CMB anisotropies from acausal scaling seeds
(arXiv:0901.1845v1)

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Acausal scaling seeds, Firenze GGI, February 3, 2009

Outline

1 Introduction
2 Causal scaling seeds
3 Acausal scaling seeds
4 Results
5 Conclusions

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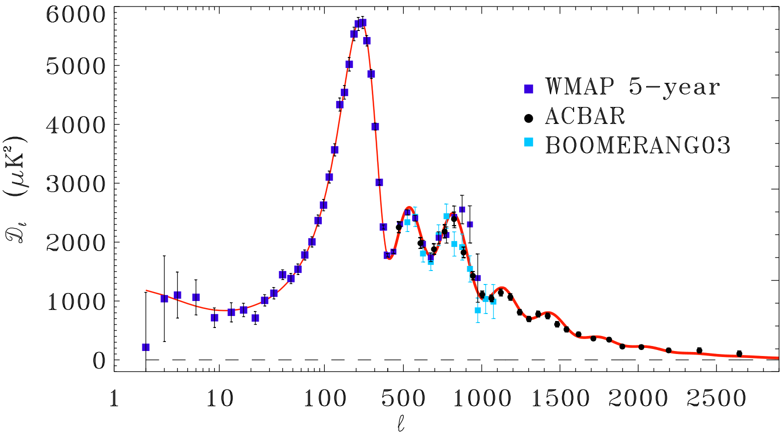
The main success of inflation is the fact that it leads to a spectrum of scale-invariant fluctuations as seen in the cosmic microwave background.



Reichardt et al. 0801.1419

Successes of inflation?

- The problem of the initial singularity is not resolved.
- Homogeneity and isotropy?
- Flatness?
- Cosmological constant problem is acute!
- So far mainly simple toy models, not well motivated by high energy physics, provide successful models of inflation.
  E.g. string theory has serious difficulties to accommodate sufficiently flat potentials.

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Causal scaling seeds

- Seeds are an inherently inhomogeneously distributed component of energy and momentum. Ex: Topological defects
- The perturbation equations then take the form

$$DX = S$$

where D is a linear differential operator, X denotes the perturbation variables of all the components contributing to the background (e.g. the $\Delta_\ell(k,t)$ for the CMB anisotropies) and S is the source vector.
- The resulting power spectra are of the form

$$\langle X_m(t,k)X_n^*(t,k')\rangle = \int_{t_{\rm in}}^{t} dt_1 dt_2 G_{mi}(t,t_1,k)G_{nj}^*(t,t_2,k') \langle S_i(t_1,k)S_j^*(t_2,k')\rangle.$$

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- The seeds are called scaling, if apart from a pre-factor $\epsilon^2 = (\kappa M^2)^2$, only functions of kt and t enter. No other dimensional parameters.
- They are causal, if all source correlators, $C(t,x-x')$, vanish for $|x-x'| > t$. Then, the seed power spectrum is an analytic function and the behavior of its components for $kt < 1$ is known. (RD, Kunz '97)
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- The best motivated example of causal scaling seeds are topological defects which can form during a symmetry breaking phase transition Kibble '76
- It has been shown that they do not lead to the formation of acoustic peaks RD, Gangui & Sakellariadou '96, Contaldi et al. '99

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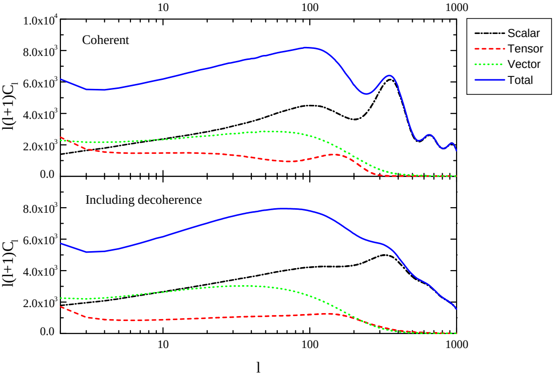

RD, Kunz & Melchiorri '99

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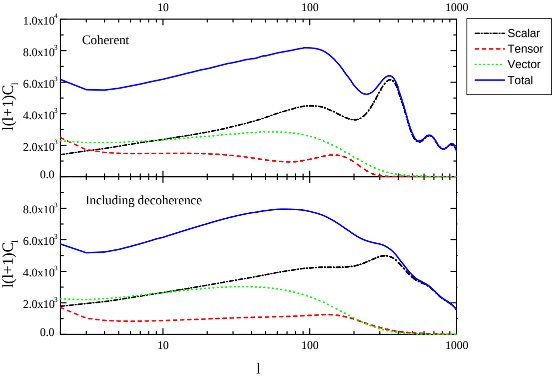

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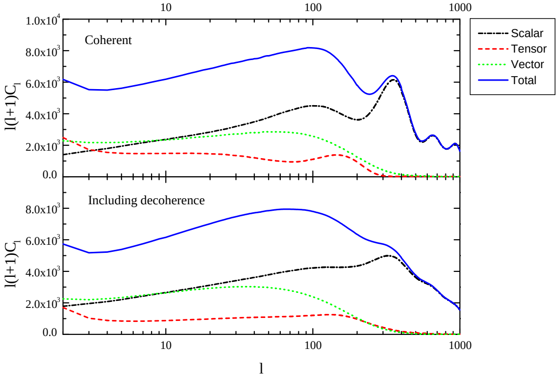

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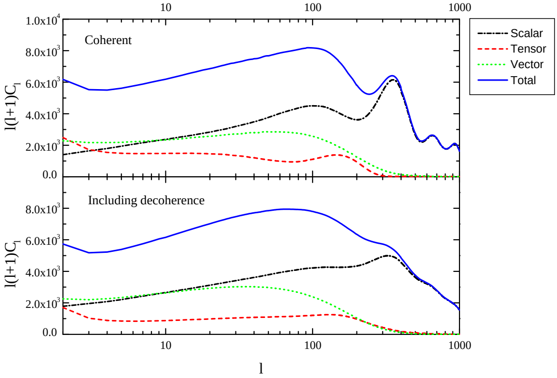

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The model

The sources are independent expanding spherical shells Turok '96.

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\begin{aligned}
T_0^0 &= -\frac{M^2}{a^2} f_\rho \,, \\
T_j^i &= \frac{M^2}{a^2}\left[f_p \delta_j^i + \left(\partial_i\partial_j - \frac{1}{3}\delta_j^i \Delta\right) f_\pi\right] \,, \\
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f_\rho(x,t) + 3f_p(x,t) = \sum_n \frac{\delta(|x - z_n| - v_1 t)}{4\pi \mathcal{H} t^{3/2}|x - z_n|^2} \,,
$$

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Here the positions z_n are the centers of the exploding shells which are at random, uncorrelated positions.

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The model

The two remaining functions are determined by energy momentum conservation and $E(t)$ is chosen such that also f_π has compact support, $f_\bullet(x,t) = 0$ for $|x - z_n| > vt$. The power spectra are proportional to the Fourier transform of the 1-shell em tensor and can be calculated analytically.

The Bardeen potentials of the shells are

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They source the fluctuations in the matter & radiation.
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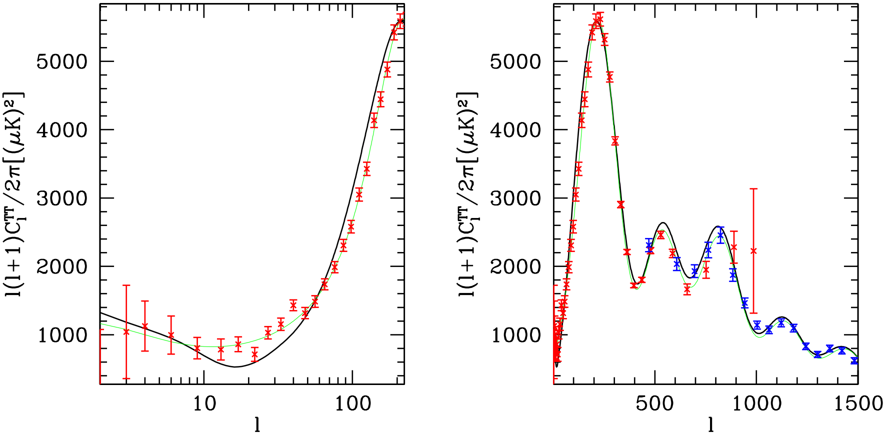

Scodeller, Kunz & RD ’09

Reasonable but not very good fit to the temperature spectrum.

The first polarization peak

The first polarization peak at $\ell \simeq 130$ stems from recombination when this scale was still super-horizon.
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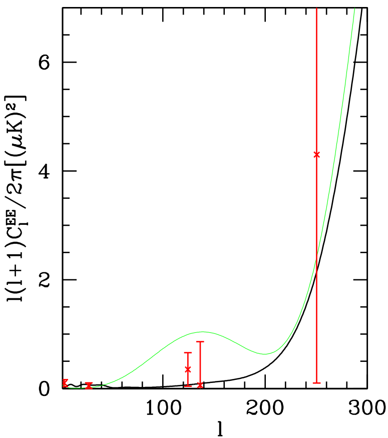
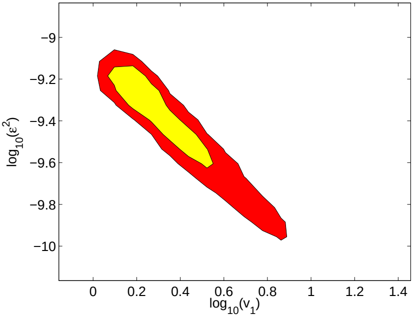


Scodeller, Kunz & RD, '09

The parameters

The velocity v_1 and ϵ are strongly correlated and effectively represent just one free parameter, $\epsilon^2 = 9.4 \times 10^{-10}/v_1$.



'Best fit' values for the causal model:
$v_1 = 0.77$ $v_2 = 1$, $\Omega_b h^2 = 0.022$, $\Omega_m h^2 = 0.137$, $h = 0.68$, $\tau = 0.36$.
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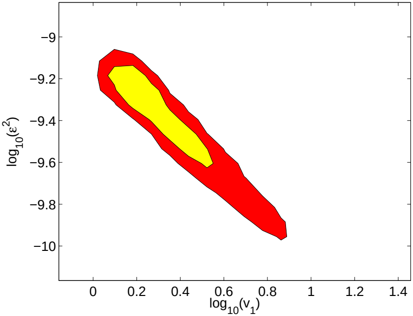

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- In cosmology, we have a preferred frame (cosmological time). If signals propagate forward in time w.r.t. this frame, no closed signal curves can form and no evident inconsistencies seem to emerge Babichev, Mukhanov & Vikman '07.
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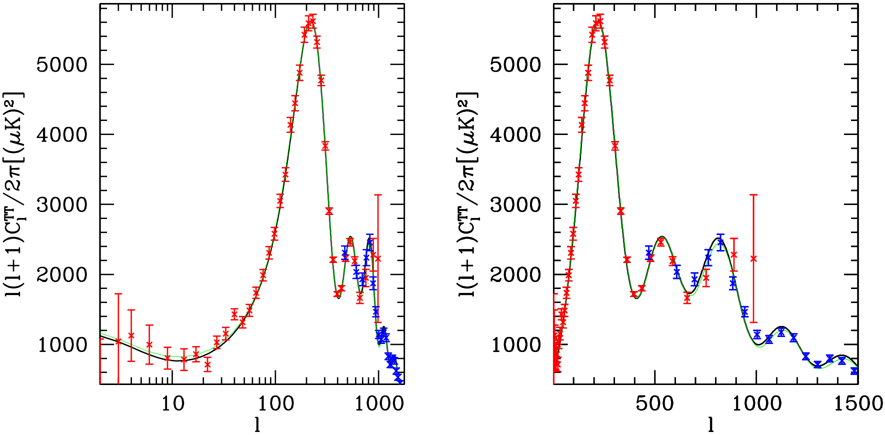
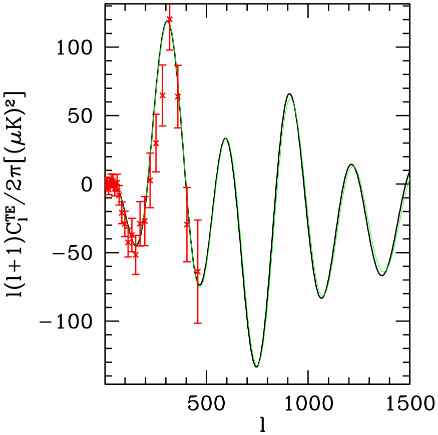
Acausal scaling seeds, allowing for $v_1, v_2 > 1$



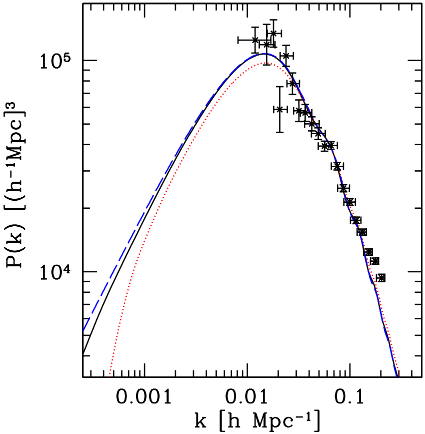
Scodeller, Kunz & RD '09

A perfect fit to the present temperature anisotropy data.



Scodeller, Kunz & RD ’09

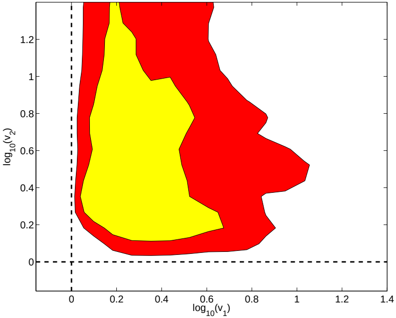
A perfect fit to the present polarization data. Indistinguishable from inflationary ΛCDM.



Scodeller, Kunz & RD '09

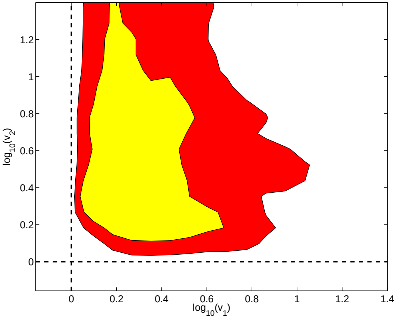
The matter power spectrum from acausal seeds is indistinguishable from the one from inflationary ΛCDM. Causal seeds (red) have less power on super-Hubble scales (unmeasurable).

Parameters



v_1	v_2	$\Omega_m h^2$	$\Omega_b h^2$	H_0	τ
$1.65^{+7.1}_{-0.35}$	$5.66^{+\infty}_{-4.26}$	$0.134^{+0.007}_{-0.008}$	$0.023^{+0.001}_{-0.001}$	75^{+3}_{-3}	$0.11^{+0.07}_{-0.04}$

Data used: WMAP 3year, Boomerang '03, CBI '02, LRG from SDSS
$\ln \mathcal{L}_{\rm ac} = -1750.4$, $\ln \mathcal{L}_{\rm inf} = -1748.1$, $\Delta \ln \mathcal{L} = 2.3$, negligible ($\Delta\chi^2_{\rm red} = 1.3 \times 10^{-3}$).



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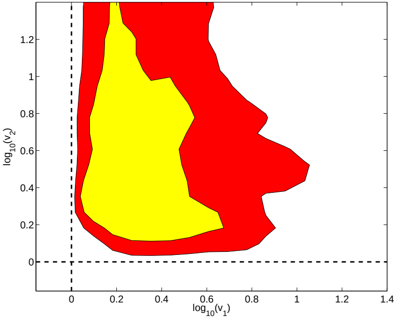

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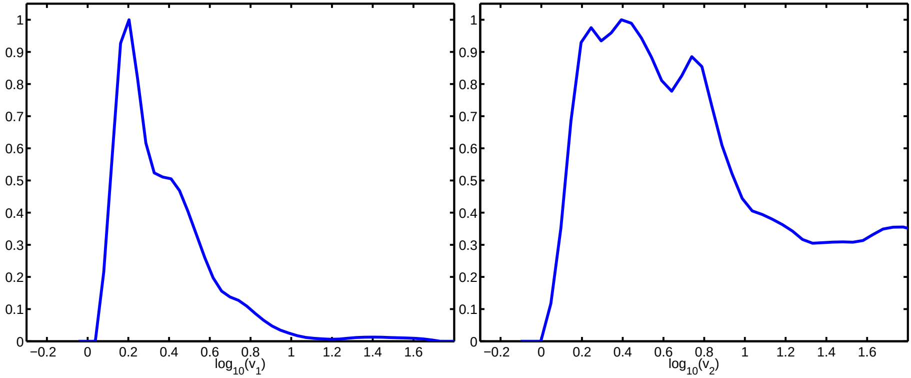
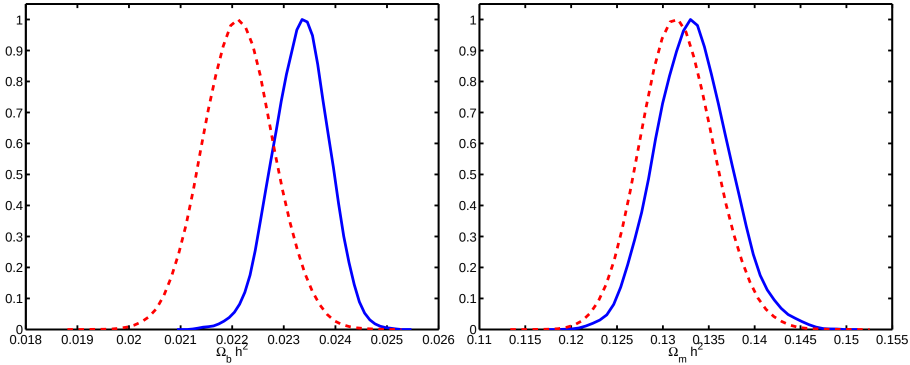


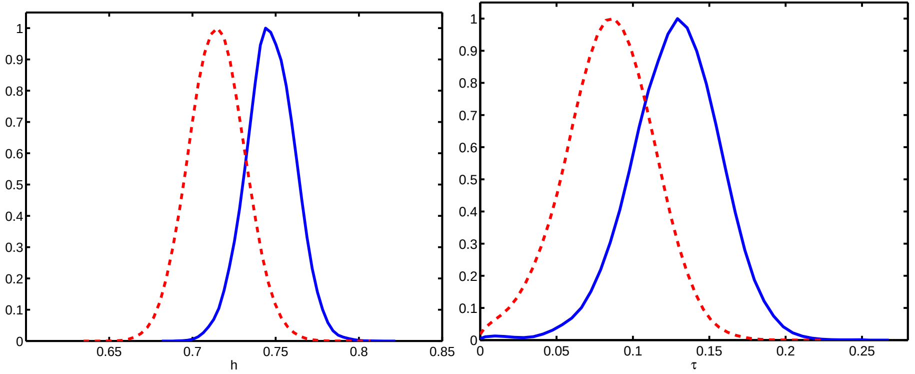
Velocities $v > 1.5 \simeq 1/(kt_{\rm dec})$ are required. v_2 is not constrained from above.

Parameters



Standard cosmological parameters are very similar to their inflationary best fit values.

Parameters


1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.65
0.7
0.75
0.8
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h
1
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τ

Conclusions

- Acausal exploding shells generate as good a fit to the present CMB and LSS data as standard inflationary models with the same number of parameters.
- The model can be ruled out. e.g. with the consistency relation for slow roll inflation, $r(n_T)$ or with tighter bounds on $\Omega_b h^2$ from both CMB and nucleosynthesis.
- The model can be enlarged to accommodate tensors (slight a-sphericity of explosions).
- This needs super-luminally expanding shells of energy and momentum...
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