Spectroscopic Interferometry Using Slow-Light Media

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Introduction to Slow Light

- In a dispersive medium, pulses propagates at the group velocity

$$v_g = \frac{d\omega}{dk} = \frac{c}{n_g}$$

- Group index

$$n_g = n + \omega\frac{dn}{d\omega}$$

- Slow light medium:

$$n_g \gg n$$

Atomic Vapor $n_g \approx 1.76 \times 10^7$ Hau, *et al.*, Nature **397**, p.594 (1999).

Solid system $n_g \approx 5.2 \times 10^6$ Bigelow, *et al.*, Science, **301** , p.200 (2003).

Introduction to Slow Light

- Promising Applications in Communications Systems
  - Optical Buffers/Delay lines
  - Data Re-synchronization
  - Jitter Correction

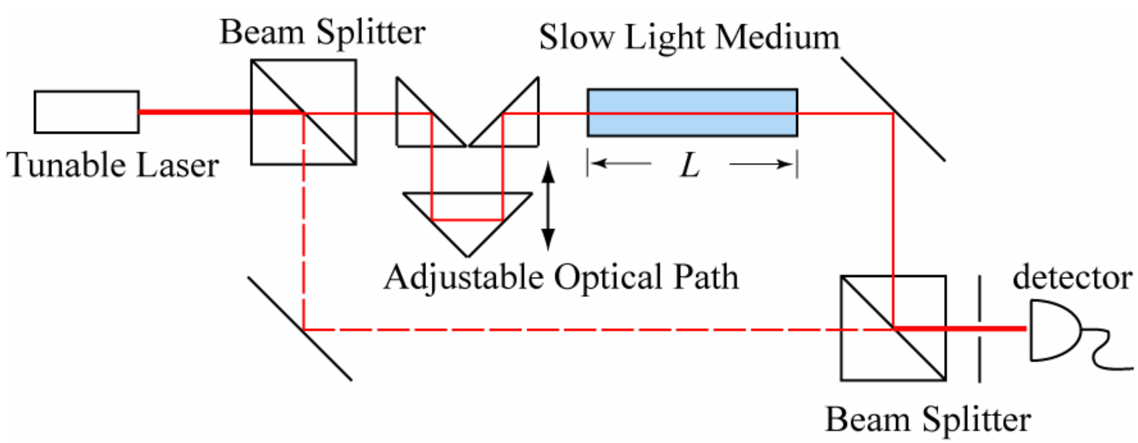
- How About Applications in Other Areas?
  - Interferometry

Spectroscopic Interferometry

- Certain types of spectroscopic interferometers are sensitive to frequency change
  - Mach-Zehnder type[1]
  - Michelson type
  - Fabry-Perot type[2]
  - Sagnac type
  - …

1. M. Soljačić *et al.*, JOSA B **19(**9) p. 2052, 2002
2. M.S. Shahriar *et al.,* ArXiv*,* quant-ph/0507139

Mach-Zehnder Interferometer

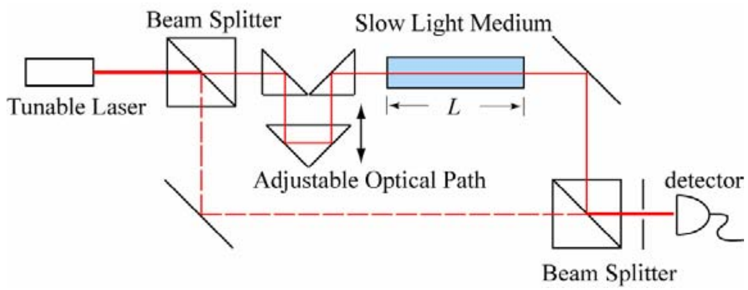


$$T(\omega) = \frac{1}{2}(1 + \cos\Delta\phi) = \frac{1}{2} + \frac{1}{2}\cos\frac{L\omega n(\omega)}{c}$$

Sensitivity: $$\frac{d\Delta\phi}{d\omega} = \frac{L}{c}n_g$$

Mach-Zehnder Interferometer

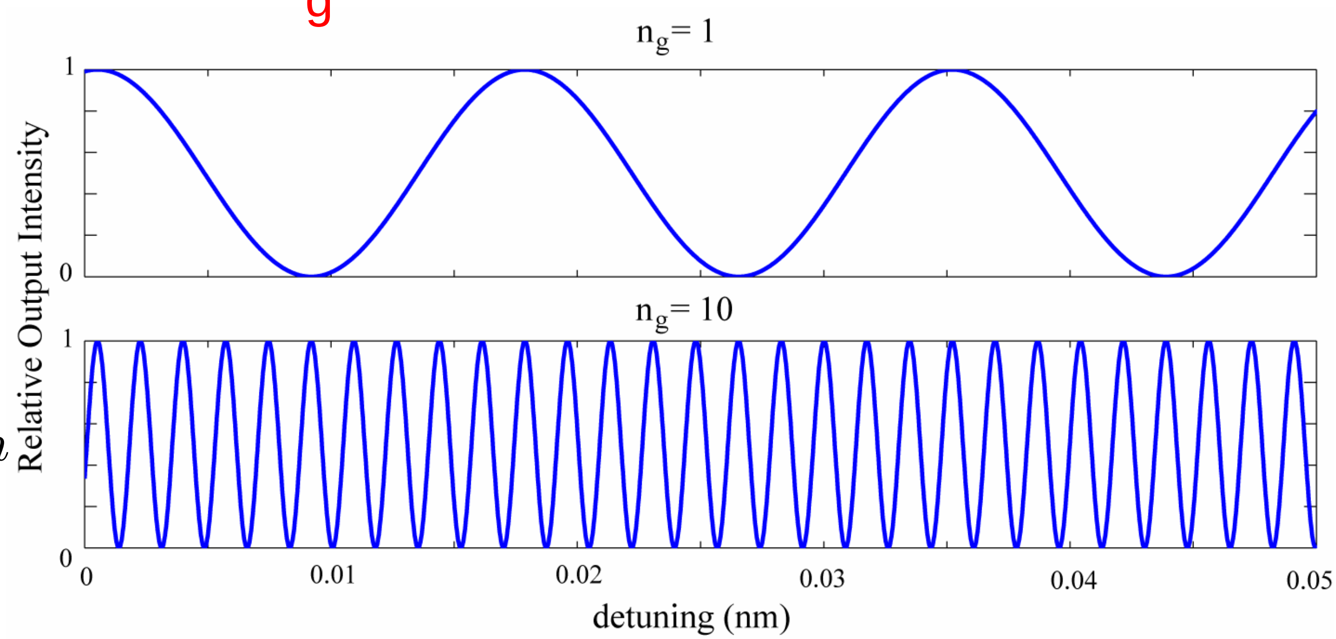
- Numerical Ex. L = 2cm



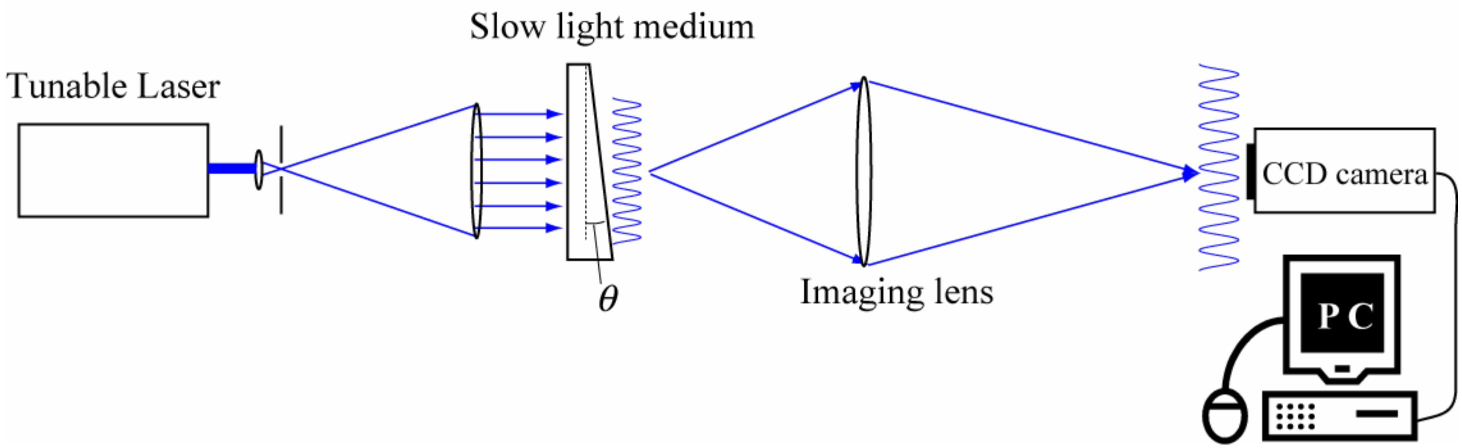
- Spectral Resolution can be enhanced n_g times

$$\Delta\lambda \approx 0.01nm$$

$$\Delta\lambda \approx 0.001nm$$



Wedge Etalon Interferometer



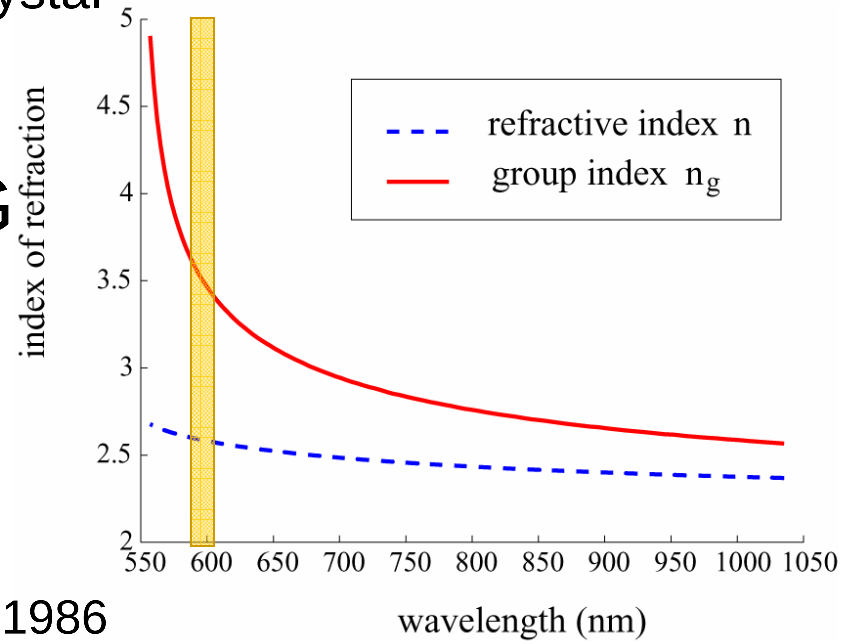
Frequency change -> fringe movement

Moving rate of fringe patterns

$$\frac{dx_m}{d\omega} = -\frac{cm\pi n_g}{\theta n^2 \omega^2}$$

Experiment

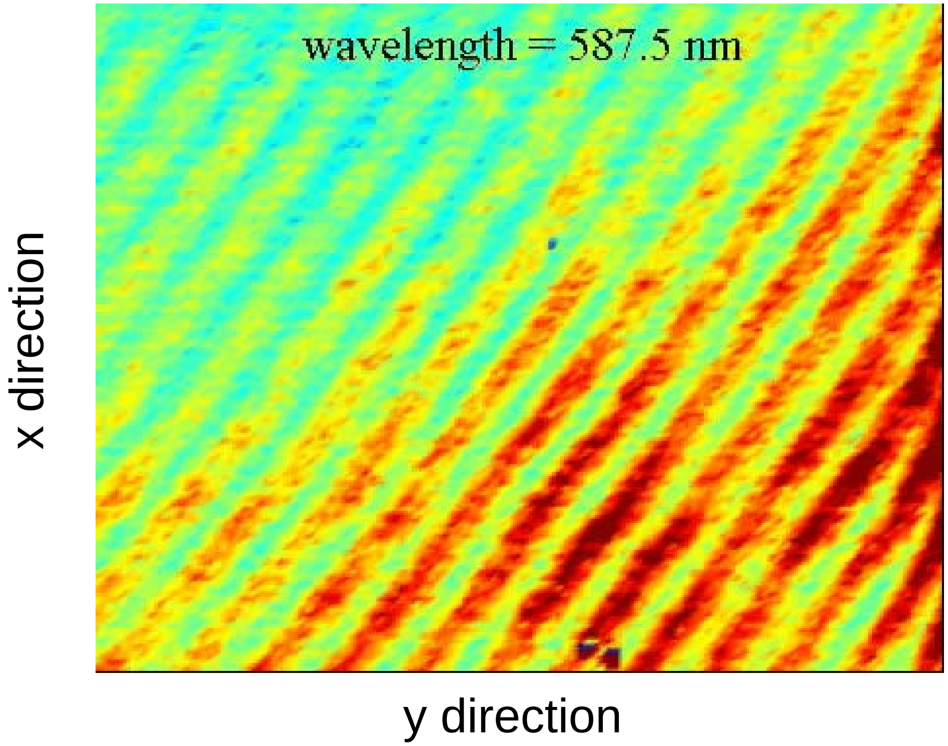
- Material: $CdS_{0.75}Se_{0.25}$
  - Absorption band edge at 2.24eV (theory); 2.15eV (measured)
  - ~0.5mm thick, c-cut, single crystal
- Laser: Rhodamine 6G Dye laser
  - Range: 585 - 605 nm



Ref.: Jensen *et al.*, JOSA B, **3**(6) p.857, 1986

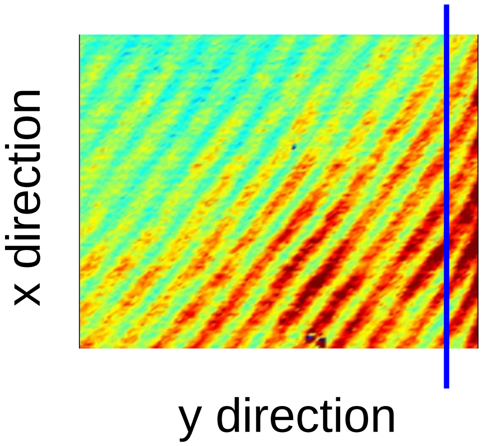
Experimental Result

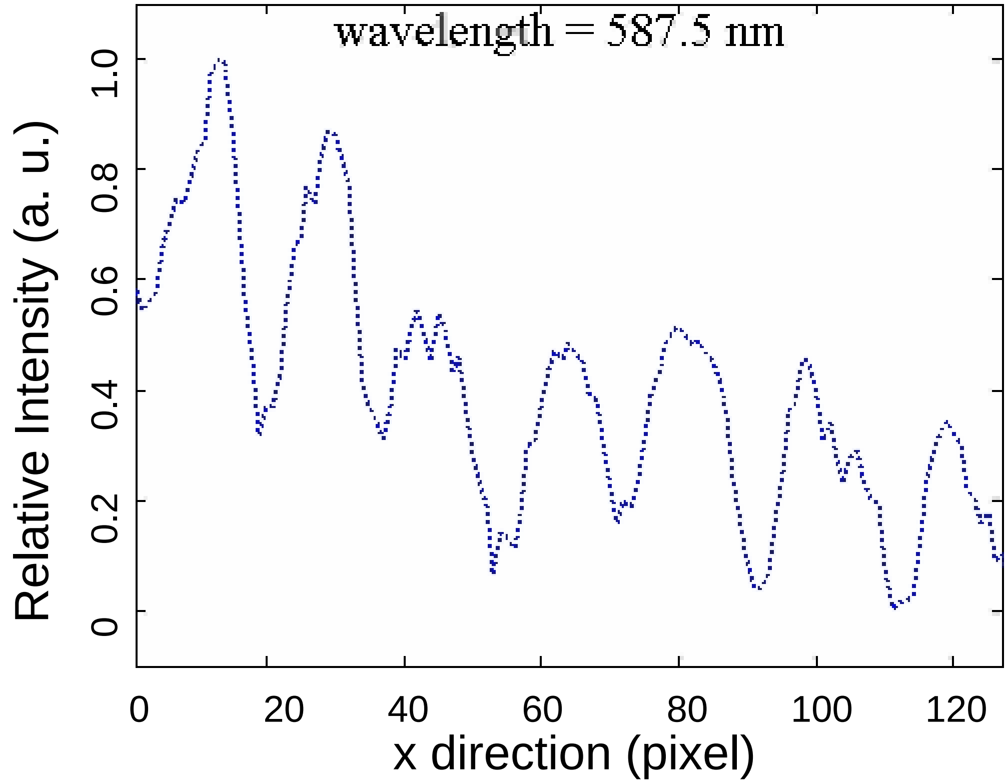
- Fringe Patterns (CCD image)
  - 587.5 – 587.7 nm w/ 0.01 nm increment



Detection of Fringe Movement

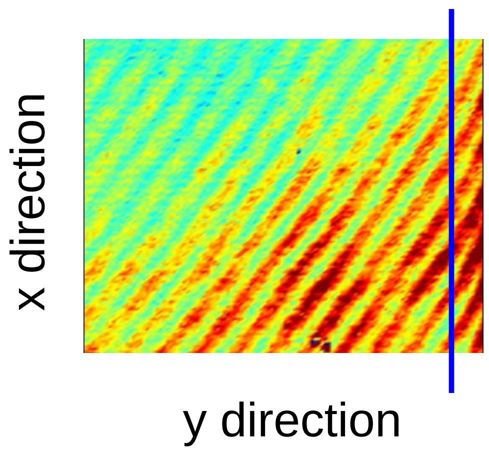
- Raw data: single cross-section

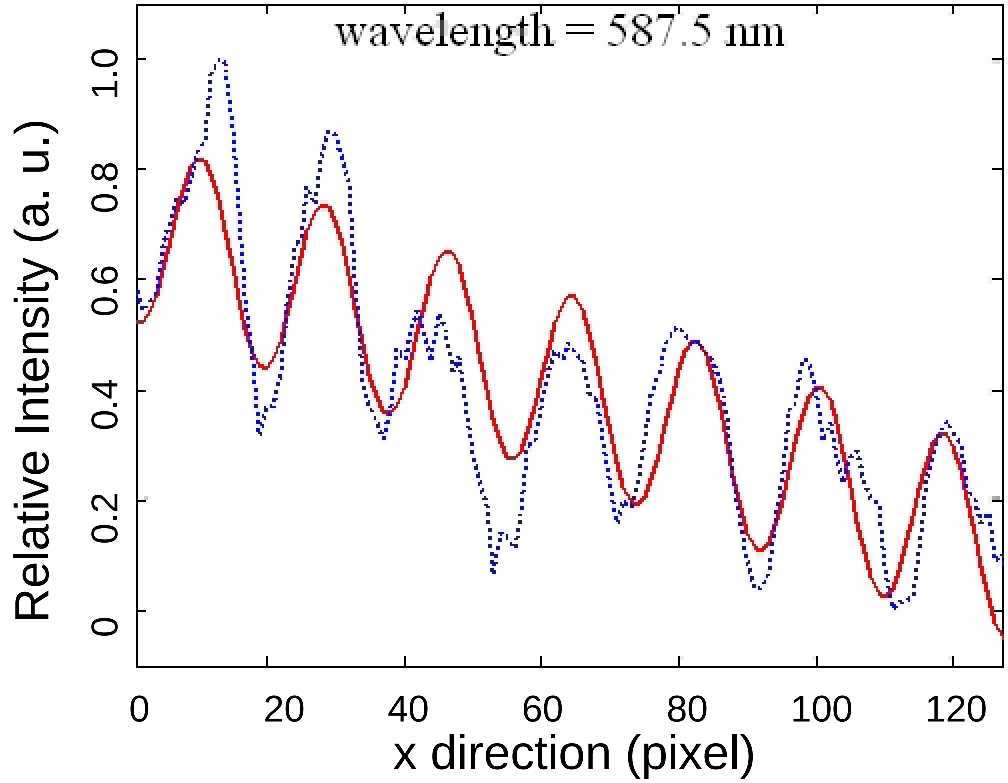




Detection of Fringe Movement

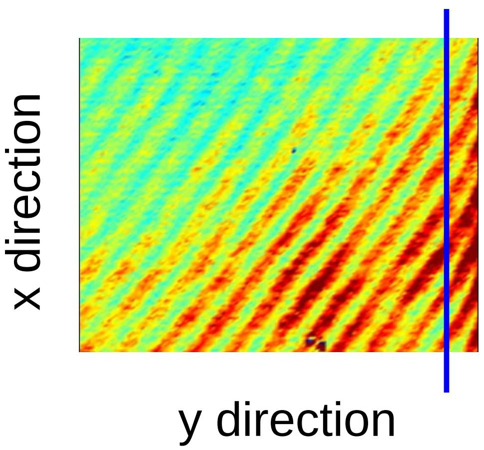
- Sinusoidal fitting

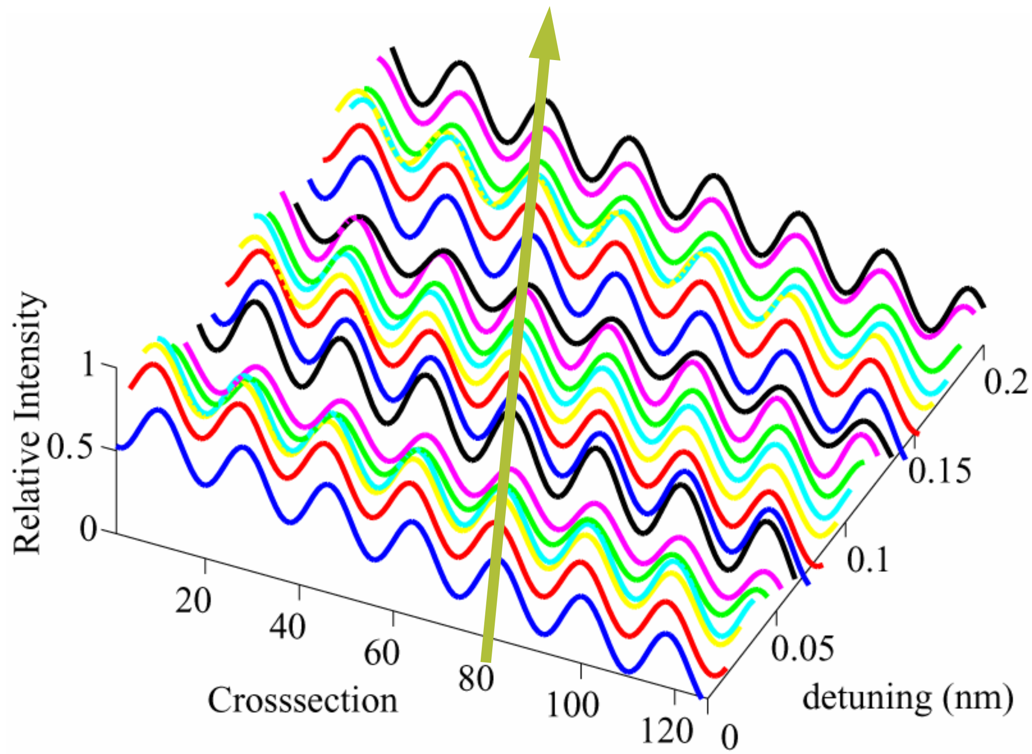




Detection of Fringe Movement

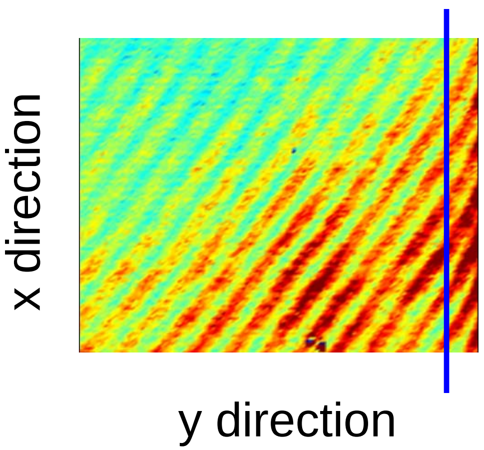
- Fringe movement = Phase Change of the fitted sinusoidal function

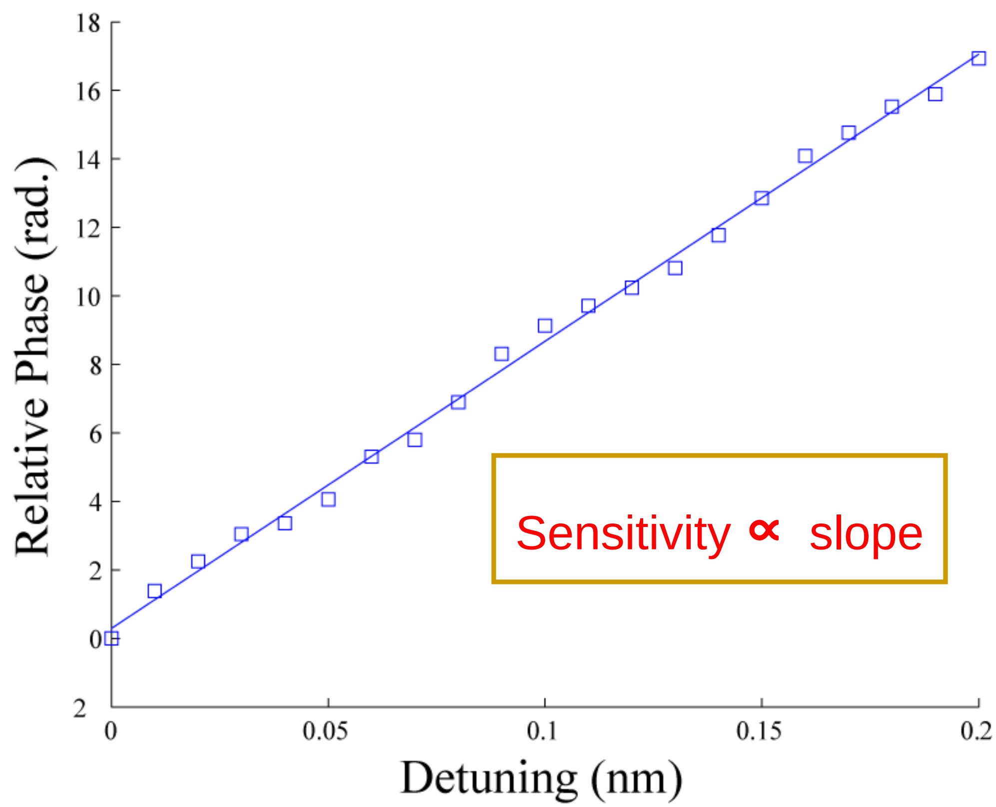




Spectral Sensitivity Analysis

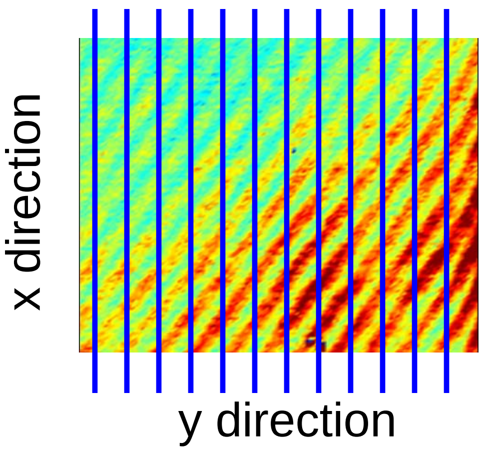
- Relative phase vs. detuning
  - One cross-section, detuned near 587.5nm

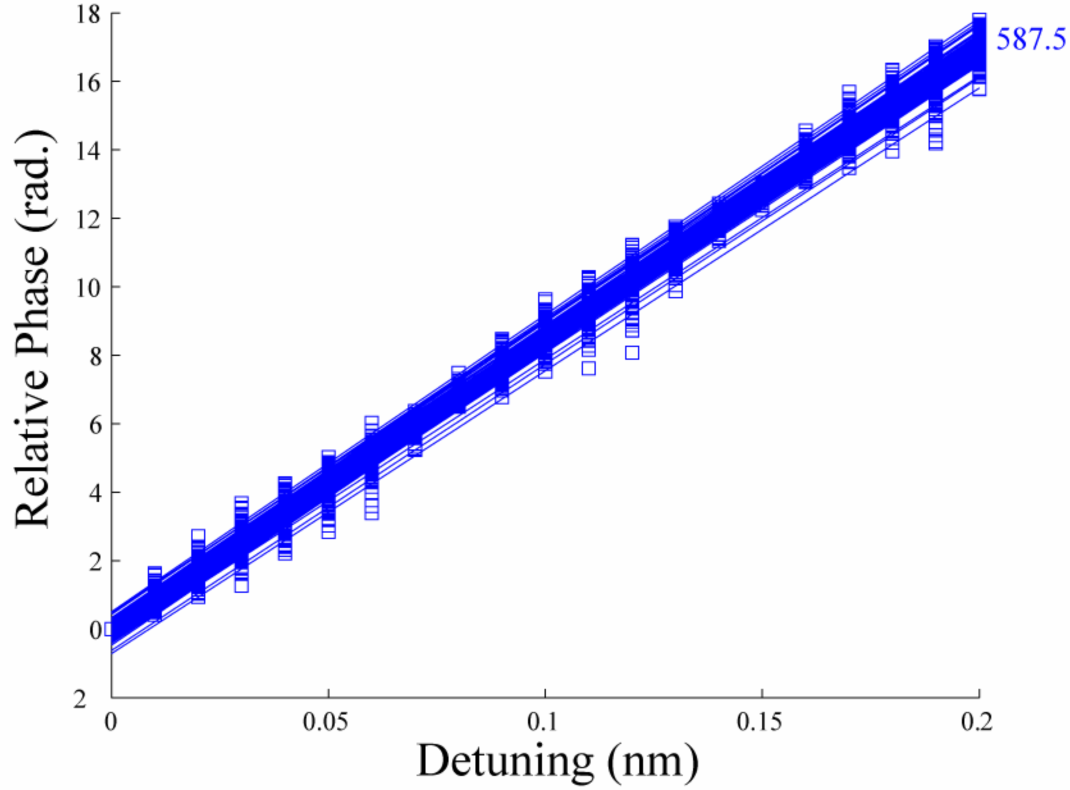




Spectral Sensitivity Analysis

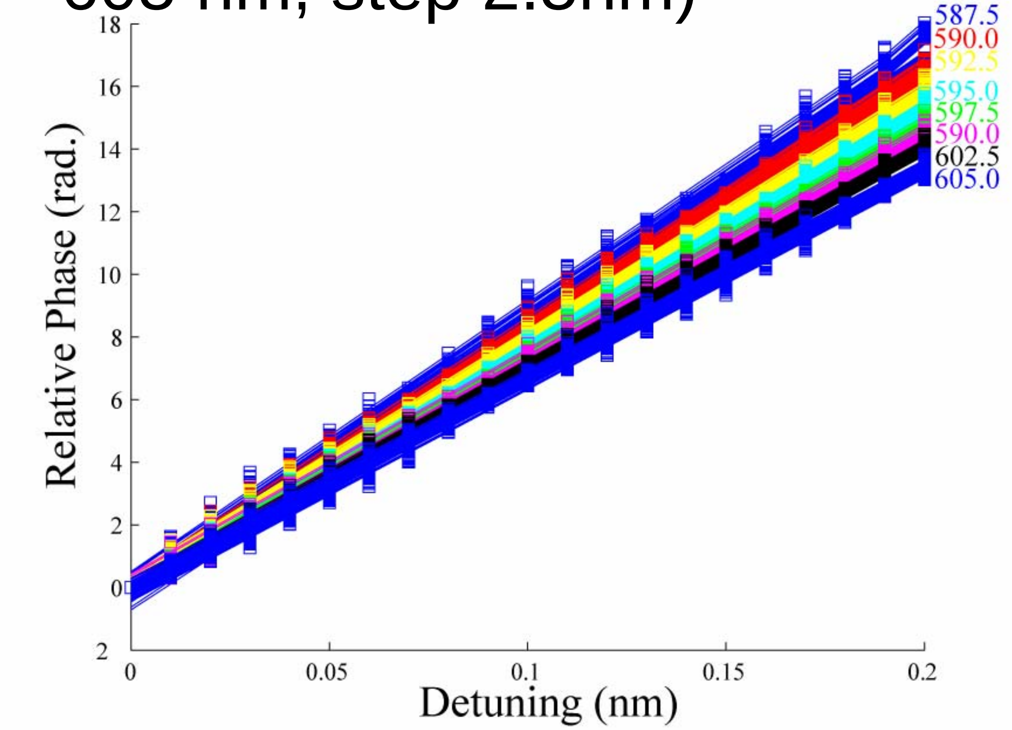
- Relative phase vs. detuning
  - All cross-sections, detuned near 587.5nm





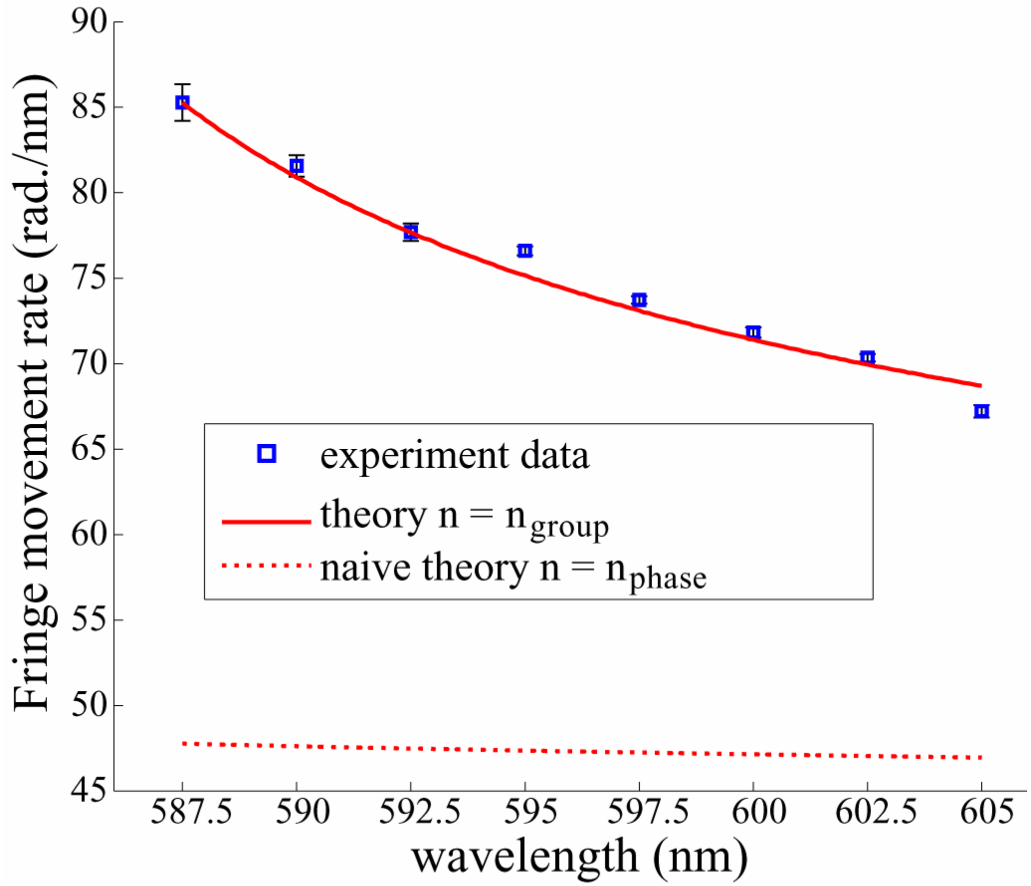
Spectral Sensitivity Analysis

- Relative phase vs. detuning
  - Detuned near different wavelengths
    (587.5 – 605 nm, step 2.5nm)



Spectral Sensitivity Analysis

- Phase change rate (i.e., spectral sensitivity) vs. wavelength



Ref. for *n* data: Jensen *et al.*, JOSA B, **3**(6) p.857, 1986

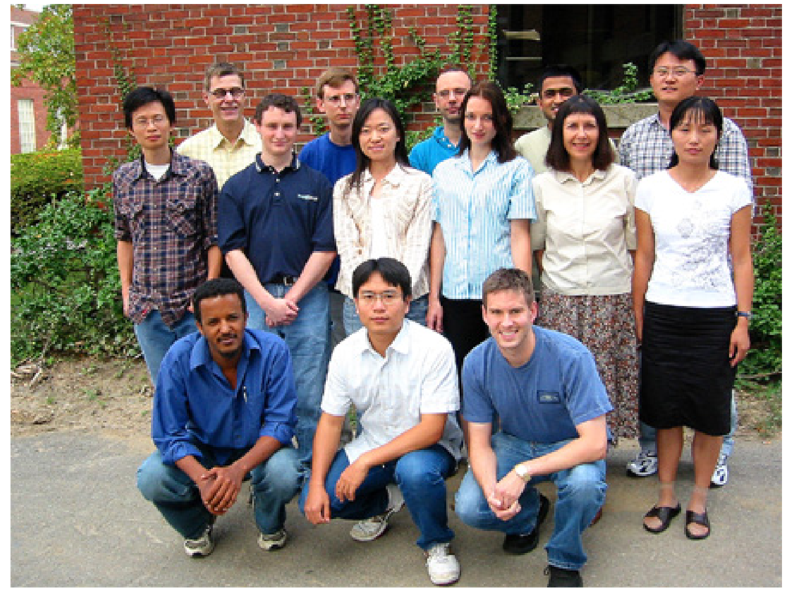
Summary

- The sensitivity of certain types of spectroscopic interferometers are proportional to the group index n_g of the media in its optical paths.
- The spectral resolution of such interferometers can be greatly enhanced (in the order of 10^6 or larger is possible) by introducing a slow light medium into it.

The Institute of OPTICS

Acknowledgement

- Dr. Gary W. Wicks and Renee Pedrazzani
- Research Group of Nonlinear Optics at U or R.
- Funding Agencies



DARPA SLOW LIGHT NSF

Thank you for your attention!