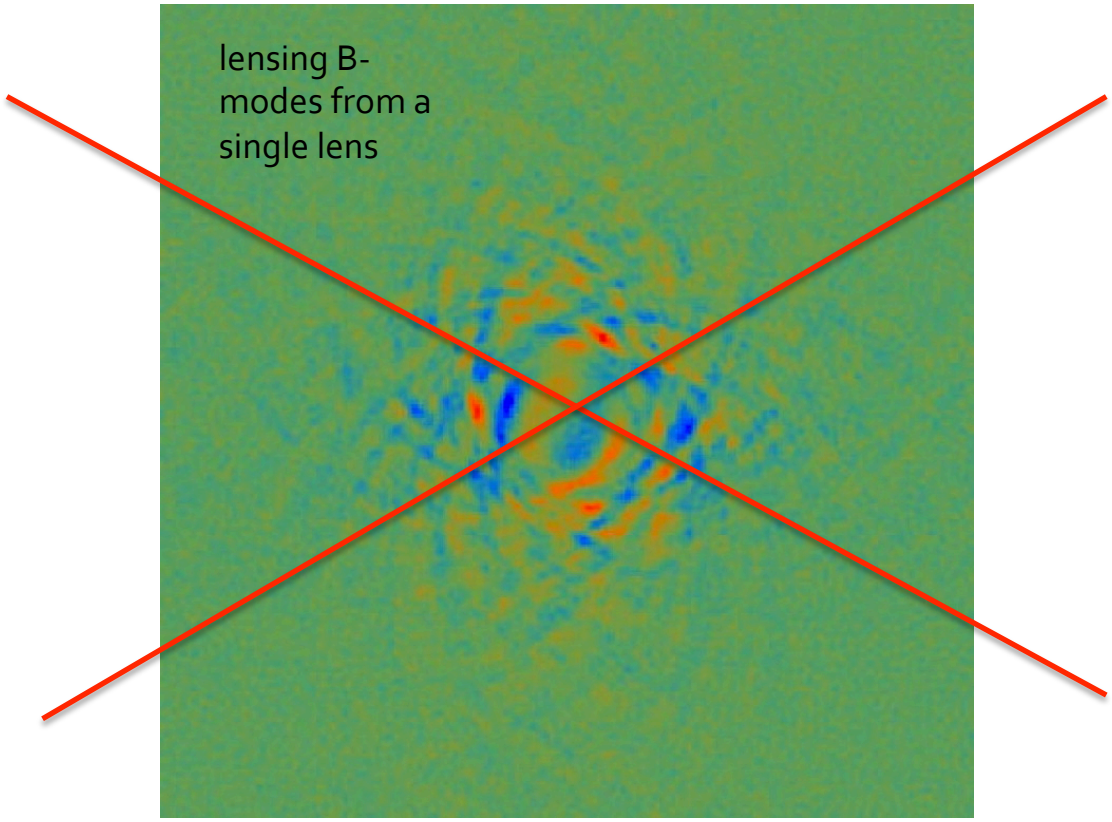
Delensing LiteBIRD's B-modes



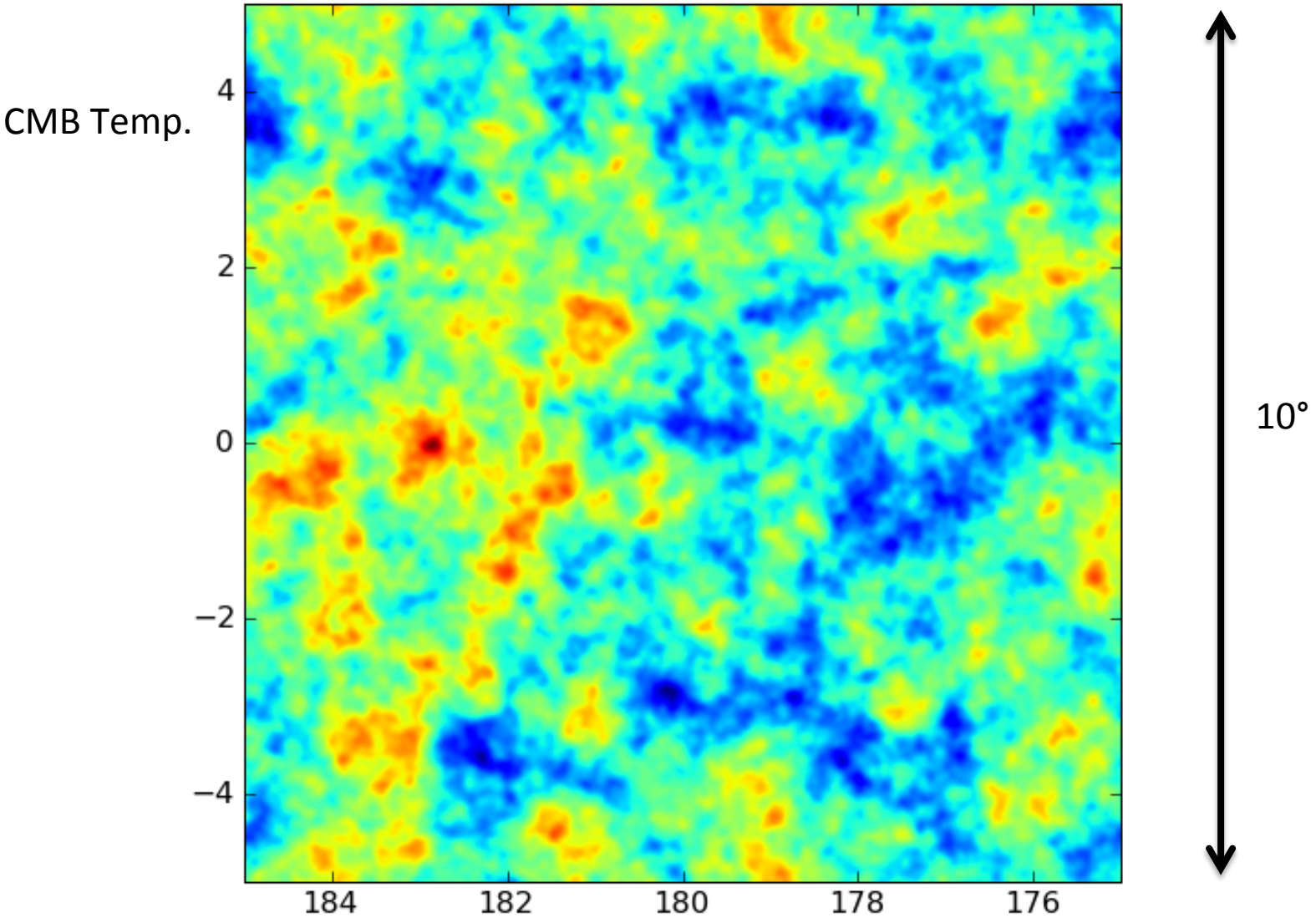
Blake Sherwin
Miller Fellow, UC Berkeley

(work with T. Namikawa, M. Schmittfull and others)

Outline

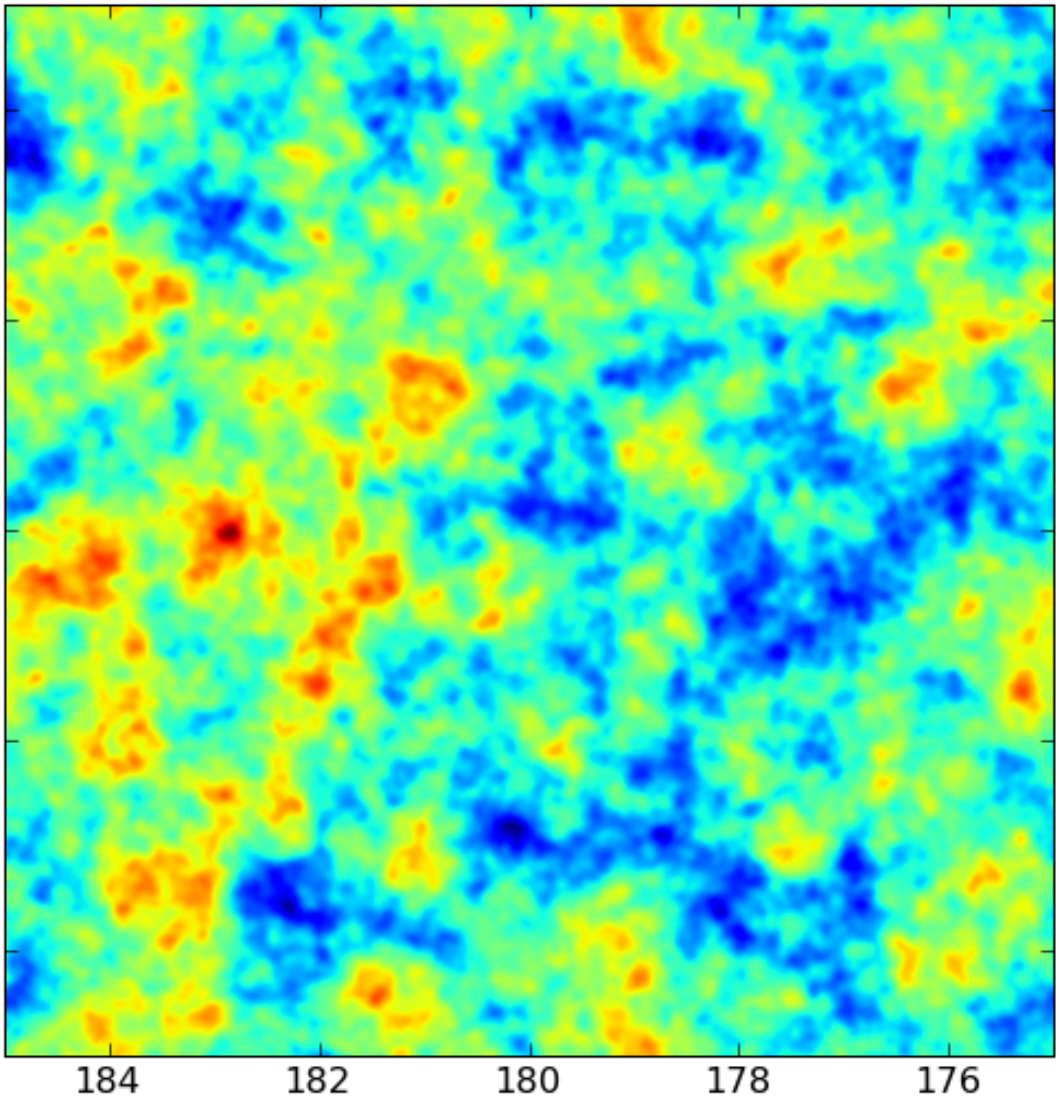
- Delensing the B-mode polarization: motivation and methods
- Forecasted LiteBIRD Delensing Performance with:
  - Lensing reconstruction from CMB S_4 or S_3
  - CIB and Large Scale Structure
- Subtleties, Challenges and Open Questions for LiteBIRD Delensing

CMB temperature with no r



CMB temperature with very small r

CMB Temp. (cartoon picture)

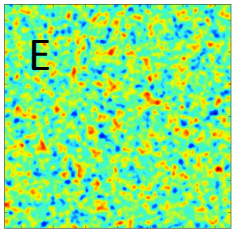


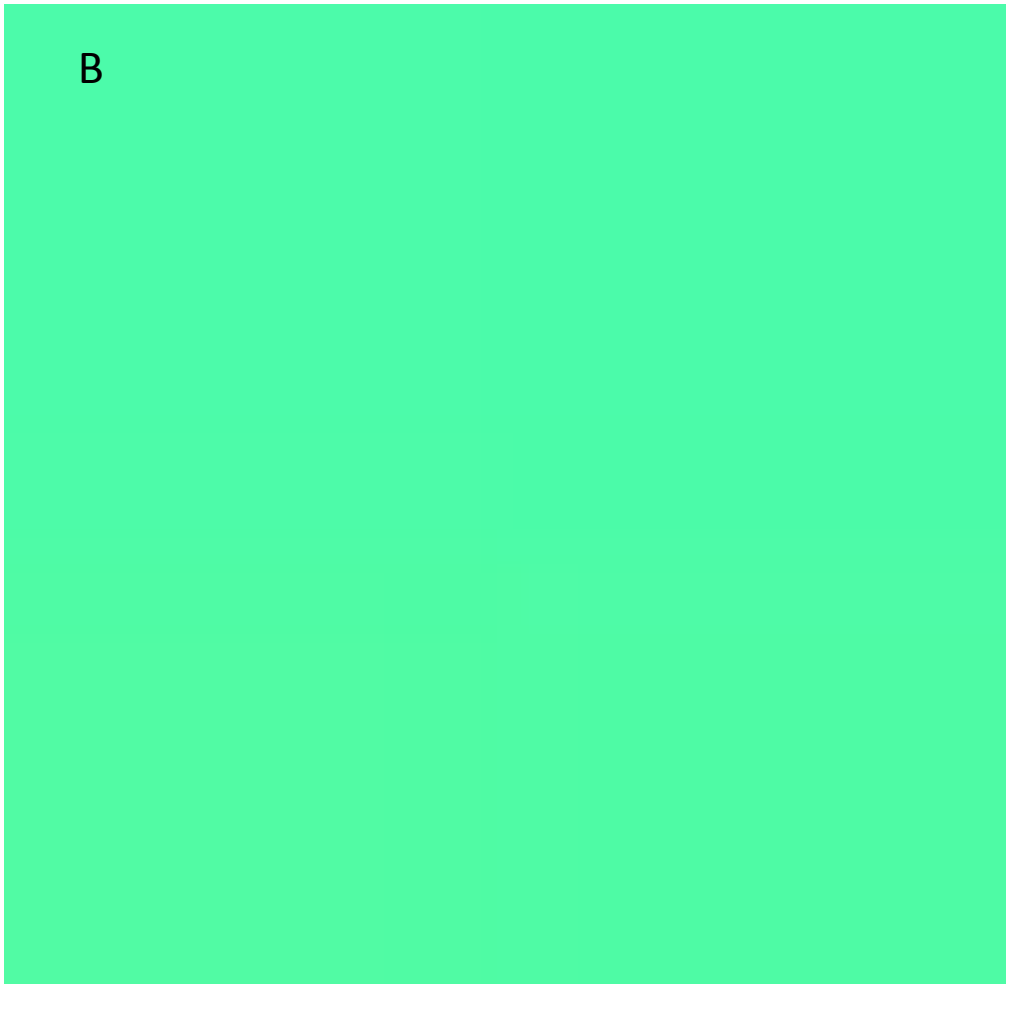
10°

difficult to find r due to cosmic variance and confusion from scalar density perturbations

CMB B polarization* with r = 0

No leading order signal from scalar density perturbations!



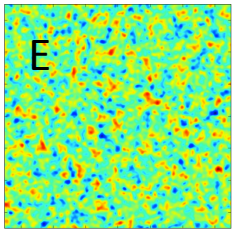


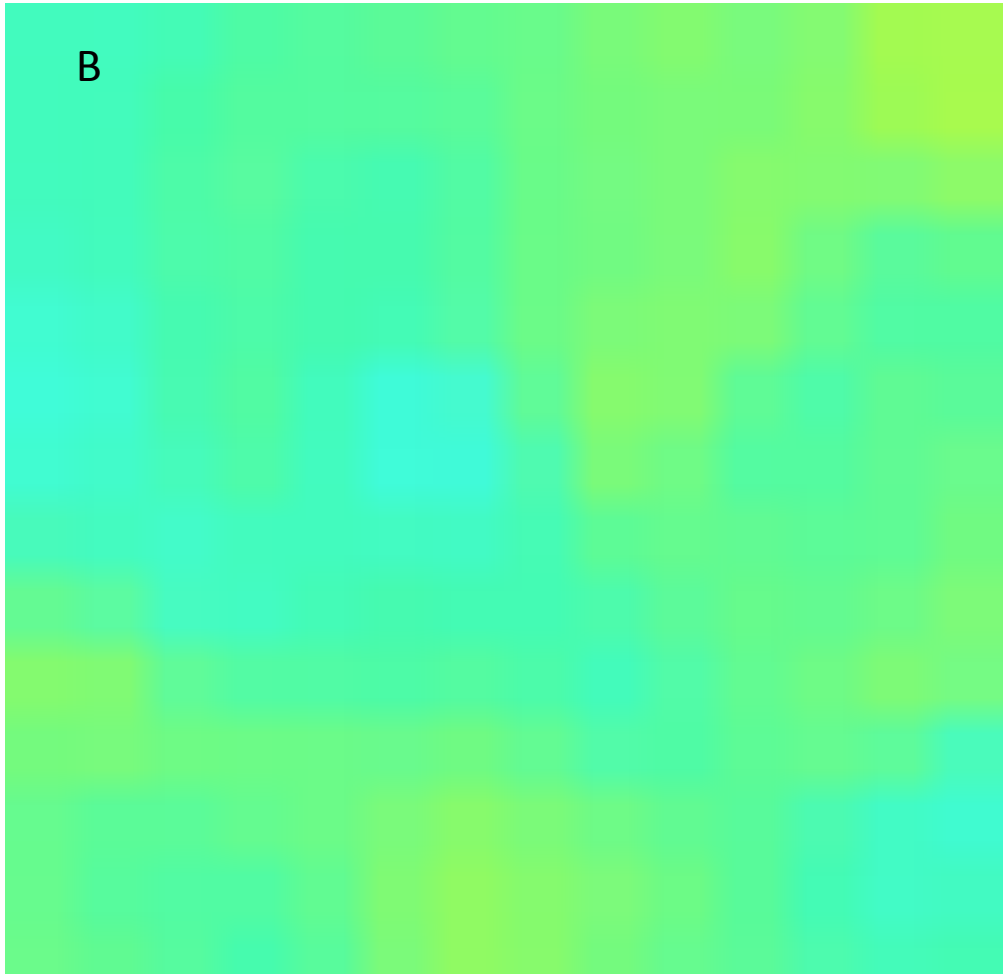
*ignoring foregrounds, lensing for now

CMB B polarization* with small r

See r clearly as there is no background variance from scalar density perturbations

B-modes are a "null channel"





10°

*ignoring foregrounds, lensing for now

A Challenge: Gravitational Lensing

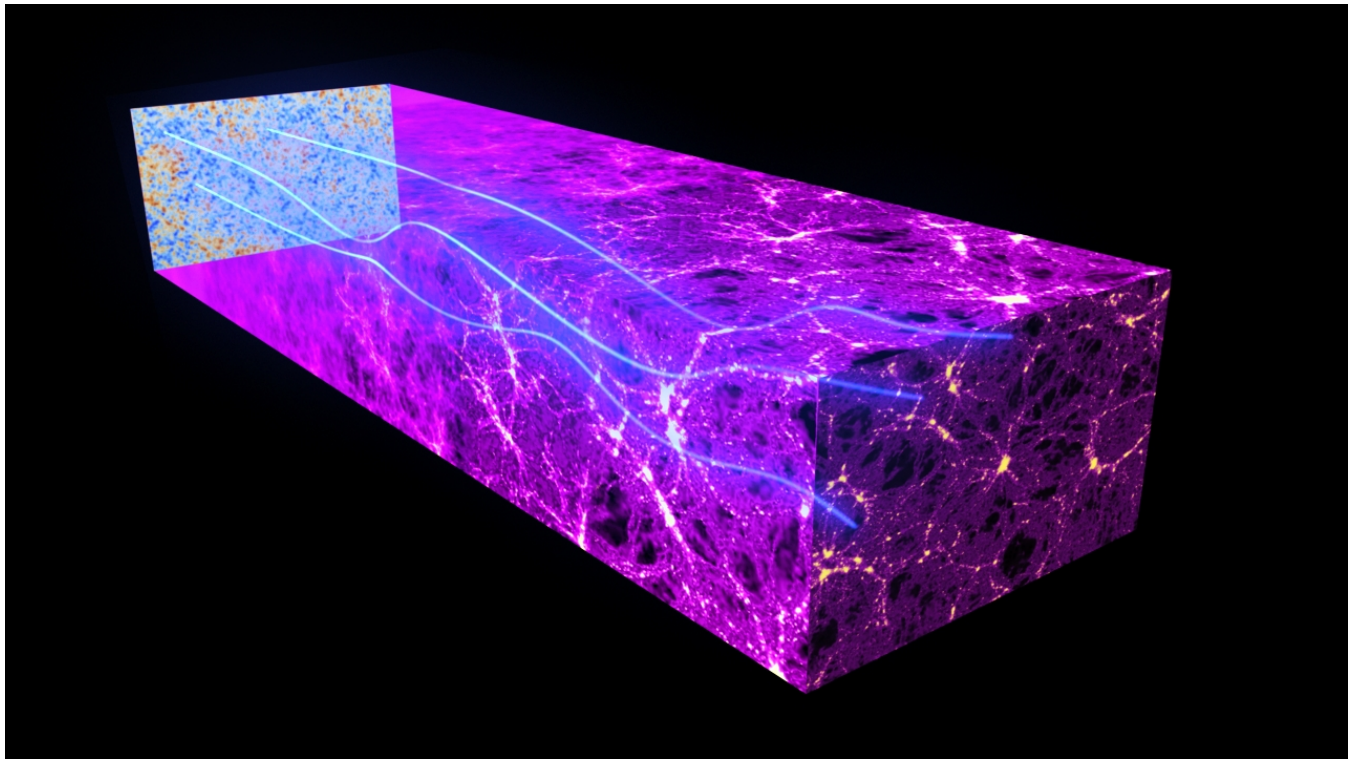
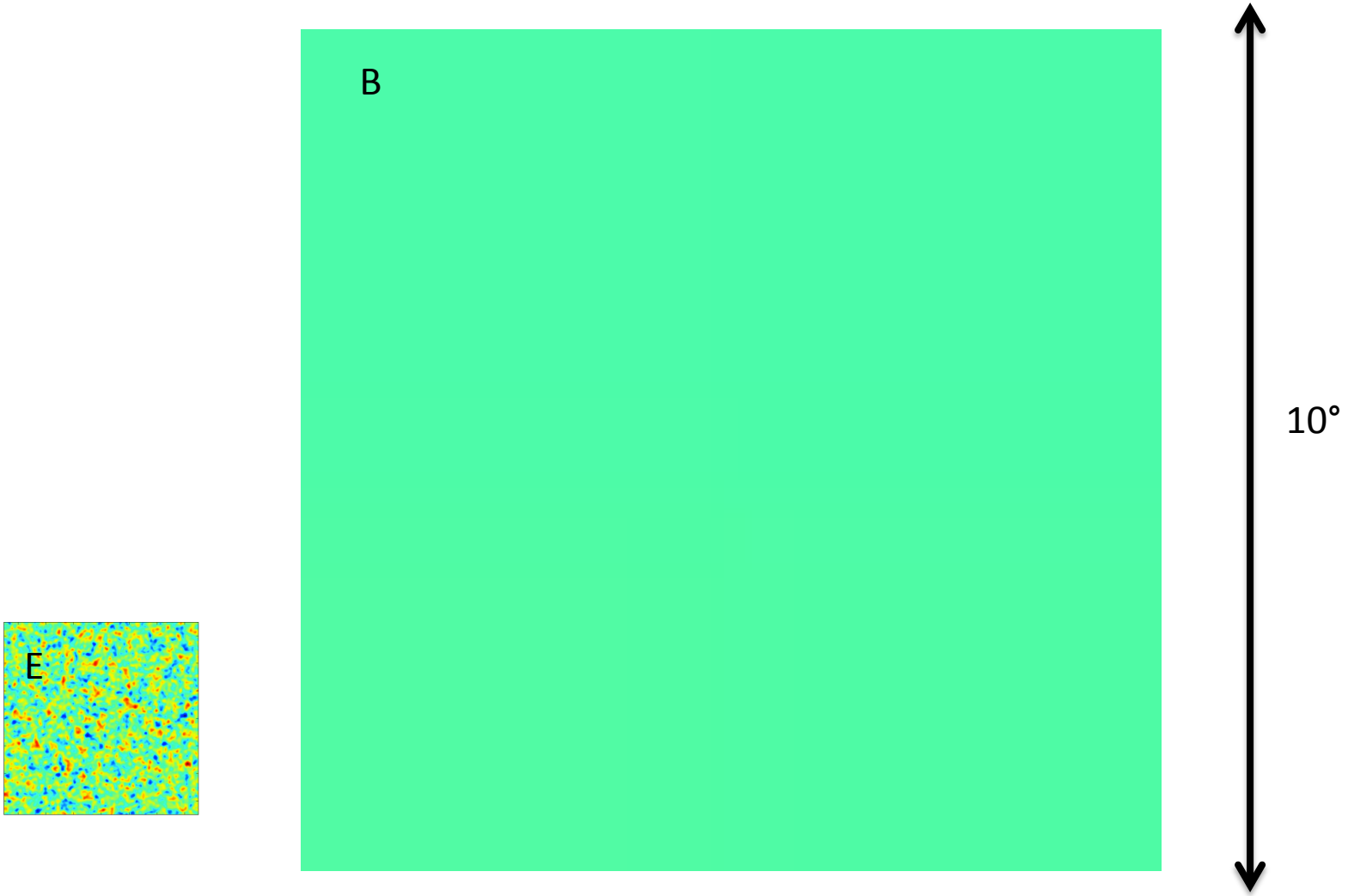


Image Credit: ESA

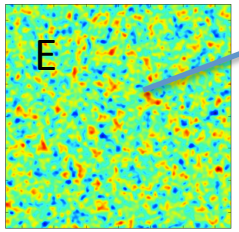
- CMB photons are gravitationally lensed by the large scale mass distribution
- Many small deflections remap the observed CMB

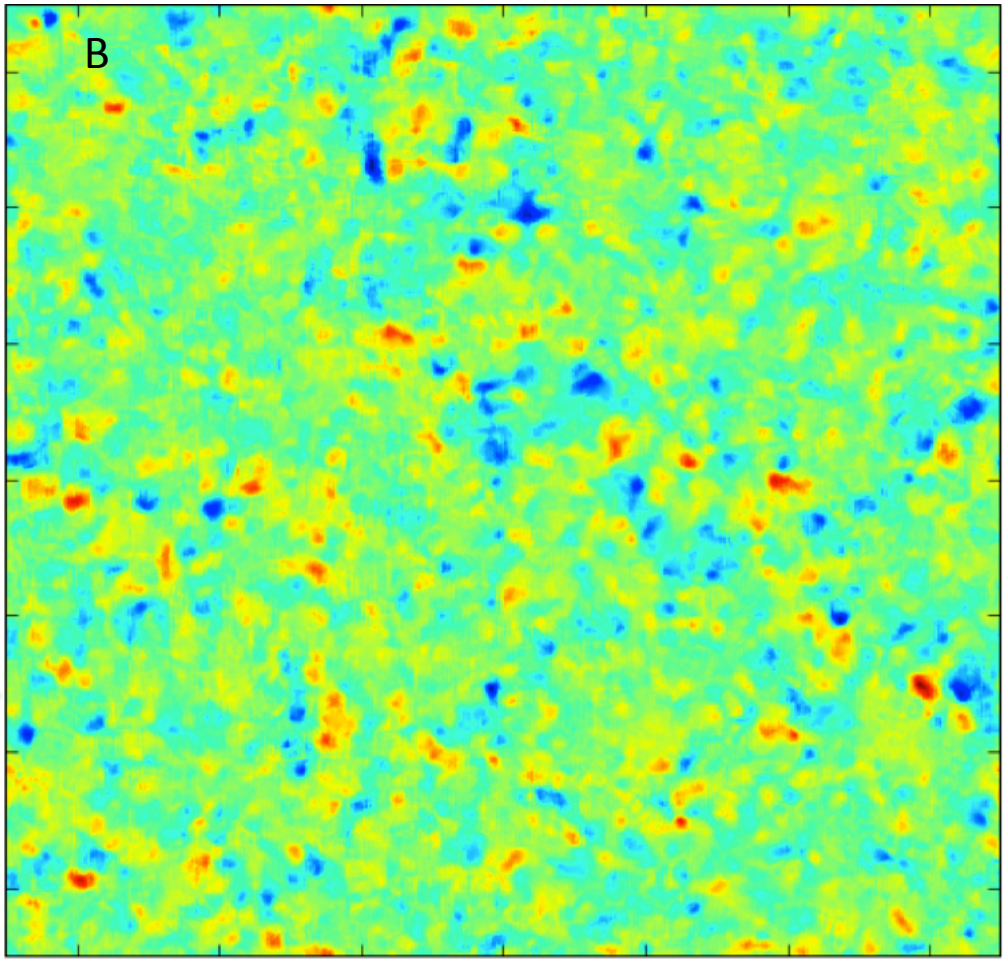
Unlensed CMB B-Polarization



Lensed CMB B-Polarization

Gravitational lensing converts E- to B-polarization: gives variance





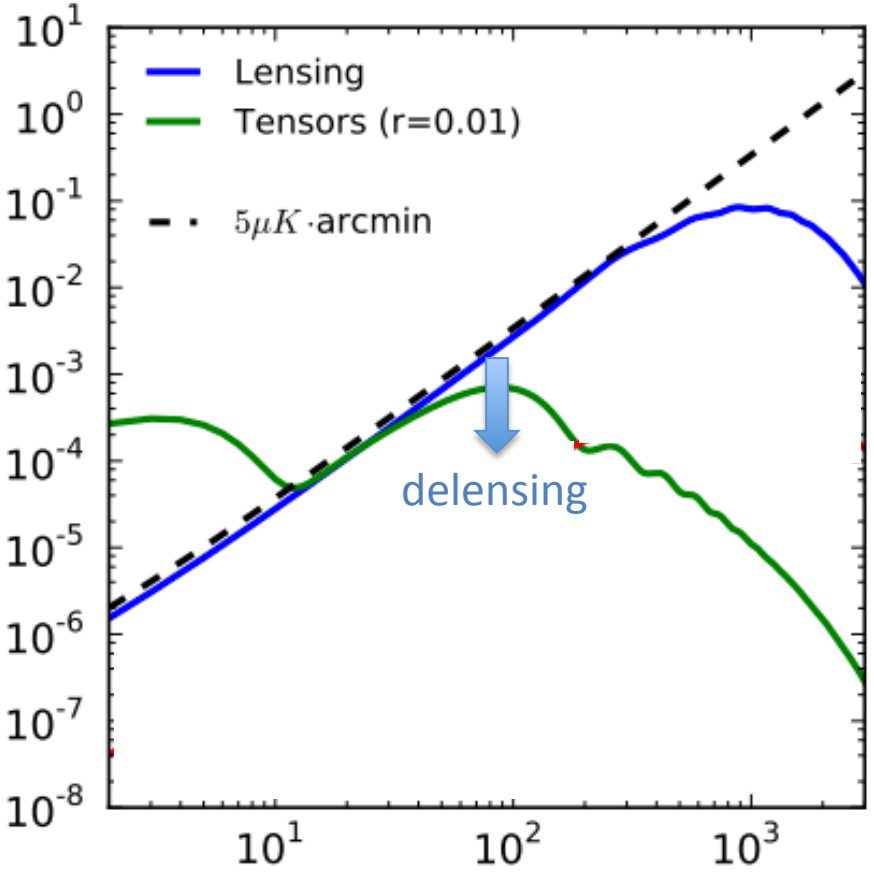
10°

$$B^{\rm lens}(\mathbf{l}) = \int \frac{d^2\mathbf{l}'}{(2\pi)^2} W(\mathbf{l},\mathbf{l}') E(\mathbf{l}') \kappa(\mathbf{l}-\mathbf{l}')$$

κ: lensing convergence

The Need for Delensing

- Lensing B lies on top of any primordial signal
  $B = B_{primordial} + \mathbf{B_{lensing}}$
- Hence lensing B-mode **cosmic variance** adds to error,
  $\sigma \sim (\mathbf{C_l^{BB}} + N_l^{BB})/n_{modes}^{0.5}$
- Note: assume mean lensing-C_l^{BB} is known, so can just "de-bias"



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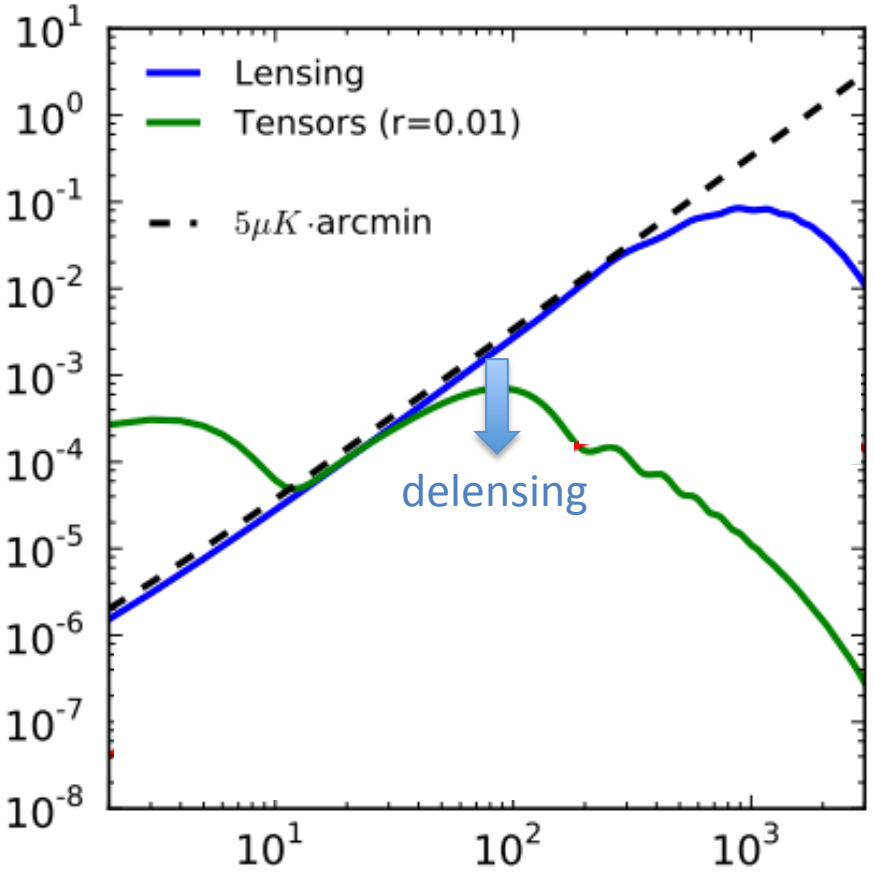
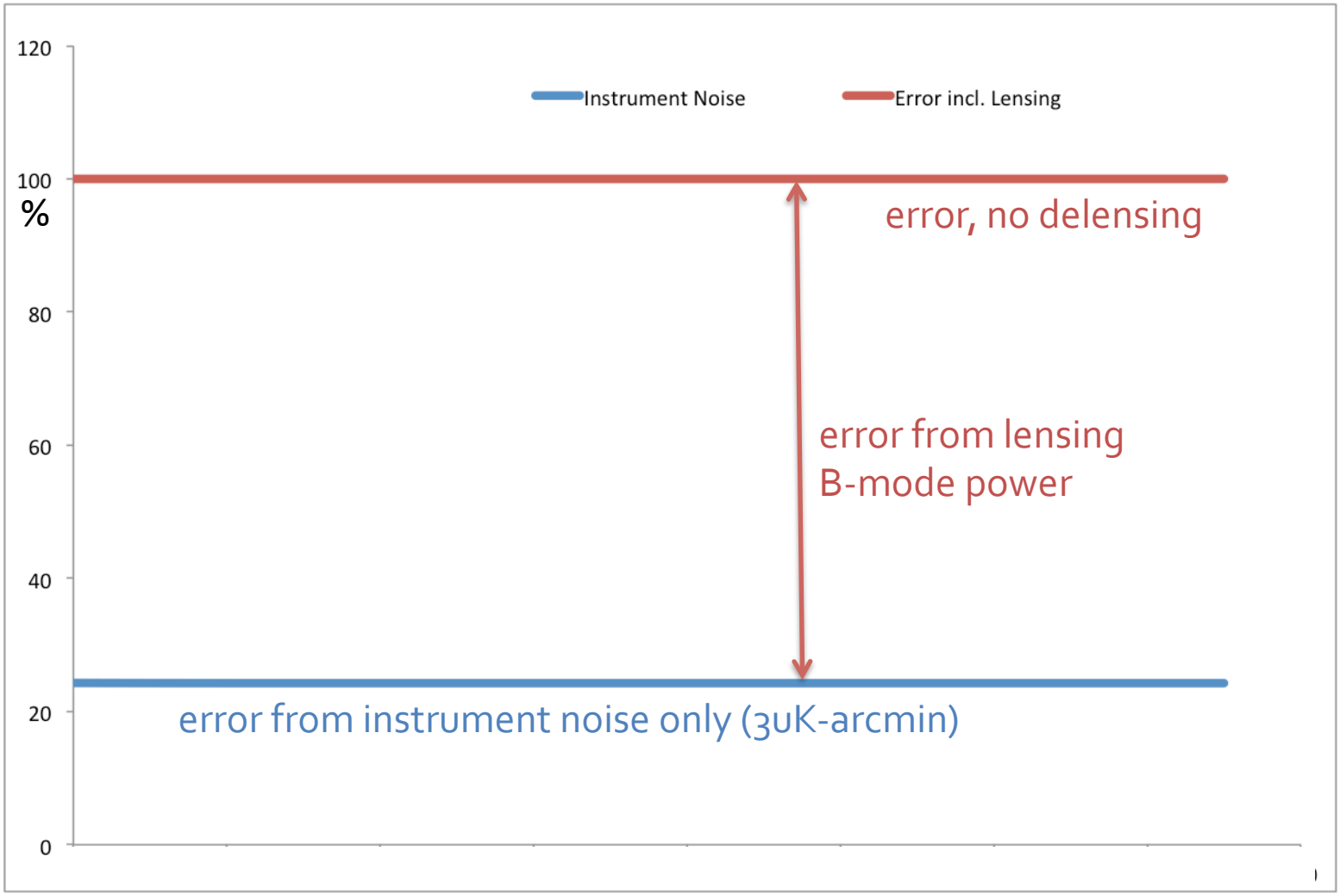
- **When $N_l^{BB} < C_l^{BB}$ ~5uK', lensing B is limiting noise!**



LiteBIRD Error Budget for r: Instrumental Noise vs. Lensing

$\sigma_0(r) \sim 4 \times 10^{-4} \times$



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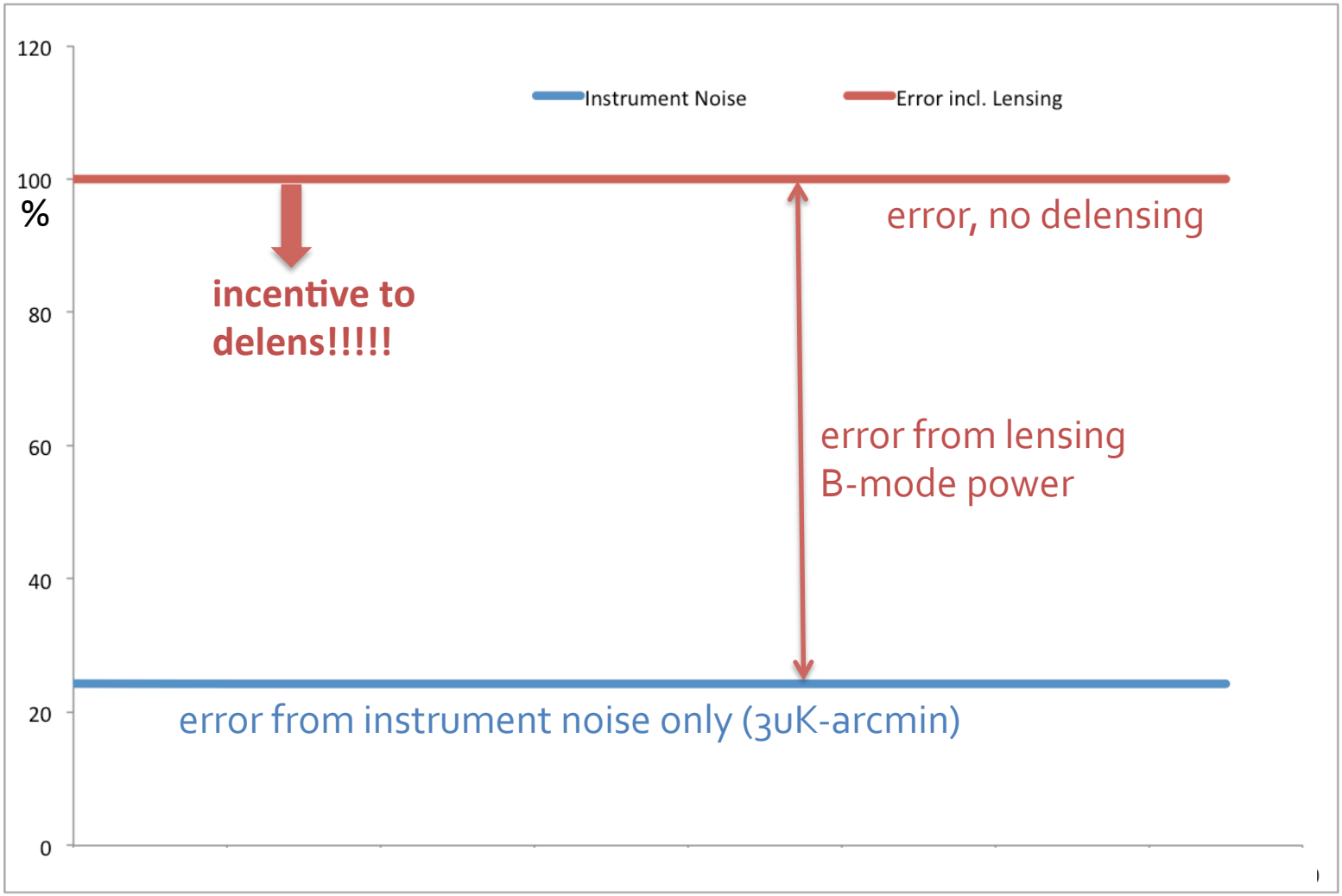
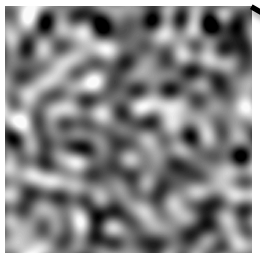


Delensing The CMB

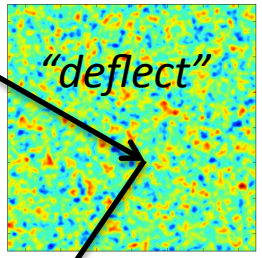
- How to reduce lensing noise?

$$B^{\rm lens}(\mathbf{l}) = \int \frac{d^2\mathbf{l}'}{(2\pi)^2} W(\mathbf{l},\mathbf{l}') E(\mathbf{l}') \kappa(\mathbf{l}-\mathbf{l}')$$

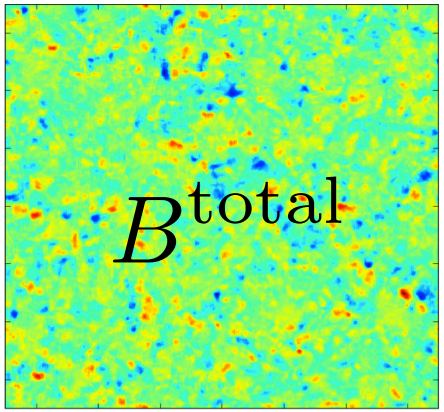
- Delensing: construct $B_{lensing}$~Eκ map from measured κ and E and subtract: B - $B_{lensing}$



lensing estimate κ



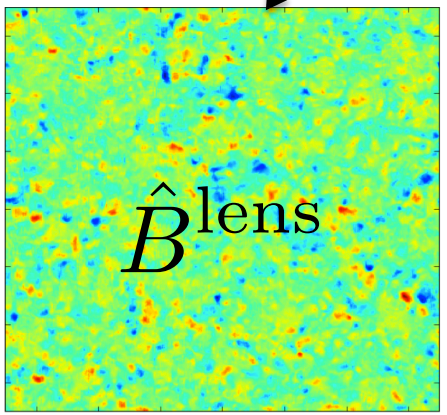
E mode map



measured B map – tensors + lensing

subtract

−



estimate of lensing B (from d+E)

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Delensing: Forecasting Performance

- Error reduction depends on residual lensing B-mode

$$\sigma(r) \sim \langle C_l^{BB,\mathrm{lens}} + N_l^{BB} \rangle_{l<100}$$

$$C_l^{BB,res}$$

- Find that delensing reduces B-mode power by a factor $(1-\rho^2)$

$$C_l^{BB,res} = \int \frac{d^2\mathbf{l}'}{(2\pi)^2} W^2 C_l^{EE} C_{l-l'}^{\kappa\kappa} (1-\rho_{l-l'}^2)$$

[ρ: correlation coefficient of delensing map with true lensing field]

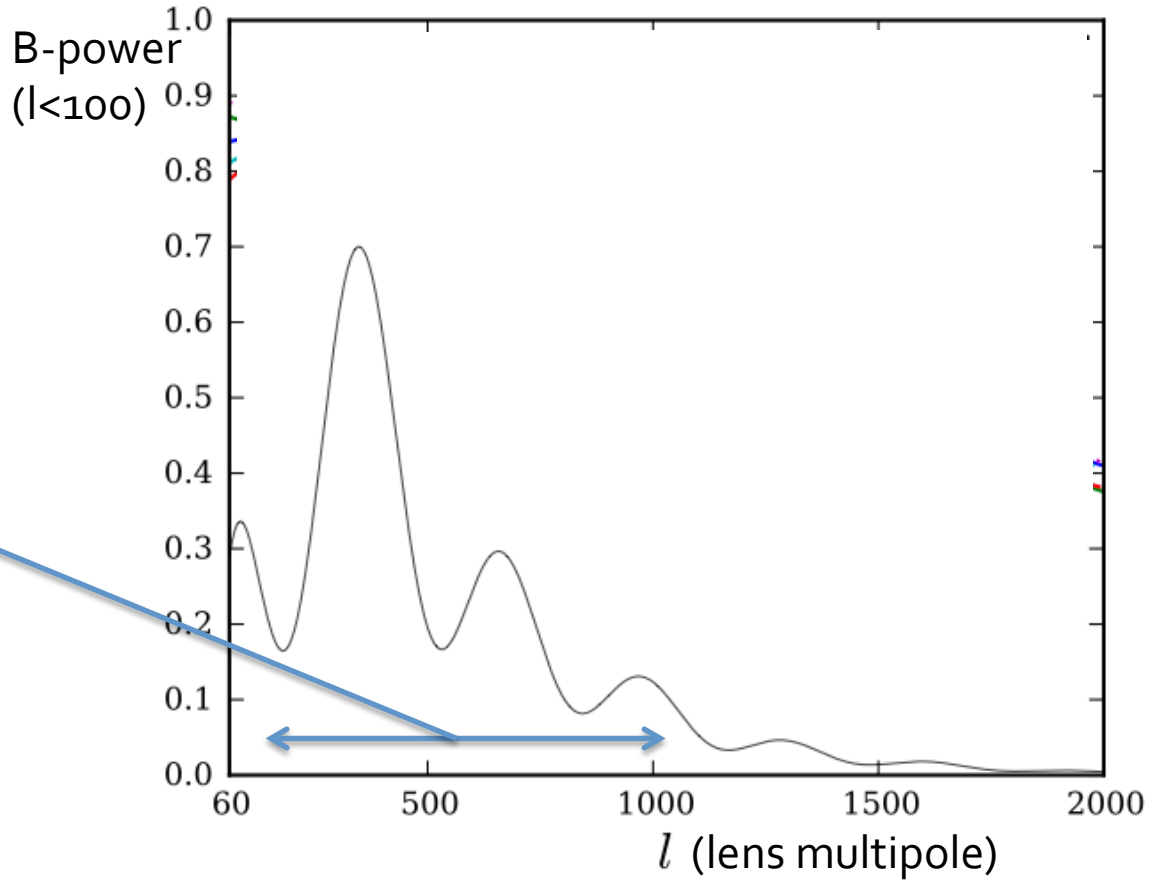
- Need good tracers! (but: not v. sensitive to E noise)

On what scales do we need lensing information?

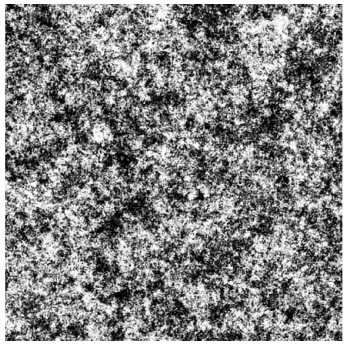
- Lenses at L ~200-800 contribute most to B-power

- So: L~200-800 lenses most important for delensing, but higher L also matter

How much does each lensing scale contribute to lensing B?



To Delens LiteBIRD, Need To Measure Good Maps of CMB Lensing - How?



CMB lensing is a probe of the projected mass distribution

$$\kappa = \int dz W(z)\delta(z)$$

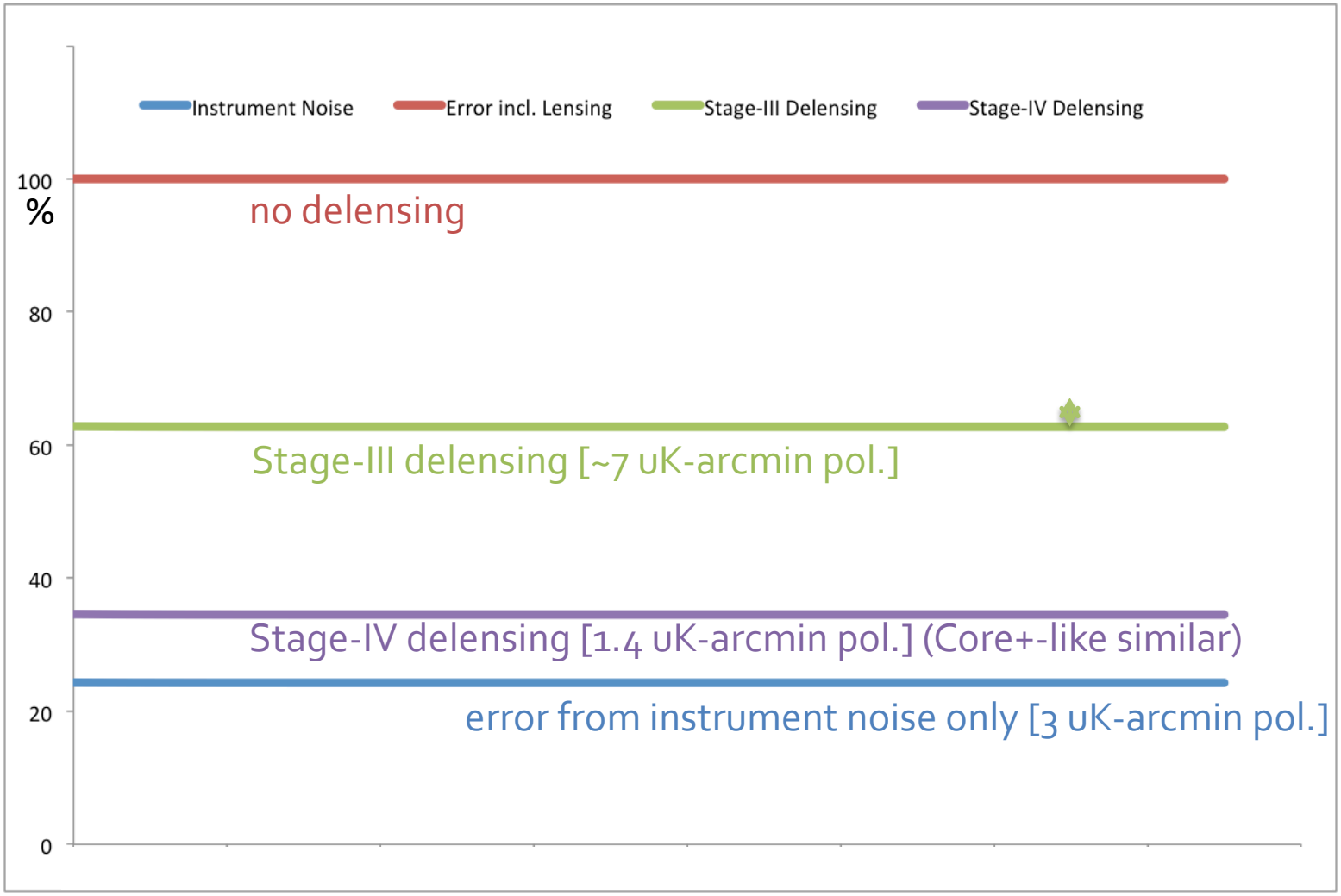
1) Reconstruct lensing from changes in high-res background CMB,
e.g., **CMB Stage 4 + Stage 3**
(NB: LiteBIRD too low-res)

2) Estimate lensing from Large Scale Structure tracers of lensing,
e.g. **CIB, SKA**

LiteBIRD Error on r: Stage-III and CMB Stage-IV Delensing

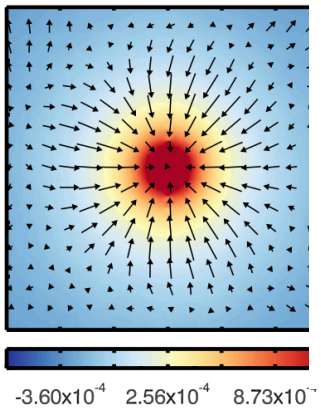
$\sigma_0(r) \sim 4 \times 10^{-4} \times$

percent of detection error



The Cosmic Infrared Background: An Excellent Lensing Tracer

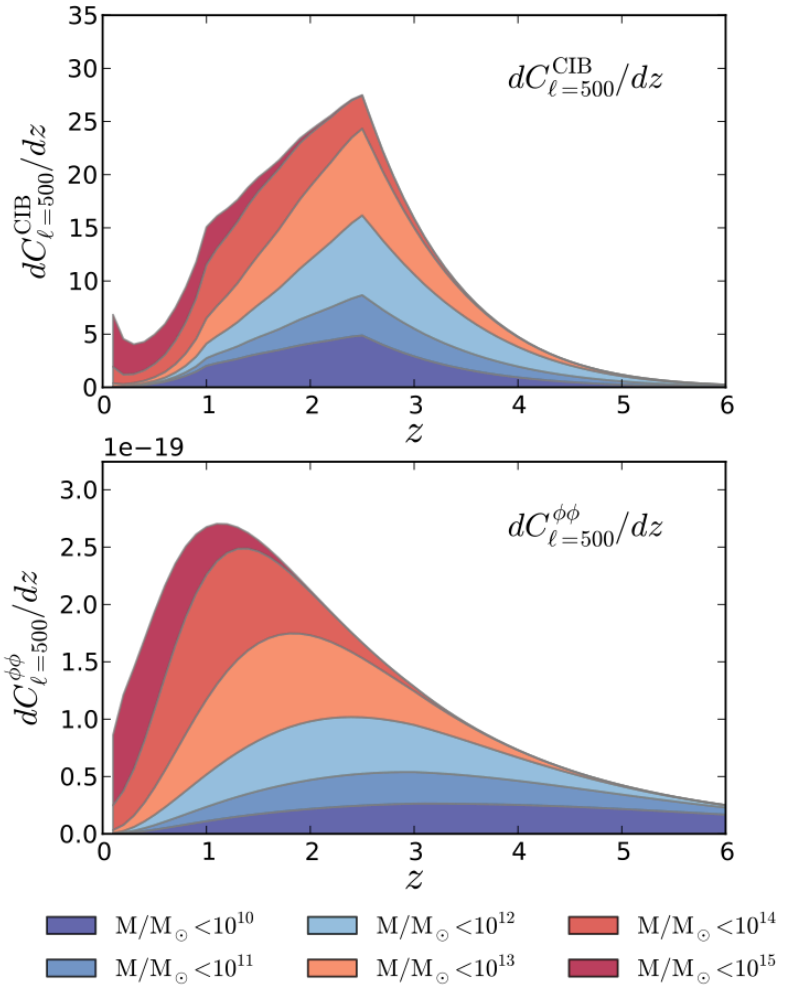
- ~80% correlated with lensing! (Planck CIB)
- Due to similar high-redshift origin as CMB lensing, from z~2
- Weight and scale CIB map to give lensing proxy



Planck lens deflection data stacked on CIB bright spot

[Sherwin & Schmittfull 2015]

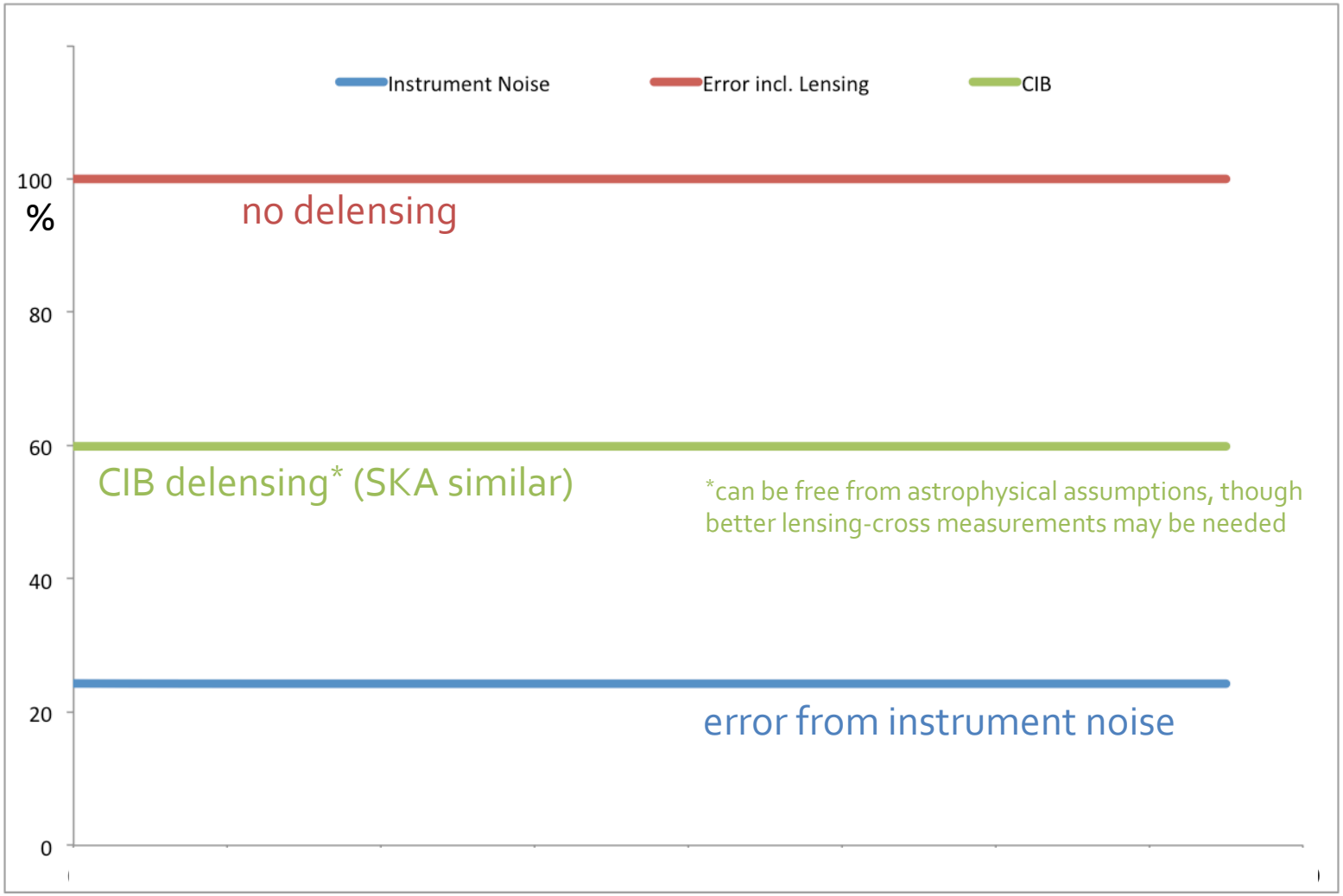
Redshift origin of CIB



Redshift origin of CMB Lensing

LiteBIRD Error on r: CIB Delensing

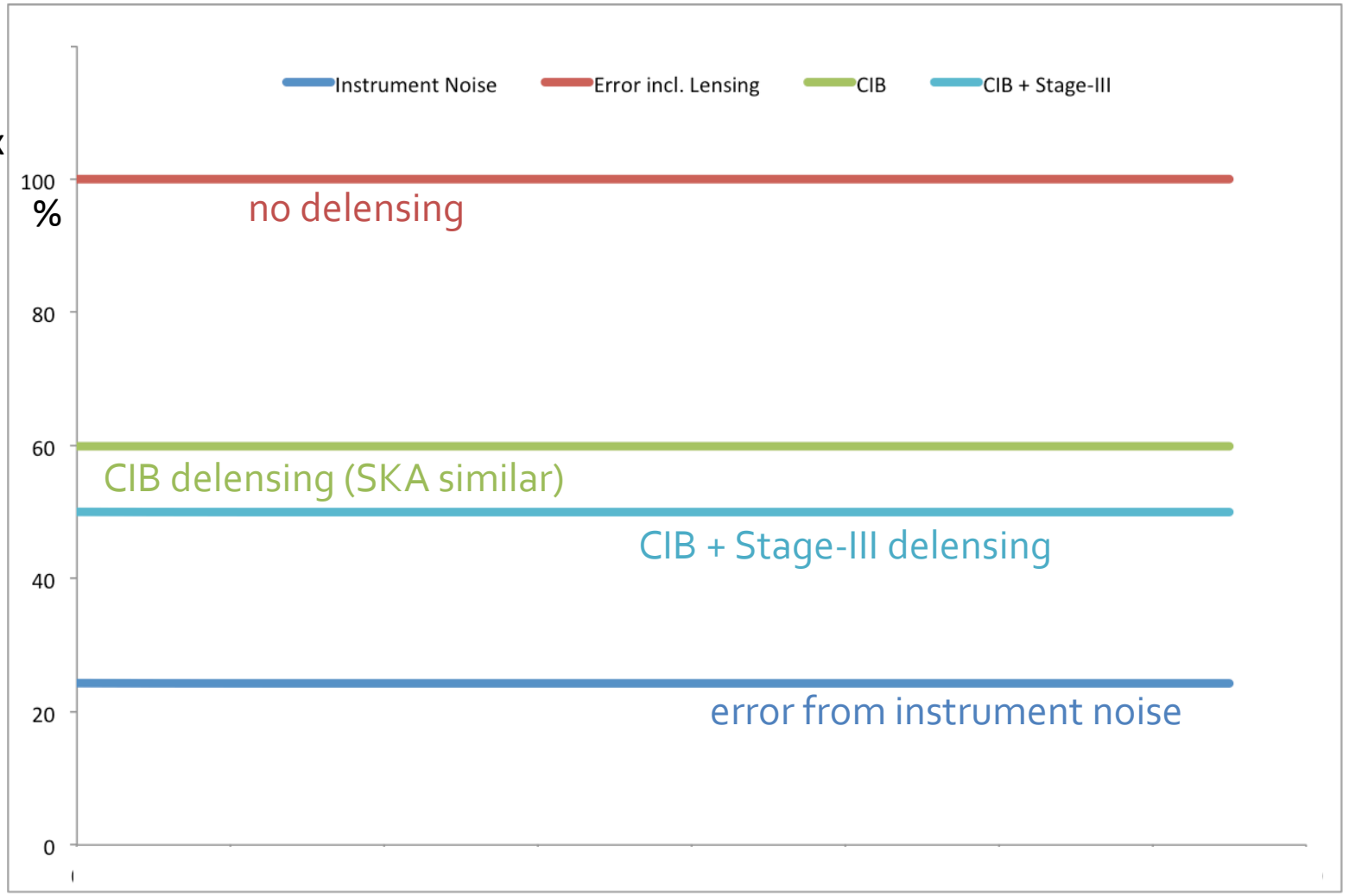
$\sigma_0(r) \sim 4 \times 10^{-4} \times$



[CIB: Sherwin & Schmittfull 2015; SKA: Namikawa, Yamauchi, Sherwin, Nagata 2015]

LiteBIRD Error on r: CIB + CMB Stage-III Delensing

$\sigma_0(r) \sim 4 \times 10^{-4} \times$



[CIB: Sherwin & Schmittfull 2015; SKA: Namikawa, Yamauchi, Sherwin, Nagata 2015]

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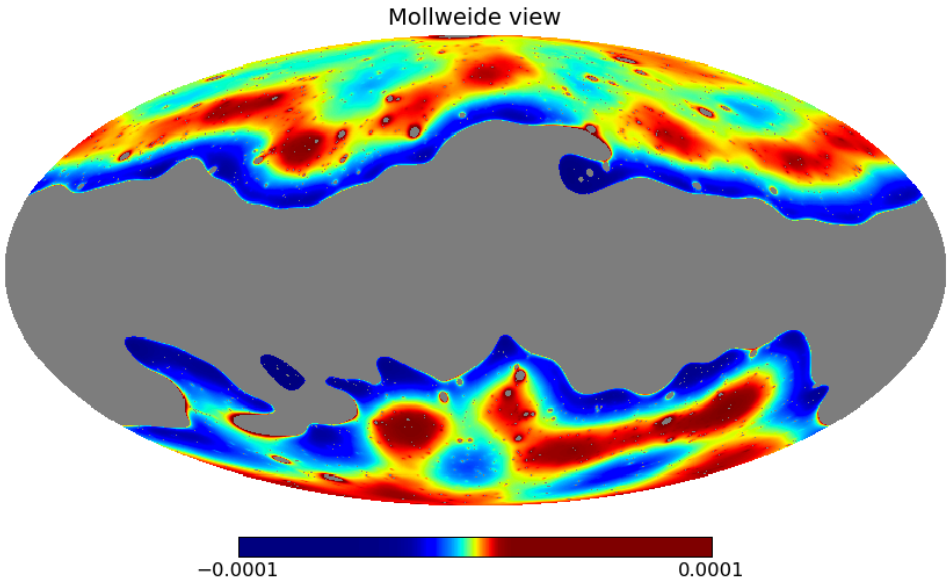
Challenge I: Analysis Choices

- Default analysis would probably just measure the power spectrum of the template-subtracted B-mode map, B-Eκ
- Other options:
  - don't delens a B *map*: jointly analyze all cross/auto-spectra of B and the B-mode template (Eκ) [i.e. BxB, Bx(Eκ), $(E\kappa)^2$]
  - sampling (both lensing and primordial sky)
- Question: What is the best analysis method for LiteBIRD?

Challenge II: Extra "Noise" in Delensing Maps

- **Delensing performance reduced** by
  - remaining dust (CIB), systematics or noise in the delensing maps (will decorrelate them from the true lensing)
  - noise and missing modes in E
- Questions: to what extent can dust be cleaned from CIB? How many modes are missing or noisy from E?

scaled Planck CIB "lensing" map; contains dust, sources…



Challenge III: **Knowing** the "Noise" in Delensing Maps!

- Need to know how much lensing B-mode power is left to constrain r! We need to know the **mean** residual B power very well (~1%) to "de-bias"!

$$C_l^{BB,\mathrm{del}}(r, a_i, b_i) = C_l^{BB,r}(r) + C_l^{BB,\mathrm{res}}$$

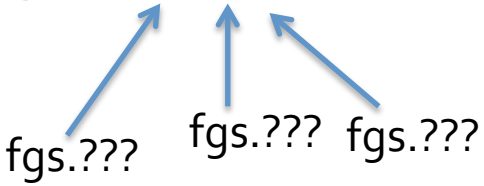
???

- Question: will we know the correlation / noise well enough to know the residual B power to ~1%?

N.B. For CIB, Stage-III cross-correlations will be very useful.

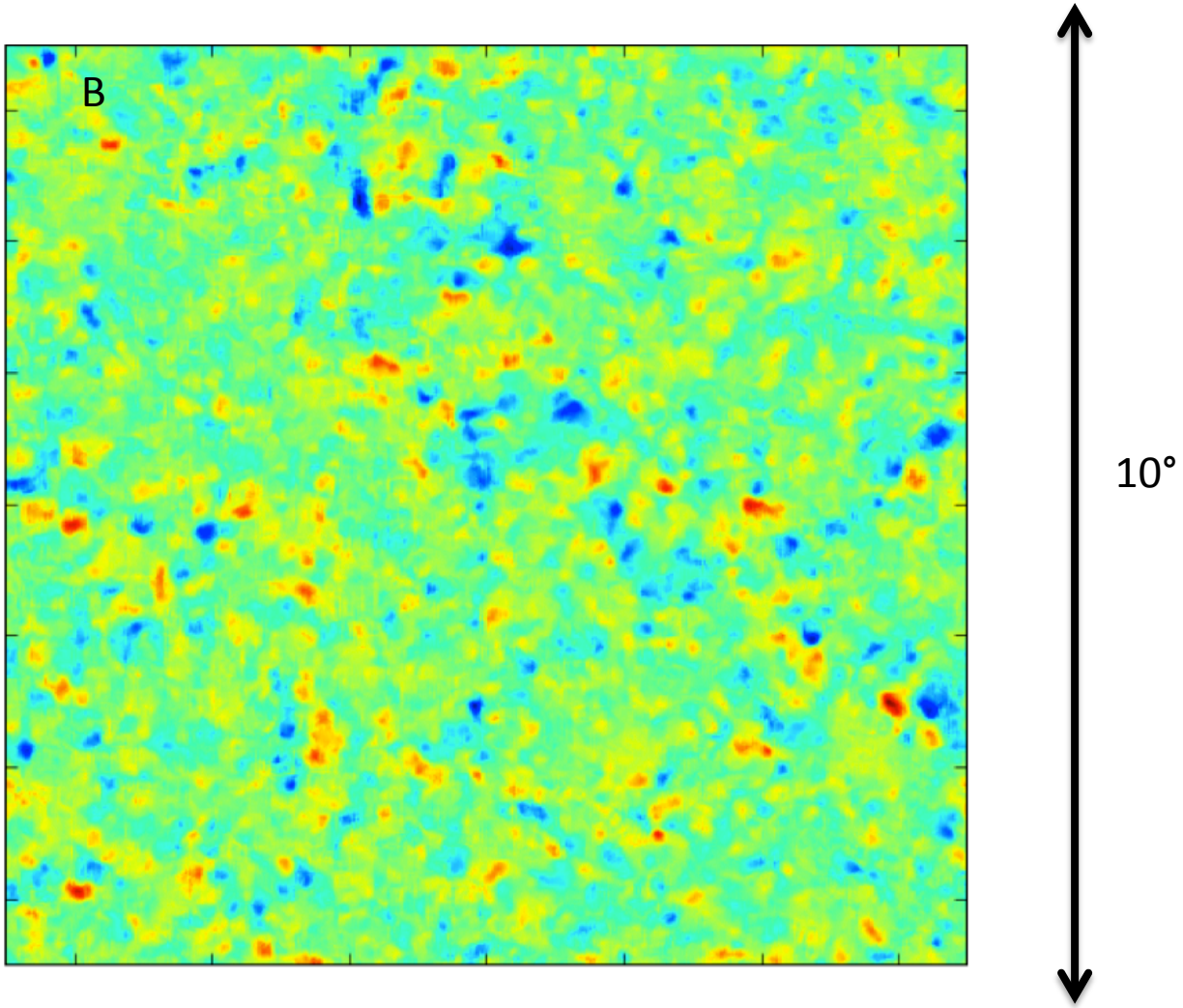
Challenge IV: Correlated Systematics Propagation

- Lensing foregrounds correlated with B foregrounds can give biases, e.g., <(B-Eκ) x (B-Eκ)>, cross terms involving <BEκ>

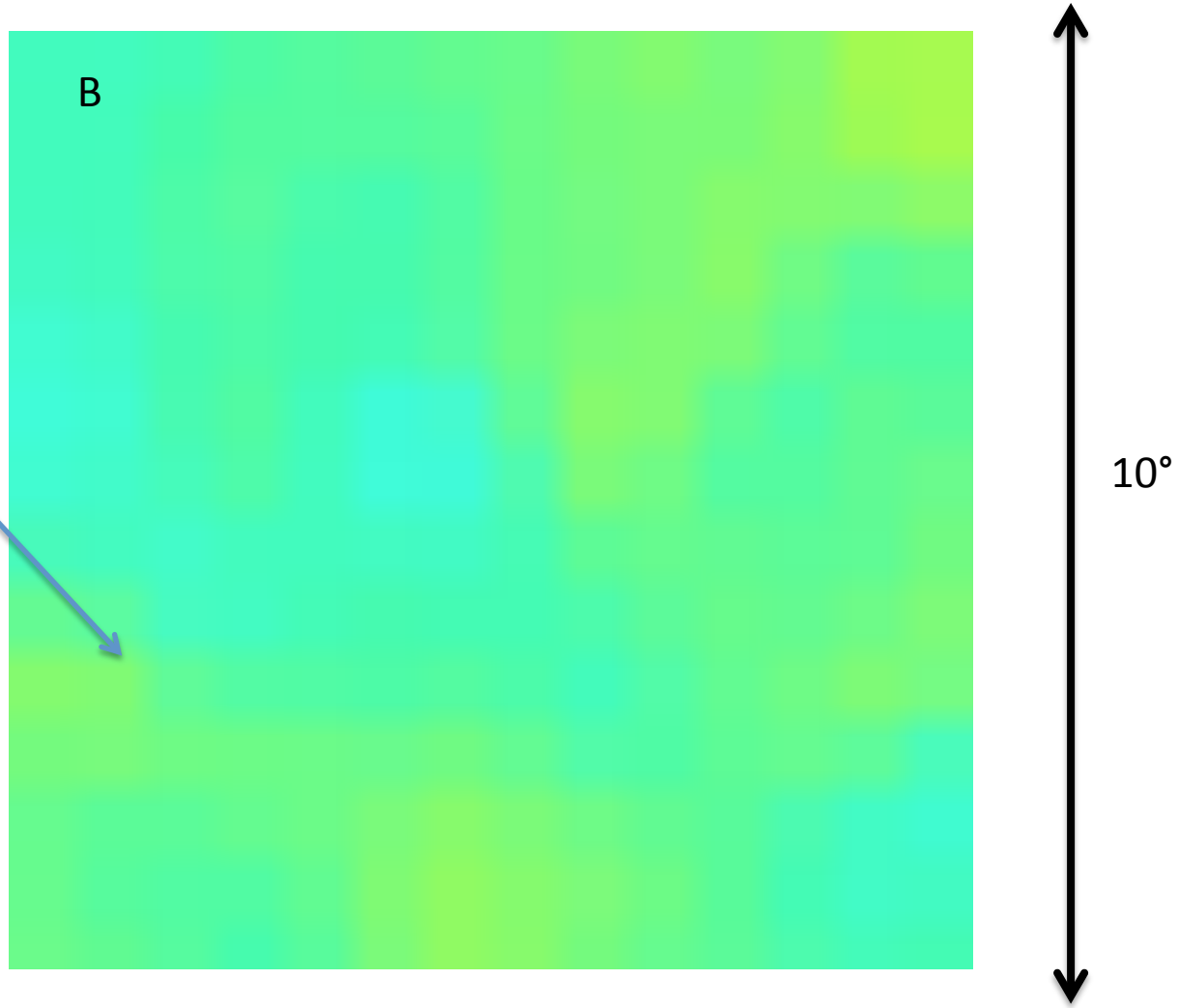


- Foregrounds in B, E, and κ all could matter
- Similar concerns for instrumental systematics
- Question: biases probably small, but can we demonstrate these are negligible?

Full B Mode Map



Perfectly (?) Delensed B Map



Delensing analysis challenge: be certain an excess in B is r

(delensing problems will typically give an excess)

Summary

- Delensing can **greatly** improve LiteBIRD constraints on r
- CMB Stage-IV is ideal; CIB/SKA + Stage-III is fine
- Lots of work required on delensing analysis: foregrounds, systematics, pipelines…