Probing leptogenesis with gravitational waves

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Based on an upcoming work with
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Motivation

Golden era of precision cosmology: Use gravitational wave (GW) experiments as a complementary probe of neutrino physics?

GWs as a probe of:

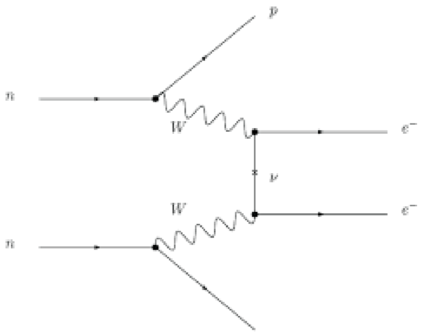
1) Majorana mass vs. Dirac mass?
2) Origin/ mass scale of right-handed neutrinos?
3) How the baryon asymmetry of the universe was generated?

This talk:
Consider LG scenarios where gauged $U(1)_{B-L}$ is broken and detectable GWs from cosmic strings are produced.

(We also consider leptogenesis with FOPT in our work, see poster).

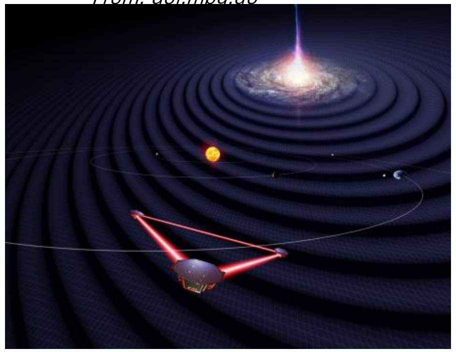
$$\mathcal{L} \supset Y_M \Phi \overline{N^c} N + \overline{N^c} i\gamma^\mu D_\mu N$$

In the models we consider, $U(1)_{B-L}$ breaking gives the RHNs mass.



From: F.Granena et.al. (09)

From: aei.mpg.de



From: Nanograv.org

Outline

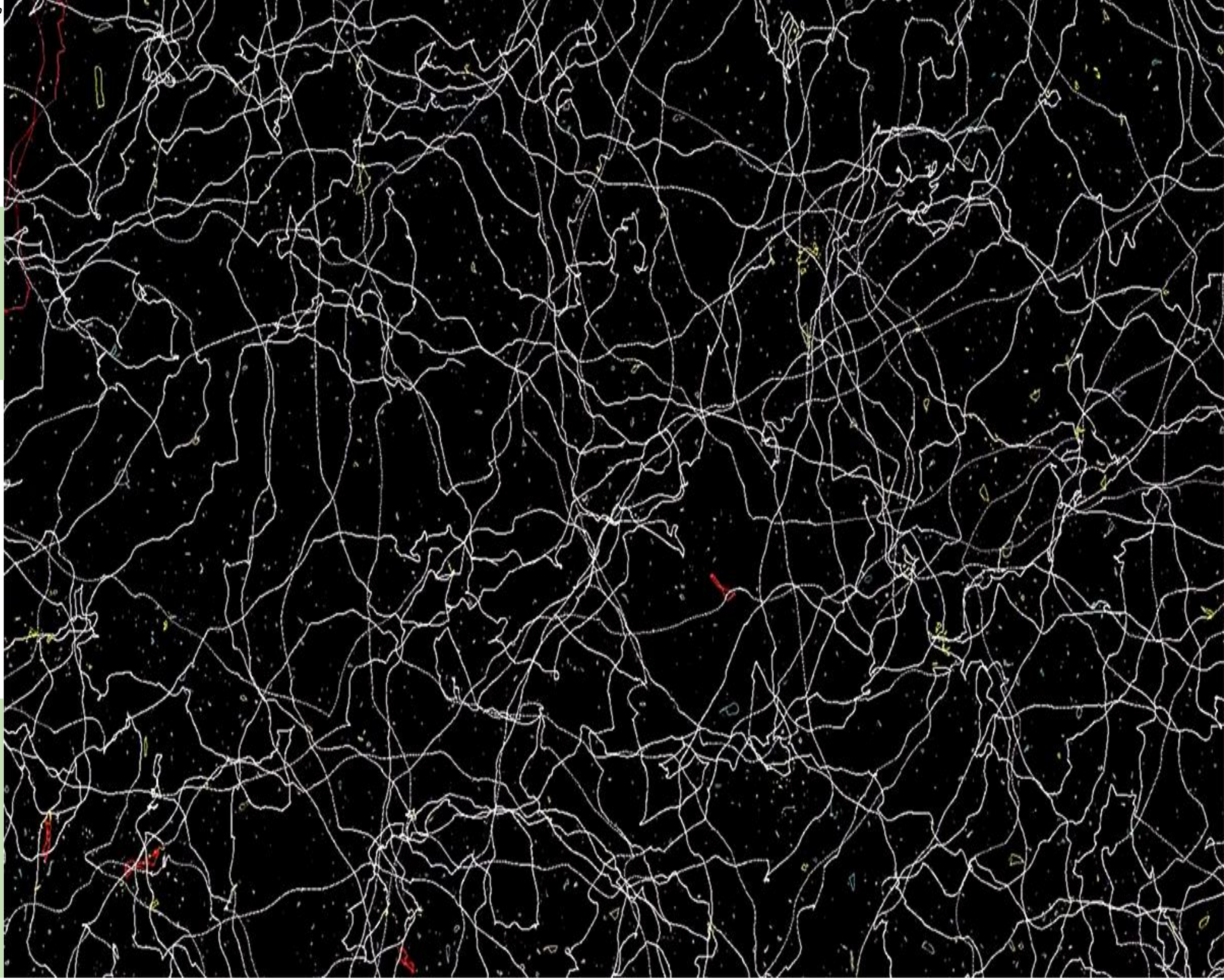
1) Cosmic strings: origin and dynamics

2) Cosmic strings as a non-thermal source for leptogenesis

3) Conclusions

Cosmic string basics:

Quanta Magazine



Cosmic strings are topological defects. Arise in symmetry-breaking phase transitions in the early universe when:

$$G \to H \text{ and } \pi_1(G/H) \neq 0.$$

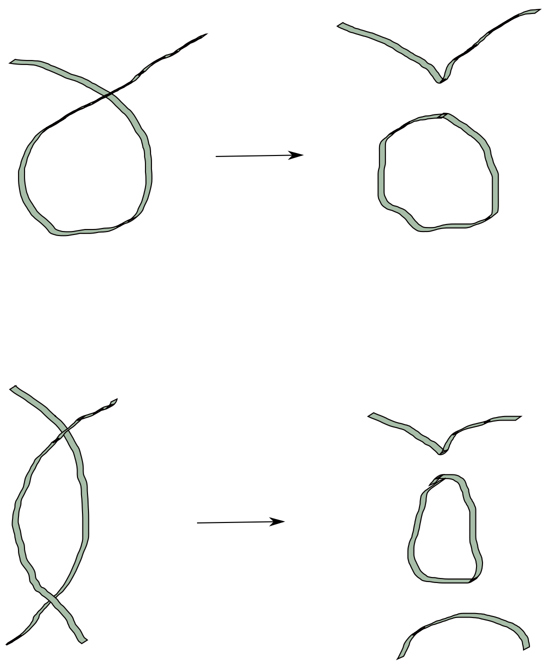
Similar objects observed in condensed matter systems.

The universe is in the *unbroken* phase inside the string.

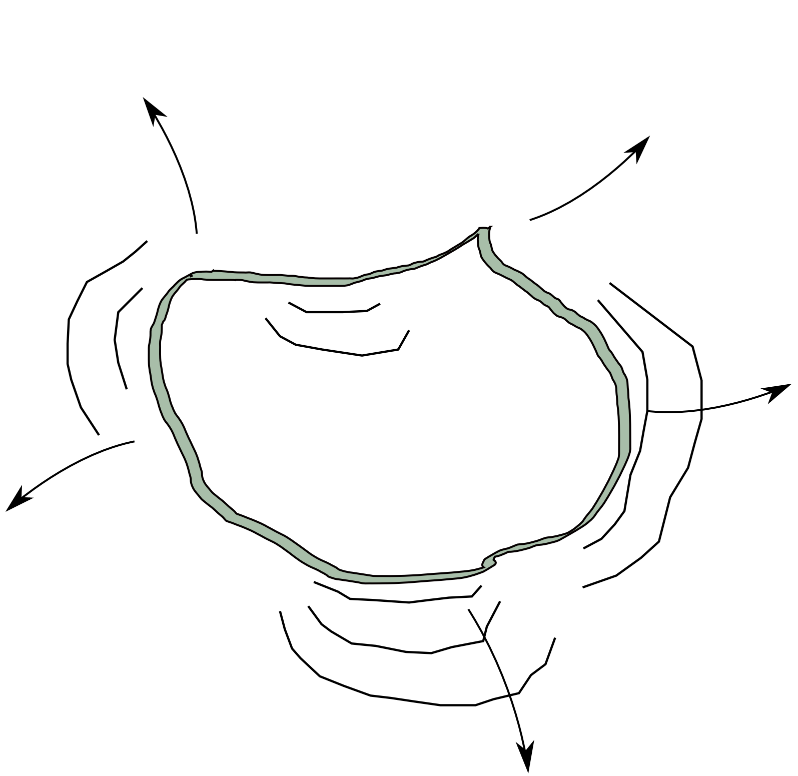
Cosmic string dynamics and loop production

Vilenkin and Shellard (1994)
Martins & Shellard (1996)

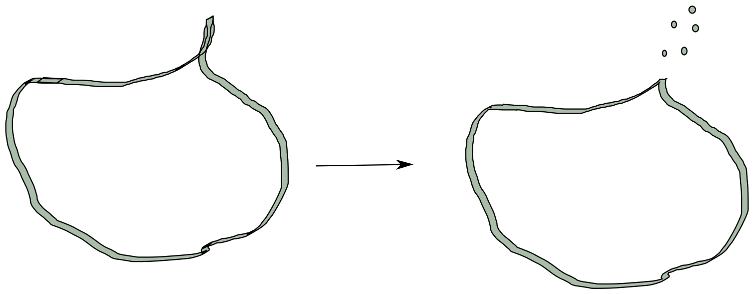
Intersect and create loops:



Wiggle and emit GWs:



Produce Particles:



Mechanisms:

Cusp evaporations

Kink collisions

Final collapse

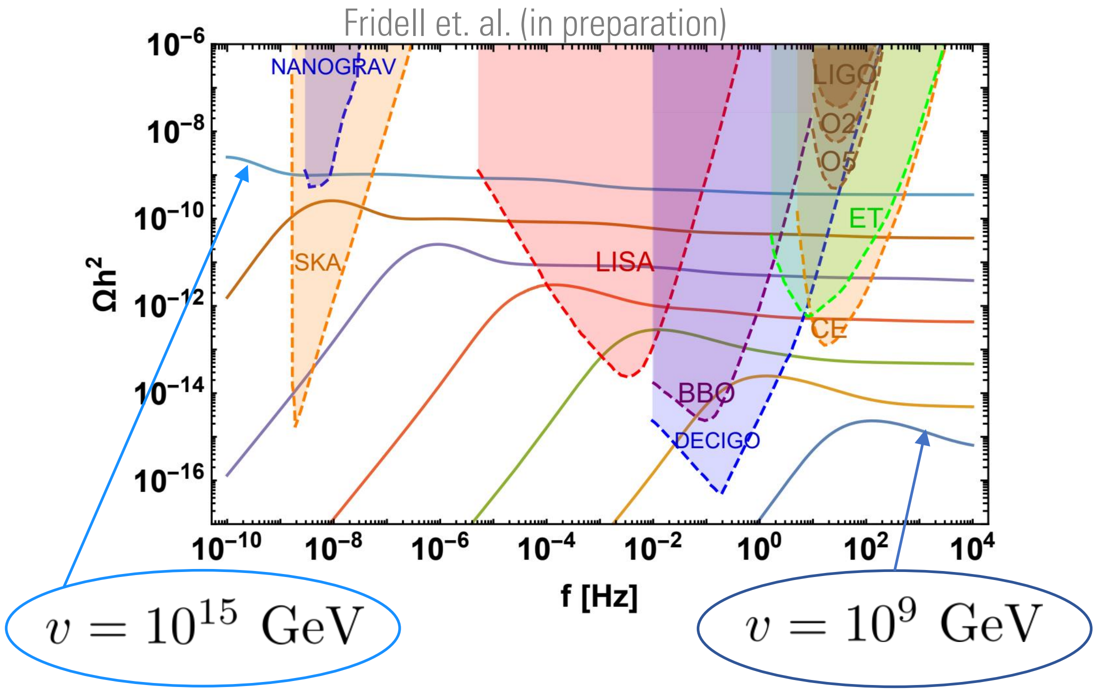
$U(1)_{B\text{-}L}$ strings and leptogenesis

Right-handed neutrinos (RHN) couple to $U(1)_{B\text{-}L}$ gauge field and the symmetry-breaking scalar field:

$$\mathcal{L} \supset Y_M \Phi \overline{N^c} N + \overline{N^c} i \gamma^\mu D_\mu N$$

A cosmic string arising from $U(1)_{B\text{-}L}$ -breaking can source RHNs!

Stochastic GWs from strings (magnitude signal set by string tension) $\mu \sim v^2$



Connects neutrino masses, leptogenesis w/ non-thermal source, and gravitational wave experiments.

Leptogenesis with cosmic strings (general case)

$$\frac{dE_\phi}{dy} = -\frac{1}{Hy}\left[\Gamma_{\phi N} + \Gamma_{\phi R}\right] E_\phi,$$

$$\frac{dE_N}{dy} = -\frac{1}{Hy}\left[-\Gamma_{\phi N} E_\phi + \Gamma_N \left(E_N - E_N^{\rm eq}\right) - E_X y^3 a_I^3 \frac{dn_N^{\rm cs}(y)}{dt} \Theta(y - y_{\rm fric})\right],$$

$$\frac{dN_{B-L}}{dy} = -\frac{1}{Hy}\left[\epsilon D \left(N_N - N_N^{\rm eq}\right) + W N_{B-L}\right],$$

$$\frac{dE_R}{dy} = \frac{a_I}{H}\left[\Gamma_N \left(E_N - E_N^{\rm eq}\right) + \Gamma_{\phi R} E_\phi\right].$$

- Changes as string network evolves.
- Different for strings with different small-scale structure.

Leptogenesis with cosmic strings (radiation domination)

$$\frac{dN_{N1}}{dz} = -(D+S)(N_{N1} - N_{N1}^{\rm eq}) + \frac{dN_{N1}^{\rm CS}}{dz}$$

$$\frac{dN_{B-L}}{dz} = -\epsilon D(N_{N_1} - N_{N_1}^{\rm eq}) - W N_{B-L}$$

Davis & Earnshaw (1993)
Lew & Riotto (1994)
Jeannerot (1996)
Sahu, Bhattacharjee & Yajnik (2004+2006)

We have calculated the injection rate for different epochs of network evolution.

Based on field-theory simulations of loop evolution by Matsunami et. al. (PRL 2019).

We have considered loops with small-scale structure dominated by cusps, kinks, and loops primarily decaying via emission of GWs.

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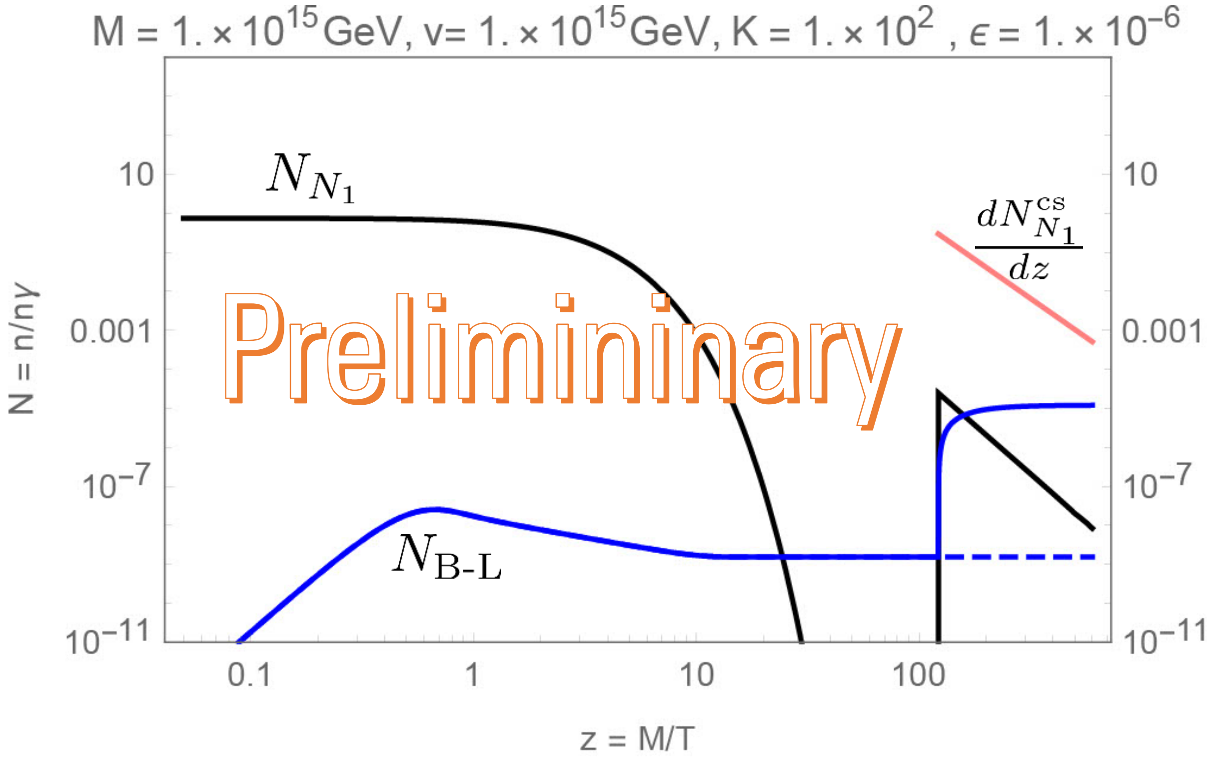
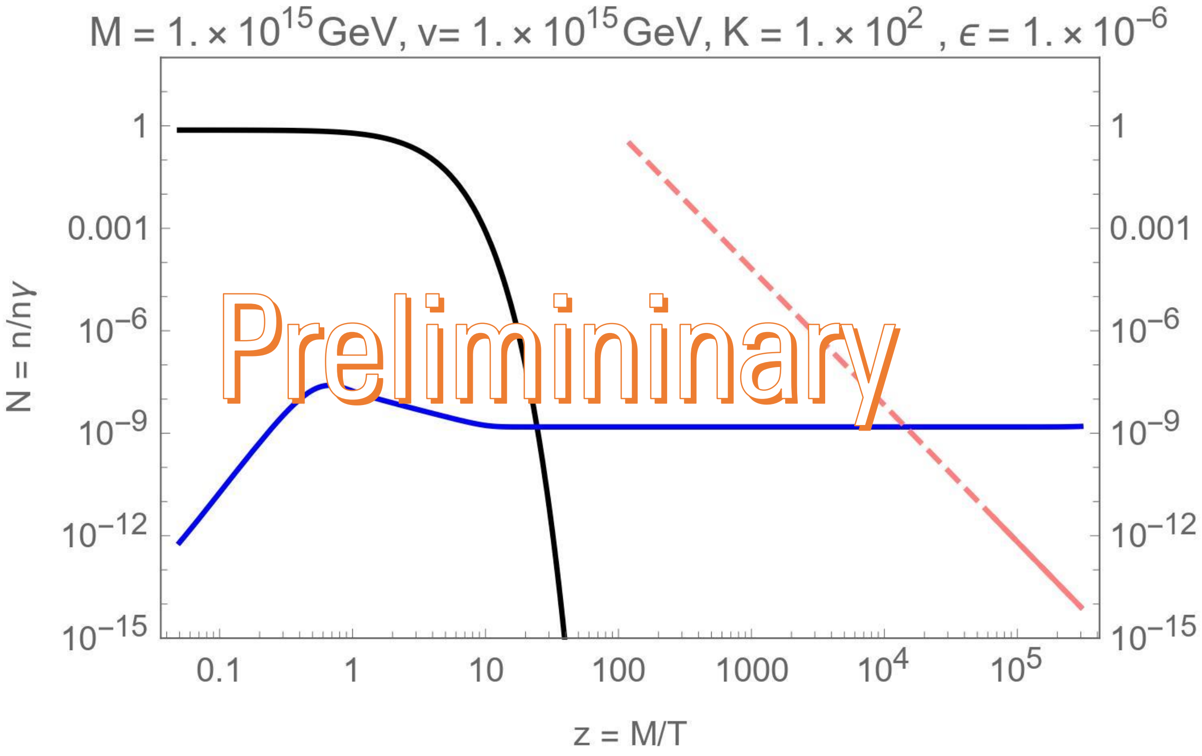
Example of overestimate v.s. more careful estimate of CS contribution from big collapsing loops produced during linear scaling

"Overestimate"



"Conservative estimate"



Turn on RHN injection too early, achieve false enhancement of BAU.

Turn on RHN injection when first loops produced during linear scaling collapse.

Considered scenarios

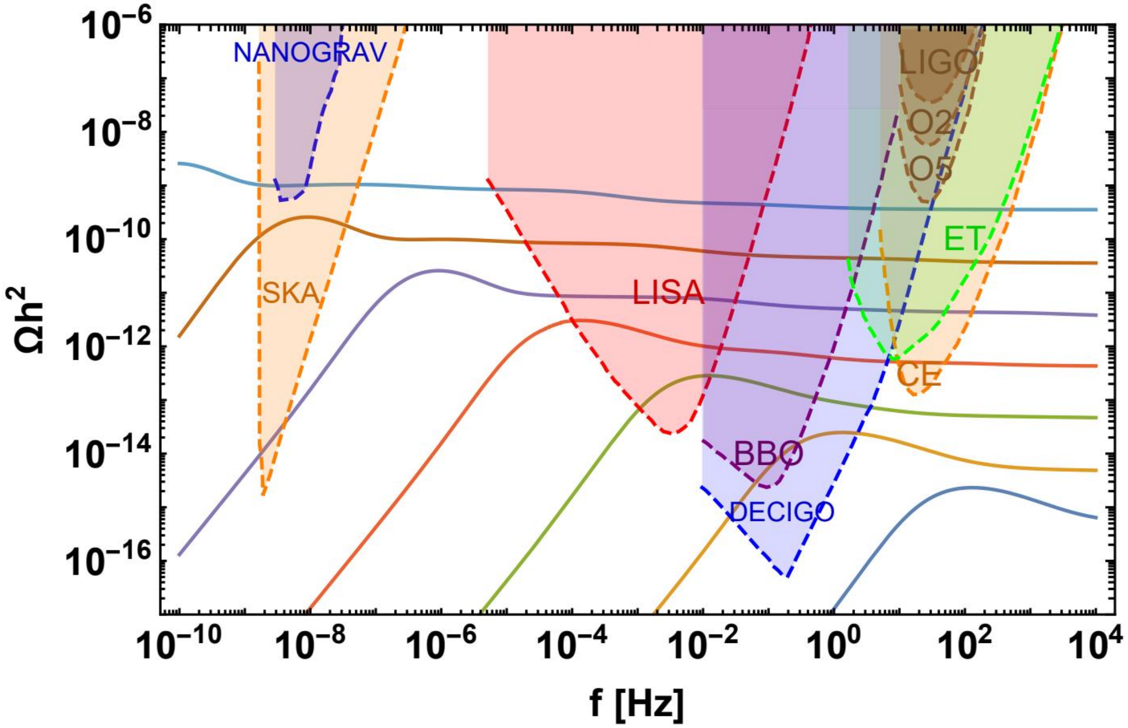
Network epoch	Size of loops	Small-scale structure	Particle-emission mechanism
Stretching (friction)	-	-	Final collapse
Kibble (friction)	-	-	Final collapse
Linear scaling	small	cusps	Final collapse
Linear scaling	small	cusps	Cusp evaporations
Linear scaling	big	cusps	Final collapse
Linear scaling	big	cusps	Cusp evaporations
Linear scaling	small	kinks	Final collapse
Linear scaling	small	kinks	Kink-kink collisions
Linear scaling	big	kinks	Final collapse
Linear scaling	big	kinks	Kink-kink collisions
Linear scaling	small	-	Final collapse
Linear scaling	big	-	Final collapse

Preliminary comments on CS impact on BAU

- Cosmic String Loops seem to have little/ no effect on the BAU, contrary to previous estimates.

Summary

- Considered gauged $U(1)_{B-L}$ breaking giving masses to right-handed neutrinos.
- Network of cosmic strings form after the $U(1)_{B-L}$ phase transition.
- The cosmic strings can source gravitational waves *and* right-handed neutrinos.
- Calculated the injection rate of RHNs from cosmic strings for different epochs of network evolution and for different types of loops.
- Currently finalizing analysis: Do not find large effects.



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Thank you for your attention!