Stopped Light With Storage Times Greater than 1 second using Electromagnetically Induced Transparency in a Solid

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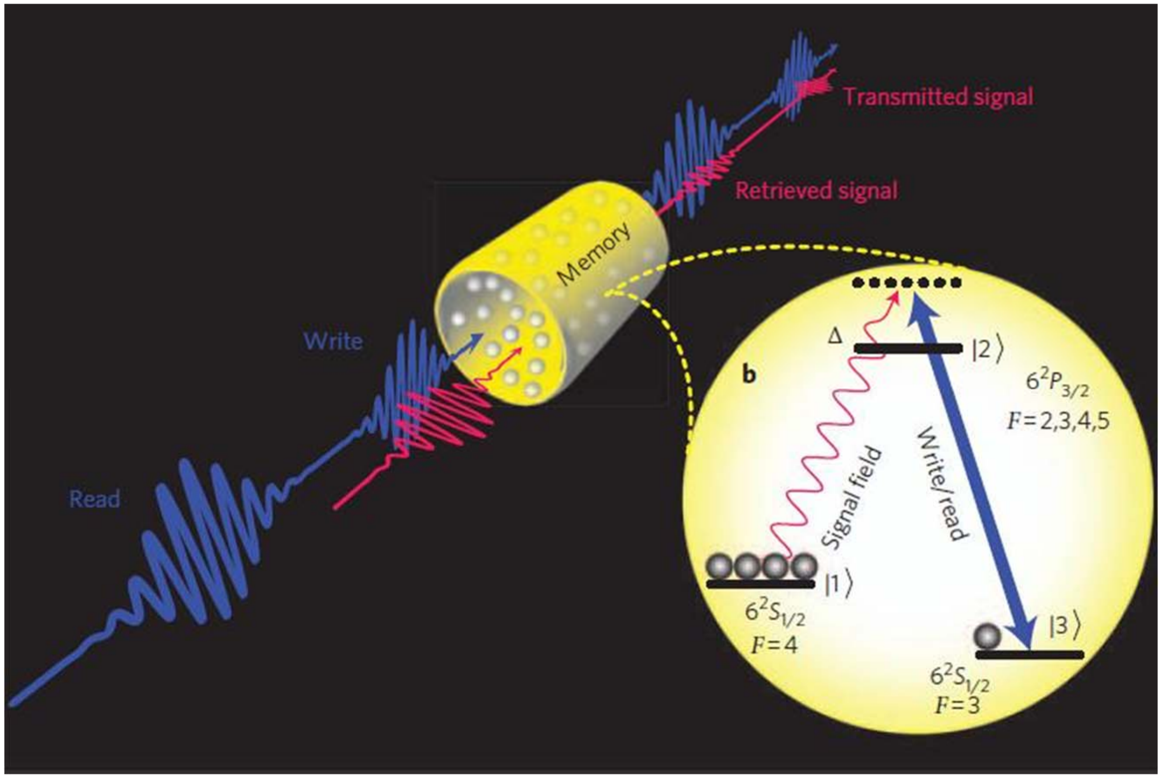
Presented by: Arka, Atma, Courtney, and Del

The Need for Quantum Memory

- Why quantum memory?
- How do we create a quantum memory device?
  - slowing down and stopping of a light pulse within a material.
  - the information is stored in the material and can be retrieved later.



Is it possible to slow and store light?

D-4 THE NEWS-GAZETTE Friday, February 19, 1999

NEWS / HEALT

Scientists slow speed of light to a mere crawl

BOSTON (AP) — Scientists have managed to slow down light so much that if it were a car on a highway, it could get a ticket for not getting over to the right-hand lane.

The speed of light is normally about 186,000 miles per second, or fast enough to go around the world seven times in the wink of eye.

Scientists succeeded in slowing it down to 38 mph.

They did this by shooting a laser through extremely cold sodium atoms, which worked like "optical molasses" to slow the light down.

While slow-speed light now is just a laboratory plaything for top physicists, Lene Vesergaard Hau, the Danish scientist who led the project, said practical applications could be a few years away. She envisions improved communications technology, switches, even night-vision devices.

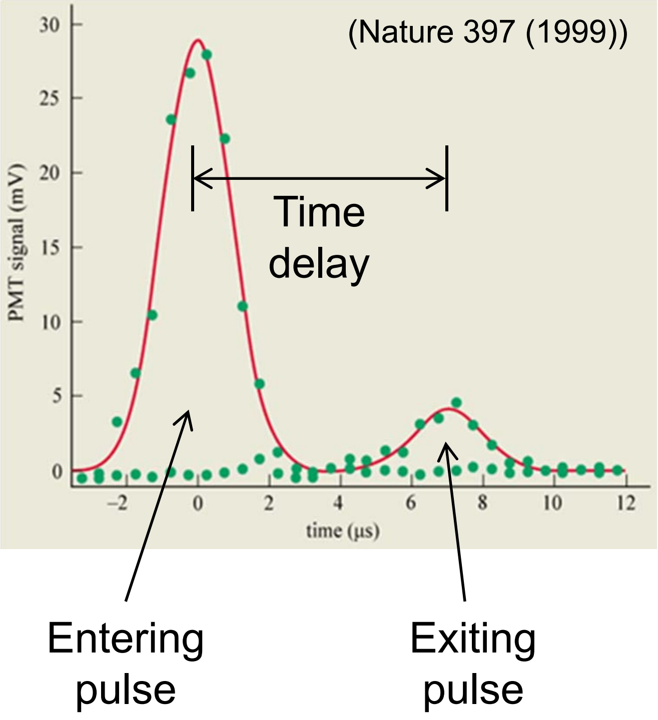
The atoms were contained in what is called a Bose-Einstein condensate, a condition created when matter is cooled almost to absolute zero, the lowest temperature theoretically possible.

"We have really created an optical medium with crazy, bizarre properties," Hau said. "Everybody knows that light is something that goes incredibly fast. If you could possibly slow it down to a real human dimension. That was really fantastic."

Associated Press

This photograph from the Rowland Institute of Science shows Danish physicist Dr. Lene Vestergaard Hau, who with a team of collaborators, has found a way to slow the speed of light.

The research, conducted at the Rowland Institute for Science in Cambridge and Harvard University, was described in Thursday's issue of the journal Nature.



(Nature 397 (1999))

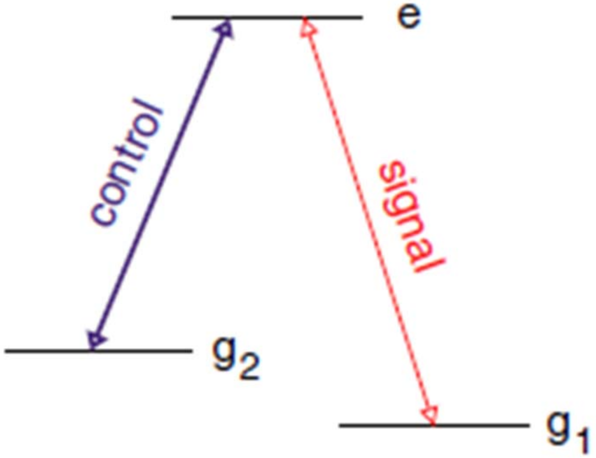
Time delay

Entering pulse

Exiting pulse

- A. Kasapi, M. Jain, G. Y. Yin, and S. E. Harris, Phys. Rev. Lett. 74, 2447-2450 (1995).
- Lene Vestergaard Hau, S. E. Harris, Zachary Dutton & Cyrus H. Behroozi, Nature 397, 594-598.
- D. F. Phillips, A. Fleischhauer, A. Mair, and R. L. Walsworth, Phys. Rev. Lett. 86, 783–786 (2001).
- Chien Liu, Zachary Dutton, Cyrus H. Behroozi & Lene Vestergaard Hau Nature 409, 490-493 (January 2001)

How can light be stopped?

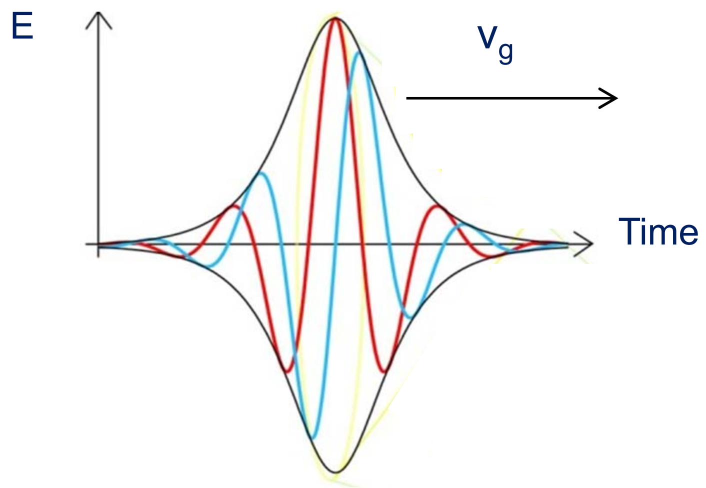


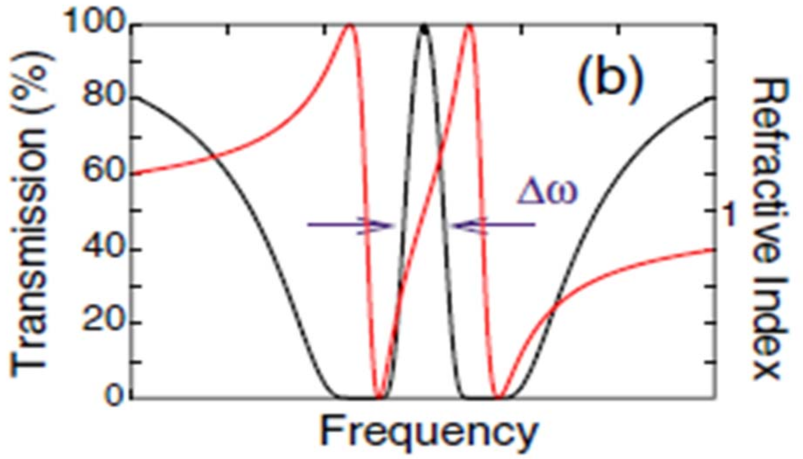
- Electromagnetically Induced Transmission (EIT)
  - uses two beams to create a window of transparency in an opaque medium.
- Creation of a dark state
  - a toy model:

$$|g_1>|g_2> - |g_2>|g_1> \xrightarrow{absorption} |e>|e> - |e>|e> = 0$$

  - the states (g_1, g_2) are close in energy level to reduce transition between them
- Constraint: $\hbar\omega_{Signal} - \hbar\omega_{Control} = E_{g_2} - E_{g_1}$

Narrow transparency window creates sharply changing refractive index



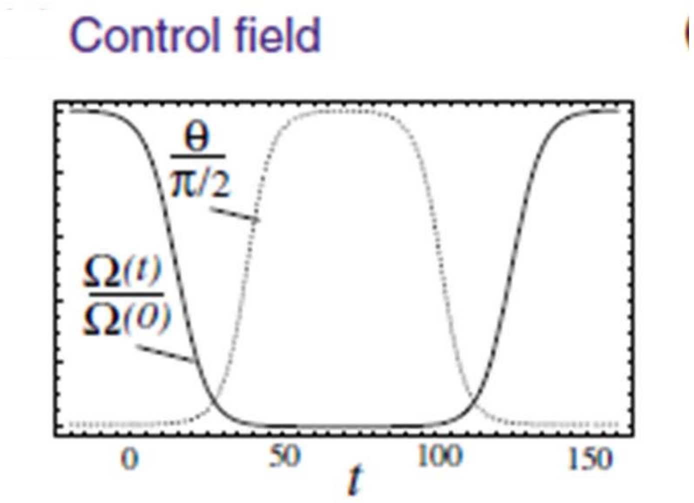


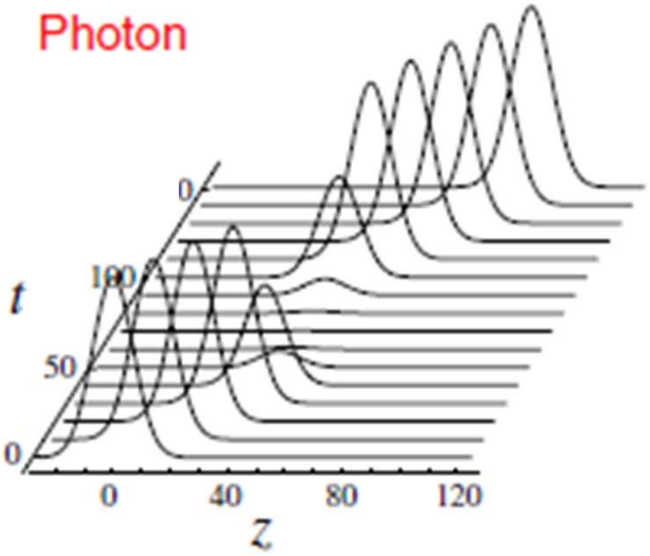
$$v_g = \frac{d\omega}{dk} = \left[\frac{dk}{d\omega}\right]^{-1} = \left[\frac{d\left(k_{vacuum} n(\omega)\right)}{d\omega}\right]^{-1} = \frac{1}{k_{vacuum}}\left[\frac{dn(\omega)}{d\omega}\right]^{-1}$$

**Note that Δω and $[dn(\omega)/d\omega]^{-1}$ are proportional to control beam intensity

EIT is not the final answer

- Though this technique can slow down light, it cannot by itself stop light.
- Stopping light requires a technique called dynamic EIT in which one of the beams is switched off adiabatically.


Control field

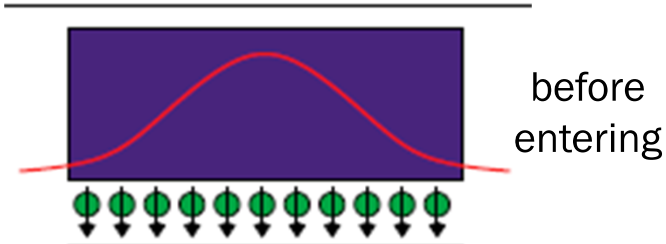

Photon

What happens when a slowed light *pulse* is travelling in a medium?

- A “spin wave” is created

- Light pulse travels together with the spin wave at velocity v_g

- A quasiparticle excitation is created
    - Dark-State Polariton



Travel of a light pulse in EIT medium

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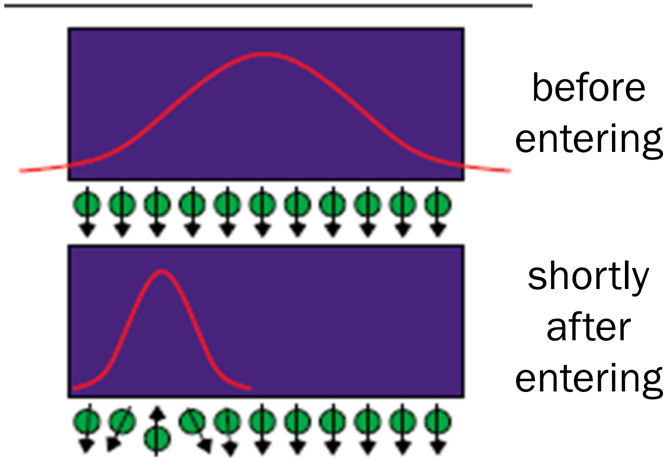

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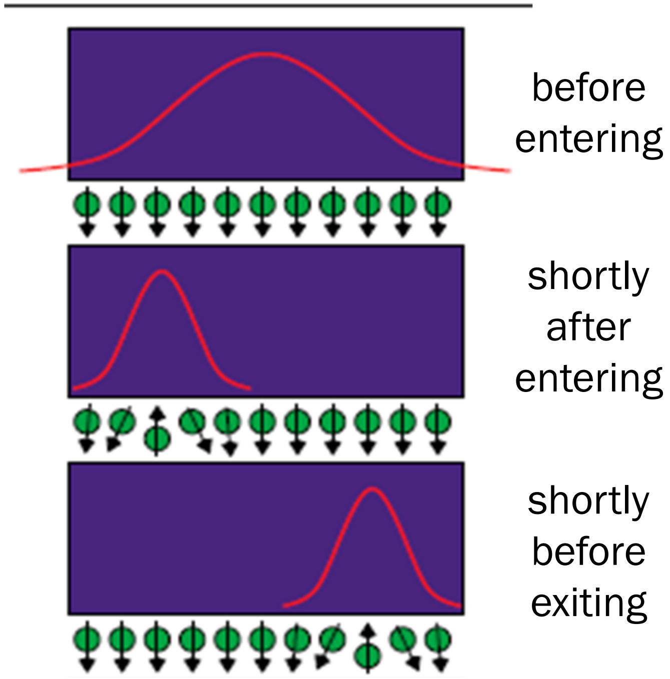

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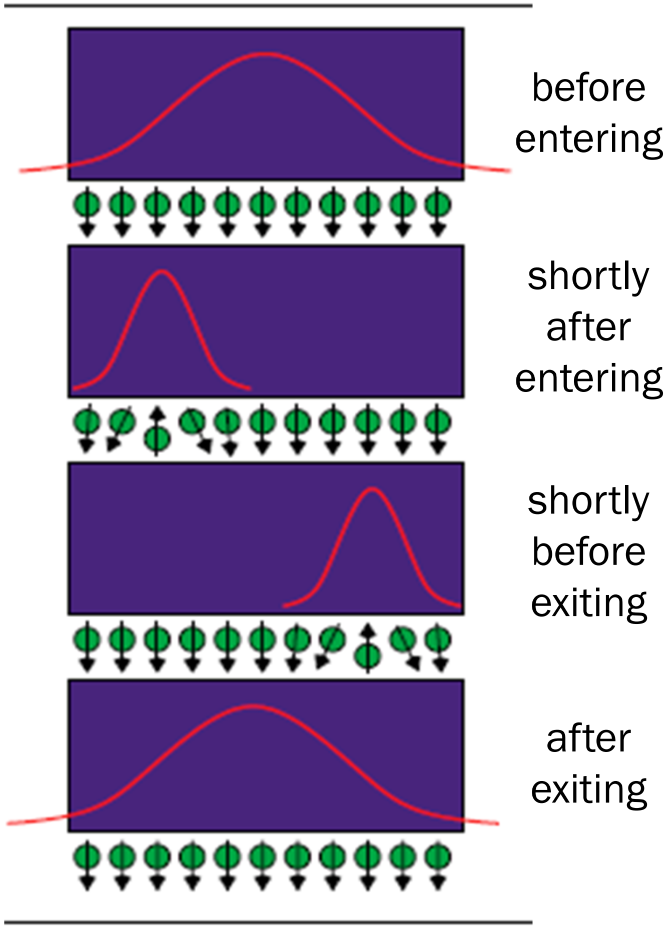
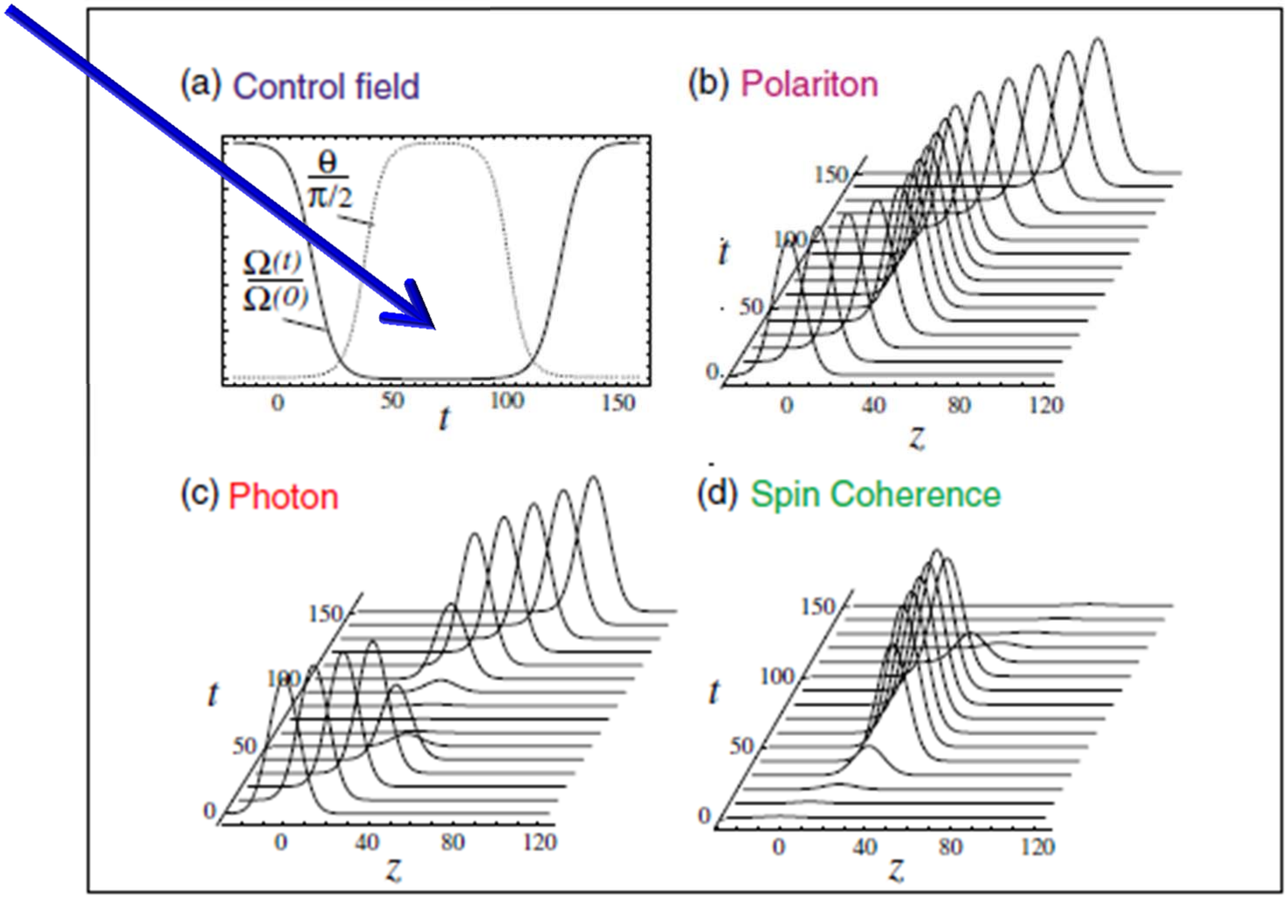


Travel of a light pulse in EIT medium

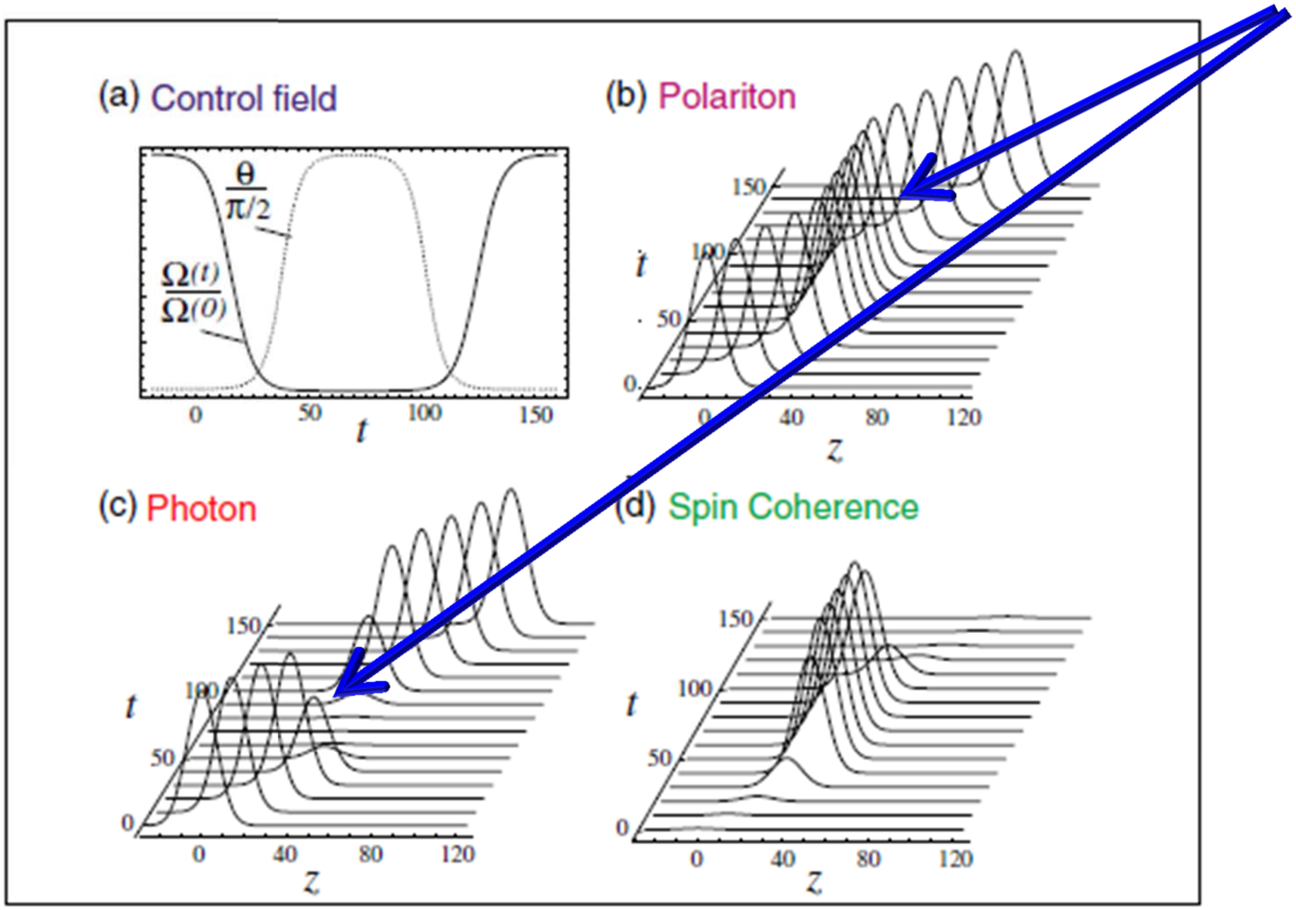
$v_g = 0$ when the control beam is turned off

Control Beam is turned off



$v_g = 0$ when the control beam is turned off

Polaritons and photons stop



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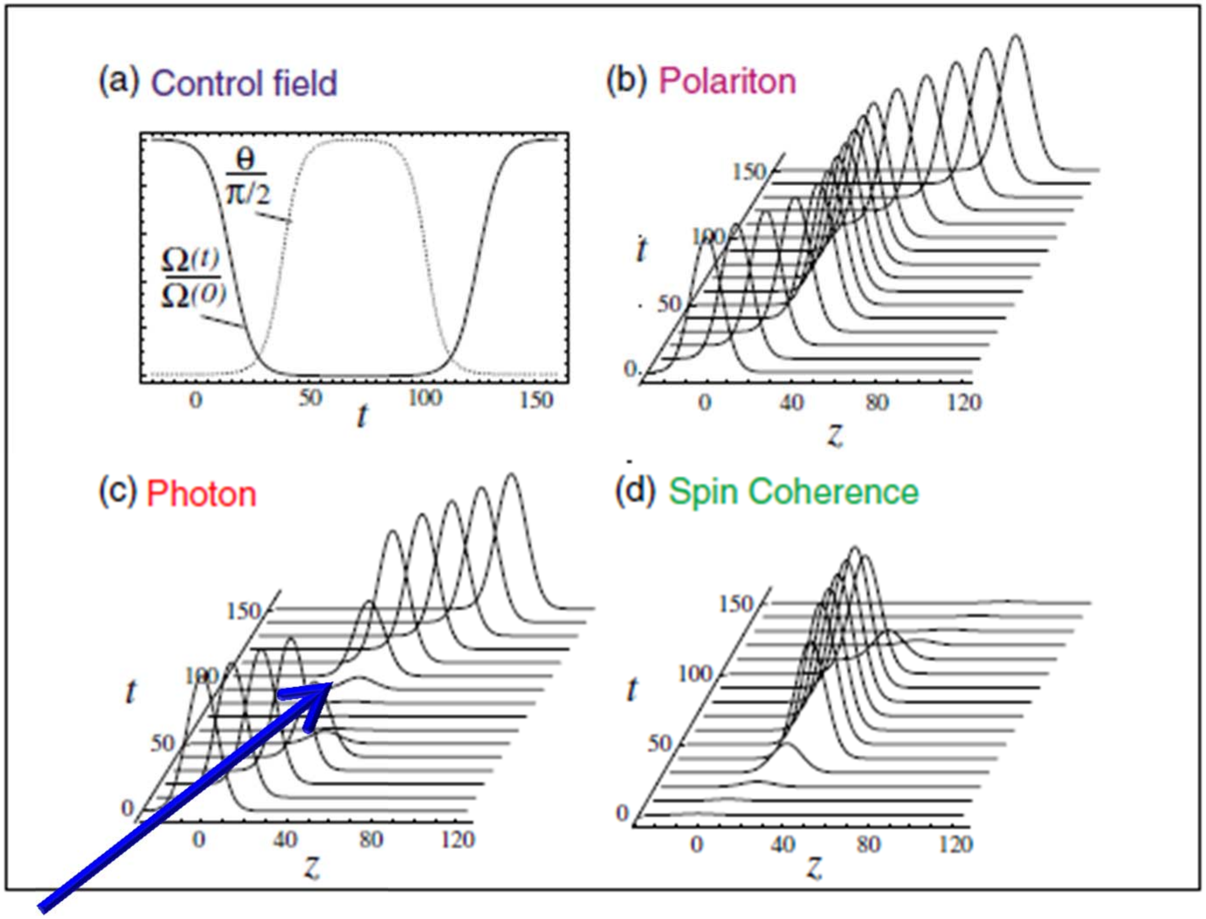
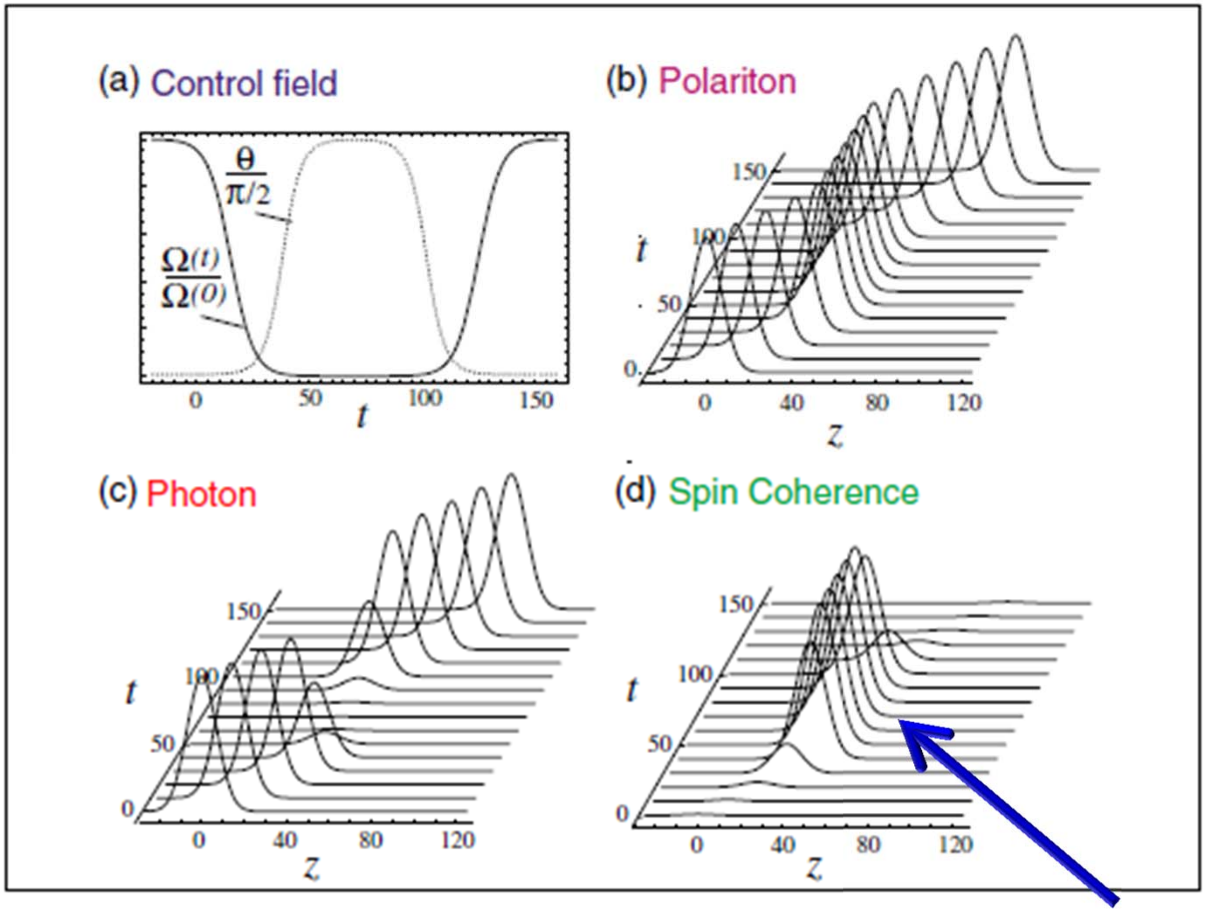


Photons of the signal beams
are carried away

$v_g = 0$ when the control beam is turned off



Information recorded through the spin coherence of the atoms

Remarks

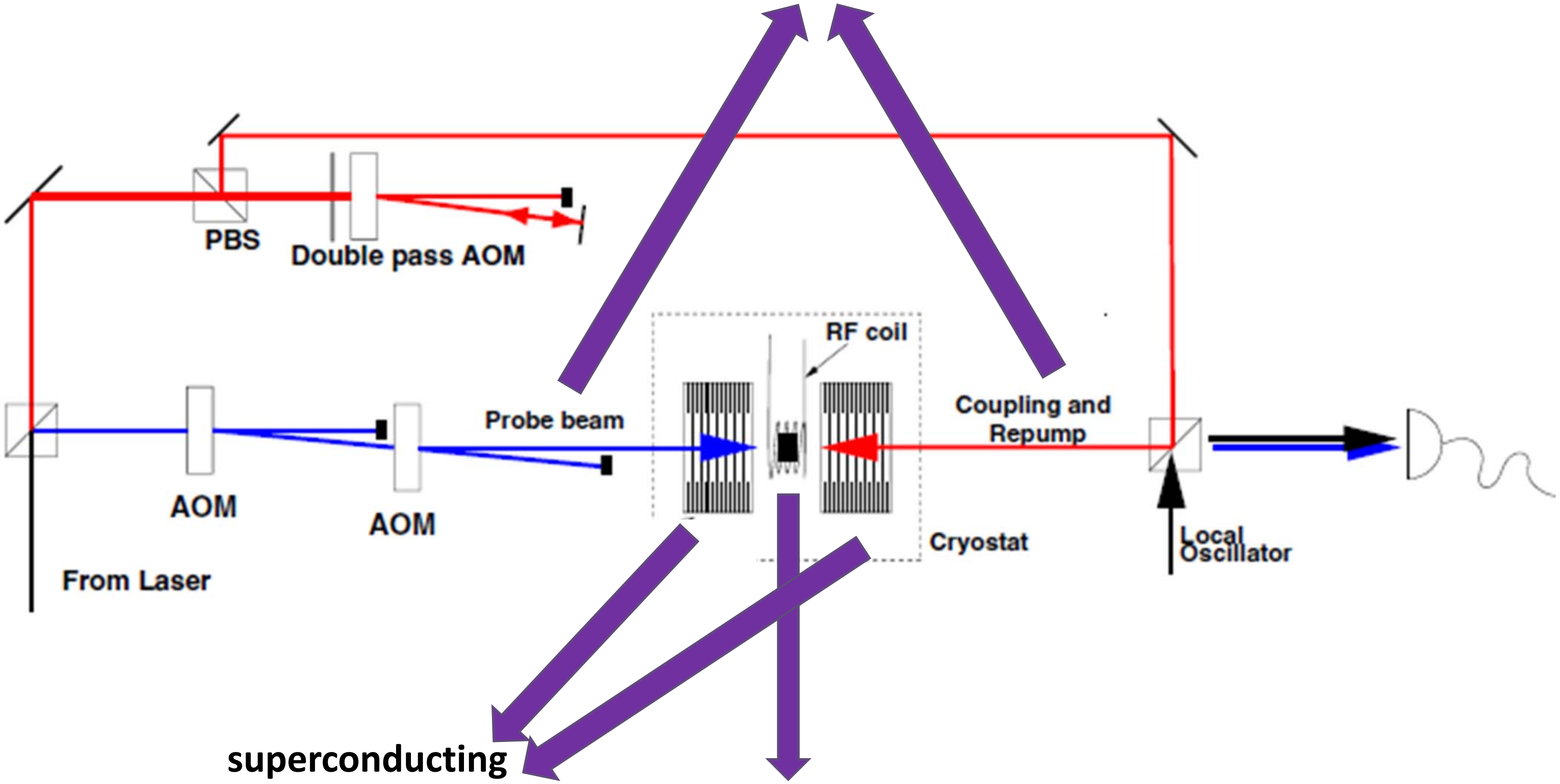
- Reduction of v_g should be slow to avoid information loss
- the polariton state is maintained at any instant of the process
- The frequency range of the whole pulse must always lie within the transparency frequency window

Earlier experiments…

- use atomic vapor systems though they are cooled to very low temperatures, the motion of the atoms affects the performance.

- Use of a solid state device allowed the authors to achieve a 1000 fold increase in storage times.

Setup

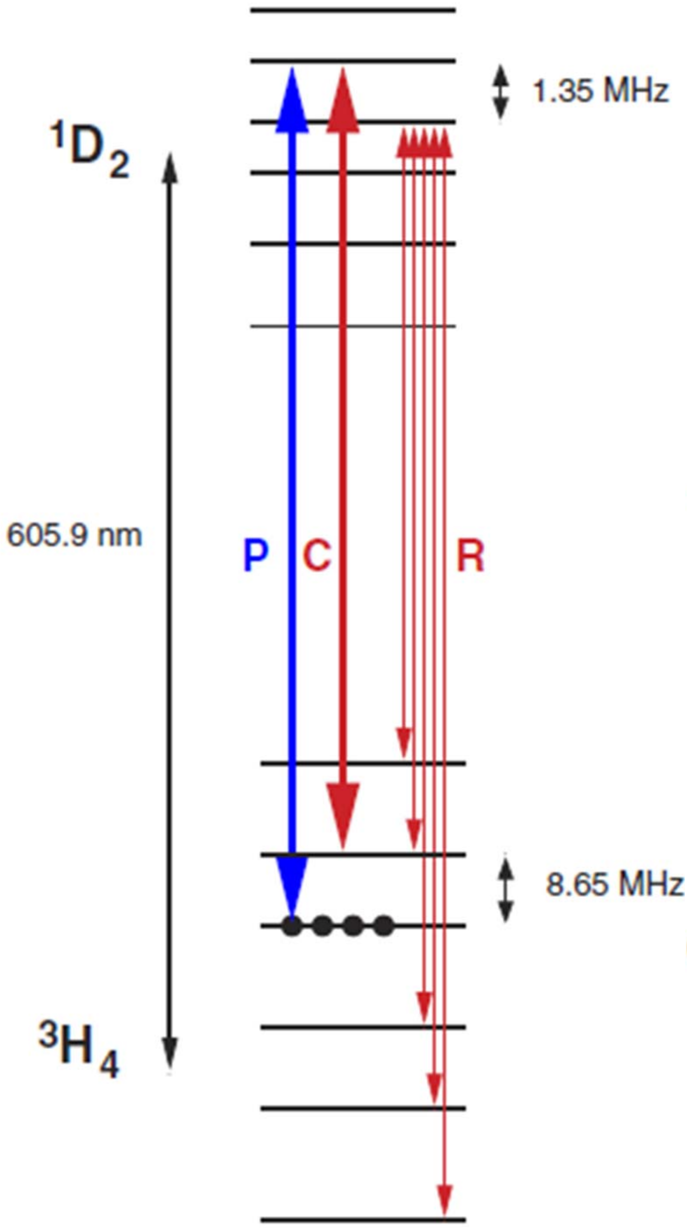


counterpropagating beams

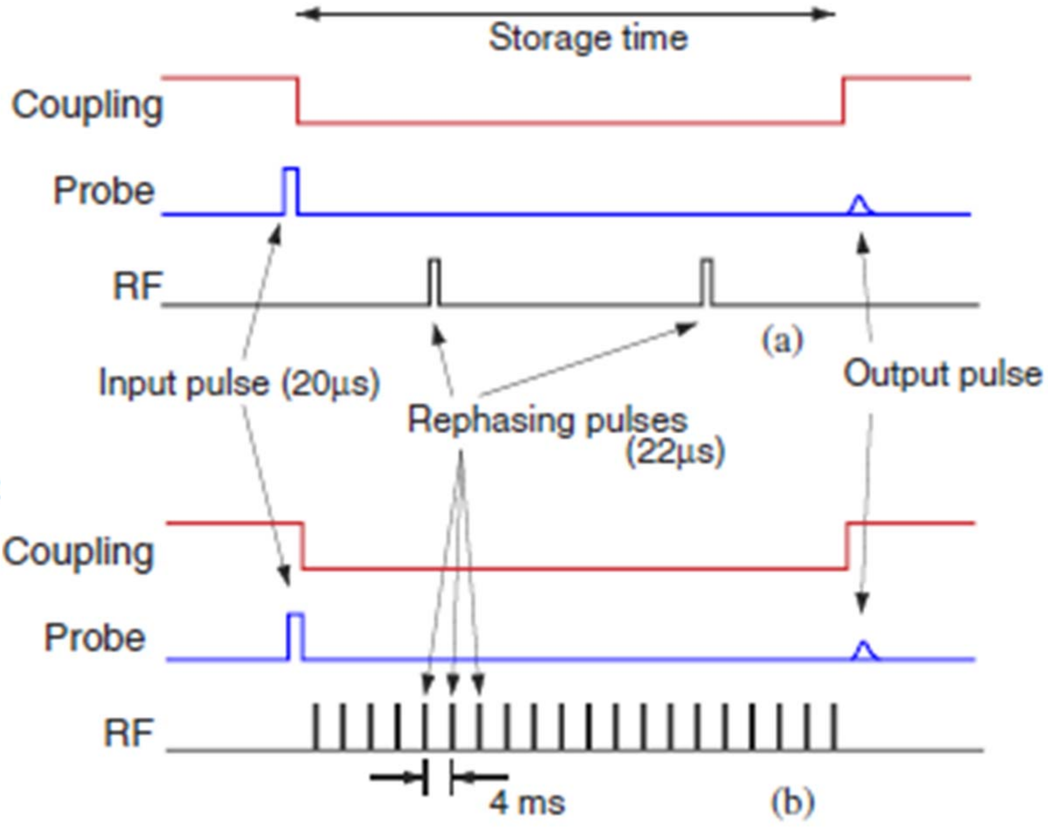
superconducting magnets

$Pr+:Y_2SiO_5$

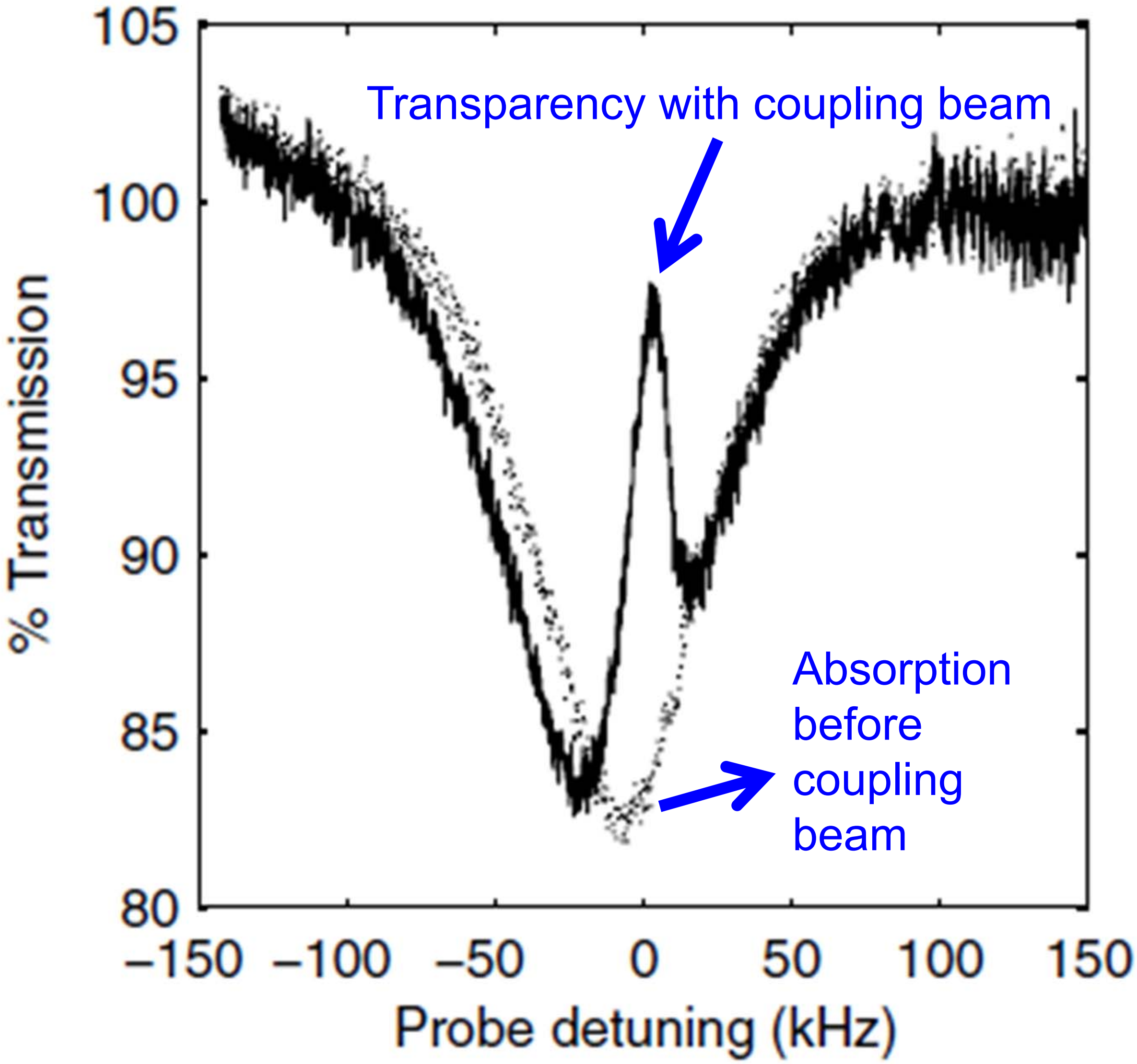
EIT in Pr+:Y_2SiO_5



P = pump
C = coupling
R = repump
RF = rephasing



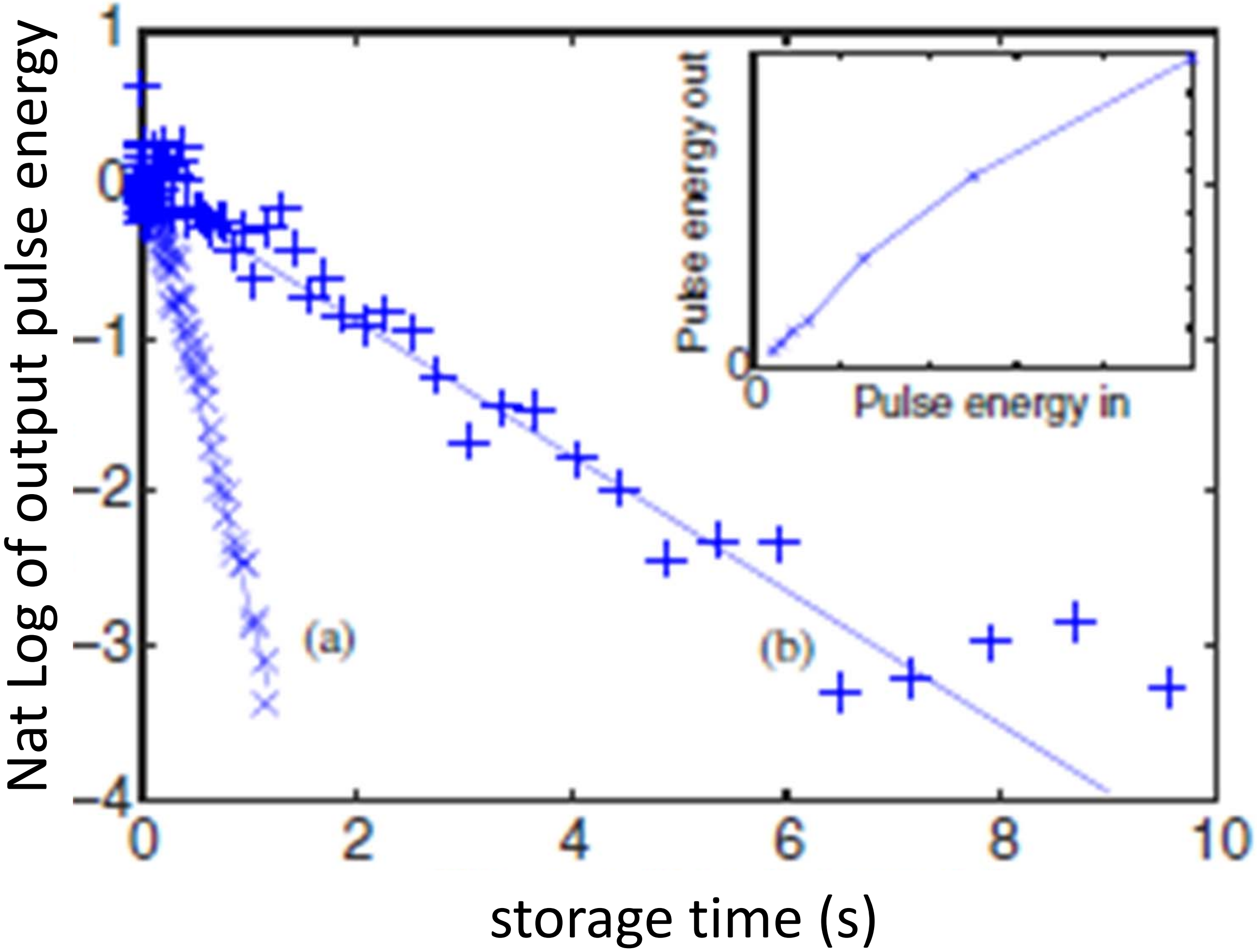
Results show a narrow transmission window



Transparency with coupling beam

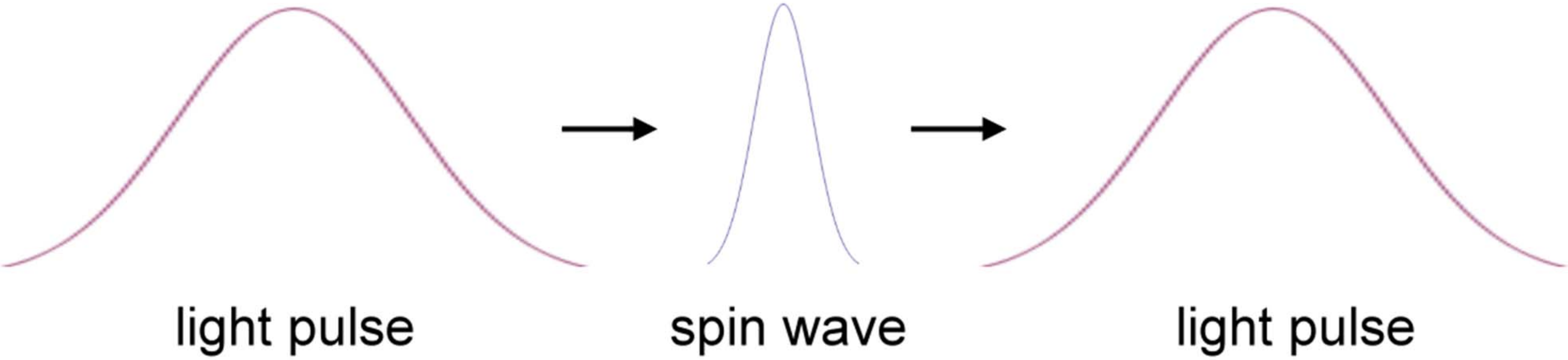
Absorption before coupling beam

Storage time was increased



Summary

1. Shoot a probe pulse onto the lattice.
2. The pulse is slowed down and compressed in the medium.
3. The pulse is saved as a spin wave.
4. The spin wave is converted back to pulse .



Application: Quantum memory

- Information in the form of light pulse is saved inside a crystal lattice.

- Information is exchanged between light fields and material systems in a controlled fashion.

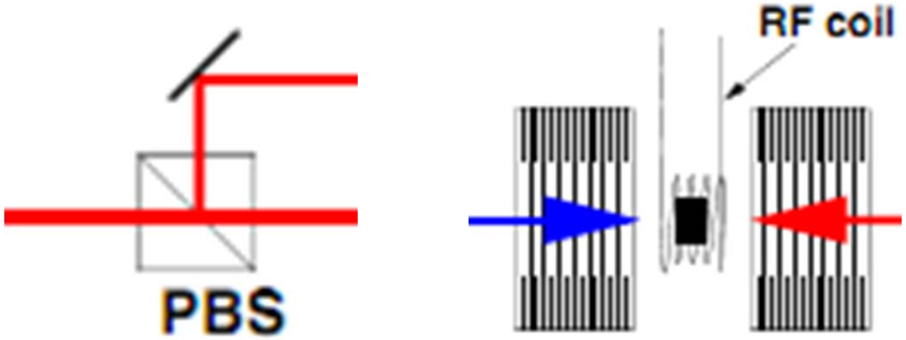
- Unaffected by the loss of atoms since spin wave gives rise from collective motion.

Critique

Though not much theory is mentioned, references are cited appropriately so as to enable us to follow.

Critique

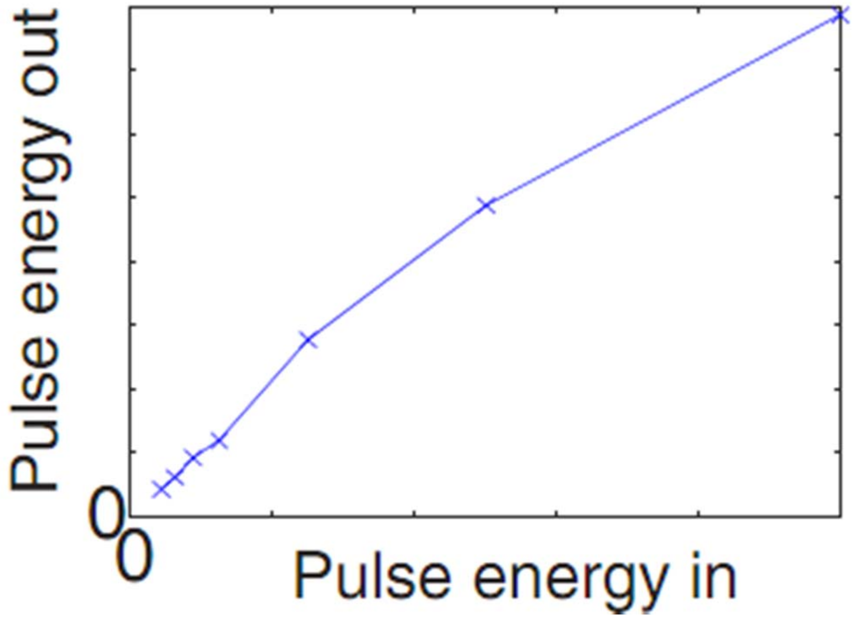
Some of the abbreviations were never defined.



- Cannot know the meaning without guessing
- The case would be even worse if there is not figure

Critique

Some plots are not labeled well.



- No numbers or units.
- Cannot be reproduced

Critique

The method of rephasing is only mentioned in the caption.

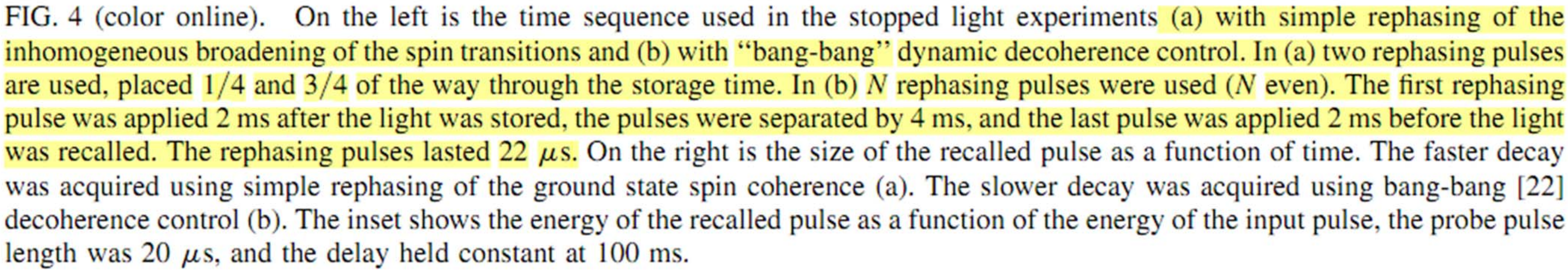
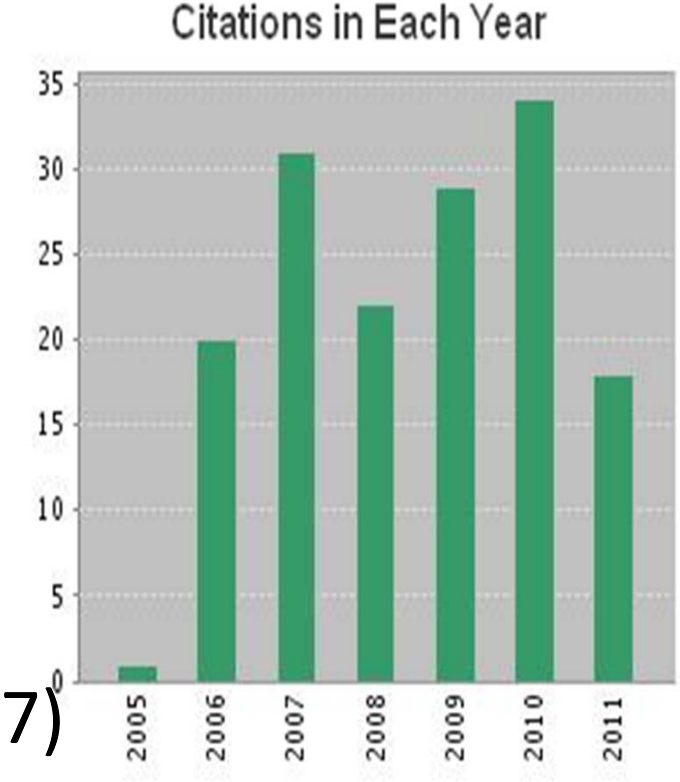


FIG. 4 (color online). On the left is the time sequence used in the stopped light experiments (a) with simple rephasing of the inhomogeneous broadening of the spin transitions and (b) with "bang-bang" dynamic decoherence control. In (a) two rephasing pulses are used, placed $1/4$ and $3/4$ of the way through the storage time. In (b) N rephasing pulses were used (N even). The first rephasing pulse was applied 2 ms after the light was stored, the pulses were separated by 4 ms, and the last pulse was applied 2 ms before the light was recalled. The rephasing pulses lasted 22 μs. On the right is the size of the recalled pulse as a function of time. The faster decay was acquired using simple rephasing of the ground state spin coherence (a). The slower decay was acquired using bang-bang [22] decoherence control (b). The inset shows the energy of the recalled pulse as a function of the energy of the input pulse, the probe pulse length was 20 μs, and the delay held constant at 100 ms.

Citations

- 157 citations total
- Journal of Physics B-Atomic Molecular and Optical Physics, 44, 135501(2011)
  - Effect of open system
- Nature Photonics, 2, 465 (2008)
  - Storing light in photonic crystal
- Physical Review Letter, 2, 465 (2007)
  - Optimal photon storage



Questions?