Superconducting Strings

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Cosmic Strings

- Cosmic Strings may arise in theories with spontaneously broken symmetry
- the scalar field ϕ acquires a non-zero vacuum expectation value on a non-trivial manifold
- two possibilities to make the string superconducting
- fermionic currents occur when fermionic zero modes exist on the string
- currents can be induced when the string travels through a primordial, magnetic field

Bosonic Superconducting Strings

- if a second scalar field σ (electromagnetically charged) is condensed in the string core, it can carry a current along the string

$$
\begin{aligned}
L &= (D_\mu\phi)(D^\mu\phi)^* + (D_\mu\sigma)(D^\mu\sigma)^* - \frac{1}{4}F_{\mu\nu}F^{\mu\nu} \\
&\quad -\frac{1}{4}F'_{\mu\nu}F'^{\mu\nu} - V(\phi,\sigma) \qquad (1) \\
V &= \lambda_\phi(|\phi|^2 - \underbrace{\frac{m_\phi^2}{2\lambda_\phi}}_{v_\phi^2})^2 - m_\sigma^2|\sigma|^2 + \lambda_\sigma|\sigma|^4 + f|\sigma|^2|\phi|^2 \qquad (2)
\end{aligned}
$$

- the first term of the potential V is responsible for the string creation
- the others are needed for the superconducting condensate

Bosonic Superconducting Strings

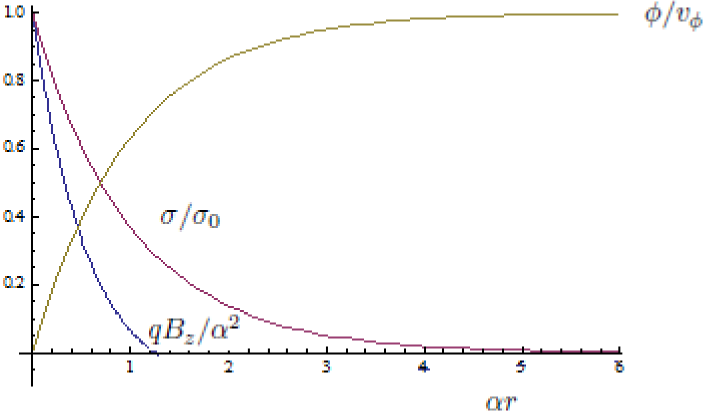

Figure: B_z, ϕ and σ for $\alpha = \beta = \kappa$.

$$\phi \quad = \quad v_\phi e^{i\theta}\left(1 - e^{-\alpha r}\right) \; ; \; \sigma = \sigma_0 e^{-\kappa r} e^{-i\rho}$$

Bosonic Superconducting Strings

- $\rho(z,t)$ is the massless Goldstone mode which carries the electromagnetic charge along the string ($J = dS/dA_\theta \propto \frac{d\rho}{ds}$)

$$\oint ds \frac{d\rho}{ds} = 2\pi N \rightarrow \frac{N}{R} = \frac{d\rho}{ds} \tag{3}$$

- this follows from the boundary conditions on ρ

$$J(z,t) = \frac{2q\sigma_0^2 A}{1 + Aq^2\sigma_0^2 \ln(\kappa R)/\pi} \frac{N}{R} \tag{4}$$

Vortons

- pressure force of the superconducting current stabilizes the vorton against the force caused by the tension

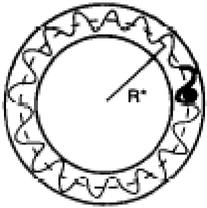

Figure: Vorton (circular, cosmic string) with stabilization radius R^*.

- stabilization radius is determined by extremizing the string energy with respect to R

$$E = 2\pi R T \approx 2\pi R T_0 + C\frac{N^2}{R} \; ; \; R^* = \sqrt{\frac{N^2 C}{2\pi T_0}} \qquad (5)$$

Vortons

- if one minimizes V with respect to σ and ϕ, one obtains two conditions ($fv_\phi^2 > m_\sigma^2$, $\frac{m_\phi^4}{\lambda_\phi} > \frac{m_\sigma^4}{\lambda_\sigma}$)
- by extremizing the action with respect to σ_0, κ and R, one gets an additional constraint on the allowed parameter space

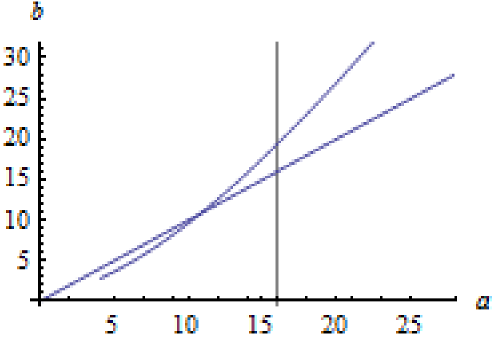

Figure: $b = \frac{fv_\phi^2}{\alpha^2}$. $a = \frac{m_\sigma^2}{\alpha^2}$. The triangle corresponds to the allowed region. The parameters are $\lambda_\sigma = 1$ and $q^2/(2\lambda_\phi) = 1$.

Vortons

- vortons can decay via tunnel effect

$$\tau \propto \exp\left[N \frac{{m'_\sigma}^3}{T_0^{3/2}}\right] \tag{6}$$

- large vortons (large N) are more stable
- decay becomes less probable for large mass outside the string (${m'_\sigma}^2 = f v_\phi^2 - m_\sigma^2$)
- for small couplings it follows $f v_\phi^2 \approx m_\sigma^2 \rightarrow$ small lifetime τ
- in principle vortons could be stabilized, so that they exist today

Bibliography

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