The magic of three levels: Robust quantum magnetometry at ultra low frequencies

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Neural currents produce weak magnetic fields prompting the idea that they can be measured non-invasively. It is desired to be able to do this with cellular resolution. Trapped ultracold atoms make highly sensitive magnetometers and good candidates for neurosensing due to their small size, of the order of a neuron, and their tunability to frequencies 300 Hz-3000 Hz where most of the neural signal power is concentrated. Spectrally-adjacent noise from power-lines dominates any neural signal. We exploit the quadratic Zeeman shift q, inherent to the three-level rubidium-87 ground state to create a highly robust quantum sensor. This is done by continuously dressing the system with rf radiation to induce Rabi flopping. If we do this at a precise ratio of the dressing amplitude Ω, with the quadratic Zeeman shift such that $q_R = \frac{q}{\Omega} \approx 0.348$ it will produce a two-level subspace that has fourth-order decoupling to detuning errors [1, 2]. Using this subspace we can measure signal amplitudes and frequencies in the presence of much stronger noise and thus detect a weak environmental signal of 5 nT at 525 Hz despite line noise 30 dB louder in a single shot using a weakly interacting continuous measurement.

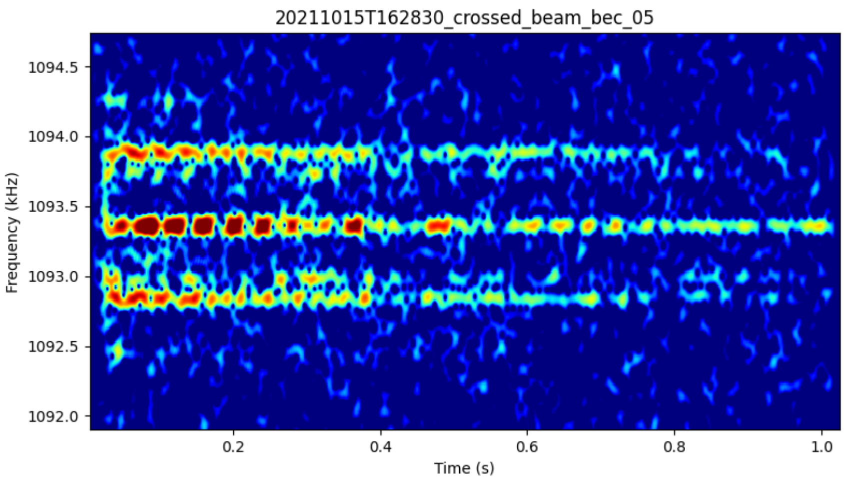

Figure 1: Spectrogram of a three-level dressed system, near the magic ratio. It contains five tones corresponding to the carrier frequency bordered by the dressed frequencies. The pulsing of the carrier frequency and the strongest dressed tone demonstrate Rabi flopping at the frequency of this dressed tone 525 Hz and amplitude of 25 Hz, corresponding to 5 nT.

[1] R. P. Anderson, M. J. Kewming, and L. D. Turner, *Physical Review A* **97**, 013408 (2018).

[2] D. Trypogeorgos, A. Valdés-Curiel, N. Lundblad, and I. B. Spielman, *Physical Review A* **97**, 013407 (2018).