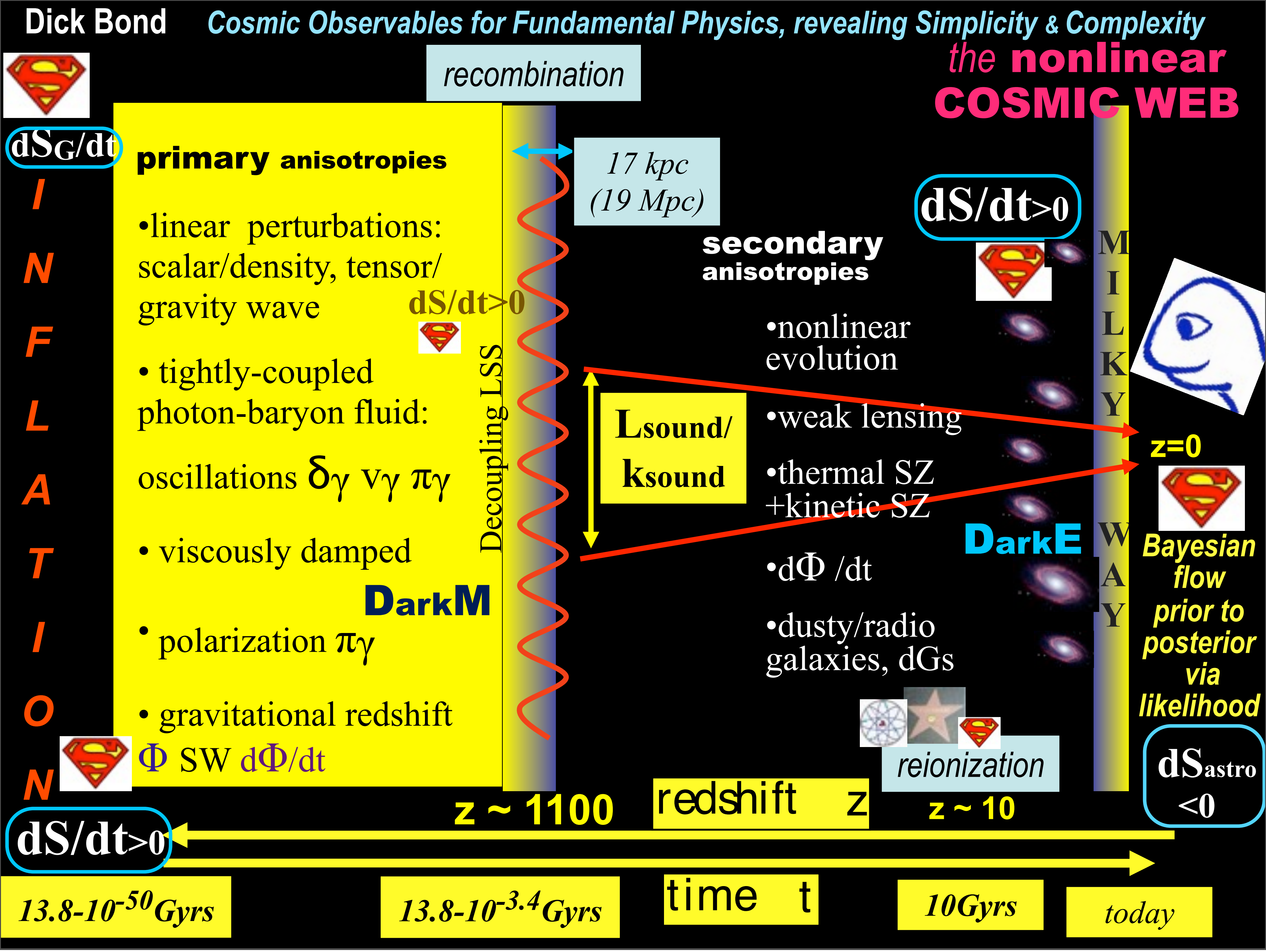
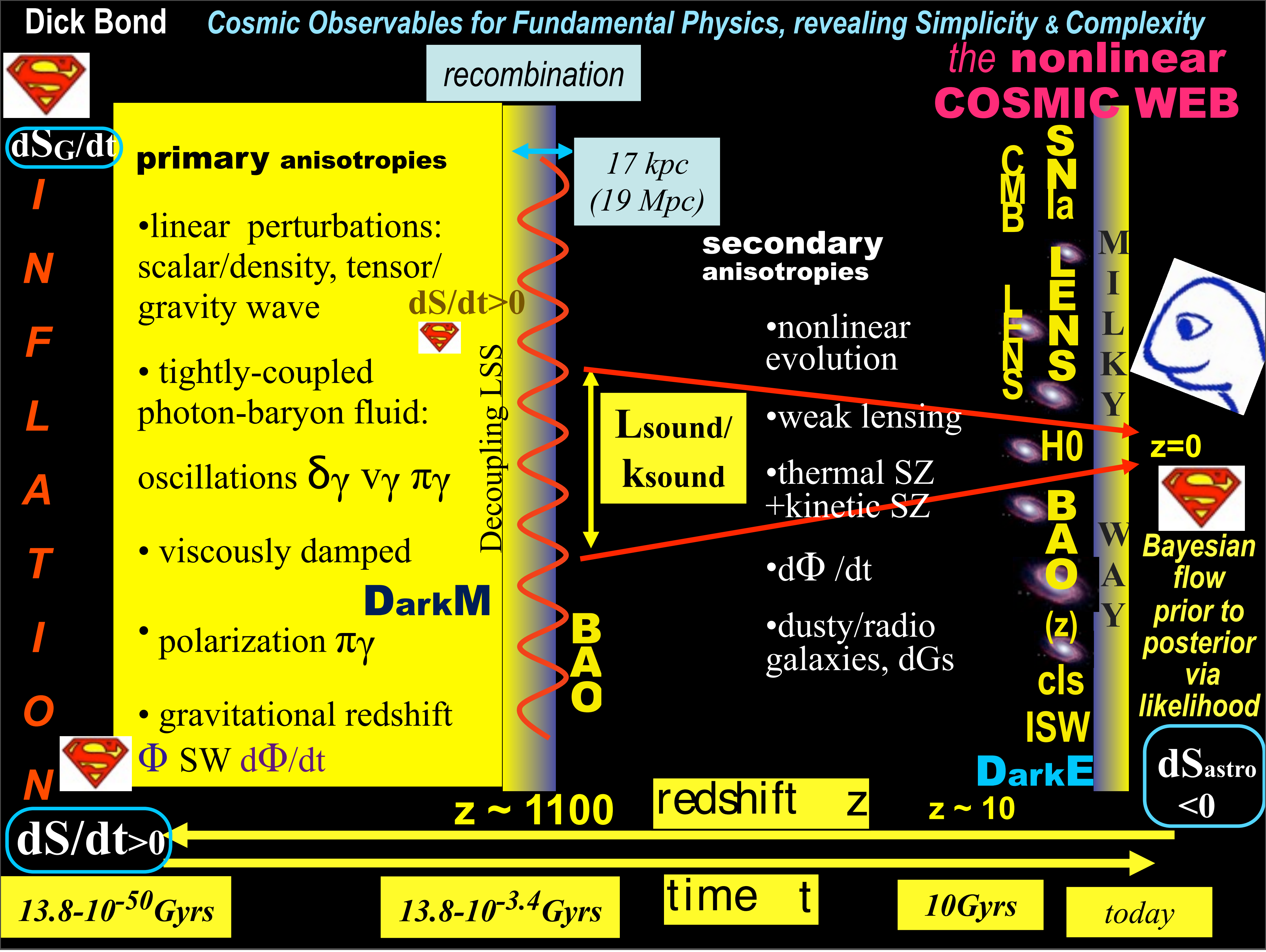
CIFAR
CANADIAN INSTITUTE FOR ADVANCED RESEARCH

pix of
Steve's
Secret
Stanford
Scotch
Society

CLASSIFIED

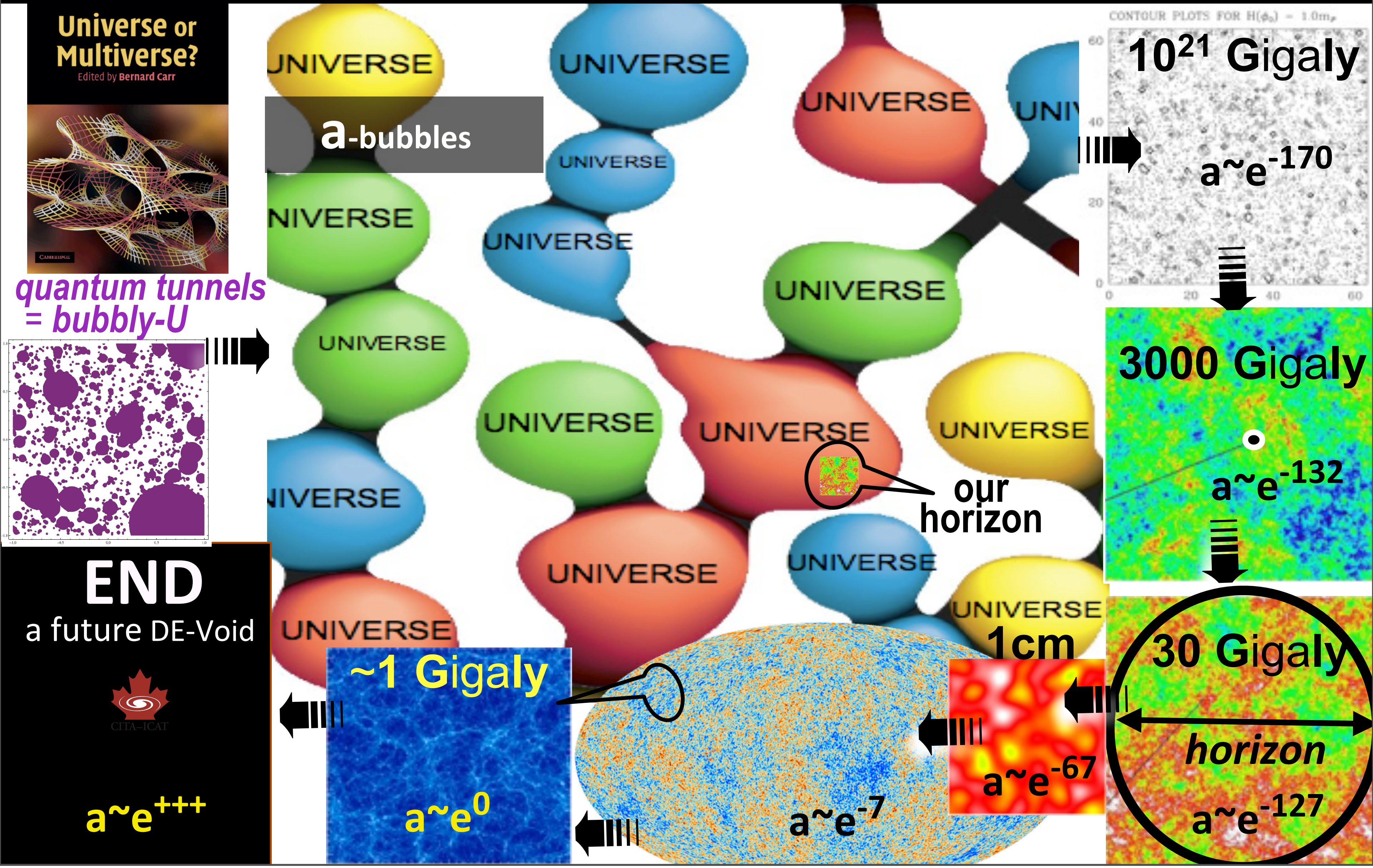
Text


Dick Bond
Cosmic Observables for Fundamental Physics, revealing Simplicity & Complexity
the nonlinear COSMIC WEB
recombination
dSG/dt
INFLATION
primary anisotropies
•linear perturbations: scalar/density, tensor/ gravity wave
dS/dt>0
• tightly-coupled photon-baryon fluid:
oscillations δγ vγ πγ
• viscously damped
DarkM
• polarization πγ
• gravitational redshift
Φ SW dΦ/dt
Decoupling LSS
17 kpc
(19 Mpc)
Lsound/
ksound
dS/dt>0
secondary anisotropies
•nonlinear evolution
•weak lensing
•thermal SZ +kinetic SZ
•dΦ /dt
•dusty/radio galaxies, dGs
DarkE
MILKY WAY
z=0
Bayesian flow prior to posterior via likelihood
reionization
dSastro <0
z ~ 1100
redshift z
z ~ 10
dS/dt>0
time t
13.8-10^-50 Gyrs
13.8-10^-3.4 Gyrs
10Gyrs
today


Dick Bond
Cosmic Observables for Fundamental Physics, revealing Simplicity & Complexity
the nonlinear COSMIC WEB
recombination
dSG/dt
INFLATION
primary anisotropies
•linear perturbations: scalar/density, tensor/ gravity wave
dS/dt>0
• tightly-coupled photon-baryon fluid:
oscillations δγ vγ πγ
• viscously damped
DarkM
• polarization πγ
• gravitational redshift
Φ SW dΦ/dt
Decoupling LSS
17 kpc
(19 Mpc)
Lsound/
ksound
BAO
secondary anisotropies
•nonlinear evolution
•weak lensing
•thermal SZ +kinetic SZ
•dΦ /dt
•dusty/radio galaxies, dGs
CMB
LENS
SN Ia
LENS
H0
BAO
(z)
cls
ISW
DarkE
MILKY WAY
z=0
Bayesian flow prior to posterior via likelihood
dSastro <0
z ~ 1100
redshift z
z ~ 10
dS/dt>0
time t
13.8-10^-50 Gyrs
13.8-10^-3.4 Gyrs
10Gyrs
today

ultra-Ultra Large Scale Structure of the Universe

Horizons: the ultimate-speed constraint on light & information



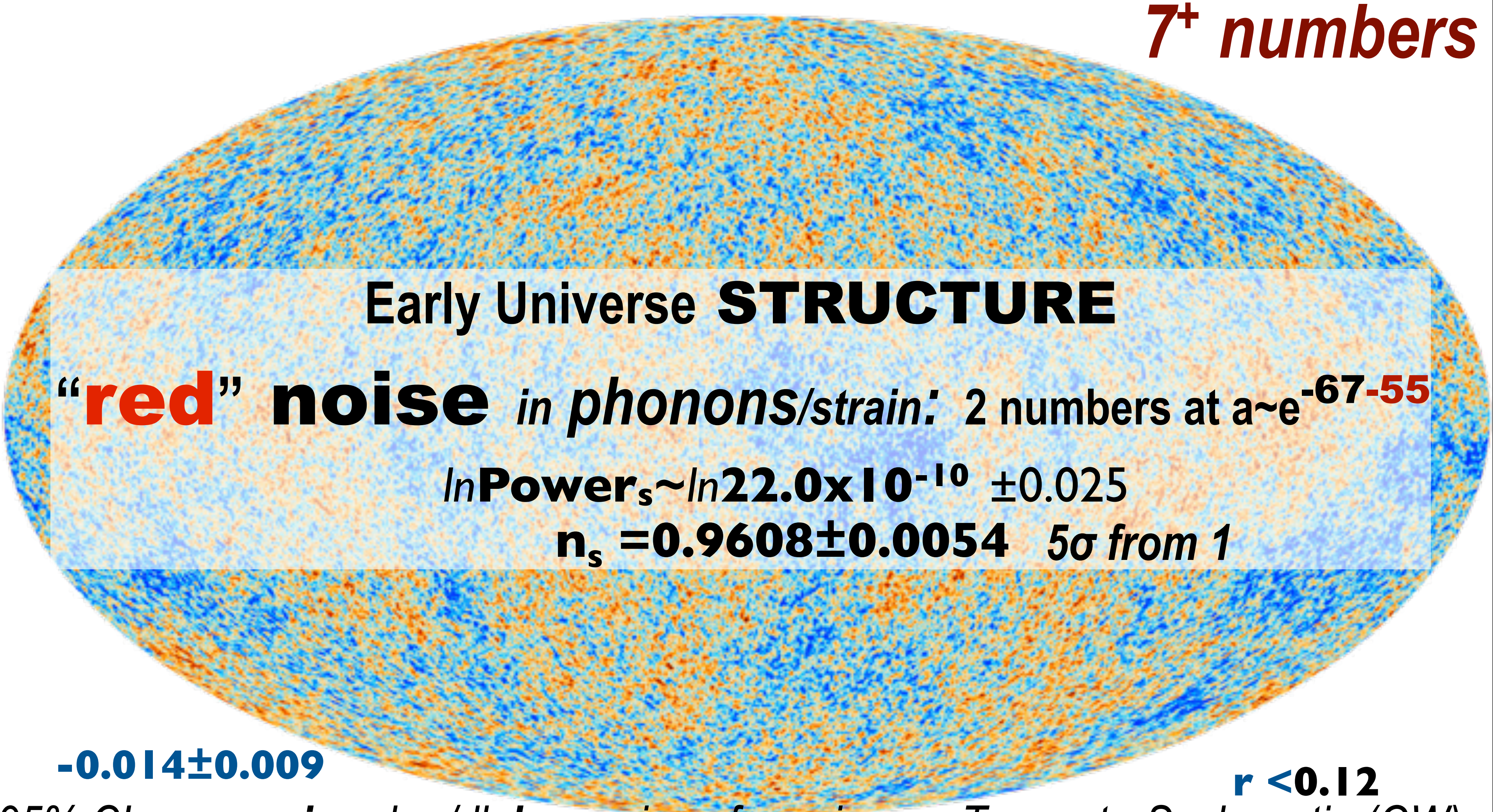
Monday, 9 September, 13

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

$ln\mathbf{Power_s} \sim ln\,\mathbf{22.0 \times 10^{-10}}$ ±0.025

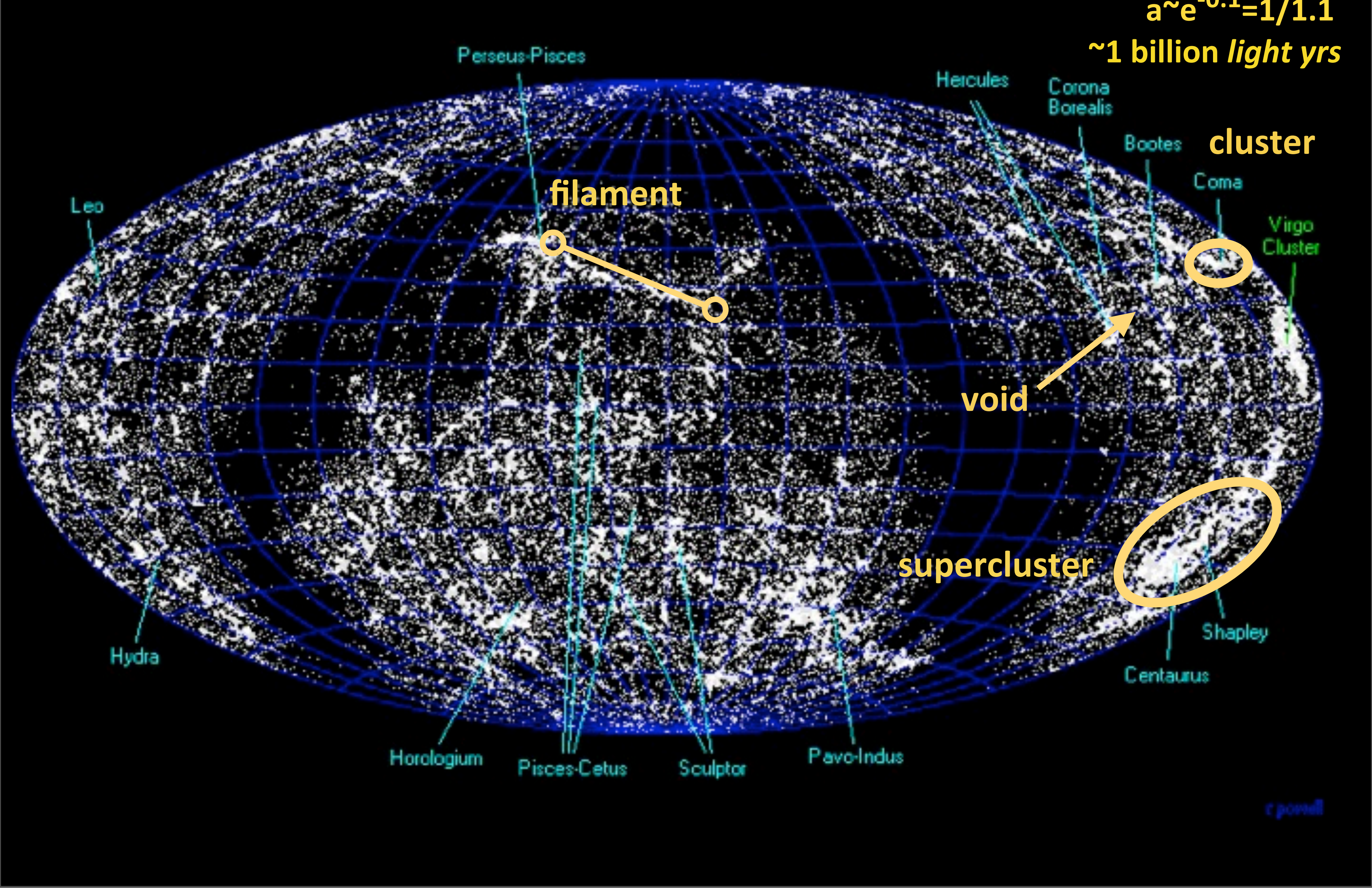
$\mathbf{n_s = 0.9608 \pm 0.0054}$ *5σ from 1*

-0.014±0.009

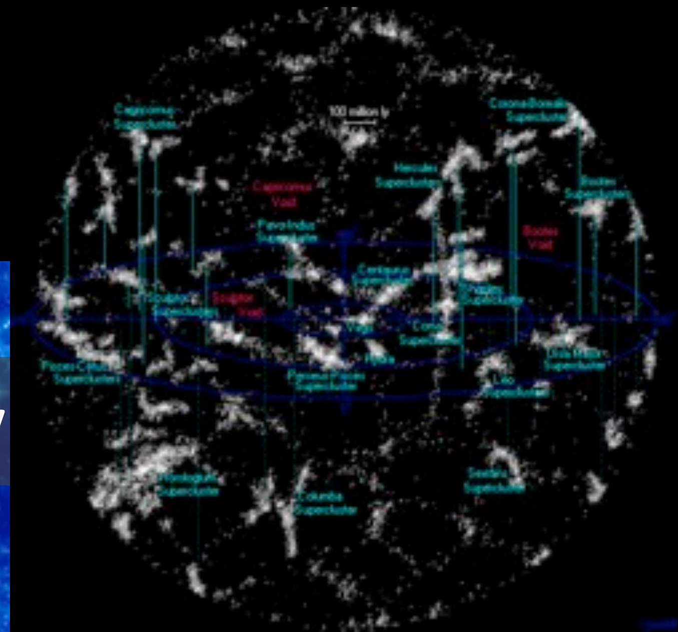
r <0.12

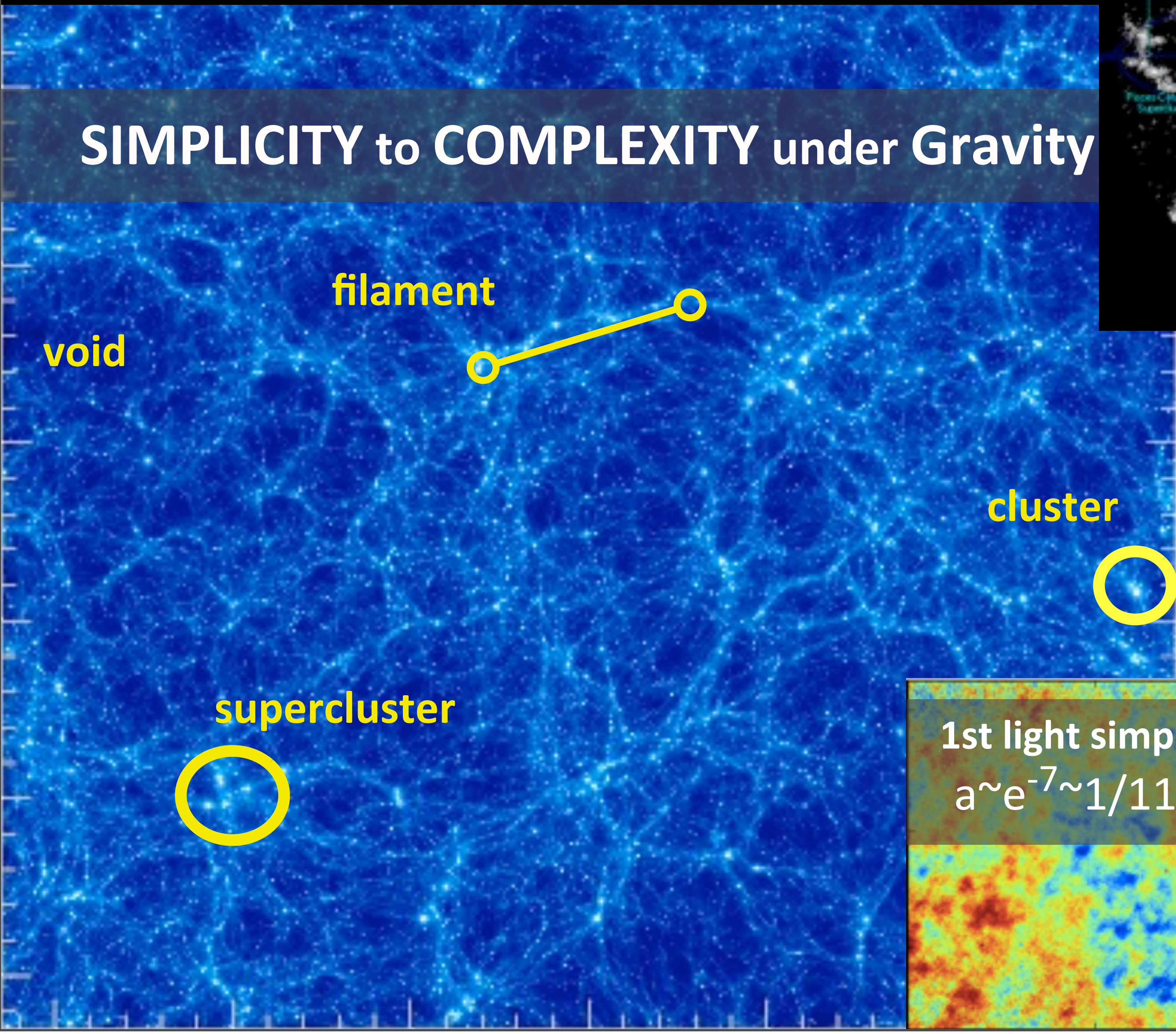
*95% CL on **running** d$\mathbf{n_s}$/dln**k**, running of running, **r** =Tensor-to-Scalar ratio (GW),*
***isocurvature modes** for axions (<3.9%), baryons, neutrinos, curvatons (<0.25%)*

Cosmic Web of 60,000 nearby galaxies:
exhibits “local” **COMPLEXITY**



Simulation of the 7^+ numbers
begets the **Cosmic Web** of clusters
now a~1 & galaxies then a~1/4

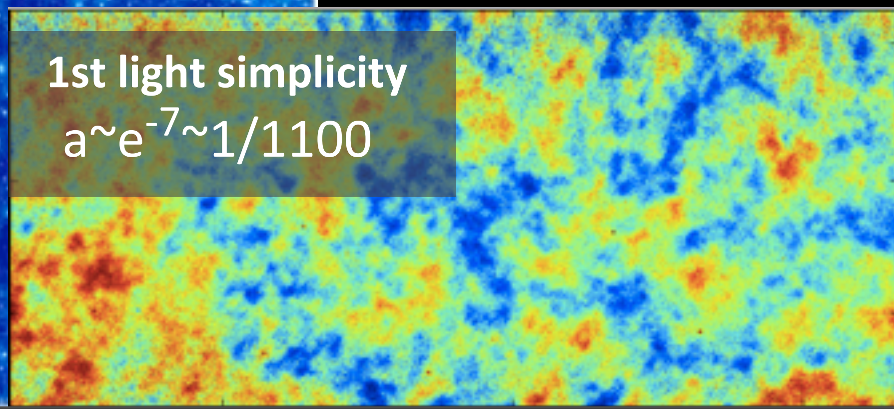




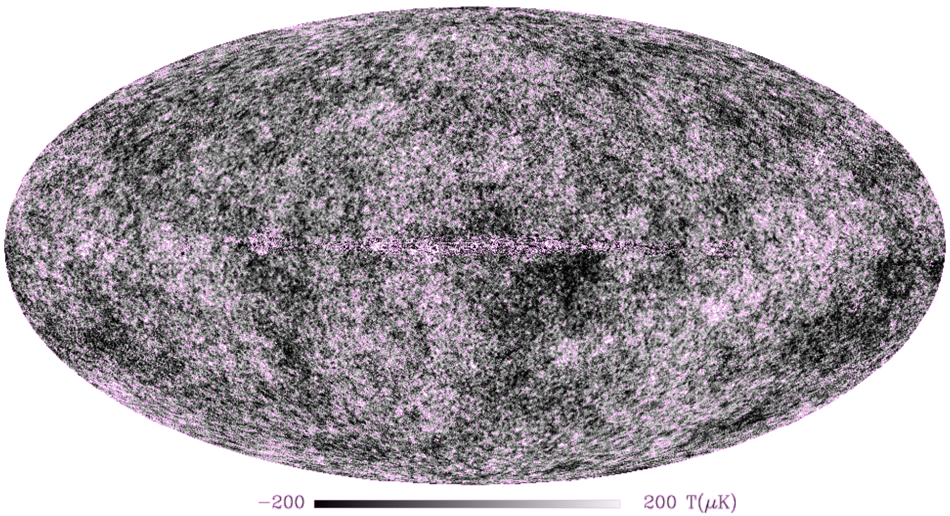
~ billion light years

state of the art simulations
a~1 to 1/1.1

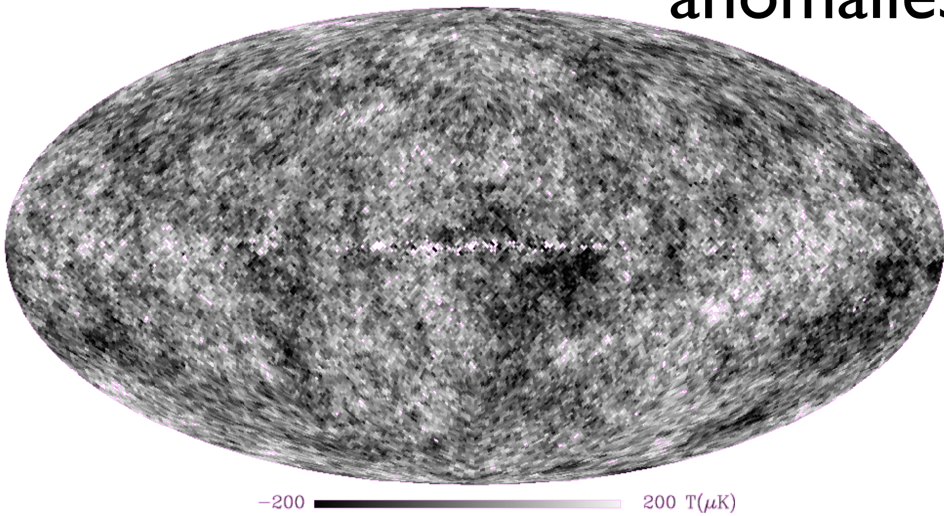
ordinary matter
dark matter
dark energy



full Planck resolution

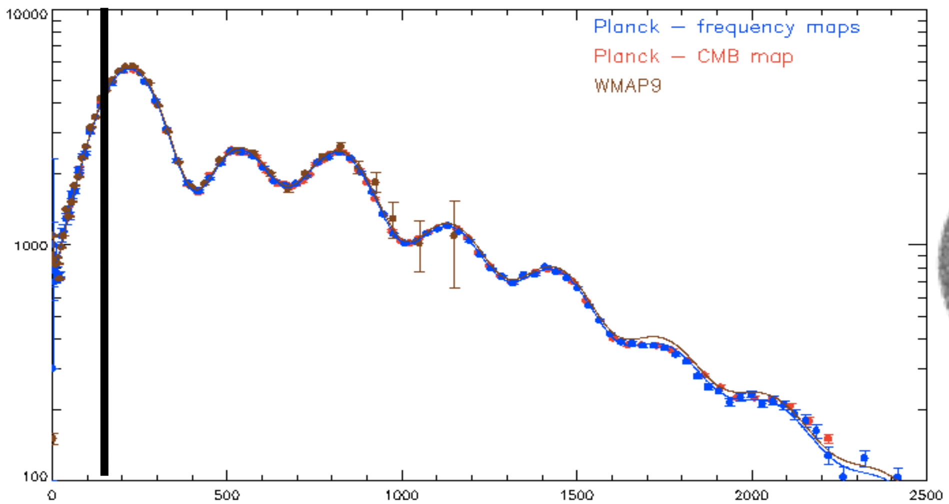


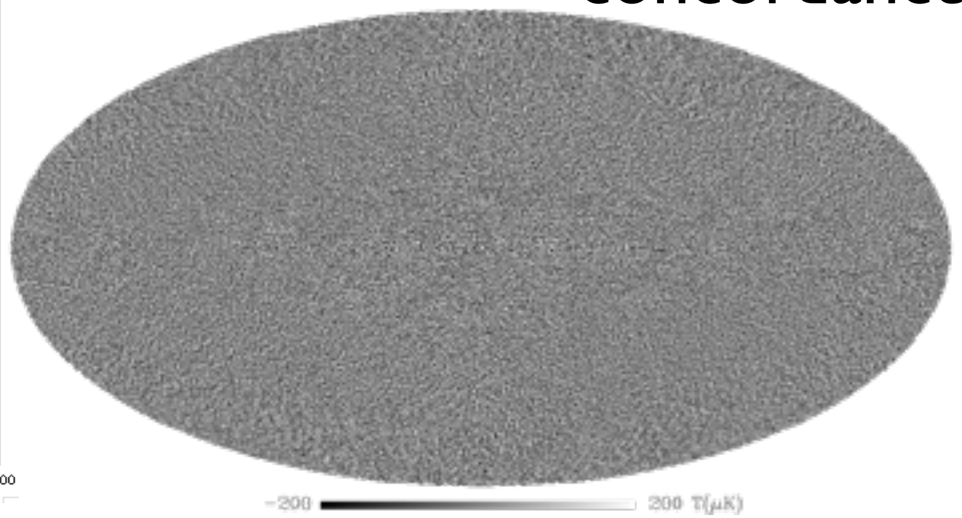
Planck smoothed to 1deg fwhm



L<134
anomalies

L>134
concordance





small scale leftover = where most of Planck's information resides> 120X, > 4X WMAP9

Fundamental Physics from the Planck Satellite

Planck 2013 results. XXII. Constraints on inflation

Planck 2013 Results. XXIV. Constraints on primordial non-Gaussianity

Planck 2013 results. XXIII. Isotropy and Statistics of the CMB

Planck 2013 results. XXV. Searches for cosmic strings and other topological defects

Planck 2013 results. XXVI. Background geometry and topology of the Universe

CMB in Canada: @CITA Boomerang, Acbar, CBI1,2, WMAP, **Planck, ACT, Spider, Blast, & ACTpol, ABS, QUIET2; GBT-Mustang2, CARMA/SZA, SCUBA2, ALMA, CCAT.**
CMB@CIFAR:+ APEX, SPT, SPTpol, EBEX

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.

Planck 2013 results. XII. Component separation

Planck 2013 results. XV. CMB power spectra and likelihood

Planck 2013 results. XVI. Cosmological parameters

Planck 2013 results. XVII. Gravitational lensing by large-scale structure

Planck 2013 results. XXVII. Doppler boosting of the CMB: Eppur si muove

Planck 2013 results. XIX. The integrated Sachs-Wolfe effect

Planck 2013 results. XIa. Profile likelihoods for cosmological parameters *frequentist cf. Bayesian of XVI*

Standard Parameters of Cosmic Structure Formation

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

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

T_{cmb} $m_{neutrinos}$ $\theta \sim \ell_s^{-1}$

n_s $r = A_t/A_s$

$\ln A_s$ $dn_s/d\ln k$ n_t

$\sim \ln \sigma_8^2$

Inflation Histories
(CMBall+LSS+SN+WL)

***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 (P1.3+WP+hiL+BAO) 0.9678±0.0088 A12+S12+w9

± 0.002 (P2.5ext)

$dn_s/d\ln k$=-0.014±0.009 (P1.3+WP, P1.3+WP+hiL+BAO) -0.028 ± 0.010 SPT12+

-0.003 ± 0.013 (ACT12+ WMAP7+BAO+H0)

r <0.12, 0.11,0.16,0.11,0.13 (95% CL: P1.3+WP, P1.3+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

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}

T_{cmb} $m_{neutrinos}$ $\theta \sim \ell_s^{-1}$ $n_e(a)$ $\sim \ln \sigma_8^2$

Inflation Histories (CMBall+LSS+SN+WL)

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

trajectories: *ln* **Primordial power spectra** *(lnk):*

scan $\ln \mathbf{P_s}(\ln k)/A_s$, $\ln \mathbf{A_s} = \ln P_s(k_{pivot,s})$, $\mathbf{r}(k_{pivot,t})$

Hamilton Jacobi works well cf. exact k-mode integration even for quite wild ε trajectories

reconstruct $\varepsilon(\ln Ha) = -\, d\ln H / d\ln a = 3/2(1+w_t)$

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

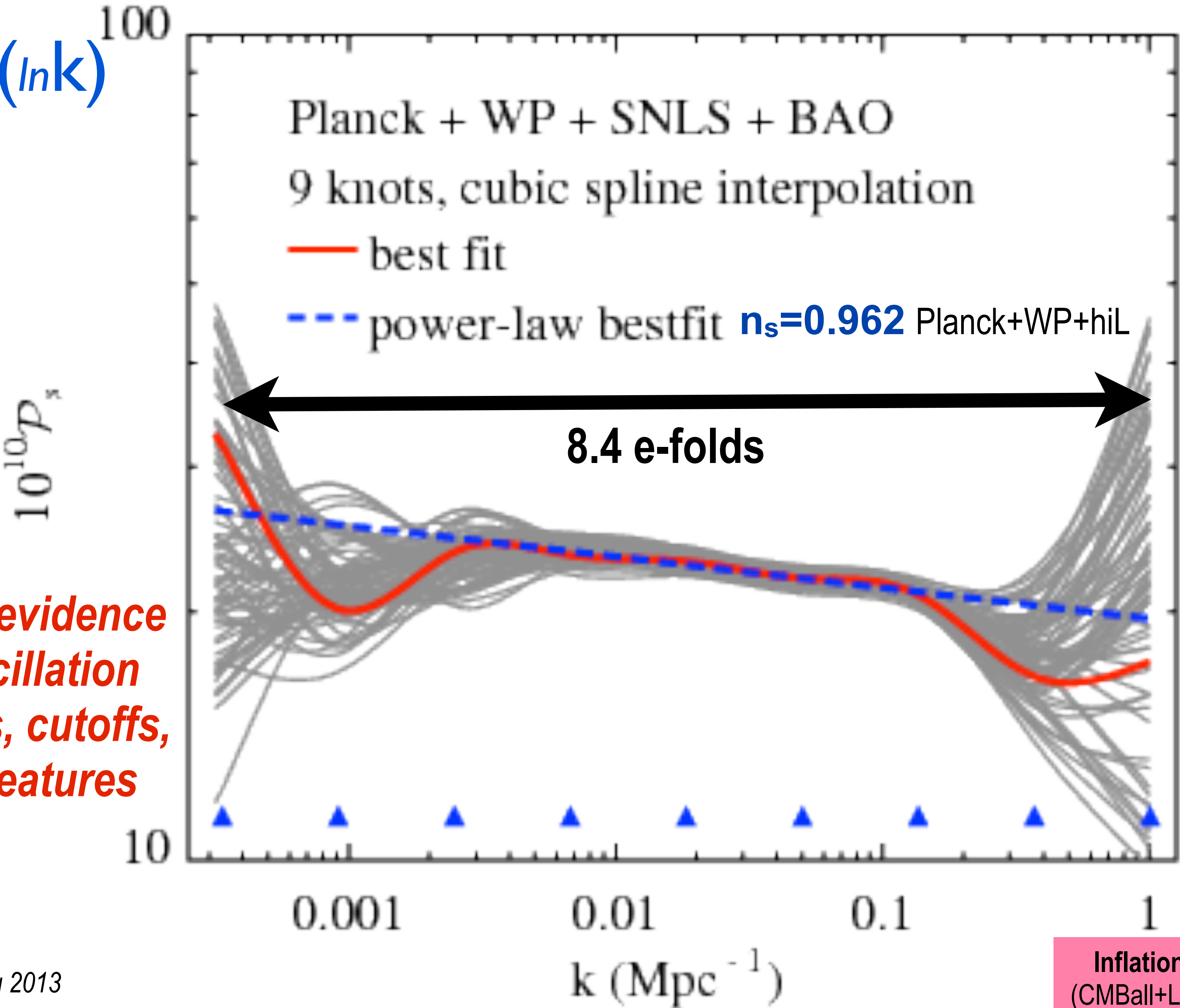
inflation consistency $-n_t \approx r/8 \approx 2\varepsilon(k)$ $1-n_s \approx 2\varepsilon + d\ln\varepsilon/d\ln Ha$

we can **post-process bandpowers in any trajectory modes** *key is to characterize the likelihood surface*

late-inflaton **DE trajectories** ***informed = 3-parameter*** $\mathbf{w}_{de}(a|\varepsilon_s \varepsilon_{de\infty} \varsigma_s)$

PS new parameters: **trajectory probabilities for recombination histories & reionization histories $n_e(a)$ (partially) blind cf. informed "theory" priors** *scan* $ln\mathbf{P_s}(ln k)/A_s$, $ln\mathbf{A_s}=lnP_s(k_{pivot,s})$, $\mathbf{r}(k_{pivot,t})$; *consistency => reconstruct* $\boldsymbol{\varepsilon}(ln\mathbf{Ha})$, $\mathbf{V}(\boldsymbol{\psi})$

$lnP_s(ln k)$



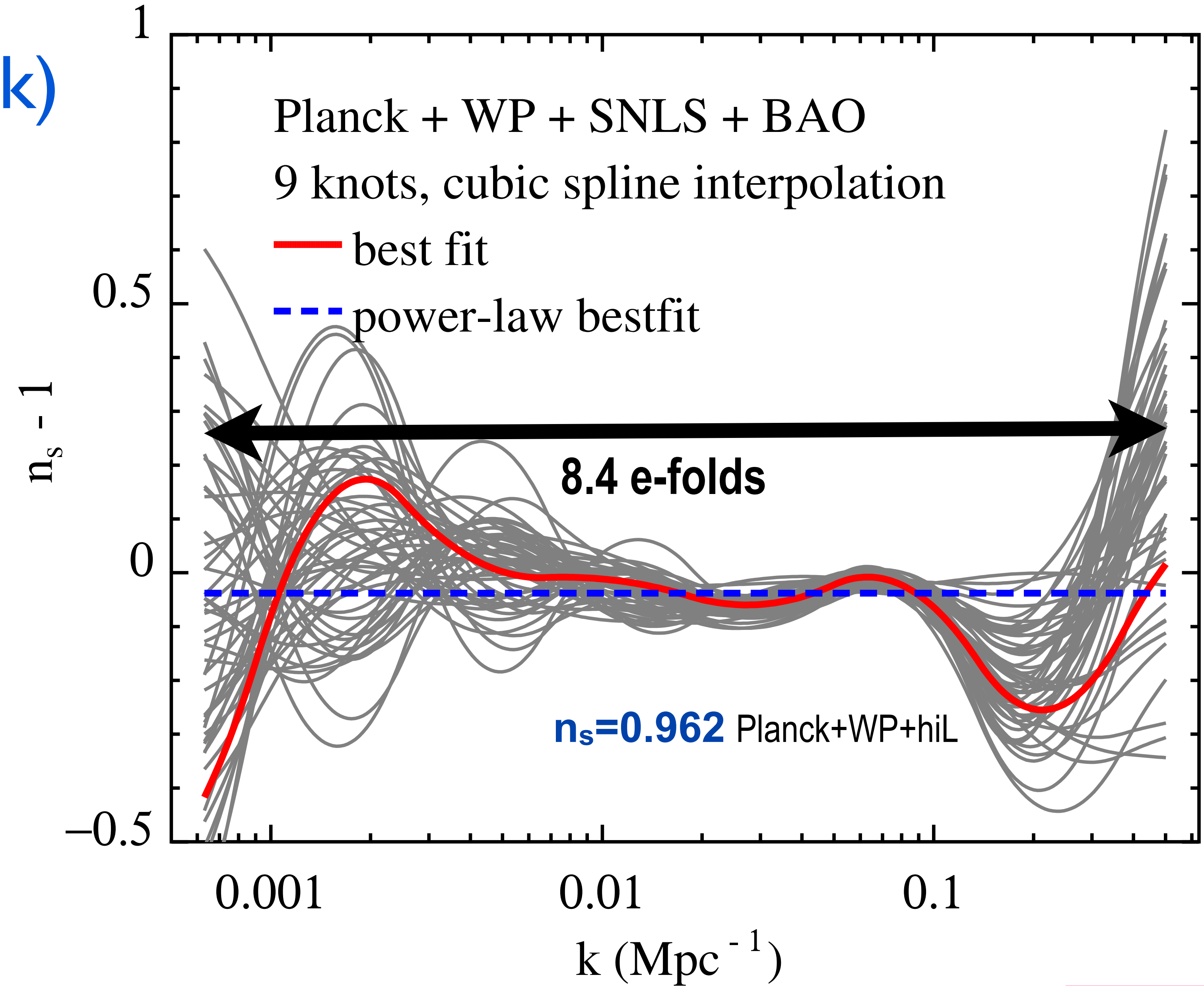
no strong evidence for oscillation patterns, cutoffs, local features

Bond, Huang 2013

Inflation Histories
(CMBall+LSS+SN+WL)

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* $\boldsymbol{\varepsilon}(\ln \mathbf{Ha})$, $\mathbf{V}(\boldsymbol{\psi})$

$n_s(\ln k)$



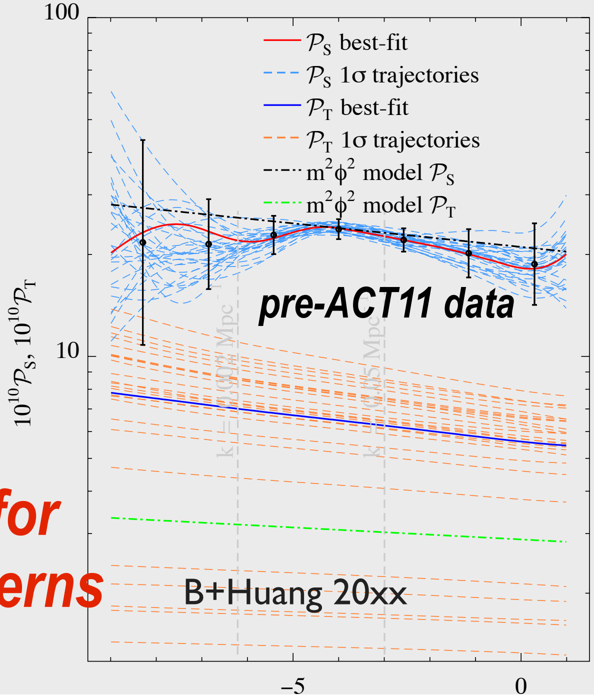
Bond, Huang 2013

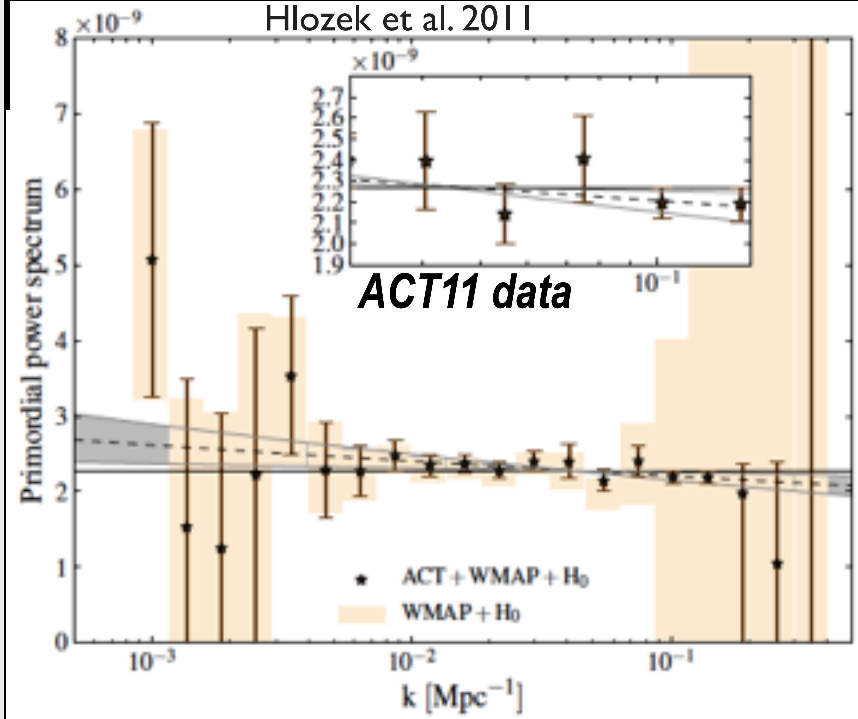
Inflation Histories
(CMBall+LSS+SN+WL)

early-U, NOW

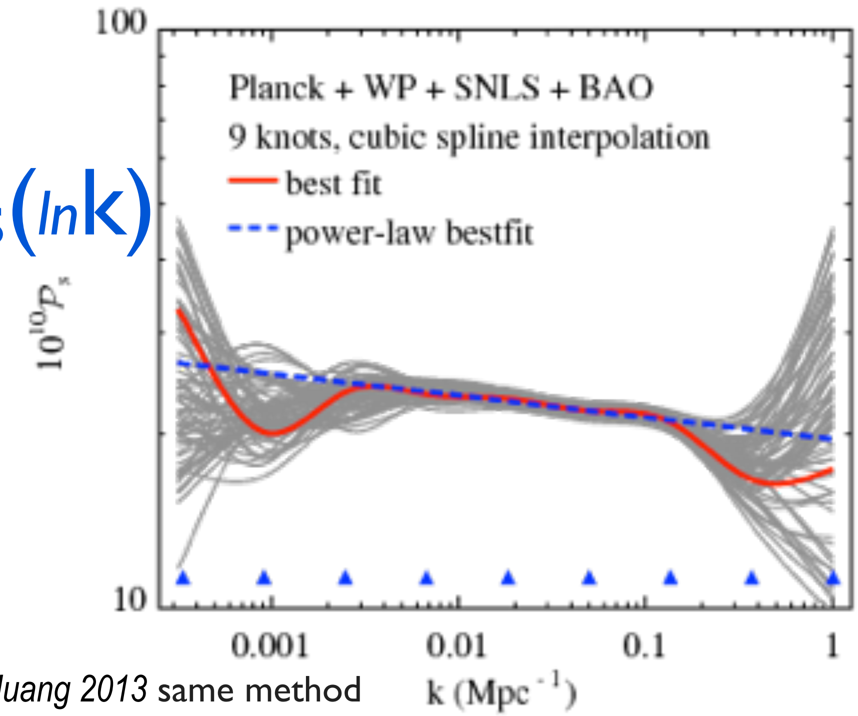
semi-blind & informed reconstruction of acceleration histories & S/T power spectra

no evidence for oscillation patterns





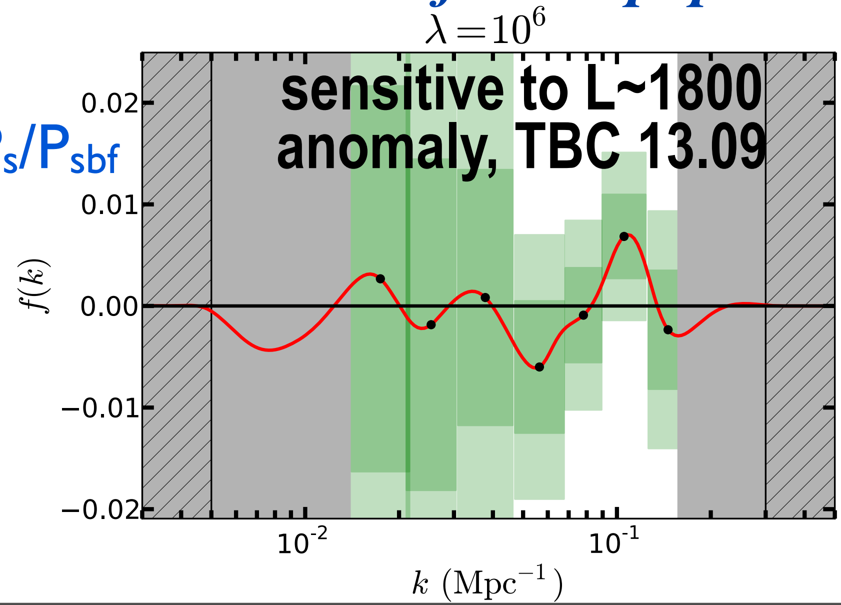
$\ln P_s(\ln k)$



Bond, Huang 2013 same method

Planck1.3 inflation paper

$\delta P_s/P_{sbf}$



NO TENSIONS

Planck HFI cf. Planck LFI *"P13 Comparison Paper"*

Planck HFI cf. ACT *Calabrese+13, TBD*

Planck cf. BAO z-surveys, compatible with tLCDM

TENSIONS

Planck cf. WMAP9 *"P13 Comparison Paper", still ~1% amplitude difference, map level by eye agreement spectacular*

Planck cf. SPT *not really, in overlap region*

Planck primary cf. Planck SZ ncl & y-maps, gastrophysics, neutrino mass?

Planck primary cf. PlanckSZ/WMAP9 X ROSAT cross spectra
Hajian, Battaglia+13, slightly less tension

Planck primary cf. H0 Reiss+, Freedman+ systematic errors GPE reanalysis H0 from 74 to 70

Planck primary cf. SN1a w<-1 but CFHT-SNLS relative calibration change

Planck primary cf. maser H0. changed before the ESLAB mtg

Planck primary cf. CFHT-LENS

Planck non-G f_{NL} cf. non-G large-scale Planck/WMAP anomalies. *consistent*

Old view: Theory prior = delta function of THE correct one and only theory

New: Theory prior = probability distribution of late-flows on an *action* LANDSCAPE

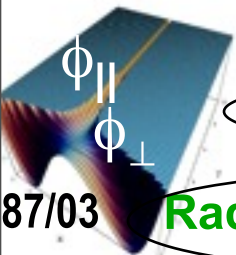
6/7 tiny extra dimensions

1980

R^2-inflation

Old Inflation

Chaotic inflation



New Inflation

Double Inflation

Power-law inflation

SUGRA inflation

87/03

Radical BSI inflation

running (nee variable M_P) inflation

Higgs inflation

Extended inflation

1990

Natural pNGB inflation

Hybrid inflation

KLS94 preheating

SUSY F-term inflation

SUSY D-term inflation

Assisted inflation

Brane inflation

2000

SUSY P-term inflation

Super-natural Inflation

K-flation

2003 KKLT

N-flation

ekpyrotic/ cyclic

D3,D7 brane inflation

DBI inflation

moving brane separations

Racetrack inflation

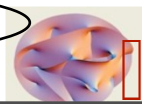
Tachyon inflation

Warped Brane inflation

moduli fields

monodromy

Higgs inflation



Roulette inflation Kahler moduli/axion

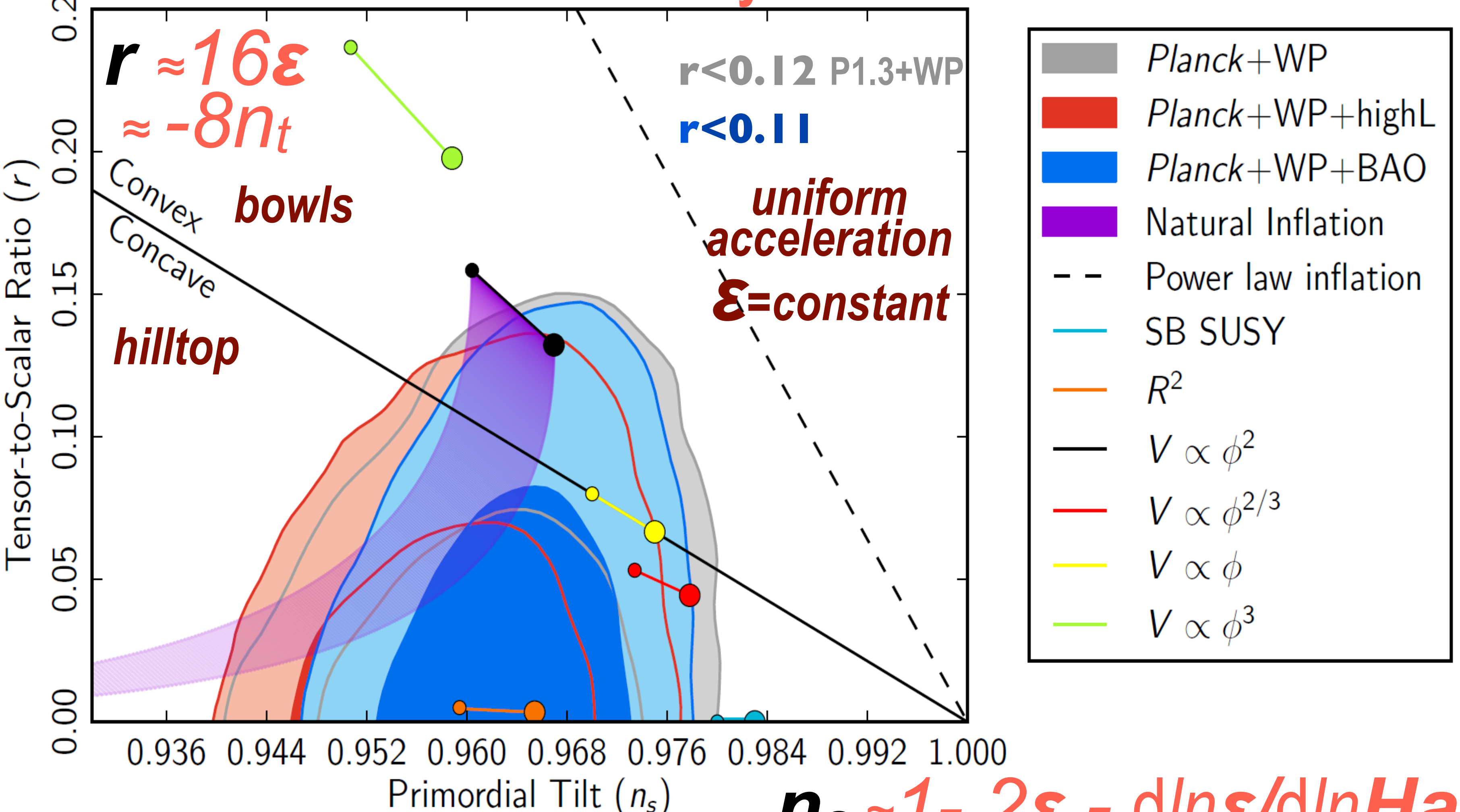
fibre inflation

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

uniform acceleration *line* ***ε ≡ 3KE /(KE+PE)*** *= constant is* ***strongly ruled out***

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

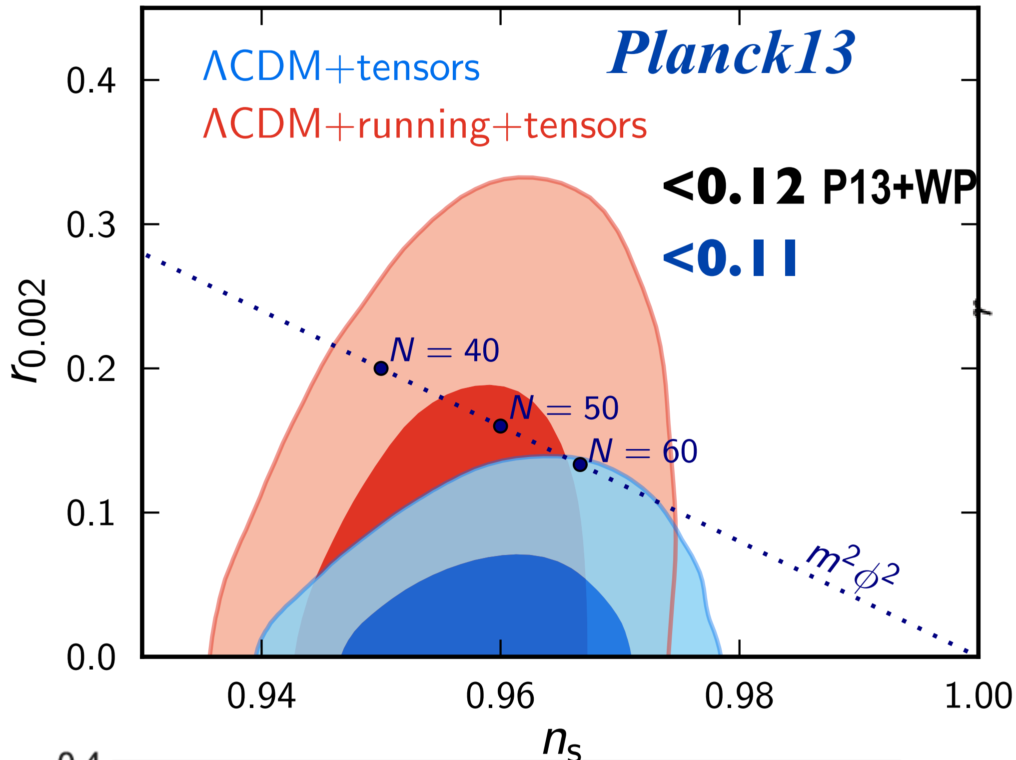
inflation consistency

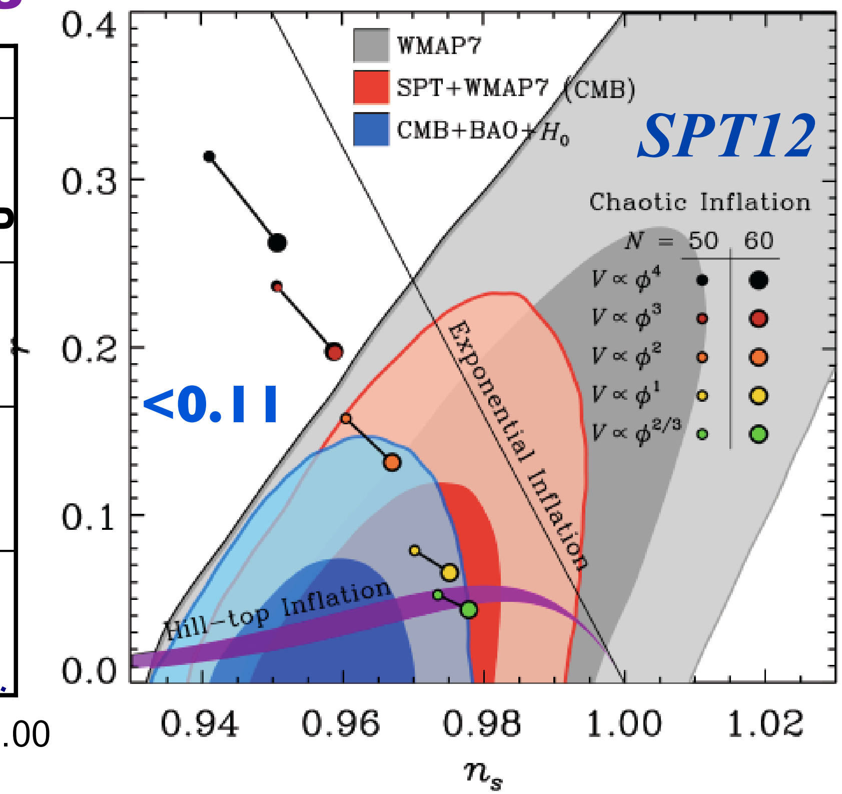


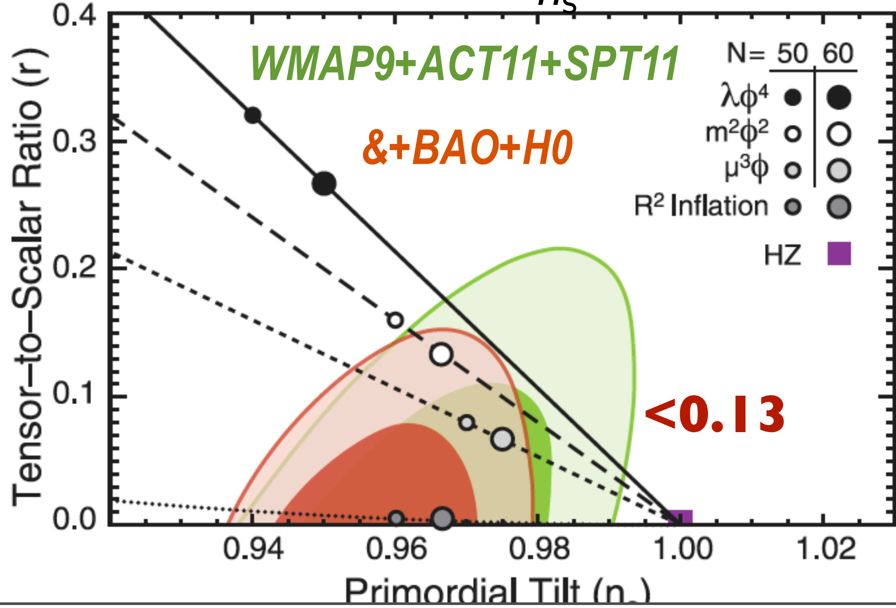
$$n_s \approx 1 - 2\varepsilon - d\ln\varepsilon / d\ln Ha$$

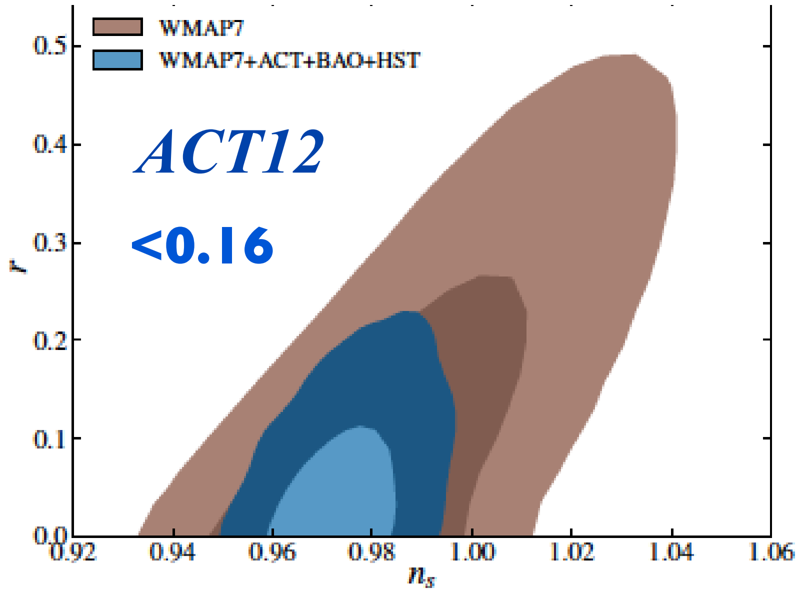
r without B-mode pol is delicate **rule out: exponential potential models(power-law inf)**, the simplest hybrid inflationary models (Spontaneously Broken SUSY) & **Φ^n, n >2 monomial potentials of chaotic inflation** ***some*** **popular** ***inflation survivors:*** ***Natural = pNGB, monodromy =driven pNGB, Roulette (shrinking holes in extra-dim), brane (separation), Higgs, flattened potentials*** *= non-monomial, ...*

early-U Gravity Wave Constraints





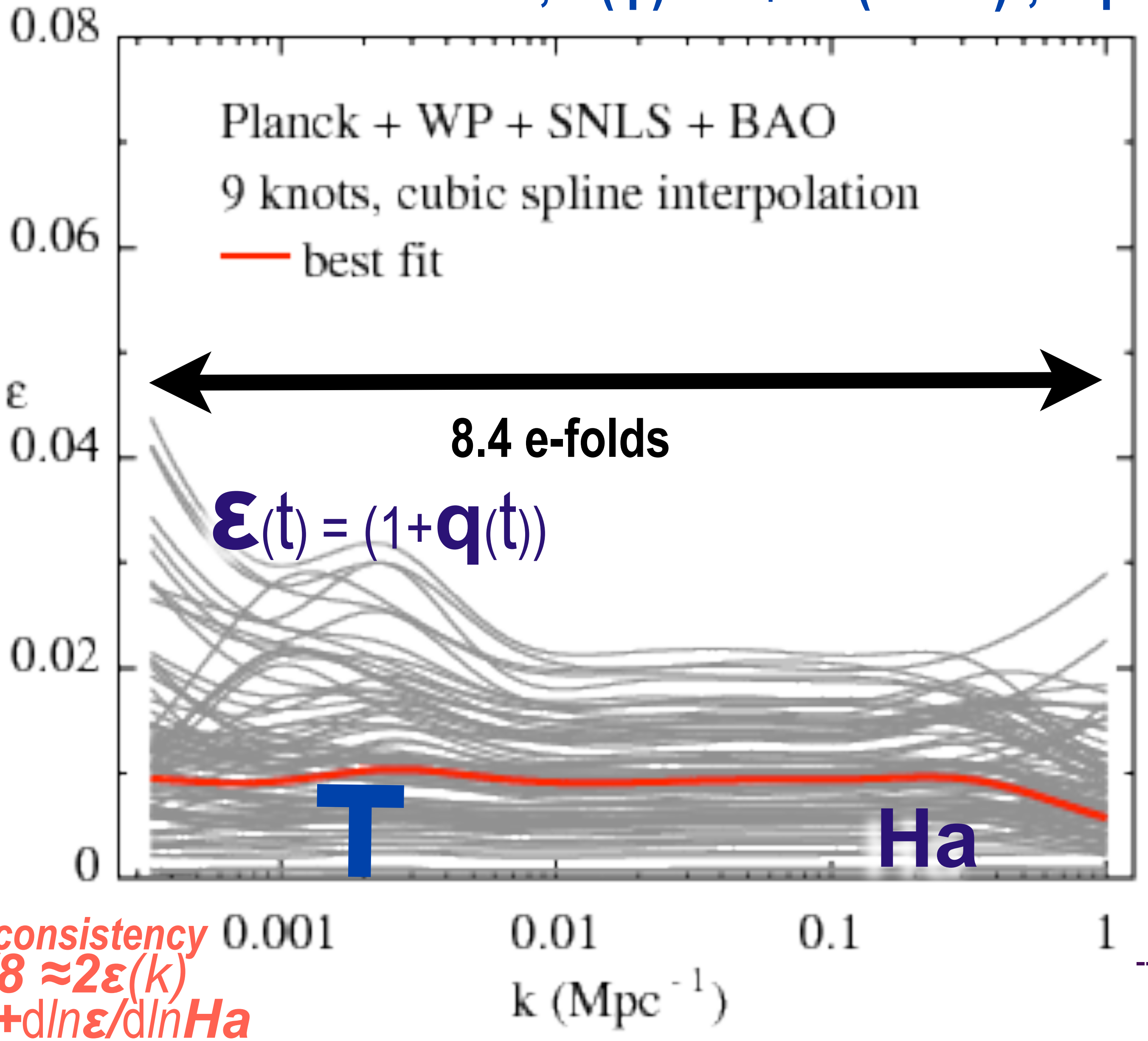




early-inflaton DE acceleration trajectories then

Bond, Huang 2013

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



aka

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

then

(hydro)

resolution
lnk ~ lnHa
dynamics

$\varepsilon \approx r/16$

inflation consistency

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

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

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

early-inflaton DE acceleration trajectories then

Bond, Huang 2013

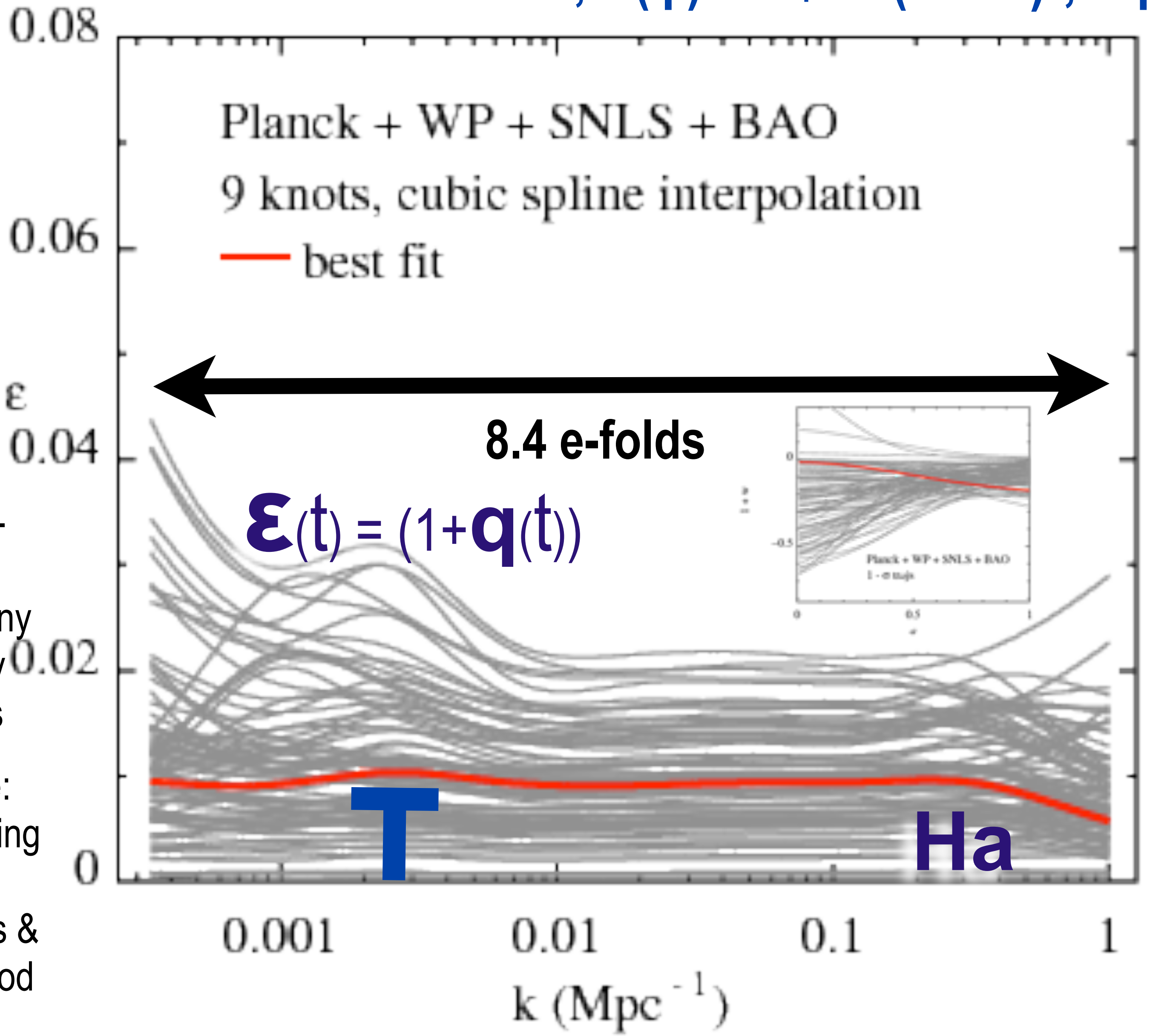
$\epsilon = -d\ln H / d\ln a$; $V(\psi) \approx 3M_P^2H^2(1-\epsilon/3)$; $d\psi / d\ln a = \pm\sqrt{\epsilon}$

aka

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

then

(hydro)



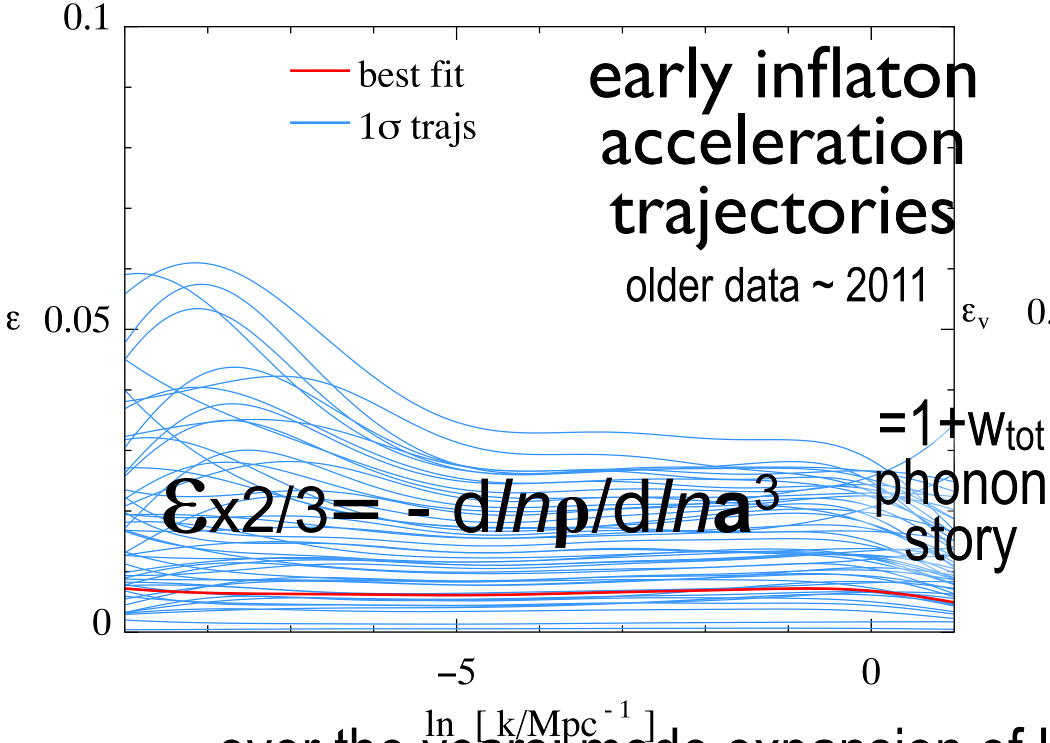
can post-process bands in any trajectory variables

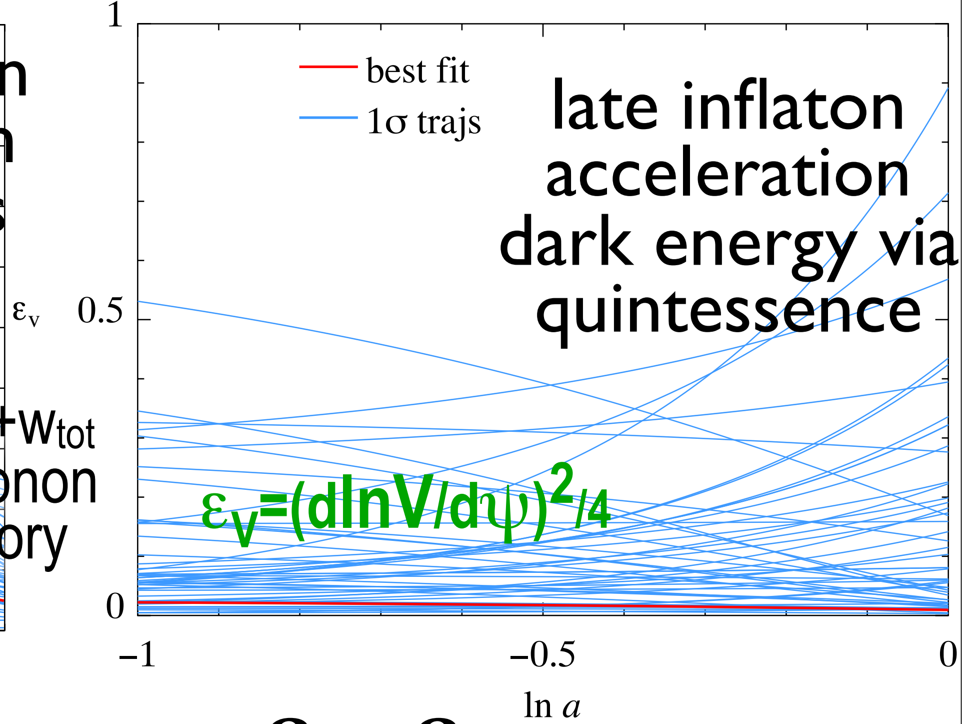
key issue: characterizing the correlations & the likelihood surface

resolution *lnk ~ lnHa* **dynamics**

$\epsilon \approx r/16$

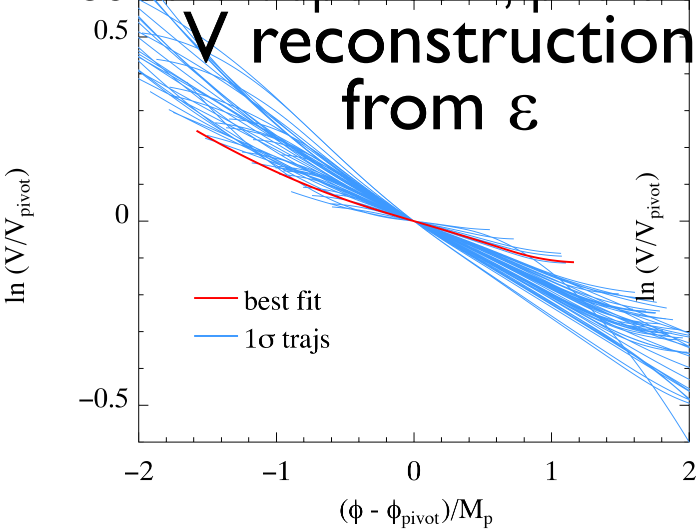
$\frac{\epsilon}{0.0005} \approx \frac{V}{(10^{16}\text{Gev})^4}$

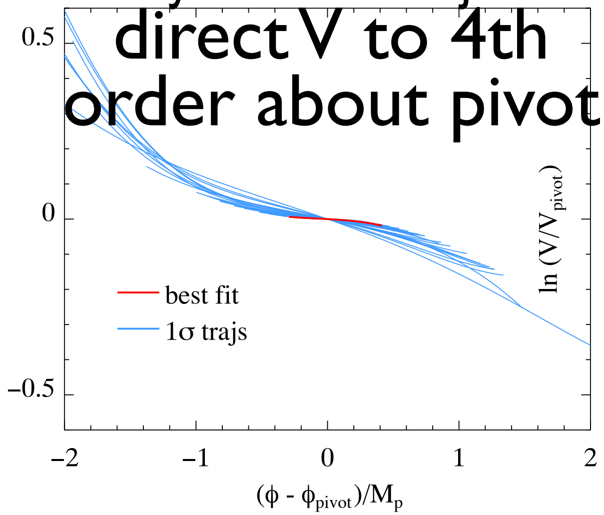


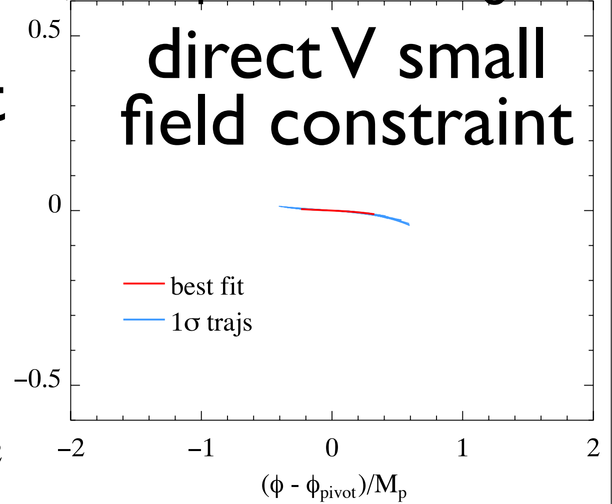


over the years: mode expansion of H, *ln*H, ε, d*ln*ε/d*ln*k, n_s, *ln*P_s

measure-dependent, priors from only allowed trajectories, V-expansion not great





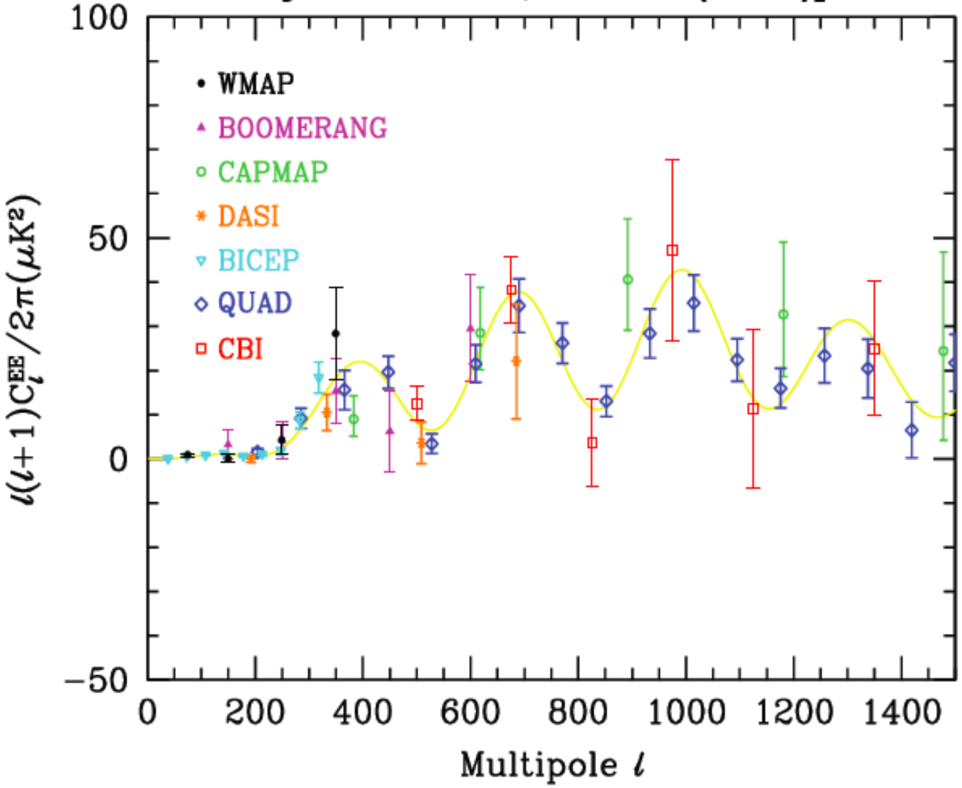


best-fit P1.3yr TT model predicts the polarization. works perfectly at all frequency cross correlations strengthens the case for the Galactic/extragalactic nuisance parameter model being accurate

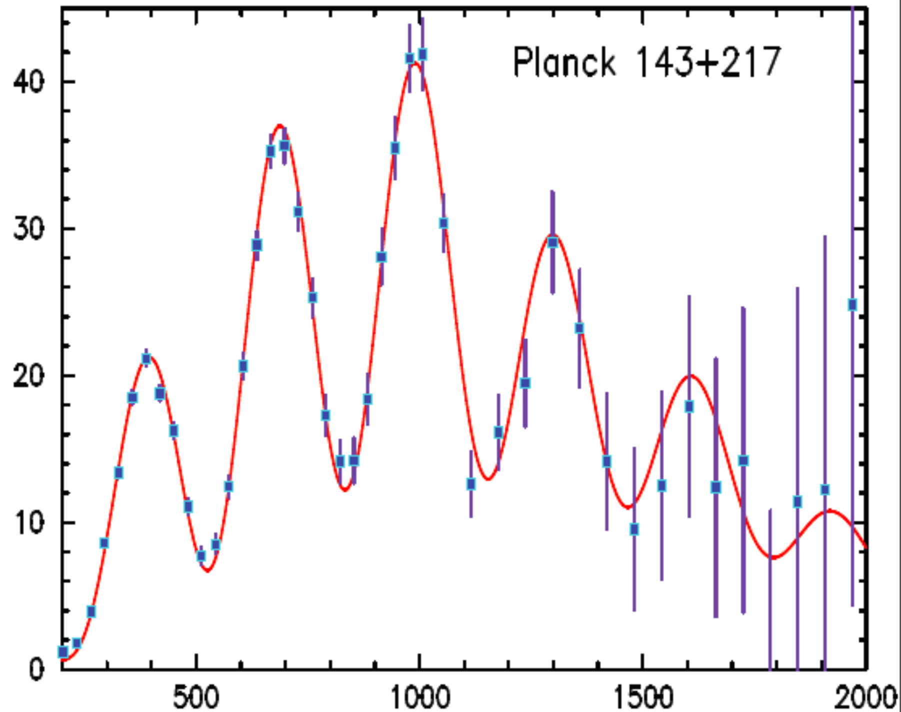
teaser for 2014

EE polarization

[J. Beringer et al. (Particle Data Group), Phys. Rev. D86, 010001 (2012)]



[Planck 2013 results. XVI. Cosmological parameters]

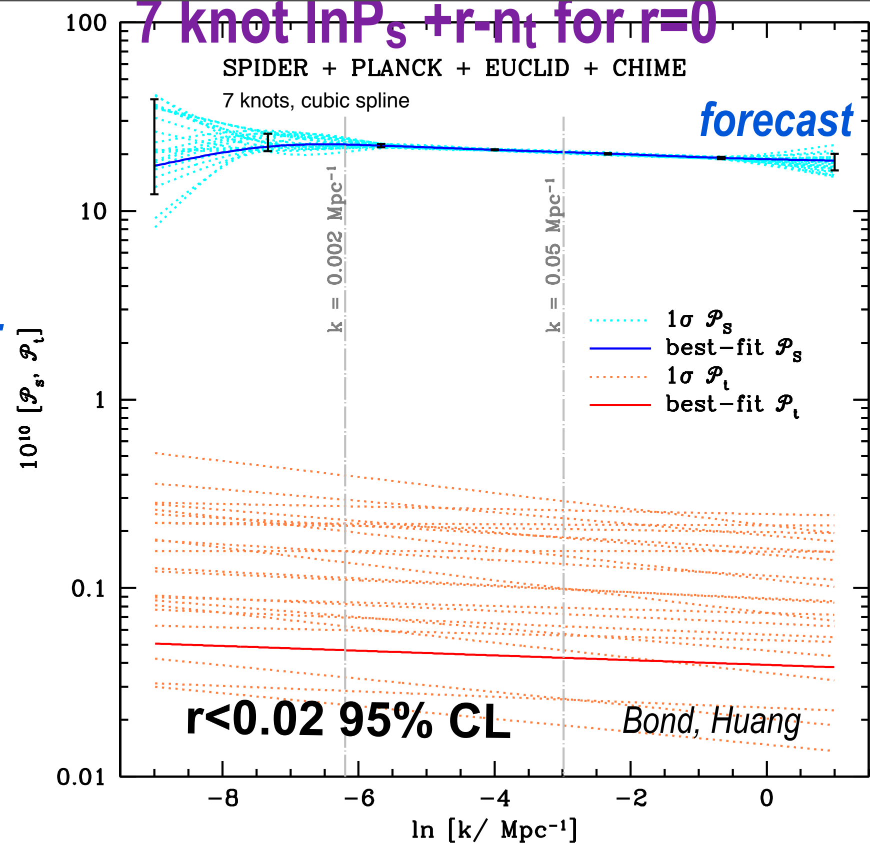


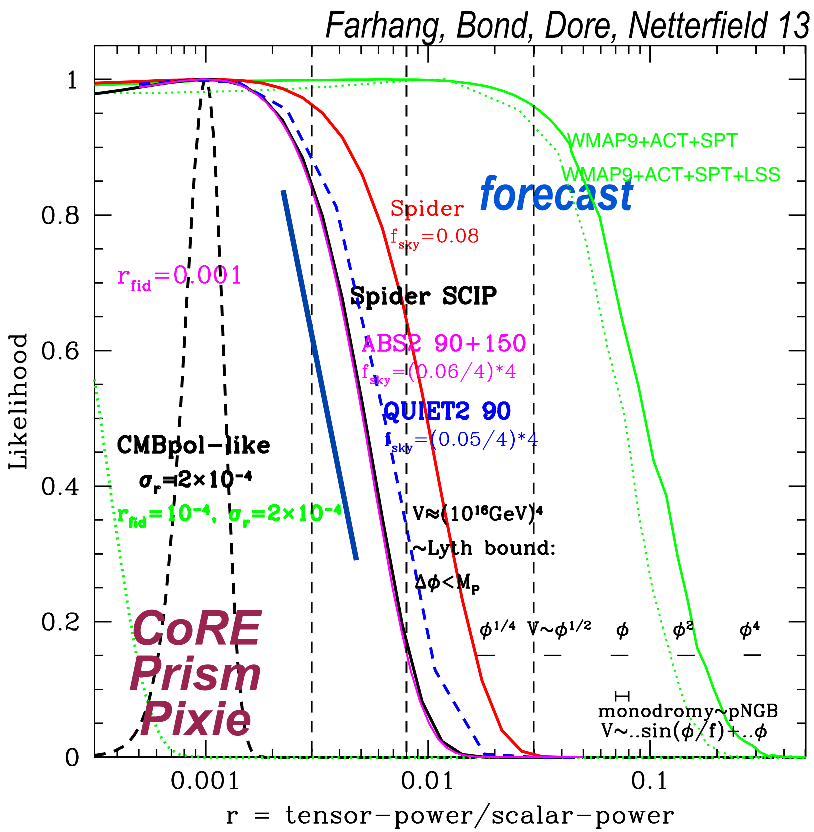
a long path to constrain** the **B-mode of polarization** at the **r =.02 to .05 level of P2.5 forecasts

CMB Lensing induces B-mode of polarization from E-mode: *Detection of **B**-mode Polarization in the Cosmic Microwave Background with Data from the South Pole Telescope* **Hanson+13 using Herschel sub-mm+SPT-E-mode x SPT B-mode to confirm detection at 7.7sigma**

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

similar r-forecasts for ***ABS+, Quiet2, Keck, ..***

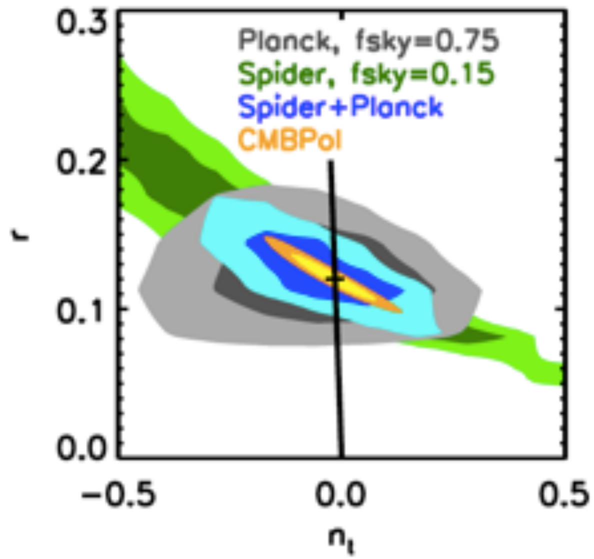




can get B-mode shapes but without the precision needed to check

$-n_t \approx r/8$ consistency

COBE-like errors on tilt

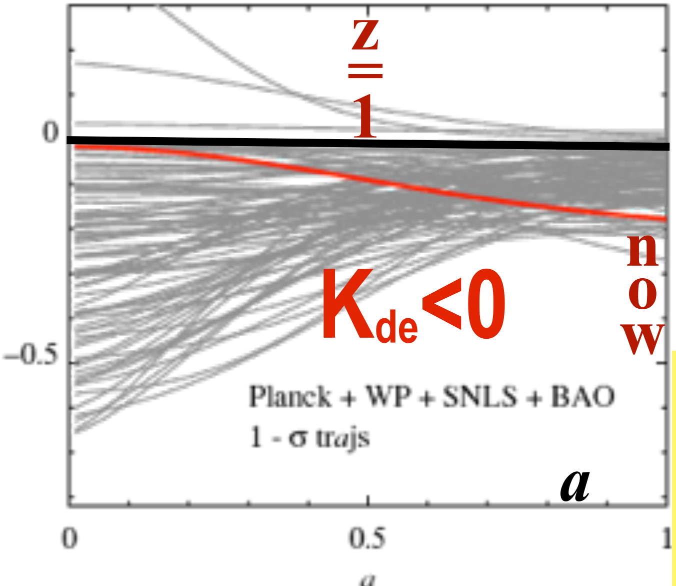


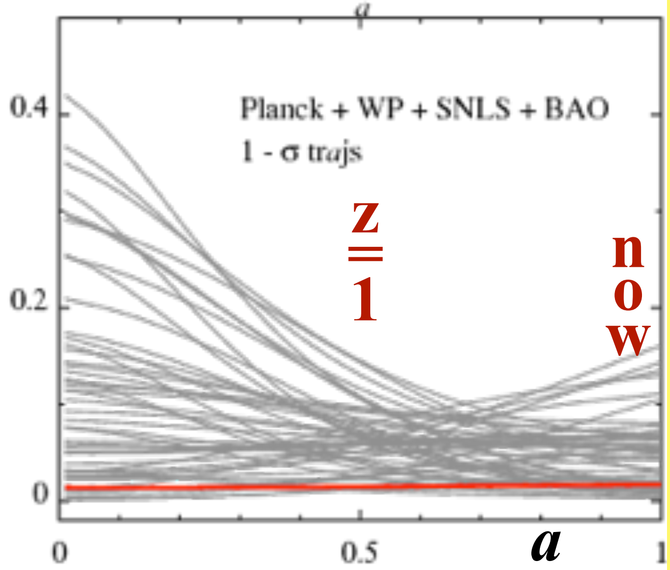
late-inflaton DE trajectories

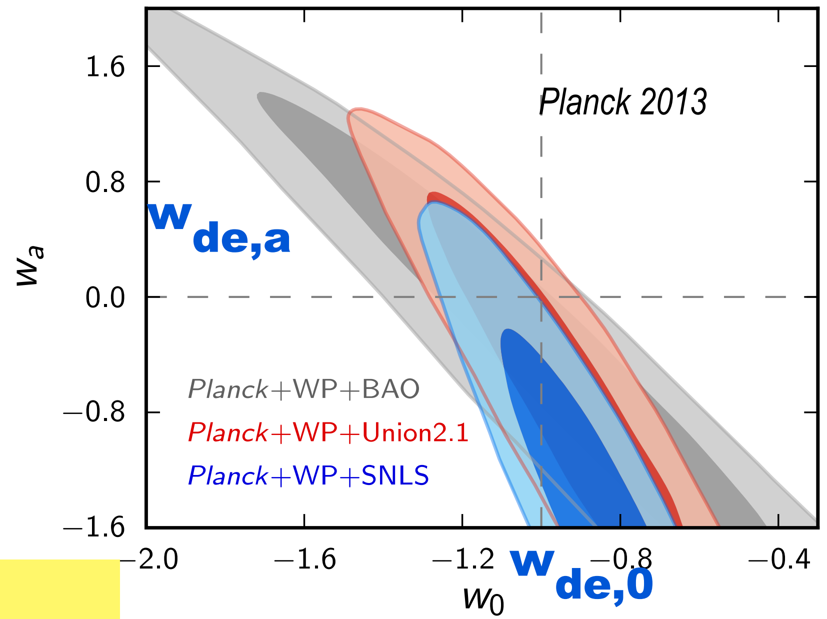
informed = 3-parameter $W_{de}(a|\varepsilon_s \varepsilon_{de\infty} \varsigma_s)$

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

Bond, Huang 2013







$1+w_{de,0}$

$= -0.13 \pm 0.12$

if $w_{de,a}$

V_{de}, $\varepsilon_{de\infty}$

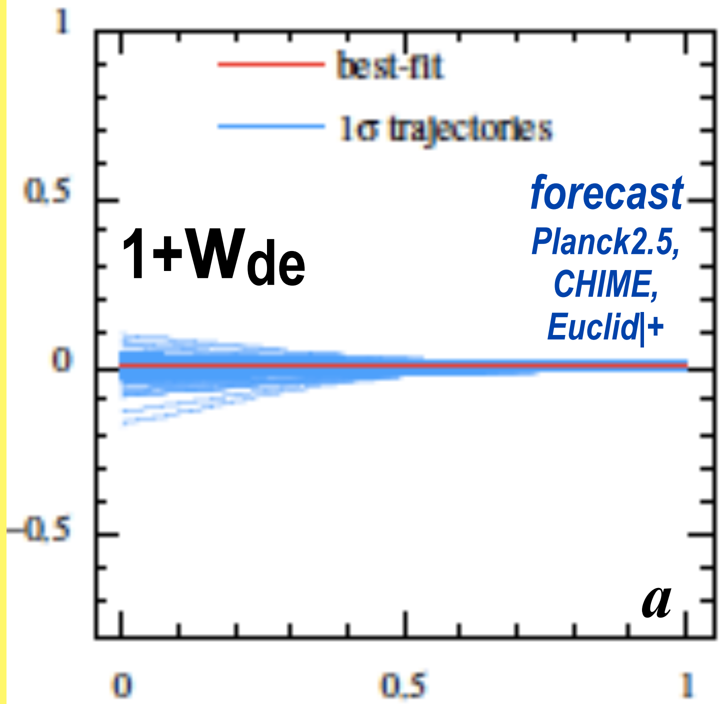
$\varepsilon_s = (d\ln V/d\psi)^2/4$

@pivot a_{eq}

= -0.25 +.20 -.26

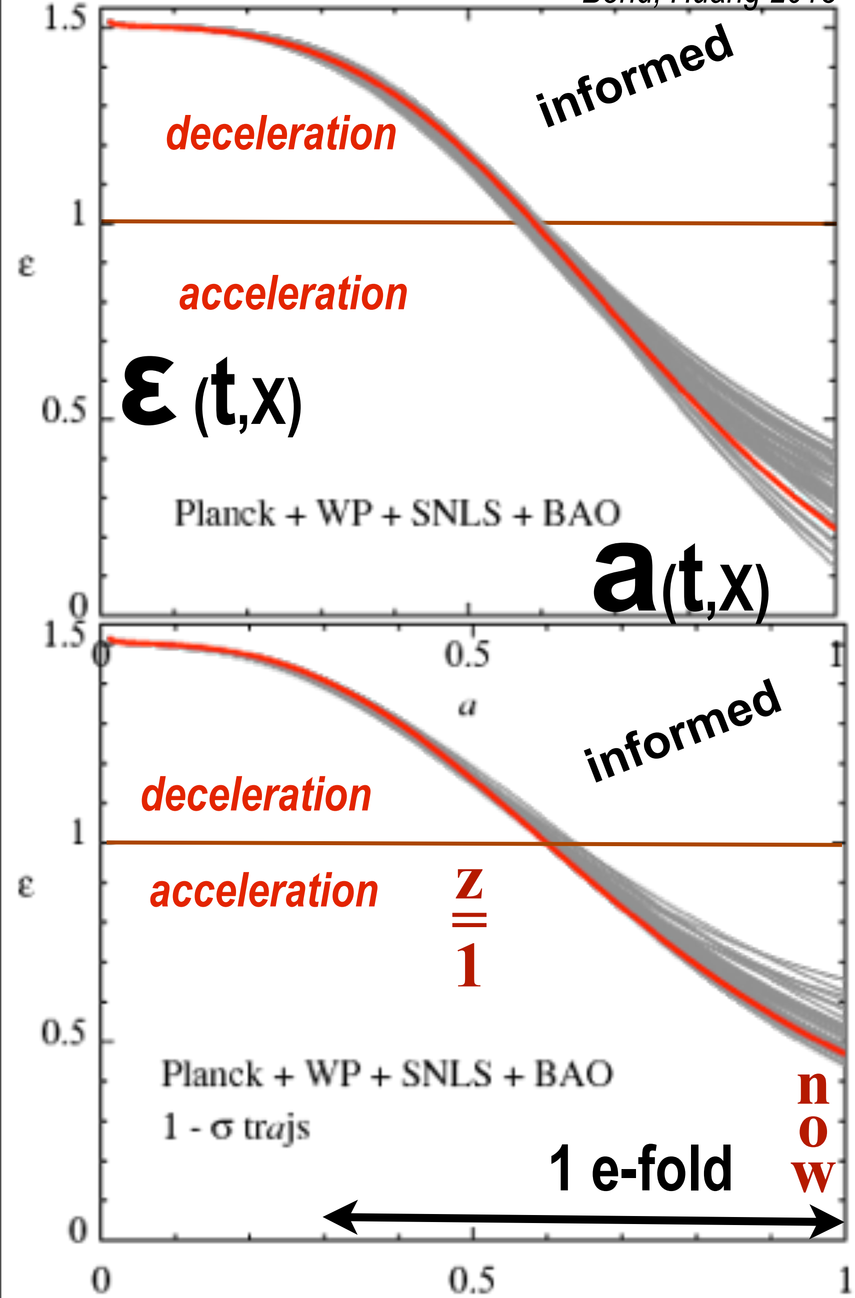
P1.3+SNLS3 =0.0 +.21

future .005 +.031 -.025



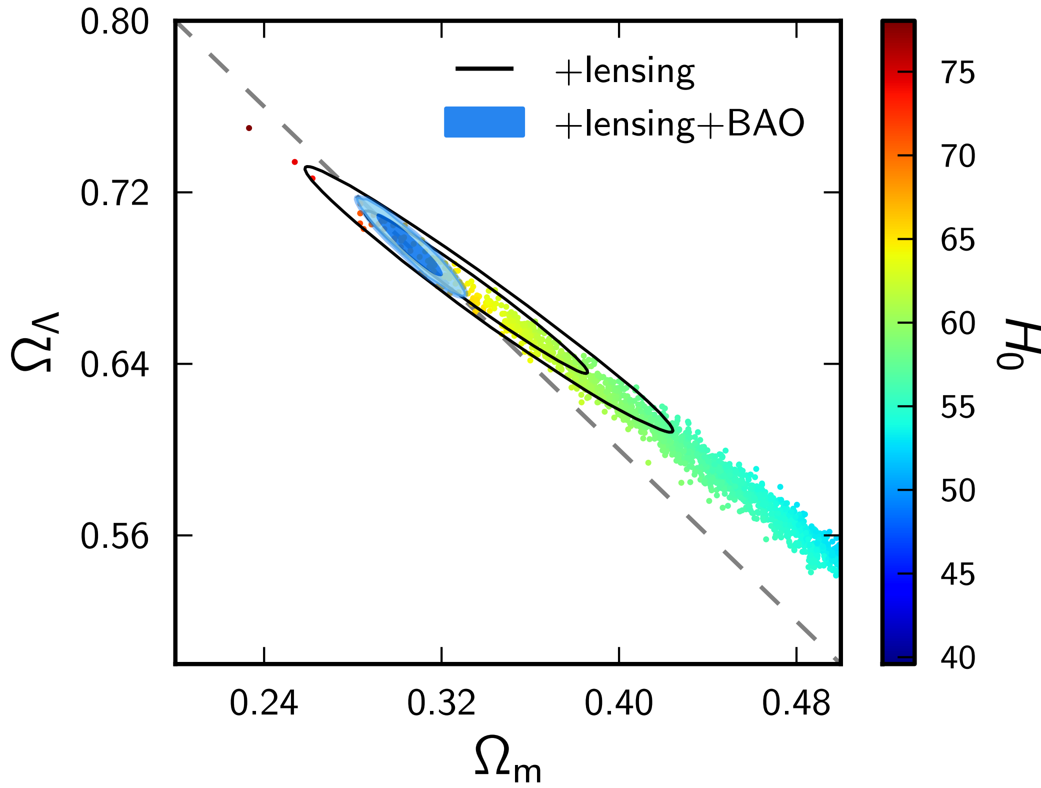
late-inflaton DE trajectories

Bond, Huang 2013

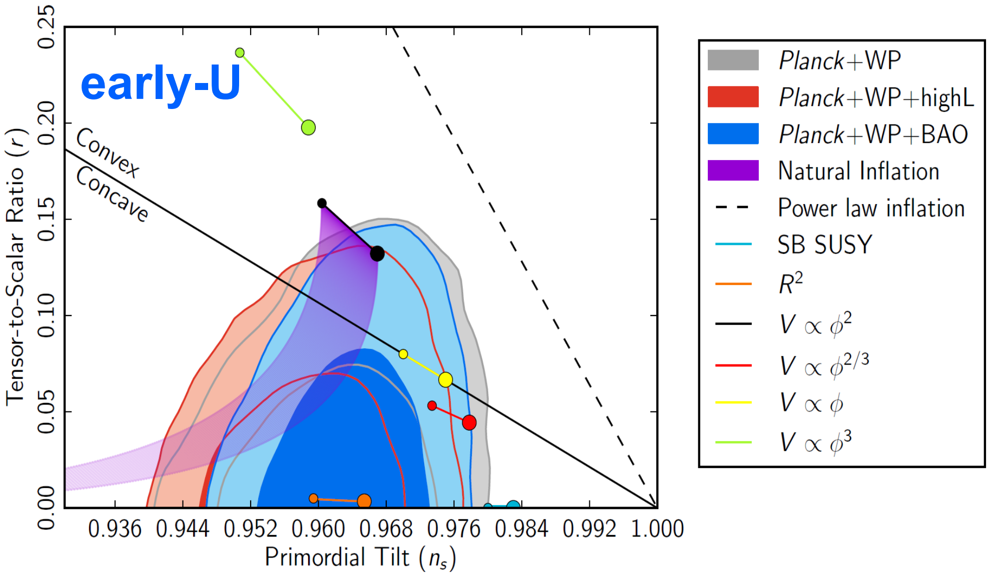


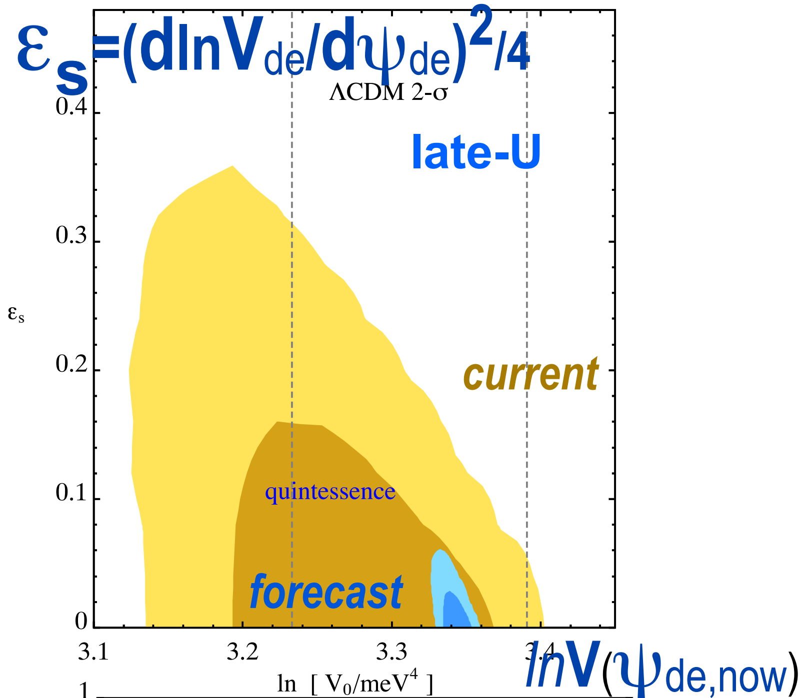
lensing breaks geometrical degeneracy:

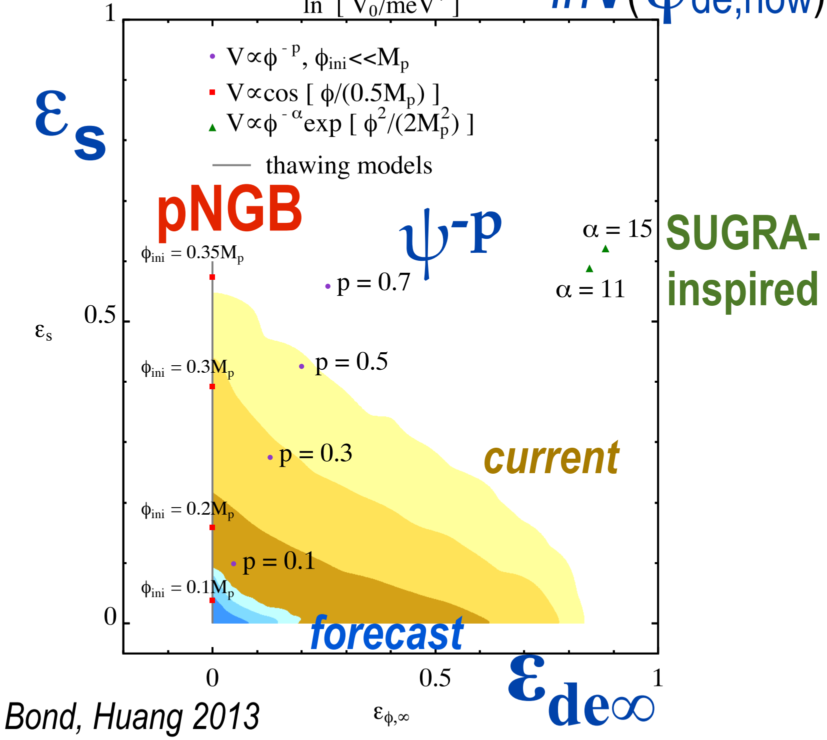
Planck alone gives dark energy cf. Planck+BAO



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.







primordial nonGaussianity

nonG 3-point-correlation-pattern measure

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

=> *f_{NL*} =0.44 ± 3.5* *for phonons/3-curvature*

$-f_{nl}$: 42.3 ± 75.2 equil

-25.3 ± 39.2 ortho

$\zeta_{NL}(x)= \zeta_G(x)+$
$f_{NL*}\ (\zeta_G^2(x)-<\zeta_G^2>)$
local smooth.
use optimal pattern estimators

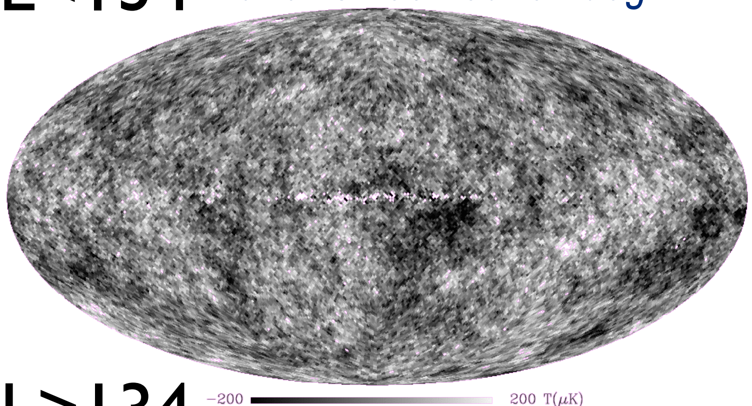
cf. *DBI inflation: non-quadratic kinetic energy*

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

$\zeta_{NL}(x)=$
equilateral pattern &
orthogonal pattern

L<134 *Planck smoothed to 1deg fwhm*

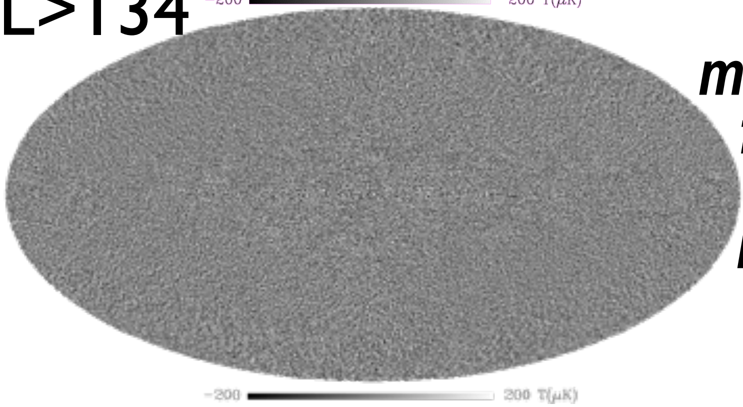
P13 XXIV, XXII



scale (k) dependent patterns: connecting to power spectrum broken scale invariance. hint?

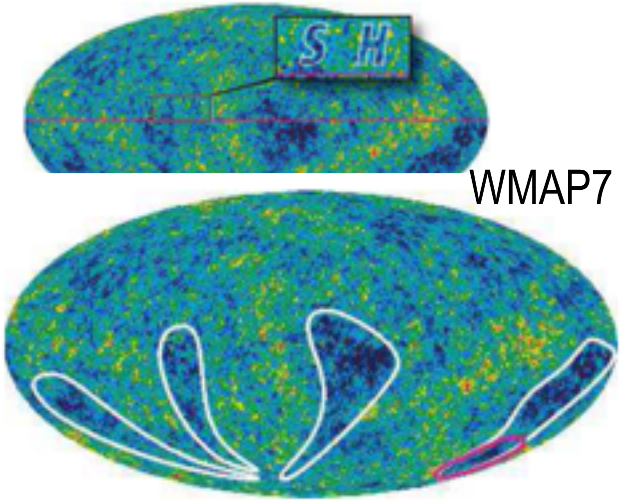
cosmic/fundamental strings/defects *P13 XXV*

L>134

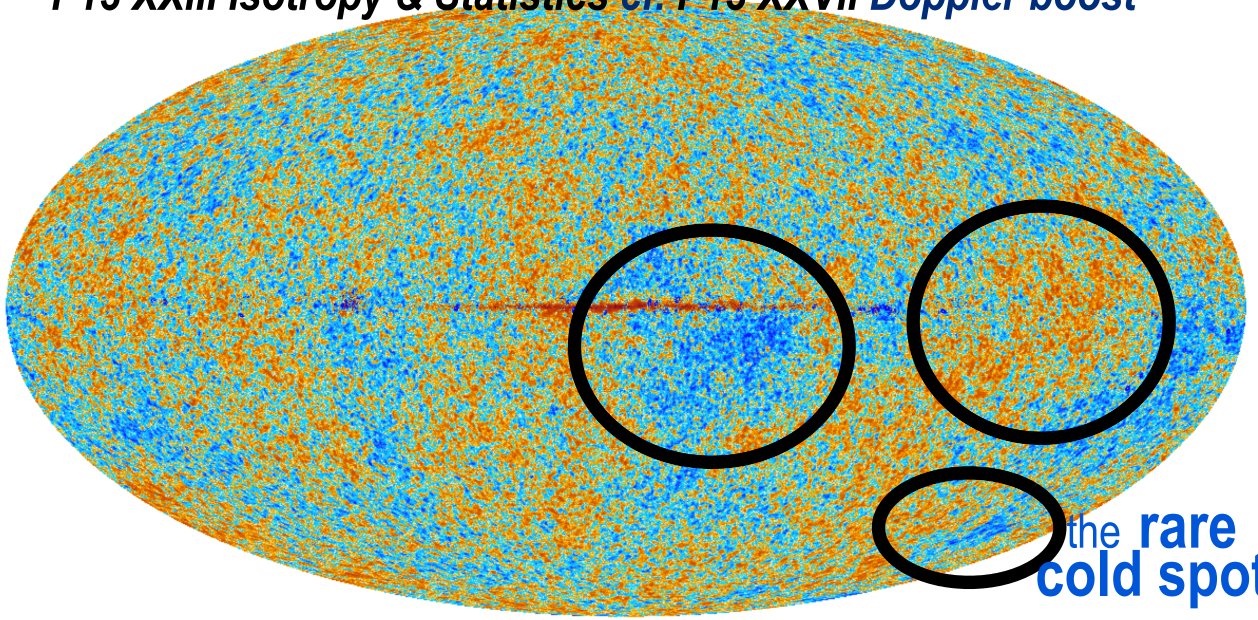


most nonG info from high L: why Planck improved so much over WMAP9

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



P13 XXIII Isotropy & Statistics cf. P13 XXVII Doppler boost



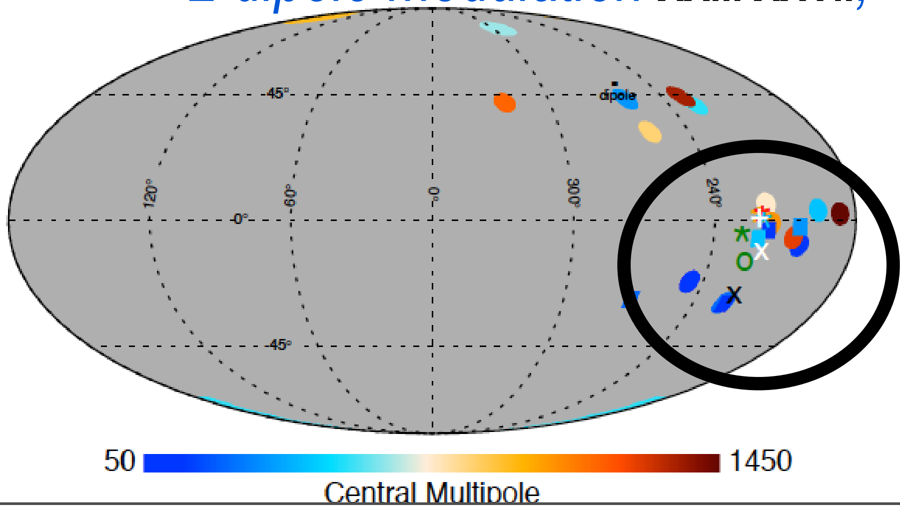
the **rare cold spot**

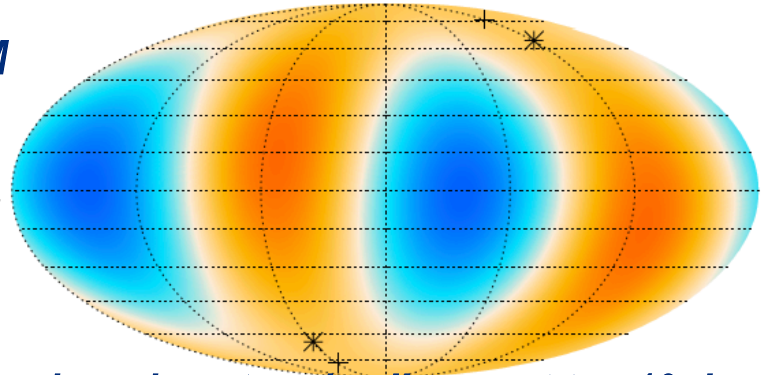
***C_L @$L<200$** is low cf. L~200-2000 forecast for tilted LCDM*

***$\Delta C_L / C_L$ @$L<400$ ~7%** (P13 XXIII & WMAP9),*

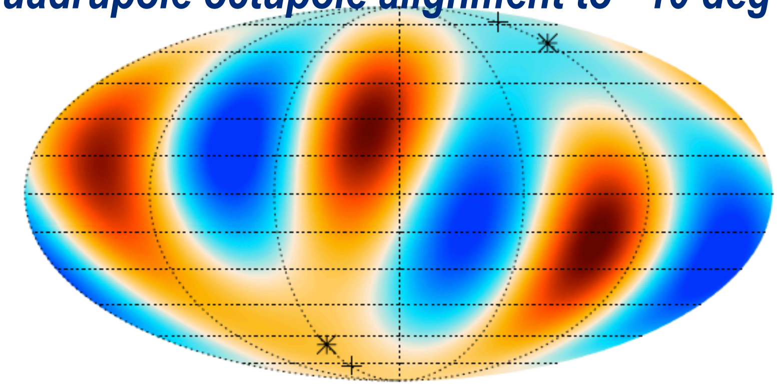
high L C_L asymmetry small **<0.2% with L_{max}=1500?**

*∃ dipole modulation **XXIII XXVII**, +?*





quadrupole octupole alignment to ~10 deg



SIMPLICITY

at a~e^{-7}~1/1100 =>

at a~e^{-67+60}~1/10^{30+25}

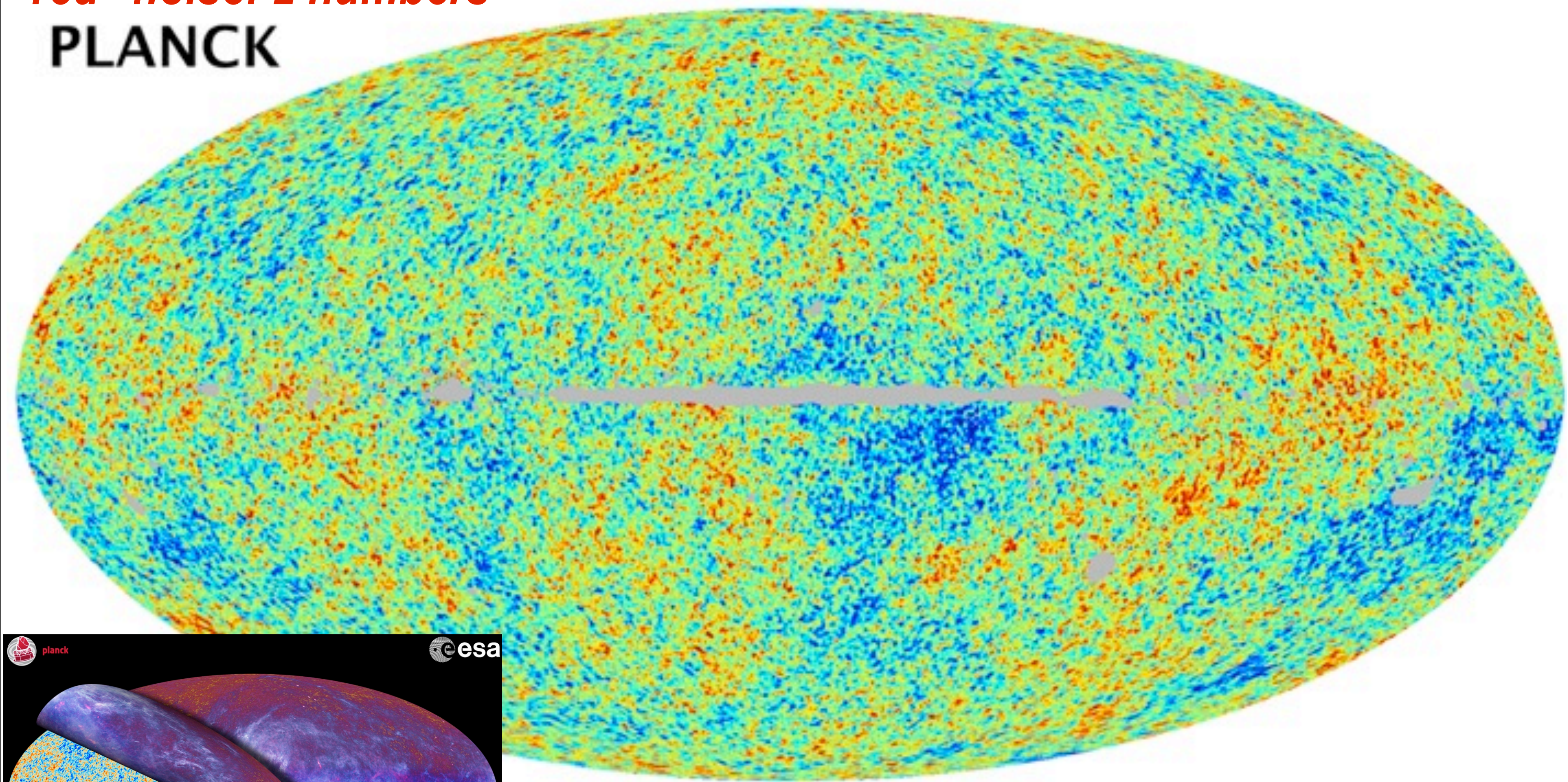
"red" noise: 2 numbers

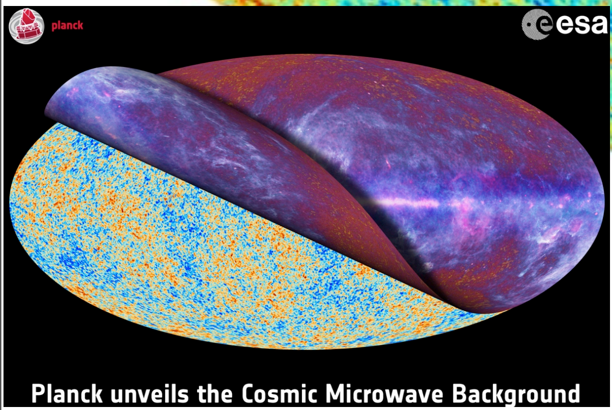
PLANCK

Planck 09 launch

Planck SMICA Map

CMB-data Concordance





Planck CMB/SMICA map, ~5′ resolution
+ NILC, SEVEM, C-R 3 independent component separated CMB maps show the same features

SIMPLICITY

WMAP 01 launch

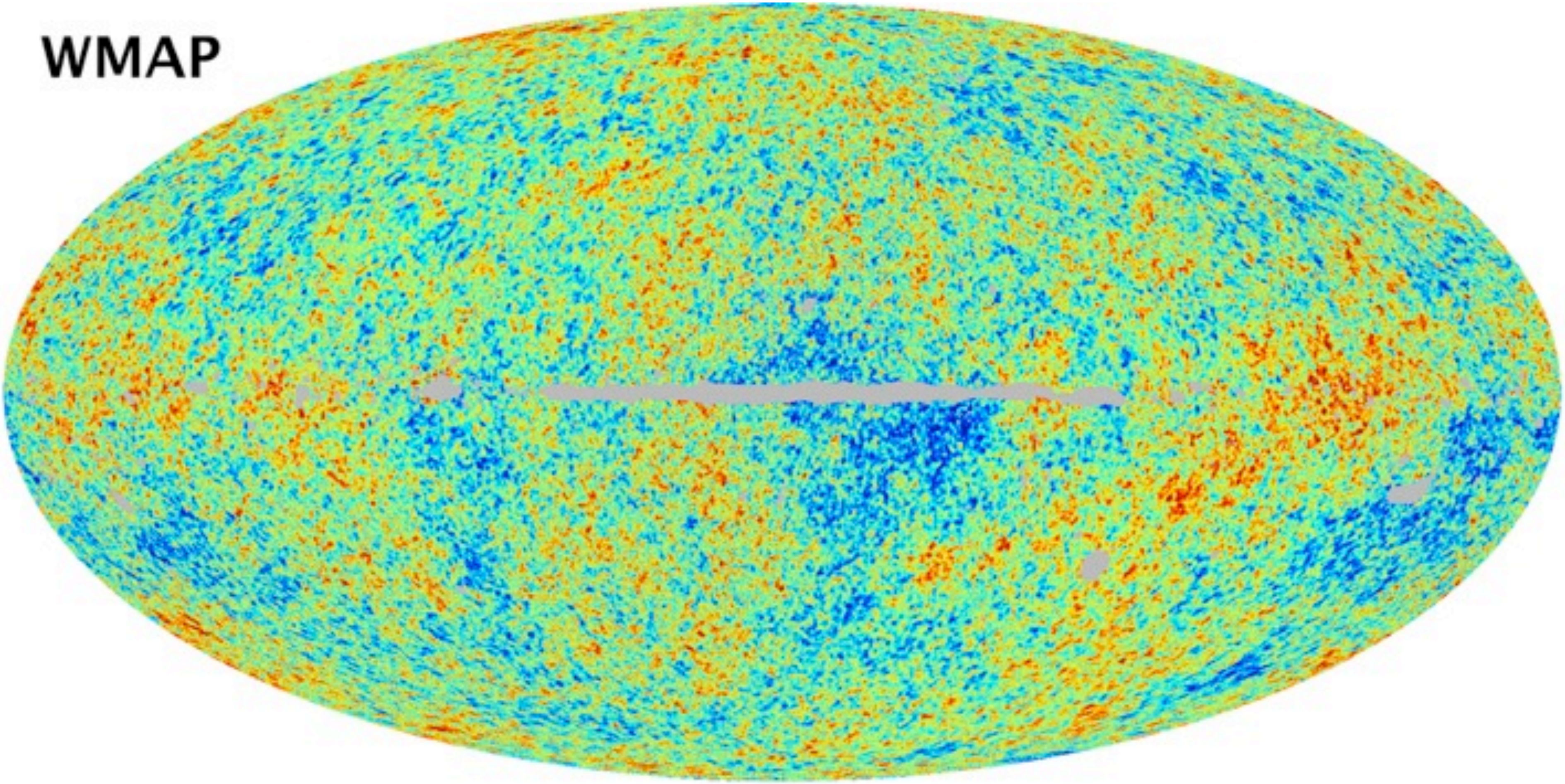
WMAP W–band, Template Cleaned

CMB-data Concordance

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

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

"red" noise: 2 numbers



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

SIMPLICITY

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

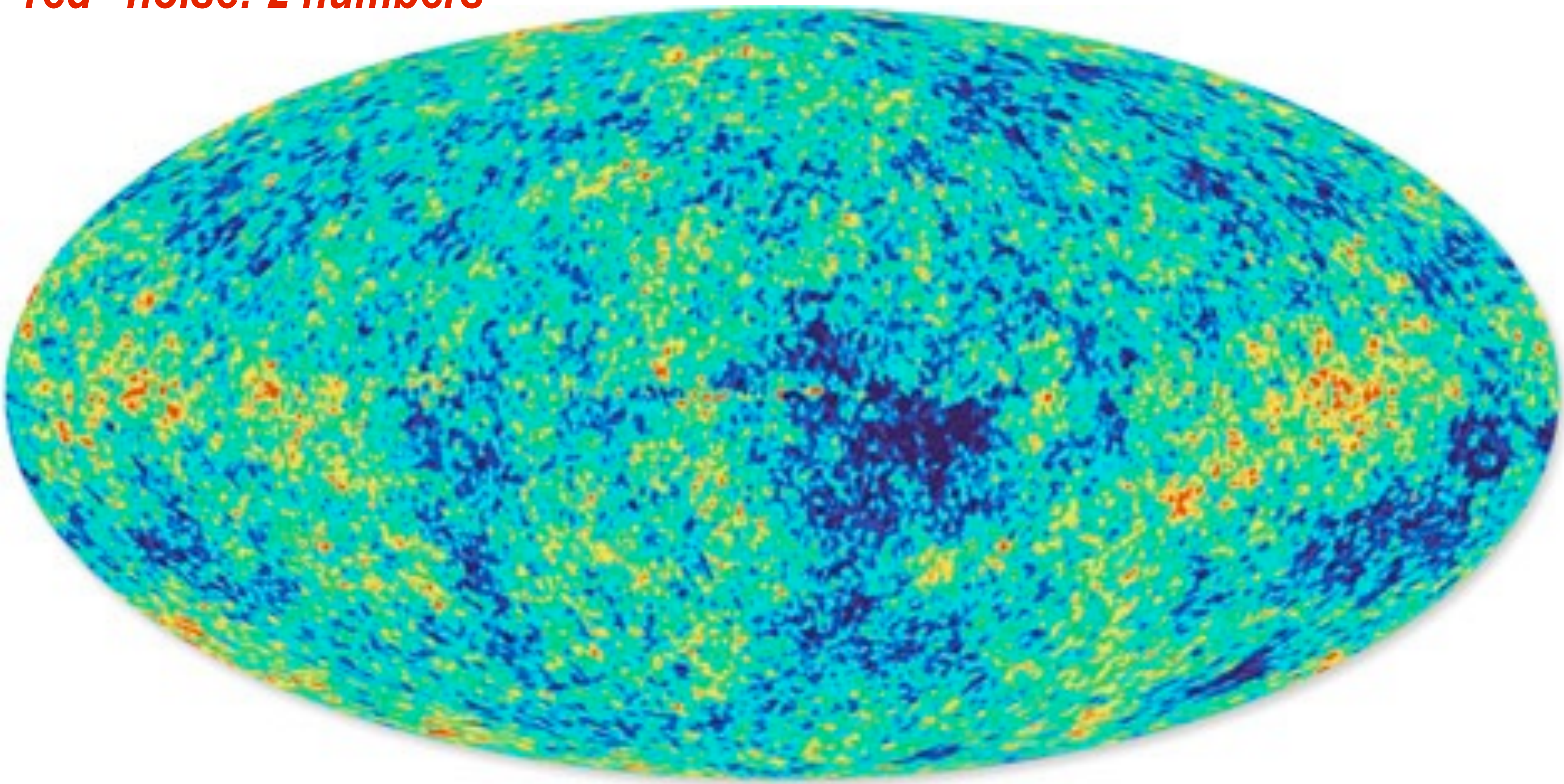
at $a \sim e^{-67+60} \sim 1/10^{30+25}$

"red" noise: 2 numbers

WMAP 01 launch

WMAP W–band, Template Cleaned

CMB-data Concordance



Cleaned with low-frequency templates only.

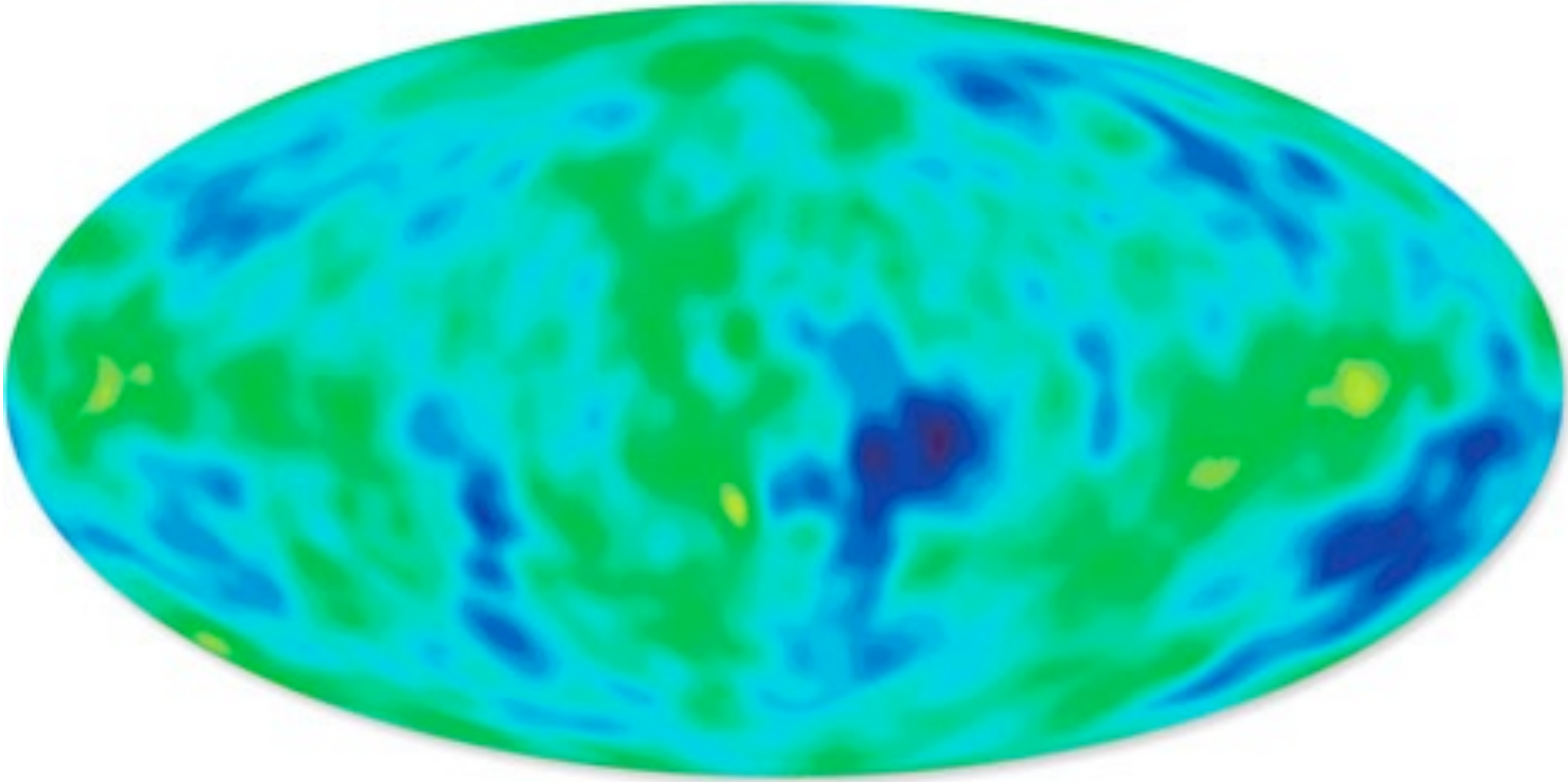
similar tremendous agreement with the much higher (5X) resolution ACT & SPT maps

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

COBE 89 launch

COBE

CMB-data Concordance



primordial nonGaussianity

nonG 3-point-correlation-pattern measure

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

=> f_{NL*} =0.44 ± 3.5 *for phonons/3-curvature*

-f_{nl}: 42.3 ± 75.2 equil

-25.3 ± 39.2 ortho

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

local smooth.

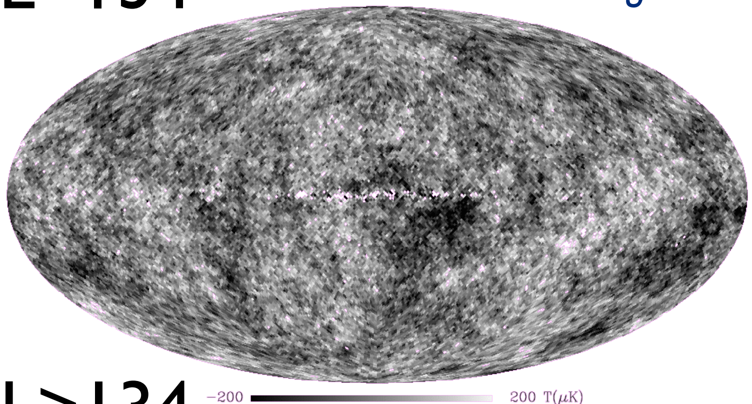
use optimal pattern estimators

cf. *DBI inflation: non-quadratic kinetic energy*

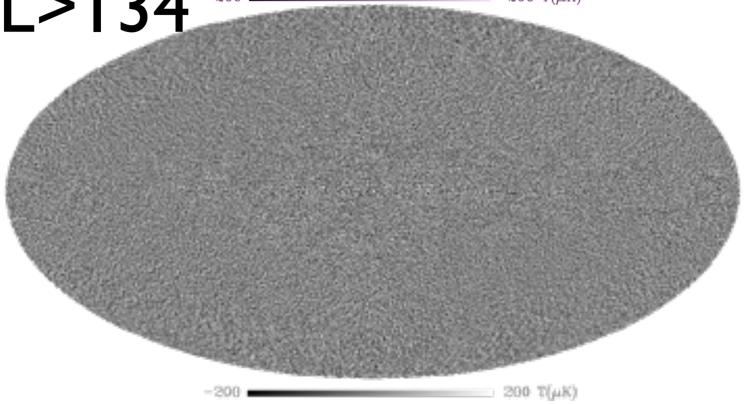
phonon ~ $\zeta_{NL} = \ln(\rho\, a^{3(1+w)})/3(1+w)$ => $f_{NL*} = 3/5\, f_{NL} - 1$

$\zeta_{NL}(x)$= equilateral pattern & orthogonal pattern

L<134 *Planck smoothed to 1deg fwhm*



L>134



scale (k) dependent patterns: connecting to power spectrum broken scale invariance. hint? *P13 XXIV*

from end-of-inflation & preheating chaos

$F_{NL}(\chi_b(x), g(x))$

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

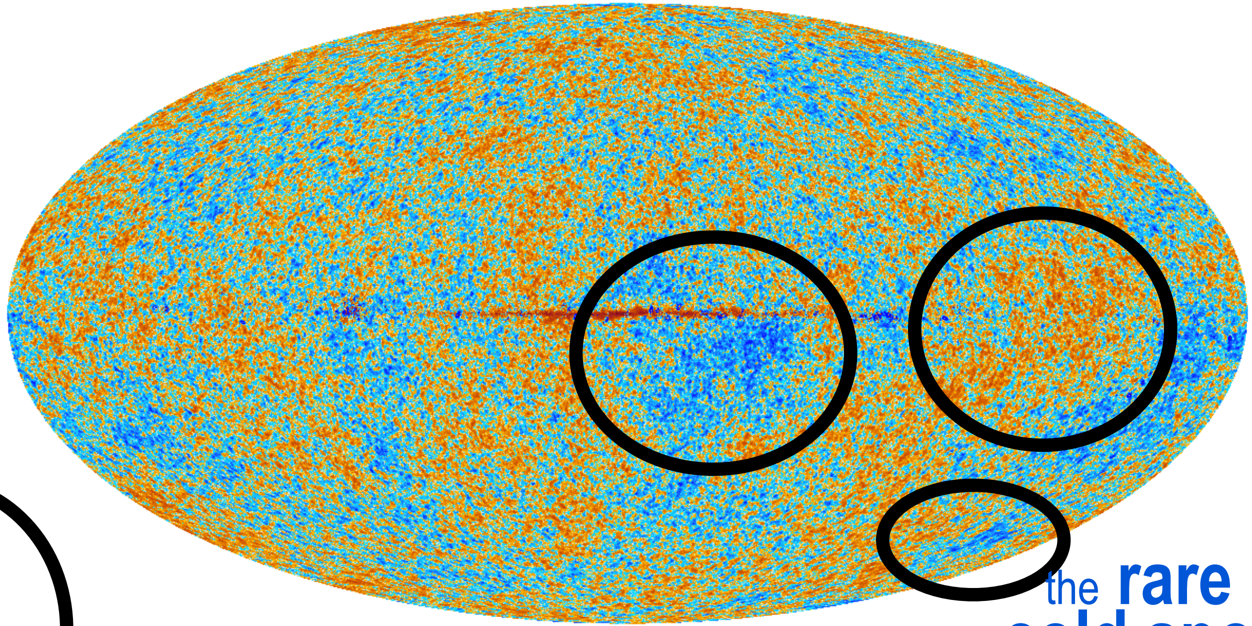
cosmic/fundamental strings/defects **@EoI**

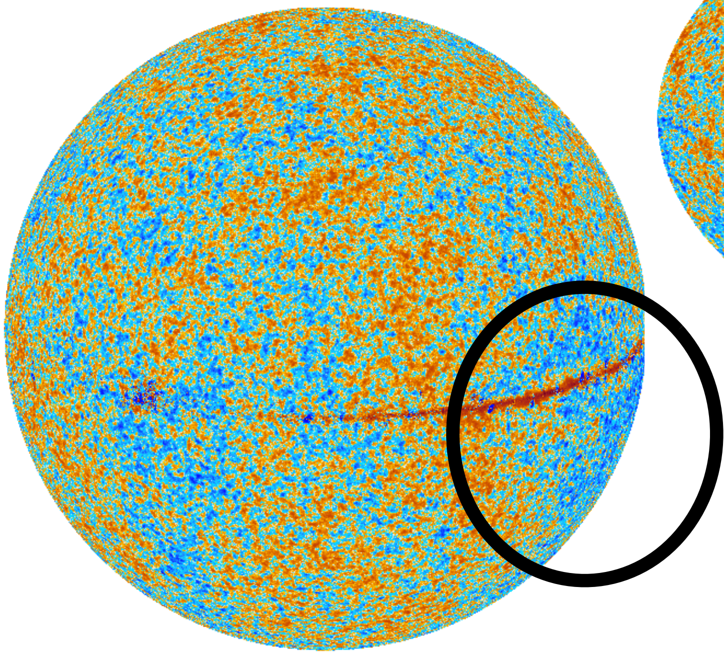
bubble collisions ***CMB***

Euclidean SO(4) => real SO(3,1) => SO(2,1) collisions, oscillon broken

COMPLEXITY

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





the **rare cold spot**

WHITEN => MASK => FILTER BANK *(SSG42 filter)*

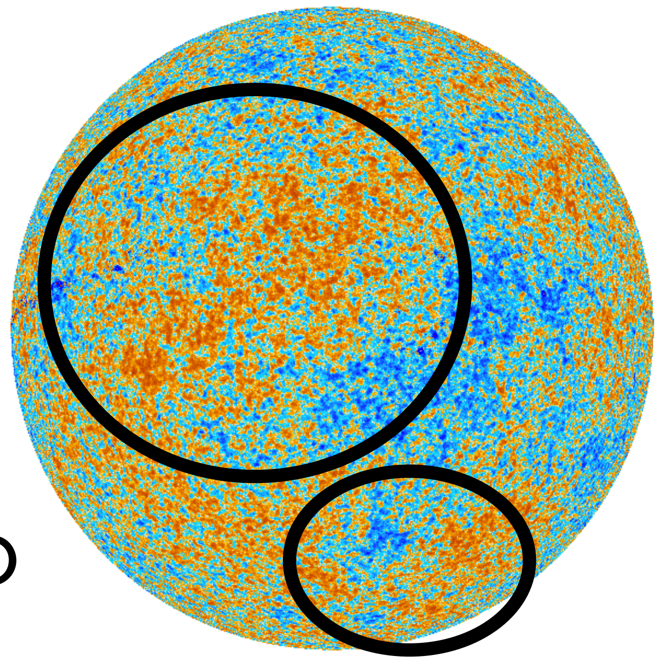
=> EXTRACT PEAKS *(hierarchical peak patches)*

filter = extra dimension: **scale space** analysis ADS of our CFT

hot & cold peaks** agree with BE87 **Gaussian stats $n_{pk}(<\nu)$

PLANCK2013: 826', 105 peaks, coldest -4.97σ 1:497

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



Grand Unified Theory of Anomalies TBD

Anomalies in Polarization? TBD

SSG42 Filter Sweep

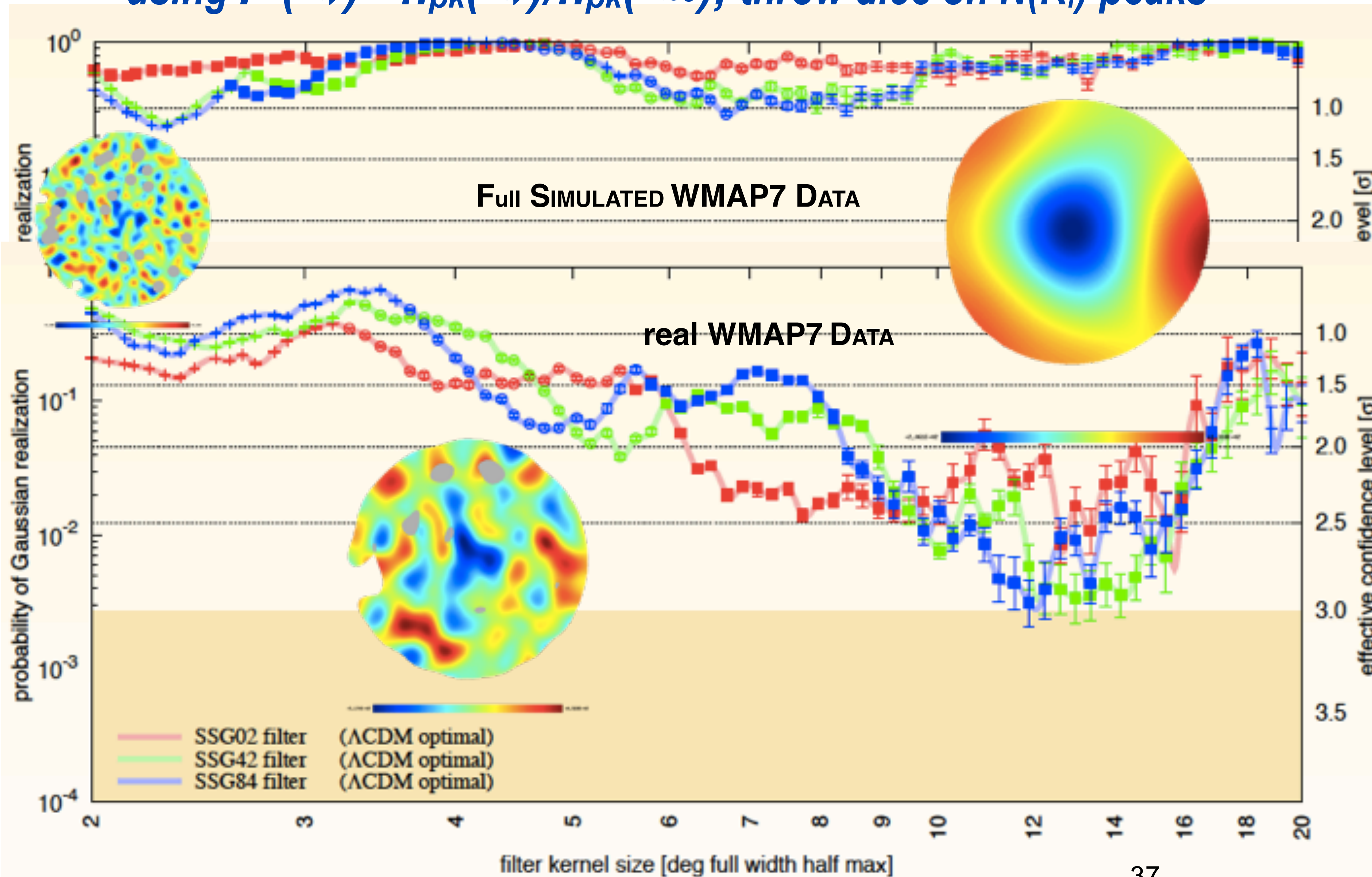
WMAP7

36

SIGNIFICANCE VS. FILTER SIZE

Bond, Braden, Frolov, Huang, Nolta, 2013

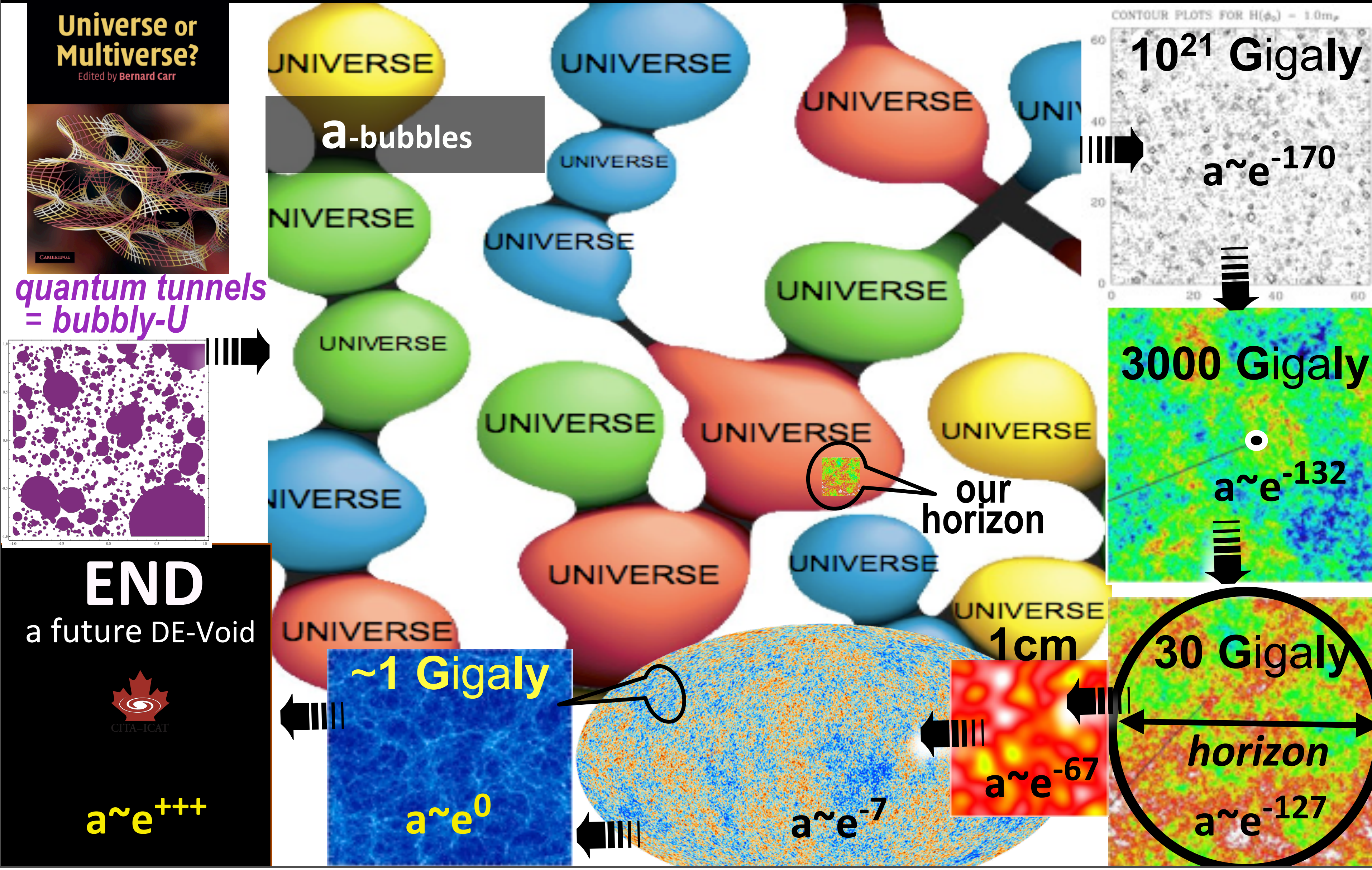
using $P(<\nu) = n_{pk}(<\nu)/n_{pk}(<\infty)$, throw dice on $N(R_f)$ peaks



P13 XXIII Spherical Mexican Hat Wavelets, 3 filters, kurtosis & excursion areas $\nu > 4$, .3% significance

ultra-Ultra Large Scale Structure of the Universe

Horizons: the ultimate-speed constraint on light & information

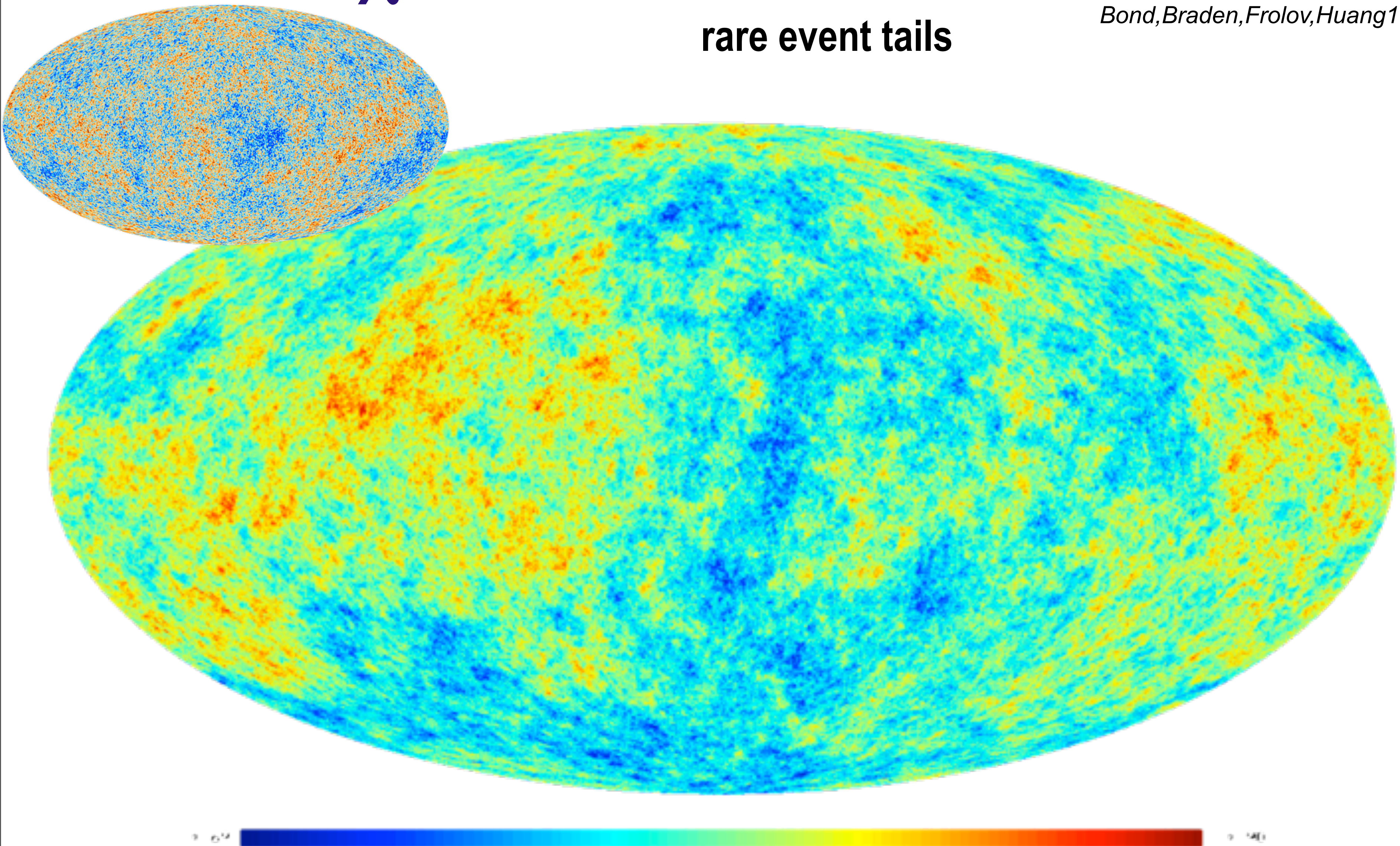


simulated sky with Gaussian inflaton-induced + **uncorrelated subdominant non-Gaussian isocon-modulated preheating**. Landscape-accessing super-horizon

control variable = χ **>h** => ***super-bias, intermittent, extended source-like***

Bond,Braden,Frolov,Huang13

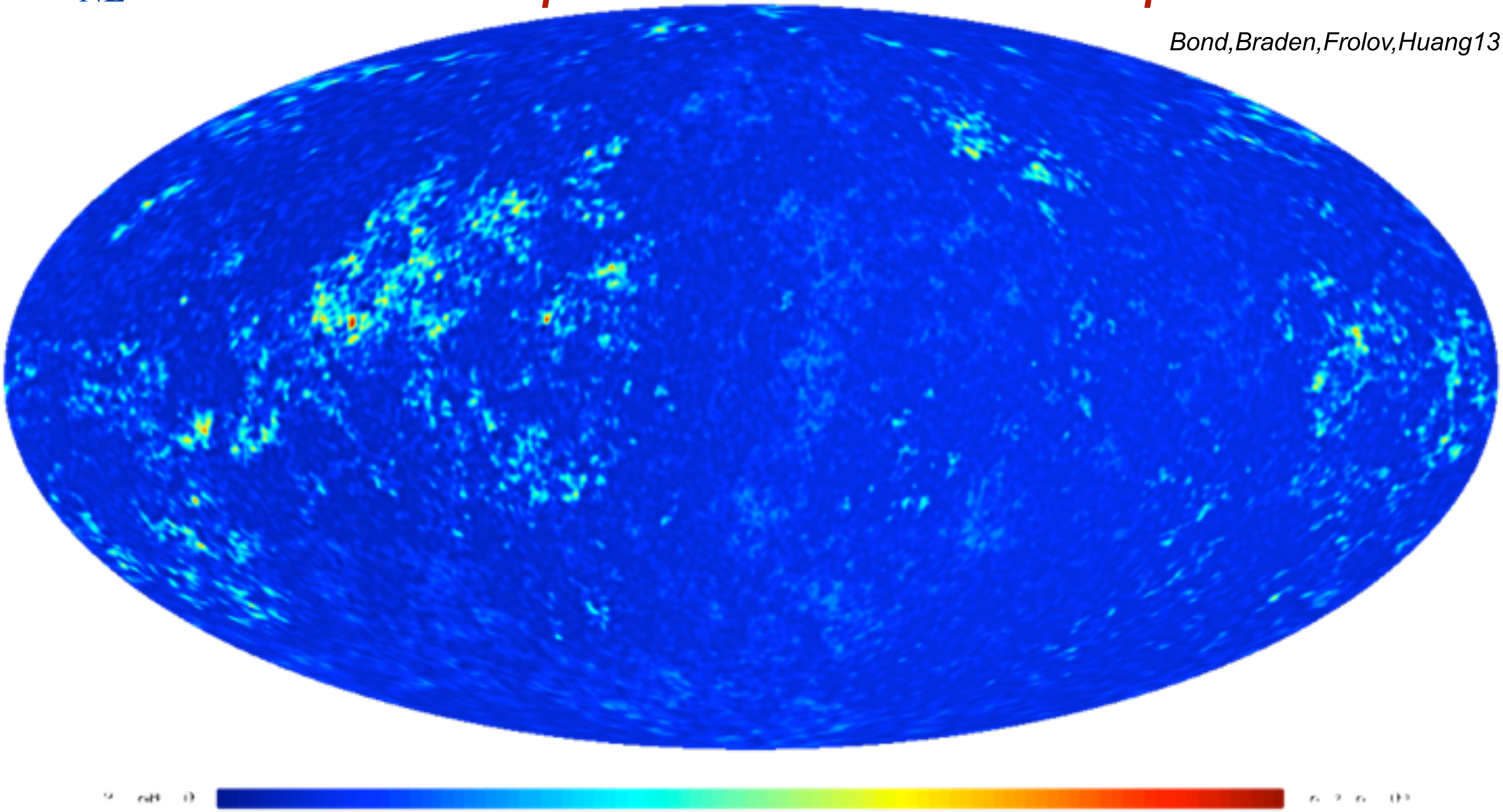
rare event tails



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

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

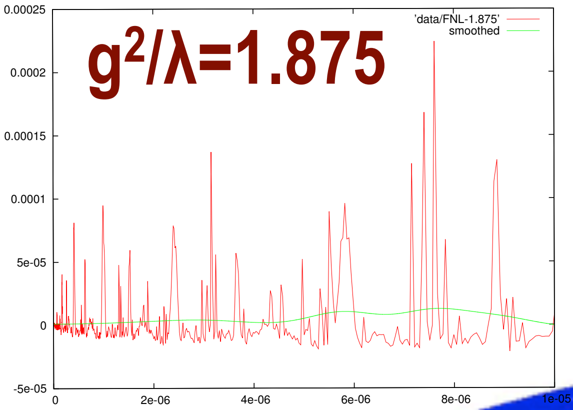
Bond,Braden,Frolov,Huang13



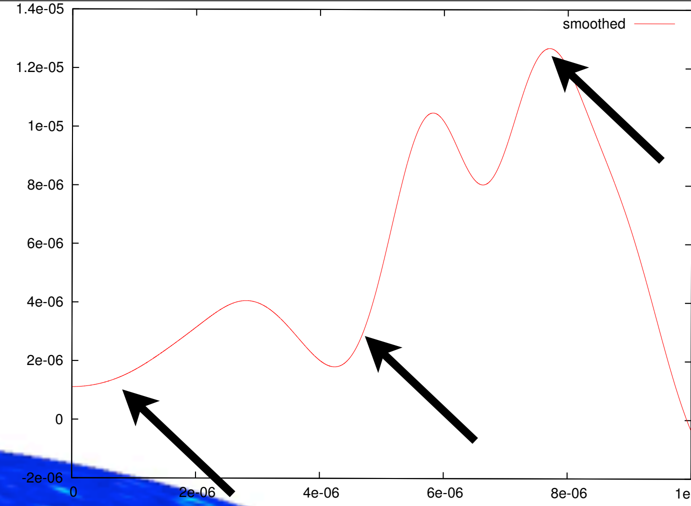
for some $\chi_{>h}$ there is a perturbative regime:

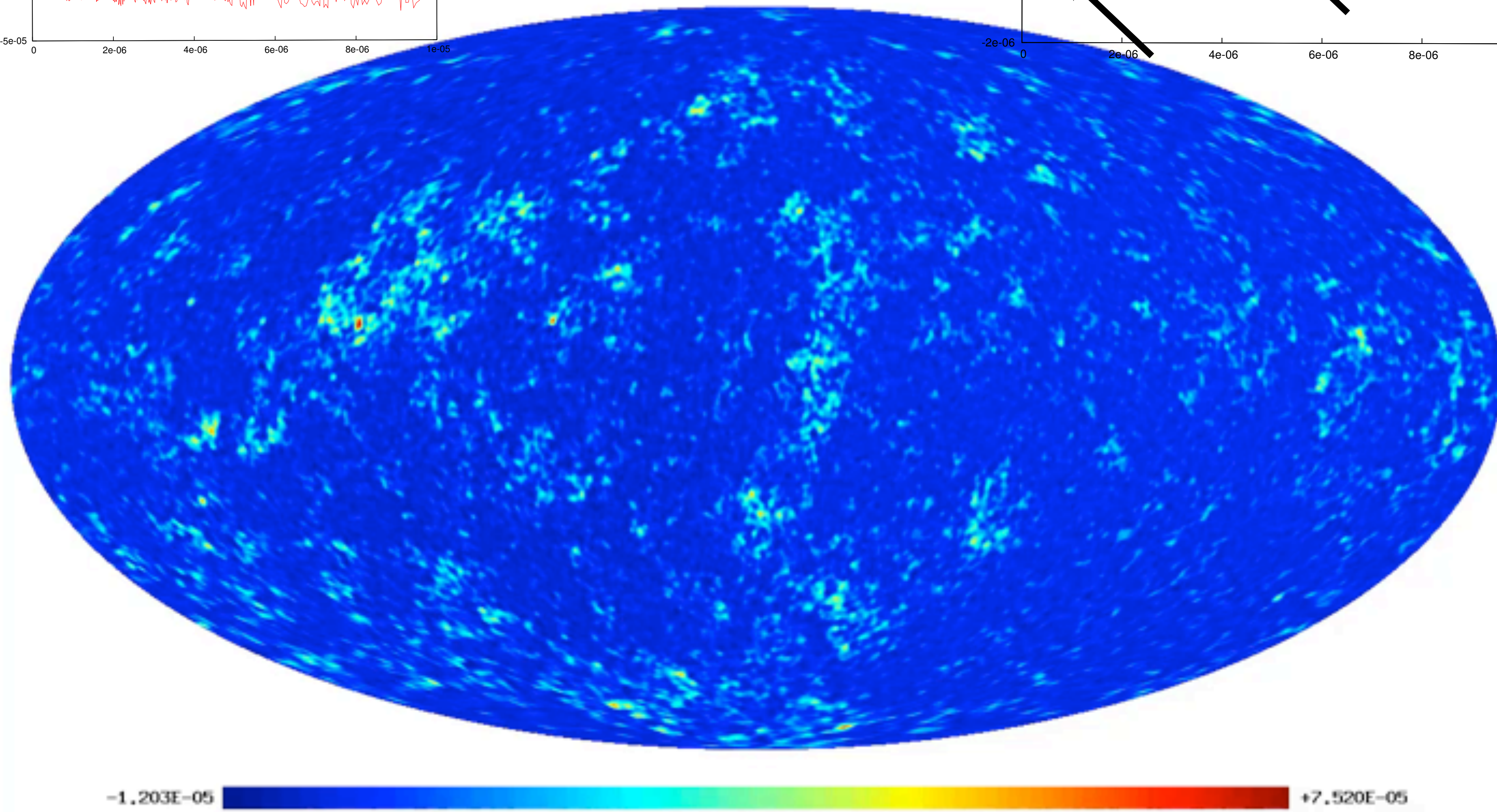
$$f_{NL}^{equiv} = \beta\chi^2 f_\chi \, [P_\chi / P_\phi]^2 (k_{pivot})$$ => constrain $f_\chi^3 \; \chi_{>h}^2$

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



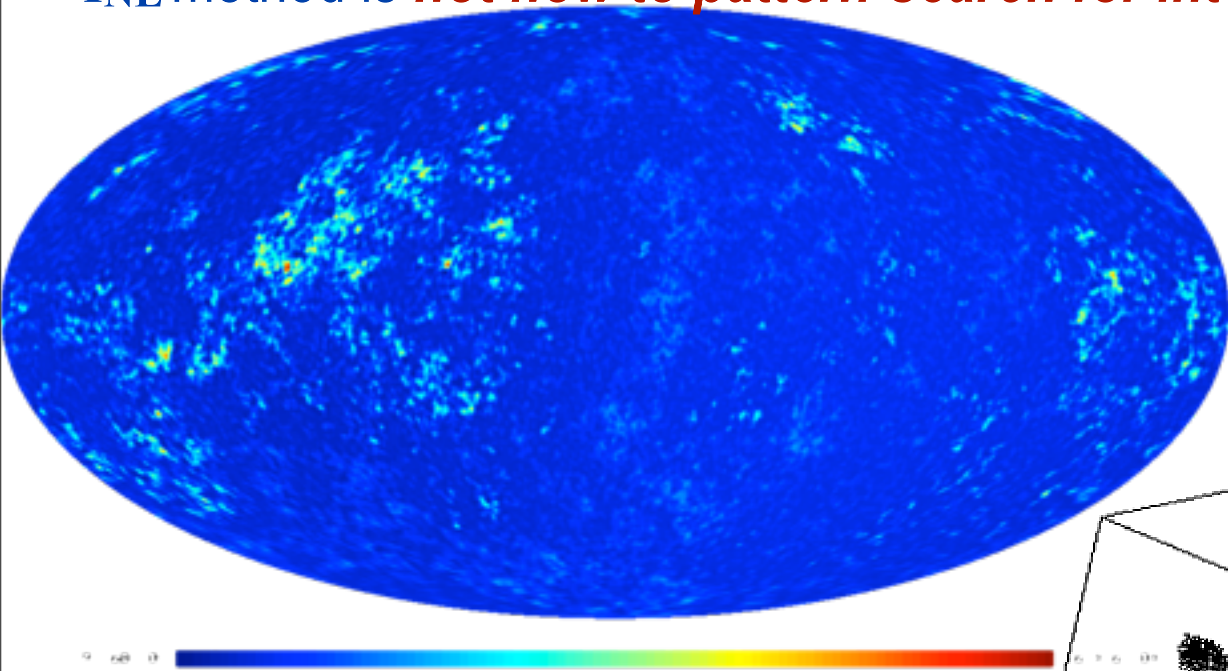
Bond,Braden,Frolov,Huang13



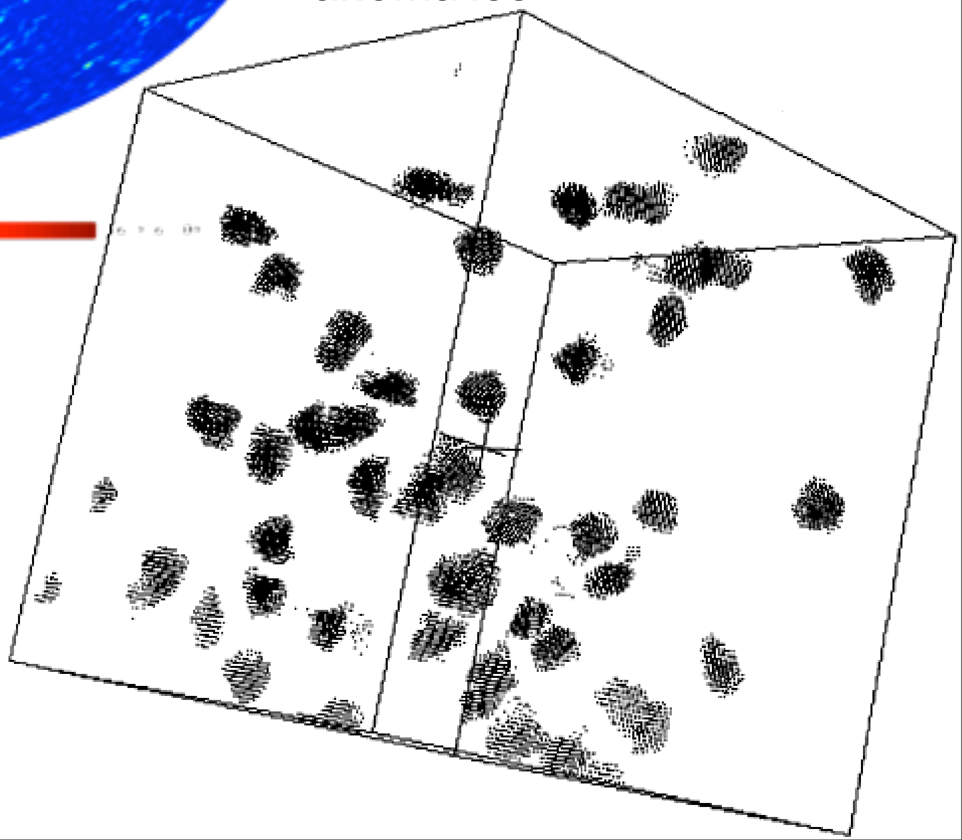


bispectrum & 3-point ~ $f_{sky,patches}^3$ => not overly constraining & standard f_{NL} method is *not how to pattern-search for intermittent power bursts*

Bond,Braden,Frolov,Huang13

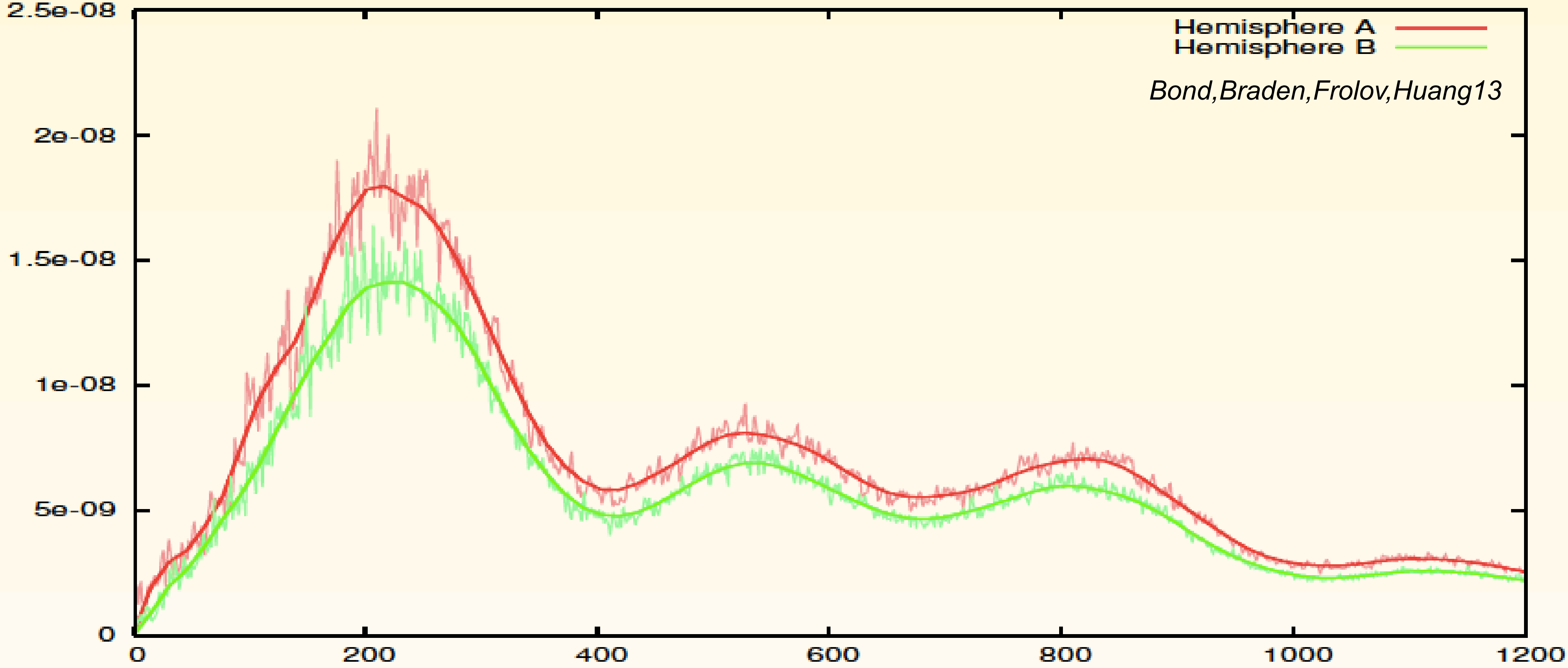


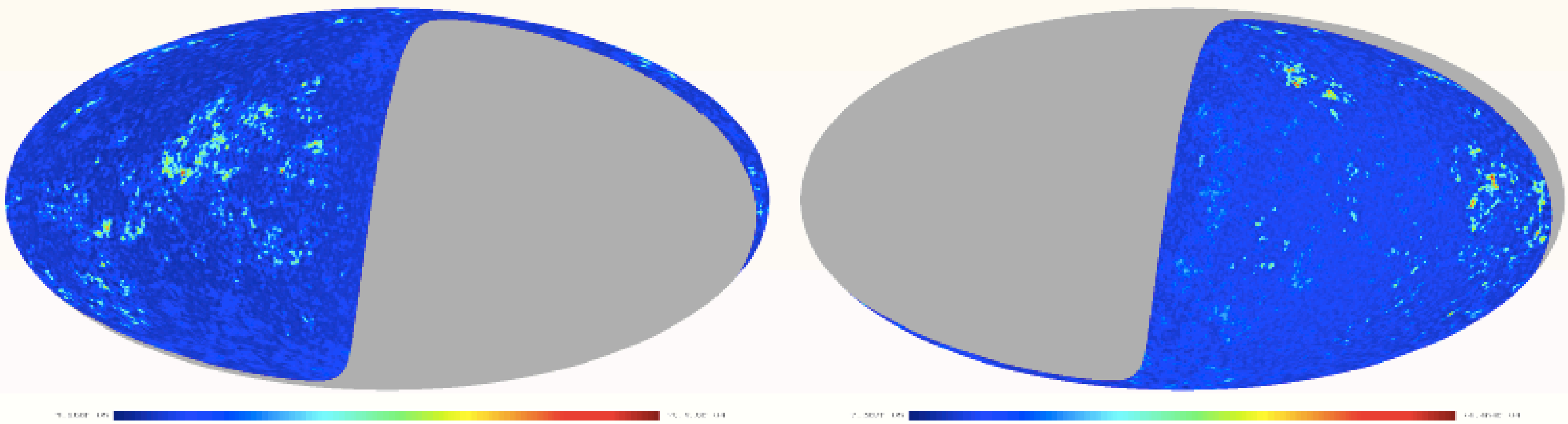
intermittency from steep threshold functions acting on a slightly red curvature field (gravitational potential) lead to very-large-scale splotch "anomalies"



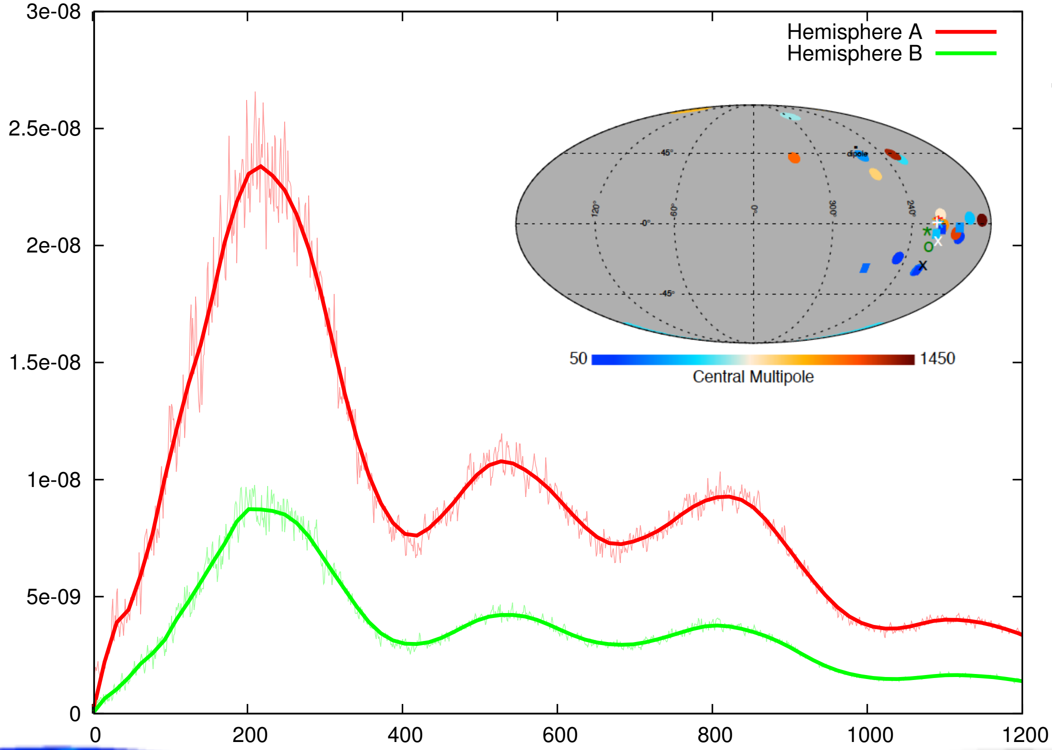
cf. the more localized Lagrangian space **intermittency** from steep cluster-threshold functions acting on the **density field**. **Cluster-patches** lead to pressure intermittency and SZ sources in the CMB

associated hemispherical power asymmetry extends to high L, though diminished. the symmetric inflaton-induced power swamp the power bursts



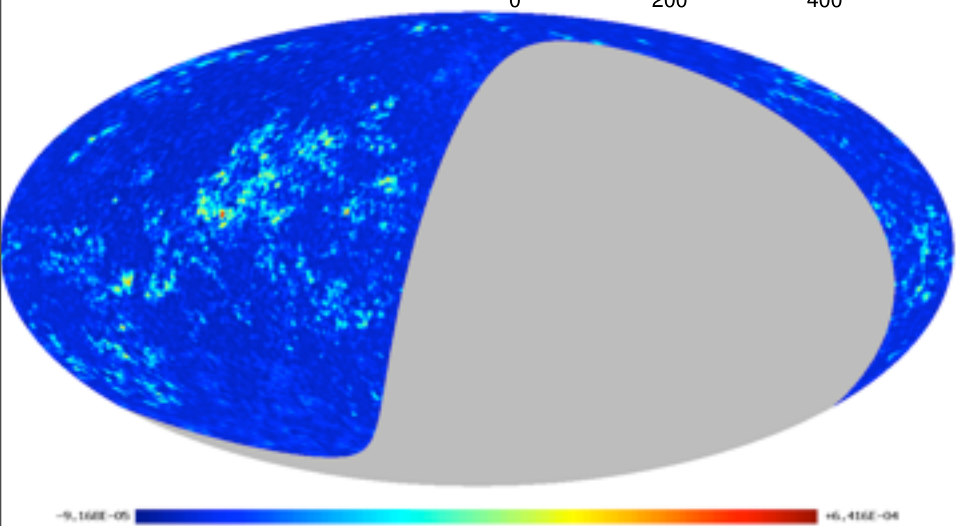


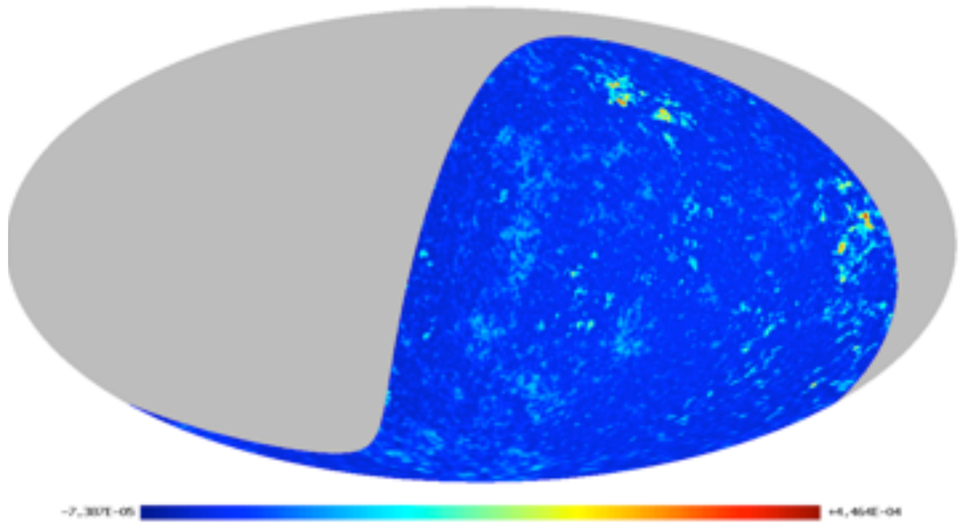
associated hemispherical power asymmetry extends to high L, though diminished. the symmetric inflaton-induced power swamp the power bursts



Bond,Braden,Frolov,Huang13

the achilles heel of intermittency models? TBD, *depends on damping & fuzziness, complicated computations B^2FH' are into*



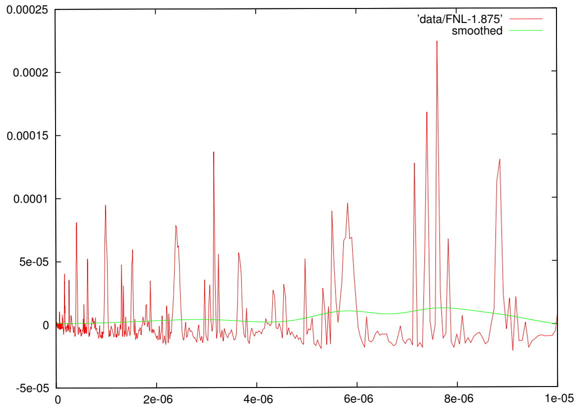


quartic inflaton variable Planck mass $V(\phi,\chi) = 1/4\ \lambda\phi^4 - 1/2\ \xi\ \phi^2 R + 1/2\ g^2 \phi^2 \chi^2$

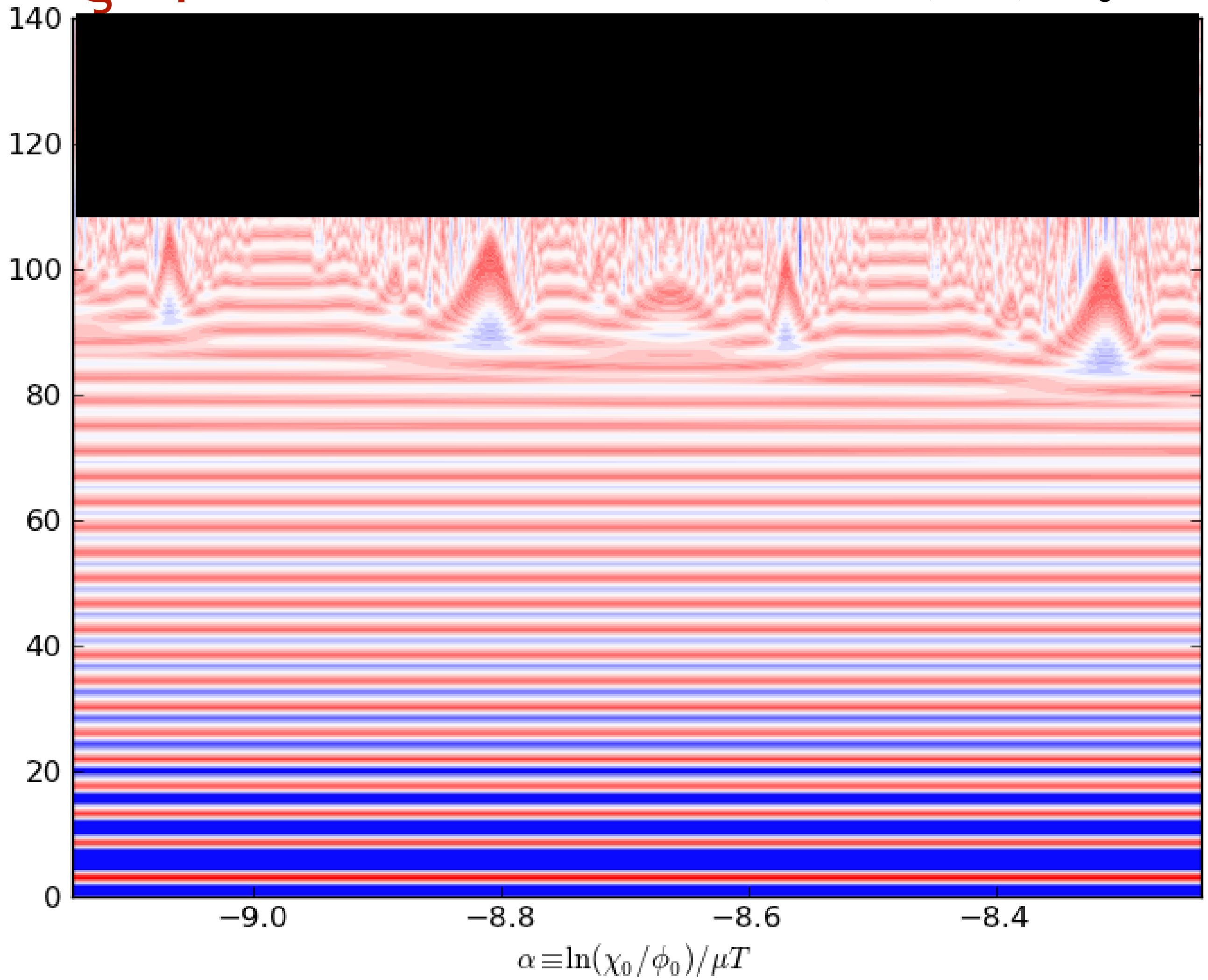
spikes persist with flattened effective potentials

only the potential bowl at the bottom matters

Bond,Braden,Frolov,Huang13



ξ=-1



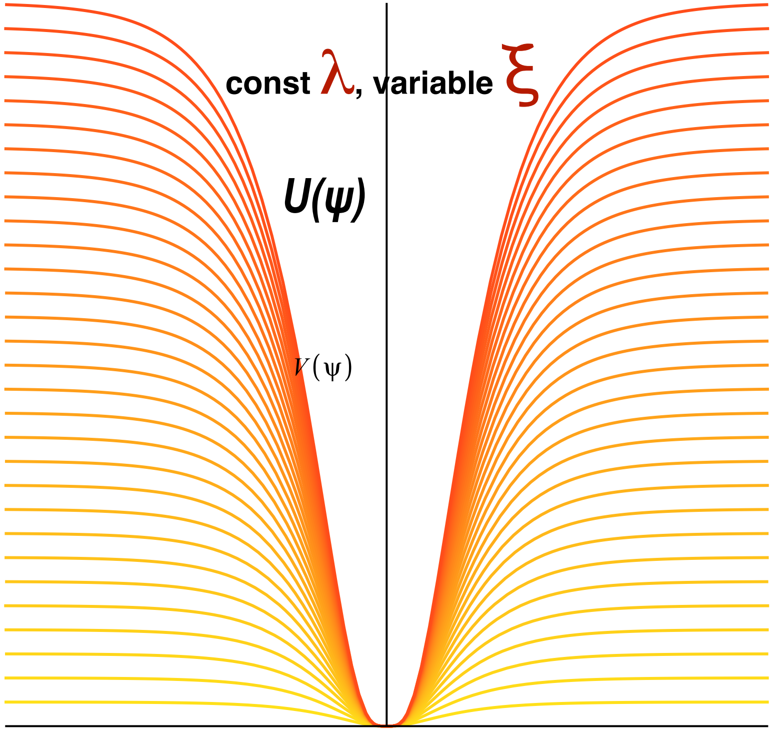
calculating ballistic evolution to caustics gives the spikes in perfect agreement with full nonlinear lattice simulations

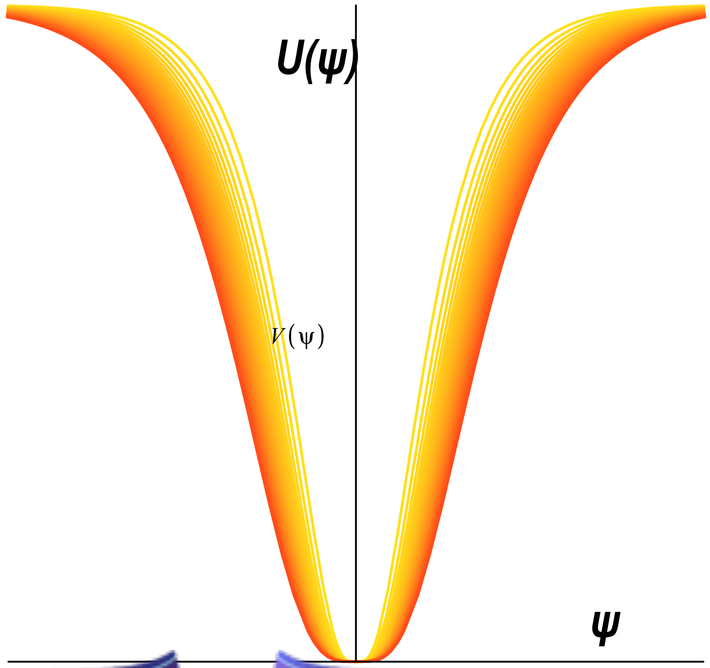
nonG from post-inflation but pre-entropy generation ballistic trajectories can lead to pre-shock-in-time caustics and other phase space convergences in the deformations (!) Zeldovich map-ish

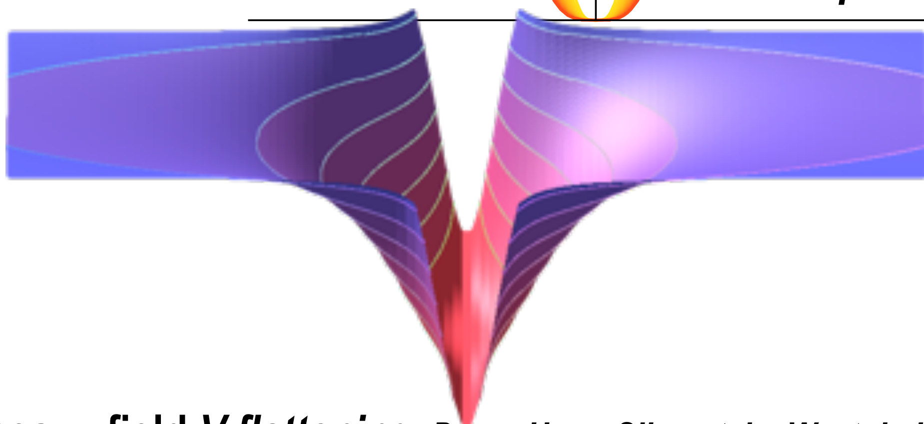
eg $\partial \ln a / \partial \chi_i(x)$, $\partial \ln a / \partial g(x)$ => $P[\ln a(x),\ t_{shock} \mid \chi_i(x), g(x), t_{end\text{-}of\text{-}inflation}]$

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

in Einstein frame for new (canonically normalized) field $\boldsymbol{\psi}$







$$\psi\chi = \int [K^{11}(\phi)]^{1/2} d\phi \ ,$$

$$K^{11} = \frac{\dfrac{m^2}{m_P^2} + 8\pi|\xi|(1+6|\xi|)\dfrac{\phi^2}{m_P^2}}{\left[\dfrac{m^2}{m_P^2} + 8\pi|\xi|\dfrac{\phi^2}{m_P^2}\right]^2} \ .$$

$$U(\chi) = \left[\frac{m^2}{m_P^2} + 8\pi|\xi|\frac{\phi^2(\chi)}{m_P^2}\right]^{-2} V(\phi(\chi)) \ .$$

***conformal V-flattening of SBB89**, Higgs inflation*

cf. **Kallosh**/Linde KITP 06/19 ξ = 1/6 -Δ, Δ small

heavy field *V-flattening*: *Dong, Horn, Silverstein, Westphal 2011*

ϕ^{2n}, **n<1** via heavy field trough driving light inflaton Veff =>

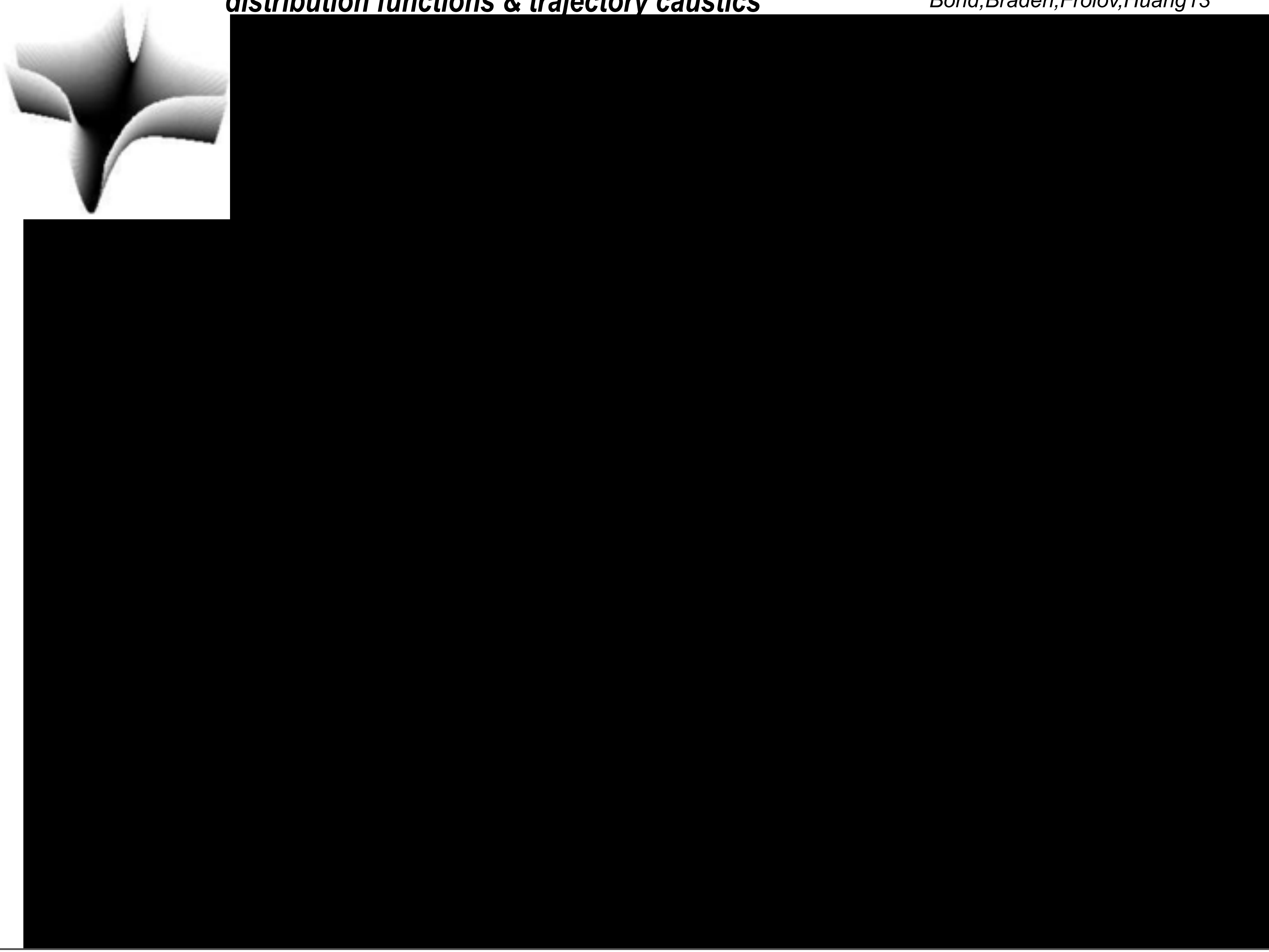
r = 8n/(N_I+n/3) 1-n_s = (n+1)/(N_I-n/6) P13 OK

e.g., ***monodromy*** **SW08 p=1/3, MSW08 p=1/2 & cos = shift symmetry**

***V-flat natural** in **roulette inflation** (Kahler moduli) BKKV*

distribution functions & trajectory caustics

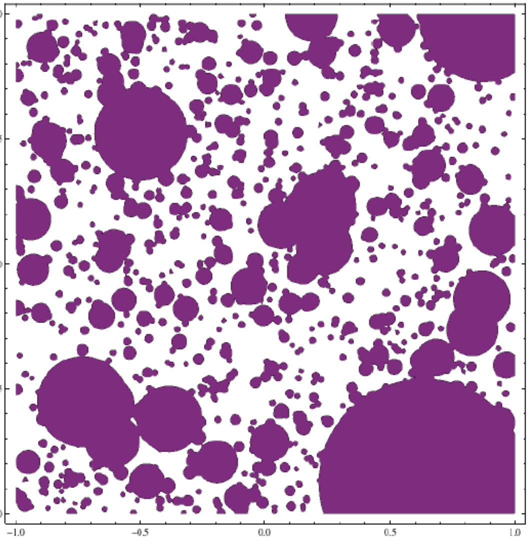
Bond,Braden,Frolov,Huang13



Bubbly U

Kleban11 review

+ KITP13 review



the **bubbly gospel**, a la Susskind, Kleban11 + many others

we live in a bubble, one among many, the nature of the universe ***BUT stochastic semi-eternal inflation***

Coleman de Luccia instanton with SO(4) Euclidean symmetry => SO(3,1) real symmetry is gospel ***BUT thick wall bubbles may be endemic in the landscape, depends upon V. bubble formation fluctuations about instanton. multiple field instantons, always one dof Euclidean-stochastic path?***

negative curvature, initially ~ initial bubble radius, diminished by subsequent inflation. if prob(N efolds) ~ 1/N^p p>>1 then N just enough => negative curvature likely observable ***BUT it is not observed, our patch inflated alot if stochastic semi-eternal inflation***

all bubbles eventually collide ***BUT with what probability: to see one seems quite unlikely***

look for SO(2,1) symmetric collision debris on the CMB sky ("cosmic wakes") as circular spots, scale TBD ***BUT improbable. But if probable, why subdominant and not booming. BUT 3D instabilities from inevitable quantum fluctuations make complex interiors, oscillons etc. CMB smoothing fuzzes over this always? searches to prove landscape exists too naive?.***

bubble collisions make largescale modulations possible ***BUT too large?***

in BBM13a,b,c *(Bond, Braden, Mersini 2013)* ***we treat bubble creation and propagation as interesting nonlinear field theory problems in their own right, that may have a cosmological setting, still TBD. non-inflation domain walls and bubbles.***

now BB are imbedding subdominant isocon-tunnels into an overall inflationary flow

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)

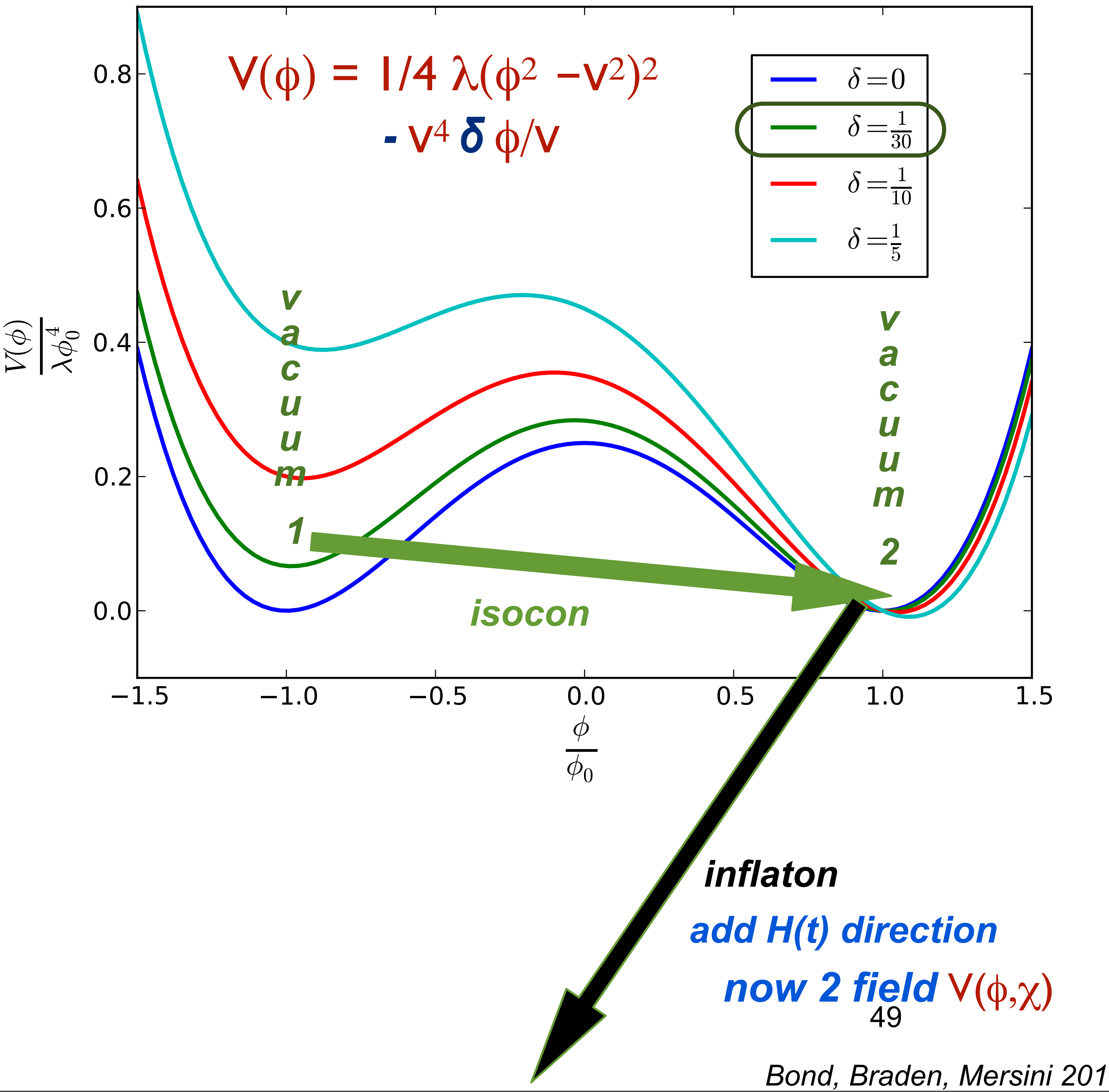
+ long-lived oscillons, size related to the mass

cf. 1D work that dominates the subject

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

an oscillon phenomenon is possible in preheating Easther+

CMB+ observables?



Bond, Braden, Mersini 2013

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

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

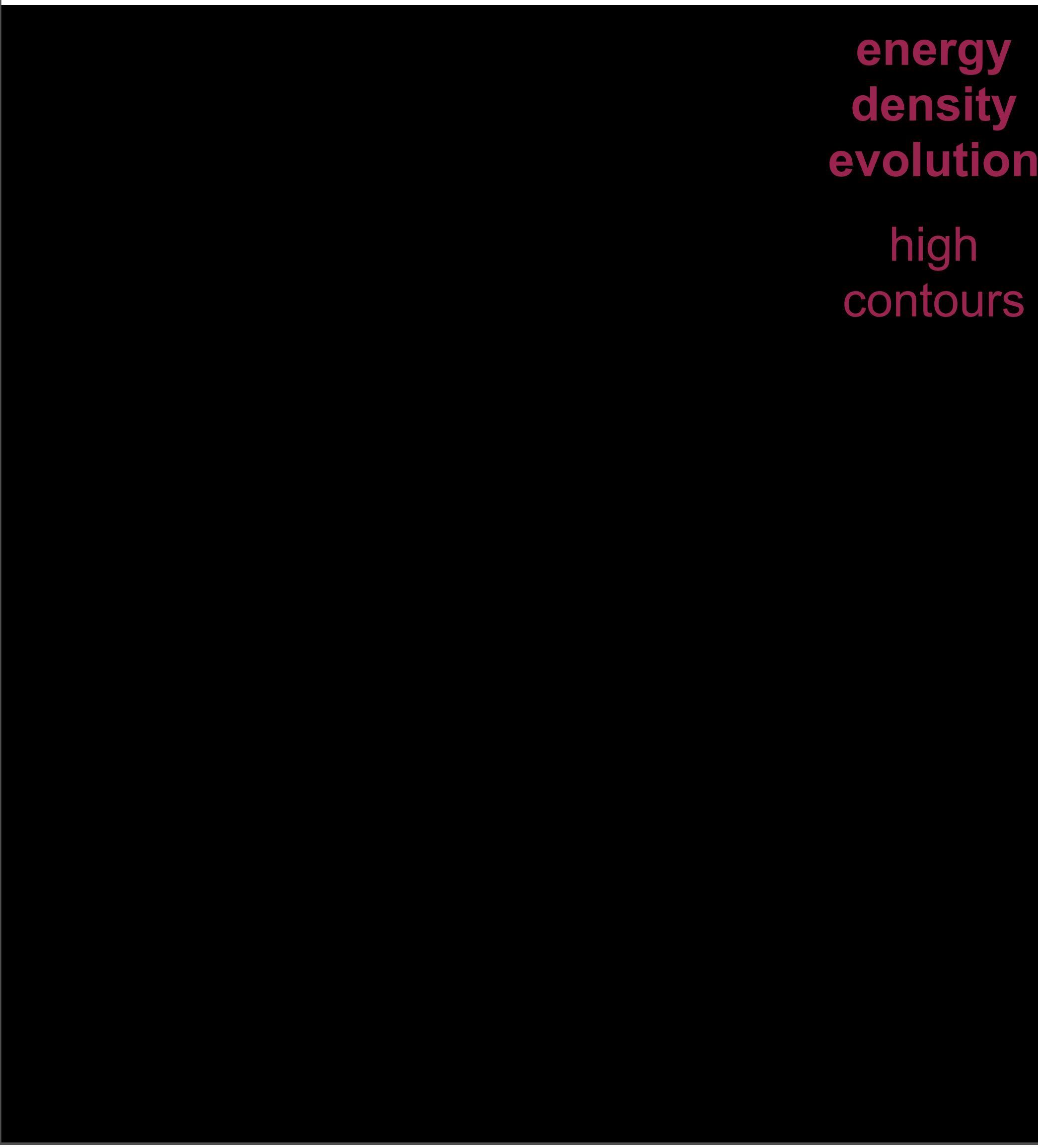
$\Delta X_{bubble} = 0.25\ H^{-1}$

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

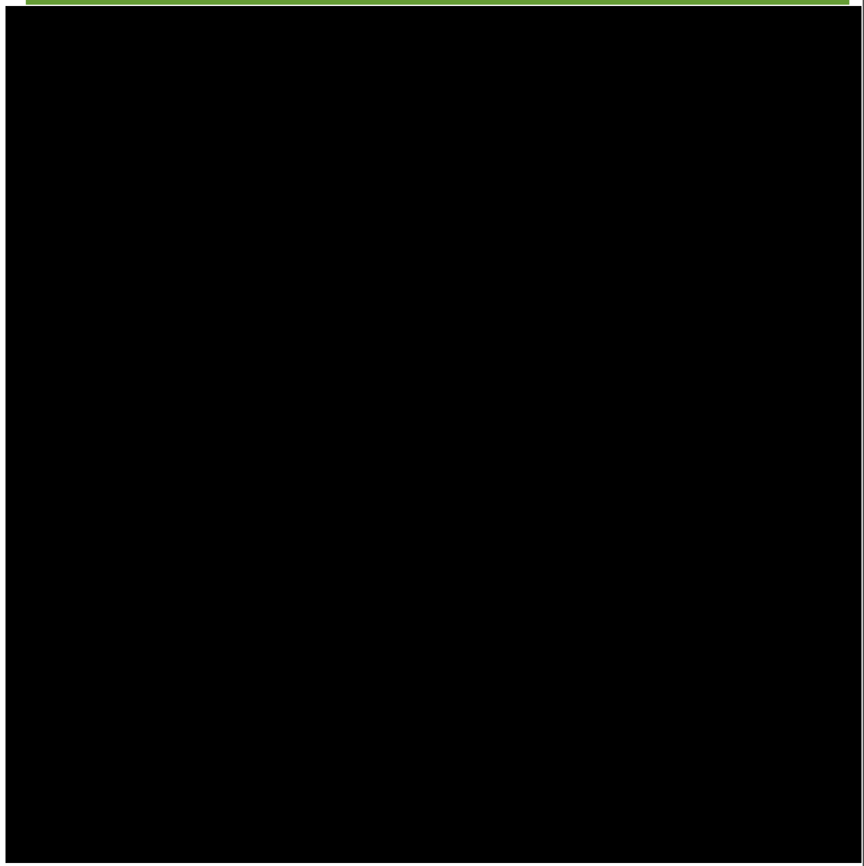
with tiny zero point & wall fluctuations

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

+ long-lived oscillons, size related to the mass

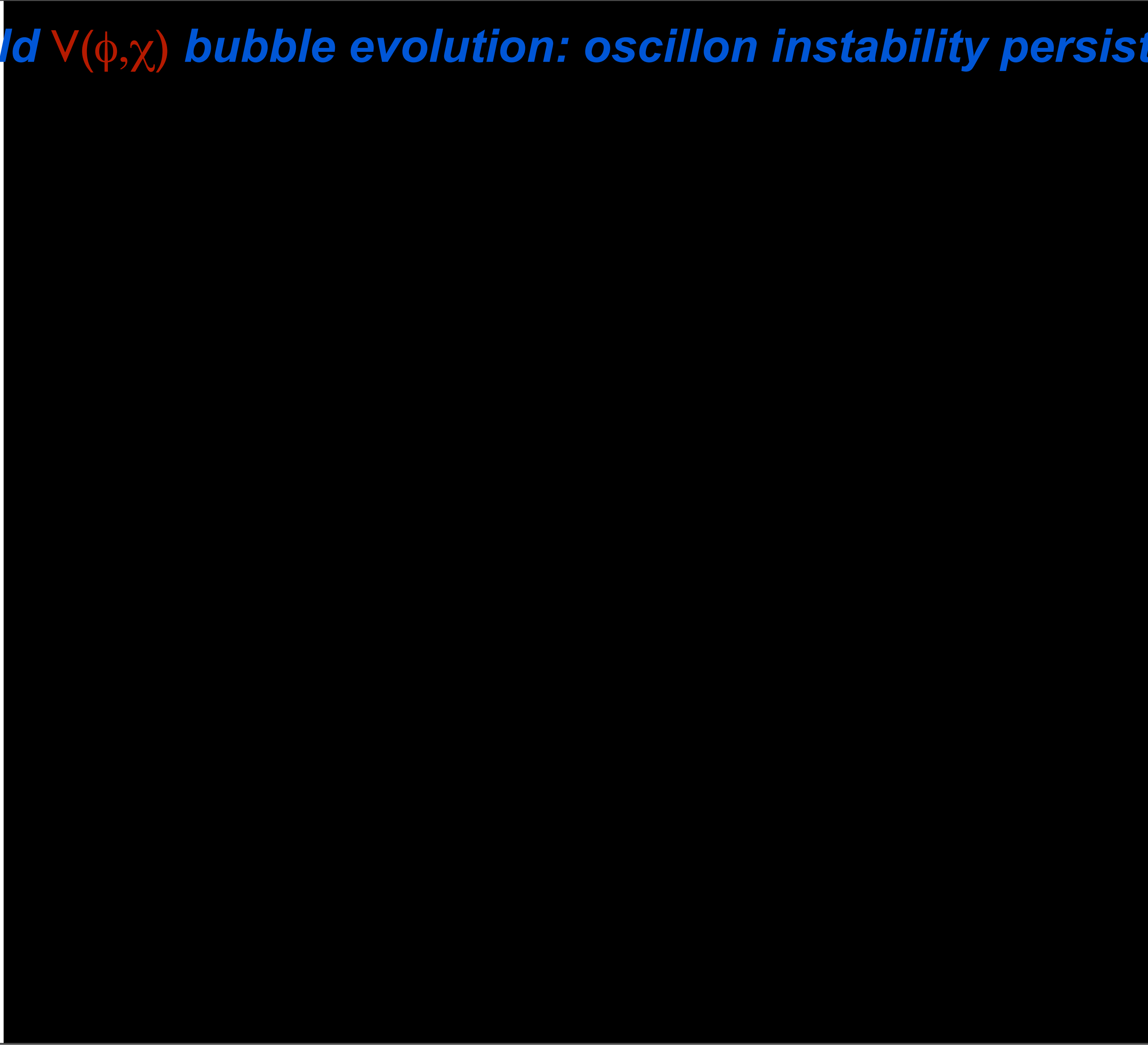


does the observable universe use double hubble bubble - iciousness? CMB intermittency?



Bond, Braden, Mersini 2013

2 field $V(\phi,\chi)$ *bubble evolution: oscillon instability persists*



rsini 2013

oscillon in early universe, e.g., Amin++++, Gleiser, BBM13a,b,c

oscillatory, spatially local, long-lived, most work 1D, a few 3D sims for preheat + our bubbly sims

history: Bogolubsky+Makhankov76, Gleiser94, Copeland+95, ..., Amin+Shiokoff 10, Amin 13 - single 1D oscillon blob

relation to mulifield Qballs?

small amp conditions

$(m^2 - \omega^2)\,\varphi + (-\nabla^2\,\varphi) + (\partial V/\partial\varphi - m^2\,\varphi) \sim 0$ freq (>0) curvature (>0) nonlinear (must be <0)

BUT no theorems (so far) for when oscillons arise. V shallow at large φ ***BUT how shallow for bubbles***

shallow flattened V for preheating oscillons ***BUT not for nearly symmetric bubble potentials***

Floquet analysis of μ_k >>H, exponential instability ***BUT modified for bubbles and domain walls BBM1***

want Re μ_k /H >10, M_P/m>>1, potential n <1 far out ***BUT n varies***

energy fraction in oscillons > 80% Farhi etal 08 but 1D, E thresholding => non-oscillon pickup. Amin+ >> 50% ***BUT not in our bubble sims ~10%, 90% scalar radiation: 3D, rad propagates => no log-norm tail***

preheat with pspectre pseudo spectral code Easther, Finkel, Roth 256^3 checked with defrost (Frolov) LatticeEasy (Felder+Tkachev) ***BUT defrost++ with symplectic integration + radiation boundary conditions (good for scanning many cases) + new (much) faster parallel spectral code (for bubbles++)***

oscillons overdense by a few ***BUT we see higher ~10, though gravitational collapse not important***

Primordial Black Holes are hard to form ***YES***

expansion history change ***YES***

delayed preheating (store in oscillons) ***YES***

number density modulation (using our nonG from preHeating ideas B+09) ***YES, maybe***

characteristic oscillon 3D scale few/m, m curvature of V_{isoc} bottom, $(m/H)_{initial}$ inflate => expand to observable? In tunneling rate ~ height $(\nabla V)_{height}$ width $(\nabla\chi)_{height}$ of isocon barrier, maybe not so tiny?

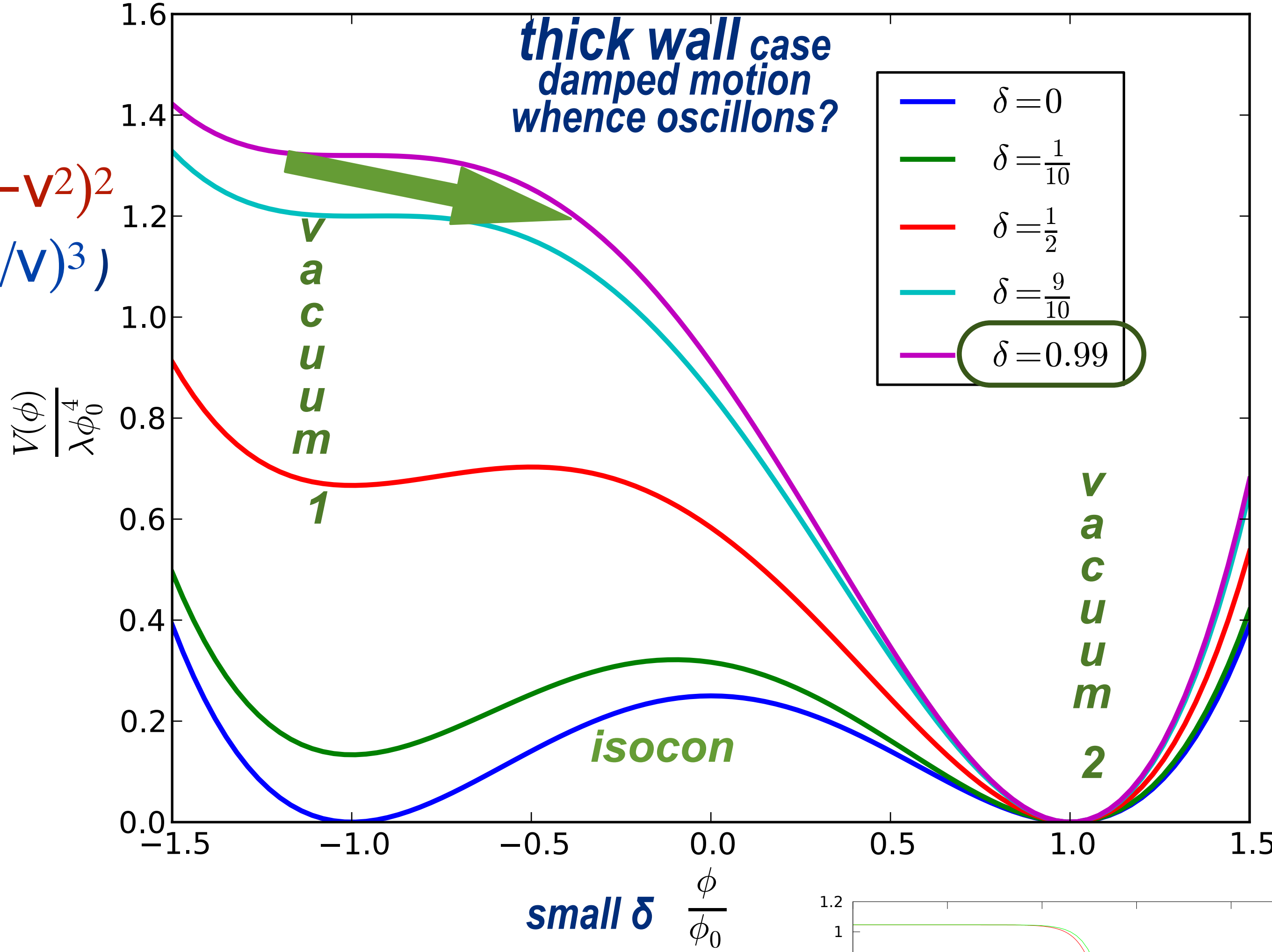
$V(\phi) = 1/4\ \lambda(\phi^2 - v^2)^2$
$- v^4 \delta\ (\phi/v - 2(\phi/v)^3\ )$

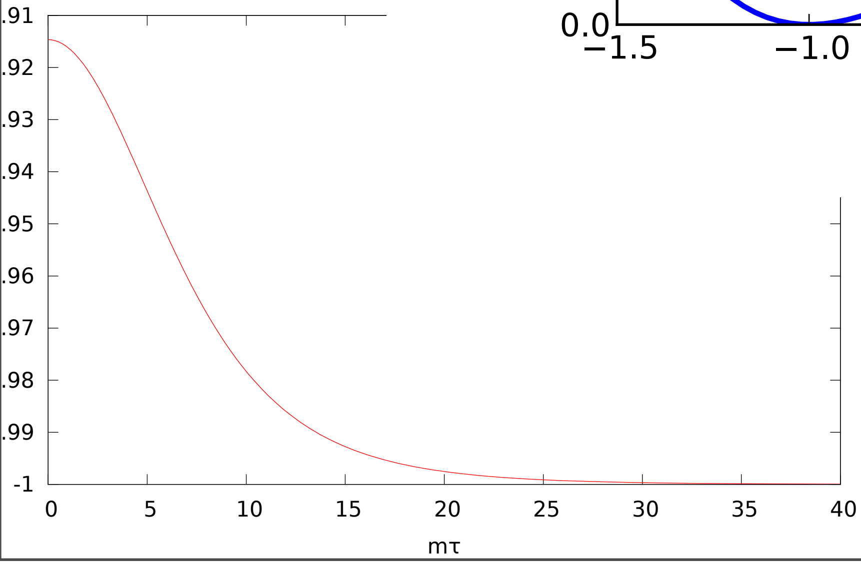
large δ

thick wall
instanton

how important are fluctuations in the Euclidean trajectory from the (classical) instanton

JBraden spectral code



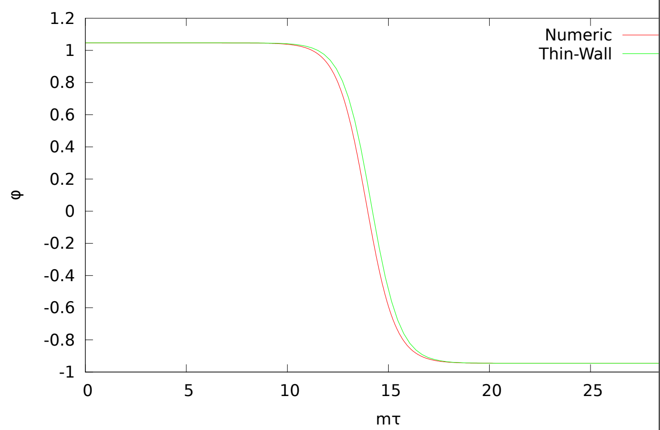


small δ

thin wall
instanton

OK approximation, but accurate numerical instanton is needed for instability work

JBraden spectral code



Bond, Braden, Mersini 2013

conclusions:

highly nonlinear field evolutions happened (EoI, bubble collisions).

do they lead to observable rare-event CMB or SSS/LSS/ULSS anomalies?

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

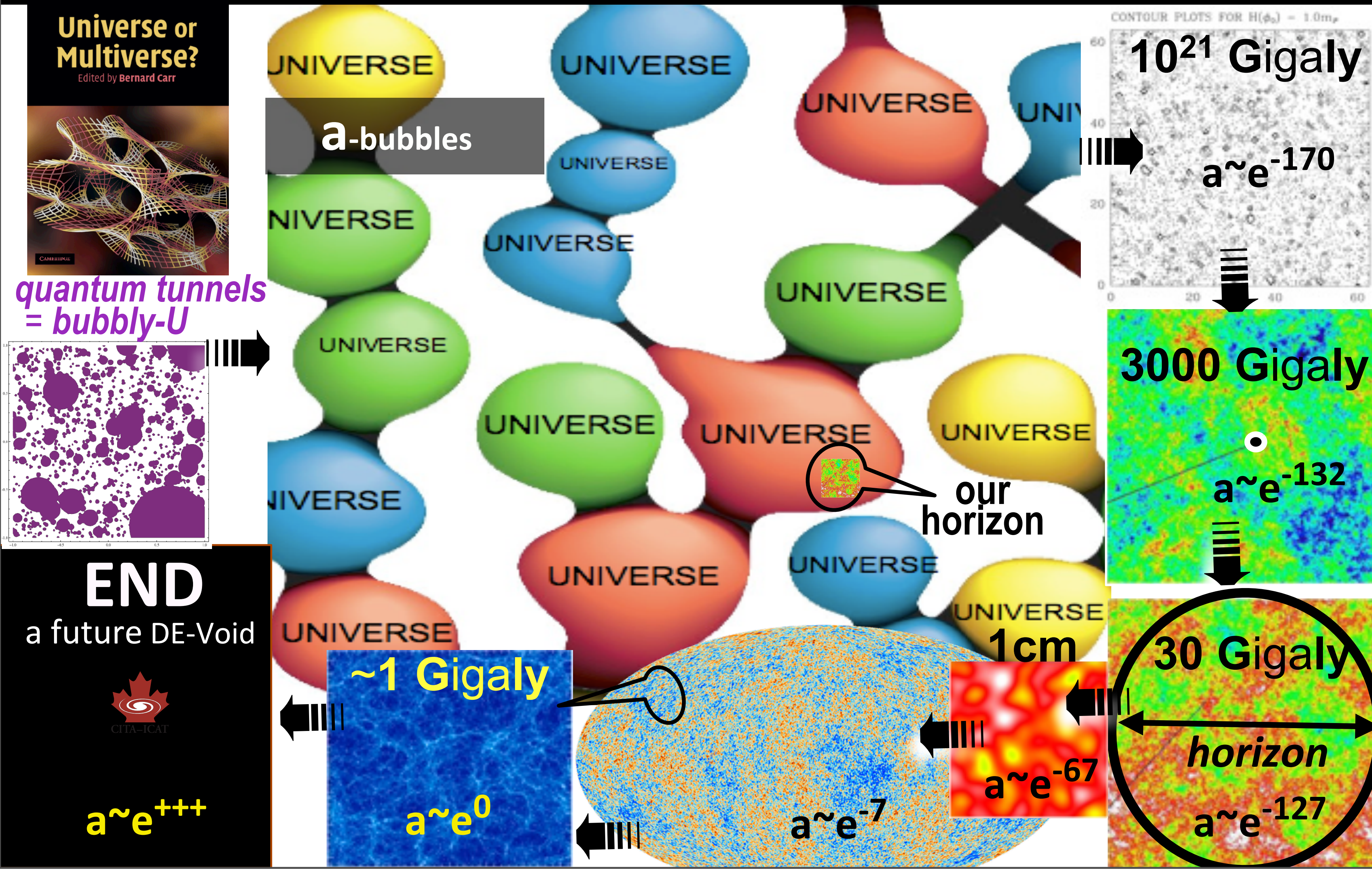
isocon modulators, coupling(isocon) modulators, isocon tunneling, isocon oscillons, isocon short-lived fuzzy-strings, + very long-lived strings

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

amusing subdominant patterns do arise!

ultra-Ultra Large Scale Structure of the Universe

Horizons: the ultimate-speed constraint on light & information



Cosmic Observables for Fundamental Physics

Dick Bond

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

CIFAR CANADIAN INSTITUTE FOR ADVANCED RESEARCH

Early & Late Universe: from Simplicity to Complexity

∃ acceleration then & now {a, H ~$\rho^{1/2}/M_p$, ε=-dlnH/dlna =1+q=3/2(1+w)}

∃ inflation then (a ~ e^{-67} to $e^{-67-55++}$ < 10^{-35} s) & now (a ~1 to e^{-1+} 10^{17} s)

∃ dark potential energy then $V_{de} \lesssim (10^{25.3}\ \mathrm{ev})^4$ & now $V_{de} \sim (10^{-2.9}\ \mathrm{ev})^4$

∃ dark kinetic energy then $K_{de} \lesssim (.003)V_{de}$ & now? $K_{de} \sim (-0.1$!! to $0)\ V_{de}$

modified gravity = de: conformally equivalent to Einstein gravity + late-time inflaton + fifth forces matter-de interaction (~ $\rho_m - 3p_m$=TraceT_m)

∃ (zero-point) quantum fluctuations => the origin of observed cosmic structure

∃ curvature fluctuations. scalar: adiabatic + isocons, tensor: gravity wave

∃ phonons in earlyU $\ln(\rho a^{3(1+w)})/3(1+w)$ = scalar adiabatic+ inflaton is a collective field

the driven "vacuum" accelerates. but differentially? yes, both then & now

we compute it, but we don't really understand it: vacuum tightly coupled to gravity

we know more about early-inflaton dynamics than late-inflaton dynamics!!

10 e-folds then cf. 1 e-fold now: because resolution (comoving wavenumber k) is related to dynamics (Ha) then, but not now

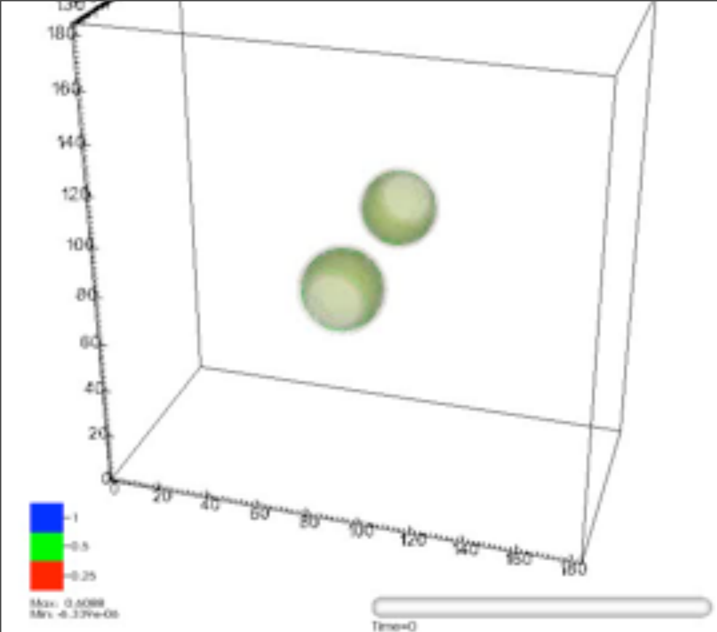
the quantum fluctuations here & now are not important for cosmic structure

CIFAR
CANADIAN INSTITUTE FOR ADVANCED RESEARCH

pix of
Steve's Secret Stanford Scotch Society

CLASSIFIED

END



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

with tiny zero point & wall fluctuations

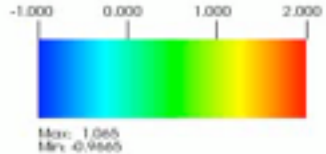
=> burst of scalar radiation at c (with outgoing radiation BCs)

+ long-lived oscillons, size related to the mass

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

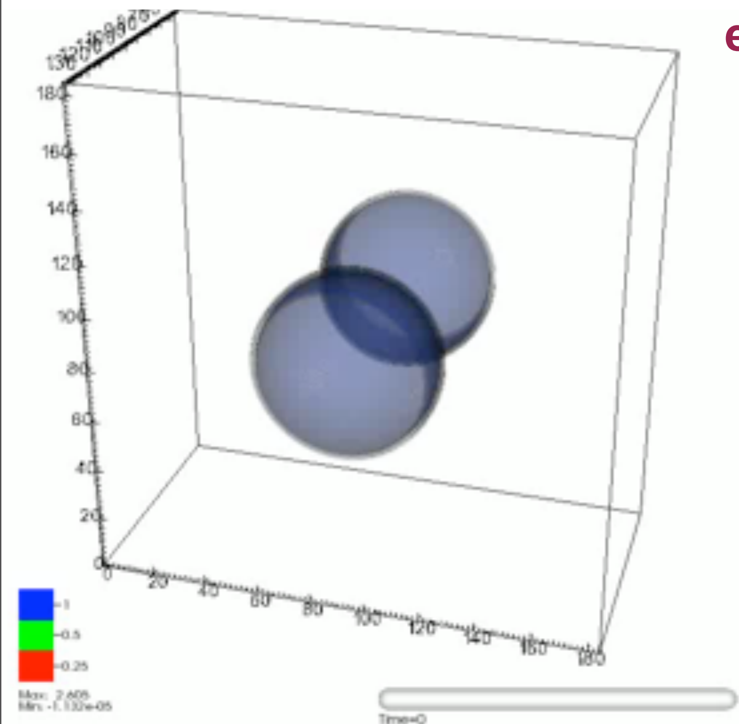
an oscillon phenomenon is possible in preheating CMB+ observables?

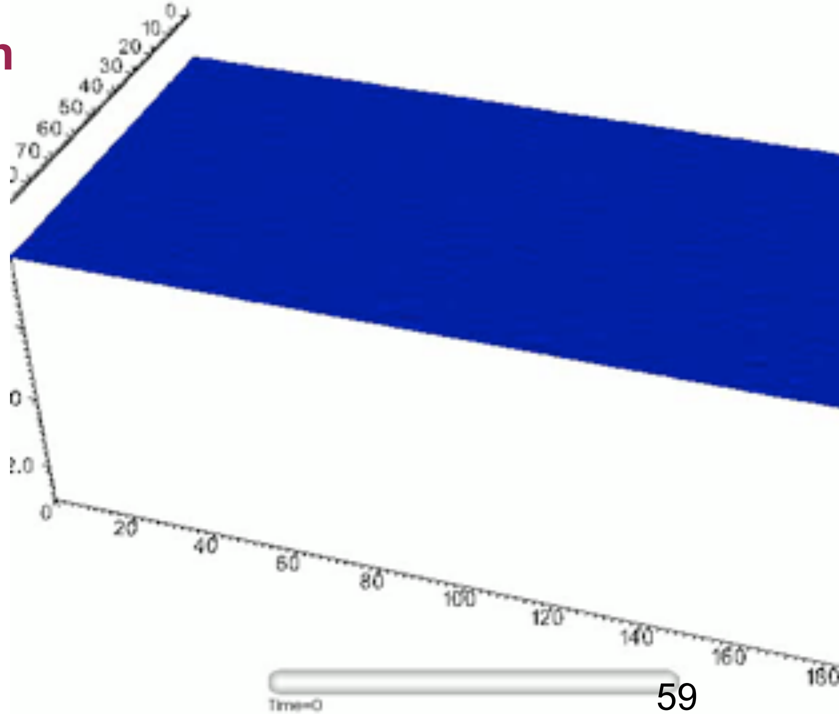
long-lived oscillon energy ~ 10%



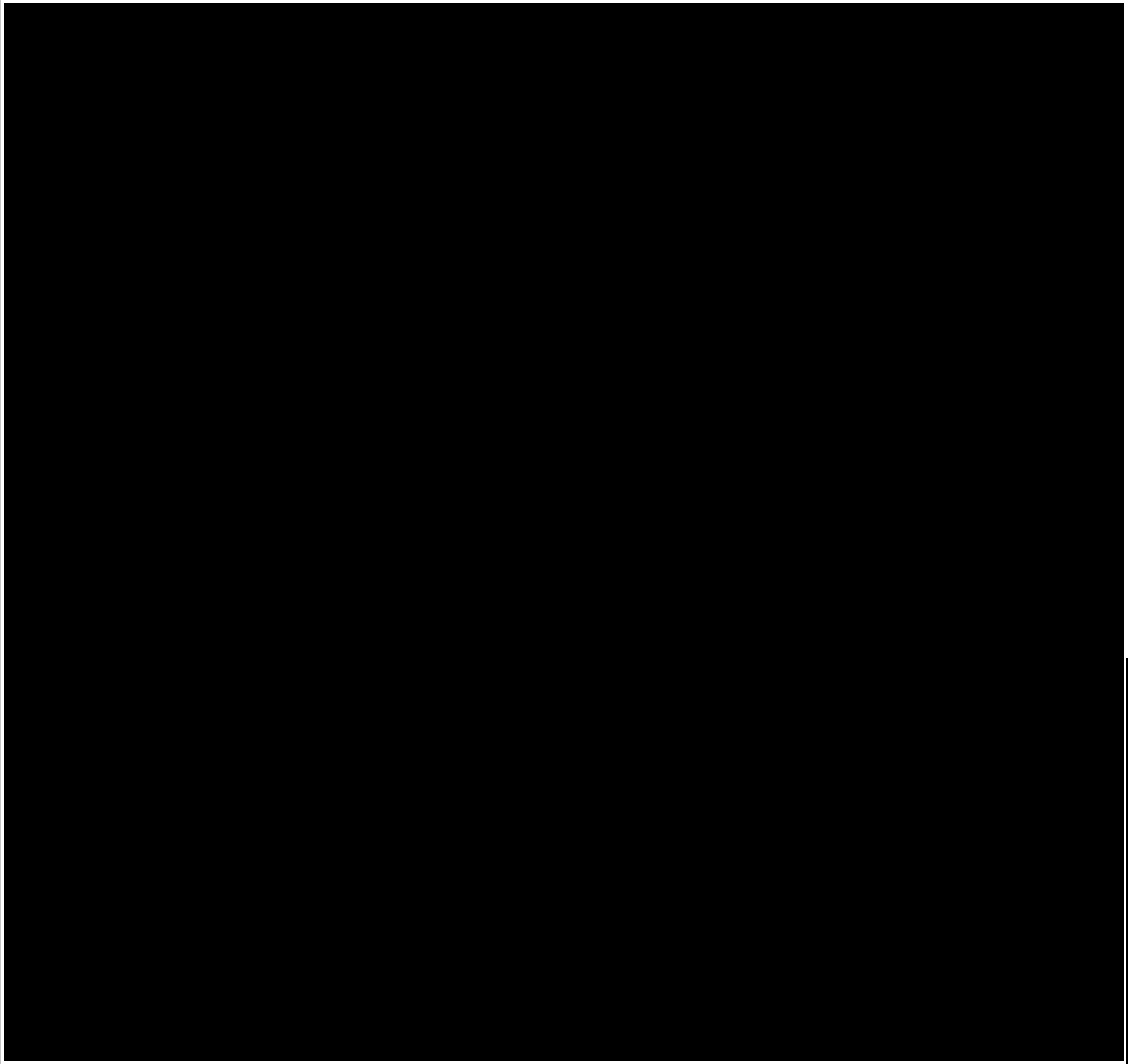
energy density evolution

high contours





Bond, Braden, Mersini 2013

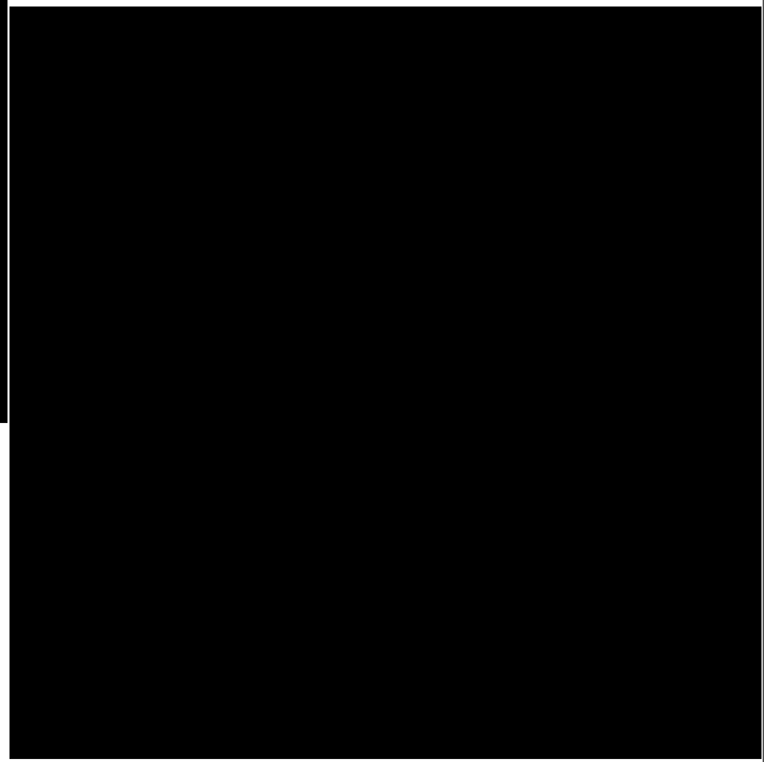


axionic potential

$V \sim 1-\cos(\theta)$

kink-antikink instanton = IC

continued wall collisions
because of periodicity =>
amplification of quantum noise
fluctuations
not quite applicable to Kleban+
unwinding inflation of D-branes



Let there be.....

Early **Dark Energy** from $e^{-170?}$ to e^{-67}

2 numbers quantum **noise** e^{-127} to e^{-67}

semi **ETERNAL** Universe
most of it never Banged

Heat: matter & **radiation** $a \sim e^{-67}$

Our little **Big Bang**

Dark Matter, light nuclei $a \sim e^{-21}$ to e^{-35}

Cosmic **Light**: 1st light released, 1st atoms $a \sim e^{-7}$

1st stars $a \sim e^{-3}$, 1st heavy nuclei (O, C, Fe,..)

Galaxies > $e^{-2.2}$

Earth $a \sim e^{-0.34}$

1st human writing $a \sim e^{-0.0000004}$

Late **Dark Energy** to e^{+++}

Will our bit of the Universe re-Bang?
NO... maybe

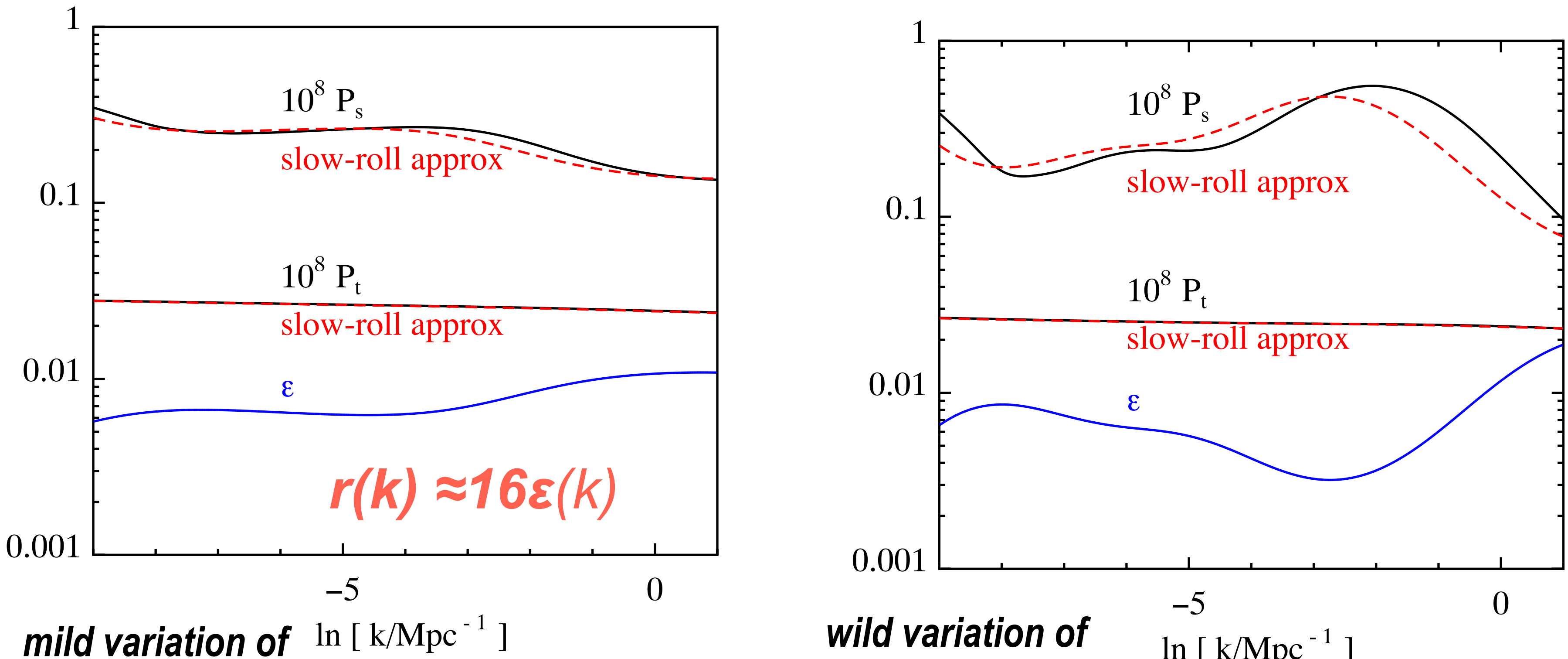
inflation = **accelerating driven "vacuum",**
then *differentially* & now *differentially?*

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

inflation consistency
$-n_t \approx r/8 \approx 2\varepsilon(k)$ $\quad 1-n_s \approx 2\varepsilon + d\ln\varepsilon/d\ln Ha$

if relax prior of c_s=1, need that trajectory

a path approach to inflation: ε trajectories drive scalar power, indirectly tensor power, V and ψ. use full k-mode integration *but Langevin equation stochastic inflation framework - usually very accurate, very for tensor, but full built into MCMC*

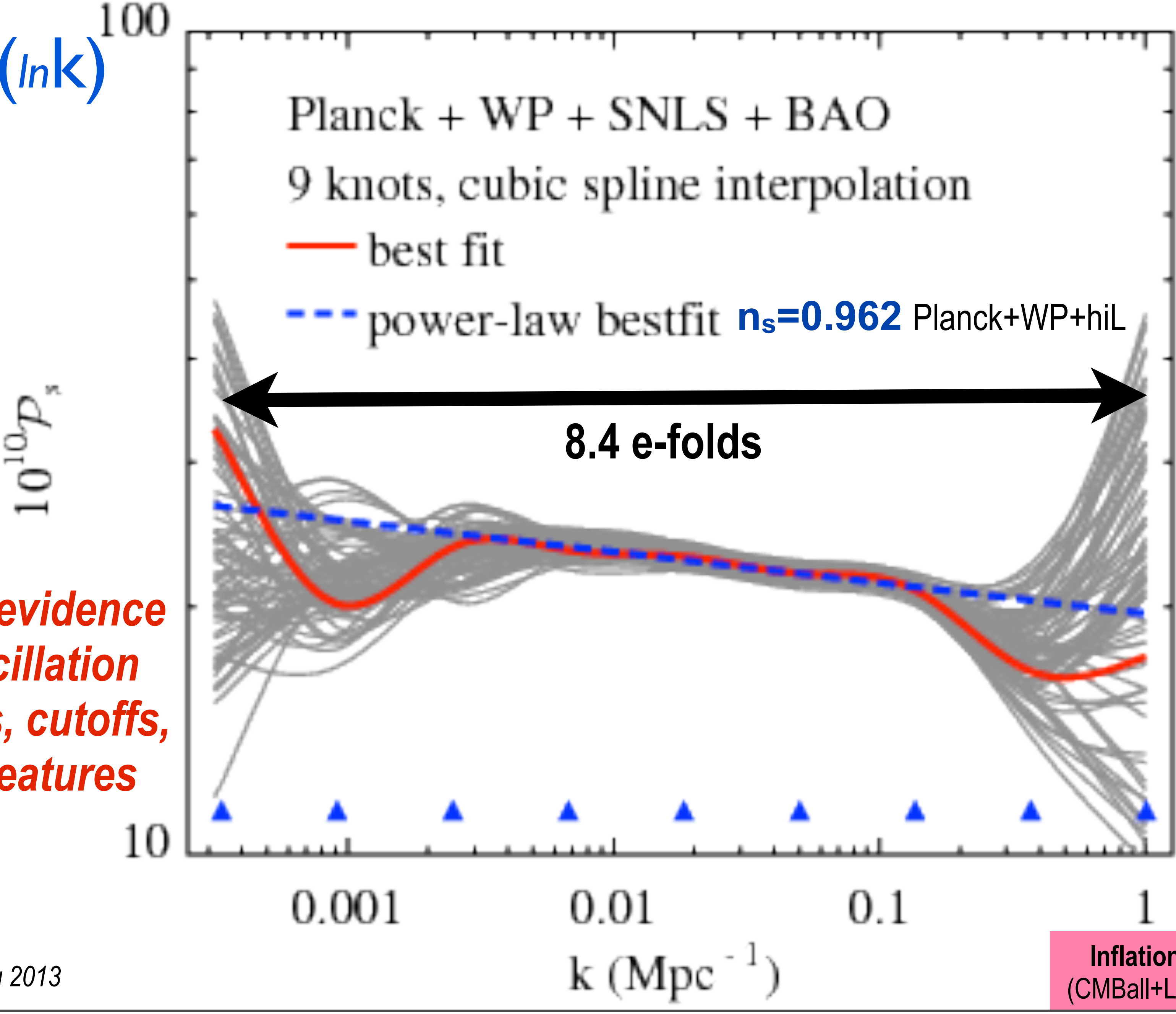


mild variation of acceleration history   ***wild variation of acceleration history***

Monday, 9 September, 13

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* **$\varepsilon(\ln Ha)$, $V(\psi)$**

$\ln P_s(\ln k)$



no strong evidence for oscillation patterns, cutoffs, local features

Bond, Huang 2013

Inflation Histories
(CMBall+LSS+SN+WL)

Intermittent non-Gaussianity & Anomalies: rare patchy subdominants from Modulated Heating, Bubble Collisions & Oscillons

CITA ICAT Canadian Institute for Theoretical Astrophysics L'institut canadien d'astrophysique theorique **Dick Bond** CIFAR CANADIAN INSTITUTE for ADVANCED RESEARCH

Grand Unified Theory of Anomalies TBD *Anomalies in Polarization? TBD*

anomalies are nonG, non-statistical-isotropy. *just from* **broken Gaussianity?**

WMAP ***cold spot anomaly: coherent in scale space 1:497 @826', 1:9 @360'***

power spectrum asymmetry: 7% at lowL, unclear if any at hiL. Doppler dipole modulation exists

P13 hiL nonG pattern constraints are restrictive, but open up with decoupled ζ_{NL}, support(ζ_{NL})^3
& need further exploration of nonG with a built-in scale, related to radically broken scale invariance

$\zeta_{NL}(x)$ from ***"isocon" degrees of freedom cf.*** $\zeta_{inf}(x)$ from ***inflaton***

modulated heating, ***ballistic chaos, caustics, shock-in-time,***

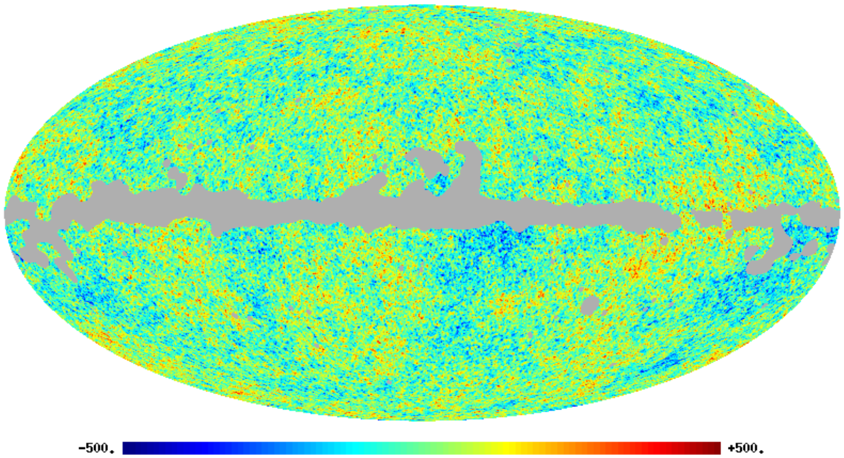
modulators ***isocon*** $\chi(x)$, ***axionic-isocon***(x) ***couplings*** $g(x)$ super-horizon accessible

quantum tunneling landscape, inflating bubbles & bubble-bubble collisions

aka ***theory of nonlinear multi-field dynamics using lattice simulations. symplectic defrost++ code + new spectral code.***
intermittent nonG: ∃ a statistical landscape of possibilities.
allowed level highly constrained, but as observed anomalies? unknown, ∃ much to explore

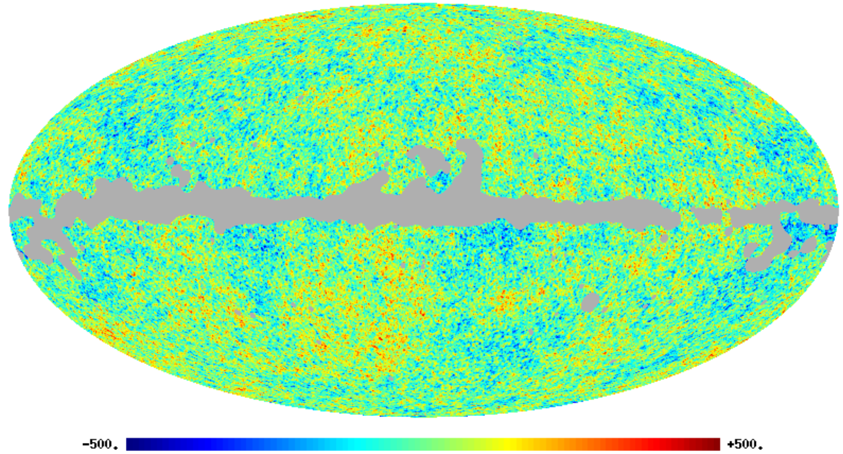
Bond, Huang 13a,b
Bond, Frolov, Huang, Kofman 09
Bond, Braden 13
Bond, Braden, Frolov, Huang 13
Bond, Braden, Frolov, Huang, Nolta 13
Bond, Braden, Mersini 13a,b,c

real CMB Sky



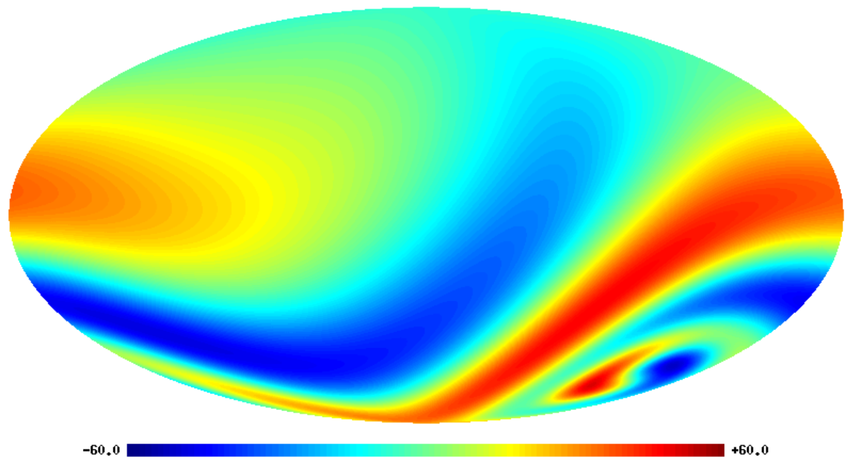
=

Fluctuation CMB Sky



+

mean field CMB Sky



homogeneous, anisotropic Bianchi VII_h model: ultralarge scale rotation/vorticity and shear, *fit parameters violently disagree with Planck13 parameters. but maybe there is a grand unified theory of anomalies, as this tries to do.*

Grand Unified Theory of Anomalies TBD

quest for B mode similar to first T detections, first E detections => broad-band analyses

Farhang BDN 11/13: use full matrix quadratic matrix analysis of Q/U if possible. ancient COBE history. feasible with modest parameter numbers r and most correlated, rBB, rEE and broadband rband phenomenology
sigma(r) as a function of fsky partially informed the spider 8% decision, but broad region where ok
lose information if you project onto pure B given sky cuts
must model Correlation Matrices accurately, including foregrounds
CBI approach to pol:
gather UV onto wavenumber pixels semi-optimally. ACT, BICEP, KECK FT not semi-optimal
use a quadratic pix-pix matrix analysis for bandpowers. mode/template optimal quadratic filtering similar to Wiener filtering, projects out the most relevant information

make Wiener maps for E, B to see what it looks like, but no scientific analysis (fluctuations important to see where it is not well probed

can inform the quest with consistency-informed analyses, although of course blind is better, though not for parameters. ***ε expansion only over the observable range, < 10 e-folds, tried extrapolating to ε =1, 50-60 efolds downstream - too much freedom, smooth approach, waterfalls, isocurvature onset, etc.***

Fundamental Physics from the Planck Satellite

Planck 2013 results. XXII. Constraints on inflation

Planck 2013 Results. XXIV. Constraints on primordial non-Gaussianity

Planck 2013 results. XXIII. Isotropy and Statistics of the CMB

Planck 2013 results. XXV. Searches for cosmic strings and other topological defects

Planck 2013 results. XXVI. Background geometry and topology of the Universe

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

END

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.

Planck 2013 results. XII. Component separation

Planck 2013 results. XV. CMB power spectra and likelihood

Planck 2013 results. XVI. Cosmological parameters

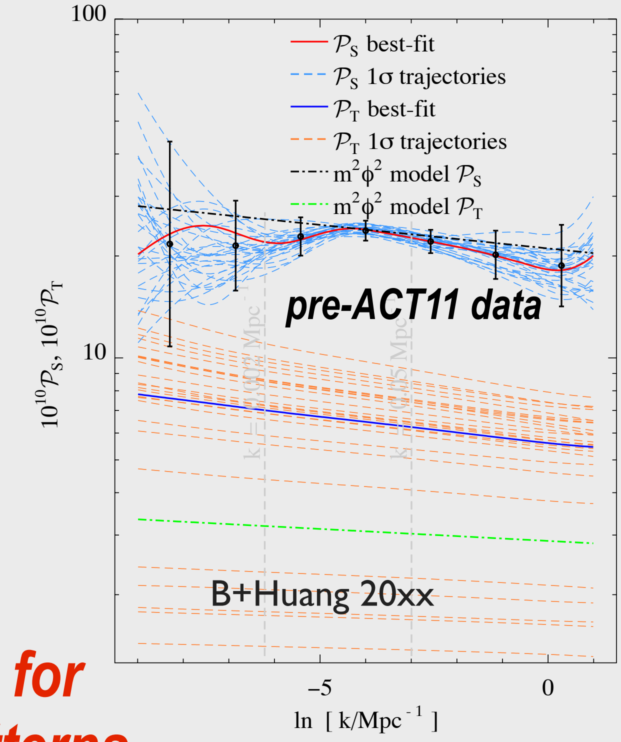
Planck 2013 results. XVII. Gravitational lensing by large-scale structure

Planck 2013 results. XXVII. Doppler boosting of the CMB: Eppur si muove

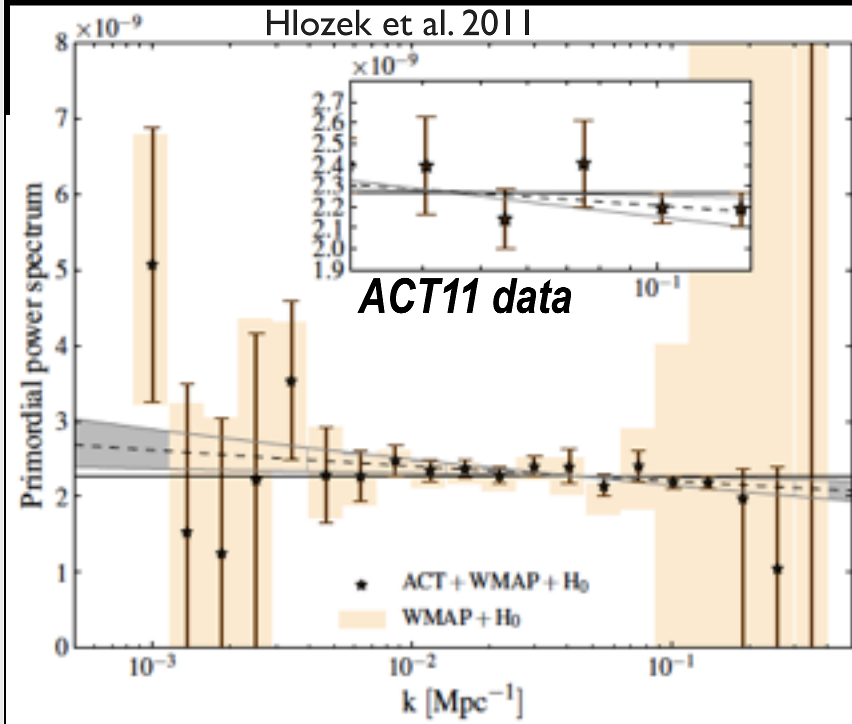
Planck 2013 results. XIX. The integrated Sachs-Wolfe effect

early-U, NOW

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

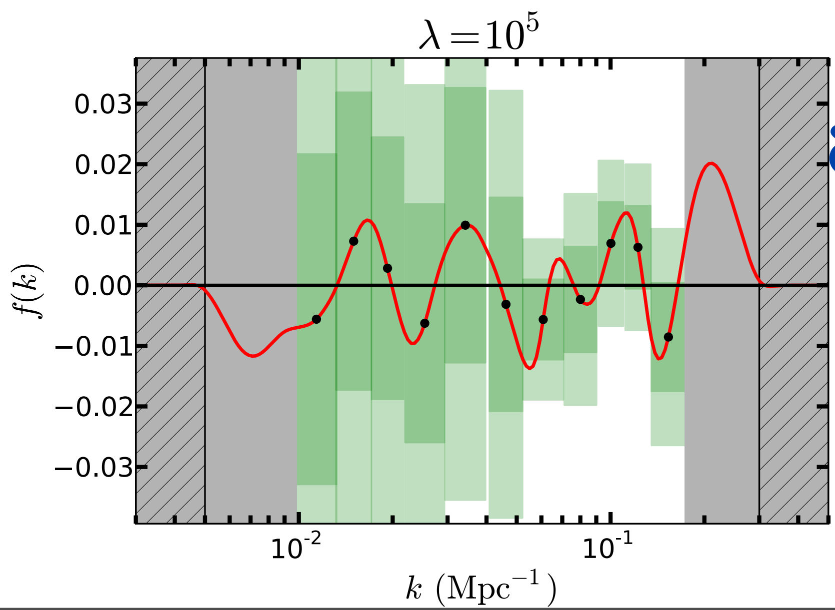


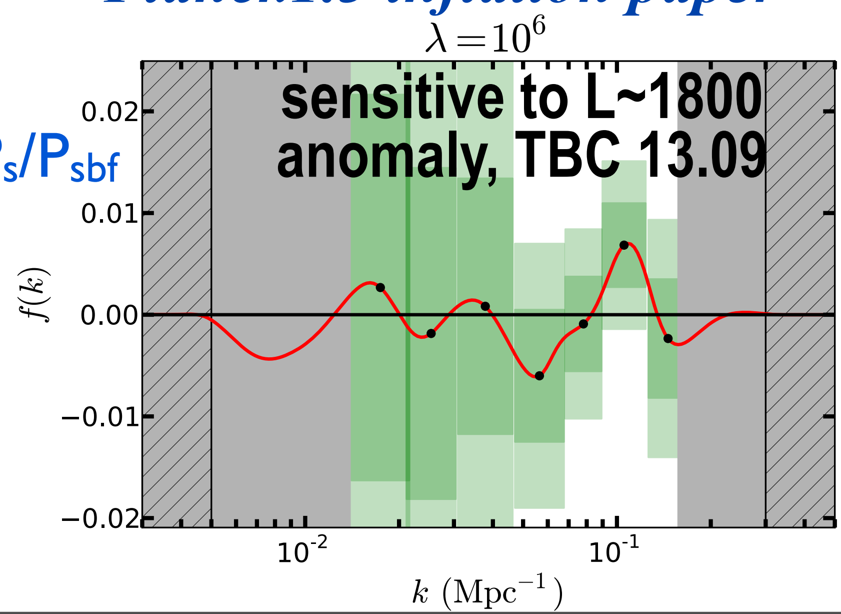
no evidence for oscillation patterns



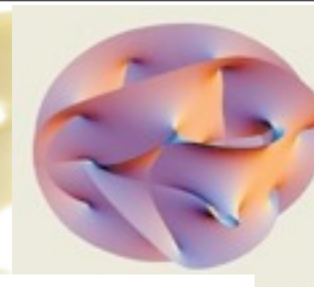
Planck1.3 inflation paper

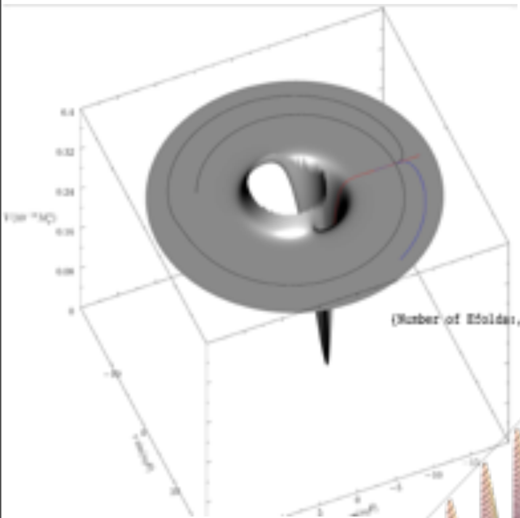
$\delta P_s/P_{sbf}$

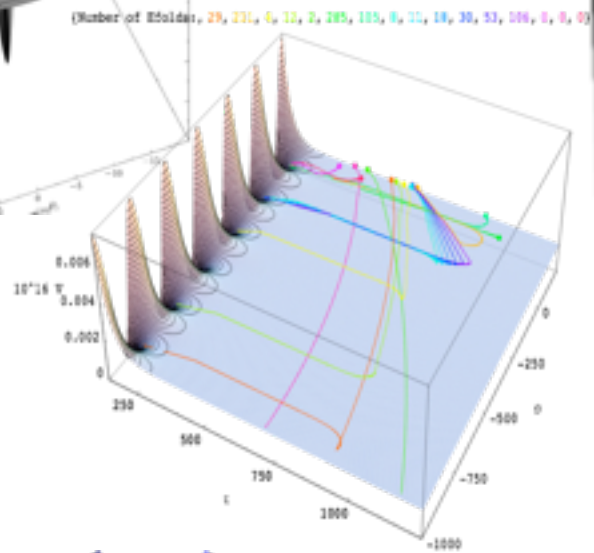


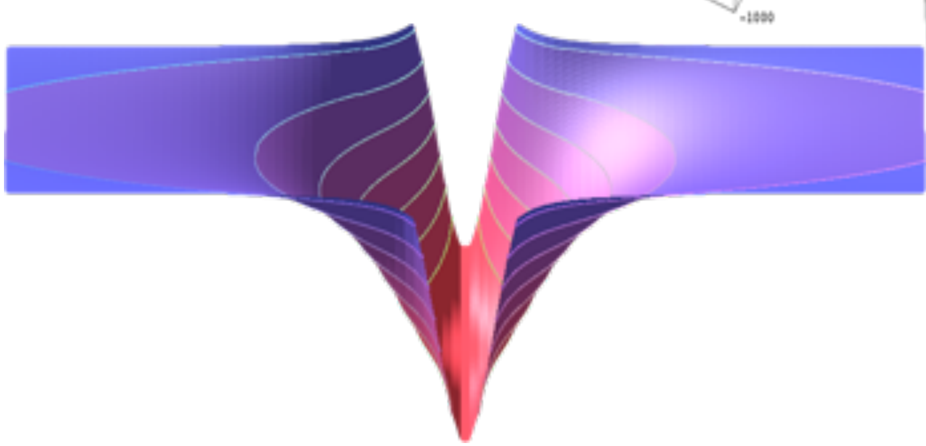


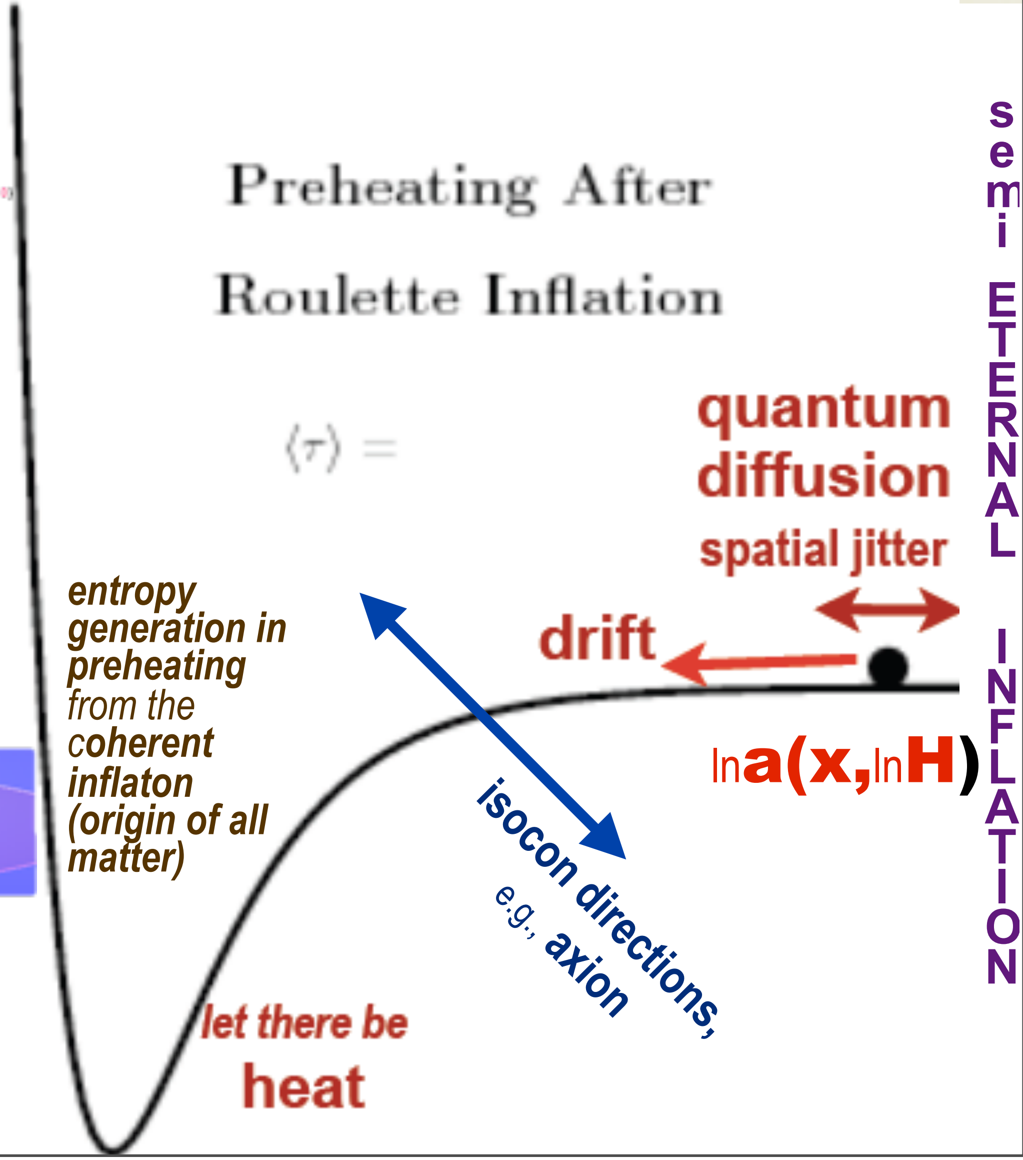
non-Gaussianity





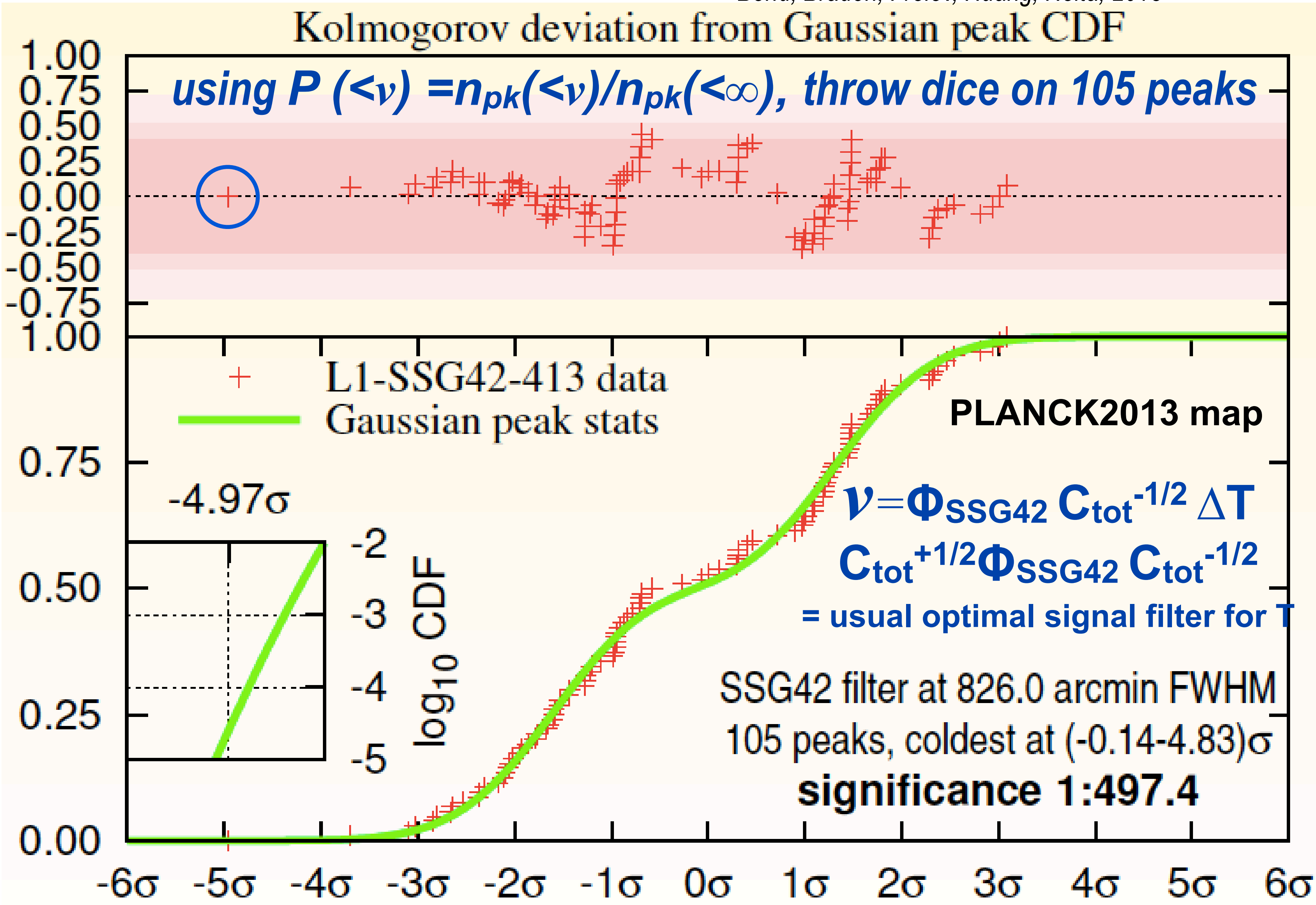






TESTING CMB PEAK STATISTICS

Bond, Crittenden 2001
Bond, Braden, Frolov, Huang, Nolta, 2013



P13 XXIII Spherical Mexican Hat Wavelets, 3 filters, kurtosis & excursion areas $\nu > 4$, .3% significance