Distinguishing Defects with (CM)Bpol

Mark Hindmarsh

Dept. of Physics & Astronomy

Sussex University

m.b.hindmarsh@sussex.ac.uk

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N. Bevis, M.Kunz, A. Liddle, P. Mukherjee, J. Urrestilla

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Inflationary cosmology & cosmic strings

- Some models of inflation (“hybrid”) end by producing cosmic defects[a]
- Defects may also be formed in subsequent thermal transitions[b]
- String/M-theory: strings from $(D\bar{D})$-brane collisions[c]
- Defects have gravitational fields & contribute to perturbations[d]
- Defects and gravitational waves produce B-modes: will we wrongly identify?

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[a] Yokoyama (1989); Copeland et al (1994); Kofman, Linde, Starobinski (1996); Garcia-Bellido et al (2010)

[b] Kibble (1976); Zurek (1996); Rajantie (2002)

[c] Jones, Stoica, Tye (2002); Dvali & Vilenkin (2003); Copeland, Myers, Polchinski (2003)

[d] Kibble (1976); Zel’dovich (1980); Vilenkin (1981)

Fitting CMB power spectrum with inflation & cosmic defects

- Two uncorrelated sources of perturbations: add in quadrature
- Cosmological model with 1 more (dimensionless) parameter: $G\mu$
- Our definition: $\mu = 2\pi G v^2$, symmetry-breaking scale v.
- Use $f_{10} = C_{10}^{\mathrm{defect}}/C_{10}^{\mathrm{total}}$. Proportional to $(G\mu)^2$.

Cosmic string CMB using Abelian Higgs field theory simulations

Multipole moments:

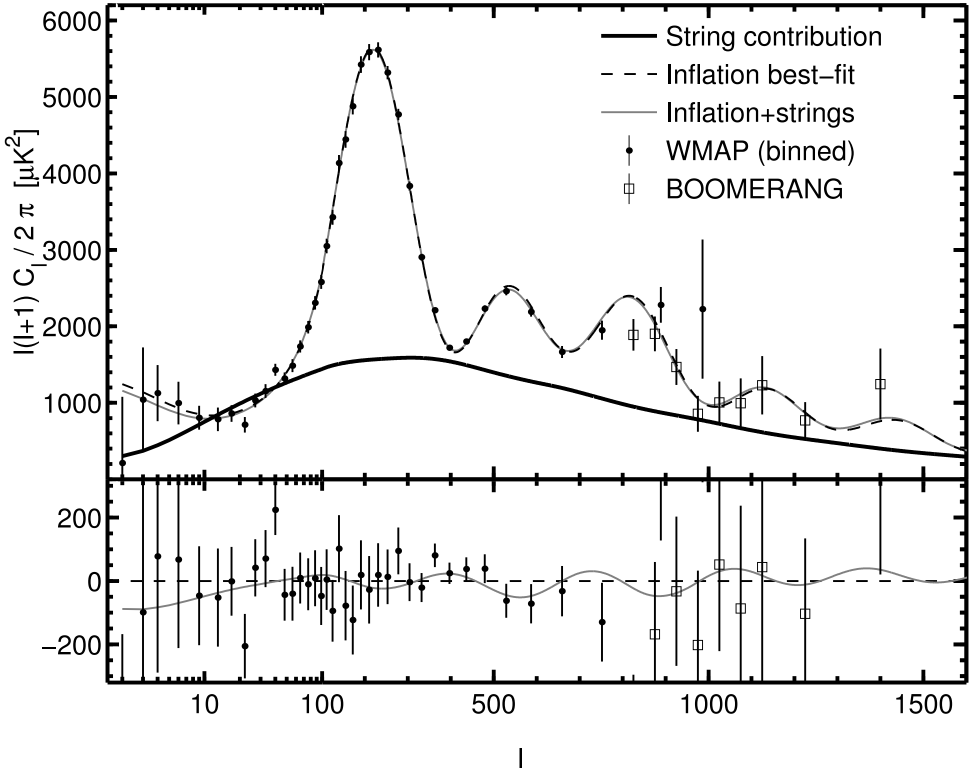
$$a_{lm} = \int d\Omega \Delta T(\mathbf{n}) Y^*_{lm}(\mathbf{n})$$

Angular power spectrum:

$$C_l = \sum_{m=-l}^{l} |a_{lm}|^2$$

Anisotropy power:

$$l(l+1)C_l/(2\pi)$$



Top: Strings normalised to WMAP3 ($\ell = 10$)[a]

Bottom: Differences from best-fit ΛCDM

[a] Bevis, Hindmarsh, Kunz, Urrestilla (2006)

Latest Abelian Higgs cosmic string results

7 parameter MCMC fit to CMB data (WMAP7+CBI09 + ACBAR)

Cosmic string perturbations from Classical Abelian Higgs model[a]

$f_{10} < 0.088$ (95%) $G\mu < 0.55 \times 10^{-6}$ (95%)

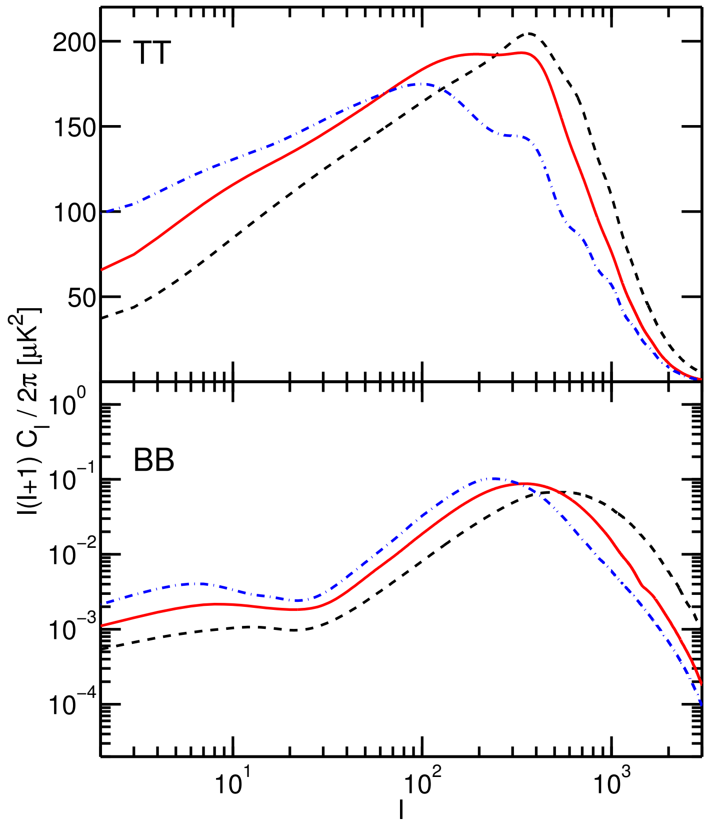
[a] Bevis et al. (2010); Bevis et al (in preparation)

Comparison: strings, semilocal strings, textures

Urrestilla et al (2008)

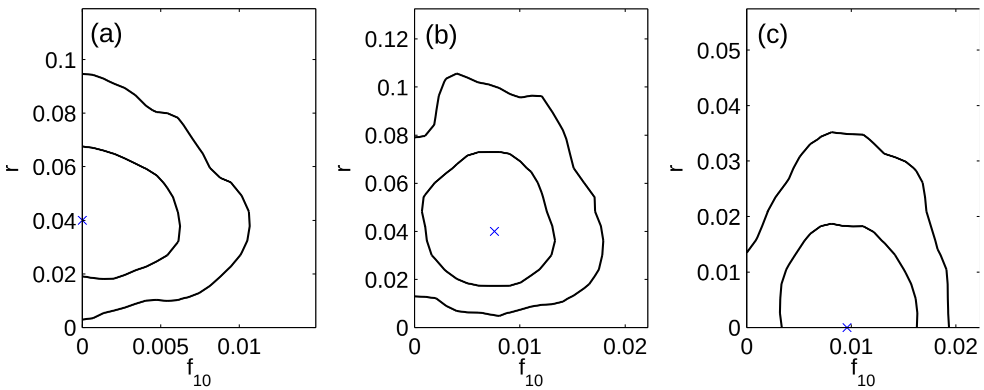
Different field theories, different defects

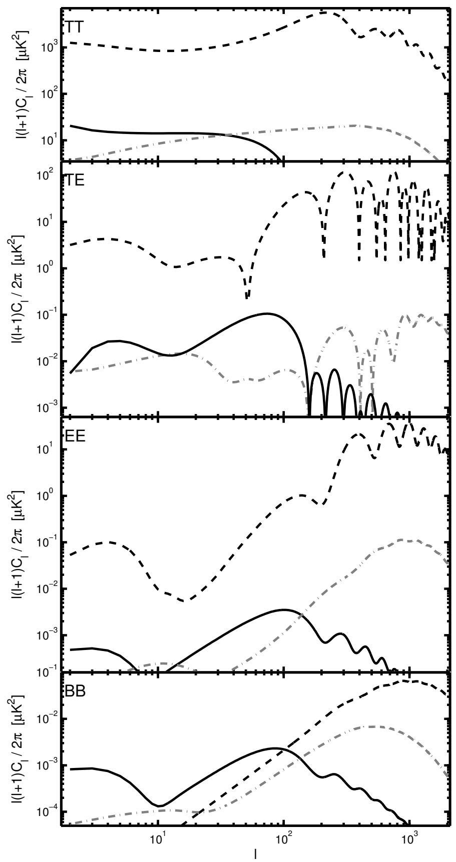
- Abelian Higgs strings (dashed black)
- semilocal strings (solid red)
- textures (dot-dash blue)



Planck: distinguishing defects & tensors

- Inflation - B-modes from gravitational waves
- Defects - B-modes from vector modes
- Parameters: $r = \frac{|A_{\text{tensor}}|^2}{|A_{\text{scalar}}|^2}$, $f_{10}^{\text{string}} = \frac{C_{10}^{\text{TT,string}}}{C_{10}^{\text{TT,total}}}$
- Planck can distinguish, $f_{10} \gtrsim 0.02$[a]





$r = 0.04$, grey dot-dash

$f_{10} = 0.01$, solid

[a] Urrestilla et al. 2008

Modelling for (CM)Bpol (high-resolution version)

Freq (GHz)	FWHM (arcmin)	δT (K arcmin)[a]
30	26	13.58
45	17	5.85
70	11	2.96
100	8	2.29
150	5	2.21
220	3.5	3.39
340	2.3	15.27

[a] Stokes I

- Delensing error: cosmic variance on B-mode lensing signal
- Fiducial model: $H_0 = 72$ km s^{-1} Mpc^{-1}, $\Omega_b h^2 = 0.0227$, $\Omega_c h^2 = 0.1099$, $\tau = 0.087$, $A_s = 2.41 \times 10^{-9}$, $n_s = 0.963$.
- Assume 80% sky coverage

Polarised foreground model

Baumann et al (2008), following Verde, Peiris, Jimenez (2006)

Synchrotron: $C_\ell^{S,XY}(\mu) = A_S \left(\frac{\nu}{\nu_0}\right)^{2\alpha_S} \left(\frac{\ell}{\ell_0}\right)^{\beta_S}$

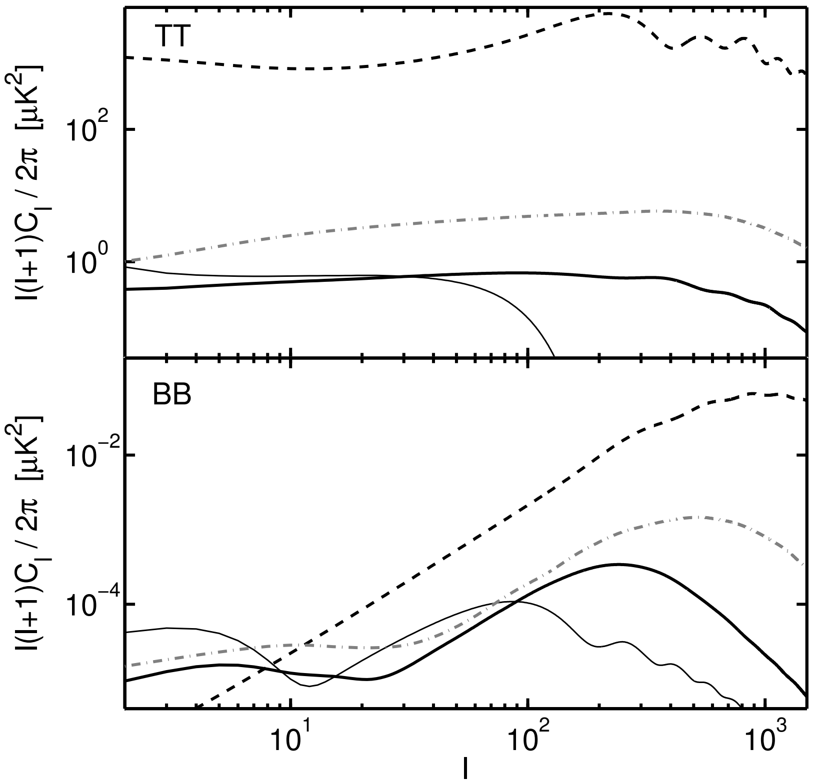
Dust: $C_\ell^{D,XY}(\mu) = p^2 A_S \left(\frac{\nu}{\nu_0}\right)^{2\alpha_D} \left(\frac{\ell}{\ell_0}\right)^{\beta_D} \left[\frac{e^{h\nu_0/kT}-1}{e^{h\nu/kT}-1}\right]^2$

Residual: $\sum_{f=S,D}\left[C_\ell^{f,XY}(\nu)\sigma^{f,XY} + N_\ell^{f,XY}(\nu/\nu_t)^{2\alpha}\right]$

Parameter	Synchrotron	Dust
$A_{S,D}$	$4.7\times10^{-5}\ \mu\mathrm{K}^2$	$1\ \mu\mathrm{K}^2$
p	–	5%
ν_0	30 GHz	94 GHz
ℓ_0	350	10
α	-3	2.2
β^{EE}	-2.6	-2.5
β^{BB}	-2.6	-2.5
β^{TE}	-2.6	-2.5
Subtraction $\sigma^{f,XY}$	5%	5%

Detecting strings/textures/tensors

- Threshold detection, assuming true model known (3σ):
  - $f_{10}^{\text{string}} \gtrsim 0.003$ ($G\mu = 1.0 \times 10^{-7}$)
  - $f_{10}^{\text{texture}} \gtrsim 0.0006$ ($G\mu = 1.0 \times 10^{-7}$)
  - $r = 0.0015$
- No foreground, iterative delensing:
  - $f_{10}^{\text{string}} \gtrsim 10^{-4}$ ($G\mu \simeq 8 \times 10^{-9}$)[a]

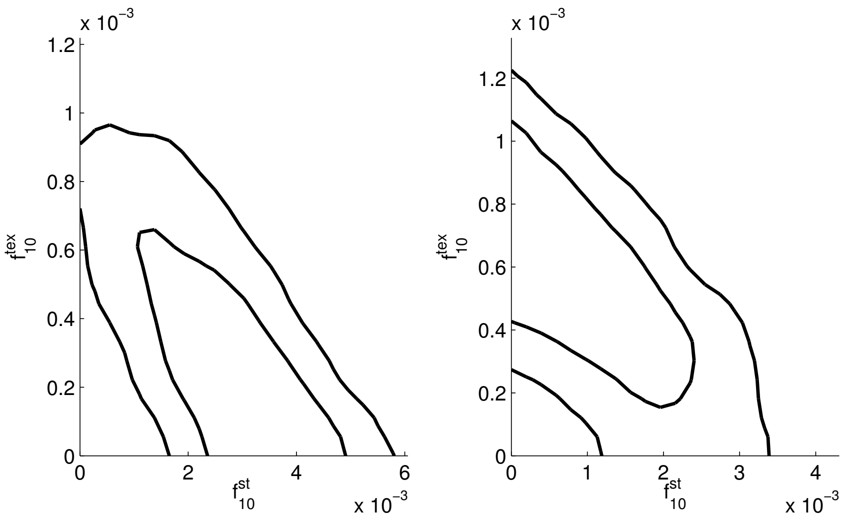


scalar (black dashed),
tensor (black thin), $r = 0.0015$
cosmic strings (grey dot-dashed), $f_{10}^{\text{string}} = 0.003$
textures (black thick) $f_{10}^{\text{texture}} = 0.0006$

[a] Seljak, Slosar (2006); Garcia-Bellido et al (2010)

Distinguishing strings/textures/tensors

- Can correctly identify, fitting all three components (3σ):
  - $f_{10}^{\text{string}} \gtrsim 0.005$ ($G\mu = 1.3 \times 10^{-7}$)
  - $f_{10}^{\text{texture}} \gtrsim 0.0013$ ($G\mu = 1.5 \times 10^{-7}$)
  - $r \gtrsim 0.0015$



Conclusions

- (CM)Bpol-like satellite mission can distinguish tensors from defects ($r \sim 10^{-3}$, $G\mu \sim 10^{-7}$)
- (CM)Bpol-like satellite mission can distinguish between kinds of defect ($G\mu \sim 10^{-7}$)
- Both low and high ℓ appear important for sensitivity
- Should investigate how sensitivity affected by beam FWHM
- Foregrounds!