Singling out SO(10) GUT models using recent PTA results

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arXiv:2307.04595 (S. Antusch, K. Hinze, S. Saad, J. Steiner)

Outline

- Motivations
- Promising SUSY SO(10) GUT models
- Gravitational wave signals

SO(10) GUT: Most Elegant Candidate?

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

all fermions + neutrino mass

Motivations

Promising models:

- Gauge coupling unification
- Cosmic inflation
- Doublet-Triplet splitting
- Fermion mass
- Proton decay bounds
- ...

Features of the models

- Lower-dimensional reps.: 10 , 16 , 45

- Superpotential:

$$W = W_{\text{GUT-breaking}} + \underbrace{W_{\text{Inflation}} + W_{\text{Mixed}}}_{W_{\text{Intermedite-breaking}}} + W_{\text{DTS}} + W_{\text{Yukawa}}$$

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DTS problem

- Doublets & Triplets

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

- $\langle 45_H \rangle \propto i\tau_2 \otimes \mathrm{diag}(a_1, a_2, a_3, a_4, a_5)$

- GUT scale mass:

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

Dimopoulos-Wilczek mechanism

Missing VEV mechanism: S. Dimopoulos, F. Wilczek 1981, M. Srednicki 1982

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

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

$B - L$-case: Monopole problem

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

$$SO(10) \xrightarrow[45_H]{M_{\mathrm{GUT}}} SU(3)_C \times SU(2)_L \times SU(2)_R \times U(1)_{B-L}$$
$$\xrightarrow[16_H + \overline{16}_H]{M_I} SU(3)_C \times SU(2)_L \times U(1)_Y$$

- Monopole problem.

- (no cosmic strings)

$B - L$-case: Inflation

$$SO(10) \xrightarrow[45_H]{M_{\rm GUT}} SU(3)_C \times SU(2)_L \times SU(2)_R \times U(1)_{B-L}$$
$$\xrightarrow[16_H+\overline{16}_H]{M_I} SU(3)_C \times SU(2)_L \times U(1)_Y$$

- Hybrid inflation: A. Linde 1991, G. R. Dvali et. al. 1994

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

- Vacuum energy $V \sim \kappa^2 m_{16}^4$
- Waterfall at the end of the inflation

$B - L$-case: DTS

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

$$10_{1H}\langle 45_H \rangle 10_{2H} = \cancelto{0}{\bar{2}_{1H}2_{2H}} + \cancelto{0}{\bar{2}_{2H}2_{1H}} + \bar{3}_{1H}3_{2H} + \bar{3}_{2H}3_{1H}$$

- Single pair of light doublets:

$$10_{2H}10_{2H} = \bar{2}_{2H}2_{2H} + \bar{3}_{2H}3_{2H}.$$

- $d = 5$ proton decay:

$$\bar{3}_{1H}\langle 45_H \rangle 3_{2H} \qquad \bar{3}_{2H} m_{10} 3_{2H} \qquad \bar{3}_{2H}\langle 45_H \rangle 3_{1H}$$

Effective triplet mass $\sim M_{\mathrm{GUT}}^2/m_{10}$.

I_{3R}-case: Symmetry breaking

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

$$SO(10) \xrightarrow[45_H]{M_{\mathrm{GUT}}} SU(4)_C \times SU(2)_L \times U(1)_R$$
$$\xrightarrow[16_H + \overline{16}_H]{M_I} SU(3)_C \times SU(2)_L \times U(1)_Y$$

- Monopole problem...
- (no cosmic strings) ...
- Inflation ...

I_{3R}-case: DTS

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

$$10_{1H}\langle 45_H \rangle 10_{2H} = \overline{2}_{1H}2_{2H} + \overline{2}_{2H}2_{1H} + \cancelto{0}{\overline{3}_{1H}3_{2H}} + \cancelto{0}{\overline{3}_{2H}3_{1H}}$$

- $\overline{16}_H\langle 45_H \rangle 16_H$ ✗ $\qquad\qquad$ $\overline{16}'_H\langle 45_H \rangle 16'_H$ ✓

$$\overline{16}'_H\langle 45_H \rangle 16'_H = \cancelto{0}{\overline{2}'_H 2'_H} + \overline{3}'_H 3'_H$$

- Masses to all the color-triplets:

$$W_{\mathrm{DTS}} \supset \lambda_3 \overline{16}'.45.16' + \lambda_4 10.16.16 + \lambda_5 10.\overline{16}.\overline{16}$$

$B - L$ & I_{3R}-case

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

- (a) $\langle 45_H \rangle > \langle 45'_H \rangle > \langle 16_H \rangle, \langle \overline{16}_H \rangle$:

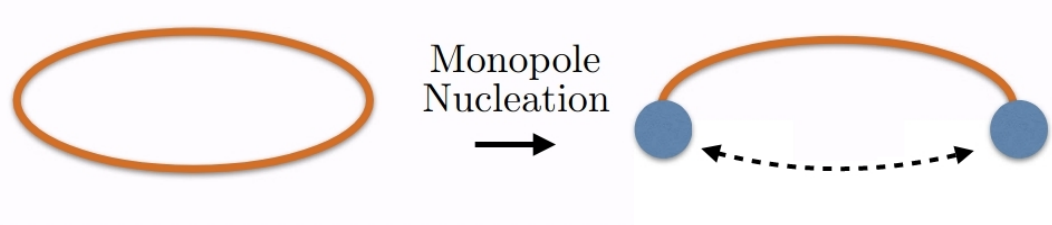
$$SO(10) \xrightarrow[45_H]{M_{\rm GUT}} SU(3)_C \times SU(2)_L \times SU(2)_R \times U(1)_{B-L}$$
$$\xrightarrow[45'_H]{M_I} SU(3)_C \times SU(2)_L \times U(1)_R \times U(1)_{B-L}$$
$$\xrightarrow[16_H + \overline{16}_H]{M_{II}} SU(3)_C \times SU(2)_L \times U(1)_Y$$

- cosmic string network

Metastable strings

P. Langacker and S. Y. Pi, 1980

- Example: $SU(2) \xrightarrow{M_m} U(1) \xrightarrow{Ms}$ broken



- lifetime determined by:

$$\kappa_m = \frac{m^2}{\mu} \sim \frac{8\pi}{g^2}\left(\frac{M_m}{M_s}\right)^2$$

($\kappa_m^{1/2} < 9$ metastable)

$B - L$ & I_{3R}-case

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

- (b) $\langle 45'_H \rangle > \langle 45_H \rangle > \langle 16_H \rangle, \langle \overline{16}_H \rangle$:

$$SO(10) \xrightarrow[45'_H]{M_{\rm GUT}} SU(4)_C \times SU(2)_L \times U(1)_R$$
$$\xrightarrow[45_H]{M_I} SU(3)_C \times SU(2)_L \times U(1)_R \times U(1)_{B-L}$$
$$\xrightarrow[16_H + \overline{16}_H]{M_{II}} SU(3)_C \times SU(2)_L \times U(1)_Y$$

- cosmic string network

$B - L$ & I_{3R}-case

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

- (c) $\langle 45_H \rangle = \langle 45'_H \rangle > \langle 16_H \rangle, \langle \overline{16}_H \rangle$:

$$SO(10) \xrightarrow[45_H + 45'_H]{M_{\mathrm{GUT}}} SU(3)_C \times SU(2)_L \times U(1)_R \times U(1)_{B-L}$$
$$\xrightarrow[16_H + \overline{16}_H]{M_I} SU(3)_C \times SU(2)_L \times U(1)_Y$$

- cosmic string network

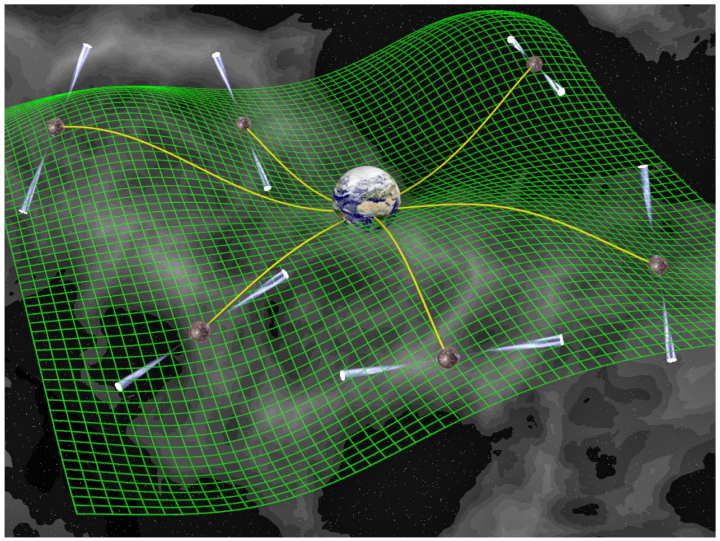
Fermion mass

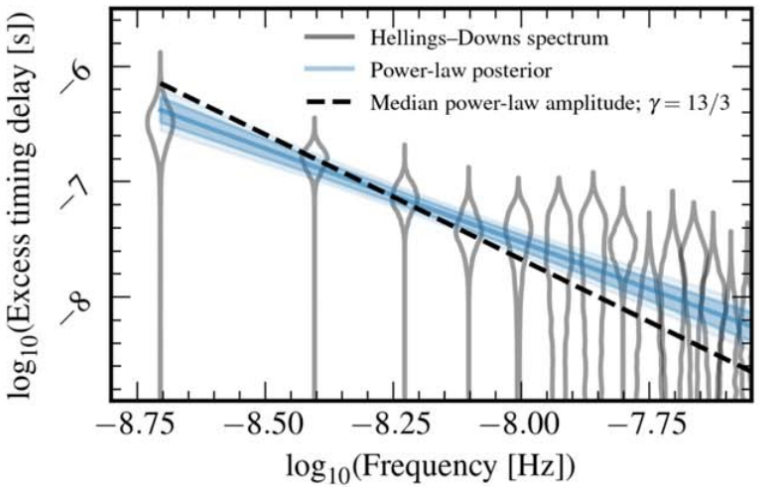
- Charged fermions: higher dimensional operators
- Right-handed neutrino mass:

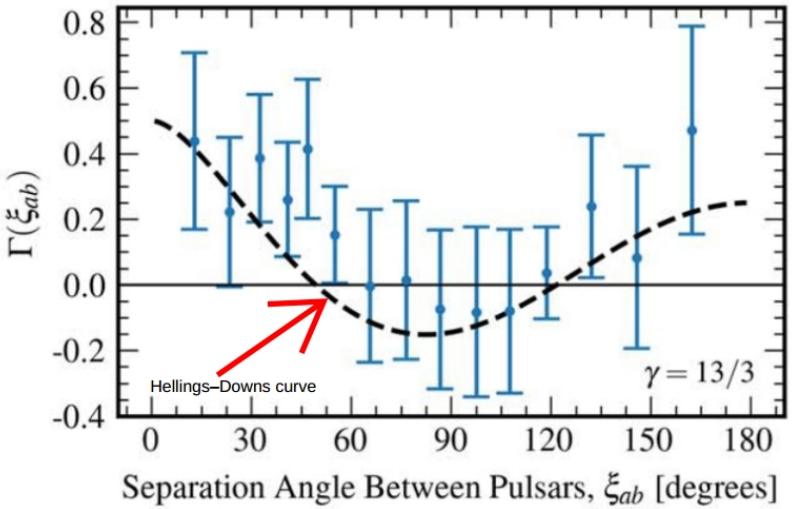
$$W_{\text{Yukawa}} \supset Y_R 16_i 16_j \frac{\overline{16}_H \overline{16}_H}{\Lambda} \sim Y_R \frac{v_R^2}{\Lambda} \nu^c \nu^c$$

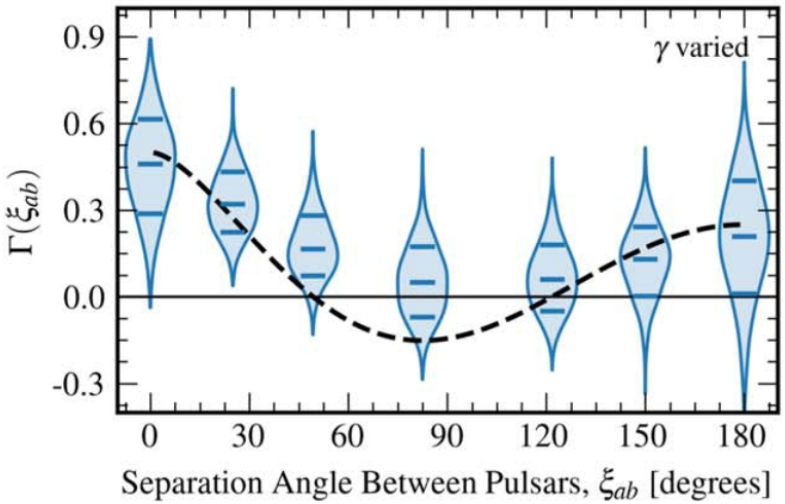
- Neutrino mass: Type-I seesaw

Pulsar timing data



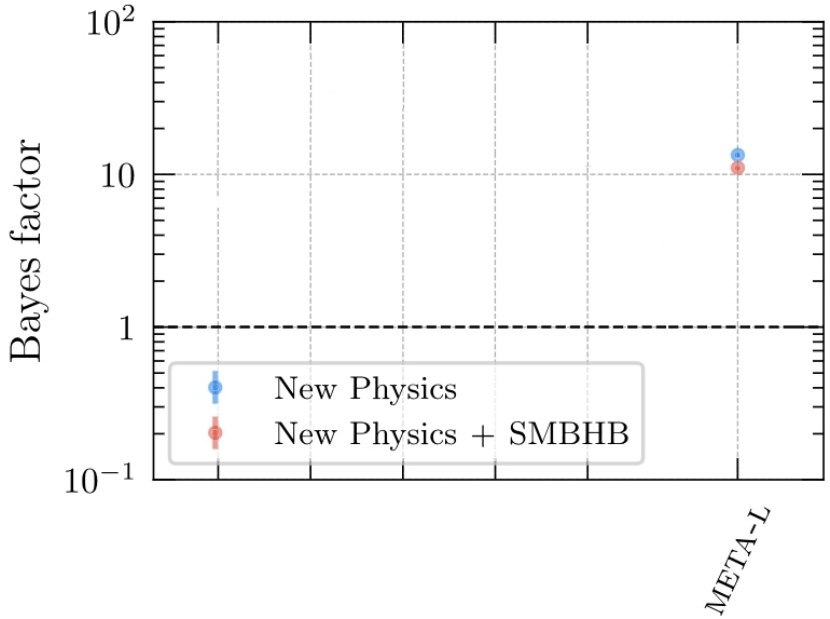


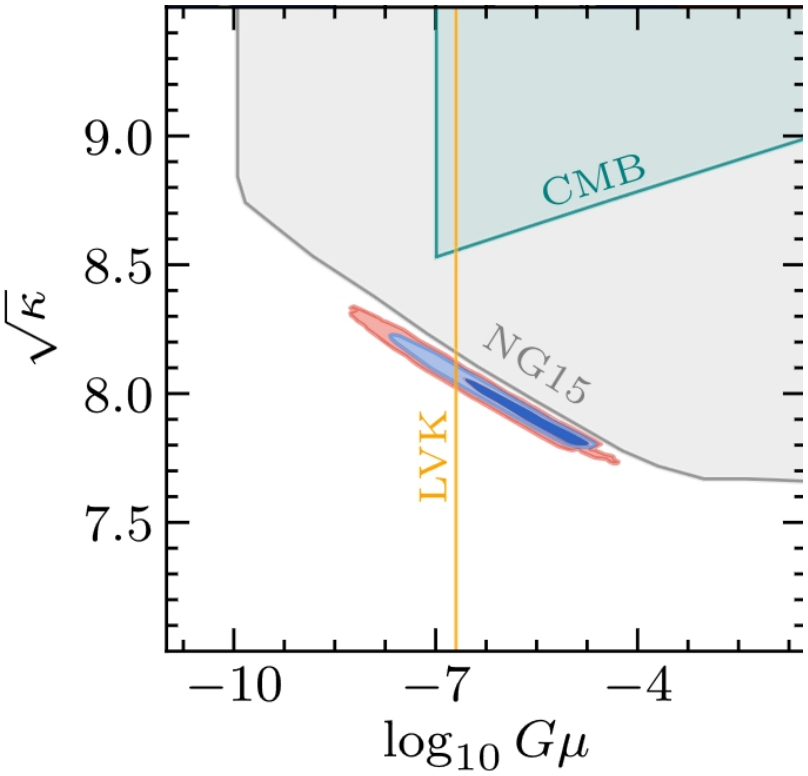




Gabriella Agazie et al 2023 ApJL 951 L8

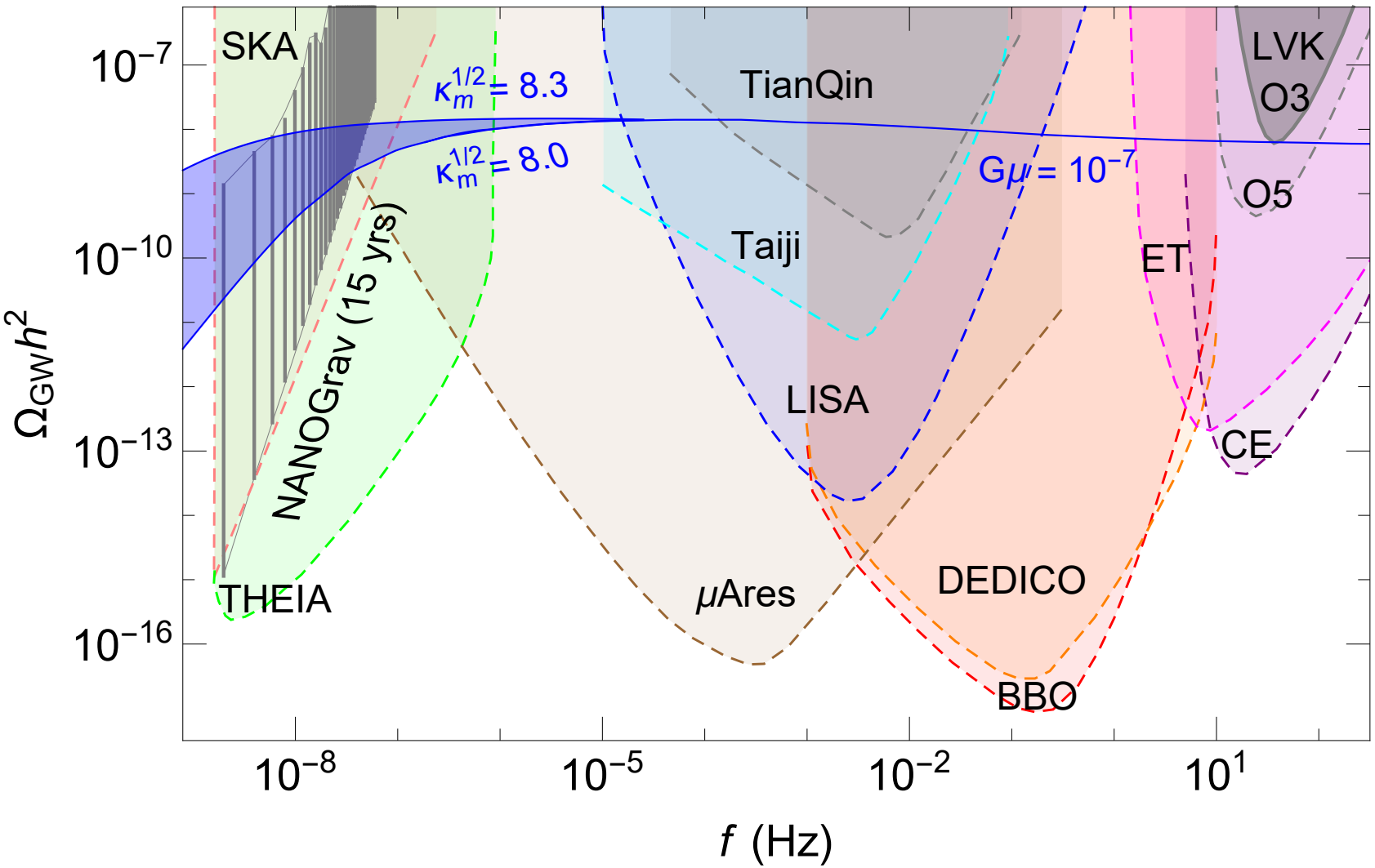
PTA data: Metastable strings





Adeela Afzal et al 2023 ApJL 951 L11

Gravitational Wave signal



$m_S \sim 10^{15}$ GeV (string scale= seesaw scale= inflation scale)

Summary

- Promising models towards SO(10) GUT
- Inflation, DTS, Unification, Fermion mass, Gravitational waves
- Minimal models: $10_H, 16_H, 45_H$
- $\langle 45_H \rangle \propto B - L$ and $\langle 45_H \rangle \propto I_{3R}$ no stable/metastable strings
- $\langle 45_H^{(\prime)} \rangle \propto B - L, I_{3R}$ metastable strings
- GW/PTAs: $v_m \sim v_s \sim 10^{15}$ GeV $(v_s = v_R = M_{\rm inflation})$
- Fully testable in a number of gravitational wave observatories

THANK YOU!

$B - L$-case

- $$W_{\rm GUT-breaking} \supset \frac{m_{45}}{2}{\rm Tr}[45_H^2] + \frac{\lambda}{4\Lambda}{\rm Tr}[45_H^4],$$

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

- $$W_{\rm Mixed} \supset$$
  $$\overline{16}_H(\lambda_1 45_H + \lambda_1' 1_H)16_H' + \overline{16}_H'(\lambda_2 45_H + \lambda_2' 1_H')16_H.$$

- $$W_{\rm DTS} \supset \gamma 10_{1H} 45_H 10_{2H} + m_{10} 10_{2H} 10_{2H}$$

$B - L$ & I_{3R}-case: DTS

- $10_{2H}10_{2H}$ ✗ (forbidding effective triplet mass)

$$10_{2H}45'^{2}_{H}10_{2H} =$$

$$\overline{2}_{2H}2_{2H} + \overline{2}_{2H}2_{2H} + \cancel{\overline{3}_{2H}3_{2H}}^{0} + \cancel{\overline{3}_{2H}3_{2H}}^{0}.$$

- To give mass to (rest) one pair of color-triplets and an additional pair of weak doublets:

$$W_{\rm DTS} \supset$$

$$\gamma_1 10_{1H}45_H10_{2H} + \frac{\gamma_2}{\Lambda}10_{2H}45'^{2}_{H}10_{2H} + \omega_{16}\overline{16}''_H16'_H$$