Tracking down the Route of GUT Breaking

EJC, Velasco-Sevilla, 2112.14483

EJC, Dutka, Jung, Nagels, Vanvlasselaer, 2305.10759

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Eung Jin Chun

KIAS KOREA INSTITUTE FOR ADVANCED STUDY

Outline

- Motivation: GW probe of GUT breaking routes to SM predicting different types of topological defects and FOTP at various scales.

$$G_{\rm GUT} \rightarrow H_1 \rightarrow H_2 \rightarrow \cdots \rightarrow G_{\rm SM}: \quad \pi_k(G/H) \neq I, k = 0\ (\rm DW), 1\ (\rm CS), 2\ (\rm MP)$$

- Review: GW signals from topological defects & FOTP.
- Phenomenologically viable routes: unification, proton decay, and inflation removing dangerous defects.
- Prediction of a certain combination of GW signals may be probed.

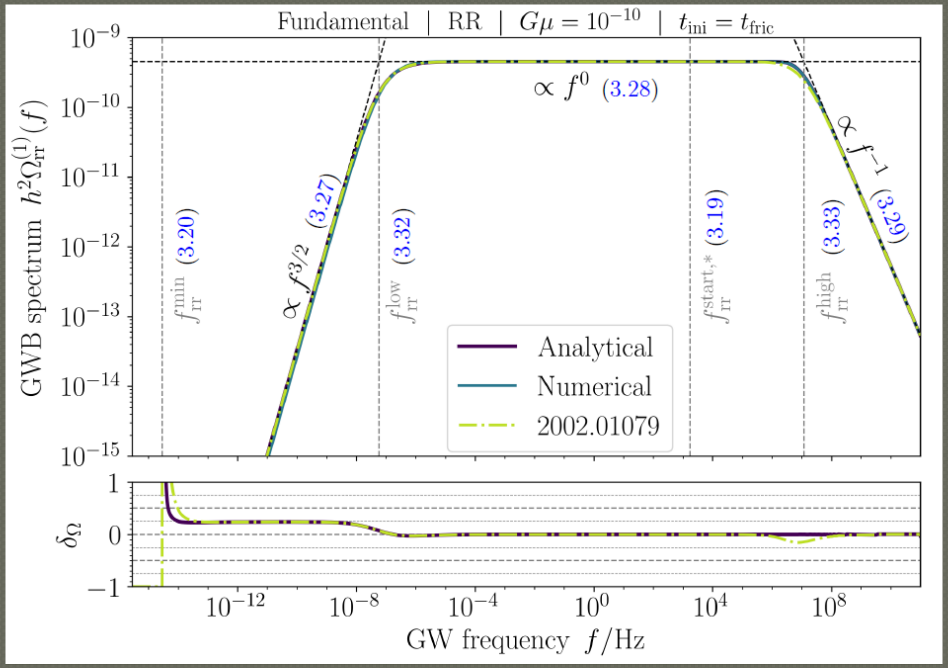
GW from Cosmic Strings

Flat spectrum from a scaling solution during radiation era

Schmitz, Schroeder, 2412.20907

$$\Omega_{\rm GW} h^2 \sim 4.5 \times 10^{-10} \left(\frac{G\mu}{10^{-10}} \right)^{1/2} \qquad \mu \approx M_{\rm CS}^2$$

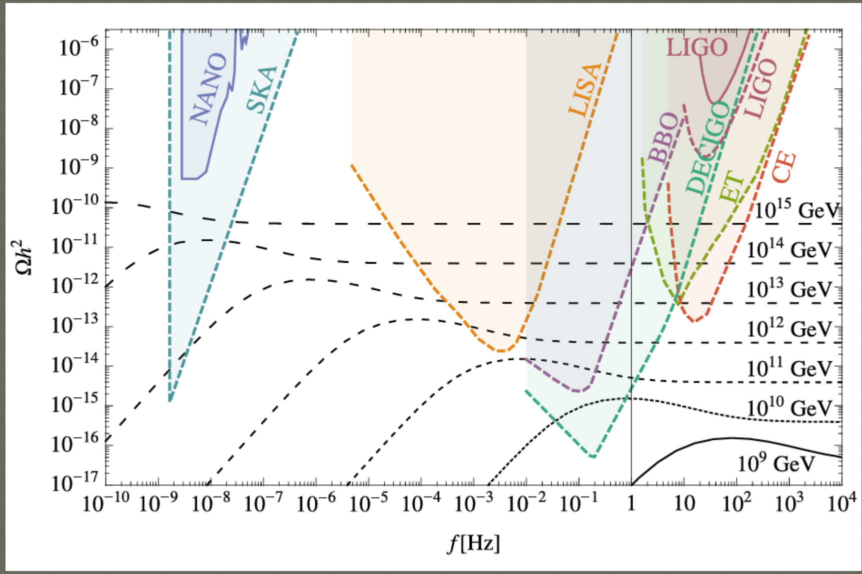
$$5.7 \times 10^{-8} {\rm Hz} \left(\frac{10^{-10}}{G\mu} \right) < f < 3.5 \ \times 10^{10} \ {\rm Hz}$$



GW probing Seesaw/GUT

Seesaw scale of $U(1)_{B-L}$ breaking

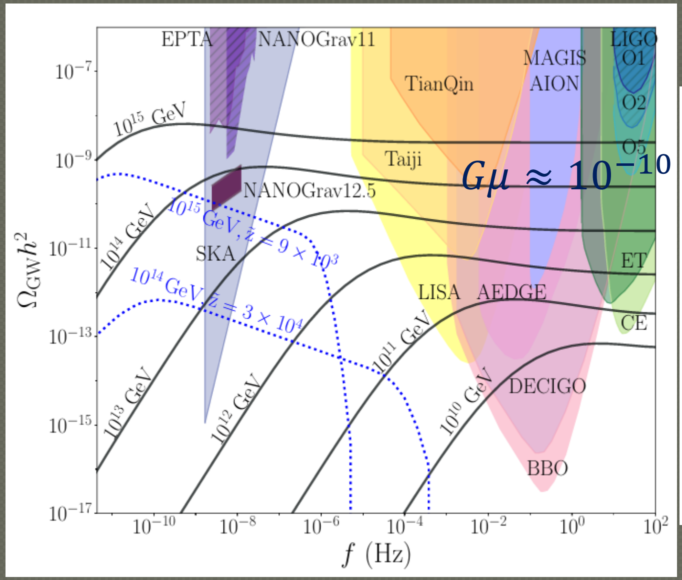
Dror, et.al., 1903.03227

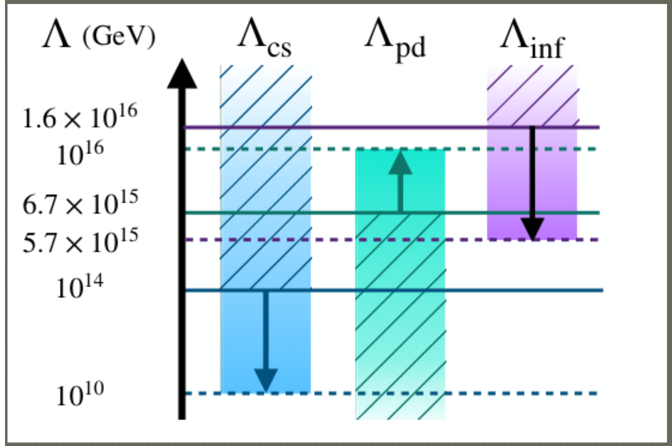


SO(10) GUT with proton decay

$$SO(10) \to G_I \times U(1)_{B-L} \to \cdots \to G_{SM}$$

King, Pascoli, Turner, Zhou, 2005.13549





GW from unstable Domain Walls

- Stable overclose the Universe.
- They may be diluted by inflation, or destabilized by a bias potential ΔV breaking softly the symmetry.
- GW signals are controlled by two parameters: wall tension $\sigma \sim M_{\rm DW}^3$ and ΔV.

$$T_{\rm ann} \approx 4 \times 10^{-2}{\rm GeV} \left(\frac{\sigma}{\rm TeV^3}\right)^{-\frac{1}{2}} \left(\frac{\Delta V}{\rm MeV^4}\right)^{\frac{1}{2}} > 10{\rm MeV}$$

$$f_{\rm peak} \approx \left(\frac{a_{\rm ann}}{a_0}\right) H_{\rm ann} \approx 10^{-9}{\rm Hz} \left(\frac{T_{\rm ann}}{10^{-2}{\rm GeV}}\right)$$

$$\Omega_{\rm GW} h^2_{\rm peak} \approx 10^{-18} \left(\frac{\sigma}{\rm TeV^3}\right)^2 \left(\frac{T_{\rm ann}}{10^{-2}{\rm GeV}}\right)^{-4}$$

Saikawa, 1703.02576

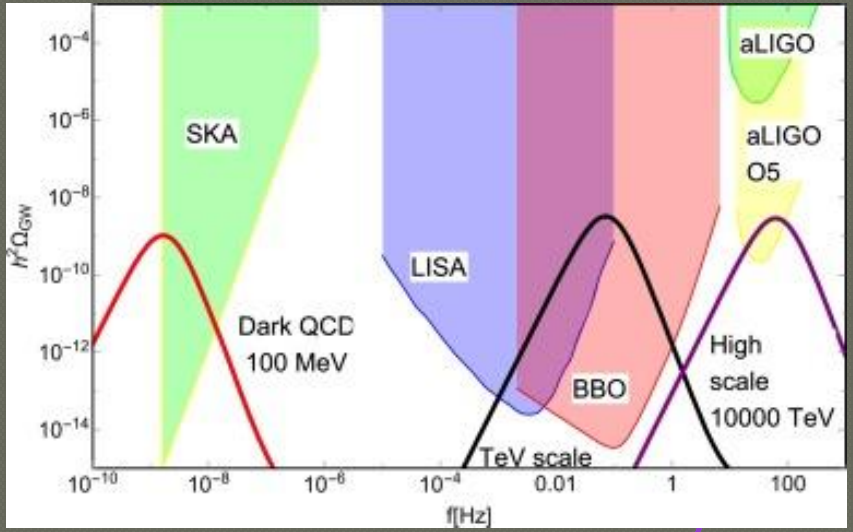
GW from FOPT

- FOPT characterized by nucleation temperature T_*, burble wall velocity v_w, latent heat $\alpha = \Delta\rho/\rho_R$, change of burble nucleation rate β/H_*, which control GW signals:

Caprini, et.al., 1512.06239 (LISA)

$$f_{\rm peak}^{\rm sw} \approx 2 \times 10^{-5} {\rm Hz} \frac{1}{v_w} \left(\frac{\beta}{H_*}\right) \left(\frac{T_*}{100 {\rm GeV}}\right)$$

$$\Omega_{\rm GW}^{\rm sw} h^2{}_{\rm peak} \approx 2.7 \times 10^{-6}\, v_w \left(\frac{H_*}{\beta}\right) \left(\frac{\kappa_{\rm sw}\alpha}{1+\alpha}\right)^2$$



Huang, Zhang, 1701.04338 (3-3-1 model)

GUT breaking routes

- We consider SUSY SO(10) GUT.
- For a given breaking pattern, intermediate breaking scales are to be fixed consistently with gauge unification and proton decay constraints depending on matter content.
- Multiple topological detects and FOPT appear, which may be probed by GW detection.

Phenomenological consideration

- Observables:

Experimental/Lattice values used			
Parameter	Current Value	Projected Bound	$3\,\sigma$ Discovery
$M_Z(M_Z)$	91.1876 (21) GeV		
$\alpha_S(M_Z)$	0.1179(10)		
$\alpha_{\mathrm{e.m.}}(M_Z)$	1/127.9		
$\sin^2\theta_W(M_Z)$	0.23121(4)		
$m_t(m_t)$	172.5 ± 0.7		
$\langle \pi^0 \| (ud)_R\, u_L \| p\rangle$	$-0.131(4)(13)$ [67]		
$\langle \pi^0 \| (ud)_L\, u_L \| p\rangle$	0.134(5)(16) [67]		
$\tau(p \to \pi^0\, e^+)$	$> 1.6 \times 10^{34}$ yrs [67] [68] 95% C.L	7.8×10^{34} yrs 90% C.L [HK [63]]	6.3×10^{34} yrs [HK [63]]
$\tau(p \to K^+ \bar{\nu})$	$> 6.6 \times 10^{33}$ yrs 95% C.L	5×10^{34} yrs [DUNE [62]] 3.2×10^{34} yrs 90% C.L. [HK [63]]	2×10^{34} yrs [HK [63]]

- Common outputs: $M_{GUT} \approx (8.9 - 1.6) \times 10^{16}$ GeV

$$\tau(p \to K^+\bar{\nu}) \sim 4 \times 10^{33} \left(\frac{M_S}{10\mathrm{TeV}}\right)^2 \left(\frac{M_{HC}}{10^{16}\mathrm{GeV}}\right)^2 \mathrm{yr}$$

Standard routes

Intermediate steps of breaking and the corresponding Higgs multiplets

Appearance of FOPT and topological defects: 2(MP), 1(CS), 0(DW)

$$\mathrm{SO}(10) \xrightarrow[126\ (2)]{M_{\rm GUT}} \mathrm{SU}(5)\times \mathrm{U}(1)_V \xrightarrow[45\ (2)]{M_R} \mathrm{SU}(3)_C\times \mathrm{SU}(2)_L\times \mathrm{U}(1)_V\times \mathrm{U}(1)_Z, \xrightarrow[45\ (1)]{M_{B-L}} G_{\rm SM}\times \mathbb{Z}_2$$

$$\xrightarrow[10]{M_{\rm EW}} \mathrm{SU}(3)_C\times \mathrm{U}(1)_Y\times \mathbb{Z}_2,$$

$$\mathrm{SO}(10) \xrightarrow[45\ (2)]{M_{\rm GUT}} \mathrm{SU}(3)_C\times \mathrm{SU}(2)_L\times \mathrm{SU}(2)_R\times \mathrm{U}(1)_{B-L} \xrightarrow[126\ (1,\mathrm{pt})]{M_{B-L}} G_{\rm SM}\times \mathbb{Z}_2$$

$$\xrightarrow[10]{M_{\rm EW}} \mathrm{SU}(3)_C\times \mathrm{U}(1)_Y\times \mathbb{Z}_2,$$

$$\mathrm{SO}(10) \xrightarrow[210\ (2,1)]{M_{\rm GUT}} \mathrm{SU}(3)_C\times \mathrm{SU}(2)_L\times \mathrm{SU}(2)_R\times \mathrm{U}(1)_{B-L}\times D \xrightarrow[45\ (0)]{M_D}$$

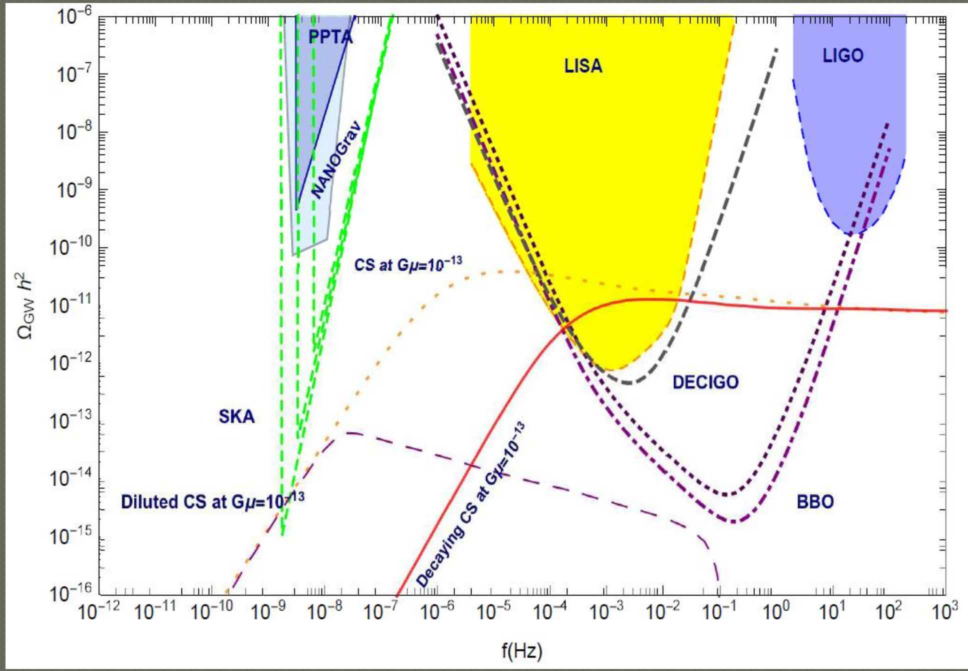
$$\mathrm{SU}(3)_C\times \mathrm{SU}(2)_L\times \mathrm{SU}(2)_R\times \mathrm{U}(1)_{B-L} \xrightarrow[126\ (1)]{M_{B-L}} G_{\rm SM}\times \mathbb{Z}_2$$

$$\xrightarrow[10]{M_{\rm EW}} \mathrm{SU}(3)_C\times \mathrm{U}(1)_Y\times \mathbb{Z}_2.$$

SU(5) route

$$SO(10) \Longrightarrow SU(5)\times U(1)_V \Longrightarrow SU(3)_c\times SU(2)_L\times U(1)_Z\times U(1)_V \Rightarrow G_{SM}\times\ Z_2$$

$M_{GUT}\approx 10^{16}\text{GeV}$ MP | $M_R > 10^{14}\text{GeV}$ MP | T_{RH} | $M_{B-L}\approx 10^{14}\text{GeV}$ CS



Diluted CS

Regeneration after inflation

Cui, Levicki, Morrissey, 1912.08832

Decaying CS

Strings connecting MP-antiMP

$$\frac{\Gamma_{\rm dec}}{\mu} = \frac{1}{2\pi} e^{-M_R^2/\mu}$$

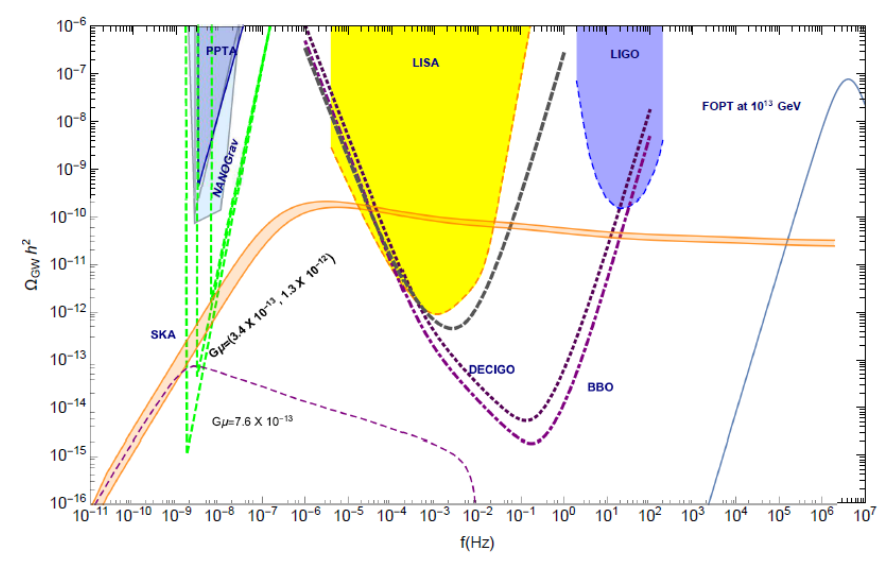
Martin, Vilenkin, 9606022

LR route

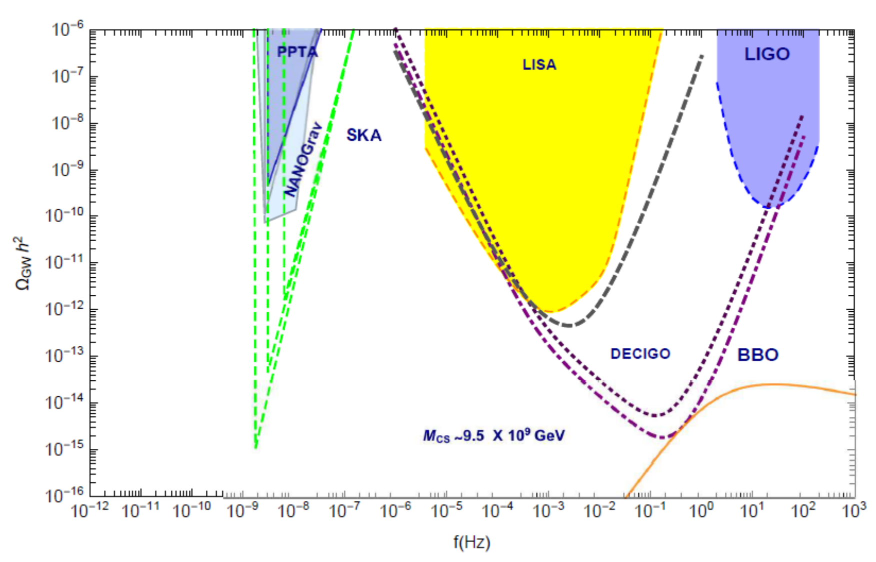
$$SO(10) \Longrightarrow SU(3)_c \times SU(2)_L \times SU(2)_R \times U(1)_{B-L} \Rightarrow G_{SM} \times Z_2$$

$M_{GUT} \approx 10^{16}\text{GeV}$ T_{RH} $M_{B-L} \approx 3 \times 10^{13}\text{GeV}$

MP CS, FOPT



SUSY



non-SUSY

LR route with D-parity

$SO(10) \Rightarrow SU(3)_c \times SU(2)_L \times SU(2)_R \times U(1)_{B-L} \times D$

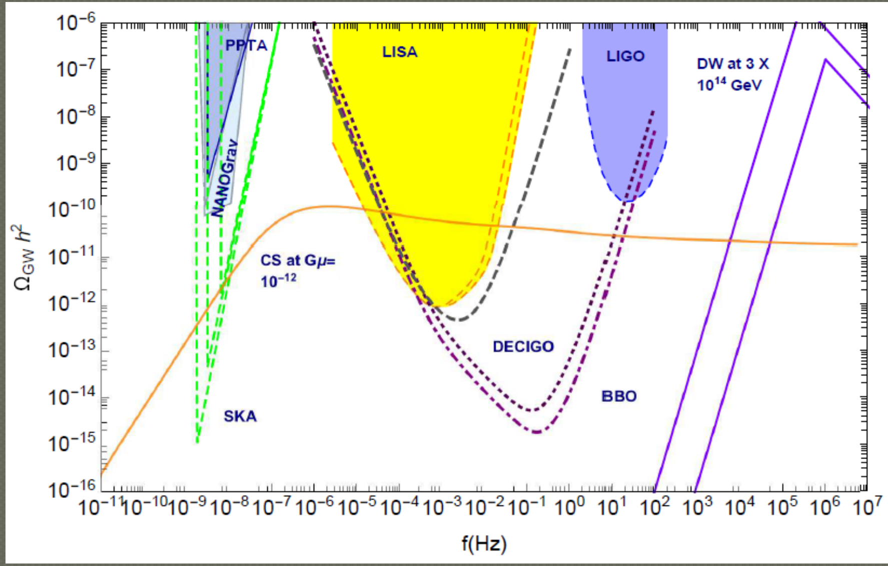
$M_{GUT} \approx 10^{16}\text{GeV}$
MP, CS

T_{RH}

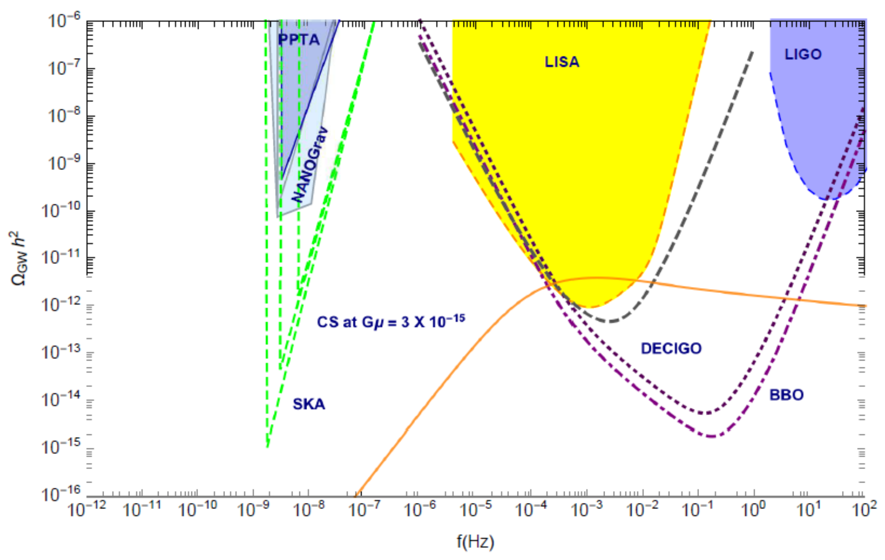
$\Longrightarrow SU(3)_c \times SU(2)_L \times SU(2)_R \times U(1)_{B-L} \Rightarrow G_{SM} \times \ Z_2$

$M_R \approx 3 \times 10^{14}\text{GeV}$
DW

$M_{B-L} \approx 4 \times 10^{13}\text{GeV}$
CS

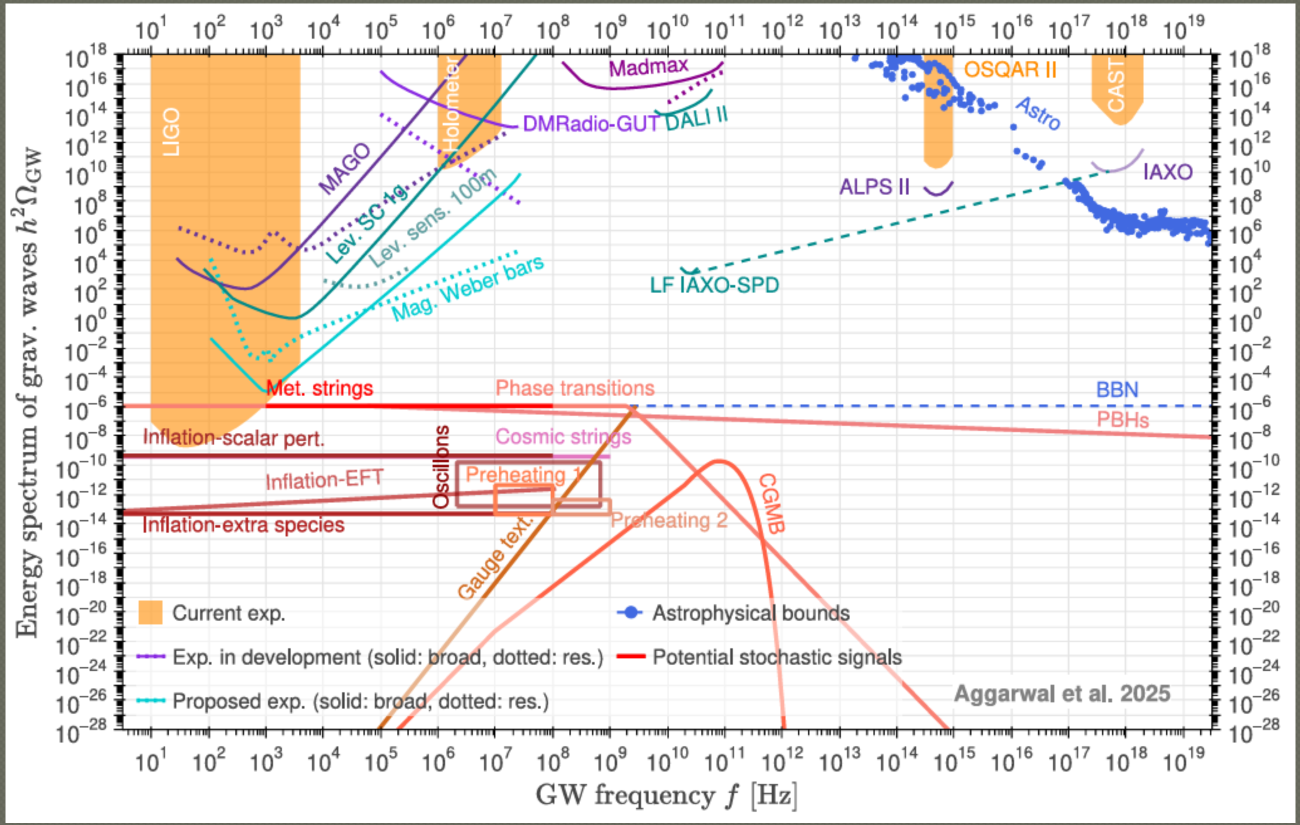


SUSY



non-SUSY

HFGW detection



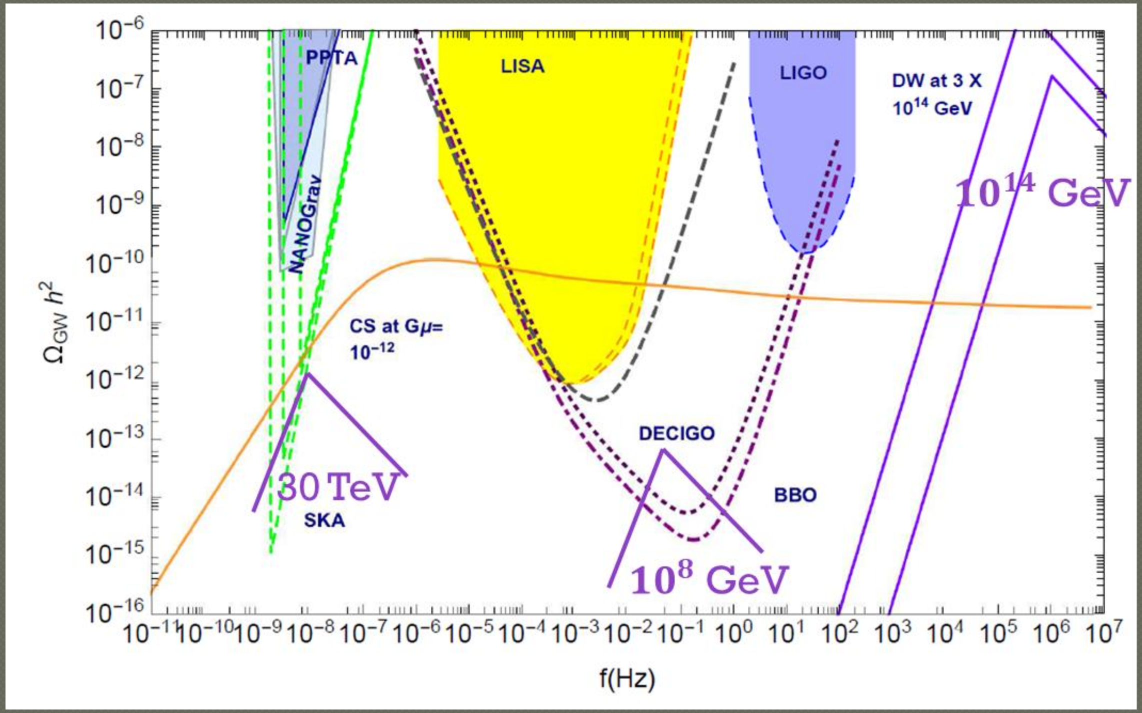
2501.11723

DW at lower scale?

Consistent Z_2 breaking with an additional Higgs?

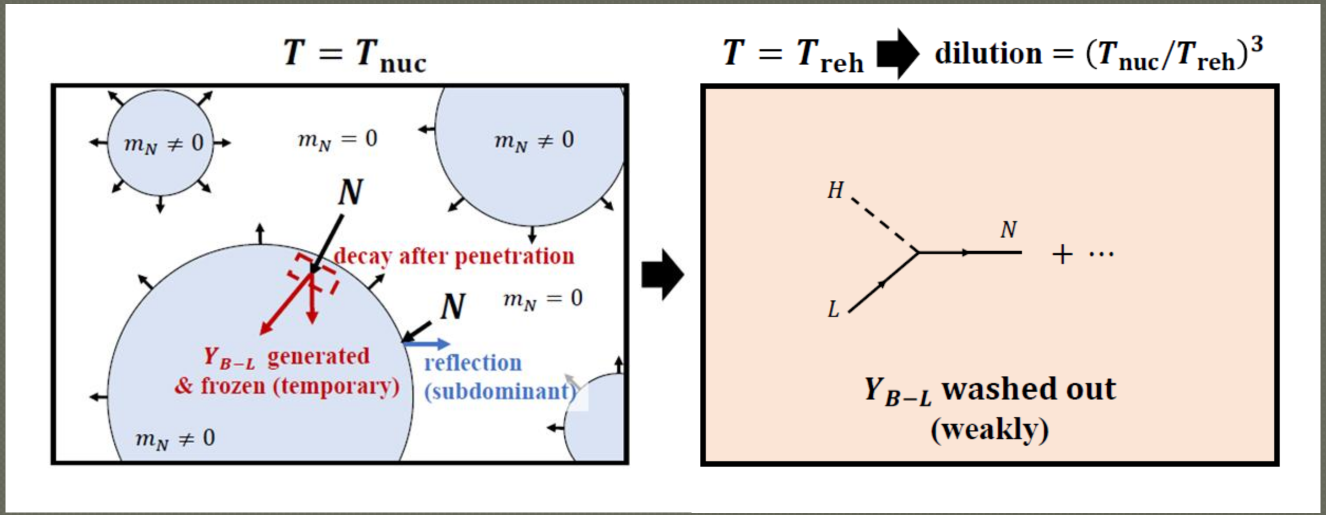
$$f_{\rm peak} \approx \left(\frac{a_{\rm ann}}{a_0}\right) H_{\rm ann} \approx 10^{-9}{\rm Hz}\left(\frac{T_{\rm ann}}{10^{-2}{\rm GeV}}\right)$$

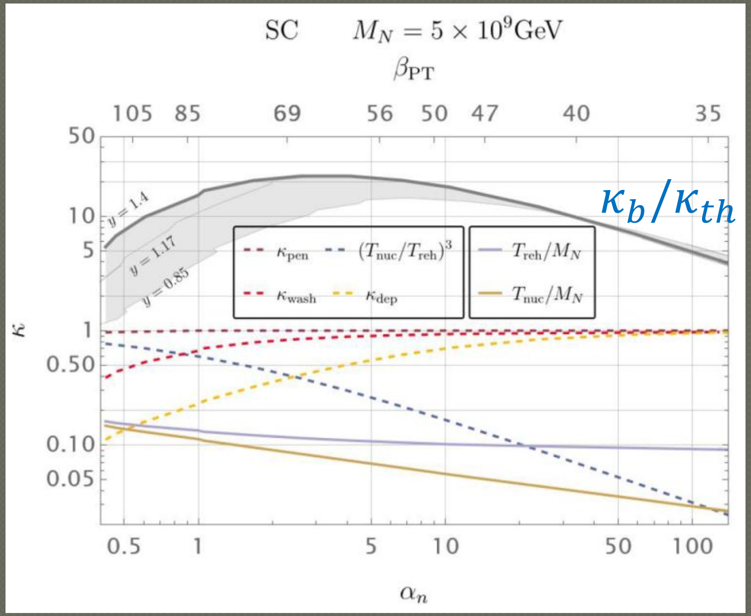
$$\Omega_{\rm GW} h^2_{\rm peak} \approx 10^{-18}\left(\frac{\sigma}{{\rm TeV}^3}\right)^2\left(\frac{T_{\rm ann}}{10^{-2}{\rm GeV}}\right)^{-4}$$



A route with Bubble Leptogenesis

EJC, Dutka, Jung, Nagels, Vanvlasselaer, 2305.10759





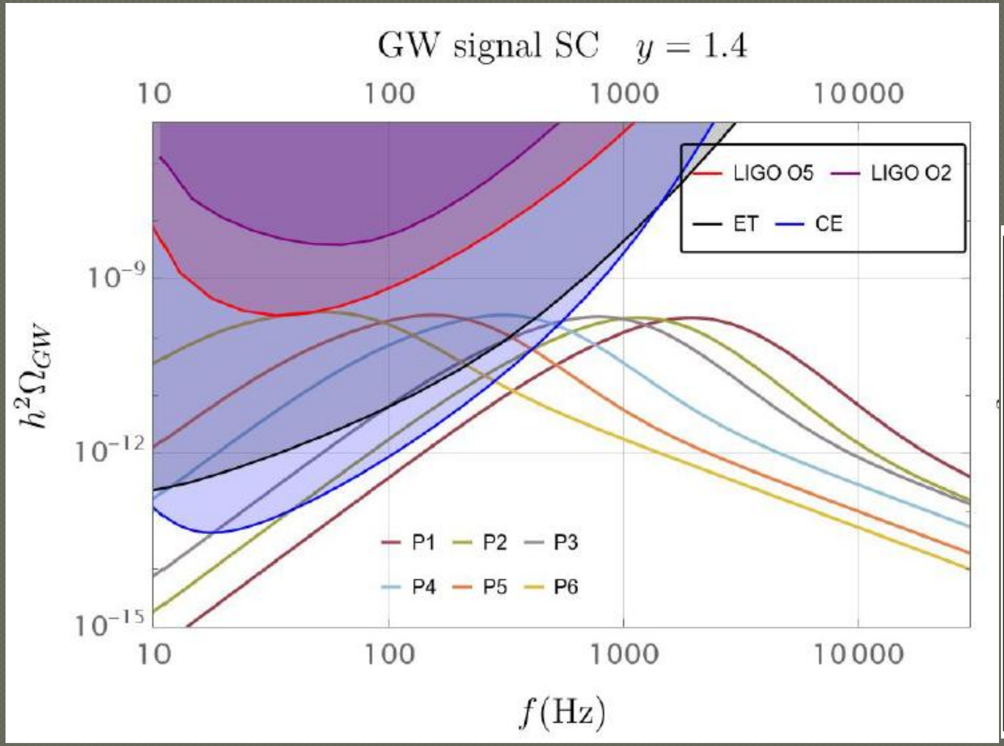
Penetration

Depletion

$$\Gamma(NN \to \phi\phi) \sim y^4 \left(\frac{T}{M_N}\right)^4 M_N$$

$$Y_B = Y_N^{\rm eq} \epsilon_{\rm CP}\, \kappa_{\rm sph} \kappa_{\rm wash} \kappa_{\rm pen} \kappa_{\rm dep} \left(\frac{T_{\rm nuc}}{T_{\rm reh}}\right)^3$$

FOPT at lower scale?



$M_{B-L} = 10^{8-9}\text{GeV}$

	SC		
	$M_N/10^8\text{GeV}$	$\frac{n_B^{FOPT}}{n_B^{\text{thermal}}}$	α_n
P1	62	26	4.4
P2	34	21	6
P3	26	18	6.
P4	10	12	10
P5	4.2	8	25
P6	1.4	3.5	25

Conclusion

- To track a route from SO(10) down to SM using GW signals, we identified appropriate intermediate breaking scales consistently with gauge unification and proton decay.
- SUSY models can be different from non-SUSY models.
- Typically appear observable CS signals and very high frequency GW from DW and FOPT.
- Desirable to explore the possibility of DW/FOPT formation at low scales.