ELI-ALPS Research Institute
TOWARDS THE SHARP END OF ATTOSCIENCE

The ELI ALPS infrastructure
Basics of high energy, short pulsed lasers

Katalin Varjú

12-07-2017

SZÉCHENYI 2020
Hungarian Government
European Union
European Regional Development Fund
INVESTING IN YOUR FUTURE

Summer School on Lasers in Medicine and Life Sciences

Outline

I. The ELI project

II. Lasers

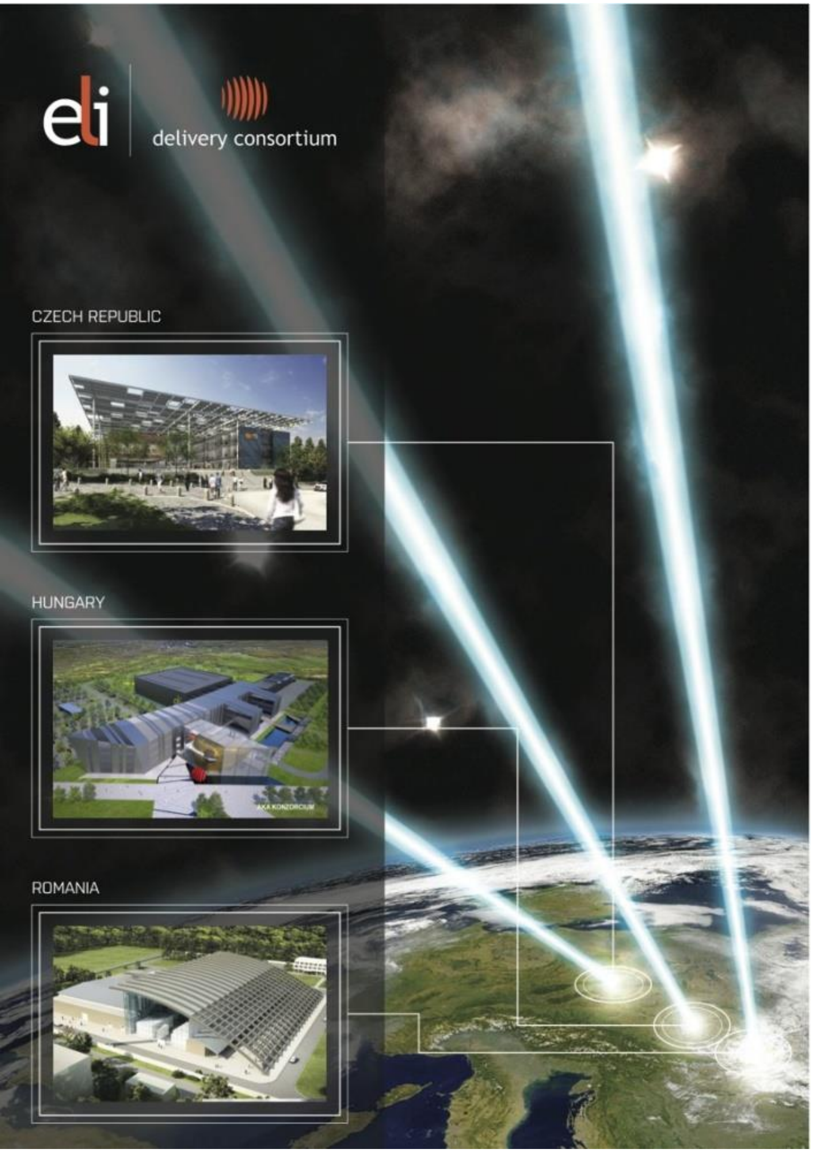
III. … in Medicine

LAMELIS

Lasers in Medicine and Life Sciences

Advanced summer school for undergraduate and postgraduate students of medicine and physics. 12^{th} — 21^{st} July 2017, Szeged

The ELI (Extreme Light Infrastructure) project
A distributed RI of the ESFRI roadmap



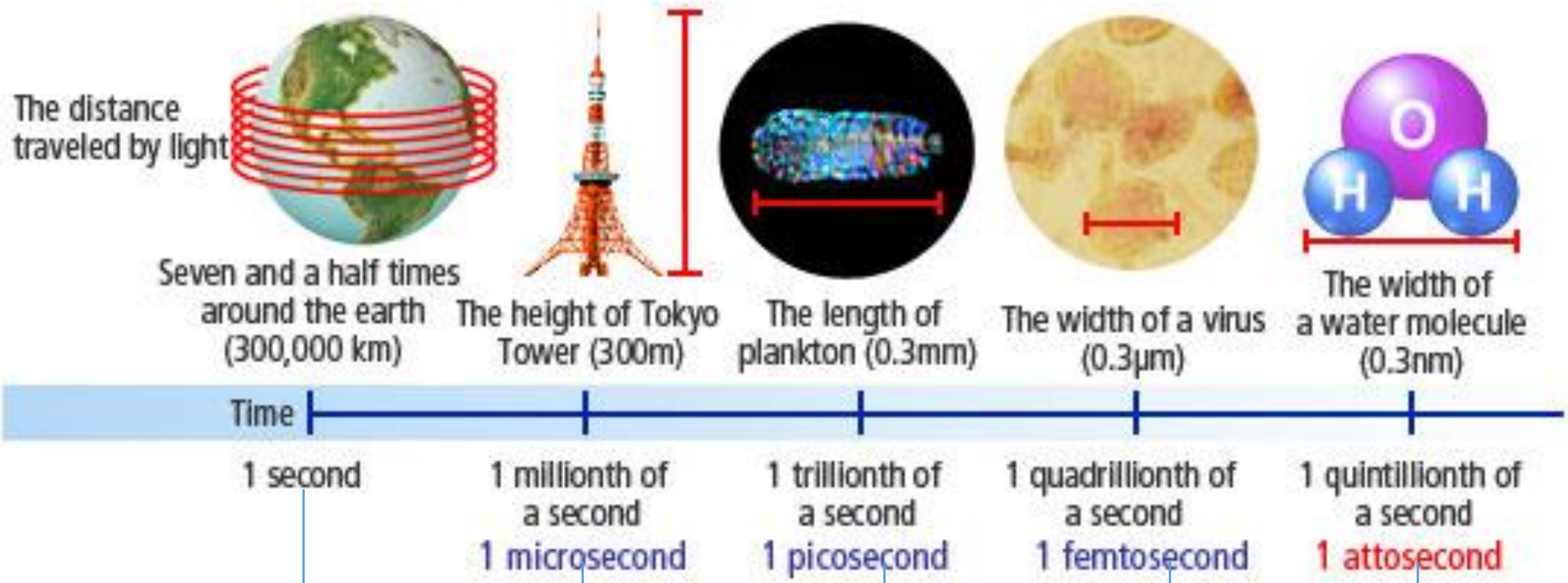
- ELI Attosecond Light Pulse Source (ELI-ALPS) (Szeged, Hungary)
- ELI High Energy Beam-Line Facility (ELI-Beamlines) (Dolni Brezhany, Czech Republic)
- ELI Nuclear Physics Facility (ELI-NP) (Magurele, Romania)

Missions of ELI ALPS

1) To generate X-UV and X-ray fs and atto pulses, for temporal investigation at the attosecond scale of electron dynamics in atoms, molecules, plasmas and solids.

2) To contribute to the technological development towards high average power, high intensity lasers.

How short is an attosecond?



1 s

0,000 001 s

0,000 000 000 001 s

0,000 000 000 000 001 s

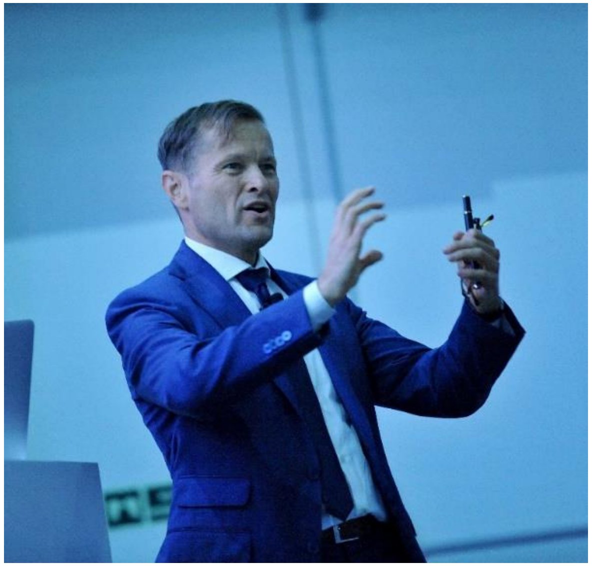
0,000 000 000 000 000 001 s

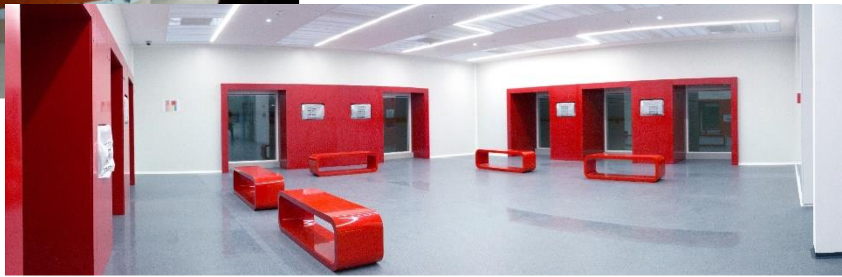
How it all started

Building - foundations

Building – 18th January, 2015

Inauguration May, 2017





Construction completed

Building A 6209 m²
laser halls and experimental areas

Building D 2926 m²
maintenance, support services

Building B 7936 m²
laboratories, workshops, offices, machinery

Building C 7391 m²
offices, lecture halls, library, restaurant

Building - facts

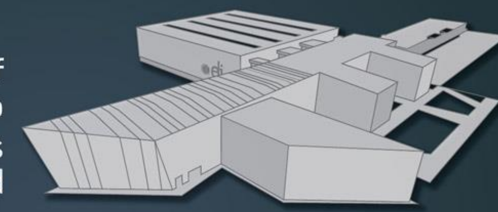
GROUNDWORK

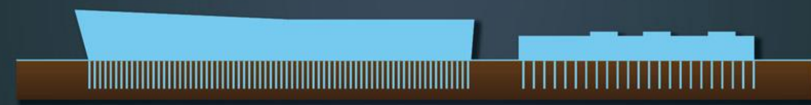
133.000m^3 of soil was removed from under building ”A” the rain reservoir.

12.091 db
DUMPER

PILING

To provide the stability of the buildings, according to soil mechanical, 819 piles were drilled under ground level.



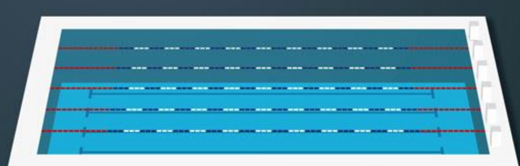


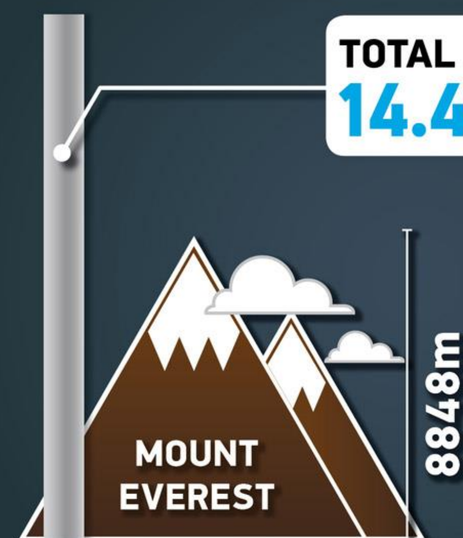
TOTAL AMOUNT OF CONCRETE

The total amount of concrete used during the construction would fill up 18 olympic swimming pools.
This is approximately 45.656 m^3.

MORE THAN 18 pc
OLYMPIC
SWIMMING POOLS
COULD BE FILLED
UP WITH CONCRETE

5707 pc
CONCRETE MIXER





TOTAL LENGTH OF PILES
14.400 meters

241pc
piles with a diameter of more than 1 m

578pc
piles with a diameter less than 1 m

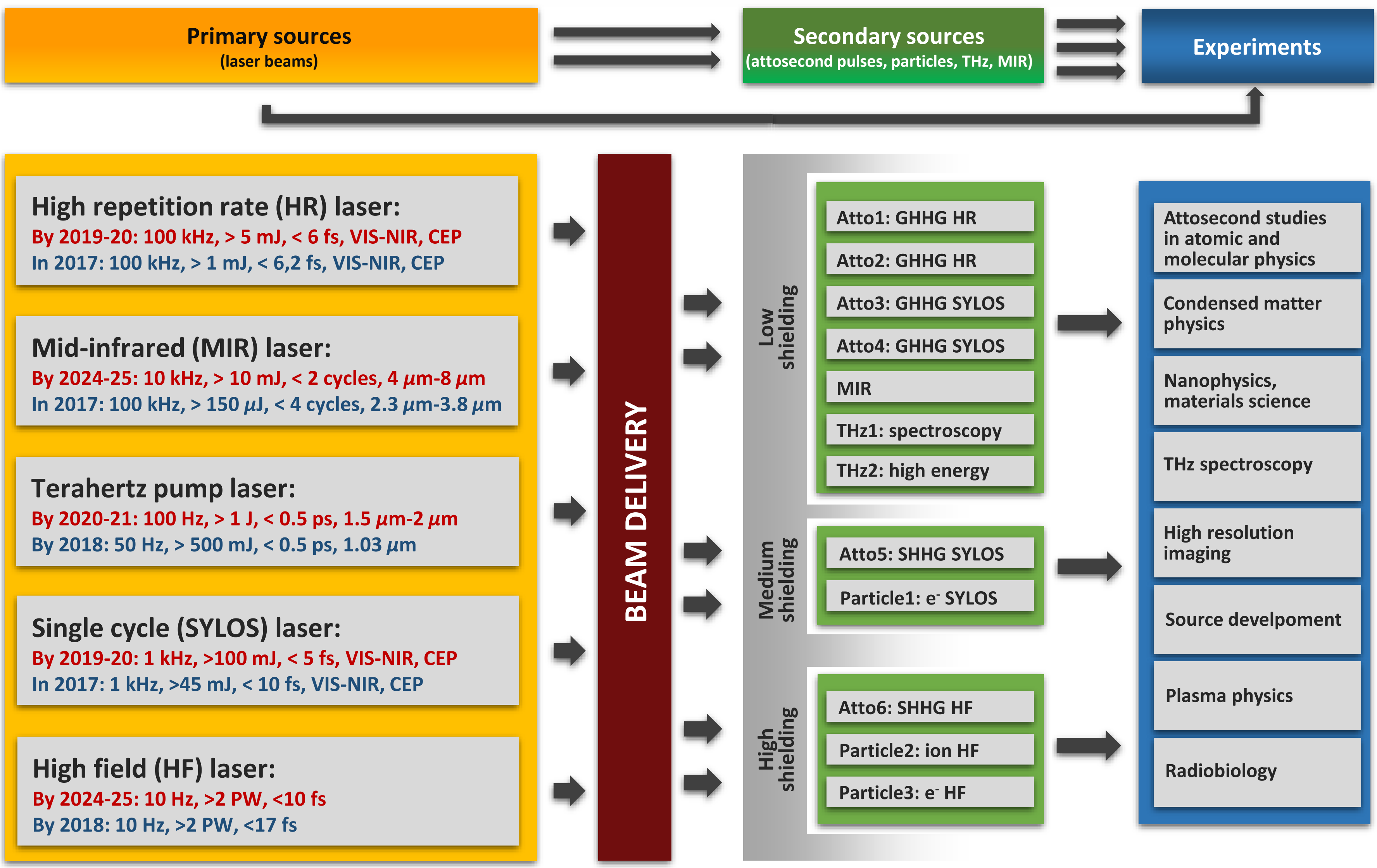
Laboratories A & B

Clean room environment.
ISO 7 for laser halls, ISO 8 for secondary sources / user areas.

Temperature and relative humidity.
21°C (±0.5°C), 35±5% (tunable).

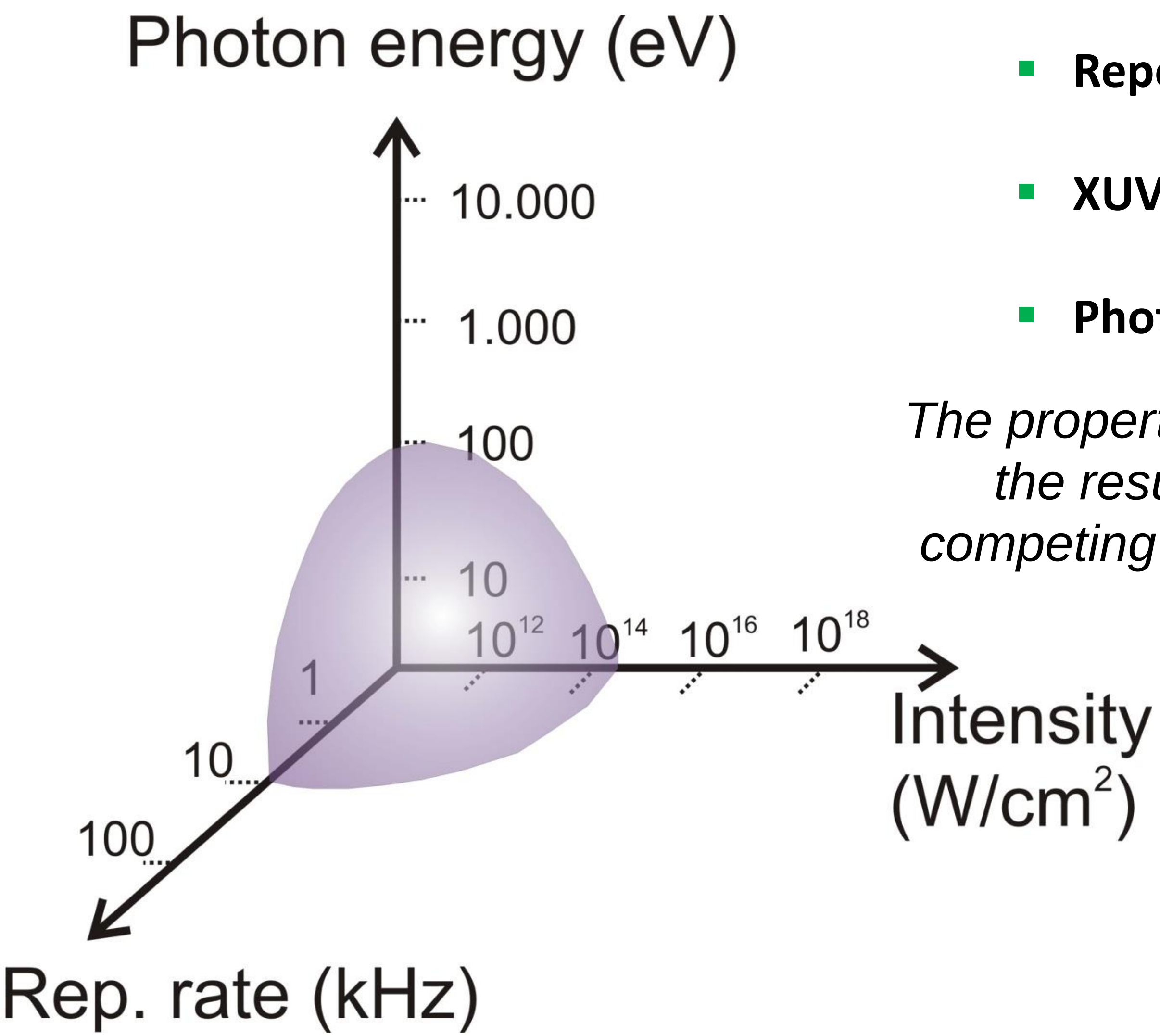
Vibration isolation
VC-E (ASHRAE)

Schematics of ELI-ALPS



Kühn, et al., Journal of Physics B, 50, 132002 (2017)

New directions in attosecond science

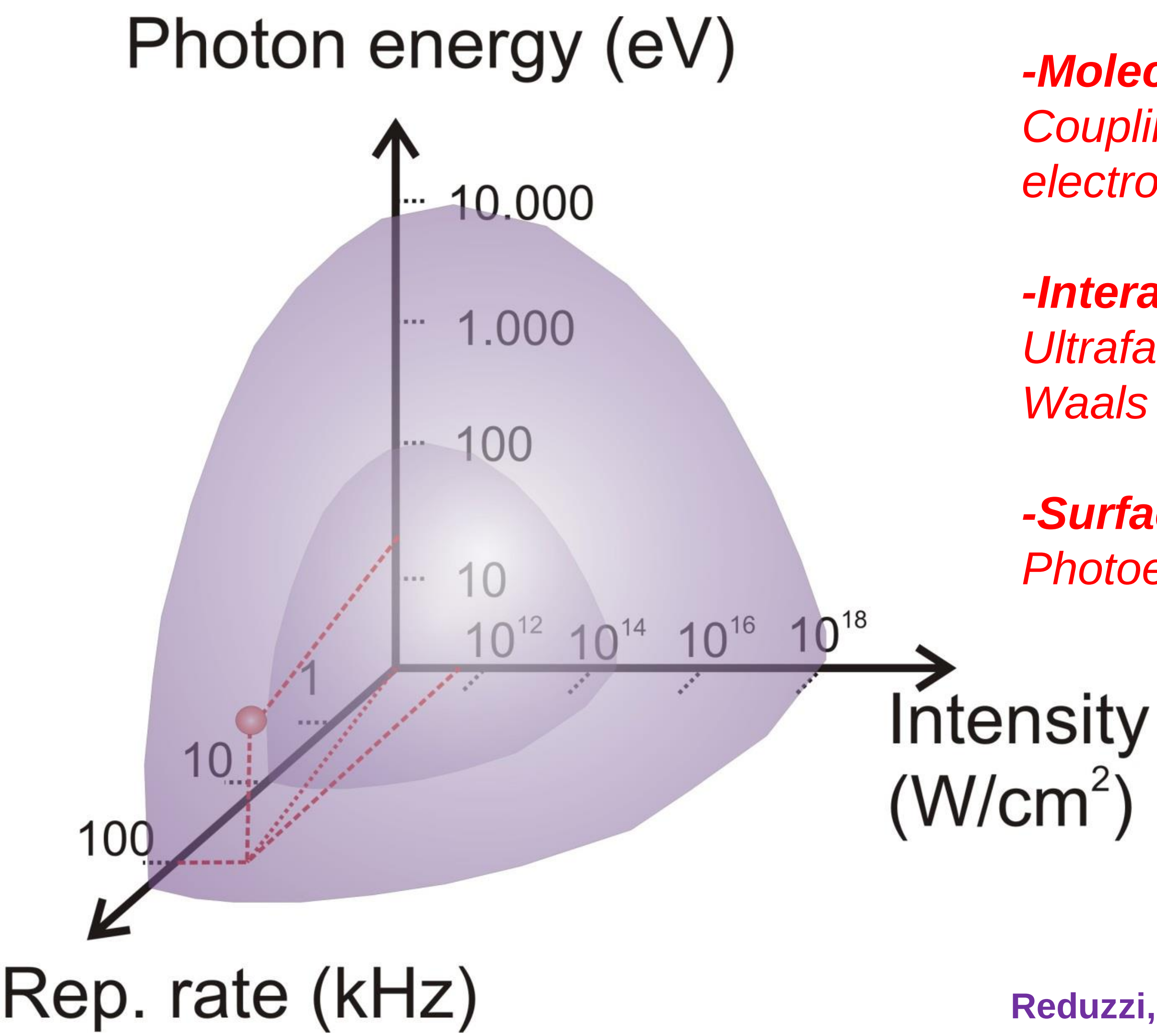


- **Repetition rate** (few Hz-10 kHz)
- **XUV Intensity** (10^9-10^{12} W/cm^2)
- **Photon energy** (10-150 eV)

The properties of attosecond pulses are the result of a trade-off between competing requirements on the driving sources.

Reduzzi, J Electron Spectr & Rel Phenom (2015)

High-rep. rate for coincidence spectroscopy



Repetition rate = 100 kHz

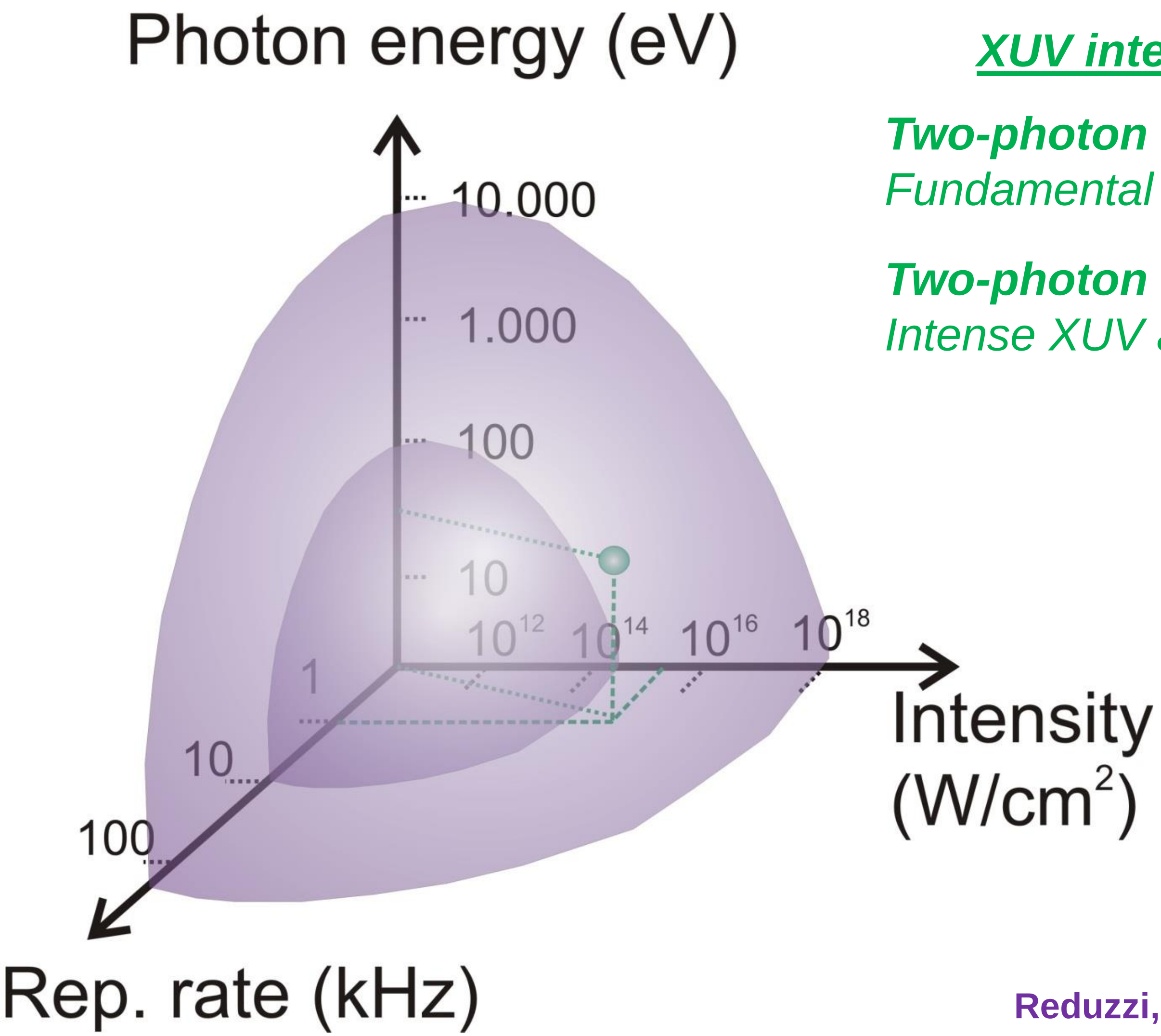
-Molecular-frame autoionization
Coupling between nuclear and electronic degrees of freedom

-Interatomic Coulombic Decay
Ultrafast energy relaxation in van der Waals and hydrogen-bonded clusters

-Surface attosecond science
Photoelectron emission microscopy

Reduzzi, J Electron Spectr & Rel Phenom (2015)

High-intensity for nonlinear XUV spectroscopy



XUV intensity= 10^{15}-10^{18} W/cm^2

Two-photon double ionization of helium

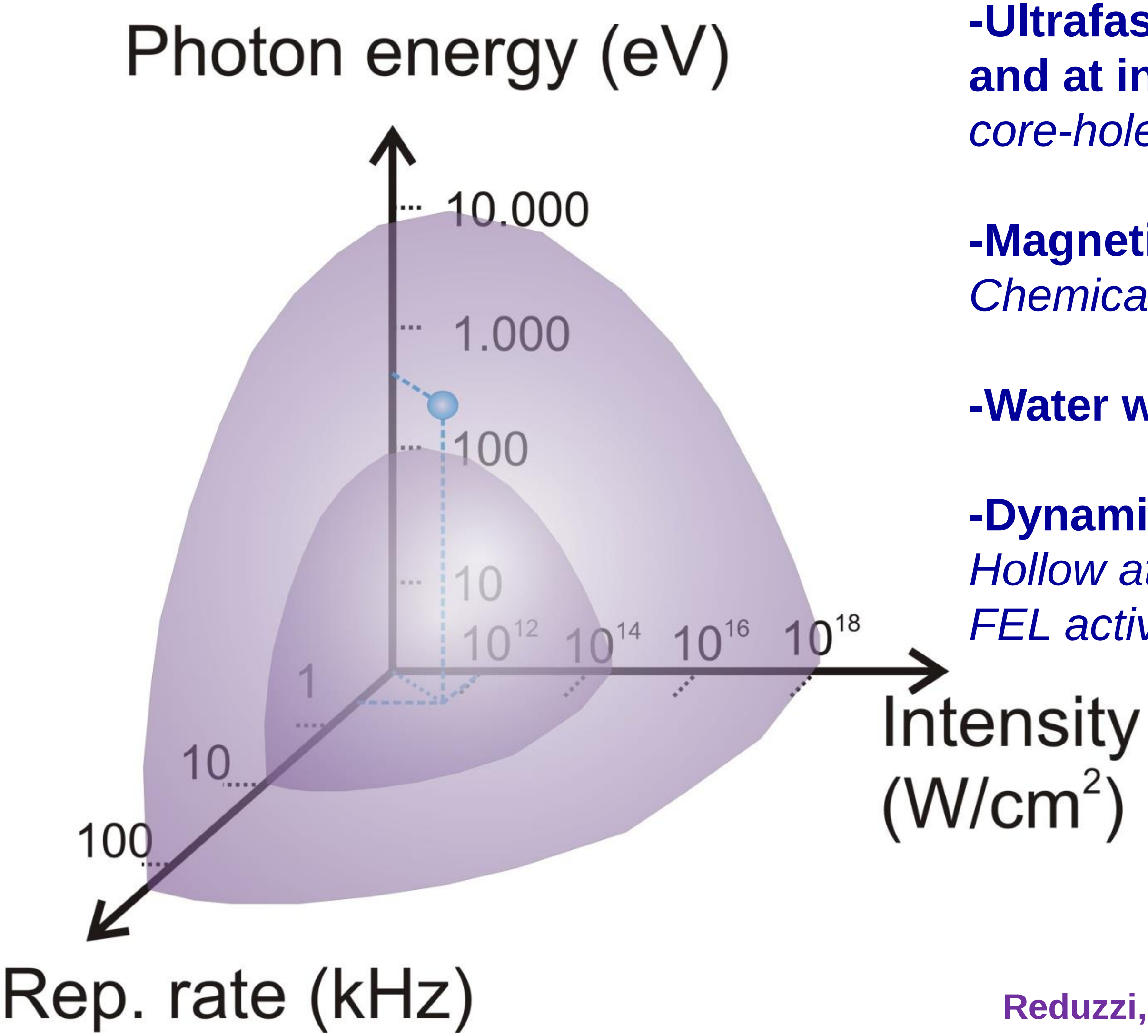
Fundamental problem of electronic correlation

Two-photon double ionization of neon

Intense XUV and soft-X ray physics

Reduzzi, J Electron Spectr & Rel Phenom (2015)

High photon energy for core electrons



High photon energy= 200-10.000 eV

-Ultrafast charge delocalization in DNA and at interfaces
core-hole spectroscopy

-Magnetic materials (L-shell)
Chemical selectivity

-Water window

-Dynamics of highly excited ions
Hollow atoms and connection with FEL activity

Reduzzi, J Electron Spectr & Rel Phenom (2015)

ELI-ALPS: the people

SCIENTIFIC ADVISORY COMMITTEE
Chair: Sandro De Silvestri

Dimitris Charalambidis
Chief Scientific Advisor

Giuseppe Sansone
Scientific Advisor

Karoly Osvay
Research Technology Director

Attosecond and Strong Field Science
Franck Lepine

- Laser Plasma Theory Group – Alexander Andreev
- Strong Field and Quantum Optics Theory Group – Sandor Varro
- Computational and Applied Materials Science Group – Mousumi Upadhyay Kahaly
- Theoretical and Computational Group of Molecular Structure and Dynamics Group – Agnes Vibok
- Attosecond and Strong Field Processes in Few-body Systems
- Charge Dynamics in (Bio)materials – Sophie Canton

Scientific Application
Peter Dombi

- Biomedical Application Group – Katalin Hideghety
- Ultrafast 4D Imaging Group – Laszlo Ovari
- Ultrafast Nanoscience Group – Peter Dombi
- Ultrafast Dynamics in Semiconductors Group – Csaba Janaky
- THz Reaction Control Group – Viktor Chikan
- Service Diagnostics Laboratories

Attosecond Sources
Katalin Varju

- HR Attosource Group – Miklos Füle
- SYLOS Gas Attosource Group – Sergei Kühn
- Surface Plasma Attosource Group – Subhendu Kahaly
- Diagnostics of Attosources – Paraskevas Tzallas
- Attosources R&D Group – Katalin Varju

Particle and Terahertz Sources
Patrizio Antici

- Ion Acceleration Group – Patrizio Antici
- Electron Acceleration Group – Christos Kamperidis
- Terahertz Source and Applications Group – Jozsef Fulop

Laser Infrastructure
Karoly Osvay

- Mid-Infrared Laser Group – Eric Cormier
- High Field Laser Group – Mikhail Kalashnikov
- Single Cycle Laser Group – Adam Borzsonyi
- High Repetition Rate Laser Group – Zoltan Varallyay
- Laser Research and Development Group – Mikhail Kalashnikov

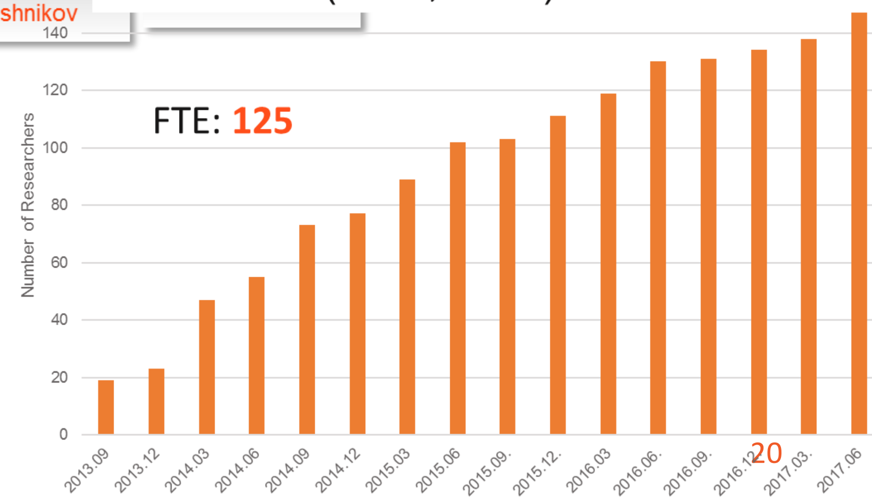
Engineering and integration
Lajos Fulop

- Beam Transport Group – Arpad Mohacsi
- Infrastructure Liaison Group – Imre Kiss
- Software Engineering Group – Lajos Schrettner
- Electrical Engineering Group – Ferenc Horvath
- Mechanical

Research Technology Service Unit
Gergo Meszaros

- Optical Preparatory Workshop – Gergo Meszaros
- Mechanical Workshop – Zoltan Vajna
- Electrical Workshop – Viktor Varkonyi

Number of researchers, engineers, technicians (June, 2017)



Applications are welcome!

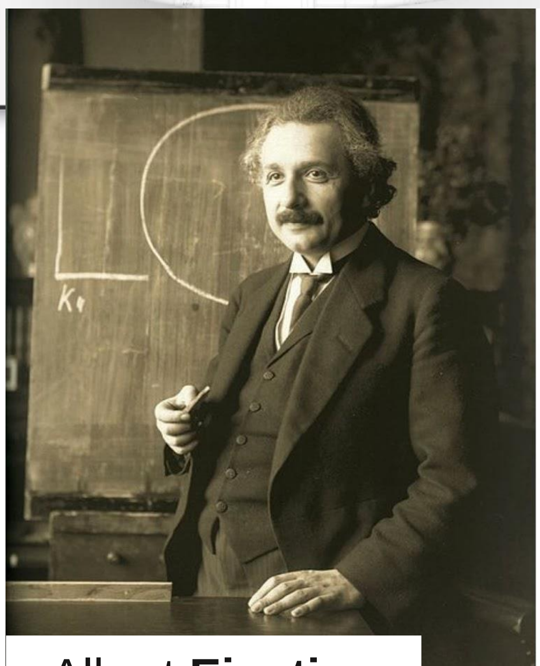
http://www.eli-alps.hu/career/

What is a laser?

Light
Amplification by
Stimulated
Emission of
Radiation

Source
producing
light with very special
properties

Laser – the beginnings



Albert **Einstien**
1916.

Zur Quantentheorie der Strahlung.

Von A. Einstein[1])

Die formale Ähnlichkeit der Kurve der chromatischen Verteilung der Temperaturstrahlung mit Maxwellschen Geschwindigkeits-Verteilungsgesetz ist zu frappant, als daß sie lange hätte verborgen bleiben können. In der Tat wurde bereits W. Wien in der wichtigen theoretischen Arbeit, in welcher er sein Verschiebungsgesetz

$$\varrho = \nu^3 f\left(\frac{\nu}{T}\right) \qquad (1)$$

ableitete, durch diese Ähnlichkeit auf eine weitergehende Bestimmung der Strahlungsformel geführt. Er fand hierbei bekanntlich die Formel

$$\varrho = \alpha \nu^3 e^{-\frac{h\nu}{kT}} \qquad (2)$$

welche als Grenzgesetz für große Werte von $\frac{\nu}{T}$ auch heute als richtig anerkannt wird (Wien-

1) Zuerst abgedruckt in den Mitteilungen der Physikalischen Gesellschaft Zürich. Nr. 18, 1916.

Theodore **Maiman**
1960

...t experiments two peaks ...y only about 40 gauss so ... that the broadening is ex... resonance extends to ... no additional structure. This may be related to the characteristic of the magnetic method that even unbroadened lines possess apparent magnetic widths which are proportional to the applied magnetic field.

Although the interpretation is admittedly incomplete, the extreme sharpness of the resonance is apparent. In further study, involving the development of a Doppler shift drive, we hope to measure a number of the energy shifts and level splittings mentioned in previous paragraphs.

We wish to thank S. D. Stoddard and R. E. Cowan for preparation of the ZnO source buttons and for compacting the enriched ZnO absorber. The generous cooperation of the cyclotron group is gratefully acknowledged. W. E. Keller and J. G. Dash each contributed a number of ideas to the experiment.

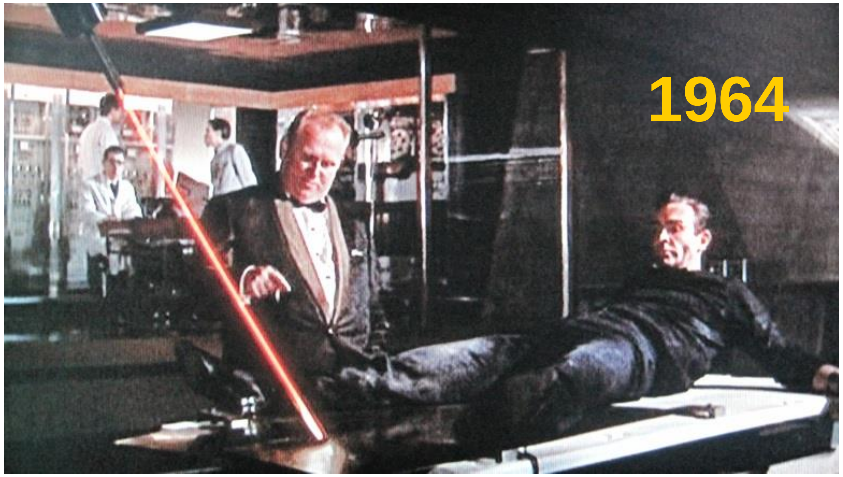
†Work done under the auspices of the U. S. Atomic Energy Commission.

[1]R. L. Mössbauer, Z. Physik 151, 124 (1958); Naturwissenschaften 45, 538 (1958); Z. Naturforsch. 14a, 211 (1959).
[2]D. E. Nagle, P. P. Craig, and W. E. Keller, Nature (to be published).
[3]R. V. Pound and G. A. Rebka, Phys. Rev. Letters 4, 397 (1960).
[4]R. V. Pound and G. A. Rebka, Phys. Rev. Letters 4, 337 (1960); B. D. Josephson, Phys. Rev. Letters 4, 341 (1960).
[5]O. C. Kistner and A. W. Sunyar, Phys. Rev. Letters 4, 412 (1960).
[6]G. Heiland, E. Mollwo, and F. Stöckmann, Solid-State Physics, edited by F. Seitz and D. Turnbull (Academic Press, New York, 1959), Vol. 8, p. 191.
[7]H. Kopfermann, Kernmomente (Akademische Verlagsgesellschaft, Frankfurt am Main, 1956).

OPTICAL AND MICROWAVE-OPTICAL EXPERIMENTS IN RUBY

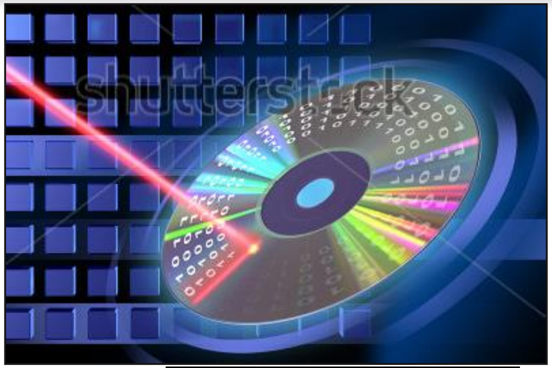
T. H. Maiman
Hughes Research Laboratories, Malibu, California
(Received April 22, 1960)

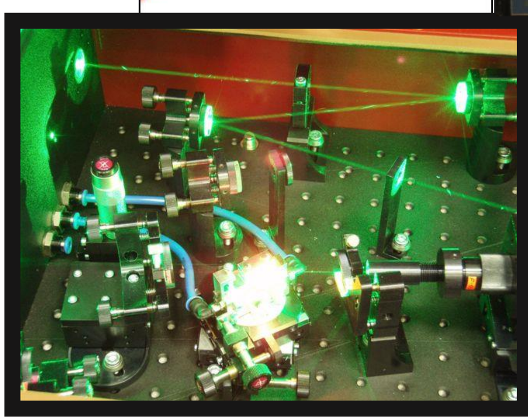
Several recent papers[1-4] have reported optical and microwave-optical measurements in ruby (Cr^{+++} in Al_2O_3). We wish to report here some ... tained in the following way. A crystal of ruby was irradiated with 5600A radiation causing absorption into the lower band (${}^4A_2$–${}^4F_2$). The sam-


1964


1977

Lasers – all around us





Basic questions

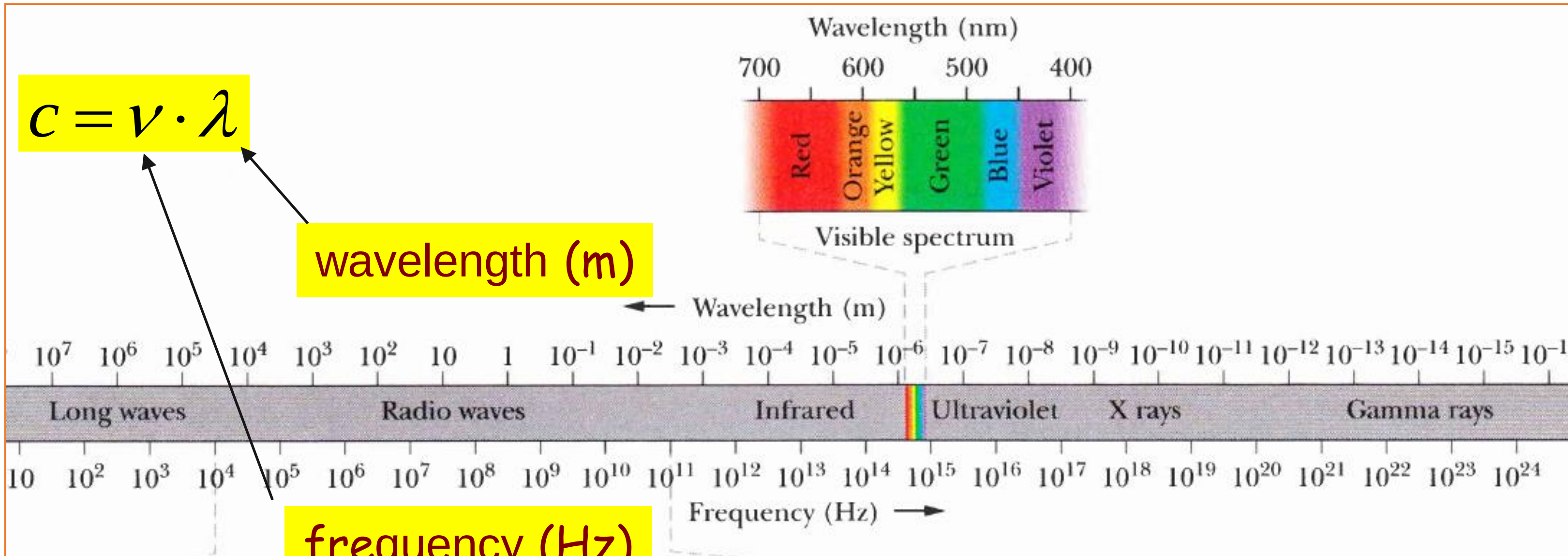
- What is a laser? What is its specialty?
- How the special properties come about?
- Main components of lasers ensuring the special properties.
- What properties qualify lasers an ideal tool for medical applications?

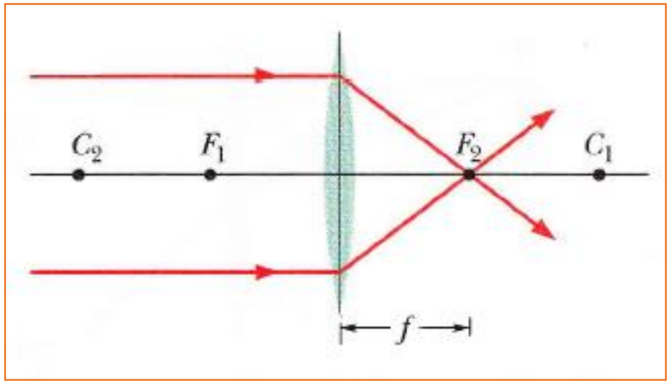
Laser = light with special properties

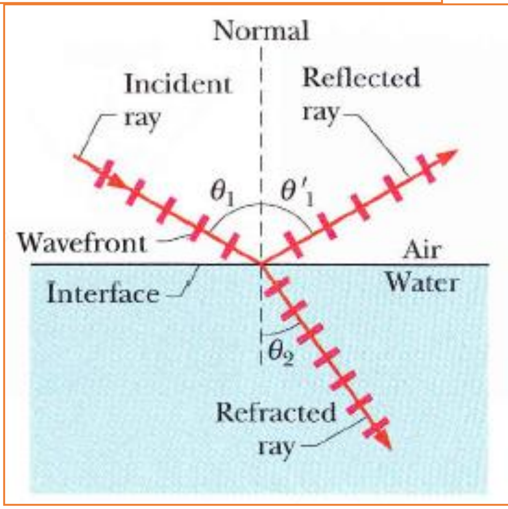
$c = \nu \cdot \lambda$

wavelength (m)

frequency (Hz)



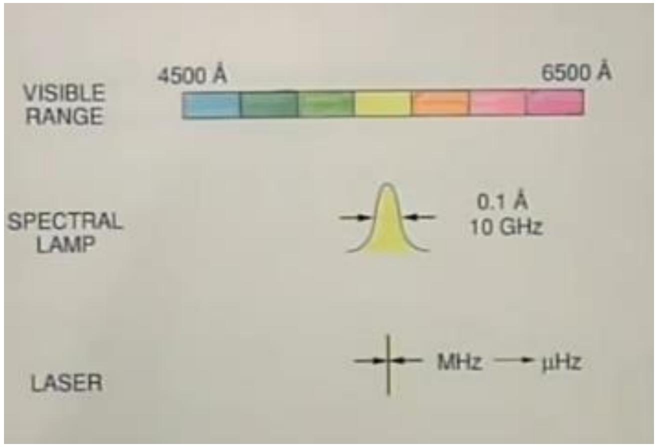


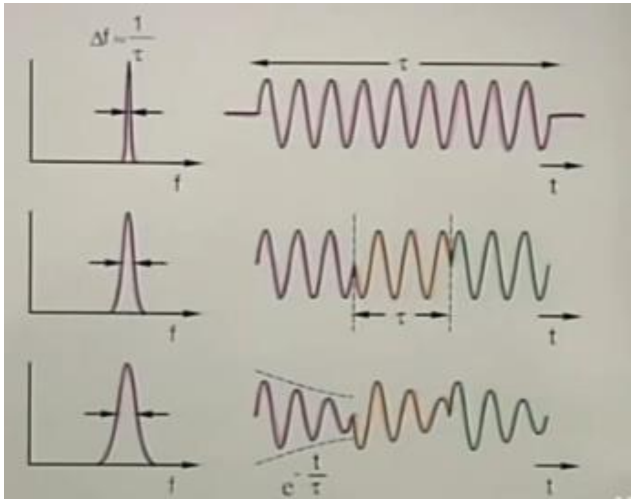


Special properties of laser light

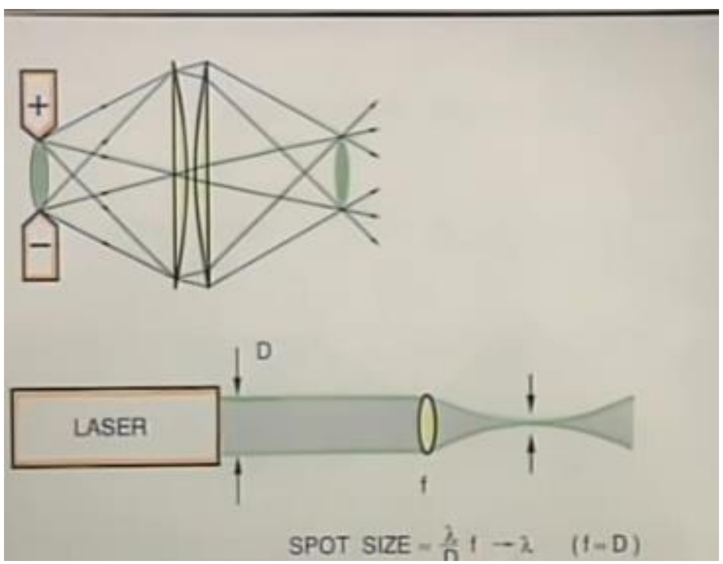
Monochromaticity

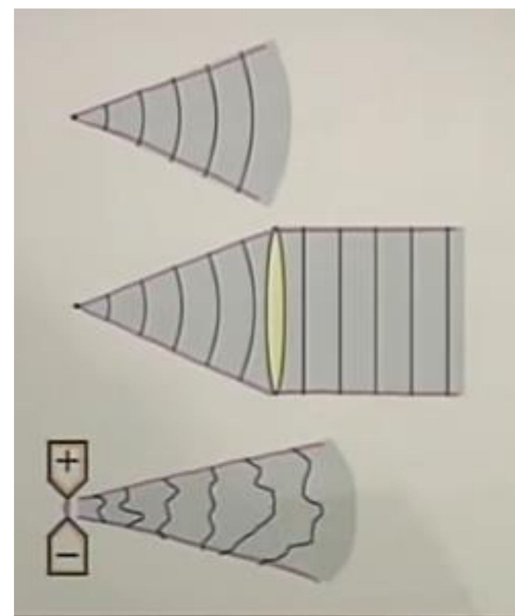
- single color
- narrow bandwidth
- temporal coherence (able to interfere, ordered, „well behaved phase")





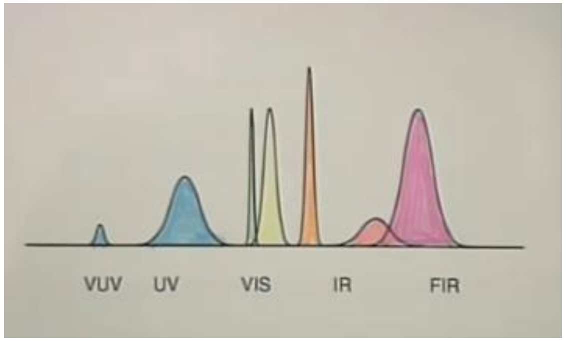
Small divergence (parallel)
- well collimated
- good focusability to a small spot
- spatial coherence (able to interfere, ordered, „well behaved phase")



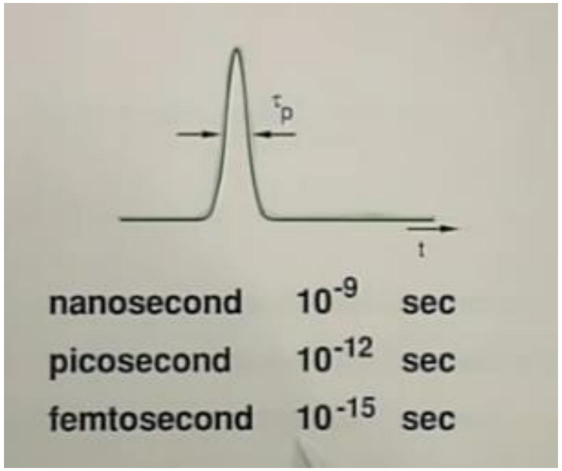


Special properties of laser light

- Tunability



- Short pulse durations



- High power

Interaction of radiation and atoms elementary processes

Quantum physics:
Radiation can only exchange energy with matter in discrete packages (photon)

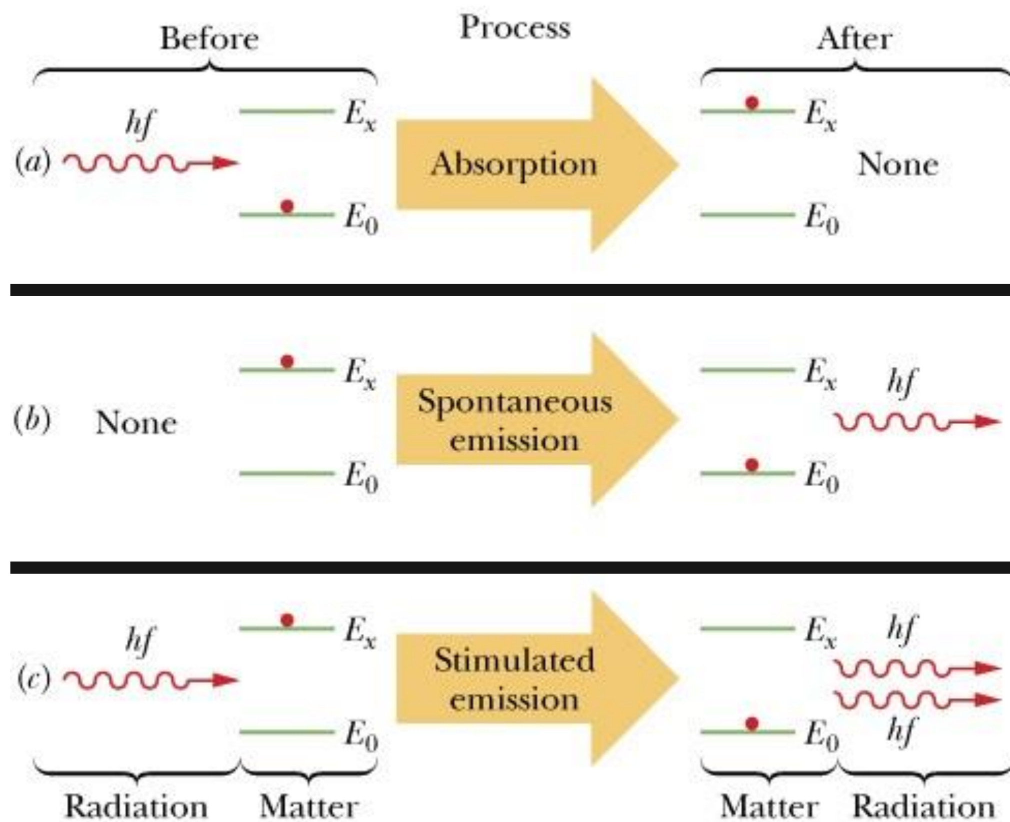
$$hf = E_x - E_0$$

2-level system

absorption

spontaneous emission

induced/stimulated emission

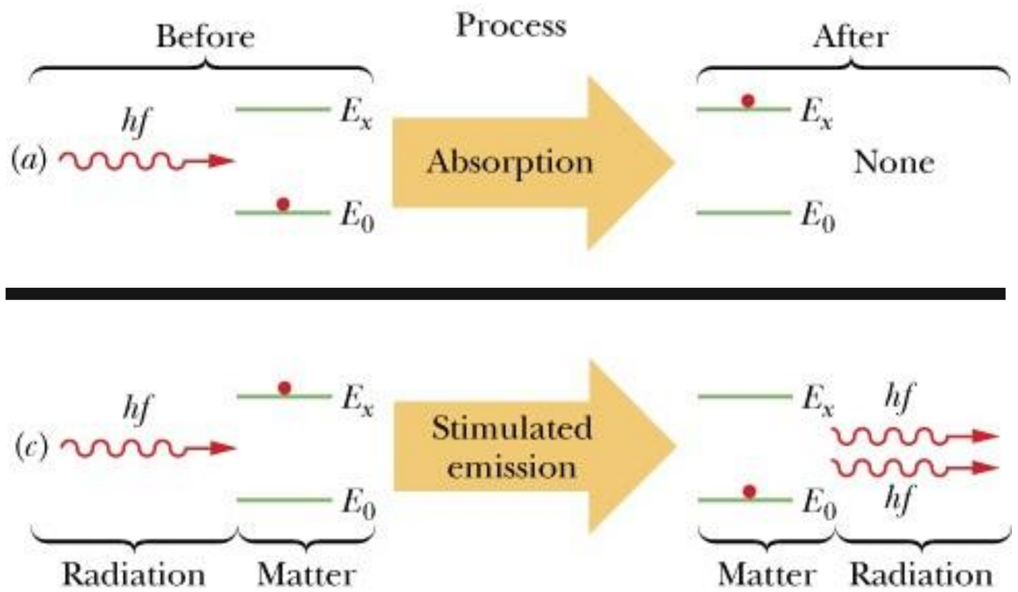


LASER (Light Amplification by Stimulated Emission of Radiation)

Optical pumping

„more light out than in"

Competition between absorption and induced emission

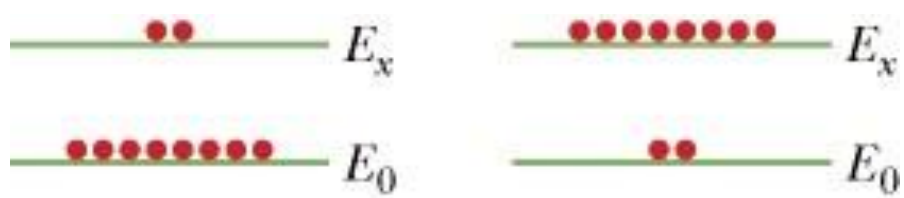


~N_0

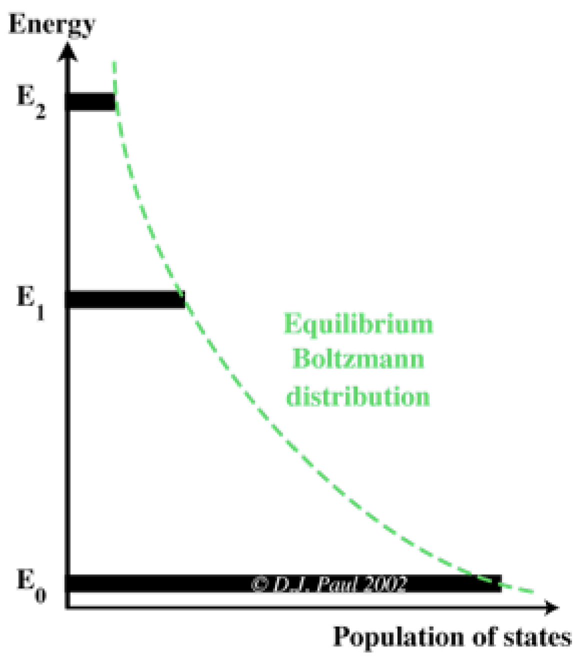
~N_x

$N_x > N_0$

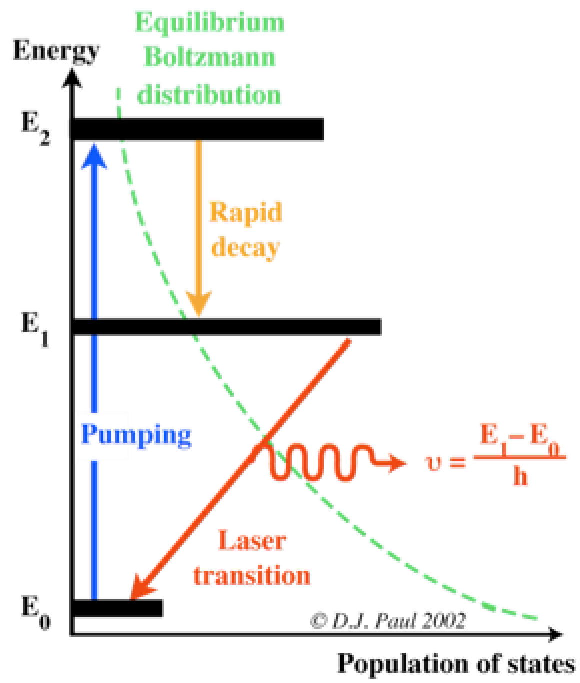
population inversion, larger population in excited state



Population is a measure of how the particles occupy the available energy levels.

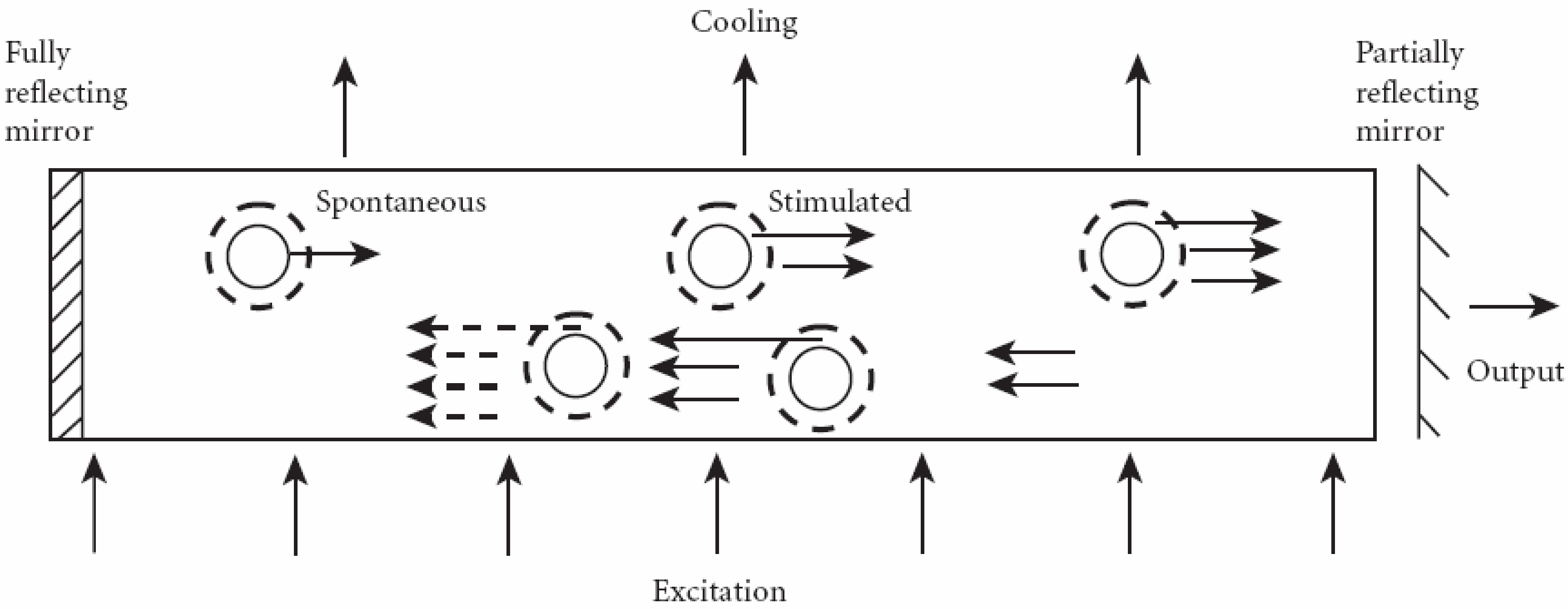


In thermodynamical equilibrium:
Higher levels have exponentially lower occupancy.



Pumped system:
Investing energy in the system leads to more populated higher levels, that decay to the lower levels spontaneously.

Stable operation

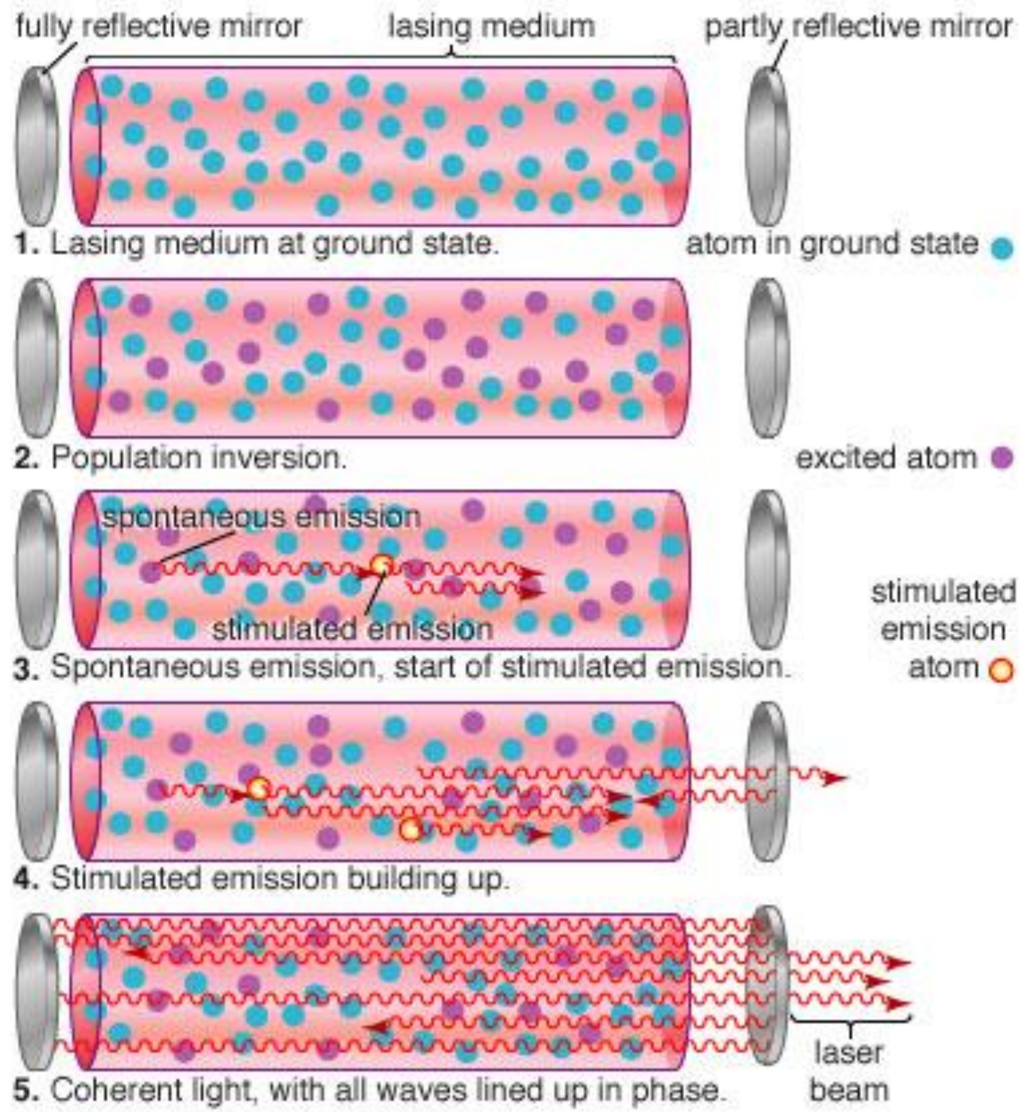


If more photons are generated than absorbed in each round (positive amplification).

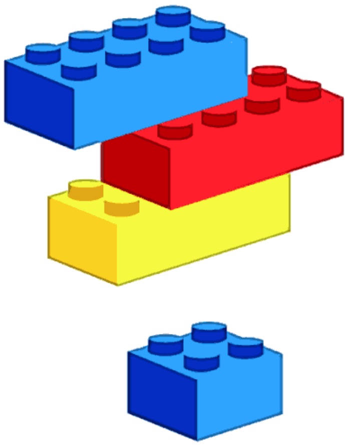
LASER - steps

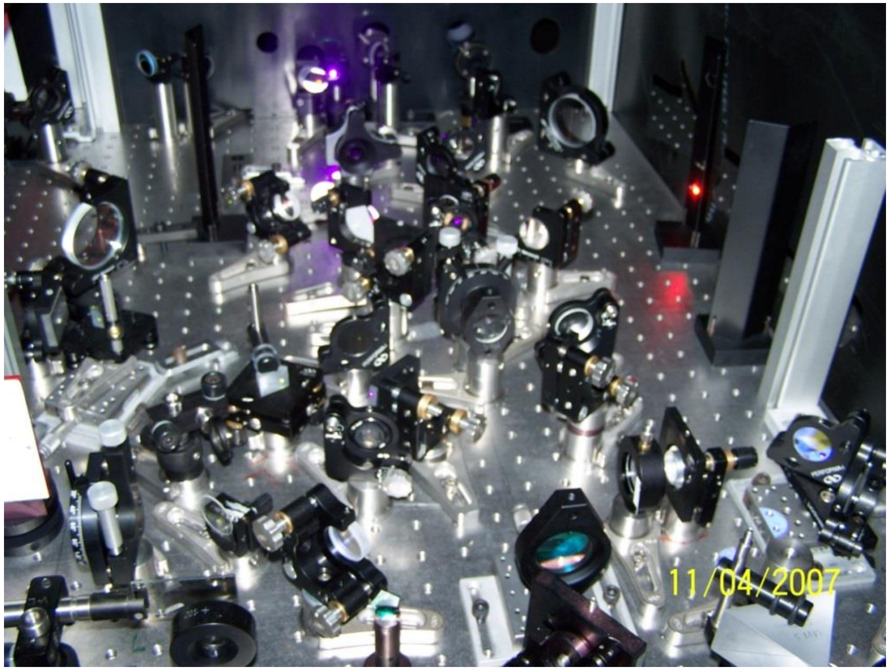
Light originally produced in spontaneous emission is amplified via stimulated emission.

Reflections (positive feedback) make it a self-maintaining procedure.

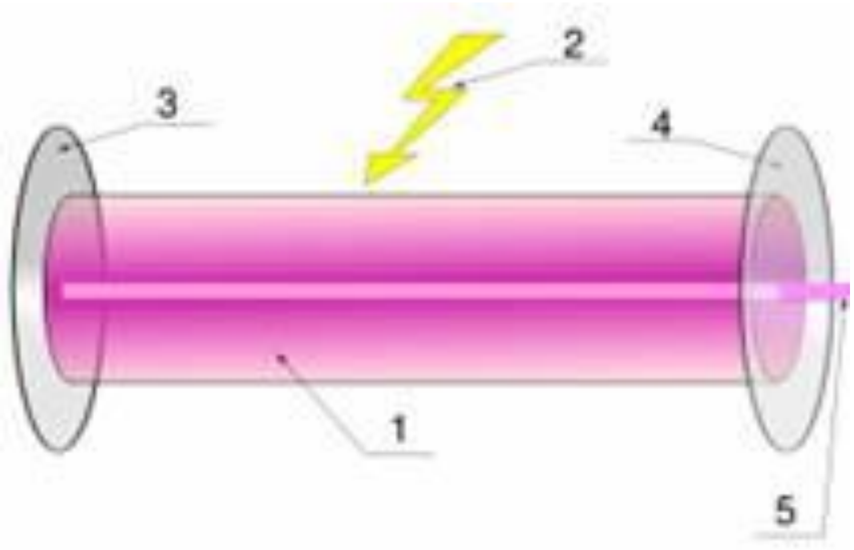


How to build a laser?





LASER – functional parts



(1) Laser (active) material (gas, liquid, solid state) – to amplify light

(2) Pumping (electric current, intense lighting) - to create and maintain population inversion

(3 and 4) optical resonator (mirrors) – to feed light back to the active medium

(3) Perfect mirror

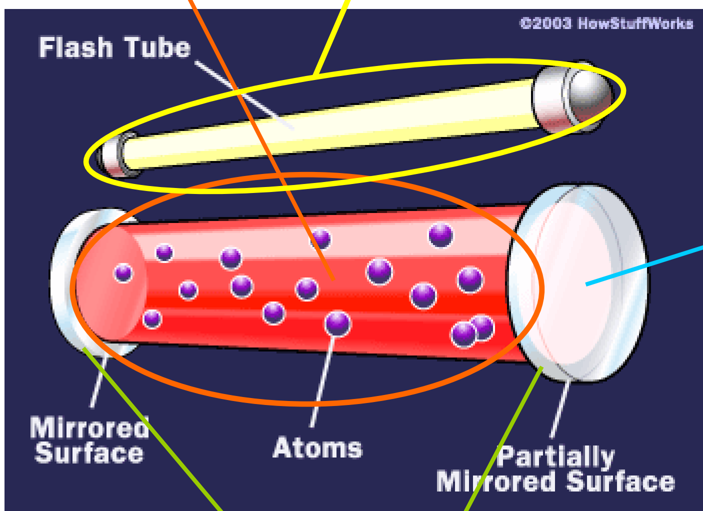
(4) Partial reflector (1-0.1% transmittance) to couple out some light, above 99% reflected to keep the lasing on

+ additional: voltage supply, control, cooling system, etc.

The first manifestation: Ruby laser

Active medium

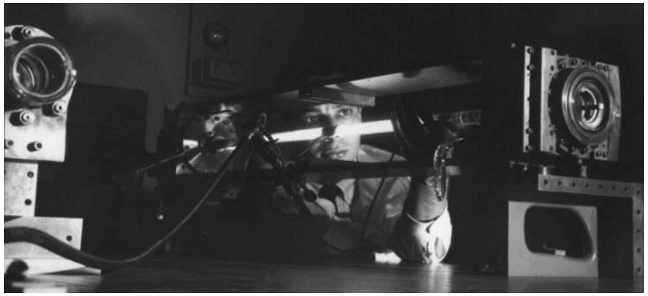
Pumped by a flashlamp

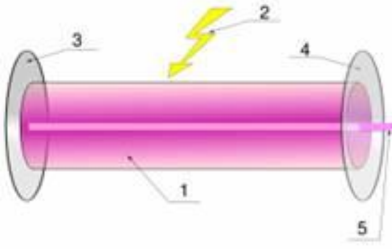


Output coupler

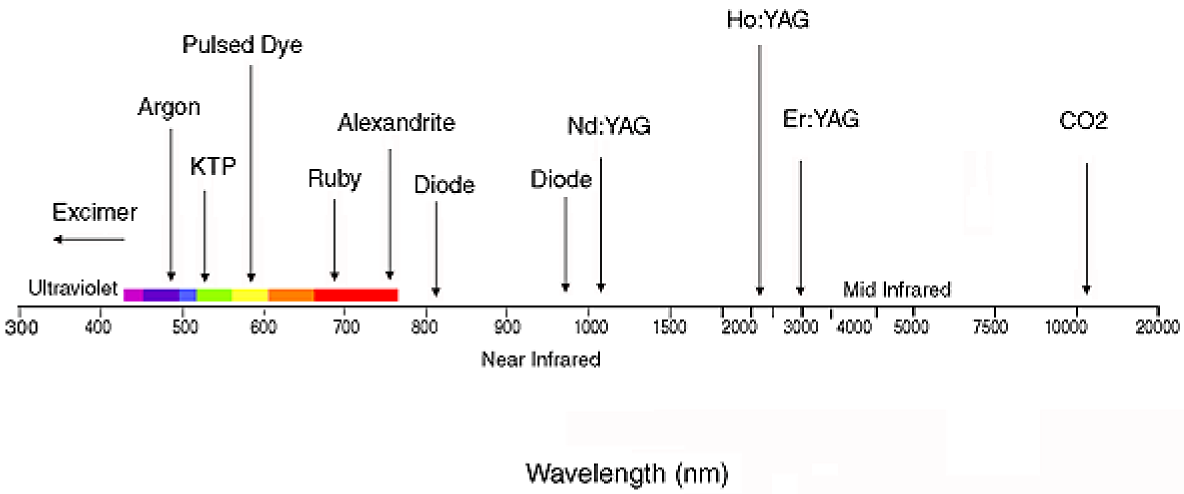
Optical resonator

Lasers come in different sizes and shapes

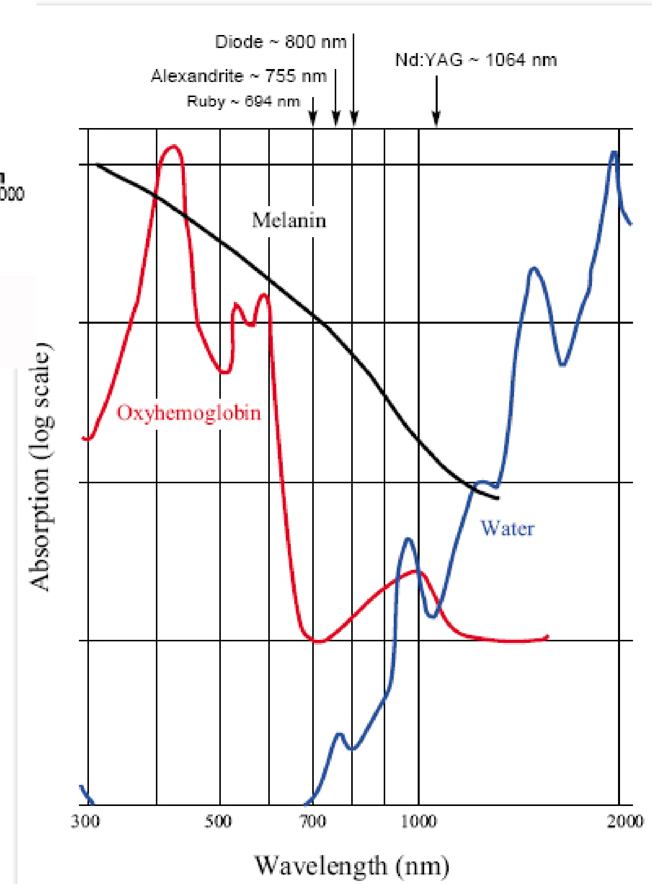




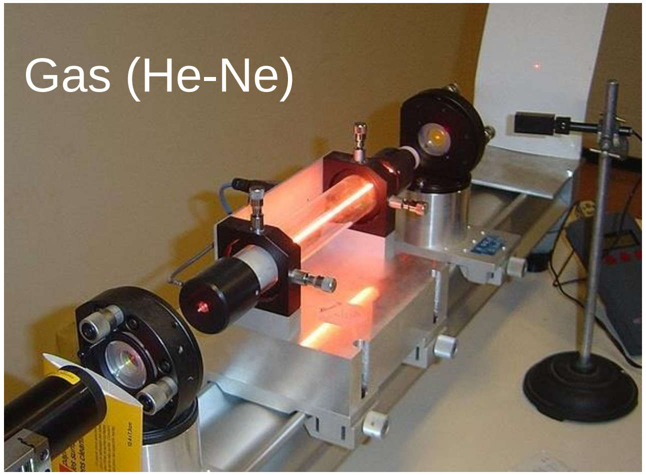
1. Active / laser medium



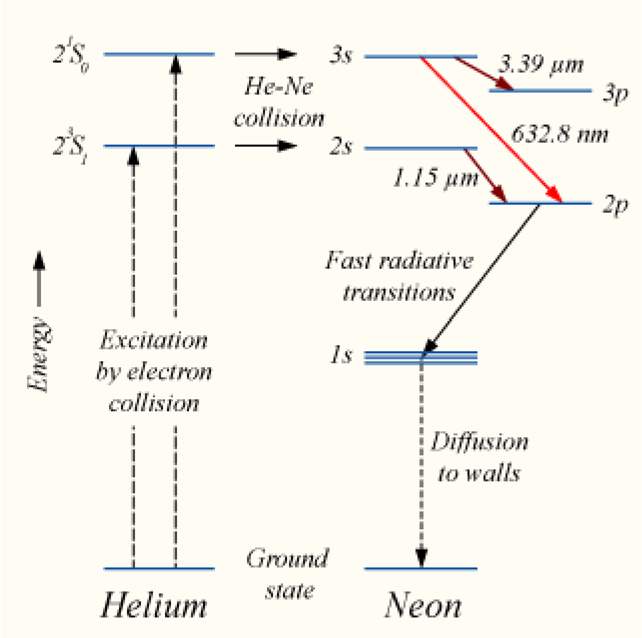
choice of wavelength enables choosing which material you interact with /address

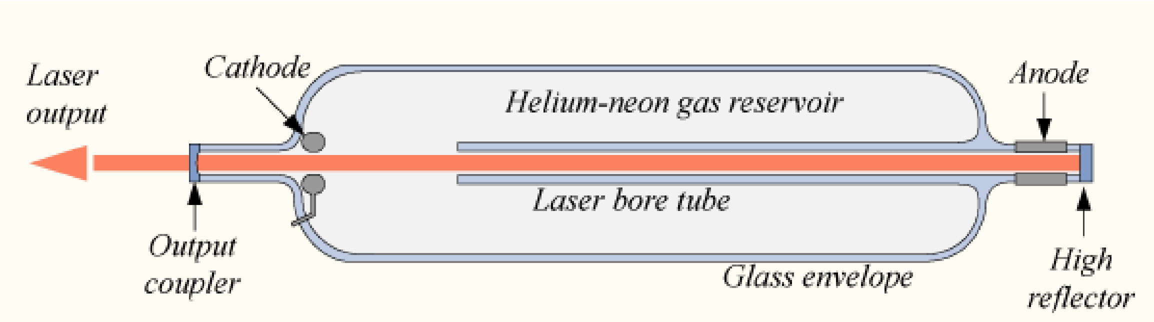


Active / laser medium: gas



Gas discharges have been found to amplify light coherently.
Homogeneous, allows flexible resonator geometries





Active / laser medium: gas

Gas lasers use many different gases, eg.

- noble gases or mixtures (He-Ne)
- ionic (Ar+, Kr+)
- molecules (N_2, CO_2, CO),
- metal vapours (HeCd),
- neutral atoms (Cu-vapour),
- excimer (excited dimer) – molecule formed from two species, at least one of which is in an electronic excited state

  powered by an electric discharge

  once the molecule transfers its excitation energy to a photon, atoms are no longer bound to each other and the molecule disintegrates, this drastically reduces the population of the lower energy state

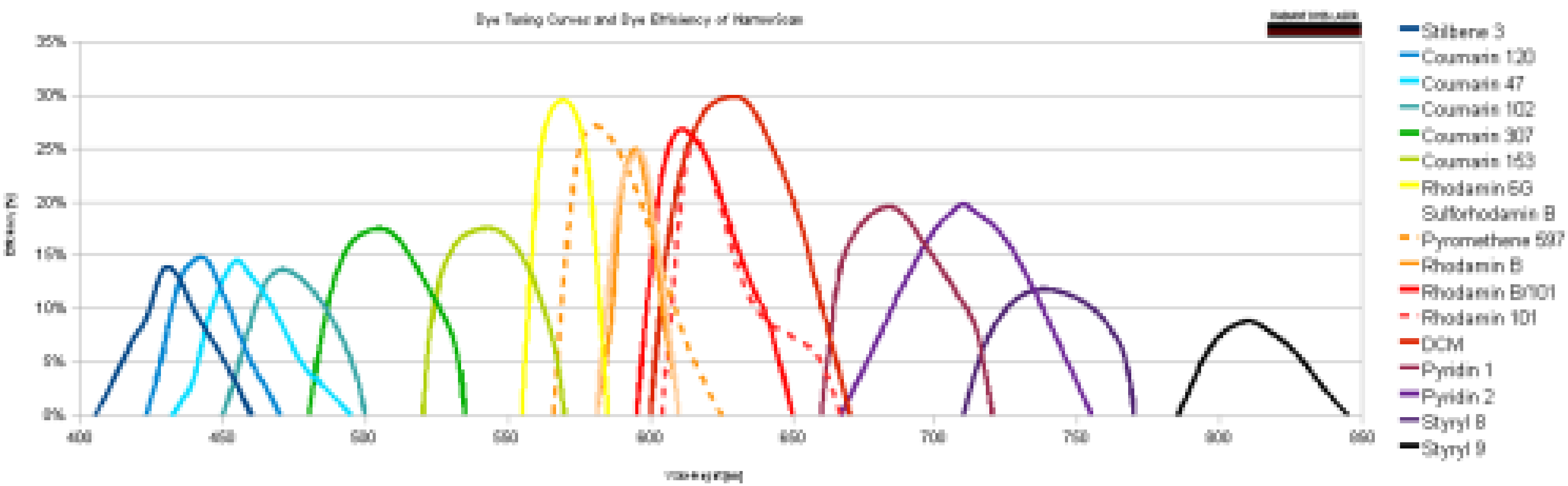
Active / laser medium : liquid (dye solution)

large organic molecules dissolved in a suitable liquid solvent (such as ethanol, methanol, or an ethanol-water mixture)

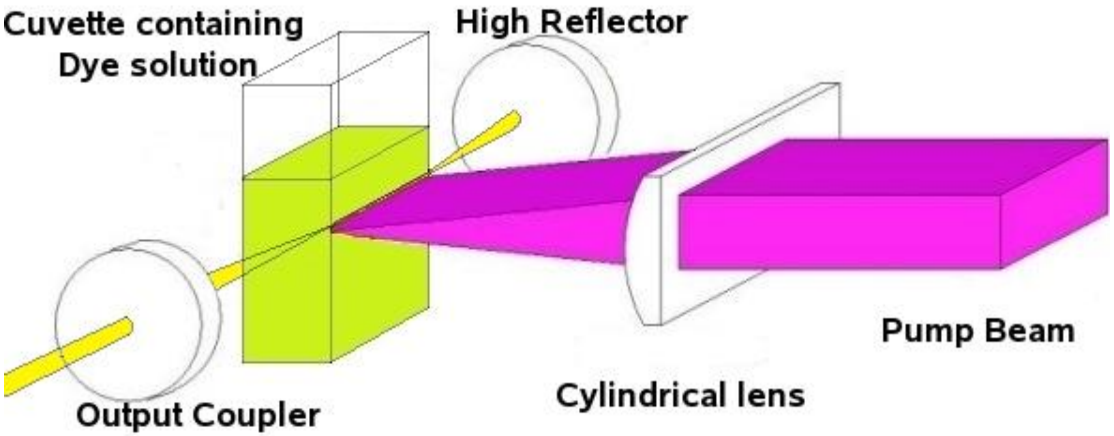
higher density of particles

wider emission bandwidth → tuning via resonator setup

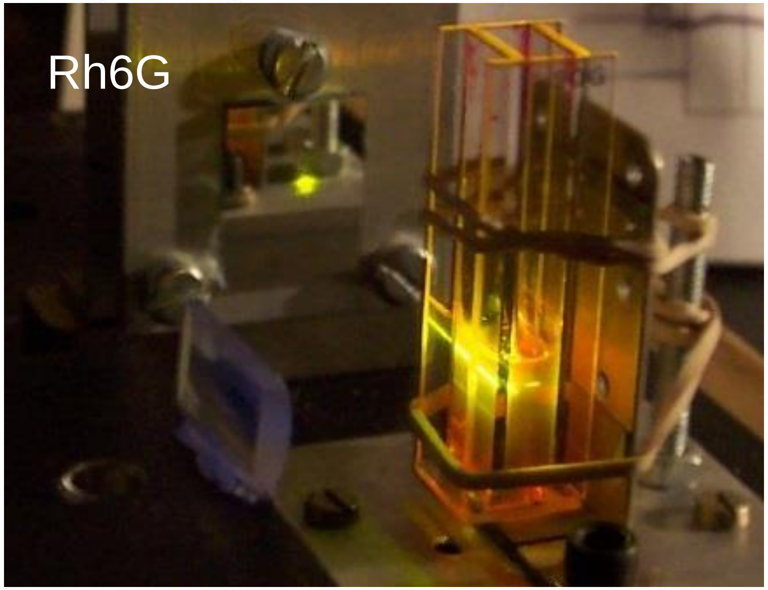
more than 50 dye molecules are in use

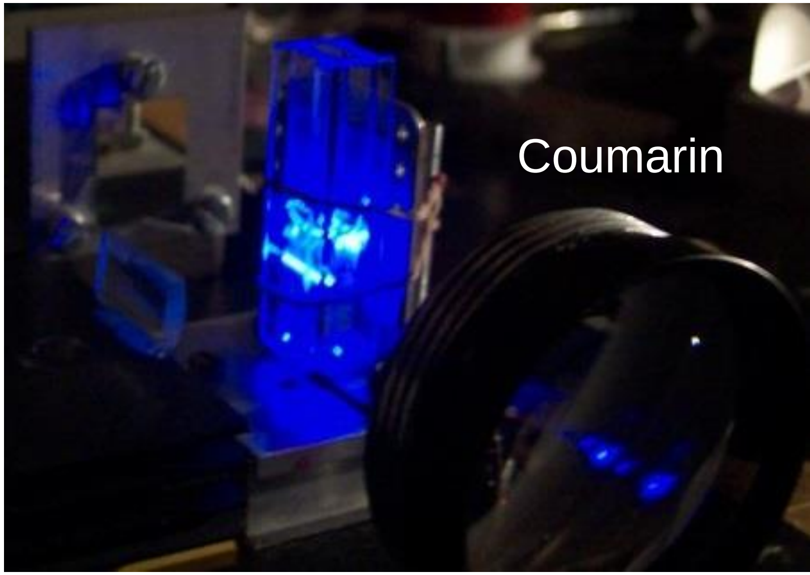


Active / laser medium : liquid (dye solution)



#Coumarin
#DCM
#Fluorescein
#polyphenyl
#Rhodamine 6G, B, 123
#Umbelliferone (aka 7-hydroxycoumarin)

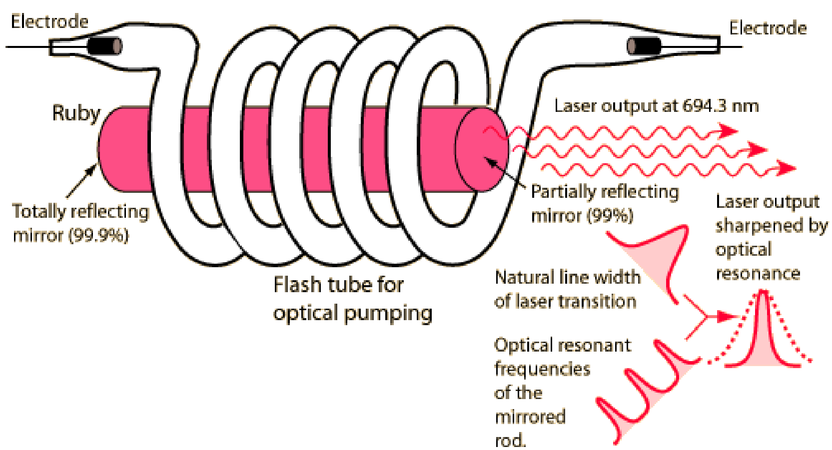


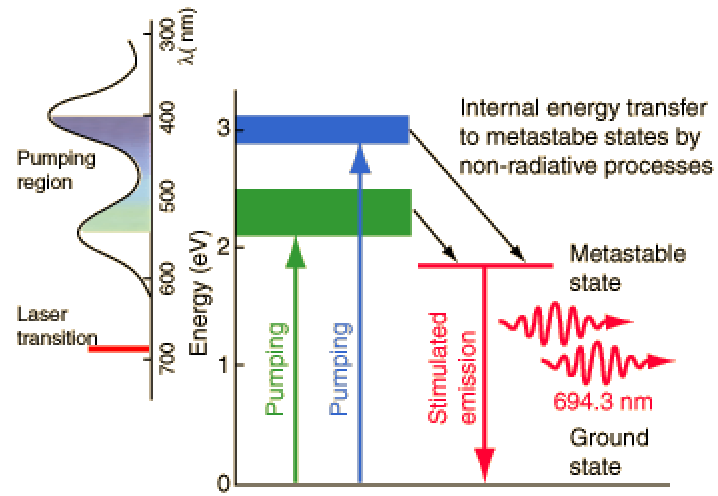


Active / laser medium: solid state

simple architecture, small size

crystalline or glass rod which is "doped" with ions that provide the required energy states

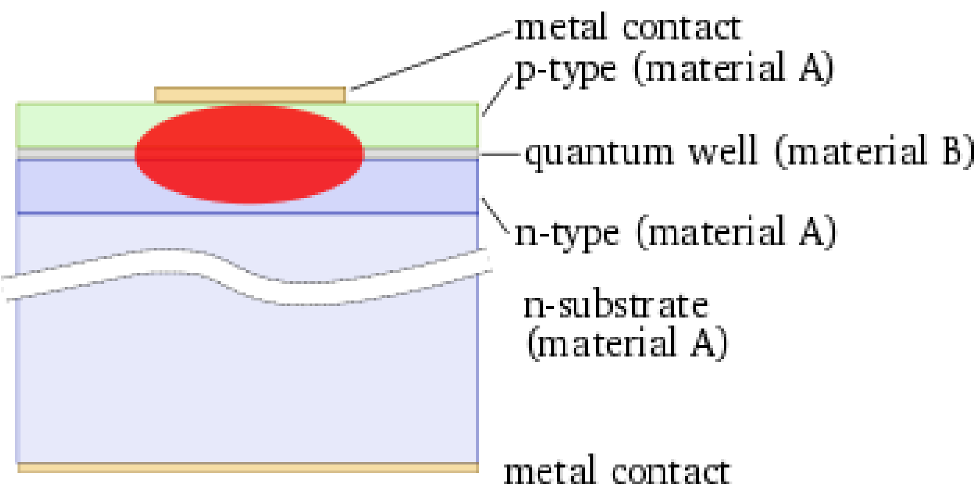




These materials are pumped optically using a shorter wavelength than the lasing wavelength, often from a flashtube or from another laser.

Active / laser medium: diode

Recombination of electrons and holes created by the applied current introduces optical gain.

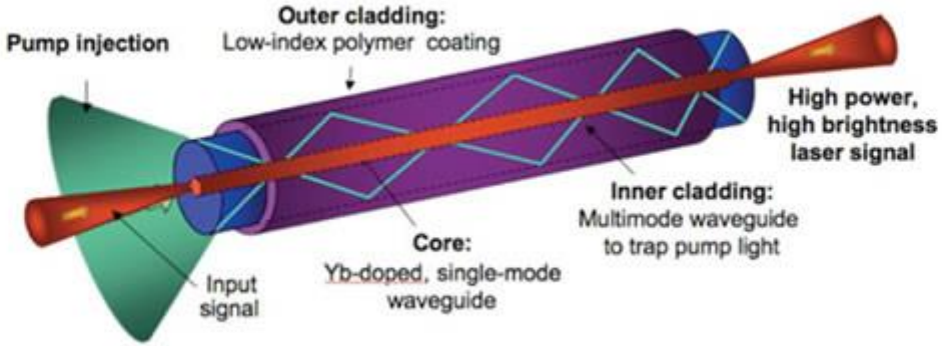


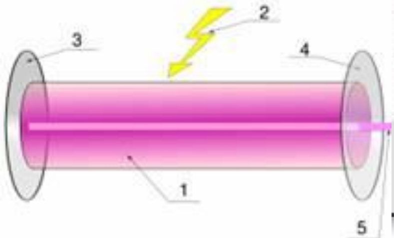
Commercial laser diodes emit at wavelengths from 375 nm to 1800 nm, and wavelengths of over 3 μm have been demonstrated. Low to medium power laser diodes are used in laser printers and CD/DVD players. Laser diodes are also frequently used to optically pump other lasers with high efficiency.

Active / laser medium: optical fiber

the active gain medium is an optical fiber doped with rare-earth elements such as erbium, ytterbium, neodymium, dysprosium, praseodymium, and thulium

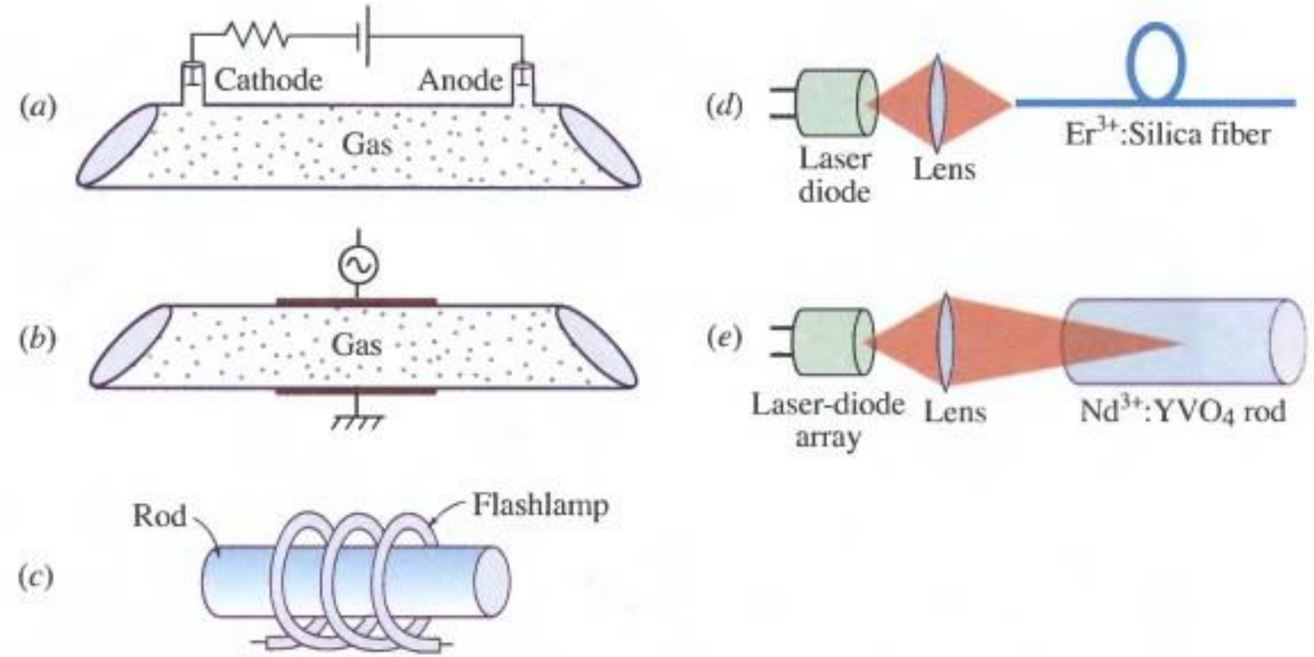
- light is already in a fiber allows it to be easily delivered to a movable focusing element (eg. for laser cutting, welding)
- high output power (active region can be several kilometer long provide very high optical gain, kilowatt level)
- high optical quality
- compact size (compared to rod or gas lasers of comparable power, since the fiber can be bent and coiled to save space)





2. Pumping

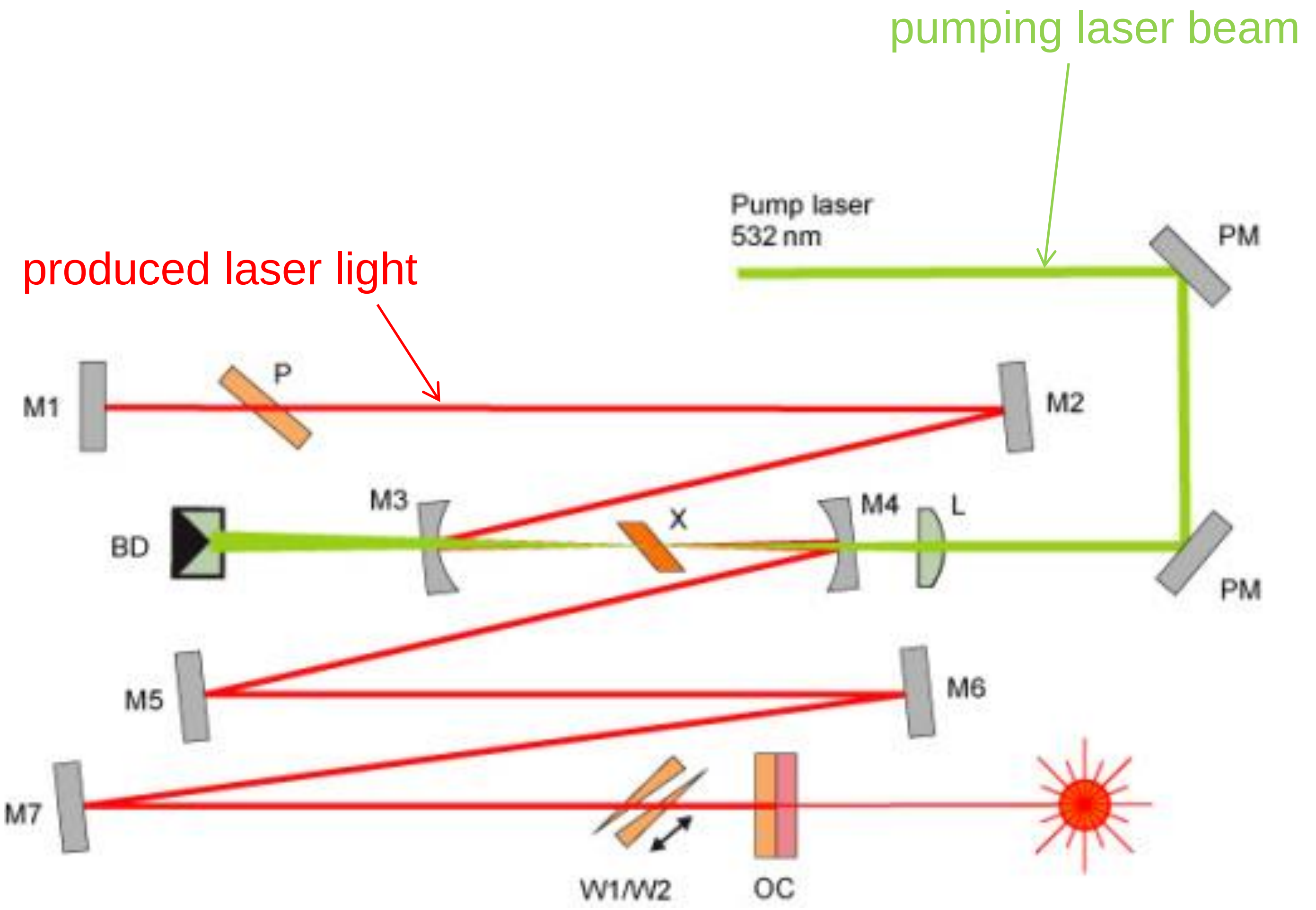
To create and maintain population inversion (energy source)

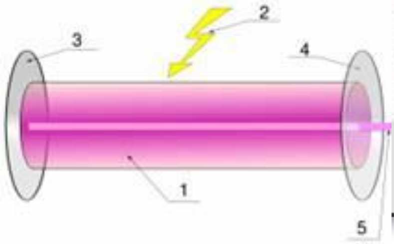


Types:

- electrical discharge
- optical (flashlamps (Xe, Kr), discharge lamps)
- chemical reaction feeding the system (initiated by a flashlamp e.g. photo-dissociation)

Laser pumping a laser





3. The optical resonator

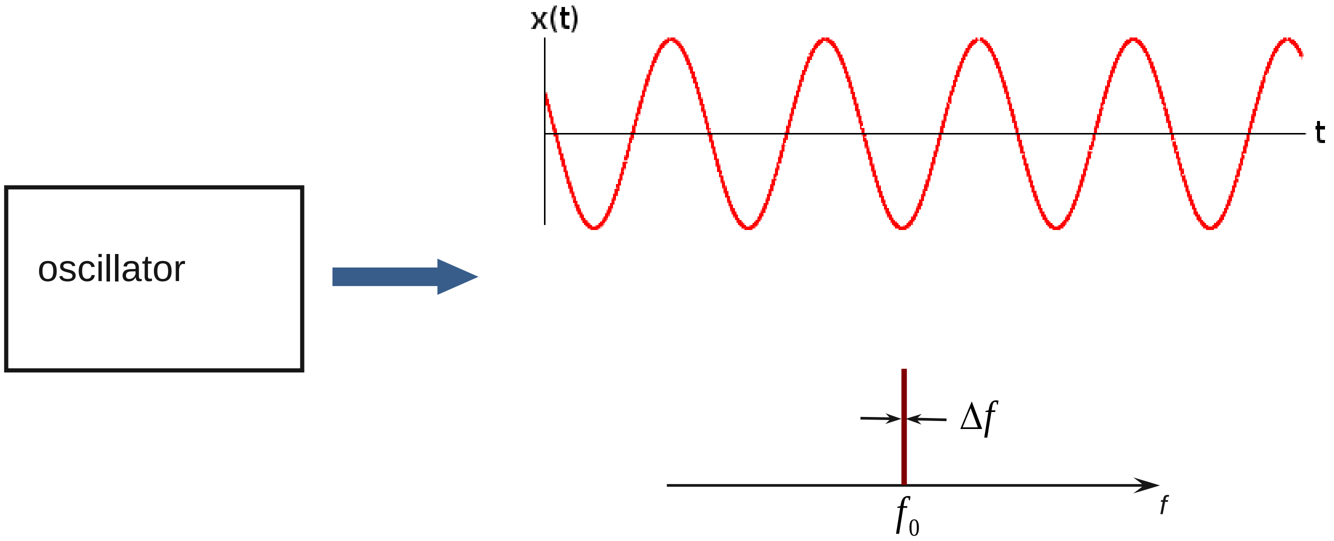
The optical resonator / cavity = an arrangement of mirrors that forms a standing wave cavity resonator for light waves

parameters: distance, curvature and reflectance of mirrors

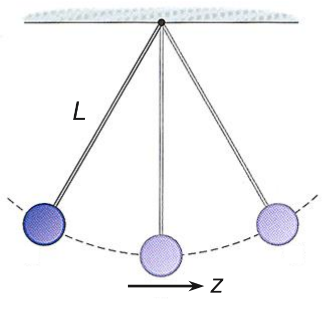
Back and forth reflection of light

- increases time the photons spend in the amplifier medium
- enables feedback

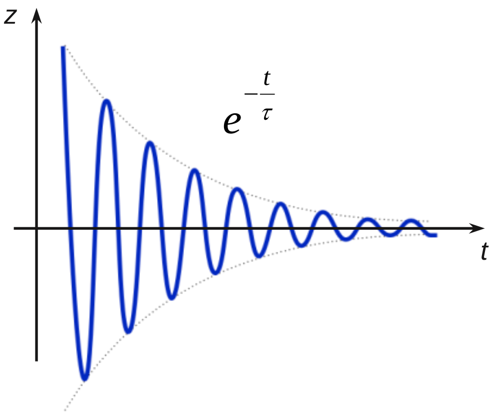
LASER = an optical oscillator

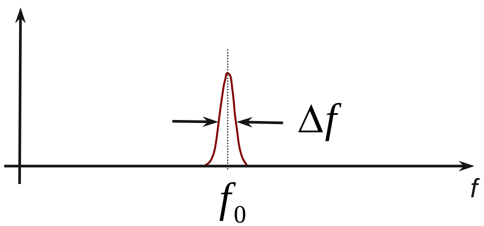


Resonator (low loss) $\rightarrow$ to define the narrow oscillation frequency f_0



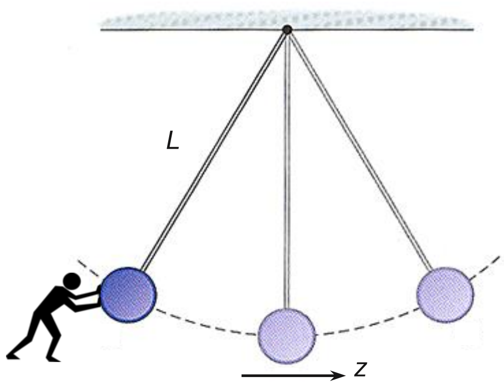
$$f_0 = \frac{1}{2\pi}\sqrt{\frac{g}{L}}$$

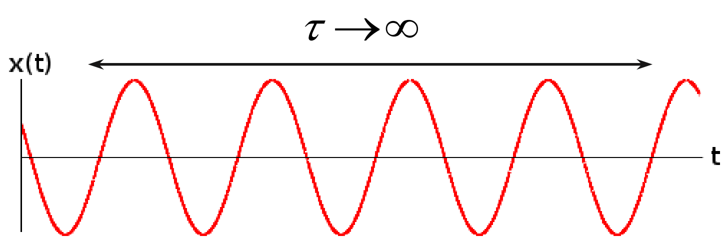


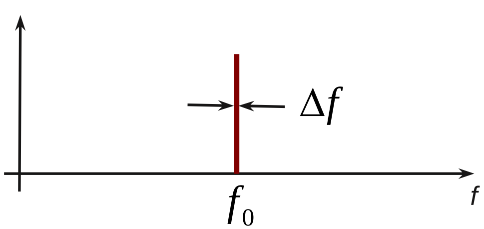


$$\Delta f \approx \frac{1}{\tau} \approx loss$$

Means to overcome losses at the oscillation frequency: amplifier.

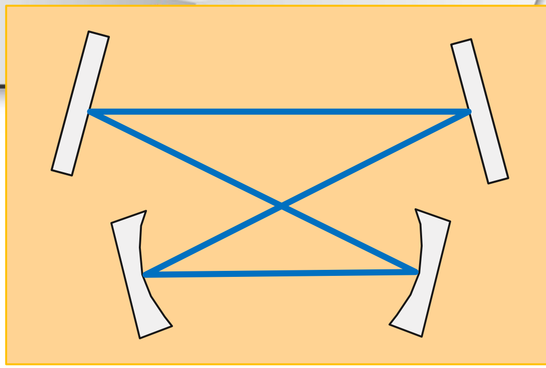




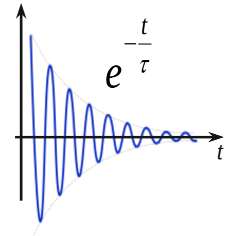


$$\Delta f \approx \frac{1}{\tau} \approx 0$$

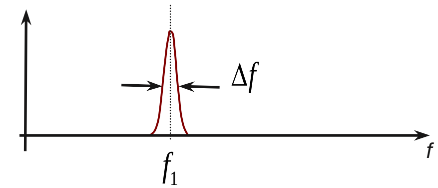
An optical (multimode) resonator

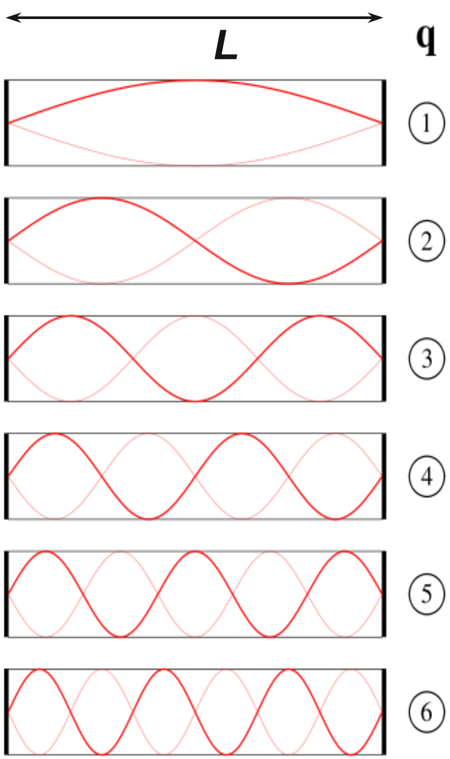


$$\lambda \cdot f = c$$



$$\Delta f \approx \frac{1}{\tau} \approx loss$$

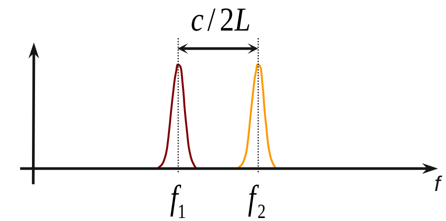


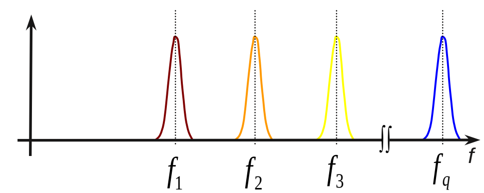


$$L = \frac{\lambda_1}{2} \qquad f_1 = \frac{c}{2L}$$

$$L = 2\frac{\lambda_2}{2} \qquad f_2 = 2 \cdot \frac{c}{2L}$$

$$L = 3\frac{\lambda_3}{2} \qquad f_3 = 3 \cdot \frac{c}{2L}$$





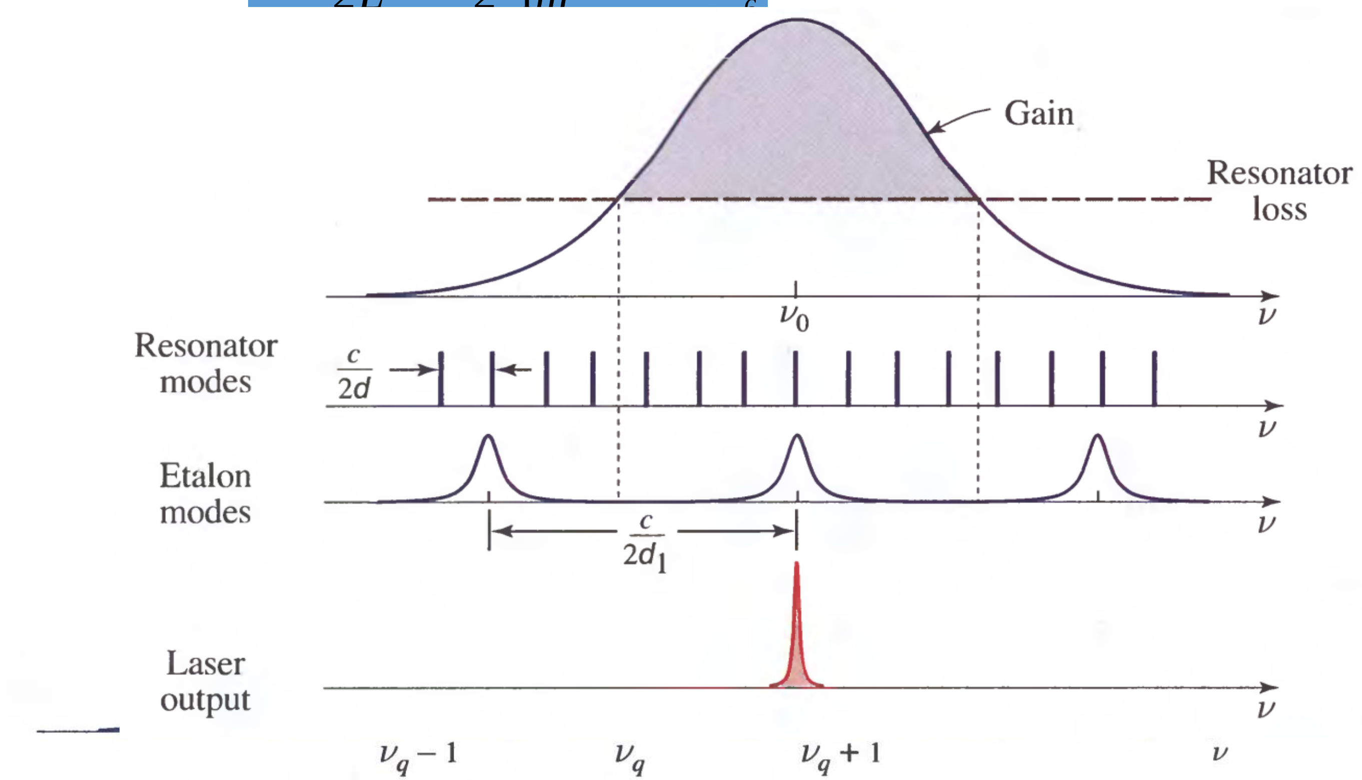
$$q = 6 \qquad L = q\frac{\lambda_q}{2} \qquad f_q = q \cdot \frac{c}{2L}$$

„resonances"

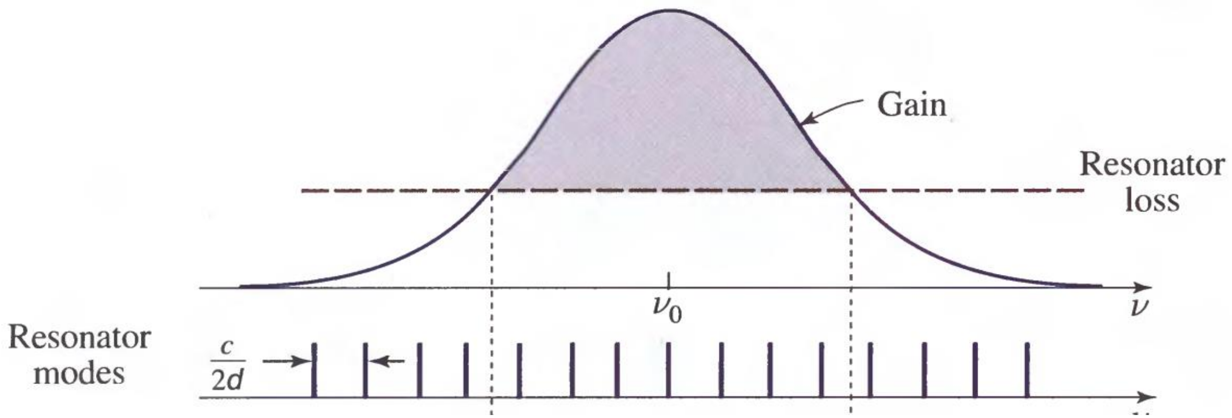
Standing waves in a 1 m long resonator

$$\lambda_q = 500nm = 5\cdot 10^{-7}m \qquad L = 1m$$

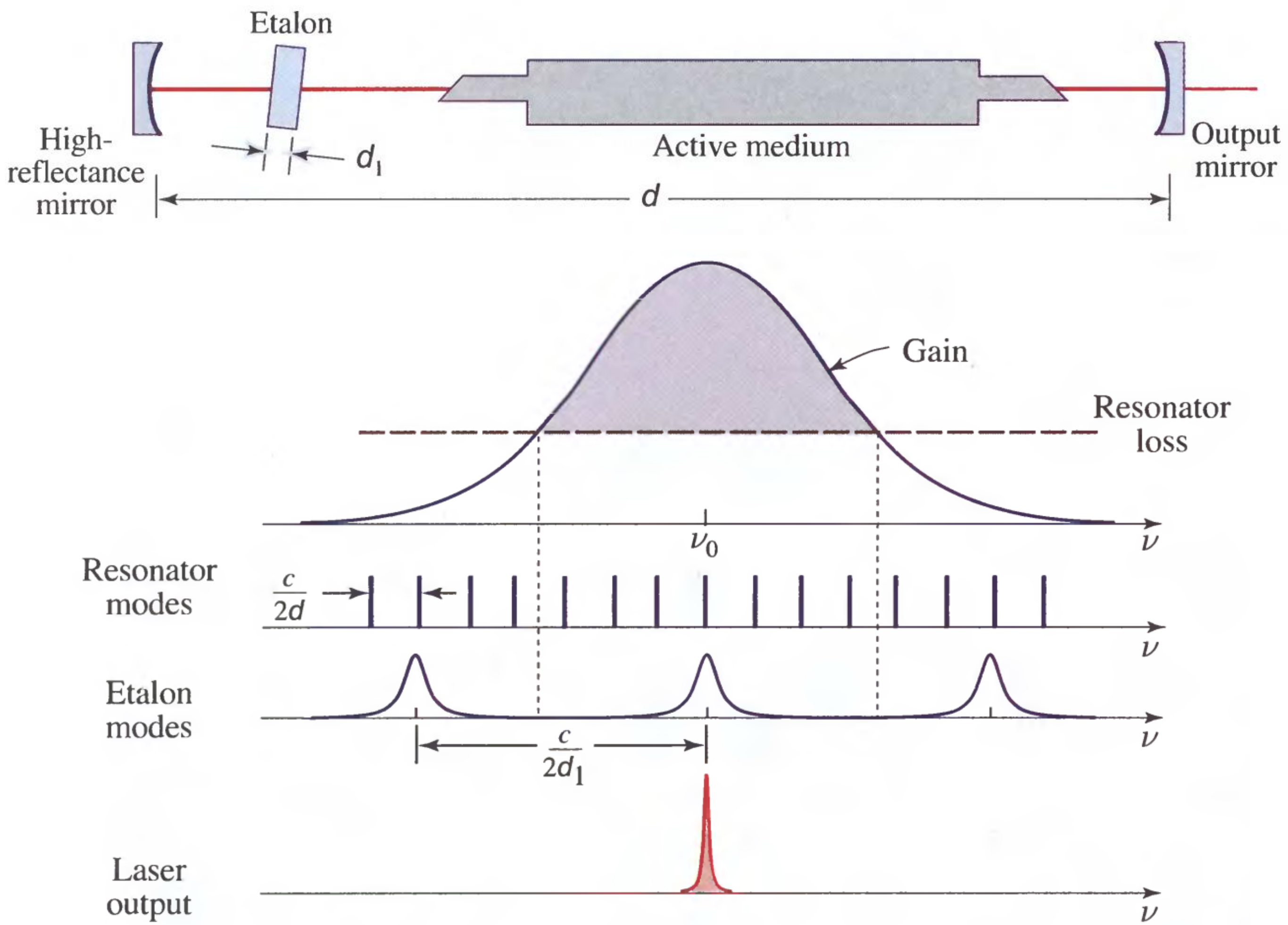
$2L \qquad 2\cdot 1m$



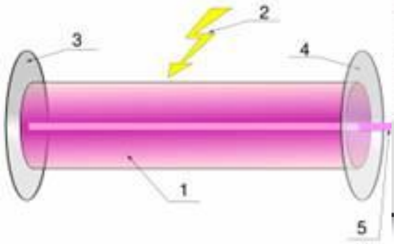
Laser frequency components



Resonator modes under the gain curve.

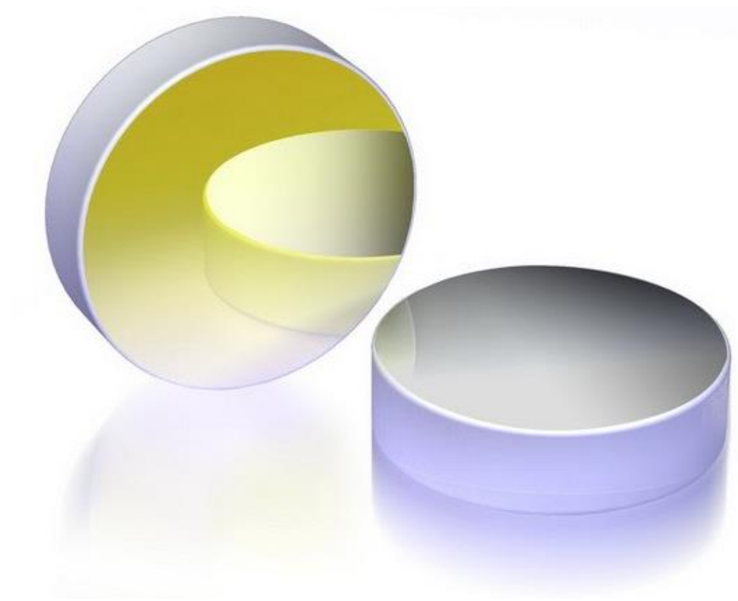


When only one frequency component is allowed.

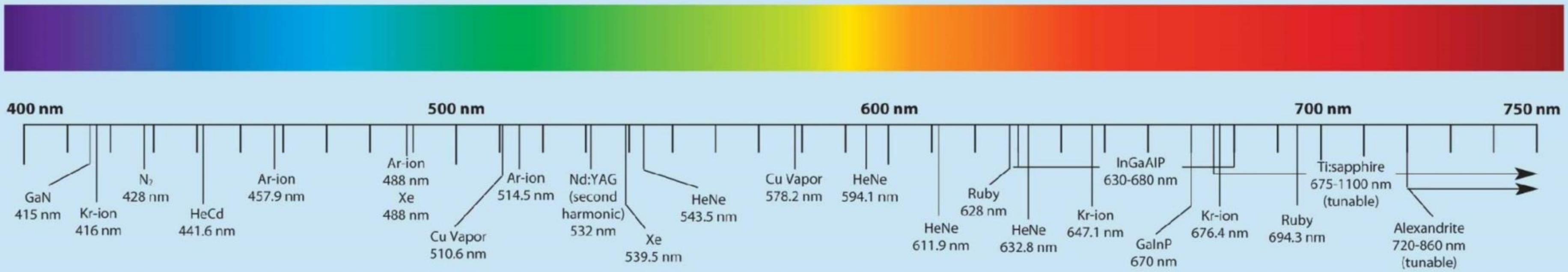


Partially reflecting mirror

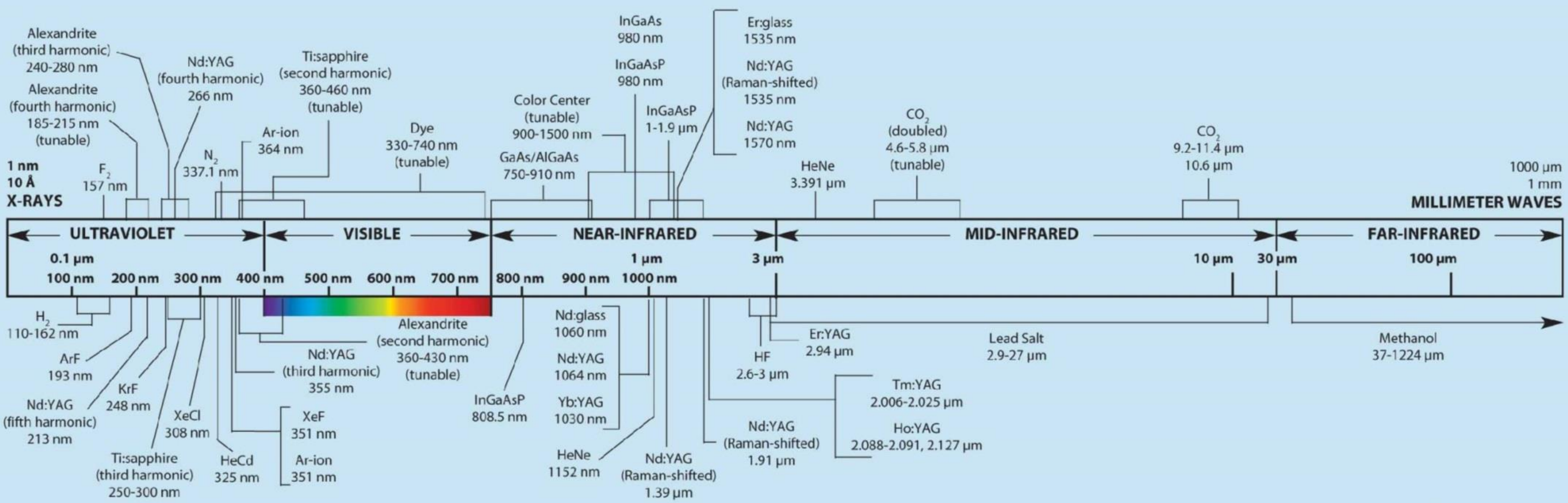
- given reflection coefficient (90-99.5%) **at lasing wavelength**
- substrate does not absorb at lasing wavelength (BK7 glass or fused silica)
- usually wedged to eliminate interference between front and back reflection



Available laser wavelengths

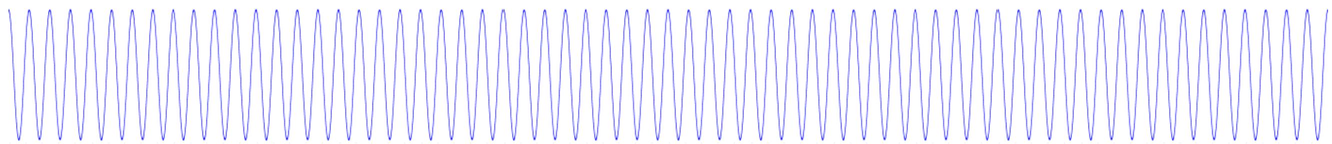


The photonics spectrum reference chart displays the major commercial laser lines in the ultraviolet to the far-infrared and beyond. Space limitations make it impossible to include all available lasing media, and, particularly in the crowded areas of the visible spectrum and the near-infrared, we were forced to limit their multiple secondary lines to the more familiar. In drawing the full spectrum band, legibility received a higher priority than accurate scale or proportion.

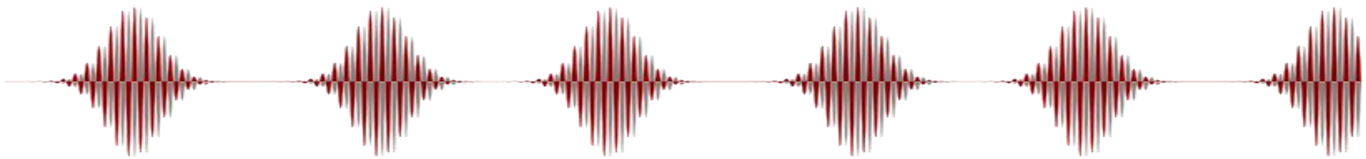


THE PHOTONICS SPECTRUM AND COMMERCIAL LASER LINES
(wavelength increases left to right)

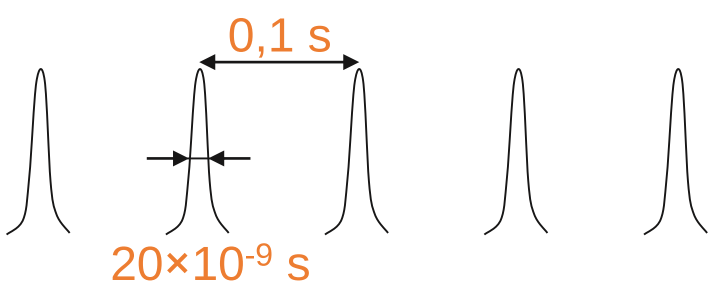
- continous mode



- pulsed mode



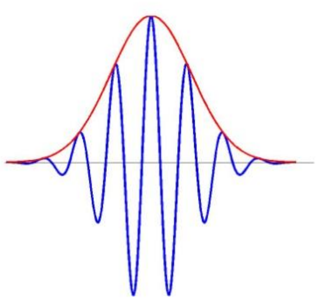
eg: Nd-YAG laser
(neodimium doped yttrium aluminium garnet $Y_3Al_5O_{12}$)



$E = 2\ \mathrm{J}$

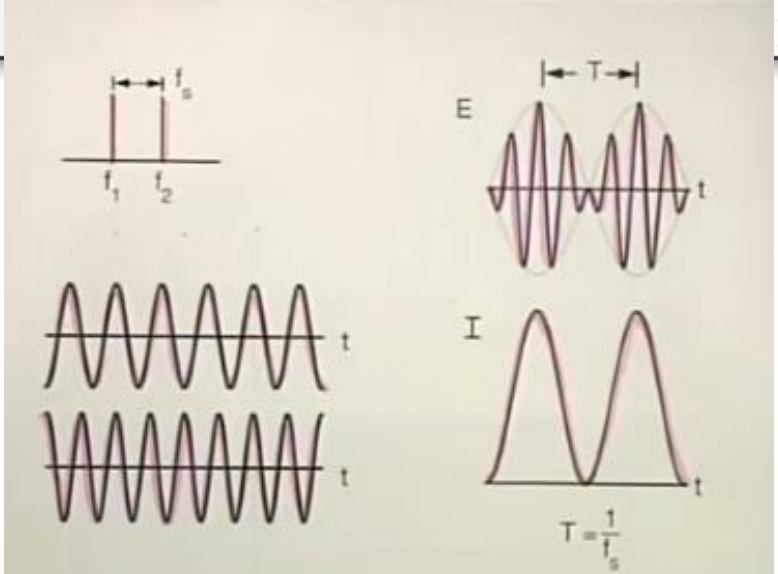
$\tau = 20\ \mathrm{ns} = 2\times10^{-8}\mathrm{s}$ pulse duration

10 Hz repetition rate

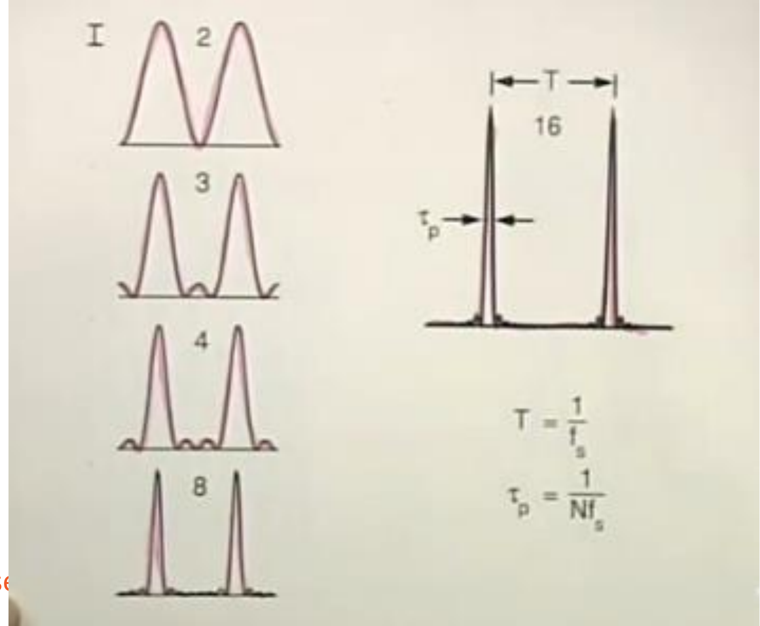


limited by carrier wavelength
WR: 800nm 3,8 fs

Pulsed laser mode



Two nearby frequencies produce beating.



More frequency component enables shorter pulse production.

Pulsed operation requires

Ti-sapphire

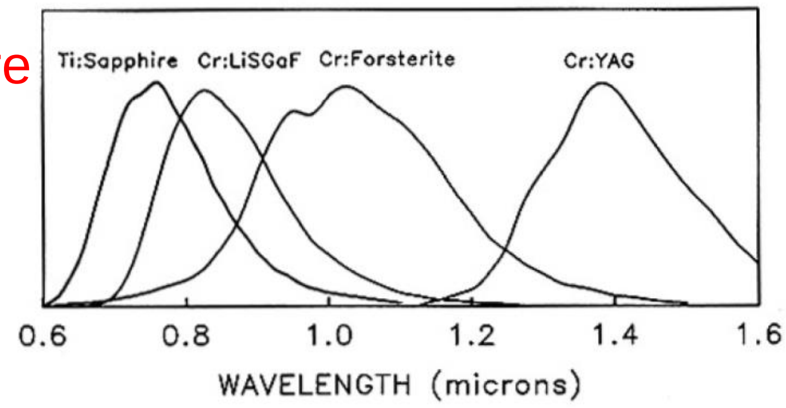
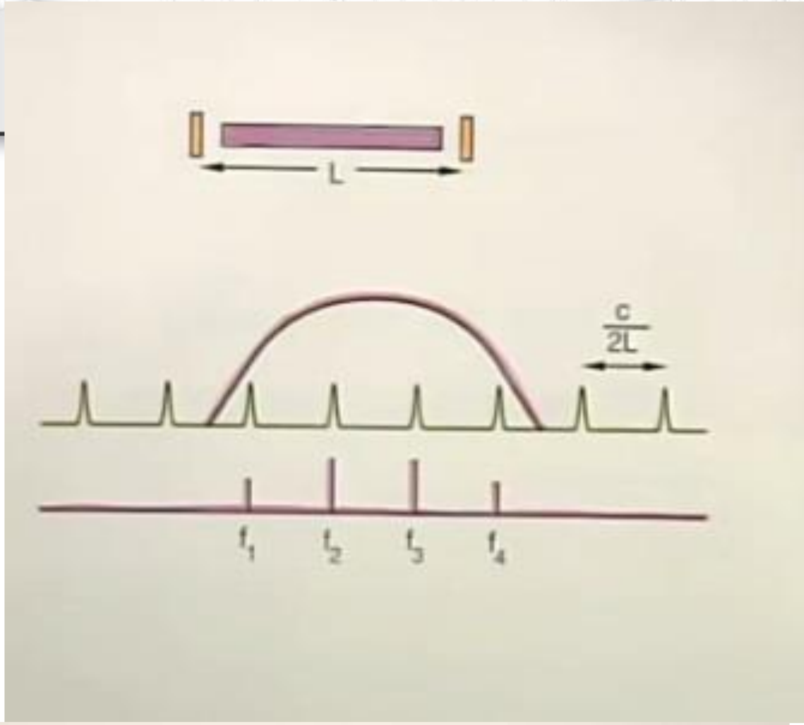


Fig. VIII-46: Fluorescence emission line (gain curve) of broad-band solid-state laser materials.

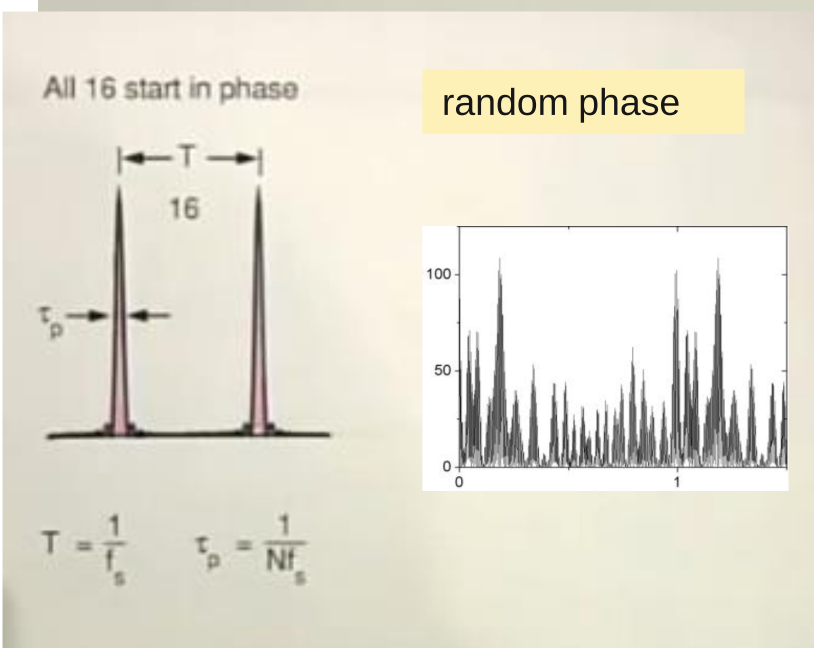
1. broadband amplifier medium
2. resonator
3. output coupler
4. phase/amplitude modulator
5. gain/loss mechanism controlled by intensity of pulse
6. dispersion compensation

modelocking

Pulsed laser mode



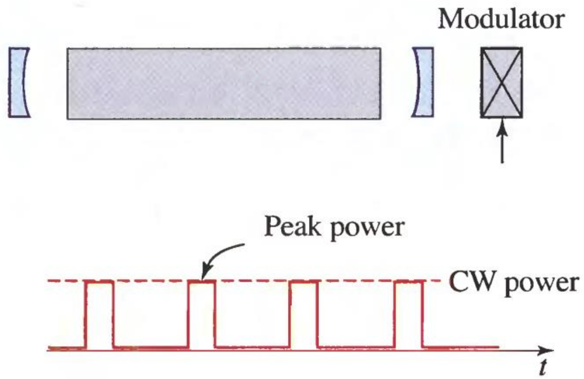
A broad amplifier gain can support multiple modes.

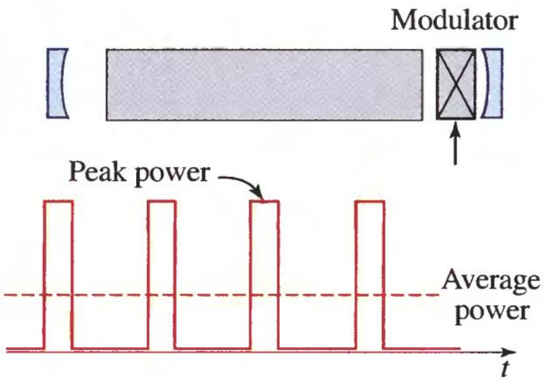


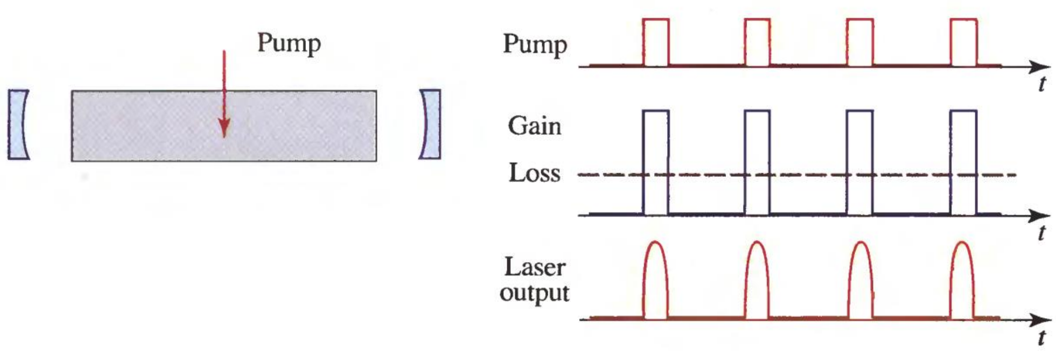
Short pulse production requires locking the phase of the components.

How can we induce pulsed mode of a laser?

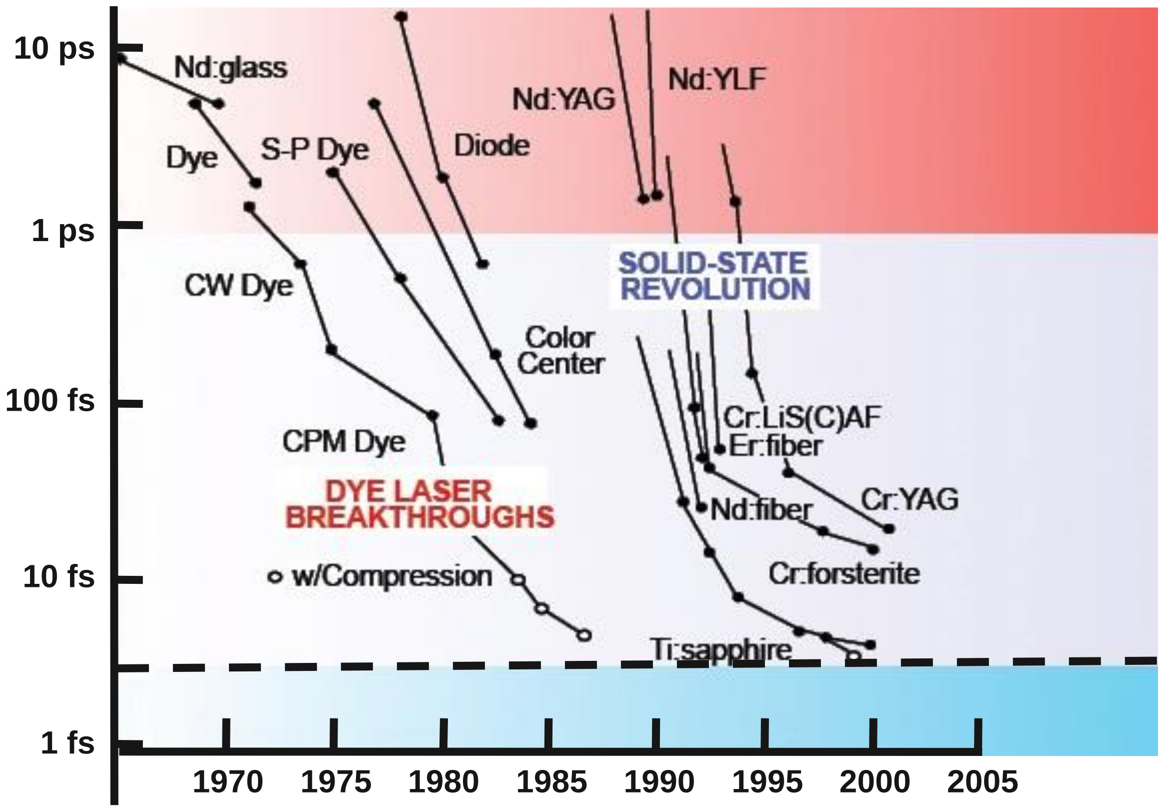
Modulators







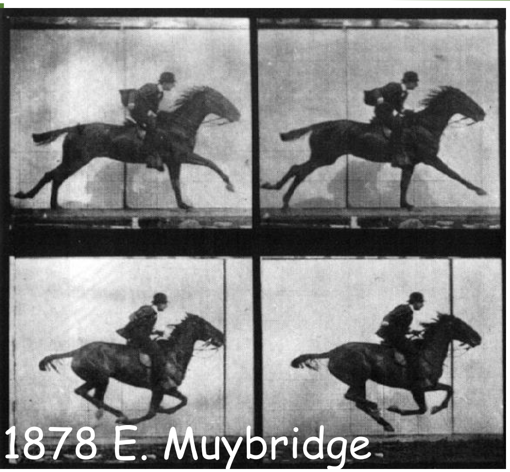
Quest for shorter pulse durations

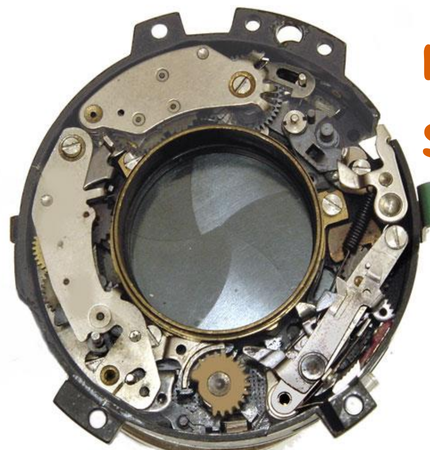


1) to concentrate energy (high power)

2) to freeze fast processes

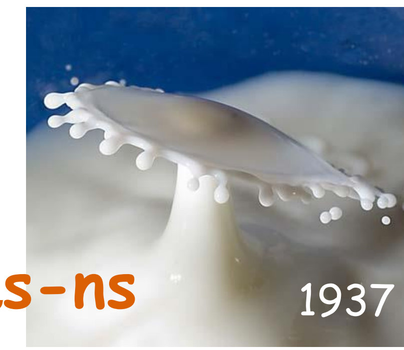
Picturing fast processes

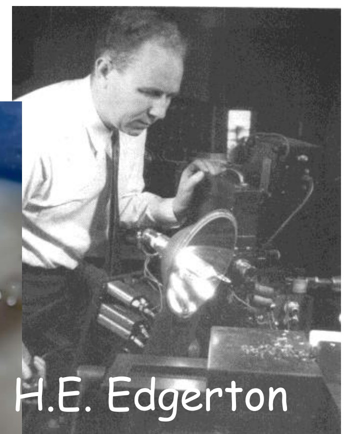


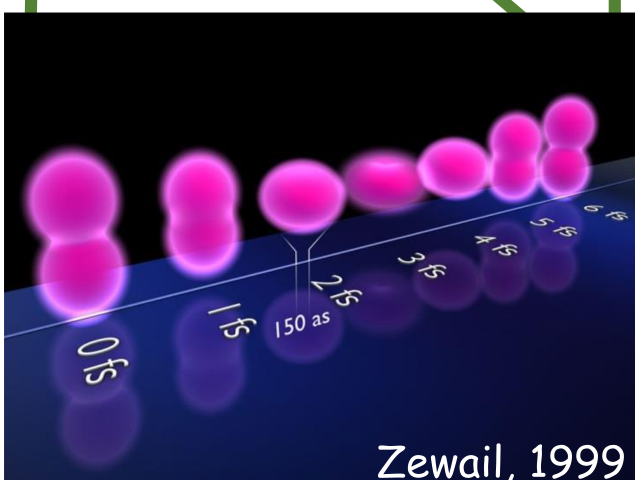


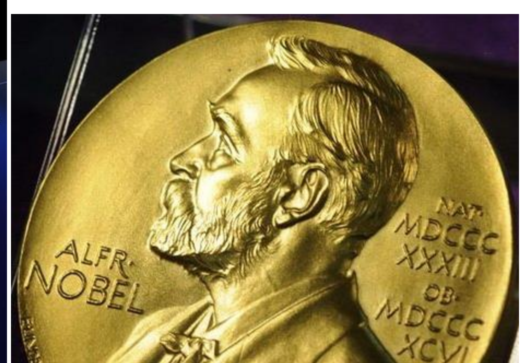
mechanical shutter: ms

electronically synched flash: µs-ns



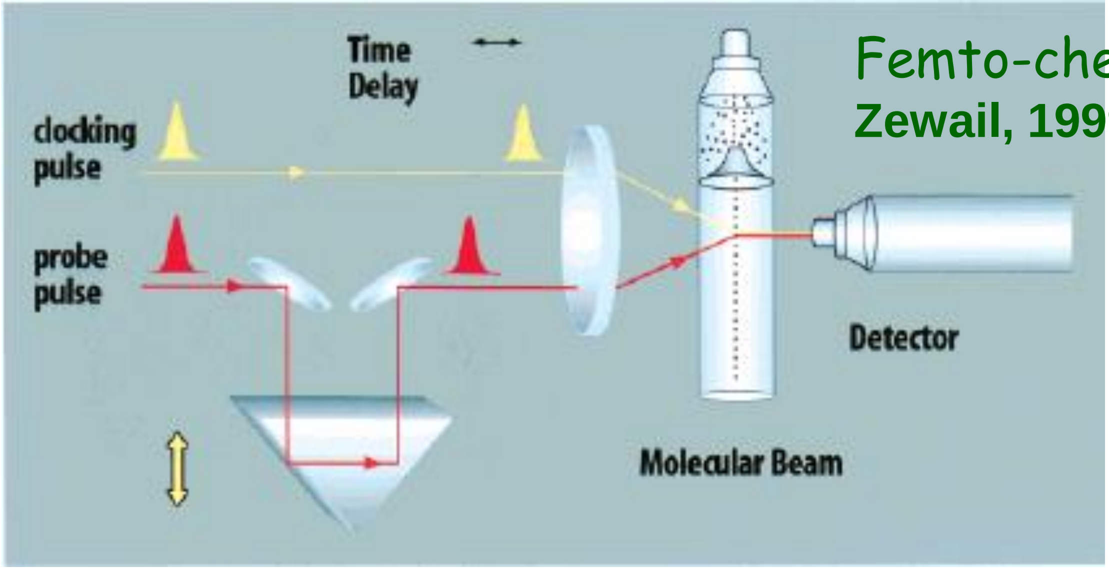






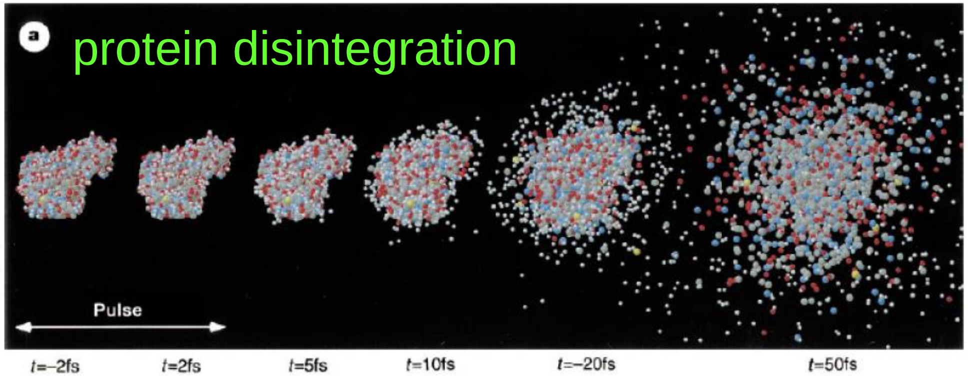
laser pump-probe ps – fs – as

Picturing fast processes

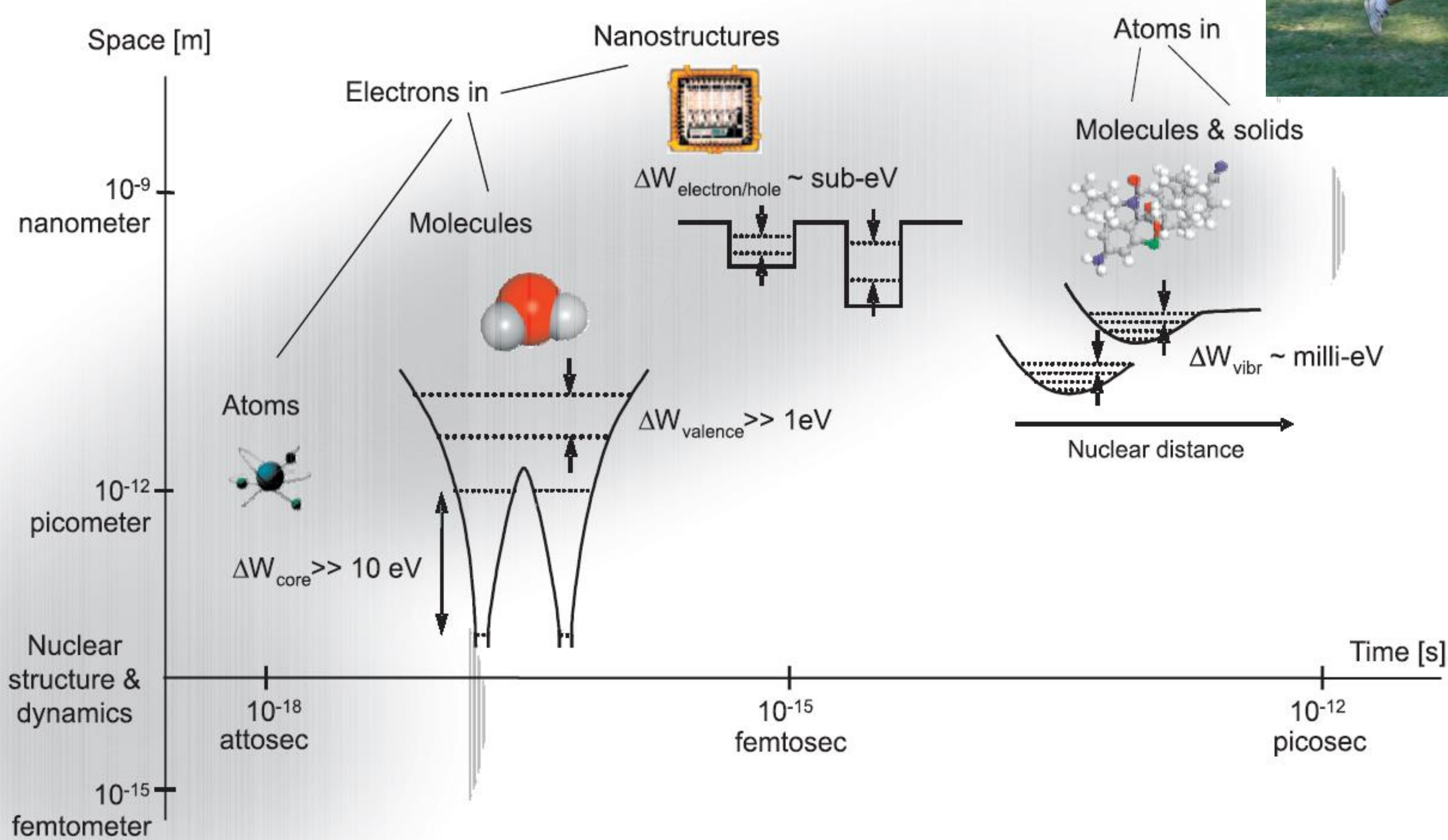


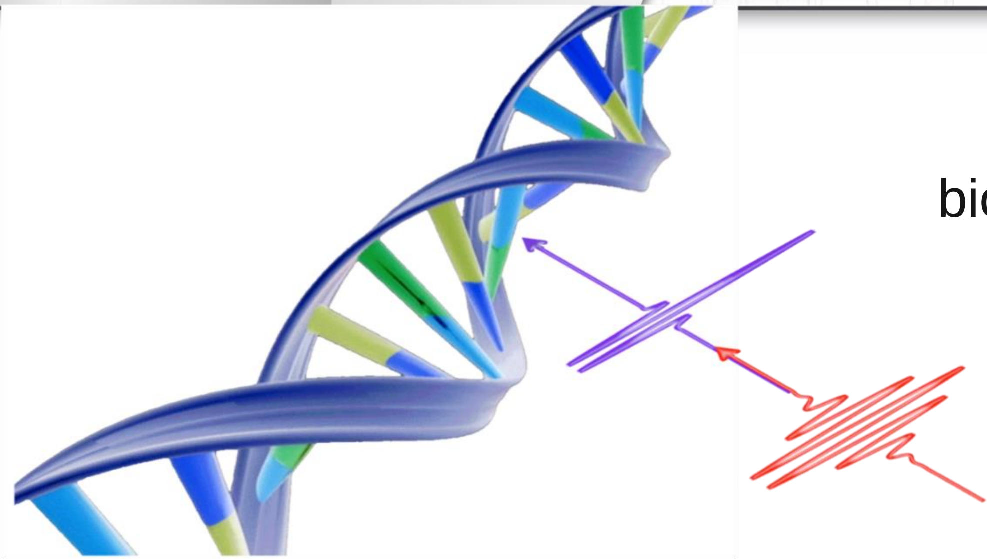
Femto-chemistry
Zewail, 1999

laser pump-probe method: ns – fs – as



Characteristic time – characteristic size





biological signal transfer in proteins

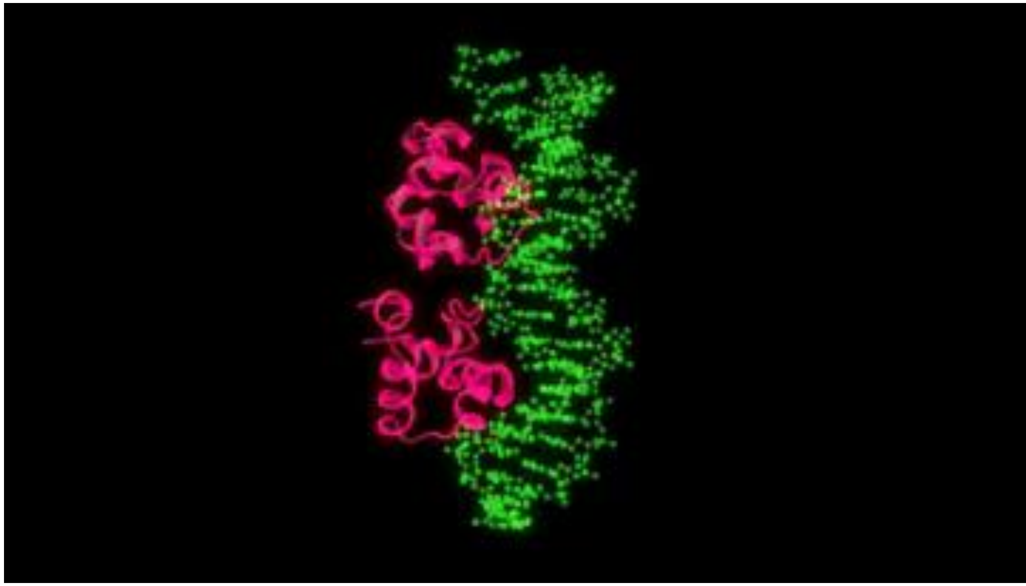
Changes in the electronic configuration (radiation, drug)

↓

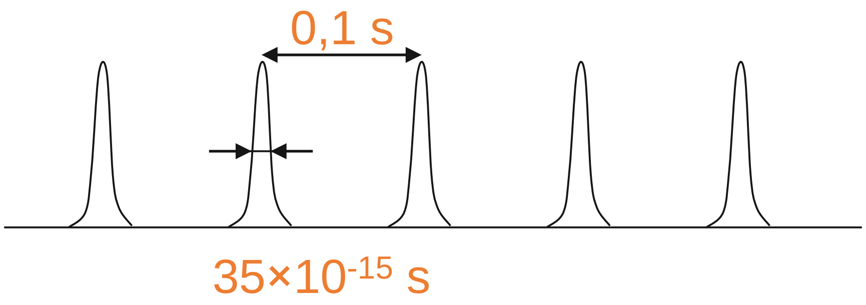
global electron-rearrangement

↓

structural changes of the molecule (diagnosis/therapy)



How „powerful” a laser pulse is?



E – energy in each pulse
τ – pulse duration
A – illuminated (focal) area

$\rho = \frac{E}{A}$ fluence (J/cm^2)

$P = \frac{E}{\tau}$ peak power (J/sec=W)

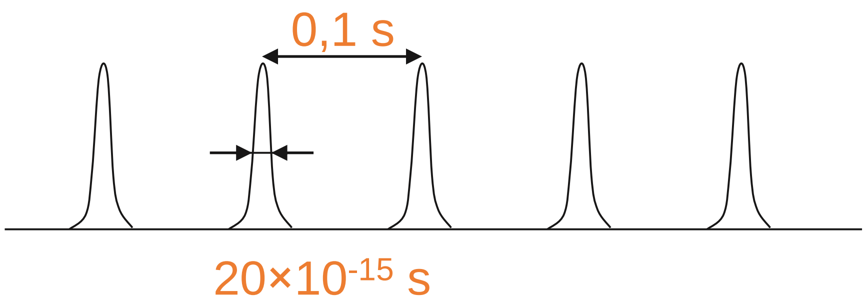
$I = \frac{P}{A} = \frac{E}{\tau \cdot A}$ intensity, power density (W/cm^2)

Average vs. peak power

Example

$$E = 35\ \text{mJ} = 0{,}035\ \text{J}$$

$$\tau = 20\ \text{fs} = 20\times10^{-15}\,\text{s}$$



$$P = \frac{E}{\tau} = 1{,}75\times10^{12}\,\text{W} = 1{,}75\ \text{TW}$$ peak power

repetition rate is 10 Hz, i.e. 10 pulses flash in 1 s

$$P = \frac{10\times E}{1\,\text{s}} = 0{,}35\ \text{W}$$ average power (related to the power consumption)

Paks nuclear power plant: 4 × 465 MW = 1,86 GW = 1,86 × 10^9 W

TeWaTI research lab (SZTE): $35\ \text{mJ}/20\ \text{fs} = 1{,}75\ \text{TW} = 1{,}75\times10^{12}\,\text{W}$

ELI „superlaser”: 1 EW=10^{18} W

How high these intensities are?

light is an electromagnetic wave, how strong is the electric field?

$$I = S = \frac{1}{2\mu_0} E_{max} B_{max} = \frac{1}{2}\varepsilon_0 c E_{max}{}^2$$

„university lab" laser pulse

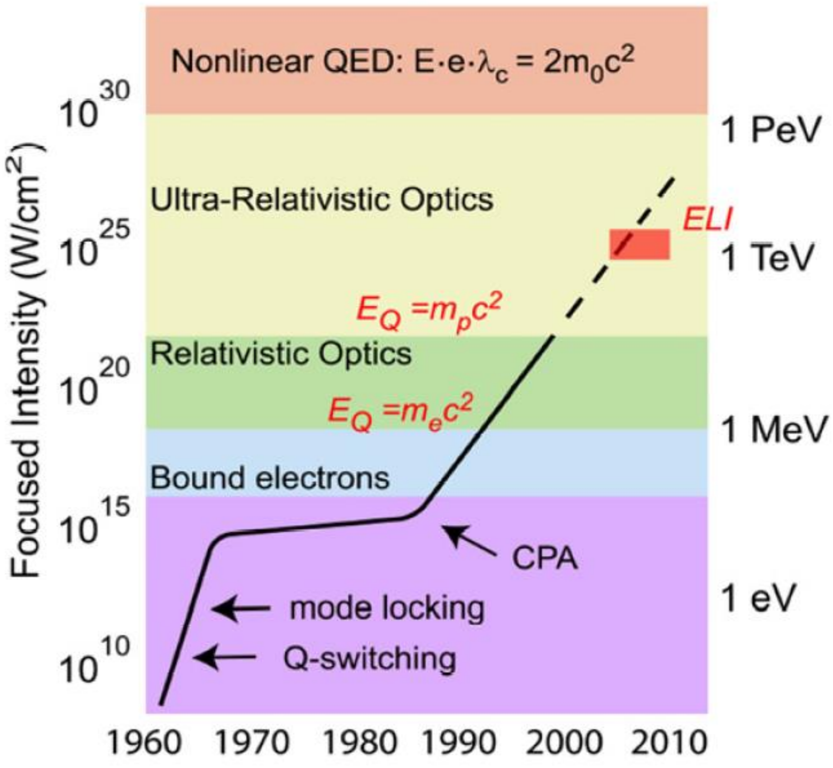
$$I = 35\,\mathrm{mJ} / 20\,\mathrm{fs} / (100\mu\mathrm{m})^2 = 1{,}75 \times 10^{20} \frac{\mathrm{W}}{m^2} = 1{,}75 \times 10^{16} \frac{\mathrm{W}}{cm^2}$$

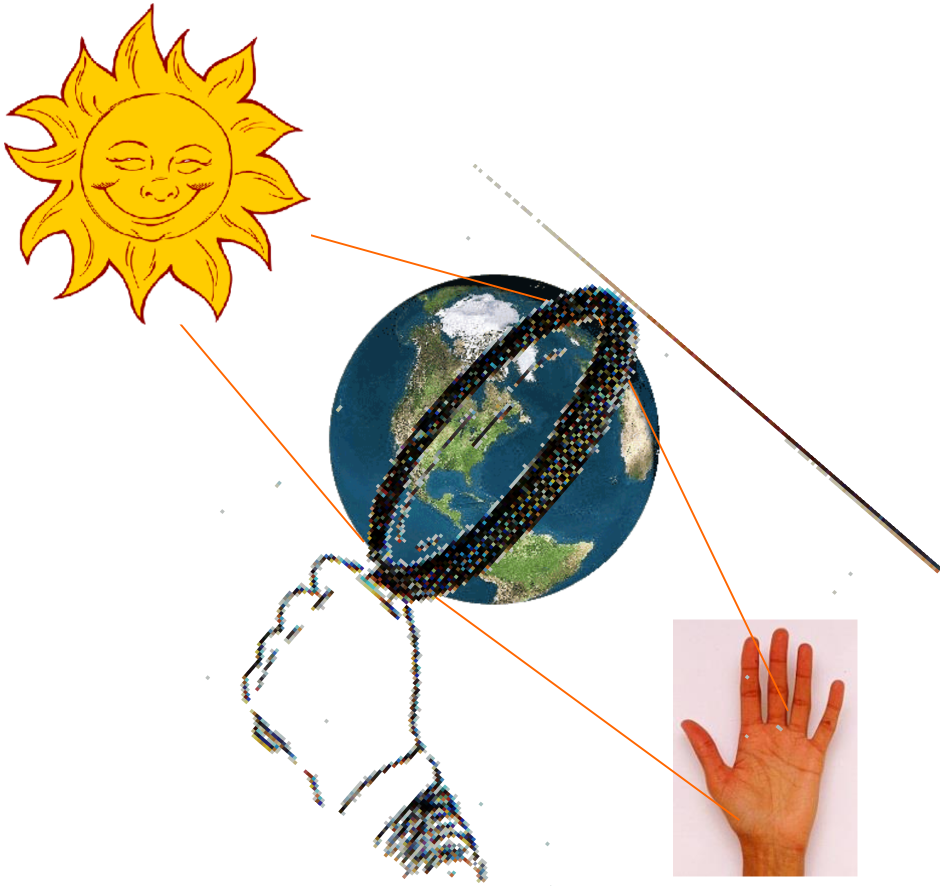
$$E_{max} = \sqrt{\frac{2 \cdot I}{\varepsilon_0 c}} = \sqrt{\frac{2 \cdot 1{,}75 \times 10^{20} \frac{\mathrm{W}}{\mathrm{m}^2}}{8{,}8 \times 10^{-12} \frac{\mathrm{As}}{\mathrm{Vm}} \cdot 3 \times 10^8 \frac{\mathrm{m}}{\mathrm{s}}}} \approx 10^{11} \frac{\mathrm{V}}{\mathrm{m}}$$

Coulomb force for an atomic electron:

$$E(r) = -\frac{1}{4\pi\varepsilon_0} \frac{e}{r^2} \qquad r \approx 10^{-10}\,\mathrm{m} \qquad E \approx 10^{11} \frac{\mathrm{V}}{\mathrm{m}}$$

How high these intensities are?



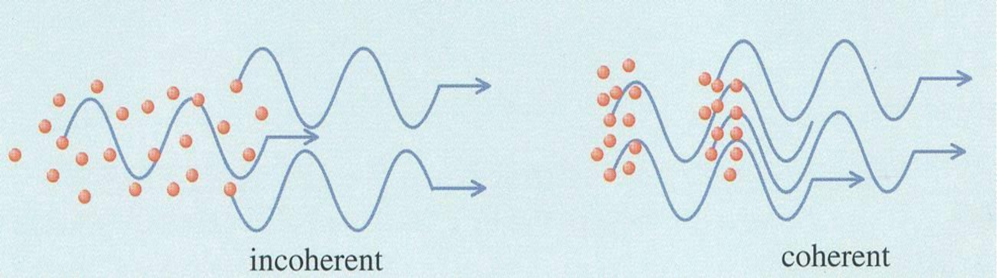


at ELI, everything evaporates
the question to ask: how?

~ 10^{14} W/cm²

Which properties of laser light serve medicine?

- monochromaticity
- coherence
- collimated, small divergence beam
- good focusability, high intensity (W/cm^2)



	12 Jul Wed	13 Jul Thu	14 Jul Fr	15 Jul Sat	16 Jul Sun
AM	▸ *Arrival*	▸ 9⁰⁰–10³⁰ • Péter Maróti, *Lasers in biophysics: why is laser light unique?* ▸ 11⁰⁰–12³⁰ • Ferenc Bari, *What did we learn about microcirculation using lasers?*	▸ 9⁰⁰–10³⁰ • Kinga Turzó, *Lasers for the surface modification of dental implants* ▸ 11⁰⁰–12³⁰ • Zsolt Tóth, *Lasers for dental applications*	▸ *Free period*	▸ *Excursion: Ópusztaszer Heritage Park*
Break	▸ 13⁰⁰–14⁰⁰ • *Lunch*	▸ 13⁰⁰–14⁰⁰ • *Lunch*	▸ 13⁰⁰–14⁰⁰ • *Lunch*	▸ 13⁰⁰–14⁰⁰ • *Lunch*	
PM	▸ 14⁰⁰–14³⁰ • Ferenc Bari, *Opening ceremony* ▸ 14³⁰–16⁰⁰ • Katalin Varjú, *The ELI-ALPS infrastructure – Basics of high-energy, short pulsed lasers* ▸ 16³⁰–18⁰⁰ • Adrian Podoleanu, *Optical coherence tomography* ▸ 19⁰⁰–22⁰⁰ • *Welcome party*	▸ 14⁰⁰–15³⁰ • Beáta Bugyi, *TIRF microscopy* ▸ 16⁰⁰–17³⁰ • András Lukács, *Transient absorption and fluorescence spectroscopy*	▸ 14⁰⁰–15³⁰ • Petar Lambrev, *Ultrafast two-dimensional spectroscopy of photosynthetic light harvesting complexes* ▸ 16⁰⁰–17³⁰ • Gusztáv Schay, *THz pulsed laser can be used to selectively pump protein vibrations*	▸ *Free period*	▸ *Excursion: Ópusztaszer Heritage Park*

	17 Jul Mon	18 Jul Tue	19 Jul Wed ELI	20 Jul Thu	21 Jul Fri
AM	▸ 9⁰⁰–10³⁰ • Justin Molloy, *Optical tweezers* ▸ 11⁰⁰–12⁰⁰ • Zoltán Bajory, *Lasers in urology*	▸ 9⁰⁰–10³⁰ • Miklós Erdélyi–Eric Rees, *Localisation-based super-resolution microscopy* ▸ 11⁰⁰–12⁰⁰ • Eric Rees, *Super-resolution microscopy and the importance of mathematical inference*	▸ 9⁰⁰–10³⁰ • Katalin Hideghéty, *Hadron therapy* ▸ 11⁰⁰–12³⁰ • Elke Beyreuther, *Radiobiology of pulsed particle beams*	▸ 9⁰⁰–12³⁰ • *Laboratory visits in the Biological Research Centre*	▸ 9⁰⁰–10³⁰ • Tomáš Čižmár, *Photonics in disordered environments and fibre-based imaging* ▸ 11⁰⁰–12⁰⁰ • Attila Thury, *Application of optical coherence tomography in coronary interventions*
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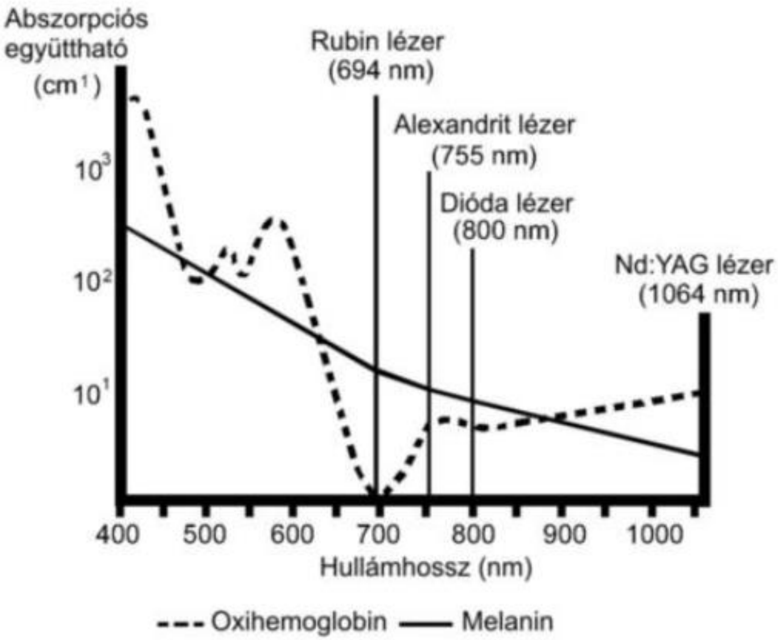
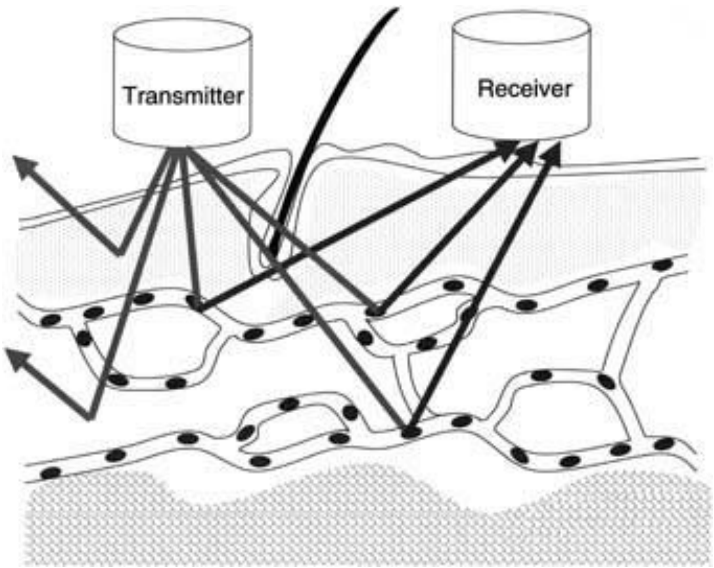
epilation

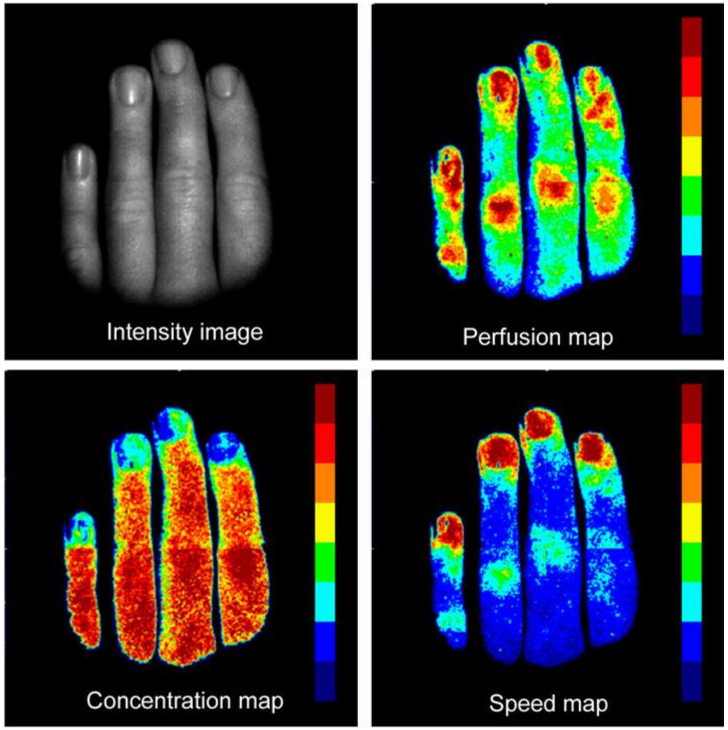

Abszorpciós
együttható
(cm⁻¹)
10³
10²
10¹
Rubin lézer
(694 nm)
Alexandrit lézer
(755 nm)
Dióda lézer
(800 nm)
Nd:YAG lézer
(1064 nm)
400
500
600
700
800
900
1000
Hullámhossz (nm)
Oxihemoglobin
Melanin

Narrow bandwidth



Doppler effect: frequency of scattered light is shifted

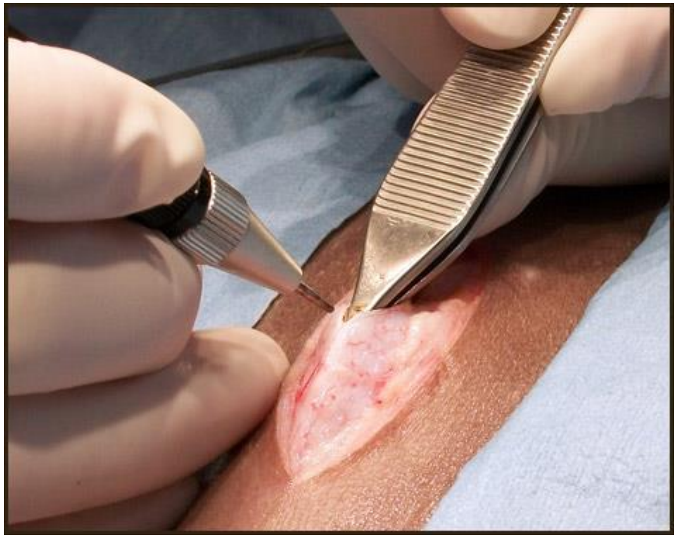
due to the narrow bandwidth of laser light, the shift can be accurately determined



High power

Stone fragmentation

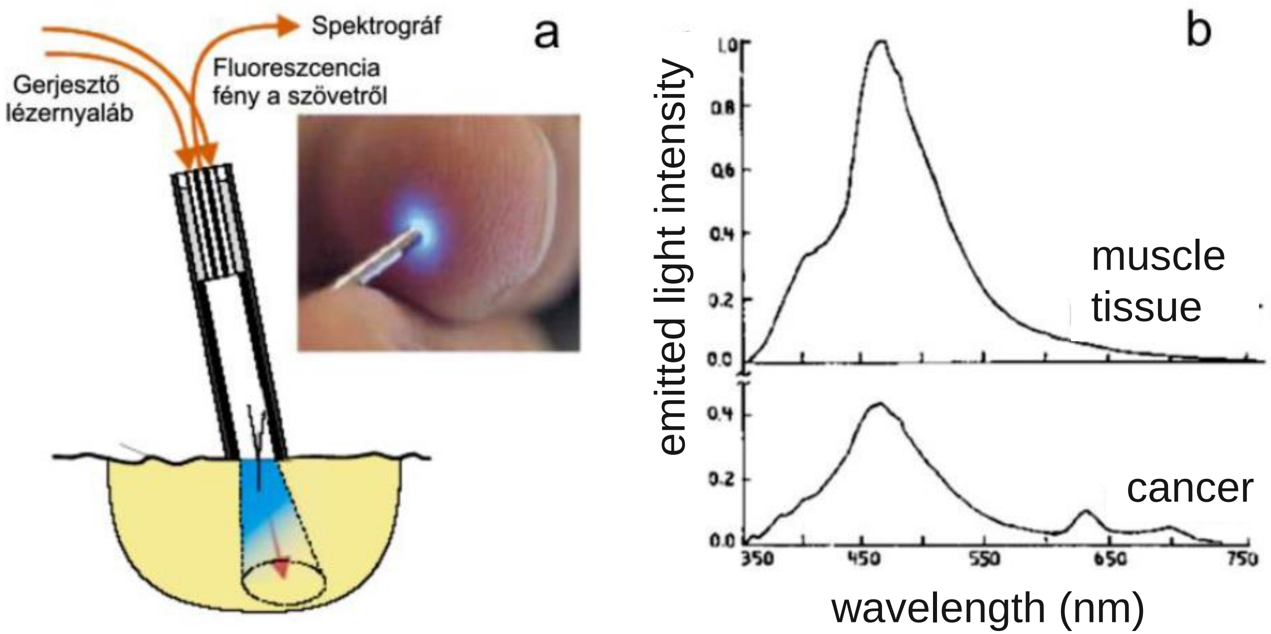
Laser-knife



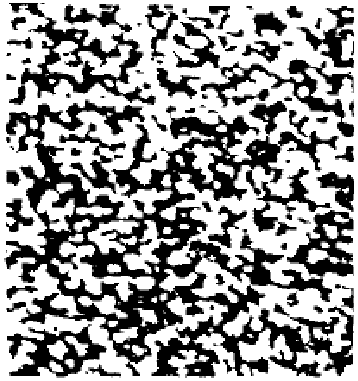
Monochromaticity, tunability, low divergence, short duration

I. Laser spectroscopy

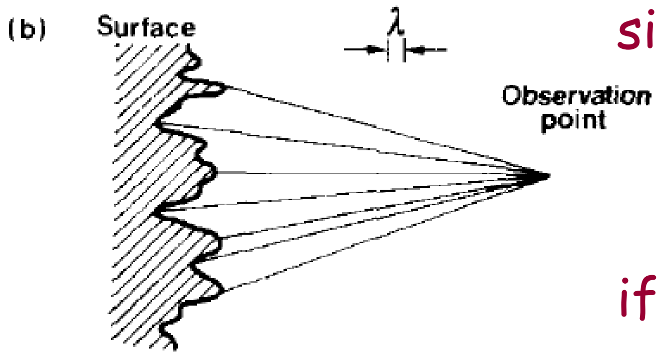
- focusable to a small volume » increased spatial resolution
- tunable narrowband lasers » increased spectral resolution
- pulsed (<10^{-12} s) lasers » temporal resolution



Lasers in Medicine and Life Sciences, 201



Laser speckle



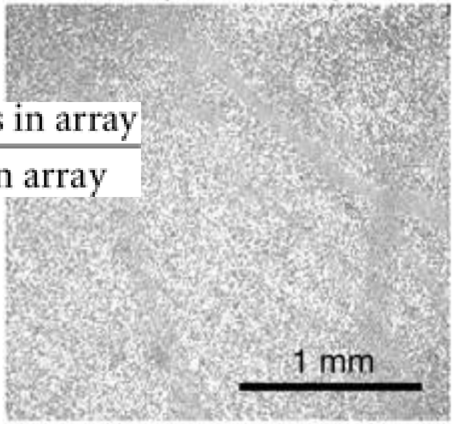
since laser light is coherent, reflections from different points interfere

if the scattering particle moves, the speckle image gets blurred during exposion time

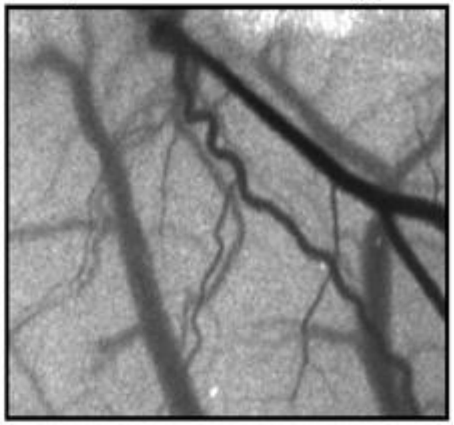
$$\text{Speckle contrast value} = \frac{\text{standard deviation of pixels in array}}{\text{mean intensity of pixels in array}}$$

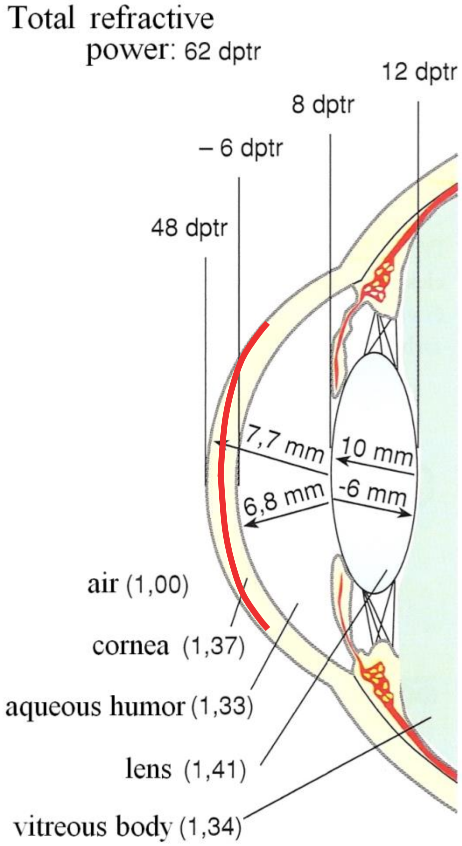
$$\text{Velocity } \alpha \ \frac{1}{(\text{speckle contrast})^2}$$

Raw speckle image

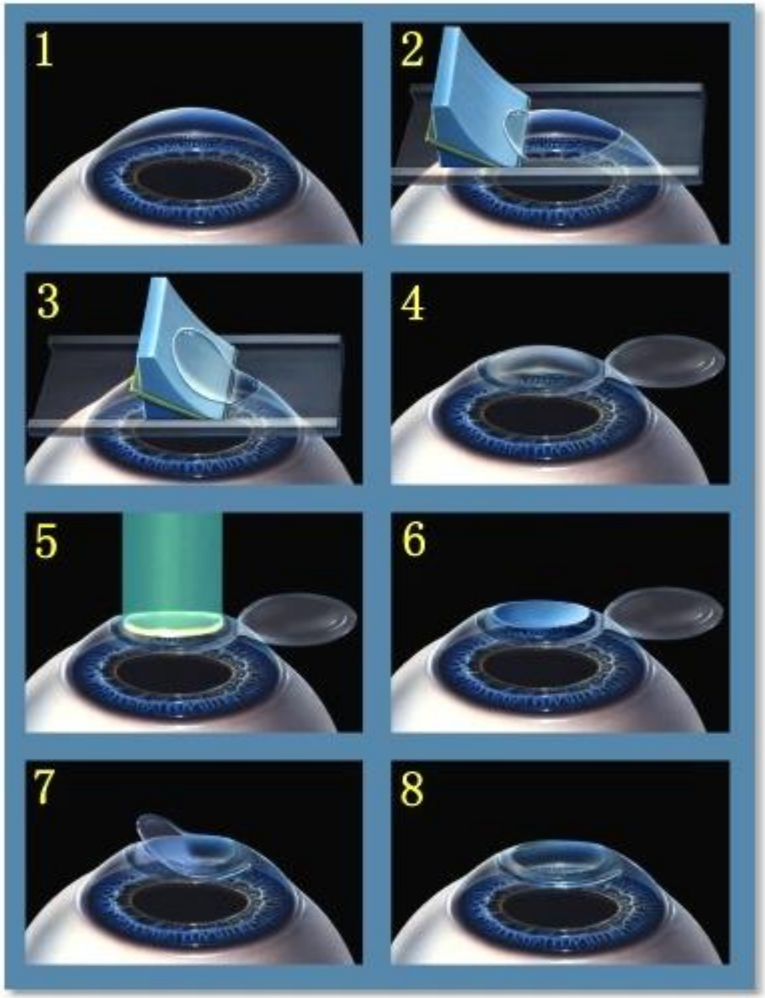


Speckle contrast image



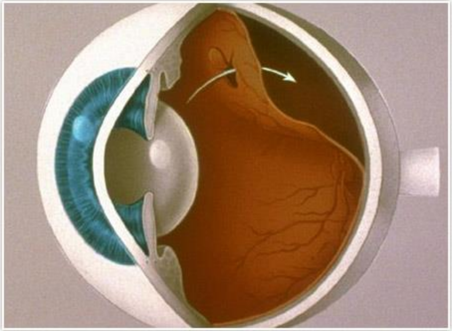


LASer In-situ Keratomileusis

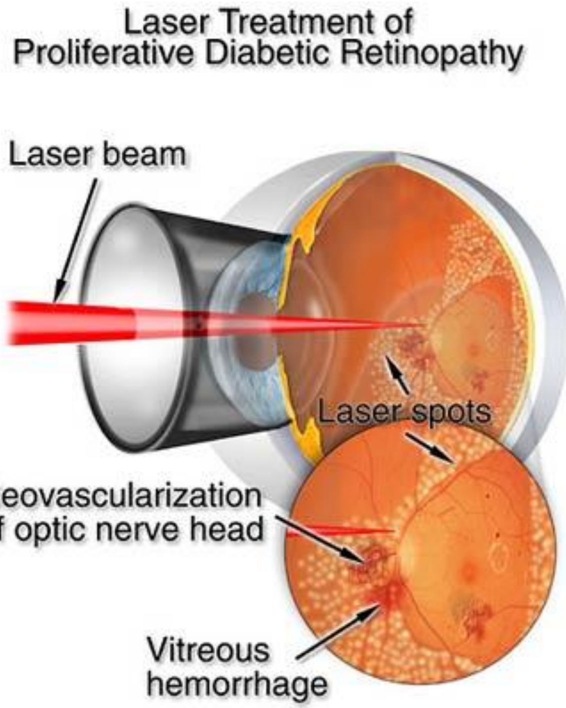


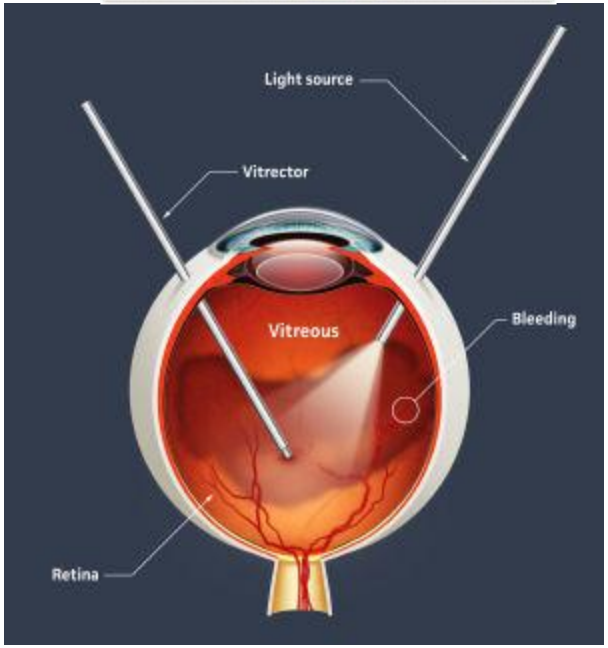
surgery behind a transparent medium

reattach torn retina



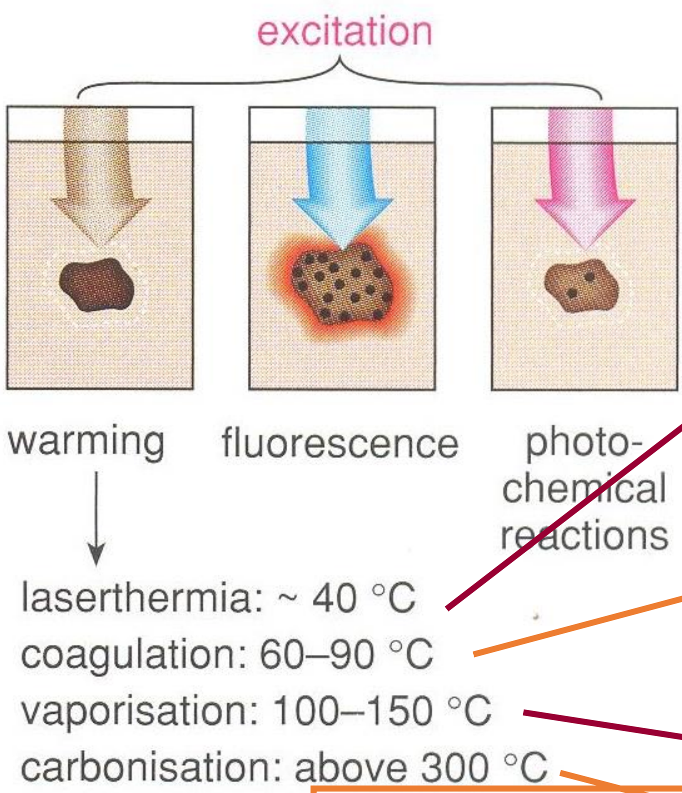
treatment of diabetic retinopathy





Well-controlled dosage

monochromatic (wavelength matched to absorption of tissue)
good focusability (high power density), good pointing definition



no short-term tissue damage, biostimulant (increased diffusion and metabolism increase wound healing: ulcers, open wounds, muscle strains, nerve injuries)

protein coagulation, cell destruction (staunch bleeding, cure blood vessel profileration)

boiling water, rapid expansion (tissue lesion, cutting, ablation of stones)
not advised for tumour elimination due to spreading of bio-molecules

cutting with coagulated blood vessels in the surrounding areas

laser material				typical wave-length (nm)	typical power (W)		applications
main type (state)	sub-type	name	notation		continuous or quasi-continuous mode	impulse mode, during an impulse	
gas		Helium-neon	HeNe	633	$5 \cdot 10^{-3}$		*infrared targeting laser*
		argon	Ar	488 514	10	10^2	*ophthalmology, dye lasers, pumping*
		krypton	Kr	548 647	10		*ophthalmology*
		carbon-dioxide	CO_2	10 600	$2 \cdot 10^2$	10^9	*surgery*
	Excimer (excited dimer) (rare gas or halogen gas)	*e.g.* krypton-fluor	KrF	248		$5 \cdot 10^4$	*ophthalmology*
liquid	dye (solution)	*e.g.* rhodamine 6G	$C_{28}H_{31}N_2O_3Cl$	560-610	1	10^5	*ophthalmology, dermatology, PDT (IX/2.2.)*
solid state		ruby	$Cr\text{-}Al_2O_3$	694		10^9	*dermatology*
	YAG (yttrium-aluminium-garnet) + lanthanides: Nd, Ho, Er, ...	*e.g.* neodymium-YAG	$Nd\text{-}Y_3Al_5O_{12}$	1064	50	10^8	*surgery*
	semiconductor	*e.r.* gallium-arsenide	GaAs	840	$5 \cdot 10^{-3}$		*laser pointer, CD player*

Lasers of ELI

	Av.power / *Peak power*	
ALPS High Repetition Rate (HR) beamline **100kHz, >5mJ, <6fs**, 1030nm	**100 W** ***0.16TW***	10^{12}W
ALPS Single Cycle (SYLOS) beamline **1kHz, >100mJ, <6fs**, 860nm	**45 W** ***4.5TW***	10^{12}W
ALPS High Field (HF) beamline HF PW: **10Hz, 34J, <20fs**, 800nm	**340 W** ***>2 PW***	10^{15}W
ALPS Mid-IR beamline **100kHz, 3.1μm, 150μJ, <4 cycles**	**15 W** ***3.75 GW***	10^{9}W

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Chair: Sa...

ELI-type lasers in Medicine and Life Sciences

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- Laser Plasma Theory Group — Alexander Andreev
- Strong Field and Quantum Optics Theory Group — Sandor Varro
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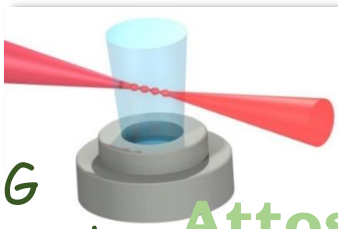
ELI-ALPS: collection of sources

Primary sources (laser pulses)

Secondary sources (harmonics, particles, THz, etc.)

Experiment / User stations

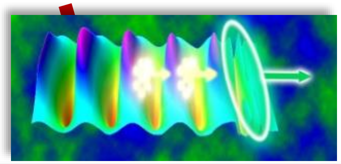


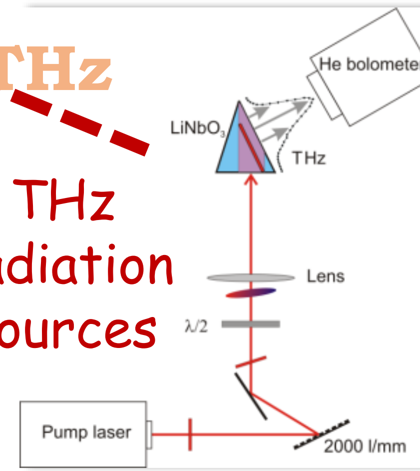
GHHG attosecond sources

Attosecond Sources

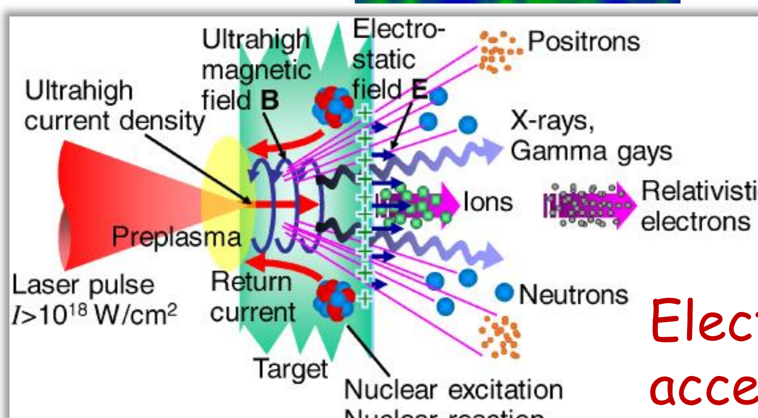
SHHG attosecond sources

Particle and THz Sources





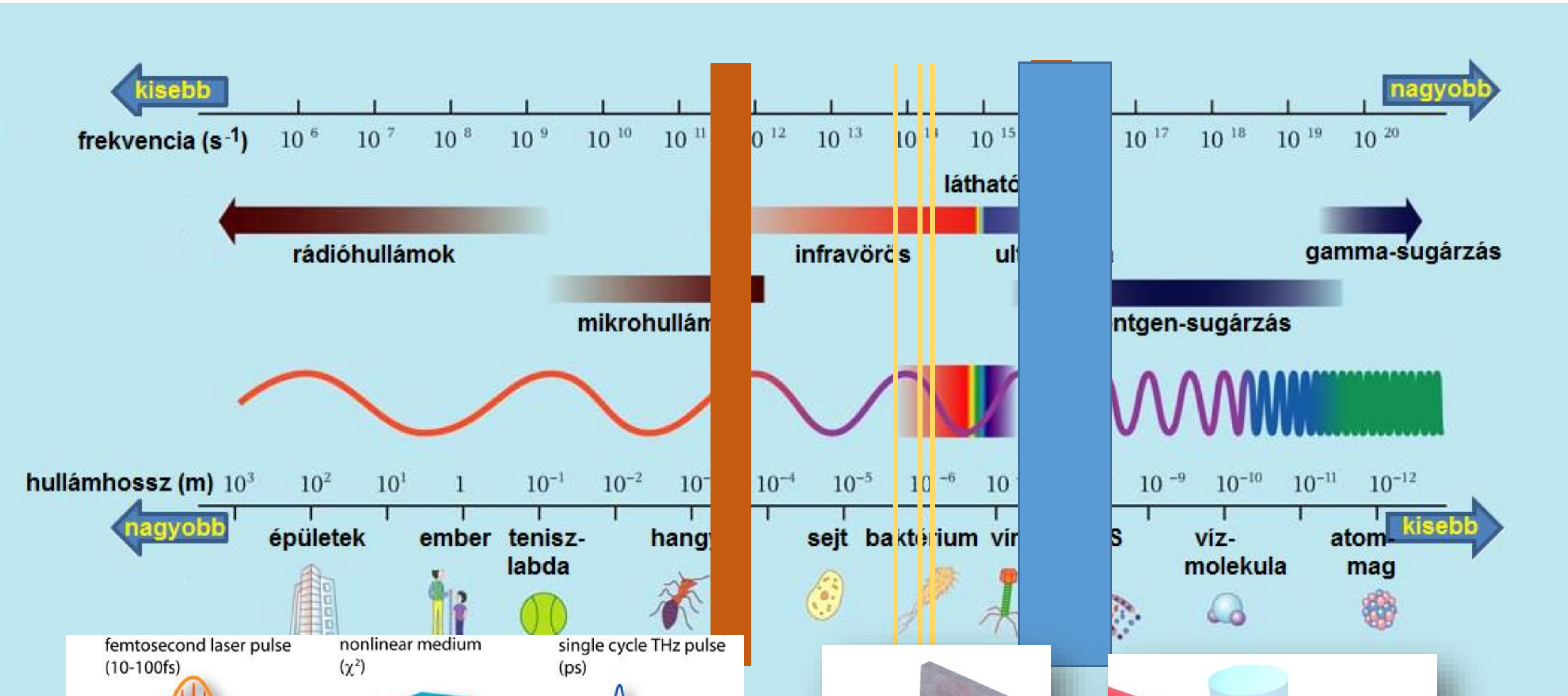
THz radiation sources

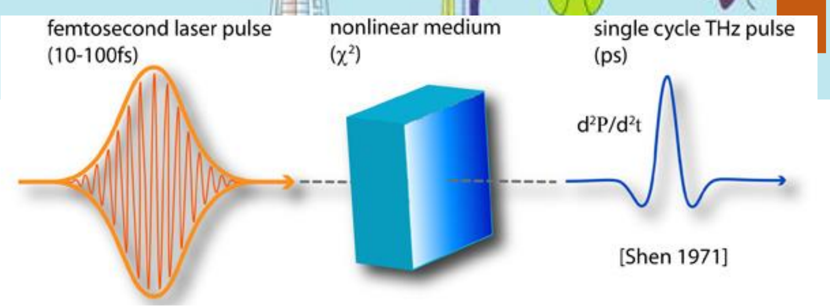


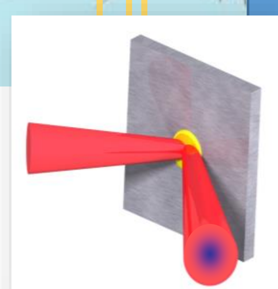
Electron, ion accelerators

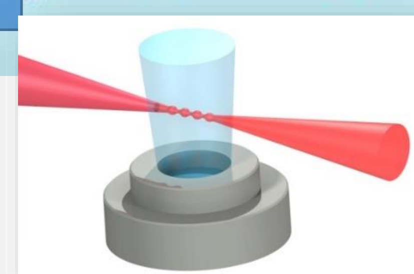
Secondary sources of ELI ALPS (XUV to THz)

Based on nonlinear interaction between laser pulse and matter.









An attosecond experiment

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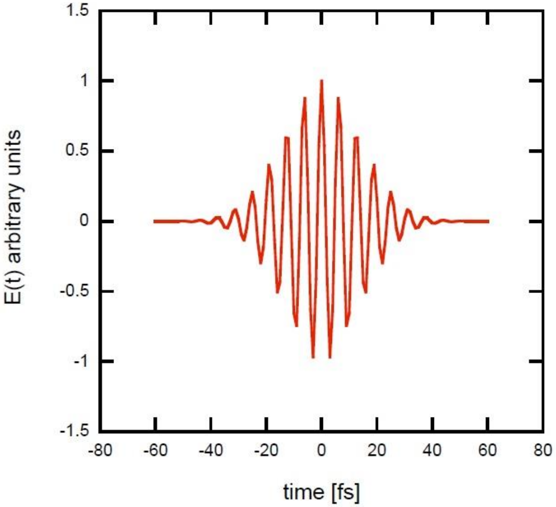
Lasers in Medicine and Life Sciences

Mayfly



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Lasers in Medicine and Life Sciences

eli attosecond

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