Gravitational Wave Bursts from Cosmic Superstrings

Henry Tye
(with David Chernoff)

Hong Kong University of Science and Technology
Cornell University

NCTS, NTHU, Taiwan
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Motivation

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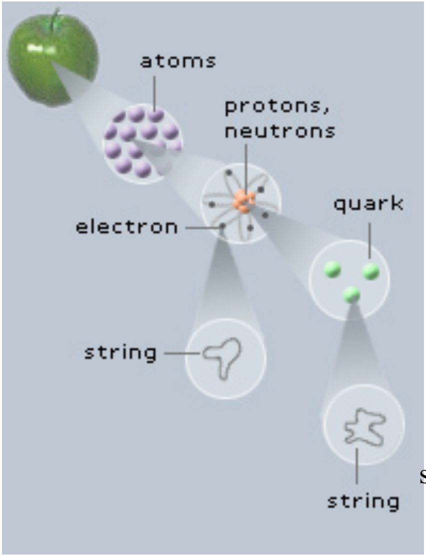
Cosmic strings have been proposed earlier as a source to generate density perturbation for structure formation. That has been ruled out by 2000.



String Theory

弦理论

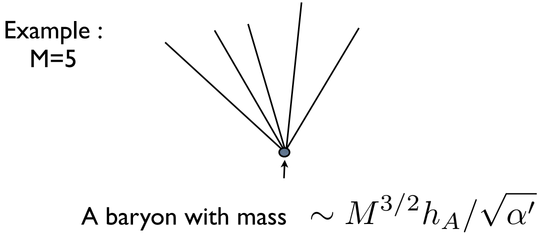
String theory has
9 spatial dimensions.

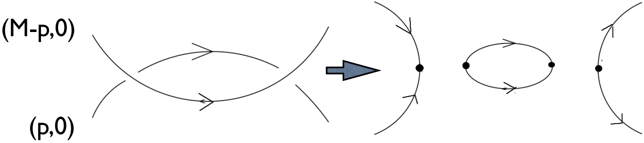
3 dimensions are large, spanning our universe.

The other 6 dimensions are very small, compactified into a Calabi-Yau manifold.

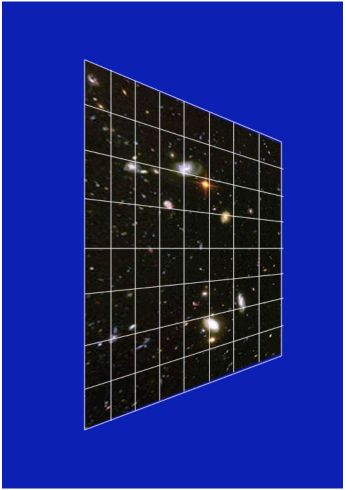
Cosmic superstrings are very different from standard cosmic strings.

There are two types of strings : fundamental strings (F1-strings or F-strings), and D1-branes (D1-strings or D-strings)

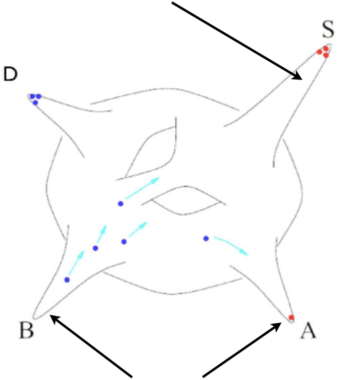




Brane World



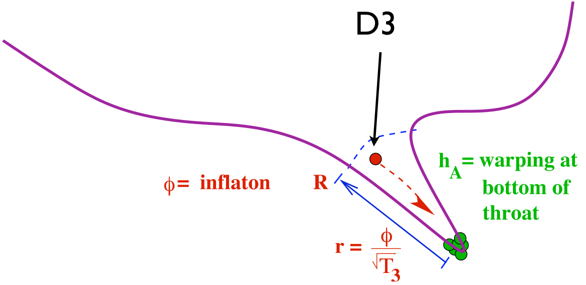
Dozens to hundreds of Warped Throats



Cosmic superstrings at the bottoms of throats

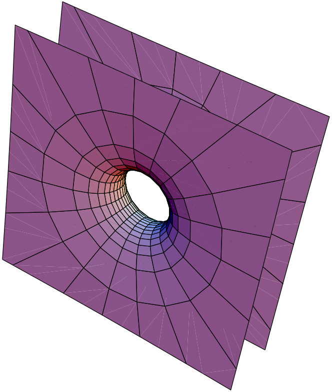
A simple inflationary scenario

Brane inflation:
D3-brane attracted towards
anti-D3-brane



Brane inflation:

D3-anti-D3-branes tensions provide the vacuum energy that drives inflation



D3-brane and anti-D3-brane annihilate at the end of inflation:

All energy released goes to strings:

fundamental strings and D1-strings

Cosmic superstrings produced towards the end of inflation

Simplest version of D3-$\bar{D}$3-Brane Inflation

$$V(\phi) = V_A + V_{D\bar{D}} = \frac{64\pi^2}{27}\frac{\phi_A^4}{N_A}\left(1 - \frac{\phi_A^4}{N_A}\frac{1}{\phi^4}\right)$$

$$n_s = 0.967, \qquad r \simeq 10^{-9}$$

F-strings and D-strings were produced towards the end of inflation.

The tension of $F1$-strings is $G\mu \simeq 10^{-10}$

The bound from pulsar timing was

$G\mu \lesssim 10^{-9}$

$\rightarrow G\mu < 10^{-11}$ (preliminary result)

Presumably, cosmic superstrings are produced in other stringy inflationary scenarios.

$$H^2 \propto \Lambda + \frac{\rho_{strings}}{a^2} + \frac{\rho_{matter}}{a^3} + \frac{\rho_{radiation}}{a^4}$$

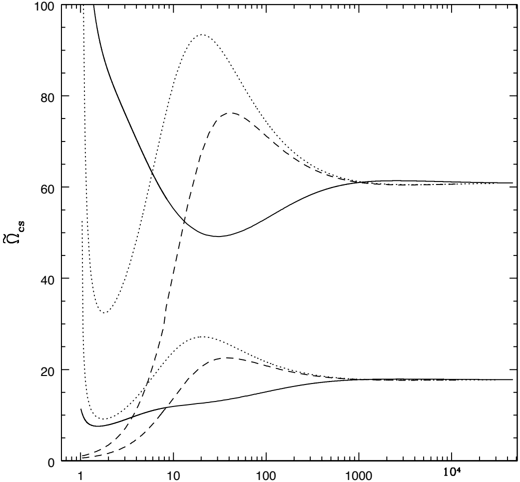
$$\rightarrow \qquad \Omega_{strings} \simeq \Gamma G\mu \sim 50 G\mu$$

• Besides fundamental F-strings, only "defect" produced is D-strings.

• D-strings and F-strings can form bound states, with junctions and beads. So we have a tension spectrum that depends on the throat they are in.

(Cosmic strings approaches a scaling network, dictated mostly by the string tension $G\mu$.)

$$\Omega_{cs} = 8\pi G\mu\Gamma$$



• Cosmic superstrings in different throats evolve independently. Multiple throats ($N_T \sim 10 - 10^2$), each throat with $G\mu_i < 10^{-10}$ and a spectrum of bound strings ($N_s \sim 1 - 3$).

• The inter-commutation probability $P_{ic} = 1$ for ordinary strings, but $P_{ic} \leq 1$ for superstrings. It can be as small as $P_{ic} \simeq 10^{-3}$. (Jackson, Jones, Polchinski, 2005)

• A superstring loop can oscillate at the bottom of a throat : varying tension along the loop and in time.

$$\Omega_{superstrings} \sim \mathcal{G}\Omega_{string} \simeq (N_T N_s P_{ic}^{-1/2})(\Gamma G\mu)$$

• $10^4 > \mathcal{G} > 1$ so $\mathcal{G} \simeq 10^2$ is easy. $\Gamma \sim 50$.

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• $10^4 > \mathcal{G} > 1$ so $\mathcal{G} \simeq 10^2$ is easy. $\Gamma \sim 50$.

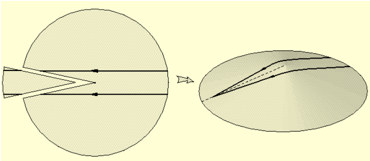
• The string loops decay via gravitational radiation. Low tension ($G\mu < 10^{-11}$) string loops live long and their relativistic motions get damped. So they cluster, just like dark matter.

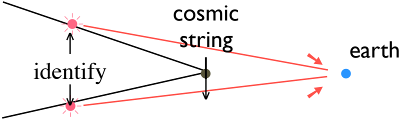
String density in galaxy is enhanced via clustering by up to about 2×10^5 for $G\mu < 10^{-11}$.

Lensing of objects :

If the tension is low, it can lens only stars.

If we cannot resolve them, then we can only find that the luminosity doubles. This is mocro-lensing.

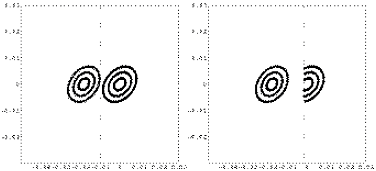


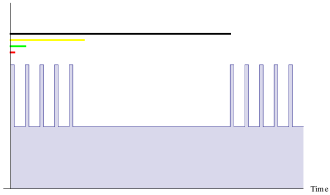


Micro-Lensing

Lensing by a straight string segment :

- Double images but not resolved.
- Can reach $G\mu \sim 10^{-14}$
- Exoplanet search may reach $G\mu \sim 10^{-18}$.
- Fingerprint: Achromatic, repetitive flux doubling. Lensing duration $\rightarrow G\mu$. Lensing repetitions $\rightarrow l_g$. Direction!





2 Key Points :

• String density is enhanced:

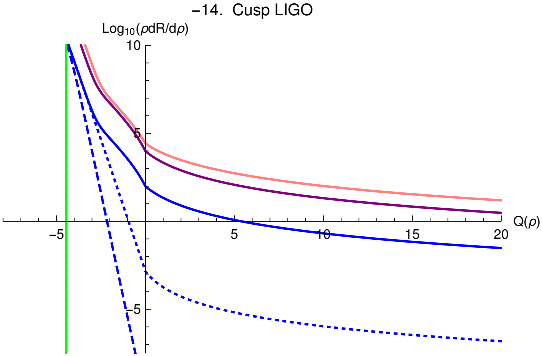
$$\Omega_{superstring} \simeq \mathcal{G}\Omega_{string}$$

where $1 \ll \mathcal{G} \lesssim 10^4$
Below, we choose $\mathcal{G} = 1$ or 100.
Some of the superstring enhancement effects have already been incorporated into estimate of detection event rate.

• Low tension strings loops live long and their relativistic motions get damped. So they cluster, just like dark matter.
String density in galaxy is enhanced by about 2×10^5 for $G\mu < 10^{-10}$.

Detectable range for LIGO-VIRGO-KAGRA : $10^{-15} < G\mu < 10^{-13}$

Gravitational wave bursts from cusps for $G\mu = 10^{-14}$ for aLIGO



Damour and Vilenkin

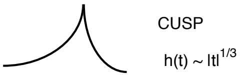
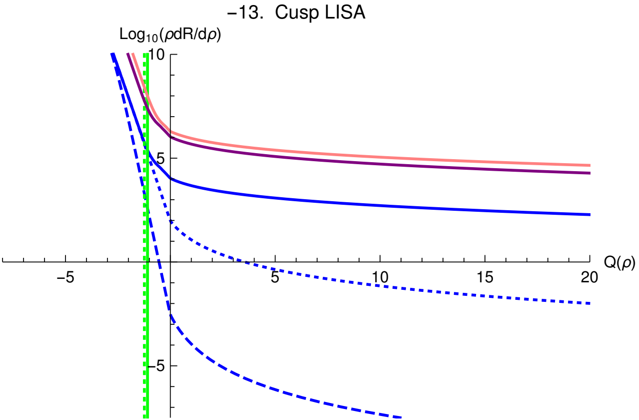


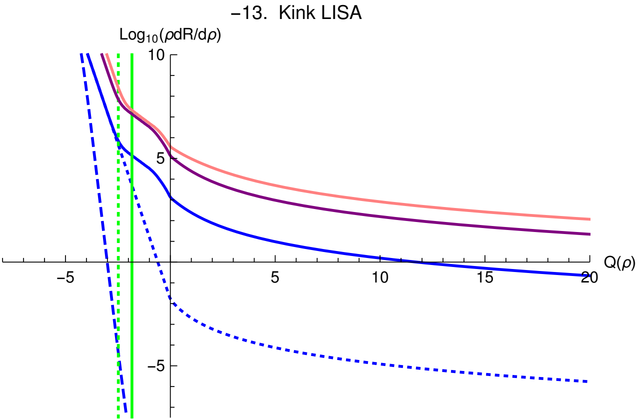
Figure: $G\mu = 10^{-14}$ - The estimated gravitational wave burst rate from cosmic superstring cusps versus the signal to noise ratio $Q(\rho) = \rho - 1$ where $\rho = S/N$. The solid blue curve is for $\mathcal{G} = 1$. The purple curve is for $\mathcal{G} = 100$. The pink curve assume a $\sqrt{3}$ improvement in S/N. The dashed curve is for distant cosmological events (outside our galaxy), the dotted curve is for a homogeneous universe (i.e., without clustering in our galaxy).

Detectable range for LISA-TAIJI : $10^{-16} < G\mu < 10^{-8}$

Gravitational wave from cusps for $G\mu = 10^{-13}$ for LISA-TAIJI



Gravitational wave from Kinks for $G\mu = 10^{-13}$ for LISA



Remarks :

- Cosmic string network has been extensively studied.
- Cosmic superstrings are very different from the standard cosmic strings.
- Cosmic superstrings have also been intensively studied in recent years.
- Micro-lensing and gravitational wave bursts are best ways to detect them.
- If cosmic superstrings are discovered, that will be the smoking gun for string theory.

THANKS