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Cosmic (Super)strings

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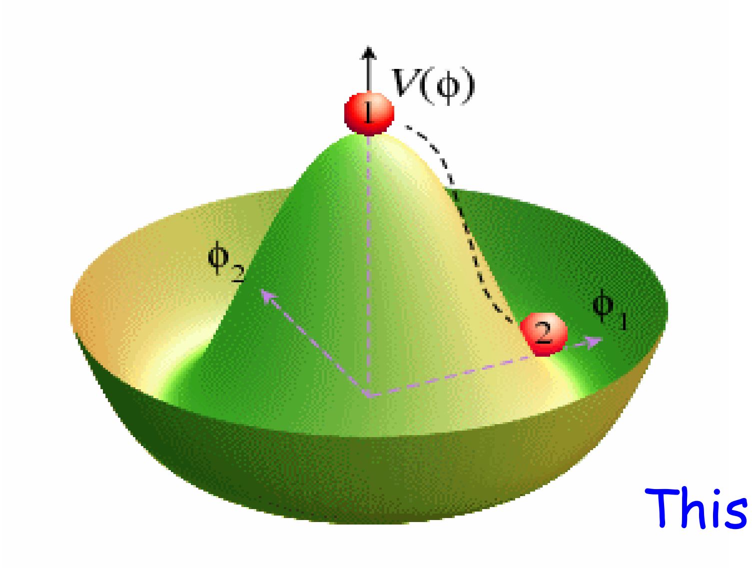
Outline

- Formation of Cosmic Strings
- Cosmic strings in the early universe
  - evolution
  - network properties
  - cosmological consequences
- Cosmic superstrings
  - production
  - observability conditions and distinctive features
- Stability of cosmic strings Y-junctions

Production of cosmic strings

- They arise in GUTs

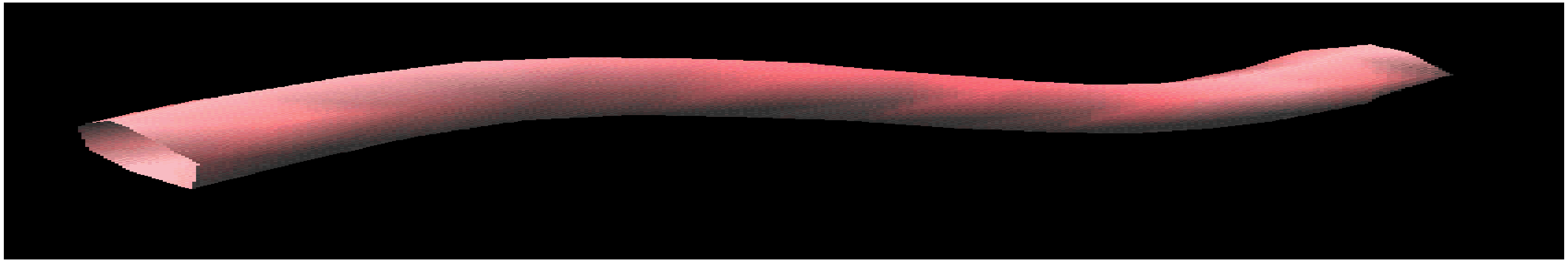
- 1D defects following U(1) symmetry breaking



• As the temperature falls, energy not more sufficient to permit all fluctuations

• The field has to choose one ground state

This process leaves behind linear defects (cosmic strings)



Cosmic strings in the early universe : Evolution

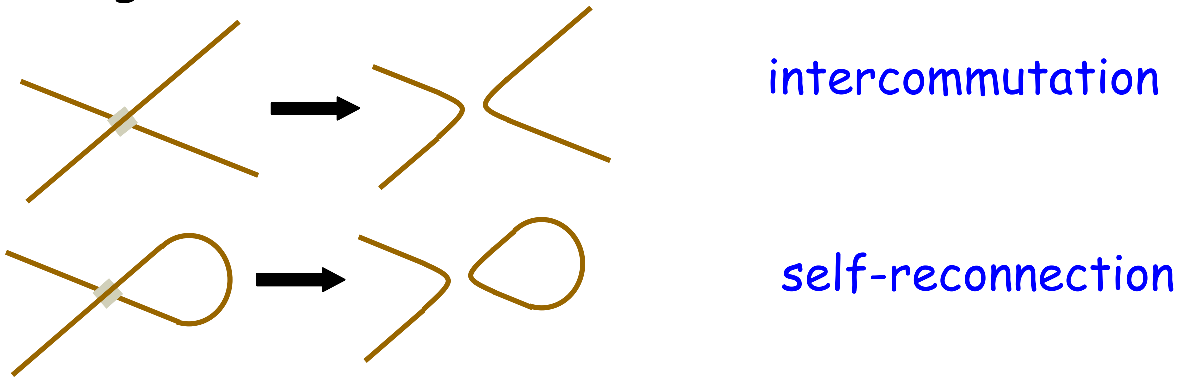
- Effectively 1D, so can be modelled using Nambu-Goto action

$$S = -\mu \int dt d\sigma \sqrt{(1-\dot{\mathbf{x}}^2)\mathbf{x}'^2}$$

- Eom is the wave equation

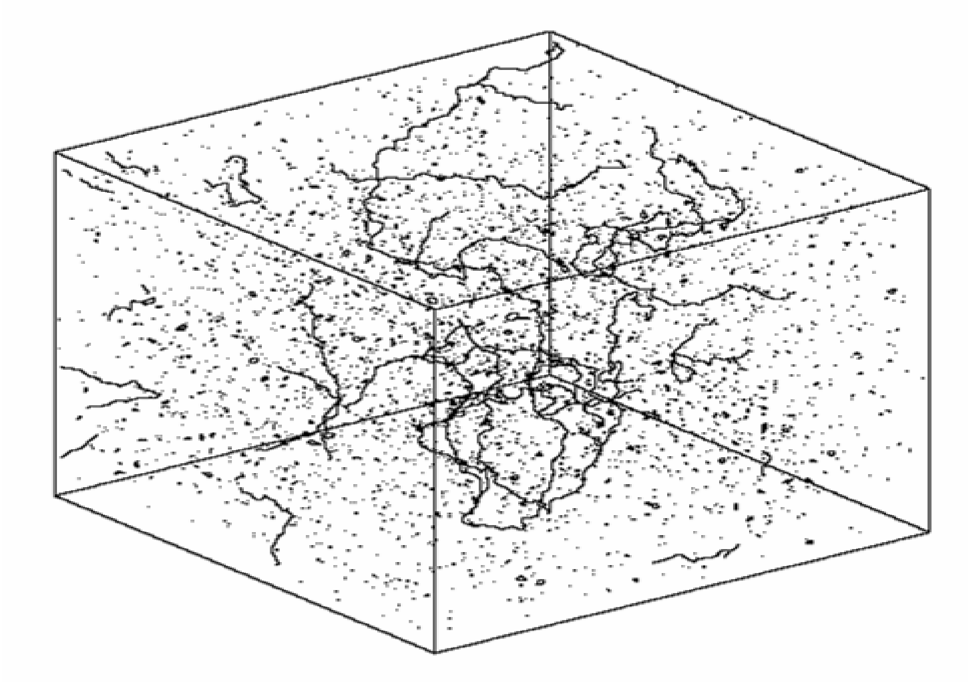
$$\ddot{\mathbf{x}} - \mathbf{x}'' = 0$$

- Long string intercommutation & loop production
- Intercommutation probability essentially 1 (they never pass through one another)



Evolution of a network of cosmic strings

(e.g.Allen & Shellard,Bennett & Bouchet)



start with a network of long strings + loops and let it evolve

- Loops decay emitting gravitational radiation
- Long strings can survive
- Scaling solution ⟶ $\rho_s/\rho_m = 60G\mu$

Cosmic strings in the early universe : Cosmological effects

- Very thin (effectively 1D), very massive
- Tension (mass per unit length) $\mu = 10^{21} kg/m$

$G\mu = 10^{-7}$ $\longrightarrow$ characterises the gravitational effects

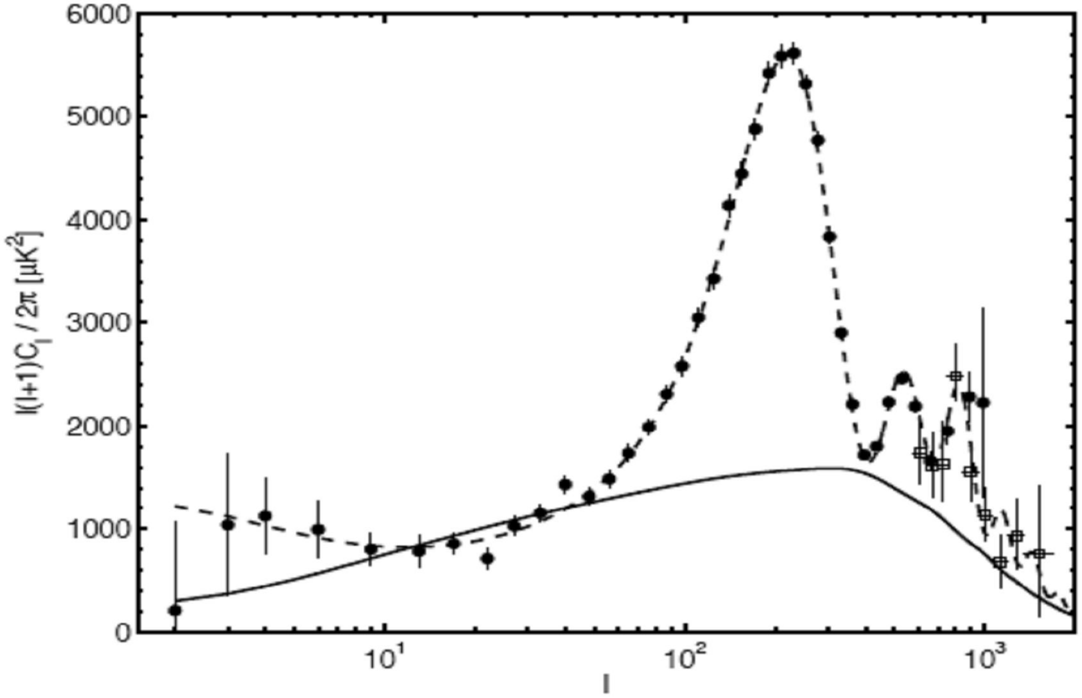
- In the early universe, they would produce density perturbations

$$\frac{\delta\rho}{\rho} = G\mu = 10^{-7}$$

- Maybe an alternative to inflation?

<u>No:</u> confrontation with data showed that they produce the wrong power spectrum

CMB power spectrum and Cosmic Strings



- Strings unable to produce the acoustic peaks
- Supporting role ~10% still possible $G\mu < 10^{-6}$

(e.g. Pogosian et al, Bevis et al)

The revival of cosmic strings through superstring theory

- Witten (1985) first considered the possibility of cosmic superstrings

Problems

- energy scale too high (Planck scale), inhomogeneities too large
- produced before inflation - diluted
- unstable

Conditions for Cosmic Superstrings

(Dvali and Vilenkin, Copeland, Myers and Polchinski)

- production after inflation, not too massive
- cosmological stability
- observability & distinctive features

The revival of cosmic strings through superstring theory

- Fundamental strings originally very different from cosmic:
  - energy scale much higher (Planck scale)
  - this means $G\mu \geq 10^{-3}$

- But, things can change radically when we consider compactification
- The braneworld scenario introduces the idea of warped spacetime

$$ds^2 = e^{-A(y)}(dt^2 - d\mathbf{x}^2) - dy^2$$

- Consequently, the effective tension can be

$$\mu_{eff} = e^{-A(y)}\mu_0$$

<u>Thus tension sufficiently lower!</u>

Brane Inflation

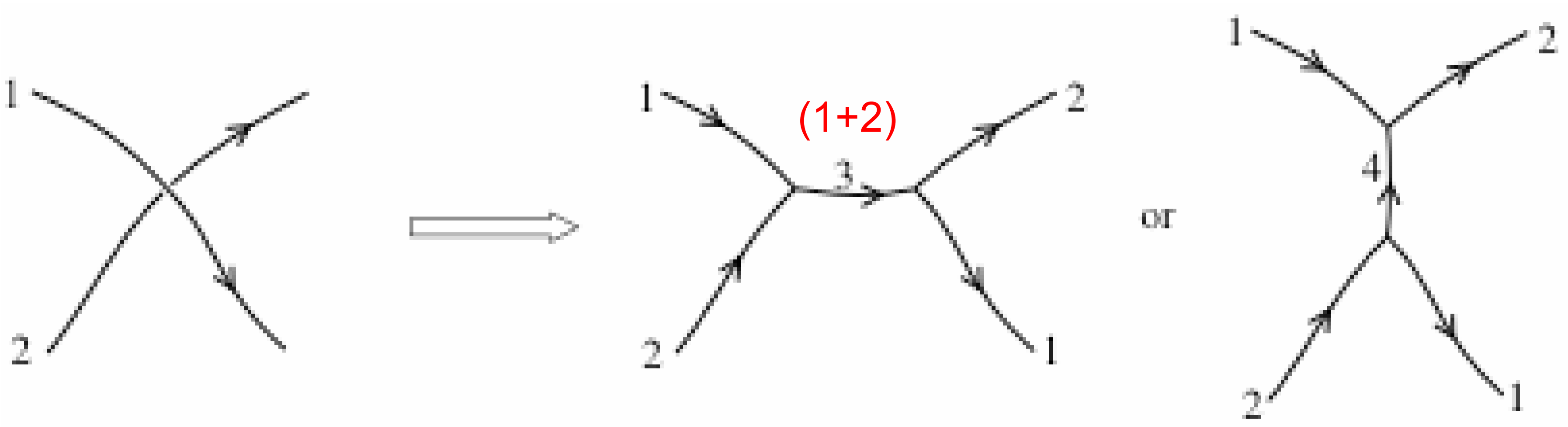
(Burgess et al ; Jones, Sarangi & Tye ; Stoica & Tye)

- D-strings are formed in brane – antibrane annihilation
- Fortunately, no monopoles or domain walls (these would be cosmologically disastrous)
- In addition, F-strings can also be formed
- The energy scale of the formed strings is now

$$10^{-12} < G\mu < 10^{-6}$$

Interesting new possibility: (p,q) string networks

- Two strings of different type cross
- Cannot always intercommute (not like gauge strings!)
- Produce pair of trilinear vertices connected by segment of string



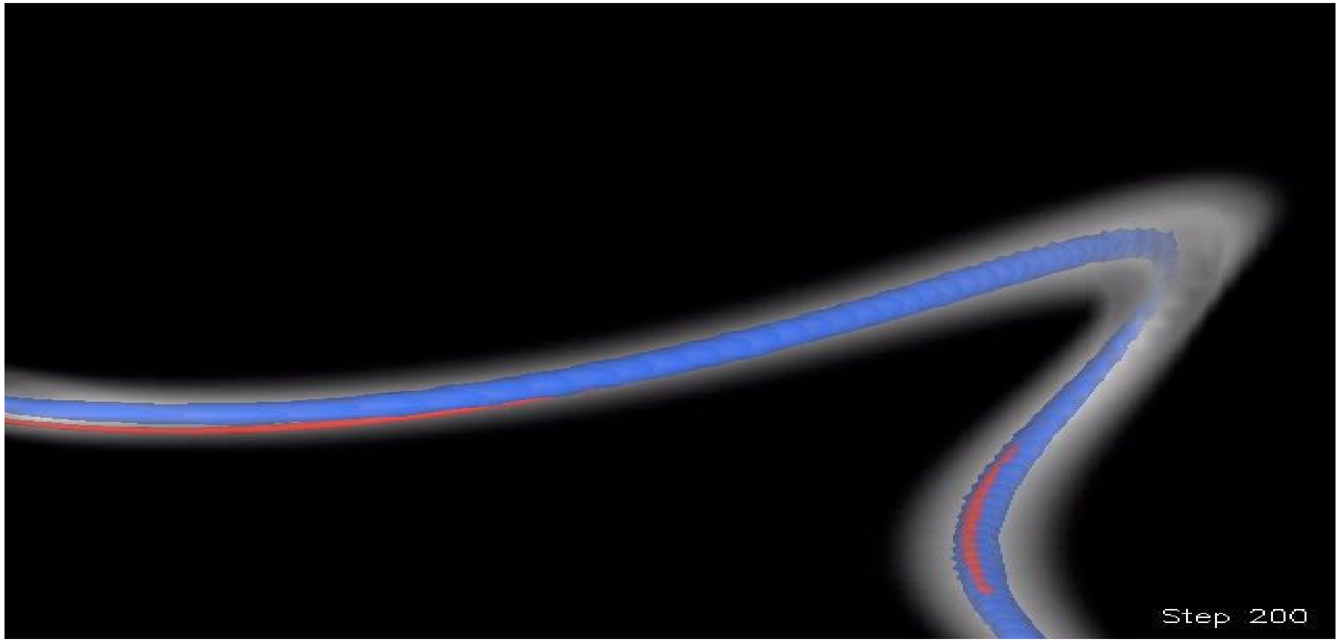
This is a new and very distinctive feature!

Observational signatures

Gravitational radiation

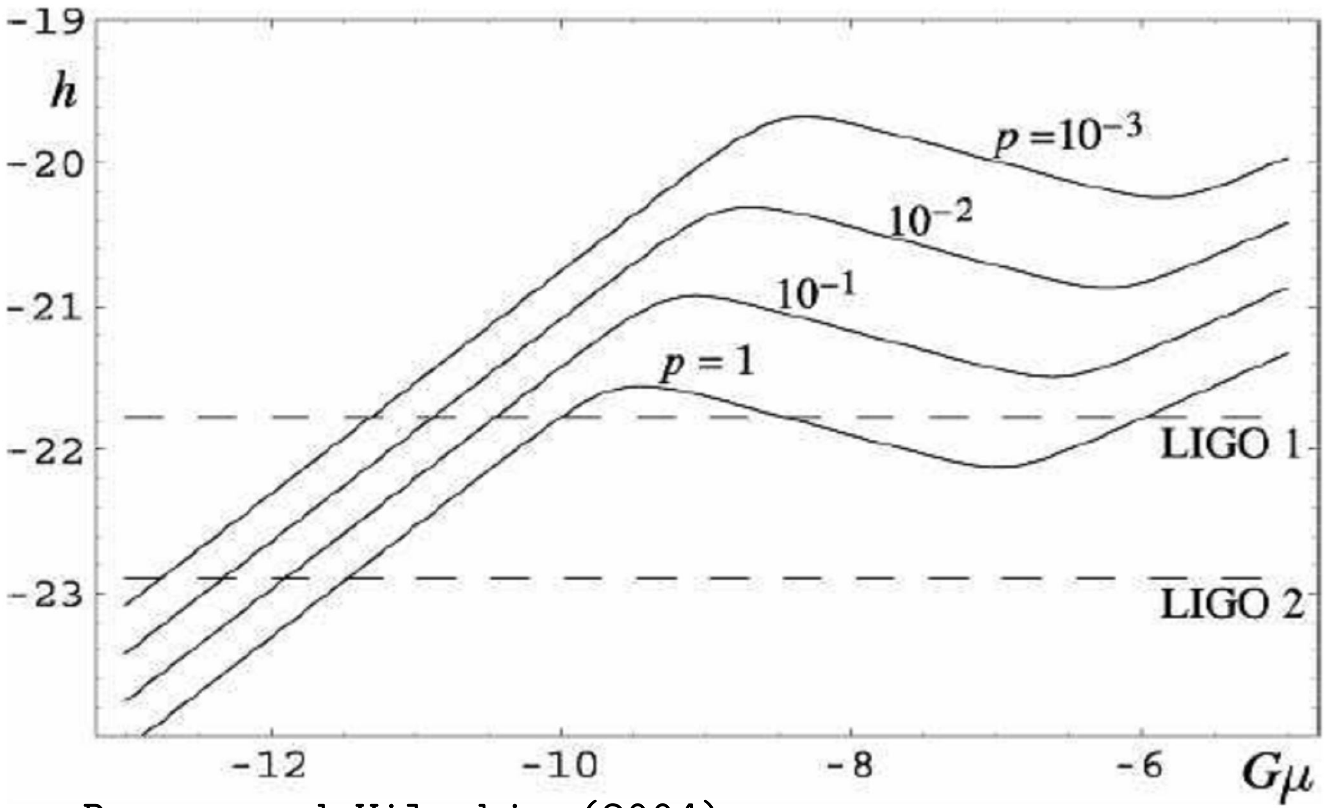
- -strong signal from cusps $|\dot{\mathbf{x}}| = 1$
- -also signal from kinks
- -could be detected by LIGO, LISA

(Blanco-Pillado)



GW emission from cusps (and kinks)

- If 10% of the loops are cuspy, gravitational wave bursts could be detected by LIGO and LISA



Damour and Vilenkin (2004)

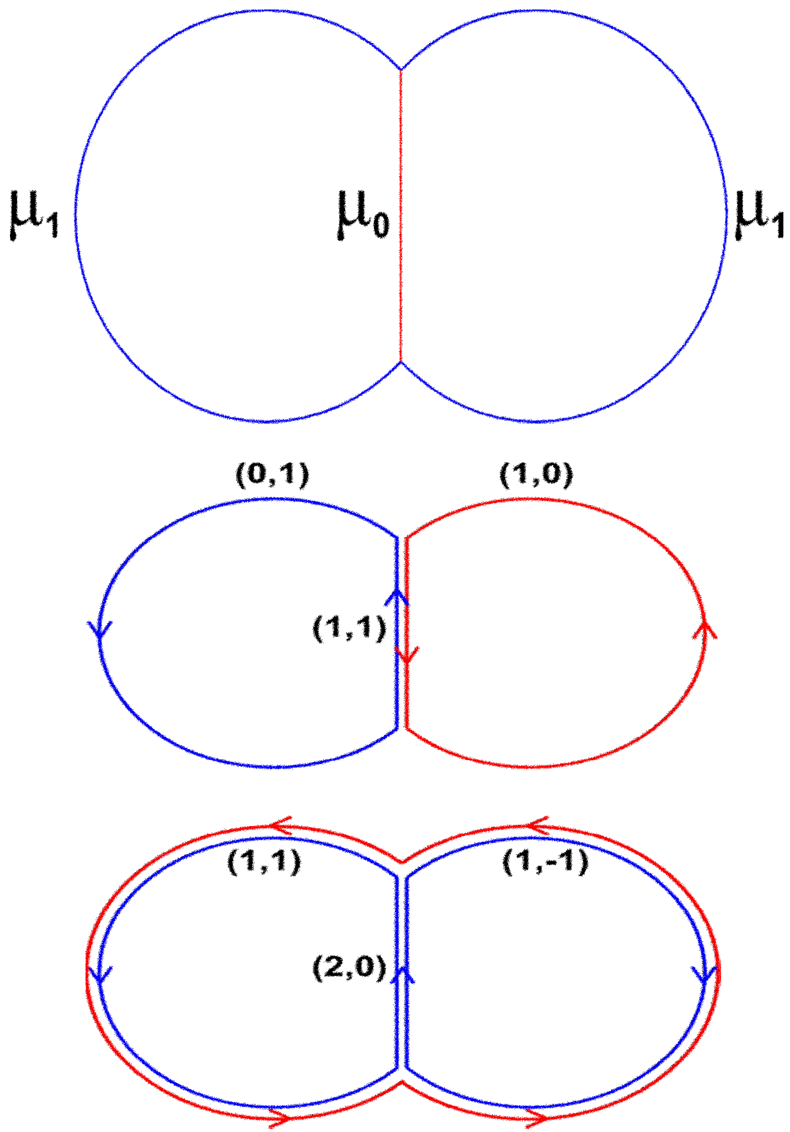
Summary and Conclusions

- Cosmic strings arise almost everywhere, from GUTs to string theory models
- Cosmic superstrings can be formed at the end of inflation, be stable and have sufficiently low tension
- Good possibility of detection through (mainly) gravitational radiation
- A window to string theory through cosmology !

On the stability of cosmic strings Y-junctions

(hep-th/0904.2127)

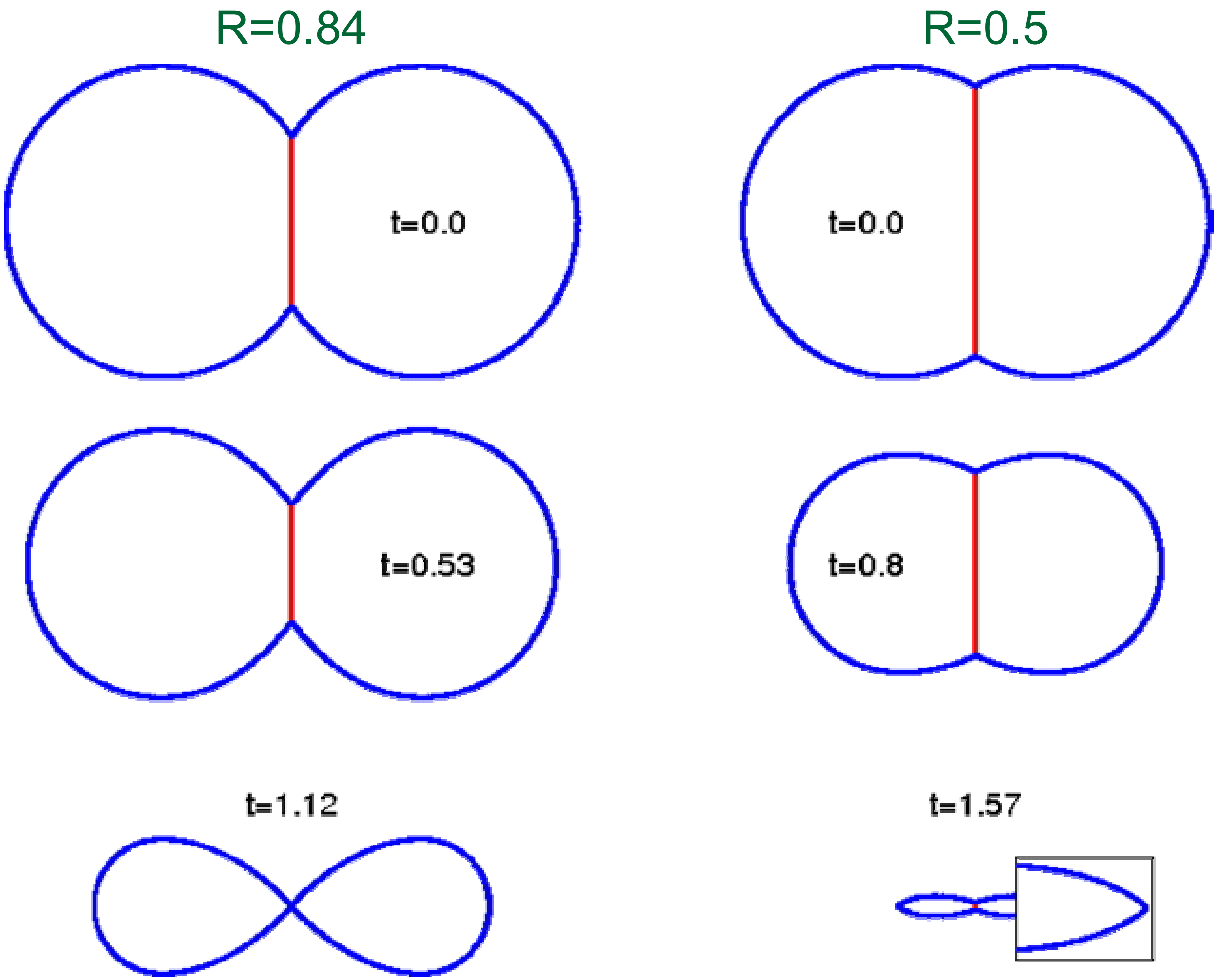
- First modelled by Copeland, Kibble and Steer using Nambu-Goto action + junction conditions
- Field theory simulations from Bevis and Saffin using a U(1)XU(1) model
- Detailed comparison of Nambu-Goto and field theory approach using the butterfly configuration



(N. Bevis, E. Copeland, P.Y. Martin, G. Niz, AP, P. Saffin, D. Steer)

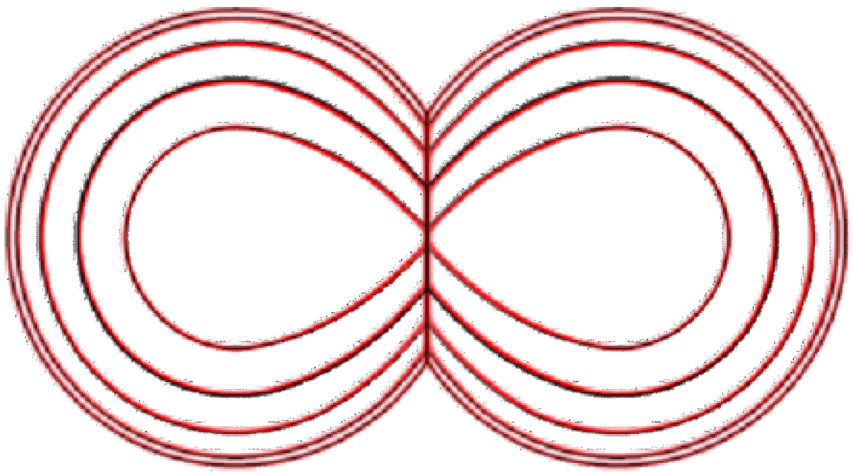
Nambu-Goto simulations: Results

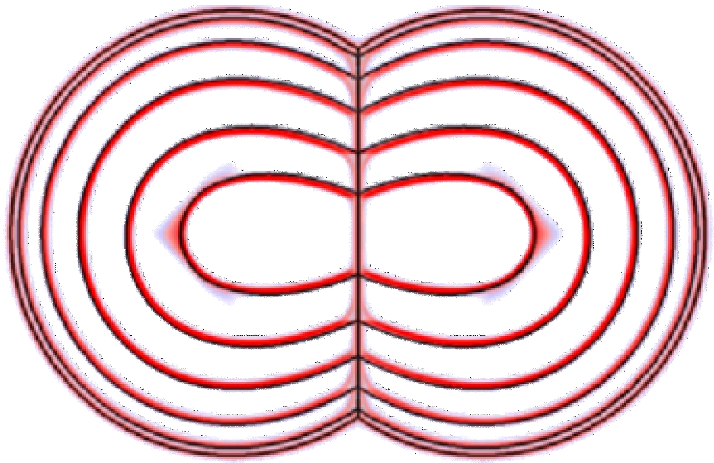
- Evolution depends on the ratio $R = \frac{\mu_0}{2\mu_1}$



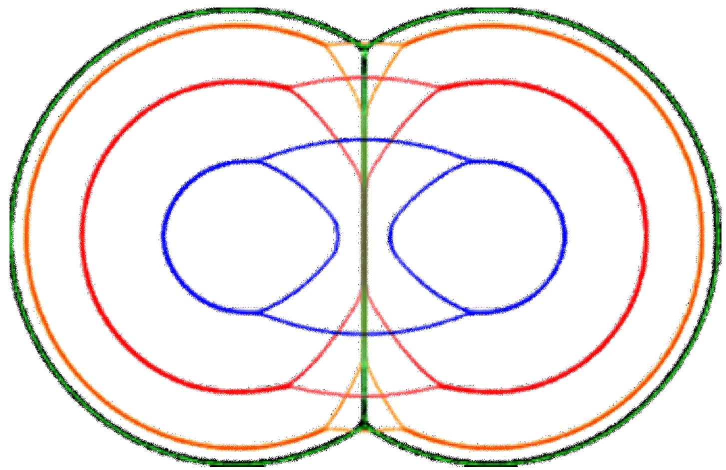
NG and field theory: Comparison

- compare for (1,0) + (0,1) ⟶ (1,1)





-now compare for (1,1) + (1,-1) ⟶ (2,0)



Unstable Junction!

Conclusions

- Junctions are either stable or unstable
- The unstable ones decay (split) into 3 separate junctions which run away from each other depending on the local curvature
- Field theory simulations agree with Nambu-Goto, so can be used complementary when studying string networks