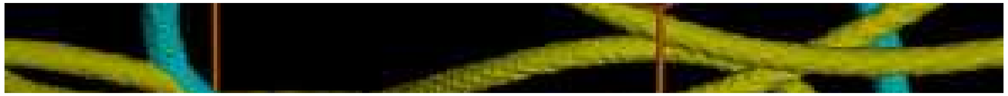
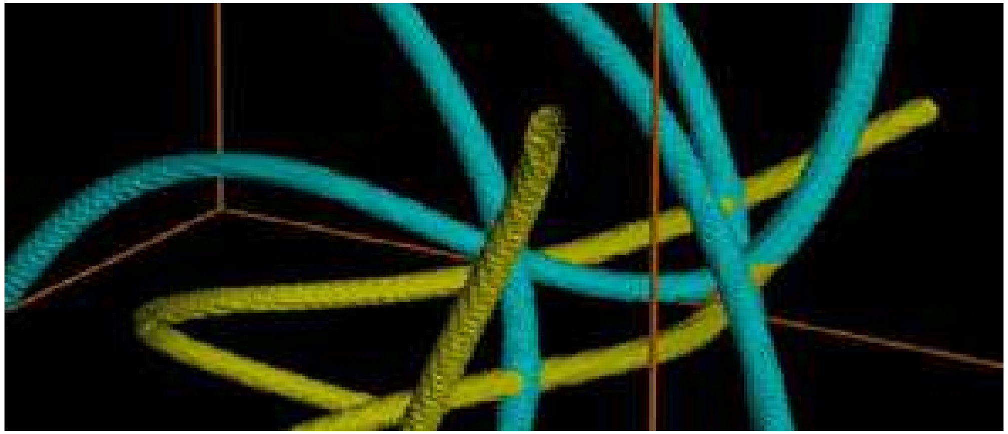
dynamics of cosmic superstring networks



Rajantie, Sakellariadou, Stoica (JCAP 2007)

Sakellariadou, Stoica (JCAP 2008)

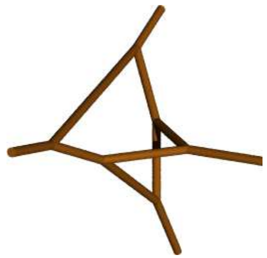
Davis, Nelson, Rajamanoharan, Sakellariadou (2008)



Mairi Sakellariadou
King's College London

Fundamental (F) strings and 1-dim Dirichlet branes (D-strings) are generically produced at the end of brane inflation

collisions of F-strings & D-strings produce FD bound states



superstring intercommutations form a trilinear vertex

does a cosmic superstring network reach scaling, or does it freeze leading to predictions inconsistent with our observed universe?

evolution of cosmic superstring networks

aim: build a simple field theory model of bound states, in analogy with the Abelian Higgs model, and study its properties using lattice simulations

characteristics:

- bound states have different tension than single-charge strings

- set long-range interaction of each species of strings individually;

  different components of the FD-string are expected to exhibit different types of long-range interactions

the model

- two different species of cosmic strings:

  include two sets of fields of the Abelian Higgs model

- formation of bound states:

  introduce a coupling of the scalar fields via a potential

- one non –BPS species of strings (such strings have long range interactions):

  consider the second type of string to be the topological defect of a scalar field with a global U(1) symmetry

Rajantie, Sakellariadou, Stoica (JCAP 2007)

if both species of strings are BPS:

$$S = \int \mathrm{d}^3x\mathrm{d}t\Big[-\tfrac{1}{4}F^2 - \tfrac{1}{2}(D_\mu\phi)(D^\mu\phi)^\star - \tfrac{\lambda_1}{4}(\phi\phi^\star - \eta_1^2)^2$$
$$- \tfrac{1}{4}H^2 - \tfrac{1}{2}(D_\mu\chi)(D^\mu\chi)^\star - \tfrac{\lambda_2}{4}\phi\phi^\star(\chi\chi^\star - \eta_2^2)^2$$

$$D_\mu\phi = \partial_\mu\phi - ie_1 A_\mu\phi \qquad D_\mu\chi = \partial_\mu\chi - ie_2 C_\mu\chi$$

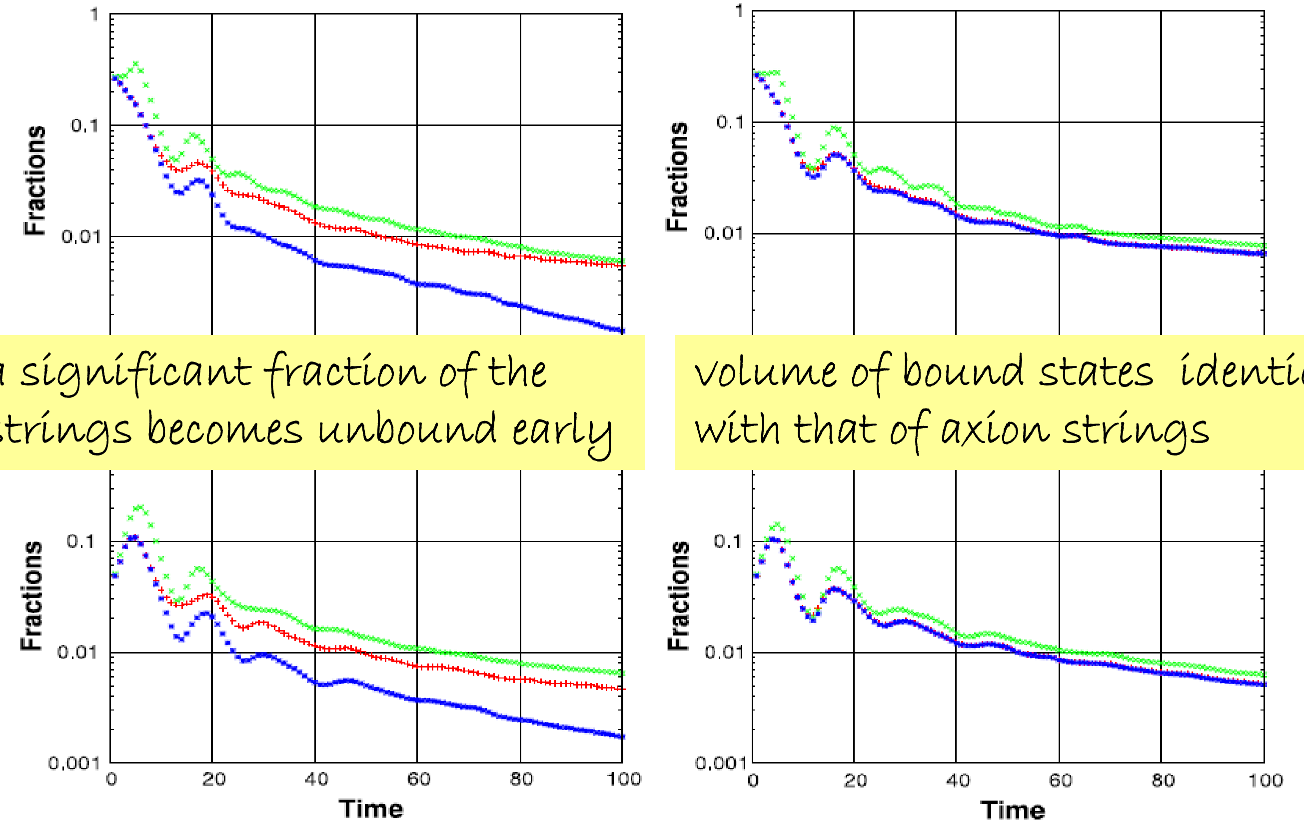
$$F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu \qquad H_{\mu\nu} = \partial_\mu C_\nu - \partial_\nu C_\mu$$

ϕ the *Higgs* field $\qquad$ χ the *axion* field

- in the case of a non-BPS species of string: set $e_2 = 0$

the total physical volume of the simulation box occupied by Higgs strings the axion strings, and their bound states

local-global networks



a significant fraction of the strings becomes unbound early

volume of bound states identical with that of axion strings

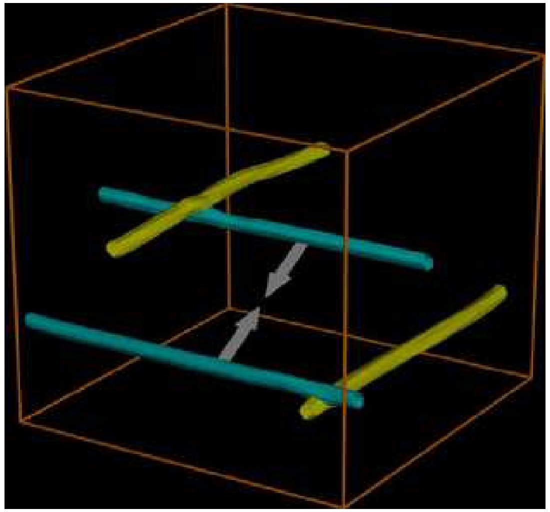
local-local networks

Rajantie, Sakellariadou, Stoica (JCAP 2007)

only one pair of local and one pair of global strings

attractive interactions between global strings result in their motion towards the local ones

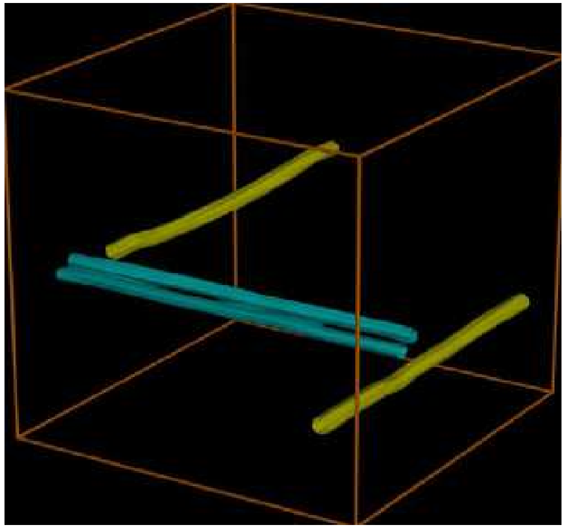
does the formation of bound states can stop the motion of the global strings?



global strings move towards local ones and cross them, forming bound states

bound states split as global strings continue to move towards each other

finally they collide and annihilate



bound states do not survive the long-range interactions of global strings

Rajantie, Sakellariadou, Stoica (JCAP 2007)

does the existence of bound states prevent a cosmic superstring network from reaching a scaling solution?

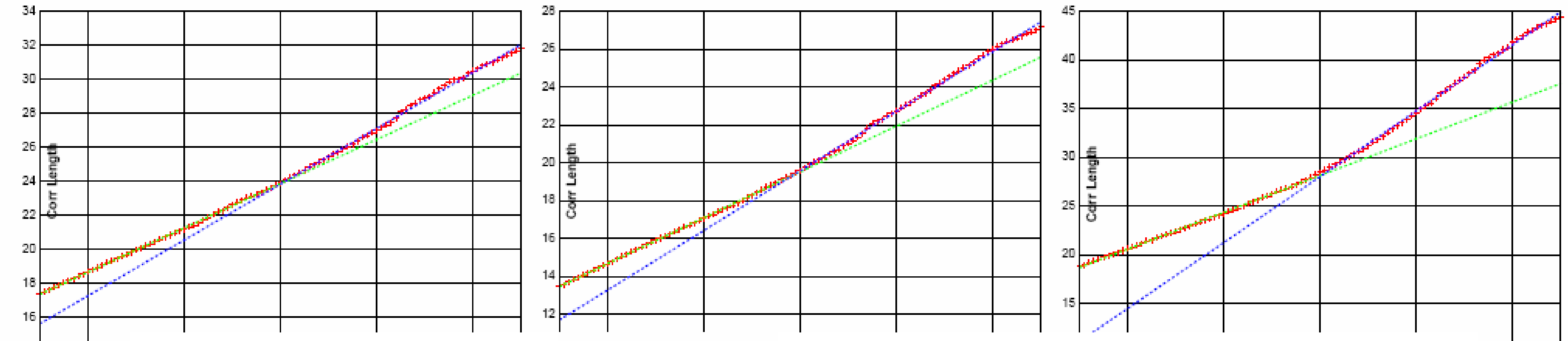
use a field theory model to study the effect of junctions in the evolution of a network composed by F, D and FD-strings

we have control over the initial population of bound states

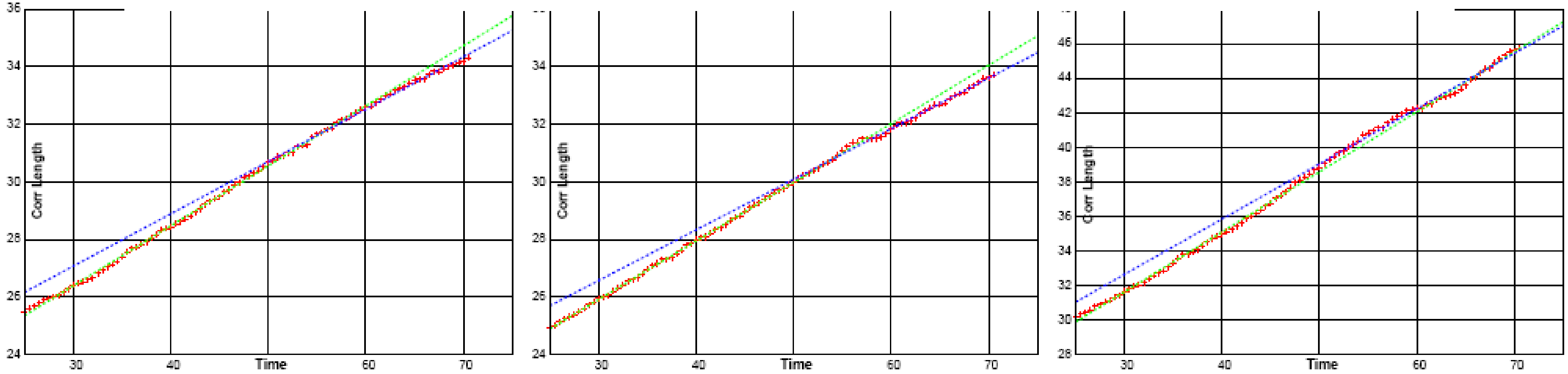
Sakellariadou, Stoica (JCAP 2008)

correlation length as function of time in a local-global network

$$\xi = \sqrt{V/L}$$



there is scaling $\xi(\tau) = \gamma\tau$, characterised with a change of correlation length during network evolution



correlation length as function of time in a local-local network

- scaling of F,D,FD-strings is robust and independent of initial configurations

- the existence of bound states effects the evolution of the network

- there is a supplementary energy loss mechanism, in addition to chopping off loops

<u>new mechanism</u>: formation of bound states with increasing length

the overall network does not freeze because the string length of the unbound states decreases faster

Sakellariadou, Stoica (JCAP 2008)

the three-string junction

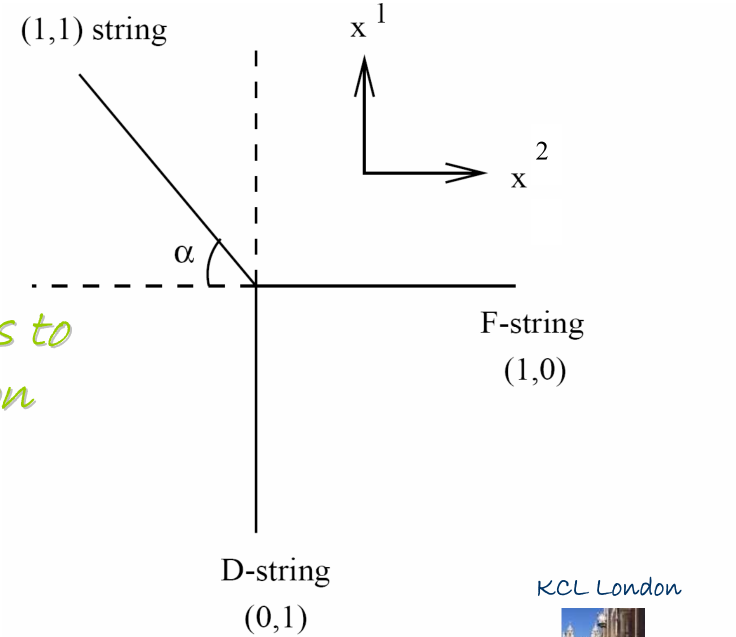
BPS saturated formula

$$\tau_{(p,q)} = \sqrt{[p\tau_{(1,0)}]^2 + [q\tau_{(0,1)}]^2}$$

solution:

$$\tau_{(p,q)} \sin\alpha = q\tau_{(0,1)} \qquad \tau_{(p,q)} \cos\alpha = p\tau_{(1,0)}$$

where $\tan\alpha = q/(pg_s)$



balance conditions for three strings

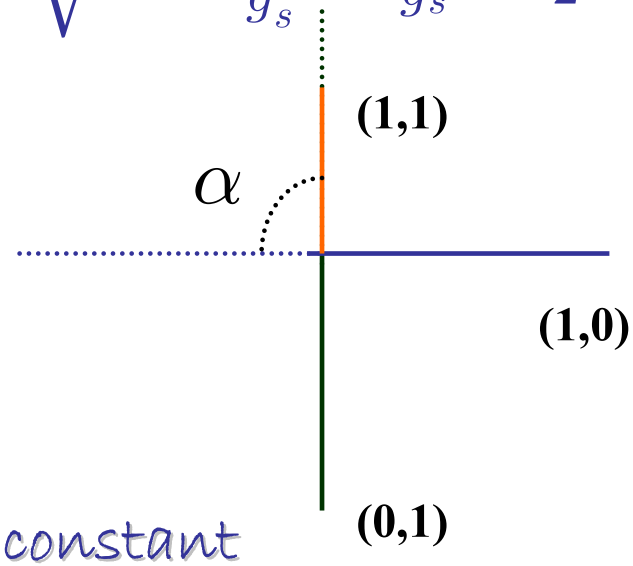
when an F-string ends on a D-string it causes to bend at an angle set by the string coupling; on the other side of the junction is a (1,1) string

F-string: $\tau_1 = 1$

D-string: $\tau_2 = 1/g_s$

FD-bound state: $\tau_3 = \sqrt{1 + \frac{1}{g_s^2}} = \frac{1}{g_s} + \frac{g_s}{2} + \mathcal{O}(g_s^2)$

in the small g_s -limit:



the angle α goes to $\pi/2$ in the limit of zero string coupling

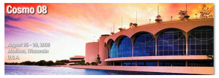
- length of F-string remains constant
- length of D-string decreases and length of FD-bound state increases

cosmic superstring detection

cosmic superstrings interact with SM particles via gravity

⇨ detection involves the gravitational interactions of cosmic superstrings

- gravitational lensing
- micro-lensing
- CMB anisotropies
- gravity waves
- RR/dilaton emission



cosmic strings in flat space-time

$$\mathbf{x}(\sigma, t)$$

constraint equations and string e.o.m.:

$$\dot{\mathbf{x}} \cdot \mathbf{x}' = 0$$

$$\dot{\mathbf{x}}^2 + \mathbf{x}'^2 = 1$$

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

general solution to string e.o.m. in flat space-time:

$$\mathbf{x} = \frac{1}{2}\Big[\mathbf{a}(\sigma - t) + \mathbf{b}(\sigma + t)\Big]$$

continuous arbitrary functions which satisfy:

$$\mathbf{a}'^2 = \mathbf{b}'^2 = 1$$

cusps

property of loop solutions:
points along the string can reach the velocity of light

$$\dot{\mathbf{x}}^2(\sigma, t) = \tfrac{1}{4}[\mathbf{a}'(\sigma - t) - \mathbf{b}'(\sigma + t)]^2$$

$\mathbf{a}'(\sigma)$ and $-\mathbf{b}'(\sigma)$ describe closed curves on a unit sphere

the satisfy: $\int_0^L \mathbf{a}' \mathrm{d}\sigma = \int_0^L \mathbf{b}' \mathrm{d}\sigma = 0$

but otherwise are arbitrary

if the two curves intersect then: $\dot{\mathbf{x}}^2(\sigma, t) = 1$

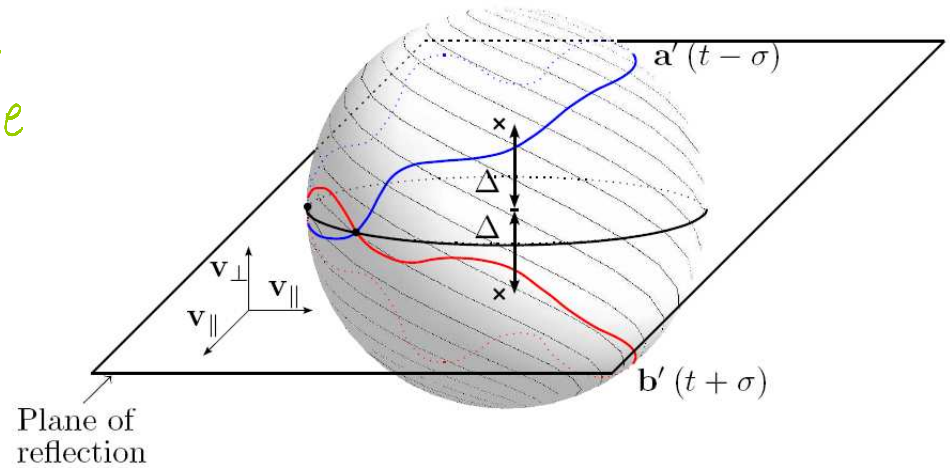
smooth loops will in general have such luminal points: cusps

non-periodic strings ending on branes

a DBI string ending on two stationary and parallel Dn-branes

from BC, a′ and b′ curves are related by inversion through a surface of identical dimension and orientation to the D-branes, that passes through the center of the unit sphere

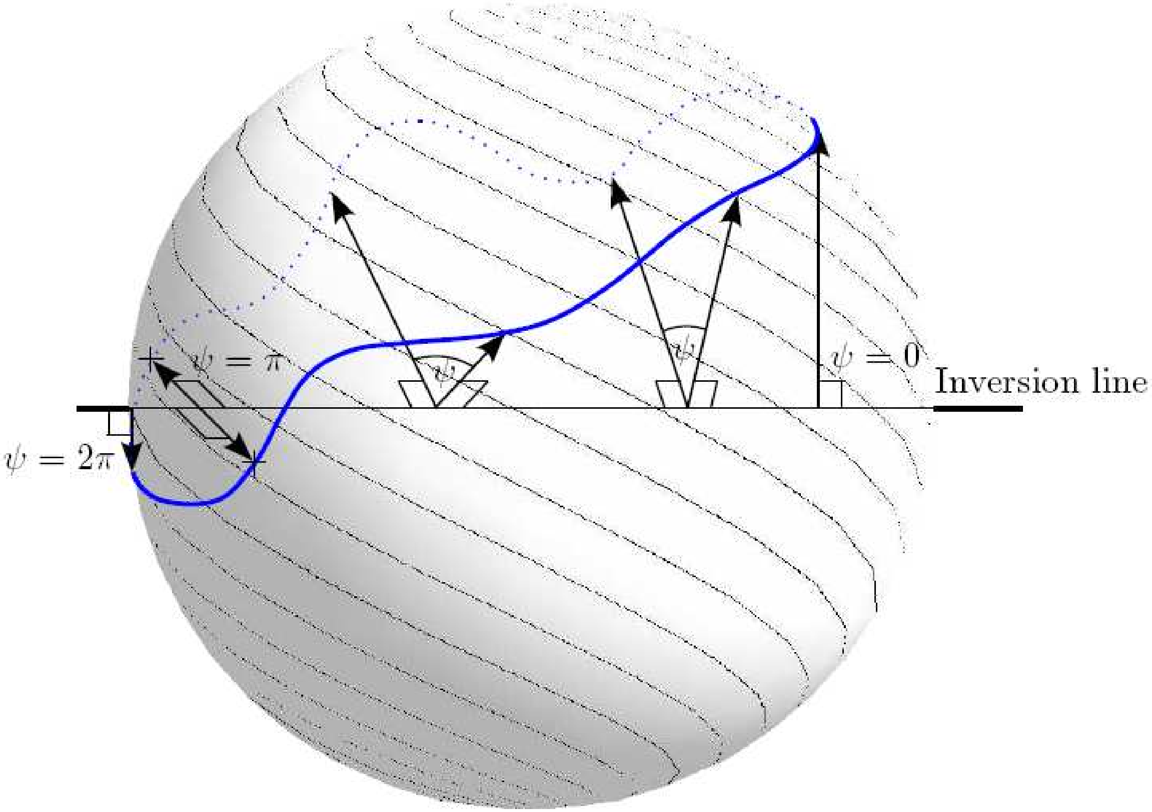
a′ and b′ trace out closed curves on a unit sphere separated by the inter-brane distance



cusps: if a′ and b′ intersect

D1-branes

a' and b' intersect whenever the line through which they are inverted is enclosed by the closed curves



when the angle between the 2 vectors perpendicular to the inversion line and ending on the curve is equal to π, the inverted curve will intersect the original one

Davis, Nelson, Rajamanoharan, Sakellariadou (2008)

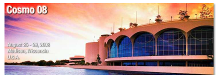
genericity of cusps on non-periodic strings ending on branes

- cusps are generic features of an F-string ending on two parallel D-strings

- an F-string stretched between 2 three-string junctions behaves as an F-string between 2 D1-branes (to order g_s)

a pair of three-string junctions would have cusps

Davis, Nelson, Rajamanoharan, Sakellariadou (2008)



$g_s \to 0$ *limit*: the heavy D/FD string behaves as a single string unaffected by dynamics of light F-string

cusps are significant if the typical separation of the heavy strings must be small w.r.t. length of the F-string stretched between them

as heavy strings move apart, F-strings stretch increasing the distance and the importance of cusps gets reduced

under S-duality the role of F and D strings is reversed:

F-strings and bound FD-strings are the heavy ones

cusps exist on light D-strings ending on three-string junctions

➢ cosmic strings

- cusps can be formed on smooth closed string loops
- intercommutation leads to kinks, which may reduce cusp formation
- GW and SM fields can be emitted

➢ cosmic superstrings

- cusps exsit in non-periodic strings ending on D-branes
- cusps in loops may be less important
- intercommutation leads to junctions
- GW and SM fields + dilaton/RR/moduli/gravitinos/stable SUSY particles can be emitted

conclusions

towards the end of brane inflation cosmic superstrings are produced

their properties and subsequent cosmological evolution into a scaling network open up their possible detections in the near future, via cosmological, astrophysical and gravitational wave measurements

finding distinctive stringy signatures in observations will reveal the particular brane inflationary scenario and validate string theory and the brane world scenario