Probing Cosmic Strings with LISA

instituto de astrofísica
e ciências do espaço

Institute of Astrophysics
and Space Sciences

www.iastro.pt

LARA SOUSA
Lara.Sousa@astro.up.pt

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LISA
CosWG-19-03

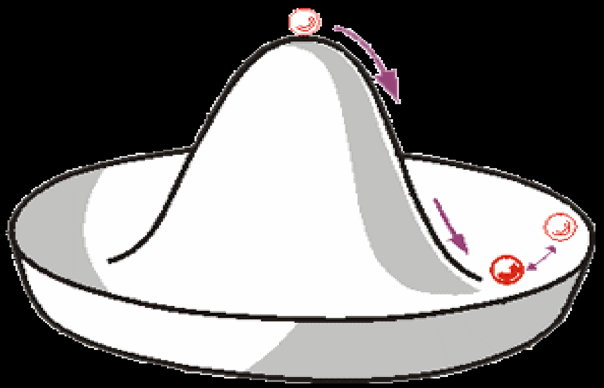
Probing the gravitational wave background from cosmic strings with LISA

Pierre Auclair[a], Jose J. Blanco-Pillado[b,c], Daniel G. Figueroa[d,e,†], Alexander C. Jenkins[f], Marek Lewicki[f,g], Mairi Sakellariadou[f], Sotiris Sanidas[h], Lara Sousa[i,j], Danièle A. Steer[a], Jeremy M. Wachter[c], Sachiko Kuroyanagi[k]

For the LISA Cosmology Working Group

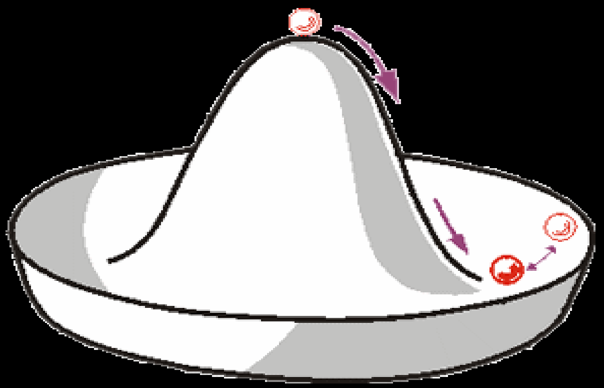
arXiv: 1909.00819

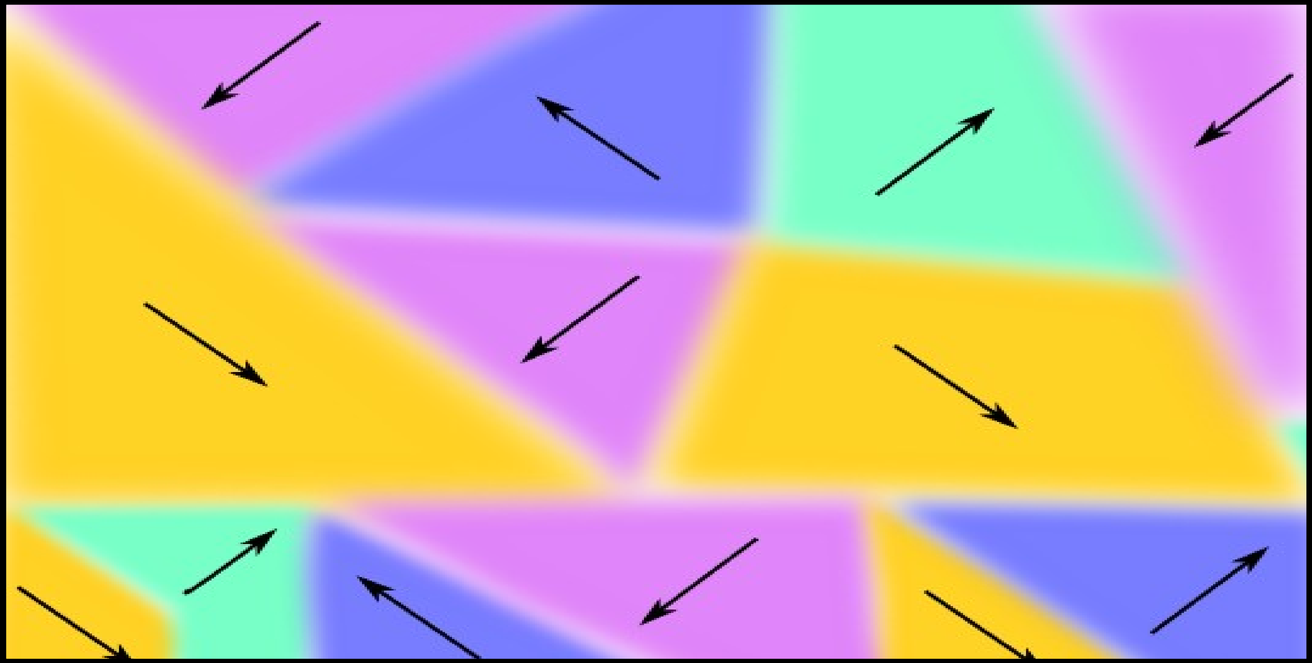
Cosmic String Formation



Cosmic String Formation

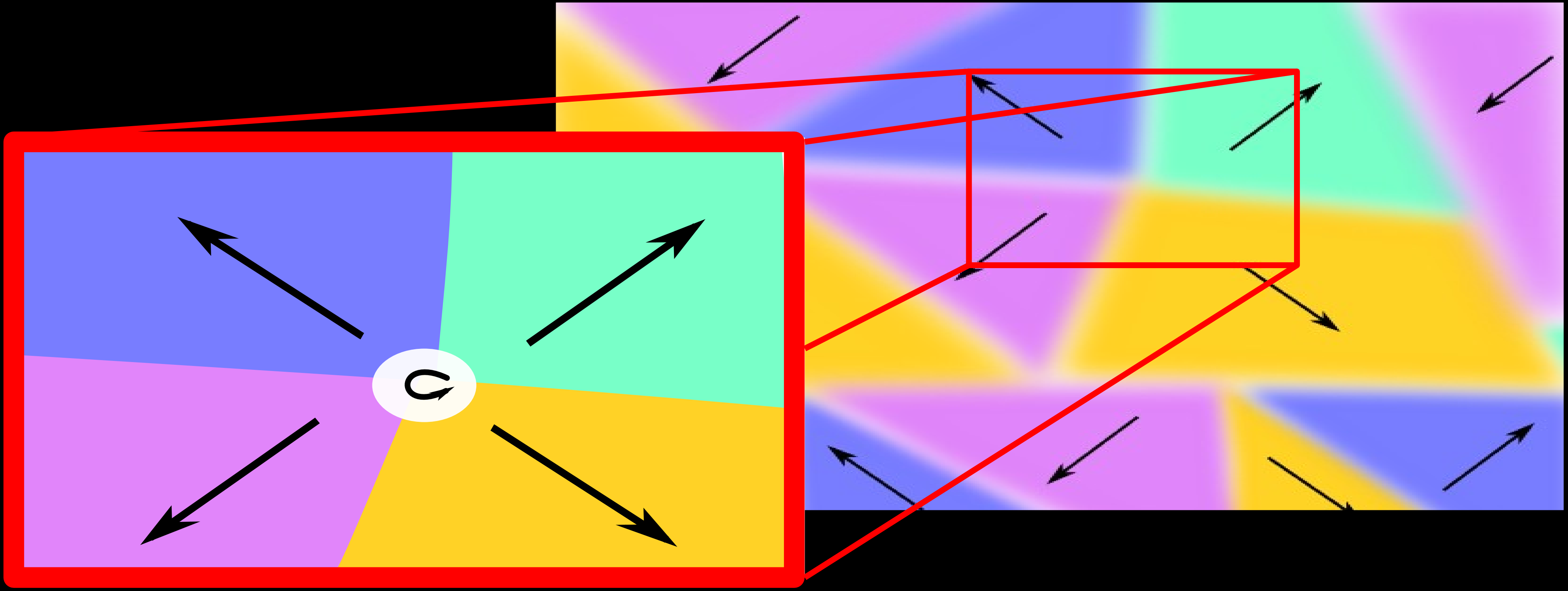
DIFFERENT PATCHES OF THE UNIVERSE FALL INTO DIFFERENT MINIMA!





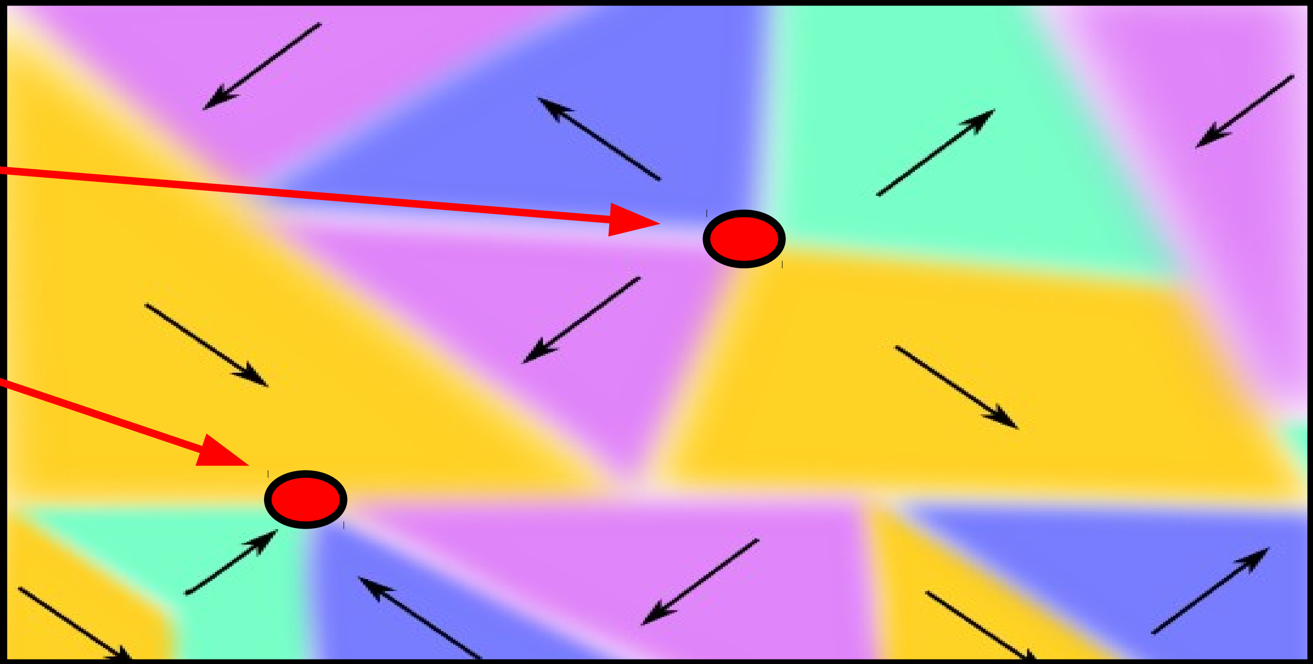
Cosmic String Formation

WHAT LURKS IN THE EDGES?



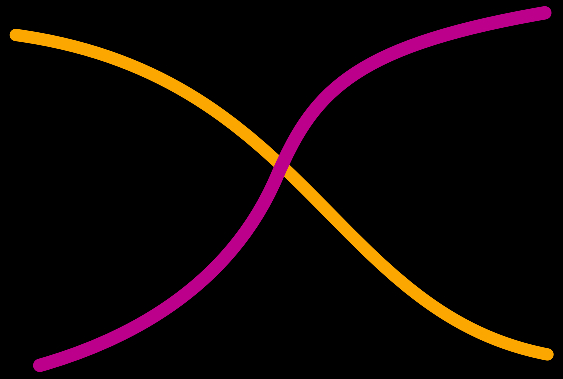
Cosmic String Formation

COSMIC STRINGS!



Intercommutation & Loops

UPON COLLISION...



...STRINGS EXCHANGE PARTNERS AND RECONNECT!

INTERCOMMUTATION & LOOPS

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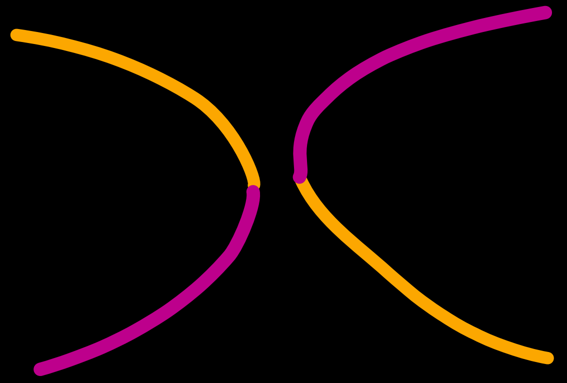

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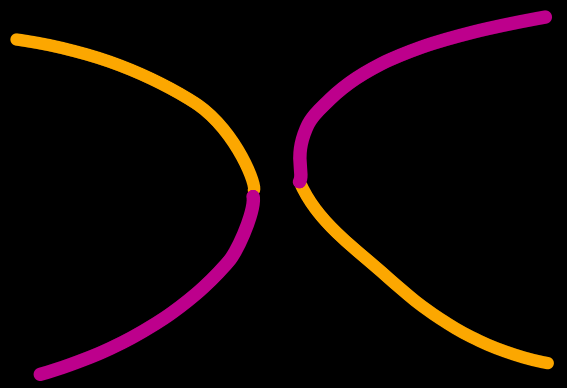

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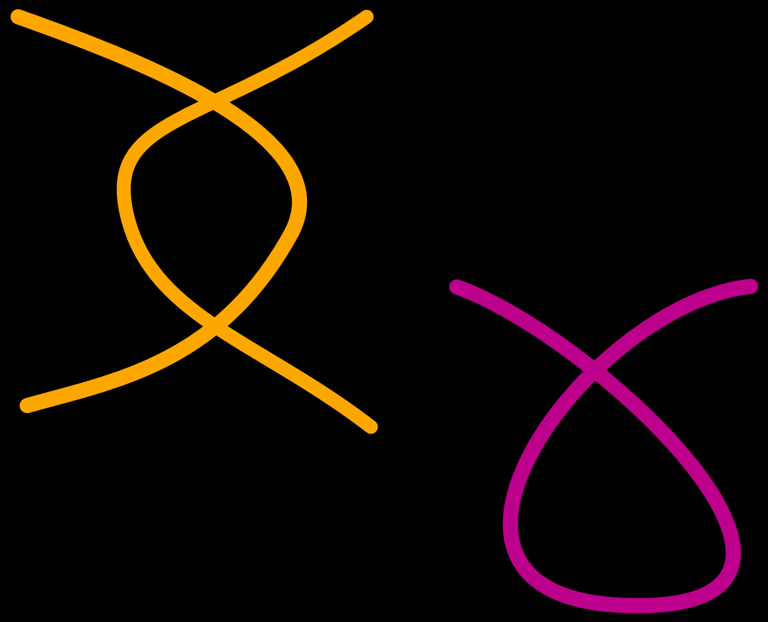
BUT IN SOME SITUATIONS,



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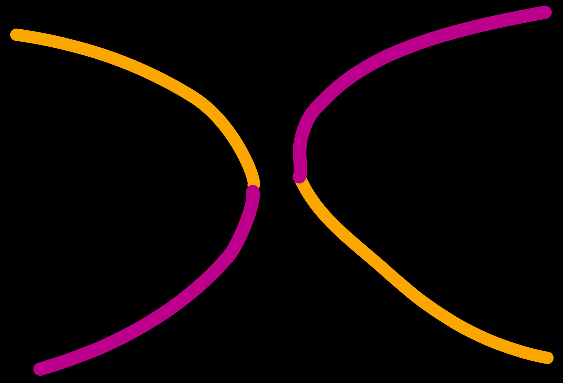

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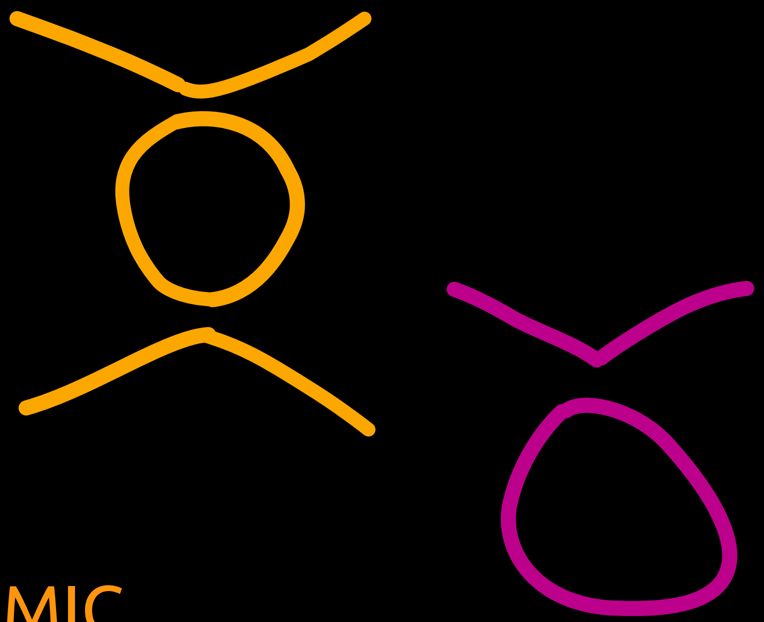
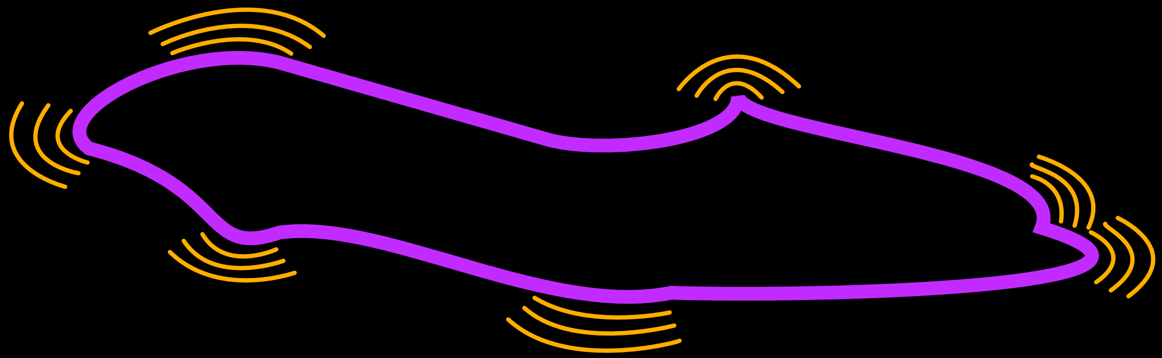


COSMIC STRING LOOPS ARE CREATED!

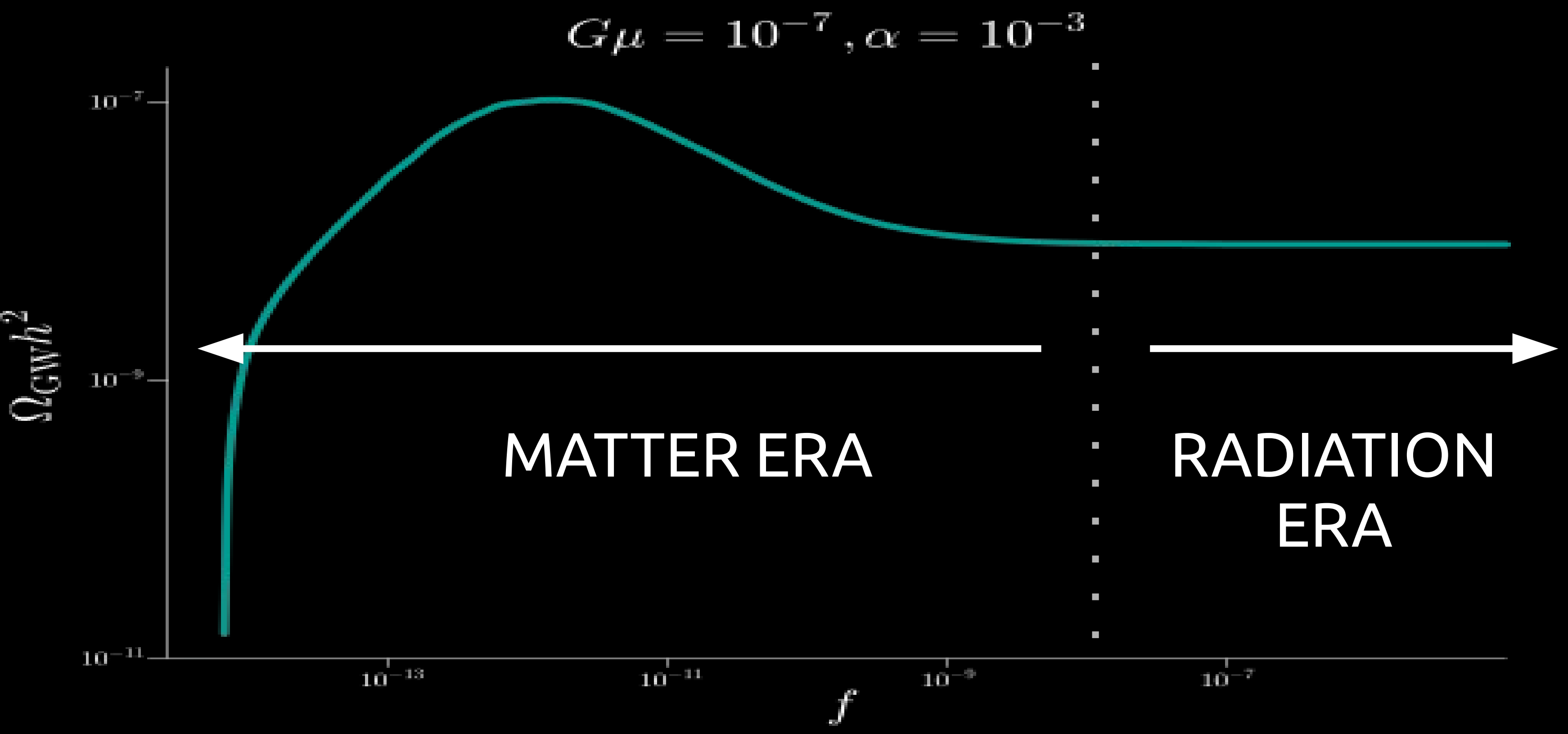
Loops and Gravitational Waves

LOOPS ARE EXPECTED TO RADIATE GRAVITATIONAL WAVES



AND ARE COPIOUSLY CREATED THROUGHOUT COSMOLOGICAL HISTORY.

The Typical Cosmic String SGWB



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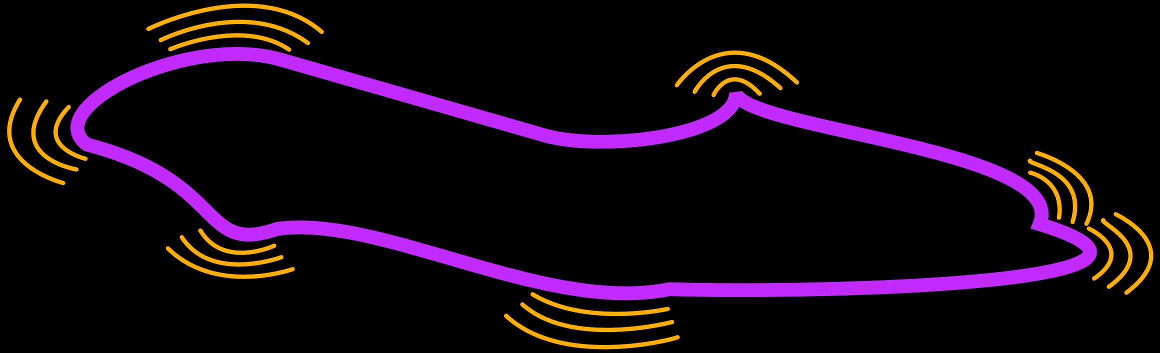

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LOOPS AND GRAVITATIONAL WAVES

TO ACCURATELY CHARACTERISE THE SGWB ONE NEEDS TO DETERMINE THE LOOP DISTRIBUTION FUNCTION $n(\ell(t), t)$

EFFICIENCY OF LOOP-CHOPPING MECHANISM

LOOP SIZE

EMISSION SPECTRUM

Loops and Gravitational Waves

MODEL I

ANALYTICAL
(PARAMETRIC)
APPROACH

CALIBRATED
USING
SIMULATIONS

Loops and Gravitational Waves

MODEL I	MODEL II	MODEL III
ANALYTICAL (PARAMETRIC) APPROACH	OF BLANCO-PILLADO, OLUM, SHLAER	OF LORENZ, RINGEVAL, SAKELLARIADOU
CALIBRATED USING SIMULATIONS	INFERRED FROM NAMBU-GOTO SIMULATIONS	

A Word of Warning...

IN ABELIAN-HIGGS SIMULATIONS:

* ENERGY IS LOST INTO CLASSICAL RADIATION OF SCALAR AND GAUGE FIELDS;

* THERE IS NO STABLE POPULATION OF LOOPS;

A Word of Warning…

IN ABELIAN-HIGGS SIMULATIONS:

* ENERGY IS LOST INTO CLASSICAL RADIATION OF SCALAR AND GAUGE FIELDS;

* THERE IS NO STABLE POPULATION OF LOOPS;

STRICTLY SPEAKING WE ARE REFERING TO NAMBU-GOTO COSMIC STRINGS!

ASIDE: GW EMISSION BY LONG STRINGS

* IRREDUCIBLE BACKGROUND (cf. Lizarraga's talk!)

* SMALL-SCALE STRUCTURE ON LONG STRINGS EMITS GWS DIRECTLY

Aside: GW emission by Long Strings

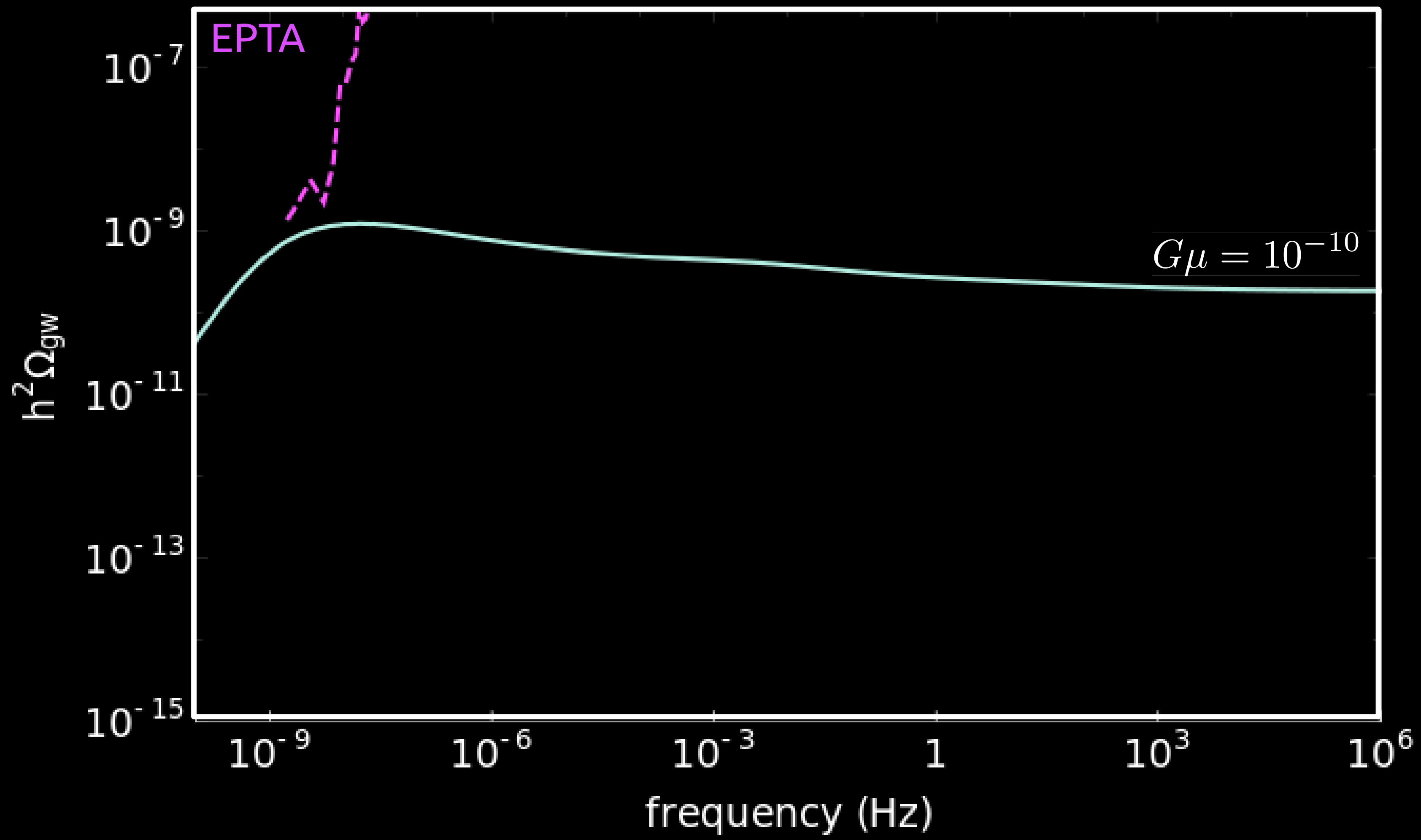
* IRREDUCIBLE BACKGROUND (cf. Lizarraga's talk)

* SMALL-SCALE STRUCTURE ON LONG STRINGS EMITS GWS DIRECTLY

IN BOTH CASES, $\Omega_{\rm gw} h^2 \sim (G\mu)^2$

SO THIS CONTRIBUTION IS EXPECTED TO BE SUBDOMINANT.
(See however arXiv: 1902.09120)

What Can LISA do?



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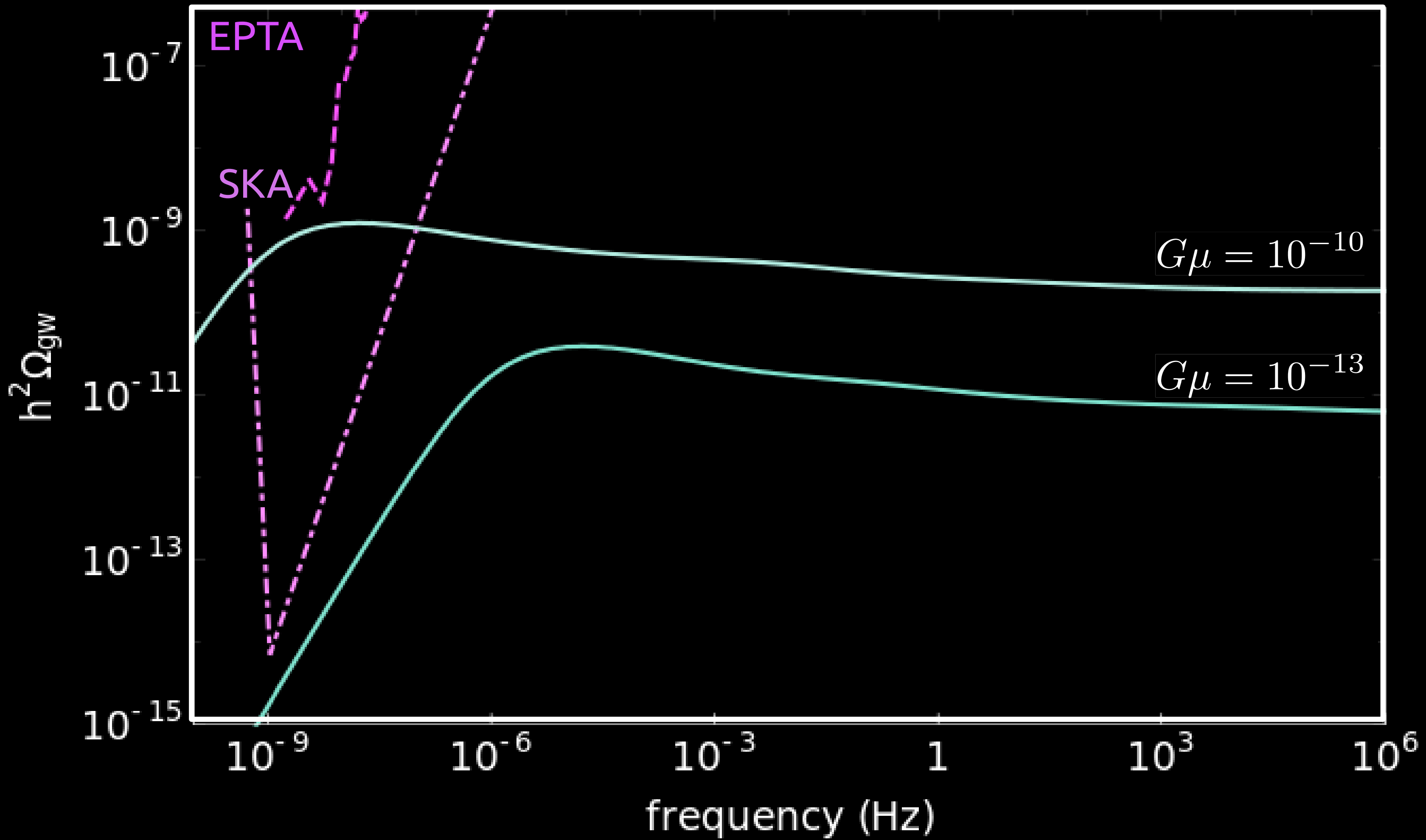

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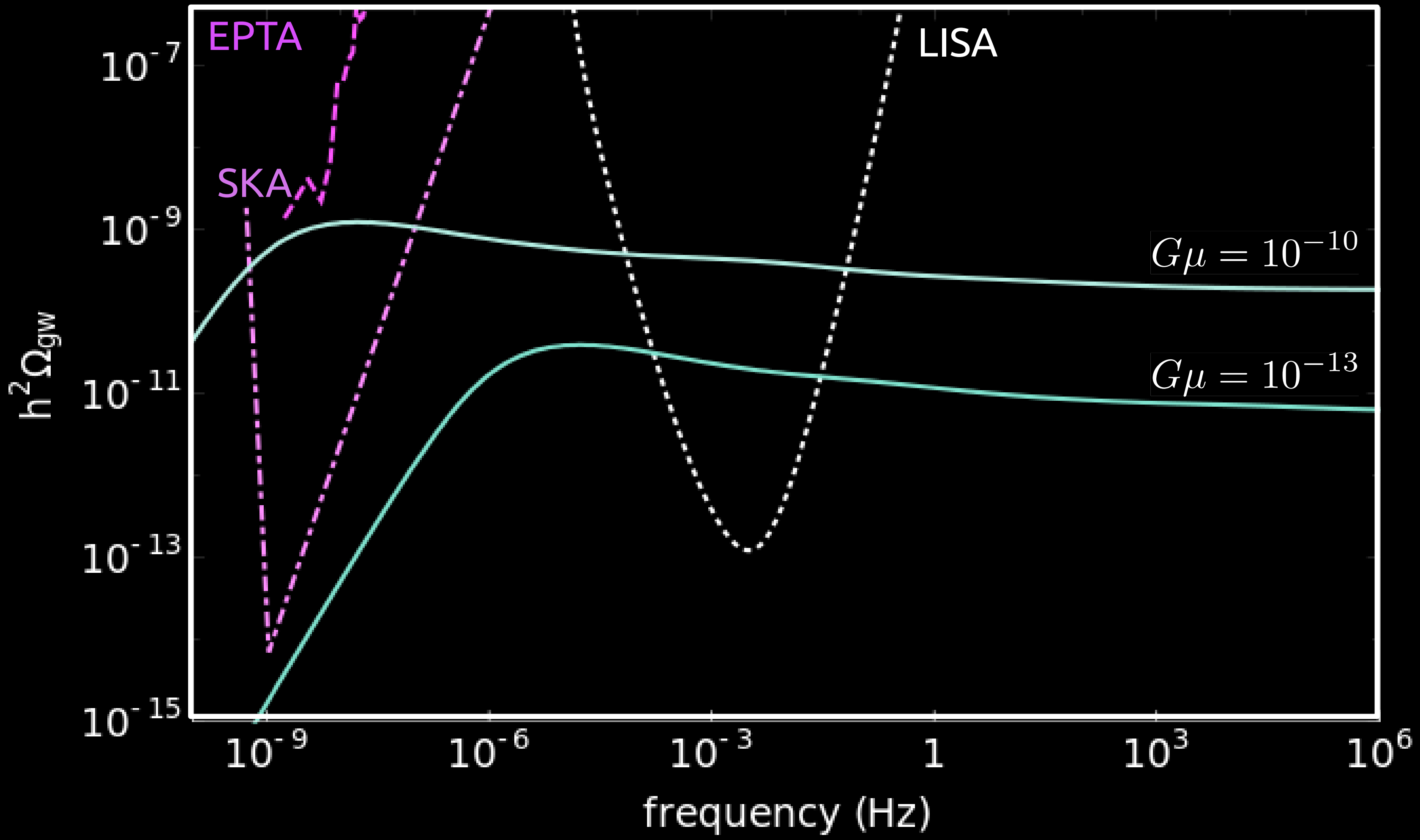

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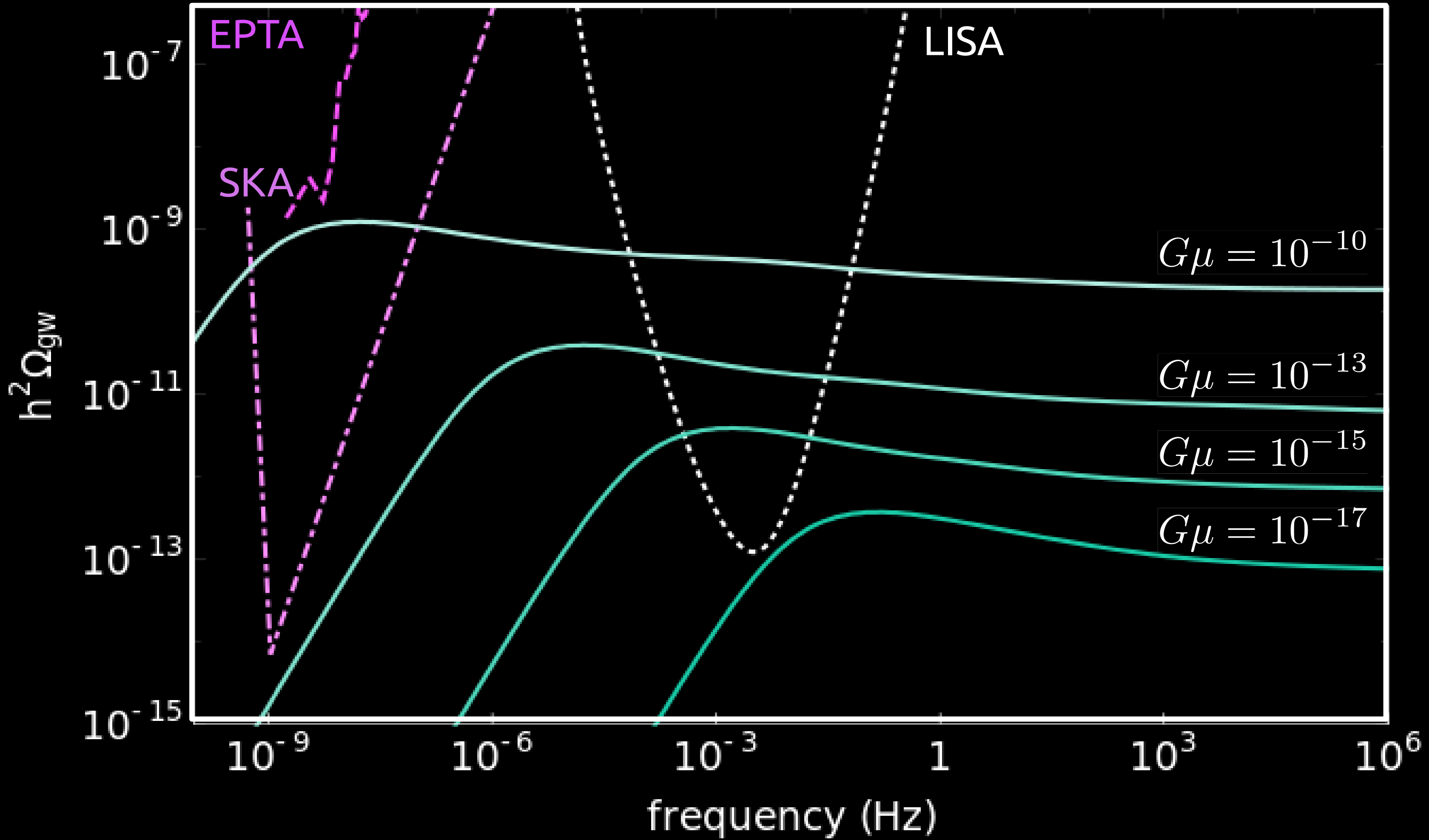
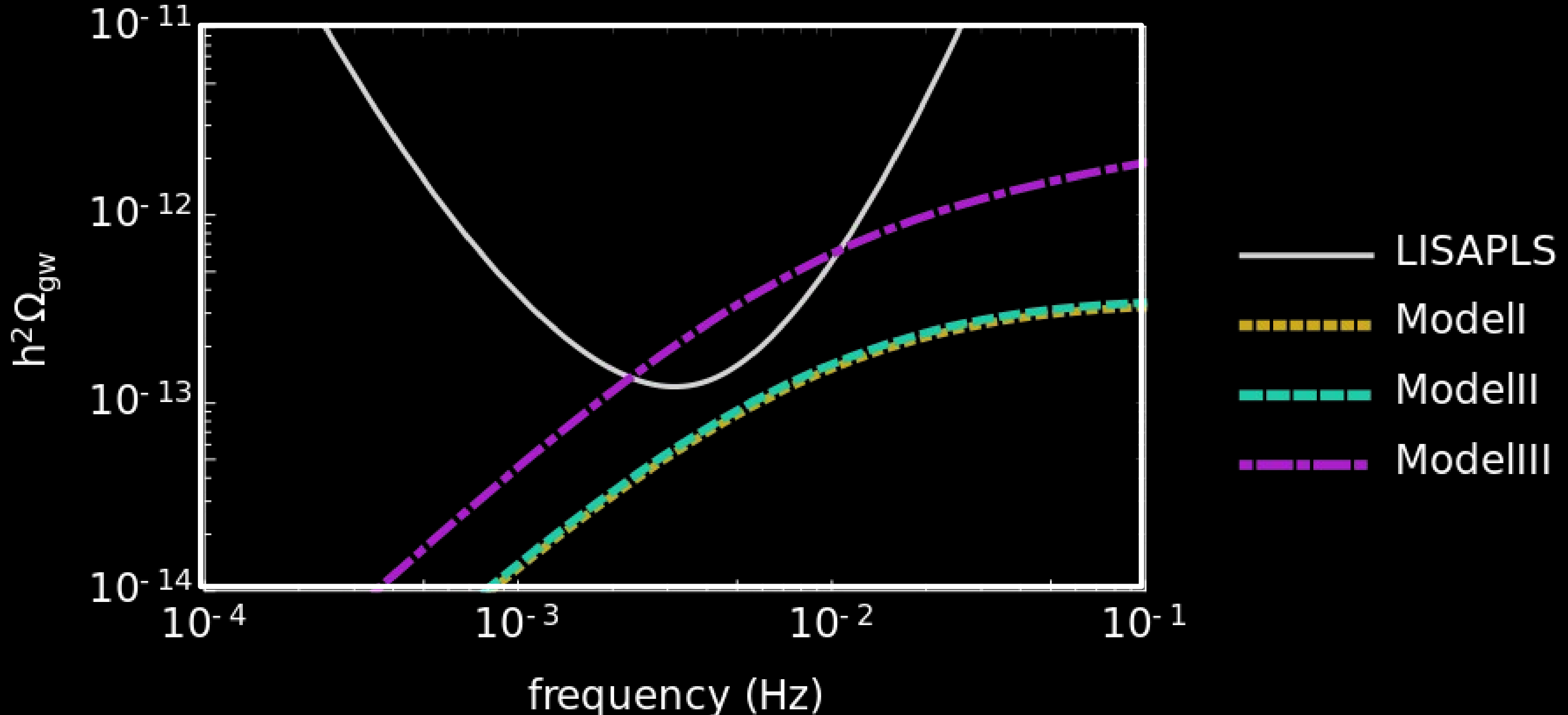


What Can LISA do?

LISA WILL BE THE IDEAL INSTRUMENT
TO EITHER DETECT NG COSMIC STRINGS
OR SIGNIFICANTLY TIGHTEN CONSTRAINTS
ON THE ENERGY-SCALE OF THE STRING-
FORMING PHASE TRANSITION.

What Can LISA do for NG Strings?

LISA SHALL BE ABLE TO PROBE NG STRINGS UP TO $G\mu \sim 10^{-17}$

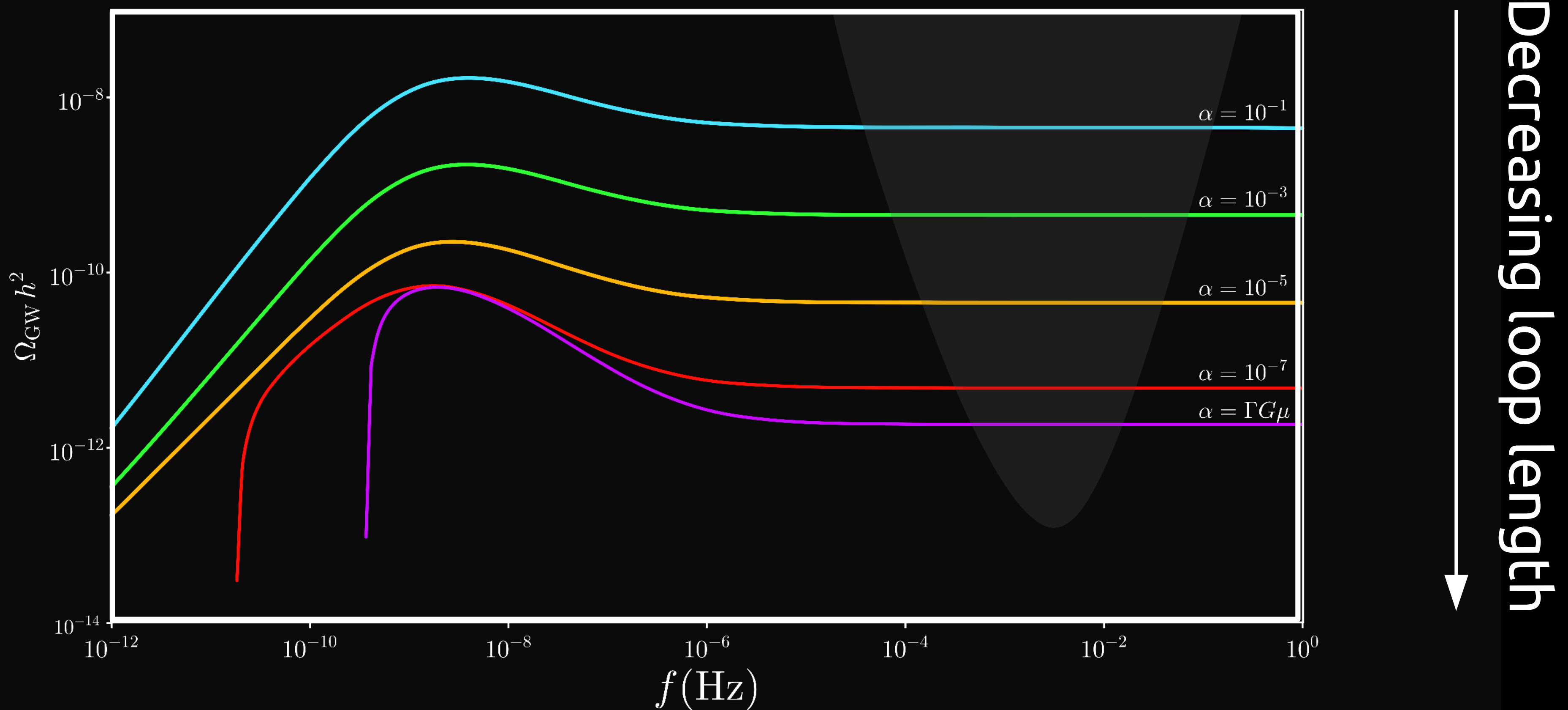


What Can LISA do?

LISA MAY IMPROVE CONSTRAINTS ON COSMIC STRING TENSION BY ABOUT 6 ORDERS OF MAGNITUDE

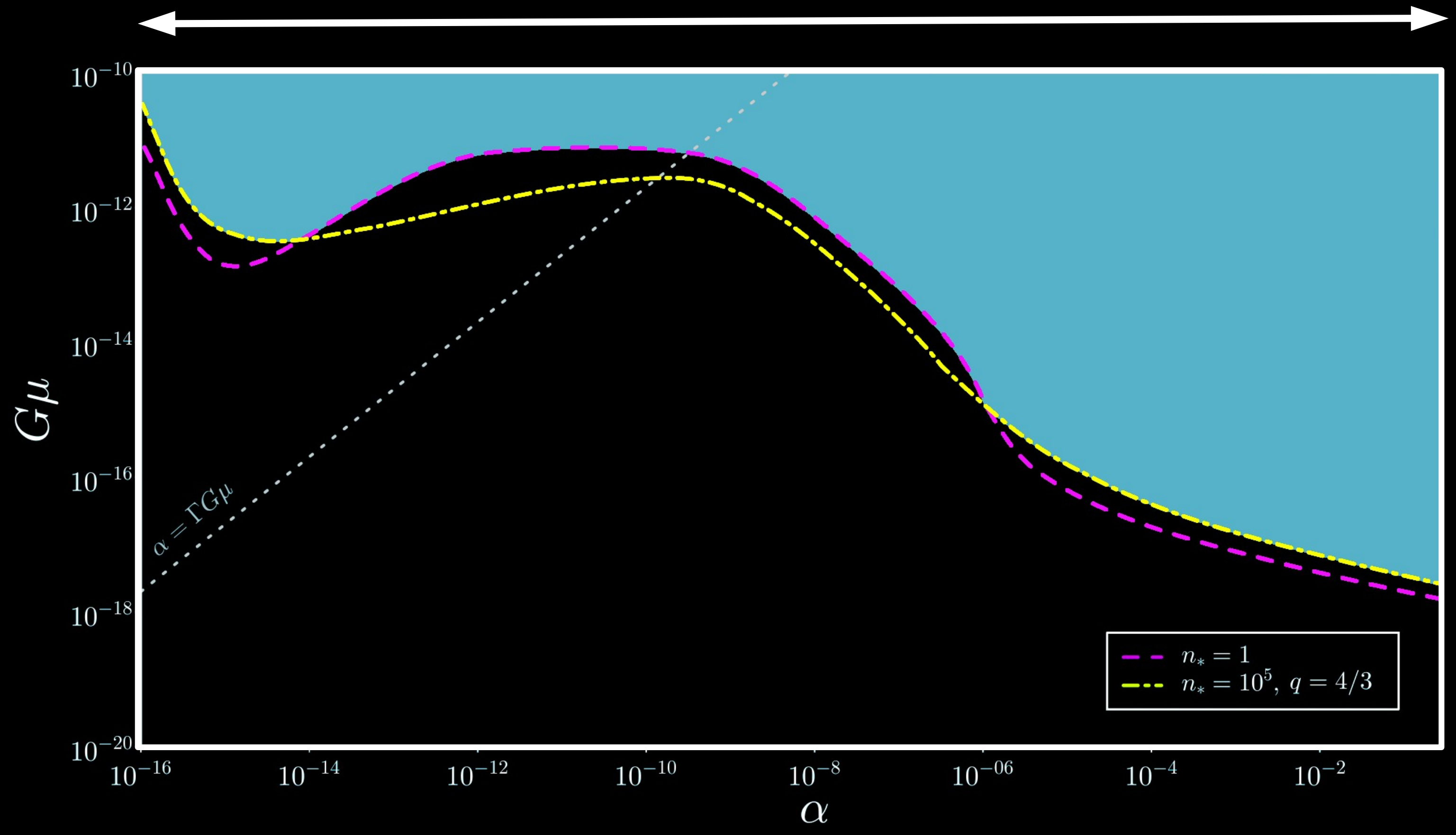
What Else Can LISA do?

OTHER SCENARIOS:



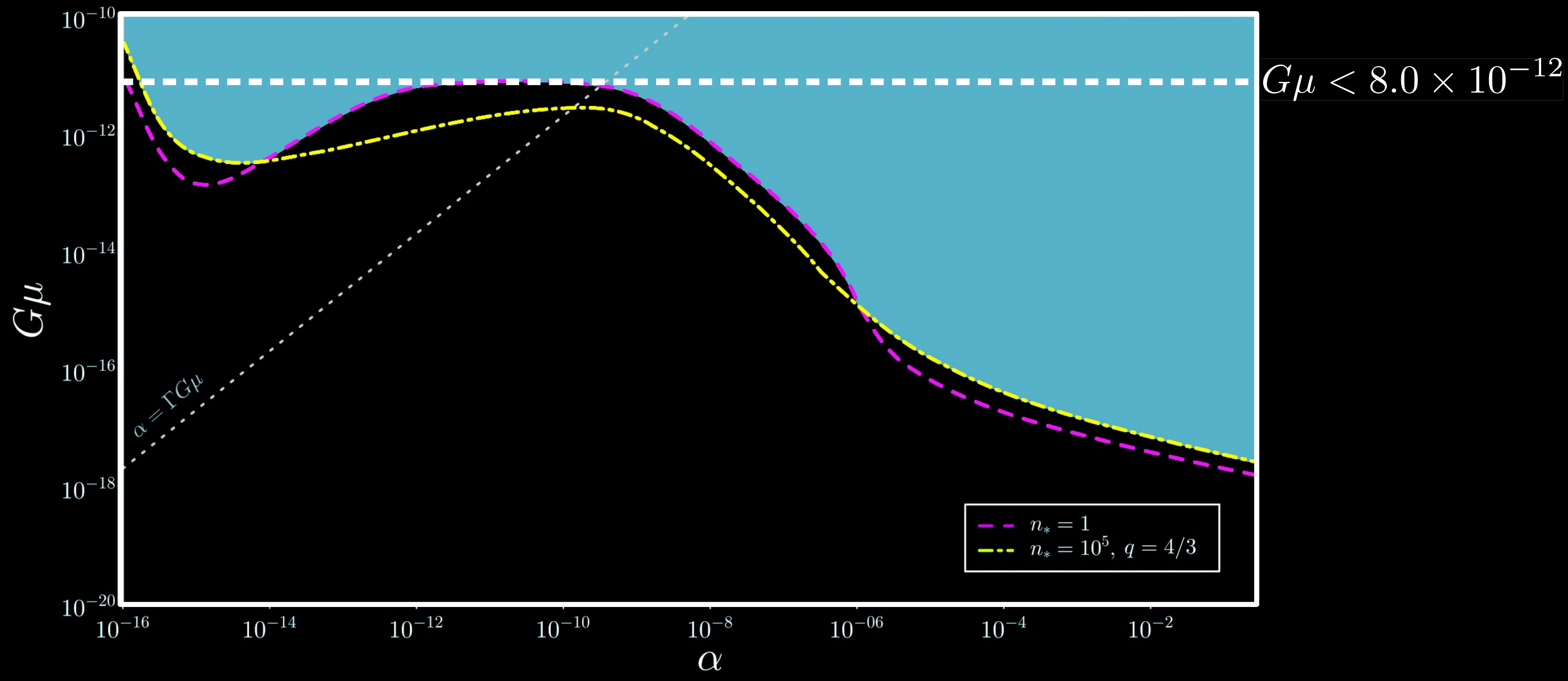
What Else Can LISA do?

16 ORDERS OF MAGNITUDE IN LOOP SIZE



What Else Can LISA do?

LISA PARAMETER SPACE:



What Can LISA do?

LISA WILL BE ABLE TO LARGE
VARIETY OF COSMIC STRING SCENARIOS

Testing Cosmology: Background

DEVIATION FROM STANDARD RADIATION DOMINATION OF THE FORM: $H^2 \propto a^{-\beta}$

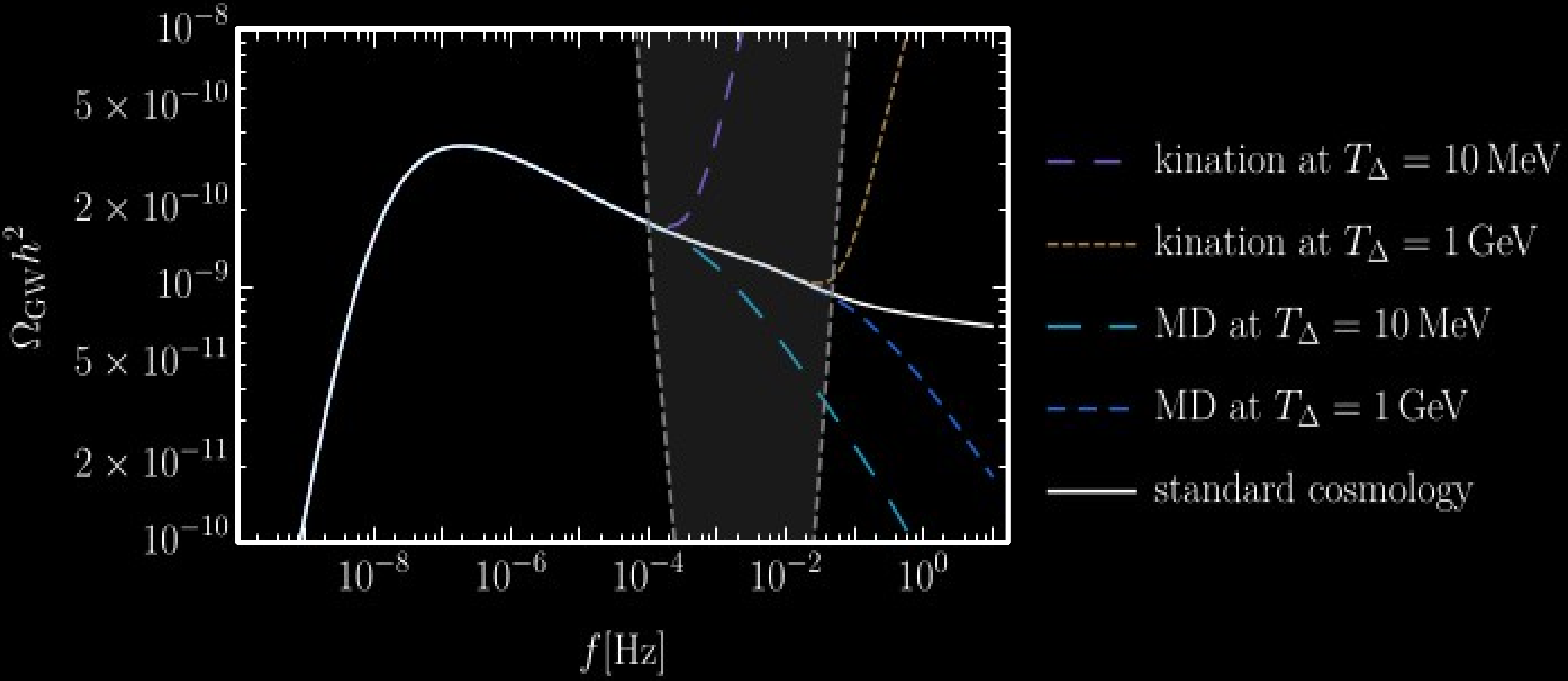
↓

CHANGE THE SLOPE OF THE SPECTRUM

$$\Omega_{gw}(f > f_\Delta) \propto \begin{cases} f^{\frac{8-2\beta}{2-\beta}} & \beta \geq \frac{10}{3} \\ f^{-1} & \beta < \frac{10}{3} \end{cases}$$

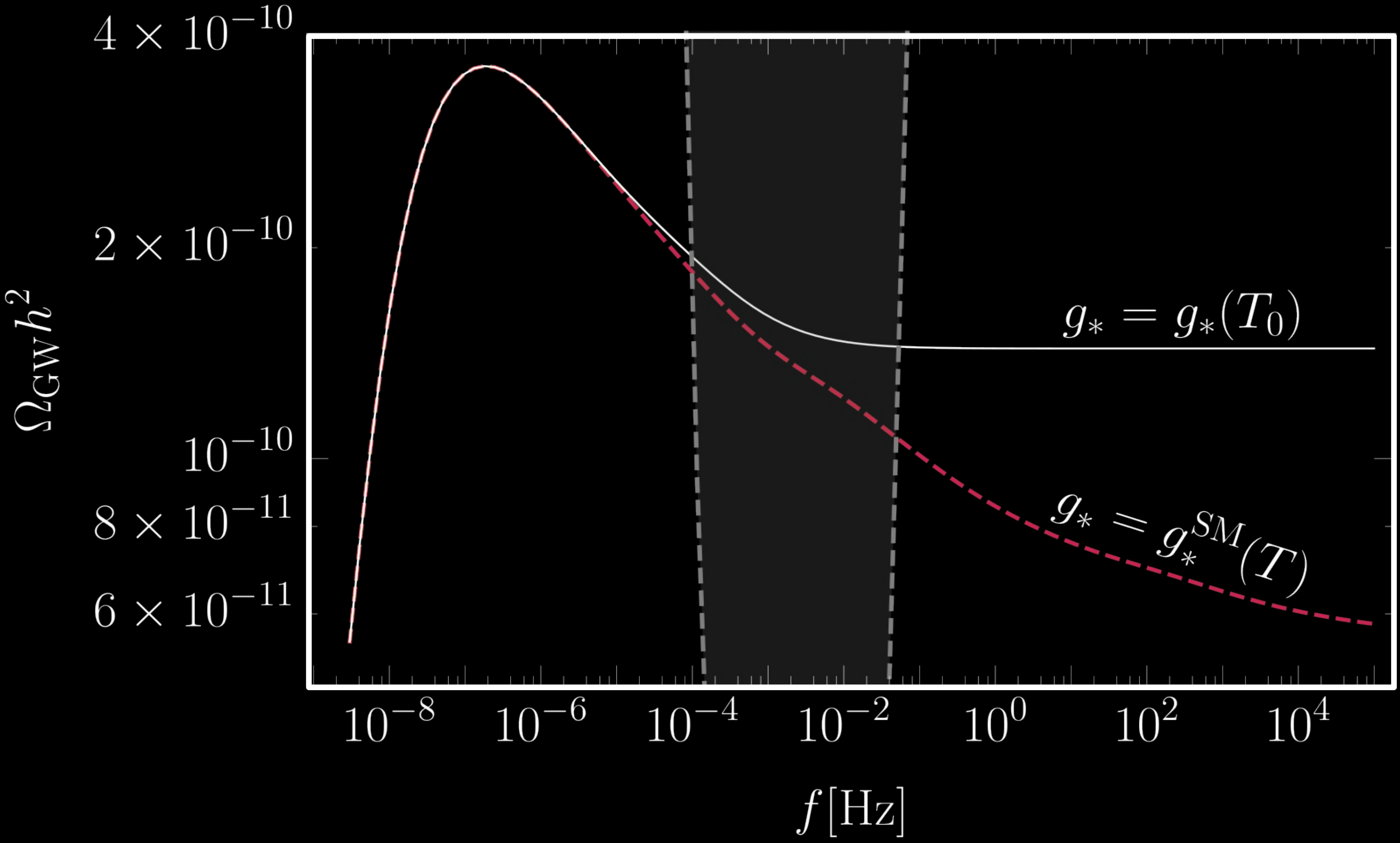
Testing Cosmology: Background

WE CAN TEST RADIATION DOMINATION



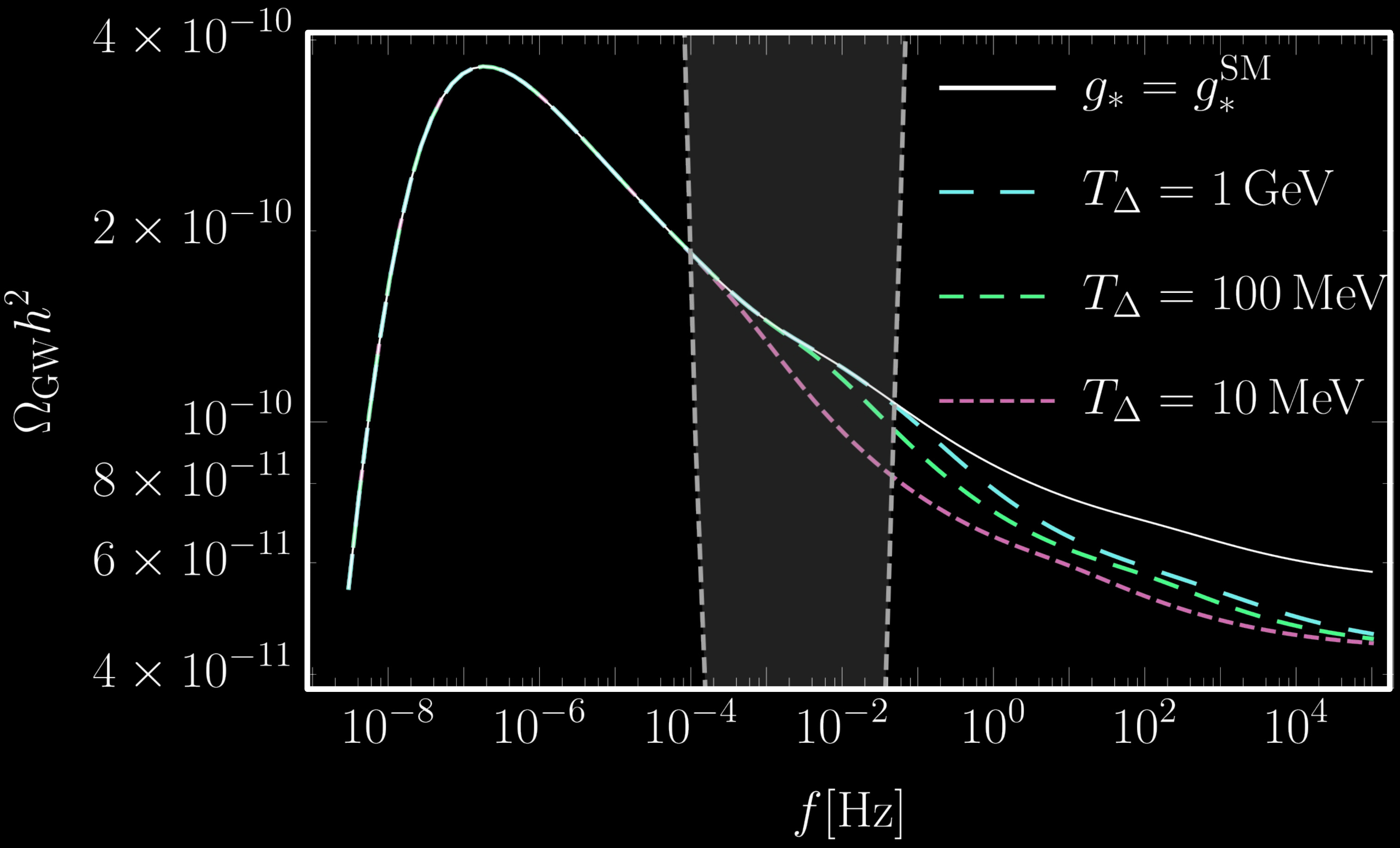
Testing Cosmology: New DoF

DECREASE IN THE NUMBER OF DOF LEAVES A SIGNATURE:



Testing Cosmology: New DoF

We may see new degrees of freedom:



Testing Cosmology

THE SGWB GENERATED BY COSMIC STRINGS MAY ALLOW US TO PROBE THE COSMOLOGICAL EQUATION OF STATE AND THE EXISTENCE OF NEW DoF BETWEEN 1GeV AND 10MeV

To Sum up...

* LISA WILL TEST NAMBU GOTO STRINGS TO UNPRECEDENTED PRECISION: $G\mu \sim 10^{-17}$

* IT WILL BE SENSITIVE TO A LARGE VARIETY OF SCENARIOS;

*THE SGWB IF DETECTED WILL ALLOW US TO TEST RADIATION-DOMINATION ON ENERGY SCALES $10\,\mathrm{MeV} - 1\,\mathrm{GeV}$

THANKS!

Model I

ASSUMING THAT LOOPS HAVE A LENGTH THAT IS FIXED FRACTION OF THE CORRELATION LENGTH $\ell = \alpha L$

RATE OF LOOP PRODUCTION: $$\frac{dn_c}{dt} = \mathcal{F}\frac{\tilde{c}}{\alpha}\frac{v}{L^4}$$

LOOP DISTRIBUTION FUNCTION

$$n(\ell,t) = \sum_i \left\{ \left(\alpha \left.\frac{dL}{dt}\right|_{t=t_b^i} + \Gamma G\mu \right)^{-1} \left.\frac{dn_c}{dt}\right|_{t=t_b^i} \left(\frac{a(t_b^i)}{a(t)} \right)^3 \right\}$$

MODEL II

RADIATION ERA

$$\mathsf{n}_r(l,t) = \frac{0.18}{t^{3/2}\left(l+\Gamma G\mu t\right)^{5/2}} \,.$$

MATTER ERA

$$\mathsf{n}_{rm}(l,t) = \frac{0.18\left(2\sqrt{\Omega_{rad}}\right)^{3/2}}{(l+\Gamma G\mu t)^{5/2}}\,(1+z)^3 \,.$$

$$\mathsf{n}_m(l,t) = \frac{0.27-0.45(l/t)^{0.31}}{t^2(l+\Gamma G\mu t)^2}$$

(subdominant)

Model III

MEASURED IN SIMULATIONS:

$$\mathsf{n}(x) = \frac{C_0}{x^p}\,, \qquad \text{with} \qquad x \gg \Gamma G\mu\,,$$

$$p = 2.60^{+0.21}_{-0.15}\Big|_{\rm rad}\,, \qquad p = 2.41^{+0.08}_{-0.07}\Big|_{\rm mat}\,,$$

$$C_0 = 0.21^{-0.12}_{+0.13}\Big|_{\rm rad}\,, \qquad C_0 = 0.09^{-0.03}_{+0.03}\Big|_{\rm mat}\,.$$

Model III

USED TO CALIBRATE A POLCHINSKI-ROCHA DISTRIBUTION:

- For loops with length scale large compared to $x_d \equiv \Gamma G\mu$:

$$\mathsf{n}(x \gg x_\mathrm{d}) \simeq \frac{C}{(x + x_d)^{3-2\chi}},$$

- For loops with length scale smaller than x_d, but larger than x_c:

$$\mathsf{n}(x_c < x \ll x_\mathrm{d}) \simeq \frac{C(3\nu - 2\chi - 1)}{2 - 2\chi} \frac{1}{x_d} \frac{1}{x^{2(1-\chi)}},$$

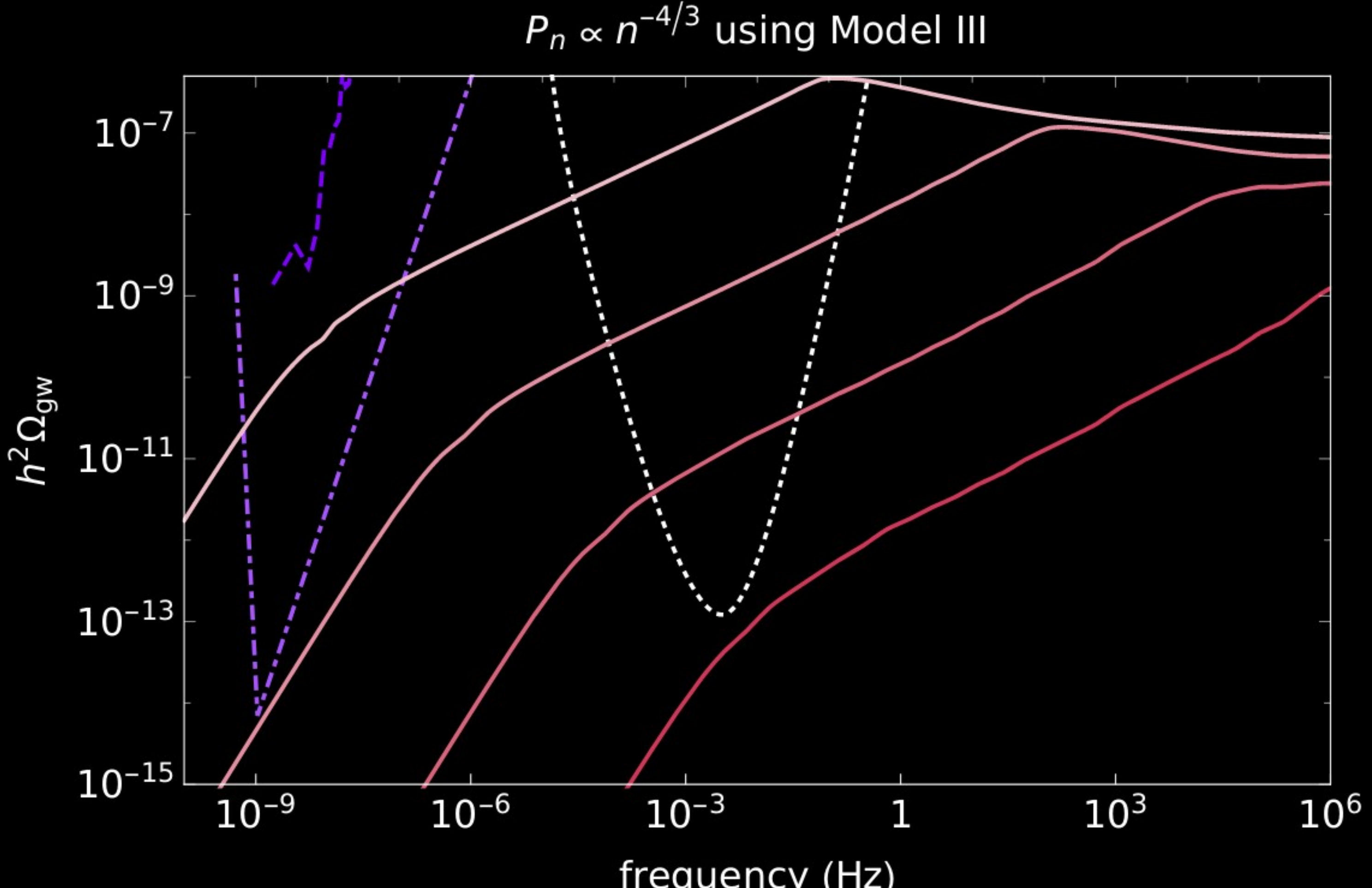
- For loops with length scale smaller than x_c, the distribution is flat:

$$\mathsf{n}(x \ll x_\mathrm{c} \ll x_\mathrm{d}) \simeq \frac{C(3\nu - 2\chi - 1)}{2 - 2\chi} \frac{1}{x_\mathrm{c}^{2(1-\chi)}} \frac{1}{x_\mathrm{d}}.$$

where

$$C = C_0(1 - \nu)^{2-p}.$$

Model III



$P_n \propto n^{-4/3}$ using Model III
10^{-7}
10^{-9}
10^{-11}
10^{-13}
10^{-15}
$h^2\Omega_{gw}$
10^{-9}
10^{-6}
10^{-3}
1
10^{3}
10^{6}
frequency (Hz)