中国科学院大学
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Universal two-zero texture in SO(10): Implications of JUNO observations and realization from non-invertible symmetries

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MOTIVATION

Open questions about fermion mass

Mass hierarchy
Flavor mixing
CP violation

A unified answer:
UTZT - SO(10) with NIS

TEXTURE ZERO

Reducing parameters

Mass hierarchies & Flavor mixing

$$M_d \sim \begin{pmatrix} 0 & B \\ B^* & A \end{pmatrix} \quad \Rightarrow \quad \text{Cabibbo angle: } \theta_c \approx \sqrt{\frac{m_d}{m_s}}$$

S. Weinberg, 1977; H. Fritzsch, 1977; F. Wilczek & A. Zee, 1977

$$M_q \sim \begin{pmatrix} 0 & C & 0 \\ C^* & 0 & B \\ 0 & B^* & A \end{pmatrix} \longrightarrow \begin{pmatrix} 0 & C & 0 \\ C^* & \tilde{B} & B \\ 0 & B^* & A \end{pmatrix} \longrightarrow \text{Lepton sector}$$

H. Fritzsch, 1978

D. Du & Z. z. Xing, 1993

P. H. Frampton, S. L. Glashow, & D. Marfatia, 2002
Z. z. Xing & H. Zhang, 2003

$\longrightarrow$ **Universal two-zero texture (UTZT)**

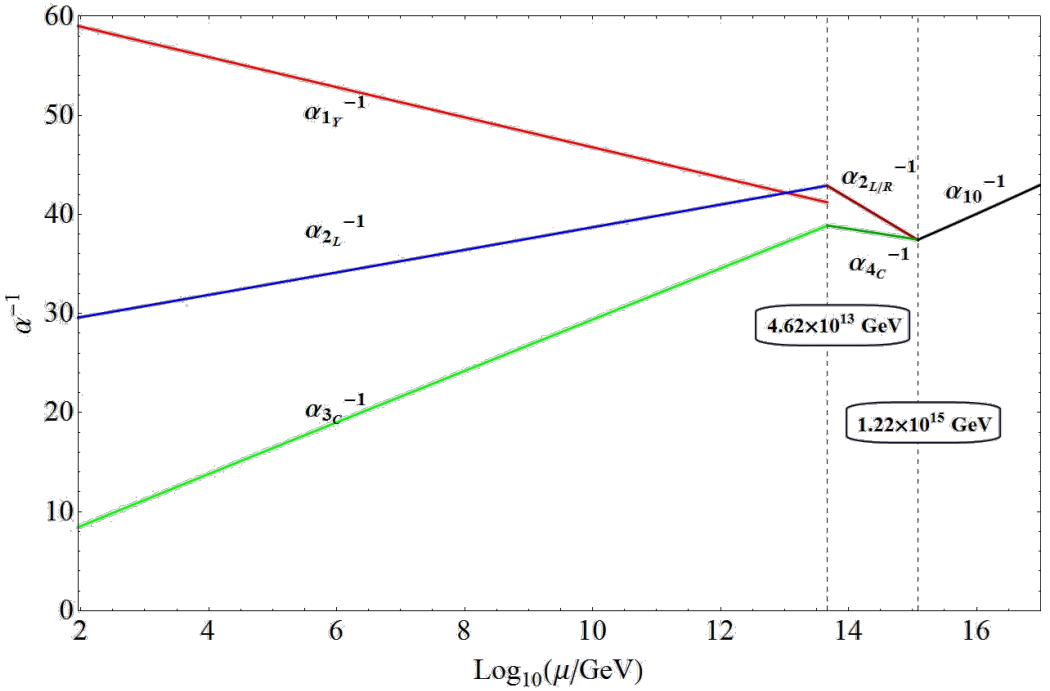
Z. z. Xing & H. Zhang, 2003
Y. L. Zhou, 2012

SO(10) GUT

H. Fritzsch & P. Minkowski, 1975

Fermions: 16_F (15 SM fermions + 1 RH neutrino)

Higgs: $10_H, 120_H, \overline{126}_H$



- Gauge unification
- Fermion unification → Quark-lepton correlation
- Anomaly free

K. S. Babu & S. Khan, 2015

Z. Q. Chen, G. X. Fang & Y. L. Zhou, 2026

UTZT - SO(10)

$$\begin{pmatrix} 0 & \times & 0 \\ \times & \times & \times \\ 0 & \times & \times \end{pmatrix}$$

$$-\mathcal{L}_Y = (A)_{\alpha\beta}\, 16_F^\alpha 16_F^\beta\, 10_H + (B)_{\alpha\beta}\, 16_F^\alpha 16_F^\beta\, \overline{126}_H$$

$$+(C)_{\alpha\beta}\, 16_F^\alpha 16_F^\beta 120_H + \text{H. c.}$$

Quark-lepton correlation

$$Y_u = H + r_2 F + i r_3 G$$

$$Y_d = r_1 (H + F + i G)$$

$$Y_\nu = H - 3 r_2 F + i c_\nu G$$

$$Y_e = r_1 (H - 3F + i c_e G)$$

$$M_\nu = -m_R Y_\nu F^{-1} Y_\nu^T + m_L F$$

H, F, and G are proportional to A^*, B^*, and C^*, respectively.

PARAMETER FITTING

SO(10) CP

A & *B*: Symmetric & Real

C: Antisymmetric & Real

Vacuum

Hermitian/Symmetric, Two-zero

$Y_u, Y_d, Y_e, Y_\nu, M_\nu, M_R$

- Type-(I + II) Seesaw
- CP is spontaneously broken by the VEVs of the 120_H.

CP transformation on gauge indices:

$$\psi_L(x) \to iC\psi^*(\hat{x}),$$

$$H_{10\,p}(x) \to \xi_p H^*_{10\,p}(\hat{x}), \ldots$$

W. Grimus & H. Kühböck, 2007

Parameter fitting

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Step 1: fit the quark sector
4 free parameter + 2 sign ambiguities
vs 4 observables

Quark-lepton correlation

Step 2: fit the lepton sector
3 free parameter + 2 sign ambiguities
vs 5 observables

$\chi^2_{tot} < 10$

Predictions on
$m_{\beta\beta}, m_{\text{lightest}}, \delta^l$, RHN mass

	Free parameters	Sign	Observables
Quark	$\boldsymbol{A_u}, \boldsymbol{A_d}, \boldsymbol{\phi_1}, \boldsymbol{\phi_2}$	η_u, η_d	$\theta^q_{12}, \theta^q_{13}, \theta^q_{23}, \delta^q$
Lepton	$\boldsymbol{m_L}, \boldsymbol{m_R}, \boldsymbol{c_\nu}$	η_e, ζ_d	$\theta^l_{12}, \theta^l_{13}, \theta^l_{23}, \Delta m^2_{21}, \Delta m^2_{23}$

Eigenvalues of Yukawa matrices are

fixed at best-fit values at M_{GUT}

$$y_u, y_c, y_t, y_d, y_s, y_b, y_e, y_\mu, y_\tau$$

(JHEP02(2017)136)

Parameter fitting

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JUNO's most recent result (NO):

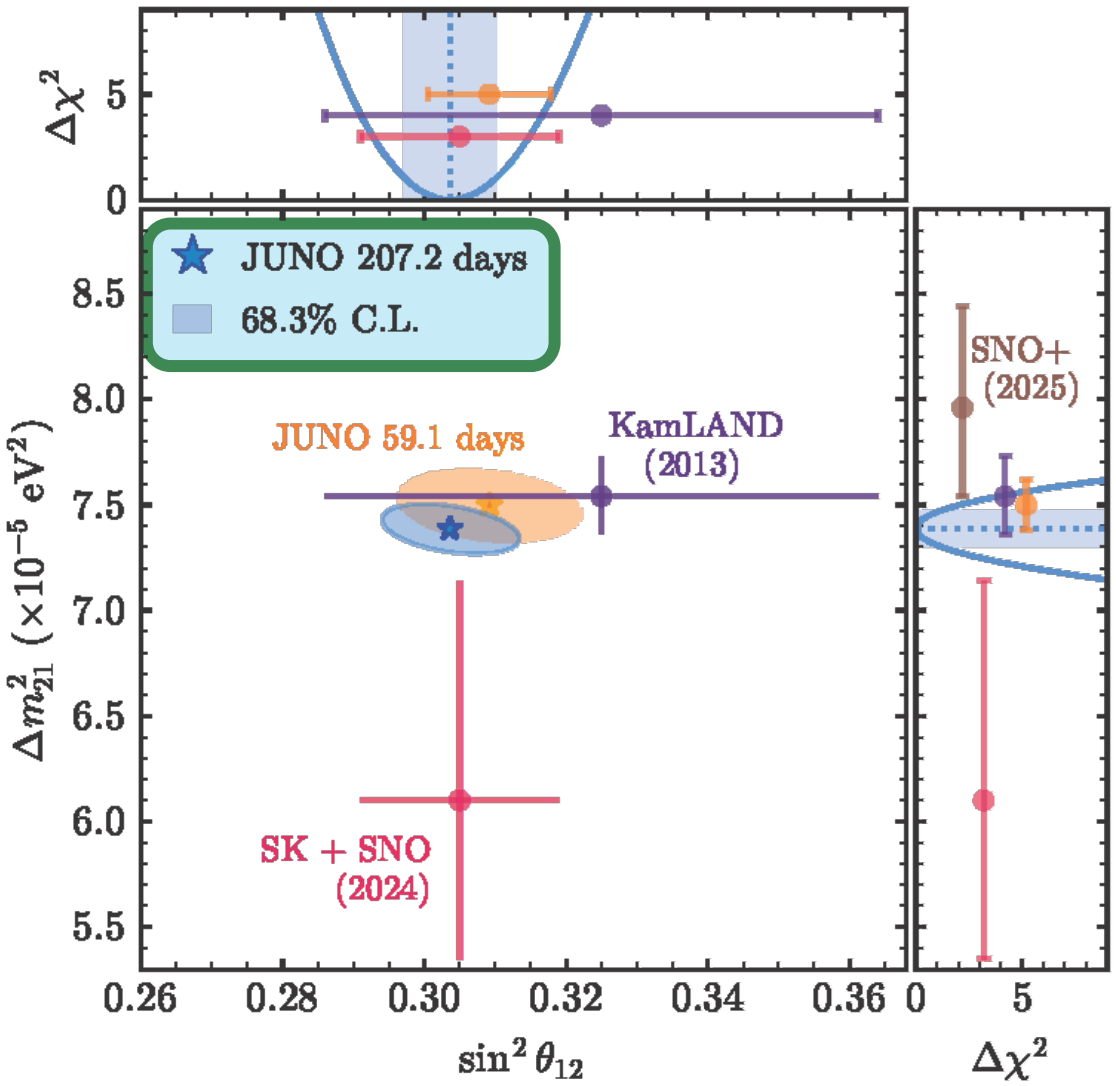
$\Delta m^2_{21} = (7.388 \pm 0.078) \times 10^{-5}\ \mathrm{eV}^2,$

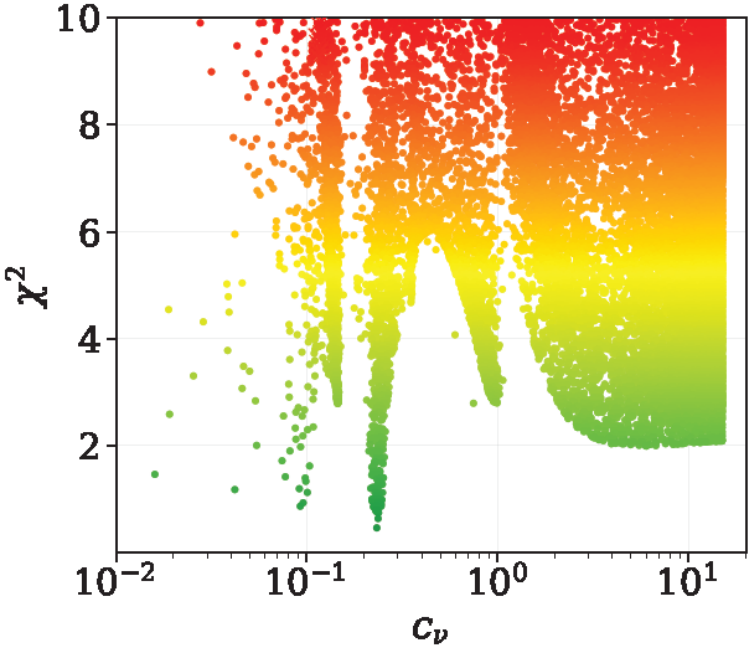
$\Delta m^2_{31} = \left(2.509^{+0.027}_{-0.025}\right) \times 10^{-3}\ \mathrm{eV}^2,$

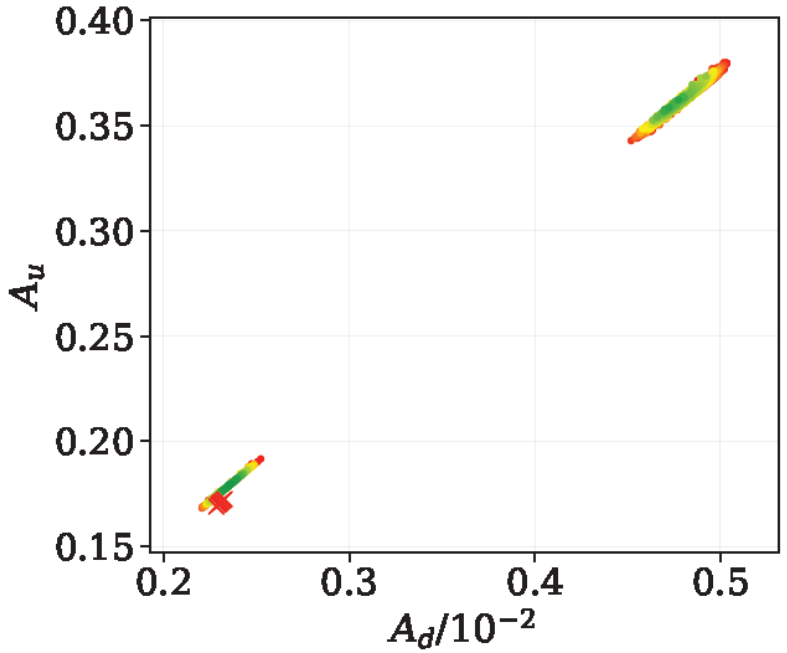
$\sin^2\theta^l_{12} = 0.3036 \pm 0.0064.$

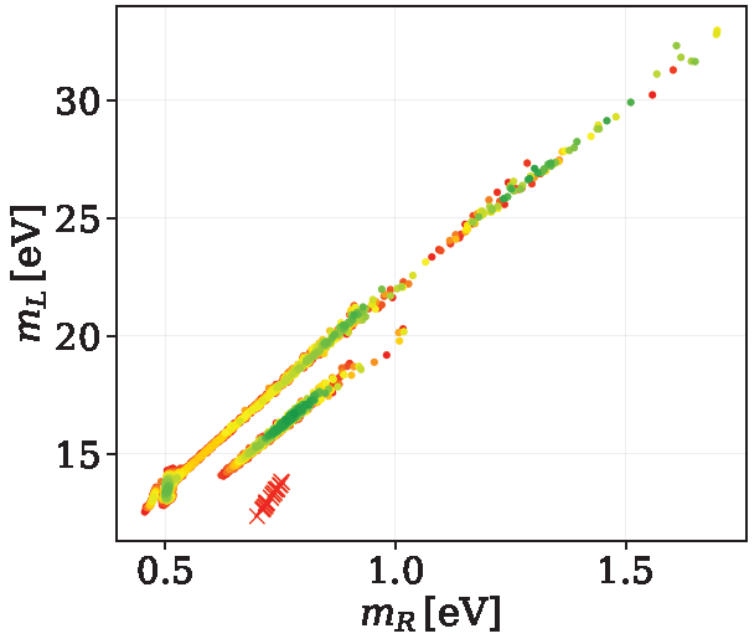
$\theta^q_{12}, \theta^q_{13}, \theta^q_{23}, \delta^q$ *(JHEP02(2017)136)*

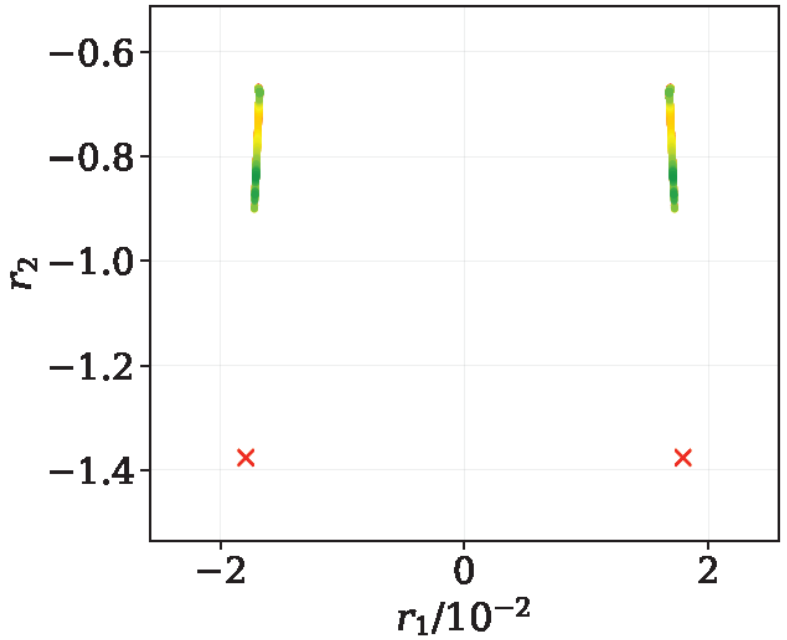
$\theta^l_{13}, \theta^l_{23}$ *(NuFIT 6.1)*

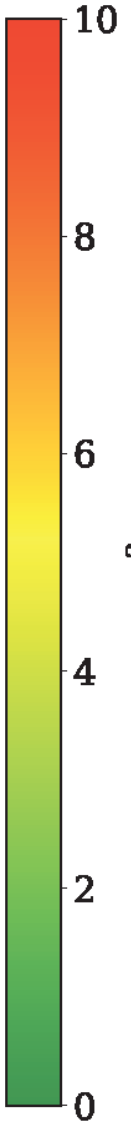












$$M_\nu = -\frac{v^2}{2} Y_\nu M_R^{-1} Y_\nu^T + M_L$$

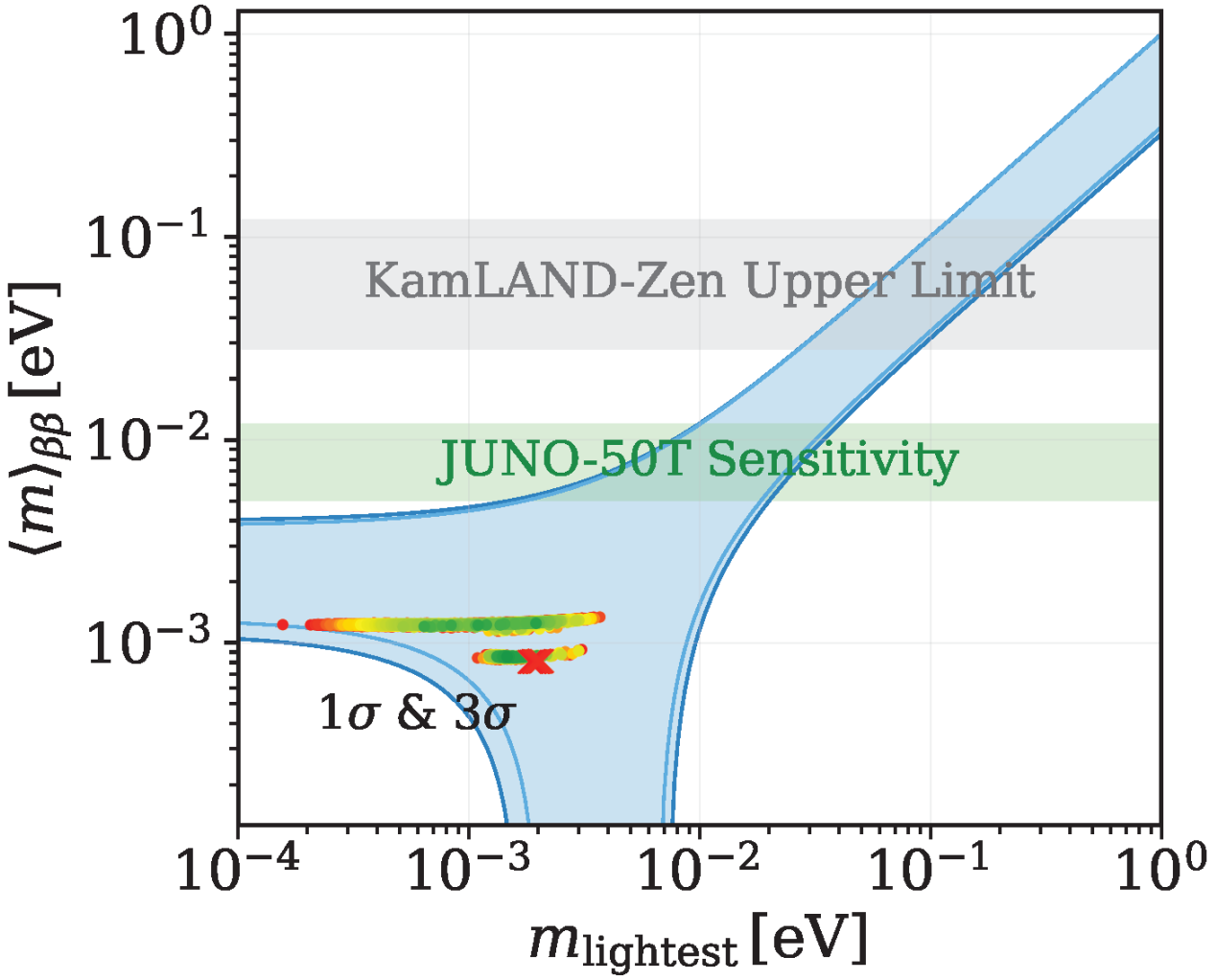
$$M_R = \frac{v^2}{2m_R} F, \qquad M_L = m_L F$$

No vanishing m_L & m_R

$\Rightarrow$ Both Type-I and Type-II seesaw are crucial.

- Points: $\eta_d = +1$
- Crosses: $\eta_d = -1$
- No solution with $\eta_e = -1$

$m_{\beta\beta}$ is insensitive to m_{lightest},
and thus, confined to narrow bands.





Two zero elements in
$M_\nu = U_e U_{\text{PMNS}} \widehat{M}_\nu U_{\text{PMNS}}^T U_e^T$

4 constraints

$\{m_1, \delta^l, \rho, \sigma, U_e\}$

Y_e is constrained
by quark sector.

$m_{\beta\beta} = |m_1 U_{e1}^2 + m_2 U_{e2}^2 + m_3 U_{e3}^2|$

Parameters in quark sector
Lepton mixing angles & Δm^2 } $m_{\beta\beta}$

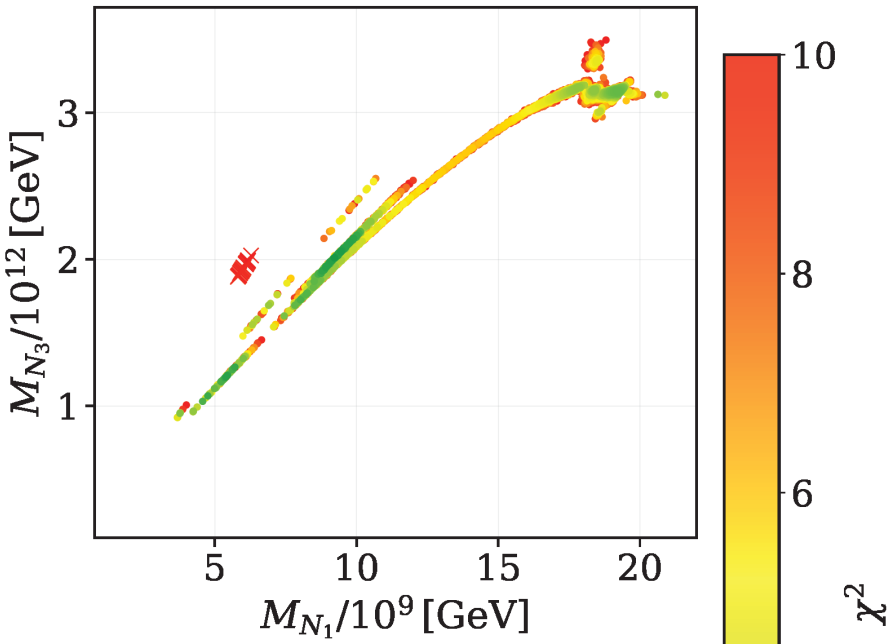
- RHN masses with hierarchy

$$M_{N_1} \in (0.3, 2.0) \times 10^{10}\ \text{GeV}$$

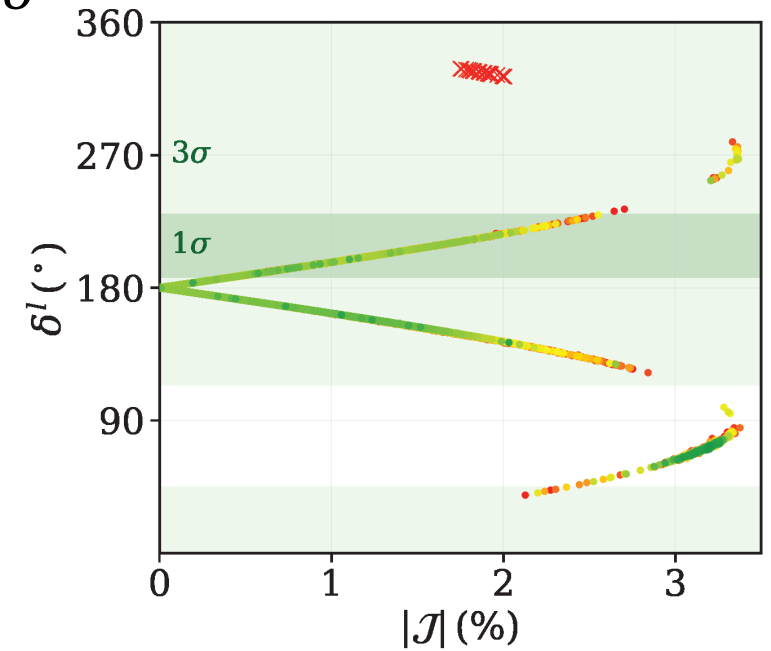
$$M_{N_3} \in (0.9, 3.6) \times 10^{12}\ \text{GeV}$$

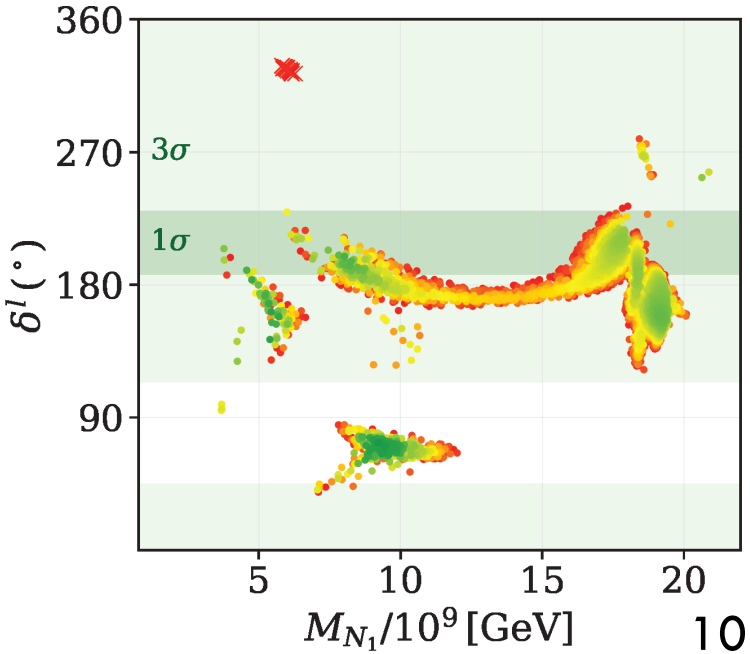
Compatible with hierarchical thermal leptogenesis

S. Davidson & A. Ibarra, 2002



- Multibranch distribution of δ^l





NON-INVERTIBLE SYMMETRY

- Representation decomposition & Selection rules in group theory :

$$\mathrm{Rep}_a \otimes \mathrm{Rep}_b = \oplus_c N_{ab}^c \, \mathrm{Rep}_c$$

$$\mathbb{I} \in \mathrm{Rep}_a \otimes \mathrm{Rep}_b \otimes \mathrm{Rep}_c \quad \Leftrightarrow \quad \phi_a \phi_b \phi_c \text{ is allowed in } \mathcal{L}.$$

- Non-invertible symmetry(NIS) & Selection rules:

Fields are labeled by conjugacy class of a group, $[g_a] = \{h g_a h^{-1} | h \in G\}$

$$[\mathbb{I}] \in [g_a] \otimes [g_b] \otimes [g_c] \quad \Leftrightarrow \quad \phi_a \phi_b \phi_c \text{ is allowed in } \mathcal{L}.$$

NON-INVERTIBLE SYMMETRY

Z_3 gauging of Z_7 $\sim$ $Z_7 \rtimes Z_3$

Generators: a & b, with $a^N = e$, $b^3 = e$, $b^{-1}ab = a^2$

Conjugacy class:

- $C_1 = \{e\}$
- $C_3^1 = \{a, a^2, a^4\}$
- $C_3^2 = \{a^3, a^6, a^5\}$
- …

Fusion rules:

	C_1	C_3^1	C_3^2
C_1	C_1	C_3^1	C_3^2
C_3^1	C_3^1	$C_3^1 + 2C_3^2$	$3C_1 + C_3^1 + C_3^2$
C_3^2	C_3^2	$3C_1 + C_3^1 + C_3^2$	$2C_3^1 + C_3^2$

J. Dong, T. Jeric, T. Kobayashi, R. Nishida & H. Otsuka, 2026

Economical

$$(C_1 \quad C_3^1 \quad C_3^2)\begin{pmatrix} 0 & \times & 0 \\ \times & \times & \times \\ 0 & \times & \times \end{pmatrix}\begin{pmatrix} C_1 \\ C_3^1 \\ C_3^2 \end{pmatrix} * C_3^2$$

e.g. $C_1 \notin C_1 \times C_3^2 \times C_3^2 = 2C_3^1 + C_3^2$

	Fields in SO(10)	Class assignment in Z_3 gauged Z_7
Fermions	$(\mathbf{16}_F^1, \mathbf{16}_F^2, \mathbf{16}_F^3)$	(C_1, C_3^1, C_3^2)
Higgses	$\mathbf{10}_H, \mathbf{120}_H, \overline{\mathbf{126}}_H$	C_3^2

Outer automorphism: $a \leftrightarrow a^{-1} = a^6$

Generalized *CP* :

$$C_1 \leftrightarrow C_1; \quad C_3^1 \leftrightarrow C_3^2$$

T. Kobayashi & H. Otsuka, 2025

Compatible with CP transformation on gauge indices

CONCLUSION

- UTZT-SO(10) still fits very well with the latest precision data from JUNO.
- 7 free parameters are used to fit 9 observables, predicting

$$\delta^l \simeq (120°, 235°), \qquad m_{\beta\beta} \simeq 1\ \text{meV}.$$

- UTZT with NIS requires no additional low-energy degrees of freedom, thus exhibit a better RG behavior than that with Abelian or non-Abelian discrete symmetries.

Thanks for your attention!

BACKUP

$$\chi^2_{tot} = \sum_{i=1}^{n_{obs}} \left(\frac{\mathcal{O}_i - \mathcal{O}_i^{\rm bf}}{\sigma_{\mathcal{O}_i}} \right)^2 < 10$$

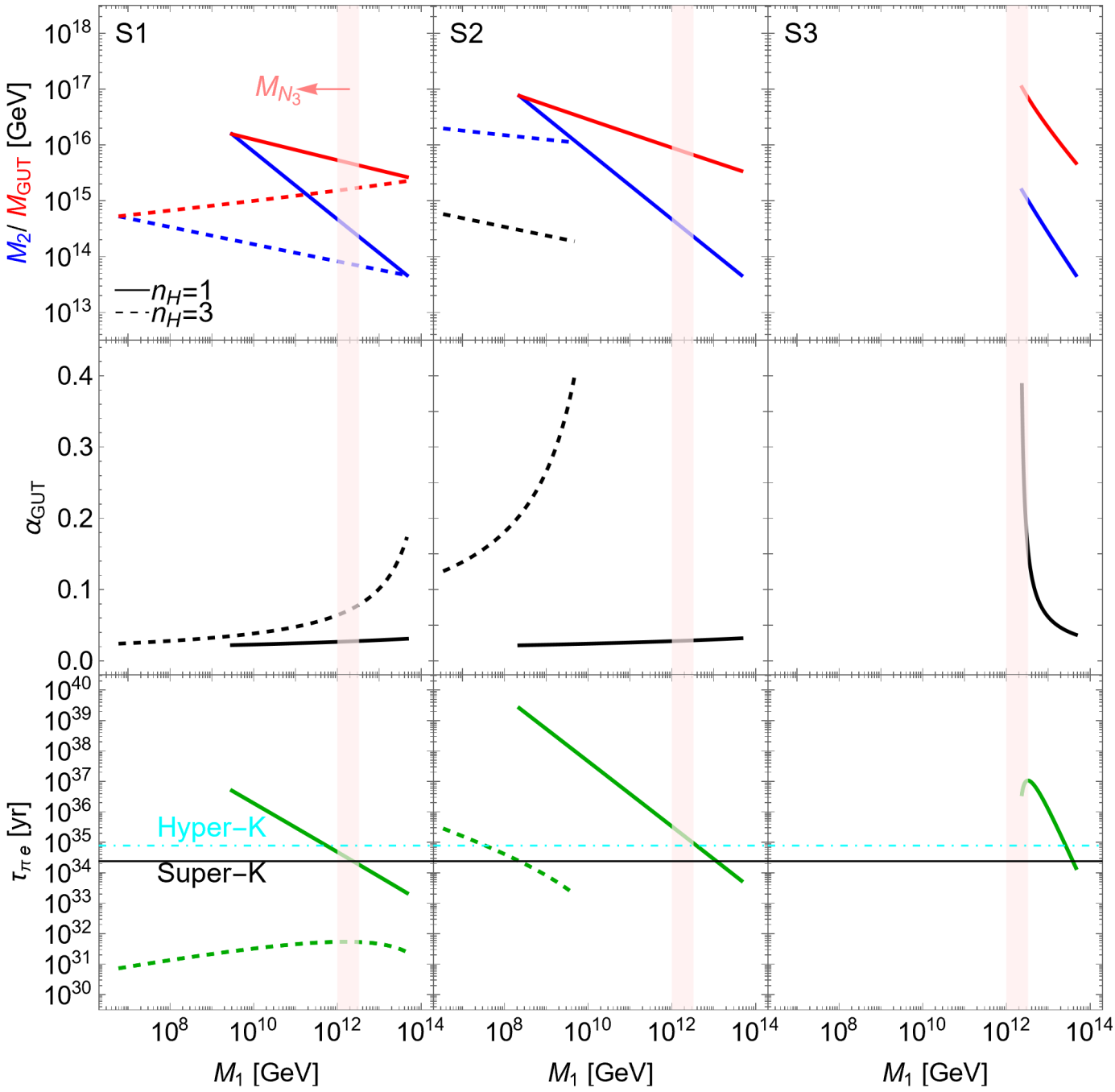
$$\begin{aligned} SO(10) \quad & \xrightarrow[\mathbf{54}]{M_{\rm GUT}} \quad G^{\rm C}_{422} = SU(4)_c \times SU(2)_L \times SU(2)_R \times Z_2^{\rm C} \\ & \xrightarrow[\mathbf{45}]{M_2} \quad G_{3221} = SU(3)_c \times SU(2)_L \times SU(2)_R \times U(1)_X \\ & \xrightarrow[\mathbf{126}]{M_1} \quad G_{\rm SM} = SU(3)_c \times SU(2)_L \times U(1)_Y \,, \end{aligned}$$

$$C_3^2 \times C_3^2 \times C_3^2 = 2C_3^1 + C_3^2 \ldots\ldots$$

G. X. Fang & Y. L. Zhou, 2025

BACKUP

Predictions of GUT scale M_{GUT}, intermediate scales, M_1 and M_2, gauge coupling at GUT scale α_{GUT}, and the partial lifetime for proton decaying to $\pi^0 e^+$ in three scenarios, S1 (left), S2 (middle) and S3 (right). The energy scale hierarchy $M_1 \leq M_2 \leq M_{GUT}$ is required. $n_H = 1$ (solid curve) and 3 (dashed curve) refer to the repetition number of the Higgs fields 10_H, $\overline{126}_H$, 120_H. The predicted range of M_{N_3} in the last section is shown in the pink band as a reference. S3 gives no solution for $n_H = 3$ and is thus not shown in the right panel.



BACKUP

Impossible ways: $Z_N \rtimes Z_2$, $Z_{13} \rtimes Z_3$, $(Z_2 \times Z_2' \times Z_2'') \rtimes Z_3$, $(Z_3 \times Z_3') \rtimes Z_3$

(one generation of Higgs)

An alternative with two generations of Higgs: $Z_6 \rtimes Z_2$

- $[e] = \{e\}$
- $[a] = \{a, a^5\}$
- $[a^2] = \{a^2, a^4\}$
- $[a^3] = \{a^3\}$

$$([e] \quad [a^2] \quad [a]) \begin{pmatrix} 0 & \times & 0 \\ \times & \times & 0 \\ 0 & 0 & \times \end{pmatrix} \begin{pmatrix} [e] \\ [a^2] \\ [a] \end{pmatrix} * [a^2]$$

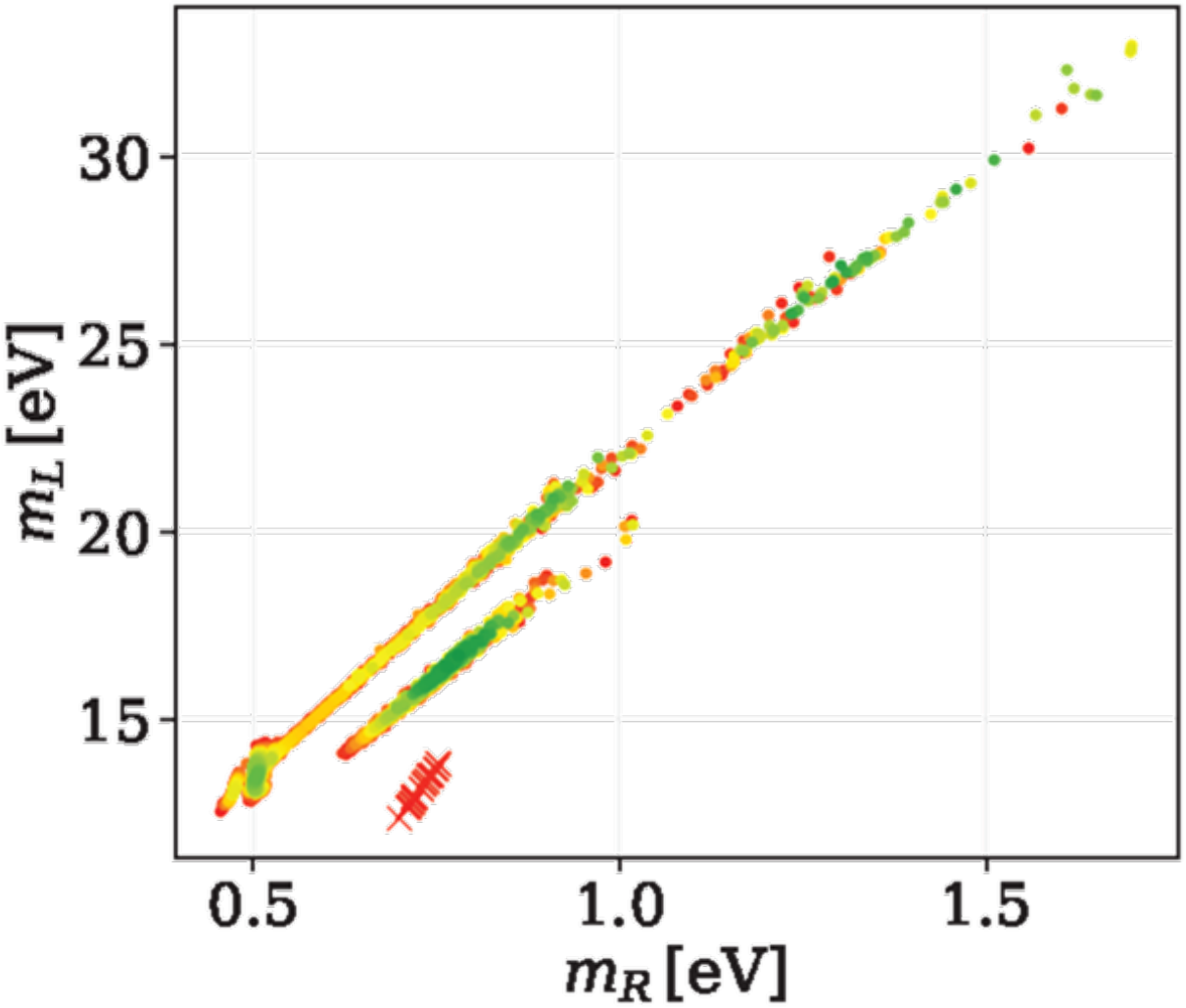
$$+ ([e] \quad [a^2] \quad [a]) \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & \times \\ 0 & \times & 0 \end{pmatrix} \begin{pmatrix} [e] \\ [a^2] \\ [a] \end{pmatrix} * [a^3]$$

BACKUP

$$M_\nu = -m_R Y_\nu F^{-1} Y_\nu^T + m_L F$$

$$F^{-1} \sim \begin{pmatrix} \times & \times & \times \\ \times & 0 & 0 \\ \times & 0 & \times \end{pmatrix}$$

$$\Rightarrow \quad (M_\nu)_{33} = m_L F_{33} + m_R \frac{(Y_{\nu\,33})^2}{F_{33}}$$



$$F = \frac{\mathrm{Re}(Y_u)}{r_2 - 1} - \frac{\mathrm{Re}(Y_d)}{r_1(r_2 - 1)}$$

$$Y_\nu = -\frac{3r_2+1}{r_2-1}\mathrm{Re}(Y_u) + \frac{4r_2}{r_1(r_2-1)}\mathrm{Re}(Y_d) + i\frac{c_\nu}{r_1}\mathrm{Im}(Y_d)$$

$Y_{\nu\,33}$ is real. $\Rightarrow$ No c_ν reliance.

r_1 & r_2 are totally depend on quark sector. $\Rightarrow$ F_{33} & $Y_{\nu\,33}$ are totally depend on quark sector.