

Cosmic microwave background constraints for global strings and global monopoles

JCAP07(2017)026 [1705.04154]

Joanes Lizarraga

University of the Basque Country (EHU/UPV)
Bilbao

in collaboration with Asier Lopez-Eiguren, Mark Hindmarsh and
Jon Urrestilla.

Paris
September 28, 2017

Outline

1. Global defects

- ▶ The model
- ▶ Simulations

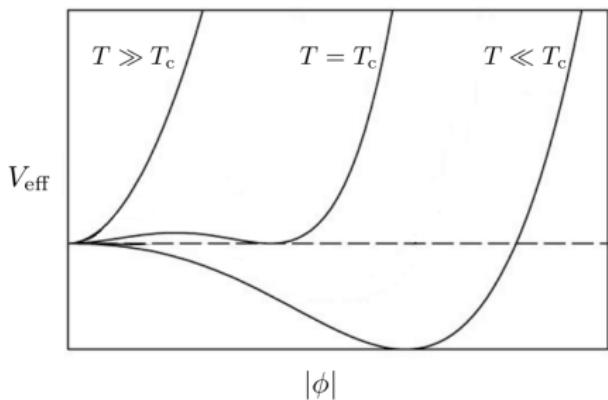
2. Source functions at cosmological transitions

- ▶ Fixed- k UETC interpolation
- ▶ Interpolating functions: simulations at transitions

3. C_ℓ 's and constraints

Cosmic Defects

1. Cosmological phase transitions
2. Symmetry spontaneously broken



$$V(\phi) = \frac{\lambda}{4} (|\phi|^2 - \eta^2)^2$$

The model: O(N)

$$\mathcal{S} = \int d^4x \sqrt{-g} \left(\frac{1}{2} \partial_\mu \Phi^i \partial^\mu \Phi^i - \frac{1}{4} \lambda (|\Phi|^2 - \eta^2)^2 \right)$$

$i = 1, \dots, N$ Real scalar fields

- ▶ $N = 2$ Global strings

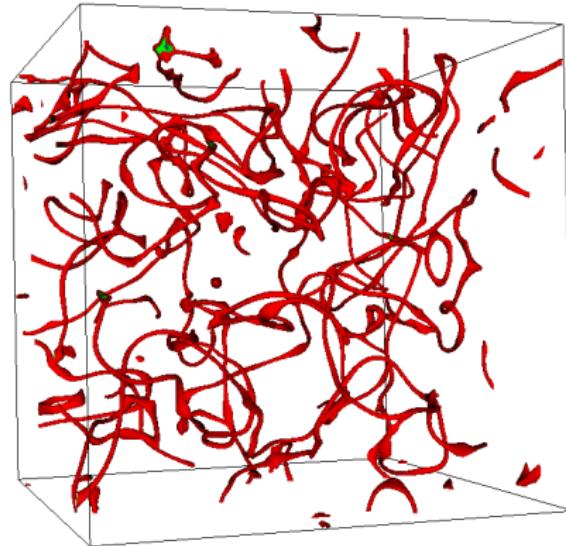
$$\Phi = \begin{pmatrix} \Phi^1 \\ \Phi^2 \end{pmatrix}$$

- ▶ $N = 3$ Global monopoles

$$\Phi = \begin{pmatrix} \Phi^1 \\ \Phi^2 \\ \Phi^3 \end{pmatrix}$$

- ▶ $N = 4$ Textures
- ▶ $N = 8, 12, 20$
- ▶ ...
- ▶ ...
- ▶ ...
- ▶ Large-N [Analytic solution]

Simulations



- ▶ Field theory simulations
- ▶ Solve e.o.m. in Lattices
- ▶ Expanding background: radiation and matter domination
- ▶ Several tests of scaling
- ▶ Extraction of UETCs

user: Lopez-Eiguren
Thu Aug 24 11:38:46 2017

UnEqual Time Correlator of Energy Momentum Tensor

$$U_{\lambda\kappa\mu\nu}(\mathbf{k}, \tau, \tau') = \langle T_{\lambda\kappa}(\mathbf{k}, \tau) T_{\mu\nu}(\mathbf{k}, \tau') \rangle$$

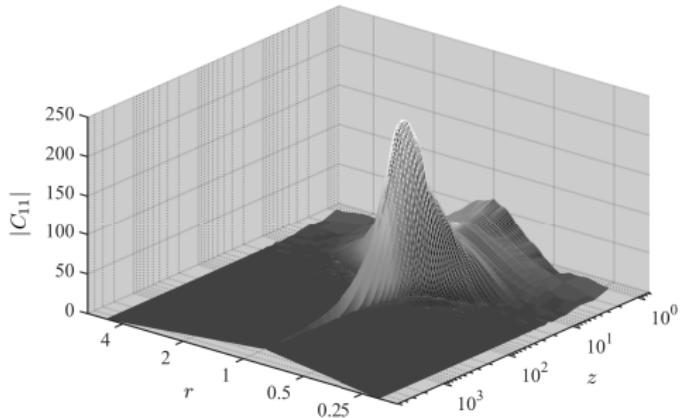
In principle 55



Symmetry



Only 5:



- ▶ C_{11} ($\phi\phi$), C_{22} ($\psi\psi$), C_{12} ($\phi\psi$)
- ▶ C_{vv}
- ▶ C_{tt}

Source functions: general theory

Scaling UETCs \Rightarrow Diagonalizable

$$U(k, \tau, \tau') \Rightarrow C(x, x') \quad x = k\tau$$



Decomposition into coherent functions,

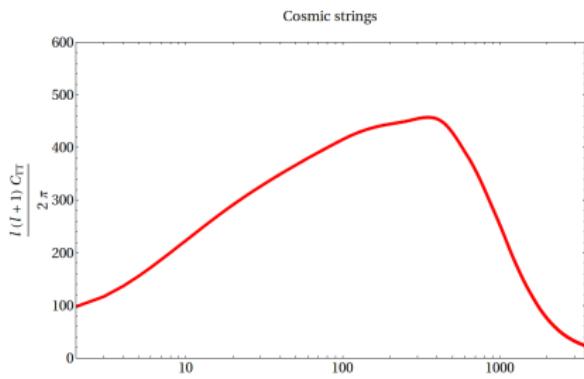
Source function for E-B integrators:

$$\sqrt{\lambda_n} c_n(x)$$

Pen, Spergel and Turok
PRD49 692-729



CMB Power Spectra
(CMBeasy, CAMB,
CLASS...)



Scaling and transitions

Scaling only at constant expansion rates

BUT

it is broken at transitions.

1. : Radiation-Matter transition (τ_{eq})
2. : Matter- Λ transition (τ_{Λ})

How can we incorporate info from transitions?

1. Simple eigenvector interp.

Bevis et al PRD 75, 065015

2. Multi-Stage eigenvector interp.

Bevis et al PRD 82, 065004

2. Multi-Stage eigenvector interp.

Fenu et al PRD 89, 083512

3. Fixed- k UETC interp.

Daverio et al PRD 93, 085014

Lizarraga et al JCAP 1610 (2016) 042

Fixed- k UETC interp. method

Full UETCs: $C(k, \tau, \tau')$ \Rightarrow for every k
symmetric in τ and τ'

Fixed- k :

- ▶ Approximations to $C(k, \tau, \tau')$ at every k
- ▶ Fits naturally in E-B integrators:

for k {

 for time {

Proposal: ... Integration ... }}

$$C(k, \tau, \tau') = f \left(\frac{\sqrt{\tau\tau'}}{\tau_{\text{eq}}} \right) C^R(x, x') + \left(1 - f \left(\frac{\sqrt{\tau\tau'}}{\tau_{\text{eq}}} \right) \right) C^M(x, x')$$

Source functions (for every k): $\sqrt{\lambda_n} c_n(\tau/\tau_{\text{eq}})$

Interpolating functions: Rad-Mat

Recipe:

Fenu et al PRD 89, 083512

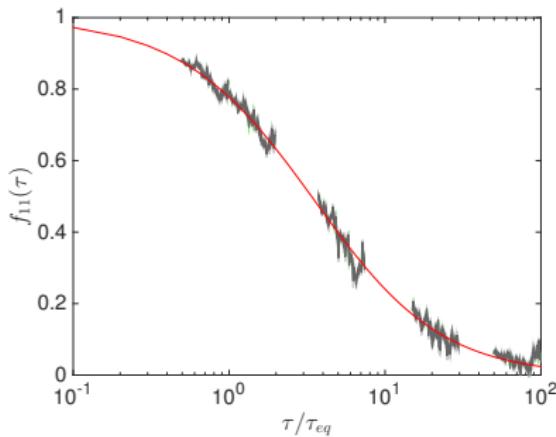
$$f_{ab}(k, \tau) = \frac{E_{ab}^{\text{RM}}(k, \tau) - \bar{E}_{ab}^{\text{M}}(k\tau)}{\bar{E}_{ab}^{\text{R}}(k\tau) - \bar{E}_{ab}^{\text{M}}(k\tau)} \stackrel{?}{=} f_{ab}(\tau)$$

Equal Time Correlator: $E(k\tau) = C(k\tau, k\tau)$

Simulations at transition:

- ▶ Record $E^{\text{RM}}(k, \tau)$
- ▶ Compute $f(k, \tau)$

Interpolating functions: Rad-Mat



- ▶ Independent of k ✓
- ▶ Slow transition
- ▶ Same for all correlators

Same function for different defects:

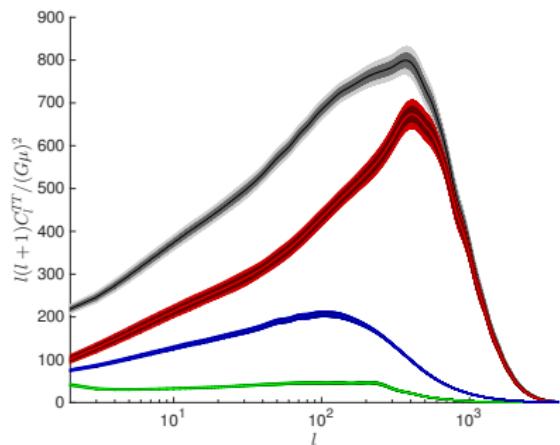
$$f(\tau) = \left(1 + \lambda \frac{\tau}{\tau_{eq}}\right)^{\kappa}$$

$$\lambda \sim \frac{1}{4} \quad \forall \text{ defects}$$

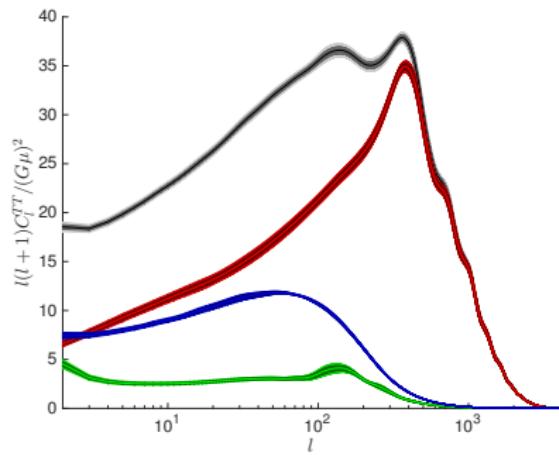
$$\kappa = \begin{cases} -1 & \text{AH strings} \\ -1.15 & N = 2 \\ -1.4 & N = 3 \\ \dots(??) \\ -2 & \text{Large } N \end{cases}$$

Power Spectra

Strings



Monopoles



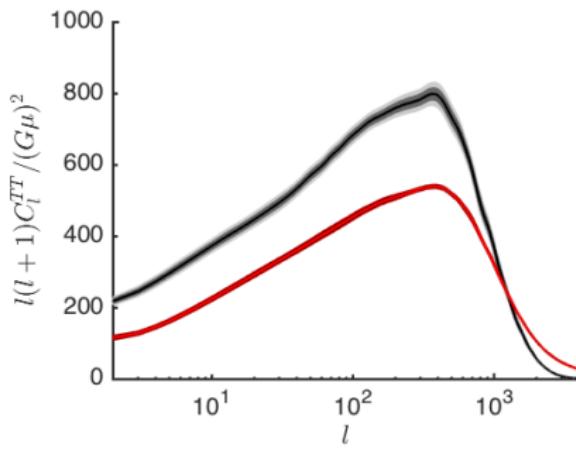
- ▶ Total
- ▶ Scalar
- ▶ Vector
- ▶ Tensor

Power Spectra: Comparison

Lizarraga et al JCAP 1610 (2016)

Strings vs AH strings

O(2)

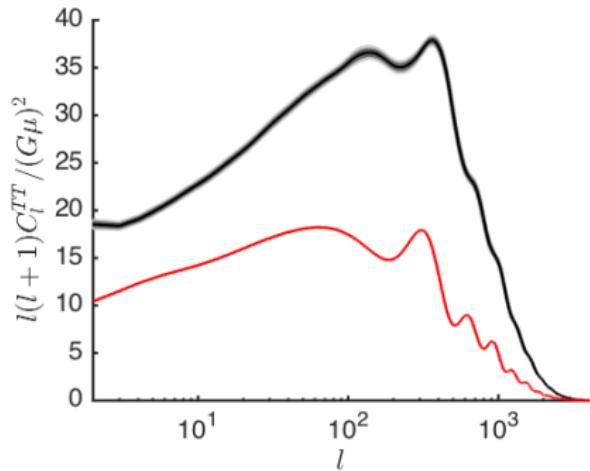


Fenu et al PRD 89, 083512

Monopoles vs large-N

O(3)

O(N)



Constraints

Dataset: Planck 2015 (TT, TE, EE + lowTEB)

Defect	O(2)	O(3)
f_{10}	< 0.017	< 0.024
$10^{12}(G\mu)^2$	< 0.031	< 0.73
$-\ln \mathcal{L}_{\max}$	6472	6470

$$f_{10} = \frac{C_{\ell=10}^{\text{def}}}{C_{\ell=10}^{\text{inf}} + C_{\ell=10}^{\text{def}}}$$

- ▶ Similar to AH
- ▶ Monopoles: more contribution at $\ell = 10$ & slightly preferred
- ▶ No considerable improvement

GWs background

Extrapolate bounds to the amplitude of a possible GWs background:

$$\Omega_{\text{GW}} = \frac{650}{N} \Omega_{\text{rad}} \left(\frac{G\mu}{\pi} \right)^2 \frac{\Omega_{\text{GW}}^{\text{num}}}{\Omega_{\text{GW}}^{\text{th}}} \quad [\text{Scale invariant!}]$$

Figueroa, Hindmarsh and Urrestilla PRL110, 101302

Correction factor

$$\frac{\Omega_{\text{GW}}^{\text{num}}}{\Omega_{\text{GW}}^{\text{th}}} = \begin{cases} 130 & \text{Strings} \\ 7.5 & \text{Monopoles} \end{cases}$$

$$\Omega_{\text{GW}} \lesssim 2 \times 10^{-15}$$

Below LISA

Summary

- ▶ Field theory simulations of global defects $O(N)$
 - ▶ Global strings
 - ▶ Global monopoles
 - ▶ Upcoming: higher N 's
- ▶ Unequal time correlators extraction
- ▶ Interpolating functions (Rad-Mat)
 - ▶ Interesting trend:
 $AH \rightarrow O(2) \rightarrow O(3) \rightarrow \dots \rightarrow O(N)$
 - ▶ Future work
- ▶ First CMB PS prediction and constraints
- ▶ GWs spectrum: below LISA sensitivity

Cosmic microwave background constraints for global strings and global monopoles

JCAP07(2017)026 [1705.04154]

Joanes Lizarraga

University of the Basque Country (EHU/UPV)
Bilbao

in collaboration with Asier Lopez-Eiguren, Mark Hindmarsh and
Jon Urrestilla.

Paris
September 28, 2017

Backslides

Scaling

Scaling ✓

