Optical methods in chemistry
or
Photon tools for chemical sciences

Session 2:

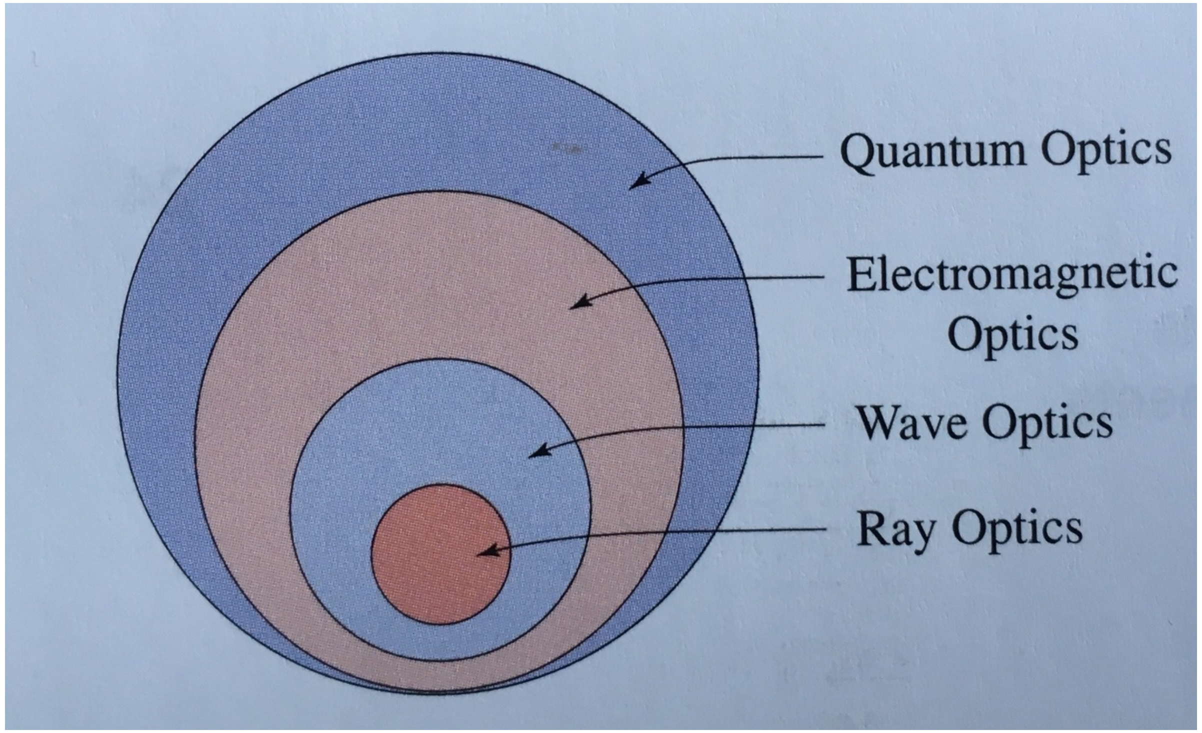
Course layout – contents overview and general structure

- Introduction and ray optics
- Wave optics
- Beams
- From cavities to lasers
- More lasers and optical tweezers
- From diffraction and Fourier optics
- Microscopy
- Spectroscopy
- Electromagnetic optics
- Absorption, dispersion, and non-linear optics
- Ultrafast lasers
- Introduction to x-rays
- X-ray diffraction and spectroscopy
- Summary

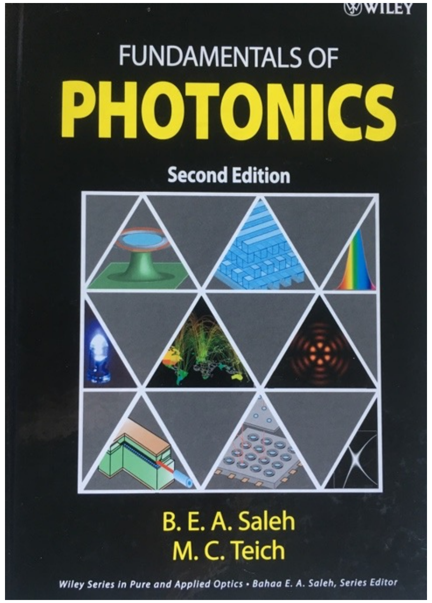
Todays learning goal:

Repeat fundamentals of wave optics

Much exciting science – but you need to know some basics

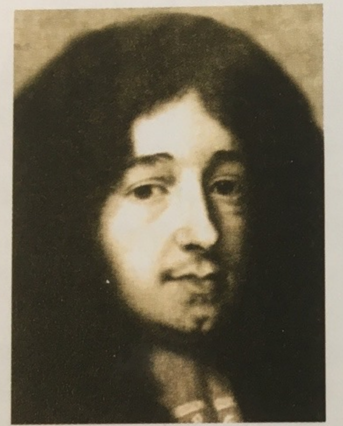


Main source for next topics



Wave optics

Last week: Ray optics which is limit of wave optics for infinitesimally short wavelength.



Christiaan Huygens (1629–1695) advanced several new concepts concerning the propagation of light waves.

Thomas Young (1773–1829) championed the wave theory of light and discovered the principle of optical interference.

Postulate of wave optics

- Light propagates in the form of waves, in vacuum light travels with c_o.

- An homogenous transparent medium is characterized by a single constant, the refractive index n>=1. In the medium light travels with reduced speed $c = c_0/n$.

- An optical wave is described by a wave function u(r,t) at position r and time t.

Wave function

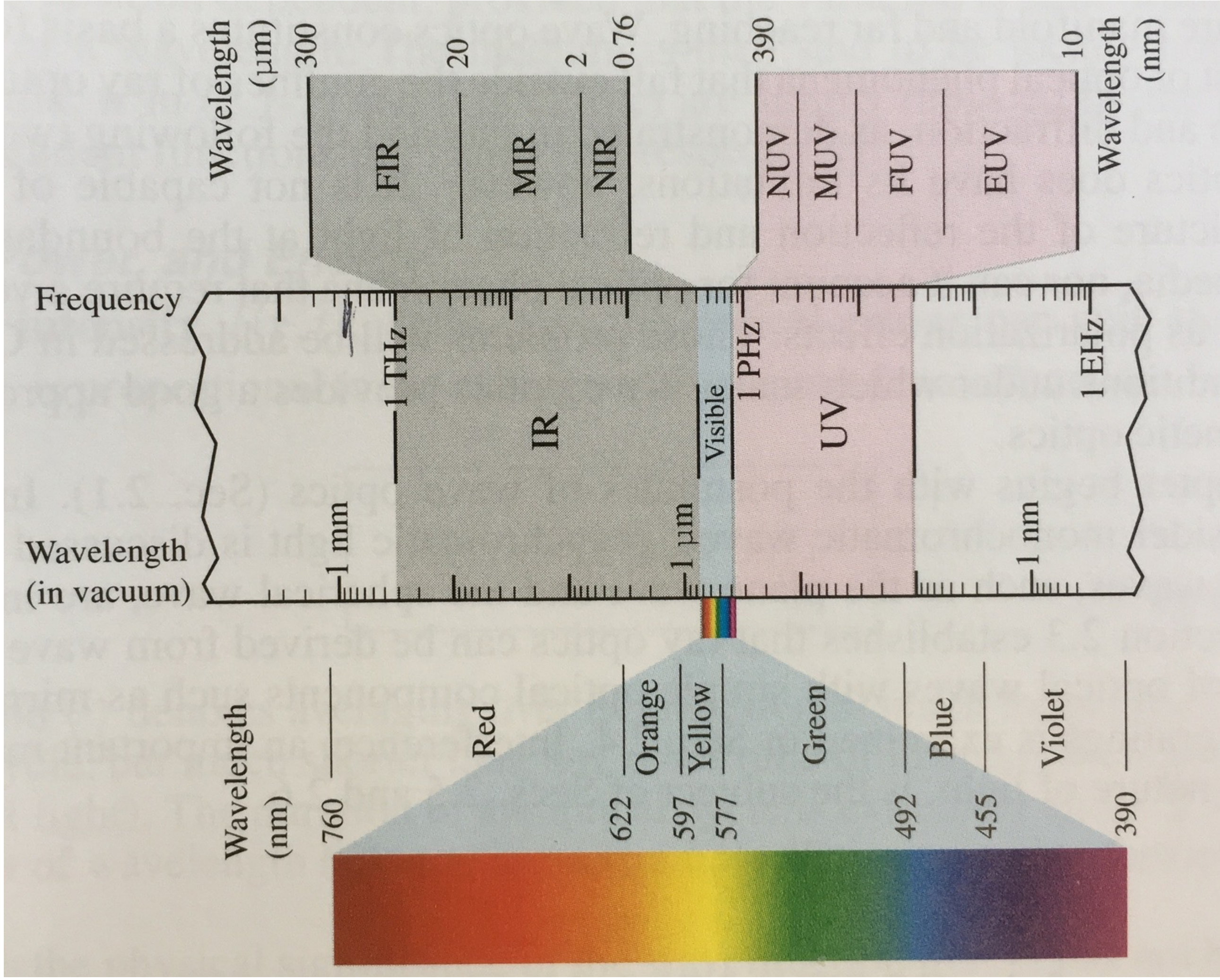
The wave function satisfies the (partial) differential equation

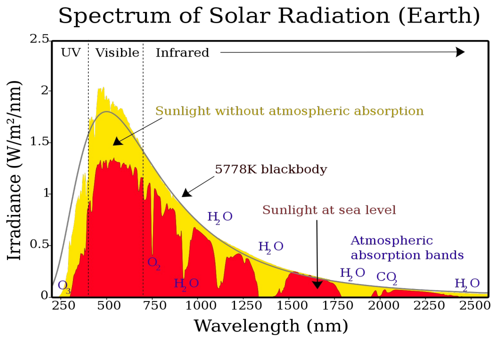
___________ Laplace operator in cartesian coordinates

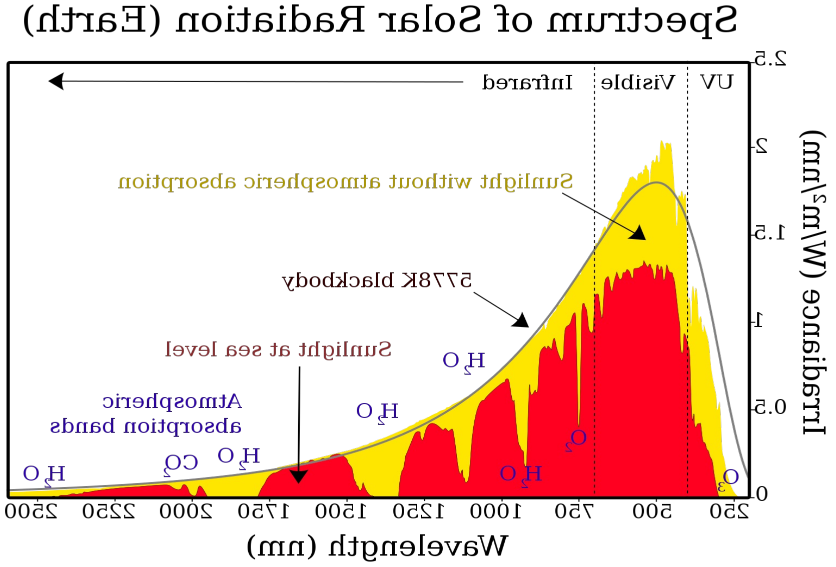
The principle of superposition applies, i.e., if u1 and u2 are optical waves then

Also represents an optical wave

Optical frequencies and wavelengths







Source: wikipedia

Optical intensity, power, energy

- The optical intensity I(r,t) is the optical power per unit area.
  - The unit is Watts/cm^2
  - average of the squared wave function.

- The optical power (in units of Watts) flowing into an area A normal to the direction of propagation is the integrated intensity

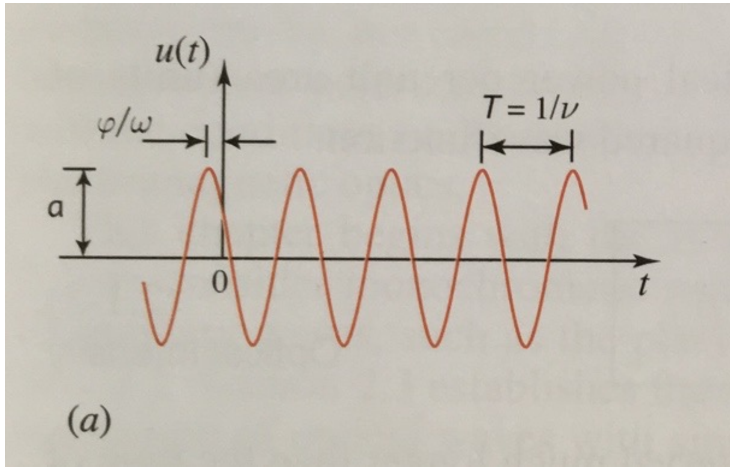
- The optical energy (in units of Joules) in a given time interval is the integral of the optical power over the time interval

Simple example: Monochromatic wave

- For a monochromatic wave the, the wave function reduces to

With:

- The amplitude and phase are generally position dependent
- Representation of a monochromatic wave



Simple example: Monochromativ wave but as complex wave function

- A monochromatic wave can be explained by complex wave function

- This general description satisfies the

  Helmholtz equation:

  With wavenumber k =

- Note intensity:

  - Monochromatic wave intensity is (complex amplitude)^2
  - Intensity does not vary in time

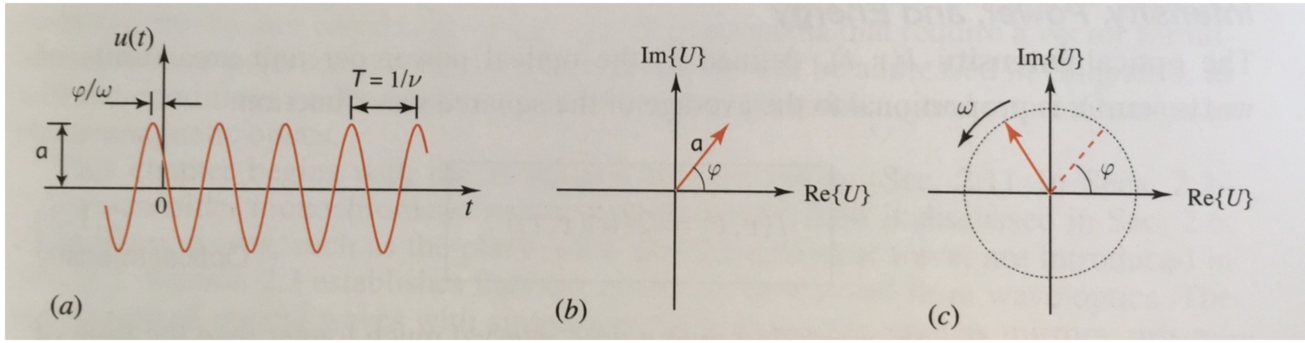
- Note: Wavefronts are surfaces of equal phase

Simple example: Monochromatic wave

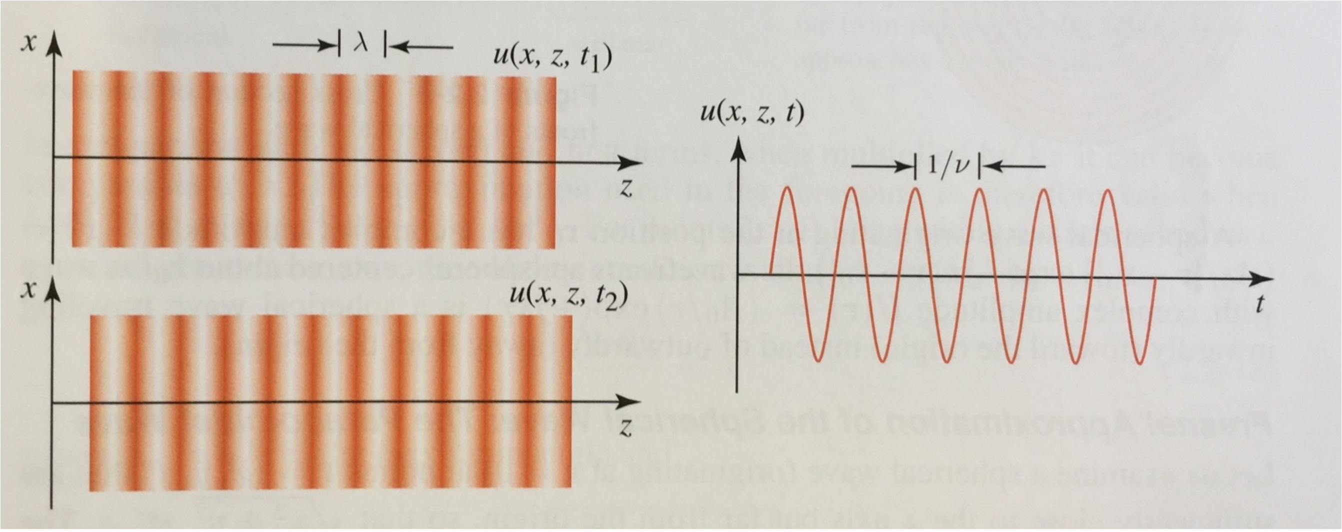
- For a monochromatic wave the, the wave function reduces to

With:

- The amplitude and phase are generally position dependent
- Representation of a monochromatic wave



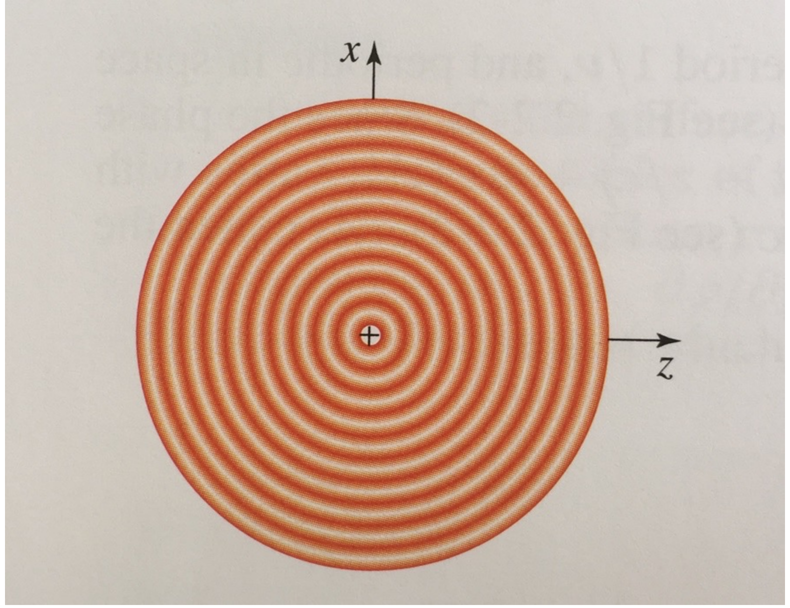
Special case: plane wave



Plane waves: wavefronts are parallel planes perpendicular to k and separated by λ

For graphical animations visit https://en.wikipedia.org/wiki/Sinusoidal_plane_wave

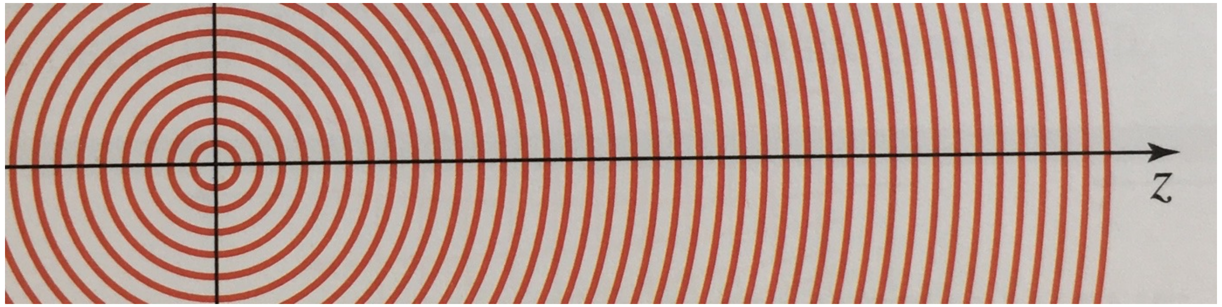
Special case: spherical wave



Spherical waves: wavefronts are concentric spheres separated by $\lambda=2\pi/k$

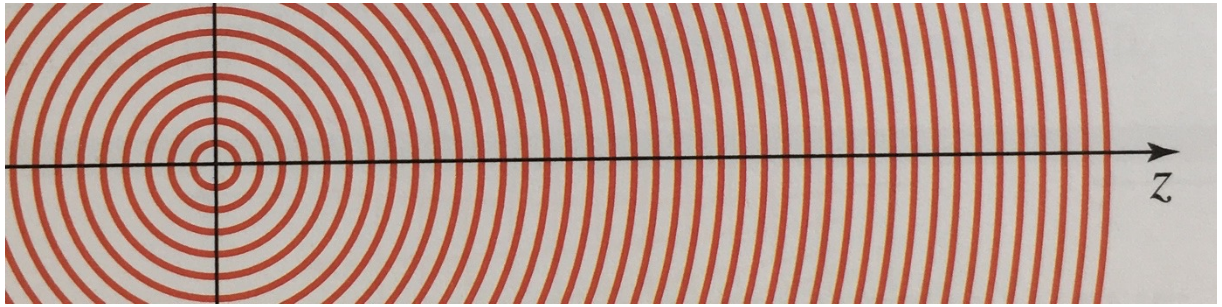
For graphical animations visit https://en.wikipedia.org/wiki/Wave_equation#Spherical_waves

Special case: Fresnel approximation



- Spherical wave close to z-axis but far away from origin

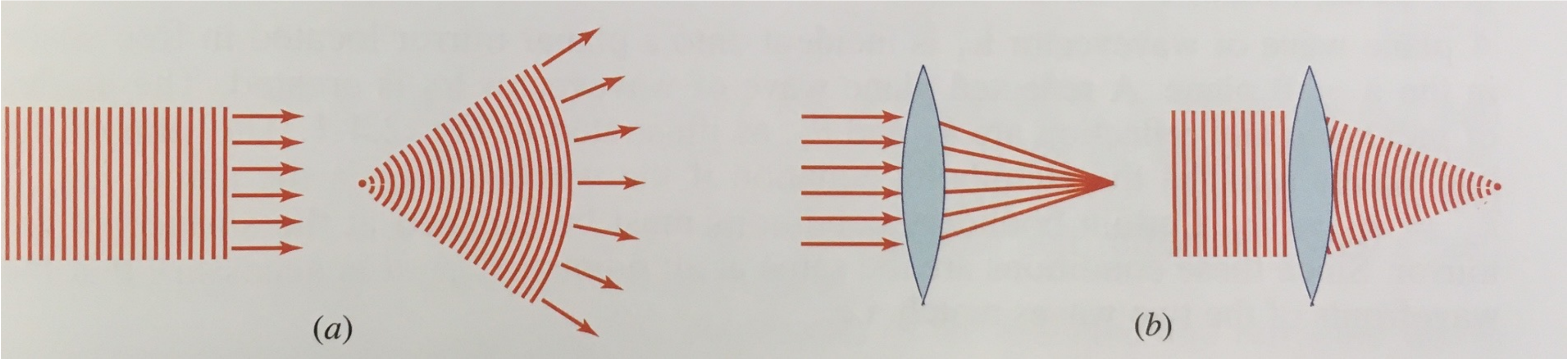
Special case: Fresnel approximation



- Spherical wave close to z-axis but far away from origin

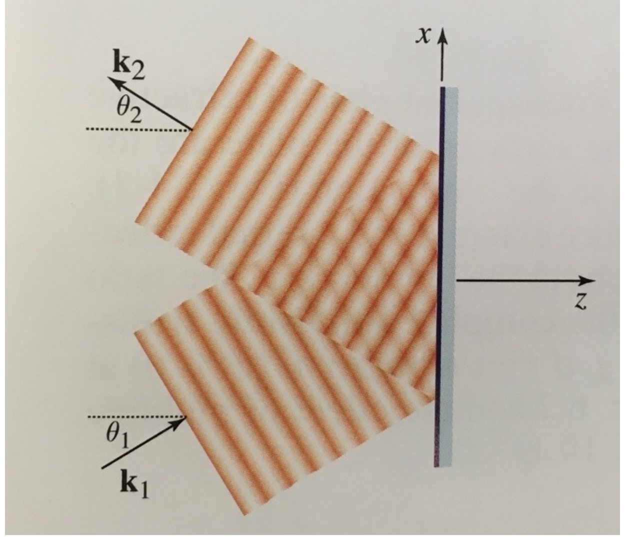
Comment: Taylor series

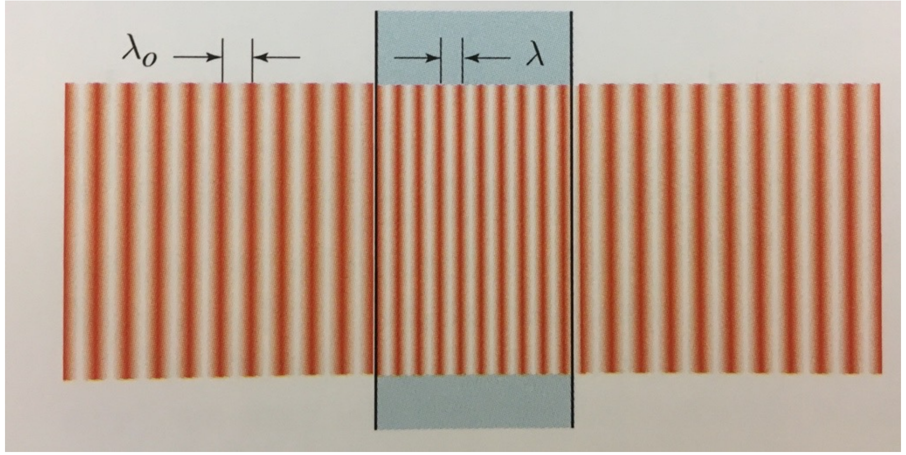
From ray to wave optics

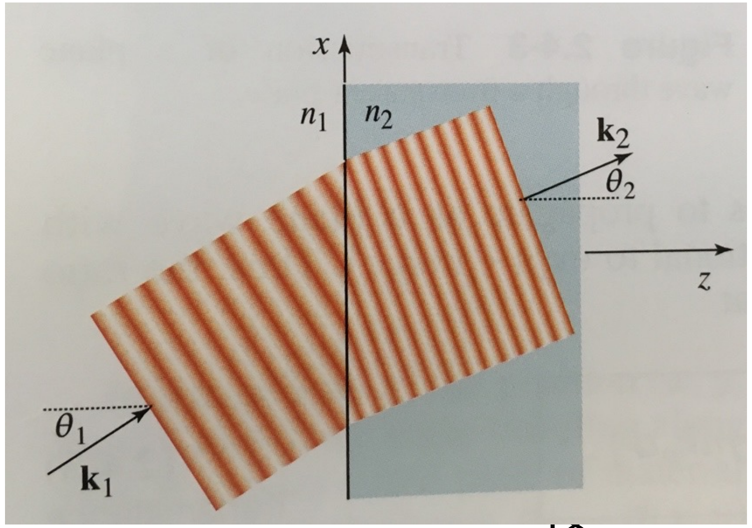


What happens after focal point?

Wave optics and simple optical components







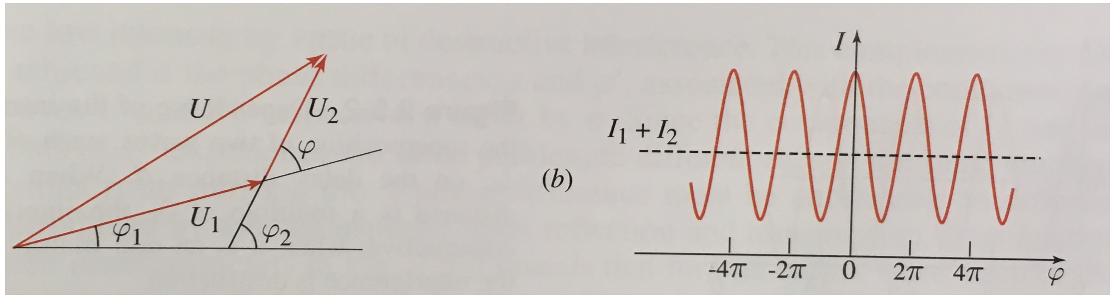
Interference of two waves

When two monochromatic waves with complex amplitudes U_1 and U_2 are superimposed, the result ia a monochromatic wave of the same frequency that has a complex amplitude

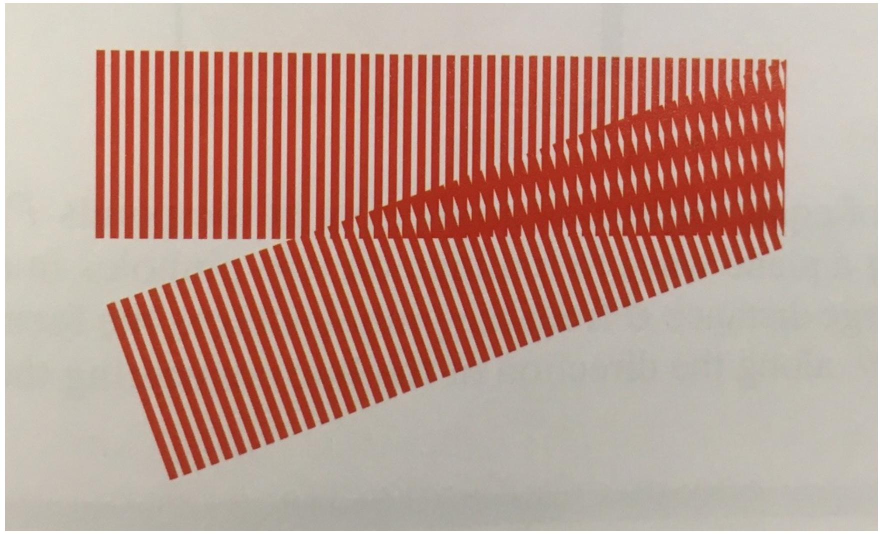
$$U(r) = U_1(r) + U_2(r)$$

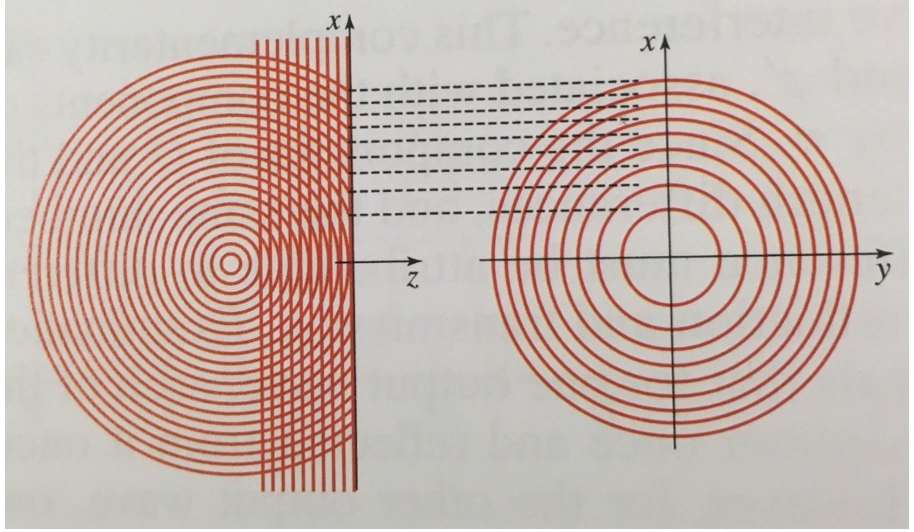
The intensity of the resulting wave is:

Resulting in the interference equation:

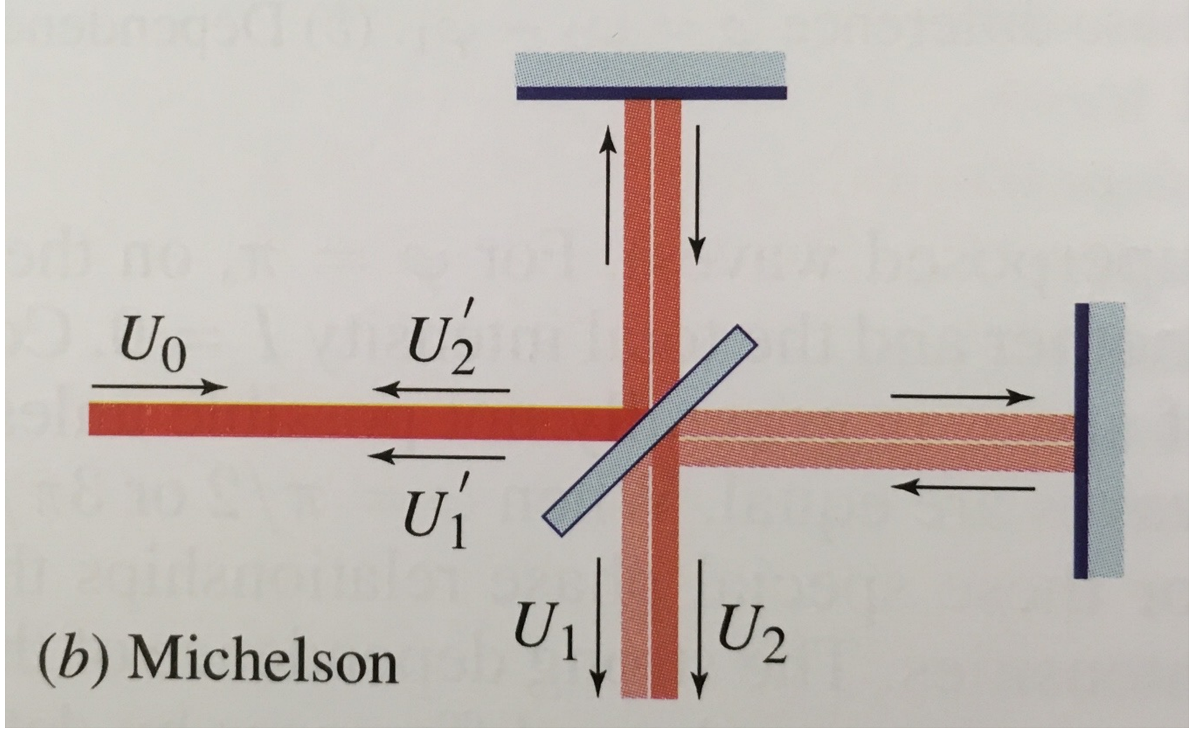


Interference: Some examples



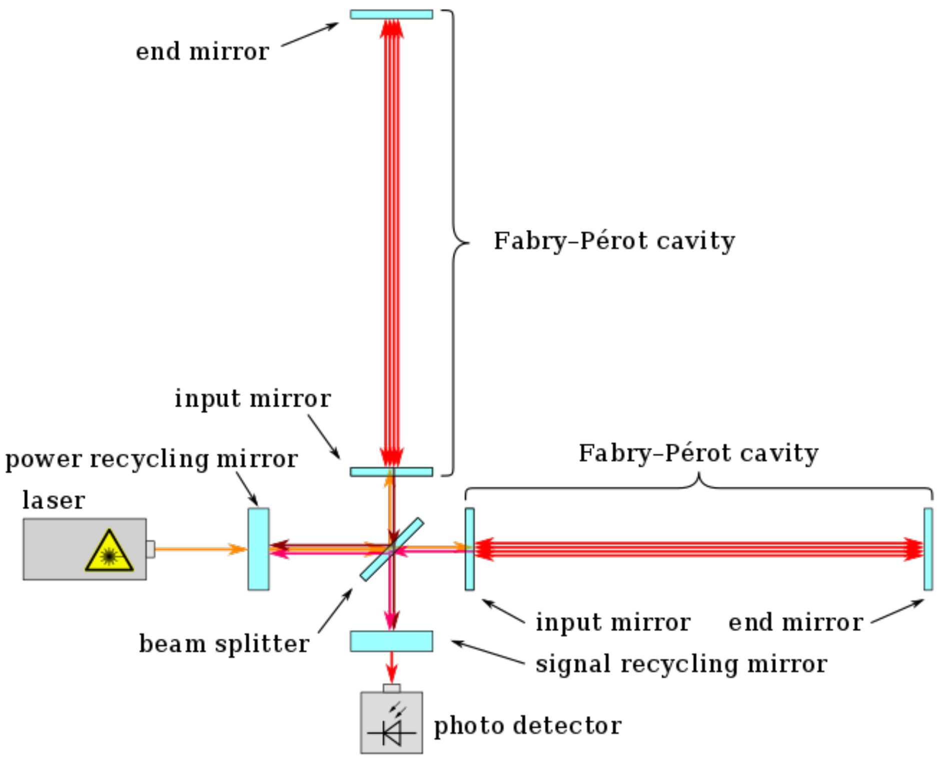


Interferometer, example Michelson

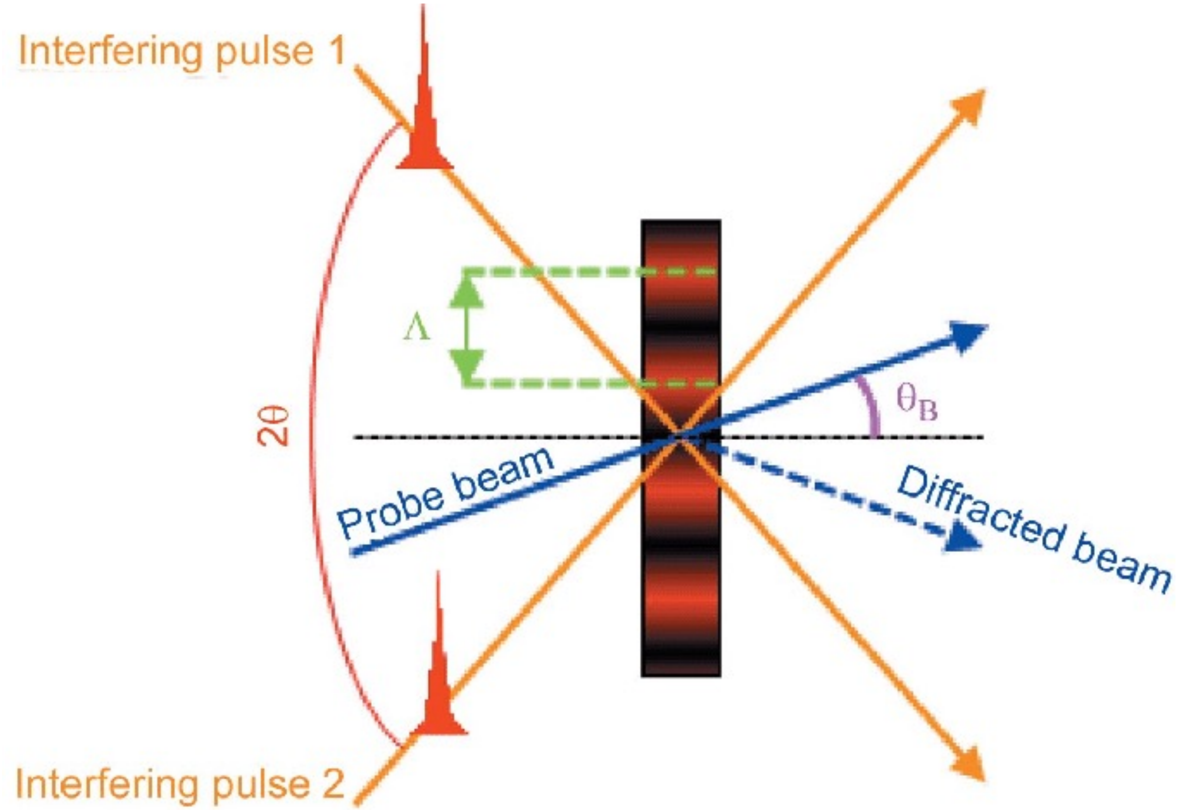


Nice demonstration: https://www.youtube.com/watch?v=j-u3IEgcTiQ

Guess what this is? Or: How precise can interferometers be?



An ultrafast example: transient grating spectroscopy



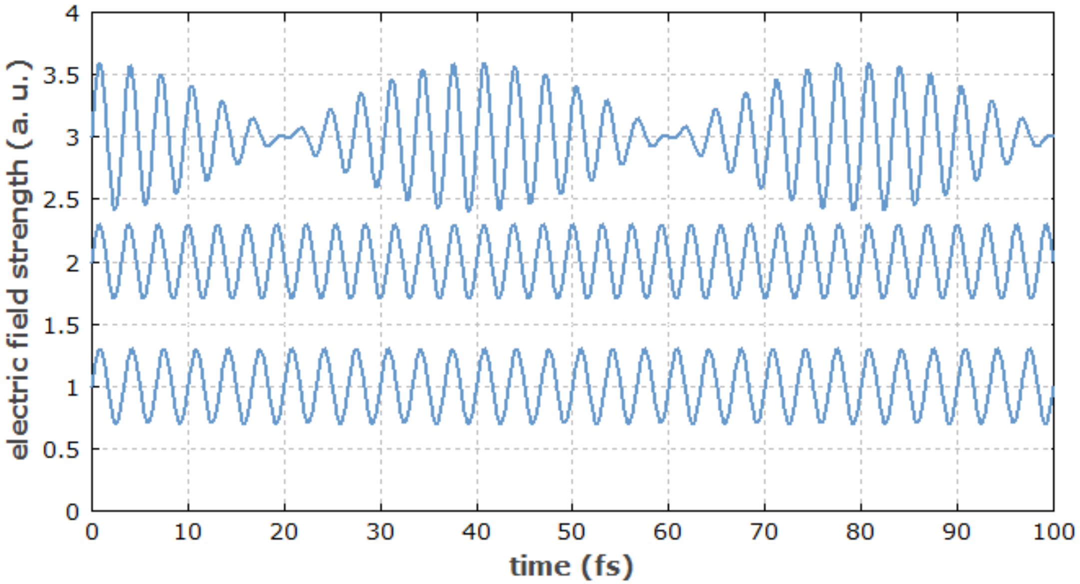
Source: Fermi FEL at Elletra

Optical beating

- Optical wave composed of two monochromatic waves

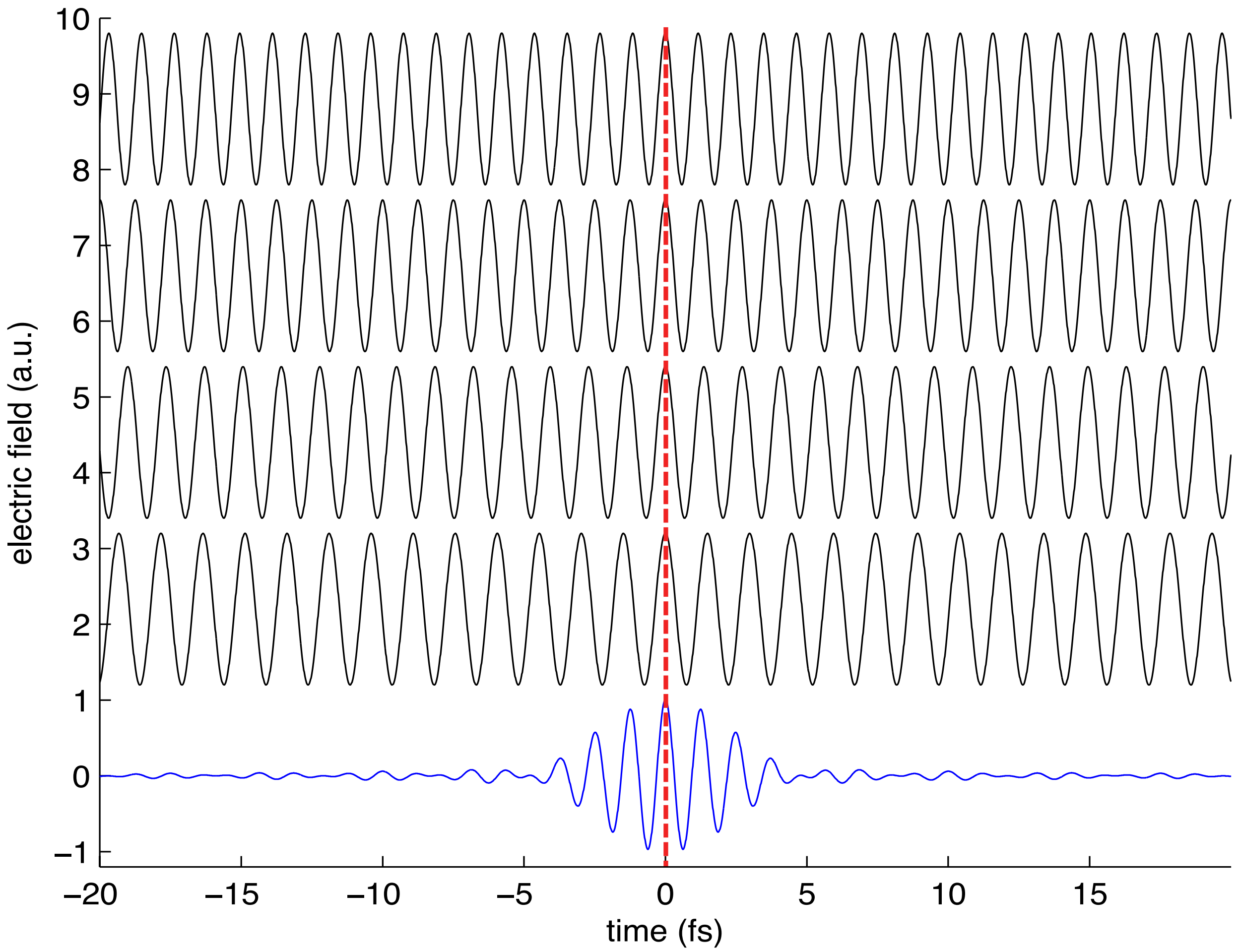
- Intensity of this wave is

- With beat frequency



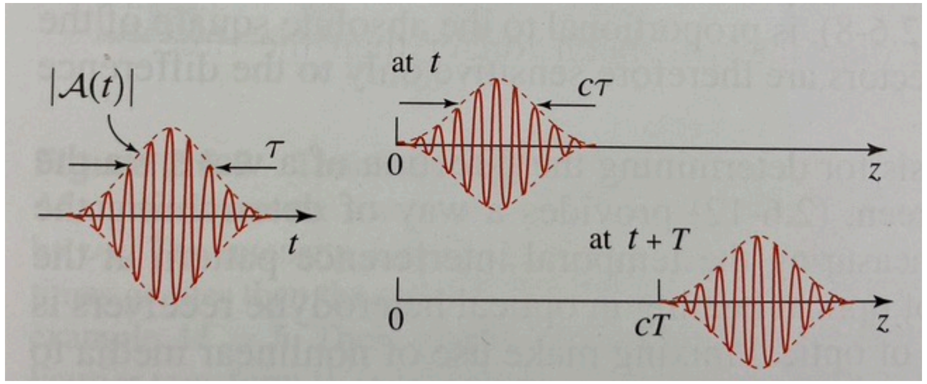
- Note: known as light beating, optical mixing, heterodyning, and others

Now do this with many frequencies – short pulse

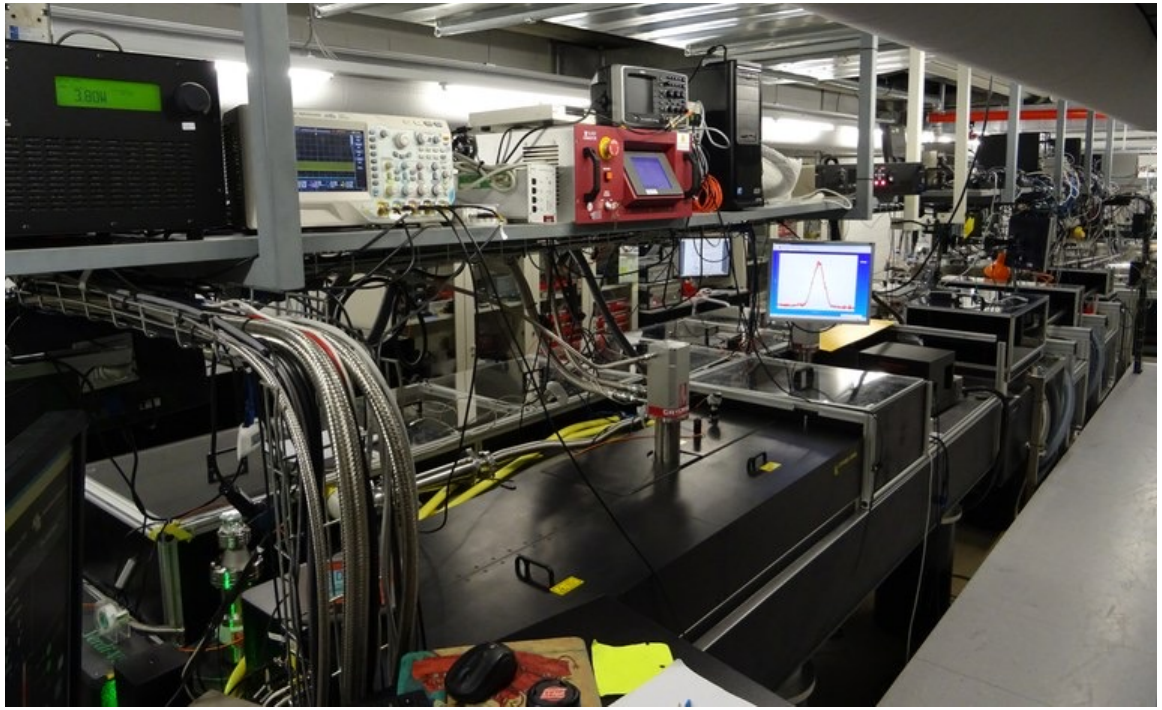


Pulsed light

- Formal description: Add time varying complex envelope A(t) to wave function



Excursion: High-intensity lasers



The end.