Cosmic Superstrings II

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**Cosmic Superstrings**


**Type I**: theory of open strings → long strings fragment on stringy time scales

**Heterotic**: long strings bound axion domain wall, whose tension collapses strings

\[ dH = \int_s^2 F \wedge F \]

**Type II**: macroscopic strings possible, but theories do not appear phenomenologically interesting
**Cosmic Superstrings**


**Type I**: theory of open strings $\rightarrow$ long strings fragment on stringy time scales

**Heterotic**: long strings bound axion domain wall, whose tension collapses strings

$$dH = \int_s^2 F \wedge F$$

**Type II**: instantonic NS5-branes produce axion potential so axion domain walls collapse strings

Becker, Becker and Strominger (1995)
Other Problems (pre-1995):

• fundamental strings have tension $T_{F1} \approx 1/\lambda^2_S$ close to Planck scale, but isotropy of CMB constrains

$$G_4 T_{\text{cosmic}} \leq 10^{-5}$$

• inflation would dilute away any such relic strings from Planck scale era
After the 2nd superstring revolution:

1. More kinds of strings:
   fundamental strings, D-strings, partially wrapped D-, M- or NS5-branes
   (Dualities may relate these objects)

2. More exotic kinds of compactifications:
   - large extra dimensions
   - warped compactifications

We should reconsider cosmic superstrings
Pre-1995 thinking on cosmic superstrings:

1. Strings are unstable

2. Strings have Planck scale tension

3. Strings are diluted away by inflation
2. String tension reduced in “exotic” compactifications:

b) Warped compactifications: tension is redshifted by internal warp factors

\[ ds^2 = e^{2A(y)} (g_{\mu\nu} dx^\mu dx^\nu) + ds_\perp^2(y) \]

**UV:** \[ e^{2A} = 1 \]

**IR:** \[ e^{2A} \ll 1 \]

\[ T_{\text{eff}} = e^{2A(IR)} T_{\text{fun}} \ll T_{\text{fun}} \]
Pre-1995 thinking on cosmic superstrings:

1. Strings are unstable

2. Strings have Planck scale tension

String tension decoupled from Planck scale

3. Strings are diluted away by inflation
3. Cosmic strings from brane inflation:

D1-strings form in D3-D3 annihilation as defects in tachyon field by Kibble mechanism.

Strings, but no monopoles or domain walls.
3. Cosmic strings from brane inflation:

D1-strings form in D3-D3 annihilation as defects in tachyon field by Kibble mechanism

\[ T_{(p,q)} = T_{F1} \sqrt{(p - \chi q)^2 + q^2 / g_s^2} \]

(p,q)-strings
Pre-1995 thinking on cosmic superstrings:

1. Strings are unstable

2. Strings have Planck scale tension
   
   String tension decoupled from Planck scale

3. Strings are diluted away by inflation
   
   Rich network of strings may be generated at end of brane inflation
1. Many potential sources of instability:
   a) Breaking on D-branes
   b) Collapsing with domain walls
   c) “Baryon decay”
   d) Tachyon decay
1.c) “Baryon decay”

Compactifications may contain topologically nontrivial 3-cycles which carry fluxes, eg, RR 3-form flux: \[ \int_{K_3} F_3 = M \]

For D3-brane wrapping \( K_3 \), vector eom is:

\[ *d*dA = -F_3 \]  \( \text{RR flux like uniform electric charge density} \)

M F-strings required to cancel charge density

“Baryon”: M F-string vertex

For \( M=1 \), F-strings can snap by production of baryon-baryon pairs
If $M > 1$, stable strings have: $|p| \leq M/2$

Analogous to charged particle production in a uniform electric field

Exotic vertices:

$q_1 = q_2 + q_3$
$p_1 = p_2 + p_3 - M$
Pre-1995 thinking on cosmic superstrings:

1. Strings are unstable
   Many potential instabilities, but model specific

2. Strings have Planck scale tension
   String tension decoupled from Planck scale

3. Strings are diluted away by inflation
   Rich network of strings may be generated at end of brane inflation
(p,q)-strings naturally produced after brane inflation. Stability?

\[ ds^2 = e^{2\phi(y)} (\eta_{\mu\nu} dx^\mu dx^\nu) + ds_1^2(y) \]

Kachru, Kallosh, Linde, McAllister, Maldacena, McAllister & Trivedi; Kachru, Kallosh, Linde, Trivedi;

K2LM2T model:
a) Instabilities ignoring any extra branes in throat

Note: massless 4d modes of B and C are projected out

Strings are non-BPS

In 2-fold cover, a string and it’s image may annihilate

requires worldsheet instanton

\[ \Delta I_E \approx T_{\text{fun}} L \pi r - 2T_{\text{eff}} \pi r^2 \]

\[ r \approx (T_{\text{fun}} L)/(4T_{\text{eff}}) \approx e^{-2A_0} \]

\[ \Delta I_E \approx e^{-2A_0} \]

Strings effectively stable!

\[ (= 10^8) \]
a) Instabilities ignoring any extra branes in throat

**Baryon decay**: D3 can wrap $S^3$ in KS-throat

M units of RR $F_3$-flux: **stable strings** have $|p| \leq M/2$

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(p,q)  (p-M,q)  (p,q)
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Similar instanton calculation:

$$I_E \approx \frac{qM^2}{2p - M}$$

Not suppressed by warp factors, but ineffective for very large flux quantum $M$

( $M > 10 N_{D3}$ to ensure stability of $\overline{D3}$'s )

Kachru, Pearson and Verlinde
b) Stabilizing $\overline{D}3$-branes in throat

$\rightarrow$ all strings decay

c) Standard model branes in throat

- D3- or $\overline{D}3$-branes $\rightarrow$ all strings decay
- D7-branes $\rightarrow$ F1-strings decay
  $\rightarrow$ D1-strings stable
**Tension:**

$K^2L^2M^2T$ calculation of density perturbations yields:

\[
\frac{\left(G_4 e^{2A_0}\right)^2}{\left(2\pi l_s^2\right)^2 g_s} \approx \frac{\delta_H^3}{32\pi N_e^{5/2}}
\]

(Recall: $T_{F1}/T_{D1} = g_s$)

Similarly for large extra dimensions models:

\[10^{-11} \leq G_4 T \leq 10^{-6}\]

Jones, Stoica & Tye; Sarangi & Tye
Observational Bounds:

CMB power spectrum: \[ G_4 T \leq 7 \times 10^{-7} \]

Pulsar timing: \[ G_4 T \leq 10^{-6} \] (\[ \rightarrow 10^{-11} \])

Gravitational radiation from cusps and kinks:

- LIGO I: \[ G_4 T \leq 10^{-10} \]
- LIGO II: \[ G_4 T \leq 10^{-11} \]
- LISA: \[ G_4 T \leq 10^{-13} \]

Wide-field surveys (LSST, JDEM, Pan-STARRS) may observe strings through lensing events (e.g., Vachaspati):

Sazhin et al: \[ G_4 T \approx 4 \times 10^{-7} \]?
Conclusions:

F1-, D1- or (p,q)-strings may be observed as cosmic superstrings

Requires: (a) brane inflation to produce strings and (b) a scenario in which strings are stable

The results are highly model dependent and in some cases, very rich (eg, (p,q)-strings)

Future directions: study evolution of string networks
- intercommutation probabilities
- (p,q)-networks
- scaling solutions or frustrated networks or ??