Irreducible cosmic production of relic vortons : 2010.04620

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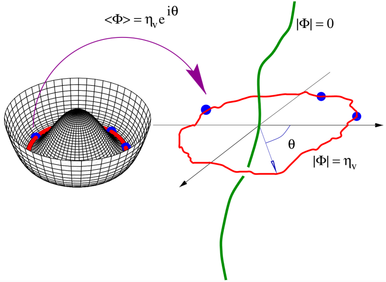
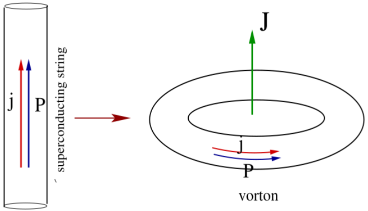
Zooming in on Strings and Vortons

Introduction and motivation

- **Cosmic strings** are one-dimensional topological defects
  - May have formed during symmetry-breaking phase transition in the early Universe
  - Topologically stable if the new vacuum manifold is not simply connected $\pi_1(\mathcal{M}) \neq 0$
  - Wide range of observable signatures : lensing, **gravitational waves (GW)**, emission of particles, anisotropies in the CMB...
- **Current carrying strings**
  - Particles coupled to the *Higgs* can condense on the string and induce a **current**
  - The angular momentum carried by the current can stabilize the loops and prevent the collapse
  - These stable configurations are called **vortons**

$\Rightarrow$ We quantitatively study the dynamical evolution of the cosmic string loops and the accumulation of vortons.





Assumptions on the physics of current carrying strings

The current appears on the cosmic string network at a time $t_{\rm cur}$

- λ is the **Compton wavelength** of the current carrier
- μ is the **mass per unit length** of the string
- $\mathcal{R} = \lambda\sqrt{\mu}$ ratio between the typical lengths of the current carrier and the Higgs field
- Current-carrying loops are characterized by two **classically conserved** integral quantum numbers N and Z randomly distributed

In this paper we focus on **nearly chiral vortons** for which

- $|Z| \approx N$
- Tension of the string $\mathcal{T} \approx \mu$ and $\mathcal{R} \gg 1$

Finally, we assume that the **current sets in rapidly** on the cosmic strings.
Using the central limit theorem, on a loop of initial invariant length $\ell_\star$

$$N = \sqrt{\frac{\ell_\star}{\lambda}}$$

Note: in this paper, a subscript $\star$ denotes quantities evaluated at the formation of a loop

Assumptions on the physics of vortons

We follow individual loops with conserved charge N

$$\frac{\mathrm{d}\ell}{\mathrm{d}t} = -\Gamma G\mu \mathcal{J}(\ell, N)$$

- On large scales, the cosmic string network behaves according to the Nambu-Goto action : **emission of GW** $\Rightarrow \mathcal{J} \approx 1$
- When the string reach the vorton size $\ell_0(N) \approx N/\sqrt{\mu} = \sqrt{\frac{\ell_\star}{\lambda\mu}}$, if $\ell_0 > \lambda$ it stabilizes if $\Rightarrow \mathcal{J} \approx 0$

In the following analysis, we leave $\mathcal{J}$ **unspecified**, but one could imagine having

$$\mathcal{J}(\ell, N) = \frac{1}{2}\left[1 + \tanh\left(\frac{\ell - \ell_0}{\sigma}\right)\right]$$

In the limit $\sigma \to 0$, $\mathcal{J}$ reduces to $\Theta(\ell - \ell_0)$ and the vortons accumulate around $\ell_0(N)$.

Cosmological distribution of vortons

- We solve a **continuity equation for the flow of loops in phase space**

$$\frac{\partial}{\partial t}\left(a^3 \frac{\partial^2 \mathcal{N}}{\partial \ell \partial N}\right) + \frac{\partial}{\partial \ell}\left(a^3 \frac{\mathrm{d}\ell}{\mathrm{d}t} \frac{\partial^2 \mathcal{N}}{\partial \ell \partial N}\right) = a^3 \mathcal{P}$$

- $\mathcal{P}$ is the loop production function
- In the present work, we assume there exist a scaling solution for $\mathcal{P}$ and loops are produced at a single scale[1]

$$\mathcal{P}(\ell, t) = C t^{-5} \delta\left(\frac{\ell}{t} - \alpha\right)$$

- We distinguish loops that originate from before the condensation and those produced by the infinite network after condensation

$\Rightarrow$ We find the distribution of loops with length ℓ and charge N : $\dfrac{\partial^2 \mathcal{N}}{\partial \ell \partial N}$

[1] Other choices are possible, like having a power-law $\mathcal{P} = C t^{-5} \left(\frac{\ell}{t}\right)^{2\chi - 3}$

Different populations of loops

- *Doomed loops*: they have an initial size too small to support a current, decay through gravitational radiation never becoming vortons

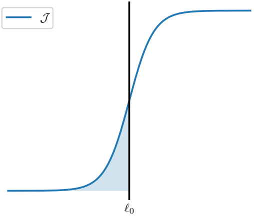
$$\left.\frac{\partial \mathcal{N}}{\partial \ell}\right|_{\mathrm{doomed}}(\ell, t) = \int \mathrm{d}N \, \frac{\partial^2 \mathcal{N}}{\partial \ell \partial N} \Theta(\mathcal{R} - N)$$

- *Proto-vortons*: they are initially large enough to be stabilised by a current. They have not yet reached the vorton size ℓ_0.

$$\left.\frac{\partial \mathcal{N}}{\partial \ell}\right|_{\mathrm{proto}}(t, N) = \int \mathrm{d}N \, \Theta(N - \mathcal{R}) \frac{\partial^2 \mathcal{N}}{\partial \ell \partial N} \Theta\left[\ell - \ell_0(N)\right]$$

- *Vortons*: all those proto-vortons which have decayed by gravitational radiation to become vortons.

$$\left.\frac{\partial \mathcal{N}}{\partial N}\right|_{\mathrm{vort}}(t, N) = \Theta(N - \mathcal{R}) \int \mathrm{d}\ell \, \frac{\partial^2 \mathcal{N}}{\partial \ell \partial N} \Theta\left[\ell_0(N) - \ell\right]$$

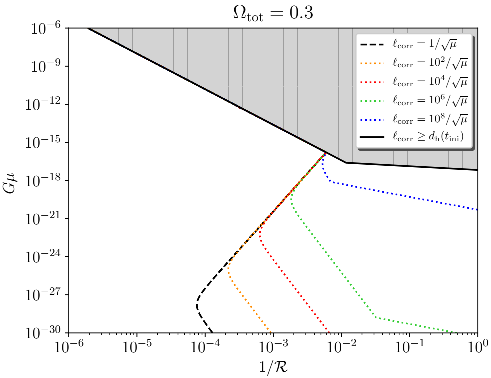


Relic abundance

- Fraction of energy contained in the stable vortons

$$\Omega_{\rm vort} = \frac{8\pi G}{3{\rm H_0}^2}\int {\rm d}\ell\,(\mu\ell)\frac{\partial\mathcal{N}}{\partial\ell}$$

- Over-production of vortons, $\Omega_{\rm vort} > 0.3$ is excluded
- There is a dependence on the initial correlation length at the formation of strings
  - $\ell_{\rm corr} \approx 1/\sqrt{\mu}$: *Vachaspati-Vilenkin* initial conditions, thermal process
  - $\ell_{\rm corr} \approx d_{\rm h}$: *Kibble's argument*, causality



Conclusion

In this paper we propose a phenomenological framework to calculate the number of vortons as a function of the string tension and the current carrier energy scale

- We estimate the cosmological distribution of vortons and estimate their relic abundance today
- We expect vortons to be massively present today even if no loops are created at the time of string formation
- This allows us to rule out new domains of this parameter space
- At the same time, given some conditions on the string current, vortons are shown to provide a viable and original dark matter candidate

Different populations of loops