The SGWB from cosmic string loops based on the one-scale model

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Loop number density

- Loops are born at a characteristic length scale

$$\ell_{\rm b} = \alpha d_{\rm H}(t_{\rm b})$$

$\rightarrow$*Fundamental prerequisite*: The network follows a scaling evolution.

- Energy lost to attain scaling $\rightarrow$ Loop creation rate:

$$\frac{dN_{\rm loop,css}}{dt}$$

$\rightarrow$ For cosmic superstrings $\frac{dN_{\rm loop,css}}{dt} = \frac{1}{p^k}\frac{dN_{\rm loop,css}}{dt}$

- Loops decay through GW emission only

$$\ell(t, t_{\rm b}) = f_{\rm r}\alpha d_{\rm H}(t_{\rm b}) - \frac{\Gamma G\mu}{c}(t - t_{\rm b})$$

From these we can compute the *loop number density* $n(\ell, t)$

GW emission from cosmic string loops

- Emission in a series of harmonics (modes) n:

$$f_{\rm n} = 2nc/\ell, \qquad n = 1 \to \infty$$

- Emitted GW power per mode:

$$\frac{dE_{\rm gw,loop}}{dt} = P_n G\mu^2 c\,, \quad P_n = \Gamma n^{-q} / \sum_{m=1}^{n_*} m^{-q}$$

$q = 4/3$ (cusps), $q = 5/3$ (kinks)
n_*: gravitational backreaction effects

- Given a loop number density $n(\ell, t)$

$$\Omega_{\rm gw}(f) = \frac{2G\mu^2 c^3}{\rho_{\rm crit} a^5(t_0) f} \sum_{j=1}^{\infty} j P_j \int_{t_{\rm f}}^{t_0} a^5(t') n_j(f, t') dt'$$

- Correction due to change in relativistic degrees of freedom:

$\left(\frac{g_{*,t_0}}{g_{*,t_{\rm cor.}}}\right)^{1/3}$ applied at $t_{\rm cor.} = \left(\frac{32\pi G\rho}{3}\right)^{-1/2}$, $\rho = \frac{\pi^2}{30} g_* T$

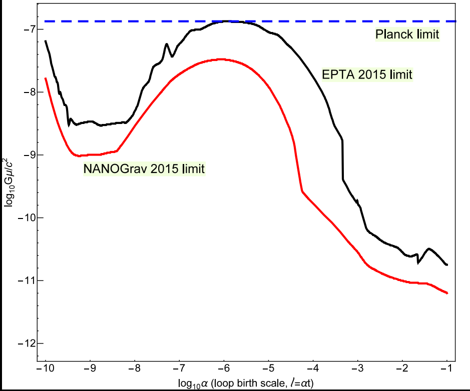
SGWB modelling

Generic SGWB formulation: Five free parameters

- Tension: $G\mu/c^2$
- Loop birth scale: $\alpha \in [0.1 - \alpha_{\rm min}]$
  $\alpha_{\rm min} \approx 10^{-9}$ (PTAs), 10^{-16} (LISA), 10^{-20} (LIGO)
- Intercommutation probability: p (and its scaling law dependence, k)
  $p = [10^{-3}, 1]$, $k = -0.1 \text{ or } -0.6$
- Loop emission spectrum:
  i. spectral index q (emission mechanism)
  cusps: $-4/3$, kinks: $-5/3$
  ii. emission mode cut-off n_* (gravitational backreaction)
  cusps: $n_* \in [1, 10^4]$, kinks: $n_* \in [1, 10^3]$

- Conservative - *No* assumptions made on the model parameters.

PTA Upper Limits



For upper limits:
Only $p = 1$, $n_* = 1$, and
$n_* = 10^4 / \, q = -4/3$ needed

Match amplitude+spectral index

Planck:

$$G\mu/c^2 < 1.3 \times 10^{-7}$$

EPTA:

$$G\mu/c^2 < 1.3 \times 10^{-7}$$

for $\alpha = 0.05$

$$G\mu/c^2 < 2.9 \times 10^{-11}$$

NANOGrav:

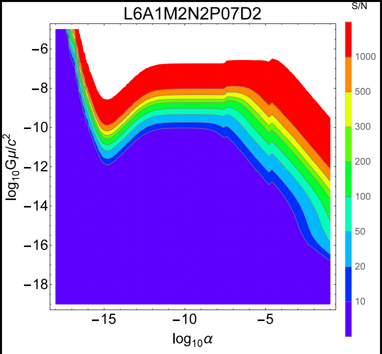
$$G\mu/c^2 < 3.3 \times 10^{-8}$$

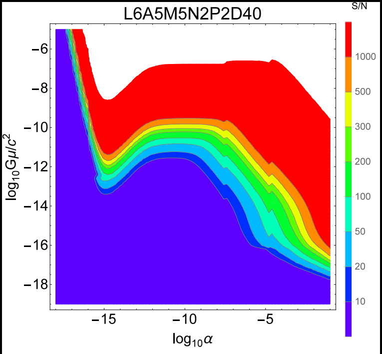
for $\alpha = 0.05$

$$G\mu/c^2 < 8.1 \times 10^{-12}$$

LISA

Arms: 10^6 m Duration: 2 years	Arms: 5×10^6 m Duration: 5 years





Based on Thrane & Romano 2013
From the eLISA Cosmology Working Group report

LISA

Results for 6 links, SNR=20

- A1M2
  Conservative limit: $G\mu/c^2 < 4.4 \times 10^{-10}$
  Large loops: $G\mu/c^2 < 1.5 \times 10^{-16}$
- A2M2
  Conservative limit: $G\mu/c^2 < 1.1 \times 10^{-10}$
  Large loops: $G\mu/c^2 < 2.1 \times 10^{-17}$
- A2M5
  Conservative limit: $G\mu/c^2 < 7.0 \times 10^{-11}$
  Large loops: $G\mu/c^2 < 1.3 \times 10^{-17}$
- A5M5
  Conservative limit: $G\mu/c^2 < 1.4 \times 10^{-11}$
  Large loops: $G\mu/c^2 < 4.4 \times 10^{-18}$

Improvement (on conservative upper limits):

- A1→A2: $\times 3.8 - 4.8$
- A2→A5: $\times 4.6 - 5$
- M2→M5: $\times 1.6$