Can the Helium Ionization-Energy Anomaly Indicate New Physics?

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Introduction

- A recently reported 9σ theory–experiment discrepancy in the ionization energy of metastable helium.
- The persistence of the anomaly across the two isotopes has been discussed as a possible indication of new physics.

1. 2^3S_1 ionization energy anomaly

- A 9σ discrepancy in the ionization energy of the metastable 2^3S_1 state of ^{4}He has now also been observed in ^{3}He [1, 2].

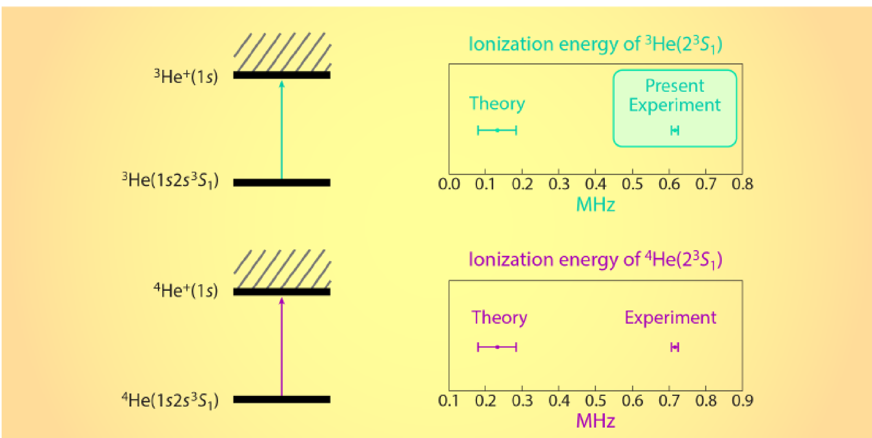

Figure 1: Discrepant values for the ionization energy of helium [3].

2. Exotic electron-electron interactions

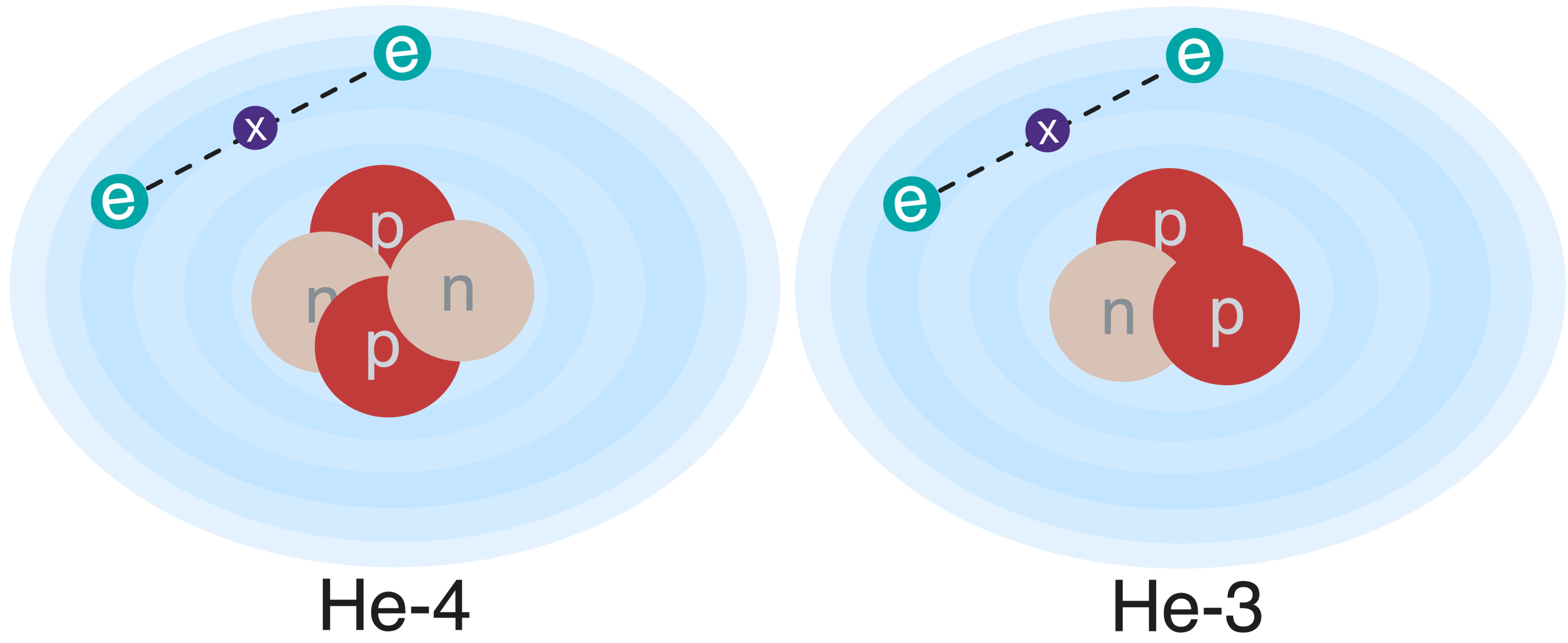

Figure 2: Schematic illustration of the assumed exotic interaction, mediated by a new boson (X), between electrons within ^{4}He and ^{3}He. Only electron–electron exotic interactions are considered, as they generate identical leading-order energy shifts ($\Delta E_{ee}^{(^3\mathrm{He})} \approx \Delta E_{ee}^{(^4\mathrm{He})}$) in both isotopes despite their different nuclear structures.

- Spin-dependent interactions attract growing interest [4].
- They may signal new bosons like the axion, potentially explaining dark matter and the strong CP problem.
- This has motivated extensive experimental searches across both subatomic and astrophysical scales.

  As an example:

$$V_{AA} = -g_A^e g_A^e \frac{\hbar c}{4\pi} \boldsymbol{\sigma}_e \cdot \boldsymbol{\sigma}'_e \frac{1}{r} e^{-r/\lambda}. \tag{1}$$

3. Main results [5]

✗ Pseudoscalar and vector explanations are excluded.

✗ Axial-vector scenarios are incompatible with existing constraints.

✓ A scalar-mediated interaction remains viable:

$\boxed{50 < M < 1200\,\mathrm{eV}}$.

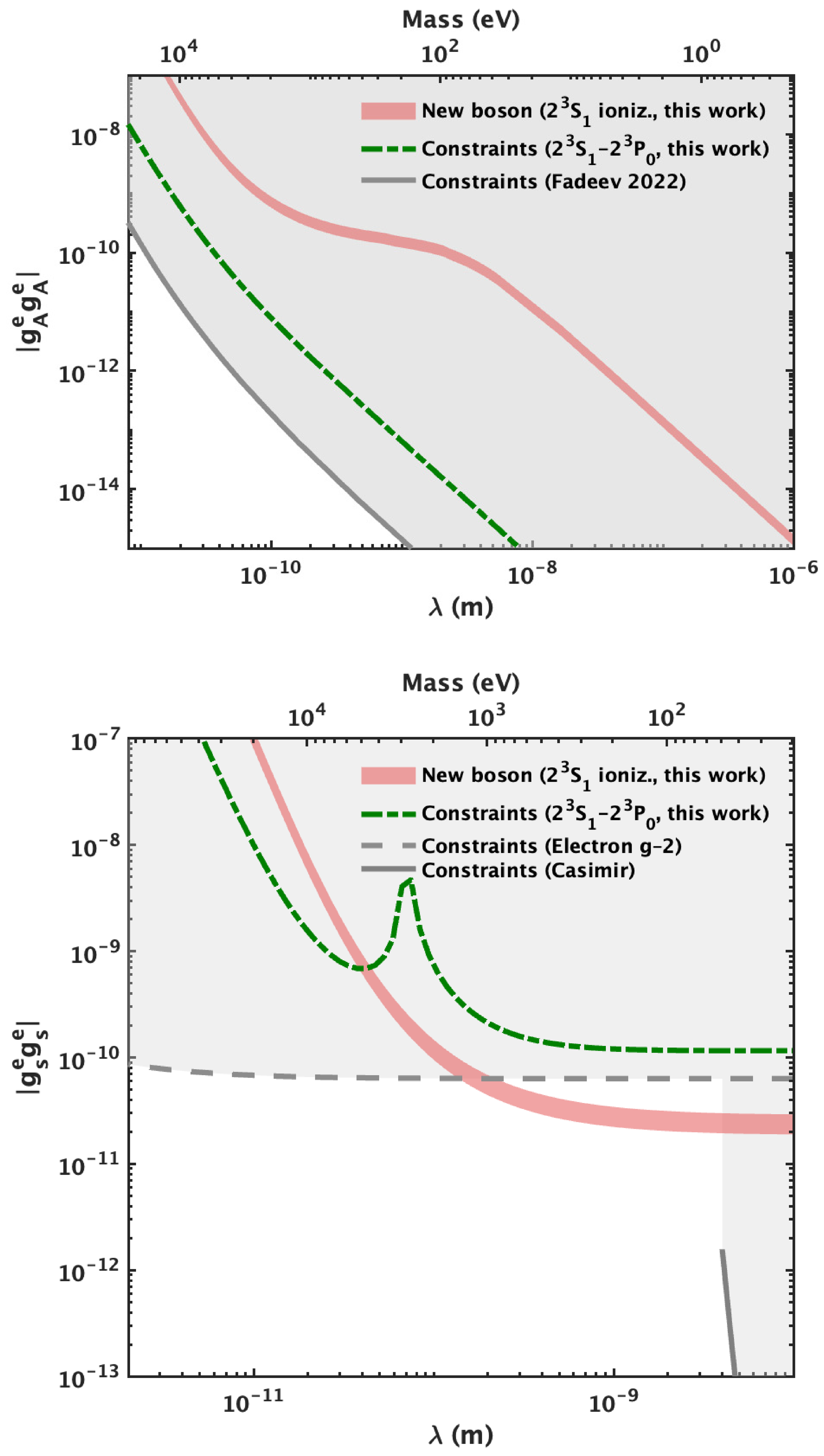

Figure 3: New-boson coupling inferred from the ^{4}He discrepancy (pink band), shown together with existing constraints (gray curves) and the new constraints obtained in this work (green dash-dotted curves) as a function of the new boson mass (M) (top axis) or interaction range λ (bottom axis).

References

[1] Gloria Clausen et al. *Phys. Rev. Lett.*, 134(22):223001, 2025.

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[3] Aaron T. Bondy. *Physics*, 18:110, 2025.

[4] Lei Cong et al. *Rev. Mod. Phys.*, 97(2):025005, 2025.

[5] Lei Cong et al. (arXiv:2602.09743), 2026.

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