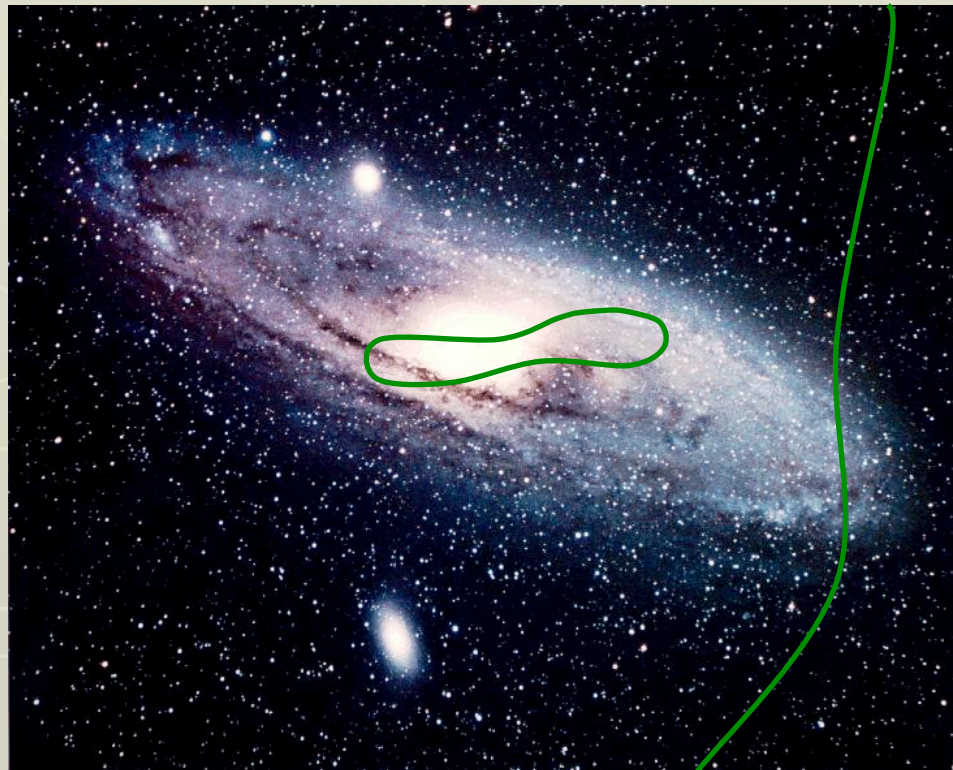


Cosmic F and D Strings

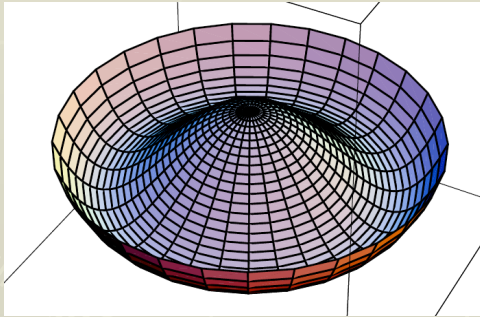
Joseph Polchinski, KITP/UCSB



APS-DPF 8/27/04

Review of `old' cosmic strings, in gauge theory GUTS:

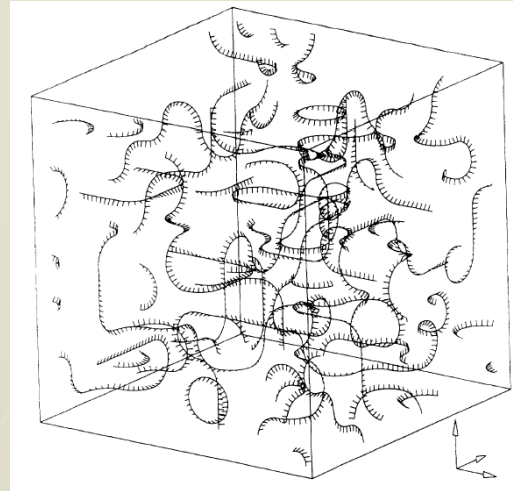
In any field theory with a spontaneously broken $U(1)$ symmetry, there are magnetic flux tube solutions (Abrikosov/Nielsen-Olesen vortices).



As one circles the string, the Higgs field makes a circuit around the minimum of the potential.

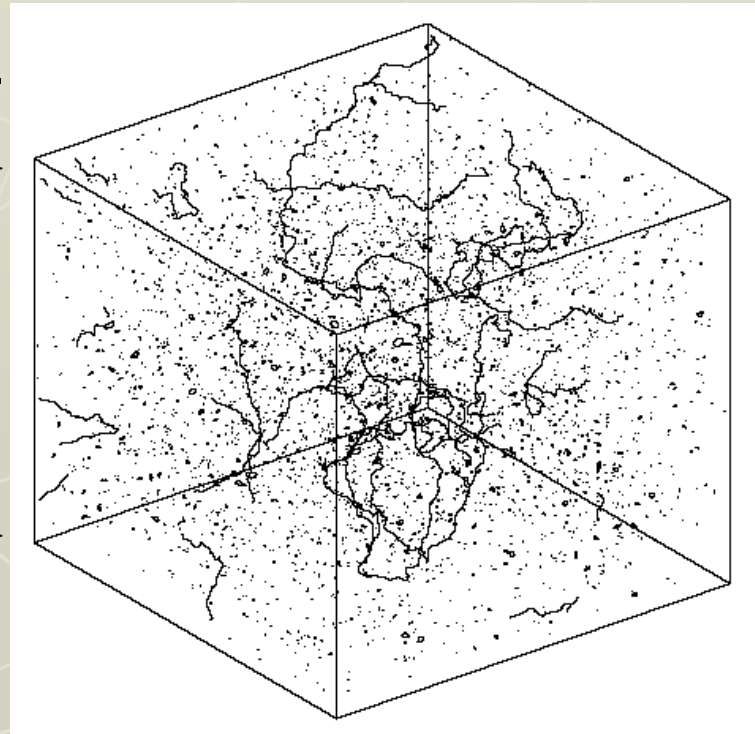
If there is a phase transition in the early universe at which a $U(1)$ symmetry *becomes* broken, then a network of such flux tubes *must* form, as the Higgs field rolls down the potential in different directions in different regions (Kibble).

Network at formation:



Network today (after expansion and reconnection):

3×10^9 lightyears



Allen and Shellard (1990)

An important dimensionless quantity: $G\mu$

G = Newton's constant ($\hbar = c = 1$)

μ = string tension

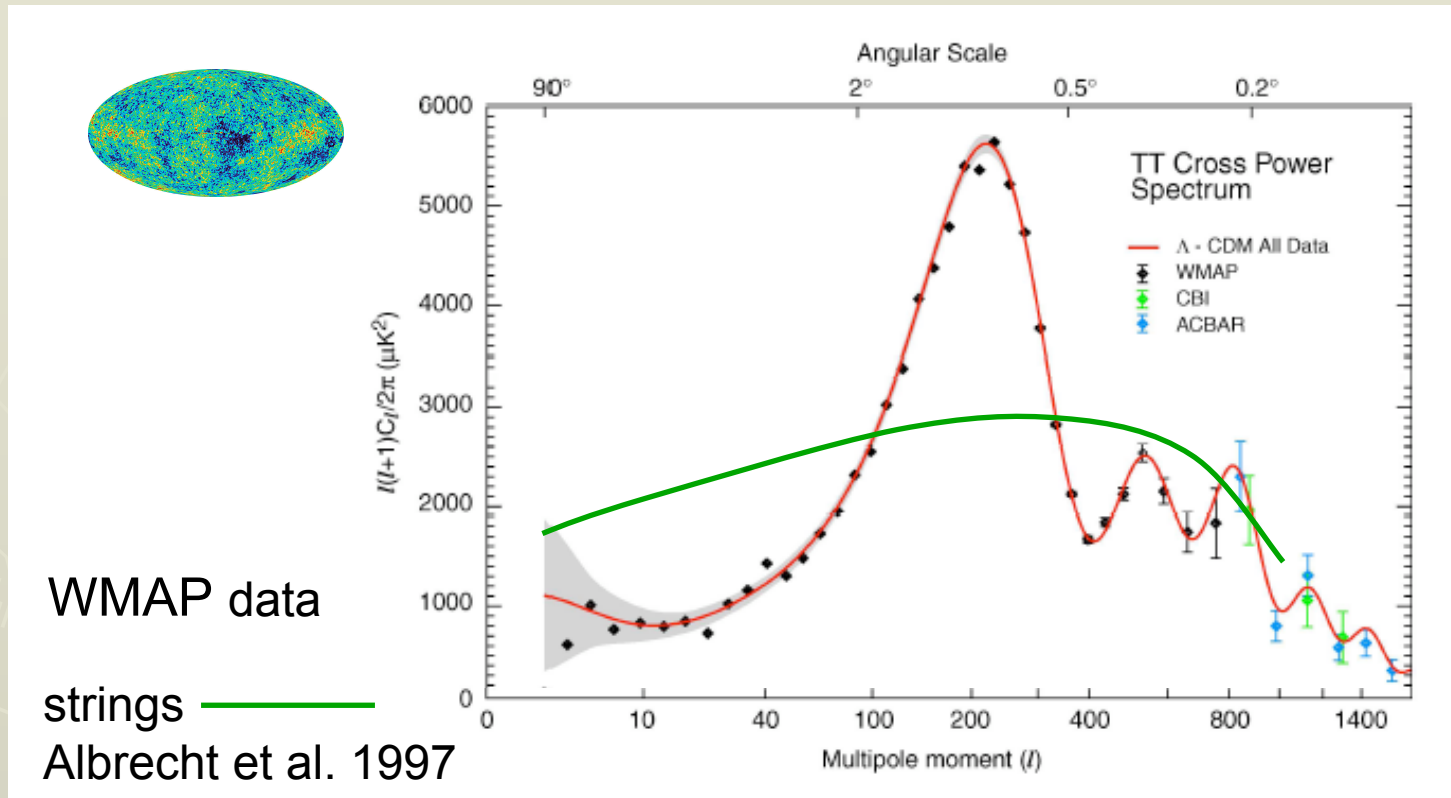
$G\mu \sim$ string tension in Planck units

\sim gravitational coupling of string = size of metric perturbation.

Strings with $G\mu \sim 10^{-5.5}$ produce observed $\delta T/T$ and $\delta\rho/\rho$ (Zeldovich 1980, Vilenkin 1981).

However, they produce the wrong CMB power spectrum (Albrecht, Battye, Robinson 1997).

CMB power spectrum



Acoustic peaks come from temporal coherence. Inflation has it, strings don't. String contribution $< 10\%$ implies $G\mu \lesssim 10^{-6}$ (best current bound).

E.g. Pogosian, Wyman, Wasserman 2004.

End review.

Fundamental strings might similarly reach cosmic size (Witten 1985).

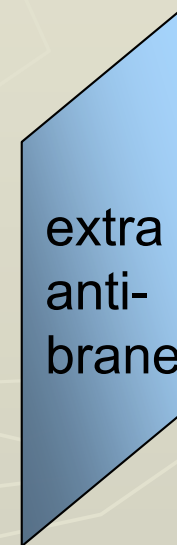
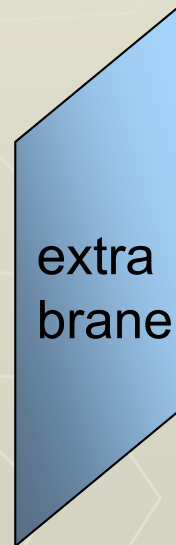
Necessary conditions for this to be interesting:

1. The strings must be **produced** at the appropriate time in the early universe.
2. They must be **stable** on cosmological time scales.
3. They must be **observable**, but not already excluded.
4. They should be **distinguishable** from gauge theory strings.

Each of these conditions is model dependent, but there exist simple models in which all are satisfied.

I. Production:

An attractive model for inflation is that there were extra brane-antibrane pairs in the early universe (Dvali and Tye). Their energy density induced inflation; subsequently they annihilated:



Inflaton = brane-antibrane inflation. Weak attraction at long distance gives a flat potential, which steepens as the branes come together.

For D-branes/antibrane, there is a $U(1)\times U(1)$ symmetry, which disappears when the branes annihilate. This leads to production of strings just as in field theory. One $U(1)$ gives D-strings [K theory!] (Jones, Stoica, Tye; Sarangi & Tye); the other gives F-strings (Copeland, Myers, JP; Dvali & Vilenkin).

radiation + D-strings + F-strings



How generic are these strings?



There may be other ways to realize inflation in string theory.



A symmetry-breaking transition at the end of inflation is also favored in order to get reheating (hybrid inflation).



Other kinds of branes (e.g. M-branes) may lead to different symmetry breaking patterns, without strings.

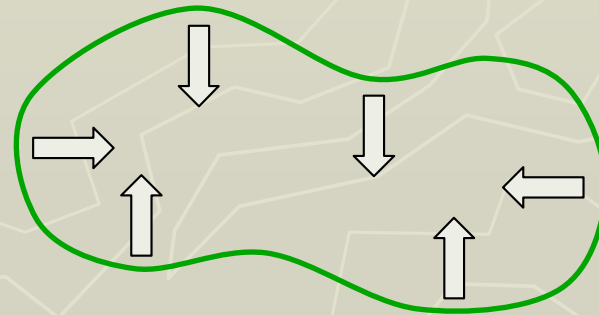
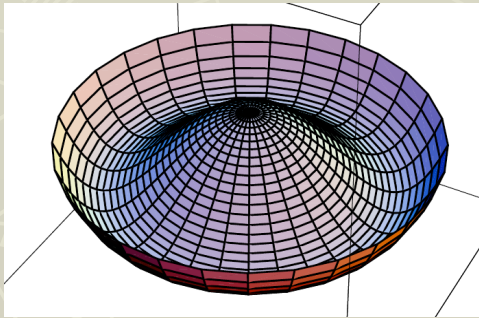
The study of inflation in string theory is still in its early stages.

II. Stability

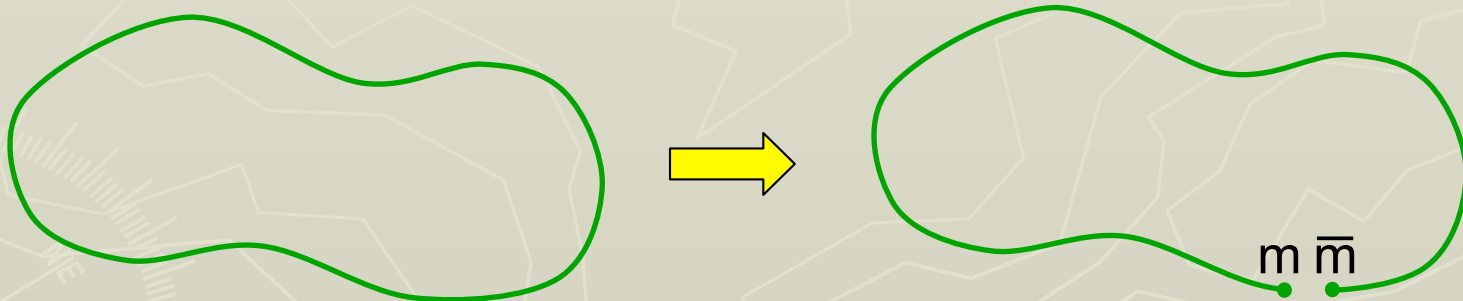
(I will focus on field theory strings, the discussion for F- and D-strings is largely parallel).

There are two kinds of field theory strings, depending on whether the broken $U(1)$ is a global or a gauge symmetry. Global strings have a long-ranged Goldstone boson field, gauge strings do not. Each has a characteristic instability. (There can be totally stable strings, associated with a discrete symmetry, but these do not arise in the simplest models.)

Instability of global strings: in string theory, and more generally in quantum gravity, we do not expect exact global symmetries (e.g. breaking by instantons). Therefore the bottom of the sombrero potential is not exactly flat. This costs extra energy, leading to a confining force that makes the strings collapse.



Instability of gauge strings: gauge strings are characterized by a magnetic flux running down their core. However, in unified theories there are always *magnetic monopoles*. Flux can end at a monopole, corresponding to breaking of the string:



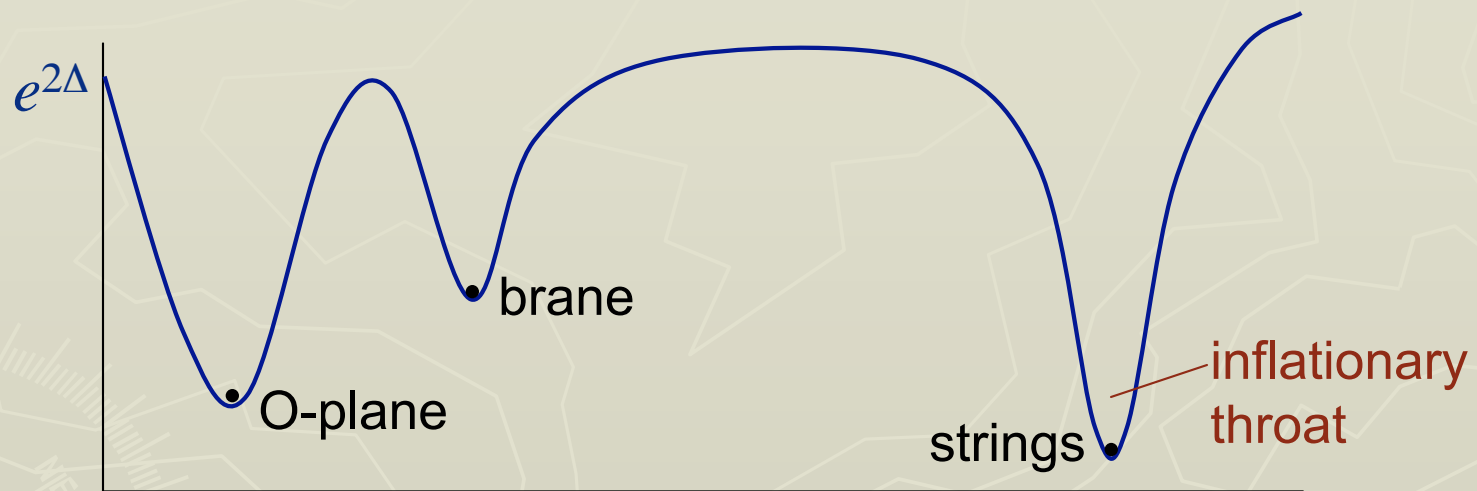
This will take place everywhere along the string, breaking it up into strings of microscopic length.

The strings that arise in models of brane inflation thus far are essentially gauge strings (not obvious: in ten dimensions they couple to a form field, but in these models this has no massless zero mode due to the orientifold or F-theory boundary conditions).

The rate of monopole production is $\exp(-2\pi M_m^2/\mu)$. This is slow provided that the monopole mass M_m is an order of magnitude heavier than the string tension.

String picture:

The strings and branes feel a potential due to a gravitational redshift (warp factor) in the compact directions:



To break the strings must tunnel to one of the other wells. This can be very slow (Copeland, Myers, JP). This is highly model-dependent...

III. Observability

First question: what is $G\mu$? In ten dimensions the strings have Planckian tension, but in four dimensions this can be reduced by large compact dimensions (ADD) or large warp factors (RS).

In specific brane inflation models,

$$\delta T/T \implies H_{\text{inflation}} \implies G\mu$$

First step depends on geometry of branes, and assumes that the inflaton is the source of fluctuations.

Result:

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

Current bounds:

CMB (power spectrum): $G\mu < 10^{-6}$

Gravitational waves:

Effect on Big Bang nucleosynthesis: $G\mu < 10^{-5.5}$.

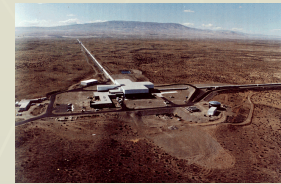
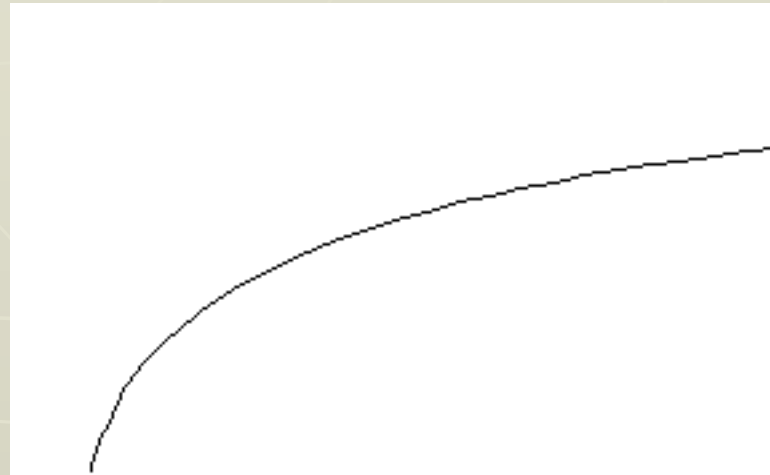
Effect on pulsar timing: $G\mu < 10^{-6}$.

These are all near the upper end of the range from brane inflation, $10^{-12} < G\mu < 10^{-6}$. What are the prospects for improvement?

LIGO and LISA are sensitive to higher frequencies than pulsar timing, and are normally less sensitive to cosmological GW. However...

String cusps

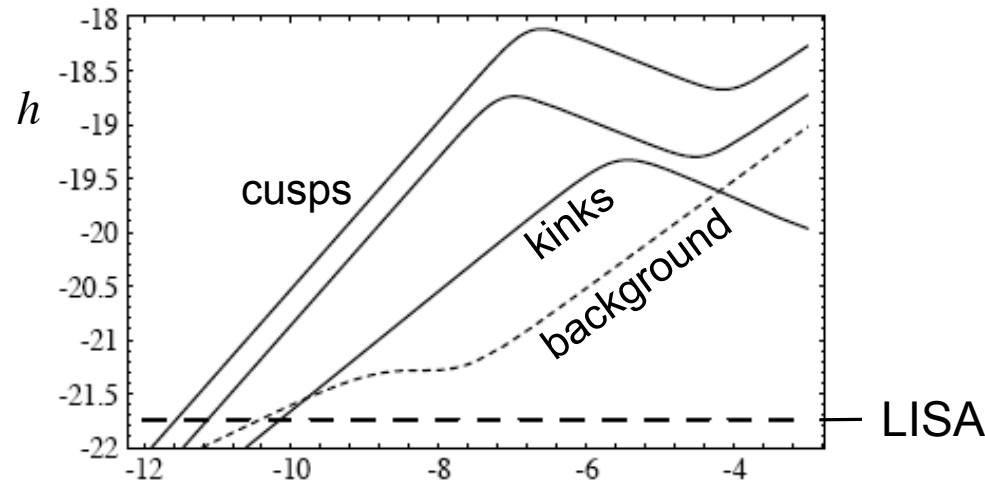
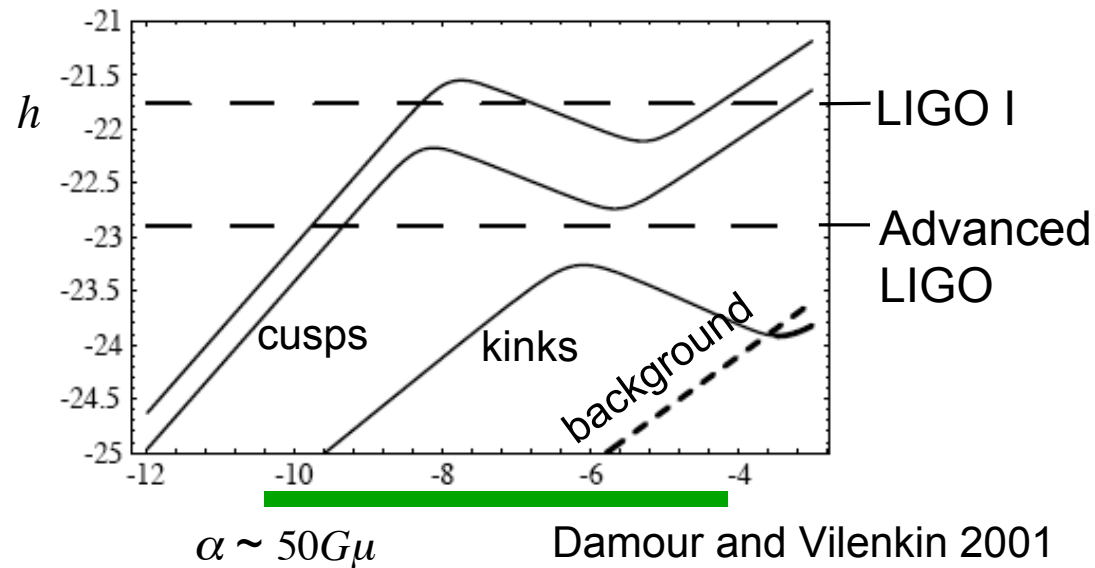
Typically, several times per oscillation a cusp will form somewhere on a cosmic string (Turok 1984).



The instantaneous velocity of the tip approaches c .

The cusp emits an intense beam of GW.

LIGO/LISA signals from string cusps

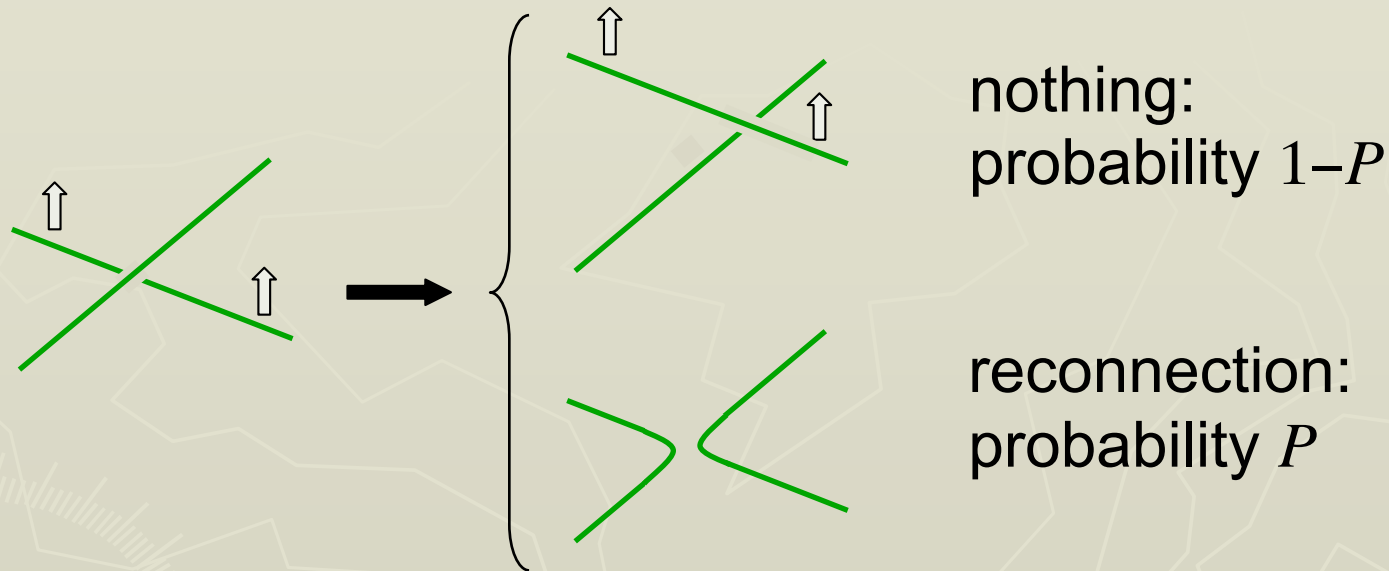


Cosmic strings could be the brightest GW sources, over a wide range of $G\mu$.

Current data:
~ 0.1 LIGO I design-year, perhaps full year in 2005.

IV. Distinguishing superstrings

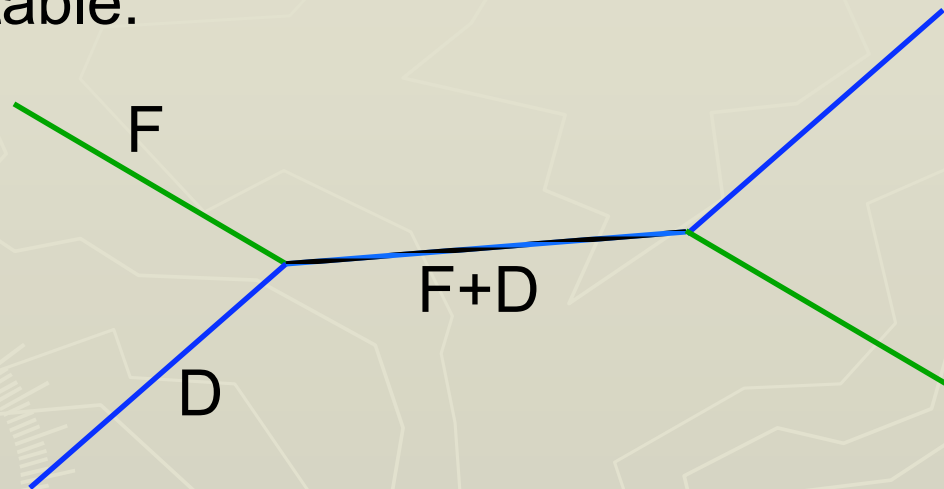
When two strings collide, two things can happen:



Gauge theory solitons always reconnect (energetics: Matzner 1989). Superstrings reconnect with $P \sim g_s^2$ (Jackson, Jones, JP 2004). Model dependence: string coupling, log of compactification scale.

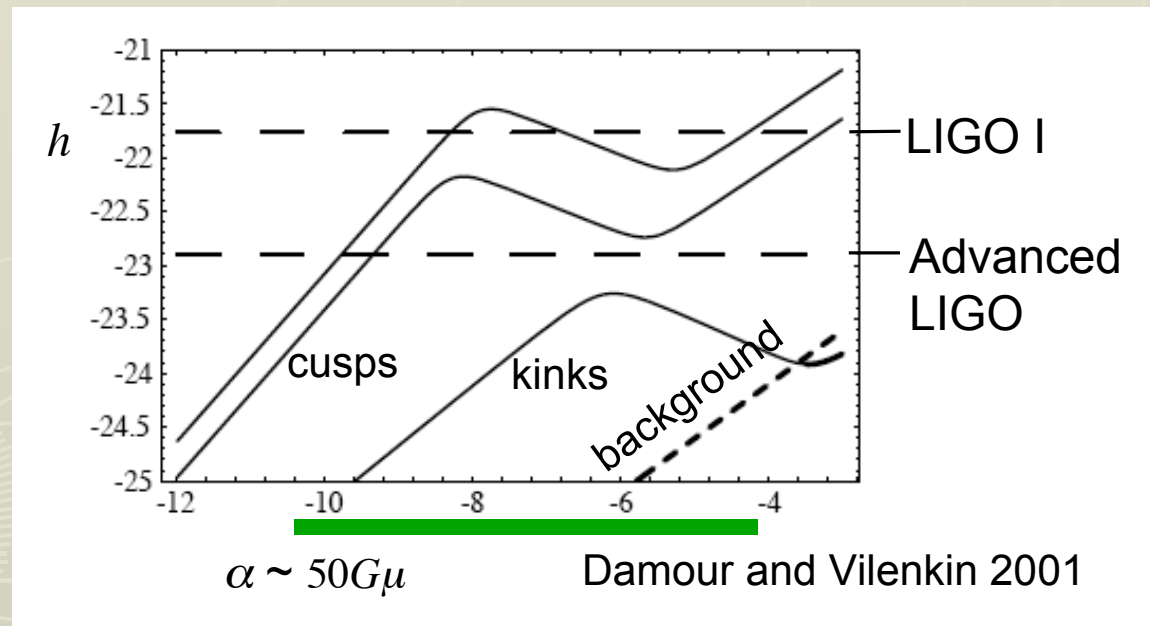
Distinguishing superstrings II

Superstring theories have a special kind of 'defect', the D-brane. One-dimensional D-brane = D-string. This gives richer networks, if both kinds of string are stable:



Distinctive spectrum of strings and bound states.

Superstrings involve new regions of parameter space: smaller $G\mu$, smaller P , as well as the FD networks. All of these may tend to *increase* the signals, but simulations are needed. So it may be even better than



Conclusions

We need cosmic superstrings to be

- Produced
- Stable
- Observable
- Distinguishable

First discovery, then precision science

Cosmic superstrings exist only in some models, but if they do then they have a spectacular signature.