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Information velocity in ultra-slow and fast light media

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Outline

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- Review of ultra-slow light.
- Review superluminal light.
- Understanding information velocity.
- Our results.
- Summary.

Review of Ultra-Slow Light

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Light speed reduction to 17 metres per second in an ultracold atomic gas

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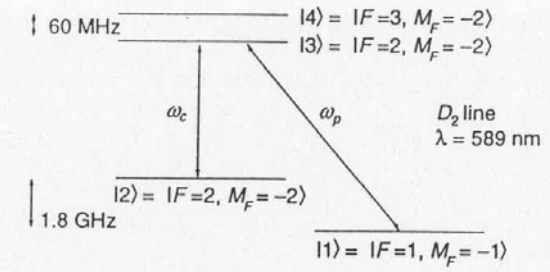
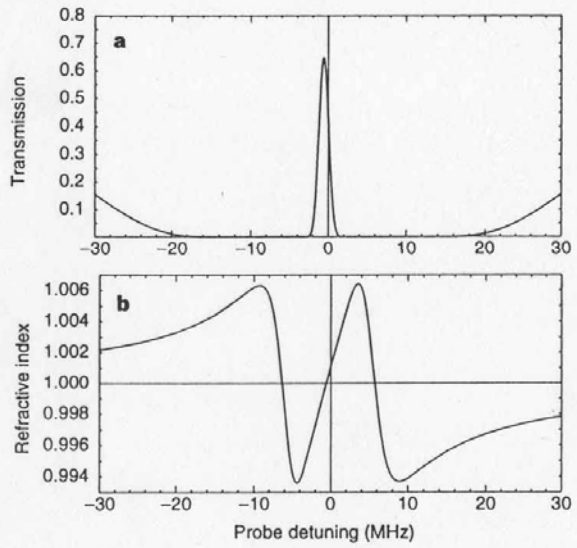
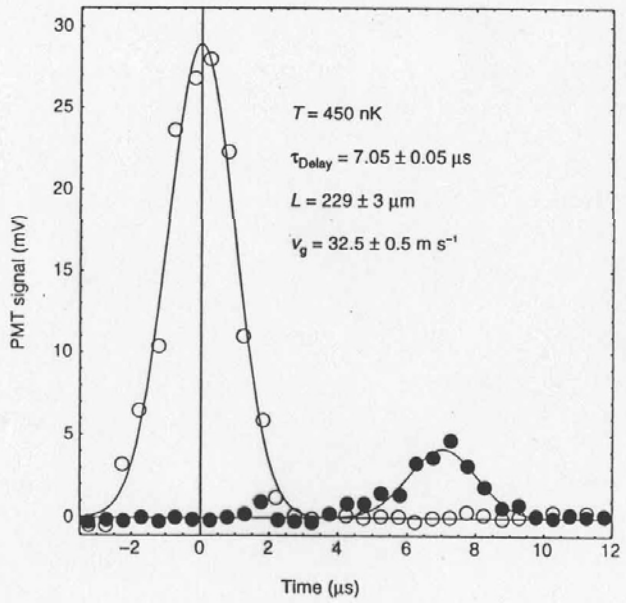
Nature 397, 594 1999

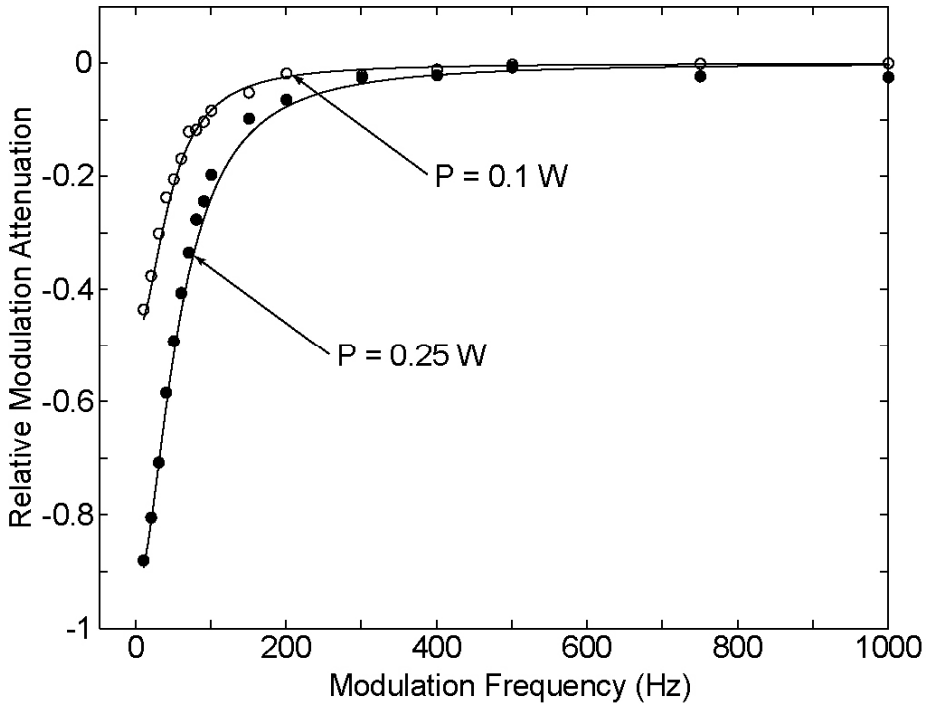


$$v_g = \frac{c}{n(\omega_p) + \omega_p \frac{dn}{d\omega_p}} \approx \frac{\hbar c \epsilon_0}{2\omega_p} \frac{|\Omega_c|^2}{|\mu_{13}|^2 N}$$

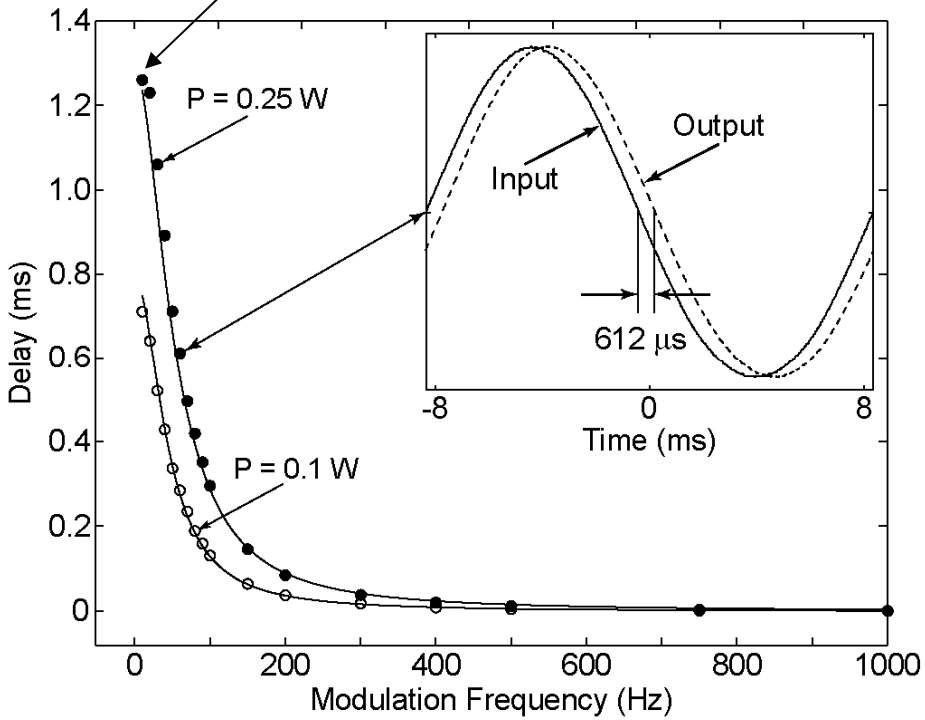




Ultra-Slow Light in Ruby



58 m/s



Published in Physical Review Letters **90**, 113903 (2003).

Superluminal Light

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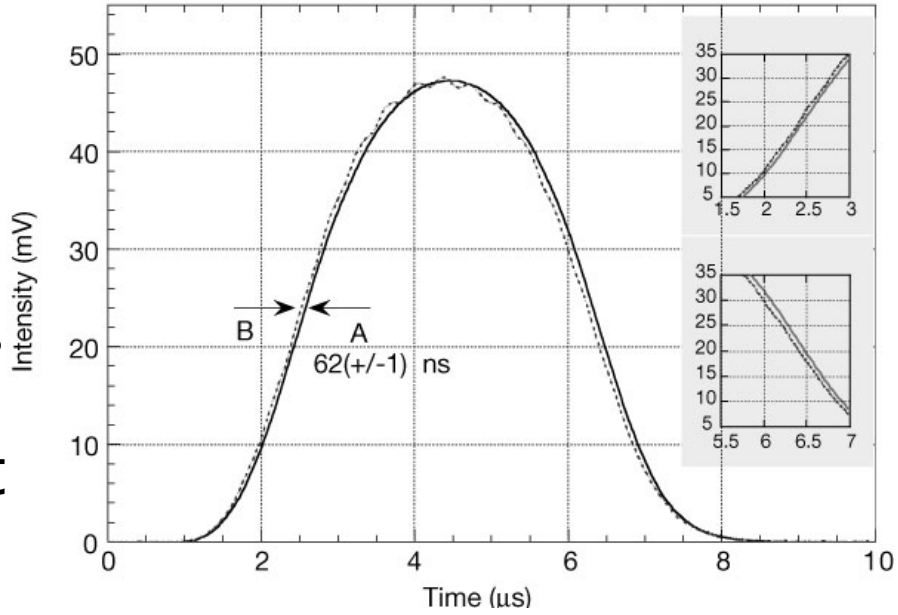
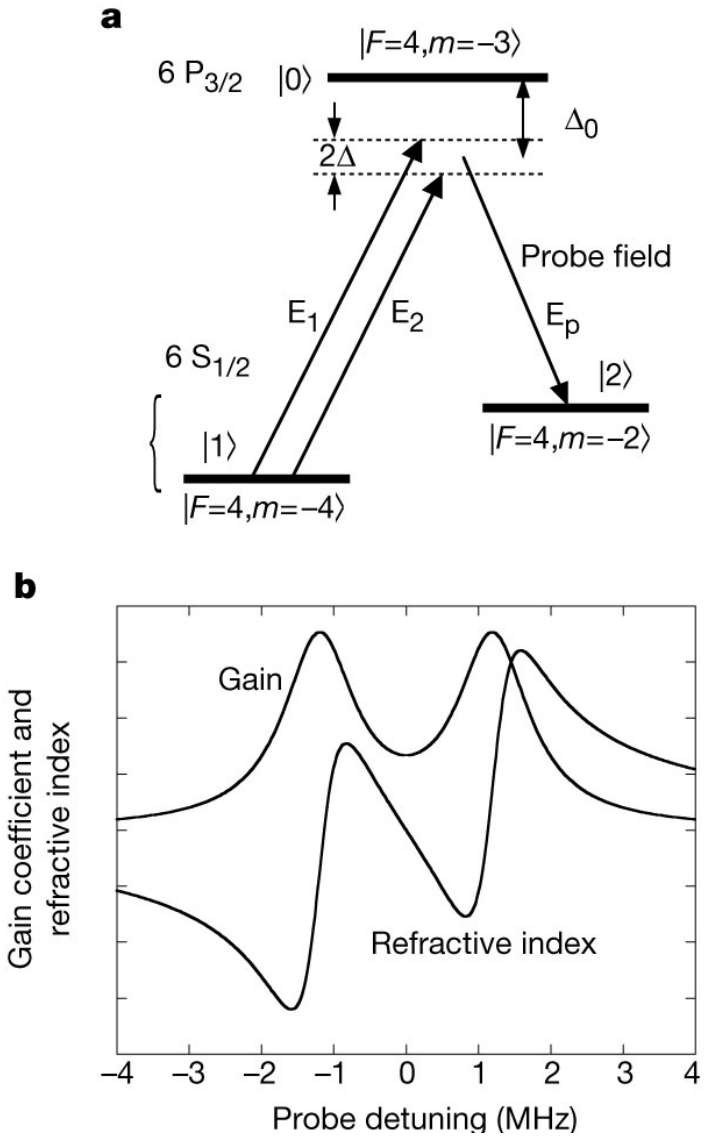
- Resonant Absorber
  - S. Chu and S. Wong, Phys. Rev. Lett. **48**, 738 (1982).
- EIA
  - v_g = -c/23,000: A. V. Akulshin *et al.*, Phys. Rev. Lett. **83**, 4277 (1999).
  - v_g = -c/14,400: K. Kim *et al.*, Phys Rev. A **68**, 013810 (2003).
- Gain-assisted superluminal light propagation
  - L.J. Wang, A. Kuzmich, and A. Dogariu, Nature **406**, 277 (2000).

v_g = -c/310



Superluminal Light



Fast and Slow Light in Alexandrite at 476 nm

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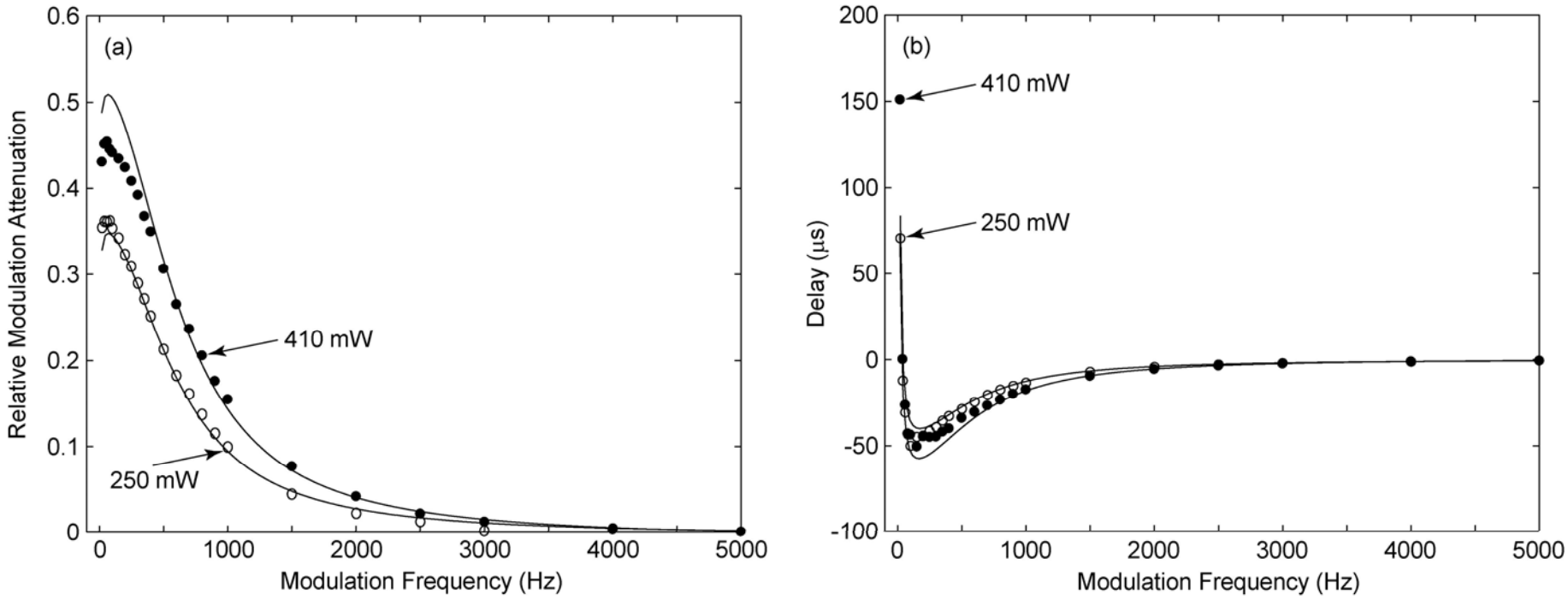
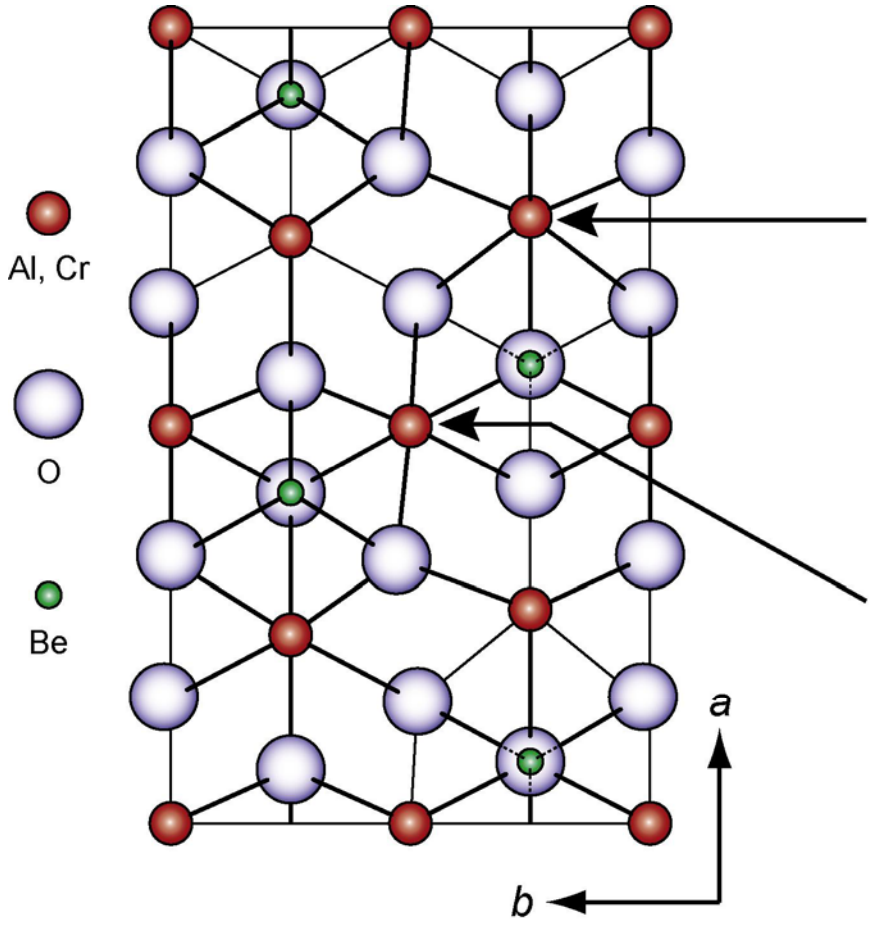
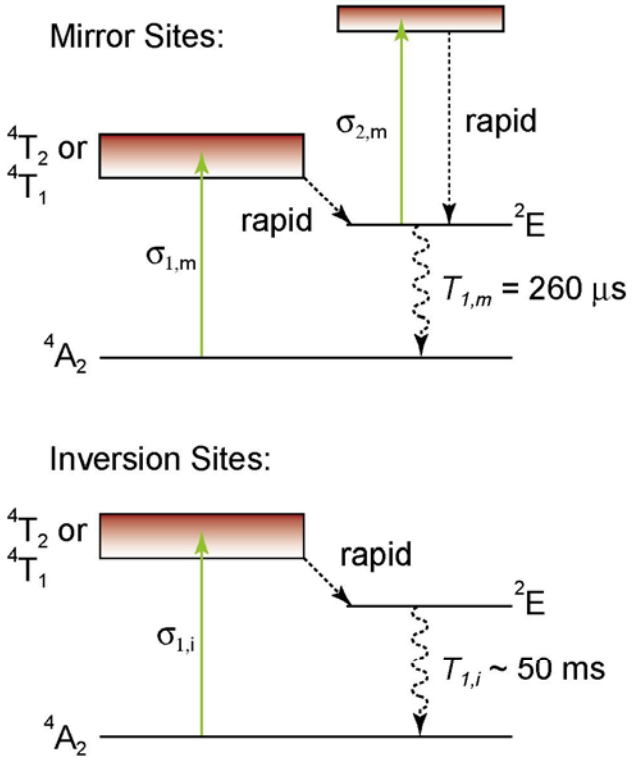


Published in Science **301**, 200 (2003).

Alexandrite Crystal Structure





Information Velocity

- What is a signal?
  - Brillouin: "*A signal is a short isolated succession of wavelets, with the system at rest before the signal arrived and also after it has passed.*" – L. Brillouin (1960), p. 7.
  - Finite Duration = Infinite Spectrum!
- What is information (or signal) velocity?
  - Brillouin:
    - Normal Dispersion: $v_s = v_g$
    - Anomalous Dispersion: $v_s \leq c$
  - Sommerfeld: "*It can be proven that the signal velocity is exactly equal to c if we assume the observer to be equipped with a detector of infinite sensitivity, and this is true for normal or anomalous dispersion, for isotropic or anisotropic medium, that may or may not contain conduction electrons.*"

Information Velocity in a Fast Light Medium.

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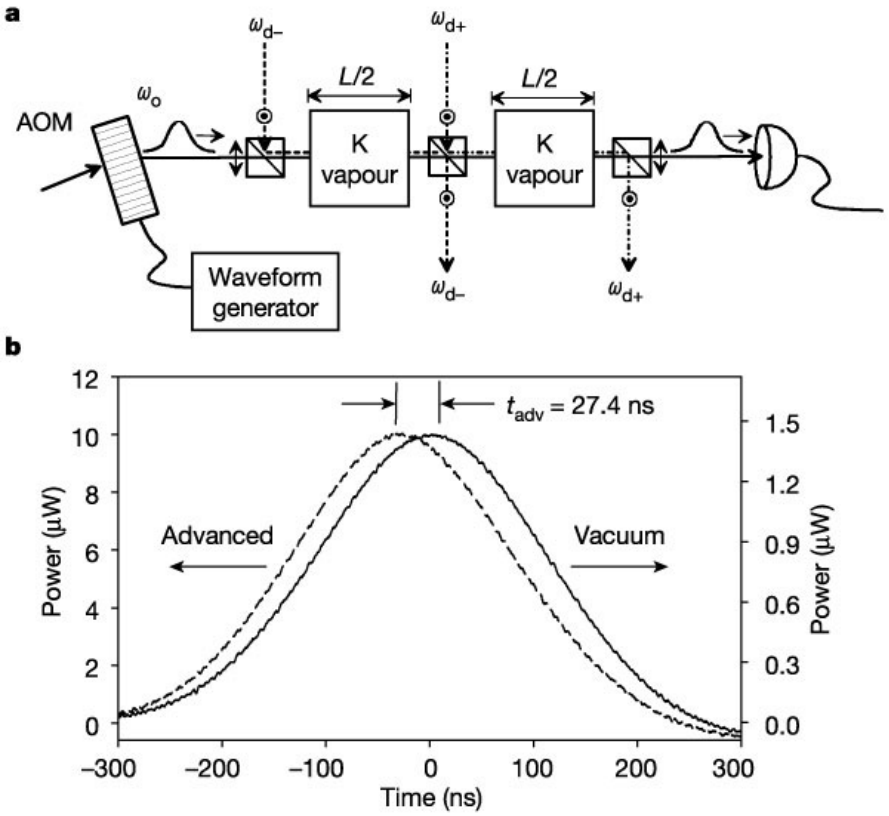

$v_g = -c/19.6$

- M.D. Stenner, D.J. Gauthier, and M.I. Neifeld, Nature **425**, 695 (2003).
- Pulses are not distinguishable "early."
- $v_i \leq c$

Information Velocity in a Fast Light Medium.

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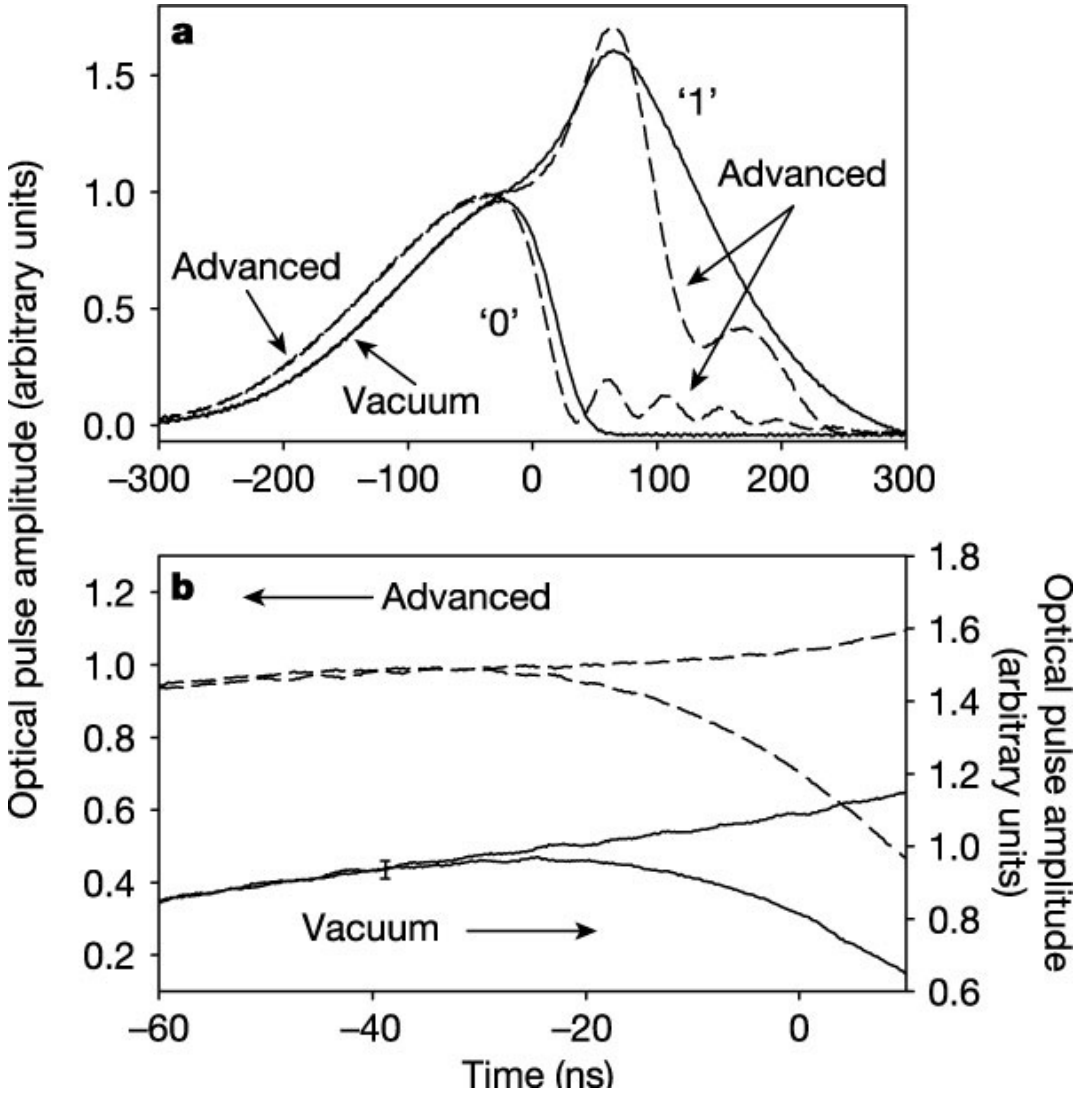


Precursors

- Finite Signal Duration = Infinite Spectrum

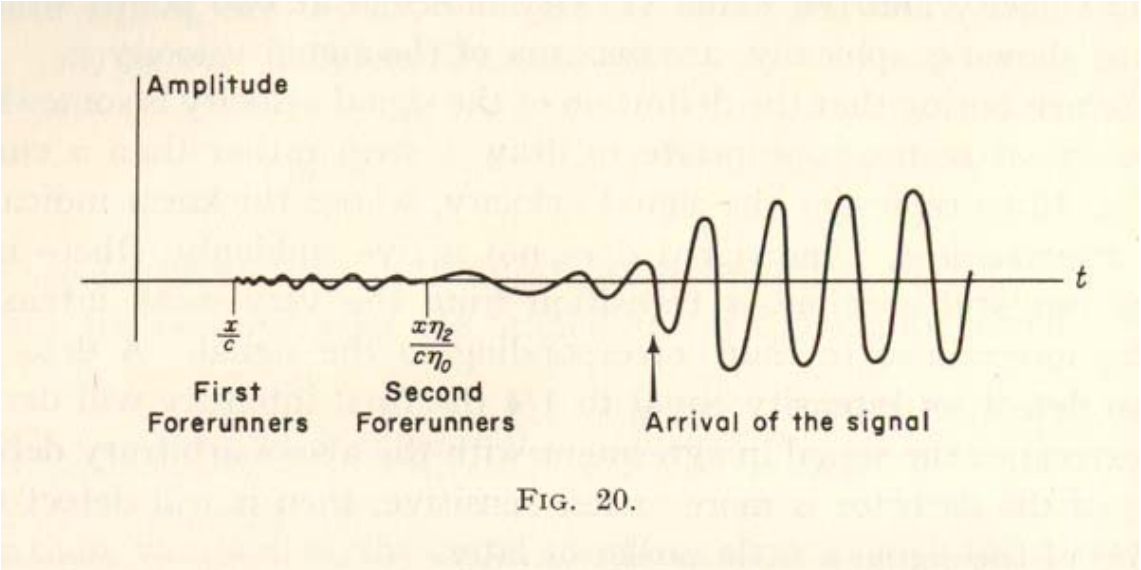


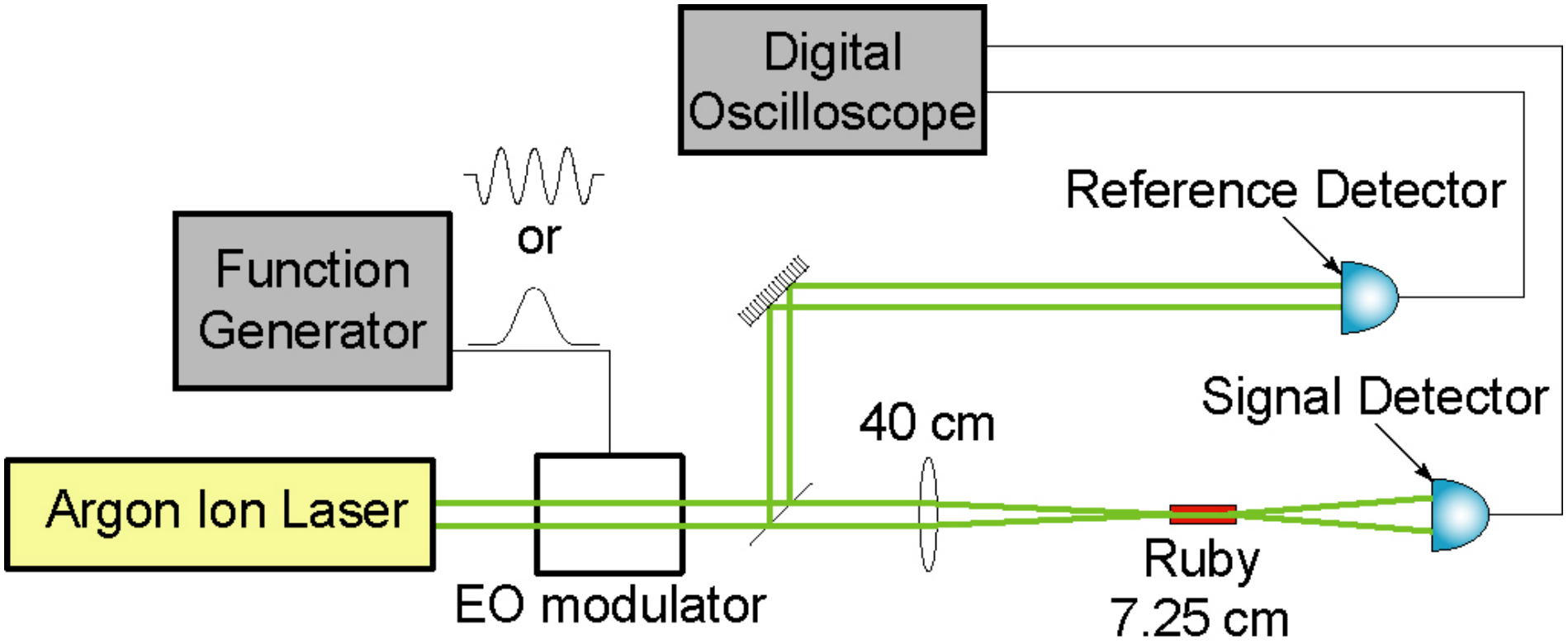
FIG. 20.

- Physical interpretation: Front travels through medium before a polarization can build up.
  - Sommerfeld Precursor: High frequency components
  - Brillouin Precursor: Low frequency components

Can you detect a precursor?

- Microwaves – P. Plesko and I. Palócz, Phys. Rev. Lett. **22**, 1201 (1967).
- Optical Precursors in Semiconductors – J. Aaviksoo, J. Kuhl, and K. Ploog, Phys. Rev. A **44**, R5353 (1991).

Experimental Setup



Issue of Bandwidth – Fast Light Material

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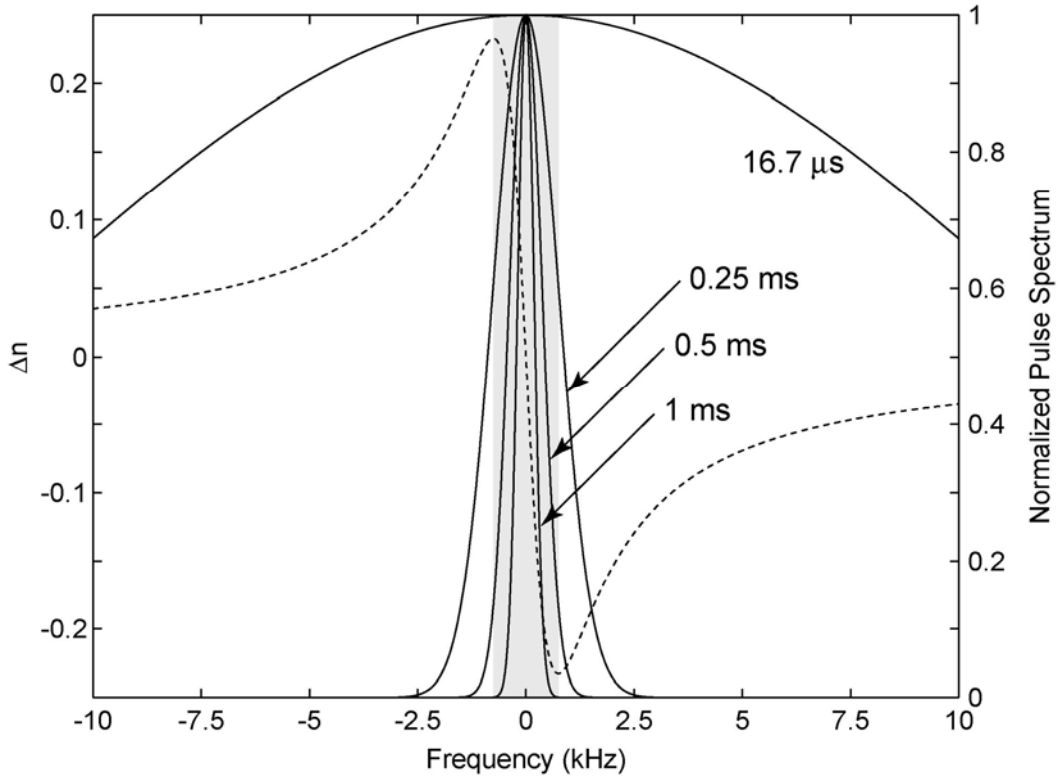

Issue of Bandwidth – Fast Light Material

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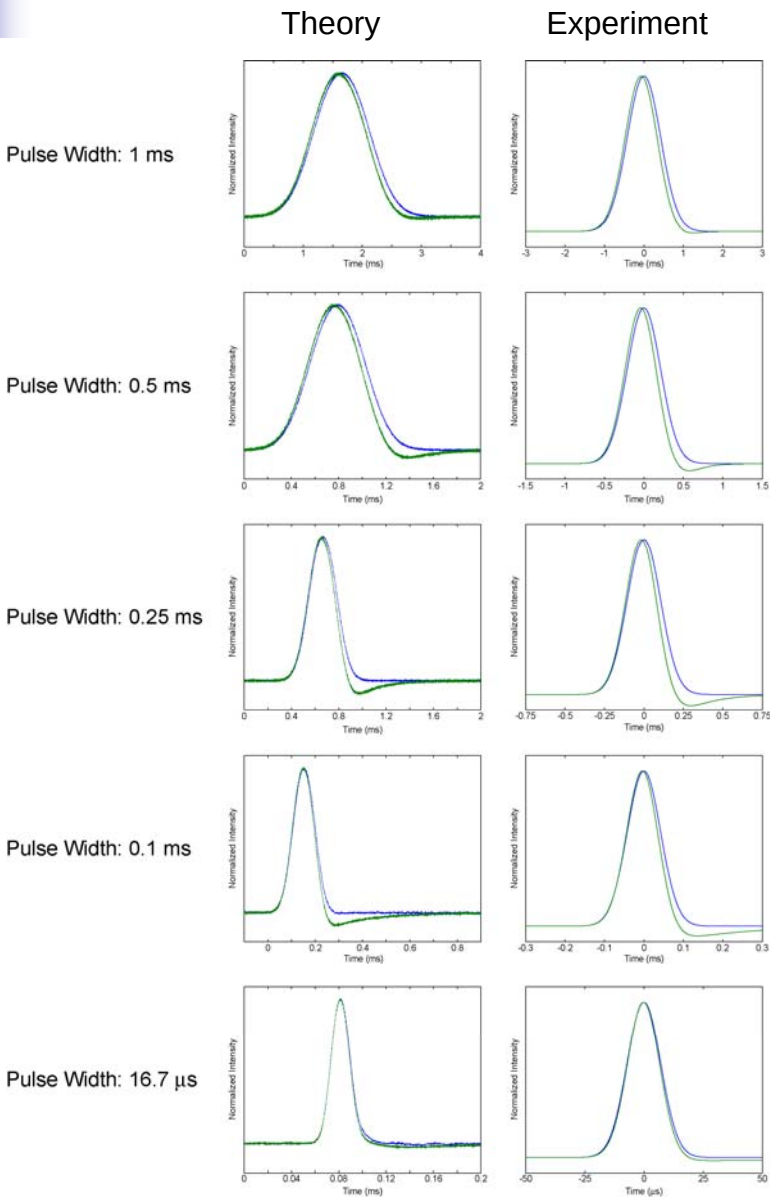

Issue of Bandwidth – Slow Light Material

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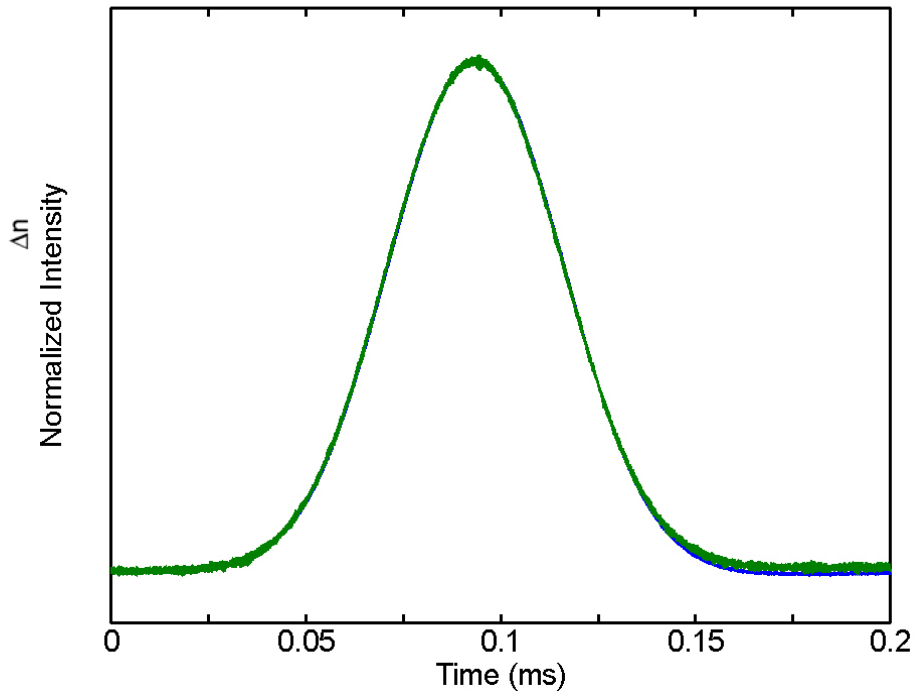
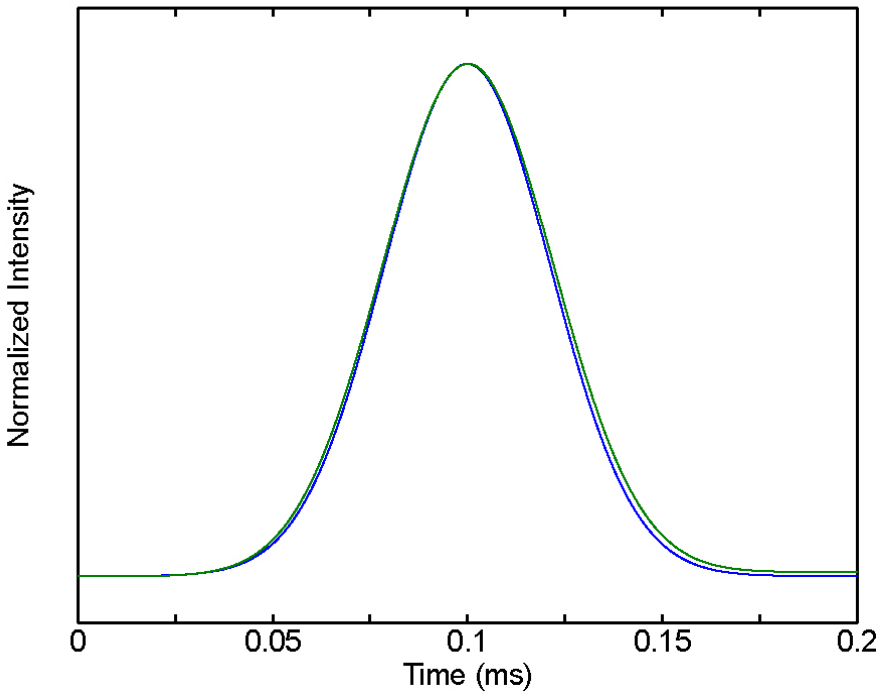
50 μs pulse in ruby

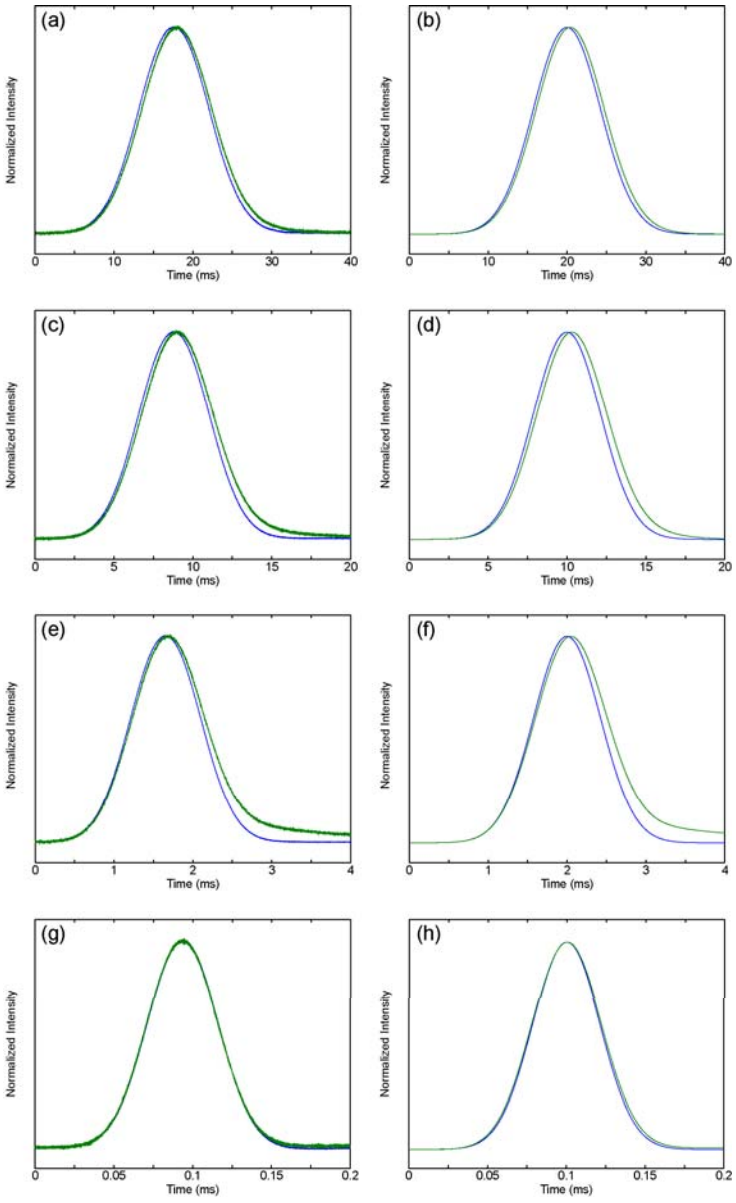
Experiment



Theory



Issue of Bandwidth – Slow Light Material



Summary

- We investigated the effect that pulse length has on pulse propagation.
- Pulses are distorted whenever the pulse bandwidth becomes comparable to the region of large dispersion.
- If the pulse bandwidth too large, the distortion disappears – and so does the delay.
- Bandwidth must be considered in any discussion on information velocity.

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