Punctuated inflation and the low CMB multipoles

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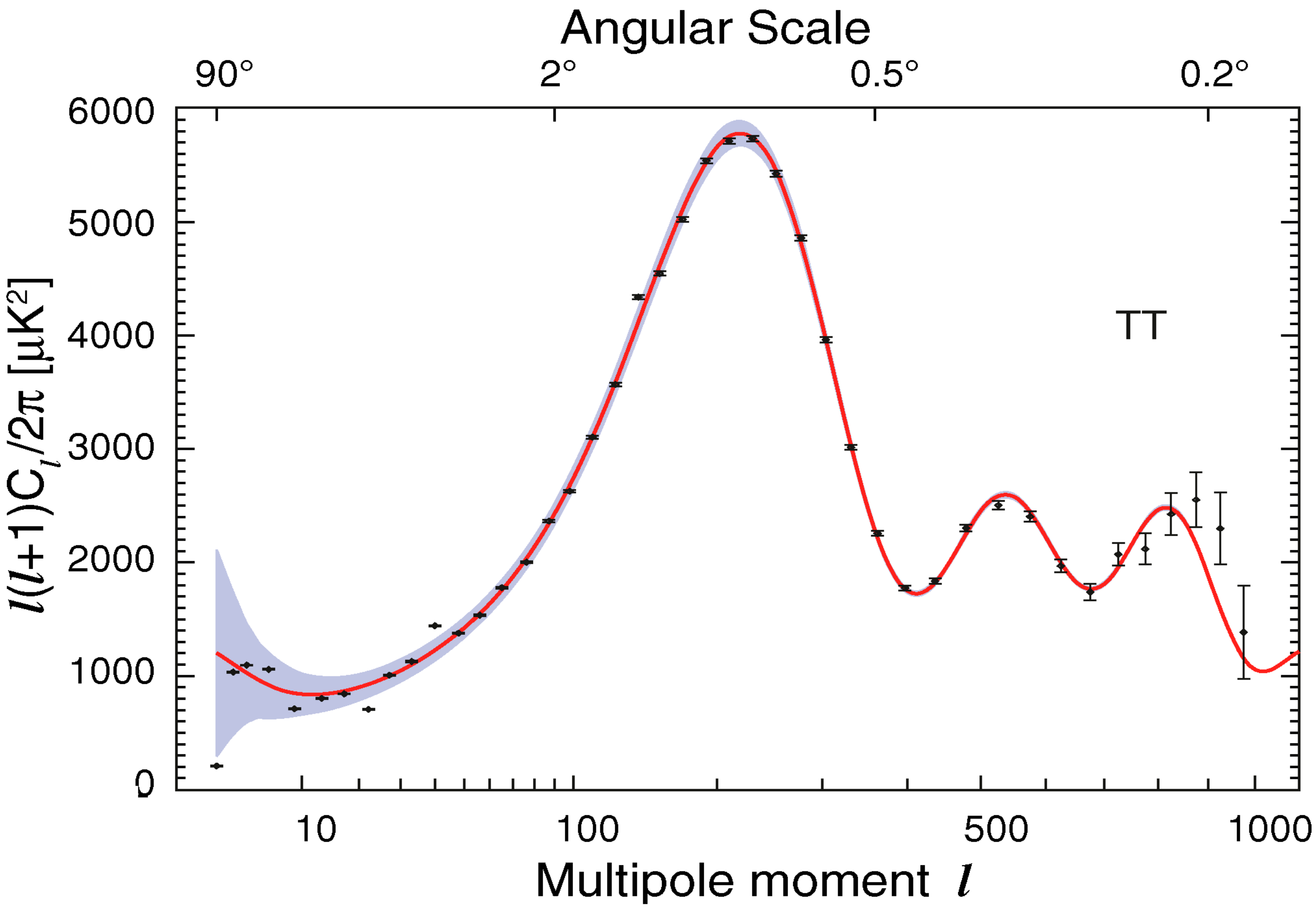
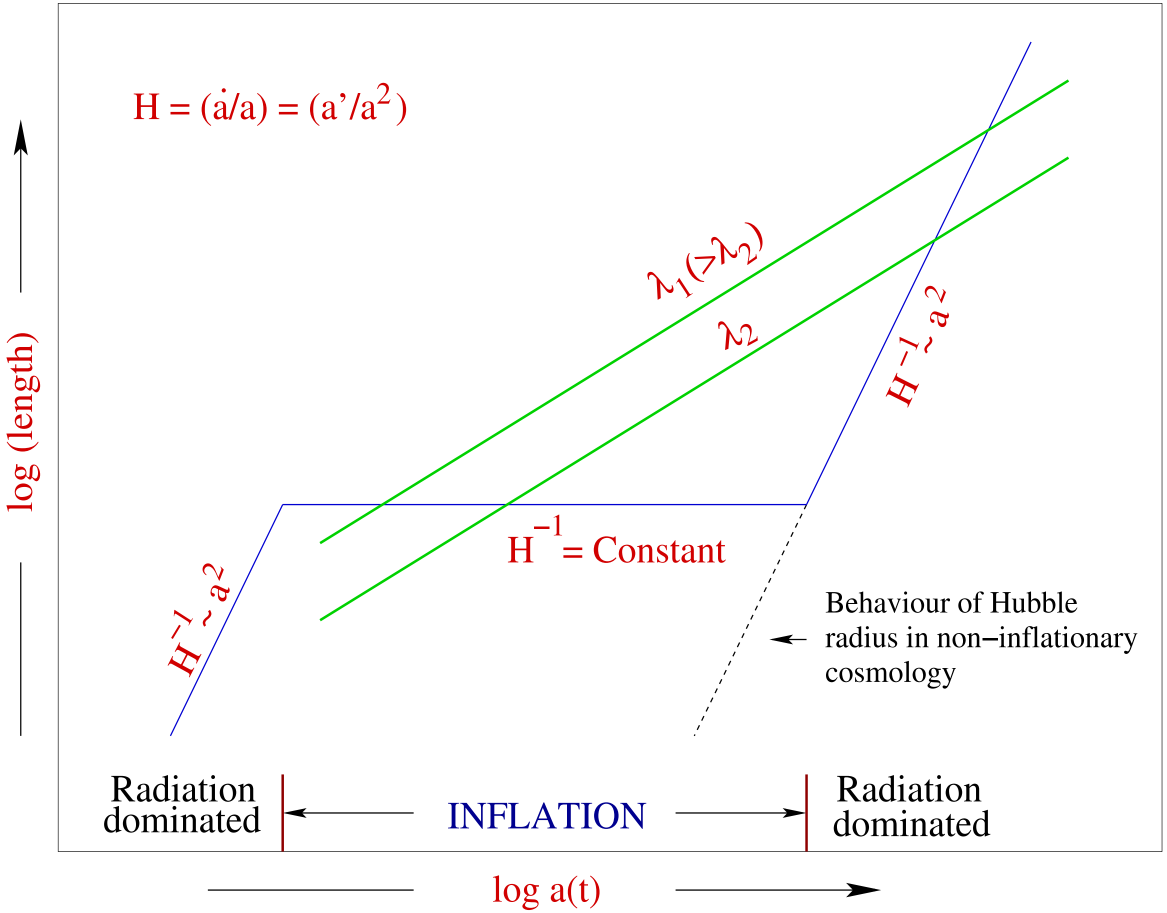
Angular power spectrum from the WMAP 5-year data[a]



The WMAP 5-year data for the CMB TT angular power spectrum (the black dots with error bars) and the theoretical, best fit ΛCDM model with a power law primordial spectrum (the solid red curve). Note the outliers near the multipoles $\ell = 2$, 22 and 40.

[a] G. Hinshaw *et. al.*, Astrophys. J. Suppl. **180**, **225** (2009).

Evolution of modes in the inflationary scenario[a]



Plots of the physical wavelength $\lambda_{\rm P}$ $[= (\lambda_0\, a)]$ (the green lines) and the Hubble radius $d_{\rm H}$ $(= H^{-1})$ (in blue) illustrating as to how inflation allows us to bring the modes inside the Hubble radius at a suitably early time.

[a] E. W. Kolb and M. S. Turner, *The Early Universe,* (Addison-Wesley Publishing Company, 1990), Fig. 8.4; T. Padmanabhan, *Structure Formation in the Universe* (Cambridge University Press, Cambridge, 1993), Fig. 10.1.

This talk is based on

- ✦ R. K. Jain, P. Chingangbam and L. Sriramkumar, *On the evolution of tachyonic perturbations at super Hubble scales*, JCAP **0710**, 003 (2007).
- ✦ R. K. Jain, P. Chingangbam, J.-O. Gong, L. Sriramkumar and T. Souradeep, Punctuated inflation and the low CMB multipoles, JCAP **0901**, 009 (2009).
- ✦ R. K. Jain, P. Chingangbam, L. Sriramkumar and T. Souradeep, *The tensor-to-scalar ratio in punctuated inflation*, arXiv:0904.2518v1 [astro-ph.CO].

Outline of the talk

1 Does the primordial spectrum contain features?

Do we require lower power at large scales?

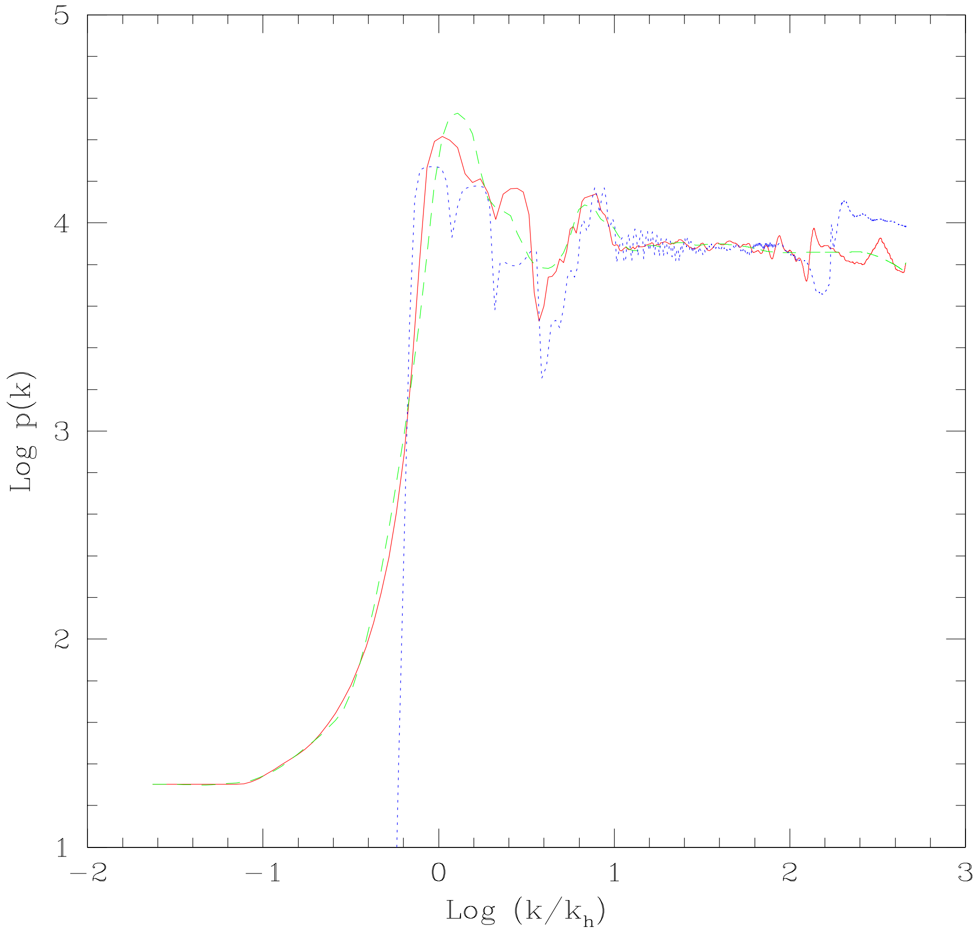
The following scalar power spectrum with a sharp cut off at $k_c \simeq 3 \times 10^{-4}$ Mpc^{-1}:

$$\begin{aligned} \mathcal{P}_{\rm S}(k) &= 0, & k \le k_c, \\ &= A_{\rm S}\,\left(\frac{k}{k_0}\right)^{(n_{\rm S}-1)}, & k > k_c, \end{aligned}$$

was found to improve the fit to the WMAP 3-year data by $\Delta\chi^2_{\rm eff} \simeq 1$, with respect to the best fit power law primordial spectrum[a].

[a] D. Spergel *et al.*, Astrophys. J. Suppl. **170**, 377 (2007).

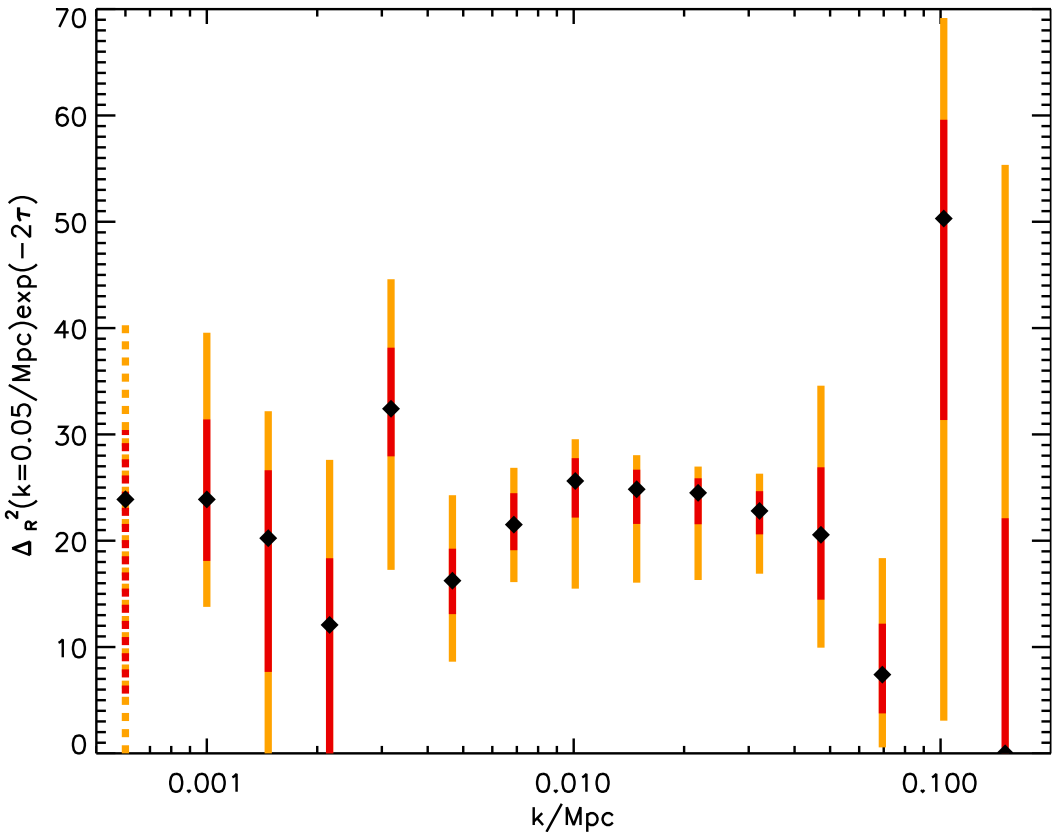
Reconstructing the primordial spectrum



The 'recovered' primordial spectrum (the blue-dotted line), assuming the standard background ΛCDM model. The recovered spectrum improves the fit to the WMAP 3-year data by $\Delta\chi^2_{\rm eff} \simeq 15$, with respect to the best fit power law spectrum[a].

[a] A. Shafieloo, T. Souradeep, P. Manimaran, P. K. Panigrahi and R. Rangarajan, Phys. Rev. D **75**, 123502 (2007).

Does the primordial spectrum contain other features?



A primordial spectrum 'reconstructed' in 15 bins between $k = 0$ and $k = 0.15\ \mathrm{Mpc}^{-1}$ using the WMAP 3-year data. The vertical bars indicate the 68% (in red) and 95% (in orange) constraints, about the peak likelihood values (marked as black diamonds). Such a spectrum was found to improve the fit to the 3-year WMAP data by $\Delta\chi^2_{\mathrm{eff}} \simeq 22$[a].

[a] D. Spergel *et al.*, Astrophys. J. Suppl. **170**, 377 (2007).

2 Generating features in the primordial spectrum

2.1 Key equations and quantities

A couple of words on the notation

- We shall set c, $\hbar$, as well as the Planck mass, viz. $M_{_{\rm P}} = (8\,\pi\,G)^{-(1/2)}$, to unity.
- We shall denote differentiation with respect to the cosmic and the conformal times by an overdot and an overprime, respectively.

Essential equations and quantities

For the case of inflation driven by the canonical scalar field, say, ϕ, the curvature and the tensor perturbations $\mathcal{R}_k$ and $\mathcal{U}_k$ satisfy the differential equations

$$\mathcal{R}_k'' + 2\,(z'/z)\,\mathcal{R}_k' + k^2\,\mathcal{R}_k = 0 \quad \text{and} \quad \mathcal{U}_k'' + 2\,\mathcal{H}\,\mathcal{U}_k' + k^2\,\mathcal{U}_k = 0,$$

where $z = (a\,\phi'/\mathcal{H})$, with a being the scale factor, and $\mathcal{H} = (a'/a)$.

The scalar and the tensor power spectra, viz. $\mathcal{P}_{_{\mathrm{S}}}(k)$ and $\mathcal{P}_{_{\mathrm{T}}}(k)$, are given by

$$\mathcal{P}_{_{\mathrm{S}}}(k) = \left(\frac{k^3}{2\,\pi^2}\right)\,|\mathcal{R}_{\mathrm{k}}|^2 \quad \text{and} \quad \mathcal{P}_{_{\mathrm{T}}}(k) = 2\,\left(\frac{k^3}{2\pi^2}\right)\,|\mathcal{U}_{\mathrm{k}}|^2,$$

with the amplitudes $\mathcal{R}_k$ and $\mathcal{U}_k$ evaluated, in general, in the super-Hubble limit.

Finally, the tensor-to-scalar ratio r is defined as follows:

$$r(k) \equiv \left(\frac{\mathcal{P}_{_{\mathrm{T}}}(k)}{\mathcal{P}_{_{\mathrm{S}}}(k)}\right).$$

2.2 Deviations from slow roll inflation and features in the primordial spectrum

Characterizing deviations from slow roll inflation

Recall that, for the case of the canonical scalar field, the first two Hubble slow roll parameters are given by

$$\epsilon = -\left(\frac{\dot{H}}{H^2}\right) \quad \text{and} \quad \delta = \left(\frac{\ddot{\phi}}{H\,\dot{\phi}}\right),$$

where $H = (\dot{a}/a)$ is the standard Hubble parameter.

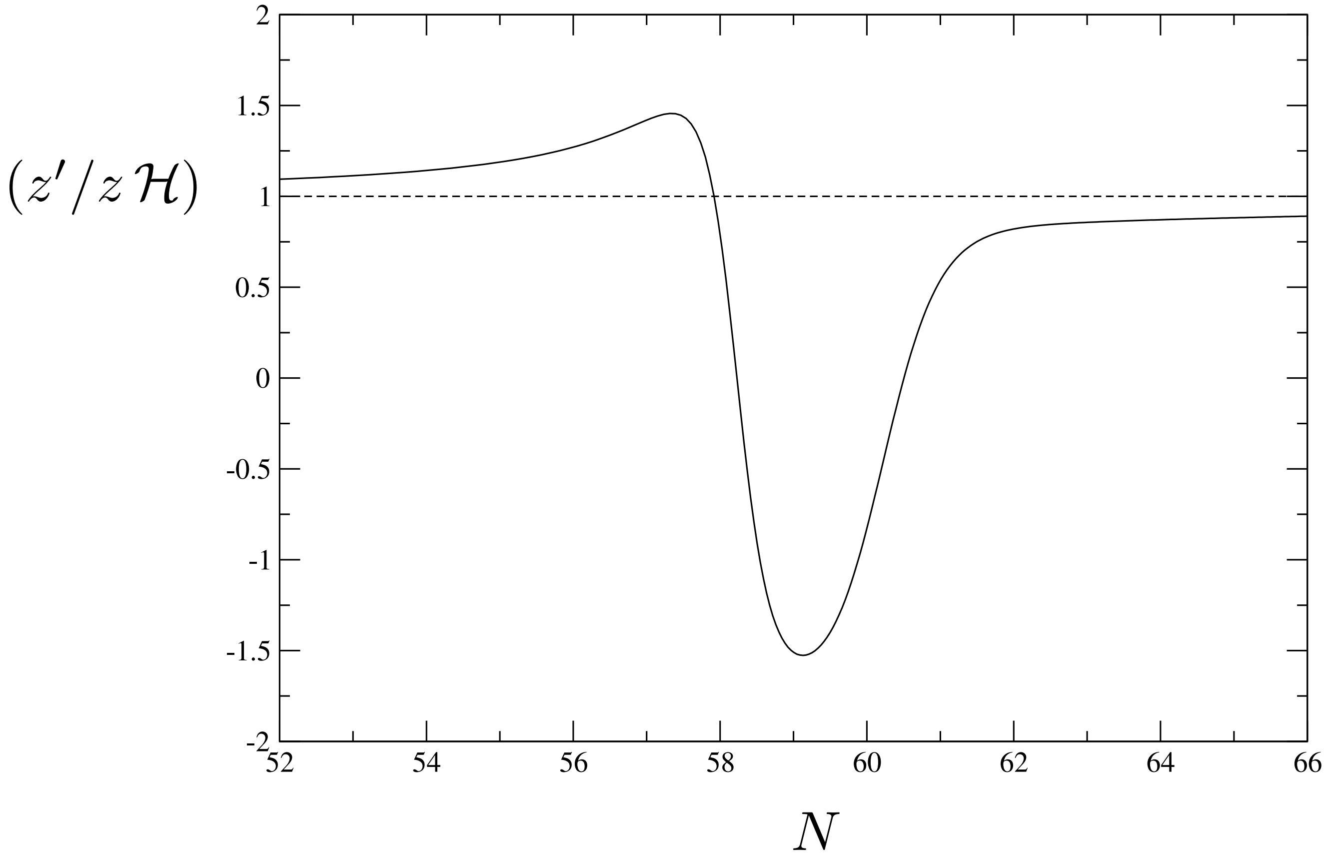
The quantity (z'/z) that appears in the differential equation for the curvature perturbation $\mathcal{R}_k$ can be expressed in terms of the above two Hubble slow roll parameters as follows[a]:

$$\left(\frac{z'}{z\,\mathcal{H}}\right) = (1+\epsilon+\delta)\,.$$

Note that, during slow roll inflation (i.e. when $\epsilon \ll 1$ and $\delta \ll 1$), the quantity $(z'/z\,\mathcal{H})$ remains close to unity.

[a]See, for example, S. M. Leach and A. R. Liddle, Phys. Rev. D **63**, 043508 (2001); S. M. Leach, M. Sasaki, D. Wands and A. R. Liddle, *ibid.* **64**, 023512 (2001); R. K. Jain, P. Chingangbam and L. Sriramkumar, JCAP **0710**, 003 (2007).

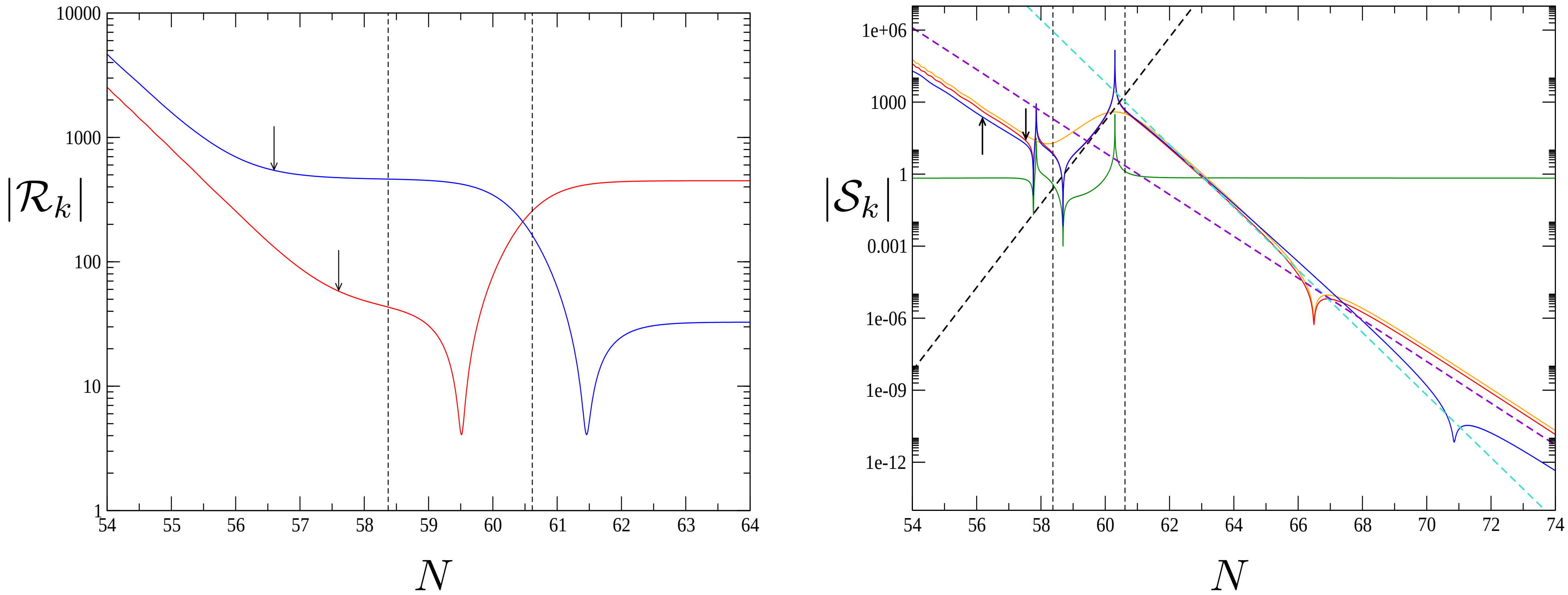
A specific example[a]



The evolution of the quantity $(z'/z\,\mathcal{H})$ plotted as a function of the number of e-folds N for the tachyonic potential $V(T) = V_0\,\left(1 + V_1\,T^4\right)$. Note that the quantity becomes negative for a little less than three e-folds between N of 58 and 61.

[a] R. K. Jain, P. Chingangbam and L. Sriramkumar, JCAP **0710**, 003 (2007).

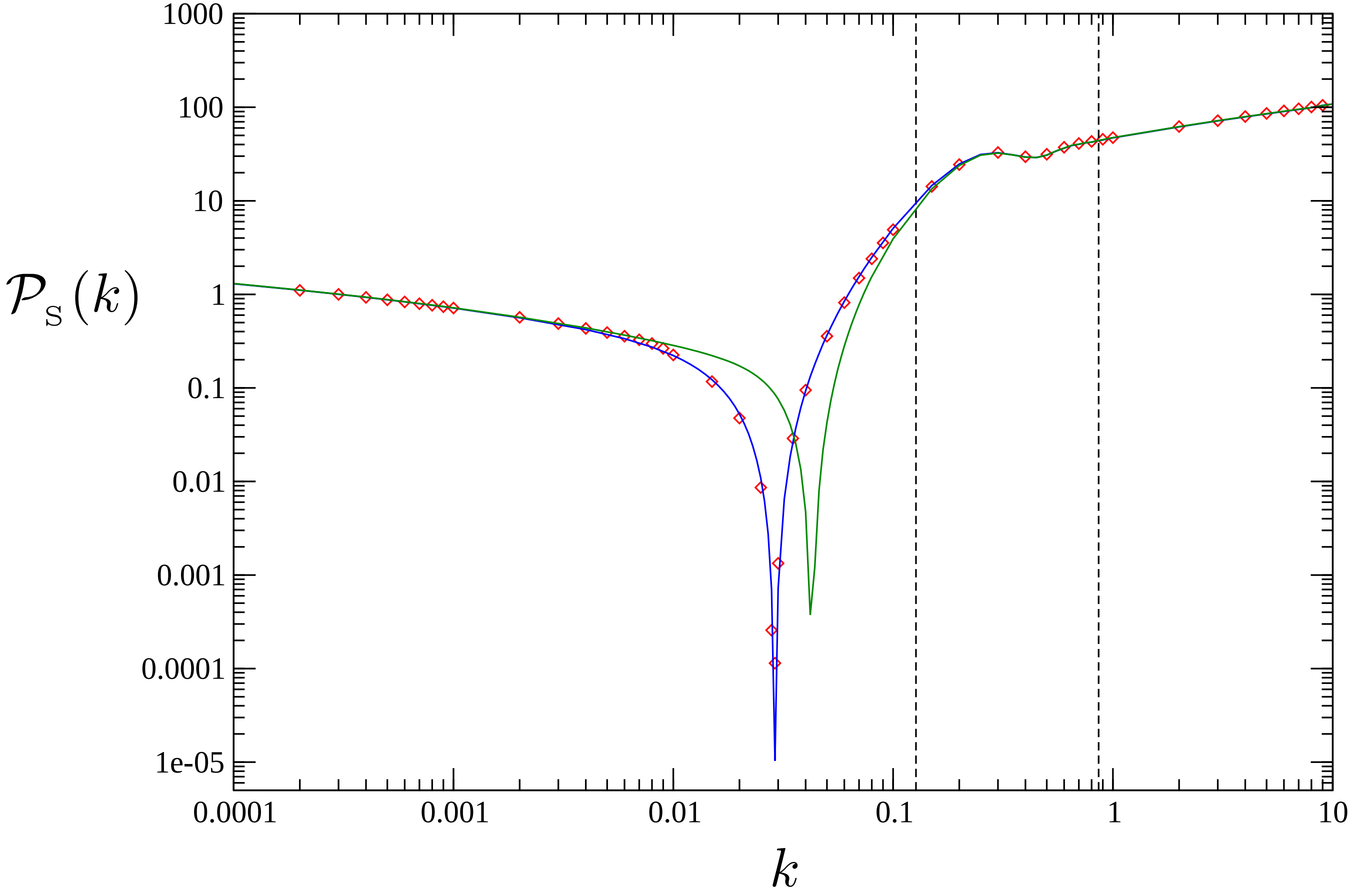
Evolution of the curvature and the entropy perturbations[a]



The evolution of the amplitude of the curvature (on the left) and the entropy (on the right) perturbations plotted as a function of the number of e-folds N for the modes with wave numbers $k = 0.03$ (in blue) and $k = 0.1$ (in red). The vertical lines delineate the regime where (z'/z) is negative. The arrows indicate the time at which the modes leave the Hubble radius.

[a] R. K. Jain, P. Chingangbam and L. Sriramkumar, JCAP **0710**, 003 (2007).

The power spectrum at Hubble exit and at super Hubble scales[a]



Plots of the scalar power spectrum evaluated at the end of inflation (in blue) and soon after the modes leave the Hubble radius (in green). The vertical lines indicate the modes that leave the Hubble scale during the period of fast roll. Note that the two spectra differ for modes that leave the Hubble radius just before the fast roll regime.

[a] R. K. Jain, P. Chingangbam and L. Sriramkumar, JCAP **0710**, 003 (2007).

2.3 Fitting the low quadrapole, and the outliers near $\ell = 22$ and 40

Suppressing the power at the largest scales

- Within the inflationary scenario, a variety of single and two field models have been constructed to produce a drop in power at the largest scales today so as to provide a better fit to the low quadrapole[a].

- However, in the single field inflationary models, in order to produce such a spectrum, many of the scenarios either assume a specific pre-inflationary regime, say, a radiation dominated epoch[b], or special initial conditions for the background scalar field, such as an initial period of fast roll[c], or special initial states for the perturbations[d].

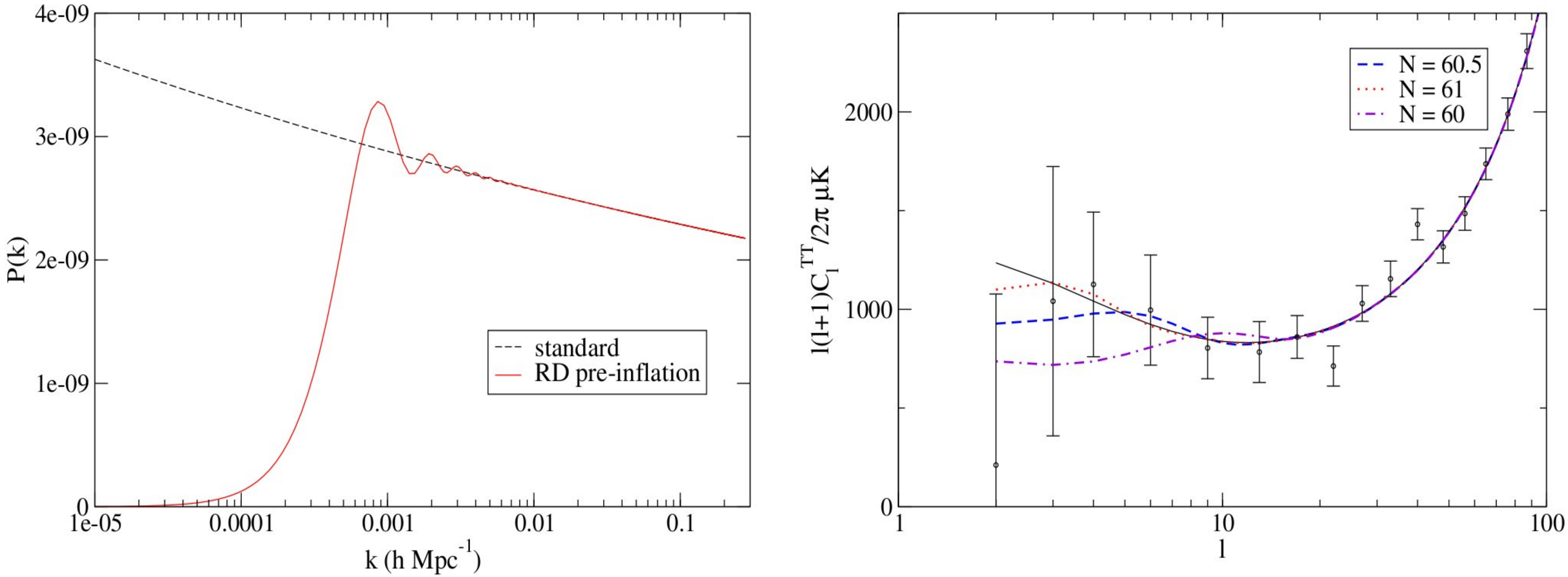
[a]See, for instance, B. Feng and X. Zhang, Phys. Lett. B **570**, 145 (2003); R. Sinha and T. Souradeep, Phys. Rev. D **74**, 043518 (2006).

[b]See, for example, D. Boyanovsky, H. J. de Vega and N. G. Sanchez, Phys. Rev. D **74**, 123006 (2006); *ibid* **74**, 123007 (2006); B. A. Powell and W. H. Kinney, Phys. Rev. D **76**, 063512 (2007).

[c]See, for instance, C. R. Contaldi, M. Peloso, L. Kofman and A. Linde, JCAP **0307**, 002 (2003); J. M. Cline, P. Crotty and J. Lesgourgues, JCAP **0309**, 010 (2003).

[d]L. Sriramkumar and T. Padmanabhan, Phys. Rev. D **71**, 103512 (2005).

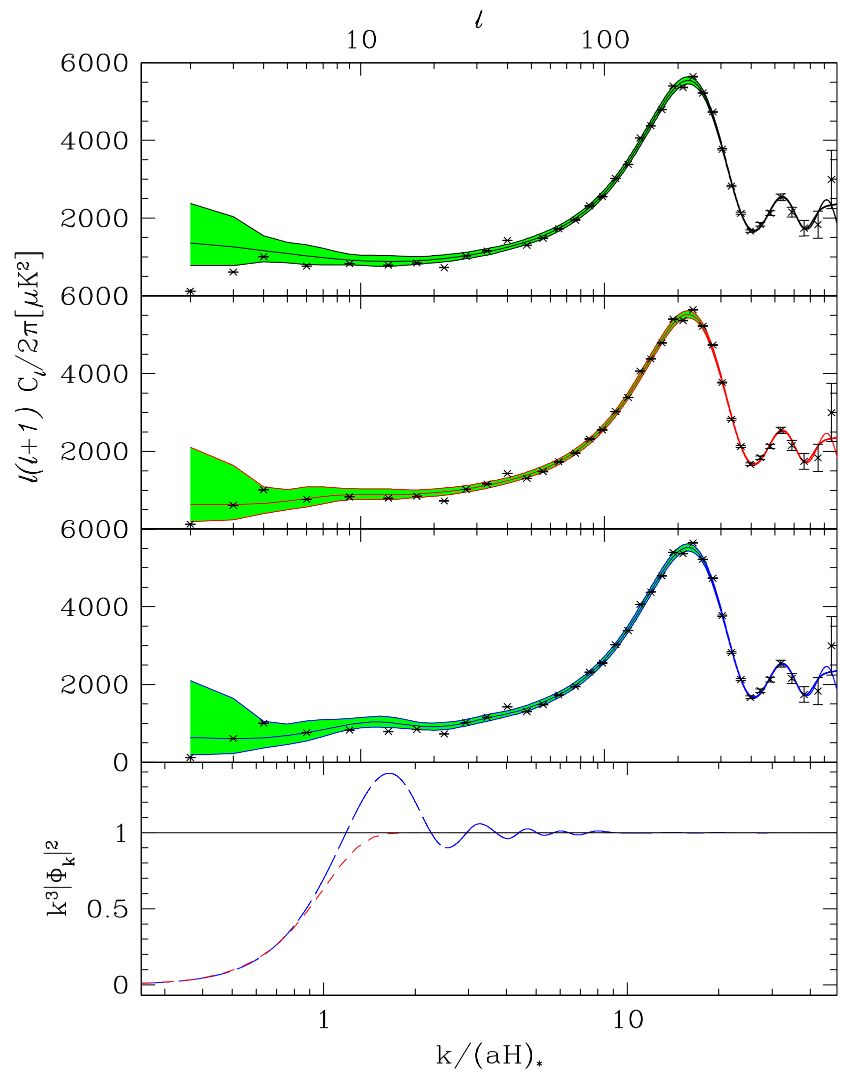
Spectra due to a pre-inflationary, radiation dominated phase[a]



The scalar power spectrum in a model with a pre-inflationary radiation dominated epoch (on the left) and the corresponding CMB TT angular power spectrum (on the right). The modified scalar spectrum was found to improve the fit to the WMAP 3-year data by $\Delta\chi^2_{\rm eff} \simeq 2$, with respect to the standard power law case.

[a] B. A. Powell and W. H. Kinney, Phys. Rev. D **76**, 063512 (2007).

Spectra in an initially fast rolling inflationary model



The scalar power spectrum in the chaotic [i.e. $(m^2\,\phi^2)$] inflation model with an initial period of fast roll (bottom panel), and the corresponding CMB TT angular power spectrum (the second panel from the bottom). The scalar spectrum was found to improve the fit to the WMAP 1-year data by $\Delta\chi^2_{\rm eff} \simeq 4$, with respect to the best fit power law spectrum[a].

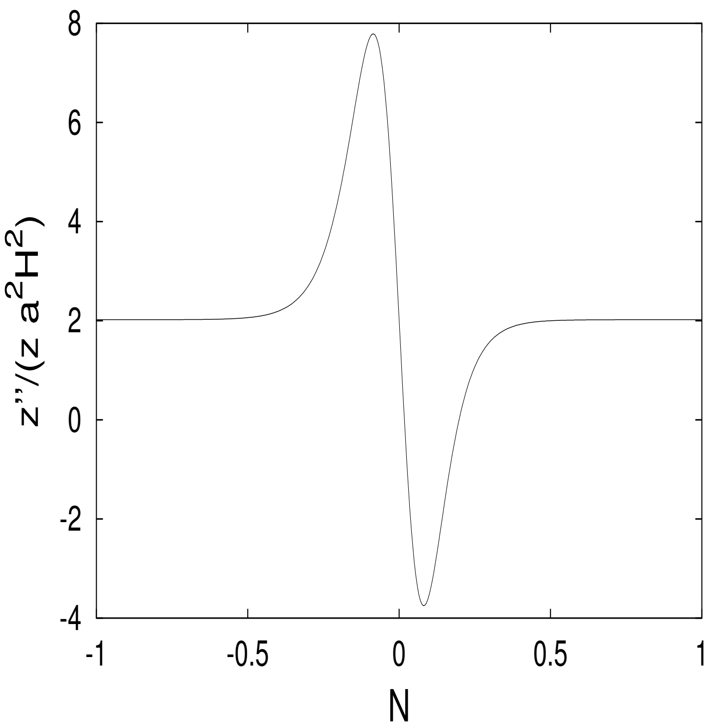
[a] C. R. Contaldi, M. Peloso, L. Kofman and A. Linde, JCAP **0307**, 002 (2003).

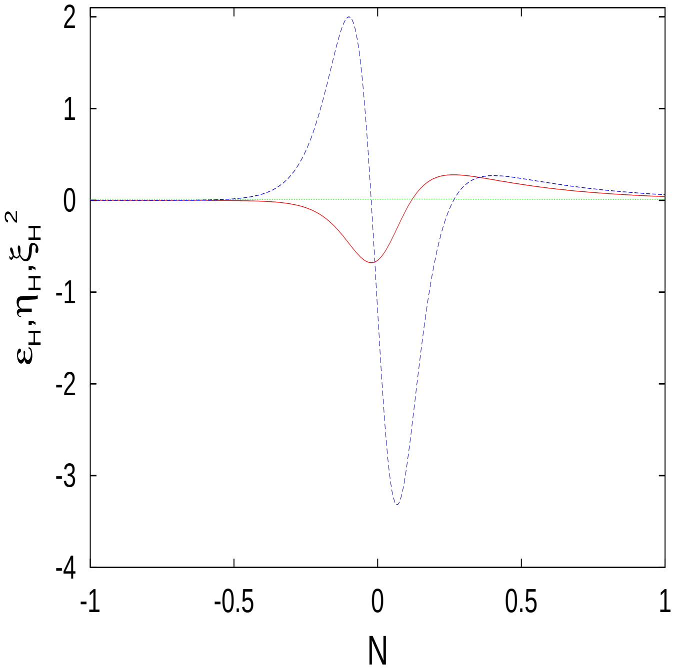
Drawbacks of these approaches

- ✦ Evidently, these models assume either a specific pre-inflationary phase or special initial conditions for the inflaton.
- ✦ Also, these models impose the initial conditions on the perturbations when the largest scales are outside the Hubble radius during the pre-inflationary or the fast roll regime.
- ✦ Moreover, though a very specific pre-inflationary phase such as the radiation dominated epoch may allow what can be considered as natural (i.e. Minkowski-like) initial conditions for the perturbations even at super-Hubble scales, choosing to impose initial conditions for a small subset of modes when they are outside the Hubble radius, while demanding that such conditions be imposed on the rest of the modes at sub-Hubble scales, is highly unsatisfactory.

Ideally, it would be preferable to produce the desired power spectrum during an inflationary epoch without invoking any specific pre-inflationary phase or special initial conditions for the inflaton. Also, one would like to impose the standard Bunch-Davies initial conditions on *all* the modes when they are well inside the Hubble radius.

Inducing fast roll in the chaotic inflation model



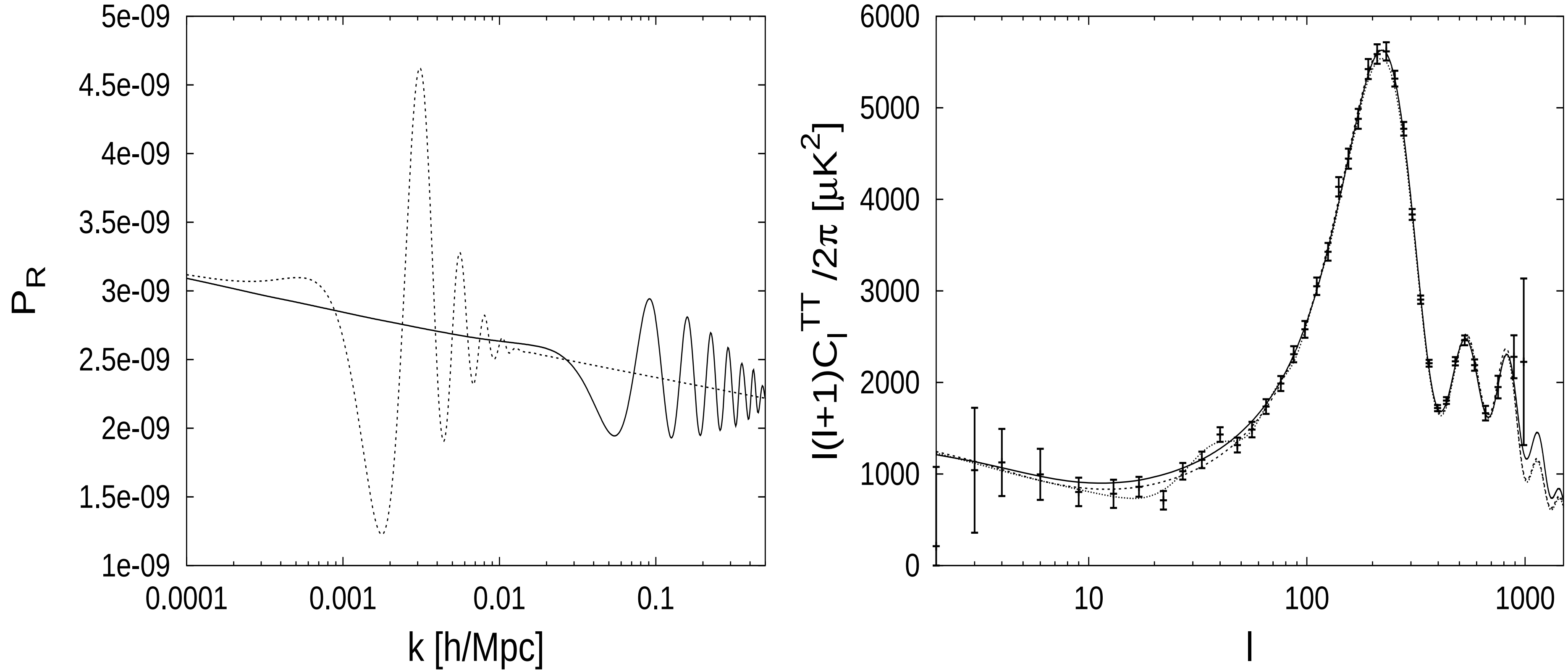


The evolution of the quantity $(z''/z\,\mathcal{H}^2)$ (on the left) and the first three Hubble slow roll parameters (on the right) in the following 'modified' chaotic inflation potential[a]:

$$V(\phi) = \left(\frac{m^2\,\phi^2}{2}\right)\,\left[1 - c\,\tanh\left(\frac{\phi - b}{d}\right)\right].$$

[a] L. Covi, J. Hamann, A. Melchiorri, A. Slosar and I. Sorbera, Phys. Rev. D **74**, 083509 (2006); J. Hamann, L. Covi, A. Melchiorri and A. Slosar, Phys. Rev. D **76**, 023503 (2007).

The scalar and the CMB angular power spectrum



The CMB TT angular spectrum (on the right) resulting from the primordial spectrum with features (on the left)[a]. The dashed line (on the right) corresponds to the spectrum arising from the standard power law model and the solid line refers to best fit model which improves the fit by $\Delta\chi^2_{\rm eff} \simeq 7$ with respect to the standard model.

[a] See L. Covi, J. Hamann, A. Melchiorri, A. Slosar and I. Sorbera, Phys. Rev. D **74**, 083509 (2006); for a more recent discussion, see M. J. Mortonson, C. Dvorkin, H. V. Peiris and W. Hu, Phys. Rev. D **79**, 103519 (2009).

3 Punctuated inflation

3.1 The model and background dynamics

Motivations

- Our aim is to consider a single field model of inflation that leads to a suppression of the power on large scales without the need for any special initial conditions on either the background or the perturbations.

- Also, we would like to arrive at the desired power spectrum using an inflaton potential that does not contain any ad hoc, sharp feature.

The model

- We find that the form of the potentials motivated by a class of certain minimal supersymmetric extensions of the standard model provide us with the desired behavior[a].
- These large field models allow a period of fast roll sandwiched between two stages of slow roll inflation.
- The first phase of slow roll inflation allows us to impose the standard Bunch-Davies initial conditions on the modes which exit the Hubble radius during the subsequent fast roll regime, an epoch due to which the curvature perturbations on the super-Hubble scales are suppressed.
- The second slow roll phase lasts for 60 or more e-folds, thereby allowing us to overcome the standard horizon problem associated with the hot big bang model.

[a] See, R. Allahverdi, J. Garcia-Bellido, K. Enqvist and A. Mazumdar, Phys. Rev. Lett. **97**, 191304 (2006); R. Allahverdi, K. Enqvist, J. Garcia-Bellido, A. Jokinen and A. Mazumdar, JCAP **0706**, 019 (2007); J. C. B. Sanchez, K. Dimopoulos and D. H. Lyth, JCAP **0701**, 015 (2007); R. Allahverdi, A. Mazumdar and T. Multamaki, arXiv:0712.2031 [astro-ph].

The effective potential[a]

The effective potential that we shall consider is given by

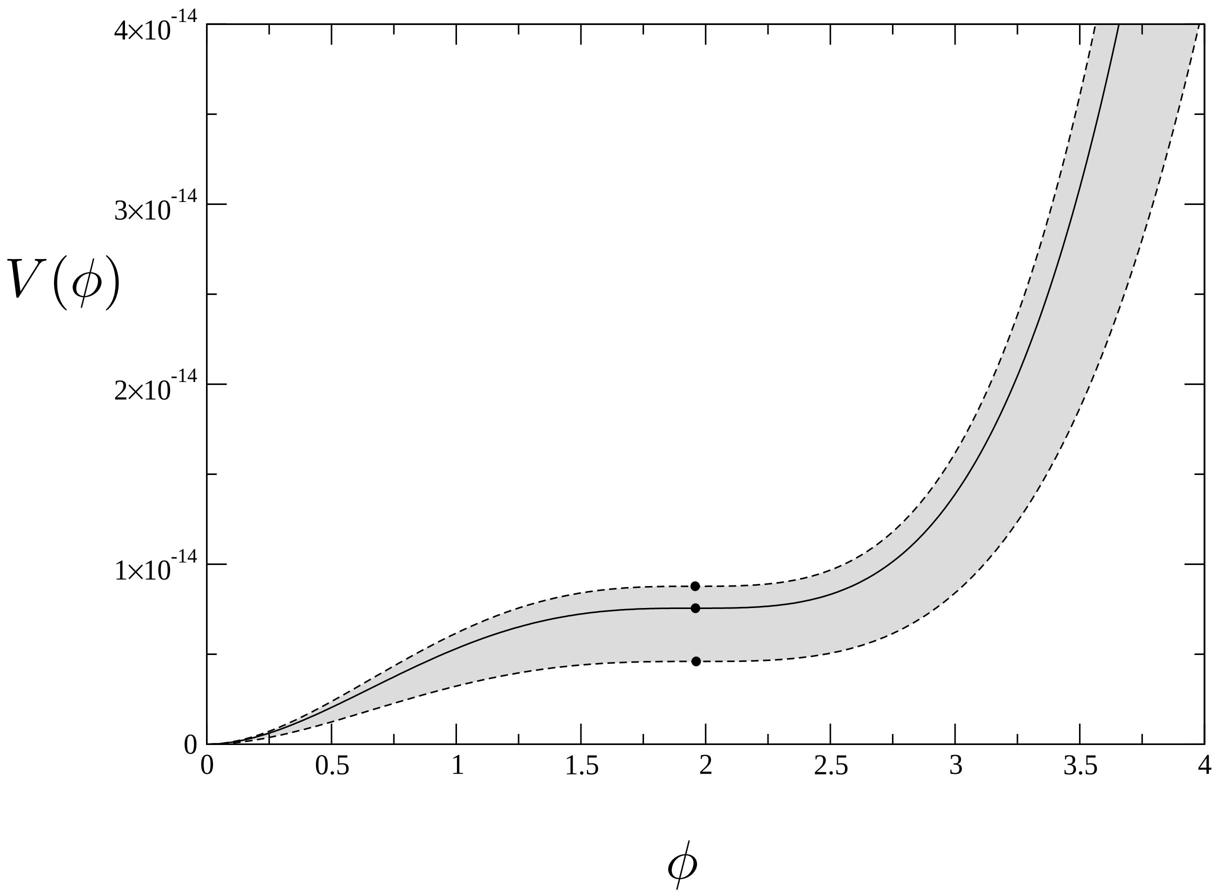
$$V(\phi) = \left(m^2/2\right)\,\phi^2 - \left(\sqrt{2\,\lambda\,(n-1)}\,m/n\right)\,\phi^n + (\lambda/4)\,\phi^{2(n-1)},$$

where $n > 2$ is an integer. This potential has a point of inflection at

$$\phi_0 = \left[\frac{2\,m^2}{(n-1)\,\lambda}\right]^{\frac{1}{2\,(n-2)}}.$$

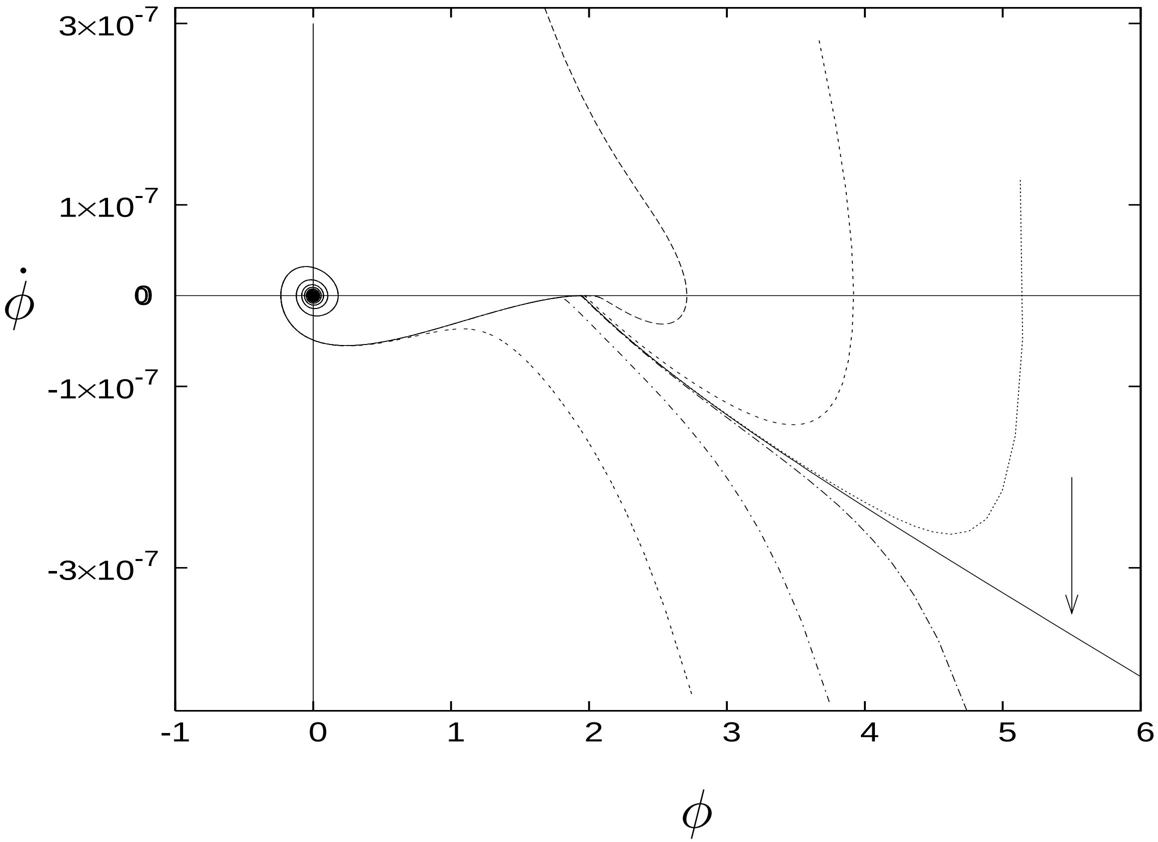
[a] R. Allahverdi, K. Enqvist, J. Garcia-Bellido, A. Jokinen and A. Mazumdar, JCAP **0706**, 019 (2007).

Illustration of the effective potential



The inflaton potential for the case of $n = 3$. The solid line corresponds to the values for the potential parameters that provide the best fit to the WMAP 5-year data. The dashed lines correspond to values that are 1-σ away from the best fit ones. The black dots denote the points of inflection.

Phase portrait in the $n = 3$ case[a]

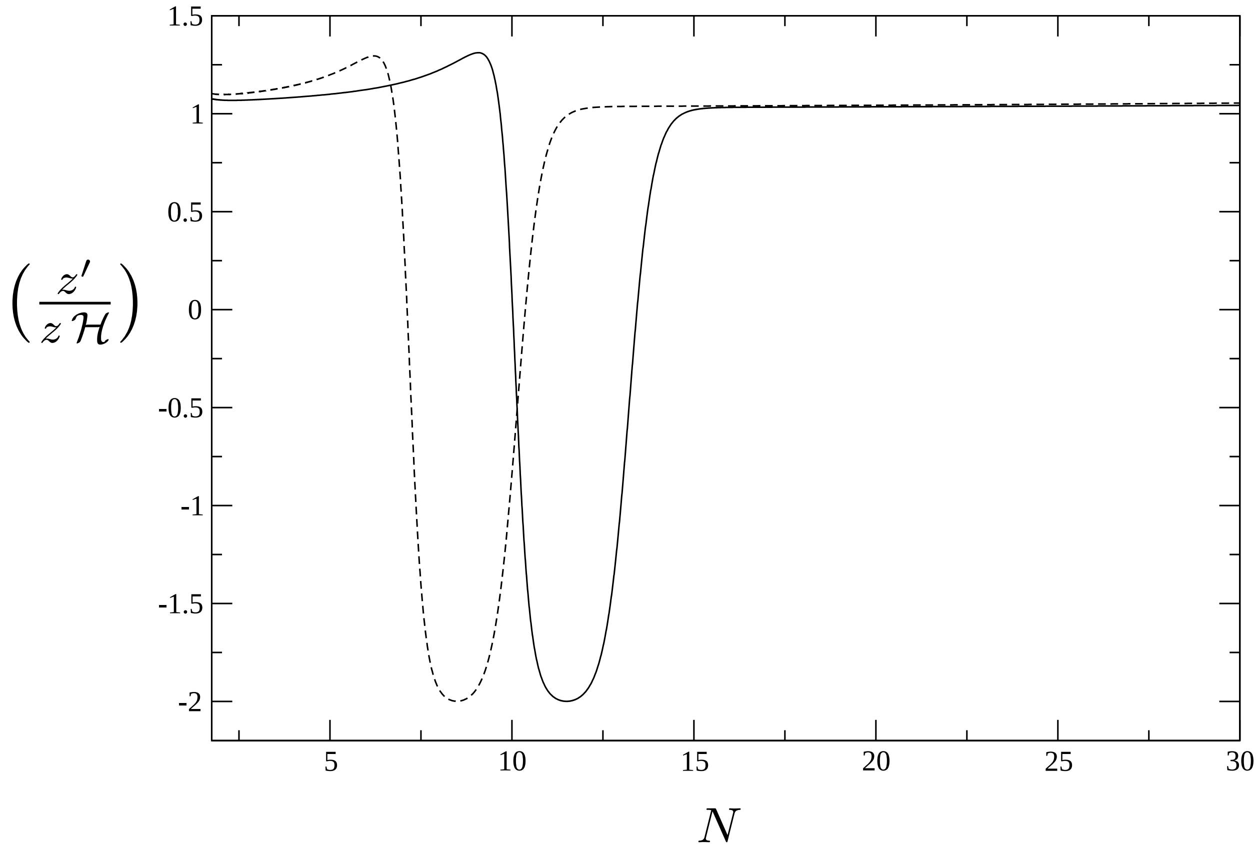


The phase portrait of the scalar field in the case of $n = 3$ and for the best fit values of the parameters m and λ used in the last figure. The arrow points to the attractor. Note that all the trajectories quickly approach the attractor. We find that such a behavior is exhibited by higher values of n (such as, for example, $n = 4, 6$) as well.

[a] R. K. Jain, P. Chingangbam, J.-O. Gong, L. Sriramkumar and T. Souradeep, JCAP **0901**, 009 (2009).

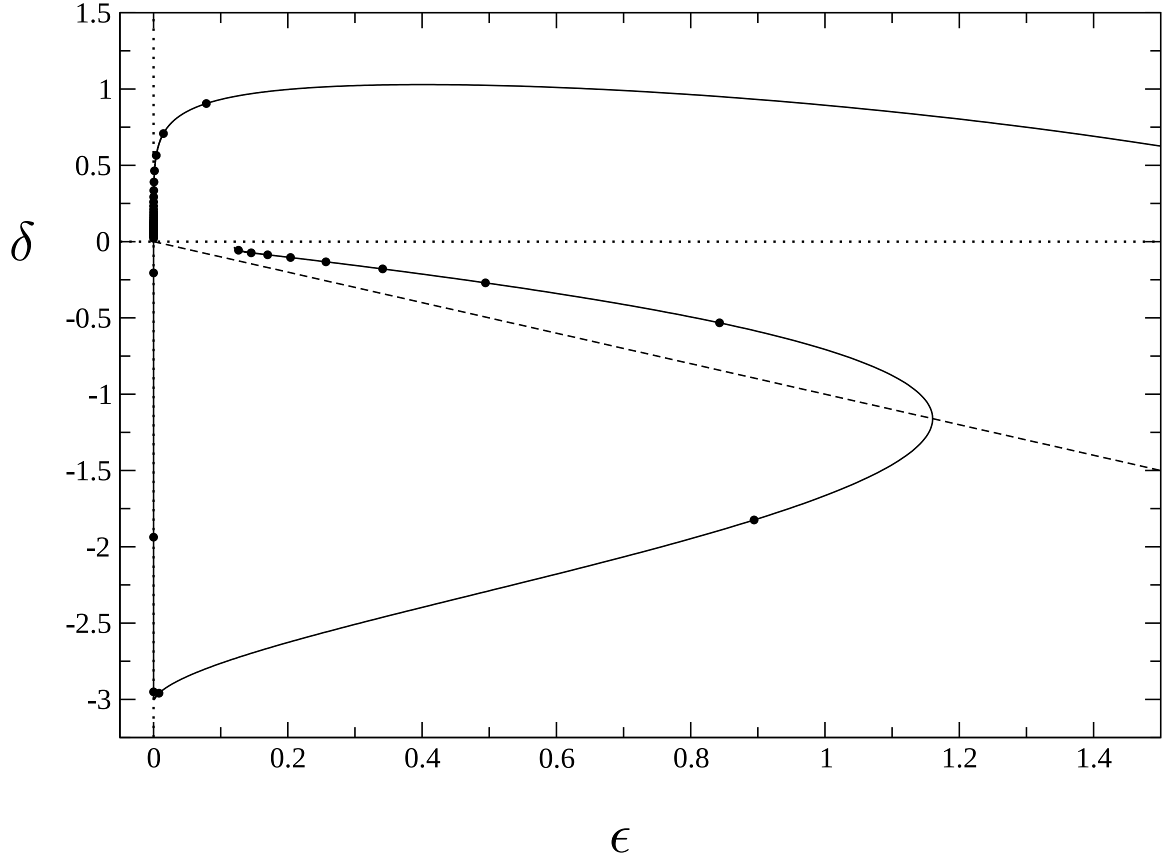
3.2 The scalar and the tensor power spectra

Evolution of the friction term



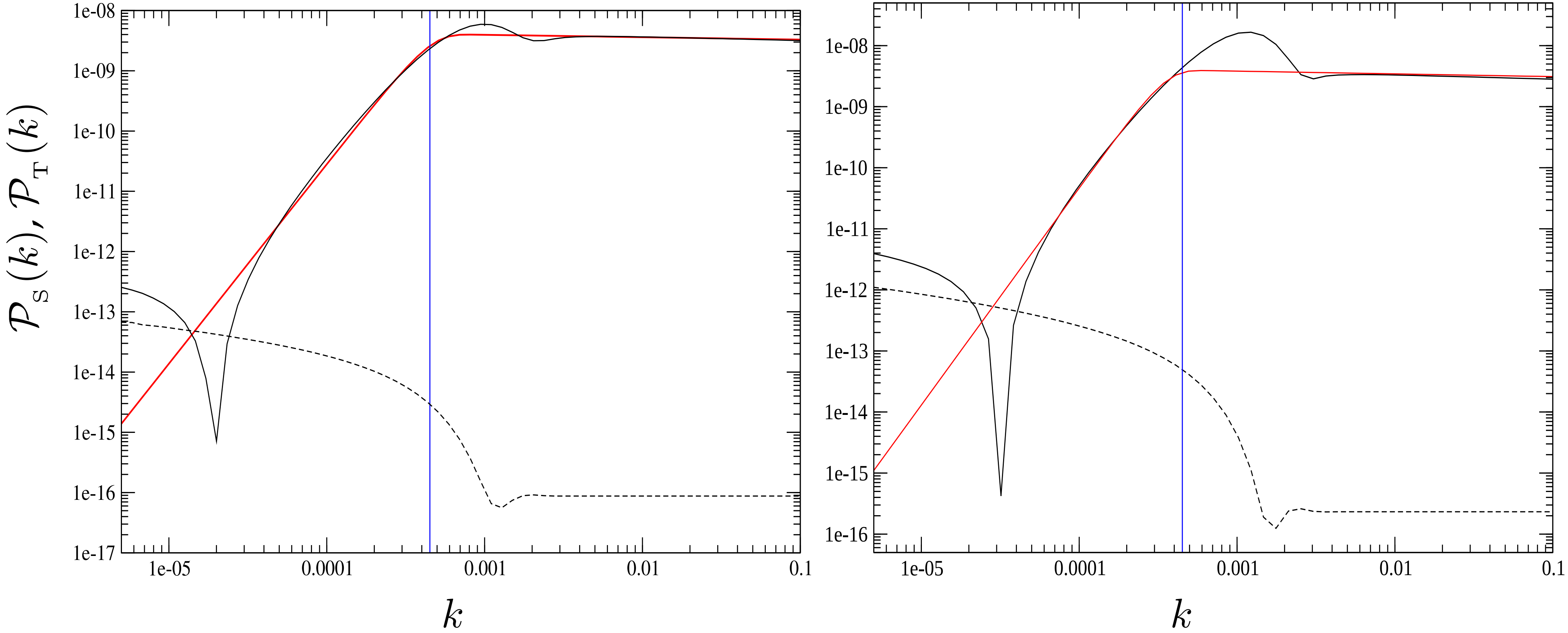
The evolution of background quantity $(z'/z\,\mathcal{H})$ has been plotted for the cases of $n = 3$ (the solid line) and $n = 4$ (the dashed line). We have chosen parameters that provide the best fit to the WMAP 5-year data. Evidently, the $n = 3$ case departs from slow roll when $7 \lesssim N \lesssim 15$, while the departure occurs during $4 \lesssim N \lesssim 12$ in the case of $n = 4$.

Evolution in the ϵ-δ plane



The evolution of the scalar field has been plotted (as the solid black line) in the plane of the first two Hubble slow roll parameters ϵ and δ in the case of $n = 3$. The black dots have been marked at intervals of one e-fold, while the dashed line corresponds to $\epsilon = -\delta$. Note that $\epsilon > 1$ during $8 < N < 9$. In other words, during the fast roll, inflation is actually interrupted for about a e-fold.

Power spectra for the $n = 3$ and $n = 4$ cases



The scalar power spectrum $\mathcal{P}_{\rm S}(k)$ (the solid line) and the tensor power spectrum $\mathcal{P}_{\rm T}(k)$ (the dashed line) have been plotted as a function of the wavenumber k for the cases of $n = 3$ (on the left) and $n = 4$ (on the right). We have chosen the same values for the potential parameters as in the earlier figures. Moreover, we should emphasize that we have arrived at these spectra by imposing the standard, Bunch-Davies, initial condition on *all* the modes.

3.3 Comparison with the WMAP 5-year data

Datasets and packages used

- **Datasets used:** WMAP 5-year data[a] (TT as well as TE)
- **Packages used:**
  - CAMB[b]: To compute the CMB angular power spectrum for a given inflationary perturbation spectrum
  - COSMOMC[c]: To explore the cosmological parameter space using the Markov Chain Monte Carlo method for a given set of priors
  - WMAP 5th year likelihood code[d]: To compute the $\chi^2_{\rm eff}$ for a given model

The reference model we shall compare with is the standard ΛCDM model with a power law primordial spectrum. Also, since, in our model, $r < 10^{-4}$ over scales of cosmological interest, we shall ignore the contributions due to the tensors in our analysis. Further, we shall ignore gravitational lensing when computing the CMB angular power spectrum using CAMB.

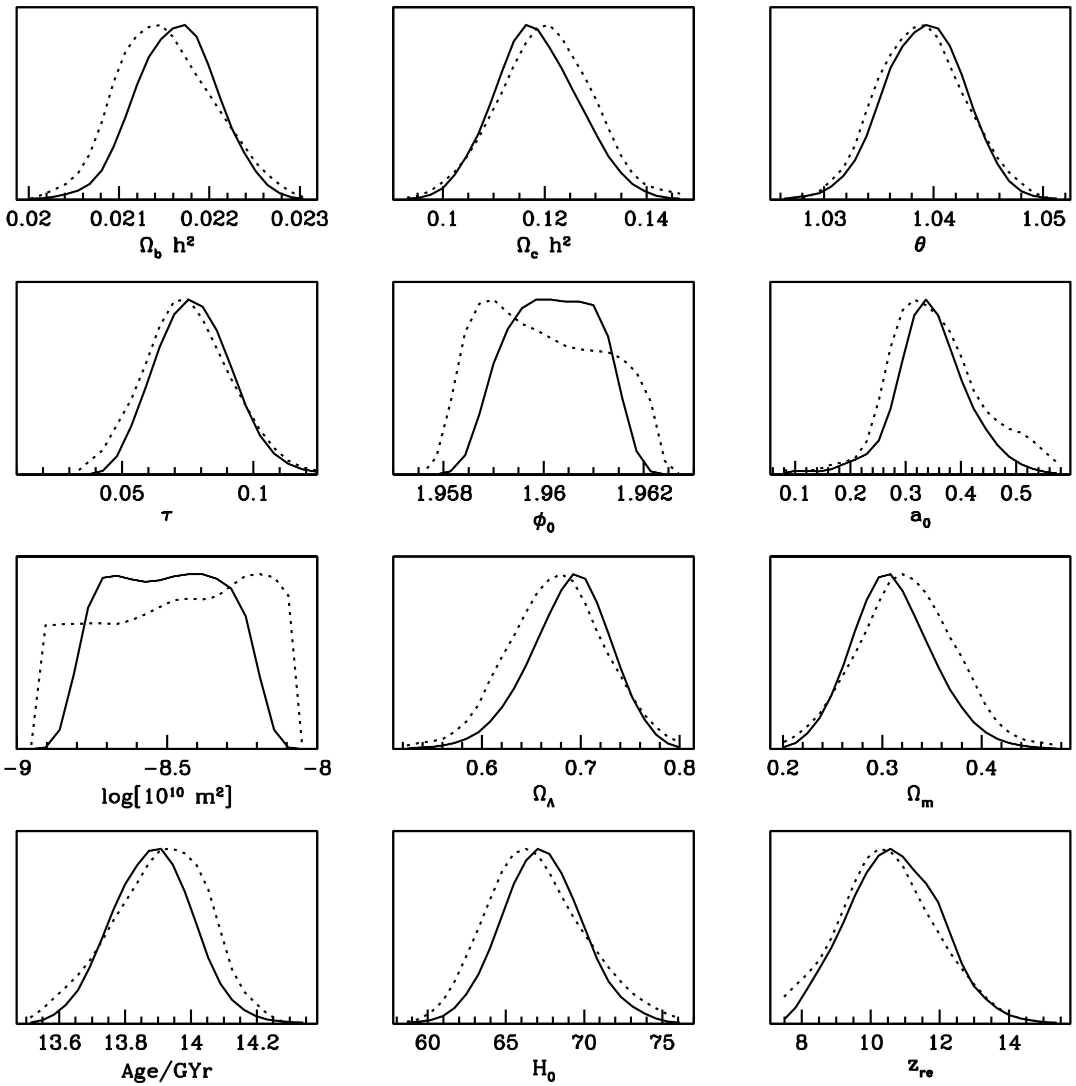
[a] http://lambda.gsfc.nasa.gov
[b] http://camb.info
[c] http://cosmologist.info/cosmomc
[d] http://lambda.gsfc.nasa.gov

The parameters in our model and the priors

Model	Parameter	Lower limit	Upper limit
Common parameters	$\Omega_{\rm b}\, h^2$	0.005	0.1
	$\Omega_{\rm c}\, h^2$	0.001	0.99
	θ	0.5	10.0
	τ	0.01	0.8
Reference model	$\log\,\left[10^{10}\, A_{\rm S}\right]$	2.7	4.0
	$n_{\rm S}$	0.5	1.5
Our model	$\log\,\left[10^{10}\, m^2\right]$	-9.0	-8.0
	ϕ_0	1.7	2.3
	a_0	0.1	2.0

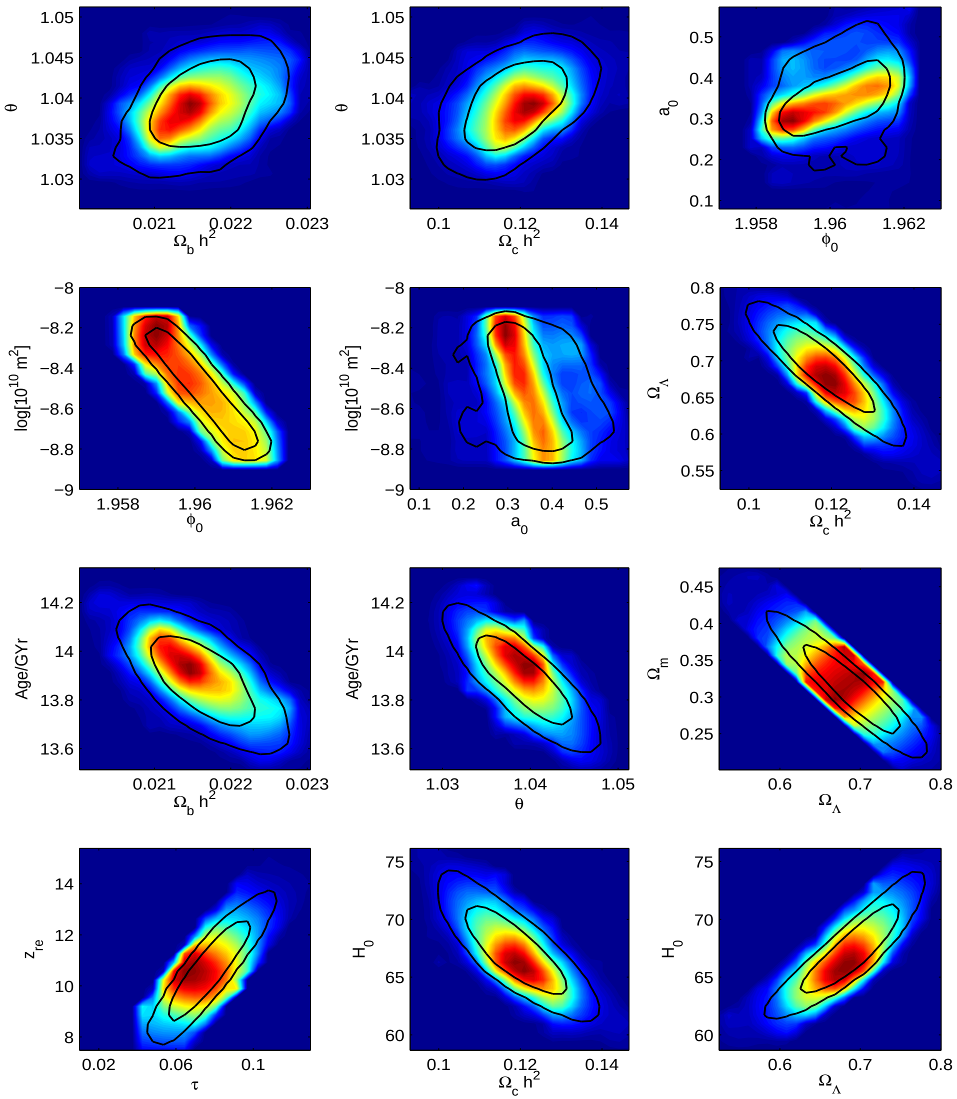
The priors on the various parameters describing the reference ΛCDM model with a power law primordial spectrum and our model. While the first four background cosmological parameters are common for both the models, the fifth and the sixth parameters describe the power law primordial spectrum of the reference model. In our model, we have traded off the scalar amplitude $A_{\rm S}$ for m and the spectral index $n_{\rm S}$ for ϕ_0. The additional parameter in our model, viz. a_0, represents the value of the scale factor at $N=0$ and it essentially identifies the location of the cut-off in the power spectrum.

Likelihood distributions for the $n = 3$ case



The one-dimensional mean (the solid lines) and marginalized (the dashed lines) likelihood curves for the input as well as the derived parameters in the $n = 3$ case.

Joint constraints on the parameters in the $n = 3$ case



The 1-σ and 2-σ two-dimensional joint constraints on the different input and derived parameters in the $n = 3$ case.

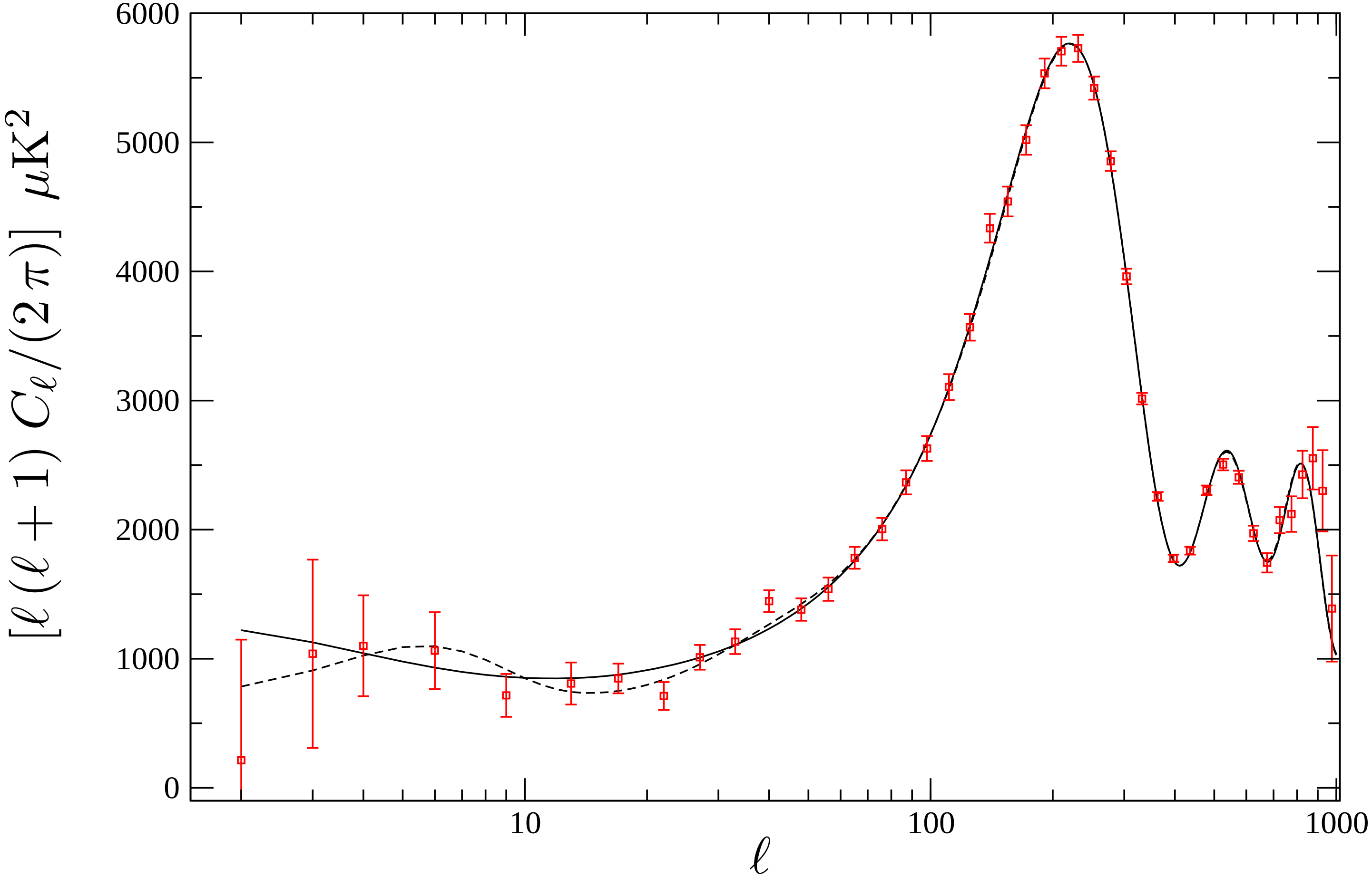
The best fit values of the parameters in the $n = 3$ case[a]

Parameter	Reference model	Our model
$\Omega_{\rm b}\, h^2$	0.02242	0.02146
$\Omega_{\rm c}\, h^2$	0.1075	0.12051
θ	1.0395	1.03877
τ	0.08695	0.07220
$\log\, \left[10^{10}\, A_{\rm S}\right]$	3.0456	—
$n_{\rm S}$	0.9555	—
$\log\, \left[10^{10}\, m^2\right]$	—	-8.3509
ϕ_0	—	1.9594
a_0	—	0.31439

The mean values of the various parameters that describe the reference model and our model. We find that the $n = 3$ case provides a better fit to the data than the reference model with an improvement in $\chi^2_{\rm eff}$ of about 6.

[a] R. K. Jain, P. Chingangbam, J.-O. Gong, L. Sriramkumar and T. Souradeep, JCAP **0901**, 009 (2009).

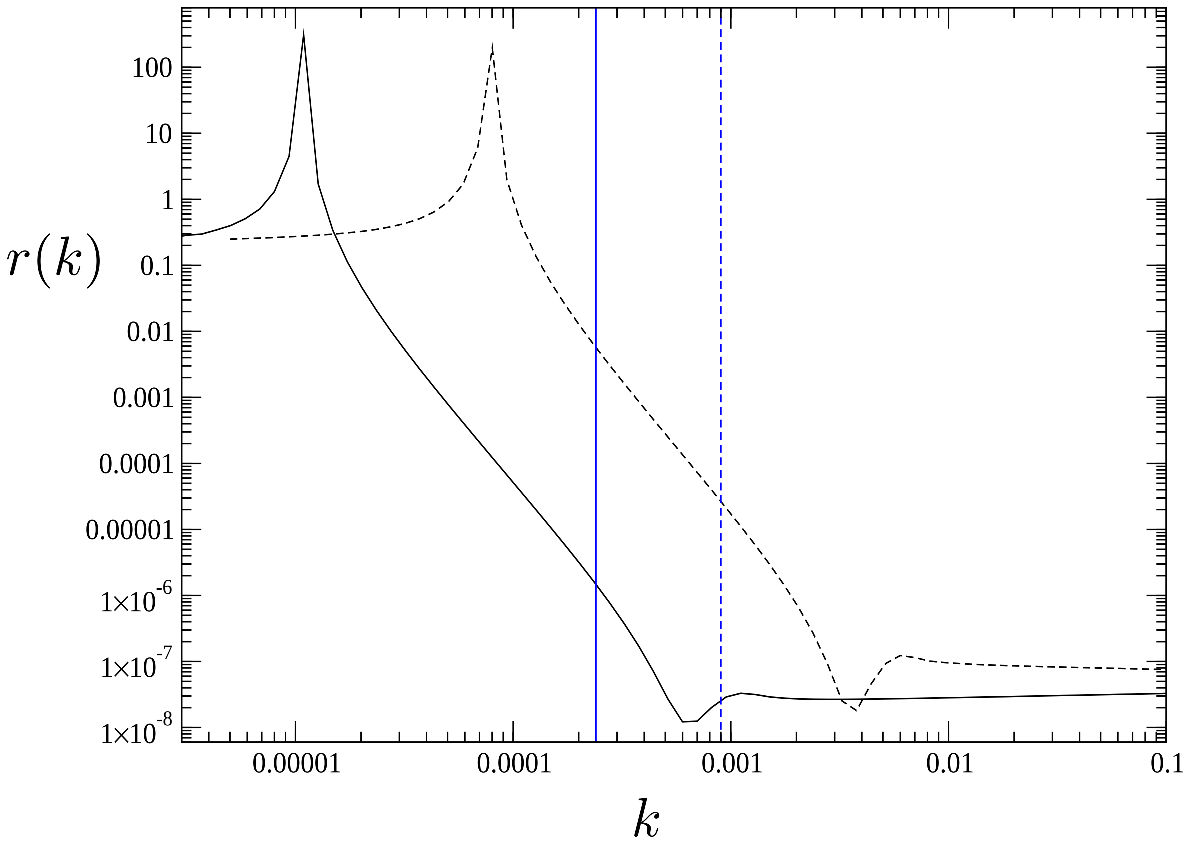
The CMB angular power spectrum for the best fit values



The CMB TT angular power spectrum for the best fit values in the $n = 3$ case (the dashed line) and the best fit power law, reference model (the solid line). Visually, it is evident that our model fits the data better than the standard power law case at the lower multipoles. Also, note that there is hardly any difference between the angular spectrum from our model and the power law spectrum at the higher multipoles.

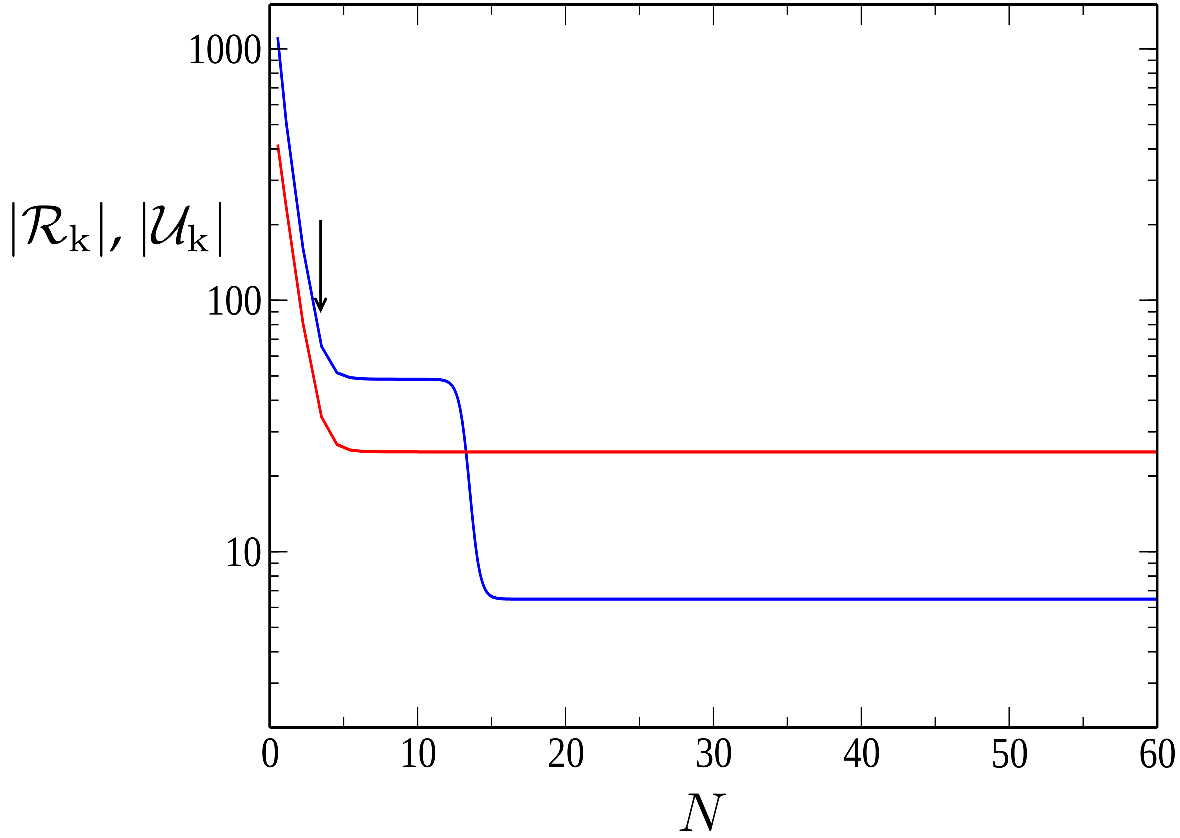
4 The tensor-to-scalar ratio in punctuated inflation

The tensor-to-scalar ratio in the MSSM motivated models



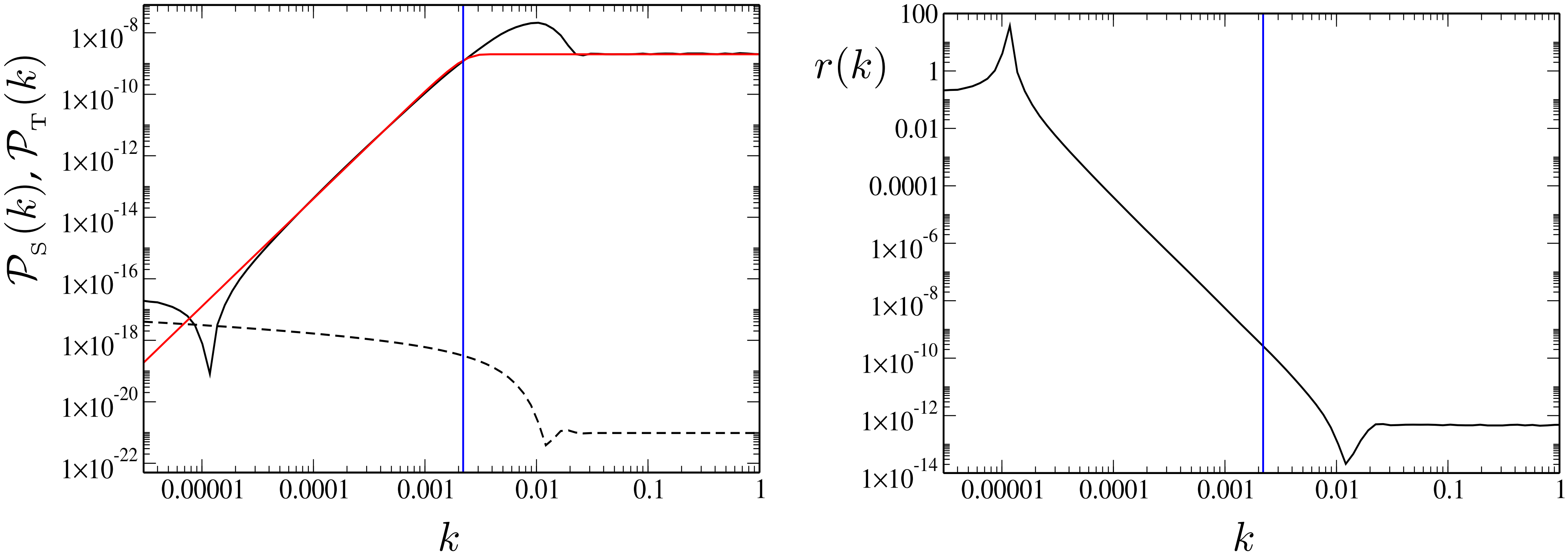
The tensor-to-scalar ratio r for the cases of $n = 3$ (the solid line) and $n = 4$ (the dashed line) plotted as a function of the wavenumber k. These plots have been drawn for the same choice of parameters as in the earlier figures. Note that, in spite of the rise at larger wavelengths, the tensor-to-scalar ratio remains smaller than 10^{-4} for modes of cosmological interest. It should also be pointed out that there exists a small range of mode for which $r > 1$.

Evolution of the scalar and the tensor amplitudes when $r > 1$



The evolution of the amplitudes of the curvature perturbation $\mathcal{R}_{\mathrm{k}}$ (in blue) and the tensor perturbation $\mathcal{U}_{\mathrm{k}}$ (in red) has been plotted as a function of the number of e-folds N for the best fitting $n = 3$, MSSM case. These perturbations correspond to the mode $k = 10^{-5}\ \mathrm{Mpc}^{-1}$, and the arrow denotes the time when the mode leaves the Hubble radius. Notice that, as expected, the tensor amplitude freezes at its value near Hubble exit. In contrast, the amplitude of the curvature perturbation is suppressed on super-Hubble scales.

r in a hybrid, punctuated inflationary model[a]

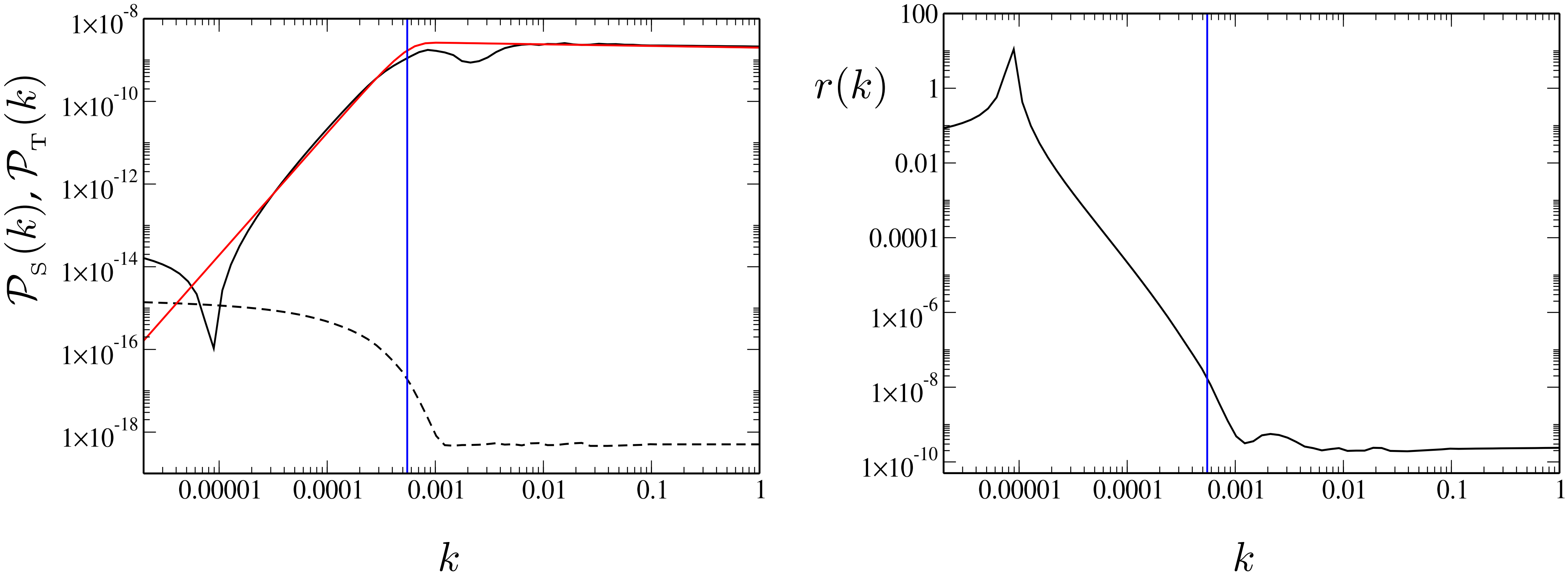


Left: The scalar power spectrum $\mathcal{P}_{\rm S}(k)$ (the solid black line) and the tensor power spectrum $\mathcal{P}_{\rm T}(k)$ (the dashed black line) have been plotted for a hybrid inflation model described by the potential $V(\phi) = (M^4/4)\,\left(1 + B\,\phi^4\right)$.

Right: The corresponding tensor-to-scalar ratio $r(k)$.

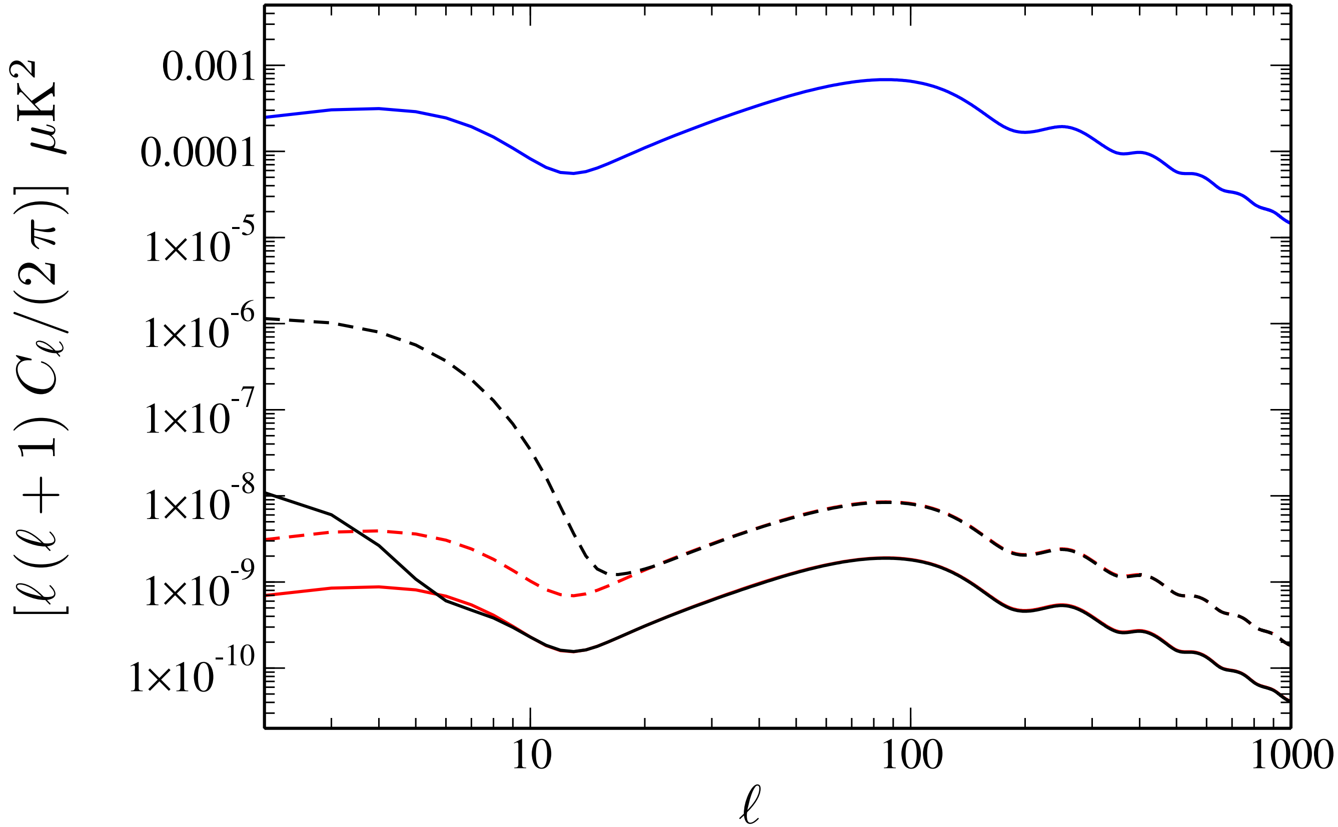
[a] R. K. Jain, P. Chingangbam, L. Sriramkumar and T. Souradeep, arXiv:0904.2518v1 [astro-ph.CO].

r in a tachyonic, punctuated inflationary model



The scalar and the tensor power spectra as well as the corresponding tensor-to-scalar ratio in a tachyonic, punctuated inflationary model. The potential describing the model contains a point of inflection that has been introduced by hand.

The effects on the B-modes of the CMB[a]



The B-mode CMB angular power spectrum C_ℓ^{BB} for the best fit values of the $n = 3$ (the solid black line) and $n = 4$ (the dashed black line) MSSM motivated models. For comparison, we have also plotted the C_ℓ^{BB} for a strictly scale invariant tensor spectrum and a tensor-to-scalar ratio of $r = 0.01$ (the solid blue line), $r = 2 \times 10^{-8}$ (the solid red line) and $r = 10^{-7}$ (the dashed red line).

[a] R. K. Jain, P. Chingangbam, L. Sriramkumar and T. Souradeep, arXiv:0904.2518v1 [astro-ph.CO].

5 Summary and prospects

Summary

- We have investigated the scalar and tensor spectra that arise in punctuated inflation, i.e. a two stage slow roll inflationary scenario sandwiching an intermediate period of fast roll.
- We find that the period of fast roll period produces a sharp drop in the scalar power spectrum for the modes that leave the Hubble radius just before the second slow roll phase. We also find that, if we choose our scales such that the drop in power corresponds to the largest cosmological scales observable today, then the resulting scalar power spectrum provides a better fit to the recent WMAP data than the conventional, nearly scale invariant, power law, primordial spectrum.
- We find that, in punctuated inflation, a drop in scalar power is *always* accompanied by a rise in the tensor power. Interestingly, in such scenarios, there actually exists a small range of modes for which the tensor-to-scalar ratio rises to well beyond unity.

Prospects

- Recent analysis of the WMAP 5-year data seem to indicate that non-Gaussianities may possibly be large. The parameter $f_{\rm NL}$ that reflects the amplitude of the bi-spectrum is found to be $f_{\rm NL} = (38 \pm 21)$, at 68% confidence level[a].
- If forthcoming missions such as PLANCK detect a large level of non-Gaussianity, then it can result in a substantial tightening in the constraints on the various inflationary models. For example, the canonical scalar field models that lead to a nearly scale invariant primordial spectrum contain only a small amount of non-Gaussianity and, hence, may cease to be viable[b].
- However, it is known that primordial spectra with features can lead to reasonably large non-Gaussianities[c]. Therefore, if the non-Gaussianity indeed proves to be large, then either one has to reconcile with the fact that the primordial spectrum contains features or one has to take non-canonical scalar field models such as, say, D brane inflation models, seriously[d].

[a] K. M. Smith, L. Senatore and M. Zaldarriaga, JCAP **0909**, 006 (2009).

[b] J. Maldacena, JHEP **05**, 013 (2003).

[c] See, for instance, X. Chen, R. Easther and E. A. Lim, JCAP **0706**, 023 (2007).

[d] See, for example, X. Chen, M.-x. Huang, S. Kachru and G. Shiu, JCAP **0701**, 002 (2007).

Thank you for your attention