Complementary signatures of α–attractor inflation in CMB and GWs from cosmic strings

Based on - arXiv:2501.XXXXX

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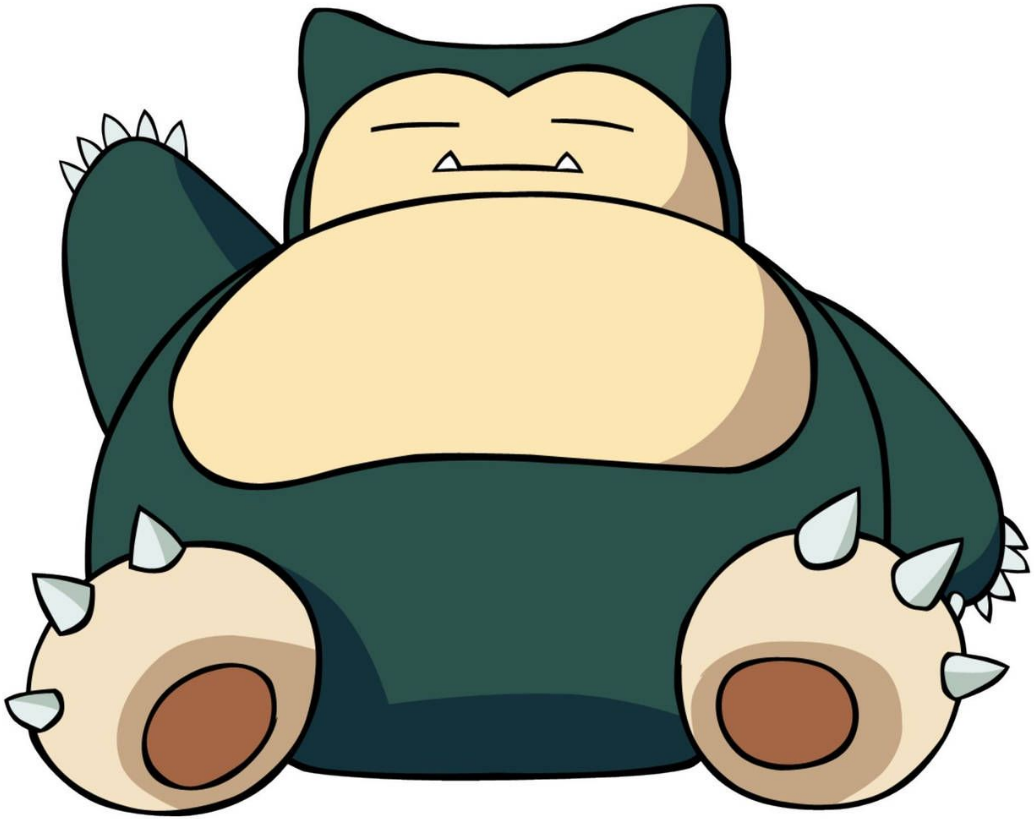
Department of Physical Sciences, IISER Kolkata, India.
Visitor, HRI, Allahabad, India.

Collaborators: Anish Ghoshal (University of Warsaw) and David F. Mota (University of Oslo)

Hearing Beyond Standard Model with cosmic sources of Gravitational Waves,
International Centre for Theoretical Sciences (ICTS), Bangalore.



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- Topological Defects

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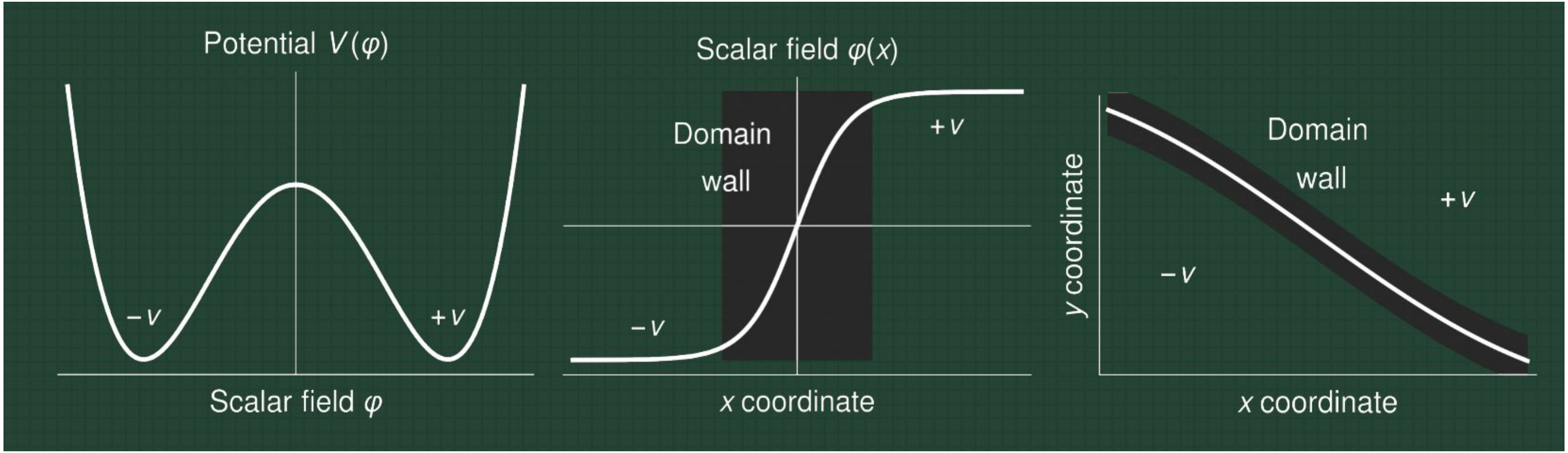
- ❖ Impact of Inflation of Cosmic Strings.
- ❖ Complementarity between **CMB** and **GW Detectors**
- ❖ Summary and Conclusion

Topological Defects: A brief introduction



[Viatcheslav Mukhanov: Physical Foundations of Cosmology, Cambridge University Press (2005)]

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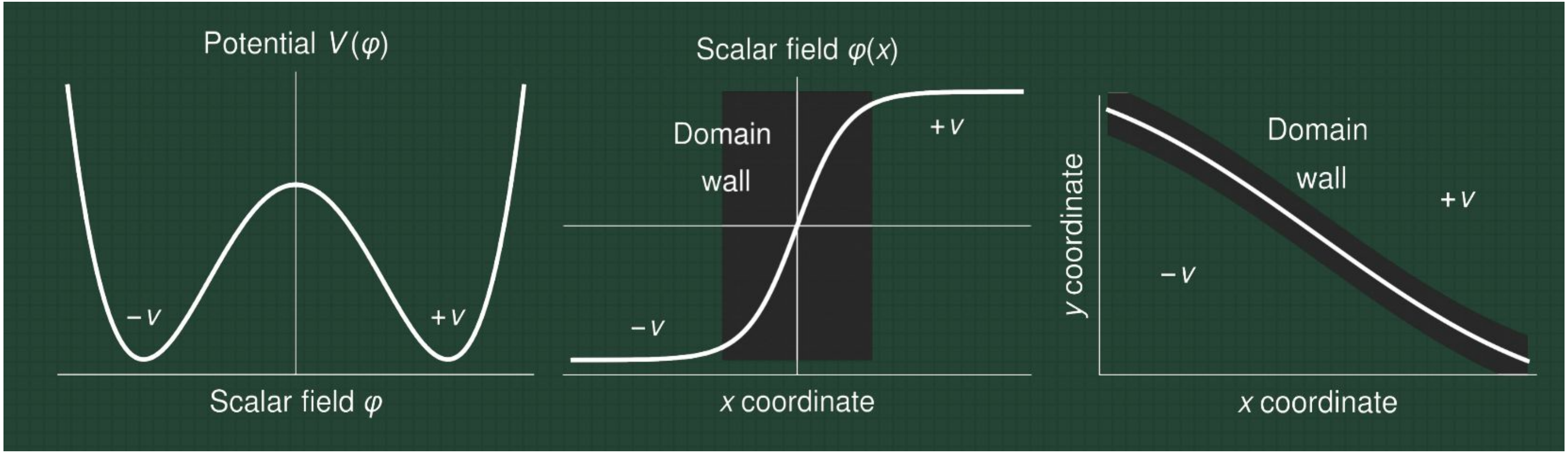

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Spontaneous Breaking of $\mathbb{Z}_2$ symmetry by a real scalar field φ:

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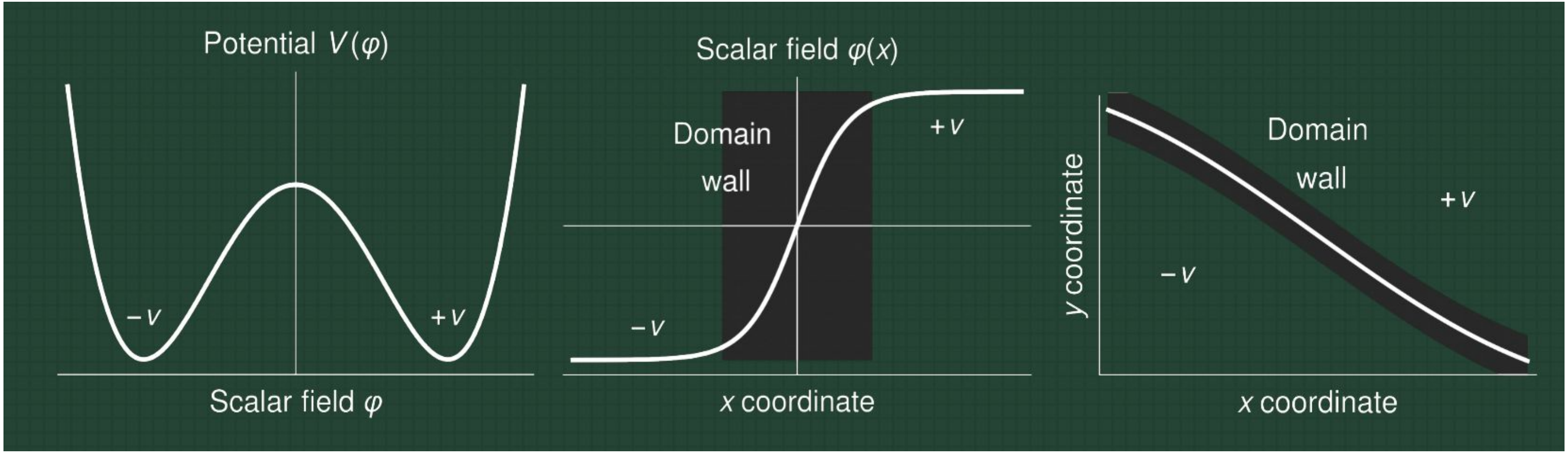

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Spontaneous Breaking of $\mathbb{Z}_2$ symmetry by a real scalar field φ:

$$V(\varphi) = \frac{\lambda}{4}(\varphi^2 - v^2)^2$$

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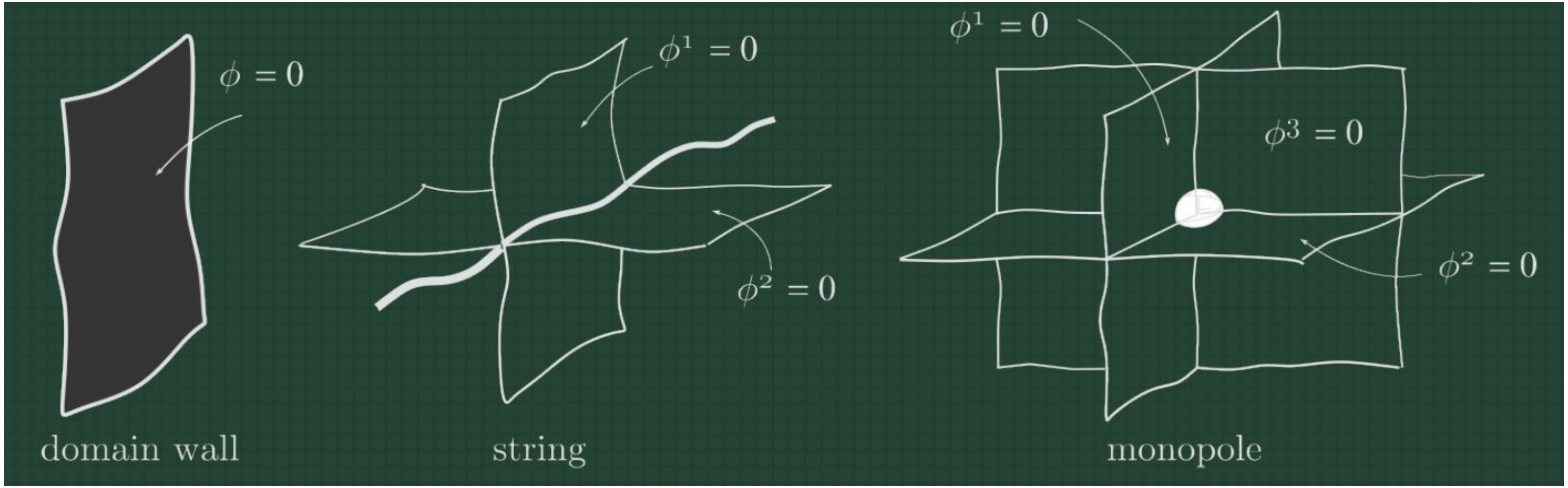

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- Consider spontaneous symmetry breaking of a N-dimensional scalar field space:

$$V(\Phi) = \frac{\lambda}{4}(\Phi^2 - v^2)^2 \qquad \Phi = \frac{1}{\sqrt{N}}(\phi_1, \phi_2, \ldots, \phi_N)^T$$

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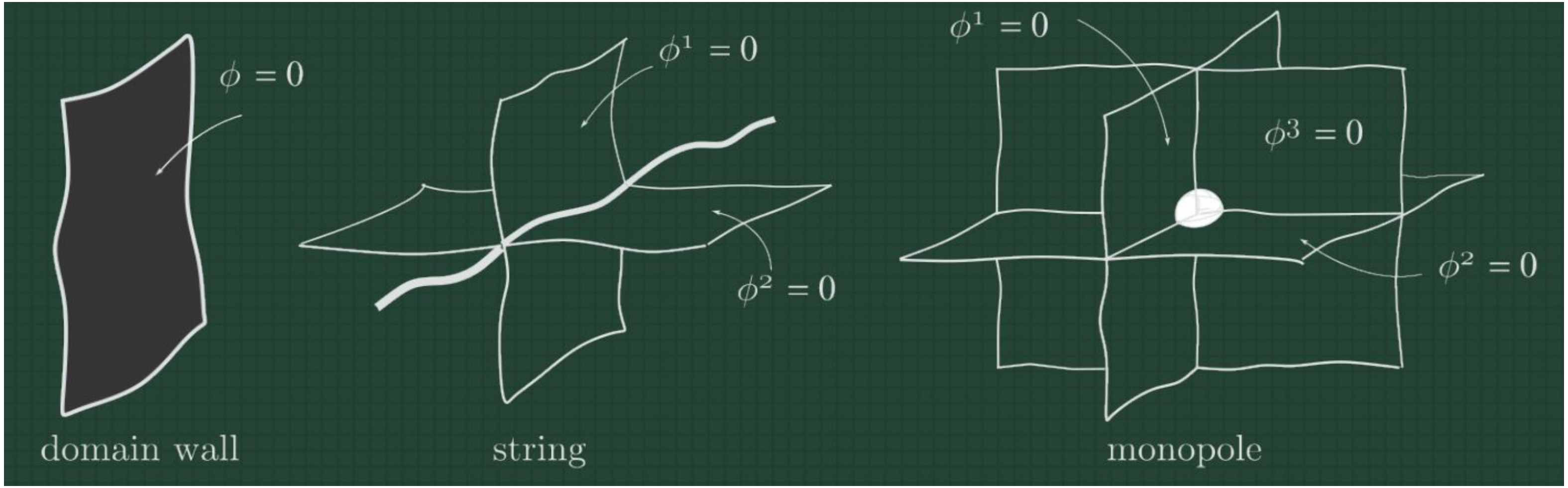

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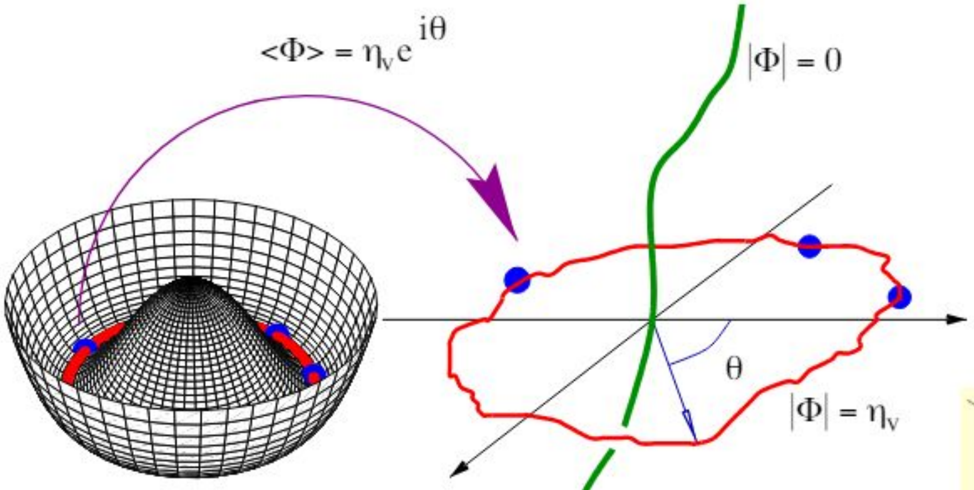
- A more general description can be given in terms of the homotopy group of the vacuum manifold:

$$\pi_n(\mathcal{M}) \neq \mathbb{I}$$

Topological Defects: A brief introduction

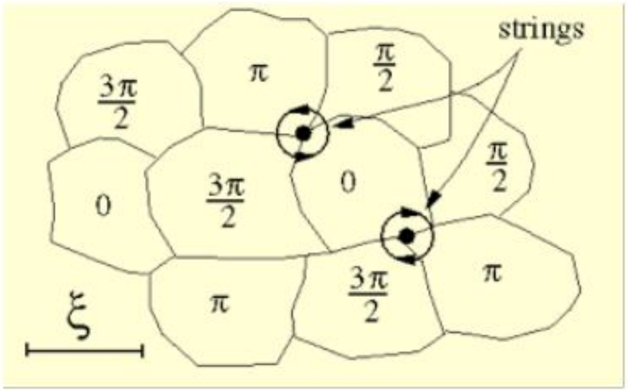
$\pi_0(\mathcal{M}) \neq \mathcal{I}$	$\mathcal{M}$ disconnected	Domain Walls
$\pi_1(\mathcal{M}) \neq \mathcal{I}$	non-contractible loops in $\mathcal{M}$	Cosmic Strings
$\pi_2(\mathcal{M}) \neq \mathcal{I}$	non-contractible 2-spheres in $\mathcal{M}$	Monopoles
$\pi_3(\mathcal{M}) \neq \mathcal{I}$	non-contractible 3-spheres in $\mathcal{M}$	Textures

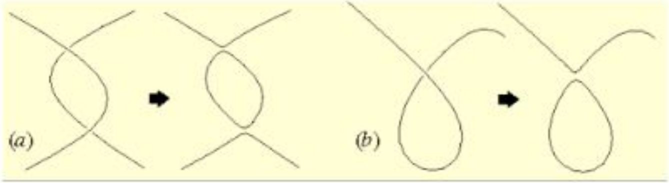
SGWB from Cosmic Strings: the 'Standard' scenario



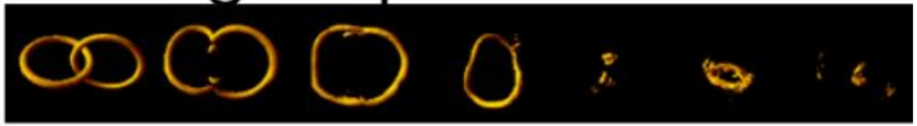
Ringeval 2010

- U(1) symmetry breaking





- String loops radiate GWs



Slide taken from Stephen King's talk at the CATCH22+2 conference

SGWB from Cosmic Strings: the 'Standard' scenario

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Master Equation: $$\Omega_{\rm GW}^{(k)}(f) = \frac{1}{\rho_c}\cdot\frac{2k}{f}\cdot\frac{\mathcal{F}_\alpha \Gamma^{(k)} G\mu^2}{\alpha(\alpha+\Gamma G\mu)}\int_{t_0}^{t_0} d\tilde{t}\frac{C_{\rm eff}\left(t_i\right)}{t_i^4}\left[\frac{a(\tilde{t})}{a\left(t_0\right)}\right]^5\left[\frac{a\left(t_i\right)}{a(\tilde{t})}\right]^3\Theta\left(t_i-t_{\rm osc}\right)\Theta\left(t_i-\frac{l_*}{\alpha}\right)$$

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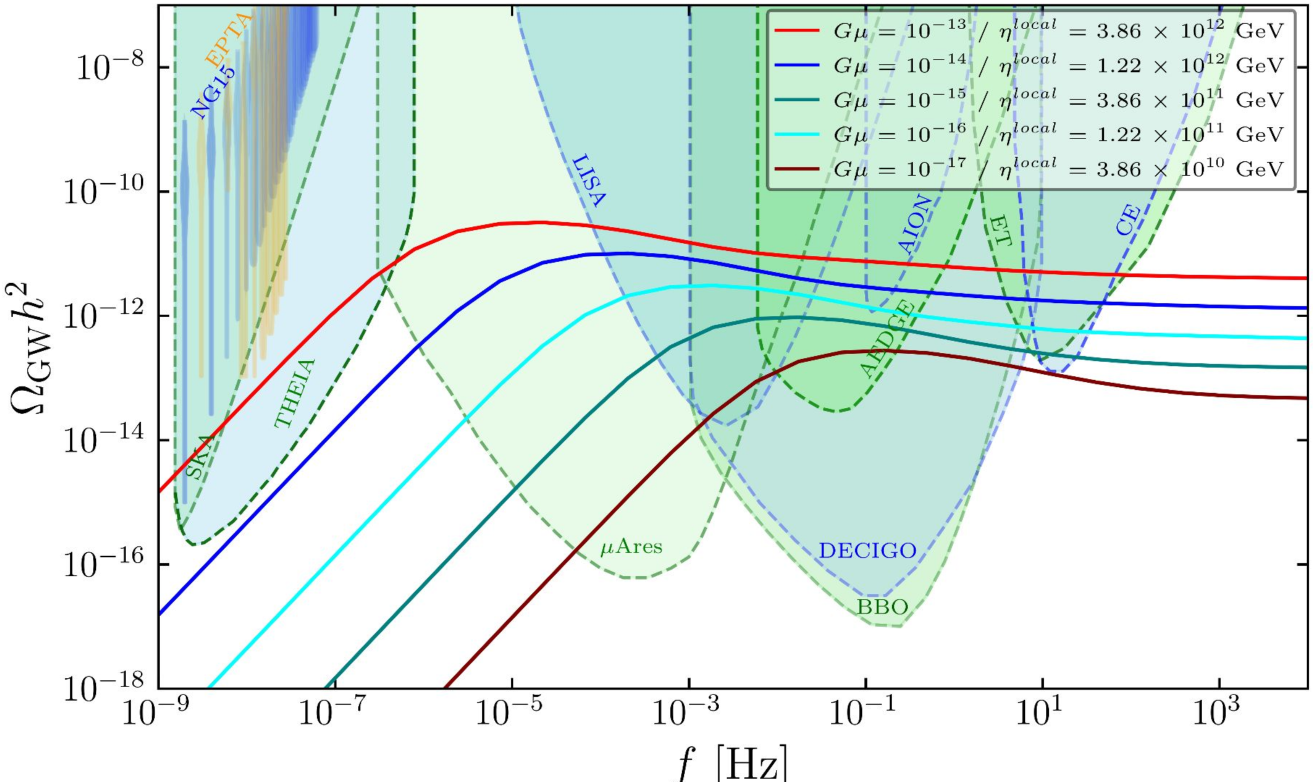

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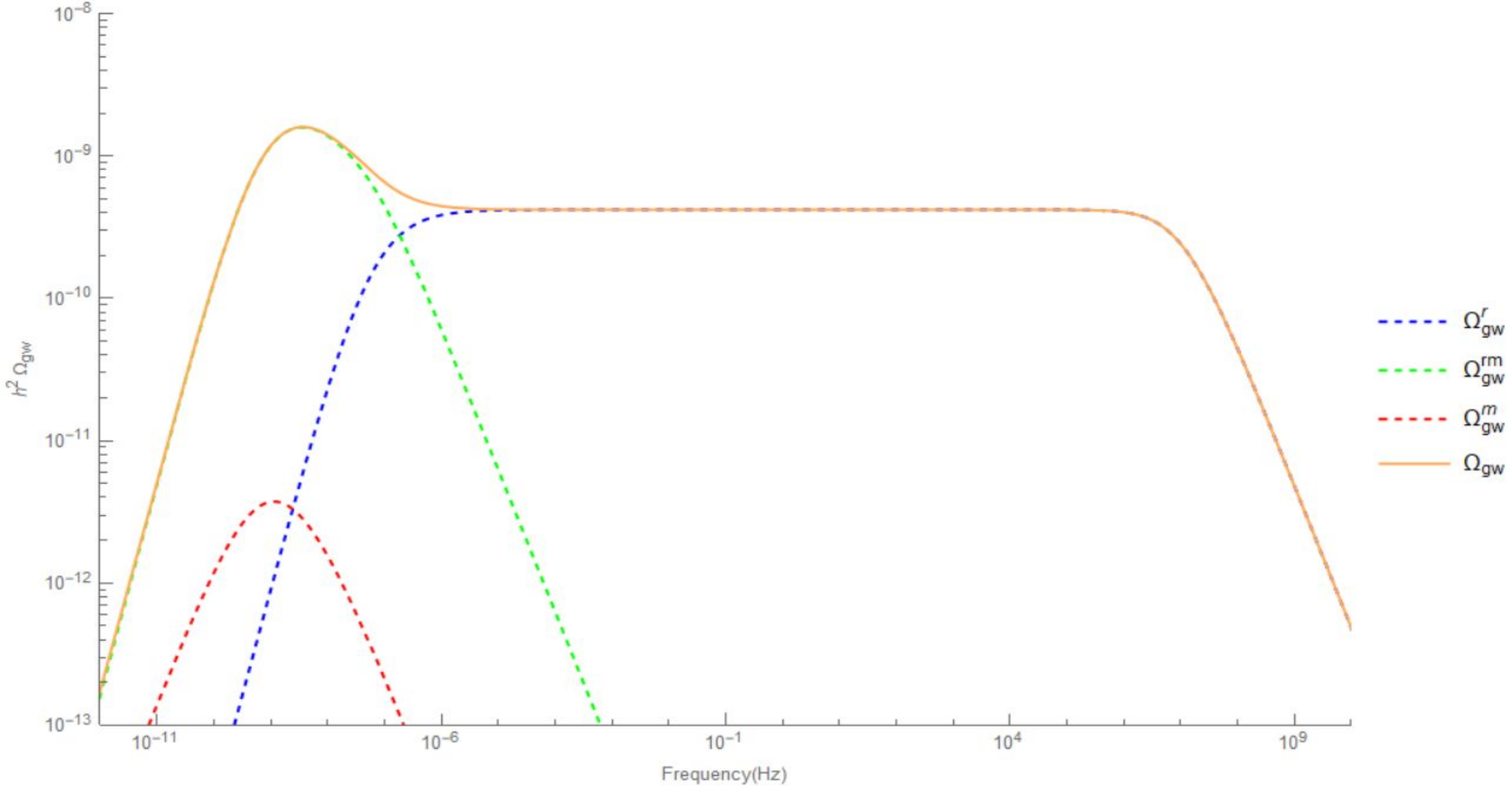

Ref to e-Print: 1809.10802 [astro-ph.CO]: G.S.F. Guedes, P.P. Avelino (Porto U. and Porto U., Astron. Dept.), L. Sousa (Porto U. and Porto U., Astron. Dept.) for a detailed explanation on how to plot the analytical spectrum.


MARVEL ANIMATION
WHAT IF...?

What If the strings are formed during inflation?

What If the strings are formed during inflation?

How generic is cosmic string formation in SUSY GUTs

Rachel Jeannerot*

The Abdus Salam ICTP, strada costiera 11, 34100 Trieste, Italy

Jonathan Rocher†

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D-term inflation, cosmic strings, and consistency with cosmic microwave background measurements

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MODULI INFLATION WITH LARGE SCALE STRUCTURE PRODUCED BY TOPOLOGICAL DEFECTS

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Physics Department, University of Michigan
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Signature of inflation in the stochastic gravitational wave background generated by cosmic string networks

G. S. F. Guedes,[1,*] P. P. Avelino,[1,2,3,†] and L. Sousa[2,3,‡]

[1]*Departamento de Física e Astronomia, Faculdade de Ciências, Universidade do Porto, Rua do Campo Alegre 687, PT4169-007 Porto, Portugal*
[2]*Instituto de Astrofísica e Ciências do Espaço, Universidade do Porto, CAUP, Rua das Estrelas, PT4150-762 Porto, Portugal*
[3]*Centro de Astrofísica da Universidade do Porto, Rua das Estrelas, PT4150-762 Porto, Portugal*

The 2 Important Ingredients

1. The Turning Point Frequency:

2. The Inflation Model:

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$$f_\Delta = (1.5 \times 10^{-4}\ \mathrm{Hz}) \left(\frac{T_{\mathrm{re}}}{\mathrm{GeV}}\right) \left(\frac{0.1 \times 50 \times 10^{-11}}{\alpha\,\Gamma G\mu}\right)^{1/2} \left(\frac{g_*(T_{\mathrm{re}})}{g_*(T_0)}\right)^{1/4}$$

BSM with Cosmic Strings. e-Print: 1912.02569 [hep-ph]. Yann Gouttenoire, Géraldine Servant, Peera Simakachorn.

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BICEP2+Keck+BICEP3+Planck 18: $r_{0.05} < 0.036$ at 95% confidence

P. A. R. Ade et al. (BICEP/Keck Collaboration)

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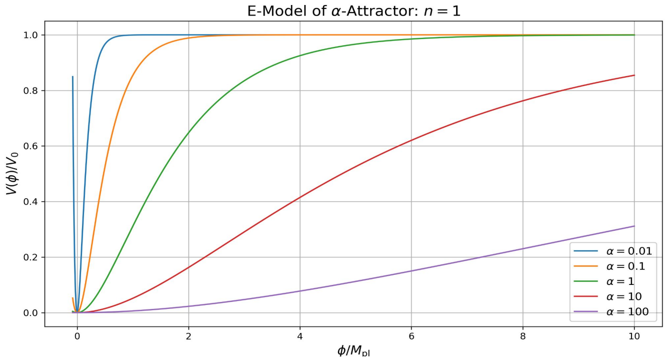

$$V = V_0 \left(1 - e^{-\sqrt{\frac{2}{3\alpha}}\frac{\phi}{M_{pl}}}\right)^{2n}$$

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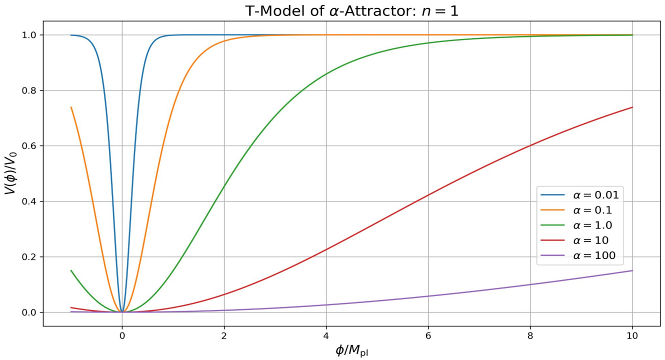
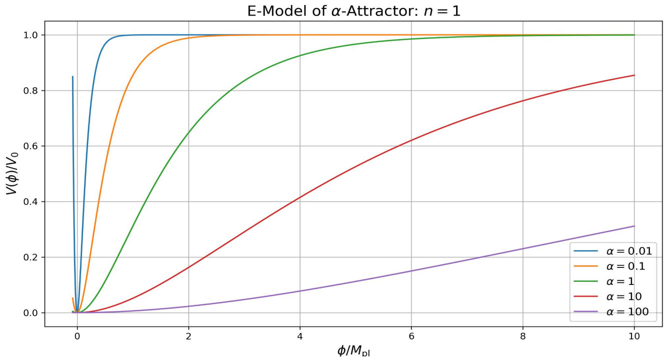


$$V(\phi) = V_0 \tanh^{2n}\left(\frac{\phi}{\sqrt{6\alpha}M_{pl}}\right)$$



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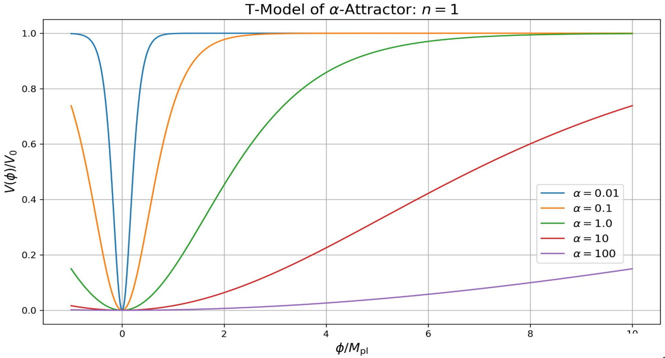

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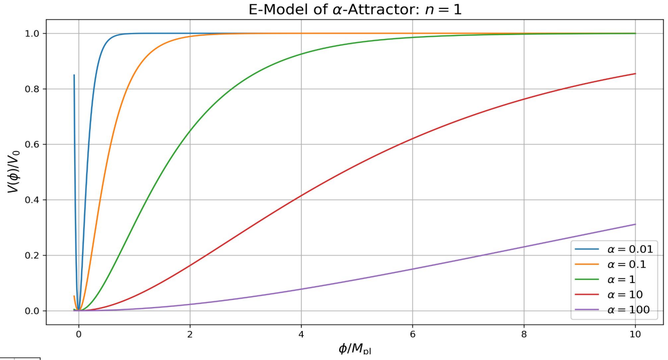

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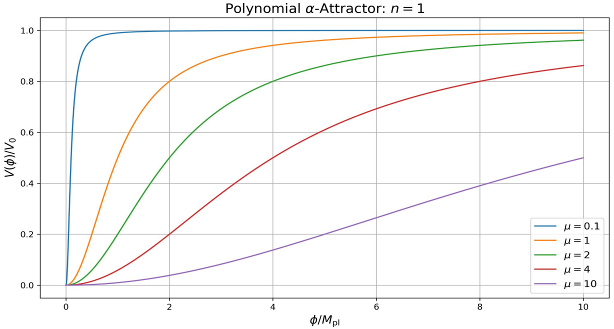
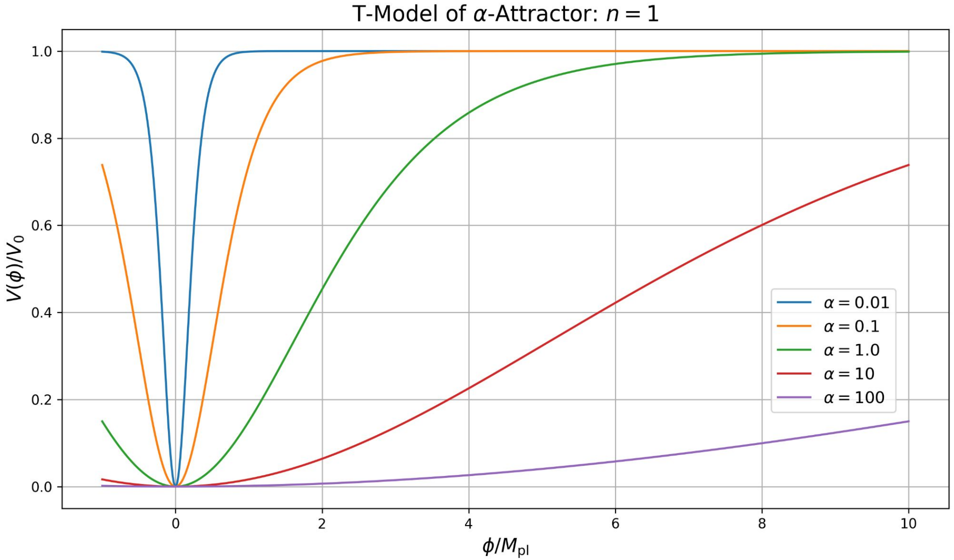


$$V(\phi) = V_0 \frac{\phi^{2n}}{\phi^{2n} + \mu^{2n}}$$

The final ingredient: T-Model



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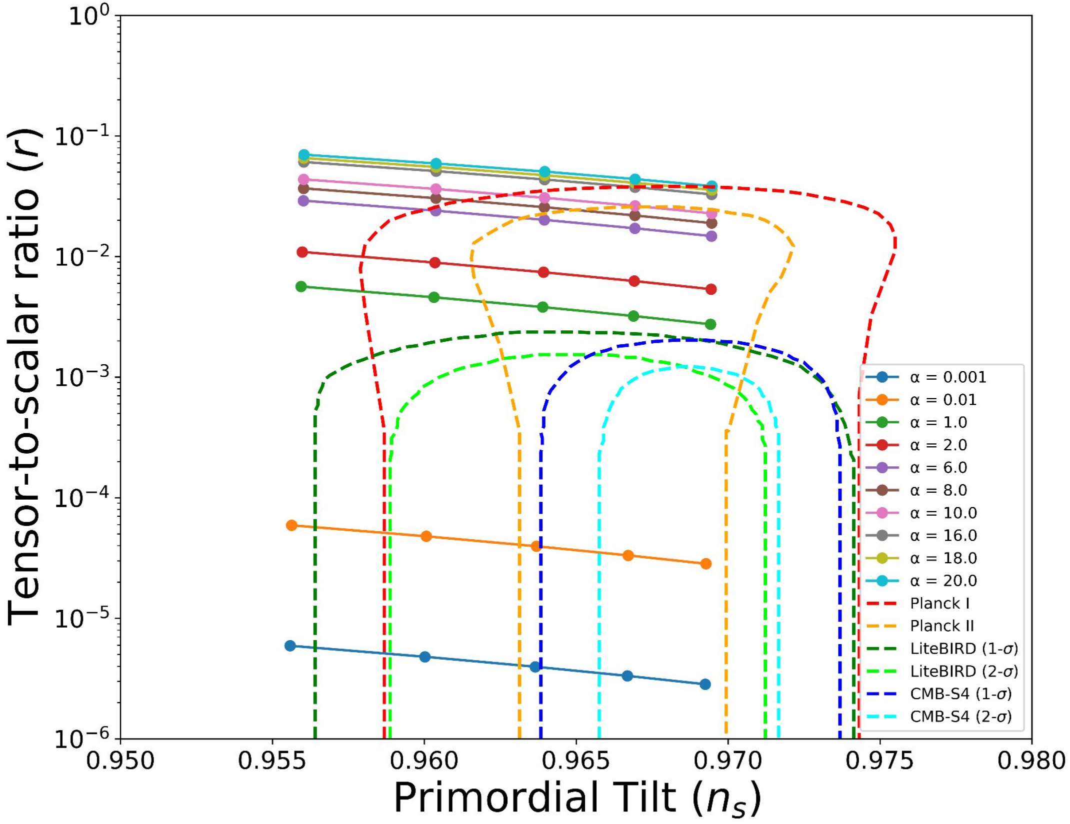
n_s -r predictions of the T-Model with n=1



Understanding the evolution of CS: The VOS Equations

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$$\frac{dL}{dt} = HL\,(1+\bar{v}^2) + \frac{1}{2}\tilde{c}\,\bar{v},$$
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- L is the correlation length.
- $\bar{v}$ is the mean velocity of the CS.
- The momentum parameter measures deviation from a straight string.

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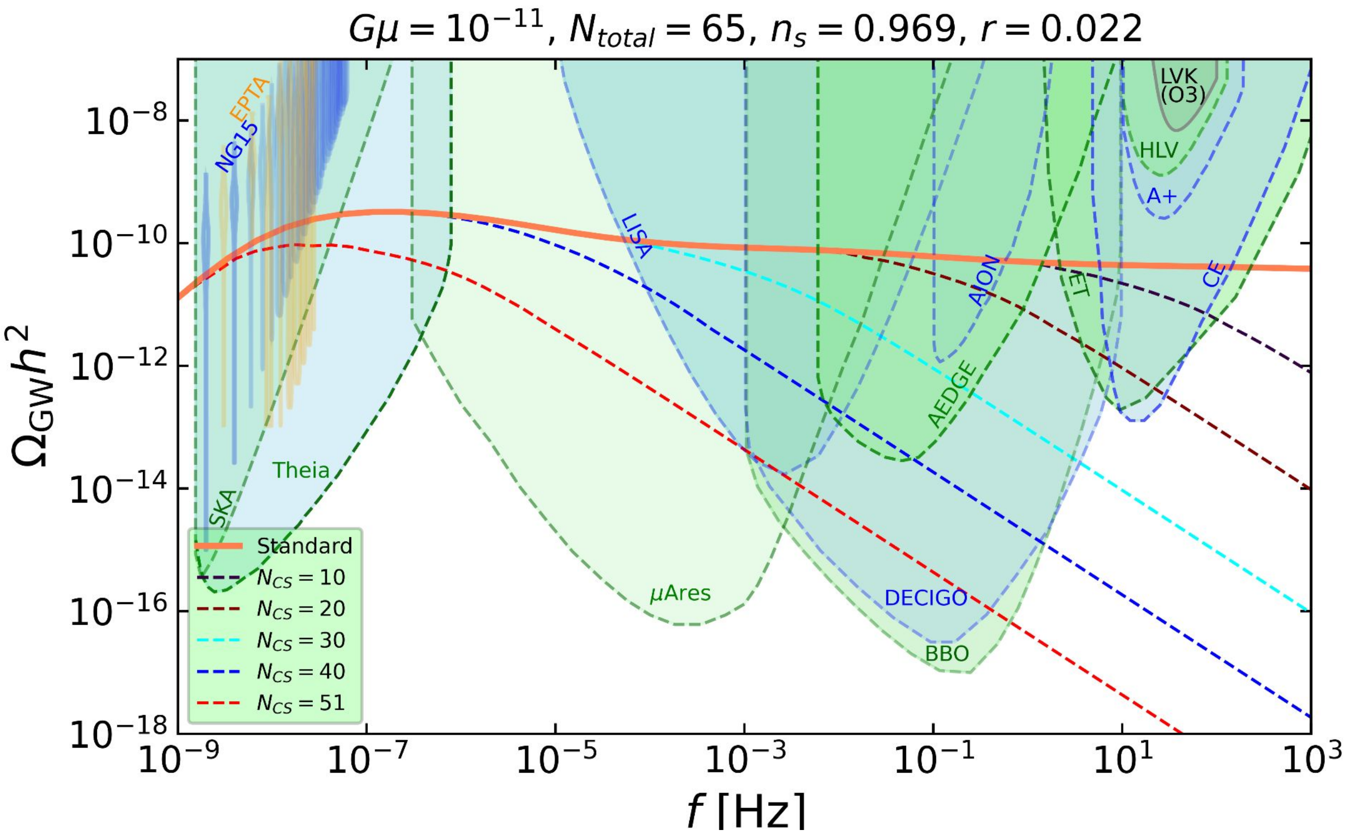
- For n > 2, the Hubble horizon will eventually catch up with the string length, allowing them to re-enter, and initiate the loop production.

SGWB from Local Cosmic Strings (T-Model with n=1 and α=1)



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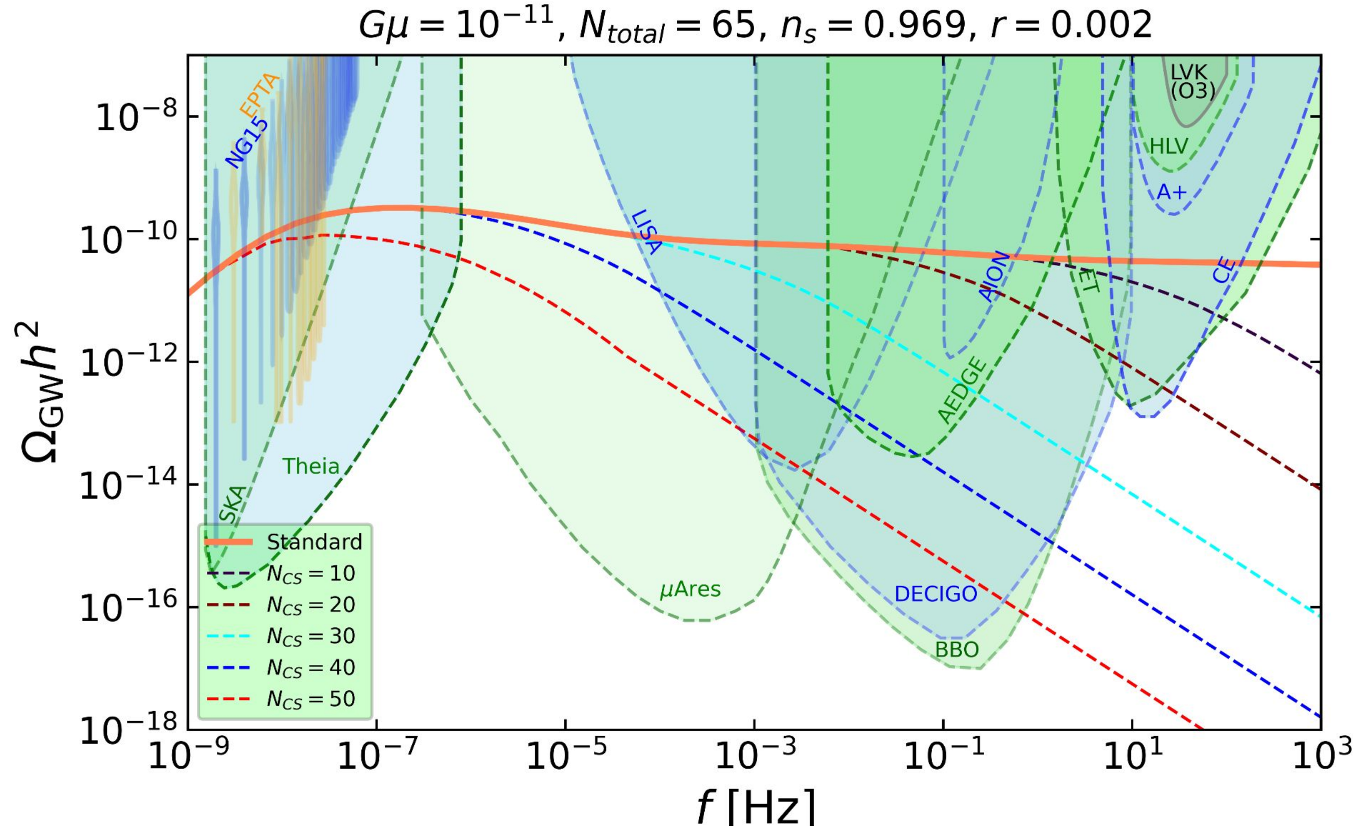

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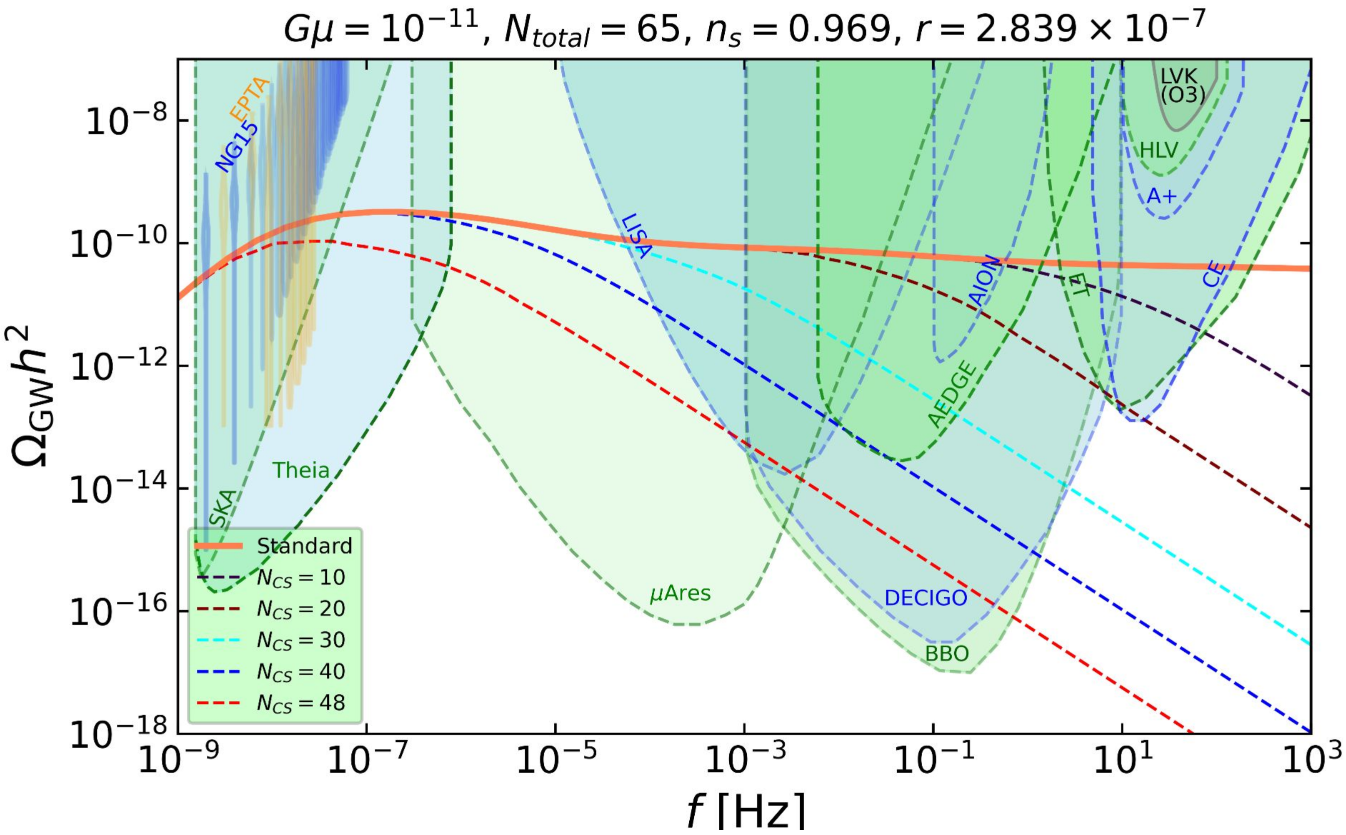

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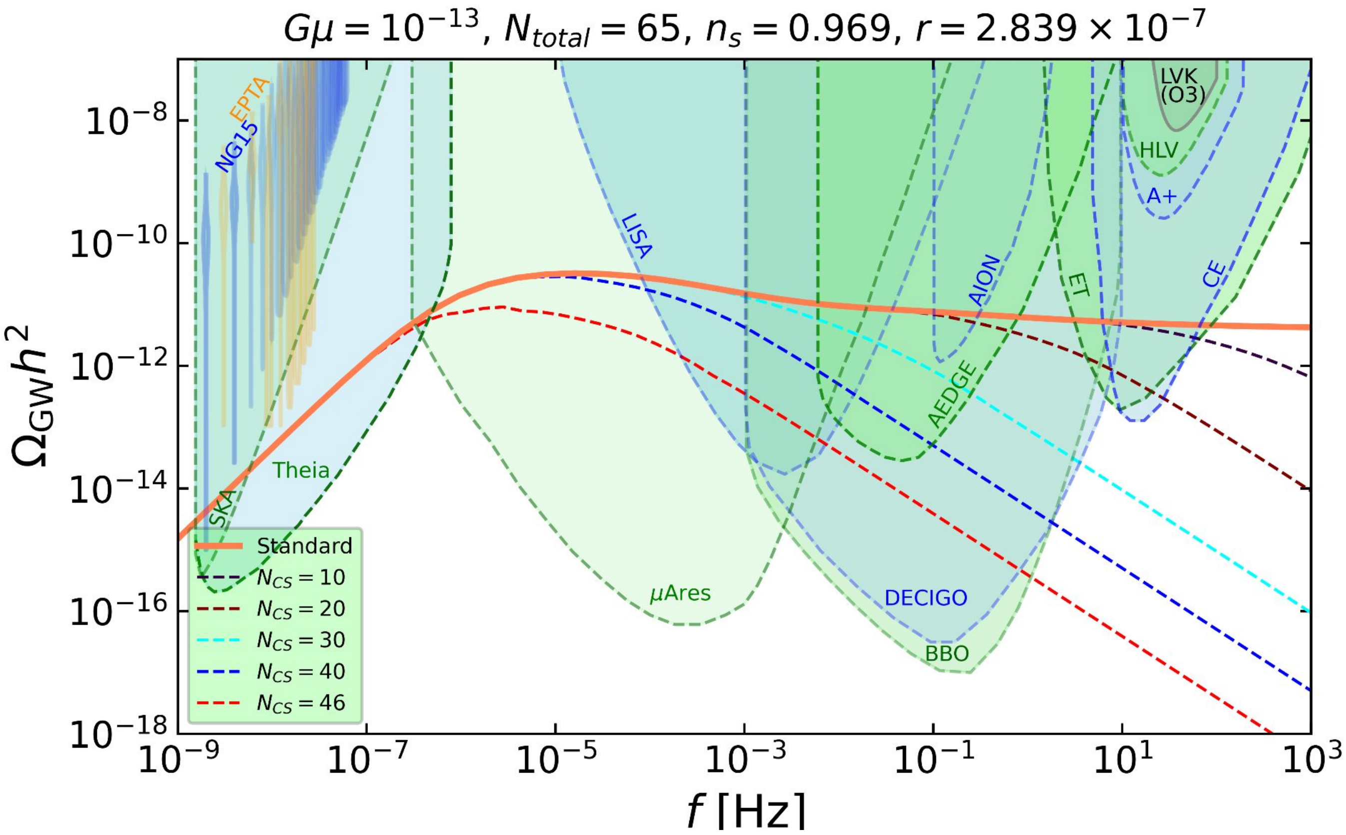

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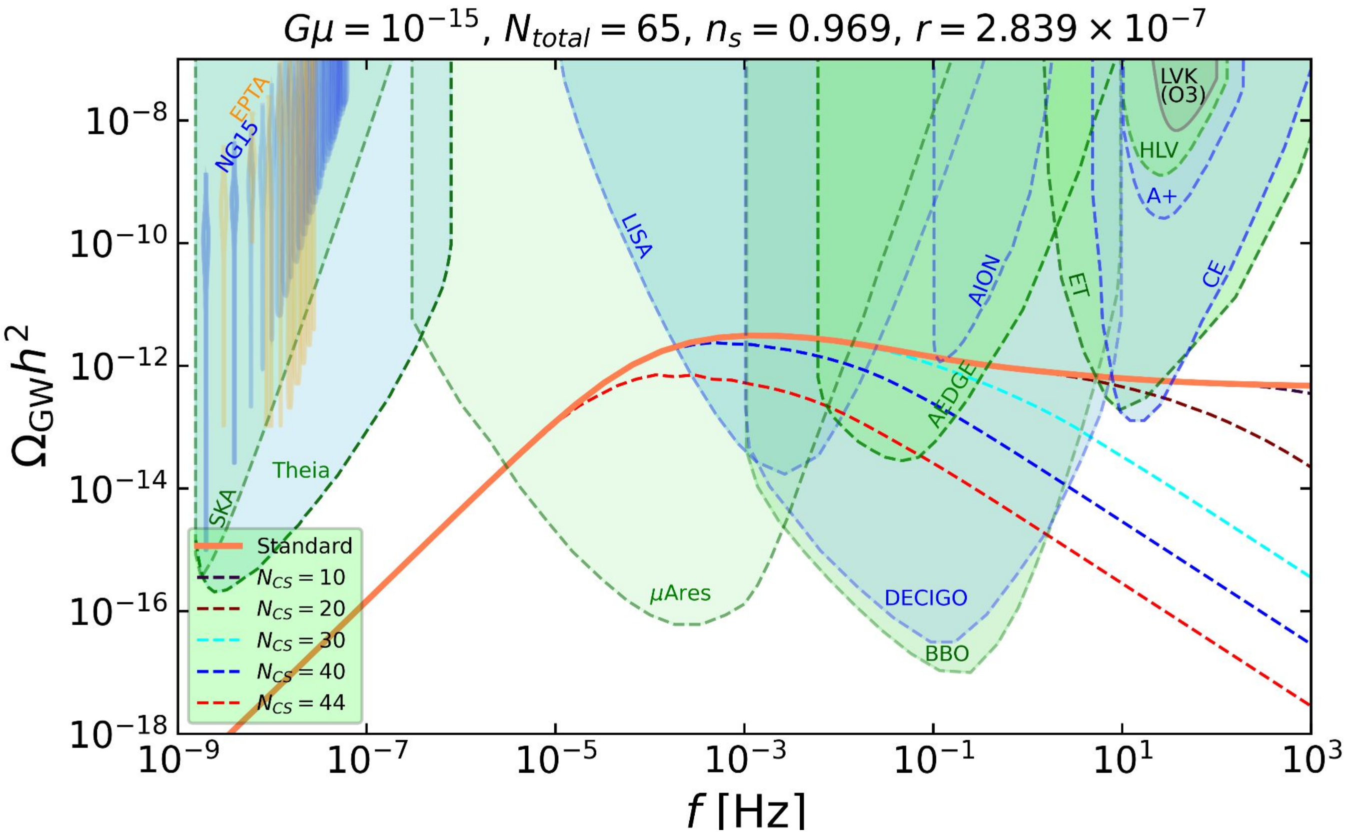

Complementarity between GW detectors and CMB

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Connecting the tensor-to-scalar ratio (*r*) to the turning-point frequency (f_{Δ})

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$$f_\Delta = (1.5 \times 10^{-4}\mathrm{Hz}) \left(\frac{T_{\mathrm{re}}}{\mathrm{GeV}}\right) \left(\frac{0.1 \times 50 \times 10^{-11}}{\alpha \Gamma G\mu}\right)^{1/2} \left(\frac{g_*(T_{\mathrm{re}})}{g_*(T_0)}\right)^{1/4}$$

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$$E_{\mathrm{inf}} = 1.06 \times 10^{16} \times (\frac{r}{0.01})^{1/4}$$

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- ➢ SKA: $f_\Delta^{SKA} \simeq 1.54 \times 10^{-9}$ Hz to 1.69×10^{-6} Hz and $G\mu \lesssim 10^{-13}$.

  LISA: $f_\Delta^{LISA} \simeq 6.45 \times 10^{-6}$ Hz to 82.7 Hz and $G\mu \lesssim 10^{-17}$.

  DECIGO/BBO: $f_\Delta^{DECIGO/BBO} \simeq 10^{-3}$ Hz to 10 Hz and $G\mu \lesssim 10^{-20}$.

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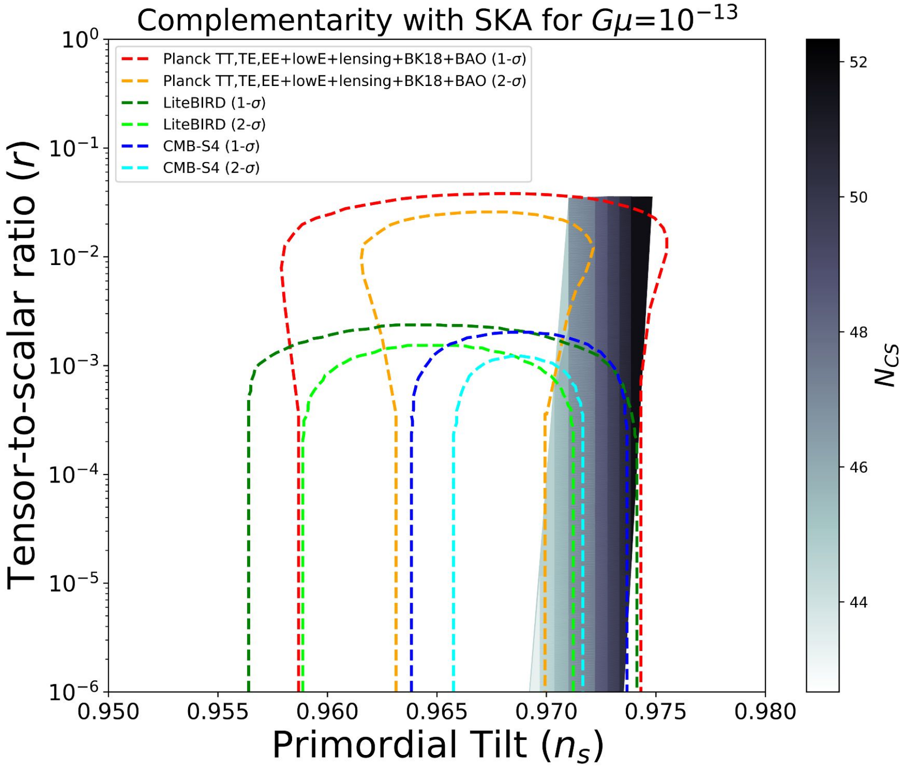
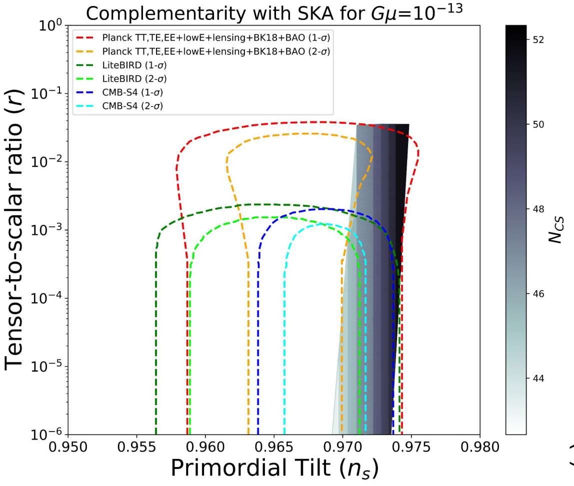
- Constrained by the tensor-to-scalar ratio, $r < 0.036$, we look for all possible integer values of $N_{CS} \in [1, 65]$ that satisfy these conditions.

Complementarity between GW detectors and CMB



$$0.969 \lesssim n_s \lesssim 0.973$$

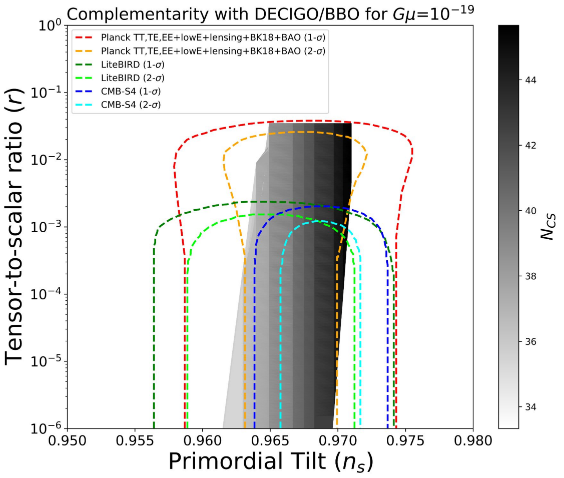
Complementarity between GW detectors and CMB (Polynomial Attractor) for Local Strings



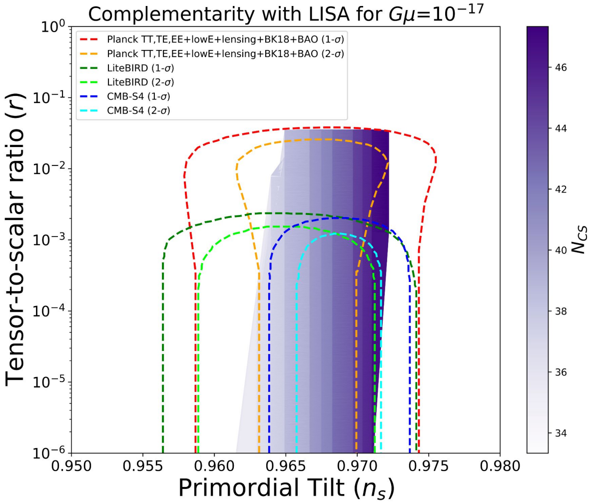
$0.969 \lesssim n_s \lesssim 0.973$

$$V(\phi) = V_0 \frac{\phi^{2n}}{\phi^{2n} + \mu^{2n}}$$

$n = 1$

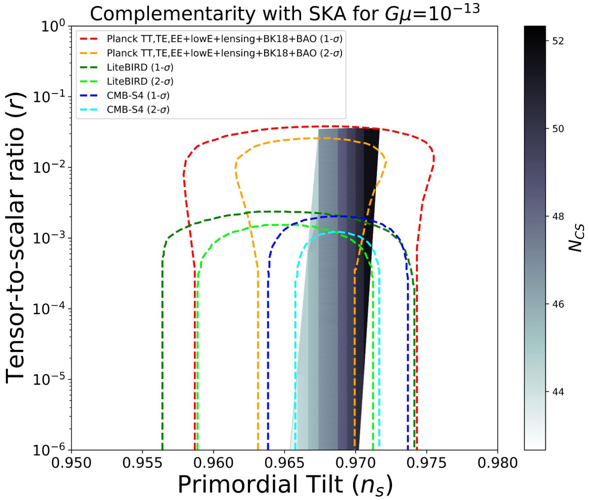


$0.962 \lesssim n_s \lesssim 0.969$



$0.962 \lesssim n_s \lesssim 0.972$

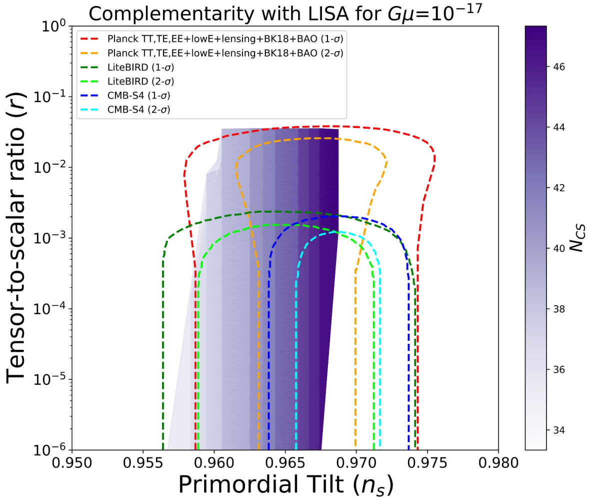
Complementarity between GW detectors and CMB (Polynomial Attractor) for Local Strings



$0.969 \lesssim n_s \lesssim 0.973$

$$V(\phi) = V_0 \frac{\phi^{2n}}{\phi^{2n} + \mu^{2n}}$$

$n = 2$



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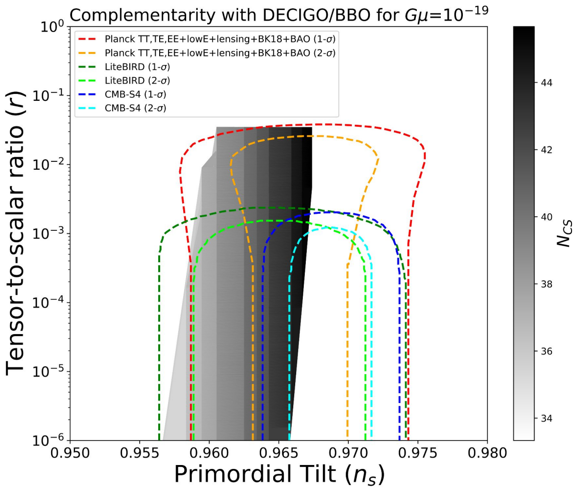

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Summary and Conclusion

- Both Local and Global CS that experience certain e-foldings of inflation can be detected in the upcoming GW detectors like LISA and ET.

- There is a limit to the maximum number of e-folds of inflation they can undergo so that we can have observable GW signatures at the detectors. This number is controlled primarily by the string tension $G\mu$ determined by the vev of the scalar field η_{local} and the energy scale of inflation, or the tensor-to-scalar ratio r.

- Roughly, the maximum value of N_{CS} decreases as we reduce the string tension. The maximum value of N_{CS} to have observable GW signals also decreases as we decrease the energy scale of inflation.

- The GW spectrum from local cosmic strings formed during inflation sees a departure from the flat plateau behaviour. The extent of this deviation depends on the number of e-folds of inflation N_{CS} that the strings experience: the greater the value of N_{CS}, the shorter the flat plateau region becomes, which is determined by the turning point .

- Besides putting bounds on the N_{CS} values, one can also use this method to put constraints on the permissible $n_s - r$ values that the inflation model can take. For instance, LISA can probe $N_{CS} \sim 34 - 47$ irrespective of the value of the local string tension.

- It allows us to constrain the spectral index n_s within the range $0.962 \lesssim n_s \lesssim 0.972$ for n = 1, $0.956 \lesssim n_s \lesssim 0.968$ for n = 2, $0.954 \lesssim n_s \lesssim 0.965$ for n = 3 and $0.963 \lesssim n_s \lesssim 0.964$ for n = 4.

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- ❖ Thanks to Ivonne Zavala, Dibya Chakraborty and Swagat Mishra for some fruitful discussions.

- ❖ Thanks to HRI for their support and hospitality.


Thank you