Scaling in a network of Z_2 strings

Mark Hindmarsh[*,†], Kari Rummukainen[†], David J. Weir[‡]

[*]University of Sussex [†]University of Helsinki [‡]University of Stavanger

Universitetet i Stavanger

University of Sussex

What was known

- Spontaneous breaking of a non-abelian symmetry can produce 'beads' consisting of 't Hooft-Polyakov monopoles, on cosmic strings.
- It is not known how the monopoles influence the dynamics of the resulting string network.

What this work adds

- We have carried out simulations of this scenario for the first time.
- Monopoles are carried along by the strings; the network behaves similarly to an abelian string network.

Next steps

- Study larger ratios between the monopole and string scales, to check whether monopoles eventually slow strings down.
- Observational predictions for strings in grand unified models, e.g. $\mathrm{SO}(10)$.

Introduction

- We study the formation of cosmic string networks in the model with Lagrangian [1,2]

$$\mathcal{L} = -\frac{1}{4}F^a_{\mu\nu}F^{\mu\nu a} + \sum_n \mathrm{Tr}[D_\mu, \Phi_n][D^\mu, \Phi_n] - V(\Phi_1, \Phi_2); \qquad V(\Phi_1, \Phi_2) = -m_1^2 \,\mathrm{Tr}\,\Phi_1^2 - m_2^2 \,\mathrm{Tr}\,\Phi_2^2 + \lambda\left[\left(\mathrm{Tr}\,\Phi_1^2\right)^2 + \left(\mathrm{Tr}\,\Phi_2^2\right)^2\right] + \kappa\left(\mathrm{Tr}\,\Phi_1\Phi_2\right)^2$$

where $D_\mu = \partial_\mu + igA_\mu$, $F_{\mu\nu} = F^a_{\mu\nu}\tau^a$ and $A_\mu = A^a_\mu\tau^a$, $\tau^a = \sigma^a/2$. Here, Φ_1 and Φ_2 are adjoint Higgs fields ($\Phi = \phi^a\sigma^a$).
- The system undergoes two symmetry breaking phase transitions, $\mathrm{SU}(2) \to \mathrm{U}(1) \to \mathrm{Z}_2$.
The first, $\mathrm{SU}(2) \to \mathrm{U}(1)$, creates 't Hooft-Polyakov monopoles with mass M, the second, $\mathrm{U}(1) \to \mathrm{Z}_2$, confines the flux of those monopoles to cosmic strings with tension μ, like beads on a wire.
- We carry out simulations in a comoving $V = 720^3$ box with lattice spacing $a = 1$, with Hubble damping corresponding to an expanding radiation-dominated universe.
- We determine the location of strings and monopoles within the box, yielding L, the total (Manhattan) length of string and N, the number of monopoles. From these we get the average monopole and string separations ξ_m and ξ_s

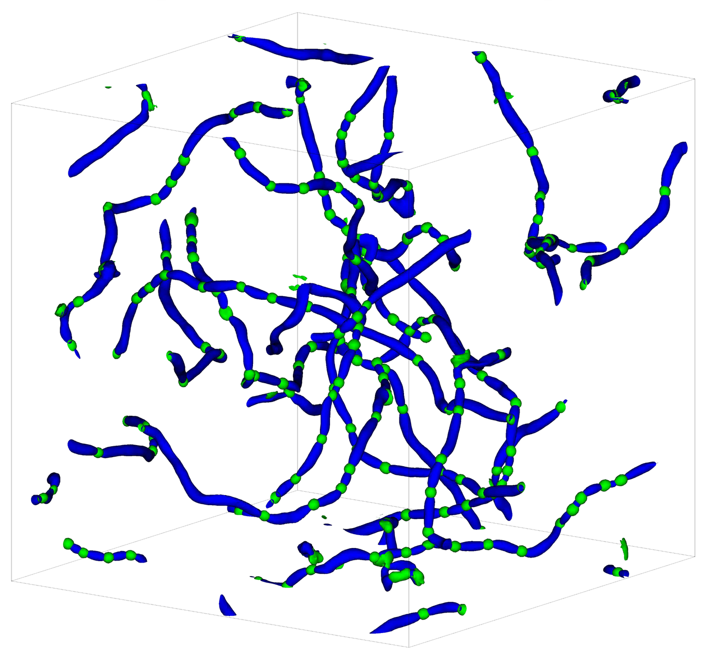
$$\xi_\mathrm{m} = \left(\frac{V}{N}\right)^{1/3}; \qquad \xi_\mathrm{s} = \left(\frac{V}{L}\right)^{1/2}.$$

The monopole locations are also used to measure $\overline{v}_m$, root mean square monopole velocity.
- We also determine the monopole separation along the string $d = L/N$ and hence the ratio $r = M/\mu d$ that measures the importance of the monopoles for the string dynamics [3,4,5].

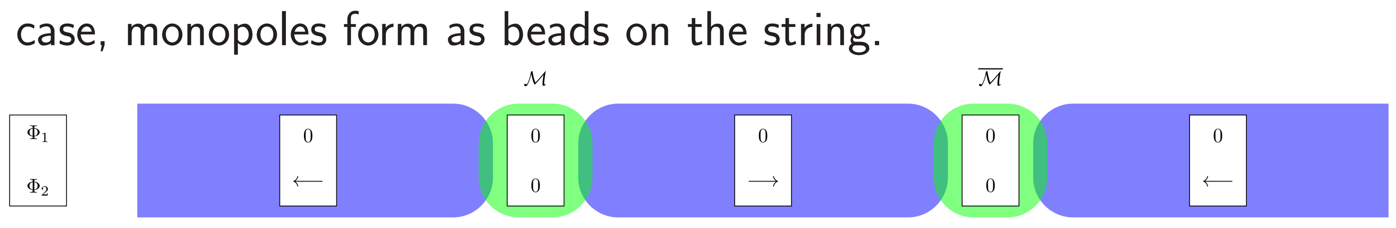
Case 1: $m_1^2 > m_2^2$

- The most widely-studied case is where the mass parameters are different.

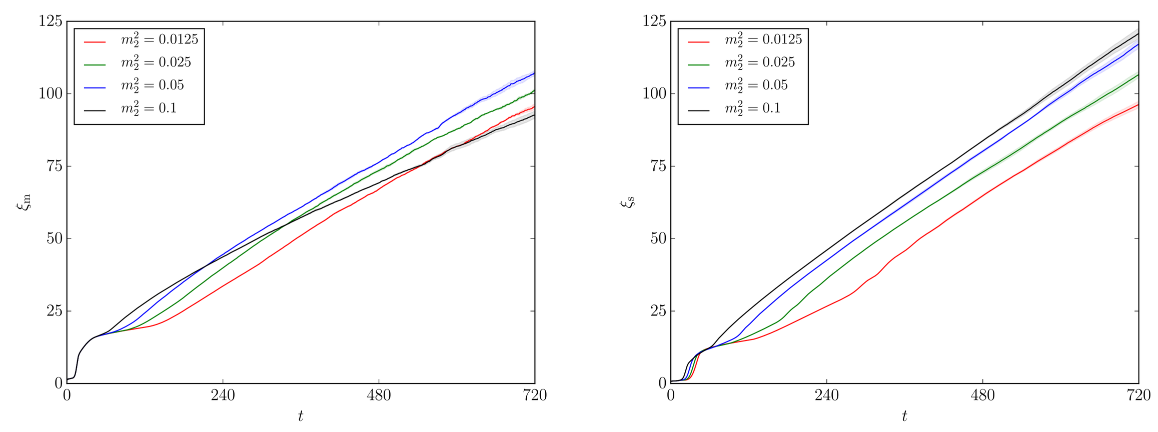
240^3 *simulation with* $m_1^2 = 0.25$, $m_2^2 = 0.1$, *isosurfaces* $\mathrm{Tr}\Phi_1^2 = 0.2$, $\mathrm{Tr}\Phi_2^2 = 0.04$, *time* $t = 240$.



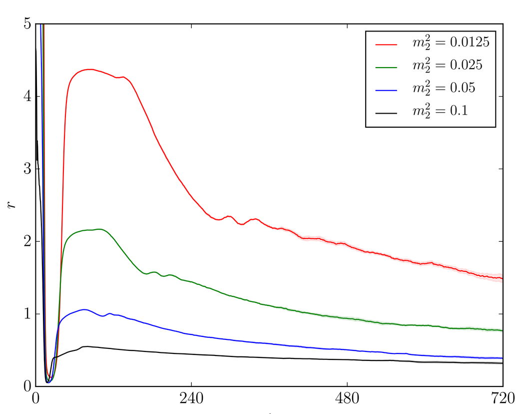
- In this case, monopoles form as beads on the string.



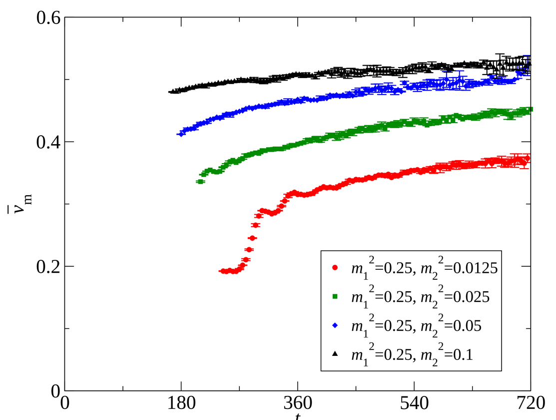
- However, we measured the average string and monopole separations, ξ_s and ξ_m. They grow linearly: a scaling network forms.



There is little apparent difference between the scaling for different string tensions.
- Our simulations show that r always decreases.



- In addition, we measured the root mean square monopole velocity $\overline{v}_m$, and it *increases*, appearing to asymptote to a relativistic value.



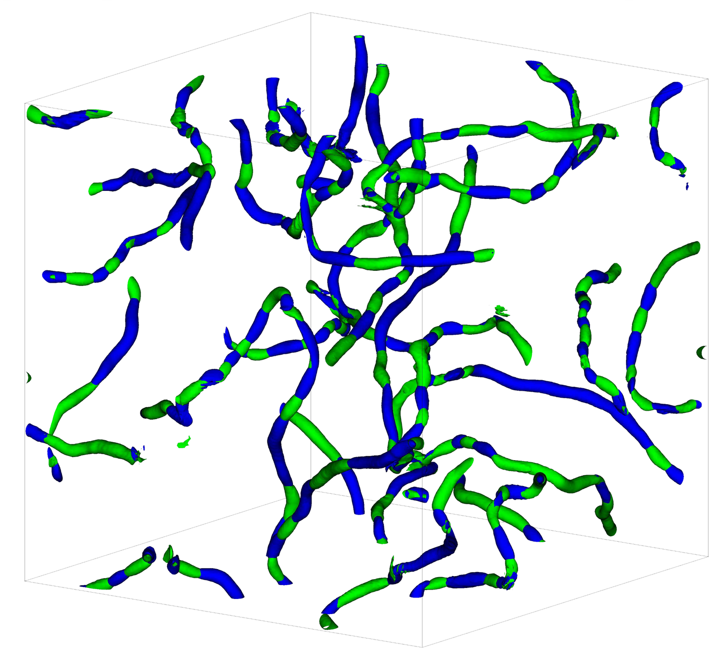
These monopole velocities are also in line with expected string velocities.

Key results: Scaling network forms; monopoles are unimportant; average monopole velocity does not decrease.

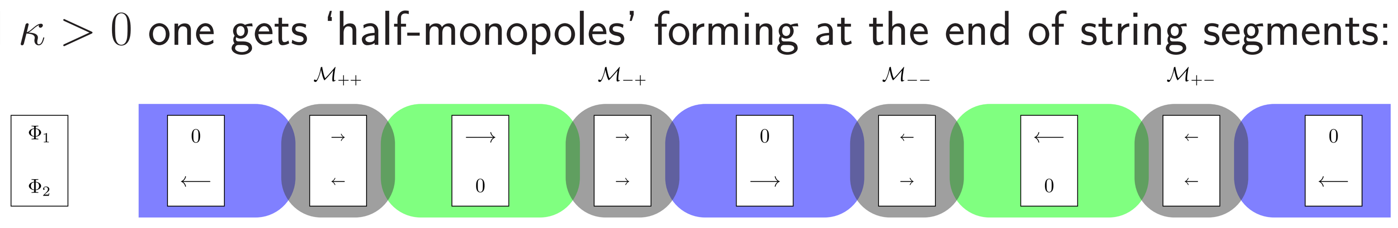
Case 2: $m_1^2 = m_2^2$

- Another possibility is when the two masses are degenerate.

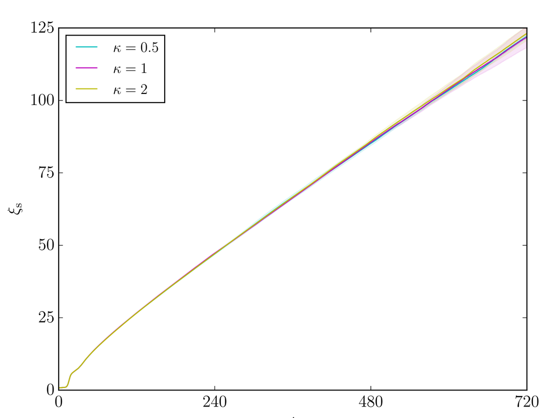
240^3 *simulation with* $m_1^2 = m_2^2 = 0.25$, $\kappa = 1$, *isosurfaces* $\mathrm{Tr}\Phi_1^2 = \mathrm{Tr}\Phi_2^2 = 0.2$, *time* $t = 240$.



This can happen, for example, when the fields are embedded in a larger model.
- For all $\kappa > 0$ one gets 'half-monopoles' forming at the end of string segments:



- There is a global symmetry between the two scalar fields, and the larger κ is, the less the two fields overlap.
- However, for all values of κ, the result is a scaling network of strings:



- We find that ξ_s scales with coefficient 0.16 ± 0.01, which corresponds to string densities approximately 40% higher than in the abelian Higgs model. CMB constraints are therefore stronger for this model [6].
- Because of the global symmetry between the fields, we are unable to count the number of half monopoles here.

Key results: When $m_1^2 = m_2^2$, we get novel strings with 'half-monopole' structures. These still produce a scaling network.

Acknowledgements and References

1. M. Hindmarsh and T. Kibble, *Phys. Rev. Lett.* **55**, 2398 (1985)
2. T. Vachaspati and A. Vilenkin, *Phys. Rev. D* **35**, 1131 (1987)
3. V. Berezinsky and A. Vilenkin, *Phys. Rev. Lett.* **79**, 5202 (1997)
4. J. J. Blanco-Pillado and K. D. Olum, *JCAP* **1005**, 014 (2010)
5. C. J. A. P. Martins, *Phys. Rev. D* **82**, 067301 (2010)
6. N. Bevis *et al.*, *Phys. Rev. D* **82**, 065004 (2010)

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