Cosmic Microwave Background Constraints for Global Defects

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COSMO-18

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OBJECTIVE:
Obtain first CMB power spectra predictions and constraints for Global Defects

1. Perform ***Field Theory Simulations*** for global defects
2. Compute the ***U***n***E***qual ***T***ime ***C***orrelators
3. Model Radiation-Matter ***Transition***
4. Obtain ***Power Spectra*** and ***Constraints***

Cosmic Defects

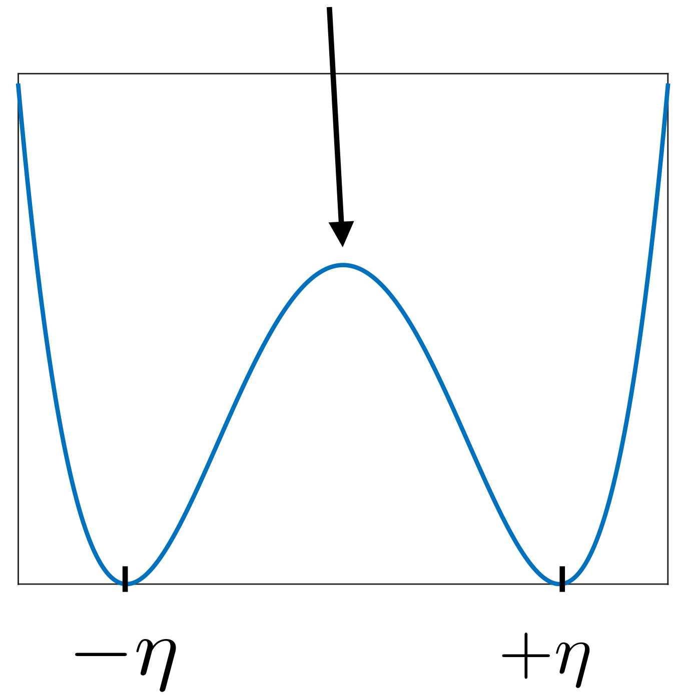
+ Kink (1+1):

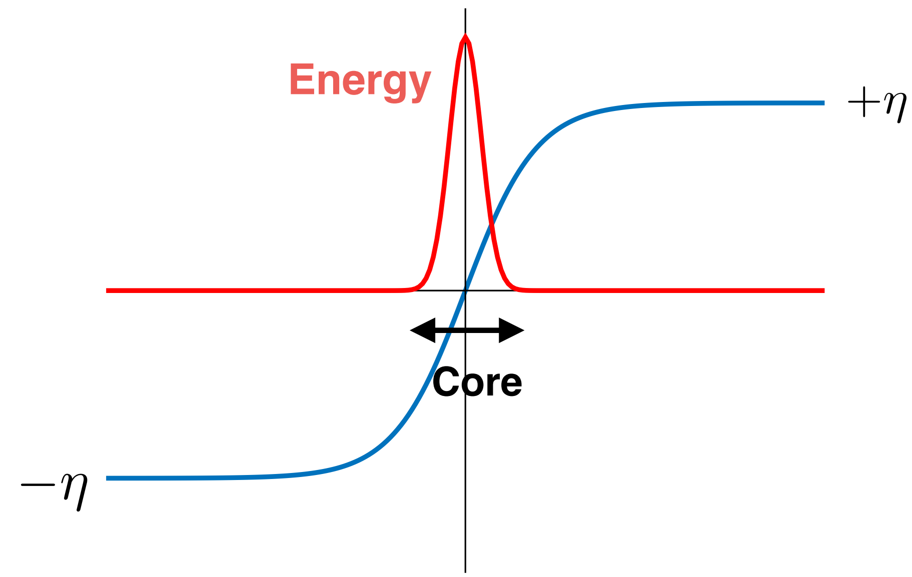
$$\mathcal{L} = (\partial_t \phi)^2 - (\partial_x \phi)^2 - V(\phi) \qquad \phi(t,x) \in \mathbb{R}$$

$$V(\phi) = \frac{\lambda}{2}(\phi^2 - \eta^2)^2 \underset{\phi\,=\,0}{\rightarrow} \frac{\lambda \eta^4}{2}$$

$$\phi(t, -\infty) = -\eta$$

$$\phi(t, +\infty) = +\eta$$





Defect Types:

- $\pi_0(\mathcal{M}) \neq 1 \longrightarrow$ Domain Wall
- $\pi_1(\mathcal{M}) \neq 1 \longrightarrow$ Cosmic String
- $\pi_2(\mathcal{M}) \neq 1 \longrightarrow$ Monopole
- $\pi_3(\mathcal{M}) \neq 1 \longrightarrow$ Texture

Global Defect Model

+ 3+1

$$\mathcal{L} = \frac{1}{2}\partial_\mu \Phi^i \partial^\mu \Phi^i - \frac{1}{4}\lambda(|\Phi|^2 - \eta^2)^2$$

$$\Phi^i \in \mathbb{R}$$
$$i = 1, ..., N$$

$\phi(\mathbf{x}) \to e^{i\alpha}\phi(x) \mapsto$ Global

Our Simulations

$N = 2 \longrightarrow$ **Strings**

$N = 3 \longrightarrow$ **Monopoles**

$N = 4 \longrightarrow$ **Textures**

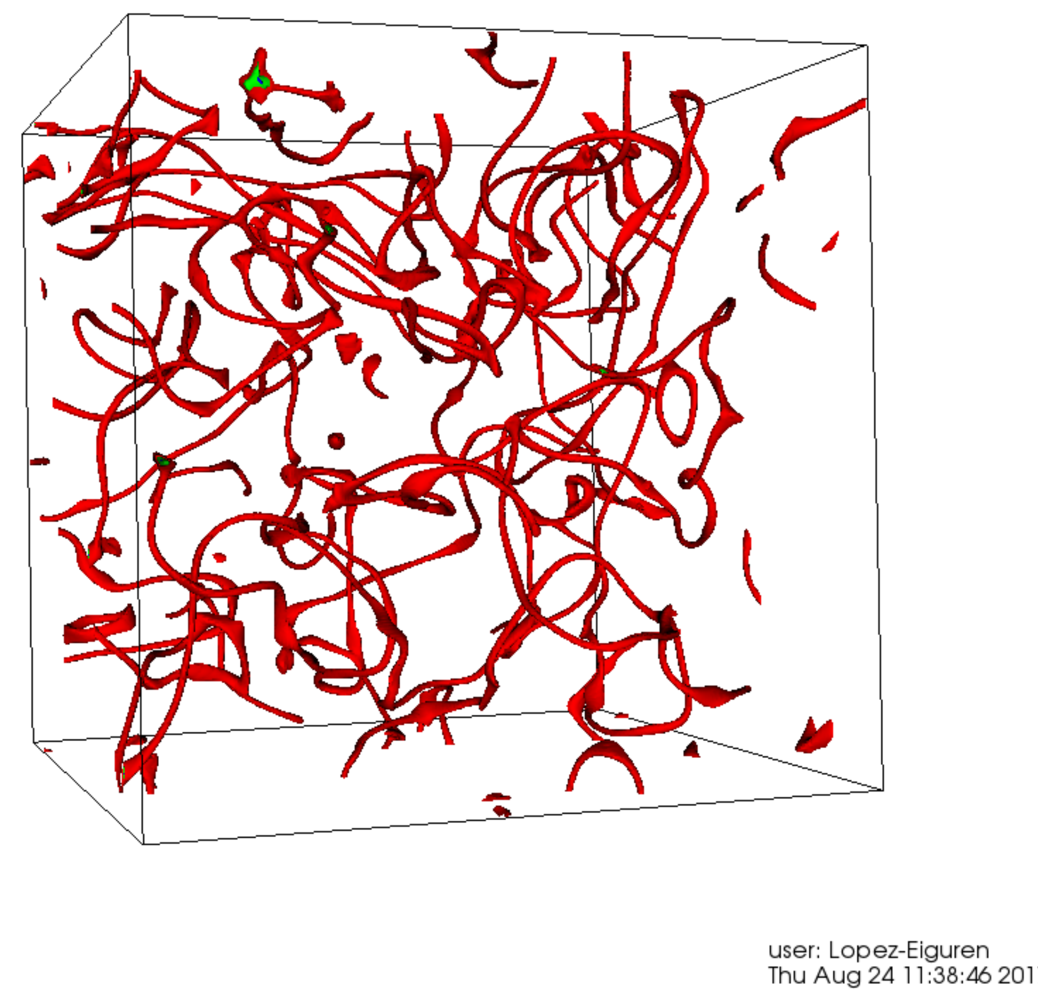
$N = 8, 12, 20$

Large-N $\longrightarrow$ **Analytic Solution**

- Presence of Goldstone bosons -> energy not confined
- Long range interactions

Field Theory Simulations

- Field Theory Simulations
- Discrete e.o.m.
- Evolve e.o.m. in N^3 lattices
- Expanding background: Radiation, Matter and Transition
- Scaling is indispensable $\xi(\tau) \propto \tau$:
  - In Radiation and Matter eras ✓
  - In Rad-Mat transition ✗
- Extraction of UETCs



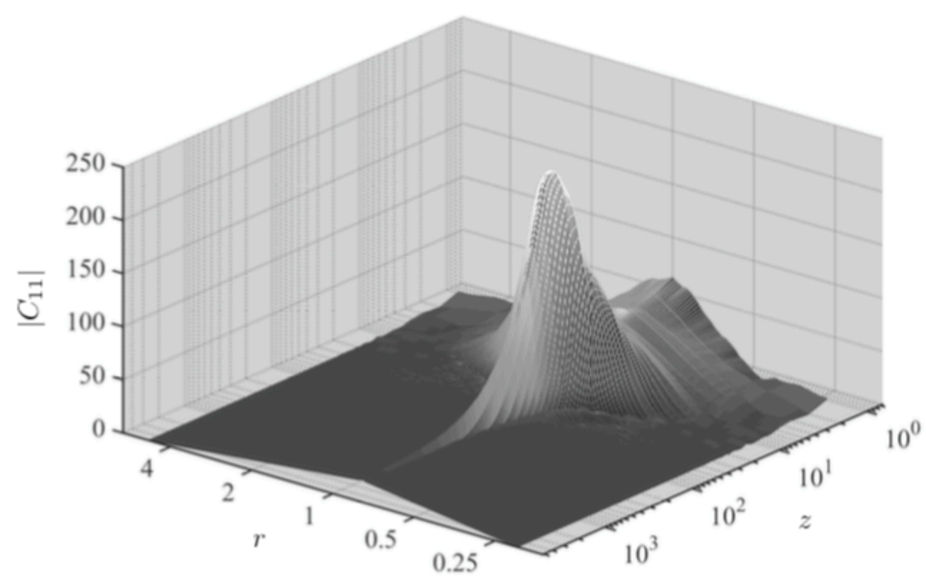
UETC method

- Cosmic defects perturb background
- Creating CMB Temperature and Polarization anisotropies

Power Spectra can be obtained using:

Un**E**qual **T**ime **C**orrelators of the energy-momentum tensor

$$U_{\lambda\kappa\mu\nu}(\mathbf{k},\tau,\tau') = \langle T_{\lambda\kappa}(\mathbf{k},\tau)T^*_{\mu\nu}(\mathbf{k},\tau')\rangle$$



UETC method

$$U_{\lambda\kappa\mu\nu}(\mathbf{k},\tau,\tau') = \langle T_{\lambda\kappa}(\mathbf{k},\tau)T^{*}_{\mu\nu}(\mathbf{k},\tau')\rangle$$

Scaling + Symmetry

$$C(k\tau, k\tau')$$

$C_{\phi\phi}$ $C_{\psi\phi}$
$C_{\psi\psi}$ C_{vv} C_{tt}

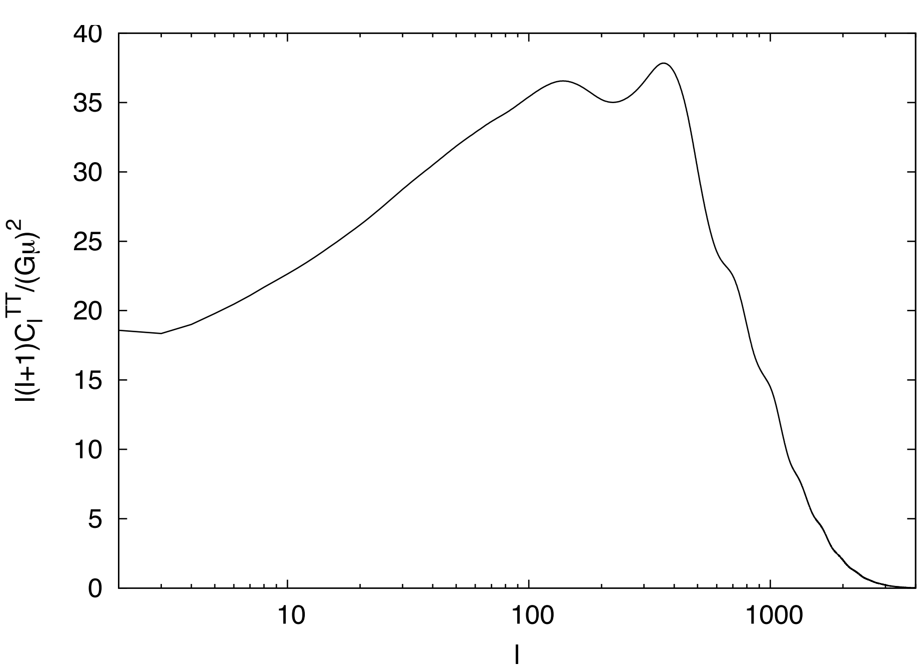
Decompose into coherent functions

$$\sqrt{\lambda_n}c_n(k\tau)$$

Pen, Spergel and Turok PRD49 692-729

CMBeasy, CAMB
CLASS

Einstein-Boltzmann solver



Transition

- Important information in cosmological transition
- Scaling is broken
- We can model transition with fixed-k interpolation method *Daverio et al. 2015*

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

$$f_{ab}(k,\tau) = \frac{E^{RM}_{ab}(k,\tau) - \bar{E}^M_{ab}(k\tau)}{\bar{E}^R_{ab}(k\tau) - \bar{E}^M_{ab}(k\tau)}$$

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

Simulations at transition to compute:

$$E^{RM}(k,\tau)$$

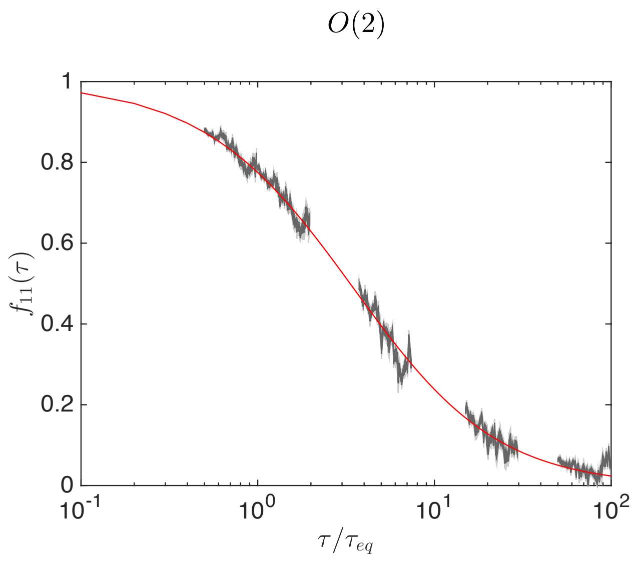
$$f(\tau) = \left(1 + \gamma\frac{\tau}{\tau_{\rm eq}}\right)^{\kappa}$$

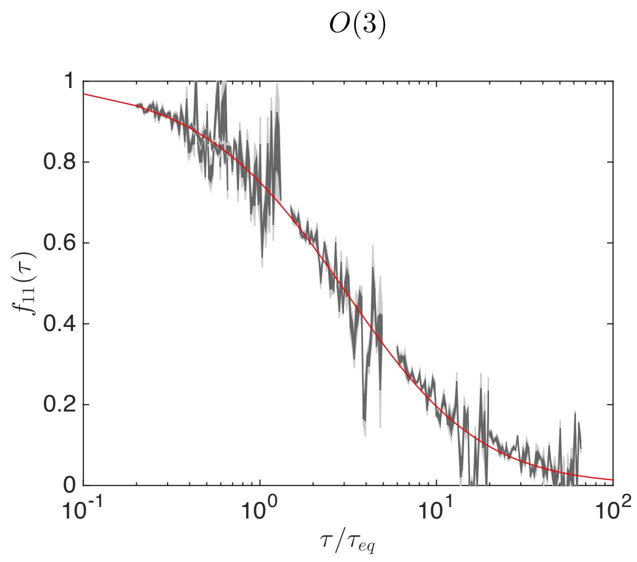
Source functions (for every k): $\boxed{\sqrt{\lambda_n}c_n(\tau/\tau_{\rm eq})}$

Transition

O(2) and O(3)

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





	γ	κ
O(2)	0.26$\pm$0.03	-1.15$\pm$ 0.02
O(3)	0.23$\pm$0.05	-1.4$\pm$ 0.2
AH	0.25	-1

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

N > 3

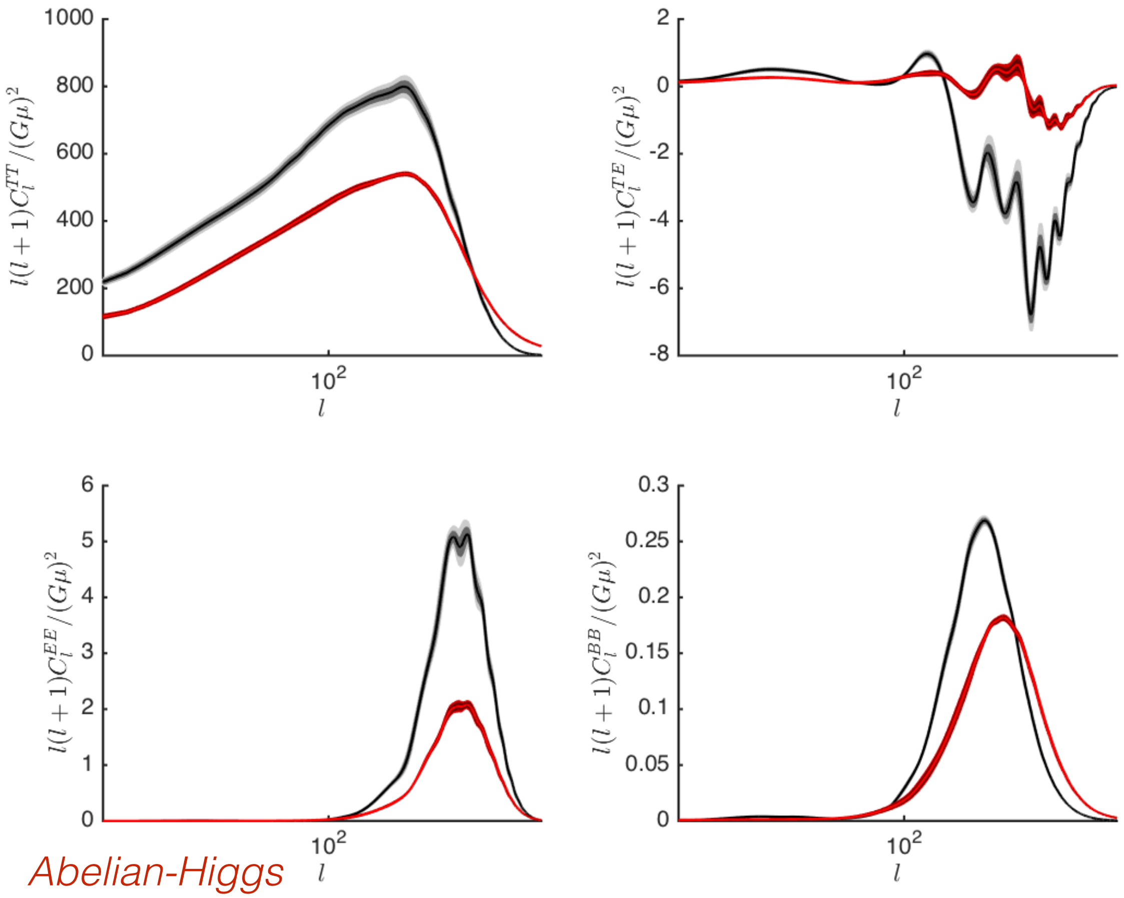
- Interpolation function depends on k
- Currently working on new approach to describe transition

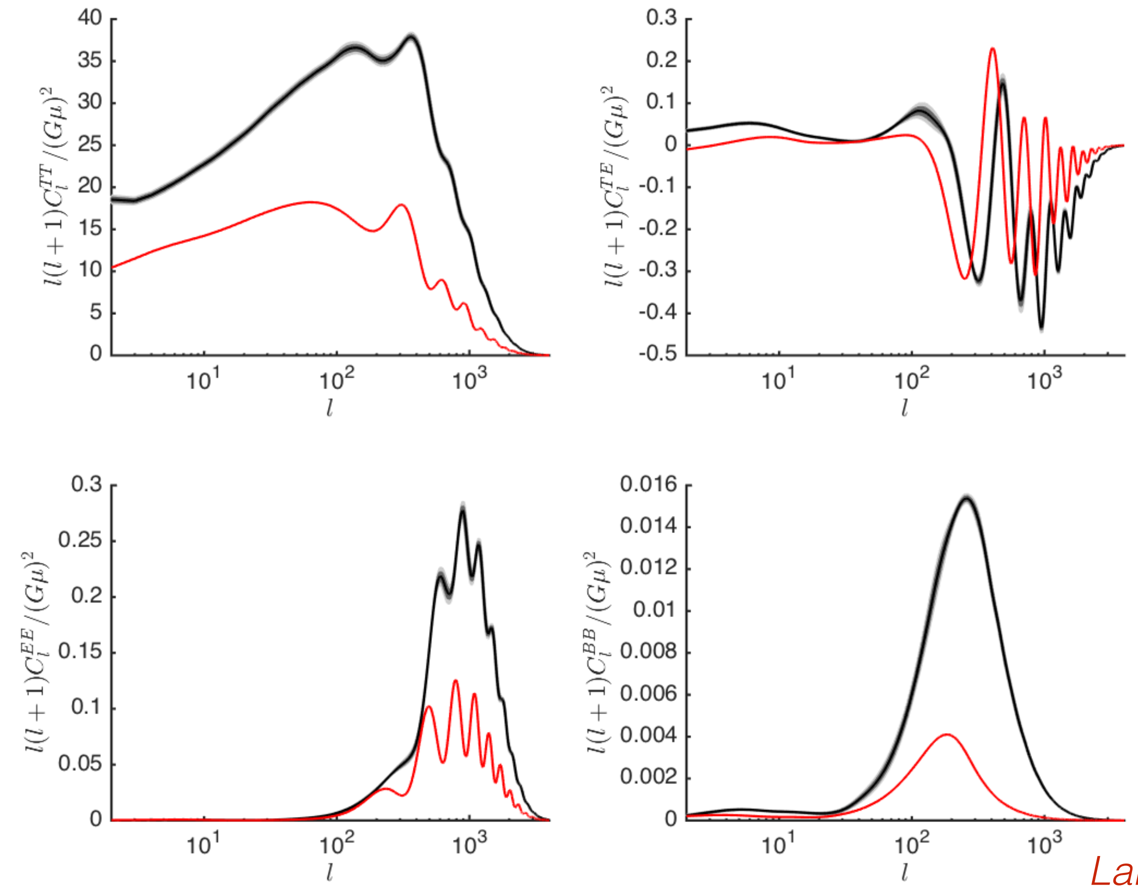
(Work in progress)

Power spectra

O(2)

O(3)





Abelian-Higgs

Lizarraga et al. 2016

Large-N

Fenu et al. 2013

- O(2) and O(3) relatively similar although O(2) has bigger amplitude
- O(2) and AH relatively similar although O(2) has bigger amplitude
- O(2) and Large-N are not similar
- O(3) and Large-N are more similar:
  - The amplitudes are different
  - Details are different

Bounds

Dataset	*Planck* 2015 CMB		
Defect	O(2)	O(3)	
Model	$\mathcal{PL} + G\mu$	$\mathcal{PL} + G\mu$	$\mathcal{PL}$
f_{10}	< 0.017	< 0.024	–
$10^{12}(G\mu)^2$	< 0.031	< 0.73	–
$-\ln \mathcal{L}_{\max}$	6472	6470	6472

95% upper limits obtained using Monte Carlo analysis

- Models are consistent with no defects

$$G\mu \xrightarrow[\text{Figueroa et al. 2013}]{} \Omega_{GW} \xrightarrow{\text{O(2) and O(3)}} \Omega_{\mathrm{GW}} \lesssim 2 \times 10^{-15}$$

- The gravitational wave background below the LISA sensitivity window

Summary

- **Field theory simulations** of global defects O(N)
  - Global Strings
  - Global Monopoles
  - Work in progress with higher N's
- **U**n**E**qual **T**ime **C**orrelation extraction
- **Transition** (Rad-Mat)
  - k independent transition in N=2,3
  - New approach needed for N>3 *(Work in progress)*
- **First CMB PS predictions and constraints**
- GWs spectrum: below LISA sensitivity

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