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Non-Gaussianity from Preheating

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A.Chambers & AR, PRL100(2008)041302
A.Chambers & AR, JCAP08(2008)002
A.Chambers, S.Nurmi & AR, JCAP01(2010)012

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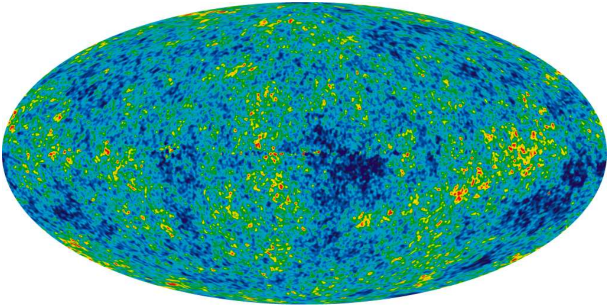
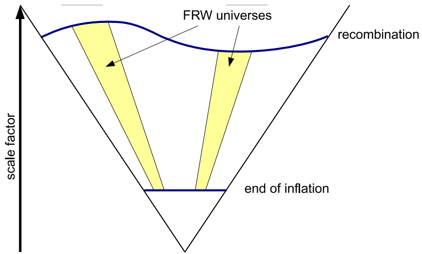
Perturbations from Non-Equilibrium Fields



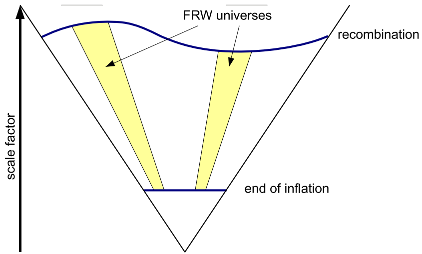
- Light scalar fields $\Rightarrow$ Nearly scale invariant perturbations
- Non-equilibrium field evolution $\Rightarrow$ Non-Gaussian contribution
- Sensitive test of models – But how can we calculate it?

Separate Universes



- Each Hubble patch $\sim$ separate FRW universe (Salopek&Bond 1990)
- Curvature perturbation $\zeta = \delta N = \delta \ln a|_{\rho=\rho_*}$
- Valid at distances $d \gg 1/H$

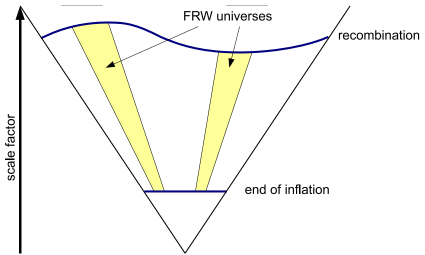
Separate Universes



- Curvature perturbation $\zeta = \delta N = \delta \ln a|_{\rho=\rho_*}$
- Conserved if $w = w(\rho)$:

$$\frac{d \ln a}{d\rho} = -\frac{1}{3\rho(1+w(\rho))}$$

Light Scalar Field χ



- $m_\chi < H \Rightarrow$ Gaussian scale-invariant perturbations
- Different "universes" have different initial value χ_0
- Affects expansion $\Rightarrow$ Scale factor depends on χ_0

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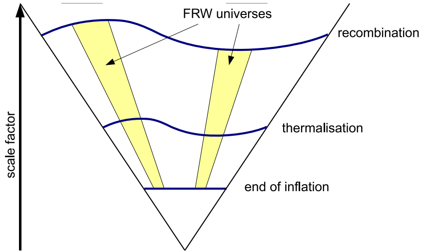
Light Scalar Field χ



- Thermalisation erases memory of $\chi_0 \Rightarrow w = w(\rho)$
- Curvature perturbation determined at thermalisation:
  $\zeta_{\rm rec} = \zeta_{\rm therm} = \delta \ln a|_{\rho=\rho_{\rm therm}}$

Calculating the Curvature Perturbation

- Solve Friedmann eq. for each separate universe $\Rightarrow a(t)$, $\rho(t)$
  - Non-linear, includes gravity, valid at $d \gg H^{-1}$
- Pick $\rho_* < \rho_{\rm therm}$, and calculate $\zeta = \delta \ln a|_{\rho=\rho_*}$
  - Two fields: $\zeta = \zeta(\phi_0, \chi_0)$
  - $\delta\phi_0 \Leftrightarrow$ Shift in time:
    Usual inflationary perturbations
  - $\delta\chi_0$: New contribution
- Need to calculate $N(\chi_0) = \ln a(\chi_0)$
  - Perturbative approach: Taylor expand

$$\zeta = \zeta_\phi + \frac{\partial N}{\partial \chi_0}\delta\chi_0 + \frac{1}{2}\frac{\partial^2 N}{\partial \chi_0^2}\delta\chi_0^2 + \ldots$$

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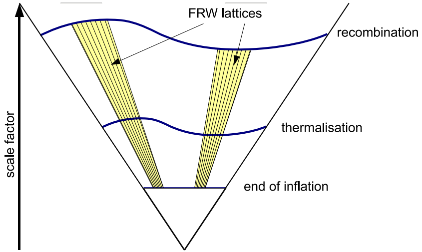
  - $\delta\chi_0$: New contribution
- Need to calculate $N(\chi_0) = \ln a(\chi_0)$
  - Instead: Solve field and Friedmann eqs numerically
  - Solve for many different initial values χ

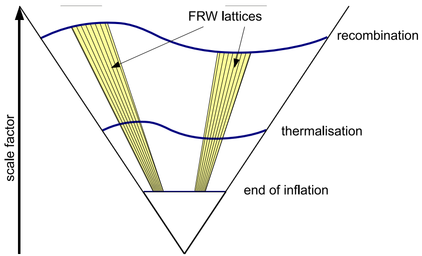
  $\Rightarrow$ Whole non-linear function $N(\chi_0)$ (Bassett&Tanaka 2003, Suyama&Yokoyama 2006)

Lattice Calculation of Curvature Perturbations



- Describe each "universe" as a lattice (Chambers&AR 2007)
- Inhomogeneous fields, FRW metric
- Lattice size $L \sim 1/H$

Lattice Calculation of Curvature Perturbations



- Solve field evolution on lattice, coupled to Friedmann eq with average ρ
- Find curvature perturbation as $\zeta(\chi_0) = \delta \ln a(\chi_0)|_{\rho=\rho_*}$, where χ_0 is the lattice average

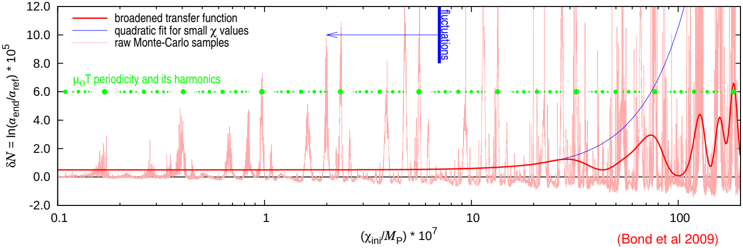
Initial Conditions

- Sub-horizon modes: Quantum vacuum
  - Gaussian classical fluctuations with (Khlebnikov&Tkachev 1996)

$$\overline{|\chi_k|^2} = \frac{1}{V}\frac{1}{2\omega_k}, \quad \overline{|\dot{\chi}_k|^2} = \frac{1}{V}\frac{\omega_k}{2}$$

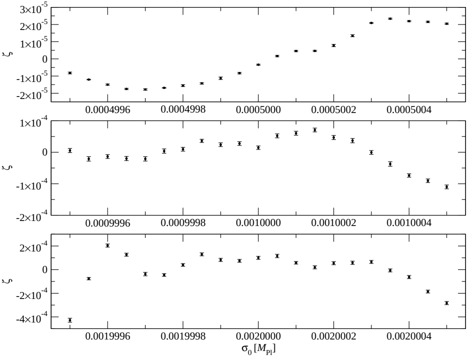
  - Linear dynamics: quantum = classical
  - Non-linear dynamics: quantum $\approx$ classical
- Mean value $\leftrightarrows$ Super-horizon modes
  - Initial field value χ_0
  - Input parameter – we are calculating $\zeta(\chi_0)$!

Massless Preheating



- Chaotic behaviour: Highly non-Gaussian (Chambers&AR 2007)
- Not well approximated by a quadratic $f_{\rm NL}$

Curvaton Resonance



- Curvaton decays through parametric resonance (Enqvist et al 2009)
- Again, not well described by $f_{\rm NL}$ (Chambers,Nurmi&AR 2009)

Conclusions

- Non-linear calculation of curvature perturbation due to non-equilibrium physics
  - Separate universes + lattice field theory
  - Works with any (bosonic) field dynamics
- Massless preheating, Curvaton resonance:
  - Possibly observable effects $\Delta\zeta \sim 10^{-5}$
  - Highly non-linear
  - How should we look for these signals?