Testing **Inflation** *with the* **CMB: Beyond the Standard Model** *of Cosmology*

Dick Bond, CITA & CIFAR @ gpe@60

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

TOPOGRAPHY of the universe & our Hubble patch bit of it *in one (Bondian) slide*

parameter space = spacetime-space + field-space

(aka superspace = gravity dof + all else) *supergravity, superstrings*

$V_{eff}(|\phi|, angle_1, \ldots, angle_{n-1})$ … $d\phi_a K_{ab}(\phi) d\phi_b$ … $M_P^2(\phi, {}^{(4)}R)$ … *fermions =>*

Standard Model of Particle Physics SMpp

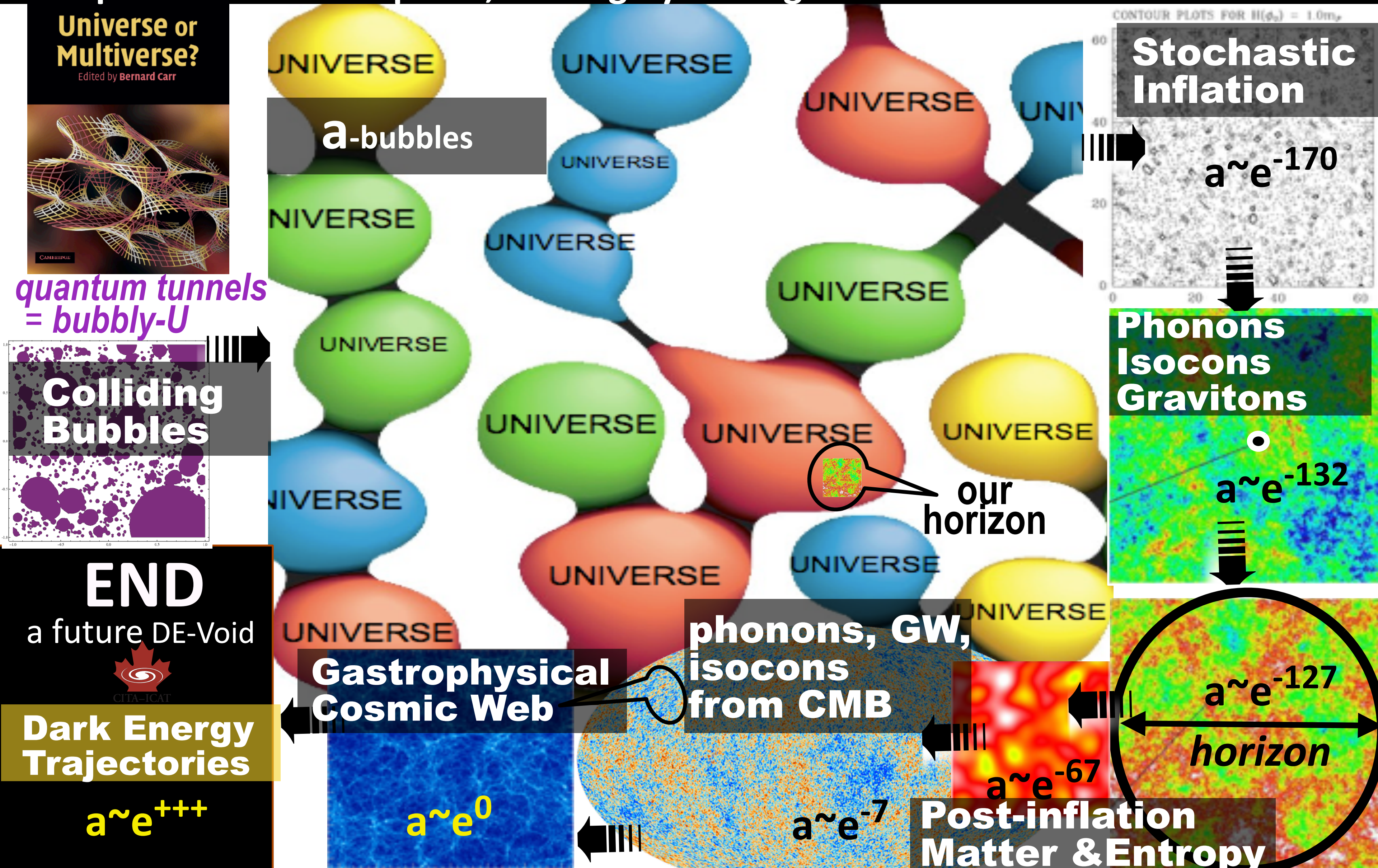
LHC goal BeyondSMpp, we search within the anomalous for the sub-dominant

CMB+LSS => Standard Model of Cosmology SMc=tilted ΛCDM, nearly scale invariant

Planck etal goal BSMc, we search within the anomalous for the sub-dominant

SuperWeb of ultra-Ultra Large Scale Structure of the Universe

a highly strained & stressed state in the universe at large *(very, very)*, randomly simple in our Hubble patch, and highly entangled in the small to medium scale



Bond & Efstathiou 80-15 what did we know (& do) when we began in ~80, cosmologically speaking?

80s Berkeley, 82-83 Cambridge, 81-85 Stanford, 84 Santa Barbara ITP, ..
90s, .. 00s, 10s

the great dragon of quantum gravity breathed out the "initial conditions"
BSMpp - a Grand Unified Theory quest
a particle desert => SMpp dof +

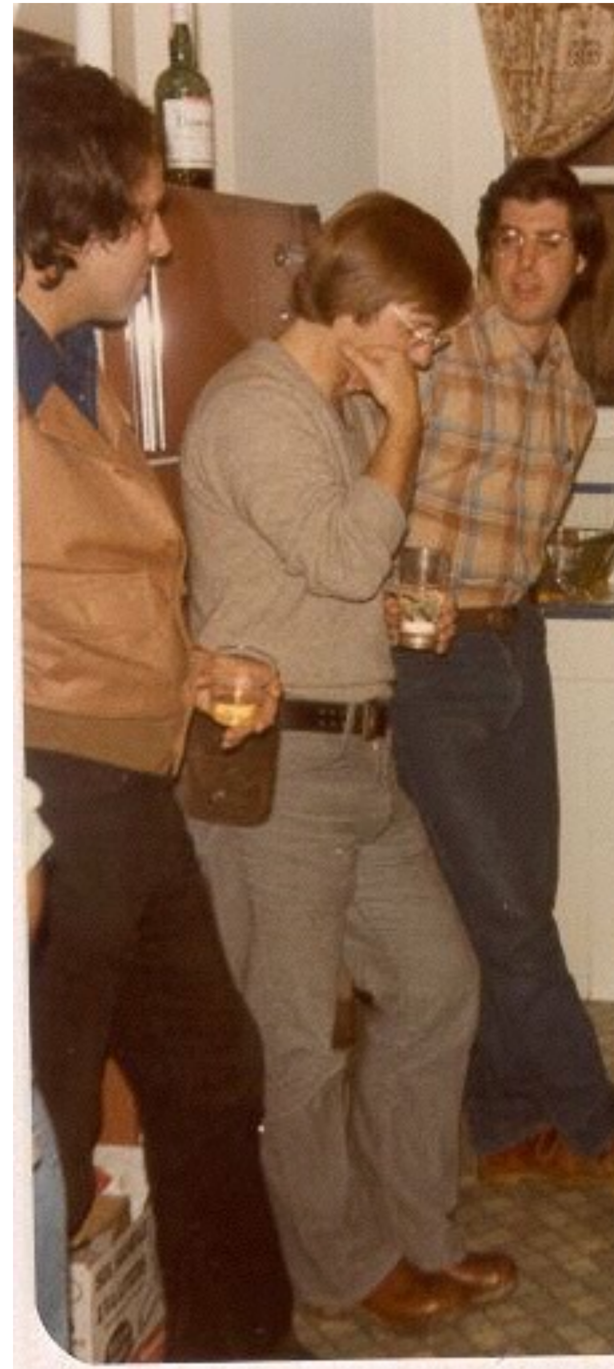
Begelman
Bond &
Brodie

invite you to a

Booze &
Bop
Bash

on Saturday .. December 1980

Byob
wise &
there



COSMIC PARAMETERS THEN e.g.,

BBE1987 vary *x* in *x*CDM

Xtra power anomalies cf. sCDM => vary k_{Heq}, $k_{hot=m\nu}$, mode, k_{ς}, B/DM

for xCDM, predict CMB (6deg, 5min); LSS cluster-cluster, cluster-galaxy, bulk flows, σ_8: redshift of "galaxy formation"

14 Gyr, Ω_Λ=0.8, H0=75, b~c, 50mK cf 30mK cobe, σ_8~0.72

***x*= s /H0 / Λ / Open/ is /is+ad/ h-c/ h+/ b/ b / Λ+b / Op+b /t /BSI /BSI2**

Predictions for Models

Parameter	OBS	CDM	C40	VAC/C	OP/C	ISO/C	ISO/AD	HOT	HC	C + B	B + C	BCV	BCO	CDM + dec	$(CDM + X)_1$ ($k_*^{-1} = 300$)	$(CDM + X)_2$ ($k_*^{-1} = 200$)
Ω, Ω_B, H_0	...	1, 0.1, 50	1, 0.1, 40	1, 0.03, 50	0.2, 0.03, 50	1, 0.1, 50	1, 0.1, 50	1, 0.1, 50	1, 0.1, 50	1, 0.2, 40	1, 0.5, 50	1, 0.1, 75	0.2, 0.1, 75	1, 1, 50	1, 0.1, 40	1, 0.1, 50
$\Omega_x(\Omega_\nu), \Omega_{vac}$	...	0.9, 0	0.9, 0	0.17, 0.8	0.17, 0	0.9, 0	0.9, 0	(0.9), 0	0.5(0.4), 0	0.8, 0	0.5, 0	0.1, 0.8	0.1, 0	1, 0	0.9, 0	0.9, 0
b	...	1.7	1.8	1	1	1.7	1.7	0.53	1.7	1.8	1.7	1	1	1.7	1.8	1.7
t_0 (by)	GC: 14–22 NC: 13–26	13	17	22	17	13	13	13	13	17	13	14	11	13	17	13

radically broken scale invariance =>

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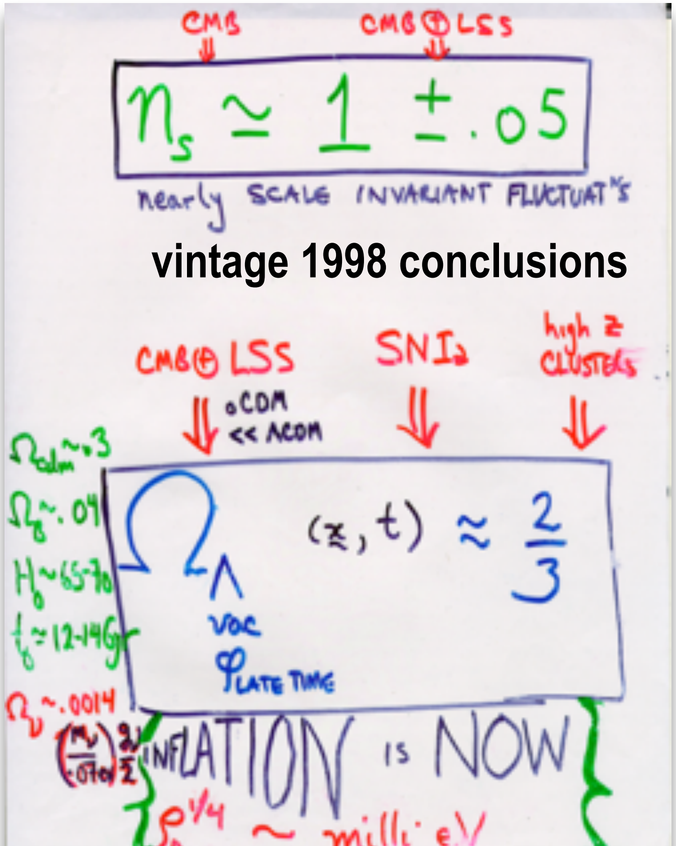
Ω, Ω_B, H_0	...	1, 0.1, 50	1, 0.1, 40	1, 0.03, 50	0.2, 0.03, 50	1, 0.1, 50	1, 0.1, 50	1, 0.1, 50	1, 0.1, 50	1, 0.2, 40	1, 0.5, 50	1, 0.1, 75	0.2, 0.1, 75	1, 1, 50	1, 0.1, 40	1, 0.1, 50
$\Omega_X(\Omega_\nu)$, Ω_{vac}	...	0.9, 0	0.9, 0	0.17, 0.8	0.17, 0	0.9, 0	0.9, 0	(0.9), 0	0.5(0.4), 0	0.8, 0	0.5, 0	0.1, 0.8	0.1, 0	1, 0	0.9, 0	0.9, 0
b	...	1.7	1.8	1	1	1.7	1.7	0.53	1.7	1.8	1.7	1	1	1.7	1.8	1.7
t_0 (by)	GC: 14–22 NC: 13–26	13	17	22	17	13	13	13	13	17	13	14	11	13	17	13
$\sigma_0(R_g = 0.35)$	...	2.9	2.4	2.7	2.7	1.6	2.5	2.0	1.3	2.2	1.9	2.4	2.4	6.8	2.2	2.7
z_g	...	3.7	2.9	2.3	4.0	1.3	3.1	1	1.1	2.5	2.0	1.3	2.0	13	2.6	3.4
$\sigma_0(R_{cl} = 5)$	...	0.42	0.39	0.75	0.75	0.43	0.42	1.4	0.44	0.40	0.44	0.72	0.72	0.47	0.41	0.43
$\langle v \rangle_c$	...	3.2	3.1	3.1	3.1	3.0	3.2	3.1	2.9	3.1	3.0	2.8	2.8	2.7	3.1	3.1
$\xi_{cc}(20)$	1.5	0.15	0.26	1.7	1.7	0.70	0.35	1.1	1.0	0.49	1.3	2.2	2.2	1.8	1.0	0.85
$\xi_{cc}(25)$	1.0	0.08	0.15	1.2	1.2	0.42	0.21	0.45	0.51	031	0.93	1.7	1.7	0.92	0.83	0.68
$\xi_{cc}(30)$	0.72	0.03	0.07	0.85	0.85	0.25	0.11	0.20	0.24	0.20	0.61	1.4	1.4	0.49	0.64	0.51
$\xi_{cc}(50)$	0.29	−0.01*	−0.006*	0.24	0.24	0.02	−0.01*	−0.009*	−0.02*	0.04	0.23	0.59	0.59	0.16	0.28	0.21
$\xi_{cc}(100$	0.08	−0.002*	−0.003*	0.02	0.02	−0.003*	−0.003*	−0.003*	−0.009*	−0.007*	−0.01*	036	0.36	0.02	0.08	0.06
$\xi_{cg}(20)$	0.49	0.13	0.17	0.57	0.57	0.32	0.19	0.96	0.44	0.23	0.50	0.76	0.76	0.70	0.39	0.32
$\xi_{cg}(25)$	0.33	0.04	0.06	0.37	0.37	0.16	0.08	0.35	0.23	0.11	0.32	0.54	0.54	0.42	0.26	0.20
$\xi_{cg}(30)$	0.24	0.01	0.02	0.25	0.25	0.09	0.03	0.12	0.11	0.06	0.22	0.41	0.41	0.24	0.19	0.15
$\xi_{cg}(40)$	0.14	−0.003	0.002	0.13	0.13	0.03	0.006	−0.001	0.02	0.03	0.13	0.26	0.26	0.09	0.12	0.10
$v(R_f = 3.2)$	610 ± 50	136–654	134–650	166–797	157–752	172–824	148–709	594–2850	185–889	149–714	208–1000	232–1120	218–1050	293–1399	280–1331	241–1151
$v(R_f = 15)$	599 ± 104	71–340	76–365	134–639	126–601	114–544	86–409	387–1850	124–587	95–450	154–735	206–987	194–928	244–1170	250–1190	202–970
$v(R_f = 25)$		53–250	56–269	115–550	108–516	89–421	64–309	419–1350	91–435	71–342	119–573	186–894	174–839	215–1028	233–1106	185–882
$v(R_f = 40)$	970 ± 300	35–180	40–192	95–456	90–430	66–315	47–221	200–958	65–311	52–251	87–419	160–771	151–724	184–879	214–1016	165–787
$\Delta T/T$ (4'.5)	<25	5	6	20	70	...	...	20	...	6	8	10	80	...	...	...
$\times 10^6$ (6°)	<48	7	8	20	40	60	30	20	8	8	15	25	50	40	72 (98)	40 (64)

inflation 1997/98

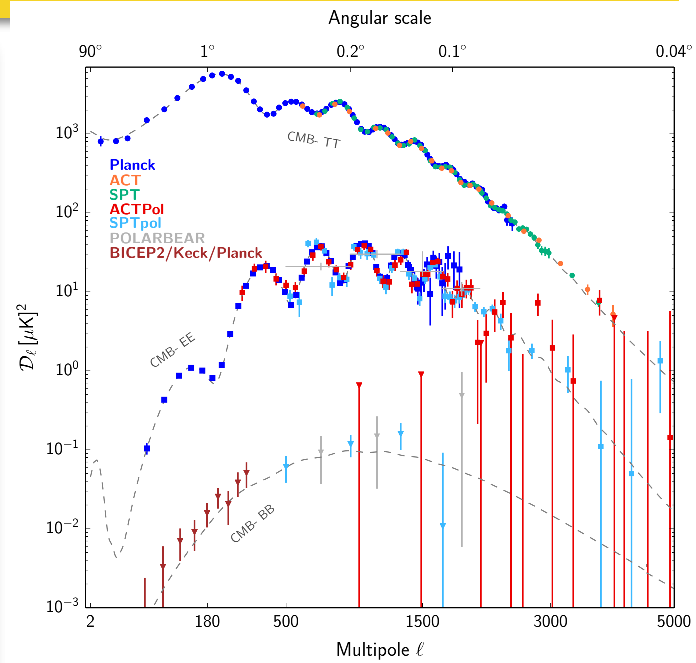
cf. inflation 2015

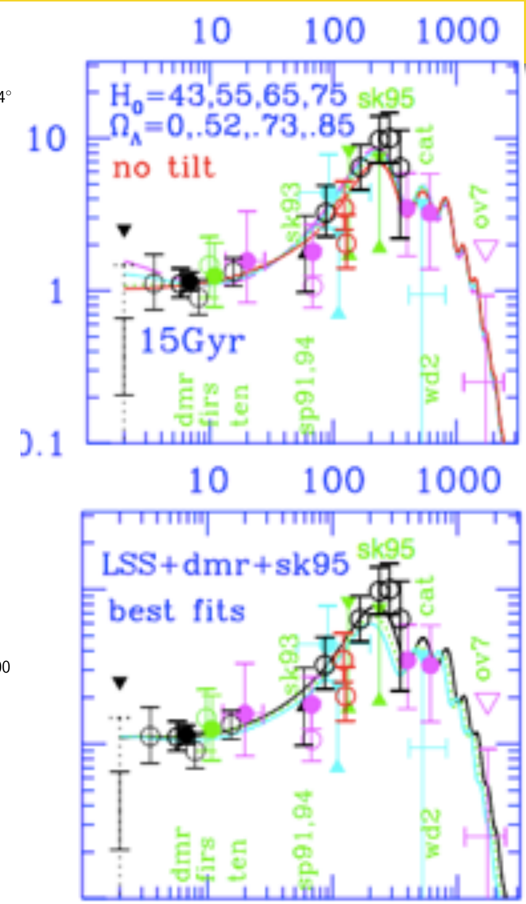
Grand Unified CMB Spectra

cf. Princeton@250 1997



vintage 1998 conclusions





n_s =0.968±0.006 P15 XIII

5.6σ from 1

B+Jaffe'96,'98

$\Omega_\Lambda \approx 2/3 \pm .07$ +LSS

$n_s =$

$.98 \pm .07$

$.96 \pm .06$

Ω_Λ =0.691±0.006 P15 XIII

w_0: -1.02± 0.08

Ω_K: .0008 ± 0.004

SMc=tilted ΛCDM

emerged via heterogeneous CMB+LSS, Boomerang, .., WMAP, Planck, .. (ACT/SPT,BICEP/KECK) *(oh, and SN1a)*

anomalies had also emerged, but "see no evil, here no evil, say no evil" aka look elsewhere - almost all LSS anomalies went away over time, but the Xtra power anomalies solved with LCDM. *CMB anomalies persist, but at low multipoles*

Testing **Inflation** *with the* **CMB: Beyond the Standard Model** *of Cosmology*

CIFAR

Dick Bond *for*

planck

2015 data release

papers: 20 Feb, > 4 Jun

Bond since 1993, Canada since 2001

executive summary of Planck 2015 (+BICEP/KECK, ACT, SPT,..) on inflation *in one (high entropy Bondian) slide*

without deconstruction

2^+ numbers encode our Hubble bit of the Super-duper Web

SIMPLICITY

at $a \sim e^{-7} \sim 1/1100$ =>

at $a \sim e^{-67-60} \sim 1/10^{30+25}$

tΛCDM

Planck2015 early U structure map

reveals primordial ***sound waves*** *in matter*

=> *learn* ***contents*** & ***structure*** *at 380000 yr,* $a \sim e^{-7}$

=> *infer the structure far far earlier* $a \sim e^{-67-60}$

$<\zeta|T,E>$ **2^{+} *numbers***

Early Universe **STRUCTURE:** ***phonons**/strain* @ $a \sim 1/10^{30+25}$

"**red**" **noise** *in* ***phonons**/strain:* 2 numbers at $a \sim e^{-67-55}$

*ln*Power$_s$~*ln*30.6x10^{-10} ±0.025

n_s =0.968±0.006 XIII *5.6σ from 1*

Tensor-to-Scalar ratio (GW) r <0.09 P15+BKP XIII, XX

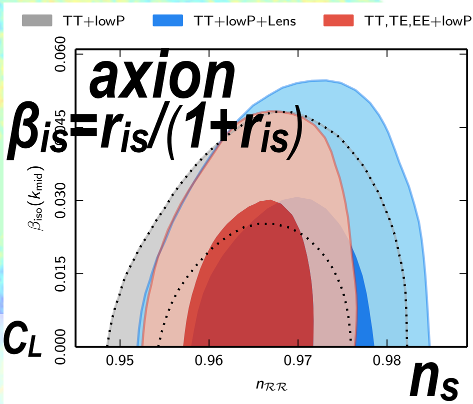
r <0.10 P15 XIII, XX r <0.13 BKP

nonG 3-pt f_{nl}: 0.8 ± 5.0 local for Φ_N

=> *f_{NL^*} =-0.52 ± 3.0 for ζ phonons/3-curvature*

< *2% role in broad-band C_L*

isocurvature



robust to adding Ω_k $N_{\nu eff}$ Y_{He} m_ν

extra data CMB lens, BAO, .., P15 EE & TE polarization

vary $n_s(k)$ *many k-bands:* uniform-n_s superb fit 0.008 to 0.3/*Mpc*

cosmic-variance-swamped $n_s(k)$ *anomaly: a 2σ dip ~.0002-.005/Mpc L~20-30*

& r <0.11 12 bands P15+BKP XX

other anomalies: hemispherical max ΔC_L^{TT} ~7% @ low L; C(>60)~0; WMAP cold spot

-35.0 +35.0

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with deconstruction: n_s & r = T/S

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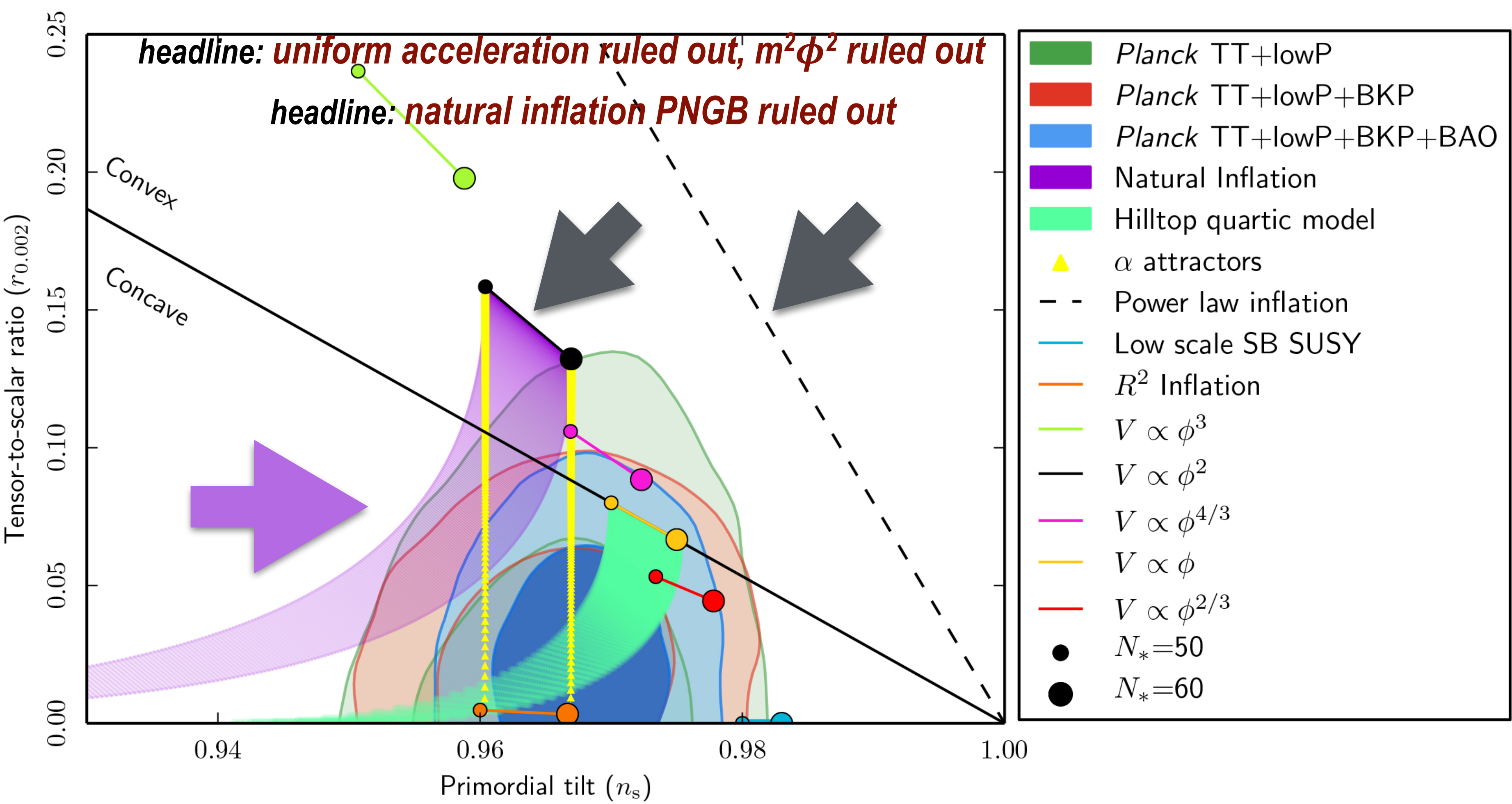

key figure in WMAPn, Planck 2013, Planck 2015, …

P15+BKP r<0.09 uniform n_s

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

near-degeneracy broken by BB

cf. **P15+TT,TE,EE loP r<0.10 uniform n_s**

cf. **P15+loP+WMAP r<0.09 uniform n_s**

WMAP9 cleaned with 353 pol data

***headline:** conformally flattened potentials OK, includes R^2 inflation & Higgs inflation, α-attractors*

executive summary of Planck 2015 (+BICEP/KECK, ACT, SPT,..) on inflation *in one (high entropy Bondian) slide*

with deconstruction: non-Gaussian 3 pt f_{nl}

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$t\Lambda CDM$

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with deconstruction: n_s robustness to extra cosmic parameters**, including **extra k-bands

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*t*ΛCDM

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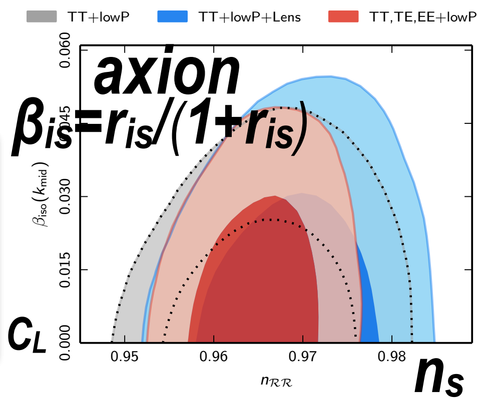

robust to adding Ω_k $N_{\nu eff}$ Y_{He} m_ν **isocurvature**

extra data CMB lens, BAO, .., *P15 EE & TE polarization*

vary $n_s(k)$ *many k-bands:* uniform-n_s superb fit 0.008 to 0.3/*Mpc*

executive summary of Planck 2015 (+BICEP/KECK, ACT, SPT,..) on inflation *in one (high entropy Bondian) slide*

with deconstruction: anomalies at low L $n_s(k)$

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<ζ|T,E>   *2⁺ numbers*

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[redacted]

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& r <0.11 12 bands P15+BKP XX

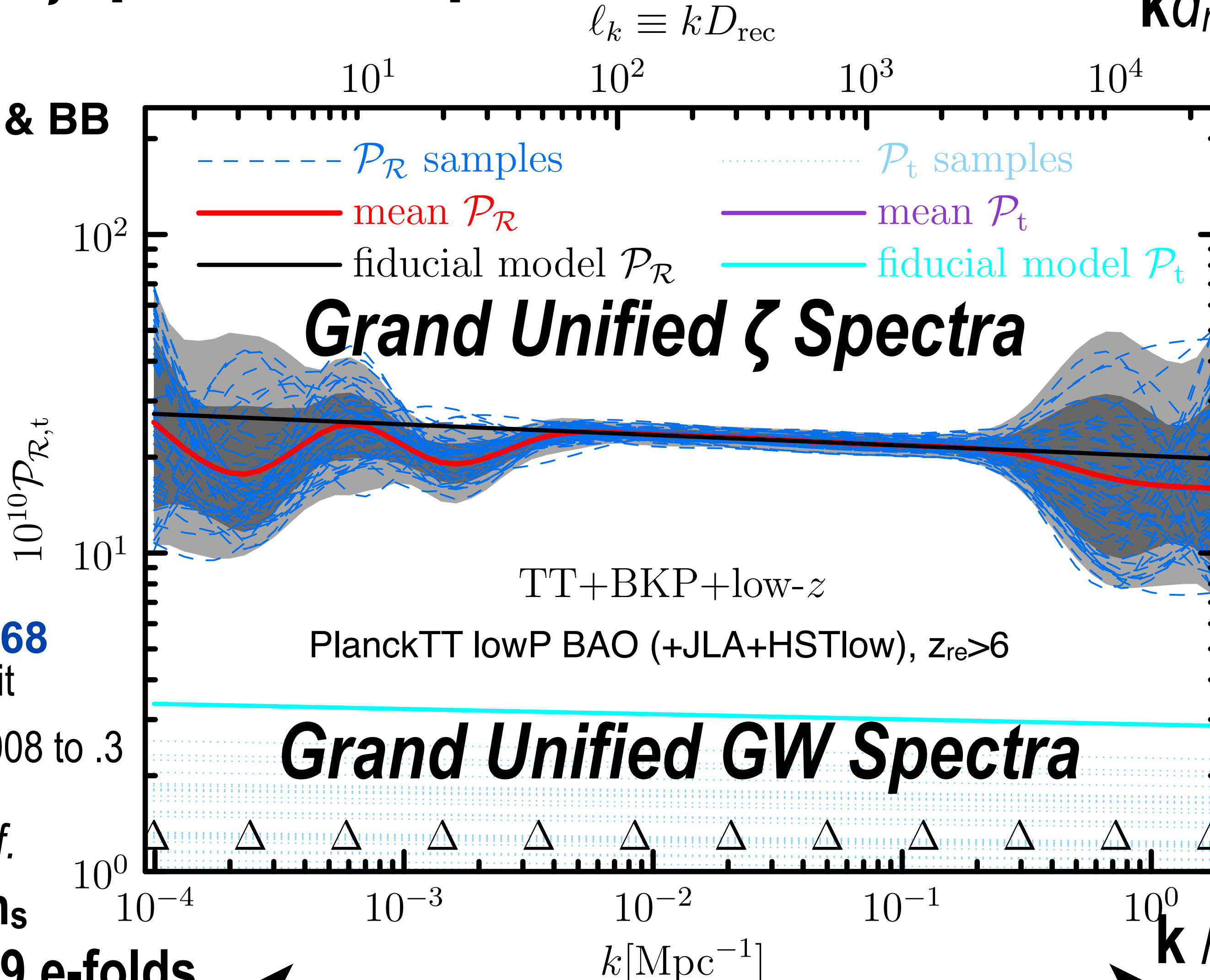
the ζ-**scape** & the **CMB**

aka mapping early U sound/phonons

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

k$d_{rec} \gtrsim L$

quadratic map,
includes lensing & BB



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

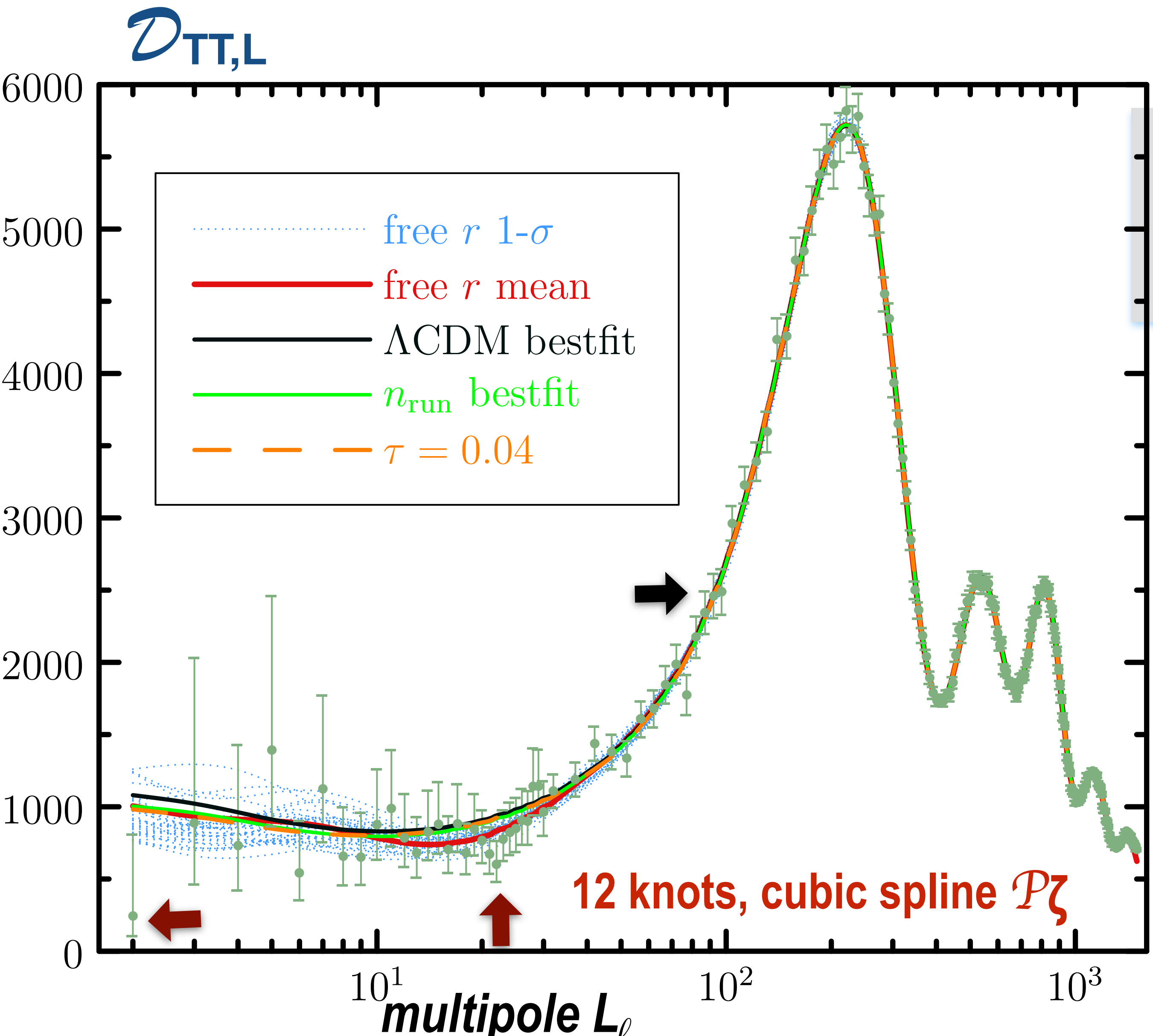
9 e-folds

EE (L>30) looks similar

=> V(ϕ)

k /Mpc

‘trajectories’ of *Planck 2015 temperature* power spectra $\mathcal{D}_{TT,L}$
cf. Planck 2015 Commander Low L spectrum + Likelihood high L $\mathcal{D}_{TT,L}$



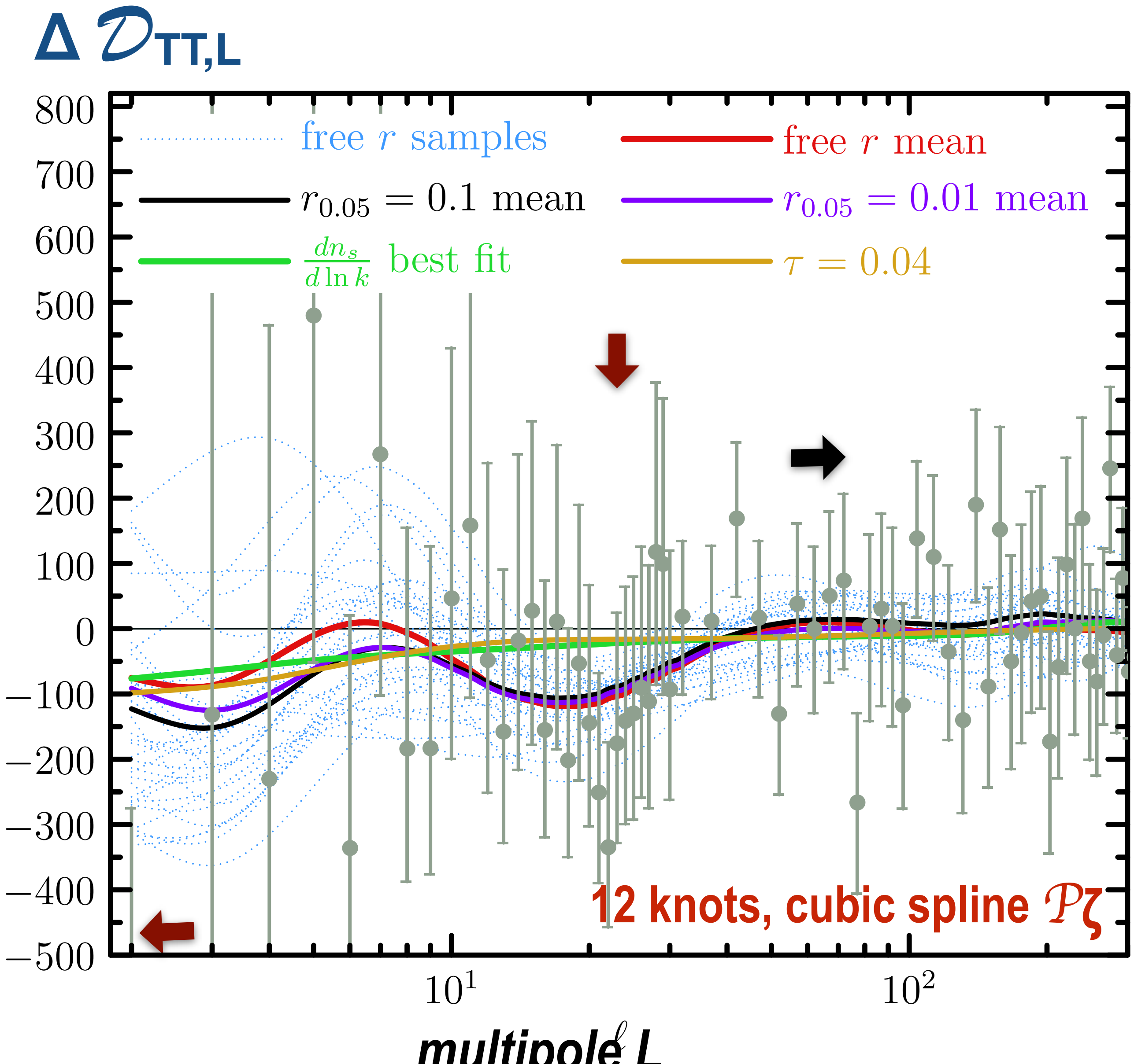
at L > 50 uniform-tilt LCDM fits $\mathcal{D}_{TT,L}$ very well

at L < 50
L ~20-30 anomaly
=> down-up-down $\mathcal{P}\zeta$ tendency
is here to stay, 2014-2022-…
alas we are sample-variance limited at low L

running of $\mathcal{P}\zeta$
-NOT wanted

‘trajectories’ of *Planck 2015 temperature* power spectra $\mathcal{D}_{TT,L}$

cf. Planck 2015 Commander Low L spectrum with Blackwell-Rao errors



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running of $\mathcal{P}_\zeta$

-NOT wanted

executive summary of Planck 2015 (+BICEP/KECK, ACT, SPT,..) on inflation *in one (high entropy Bondian) slide*

with deconstruction: hemispherical anomaly, correlation function anomaly at low L

2^{+} numbers encode our Hubble bit of the Super-duper Web

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at $a \sim e^{-7} \sim 1/1100$ =>

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tΛCDM

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=> *infer the structure far far earlier* $a \sim e^{-67-60}$

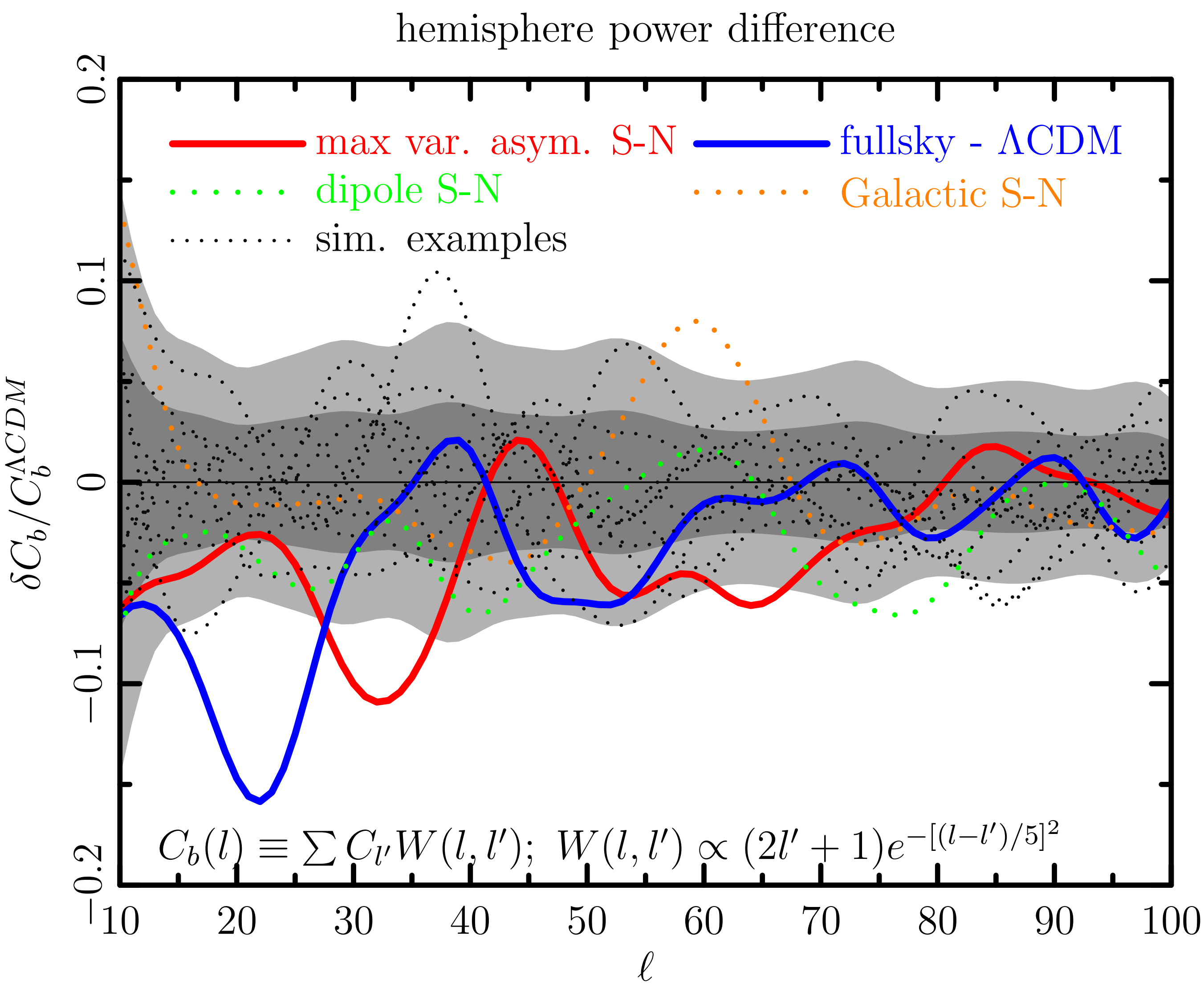
<ζ|T,E> ***2^+ numbers***

Early Universe **STRUCTURE:** *phonons/strain* @ $a \sim 1/10^{30+25}$

“**red**” **noise** *in phonons/strain:* 2 numbers at $a \sim e^{-67-55}$

other anomalies: hemispherical max ΔC_L^{TT} ~7% @ low L; C(>60)~0; WMAP cold spot

hemispherical max ΔC_L^{TT} ~7% @ low L deconstructed into L bands and compared with the full sky power dip anomaly at L~20-30 in C_L^{TT}



Will any

Anomalies in the CMB

turn into Subdominant Physics?

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

Planck 2013, 2015 cf. WMAP7,9 basic verification. polarization aspects coming, P15, only polarized stackings of various sorts

B+Huang this summer, more exploration of relations - instructive mapping, - spatial and L-bands, but nothing really compelling

Beyond the Standard Model of cosmology? SMc = *tilted*ΛCDM+r *(ζ,h_{+x})*

BSMc = SMc + primordial anomalies

~10,000,000 T/E modes = *t*ΛCDM, ≲500 modes of anomaly

vast unexplored parts of the *ζ-scape* CMB is 2D

hope to use 3D **LSS tomography f_{sky} L_{max}^2 k_{max} d_{max}**

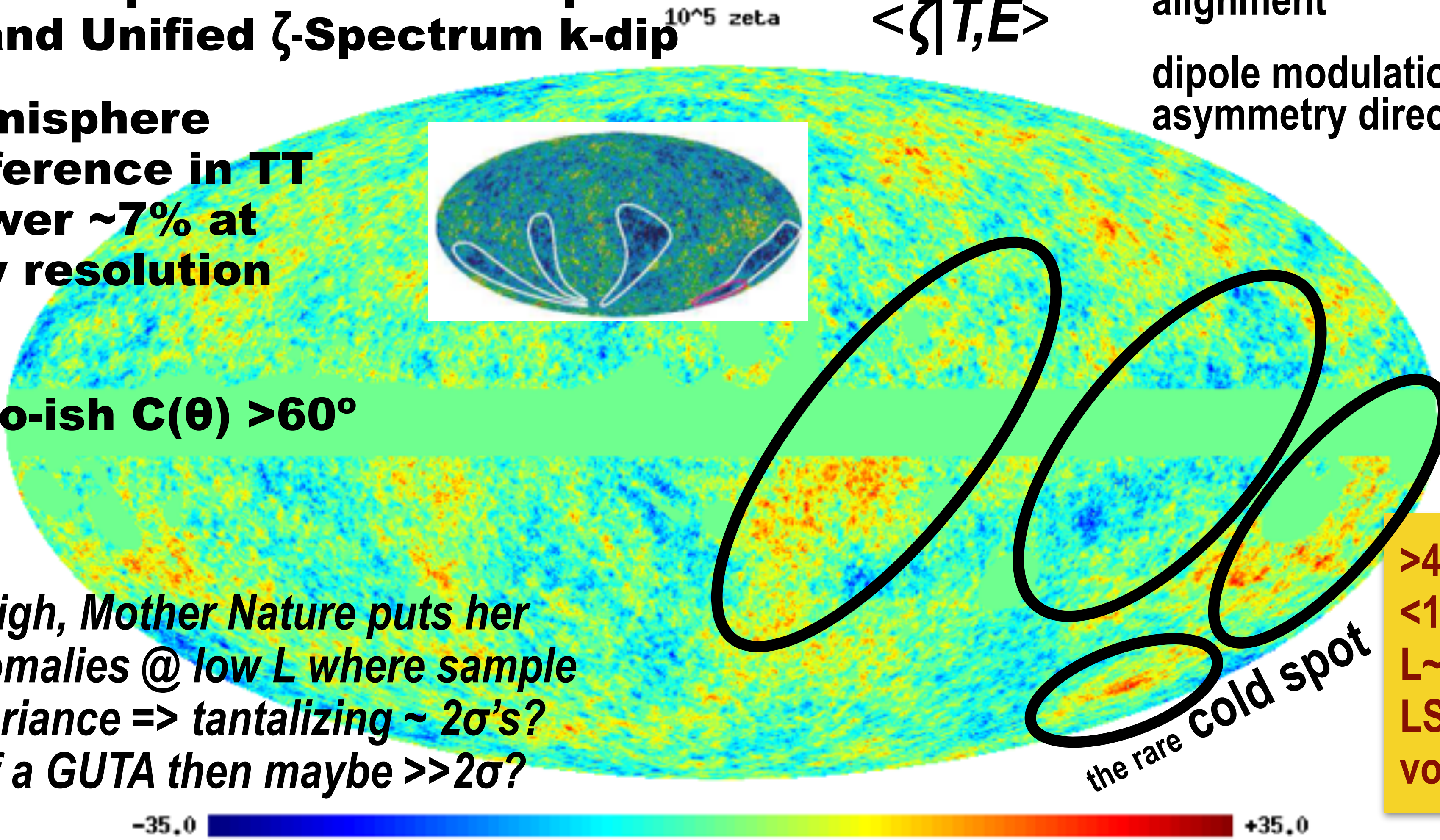
CMB TT power L~ 20-30 dip =>
Grand Unified ζ-Spectrum k-dip

<ζ|T,E>

octupole/quadrupole alignment

dipole modulation/ asymmetry direction

hemisphere difference in TT power ~7% at low resolution



zero-ish C(θ) >60°

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

the rare cold spot

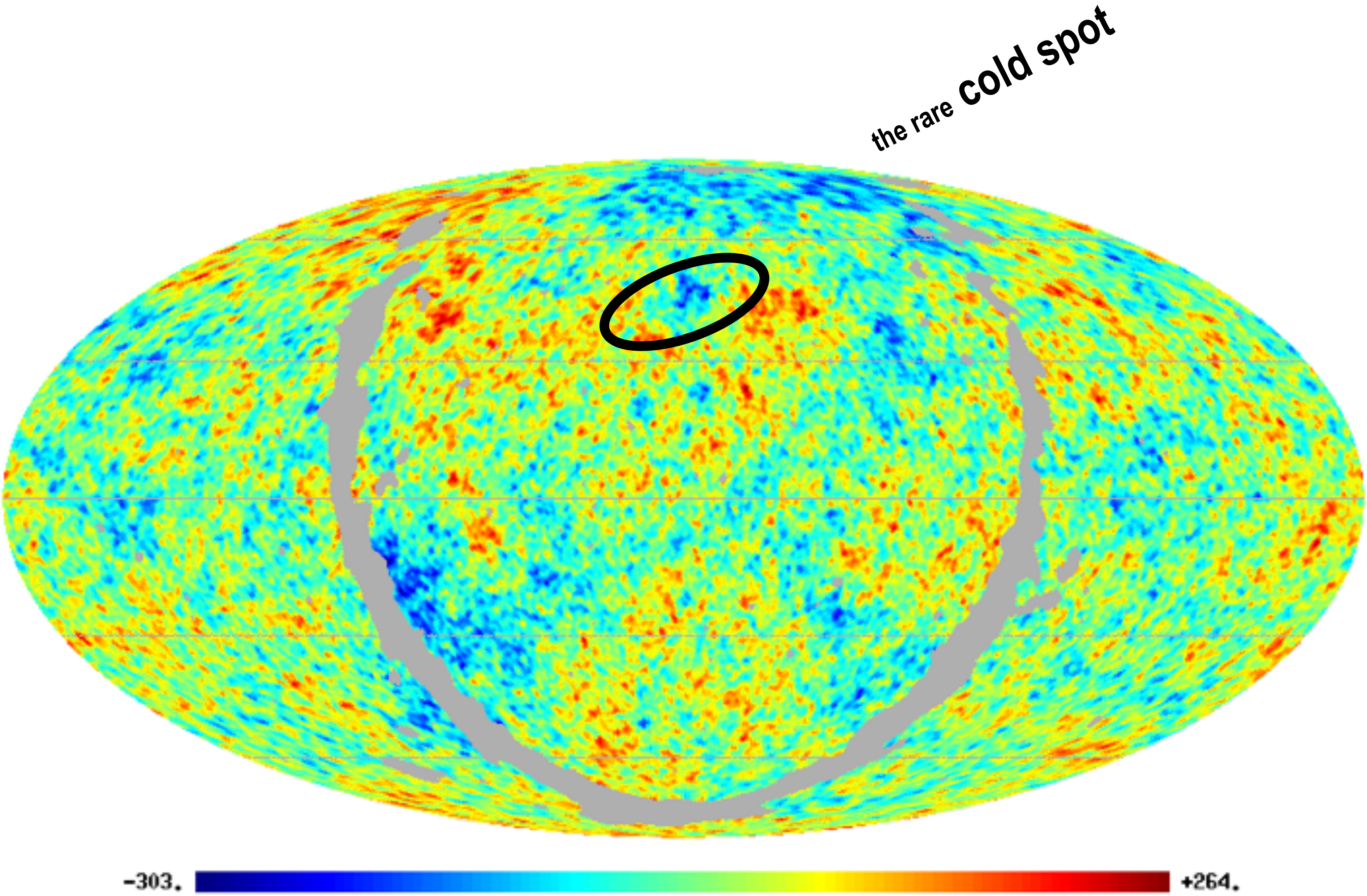
>4.5σ
<1%
L~20
LSS
void?

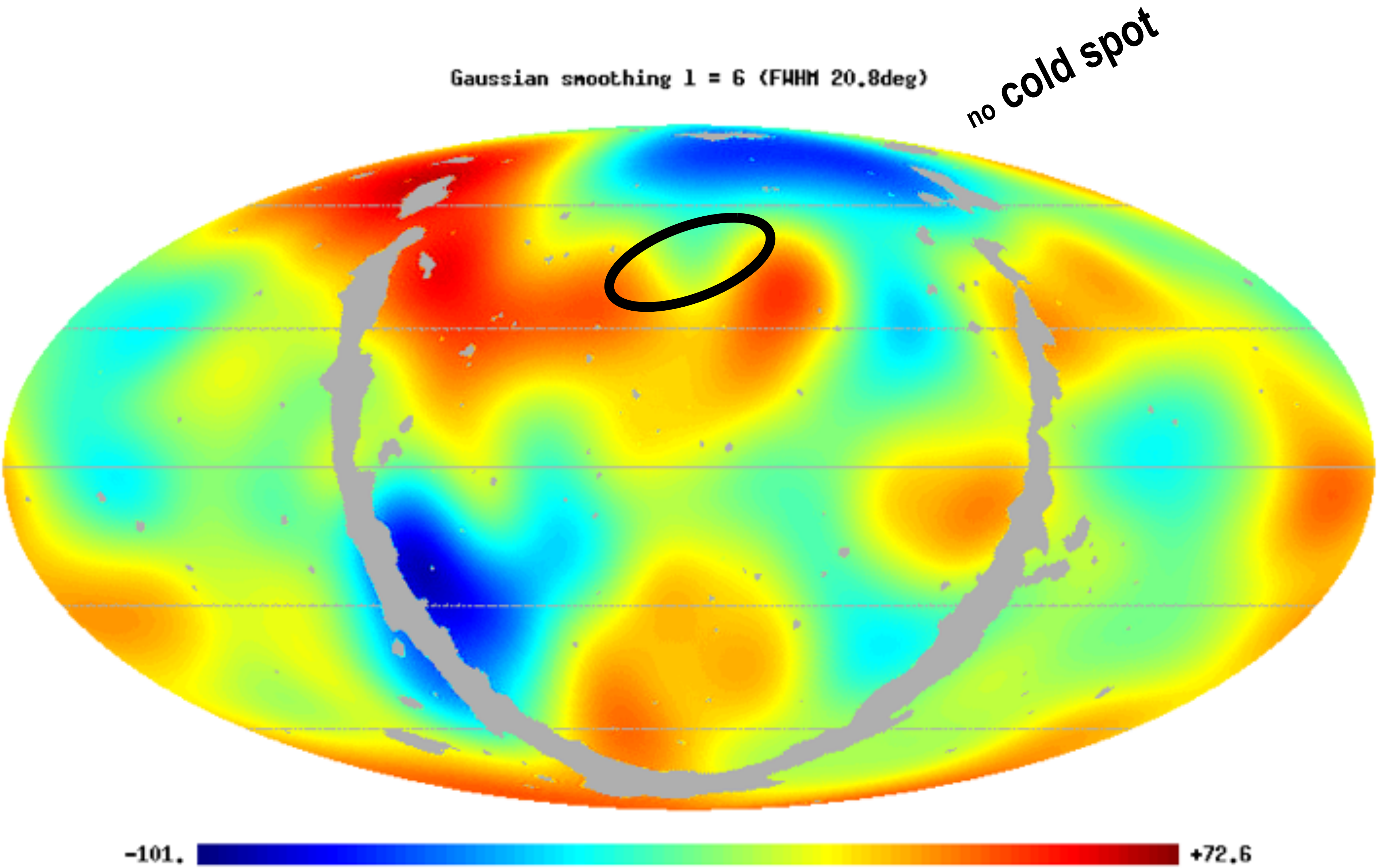
GUTA = Grand Unified Theory of Anomalies? TBD **intermittent**?

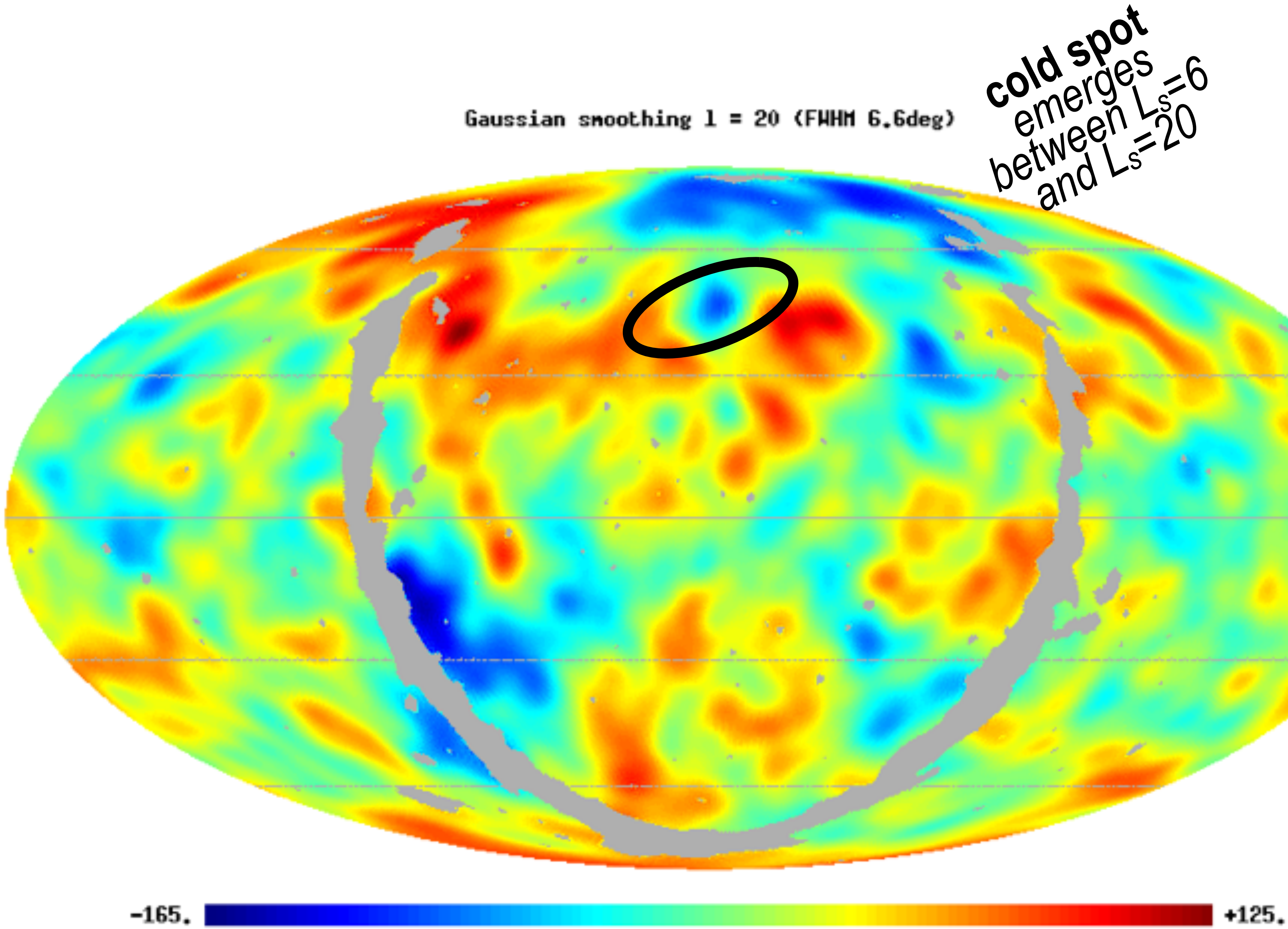
executive summary of Planck 2015 (+BICEP/KECK, ACT, SPT,..) on inflation *in one (high entropy Bondian) slide*

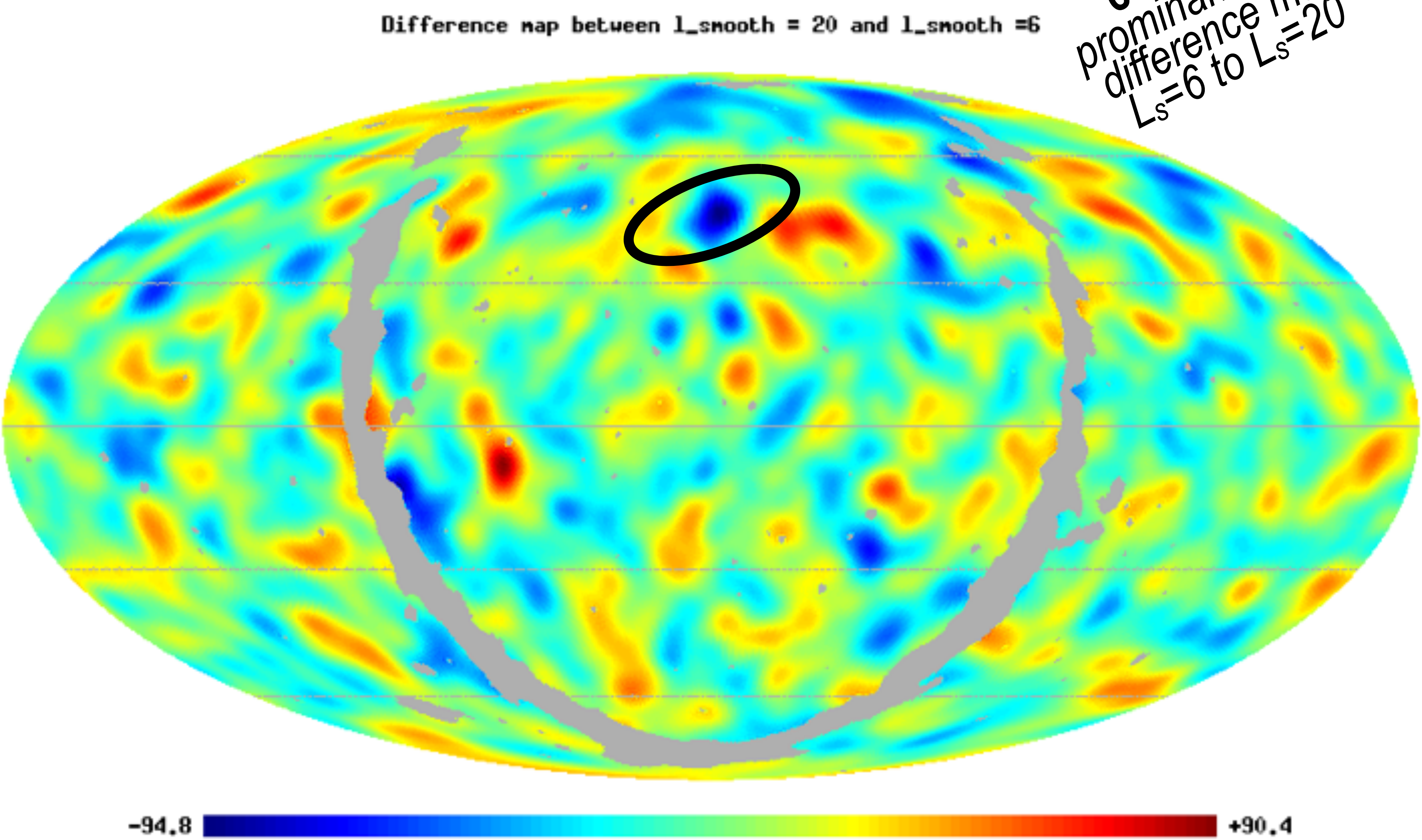
with deconstruction: WMAP cold spot anomaly

2^+ numbers encode our Hubble bit of the Super-duper Web


the rare cold spot
-303.
+264.


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

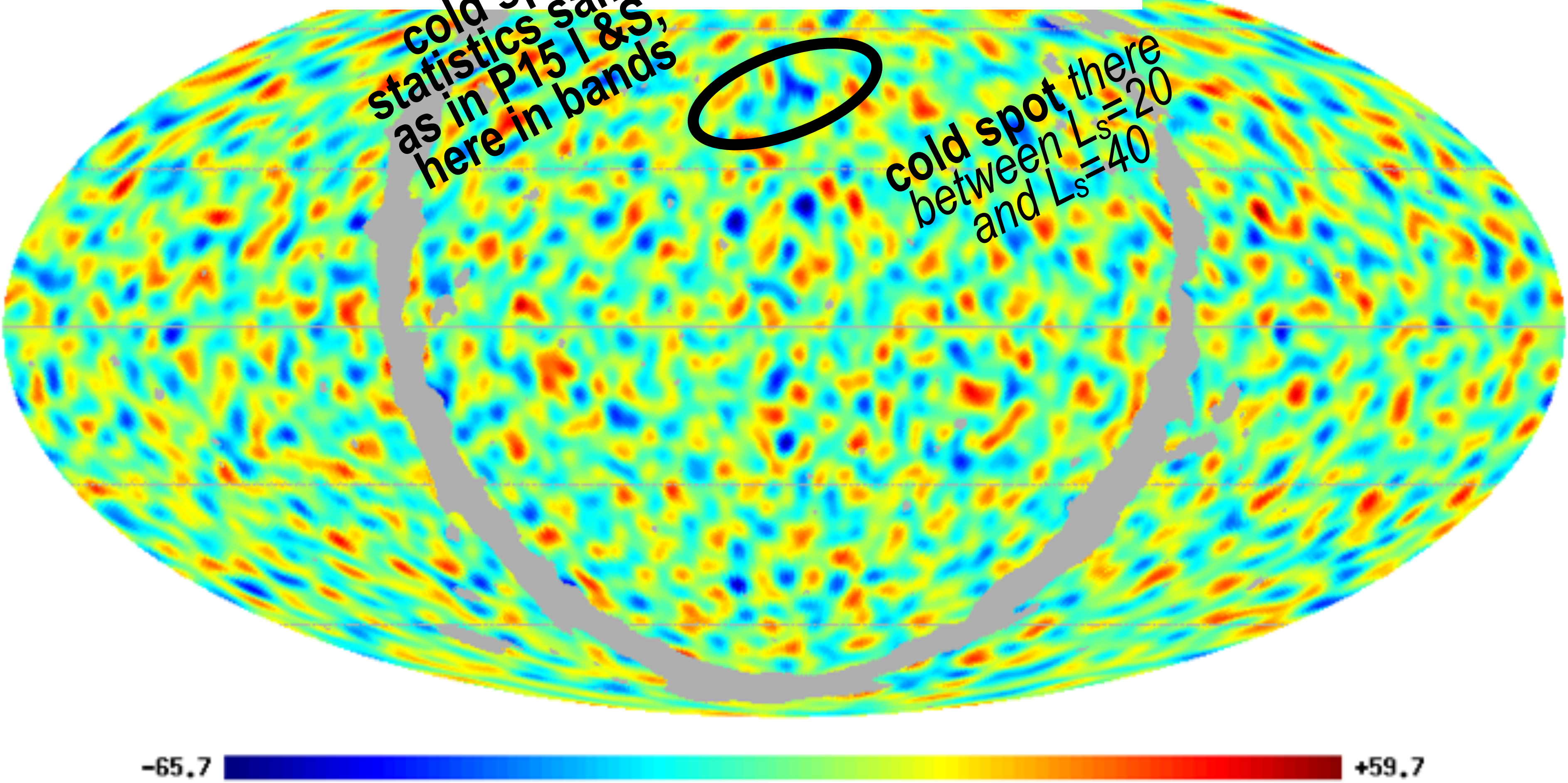
$$W(\ell) = e^{-\frac{\ell(\ell+1)}{2(l_2+1/2)^2}} - e^{-\frac{\ell(\ell+1)}{2(l_1+1/2)^2}} \; (l_2 > l_1)$$

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

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



Testing **Inflation** *with the* **CMB: Beyond the Standard Model** *of Cosmology*

Dick Bond, CITA & CIFAR @ gpe@60

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

CARTOGRAPHY of the universe & our Hubble patch bit of it

the ζ*-LAND-***scape** from the **CMB**

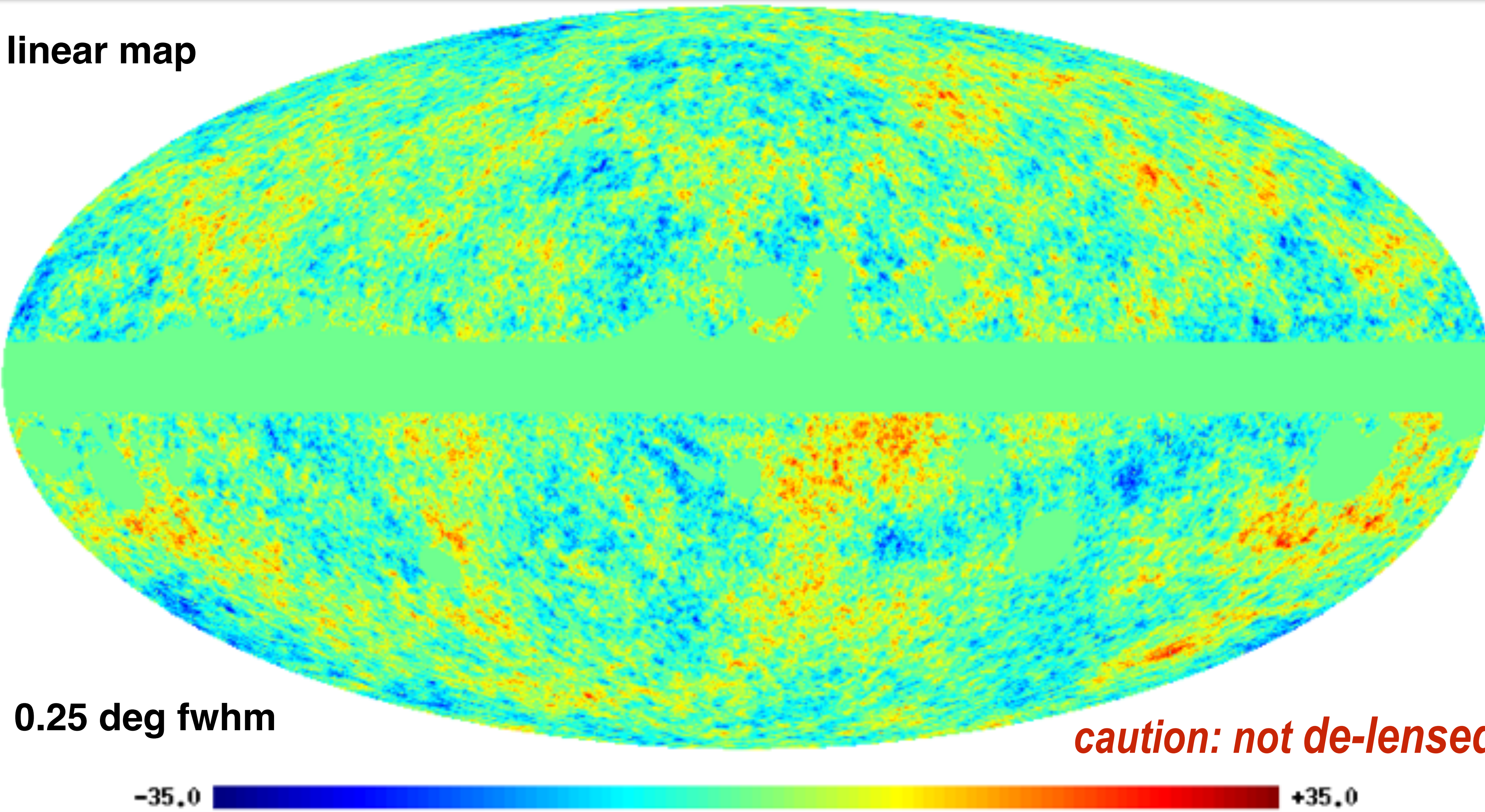
similar in philosophy to Roger Blandford's gpe@60 talk on Tuesday

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

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

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

linear map



0.25 deg fwhm

caution: not de-lensed

visibility mask

Reconstructing the Early Universe

primordial scalar curvature map of the inflation epoch

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

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

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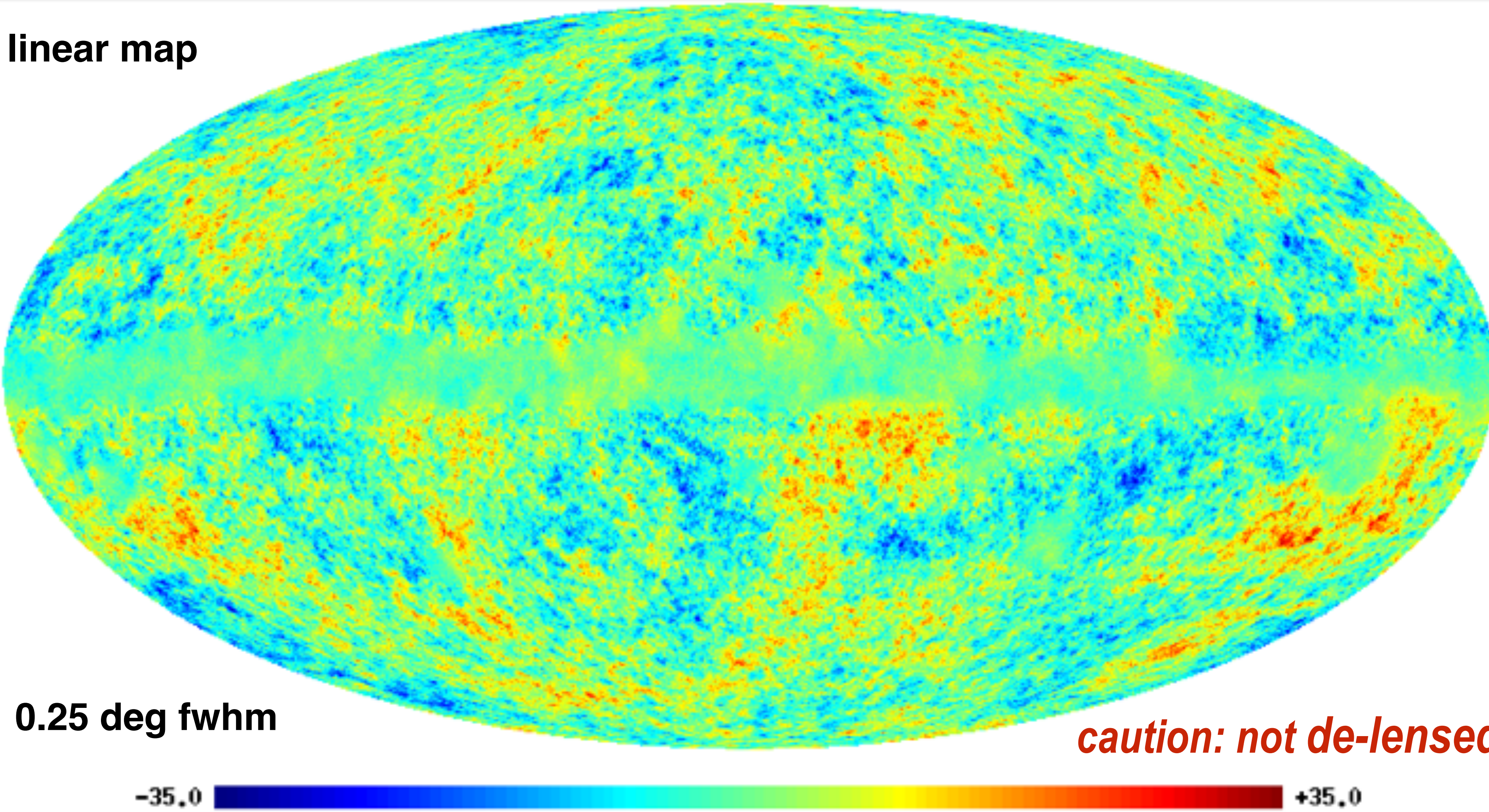

0.25 deg fwhm

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visibility mask

Reconstructing the Early Universe

SIMPLICITY

at $a \sim e^{-7} \sim 1/1100$ =>

at $a \sim e^{-67-60} \sim 1/10^{30+25}$

stacked linear map aka mean-field map

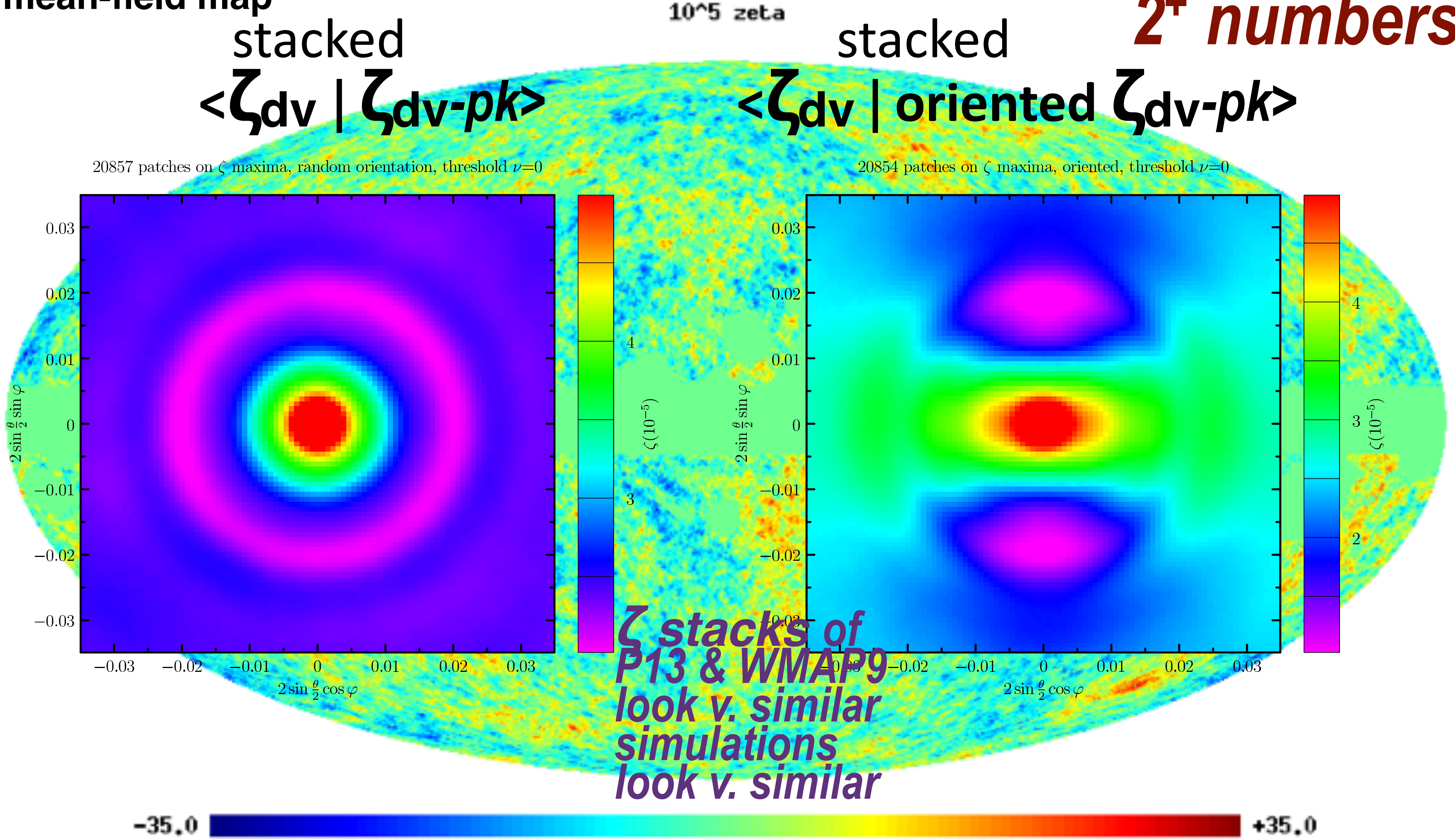
Planck2015 early U structure map

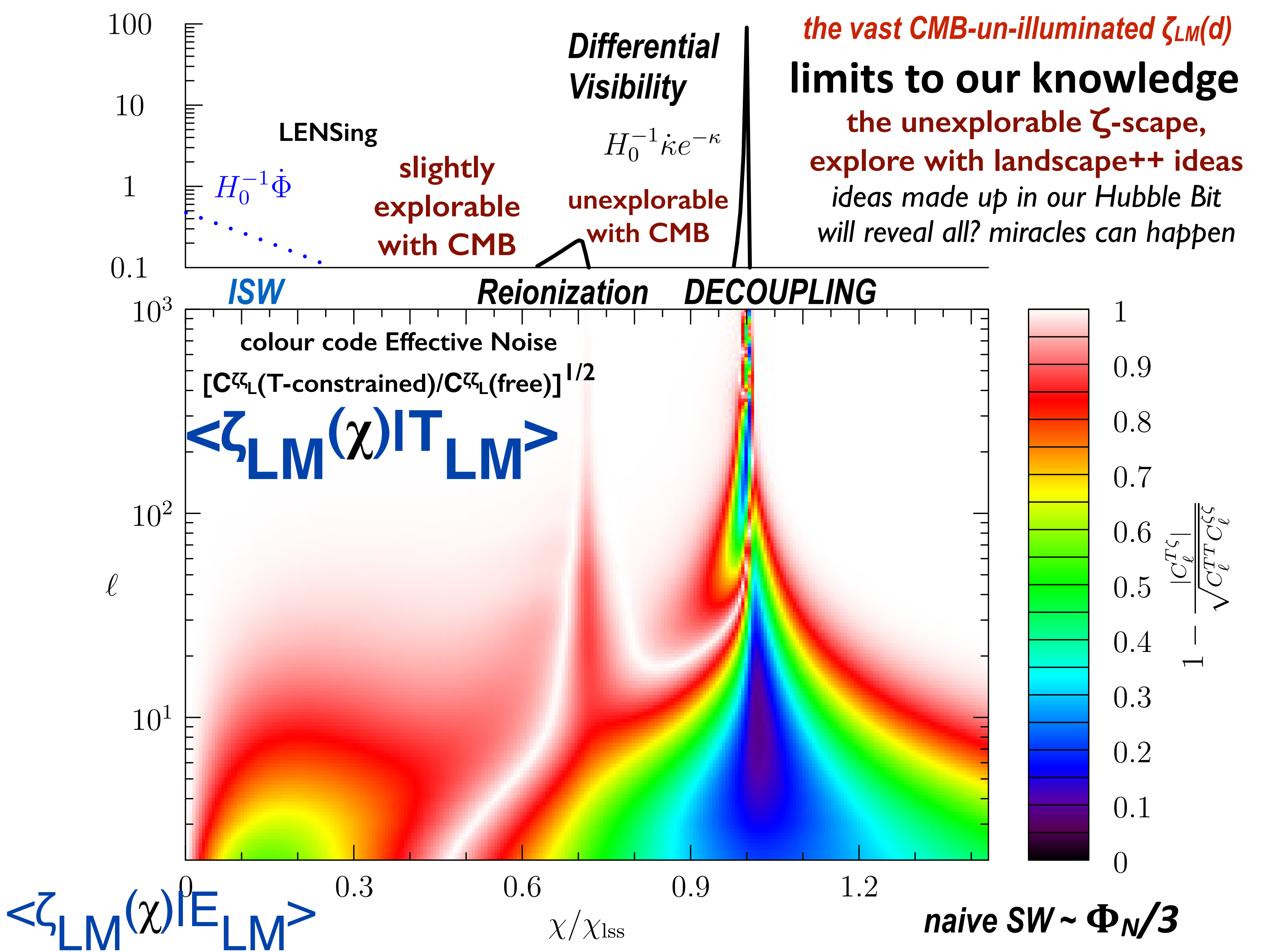
reveals ***primordial sound waves in matter***

=> *learn* ***contents*** *&* ***structure*** *at 380000 yr,* $a \sim e^{-7}$

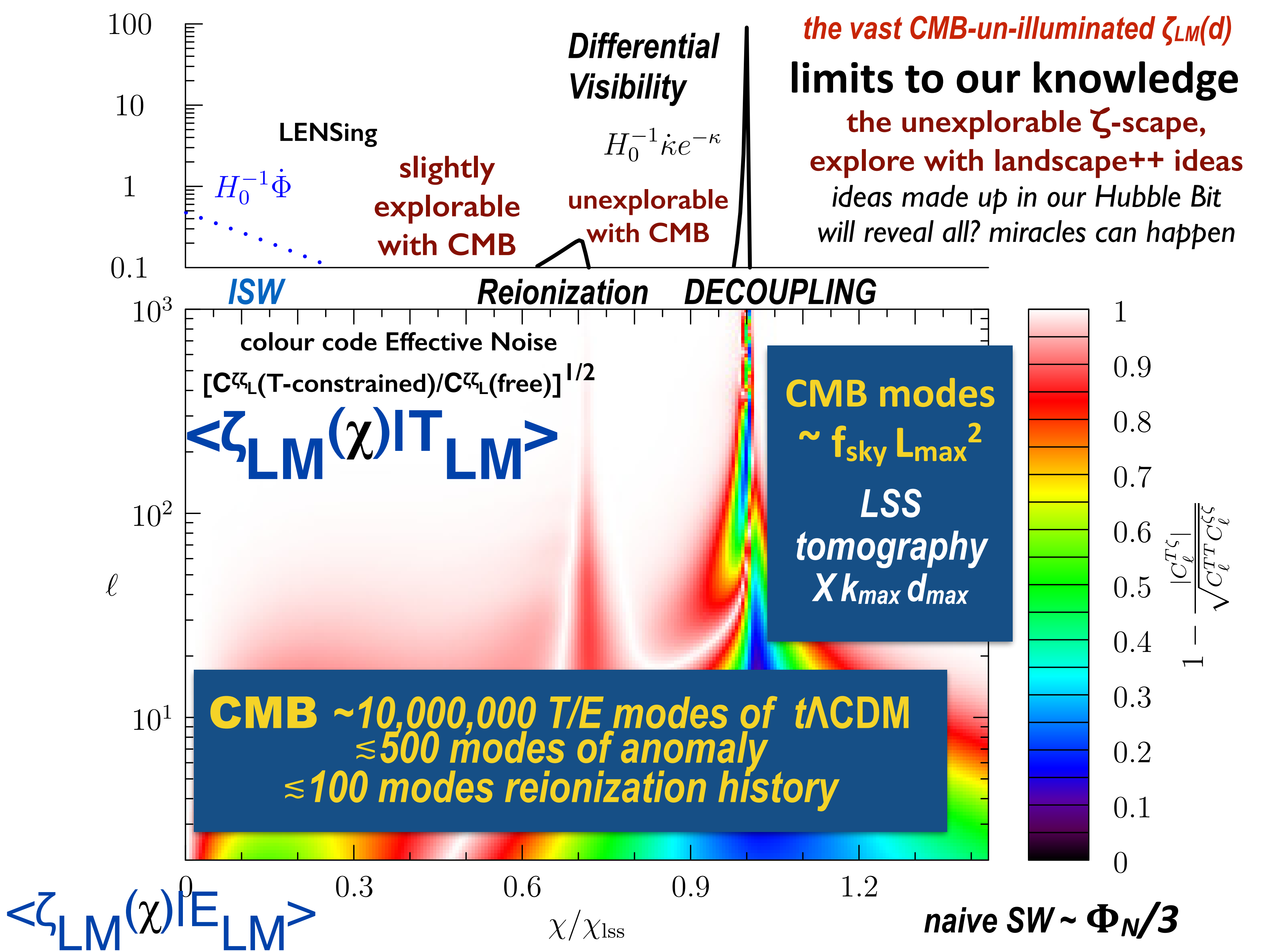
=> *infer the sound structure far far earlier* $a \sim e^{-67-60}$

2⁺ numbers





the vast CMB-un-illuminated $\zeta_{LM}(d)$
limits to our knowledge
the unexplorable ζ-scape,
explore with landscape++ ideas
ideas made up in our Hubble Bit
will reveal all? miracles can happen
Differential Visibility
$H_0^{-1}\dot{\kappa}e^{-\kappa}$
LENSing
$H_0^{-1}\dot{\Phi}$
slightly explorable with CMB
unexplorable with CMB
100
10
1
0.1
ISW
Reionization
DECOUPLING
colour code Effective Noise
$[C^{\zeta\zeta}_L(\text{T-constrained})/C^{\zeta\zeta}_L(\text{free})]^{1/2}$
$\langle\zeta_{LM}(\chi)|T_{LM}\rangle$
10^3
10^2
10^1
ℓ
0
0.3
0.6
0.9
1.2
$\chi/\chi_{\rm lss}$
$\langle\zeta_{LM}(\chi)|E_{LM}\rangle$
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
$1-\frac{|C_\ell^{T\zeta}|}{\sqrt{C_\ell^{TT}C_\ell^{\zeta\zeta}}}$
naive SW ~ $\Phi_N/3$



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$[C^{\zeta\zeta}_L(\text{T-constrained})/C^{\zeta\zeta}_L(\text{free})]^{1/2}$
$<\zeta_{LM}(\chi)|T_{LM}>$
CMB modes
$\sim f_{sky} L_{max}^2$
LSS tomography
$X\, k_{max}\, d_{max}$
CMB ~10,000,000 T/E modes of tΛCDM
≲500 modes of anomaly
≲100 modes reionization history
0
0.3
0.6
0.9
1.2
$\chi/\chi_{\rm lss}$
$<\zeta_{LM}(\chi)|E_{LM}>$
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
$1-\frac{|C_\ell^{T\zeta}|}{\sqrt{C_\ell^{TT}C_\ell^{\zeta\zeta}}}$
naive SW ~ $\Phi_N/3$

executive summary *of oft-expressed* **inflation controversies**

much ado about acceleration being unlikely (!?!)

BSM of inflation:

there exists no SM of inflation, just (1) acceleration (2) acceleration/deceleration boundary (3) a shock-in-time *aka a Little Bang aka* ***Let there be Heat /Light/ Baryons / .. SMpp*** ..

=> search for the generic, for the natural *(in the technical sense),* for the protected *multi-field* TOPOGRAPHY is natural

mother nature likes inflation now, likes Higgs "fundamental" scalars, likes collective modes & short scale modes, likes the humble in her U => wide open theory prior on ENERGYinf, r=T/S, ns (k), ..

=> avoid protaganist polemic. "unfalsifiable, not a theory, infinitely improbable, .., ns=.96-.97 since 1980, ..no r from superstring theory

executive summary *of oft-expressed* inflation controversies

Bond's own historical flow of inflation ideas, generality & signatures to search for

Beyond tilted ΛCDM & *nearly* scale-invariant slow-roll

V(|ϕ|,angle$_1$,…,angle$_{n-1}$) potential "landscape" *of Grand Unified Theories with* multiple minima*, which is ours? e.g., Gupta, **Helen Quinn @ SLAC/SU** 83/84, Linde much later;*

flows *on potential surfaces. importance of* angles & angular *cf.* radial flows

cf. axions: *Peccei-Quinn/Weinberg 77*; *as CDM example hot/warm/***cold** *- early 80s;*

isocurvature axions *eb86 ruled out!, bbks86, be87*

early "axions" in natural inflation *abffo92 - natural **shift symmetry => monodromy** as **accelerating axion, Roulette inflation: hole radii (moduli) + imaginary partners, ..***

SBB89 Designing Density Fluctuation Spectra in Inflation

multi-field topography of V_{eff} .. $d\phi_a K_{ab}(\phi) d\phi_b$ … $M_P^2(\phi, {}^{(4)}R)$ *dynamical Planck mass*

Higgs inflation, conformally-flattened potentials in Einstein frame, Starobinsky R^2

mountains, valleys, plateaus, .. of ς**-power** <δP_ζ | δH,δm^2_{ab},..>***, moguls, waterfalls,***
δm^2<=0 "tachyonic instabilites", non-Gaussianity via bifurcating trajectories

ρ(ϕ_b,π_b,*ln*a) =>***coarse-grained k<Ha Hamiltonian-density*** **attractor** ρ(ϕ_b)=3$M_P^2H^2$

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

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

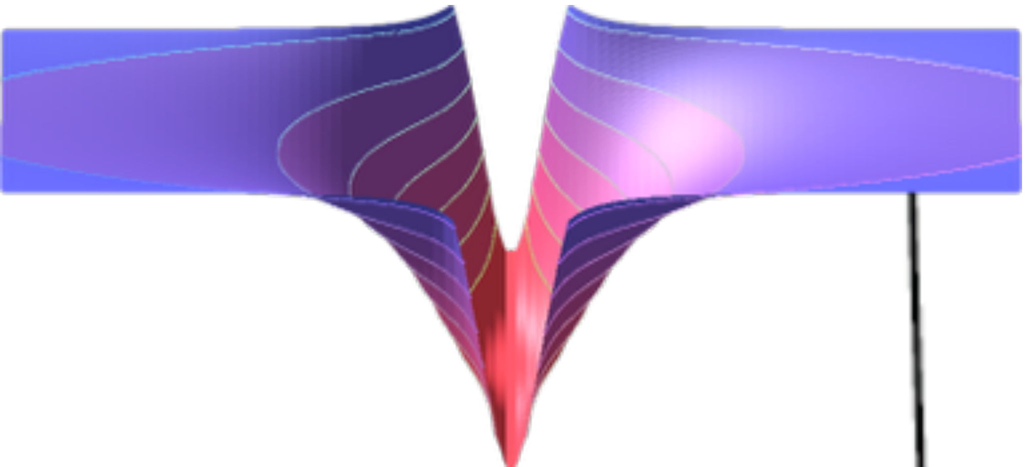
isocurvature directions ⊥ flow: basins, saddles, watersheds, valley-to-valley tunnels, ..

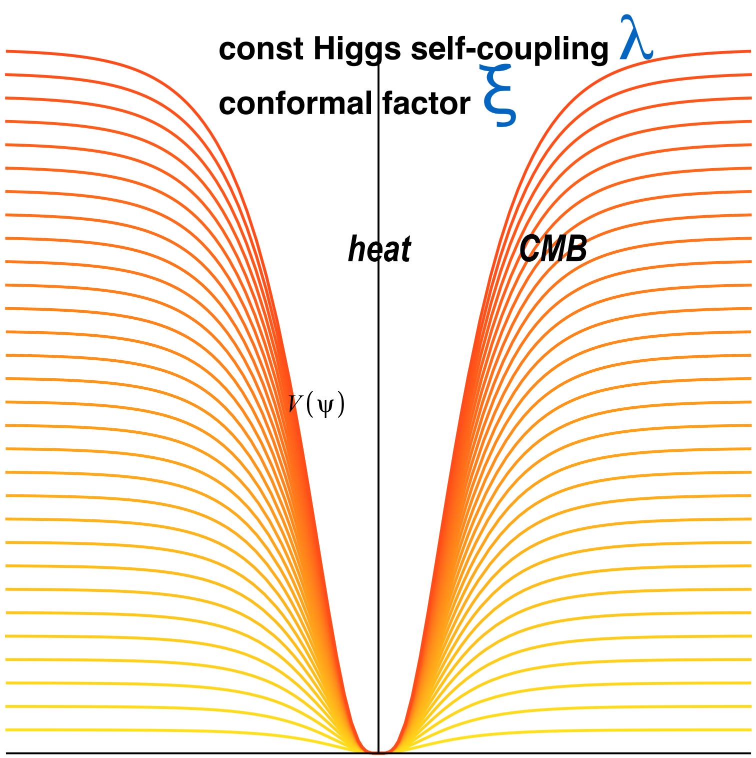
reduced action (Hamilton's Principal function) ~ H ~ ρ$^{1/2}$

stochastic kicks **δϕ_b** ***along the attractor & off (δπ_b damps) = δζ_{NL} entropy*** *fine->coarse*

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?***

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

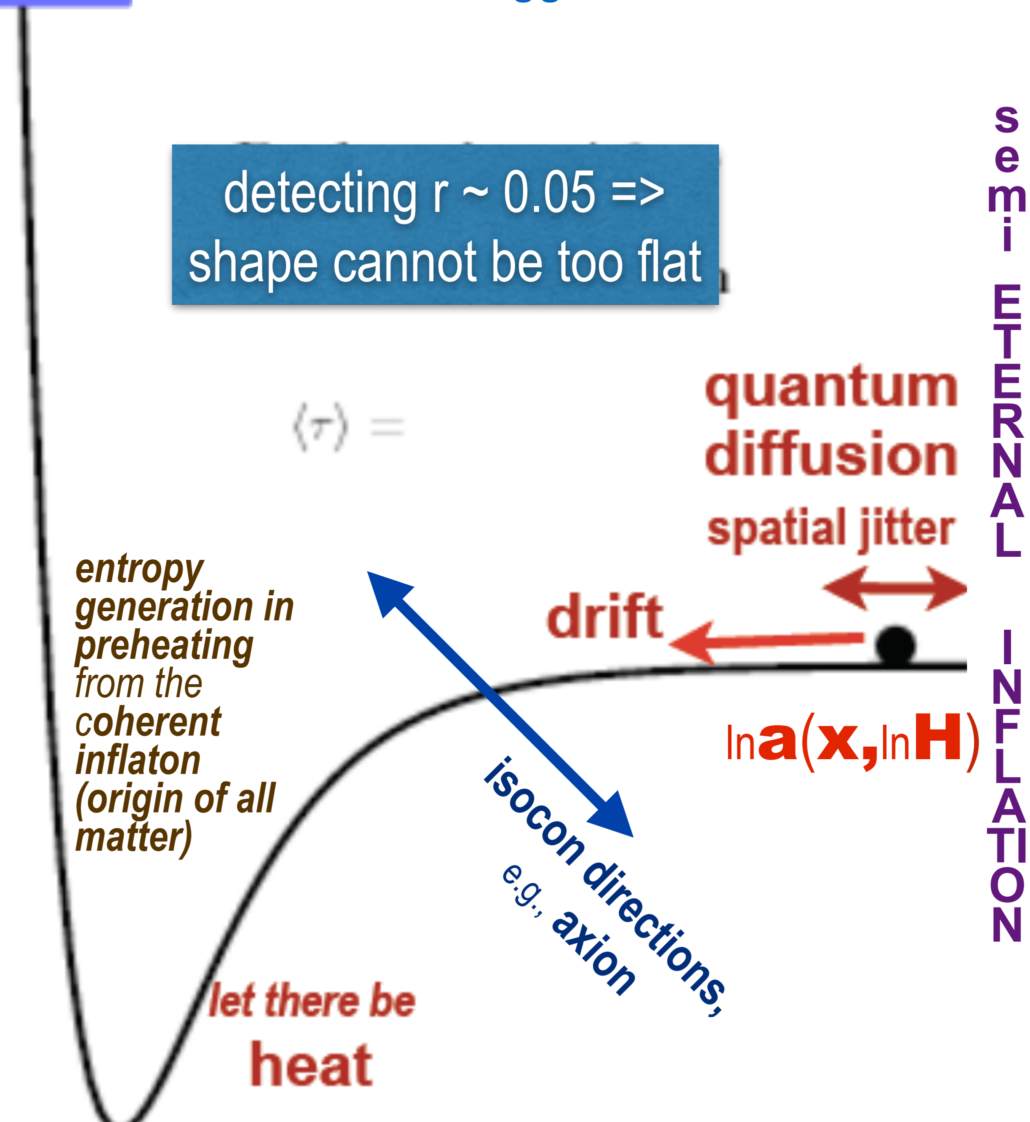




conformal potential-flattening SBB89

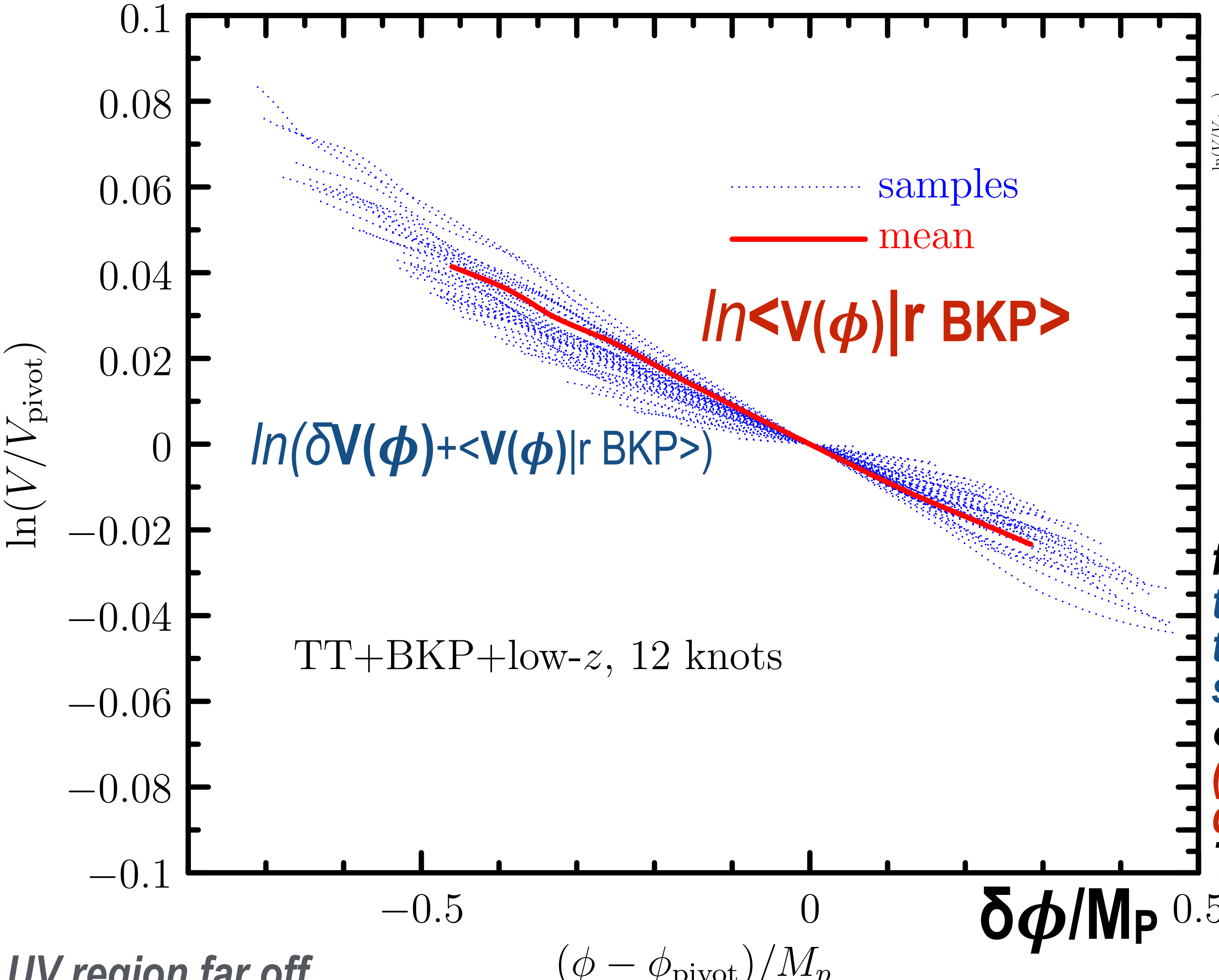
how was ***matter & entropy generated at the end of acceleration = inflation***?

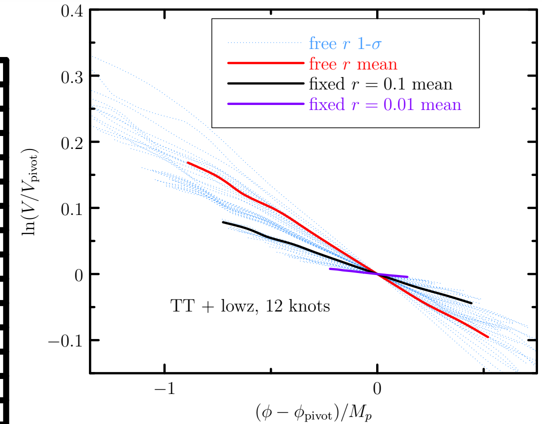
Relate it to the Higgs & standard model?



inflaton $V(\phi)$-maps $=3M_P^2 H^2 (1-\varepsilon/3)$ *HJ eqn,* $d\phi/M_P/d\ln a = \pm\mathrm{sqrt}(2\varepsilon)$

along the gradient / Morse flow





IR heating region is far off => many ways to extrapolate

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

UV region far off => many ways to extrapolate

r to **+-0.02 Spider** forecast

r to **+-0.003 AdvACTpol** forecast w/ fgnds

executive summary *of* **inflation futures via CMB & large-volume LSS probes** *& limits to cosmic knowledge*

Testing **Inflation** *with the* **CMB: Beyond the Standard Model** *of Cosmology*

Inflation features BSMi have not been found at >2σ significance, source of the GPE Planck-triste. *my answer to George:* **its not nice to tell mother nature what to do.** *bond-triste: bound by finite c, so confining.*

alas **a 2-number A_s-n_s early universe so far, simplest outcome but we want more, we are in quest of the subdominant**

CMB *restricts us to a* **projected 2D ζ-scape.** we will **reconstruct phonon/isotropic-strain power,** *but the future may look much the same as now for* **ζ**=>potential **V**(ϕ)=>acceleration **ε**(a)

r futures look bright (balloon, Stage 4, space) modulo the **dirty MW**
we will reconstruct graviton power
we will de-lens for consistency check: r-n_t ***optimism TBD***

we mock the LSS future *end-to-end*
we hope to probe the **3D ζ-scape** *where* **modes abound & success is possible** ***modulo large scale mode control of systematics*** => **non-Gaussianity at a much deeper level, to what must be there f_{NL} < 1? yes, maybe**

$\Delta T/T$ time dependent!! $(T_{gpe}-T_{bond}/)T_{bond} =$ .17@25 to .07@60 to .05@100 to 0.0000000006@$1/H_\Lambda$

$\Delta \langle \ln a \rangle = 0.0000000005$

Motto > 60: ***Forever Young***