The University of British Columbia, Department of Physics and Astronomy

Constraining Cosmic String Parameters Via Gravitational Waves

Eli Cohen, Thomas Seo

What are cosmic strings?

During the rapid cooling of the universe 10^{-35} seconds after the big bang, it is hypothesized that the universe underwent a phase transition in which there was a spontaneous breaking of gauge symmetries. As a result, cosmic strings may have emerged as a 1-dimensional topological defect, similar to the way cracks form in rapidly freezing ice [1]. We can describe these entities through parameters such as the string tension, $G\mu$, which indicates the energy scale at which the strings are formed, their length, and their distribution in space. Moreover, we expect these strings to be incredibly massive with some models exceeding 10^{26} kg/m.

Detecting cosmic strings

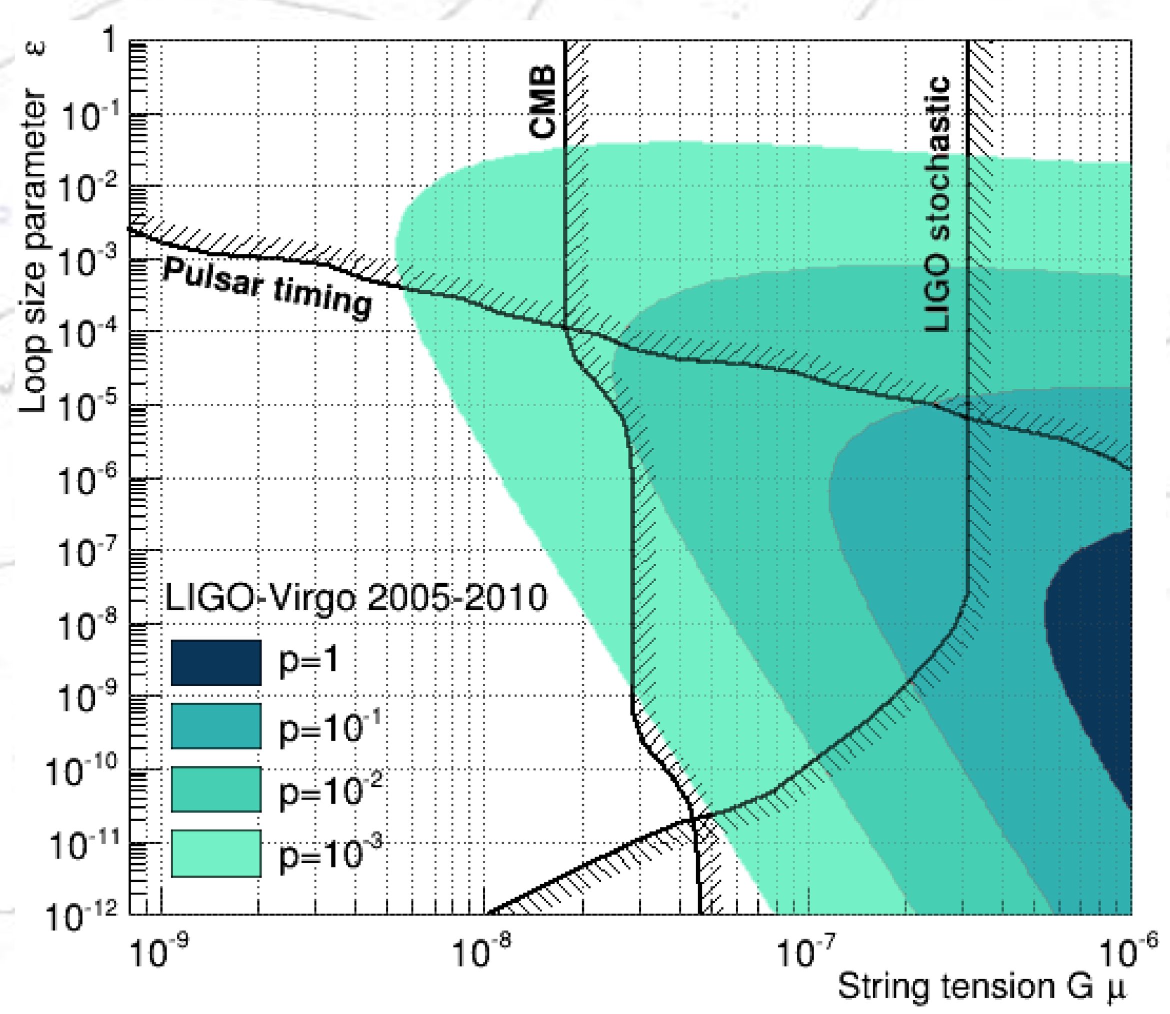
The substantial mass of cosmic strings results in signals that are prominent enough to be picked up by detectors like LIGO, a present-day ground-based interferometer [2]; NANOGrav, a carefully managed pulsar timing array [3]; and LISA [4], an upcoming space-based interferometer. Researchers anticipate that cosmic strings could form loops that oscillate and produce distinctive features like cusps, loops and kinks, leading to the emission of gravitational waves (GWs) that ripple through space-time. These signals might be significant enough to be identified as individual bursts or regular enough to be distinguished as a stochastic background.

How are gravitational waves detected?

When a GW passes through space, it alternately squeezes and stretches the fabric of spacetime, creating variations in the distances travelled by light. LIGO measures tiny changes in the length travelled by laser beams, caused by passing waves. Alternatively, NANOGrav uses precise measurements of many pulsar signals to detect variations in timing caused by perturbations of space. By comparing the sensitivity of these detectors with the predicted emission models of GWs, researchers can exclude specific parameter configurations and models of cosmic strings based on the presence or absence of detected events.

Constraints on Cosmic String Parameters

This plot displays current limits on cosmic string parameters: Gμ (string tension), ε (loop size), and p, the interaction probability when two string segments meet, derived from LIGO data collected from 2005-2010. Regions shaded in blue are rejected by the analysis. Other constraints from searches for a stochastic background are provided, assuming p is 1e-3. [5]



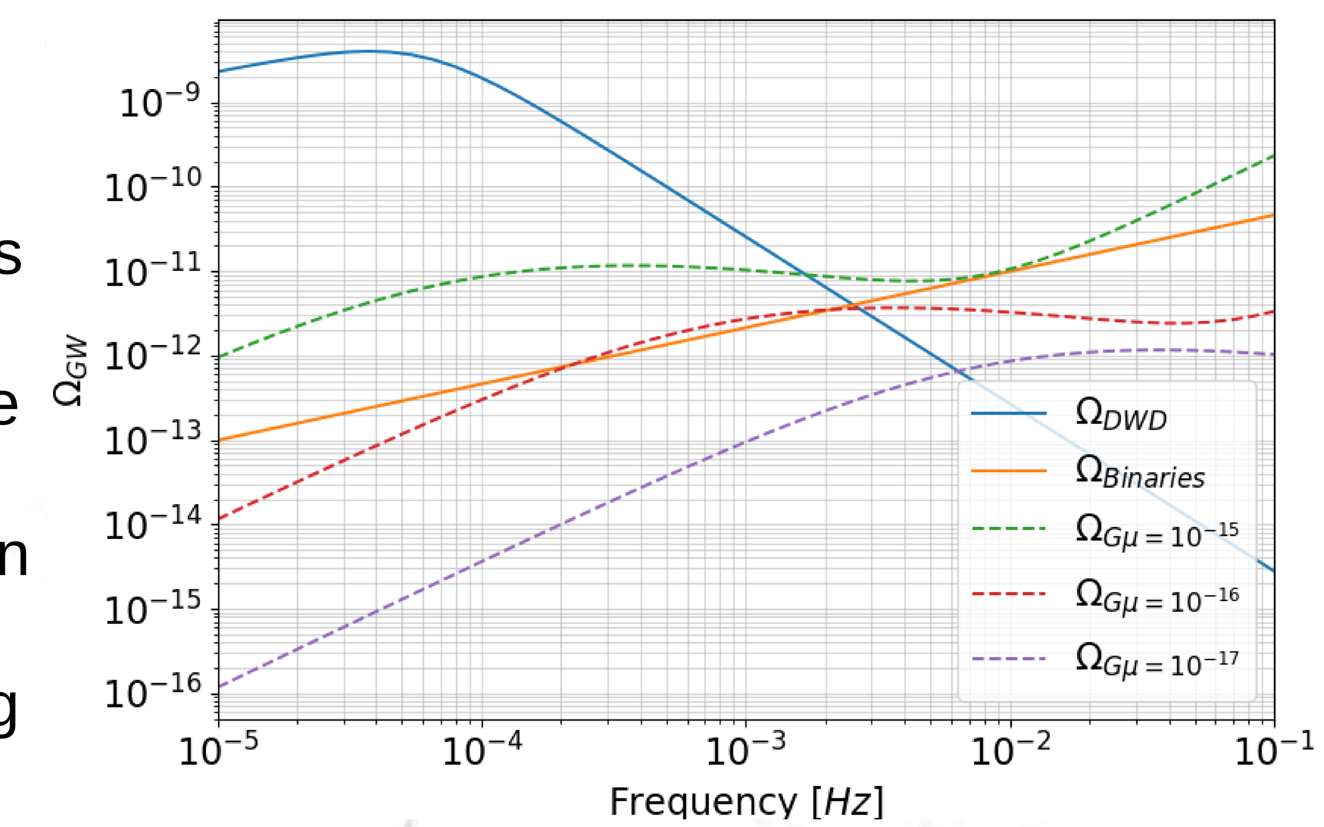
Searching the Stochastic Background

The NANOGrav 15-year dataset suggests that contributions from supermassive black hole binaries are consistent with the confirmed stochastic gravitational wave background (SGWB) [3]. Yet hidden within the SGWB could lie contributions from cosmic strings; the formation of oscillating cosmic string loops coincides with the continual shedding of gravitational waves as the string decays [6].

In one analytical model, the sources of the cosmic string background can be attributed to when the loop was formed and decayed, either during the radiation-dominated, matter-dominated, or the radiation-matter transition eras of the early universe [7]. As such, the sum of these distinct sources would form the signal seen in the SGWB by cosmic strings. This is represented by the equation:

$$\Omega_{G\mu}(f) = \Omega^{r}_{G\mu}(f) + \Omega^{rm}_{G\mu}(f) + \Omega^{m}_{G\mu}(f)$$

Applying the Lambda-CDM (benchmark) model with density parameters $\Omega_{r,0} = 9.15 \times 10^{-5}$, $\Omega_{m,0} = 0.308$ provides an estimate of the strings' contribution to the SGWB [8]. In practice however, this range of frequencies and energies in the SGWB would be cluttered by unwanted signals from various astronomical objects, such as binary black holes, binary neutron stars, or double white dwarfs present in our own galaxy.



Model Stochastic GW background of Different Sources

Dotted lines represents the contribution from cosmic strings at various string tensions, Gμ, detectable with a space-based interferometer network. Contributions from double white dwarfs (Ω_{DWD}) and binary black holes or neutron stars ($\Omega_{Binaries}$) are shown to illustrate the relative contributions to the net SGWB.

Results (or non-results!)

Even though current data suggests that cosmic strings have not been directly detected in the stochastic background or as standalone burst signals [3, 9], the non-detection of their GW emissions has allowed researchers to put stringent constraints on models and parameters governing their properties. We look to upcoming space-based laser interferometers, like LISA [4,10], to provide evidence for the existence of cosmic strings with $G\mu \geq 10^{-17}$.

Bibliography

[1] T. W. Kibble, Journal of Physics A: Mathematical and General **9**, 1387 (1976).
[2] J. Aasi, B. P. Abbott, R. Abbott, et al., Classical and Quantum Gravity **32**, 074001 (2015)
[3] G. Agazie, M. F. Alam, A. Anumarlapudi, et al., The Astrophysical Journal Letters **951** (2023)
[4] P. Amaro-Seoane, H. Audley, S. Babak, et al., Laser interferometer space antenna (2017)
[5] J. Aasi, J. Abadie, B. Abbott et al., Physical Review Letters **112** (2014)
[6] J. Ellis and M. Lewicki, Physical Review Letters **126** (2021)
[7] B. Wang and J. Li., Physical Review D. **109** (2024)
[8] L. Sousa, P. P. Avelino, and G. S. Guedes, Physical Review D. **101** (2020).
[9] R. Abbott, et al., Physical Review Letters **126** (2021)
[10] Z. Luo, Y. Wang et al., Progress of Theoretical and Experimental Physics **2021** (2020)