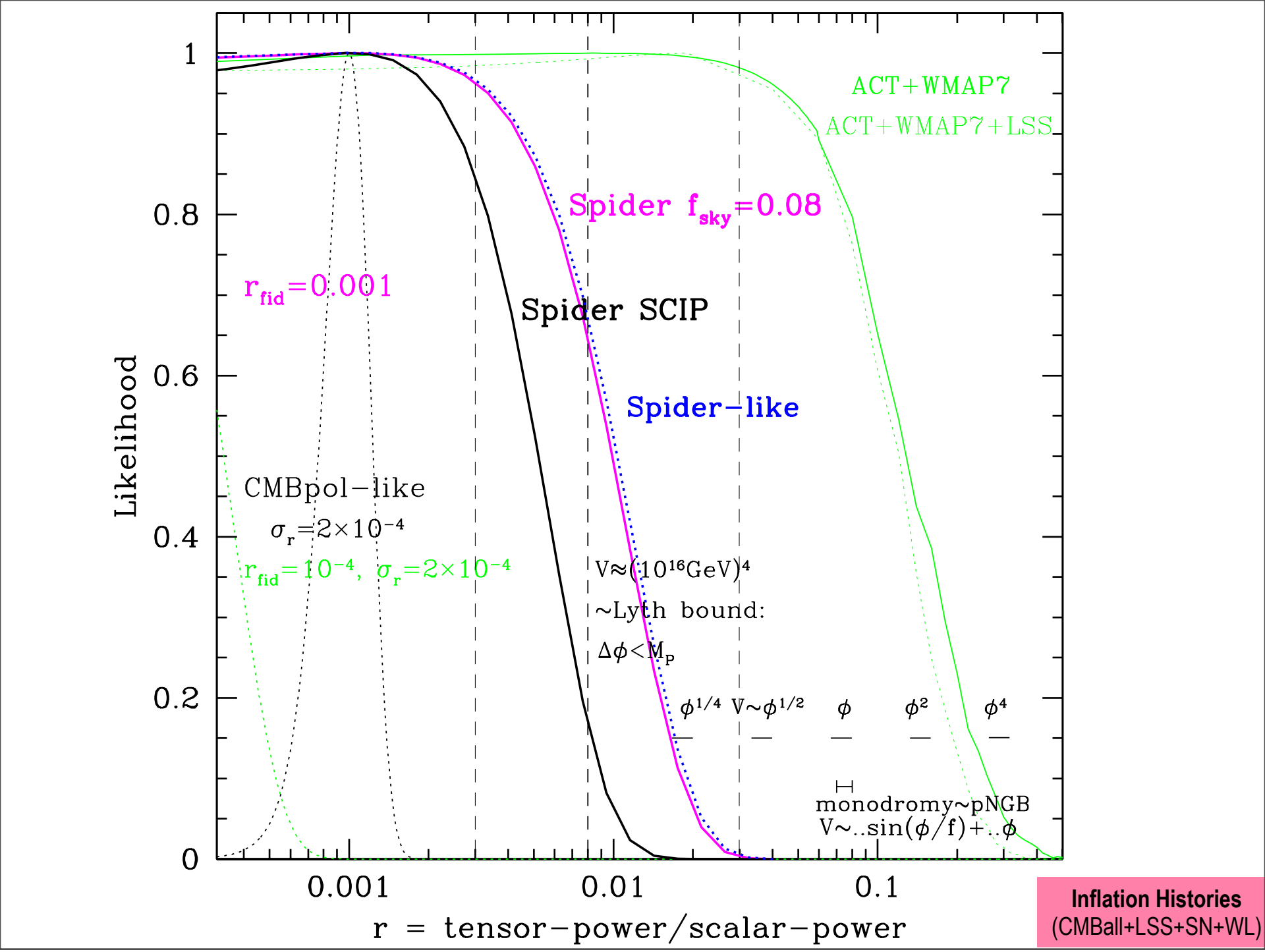
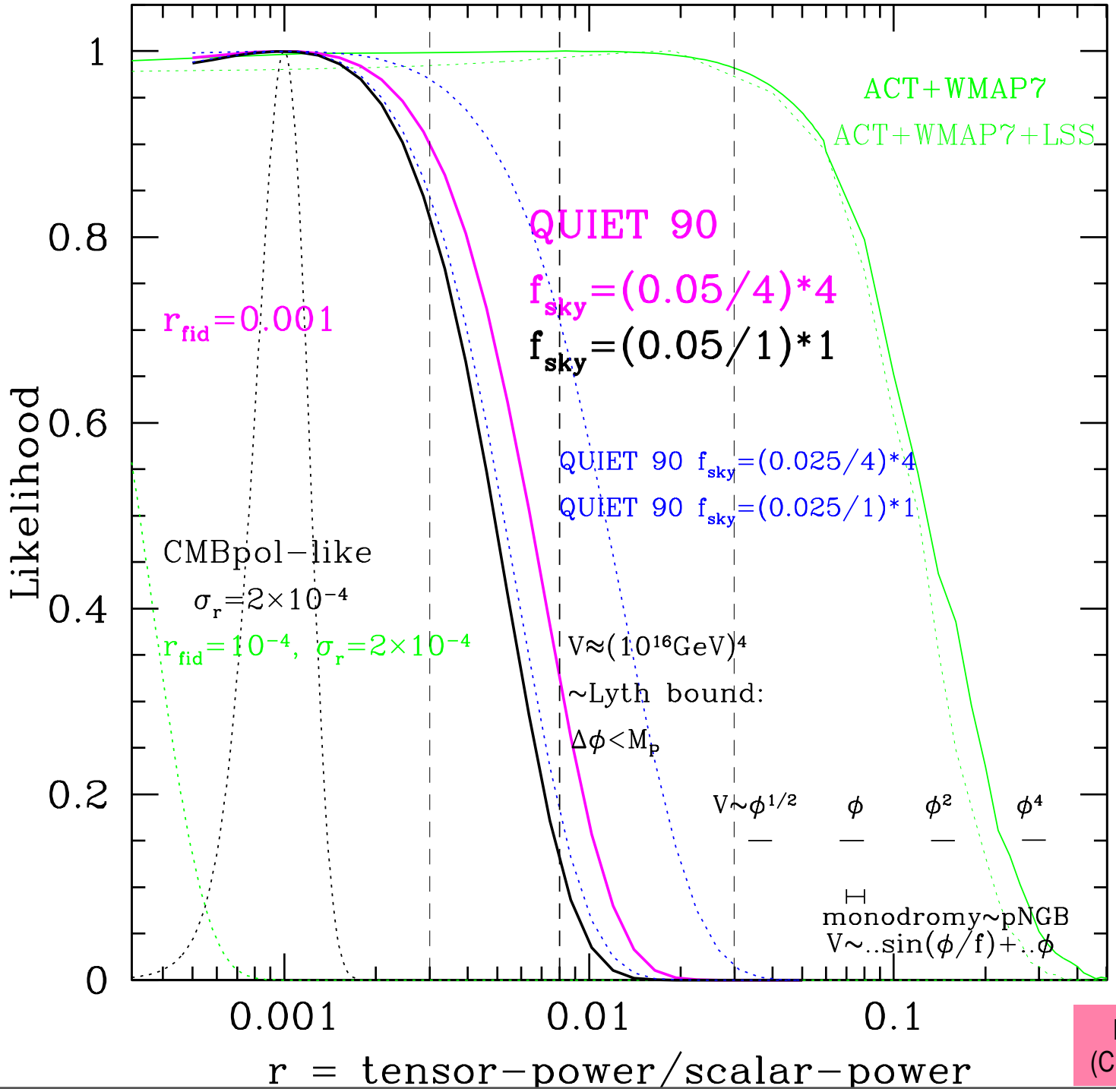
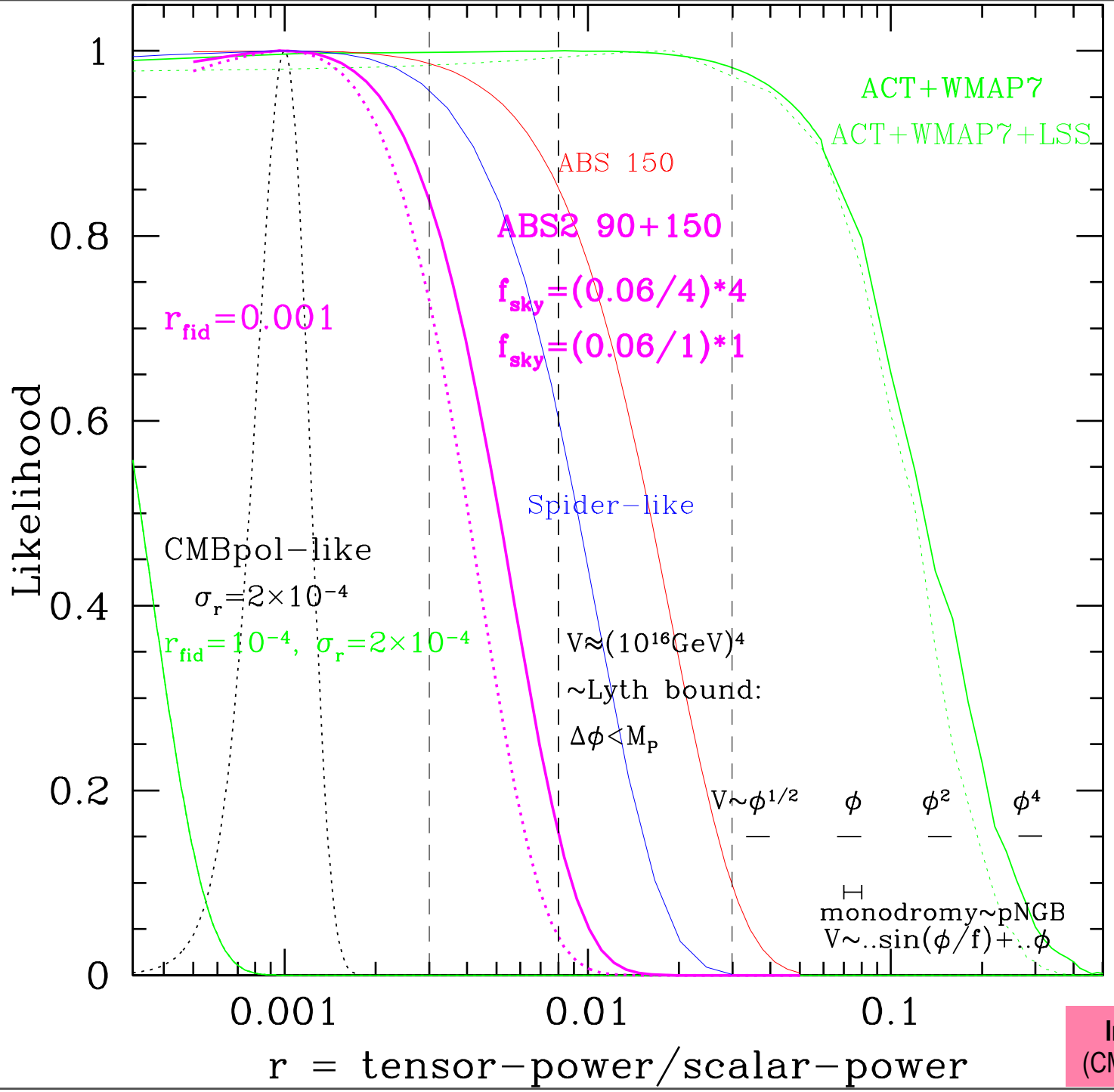


Inflation Histories
(CMBall+LSS+SN+WL)



Inflation Histories
(CMBall+LSS+SN+WL)



Inflation Histories
(CMBall+LSS+SN+WL)

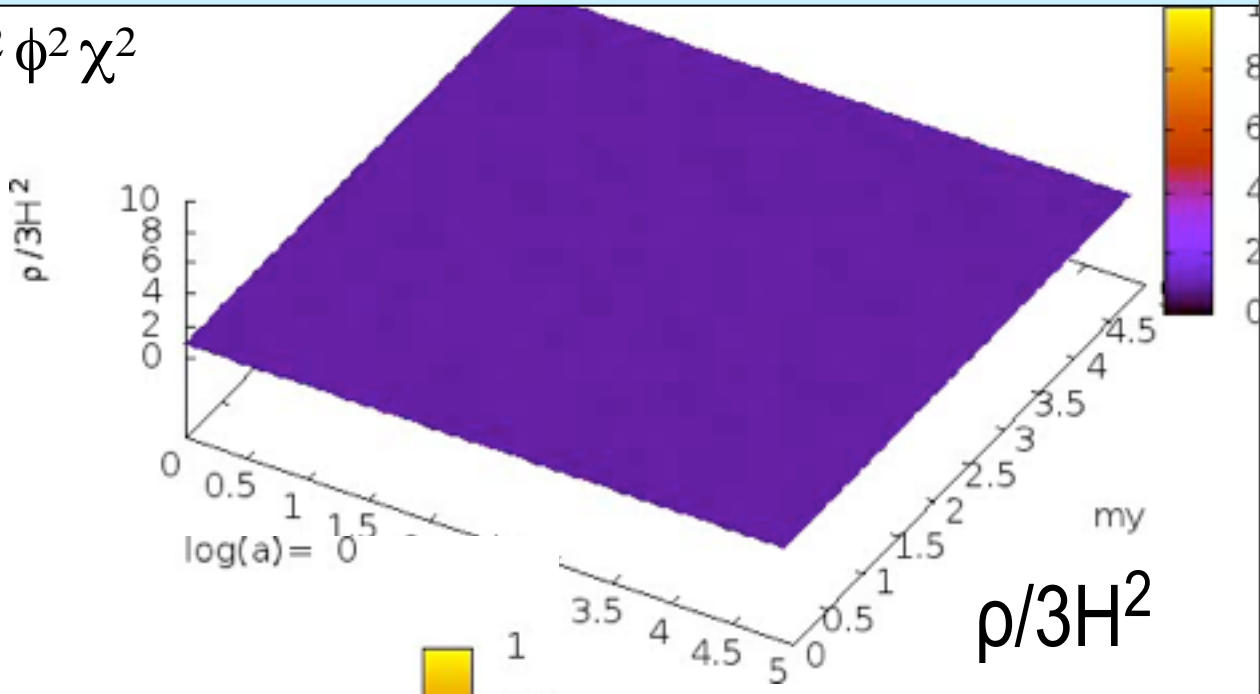
coherent inflaton => incoherent mode cascade of fields thru a shock-in-time to thermal equilibrium

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

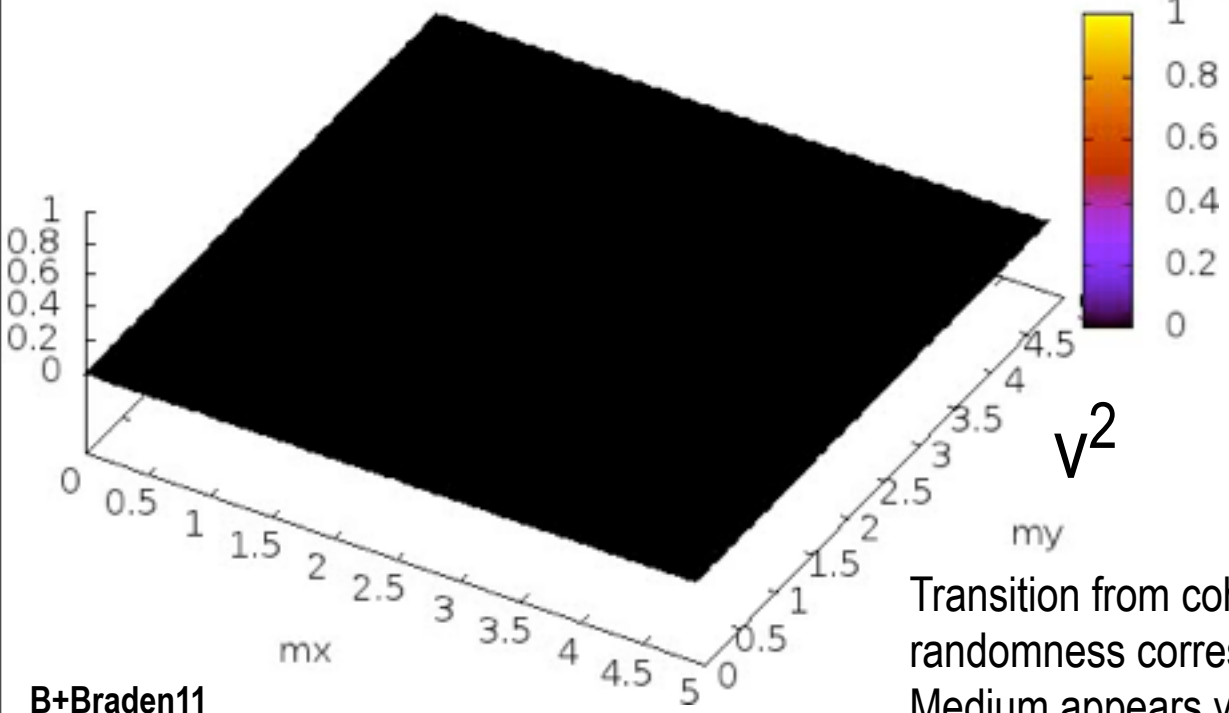
Slow Dynamics of IR Modes ⇒
Hydrodynamic Description

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

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



$\rho/3H^2$



v^2

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

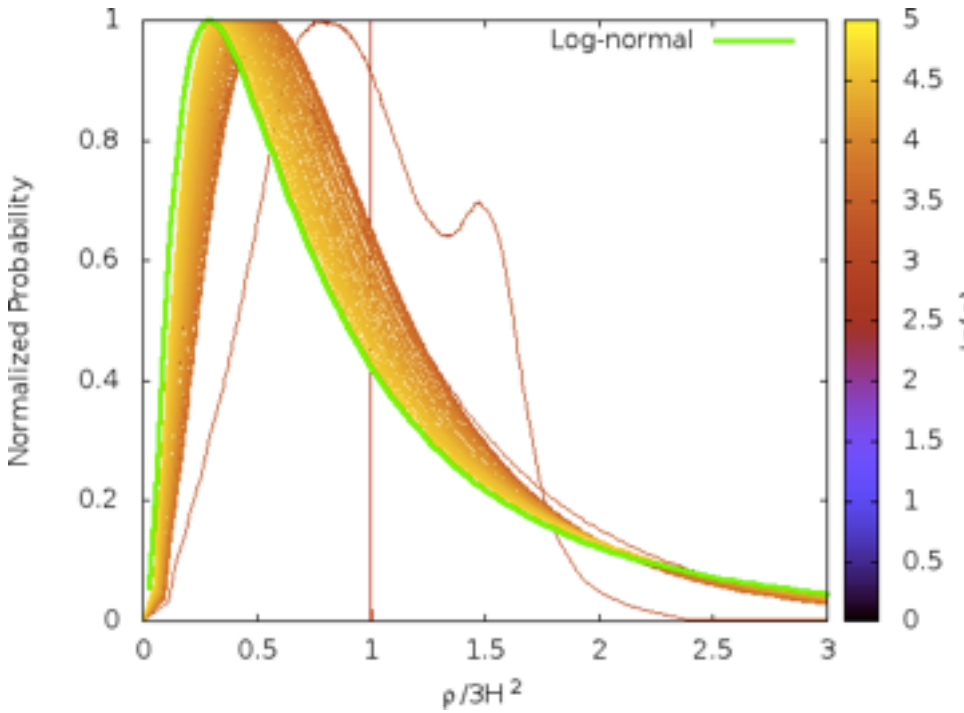
Transition from coherent wall-like structures to randomness corresponds to the shock-in-time.
Medium appears very complex in space and time, but ...

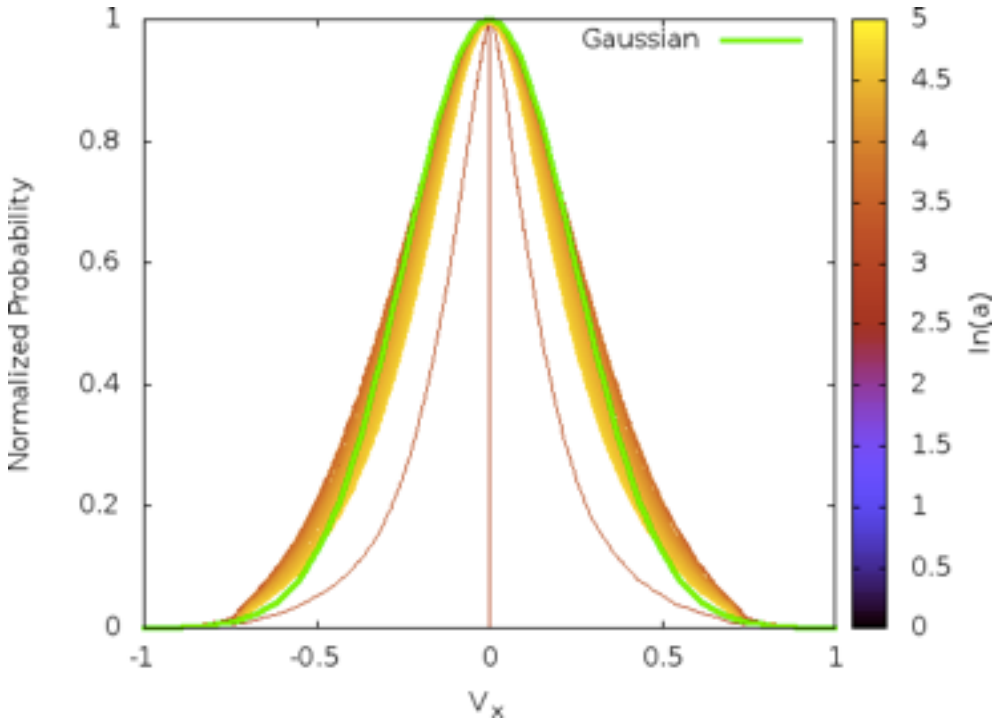
B+Braden11

but Statistical Simplicity

Density PDF~ log-normal after initial transient Frolov

Velocity components ~ Gaussian PDF

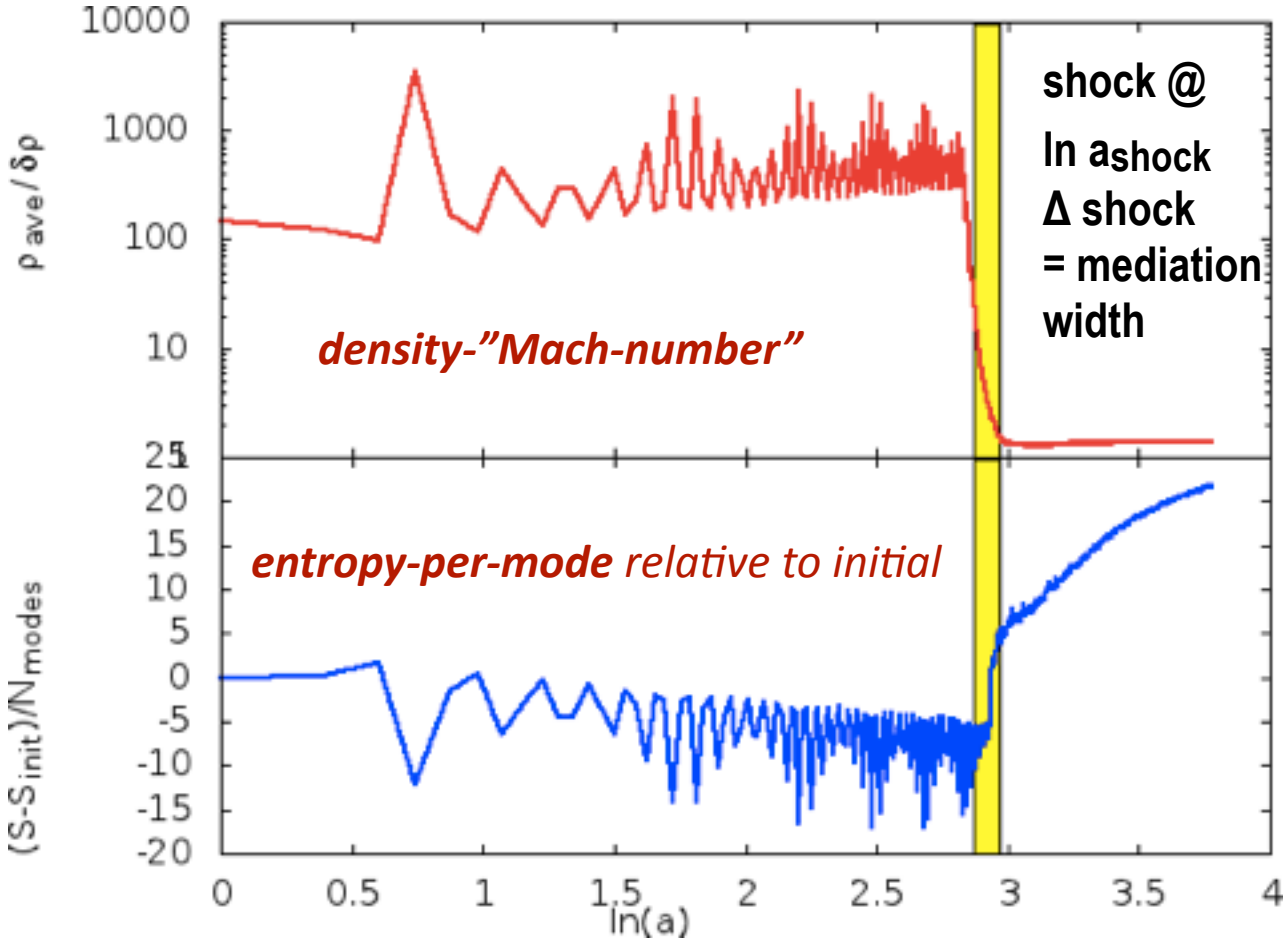




non-Gaussianity
(WMAP, **Planck**, LSS)
spiky nG preheating

B+Braden11

the Shock-in-time: entropy production & (density-contrast)$^{-1}$



true thermal equilibrium far off

➤

& on to coupling to standard model degrees of freedom

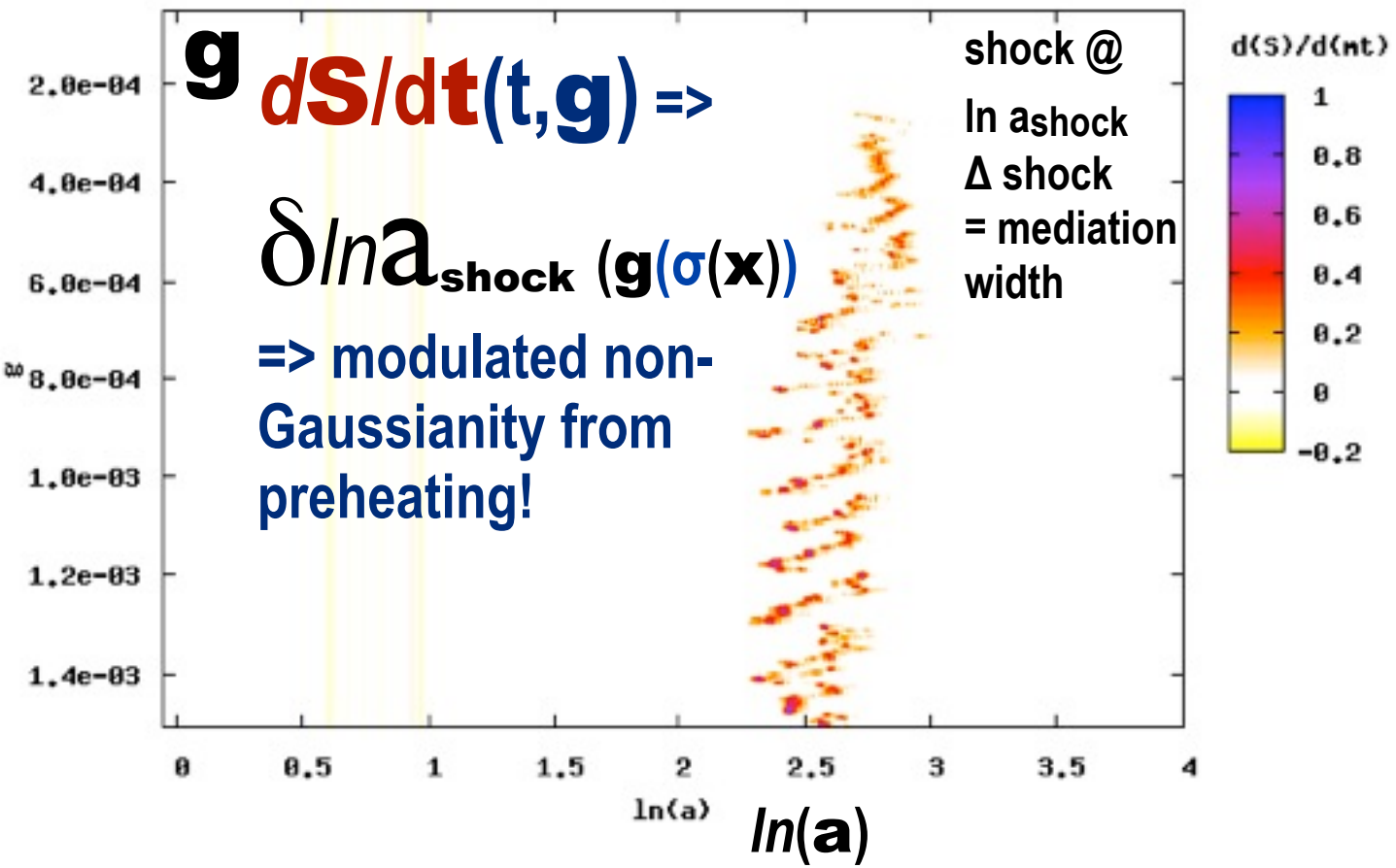
$$V(\phi,\chi)=1/2\ m^2\ \phi^2+1/2\ g^2\ \phi^2\ \chi^2$$

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.

non-Gaussianity
(WMAP, **Planck**, LSS)
spiky nG preheating
B+Braden11

the Shock-in-time: entropy production rate



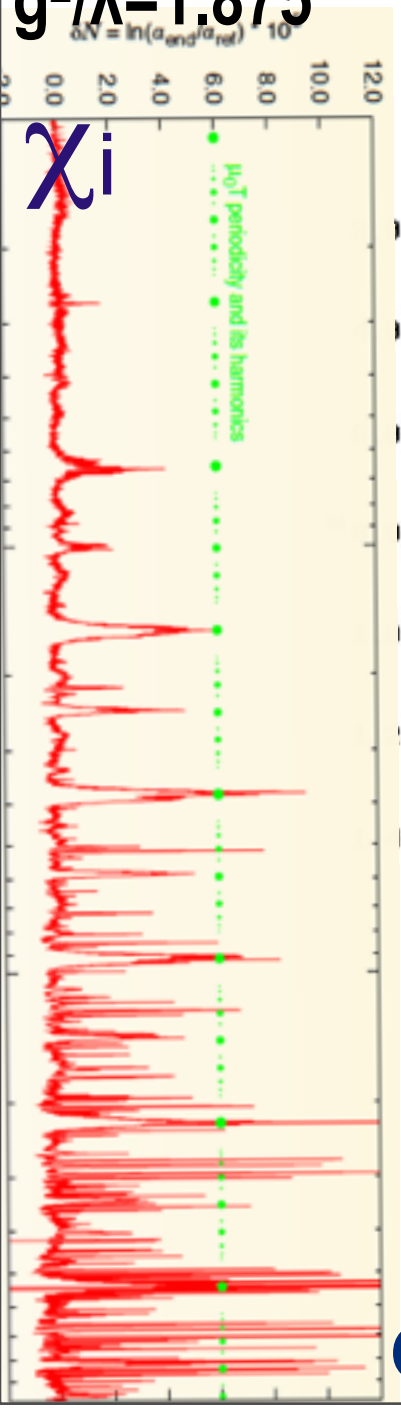
$$V(\phi,\chi)=1/2\, m^2 \phi^2 + 1/2\, g^2 \phi^2 \chi^2$$

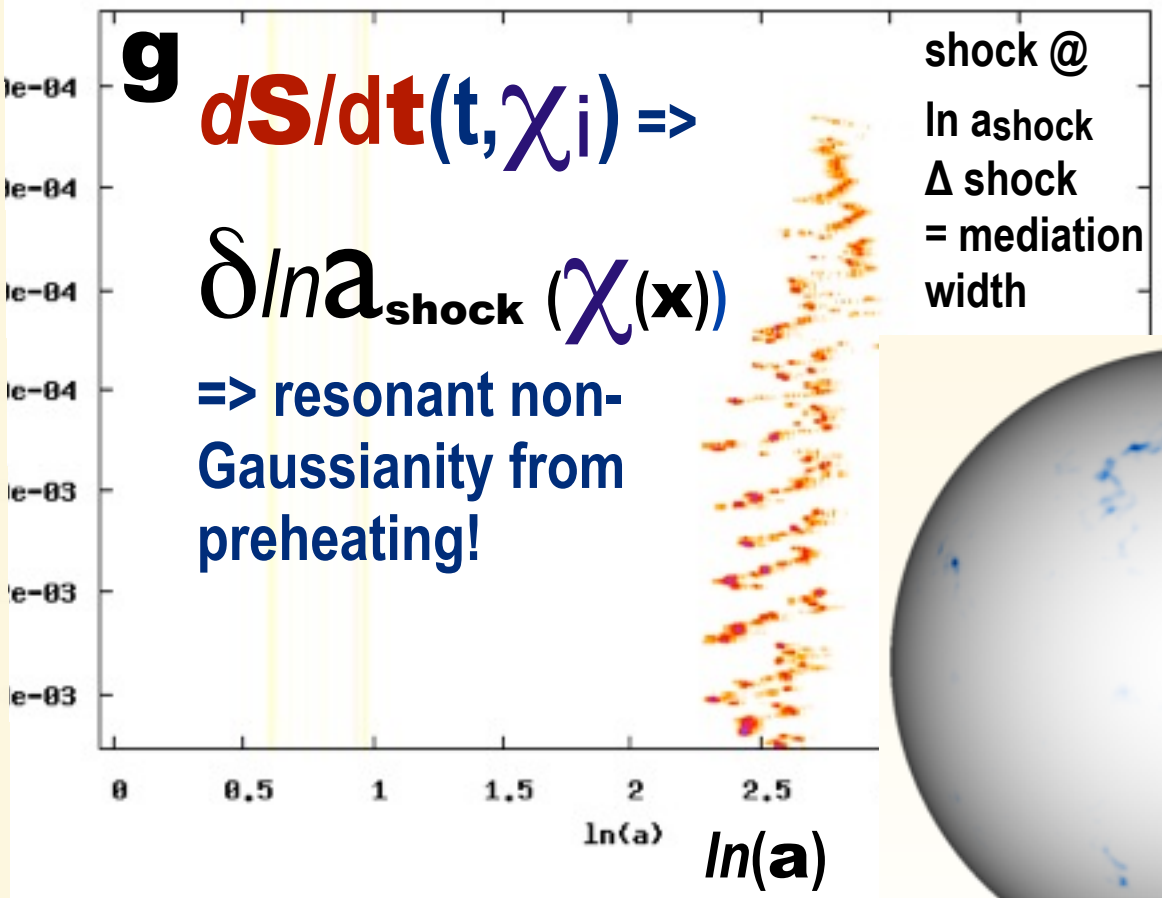
non-Gaussianity
(WMAP, **Planck**, LSS)
spiky nG preheating

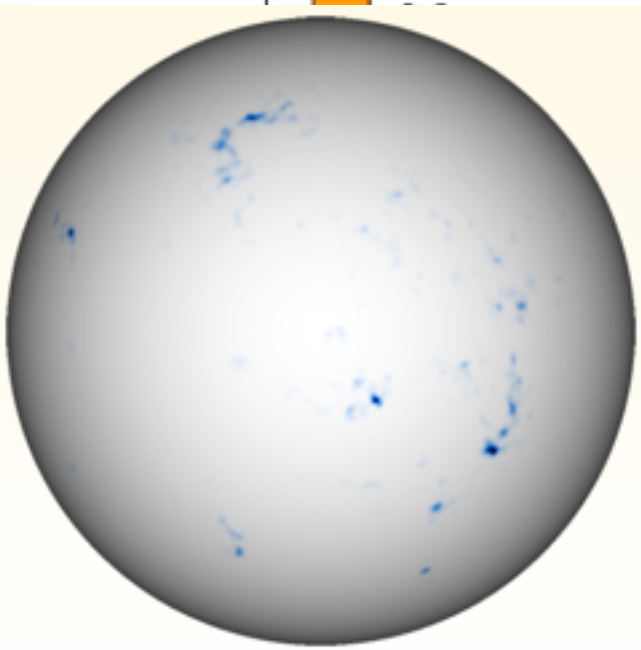
modulated non-G **Kofman03**
B+Braden11

$g^2/\lambda=1.875$

the Shock-in-time: entropy production rate







& f_{NL}^{equiv}

Chaotic Billiards: NonGaussianity from Parametric Resonance in Preheating

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

$\delta ln a\ (\chi_i(x,t))$

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

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*

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

a new figure of merit for experiments, <ln VOLUME$_{ps}$> = posterior Shannon entropy: how the (radically compressed) one-dimensional entropy of cosmic parameters, the high quality bits we quest, changed as the experiments became more & more precise:

	now ACT1 Mar03 Jan03 Jan02 Jan00 Jan13-15 then	$\sum m_\nu \lesssim 0.06$ eV (Pext-ACTpol)
$\Delta S_{1f}(\Omega_\Lambda)$	0 1.60 2.32 2.49 3.91 -4.00	± 0.012 =>± 0.001 (Pext)
$\Delta S_{1f}(w_0)$	0 - - - - -2.5 (-2.2)	± 0.06 =>± 0.01 (Pext) (± 0.14 =>± 0.03)
ΔS_{1f} (V-slope^2)	0 - - - - -2.4	0.0± 0.18 =>± 0.03 (Pext)
$\Delta S_{1f}(n_s)$	0 0.24 2.24 2.03 3.86 -2.59	0.963± 0.011 =>± 0.002 (Pext)
$\Delta S_{1f}(r)$	0 0.92 - - - -3.70	< 0.17 => < 0.007-0.013 (Pext)
$\Delta S_{1f}(f_{nl})$	0 - - - - -4.00	-10< f_{NL} <74 => ± 5 (Pext)

end

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

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

Probing the Cosmic Theory of Early & Late Universe Physics

Probing the Cosmic Theory of Early and Late Universe Physics

The Universe is fundamentally quantum and statistical, a many-paths/many-worlds information-theoretic random-field story that now pervades all discussions in cosmic theory. This lecture uses Cosmic Information Theory and Analysis (CITA) as a unifying theme to explore our ideas of how the Universe morphed from a smooth Hubble-patch within a vast and wild landscape into the ephemeral cosmic web we observe, with focus on early inflation, including preheating, and late inflation (aka Dark Energy). Particular topics will include: gravity waves from the inflation epoch (with comments on optimal CMB sky coverage for fixed observing time to constrain GW-induced B-modes of polarization); the acceleration trajectory approach to inflation and current and forecasted constraints on gently-broken and radically-broken scale invariance; isocurvature modes; the delivery of almost all of the entropy in the universe through a preheating "shock-in-time"; gently-broken and radically-broken Gaussianity of primordial curvature fluctuations and its constraints; physically-motivated parameterizations for Dark Energy equation of state trajectories and their current and forecasted constraints. And, after I have run out of time, the confrontation of nonlinear gastrophysical simulations with the observables of the cosmic web.

time hypersurfaces, what ends & begins on these branes of a sort?

the basis of classical gravity: the relative tick/tock of flowing clocks & inching along of flowing yardsticks

the uncertainty of quantum gravity: we can't keep track of time & space, quantum diffusion trumps classical drift

phase front synchronization ~ uniform Ha, SB90,91

inhomogeneous mini-superspace ln a (x|T), ln H (x|T), phi (x|T), Pi_phi (x|T)

ln removes ULSS by subtraction, at zeroth order

action a^3H sb90, "comoving (reduced) action H"

rho_t ~ 3MP2 H2

when do internal dimensions become space dimensions? at our leisure. a dimension per continuous degree of freedom, or pseudo dof such as resolution

entropy generation rate in stochastic inflation, or in Langevin equations

dS = 1/2<ln (y(T+DT)-y(T)-Fy(T)DT)^2 > = 1/2 ln QdTQ^dagger has a ln DT entering. need full ln-variance difference. unclear?

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

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)**

S of Gaussian fields
spatial **CMB entropy**
& how we capture it.
dark matter entropy,
cluster/protocluster / cosmic web entropy.
info-entropy flow from CMB time-streams to marginalized cosmic parameters via Bayesian chains
MHD turbulence S

cosmology forecasts for PlanckEXT

$n_s(k)$, GW $r(k)$, nonG f_{NL}++, $\rho_{de}(t)$, m_ν, strings, isocurvature, ...

current CMB+LSS+WL+SN1a+Lyα **PEXT**=Planck2.5yr + low-z-BOSS + CHIME + Euclid-WL + JDEM-SN

Huang, Bond, Kofman 2010, Bond, Huang 2011

$n_s = 0.963 \pm 0.011 \Rightarrow \pm 0.002$ (Pext)

Power$_s$~25×10^{-10} $\ln A_s = \pm 0.03 \Rightarrow \pm 0.008$ (Pext)

Farhang, Bond, Dore, Netterfield 2011 ***forecasting QU not EB***

Spider $2\sigma_r \sim 0.013$ => ~0.02 *for* $0.02 < f_{sky} < 0.15$

Planck2.5yr $2\sigma_r \sim 0.02$ => ~0.05 *(foregrounds)*

quadratic local nonG $-10 < f_{NL} < 74$ (+- 5 Planck)

$\Omega_m = \pm 0.012 \Rightarrow \pm 0.001$ (Pext) $1-\Omega_{\Lambda de}$ ie, V_{de}

$w_0 = \pm 0.06 \Rightarrow \pm 0.01$ (Pext) if $w_a=0 \pm 0.14 \Rightarrow \pm 0.03$ $w_a \neq 0$

DEslope $(d\ln V/d\psi)^2/4$ @pivot $a_{eq} = 0.0 \pm 0.18 \Rightarrow \pm 0.03$ (Pext)

$z_{re} = \pm 1.2 \Rightarrow \pm 0.3$ (Pext)

$\sigma_8 = \pm 0.016 \Rightarrow \pm 0.002$ (Pext)

$\Delta \sum m_\nu \sim 0.06$ eV

Planck + ACTPol

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Dick Bond + cast of 1000s

25 years cifar

Probing the Cosmic Theory of Early & Late Universe Physics

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

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

s_{Ui}~*0;* $s_{Utot,m+r}/n_b$ ~*1.66x10*^{10} bits/b; s_γ / n_γ = *5.2 bits/*Υ = *2130/411*; s_ν =*21/22* s_γ

s_m/n_b ~1 bits/b atmosphere ~1 preSN collapse, ~27 centre of sun, ~190 in clusters, s_{kin+th}-s_{th} non-equilibrium entropy of density fluctuations & of cosmic structures Δs_{dm} ~*7 bits/DM-particle*

the **gravo-thermal catastrophe** = negative specific heat - goal to localize mass into black holes & make accelerating voids ***to straighten U*** *out.* **gravitational** $S_G = M_P^2/2(H/2\pi)^2$; $M_P^2/2(g/2\pi)^2$; $M_{bh}^2/2M_P^2$ **??**

S_G (HubbleΛVolume)~$10^{121.9}$; $S_{Utot,m+r}$ (HubbleVolume)~$10^{88.6}$ compressed onto $T_\gamma \approx 2.725$K & H0≈70km/s/Mpc

the extra bit of S_γ in CMB spatial fluctuations $T_{\gamma,here,now}(\theta,\varphi)$ is also compressed onto 7++ cosmic parameters

CBI pol to Apr'05 @Chile

CBI2

Quiet1 @Chile

Quiet2 1000 HEMTs

QUaD @SP

Keck@SP

Boom03@LDB

Bicep @SP

Bicep2

ABS@ Chile

EBEX @LDB

WMAP @L2 to 2010

Planck09.4

Spider 2312 bolos @LDB

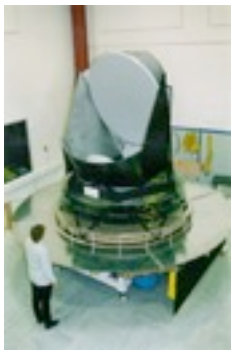
DASI @SP

CAPMAP

52 bolometers + HEMTs @L2

9 frequencies

Herschel



2013

BLAST

Pixie/ COrE/ LiteBird @space

2004 2006 2008 LHC 2011

2005 2007 2009

SPT 1000 bolos @SPole

BLASTpol

Piper

Acbar to Jan'06, 08f @SP

SZA @Cal

Polarbear @Chile

ACT 3000 bolos 3 freqs @Chile

SPTpol

ACTpol

AMI

APEX ~400 bolos @Chile

SCUBA2 12000 bolos JCMT @Hawaii

ALMA

CCAT@Chile

GBT

LMT@Mexico