Inflation Physics & Planck 2013's Small Scale Concordance & Large Scale Anomalies

CITA ICAT Canadian Institute for Theoretical Astrophysics L'institut canadien d'astrophysique théorique

Dick Bond

25 years cifar

Mining the **Cosmic** Frontier in the Planck Era

data phenomenology & theory phenomenology

Fundamental Questions in **Cosmology**

the Planck Collaboration, including individuals from more than 100 scientific institutes in Europe, the USA and Canada

esa planck

Planck is a project of the European Space Agency, with instruments provided by two scientific Consortia funded by ESA member states (in particular the lead countries: France and Italy) with contributions from NASA (USA), and telescope reflectors provided in a collaboration between ESA and a scientific Consortium led and funded by Denmark.

Bond, Huang 13a,b

Bond, Frolov, Huang, Kofman 09

Bond, Braden 13

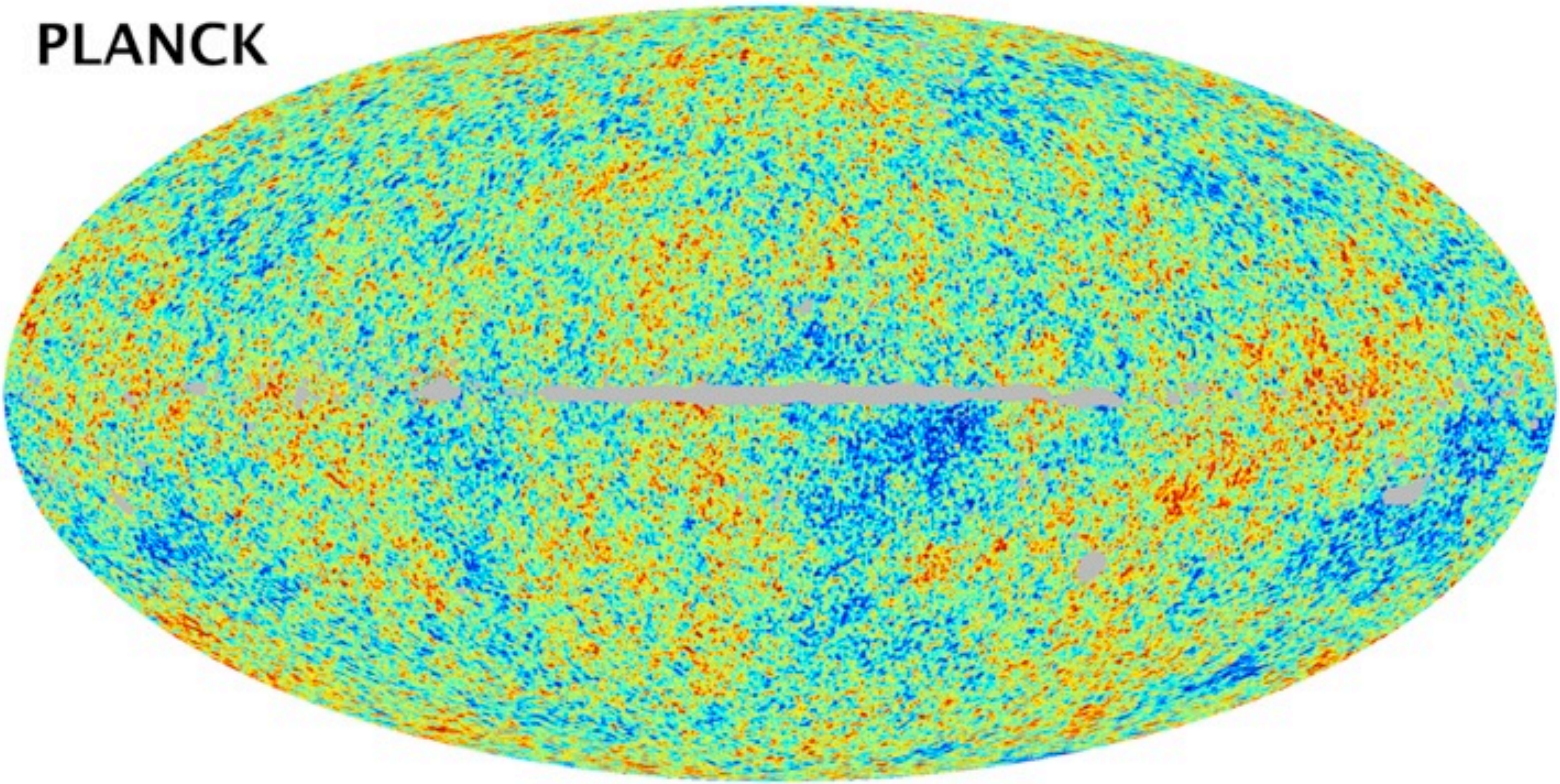
Bond, Braden, Frolov, Huang 13

Bond, Braden, Frolov, Huang, Nolta 13

Bond, Braden, Mersini 13a,b,c

Planck SMICA Map

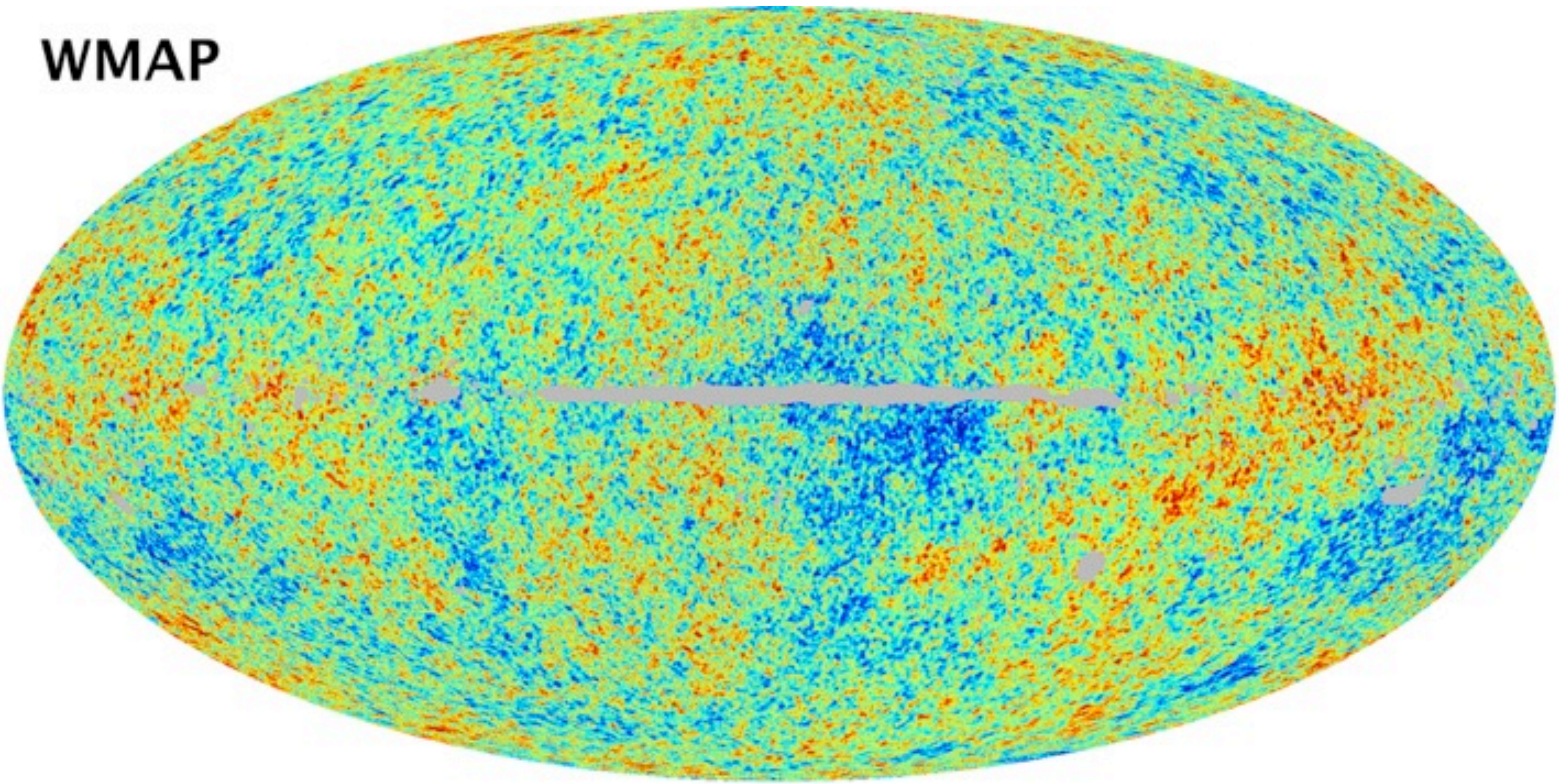
CMB-data Concordance



Planck/SMICA map, 5′ resolution.

WMAP W-band, Template Cleaned

CMB-data Concordance

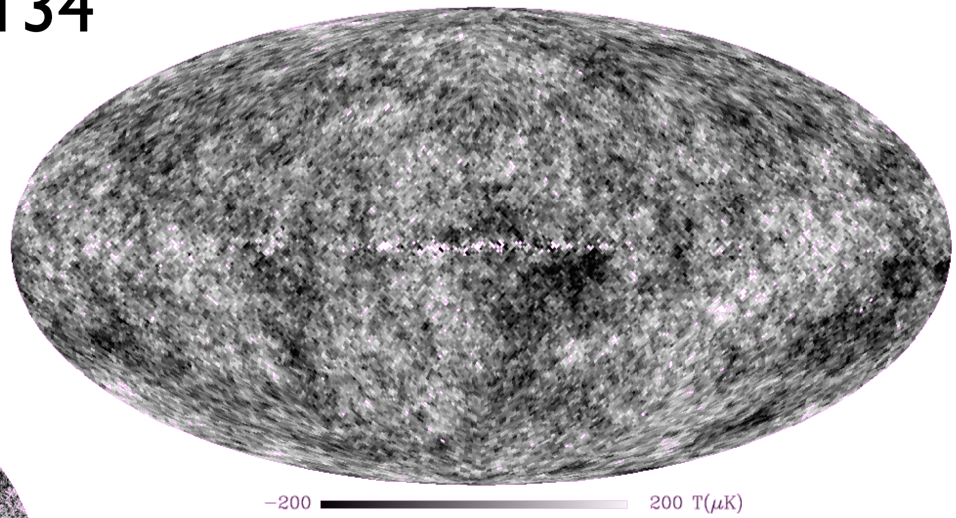


Cleaned with Planck 353 GHz dust map and low-frequency templates. 12′ resolution.

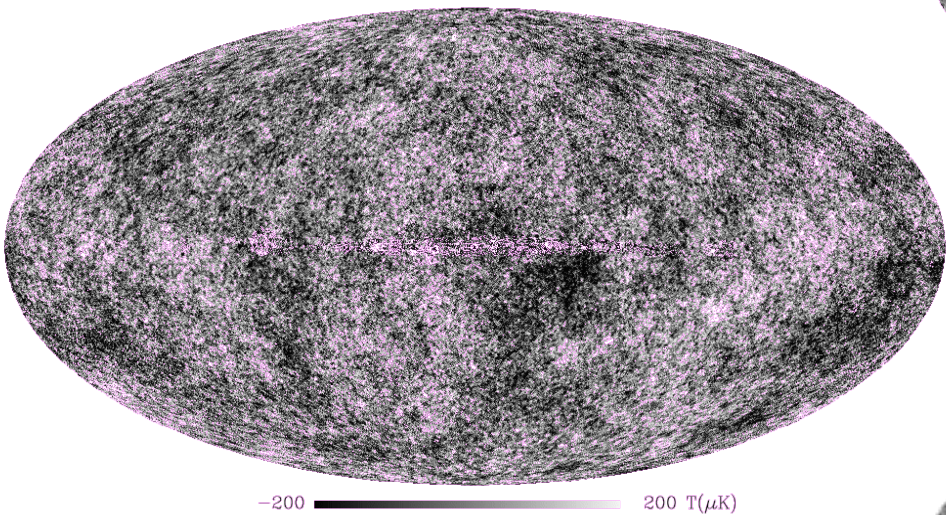
similar tremendous agreement with the much higher (5X) resolution ACT & SPT maps

total focus on the 1.2% difference in "calibration" between P13 (HFI &LFI) & WMAP9

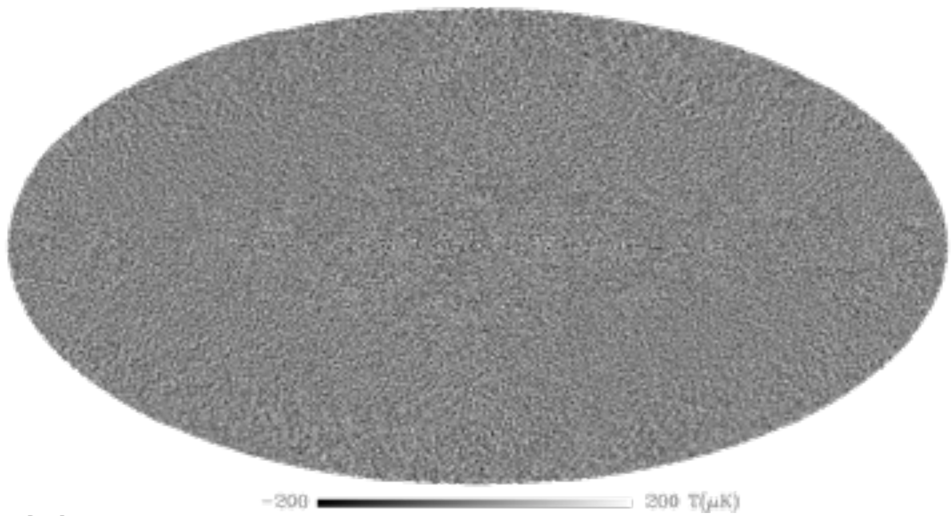
anomalies
L<134



full Planck resolution



Planck smoothed to 1deg fwhm

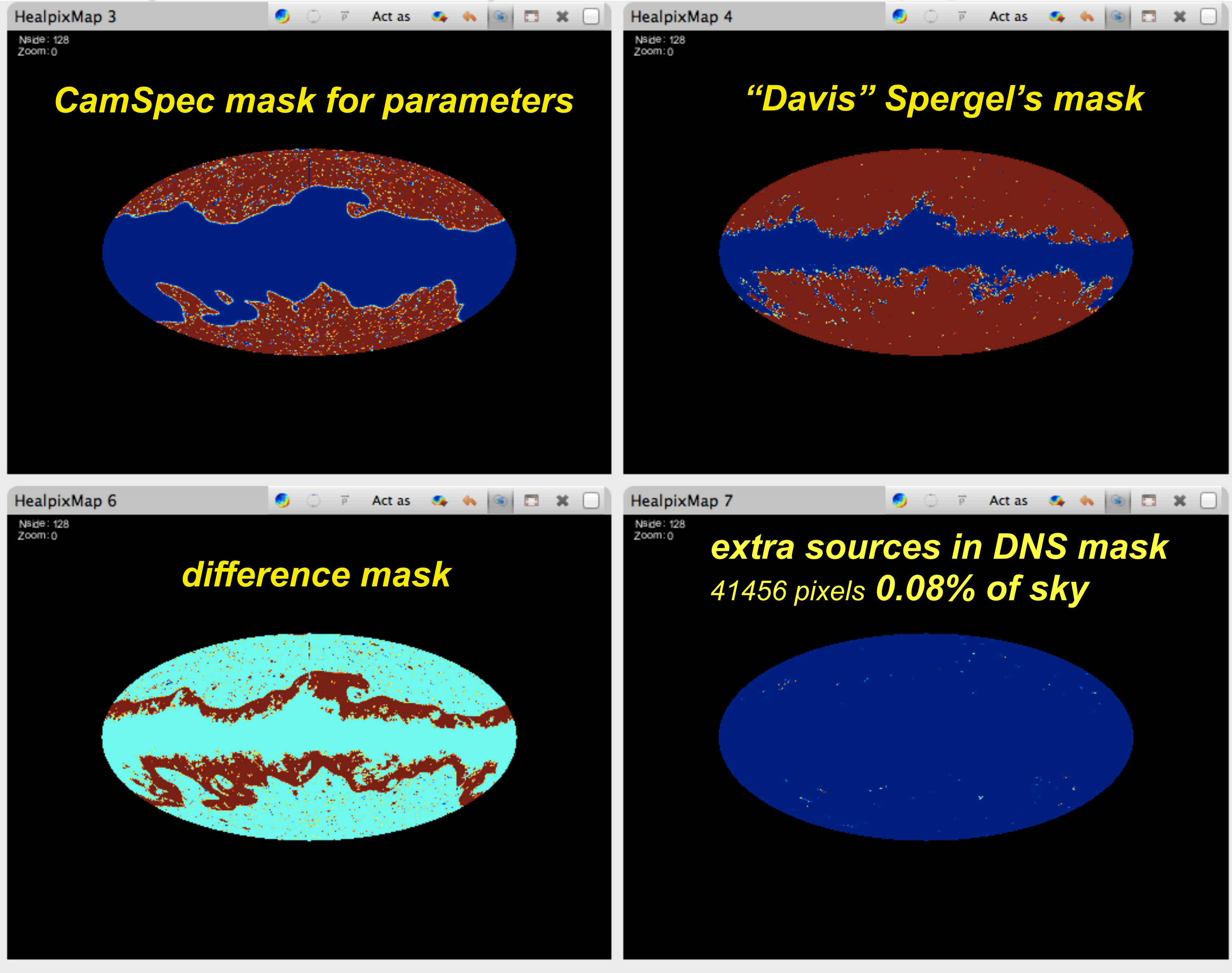


L>134
concordance

small scale leftover = where most of Planck's information resides> 120X

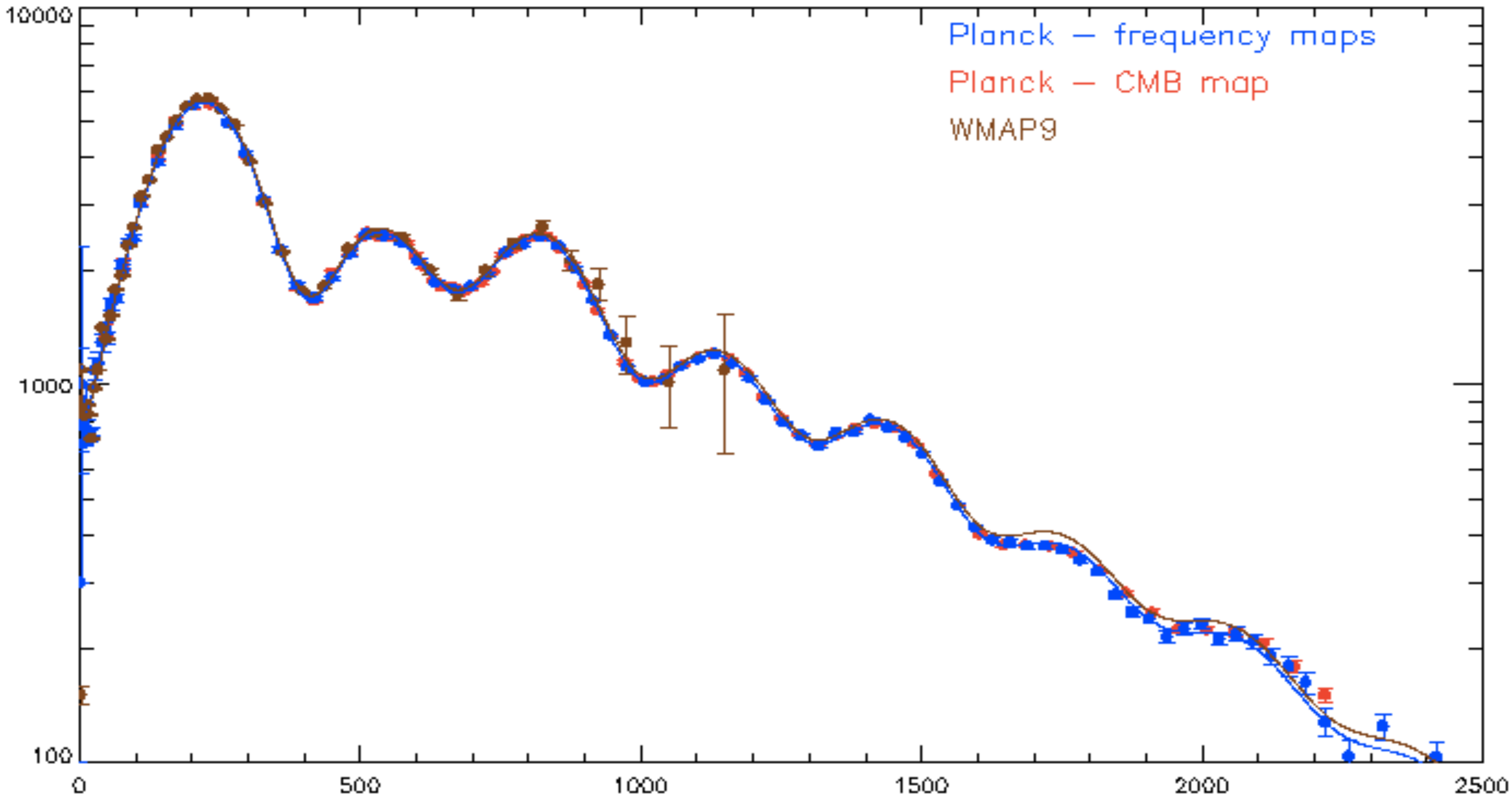
masks & point sources & 1-point tails tales: Davis Spergel cf. Gorski summary

Davis
Rocha
figs



component-separation mask: extra-masked DNS pixels: 3570765 pixels (7.09% of the sky)

WMAP9 C_L *cf.* P1.3 C_L for params *cf.* P1.3 comp sep C_L



=> Planckian mystification: why the (*not-big*) param shift

Standard Parameters of Cosmic Structure Formation

$\Omega_b h^2$ $\Omega_{dm} h^2$ Ω_Λ Ω_k | τ_c | $\ln A_s$ n_s $r = A_t/A_s$ $dn_s/d\ln k$ n_t

$\Omega_{er}h^2$ $\Omega_{m\nu}h^2$ X_{He}

$1+w_0, w_a$ $\theta \sim \ell_s^{-1}$ $n_e(a)$ $\sim \ln \sigma_8^2$

Inflation Histories
(CMBall+LSS+SN+WL)

new parameters: **trajectory probabilities for early-inflatons & late-inflatons (partially) blind cf. informed "theory" priors**

P1.3 *like,* ***ACT****12 final spectra & params, 1500 sq deg, ~600 for params,* ***SPT****12 2540 sq deg*

Calabrese+13 ACT12+SPT12+WMAP9

standard inflation space: n_s $dn_s/d\ln k$ r =T/S @k-pivots f_{nl}

ln **Power**$_s$~*ln***22.0x10^{-10}** ±0.025 **P**1.3+ *ln***22x10^{-10}** ±0.028 **A12+S12+w9**

n_s =0.9608±0.0054 (**P**1.3+**WP+hiL+BAO**) **0.9678±0.0088 A12+S12+w9**

± 0.002 (P2.5ext)

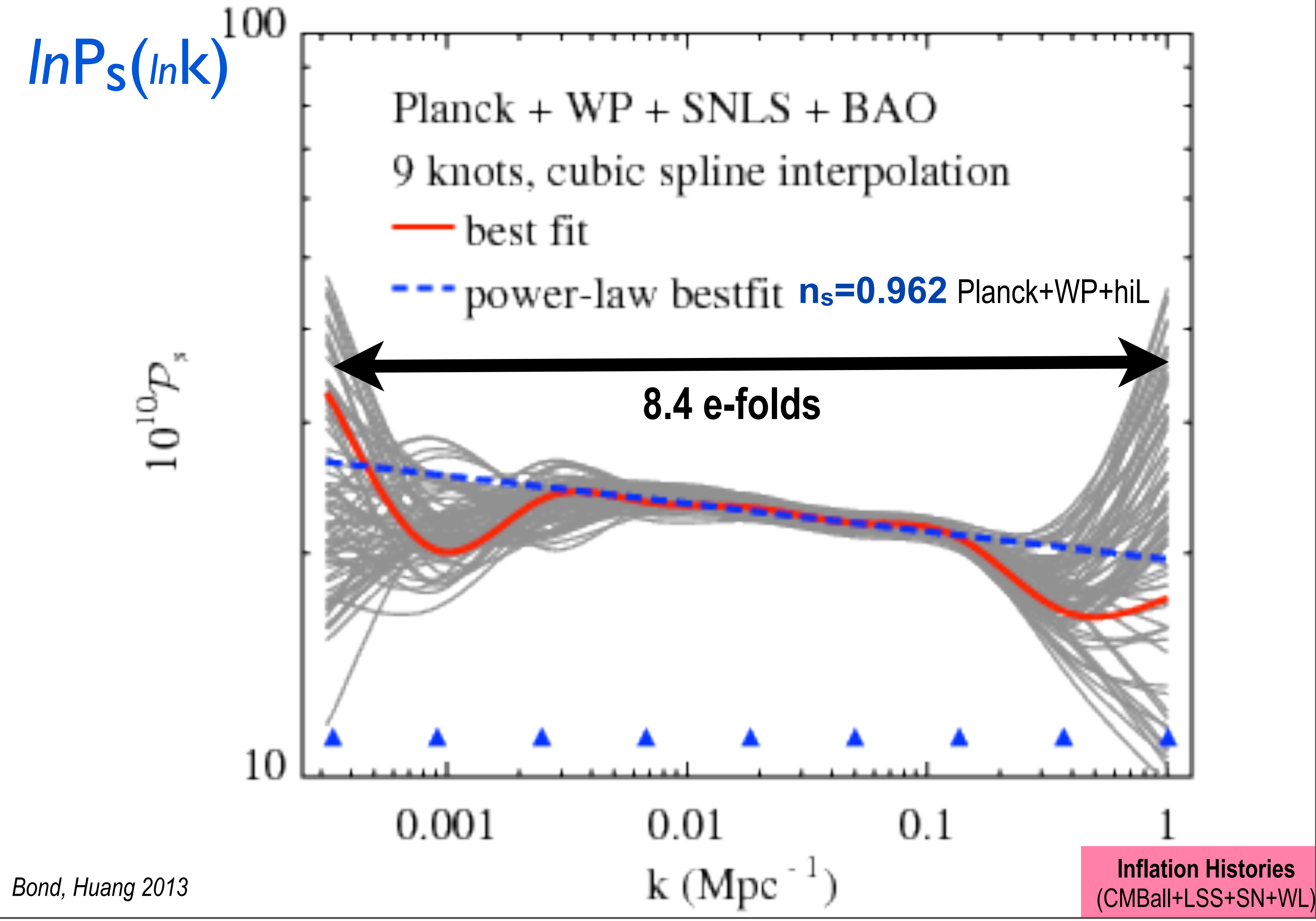
$dn_s/d\ln k$=-0.014±0.009 (**P**1.3+**WP**, **P**1.3+**WP+hiL+BAO**) **-0.028 ± 0.010 SPT12+**

-0.003 ± 0.013 (**ACT**12+ WMAP7+BAO+H0)

r <0.12, 0.11,0.16,0.11,0.13 (**95% CL: P**1.3+**WP**, **P**1.3+**WP+hiL+BAO**, A12,S12, W9)

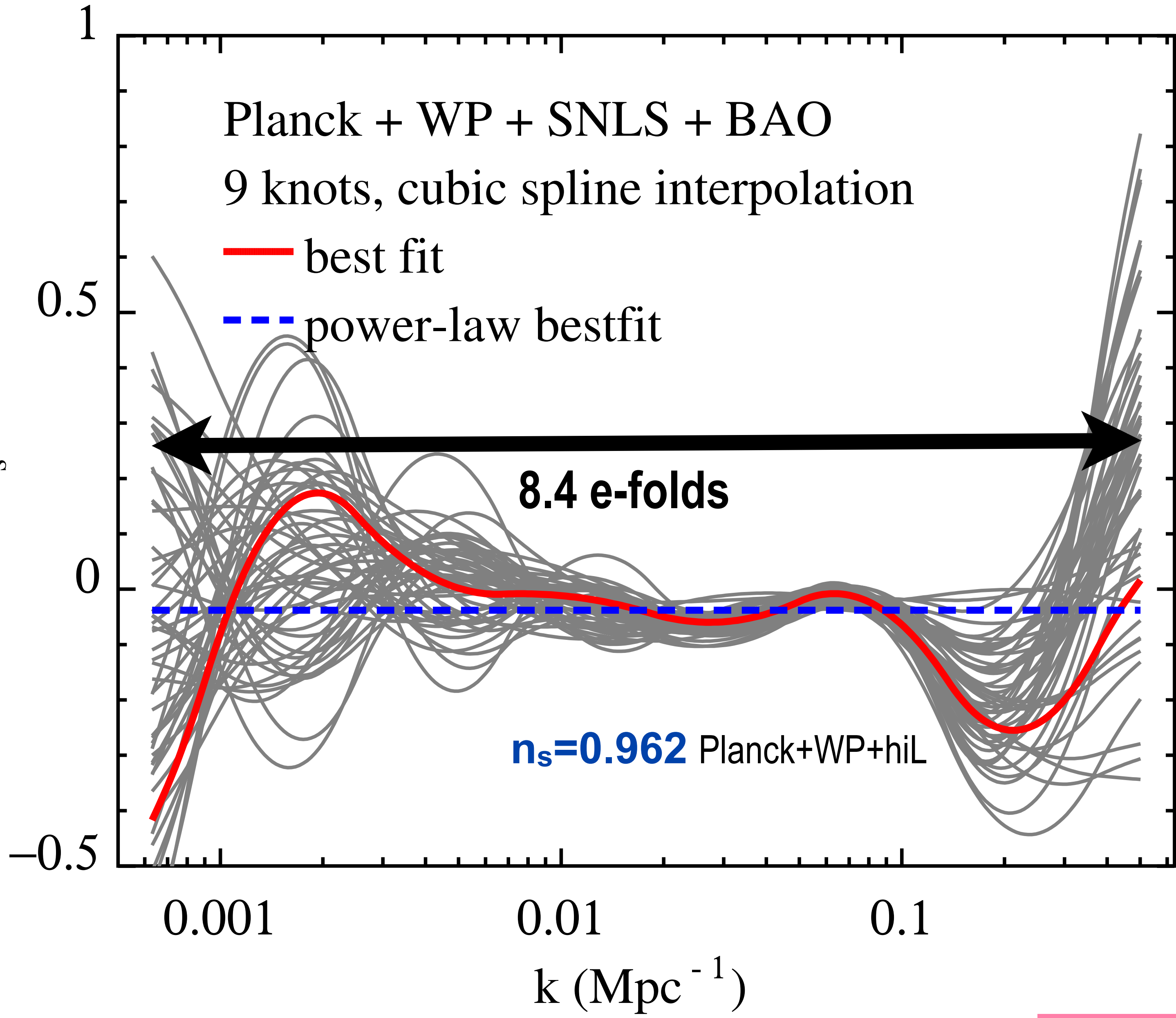
< 0.007-0.013 (P2.5ext) f_{nl}: 2.7 ± 5.8 local => ± 5 (Pext) f_{nl}: -42.3 ± 75.2 equil -25.3 ± 39.2 ortho

trajectories: *ln* **Primordial power spectra** (*ln***k**), **n_s**(**k**), ε(Ha)=3/2(1+w_t), V(ψ), ψ(a) *scan* $ln\mathbf{P_s}(ln\mathrm{k})/A_s$, $ln\mathbf{A_s}=lnP_s(k_{pivot,s})$, $\mathbf{r}(k_{pivot,t})$; *consistency => reconstruct* **ε(*ln*Ha), V(ψ)**



scan $\ln \mathbf{P_s}(\ln k)/A_s$, $\ln \mathbf{A_s} = \ln P_s(k_{pivot,s})$, $\mathbf{r}(k_{pivot,t})$; *consistency => reconstruct* $\boldsymbol{\varepsilon}(\ln \mathbf{Ha})$, $\mathbf{V}(\boldsymbol{\psi})$

$n_s(\ln k)$



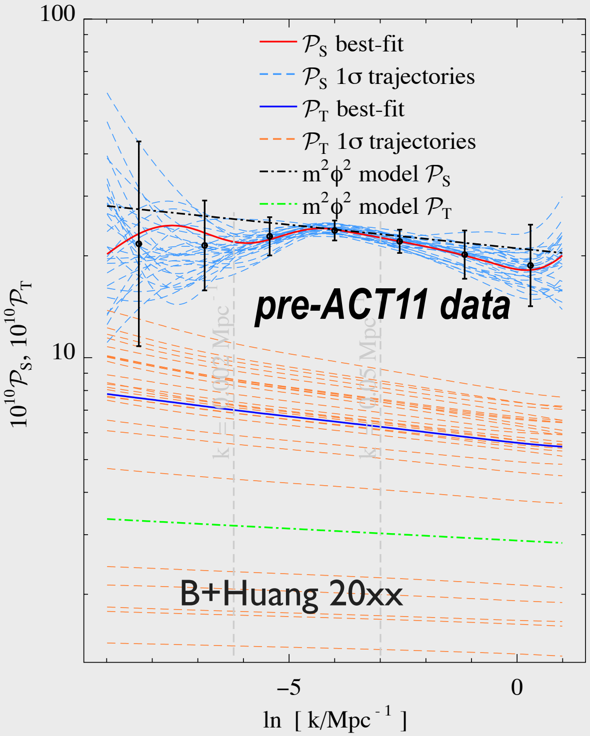
Bond, Huang 2013

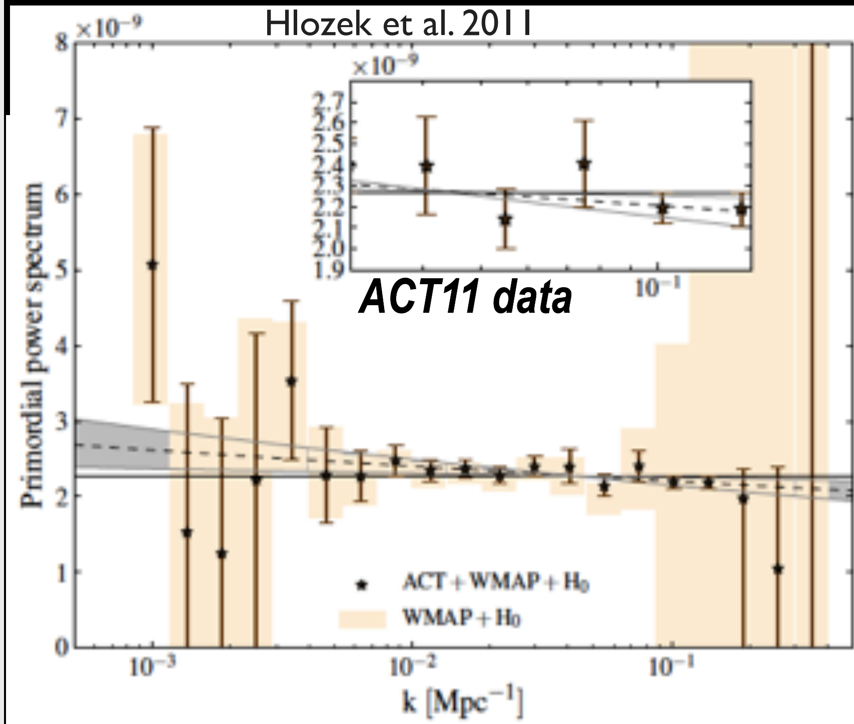
Inflation Histories
(CMBall+LSS+SN+WL)

Sunday, 26 May, 13

early-U, NOW

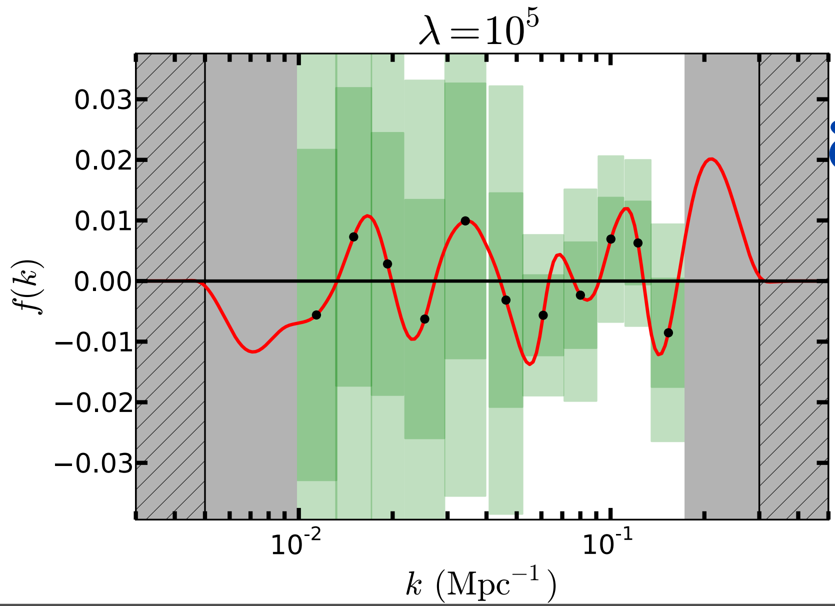
semi-blind & informed reconstruction of Scalar / Tensor power spectra, acceleration histories

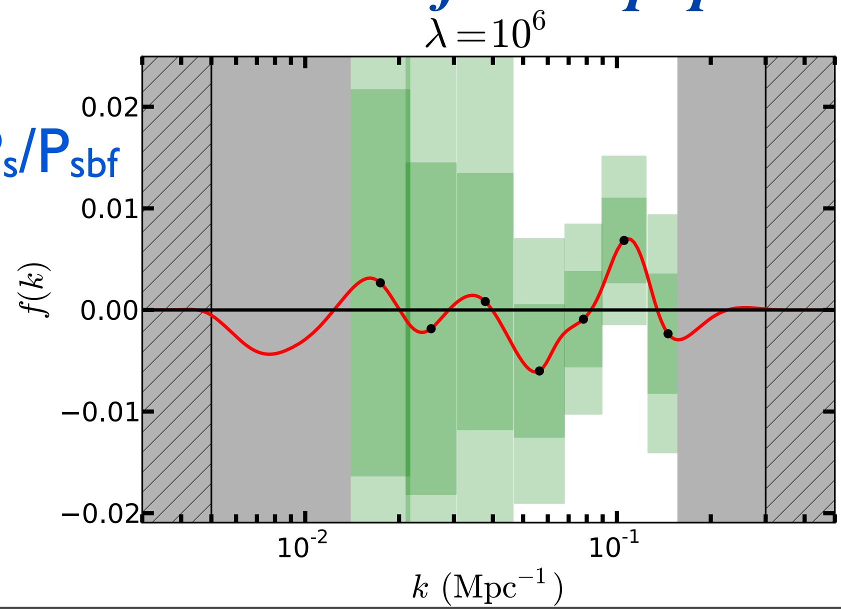




Planck1.3 inflation paper

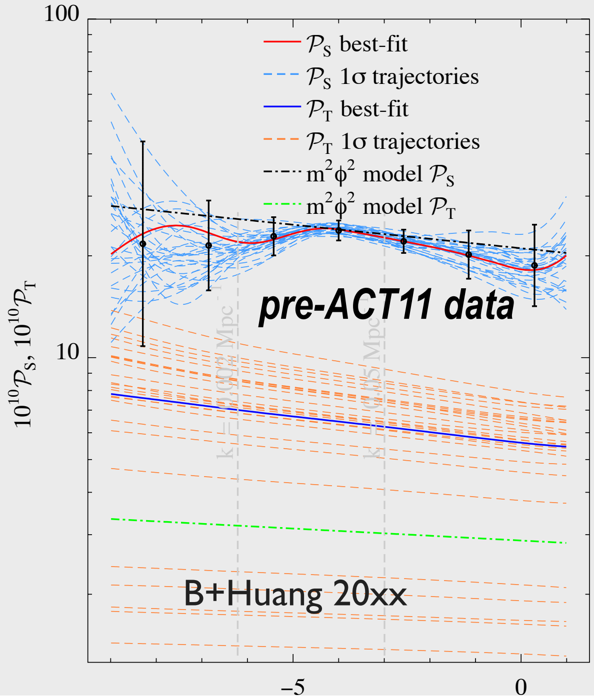
$\delta P_s/P_{sbf}$

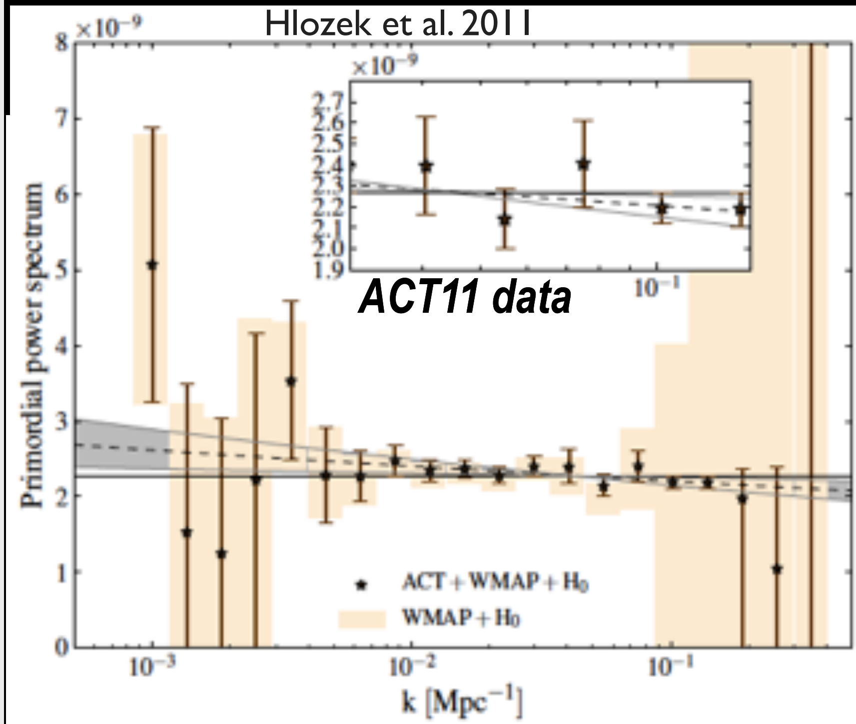




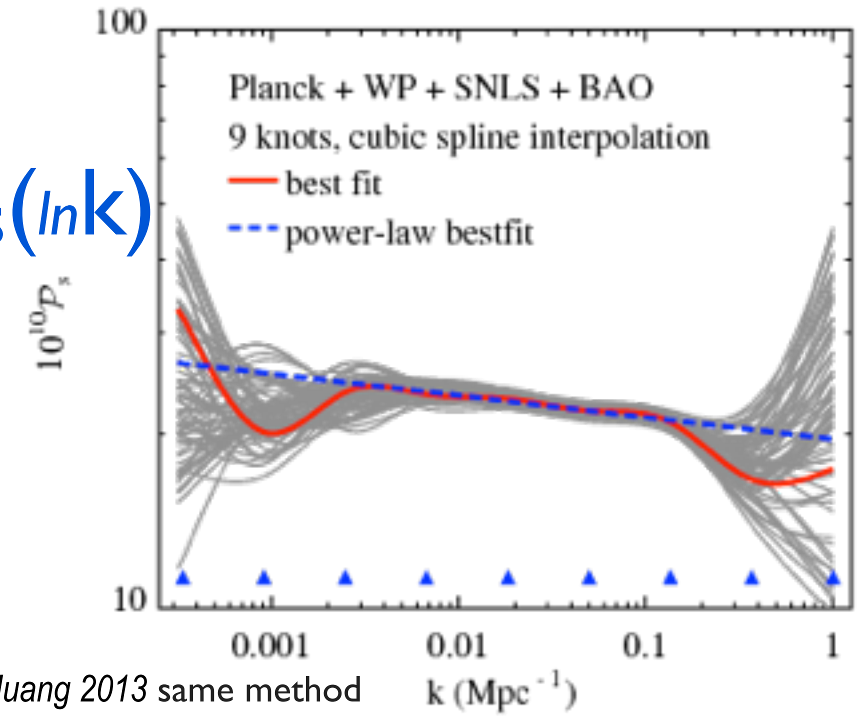
early-U, NOW

semi-blind & informed reconstruction of acceleration histories & S/T power spectra





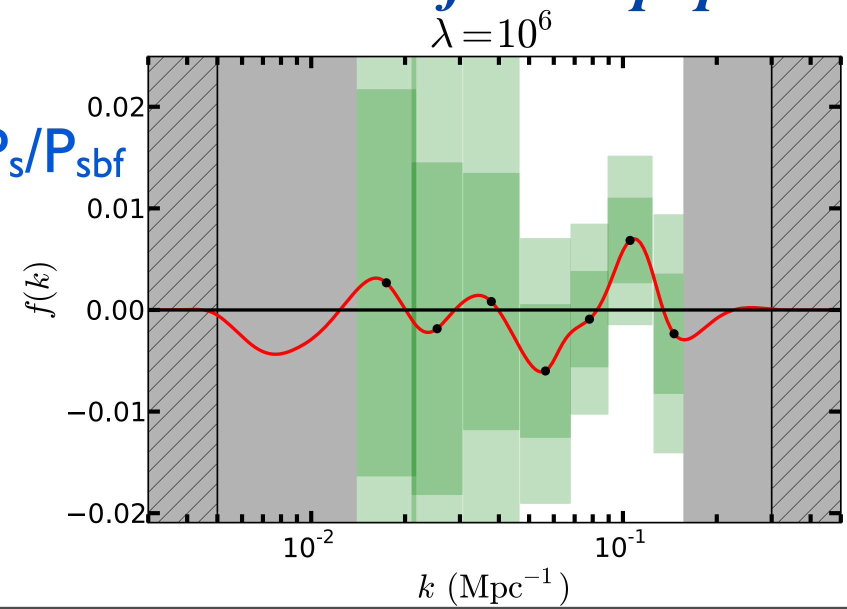
$lnP_s(lnk)$



Bond, Huang 2013 same method

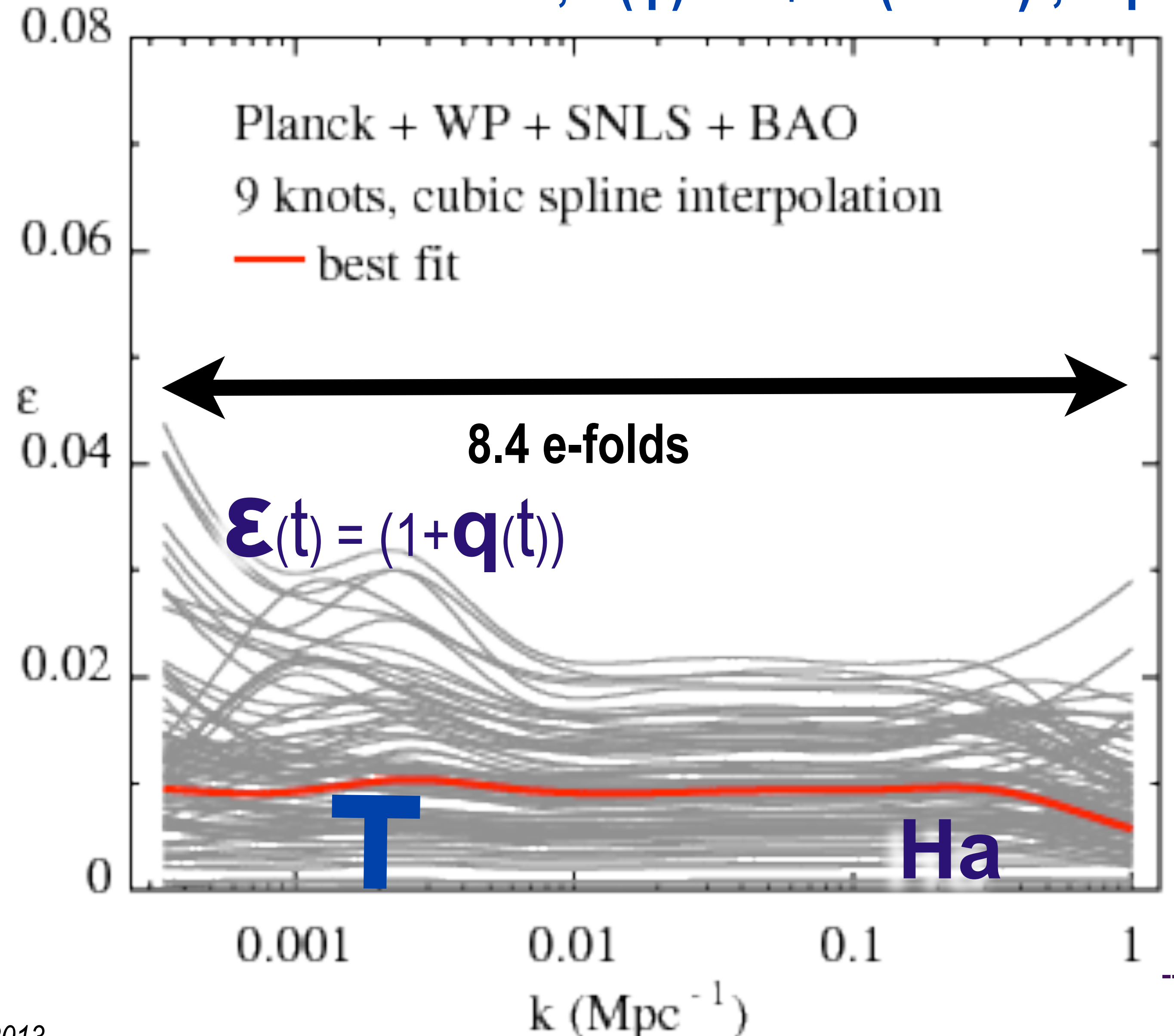
Planck1.3 inflation paper

$\delta P_s/P_{sbf}$



late-inflaton **DE** **acceleration trajectories then**

$\epsilon = -\, d\ln H / d\ln a$; $V(\psi) \approx 3 M_P^2 H^2 (1-\epsilon/3)$; $d\psi / d\ln a = \pm\sqrt{\epsilon}$



aka

$(1+w_{de})^{3/2}$

then

(hydro)

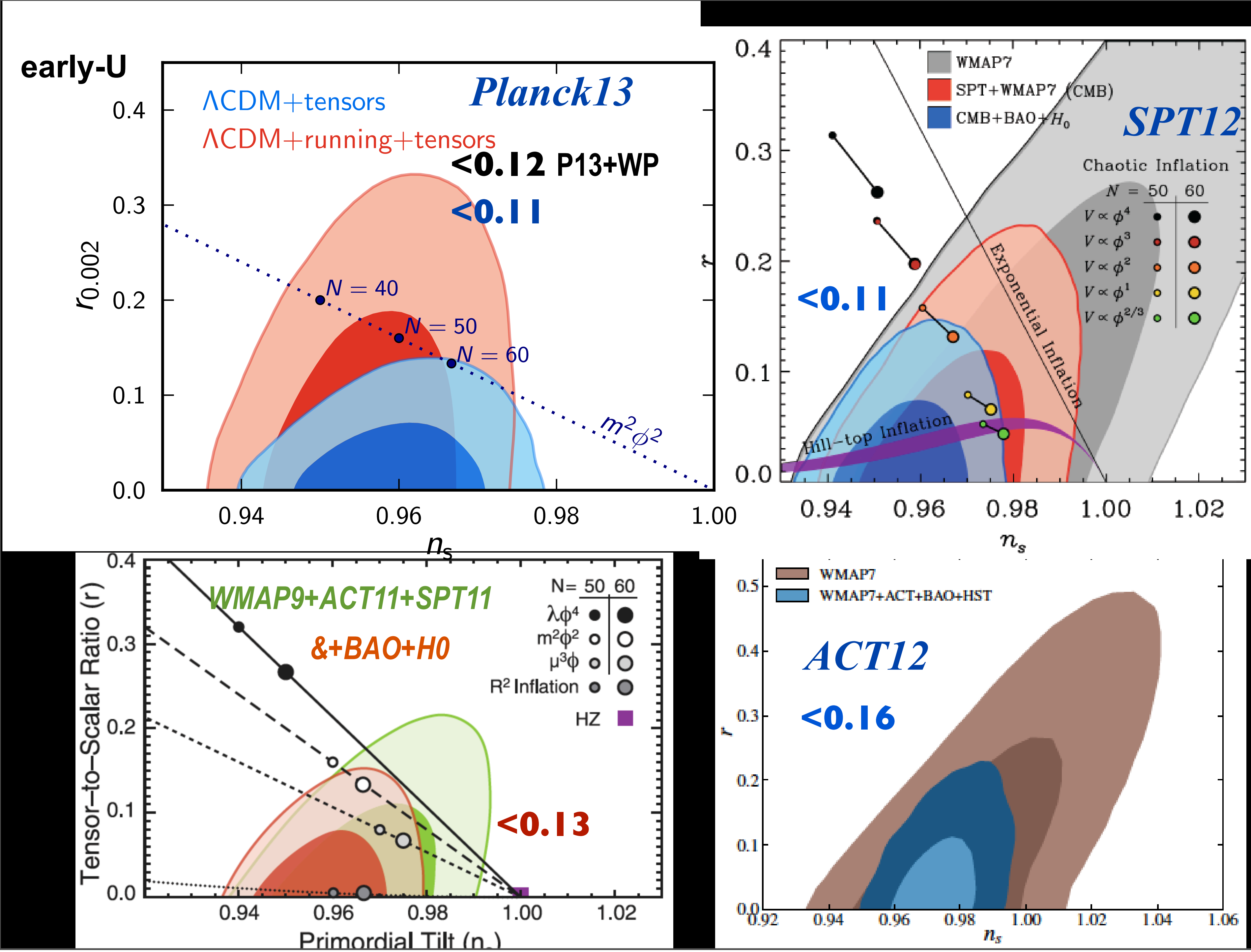
resolution
lnk ~ lnHa
dynamics

$\epsilon \approx r/16$

$\epsilon \approx \frac{V}{0.0005\,(10^{16}\,\mathrm{Gev})^4}$

Bond, Huang 2013

Sunday, 26 May, 13

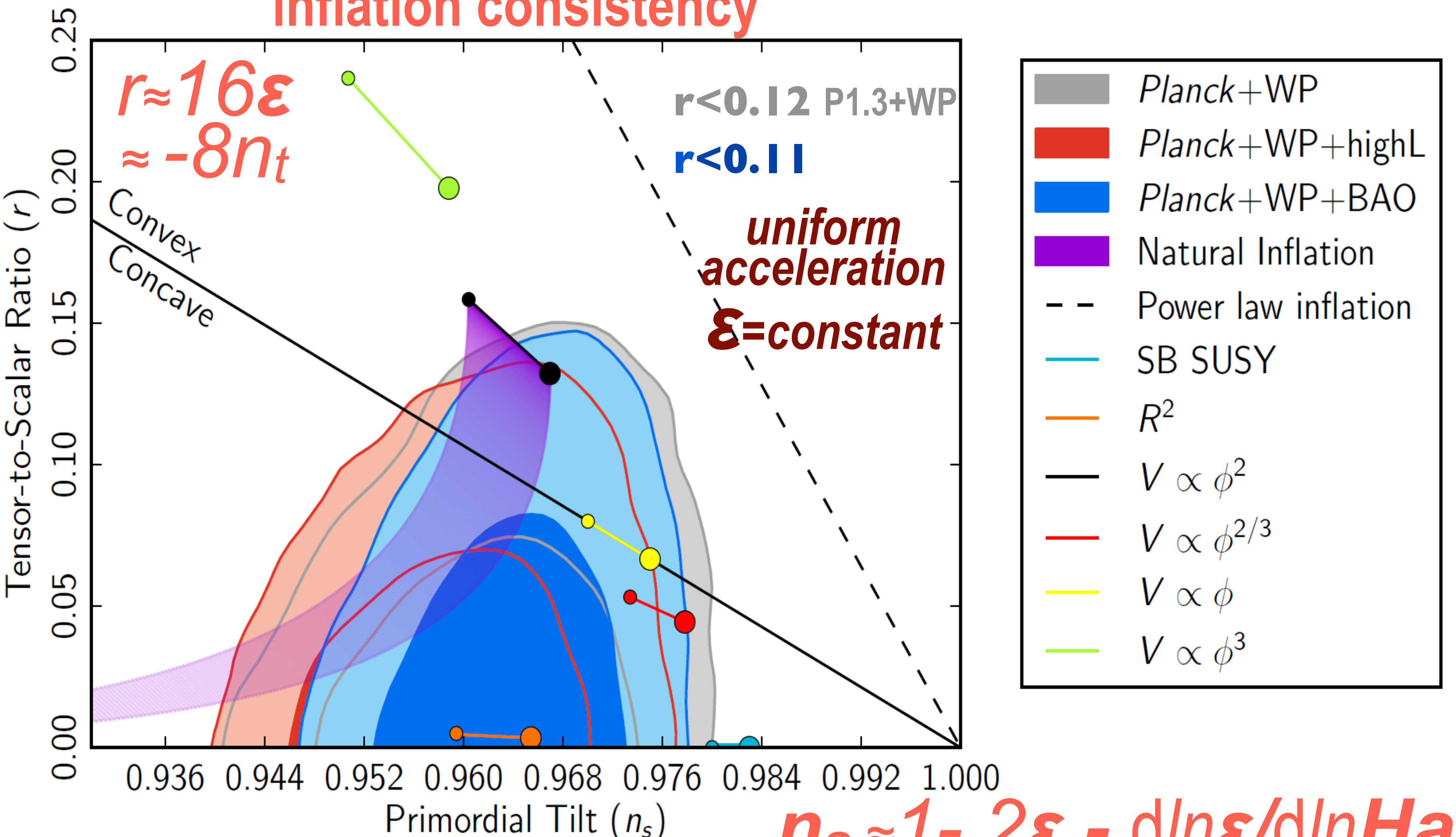

early-U
Planck13
ΛCDM+tensors
ΛCDM+running+tensors
<0.12 P13+WP
<0.11
N = 40
N = 50
N = 60
m²φ²
r0.002
ns
SPT12
WMAP7
SPT+WMAP7 (CMB)
CMB+BAO+H0
Chaotic Inflation
N = 50 60
V ∝ φ⁴
V ∝ φ³
V ∝ φ²
V ∝ φ¹
V ∝ φ^{2/3}
Exponential Inflation
Hill-top Inflation
<0.11
r
ns
WMAP9+ACT11+SPT11
&+BAO+H0
N= 50 60
λφ⁴
m²φ²
μ³φ
R² Inflation
HZ
<0.13
Tensor-to-Scalar Ratio (r)
Primordial Tilt (ns)
ACT12
WMAP7
WMAP7+ACT+BAO+HST
<0.16
r
ns

Consistent with single field slow roll, standard kinetic term & vacuum (with f_{NL} upper limits)

uniform acceleration *line* $\varepsilon \equiv 3KE/(KE+PE)$ *= constant is* ***strongly ruled out***

=> early universe acceleration must change over observable scales (as well as to end inflation)

inflation consistency



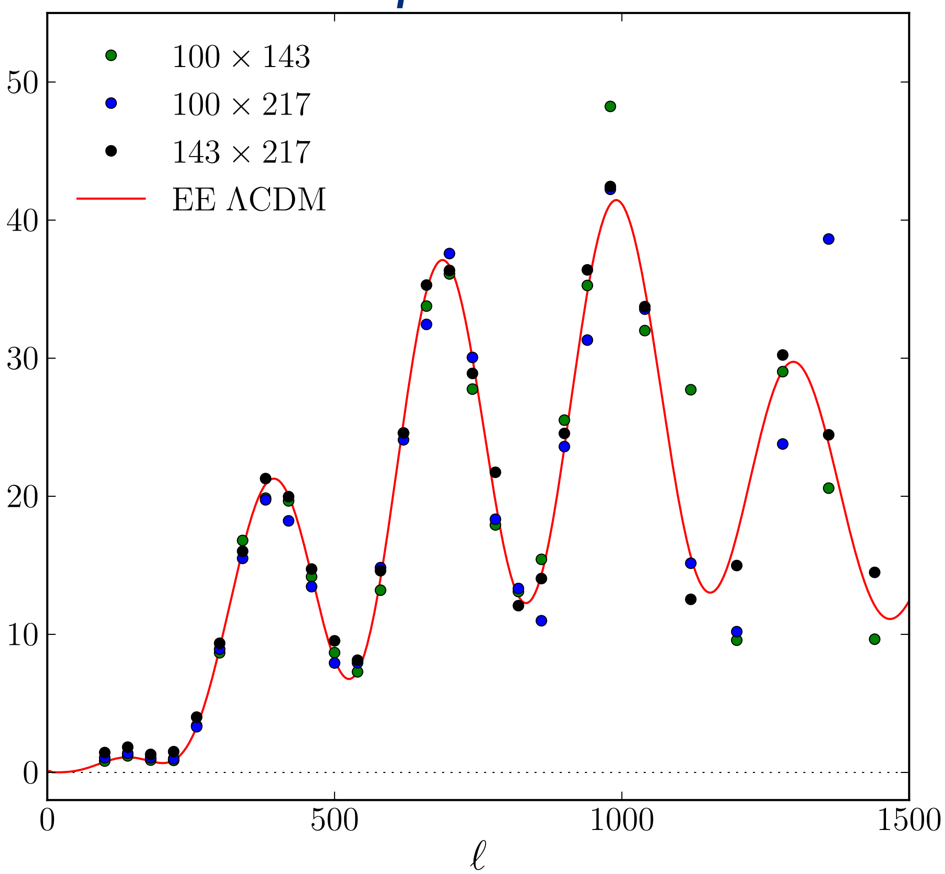
$n_s \approx 1 - 2\varepsilon - d\ln\varepsilon/d\ln Ha$

exponential potential models(power-law inf), the simplest hybrid inflationary models (Spontaneously Broken susy), and monomial potential models of degree n >2 do not provide a good fit to the data. No running. no CDM isocurvature of axion <3.9% (95% CL) & curvaton (< 0.25%) types.

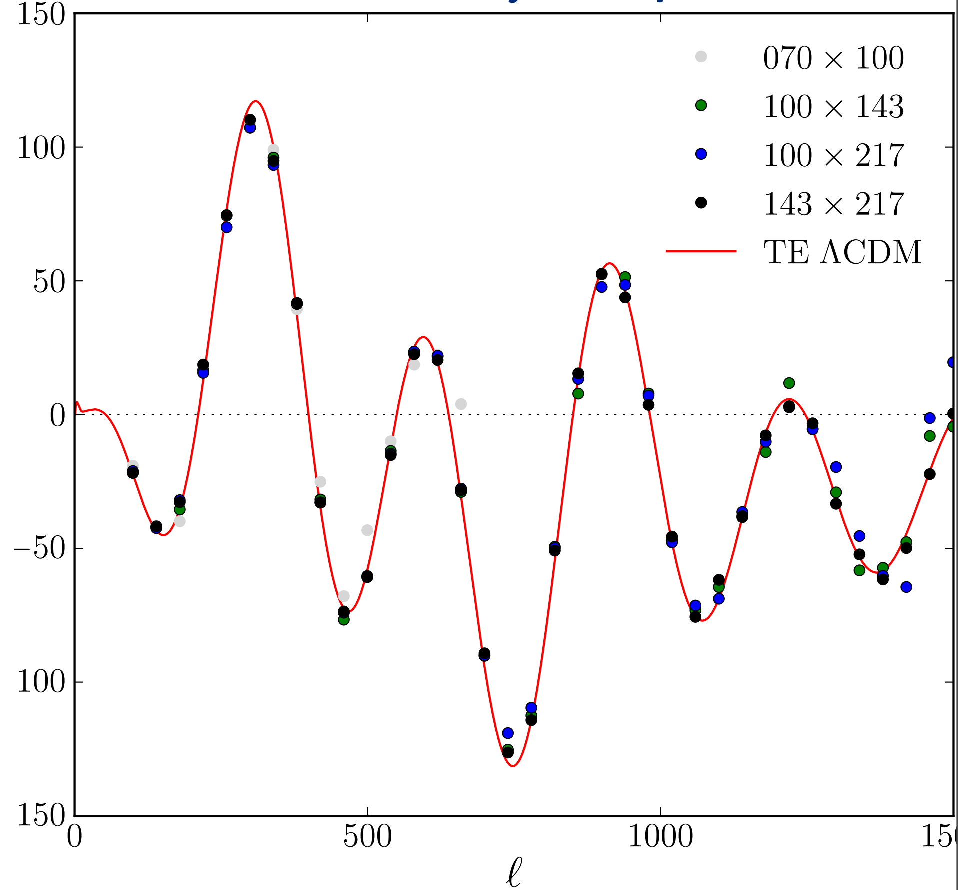
Natural = pNGB-Inflation, monodromy = driven pNGB-Inflation, Roulette Inflation (shrinking holes in extra-dim), brane inflation survive.

best-fit P1.3yr TT model predicts the polarization. works perfectly at all frequency cross correlations
strengthens the case for the Galactic/extragalactic nuisance parameter model being accurate
- error bars on EE and TE are not shown. for 2014

EE polarization



TE intensity cross polarization



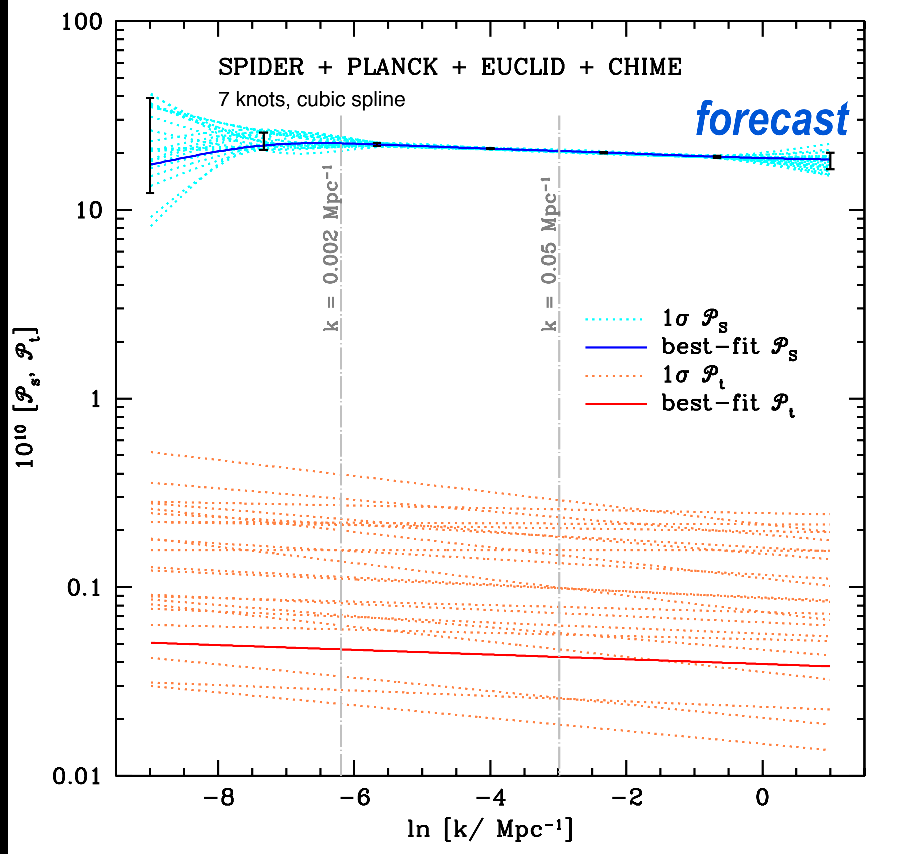
Spider24days+Planck2.5yr: r-n_t *matrix*-forecast for r=0.12 input for $m^2\varphi^2$ ($2\sigma_r$ ~0.02 including fgnds)

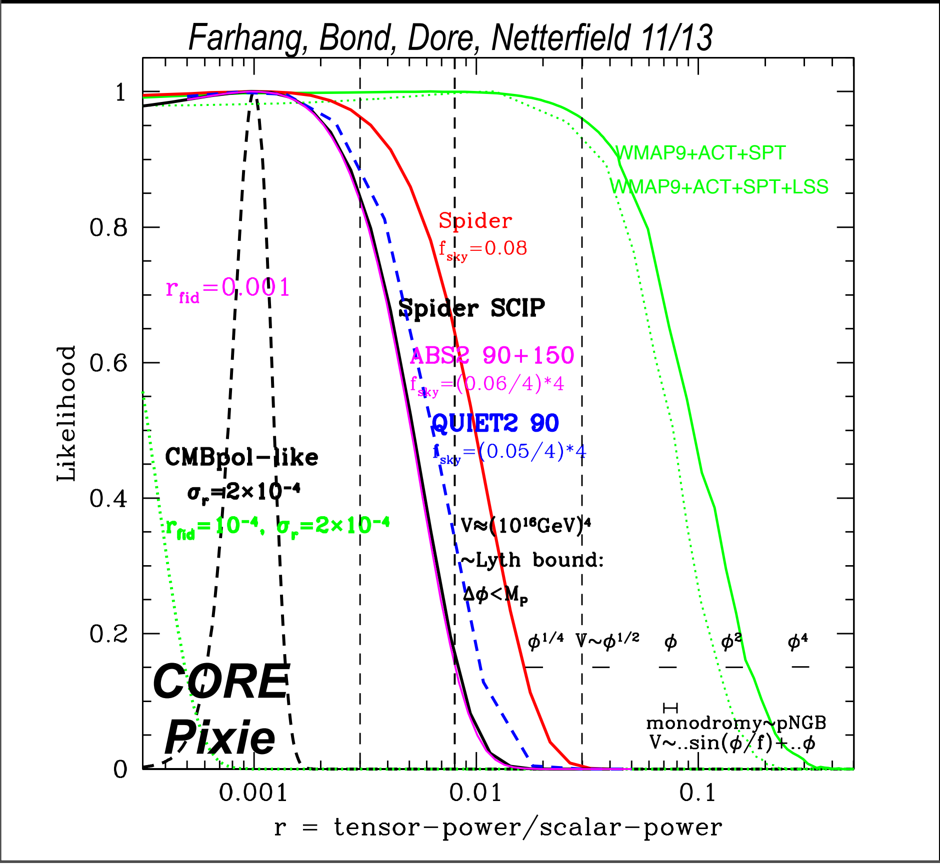
*similar r-forecasts for **ABS+/VIP, Quiet***

inflation consistency

$$-n_t \approx r/8 \approx 2\varepsilon(k)$$

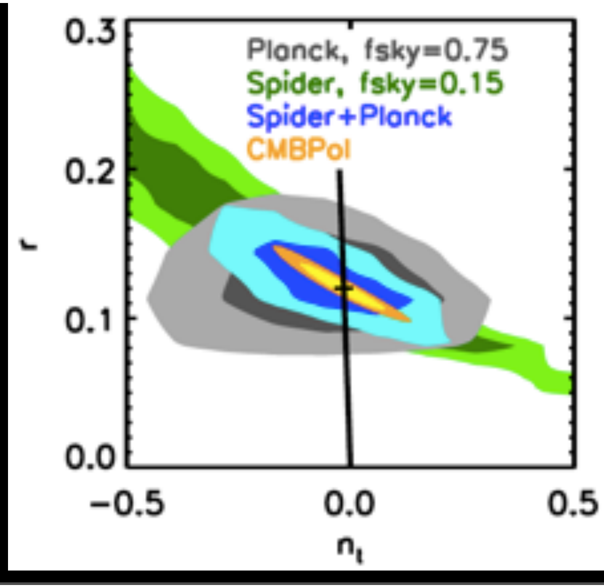
$$1-n_s \approx 2\varepsilon + d\ln\varepsilon/d\ln Ha$$





can get B-mode shapes but without the precision needed to check

$-n_t \approx r/8$ consistency



Standard Parameters of Cosmic Structure Formation

$\Omega_b h^2$ $\Omega_{dm} h^2$ Ω_Λ Ω_k τ_c

$\ln A_s$ n_s $r = A_t/A_s$ $dn_s/d\ln k$ n_t

$\Omega_{er}h^2$ $\Omega_{m\nu}h^2$ X_{He}

$1+w_0, w_a$ $\theta \sim \ell_s^{-1}$ $n_e(a)$ $\sim \ln \sigma_8^2$

Inflation Histories
(CMBall+LSS+SN+WL)

new parameters: **trajectory probabilities for early-inflatons & late-inflatons (partially) blind cf. informed "theory" priors**

standard dark energy space: $\Omega_{de,0}$ $w_{de,0}$ $w_{de,a}$ Ω_k

Ω_Λ: 0.692± 0.010 $1+w_{de,0}$: -0.13± 0.12 if $w_{de,a}$

Ω_K: -.0005 ± 0.0033

$1+w_t = -d\ln p_t / d\ln a^3 = 2/3\ \varepsilon(a) = 2/3\ (1+q(a))$

cf. **dark energy trajectories**

informed = 1+3-parameter $w_{de}(a|V(\psi), IC)$

$= w(a|\varepsilon_s \varepsilon_{de\infty} \zeta_s)$ *paves even wild late-inflaton trajectories*

cf. semi-blind eigen-analysis

V_{de}, $\varepsilon_{de\infty}$ *Bond, Huang 2013*

$\varepsilon_s = (d\ln V/d\psi)^2/4$ @pivot a_{eq}

= -0.25 + .20 -.26

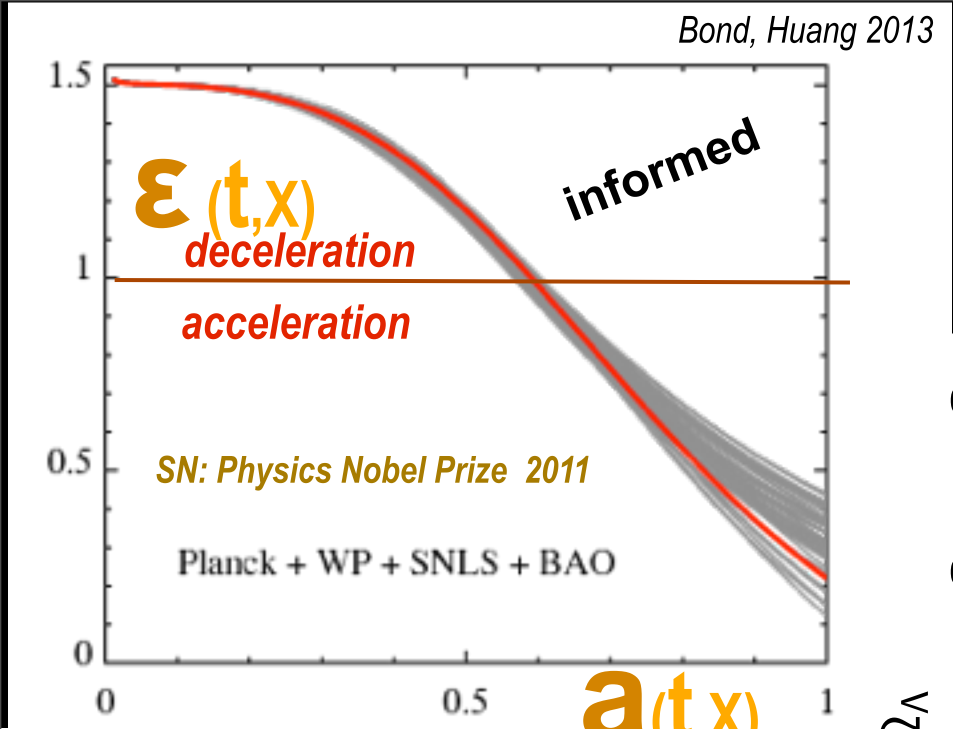
= 0.00 + .21 ***P1.3+SNLS3***

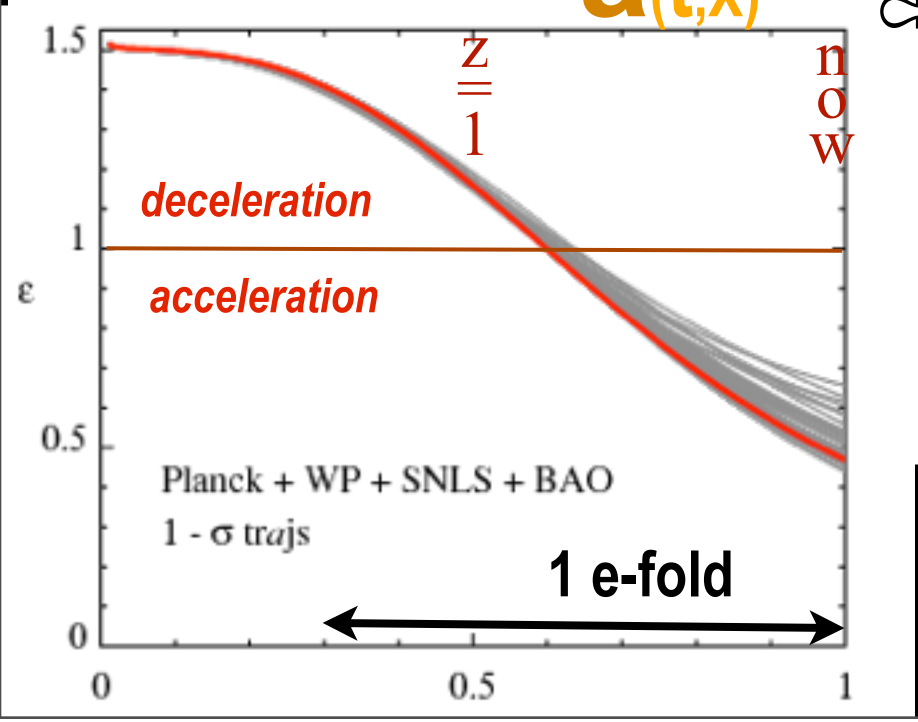
to =.005 + .031 -.025 *future*

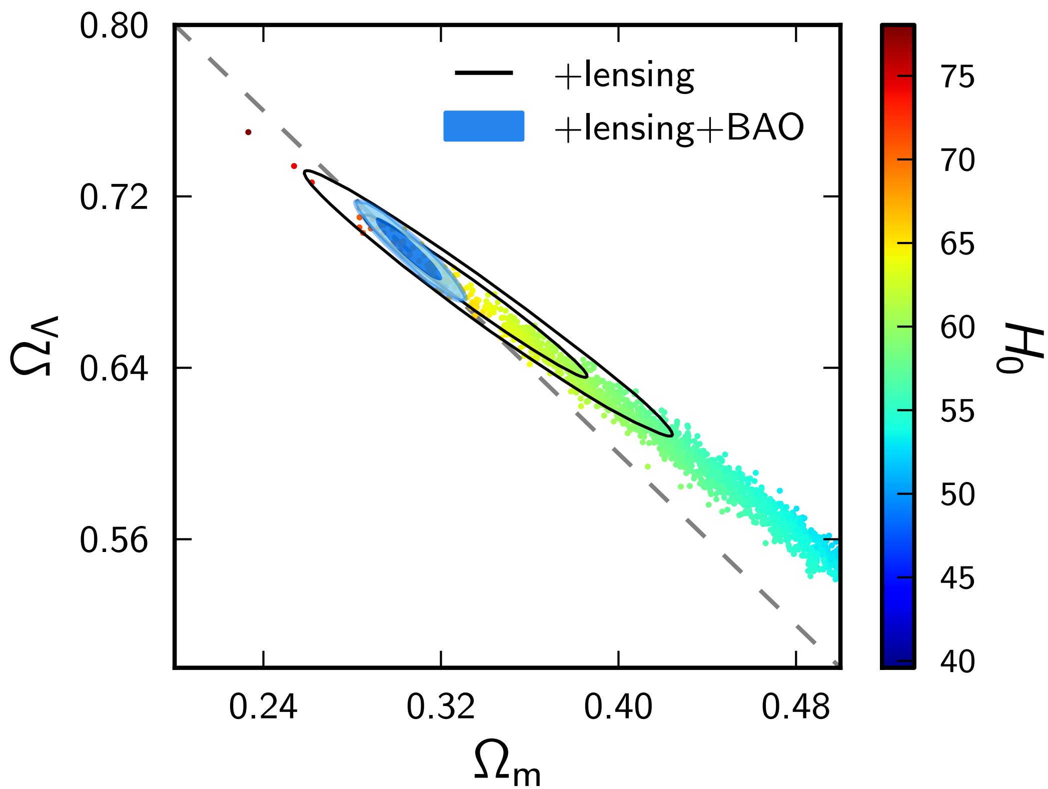
P2.5+Euclid+CHIME

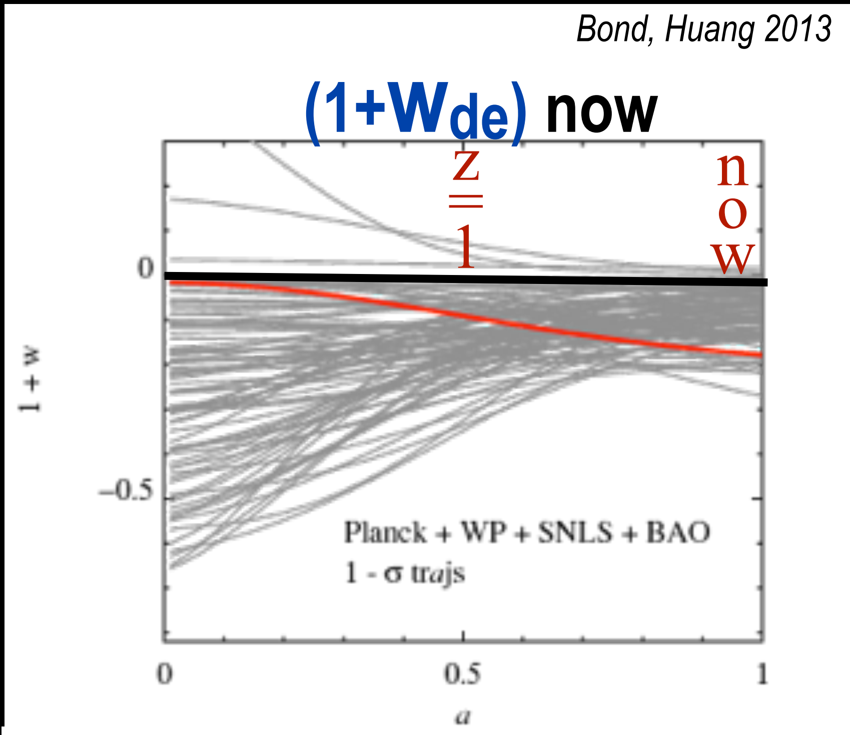
late-inflaton DE trajectories

lensing breaks geometrical degeneracy
Planck alone cf. Planck+BAO









late-inflaton DE trajectories

$(1+W_{de}) = -\, d\ln\rho_{de} / d\ln a^3$

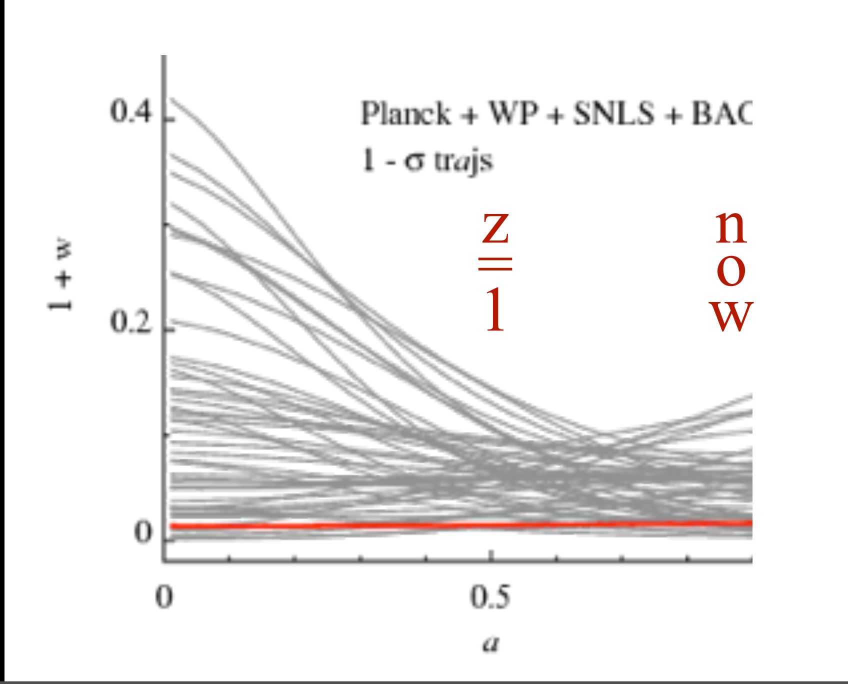
$1+w_{de,0}$: -0.13 ± 0.12 if $w_{de,a}$

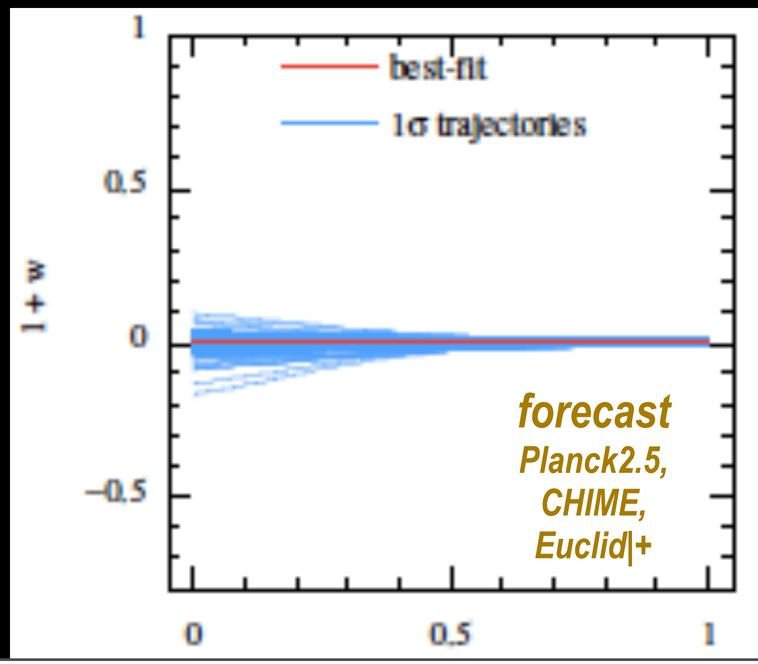
$\varepsilon_s = (d\ln V/d\psi)^2/4$ @pivot a_{eq}

$= -0.25 + .20 -.26$

$= 0.00 + .21$ *P1.3+SNLS3*

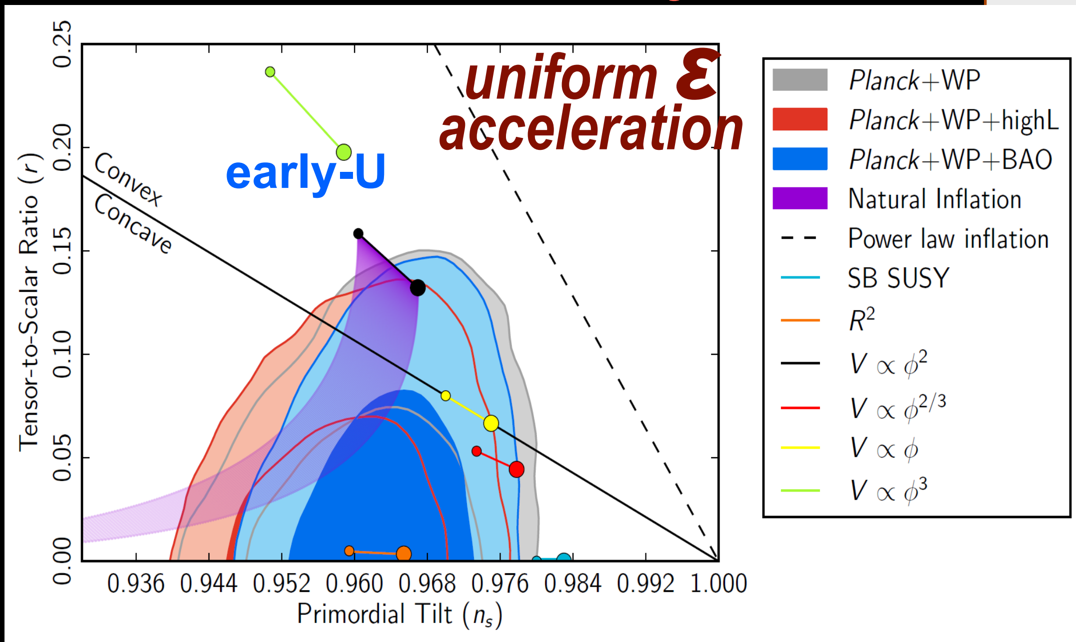
to $=.005 + .031 -.025$ future





introduce a late-U DE plot littered with theory models similar to the early-U r-n_s plot. with HBK10/BH11 parameterization of the DE trajectories this can be done.

inflation consistency



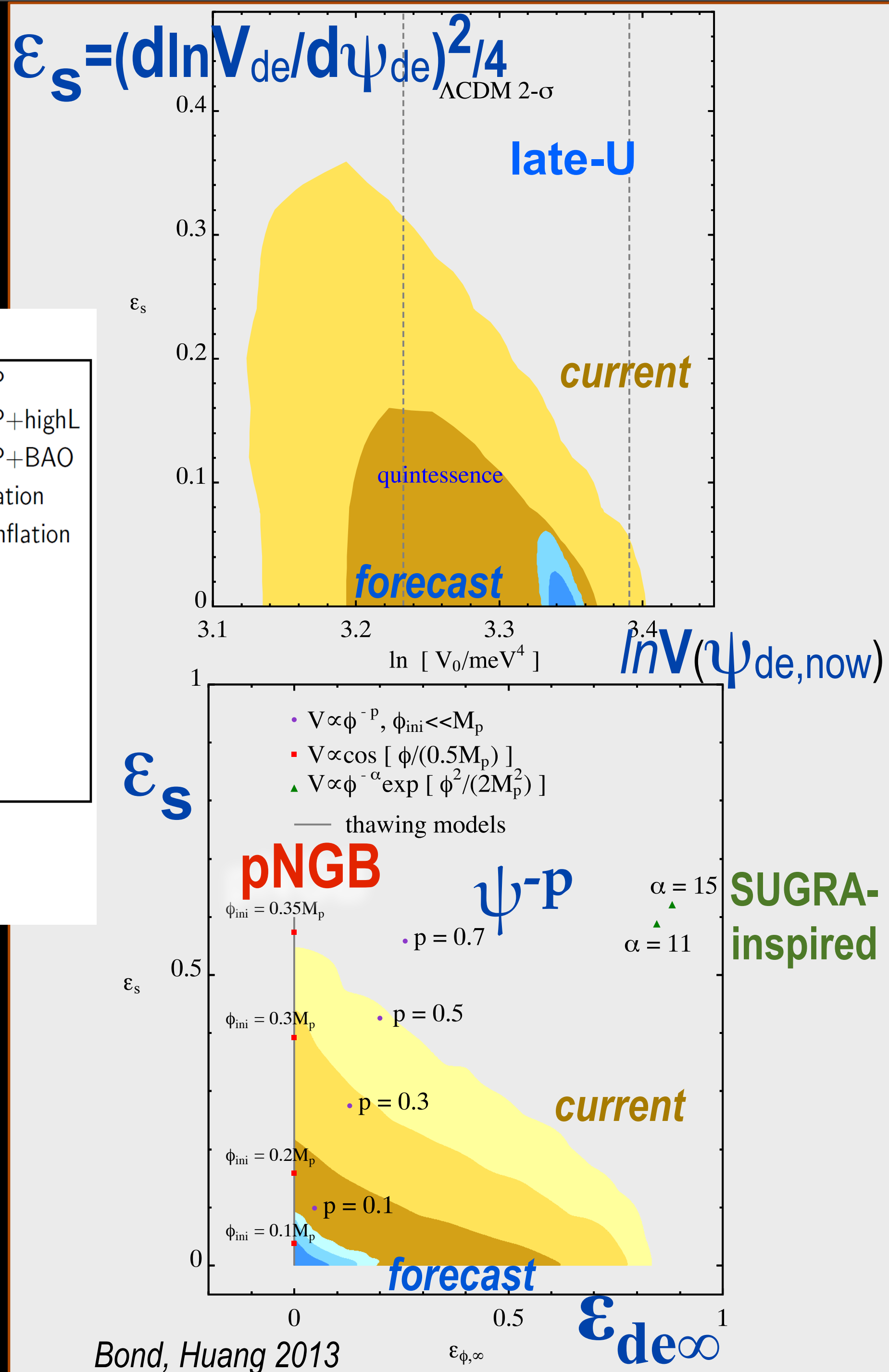
r<0.12 => $\varepsilon_{.002}$ < 0.008 P1.3+WP

uniform acceleration *line*

$\varepsilon \equiv$ ***3KE /(KE+PE)*** *= constant over*

observable e-folds is ***strongly ruled out***

=> early universe acceleration must change over observable scales (as well as to end inflation)



SIMPLICITY

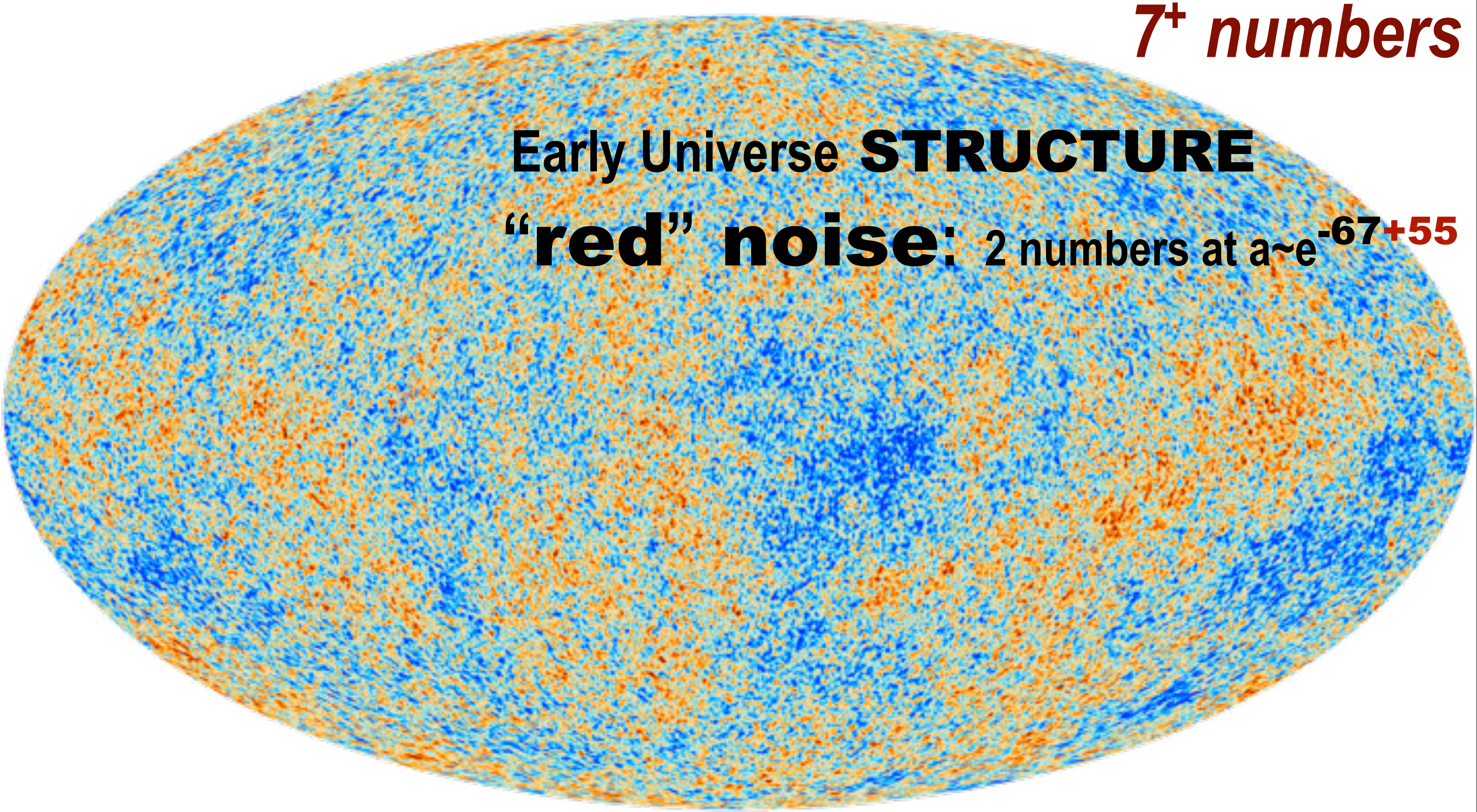
at $a \sim e^{-7} \sim 1/1100$ =>

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

reveals primordial **sound waves in matter**

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

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

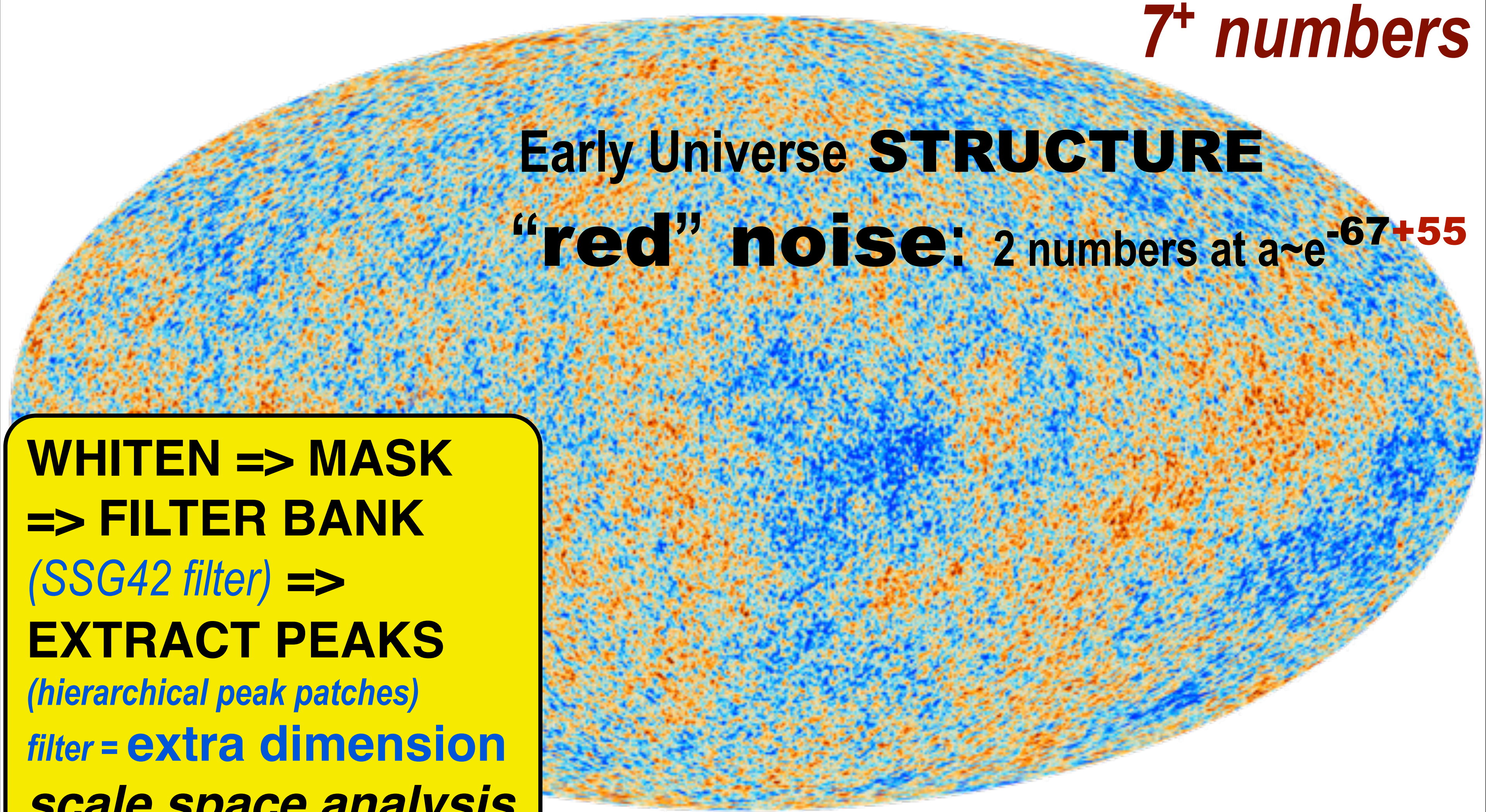


SIMPLICITY *reveals* *primordial* **sound waves** *in matter*

at $a \sim e^{-7} \sim 1/1100$ => *learn* **contents** & **structure** *at 380000 yr,* $a \sim e^{-7}$

at $a \sim e^{-67+60} \sim 1/10^{30+25}$ => *infer the structure far far earlier* $a \sim e^{-67+60}$

7⁺ numbers



Early Universe **STRUCTURE**

“red” noise: 2 numbers at $a \sim e^{-67+55}$

WHITEN => MASK
=> FILTER BANK
(SSG42 filter) **=>**
EXTRACT PEAKS
(hierarchical peak patches)
filter = **extra dimension**
scale space analysis
the ADS of our CFT

SIMPLICITY

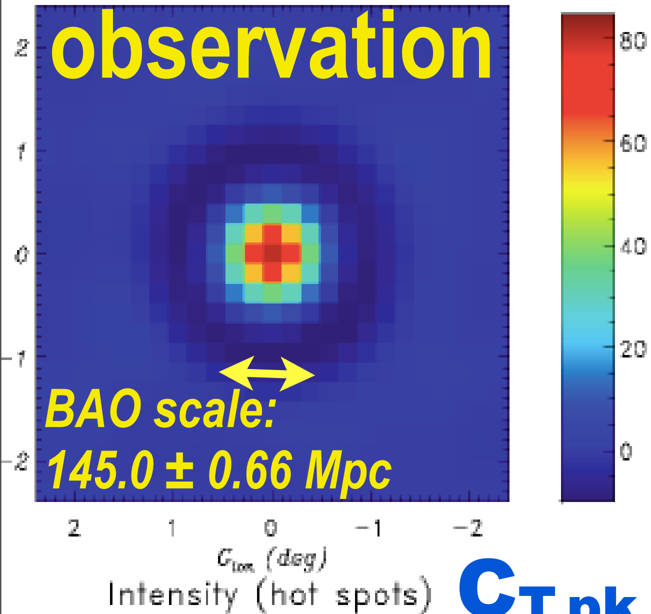
at $a \sim e^{-7} \sim 1/1100$ =>

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

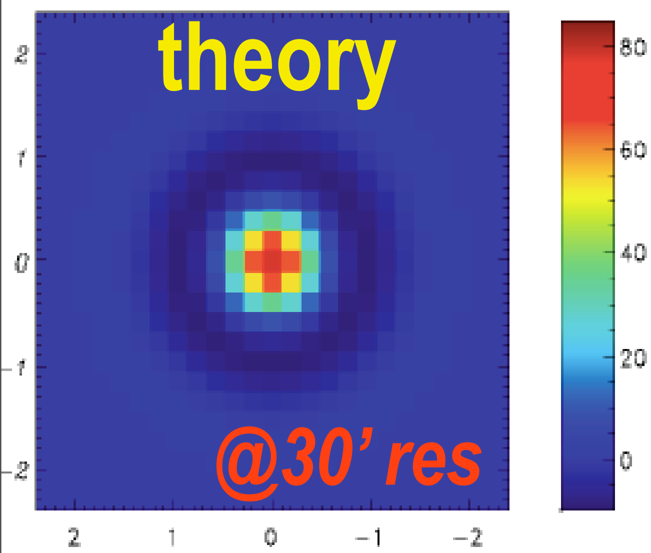
reveals primordial **sound waves** *in matter*

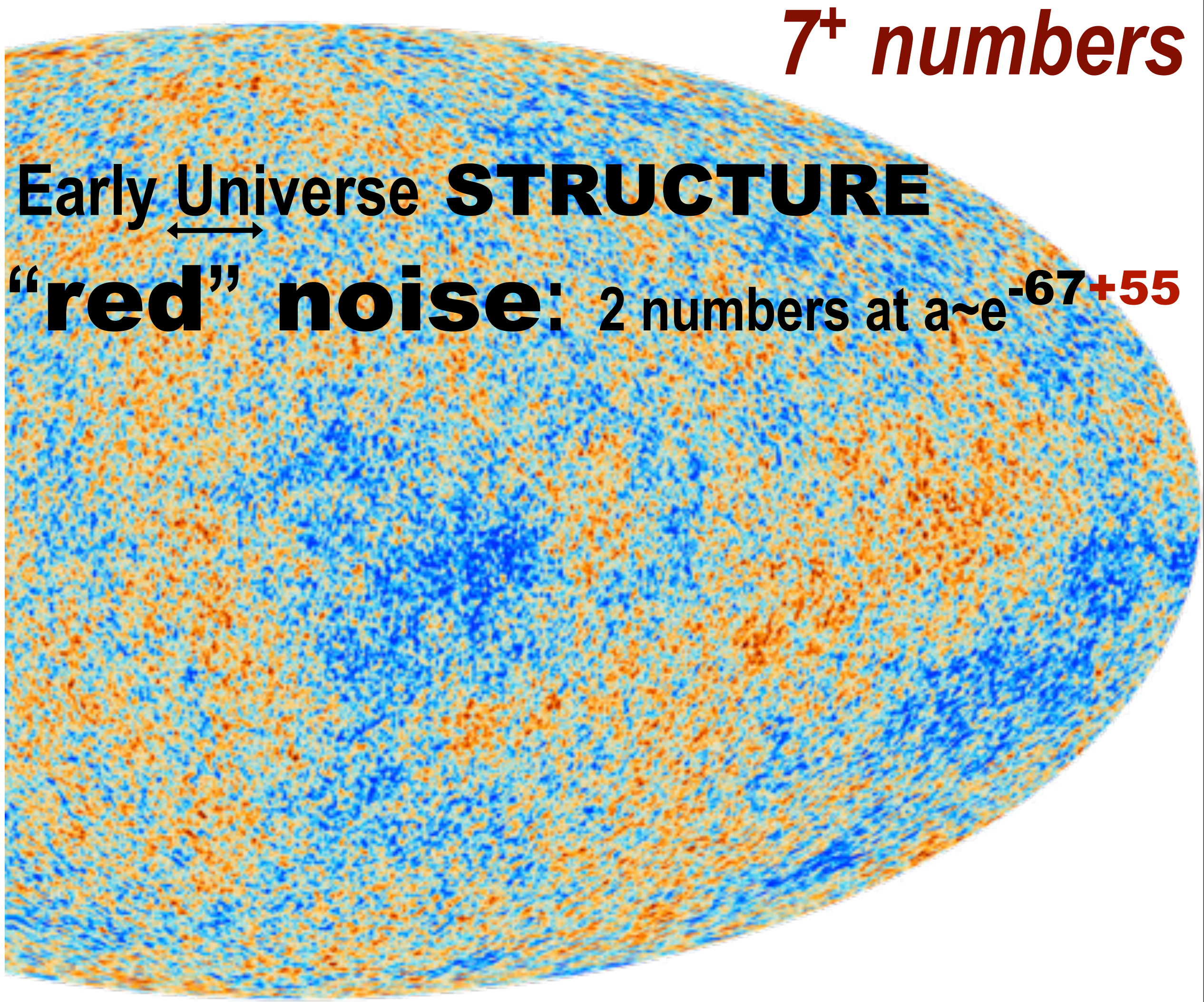
=> *learn* **contents & structure** *at 380000 yr,* $a \sim e^{-7}$

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



$C_{T,pk}$





SIMPLICITY

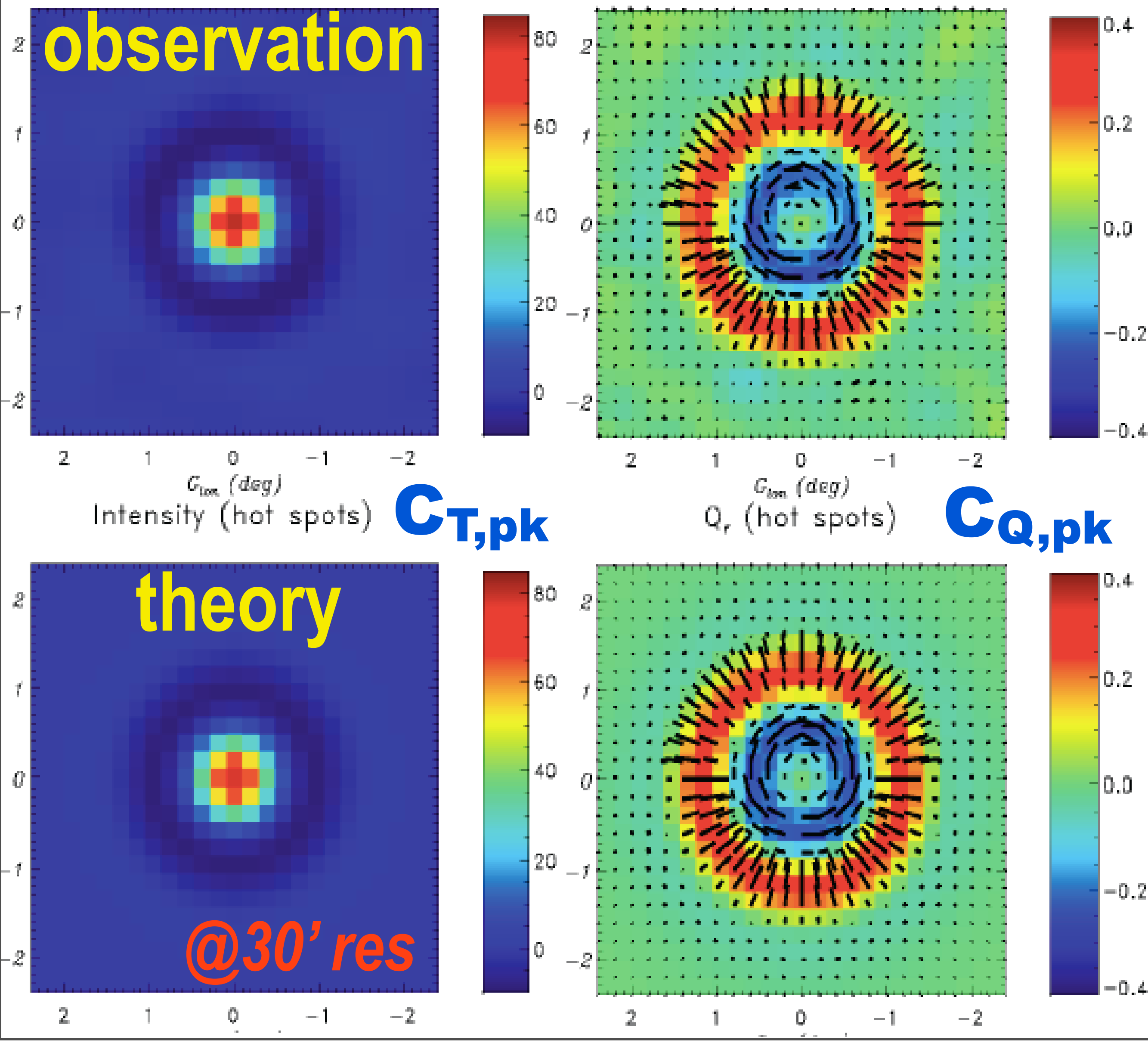
at $a \sim e^{-7} \sim 1/1100$ =>

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

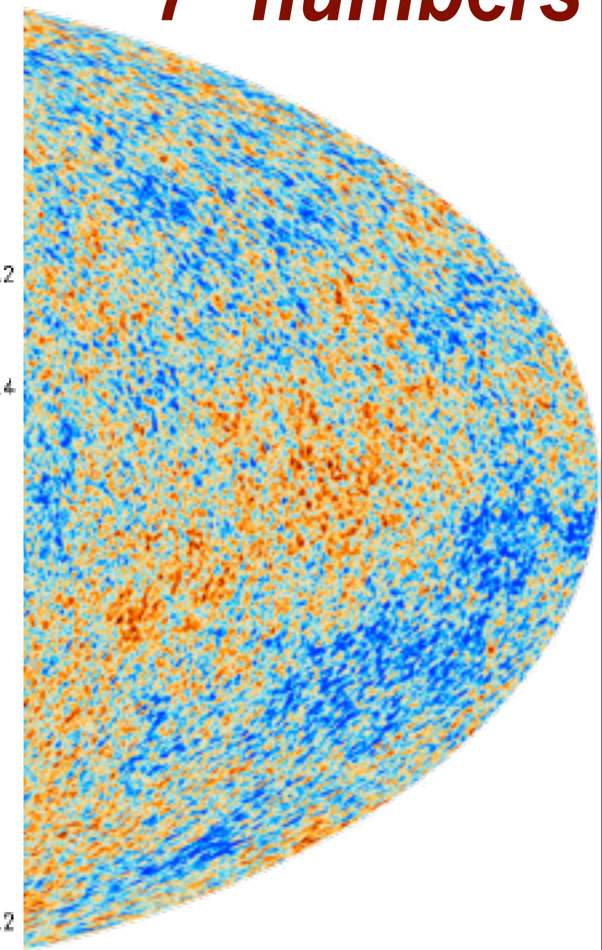
reveals primordial **sound waves** in matter

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

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



7⁺ numbers



SIMPLICITY

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

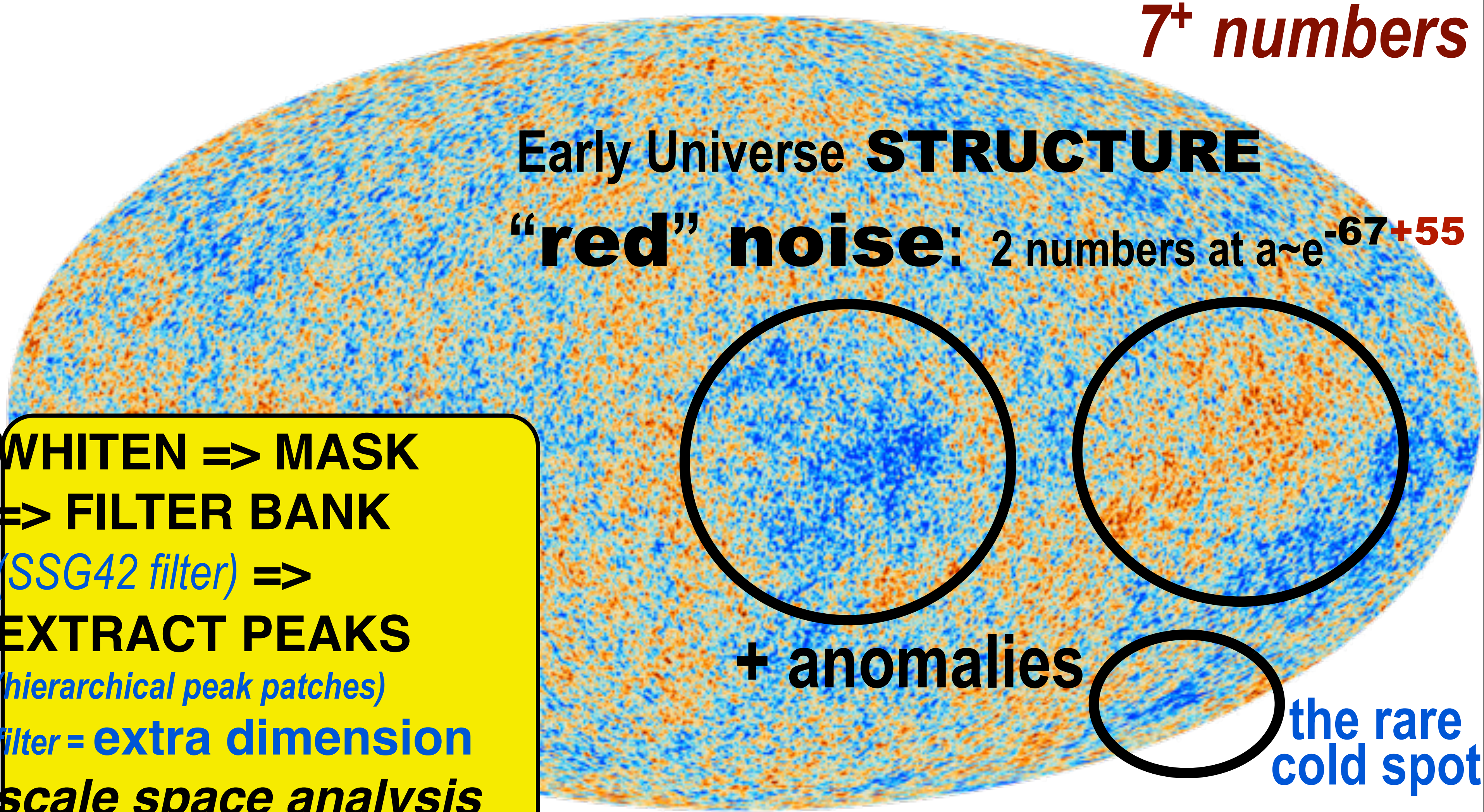
at $a \sim e^{-67+60} \sim 1/10^{30+25}$

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

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

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

7⁺ numbers



Early Universe **STRUCTURE**

"red" noise: 2 numbers at $a \sim e^{-67+55}$

+ anomalies

the rare cold spot

WHITEN => MASK

=> FILTER BANK

(SSG42 filter) **=>**

EXTRACT PEAKS

(hierarchical peak patches)

filter = **extra dimension**

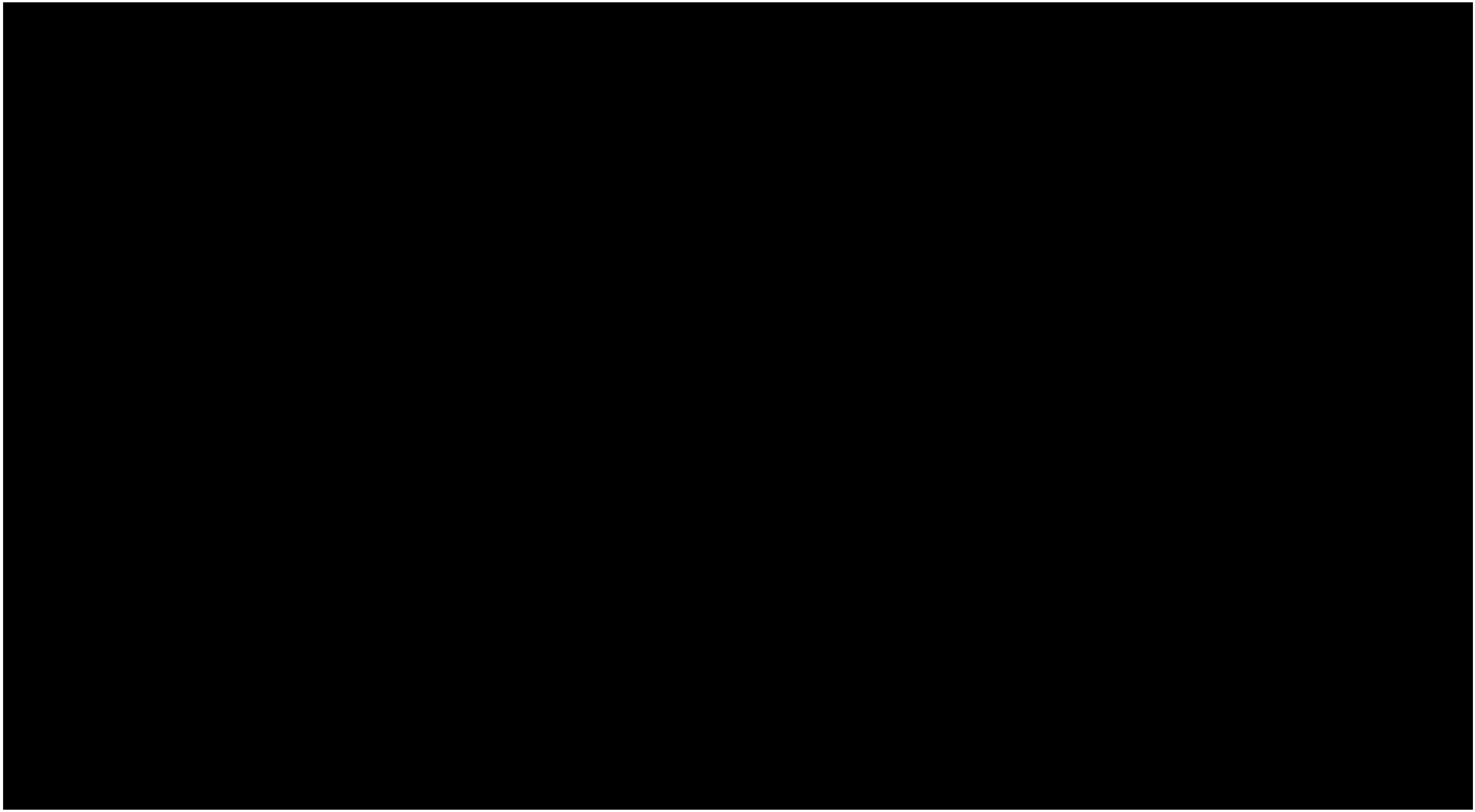
scale space analysis

the ADS of our CFT

COMPLEXITY *at* $a \sim e^{-67}$?

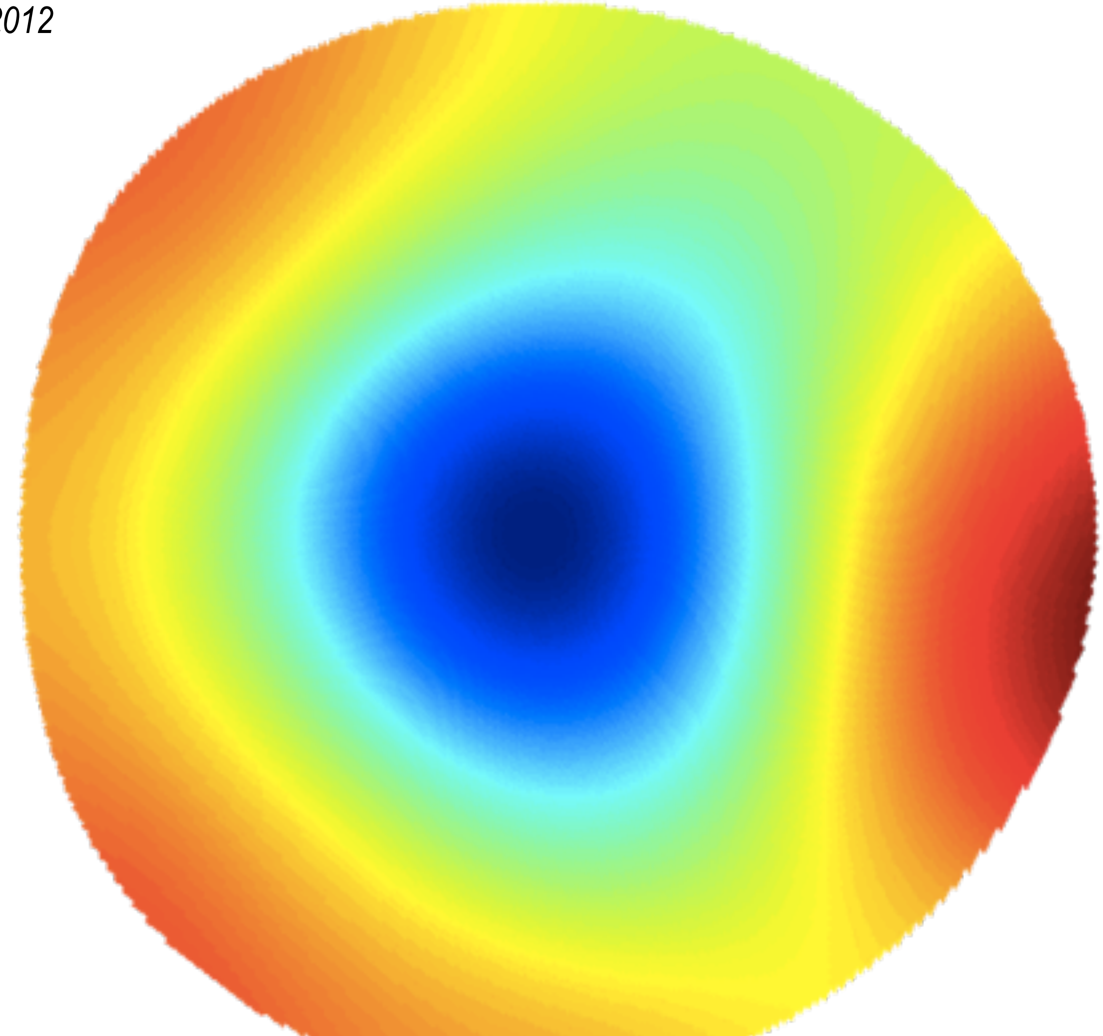
SSG42 FILTER SWEEP

WMAP7



closing in on cold spot structure *(the resolution dimension)*

Bond, Frolov, Nolta, 2012



PLANCK2013 & WMAP7: hot & cold spots agree with BE87 Gaussian stats $n_{pk}(<\nu)$
except for one cold outlier out of Galactic plane (& others near the plane)

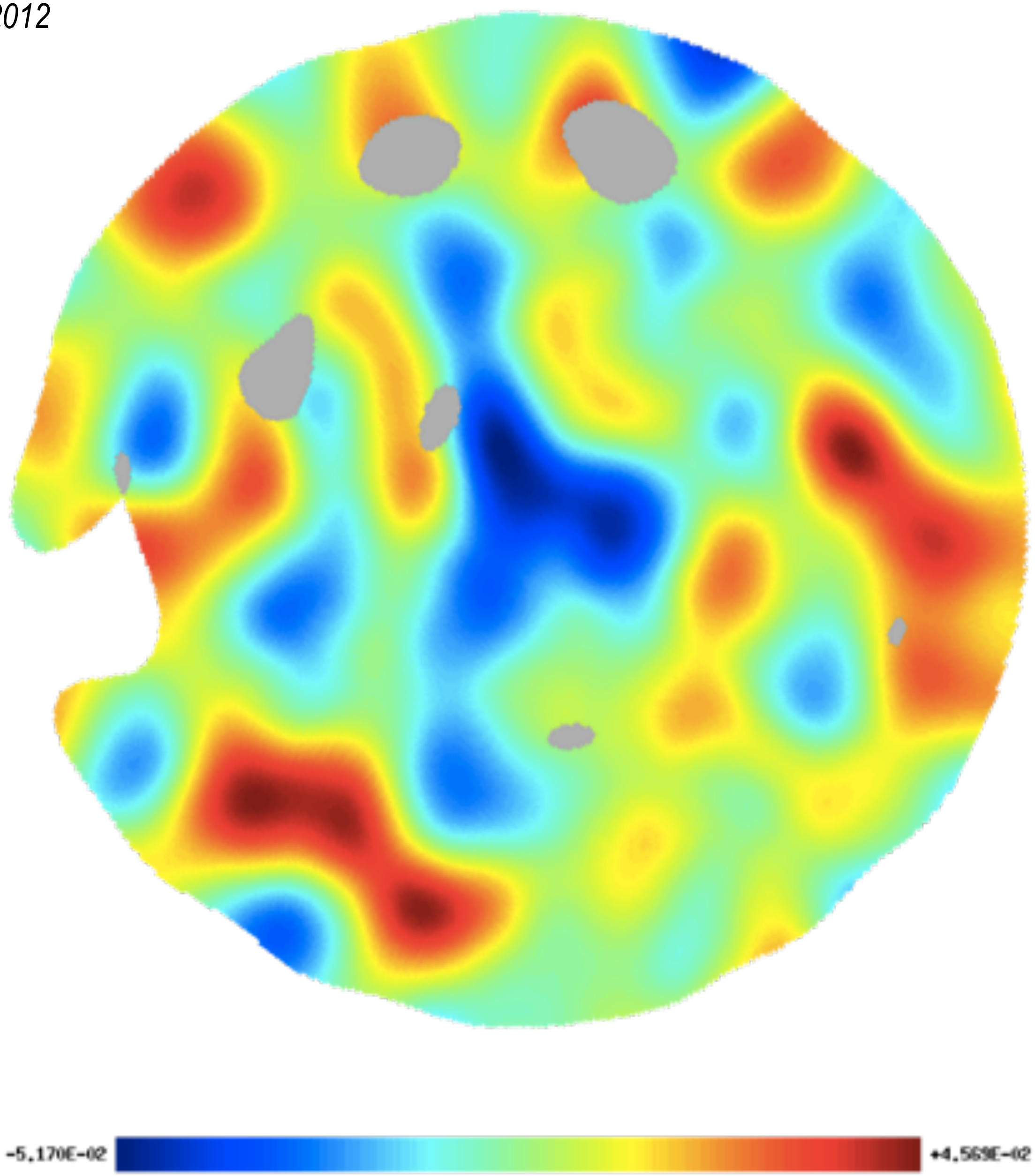
PLANCK2013: 826', 105 peaks, coldest -4.97σ

WMAP7: 800', 105 peaks, coldest -4.87σ significance 1:300

WMAP7: 360', 528 peaks, coldest -4.25σ significance 1:9.1

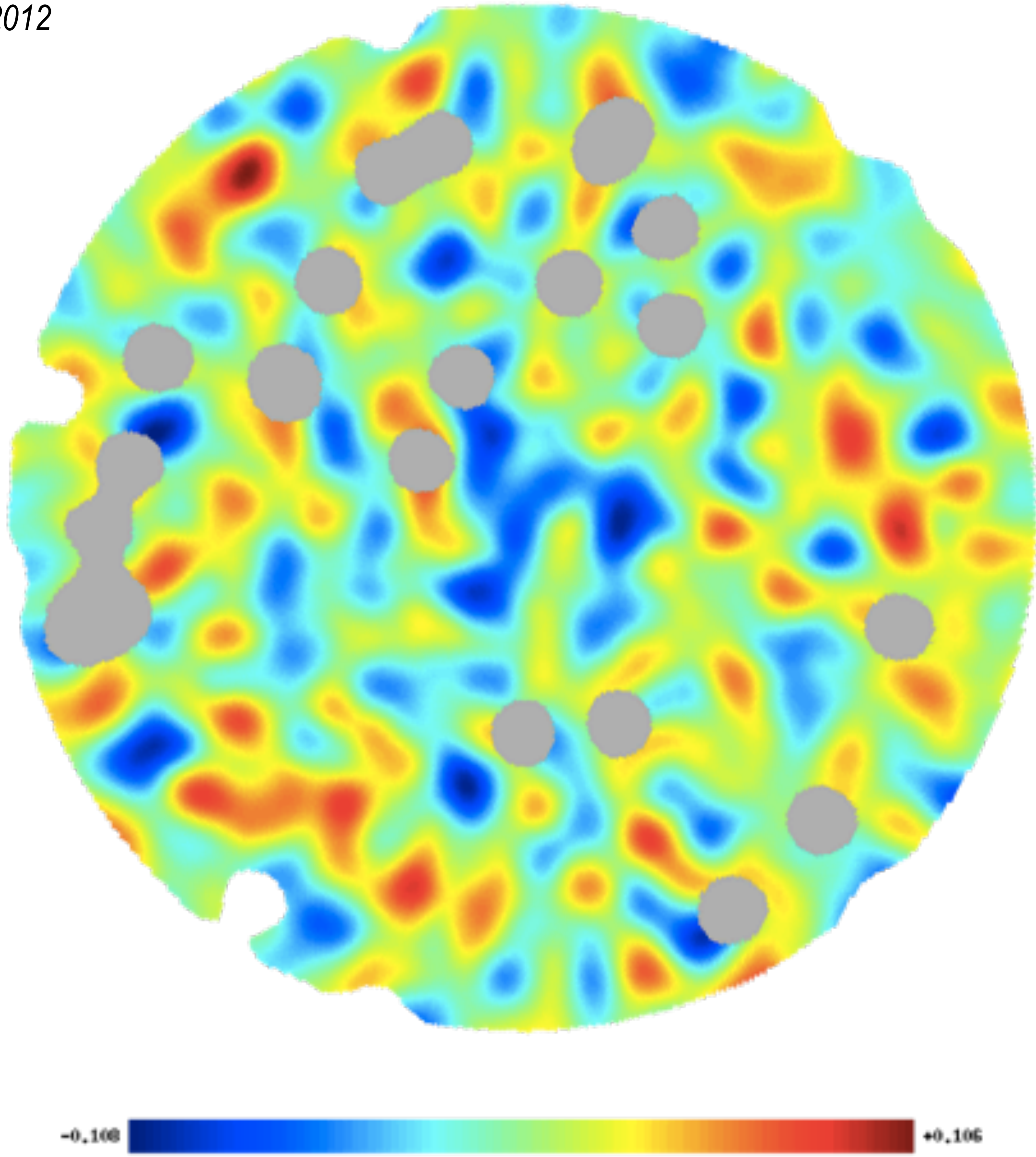
closing in on cold spot structure *(the resolution dimension)*

Bond, Frolov, Nolta, 2012



closing in on cold spot structure *(the resolution dimension)*

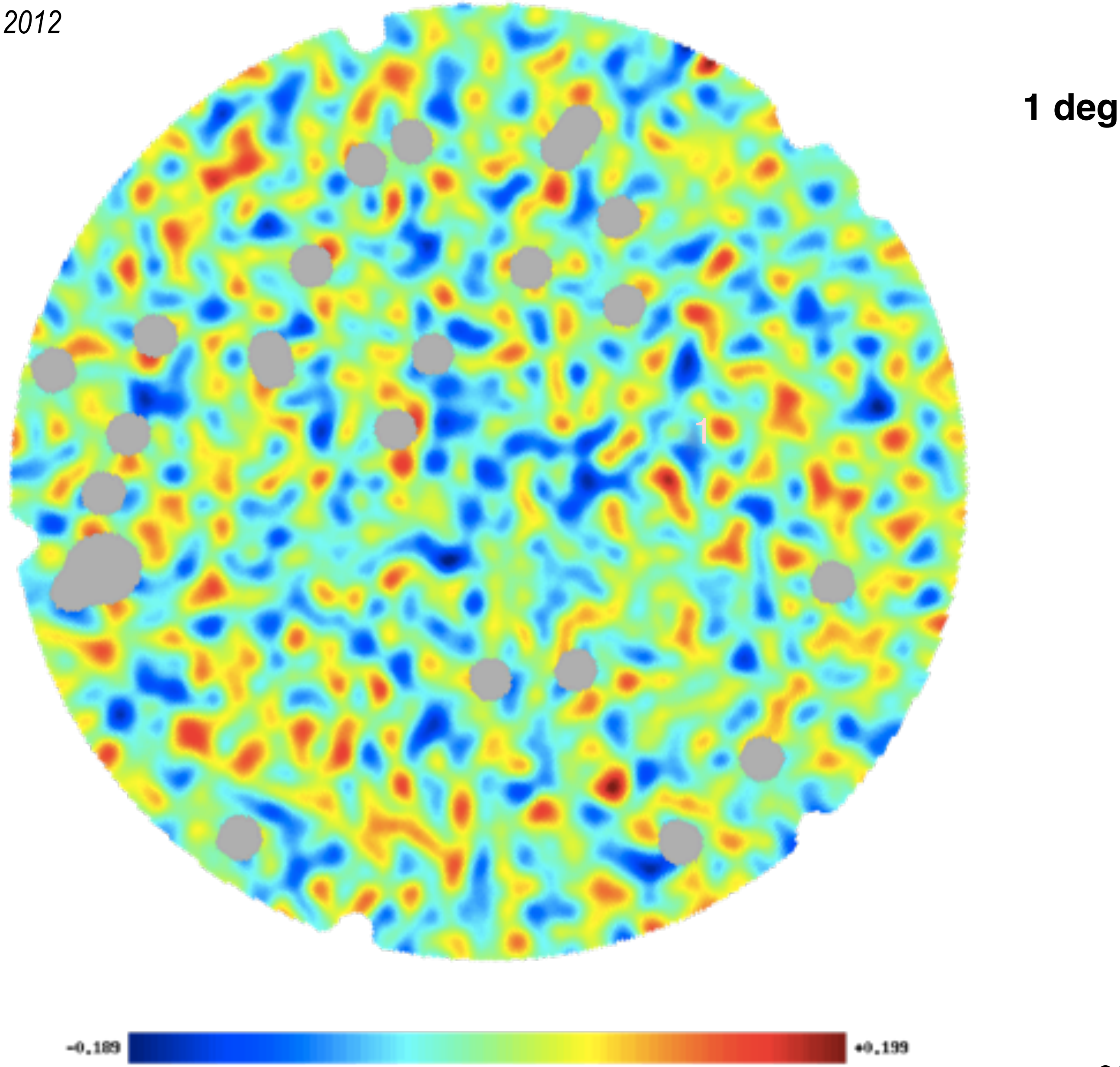
Bond, Frolov, Nolta, 2012



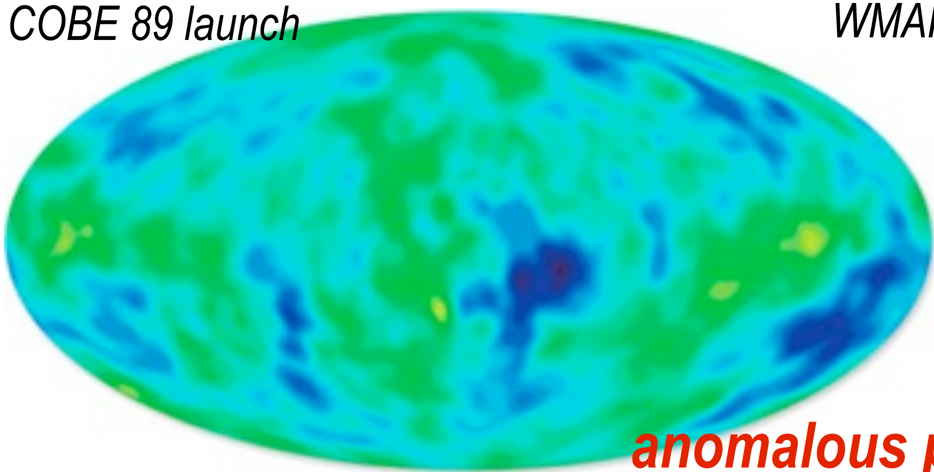
2 deg

closing in on cold spot structure *(the resolution dimension)*

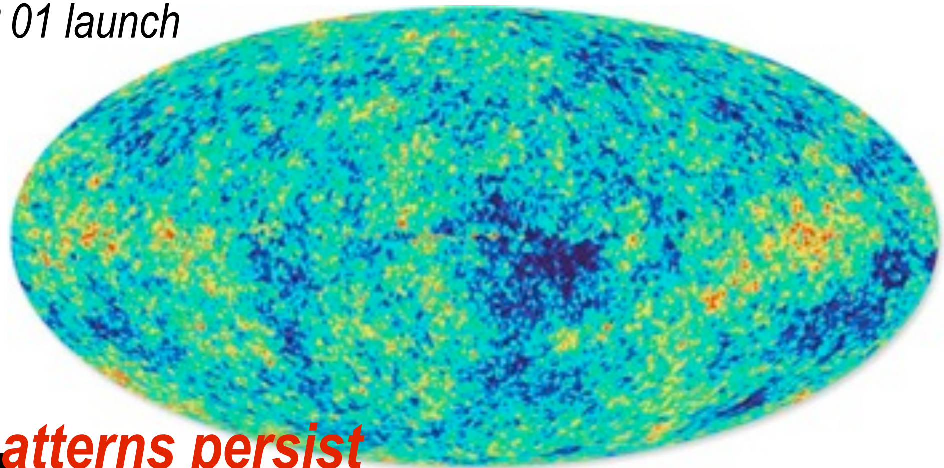
Bond, Frolov, Nolta, 2012



COBE 89 launch

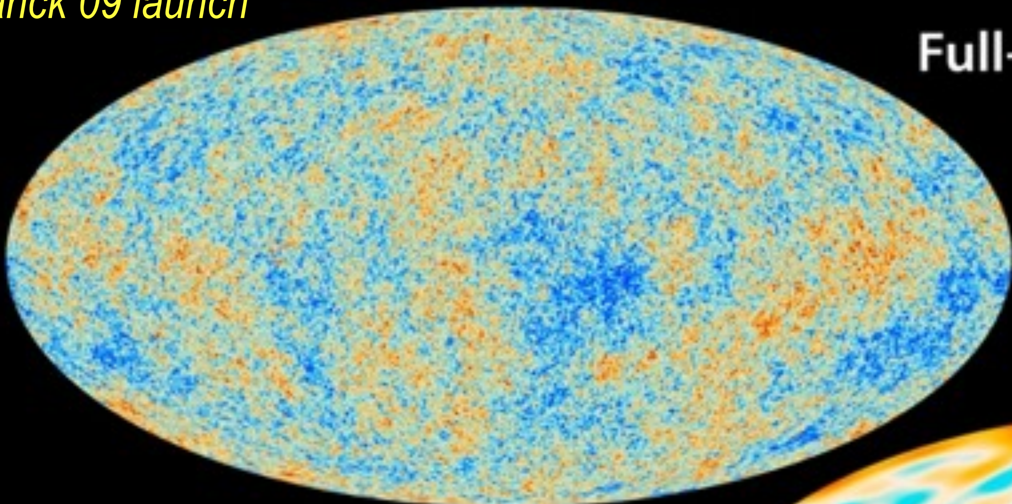


WMAP 01 launch



anomalous patterns persist

Planck 09 launch



Full-Sky Map

NonGaussian 3-point-pattern measure

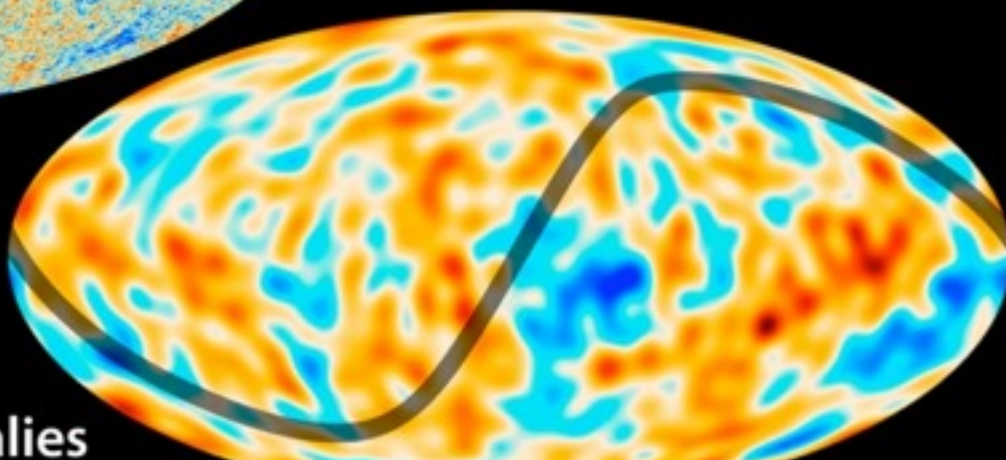
f_{nl}: 2.7 ± 5.8 local => ± 5 (Pext)

-f_{nl}: 42.3 ± 75.2 equil

-25.3 ± 39.2 ortho & f_{NL}^{eff}

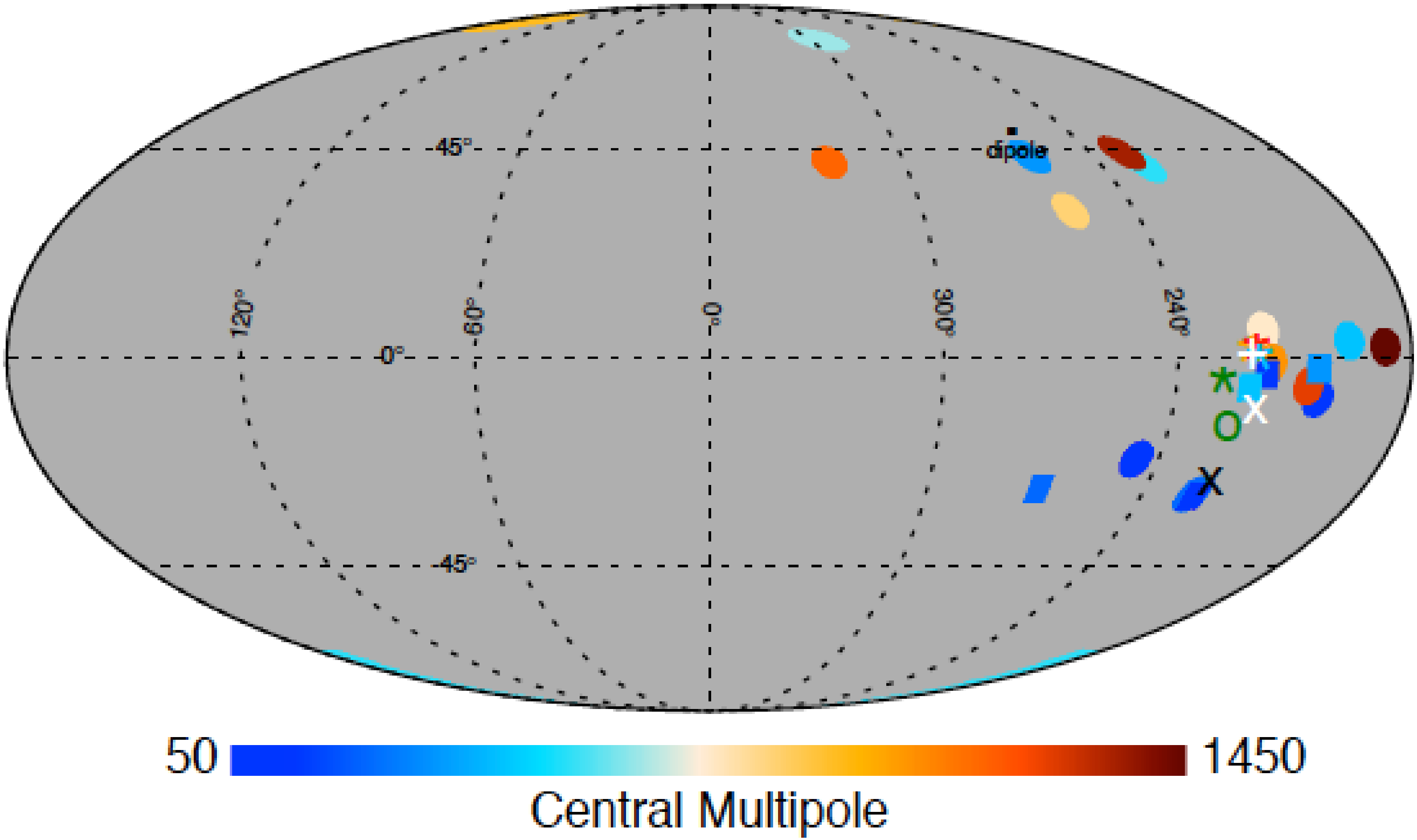
the Planck Collaboration, including individuals from more than 100 scientific institutes in Europe, the USA and Canada

Planck is a project of the European Space Agency, with instruments provided by two scientific Consortia funded by ESA member states (in particular the lead countries: France and Italy) with contributions from NASA (USA), and telescope reflectors provided in a collaboration between ESA and a scientific Consortium led and funded by Denmark.



Anomalies

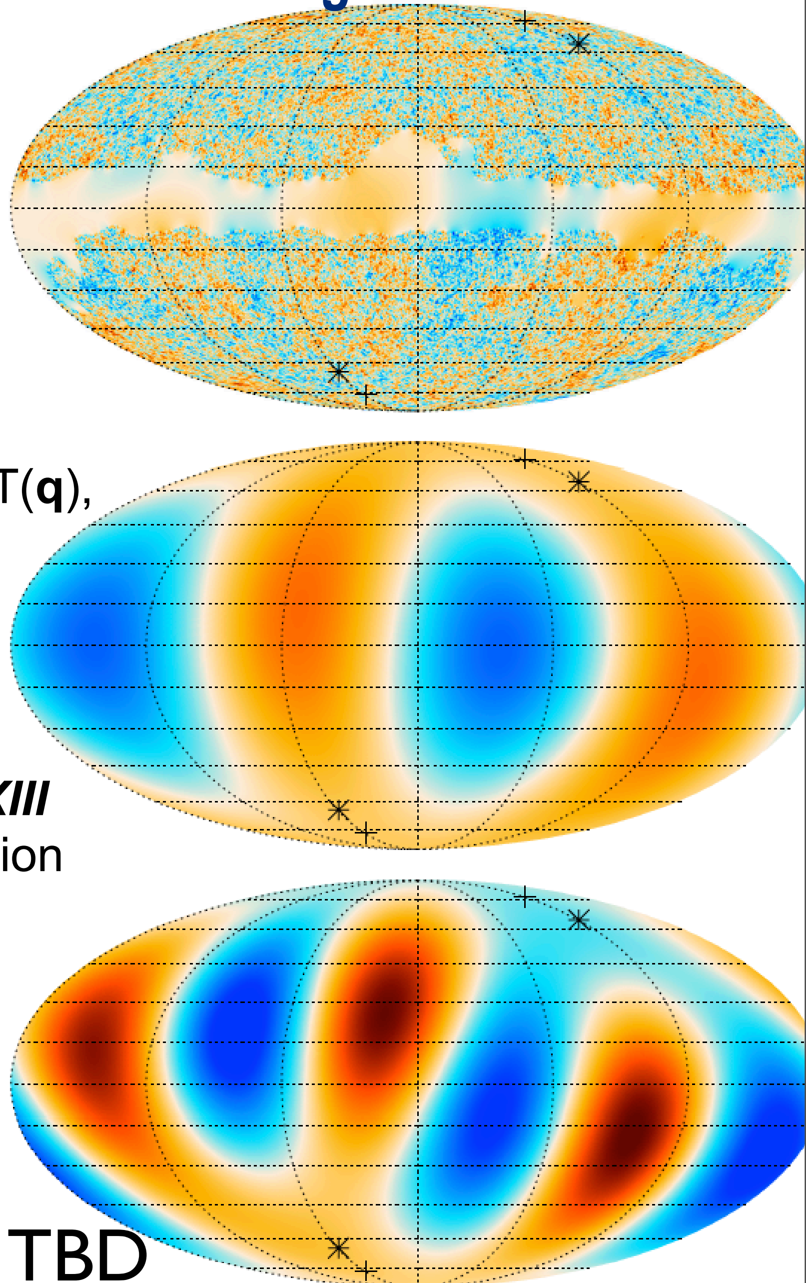
***power spectrum asymmetry**: dipole near Galactic Equator points towards LSS anomaly*



power spectrum asymmetry:
dipole near Galactic Equator points towards LSS anomaly.

Low L asymmetry is firm P13 & WMAP, high L subject to Doppler boost correction

octupole quadrupole alignment within ~10 deg



Challinor & Lewis 02, Hanson+ 09, ***Planck2103 XXVII, Doppler Boosting of the CMB***

dipole modulation $\Delta T(\mathbf{q}) \Rightarrow (1-(x\coth(x/2)-1)\,\mathbf{q.v})\,\Delta T(\mathbf{q})$, $x=h\nu/T$

aberration $\mathbf{q} \Rightarrow \mathbf{q}+\nabla(\mathbf{q.v})$

5σ detection of kinematic dipole effects

influence on high L power asymmetry (cf. ***P13 XXIII Isotropy & Statistics*** TBD) dipole power modulation $<0.2\%$ with $L_{max}=2000$?

low L (<400) power asymmetry is robust

Anomalies in Polarization? TBD

Grand Unified Theory of Anomalies TBD

how (most of) the entropy in matter =>

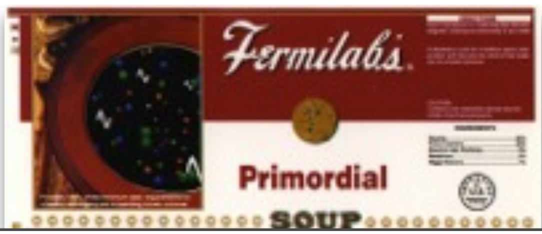
GUT plasma/quark soup => $S(\gamma,\nu)$ was generated *(through a shock-in-time)*

via nonlinear coupling of the inflaton to new interaction channels g,χ_a $V_{eff}(\varphi,\chi_a \,|\, g,\ldots)$ *aka* $V_{eff}(r,\theta_a \,|\, g,\ldots)$ *ultimately to standard model degrees of freedom*

∃ a role for *decaying particles, 1st order phase transitions?*

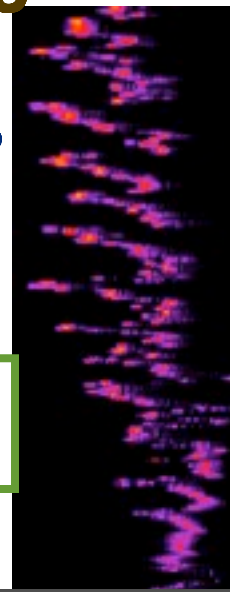
exactly who, what, where, when, why?

we search for fossil "non-Gaussian" structures from this period with Planck +WMAP9



intermittent CMB power bursts from super-bias of a GRF modulating field, a landscape scan

$a_{Shock}(g)$

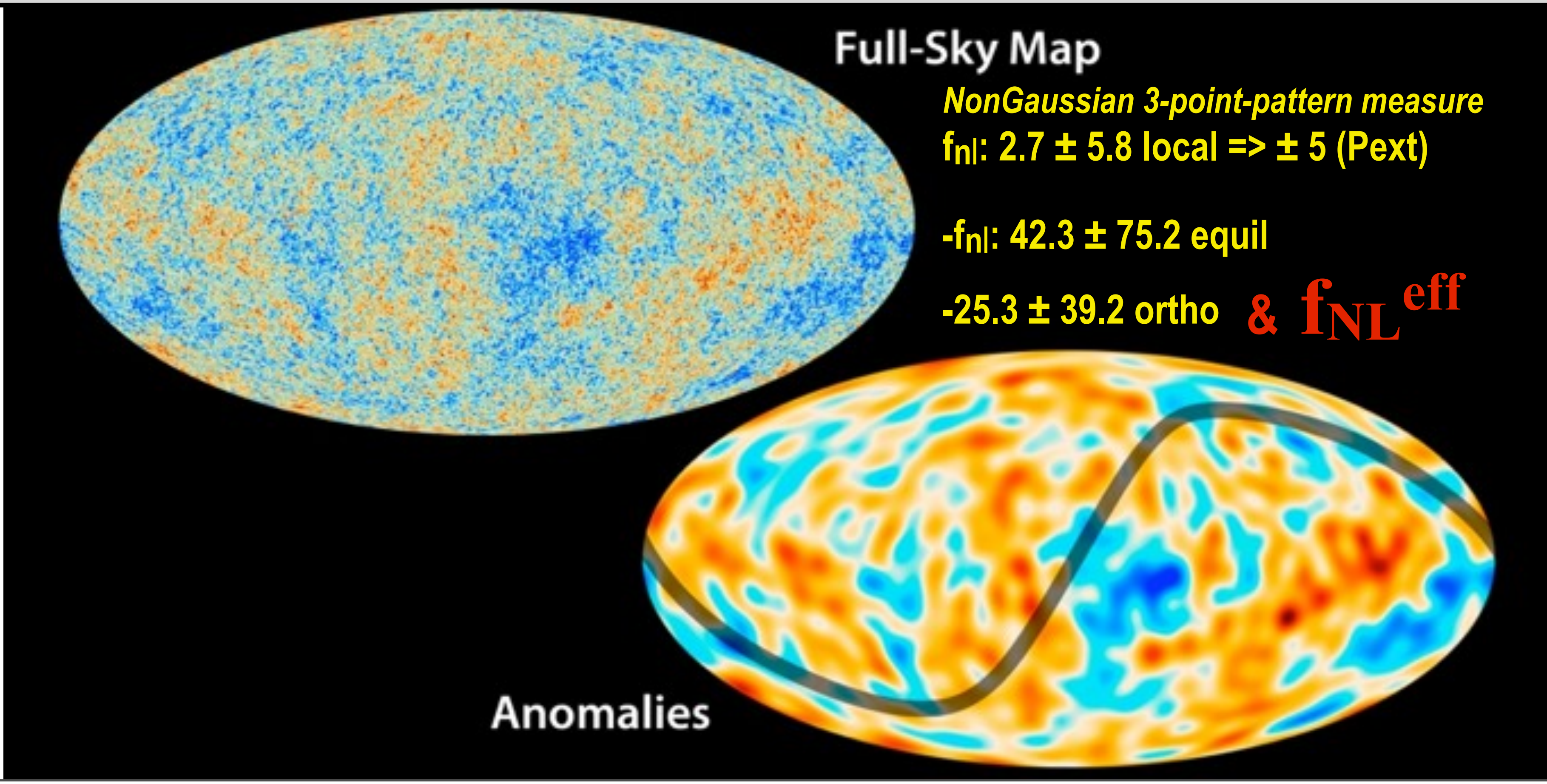


Non-Gaussianity *from* **Modulations** *of Post-inflation Ballistic Trajectories & the* **Shock-in-Times** *of Preheating*

Are LargeScale anomalies statistically significant? no said WMAP7 Bennett+
Seem to be says Planck1.3, so theorists should look again

Planck1.3 says **Size of the Universe > 2*distance to recombination** *for a variety of flat, plus and minus curved topologies, as did COBE and WMAP. Inflation models prefer a super-big universe, with nothing special just beyond our Hubble volume leaking in - maybe. Thus, can anomalies relate to inflation, given the strong non-G pattern-constraints from the 3-point function coded in f_{NL}*

e.g., **from LS-intermittency due to an ultraLS modulating field** *remembering* **post-inflation entropy generation** *BondFrolovHuangKofman09, BBraden13, B[2]FH13*



primordial non-Gaussianity

$\zeta_{NL}(x) = \zeta_G(x) + f_{NL*}\,(\zeta_G^2(x) - \langle\zeta_G^2\rangle)$

local smooth. use optimal pattern estimator

cf. DBI inflation: non-quadratic kinetic energy

cosmic/fundamental strings/defects

from end-of-inflation & preheating

$\zeta_{NL}(x) = \zeta_G(x) + F_{NL}(\chi_b(x))$

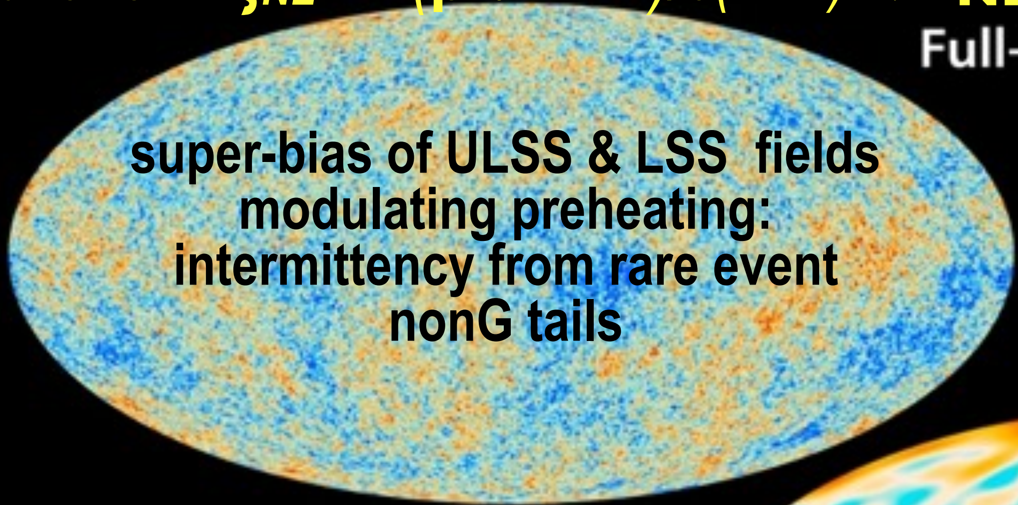
modulating preheating

f_{NLeff} + cold spots

$\zeta_{NL}(x) = \zeta_G(x) + F_{NL}(g_b(x))$

phonon ~ $\zeta_{NL} = \ln(\rho\, a^{3(1+w)})/3(1+w)$ => $f_{NL*} = 3/5\, f_{NL} - 1 = 0.44 \pm 3.5$

Full-Sky Map



super-bias of ULSS & LSS fields modulating preheating: intermittency from rare event nonG tails

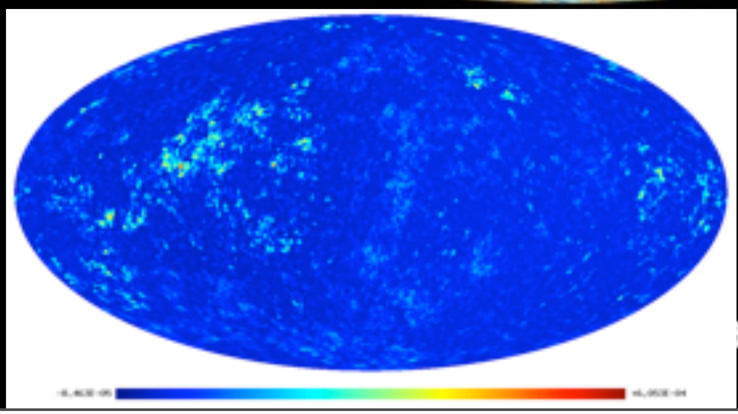
NonGaussian 3-point-pattern measure

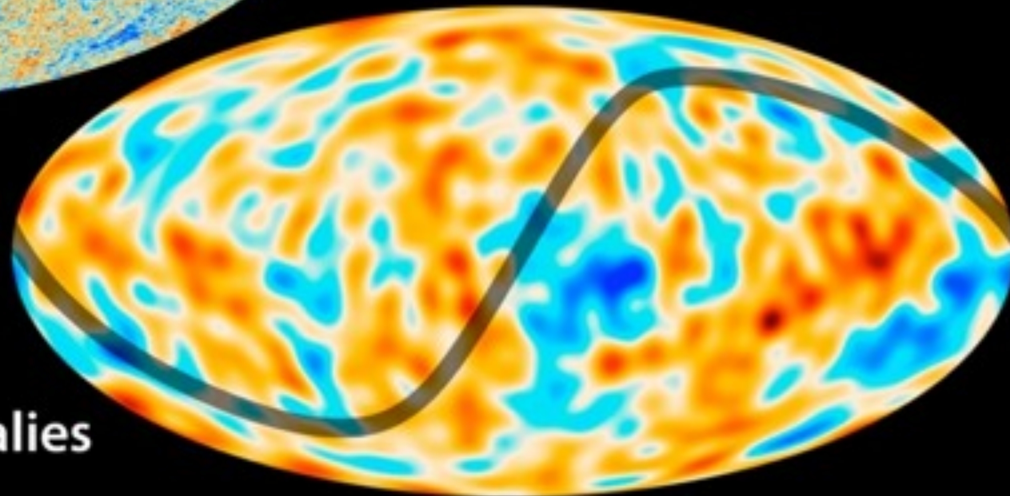
f_{nl}: 2.7 ± 5.8 local *cf.* ± 5 (Pext)

=> $f_{NL*} = 0.44 \pm 3.5$

-f_{nl}: 42.3 ± 75.2 equil

-25.3 ± 39.2 ortho



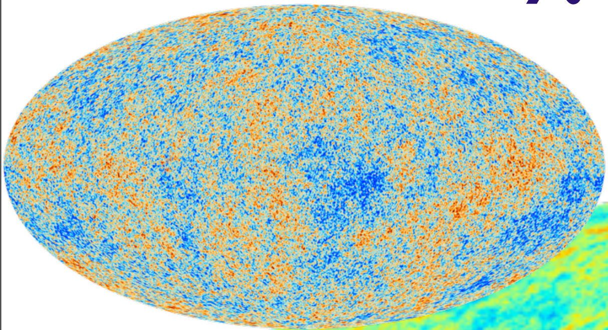


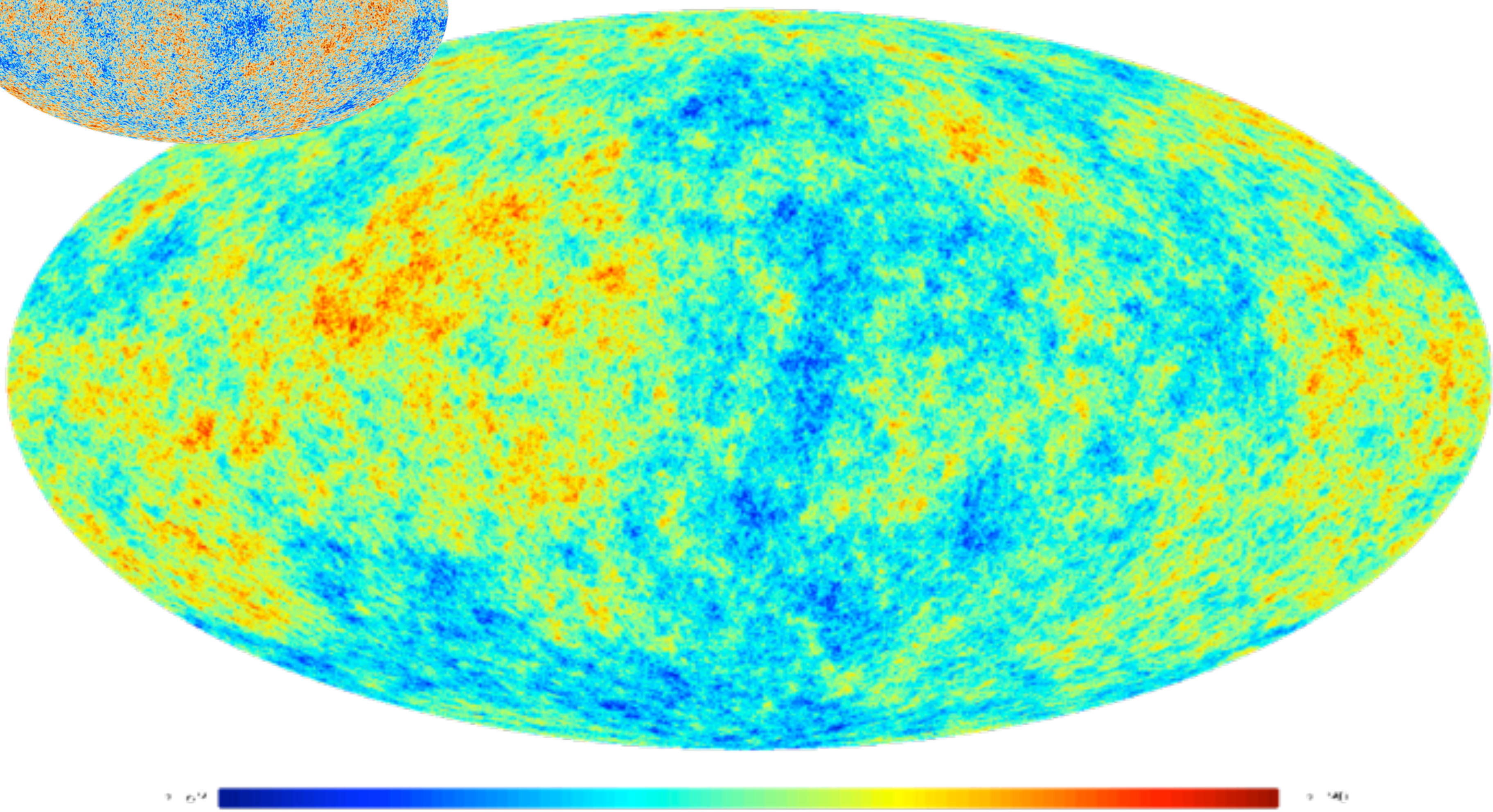
alies

simulated sky with Gaussian inflaton-induced + **uncorrelated subdominant non-Gaussian isocon-modulated preheating**. Landscape-accessing super-horizon

control variable = $\chi > h$ => *super-bias, intermittent, extended source-like*

Bond,Braden,Frolov,Huang13

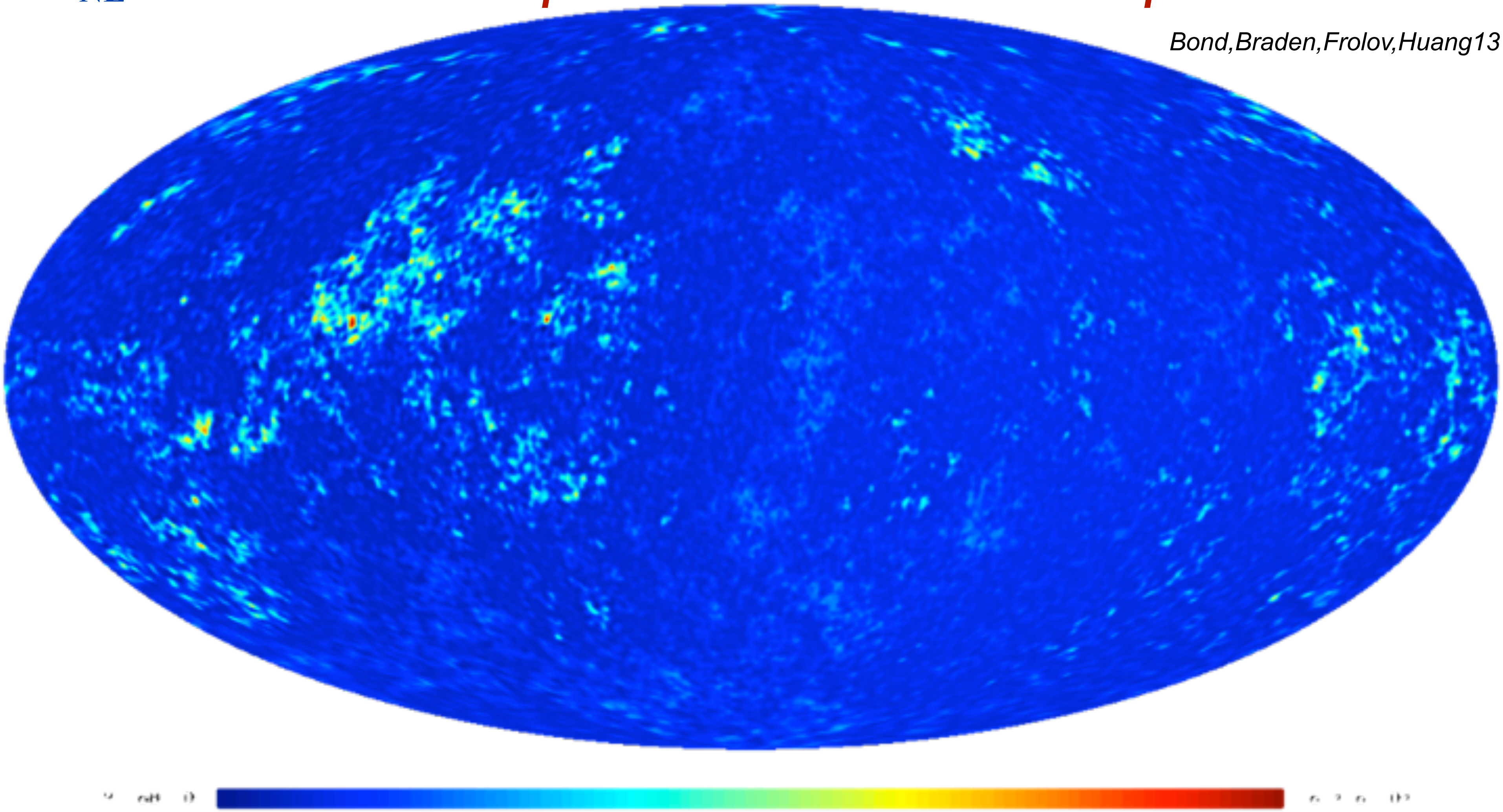




bispectrum & 3-point ~ $f_{sky,patches}^3$ => not overly constraining & standard

f_{NL} method is ***not how to pattern-search for intermittent power bursts***

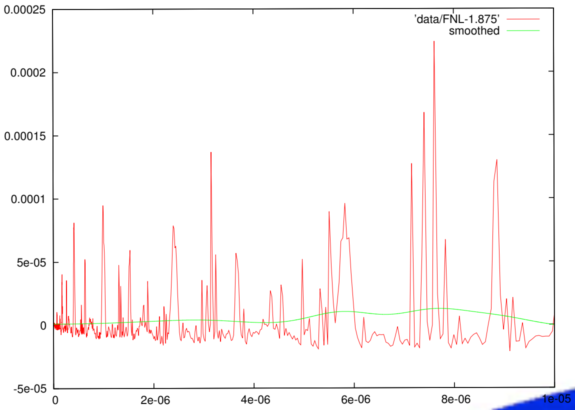
Bond,Braden,Frolov,Huang13



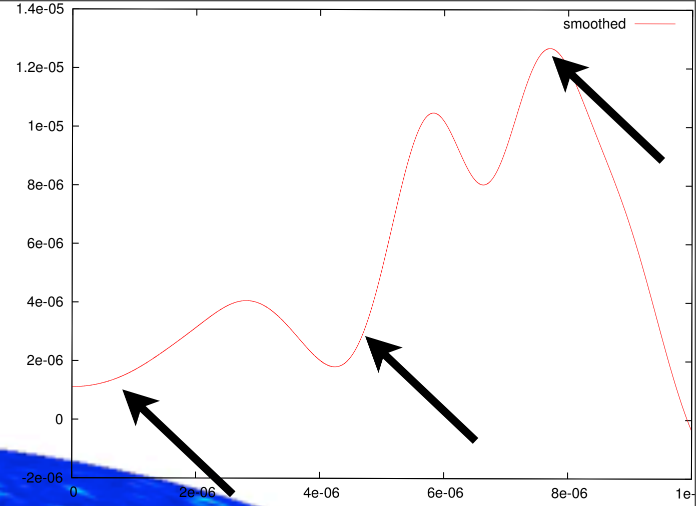
for some $\chi_{>h}$ there is a perturbative regime:

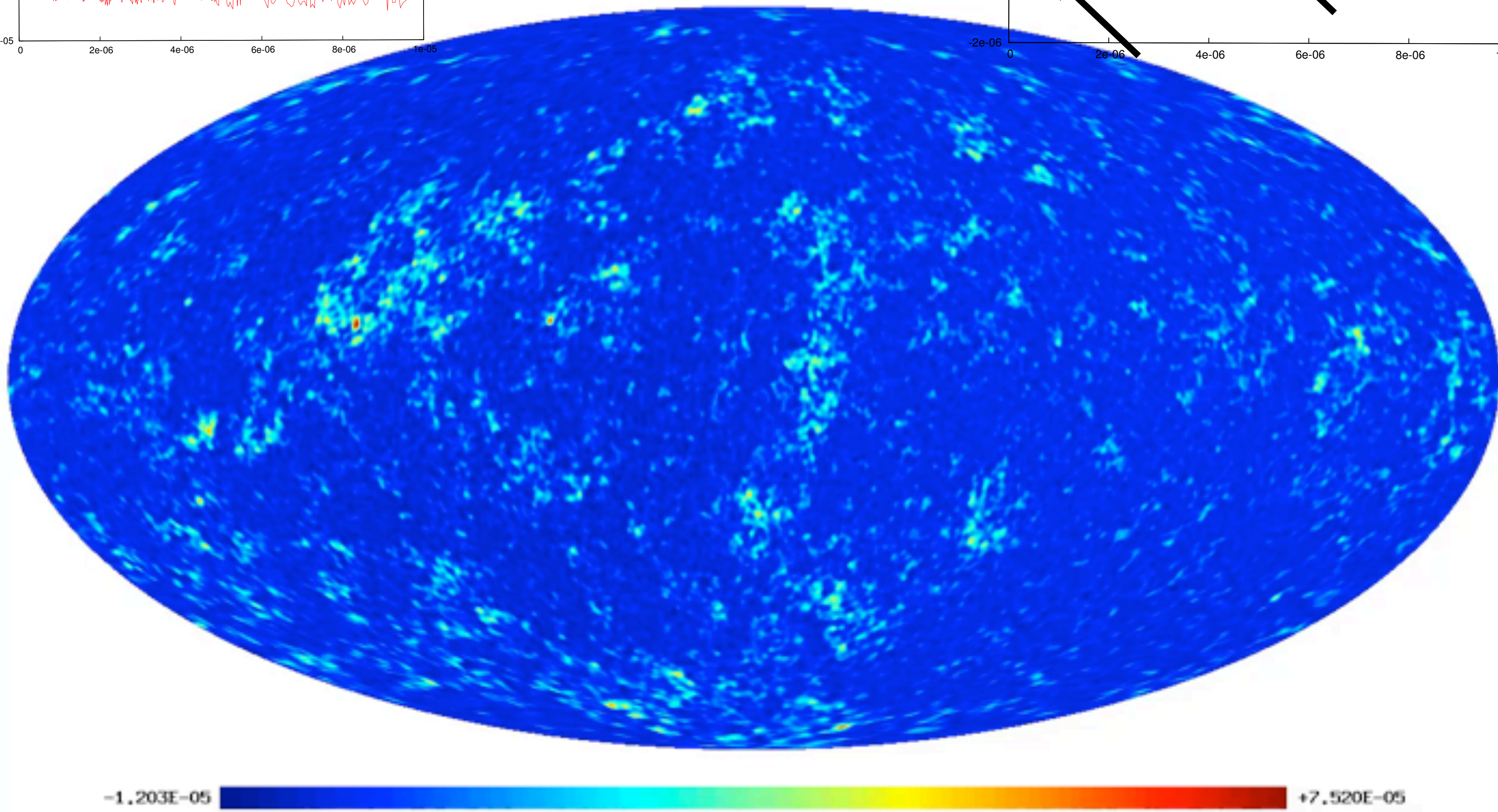
$$f_{NL}^{equiv} = \beta \chi^2 f_\chi \, [P_\chi / P_\phi]^2 (k_{pivot})$$ => constrain $f_\chi^3 \, \chi_{>h}^2$

subdominant structure change as we scan $\chi > h$

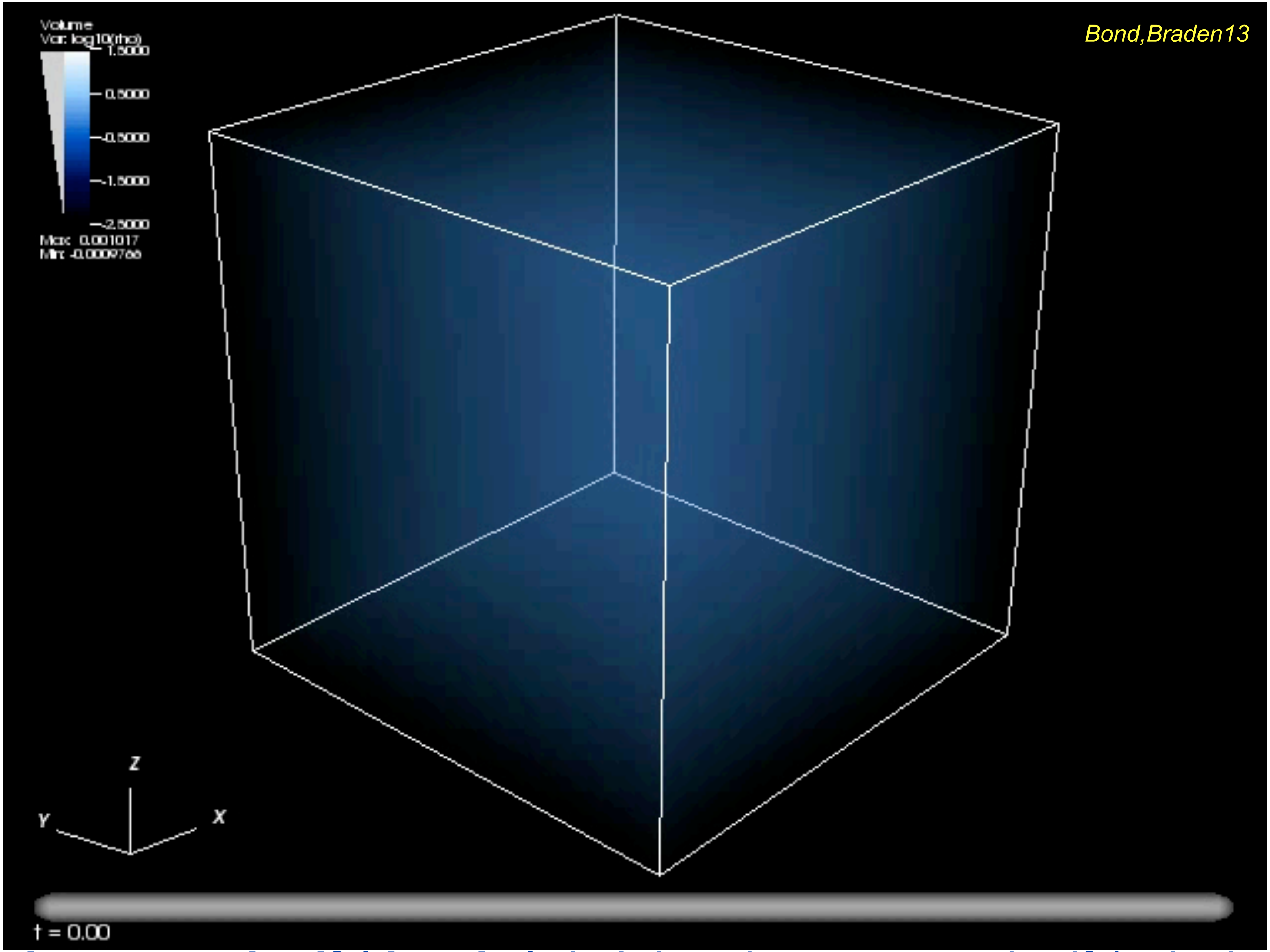


Bond,Braden,Frolov,Huang13





quadratic inflaton **trilinear coupling** $V(\phi,\chi) = 1/2\, m^2\phi^2 + 1/2\, \sigma\, \phi\chi^2 + 1/4\, \lambda\, \chi^4$



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

Bond,Braden,Frolov,Huang13

from

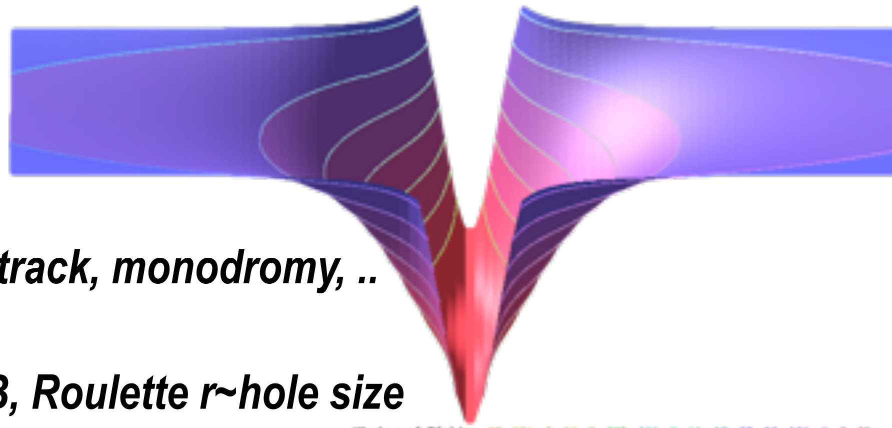
quartic inflaton $V(\phi,\chi) = 1/4\ \lambda\phi^4 + 1/2\ g^2\phi^2\chi^2$

quadratic inflaton $V(\phi,\chi) = 1/2\ m^2\phi^2 + 1/2\ g^2(\sigma)\phi^2\chi^2$ ..

quadratic inflaton trilinear coupling $V(\phi,\chi) = 1/2\ m^2\phi^2 + 1/2\ \sigma\ \phi\chi^2 + 1/4\ \lambda\ \chi^4$

quartic inflaton variable Planck mass $V(\phi,\chi) = 1/4\ \lambda\phi^4 - 1/2\ \xi\ \phi^2 R + 1/2\ g^2\phi^2\chi^2$

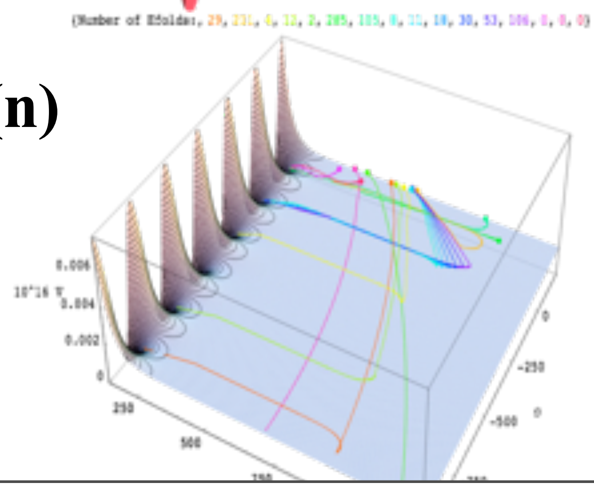
aka Higgs inflation. flattened effective potential in the Einstein frame



to

angular variables ***pNGB natural inflation, racetrack, monodromy, ..***

2 field: $V(r,\theta) = \sum_M V_M(r)\cos(m\theta)$ ***pNGB, Roulette r~hole size***



3 field: 3D $\varphi\ \chi\ \sigma$ fields $V(r,n) = \sum_{LM} V_{LM}(r) Y_{LM}(n)$

5 field: *angle variables in SU(5) & etc.*

to?

Simple exercises to flatten your potential

Xi Dong, Bart Horn, Eva Silverstein, and Alexander Westphal 2011

Stochastic Inflation = Ballistic Drift + Quantum Diffusion => Ballistic => End of Inflation => shock-in-time = HEATING

HEATING: how to damp coherent ballistic trajectories into high-k entropy

in context of fundamental scalar field nonlinear evolution equations (inflaton, isocons) & effective potentials & kinetic energies

*post KLS93: via inflaton self-couplings; isocon-inflaton field couplings, fermion-bar fermion, gauge fields, pseudo-scalar*FFdual,*

tachyonic instability: m_{eff}^2 <0 single field can preheat fast with only a few oscillations, eg roulette in the groove, 2-field trilinear is also fast

*Stochastic inflation works: ballistic trajectories for fields q_X with kicks from sub-horizon waves dW_X causing nearby trajectories to deviate, ζ_{NL} like dE+pdV a near-adiabatic invariant, sourced by stress*strain-rate & energy currents (regularizer between nearby positions X).*

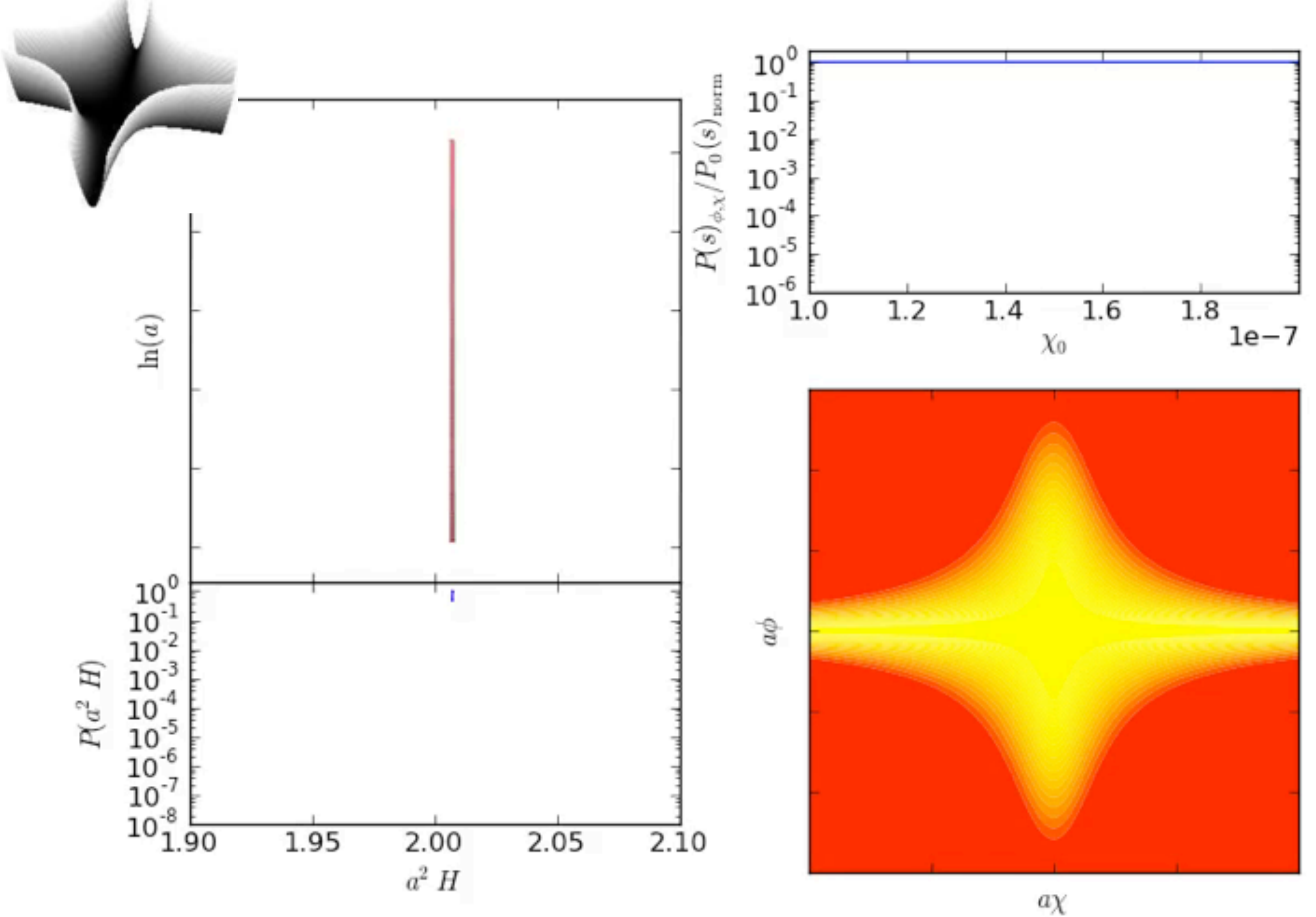
$\varepsilon = -3/2\, d\ln \rho / d\ln a^3 = 1$ defines End of Inflation (cf. ε <.0075 observable range from r?), but it is not a magic boundary, dragged trajectories break into (spatially independent) oscillations. weak point-to-point coupling until ...

new picture: ballistic until the shock-in-time = huge time-localized non-eq entropy generation; slow V-dependent S-evolution. only weak-coupling of nearby points before => very fast determination of ζ_{NL}(modulator(x)), e.g. modulator field = χ_i(x), g(x), ... ULSS & LSS & SSS

Bond,Braden13 , Bond,Braden,Frolov,Huang13

e.g., distribution functions of pre-shock nearby-trajectory caustics => spiky ζ_{NL}

initial conditions spanning (roughly) a single period (ie. \mu_o T with \mu_0 the Floquet exponent of chi_0

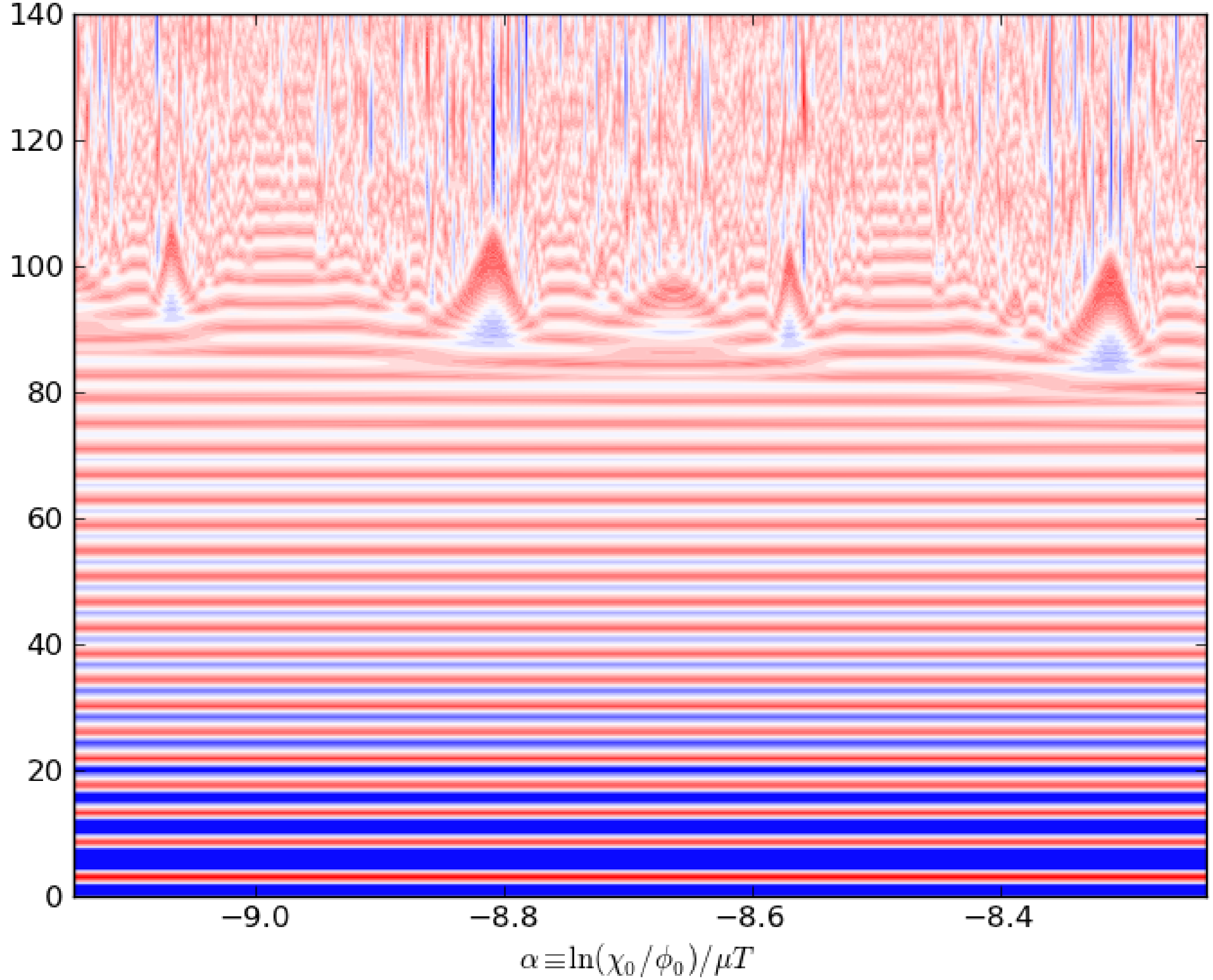


distribution functions & trajectory caustics

Bond,Braden,Frolov,Huang13

quartic inflaton variable Planck mass $V(\phi,\chi) = 1/4\ \lambda\phi^4 - 1/2\ \xi\ \phi^2 R + 1/2\ g^2\ \phi^2\ \chi^2$

ξ=-1



spikes persist with flattened effective potential

Bond,Braden,Frolov,Huang13

when domain walls (big bubbles) collide in full 3D lattice sims

with tiny zero point & wall fluctuations

=> burst of scalar radiation at c

(with outgoing radiation BCs)

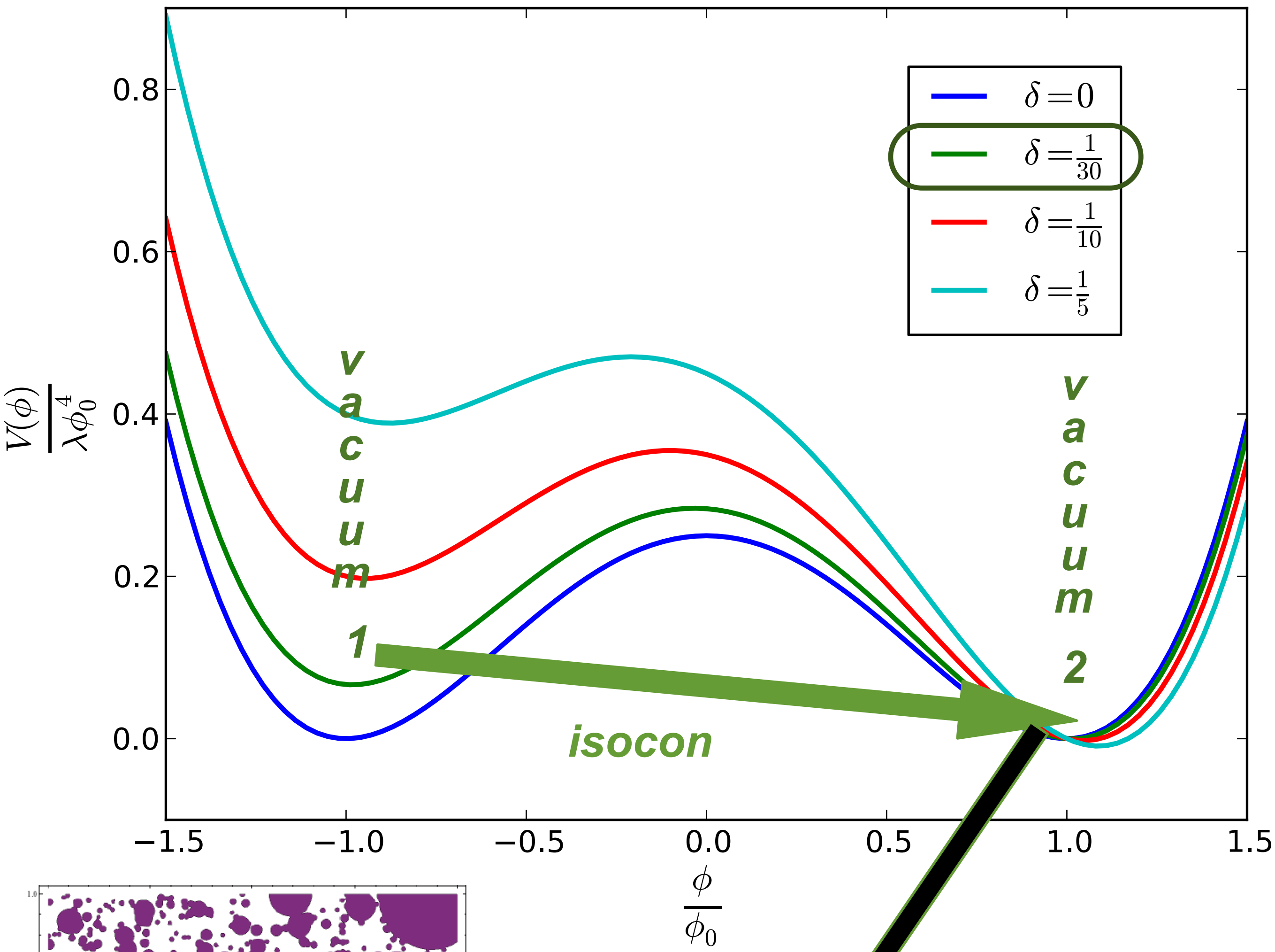
+ long-lived oscillons, size related to the mass

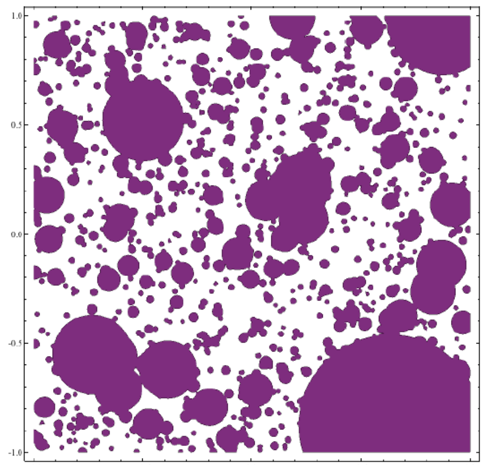
cf. 1D work that dominates the subject

Gleiser, Kleban+, Johnson,Peiris,Lehner,..

an oscillon phenomenon is possible in preheating Easther+

CMB+ observables?





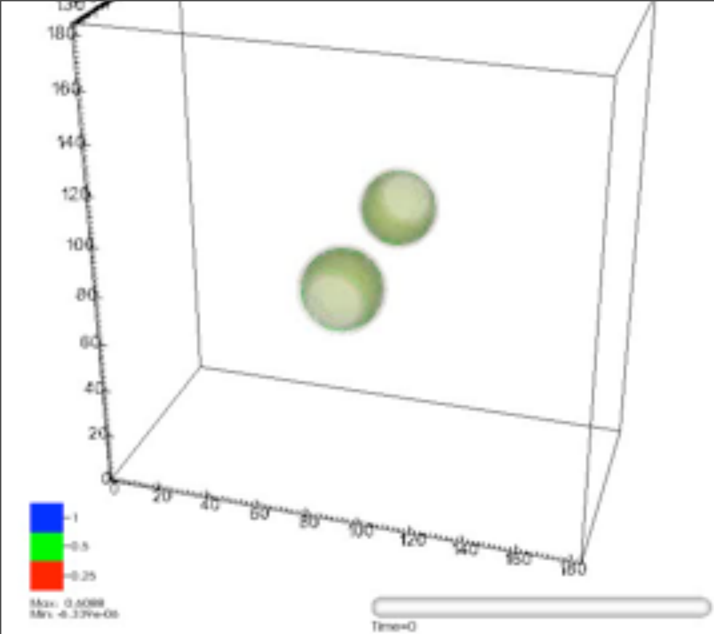
Bubbly U

Kleban11 review

inflaton

add H(t) direction

Bond, Braden, Mersini 2013



when domain walls (big bubbles) collide in full 3D lattice sims

with tiny zero point & wall fluctuations

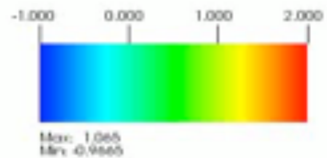
=> burst of scalar radiation at c (with outgoing radiation BCs)

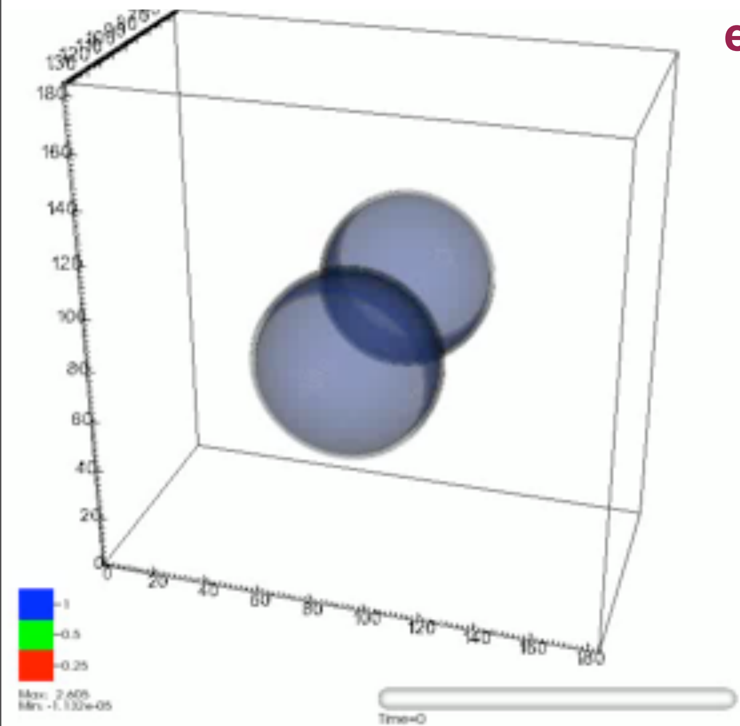
+ long-lived oscillons, size related to the mass

cf. 1D work that dominates the subject Gleiser, Kleban+, Johnson,Peiris,Lehner,.

an oscillon phenomenon is possible in preheating CMB+ observables?

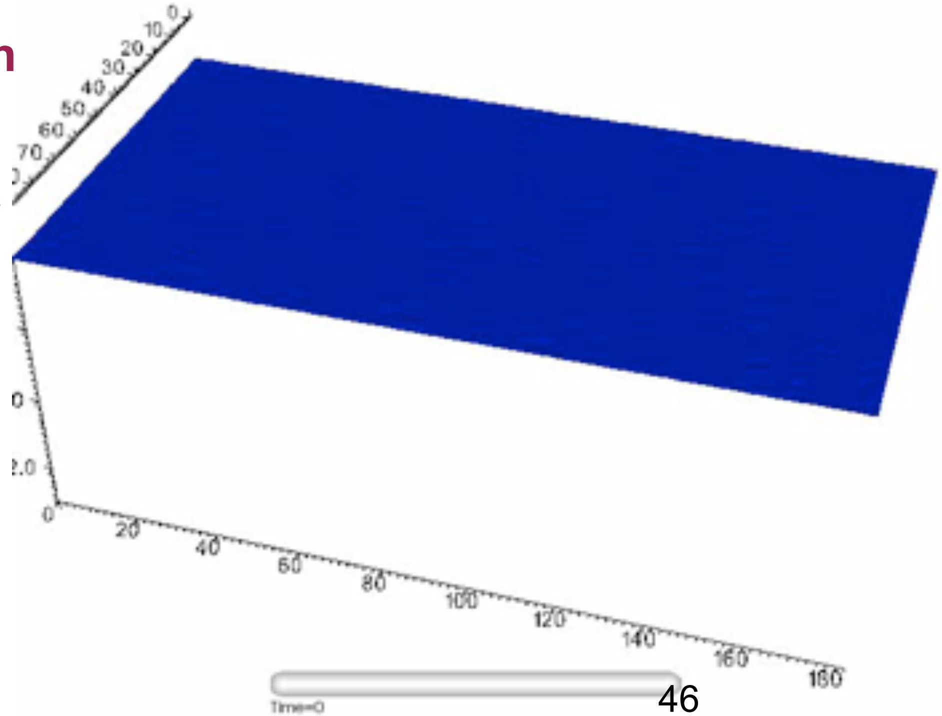
long-lived oscillon energy ~ 10%





energy density evolution

high contours



Bond, Braden, Mersini 2013

add H(t) = V_{inf} in inflaton direction

$R_{bubble,i}$ = 0.1 H^{-1}

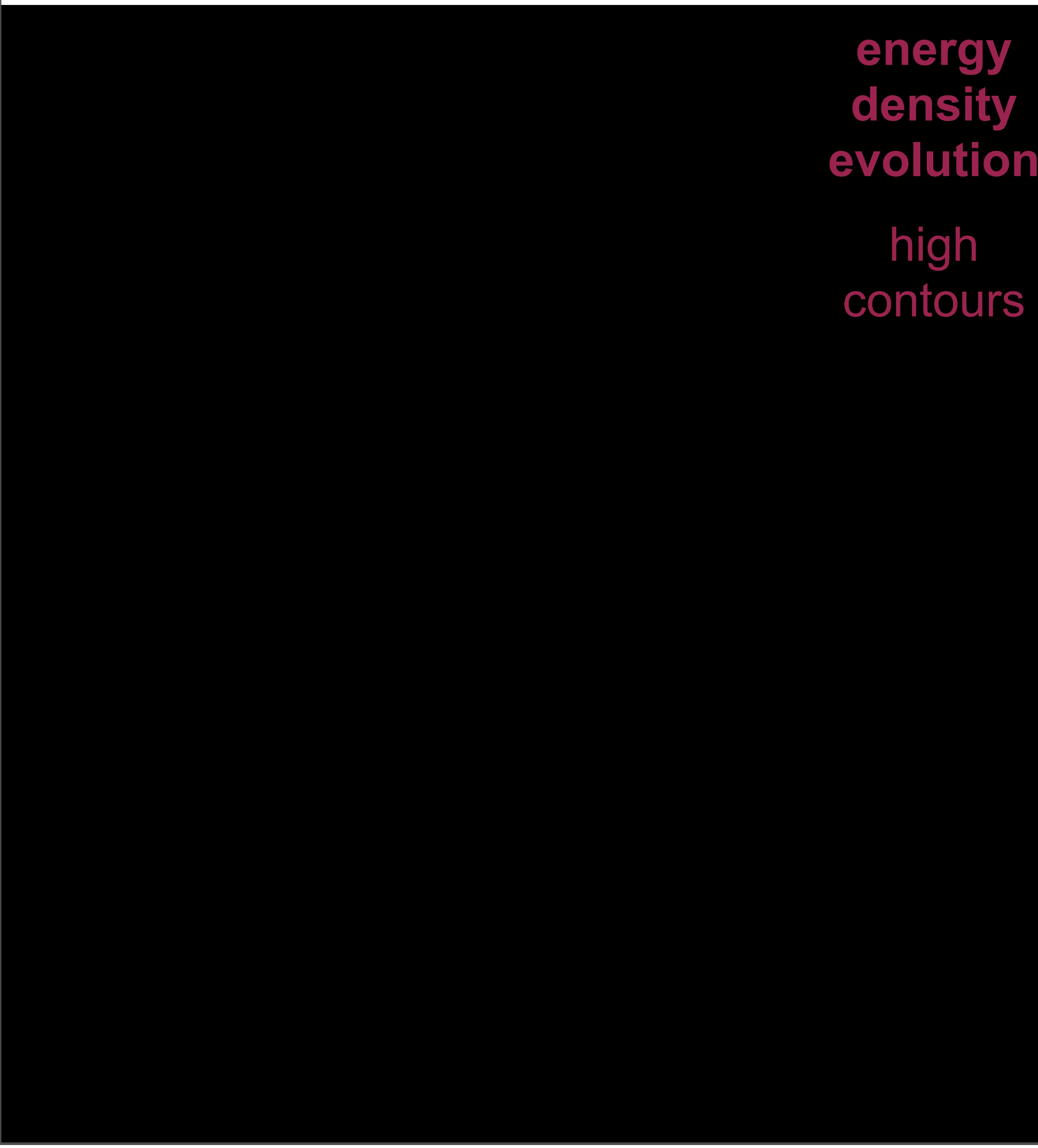
ΔX_{bubble} = 0.25 H^{-1}

when domain walls (big bubbles) collide in full 3D lattice sims

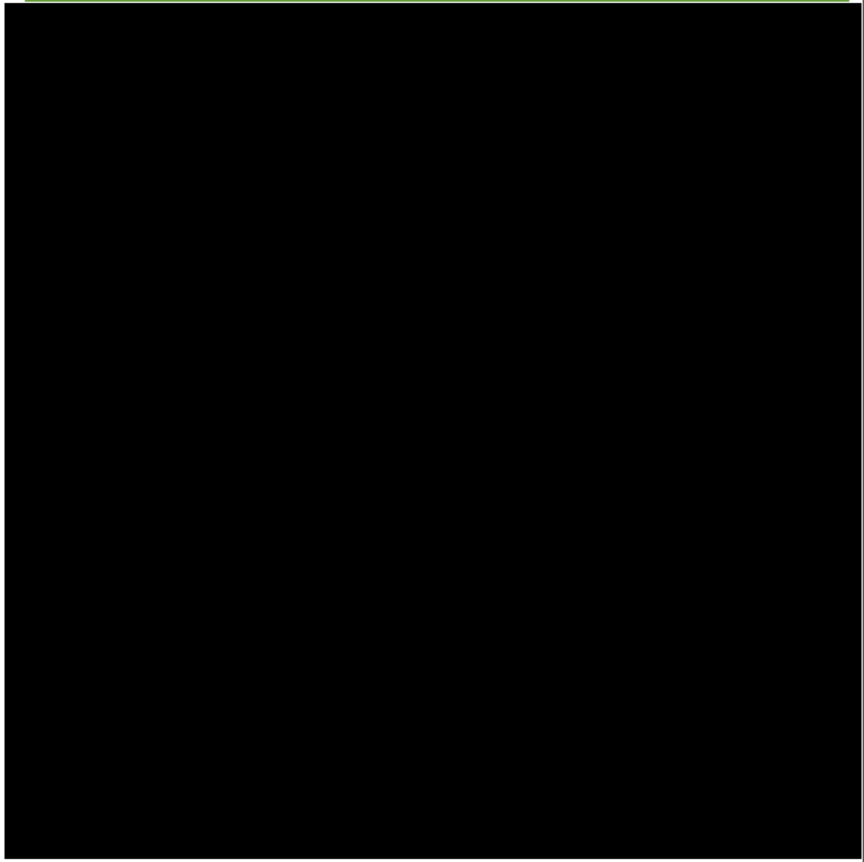
with tiny zero point & wall fluctuations

=> burst of scalar radiation at c (with outgoing radiation BCs)

+ long-lived oscillons, size related to the mass



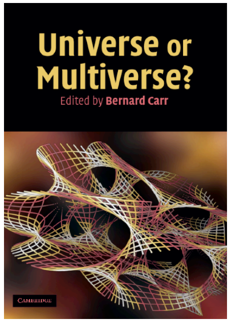
does the observable universe use double hubble bubble - iciousness? CMB intermittency?



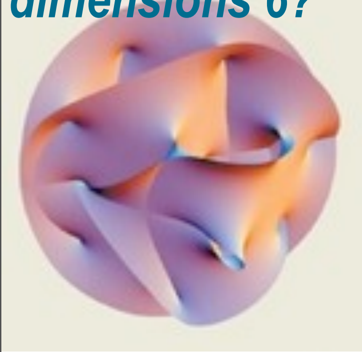
Bond, Braden, Mersini 2013

UltraUltraUltraLargeScaleStructure beyond our Horizon via *early* dark energy+quantum+gravity

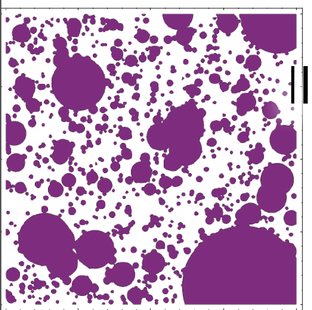
Horizons: the ultimate-speed constraint on light & information

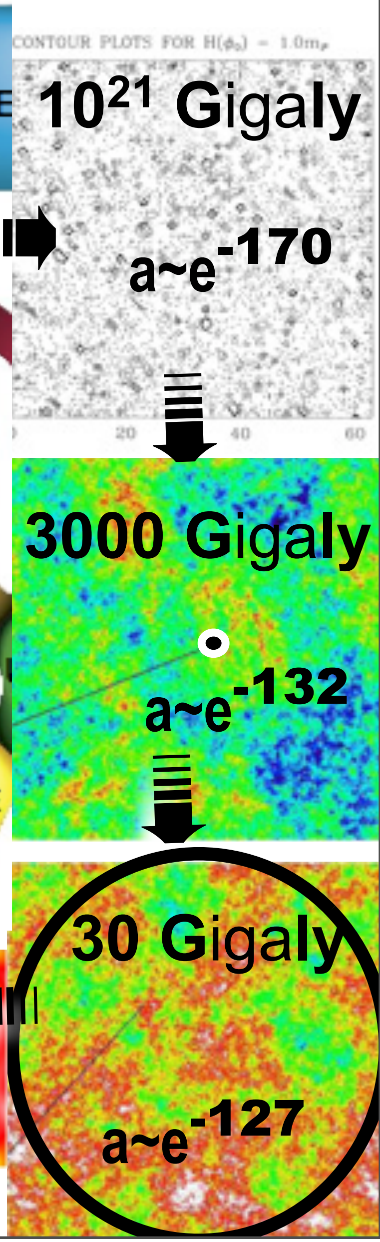


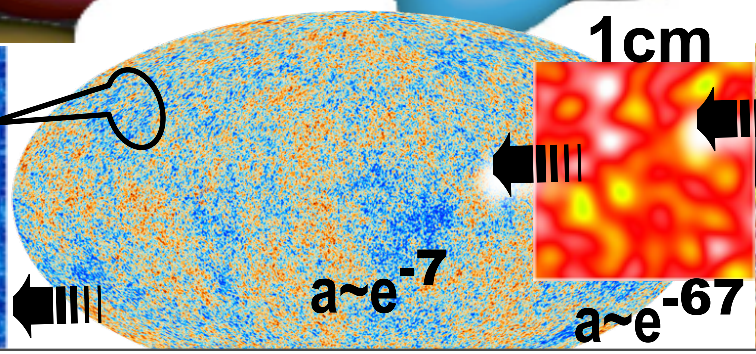
higher dimensions 6?

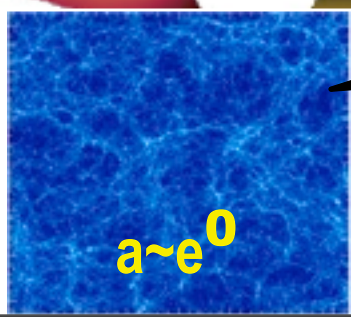


quantum tunnels









cosmic web simulation

~1 Giga light yrs

our current horizon

~50 Giga light yrs

END