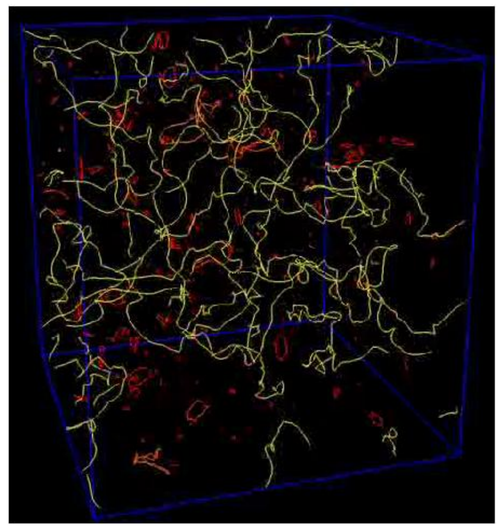
DO COSMIC STRINGS EXIST?

Cosmic strings are objects that may have formed in the early Universe, but scientists are still searching for evidence that they exist. They were first introduced by theoretical physicist Tom W. B. Kibble in the late 70s as a possible result of some field theories, including the famous Higgs theory. They are one-dimensional (line-like) objects, similar to vortex lines in liquid helium, that could be left over after the early Universe went through a phase transition. Cosmic strings were a popular research topic in the 80s, since they could have triggered the formation of large-scale structures such as galaxies. However, the presence of cosmic strings in the early universe would leave an imprint in the cosmic microwave background (CMB) Space-based experiments like COBE and WMAP revealed that cosmic strings do not make a measurable contribution to the CMB, thus ruling out a significant role for cosmic strings.

Cosmic strings were revisited in the early 2000s when it was realized that they could also form in the context of string theory. In a string theory, elementary particles are described by tiny one-dimensional objects in a multi-dimensional space. In some theories, the strings could grow to cosmological scales and behave like historical cosmic strings. These are called cosmic superstrings, and could provide precious observational signatures of string theory.

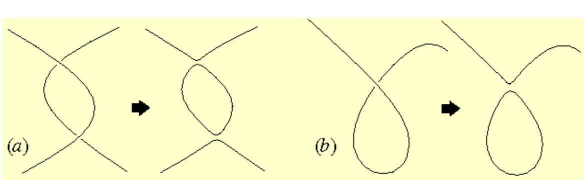
Assuming they do exist, the network of cosmic (super)strings formed in the early Universe would have evolved as the Universe expanded: strings stretched, interacted, oscillated, disintegrated... Massive computer simulations can describe this evolution from formation up to today, but they are challenging because many physical effects need to be taken into account. Some assumptions and simplifications are necessary to keep the simulation at a reasonable scale to be run by computers. An example of such a simulation is shown on the right.



Simulation of a cosmic string network. Long strings are represented in yellow and cosmic string loops are shown in red. © Cambridge cosmology group

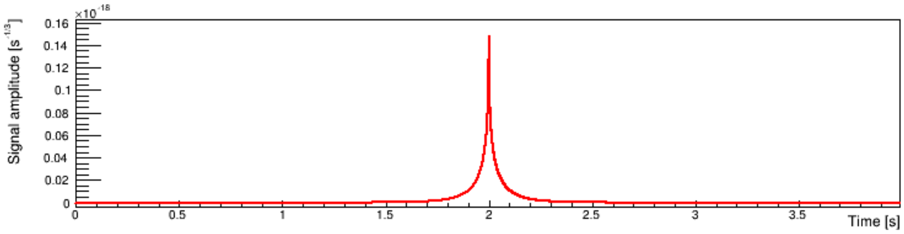
There is currently no observational evidence of the existence of cosmic strings, and the CMB evidence proves they are not abundant. One of the most promising ways to detect these elusive objects is to search for the gravitational-wave radiation they would produce. Gravitational-wave emission is the main mechanism for cosmic strings to dissipate energy. When a string in a cosmic string network crosses itself, a loop separates from the string.

Once formed, a loop is doomed. It oscillates, radiates gravitationally, shrinks and eventually evaporates. Strong gravitational emission occurs at the pinch-off points of the loop, the cusps, which move with a velocity close to the speed of light. Powerful bursts of gravitational waves are expected to be produced by cosmic string cusps. The amplitude of the signal depends on the tension in the string and the size of the loop. These signals could be detected by the ground-based laser interferometers LIGO and Virgo. An example signal is shown overleaf.



Cosmic string loop formation. A loop forms (a) when two strings interacts in 2 separate points or (b) when a string crosses itself. © Cambridge cosmology group

The chances of detecting a signal strongly depend on the sensitivity of the detectors and on our ability to distinguish a real signal from background noise in the detectors' data. We have analyzed LIGO and Virgo data collected between 2005 and 2010, when detectors worked near or at design sensitivity. In addition, specific analysis methods (match-filtering, multivariate analysis) have been developed to optimize the extraction of a cusp signal buried in the noise of the detectors.



Predicted gravitational waveform produced by a cosmic string cusp.

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In spite of all our efforts, no evidence of a cosmic string signal has been found in LIGO/Virgo data. As often in experimental physics, a null result does not mean we didn't learn anything. Knowing our search sensitivity, we can use the fact we did not detect anything to constrain the properties of cosmic strings. The constraints we obtained are the most stringent to date for some regions of the cosmic string parameter space. This new result places limits on physical models of cosmic strings and could be used to generate more accurate simulations of a string network.

In 2011 the LIGO and Virgo detectors stopped taking data and major detector upgrades are currently being installed. The advanced detectors should resume observation in 2015/16 with greater sensitivity than before. This offers a great opportunity for cosmic string searches since potential signals with much lower amplitudes should become visible. Advanced LIGO and Advanced Virgo should be able to provide a decisive input whether cosmic strings do or do not exist.

GLOSSARY

Field theories: Frameworks used to describe subatomic particles in particle physics.

Phase transition: Thermodynamical transformation of a system from one state to another. An example of a phase transition is when water cools and becomes ice.

Cosmic microwave background (CMB): Soon after the Big Bang, when the first atoms formed, the Universe became *transparent*. The electromagnetic radiation that escaped at that time appears as a faint background in the microwave region of the radio spectrum. The temperature fluctuations of this background contain the imprint of the Universe content as it was at this time.

String theory: Framework in which elementary particles are described by tiny linear objects evolving in a multi-dimensional space. String theory is a candidate for a theory of everything since it naturally unifies all fundamental forces.

Gravitational waveform: A curve describing how the disturbance caused by a gravitational wave varies with time.

Detector sensitivity: Ability to detect a signal. Detectors with lower noise are able to detect weaker signals, and therefore have higher (or greater) sensitivity.

Match-filtering: When the gravitational waveform of the signal is known it can be used as a template to optimally filter the data and extract the expected signal.

Multivariate analysis: Analysis technique where multiple parameters are used simultaneously to statistically enhance an effect of interest. This multi-dimensional approach differs from standard analyses where parameters are used one at a time

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Publication describing the analysis: http://arxiv.org/abs/1310.2384

Cosmic strings in Wikipedia: http://en.wikipedia.org/wiki/Cosmic_string

Cambridge cosmology group: cosmic strings and other defects http://www.damtp.cam.ac.uk/research/gr/public/cs_home.html

The Higgs theory in Wikipedia: http://en.wikipedia.org/wiki/Higgs_mechanism

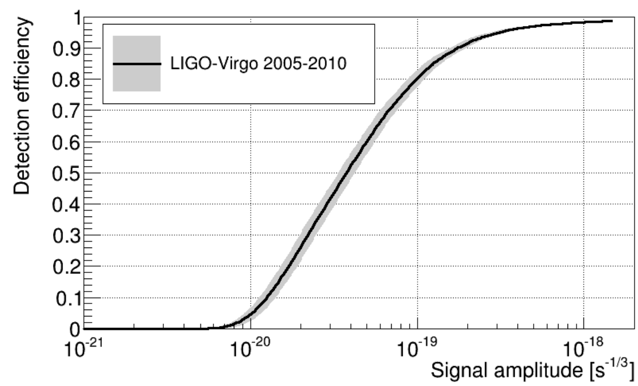
Imaging vortices: http://www.aps.org/units/dfd/pressroom/papers/gaff09.cfm

More about Advanced LIGO: https://www.advancedligo.mit.edu/

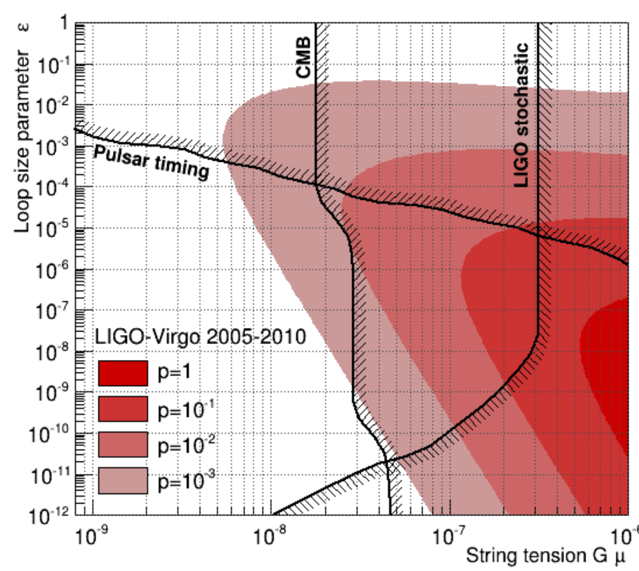
More about Advanced Virgo: https://wwwcascina.virgo.infn.it/advirgo/

FIGURES FROM THE PUBLICATION

For more information on how these figures were generated and their meaning, see the publication at arxiv.org/abs/1310.2384



This plot shows the detection efficiency as a function of the cusp signal amplitude. It tells you the fraction of cosmic string cusp events of a given amplitude that our search should be able to find.



This plot presents existing constraints on cosmic string parameters: the string tension Gμ, the loop size parameter ε and the probability p that two string segments interact when they meet. Our analysis is able to reject the regions filled in red. For comparison, other constraints derived from searches of a GW background from cosmic strings (pulsar / CMB / LIGO stochastic) are given fixing p at 1e-3.