Transient breakdown of slow-roll, homogeneity and isotropy during inflation

Rose Lerner

r.lerner@lancaster.ac.uk

Supervisor: John McDonald

Cosmology and Astroparticle Physics Group

Lancaster University

UK

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Outline

- Features and motivations
- Our model
- Mode equations and initial conditions
- Results and discussion

Features in the inflaton potential

- Data from WMAP consistent with a smooth inflaton potential, with $P_{\mathcal{R}} \propto k^{n-1}$ ($n \simeq 1$)
- However 5 year WMAP data also consistent with features in the potential *(Joy, Shafieloo, Sahni and Starobinsky arXiv:0807.3334)*
- Many examples of features have been studied such as kinks, steps and bumps *(eg Adams, Cresswell and Easther arXiv:0102236 and Covi et al arXiv:0606452)*
- We wish to consider the generic effects a space dependent inflaton potential has on the primordial power spectrum

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Motivations

A *phenomenological model* for the transient breakdown of slow-roll, homogeneity and isotropy during inflation

But also motivated by

- Inhomogeneous cosmological phase transition (tachyonic preheating)
  A second field coupled to the inflaton undergoes a phase transition; A 'mini-waterfall' transition

- Modulated fluctuations
  A third field imprints super-horizon inhomogeneity during a phase transition

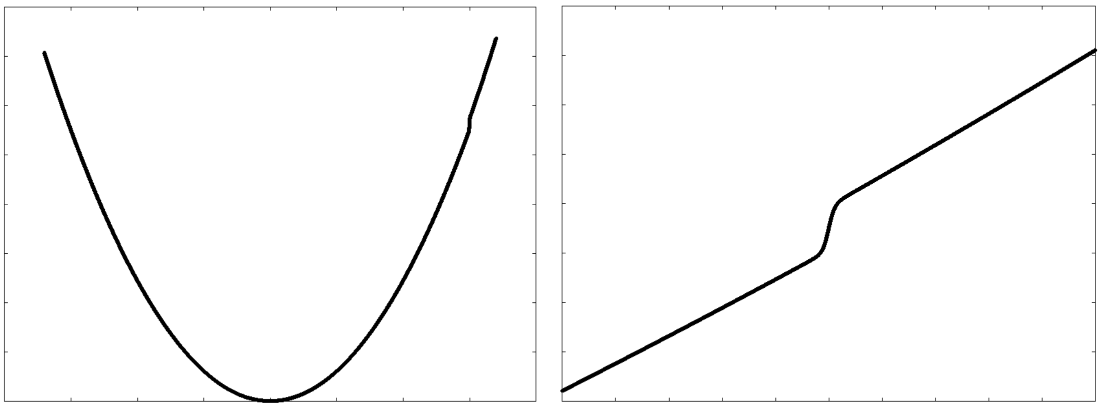
Inhomogeneity: our model

Effective potential:

$$V(\phi) = \frac{m^2\phi^2}{2}\left(1 + c\tanh(w)\left[1 + e^{-w^2}\sin(k_L x)\sin(k_L y)\sin(k_L z)\right]\right)$$

where k_L is the inhomogeneity wavenumber and $w = \left(\frac{\phi - b}{d}\right)$

- choose b so step at $N = 55$
- solve for planar case $\sin(k_L x)$



Mode equations (1)

Start with the action $S = \frac{1}{2} \int \left(\partial_\mu u \partial^\mu u + \frac{z''}{z} u^2 \right) d^4 x$,

with $u = -z\mathcal{R}$ and $z = a\dot{\phi}/H$ ($\mathcal{R}$ is the curvature perturbation)

No space dependence: use classical field equation and quantize in term of $a_{\mathbf{k}}$ and $a^\dagger_{\mathbf{k}}$:

$$u(\mathbf{x}, \tau) = \int \frac{d^3 k}{(2\pi)^{3/2}} \left[u_{\mathbf{k}}(\tau) e^{i\mathbf{k}.\mathbf{x}} a_{\mathbf{k}} + u^*_{\mathbf{k}}(\tau) e^{-i\mathbf{k}.\mathbf{x}} a^\dagger_{\mathbf{k}} \right]$$

giving

$$\boxed{u''_{\mathbf{k}} + \mathbf{k}^2 u_{\mathbf{k}} = \frac{z''}{z} u_{\mathbf{k}}}$$

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Mode equations (2)

For the space dependent potential, the mode equations become

$$u_{\mathbf{k}}^{''} + \mathbf{k}^2 u_{\mathbf{k}} - \frac{z^{''}}{z} u_{\mathbf{k}} + \frac{a^2}{2i} \frac{d^2 F}{d\phi^2} \left(u_{\mathbf{k}-\mathbf{k}_L} - u_{\mathbf{k}+\mathbf{k}_L} \right) = 0$$

where $F(\phi) = \frac{cm^2}{2} \tanh\left(\frac{\phi - b}{d}\right) e^{-\frac{\phi - b}{d}} \phi^2$

- Equation only valid for $k \neq nk_L$ (as also classical contribution)

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Initial conditions

Initial conditions set at $\mathbf{k}^2 >> a^2 H^2$ are

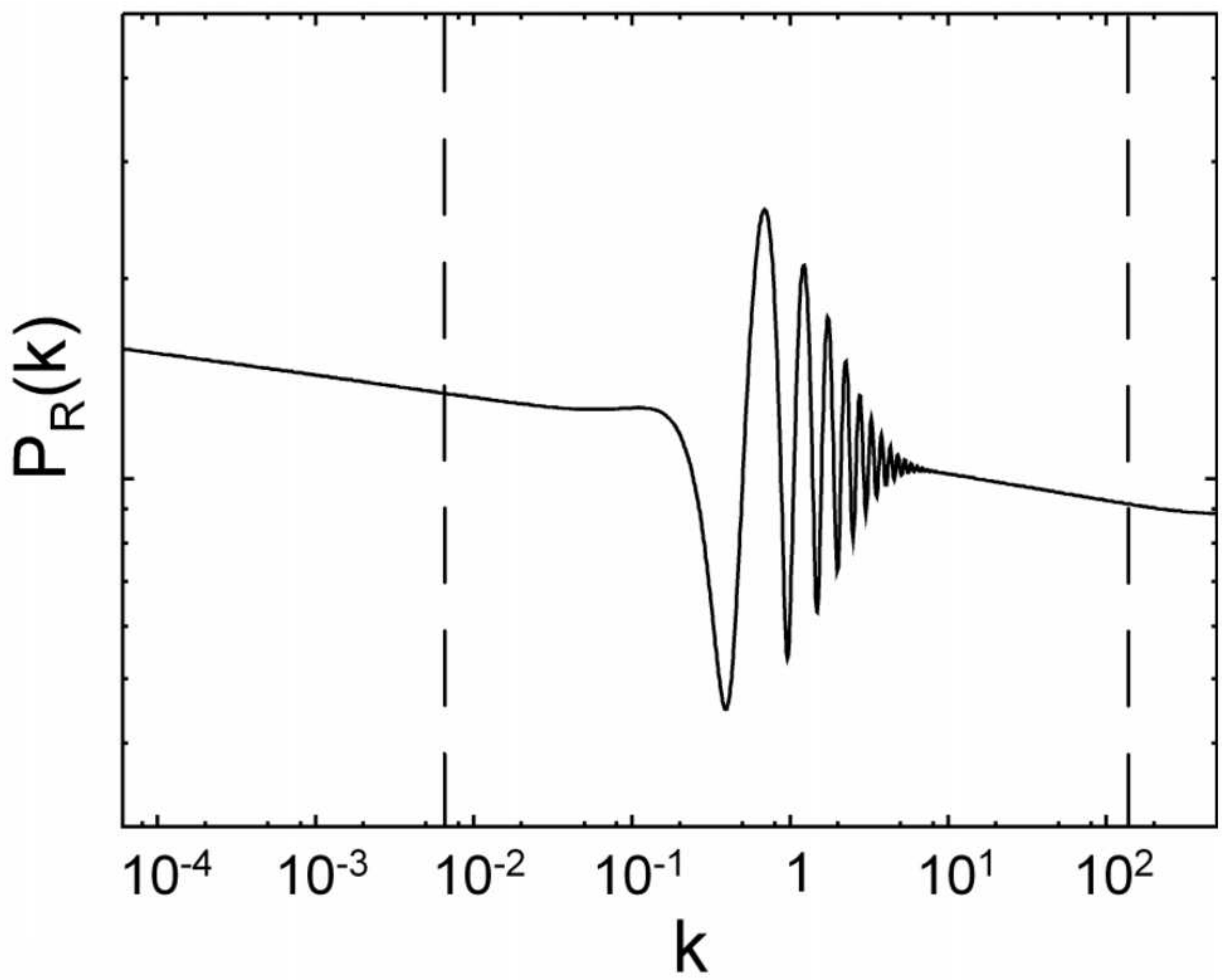
$$u_{\mathbf{k}} = \frac{e^{-i(|\mathbf{k}|\tau + \alpha_{\mathbf{k}})}}{\sqrt{2|\mathbf{k}|}}$$

where τ is conformal time and $\alpha_{\mathbf{k}}$ a random phase.
$\alpha_{\mathbf{k}}$ *only has an effect when there is mode coupling.*

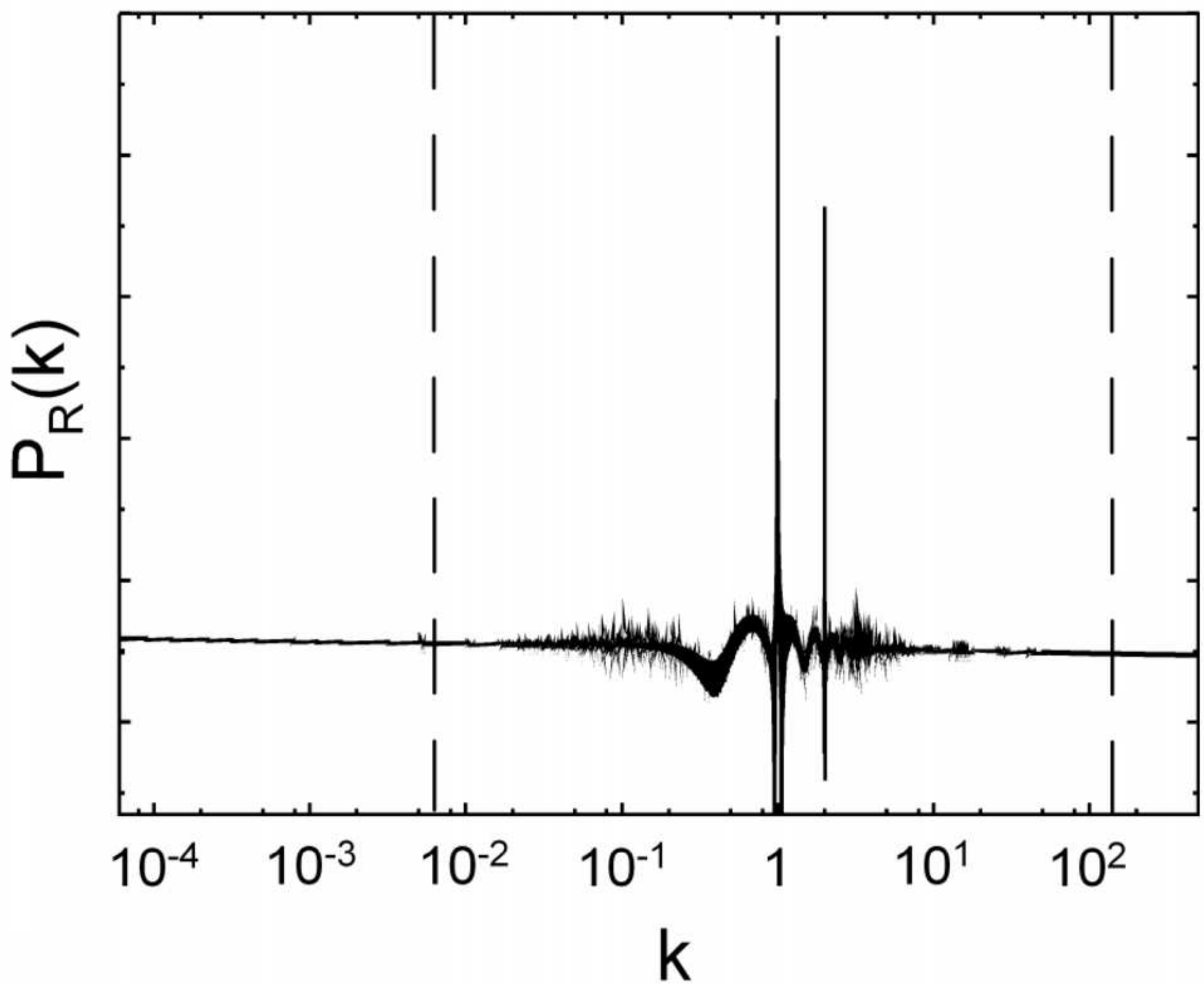
We solve for $u_{\mathbf{k}}$ and calculate the curvature perturbation power spectrum:

$$\mathcal{P}_{\mathcal{R}}{}^{1/2}(\mathbf{k}) = \sqrt{\frac{|\mathbf{k}|^3}{2\pi^2}} \left| \frac{u_{\mathbf{k}}}{z} \right|$$

Power spectrum (homogeneous)



Power spectrum ($k_L = k_{STEP}$)



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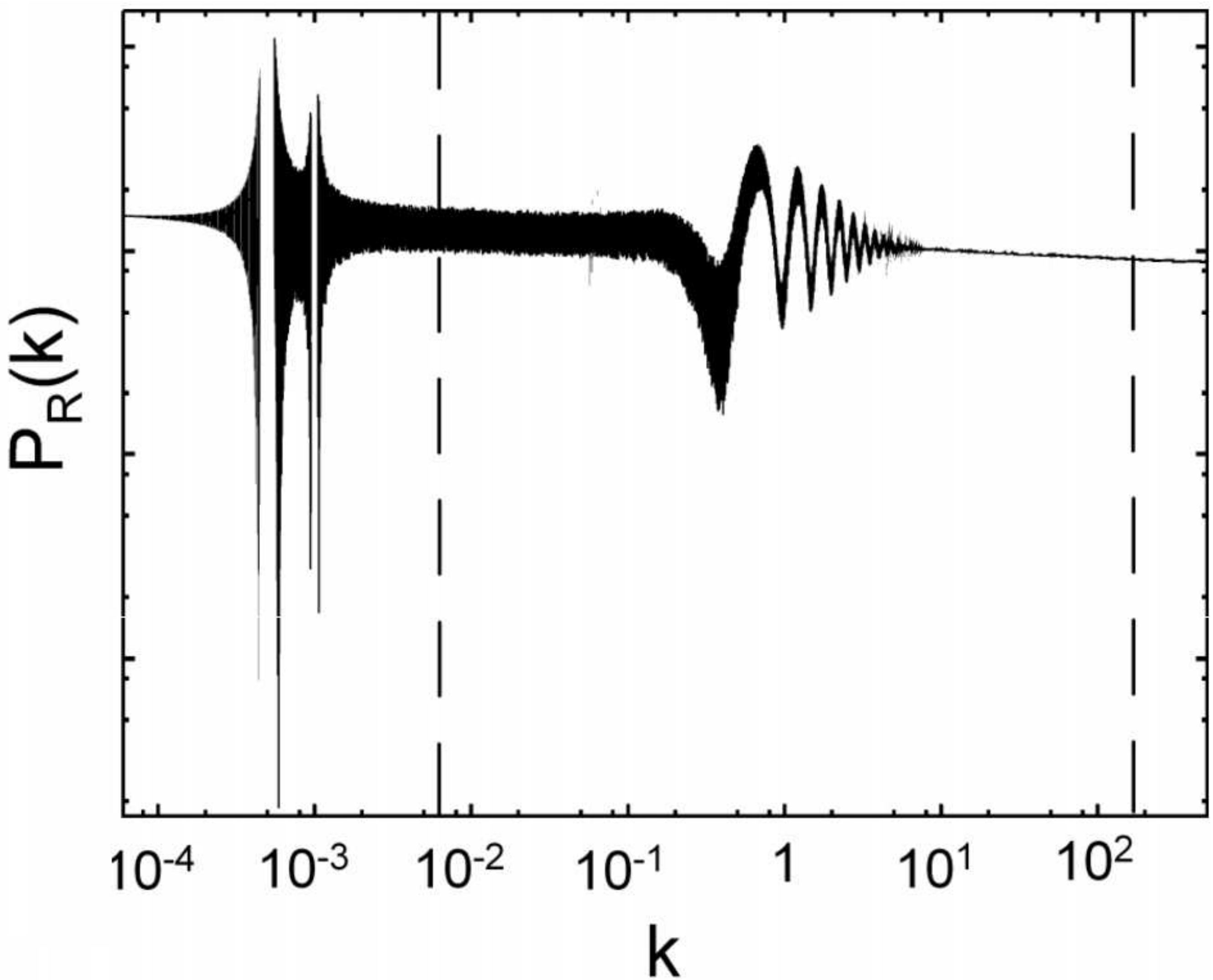
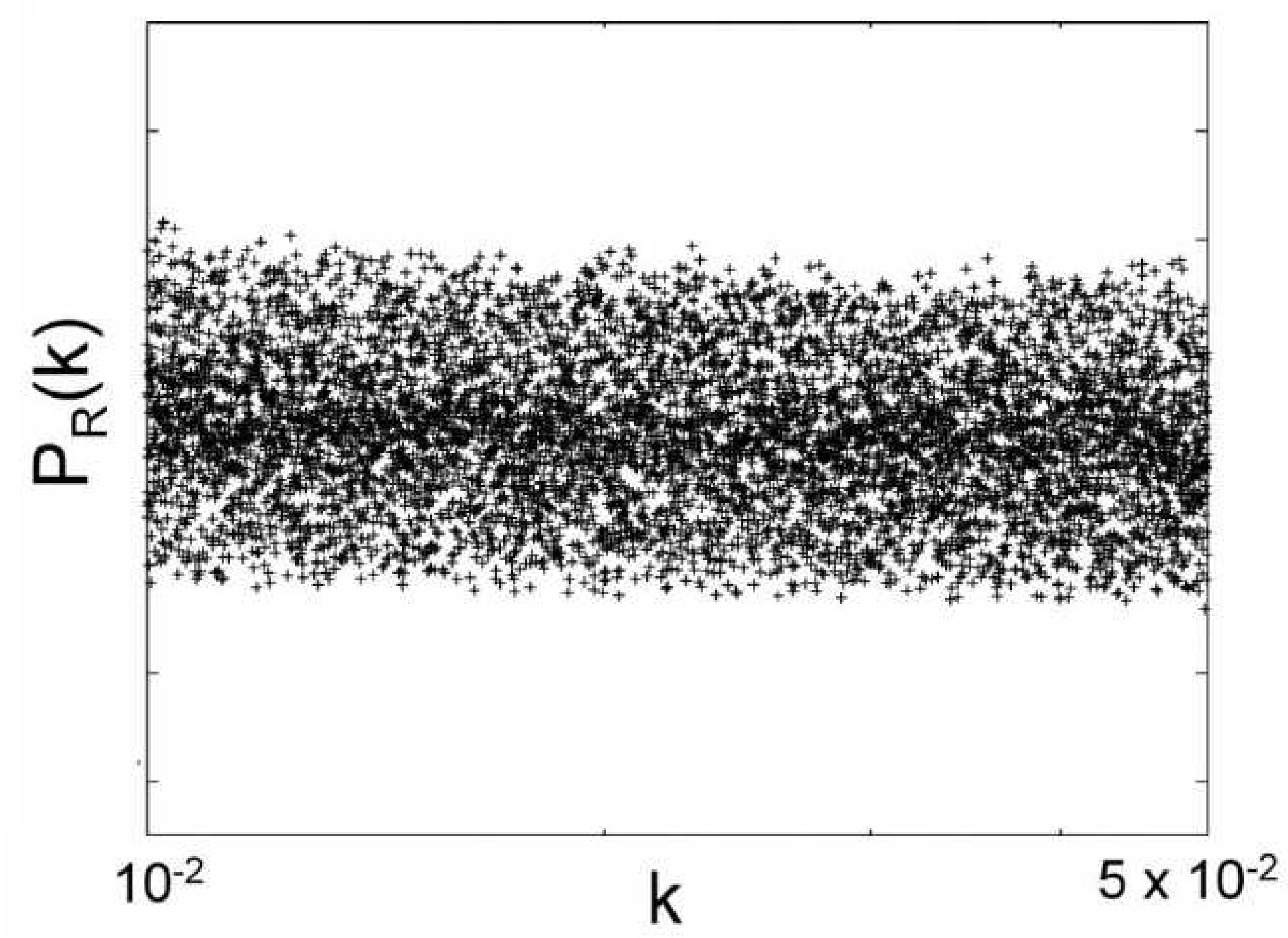
Power spectrum ($k_L < k_{STEP}$)



Effect of phases



Questions

- Could the resonances be observed?
- Does current data enable us to put a bound on inhomogeneity during inflation?
- Are there chances of producing primordial black holes at the resonances?
- Does the mode mixing generate appreciable non-gaussian curvature perturbations?
- Could this provide a mechanism for large scale statistical anisotropy?

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Summary

- Transient space dependence of the inflaton potential results in coupling between inflaton modes
- This produces interesting results including resonances and random broadening
- Resonances occur when modes are coupled to amplified super-horizon modes

arXiv:coming soon!

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