Probing New Physics at Gravitational Wave Observatories

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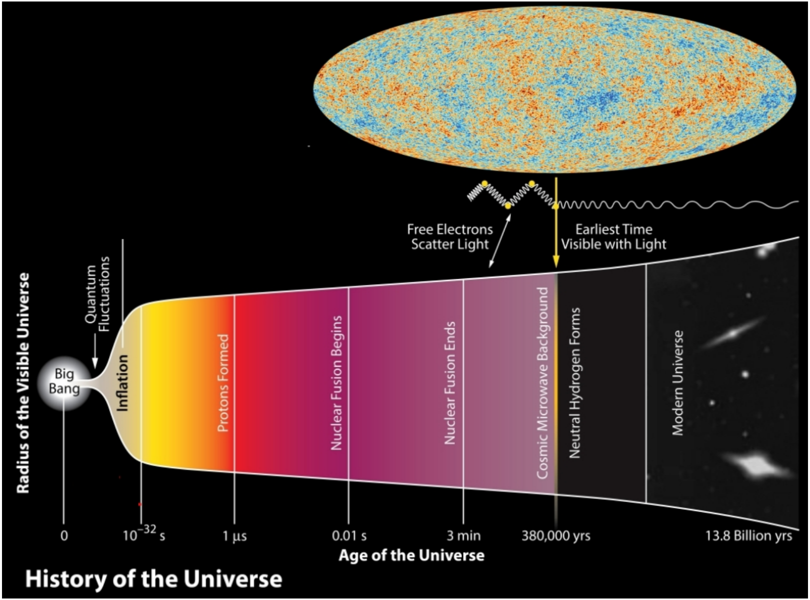
CETUP* 2024, Lead, South Dakota

Phys.Rev.D 108 (2023) 9, 095053, arXiv: 2405.03746, arXiv:2406.17014
(S. Antusch, K. Hinze, S. **Saad**, J. Steiner)

Outline

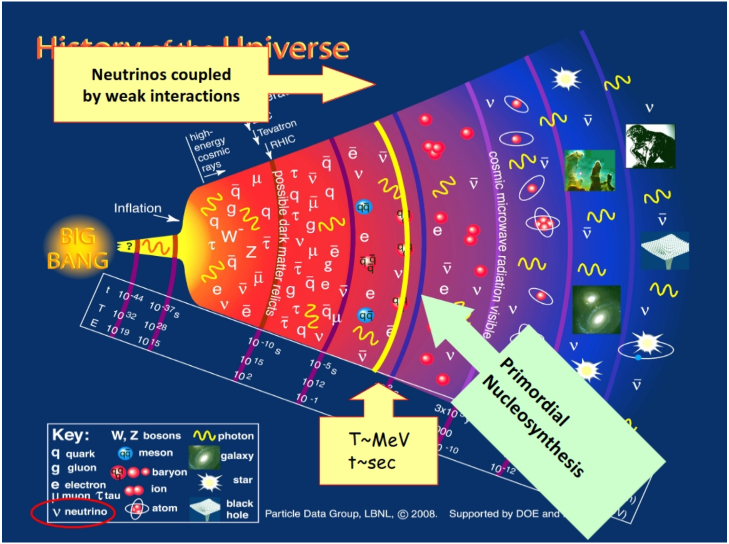
- Gravitational wave observatories and PTA data
- Promising SUSY SO(10) GUT
- Metastable cosmic strings
- Probing SUSY at GW detectors

Cosmic Microwave Background

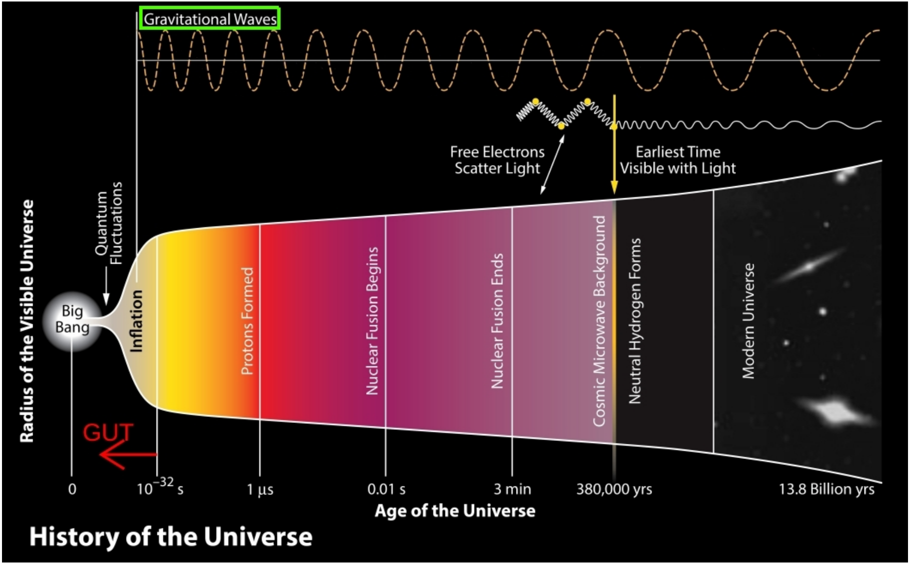


Cosmic Neutrino (ν) Background

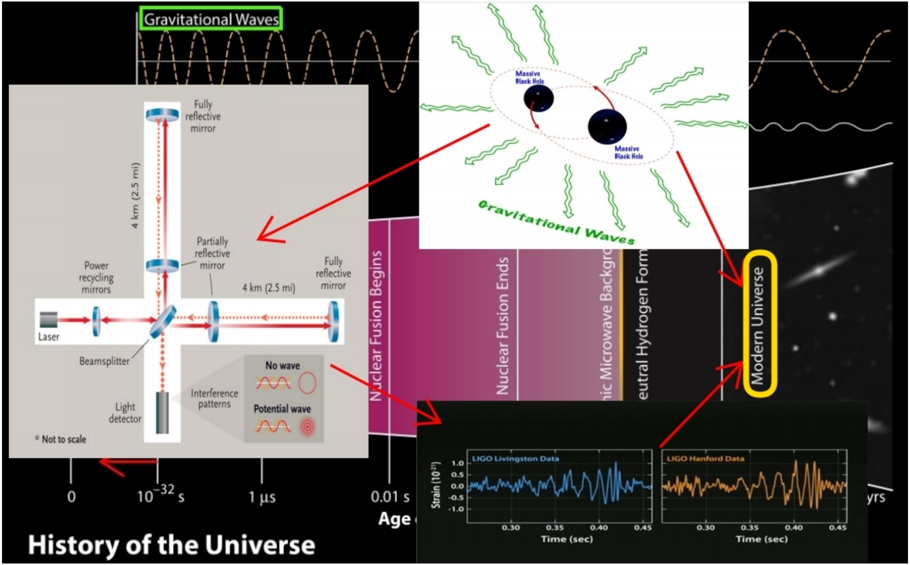
Apart from CMB, another leftover cosmic fossil



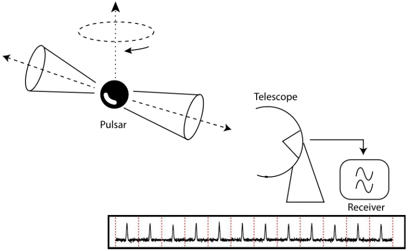
GW: The Most Powerful Tool



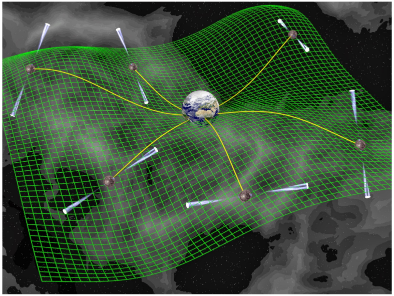
Groundbreaking Discovery : LIGO 2015

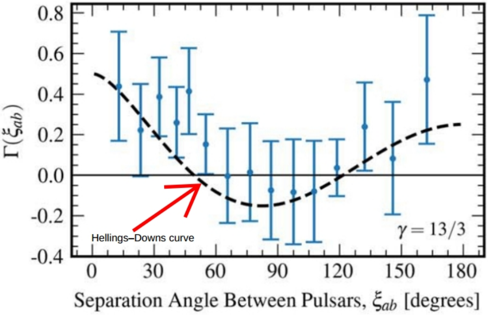


Cosmic Light-House



Pulsar Timing Arrays: 2023

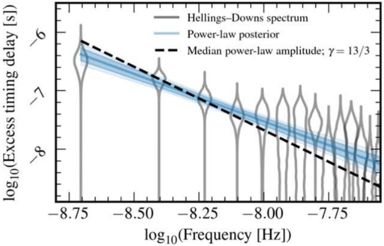


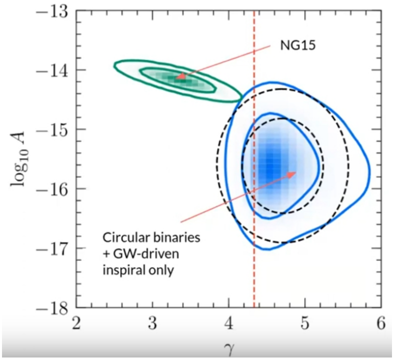


Gabriella Agazie et al 2023 ApJL 951 L8

- First evidence of Stochastic Gravitational Wave Background at nHz frequencies
- NANOGrav, EPTA, InPTA, CPTA, PPTA

PTA Data: 2023



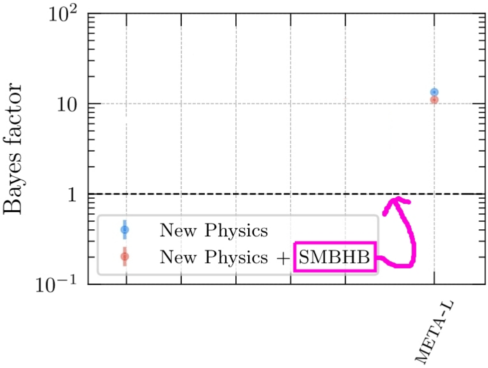


Gabriella Agazie et al 2023 ApJL 951 L8

Adeela Afzal et al 2023 ApJL 951 L11

→ Supermassive Black Hole Binaries (SMBHB): tension with data?

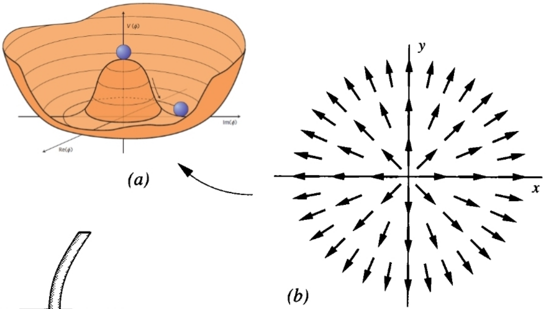
Signals from New Physics?

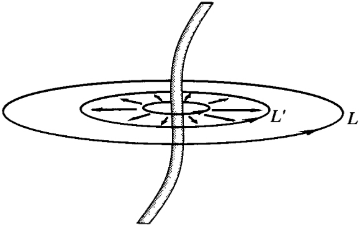


Adeela Afzal et al 2023 ApJL 951 L11

- Metastable Cosmic Strings?
- naturally arise from Grand Unified Theories →SO(10)

$U(1) \to$ nothing

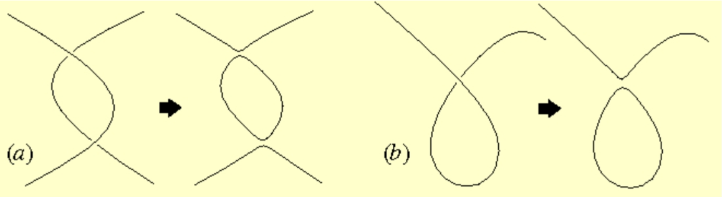


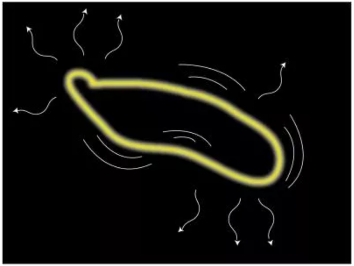


$\mu \sim 2\pi v_s^2$

Loop enclosing non-zero flux in 2-D space.

Cosmic String dynamics





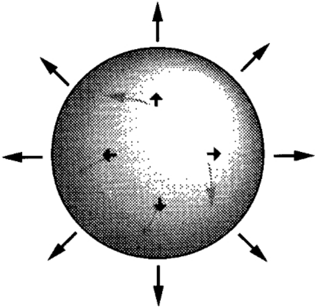
Cosmic-string loops wiggle and oscillate, producing gravitational waves, then slowly shrink as they lose energy until they disappear. (Image credit: Matt DePies/UW)

Monopoles

$SU(2) \xrightarrow{v_m} U(1)$

Cosmic Inflation*

$$m = \frac{4\pi v_m}{g}$$

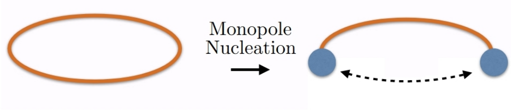


Sphere enclosing non-zero flux in 3-D space.

Metastable strings

P. Langacker and S. Y. Pi, 1980

- Example: $SU(2) \xrightarrow{v_m} U(1) \xrightarrow{v_s}$ broken



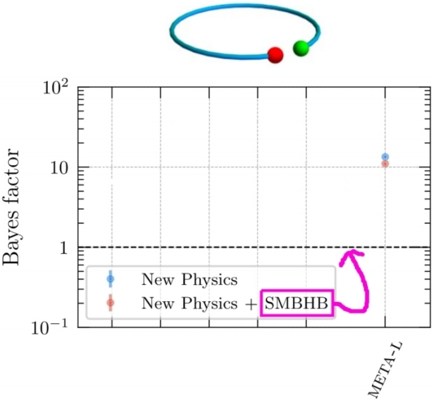
- lifetime determined by:

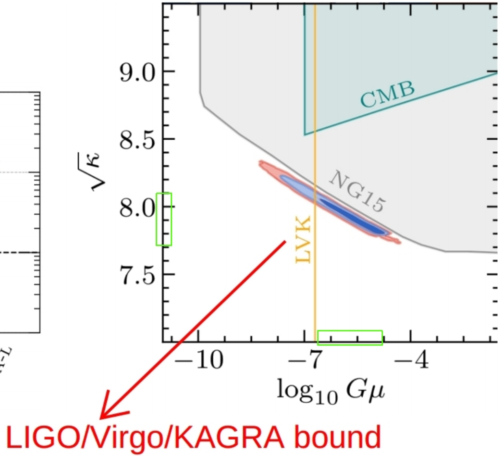
$$t_s = \Gamma_d^{-1/2}, \qquad \Gamma_d = \frac{\mu}{2\pi} e^{-\pi\kappa}$$

$$\kappa = \frac{m^2}{\mu} \sim \frac{8\pi}{g^2} \left(\frac{v_m}{v_s} \right)^2$$

$(\kappa^{1/2} < 9$ metastable $)$ $\quad \rightarrow v_{\text{monopole}} \sim v_{\text{string}}$

PTA data: Metastable strings





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SO(10) GUT: Most Elegant Candidate?

$$16 = \begin{pmatrix} \nu \\ u \\ u \\ u \\ e^- \\ d \\ d \\ d \\ d^c \\ d^c \\ d^c \\ e^+ \\ u^c \\ u^c \\ u^c \\ \nu^c \end{pmatrix}_L$$

$\mathrm{built-in\ \ neutrino\ mass}$

Origin of Metastable Cosmic Strings?

Promising SO(10) GUT models: $\rightarrow$ **SUSY** GUT

- Gauge coupling unification
- Cosmic inflation
- Doublet-Triplet splitting
- Chraged fermion + neutrino masses
- Proton decay under control
- ...

DTS problem

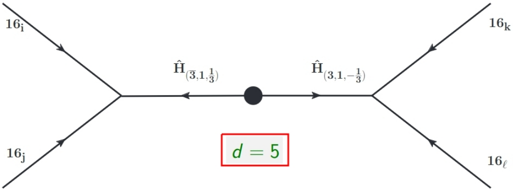
- Doublets & Triplets

$$10_H = (2_H + 3_H) + (\overline{2}_H + \overline{3}_H)$$
$$= (1, 2, 1/2) + (3, 1, -1/3) + c.c.$$

- $\langle 45_H \rangle \propto i\tau_2 \otimes \mathrm{diag}(a, a, a, b, b) \sim M_{\mathrm{GUT}}$

- GUT scale mass:

$$10_{1H} \langle 45_H \rangle 10_{2H} = \overline{2}_{1H} 2_{2H} + \overline{2}_{2H} 2_{1H} + \overline{3}_{1H} 3_{2H} + \overline{3}_{2H} 3_{1H}$$



Features of our models

- Lower-dimensional reps.: **10**, **16**, **45** (perturbativity)

- Superpotential: Antusch, Hinze, **Saad**, Steiner 2023

$$W = W_{\rm GUT-breaking} + \underbrace{W_{\rm Inflation} + W_{\rm Mixed, Inflation}}_{W_{\rm Intermedite-breaking}}$$

$$+ W_{\rm DTS} + W_{\rm Yukawa}$$

DTS without fine-tuning: S. Dimopoulos, F. Wilczek 1981, M. Srednicki 1982

- $\langle 45_H \rangle \propto B - L \propto i\tau_2 \otimes \mathrm{diag}(a, a, a, 0, 0)$
- $\langle 45'_H \rangle \propto I_{3R} \propto i\tau_2 \otimes \mathrm{diag}(0, 0, 0, b, b)$

K.S. Babu, S. M. Barr, Z. Berezhiani, R. N. Mohapatra, J. C. Pati, S. Raby, ...

Promising SO(10) GUT

- $\langle 45_H \rangle \propto i\tau_2 \otimes \mathrm{diag}(a, a, a, 0, 0)$, $\langle 45'_H \rangle \propto i\tau_2 \otimes \mathrm{diag}(0, 0, 0, b, b)$

- Symmetry breaking:

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

monopole

$$\xrightarrow[45'_H]{M_I} SU(3)_C \times SU(2)_L \times U(1)_R \times U(1)_{B-L}$$

string

Inflation

$$\xrightarrow[16_H + \overline{16}_H]{M_{II}} SU(3)_C \times SU(2)_L \times U(1)_Y$$

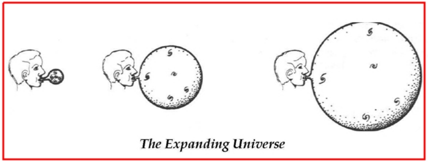
- No monopole problem

- Metastable cosmic string network

Antusch, Hinze, **Saad**, Steiner 2023

- Hybrid inflation

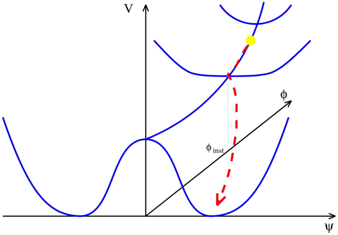
A. Linde 1991, G. R. Dvali et. al. 1994



$$W_{\rm Inflation} \supset \varkappa \underbrace{S}_{inflaton} \left(\overline{16}_H 16_H - m_{16}^2\right)$$

Antusch, Hinze, **Saad**, Steiner 2023

$$V_F^{\rm SUSY} \subset \varkappa^2 \left(\phi^2 - m_{16}^2\right) \psi^2$$



(flat direction along $\psi = 0$)

- Vacuum energy $V \sim \varkappa^2 m_{16}^4$
- Waterfall$\rightarrow$ cosmic string

Inflation

- If no mixed terms, extra Goldstones

$$45_H^{(\prime)}, 16_H, \overline{16}_H \supset (1,1,1) + (3,2,1/6) + (\overline{3},1,-2/3) + c.c.\ .$$

- Ensuring waterfall along SM direction

$$W_{\text{Mixed,Inflation}} \supset \overline{16}_H(\lambda_1 45_H + \lambda_1' 1_H)16_H' + \overline{16}_H'(\lambda_2 45_H + \lambda_2' 1_H')16_H + \overline{16}_H(\lambda_3 45_H' + \lambda_3' 1_H'')16_H'' + \overline{16}_H''(\lambda_4 45_H' + \lambda_4' 1_H''')16_H\ .$$

Inflation

$$F_{16} = S\varkappa \overline{v}_{16}^{x} \qquad F_{S} = \varkappa(\overline{16}_H 16_H - m_{16}^2)$$

16′:

$$F'_Q = \left(-\sqrt{2/3}v_{45}\lambda_1 + \lambda'_1 1_H\right)\overline{v}_{16}^{Q}$$

$$F'_{u^c} = \left(+\sqrt{2/3}v_{45}\lambda_1 + \lambda'_1 1_H\right)\overline{v}_{16}^{u^c}$$

$$F'_{d^c} = \left(+\sqrt{2/3}v_{45}\lambda_1 + \lambda'_1 1_H\right)\overline{v}_{16}^{d^c}$$

$$F'_L = \left(+\sqrt{6}v_{45}\lambda_1 + \lambda'_1 1_H\right)\overline{v}_{16}^{L}$$

$$F'_{e^c} = \left(-\sqrt{6}v_{45}\lambda_1 + \lambda'_1 1_H\right)\overline{v}_{16}^{e^c}$$

$$F'_{\nu^c} = \left(-\sqrt{6}v_{45}\lambda_1 + \lambda'_1 1_H\right)\overline{v}_{16}^{\nu^c}$$

16″:

$$F''_Q = (0 + \lambda''_3 1''_H)\,\overline{v}_{16}^{Q}$$

$$F''_{u^c} = (-2v'_{45}\lambda_3 + \lambda''_3 1''_H)\,\overline{v}_{16}^{u^c}$$

$$F''_{d^c} = (+2v'_{45}\lambda_3 + \lambda''_3 1''_H)\,\overline{v}_{16}^{d^c}$$

$$F''_L = (0 + \lambda''_3 1''_H)\,\overline{v}_{16}^{L}$$

$$F''_{e^c} = (+2v'_{45}\lambda_3 + \lambda''_3 1''_H)\,\overline{v}_{16}^{e^c}$$

$$F''_{\nu^c} = (-2v'_{45}\lambda_3 + \lambda''_3 1''_H)\,\overline{v}_{16}^{\nu^c}$$

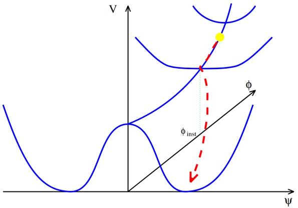
Inflation

- $v_{16}^{\nu^c} \neq 0$ allowed if $(v_{16}^{Q}, v_{16}^{u^c}, v_{16}^{d^c}, v_{16}^{L}, v_{16}^{e^c}) = 0$

- Unstable directions $\mathrm{Re}\,(\overline{\nu^c}_{16} + \nu^c_{16})$ and $\mathrm{Im}\,(\overline{\nu^c}_{16} - \nu^c_{16})$ (stable directions $\mathrm{Re}\,(\overline{\nu^c}_{16} - \nu^c_{16})$ and $\mathrm{Im}\,(\overline{\nu^c}_{16} + \nu^c_{16})$):

$$M^2_{\nu^c,\mp} = \underbrace{m^2_{\nu^c}}_{F'_{16},''} + \underbrace{|\varkappa S|^2}_{F_{16}} \mp \underbrace{|\varkappa m^2_{16}|}_{F_S}$$

- Waterfall in the RHN direction can be arranged



DTS

$$10_H \langle 45_H \rangle 10'_H \supset \cancelto{0}{\overline{2}_H 2'_H} + \cancelto{0}{\overline{2}'_H 2_H} + \overline{3}_H 3'_H + \overline{3}'_H 3_H$$

$$10'_H 45'^2_H 10'_H \supset \overline{2}'_H 2'_H + \cancelto{0}{\overline{3}'_H 3'_H}$$

$$W_{\rm DTS} \supset \gamma_1 10_H 45_H 10'_H + \frac{\gamma_2}{\Lambda} 10'_H 45'^2_H 10'_H + M_{16} \overline{16}''_H 16'_H$$

Antusch, Hinze, **Saad** 2024

DTS

Multiplet $(1,2,-1/2)+c.c.$:

$$r: H^{(1,2,-\frac{1}{2})}_{(1,2,2)},\ H'^{(1,2,-\frac{1}{2})}_{(1,2,2)},\ \chi^{(1,2,-\frac{1}{2})}_{(4,2,1)},\ \chi'^{(1,2,-\frac{1}{2})}_{(4,2,1)},\ \chi''^{(1,2,-\frac{1}{2})}_{(4,2,1)}$$
$$c: H^{(1,2,\frac{1}{2})}_{(1,2,2)},\ H'^{(1,2,\frac{1}{2})}_{(1,2,2)},\ \overline{\chi}^{(1,2,\frac{1}{2})}_{(\overline{4},2,1)},\ \overline{\chi}'^{(1,2,\frac{1}{2})}_{(\overline{4},2,1)},\ \overline{\chi}''^{(1,2,\frac{1}{2})}_{(\overline{4},2,1)}$$
$$\mathcal{M}_{(1,2,-\frac{1}{2})} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & -\frac{\gamma_2 \langle 45'_H\rangle^2}{4\Lambda} & 0 & 0 & 0 \\ 0 & 0 & 0 & 2\sqrt{6}\lambda_2\langle 45_H\rangle & 2\lambda_4\langle 45'_H\rangle \\ 0 & 0 & 2\sqrt{6}\lambda_1\langle 45_H\rangle & 0 & M_{16} \\ 0 & 0 & 2\lambda_3\langle 45'_H\rangle & 0 & 0 \end{pmatrix}.$$

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DTS

Multiplet $(\overline{3}, 1, 1/3) + c.c.$:

$$r: H^{(\overline{3},1,\frac{1}{3})}_{(6,1,1)}, H'^{(\overline{3},1,\frac{1}{3})}_{(6,1,1)}, \chi^{(\overline{3},1,\frac{1}{3})}_{(\overline{4},1,2)}, \chi'^{(\overline{3},1,\frac{1}{3})}_{(\overline{4},1,2)}, \chi''^{(\overline{3},1,\frac{1}{3})}_{(\overline{4},1,2)}$$

$$c: H^{(3,1,-\frac{1}{3})}_{(6,1,1)}, H'^{(3,1,-\frac{1}{3})}_{(6,1,1)}, \overline{\chi}^{(3,1,-\frac{1}{3})}_{(4,1,2)}, \overline{\chi}'^{(3,1,-\frac{1}{3})}_{(4,1,2)}, \overline{\chi}''^{(3,1,-\frac{1}{3})}_{(4,1,2)}$$

$$\mathcal{M}_{(\overline{3},1,\frac{1}{3})} = \begin{pmatrix} 0 & \frac{\gamma_1\langle 45_H\rangle}{2\sqrt{6}} & 0 & 0 & 0 \\ -\frac{\gamma_1\langle 45_H\rangle}{2\sqrt{6}} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 4\sqrt{\frac{2}{3}}\lambda_2\langle 45_H\rangle & 4\lambda_4\langle 45'_H\rangle \\ 0 & 0 & 4\sqrt{\frac{2}{3}}\lambda_1\langle 45_H\rangle & 0 & M_{16} \\ 0 & 0 & 4\lambda_3\langle 45'_H\rangle & 0 & 0 \end{pmatrix}.$$

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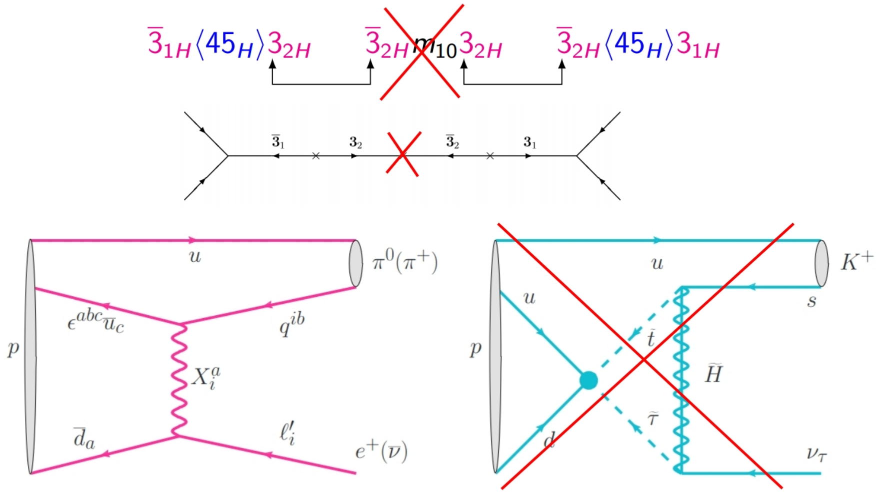
DTS & Proton Decay



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Fermion Mass

$$W_{\text{Yukawa}} = Y_{10} 16_F 16_F 10_H + \frac{Y_a}{\Lambda} (16_F 45_H)_{16} (10_H 16_F)_{\overline{16}} + \frac{Y_b}{\Lambda} (16_F 45'_H)_{16} (10_H 16_F)_{\overline{16}} + \frac{Y_{\nu^c}}{\Lambda} (\overline{16}_H 16_F)_1 (\overline{16}_H 16_F)_1 \ .$$

$$M_u = Y_{10} v_{10}^u - \sqrt{\frac{2}{3}} \frac{\langle 45_H \rangle}{\Lambda} Y_a v_{10}^u + 2 \frac{\langle 45'_H \rangle}{\Lambda} Y_b v_{10}^u \,,$$

$$M_d = Y_{10} v_{10}^d - \sqrt{\frac{2}{3}} \frac{\langle 45_H \rangle}{\Lambda} Y_a v_{10}^d - 2 \frac{\langle 45'_H \rangle}{\Lambda} Y_b v_{10}^d \,,$$

$$M_e = Y_{10} v_{10}^d + \sqrt{6} \frac{\langle 45_H \rangle}{\Lambda} Y_a v_{10}^d - 2 \frac{\langle 45'_H \rangle}{\Lambda} Y_b v_{10}^d \,,$$

$$M_\nu^D = Y_{10} v_{10}^u + \sqrt{6} \frac{\langle 45_H \rangle}{\Lambda} Y_a v_{10}^u + 2 \frac{\langle 45'_H \rangle}{\Lambda} Y_b v_{10}^u \,,$$

$$M_{\nu^c} = \frac{\langle \overline{16}_H \rangle^2}{\Lambda} Y_{\nu^c} \ .$$

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A Common Scale

- Cosmic string : $v_s = m_{16}$
- Inflation : $V_{\text{inflation}} \sim \varkappa^2 m_{16}^4$
- Neutrino mass :

$$m_\nu \sim \frac{10 M_{\text{GUT}} v_{\text{ew}}^2}{m_{16}^2}$$

$m_{16} \sim 10^{15-16}$ GeV

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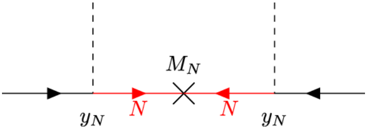
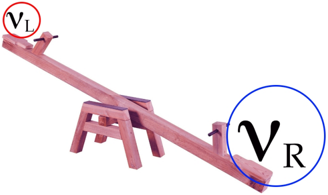
Type-I seesaw

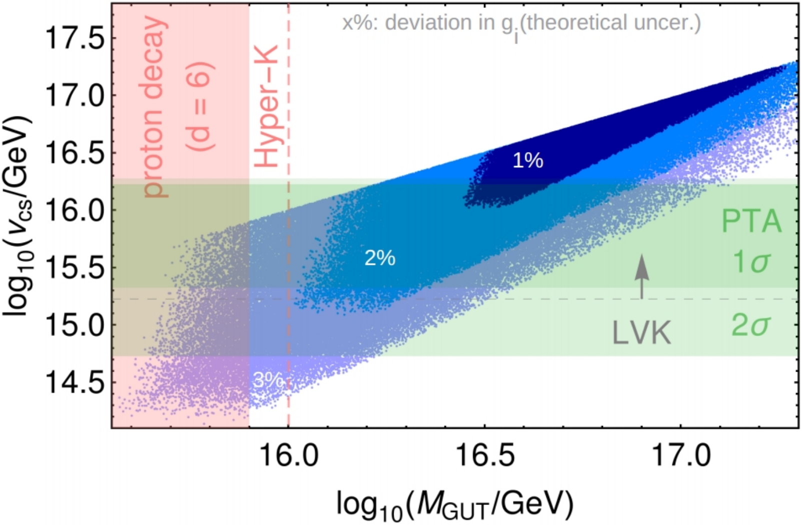




Mass Spectrum: Unification

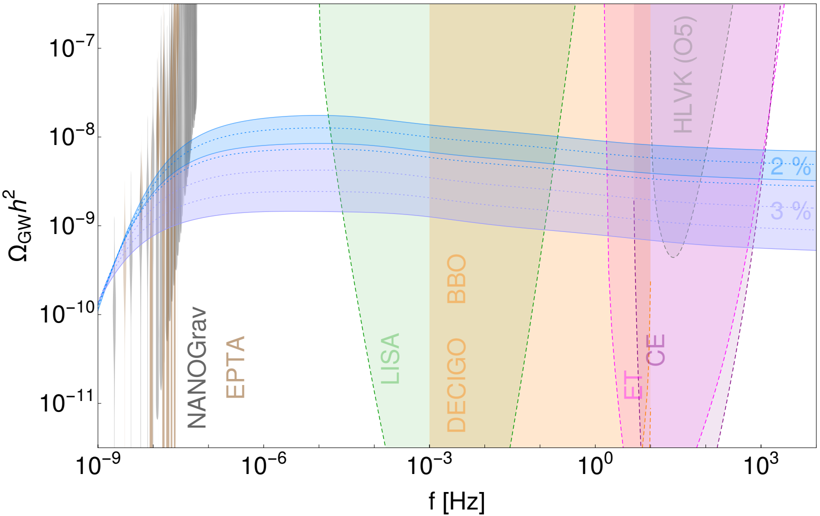
$\mathcal{G}_{321}$	$\mathcal{G}_{3211}$	$\mathcal{G}_{3221}$	$\mathcal{G}_{10}$	μ
$H^{(1,2,\frac{1}{2})}_{(1,2,2)}$	$H^{(1,2,\frac{1}{2},0)}_{(1,2,2)}$	$H^{(1,2,2,0)}_{(1,2,2)}$	10_H	m_{SUSY}
-	$\chi^{(1,1,-\frac{1}{2},\frac{1}{2})}_{(\overline{4},1,2)}$	$\chi^{(1,1,2,\frac{1}{2})}_{(\overline{4},1,2)}$	16_H	v_{16}
-	-	$A'^{(1,1,3,0)}_{(1,1,3)}$	$45'_H$	$v_{45'}$
$A^{(8,1,0)}_{(15,1,1)}$	$A^{(8,1,0,0)}_{(15,1,1)}$	$A^{(8,1,1,0)}_{(15,1,1)}$	45_H	$\frac{v^2_{\text{GUT}}}{\Lambda}$
$A'^{(8,1,0)}_{(15,1,1)}$	$A'^{(8,1,0,0)}_{(15,1,1)}$	$A'^{(8,1,1,0)}_{(15,1,1)}$	$45'_H$	$\frac{v^2_{\text{GUT}}}{\Lambda}$
$A^{(1,3,0)}_{(1,3,1)}$	$A^{(1,3,0,0)}_{(1,3,1)}$	$A^{(1,3,1,0)}_{(1,3,1)}$	45_H	$\frac{v^2_{\text{GUT}}}{\Lambda}$
$A'^{(1,3,0)}_{(1,3,1)}$	$A'^{(1,3,0,0)}_{(1,3,1)}$	$A'^{(1,3,1,0)}_{(1,3,1)}$	$45'_H$	$\frac{v^2_{45'}}{\Lambda}$
$A'^{(3,2,-\frac{5}{6})}_{(6,2,2)}$	$A'^{(3,2,-\frac{1}{2},-\frac{1}{3})}_{(6,2,2)}$	$A'^{(3,2,2,-\frac{1}{3})}_{(6,2,2)}$	$45'_H$	$\frac{v^2_{\text{GUT}}}{\Lambda}$
$A^{(1,1,1)}_{(1,1,3)}$	$A^{(1,1,1,0)}_{(1,1,3)}$	$A^{(1,1,3,0)}_{(1,1,3)}$	45_H	$\max\{v_{16}, \frac{v^2_{\text{GUT}}}{\Lambda}\}$
$\chi'^{(1,1,1)}_{(\overline{4},1,2)}$	$\chi'^{(1,1,\frac{1}{2},\frac{1}{2})}_{(\overline{4},1,2)}$	$\chi'^{(1,1,2,\frac{1}{2})}_{(\overline{4},1,2)}$	$16'_H$	$\min\{v_{16}, \frac{v^2_{16}\Lambda}{v^2_{\text{GUT}}}\}$
$\chi^{(1,1,1)}_{(\overline{4},1,2)}$	$\chi^{(1,1,\frac{1}{2},\frac{1}{2})}_{(\overline{4},1,2)}$	$\chi^{(1,1,2,\frac{1}{2})}_{(\overline{4},1,2)}$	16_H	$v_{45'}$
$\chi''^{(1,1,1)}_{(\overline{4},1,2)}$	$\chi''^{(1,1,\frac{1}{2},\frac{1}{2})}_{(\overline{4},1,2)}$	$\chi''^{(1,1,2,\frac{1}{2})}_{(\overline{4},1,2)}$	$16''_H$	$v_{45'}$
$A'^{(\overline{3},1,-\frac{2}{3})}_{(15,1,0)}$	$A'^{(\overline{3},1,0,-\frac{2}{3})}_{(15,1,0)}$	$A'^{(\overline{3},1,1,-\frac{2}{3})}_{(15,1,1)}$	$45'_H$	$\max\{v_{16}, \frac{v^2_{\text{GUT}}}{\Lambda}\}$
$\chi''^{(\overline{3},1,-\frac{2}{3})}_{(\overline{4},1,2)}$	$\chi''^{(\overline{3},1,-\frac{1}{2},-\frac{1}{6})}_{(\overline{4},1,2)}$	$\chi''^{(\overline{3},1,2,-\frac{1}{6})}_{(\overline{4},1,2)}$	$16''_H$	$\min\{v_{16}, \frac{v^2_{16}\Lambda}{v^2_{\text{GUT}}}\}$
$A^{(3,2,\frac{1}{6})}_{(6,2,2)}$	$A^{(3,2,\frac{1}{2},-\frac{1}{3})}_{(6,2,2)}$	$A^{(3,2,2,-\frac{1}{3})}_{(6,2,2)}$	45_H	v_{16}
$\chi''^{(3,2,\frac{1}{6})}_{(4,2,1)}$	$\chi''^{(3,2,0,\frac{1}{6})}_{(4,2,1)}$	$\chi''^{(3,2,1,\frac{1}{6})}_{(4,2,1)}$	$16''_H$	v_{16}
$H'^{(1,2,\frac{1}{2})}_{(1,2,2)}$	$H'^{(1,2,\frac{1}{2},0)}_{(1,2,2)}$	$H'^{(1,2,2,0)}_{(1,2,2)}$	$10'_H$	$\frac{v^2_{45'}}{\Lambda}$
$\chi''^{(1,2,-\frac{1}{2})}_{(4,2,1)}$	$\chi''^{(1,2,0,-\frac{1}{2})}_{(4,2,1)}$	$\chi''^{(1,2,1,-\frac{1}{2})}_{(4,2,1)}$	$16''_H$	$\frac{M_{16}v_{45'}}{v_{\text{GUT}}}$
$\chi''^{(\overline{3},1,\frac{1}{3})}_{(\overline{4},1,2)}$	$\chi''^{(\overline{3},1,\frac{1}{2},-\frac{1}{6})}_{(\overline{4},1,2)}$	$\chi''^{(\overline{3},1,2,-\frac{1}{6})}_{(\overline{4},1,2)}$	$16''_H$	$\frac{M_{16}v_{45'}}{v_{\text{GUT}}}$

Unification, Proton Decay, and PTA data



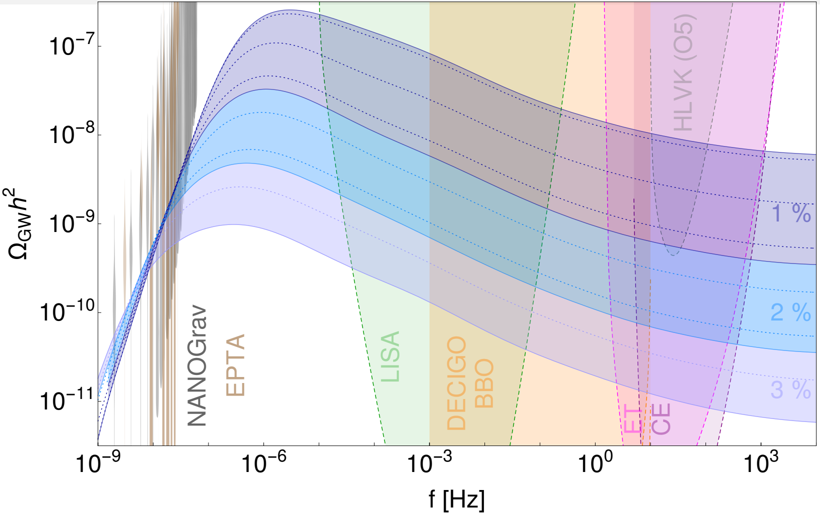
Antusch, Hinze, **Saad** 2024 (arXiv: 2406.17014)

GW Spectrum and PTAs



Soon to be discovered at LIGO?!!! Antusch, Hinze, **Saad** 2024 (arXiv: 2406.17014)

Dilution



Early Matter Domination from SUSY Moduli fields

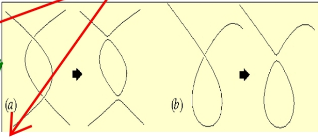
Antusch, Hinze, **Saad** 2024 (arXiv: 2406.17014)

GW spectrum

loop number density

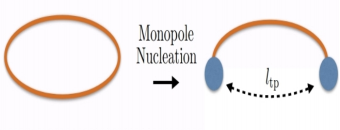
$$\Omega_{\rm GW}(f,t) = \frac{8\pi(G\mu)^2}{3H^2(t)} \sum_{n=1}^{\infty} C_n P_n, \quad C_n = \frac{2n}{f^2}\int_{z(t)}^{z_c} \frac{dz}{H(z)(1+z)^6}\, n\left(\frac{2n}{f(1+z)}, t(z)\right)$$

spectrum



$$\left[-\Gamma\, G\mu\, \partial_\ell + \partial_t\right] n(\ell,t) = S(\ell,t) - \left(3H(t) + \Gamma_d \ell\right) n(\ell,t)$$

expansion history of the universe



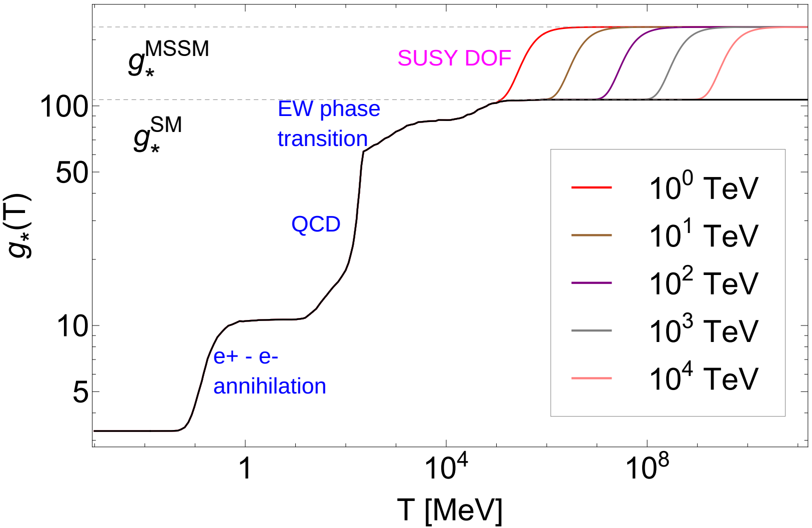
$$H(z) = H_0\left(\Omega_\Lambda + (1+z)^3\Omega_{\rm mat} + (1+z)^4\mathcal{G}(z)\Omega_{\rm rad}\right)^{1/2}$$

$$\mathcal{G}(z) = \frac{g_*(z)\, g_S^{4/3}(z_0)}{g_*(z_0)\, g_S^{4/3}(z)}$$

varies as the universe cools when species become non-relativistic

Blanco-Pillado, Olum, and Shlaer 2013, 2017; Buchmuller, Domcke, Schmitz 2021; Antusch, Hinze, **Saad**, Steiner 2024

SUSY Degrees of Freedom

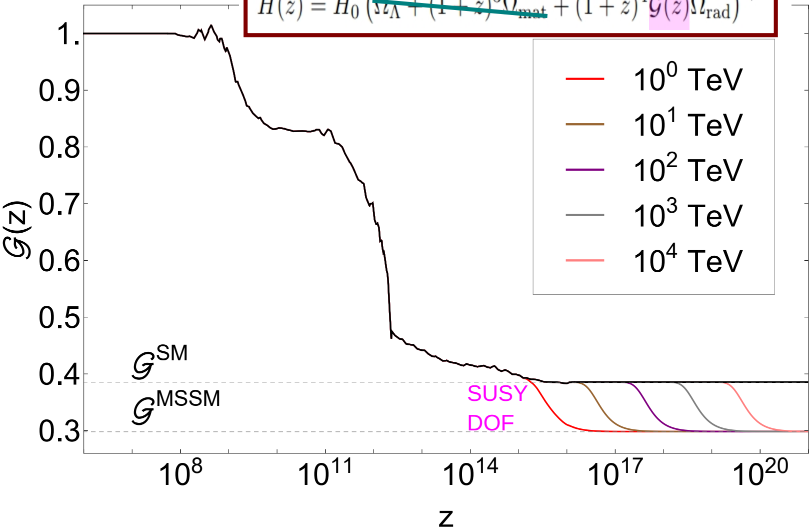


Antusch, Hinze, **Saad**, Steiner 2024

(additional dof: Battye et. al.; Blanco-Pillado et. al.; Cui et. al.; ...)

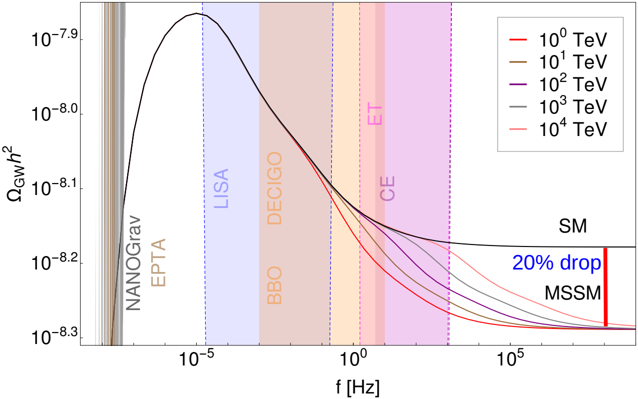
SUSY DOF

$$H(z) = H_0 \left(\Omega_\Lambda + (1+z)^3 \Omega_{\rm mat} + (1+z)^4 \mathcal{G}(z) \Omega_{\rm rad} \right)^{1/2}$$



Antusch, Hinze, **Saad**, Steiner 2024

Probing SUSY

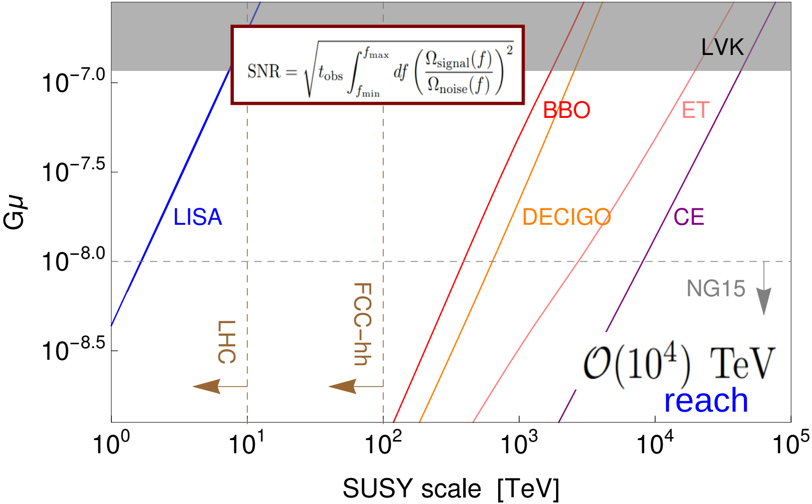


$$\Omega_{\rm GW}^{\rm NP} \sim \Omega_{\rm GW}^{\rm SM} \left(\frac{g_*^{\rm SM}}{g_*^{\rm SM} + \Delta g_*^{\rm NP}} \right)^{1/3} \longleftarrow \Delta g_*^{\rm SUSY} = 122 \longrightarrow \Omega_{\rm GW}^{\rm SUSY} / \Omega_{\rm GW}^{\rm SM} \approx 0.8$$

$$f_{\rm S} \sim (2.1 \times 10^{-9}\ {\rm Hz}) \left(\frac{m_{\rm S}}{\rm GeV} \right) (\alpha\, \Gamma\, G\mu)^{-1/2} \times \left(g_*^{\rm SM}(T_{\rm S}) + \Delta g_* \right)^{5/2} \left(g_*^{\rm SM}(T_{\rm S}) \right)^{-8/6} \left(g_{\rm S}^{\rm SM}(T_{\rm S}) \right)^{-7/6}$$

Antusch, Hinze, **Saad**, Steiner 2024

Probing SUSY



Fisher analysis: uncertainties of 10% for the number of DOF and 5% for the $m_{\rm SUSY}$ (ET and CE)

Antusch, Hinze, **Saad**, Steiner 2024

Summary

- ❄ PTAs : exciting new data → New Physics?
- ❄ New Physics → Metastable Cosmic Strings
- ❄ Promising models towards SO(10) GUT → Inflation, DTS, Unification, Fermion mass, Gravitational waves
- ❄ Probing SUSY DOF at GW detectors
- ❄ GW/PTAs: $v_{\rm monopole} \sim v_{\rm string} \sim v_{\rm inflation} \sim v_{\rm seesaw} \sim 10^{15}$ GeV
- ❄ Fully testable in a number of gravitational wave observatories

THANK YOU!