Lev Kofman Jun 17, 1957 - Nov 12, 2009

Ph.D 1984, Inst Ap & Atmos Phys, Tartu, Estonian Acad Sci & Landau Institute, Moscow. Advisor: Alexei Starobinsky

1987-90 Sr Fellow, 83-87 Fellow, Estonian Acad Sci, Tartu

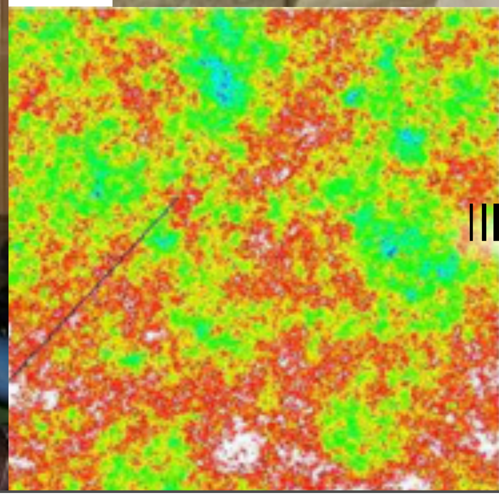
1987 Medal, Soviet Acad Sci in Phys <35

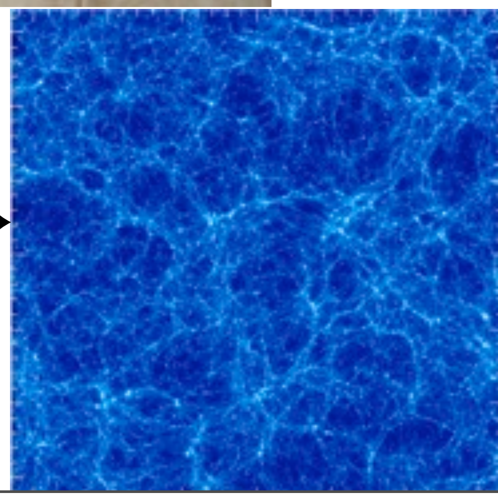
2008-09 CITA Acting Director
2006-08 CITA Associate Director
1998-2009 CITA & UofT Professor
CIFAR Fellow
1993-98 Inst for Astronomy, U of Hawaii, Associate Professor, CIFAR Associate
1992-93 CITA Sr RA, CIFAR Scholar
1992 Princeton U, Ap Sci, Lecturer
1991 CITA Postdoctoral Fellow

2007 Fellow American Physical Society
2006 Humboldt Award, Germany
2006 FInstPhys
1999 Ont Premier Research Excellence Award
1998 Fellow CIFAR
1993-98 Associate CIFAR
1992 Scholar CIFAR

Cosmic Sports with Lev Kofman:

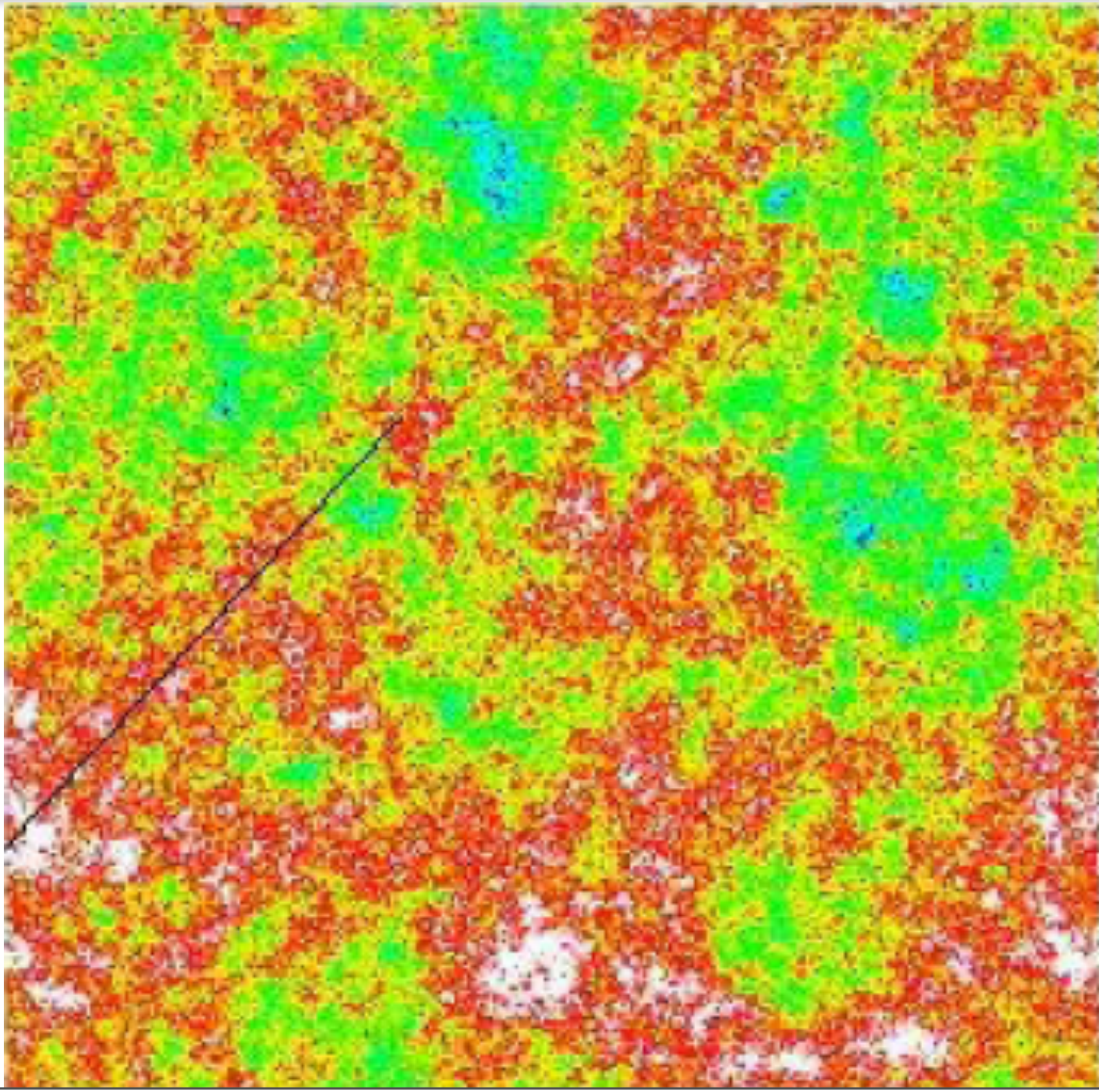
Early & Late U Inflation





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

χ



patterns in the quantum jitter evolve under gravity

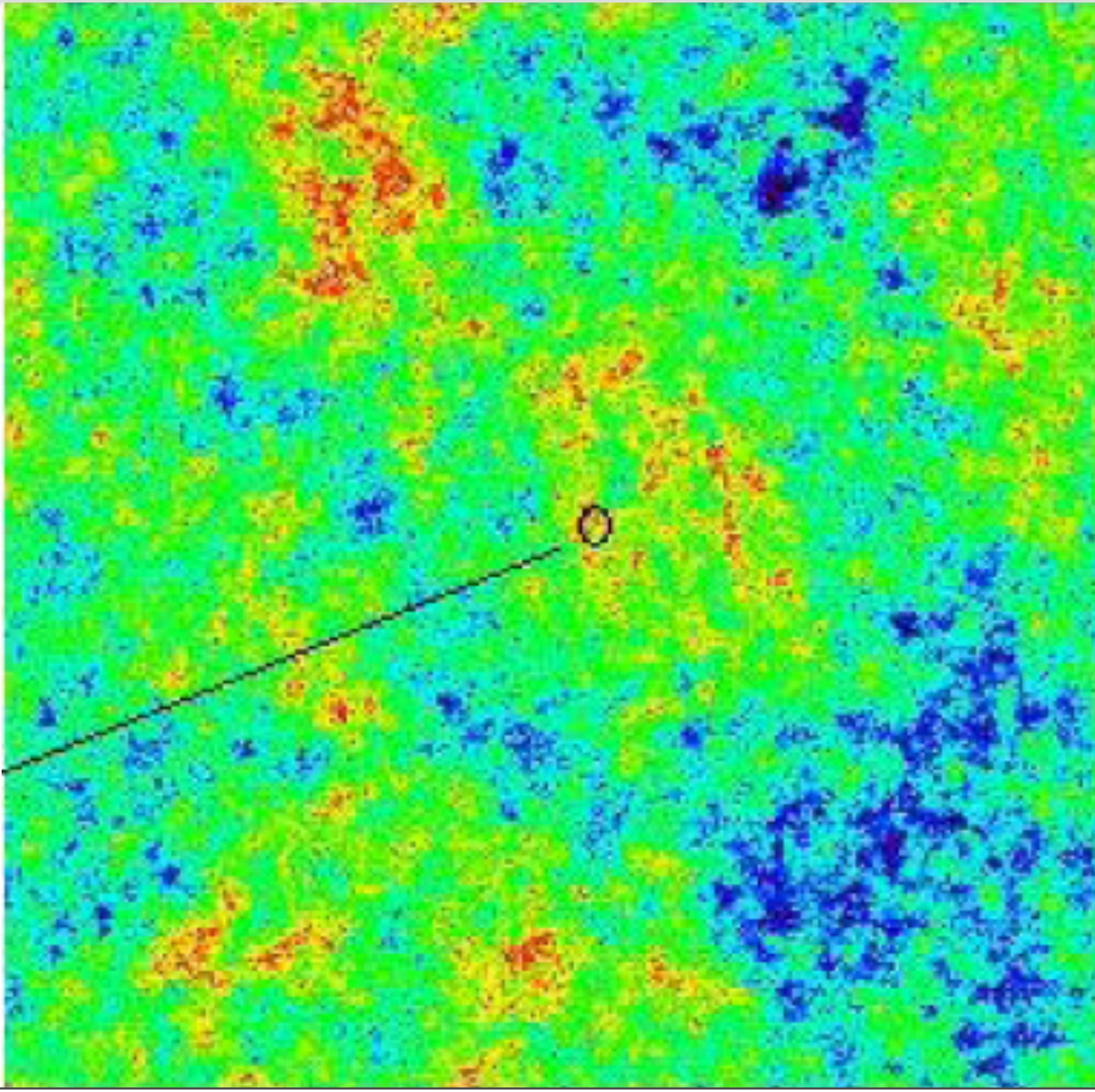
(& gas dynamics)

pre-heating patch (~1cm)

10 Gpc

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

χ



current Hubble patch ~10 Gpc

speed limit horizon

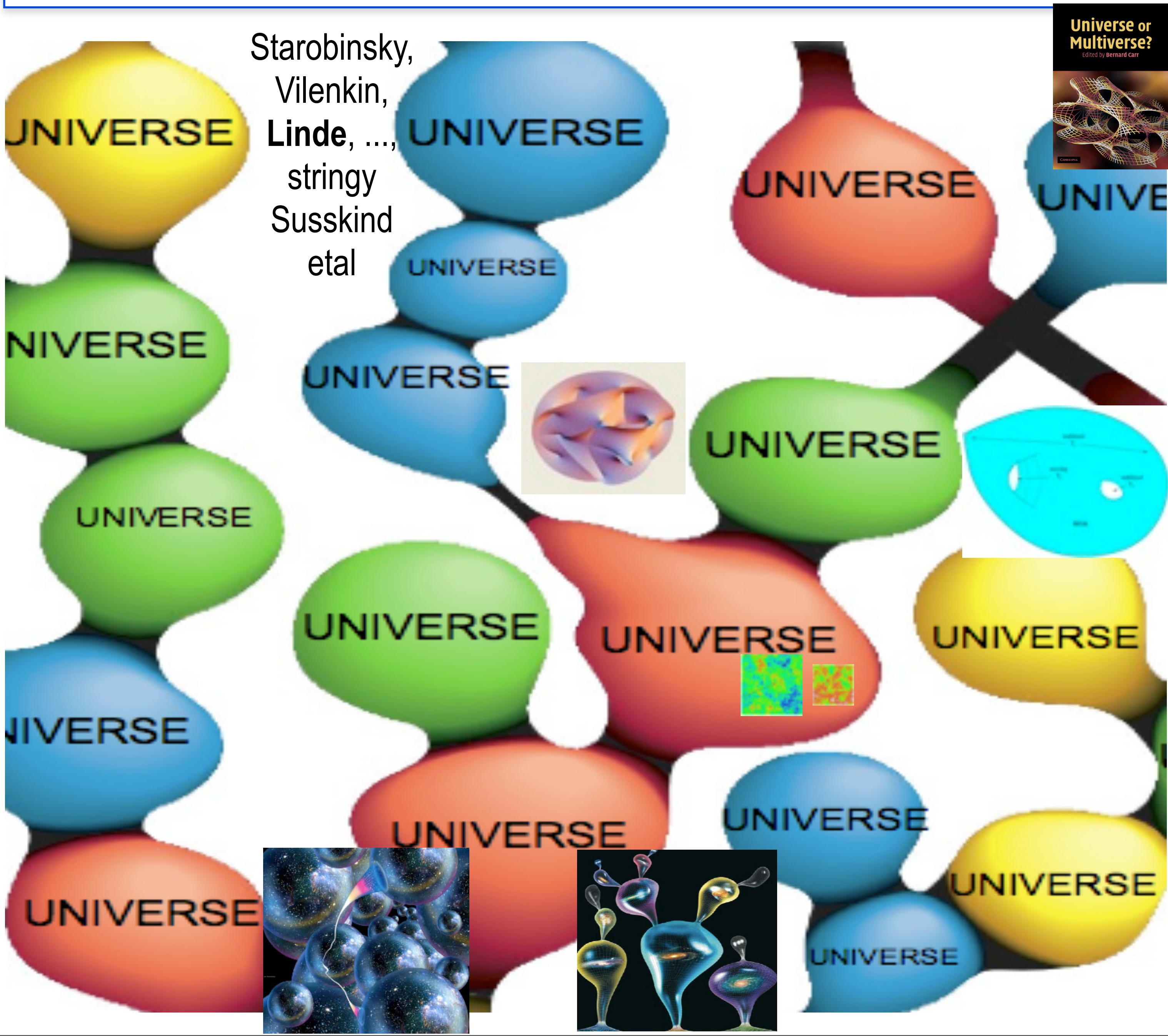
patterns in the quantum jitter evolve under gravity

(& gas dynamics)

1000 Gpc

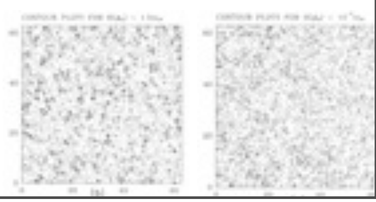
the **quantum stochastic non-G landscape** cf. the **stringy landscape**

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



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

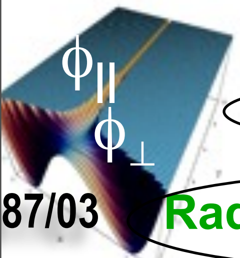
1980

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

Extended inflation

1990

Natural pNGB inflation

Hybrid inflation

KLS94 preheating

Assisted inflation

SUSY F-term inflation

SUSY D-term 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

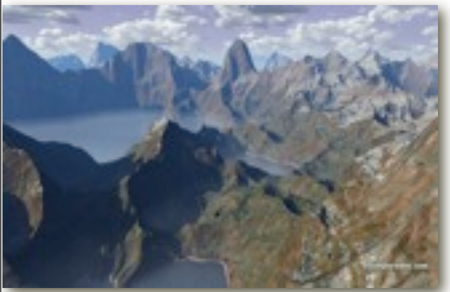
moduli fields

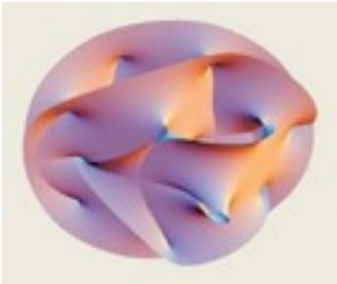
monodromy

Roulette inflation Kahler moduli/axion

fibre inflation

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





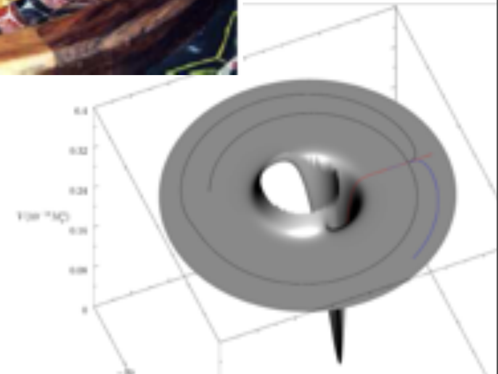
The 'house' plays roulette as well as dice with the world.

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:

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

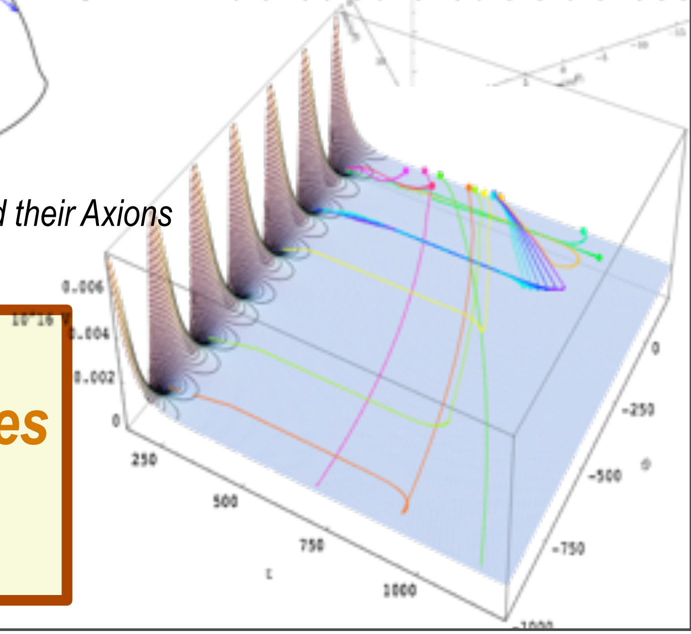
Roulette inflation
Kahler moduli/axion



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

Tuesday, June 8, 2010

Preheating After Roulette Inflation

pre-heating patch (<1cm)

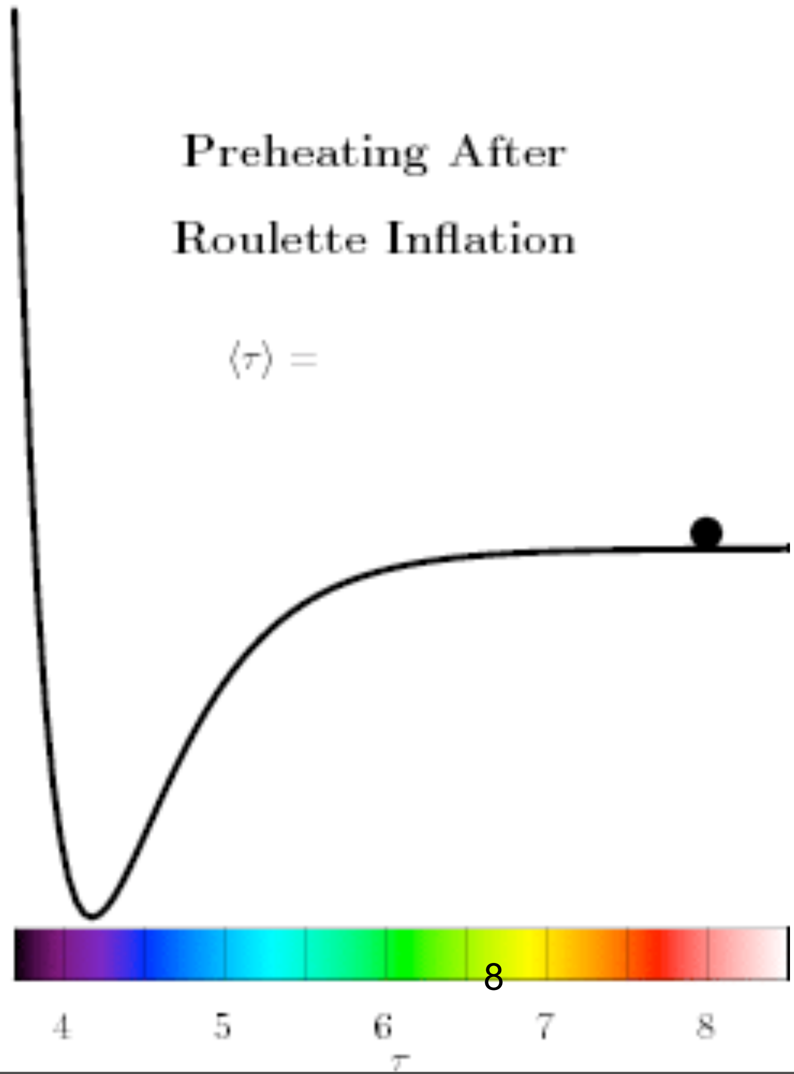
Barnaby, Bond, Huang, Kofman 2009

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

$a = \quad 1$

A visualized 2D slice

in lattice simulation

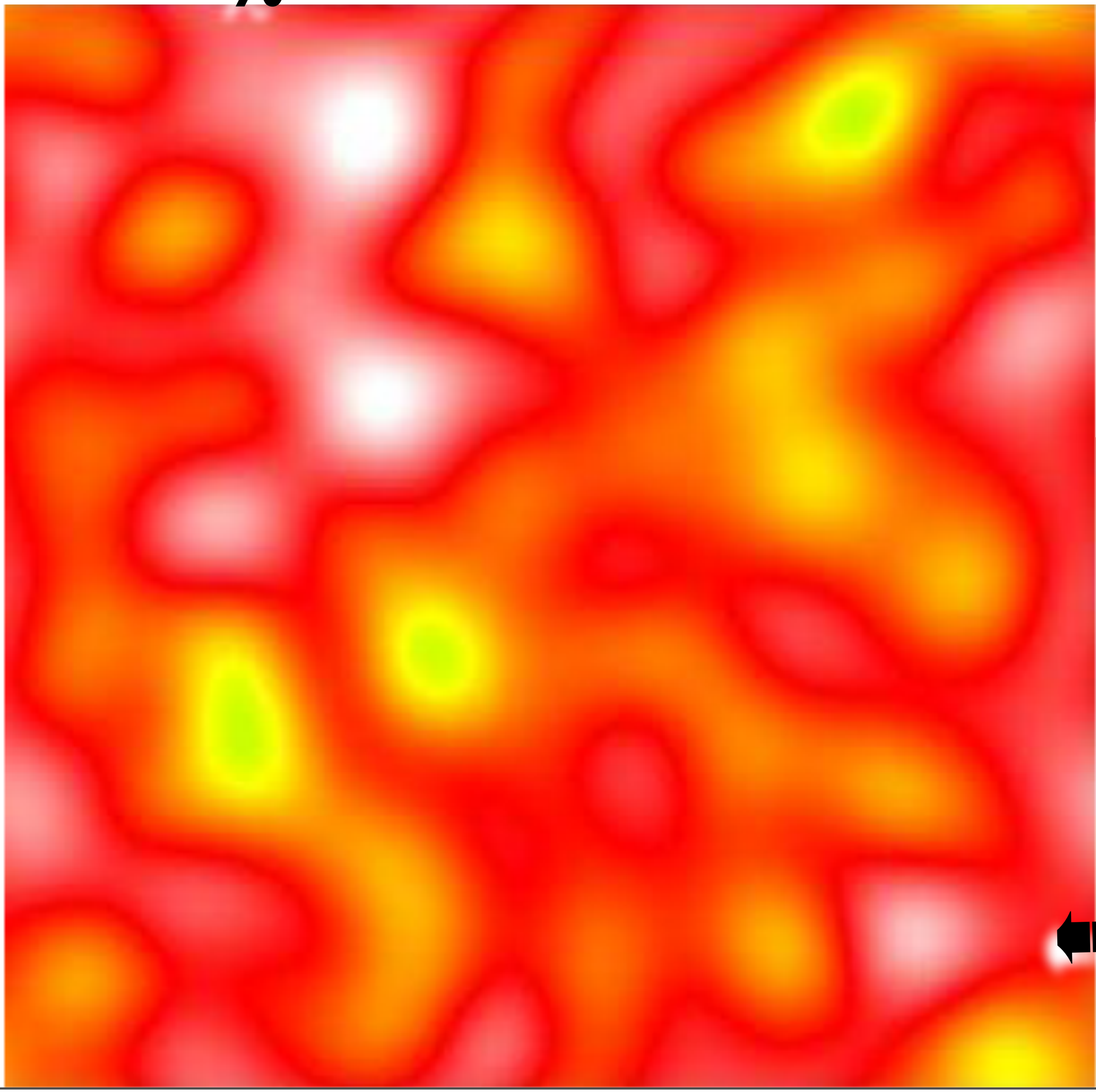


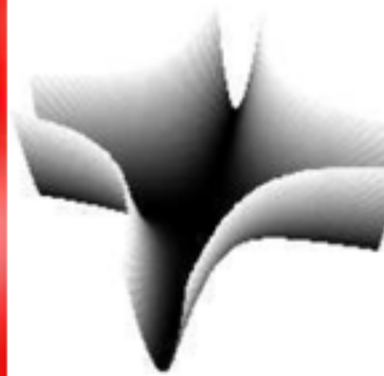
www.youtube.com/watch?v=FW__su-W-ck&NR=1

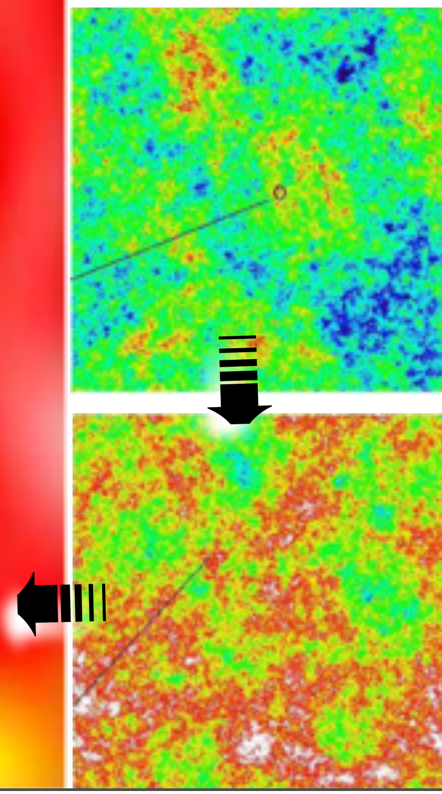
ϕ inflaton χ isocon $V(\phi,\chi) = 1/4\ \lambda\ \phi^4 + 1/2\ g^2\ \phi^2\ \chi^2$

Parametric Resonance

$g^2/\lambda \sim 1$



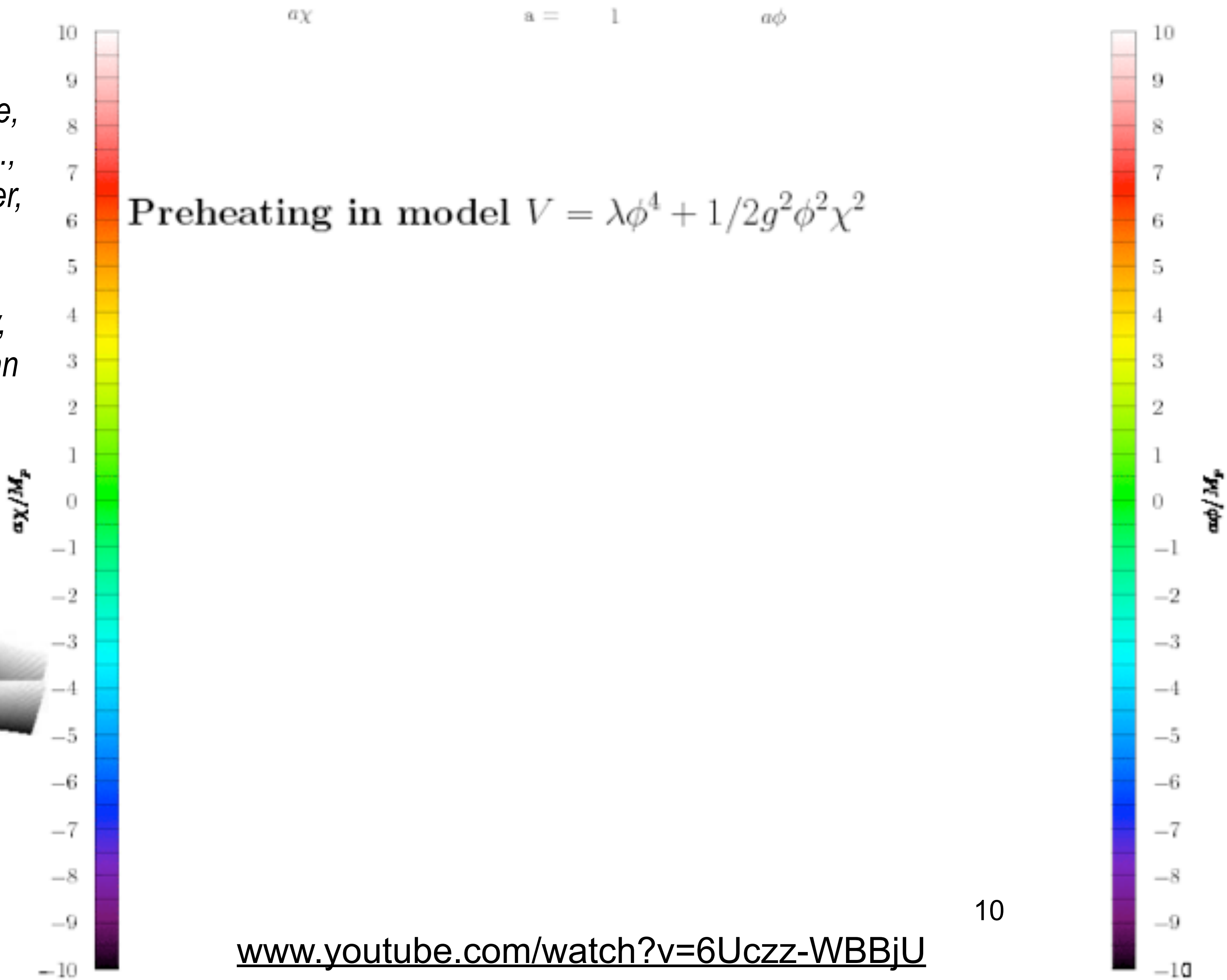




pre-heating patch (~1cm)

Cosmic Chaotic Billiards: Nongaussianity from Parametric Resonance in Preheating

***preheating ideas**: 90s*
Kofman, Linde, Starobinsky, .., Greene, Felder, Frolov, ...
nonG ideas
Bond, Frolov, Huang,Kofman 2009

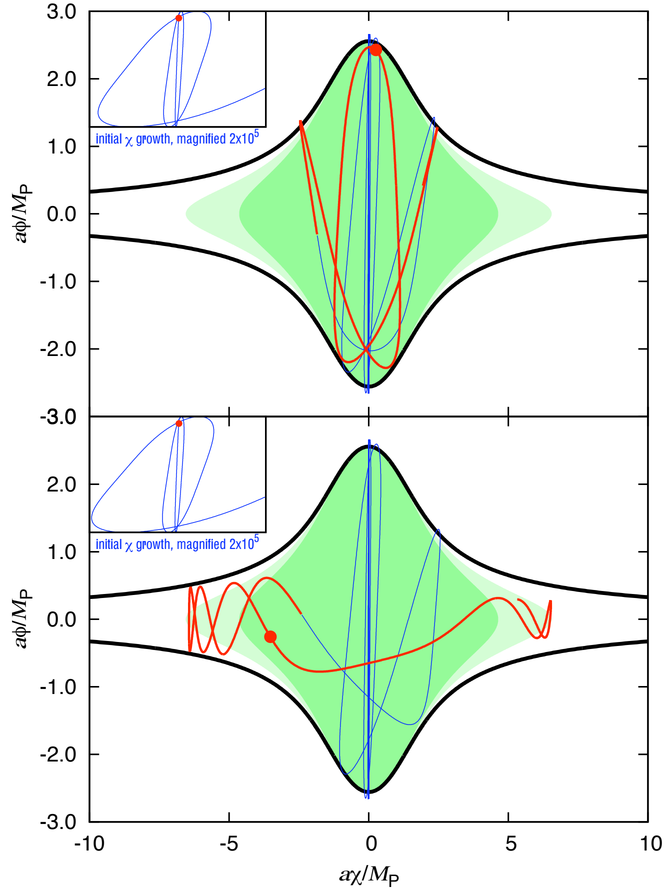


www.youtube.com/watch?v=6Uczz-WBBjU

Bond, Andrei Frolov, Zhiqi Huang, Kofman 09:

calculate how the expansion factor from the end of accelerated expansion (end of inflation) through preheating (copious mode-mode-coupling aka particle creation) to the onset of thermal equilibrium depends on $\chi_i(x,t)$

$$\delta N(\chi_i)=\delta \ln a|_H (x,t) = \textit{curvature fluctuation}$$



linear regime of zero-modes:

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

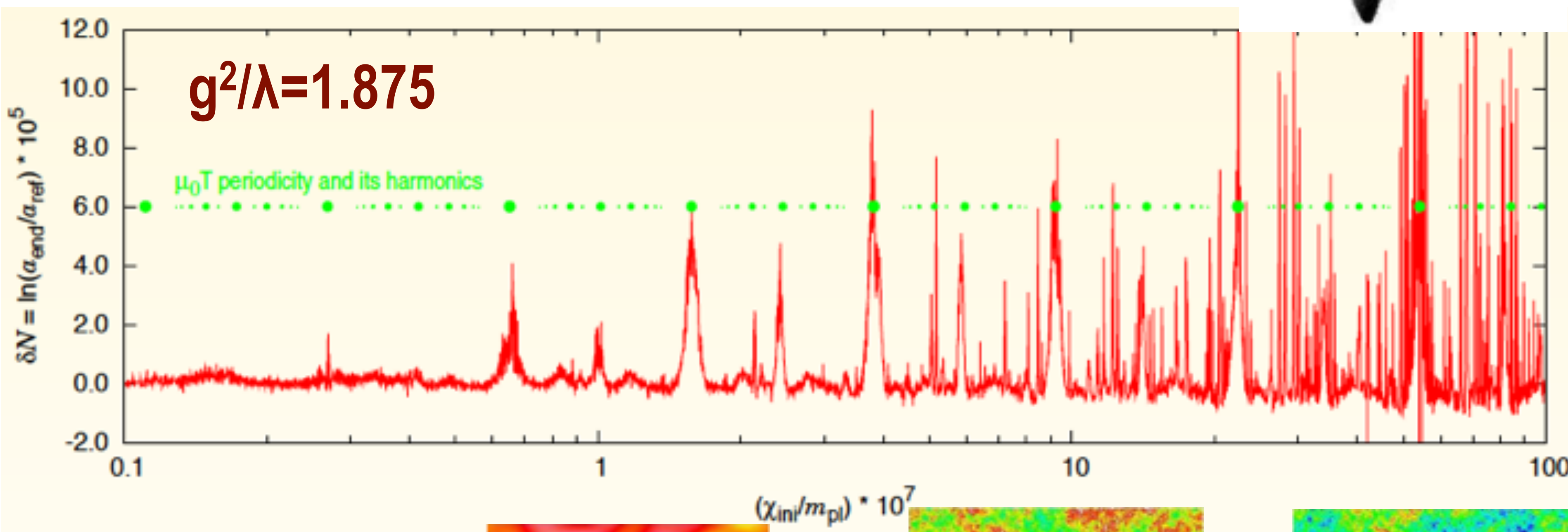
$\chi_0(t+T) = \chi_0(t) \exp[\mu_0 T]$

⇒ ***spikes are log*** χ_i ***spaced***

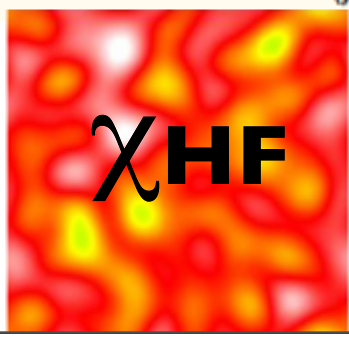
to develop the *ln*a(χ_i) response curve, we perform > 10^4 lattice simulations for each g^2/λ

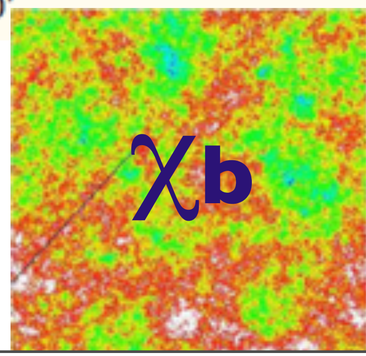
$$F_{NL}(\chi(x,t)) = \delta \ln a|_H (\chi_i)$$

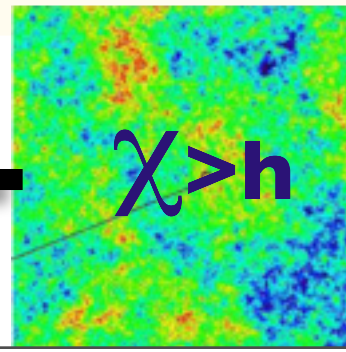
highly nonlinear function of a Gaussian random 'isocon' field



$$\chi(x,t) = \chi_{HF} + \chi_b + \chi_{>h}$$



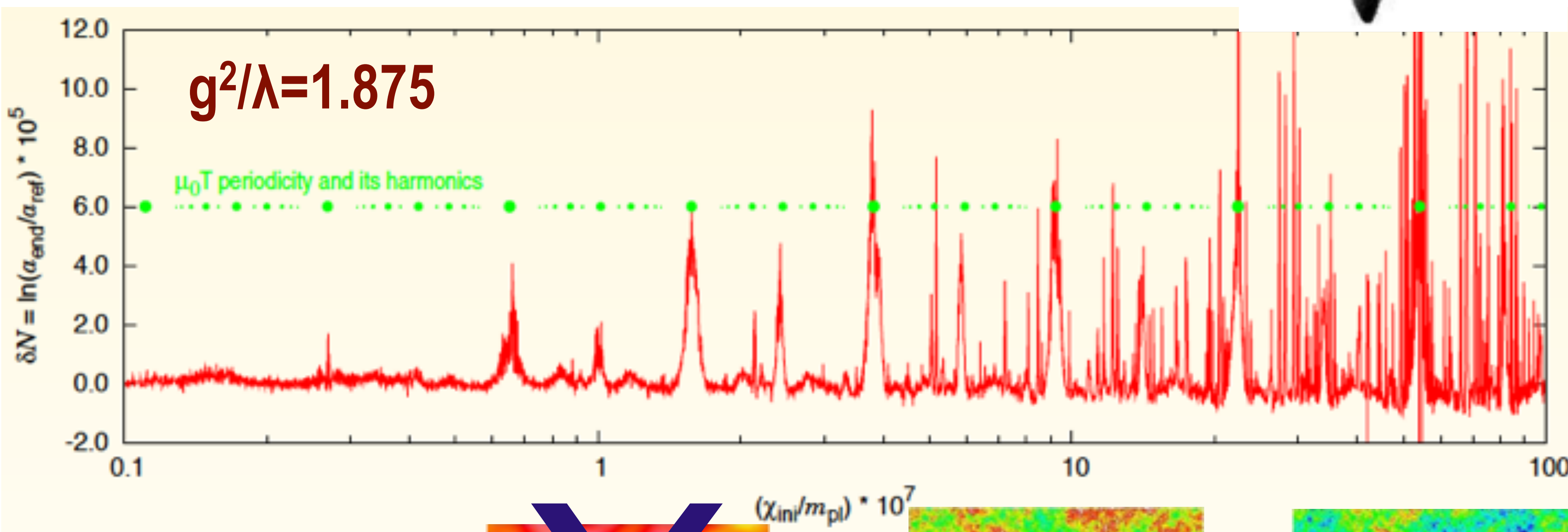




to develop the $ln\,a(\chi_i)$ response curve, we perform > 10^4 lattice simulations for each g^2/λ

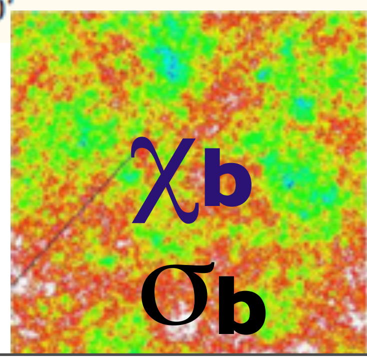
$$F_{NL}(\chi(x,t)) = \delta\, ln\,a\big|_H\, (\chi_i)$$

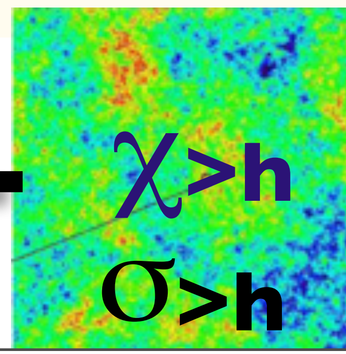
highly nonlinear function of a Gaussian random 'isocon' field



effective field theory

$$\chi_{eff}(x,t) = \sigma_{HF} + \chi_b\,\sigma_b + \chi_{>h}\,\sigma_{>h}$$





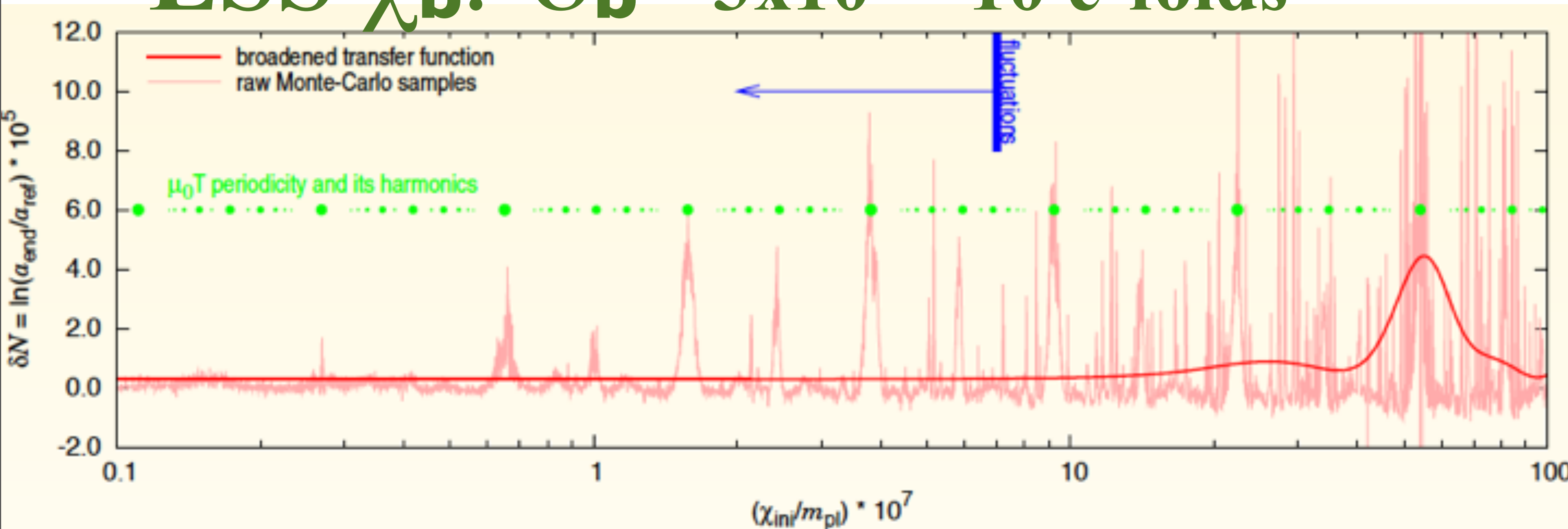
field smoothing over χ_{HF}

field smoothing over χ_{HF} $\sigma_{HF} \sim 7\text{x}10^{-7}$ ~50 e-folds

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

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

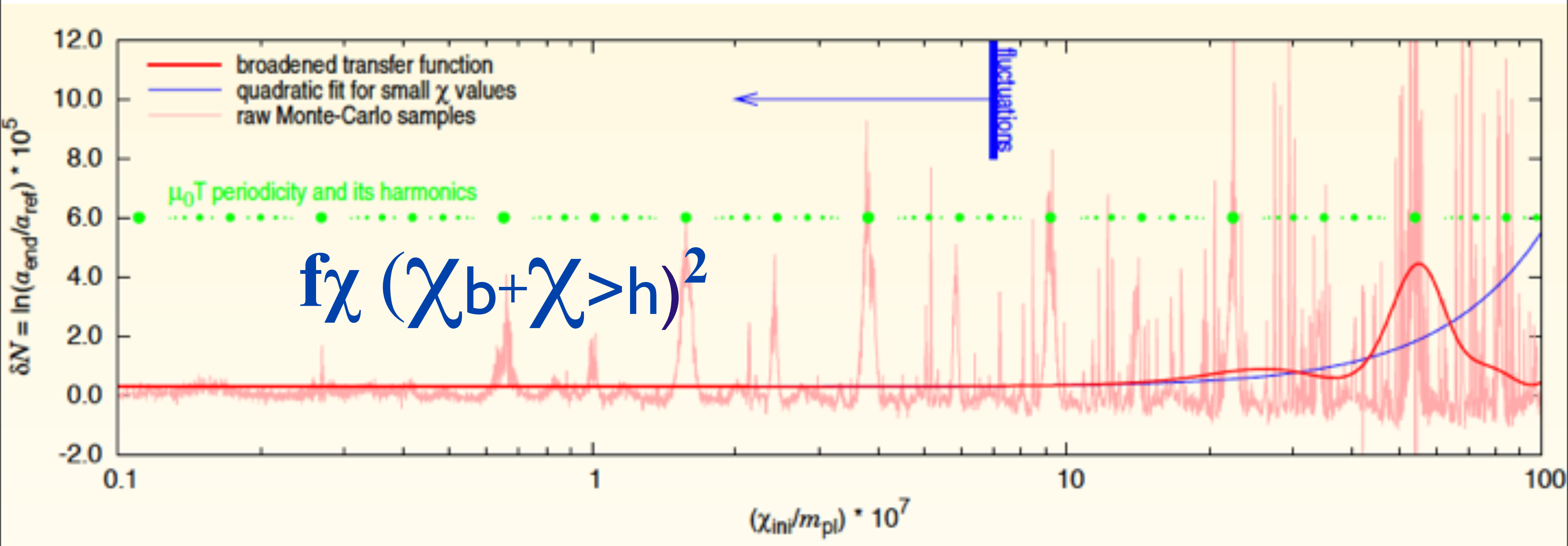
LSS χ_b: $\sigma_b \sim 3\text{x}10^{-7}$ **~10 e-folds**



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

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

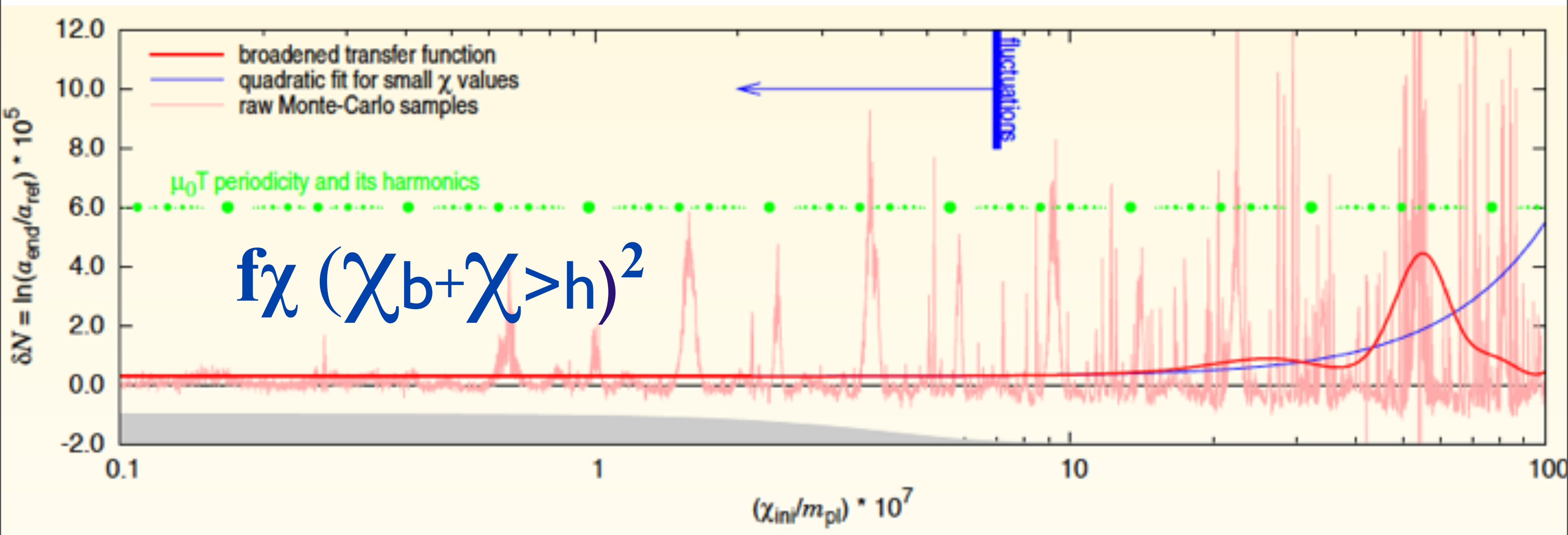
$$< F_{NL} | \chi_b + \chi_{>h} > \quad \sim \beta(\chi_{>h})\, \chi_b + f(\chi_{>h})\, \chi_b^2 + \ldots$$



local quadratic non-G constraint: -9< f_{NL}<111 ⇒ -4< f_{NL}<80 WMAP5 (± 5-10 Planck1yr)

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

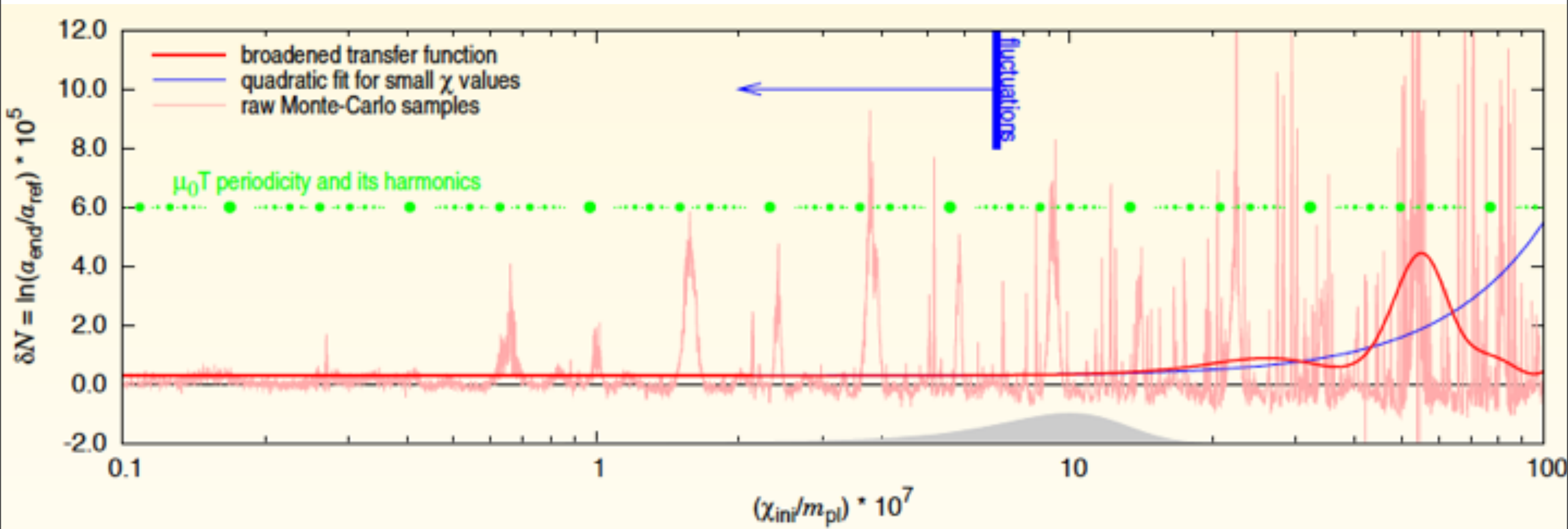
small $\chi_{>h}$ *regime:* $\beta = 2 f_\chi \chi_{>h}$ $f = f_\chi$



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

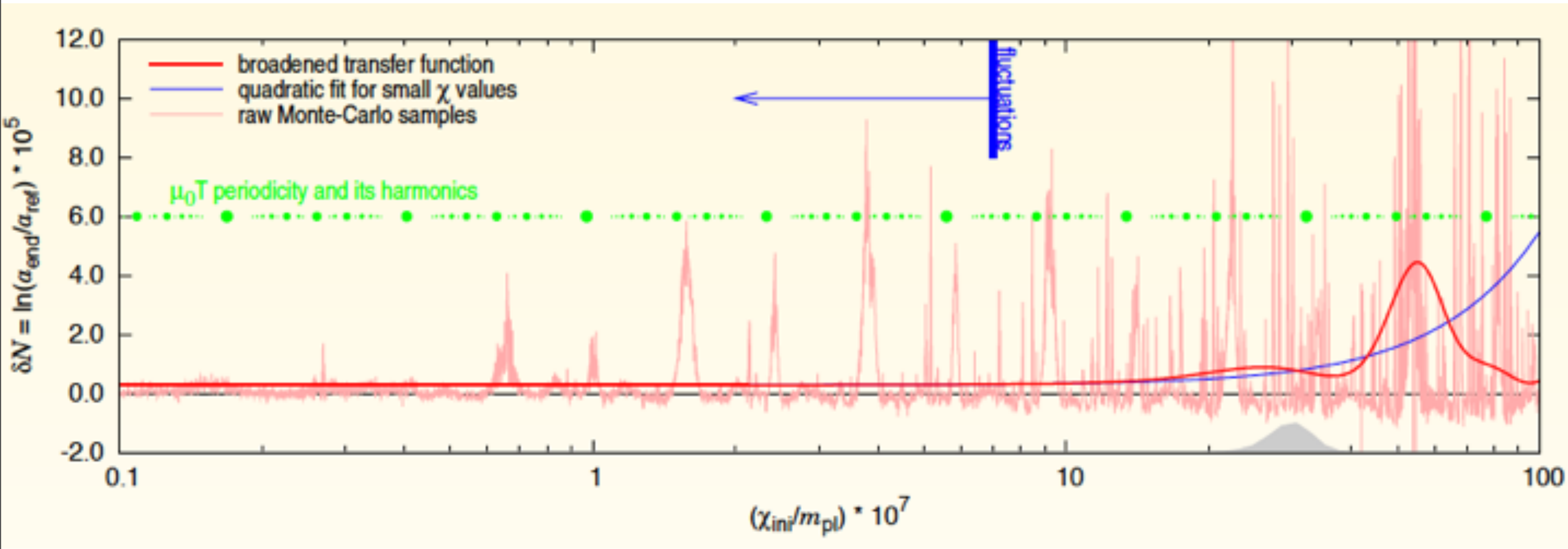
naive $P\chi/P\phi = 2\varepsilon$

medium χ>h *regime:*

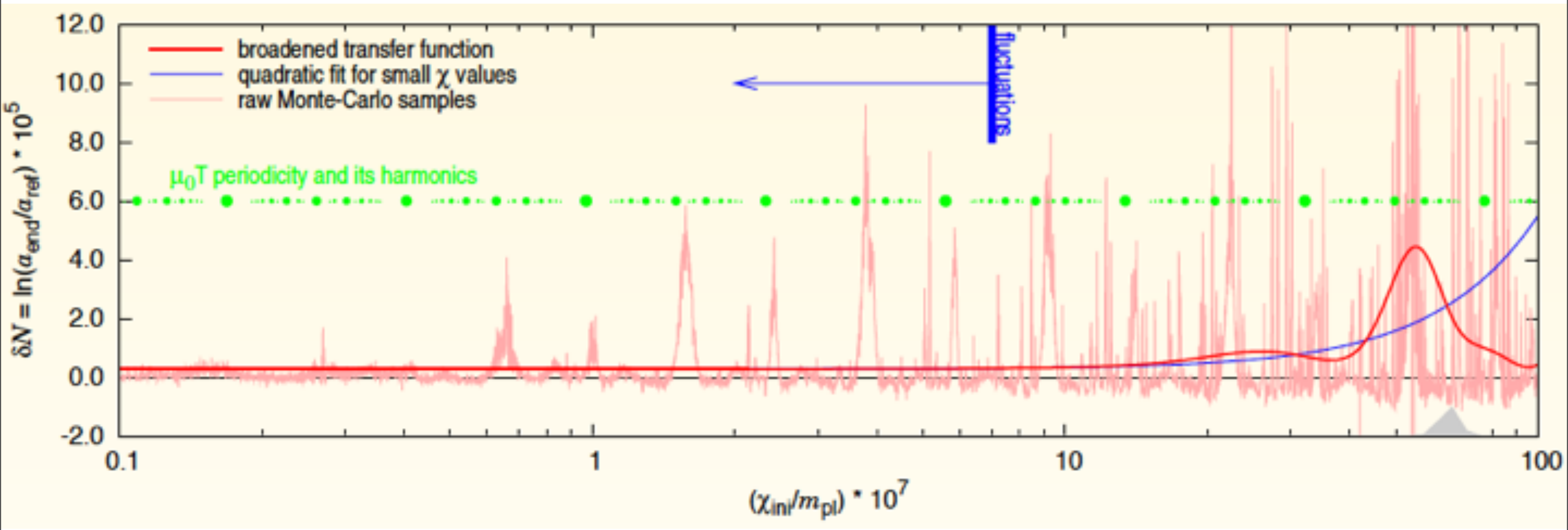


large-ish χ>h *regime:*

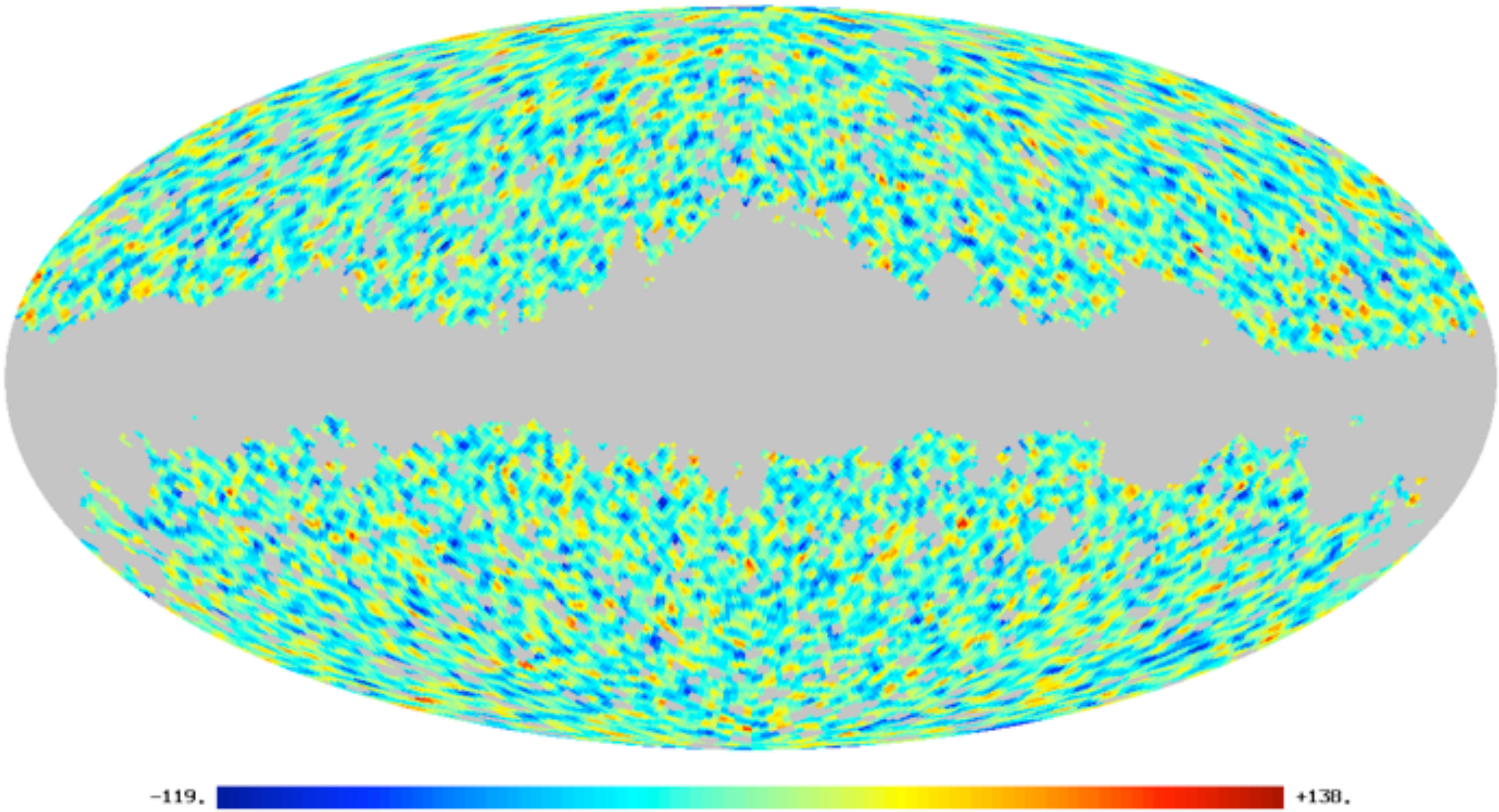
quadratic + cold spot
"rare events"



large χ>h *regime:*

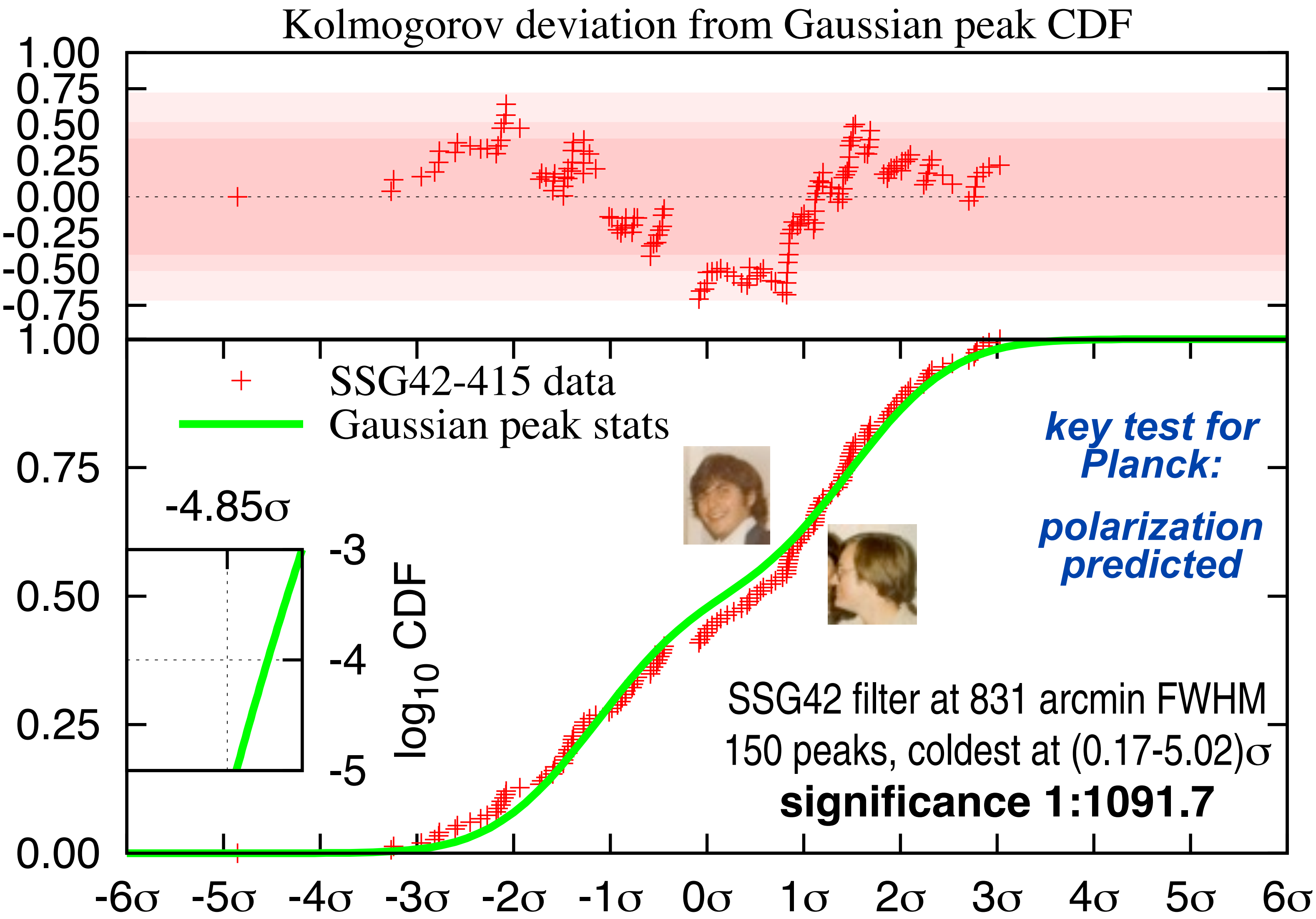


the WMAP Cold Spot



variable scale filtering 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, Kofman, Nolta 10

Standard Parameters of Cosmic Structure Formation

primordial non-Gaussianity

$$\Phi(x)= \Phi_G(x)+ \mathbf{f_{NL}} (\Phi_G^2(x)-\langle\Phi_G^2\rangle)$$

local smooth

DBI inflation: non-quadratic kinetic energy
cosmic/fundamental strings/defects
from end-of-inflation & preheating

$$\Phi(x)= \Phi_G(x)+ F_{NL}(\chi_b)-\langle F_{NL}\rangle$$

resonant preheating

+ subdominant
isocurvature, cosmic string,
& fgnds, tSZ,kSZ, ...

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

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

(partially) blind cf. informed "theory" priors

primordial non-Gaussianity

$\Phi(x) = \Phi_G(x) + f_{NL} (\Phi_G^2(x) - \langle\Phi_G^2\rangle)$

local smooth

DBI inflation: non-quadratic kinetic energy

cosmic/fundamental strings/defects

from end-of-inflation & preheating

$\Phi(x) = \Phi_G(x) + F_{NL}(\chi_b) - \langle F_{NL} \rangle$

resonant preheating

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

$\varepsilon_\phi \times 2/3 = 1 + w(a)$

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

+ subdominant isocurvature, cosmic string,

& fgnds, tSZ, kSZ, ...

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

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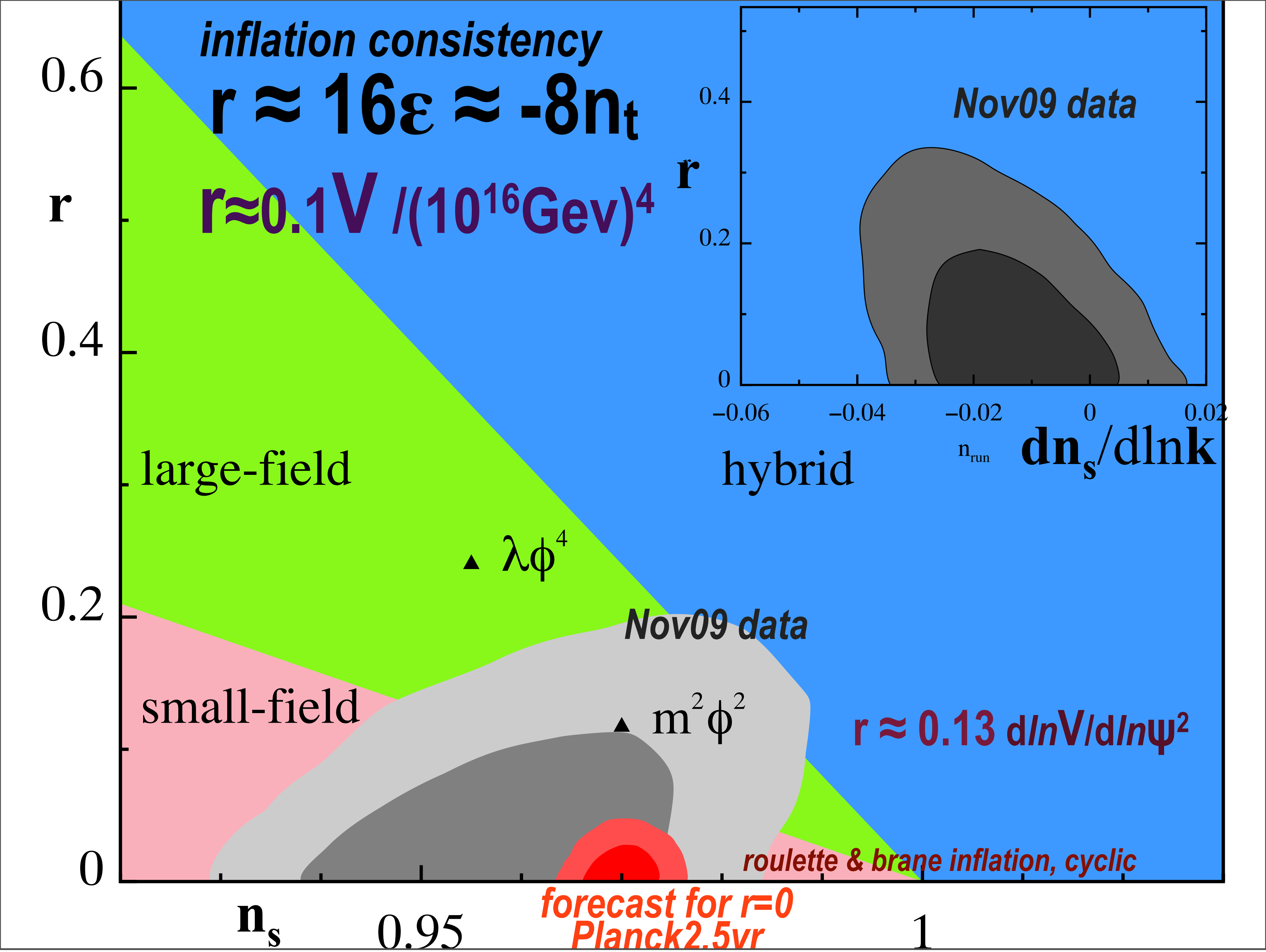
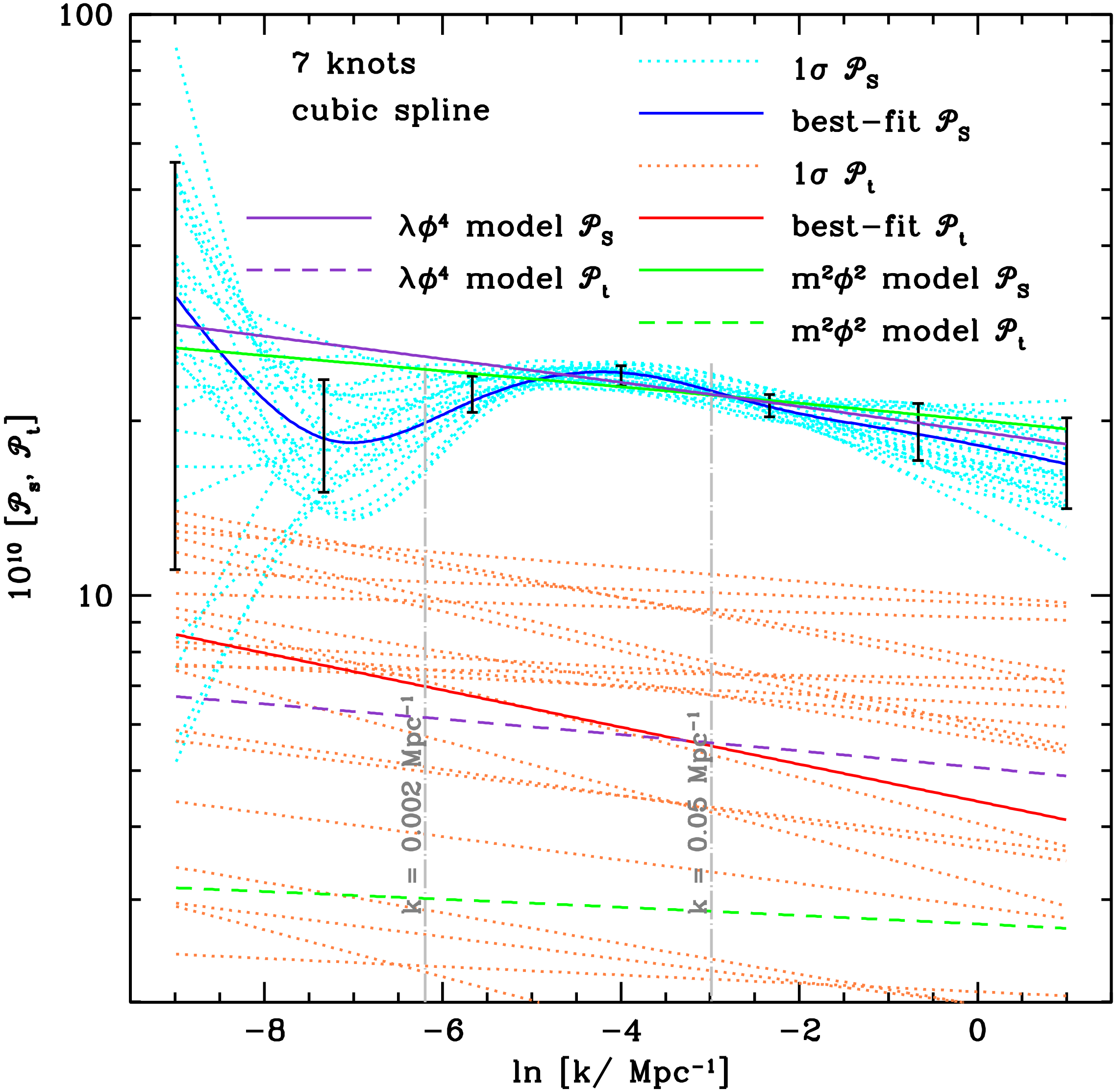
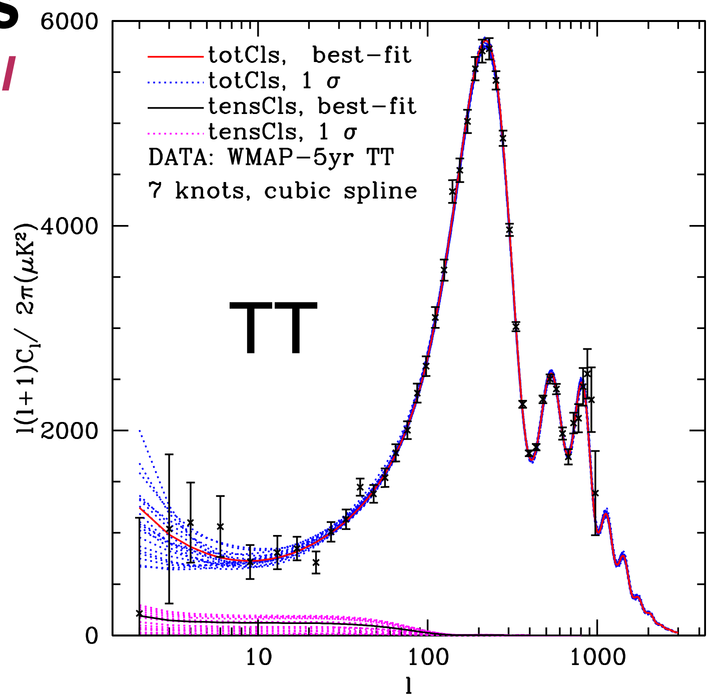


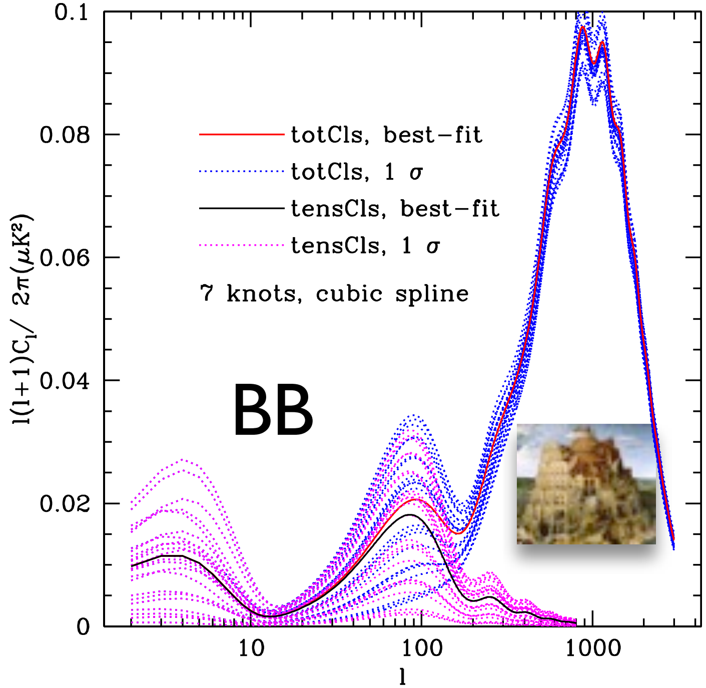
Tuesday, June 8, 2010

compress data onto non-top-hat k-modes

partially-blind scalar ln-power trajecteries & usual r-n_t tensor - no consistency relation. Nov09 data



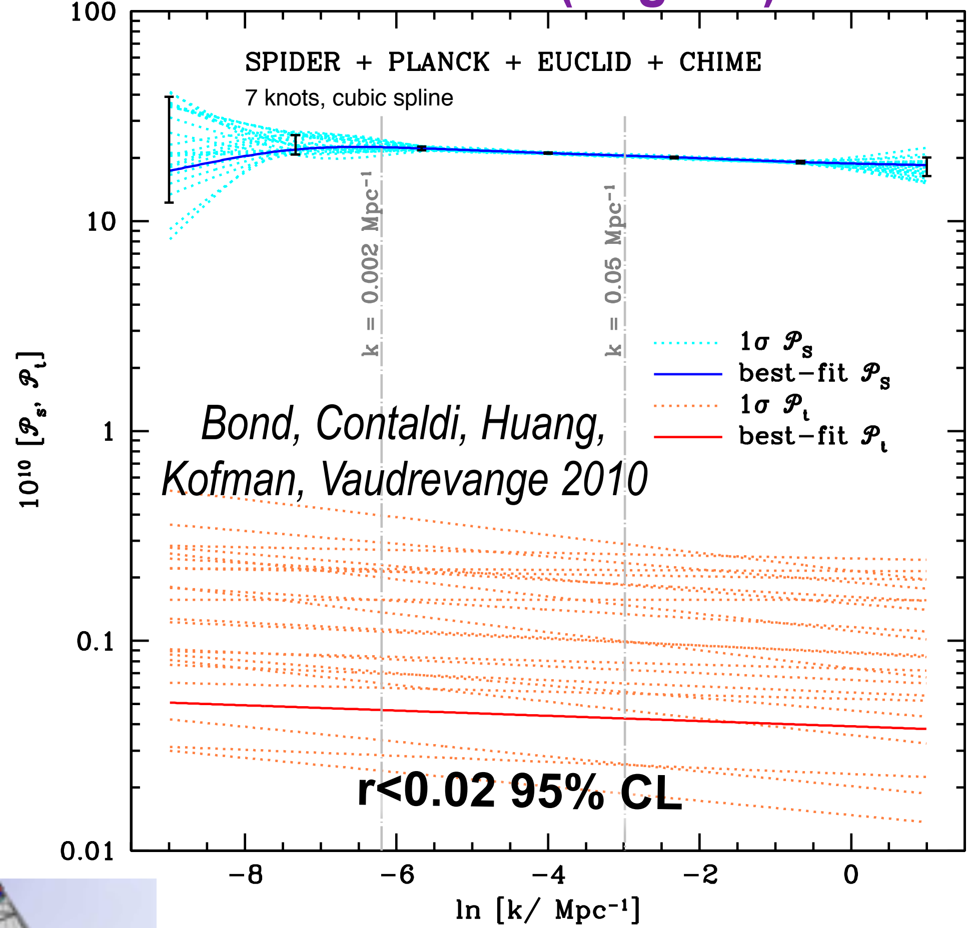


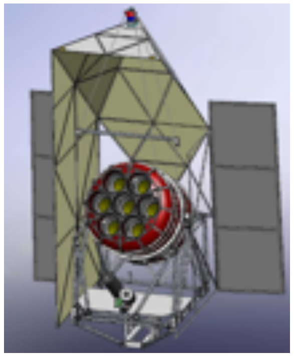


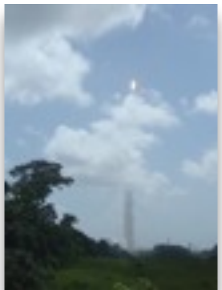
Bond, Contaldi, Huang, Kofman, Vaudrevange 2010

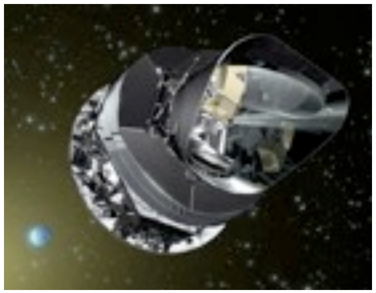
compress data onto non-top-hat k-modes

Spider-24days + Planck-2.5yr + ... 7 knot $\ln P_s$ +r-n_t forecast for r=0 (+ fgnds)



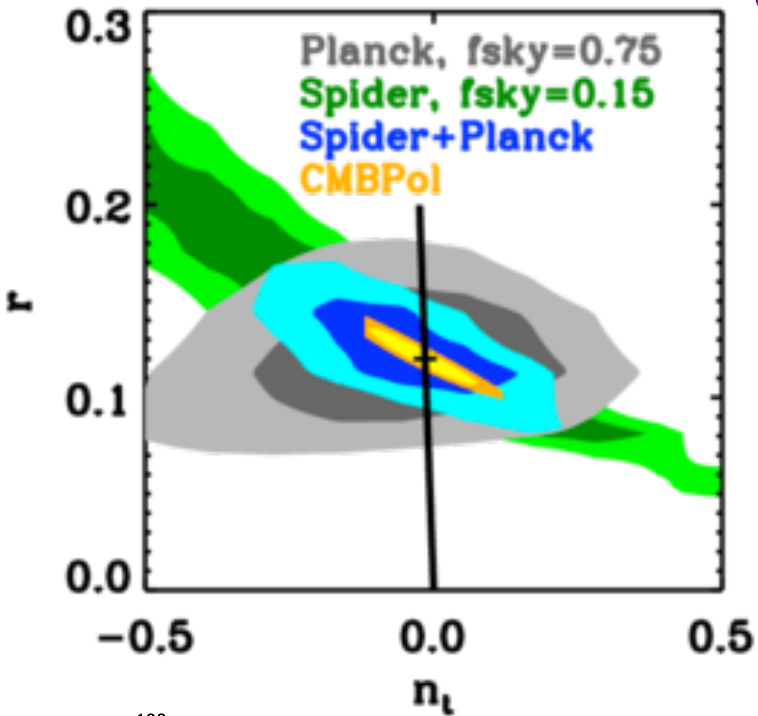


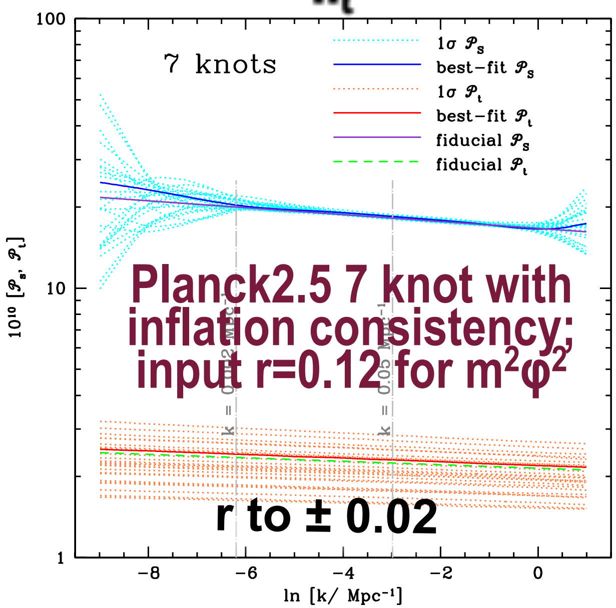




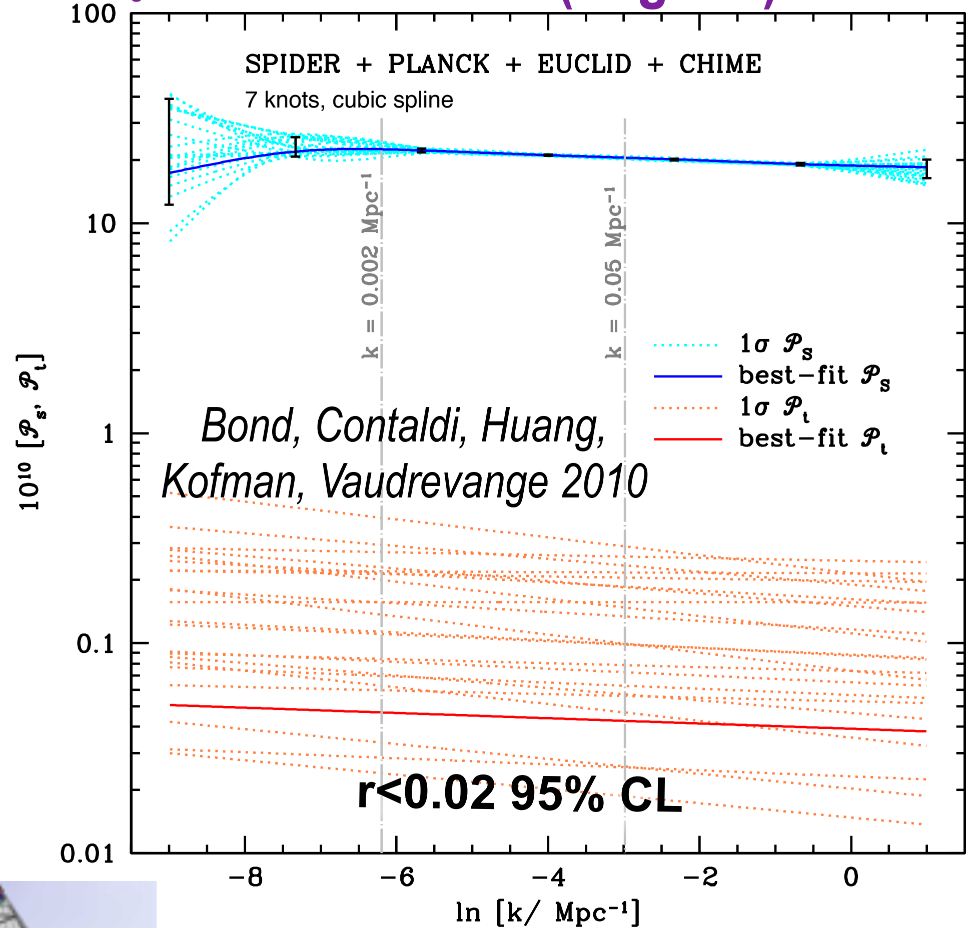
compress data onto non-top-hat k-modes

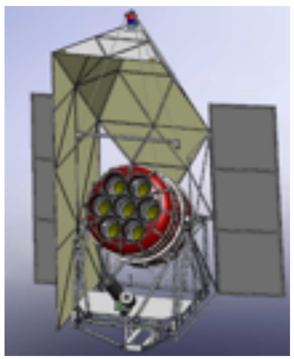
Farhang, Bond, Dore, Netterfield 2010

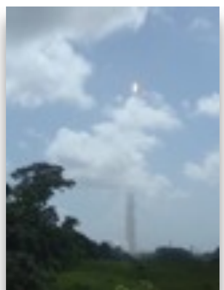


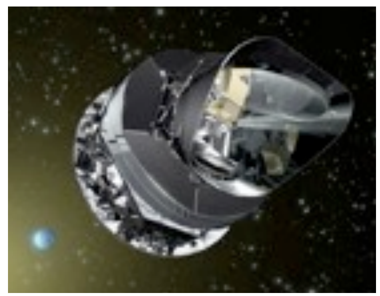


Spider-24days + Planck-2.5yr + ... 7 knot $\ln P_s$ +r-n_t forecast for r=0 (+ fgnds)



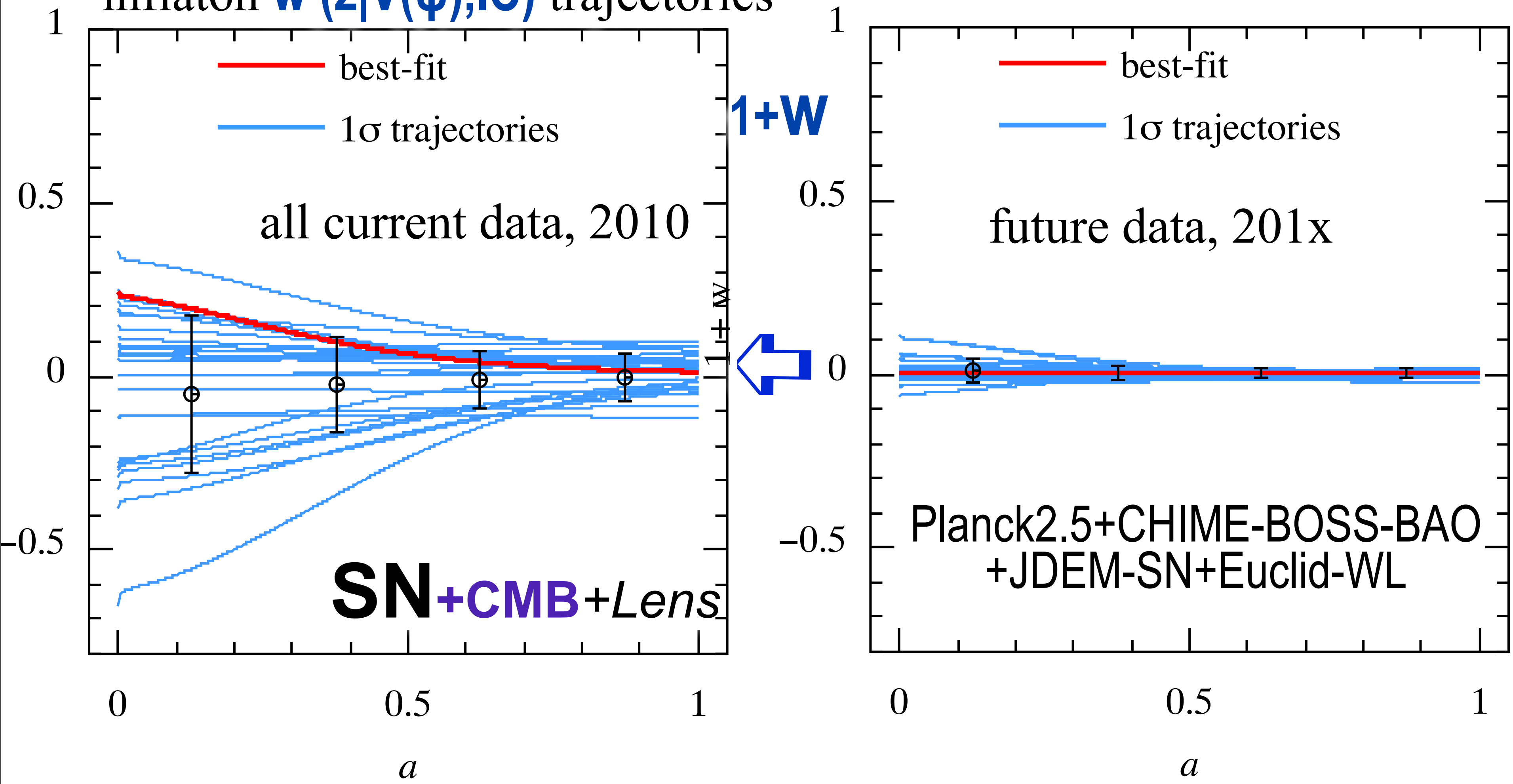






is the **dark energy** "vacuum potential energy" ?

3-parameter paves even wild late-inflaton **w (z|V(ψ),IC)** trajectories



TEST: within errors, energy-density does not change with expansion ⇨Einstein's cosmological constant is best fit so far

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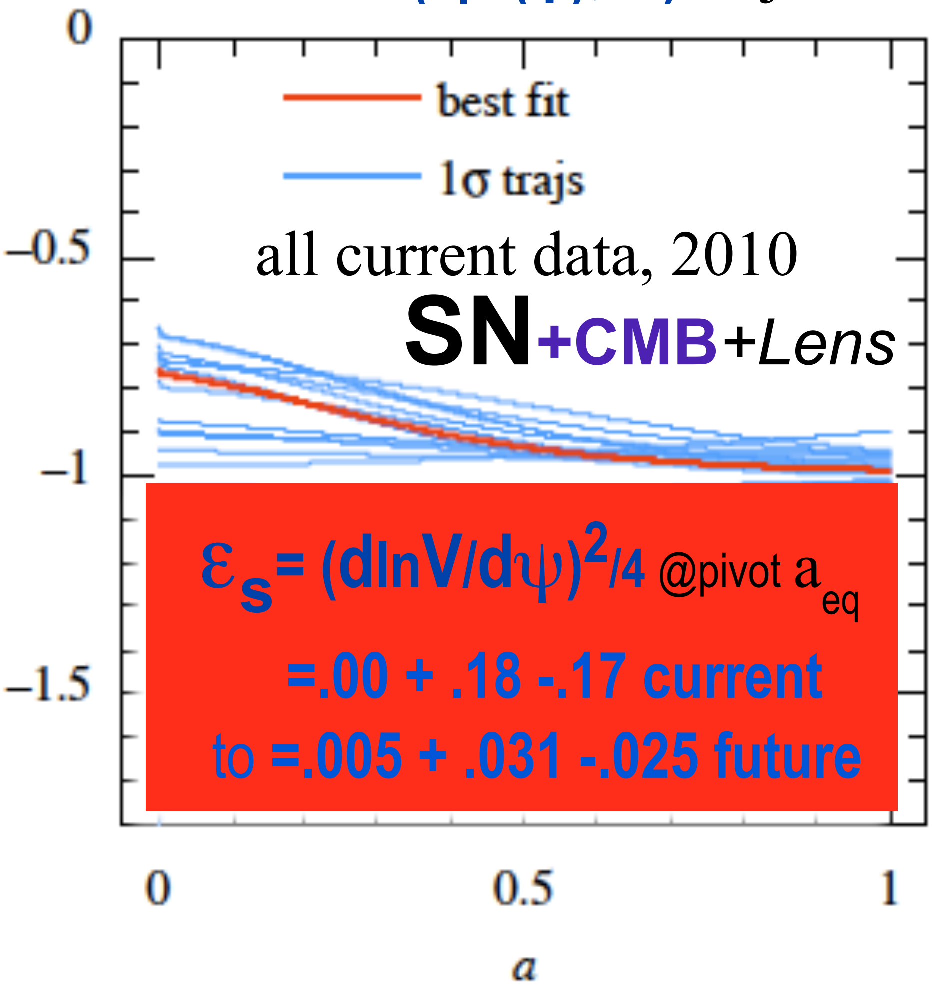

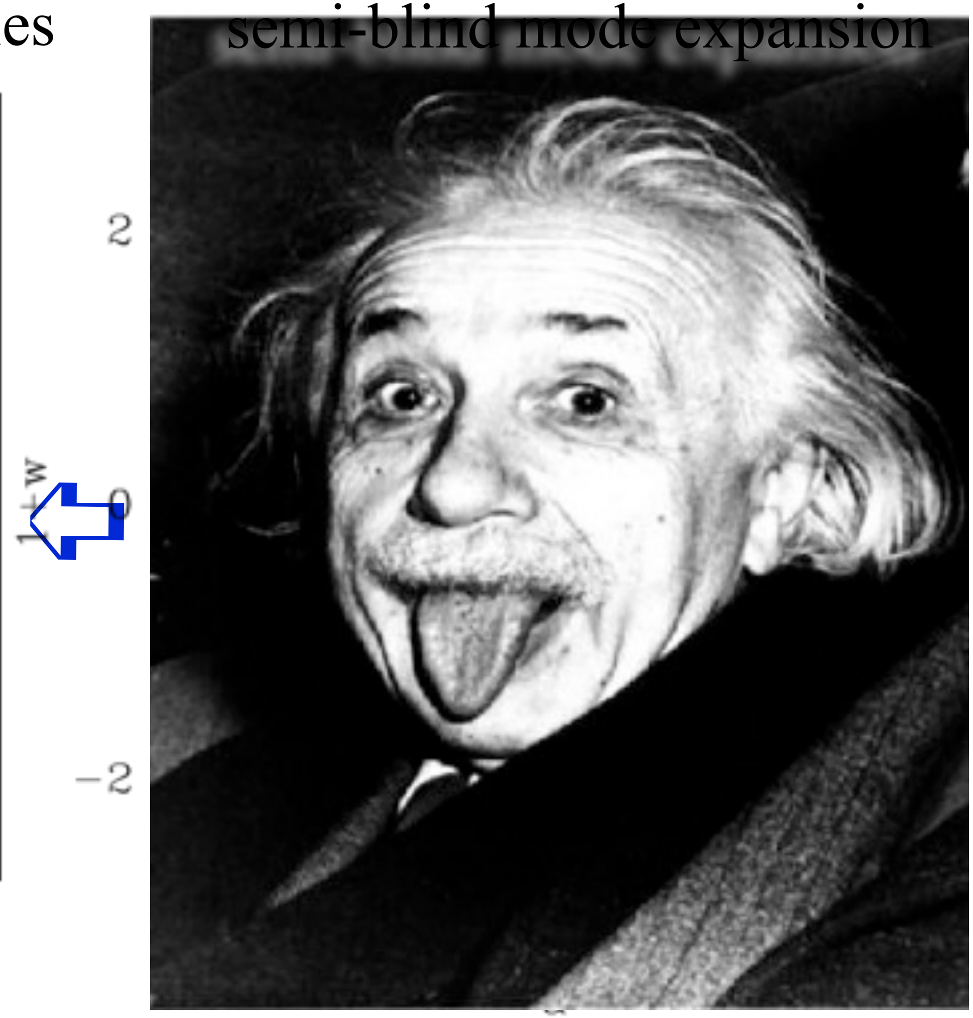

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Physics Today Jun 2010: Obituary

Classical & Quantum Gravity, special issue dedicated to Lev
nonlinear cosmological perturbations,
ed. David Wands & Misao Sasaki

END