The 2nd Symposium on
Cosmology and Ali CMB Polarization Telescope

Foreground removal pipeline in AliCPT

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Outline

- Science and current status of the project
- Progress on foreground removal: temperature & polarization
- Summary and Outlook

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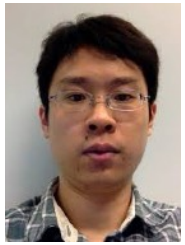
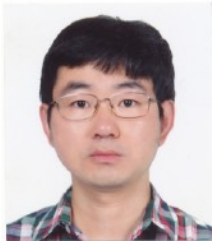

B. Hu (BNU)

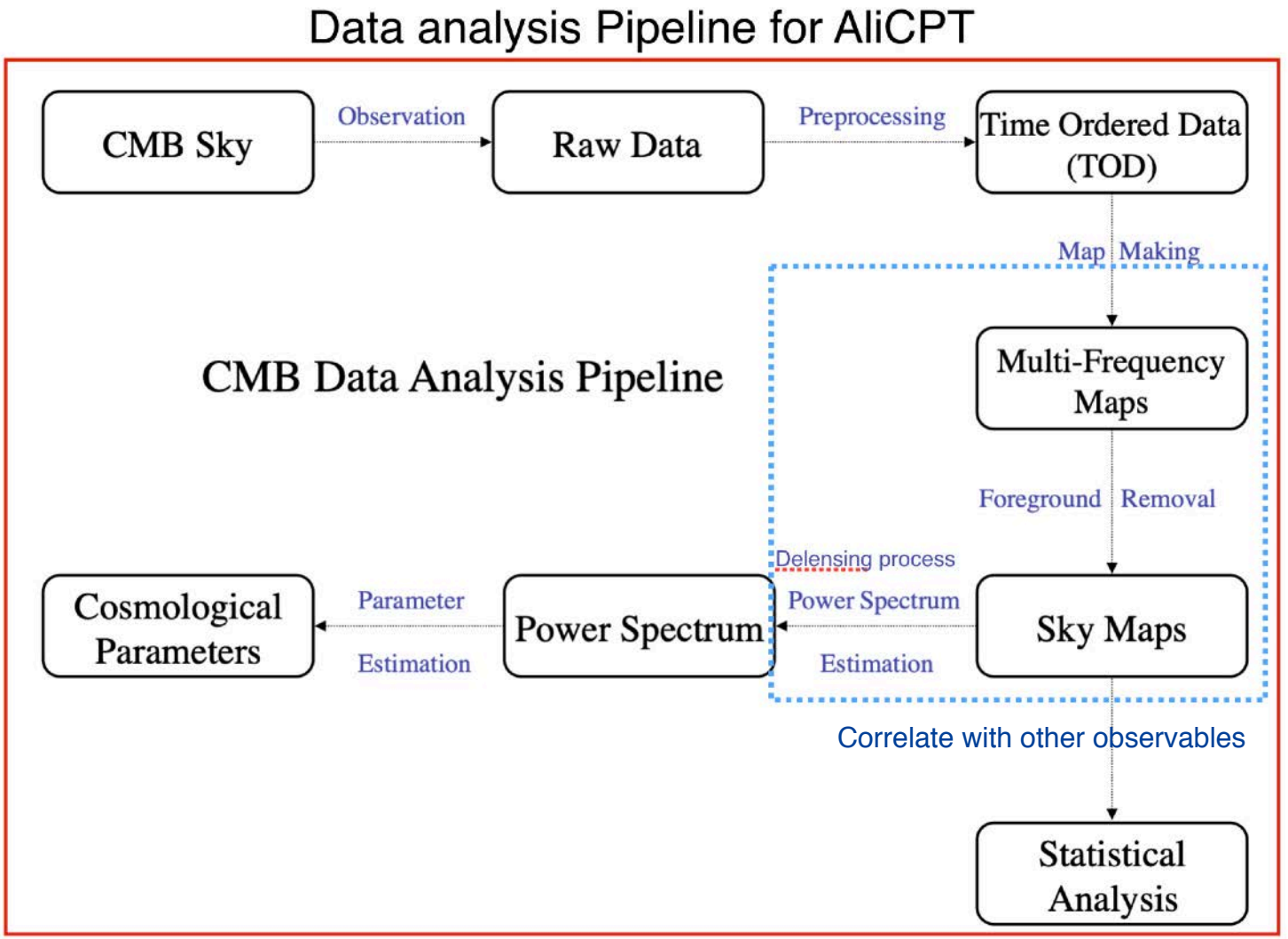

B. Yue (NAOC)

Main tasks and science

- **Foreground removal:** one of major challenges in B-mode detection
  - proposed a new algorithm for foreground removal - ABS
  - developing pipelines (at least 2-3) for AliCPT - ILC/ABS/SMICA

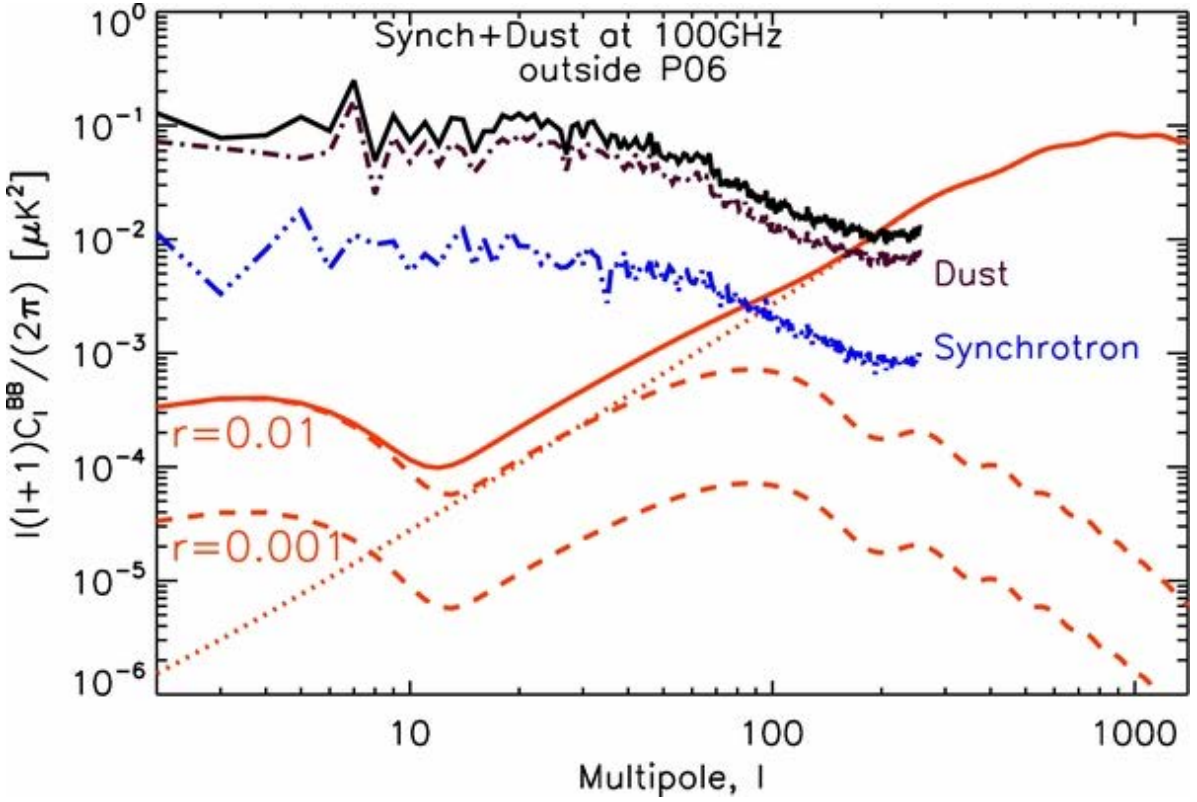
- **Foreground science:**
  - to reconstruct magnetic/dusts/electron fields
  - to understand the physical origins of foreground components

Data analysis pipeline

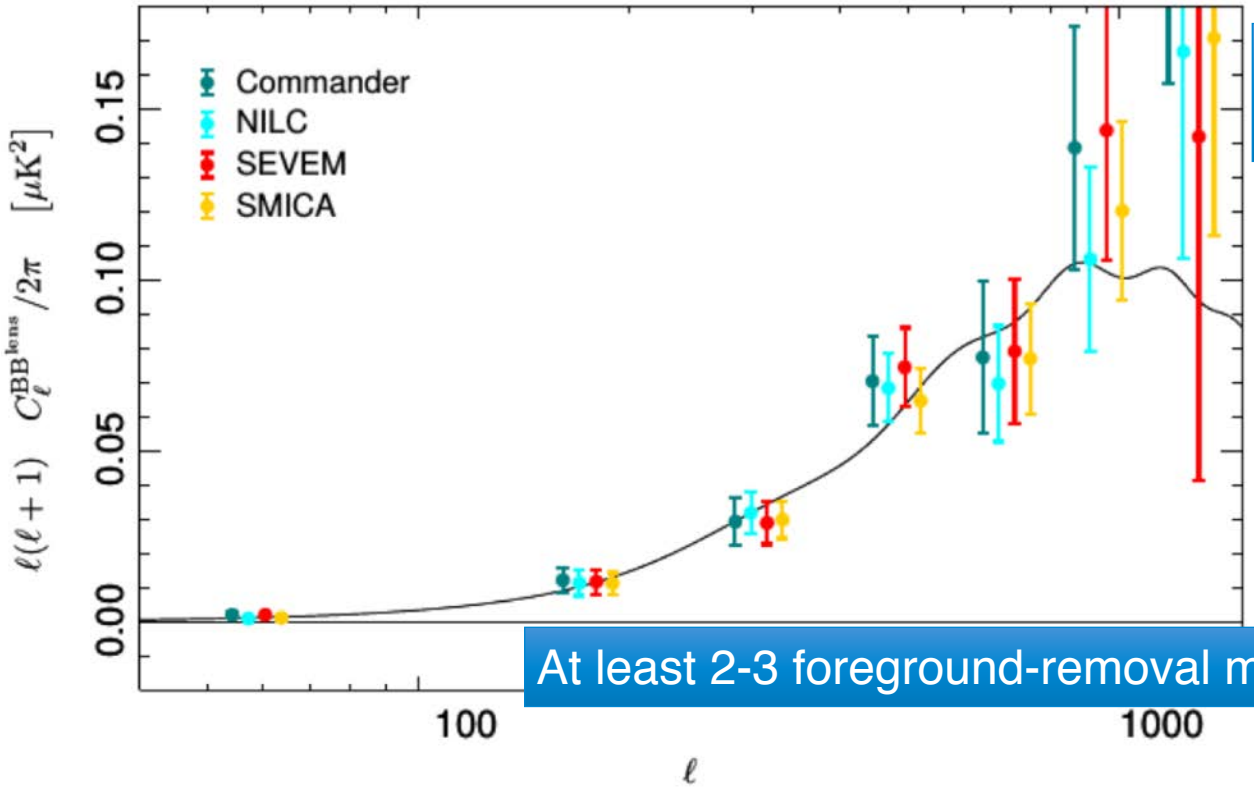


Foreground Challenge

- **Complex dust polarization**
- **subtract foregrounds (synch+dust) down to tens of nK if r~ 0.01**



Foreground removal methods in Planck



Cross-check is important for validation!

At least 2-3 foreground-removal methods to be used in AliCPT

- parametric/non-blind - model fitting
  - COMMANDER (Gibbs sampling)
- non-parametric/blind - data driven
  - SMICA, NILC, SEVEM

Foreground removal — ABS

We find an Analytical Blind Separation method (ABS)

- Goal: to solve for CMB power spectrum without any assumptions on foregrounds; Intuitively, this task seems to be impossible!

- Measured cross band powers between frequency channels

$$\mathcal{D}_{ij}(\ell) = f_i^{\rm B} f_j^{\rm B} \mathcal{D}_{\rm B}(\ell) + \mathcal{D}_{ij}^{\rm fore}(\ell)$$

An analytical unique solution of $D_B(l)$ achieved by the Sylvester's determinant theorem as long as $M < N_f$

M: rank of D^{fore}, M non-zero eigenvalues
N_f: number of frequency channels

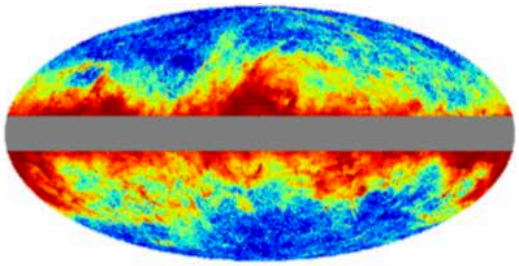
the μ-th eigenvector of $\mathcal{D}_{ij}$ is $\mathbf{E}^{(\mu)}$

$$G_\mu \equiv \mathbf{f}^{\rm B} \cdot \mathbf{E}^{(\mu)}$$

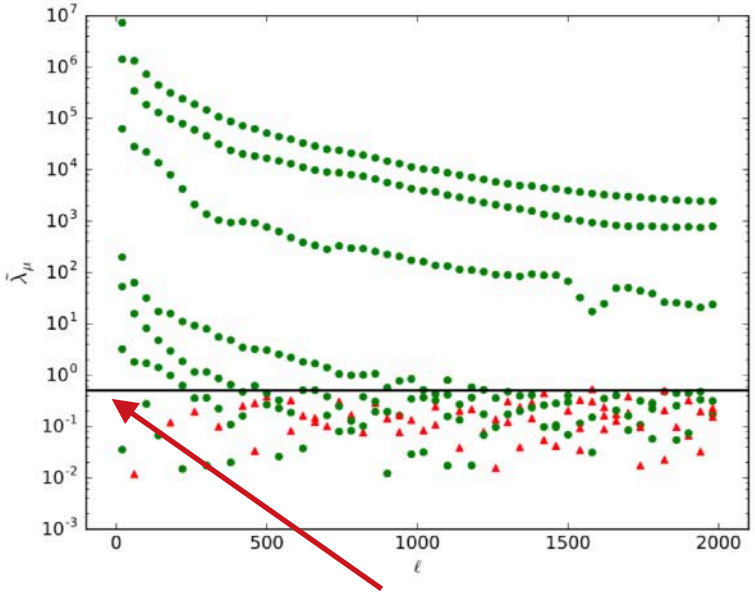
$$\mathcal{D}_{\rm B} = \left(\sum_{\mu=1}^{M+1} G_\mu^2 \lambda_\mu^{-1} \right)^{-1}$$

PJ Zhang et al, MNRAS 484,1616Z (2019)

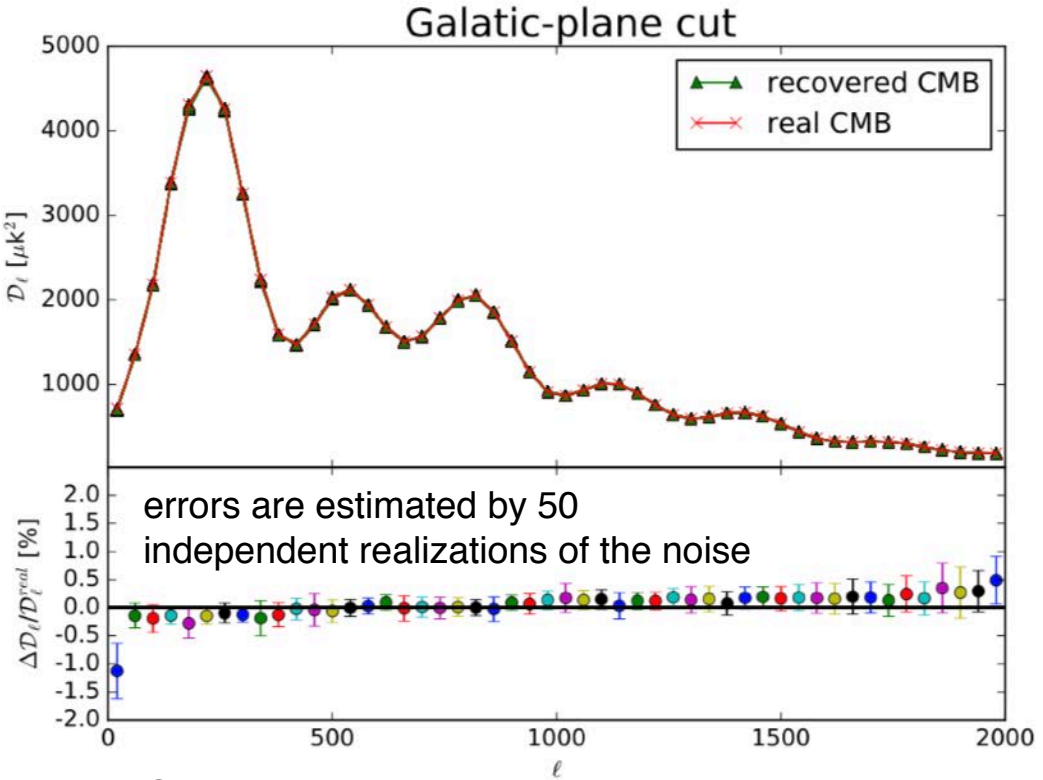
Tests in Planck Temperature maps



Eigenvalues of data matrix



Eigenmodes below 1/2 excluded, which are essentially noise-dominated modes



On average over all l-bins, the absolute error is about –0.56 μK^2 with 1-σ error of 2.66 μK^2.

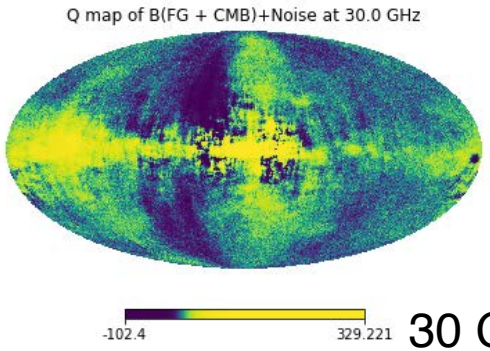
Yao et al, ApJS 848,44Z (2018)

Tests in Q/U maps

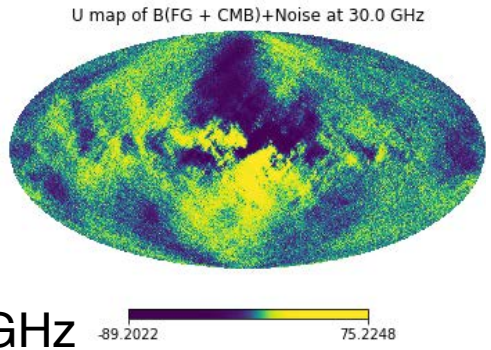
Simulation of polarization maps:

$$U/Q(\hat{n},\nu) = A(\hat{n},\nu) \otimes \left(f + s_{\rm CMB}\right)(\hat{n},\nu) + n(\hat{n},\nu)$$

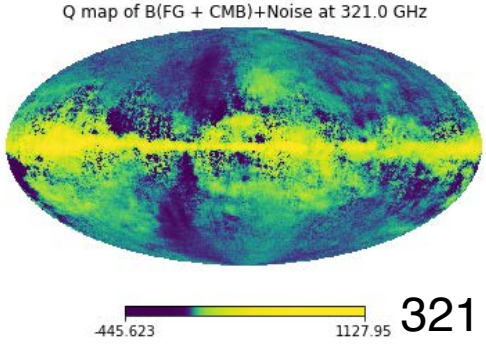
Q

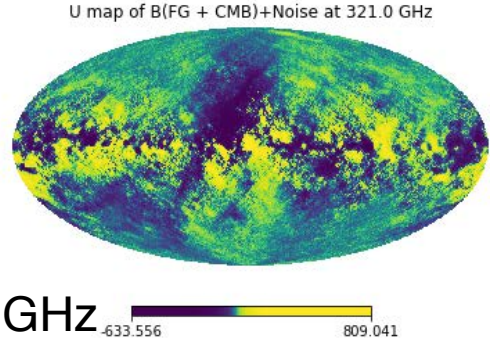


U



30 GHz





321 GHz

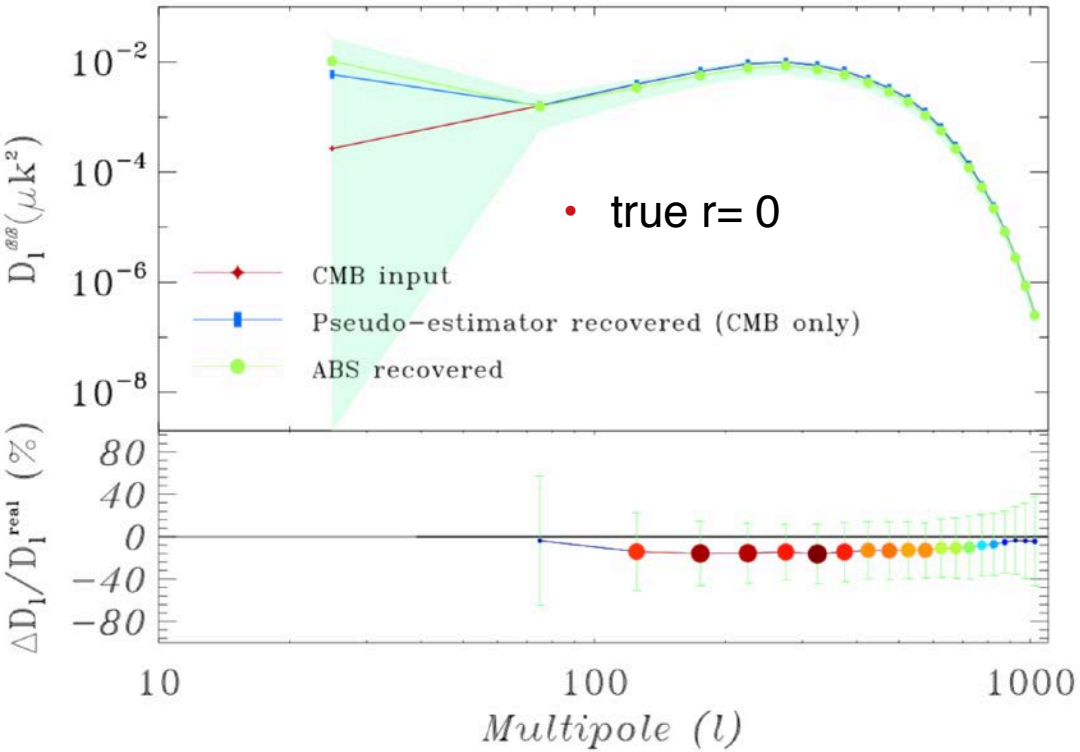
A PICO-like experiment

Band center (GHz)	Beam FWHM (arcmin)	noise level (μK_{CMB}- arcmin)
030	28.3	12.4
043	22.2	7.9
075	10.7	4.2
090	9.5	2.8
108	7.9	2.3
129	7.4	2.1
155	6.2	1.8
223	3.6	4.5
268	3.2	3.1
321	2.6	4.2

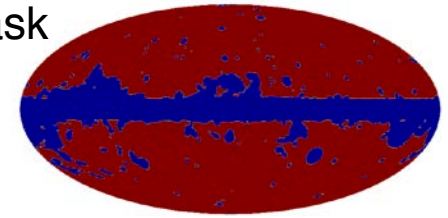
Santos &Yao et al, submitted to A&A

Results with separating E-B leakage

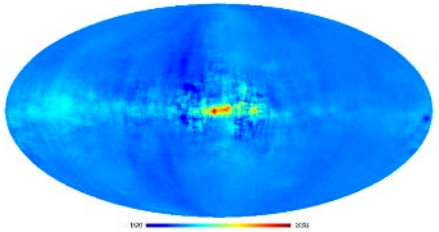
Apply ABS+ E/B separation (Smith & Zaldarriaga)



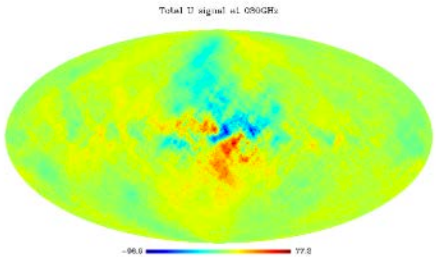
- mask



- Q



- U

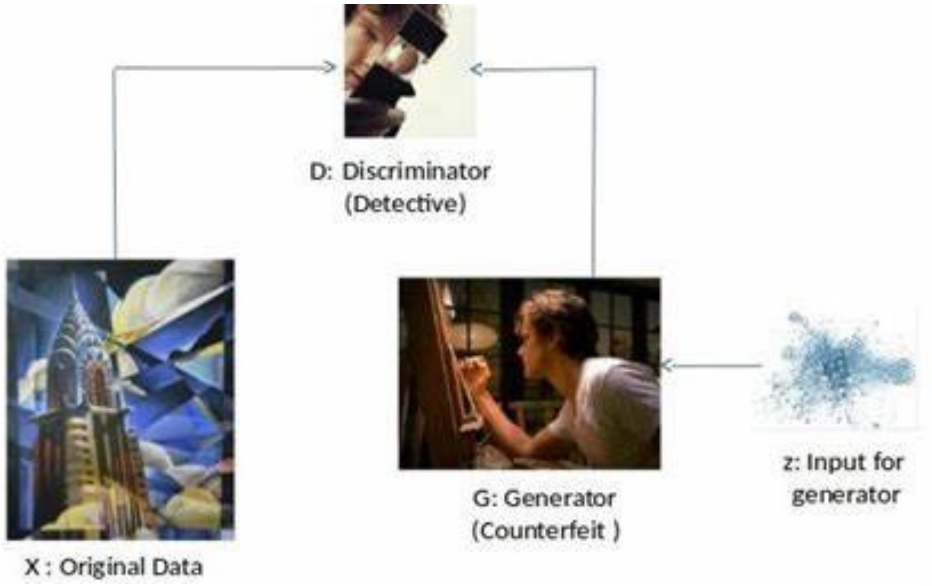


- Relative deviations of the recovered BB power spectrum ~ 20% on average at l<1000
- Big overestimate at the 1st l-bin, probably due to effects from the SZ E/B separation

Foreground removal - ML

If the frequency channels < foreground components? - above methods failed

Generative Adversarial Networks (GANs) are a way to make a generative model by having two neural networks compete with each other.



The **discriminator** tries to distinguish genuine data from forgeries created by the generator.

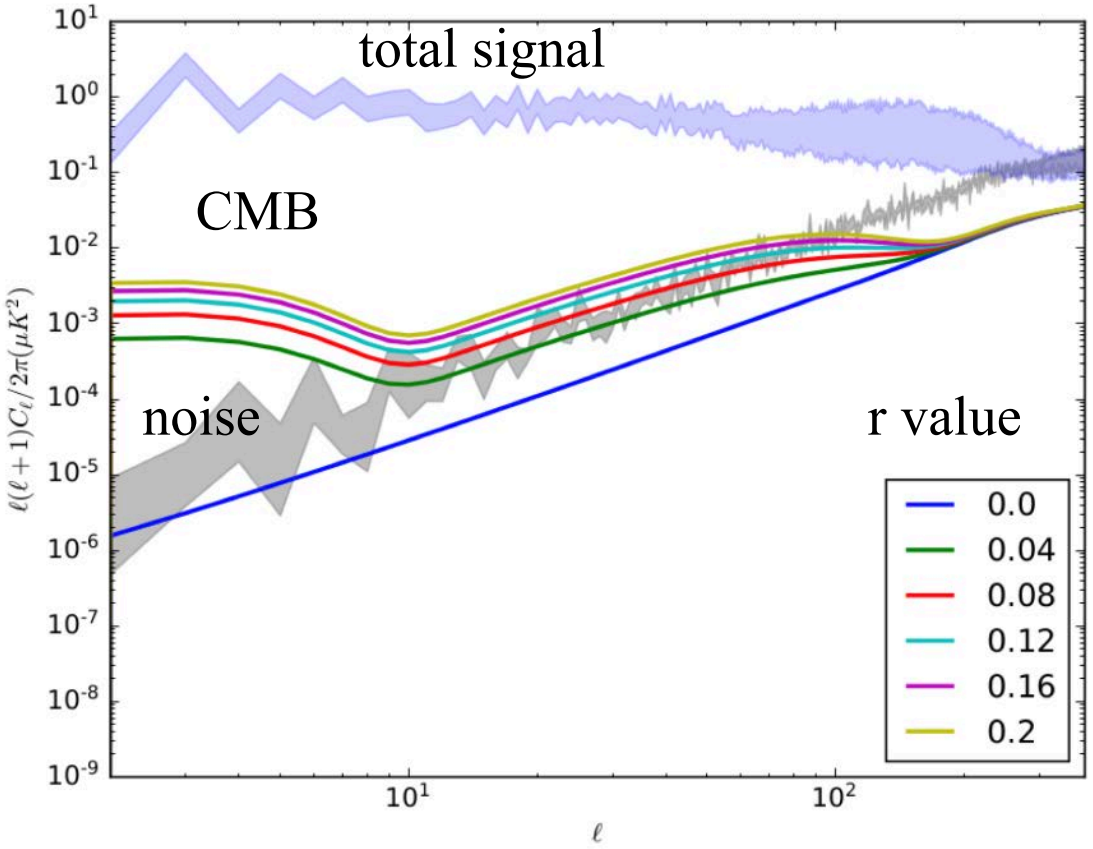
The **generator** turns random noise into immitations of the data, in an attempt to fool the discriminator.

Generative Adversarial Network (GAN)

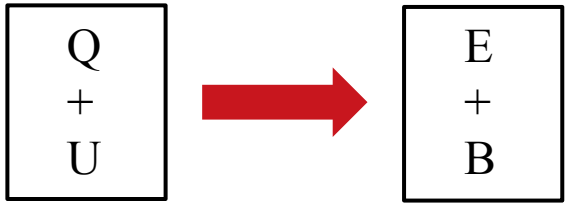
Goodfellow, 2014

Tests for ML method

components on the sky



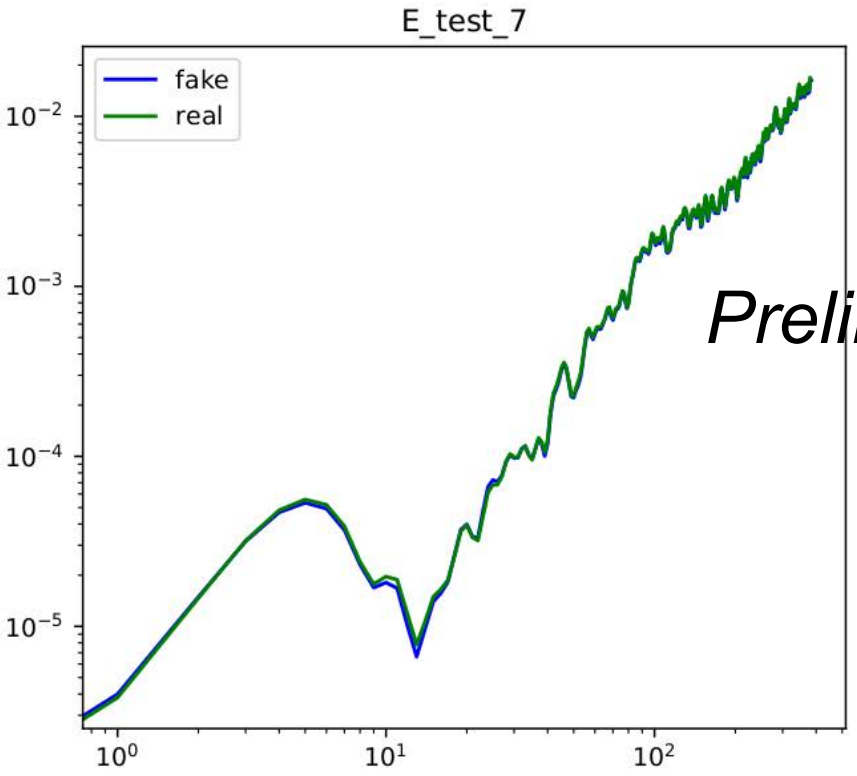
Only 95, 150, 353GHz



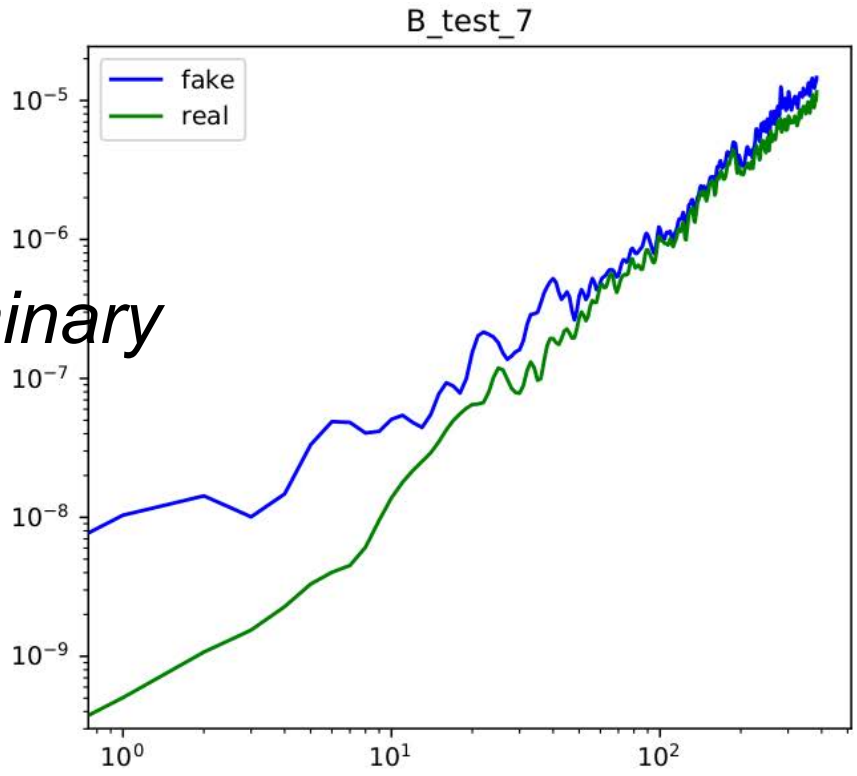
- Q/U maps measured on a partial sky (~f_{sky} = 15%)
- In training set, simultaneously learn the partial-sky (Q&U + E&B)
- Here E&B are converted from full-sky Q&U, which could automatically avoid E&B leakage problem
- Finally, for given Q&U, ML returns E&B maps

Results from ML method

E-mode



B-mode



Preliminary

Yao et al., in preparation

Summary and Outlook

- Constructing a pipeline with multiple methods (ABS/ILC/SMICA/Template fitting or their variants) for foreground removal
- Details of data selection, masking, preprocessing, convolution/deconvolution, error propagation, etc., are also the hard parts in the pipeline, which should be well investigated as the devil is in the details
- Foreground itself may provide plenty of information about our Galaxy (electrons and magnetic field …)
- Building delensing pipelines and reconstructing the lensing map, which is important when $r < 0.01$
- Cross-correlating AliCPT lensing with galaxies/lensing/CIB/shear/y-map…, to mitigate systematics and to improve understanding of DE, Planck systematics, galaxy formation, AI, tSZ, …