Collective behavior hallmarks in dense rubidium vapor spin noise spectra

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In magnetic systems, the spectroscopy of fundamental noise due to random spin fluctuations, called spin noise spectroscopy (SNS), can be optically performed by measuring the associated fluctuations of the Faraday-like rotation experienced by a linearly polarized probe beam propagating through the sample [1,2]. Using a thin 1 mm cell, we report anomalous features in the spin noise (SN) spectra of a dense vapor of rubidium (Rb) atoms: at high densities, we observe dramatic changes of the spin noise spectra (see Fig. 1), which we attribute to interactions arising between particles in the system. Indeed, one can notice a drastic increase of the linewidth of SN peaks for densities higher than 10^{14} at.cm^{-3}, which cannot be explained by transit decoherence and spin-exchange collisions. In the figure on the right, dashed and dash-dotted lines represent the expected values of the peaks half-widths at half maximum due to these mechanisms: the shaded area thus represent the additional broadening that cannot be explained by usual single-spin dynamics. With the help of a two-body model and simulations, we show that these features are in fact the hallmark of a strong and long-range dipole-dipole interaction within the ensemble. Furthermore, the additional low-frequency noise reveals the correlated evolution of pair of atoms beyond the impact approximation, opening the way for the characterization of many-body spin noise, atomic entanglement or higher order spin correlators in atomic vapors using SNS.

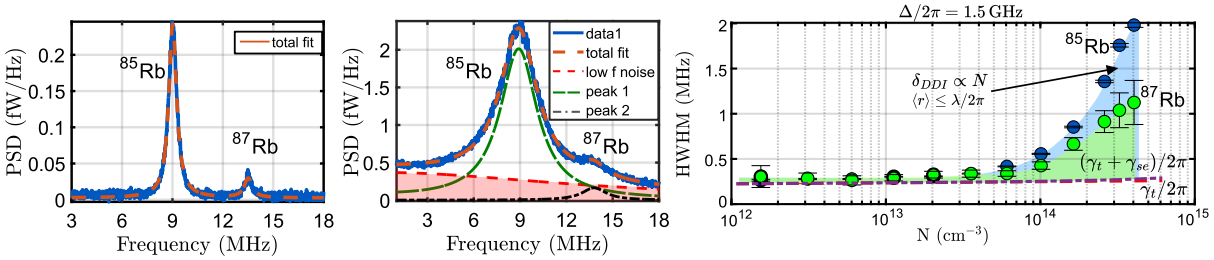

Figure 1. On the left, experimental SN spectra of rubidium obtained at a temperature $T = 90$ C: it exhibits the usual resonances due to both isotopes ^{95}Rb and ^{97}Rb. In the center, SN spectra obtained for $T = 175$ C, corresponding to a larger atomic density by more than 2 order of magnitude: they are much broader and a tail appears at low frequencies. On the right, evolution of SN peak half-widths at half maximum for both isotopes as a function of the Rb vapor density: shaded area represent the excess of broadening, compared to values expected from single spin dynamics simulations.

[1] E. B. Aleksandrov and V. S. Zapasskii, Magnetic resonance in the Faraday-rotation noise spectrum, JETP, **54**, 64 (1981).

[2] N. A. Sinitsyn and Y. V. Pershin, The theory of spin noise spectroscopy: a review, Rep. Prog. Phys. **79**, 106501 (2016).