Atom-Light Entanglement

(Project begins 2005)

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THE AUSTRALIAN NATIONAL UNIVERSITY

Atom-light entanglement

The Centre's strongest experimental strengths are
- trapping and manipulation of atoms
- generation of non-classical states of light

Given the interest in quantum information transfer/storage, we should try to combine this expertise

Possibilities:

1. Generate non-classical light from atomic samples

2. Generate non-classical atomic fields using optical methods

3. Transfer quantum state between optical and atomic fields

Atom-light entanglement

Ultimately, in optics (for us): "Non-classical" = squeezing

Task 1: Generate squeezed light at some useful atomic transition

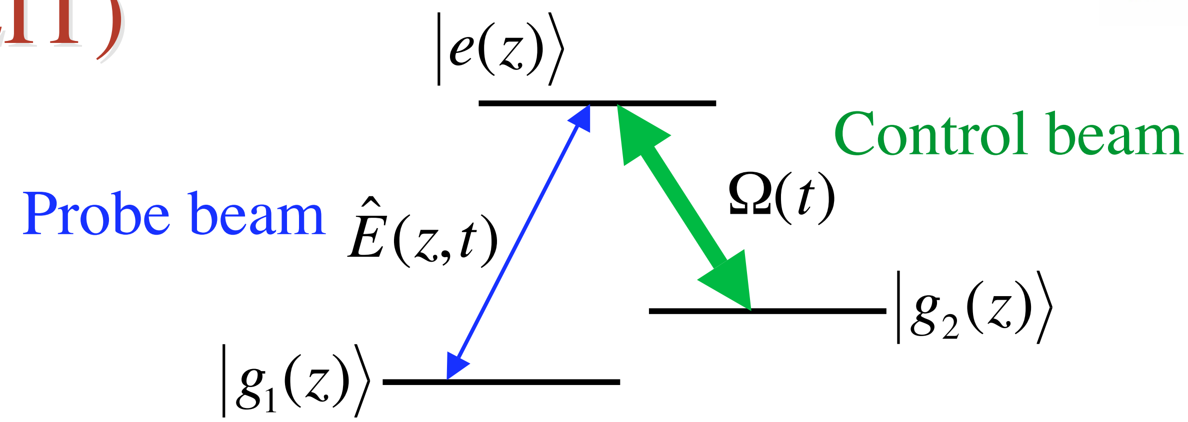
- Non-trivial
- Need new materials to use second harmonic generation
- Direct generation from atomic vapour?

Task 2: Use the non-classical light

- Use for atom laser outcoupling
    - "old-school" EPR beams
    - requires two simultaneous experimental efforts
- Storage of squeezed light in atomic media
    - requires vapour cell (not a BEC)

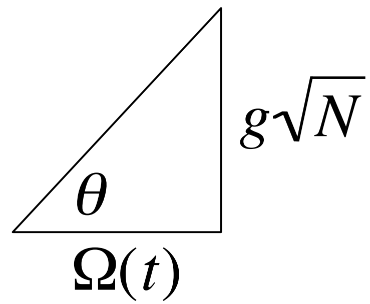
poster by
Simon Haine

Electromagnetically Induced Transparency (EIT)



- Polaritons are linear combinations of the optical and atomic fields

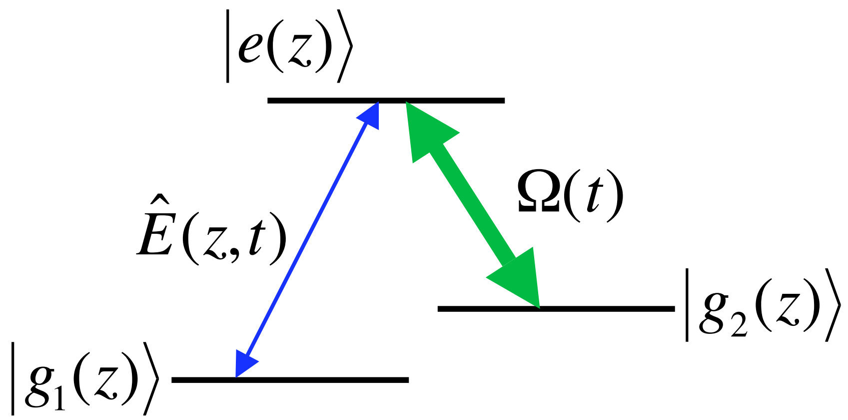
$$\hat{\Psi}(z,t) = \cos\theta(t)\ \hat{E}(z,t) - \sin\theta(t)\sqrt{N}\ \hat{\sigma}_{g_1 g_2}(z,t)$$



- This is a dark state
- It is "slow light", travelling at speed $v = c \cos^2(\theta(t))$
- High control field $\Rightarrow$ mainly optical
- Low control field $\Rightarrow$ mainly atomic

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

Time-varying control field



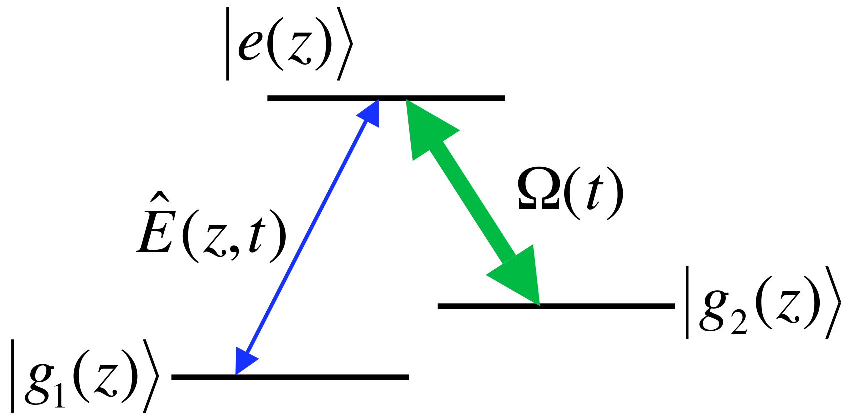
While the dark state polariton propagates, it can be altered.

- If it can be done adiabatically, then a pulse can be stored
- If it can be reversed, the pulse can be retrieved

Full quantum reconstruction - the same optical quantum field emerges.
This is "stored" light

M. Fleischauer and M.D. Lukin, Phys. Rev. A **65**, 022314, (2002)

Really?

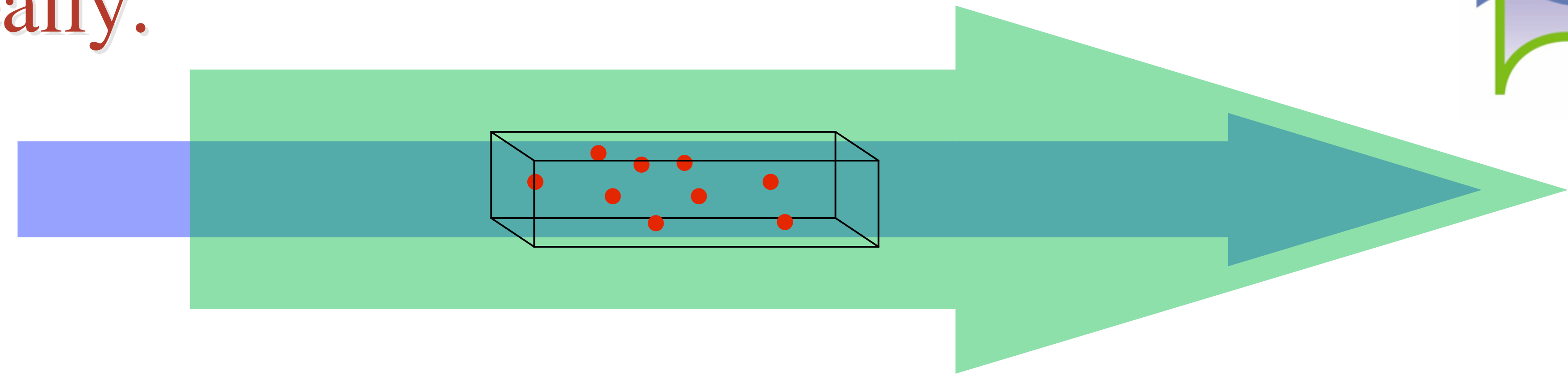


What about a more realistic model?

- Non-adiabatic entry into the dark state polariton
- Non-adiabatic exit back into the light pulse (spontaneous emission)
- Atom loss, atomic movement
- Collision-induced decoherence $\gamma_{g_1 g_2}$
- B-field decoherence

M. Fleischauer and M.D. Lukin, Phys. Rev. A **65**, 022314, (2002)

Really.



- Extension of feasibility studies to include
    - non-zero ground state decoherence (code for many effects)
    - atomic quantum noise operators in the Langevin equations

- These effects are the dominant losses, but small

poster by
Amy Peng

$$15\,\text{Hz} \le \gamma_{g_1 g_2} \le 1\,\text{kHz}$$

Expected transmission for reasonable storage (1ms): T ~ 80%

This maps squeezing from $0.7 \rightarrow 0.78$

The experiment through a theorist's eyes