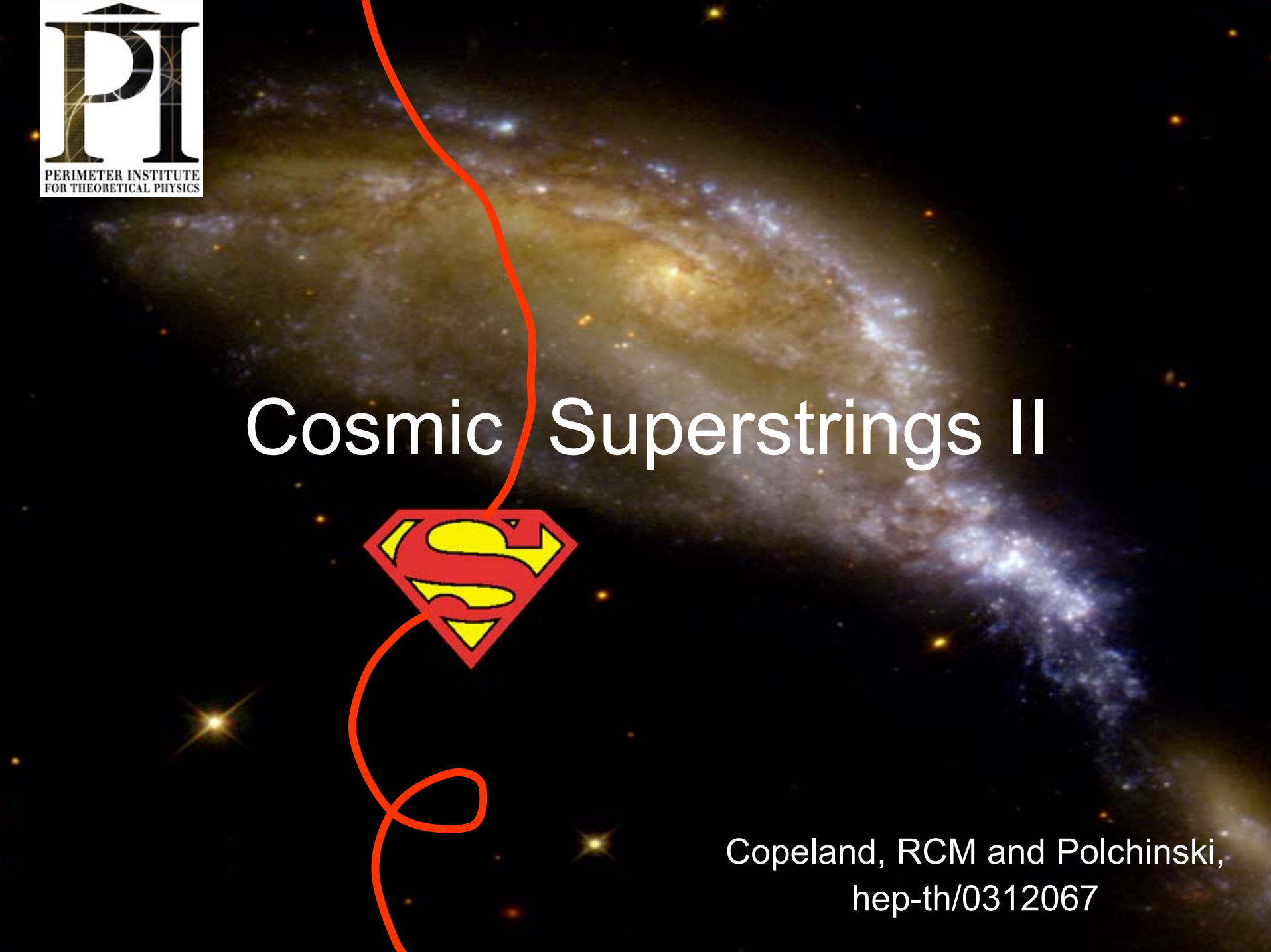

PERIMETER INSTITUTE
FOR THEORETICAL PHYSICS
Cosmic Superstrings II
Copeland, RCM and Polchinski,
hep-th/0312067

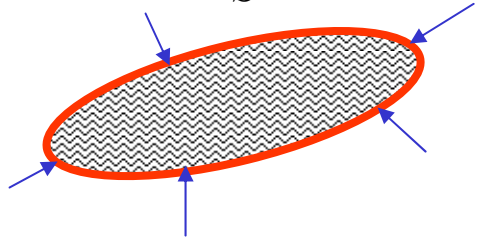
Cosmic Superstrings

E. Witten, Physics Letters **B153** (1985) 243.

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

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

$$dH = \lambda_S^2 \; F \wedge F$$



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

Cosmic Superstrings

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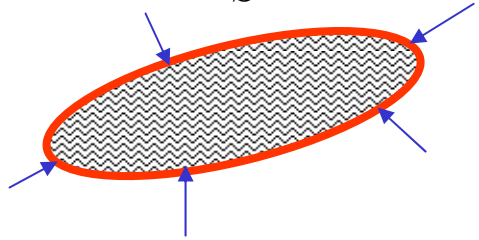


Type II: instantonic NS5-branes produce axion potential so axion domain walls collapse strings

Becker, Becker and Strominger (1995)

Other Problems (pre-1995):

- fundamental strings have tension $T_{F1} \approx 1/\lambda_S^2$ 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

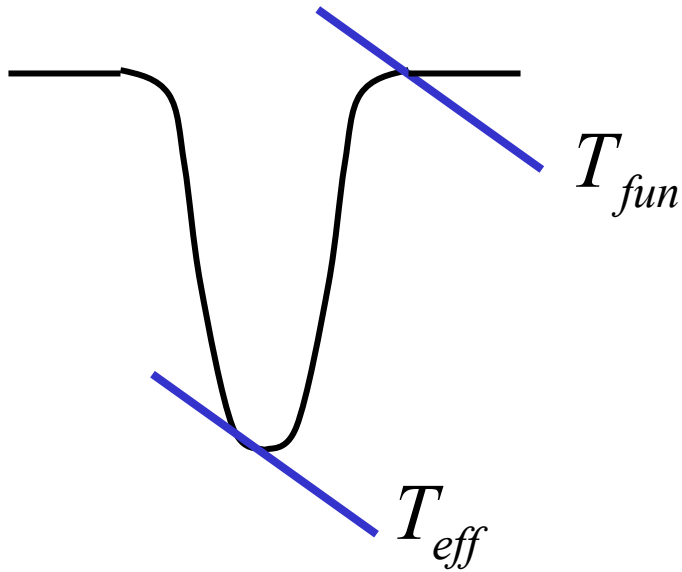
2. string tension reduced in “exotic” compactifications:

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

$$ds^2 = e^{2A(y)}\left(\eta_{\mu\nu}dx^\mu dx^\nu\right) + ds_\perp^2(y)$$

$UV: \quad e^{2A} = 1$

$IR: \quad e^{2A} << 1$



$$T_{eff} = e^{2A(IR)}T_{fun} << T_{fun}$$

Pre-1995 thinking on cosmic superstrings:

1. Strings are unstable

2. ~~Strings have Planck scale tension~~

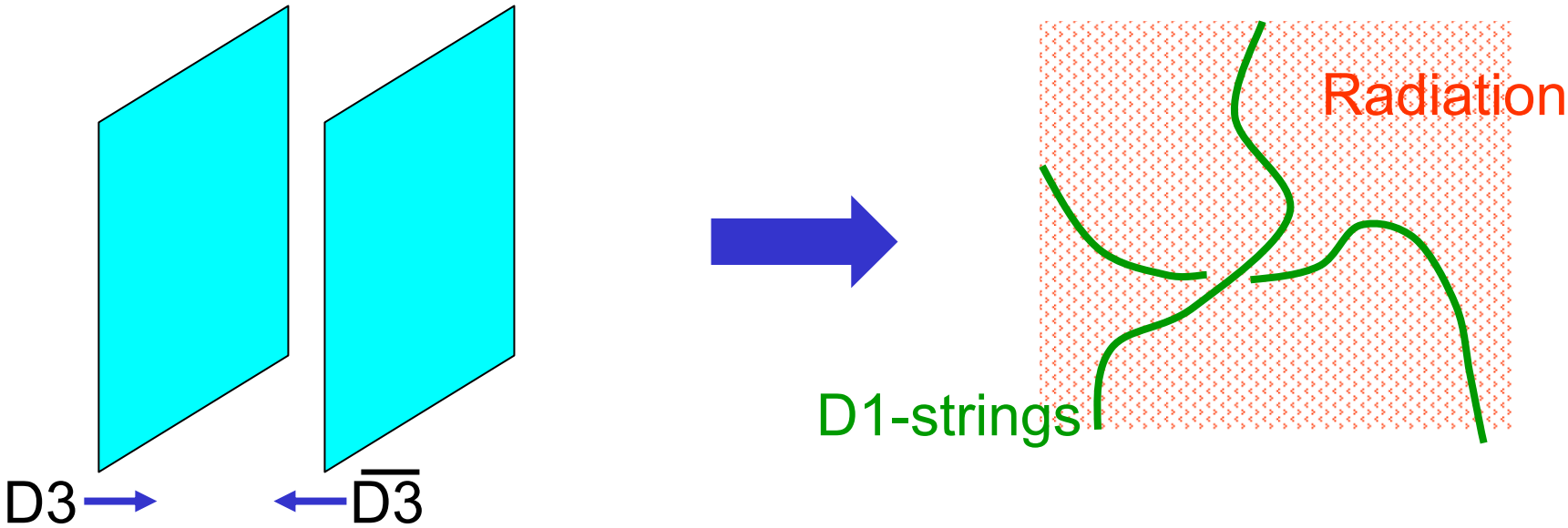
String tension decoupled from Planck scale

3. Strings are diluted away by inflation

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

3. Cosmic strings from brane inflation:

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

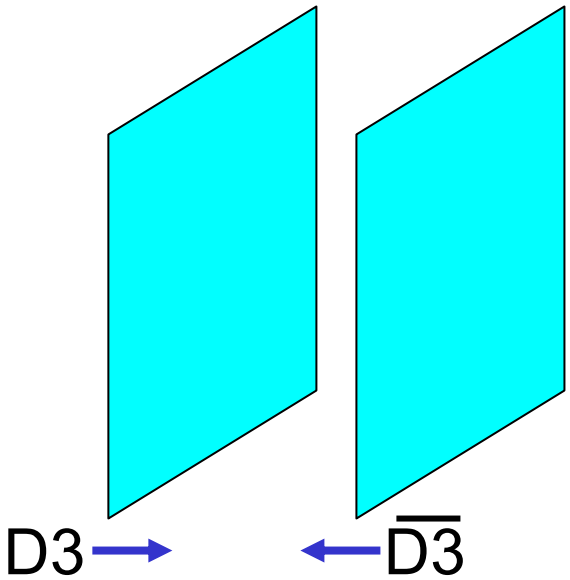


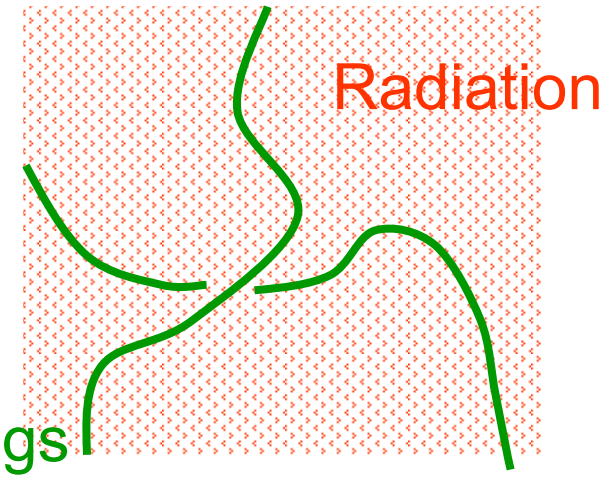
Strings, but no monopoles or domain walls

Jones, Stoica & Tye; Sarangi & Tye

3. Cosmic strings from brane inflation:

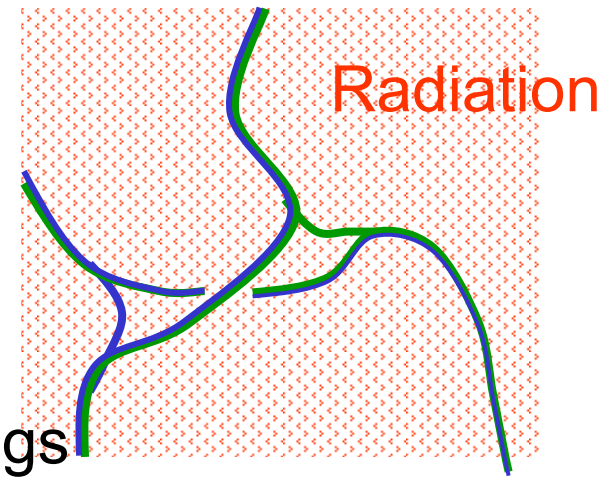
D1-strings form in D3-D3 annihilation as defects in tachyon field by Kibble mechanism





SL(2,Z) dualities:
F1-D1 bound states

$$T_{(p,q)} = T_{F1}\sqrt{(p-\chi q)^2 + q^2/g_S^2}$$



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”

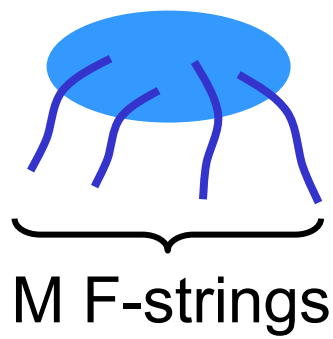
Compactifications may contain topologically nontrivial 3-cycles which carry fluxes,
eg, RR 3-form flux: $\oint_{K_3} F_3 = M$

For D3-brane wrapping K_3, vector eom is:

$$*\,d\,*\,dA = -F_3$$ ← RR flux like uniform electric charge density

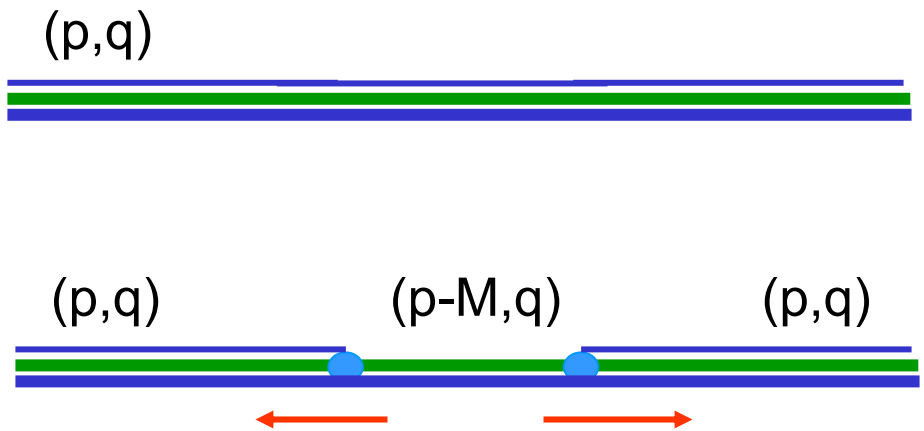
M F-strings required to cancel charge density

→ “Baryon”: M F-string vertex



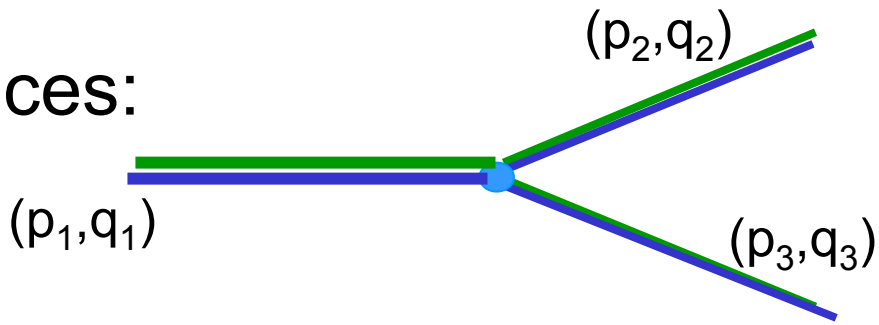
For M=1, F-strings can snap by production of baryon-$\overline{\text{baryon}}$ pairs

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

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

Pre-1995 thinking on cosmic superstrings:

1. Strings are unstable

Many potential instabilities, **but model specific!**

2. ~~Strings have Planck scale tension~~

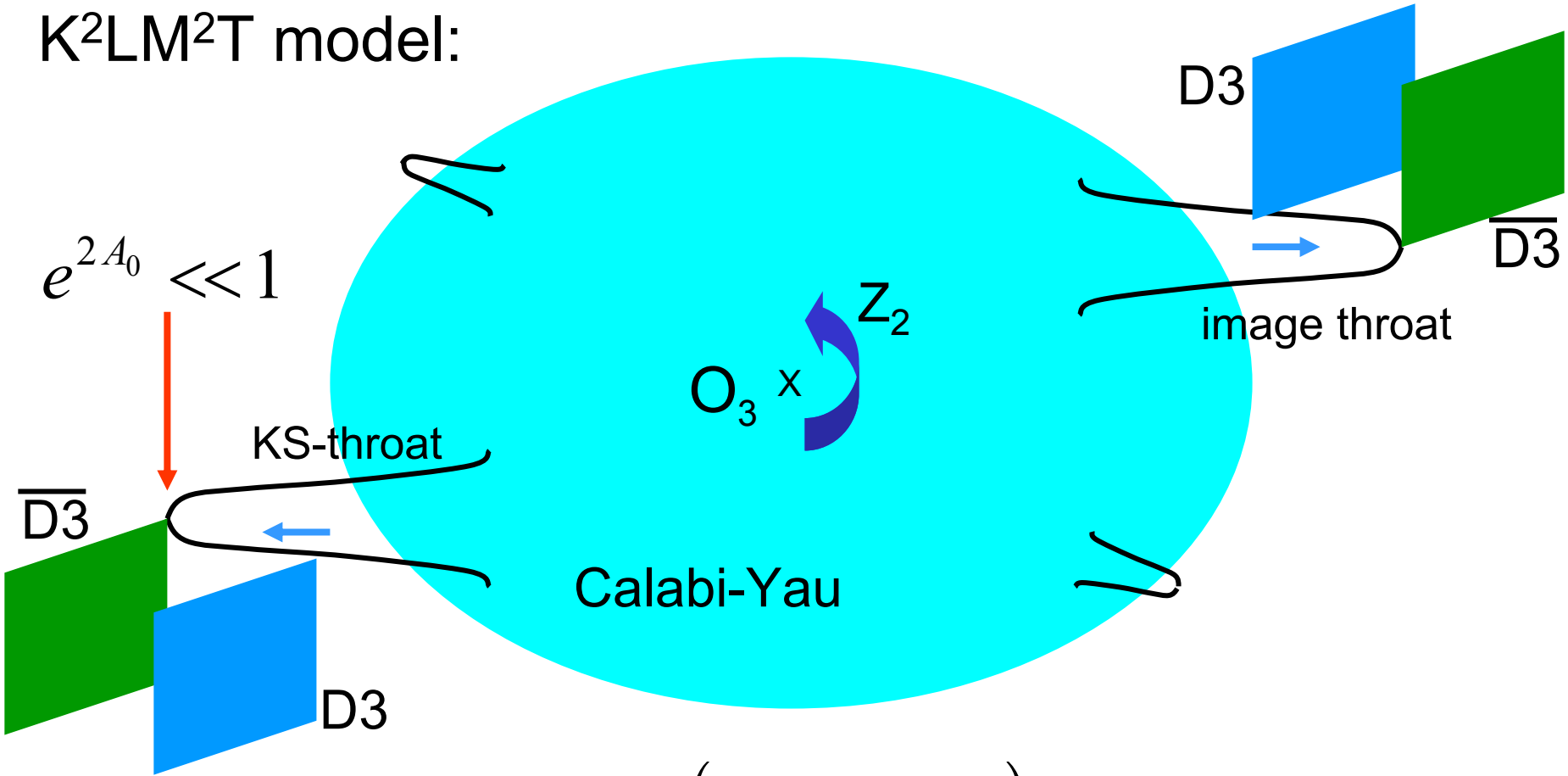
String tension decoupled from Planck scale

3. ~~Strings are diluted away by inflation~~

Rich network of strings may be generated at end of brane inflation

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

K^2LM^2T model:



$$ds^2 = e^{2A(y)}\left(\eta_{\mu\nu}dx^\mu dx^\nu\right) + ds_\perp^2(y)$$

(p,q)-strings naturally produced after brane inflation. Stability?

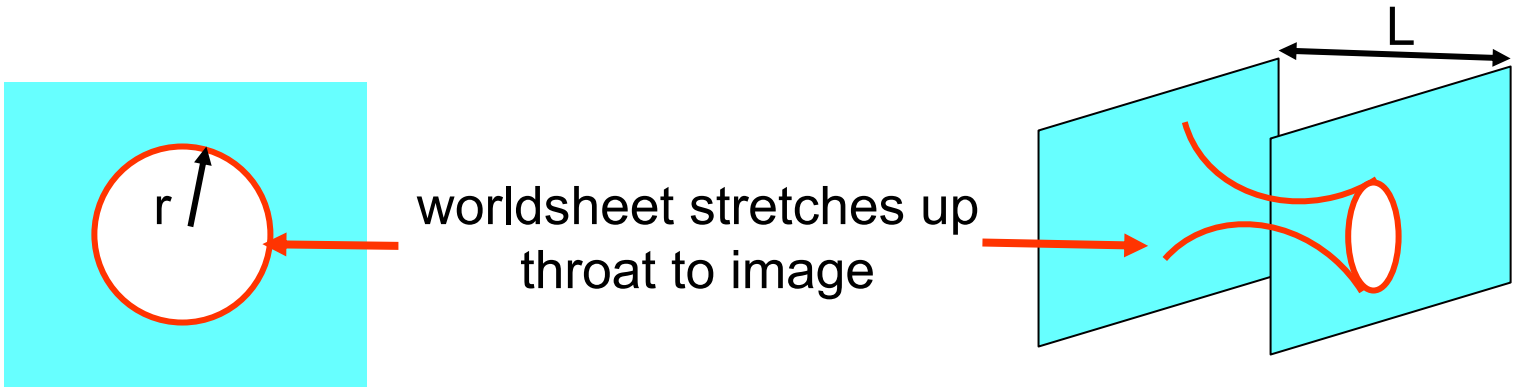
a) Instabilities ignoring any extra branes in throat

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



$$\Delta I_E \approx T_{fun} L \pi r - 2 T_{eff} \pi r^2$$

$$r \approx (T_{fun} L)/(4 T_{eff}) \approx e^{-2A_0} \rightarrow \Delta I_E \approx e^{-2A_0}$$

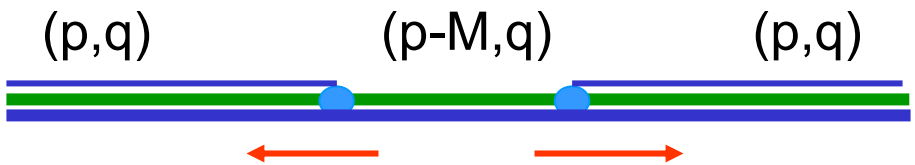
$$\left(= 10^8\right)$$

Strings effectively stable!

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 $|p| \leq M/2$



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 $N_{\overline{D3}}$ to ensure stablility of $\overline{D3}$'s)

Kachru, Pearson and Verlinde

b) Stabilizing $\overline{\text{D3}}$-branes in throat

$\longrightarrow$ all strings decay

c) Standard model branes in throat

- D3- or $\overline{\text{D3}}$-branes $\longrightarrow$ all strings decay
- D7-branes $\longrightarrow$ F1-strings decay

  $\longrightarrow$ D1-strings stable

Tension:

K²LM²T calculation of density perturbations yields:

$$\frac{\left(G_4\, e^{2A_0}\right)^2}{\left(2\pi\lambda_S^2\right)^2 g_S} \approx \frac{\delta_H^3}{32\pi\, N_e^{5/2}}$$

density perturbations

no. of e-foldings

$$G_4 T_{F1} \cdot G_4 T_{D1} \approx \left(10^{-10}\right)^2$$

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

Similarly for large extra dimensions models:

$$10^{-11} \le G_4 T \le 10^{-6}$$

Jones, Stoica & Tye; Sarangi & Tye

Observational Bounds:

CMB power spectrum: $G_4 T \leq 7 \times 10^{-7}$ Landriau & Shellard; Pogosian et al

Pulsar timing: $G_4 T \leq 10^{-6}$ ($\longrightarrow 10^{-11}$)

Shellard et al (Damour & Vilenkin)

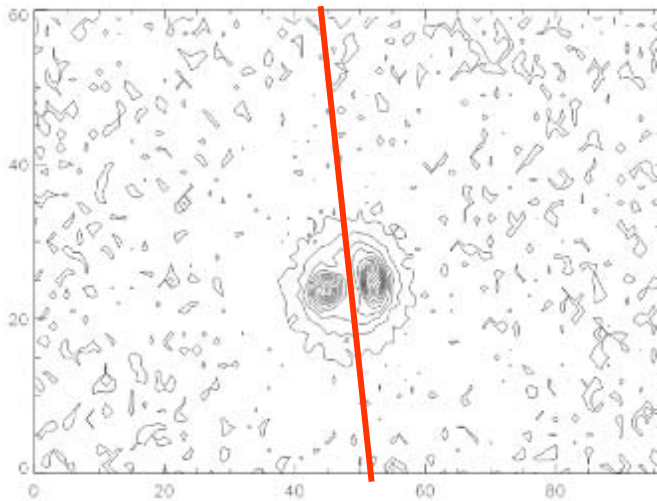
Gravitational radiation from cusps and kinks:

Damour & Vilenkin

- 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 (eg, 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 (Jones, Jackson & Polchinski)
- (p,q)-networks
- scaling solutions or frustrated networks or ??

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