Continuous protection from inhomogeneous dephasing

R. Finkelstein[1], O. Lahad[1], I. Cohen[2], O. Davidson[1], S. Kiriati[1], E. Poem[1], O. Firstenberg[1]

[1] Weizmann Institute of Science, Israel, [2] Aarhus University, Aarhus, Denmark

We introduce a scheme for protecting a qubit from inhomogeneous dephasing, and we demonstrate it by eliminating the motional dephasing of a spin wave stored on hot vapor atoms. The scheme relies on continuously dressing the qubit with an auxiliary state, which exhibits an opposite and potentially enhanced sensitivity to the same source of inhomogeneity. By employing a pair of driving fields, we increase the protection range, circumvent qubit phase rotation, and obtain robustness to drive noise, similarly to the double-dressing technique in continuous dynamical decoupling. We outline the minimal and optimal conditions for protection.

As an experimental case study, we focus on motional dephasing of a spin wave in an atomic ensemble. We employ light storage and retrieval for quantifying the coherence time, which without protection is limited by the ballistic atomic motion at random velocities along the spin wave [1]. When applying the protection scheme, the effect of the drive field can be understood as a velocity-dependent light shift, maintaining the correlations between position and phase of the spin wave. We demonstrate complete suppression of the inhomogeneous dephasing [2]. The spectroscopic manifestation of the continuous protection is the substantial enhancement and narrowing of spectral lines [3,4]. Our scheme is applicable to various gas, solid, and engineered systems suffering from dephasing due to variations of conditions in time, space, or other domains.

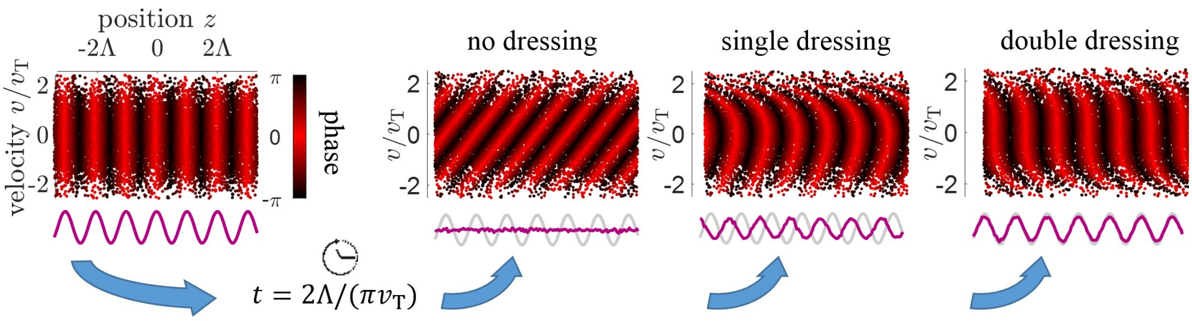

Figure 1: **Motional dephasing and protection of a spin wave.** Position-velocity representation of a collective excitation (spin wave), generated, *e.g.*, by light storage in a two-photon bi-chromatic transition. The collective state has a spatially-dependent phase with a wavelength Λ (left). Thermal atomic motion results in decoherence of the collective state. In the presence of dressing fields, atoms with different velocities experience different light shifts, and the spatial coherence is maintained over a certain velocity range.

[1] R. Finkelstein, E. Poem, O. Michel, O. Lahad, and O. Firstenberg, "Fast, noise-free memory for photon synchronization at room temperature", *Science Advances* 4 (2018).
[2] R. Finkelstein, O. Lahad, I. Cohen, O. Davidson, E. Poem, and O. Firstenberg, "Continuous protection of a collective state from inhomogeneous dephasing", *Physical Review X* 11 (2021).
[3] O. Lahad, R. Finkelstein, O. Davidson, O. Michel, E. Poem, and O. Firstenberg, "Recovering the homogeneous absorption of inhomogeneous media", *Physical Review Letters* 123 (2019).
[4] R. Finkelstein, O. Lahad, O. Michel, O. Davidson, E. Poem, O. Firstenberg, "Power narrowing: Counteracting Doppler broadening in two-color transitions", *NJP* 21 (2019).