Quantum Spectral Analysis by Landau-Zener Transitions

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Quantum spectrum analyzers promise enhanced sensitivity, resolution and noise decoupling, compared to time-domain sensing, by measuring directly in the frequency domain. To date, such analyzers have been filter banks with quantum sensors sampling fixed frequencies, arrayed in time [1] or space [2]. We present a swept-sine quantum spectrum analyzer implemented on a single preparation of an ultracold atomic ensemble qubit. Sweeping a single sensor across a band generates Landau-Zener (LZ) transitions as the sensing frequency crosses resonance with an external oscillatory field. Continuous Faraday measurement of the transverse spin [3] yields a rich time-series of characteristic LZ evolution. Retrieving the amplitude, frequency and phase of an external signal from this time-series proved to be a formidable inverse problem. Through Hilbert demodulation we perform quantum process tomography that can be represented as a Bloch sphere trajectory (Fig. 1). We then estimate signal parameters by regressing the solution of the time-dependent Schrödinger equation to the evolution of the state. Fig 1 shows successful retrieval of an LZ transition driven by a $\mathrm{B_s} = 3.4(9)\,\mathrm{nT}$ signal at $f_\mathrm{s} = 10.000(1)\,\mathrm{kHz}$, with the $\langle \hat{F}_\mathrm{z} \rangle$ fit in black retrieving parameters of $\mathrm{B_s} = 3.26(2)\,\mathrm{nT}$ and $f_\mathrm{s} = 10.0076(3)\,\mathrm{kHz}$, while phase has proven more difficult. Further developments of the protocol and analysis techniques will enable expansion to multi-frequency spectra.

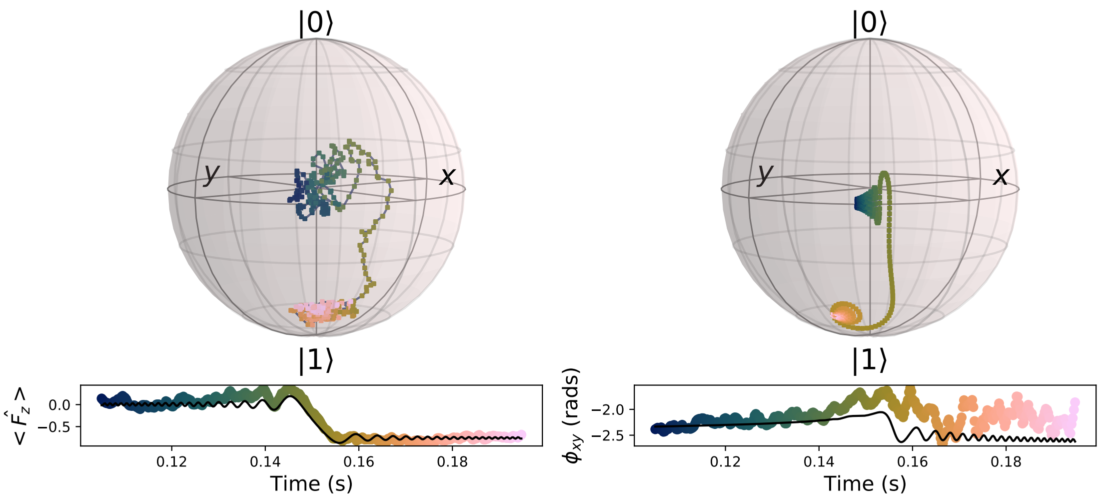

Figure 1: Bloch sphere representation, both processed data (L) and fit reconstruction (R), with projection traces for $\hat{F}_\mathrm{z}$ and equatorial angle ϕ_xy in a demodulated frame of reference.

[1] S. Schmitt et al., Science **356**, 832–837 (2017).

[2] H. Zhang et al., npj Quantum Inf. **3**, 1-8 (2017).

[3] M. Jasperse et al., Phys. Rev. A **96**, 063402 (2017).