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Quantum probing of ultracold gases

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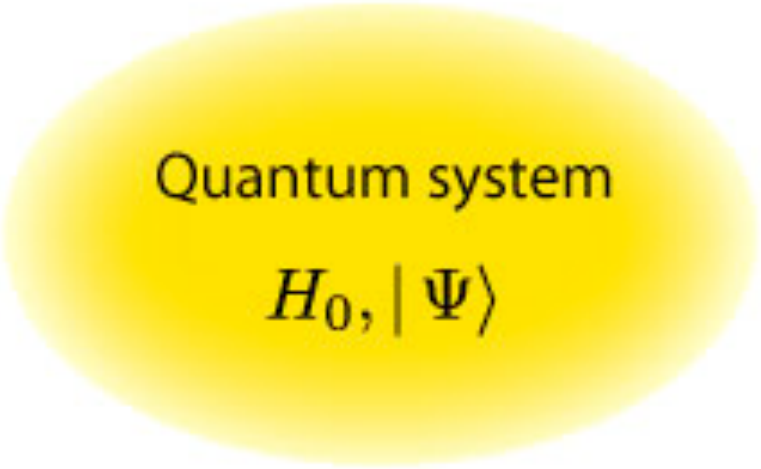
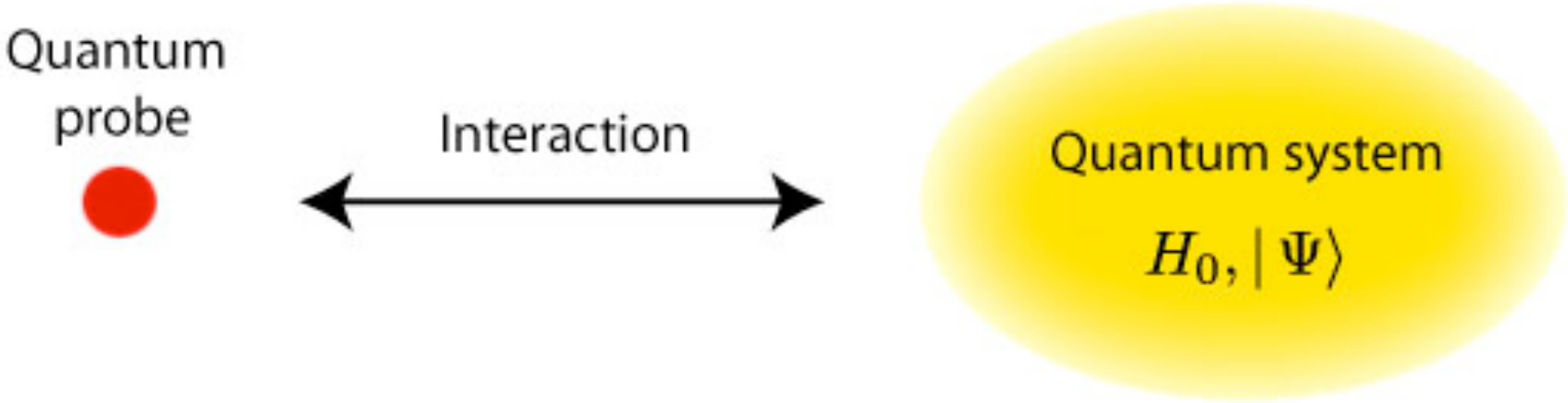
Part II – Quantum probing of ultracold gases

A quantum probe

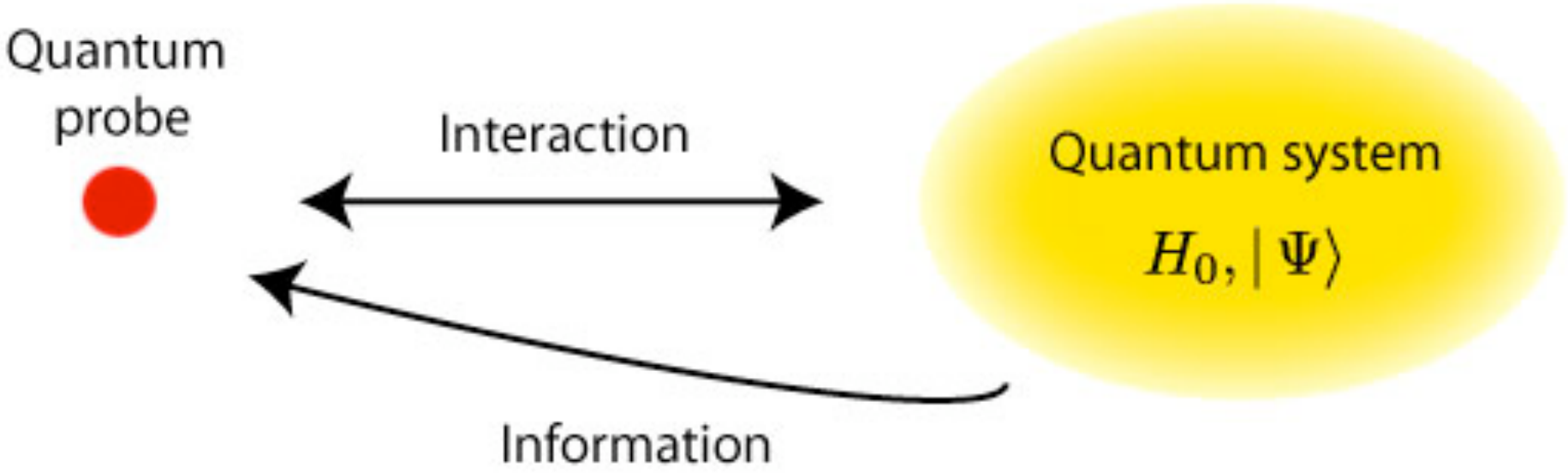


A quantum probe

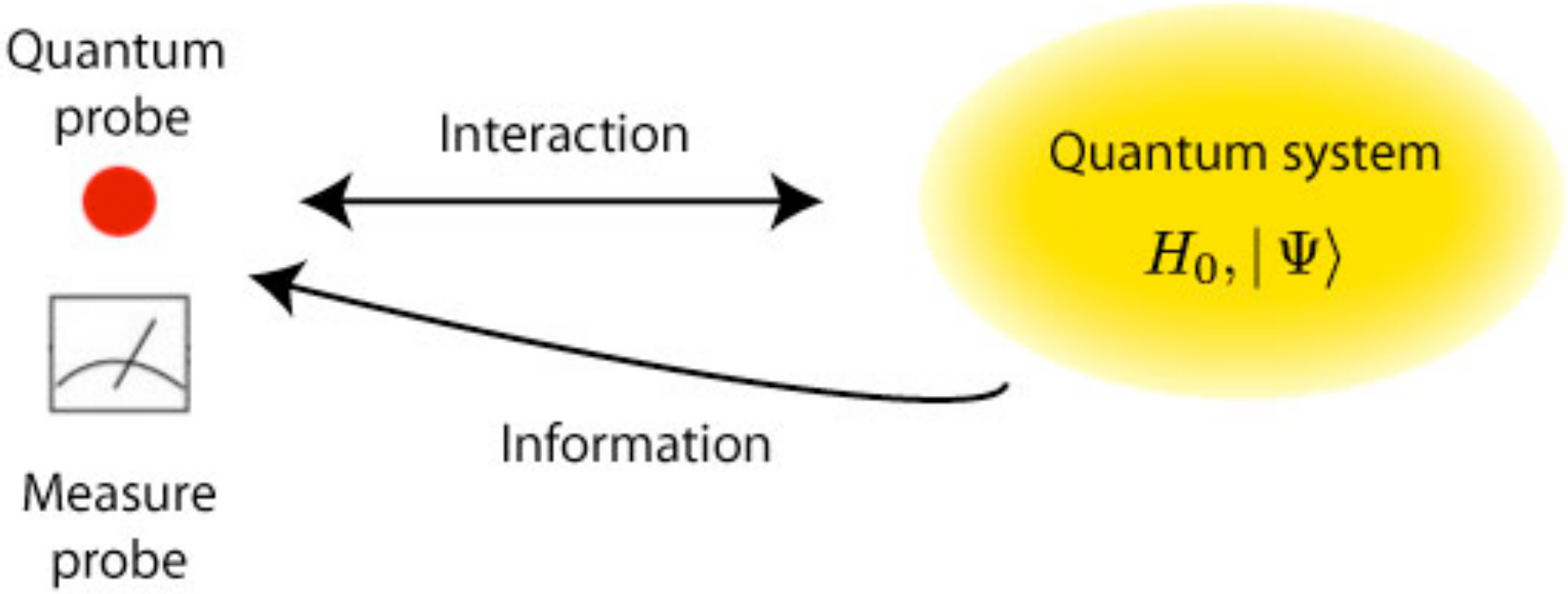
A quantum probe



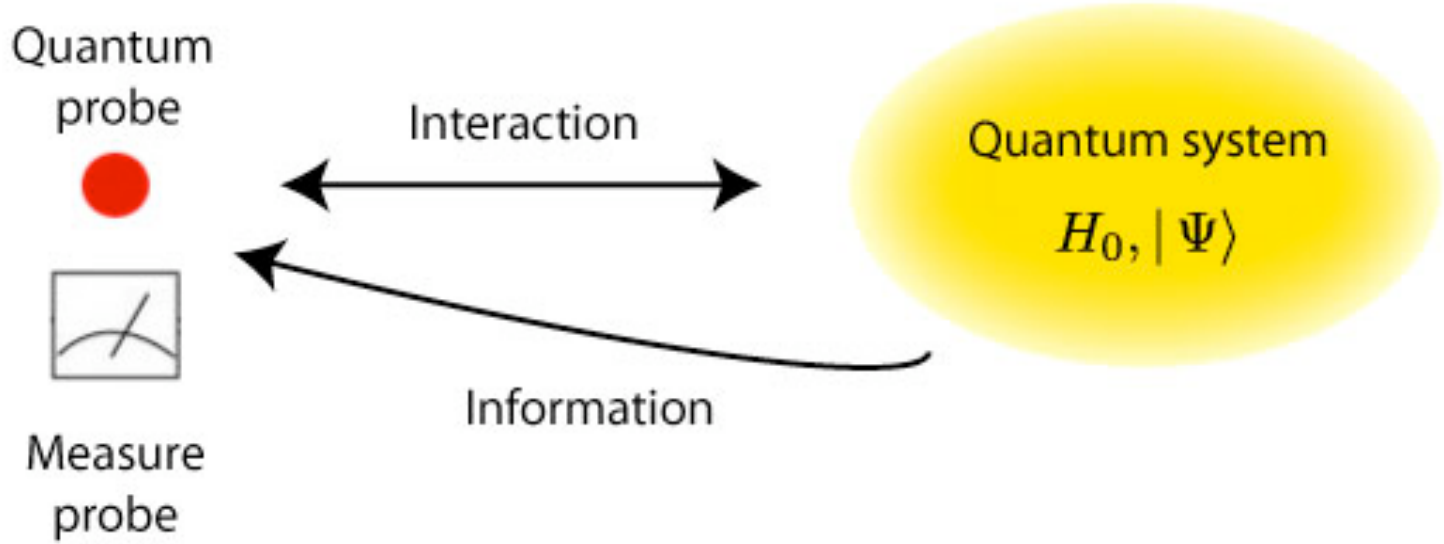
A quantum probe



A quantum probe



Why a quantum probe?



- Exploit superposition, interference and entanglement
- Study non-equilibrium properties
- Non-destructive measurements

What it's not: linear response

- Apply a weak classical field coupled to B

$$H = H_0 - F(t)B$$

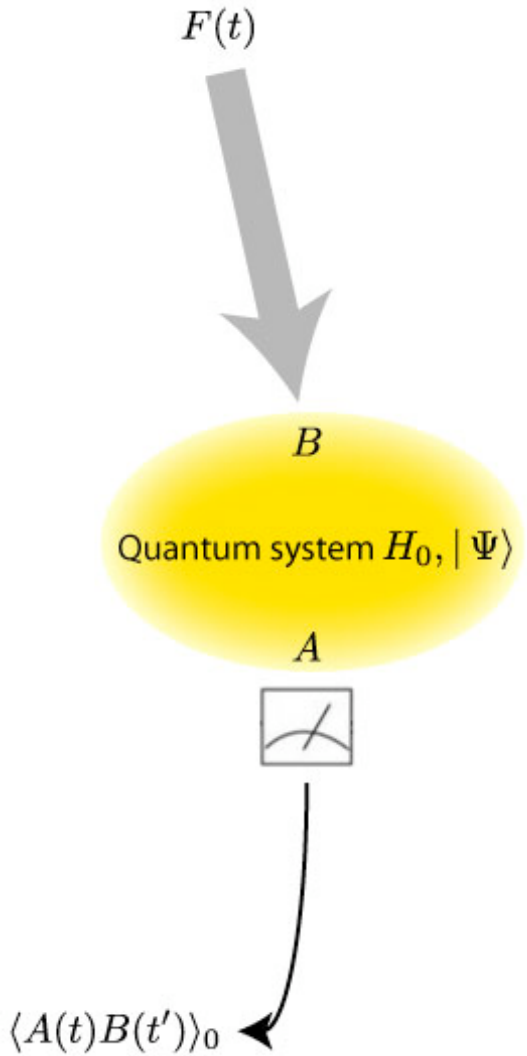
- Measure A

$$\langle A(t)\rangle = \langle A\rangle_0 + \int_{-\infty}^{\infty} \mathrm{d}t' \chi_{AB}(t-t')F(t')$$

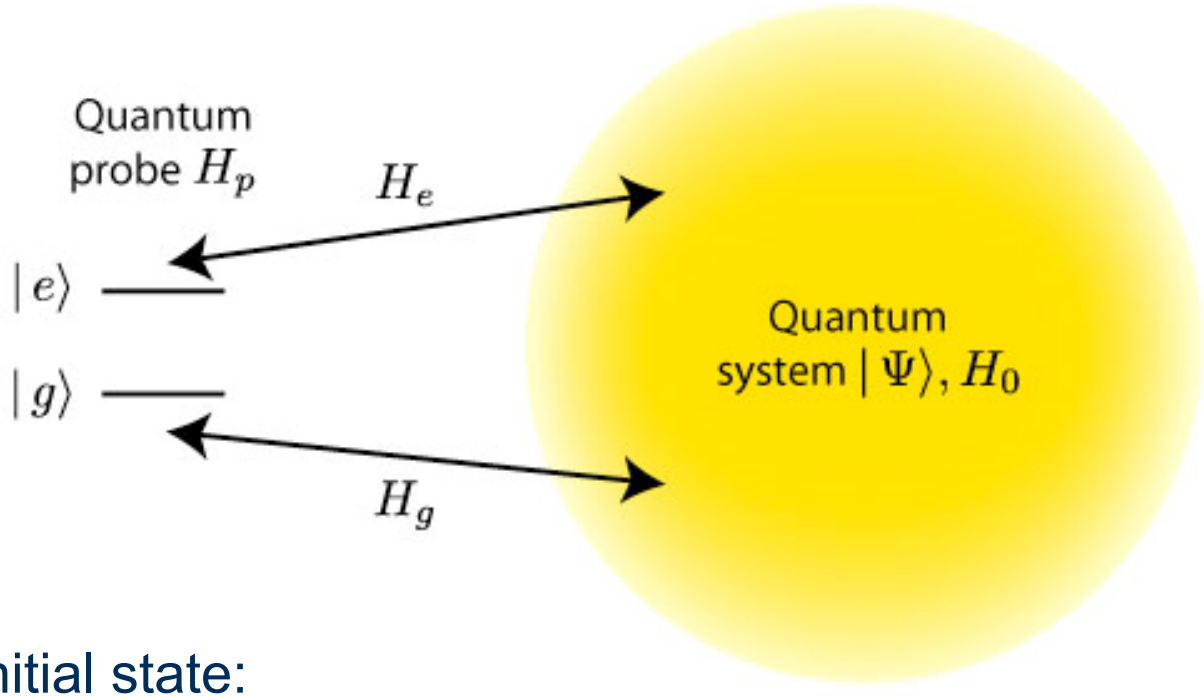
- Probe equilibrium correlation functions

$$\chi_{AB}(t-t') = \frac{\mathrm{i}}{\hbar}\theta(t-t')\langle[A(t), B(t')]\rangle_0$$

$$\langle A(t)B(t')\rangle_0 = \langle\psi\,|A\mathrm{e}^{-\mathrm{i}H_0(t-t')/\hbar}B|\,\Psi\rangle$$



Starting point: two level probe



- Probe initial state:

$$|\psi_p\rangle = c_g|g\rangle + c_e|e\rangle$$

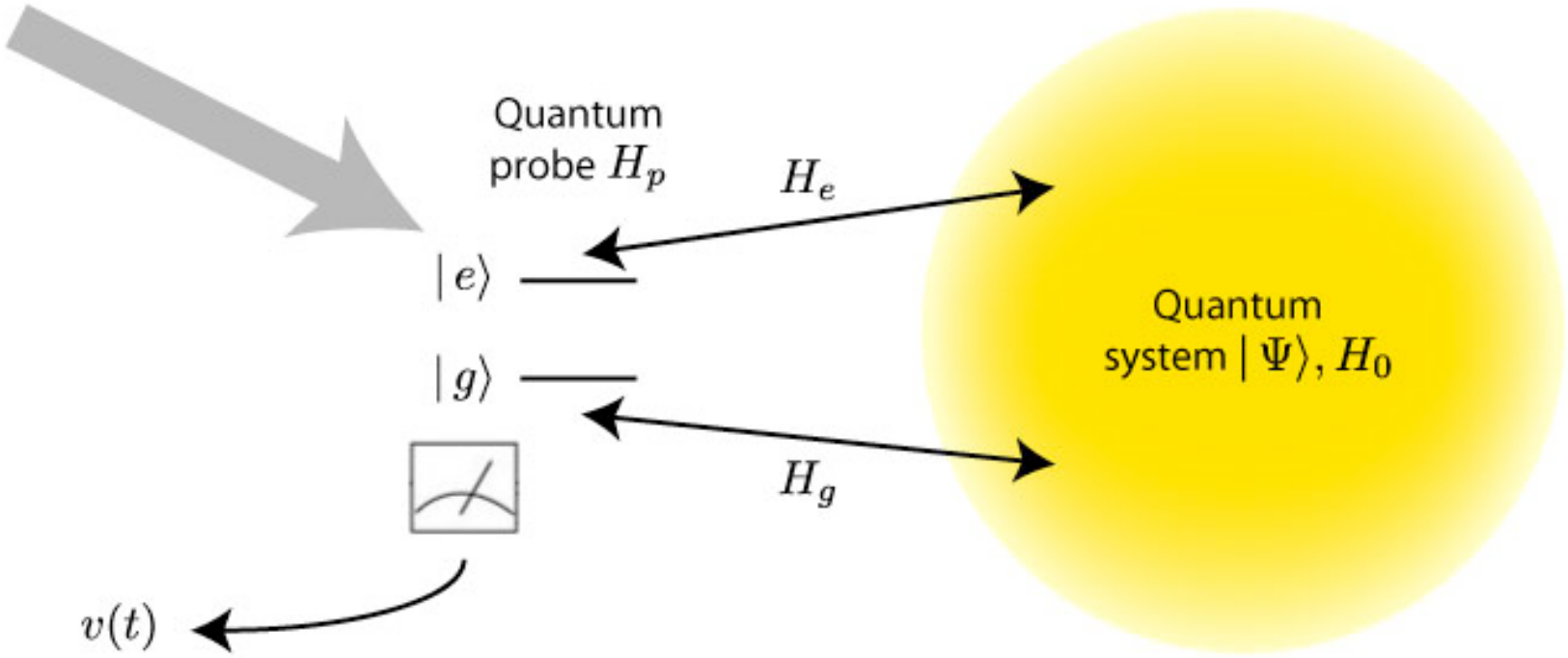
- Probe final state:

$$\rho_p = \begin{pmatrix} |c_g|^2 & c_g c_e^* v^*(t) \\ c_g^* c_e v(t) & |c_e|^2 \end{pmatrix}$$

- Loschmidt echo

$$v(t) = \langle\Psi|\mathrm{e}^{\mathrm{i}(H_0+H_g)t/\hbar}\mathrm{e}^{-\mathrm{i}(H_0+H_e)t/\hbar}|\Psi\rangle$$

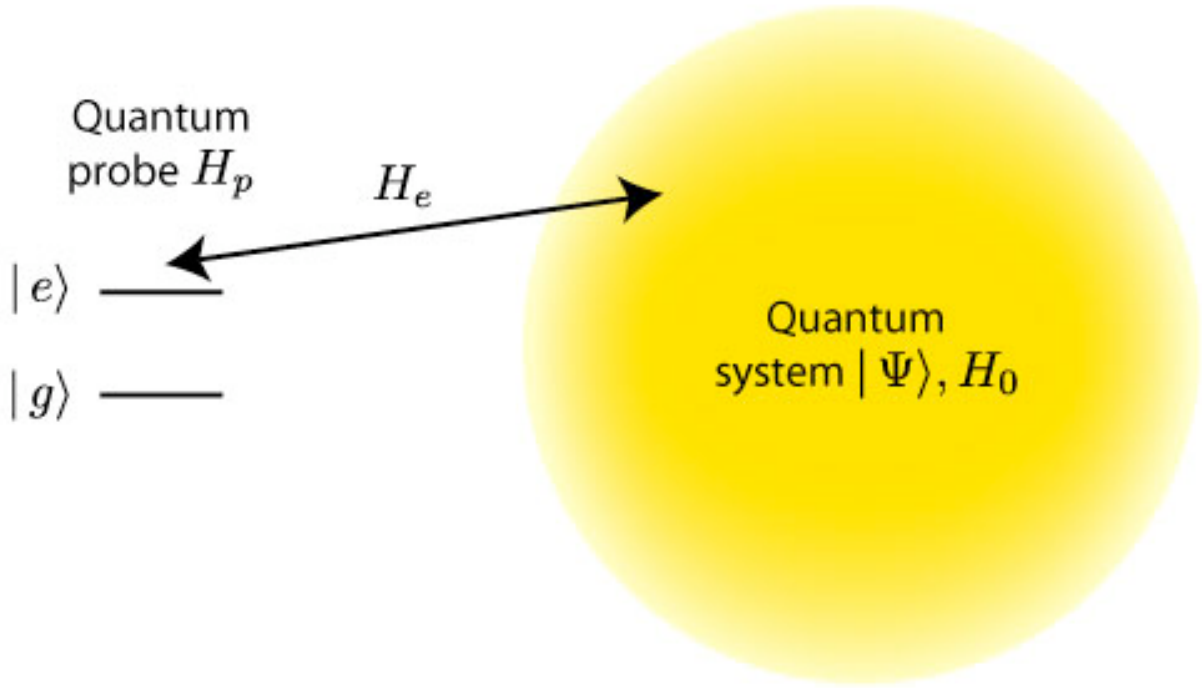
Ramsey interferometry



- Ramsey procedure

$$P_g(t,\phi) = [1 + \cos(\phi)\Re[v(t)] - \sin(\phi)\Im[v(t)]/2$$

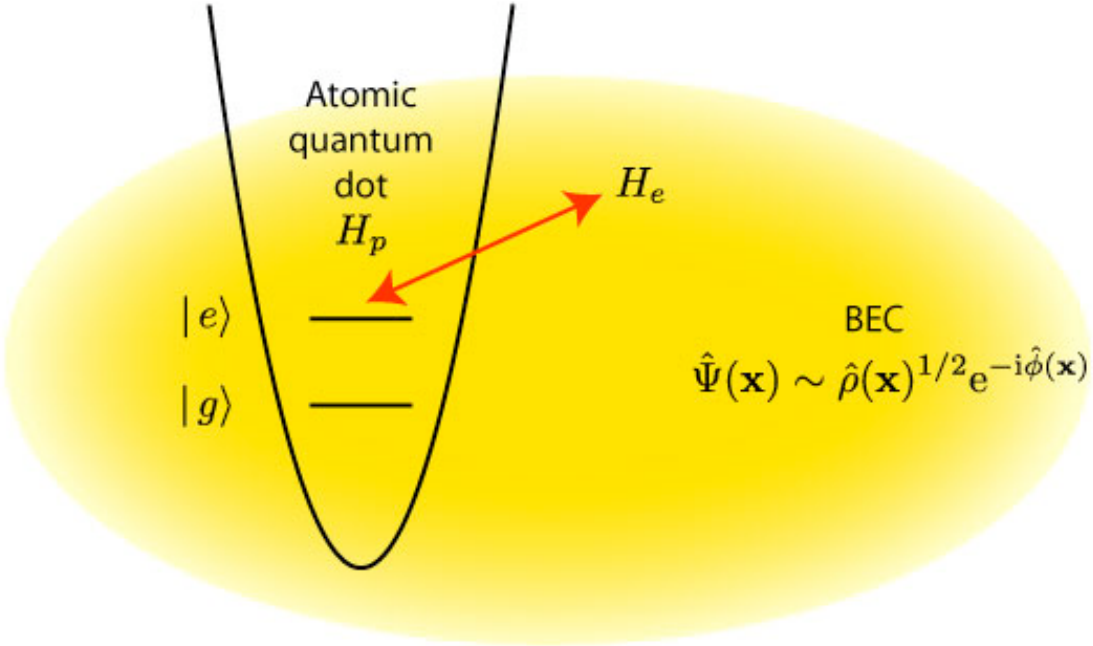
Example 1: spectrum



- Loschmidt echo can contain spectrum of H_0

$$v(t) = \langle \Psi | \mathrm{e}^{\mathrm{i}H_0 t/\hbar} \mathrm{e}^{-\mathrm{i}(H_0+H_e)t/\hbar} | \Psi \rangle$$
$$= \sum_n |\langle n | \Psi \rangle|^2 \mathrm{e}^{\mathrm{i}(E_n - E_\Psi)t/\hbar}$$

Example 2; AQD and BEC



- AQD coherences give phase fluctuations

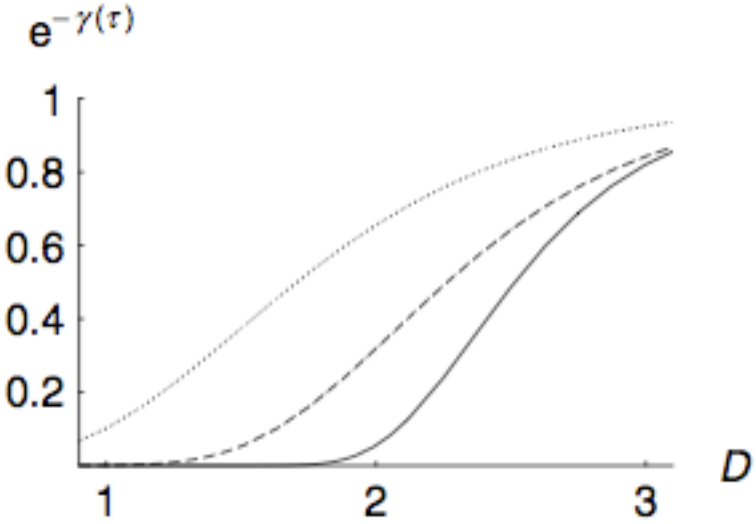
$$v(t) = \exp\left[-\frac{1}{2}\langle(\delta\hat{\phi}_\sigma)^2(\mathbf{x}_0, t)\rangle\right]$$

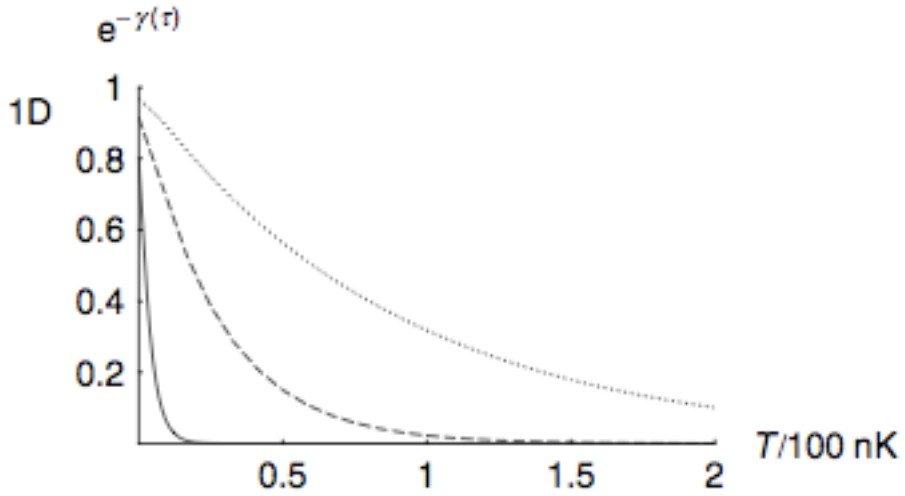
$$\delta\hat{\phi}_\sigma(\mathbf{x}_0, t) = \hat{\phi}_\sigma(\mathbf{x}_0, t) - \hat{\phi}_\sigma(\mathbf{x}_0, 0)$$

Bruderer et al. New. J. Phys. **8**, 87 (2006)

Example 2; AQD and BEC

- Extract effective dimension and temperature





Bruderer et al. New. J. Phys. **8**, 87 (2006)

Other examples

- Extracting the Luttinger parameter
  Recati et al., Phys. Rev. Lett. 94, 040404 (2005).

- Observing orthogonality catastrophe in a Fermi gas
  Goold et al., Phys. Rev. A 84, 063632 (2011).

- Gaps and bandwidth of spectrum
  Johnson et al., Phys. Rev. A 84, 023617 (2011).

Future questions

- Are there generalities to be made beyond individual examples?
- How easy is it to implement a quantum probe experimentally?
- Can we use quantum probes to characterise unknown environments?

- Multiple AQDs, entangled over long distances, with a Bose lattice gas environment.
- Simulated using tensor network theory.

Thank you

Oxford Physics

Questions?

CQT

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