Title: Detecting Cosmic Strings in the CMB

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URL: http://pirsa.org/08060116

Abstract: We further advance the application of the Canny algorithm for detecting cosmic strings in CMB maps.

Detecting Cosmic Strings in the CMB

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McGill University

Collaborator: Robert Brandenberger

Starting point: Amsel, Berger, and Brandenberger (2007)

June 3, 2008 PASCOS

1 Introduction to Cosmic Strings

- What are cosmic strings? How are they formed?
- Why might cosmic strings be present?
- What are the current bounds on cosmic strings?
- Why are current bounds not optimal?

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   - What are cosmic strings? How are they formed?
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2. **Cosmic String Signatures**
   - Cosmic String Gravity
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   - Why is the Canny algorithm ideal to detect cosmic strings?

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3. **Numerical Studies**
   - Overview
   - Simulators
   - Canny Algorithm
   - Test Results

Introduction to Cosmic Strings

What are cosmic strings?

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- One-dimensional topological defects

Introduction to Cosmic Strings

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- One-dimensional topological defects
- Very massive
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Introduction to Cosmic Strings

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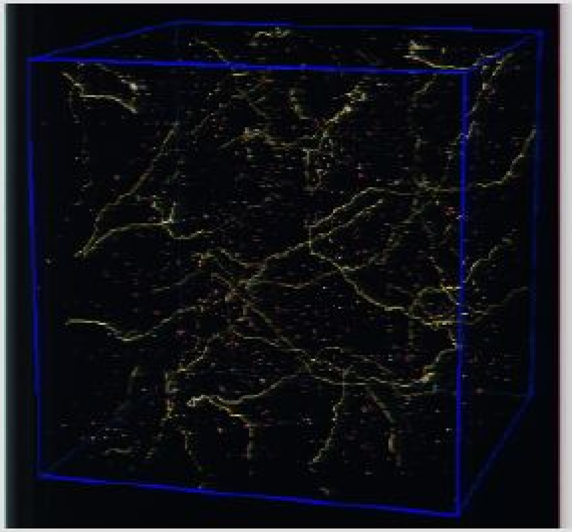
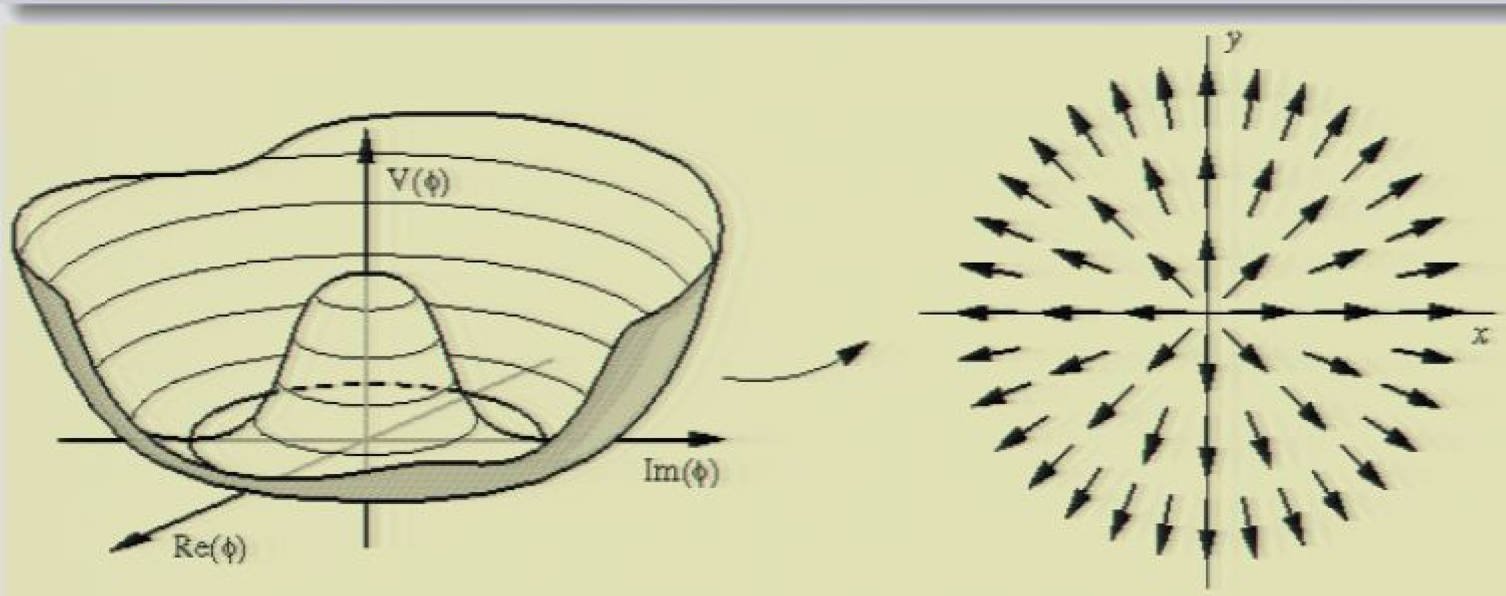
C. Martins & E. P. Shellard: Initial cosmic string network simulation



B. Allen & E. P. Shellard: Late time simulation of cosmic strings

How are cosmic strings formed?

- Spontaneous Symmetry breaking: $\langle 0|\phi|0\rangle \neq 0$
- Phase transitions $\longrightarrow$ topological defects
- Grand Unification Transition: $t = 10^{-43} \rightarrow 10^{-35}$s at $T = 10^{15} GeV$ $\Rightarrow$ Kibble Mechanism
- Causality $\Rightarrow$ Strings exist at all times on super-Hubble scales (given symmetry breaking)
- $\pi_1(\mathcal{M}) \neq 0$



(DAMTP's webpage)

Scaling Solution for String Network

Cosmic Strings

RJD

Outline

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Conclusions

Scaling Solution for String Network

- Order of 1 infinite string segment per Hubble volume

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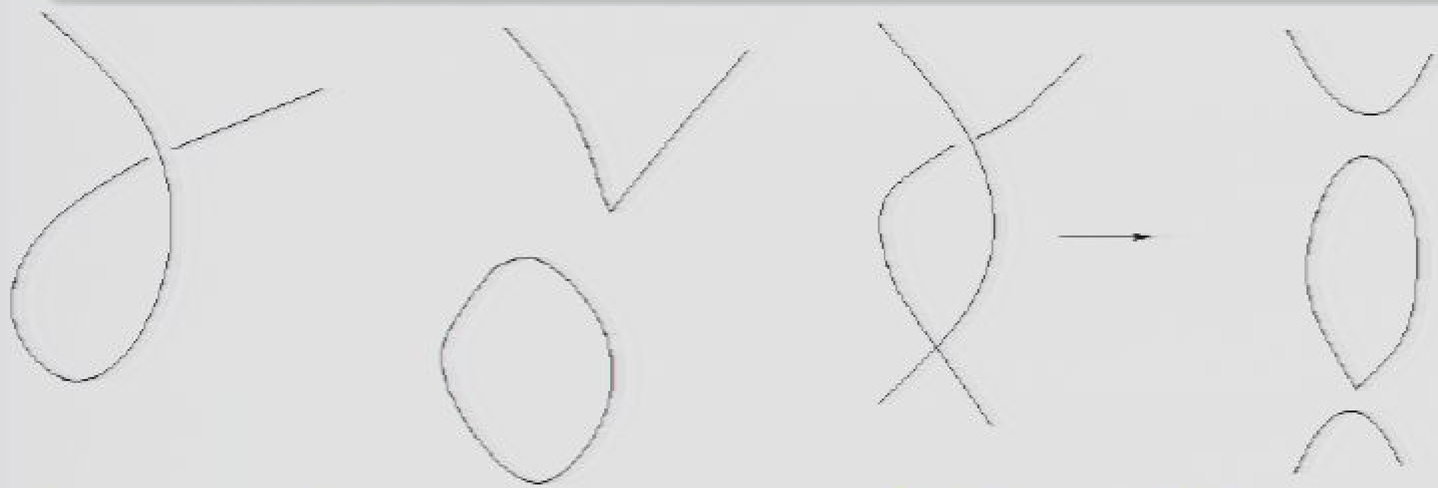

A string self-intersecting

A string collision

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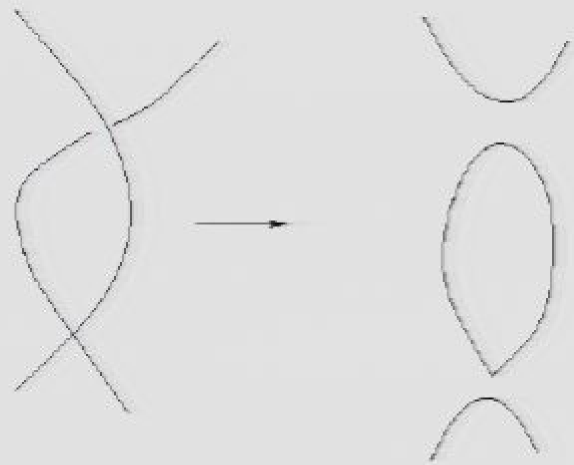

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Why might cosmic strings be present?

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Predictions of strings:

- Brane inflation models

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- Viability of Cosmic F- and D- Strings
  - Polchinski, hep-th/0412244
  - Copeland, Myers, Polchinski, hep-th/031206

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- Supergravity inflation models
  - Jeannerot hep-ph/9509365

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$G\mu < 10^{-5}$

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$G\mu < 10^{-8}$ and $G\mu < 10^{-5.5}$

- Pulsar timing measurements
  (Dependent on arguable assumptions of properties of cosmic string loop distributions$\Rightarrow$ Not robust)

Why are current bounds not optimal?

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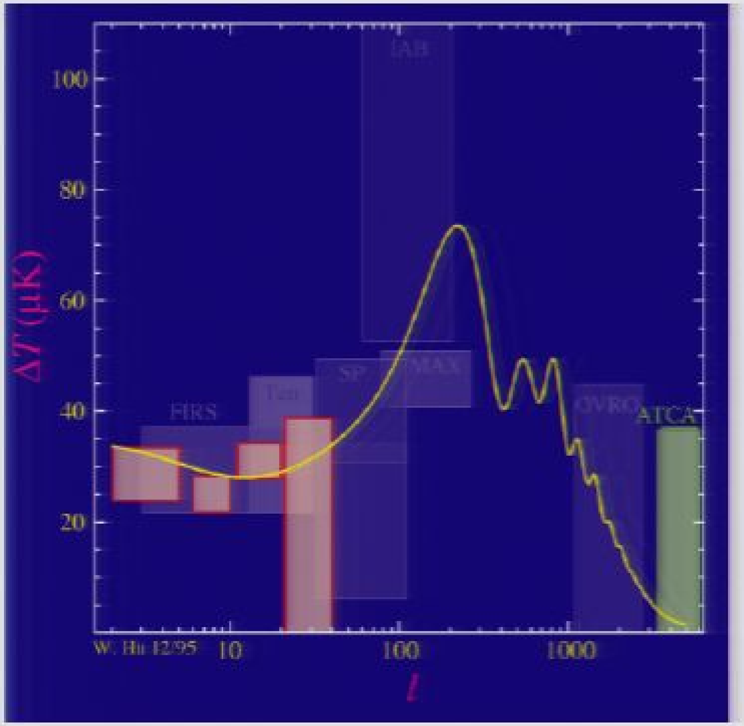
Current bounds:

- Not based on string-specific signatures.
- Based on quantities such as CMB power spectrum
  - $\Rightarrow$ string specific features are smeared out



(MAP Year 1: Wayne Hu's webpage)

Cosmic String Signatures

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Cosmic String Gravity

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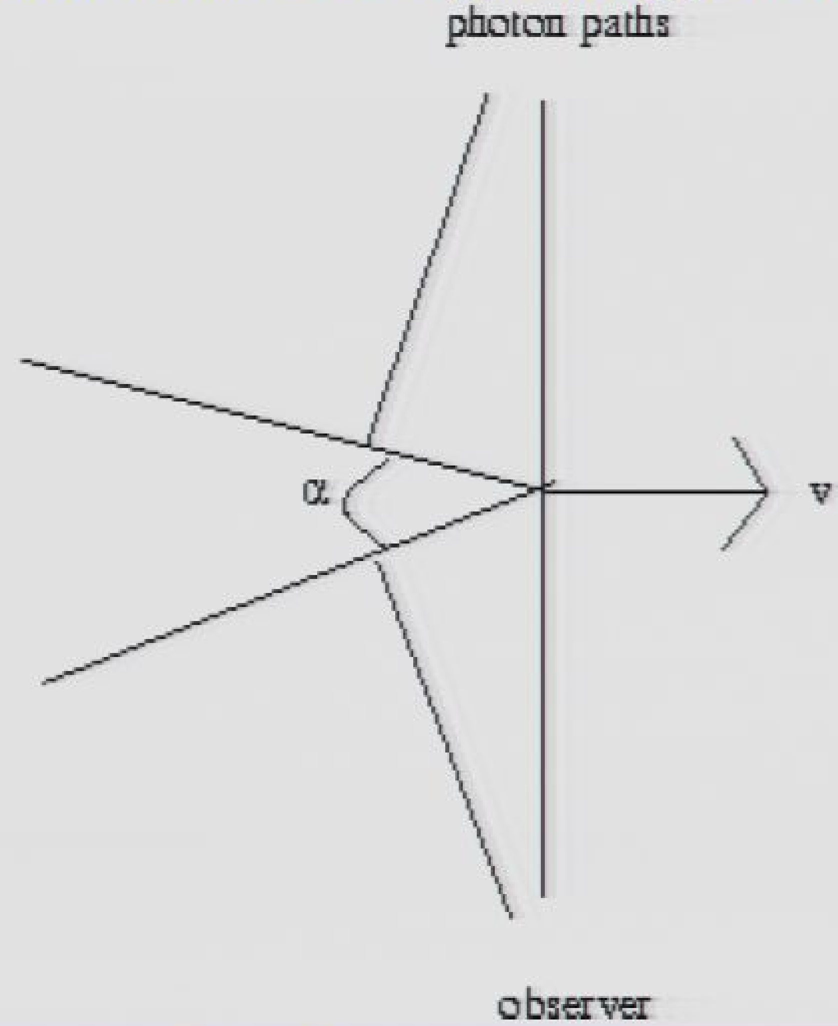
Gravitational Lensing & Doppler Shift



Kaiser Stebbins Effect:

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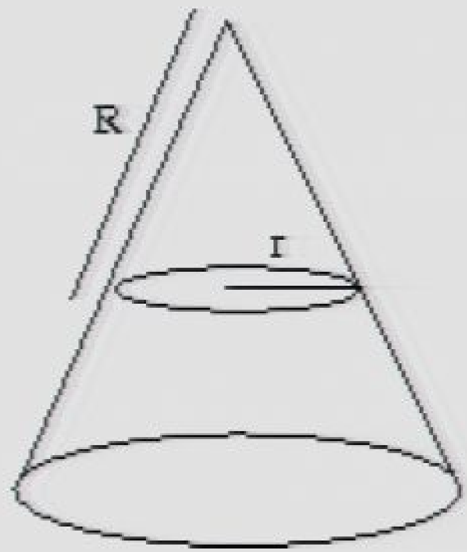

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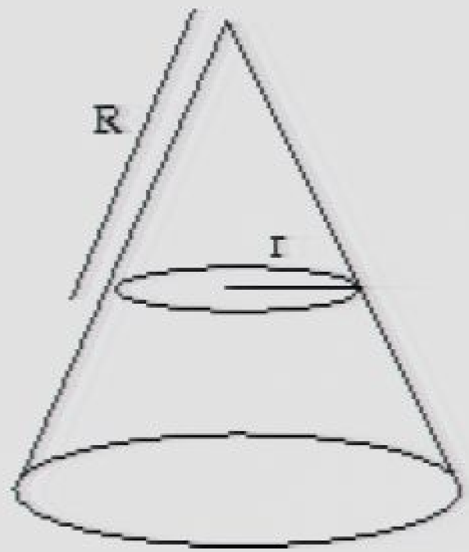

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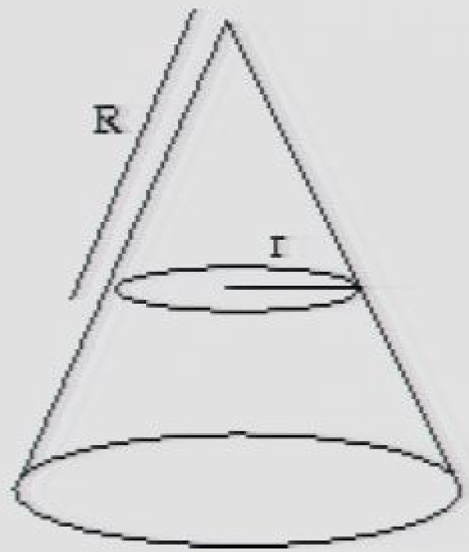

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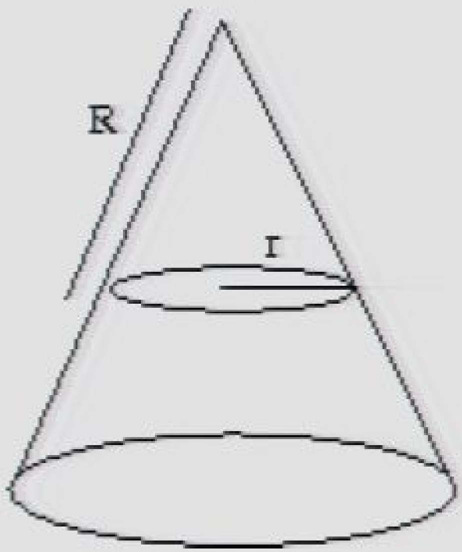

- Deficit angle: $\alpha = \frac{2\pi R - 2\pi r}{R} = 8\pi G\mu$
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- Scale invariant spectrum of cosmological perturbations

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Why is the Canny algorithm ideal to detect cosmic strings?

- Canny algorithm finds line discontinuities and produces a map of the edges.
- Because of the Kaiser-Stebbins effect, strings produce line discontinuities.

Numerical Studies

Numerical Studies

Overview

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- Simulate a Gaussian Temperature Map using CAMB

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- Simulate cosmic strings as straight line segments

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- Simulate cosmic strings as straight line segments
- Edge search: Find segments of maximum gradients in simulated maps
- Compare edge lengths in simulated maps

Simulators

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Gaussian Map Simulator

Assumption: Flat Sky Approximation

$$\frac{\Delta T}{T} = \sum_{l,m} a_{lm} Y_{lm}$$

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Gaussian Map Simulator

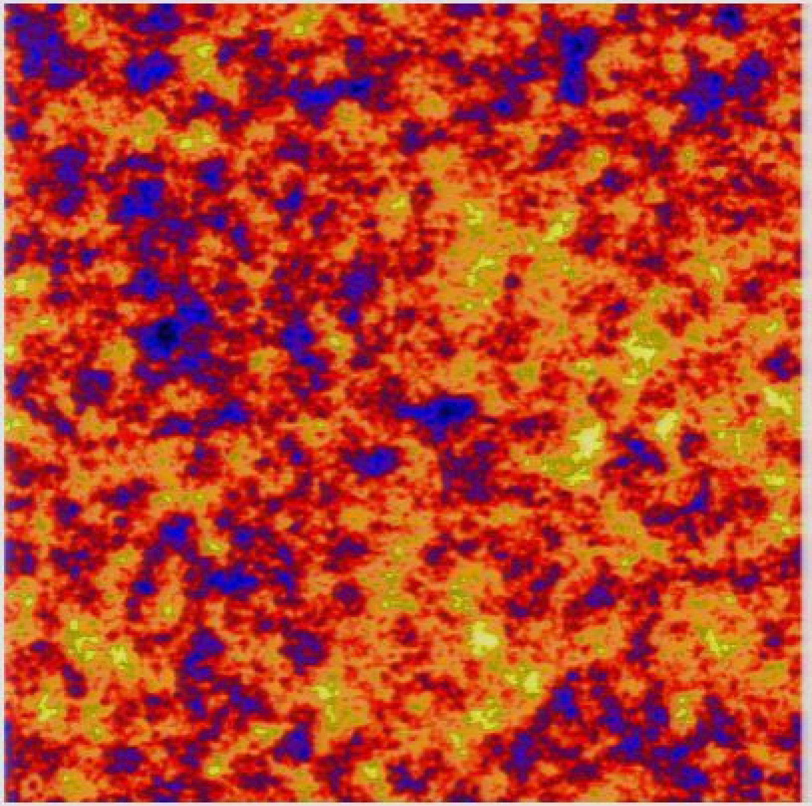
Assumption: Flat Sky Approximation

$$\frac{\Delta T}{T} = \sum_{l,m} a_{lm} Y_{lm}$$

$$\frac{\Delta T}{T} = \sum_{k} T(\boldsymbol{k}) e^{i\boldsymbol{k}\cdot\boldsymbol{x}}$$

$$\langle T(\boldsymbol{k})^2 \rangle = \langle a_{lm}^2 \rangle = C_{l(k)}$$

Gaussian Temperature Map Simulation



Cosmic String Simulator

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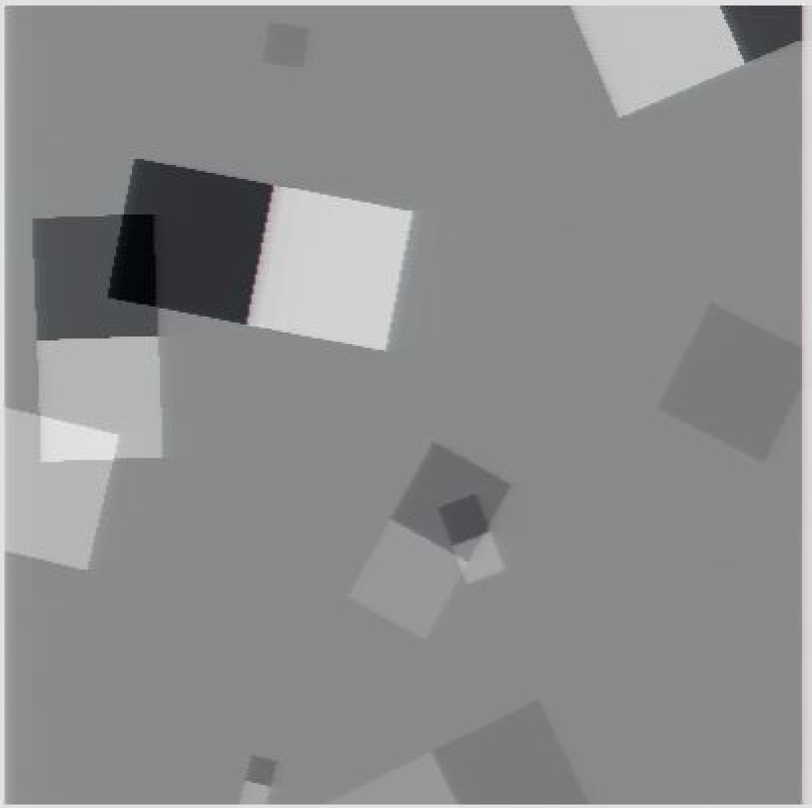
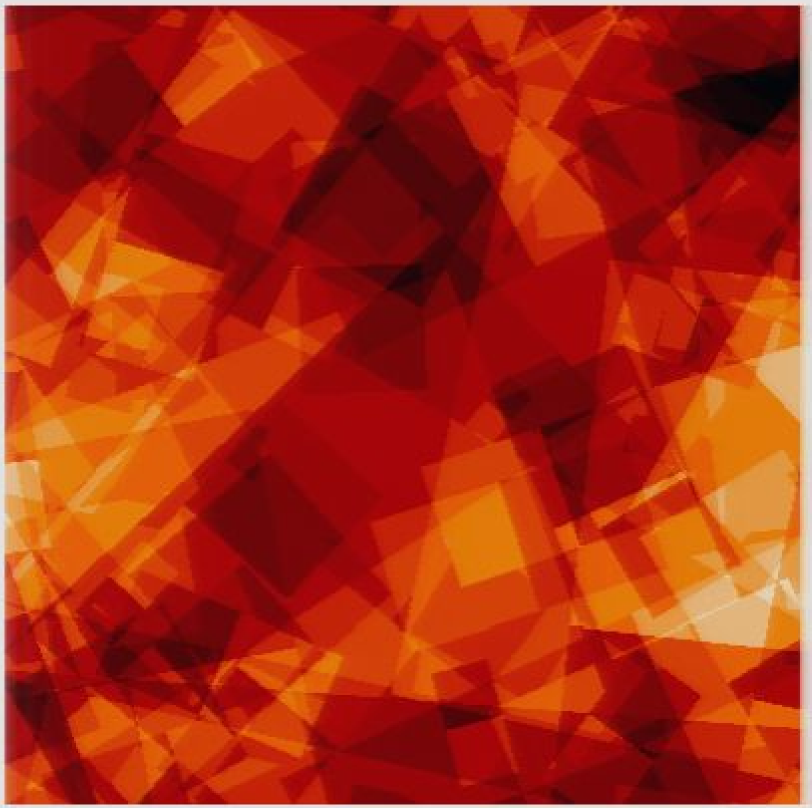
- Simulate strings via KS effect on surface of each time interval
- Superimpose simulated surfaces

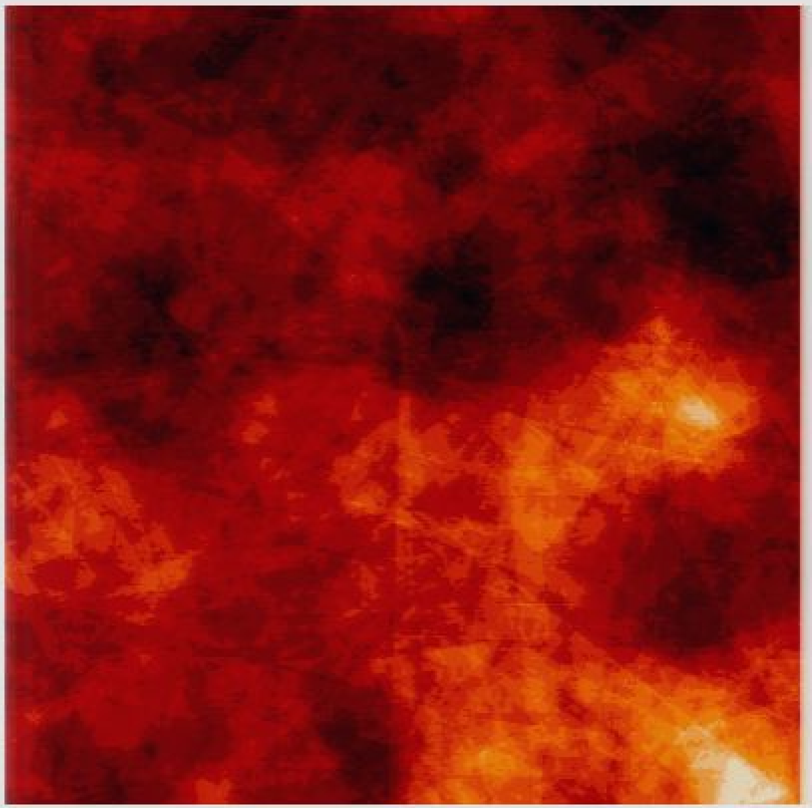
A Few Strings



Full simulation for N=1



Full simulation for N=10



Canny algorithm

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Canny algorithm

- Smooth Map: Eliminate point source noise
- Find the smoothed map's gradient
- Find local maxima in the gradients
- Sort through local maxima
- Assign grid points:
  - Greater than an upper threshold as 1
  - Between lower and the upper thresholds 1/2
- Turn grid points marked as 1/2 into 1 if criteria are met

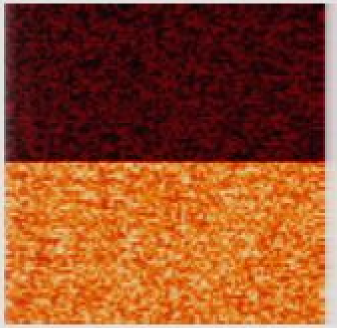
Cosmic Strings

RJD

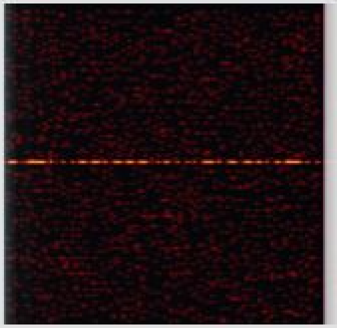
Test Results

Tests on a single string

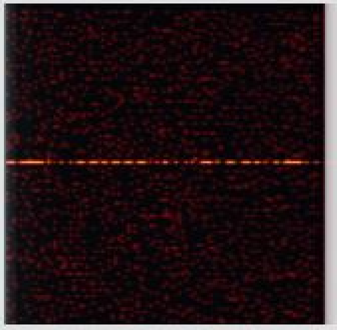
Temp. Map



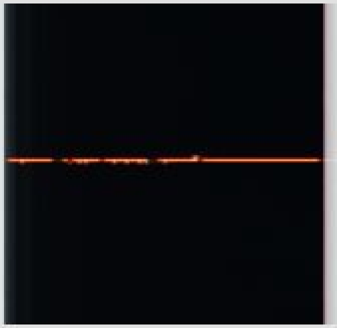
Points marked as 1 and 1/2



New pts marked as 1



Edge map



Gaussian Map

Point Marked as 1

Edges

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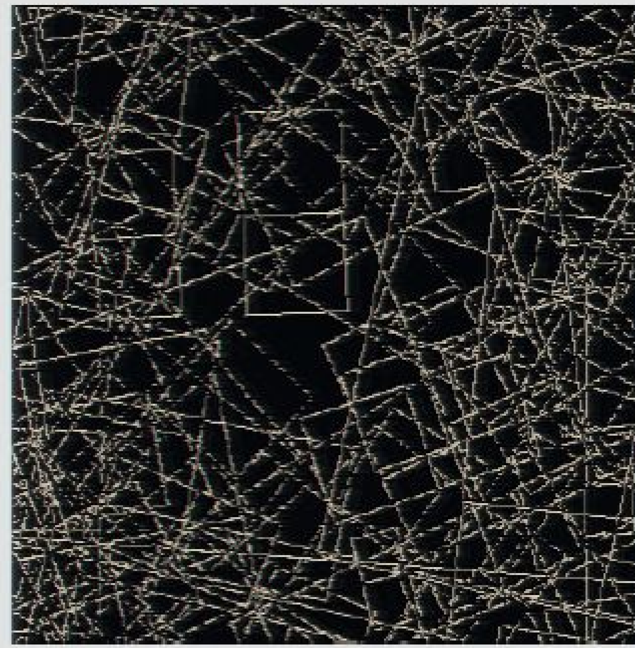
String Simulated Map N=1

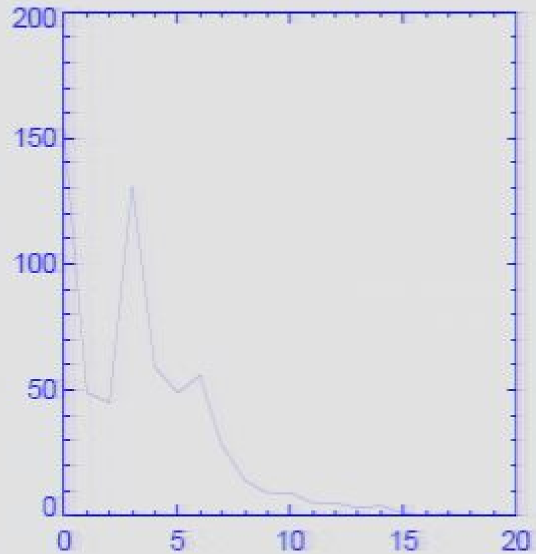
Points Marked as 1

Edges

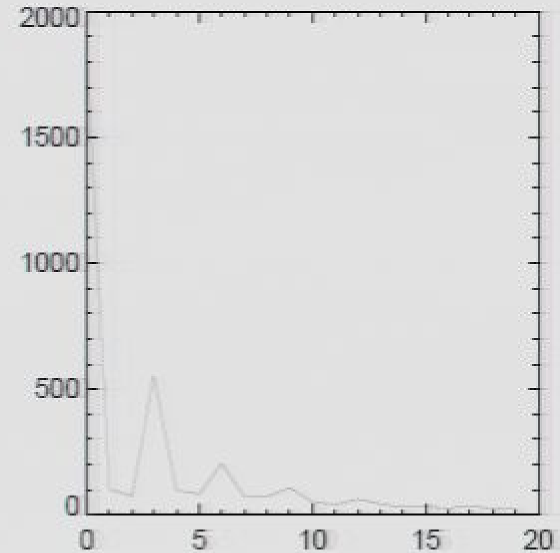


Edge Length Histograms
Number of edges versus edgelength

Gaussian Edge Lengths



String Simulated Map Edge Lengths



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- Canny algorithm finds longer edges for cosmic strings than the purely inflationary perturbation temperature map