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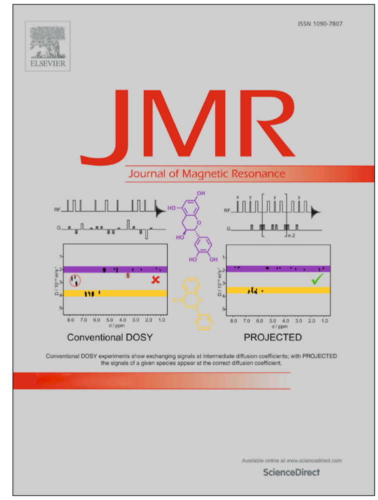

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Evolution of multiple quantum coherences with scaled dipolar Hamiltonian

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Abstract

In this article, we introduce a pulse sequence which allows the monitoring of multiple quantum coherences distribution of correlated spin states developed with scaled dipolar Hamiltonian. The pulse sequence is a modification of our previous Proportionally Refocused Loschmidt echo (PRL echo) with phase increment, in order to verify the accuracy of the weighted coherent quantum dynamics. The experiments were carried out with different scaling factors to analyze the evolution of the total magnetization, the time dependence of the multiple quantum coherence orders, and the development of correlated spins clusters. In all cases, a strong dependence between the evolution rate and the weighting factor is observed. Remarkably, all the curves appeared overlapped in a single trend when plotted against the self-time, a new time scale that includes the scaling factor into the evolution time. In other words, the spin system displayed always the *same quantum evolution*, slowed down as the scaling factor decreases, confirming the high performance of the new pulse sequence.

Keywords:

1. Introduction

Over the years, Nuclear magnetic Resonance (NMR) proved to be a powerful tool in observing and controlling many-interacting spin systems [1]. The possibility of generating new effective Hamiltonians, based on the Average Hamiltonian Theory (AVT) [2], by concatenating radiofrequency (r.f.) pulses with free evolution periods has been used in decades of research. This fact opened an ample field of possibilities to perform quantum control and explore evolutions in complex systems [3].

NMR has been extensively used in studies based on the observation of the main features of coherent and decoherent non equilibrium quantum phenomena in many-body systems [4–9]. The interaction of the many body quantum system with the environment and non-controlled degrees of freedom results in the loss of coherence, which plays an important role in the emergence of classicality.

Quantum coherences contain information on the many-body state of correlated spins. Coherences are commonly the starting points to tackle diverse problems in theoretical and experimental physics, including cold atoms [10], nitrogen vacancy in diamonds [11], quantum thermodynamics [12–14], quantum biology [15], quantum entanglement, discord and information theory [16–19], as a part of an unavoidably incomplete list.

In the context of NMR, the detailed observation of the collective spin states can be performed experimentally by the generation, detection and analysis of quantum coherences. These multiple quantum coherences (MQCs) are quantified through the intensities of density matrix elements involving quantum transitions of a given order [20–22]. In addition, further information can be extracted from the MQC distribution: the number of correlated spins achieved through the *forward* evolution, widely known as spin counting [23–27].

Decoherence phenomena in NMR can be quantified through the Loschmidt echo (LE) [24, 27, 28]. Briefly, the LE measures how much of an initial state is recovered after a time reversal procedure [29]. As the LE is directly affected by experimental imperfections and interactions with an uncontrollable environment, it constitutes a direct test for the robustness or fragility of quantum or classical evolution [30]. Indeed, the behaviour of LE in some complex systems has suggested that decoherence is driven by the coherent dynamics given by the dipolar interactions between spins [27]. In NMR, both,

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