Domain Walls as Dark Energy

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(see also astro-ph/0205520)

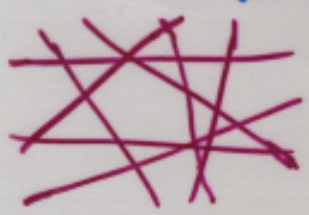
Motivation

- Domain Walls are ubiquitous in beyond-the-SM particle physics models:

discrete symmetries ↘ isolated, degenerate vacua ↗ SUSY ⇒ stable domain walls!

- Networks of static domain walls have a strongly negative effective equation of state.

Toy Model: a "gas" of infinite, planar, static, non-interacting walls



$$T^{\mu}{}_{\nu}(\text{wall}) = \sigma \times \delta(z) \times \text{diag}(1, 1, 1, 0)$$

- Define interwall separation: $L = \lim_{V\to\infty} 3V/A$
- At scales $\gg L$:

$$\langle T^{\mu}{}_{\nu} \rangle = \frac{3\sigma}{L} \times \text{diag}\left(1, \tfrac{2}{3}, \tfrac{2}{3}, \tfrac{2}{3}\right)$$

$$\Rightarrow \quad w = -2/3^{*}$$

*- NB Bean & Melchiorri, astro-ph/0110472 disfavor $w=-2/3$ at 95% c.l.

Constraints

- Parameters: tension σ, interwall separation L

  ($L \Leftrightarrow$ # of walls per Hubble volume, $N = 3LH$)

- One combination is fixed by data:

$$\frac{3\sigma}{L} = \rho_w = 0.7\,\rho_{c,0}\,.$$

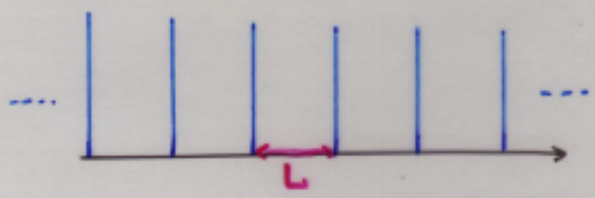
  $\Rightarrow$ effectively 1 parameter

- Assume no direct interactions between the walls and the SM particles ($\gamma, q, \ell, \ldots$) $\Rightarrow$ walls only manifest themselves through gravity.

- A wall network is inhomogeneous and (generally) anisotropic $\Rightarrow$ it will contribute to the CMBR anisotropy! (cf Zel'dovich et al, 1974)

- Small anisotropy $\Leftrightarrow$ large N, small L, small σ

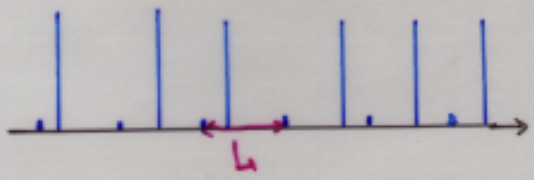
• Case 1: a PERFECTLY REGULAR wall structure, $L \ll R$



$$\Delta\Phi \sim G_N \sigma L$$

$N \gtrsim 200, \quad U \lesssim 3$ MeV

• Case 2: a SLIGHTLY IRREGULAR wall structure

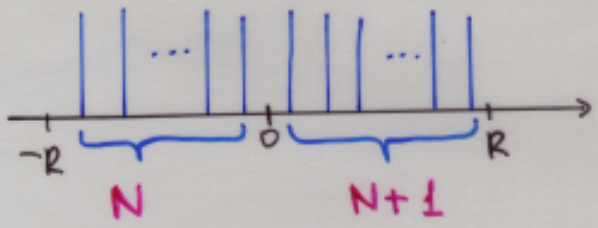


$$|\Delta x_i| \sim L/2$$

$$\Delta\Phi \sim G_N \sigma (LR)^{1/2}$$

$N \gtrsim 10^3, \quad U \lesssim 1$ MeV

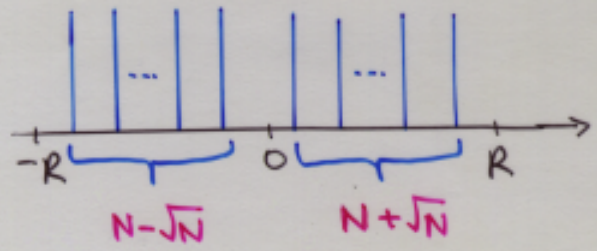
• Case 3: a MISSING WALL



$$\Delta\Phi \sim G_N \sigma R \sim G_N \sigma N L$$

$N \gtrsim 3 \times 10^9, \quad U \lesssim 500$ keV

• Case 4: RANDOM WALLS



$$\Delta\Phi \sim G_N \sigma L N^{3/2}$$

$$\sim G_N \sigma R^{3/2} L^{-1/2}$$

$N \gtrsim 10^9, \quad U \lesssim 15$ keV

Energy Scales

- CMB bounds require $v \lesssim 10$ keV - 1 MeV

  (vs. e.g. $m \sim 10^{-33}$ eV for quintessence models!)

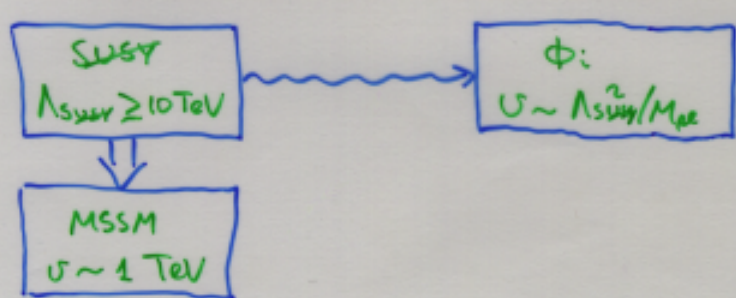
- This can be easily and naturally achieved in

  "hidden sector" models

Assumptions:

- Walls made out of scalar fields ϕ_i
- Underlying theory is supersymmetric
- Fields ϕ_i are massless in the limit of exact SUSY ("moduli")
- Interactions between ϕ_i and SUSY-breaking sector are

  Planck-suppressed (i.e., gravitational)

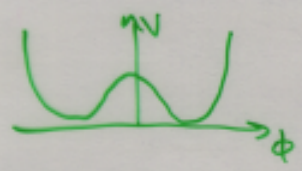


- To satisfy CMB bounds, take $\Lambda_{SUSY} \lesssim 10^7 - 10^8$ GeV

$\Rightarrow$ models with only natural, radiatively stable parameters!

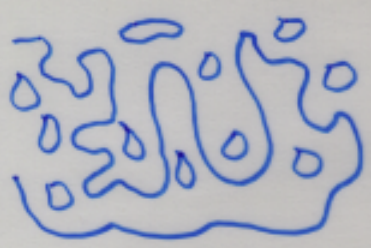
Realistic Networks

① Scaling Networks : e.g. consider a "Z_2 model"



$$V(\phi) = \lambda(\phi^2 - v^2)^2$$

- Walls form at $T \sim v$ by Kibble mechanism
- Immediately after the phase transition:



1 infinite wall

+ bubbles of size $\Delta \sim r_H(T)$

- After a few Hubble times: 1 wall per Hubble volume

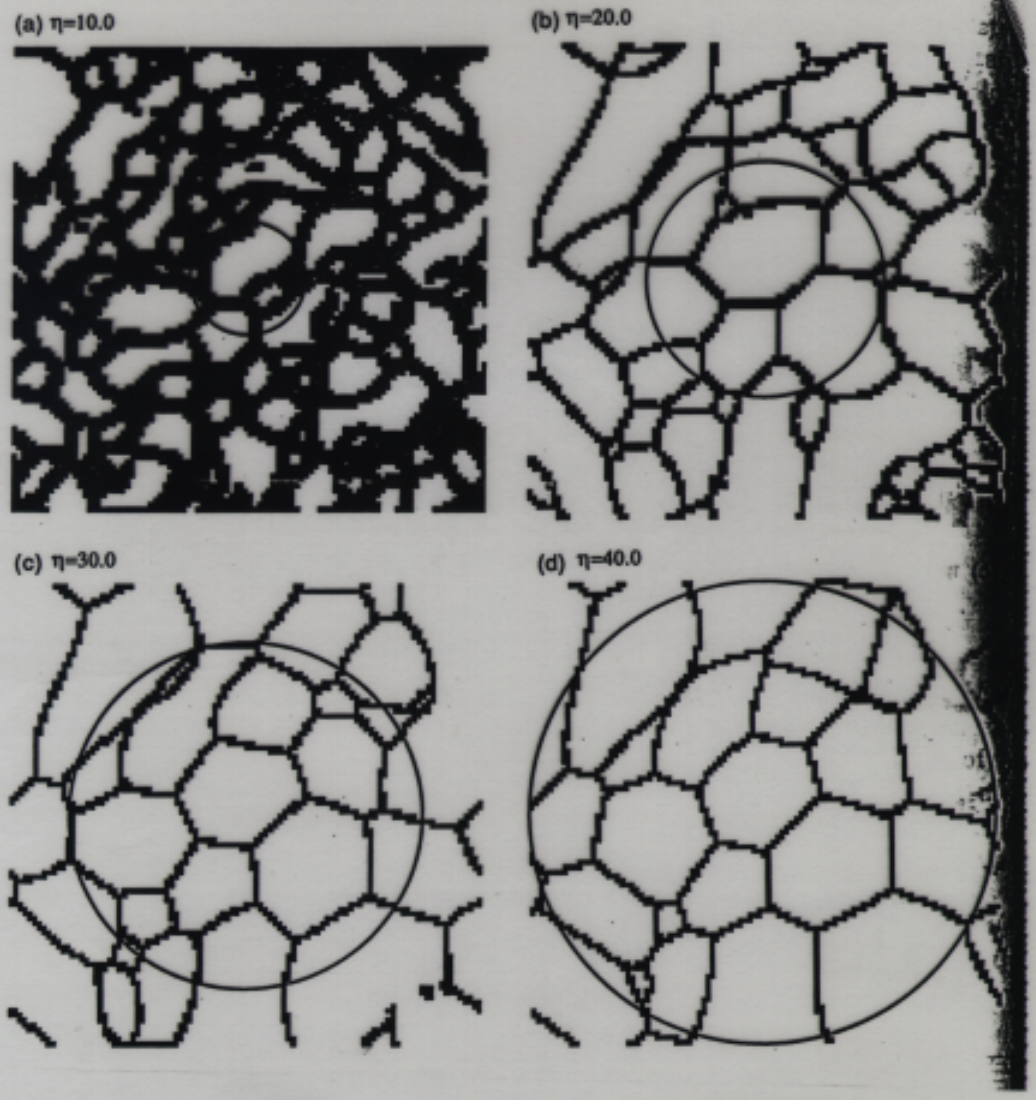
@ any given time ("scaling regime")

⇒ GROSS CONTRADICTION with large-scale isotropy!

- Unfortunately, all simple models lead to scaling networks...

② Frustrated Networks :

more vacua ⇒ hard to re-adjust, may be "stuck" in a metastable state!



Kubotani, '92

Conclusions

- Domain-wall models of dark energy are attractive from particle physics point of view
- Unfortunately, simple scalar field theory models lead to unacceptable (scaling) wall networks
- Frustrated networks may exist but more numerical simulations are needed to find them!!!
- Domain wall dark energy models make a testable prediction: $w \geq -2/3$! + observable CMBR anisotropies may be produced.