Witnessing Quantum Correlations in a Nuclear Spin Ensemble via a Proxy Qubit

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A coherent ensemble of spins interfaced with a proxy qubit is an attractive platform to create many-body coherences and probe the regime of collective excitations. An electron spin qubit in a semiconductor quantum dot is a realisation of such an interface to a dense nuclear spin ensemble consisting of multiple high-spin species. In this work, we demonstrate a species-selective spin-state reconstruction of a nuclear ensemble that exploits its response to the electron-mediated injection of collective nuclear excitations [1,2]. Following optical preparation of a reduced-variance, polarised nuclear state [1,2], we probe the electron spin population as a function of the ESR detuning. Figure 1a displays two example ESR spectra for positive (top) and negative (bottom) mean nuclear polarisation. The difference of ESR Rabi frequencies $\Omega_{\pm}$, corresponding to nuclear resonances blue- and red-detuned from the ESR, is used to obtain information about nuclear populations. The sum over reconstructed species-resolved polarisations, expressed as an asymmetry-commensurate mean field, exceeds threefold the expected mean field for a classically correlated ensemble (Fig. 1b). This stark deviation follows from a spin ensemble that contains inter-particle coherences, and manifests the formation of a dark many-body state [3]. Honing further control over the nuclear-state coherences shown here offers a route to a quantum memory hosted in a low-polarisation decoherence-free subspace [3].

Figures

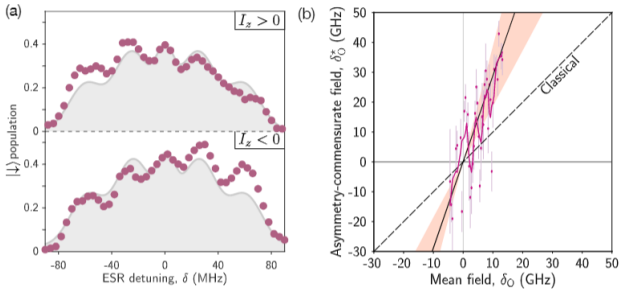

Figure 1 (**a**) Electron $|\downarrow\rangle$ population as a function of ESR detuning δ, following a 1-μs drive for positive (top) and negative (bottom) prepared Overhauser shifts. Grey curves are reference spectra at zero-polarisation ($I_z = 0$). (**b**) Derived asymmetry-commensurate Overhauser field versus Overhauser field setpoint. The solid black curve is a fit to the data with a slope of 2.9(1). The shaded coral region indicates the range of indium concentrations x = 0.25-0.75. The dashed line with a slope of 1 is the mean field that would be reconstructed for a classical nuclear state. Solid curve is the data passed through a first-order Savitzky-Golay filter with a 1.6-GHz window. Error bars indicate a 67% confidence interval.

References

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