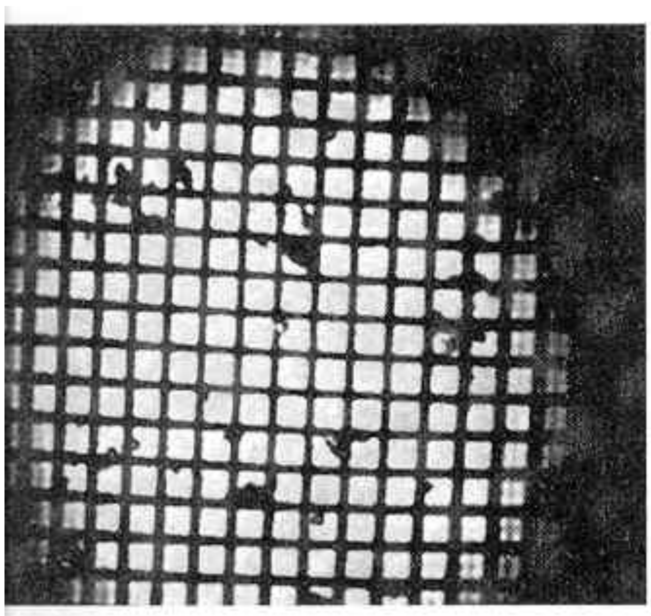
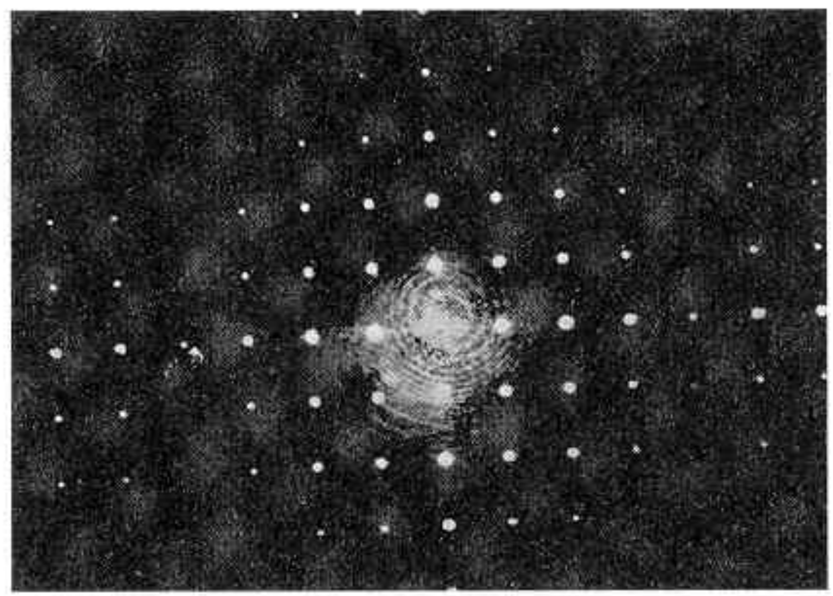
PHGN570: Physical and Fourier Optics

Today:
Course logistics
Applications of physical and Fourier optics
Linear, shift-invariant systems





Books and references

Textbooks:

The books we are using are:

Introduction to Fourier Optics by Goodman (3rd edition), and

Optical Physics, by Lipson (3rd edition).

Undergrad texts some of you already have from earlier courses will be useful for background:

Griffiths *Introduction to Electrodynamics* (3rd edition)

Hecht: *Optics*

Heald and Marion: *Classical Electromagnetic Radiation*

There are many other texts that will prove to be useful references. I have copies of all these. Please ask me if you'd like any recommendations on a particular topic.

Modern Optics, Guenther

Principles of Optics, Born and Wolf (this is the classic reference text)

Linear Systems, Fourier Transforms, and Optics, Gaskill (good basic intro to Fourier methods in optics).

Quantum Electronics, Yariv (more of a lasers book, but has good sections on Gaussian beam propagation and nonlinear optics).

Syllabus*

Linear systems theory in 1D with applications to ultrafast optics (time domain)

- **Fourier transforms, convolution, impulse response and transfer functions, amplitude and phase filters**
- **dispersive propagation and applications to pulse compression**
- **sampling theory and use of the FFT**

Extensions to 2D (spatial domain)

- **cylindrical coordinates: Bessel transforms**

Review of scalar diffraction theory

Fresnel and Fraunhofer diffraction

- **Fresnel calculation of Gaussian beam propagation**
- **Numeric Beam Propagation Method**

Waveguides and integrated optics

Coherent imaging theory

Frequency analysis of imaging systems

Wavefront modulation and pulse shaping

Spatial filtering and optical processing

***subject to change with notice**

Applications

- **Numerous applications will be discussed during the course. The selection and timing will be determined as we go. Possible topics include:**
- **Imaging analysis of spectrometers**
- **spectral interferometry**
- **Multilayer systems: using TFCalc**
- **Speckle interferometry**
- **Solitons**
- **Confocal microscopy**
- **Split-step time-domain code for nonlinear pulse propagation, nonlinear beam propagation effects**
- **Holography**

1D transforms: t-ω

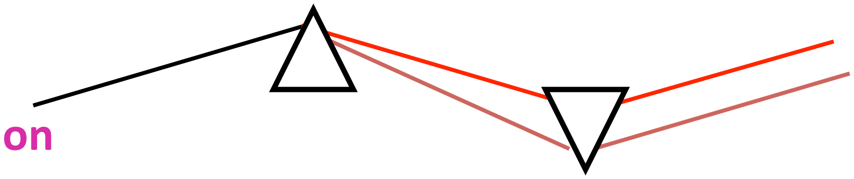
- First we will study pulses and other t-dependent signals
  - Fourier transforms, convolution, impulse response and transfer functions, amplitude and phase filters
  - dispersive propagation and applications to pulse compression
  - sampling theory and use of the FFT
  - Pulse shaping and phase retrieval

Linear dispersion elements

Optical material (e.g. glass): $n(\omega)$

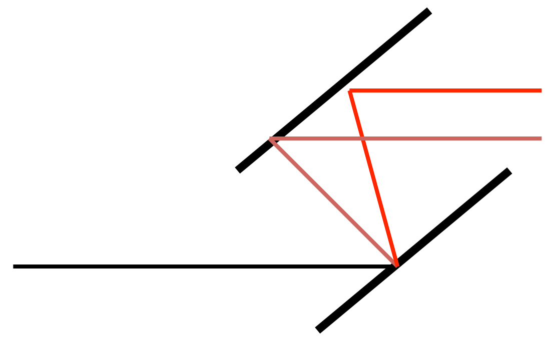
- Positive dispersion: red leads the blue

Prism pair



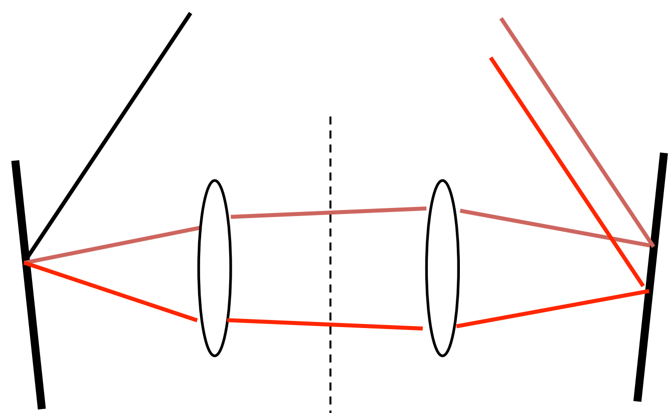
- Prism insertion controls sign of dispersion

Grating pair (compressor)



- negative dispersion

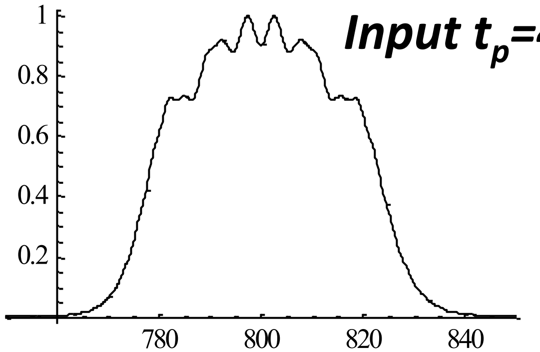
Grating stretcher



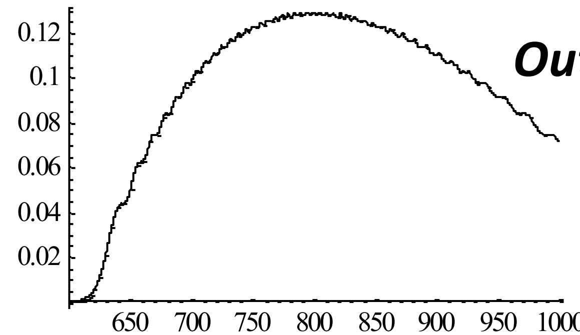
- positive dispersion
- opposite sign from compressor

Pulse compression with parabolic pulses

Input t_p=400fs

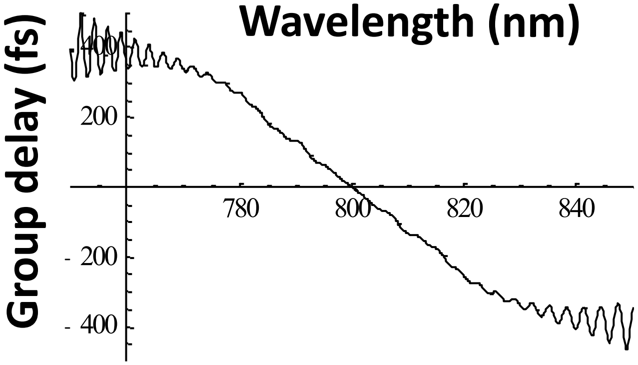


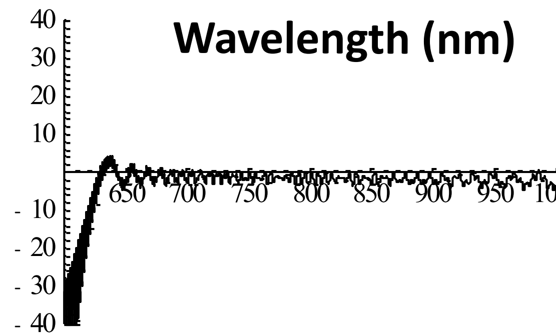
Output



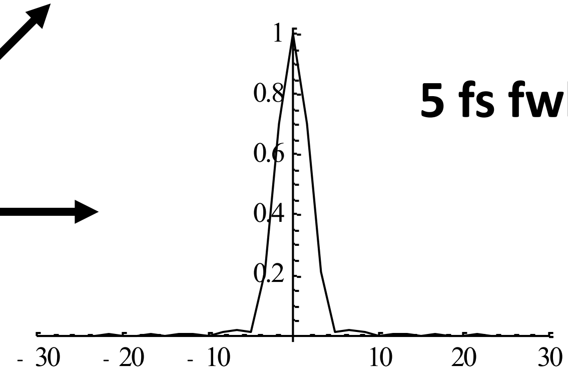
Wavelength (nm)

Wavelength (nm)



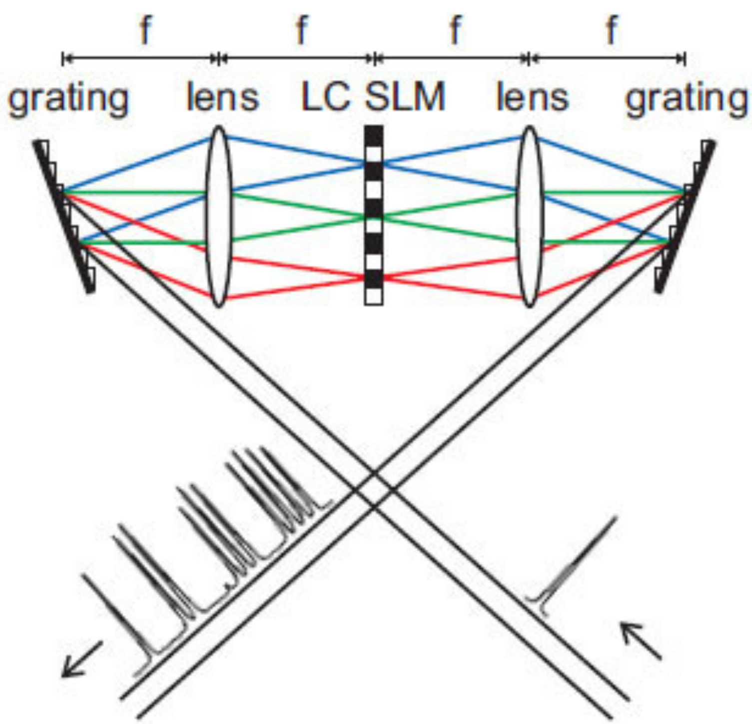


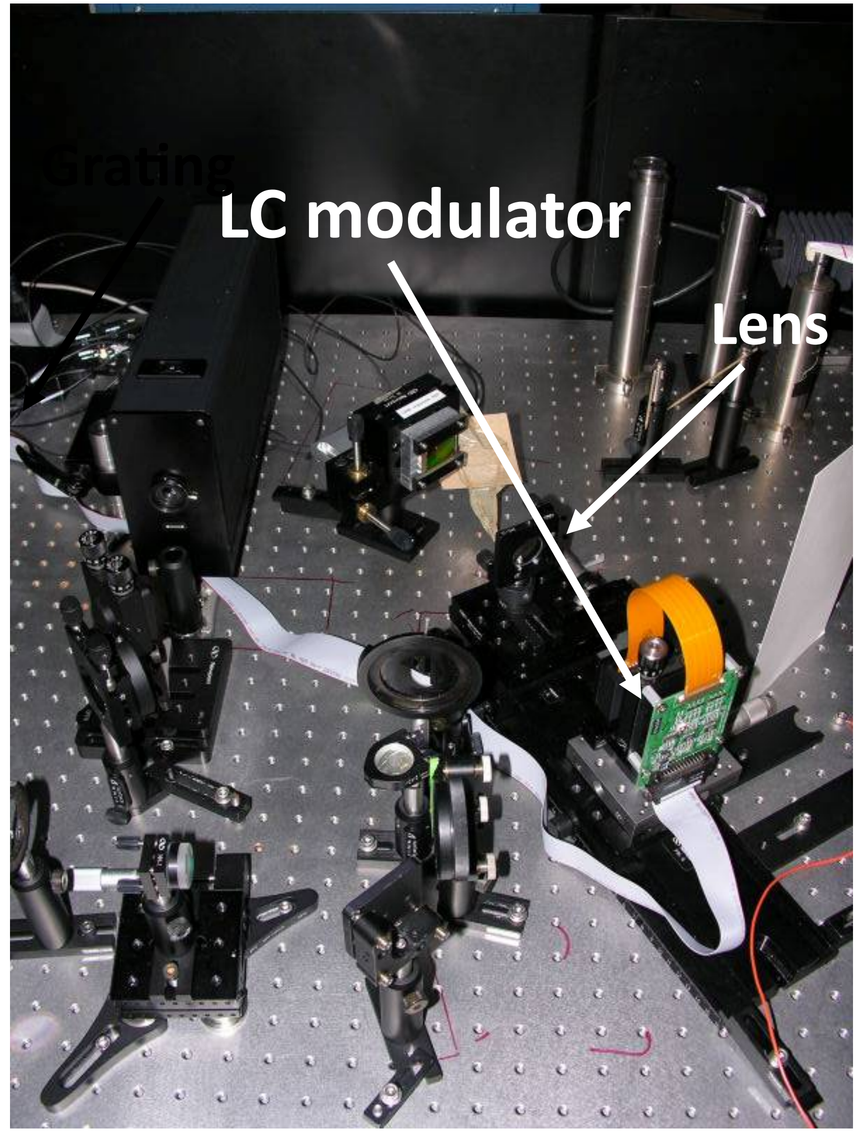
5 fs fwhm



Output compressed with linear group delay:

Pulse shaping system



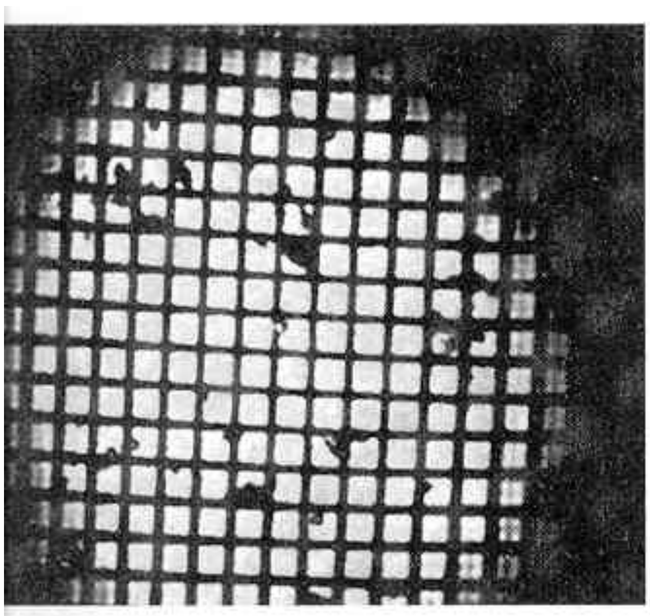


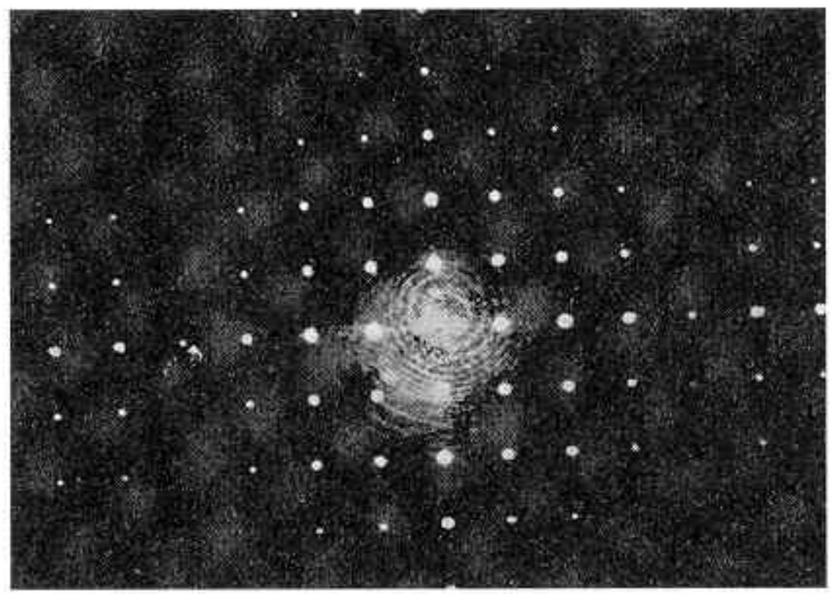
2D transforms: x-f_x, y-f_y

- Extend Fourier analysis to the spatial domain
  - Cartesian coordinates
  - Cylindrical coordinates
- Review of scalar diffraction theory
- Fresnel and Fraunhofer diffraction
  - Fresnel calculation of Gaussian beam propagation
  - Numeric Beam Propagation Method

Lens Fourier transforms

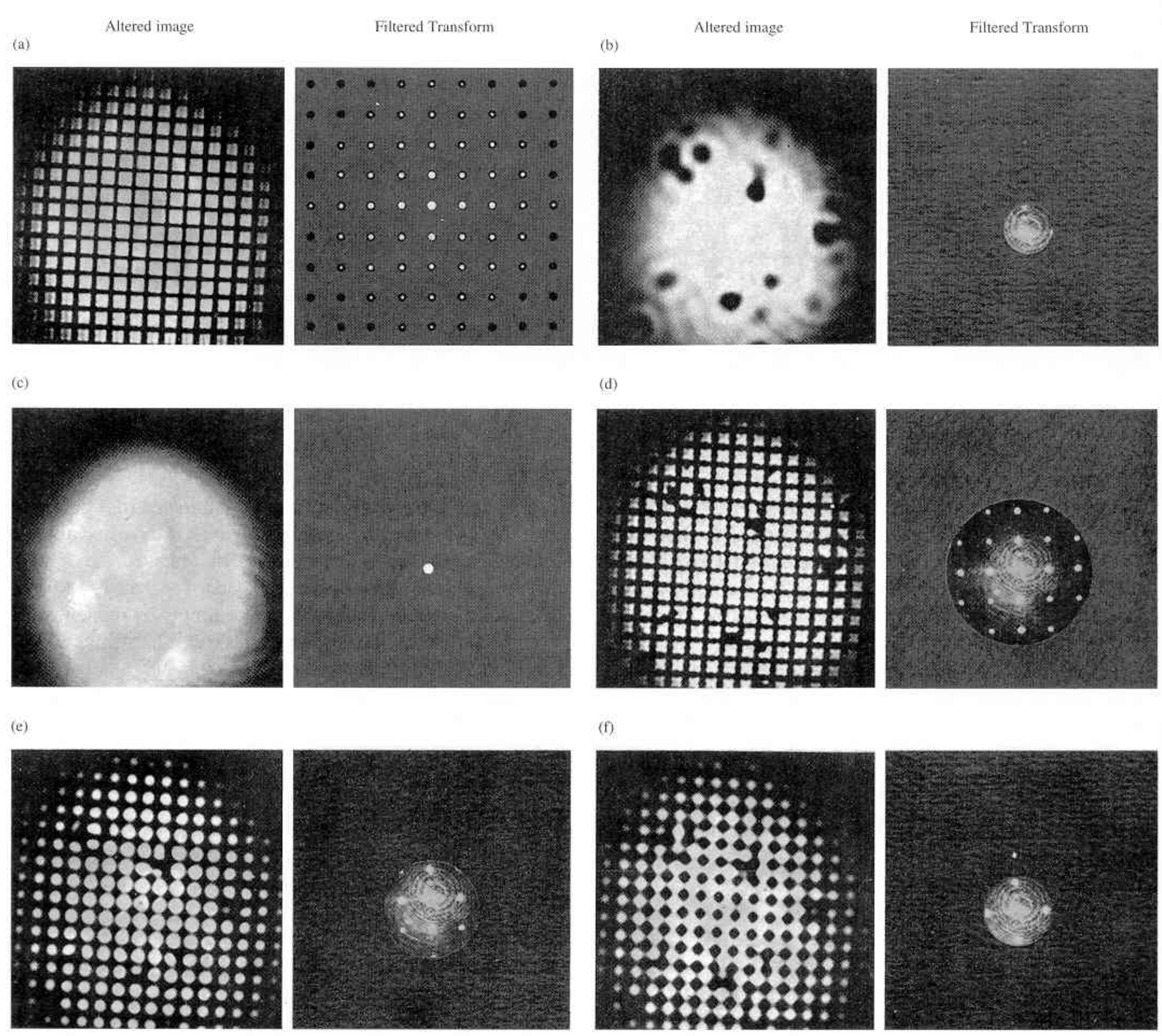
A lens puts the Fourier transform of the input field at its focal plane:



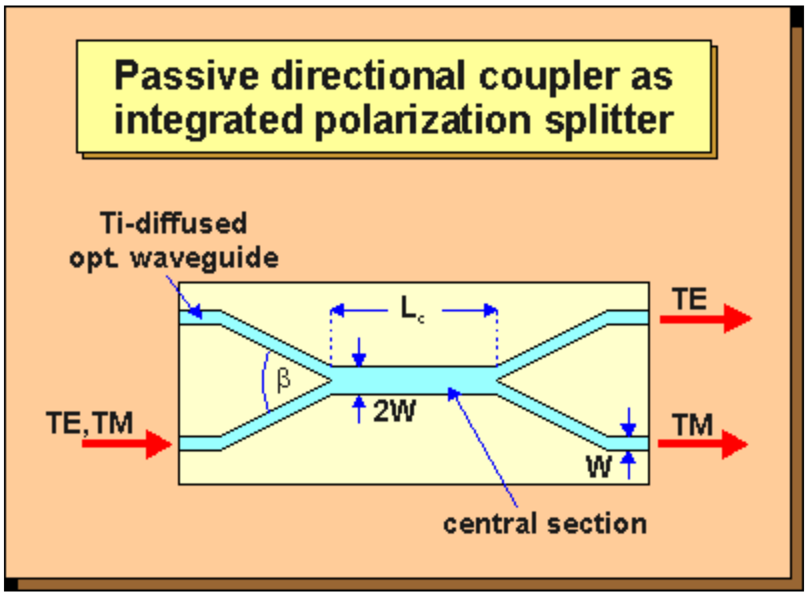


Spatial filtering

Modify the image by placing a mask in the Fourier plane:



Integrated optical devices



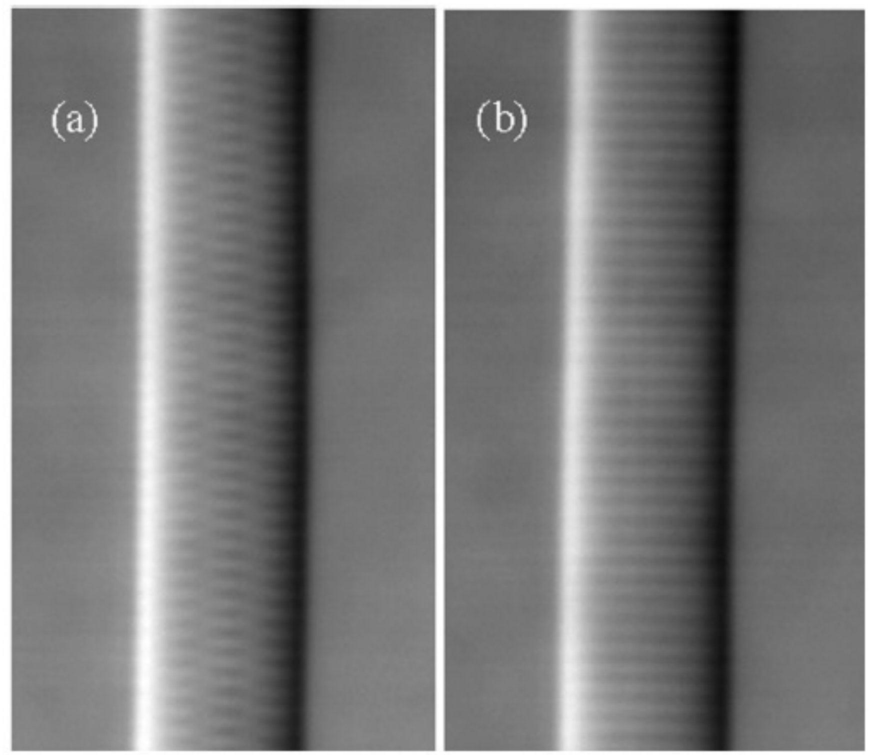
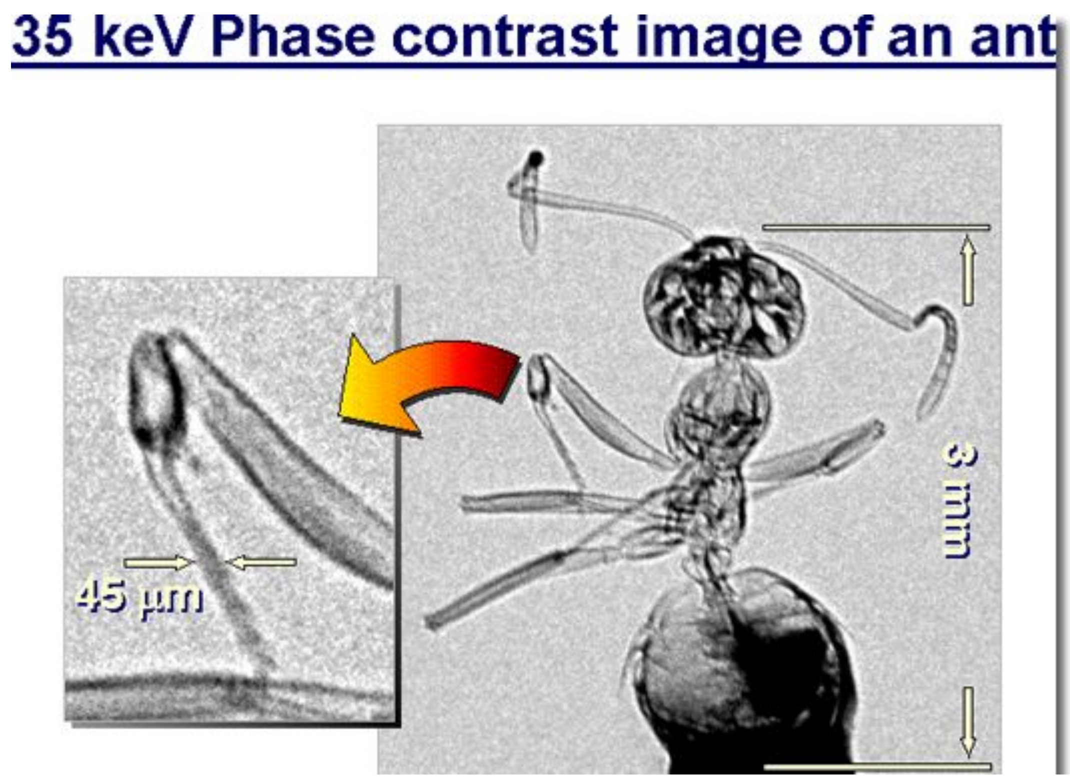


Image of a fiber Bragg grating filter

Phase-contrast imaging

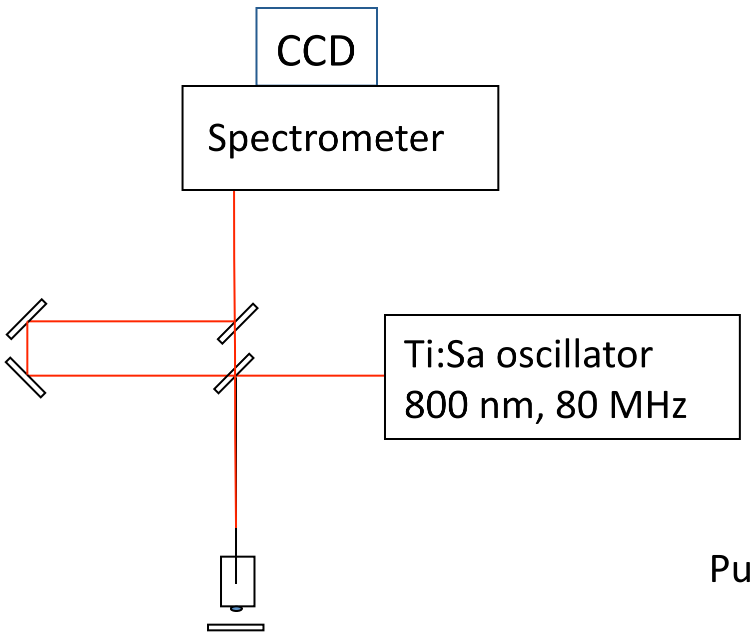
Optical microscope



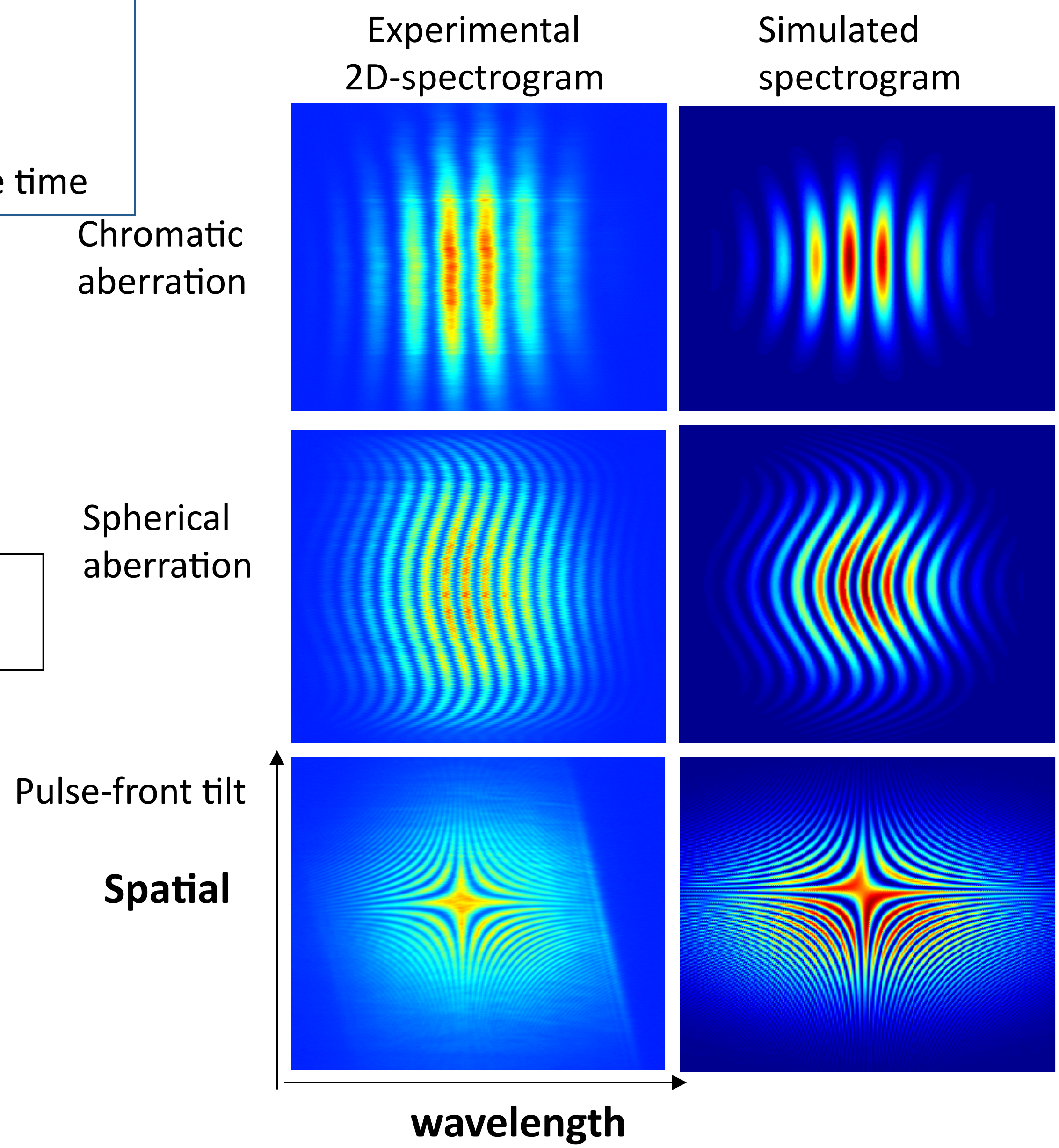
With partially coherent x-rays

2D spectral interferometry (W. Amir)

Aim :
- Characterize pulse front distortion in objectives
- Extract spatio temporal distortions : GD
- Measure wavefront aberrations at same time

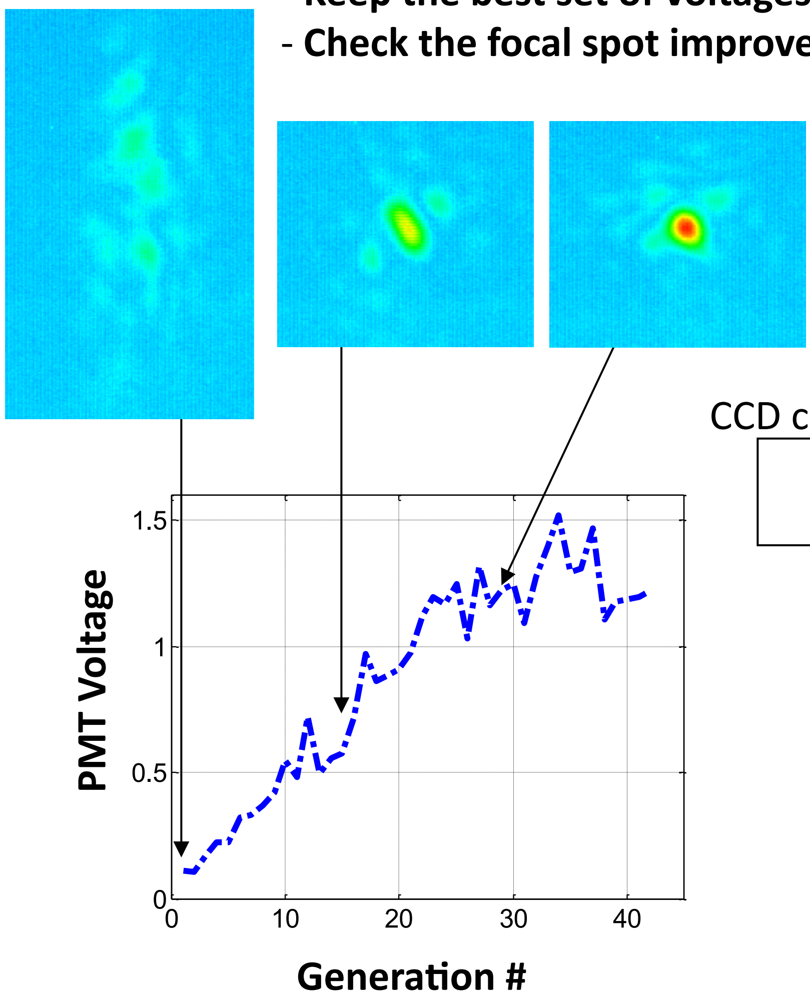


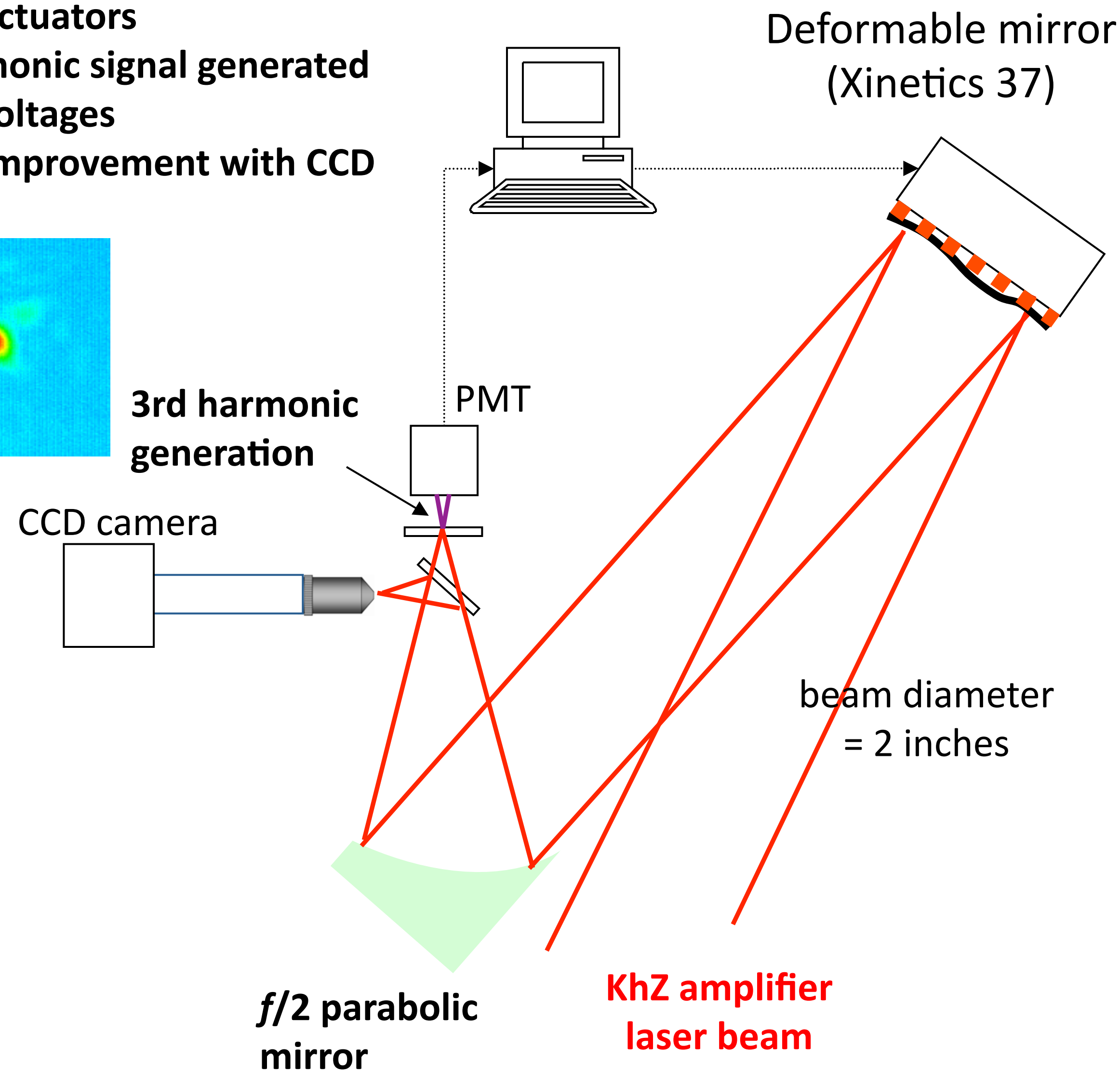
Optical system to characterize :
- High NA objectives
- Grating
- lens system



Wavefront modulation (T. Planchon)

Genetic algorithm on THG signal
- **Move randomly DM actuators**
- **Measure the 3rd harmonic signal generated**
- **Keep the best set of voltages**
- **Check the focal spot improvement with CCD**





Nonlinear propagation

Nonlinear index of refraction

- $n(I) = n_0 + n_2 I$

Self-phase modulation (SPM)

$$E(t) = A(t)e^{i[\omega t + \phi(t)]}$$

- frequency shift

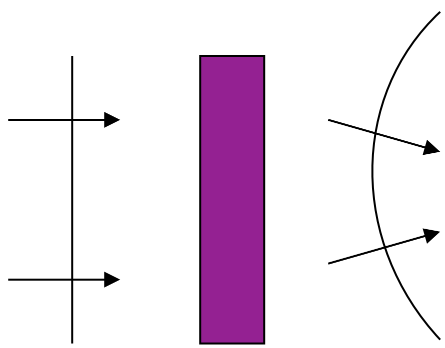
$$\Delta\omega_i(t) = \frac{d\phi}{dt} = kLn_2 \frac{dI(t)}{dt}$$

Soliton propagation

- SPM with negative dispersion

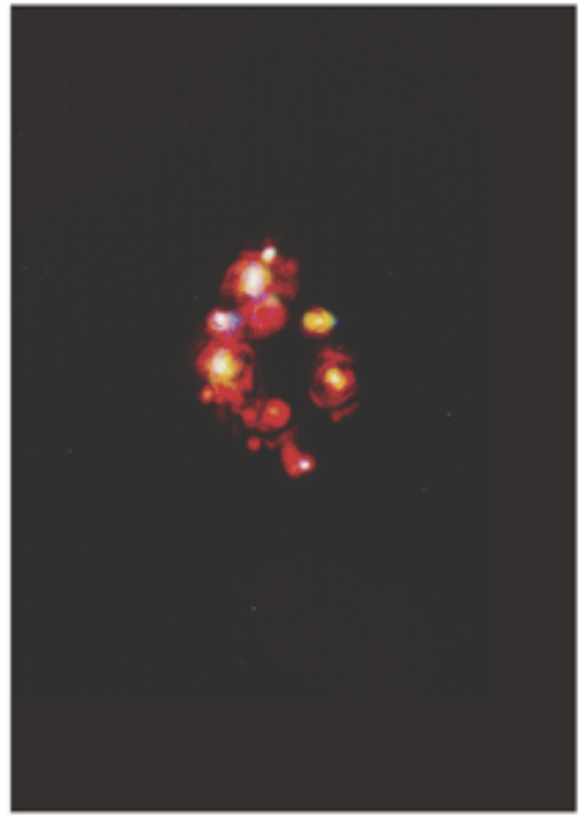
Self-focusing

- phase lags with high intensity



“Light strings:” self-focusing of terawatt fs pulses in air

White light from filament caused by a beam from the Teramobile



Cross-section of the filament

R. Sauerbrey, U. Jena, Germany

Fourier transforms: t-ω domain

$$F(\omega) = \int_{-\infty}^{\infty} f(t) e^{+i\omega t}\, dt = FT\{f(t)\}$$

$$f(t) = \frac{1}{2\pi} \int_{-\infty}^{\infty} F(\omega) e^{-i\omega t}\, dt = FT^{-1}\{F(\omega)\}$$

- In EM, our signals are complex fields
- 1/2π factor is lumped into inverse transform
- ω is our frequency variable, not ν. This affects the normalization constants.
- Note signs of exponents: this is tied to our exp(-i ω t) convention
- Techniques
  - Analytic: apply transform IDs and theorems to decompose a transform into its parts
  - Analytic in Mathematica: can do some FTs but not always expressed in recognizable way
  - Graphical: after identifying components of a transform, sketch the anticipated result
  - Numerical: FFT for calculating complicated or realistic cases for modeling/data analysis