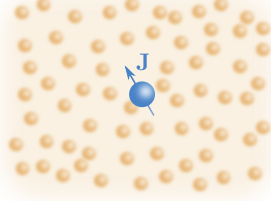


## Motivations

- How does the decoherence rate scale with the spin number  $j$  ?
- Which states are more prone to (super)decoherence ?
- How fast does non-classicality of a spin state fade over time ?



## Depolarisation master equation

### Master equation

$$\dot{\rho}(t) = \frac{i}{\hbar}[\rho(t), H] + \sum_{\alpha=x,y,z} \mathcal{D}_{\alpha}[\rho(t)]$$

$$H = \hbar\omega J_z \quad \mathcal{D}_{\alpha}[\rho] = \gamma_{\alpha} (2J_{\alpha}\rho J_{\alpha} - J_{\alpha}^2\rho - \rho J_{\alpha}^2)$$

For two non-zero decay rates  $\gamma_{\alpha}$ , the purity  $R = \text{Tr}(\rho^2)$  of the state decreases monotonically and the unique stationary state is the maximally mixed state with minimal purity.

### Isotropic depolarisation

$$\gamma_x = \gamma_y = \gamma_z$$

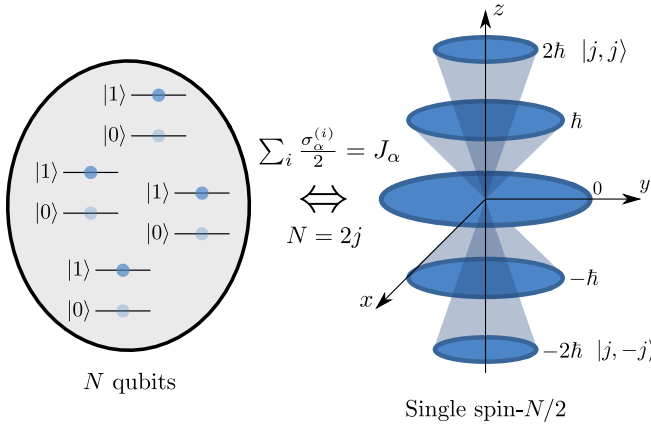
Noisy magnetic field

### Anisotropic depolarisation

$$\gamma_x = \gamma_y \neq \gamma_z$$

High temperature bath

There exists an isomorphism between the Hilbert space of a single spin system and the symmetric subspace of an ensemble of qubits (spin-1/2). Example :  $|W\rangle = |j, -j + 1\rangle$



## Anticoherent spin states

An anticoherent state<sup>1</sup> to order  $q$  is an isotropic state for which the moments of  $\mathbf{J} \cdot \mathbf{n}$  up to order  $q$  are independent of the direction  $\mathbf{n}$ , i.e.

$$\text{Tr}[\rho(\mathbf{J} \cdot \mathbf{n})^q] \neq f(\mathbf{n})$$

### Anticoherence measure to order 1

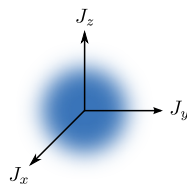
$$\mathcal{A}_1 = 1 - \frac{1}{j^2} |\langle \psi | \mathbf{J} | \psi \rangle|^2$$

### Anticoherent states to order 1

$$|\text{GHZ}\rangle = \frac{1}{\sqrt{2}} (|j, j\rangle + |j, -j\rangle) \quad |\text{DB}\rangle = |j, 0\rangle$$

### Highest-Order Anticoherent Pure (HOAP) state :

Pure anticoherent spin state with the highest  $q$  for a given  $j$ .



## Isotropic depolarisation

**Observation 1 :** HOAP states are the most superdecoherent states. They lead to the minimal purity at any time.

**Observation 2 :** For pure states, the purity loss rate depends only on the anticoherence measure to order 1 :

$$\dot{R}_{|\psi_0\rangle} = -2\gamma \left( N + \frac{N^2}{2} \mathcal{A}_1 \right)$$

Under isotropic depolarisation ( $\gamma_{\alpha} \equiv \gamma, \forall \alpha$ ) the purity loss rate can be written in terms of the purities of the state  $\rho$  and its  $N-1$  reduced density matrix  $\rho_{N-1}$ .

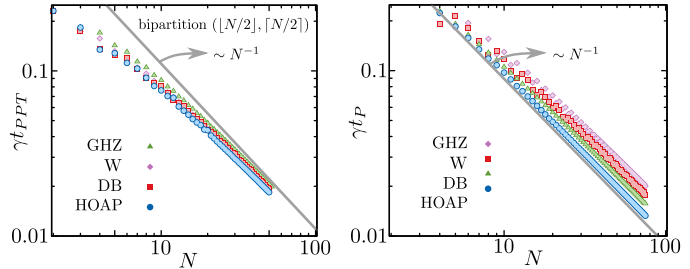
$$\dot{R}(\rho) = -2\gamma R(\rho)N - 2\gamma [R(\rho) - R(\rho_{N-1})]N^2$$

Any separable state necessarily verifies  $R(\rho) < R(\rho_{N-1})$ .

**Observation 3 :** Superdecoherence (purity loss rate scaling as  $N^2$ ) cannot occur without entanglement.

In order to study the entanglement decay, we define two times :

- $t_{PPT}$  : time at which the PPT criterion (necessary condition of separability) is fulfilled.
- $t_P$  : time at which the P-function<sup>2</sup> of the state becomes everywhere positive (sufficient condition of separability).



**Observation 4 :** The time at which the entanglement of an initial pure state is lost due to depolarisation scales as  $N^{-1}$ .

## Anisotropic depolarisation

The purity loss rate for pure states is directly related to the variances of the spin components.

$$\dot{R}_{|\psi_0\rangle} = -4 [\gamma_z \Delta J_z^2 + \gamma_{\perp z} (\Delta J_x^2 + \Delta J_y^2)]$$

**Observation 5 :** An appropriate squeezing of the initial state can reduce decoherence on short time scales.

## Perspectives

- Conditions of superdecoherence for anisotropic depolarisation
- Experimental investigation of large spin depolarisation (e.g. with Dysprosium<sup>3</sup>).
- Usefulness of anticoherent states for quantum sensing<sup>4</sup> or quantum cryptography

### References

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4. F. Gebia *et al.*, Phys. Rev. A 101, 032112 (2020).