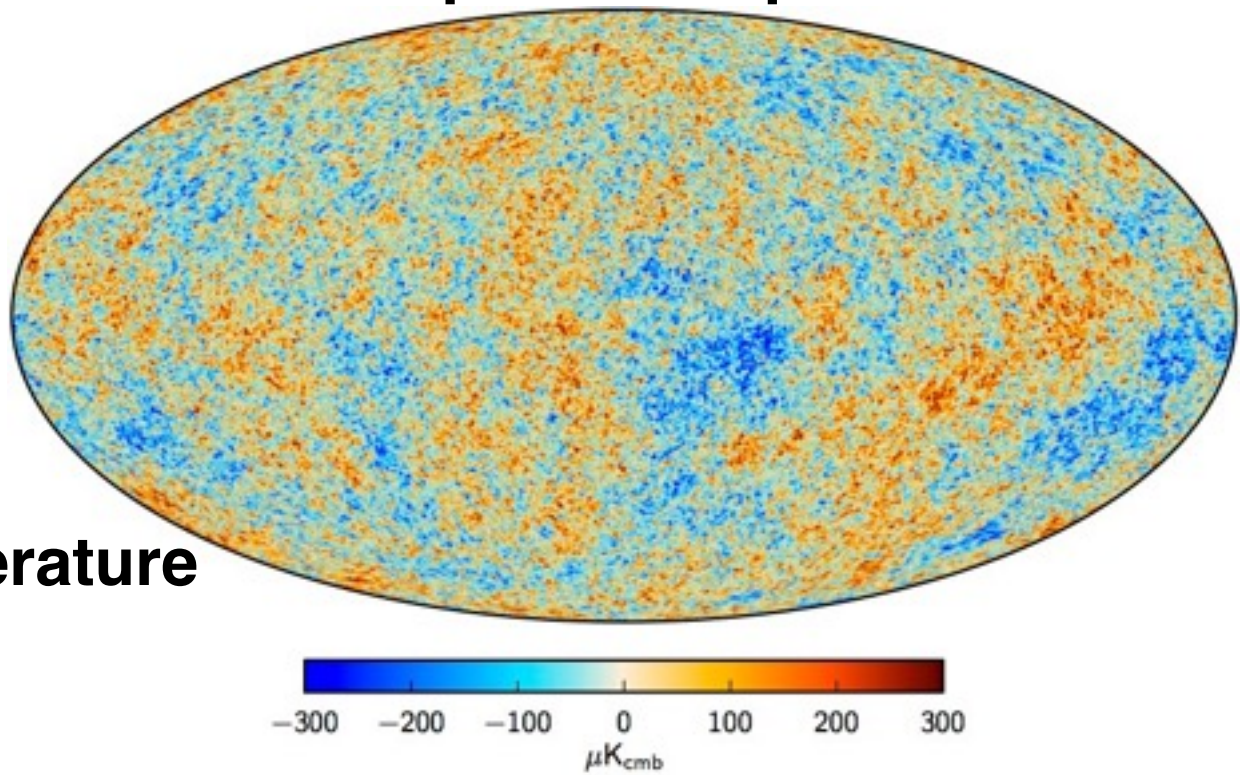
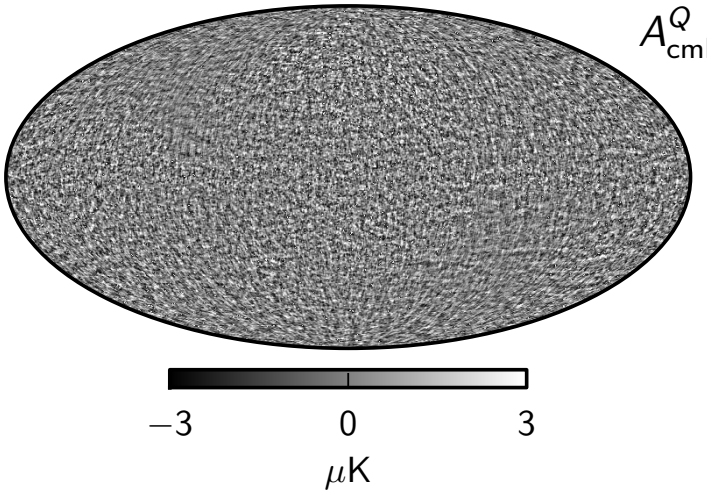
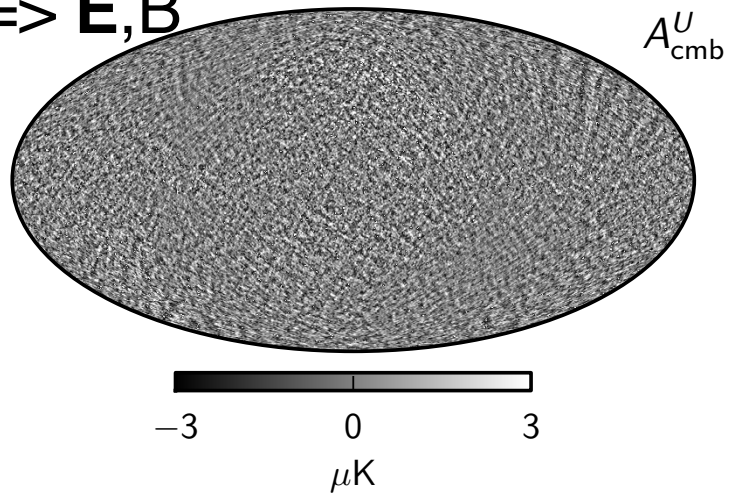
Planck 2015 Component Separated CMB Maps



CMB Temperature

CMB polarization: Stokes Q,U => E,B





Wiener-filtered ζ maps

make $\zeta_{LM}(\chi), \chi = |\mathbf{x}|$ instead of $\zeta(\mathbf{x})$

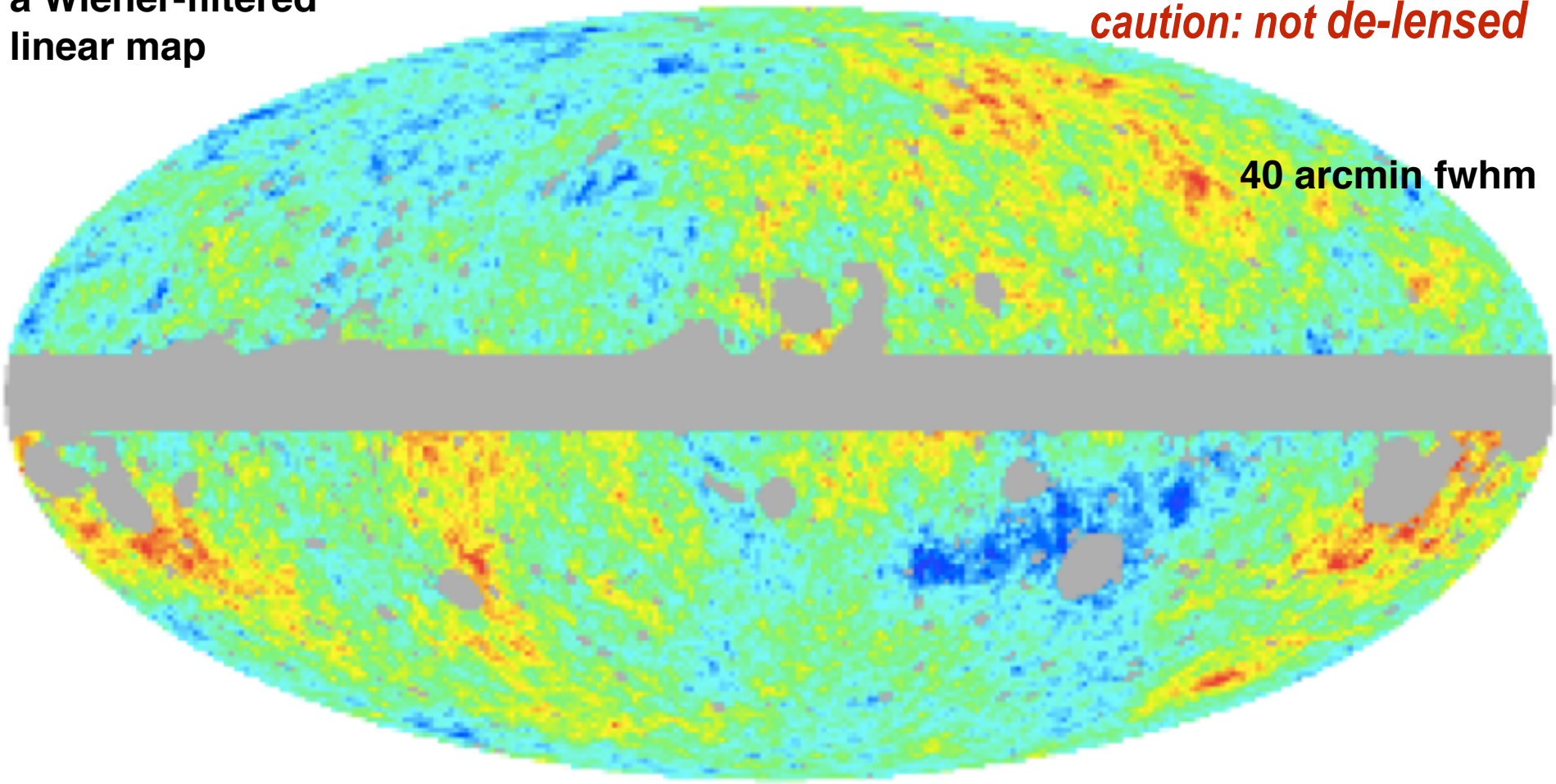
$\zeta|T,E:$

~ *Newton's gravitational potential* $\Phi_{N,dec}$ *at recombination (photon decoupling)*

a Wiener-filtered linear map

caution: not de-lensed

40 arcmin fwhm



$\zeta/10^{-5}$ −40 −32 −24 −16 −8 0 8 16 24 32 40

visibility mask

ζ-Maps of the Early Universe, G2000, Jan 20, 2016

Dick Bond, CITA & CIFAR

a ***Map*** *is an* ***ensemble = mean-map + fluctuation-maps,*** *encoding correlated errors*

Maps = *(radical)* **compressions** *of the* ***time ordered information*** **ToI** ***onto***
a parameterized space q^A***:*** ***Linear maps, Quadratic maps (power), cosmic parameter maps***
Prob(q| Data, Th prior) => $\langle q^A | D,Th\rangle$, $\langle \Delta q^A \Delta q^B | D,Th\rangle$,.. ***or q_maxL***

TOPOGRAPHY & CARTOGRAPHY

of our Hubble-patch *aka our bit of the universe*

reconstructing $\zeta = ln\,a(x,t)$ *@uniform density,*
aka primordial ***scalar curvature*** $^{(3)}R = -4\ ^{(3)}$***Laplacian***$(ln\,a)$

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$$\zeta(x,t) = ln\,\rho(x,t)/\rho_b \,/\, 3(1+p_b/\rho_b) + ln\,a(x,t)/a_b$$

phonon ***isotropic strain = volume deformation***

BST83, SBB89, SB90,91, B95, Bond+Braden2016 ζ for preheating

$\zeta(x,t) = \int (dE+pdV)/E \;\; /\langle 3(1+p/\rho)\rangle(t)$ *coarse-grained energy conservation,*
ζ~entropy, changed by fine=>coarse kicks +⊥ drifts off coarse-attractor (isocon)

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Wiener-filtered ζ maps make $\zeta_{LM}(\chi)$, $\chi = |\mathbf{x}|$ instead of $\zeta(\mathbf{x})$

$T_{LM\,c,s}$ / $E_{LM\,c,s} = \int e^{\zeta^{T/E}_{L\chi\,c,s}}\,\zeta_{LM\,c,s}(\chi)\,d\chi$, susceptibility **e** depends on cosmic parameters

=> Linear response $\zeta_{LM\,c,s}(\chi) = e^{*\zeta^{T}_{L\chi\,c,s}}\,T_{LM\,c,s} + e^{*\zeta^{E}_{L\chi\,c,s}}\,E_{LM\,c,s} + \delta\zeta_{LM\,c,s}$

susceptibility of ***ζ to T/E:*** $e^{*\zeta^{T/E}}$ *interpolates T/E to ζ, if no info relax to δζ*

project ***ζ*** *to minimize fluctuations:* $\int d$***visibility****(distance)* $(\langle \zeta | Temp, E\ pol\rangle + \delta\zeta)$

Reconstructing the Early Universe

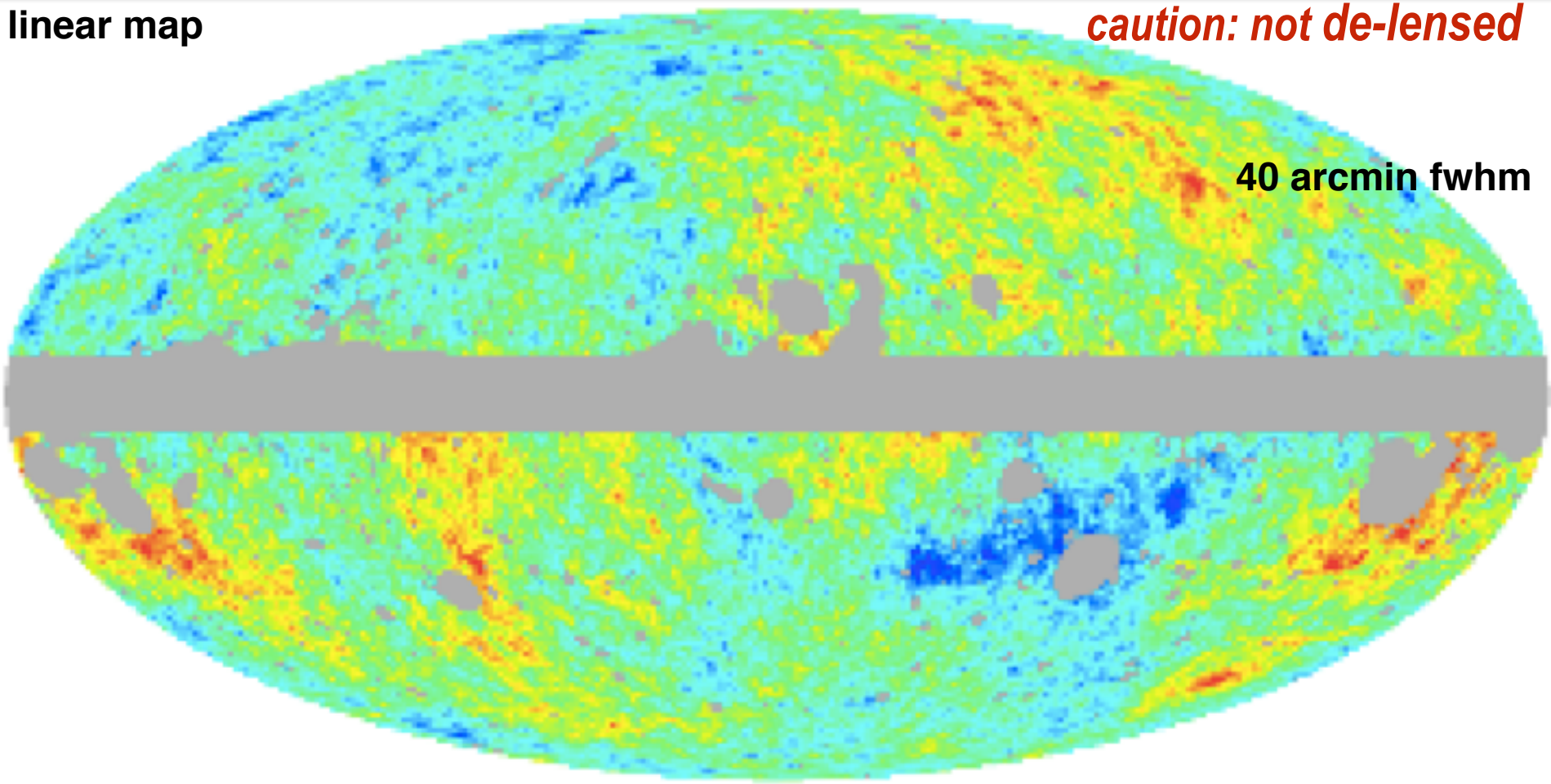
$\int d$ ***visibility***$(distance)$ $\langle \zeta | Temp, E\ pol \rangle$ $(angles, distance)$

sb89, bb15 $\zeta_{NL} = \ln(\rho\ a^{3(1+w)})/3(1+w)$ $<=$ $dE+pdV \sim dEntropy$ ***phonons / strain***

linear map

caution: not de-lensed

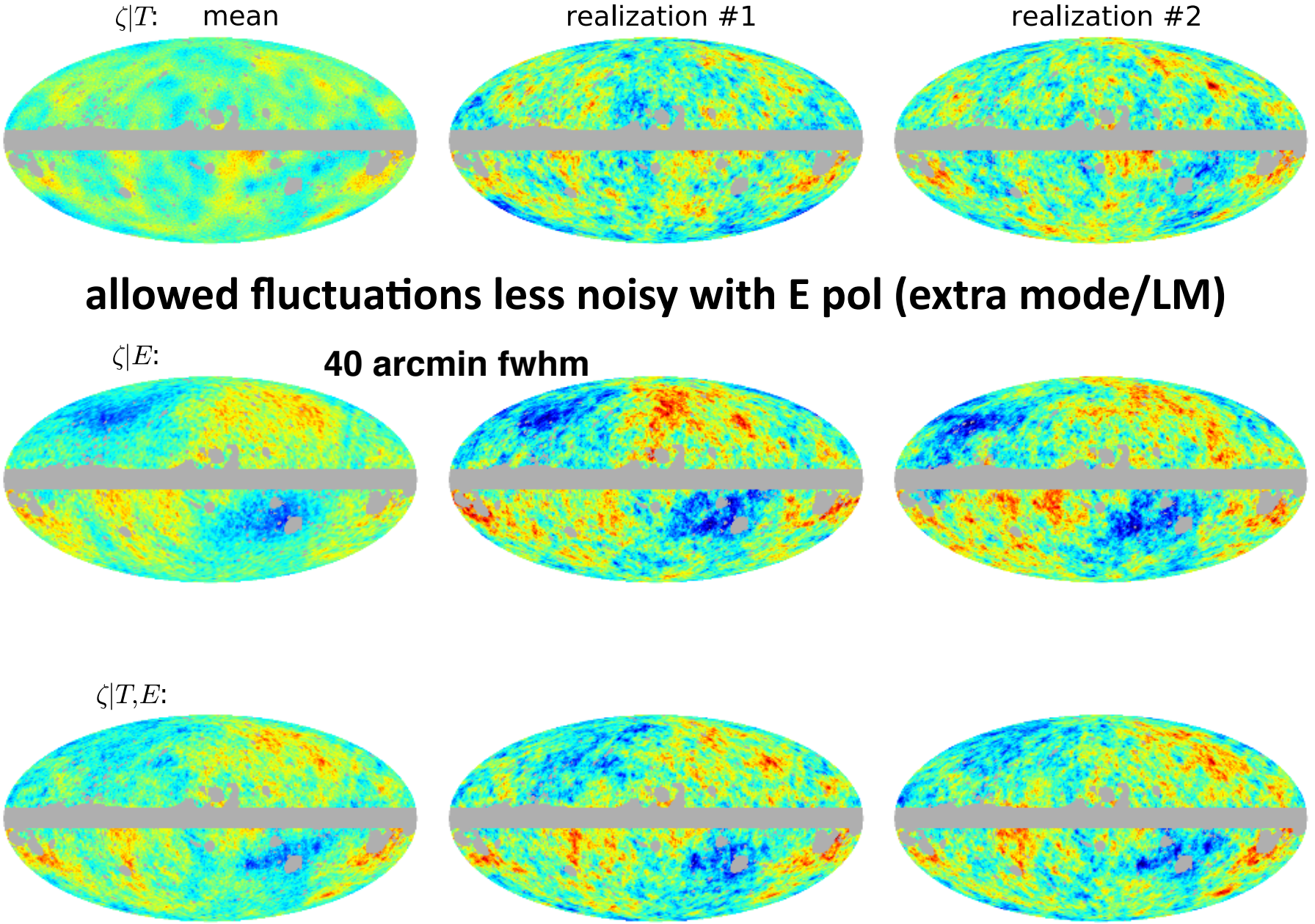
40 arcmin fwhm

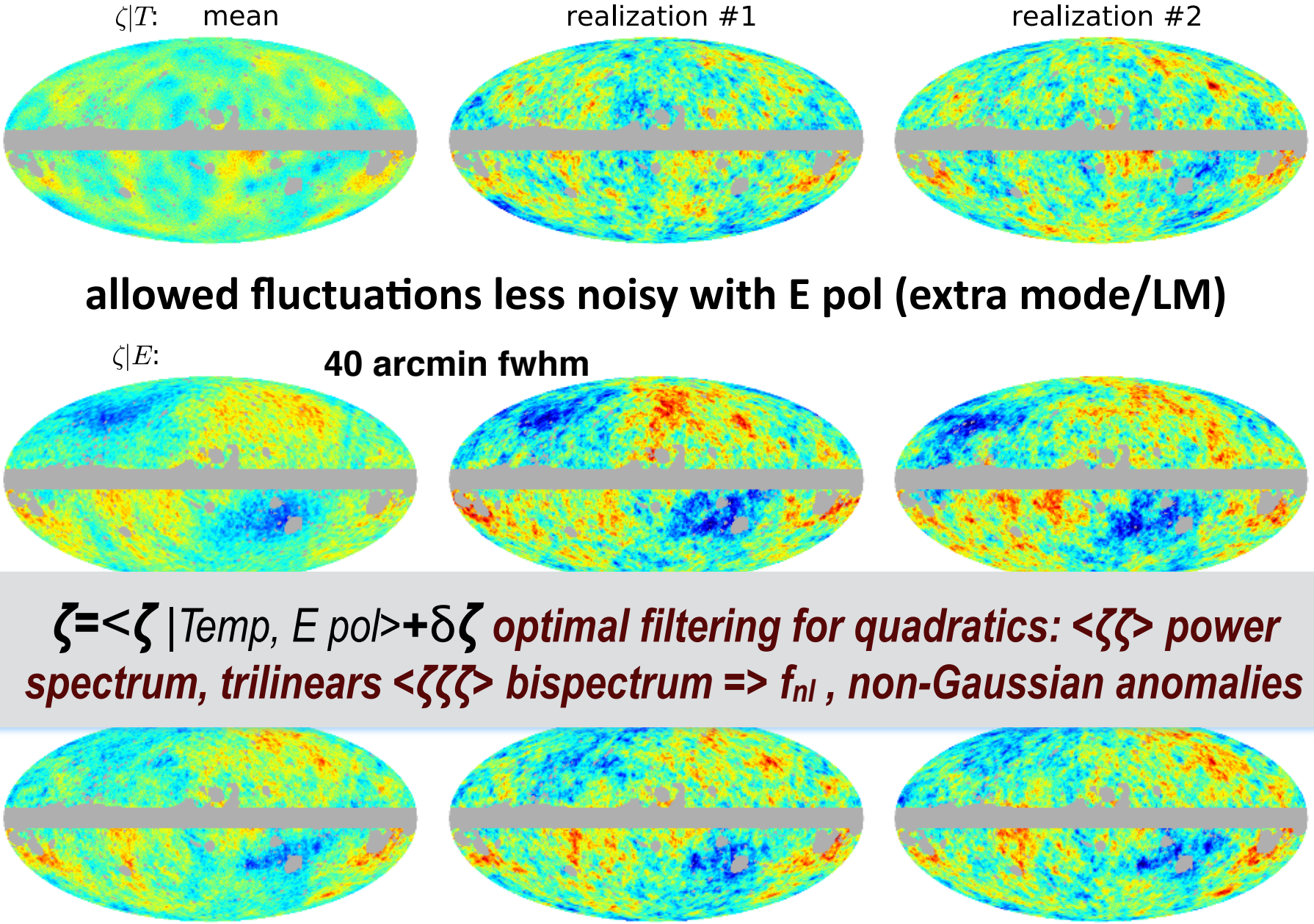


$\zeta/10^{-5}$

−40 −32 −24 −16 −8 0 8 16 24 32 40

visibility mask


$\zeta|T$: mean
realization #1
realization #2
allowed fluctuations less noisy with E pol (extra mode/LM)
$\zeta|E$:
40 arcmin fwhm
$\zeta|T,E$:
−40 −32 −24 −16 −8 0 8 16 24 32 40
$10^5\ \zeta$
caution: not de-lensed
visibility mask

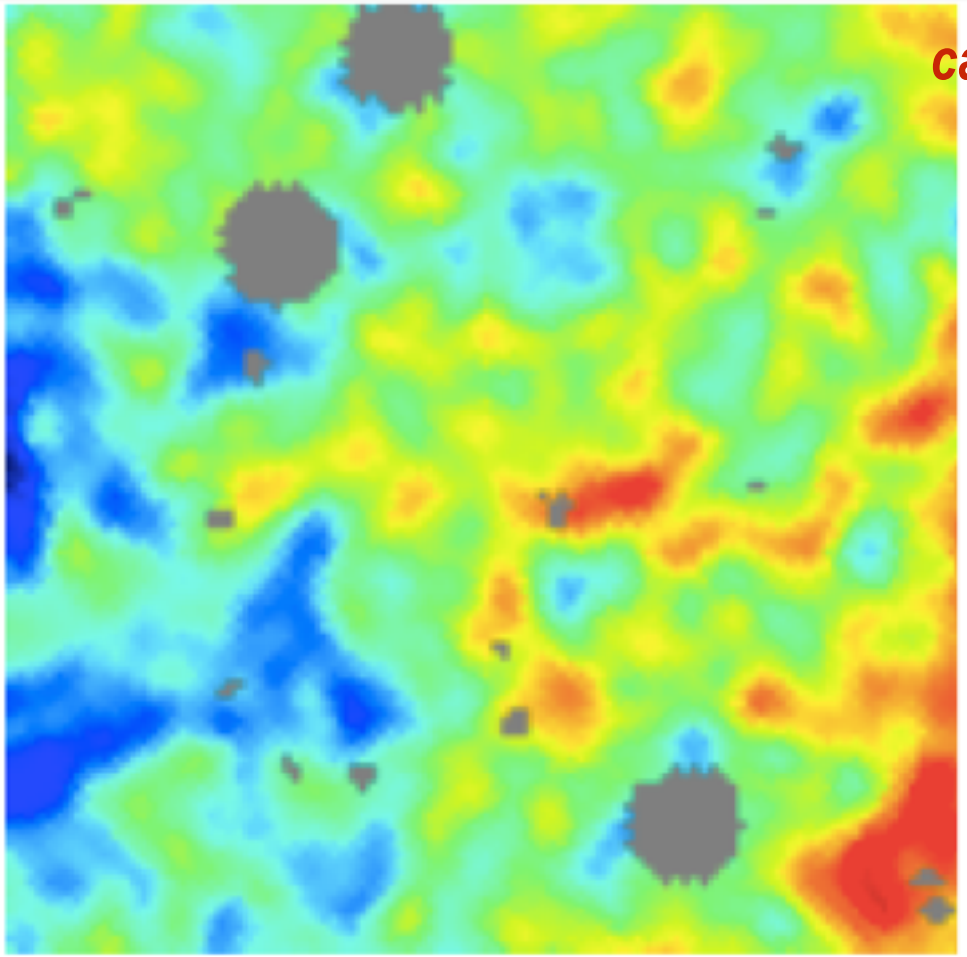

$\zeta|T$: mean
realization #1
realization #2
allowed fluctuations less noisy with E pol (extra mode/LM)
$\zeta|E$:
40 arcmin fwhm
ζ=<ζ |Temp, E pol>+δζ optimal filtering for quadratics: <ζζ> power spectrum, trilinears <ζζζ> bispectrum => f_{nl} , non-Gaussian anomalies
−40 −32 −24 −16 −8 0 8 16 24 32 40
$10^5\ \zeta$
caution: not de-lensed
visibility mask

Reconstructing the Early Universe

$\int d$ ***visibility***$(distance)\ \langle \zeta \,|\, Temp,\ E\ pol \rangle$ $(angles,\ distance)$

sb89, bb15 $\zeta_{NL} = \ln(\rho\ a^{3(1+w)})/3(1+w)$ *<= dE+pdV ~dEntropy* ***phonons / strain***

linear map



caution: not de-lensed

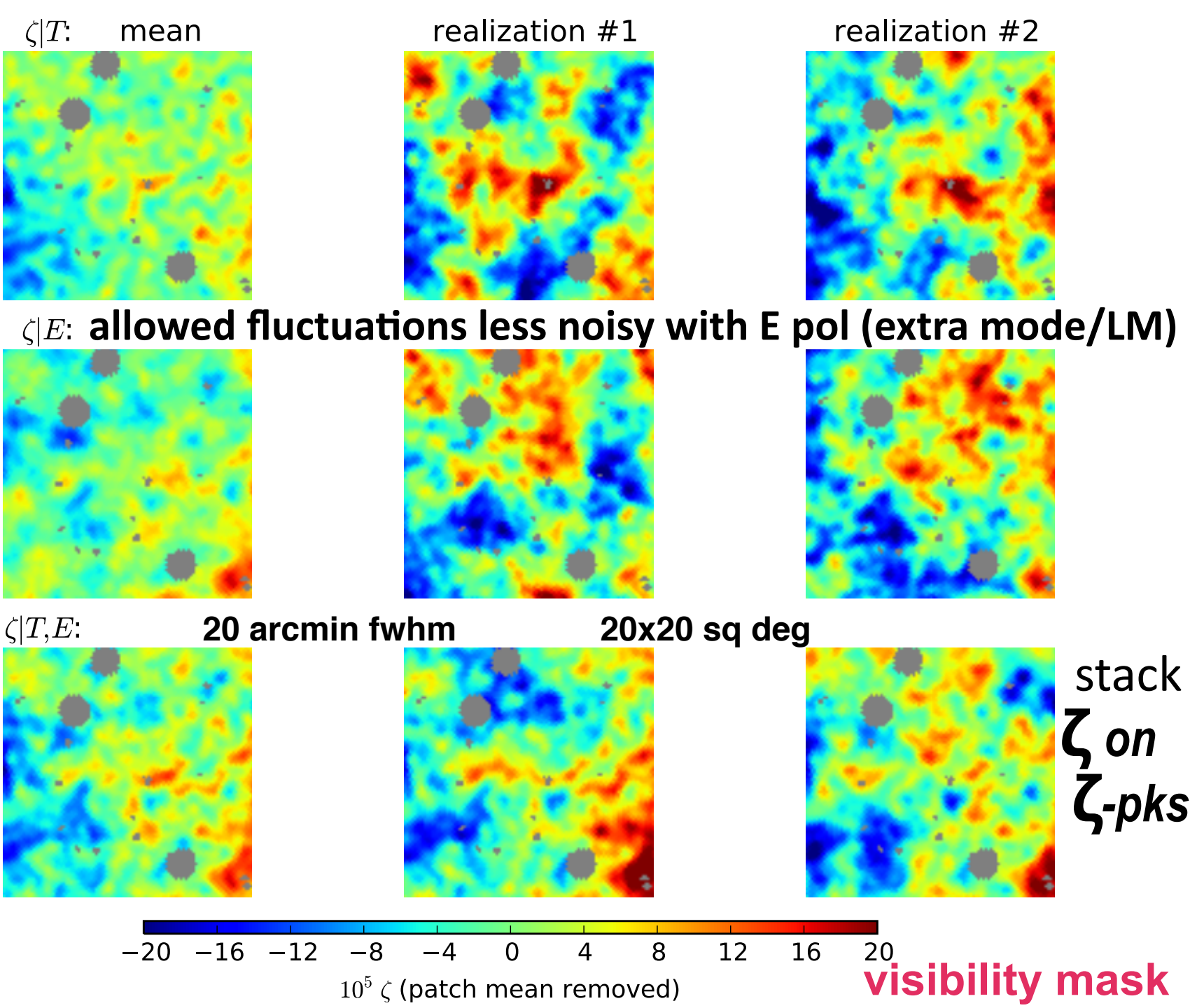
20x20 sq deg

20 arcmin fwhm

$\zeta/10^{-5}$

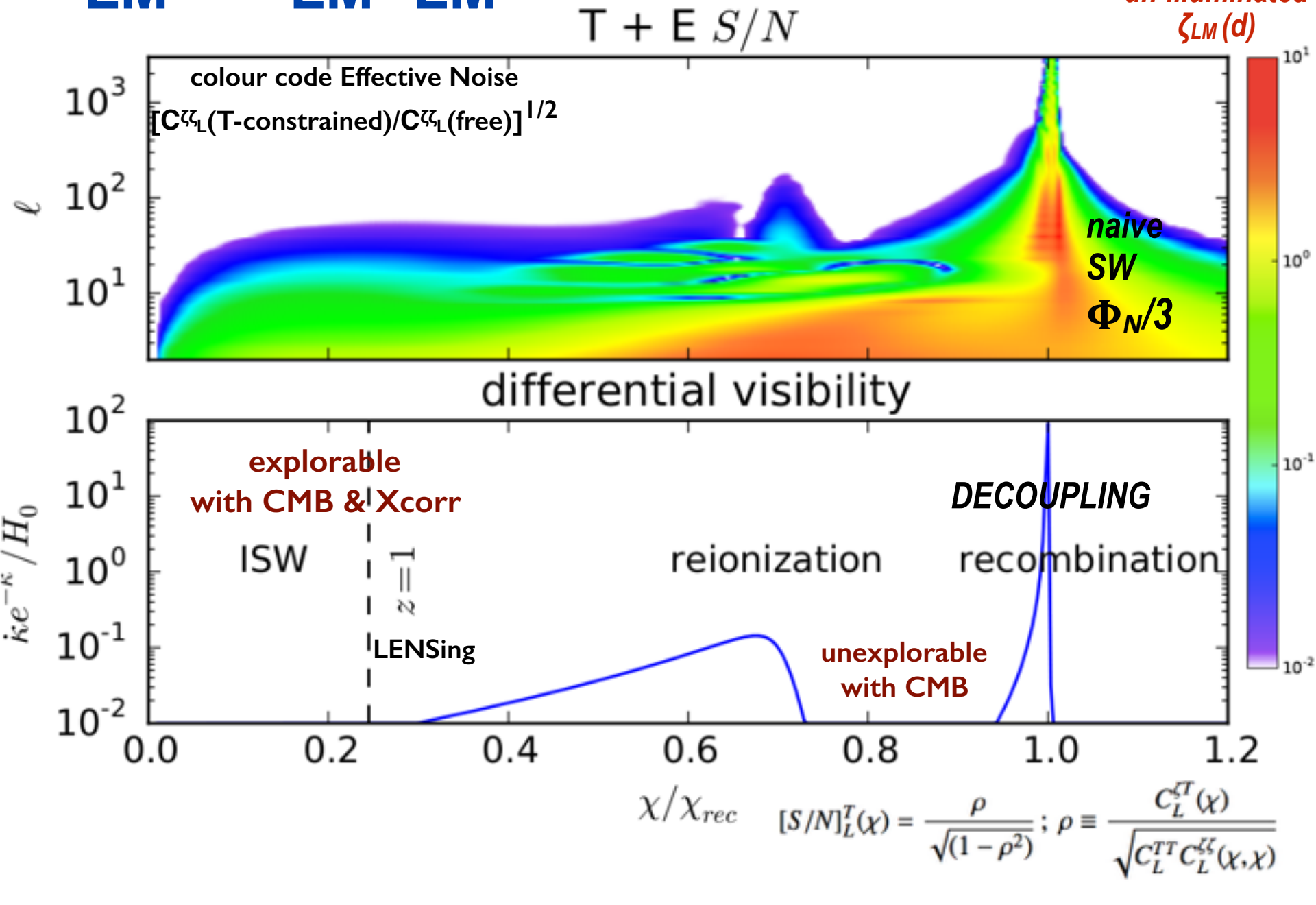
−20 −16 −12 −8 −4 0 4 8 12 16 20

visibility mask


$\zeta|T$: mean
realization #1
realization #2
$\zeta|E$: allowed fluctuations less noisy with E pol (extra mode/LM)
$\zeta|T,E$:
20 arcmin fwhm
20x20 sq deg
stack
ζ on
ζ-pks
−20 −16 −12 −8 −4 0 4 8 12 16 20
10^5 ζ (patch mean removed)
visibility mask

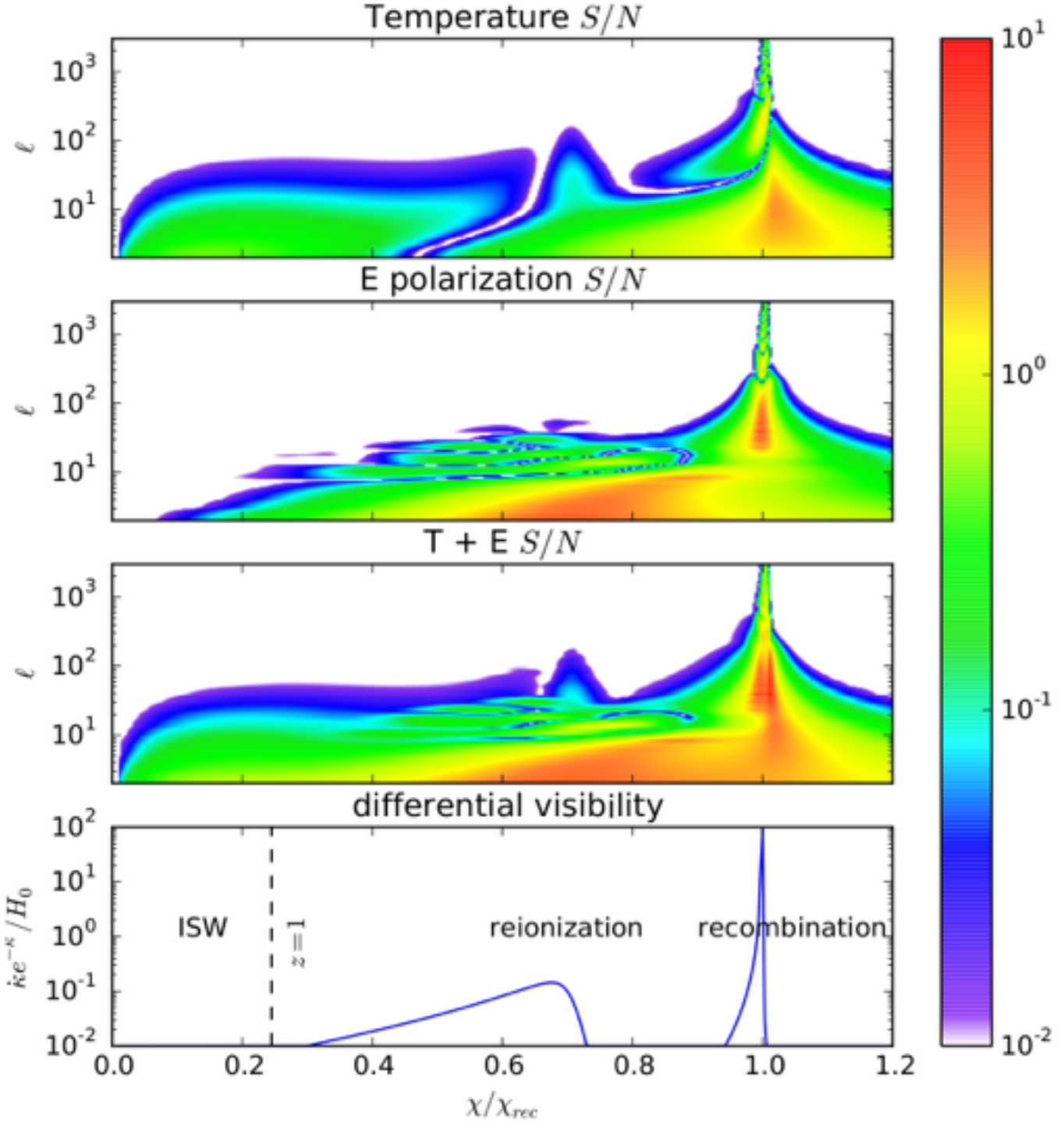
$\langle \zeta_{LM}(\chi) T_{LM} E_{LM} \rangle$

the vast CMB-un-illuminated $\zeta_{LM}(d)$



for an ideal noiseless expt

for Planck noise, E mode S/N erodes a bit

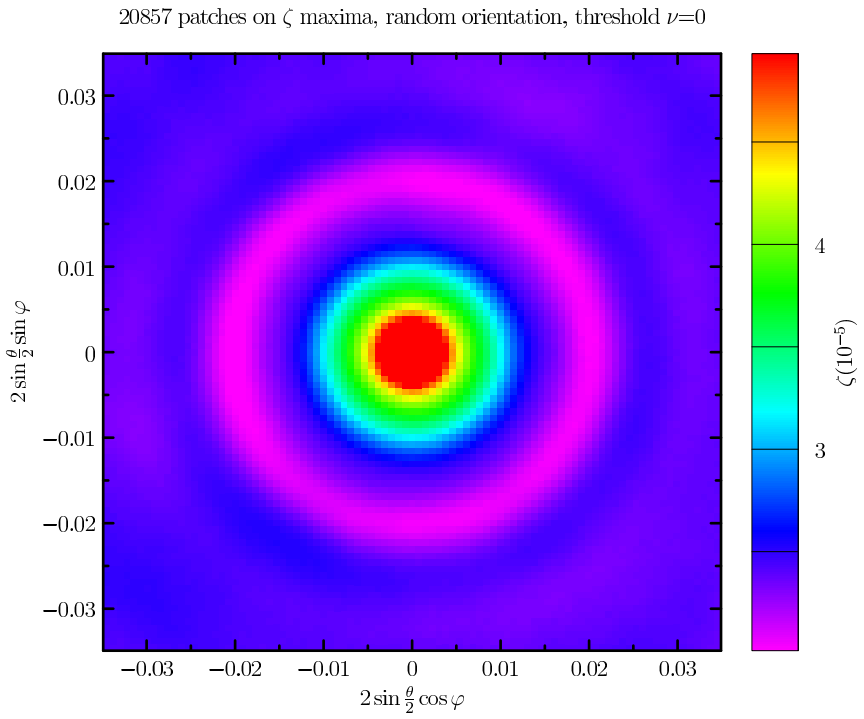


Planck2015 early U structure map

stacked linear map aka mean-field map

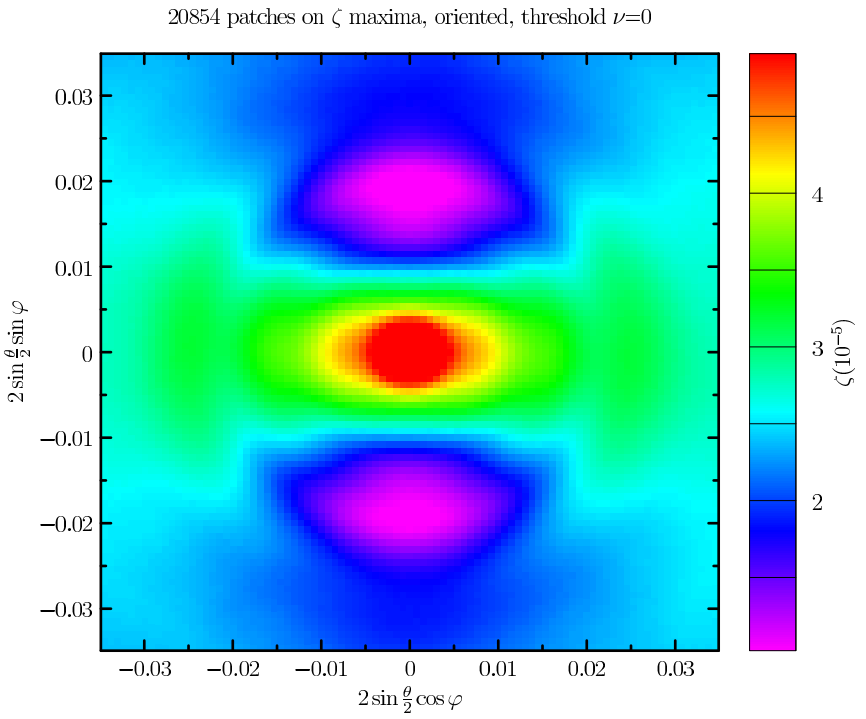
stacked

$\langle \zeta_{dv} \mid \zeta_{dv\text{-}pk} \rangle$



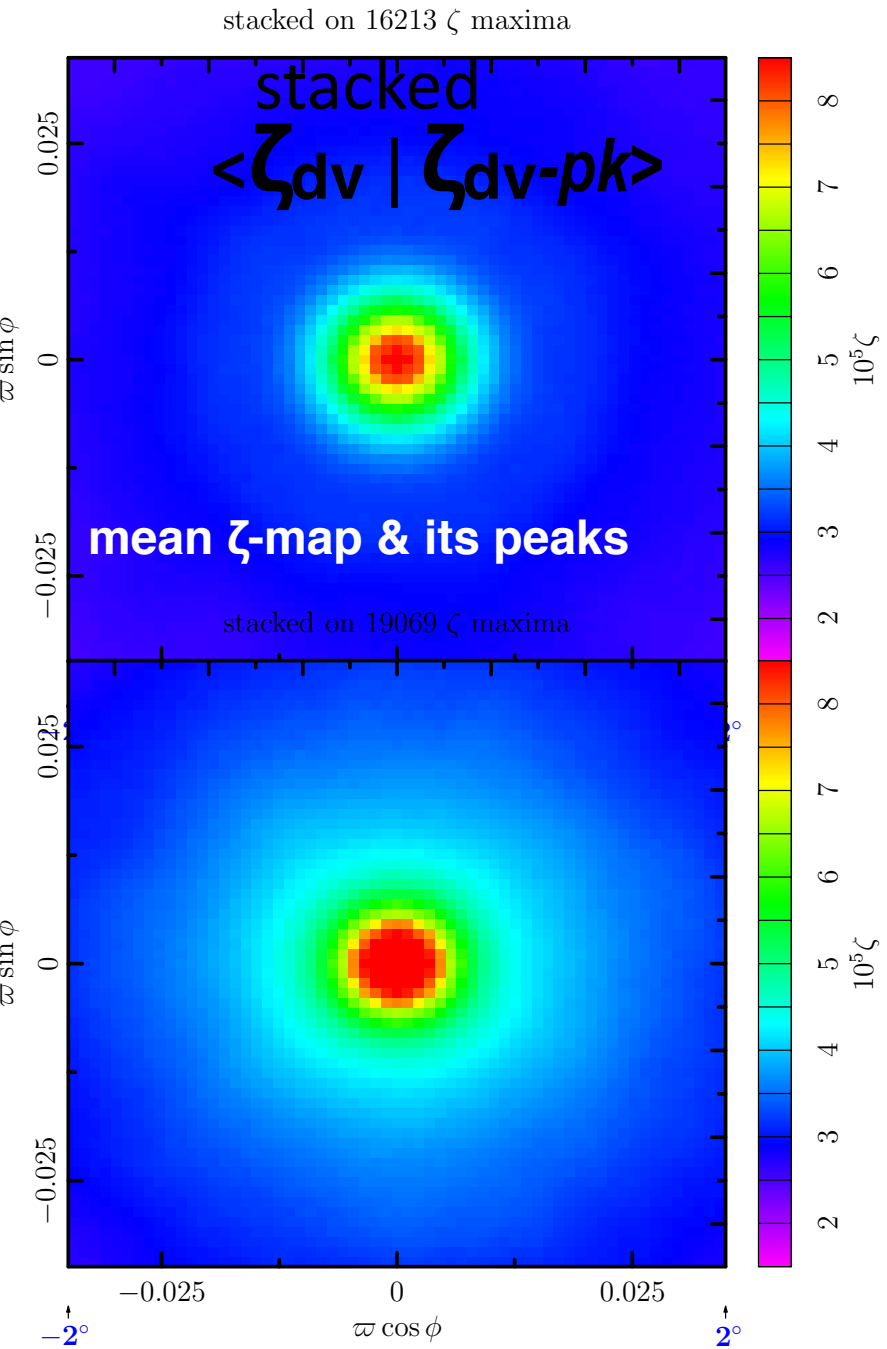
stacked

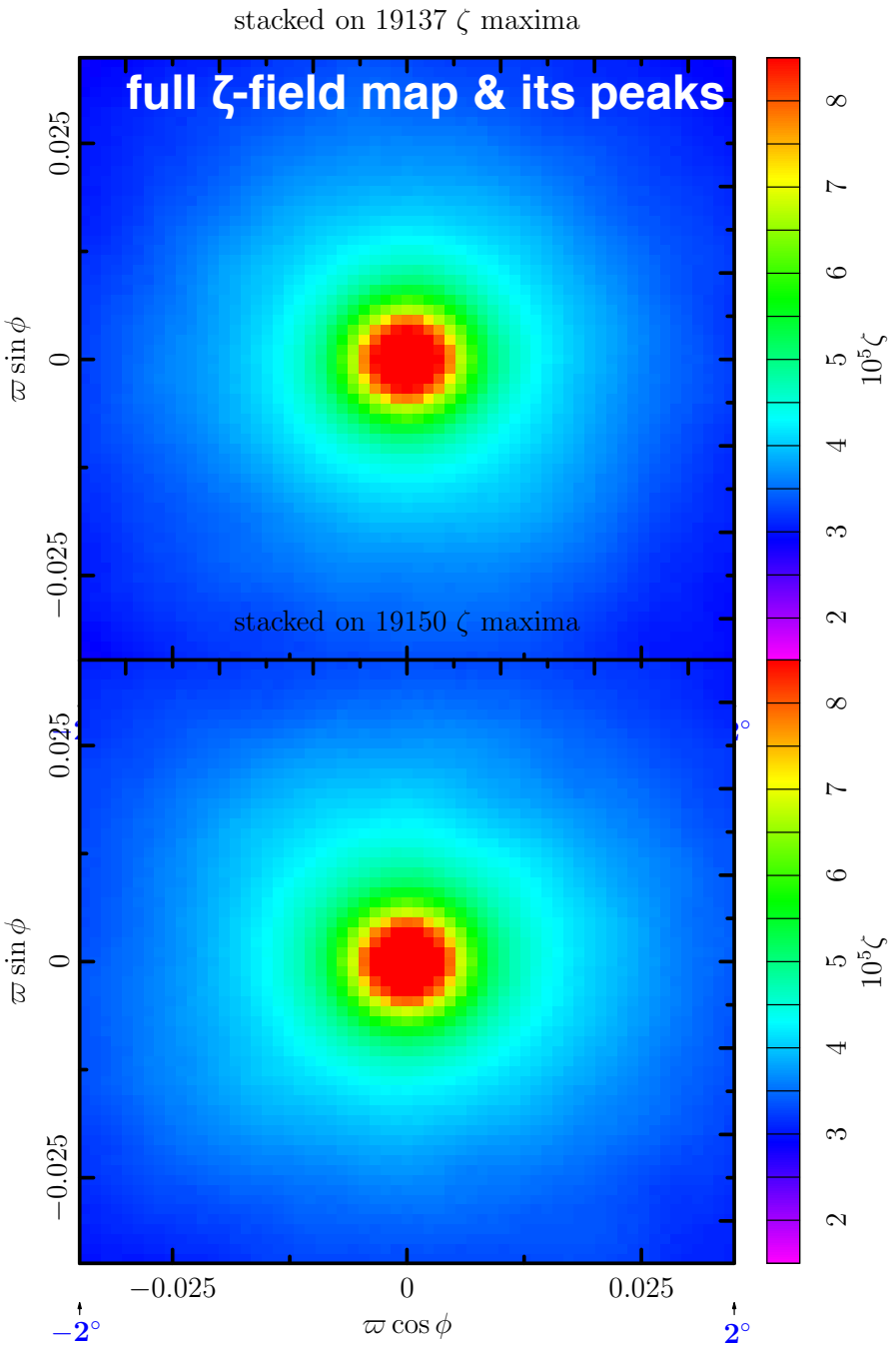
$\langle \zeta_{dv} \mid \text{oriented } \zeta_{dv\text{-}pk} \rangle$



ζ stacks of Planck 2013 & WMAP9 look very similar
simulations look very similar

Planck2015 early U structure map

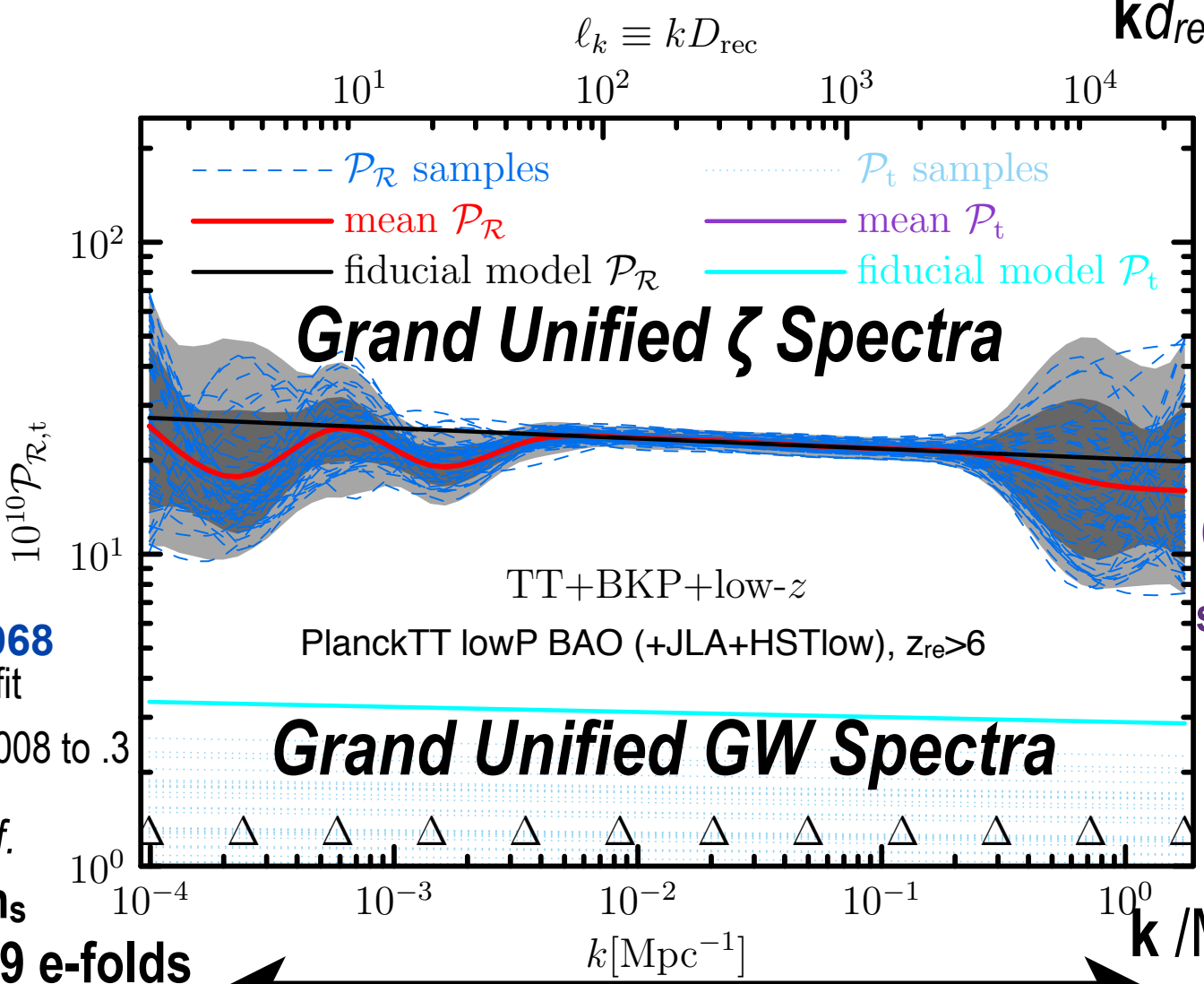




even more (radical) **compression** ***in quadratic space, using Planck likelihood rather than linear*** (**<ζ**|*Temp, E pol*> +**δζ**) *maps, e.g., onto 12 bands in k-space (LM projection)*

=> a quadratic map, includes lensing & BB from BKP

kd_{rec} ≳L



EE (L>30) looks similar

=> V(ϕ)

uniform **n_s=0.968**
P15+LSS best fit

superb 12-knot fit k~ .008 to .3

r<.11 95%CL *cf.*
r<0.09 uniform n_s

9 e-folds

k /Mpc

BSMc = SMc + primordial anomalies

$<\zeta|T,E>+\delta\zeta$ => *study non-Gaussian anomalies*

15 arcmin fwhm

sigh, Mother Nature puts her Anomalies @ low L where sample variance => tantalizing ~ 2σ's?

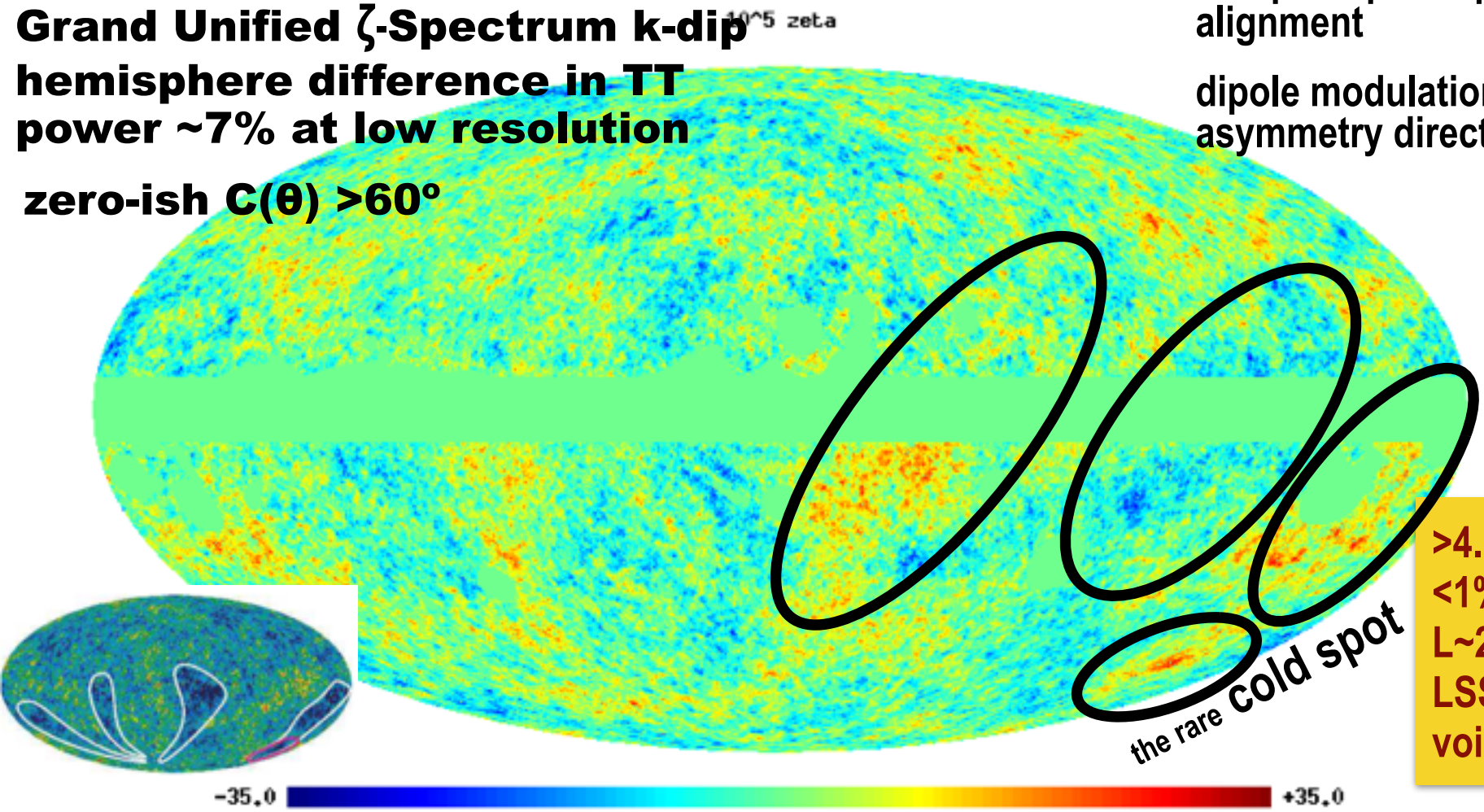
CMB TT power L~ 20-30 dip => Grand Unified ζ-Spectrum k-dip

hemisphere difference in TT power ~7% at low resolution

zero-ish C(θ) >60°

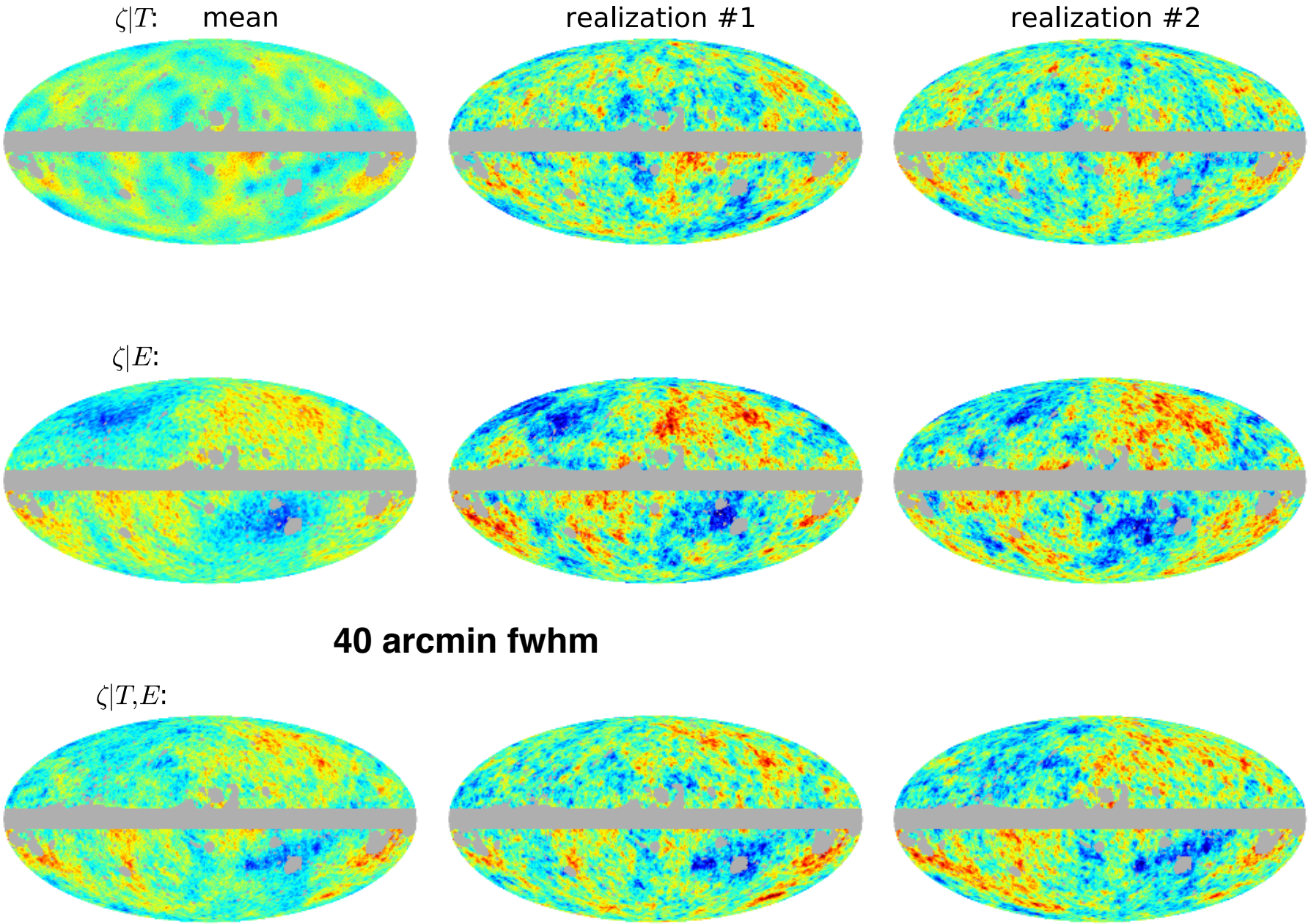
octupole/quadrupole alignment

dipole modulation/ asymmetry direction



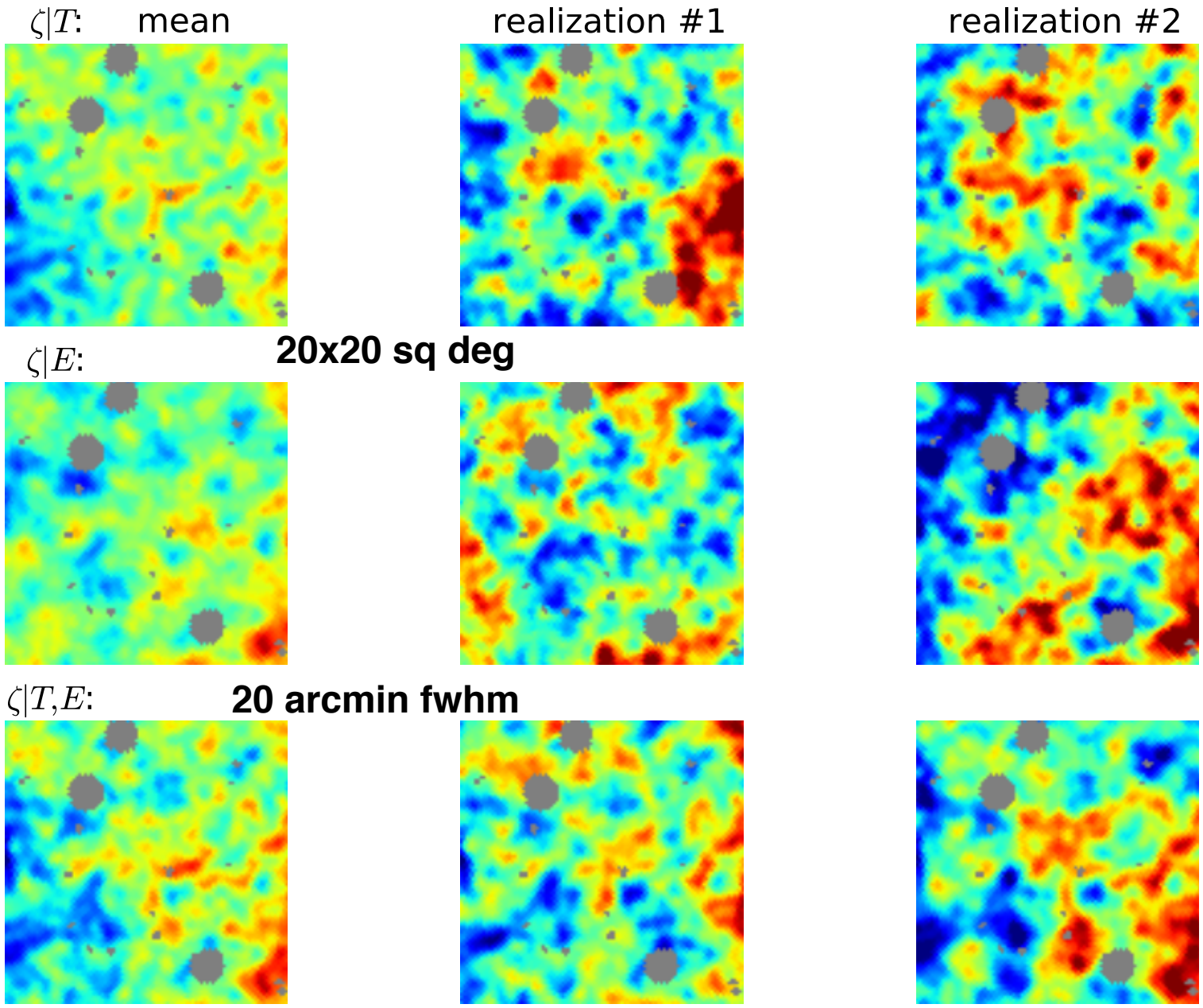
>4.5σ
<1%
L~20
LSS void?

intermittent?



caution: not de-lensed

decoupling slice



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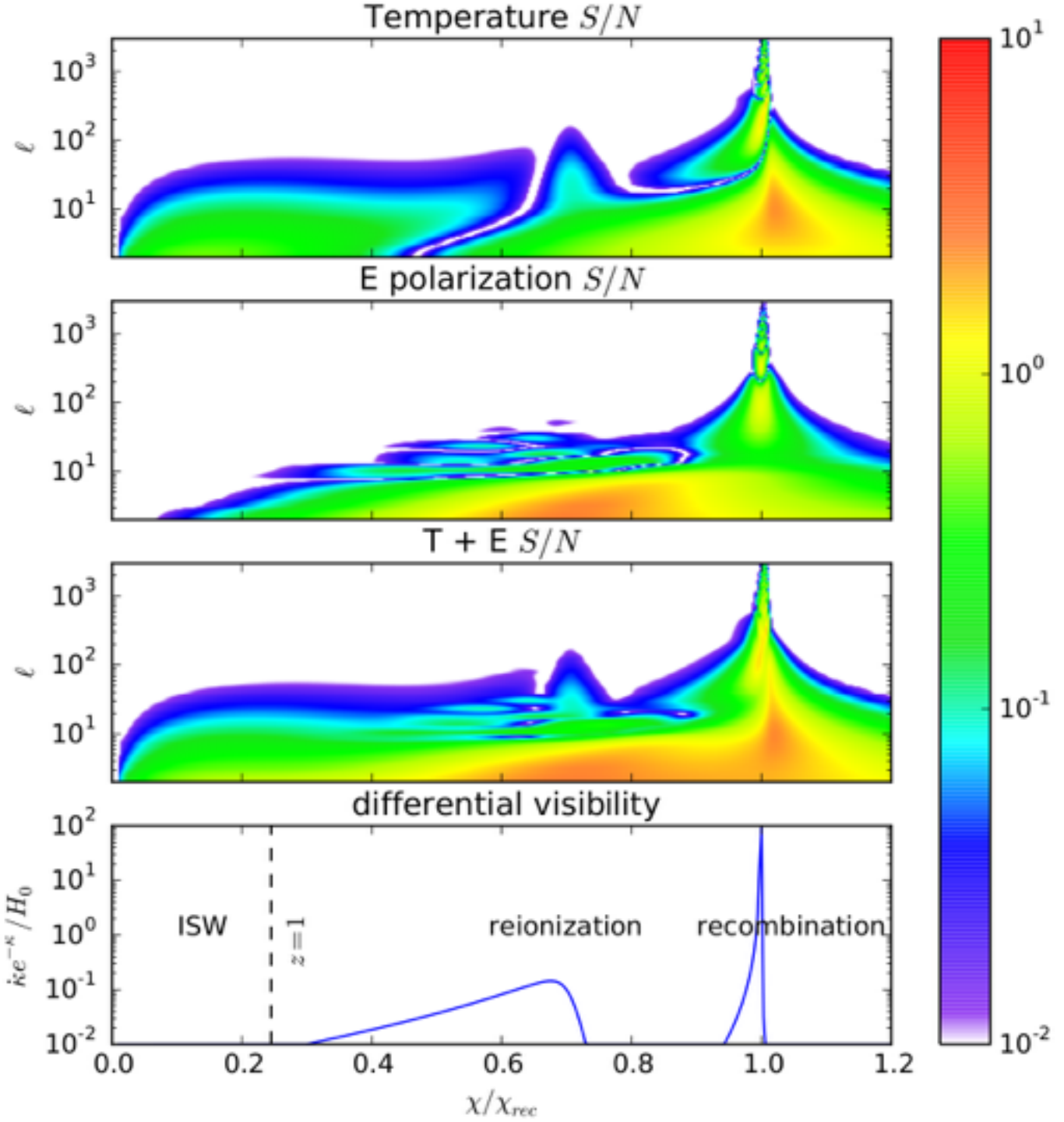
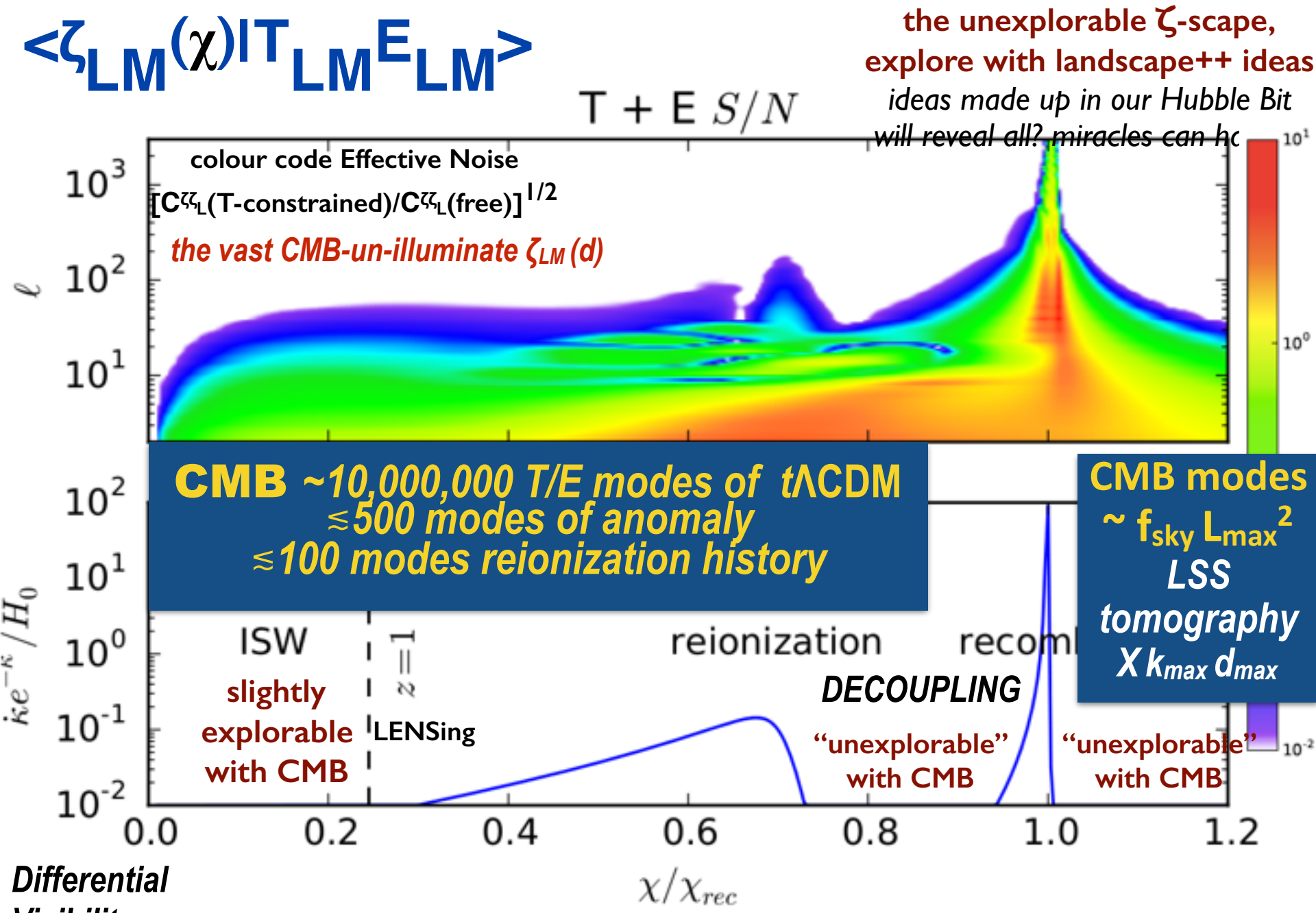


Planck noise (FFP8 sims)

$\langle \zeta_{LM}(\chi) T_{LM} E_{LM} \rangle$

the unexplorable ζ-scape,
explore with landscape++ ideas
ideas made up in our Hubble Bit
will reveal all? miracles can hc



CMB *~10,000,000 T/E modes of tΛCDM*
≲500 modes of anomaly
≲100 modes reionization history

CMB modes
~ $f_{sky} L_{max}^2$
LSS tomography
$X\ k_{max}\ d_{max}$

Differential Visibility

limits to our knowledge

naive SW ~ $\Phi_N/3$

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Super-duper LSS & the Super-WEB aka the primordial 3-curvature web aka the phonon/isotropic strain= *volume deformation* web

$ln\rho(x,t)/\langle\rho\rangle|_V$ $\quad ln\, V/\langle V\rangle|_\rho = 3\, ln\, a(x,t)/\langle a\rangle|_\rho$

$$\zeta(x,t) = \int (dE+pdV)/E \quad /\langle 3(1+p/\rho)\rangle(t)$$

BST83, SBB89, SB90,91, B95, Bond+Braden2016 ζ for preheating

$$\zeta(x,t) = ln\rho(x,t)\,/\langle 3(1+p/\rho)\rangle(t) + \int (1+p/\rho)(x,t)\, d ln a(x,t)\,/\langle 1+p/\rho\rangle(t)$$

or: $\zeta(x,t) = ln\rho(x,t)/\rho_b \,/\, 3(1+p_b/\rho_b) + ln a(x,t)/a_b$

cf. the density web ~ strain web ~ gravitational potential web

$$-\, ln\, \rho/\langle\rho\rangle = \text{Trace}\, ln\, e_j^{\,j} = ln\, V/\langle V\rangle|_\rho$$

cold $\langle p/\rho\rangle \sim 0 \Rightarrow \zeta(x,t\,|cdm)$ *conserved before shell crossing (preheating)*

the ζ-*LAND*-**scape attractor trajectories & their drift plus quantum diffusion instabilities**

Hamiltonian-density $\rho(\phi_b,\pi_b,\ln a)$ => coarse-grained k<Ha attractor $\rho(\phi_b)=3M_P^2H^2$

SB90,91 $d\phi_b/d\ln a = -M_P^2 \nabla_{\phi b} \ln\rho$, **a gradient / Morse flow** *a field superweb flow*

<= ***Hamilton-Jacobi eq^n*** $\delta\zeta_{NL} = \delta\ln a + \delta\ln\rho/3(1+p/\rho)$ = *fine-coarse kicks +⊥ drifts*

"adiabatic" fluctuations along the Morse flow river valleys (phonons)

isocurvature directions ⊥ flow: basins, saddles, watersheds, valley-to-valley tunnels, ..

reduced action (Hamilton's Principal function) ~ H ~ $\rho^{1/2}$

stochastic kicks $\delta\phi_b$ along the attractor give no $\delta\zeta_{NL}$

kicks off the attractor ($\delta\pi_b$ damps) give $\delta\zeta_{NL}$ entropy *fine->coarse drift off the attractor give* $\delta\zeta_{NL}$ *instabilities, bifurcations, pre-heating Lyapunov growth*

kls94 ***entangled isocons as heating triggers => Lyapunov instability?*** *b^{2}fh* ***ε=1 ballistics => caustics =>*** *bb* ***shock-in-time entropy*** *coarse->fine* ***observable intermittent nG?***