Dick Bond @Stanford17_12

Quantum Inflation in the Planck Era & Beyond

what are the degrees of freedom / parameters of the ultra early Universe? TBD

Quantum Inflation - if quantum energy then quantum gravity (entangled) then gravitons

Phonons *density fluctuations = Trace strain = spatial 3-volume fluctuations*

=> *combined entropy-like measure* ζ =inflaton

$\zeta(x,t) = \int_{\text{field-path}} (dE+pdV)/3(E+pV)$

Gravitons *tensor perturbations transverse traceless strain* $P_{GW} = r\, P_\zeta$ *grail* $r < .07$ *now, to* $< .001$

Isocons *when multiple particle-species - orthogonal scalar degrees of freedom to inflaton/phonon*

Dilatons *4-volume fluctuations - Higgs inflation* $L_G(R)$ *gravity - conformally-flatten potentials*

moduli, axions *connection to particle physics models "fundamental scalars" .. string theory*

fermions, vector gauge fields, *Standard model of particle physics* **.. vector perturbations**

begin-inflate => inflate => end-inflate => preheat => non-equlibrium heat+entropy

=> *Standard Model particle physics* **QG plasma radiation dominated**

=> dark matter dominated *structure via gravitational instability* **=> dark energy now**

fit into a UV-complete theory (ultra-high energy to the Planck scale) strings, landscape, ..

& IR-complete theory (post-inflation heating -> quark/gluon plasma)??? TBD

ζ *all cosmic structure from* **entropy**!

linear ***(bst1983)*** **=>nonlinear** $\zeta(x,t) = \int_{\text{field-path}} (dE+pdV) / 3(E+pV)$

SBB89, SB90,91, B95, B+Braden17 ***coarse-grained*** *horizon scale cf. fine-grained fluctuations*

system / signal *reservoir / noise*

BB, B2FH, b+braden+frolov+huang

ζ all cosmic structure from **entropy**!

linear (*bst1983*) =>nonlinear $\zeta(x,t) = \int_{\text{field-path}} (dE+pdV) / 3(E+pV)$

coarse-grained *horizon scale cf. fine-grained fluctuations*

$$\ln V / \langle V\rangle|_\rho = 3 \ln a(x,t) / \langle a\rangle|_\rho = \ln \det A^i{}_j(x,t) / \langle a\rangle|_\rho \sim 1/2 \ln \det {}^{(3)}g^i{}_j$$

volume deformation = isotropic strain

SBB89, SB90,91, B95
-> Sasaki+ δN 'formalism'

B2FH, b+braden+frolov+huang

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$\ln V / \langle V\rangle|_\rho = 3 \ln a(x,t) / \langle a\rangle|_\rho = \ln \det A^i{}_j(x,t) / \langle a\rangle|_\rho$

volume deformation = **isotropic strain**

$\ln \rho(x,t)/\langle\rho\rangle|_V$ **phonon**

SBB89, SB90,91, B95, B+Braden17

B2FH, b+braden+frolov+huang

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along coarse-grain trajectories $d\zeta = [\mathbf{d}bar\ \zeta](fg\text{->}cg)$ $(- [\mathbf{d}bar\ \zeta](cg\text{->}fg))$

regimes: 1. stochastic inflation non-adiabatic $[\mathbf{d}bar\ \zeta](fg\text{->}cg)$

reduction of Langevin network for all fields, Fokker-Planck probability evolution

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regimes: 1. stochastic inflation non-adiabatic $[\mathbf{d}bar\ \zeta](fg\text{->}cg)$

gradient flow ***+stochastic jitter,*** **simple Hamilton principle function** $S \sim H(\phi_{cg})$

origin of all cosmic structure from quantum noise story - nonGaussianity feedback of cg on fg

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ζ all cosmic structure from **entropy**!

linear (*bst1983*) =>**nonlinear** $\zeta(x,t) = \int_{\text{field-path}} (dE+pdV) / 3(E+pV)$

coarse-grained *horizon scale cf. fine-grained fluctuations*

$ln\, V / \langle V\rangle|_\rho = 3\, ln\, a(x,t) / \langle a\rangle|_\rho = ln\, det\, A^i{}_j(x,t) / \langle a\rangle|_\rho$

***volume deformation* = isotropic strain**

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regimes: 1. stochastic inflation non-adiabatic $[\bar{d}\zeta](fg\text{->}cg)$

gradient flow *+stochastic jitter,* simple Hamilton principle function $S \sim H(\phi_{cg})$

classical dynamical system theory, chaos

2. ballistic phase adiabatic thru EoI, but caustics & Kolmogorov-Sinai entropy

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ζ all cosmic structure from **entropy**!

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gradient flow ***+stochastic jitter,*** **simple Hamilton principle function** $S \sim H(\phi_{cg})$

2. ballistic phase adiabatic thru EoI, but caustics & Kolmogorov-Sinai entropy

3. shock-in-time, *cg <=> fg, origin of almost all entropy* $S_{U,m+r} \sim 10^{88.6}$

non-equilibrium S burst, slow evolution to quark/gluon plasma *cf.* $S_G \sim 10^{121.9}$ *asymptotic DE*

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ζ all cosmic structure from **entropy**!

linear (*bst1983*) =>nonlinear $\zeta(x,t) = \int_{\text{field-path}} (dE + pdV) / 3(E + pV)$

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gradient flow *+stochastic jitter*, simple Hamilton principle function S~H(ϕ_{cg})

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cf. $S_G \sim 10^{121.9}$ *asymptotic DE*

further S generation in early Unioverse: phase transitions, out-of-equilibrium decays?

*further **d**bar S: reionization epoch & beyond via nuclear/accretion, gravitational collapse **CIB***

Dick Bond *@Stanford17_12*

ζ *all cosmic structure from* **entropy**!

linear (*bst1983)* =>**nonlinear** $\zeta(x,t)= \int_{\text{field-path}} (dE+pdV) / 3(E+pV)$

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$ln\, V / \langle V\rangle|_\rho = 3\, ln\, a(x,t) / \langle a\rangle|_\rho = ln\, det\, A^i{}_j(x,t) / \langle a\rangle|_\rho$

volume deformation = **isotropic strain**

$ln\, \rho(x,t)/\langle\rho\rangle|_V$ **phonon**

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cf. $S_G \sim 10^{121.9}$ *asymptotic DE*

..7.. *cf.* late-time **density web ~ strain web ln ρdetA** /3

if cold DM $p/\rho\sim 0 \Rightarrow \zeta(x,t\,|cdm)$ *is conserved before shell crossing (preheating)* reveals **primordial early universe phonons**

ζ- TOPOGRAPHY & CARTOGRAPHY

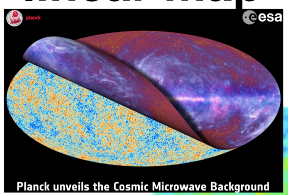
<ζ | Temp, E pol>

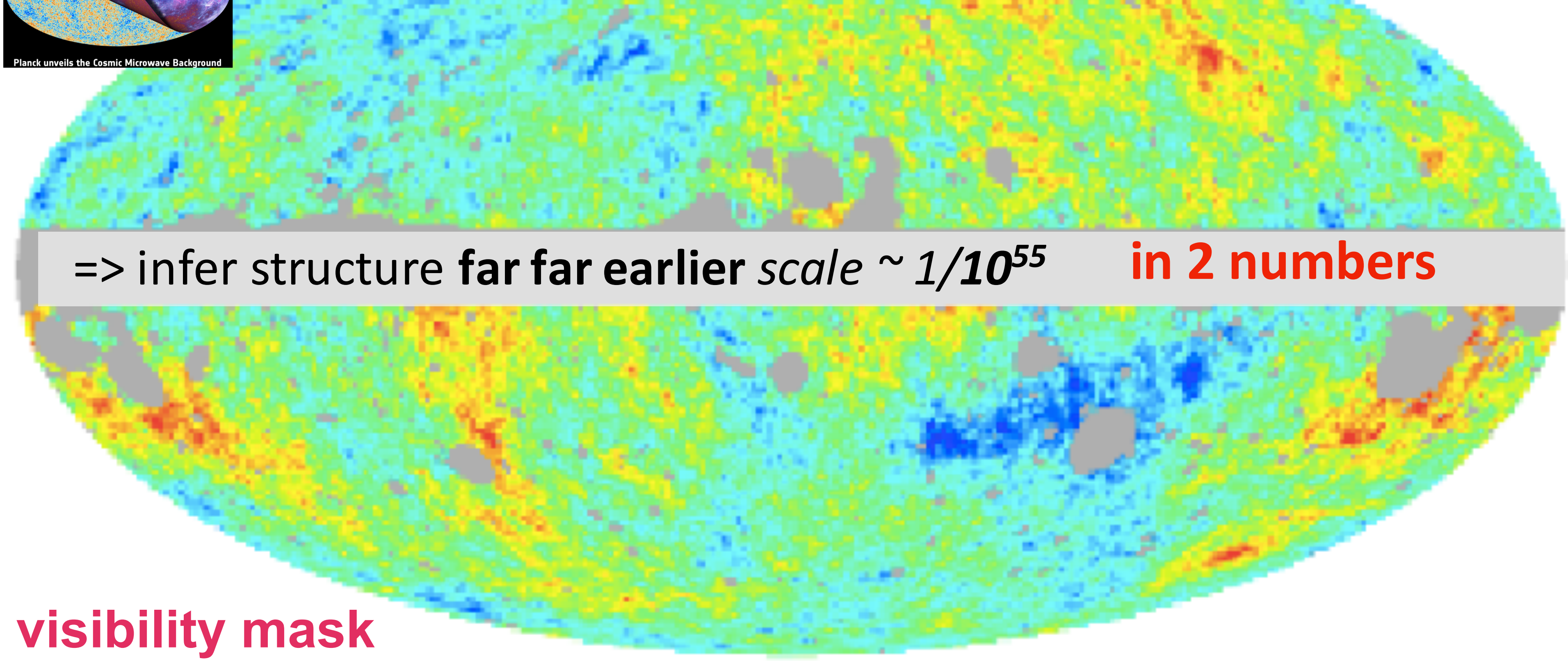
caution: not de-lensed, but the Wiener filter does partially de-lens

Planck 2015 XVII nonG

40 arcmin fwhm

linear map





=> infer structure **far far earlier** *scale ~ 1/10^{55}*   **in 2 numbers**

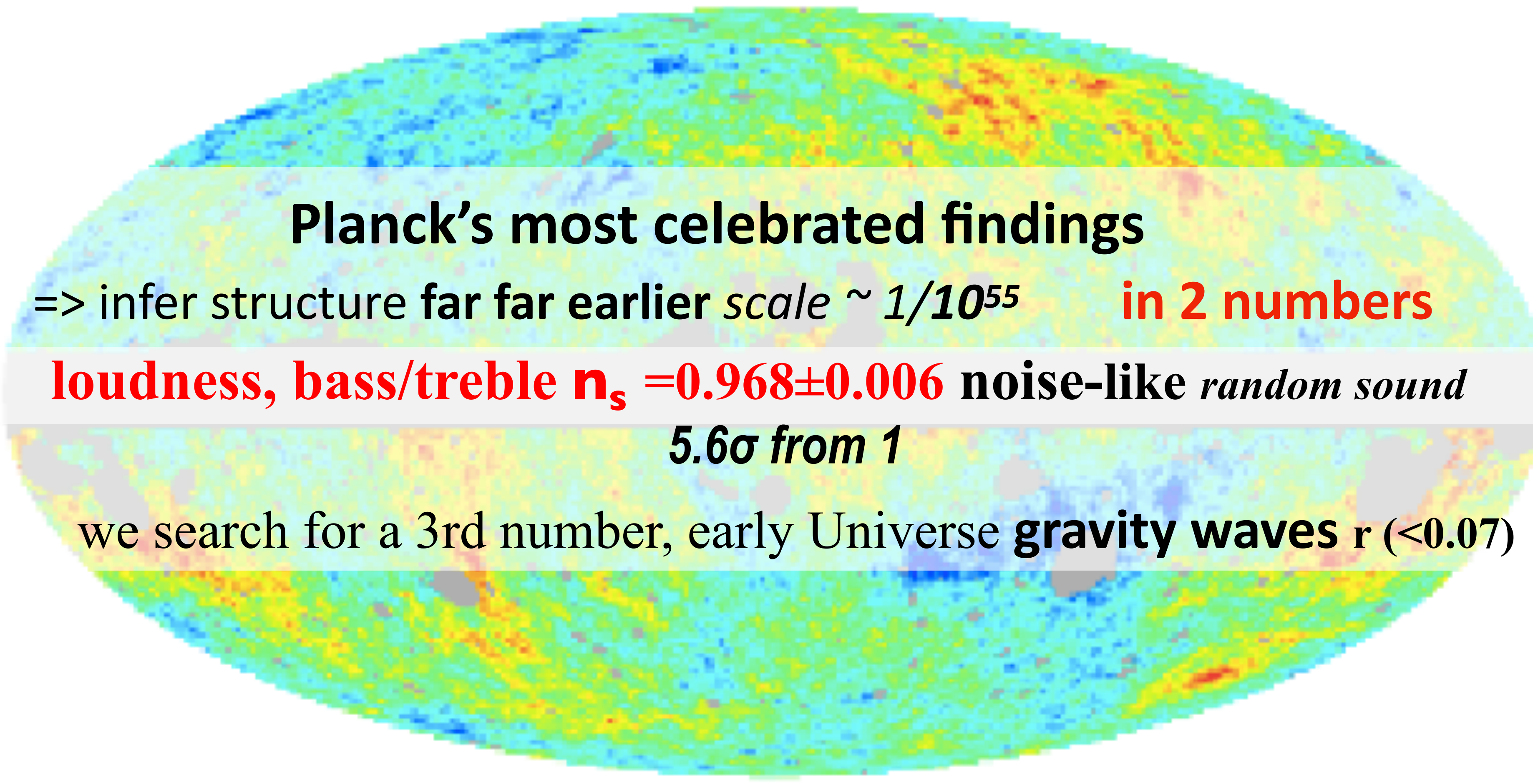
visibility mask

$\int$d ***visibility***(*distance*) <ζ | Temp, E pol> (*angles, distance*)

Planck's primordial light unveiled

reveals **primordial sound waves** from far earlier times

=> the inharmonious early Universe *'music of the spheres'*



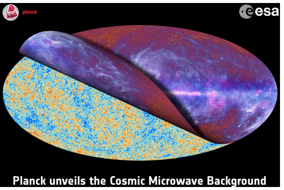
Planck's most celebrated findings

=> infer structure **far far earlier** *scale ~ 1/*10^{55} **in 2 numbers**

loudness, bass/treble n_s =0.968±0.006 noise-like *random sound*

5.6σ from 1

we search for a 3rd number, early Universe **gravity waves** **r (<0.07)**



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

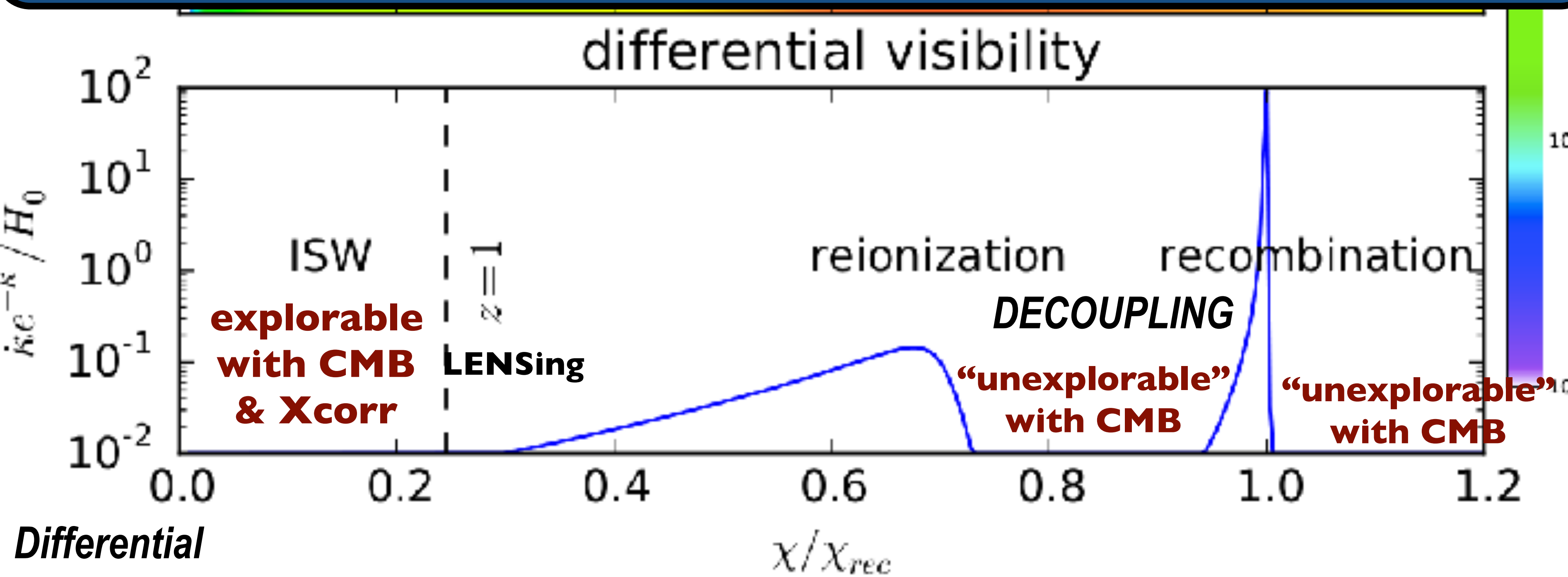
the unexplorable ζ-scape, explore with landscape++ ideas

our Hubble Bit will reveal all?

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

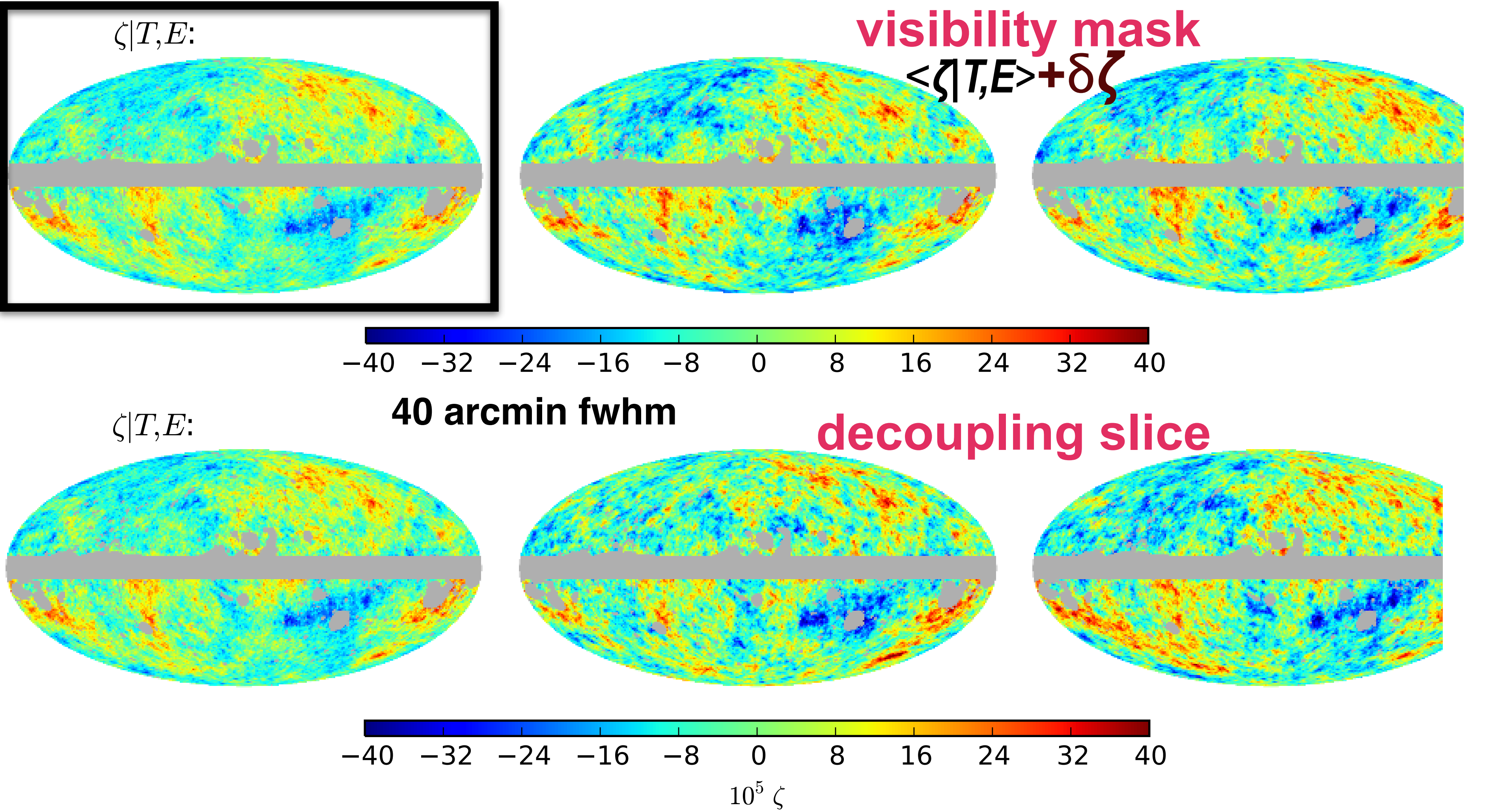
CMB modes
~ $f_{sky} L_{max}^2$

LSS tomography
X k_{max} d_{max}



Differential Visibility

limits to our knowledge



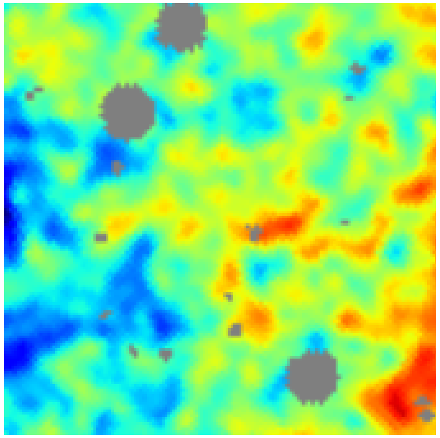
Maps = *(radical)* **compressions** *of the* ***time ordered information*** **ToI** ***onto a parameterized space*** q^A: *Linear maps, Quadratic maps (power), cosmic parameter maps*

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

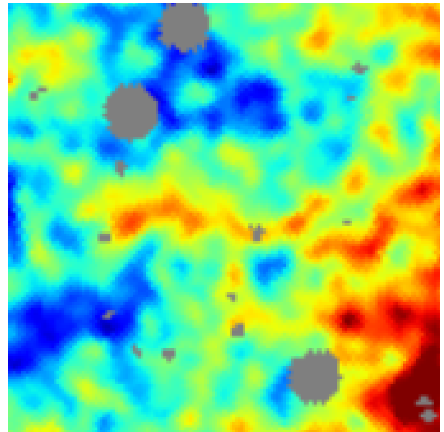
allowed fluctuations are less noisy with T +E-pol (extra mode/LM)

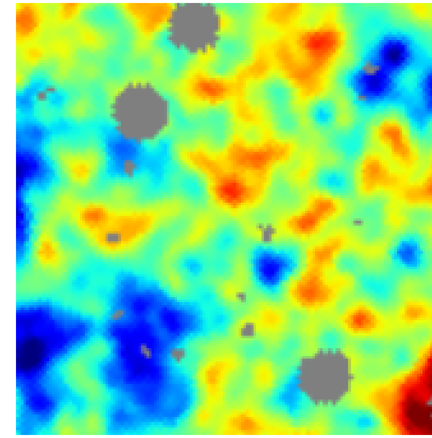
Planck 2015 XVII nonG

$\zeta|T,E$:



visibility mask



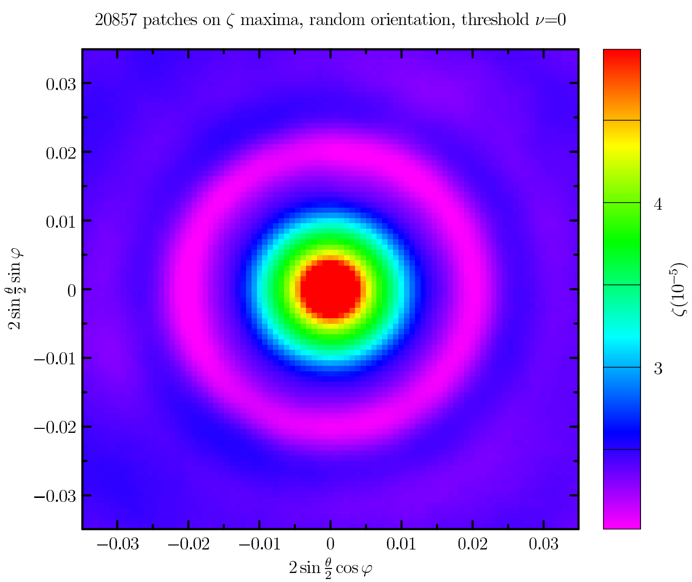


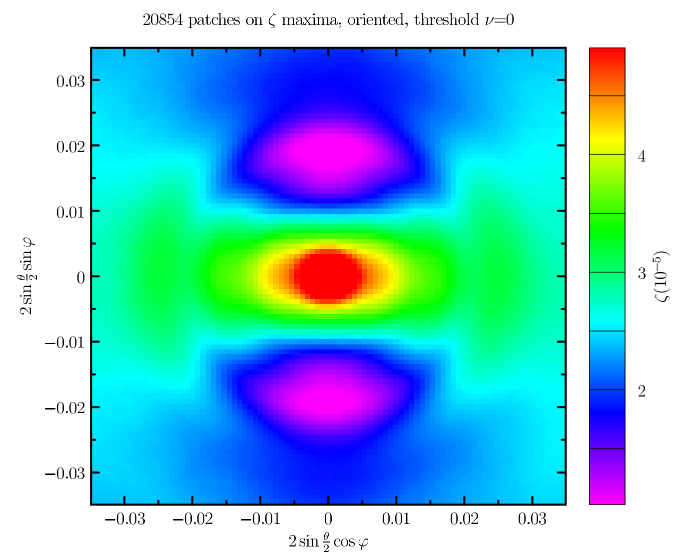
20x20 sq deg

zoom in, higher res: 20 arcmin fwhm

stack to damp fluctuations

<ζ|ζpk>|dv





oriented stacks, etc.

Quantum Inflation in the Planck Era & Beyond

relic1: ***ζ from inflaton*** *- observable = all cosmic structure CMB&LSS & stars/humans etal*
amplitude & slope <-> acceleration history & Veff simple over observable range

relic2: ***entropy*** *cooled remnant of particle/field plasma post-inflation* $S_{tot} = S_{CMB} + S_{CnuB}$

$10^{88.6}$

relic3: ***baryon asymmetry*** *of matter over antimatter* N_{baryon}/S_{tot}

$10^{-10.06}$

relic4: ***dark matter*** *from quark/gluon plasma - only seen gravitationally WIMPS, axions,..*

26.8 ± 0.9%

relic5: big bang nucleosynthesis products ***H, He, D, Li*** *(influenced by CnuB)*

relic 6: ***CMB*** *with all its fluctuations & polarization*

relic 7: galaxies & large scale clustering, flows, gravitational lensing

relic 8: ***dark energy***

68.8 ± 0.9%

Quantum Inflation in the Planck Era & Beyond

what are the degrees of freedom / parameters of the ultra early Universe? TBD

relics not yet seen: in quest of what lies Beyond *the Standard Model of cosmology* SMc

from inflation

local nonG for Φ_N =G+f_{nl} G^2 f_{nl}=0.8 ± 5.00.8 ± 5.0

non-Gaussian features in ζ from weak nonlinearities *(very nearly)* Gaussian random field

gravity waves (not so far - obscured by dust)

P15+BKP r<0.09 uniform n_s

cf. 0<r<.11 95% CL P15+BKP 12 knots

isocon relic (not so far) - Planck on CDM isocurvature, neutrino, correlated

< 2% isocurvature role

bubble remnants of tunneling during inflation

from heating

isocon memories (not so far)

strong subdominant but intermittent nonlinearities in ζ (spikes via chaotic billiards)

curvatons oscillons strings domain walls - short lived

rare WIMPzillas as dark matter

from later quark gluon plasma

late phase transitions

anomalies* in *CMB & LSS

could be *primordial. large-scale, intermittent? statistics of just a few (modes, spatial rare events)?*

Beyond the Standard Model of cosmology? SMc = *tilted*ΛCDM +r $(\zeta, h_{+\times})$

BSMc = SMc + primordial anomalies

f_{NL^*} =-0.52 ± 3.0 for ζ

std nonG $\zeta = \zeta_G + f_{NL^*} (\zeta_G^2 - \langle \zeta_G^2 \rangle)$ local & equilateral pattern & orthogonal

non-std nonG $\zeta = \zeta_{inflaton} +$ ***uncorrelated*** $\zeta_{[GRF\}}$ modulated heating intermittent?

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

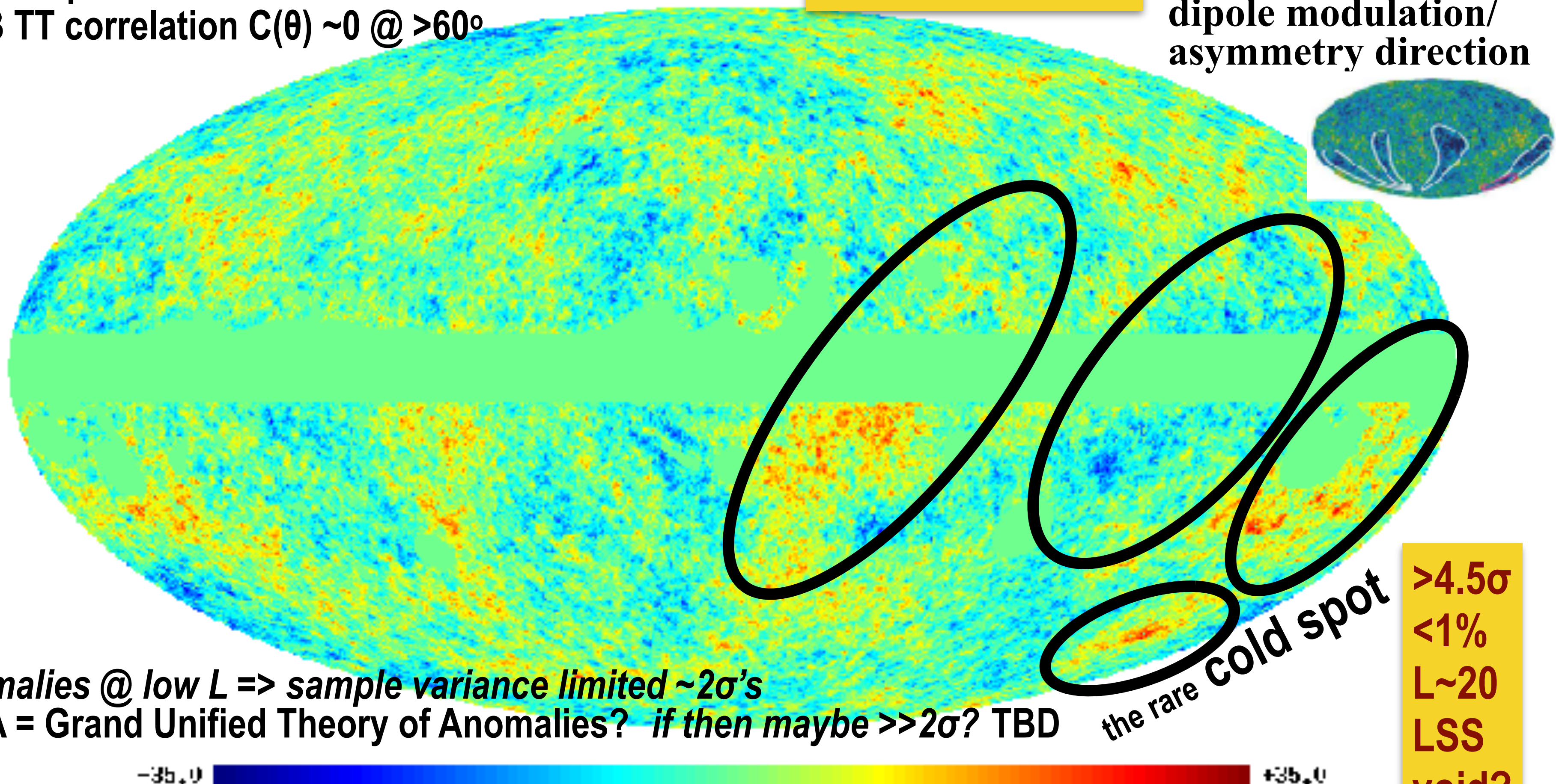
hemisphere difference ~7% at low resolution

CMB TT correlation C(θ) ~0 @ >60°

<ζ |*T,E-pol*>

octupole/quadrupole alignment

dipole modulation/ asymmetry direction



the rare cold spot

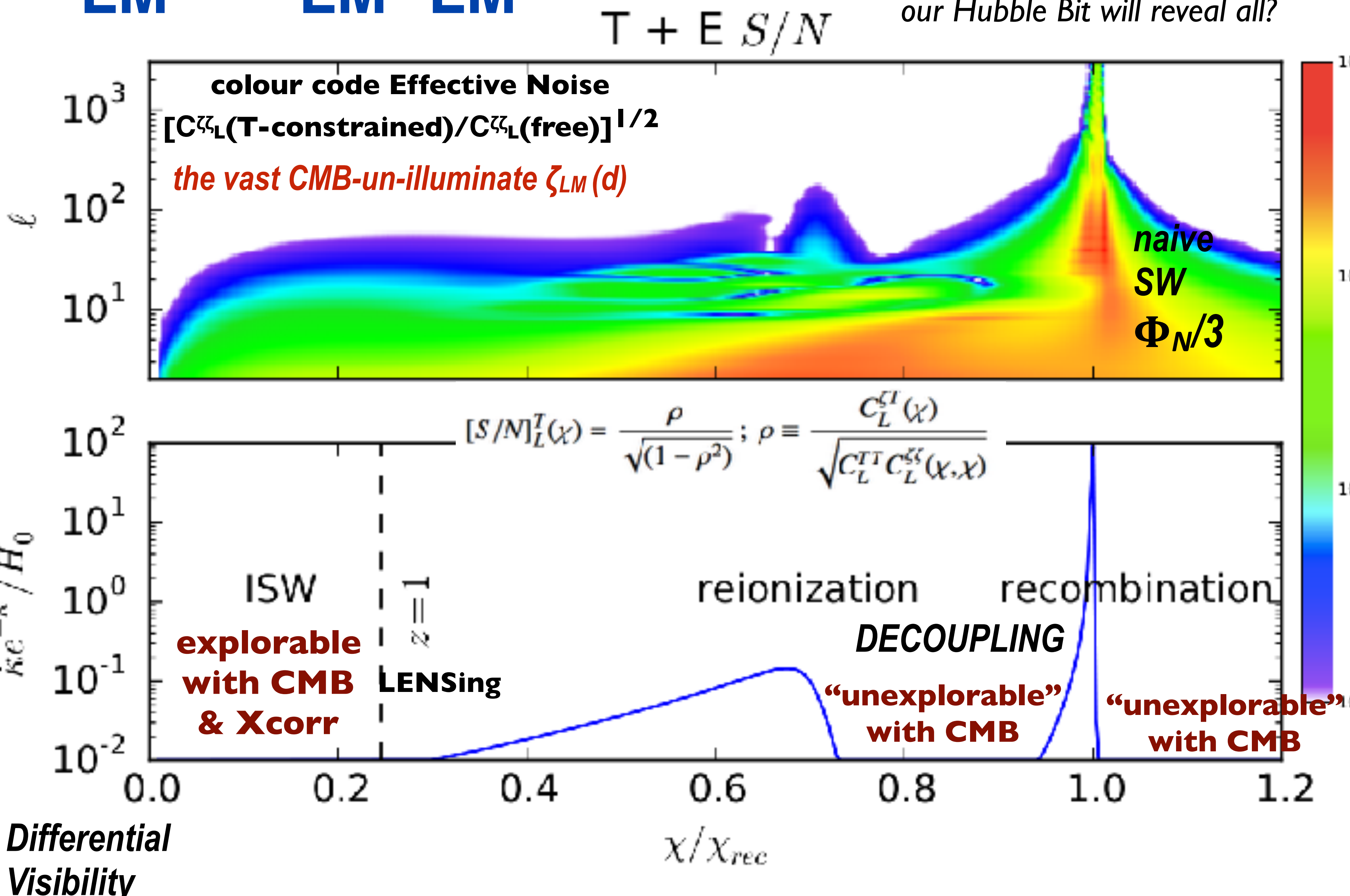
>4.5σ
<1%
L~20
LSS
void?

anomalies @ low L => sample variance limited ~2σ's

GUTA = Grand Unified Theory of Anomalies? *if then maybe >>2σ?* TBD

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

the unexplorable ζ-scape,
explore with landscape++ ideas
our Hubble Bit will reveal all?



limits to our knowledge

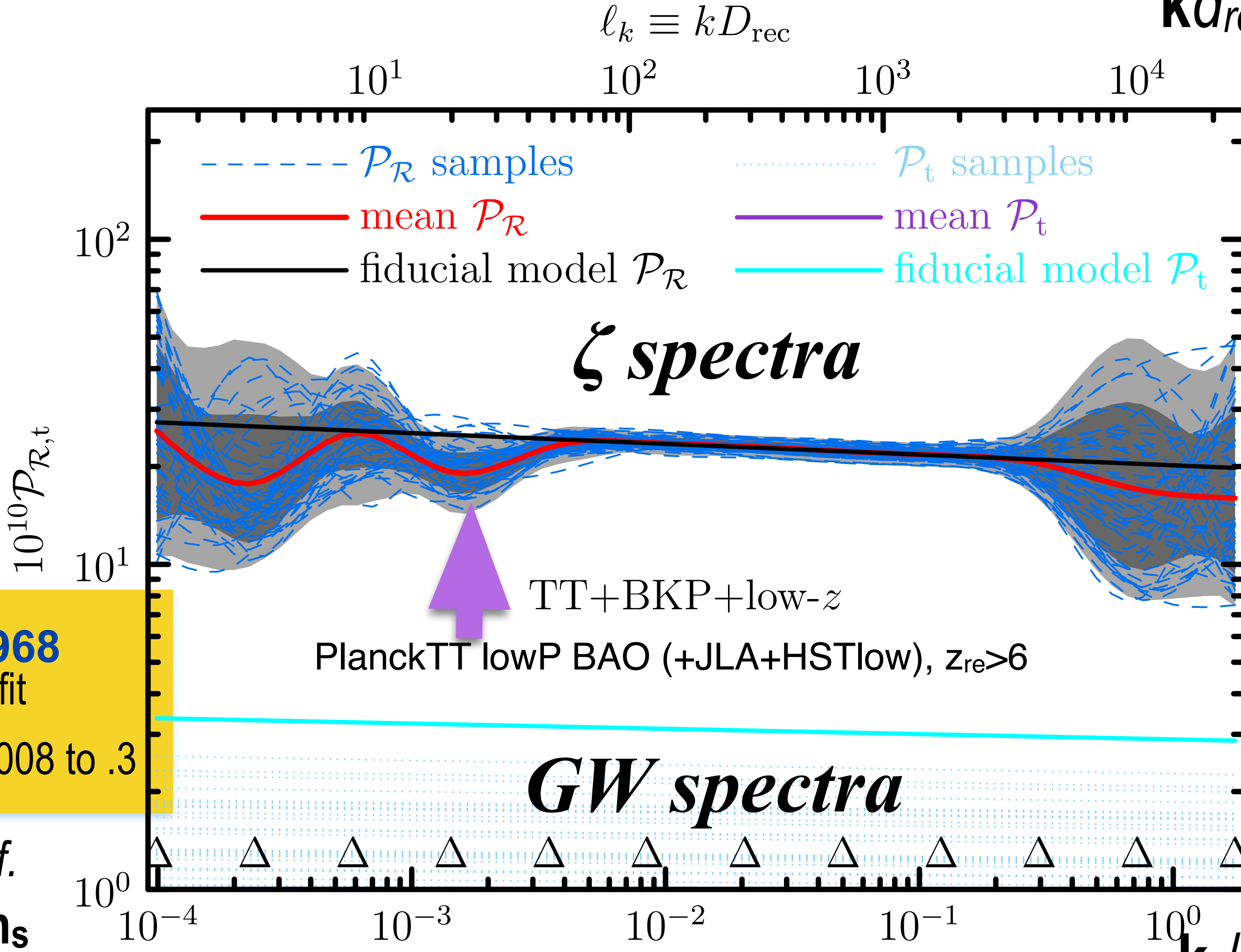
Planck 2015 XVII nonG

quadratic map of the ζ-**scape**

Planck 2015 XX inflation

CMB TT power L~ 20-30 dip => ζ-Spectrum k-dip; *includes CMB lensing, parameter marginalization*

kd_{rec} ≳L



EE (L>30) looks similar

=> V(ϕ)

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

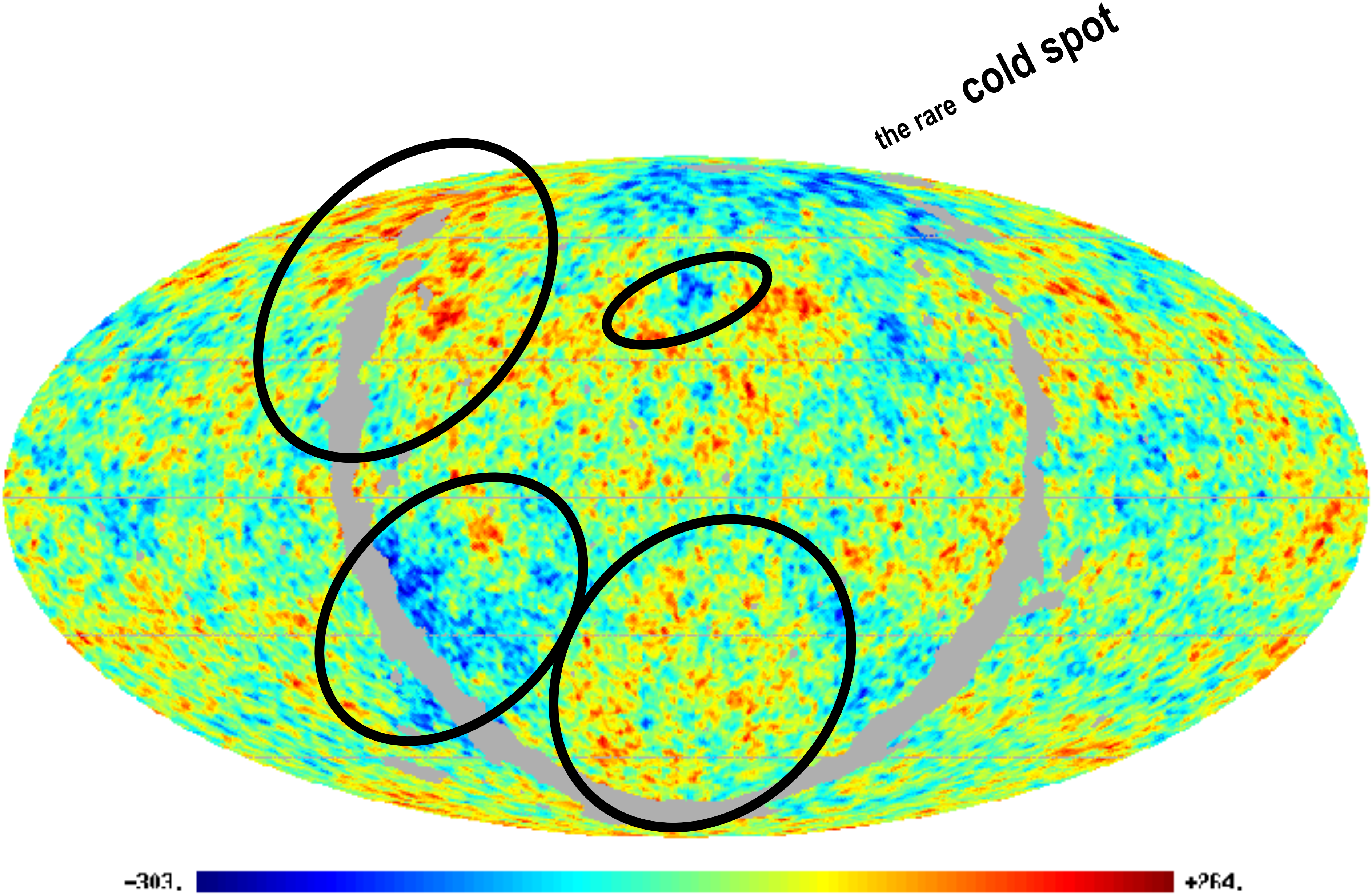
superb 12-knot fit k~ .008 to .3

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

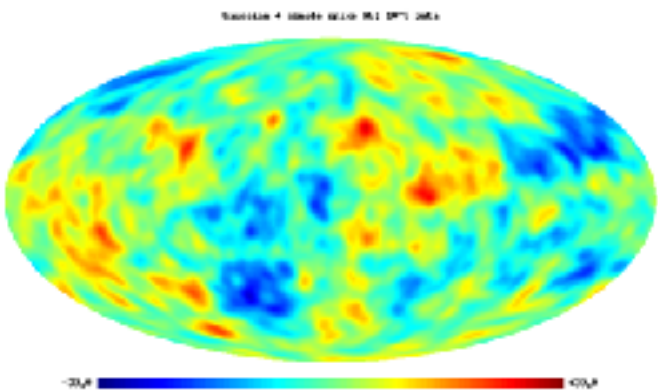
9 e-folds

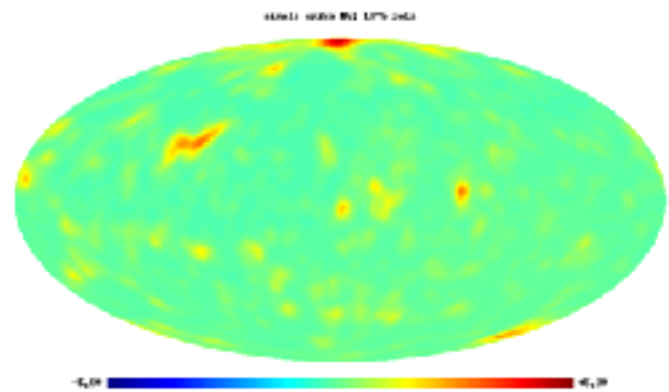
k /Mpc

BFH, b+frolov+huang



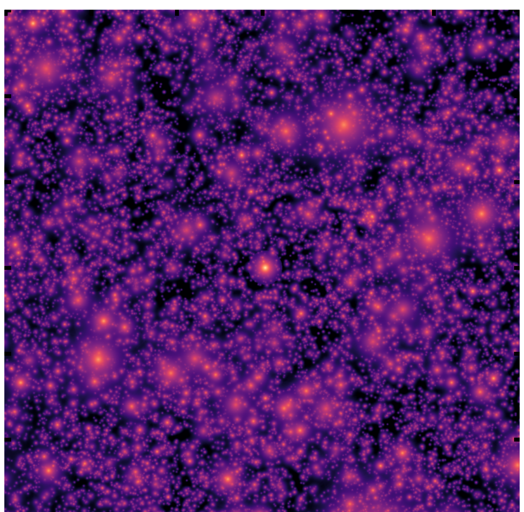
CMB+LSS mocks to test: standard Gaussian inflaton ζ_{inf}+ subdominant uncorrelated ζ_{isoc}
e.g., ***from modulated preheating by isocons***





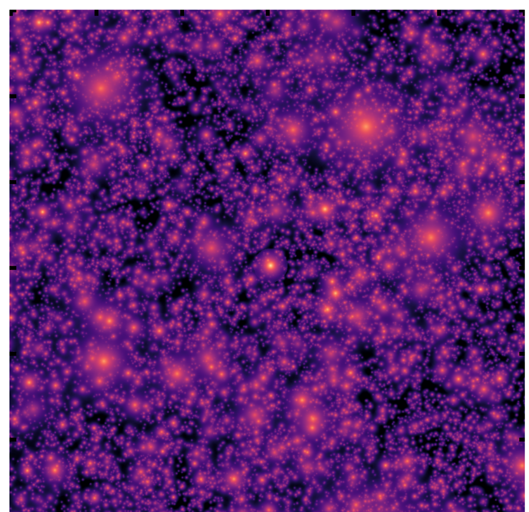
uncorrelated nonG 'wide open' cf. usual correlated highly constrained nonG

LSS tSZ: Gaussian std



B2FH, b+braden+frolov+huang

LSS tSZ: Gaussian std +
subdominant uncorrelated ζ



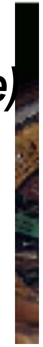
ABSB+FH, alvarez+b+stein+frolov+huang

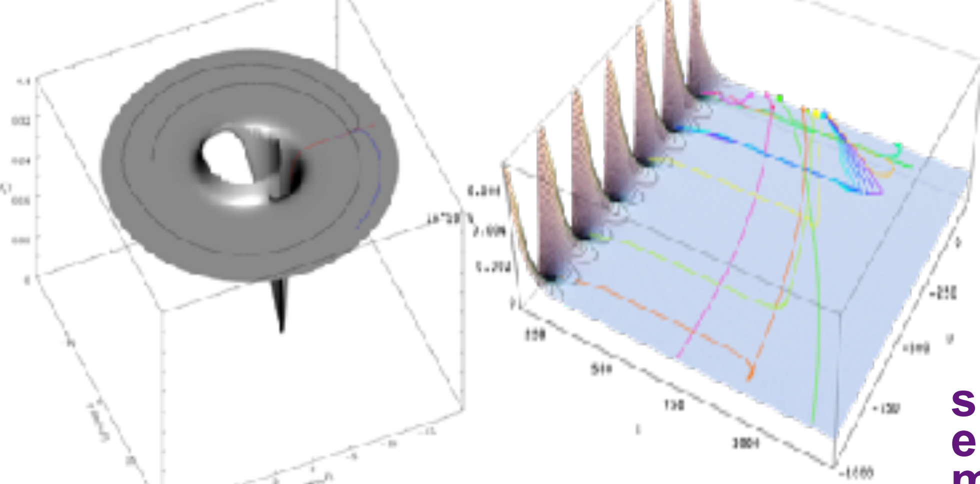
single field V heating slow, oscillating

but shaped V can give rapid heating (roulette)

Barnaby,Bond,Huang,Kofman09

coarse-grain cm-horizon
=> fine-grain fluctuations
= S generation





semi ETERNAL INFLATION

quantum diffusion

spatial jitter

drift

EoI

roulette oscillations
highly damped
=> no-non-G
if redirect by $\chi_{cg,eoi}$, **g**
=> non-G??

let there be **heat**

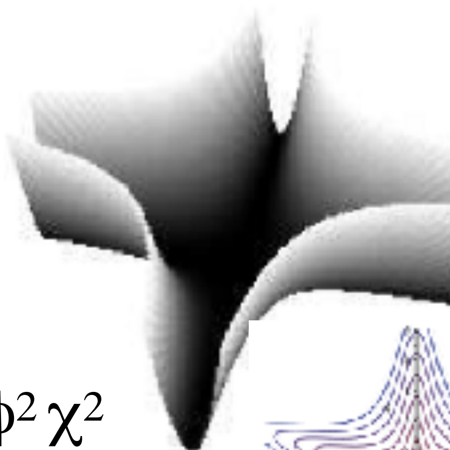
EoI horizon ~ 1cm comoving

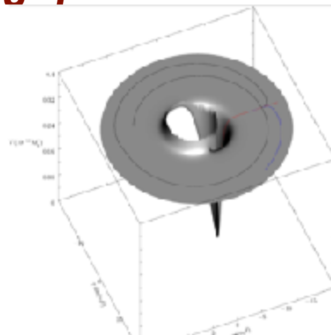
www.youtube.com/watch?v=FW__su-W-ck&NR=1

what is the **inflaton's potential**?

around a minimum is the HOT /heating question

2 filament?



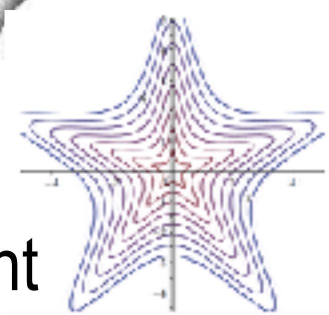


how was *matter & entropy* generated at the end of acceleration = inflation?

Relate to Higgs & standard model?

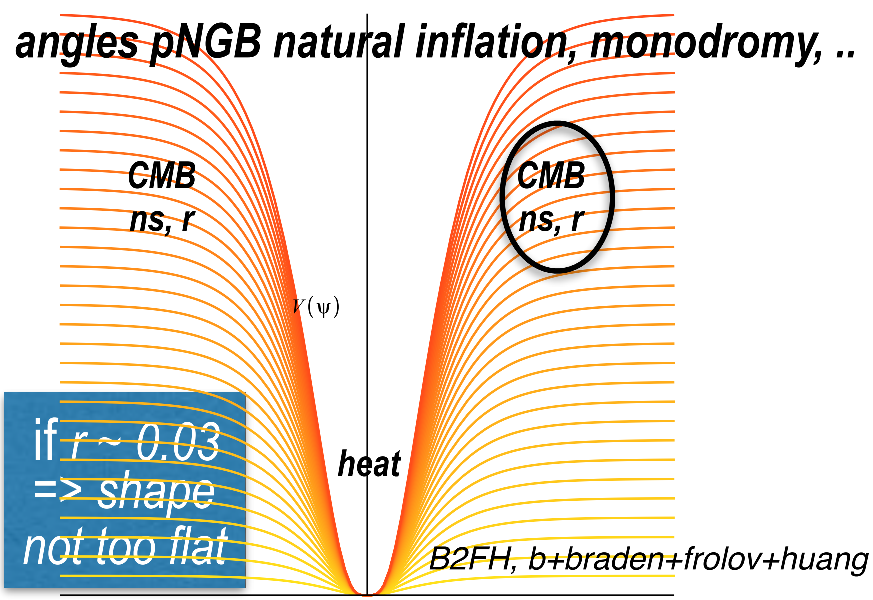
4 filament

$1/4\lambda\phi^4 + 1/2 g^2 \phi^2 \chi^2$

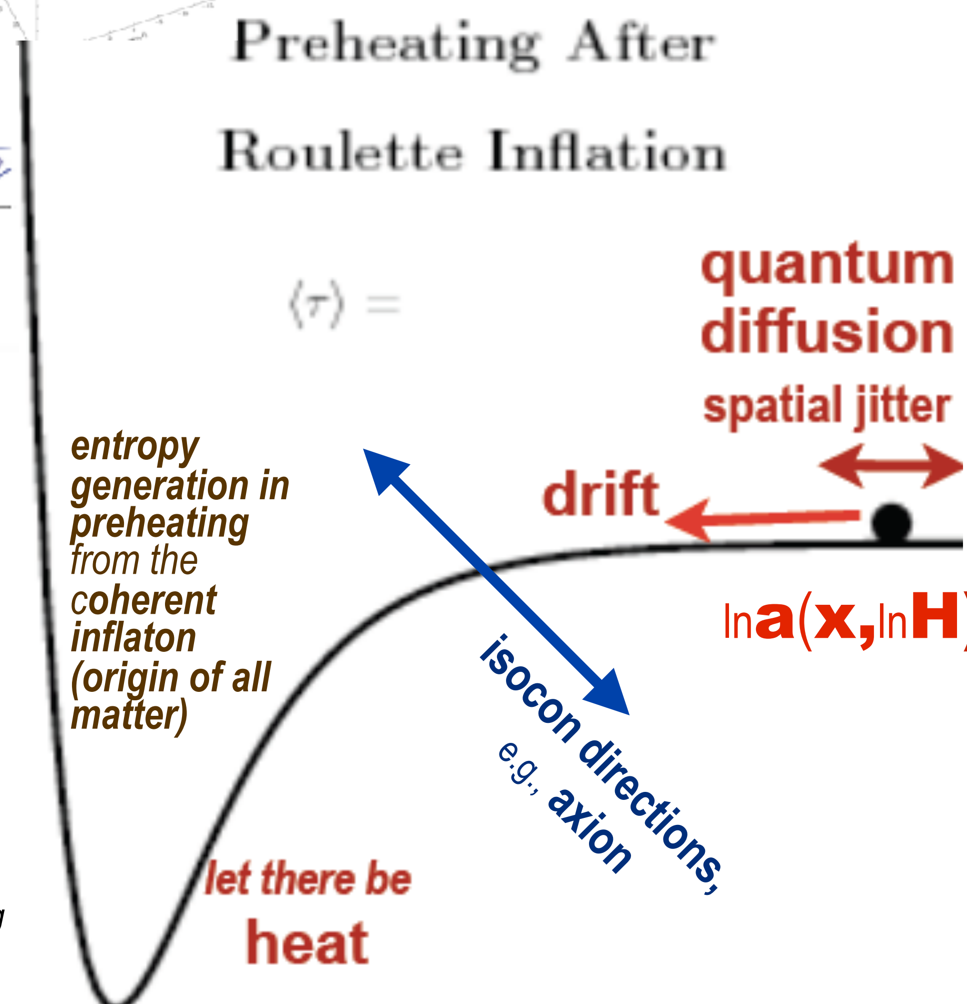


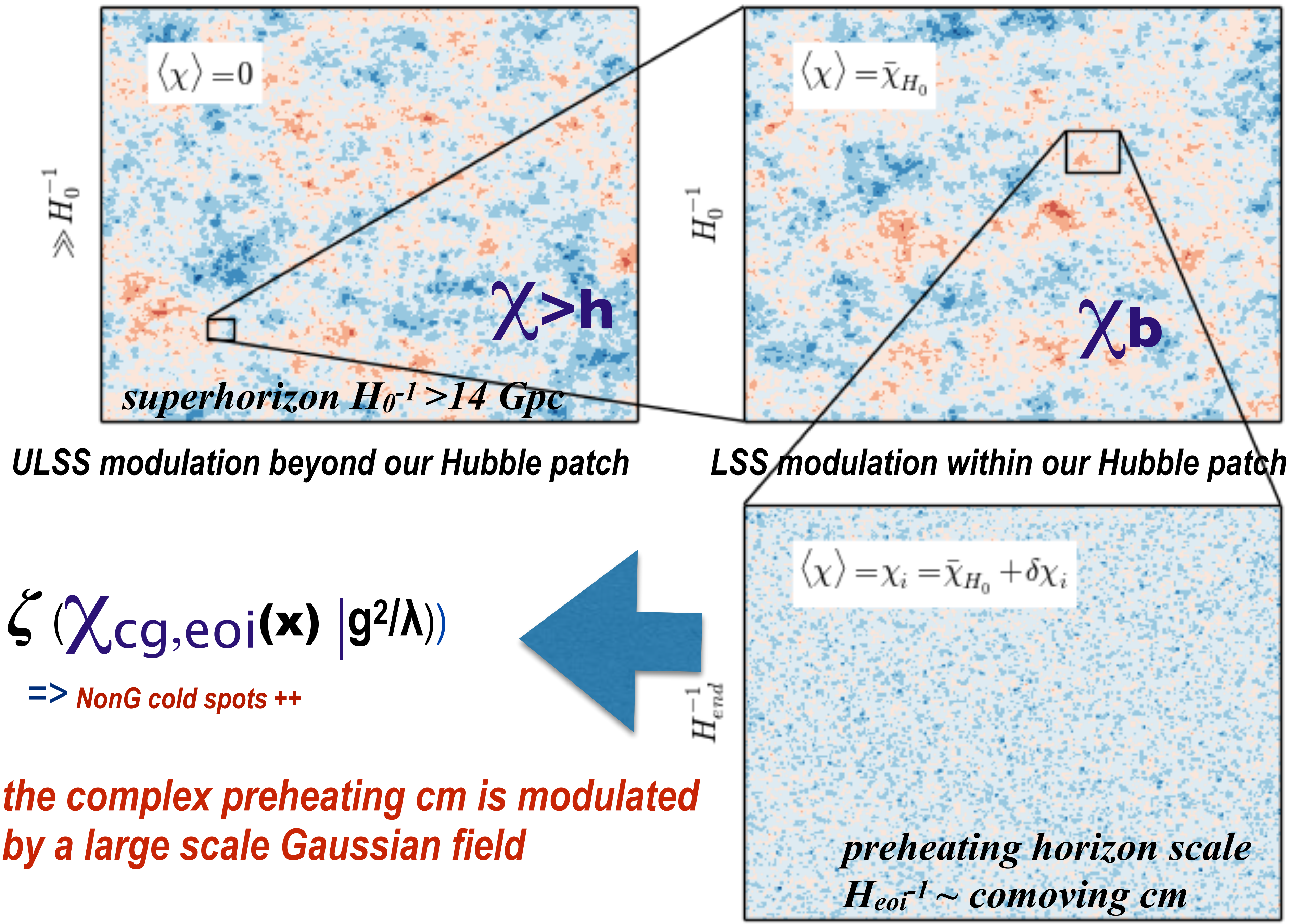
3-filament 5-filament

angles pNGB natural inflation, monodromy, ..



conformal potential-flattening eg Higgs inflation *SBB89 etc*

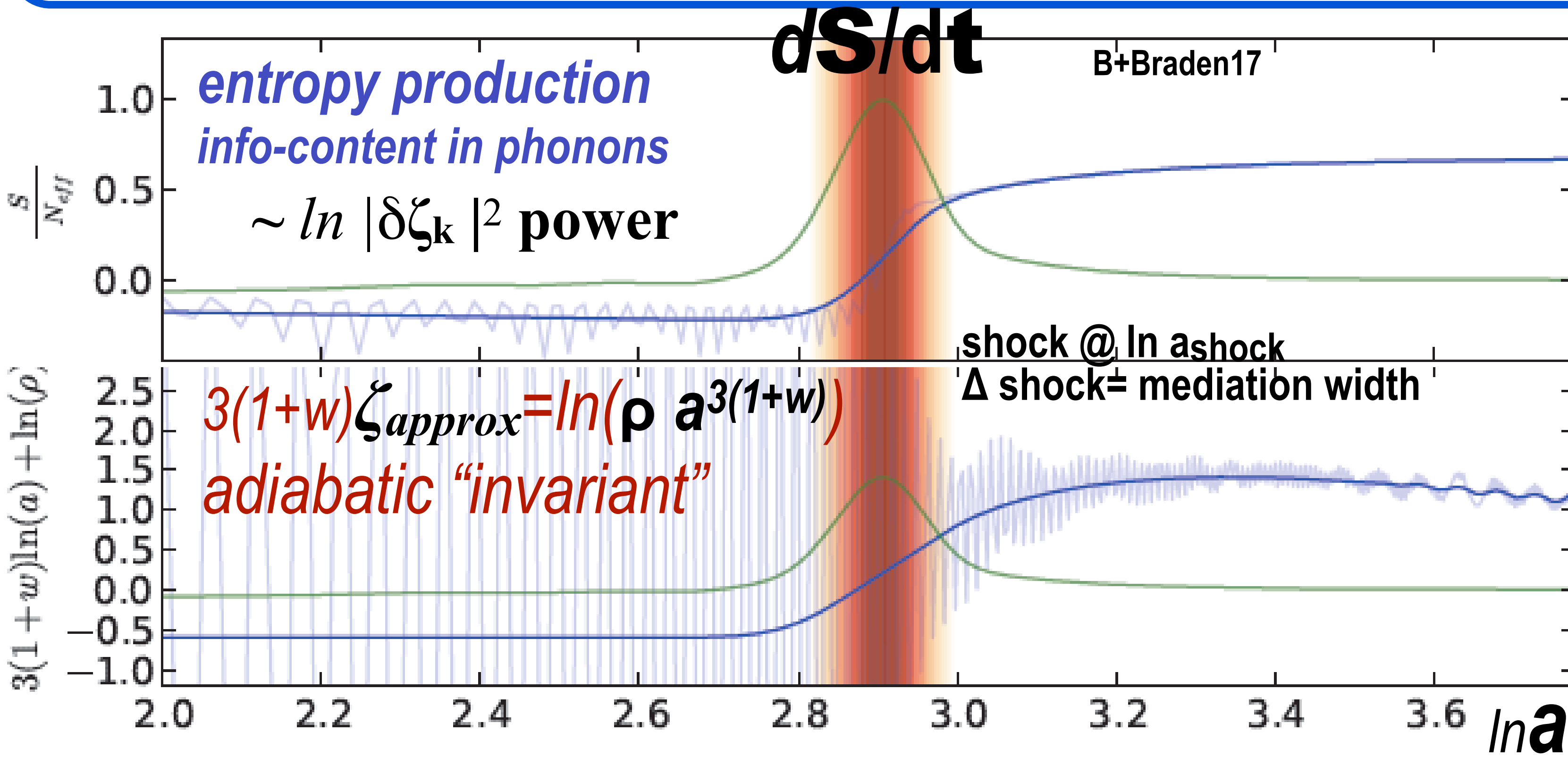



⟨χ⟩ = 0
≫ H_0^{-1}
χ>h
superhorizon H0-1 >14 Gpc
ULSS modulation beyond our Hubble patch
⟨χ⟩ = χ̄_{H_0}
H_0^{-1}
χb
LSS modulation within our Hubble patch
⟨χ⟩ = χ_i = χ̄_{H_0} + δχ_i
H_{end}^{-1}
preheating horizon scale
Heoi-1 ~ comoving cm
ζ (χcg,eoi(x) |g2/λ))
=> NonG cold spots ++
the complex preheating cm is modulated
by a large scale Gaussian field

quartic inflaton $V(\phi,\chi) = 1/4\ \lambda\phi^4 + 1/2\ g^2\phi^2\chi^2$

log-normal pdf (density *aka ζ**)**, in k-bands too; normal pdf (velocity)*

nonG from large-scale modulations of the shock-in-times of preheating



true thermal equilibrium far off ➤ & on to coupling to standard model degrees of freedom

coarse-grain $<\zeta>$ <=> fine-grain $\delta\zeta_k$ gradients, δV

$$\zeta_{final}(x,t_f\,|\chi_{cg,eoi}(x),g^2/\lambda)) \sim \zeta_{shock}$$

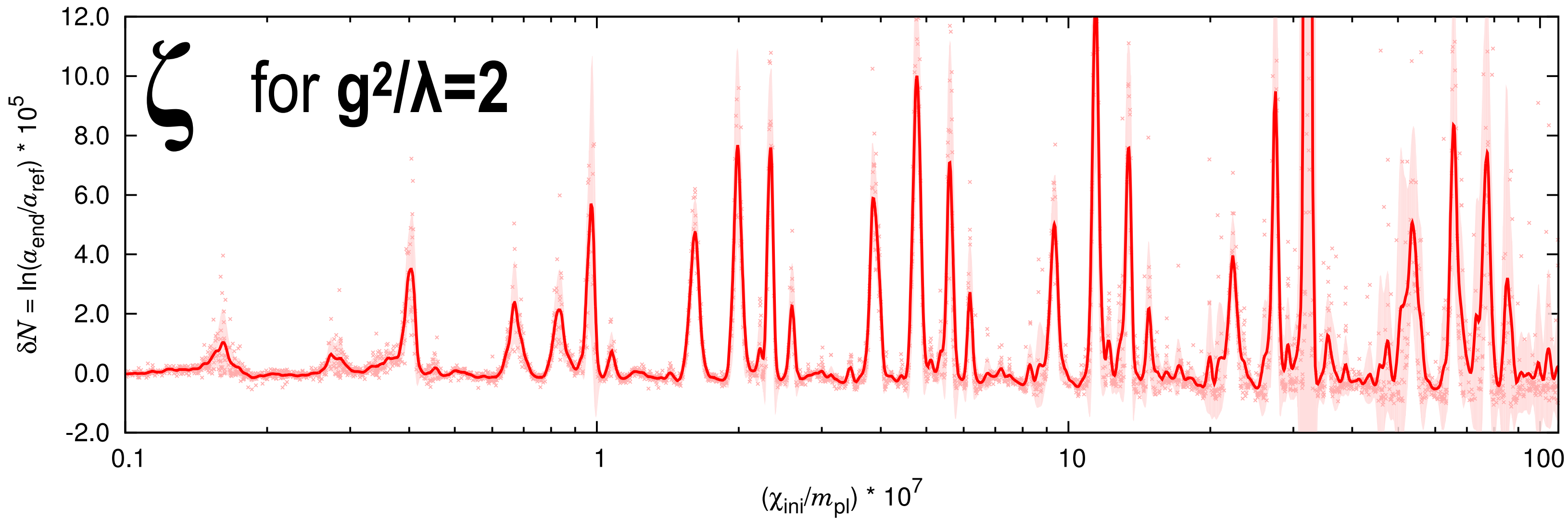
$$V(\phi,\chi)=1/4\,\lambda\phi^4+1/2\,g^2\,\phi^2\,\chi^2$$

$dS/dt(t,g)$ => *the Shock-in-time: entropy production rate*

$\zeta_{shock}(\chi_{cg,eoi}(x)\ |g^2/\lambda)$ => ***Chaotic Billiards: NonG from Parametric Resonance in Preheating***

B+Frolov, Huang, Kofman 09
B+Braden, Frolov, Huang 17

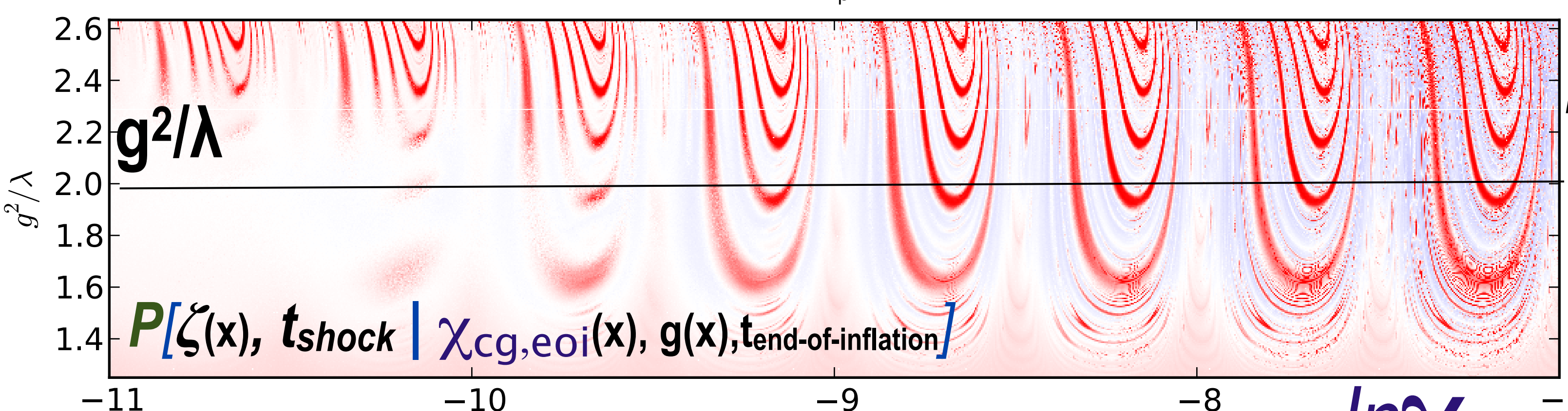
$$V(\phi,\chi)=1/4\ \lambda\phi^4+1/2\ g^2\phi^2\chi^2$$



computational tour de force

huge number of** 64^3 **sims to show the wondrous complexity of

$\zeta(\chi_i, g^2/\lambda)$

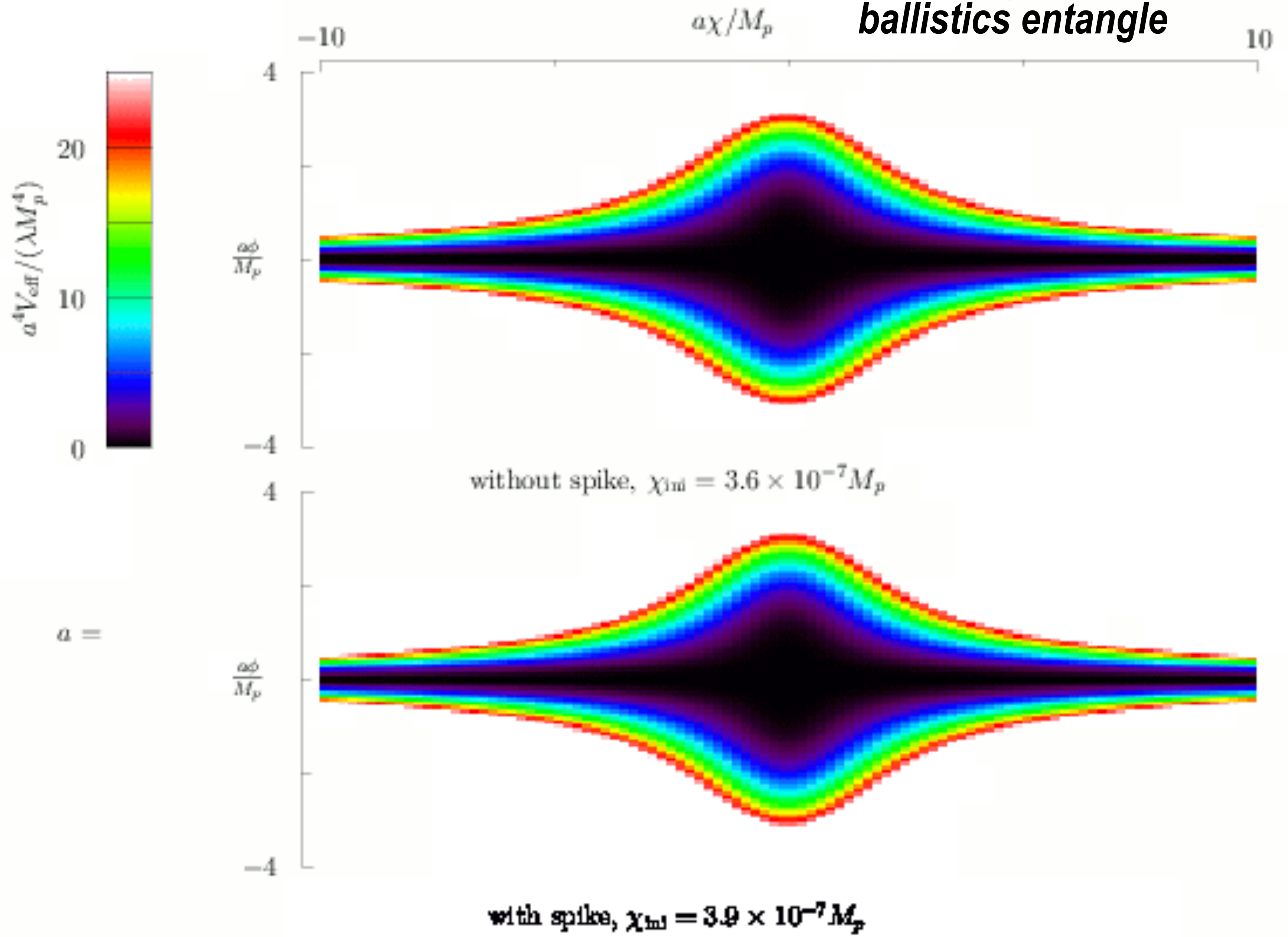


*gigafigure of **lattice** simulations*

$\ln\chi_{cg,eoi}$

full lattice simulations of coarse-grained k~0 trajectories ($\chi_{cg,eoi}$)

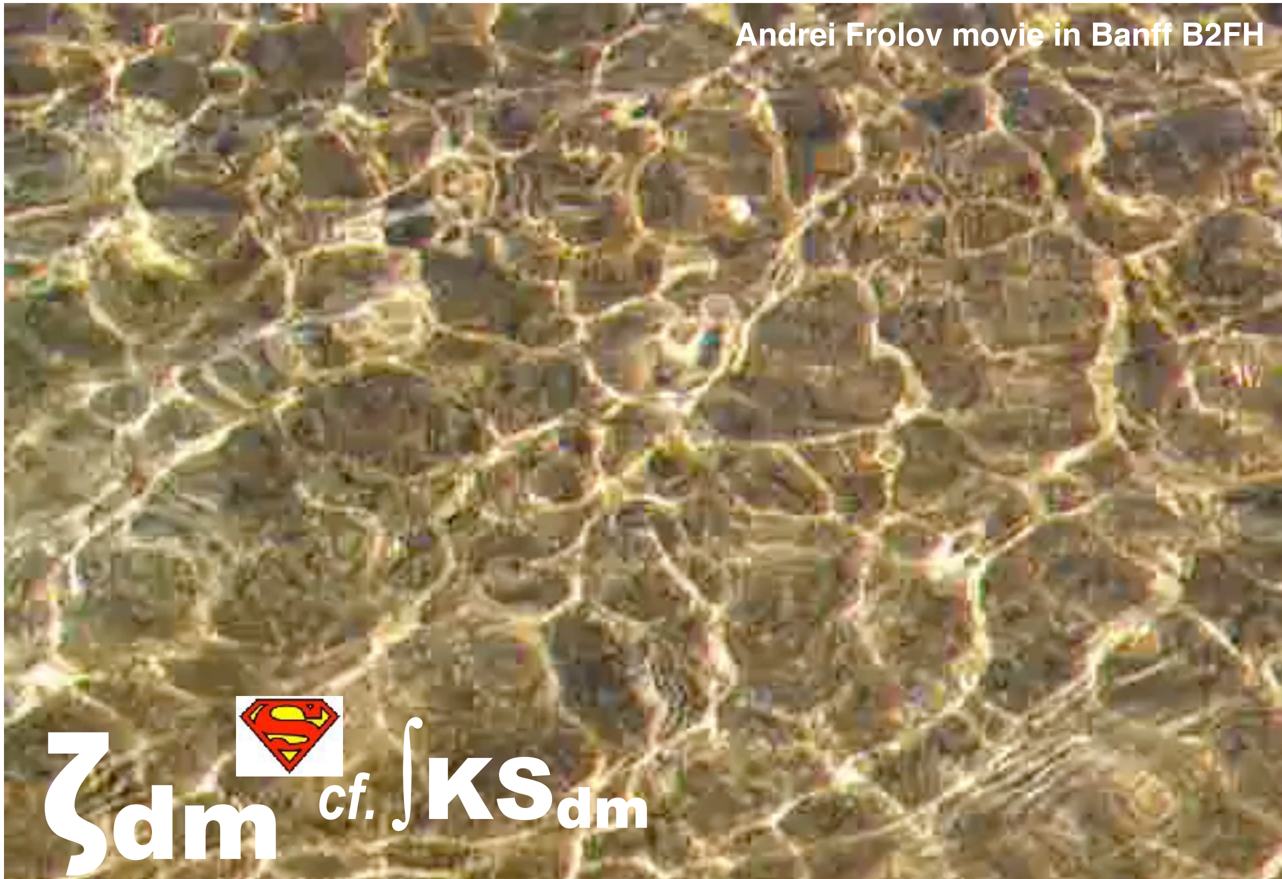
ballistics entangle

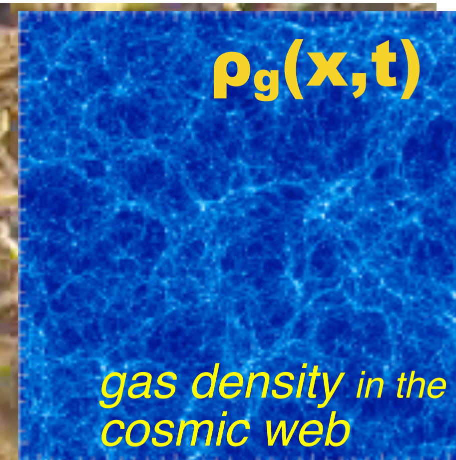


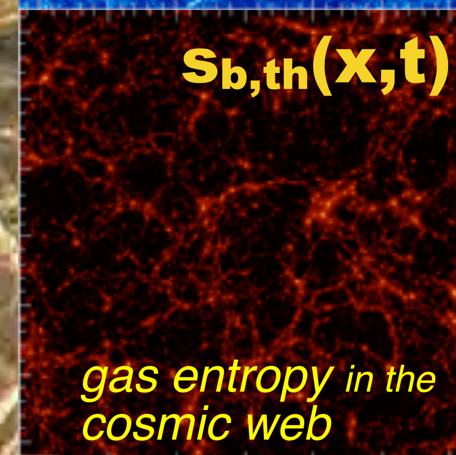
(nonlinear) **V_{eff} is trajectory-bundle dependent**

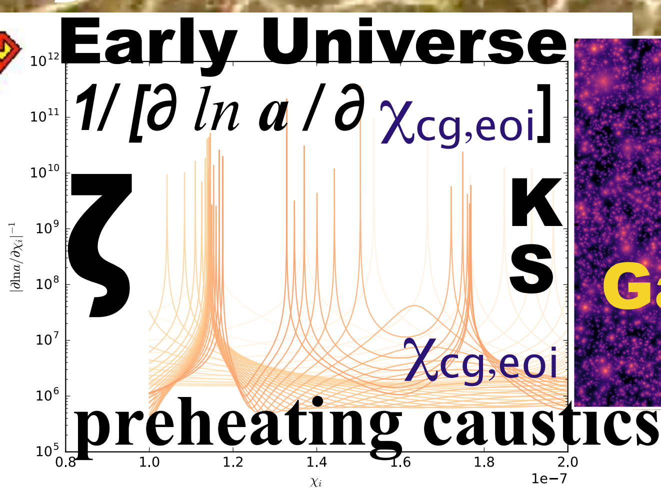
$V(\phi,\chi)=1/4\ \lambda\phi^4 + 1/2\ g^2\phi^2\chi^2$

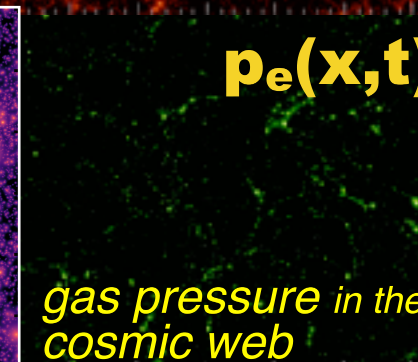
caustics are ubiquitous: **LSS/cosmic web & preheating**











cm-scale **coarse-grained** k~0
“ballistic” trajectories
become **entangled** *with fluctuations*
aka sub-cm **k-modes** *in a coarse-grained*
*non-equilibrium-***entropy***-generating*
shock-in-time
& on to the quark/gluon plasma **StandardModel-pp**

$\delta\zeta_k$ **&** $ln[\rho/\langle\rho\rangle]_k$ are **nearly Gaussian within a preheating horizon:** *shown by* **B+Braden17 lattice simulations for probability distribution functions in k-bands, and smallness of the 3 pt,** ***etc.*** (!!!)

caustics in <q^A> *ballistic* orbits

$\langle \delta q^A\ t2 \mid \delta q^B\ ti \rangle \sim \exp(\mathcal{E}(t2 \mid t1)) \langle \delta q^A\ t1 \mid \delta q^B\ ti \rangle$

early U parameters: **final φ, Π_φ, χ, Π_χ, *ln* a, ln ρ, initial $\chi_{cg,eoi}$, *couplings* g, λ, ..**

parameter strain tensor $\mathcal{E}(t2 \mid t1)$

$d\mathcal{E}/dt$ strain rate ~ local Lyapunov coefficients *Floquet instability charts*

instability to have nearby parameters diverge => chaotic billiards

Kolmogorov-Sinai entropy: ~ Sum of positive evalues of $d\mathcal{E}/dt$

small $\mathcal{E}$ eigenvalues=> coherent trajectory bundles (for a time)

= caustics (inverse -> ∞) **1/** [$\partial \zeta / \partial \chi_{cg,eoi}$]; => peaks in $\zeta(\chi_{cg,eoi})$

stopping time **tstop** ($\chi_{cg,eoi}$) when $\mathcal{E}$ evalues get large <=> local gradients $\Uparrow$

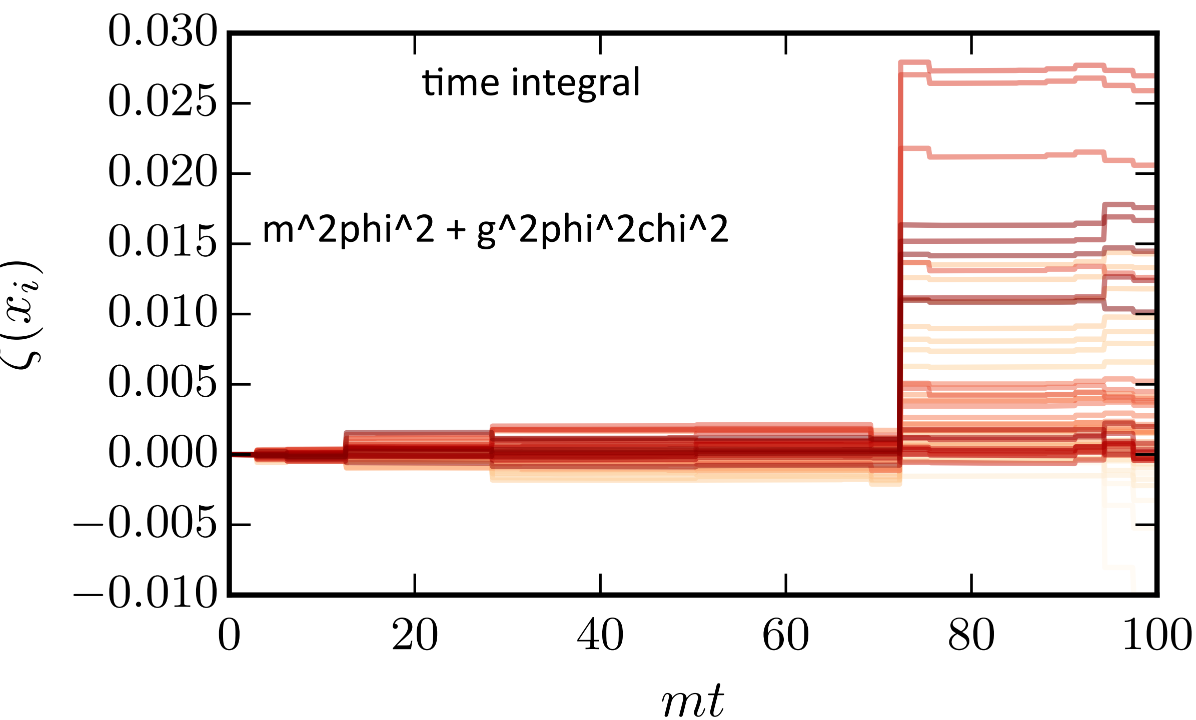
cf. LargeScaleStructure: final Eulerian position <= initial Lagrangian position

1LPT aka Zeldovich: $\partial x/\partial r = \exp(\mathcal{E})$ -> 0 density $\rho \sim \exp(-\mathrm{Tr}(\mathcal{E}))$ -> ∞

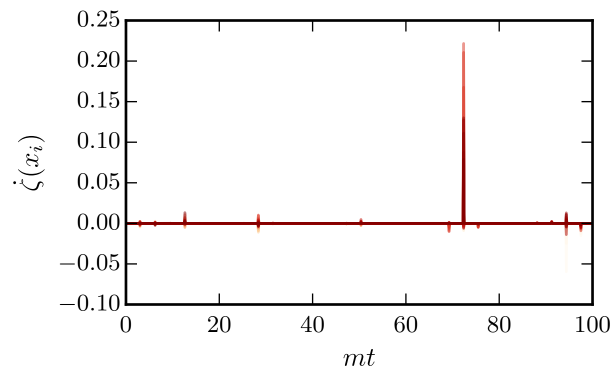
zeta conserved along trajectories until the “shock-in-time” when high k fluctuations (fine-grain) develop from coarse-grain, measure is ln rho sqrt(g)

but Dln rho = Trace dbar eps does change, KS entropy

stretching of phase strings. begin with anisotropic Gaussian at EoI and watch is stretch, eps grows, rotates, locally OK as distorted ellipsoid, but strain depends upon the central value => phase tubes



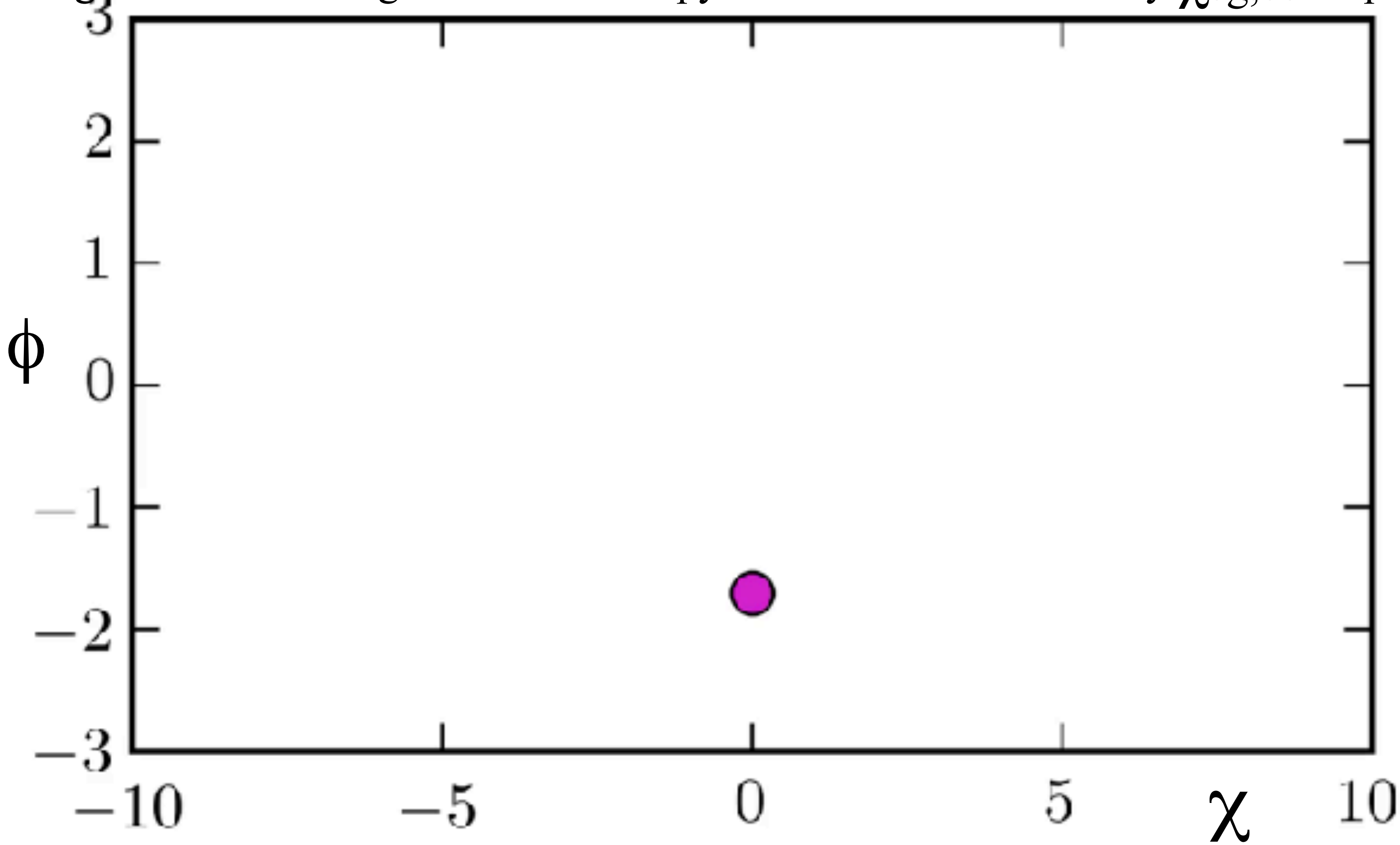
evolution of the source term



ballistic billiards k=0 mode phase space string evolution

2D constrained distribution functions

stopping criterion when coarse-grained entropy of field variables rises <=> strain $\boldsymbol{\varepsilon}$ high,
ie when integral of the Kolomgorov-Sinai entropy reaches a threshold - very $\chi_{cg,eoi}$ dependent

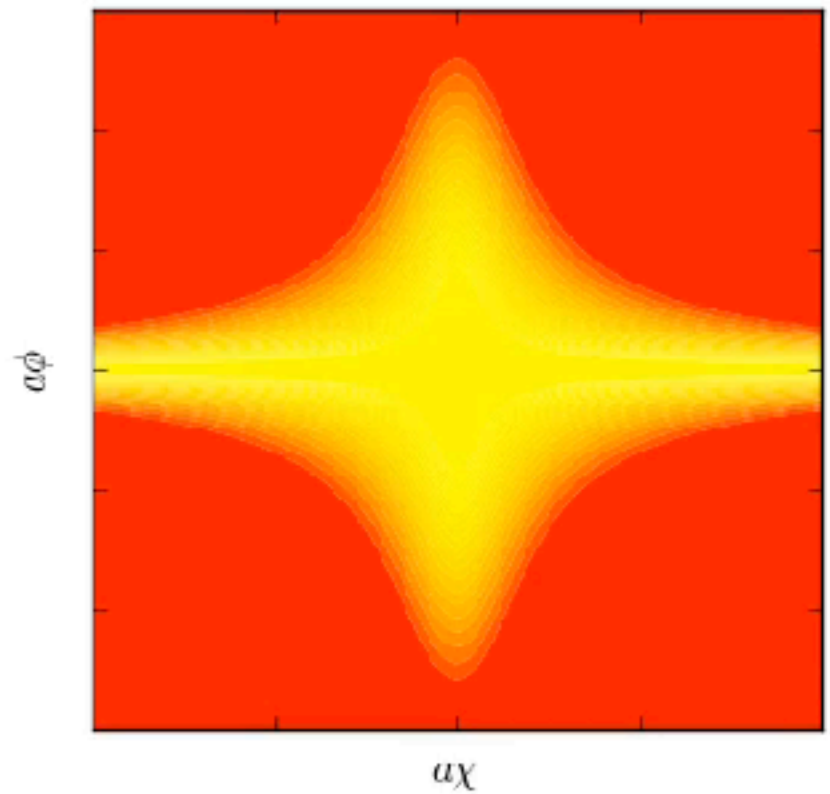


$V = 1/4\ \lambda\phi^4 + 1/2\ g^2 \phi^2 \chi^2$

phase space strings

caustics are ubiquitous

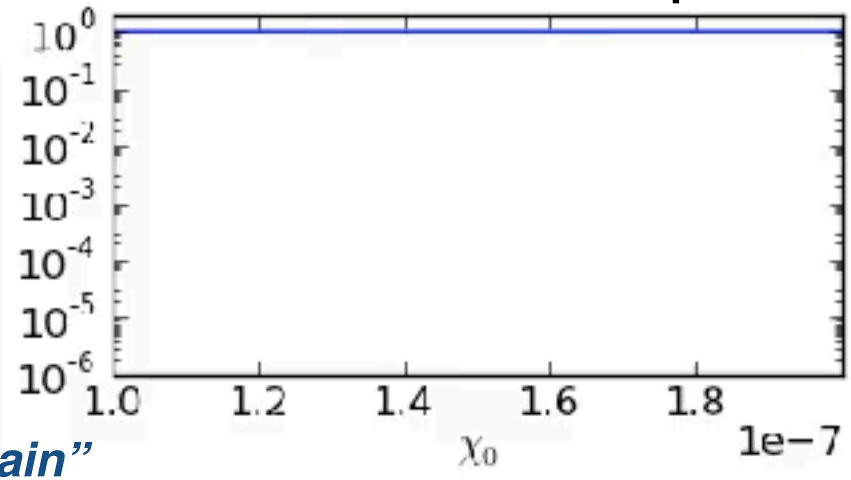
2D constrained distribution functions



B2FH, b+braden+frolov+huang

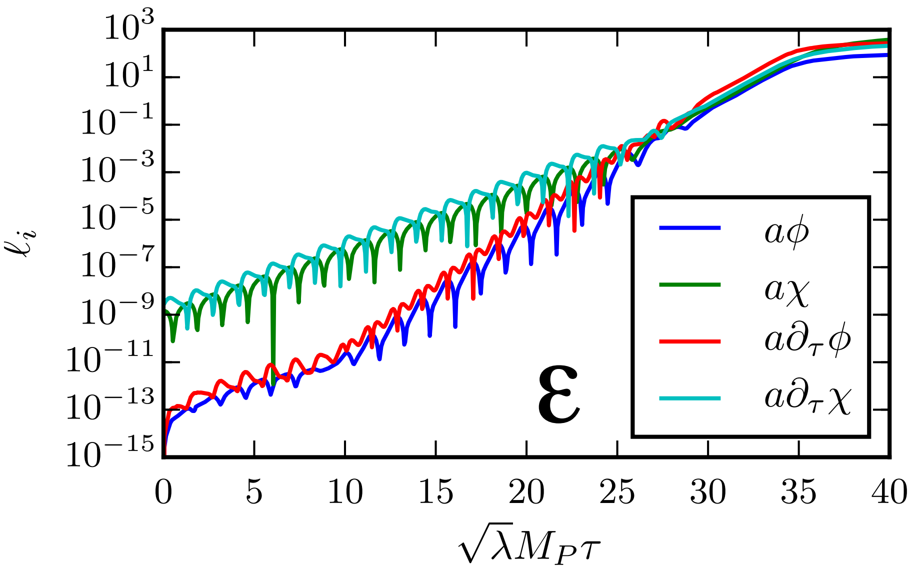
phase space strings

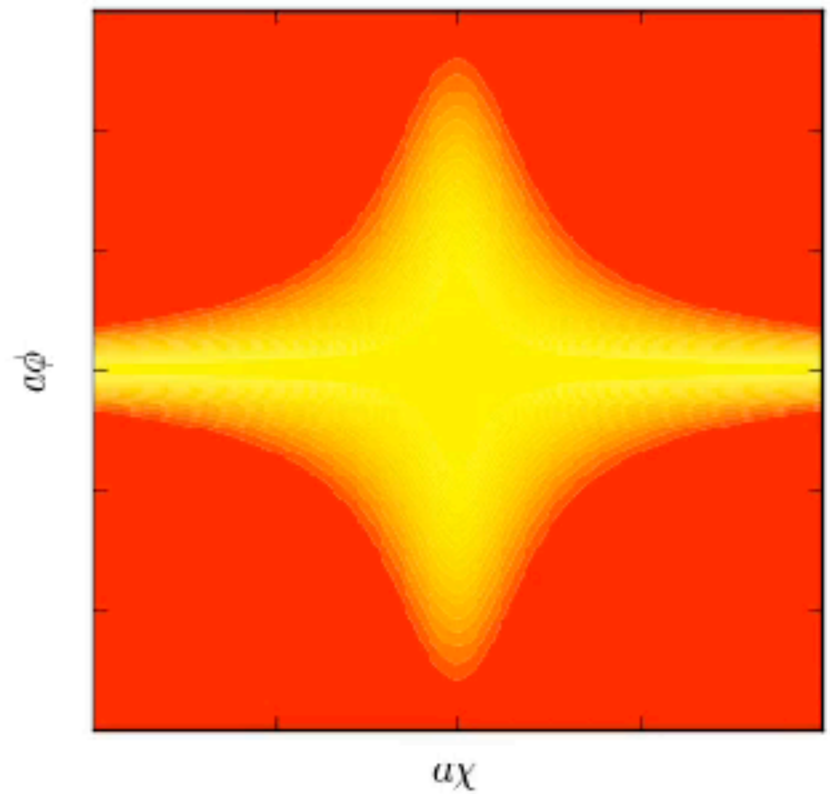
caustics are ubiquitous



2D constrained distribution functions

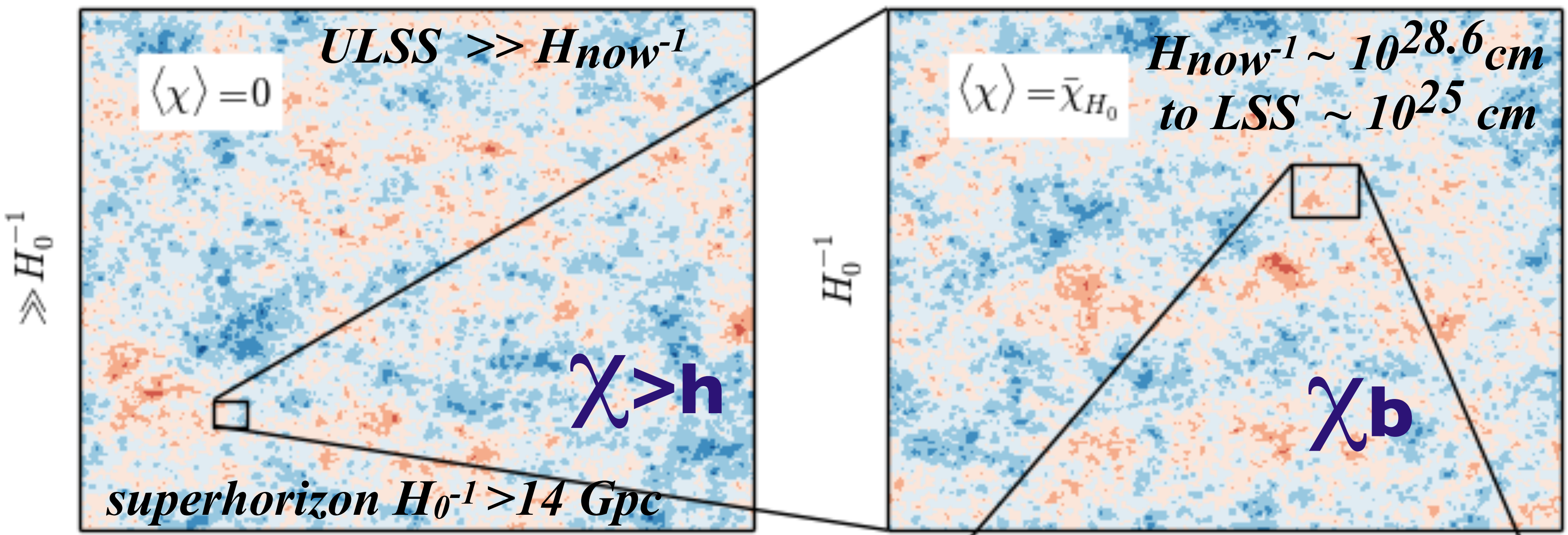
phase string growth in time "parameter strain"
integral of Kolmogorov-Sinai entropy





=> 3D constrained distribution functions

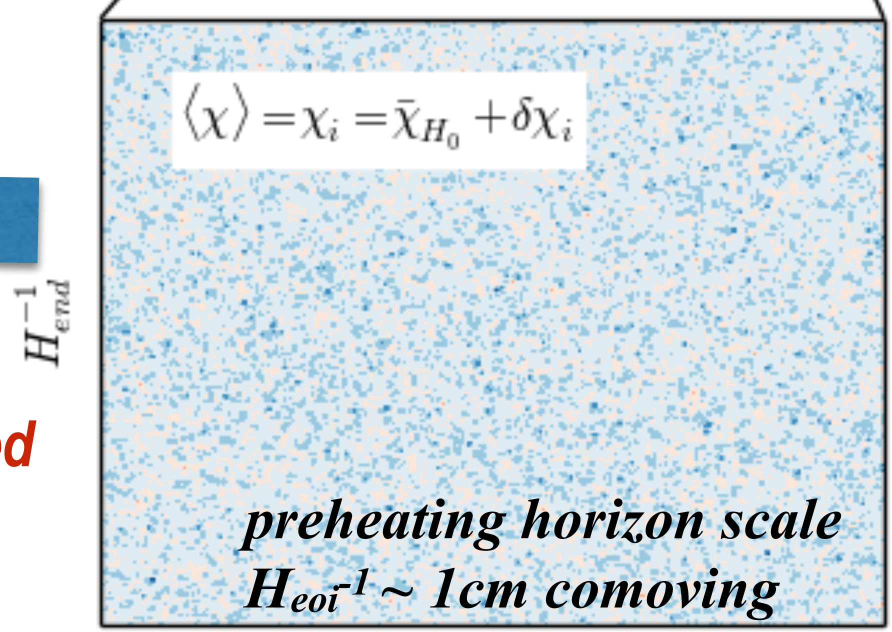
B2FH, b+braden+frolov+huang



ULSS modulation beyond our Hubble patch

LSS modulation within our Hubble patch

threading the patches together to make LSS



$\zeta\,(\chi_{cg,eoi}(\mathbf{x})\;|g^2/\lambda))$

=> NonG cold spots ++

the complex preheating cm is modulated by a large scale Gaussian field

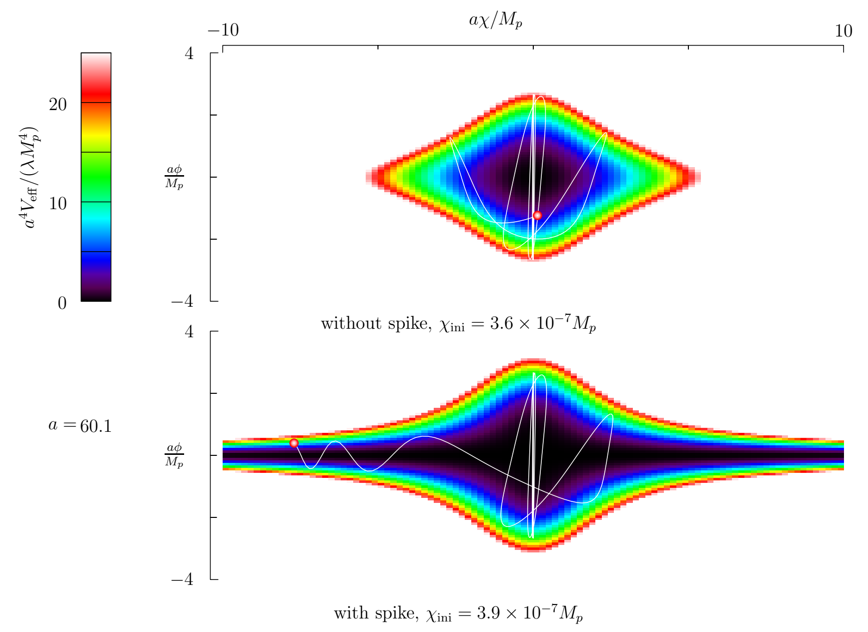
understanding the ζ -spike structure, qualitatively YES quantitatively in Progress

B²FH 17

arresting the orbits via a shock-in-time, incoherent cf. coherent (caustic) trajectory bundles

incoherent

coherent



how generic will caustic preheating be? structure around potential minima:

=> 'filamentary' potentials

=> ballistic flow channels

multi-filaments may lead to caustics

2 std inflaton, slow heating? roulette V is fast. 3-star

4 case workhorse. *the* ***5-star… 'axionic' angles works with conformal flattening of V(ϕ_A) +***

cf. filaments that join at clusters in the LSS web

how modulated caustics in preheating could give observable intermittency

via isocon power on large & super-horizon scales

=>*light particles* (χ_{eoi} (x), couplings g(x), ...)

these isocons are active, NOT spectators

looking at the CMB cold spot again as an anomaly example

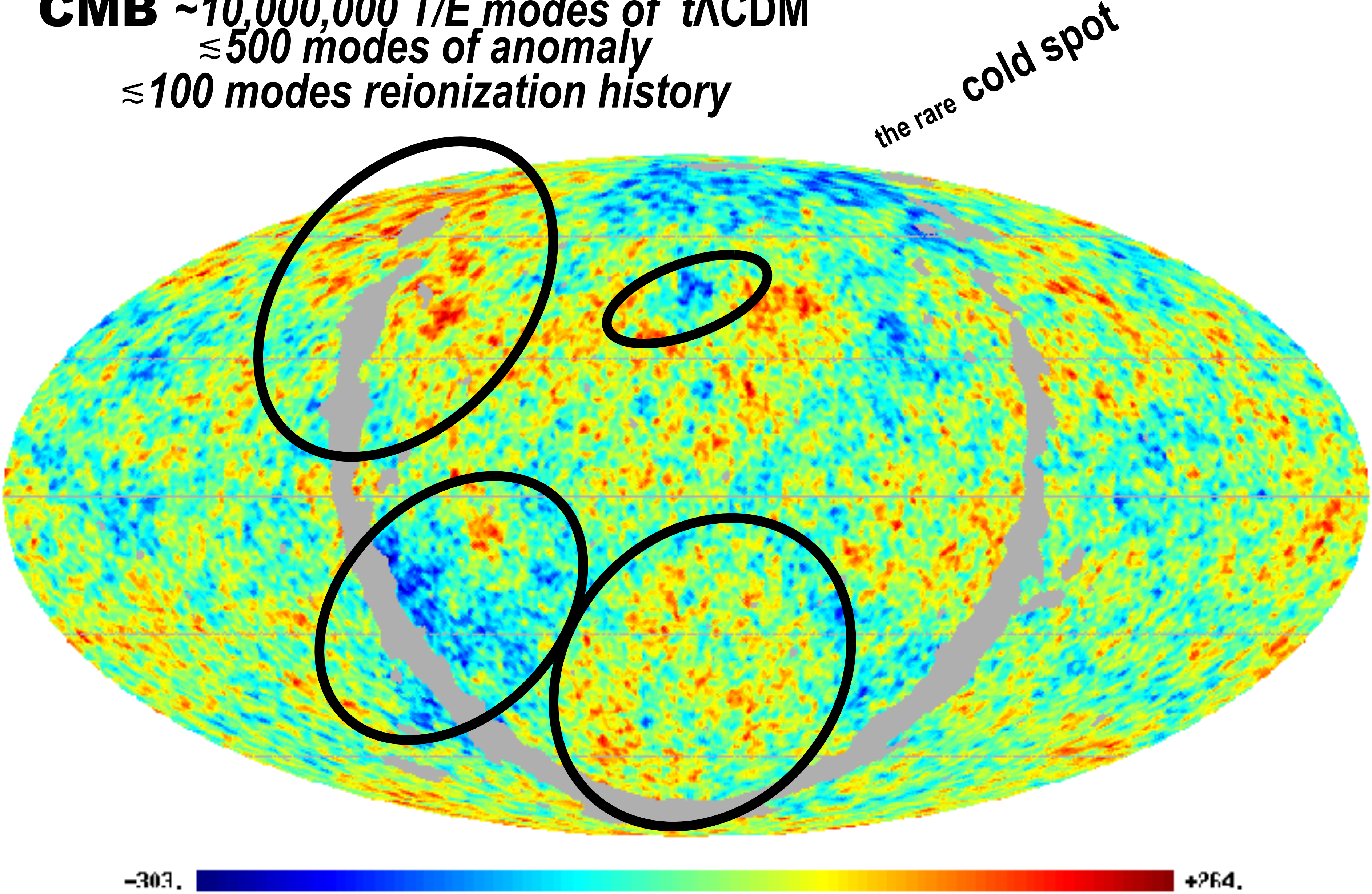
>4.5σ <1% L~20 ….. LSS void?

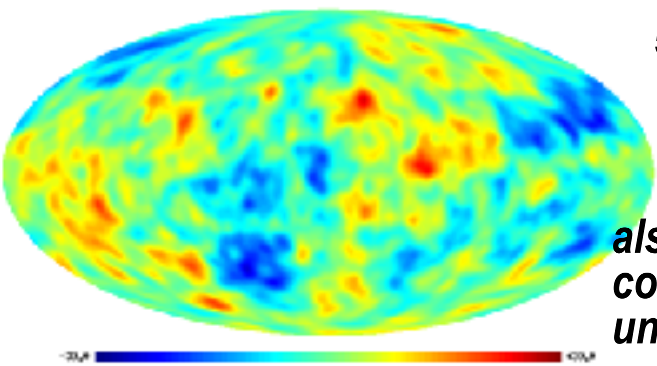
B+Huang tried hard to make a Grand Unified Theory of Anomalies? new ways of looking at the anomalies (comparing harmonic and real space in various ways) but no GUTA … TBD

CMB *~10,000,000 T/E modes of tΛCDM*

≲500 modes of anomaly

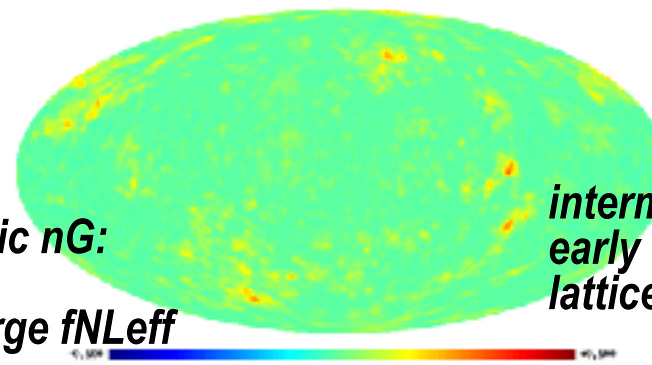
≲100 modes reionization history



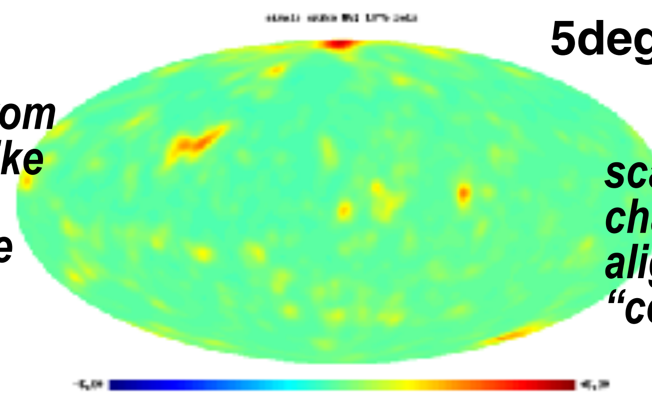


5deg fwhm

also cf. quadratic nG:
correlated fNL
uncorrelated large fNLeff



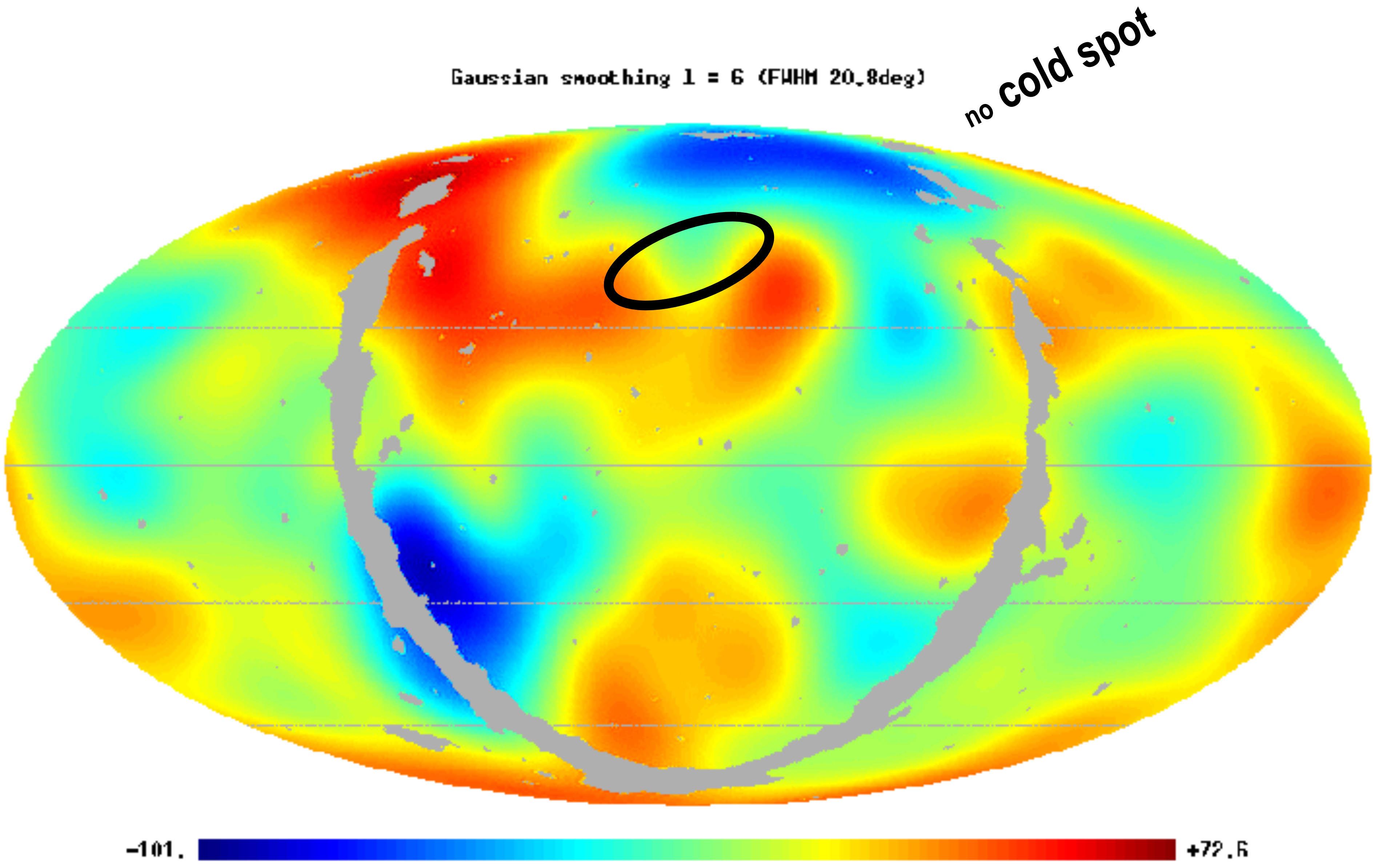
intermittent nG from
early U preheating
lattice sims - too small



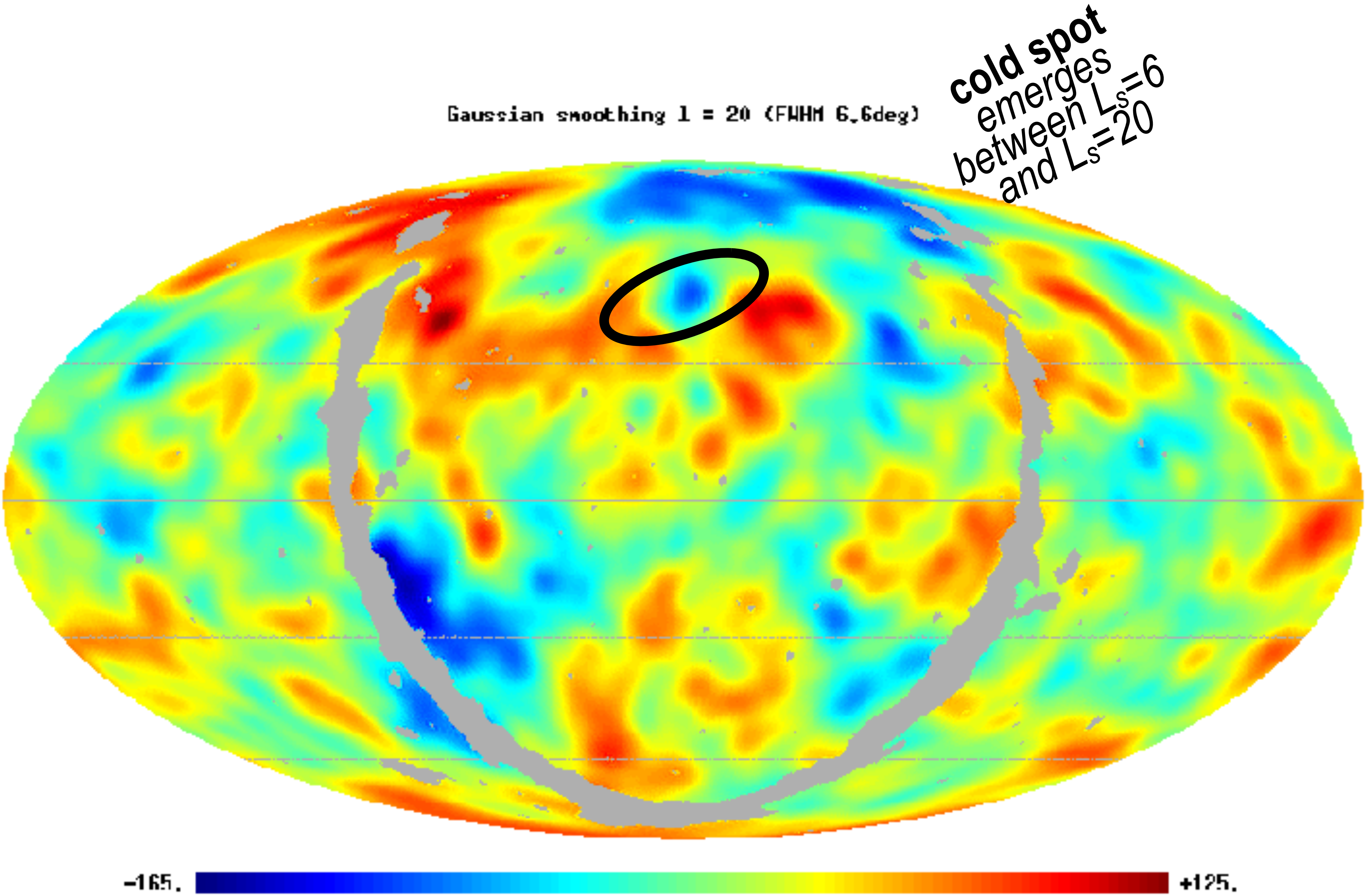
5deg fwhm

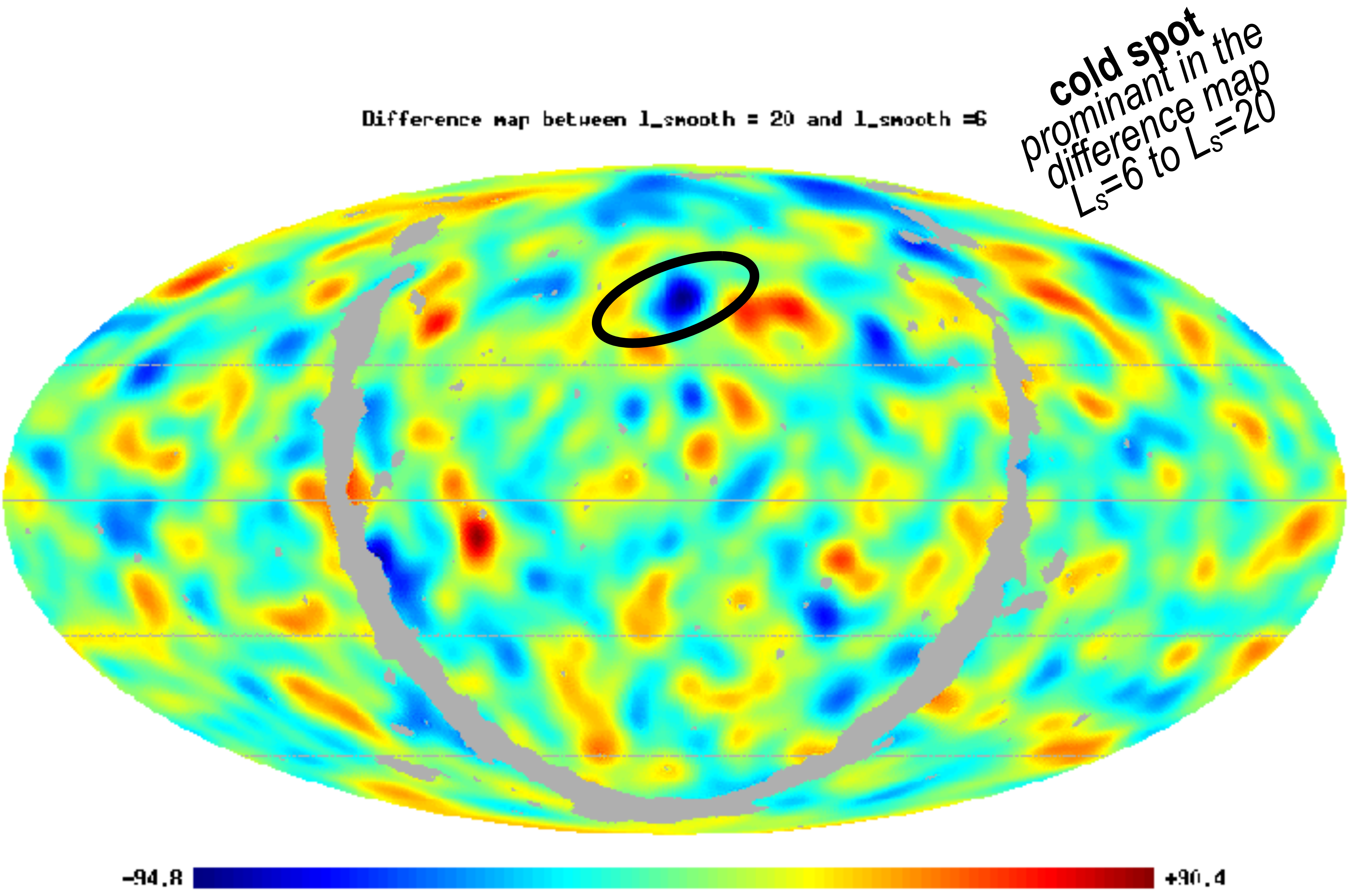
intermittent nG from
early U single spike
sims - tunable
amplitude, get the
“cold spot”

scan sims to get
chance intermittent
alignment to get a
“cold spot”



Gaussian smoothing l = 6 (FWHM 20.8deg)
no cold spot
-101.
+72.6


Gaussian smoothing l = 20 (FWHM 6.6deg)
cold spot
emerges
between L_s=6
and L_s=20
-165.
+125.


Difference map between l_smooth = 20 and l_smooth =6
cold spot
prominant in the
difference map
L_s=6 to L_s=20
-94.8
+90.4

$$W(\ell) = e^{-\frac{\ell(\ell+1)}{2(l_2+1/2)^2}} - e^{-\frac{\ell(\ell+1)}{2(l_1+1/2)^2}} \; (l_2 > l_1)$$

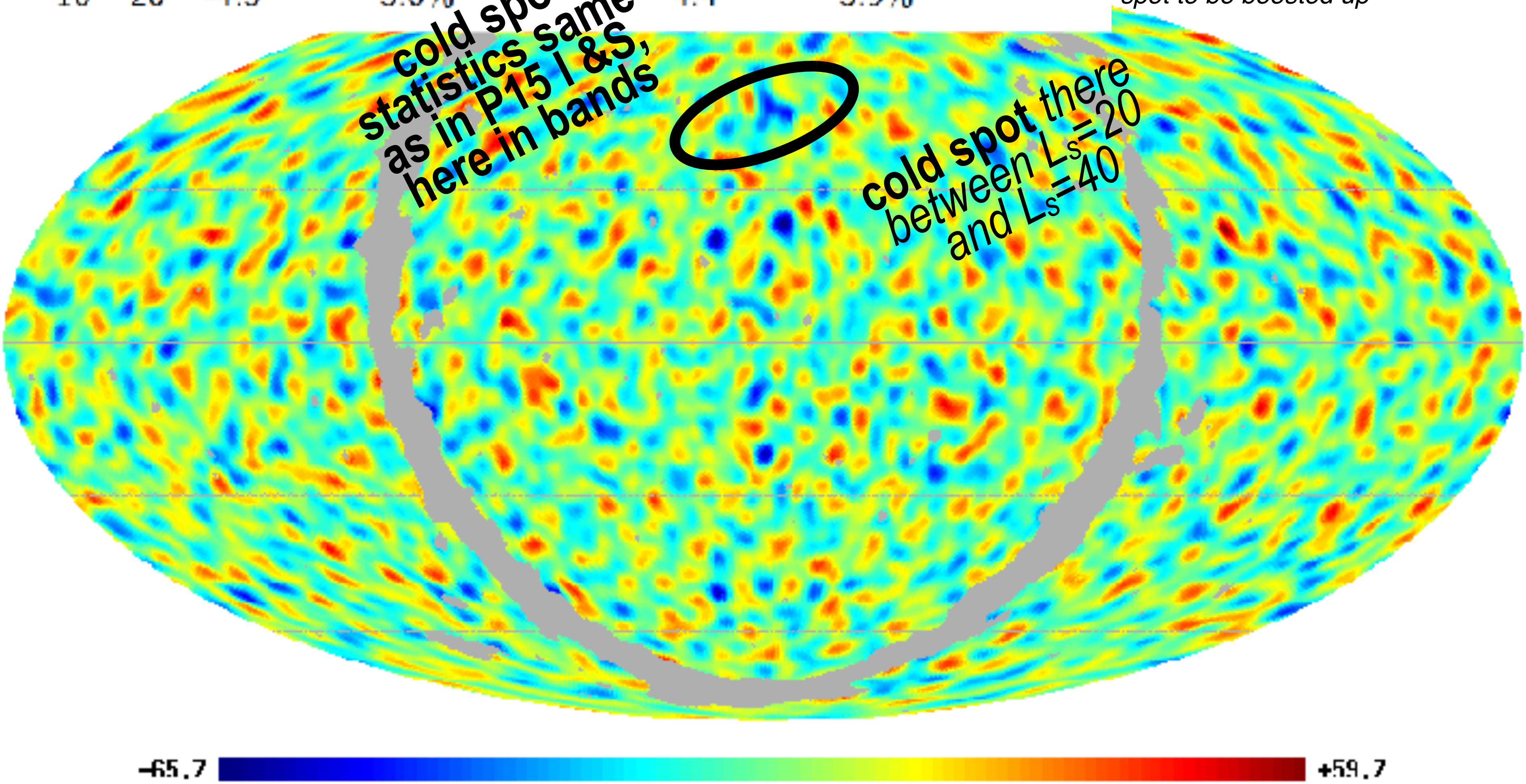
l_1	l_2	$T_{\rm cold}/\sigma_T$	cold-spot p value	$T_{\rm hot}/\sigma_T$	hot-spot p value
2	20	-3.5	29.9%	3.2	60.2%
4	20	-4.0	10.1%	3.9	13.9%
6	20	-4.5	2.0%	4.2	4.7%
8	20	-4.5	2.1%	4.3	4.5%
10	20	-4.5	3.0%	4.4	3.9%

tantalizing that the cold spot is the same L-band range as the L pspec dip, but all of our tools have not teased out a relation

B+Huang 2015

0

e.g. low L constrained fields do not make a nice low-L cavity for the cold spot to be boosted up



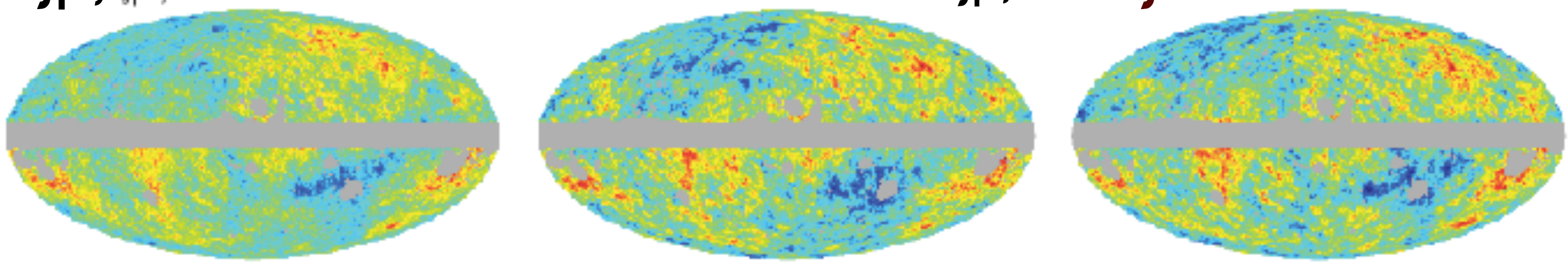
how intermittency could amplify the cold spot to statistical correctness

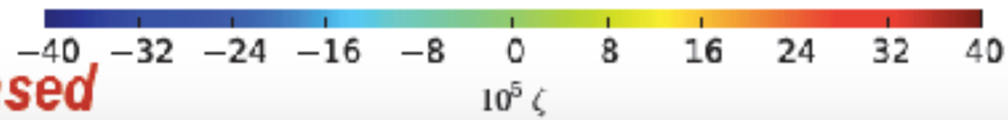
from >4.5σ Gaussian random field anomaly

<ζ|T,E>

Planck 2015 XVII nonG

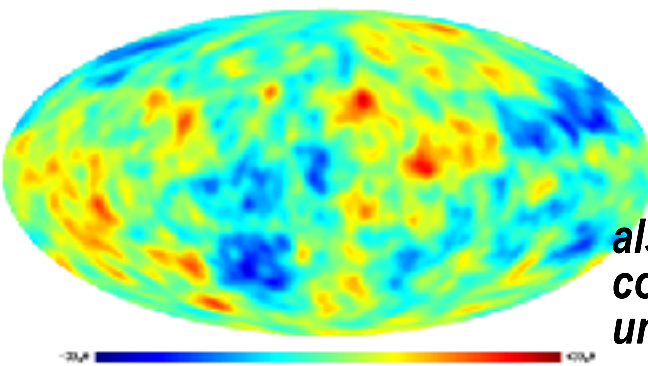
<ζ|T,E>+$\delta\zeta$



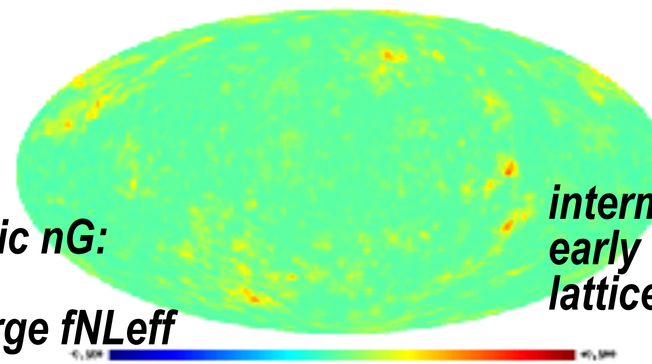


caution: not de-lensed

visibility mask

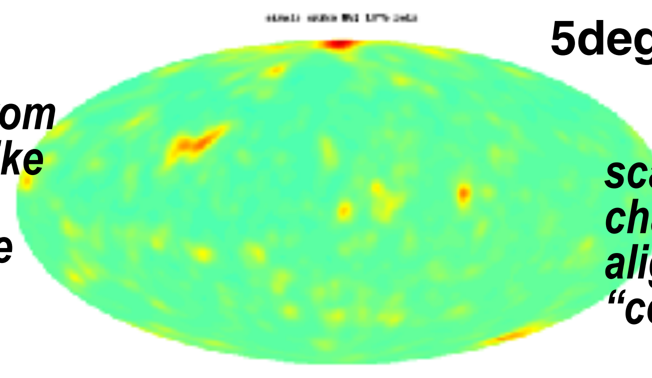


5deg fwhm



also cf. quadratic nG:
correlated fNL
uncorrelated large fNLeff

intermittent nG from early U preheating lattice sims - too small



5deg fwhm

intermittent nG from early U single spike sims - tunable amplitude, get the "cold spot"

scan sims to get chance intermittent alignment to get a "cold spot"

mocking heaven **to explore 3D intermittency** from **modulating preheating, bubble collisions**, etc

we are **in quest** of an **apparent breakdown of LSS homogeneity** - but NOT that

a nonlinear (large scale) bias response to the nearly scale invariant isocon field
cf. LSS bias of clusters/galaxies: threshold function acts on the linear density field

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

mocking heaven to

explore 3D intermittency

from **modulating preheating,**

bubble collisions, etc

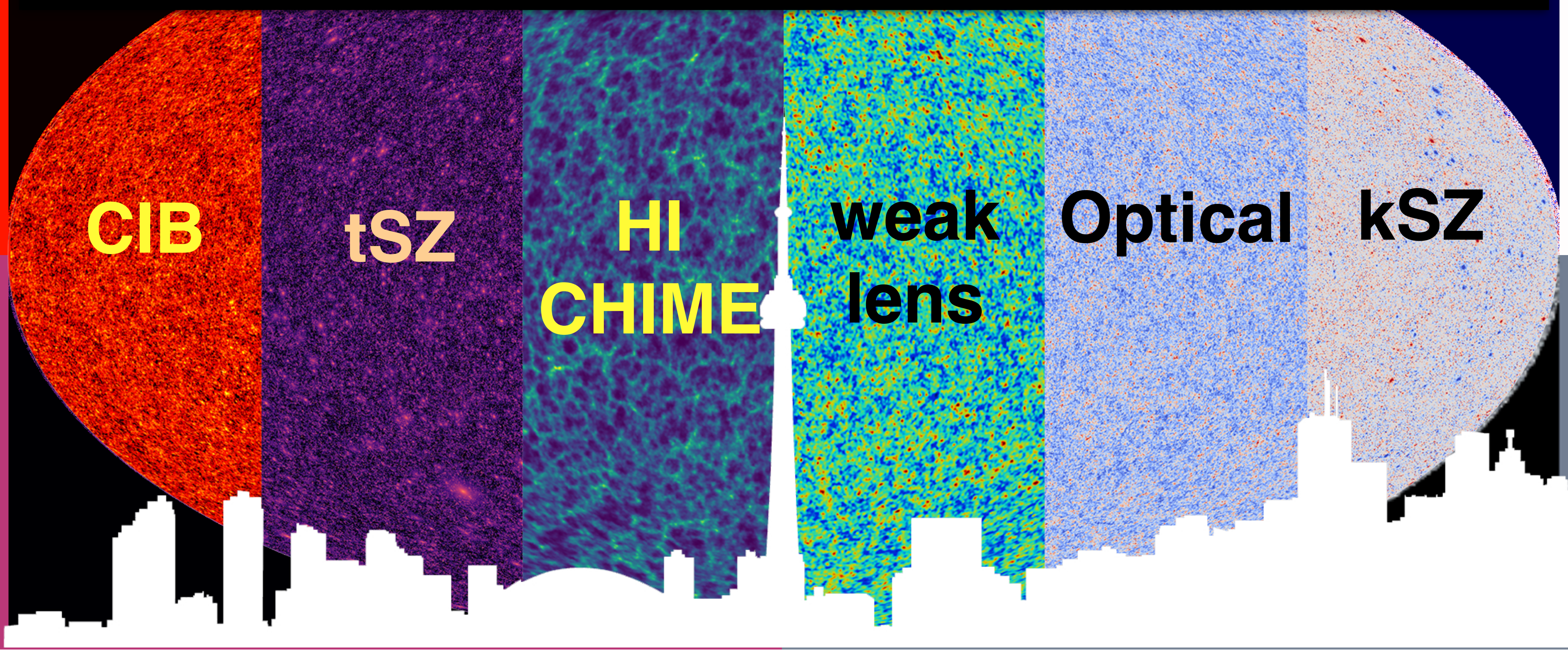
we are **in quest** of an **apparent breakdown of LSS homogeneity** *- not really broken*

a nonlinear (large scale) bias response to the nearly scale invariant isocon field
cf. LSS bias of clusters/galaxies: threshold function acts on the linear density field

Mocking Heaven @ *CITA* *Alvarez Bond Stein Battaglia ..*

Peak Patch Full Sky Models for ***Planck, AdvACT, SO, CMB-S4, CCATp, CHIME, HIRAX, SKA, COMAP, EUCLID, LSST, …***

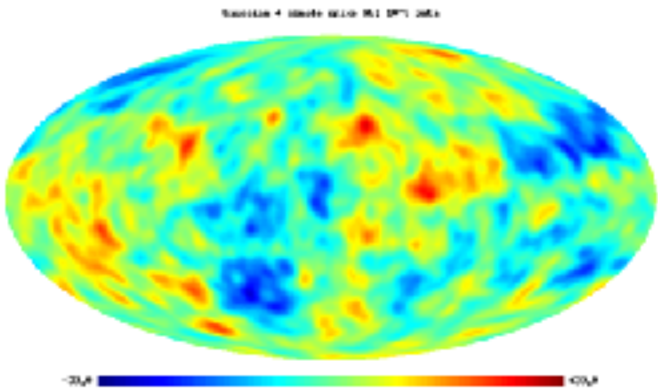
need ***End to End mocks, fully correlated to draw out:***
BSMc, DE/modG, Mnu, nonG (correlated, uncorrelated, intermittent),…

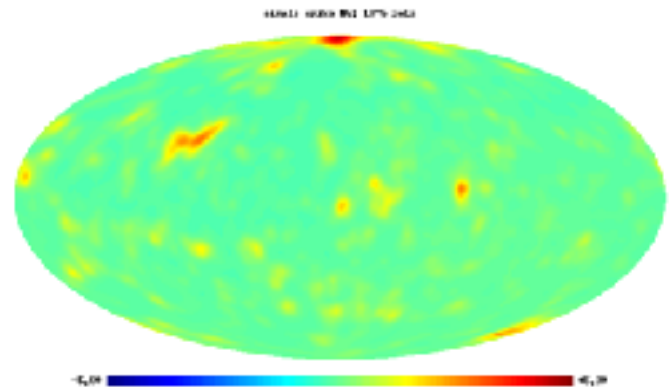


Planck 2015 XII: Full Focal Plane Sims (Nov): FFP8 ensemble of10K ***End****to****End*** *mission realizations in 1M maps. instrument noise + CMB + PSM + .. (25M NERSC CPU hrs)*

CMB+LSS mocks to test: standard Gaussian inflaton ζ_{inf}+ subdominant uncorrelated ζ_{isoc}

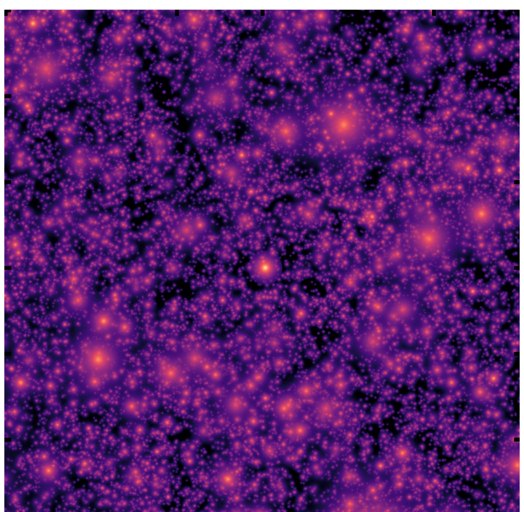
e.g., ***from modulated preheating by isocons***





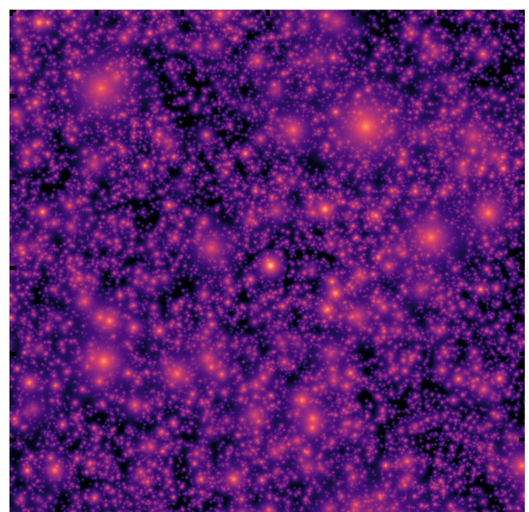
uncorrelated nonG 'wide open' cf. usual correlated highly constrained nonG f_{nl}

LSS tSZ: Gaussian std **Gaussian ζ_{inf}**



B2FH, b+braden+frolov+huang

LSS tSZ: Gaussian std +
subdominant uncorrelated ζ



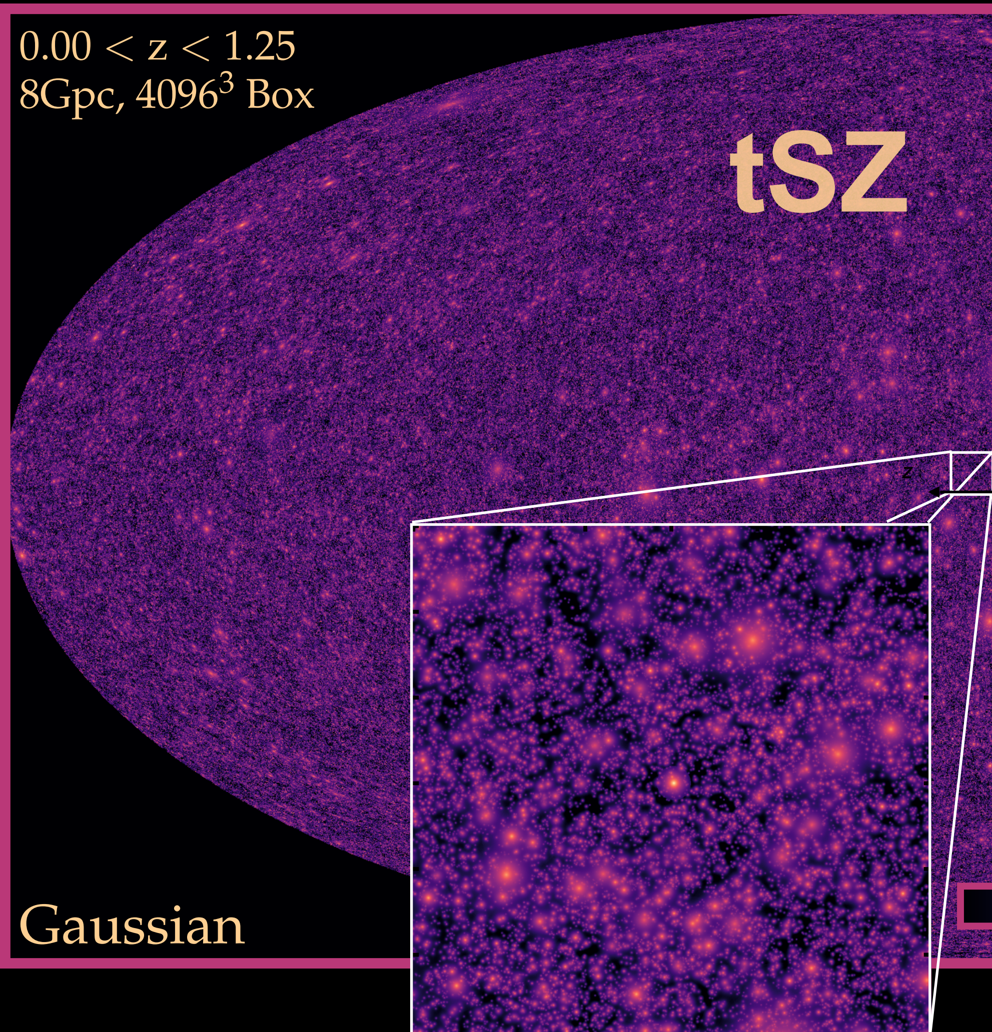
ABSB+FH, alvarez+b+stein+frolov+huang

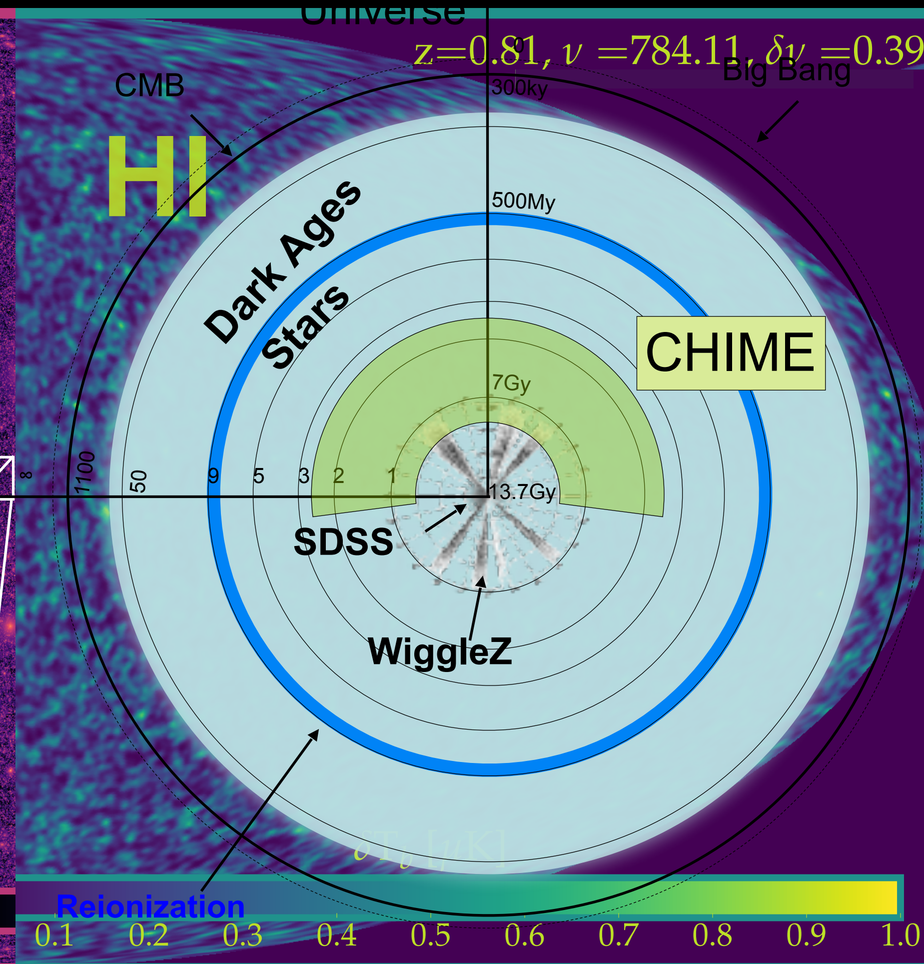
Gaussian ζ_{inf} +
uncorrelated
intermittent nonG ζ_{isoc}

Compton Scattering (Sunyaev-Zeldovich) Simulations for ACT, Planck, Simons Obs &CMB Stage 4 Cluster Observations

Using high res Gas Hydro Sims

HI Intensity Mapping simulations of CHIME / HIRAX .. z=0.8-2.5, ~(8 Gpc)^3





ABS Berger +FH

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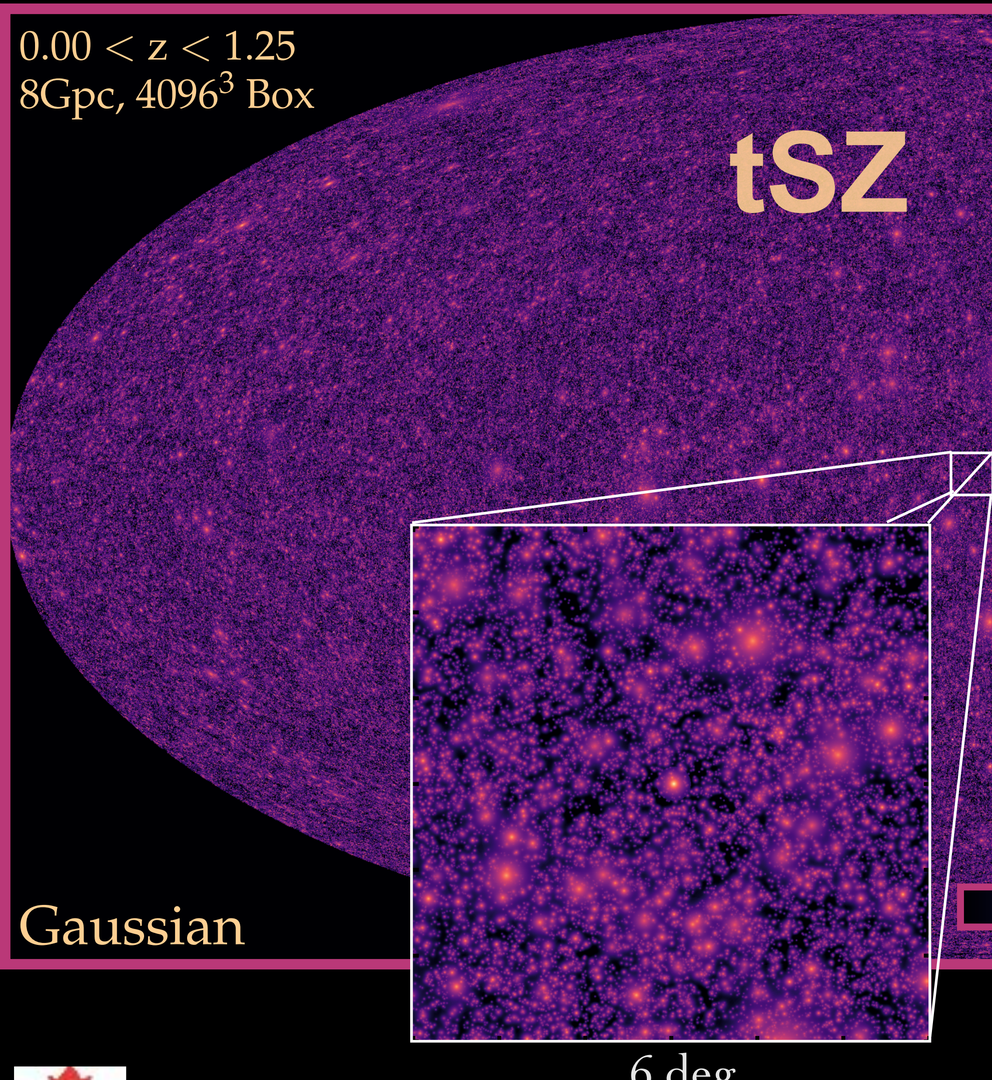

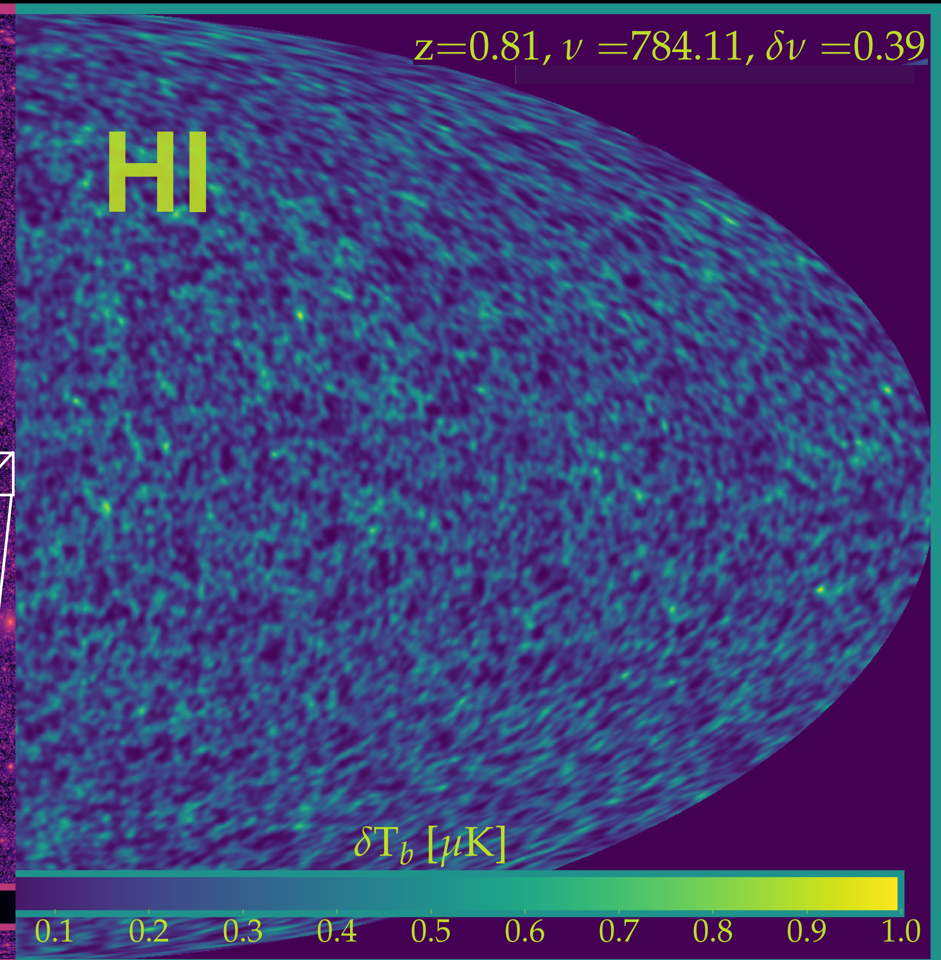

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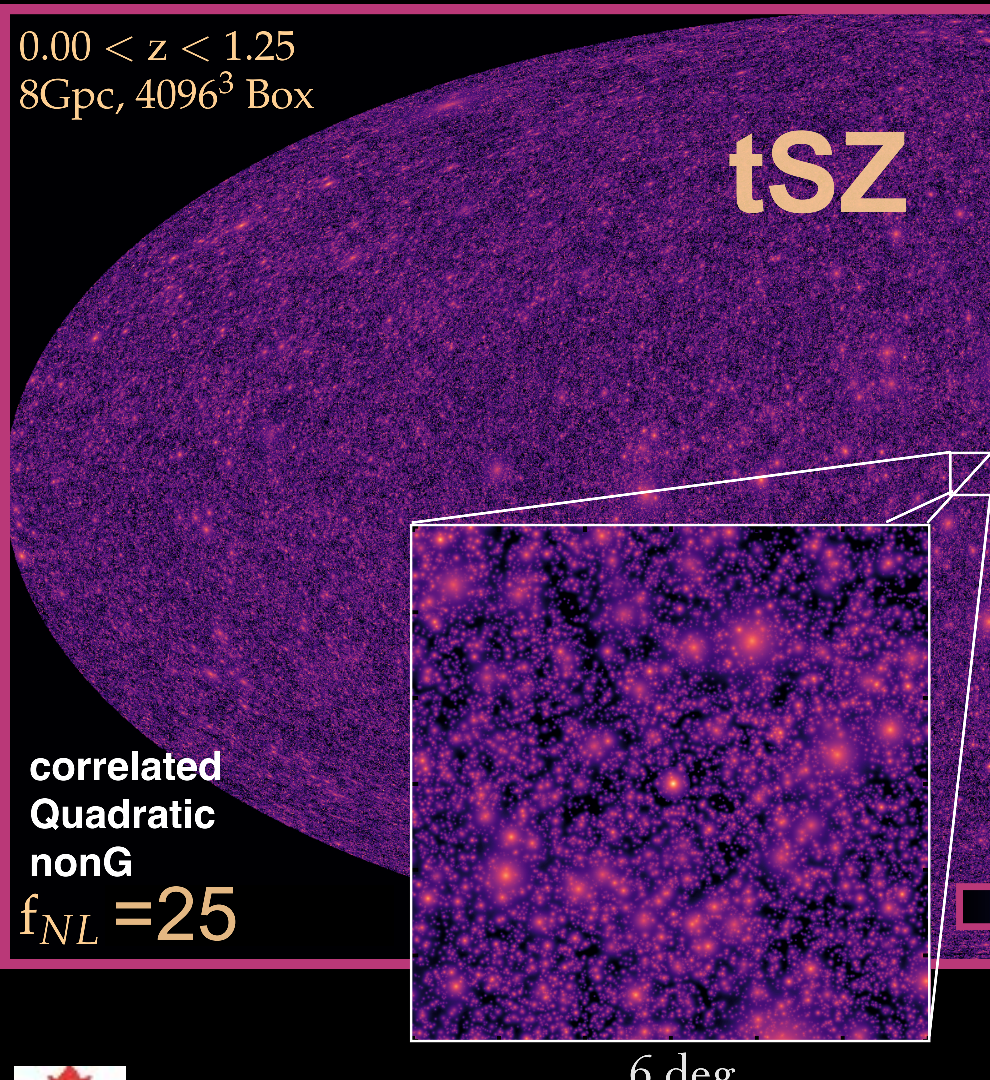

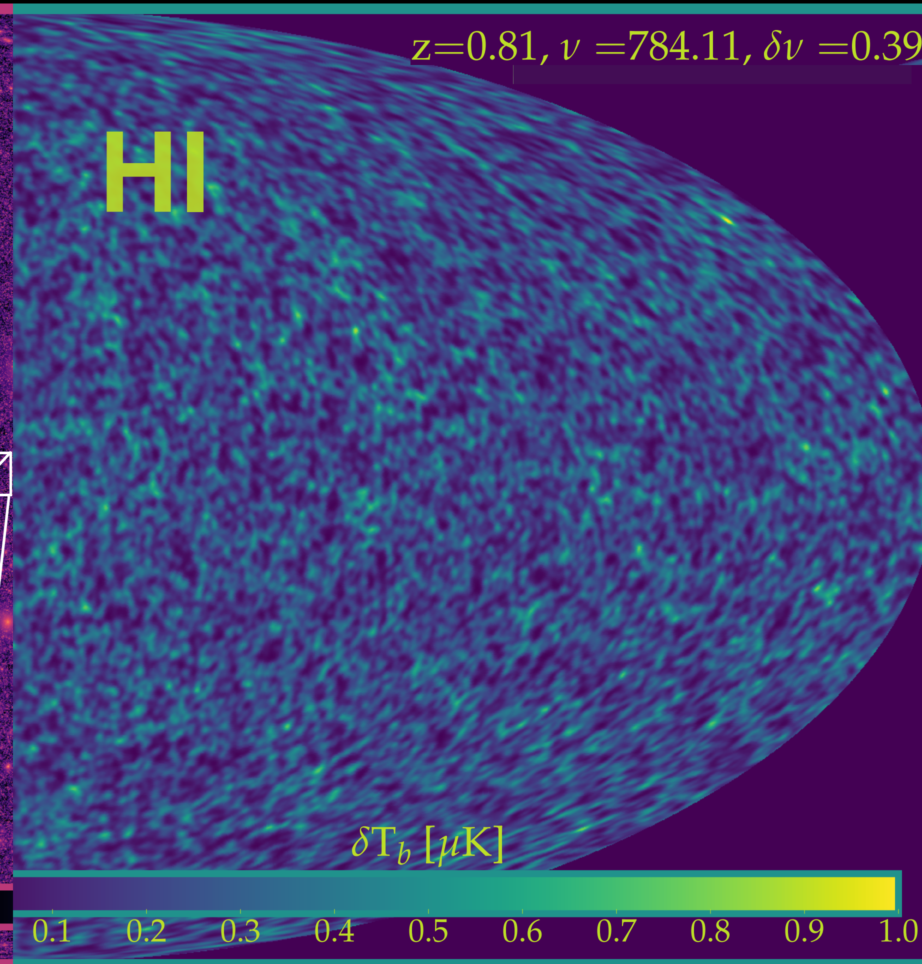

ABSB+FH, alvarez+b+stein+frolov+huang

Compton Scattering (Sunyaev-Zeldovich) Simulations for ACT, Planck, Simons Obs &CMB Stage 4 Cluster Observations

Using high res Gas Hydro Sims

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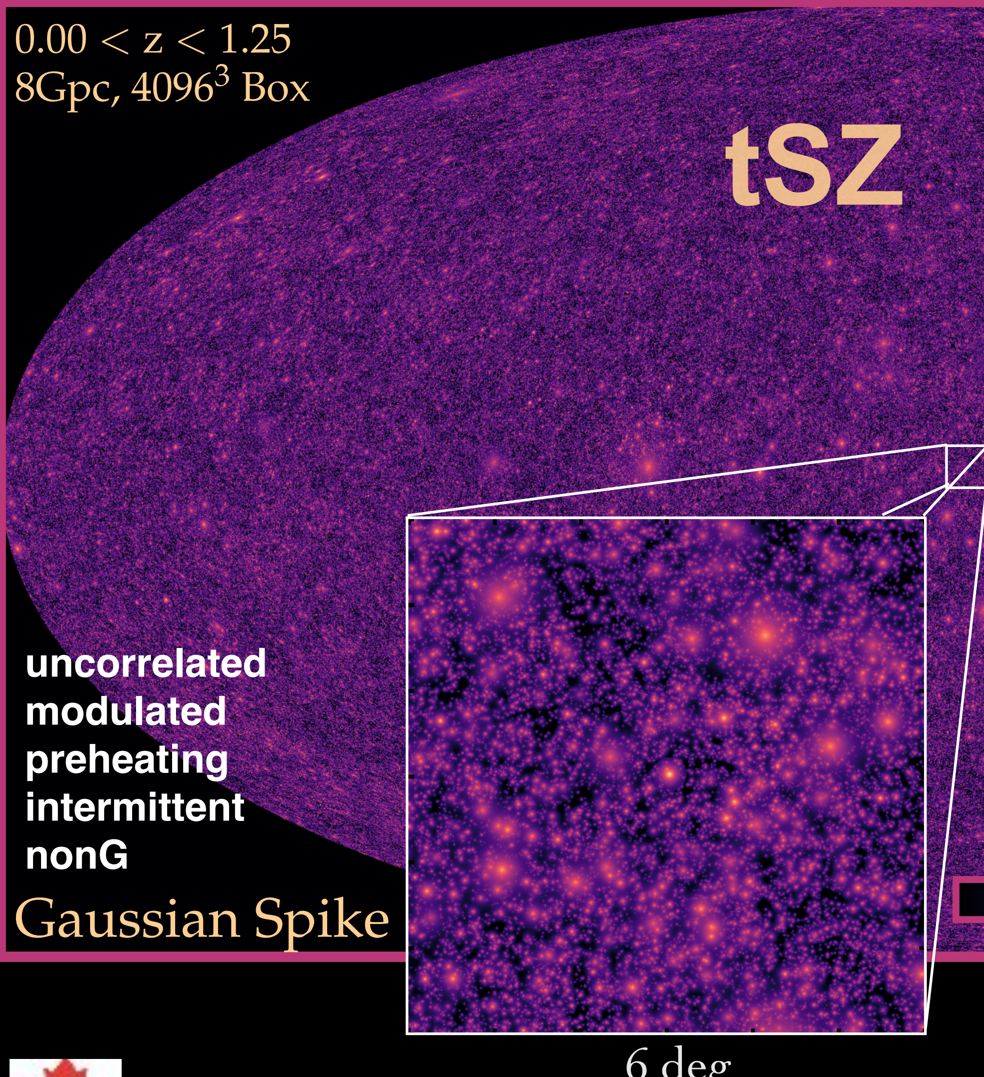
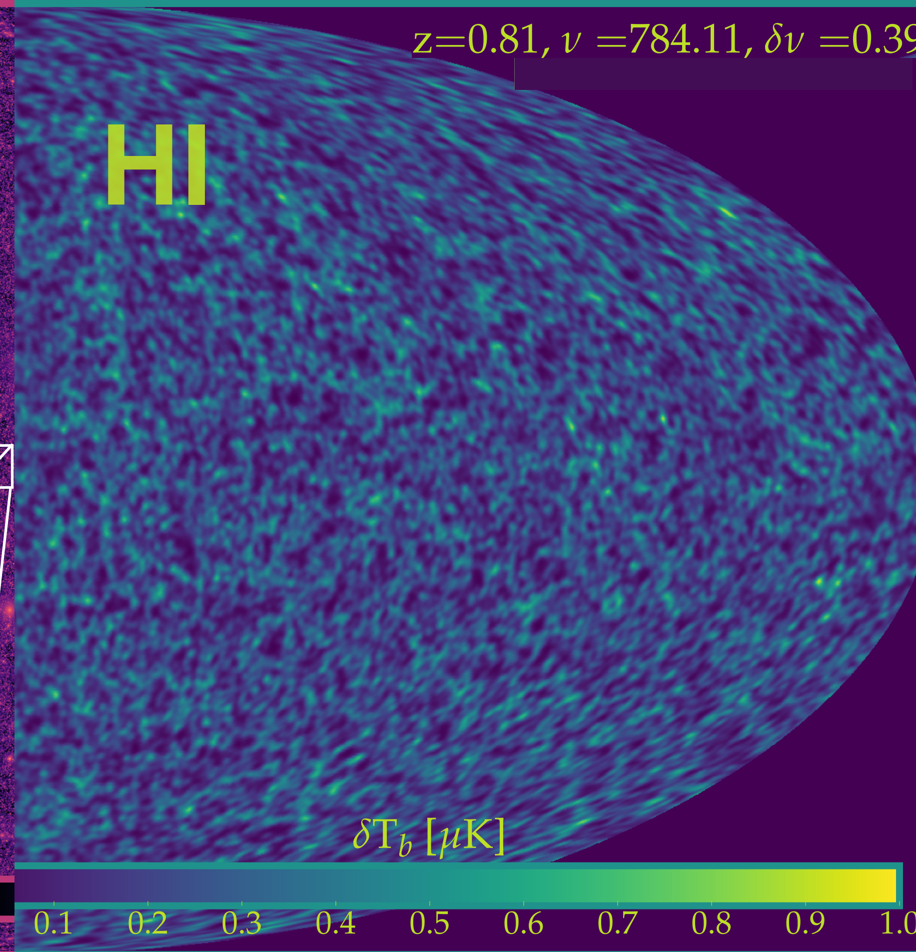


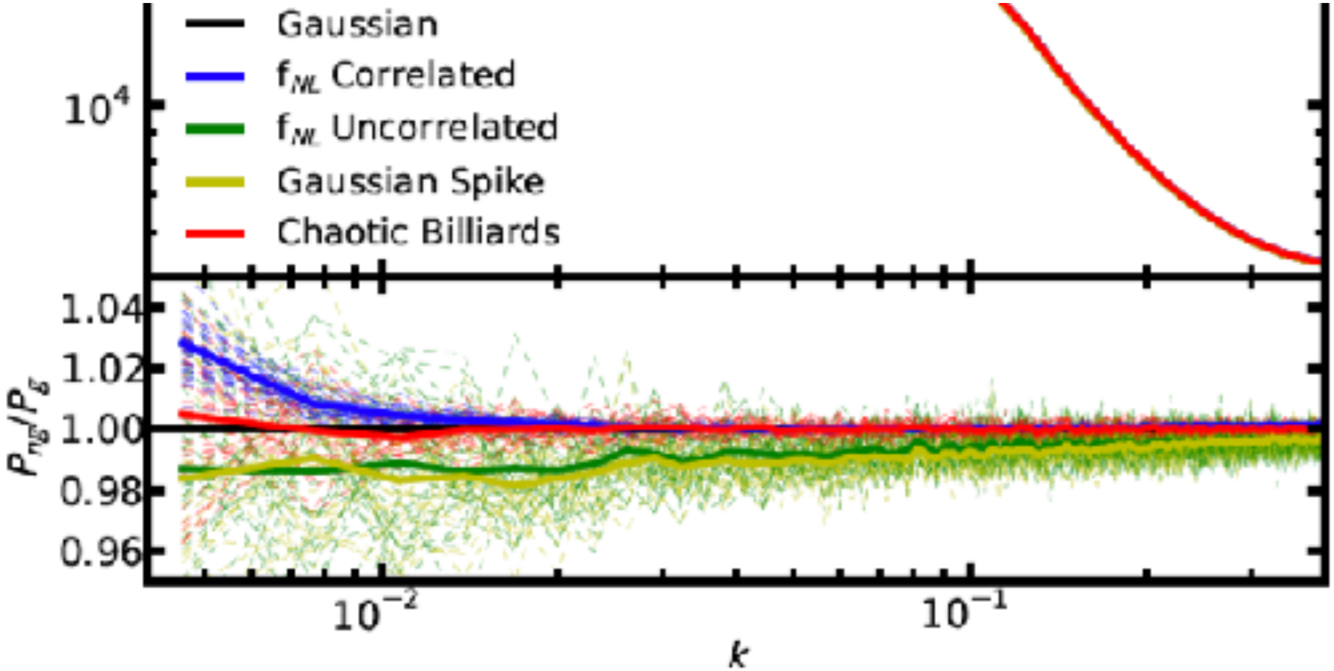


ABSB+FH, alvarez+b+stein+frolov+huang

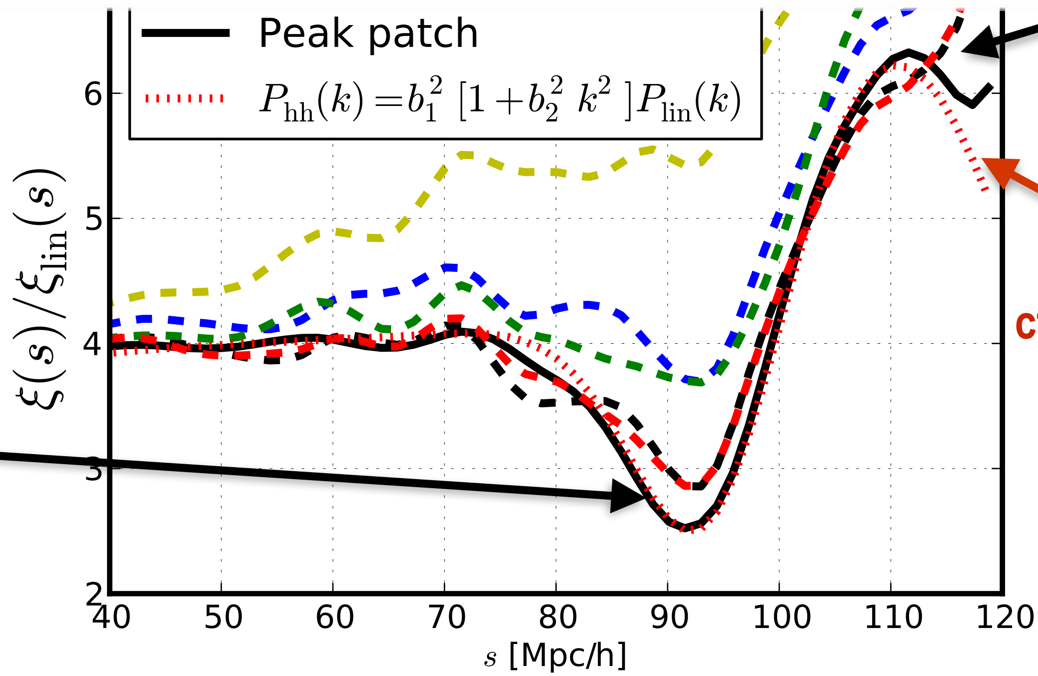
this is a quantitative exercise e.g.,

response of BAO & biasing of halos to forms of nonG - correlated cf. uncorrelated, intermittent cf. perturbative

e.g., **search for rare superBIAS events** >~ supercluster-scale



intermittent nG from early U single spike



Positive Curvature: Overabundance of Negative Extrema

Positive Curvature: Overabundance of Negative Extrema

cf. fit to N-body results: without any tuning it comes out from peak patches naturally

ABSB+FH, alvarez+b+stein+frolov+huang

highly nonlinear field evolutions happened

(EoI caustics, bubble collisions, non-eq entropy generation)

subdominant patterns do arise => will any be observable as rare-event CMB/LSS 'GaussianRandomField-biasing' anomalies?

or ***weak*** **constraints** *on* **multifield potentials, >horizon fields, nucleation rates**, *etc.*

B2FH17 ***progress in semi-analytic understanding of complex lattice sims with probability strings, caustics, trajectory stopping, shocks-in-time*** ***in the V(ϕ)-web***

light isocons cf. heavy isocons, the heavy can lighten up = original SBB nG

isocon modulators, coupling(isocon) modulators, isocon tunneling, isocon oscillons, isocon short-lived fuzzy-strings, + very long-lived strings

alas **a 2-number P_ζ-n_s ζ-verse so far …** ***r adds*** *+1?*

intermittency frustration: statistical variance is large - cf. a 2-3 parameter search

CMB ***restricts us to a*** **projected 2D ζ-scape to reconstruct ζ-maps & ζ-power,** ***the future may look much the same as now for ζ*** **=>potential V(ϕ)=>acceleration ε(a); constrained r helps**

we **mock** the LSS future ***end-to-end*** *to probe the* **mode-rich 3D ζ-scape**

end

Cosmic standard model SMc = *x*CDM, *x*=dark energy+*tilt*: what is U made of?

Planck13-15-17 *CMB, CνB, GW, dark matter, baryons, dark energy/modGravity, CIB:*

ρ_{dm}/ρ_b=5.43 ρ_{de}/ρ_{dm} =2.53 Ω_m=0.32 ±.009, Ω_Λ=0.68 ±.009 =>

BSMc Beyond the SMc *eg* Ω_Λ(t,x), neutrino properties, inflation anomalies

How Structure in the Universe Arose?: *fluctuation generation in curvature from an early inflaton: reconstruct ln a(x,t) ~ phonons, isocurvature,* **r** *Gravity Waves* ζ

HEAT ***(coherence + quantum noise => incoherence via entropy generation) via nonlinear lattice simulations of multiple scalar fields at the end of inflation*** **<=>dynamical systems** KS

=> CMB/LSS Anomalies from EarlyU intermittent non-Gaussianity cf. perturbative non-Gaussianity, *correlated & uncorrelated* => CITA in CMB + LSS large surveys

CMB*ology* **precision cosmic parameters** ***Planck*** **2013-15-17 intensity + polarization** *+ ACTpol + BKP +SPT* => *Spider, Advanced ACTpol CCATp* => *Simons Obs* => *CMB Stage 4, …* **&** **LSS*ology*** *CHIME, COMAP, Euclid …* **&** *cross correlations: CMBxLSS = webXweb*

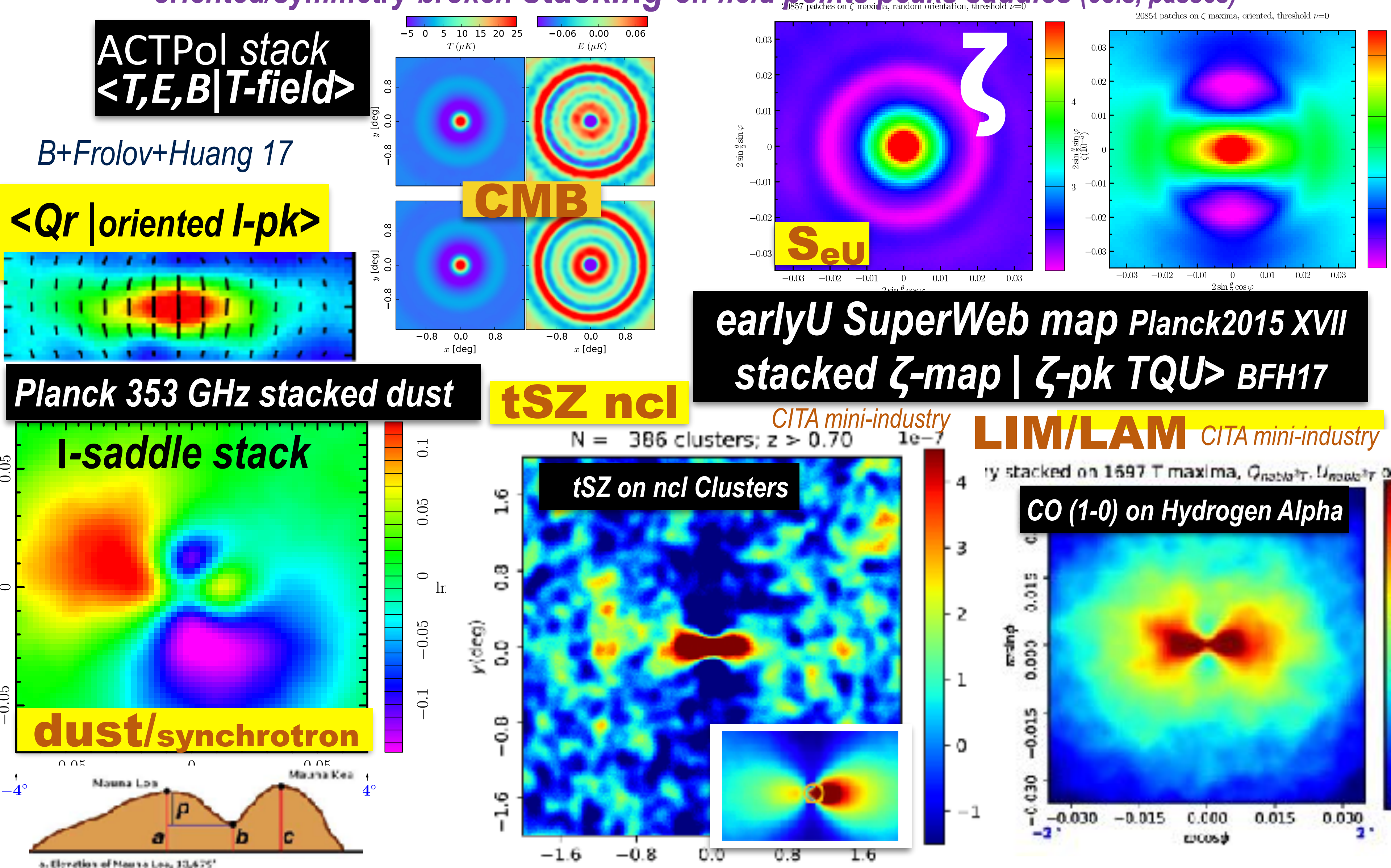
morphs *into the nonlinear* ***Cosmic Web:*** **Mocking Heaven** *clusters SZ, filaments, voids; galaxies Mass-peak-patches, N-body, gas: Lens, tSZ, kSZ, CIB,CO, HI (21cm,Hα,Lyα) optical*

LIM/LAM Line Intensity Mapping | *constrained patch stacks* | *dynamical, coupled? dark energy*

Stacking @ CITA - oriented asymmetric on extrema & other points

Topography of the CMB-web, ζ-web, IQU/ E B, ISM-web, y-web, LIM/LAM web

oriented/symmetry-broken **stacking** on field points peaks saddles (cols, passes)



Mocking Heaven *with PeakPatches*++

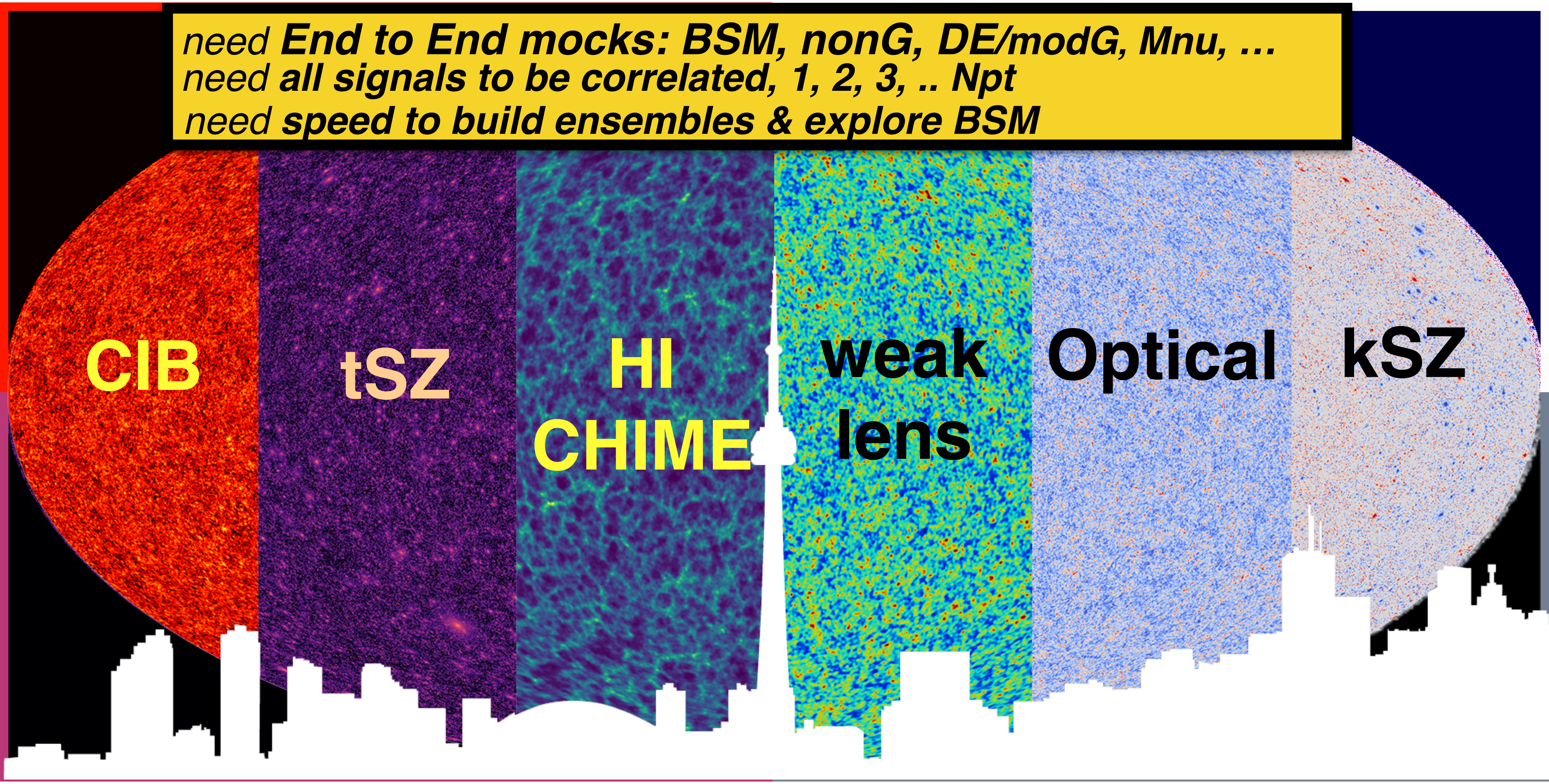
Dick Bond @ CITA Jamboree 17

Planck, AdvACT, SO, CMB-S4, CCATp, EUCLID, LSST**, *CHIME, HIRAX, COMAP, …SKA***

Line Intensity Mapping and Line Absorption Mapping *fLIMfLAM*

CITA mini-industry: Marcelo Alvarez, Dick Bond, George Stein & Battaglia, Codis, van Engelen & FIRE: Lakhlani + Murray + Hopkins + Berger & Connor Bevington, Bruno Régaldo-Saint Blancard, Ronan Kerr, Louis Pham

need ***End to End mocks: BSM, nonG, DE/modG, Mnu, …***
need ***all signals to be correlated, 1, 2, 3, .. Npt***
need ***speed to build ensembles & explore BSM***

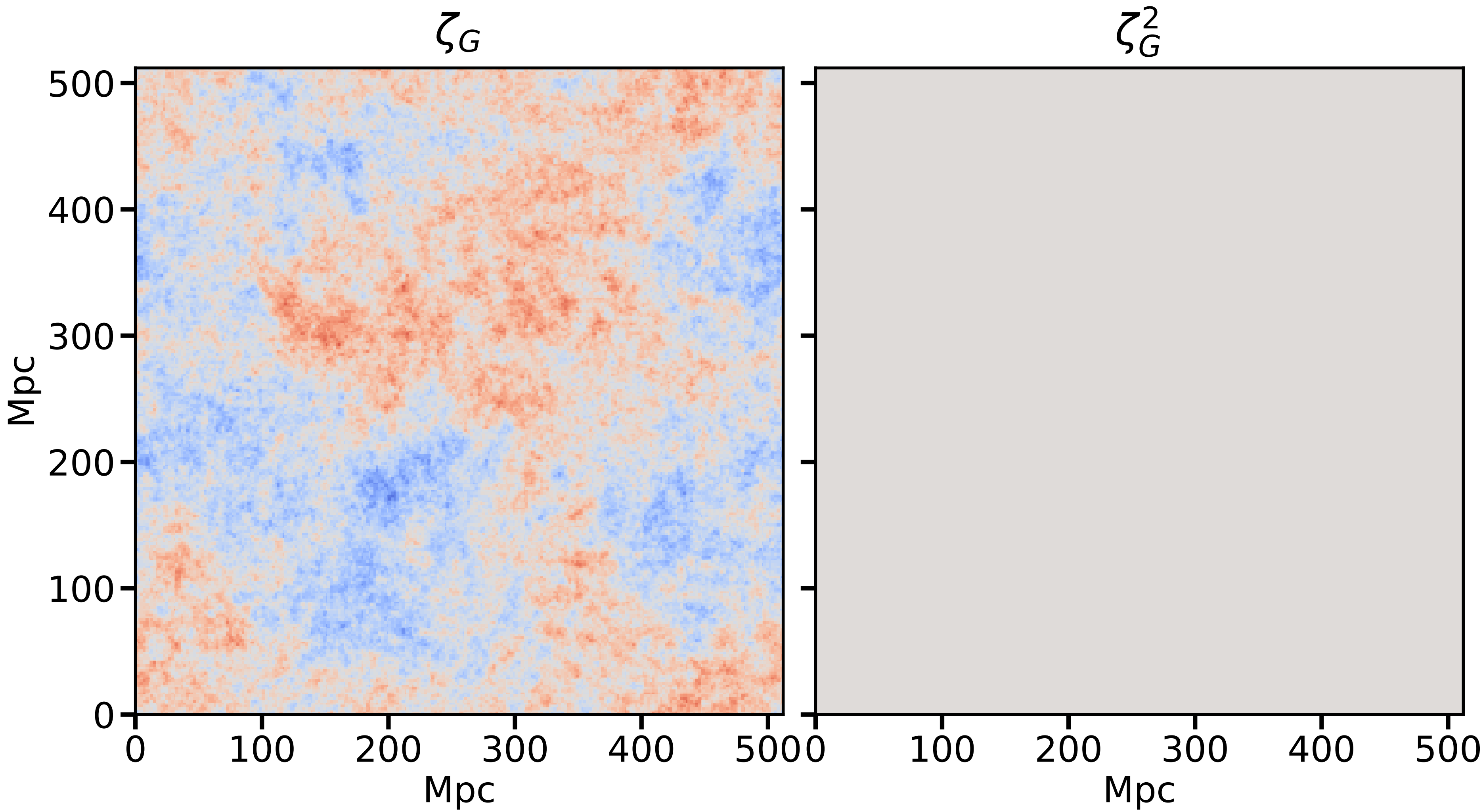


Planck 2015 XII: Full Focal Plane Sims: FFP8 ensemble of 10K ***End****to****End*** *mission realizations in 1M maps. instrument noise + CMB + PSkyModel + .. (25M NERSC CPU hrs)*

Primordial Non-Gaussianity in the Peak Patch method:

$$\Phi_{NG} = \phi(x) + f_{NL}(\phi^2(x) - <\phi^2>)$$

Classic Non-Gaussian case



Primordial Non-Gaussianity in the Peak Patch method:

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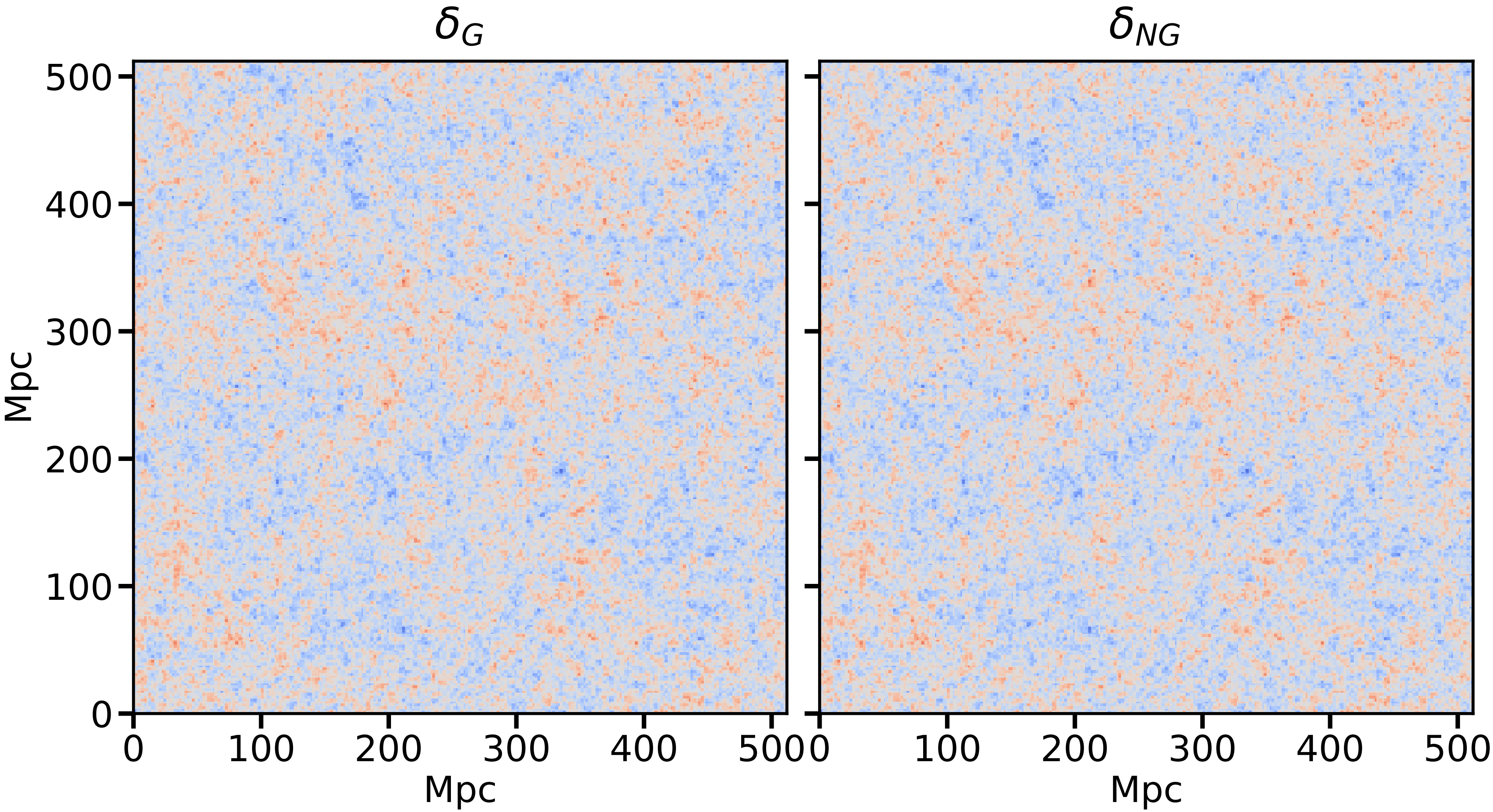
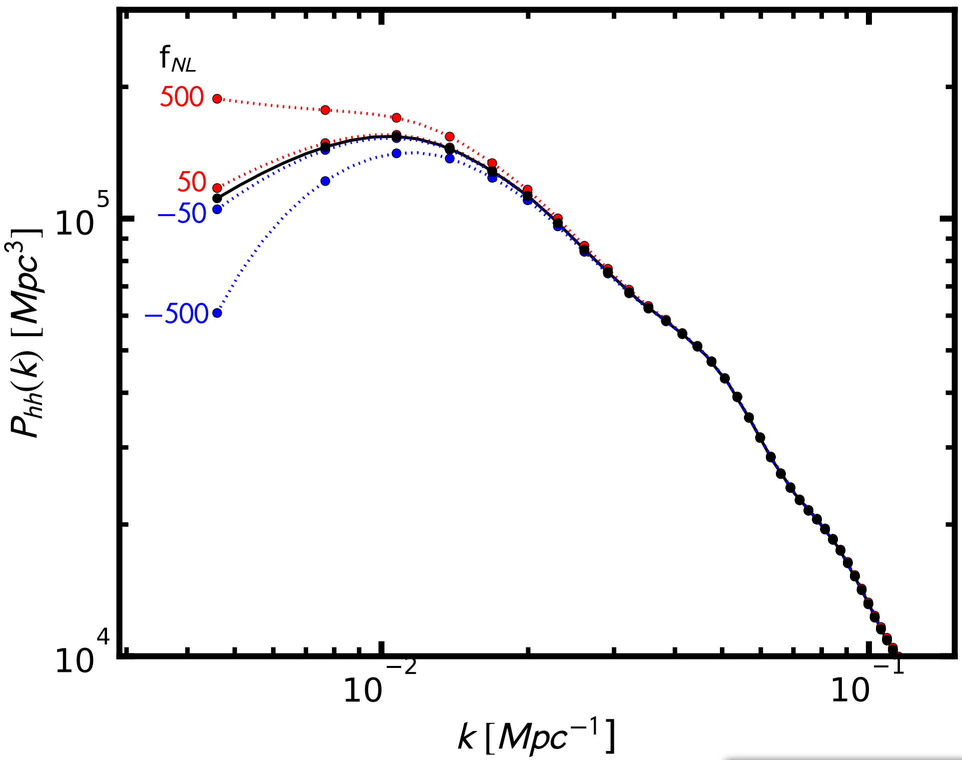
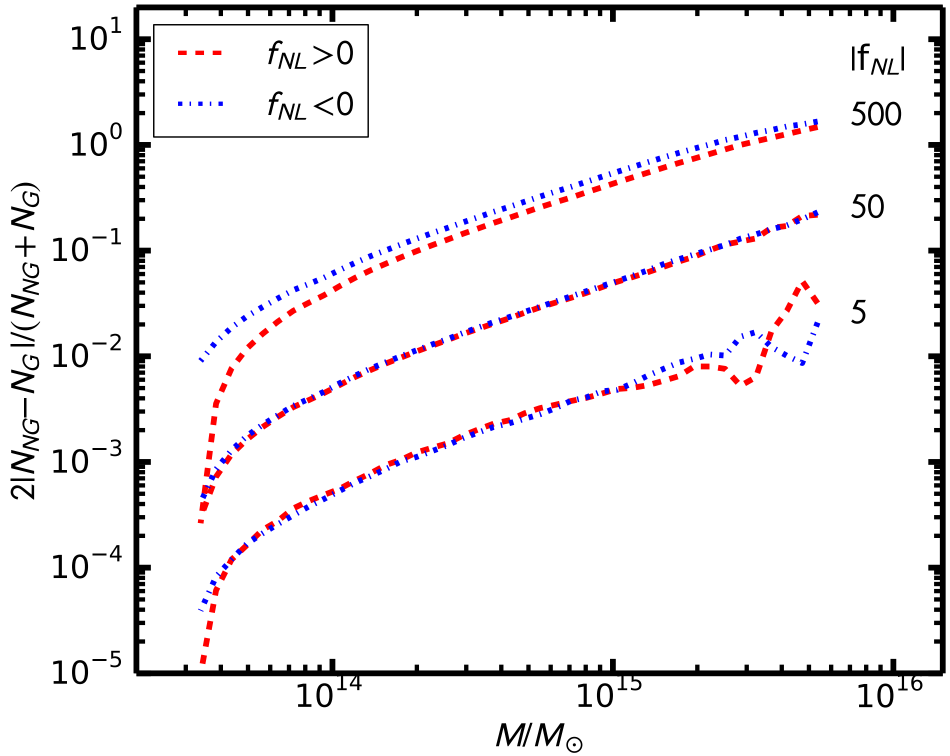


Primordial Non-Gaussianity in the Peak Patch method:

$$\Phi_{NG} = \phi(x) + f_{NL}(\phi^2(x) - <\phi^2>)$$

Validation

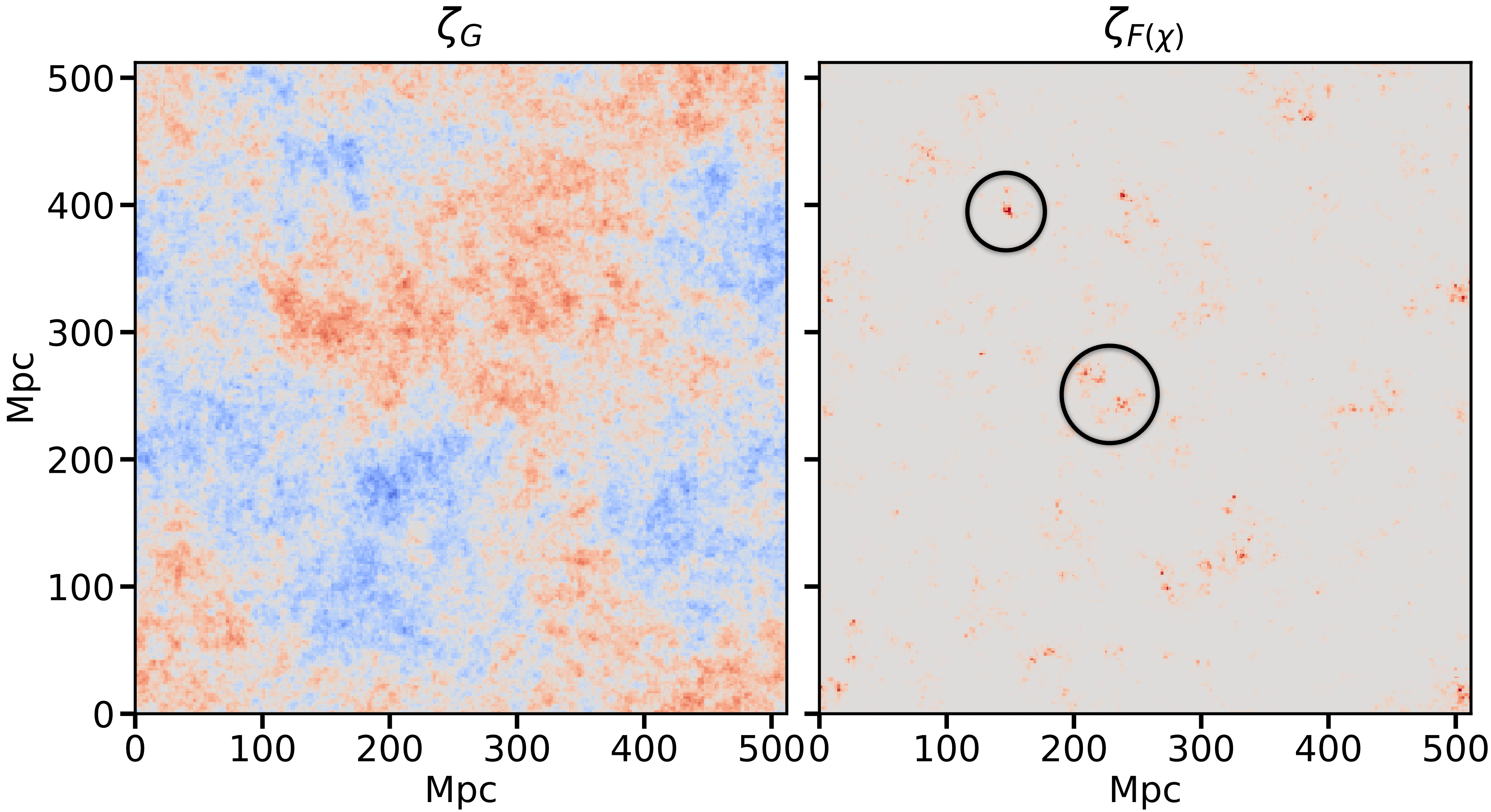




Mean statistics from 6400 2Gpc, 1024^3 runs

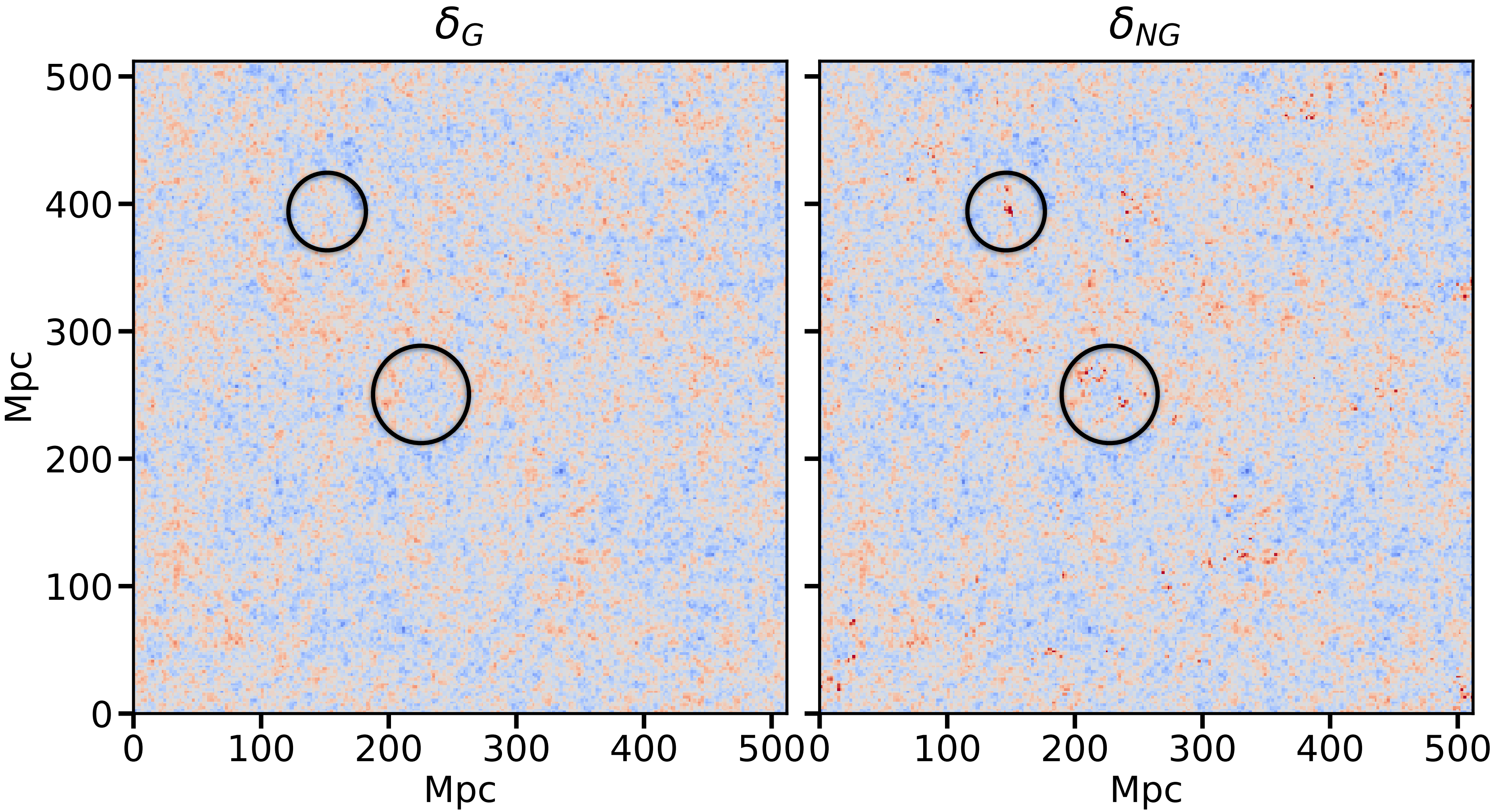
Primordial Non-Gaussianity in the Peak Patch method:

Intermittent Non-Gaussian case



Primordial Non-Gaussianity in the Peak Patch method:

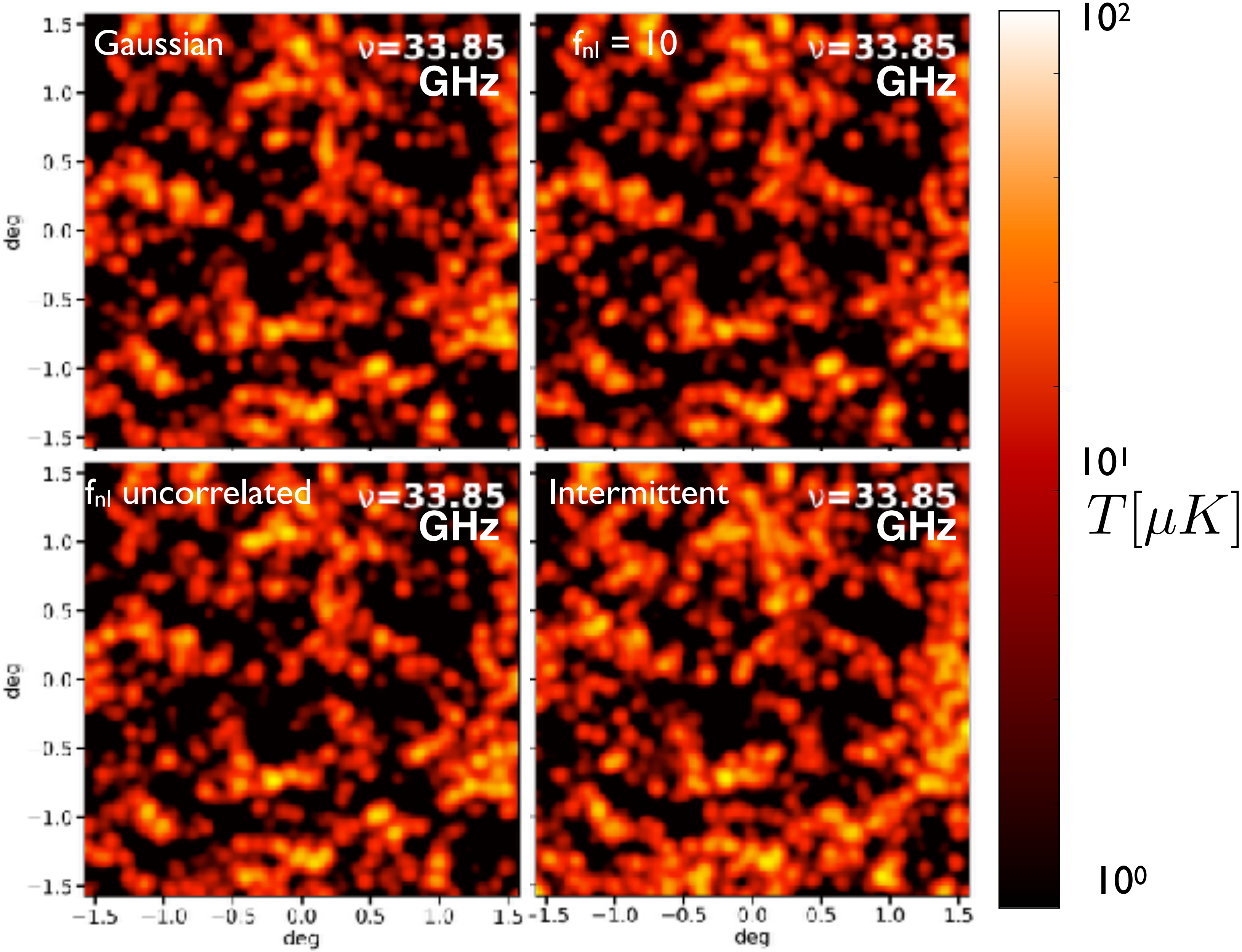
Intermittent Non-Gaussian case



Primordial Non-Gaussianity in CO

$\sigma_8 = 0.82$

In all cases



Primordial Non-Gaussianity in CO

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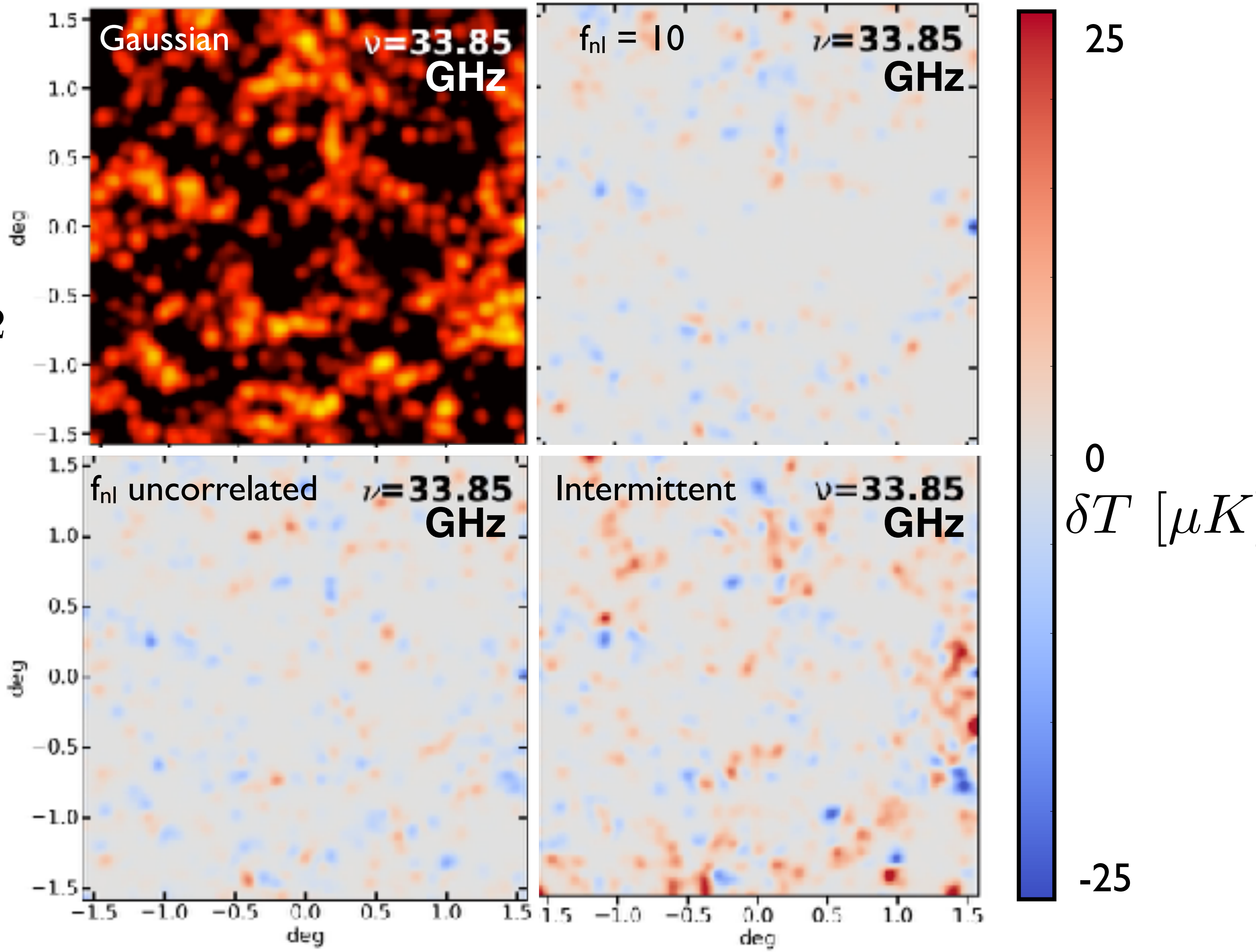

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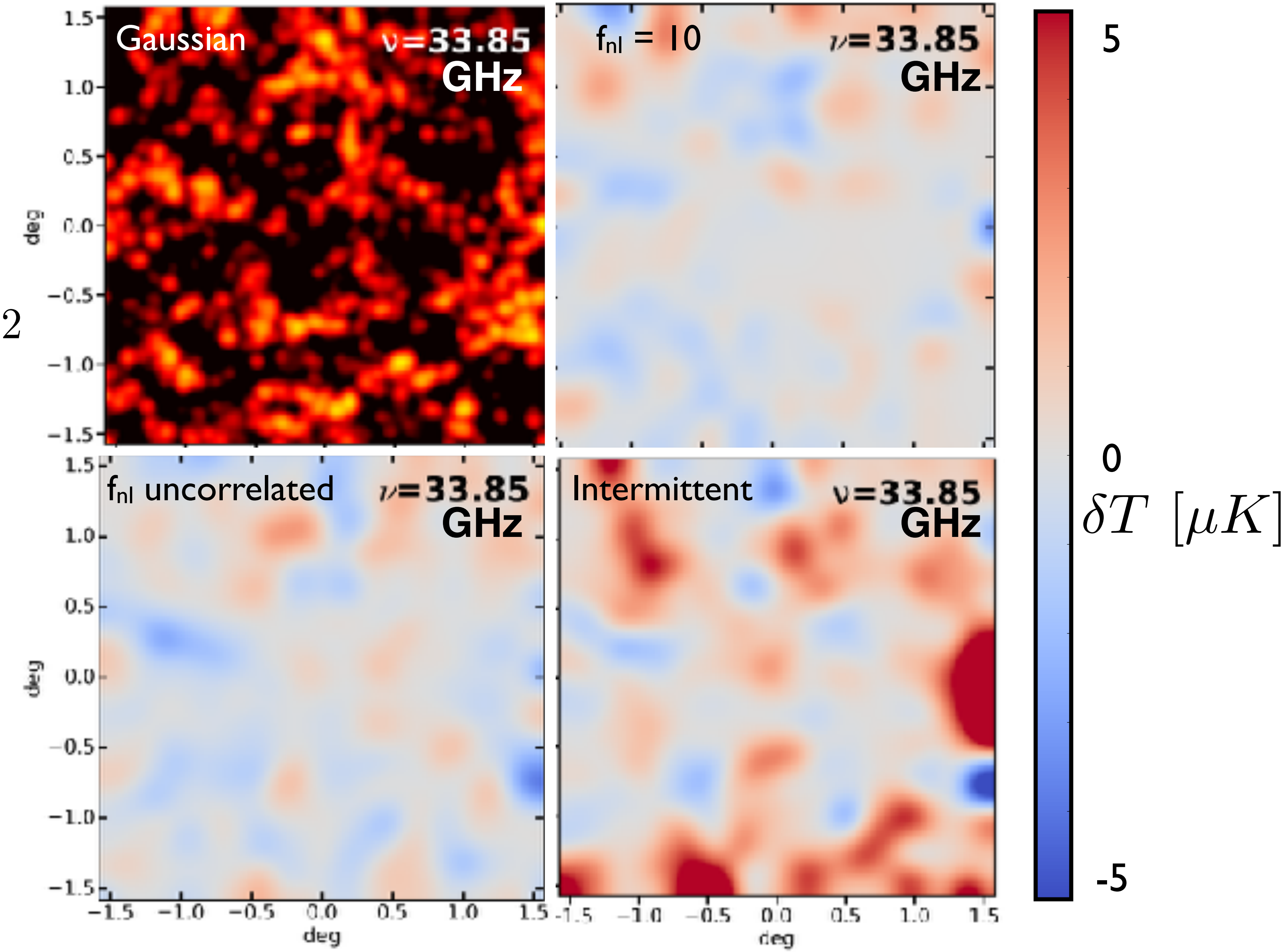

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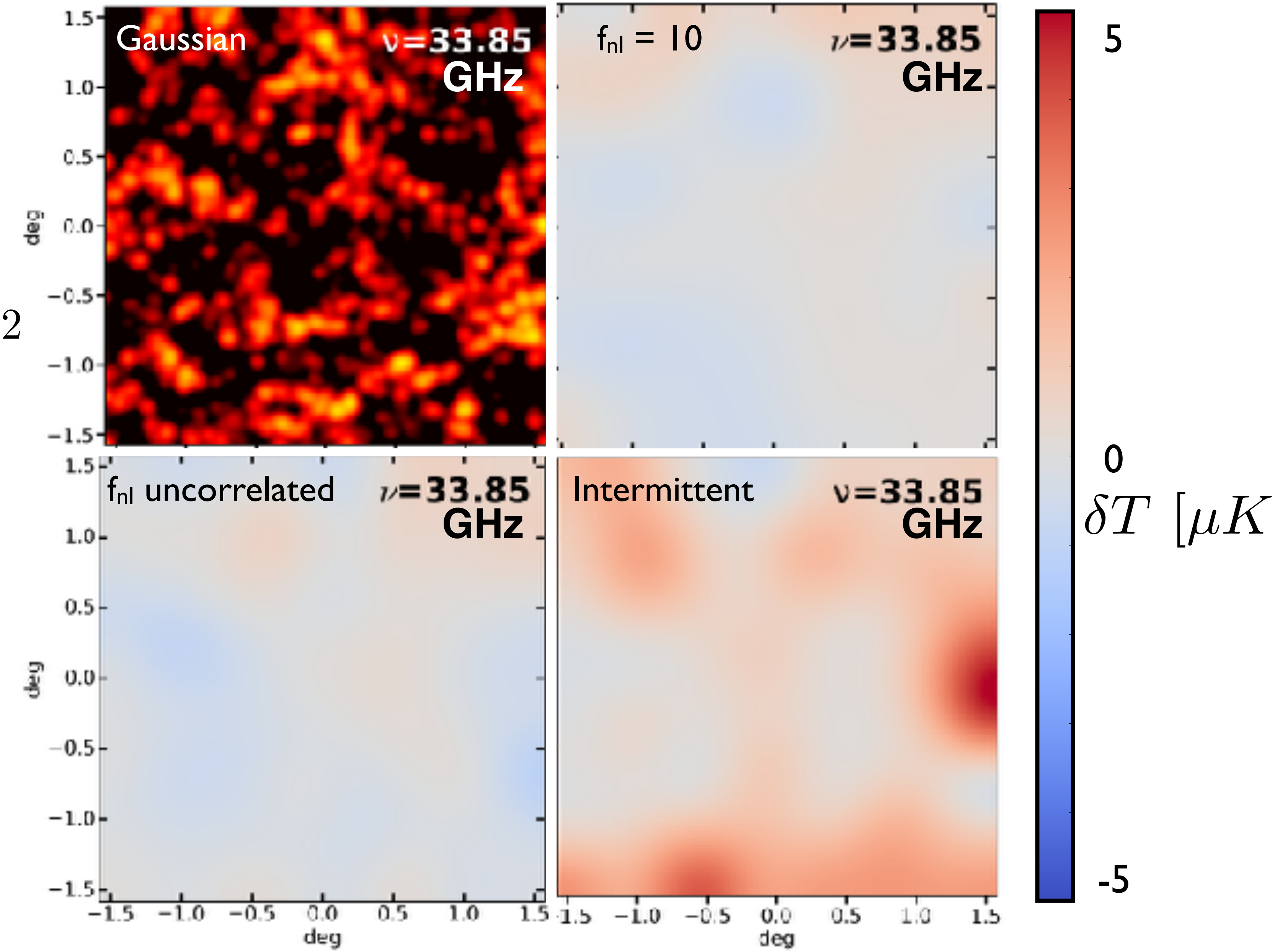
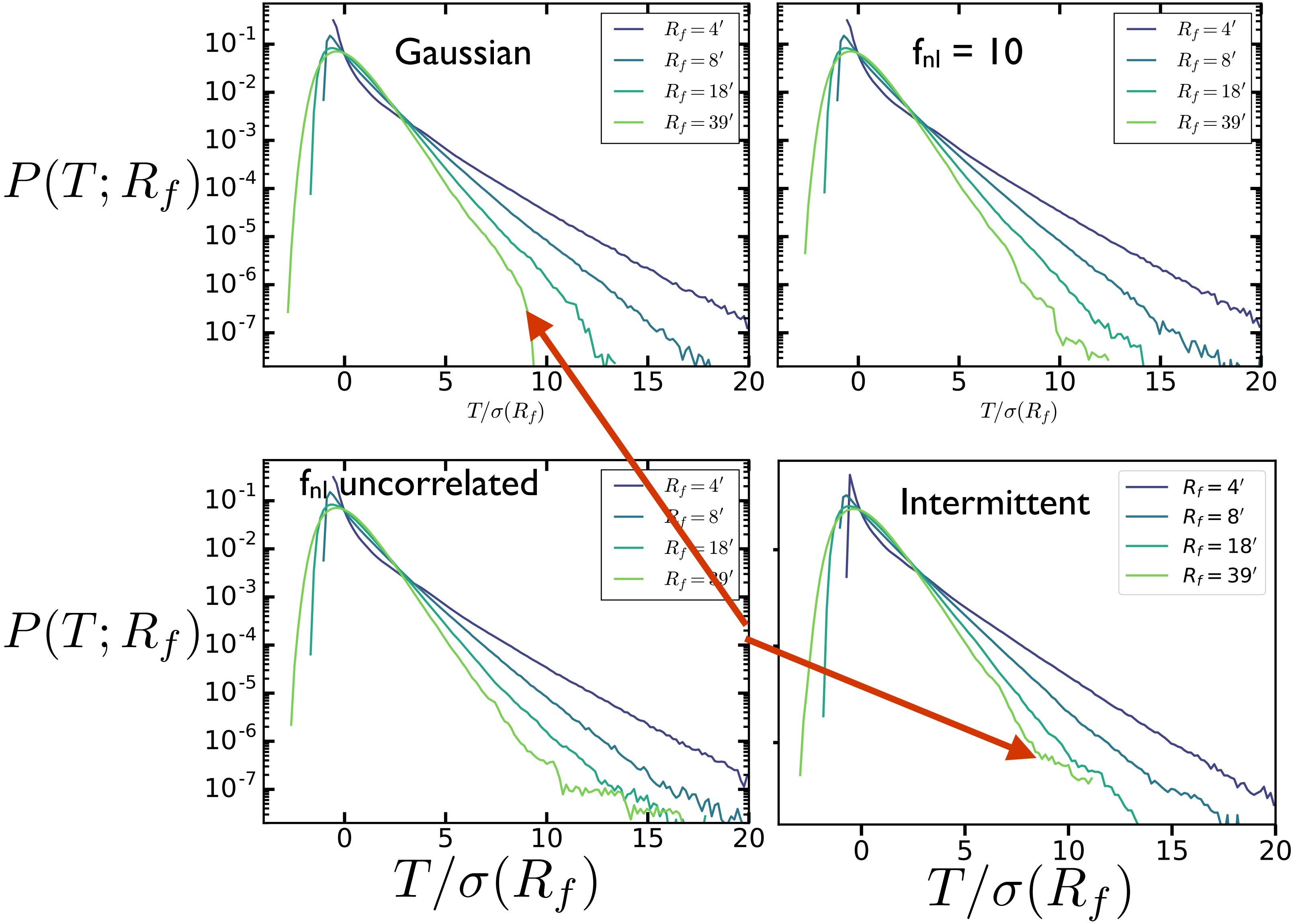


Primordial Non-Gaussianity in CO



Summary

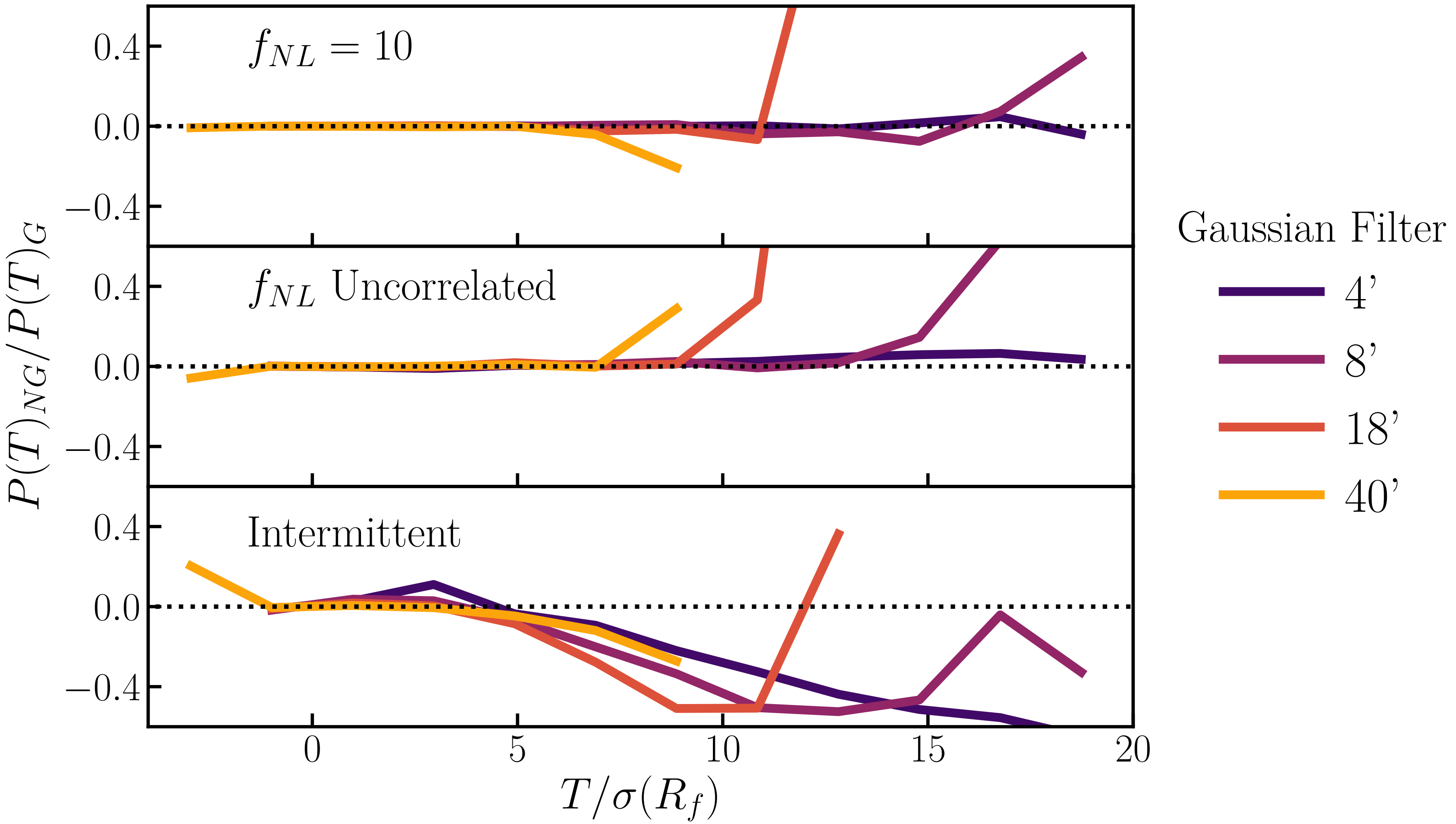
CO at high redshift is complicated to model

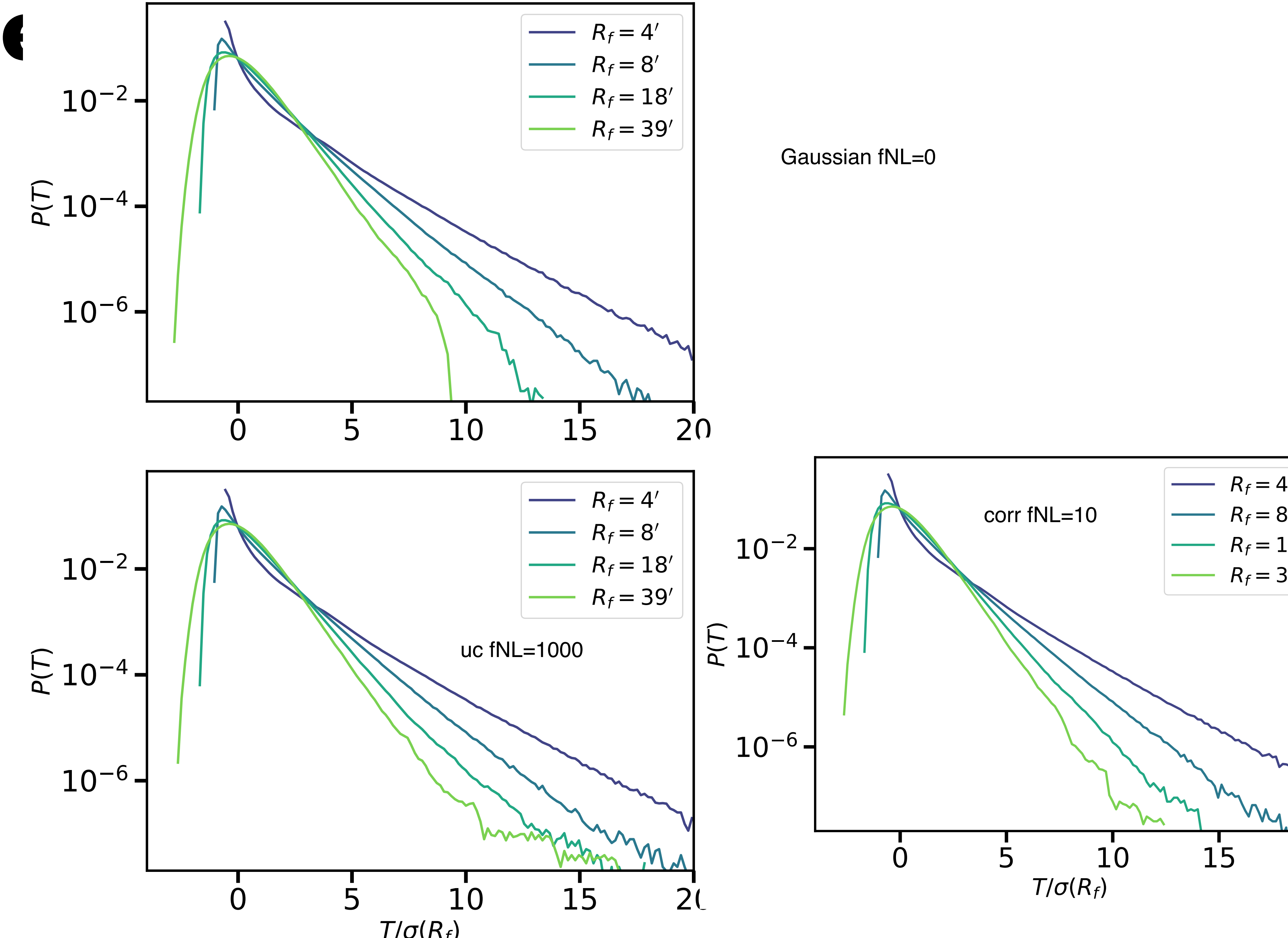
- highly correlated with star formation

To extract cosmological information we must fully understand:

- **Intrinsic Scatter**
    - eg. SFR(Mass), L_{CO}(SFR) - Li et al. 2016
    - Hydro Sims - Lakhlani, Hopkins, Stein, Murray, Bond, Alvarez
- **Cosmic Scatter**
    - COMAP fov subject to cosmic variance
    - Monte Carlo Peak Patch Sims - Stein, Alvarez, Bond
- **Beyond Powerspectrum**
    - VID analysis, line spectra, cross correlations, stacking, …
      - Stein, Bond, Alvarez, Murray, Lakhlani, Ihle, Kerr, et al.

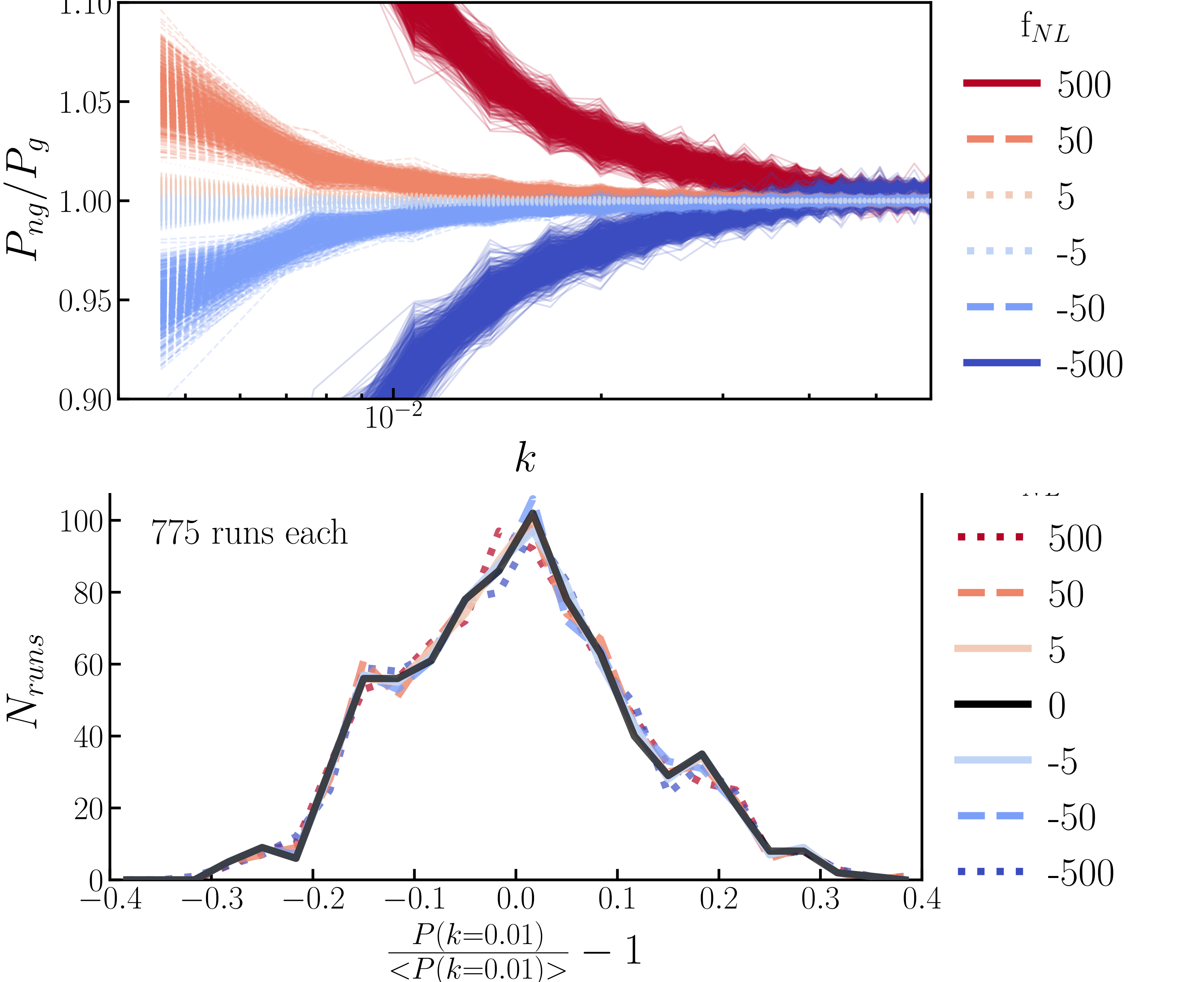
end


$f_{NL} = 10$
f_{NL} Uncorrelated
Intermittent
$P(T)_{NG}/P(T)_G$
$T/\sigma(R_f)$
0.4
0.0
−0.4
0
5
10
15
20
Gaussian Filter
4'
8'
18'
40'



Gaussian fNL=0
uc fNL=1000
corr fNL=10
$R_f = 4'$
$R_f = 8'$
$R_f = 18'$
$R_f = 39'$
$P(T)$
$T/\sigma(R_f)$

er

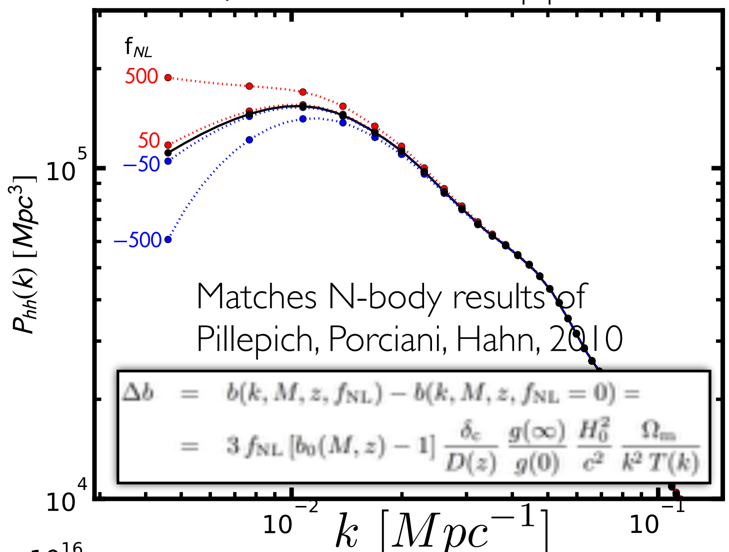


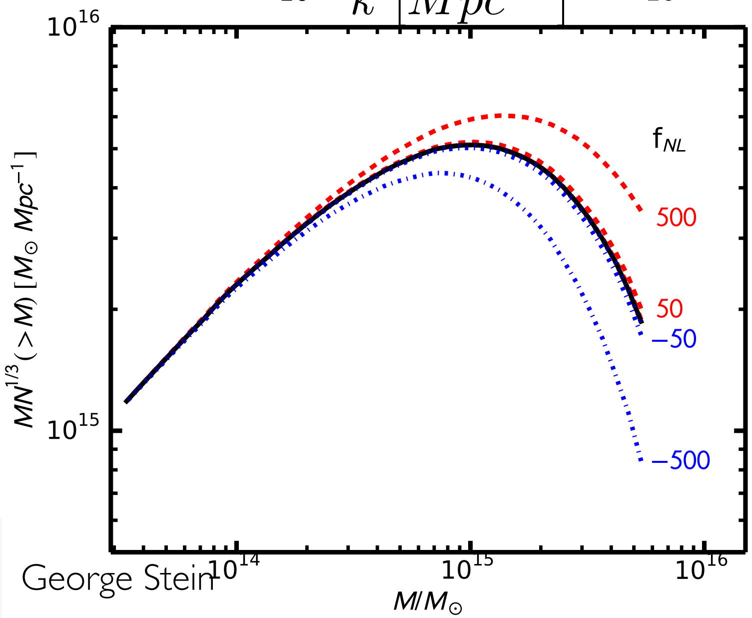
f$_{NL}$
500
50
5
-5
-50
-500
P_{ng}/P_g
1.10
1.05
1.00
0.95
0.90
10^{-2}
k
775 runs each
N_{runs}
100
80
60
40
20
0
500
50
5
0
-5
-50
-500
−0.4
−0.3
−0.2
−0.1
0.0
0.1
0.2
0.3
0.4
$\frac{P(k=0.01)}{<P(k=0.01)>} - 1$

Add in:

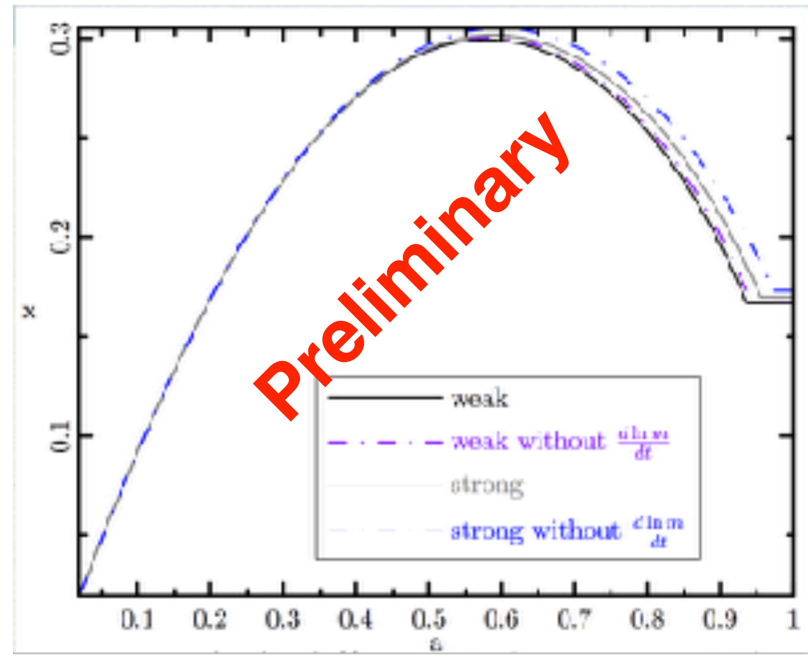
Primordial Non-Gaussianity & Modified Gravity

the Peak Patch method accurately reproduces the effects of primordial Non-Gaussianities
$\longrightarrow$ Add to full mock pipeline





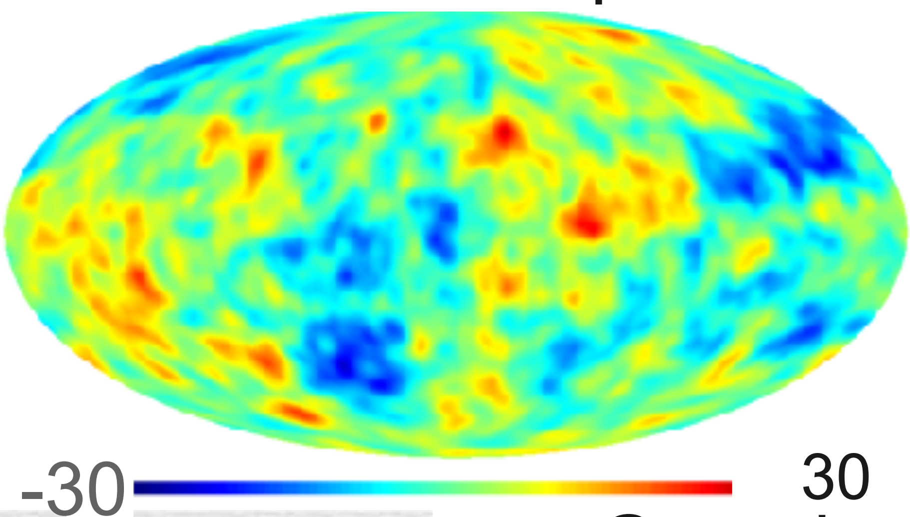
The Effect of chameleon-like f(R) gravity
On the dynamics of ellipsoidal collapse



Emma Platts, Zhiqi Huang, Alex Lague

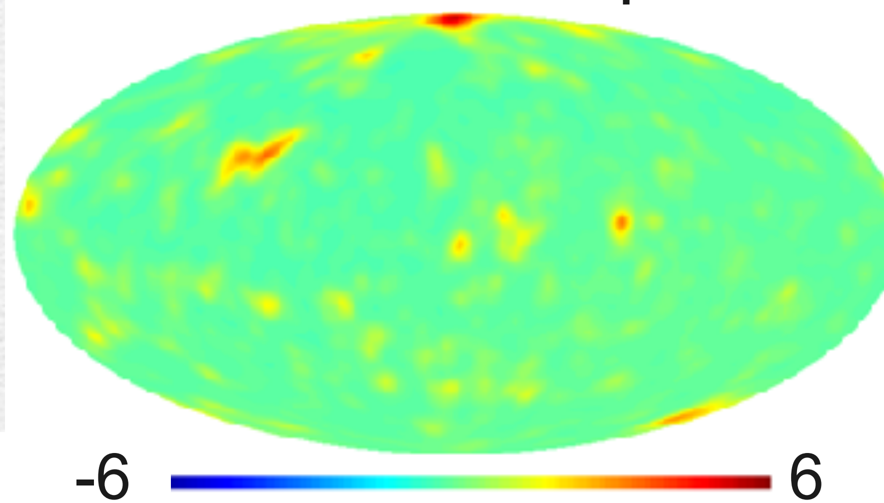
CMB Example: Gravitational Potential Maps

Gaussian Component



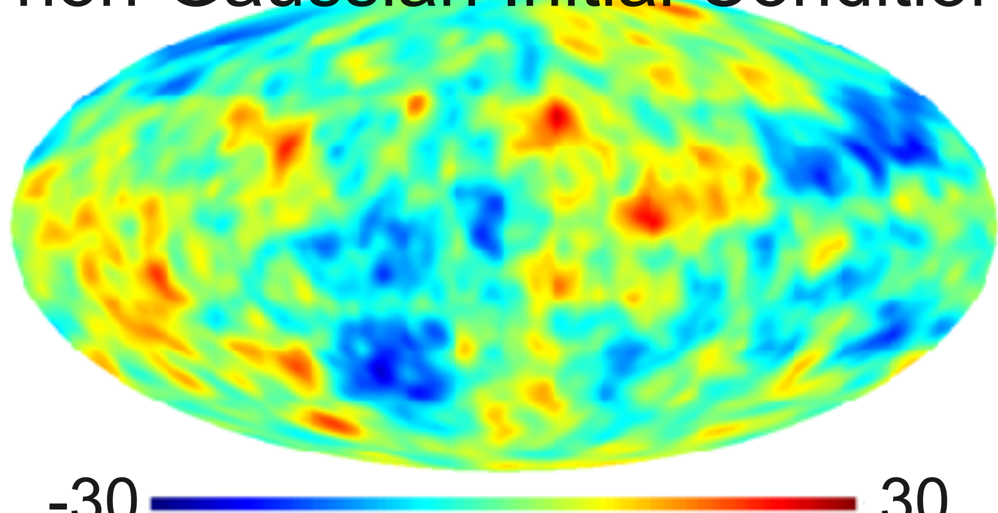
+

Intermittent Component



non-Gaussian Initial Conditions

=



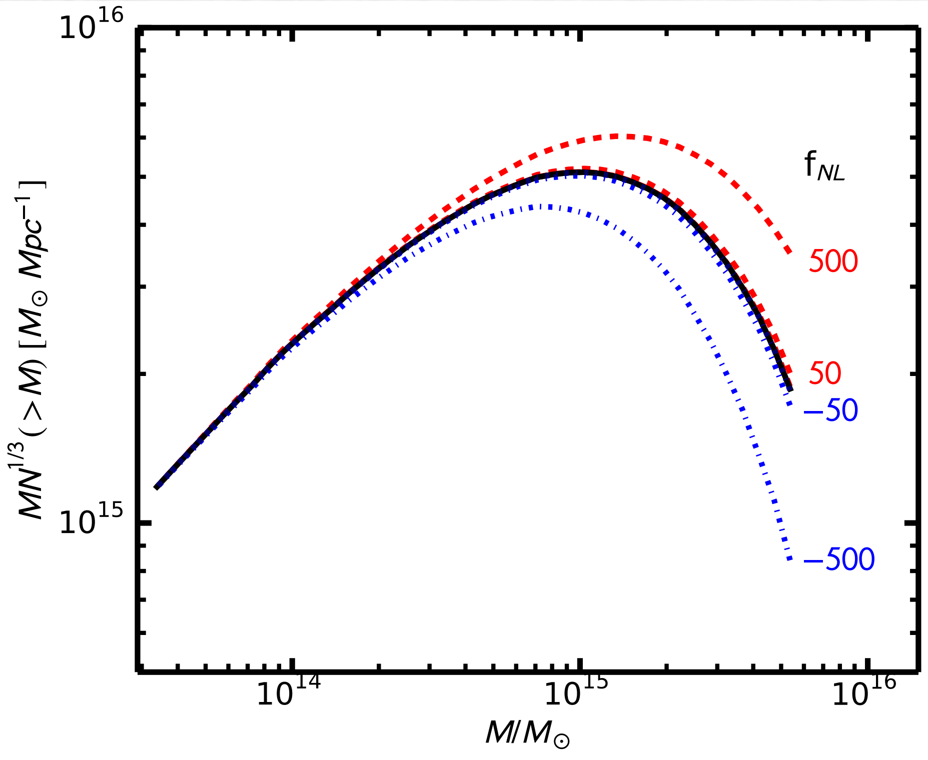
Bond, Frolov, Huang, Kofman (2009)

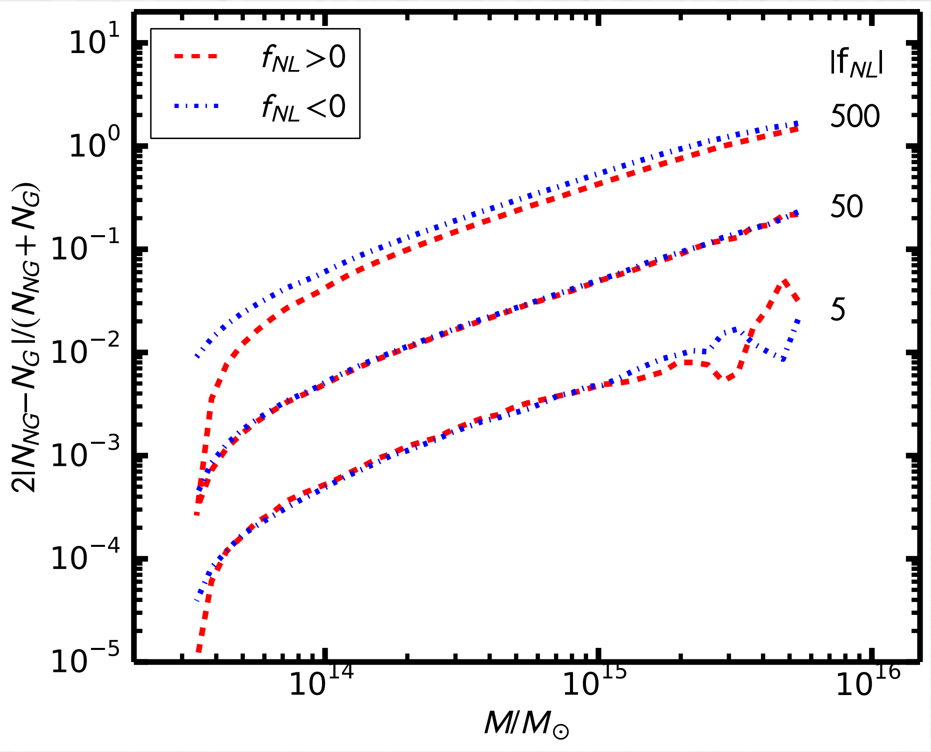
Halo Mass Function is strongly affected only for large f_{NL}

Local non-Gaussianity

$$\Phi(x) = \phi(x) + f_{NL}(\phi^2 - <\phi^2>)$$

Peak Patch Sims: 2048 Mpc box, 1024^3 cells
900 realizations, ~3 mins each on 64 cores



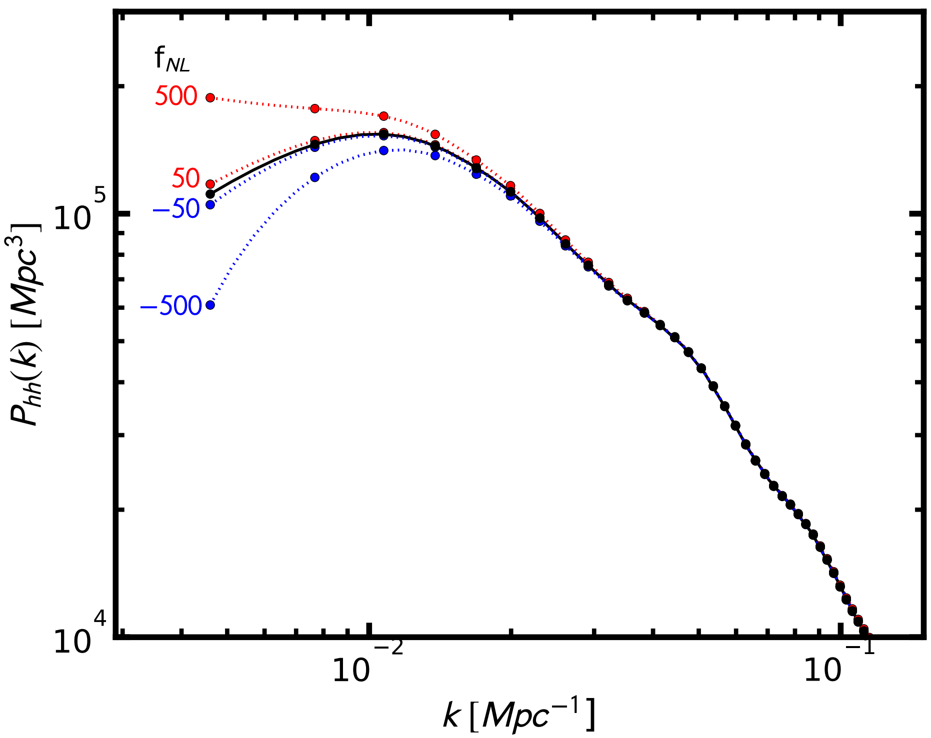


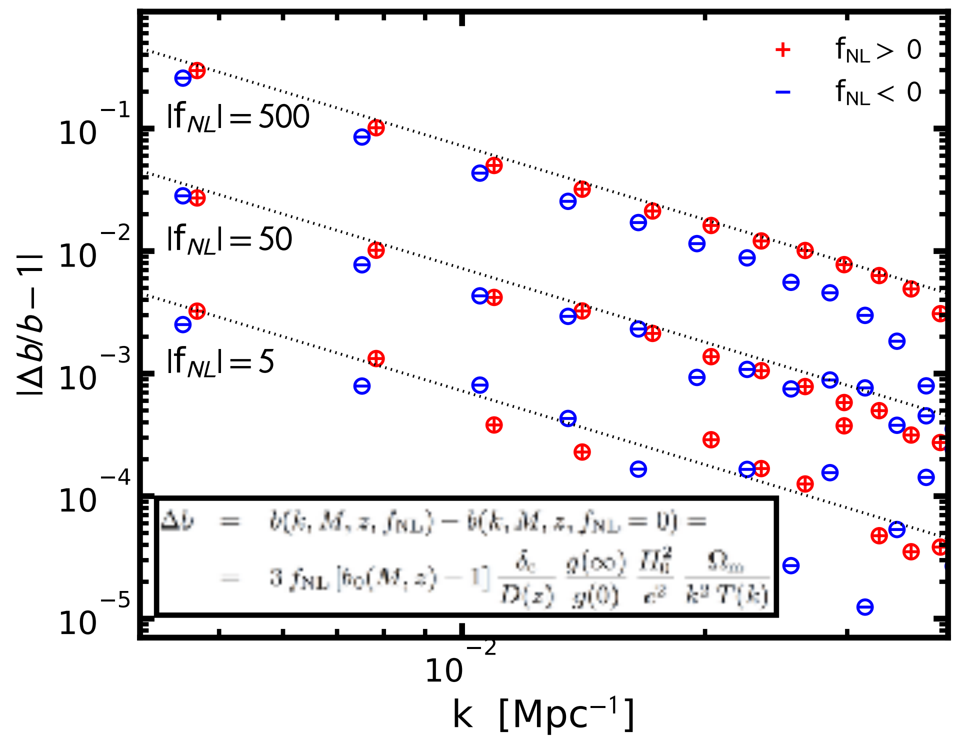
Instead look at power spectrum and scale dependent bias

Local non-Gaussianity

$$\Phi(x) = \phi(x) + f_{NL}(\phi^2 - <\phi^2>)$$

Peak Patch Sims: 2048 Mpc box, 1024^3 cells
900 realizations, ~3 mins each on 64 cores



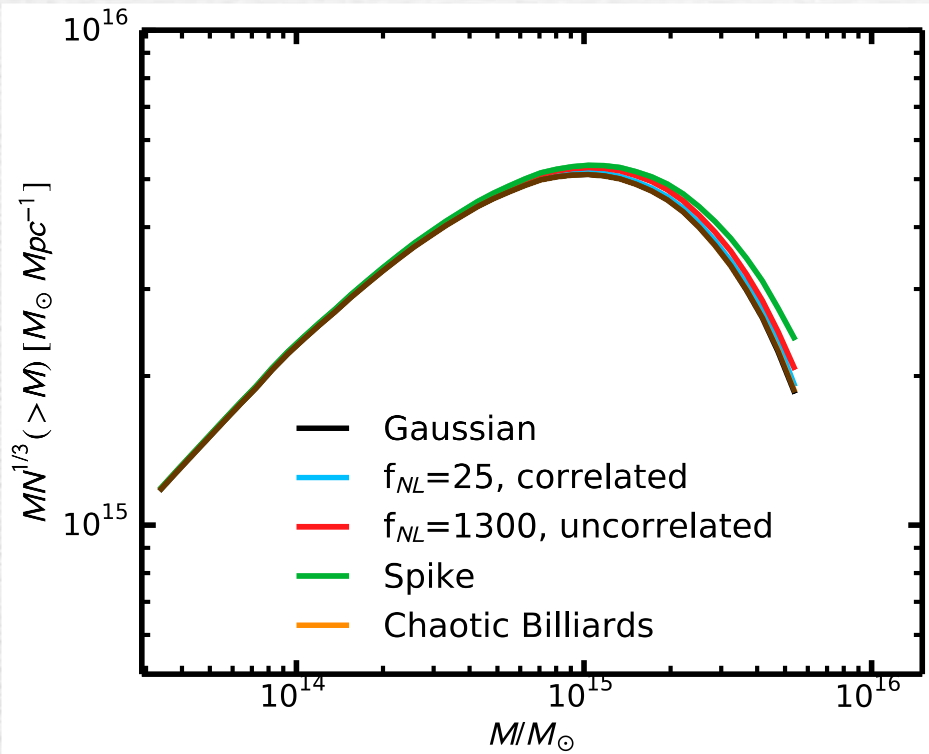


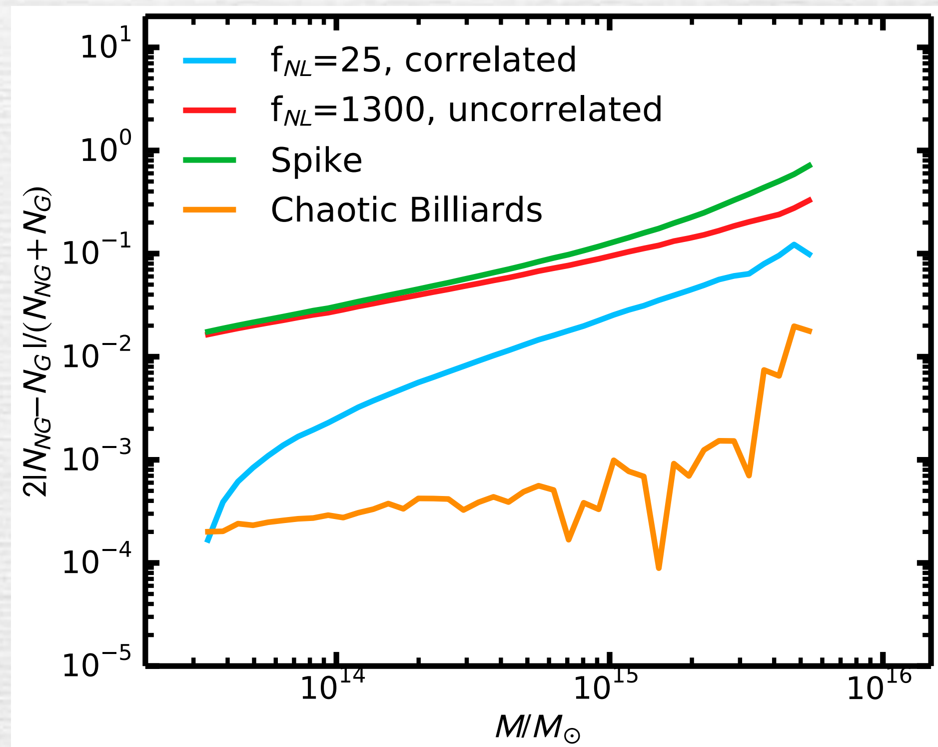
Halo Mass Function is weakly affected for intermittent cases

Intermittent non-Gaussianity

$$\zeta(x) = F_{NL}(\chi(x))$$

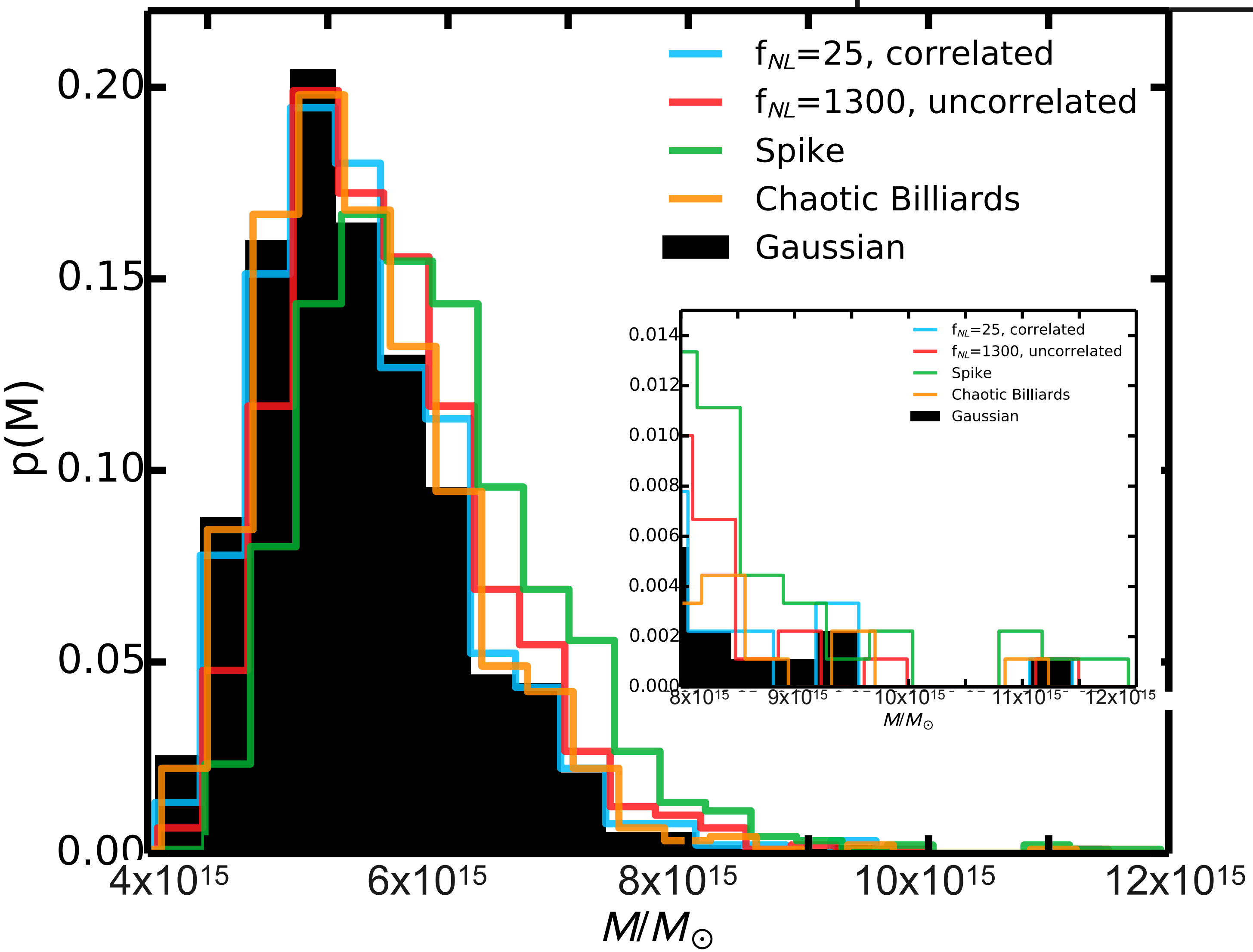
Peak Patch Sims: 2048 Mpc box, 1024^3 cells
900 realizations, ~3 mins each on 64 cores





Single Largest Halo Statistics Indeterminate

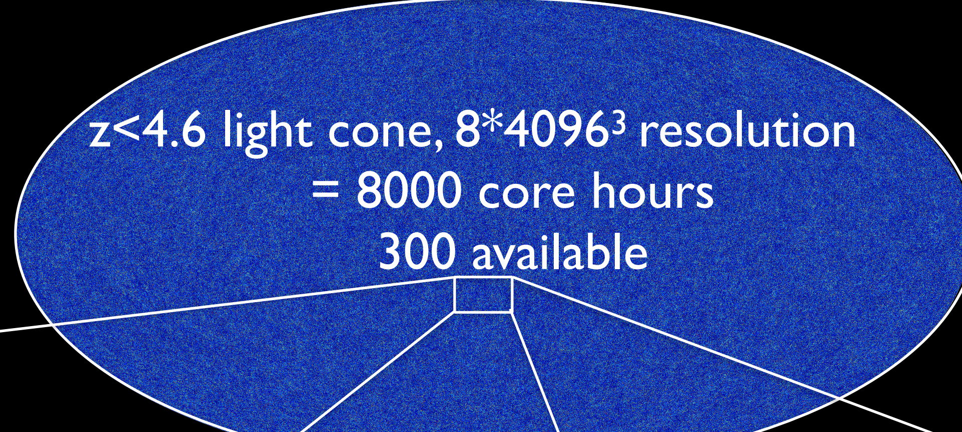
Intermittent non-Gaussianity

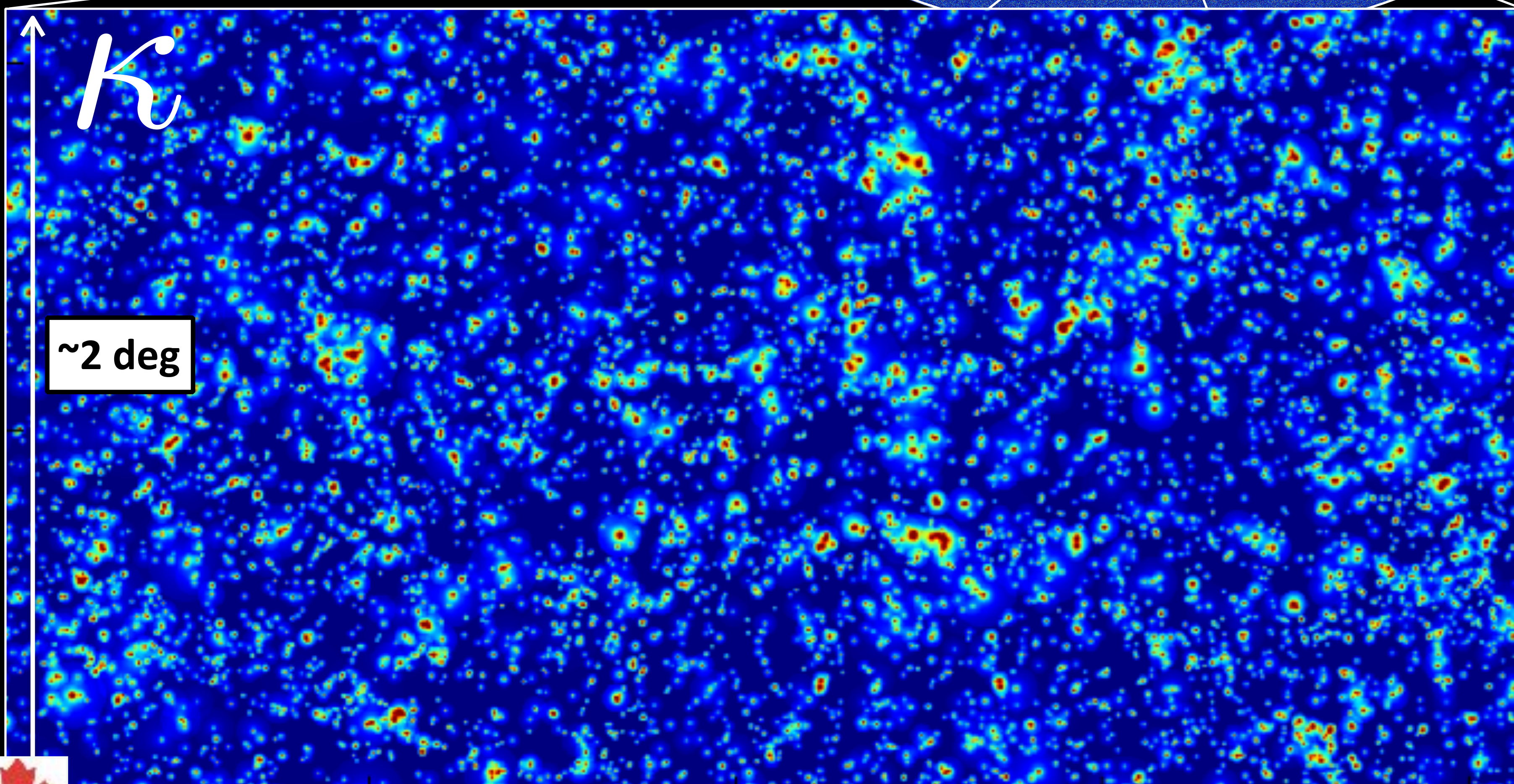


Combining LPT and Peak Patches “good enough” for lensing?

CMB

“Paint on” NFW + 2LPT Field
= Lensing Convergence Map



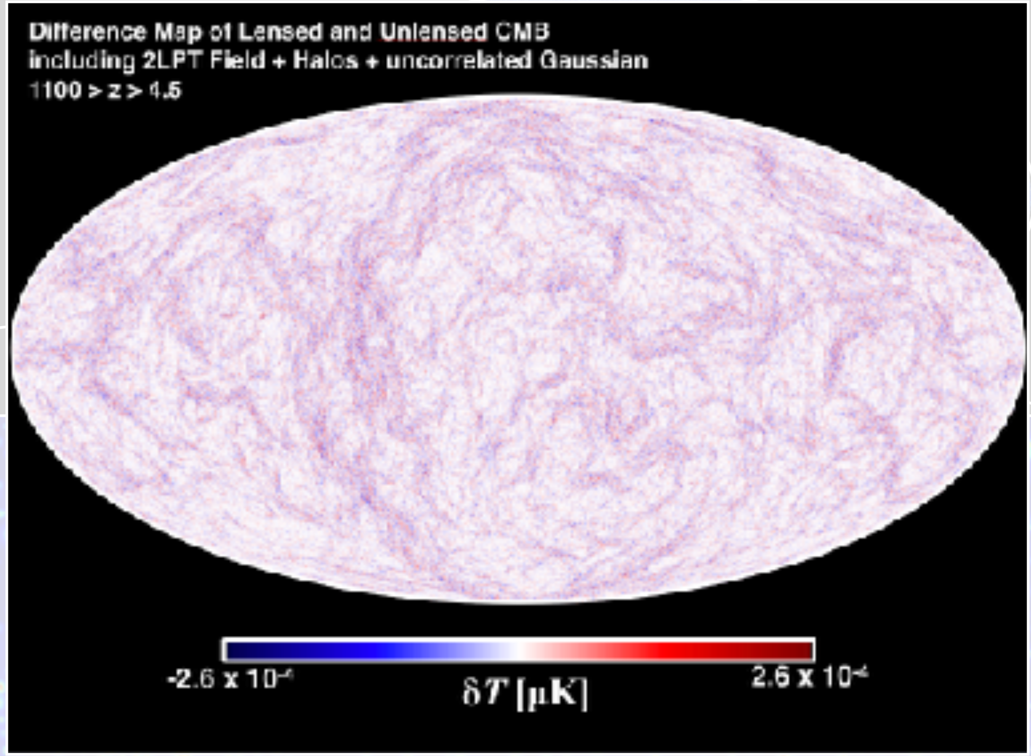


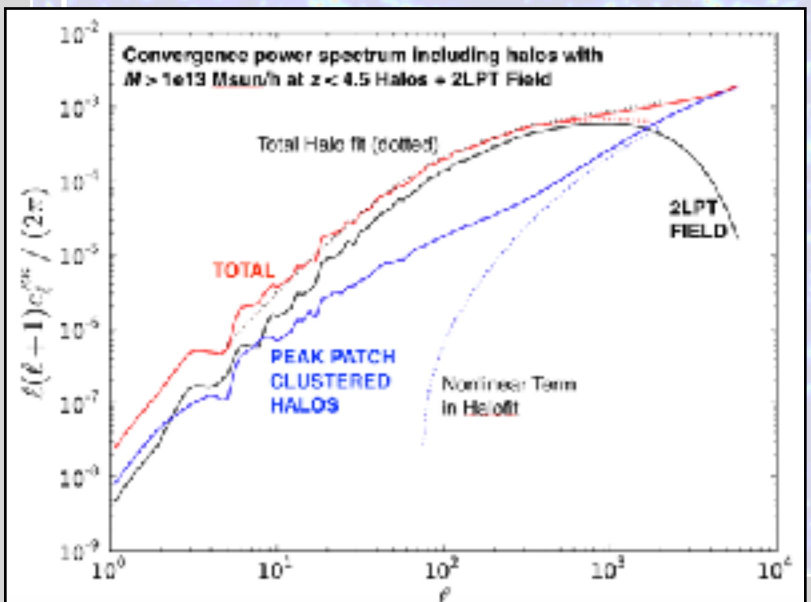
Alvarez, Bond, Stein, van Engelen, Pham

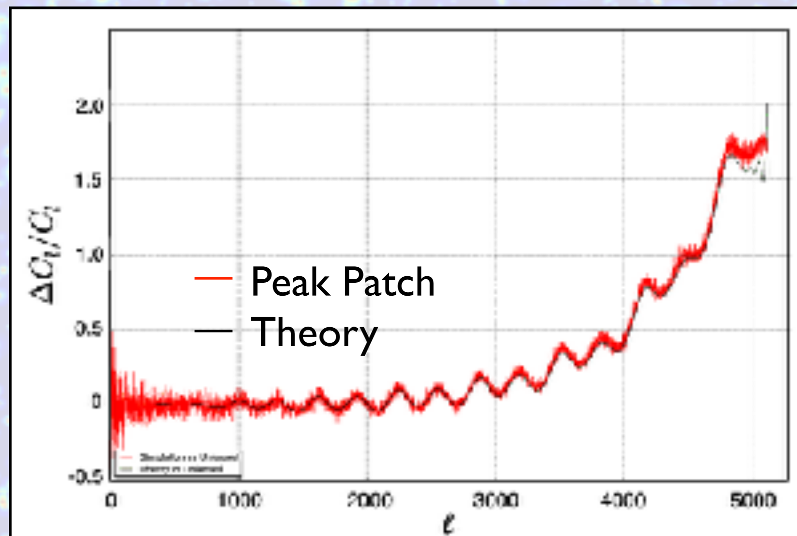
Combining LPT and
Peak Patches
“good enough” for lensing?

CMB

Modified Lenspix to read in our non-Gaussian Kappa maps







Alvarez, Bond, Stein, van Engelen, Pham

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end

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end

end

end

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