Estimating the spectral properties of the polarized foregrounds with the Correlated Component Analysis

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JBCA

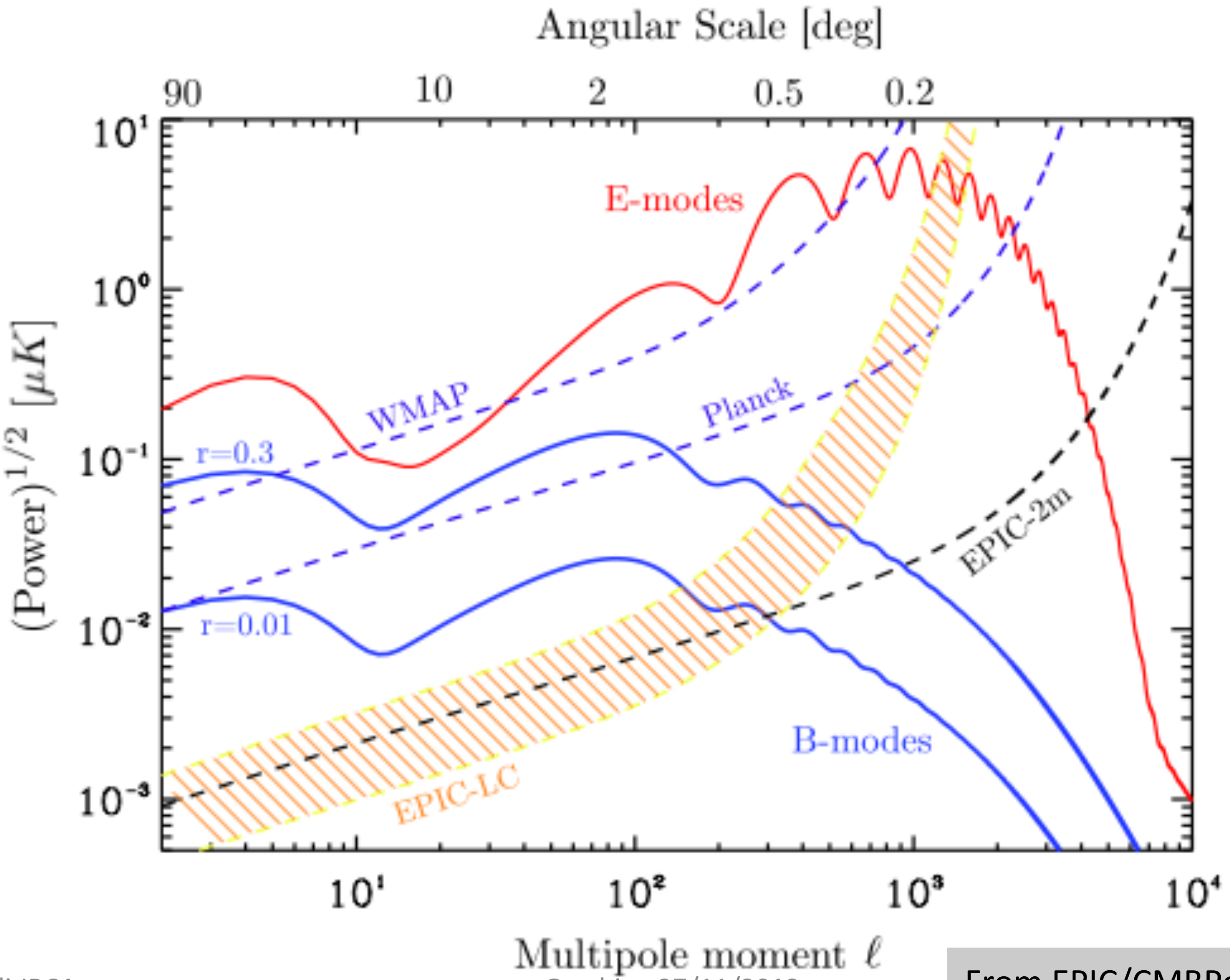
The Quest for B-modes

- Single-field inflation predicts r≈0.01 for ns=0.95
- Planck would be able to detect r≈0.1
- B-modes probes:
  - Suborbital experiments:

    http//lambda.gsfc.nasa.gov/product/suborbit
  - Satellite missions (next generation):

CMB-Pol (NASA)	cmbpol.uchicago.edu
COrE (ESA)	www.core-mission.org

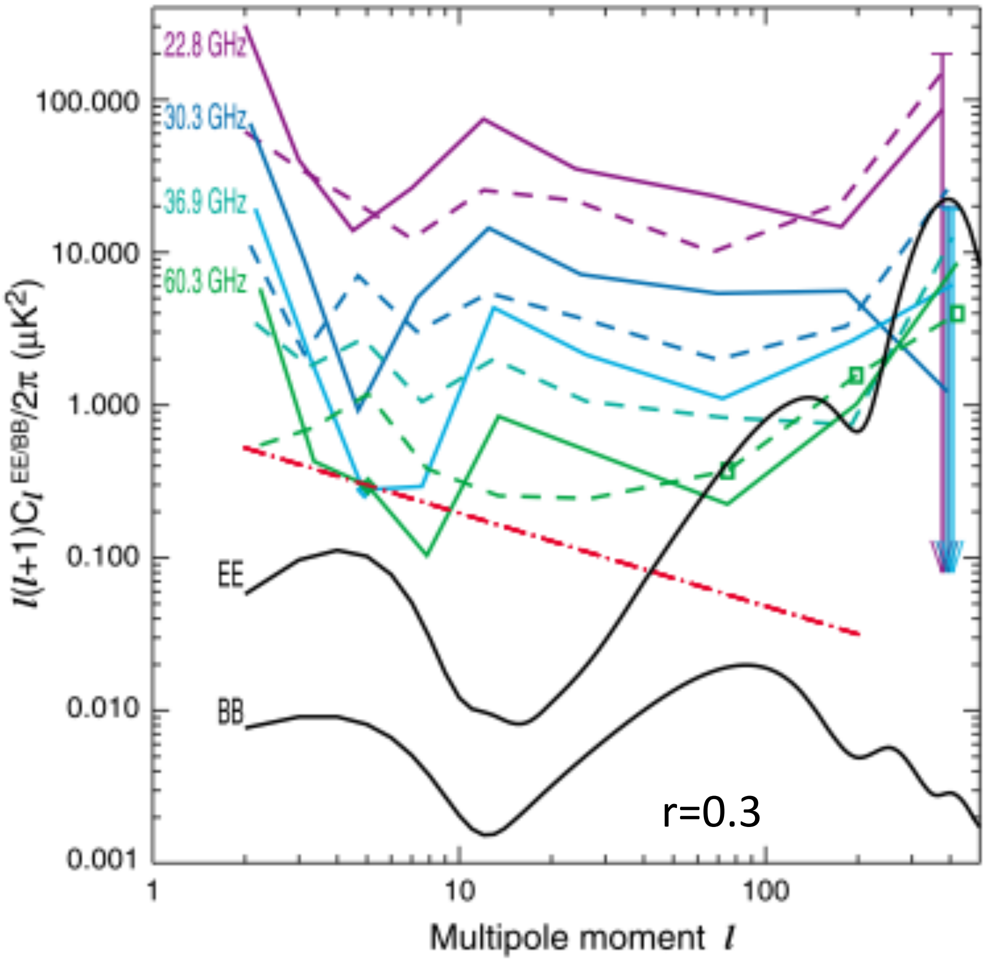
Issue for B-modes: noise (and systematics!)

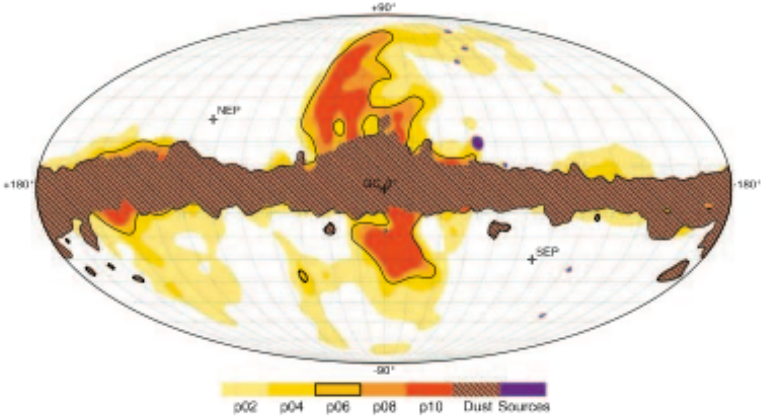


From EPIC/CMBPol white paper

Issue for B-modes: foregrounds

WMAP

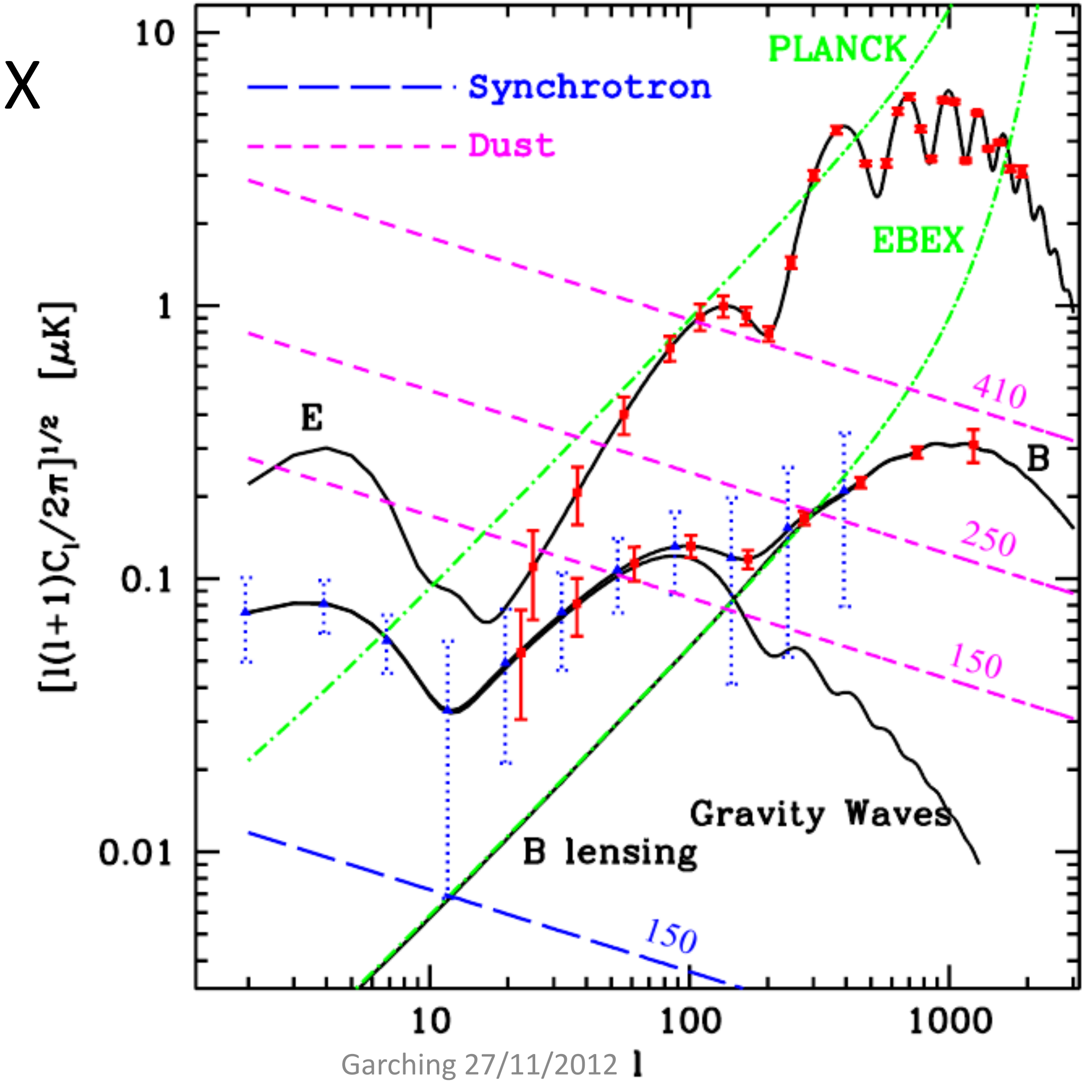




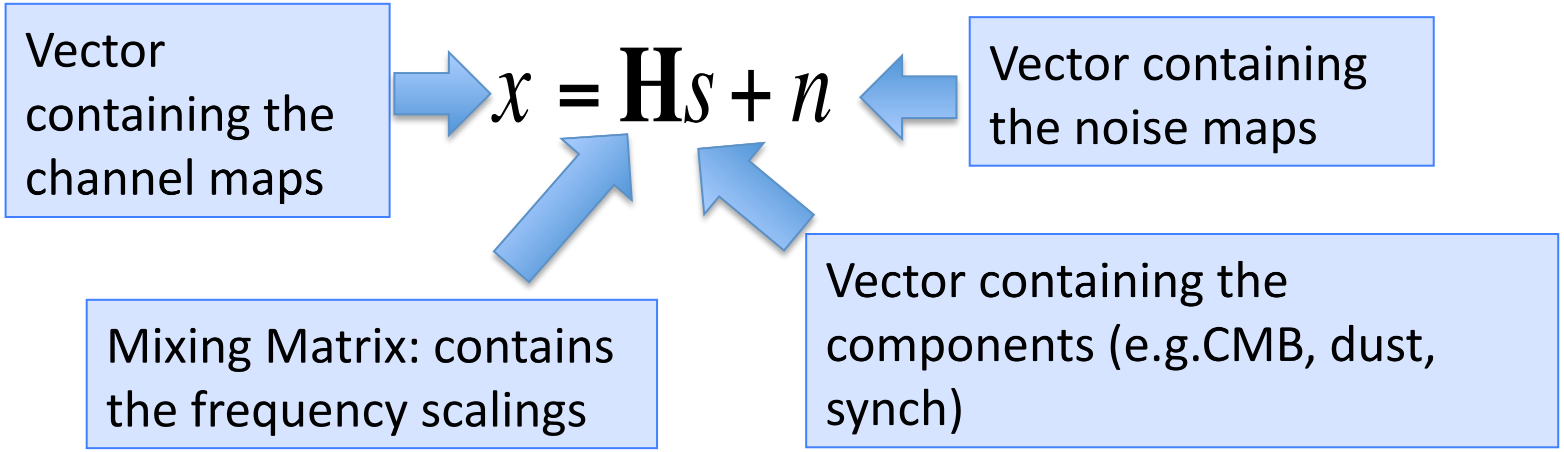
Page et al. (2007)

Issue for B-modes: foregrounds

EBEX



Component separation



Vector containing the channel maps

$$x = \mathbf{H}s + n$$

Vector containing the noise maps

Mixing Matrix: contains the frequency scalings

Vector containing the components (e.g.CMB, dust, synch)

- Source vector **s**: CMB, synchrotron, dust (AME, free-free, …)
- One approach: linear combination of frequency maps **x**
  - Needs an estimate of the Mixing Matrix **H**
  - Ideally minimize both foregrounds and noise

$$\hat{\mathbf{H}} = \left(\begin{array}{ccc} CMB & SYN & DUST \\ 1 & syn_1 & dust_1 \\ 1 & syn_2 & dust_2 \\ \dots & \dots & \dots \\ 1 & syn_n & dust_n \end{array}\right)\begin{array}{c} \\ map_1 \\ map_2 \\ \dots \\ map_n \end{array}$$

$$x = \mathbf{H}s + n$$

$\hat{\mathbf{H}}$ estimate of $\mathbf{H}$

GLS

$$\hat{s} = \mathbf{W}x$$

$$\mathbf{W} = (\hat{\mathbf{H}}^{\mathrm{T}}\mathbf{N}^{-1}\hat{\mathbf{H}})^{-1}\hat{\mathbf{H}}^{\mathrm{T}}\mathbf{N}^{-1}$$

- **Extracts both CMB and foregrounds**
- **Minimizes foregrounds and noise**
- **OK using several frequency maps**

$$\hat{\mathbf{H}} = \left(\begin{array}{ccc|cr} CMB & SYN & DUST & & \\ 1 & syn_1 & dust_1 & map_1 & \text{Synchrotron dominated} \\ 1 & syn_2 & dust_2 & map_2 & \text{Cleanest channel} \\ \dots & \dots & \dots & \dots & \\ 1 & syn_n & dust_n & map_n & \text{Dust dominated} \end{array}\right)$$

Template subtraction

$$CMB = map_2 - \frac{syn_2}{syn_1} map_1 - \frac{dust_2}{dust_n} map_n$$

- **CMB cleaning**
- **Exploits a few suitable channels**
- **Still needs mixing matrix estimation**

Mixing matrix estimation

- Parametrized mixing matrix e.g. CCA (Bonaldi et al. 2006, Ricciardi et al. 2010), Commander (Eriksen et al. 2006), Miramare (Stompor et al. 2009)
    - CMB: blackbody
    - Synchrotron: power-law (parameter βs)
    - Dust: grey-body (parameters βd, Td)
    - AME, free-free, ….
- Reduce the number of unknowns
- Model dependent

$$x = \mathbf{H}s + n$$

CCA’s Mixing matrix estimation

- Using covariance between frequency maps
  - In the pixel domain (CCA, Bonaldi et al. 2006)

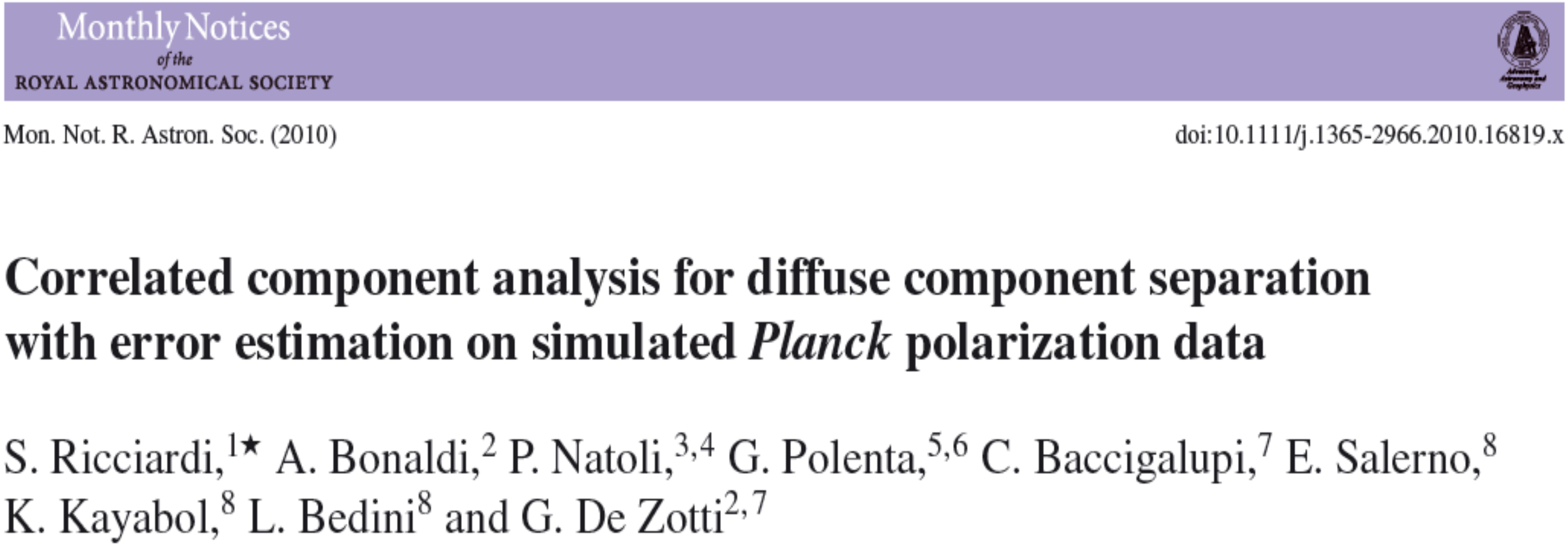
$$\boldsymbol{C}_x(\tau, \psi) = \boldsymbol{H}\boldsymbol{C}_s(\tau, \psi)\boldsymbol{H}^{\mathrm{T}} + \boldsymbol{C}_n(\tau, \psi).$$

  - In the Fourier domain (HCCA, Ricciardi et al. 2010)

$$\widetilde{\boldsymbol{C}}_x = \widetilde{\boldsymbol{B}}\boldsymbol{H}\widetilde{\boldsymbol{C}}_s\boldsymbol{H}^{\mathrm{T}}\widetilde{\boldsymbol{B}}^{\dagger} + \widetilde{\boldsymbol{C}}_n,$$

CCA's Mixing matrix estimation

- Estimation on high resolution Q and U maps
- Process sky patches for spatial variability of βs, βd
- Not a pixel-by-pixel estimation!
  - Low resolution spectral index maps
  - Good performance with high noise/multiple components
- The output is used to compute suitable linear mixture W
- Errors on the mixing matrix are propagated to maps and power spectra



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Correlated component analysis for diffuse component separation with error estimation on simulated *Planck* polarization data

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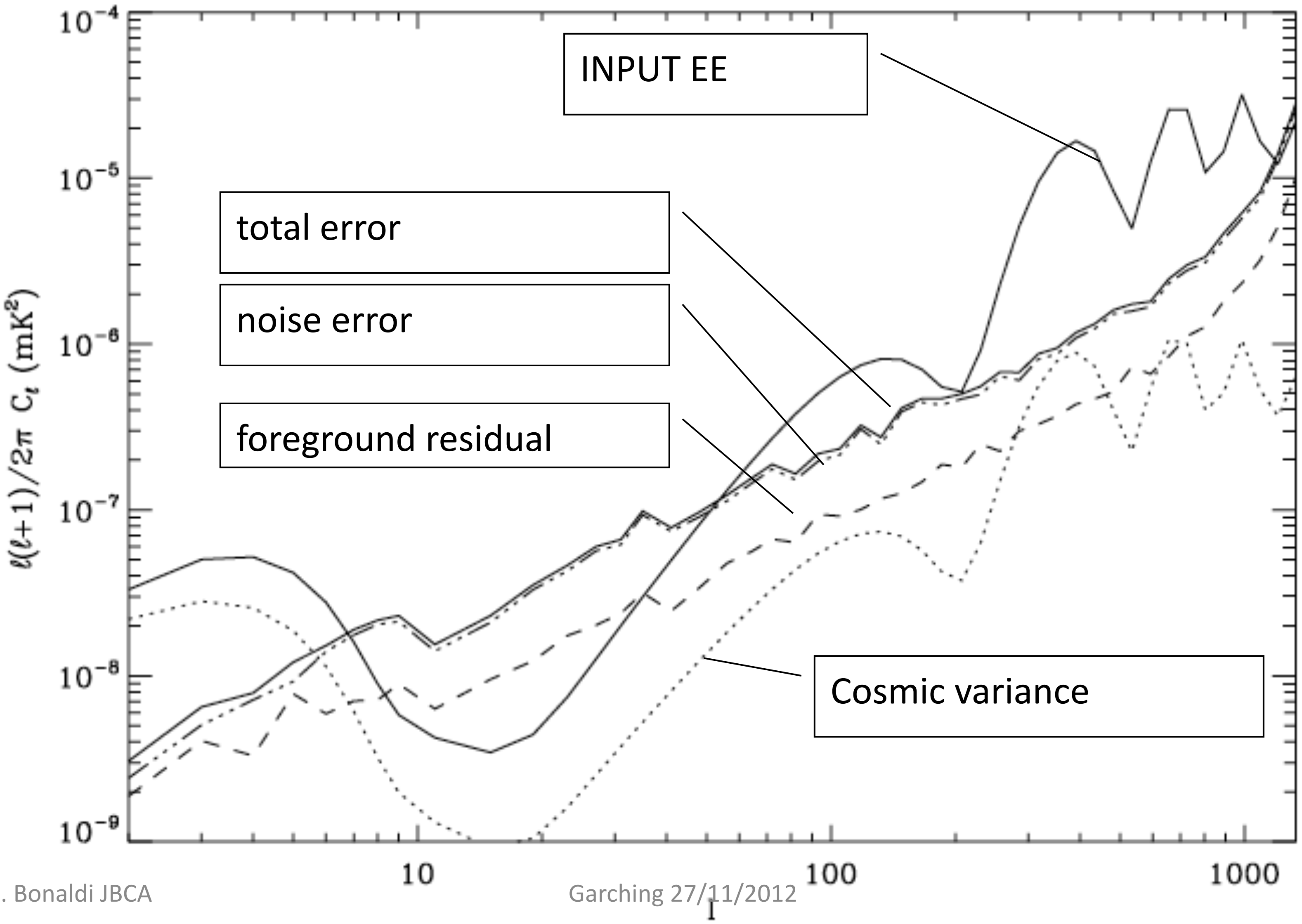
K. Kayabol,[8] L. Bedini[8] and G. De Zotti[2,7]

- Simulated Planck data
- Pixel-domain and harmonic-domain CCA
- Errors on spectral indices (mixing matrix)
- Errors propagation to separated components and power spectra
- Assessment of comp sep errors and noise errors

Ricciardi et al. (2010)

E-modes

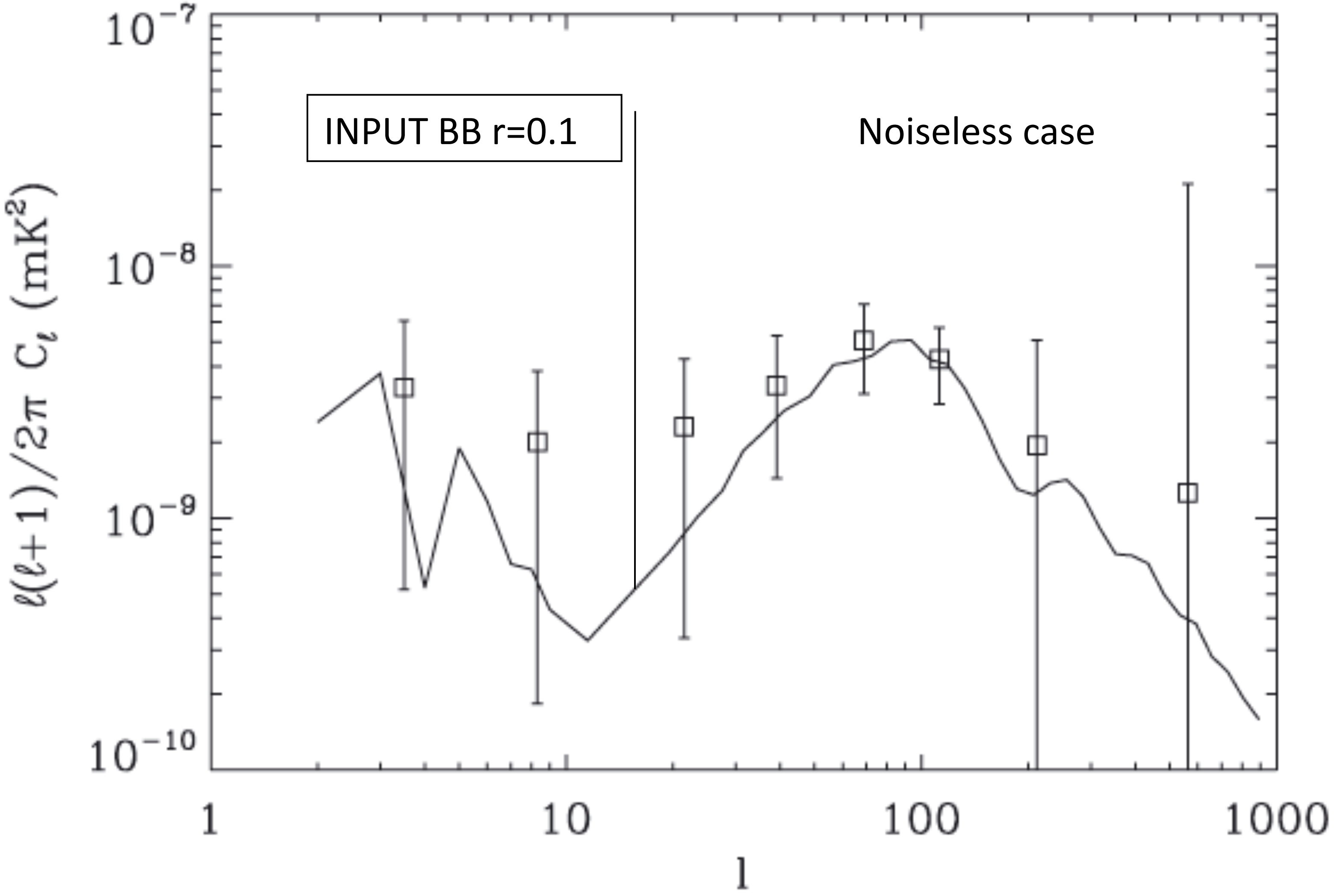
Planck simulated data



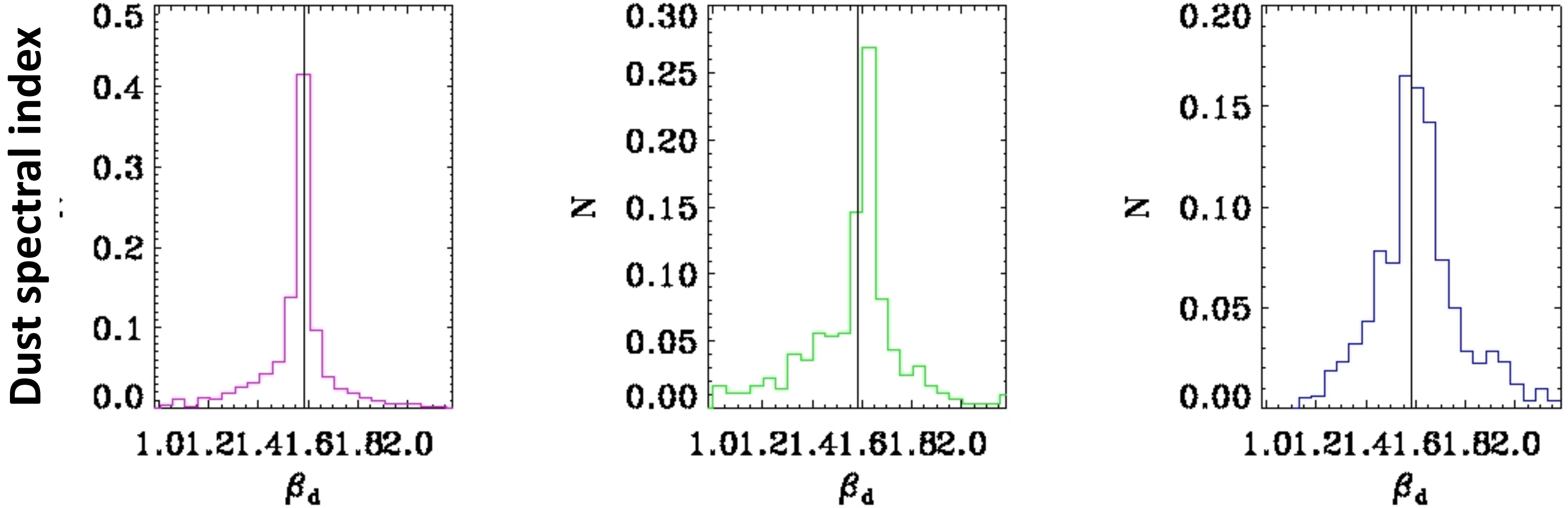
Ricciardi et al. (2010)

B-modes

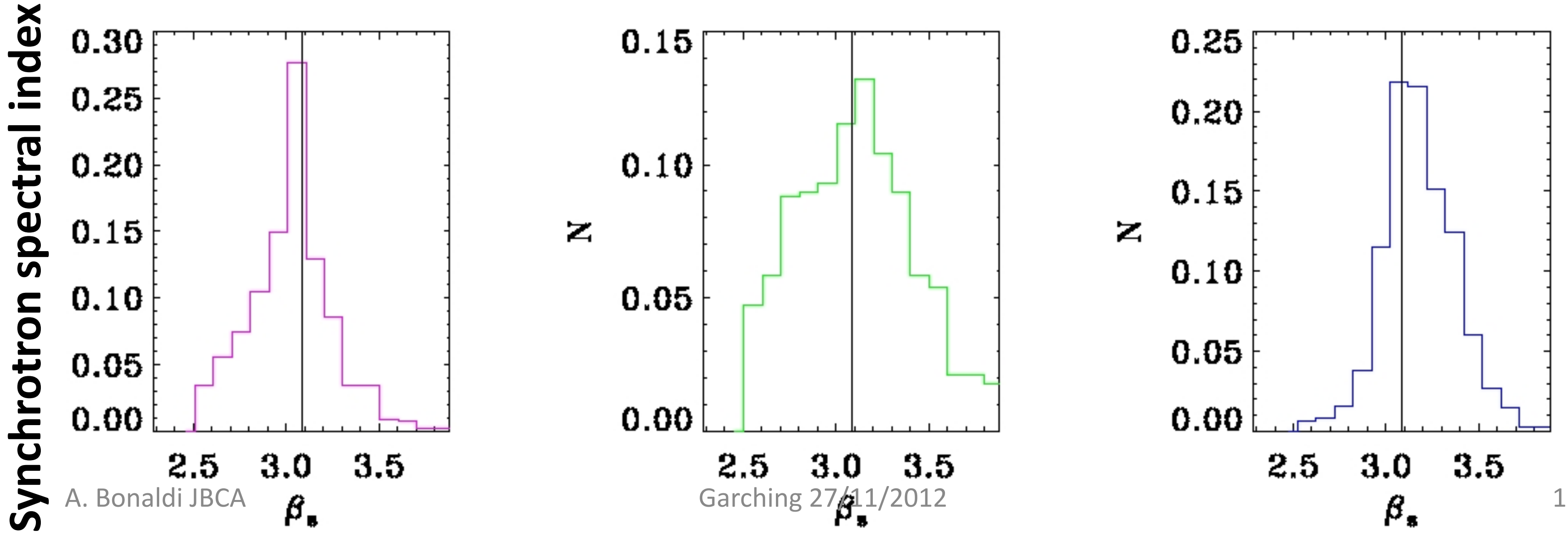
Planck simulated data



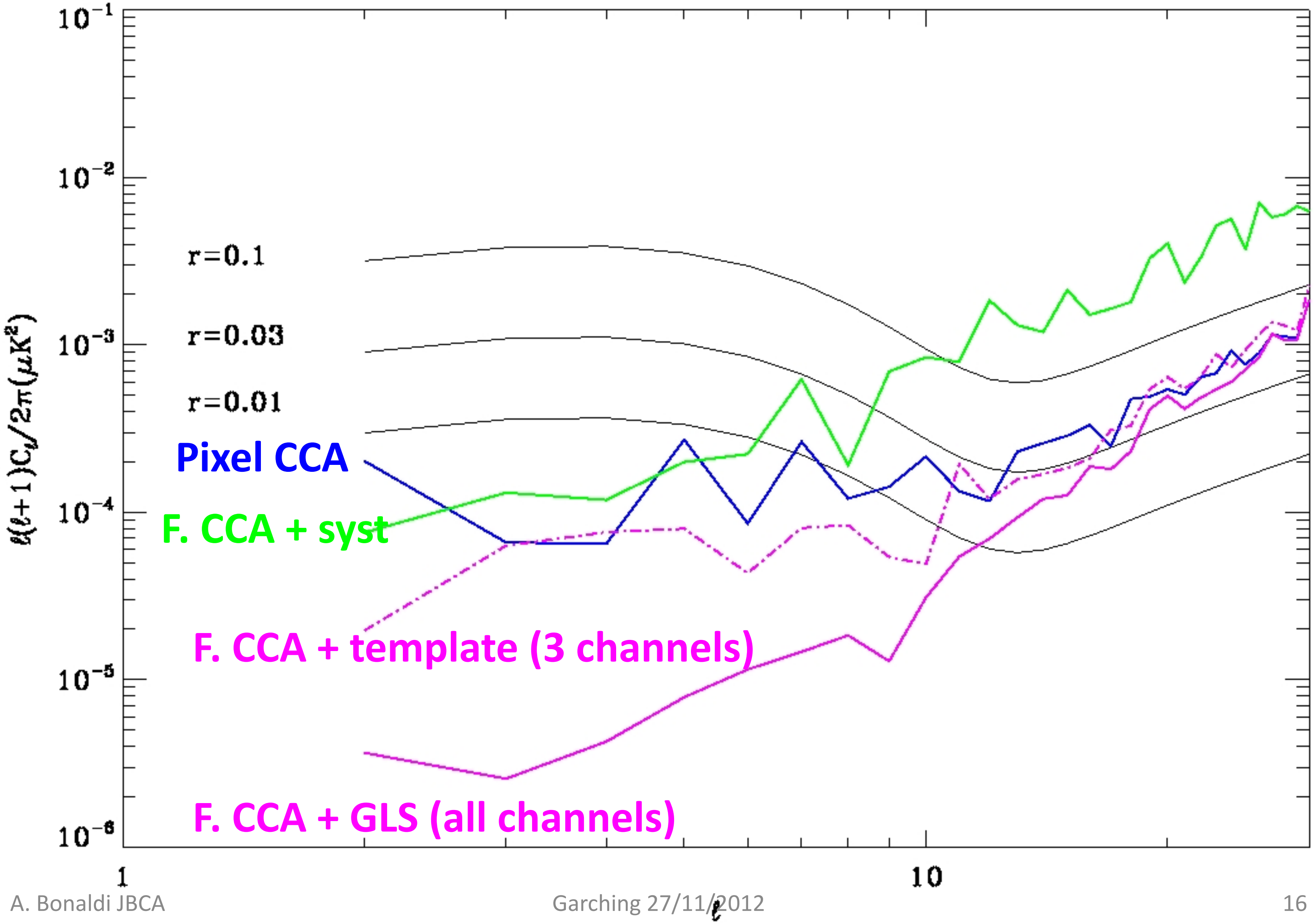
Latest results on simulated Planck



Fourier CCA **Fourier + syst. error** **Pixel CCA**



Latest results on simulated Planck



Combined foreground and noise forecaster

- Given the linear mixture component separation (with matrix W) we forecast B-mode detection
- Instrumental noise and residual foreground residuals
- Noise error:

$$\Delta CMB_{NOISE} = \underbrace{\sqrt{\frac{2}{(2l+1) f_{sky} n_{bin}}}}_{\text{Variance of actual noise bias}} \underbrace{\sum_{\nu} w_{\nu}^{CMB\,2} N_{l}}_{\text{Noise bias expectation}}$$

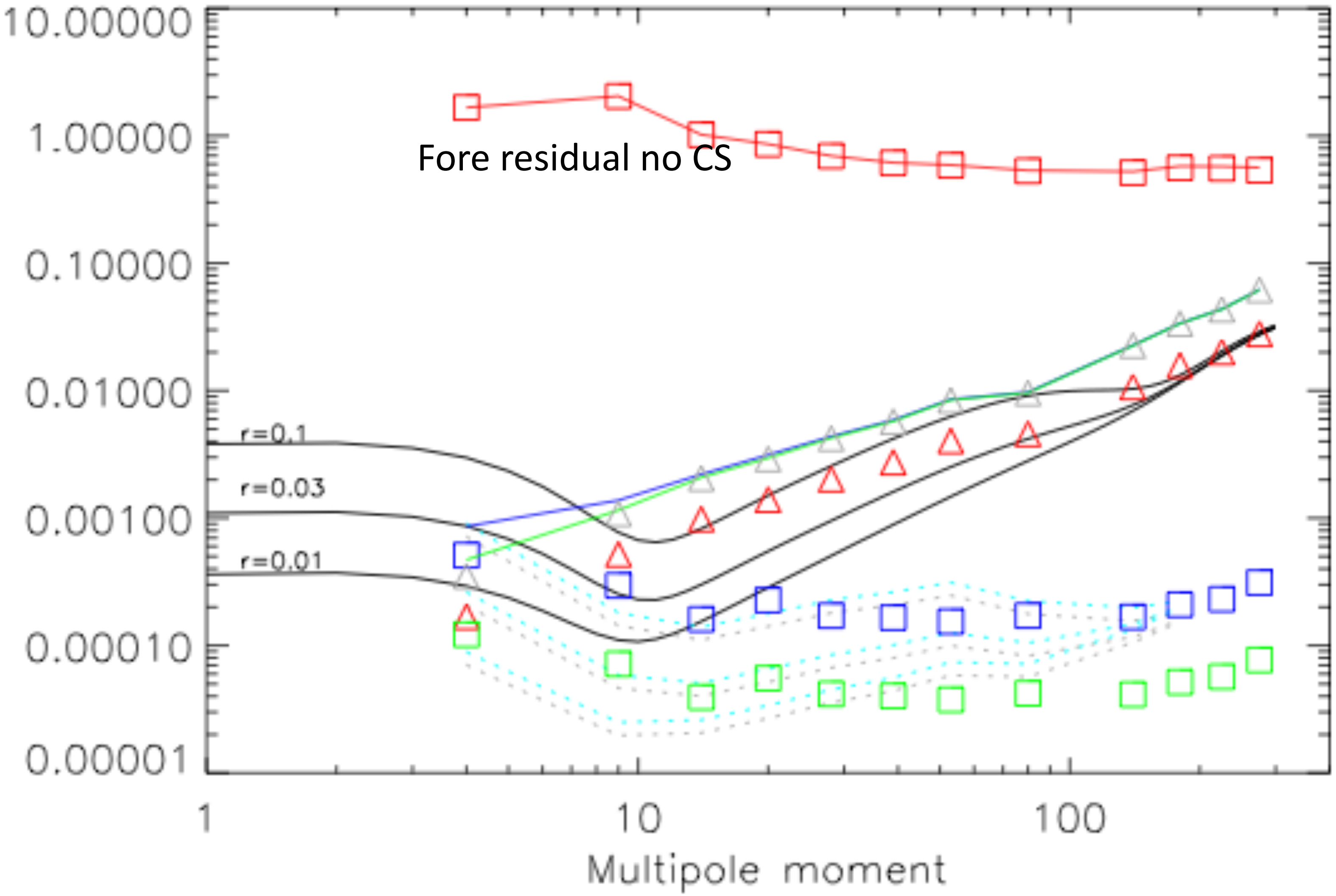
Combined foreground and noise forecaster

- The map of the foreground residuals error:

$$(WH - I)s$$

  - Power spectrum of the residuals is computed out of a Galactic mask
  - **s, H =** sky model
  - **W** from estimated **H**: the foreground error increases with the mismatch between true and estimated H

Forecasts for Planck (Bonaldi & Ricciardi 2011)

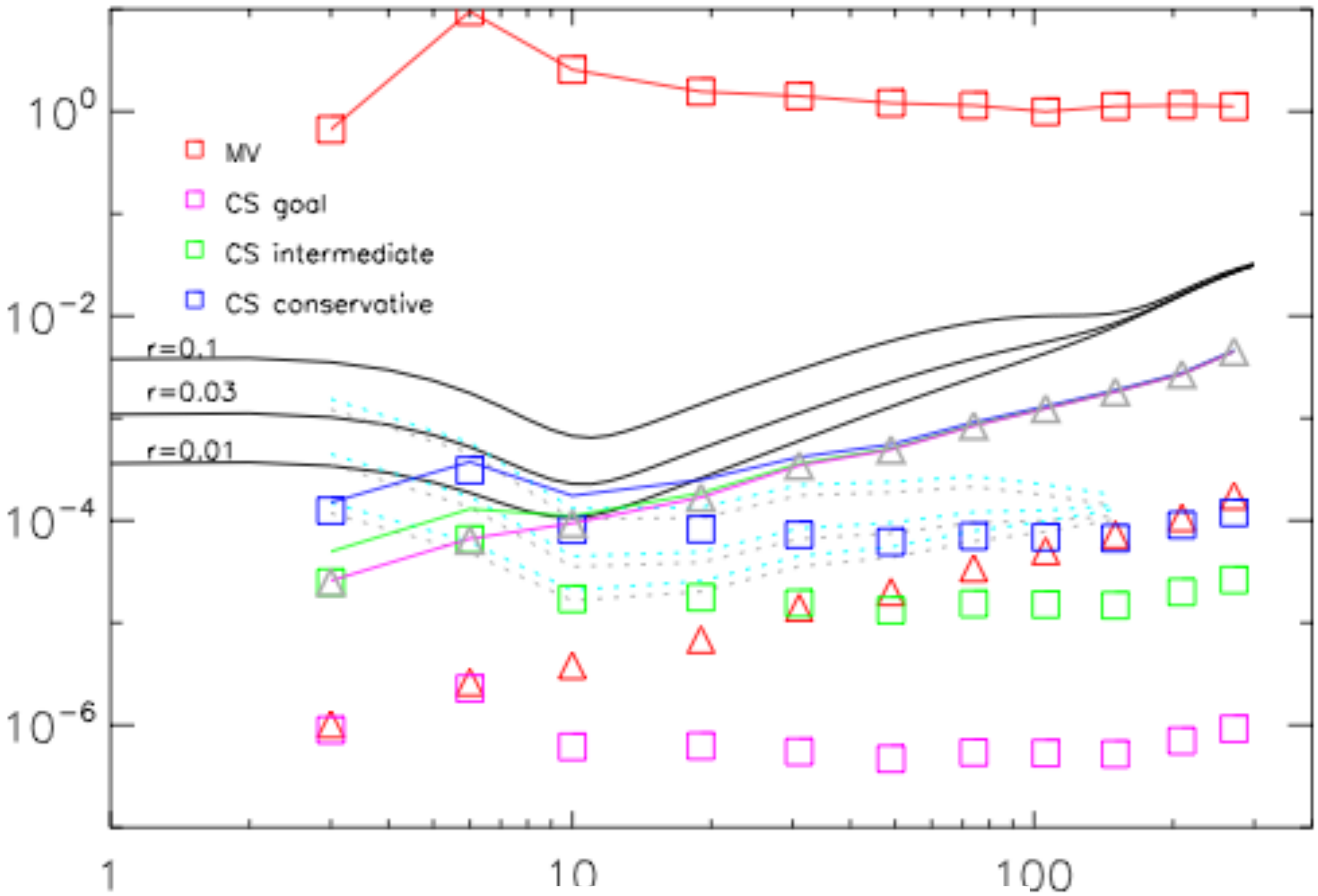


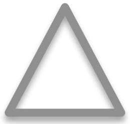
Fore residual no CS

△ Noise with CS

Fore residual with CS: conservative □ and intermediate □

Forecasts for COrE (Bonaldi & Ricciardi 2011)





Noise
with CS

* Baseline configuration De Bernardis & Masi 2010

Fore residual with CS: conservative 🟦 intermediate 🟩 and goal 🟪

Conclusions

- Component separation important for polarization
  - Crucial for B-modes
  - Next generation probes will be foreground dominated
- Accuracy depends on the knowledge of the mixing matrix
- The CCA estimates the mixing matrix
  - Patch-by-patch estimation
  - Pixel and Fourier domain
  - Fully tested for Planck
- Several cleaning methods based on mixing matrix
  - GLS
  - Template subtraction