Introduction to Electro-optics

Physics 208, Electro-optics

Peter Beyersdorf

Class Outline

- Introductions
- Electro-optics through history
- LIGO: A case study overview

Introductions

- Instructor: Dr. Peter Beyersdorf
  - Office: Science 235
  - email: peter.beyersdorf@sjsu.edu
  - Phone: 924-5236
- Office Hours
  - Tuesday, Thursday 8:15-9:00 pm
- Webpage: http://sjsu.blackboard.com/public/phys208f07pb/
- Textbook
  - Yariv & Yeh "Optical Waves in Crystals"

Electro-optics is a field that deals with the influence of electric fields on the optical properties of matter including transmission, emission and absorption of light. This course will cover the theory and use of birefringent crystals, amplitude and phase modulators, non-linear optics, and detectors.

"Electro-optics"

A number of fields of physics are closely related and often overlap.

- Optics
- Electrooptics
- Optoelectronics
- Photonics
- Quantum Optics

"Optics"

A field of physics consisting mainly of the application of classical electromagnetism and its high frequency approximations to light. Classical optics divides into two main branches: geometric optics (ray optics) and physical optics (diffraction). Tools in optics include:

- Mirrors
- Lens
- Beamsplitters

"Electro-optics"

A branch of technology involving components, devices and systems which operate by modification of the optical properties of a material by an electric field. Tools include

- Modulators
- Non-linear crystals
- Waveguides
- Layered materials

"Optoelectronics"

The study and application of electronic devices that interact with light. Tools include

- Photodiodes and photoresistors
- Photomultipliers
- Light-Emitting Diodes
- Charged Coupled Devices (CCDs)
- Lasers

“Photonics”

The term “Photonics” generally connotes applied science and development and suggests

- the particle properties of light
- the potential of creating signal processing device technologies using photons
- those quantum optical technologies which are manufacturable and can be low-cost, and
- an analogy to electronics.

“Quantum Optics”

Field dealing with the application of quantum mechanics to phenomena involving light and its interactions with matter. Generally connotes pure scientific research. The tools of quantum optics include:

- “Optical Molasses”
- “Optical Tweezers”
- Bose-Einstein Condensates

Expectations

- Student Learning Objectives: On successful completion of this course students shall be able to:
  - Understand the operational principles of optical modulators, wave-guides and periodic media
  - Determine suitable choices of electro-optic devices for use in various optical experiments.
- Prerequisites: PHYS 168 "Lasers" (or equivalent) or instructor consent. Specifically you should be familiar with
  - Plane wave propagation
  - Modal description of fields

Grades

- Course Requirements, Percent of Grade
  - Weekly Homework (25%)
  - Midterm Exam (25%)
  - Class Presentation (25%)
  - Final Exam (25%)
- Extra credit may be announced in class.

Tentative Schedule

Date	Topic	Chapter
8/23	Introductions, LIGO overview	
8/28	Complex representation of E&M waves	1
8/30	Phase velocity and group velocity	1
9/4	LIGO interferometer response calculations	
9/6	Propagation in an anisotropic media	4
9/11	Index ellipsoid	4
9/13	Crystals/Coupled mode propagation in crystals	4
9/18	Faraday rotators in LIGO	4
9/20	Propagation in periodic media	6
9/25	More propagation in periodic media	6
9/27	Periodic devices/Multilayer coatings	6
10/2	Linear electro-optic effect	7
10/4	Phase modulation	7
10/9	Sideband generation	7
10/11	Midterm Exam	

Date	Topic	Chapter
10/16	EOM devices	8
10/18	Limitations of EOM devices	8
10/23	Photo-elastic effect	9
10/25	Diffraction from acoustic waves	9
10/30	AOM devices	10
11/1	Frequency locking with AOM devices	
11/6	Dielectric wave-guides	11
11/8	Waveguide devices	11
11/13	Nonlinear interactions	12
11/15	SHG and 4-wave mixing	12
11/20	Review/Catchup	
11/22	Thanksgiving	
11/27	Student Presentations	
11/29	Student Presentations	
12/4	Photodetectors (not in our textbook)	
12/6	LEDs/Diode Lasers (not in our textbook)	
12/13	Final Exam (7:45-10pm)	

History of Electro-Optics

- Early observations of unexpected phenomena
- Development of Electromagnetic theory
- Development of tools to exploit predictions of electromagnetic theory
  - Lasers
  - Waveguides and Fiber Optics
  - Photonic Bandgap Crystals

Birefringence

1670 Erasmus Bartholinus described the double image seen in Icelandic Spar

in 1672 Christian Huygens described it in terms of birefringence

ERASMI BARTHOLINI

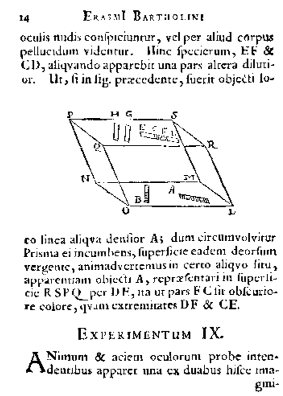
EXPERIMENTA CRYSTALLI ISLANDICI DISDIACLASTICI

Quibus mira & insolita REFRACTIO *detegitur.*

ANNO 1670.

HAFNIÆ,

Sumptibus DANIELIS PAULLI Reg. Bibl.



14 ERASMI BARTHOLINI

oculis nudis conſpiciuntur, vel per aliud corpus pellucidum videntur. Hinc ſpecierum, EF & CD, aliqvando apparebit una pars altera dilutior. Ut, ſi in fig. præcedente, fuerit objecti loco linea aliqva denſior A; dum circumvolvitur Priſma ei incumbens, ſuperficie eadem deorſum vergente, animadvertemus in certo aliqvo ſitu, apparentiam objecti A, repræſentari in ſuperficie RSPQ per DF, ita ut pars FC ſit obſcuriore colore, qvam extremitates DF & CE.

EXPERIMENTUM IX.

ANimum & aciem oculorum probe intendentibus apparet una ex duabus hiſce imagini-

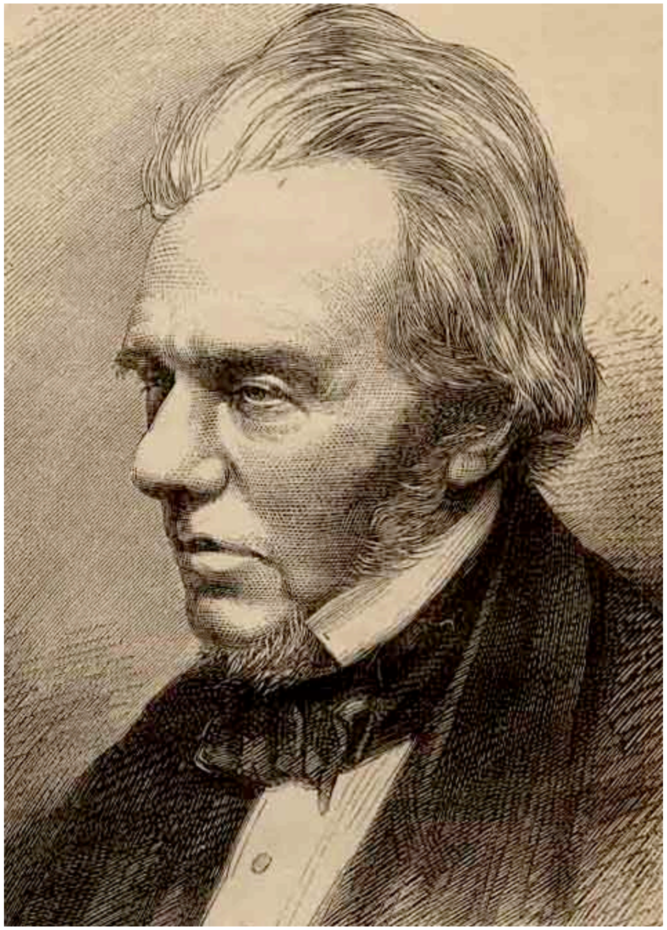
Christian Huygens

Synthetic Crystals

1837 French chemist Mark Gauden succeeds in synthesizing 1 carat mass ruby crystallites in a crucible covered with soot.

Faraday Effect

1845 Michael Faraday discovers that when a block of glass is subject to a strong magnetic field it rotates the plane of polarization of light propagating through it.

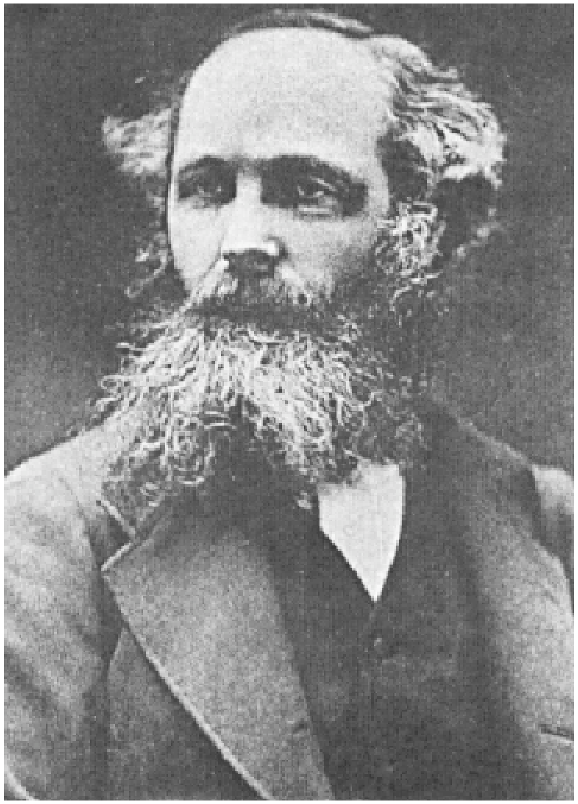


Waveguides

1854 John Tyndall demonstrates that a jet of water can act to confine light

Electromagnetic Theory

1865 James Clerk Maxwell publishes "A Dynamical Theory of the Electromagnetic Field" consolidating known laws of electricity and magnetism into 4 equations that describe the propagation of light



Electric and Magnetic Kerr Effects

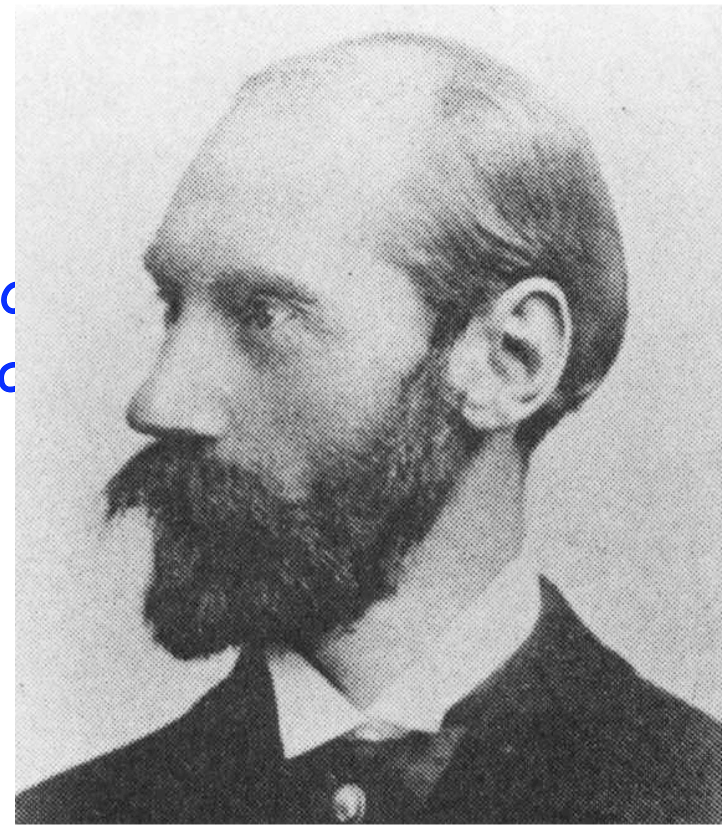
1875 John Kerr discovers that a plate of glass subject to a strong electric field becomes doubly refracting

in 1888 he discovered that when linearly polarized polarized reflects from the polished pole of a magnet it cannot be extinguished by a polarizer

John Kerr
(1824-1907)

Pockel's Effect

1893 Friedrich Pockels discovers an electric field applied to certain materials causes the refractive index to vary in proportion to the field



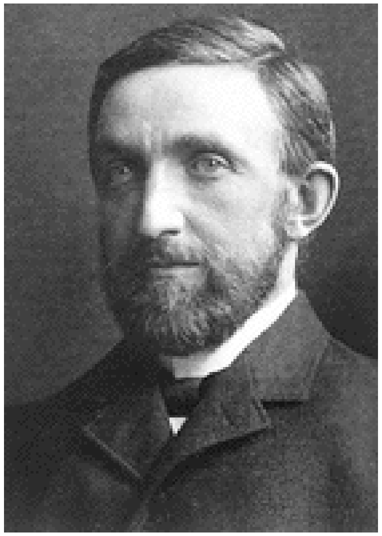
Zeeman Effect

1896 Pieter Zeeman discovers that the yellow spectral lines in a sodium flame broaden when it is placed between the poles of a strong magnet

Voigt Effect

1902 Woldemar Voigt discovers that a vapor in a strong magnetic field causes light propagating perpendicular to the field to experience double refraction

Photoelectric Effect



1902 Philipp Lenard observes a relationship between the frequency of light incident on a metal and the energy of photons ejected from it

in 1905 Einstein explained the photoelectric effect in terms of individual quanta of light, i.e. photons

Cotton-Mouton Effect

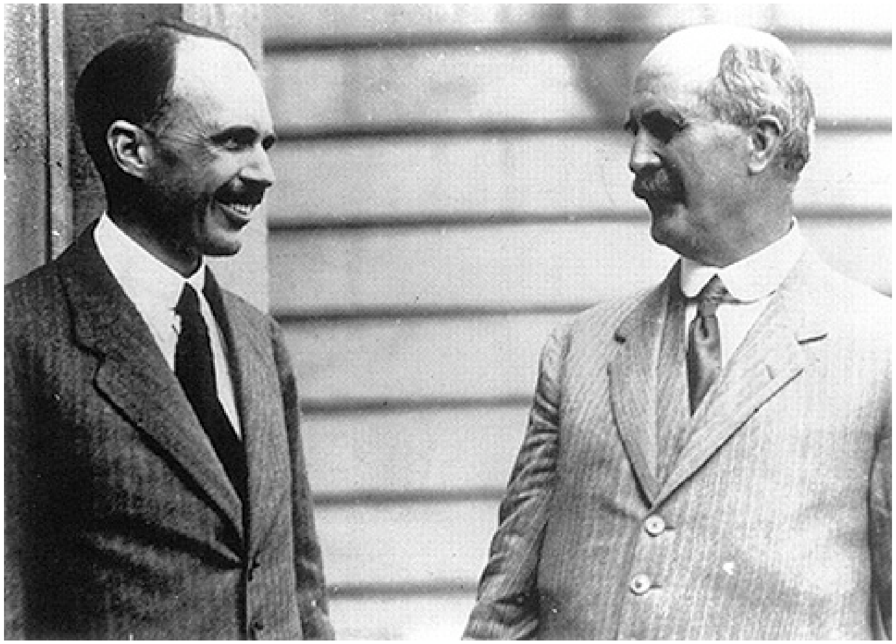
1907 double refraction of light in a liquid in the presence of a constant transverse magnetic field is observed by Aimé Cotton and H. Mouton. It is much stronger than the Voigt effect.

Aimé Cotton

H. Mouton?

Bragg Diffraction

1912 Father and Son William Bragg observe x-ray diffraction from crystals (they would receive the Nobel prize in 1915)



William Lawrence Bragg (left) and William Henry Bragg

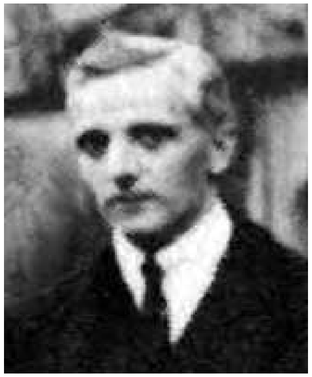
Economic Synthetic Crystals

1916 polish scientist Jan Czochralski discovers a fast and inexpensive method to produce large crystals

Acousto Optic Effect

1922 Léon Brillouin predicts the diffraction of light by an acoustic wave

in 1932 Peter Debye and Francis Weston Sears experimetnally verified Brillouin's prediction



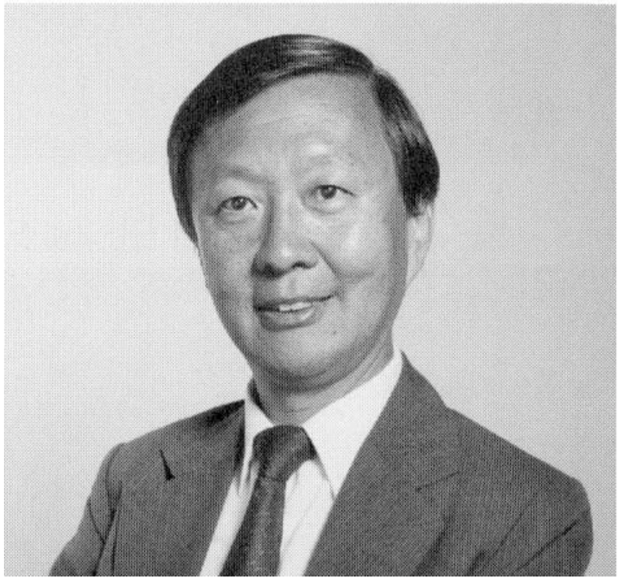
Léon Brillouin

Peter DeBye

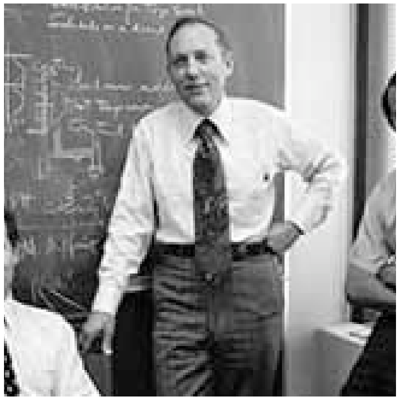
Francis Weston Sears

Fiber Optics

1965 Charles Kao carefully studies loss in glasses and found that if impurities were removed glass fibers could be viable telecommunications medium



1970 Robert Maurer demonstrates the first low-loss optical fiber

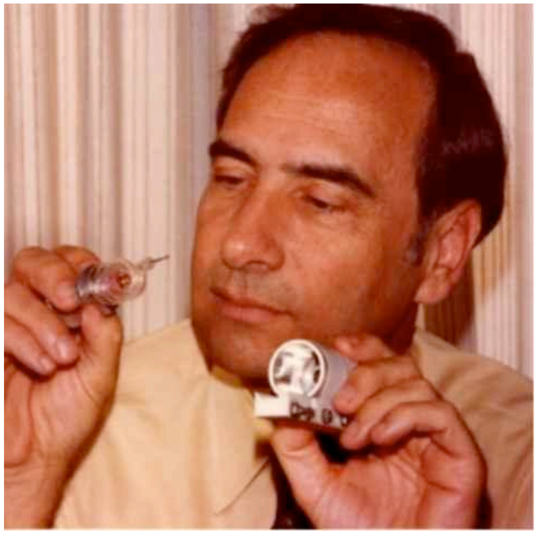


Laser

1958 Art Schawlow and Charles Townes propose "Optical Masers"

1960 the ruby laser was developed by Ted Maiman

Charles Townes and Art Shawlow

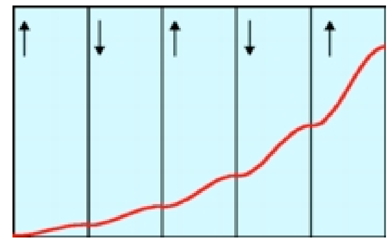


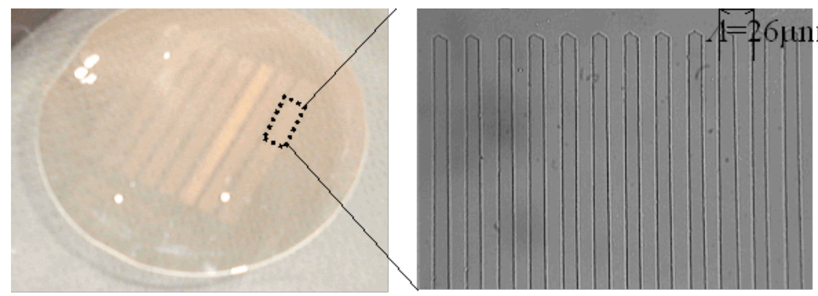
Ted Maiman

Periodic Poling

1963 P.A. Franken and J.F. Ward first use periodic poling to quasi-phasematch a non-linear interaction

1993 M. Yamada uses Ferroelectric Domain Engineering on Litium Niobate to invent PPLN





Blue Laser Diode

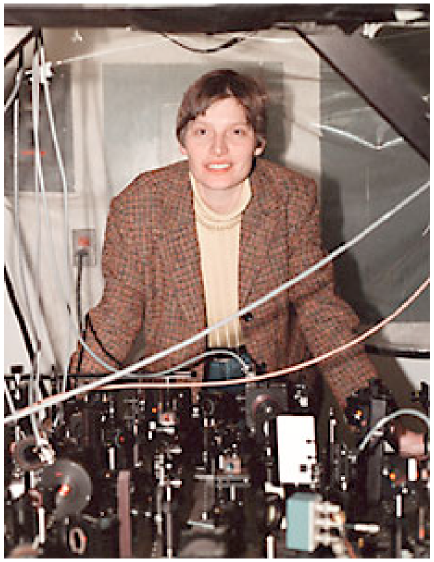
1993 Shuji Nakamura virtually single handedly produces the first blue LED

1996 he develops the first blue laser diodes

Quantum Manipulation

1999 Lene Hau uses a Bose-Einstein Condensate to slow light to 17 m/s.

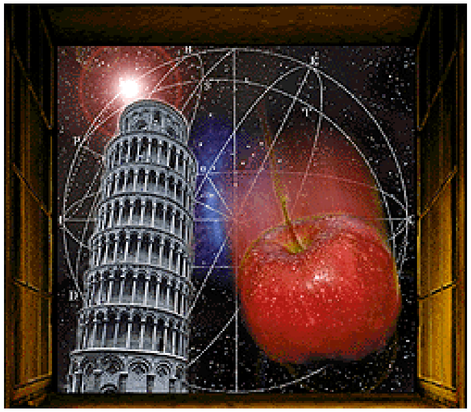
In 2007 she stops and extinguishes a light pulse in one part of space and then revives it in a completely separate location



Case Study: LIGO

A (big) optics experiment using many technologies we will be studying

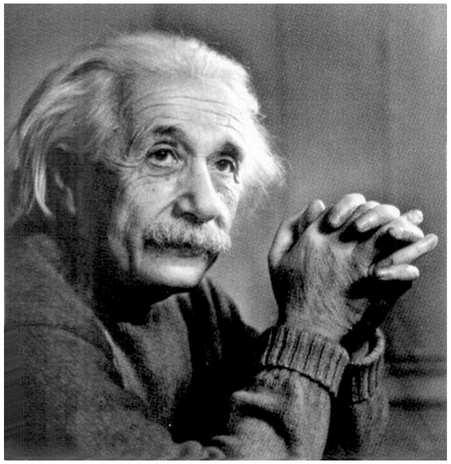
Modern Theory of Gravitation

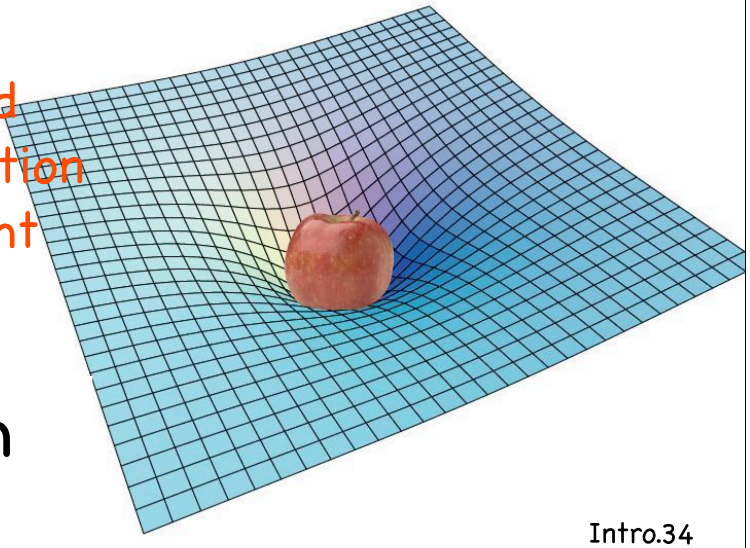


Newton's Theory

"instantaneous action at a distance"

$$\vec{F}_{12} = -G\frac{m_1 m_2}{r_{12}^2}\hat{r}_{12}$$





Einstein's Theory

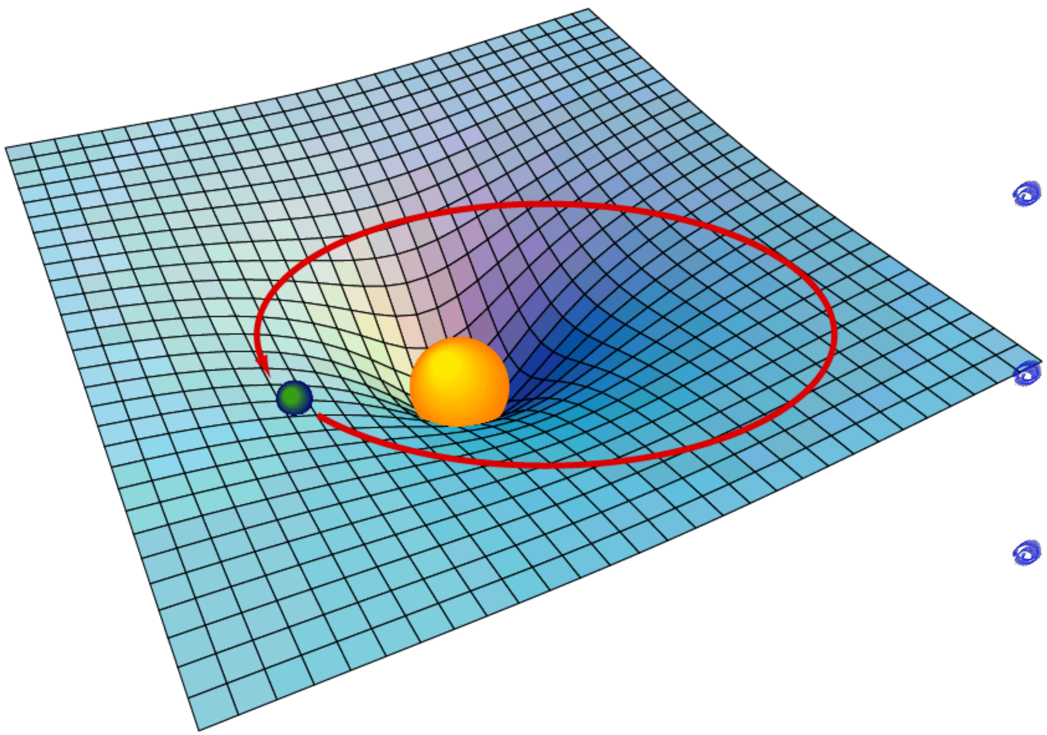
information carried by gravitational radiation at the speed of light

$$\overline{T} = \frac{c^4}{8\pi G}\overline{G}$$

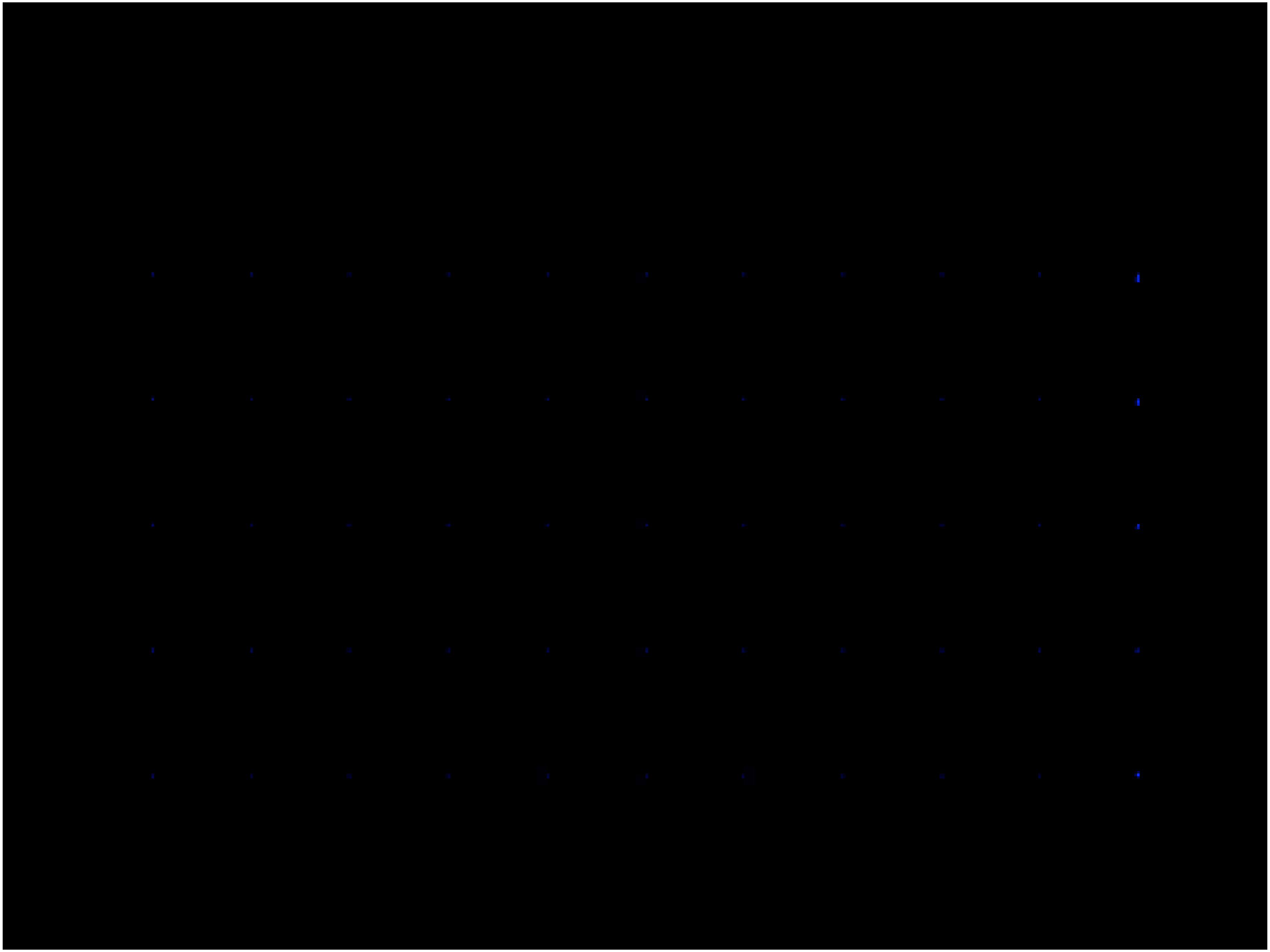
F=-kΔx with k=10^{43}!

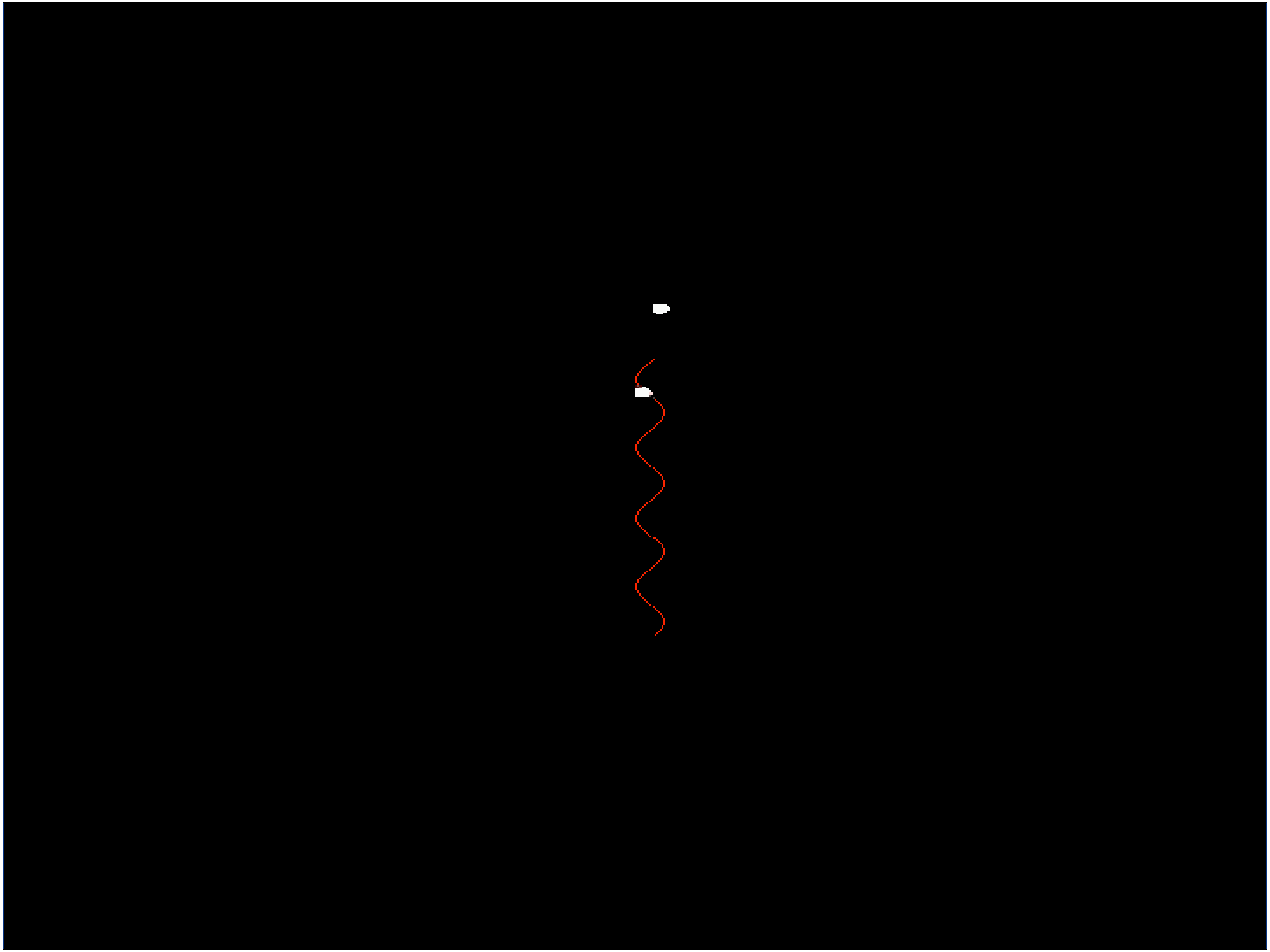
General Relativity

Einstein theorized that smaller masses travel toward larger masses, not because they are "attracted" by a mysterious force, but because the smaller objects travel through space that is warped by the larger object



- Imagine space as a stretched rubber sheet.
- A mass on the surface will cause a deformation.
- Another mass dropped onto the sheet will roll toward that mass.

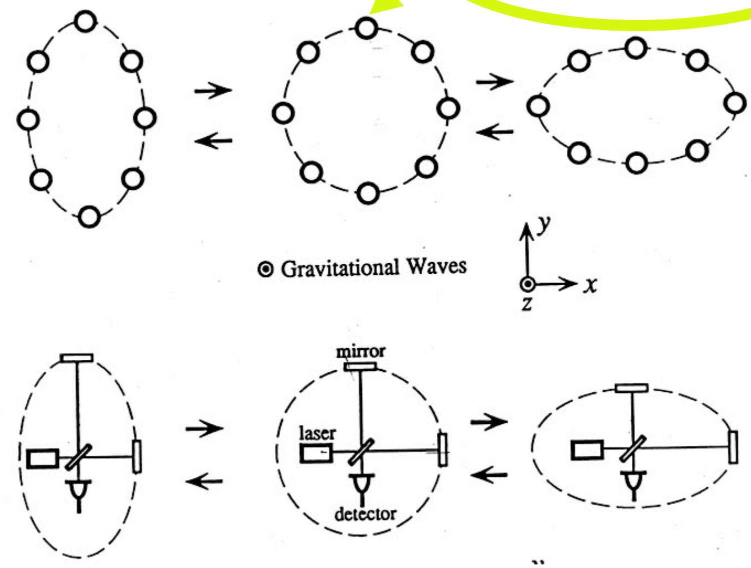


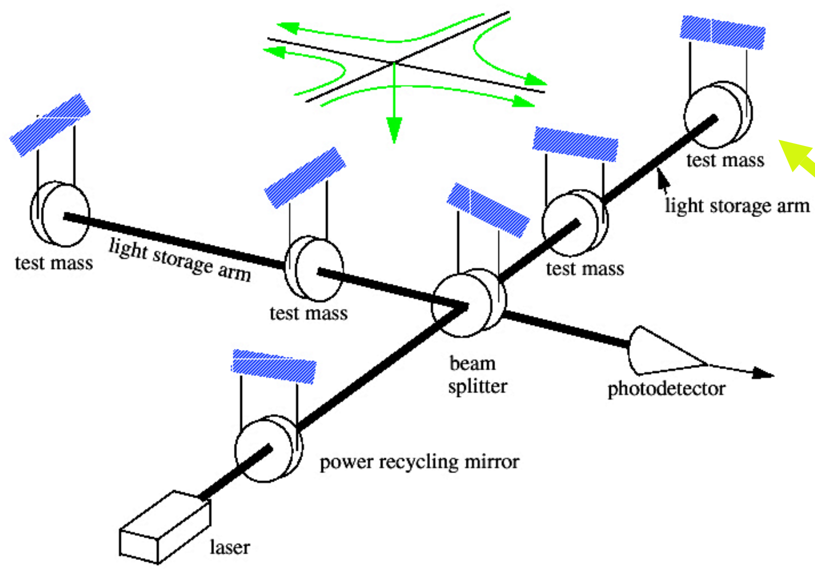


Interferometric Detectors

International network (LIGO, Virgo, GEO, TAMA) of suspended mass Michelson-type interferometers on earth's surface detect distant astrophysical sources

free masses

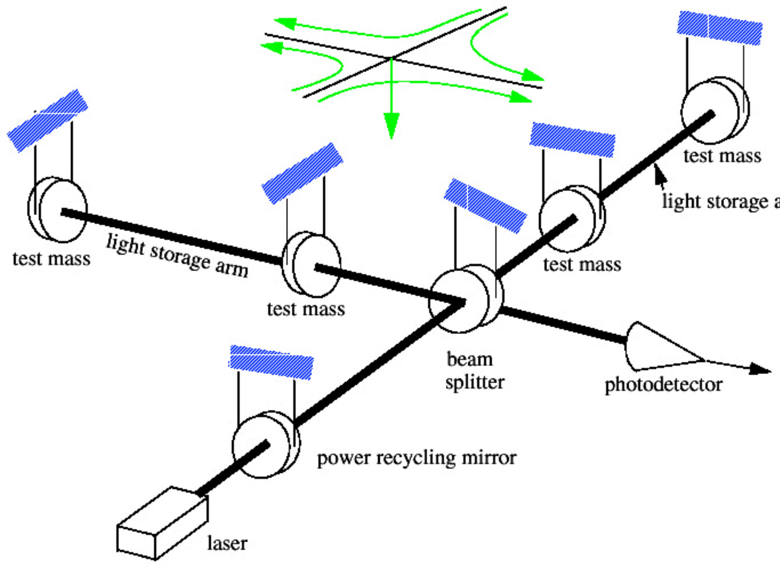




suspended test masses

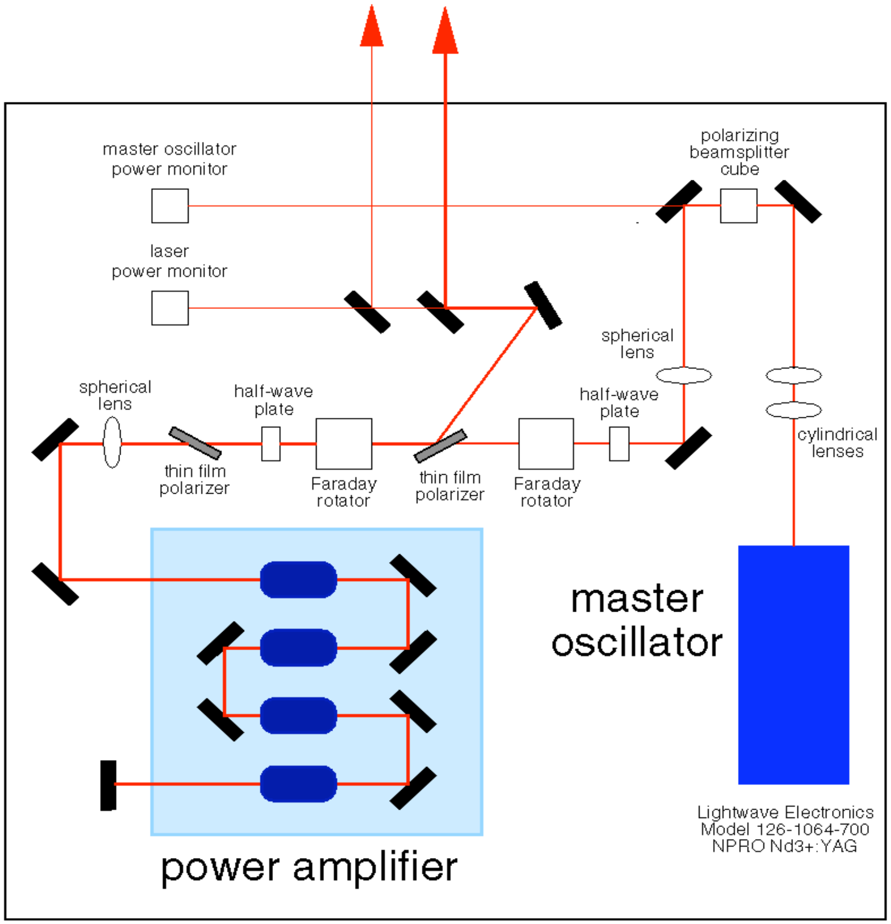
How does what we will be studying relate to this experiment?

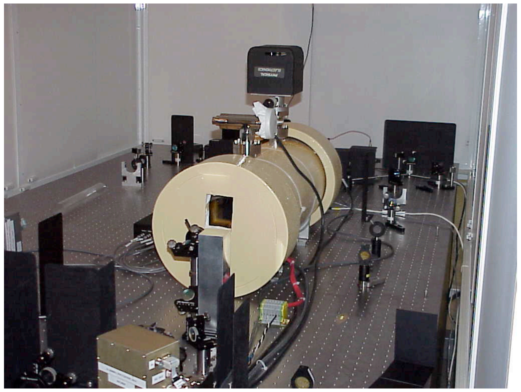
Interferometer



Complex representation of EM waves

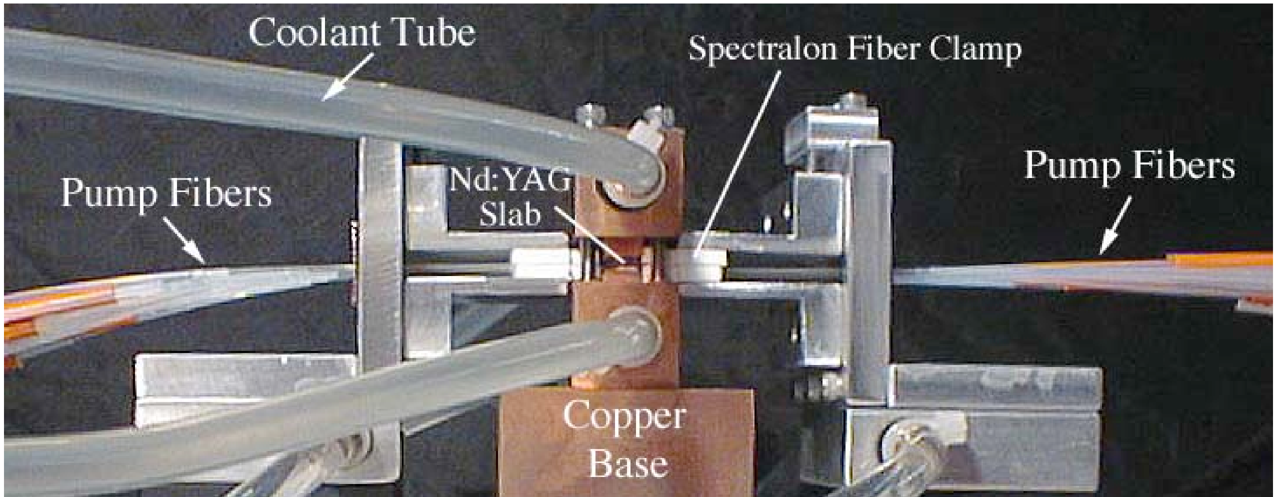
Laser Oscillator/Amplifier





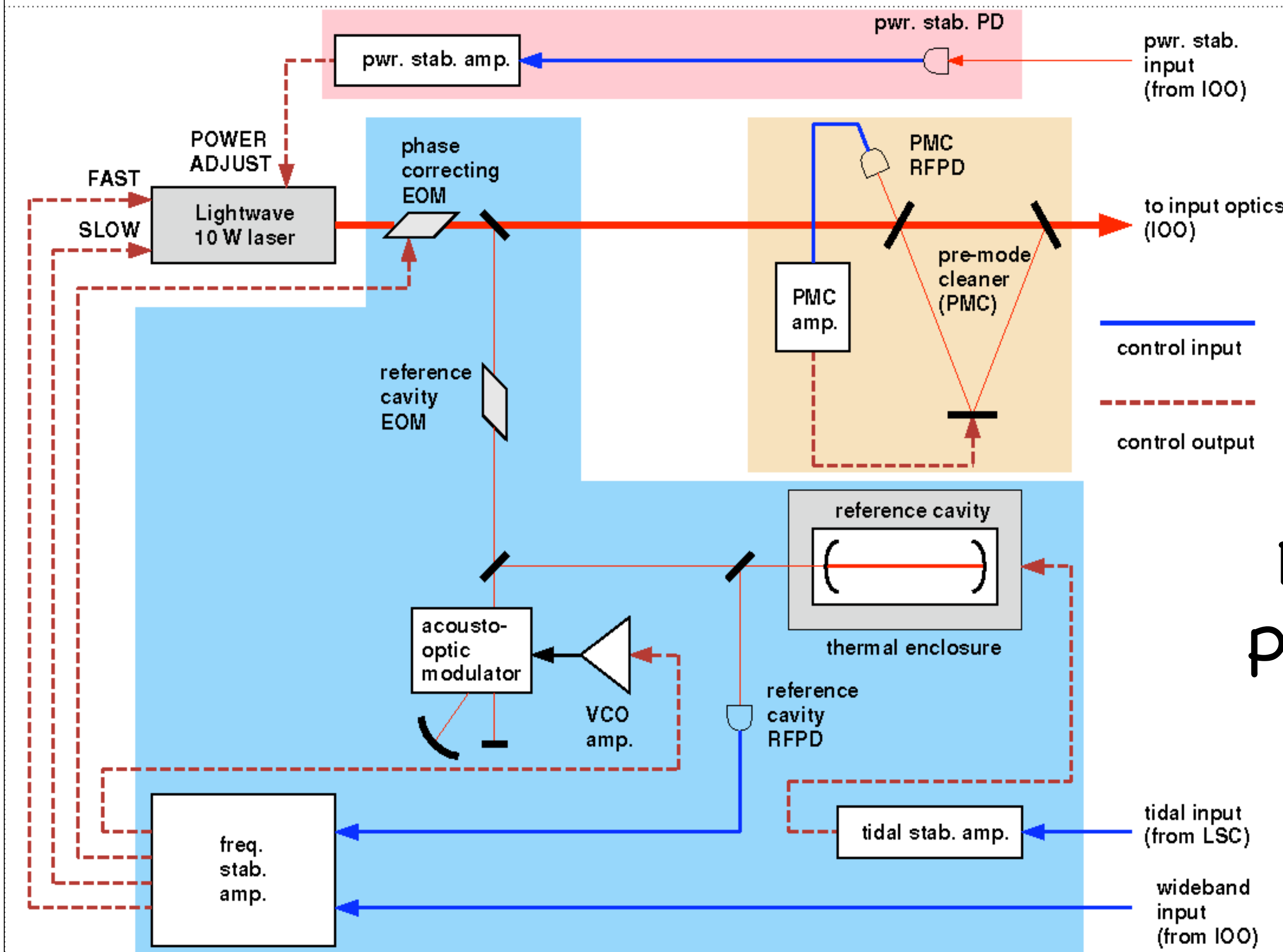
Wave plates, propagation in crystals, faraday rotation

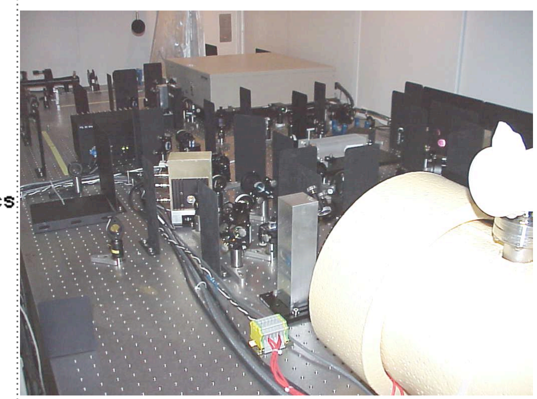
Pump Diodes



Dielectric waveguides, laser diodes

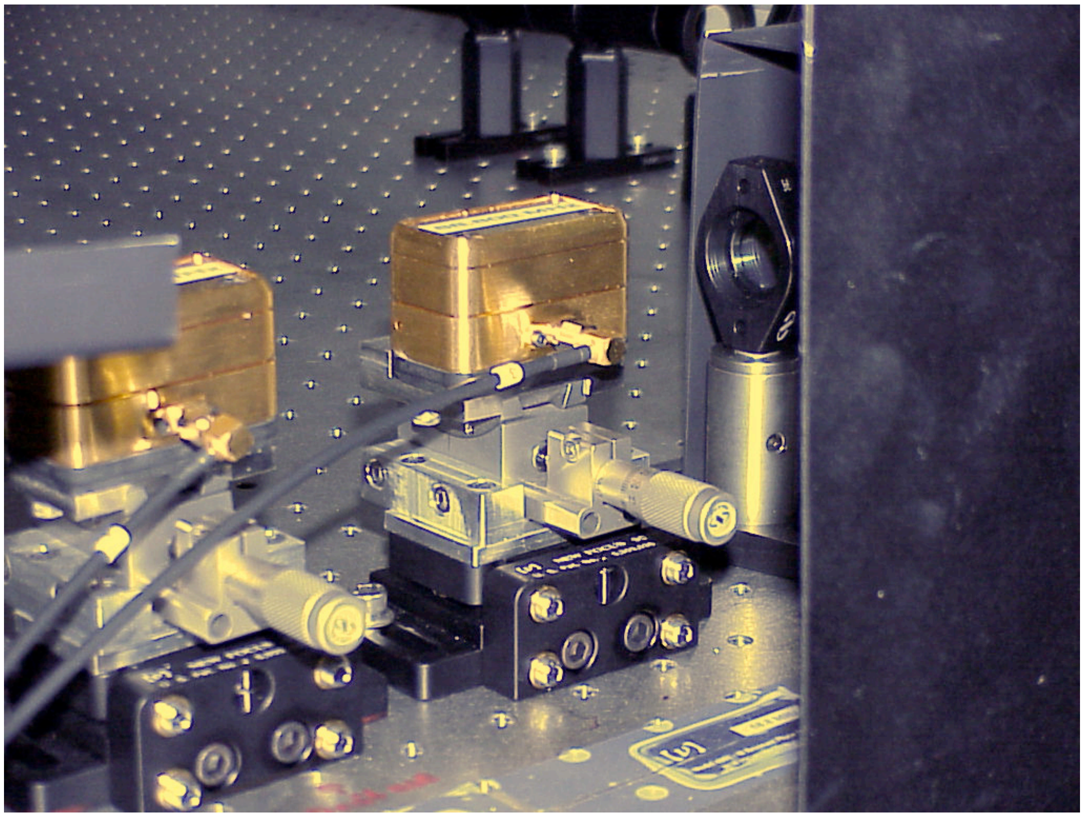
Laser Stabilization

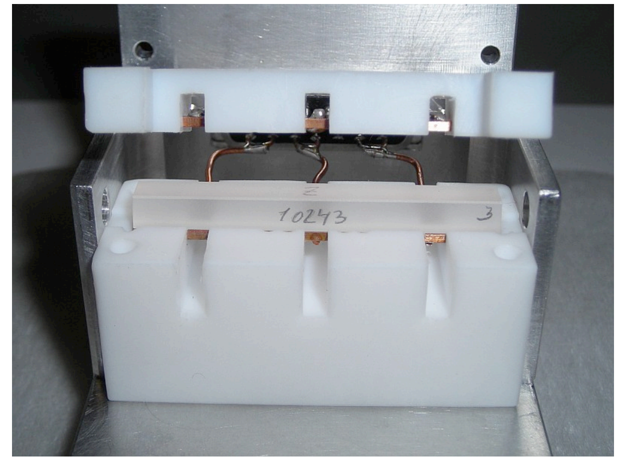


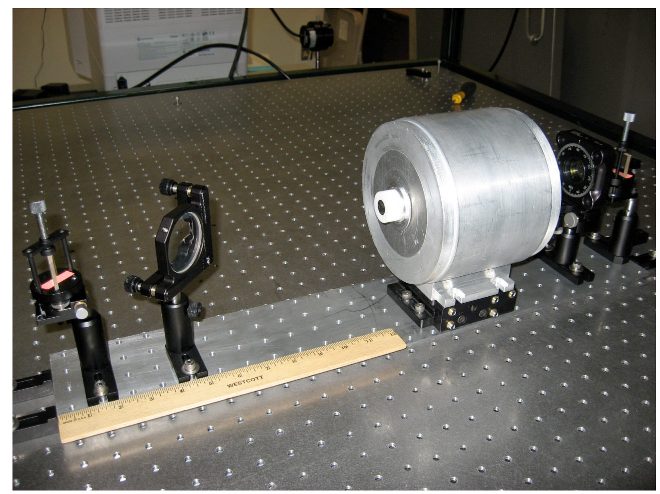


EOMs, AOMs, Photodetectors

Input Optics

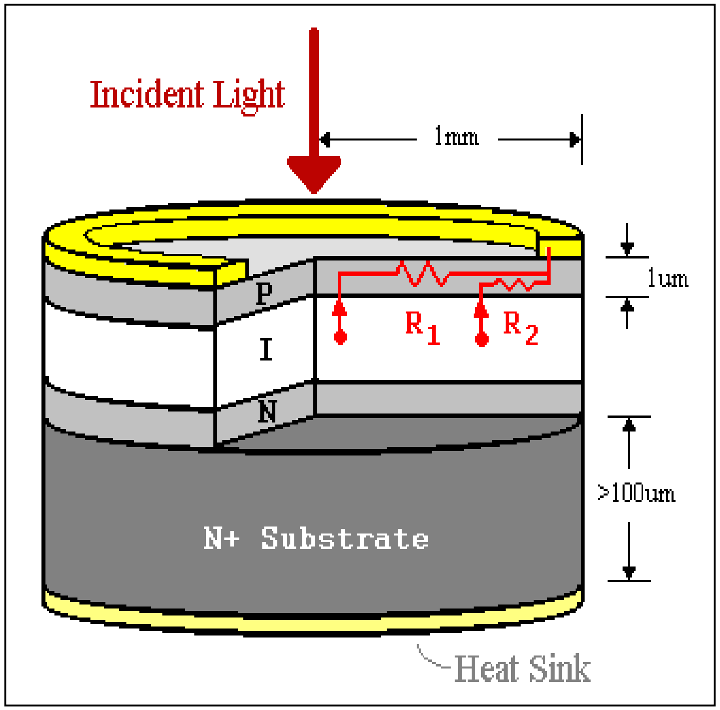


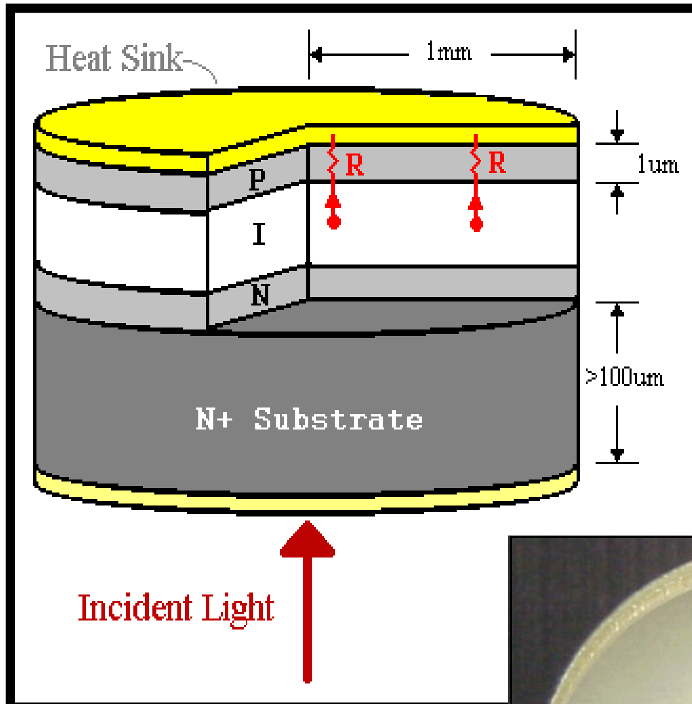


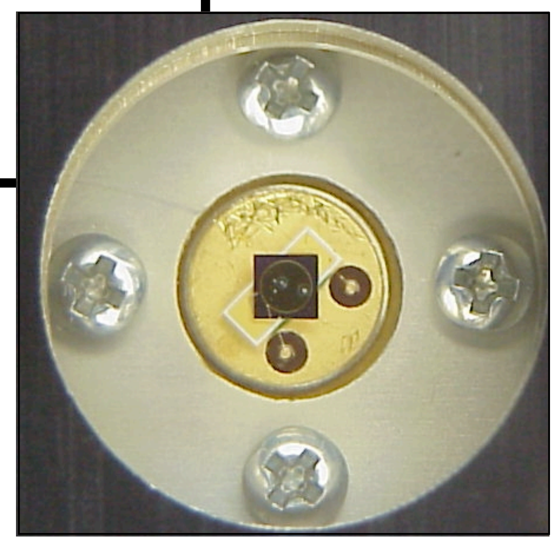


Electrooptic effect, Modulators, Faraday rotation

Photodetectors



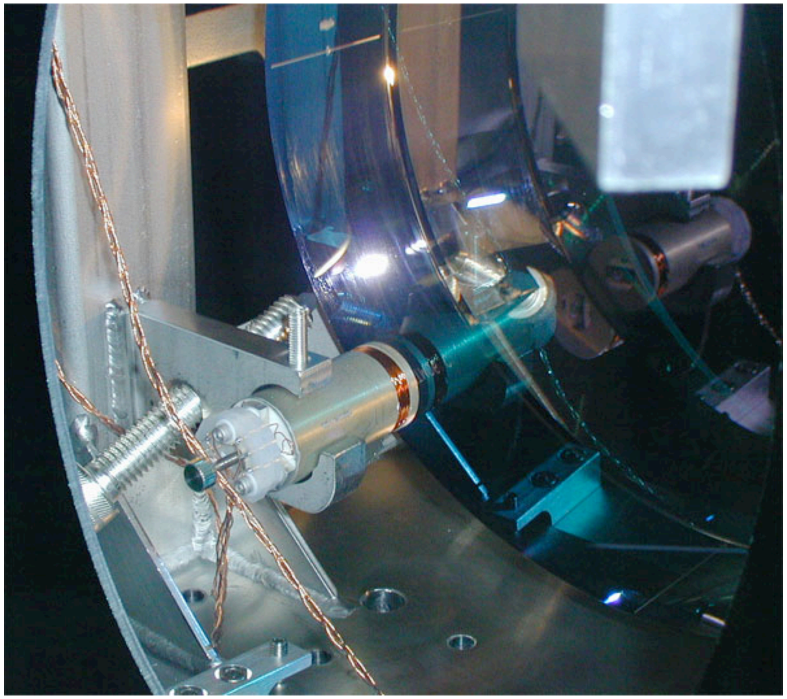




PIN junctions,
photodiodes

Mirrors

Wave propagation in periodic media



Summary

- Class information is contained in the green sheet
- Make sure to familiarize yourself with the class web site and to register your email address
- History of electro-optics is long but ongoing
- Many modern science experiments rely heavily on aspects of electro-optics

References

- Jenkins & White "Fundamentals of Optics" chapter 32
- Wikipedia