Preheating: A Shock-in-Time

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Overview

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)

Thermal Equilbrium

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

Preheating: a **shock-in-time** between the initial and transitionary regimes.

A Shocking End to Post Inflation Mean Field Dynamics

Spatial Shock $t = \mathrm{const}$

- $v_{bulk}^2 > c_s^2 \rightarrow v_{bulk}^2 < c_s^2$
- supersonic $\rightarrow$ subsonic
- Characteristic spatial scale
- Jump Conditions: $\Delta T^{\mu\nu}$
- Randomizing Shock Front: ΔS
- Mediation width via viscosity or collisionless dynamics
- Nonequilibrium post shock evolution

Shock-in-Time $x = \mathrm{const}$

- $\bar{\rho} \gg \delta\rho \rightarrow \bar{\rho} \sim \delta\rho$
- Homogeneous $\rightarrow$ Fluc.
- Characteristic timescale
- Jump Conditions: $\Delta T^{\mu 0}$
- Particle Production + Interactions: ΔS
- Mediation width via gradients and nonlinearities
- Nonequilibrium fluctuations $\rightarrow$ evolution

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

Nonequilibrium Entropy in Field Theory

Nonequilibrium Shannon (*cf.* Von Neumann) Entropy

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

$P[f]$: probability density functional

Coarse Graining and Entropy Production

- Field $\rightarrow$ Correlation Functions
- Measurements: Constraints (information) on Correlators
- Maximize entropy subject to given constraints
- Generation of higher order correlators $\rightarrow$ entropy generation

Entropy and Gaussian Distributions

Only power spectrum constrained $\rightarrow$ multivariate Gaussian maximizes S

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

Power Spectrum

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

Treat $\ln(\rho/3H^2)$ as dynamical random field.

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

- Initial distribution is simulated vacuum fluctations (low entropy)
- Rapid increase in fluctuation power ! shock-in-time.
- Slow post shock evolution of power

Power Spectrum

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

Treat $\ln(\rho/3H^2)$ as dynamical random field.

$$V = \frac{m^2}{2}\phi^2 + \frac{\sigma}{2}\phi\chi^2 + \frac{\lambda}{4}\chi^4$$

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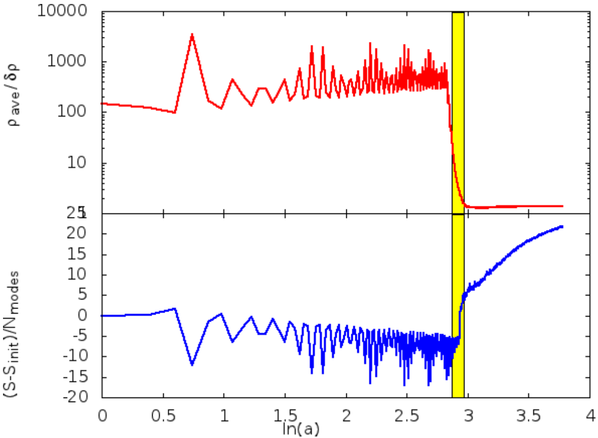
Entropy Production and a Shock-in-Time

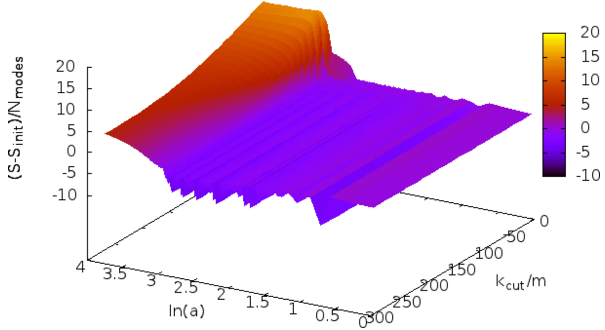


$$V = \frac{1}{2}m^2\phi^2 + \frac{1}{2}g^2\phi^2\chi^2$$

Don't "observe" n-pt power specta $\rightarrow$
constrained coarse-grained Shannon entropy > 0.
There is a spike of entropy production at the shock front.

Scale Dependence of Shock-in-Time

The entropy production is not localized to only large k or small k modes. Suppose we only have access to a limited resolution of the field (modelled here by a sharp k space cutoff $k \leq k_{cut}$.



The presence of the shock is robust to smoothing.

Post Shock Evolution

Slow Dynamics of IR Modes $\rightarrow$ Hydrodynamic Description

$$\rho \equiv -T^0_0 \qquad P \equiv \frac{1}{d} T^i_i \qquad v^i \equiv \frac{a T^i_0}{\rho + p} \tag{2}$$

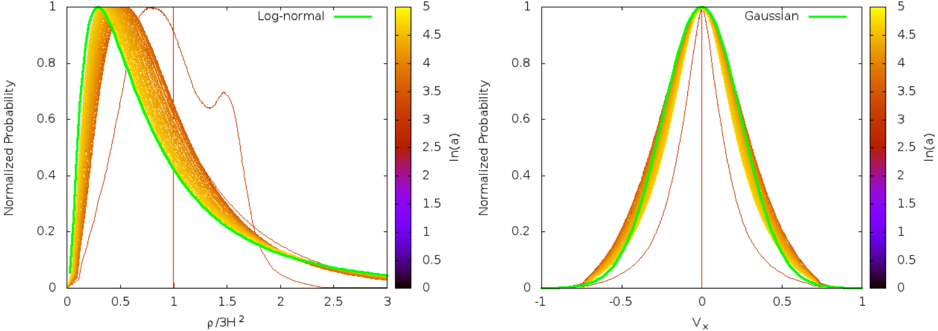
Evolution of $\rho/3H^2$

Evolution of 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

... it displays some remarkable statistical simplicity.



Density PDF is approximately log-normal after an initial transient Frolov
Velocity components are roughly a Gaussian.

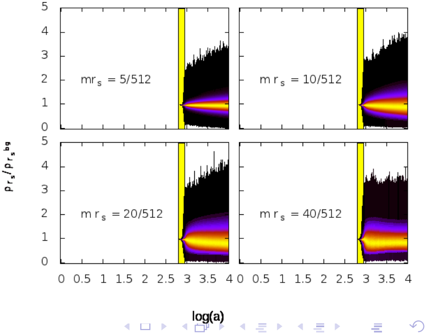
Renormalization and Scale Dependence

Wilsonian RG Blocking

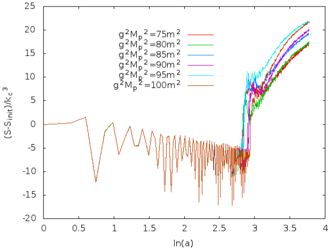
Sequence of smoothed fields ρ_{r_s} defined by averaging over groups of 8 nearest neighbours with $r_s = 2^s dx_{lat}$ the smoothing scale.

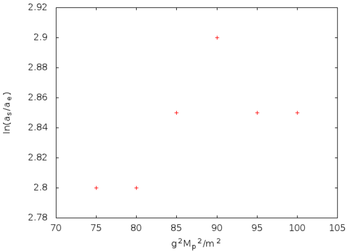
- Define local background for $\rho_{r_s}(x)$ by $\rho_{r_{s+1}}$.
  - Notion of fluctuations on fluctuations on fluctuations ...

- The shock-in-time has a more pronounced effect on larger scales
- At late times, local fluctuation PDFs evolve more slowly on larger scales on small scales
- White bounds the extremal values in the simulation box.



Relation to Nongaussianities





- Dependence of $\ln(a_{shock}/a)$ on parameters (coupling constants, $\langle\chi_{init}\rangle$, etc.)
- Relationship to nongaussianities from preheating Bond,Frolov,Huang,Kofman (2009), and *e.g.* Chambers and Rajantie (2008)

The spatial structure of $\ln\left(\frac{a_{shock}}{a_{end}}\right)$ resulting from given initial conditions encodes information about the perturbation spectra including nongaussianities.

Conclusions

Summary

- New language for preheating: a shock-in-time
- Shock-in-time: randomization front is 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 $\ln(a_s/a_e)$ and mediation width $\Delta\ln(a_x/a_e)$.

Future Work

- Determine the parameter dependence of the shock-in-time and relate it to nongaussianities