Loop decay in Abelian-Higgs string networks

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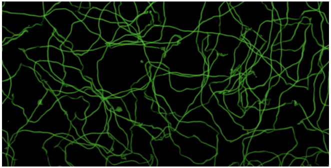
Cosmic strings

- Cosmic strings → one type of topological defect.
- Created in the phase transitions of the early universe.



- Abelian Higgs model → simplest gauge field theory with string-like solutions:

$$\mathcal{L} = D_\mu \phi^* D^\mu \phi + V(\phi) + \frac{1}{4e^2} F_{\mu\nu} F^{\mu\nu} \ ,$$

with Mexican-hat potential:

$$V(\phi) = \frac{\lambda}{4} (|\phi|^2 - \phi_0^2)^2 \ .$$

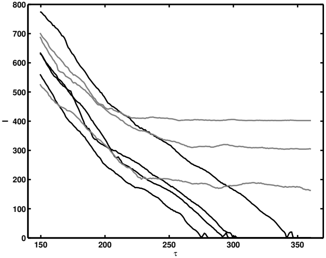
State of the art and motivation

- Two main models that describe the evolution of cosmic strings:
  - Nambu-Goto (NG) $\rightarrow$ strings idealised one-dimensional objects.
  - Field theory (FT) $\rightarrow$ considers the discretized version of the full equations of motion.
    Simulations in 3D cubic lattices.
- Models do not agree on the evolution of cosmic string loops:
  - NG loops $\rightarrow$ oscillatory/slow decay typically via gravitational radiation.
  - FT loops $\rightarrow$ rapid decay typically via gauge/scalar radiation.

Loops in field theory

Not so exhaustively studied as in NG.

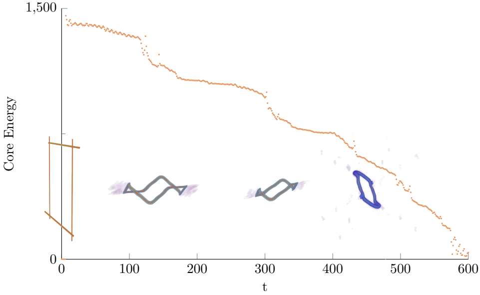
Preliminary works on loops from networks
Hindmarsh, Stuckey, Bevis
(Phys.Rev.D 79 (2009) 123504)



- Length decrease linearly with time
- Lifetime $\propto \ell_{\rm init}$.

Recent work on artificially set loops:
Matsunami, Pogosian, Saurabh and Vachaspati
(Phys.Rev.Lett. 122 (2019) 20, 201301)

- Boosted straight strings
- Long living loops
- Lifetime $\propto \ell_{\rm init}^2$.

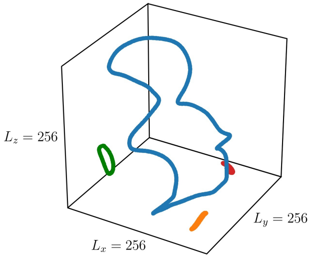


Abelian-Higgs strings in field theory

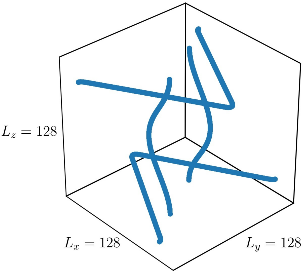
- We have evolved the discretised version of the Abelian-Higgs EOM (Minkowski spacetime), using a cubic lattice (different $N, \delta x$) with periodic boundary conditions.

- Two types of initial conditions:

  - Loops from intersections of infinite strings in networks.



  - Loops from artificially set up configurations.



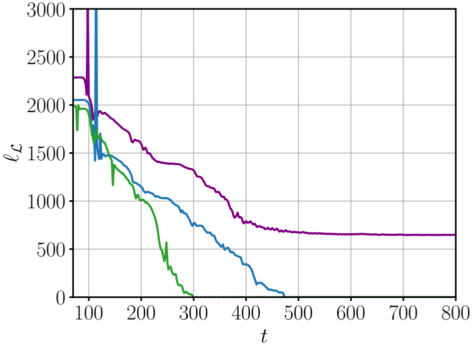
Set up of the string network simulations

String networks

- Only the scalar field is non-zero. It is set to be a stationary Gaussian random field with a power spectrum that depends on the correlation length l_ϕ.
- Excess of energy produced by the random initial conditions removed by a diffusive phase.
- Afterwards the string network evolves following the discretised AH equations of motion with $\delta t = (1/5)\delta x$.

Possible outputs from string networks

- Due to the topology of the lattice (torus), simulations can end up in:
  - Strings that wrap the box (purple).
  - Collapsing loops (green and blue).
- In total we have performed 98 simulations: only $\sim 1/3$ of them from intersections.



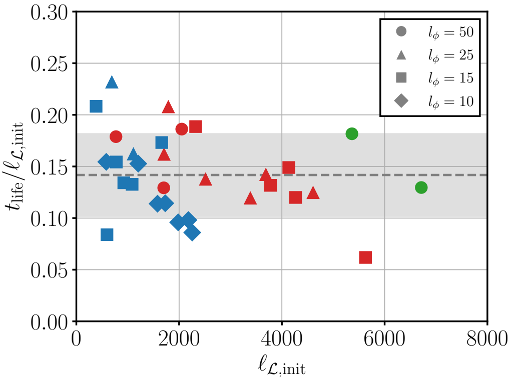
Procedure

- Observable: total string length in the box: $\ell_{\mathcal{L}}$.
- Follow the evolution of $\ell_{\mathcal{L}}$.
- Compute the initial length ($\ell_{\mathcal{L},\mathrm{init}}$) and lifetime ($t_{\mathrm{life}}$) of the loops.

Decay of network loops

Decay of network loops

- Independent of the loop size and l_ϕ loops are clustered around a constant value $\rightarrow$ $t_{\rm life} = \alpha \ell_{\mathcal{L},{\rm init}}$.
- Averaging over all cases the proportionality constant is $\rightarrow \alpha = 0.14 \pm 0.04$.
- Different from $t_{\rm life} \propto \ell^2_{\mathcal{L},{\rm init}}$ obtained by Matsunami et al. 2019.

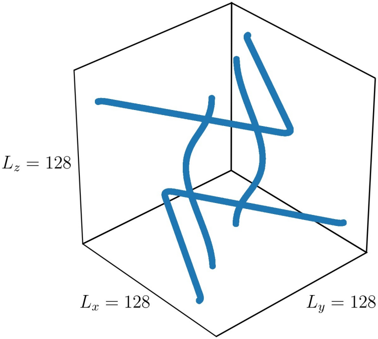


- Blue $\rightarrow N = 1024, \delta x = 0.125$.
- Red $\rightarrow N = 1024, \delta x = 0.25$.
- Green $\rightarrow N = 2048, \delta x = 0.25$.

Set up and analysis of the artificial loops

Artificial loops

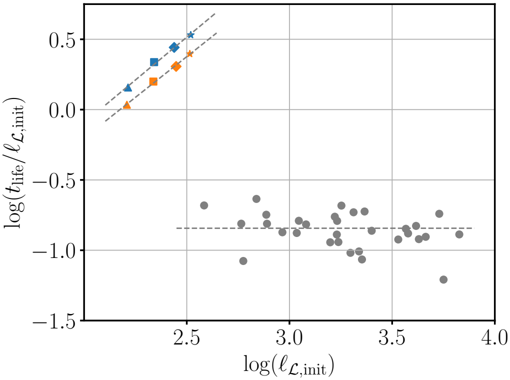
- Initial conditions:
  - Static configuration $\rightarrow$ leads to the formation of 2 loops.
  - 2 strings with kinks + 2 standing waves.
- Diffusion also applied.
- Resolution $\delta x = 0.125$ and $N = 768, 1024, 1280, 1536$.



Decay of artificial loops

Decay of artificial loops

- We computed $\ell_{\mathcal{L},\text{init}}$ and t_{life} of the 8 different inner loops obtained.
- Fitting the results obtained to $t_{\text{life}} = \alpha \ell_{\mathcal{L},\text{init}}^{\beta}$:
  - $A = 0.1L \rightarrow \beta = 2.22 \pm 0.06$.
  - $A = 0.075L \rightarrow \beta = 2.16 \pm 0.05$.
- Artificial loops decay $\propto \ell_{\text{init}}^2$ while network loops $\propto \ell_{\text{init}}$.



Conclusions

- Possibility of $\propto \ell_{\rm init}^2$ for artificial loops, but network loops $\propto \ell_{\rm init}$.
- Bad luck? From 31 network loops sample $\rightarrow f_{\rm NG} < 0.1$ at 95% confidence level.
- We have also computed the average velocity:
  Network loops $\rightarrow \bar{v}^2 = 0.40 \pm 0.04$
  Artificial loops $\rightarrow \bar{v}^2 = 0.500 \pm 0.004$
  NG in Minkowski $\rightarrow \bar{v}^2 = 0.5$
- Further investigation needed to understand loop decay.

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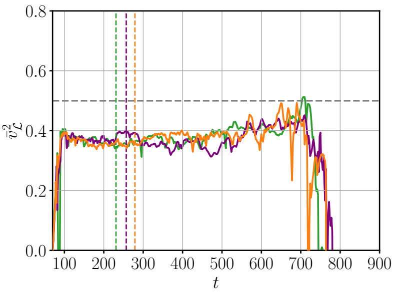
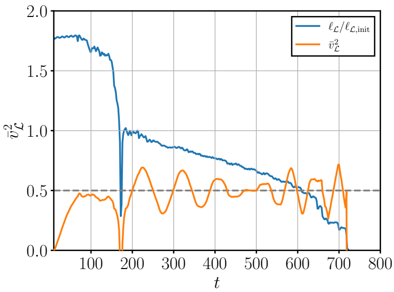
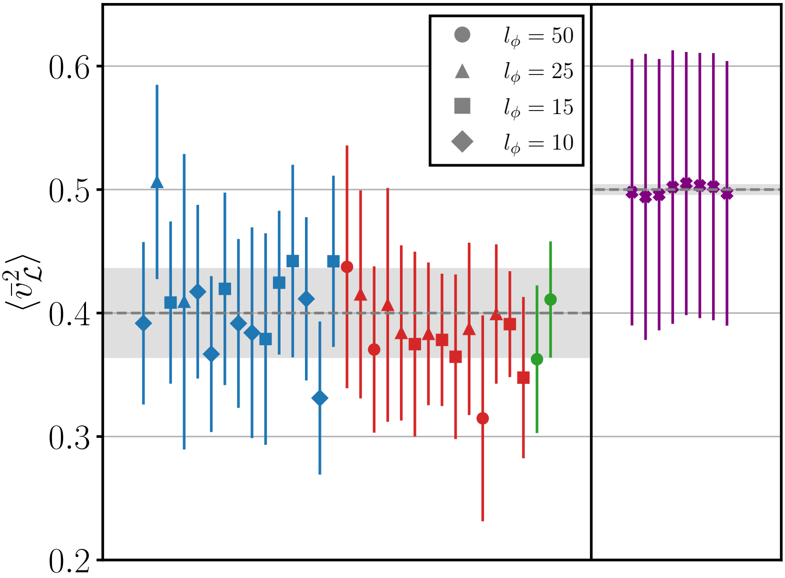

0.8
0.6
0.4
0.2
0.0
$\bar{v}^2_{\mathcal{L}}$
100
200
300
400
500
600
700
800
900
t


2.0
1.5
1.0
0.5
0.0
$\bar{v}^2_{\mathcal{L}}$
100
200
300
400
500
600
700
800
t
$\ell_{\mathcal{L}}/\ell_{\mathcal{L},\mathrm{init}}$
$\bar{v}^2_{\mathcal{L}}$


0.6
0.5
0.4
0.3
0.2
$\langle \bar{v}_{\mathcal{L}}^2 \rangle$
$l_\phi = 50$
$l_\phi = 25$
$l_\phi = 15$
$l_\phi = 10$