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CAN eLISA SAVE THE DAY?

Hunting for cosmic strings in the SKA era

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Cosmic (super)strings

Cosmic...

...Strings

- Field Theory
- Phase transitions/SSB

...Superstrings

- String theory
- Brane inflation

$G\mu/c^2$

- Energy scale of the Phase Transition

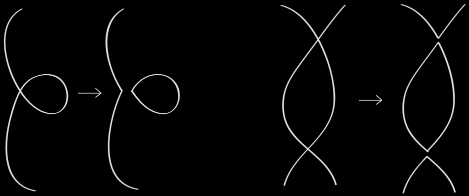
- Fundamental string coupling
- Warp factor

Cosmic (super)strings are a *unique*, natural, extremely high energy “lab”

Cosmic (super)strings

A cosmic string network consists of:
1) “Infinite cosmic strings”
2) Cosmic string loops

- *Intercommutation*



- Cosmic strings: $p = 1$
- Cosmic superstrings: $p \in [10^{-3}, 1]$

Cosmic string network evolution

Credit: Martins & Shellard

- (velocity dependent) One-Scale model:

  The dynamic behaviour of the network can be described by only *one* characteristic length scale

  $$\xi$$

- Scaling evolution in the radiation and matter eras

  $$\xi \propto t$$

- Loop formation

  $$\ell_{\rm b} \propto \alpha t$$

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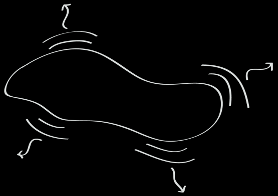
GW emission from cosmic string networks

Loops once formed, decay by radiation emission



$\longrightarrow$

- Gravitational
- Scalar/Gauge boson
- Synchrotron/Radio/γ-ray
- Neutrinos
- UHERC

GW emission “engines”: cusps and kinks

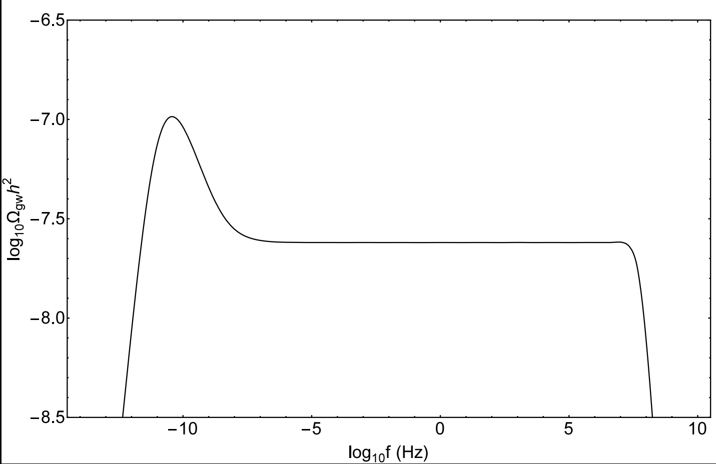
Emission in a series of harmonics (modes) n:

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

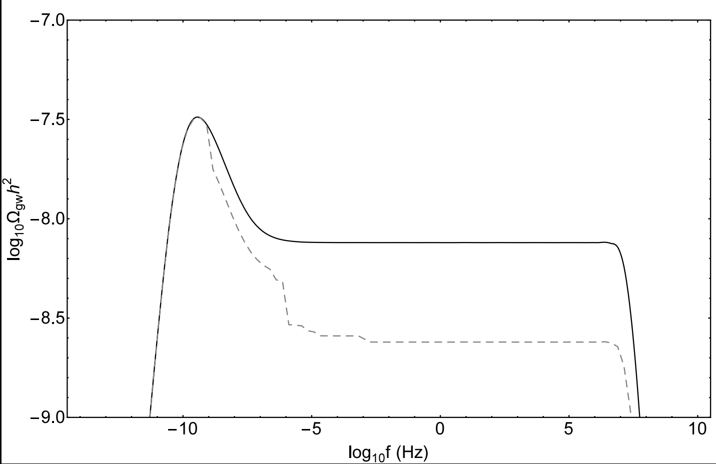
Also GW emission from:

- Infinite cosmic strings (Kawasaki et al. 2010; Matsui et al. 2016)
- Scaling evolution in the radiation era (Figueroa et al. 2013)

The cosmic string SGWB



The cosmic string SGWB



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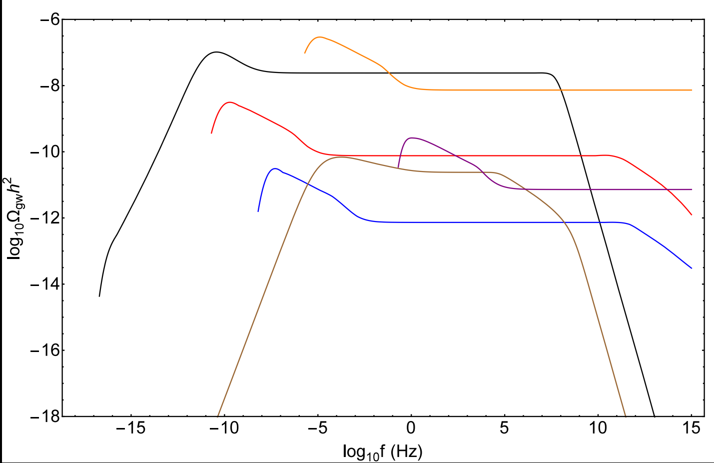
The cosmic string SGWB



Questions...

- Loop birth-scale α:
  Nambu-Goto: $\alpha \approx 0.1$
  Abelian-Higgs: Microscopic
- Dominant emission mechanism:
  Cusps? Kinks?
- Intercommutation:
  Scaling law?
  Cusp creation?
- Scaling? Is it delayed?
- Effects of *gravitational backreaction*.
  Affects loop size *and* emission mechanism!

Every work is based on approximations.

We need to *detect* something/anything!!!

SGWB modelling

GW vs. CMB tension limits

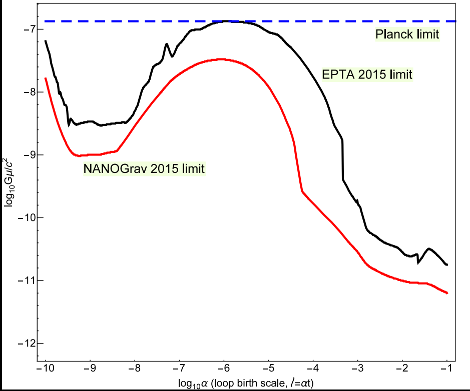
- CMB results depend only on inifinite strings - very robust
- GW results strongly depend on the inherited assumptions

Generic SGWB formulation (Sanidas et al 2012): Five free parameters

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

- Conservative - No assumptions made!
- Generic and easy to modify
  (multiple loop birth-scales, delayed scaling, ... bring on your idea!)

PTA Upper Limits



Lentati et al. 2015
Arzoumanian et al. 2015

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

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

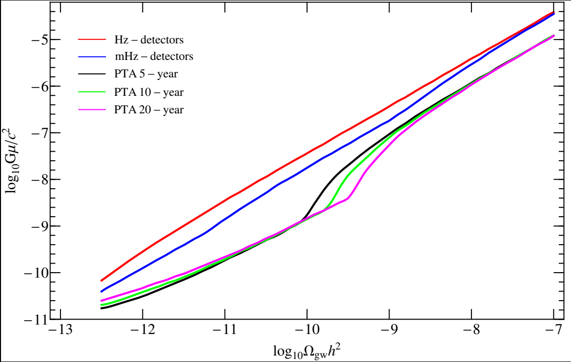
EPTA:
$$G\mu/c^2 < 1.3 \times 10^{-7}$$

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

We are as *robust* as we can be, aware of the *caveats*, and finally *competitive* to CMB results

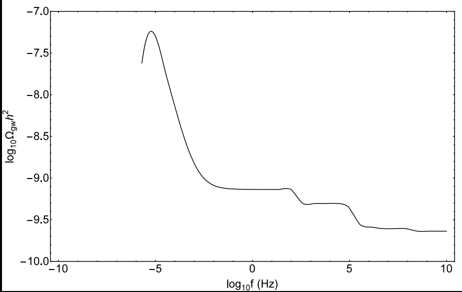
GW detectors comparison

Sanidas et al. 2013



Half the truth...

eLISA vs. PTAs: Extended parameter space



$G\mu/c^2 = 10^{-7}$
$\alpha = 10^{-12}$
$n_* = 1$
$p = 1$

Low-frequency cut-off

$$f_{\min} \approx \frac{1}{\alpha d_{\mathrm{H}}(t_0)}$$

Determined by the largest loops available

- PTAs: $\alpha_{\mathrm{min.}} \approx 10^{-9}$
- eLISA: $\alpha_{\mathrm{min.}} \approx 10^{-16}$
- LIGO: $\alpha_{\mathrm{min.}} \approx 10^{-20}$

eLISA can probe a significantly larger parameter space than PTAs

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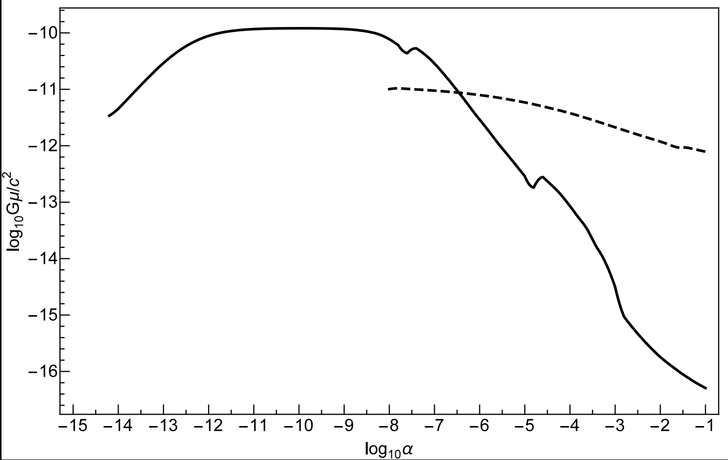
eLISA vs. SKA: $\Omega_{\rm gw}h^2 = 10^{-12}$



Battye, Sanidas 2016, in prep.

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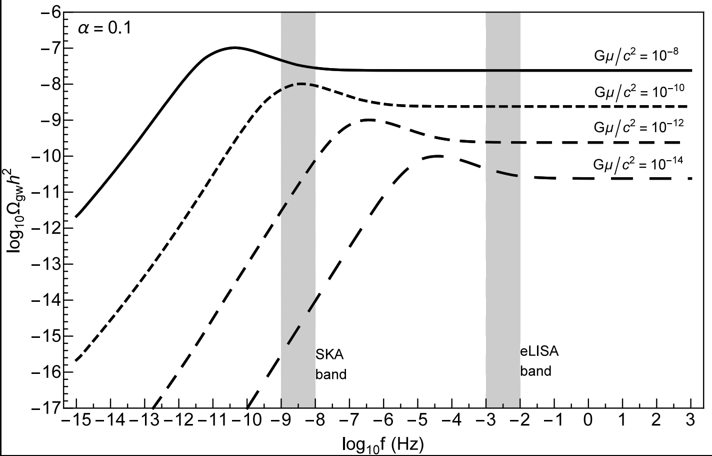
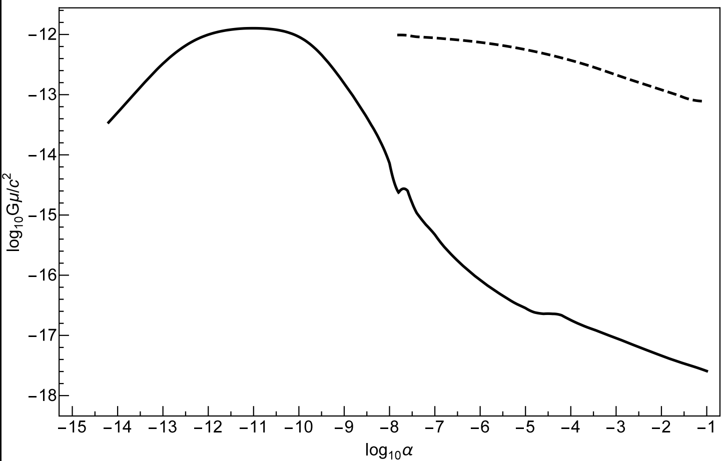
eLISA vs. SKA: Large loops scenario



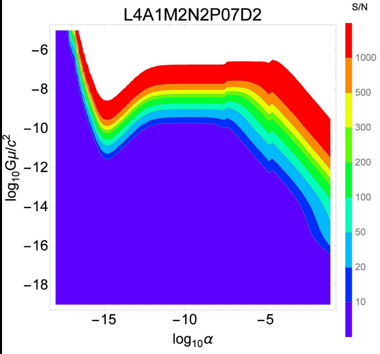
Battye, Sanidas 2016, in prep.

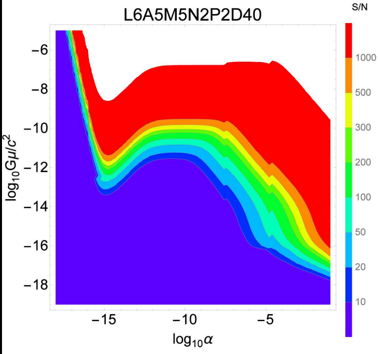
eLISA vs. SKA: $\Omega_{\rm gw} h^2 = 10^{-14}$



Battye, Sanidas 2016, in prep.

eLISA configurations: Performance





From the eLISA Cosmology Working Group report
Topological Defects subgroup: Battye, Hindmarsh, Saffin, Sanidas

eLISA configurations: Performance

- L4A1M2N2P07D25
  Conservative limit: $G\mu/c^2 < 1.0 \times 10^{-9}$
  Large loops: $G\mu/c^2 < 1.7 \times 10^{-15}$
- L6A1M5N2P07D25
  Conservative limit: $G\mu/c^2 < 2.7 \times 10^{-10}$
  Large loops: $G\mu/c^2 < 6.4 \times 10^{-17}$
- L4A2M5N2P2D28
  Conservative limit: $G\mu/c^2 < 1.3 \times 10^{-10}$
  Large loops: $G\mu/c^2 < 2.8 \times 10^{-17}$
- L6A5M5N2P2D40
  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):

- L4→L6: $\times 2$
- A1→A2: $\times 3.8 - 4.8$
- A2→A3: $\times 4.6 - 5$
- M2→M5: $\times 1.6$

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eLISA CAN save the day!

- eLISA will offer:
  1. Expanded parameter space coverage. Expect the unexpected!
  2. *Unprecedented* capabilities in detecting large loop networks
- The best eLISA configuration will be relatively close to SKA performance, but will offer ~ 5 orders of magnitude better performance in the large loops case.
- In the future, at the high GW sensitivity regime, space-borne interferometers have *no opponent*.
- We *must* aim for L6A5M5, but if I have to make a choice, let it be in favour of arm length.

Thank You!