Cosmic Superstrings

Update, Strings 2005

Joseph Polchinski
Kavli Institute for Theoretical Physics
UC Santa Barbara

1. Review

2. Lensing: have we already seen a string (or three)?

3. Short distance structure on cosmic strings

4. Intercommutation and exotic network properties

Review

Necessary conditions:

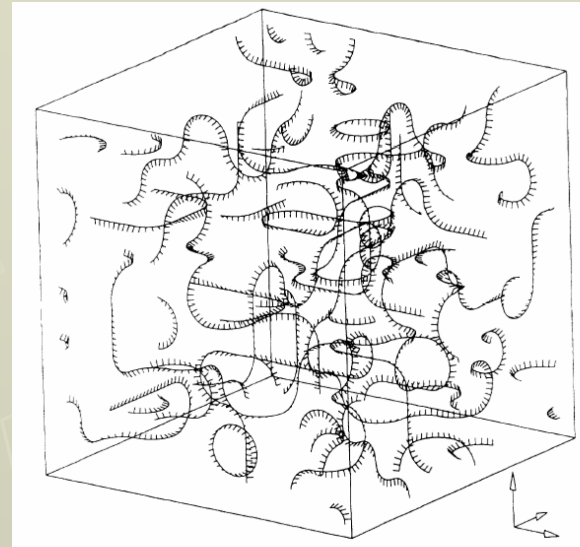
1. The strings must be produced at the appropriate time in the early universe.
2. They must be stable on cosmological time scales.
3. They must be observable, but not already excluded.

Also:

4. It would be good if there were ways to distinguish strings with different microscopic structures.

Production

In hybrid inflation, inflation ends in a symmetry-breaking transition. If a $U(1)$ breaks, a percolating network of cosmic strings forms via the Kibble mechanism (Kofman, Linde, Starobinsky `95).



D-Dbar inflation is a stringy realization of this, and so D-strings should be produced (Jones, Stoica, Tye '02; Sarangi & Tye '02), and also F-strings, since two $U(1)$'s disappear (Dvali & Vilenkin '03; Copeland, Myers, JP '03)

How generic is this?

In M5-M5bar annihilation strings are not produced. In heterotic string theory, weakly or strongly coupled, the most likely cosmic strings seem to arise from the effective gauge theory (electric or magnetic flux tubes, Witten '85)

Side note: Jeannerot, Rocher, Sakellariadou '03 consider general GUTS and (with assumption of monopole suppression and hybrid inflation) argue that cosmic strings are generic.

Stability

Three kinds of string:

Local: no long-range fields.

Global: long-range axion field.

Discrete: long-range Aharonov-Bohm effect.

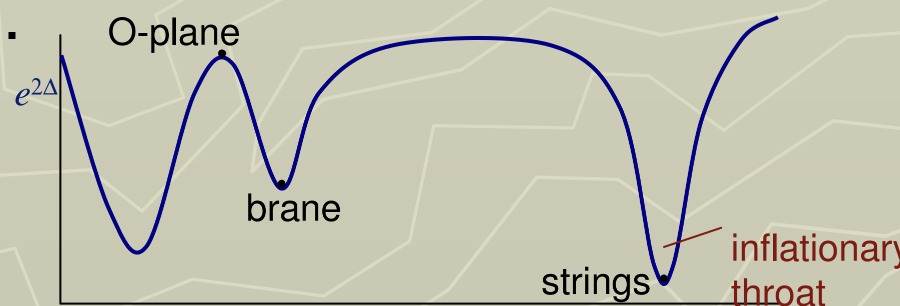
Local strings are unstable to breakage;* global strings are unstable to confinement by instantons.* (Witten '85, Preskill & Vilenkin '92). Discrete strings are stable.

*Anything that can happen will happen.

Decay rate for local strings goes as $\exp(-2\pi M_e^2/\mu)$, M_e = endpoint mass, μ = string tension; this is negligible if $M_e/\mu^{1/2}$ is at least 10.

Global strings are stable only if scale of inflaton potential is suppressed by $O(10^{25})$.

In simplest KKLMMT model strings are *local*; other brane inflation models give local or global strings. Decays of local strings can be suppressed due to warp factor or volume; highly model dependent (Copeland, Myers, JP).



A few more notes on KKLMMT:

String tension is deduced from

$\delta T/T$ (observed) $\Rightarrow H_{\text{inflation}}$ (fixes depth of throat) $\Rightarrow G\mu$

depends on form of potential

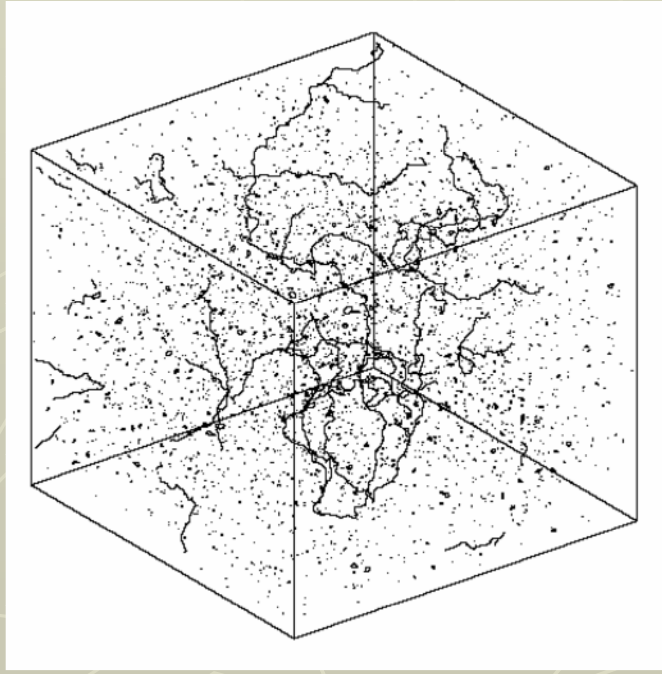
In KKLMMT, geometric mean of $G\mu_{\text{F}}$ and $G\mu_{\text{D}}$ is 2×10^{-10} (small but still interesting). However, they tune ϕ^2 term in potential to zero. More generically it will just be small enough to give enough to give enough e-foldings, in which case one gets the much more interesting range (Firouzjahi & Tye '05)

$$2 \times 10^{-10} < G\mu < 6 \times 10^{-7}$$

Seeing strings

A brief history of the cosmic string network:

1. Percolating strings form.
2. Strings expand with universe.
3. Long strings collide and reconnect, building up short scale kink structure.
4. Loops break off.
5. Loops decay by gravitational radiation.

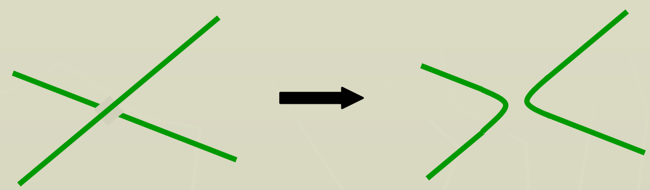


Result:

Scales with horizon size.

Total string length in Hubble volume ~ 100/Hubble length

For now assume simplest networks --- one kind of string, gravitational interactions only, and strings always reconnect when they collide:



Even then are major uncertainties: loop size and short distance structure. With standard assumptions, some bounds:

CMB power: $G\mu < 3.4 \times 10^{-7}$ (Wyman, Pogosian, Wasserman '05)
CMB pattern: $G\mu < 6 \times 10^{-7}$ to 6×10^{-6} (Jeong & Smoot '04, Lo & Wright '05)
Pulsar timing (grav. waves): $G\mu < 10^{-6}$ (Lommen '02)*
*Very sensitive to loop size, could be much stronger (Damour & Vilenkin '04)

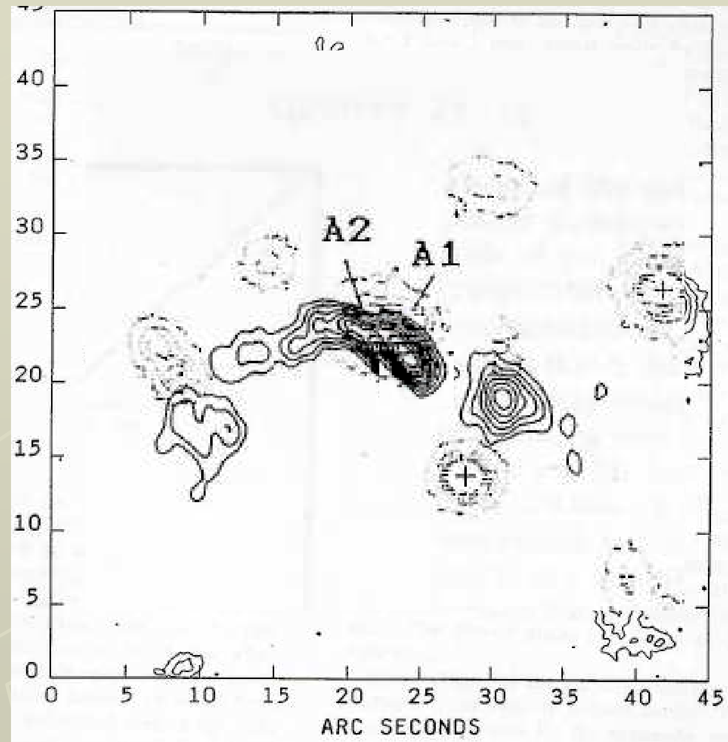
Future: CMB and lensing vs. pulsars and LISA/LIGO .

Lensing

Field of four cosmic string lens candidates. Each pair at single redshift; each separation around 2”.

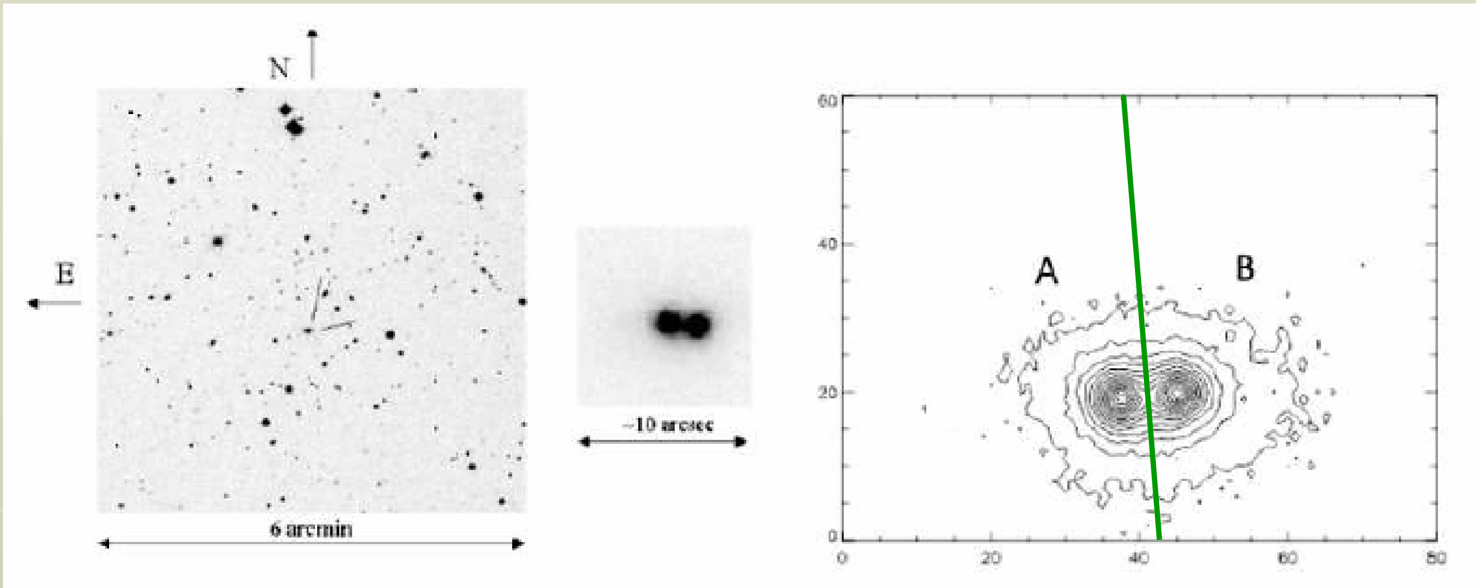
Cowie & Hu ‘87

Observations in radio ‘90.

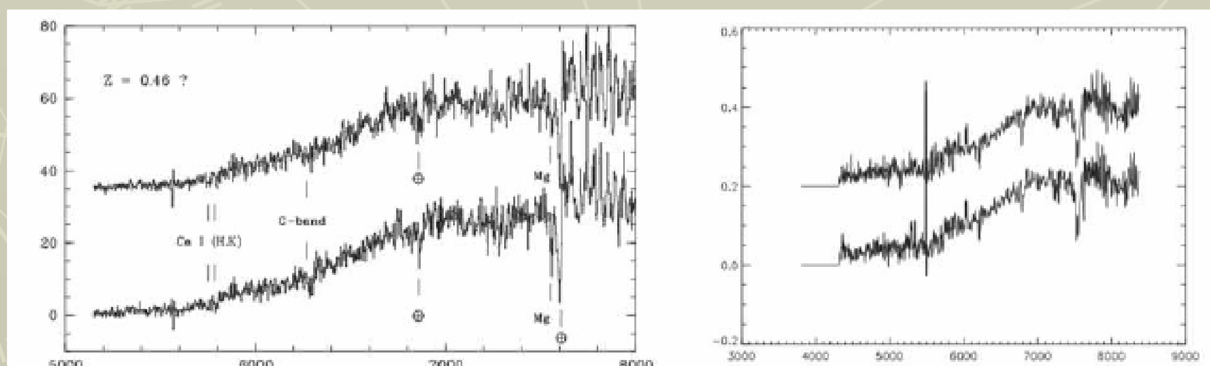


Apparent explanation:
a random group of binary galaxies. A cautionary tale.

A cosmic string lens (CSL1)?



Sazhin, et al. 2003. $\delta\phi$ ~ 2”.



Lensing angle (Schlaer & Tye '05):

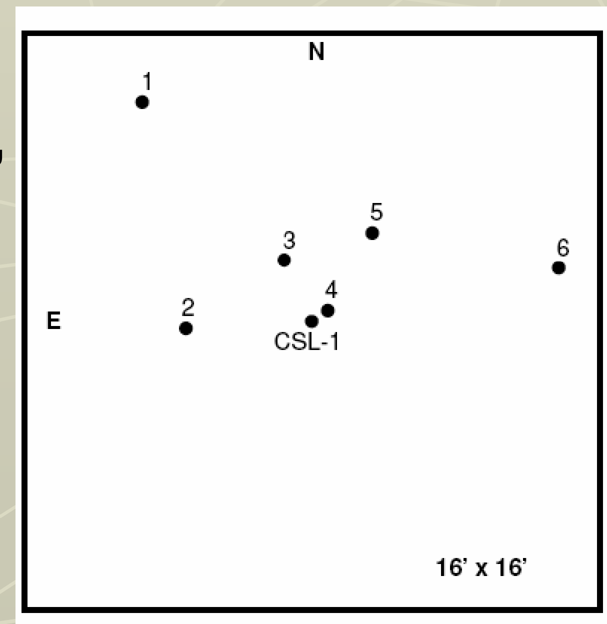
$$\delta\phi = 8\pi G\mu (D_{s,cs}/D_{s,O}) \cos\theta\, (1+\mathbf{v}\cdot\mathbf{n})/(1-v^2)^{1/2}$$

$D_{s,cs}$ = source-string distance
$D_{s,O}$ = source-observed distance
$\mathbf{n}$ = vector from observer to to source
$\mathbf{v}$ = velocity of string
θ= angle between $\mathbf{n}$ and string direction

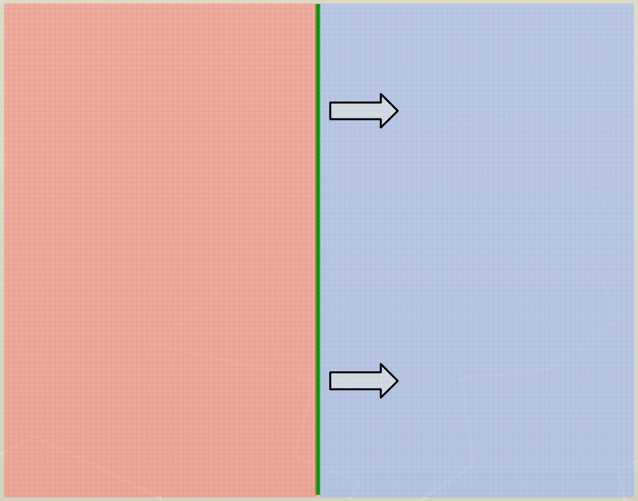
Red factors reduce $\delta\phi$, green increase, blue go either way. If geometric factors = 1, $G\mu = 4 \times 10^{-7}$.

Further indications:

- `Spectra identical with confidence level 99.9%' --- not clear what this means, spectra of ellipticals do not vary greatly.
- Residual image A - B = 0 consistent with background --- again, ellipticals have very simple shape.
- Eleven other candidate lenses in nearby field - consistent with string, vs. two expected from normal lenses. Interesting, but too disordered?



• Lo and Wright report 2-sigma feature in CMB.

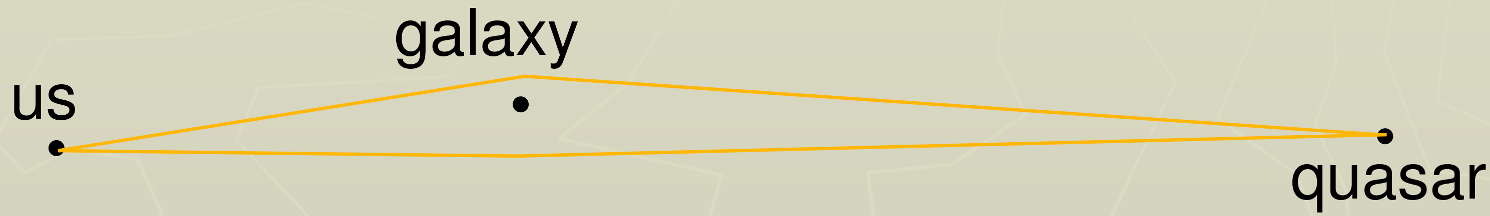


A moving string produces a differential redshift ~$8\pi G\mu\, v/(1-v^2)^{1/2}$. Consistent if $D_{s,O} v/D_{s,cs} \sim 3.3$ (angles = 90°).

• Will be observed with Hubble in the next year. Main advantage is 10 time better spatial resolution, can detect sharp edge between images.

Evidence for a string loop? (Schild, Masnyak, Hnatyk, Zhdanov '04)

Well-known lens system Q097+561:

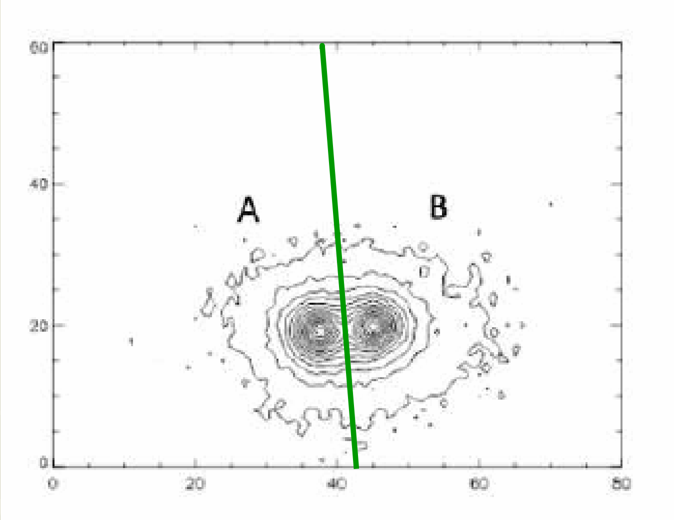


Quasar fluctuates, time delay 417 days (well-studied). Schild et. al report *simultaneous* period oscillations (4 osc., period 100 days), which they attribute to a string loop in the foreground.

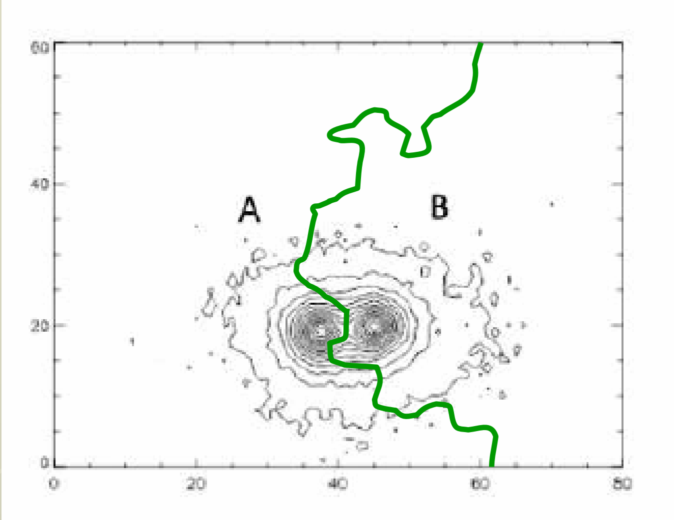
Intrinsic likelihood low.

Short distance structure

Is the CSL-1 image too good? Which do we expect:

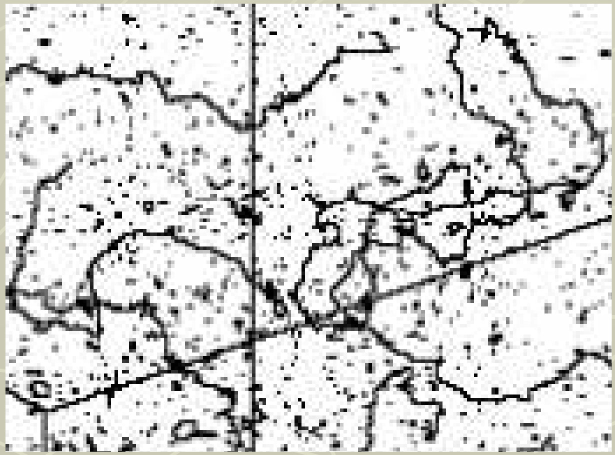


or

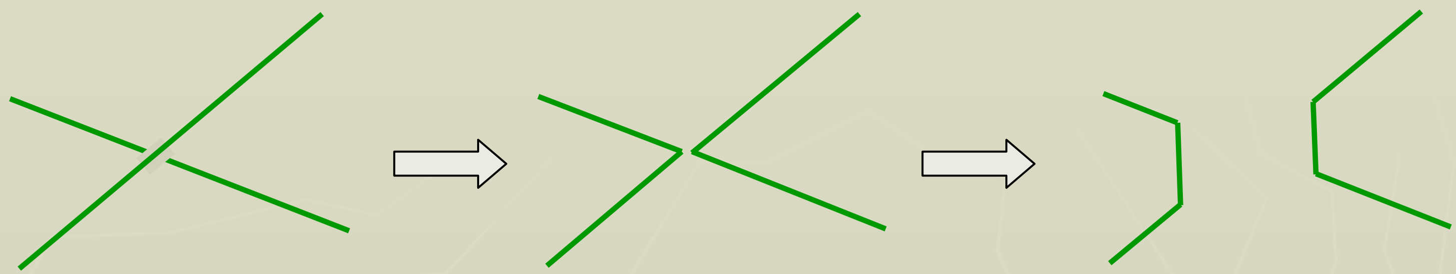


?

Cosmic string networks have a kinked structure, which persists down to short distances, but there is no good quantitative understanding.



Origin of kinked structure:



Each long-string reconnection produces four kinks, which move right or left indefinitely under Nambu action.

Kinks can decay (smooth out) due to gravitational radiation. This sets in near the scale $8\pi G\mu t$ of lensing, but does not effectively straighten the string until shorter scales (decay is power-law not exponential - Seimens, Olum, Vilenkin ‘02).*

Expansion of universe dilutes kinks:

Kinks/length $\propto a^{-1+2\overline{v^2}}$

a = scale factor

$\overline{v^2}$ = average v^2 (RD: $v^2 = 0.43$, MD: $v^2 = 0.37$)

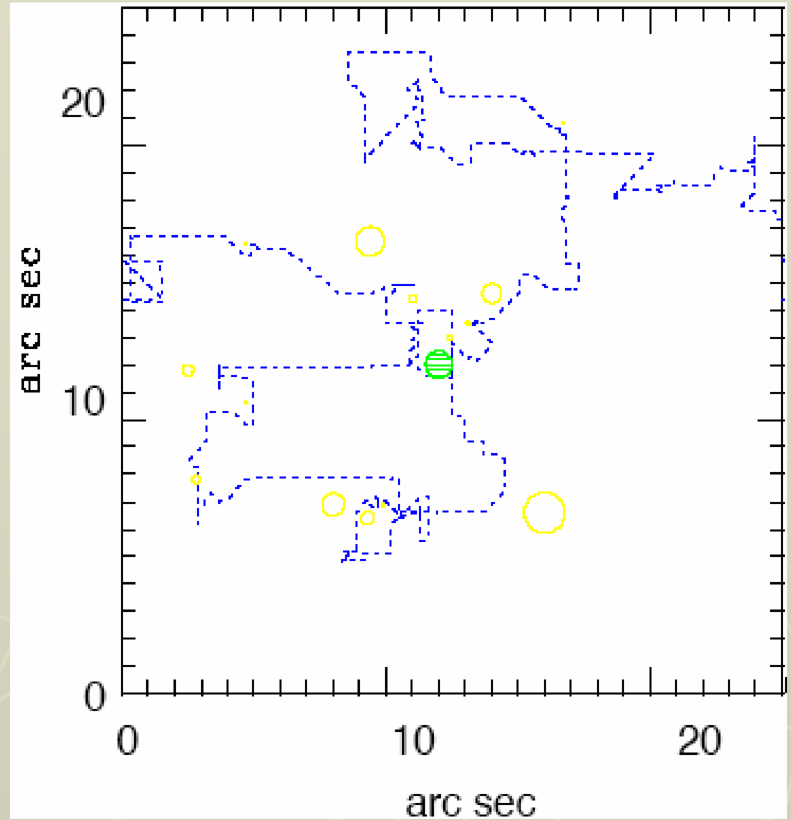
Kink angle also $\propto a^{-1+2\overline{v^2}}$

$\rightarrow$strings slowly smooth as seen at given physical scale, but as seen on horizon scale ($\propto t$) they become steadily more kinked (Bennett & Bouchet '90).

Expect largest kink in 2" length to be of order 6°, but there should be of order 100 kinks greater than 3°: correlations between kinks are all-important.

An extreme possibility:

green = source
yellow = images

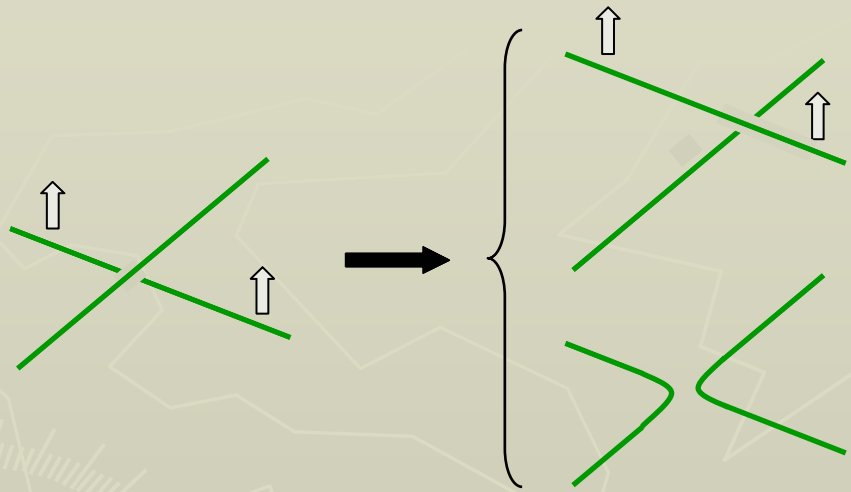


However, this is an impossible picture: loop production is too large ($10^4/H$ vs. $1/H$) --- unless $P = 10^{-4}$

--- but that is impossible too!

Studying string microphysics:

When two strings collide, two things can happen:



nothing:
probability $1-P$

reconnection:
probability P

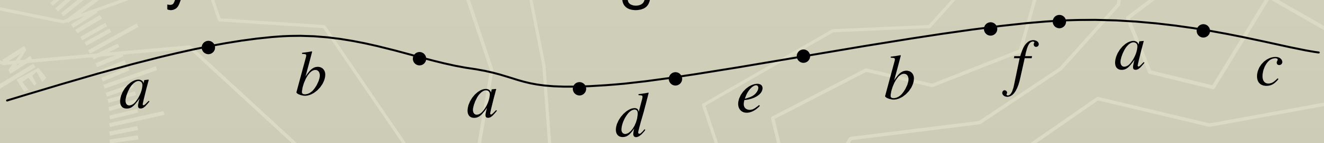
Gauge theory solitons in typical models reconnect if $v_{cm} < 0.9$; effective P around 0.98.

For F-strings $P \sim g_s^{\,2}\,(2\pi/\ln[\mu/m^2_{perp}])^3$
(Jackson, Jones, JP '04).

More on field theory string reconnection --- Hanany & Hashimoto '05, Hashimoto & Tong '05. Large P in one variant model; another has N kinds of string with $P_{\text{self}} = 1$ and $P_{\text{other}} = 0$. $P \sim 1/N$, but not exactly:

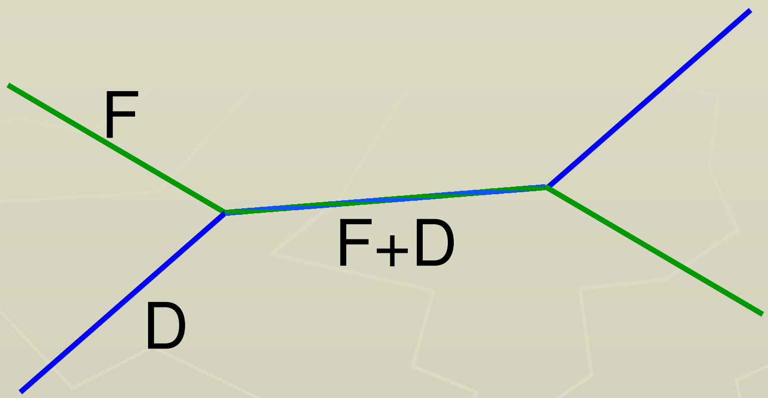
At small P long string density grows as $1/P$, and short distance kinkiness also increases. HT strings have only the former.

Probably can also distinguish



Note: *electric* flux tubes have $P \propto 1/N_c^2$.

With multiple string can also have bound states and junctions:



Apparently these networks also scale (Martins; Tye, Wasserman & Wyman; Copeland & Saffin ‘05).

Very interesting, especially for lensing.

Conclusions:

Have we already seen cosmic strings?

Will we see them in the future?

If we see them, can we learn some interesting things?

Will there be a talk on cosmic strings at Strings 2006?