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Microscopic structure of cosmic strings

Phoenix - February 5, 2014

Outline

Old stuff… *trying to convince people…*

current-carrying strings

A controversy… *solved*

type II semi-local strings

B. Hartmann and PP, *Phys. Rev.* **D86**, 103516 (2012) [1204.1270]

SUSY GUT example: *SO(10)*

$$SO(10) \longrightarrow 4_C\, 2_L\, 2_R \begin{cases} \xrightarrow{1} 3_C\, 2_L\, 2_R\, 1_{B-L} \begin{cases} \xrightarrow{1} 3_C\, 2_L\, 1_R\, 1_{B-L} \xrightarrow{2} G_{SM}\, Z_2 \\ \xrightarrow{2} G_{SM}\, Z_2 \end{cases} \\ \xrightarrow{1} 4_C\, 2_L\, 1_R \begin{cases} \xrightarrow{1} 3_C\, 2_L\, 1_R\, 1_{B-L} \xrightarrow{2} G_{SM}\, Z_2 \\ \xrightarrow{2} G_{SM}\, Z_2 \end{cases} \\ \xrightarrow{1} 3_C\, 2_L\, 1_R\, 1_{B-L} \xrightarrow{2} G_{SM}\, Z_2 \\ \xrightarrow{1} \cancel{G_{SM}\, Z_2} \end{cases}$$

1: Monopoles **2**: Cosmic strings ↑INFLATION

SO(10) : 34 possible schemes

E_6 : 1024 …

Hybrid Inflation ...

+ SUSY breaking and R-parity

Many fields $\Longrightarrow$ **many** possible couplings

R. Jeannerot, J. Rocher & M. Sakellariadou, PR**D 68**, 104514 (2003)

Witten Superconducting String Model :

(E. Witten)

Bosonic carrier

$$\mathcal{L} = \mathcal{L}_{AH}(\Phi, B_\mu) - \frac{1}{2}(D_\mu\Sigma)^\star D^\mu\Sigma - \frac{1}{4}F_{\mu\nu}F^{\mu\nu} - V(\Phi,\Sigma)$$

e,A_μ

$$V(\Phi,\Sigma) = f(|\Phi|^2 - \eta^2)|\Sigma|^2 + \frac{m_\sigma^2}{2}|\Sigma|^2 + \frac{\lambda_\sigma}{4}|\Sigma|^4$$

Fermionic carrier

$$\mathcal{L} = \mathcal{L}_{AH}(\Phi, B_\mu) + \frac{i}{2}\left[\overline{\Psi}_R\gamma^\mu D_\mu\Psi_R + \overline{\Psi}_L\gamma^\mu D_\mu\Psi_L\right] - g\overline{\Psi}_L\Psi_R\Phi + \text{h.c.}$$

e,A_μ *and q*,B_μ

How Witten current-carrying condensate works (scalar case):

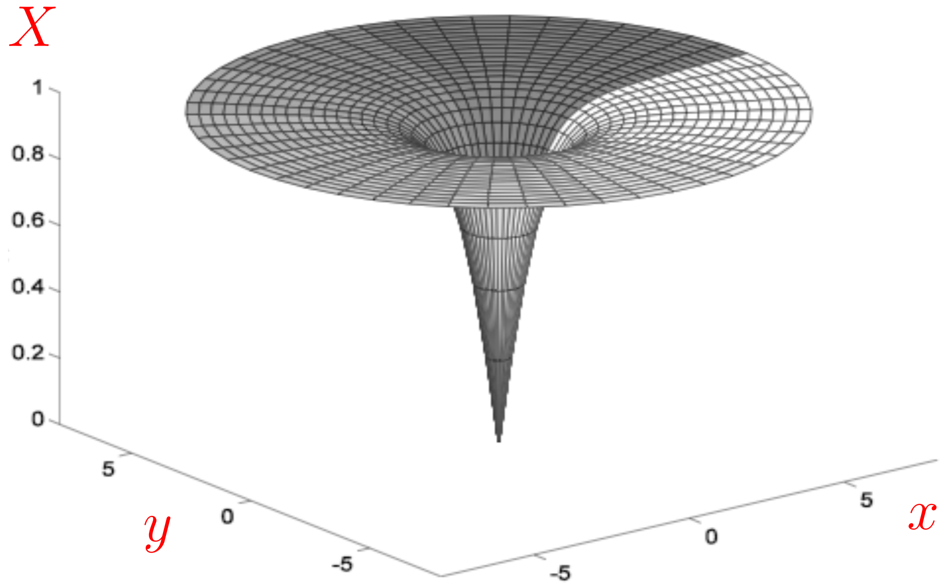
$$\mathcal{L} = -|D\Phi|^2 - V(\Phi) - |D\Sigma|^2 - V(\Phi,\Sigma) - \frac{1}{4}F_C^2 - \frac{1}{4}F_B^2$$

$\partial - iqC$

$\partial - ieB$

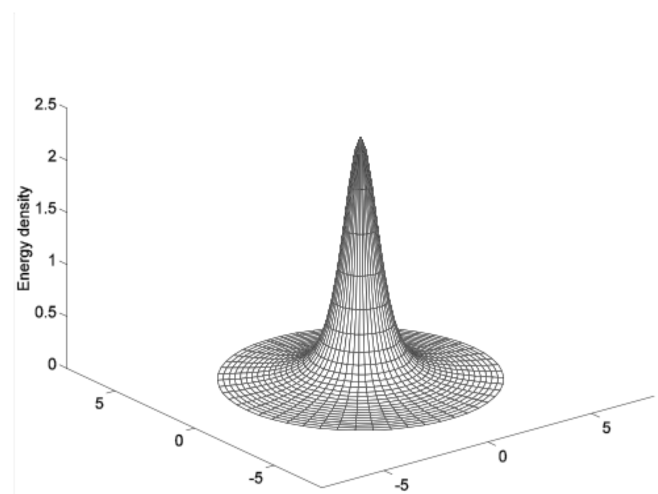
$$\frac{\lambda_\phi}{4}\left(|\Phi|^2 - \eta^2\right)^2$$

$$\frac{m_\sigma^2}{2}|\Sigma|^2 + \frac{\lambda_\sigma}{4}|\Sigma|^4 + f\left(|\Phi|^2 - \eta^2\right)|\Sigma|^2$$



Field structure

$$\Phi = \eta X(r)\mathrm{e}^{in\theta}$$

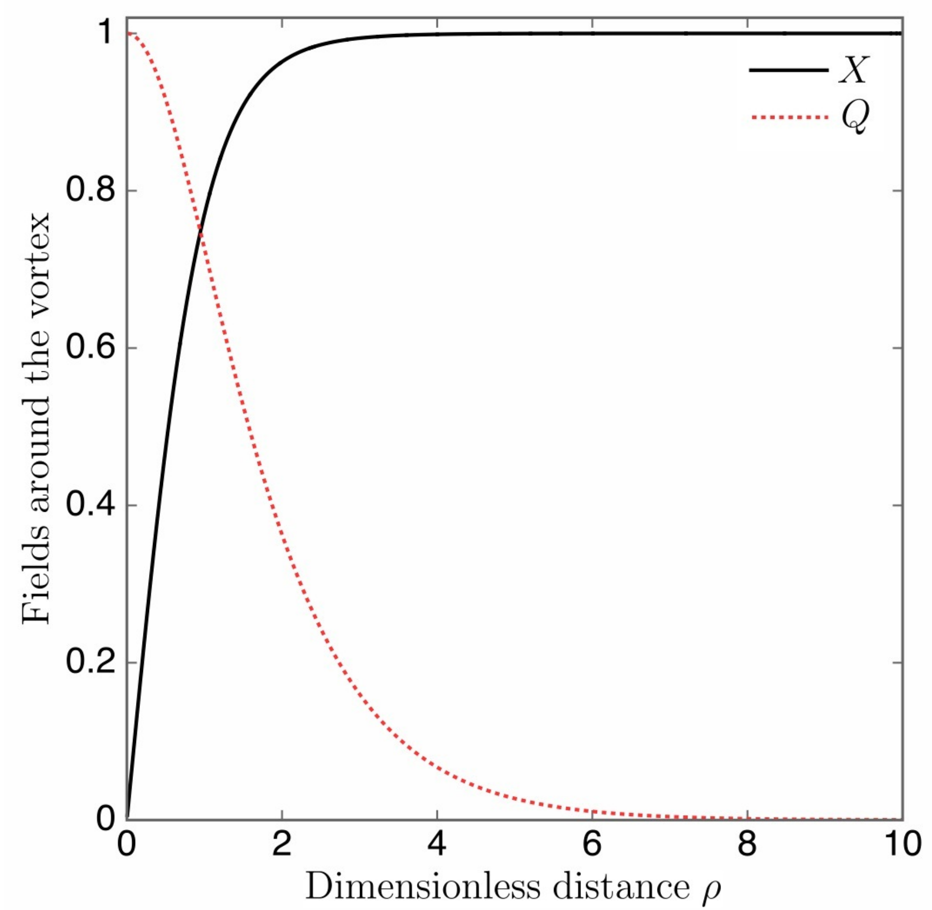


Field structure

$$\Phi = \eta X(r) \mathrm{e}^{in\theta}$$

$$Q = n + qC_\theta$$

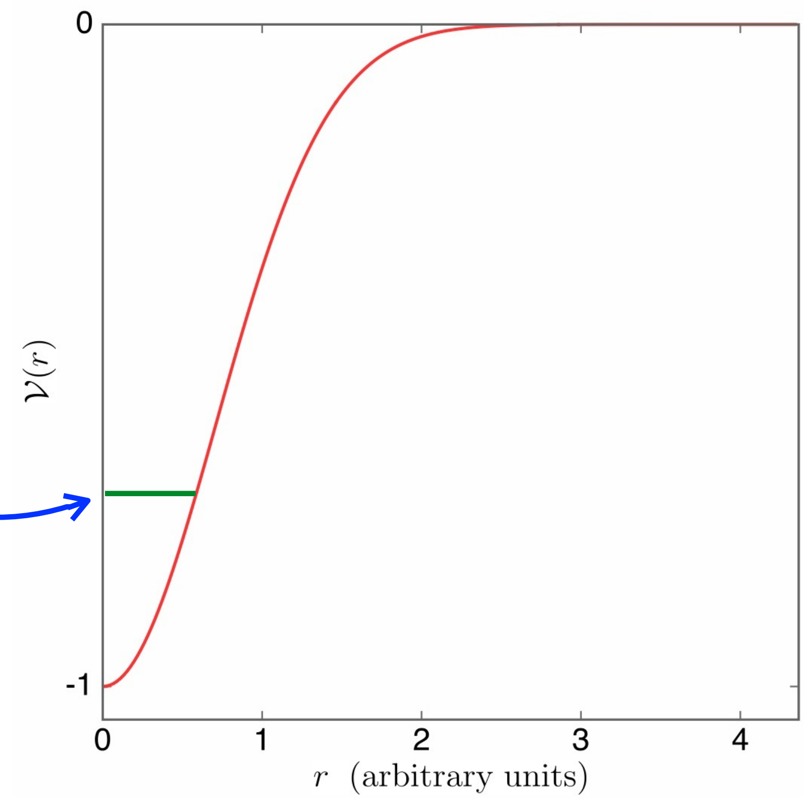
Background



Perturbations $\Sigma = \sigma(x,y)\mathrm{e}^{i\omega t}$

Schrödinger-like evolution $[-\Delta + \mathcal{V}(r)]\,\sigma = \omega^2\sigma$

bound state



$\exists\ \omega^2 < 0$

instability

$\Sigma \propto \mathrm{e}^{t/\tau}$

exponential growth tamed by non linear term

Vortex configuration

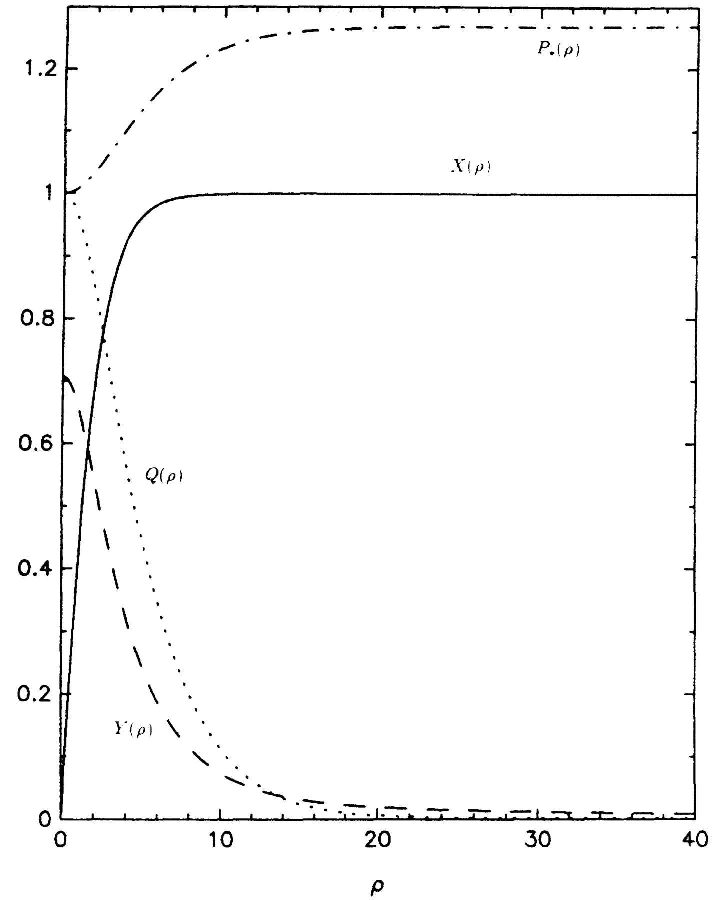
$$\Sigma\left(x^{\alpha}\right)=\sigma(r)\mathrm{e}^{i(\omega t-kz)}\equiv\sigma\left(x^{\perp}\right)\mathrm{e}^{i\psi(\xi^{a})}$$

$$P_t=\omega+eA_t$$

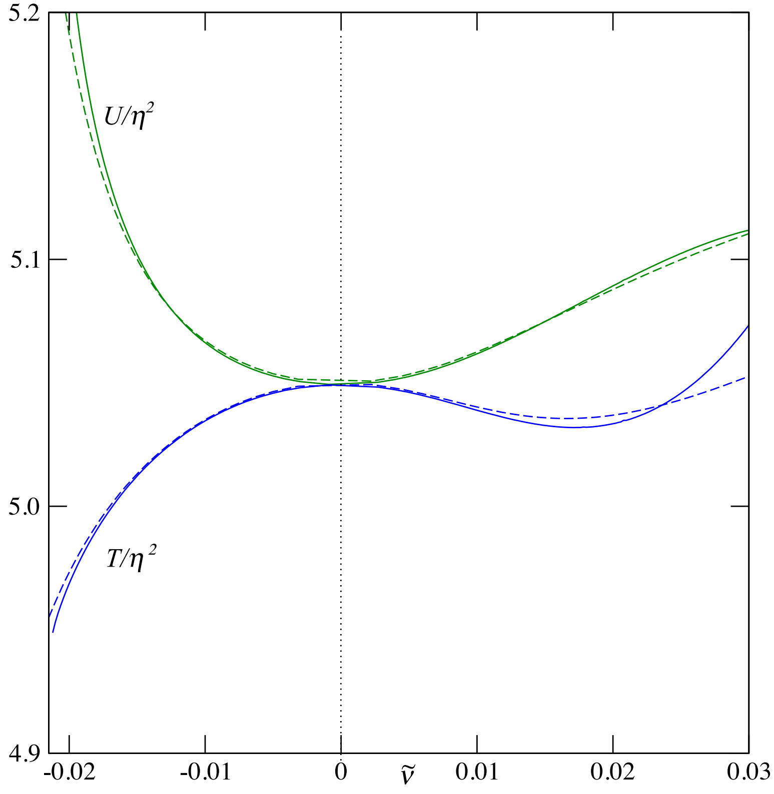
$$P_z=-k+eA_z$$

$$wP^2(r)=P_z^2-P_t^2$$

State Parameter



Equation of state (B. Carter)



$$T^{\mu\nu} = g^{\mu\nu}\mathcal{L} - 2\frac{\delta\mathcal{L}}{\delta g_{\mu\nu}}$$

Timelike u^μ and spacelike v^μ eigenvectors

$$\bar{T}^{\mu\nu} = \int \mathrm{d}^2x^\perp \, T^{\mu\nu} = U u^\mu u^\nu - T v^\mu v^\nu$$

Diagonalisation & Integration

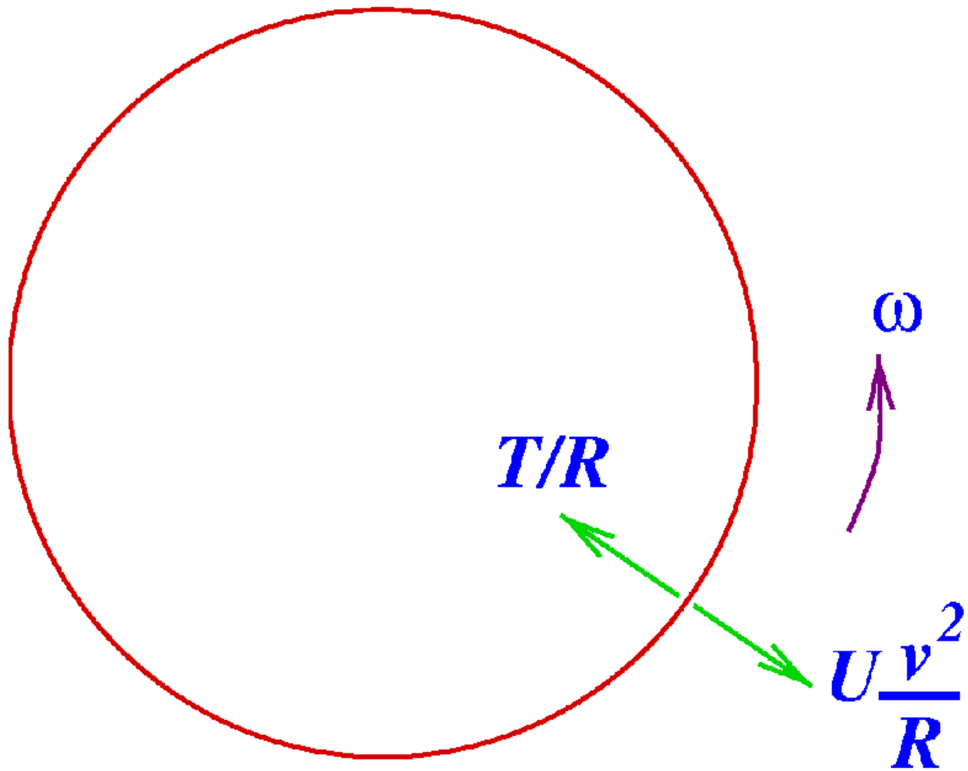
State parameter $w \equiv \gamma^{ab}\partial_a\psi\partial_b\psi$

Possible consequences

- Cusps… constraints
- currents can be electromagnetic: new effects (many already ruled out)
- $U - T \neq 0$ => gravitational pull, not only Kaiser-Stebbins
- Equation of state completely different: network dynamics?
  (most people say currents will not change the overall dynamics… argument?)

- Vortons?

Current ⇨ Stabilizing Force ⇨ VORTONS



➡ $v^2 = T/U$

$\Omega_{\text{vortons}} \gg 1$

R. Davis and P. Shellard (1989),
B. Carter (1995)…

Type II semi-local vortices?

U(1) embedded in a SU(2)

(Ana's talk)

$$\mathcal{L} = -g^{\mu\nu}(D_\mu \mathbf{\Phi})^\dagger \cdot D_\nu \mathbf{\Phi} - \frac{1}{4} F_{\mu\nu} F^{\mu\nu} - V(\mathbf{\Phi})$$

$$V(\mathbf{\Phi}) = \frac{\lambda}{2}\left(\mathbf{\Phi}^\dagger \cdot \mathbf{\Phi} - \eta^2\right)^2$$

Background

$$\mathbf{\Phi}_{\mathrm{bckd}} = \begin{bmatrix} \varphi(r)\mathrm{e}^{in\theta} \\ 0 \end{bmatrix}$$

Field equations

$$\frac{\mathrm{d}^2\varphi}{\mathrm{d}r^2} + \frac{1}{r}\frac{\mathrm{d}\varphi}{\mathrm{d}r} = \left[\frac{Q^2}{r^2} + \lambda\left(\varphi^2 - \eta^2\right)\right]\varphi$$

$$\frac{\mathrm{d}^2 Q}{\mathrm{d}r^2} - \frac{1}{r}\frac{\mathrm{d}Q}{\mathrm{d}r} = 2e^2\varphi^2 Q$$

One dimensionless parameter $\beta = \dfrac{m_\varphi^2}{m_C^2}$

$$m_\varphi = \sqrt{2\lambda}\eta$$

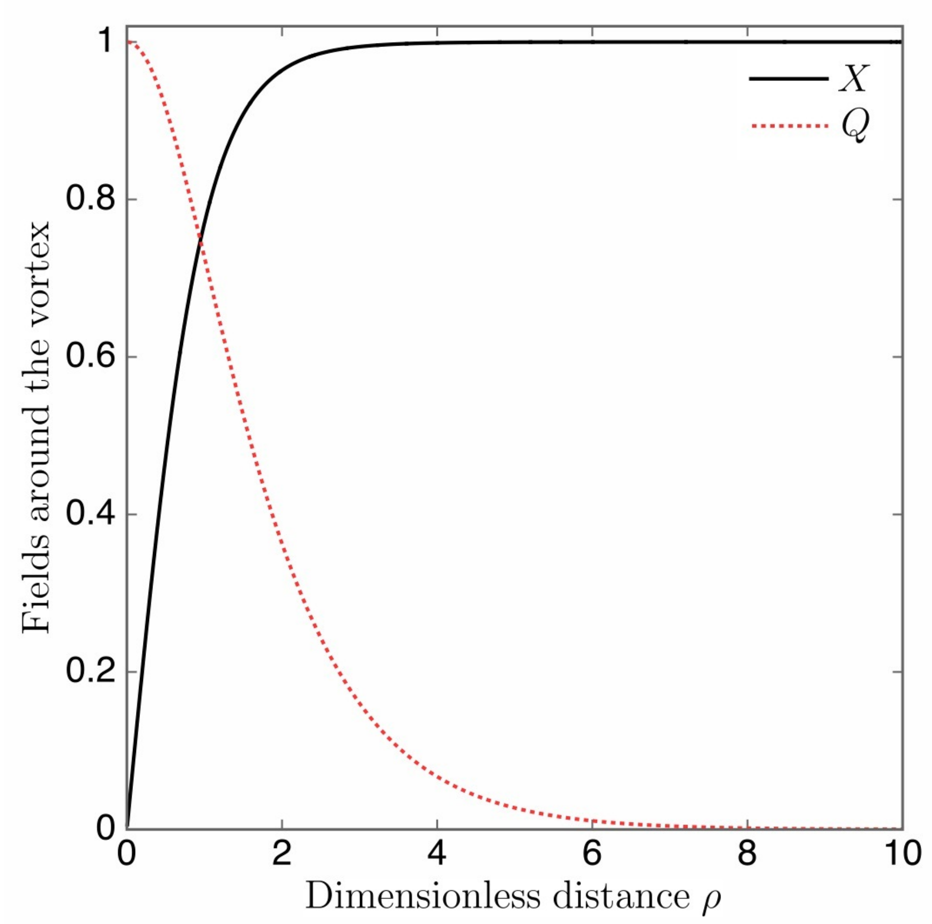
$$m_C = \sqrt{2}e\eta$$

Field structure

$$\varphi = \eta X(r)$$

$$Q = n + qC_\theta$$

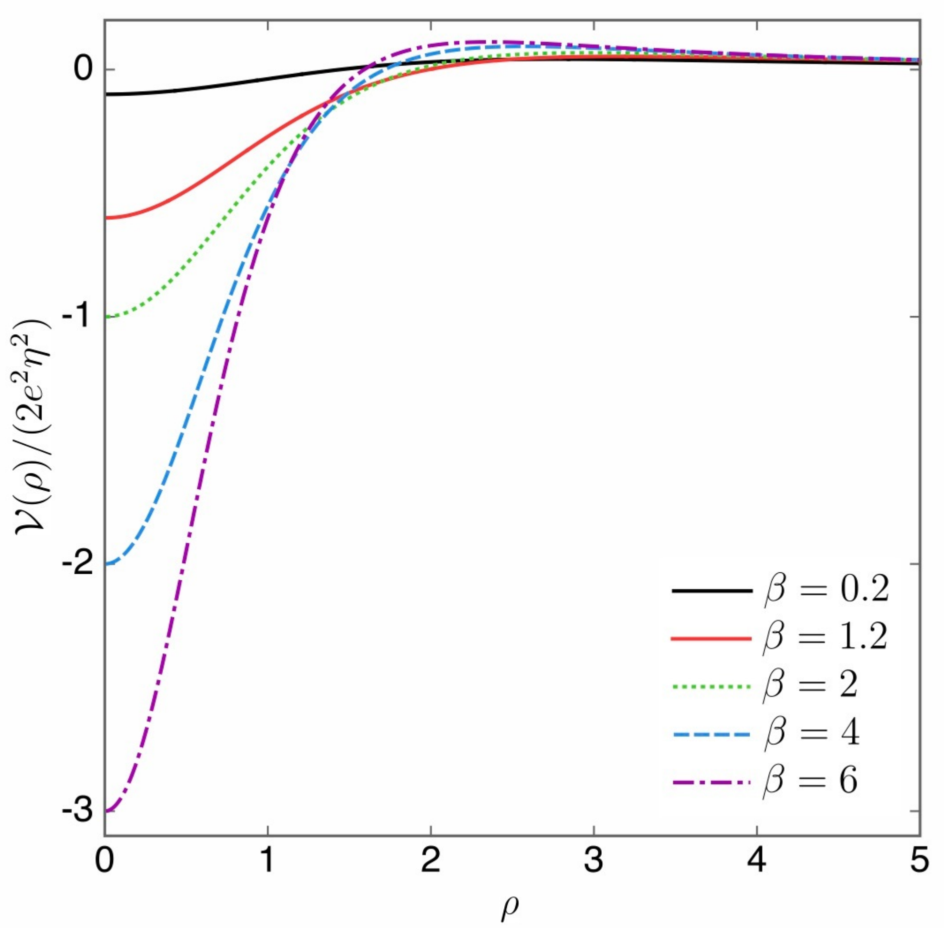
Background



Perturbation $\delta\boldsymbol{\Phi} = \begin{pmatrix} 0 \\ \sigma \mathrm{e}^{i\omega t} \end{pmatrix},$

Schrödinger like equation $-\Delta_2\sigma + \mathcal{V}(r)\sigma = \omega^2\sigma,$

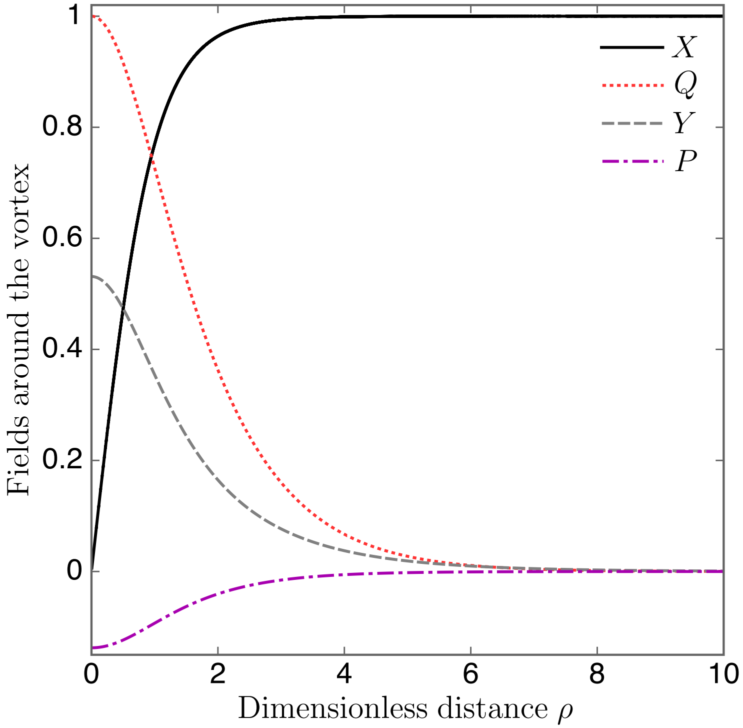
Unstable modes => condensates à la Witten...

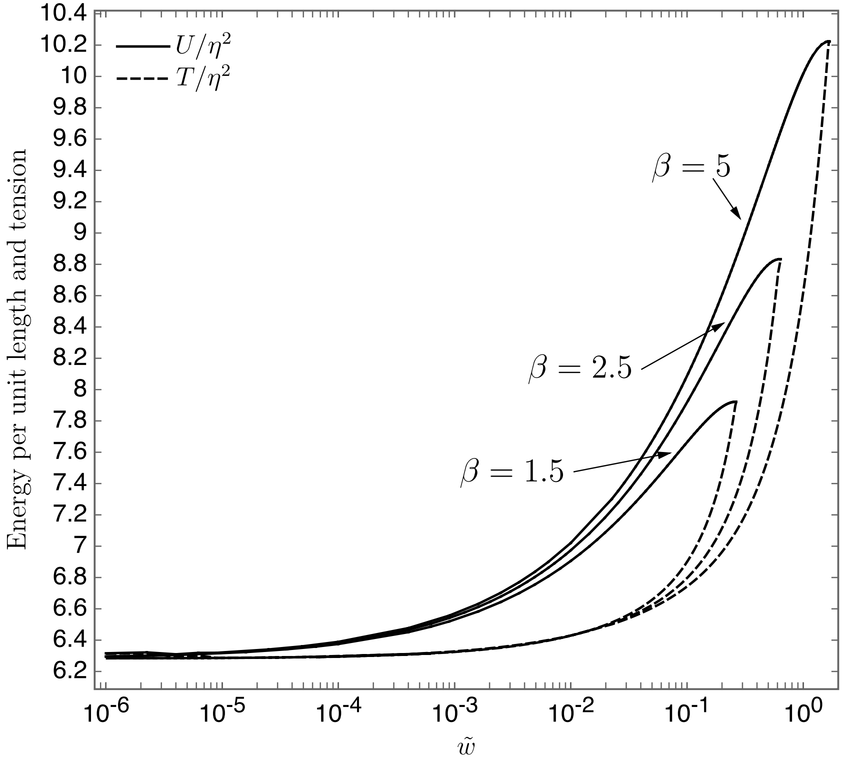


$$\boldsymbol{\Phi} = \begin{bmatrix} \varphi(r)\mathrm{e}^{in\theta + i\psi(z,t)} \\ \sigma(r)\mathrm{e}^{im\theta + i\xi(z,t)} \end{bmatrix},$$

Type I ($\beta < 1$) strings are stable (no bound state solution)

Type II ($\beta > 1$) strings are unstable ($\exists$ bound state solution)





$$c_{\rm L}^2 \equiv -\frac{\mathrm{d}T}{\mathrm{d}U} \leq 0$$ Unstable vis-à-vis longitudinal (sound like) perturbations

Conclusions

Semi-local string polemics settled…

B. Hartmann and PP, *Phys. Rev.* **D86**, 103516 (2012) [1204.1270]

Evaluating the cosmological consequences of currents

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Thank you for your attention!