Dephasing-tolerant quantum sensing for transverse magnetic fields with spin qudits

Luca Lepori[1,2,3], **Matteo Mezzadri**[1,2,3], **Alessandro Chiesa**[1,2,3], **Stefano Carretta**[1,2,3]

1. Dipartimento di Scienze Matematiche, Fisiche e Informatiche, Università di Parma, I-43124 Parma, Italy.

2. Gruppo Collegato di Parma, INFN-Sezione Milano-Bicocca, I-43124 Parma, Italy.

3. UdR Parma, INSTM, I-43124 Parma, Italy.

Abstract: We propose a dephasing-tolerant protocol for quantum sensing of magnetic fields, exploiting spin qudits and with embedded quantum error-correction.
Numerical simulations show the precision of the method, well beyond the limits from the coherence time.

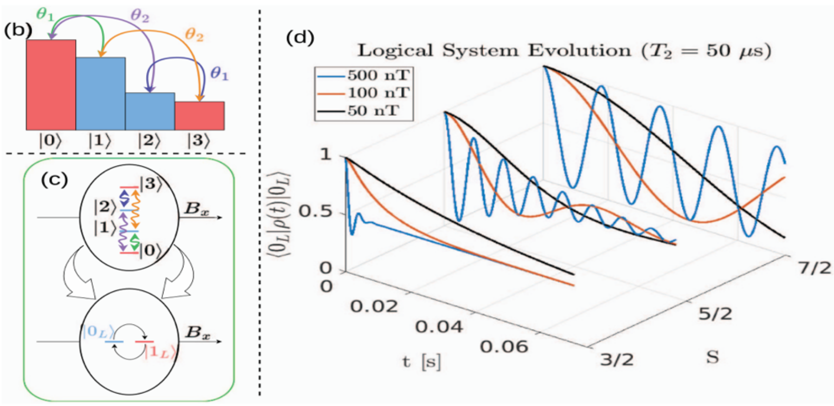
Quantum sensing exploits intrinsically quantum properties such as superposition and entanglement to estimate unknown quantities with sensitivities impossible for classical meters, with possible applications in pure and applied research and in industries [1,2]. Moreover, thanks to their nanoscale dimensions, quantum sensors such as atoms and molecules often permit a much higher spatial resolution.

In recent years, proposals emerged, potentially bringing the sensor sensitivity even well below the limit caused by the true coherence time. The idea is to use ad hoc quantum error correction (QEC) techniques to increase the coherence of the system during a sensing protocol. However, this idea carries on some crucial issues which must be taken into account.

Here, we propose a protocol for quantum sensing of transverse magnetic fields not limited by T2, in which the sensor is a multi-level spin qudit working as a logical qubit (LQ) with embedded fault-tolerant (FT) quantum error-correction [3]. In the protocol, the transverse Bx induces a FT logical Rabi oscillation between error-protected states, by exploiting a multi-frequency longitudinal drive. Thus, QEC does not correct the evolution induced by Bx, allowing for an effective detection. Remarkably, the corresponding logical Rabi frequency is monotonic and mostly linear in Bx.

A prototypical realization of the spin qudit sensor is represented by molecular nanomagnets (MNMs) [4].

We demonstrate the high sensitivity achieved by our protocol via complete numerical simulations, including decoherence and the sequence of pulses required for sensing and error correction.



References

[1] C. L. Degen, F. Reinhard, and P. Cappellaro, "Quantum sensing", Rev. Mod. Phys. **89**, 035002 (2017).
[2] L. Pezze, A. Smerzi, M. K. Oberthaler, R. Schmied, and P. Treutlein, "Quantum metrology with nonclassical states of atomic ensembles", Rev. Mod. Phys. **90**, 035005 (2018).
[3] M. Mezzadri, L. Lepori, A. Chiesa, and S. Carretta, "Dephasing-tolerant quantum sensing for transverse magnetic fields with spin qudits", Quant. Sc. and Tech. **10** 015045 (2025).
[4] A. Chiesa, P. Santini, E. Garlatti, F. Luis, and S. Carretta, "Molecular nanomagnets: a viable path toward quantum information processing ?", Rep. Progr. Phys. **87** (3), 034501 (2024).