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

25 years cifar

CITA = Cosmic Information Theory & Analysis:
IT from BIT, from BITs in IT, Studying the Cosmic Tango

Dick Bond CIAR

Universe=System+Res =Data+Theory en-TANGO-ment

the Cosmotician's Agenda: Statistical Paths in Cosmic Theory & Data

Entropy/Information Generation in Post-inflation Preheating: A Shock-in-Time

Lev Kofman @KIAS Sept 2005


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we compress the Petabit++ observed cosmic info into a precious few bits encoding 6+ parameters of the Minimal Cosmic Standard model (LCDM)

ρ_{dm}/ρ_b=5.1 ρ_m/ρ_{de} =.30 Ω_m=0.268 ±.012 Ω_Λ=0.736 ±.012

Power$_s$=25x10^{-10} *Tilt*$_s$ =0.963±0.013 **running=-0.024 ± 0.015 r=T/S<0.19**

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CMB*ology* uses WMAP7+ACT (SPT), **past: Boom, CBI, Acbar,..** (QuAD, ...). **LSS*ology* BAO H0** ***SN lens, clusters***. coming: ***Planck* cosmology** Jan2013,14 **cosmic parameters** Jan11(25p), Feb12 **SZ,CIB,ISM** ***ACTpol, ABS, Spider,*** *Quiet-2, .. CARMA, Mustang2 on GBT, CCAT, ALMA, ..*

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WMAP: 1.15 Tbits in 9yrs, cf. MyLifeBits, Gordon Bell, 1.28 Tbits in 9yrs, Planck 36 Tbits, ACT 304 Tbits. Terabit=10^12^bits=125 GigaBytes. e.g., Compress e.g., ΔS$_{1f}$ (r) = -3.7 Spider+Planck cf. ACT1

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How Structure in the Universe Arose?: *fluctuation generation in curvature from an early inflaton: isocurvature, Gravity Wave, non-Gaussianity signatures*

(coherence + quantum noise => incoherence via entropy/information generation)
morphs *into the nonlinear* ***Cosmic Web: clusters, filaments, voids; galaxies*** **(SZ)**

the fate of the U?: dark energy properties driving late inflation, ***S in asymptotic dS?***

Studying the Cosmic Tango

Cosmotician

P(cosmic parametersID,T), P(DIT)
D=CMB,LSS,SN,..,complexity, life
T=baryon, dark matter, vacuum mass-energy densities,...,early and late inflation,structure of manfolds (extra compactifying 7 + 3+1), holes, branes, fibres, strings,vacuua landscape, physical coupling 'constants'

Anthrostatician=superHorizon measurer

Studying the Cosmic Tango

en-Tango-ment, the dance of S+R=U
Universe=System(s)+Reservoir,
=Signal(s)+Residual *noise*,
=Effective Theory+*Hidden variables,*
observer(s)+observed,
ruled by (information) entropy, entangled. *the fine grains in the coarse grains*

the coherent and the entropic, in all its forms, from ultra-early-U to ultra-late-U

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the emergence of the collective from the random:
coherence from driven zero-point vacuum fluctuations ⇨ V **inflaton**, gravity waves; decohere

let there be heat: entropy generation in **preheating** from the coherent inflaton (origin of all matter)

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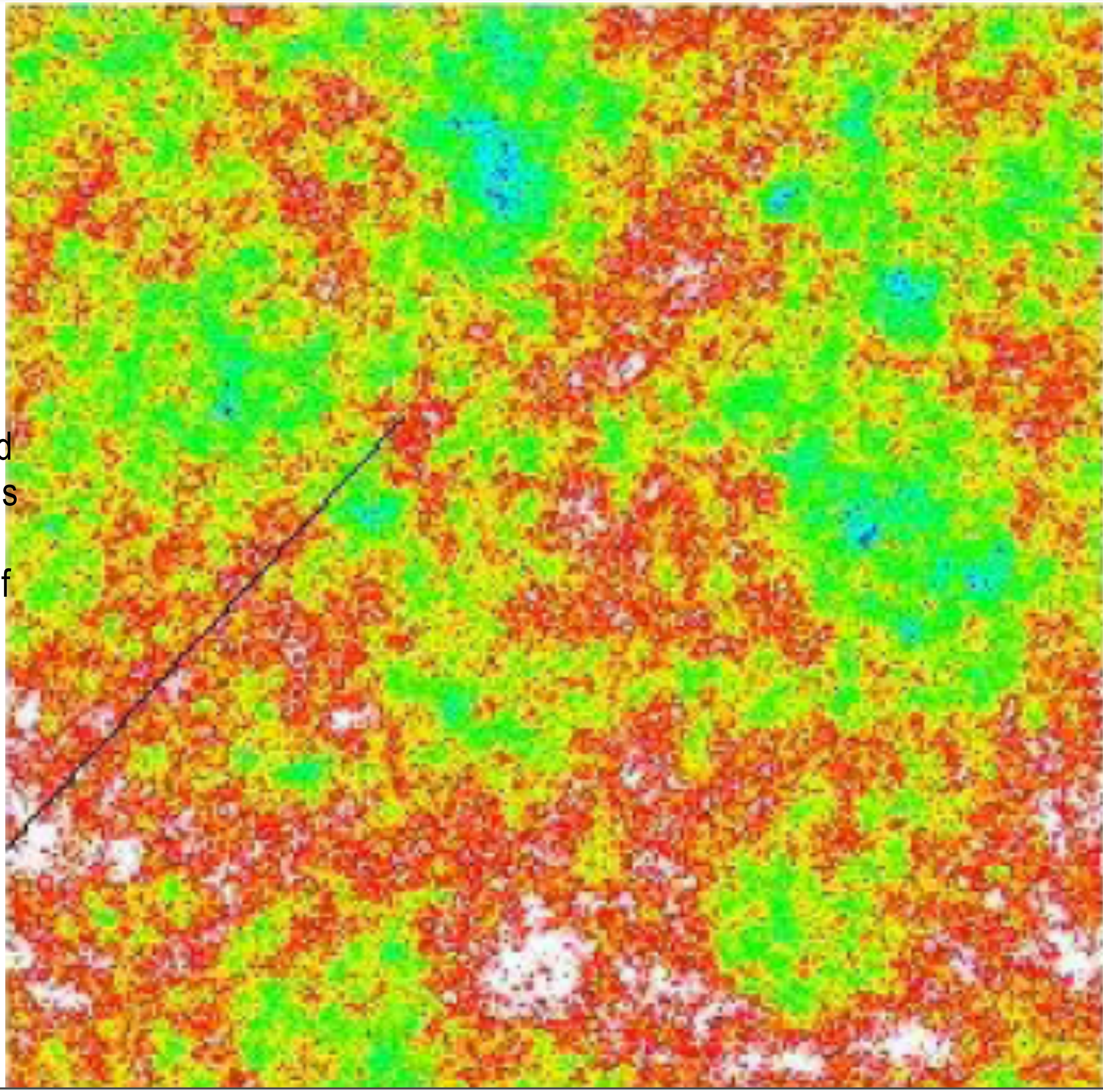
information in **nearly-Gaussian** random **fields** of U: spatial coarse-grained **CMB entropy** & how we capture it. **dark matter entropy, cluster & protocluster & cosmic web entropy. MHD turbulence entropy** with cooling & grain polarized emission - a CMB fgnd. *How Shannon info-entropy flows from CMB bolometer timestreams to marginalized cosmic parameters via* ***Bayesian chains from prior to posterior.***

Shannon entropy ~ von-Neumann entropy
= Trace $\varrho \ln \varrho^{-1}$ = full non-equilibrium S
$\varrho(U) = \varrho(S,R) = \varrho(R|S)\,\varrho(S)$ entanglement of phase & probability

fluctuations in the **early universe "vacuum" grow** to ***all*** **structure**

χ



scalar field fluctuations in the vacuum of the ultra-early Universe

pre-heating patch (~1cm)

evolve from early U vacuum potential and vacuum noise

10 Gpc

fluctuations in the **early universe "vacuum" grow** to *all* **structure**

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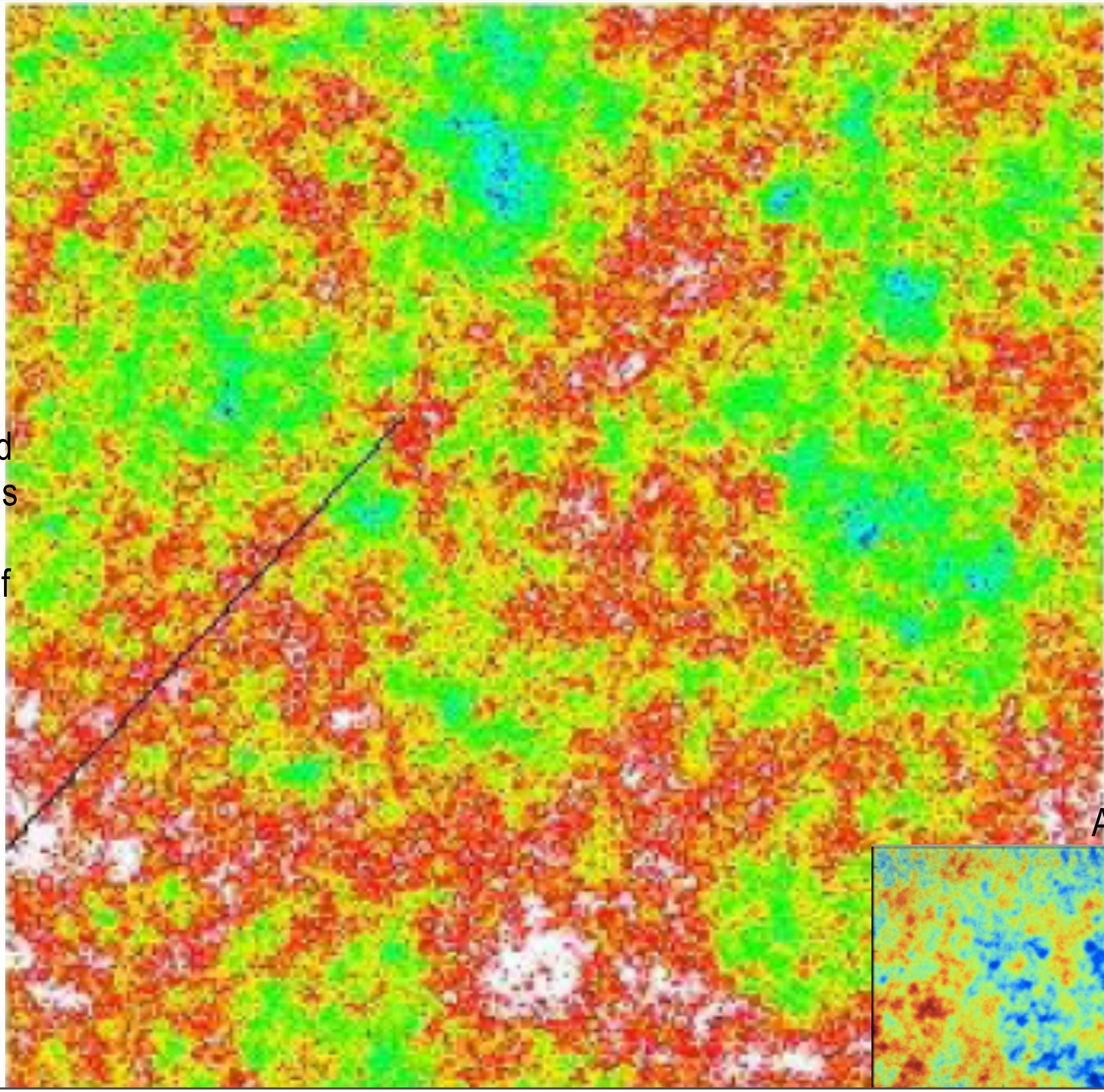

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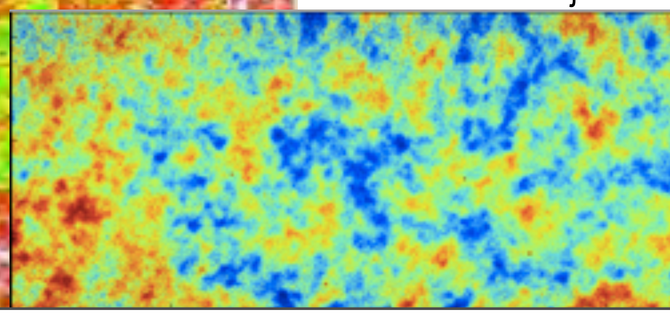
evolve from early U vacuum potential and vacuum noise

ACT+WMAP7 hajian+10



fluctuations in the **early universe "vacuum" grow** to *all* **structure**

400 Mpc

ΛCDM

WMAP5

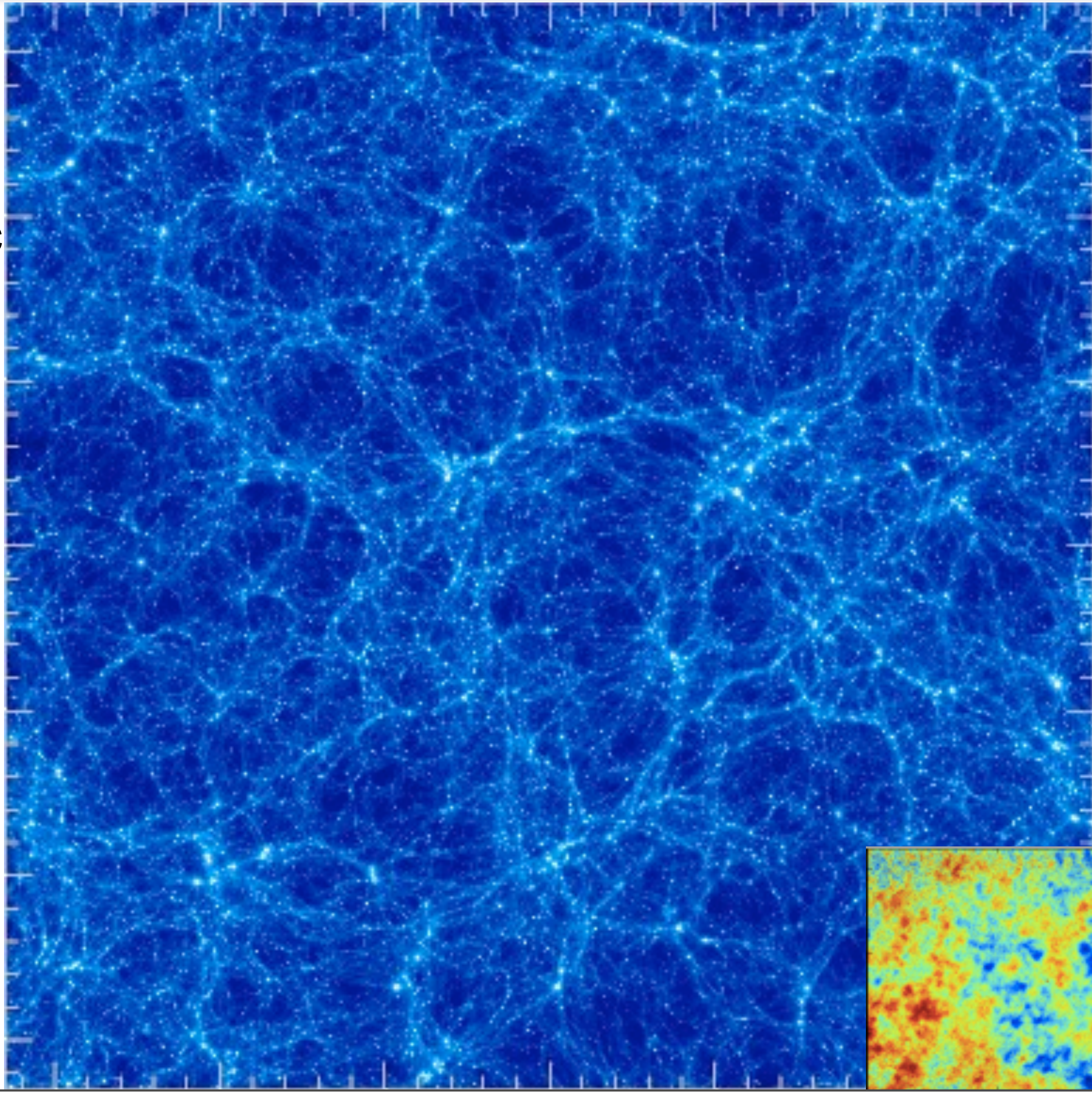
gas density

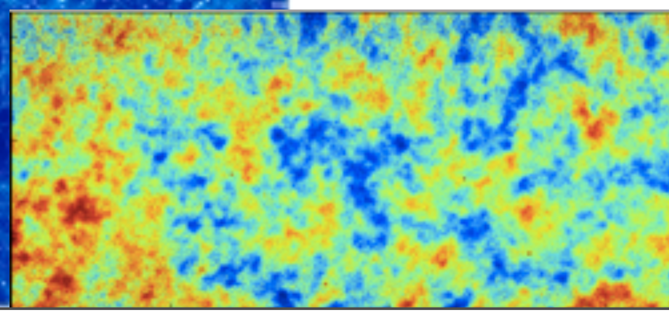
Gadget-3

SF+ SN E+ winds +CRs

512^3

BBPSS10





all this can

evolve from early U vacuum potential and vacuum noise

in the presence of late U vacuum potential aka dark energy

pressure intermittency *in the cosmic web, in cluster-group concentrations probed by* **tSZ**

400 Mpc

ΛCDM

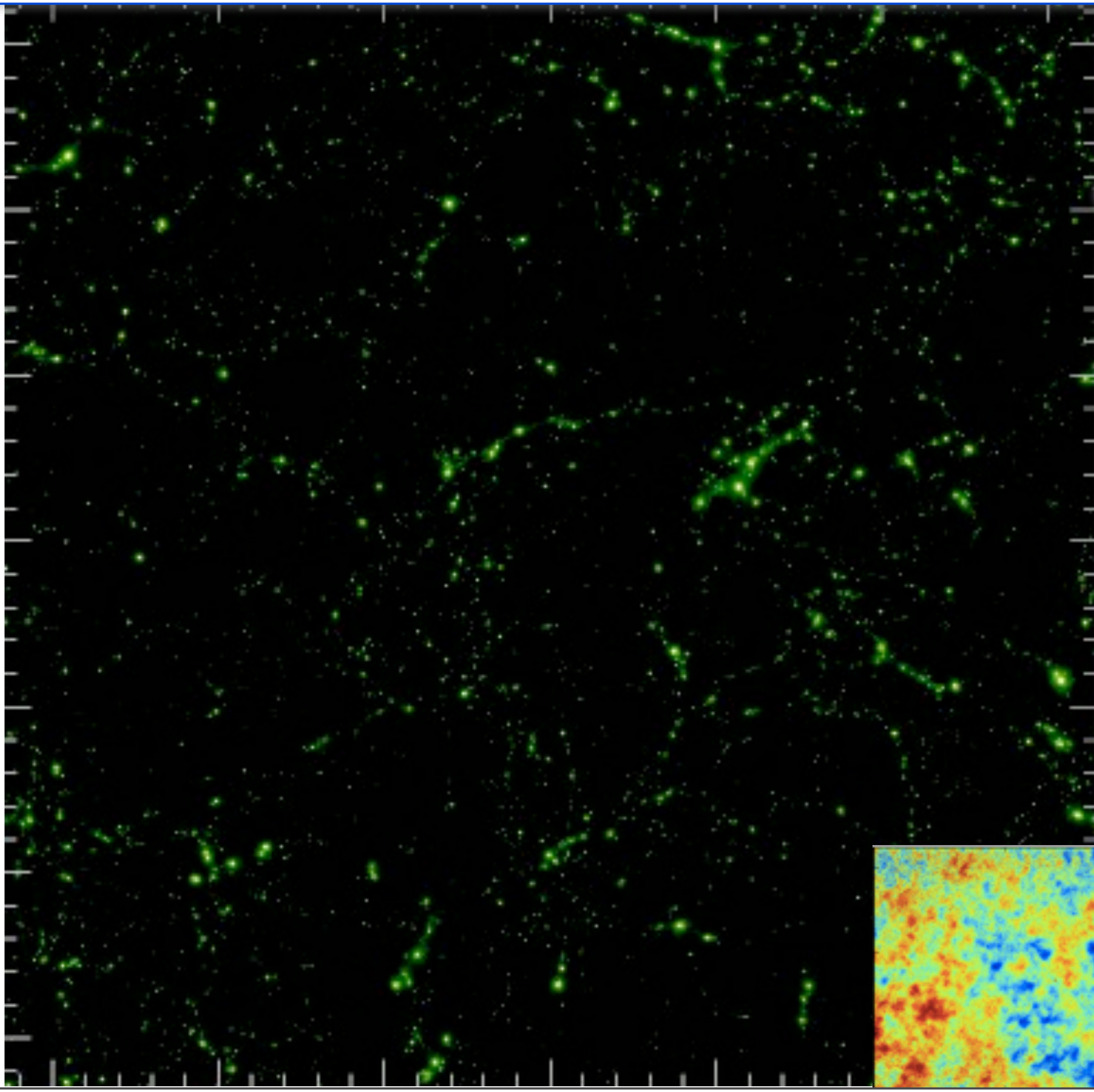
WMAP5

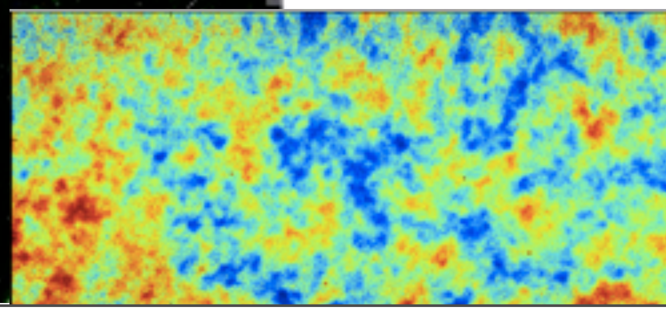
gas pressure

Gadget-3 SF+ SN E+ winds +CRs

512^3

BBPSS10





CMB gets entangled in the cosmic web

descending into the real gastrophysics

of

cosmic weather

the energetic, turbulent, dissipative, compressive

life of the IGM/ICM/ISM

My new/old passion: see JFN

Studying the Cluster Tango

en-Tango-ment, the dance of S+R=U
U = Hubble patch, oft-realized
S = a *scaled-rotated-stacked-cluster-radial-bin* (non-local, i.e., disconnected)
R = other radial bins + the web outside

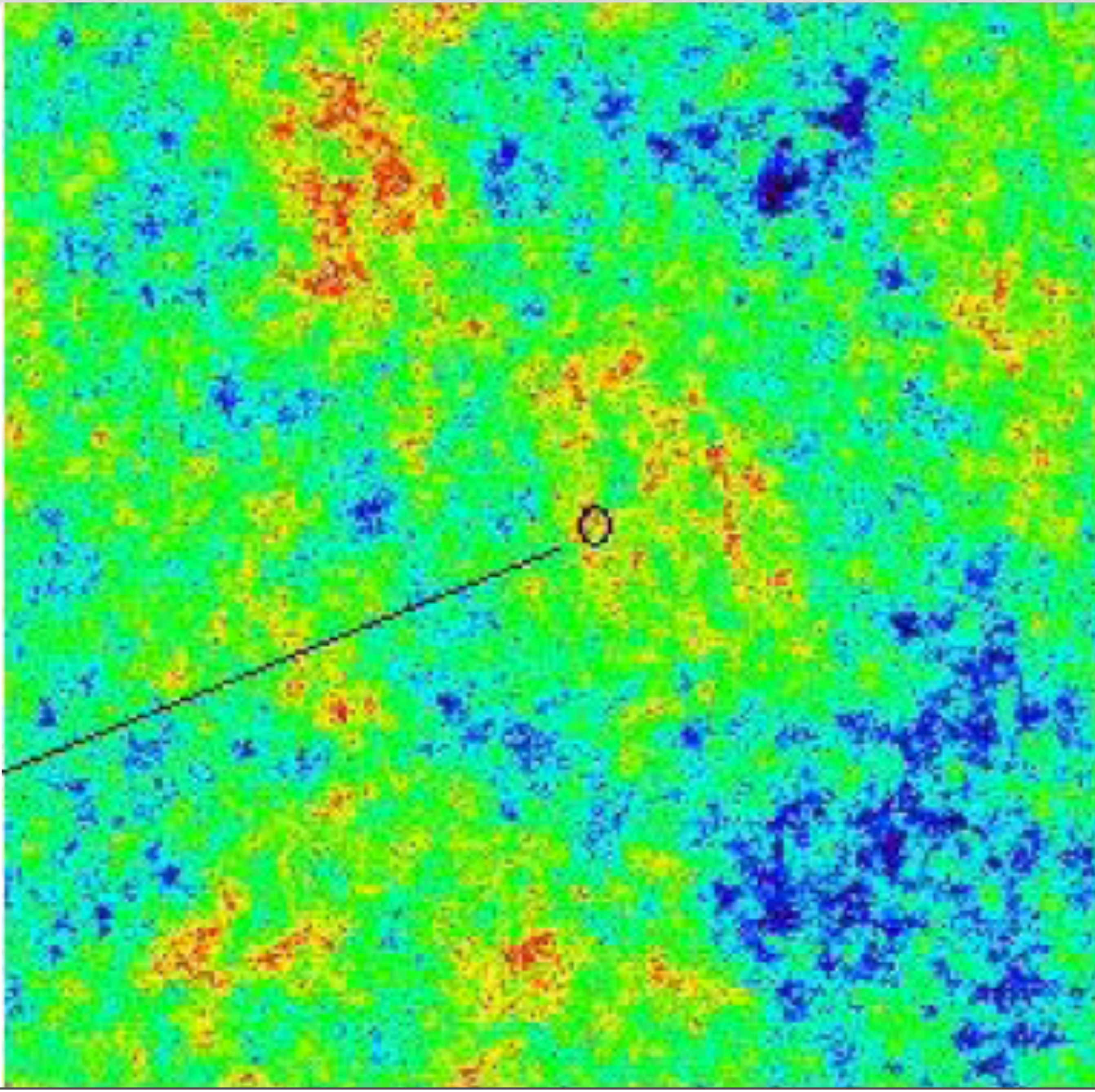
resolution dimension **$\lambda = -\mathit{ln}\ r/r_0$ to $-\mathit{ln}\ r/r_\Delta$** when res-synchronized 1D (or 6D λij)
Shannon information entropy
S(λ |coarse-grained-measures) deals with the non-equilibrium and non-thermal entropy in cls, includes DarkMatter coarse-grained entropy -

S(λ |coarse-grained-measures) can treat the entropy of protocluster/peak patches and of preheating configurations.

gravitational entropy, although somewhat included, remains a **mystery**.
the **gravo-thermal catastrophe** = negative specific heat, what gravity wants is to localize concentrating mass into black holes and make accelerating voids to straighten out U.

fluctuations in the **early universe “vacuum” grow** to ***all*** **structure**

χ



current Hubble patch ~10 Gpc

speed limit horizon

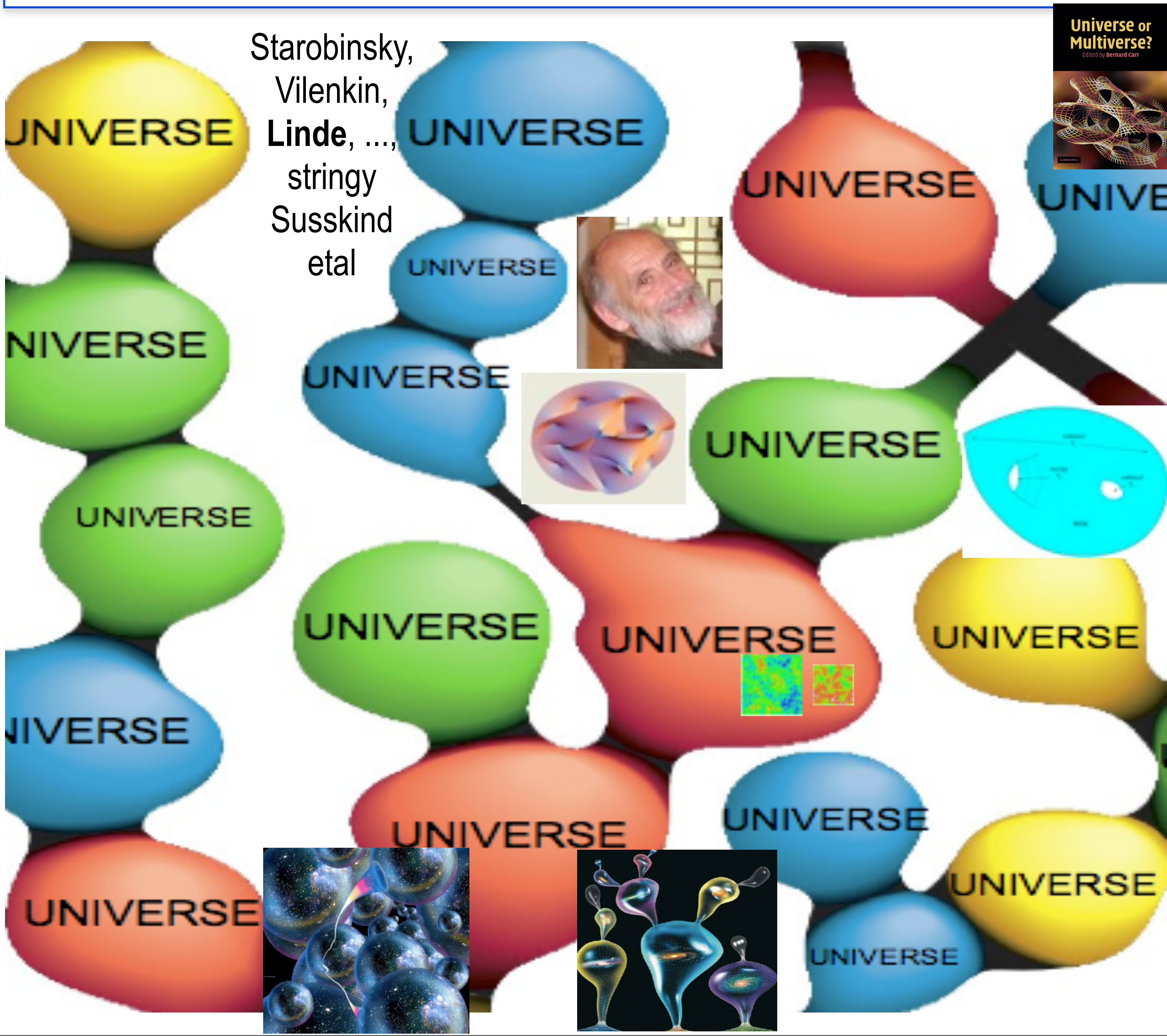
patterns in the quantum jitter evolve under gravity

(& gas dynamics)

1000 Gpc

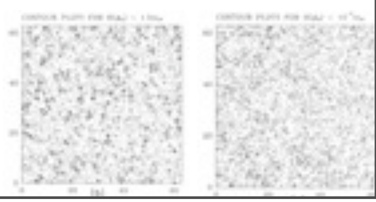
the **quantum stochastic non-G landscape** cf. the **stringy landscape**

Starobinsky, Vilenkin, **Linde**, ..., stringy Susskind etal



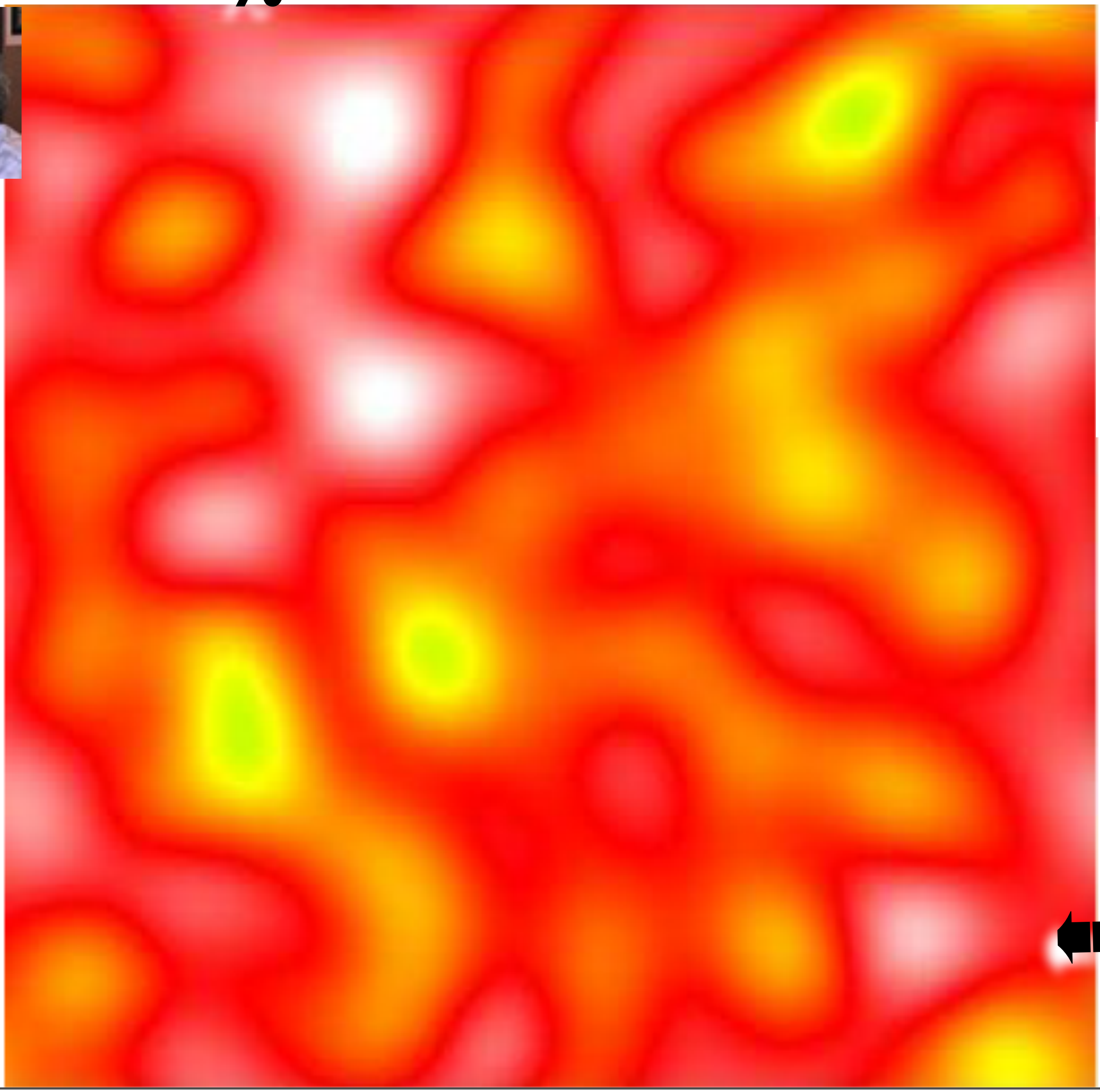
SB91: non-G on uniform Ha-hypersurfaces from a simple exponential potential via quantum kicks > drift at high $H_i \sim m_p$ uuUULSS cf. observable nearly-Gaussian at low $H_i \sim 10^{-5} m_p$

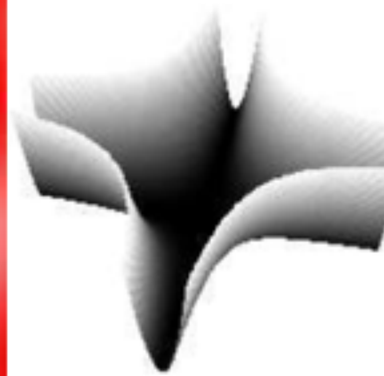
asymptotic flat eternal inflation V has similar behaviour

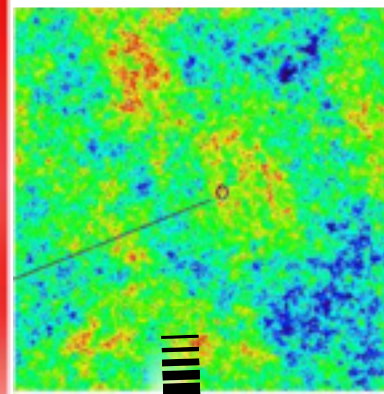


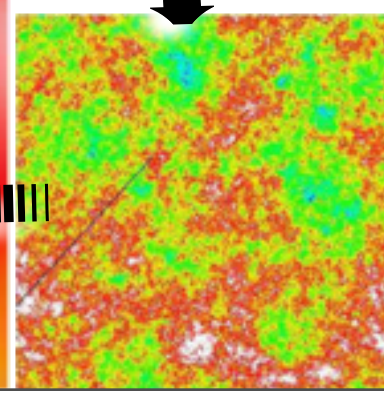
ϕ inflaton χ isocon $V(\phi,\chi) = 1/4\ \lambda\ \phi^4 + 1/2\ g^2\ \phi^2\ \chi^2$

Parametric Resonance
$g^2/\lambda \sim 1$









pre-heating patch (~1cm)

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

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

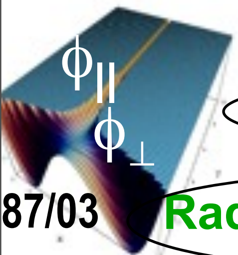
6/7 tiny extra dimensions

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

end of inflation @ε=1
through preheating
(linear resonance, nonlinear backreaction $\delta\psi,\delta\chi$)
to thermal equilibrium
$ln(n_k^{-1}+1) \Rightarrow k/T,\ \rho_k \sim E_k(n_k+1/2)$

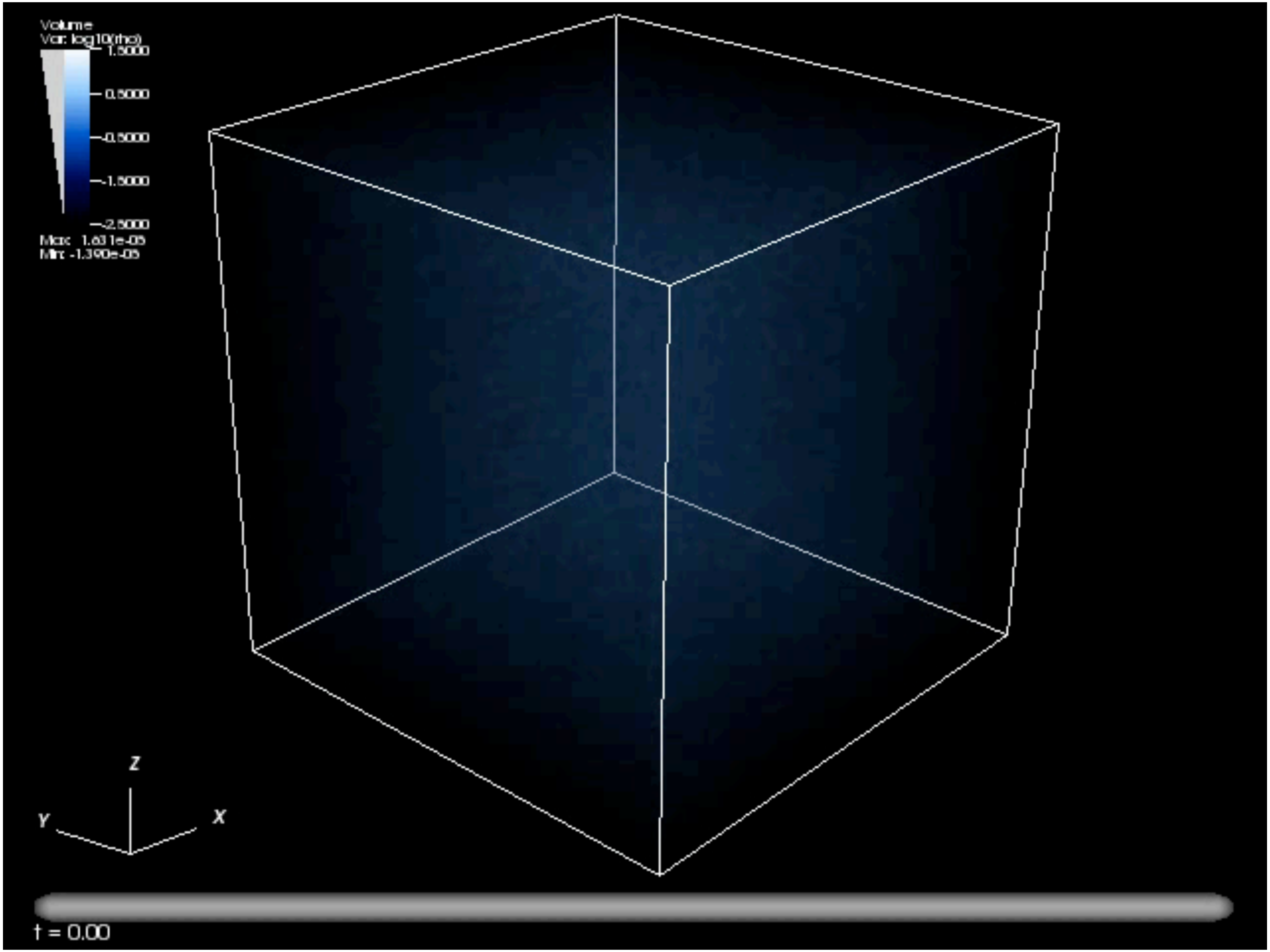
from coherent "background" field with nearly-Gaussian linear fluctuations to incoherent heat bath through a not-that-turbulence-like cascade: development of complexity: information (multi-scale entropy) b+braden 11

@ $k > H_{end}^{-1}$

=> no effect on k-observed? MAYBE:
relics (e.g., strings, isocons), HF gravity waves (kHz-GHz cf. 10^{-19}Hz), isocon modulation & non-Gaussianity

Andrei Frolov, Defrost code

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



Preheating = Shock-in-time, overview Jonathan Braden + B 2011

Initial State = Nearly Homogeneous Inflaton

Low entropy (vac fluc.), information encoded in a few parameters

Preheating

Instabilities result in nonlinear transition to an incoherent state

KLS 94, 97,e.g. Tkachev, Felder, Garcia-Bellido, ...

Transition Regime

Complex slowly evolving nonlinear, nonequilbrium state e.g. Micha and Tkachev 2004, turbulence analogy

the shock-in-time is the sharp mediator between the linear & the highly nonlinear transition

Thermal Equilibrium

Maximum spreading of information in modes subject to energy and particle number constraints.

A Shocking End to Post Inflation Mean Field Dynamics

Shock-in-space t = const

$v_{bulk}^2 > c_s^2 \Rightarrow v_{bulk}^2 < c_s^2$

supersonic ⇒ subsonic

Characteristic spatial scale

Jump Conditions: $\Delta T^{\mu\nu}$

Randomizing Shock Front: ΔS

Mediation: width via viscosity or collisionless dynamics

post-shock evolution, slow, of temperature

Shock-in-time x = const (deviations for nonG)

$\langle\rho\rangle \gg \delta\rho \Rightarrow \langle\rho\rangle \ll \delta\rho$

Homogeneous ⇒ Fluctuations

Characteristic temporal scale

Jump Conditions: $\Delta T^{\mu 0}$

Randomizing mode cascade & Particle Production: ΔS

Mediation: width via gradients and nonlinearities

post-shock evolution, slow, of fluctuations

Preheating (a shock-in-time) is an efficient entropy source.

Nonequilibrium Shannon (~ Von Neumann) Entropy

$S = -\mathrm{Tr}\, P[f]\, \ln P[f]$

$P[f]$: probability density functional

Coarse Graining and Entropy Production

Field⇒ Correlation Functions

Measurements: Constraints (information) on Correlators
Maximize entropy subject to given constraints
Generation of higher order correlators ⇒ entropy generation

Entropy and Gaussian Distributions

Only power spectrum constrained ⇒ multivariate Gaussian maximizes S

$S/N = 1/2N\, \mathrm{Tr} \ln P(k) + 1/2 + 1/2 \ln(2\pi)$

$\ln = \log_e$ measure info in nats, $\mathrm{lb} = \log_2$ measure info in bits

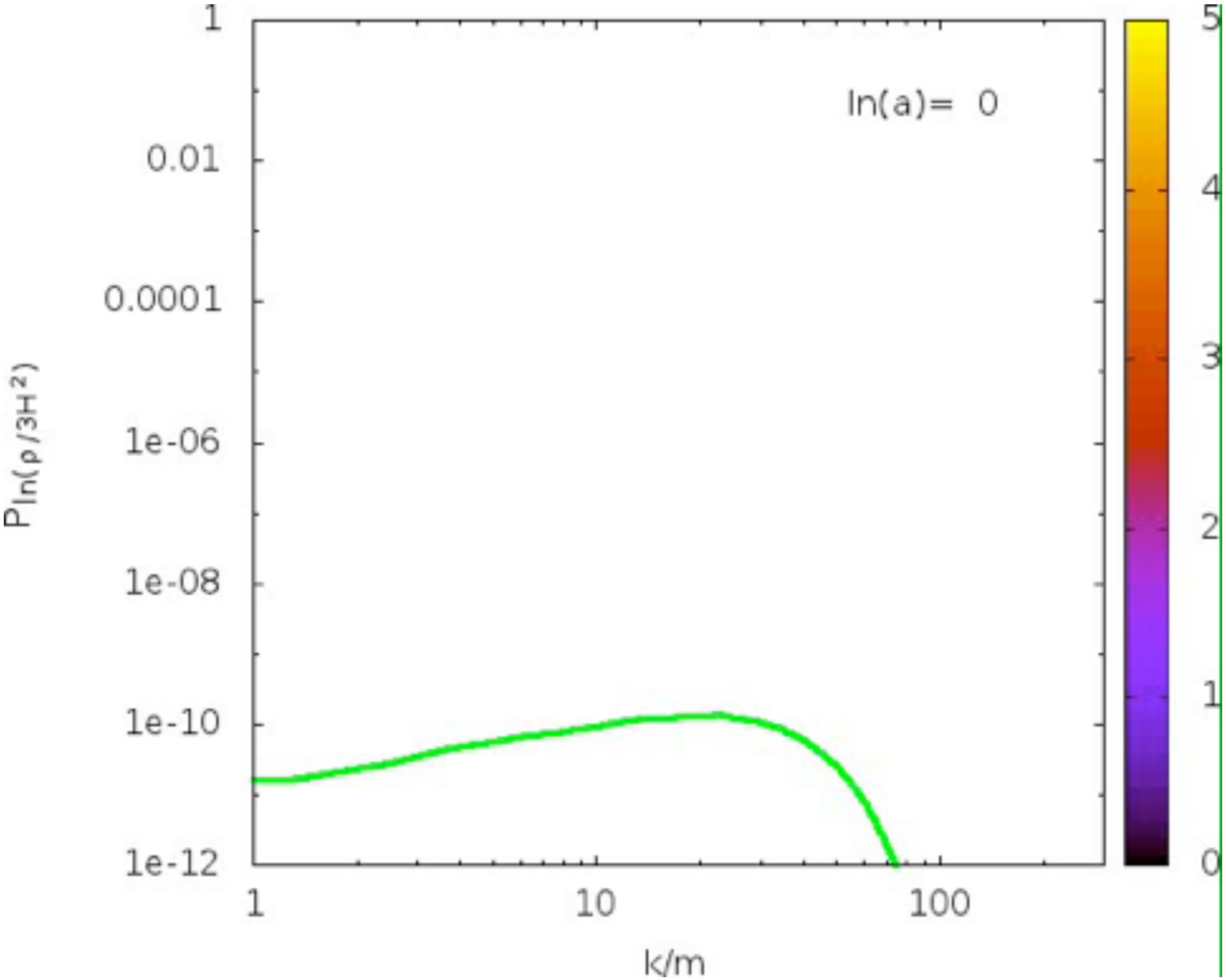
P has dimension, so S relative, if you count states then relative to 1

Power Spectrum

Nonlinear dynamics via large parallel lattice simulations using modified version of DEFROST Frolov 2008

$\ln(\rho/3H^2) \sim \ln(\rho/\langle\rho\rangle)$ as the dynamical random field.

$$V = \frac{m^2}{2}\phi^2 + \frac{g^2}{2}\phi^2\chi^2$$

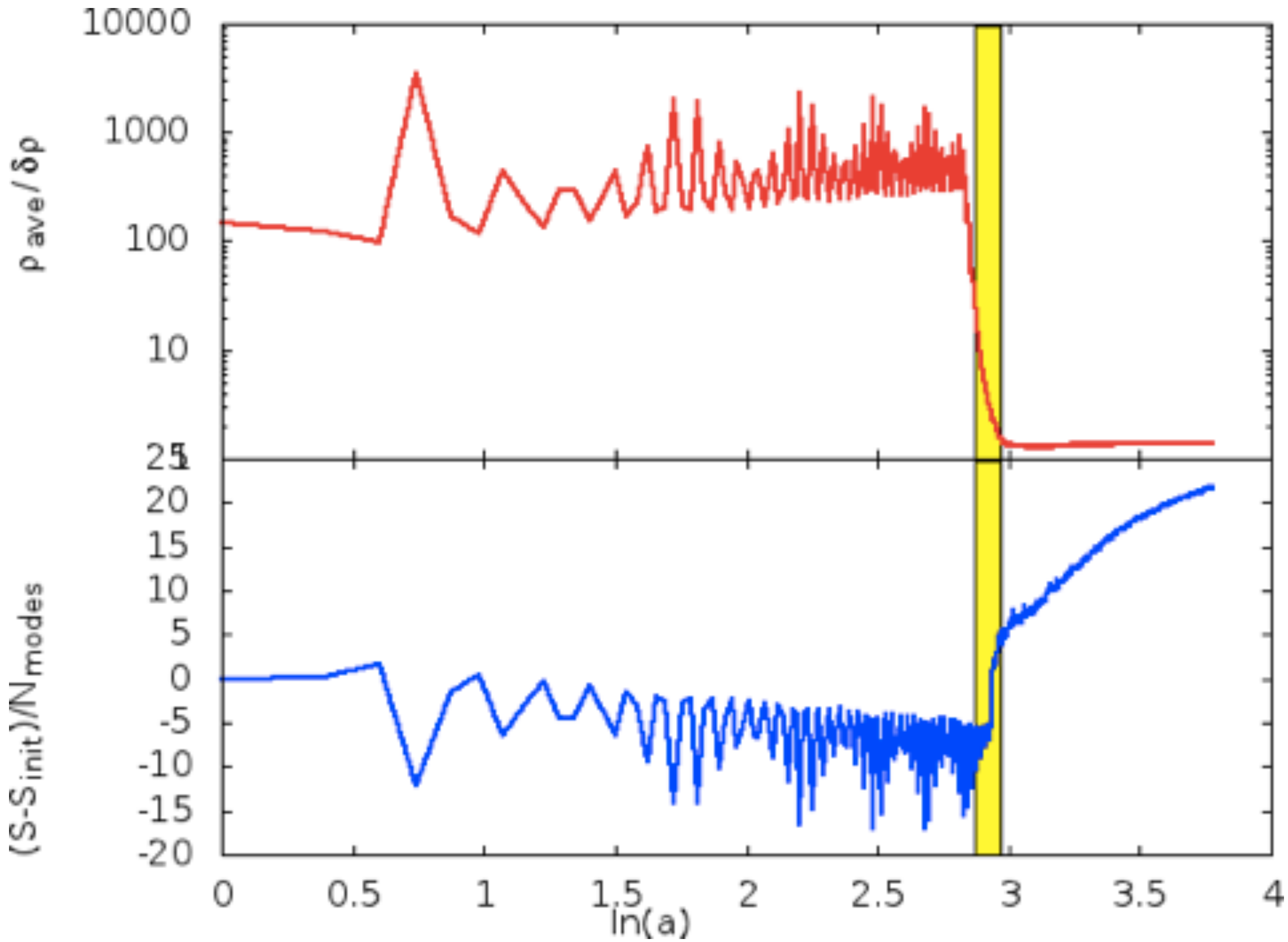


$m/M_P = 10^{-6}$,
$g^2 = 10^{-5}$

Initial distribution is simulated vacuum fluctations (low entropy) Rapid increase in fluctuation power ⇒ shock-in-time.

Slow post shock evolution of power

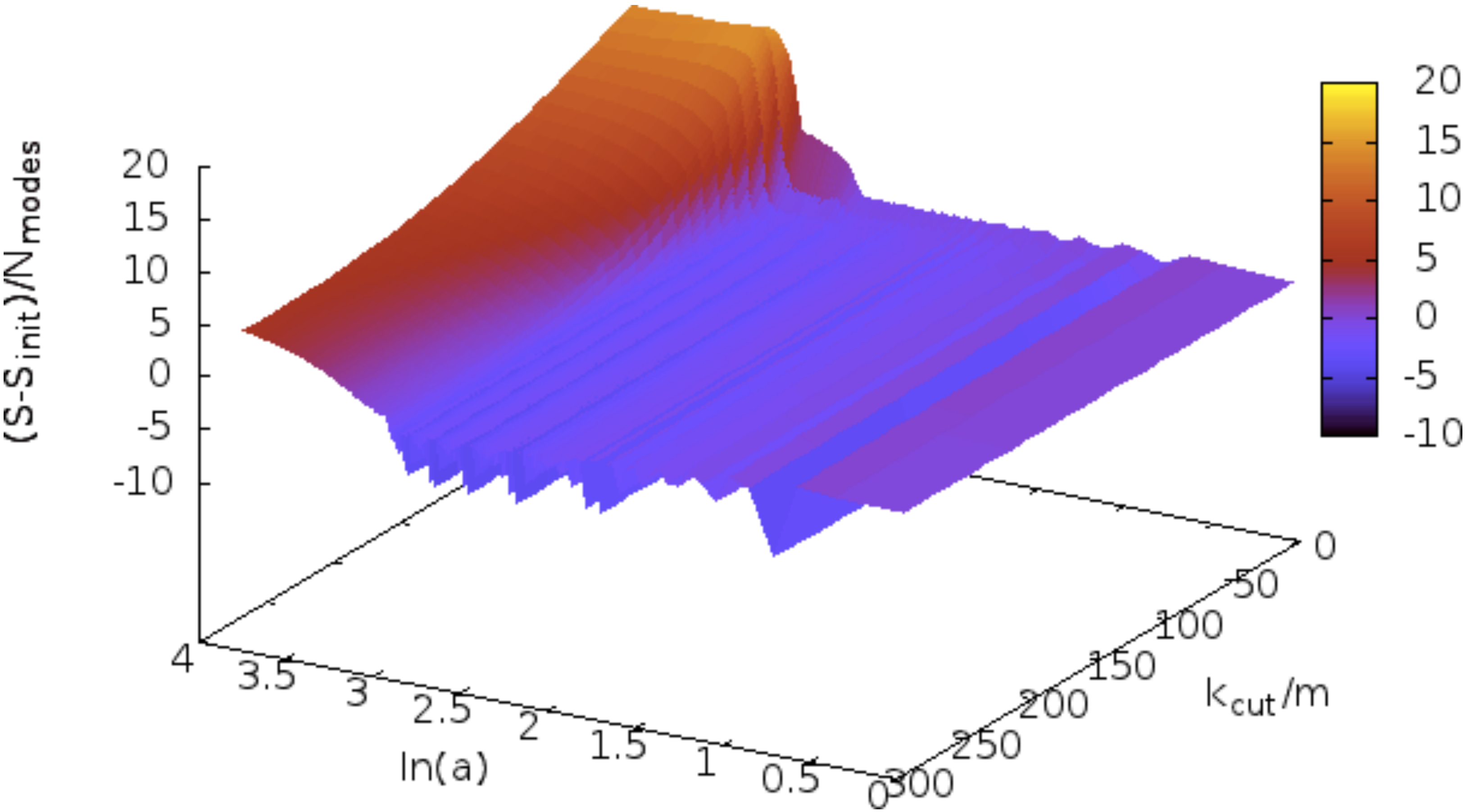
Entropy Production & the Shock-in-time



constrained coarse-grained Shannon entropy > 0 taken relative to the initial Gaussian random field entropy

there is a spike of entropy production at the shock front.

Scale Dependence of Shock-in-Time



The entropy production is not localized just large k or to small k. Suppose we only have access to a limited resolution of the field (modelled here by a sharp k space cutoff k < kcut)

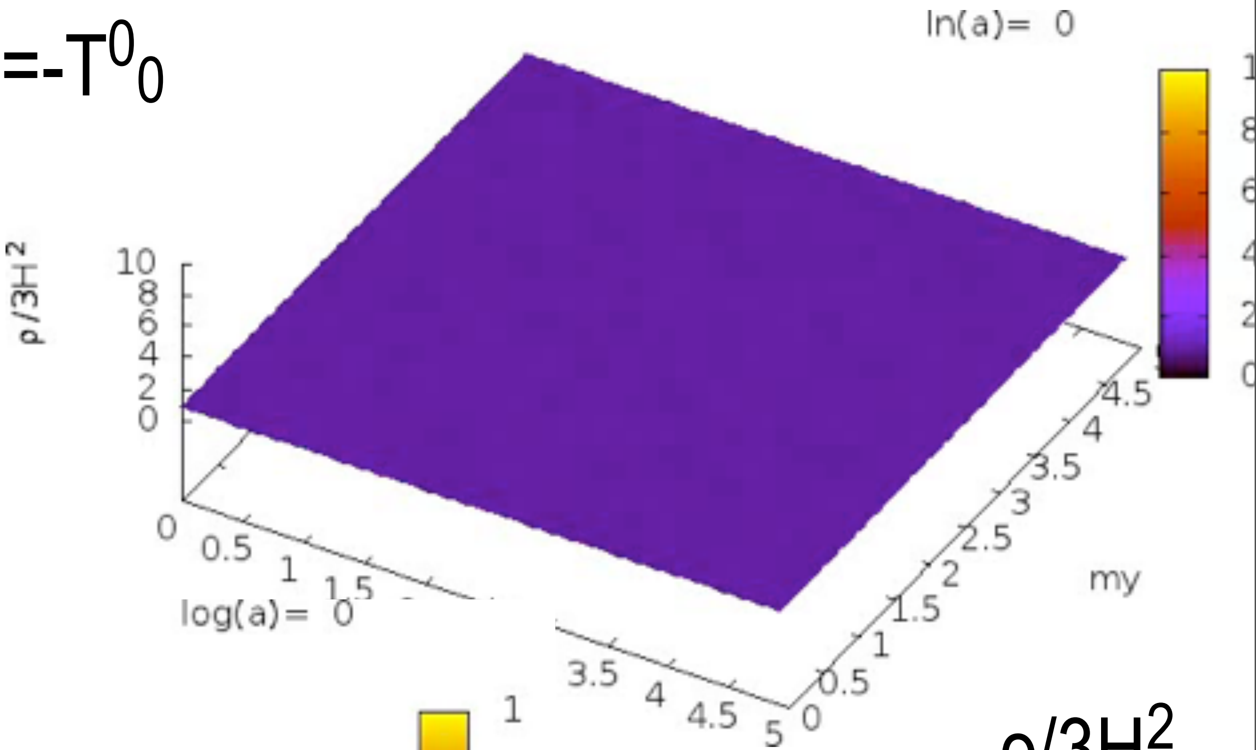
Post Shock Evolution

$\rho = -T^0{}_0$

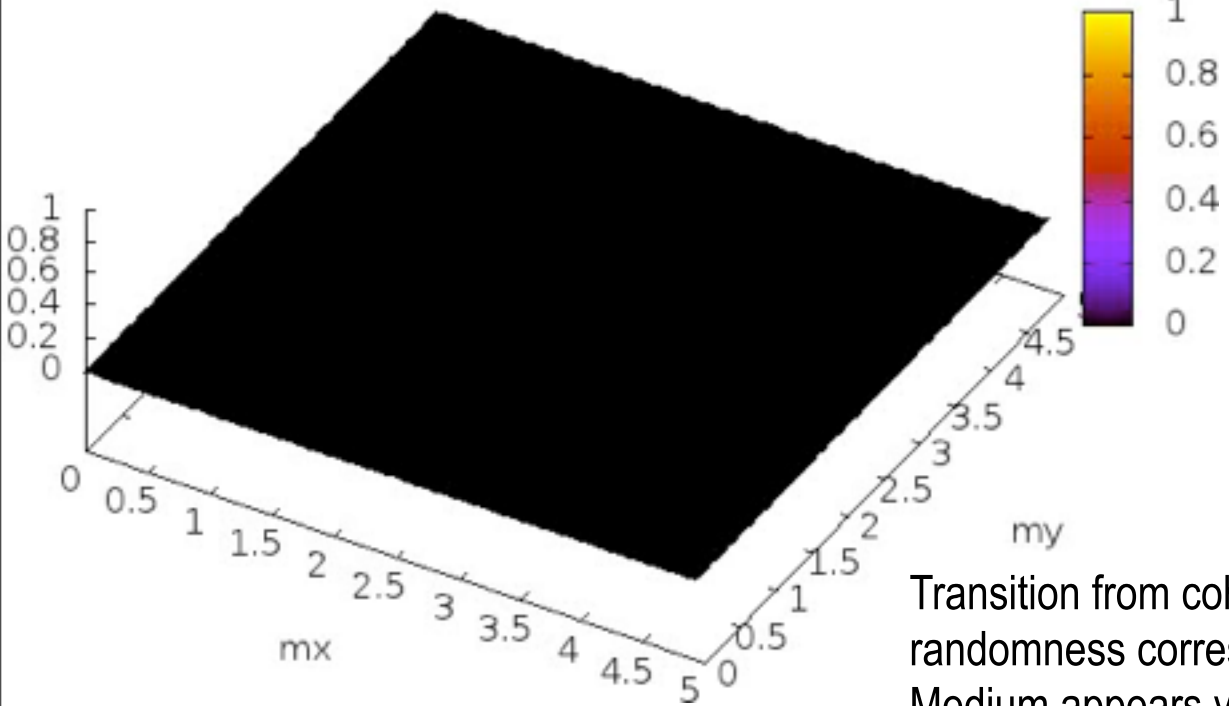
Slow Dynamics of IR Modes ⇒
Hydrodynamic Description

$P = -T^i{}_i$

$v^i = aT^i{}_0 / (\rho + P)$



$\rho/3H^2$



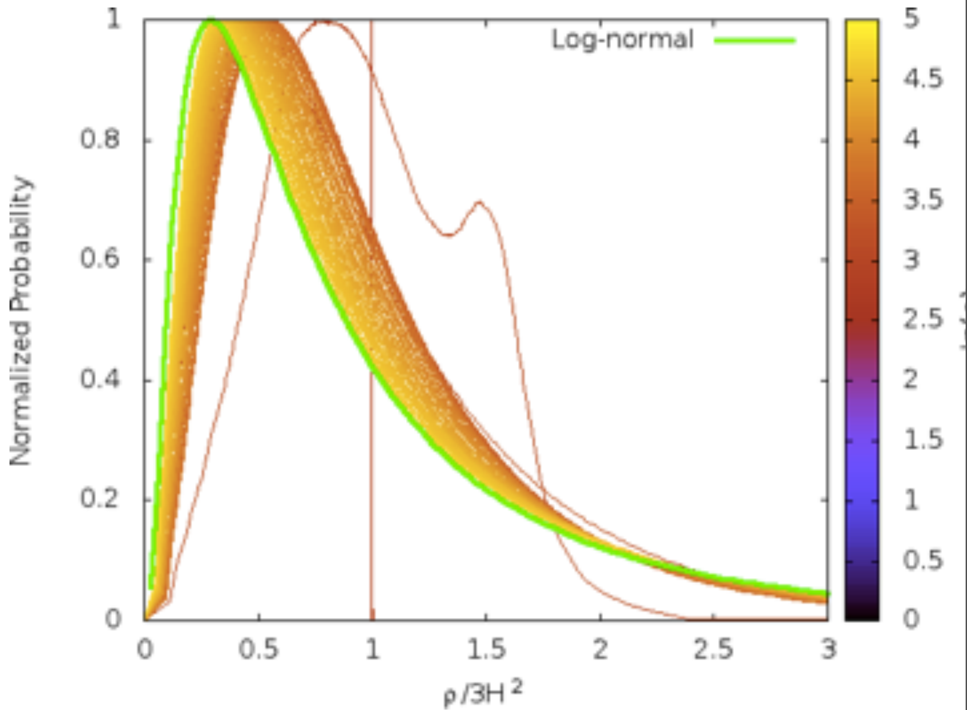
v^2

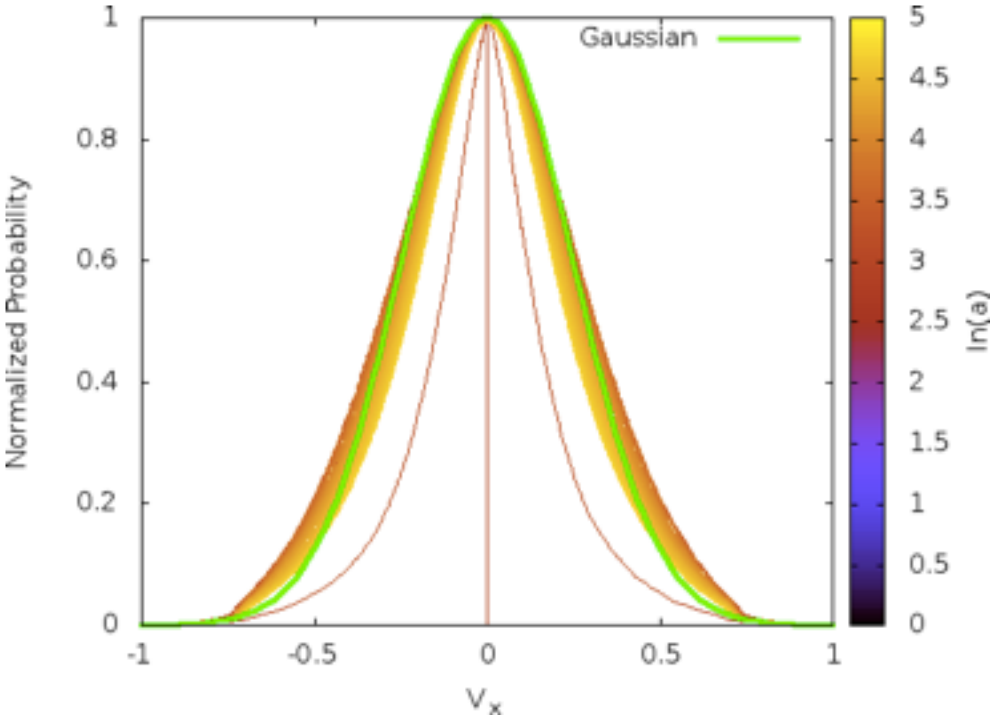
Transition from coherent wall-like structures to randomness corresponds to the shock-in-time. Medium appears very complex in space and time, but ...

Statistical Simplicity

Density PDF~ log-normal after initial transient Frolov

Velocity components ~ Gaussian.





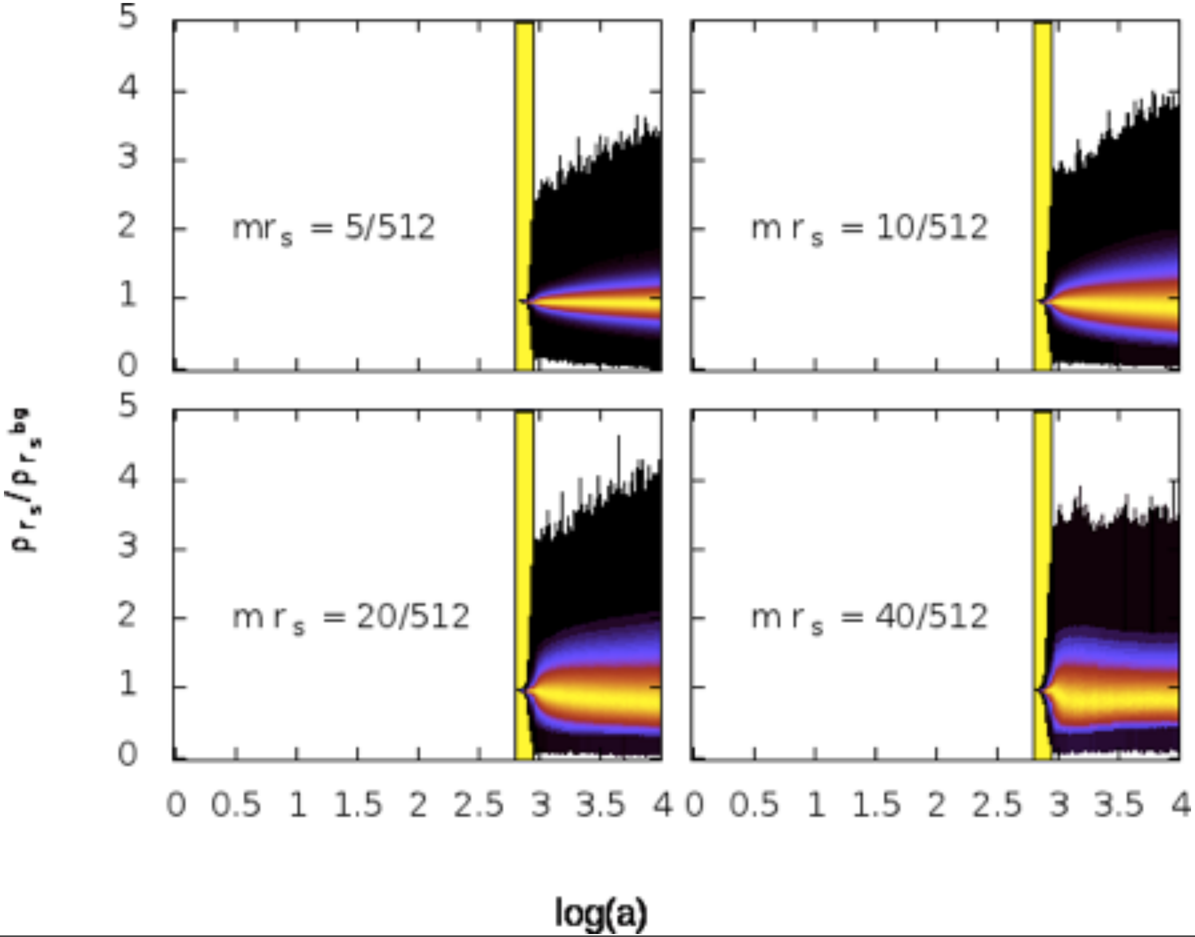
Renormalization and Scale Dependence

Wilsonian RG Blocking

Sequence of smoothed fields ρ_s defined by averaging over groups of 8 nearest neighbours with $r_s = 2^s dX_{lat}$ the smoothing scale.

Define local background for $\rho_s(x)$ by ρ_{s+1}

idea is there are fluctuations on fluctuations on fluctuations ...

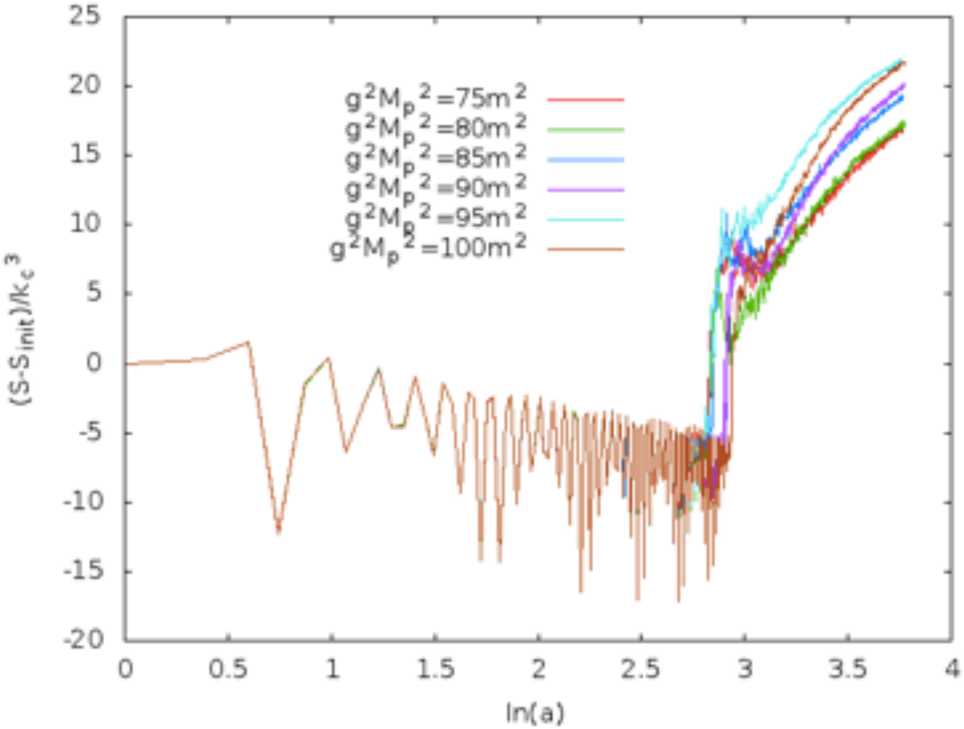


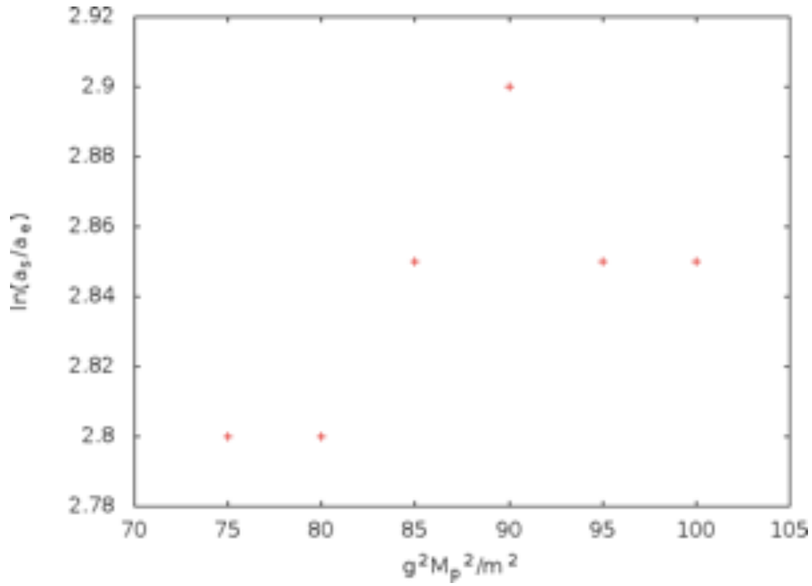
The shock-in-time has a more pronounced effect on larger scales

At late times, local fluctuation PDFs evolve more slowly on larger scales than on small scales

White bounds the extremal values in the simulation box.

Relation to Nongaussianities entropy change as coupling changes



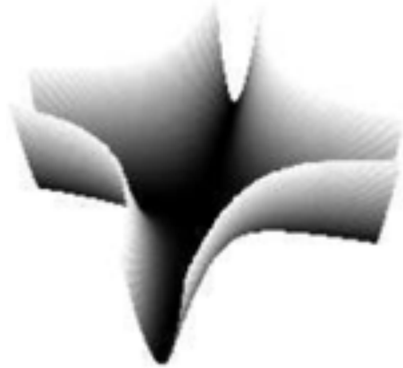


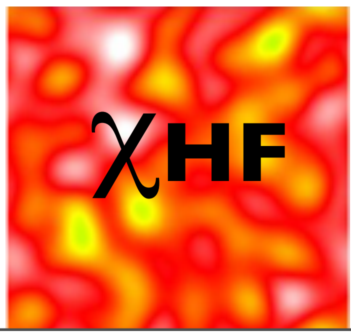
dependence of $\ln(a_{shock}/a_{end})$ on parameters (coupling constants,$\langle x_{init} \rangle$, ...)

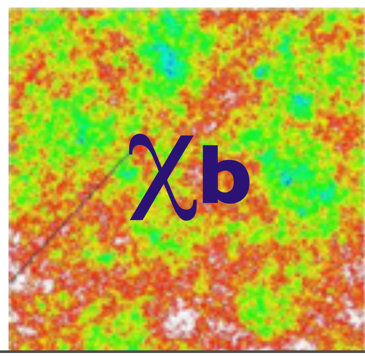
relationship to nongaussianities from preheating

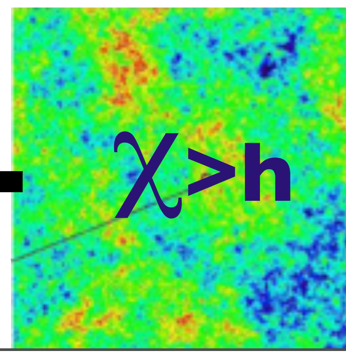
Bond,Frolov,Huang,Kofman (2009), and e.g. Chambers and Rajantie (2008)

The spatial structure of ln(ashock/aend) resulting from given initial conditions encodes information about the perturbation spectra including nongaussianities.



$\chi(x,t)=$ 

+ 

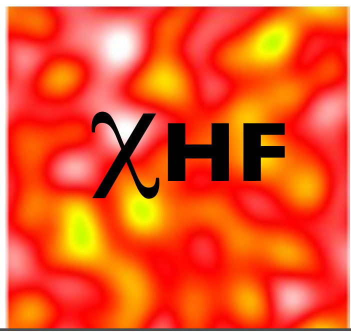
+ 

$$\ln a_{final} / a_{end} \sim \ln a_{shock} / a_{end}$$

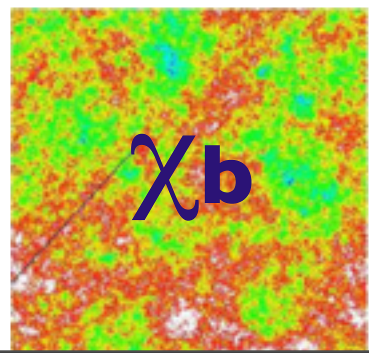
$$\text{curvature} \quad F_{NL}(\chi(x,t)) = \delta \ln a|_H (\chi_i)$$

highly nonlinear function of a Gaussian random 'isocon' field

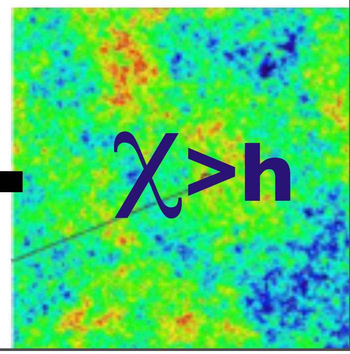
$\chi(x,t) =$



$+$

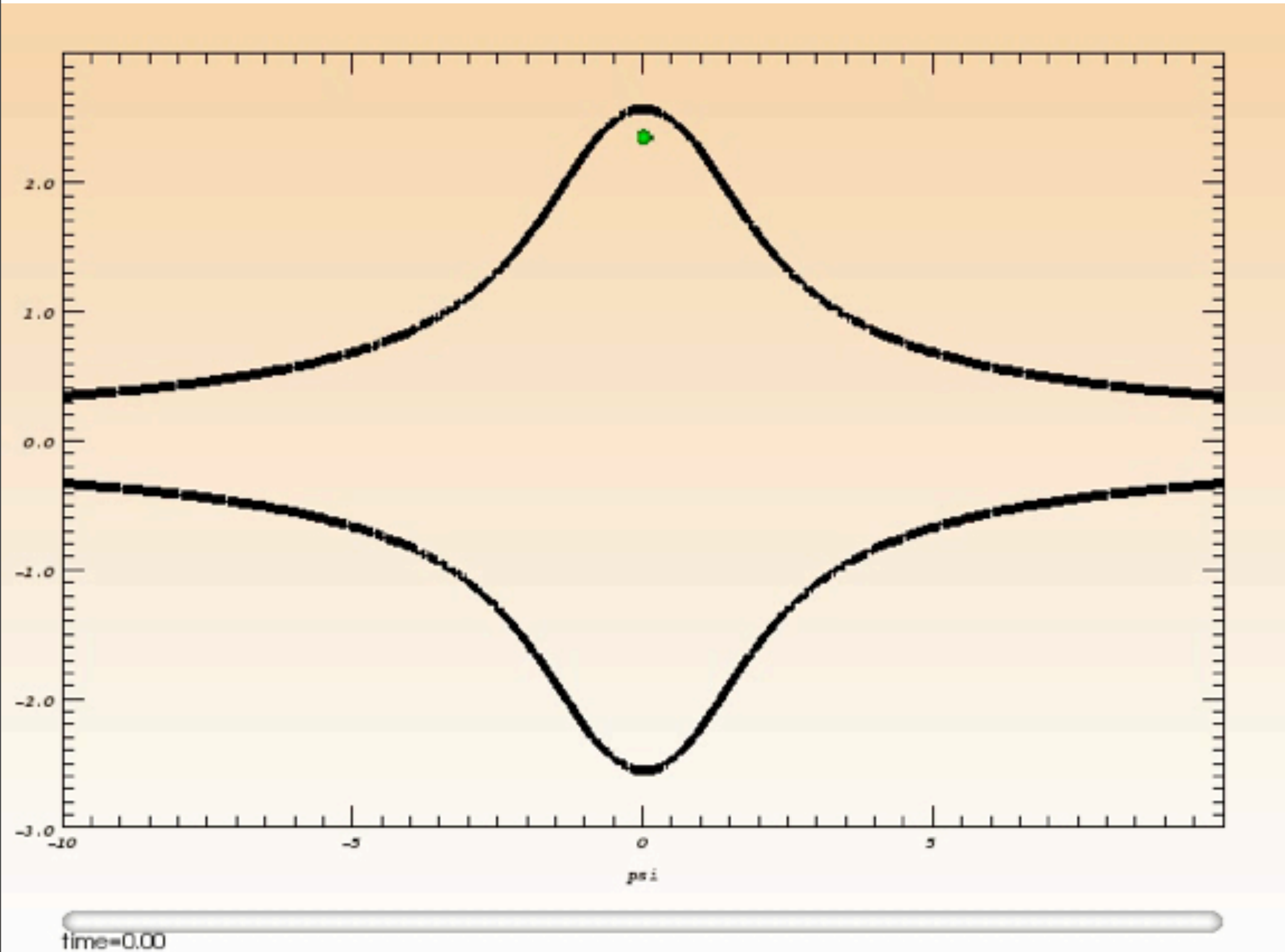


$+$



calculate $\delta \ln a\,[\chi_i(x,t)]$ *from* **ε=1** *(end of inflation)* ***through preheat***
(copious mode-mode-coupling aka particle creation) ***to thermal equilibrium***

Bond, Andrei Frolov, Zhiqi Huang, Kofman 09



linear regime of zero-modes:

$\phi_0(t+T) = \phi_0(t)$

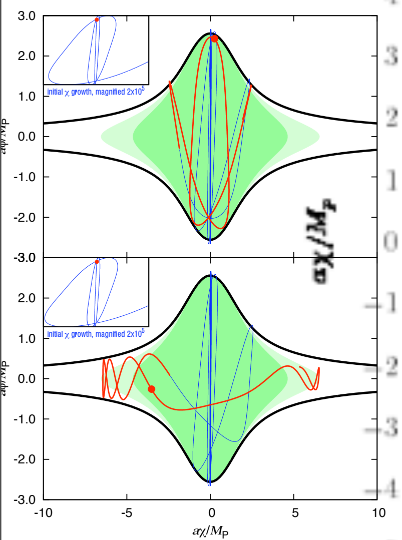
$\chi_0(t+T) = \chi_0(t)\exp[\mu_0 T]$

$\Rightarrow$ ***spikes are log χ_i spaced***

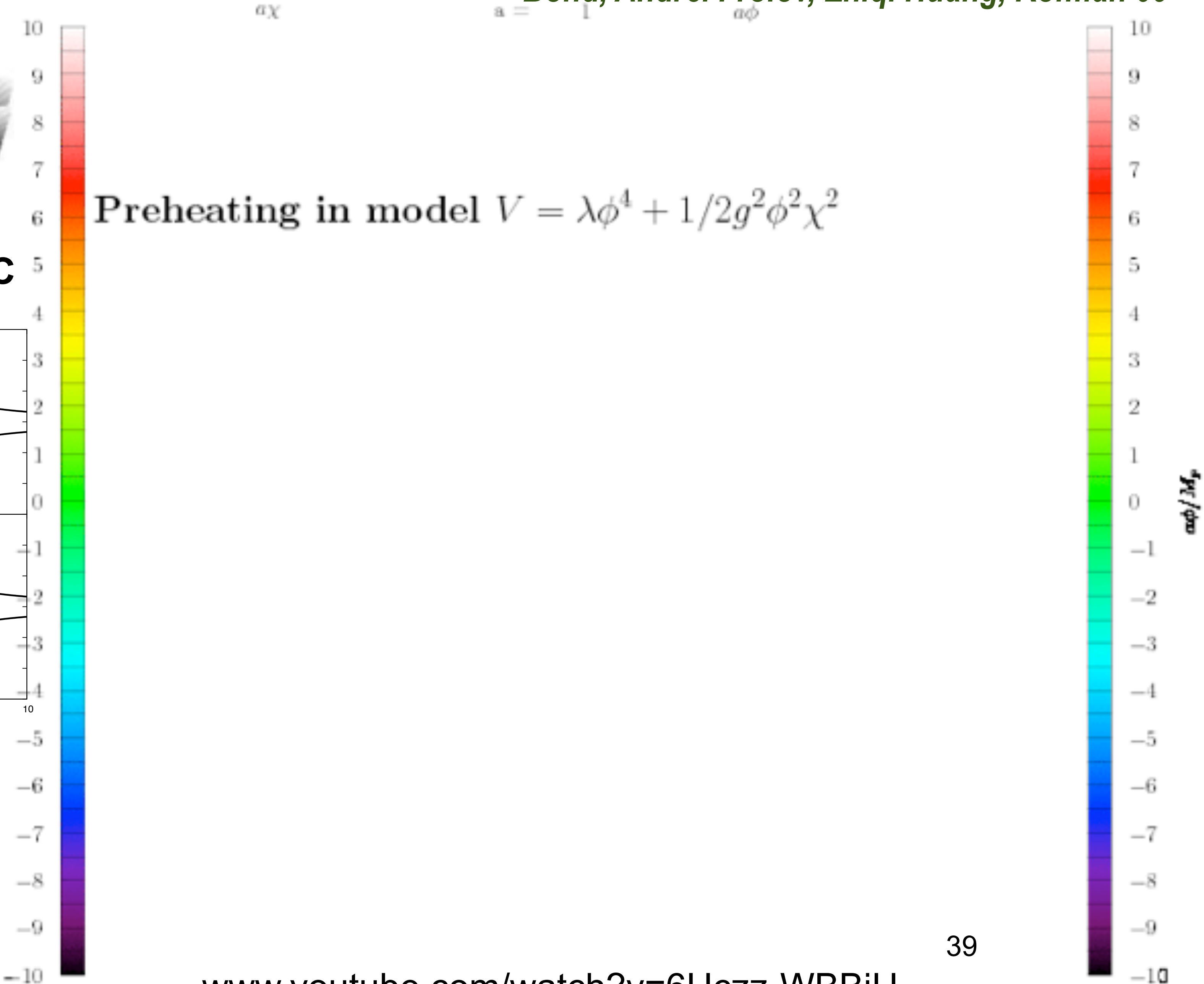
Cosmic Chaotic Billiards: NonGaussianity from Parametric Resonance in Preheating

Bond, Andrei Frolov, Zhiqi Huang, Kofman 09

non-spike IC



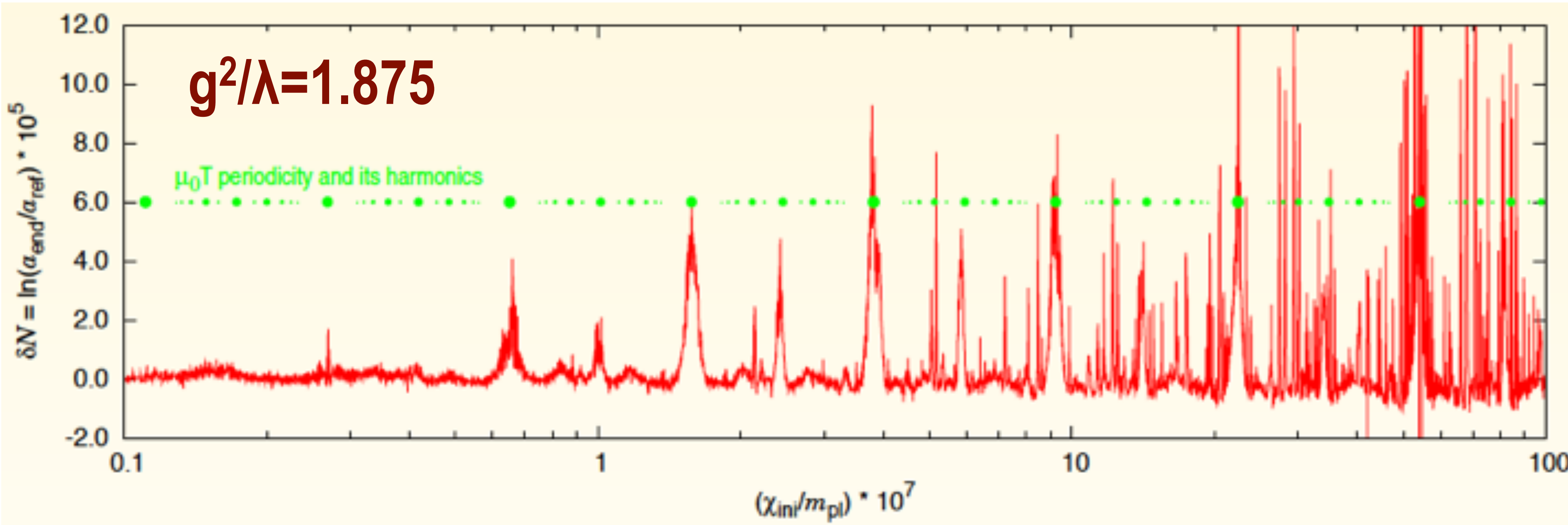
spike IC



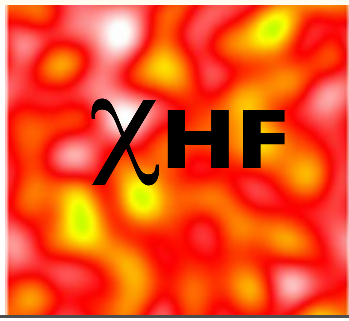
www.youtube.com/watch?v=6Uczz-WBBjU

curvature $F_{NL}(\chi(x,t))=\delta \ln a|_H\,(\chi_i)$

highly nonlinear function of a Gaussian random 'isocon' field



$\chi(x,t)=$



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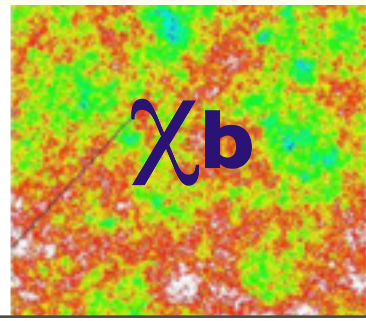
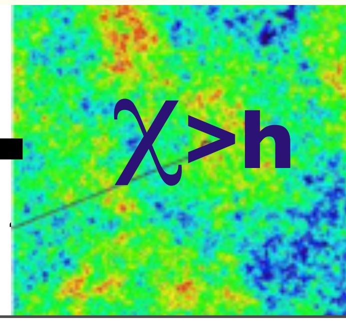
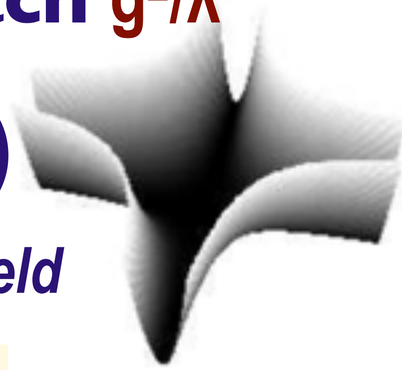


+

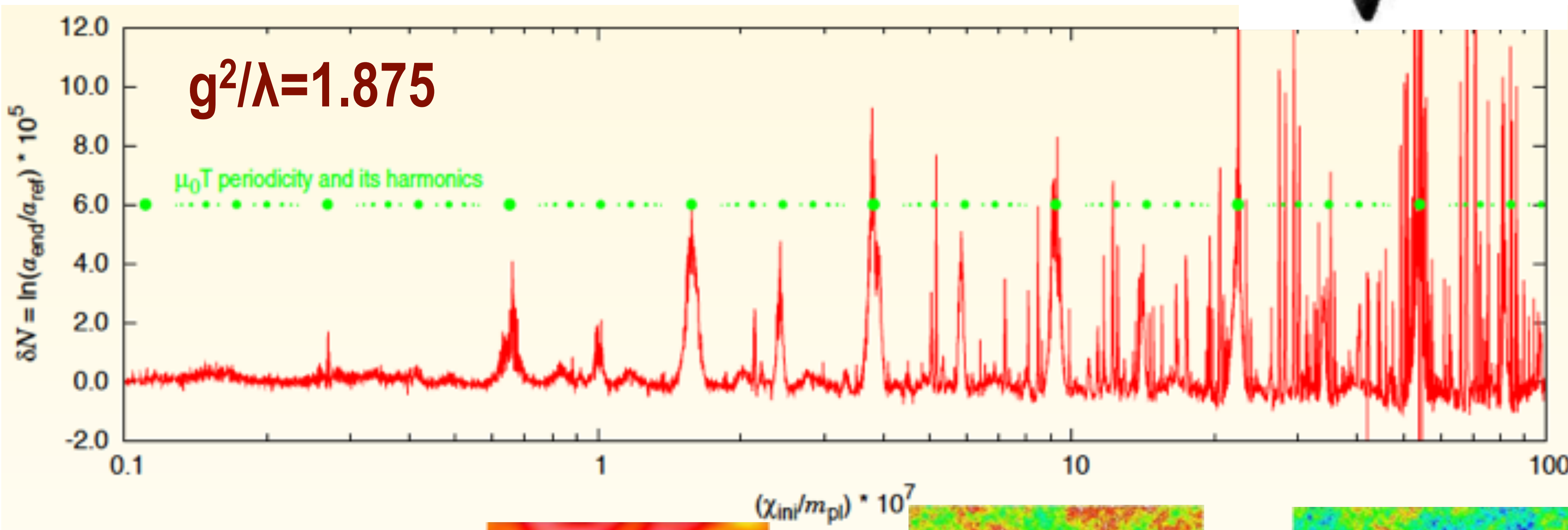


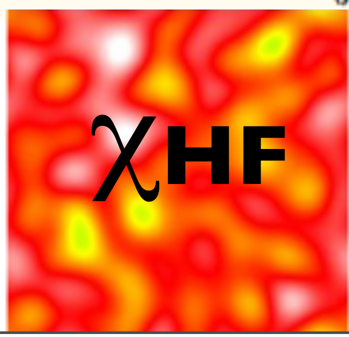
to develop the $\ln a(\chi_i)$ response curve, we perform > 10^4 lattice simulations for each g^2/λ

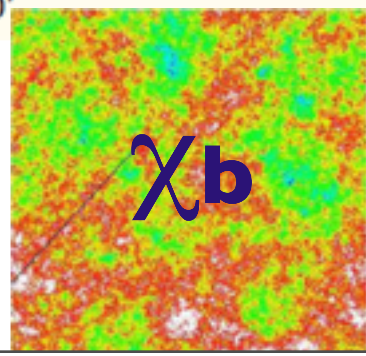


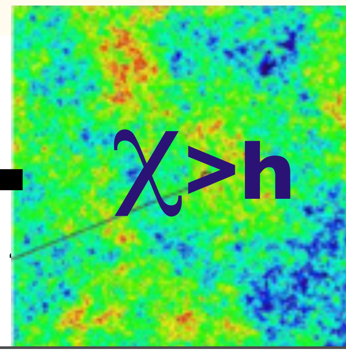
curvature $F_{NL}(\chi(x,t)) = \delta \ln a|_H (\chi_i)$

highly nonlinear function of a Gaussian random 'isocon' field



$\chi(x,t) =$ 

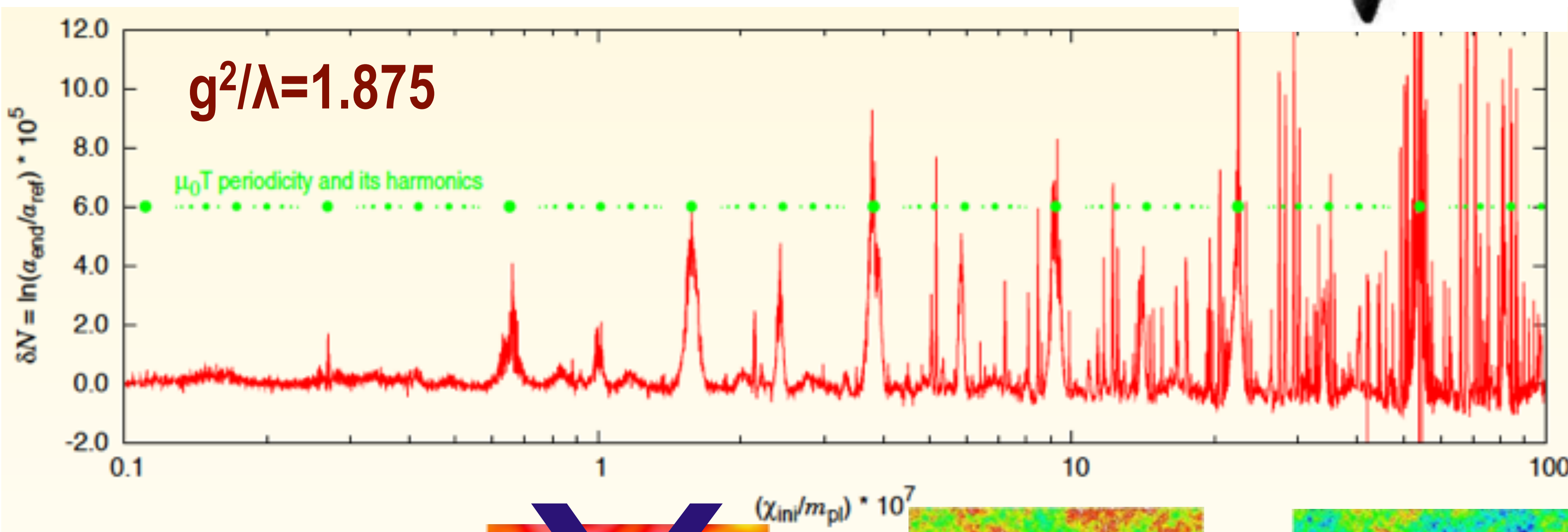
+ 

+ 

to develop the *ln*a(χ_i) response curve, we perform > 10^4 lattice simulations for each g^2/λ

curvature $F_{NL}(\chi(x,t)) = \delta \, ln a|_H (\chi_i)$

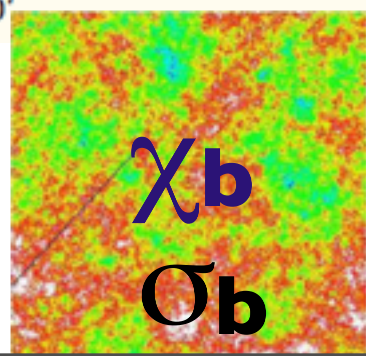
highly nonlinear function of a Gaussian random 'isocon' field



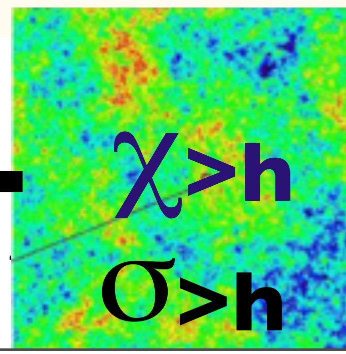
effective field theory

$\chi_{eff}(x,t) =$

\+

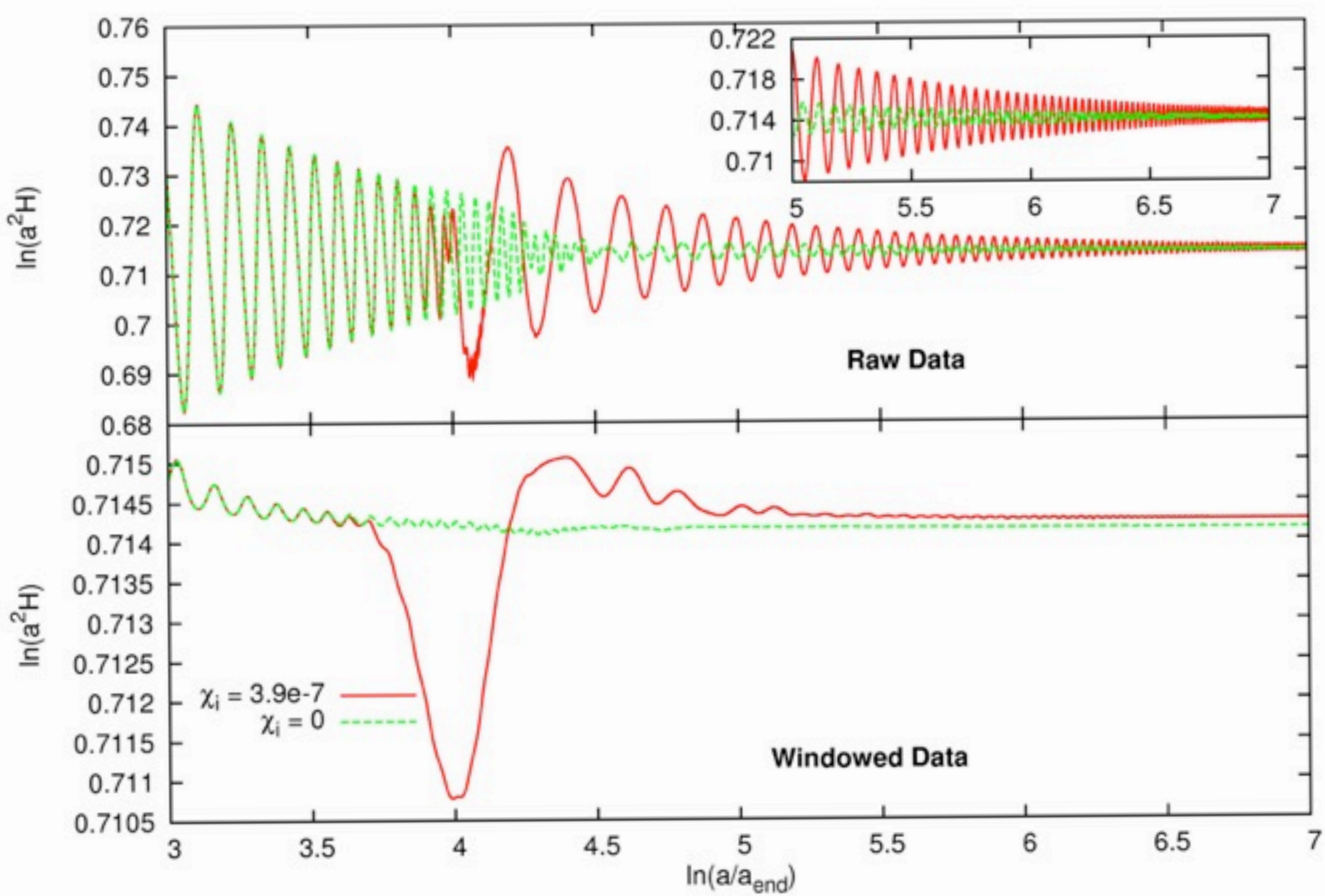


\+

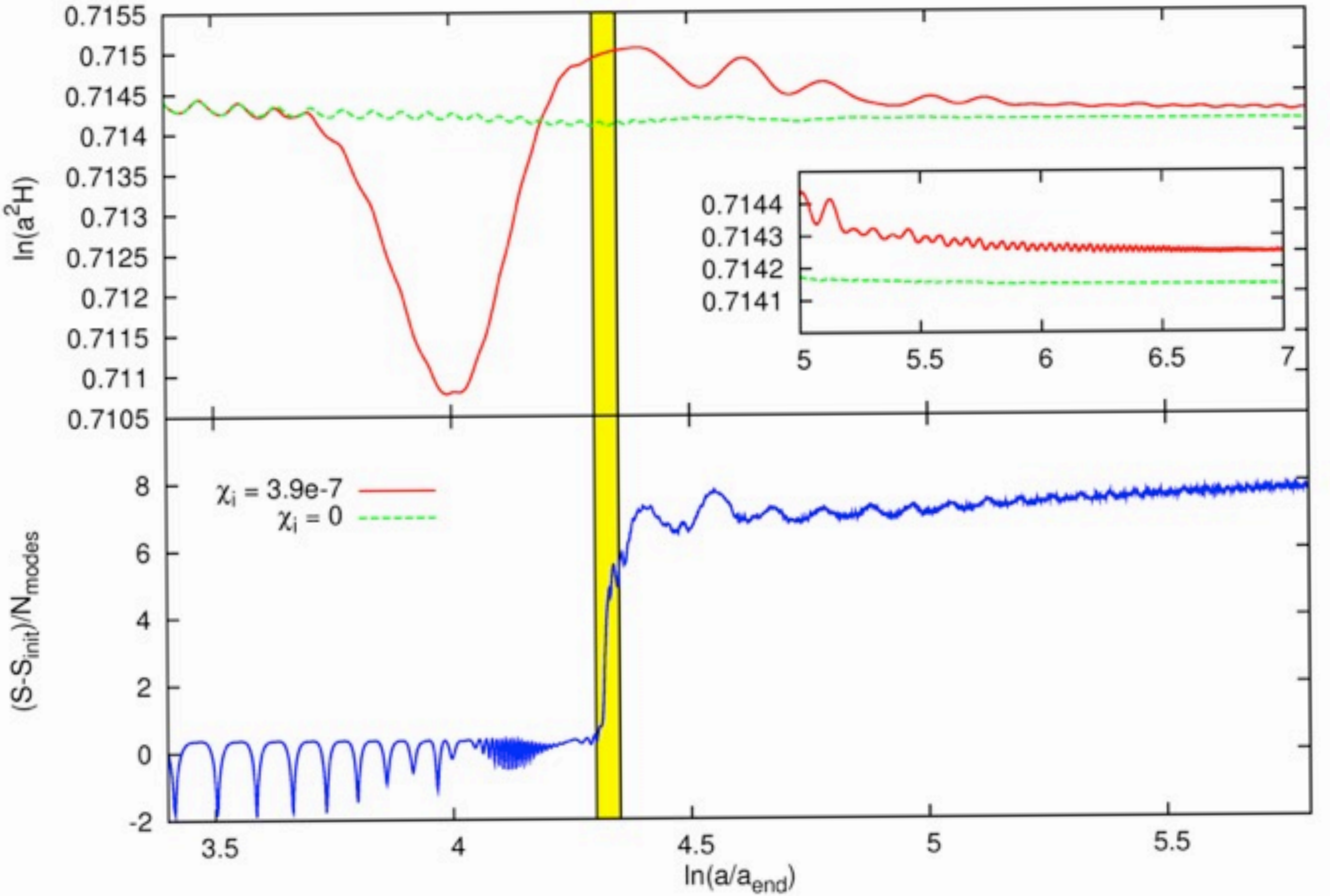


field smoothing over χ_{HF}

Relation to Nongaussianities smooth in time over oscillations gives EOS change ρa^4



Relation to Nongaussianities EOS change ρa^4 near the entropy jump



Conclusions

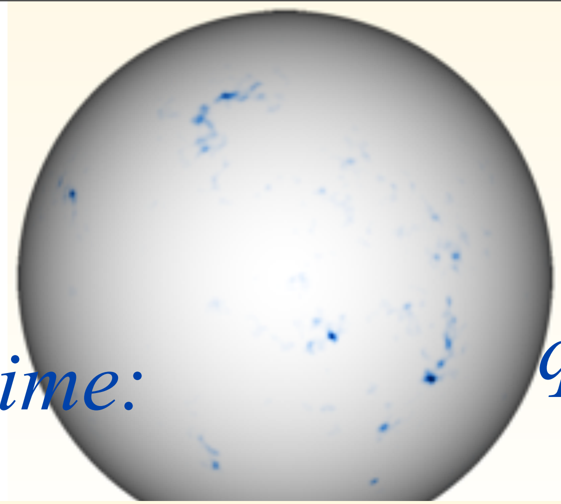
New language for preheating: a shock-in-time
= randomization front, an efficient entropy source

Spatial block RG smoothing indicates that PDF's of fluctuations around local values evolve slowly post-shock

Observable features such as nongaussianities should be encoded in the spatial structure of the shock-in-time, characterized by $\ln a_{shock}/a_{end}$ & the mediation width

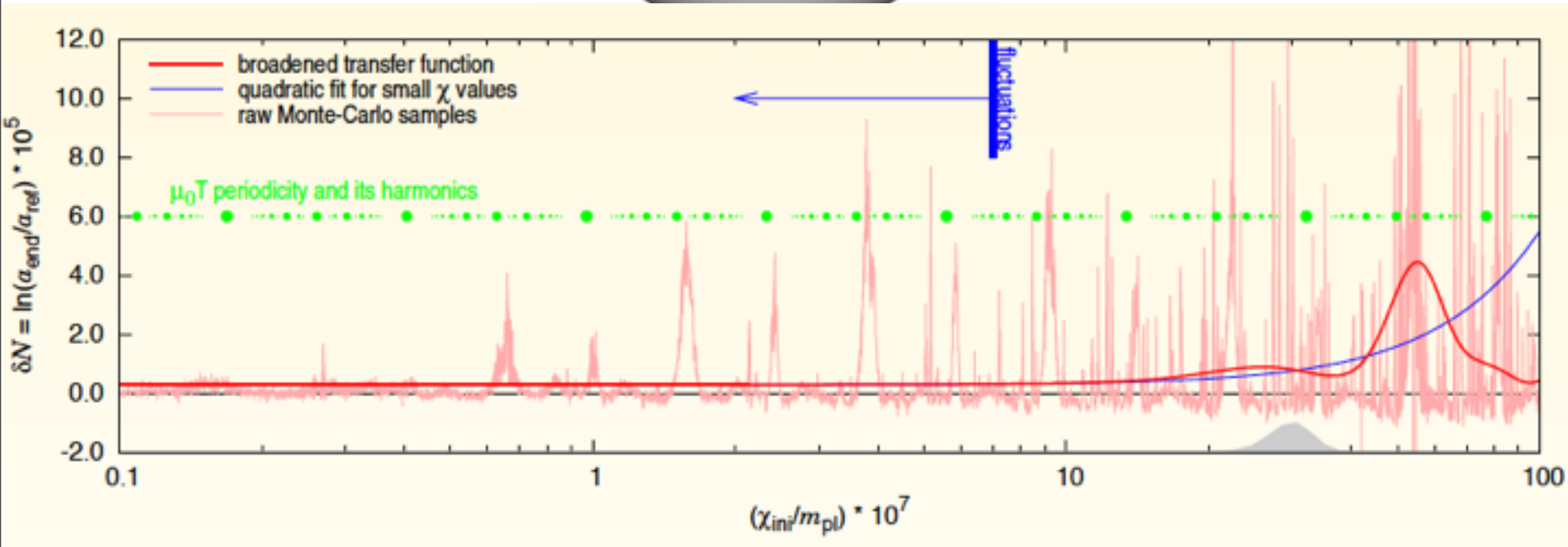
TBD: solidify the case for nongaussian structure encoded in the spatial inhomogeneity of the shock-in-time & determine the parameter dependence of it, and thus the variety of nonG that can arise. constrain/detect with Planck

end

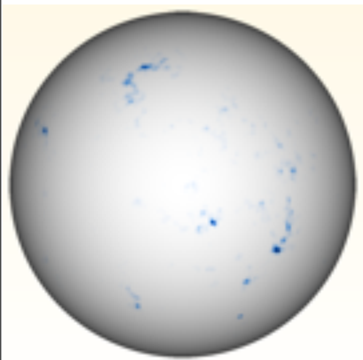


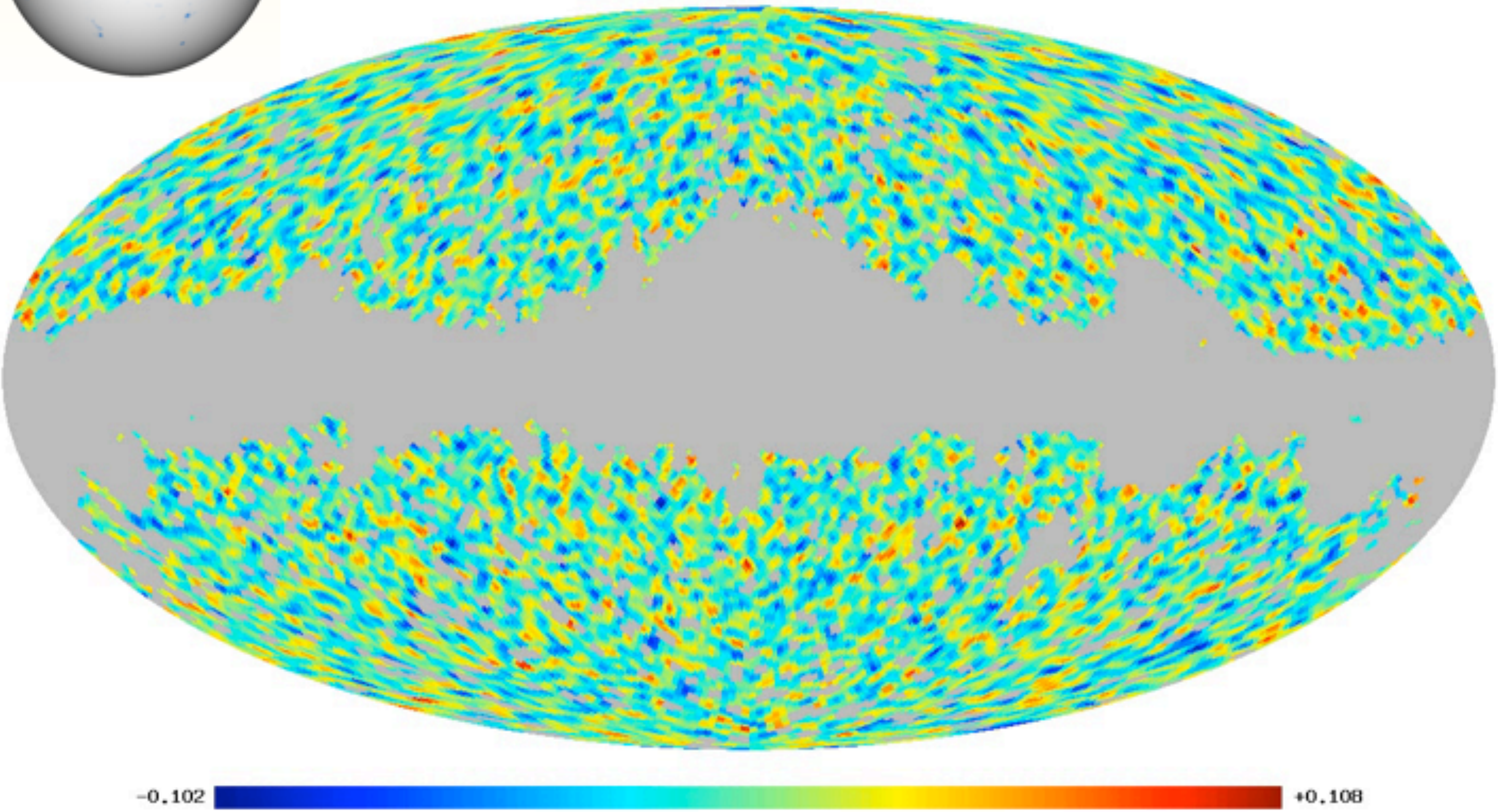
large-ish χ>h regime:

*quadratic+**cold spot***
"rare events"



CMB peaks (hot&cold) => the WMAP Cold Spot

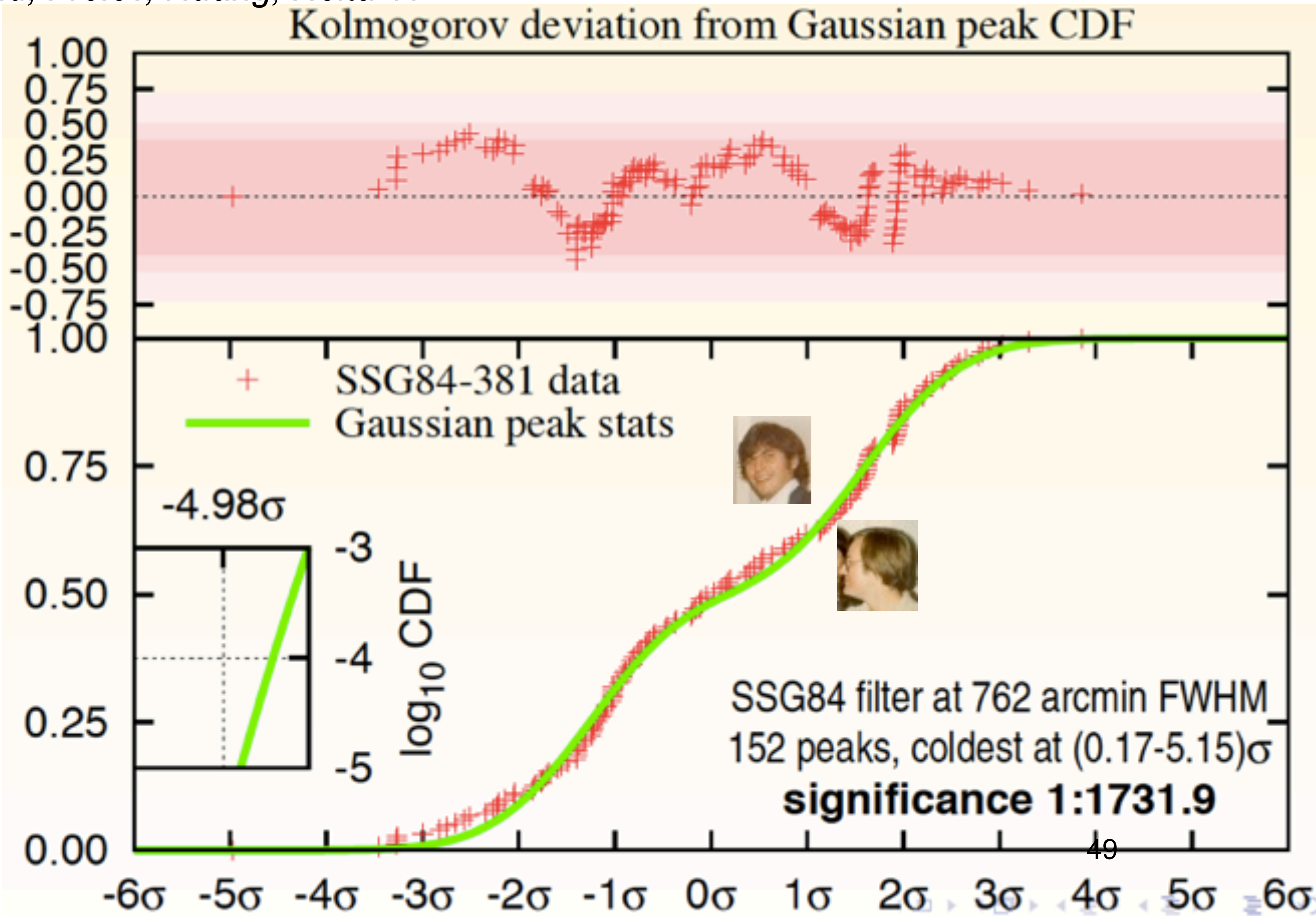




variable scale (SSG42) filtering sweep after pre-whitening the CMB signal (optimally weighting the signal is similar)

the WMAP Cold Spot: Vielva, Martinez-Gonzalez, Barr, Sanz, Cayon 2004 wavelets in WMAP1, ... Cruz etal 07 in WMAP3, & in WMAP5: needlets, steerable wavelets: ~4.5σ, others ~3σ; Zhang & Huterer 09, not as significant with other filters 20%

Bond, Frolov, Huang, Nolta 11



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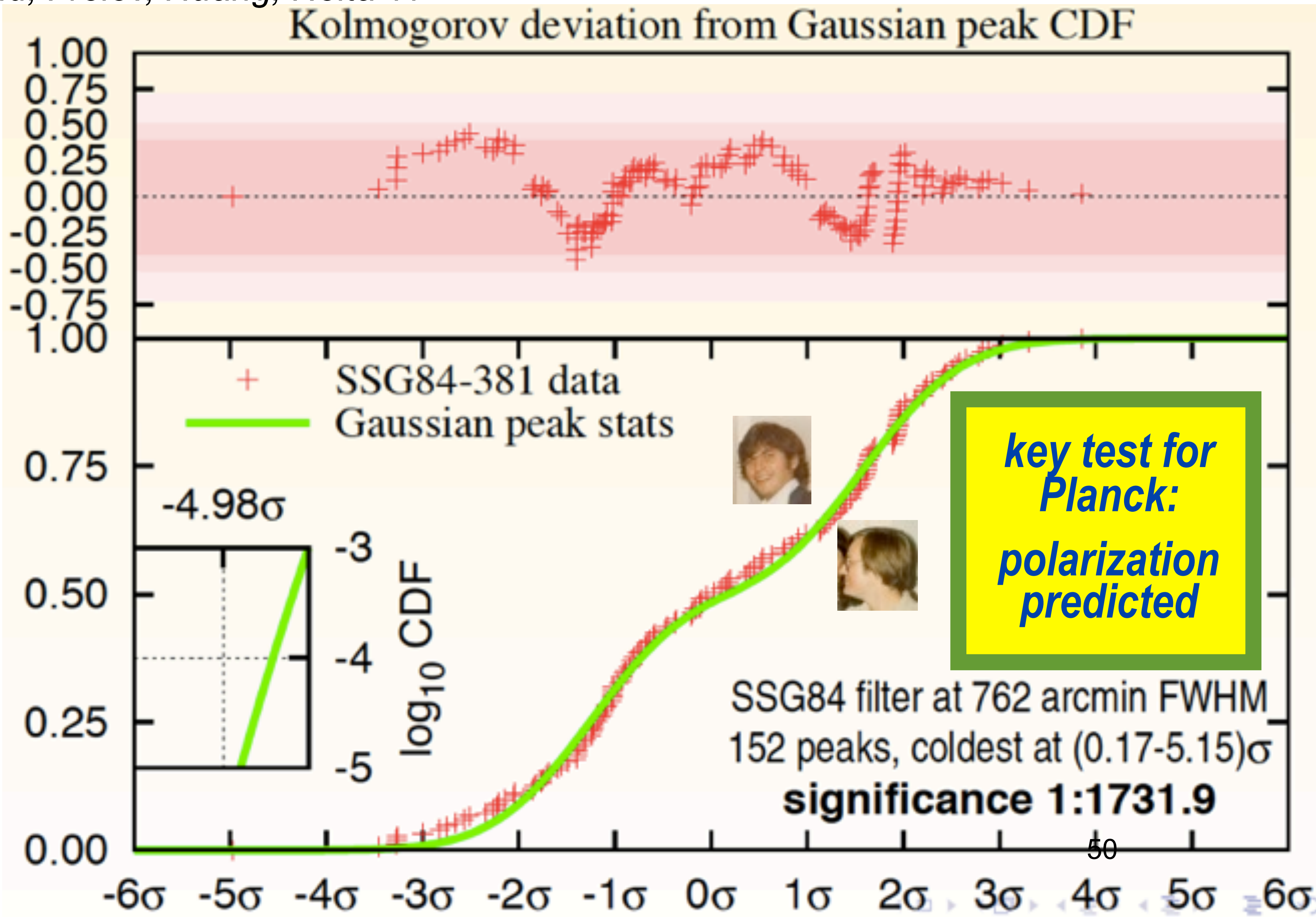
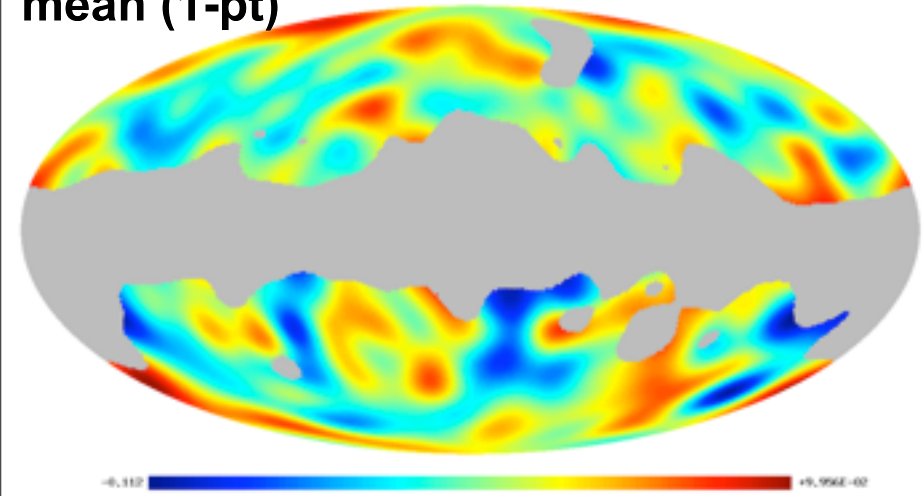
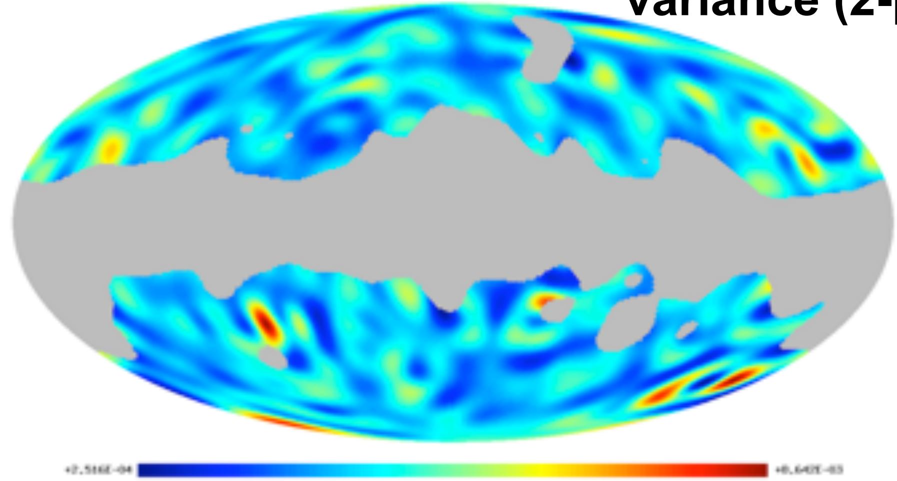


mean (1-pt)

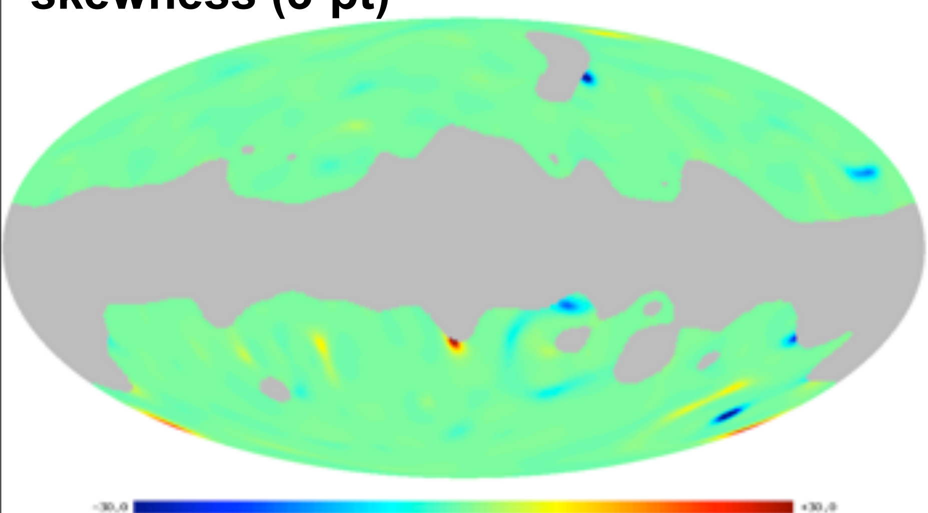


variance (2-pt)

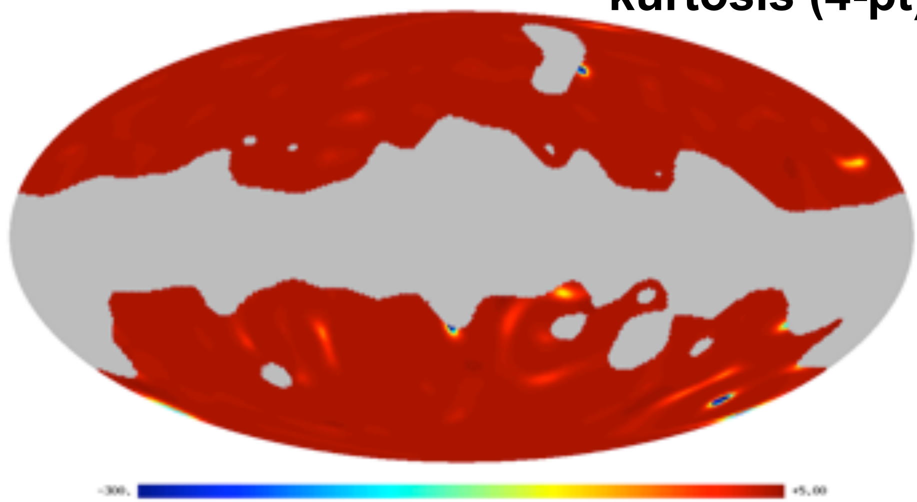


the WMAP Cold Spot dominates skewness (3-point) & kurtosis (4-point) maps

skewness (3-pt)



kurtosis (4-pt)



SSG84 381 arcmin HWHM filter-band maps, on scales where the cold spot is a maximum. the skewness & kurtosis are band-averages of the bispectrum & trispectrum. implications of intermittency for fNL determinations TBD?

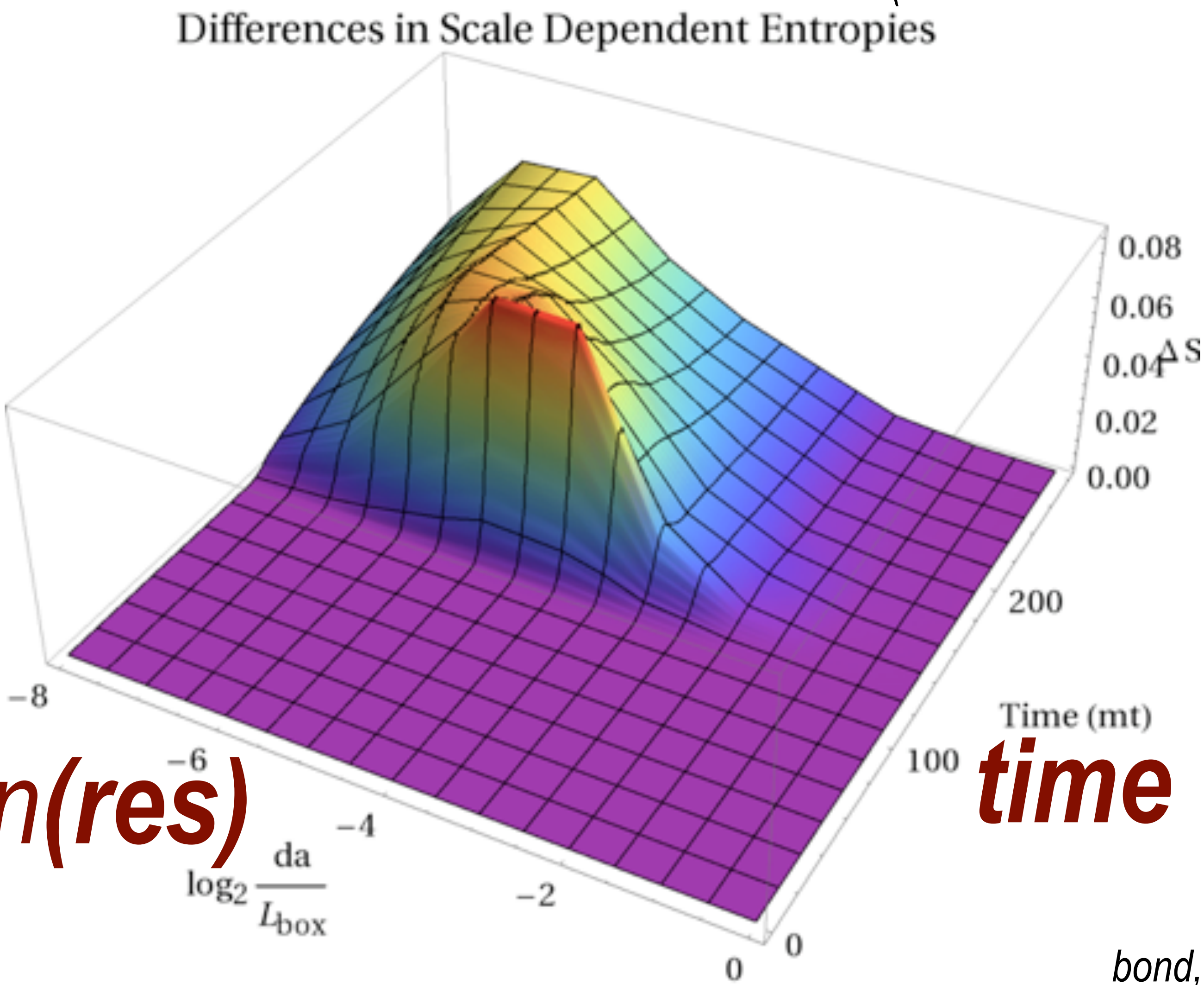
end

information content as a function of **scale** in the lattice ***=multi-scale entropy***

$$S(\text{res-scale}) = -\int dv\, \rho_s/E\,[\ln(\rho_s/E) - C], \text{ with } \int dv\, \rho_s/E = 1$$

ρ_S energy density smoothed on a hierarchy of resolutions

("Wilsonian renormalization group" block-smoothing)



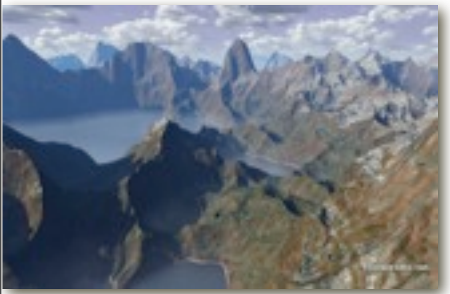
dS/dln(res)

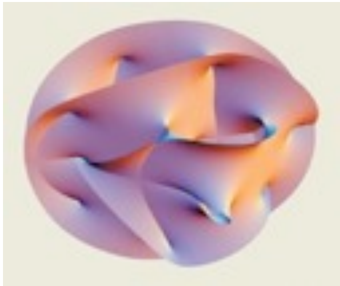
ln(res)

time *(m⁻¹ units)*

bond, jonathan ***braden*** *& frolov 2011*

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





The 'house' plays roulette as well as dice with the world.

New view: Theory prior = probability distribution on an energy landscape whose features are at best only glimpsed,

huge number of potential minima, inflation the late stage flow in the low energy structure toward these minima. Critical role of collective coordinates in the low energy landscape:

Roulette inflation
Kahler moduli/axion

moving brane/antibrane separations (D3,D7)
moduli fields, sizes and shapes of geometrical structures such as holes in a dynamical extra-dimensional (6D) manifold approaching stabilization

Balasubramanian, Berlund, Conlon, Quevedo, · · ·

Bond, Kofman, Prokushkin,Vaudrevange 2007, *Roulette Inflation with Kahler Moduli and their Axions*

Barnaby, Bond, Huang, Kofman, hep-th/0909.0503, *Preheating after Modular Inflation*

theory prior ~ probability of trajectories given potential parameters of the collective coordinates X probability of the potential parameters X probability of initial conditions

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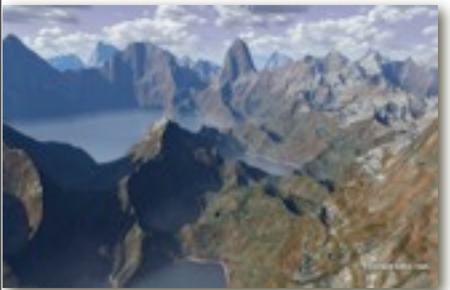

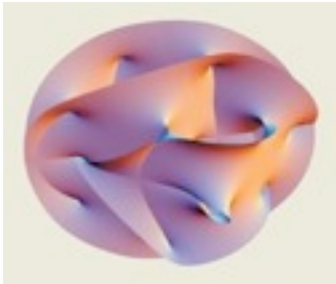

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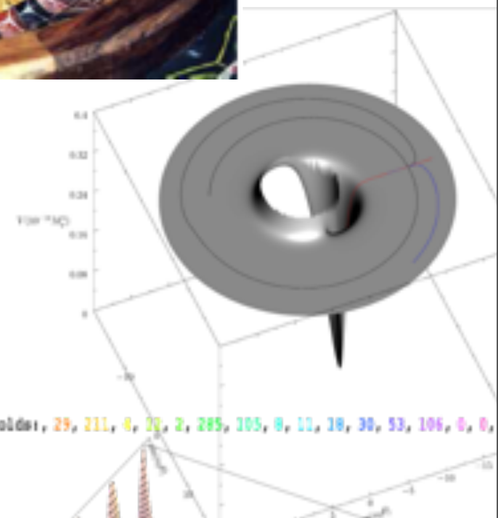

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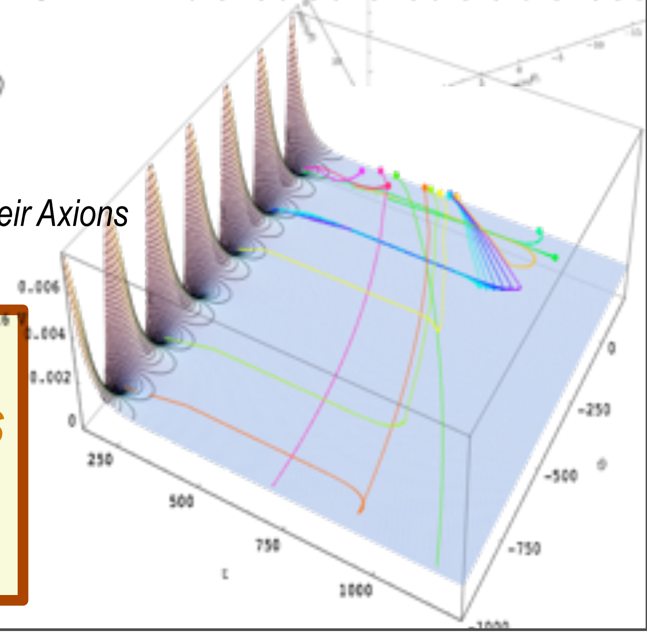

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Barnaby, Bond, Huang, Kofman 2009

Preheating After Roulette Inflation

pre-heating patch (<1cm)

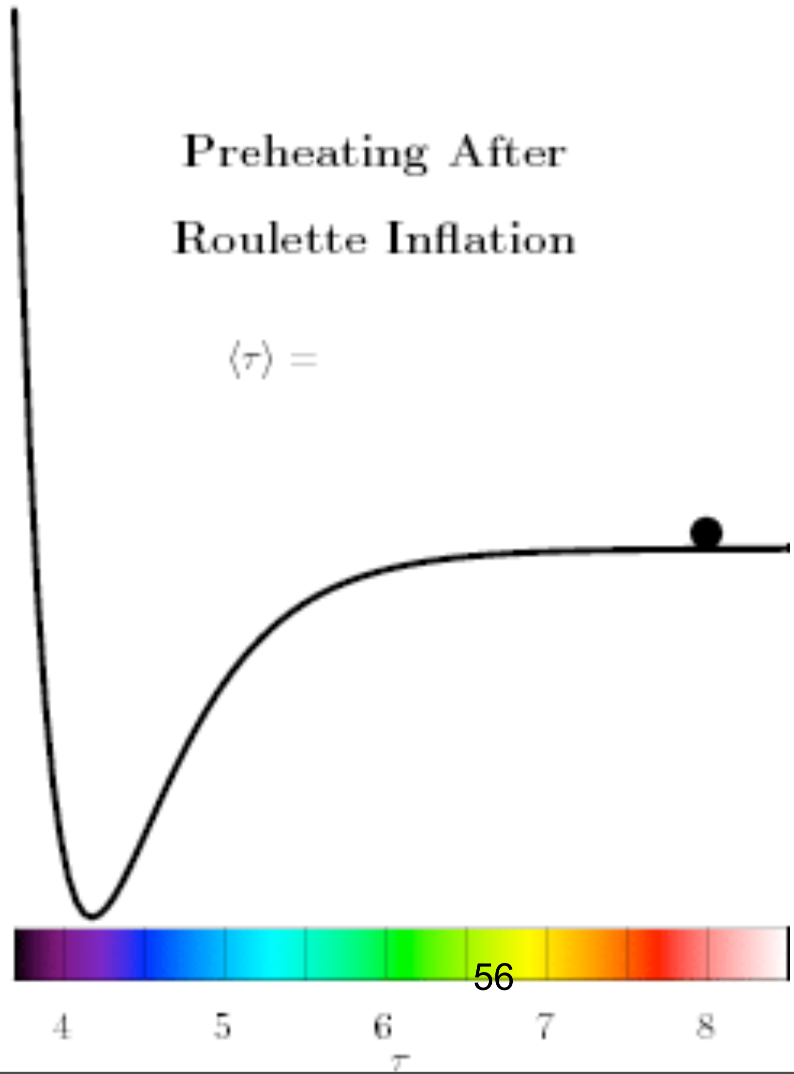
HLattice code: arbitrary number of fields, hybrid symplectic, to ~ trillionth accuracy!

Huang 2011 added full metric back action

$a =$ 1

A visualized 2D slice

in lattice simulation



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

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

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

primordial non-Gaussianity

$F(x) = F_G(x) + \mathbf{f_{NL}}\, (F_G^2(x) - \langle F_G^2 \rangle)$ local

smooth

DBI inflation: non-quadratic kinetic energy

cosmic/fundamental strings/defects

from end-of-inflation & preheating

$F(x) = F_G(x) + F_{NL}(\chi_b) - \langle F_{NL} \rangle$

resonant preheating

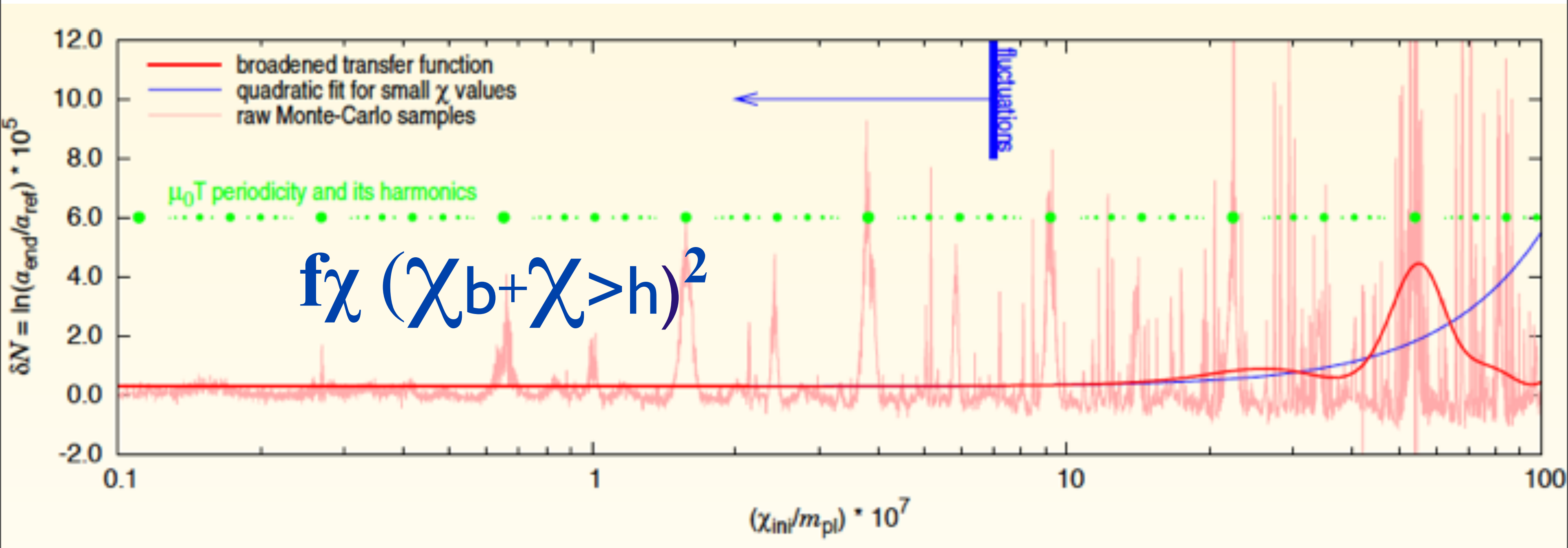
+ subdominant

isocurvature, cosmic string,

& fgnds, tSZ,kSZ, ...

field smoothing over χ_{HF} over ~50 e-folds of HF structure

$< F_{NL} | \chi_b + \chi_{>h} >$

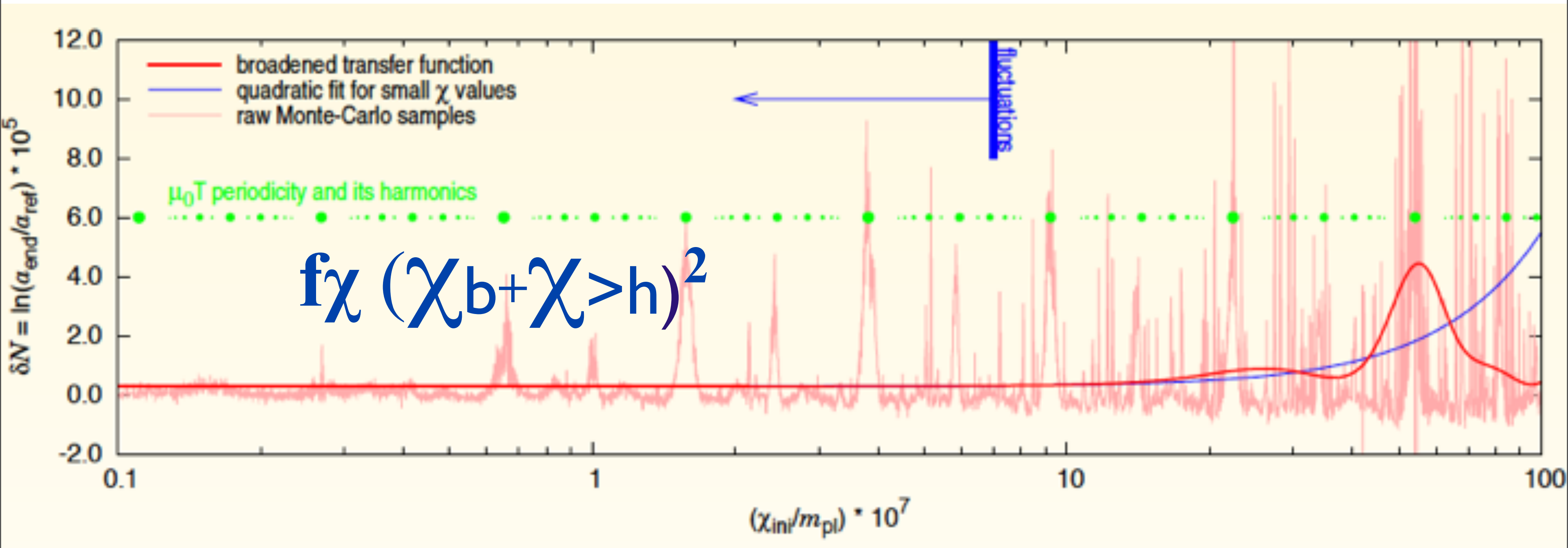


$f_\chi \, (\chi_b + \chi_{>h})^2$

field smoothing over χ_{HF} over ~50 e-folds of HF structure

$$< F_{NL} | \chi_b + \chi_{>h} > \; \sim \beta(\chi_{>h})\, \chi_b + f(\chi_{>h})\, \chi_b^2 + \ldots$$

cf. $F(x) = F_G(x) + f_{NL}\, F_G^2(x)$



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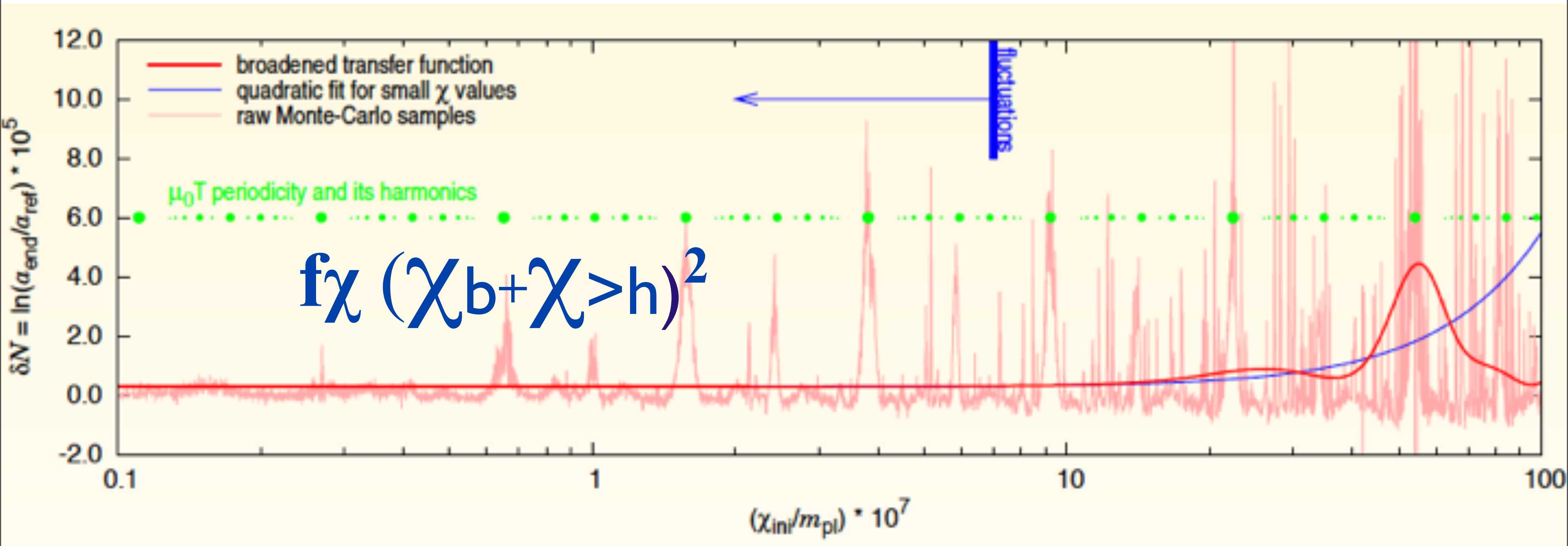

$f_{NL}^{equiv} = \beta^2 f_\chi\, [P_\chi/P_\phi]^2(k_{pivot})$

=> constrain $f_\chi^3\, \chi_{>h}^2$ ($P_\chi/P_\phi \sim 2\varepsilon$ => *relaxed limit*)

field smoothing over χ_{HF} over ~50 e-folds of HF structure

$$< F_{NL}|\chi_b+\chi_{>h} > \sim \beta(\chi_{>h})\,\chi_b + f(\chi_{>h})\,\chi_b^2 + \ldots$$

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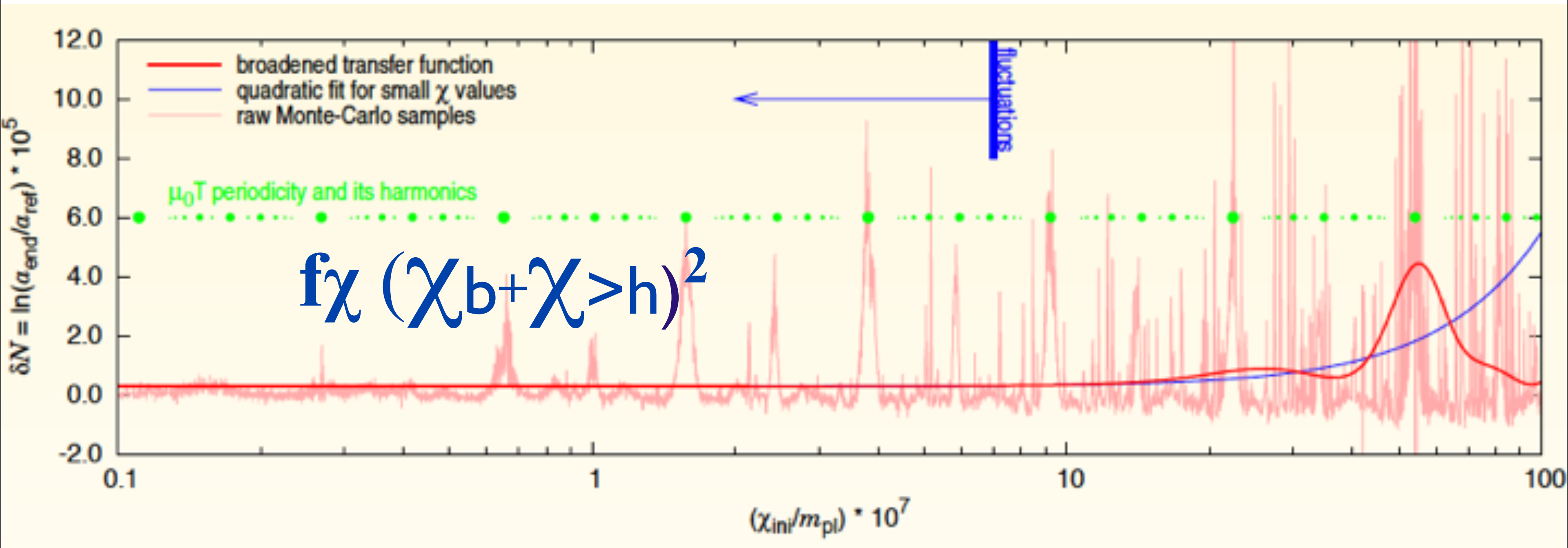
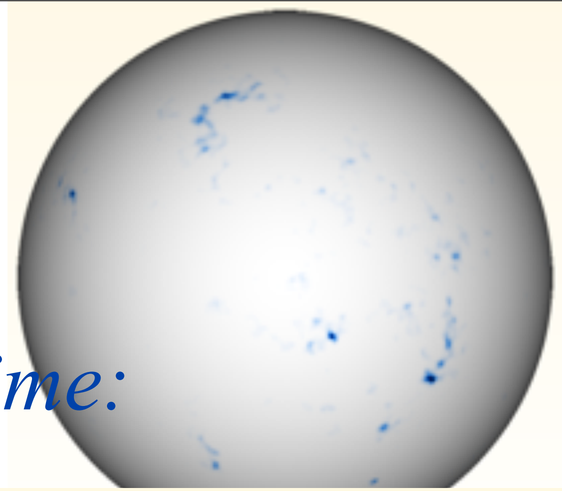
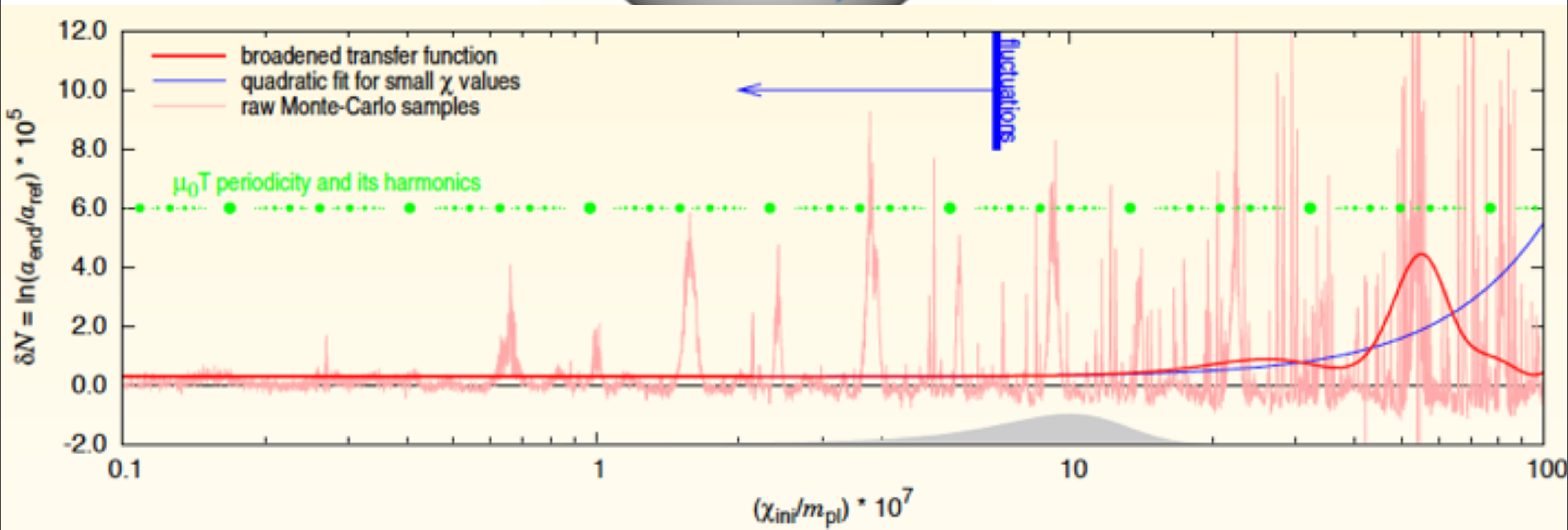


$f_\chi\,(\chi_b+\chi_{>h})^2$

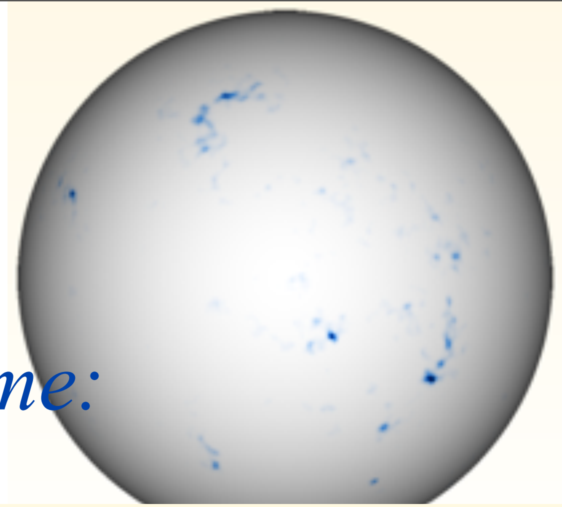
$f_{NL}^{equiv} = \beta^2 f_\chi\,[P_\chi/P_\phi]^2(k_{pivot})$ **-4< f_{NL}<80 WMAP5 (± 5 Planck)**

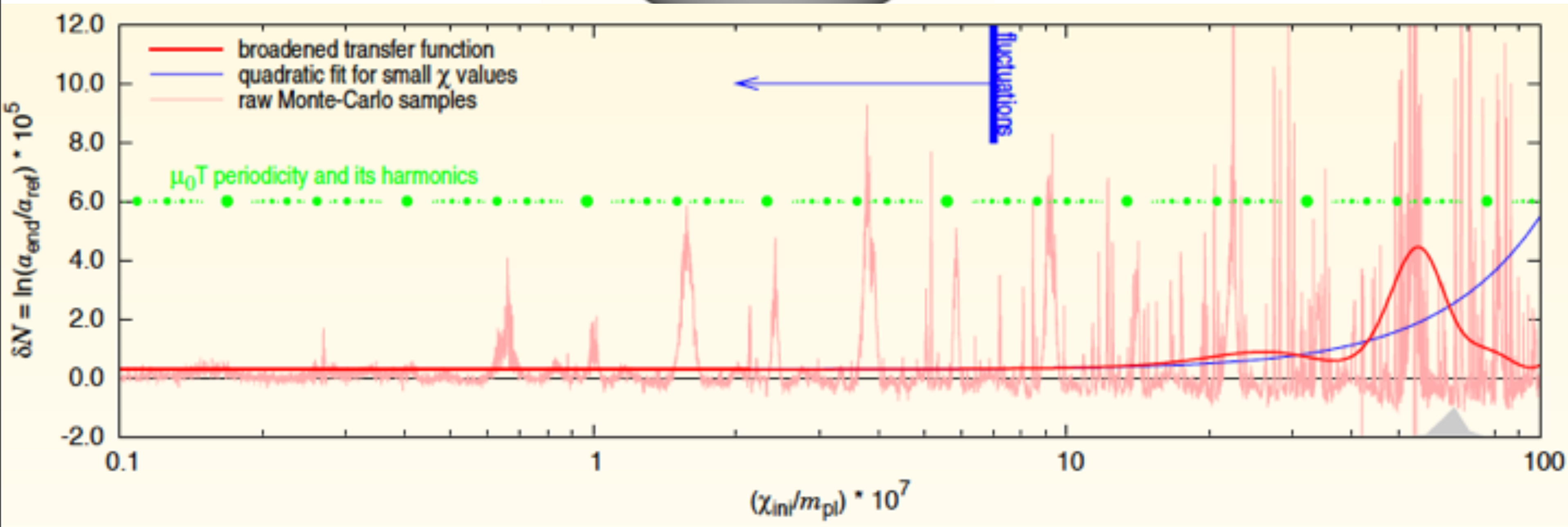
=> constrain $f_\chi^3\,\chi_{>h}^2$ ($P_\chi/P_\phi \sim 2\varepsilon$ => *relaxed limit*) *medium* χ>h *regime:*





large χ>h *regime:*





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

new parameters: **trajectory probabilities for early-inflatons & late-inflatons**

(partially) blind cf. informed "theory" priors

primordial non-Gaussianity

$F(x) = F_G(x) + \mathbf{f_{NL}}\,(F_G^2(x) - \langle F_G^2 \rangle)$ local

smooth

DBI inflation: non-quadratic kinetic energy

cosmic/fundamental strings/defects

from end-of-inflation & preheating

$F(x) = F_G(x) + F_{NL}(\chi_b) - \langle F_{NL} \rangle$

resonant preheating

$\ln P_s(\ln k)$ & $r(k_p)$

& $\ln P_t(\ln k)$

$\varepsilon_\phi \times 2/3 = 1 + w_{de}(a)$

$= - d\ln\rho_\phi / d\ln \mathbf{a}^3$

+ subdominant isocurvature, cosmic string,

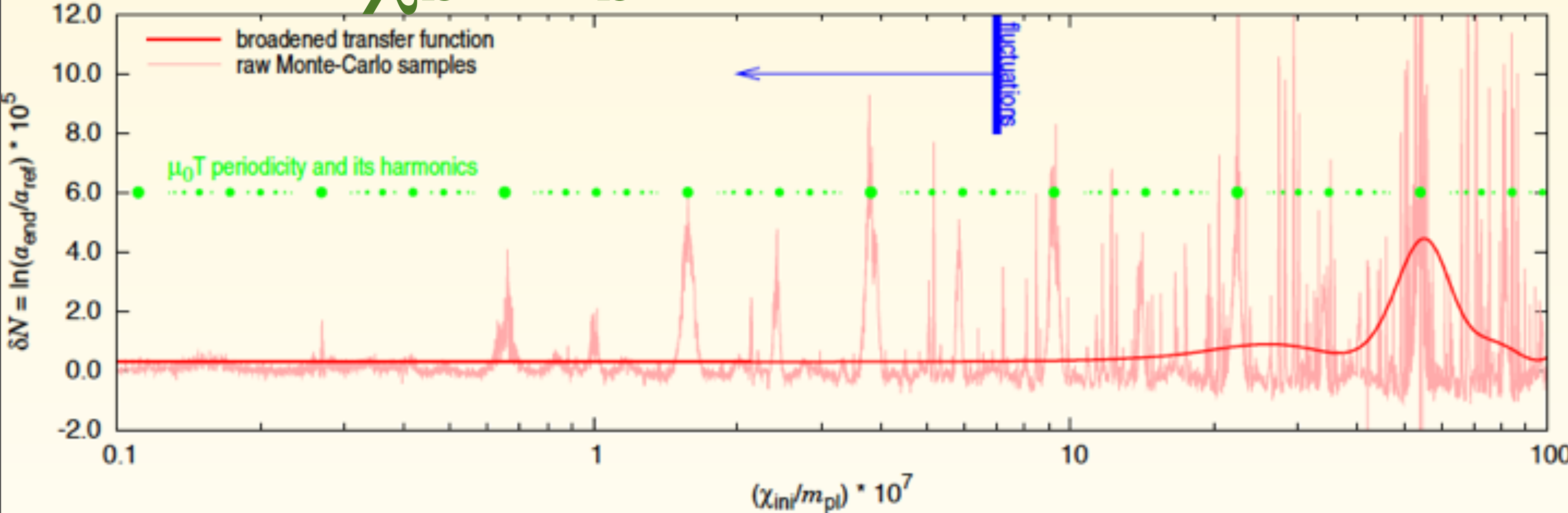
& fgnds, tSZ,kSZ, ...

field smoothing over χ_{HF} $\sigma_{HF} \sim 7\times10^{-7}$ ~50 e-folds

$P(\chi|\chi_{LF}) \sim \exp[-(\chi-\chi_{LF})^2 / 2\sigma_{HF}^2]$ $\Rightarrow < F_{NL}|\chi_b + \chi_{>h} >$

SSS χ_b: $\sigma_b \sim 5\times10^{-7}$ ~10 e-folds

LSS χ_b: $\sigma_b \sim 3\times10^{-7}$ ~10 e-folds



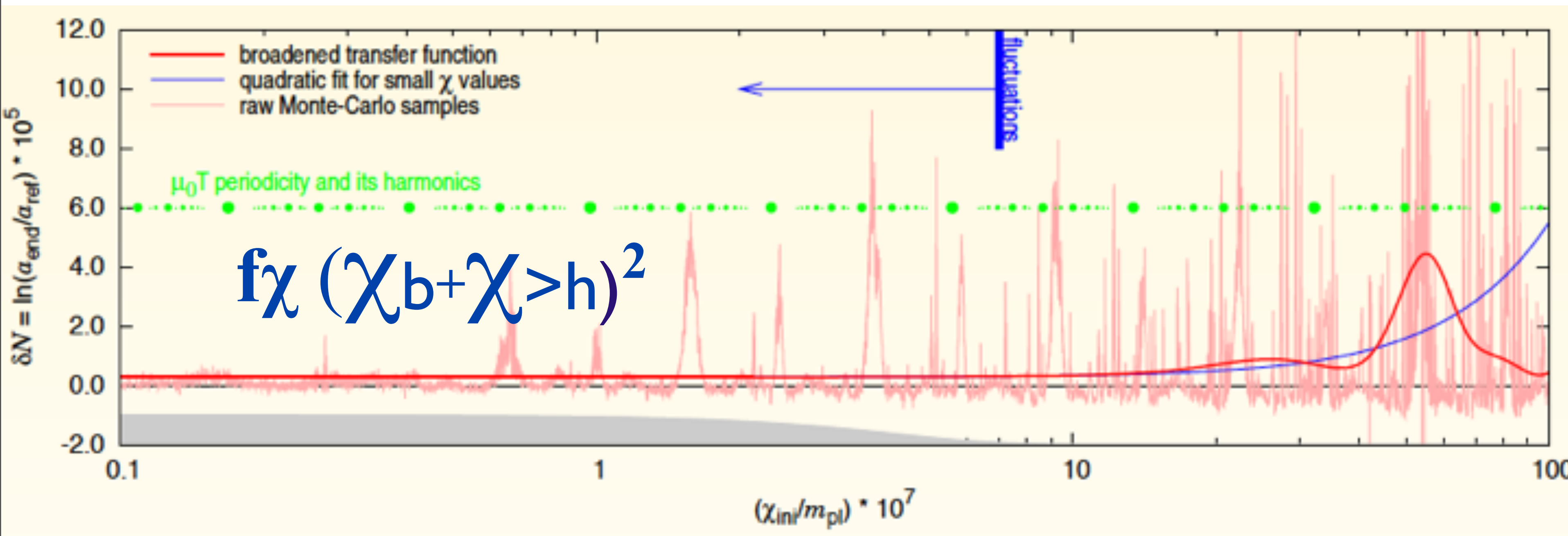
super-horizon $\chi_{>h}$: $\sigma_{>h} \sim N_{>h}^{1/2} \times 10^{-7}$ $N_{>h} \sim 10^2$-10^{4++}

"observed" $\chi_{>h}$ is a random throw of the dice $P(\chi_{>h}) \sim \exp[-\chi_{>h}^2 / 2\sigma_{>h}^2]$

local quadratic non-G constraint: $-4 < f_{NL} < 80$ WMAP5 (± 5-10 Planck1yr)

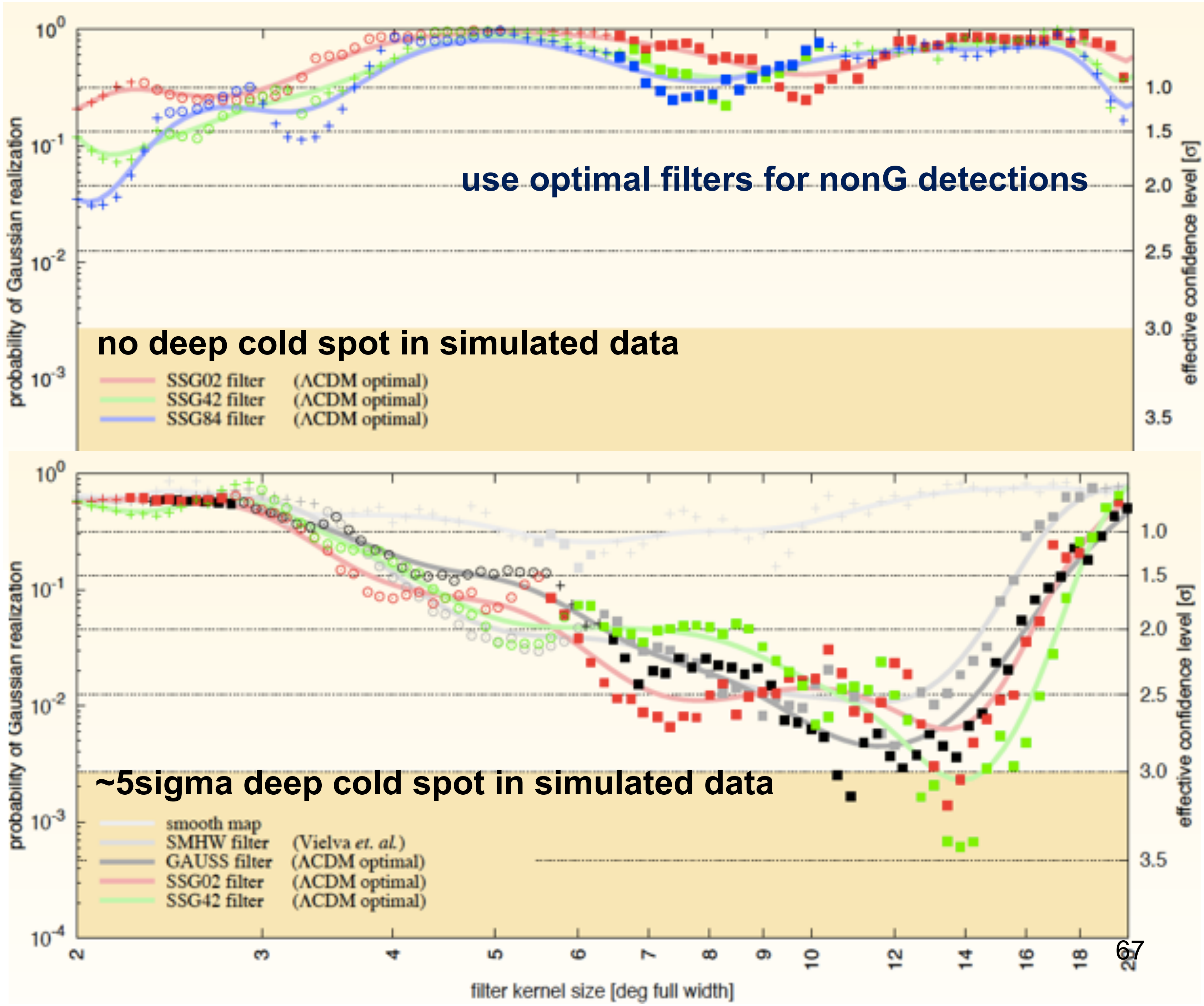
maps into (considerably relaxed) $< F_{NL} | \chi_b + \chi_{>h} >$ constraint

small $\chi_{>h}$ *regime:* $\beta = 2 f_\chi \chi_{>h}$ $f = f_\chi$



$f_{NL}^{equiv} = \beta^2 f_\chi [P\chi/P\phi]^2 (k_{pivot})$

$\Rightarrow$ constrain $f_\chi^3 \chi_{>h}^2$ *(*$P\chi/P\phi \sim 2\varepsilon \Rightarrow$ *relaxed limit)*


use optimal filters for nonG detections
no deep cold spot in simulated data
SSG02 filter (ΛCDM optimal)
SSG42 filter (ΛCDM optimal)
SSG84 filter (ΛCDM optimal)
~5sigma deep cold spot in simulated data
smooth map
SMHW filter (Vielva et. al.)
GAUSS filter (ΛCDM optimal)
SSG02 filter (ΛCDM optimal)
SSG42 filter (ΛCDM optimal)
probability of Gaussian realization
effective confidence level [σ]
filter kernel size [deg full width]