Dick Bond CIFAR@CITA with CITA aka Cosmic Information Theory & Analysis

Probing the Cosmic Theory of Early & Late Universe Physics: from Simplicity to Complexity

IT from BIT from BITs in IT

understanding the

***Complexity** to*
***Simplicity** to*
Complexity

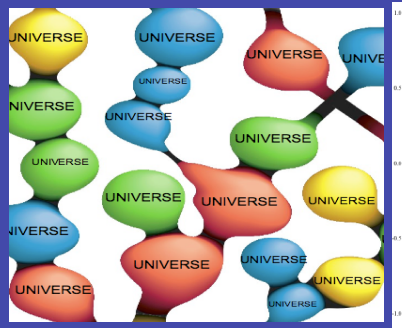
of the Universe = IT

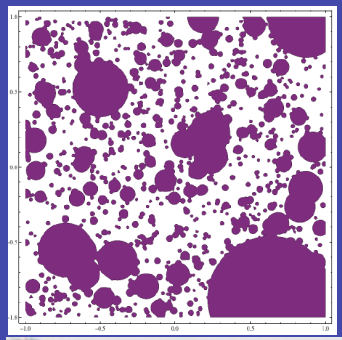
given that we are constrained to see only a BIT of IT

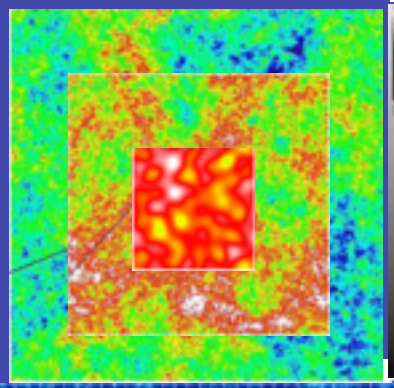
with rather few BITS from/in IT

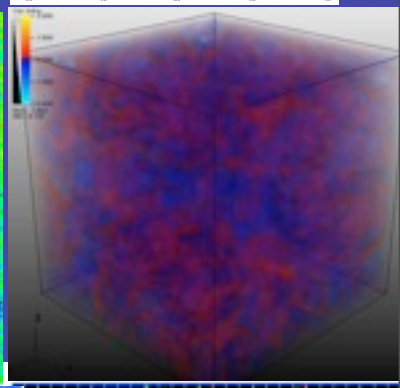
information quantity = entropy *Shannon 1948*

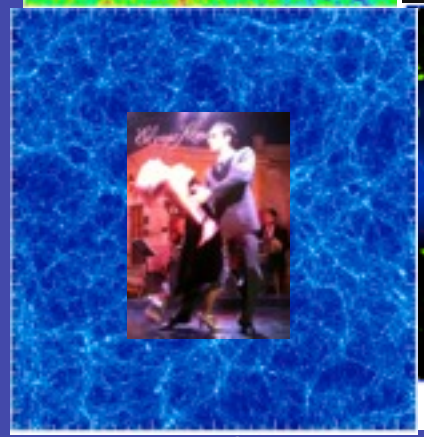
information quality = IQ *essence*

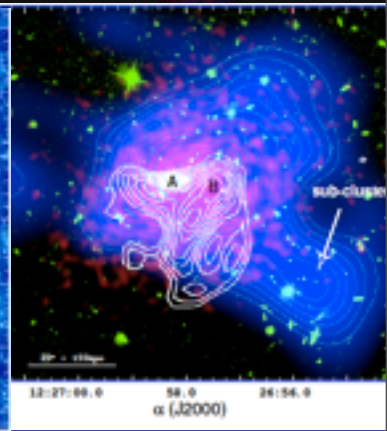












the coherent & the entropic, in all its forms, from the ultra-early-U to Now to the ultra-late-U

Bond@IAP 12.09.28

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the **nonlinear COSMIC WEB**

dS_G/dt

INFLATION

primary anisotropies

- linear perturbations: scalar/density, tensor/ gravity wave
- tightly-coupled photon-baryon fluid: oscillations $\delta\gamma$ $v\gamma$ $\pi\gamma$
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13.7-10^{-50}Gyrs | 13.7Gyrs | time t | 10Gyrs | today

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"Now I am in the grip of a new vision, that ***Everything Is Information.*** *The more I have pondered the mystery of the quantum and our strange ability to comprehend this world in which we live, the more I see possible fundamental roles for logic and information as the bedrock of physical theory. ... I continue to search."*

the ***medium*** *is the* ***message*** McLuhan 1964 UofT

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

$S_{U,m+r} \sim 10^{88.6}$ *cf.* $S_G \sim 10^{121.9}$ *asymptotic DE*

Studying the **Cosmic Tango**

en-TANGO-ment *the dance of U=R∪S*

Universe =System(s)+Reservoir =Signal(s)+Residual noise =Effective Theory+Hidden variables, =Data+Theory, **observer(s)+observed**

U=R∪S ruled by (information) entropy in bits, entangled.

the fine grains in the coarse grains

entropy =<information-content> **Quantity** **Shannon 1948**

generalized parameter space {q} ~phase space

$$S_f(D,T)=\int dq\, P_f\, ln[P_f^{-1}]$$

Boltzmann

$S=k_B ln W,$

$W=N_{states}$

$dS/dt > 0$

equal a priori probability

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A Long View of Particle Physics Frank Wilczek 2012, 25th Solvay:

Information as Foundation? *There are, I think, significant hints that it should be.*

QITA Quantum Information Theory & Analysis

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$P(q|D,T) = P(D|q,T)P(q|T)P(T)/P(D|T)$ *D=CMB,LSS,SN,..,* **complexity,** *life*

T=baryon, dark matter, vacuum mass-energy densities,..., early & late inflation as low energy flows/trajectories on a** (string) **landscape

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$$S_{fi}(D,T) = \int dq\, P_f \ln[P_f^{-1} P_i]$$

relative Shannon entropy = - Kullback Leibler divergence

$P_f(q)$ probability density functional **distribution function**

⇐ *quantum* **(von Neumann)** $S = -Tr\, \rho \ln \rho$ **density matrix**

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$dS/dt > 0$

Bayes measure

=>"$dS_f/dt < 0$"

as System knowledge ⬆

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***relative RENYI entropy of order n** a concentration measure (1 is Shannon)*

$$\exp[-(n-1)S_{n,fi}(D,T)] = \langle \exp[-(n-1)\sigma_{fi}] \rangle_f \sim - \ln \langle \rho^n \rangle_V / \langle \rho \rangle_V^n$$

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IQ=information quality

IQ~{minimal length messages/codes | error tolerance} *Planck(E/T), genetic code, recipes, axioms, algorithms, IC/BC/evolution eq^{n}s*

cat **information_overload.txt | grep fundamental | grep physics > exec_summary.tex**

filter, compress, reduce, marginalize

early U applications of "CITA" to cosmic-complexity

$S_{U,m+r} \sim 10^{88.6}$ *cf.* $S_G \sim 10^{121.9}$

☆ ***the superhorizon measure problem & the Lambda-scape***

☆ ***the emergence of the collective from the random!***
coherence from driven zero-point vacuum fluctuations ⇨ V
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some non-early U applications of "CITA" to cosmic-complexity

☛ information in **nearly-Gaussian** density/potential random **fields** of U, & in weakly and strongly non-linear fields. *ergodic theorem & constrained fields*

☛ 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 - CMB fgnd

☛ ***How Shannon info-entropy flows from CMB bolometer timestreams to marginalized cosmic parameters via Bayesian chains from prior to posterior. 1D & 2D & ... $\Delta S(q,DT)$*** *(cf. ACT10),* ***q=r, w, n_s, ...***

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Studying the Cosmic Tango *en-TANGO-ment* ***Universe=System+Res=Data+Theory*** =Signal(s)+*noise*=EFT*+Hidden variables*

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

WMAP: 1.15 Tbits in 9yrs, *cf. MyLifeBits, Gordon Bell, 1.28 Tbits in 9yrs,* ***Planck 36 Tbits, ACT 304 Tbits.***
Radically Compress to high quality Bits. Terabit=10^{12}bits=125 GigaBytes.

Shannon entropy difference $\Delta S_{fi}(q,DT)=\int dq\, P_f \ln P_f^{-1} - \int dq\, P_i \ln P_i^{-1}$

a new figure of merit for experiments, $\langle \ln VOLUME_{ps} \rangle$ ***~ posterior Shannon entropy:*** *how the (radically compressed) one-dimensional entropy of cosmic parameters, the high quality bits we quest, did/will change as the experiments became/become more & more precise:*

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

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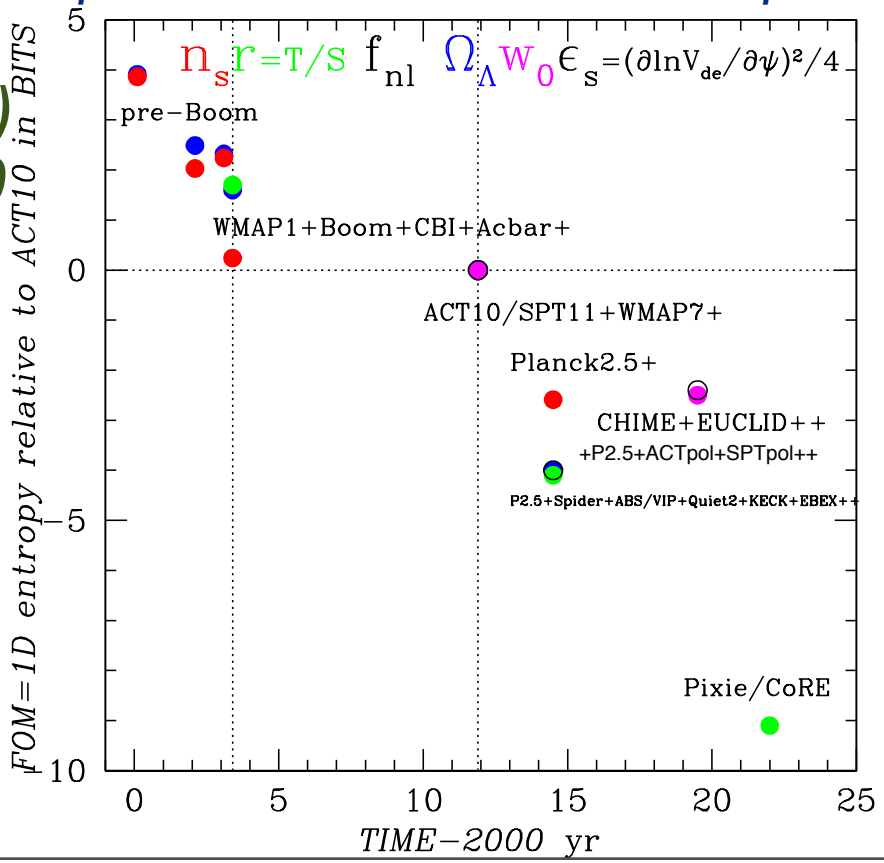

2D ΔS_{2f} for DarkE improves by ~5 bits

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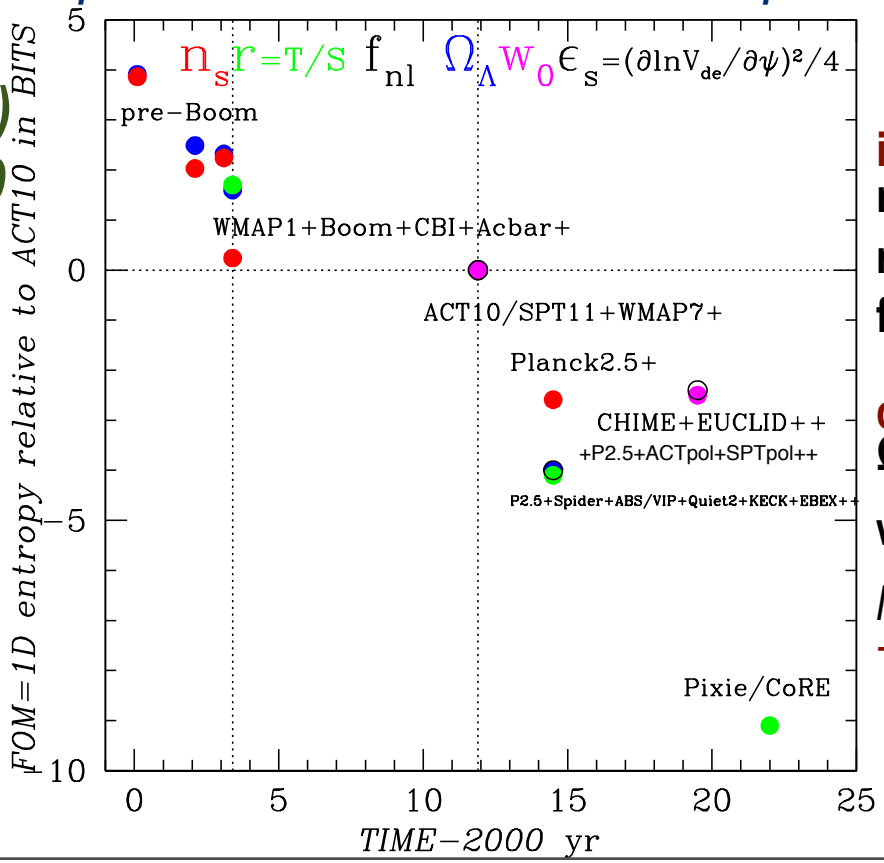

inflation

n_s : 0.963± 0.011 =>± 0.002 (Pext)

r: < 0.17 => < 0.007-0.013 (Pext)

f_{nl}: -10< f_{NL} <74 => ± 5 (Pext)

dark energy

Ω_Λ : ± 0.012 =>± 0.001 (Pext)

w_0: ± 0.06 =>± 0.01 (Pext) (± 0.14 =>± 0.03 if w_a)

ln **V-slope^2/4 0.0± 0.18 =>± 0.03 (Pext)**

+2 other w-trajectory parameters BHK11,BH12

2D ΔS_{2f} for DarkE improves by ~5 bits

late-inflaton DE trajectories

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

Ω_Λ: ± 0.012 =>± 0.001 (Pext)

w_0: ± 0.06 =>± 0.01 (Pext) (± 0.14 =>± 0.03 if w_a)

$\varepsilon_s = \ln V\text{-slope}^2/4$ 0.0± 0.18 =>± 0.03 (Pext)

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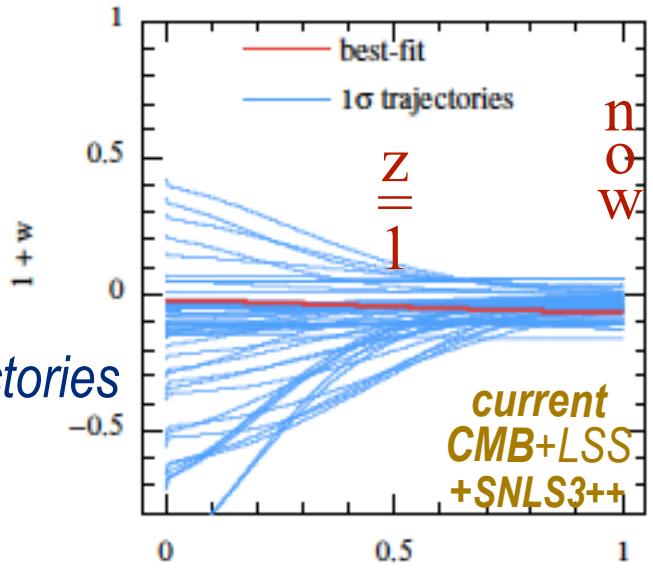
2D ΔS_{2f} for DarkE ($\varepsilon_s \varepsilon_{de\infty}$ or w_0 w_a) improves by ~5 bits

informed $\mathbf{w(a|\varepsilon_s \varepsilon_{de\infty} \varsigma_s)}$ *fits even wild late-inflaton trajectories*



Bond, Huang 2012

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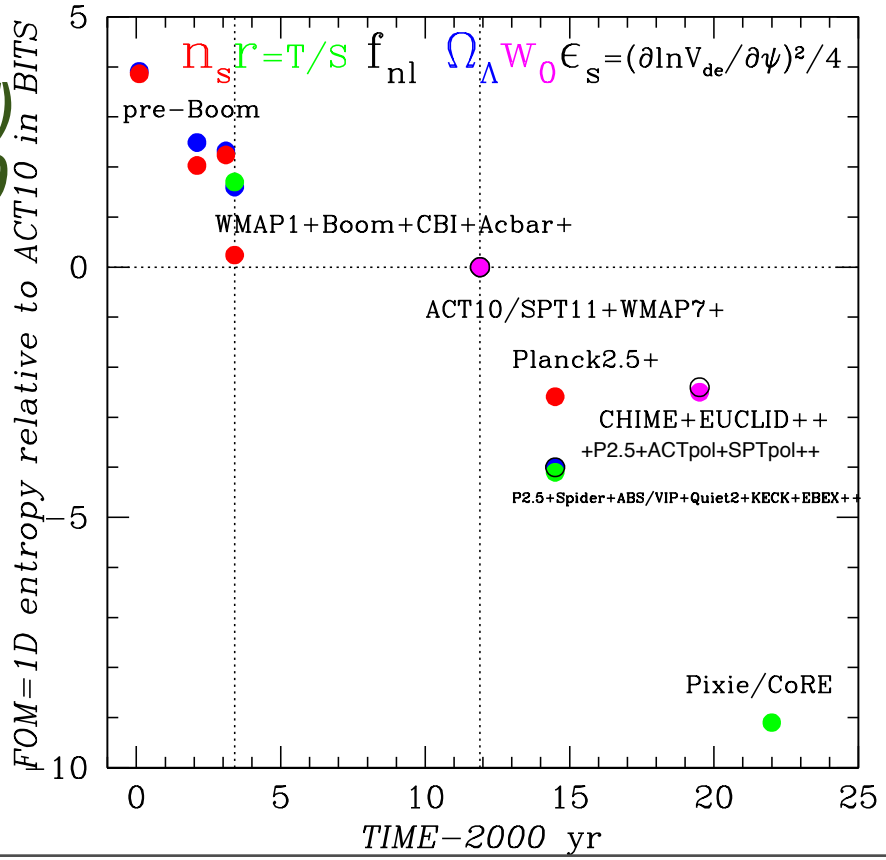

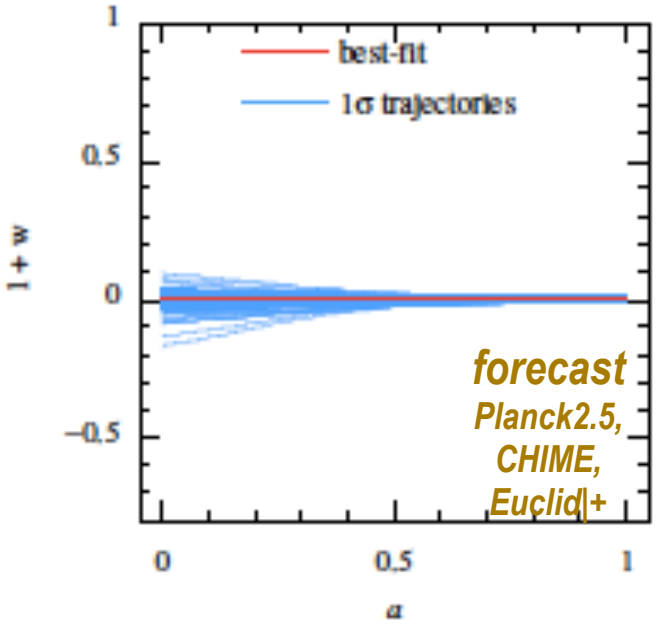

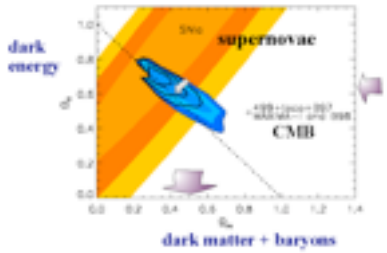

future fate of

the **cold-death** of the **Universe** (cf. ~1800s heat-death)

coherence (dark energy $\rho_{de}(t,x) \Rightarrow V_{de} \sim \Lambda$)

beats incoherence (Υ,ν,h_{+x},..p,n,e)

but **entropy/particle remains** *(for surviving particles)* e.g.,5.2 bits/photon

the **gravo-thermal catastrophe** = negative specific heat - goal to localize all mass into black holes & make accelerating voids ***to straighten U*** *out, radiating entropy along the way*

although $S_G = M_{bh}^2/2M_P^2$ decays into radiation, $S_G = M_P^2/2(H/2\pi)^2 \sim 10^{121.9}$ remains (until tunnel)

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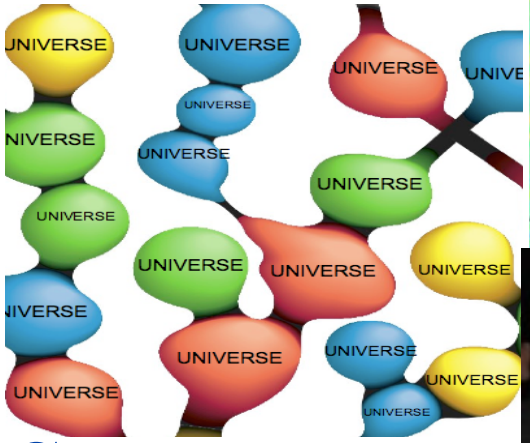
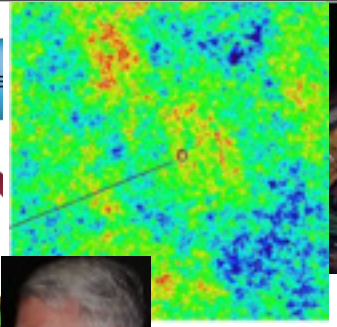
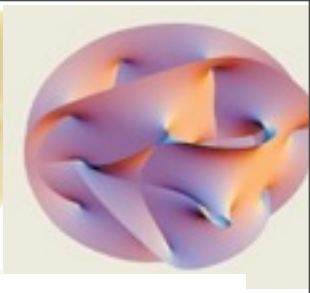
Old: Theory prior = delta function of THE correct one&only

New: Theory prior = probability distribution of **late-*ish*-flows** on a **LANDSCAPE**







$S_{U,UUULSS} = \langle \ln P[U|Time]^{-1} \rangle$

measure problem

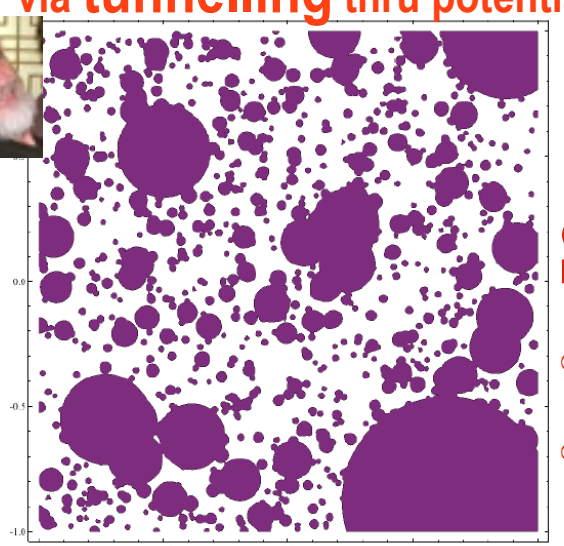
when quantum kicks

beat **classical drifts**

we are in the

semi-ETERNAL INFLATION regime

or via tunnelling thru potential wells



=> the

hubble

bubble U

$S_{G,GH}$

$\propto m_P^2/H_V^2$

$\propto m_P^4/\rho_V$

statistical mini-landscapes e.g.,

Roulette Inflation in a holey U *cf.* braney Us

Preheating After

Roulette Inflation

$\langle \tau \rangle =$

quantum diffusion

spatial jitter

drift

$\ln a(x, \ln H)$

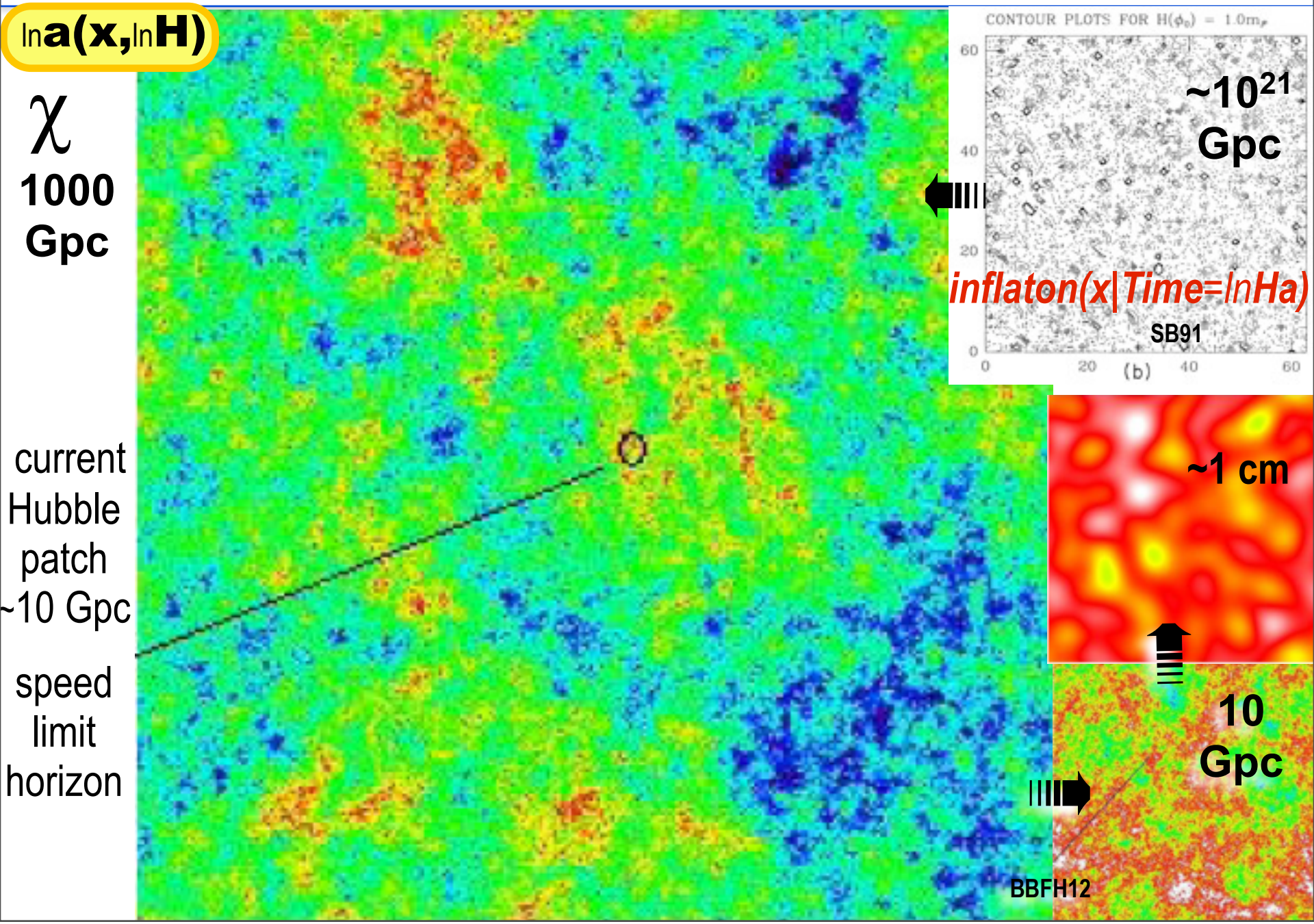
semi ETERNAL INFLATION

let there be

heat

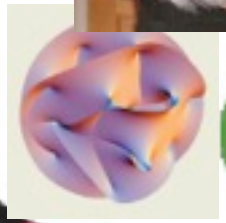
$= \langle \ln P[U|Time]^{-1} \rangle$

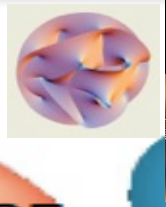
fluctuations in the **early universe "vacuum" grow** to *all* **structure**

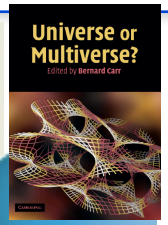


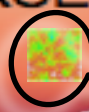
quantum stochastic *non-Gaussian* time landscape cf. stringy landscape

multiverse
Starobinsky, Vilenkin, ***Linde****, SB, Rees, ..., stringy: Susskind etal*

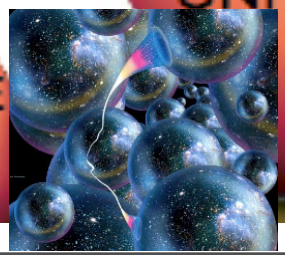


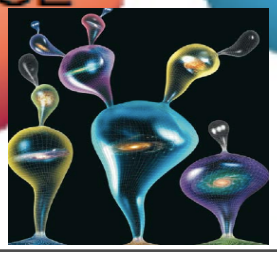






our horizon





ln$a(x,\ln H)$

a "natural" consequence of quantum mechanics of the U's uuUULSS on **ln$a(x,\ln Ha)$**

if quantum diffusion > 'classical' drift at **high H**

cf. our ***observable horizon (patch) at*** **low H**

this eternal inflation can happen even at low H

Salopek & Bond 1991

$=\langle \ln P[U|Time]^{-1} \rangle$

modulating post-inflation entropy generation shocks *via* long range fields

isocon

$\chi(\mathbf{x})$

or

$\mathbf{g}(\sigma(\mathbf{x}))$

or..

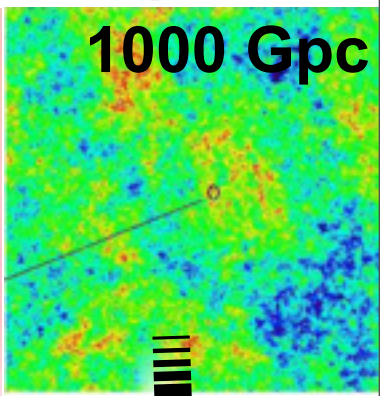
ϕ

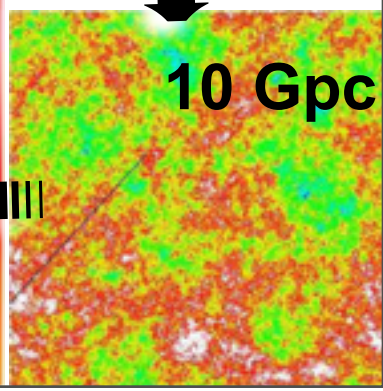
inflaton

pre-heating patch (~1cm)

Parametric Resonance

$g^2/\lambda \sim 1$





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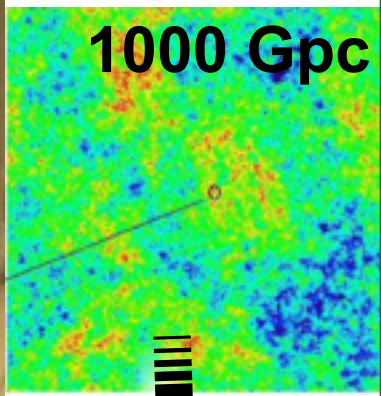
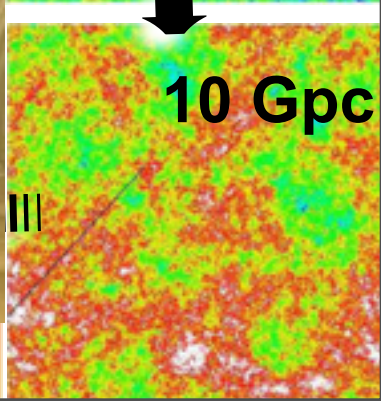
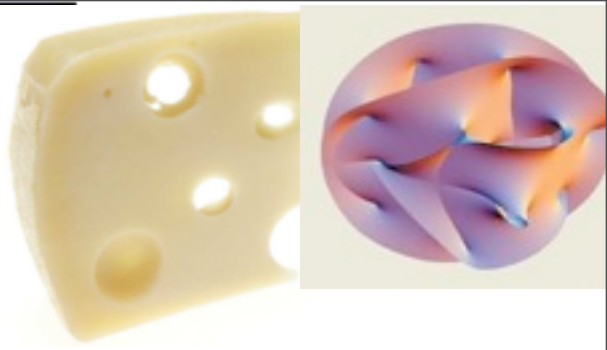
BB12





B^2FH12 @ifaUH aka Waikiki Feb12

entropy generation in preheating** from the **coherent inflaton (origin of all matter)



pre-heating patch (**<1cm**-now, **<10^{-30} cm**-then)

Barnaby,Bond,Huang,Kofman09

semi ETERNAL INFLATION

quantum diffusion

spatial jitter

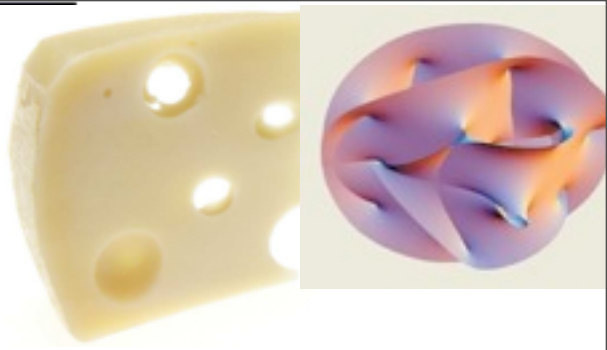
drift

let there be

heat

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

entropy generation in preheating** from the **coherent inflaton (origin of all matter)



pre-heating patch (**<1cm**-now, **<10^{-30} cm**-then)

$a =$ 1

A visualized 2D slice

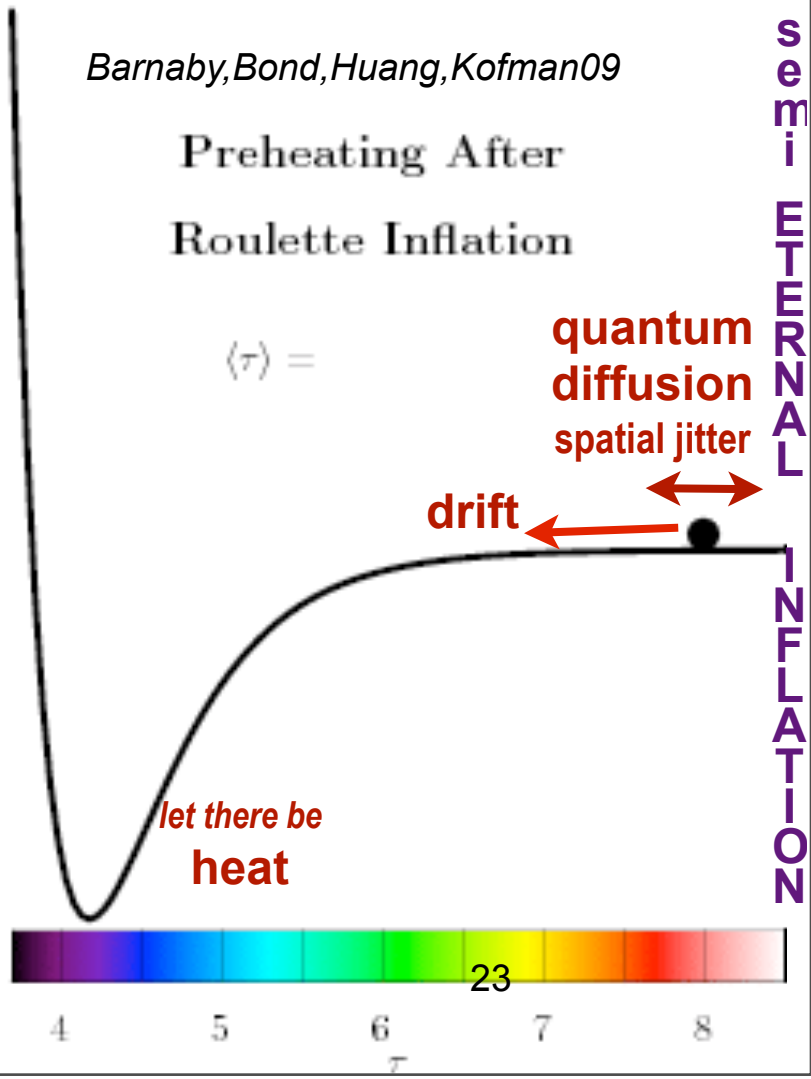
in lattice simulation

Barnaby,Bond,Huang,Kofman09

Preheating After

Roulette Inflation

$\langle \tau \rangle =$



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Coherent Inflation with Quantum Jitter to Hot Big Bang, an Incoherent Particle Soup

how (most of) the entropy in matter

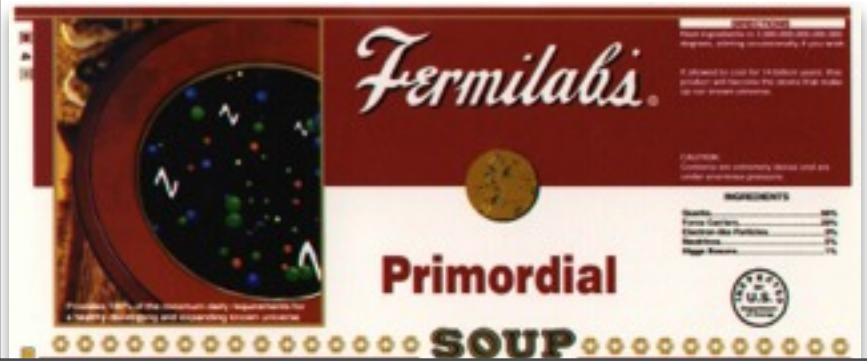
=> *GUT plasma/quark soup* => $S(\gamma,\nu)$ was generated *(through a shock-in-time)*

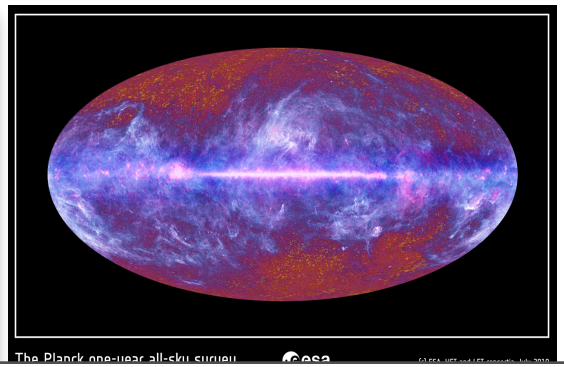
via nonlinear coupling of the inflaton to new interaction channels g,χ_a *ultimately to standard model degrees of freedom*

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

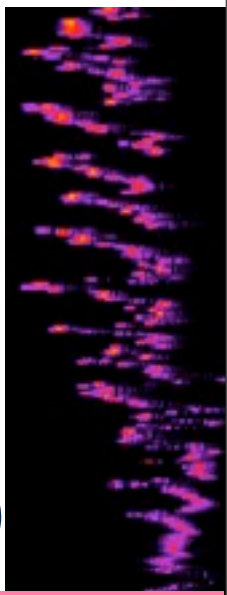
exactly who, what, where, when, why?

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





$a_{Shock}(g)$



non-Gaussianity
(WMAP, **Planck**, LSS)
spiky nG preheating

CITA = Cosmic Information Theory & Analysis: *IT from BIT, from BITs in IT,*

Studying the Cosmic Tango *en-TANGO-ment* ***Universe=System+Res=Data+Theory*** =Signal(s)+*noise*=EFT+*Hidden variables*

Shannon entropy $S_f(D,T) = -\int dq\, P_f \ln P_f$ **=information with no Quality measure on the bits IQ**

~ von-Neumann entropy= Trace ϱ ln ϱ^{-1} , ϱ(U) = ϱ(S,R) = ϱ(R|S) ϱ(S) entanglement of phase & probability

Gaussian random field *with correlation function* ***C*** *weight matrix* C^{-1}

$S = (\text{Trace } \ln C + N_{dof} \ln 2\pi + N_{dof})/2 = \langle \ln V_{phase\text{-}space} \rangle + N_{dof}/2$

=Shannon entropy subject to the constraint $\int dq\, P_f\, \delta q^i \delta q^j = C^{ij}$

relative Shannon entropy $S_{fi} = \text{Tr}\{\ln C_f\, C_i^{-1} + 1 - C_f\, C_i^{-1}\}/2$

cf. ***grand canonical ensemble: constrained*** E_{tot} ***&*** N_A ***&*** V

Lagrange multipliers (conjugate variables) $\beta = 1/T$ *&* $-\beta\mu_A$ *&* $\beta * p$*ressure; in LTE, functions of (x)*

non-eq thermodynamics*: flux* $J_{heat}^{\ i}(x)$ $J_n^{Ai}(x)$ *conjugate thermodynamical forces* B_i $(\sim \partial_i \beta)$

more constraints (e.g., higher point correlations & more complexity) reduce entropy by limiting the freedom of the degrees of freedom q: ***non-Gaussian distributions have lower S***

Lagrange multipliers: out-of-equilibrium drivers κ_i *for* $\langle \delta q^i \rangle$ *and* K_{ij} *for* $C^{ij} \langle \delta q^i \delta q^j \rangle$

problem: ***Dimensional Reduction*** *when eigenvalues of C ~ 0, S ~* $-\infty$*: but cold degrees of freedom should have S=0 (3rd). Bose-Einstein & Fermi-Dirac statistics - indistinguishable cf. distinguishable. Condensates form when too much N for E.*

nr Sackur-Tetrode: $\Delta s = \frac{1}{2}\text{Tr} \ln \langle \Delta P_{ij}/\rho \rangle + \ln \rho^{-1}$ *(+clumping+anisotropy..)*

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eU S: $\Delta s = \Delta\, 1/2 \text{Tr}\, C \ln\rho \ln\rho$ **info-content in phonons** $\sigma = -\ln[\rho\, V/E]$

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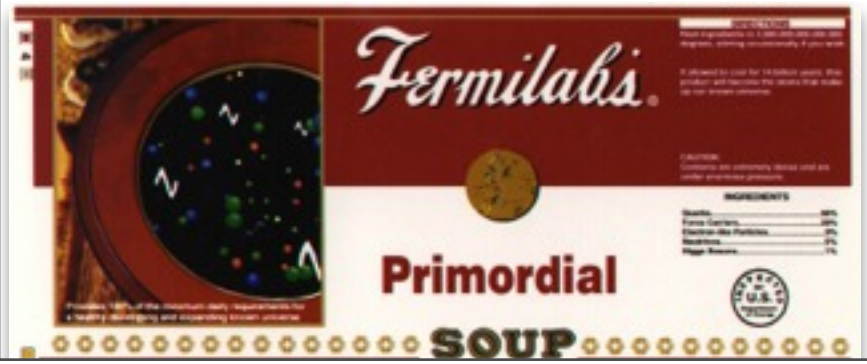

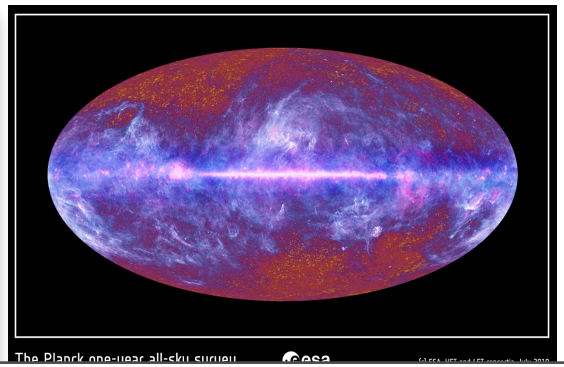

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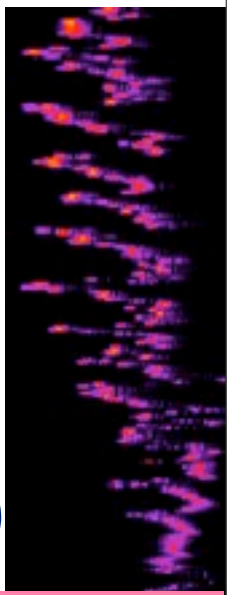

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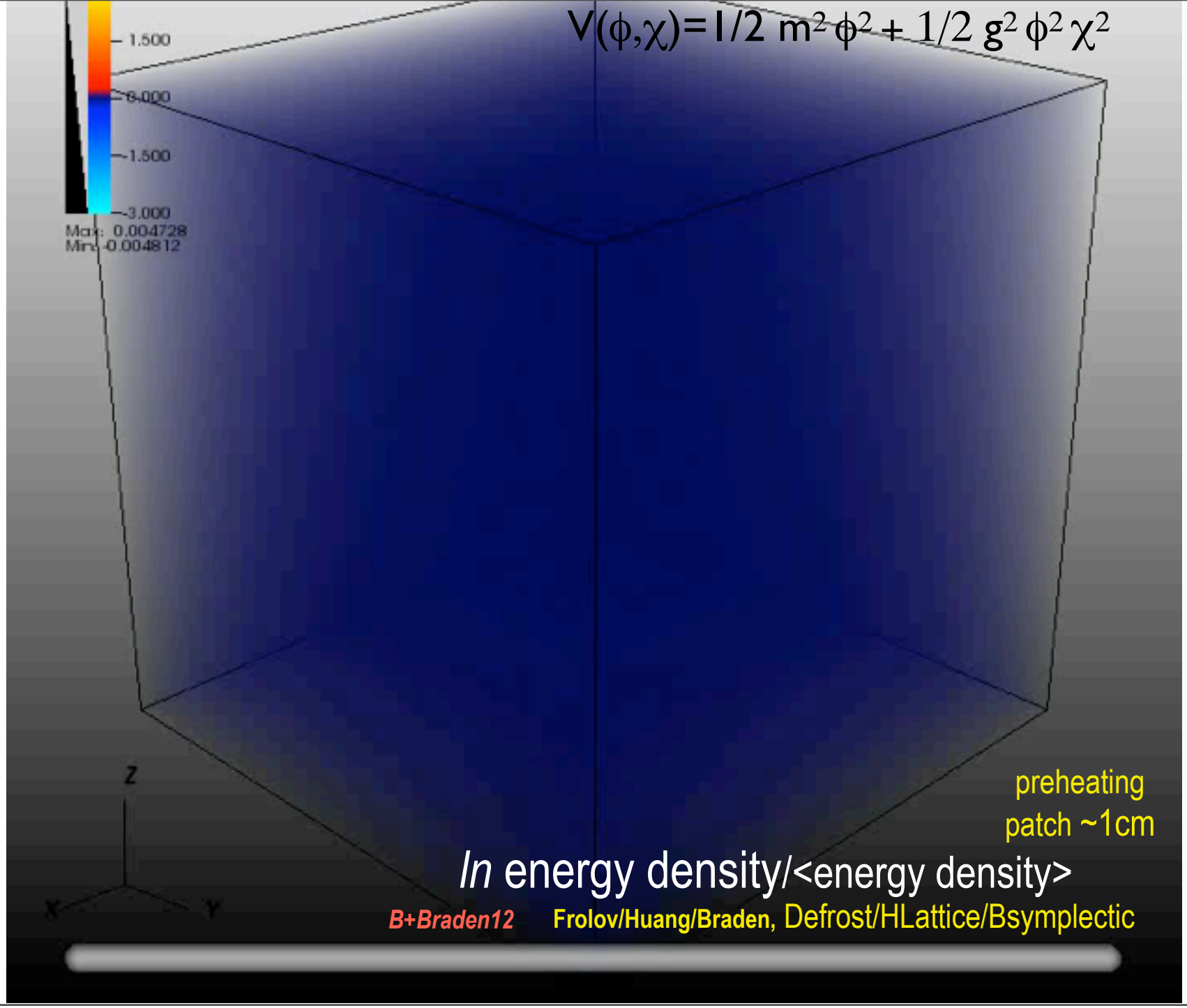
(WMAP, **Planck**, LSS)
spiky nG preheating


$V(\phi,\chi)=1/2\ m^2\phi^2+1/2\ g^2\phi^2\chi^2$
1.500
-0.000
-1.500
-3.000
Max: 0.004728
Min: -0.004812
Z
X
Y
preheating
patch ~1cm
ln energy density/<energy density>
B+Braden12
Frolov/Huang/Braden, Defrost/HLattice/Bsymplectic

post-shock ⇒ Hydrodynamics phonon description works

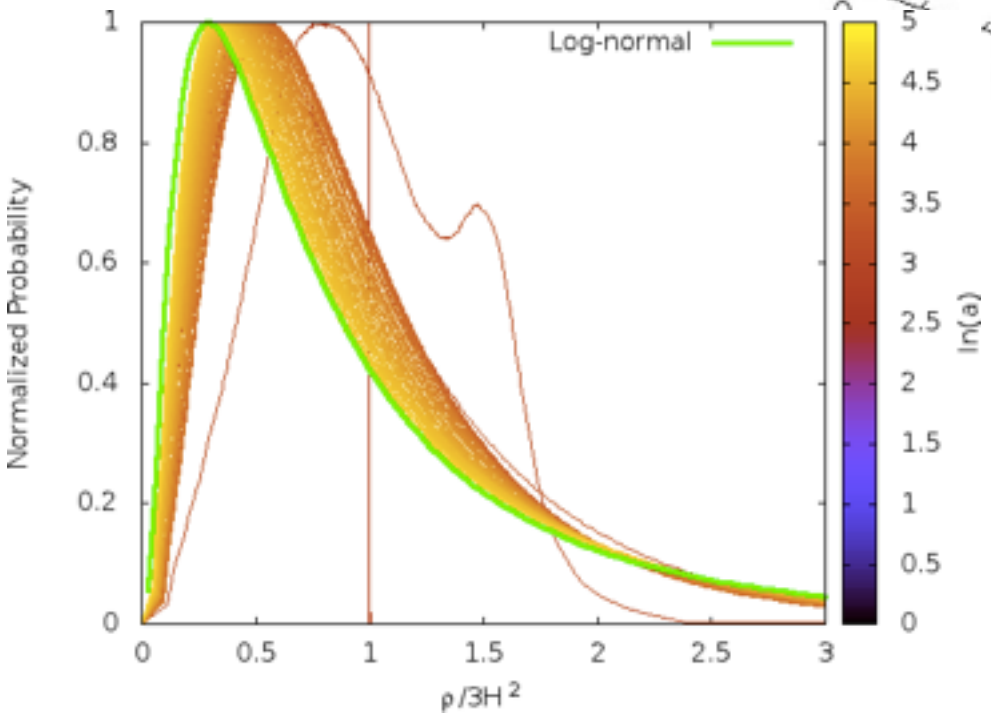
spatial complexity ⇒ statistical simplicity (1-pt, 2-pt)

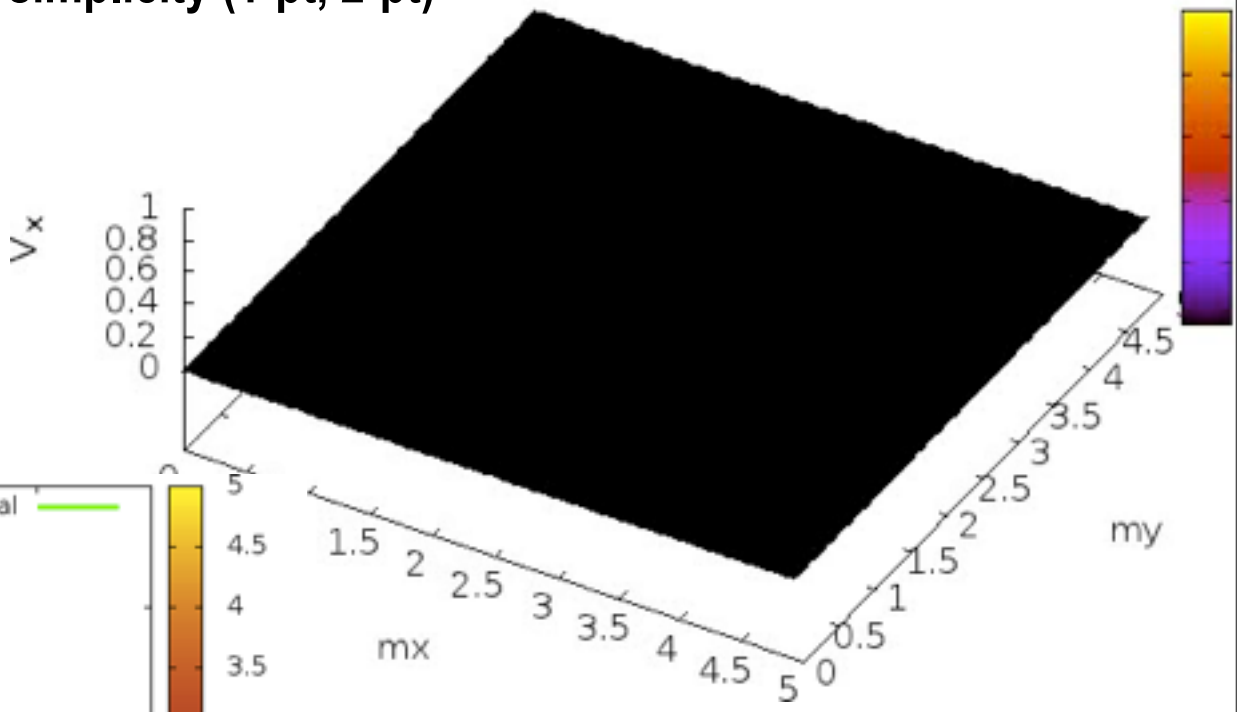
B+Braden12

$\rho = -T^0{}_0 \quad P = -T^i{}_i$

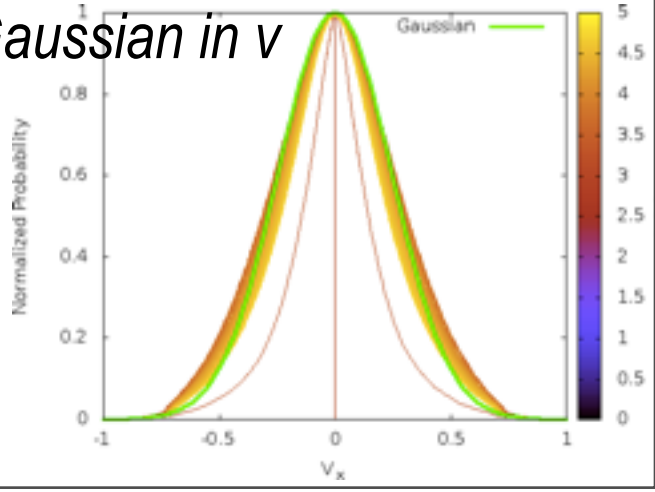
$v^i = aT^i{}_0 / (\rho + P)$

nearly Gaussian in ln ρ/<ρ>



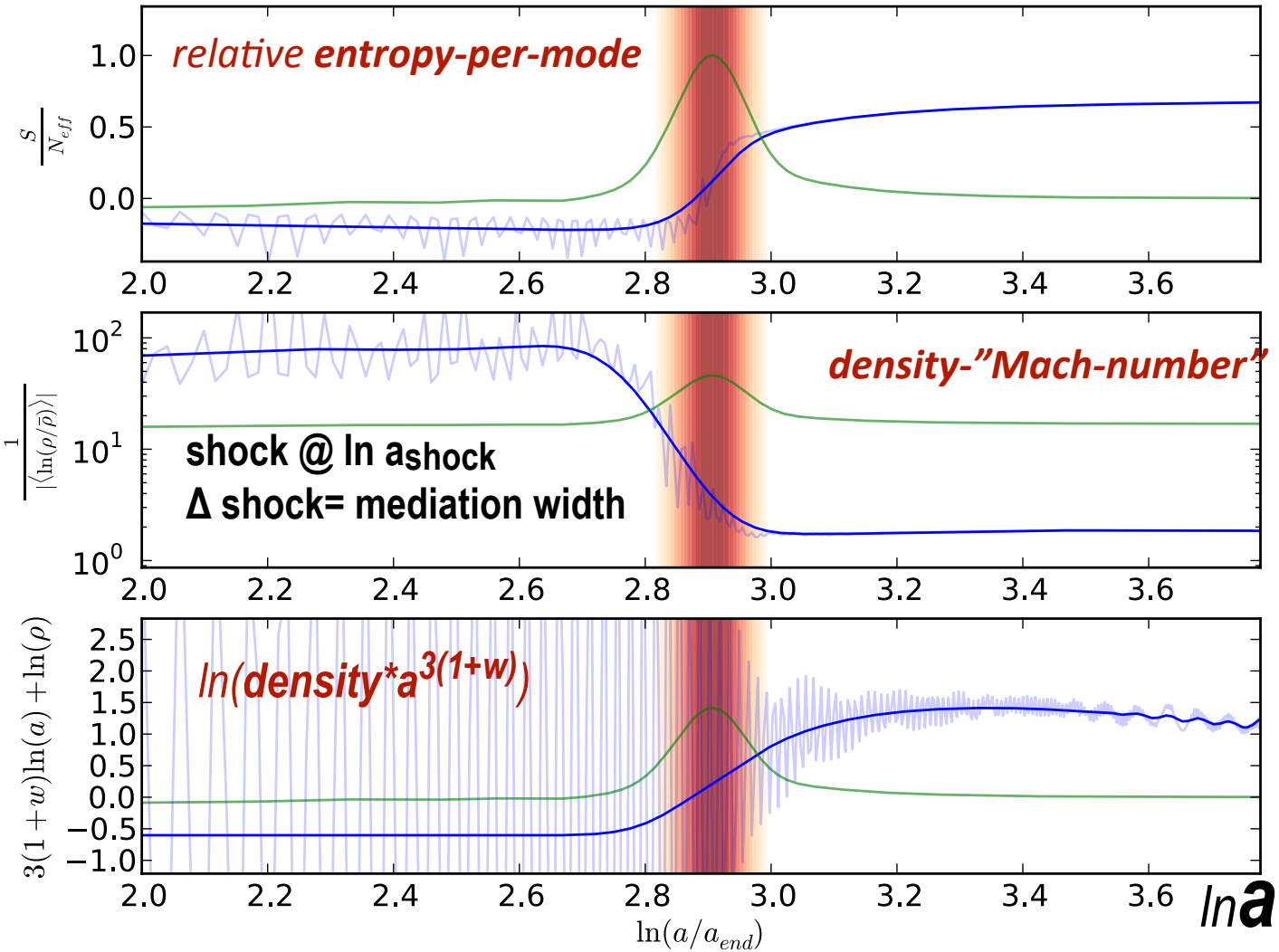


nearly Gaussian in v



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

the Shock-in-time: entropy production, <ln(density-contrast)>$^{-1}$,ln(density*$a^{3(1+w)}$)



true thermal equilibrium far off

➤

& on to coupling to standard model degrees of freedom

constrained coarse-grained ***Shannon-entropy(ln a)*** minus the initial Gaussian random field entropy (from band-limited quantum fluctuations)

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

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

B+Braden12

the Shock-in-Times of Post-inflation Preheating B+Braden12

Initial State = Nearly Homogeneous Inflaton

low entropy (coherent φ + vac fluctuations), *information encoded in a few parameters*

Preheating

Instabilities result in nonlinear transition to an incoherent state, resonances?
KLS 94, 97,e.g. Tkachev, Felder, Garcia-Bellido, ...

the shock-in-time is the sharp mediator between the linear & the highly nonlinear transition
a fascinating non-Gaussianity can arise if there is a spatial modulator field varying the shock time

(Near Adiabatic) *Transition Regime*

Complex slowly evolving nonlinear, nonequilbrium state e.g. Micha and Tkachev 2004,
turbulence analogy??? ***the evolution is NOT a Kolmogorov-like turbulent cascade to higher modes***

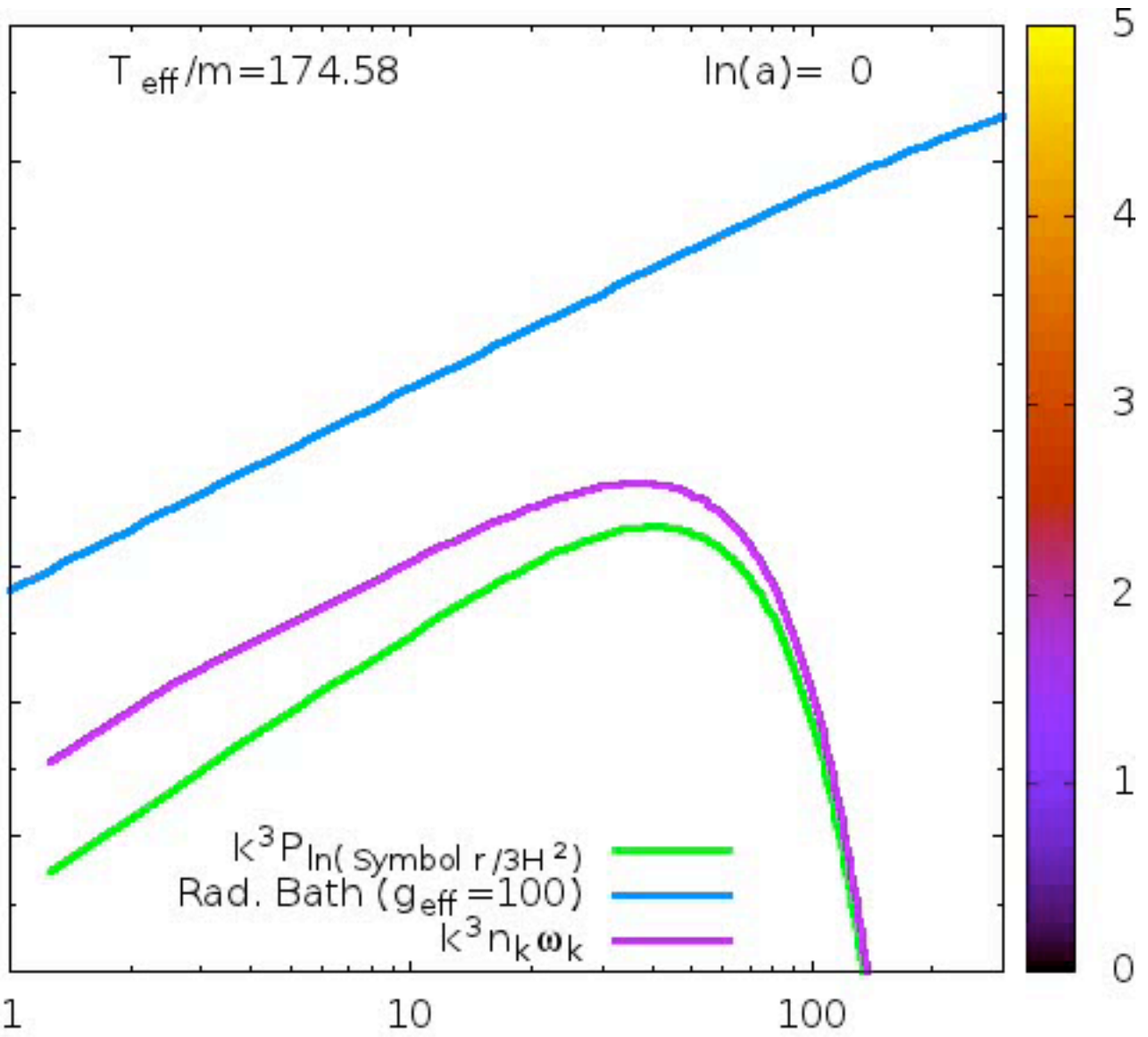
Final State = Thermal Equilibrium

= maximum spreading of information in modes subject to energy & particle number constraints. *How to couple to standard model dofs to accelerate the power spectrum evolution to a thermal bose-einstein distribution function?*

coherent inflaton => incoherent mode cascade of fields thru a shock-in-time to thermal equilibrium

$s_{Ui\sim 0}$; $s_{Utot,m+r}/n_b \sim 1.66\times10^{10}$ bits/b; $s_\gamma / n_\gamma = 5.2$ bits/Υ = 2130/411; $s_v = 21/22\ s_\gamma$

ln ρ/<ρ> power spectrum cf. instantaneous full thermal spectrum cf. conventional energy spectrum using a pseudo particle occupation number



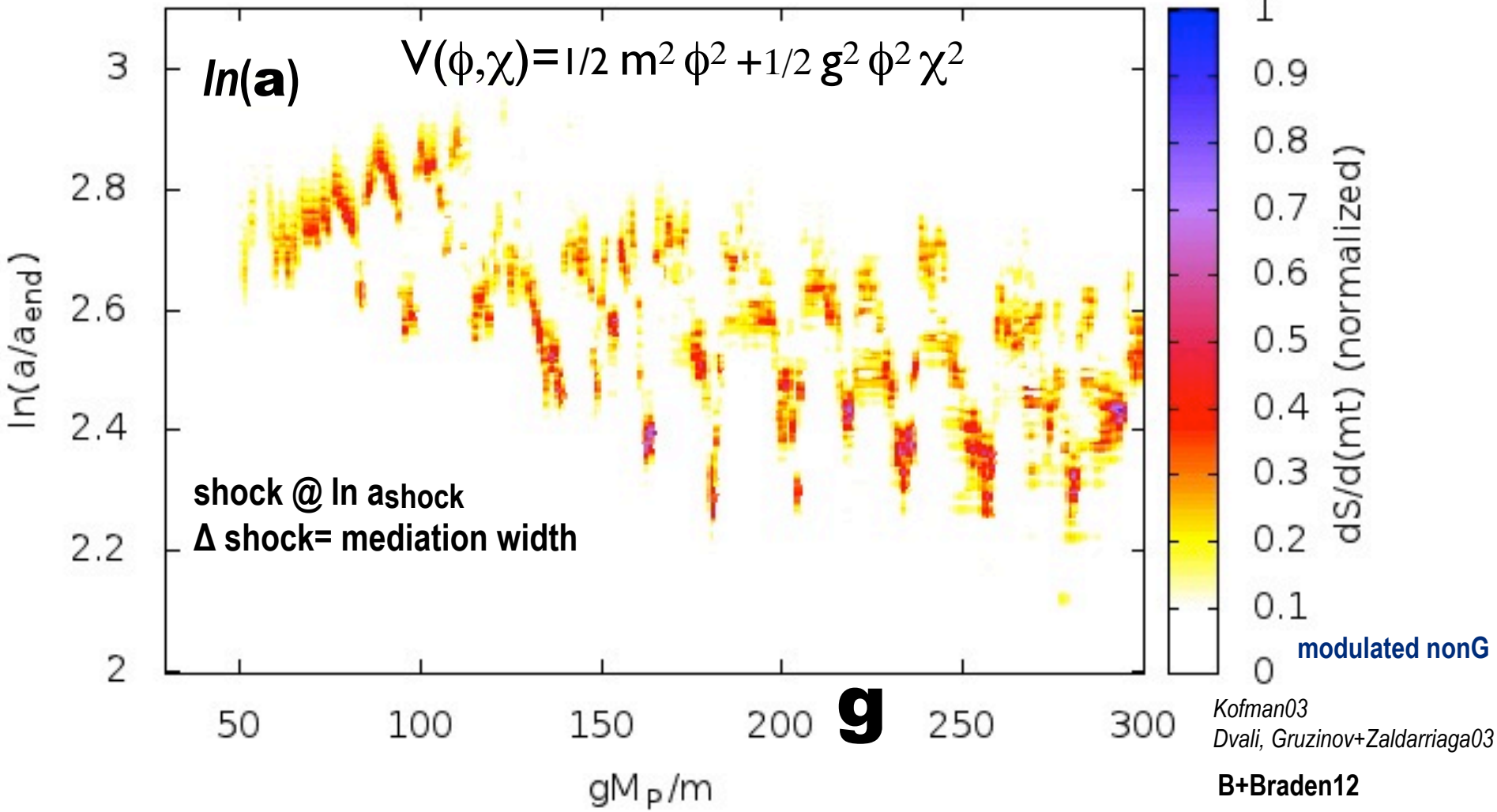
$V(\phi,\chi)=1/2\ m^2\phi^2+1/2\ g^2\phi^2\chi^2$

B+Braden12

dS/dt(t,g) => *the Shock-in-time: entropy production rate*

non-Gaussianity (WMAP, **Planck**, LSS) spiky nG preheating

$\delta ln a_{shock}$ (**g**(σ(**x**)) => modulated non-Gaussianity from preheating!



Kofman03
Dvali, Gruzinov+Zaldarriaga03

B+Braden12

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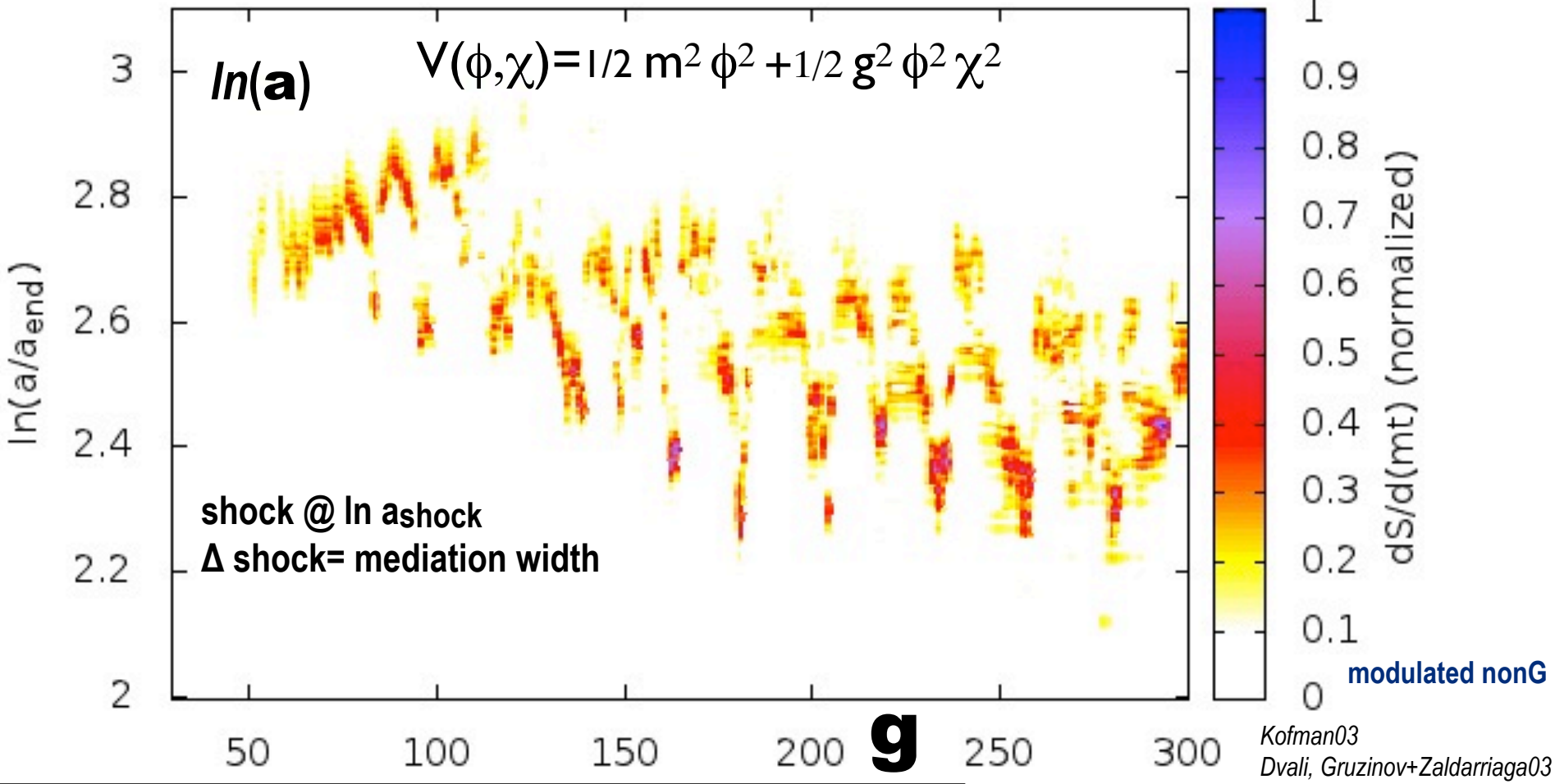


Kofman03
Dvali, Gruzinov+Zaldarriaga03

B+Braden12

B+Frolov, Huang, Kofman 09

B+Braden, Frolov, Huang 12

Chaotic Billiards NonG V(ϕ,χ)=1/4 λϕ⁴ +1/2 g² ϕ² χ²

δln a$_{shock}$(χi(x) |g²/λ)) => ***NonG of cold spots ++***

BBM12: 3D Oscillons & Colliding Bubbles?

$dS/dt(t,g)$ => *the Shock-in-time: entropy production rate*

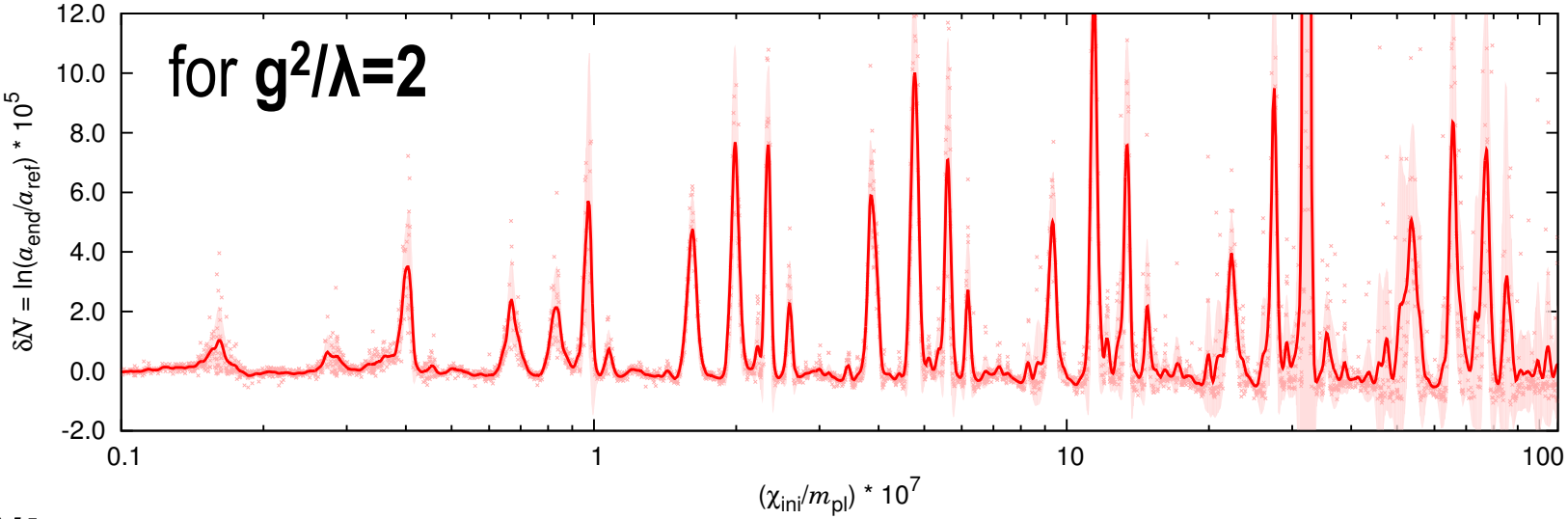
non-Gaussianity (WMAP, **Planck**, LSS) spiky nG preheating

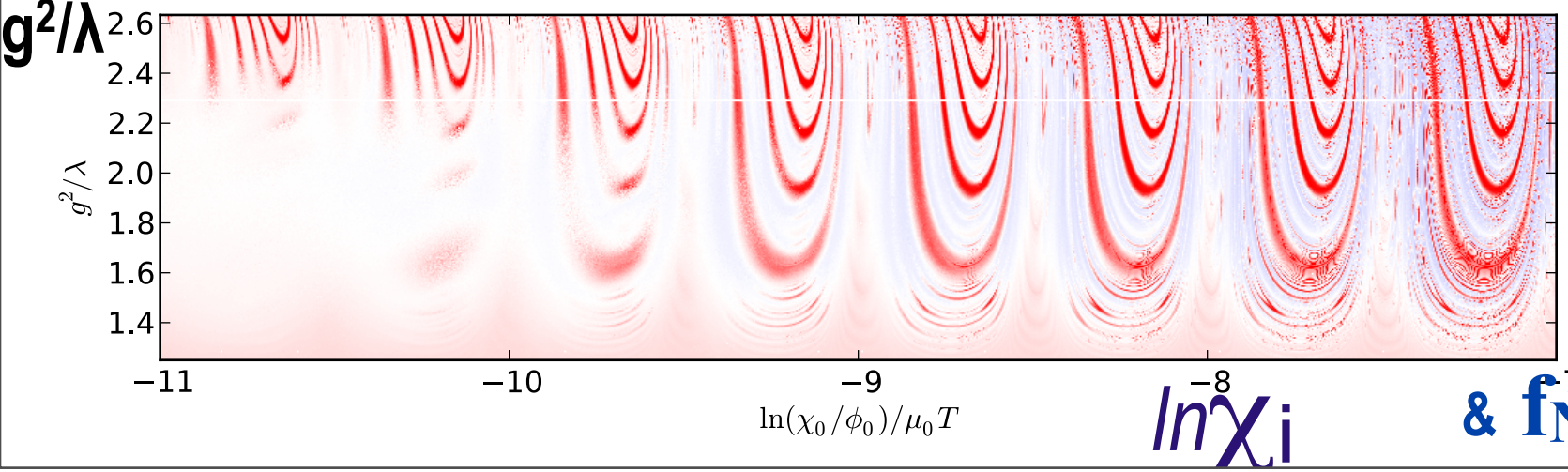
$\delta ln a_{shock}(\chi_i(x) | g^2/\lambda))$ => *Chaotic Billiards: NonG from Parametric Resonance in Preheating*

B+Frolov, Huang, Kofman 09
B+Braden, Frolov, Huang 12

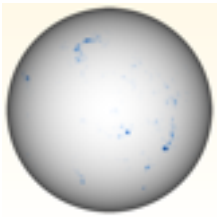
$V(\phi,\chi)=1/4\ \lambda\phi^4+1/2\ g^2\phi^2\chi^2$

$ln a$





huge number of 64^3 ***sims to show the wondrous complexity of*** $ln a(\chi_i, g^2/\lambda)$



& f_{NL}^{equiv}

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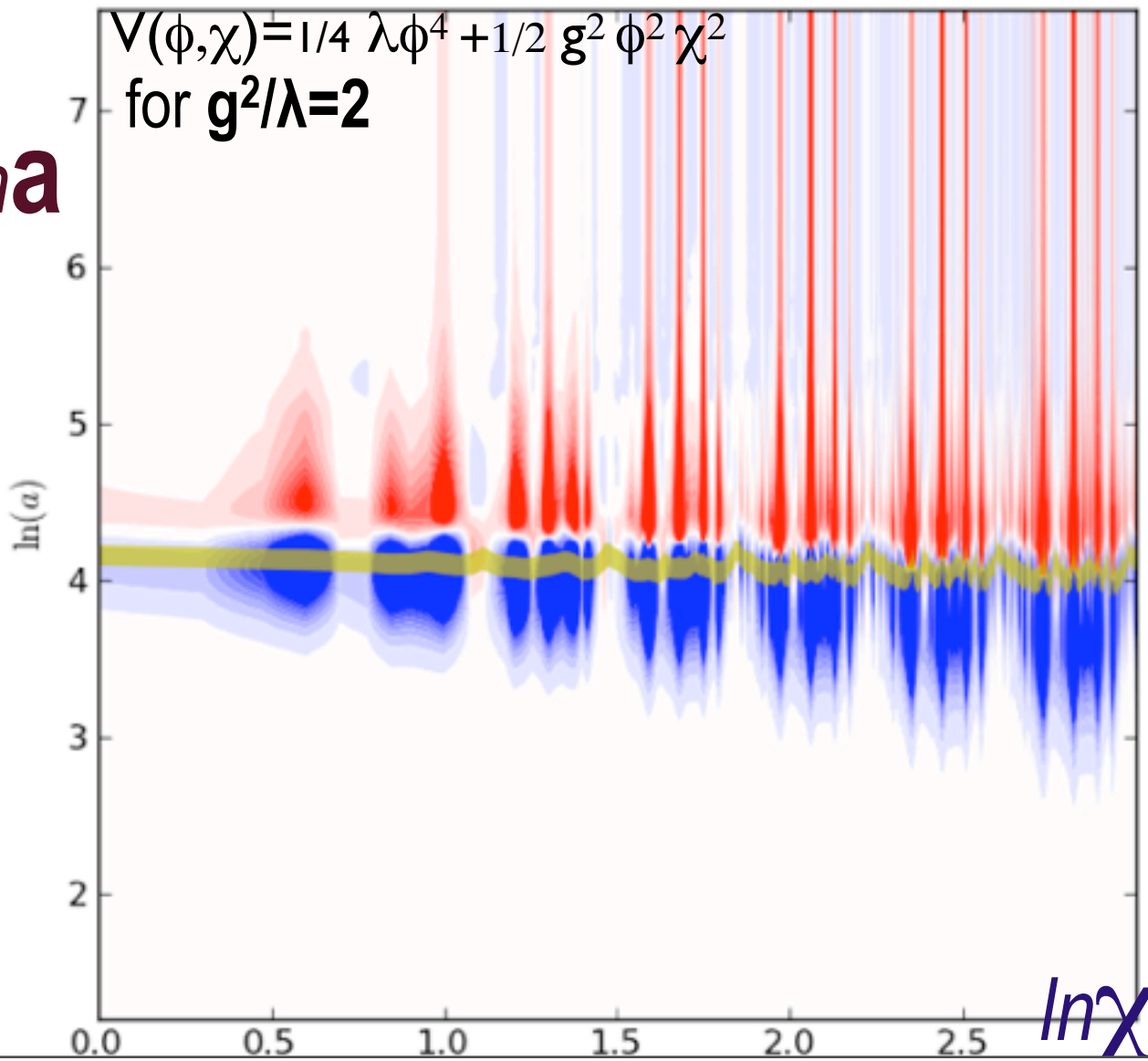
B+Frolov, Huang, Kofman 09

B+Braden, Frolov, Huang 12

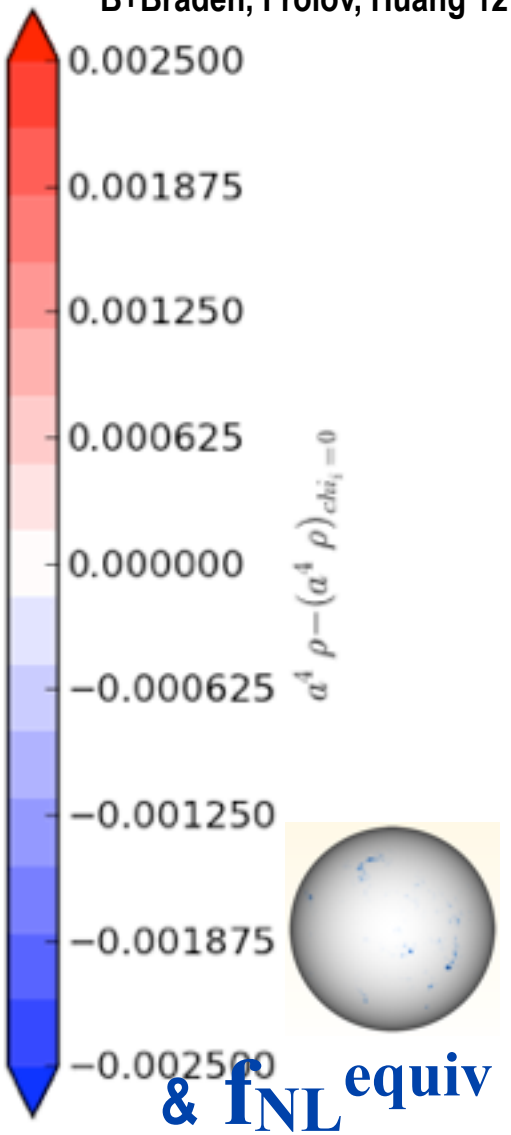
$V(\phi,\chi)=1/4\ \lambda\phi^4 + 1/2\ g^2\phi^2\chi^2$

for $g^2/\lambda=2$



ln a

ln χi



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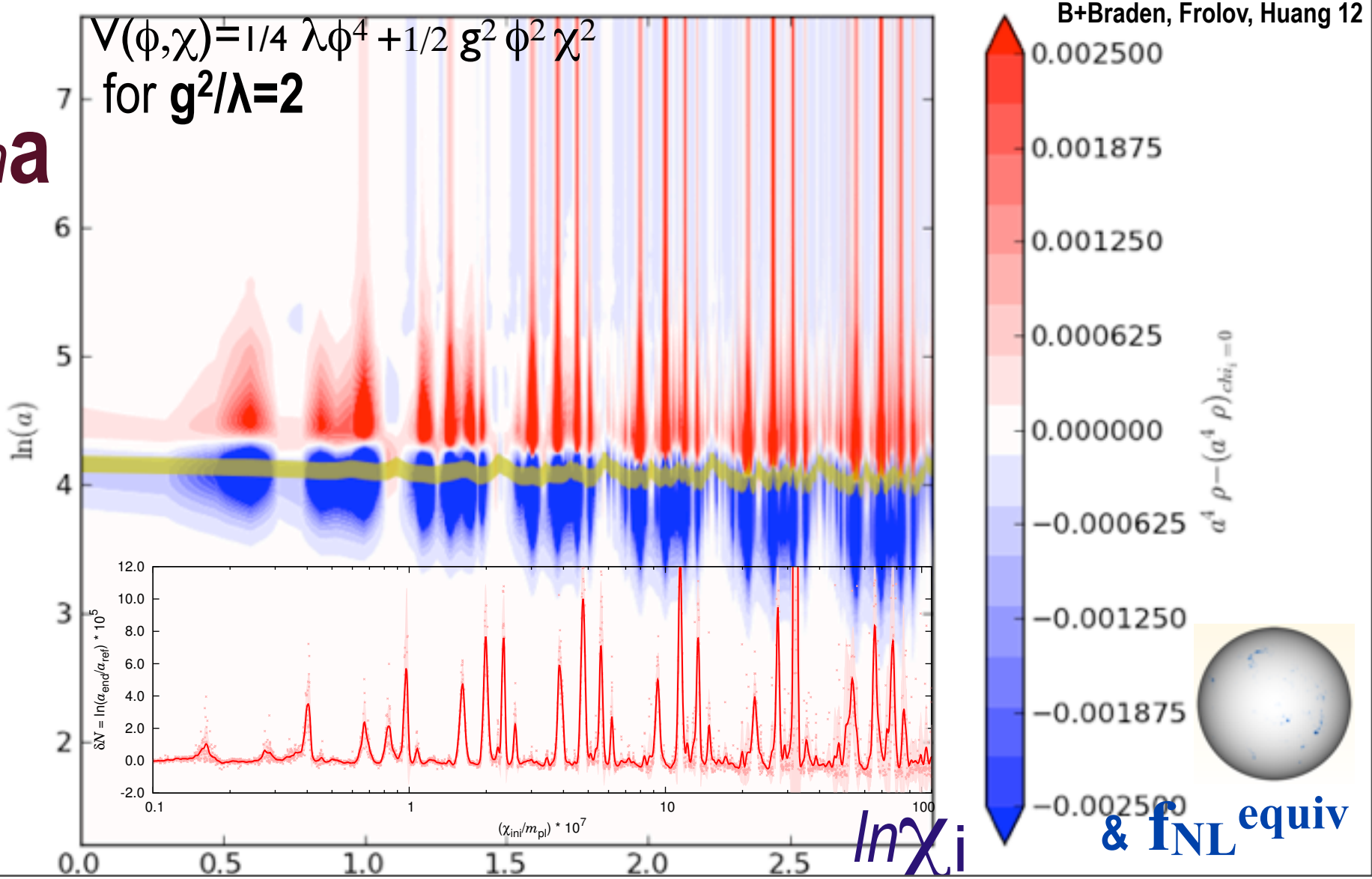
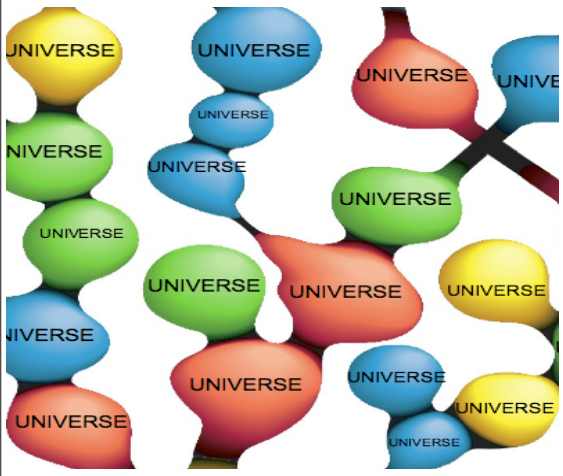
(WMAP, **Planck**, LSS)
spiky nG preheating

δlna$_{shock}$(χi(x) |g²/λ)) => ***Chaotic Billiards: NonG from Parametric Resonance in Preheating***

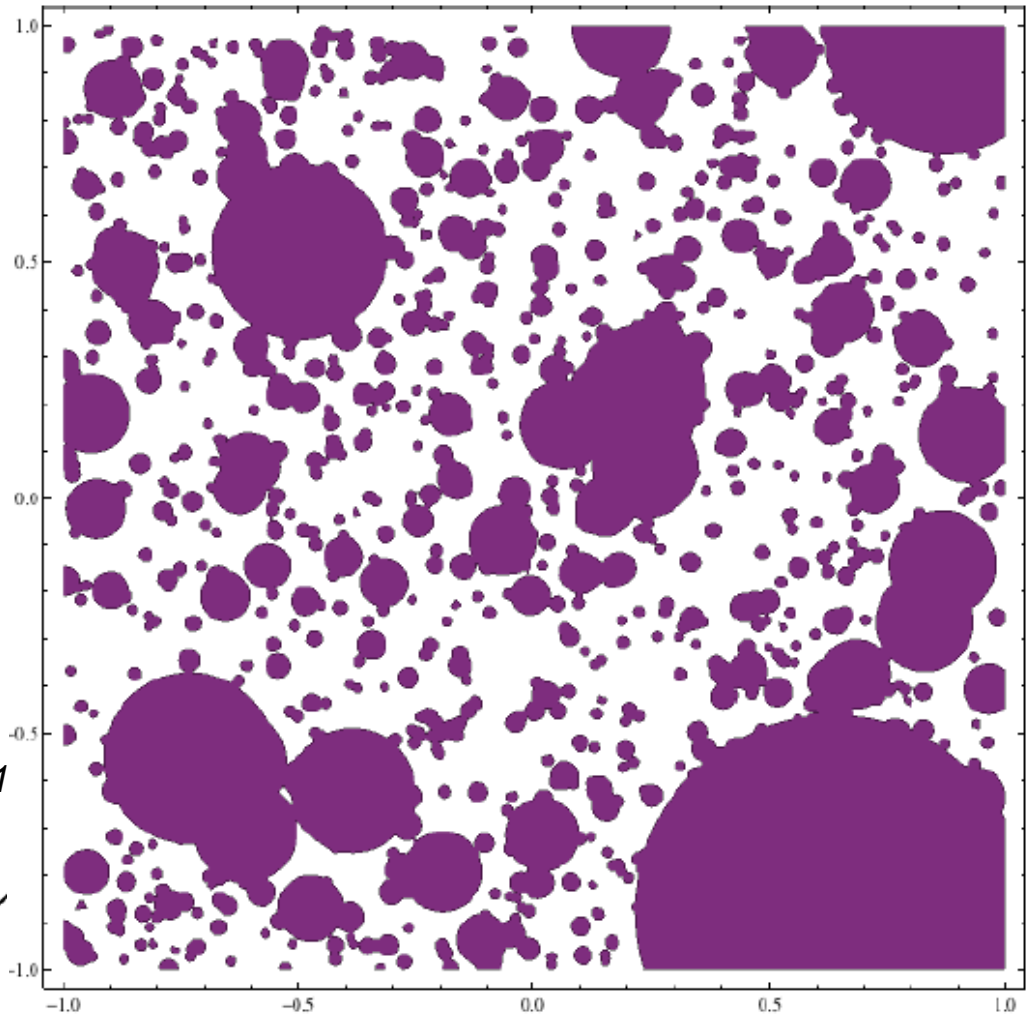
B+Frolov, Huang, Kofman 09
B+Braden, Frolov, Huang 12



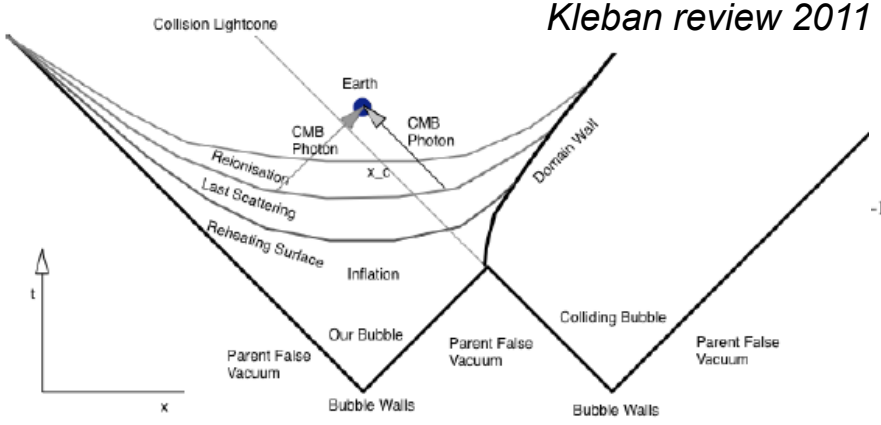
& f_{NL}^{equiv}



or thru tunnelling between potential wells when bubbles collide



Kleban review 2011



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

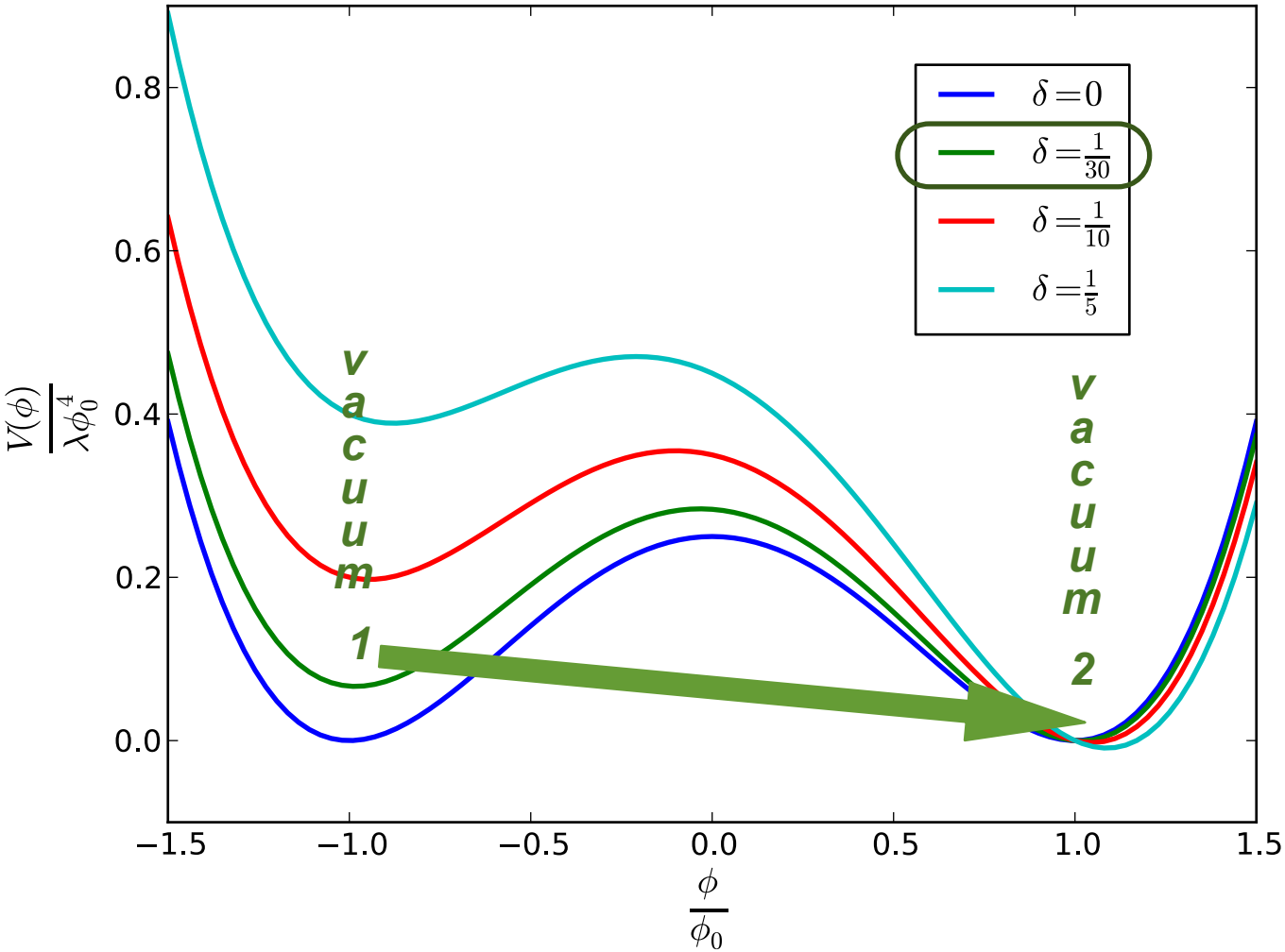
cf. 1D work that dominates the subject

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

an oscillon phenomenon is possible in preheating Easther+

CMB+ observables?

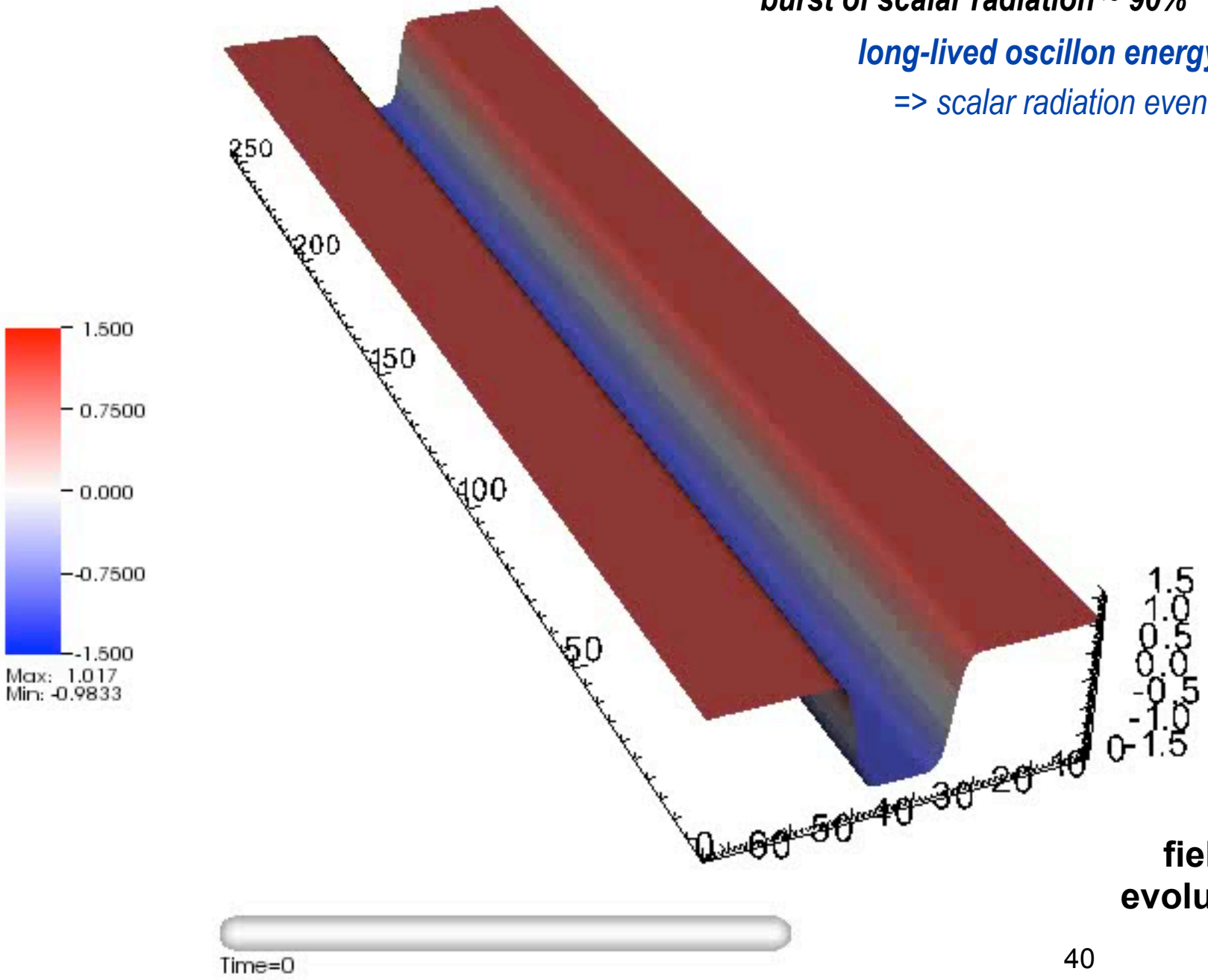
B+Braden+Mersini 2012



burst of scalar radiation ~ 90%

long-lived oscillon energy ~ 10%

=> scalar radiation eventually



field evolution

B+Braden+Mersini 2012

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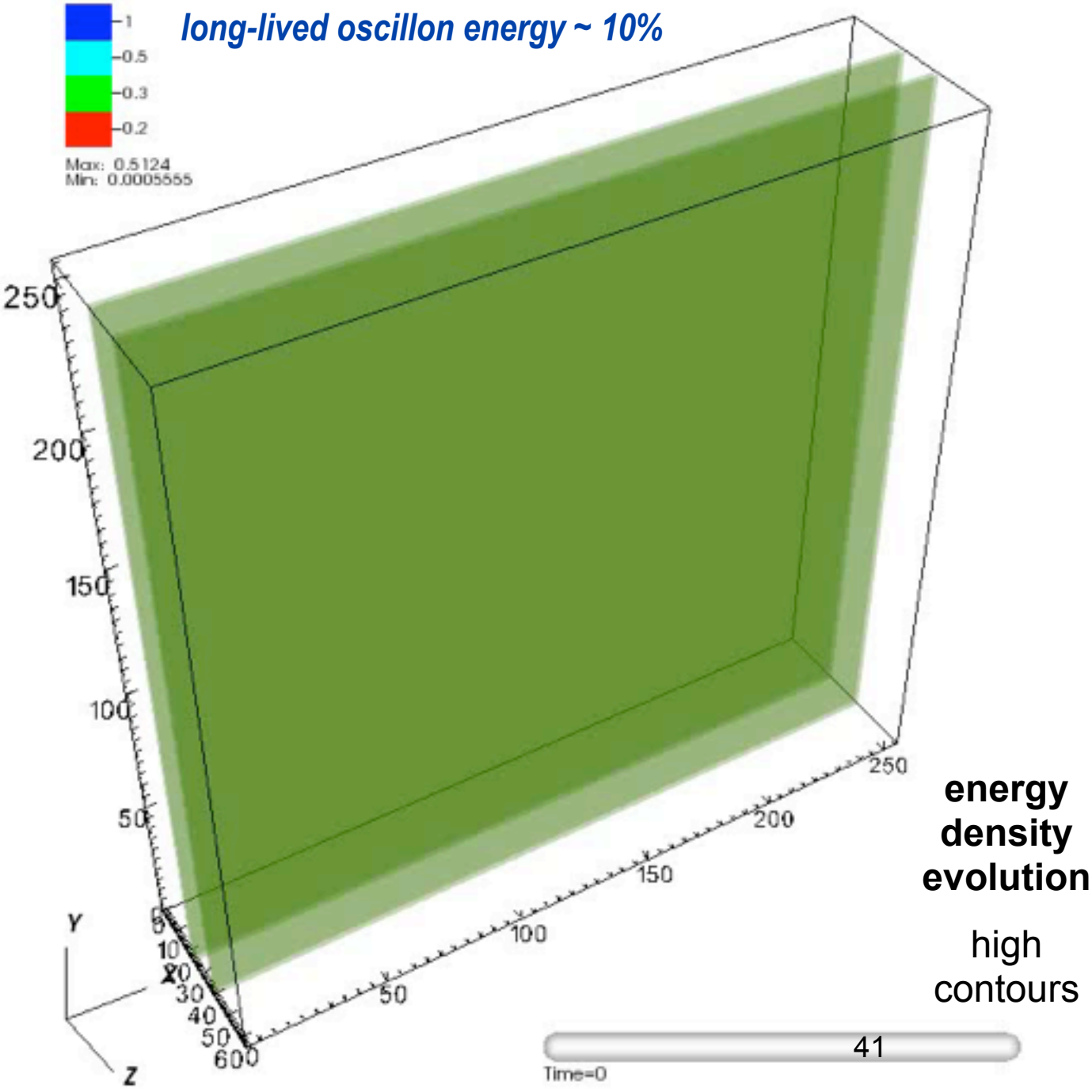

energy density evolution

high contours

Dick Bond CIFAR@CITA with CITA aka *Cosmic Information Theory & Analysis*

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the **nonlinear COSMIC WEB**

dS_G/dt

INFLATION

primary anisotropies

- linear perturbations: scalar/density, tensor/ gravity wave
- tightly-coupled photon-baryon fluid: oscillations $\delta\gamma$ $v\gamma$ $\pi\gamma$
- viscously damped
- polarization $\pi\gamma$
- gravitational redshift Φ SW $d\Phi/dt$

DarkM

Decoupling LSS

17 kpc (19 Mpc)

secondary anisotropies

$dS/dt>0$

- nonlinear evolution
- weak lensing
- thermal SZ +kinetic SZ
- $d\Phi/dt$
- dusty/radio galaxies, dGs

DarkE

MILKY WAY

z=0

Lsound/ ksound

Bayesian flow prior to posterior via likelihood

reionization

$dS_{astro}<0$

$dS/dt>0$

z ~ 1100 redshift z z ~ 10

13.7-10^{-50}Gyrs | 13.7Gyrs | time t | 10Gyrs | today

Studying the
Cosmic Tango

some non-early U applications of "CITA" to cosmic-complexity

- information in **nearly-Gaussian** density/potential random **fields** of U, & in weakly and strongly non-linear fields. *ergodic theorem & constrained fields*
- 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 - CMB fgnd

- **nr Sackur-Tetrode: $\Delta s = 1/2 \mathrm{Tr}\, ln \langle \Delta \mathrm{Pressure}_{ij} / \rho \rangle + ln\, \rho^{-1}$**

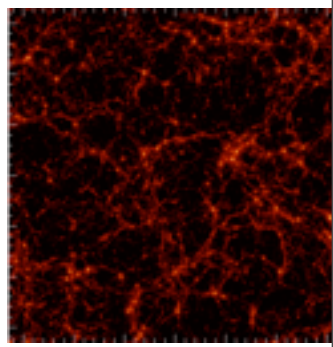
(+clumping+anisotropy..)

dS/dt 2

how most of the entropy in baryons & dark matter was generated

strain waves break => clusters/groups (galaxies/dwarfs) in the cosmic web collapse => shocked gas & extreme nonlinear phase space entanglement of dark matter / stars

then the baryons feed back entropy: exploding stars, accreting black holes, dusty CIB radiation



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Secondary Anisotropies
(tSZ, kSZ, WL, reion, CIB; hydro)

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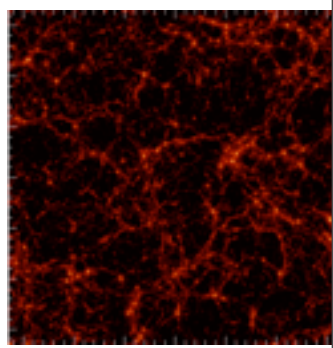


Learning the Cluster Tango

$S_{th,cl} \sim 10^{76}$

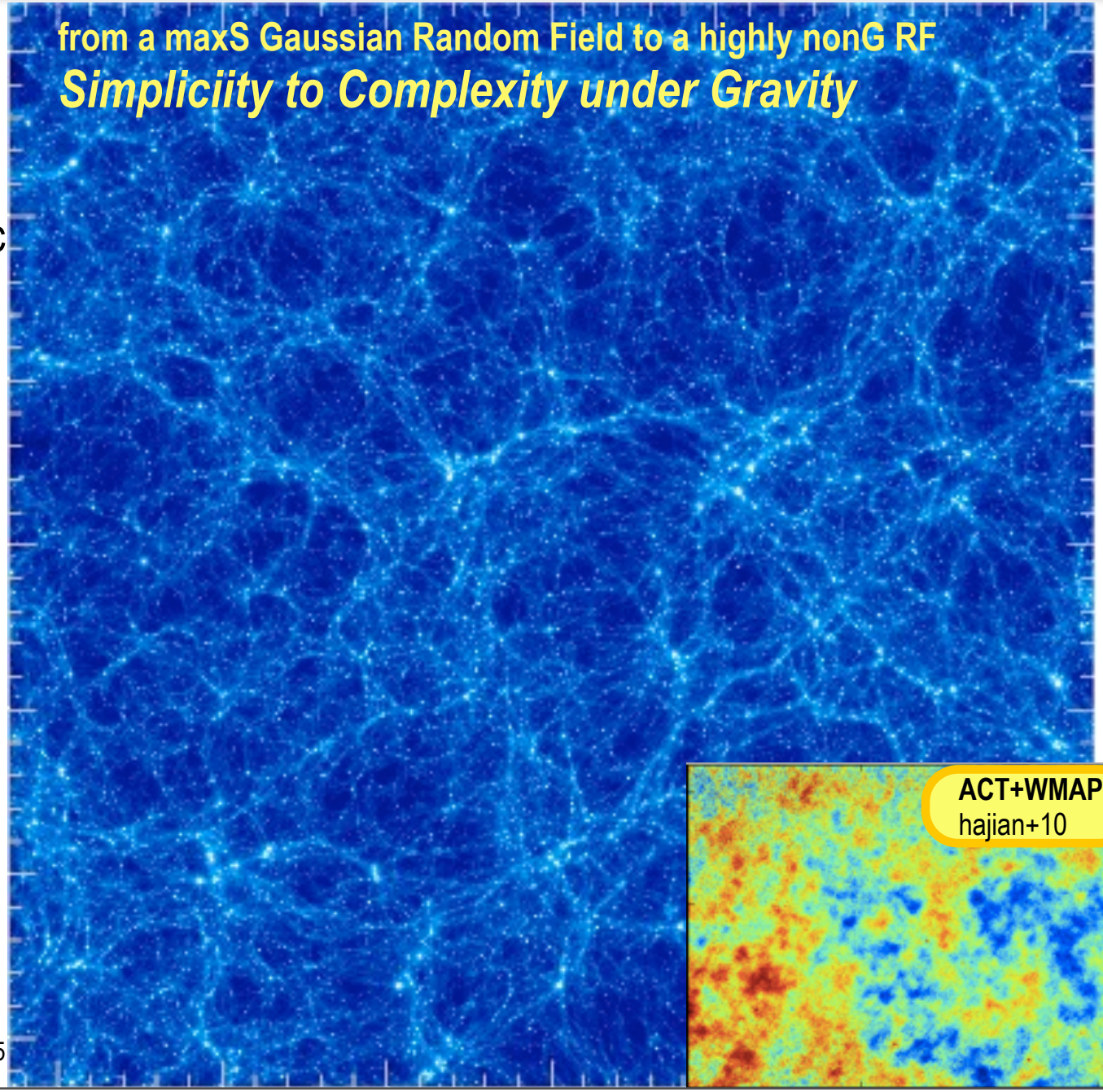
cf. $S_{U,m+r} \sim 10^{88.6}$

***Cosmic Hydro Sims** include all effects -*
***except of course those not included** Thou Shalt Mock*
(10+10+20 256^3 SPH gas+DM)
(1+1+1 512^3 gas+DM) *ΛCDM* + ...

nr Sackur-Tetrode: $\Delta s = 1/2 \mathrm{Tr}\, ln \langle \Delta P_{ij} / \rho \rangle + ln\, \rho^{-1}$ *(+clumping+anisotropy..)*

fine-*macro-small***-grain 10^6 baryons in cubic metres** cf. **sph--***macro-large***- grain 10^{65} baryons. ~26 dims per sph-grain, huge dimensional reduction, scaled-radial-***resolution***-grain further dim reduction. entanglement of fine & coarse & EFT. feedback.**

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



$\rho_g(x,t)$

a~1 now

400 Mpc

ΛCDM

WMAP5

gas density

Gadget-3

SF+ SN E+ winds +CRs

512^3

BBPSS10

BBPS1,2,3,4,5

a~e^{-7}~1/1100

entropy intermittency *in the cosmic web, via gravitation-induced shocks (then E/S-feedback)*

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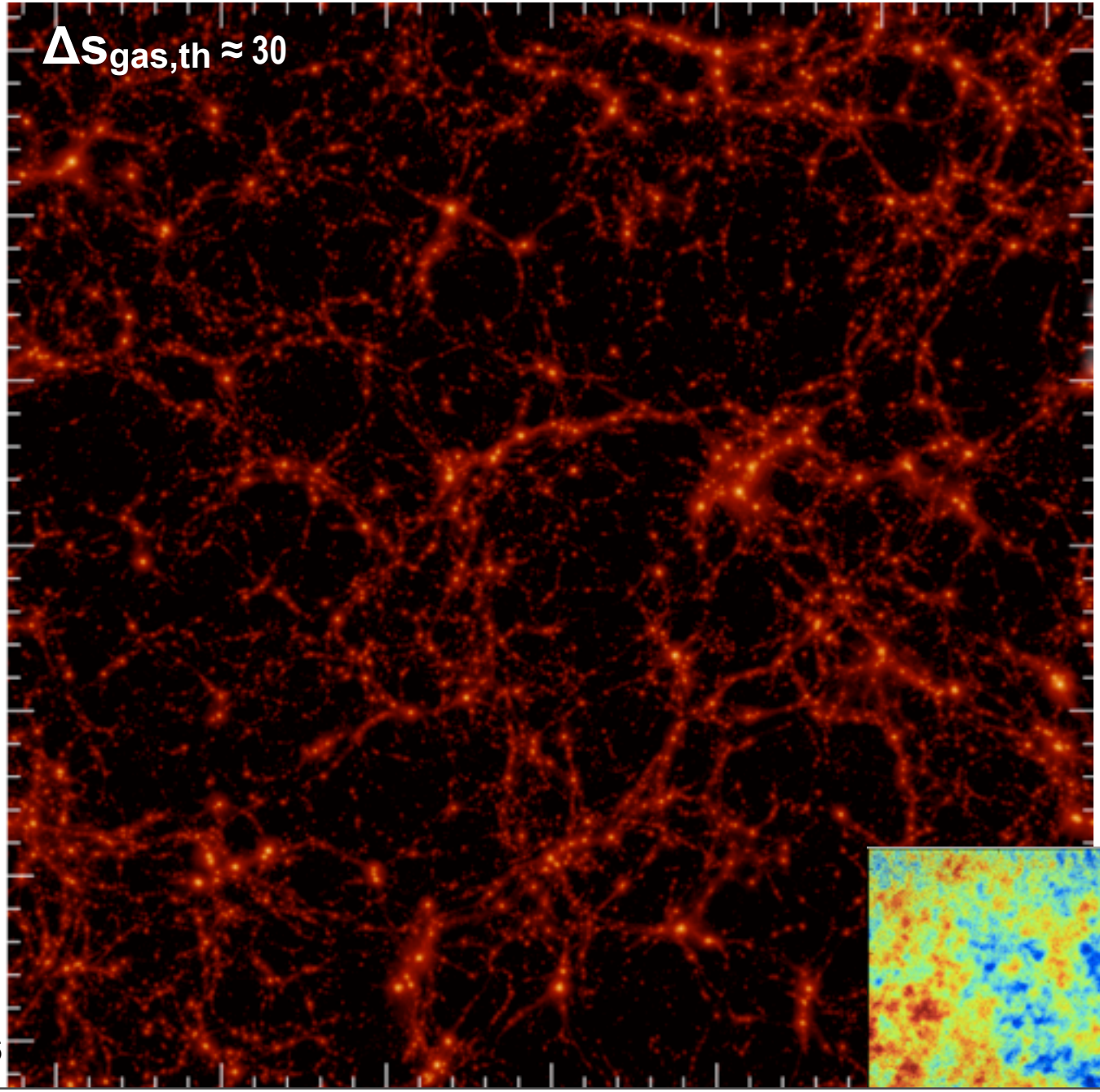
$s_{b,th}(x,t)$



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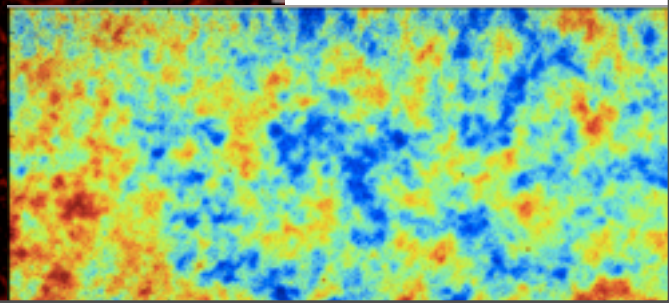
CMB gets entangled in the cosmic web

descending into the real gastrophysics of cosmic weather

the energetic, turbulent, dissipative, compressive

life of the IGM/ICM/ISM



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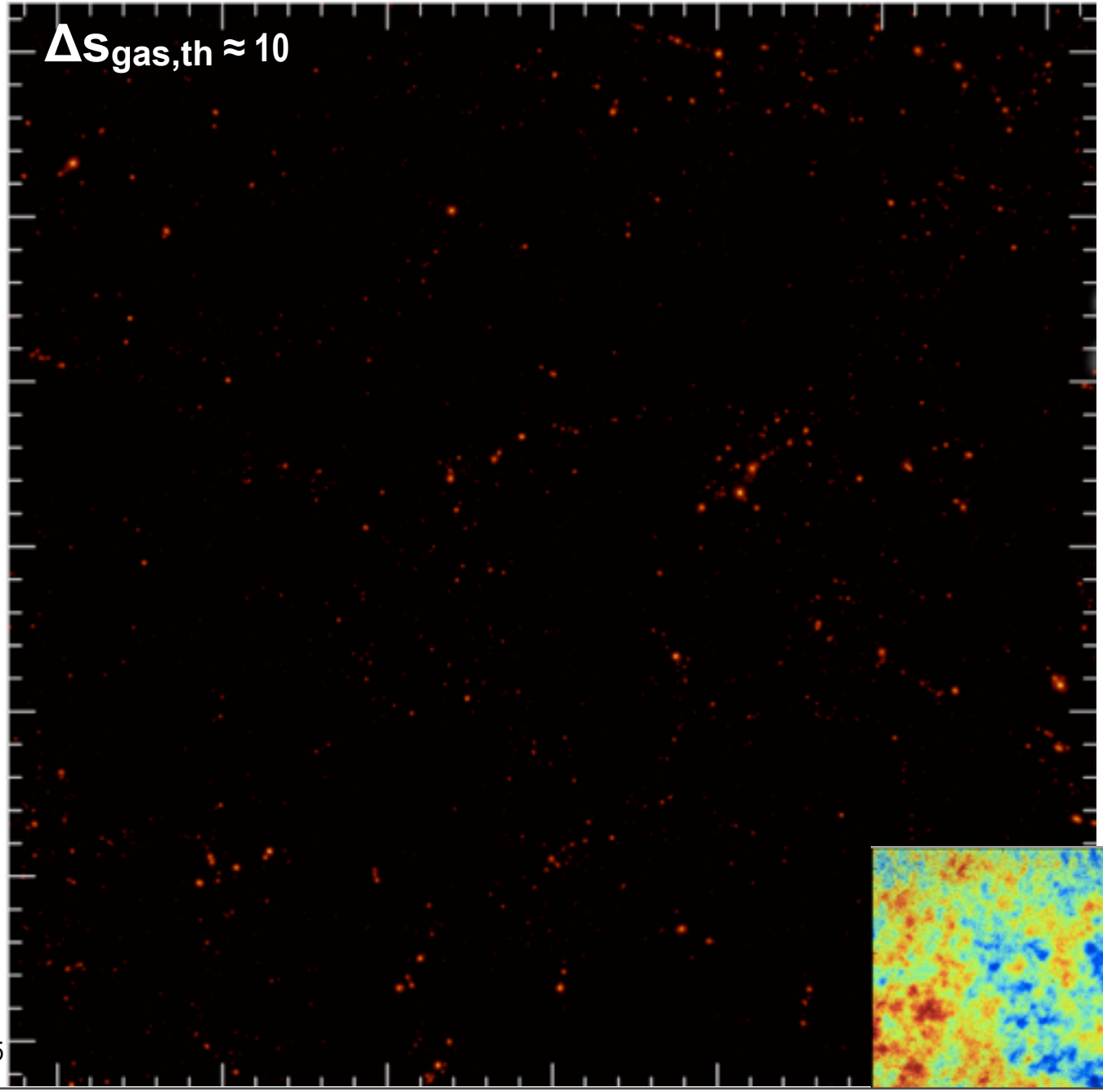

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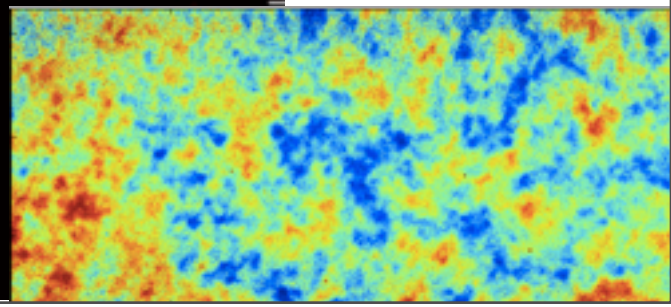

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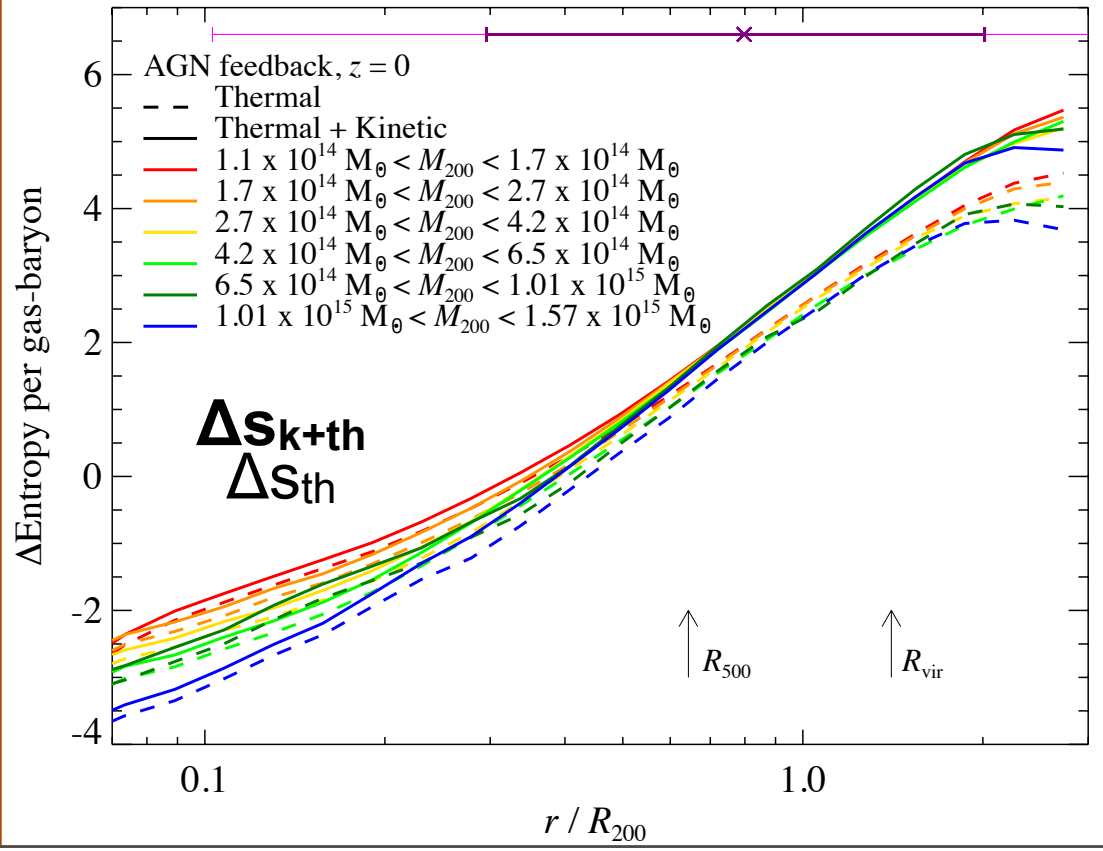
$\Delta s_{gas,th} \approx 30$

***Entropy*-per-gas-baryon**

$\Delta s_{gas,cluster} \approx$
3 *ln* X ~12bits/b +
1 bit/b non-thermal

P_{kin}/P_{th}~0.1-0.6!

zero point $s_{th,0}$ ~ 130 nats
~ 190 bits/baryon



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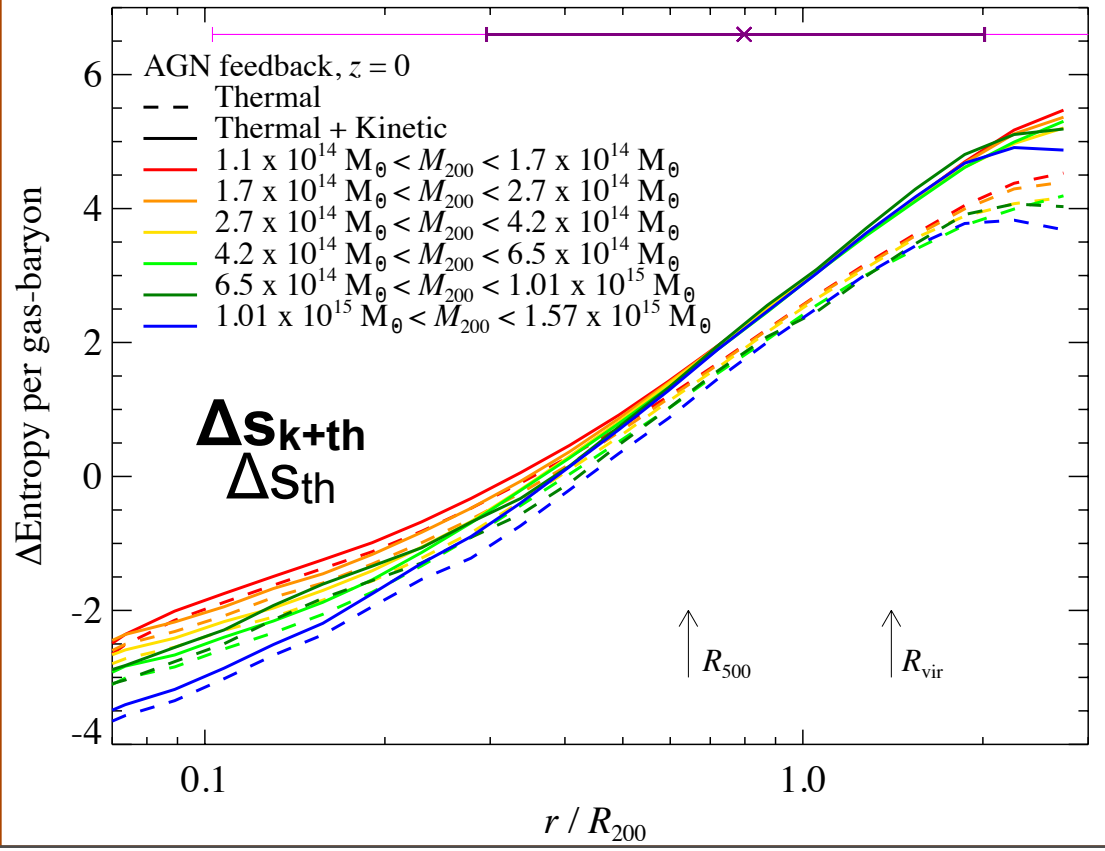
$s_{th,cl} \sim 10^{76}$

$s_{U,m+r} \sim 10^{88.6}$ ***5.2 bits/ϒ***

cf. s_m~1.4 bits/baryon atmosphere

after CMB+CvB, most $s_{U,m+r}$ is CIB = the waste heat from dust re-emission of starlight



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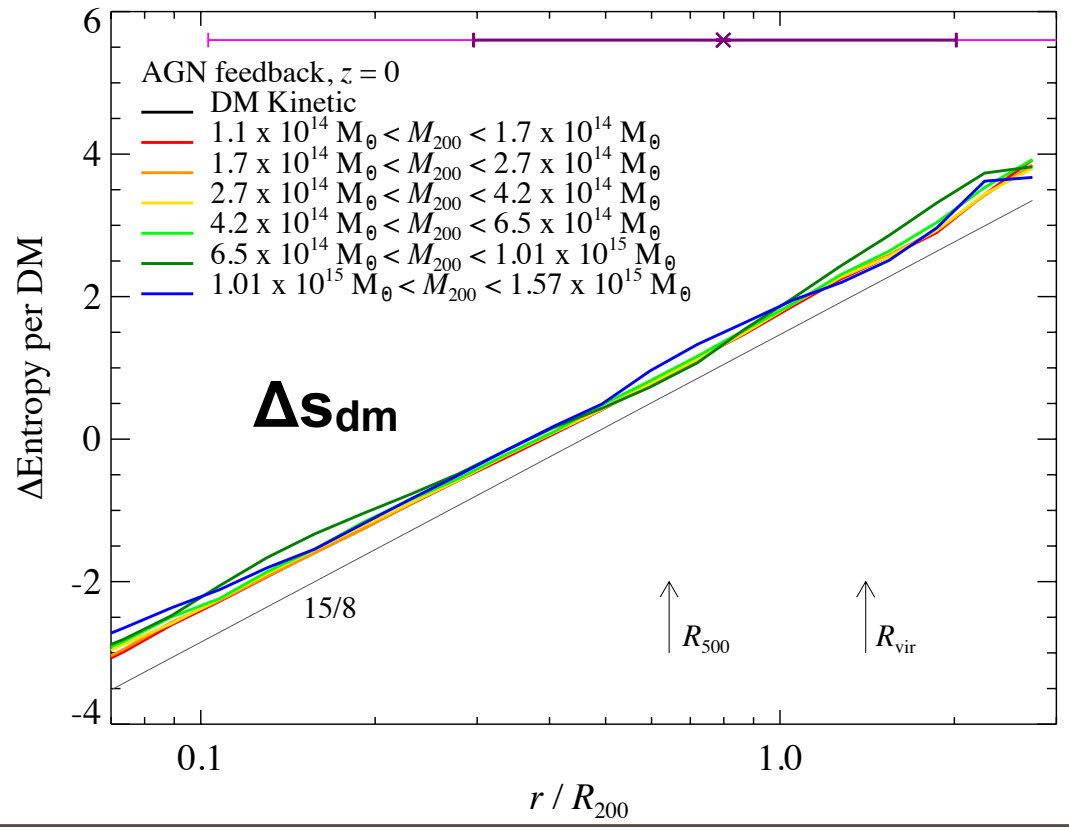
***Entropy**-per-dark-matter*

$\Delta s_{dm,halo}$
= 15/8 *ln* X
~7 *bits/DM*

beyond NFW

slope~self-similar radial infall Navarro
ongoing mystery - why halos have this entropy growth law



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

Secondary Anisotropies
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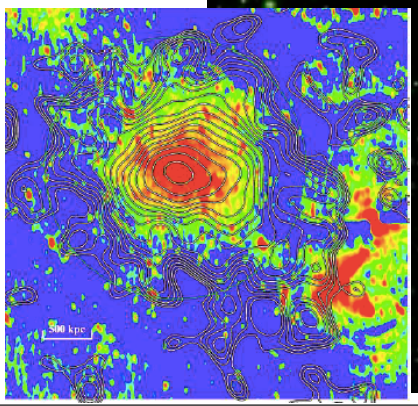
$p_e(x,t)$

2011 Planck ~200 clusters, SPT ~50 =>224cls, ACT ~50 cls; 2013 1000s

Planck's
Coma
2012.08
pip10



=end-Bond@IAP 12.09.28 CITA

Bond@IAS 12.10.04 SZ

Bond@APC 12.10.30 ACT?

the thermal Sunyaev Zeldovich Probe

$\gamma+e \rightarrow \gamma+e$
Compton cooling of hot cosmic web gas

$\langle \Delta E_\gamma / E_\gamma \rangle = 4T_e/m_ec^2$

$y = \sigma_T \int p_e$ *dline-of-sight*

$\Delta T/T = y * (x(e^x+1)/(e^x-1)-4)$,
$x = h\nu/T_\gamma$

$Y_\Delta \sim E_{th}/D_A^2$

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