NEUTRINO 2026

RESOLVING THE GALLIUM ANOMALY: STERILE NEUTRINOS AND THE BREAKDOWN OF THE FACTORIZATION OF LEPTONIC WAVE FUNCTIONS

M. Cadeddu et al. | arXiv:2512.20560

A possible solution to the gallium anomaly moving beyond the leptonic wave function factorization

SCAN ME

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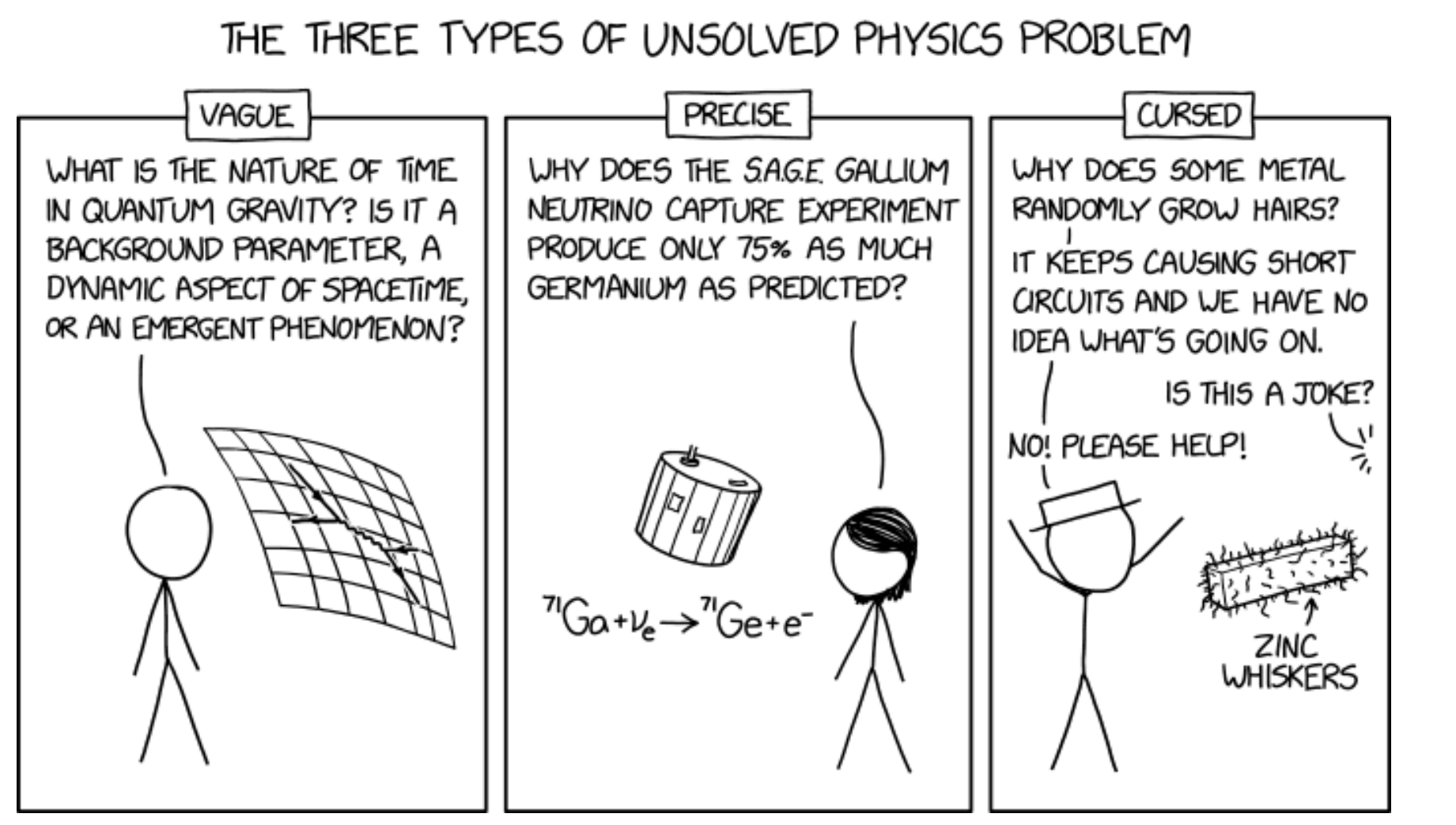
arXiv:2512.20560

Unsolved Physics Problems



https://xkcd.com/3115/

SHORT-BASELINE NEUTRINO ANOMALIES

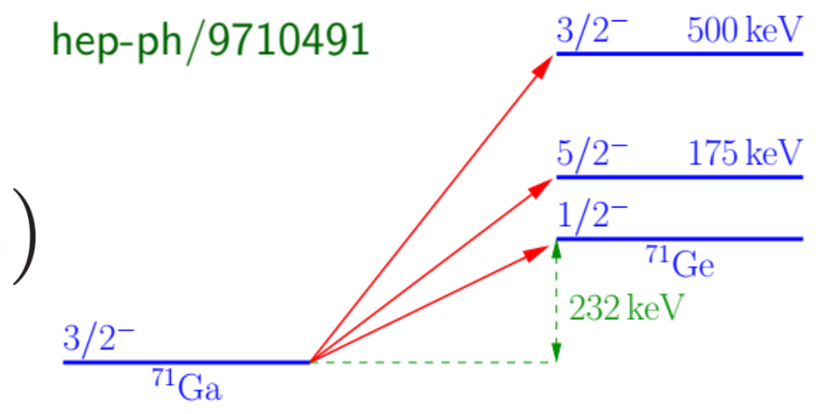
Anomaly	Channel	Status	Possible explanation
Reactor arXiv:1101.2755	$\bar{\nu}_e \to \bar{\nu}_e$	Historical anomaly ($\sim$2.5σ)	Reactor flux modeling Current status ($\sim$2.2σ) arXiv:2605.10353
LSND hep-ex/0104049	$\bar{\nu}_\mu \to \bar{\nu}_e$	Significant appearance anomaly (3.8σ)	Unknown
MiniBooNE arXiv:1805.12028 arXiv:2006.16883	$\nu_\mu \to \nu_e$ $\bar{\nu}_\mu \to \bar{\nu}_e$	Electron-like excess (4.8σ)	Unknown Sterile-neutrino hypothesis disfavored by MicroBooNE *Nature* **648**, 64–69 (2025)
Gallium arXiv:2306.03299 arXiv:1006.3244 arXiv:2109.11482	$\boldsymbol{\nu_e \to \nu_e}$	**Persistent** (>5σ)	**Unknown** Sterile-neutrino hypothesis disfavored by KATRIN *Nature* **648**, 70–75 (2025)

GALLIUM ANOMALY OVERVIEW

For more than 30 years, gallium source experiments have observed a persistent deficit in the measured ^{71}Ga(ν_e,e)^{71}Ge capture rate relative to theoretical predictions (based on detailed balance), as reported by **GALLEX**, **SAGE**, and **BEST**.

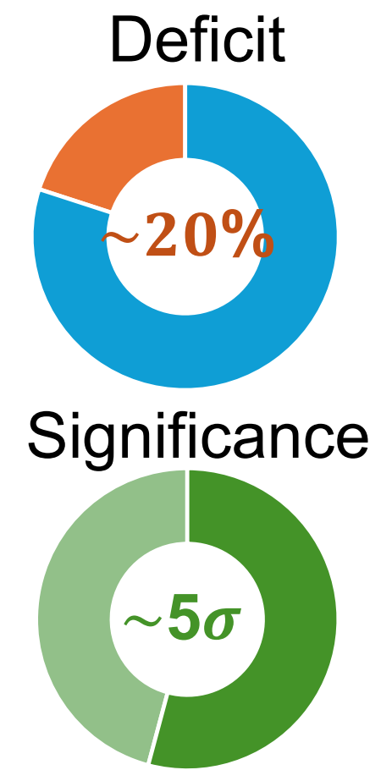
Theoretical ground-state neutrino absorption cross section

$$\sigma_{\rm gs}^{\rm db} = \frac{2\pi^2 \ln 2}{f_{\rm EC} t_{1/2}} \left(\frac{2J_{\rm Ge}+1}{2J_{\rm Ga}+1}\right) \sum_j p_e^j E_e^j \mathcal{F}(E_e, Z, r_0) \mathcal{B}(E_e^j)$$

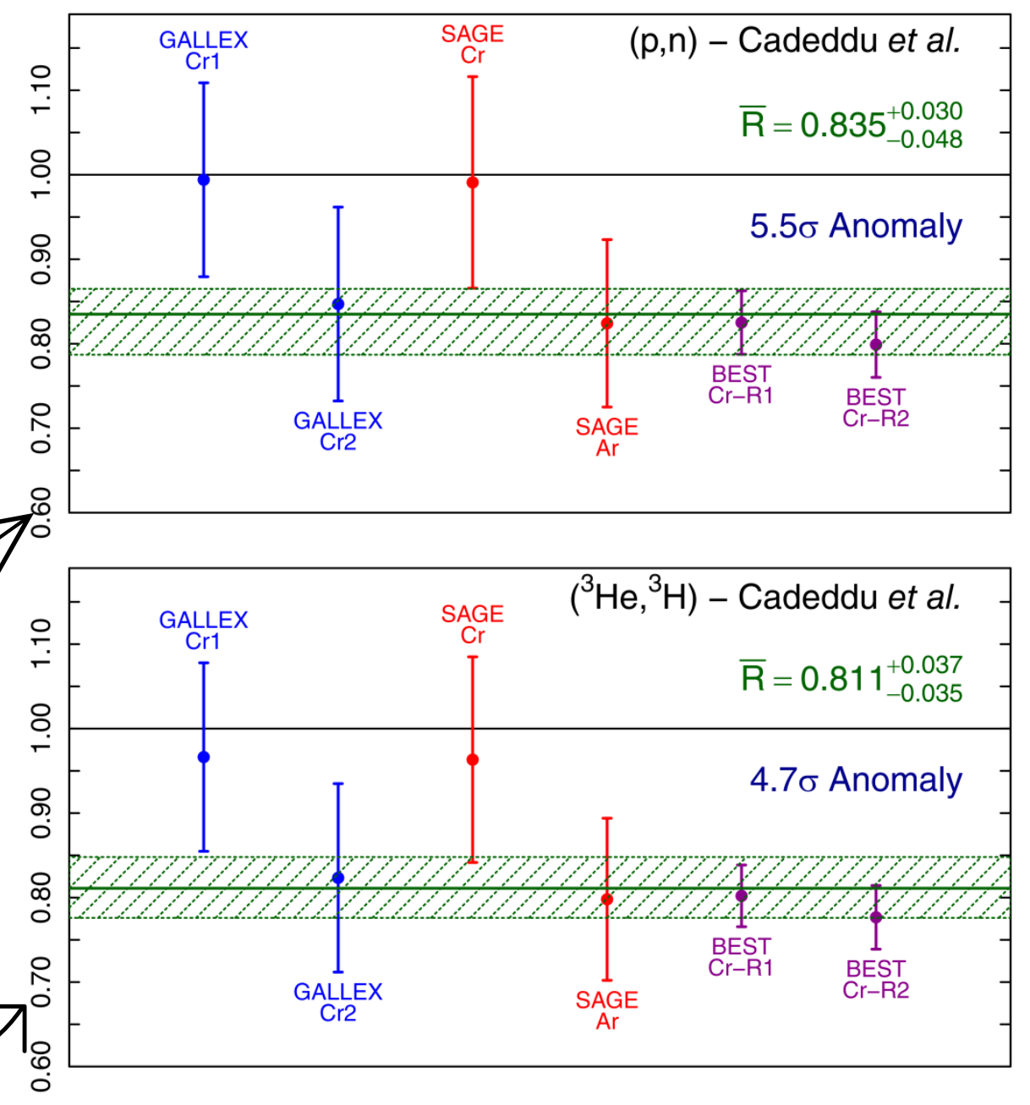


Total cross section with excited-state contributions

$$\sigma = \sigma_{\rm gs}\left[1 + \xi(5/2^-)\frac{B_{\rm GT}(5/2^-)}{B_{\rm GT}({\rm gs})} + \xi(3/2^-)\frac{B_{\rm GT}(3/2^-)}{B_{\rm GT}({\rm gs})}\right]$$



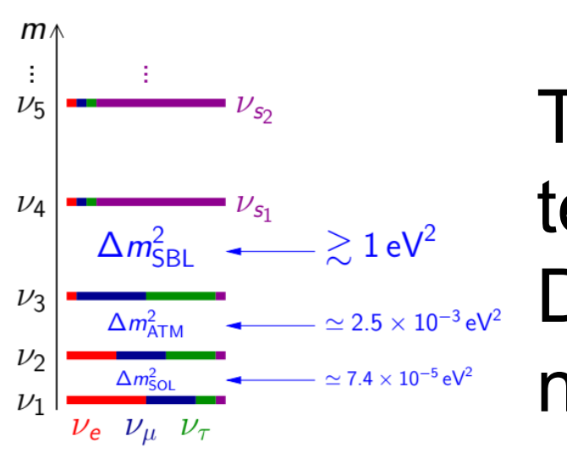
Model	$\overline{R}$	GA
Bahcall (1997) [hep-ph/9710491]	$0.800^{+0.035}_{-0.038}$	5.9σ
Elliott et al. (2023) [arXiv:2303.13623] (p, n)	$0.817^{+0.028}_{-0.047}$	6.3σ
Cadeddu et al. (2025) [arXiv:2507.13103] (p, n)	$\mathbf{0.835^{+0.030}_{-0.048}}$	$\boxed{5.5\sigma}$
Elliott et al. (2023) [arXiv:2303.13623] (^{3}He, ^{3}H)	$0.795^{+0.030}_{-0.033}$	6.5σ
Cadeddu et al. (2025) [arXiv:2507.13103] (^{3}He, ^{3}H)	$\mathbf{0.811^{+0.037}_{-0.035}}$	$\boxed{4.7\sigma}$



STERILE NEUTRINO INTERPRETATION

The Gallium Anomaly could be explained by short-baseline active-sterile neutrino oscillations with an effective "3+1" probability

$$P_{ee}^{\rm SBL} \simeq 1 - \sin^2 2\vartheta_{ee} \sin^2\left(\frac{\Delta m^2_{41} L}{4E}\right)$$



The gallium-preferred region is in tension with reactor (STEREO, DANSS, PROSPECT), solar neutrino, and KATRIN constraints.

These tensions challenge the "3+1" sterile-neutrino interpretation.

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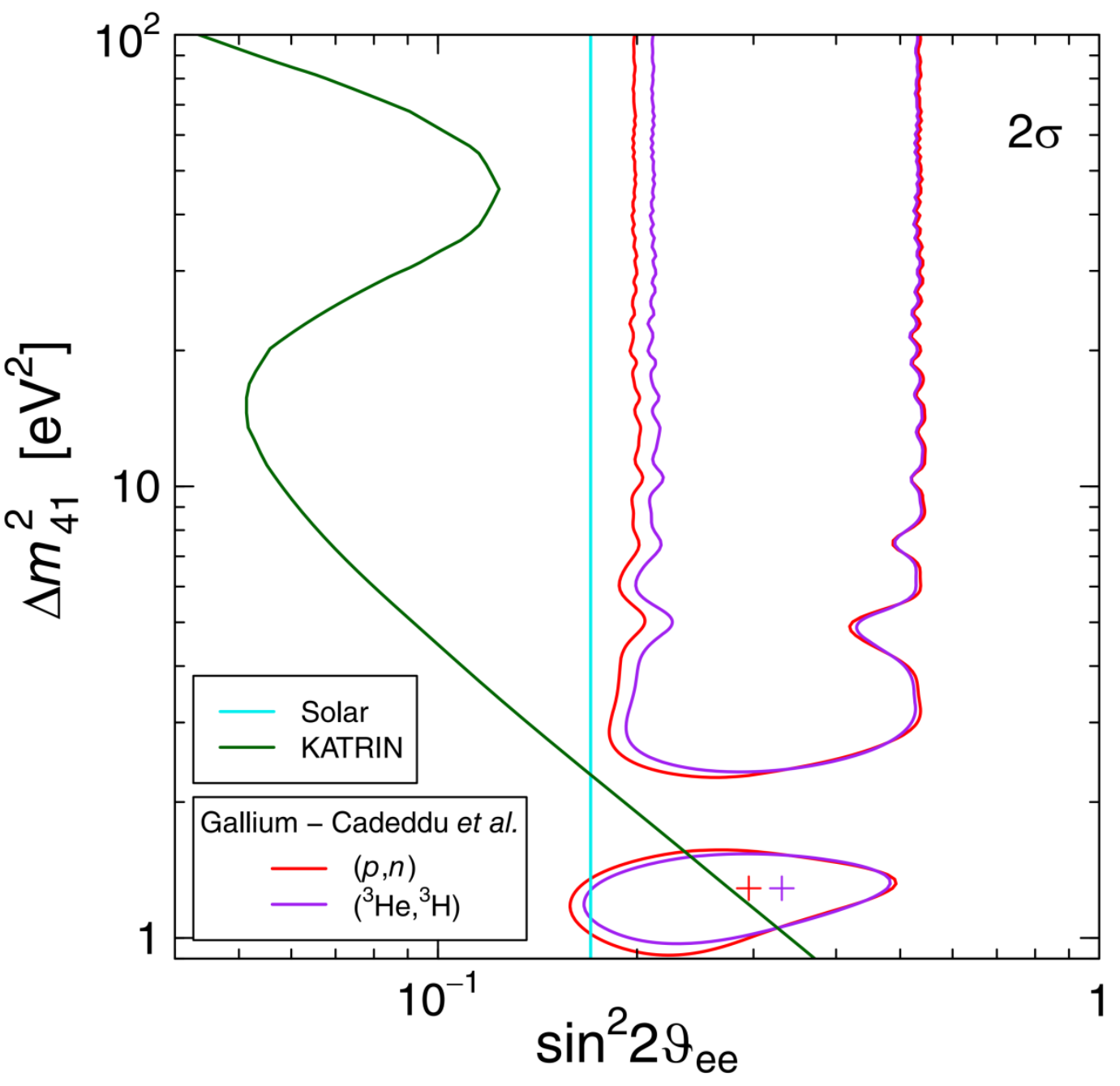
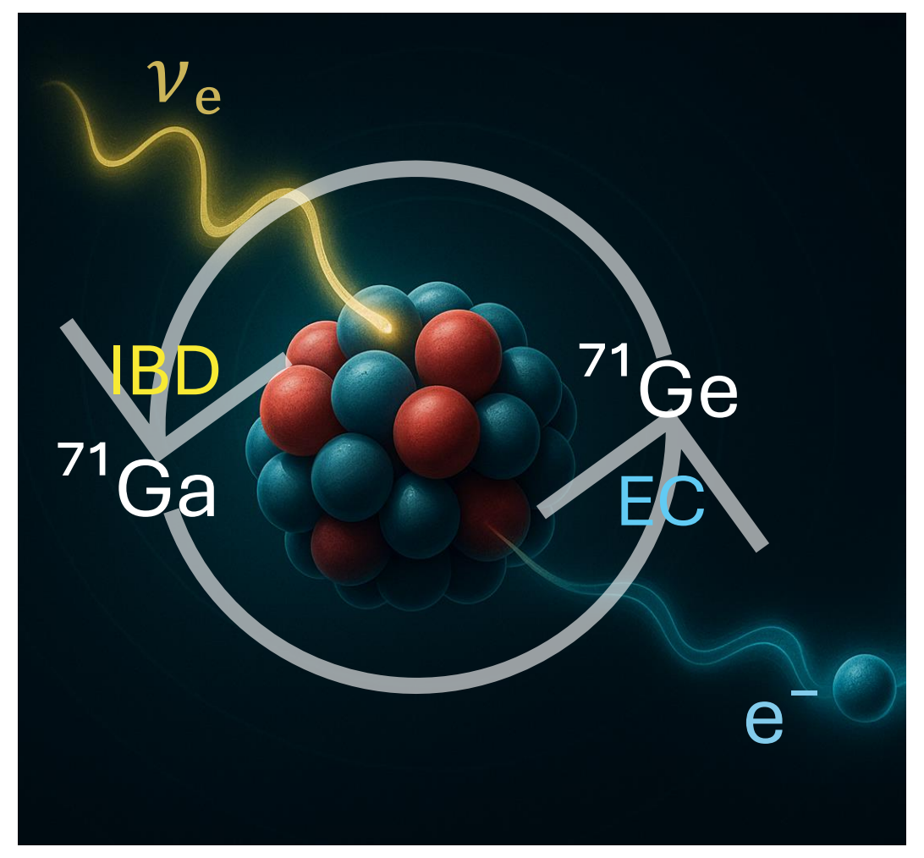


M. Cadeddu et al. *Reassessing the gallium anomaly using self-consistent electron wave functions*, PRD **113**, 033006 (2026), arXiv:2507.13103

STANDARD FACTORIZATION



$$\sigma_{\rm gs} = \frac{G_F^2 \,|V_{ud}|^2\, g_A^2}{\pi(2J_{\rm Ga}+1)} \sum_j p_e^j E_e^j \,\left|\mathcal{H}_j^{\rm IBD}\right|^2\, \mathcal{B}(E_e^j)$$

Detailed balance avoids the full calculation, which requires both leptonic and nuclear wave functions

$$\mathcal{H}_j^{\rm IBD} = \int \psi_e^{j\,*}(\mathbf{r})\, \Psi^*_{^{71}{\rm Ge}}(\mathbf{r})\, \hat{H}_{\rm GT}\, \psi_\nu^j(\mathbf{r})\, \Psi_{^{71}{\rm Ga}}(\mathbf{r})\, {\rm d}\mathbf{r}$$

This procedure relies on the standard assumption that the lepton wave functions are nearly constant inside the nucleus, allowing the leptonic and nuclear parts to be factorized

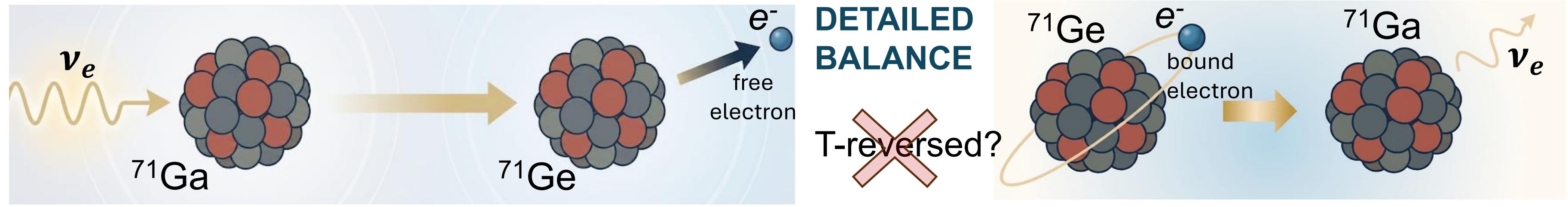
$$\mathcal{H}_j^{\rm IBD} \simeq \psi_e^{j\,*}(r_0)\psi_\nu^j(r_0) \int \Psi^*_{^{71}{\rm Ge}}(\mathbf{r})\, \hat{H}_{\rm GT}\, \Psi_{^{71}{\rm Ga}}(\mathbf{r})\, {\rm d}\mathbf{r}$$

$$= \psi_e^{j\,*}(r_0)\psi_\nu^j(r_0)\, \mathcal{M}_{\rm nuc}^{\rm IBD}$$

the nuclear matrix element can be isolated ⇨ $|\mathcal{M}_{\rm nuc}^{\rm IBD}|^2 \overset{\rm db}{=} |\mathcal{M}_{\rm nuc}^{\rm EC}|^2$

ADVANTAGE: enables the nuclear matrix element to be extracted from the ^{71}Ge half-life $t_{1/2}$

$$\frac{|\mathcal{M}_{\rm nuc}^{\rm EC}|^2}{2J_{\rm Ge}+1} = \frac{2\pi^3 \ln 2}{G_F^2 |V_{ud}|^2 g_A^2 f_{\rm EC} t_{1/2}}$$



REVISED MODEL: NON-FACTORIZED CALCULATION

Relaxing this approximation breaks factorization, requiring the full transition amplitude to be computed using exact lepton wave functions and the **weak transition density $\boldsymbol{\rho_{TD}(r)}$**

$$\rho_{\rm TD}(\mathbf{r}) = \Psi^*_{^{71}{\rm Ge}}(\mathbf{r})\hat{H}_{\rm GT}\, \Psi_{^{71}{\rm Ga}}(\mathbf{r})$$

The transition amplitude is computed using exact lepton wave functions

$$|\mathcal{H}^{\rm IBD}|^2 = (4\pi)^2\left(|I_1|^2 + |I_2|^2\right)$$

$$\boxed{I_1 = \int dr\, r^2 \rho_{\rm TD}(r)\left[g_{-1}(r) j_0(q\,r) + \tfrac{1}{3} f_{-1}(r) j_1(q\,r)\right]} \quad \boxed{I_2 = \int dr\, r^2 \rho_{\rm TD}(r)\left[f_1(r) j_0(q\,r) - \tfrac{1}{3} g_1(r) j_1(q\,r)\right]}$$

j_0 & j_1: spherical Bessel functions; $\boldsymbol{g_\kappa(r)}$, $\boldsymbol{f_\kappa(r)}$ large & small Dirac electron radial components.

FIT STRATEGY

We investigate which **phenomenological transition densities** $\rho_{\rm TD}(r,\Theta)$ yield a cross section capable of resolving the Gallium Anomaly.

$$\rho_{\rm TD}^{\rm SG}(r,\Theta^{\rm SG}) = A\, e^{-(r-r_a)^2/2a^2},$$

$$\rho_{\rm TD}^{\rm DG}(r,\Theta^{\rm DG}) = A\, e^{-(r-r_a)^2/2a^2} - B\, e^{-(r-r_b)^2/2b^2},$$

$$\rho_{\rm TD}^{\rm mDG}(r,\Theta^{\rm mDG}) = Ar\, e^{-(r-r_a)^2/2a^2} + B\, r^2\, e^{-(r-r_b)^2/2b^2}$$

$$\rho_{\rm TD}^{\rm mTG}(r,\Theta^{\rm mTG}) = Ar\, e^{-(r-r_a)^2/2a^2} + B\, r^2\, e^{-(r-r_b)^2/2b^2} + Cr^3 e^{-(r-r_c)^2/2c^2}$$

Least-squares functions used in the fit

$$\chi^2_{\rm EC}(\Theta) = \left(\frac{t_{1/2}^{\rm exp} - (1+\eta_2+\eta_3)\cdot t_{1/2}(\Theta)}{\delta t_{1/2}}\right)^2 + \frac{\eta_2^2}{\delta_{\eta_2}^2} + \frac{\eta_3^2}{\delta_{\eta_3}^2}$$

$$\chi^2_{\rm IBD}(\Theta) = \frac{\eta_1^2}{\delta_{\eta_1}^2} + \sum_X \left(\frac{\sigma_{{\rm gs},\,X}^{\rm exp} - (1+\eta_1)\sigma_{{\rm gs},\,X}(\Theta)}{\delta\sigma_{{\rm gs},\,X}^{\rm exp}}\right)^2$$

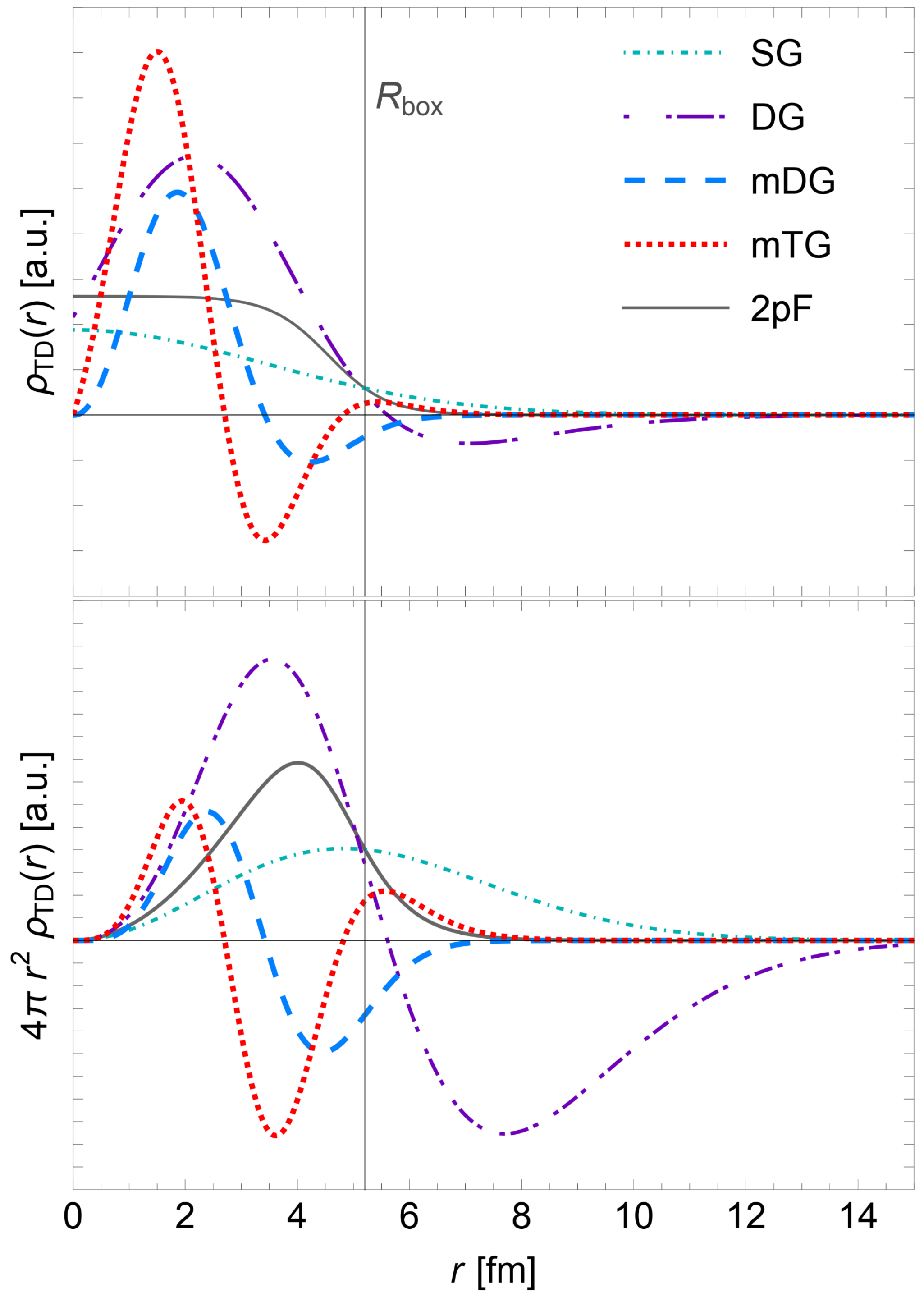
RESULTS

Model	$\sigma_{{\rm gs},^{51}{\rm Cr}}(\Theta)$ [10^{-45} cm^2]	$\sigma_{{\rm gs},^{37}{\rm Ar}}(\Theta)$ [10^{-45} cm^2]	$t_{1/2}(\Theta)$ [d]	$\chi^2_{\rm IBD}$	$\chi^2_{\rm EC}$	GA solved
SG	5.27	6.30	11.515	8.68	0.24	no
DG	4.42	5.13	11.462	0.014	0.0005	yes
mDG	4.50	5.24	11.465	0.037	0.00003	yes
mTG	4.39	5.10	11.463	0.044	0.0002	yes

The DG, mDG, and mTG transition densities **fully resolve the Gallium Anomaly** while satisfying the ^{71}Ge half-life constraint.

Unlike the extended DG solution, the compact mDG and mTG densities are **localized near the nuclear surface**, making them more consistent with standard nuclear-structure expectations.

In this mechanism, resolving the Gallium Anomaly requires **at least one node** in $\rho_{\rm TD}(r)$.



CONCLUSIONS

Using exact electron wave functions and phenomenological weak transition densities, we find sign-changing profiles that reduce the ^{71}Ga neutrino-capture cross section by $\sim 20\,\%$, resolving the Gallium Anomaly, while precisely reproducing the measured ^{71}Ge half-life, without invoking sterile neutrinos.

This highlights the importance of accurately determining weak transition densities.

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