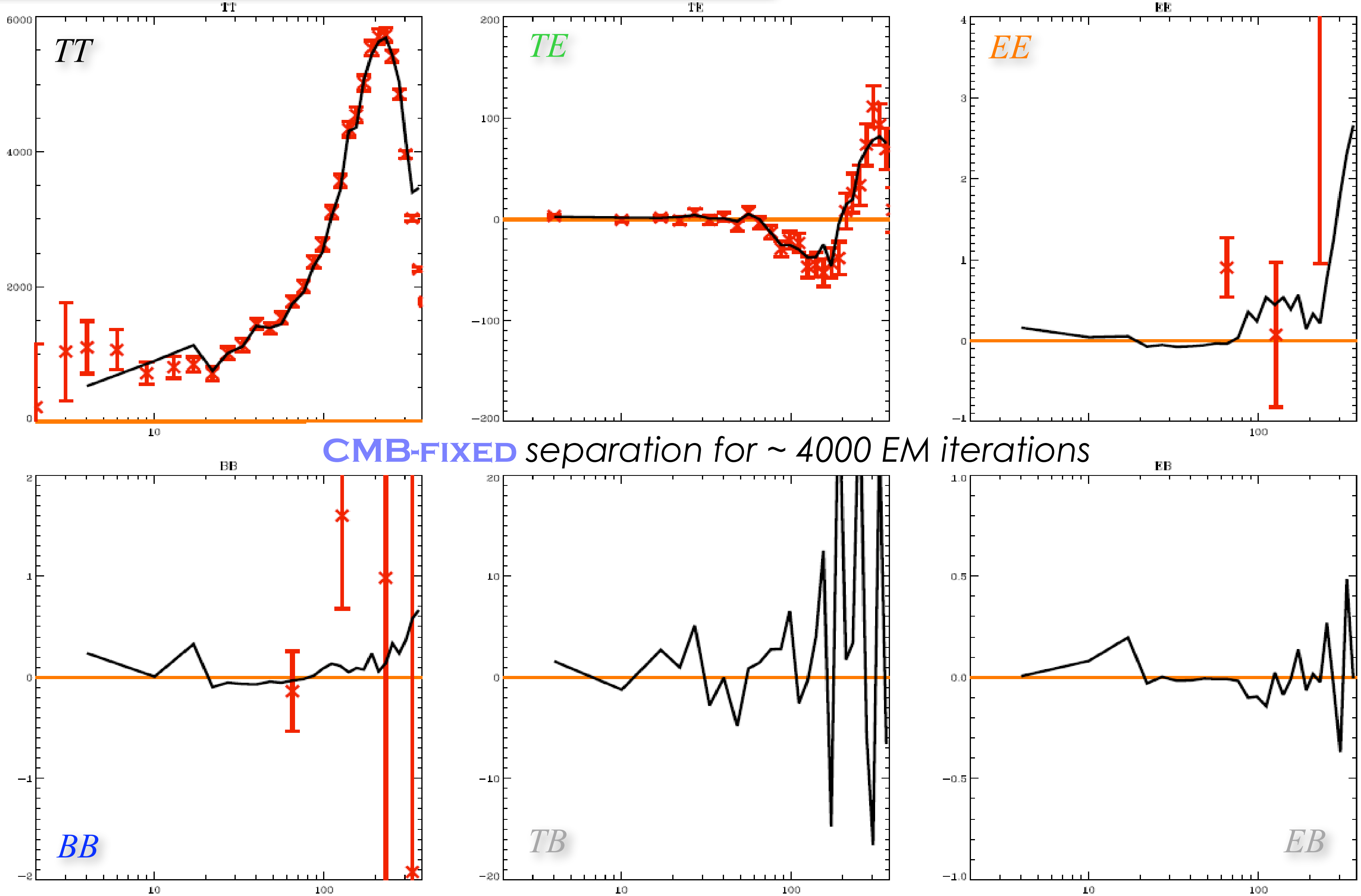


WMAP 5 years reconstruction

Jonathan Aumont, CESR

Preliminary

[Aumont & Macías-Pérez 2008, *in prep.*]



★accurate reconstruction of C_ℓ^{TT} and C_ℓ^{TE}
★bias in C_ℓ^{EE} and C_ℓ^{BB} compatible with WMAP noise level

Conclusions

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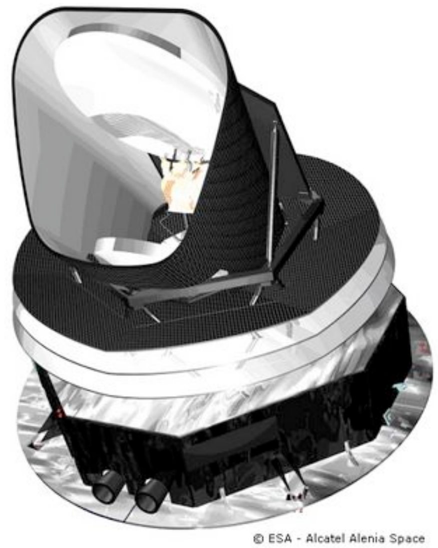
★PolEMICA allows a simultaneous reconstruction of the components in temperature and polarization
★PolEMICA has been intensively tested on PLANCK simulations to characterize the main features of the algorithm
★PolEMICA has now been applied to real data

⊕ A-fixed separation of the CMB and Galactic components of Planck simulation is efficient

⊖ bias is observe at low signal to noise level and strong spatial correlations

⊕ PolEMICA now accounts for instrumental effects as beam and incomplete sky coverage corrections
⊕ CMB-fixed separation of the WMAP5 temperature and polarization data allows to recover accurately the CMB

⊖ other components are not recovered



PolEMICA has now to be tested on realistic PLANCK simulations