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Broadband Search Strategies through Hybrid Spin Systems in the Quest for Axion Dark Matter

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Recent advances in tabletop quantum sensor technology have enabled searches for nongravitational interactions of DM. Traditional axion dark matter experiments rely on sharp resonance, resulting in extensive scanning time to cover the wide mass range. In contrast, our study (named ChangE) introduces a novel method of actively tuning alkali and noble gas spins to the same Larmor frequency, where we identify a strongly-coupled hybrid spin-resonance (HSR) regime that enhances the bandwidth of ^{21}Ne nuclear spin by three orders of magnitude while maintaining ultrahigh sensitivity. In combination with a self-compensating mode (SC) for low frequencies, we present a comprehensive broadband search for axion-like dark matter with Compton frequencies in the range of $[0.01, 1000]$\,Hz. We set new constraints on the DM interactions with neutrons and protons, accounting for the effects of DM stochasticity. For the axion-neutron coupling, our results reach a low value of $|g_{ann}| \leq 3 \times 10^{-10}$ in the frequency range $[0.02, 4]$\,Hz surpassing astrophysical limits and provide the strongest laboratory constraints in the $[10, 100]$\,Hz range. For the axion-proton coupling, we offer the best terrestrial constraints for the frequency $<$100\,Hz.

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