Cross-Correlation Spin Noise Spectroscopy of Heterogeneous Interacting Spin Systems

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Introduction:

There are numerous natural and engineered systems in which interactions between "spins of different kind" lead to the emergence of new and interesting physics. Notable examples include the interaction between electron spins from different Bloch bands that gives rise to heavy-fermion behavior and Kondo-lattice effects in correlated-electron materials, the decoherence of solid-state electronic spin qubits by a nuclear spin bath, carrier-mediated ferromagnetism in diluted magnetic semiconductors, and spin-exchange pumping of noble gas nuclei for enhanced medical imaging. Measurements of inter-species spin interactions are therefore essential to our understanding of many magnetic and spin phenomena. Traditionally, they are studied by methods that are necessarily perturbative: *e.g.*, by intentionally polarizing or depolarizing one spin species while detecting the response of the other(s).

Experiment:

In this work, we describe and demonstrate an alternative approach based on multi-probe *spin noise spectroscopy*, which can reveal inter-species spin interactions - under conditions of strict thermal equilibrium - by detecting and cross-correlating the stochastic fluctuation signals exhibited by each of the constituent spin species [1]. Specifically, we consider a two-component spin ensemble that interacts via exchange coupling, and we determine *cross-correlations* between their intrinsic spin fluctuations.

The model is confirmed using "two-color" optical spin noise spectroscopy on a well-understood system of interacting spins: a mixture of interacting Rb and Cs vapors (Fig 1a). To independently probe the intrinsic spin fluctuations of the two spin species, we perform spin noise spectroscopy using two probe lasers that are, respectively, tuned near the fundamental D1 optical transitions of Rb and Cs (~795.0 nm and ~894.6nm). Spin fluctuations of Rb and Cs atoms impart Faraday rotation fluctuations on the probe beams, which co-propagate through the vapor cell and are subsequently separated and measured independently. Cross correlations between the two stochastic noise signals are computed in real time.

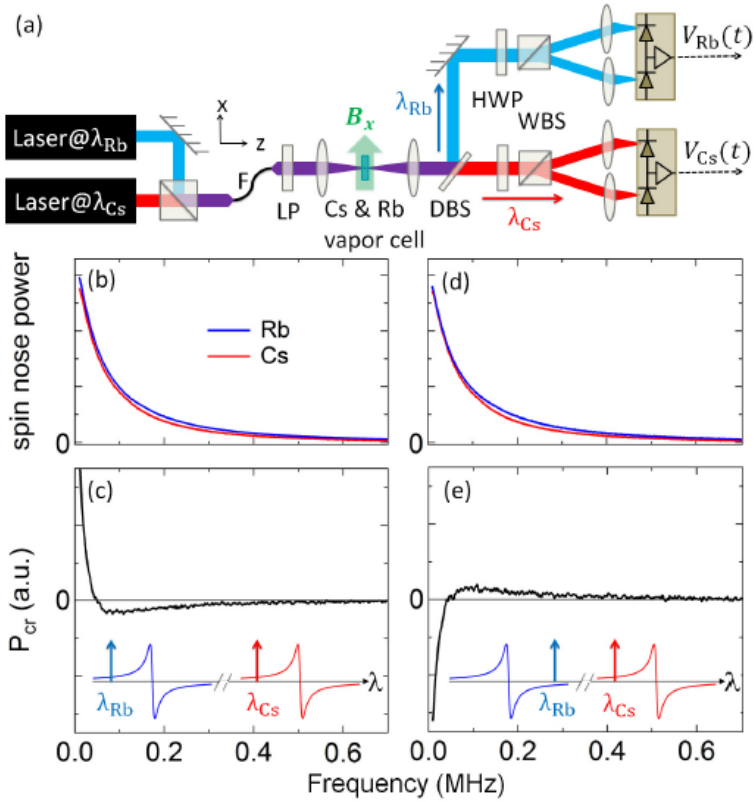

Fig.1 a) Schematic of the two-color spin noise experiment on a mixture of warm Rb and Cs alkali vapors. (b) Spin noise power for the two spin species. (c) the Rb/Cs noise cross-correlator, P_cr. Non-zero signals indicate the presence of spin interactions between Rb and Cs, which are revealed via the spin fluctuations alone.

Noise correlations directly reveal the presence of inter-species spin exchange, without ever perturbing the system away from thermal equilibrium (Figs 1b-e). These non-invasive and noise-based techniques should be generally applicable to any heterogeneous spin system in which the fluctuations of the constituent components are detectable.

Acknowledgement:
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References:

[1] D. Roy, L. Yang, S.A. Crooker & N.A. Sinitsyn, *submitted, arXiv :1408.5399*