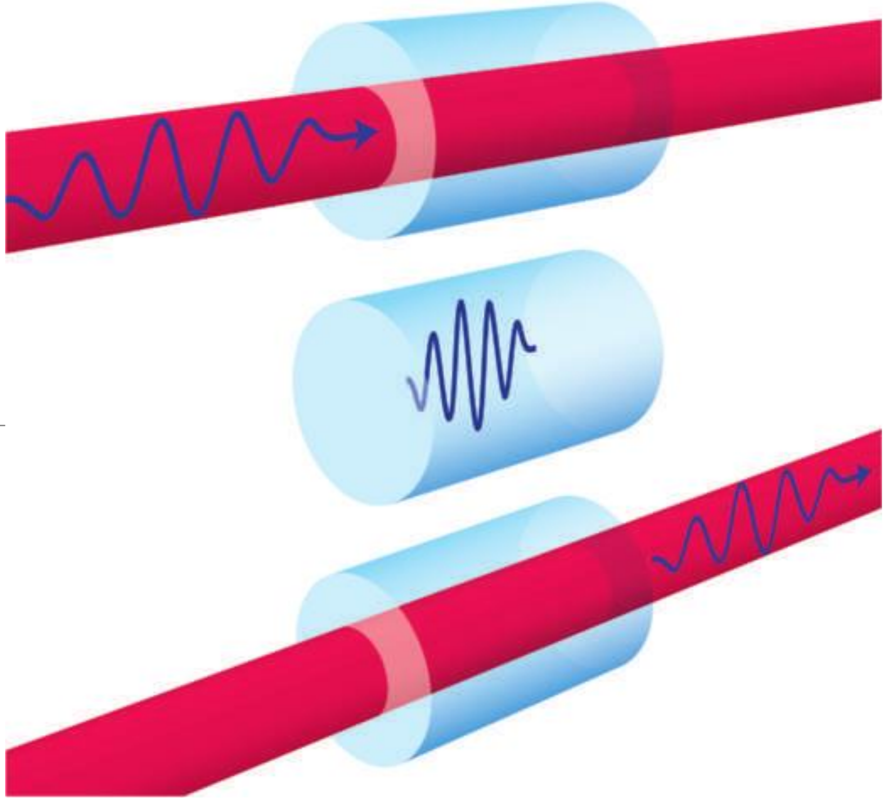
University of Ljubljana
Faculty of Mathematics and Physics

Quantum memory with cold atoms in a magnetic field



AUTHOR: VESNA PIRC JEVŠENAK
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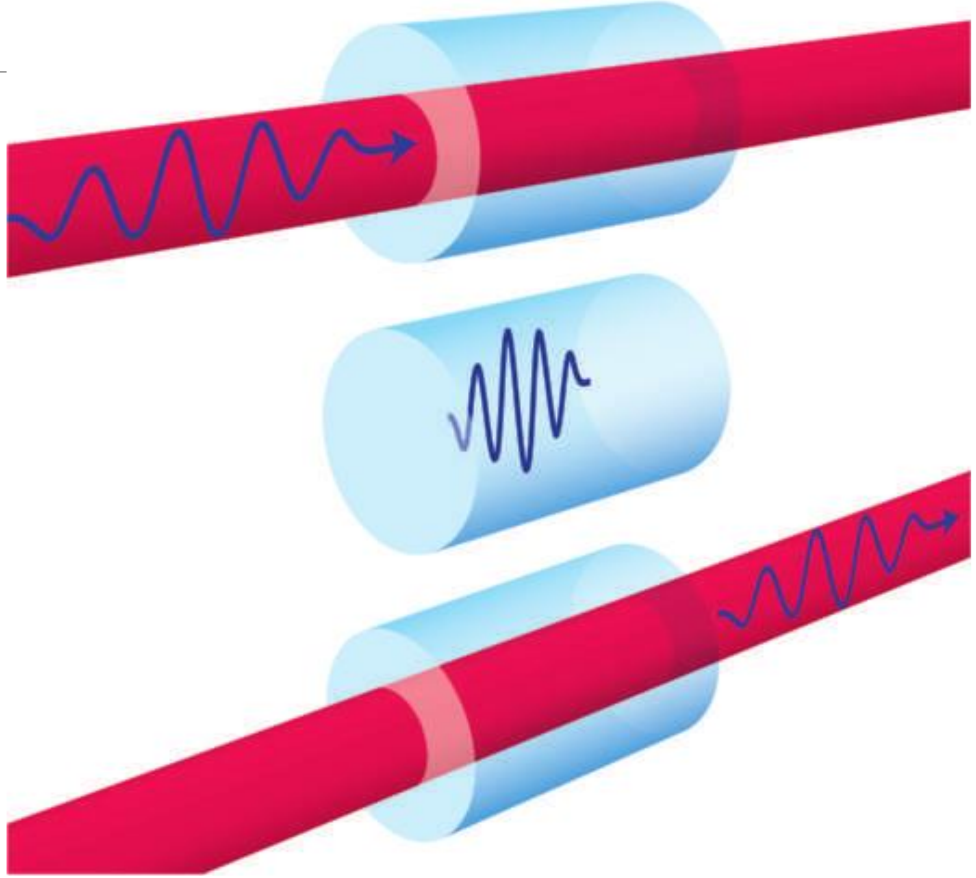
Overview

- Quantum memory
- Electromagnetically induced transparency (EIT)
- Dark-state polariton (DSP)
- The effect of magnetic fields on the DSP
- Experiment
  - Cold atoms
  - Non-polarized atoms
  - Polarized atoms
- Conclusion and outlook

Quantum memory

- Storing information → light
- Quantum communication
- Quantum repeaters
- Storage mechanism for a quantum computer



Lvovsky et al. Nature Photonics **3**, 231 (2009)

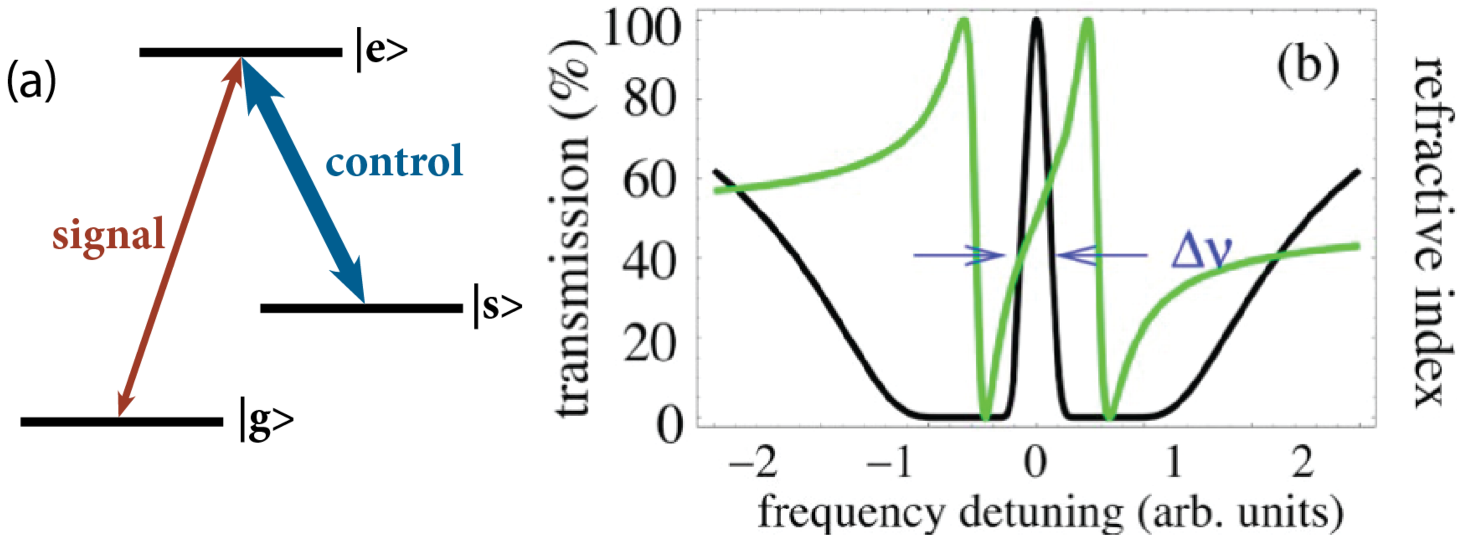
Quantum memory

- Atomic gas
  - Cold
  - Warm
- Solid state (rare-earth ion-doped crystals, diamond color centers etc.)
- Raman, DLCZ, EIT, …
- Properties:
  - Efficiency
  - Storage time
  - Spectral bandwidth …

Electromagnetically induced transparency

- EIT
- Control beam – stronger
- Signal beam – weaker
- Slow light

$$v_g = \frac{c}{n + \omega \frac{\partial n}{\partial \omega}}$$



M. D. Lukin Rev. Mod. Phys. **75**, 457 (2003)

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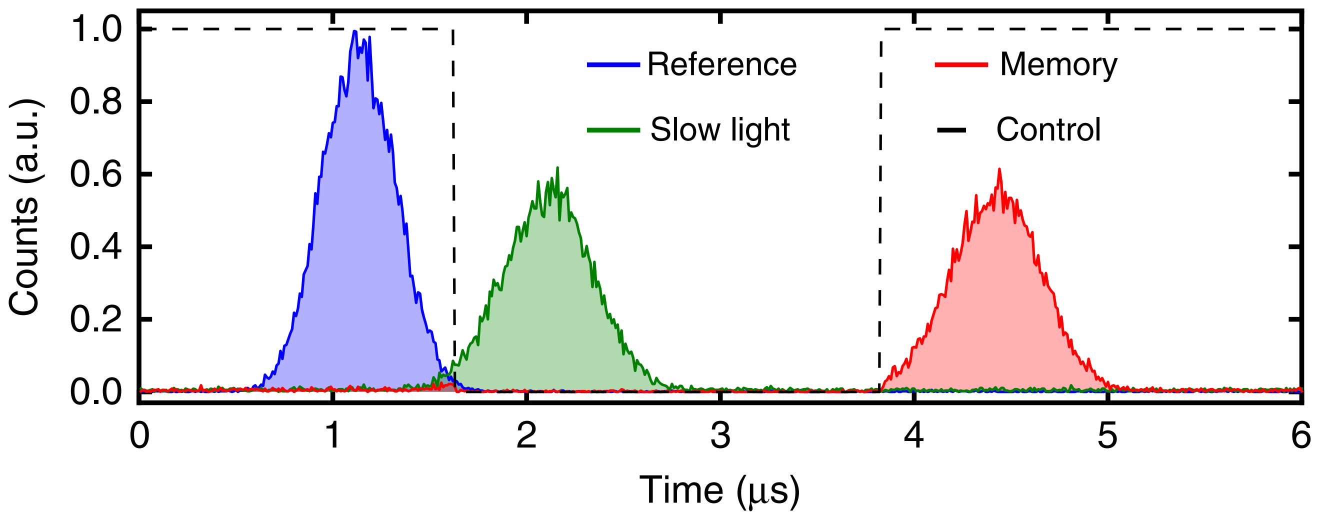
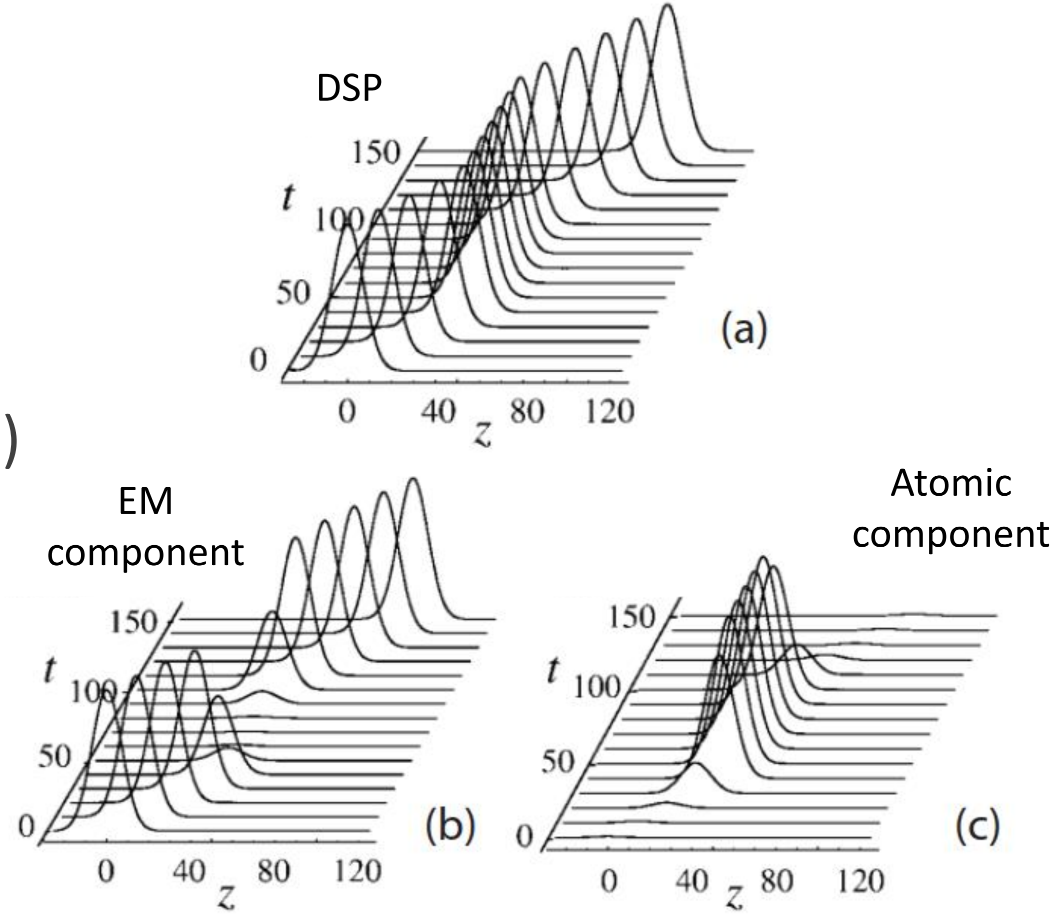


Vernaz-Gris et al. Nature Communications **9**, 363 (2018)

Dark-state polariton

- $|DSP\rangle = \frac{1}{\Omega}(\Omega_c |g\rangle - \Omega_p |s\rangle)$
- Quasi particle
- Electromagnetic component (light pulse)
- Atomic component (spin-wave)



M. Fleischhauer and M. D. Lukin Phys. Rev. Lett. **84**, 5094 (2000)

Storage lifetime

- Limited by:
  - Atomic motion
  - Magnetic field gradients

Storage lifetime

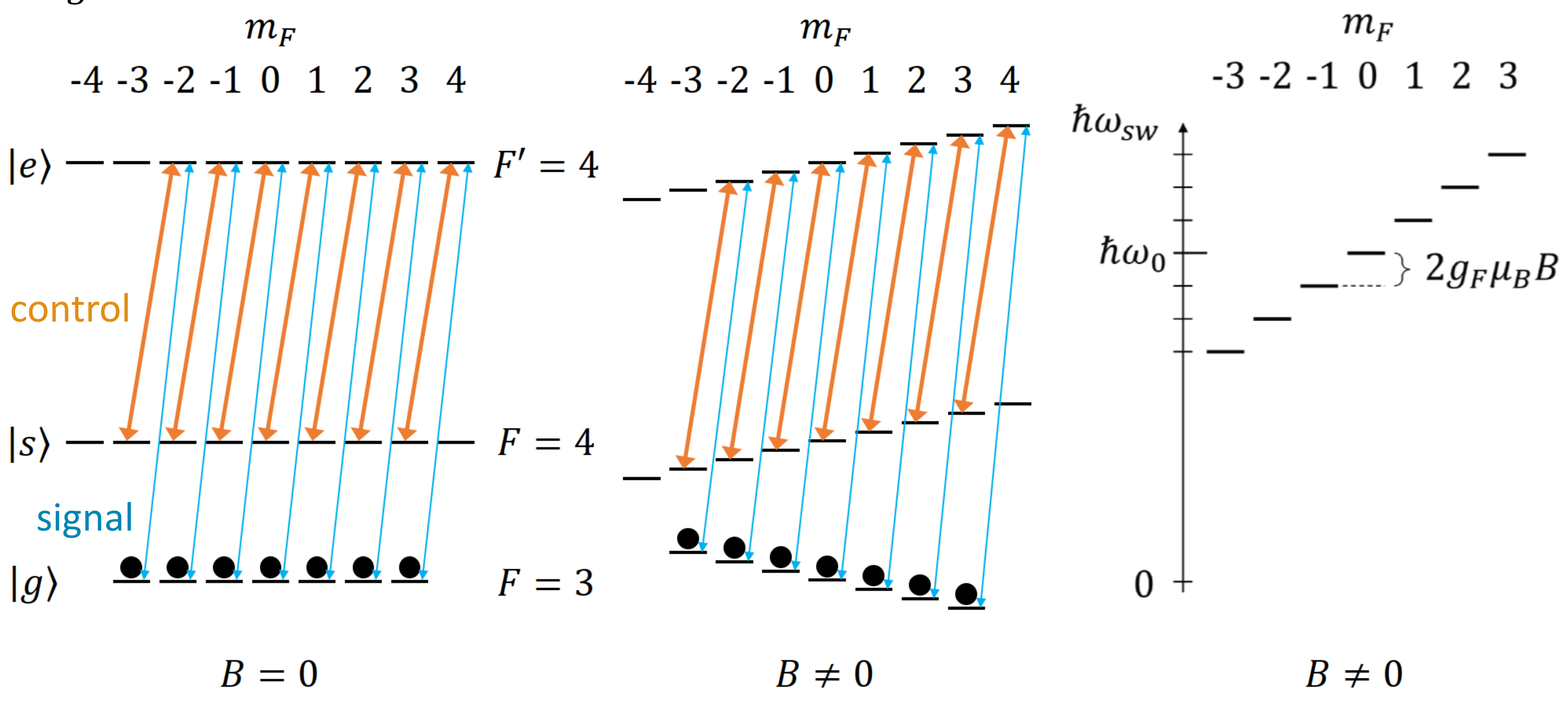
1 mG = 100 nT

- Limited by:
  - Atomic motion → cold atoms
  - Magnetic field gradients → turning on a strong homogeneous magnetic field

The effect of magnetic fields on the DSP

- Interference of spin-waves

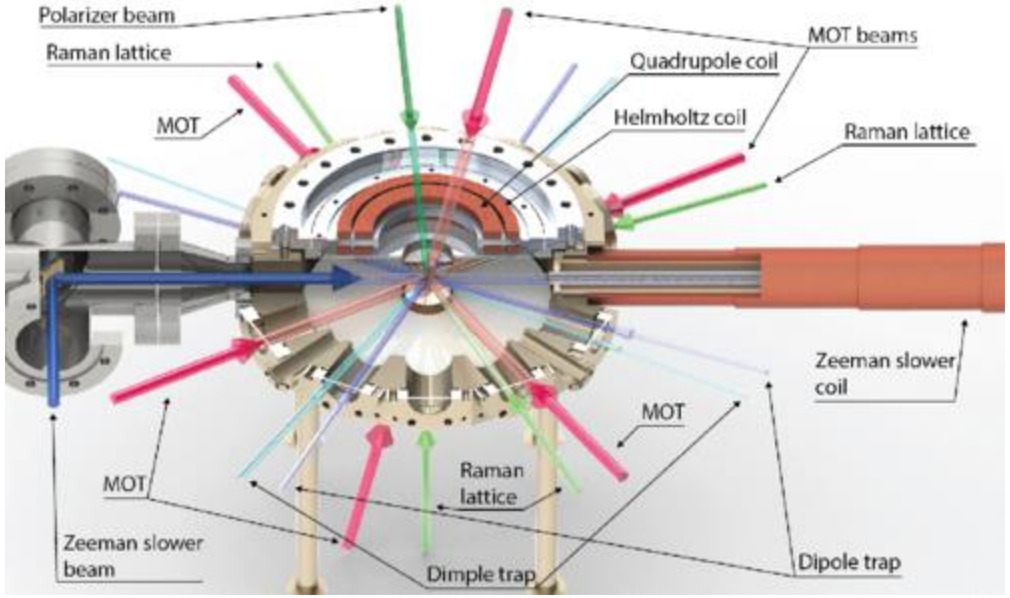
$$\omega_{sw} = \omega_s - \omega_g$$



Experiment

Cold atoms

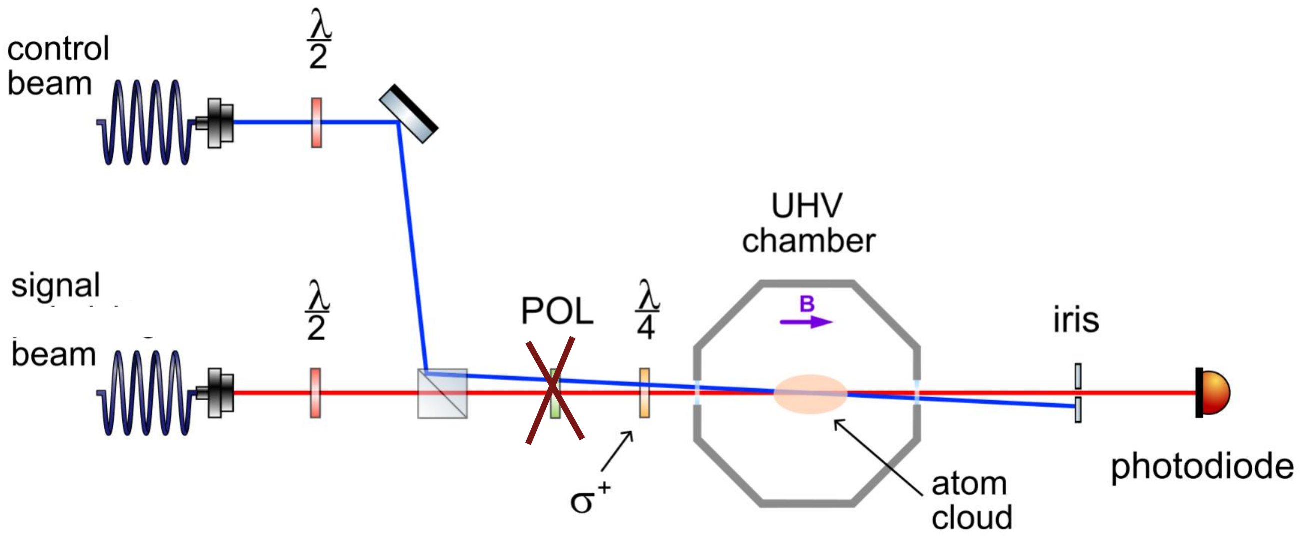
- 5×10^7 cesium atoms
- Magneto-optical trap
- 20 μK
- Non-zero magnetic field and magnetic gradients

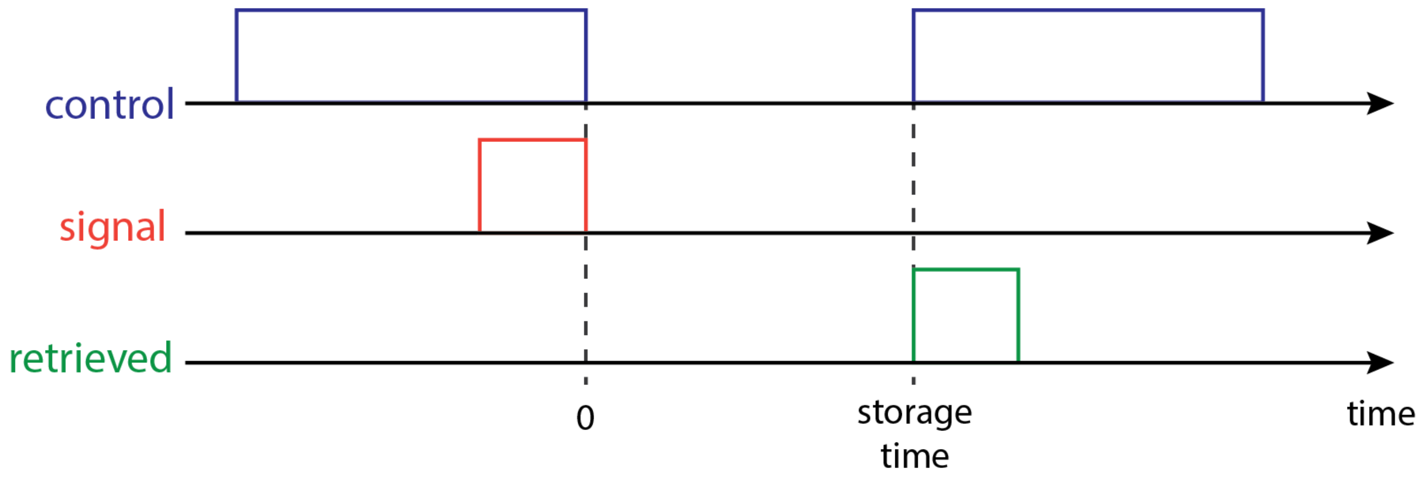


Tadej Mežnaršič, Tina Arh, Jure Brence, Jaka Pišljar, Katja Gosar, Žiga Gosar, Rok Žitko, Erik Zupanič, and Peter Jeglič
Phys. Rev. A **99**, 033625 (2019)

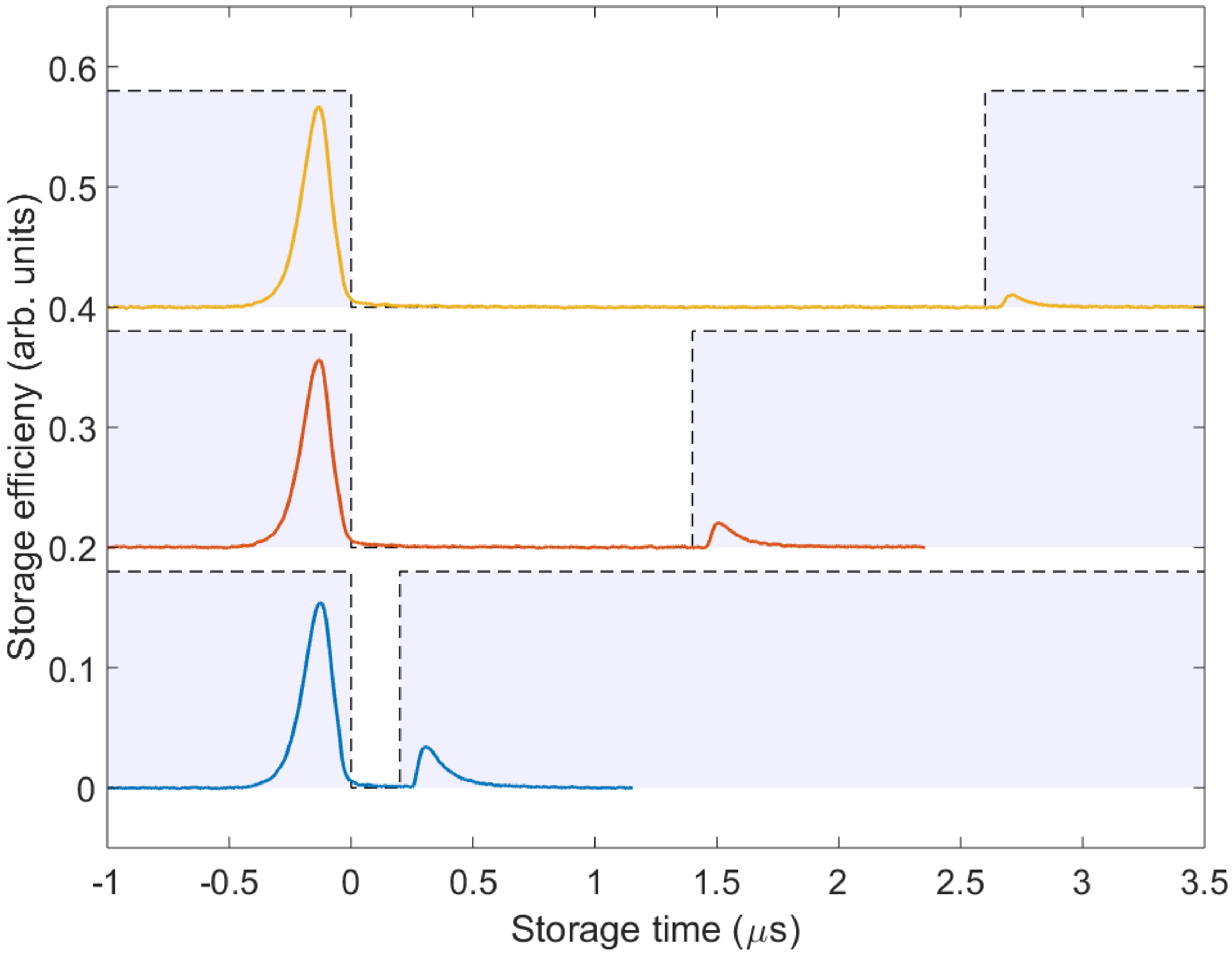
Protocol

- 0.5 μs signal pulse





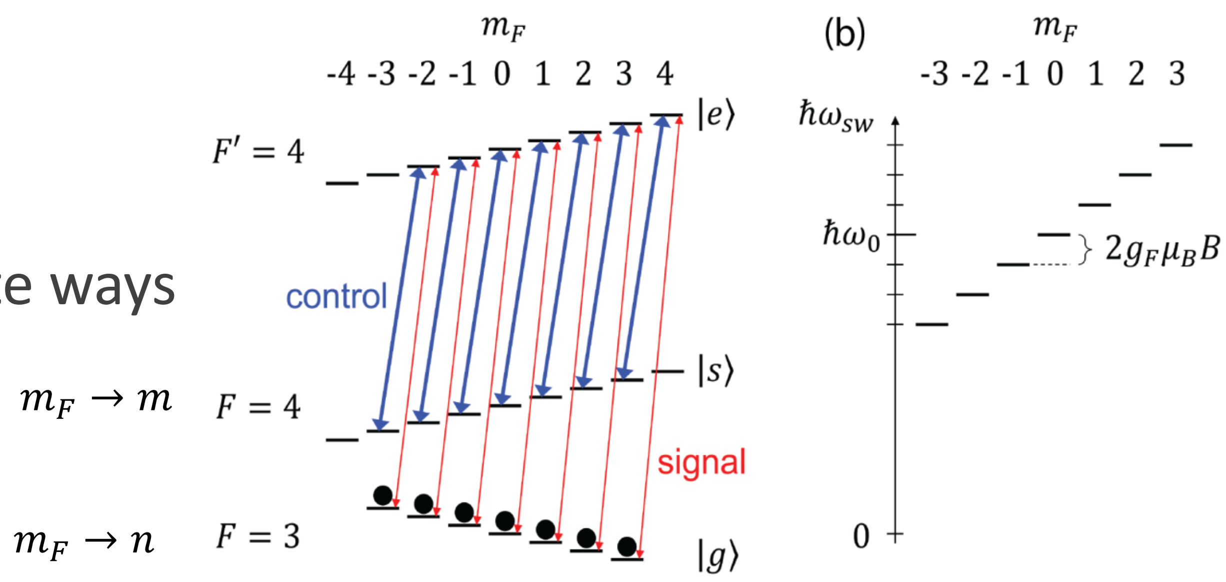
Protocol



Storage efficieny (arb. units)
0.6
0.5
0.4
0.3
0.2
0.1
0
-1
-0.5
0
0.5
1
1.5
2
2.5
3
3.5
Storage time (μs)

Non-polarized atoms

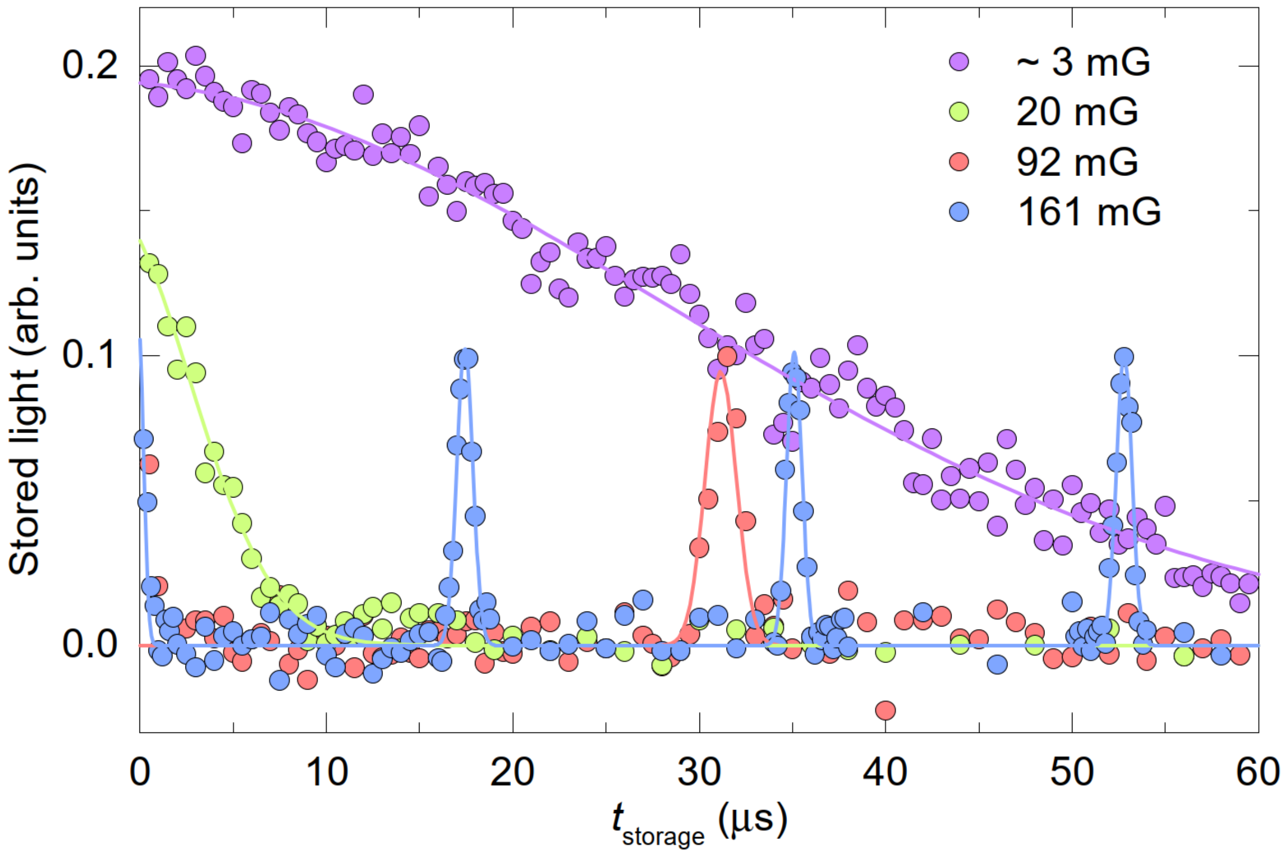
- $A(t) = A(0)\left|\sum_{n=-3}^{3}\sum_{m=-4}^{4} P_{n,m} e^{i(\omega_0+(n+m)\omega_L)t}\right|^2 e^{-t/\tau}$
- $\omega_L = g\mu_B B/\hbar$
- $g = g_g = -g_s$
- $|n-m| \leq 2$
- Beams circularly polarized in opposite ways



Non-polarized atoms

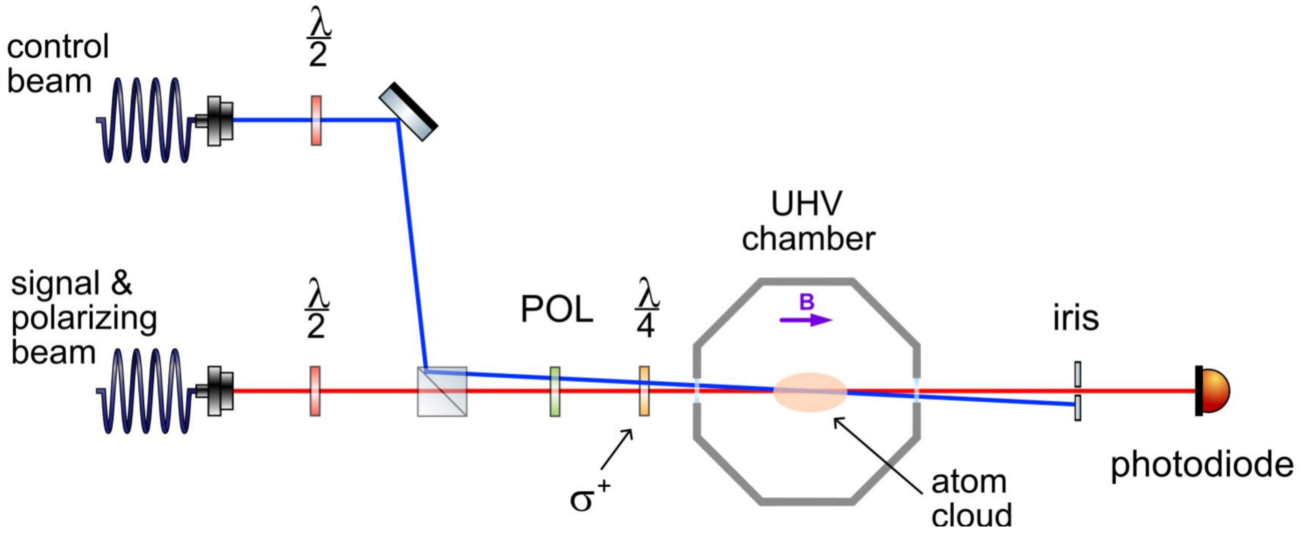
1 mG = 100 nT

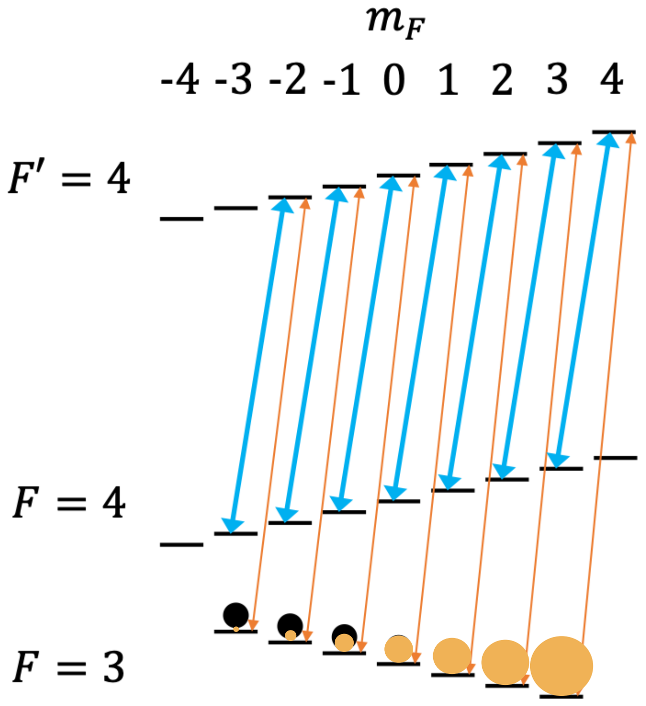
- Revivals and collapses
- Period $2\pi/\omega_L$
- Discretized QM



Polarized atoms

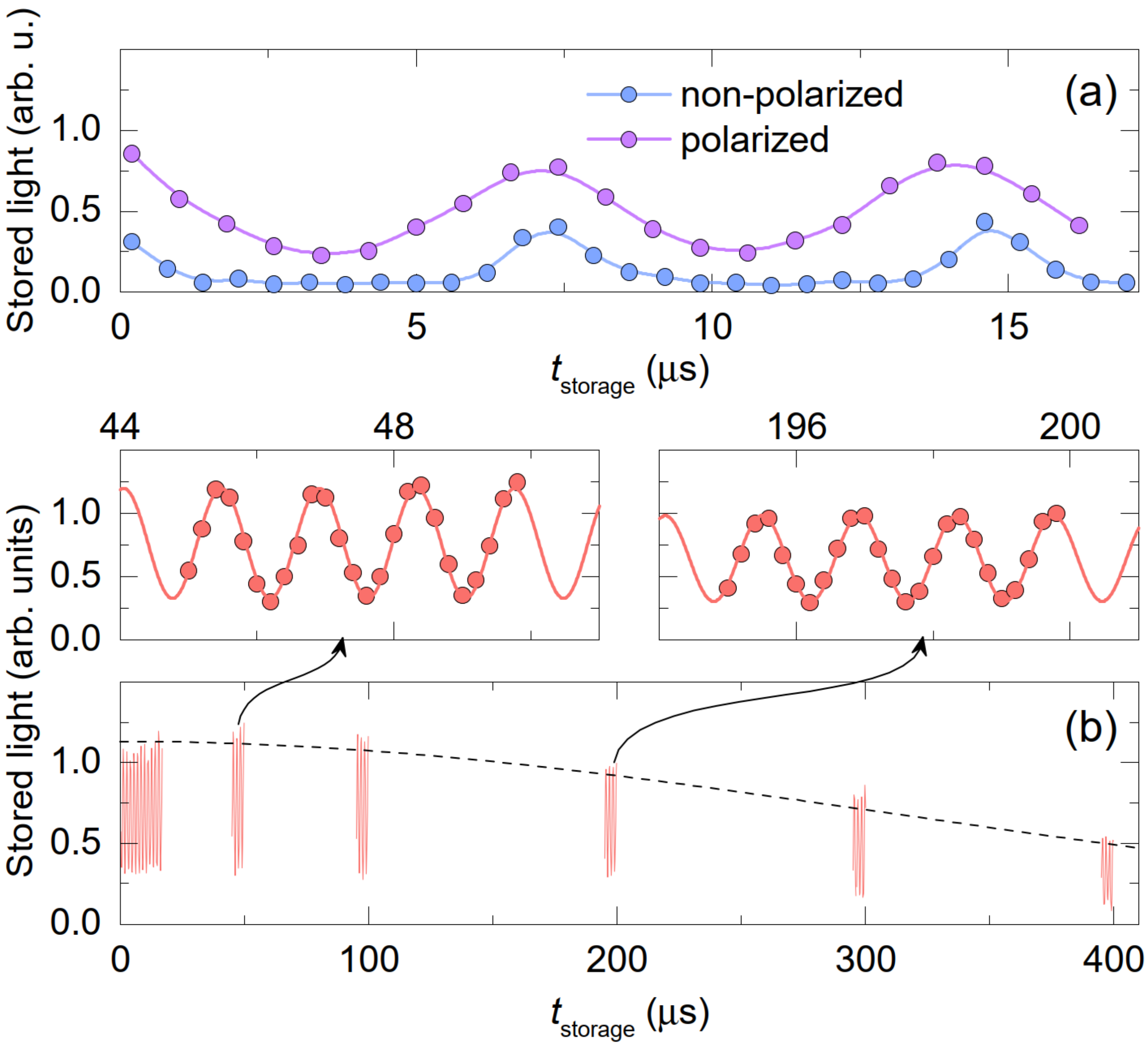
- All beams σ^+ polarized
- $n = m$
- $A(t) \; = \; A(0)\left|\sum_{n=-3}^{3} p_n e^{i(\omega_0 + 2n\omega_L)t}\right|^2 e^{-t/\tau}$
- Period π/ω_L
- $A(t) = A(0)[p_3^2 + p_2^2 + 2\, p_2 p_3 \cos(2\omega_L t)]e^{-t/\tau}$





Polarized atoms

$$A(t) = A(0)[p_3^2 + p_2^2 + 2\,p_2 p_3 \cos(2\omega_L t)]e^{-t/\tau}$$

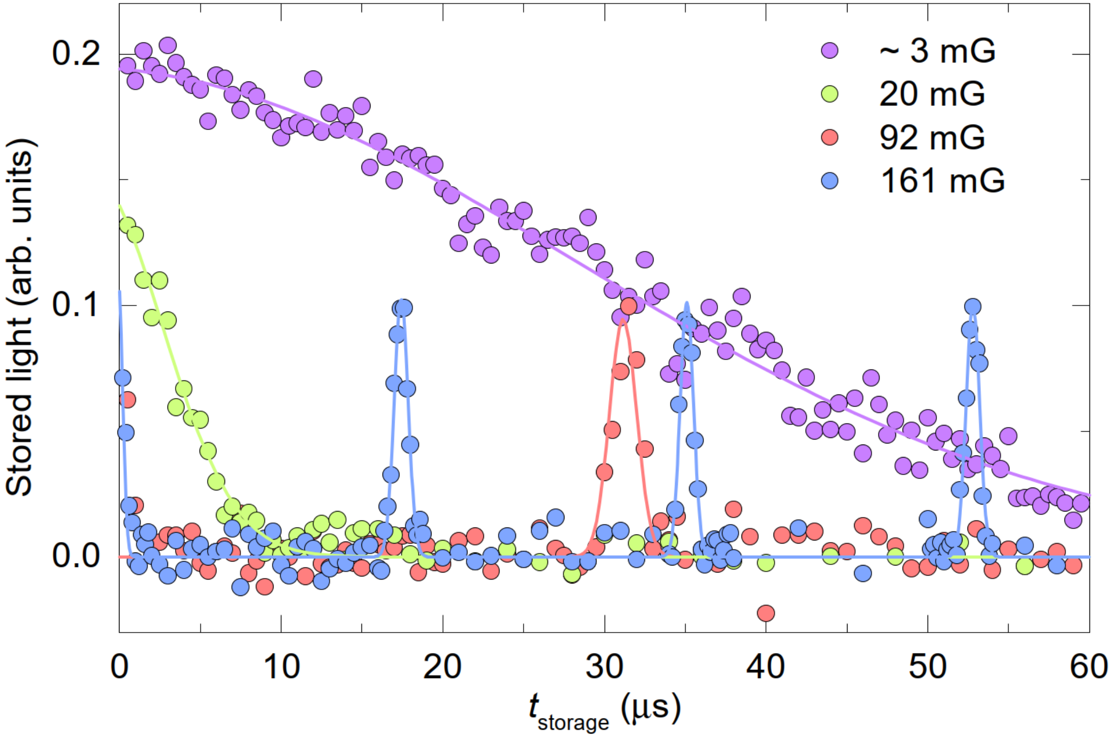


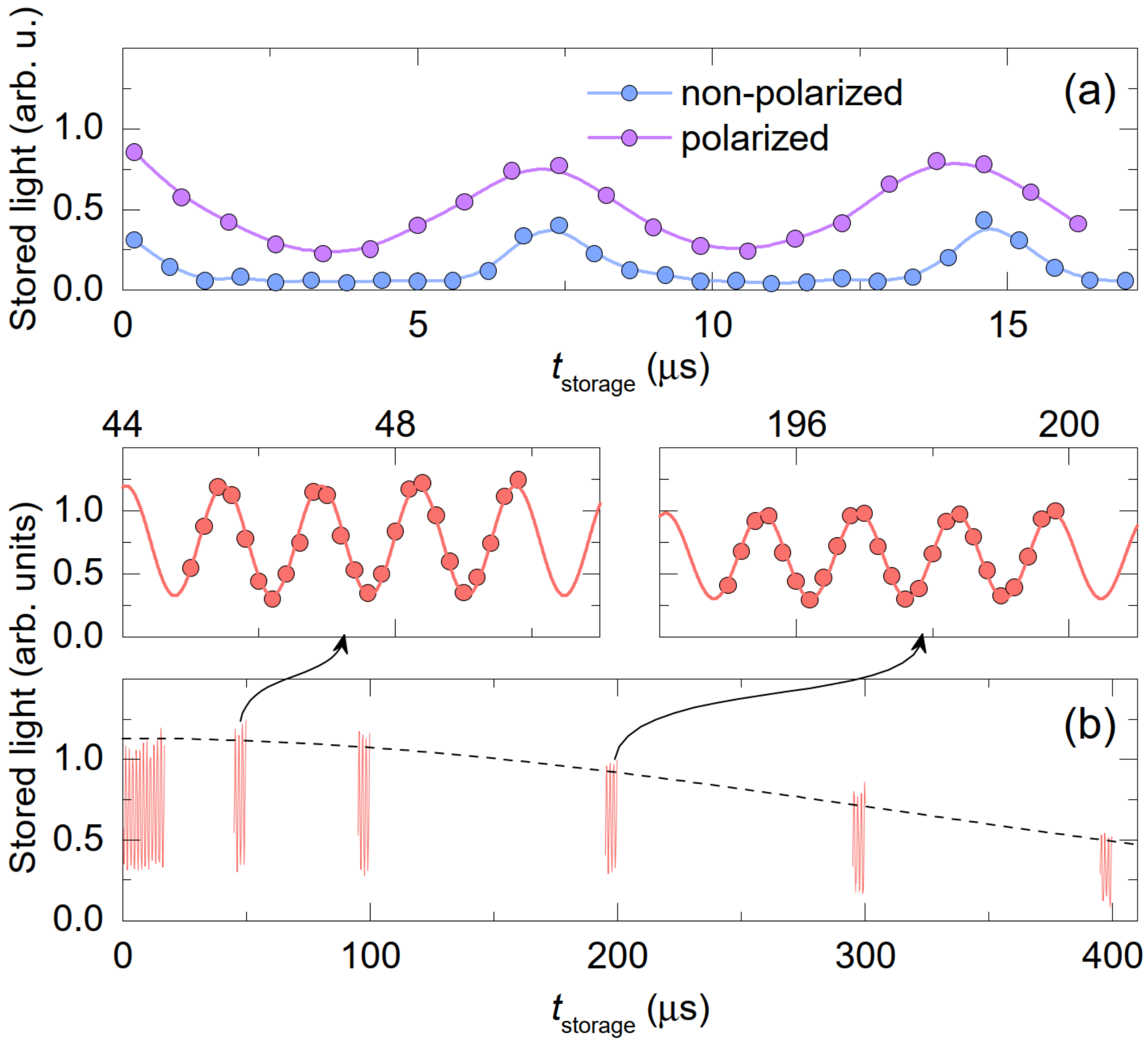
Conclusion

- Quantum memory for quantum communication
- Long storage time
- Continuous storage
- Problem:
  - Residual magnetic fields and gradients from cooling atoms
  - Stray magnetic fields from surroundings
  - Shorter effective lifetime
- Solution:
  - Turning on a strong magnetic field
  - Polarizing atoms

Conclusion

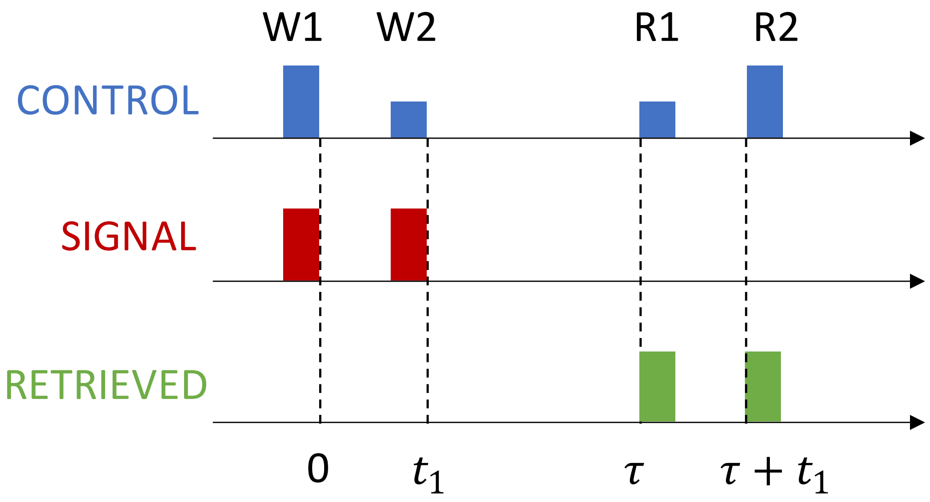
- 40 μs → 400 μs storage time

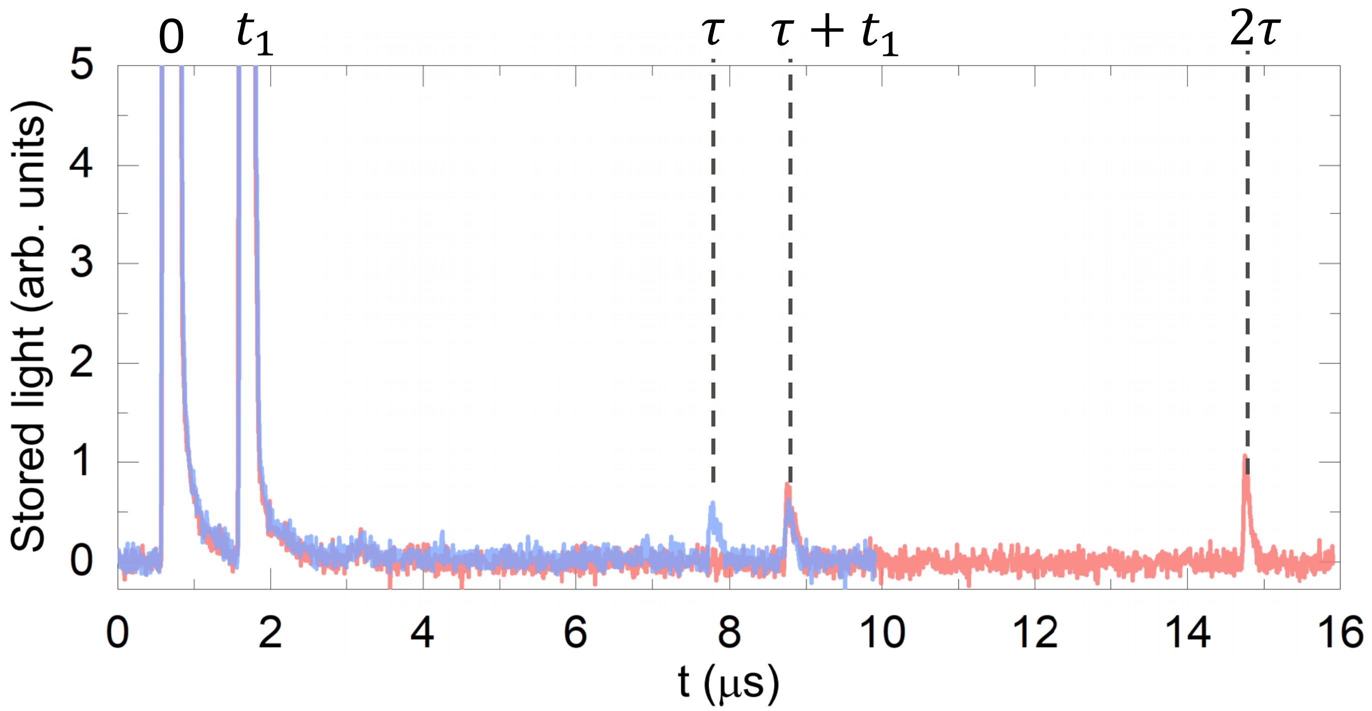




Outlook

- Non-polarized atoms
- Temporal multiplexing





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