Storage of entangled telecom-wavelength photons in an Er-doped optical fiber

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QC2 Lab

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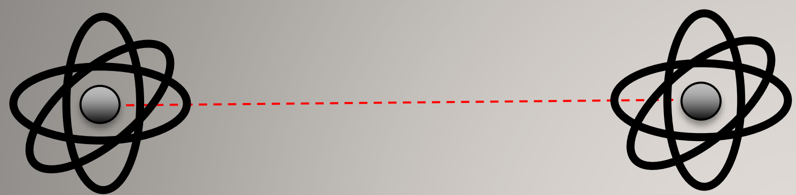
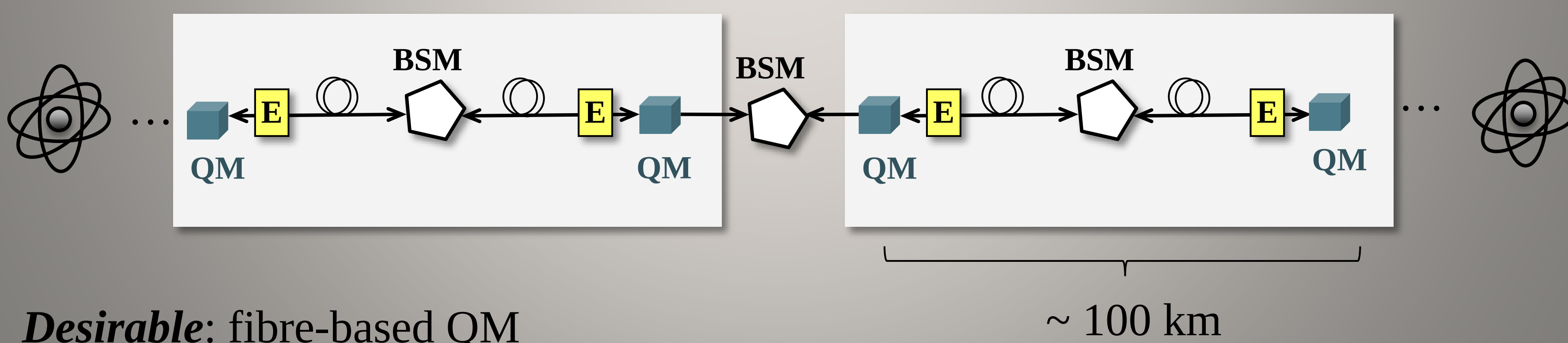


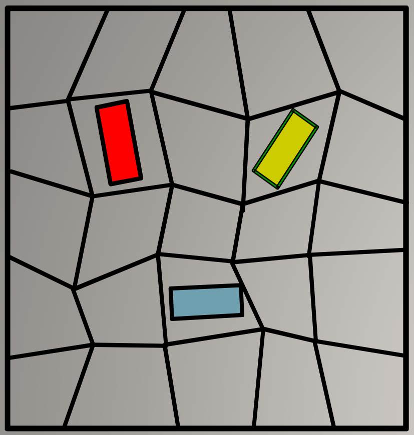
Problem: amplification (ER-doped fibres) impossible

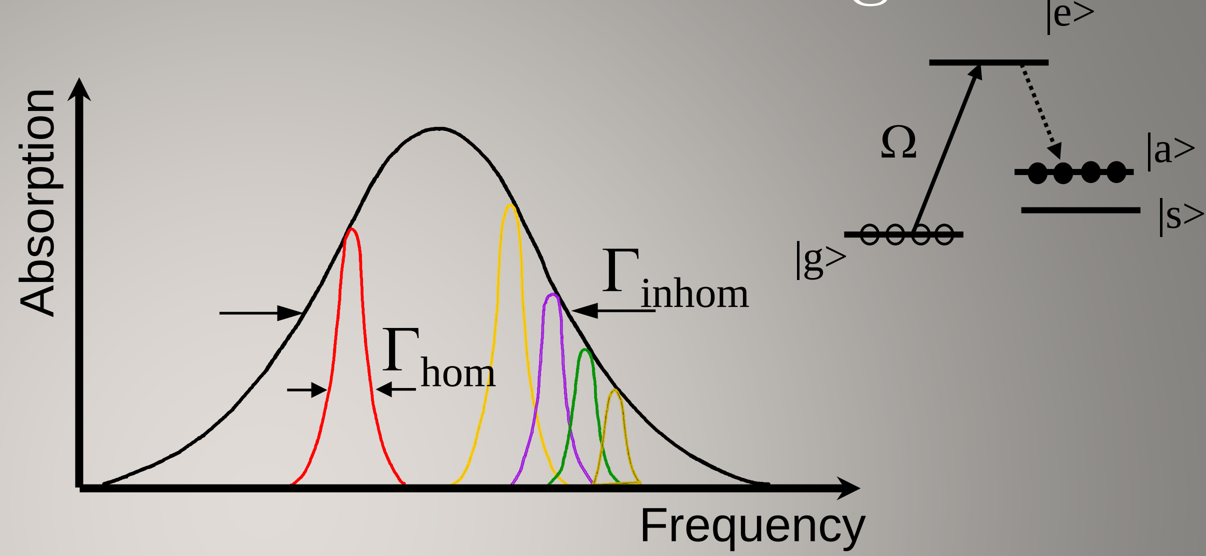
Solution: quantum repeater



Desirable: fibre-based QM operating at telecom wavelength

Rare-earth-ion doped crystals and glasses



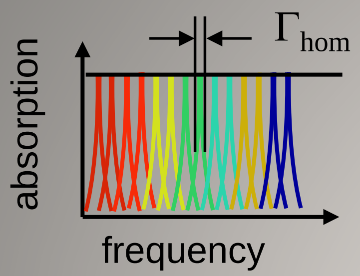


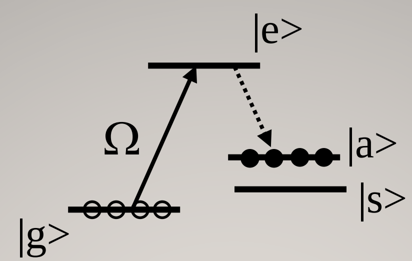
Stress and defects ⟶ Inhomogeneous broadening

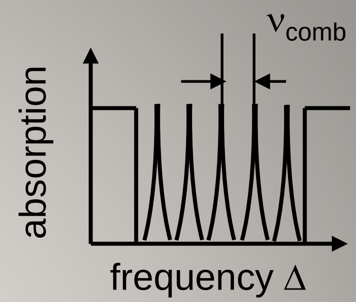
- naturally trapped emitters with free atom like spectra
- transitions at visible and telecom wavelengths
- at <1 K & (large) B: $\Gamma_{hom} \approx$ 50 Hz – 100 kHz, T_2 ~ 3 μs – 6 ms
- spin coherence >> sec
- $\Gamma_{inhom} \approx$ 500 MHz – THz
- possibility to burn persistent spectral holes

Photon-echo quantum memory (AFC)

1. Preparation of an atomic frequency comb







2. Absorption of a photon -> fast dephasing

$$|\psi\rangle = \frac{1}{\sqrt{N}} \sum_{j=1}^{N} c_j e^{-i2\pi\Delta_j t} e^{ikz_j} |g_1 \ldots e_j \ldots g_N\rangle$$

Experiments: Geneva, Lund, Paris, Calgary, Barcelona, Hefei

3. Rephasing at $t_R = 1/\nu_{comb}$ with $2\pi\Delta_j t_R = m\, 2\pi$

- Storage and re-emission of light with unity efficiency and fidelity
- Multi-qubit storage
- Spin-wave mapping allows on-demand recall of temporally multiplexed qubits
- Addition of standard optical elements allows feed-forward controlled readout of frequency-multiplexed qubits

Efficient persistent spectral hole burning in Er-doped crystals or fibres not yet shown

Hesselink *et al.*, PRL (1979); Afzelius *et al.*, PRA (2009); De Riedmatten *et al.*, Nature. (2008); Sinclair *et al.*, PRL (2014).

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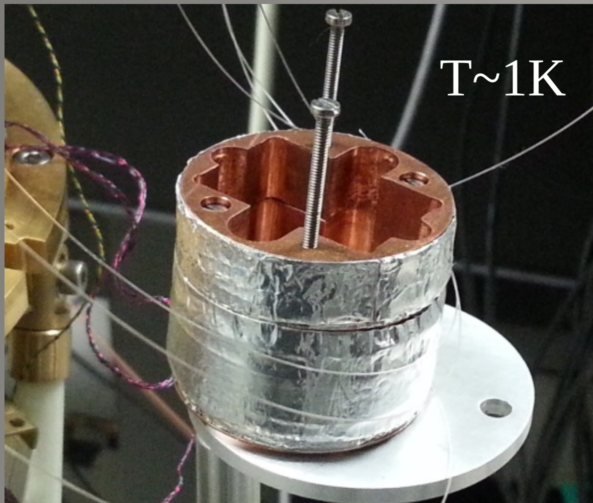
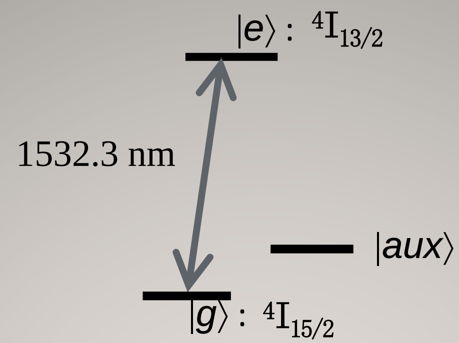
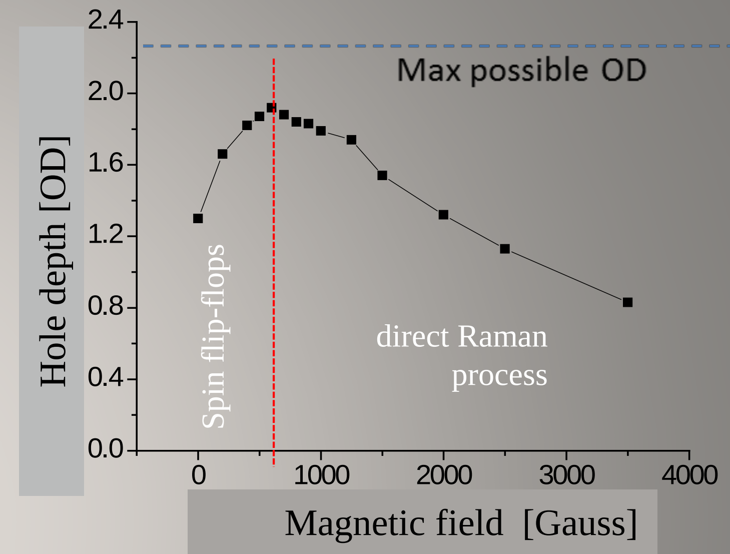
Er: silicate fibre



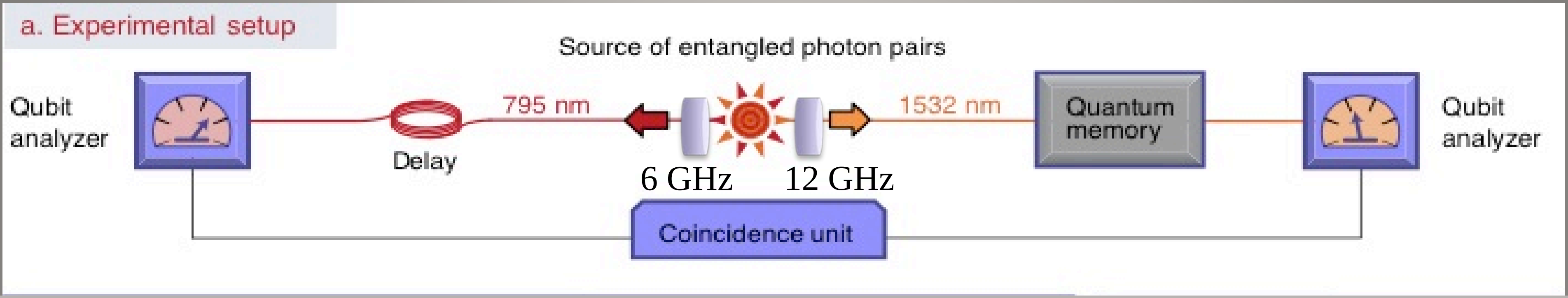


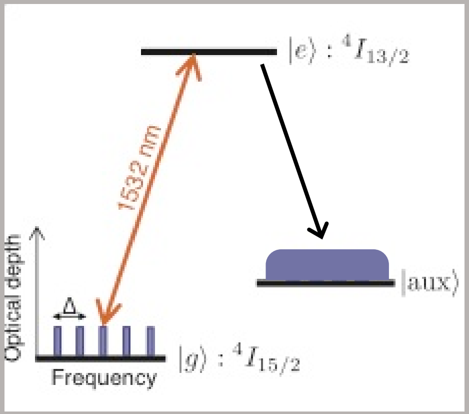


- Commercially available
- 1532 nm zero-phonon absorption line, Γ_{hom} ~100 kHz @ 0.1K
- Small, polarization-independent optical depth (α~0.6/m @ 1K &1532 nm)
- Persistent spectral hole burning (T_1 = 1.5s – 45s) through optical pumping into electronic Zeeman levels @ B~600G & T~1K with 85% efficiency
- Fibre length: 20m
- Simple (and low-loss) splicing to standard telecommunication fibres

Experimental setup

$$|\phi^{+}\rangle = \frac{1}{\sqrt{2}}\left(|e,e\rangle + |l,l\rangle\right)$$

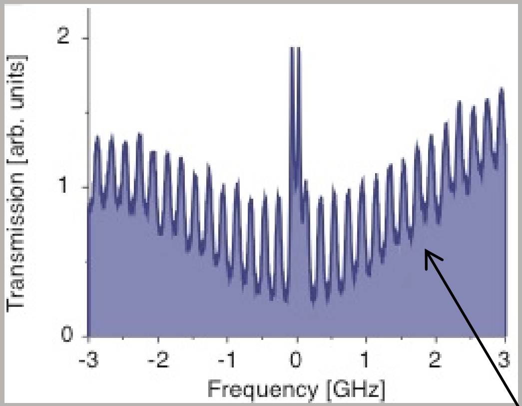




8 GHz wide AFC

→

5 ns storage with 1% efficiency



measurement-caused artifact

Experimental cycle

400 ms	300 ms	700 ms
prepare AFC	wait	store, recall & measure

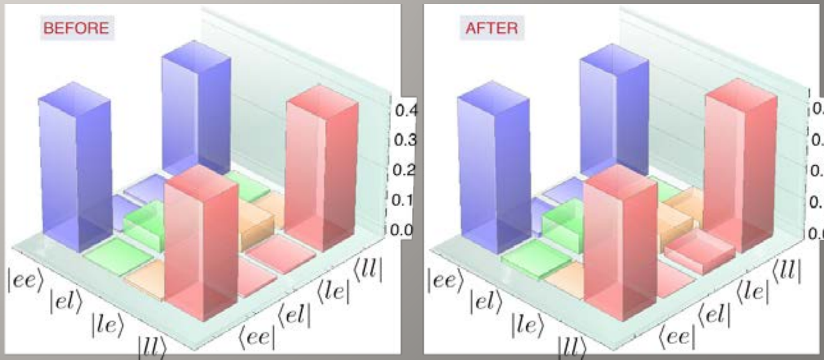
Results

	Entanglement of formation	Input-Output Fidelity	Purity	Fidelity with $\|\phi^+\rangle$	CHSH-Bell parameter S
ρ_{in}	0.531±0.011	0.971±0.049	0.694±0.07	0.824±0.04	2.38±0.05
ρ_{out}	0.499±0.105		0.673±0.047	0.808±0.048	2.33±0.22

- no measurable degradation of (post-selected) entanglement during storage

- experimental violation of CHSH Bell inequality ($S_{LHV} \leq 2$)

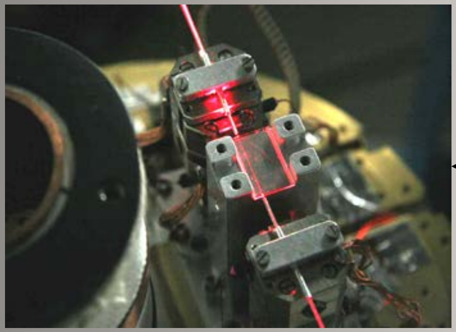
- important step towards fibre-based memories for telecom photons, but more work required to increase efficiency and storage time

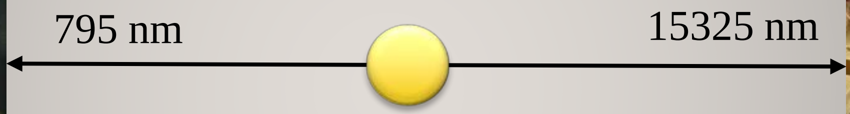


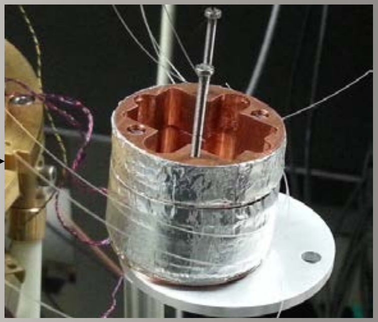
E. Saglamyurek *et al.*, submitted

Outlook

- Possibility to entangle different QMs

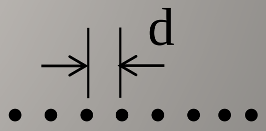






- New tests of quantum/classical transition.

Does the (entangled) Dicke state break down if d->λ?



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Collaborators:

- S.W. Nam & V.B. Verma (NIST)
- F. Marsili & M.D. Shaw (JPL)

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