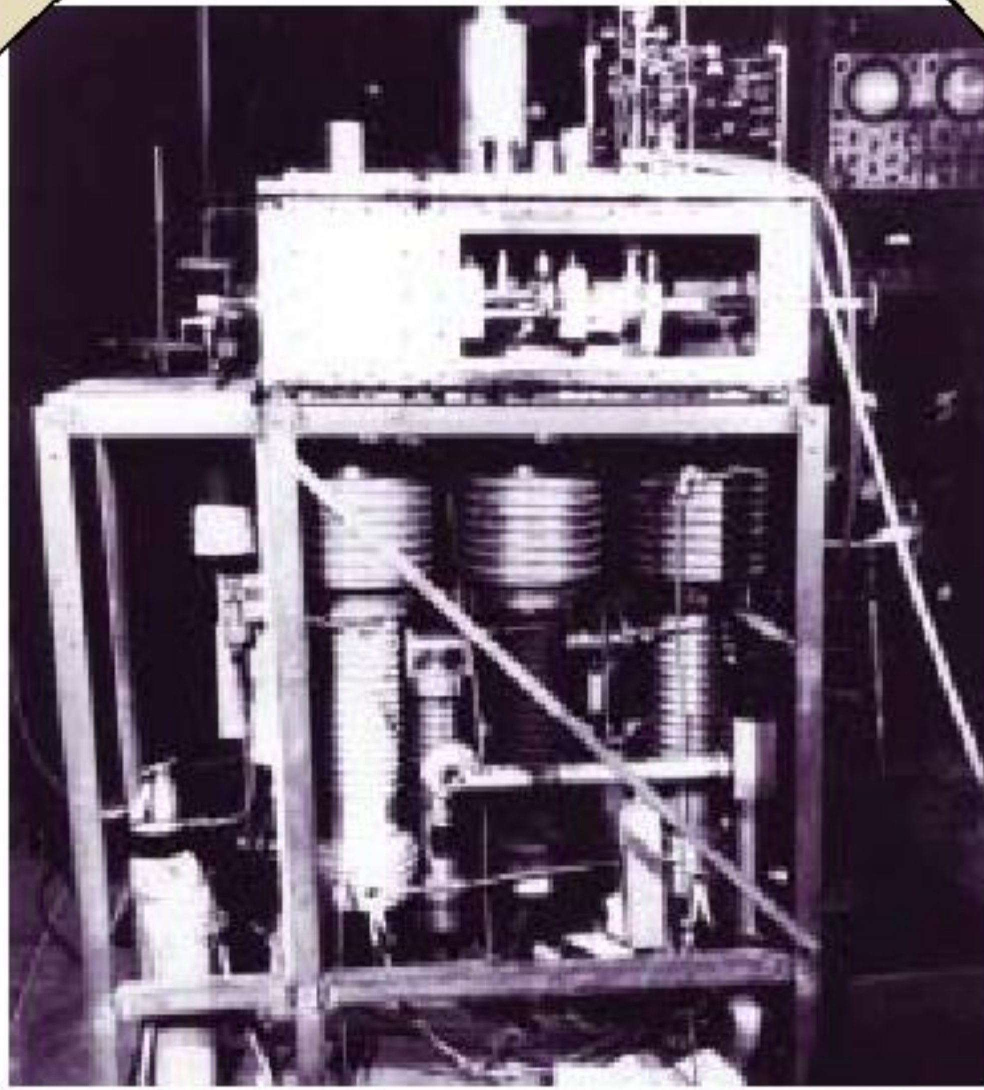
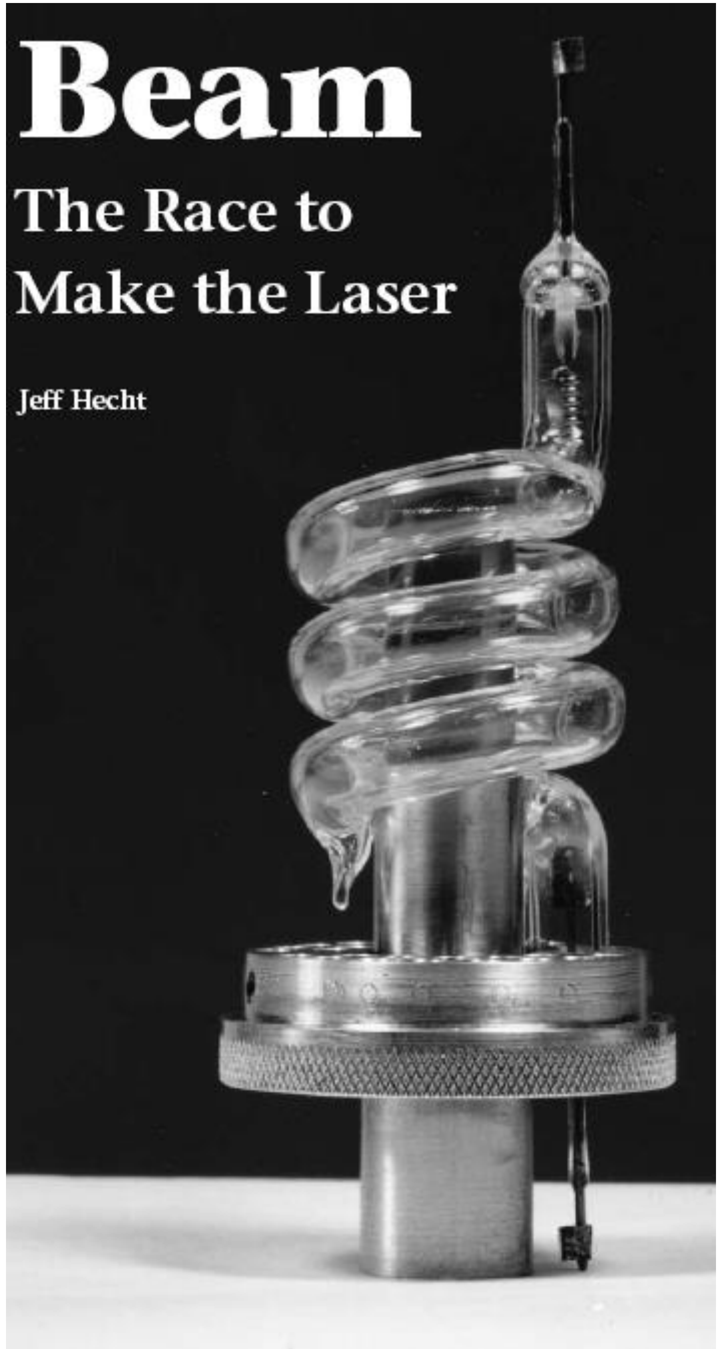


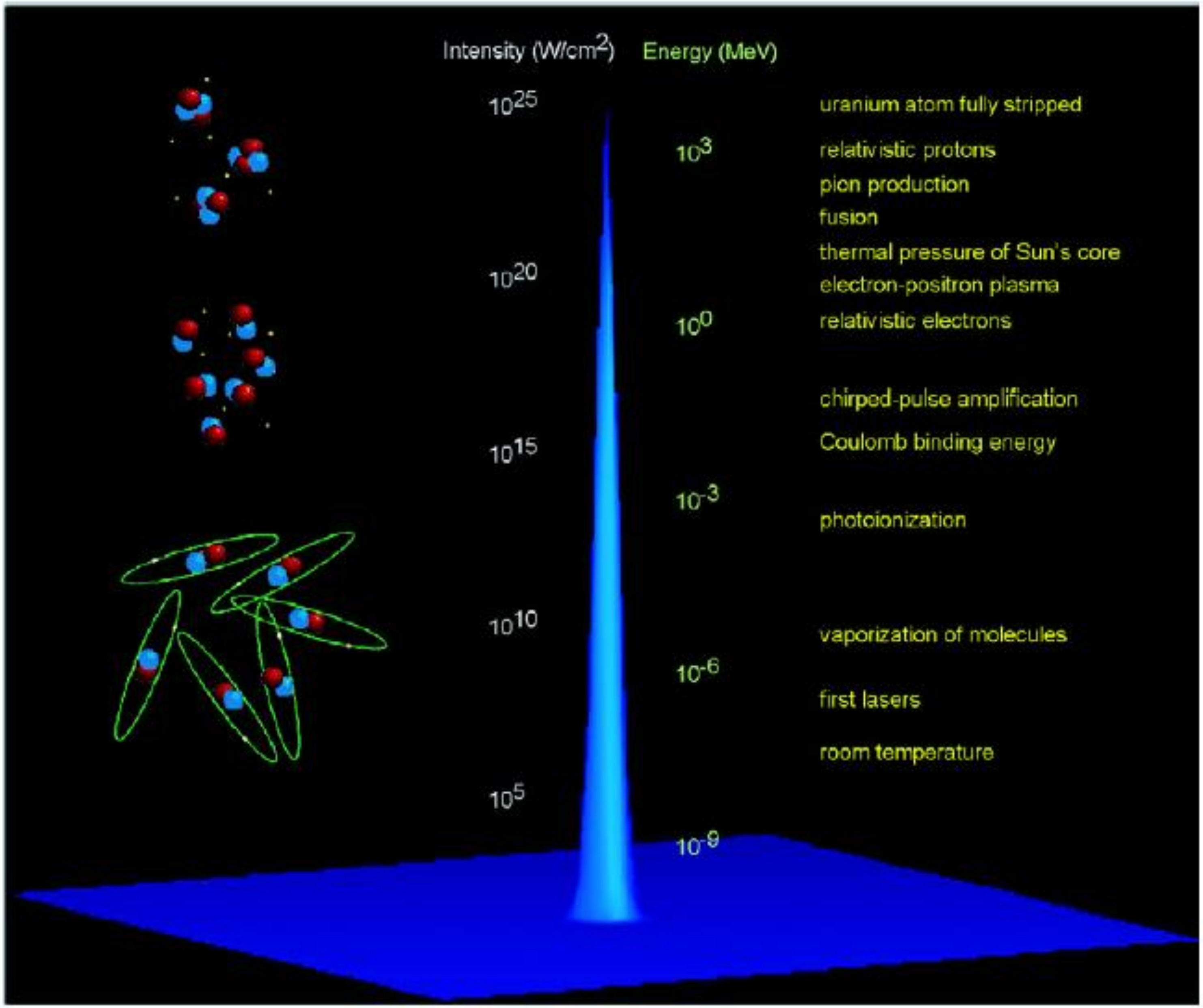
Figure 1. The first ammonia maser.

Beam

The Race to Make the Laser

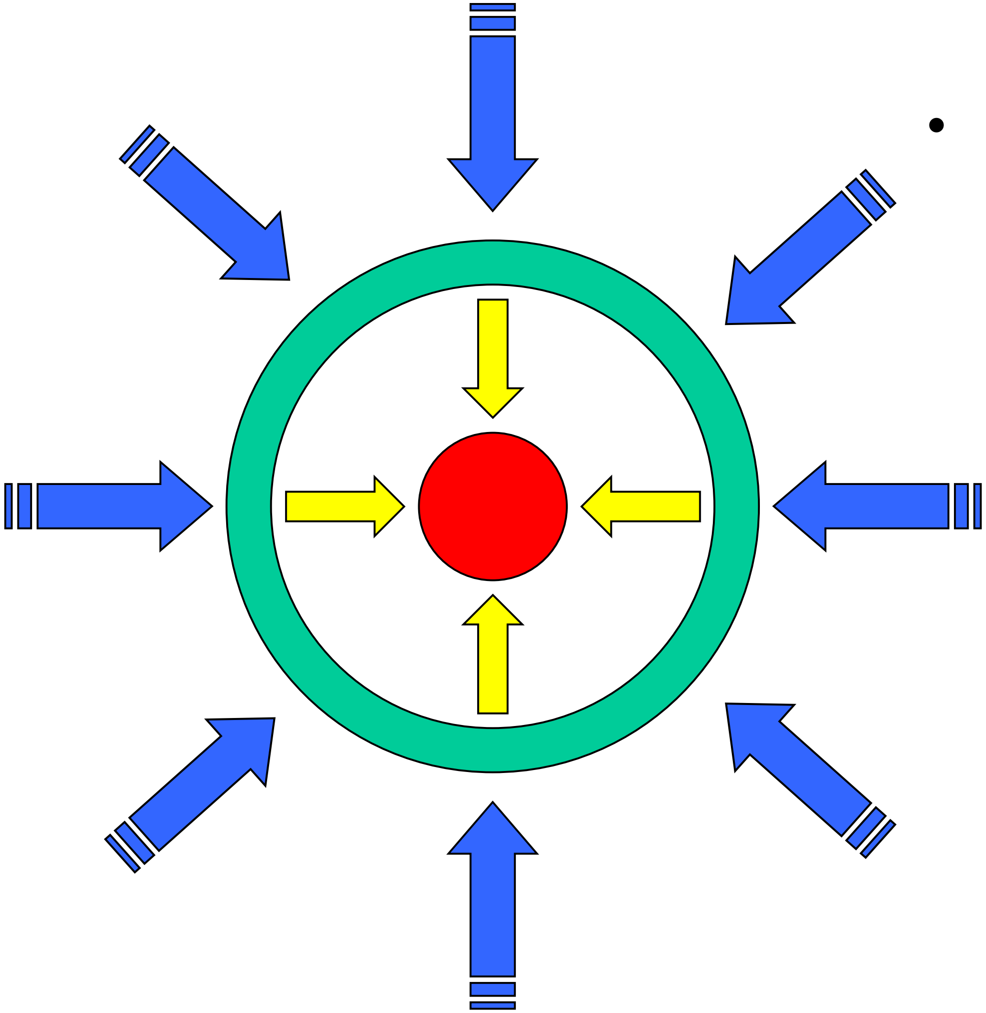
Jeff Hecht





Intensity (W/cm2)
Energy (MeV)
1025
1020
1015
1010
105
103
100
10-3
10-6
10-9
uranium atom fully stripped
relativistic protons
pion production
fusion
thermal pressure of Sun's core
electron-positron plasma
relativistic electrons
chirped-pulse amplification
Coulomb binding energy
photoionization
vaporization of molecules
first lasers
room temperature

Laser fusion



- Compression of D-T filled glass pellet to get
  - Temperature: 100,000,000K
  - Density: 10, 000g/cc

For 1 picosecond (10^{-12} seconds)

D-T fuse to form He, plus excess energy

The 60-beam Omega laser system at the University of Rochester's Laboratory for Laser Energetics (LLE) has been a workhorse on the frontier of laser fusion and high-energy-density physics for more than a decade. LLE scientists are currently extending the performance of this unique, direct-drive laser system by adding high-energy petawatt capabilities.

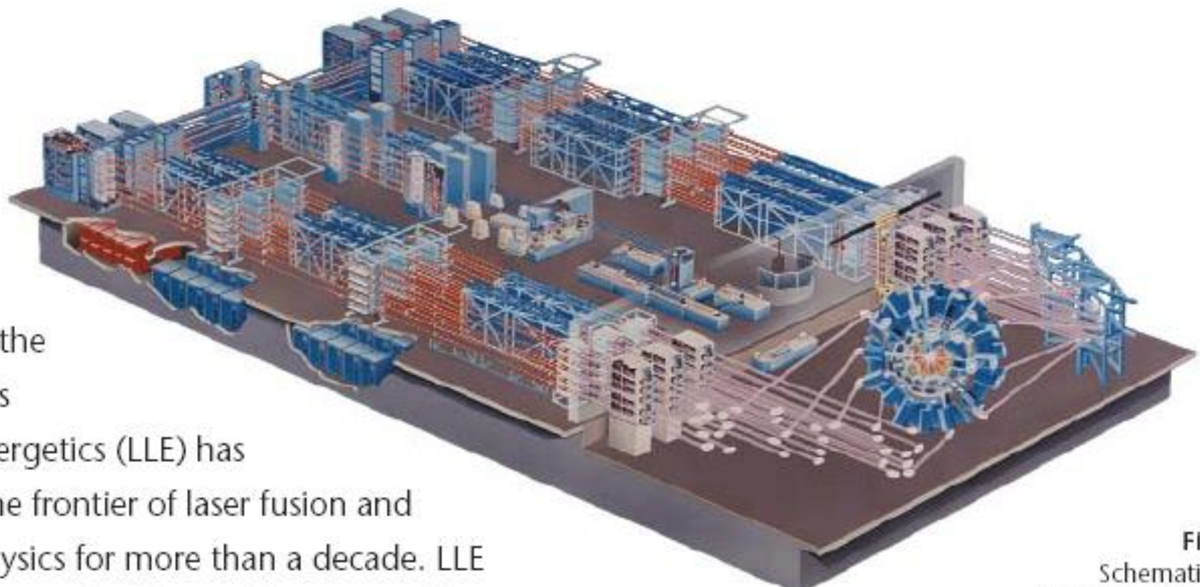
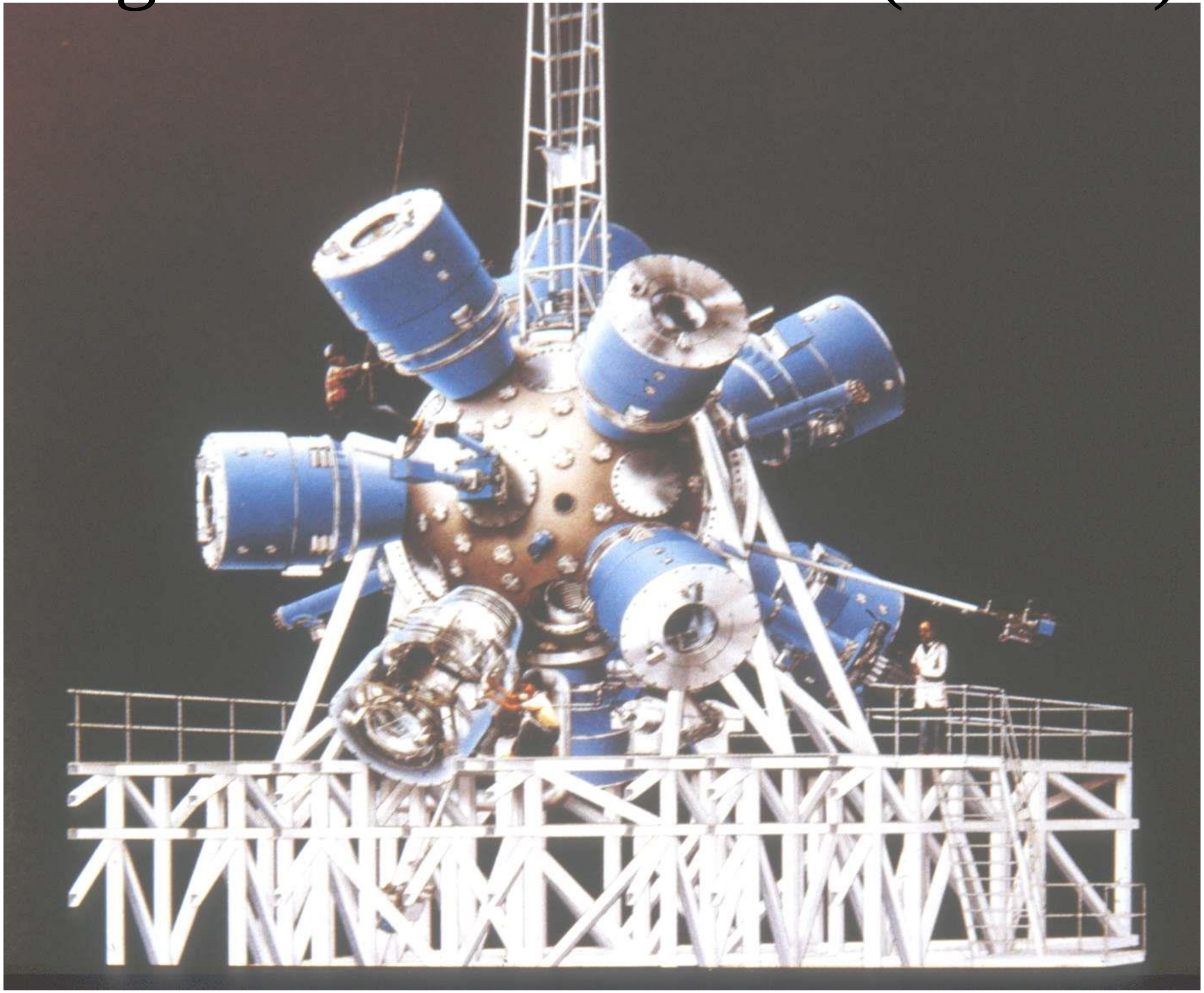
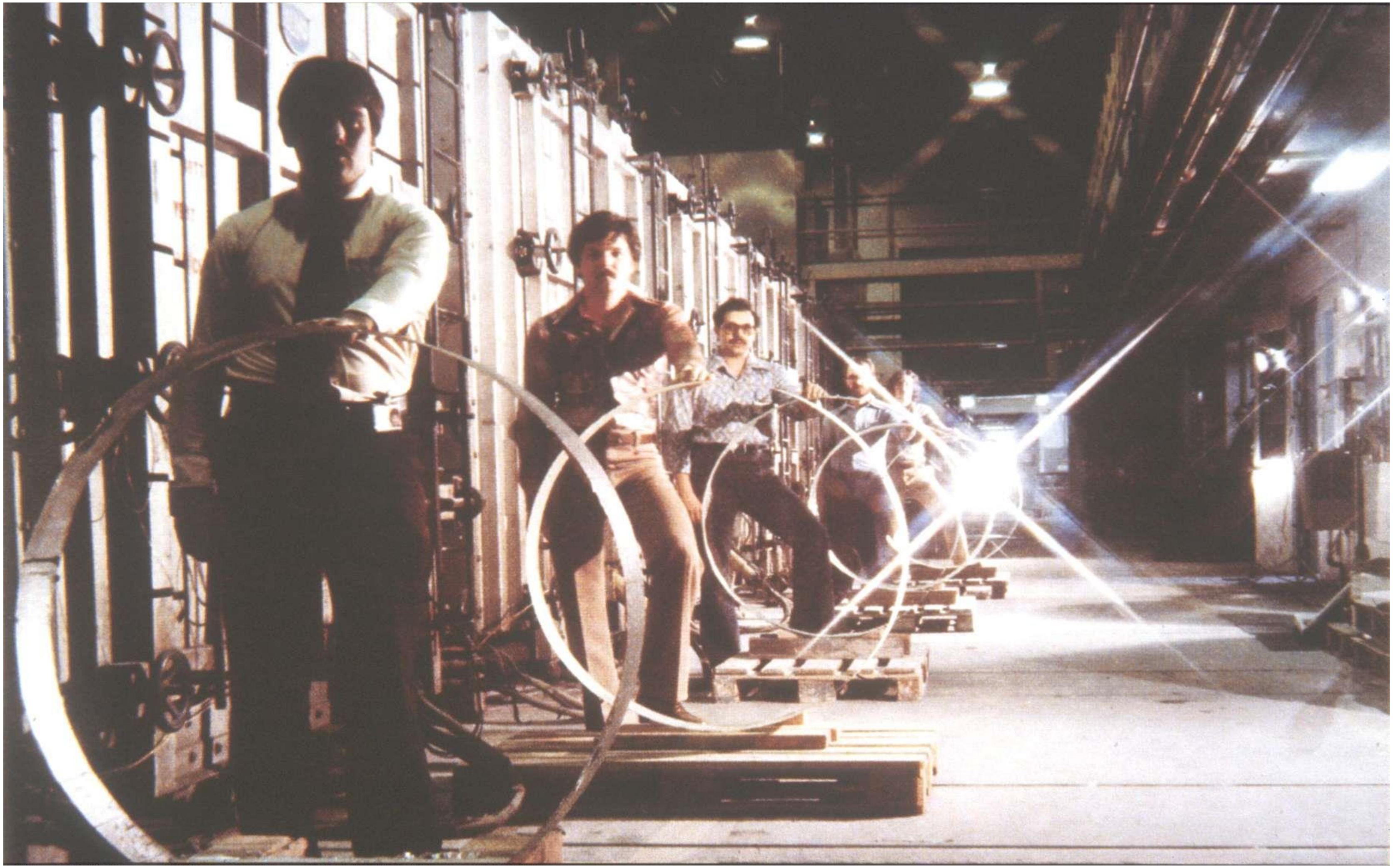
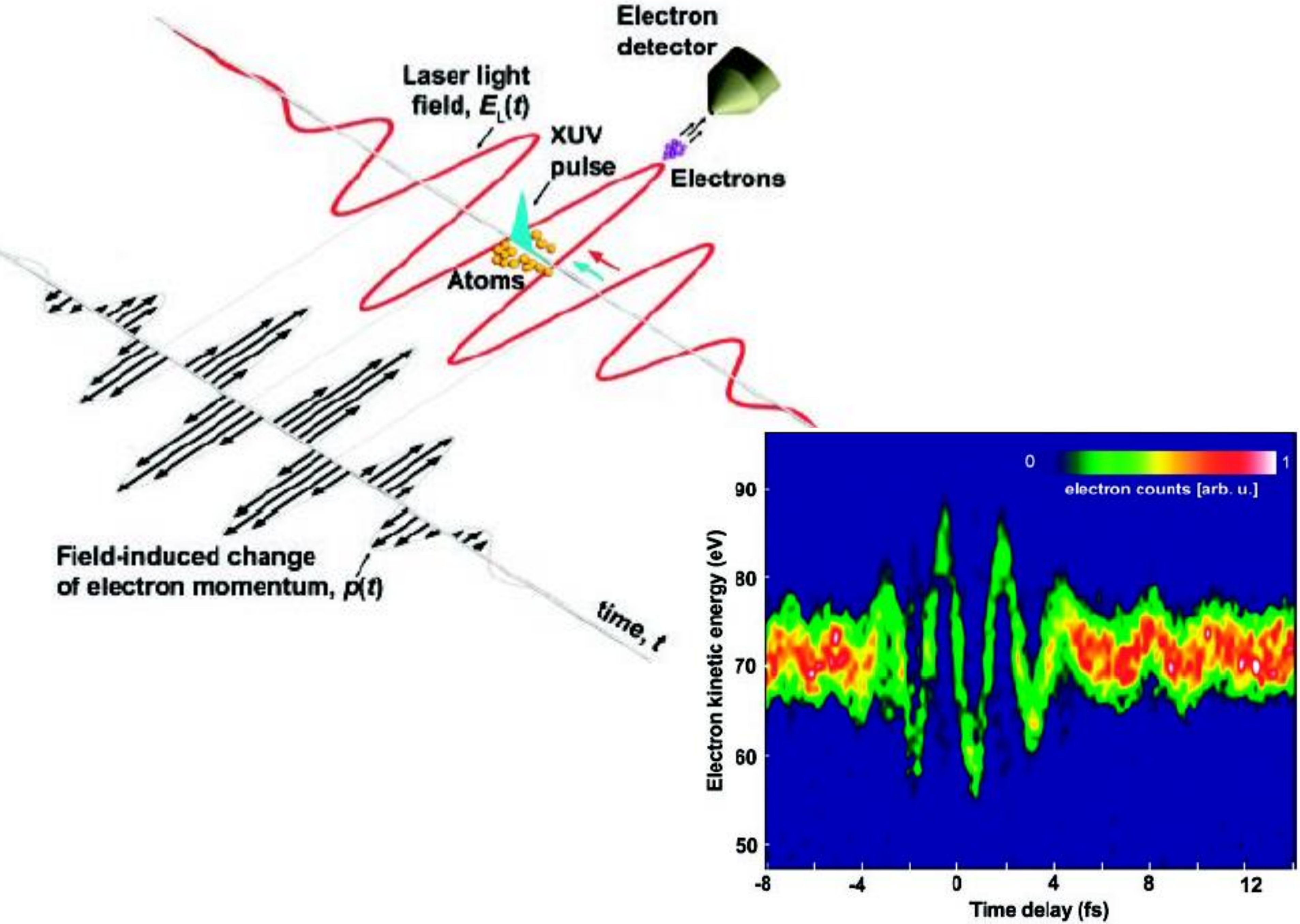


Figure 1. Schematic of the 60-beam Omega laser system showing the beam-lines and target chamber.

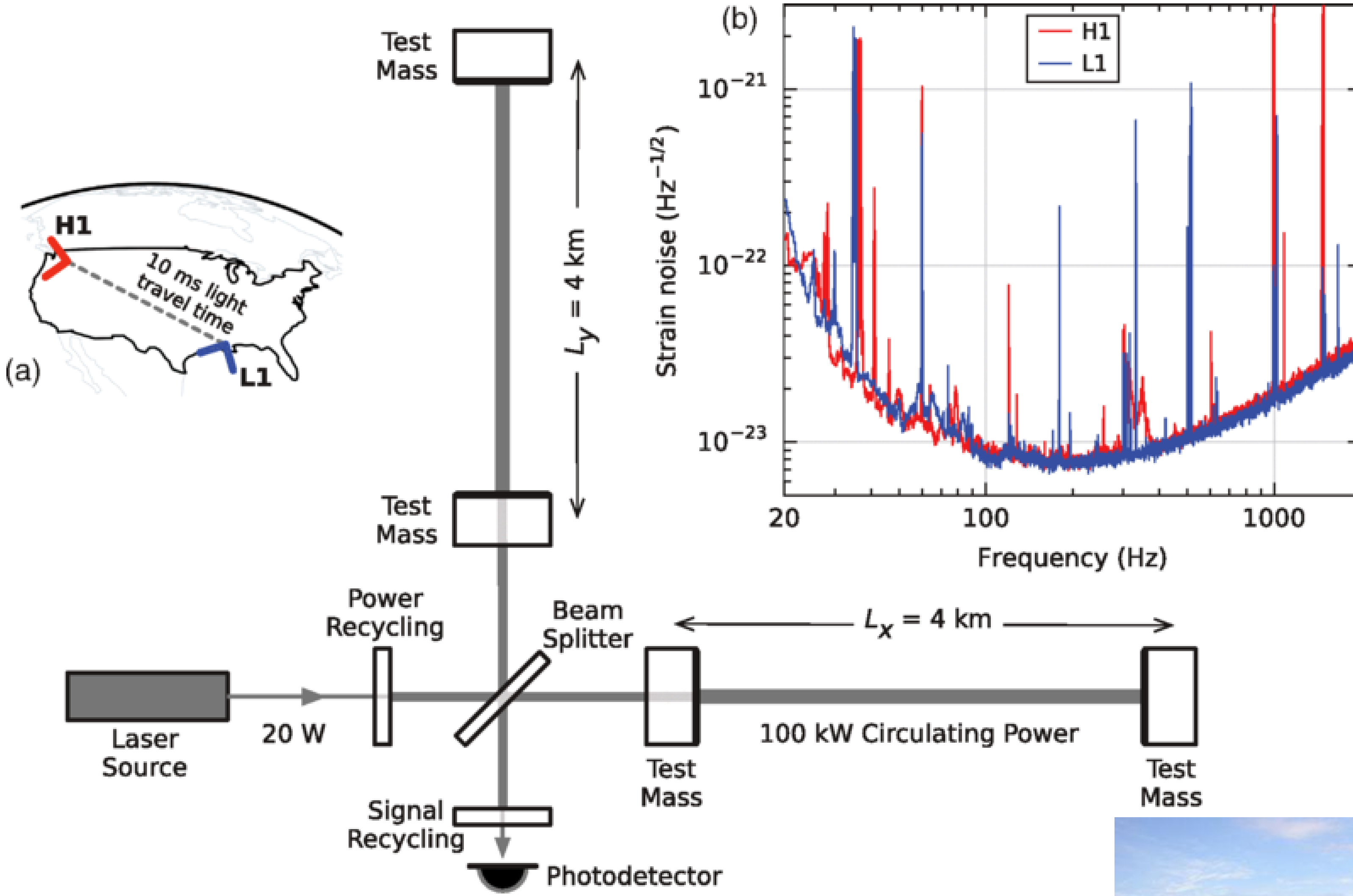
Target chamber - Vulcan (Oxford)





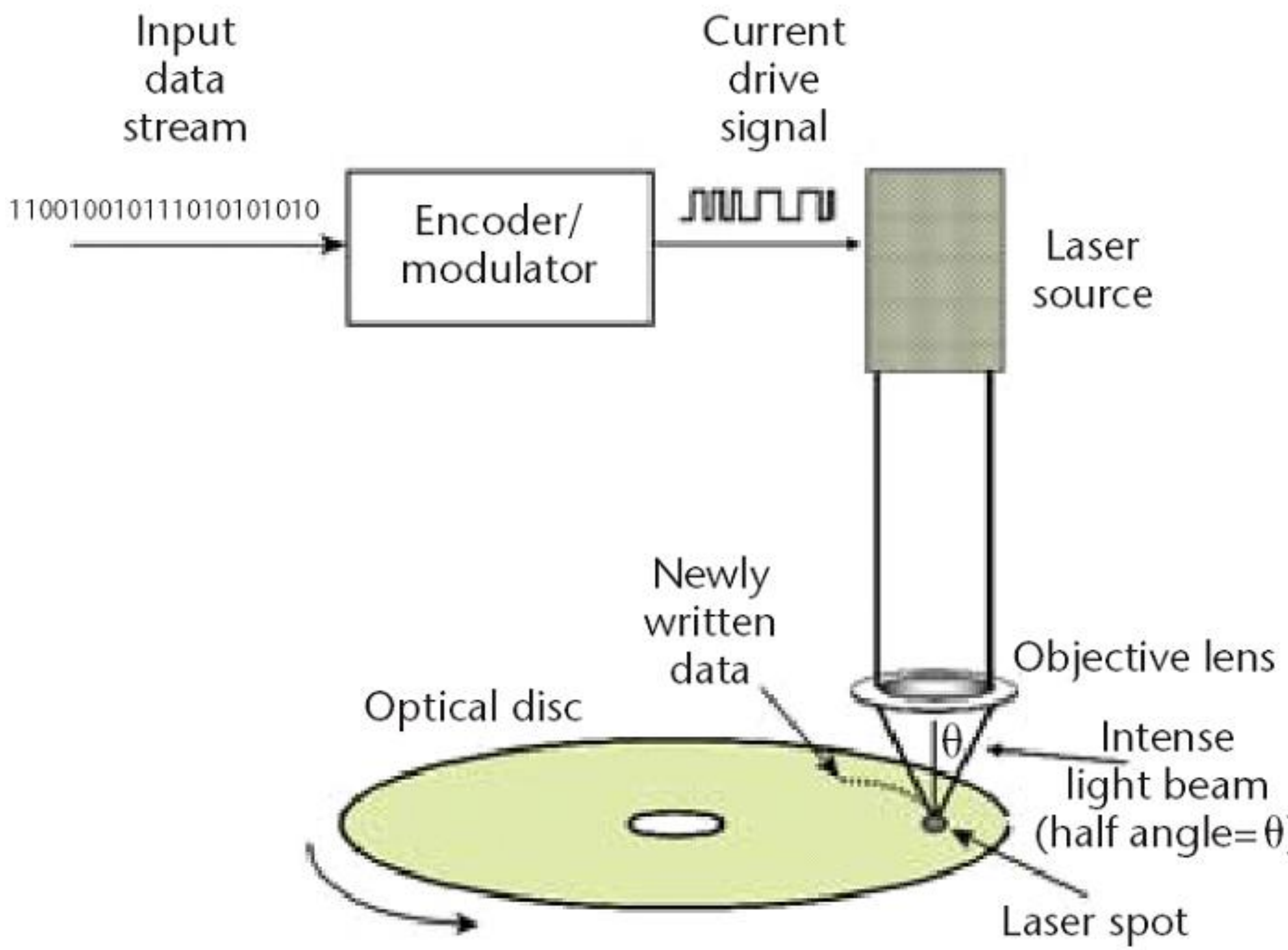


Electron detector
Laser light field, $E_L(t)$
XUV pulse
Electrons
Atoms
Field-induced change of electron momentum, $p(t)$
time, t
0
1
electron counts [arb. u.]
Electron kinetic energy (eV)
90
80
70
60
50
-8
-4
0
4
8
12
Time delay (fs)

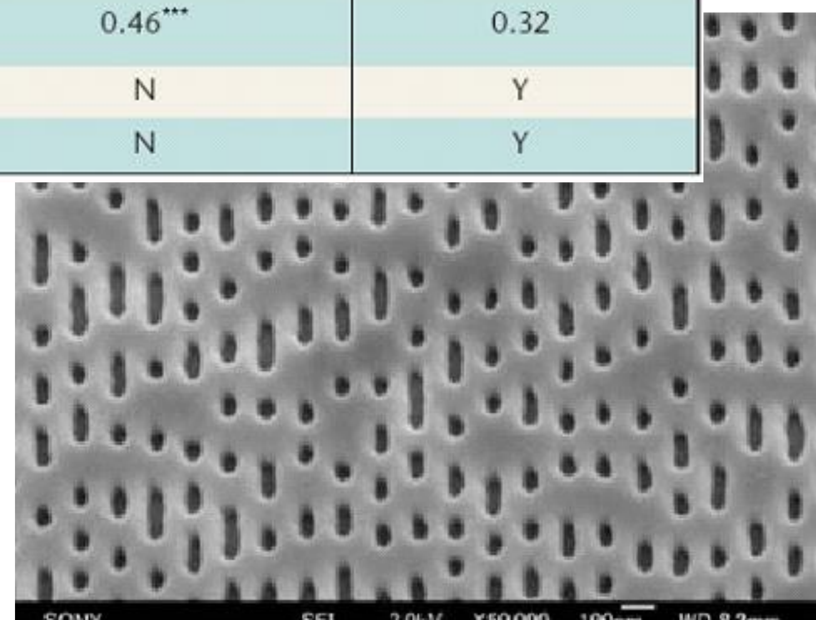

(a)
H1
L1
10 ms light travel time
(b)
H1
L1
Strain noise (Hz$^{-1/2}$)
10^{-21}
10^{-22}
10^{-23}
20
100
1000
Frequency (Hz)
Test Mass
Test Mass
L_y = 4 km
Power Recycling
Beam Splitter
L_x = 4 km
Laser Source
20 W
100 kW Circulating Power
Test Mass
Test Mass
Signal Recycling
Photodetector

Engineering applications

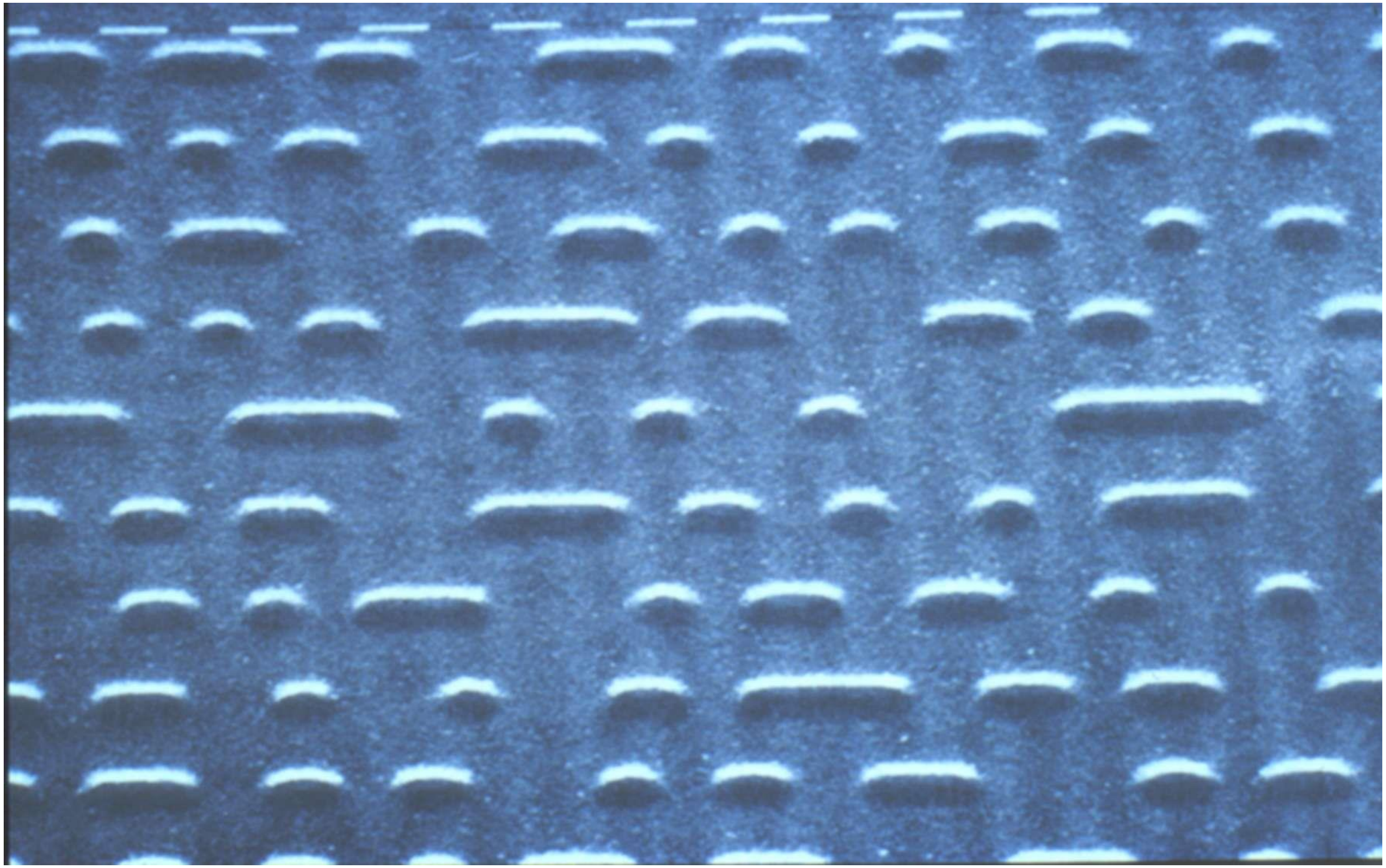
- Machining, cutting, welding – materials processing
  - Small structures
- Sensors
  - Remote sensing
  - Seismic monitoring
- Displays
  - Reprographics
  - HUD/VR systems
  - Projection TV
  - Holography
- Data handling
  - Data storage:
    - CD, CR/R, CD/RW, DVD, etc
  - Data processing – optical computing
  - Optical communications – next topic


Input
data
stream
11001001011101010101
Encoder/
modulator
Current
drive
signal
Laser
source
Newly
written
data
Objective lens
Optical disc
θ
Intense
light beam
(half angle=θ)
Laser spot

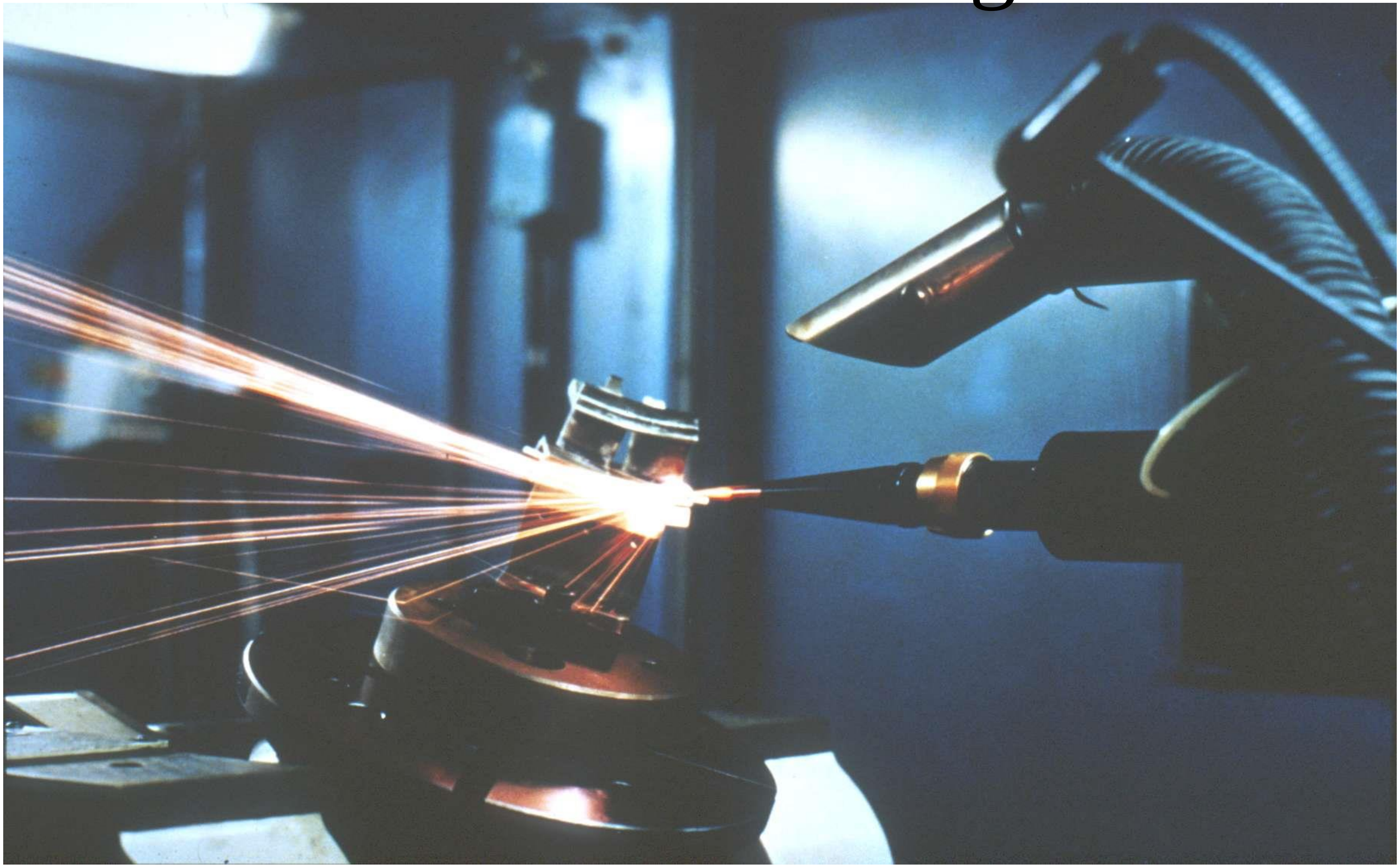
Parameter	CD	DVD	HD-DVD	Blu-Ray (BD)
Laser wavelength (λ in nm)	infrared (780)	red (650)	blue (405)	blue (405)
Objective lens numerical aperture (NA)	0.45-0.5	0.60-0.65	0.65	0.85
Spot size s (μm)	1.6	1.1	0.62	0.48
User data capacity (GB)	0.68	4.7 one side 9 both sides (same for recordable)	recordable: 20 one side 49 both sides read only: 15 one side 30 both sides	23-27 one side 50 in two-layer version
Data rate (Mbps)	1.44	10	13*	36
Protective layer thickness (mm)	1.2	0.6	0.6	0.1
Free working distance (mm)	1.2	1.0	1.0	0.05-0.10
Channel bit length** (μm)	0.277	0.13	0.08***	0.047-0.053
Track-to-track spacing (μm)	1.6	0.74	0.46***	0.32
Cartridge	N	N	N	Y
Commercially Available	Y	Y	N	Y



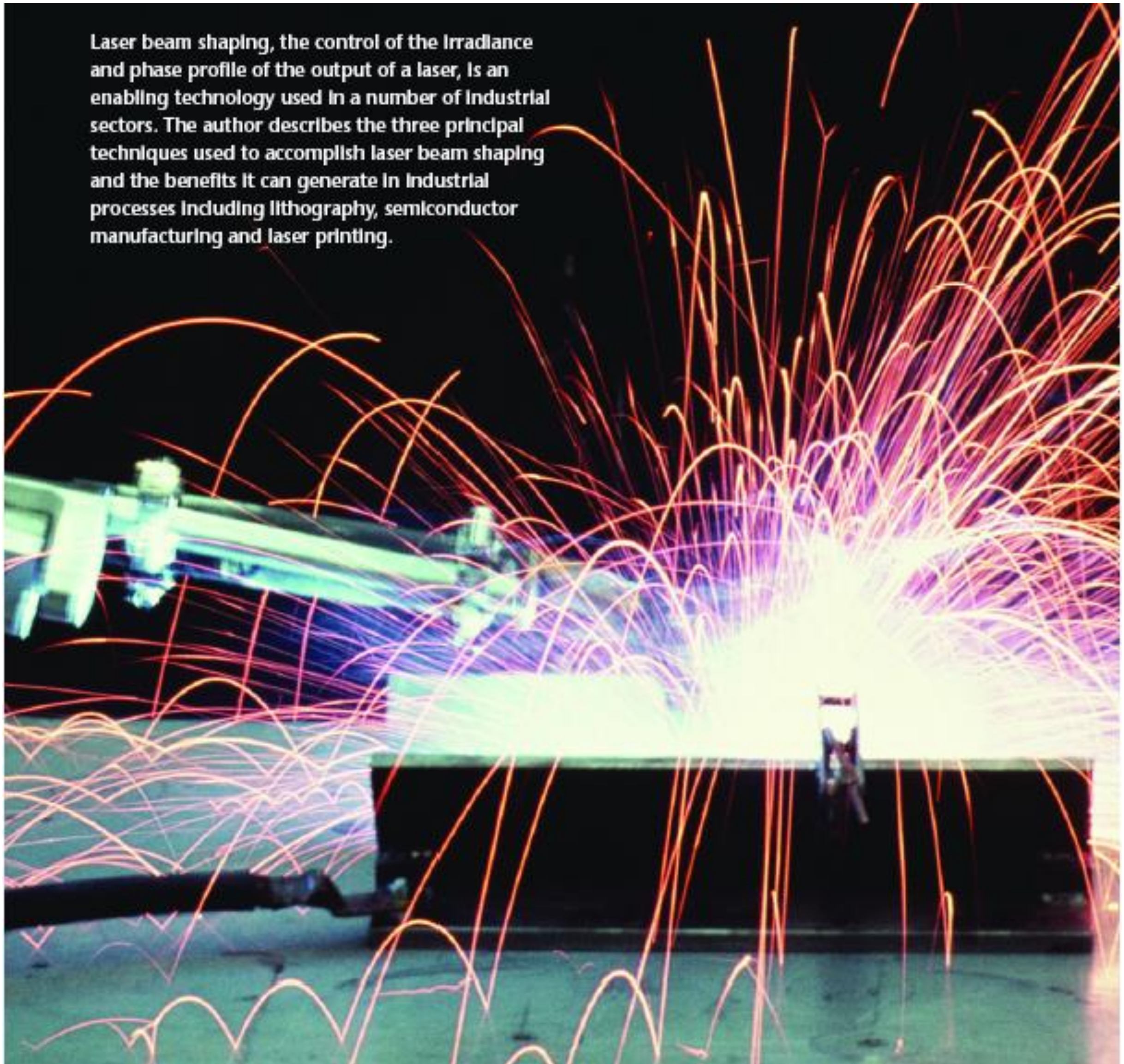
CD tracks



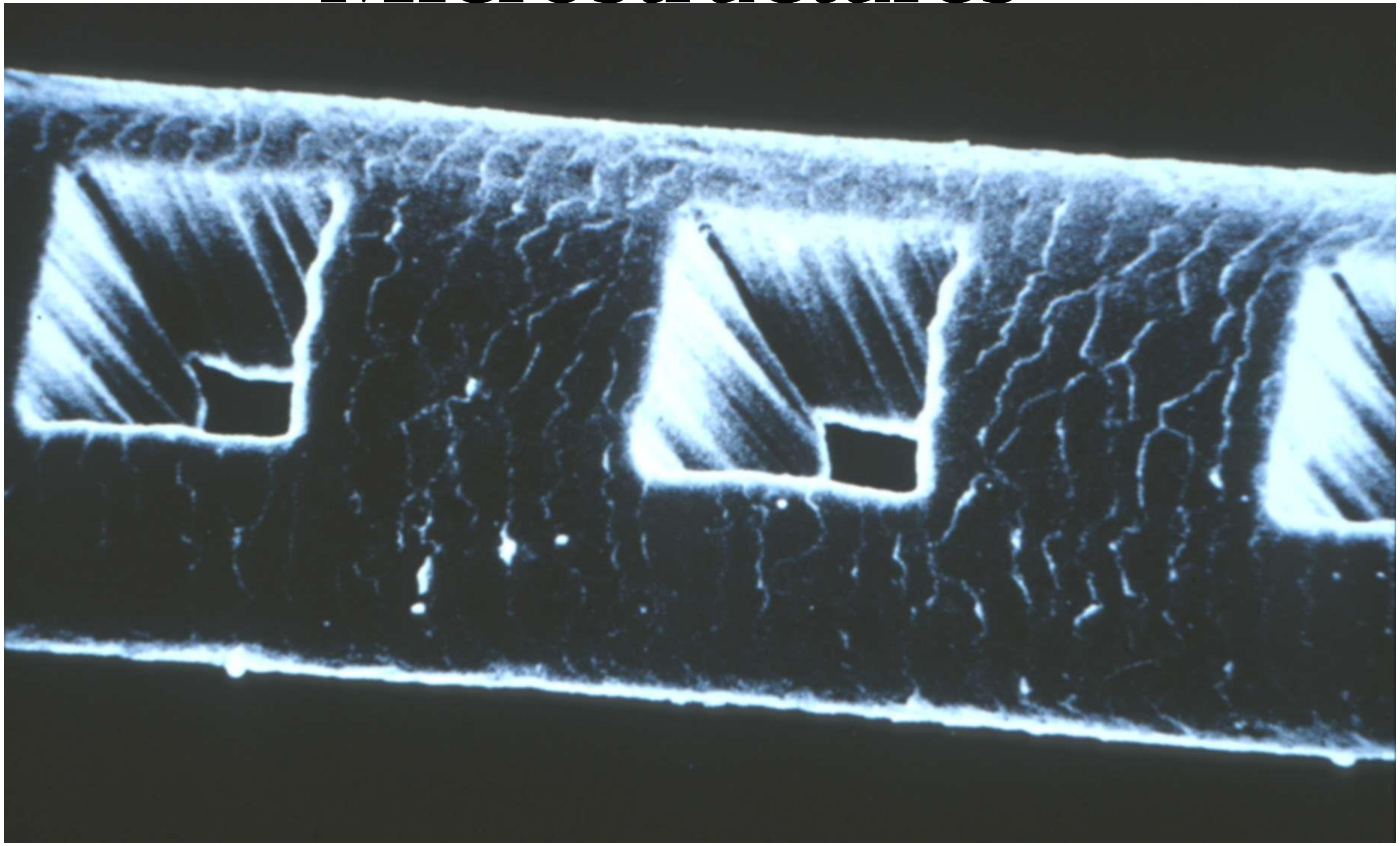
Laser machining



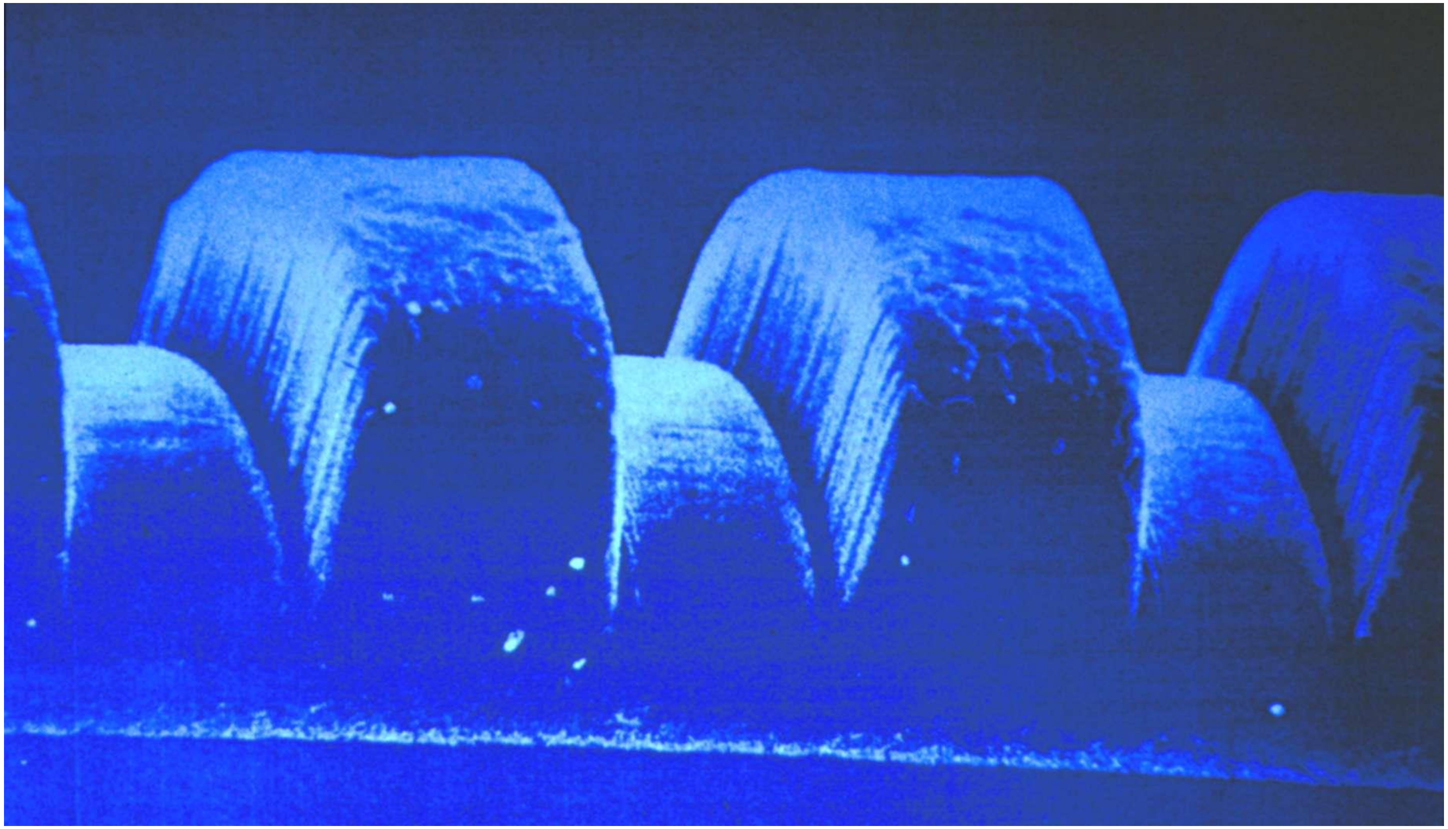
Laser beam shaping, the control of the irradiance and phase profile of the output of a laser, is an enabling technology used in a number of industrial sectors. The author describes the three principal techniques used to accomplish laser beam shaping and the benefits it can generate in industrial processes including lithography, semiconductor manufacturing and laser printing.

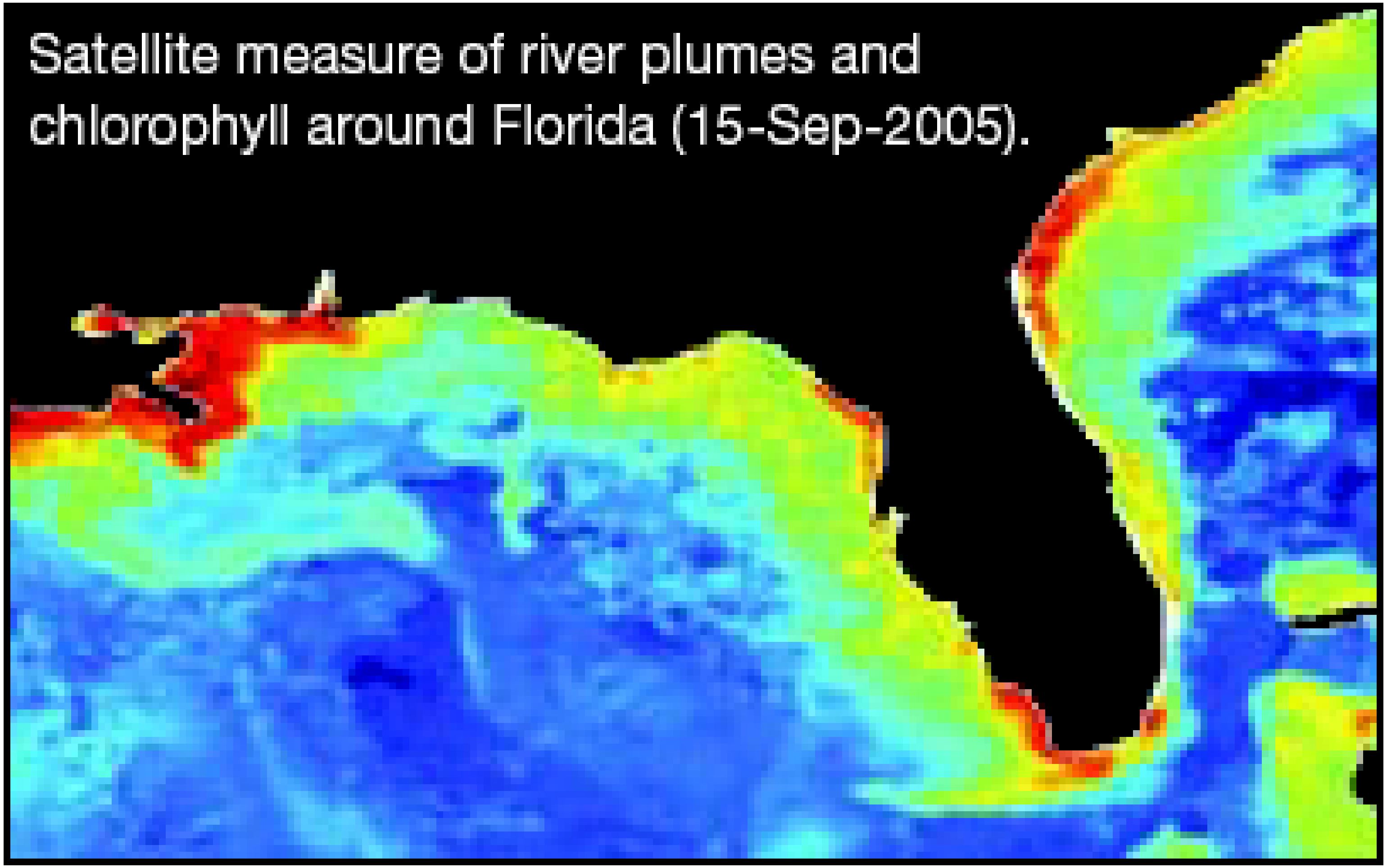


Microstructures



Microstructures




Satellite measure of river plumes and
chlorophyll around Florida (15-Sep-2005).

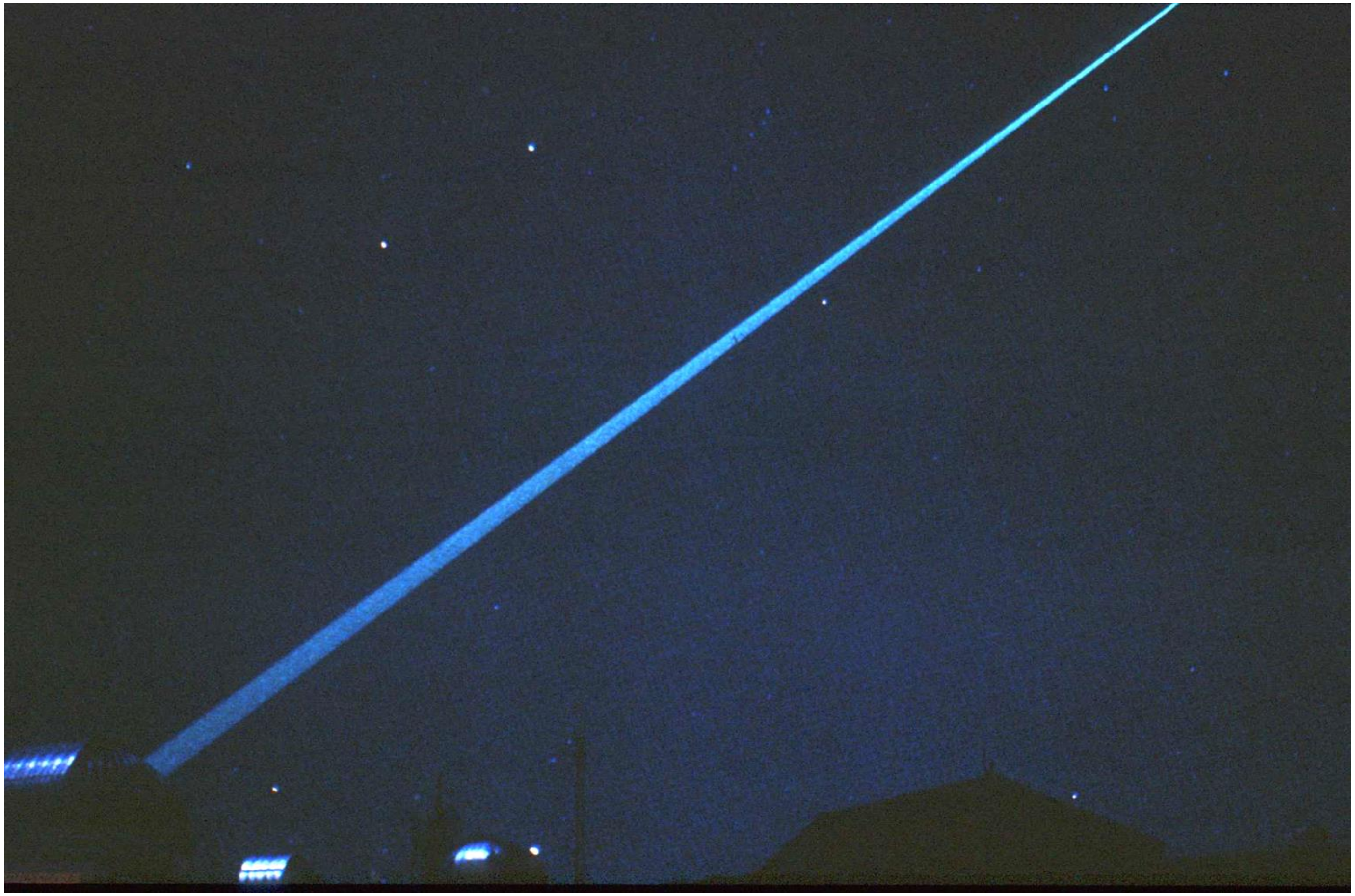
Much of current THz research revolves around spectral specificity and transmission properties. The THz frequency is more selective than X-rays and is therefore more sensitive to the nature of the materials it passes through. Here, a red pepper and a prawn are presented alongside their THz images. [Yuichi Oshima, RIKEN.]

Lasers and the Fine Art of Art Conservation

Daniel Dawes

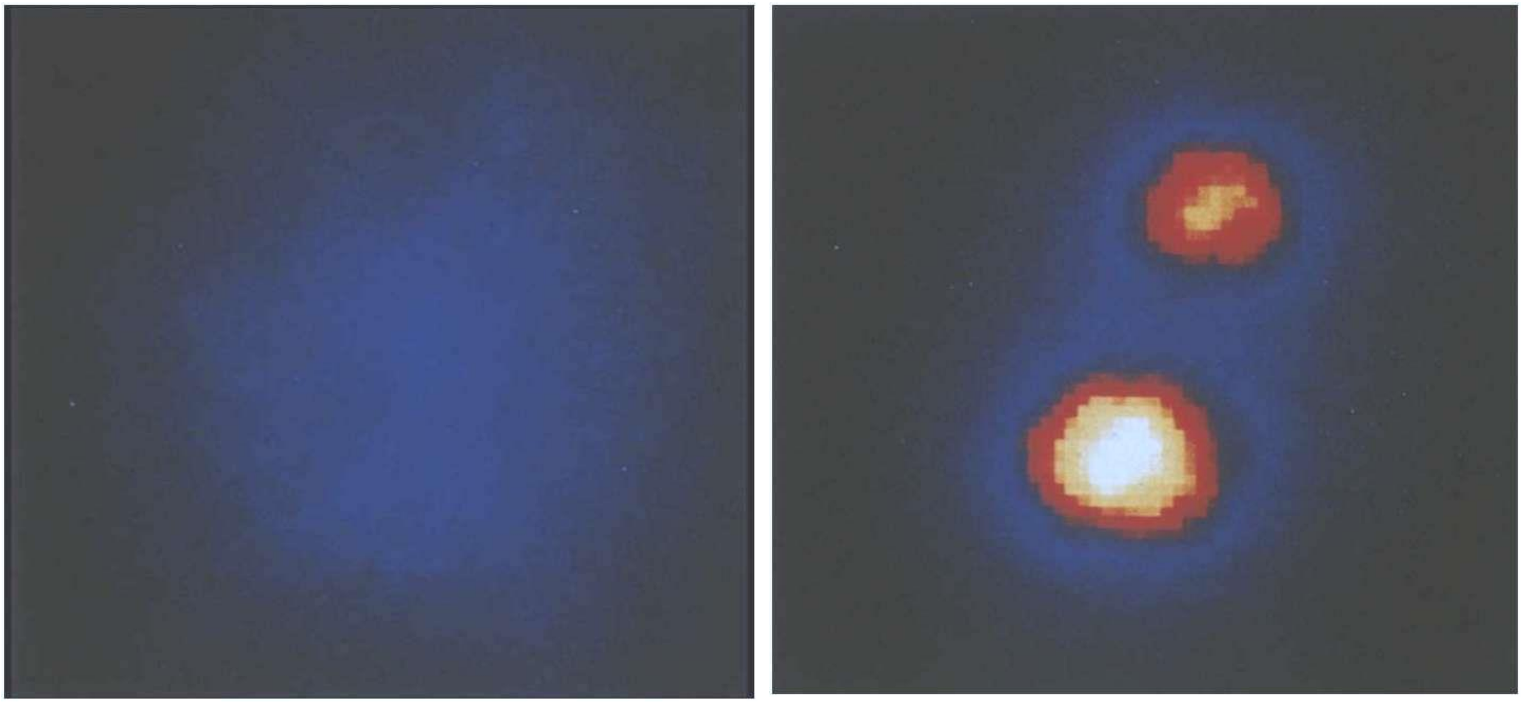
Most museums in the United States are not entrusting their priceless paintings and statues to laser cleaning, but as lasers become cheaper, safer and more precise, art conservators may find them hard to ignore as replacements for more traditional cleansing techniques.

Laser guide star adaptive optics



Laser guide star adaptive optics

Uncompensated ***With compensation***

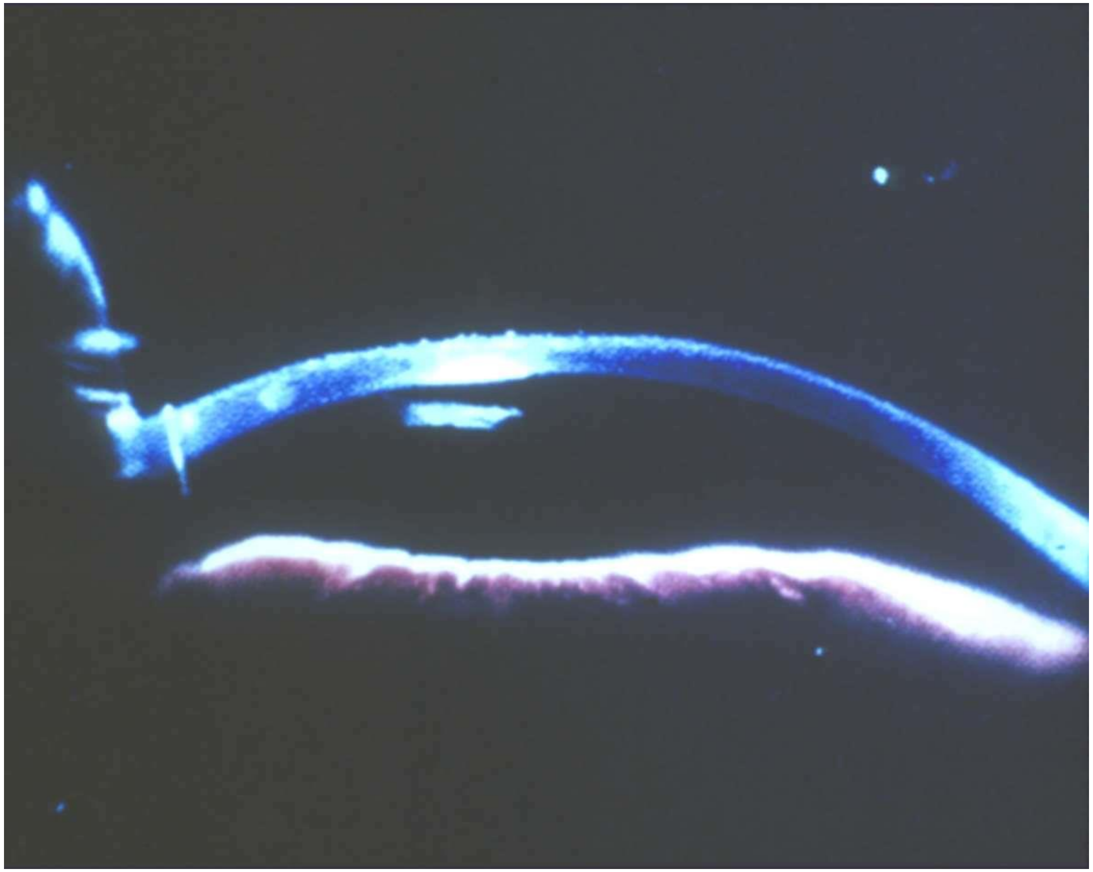


A distant double star system, 53 ξ Ursa Major, is viewed through a 1.5-m telescope at the Phillips Laboratory’s Starfire optical Range.

Medical applications

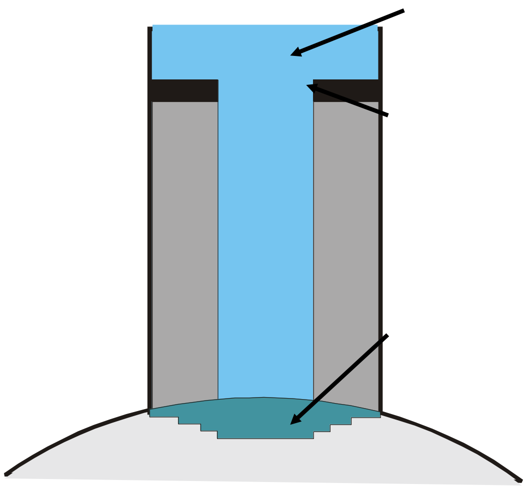
- Surgery – laser scalpels
- Retinal welding
- Corneal ablation
- Selective removal of birthmarks

Laser eye surgery

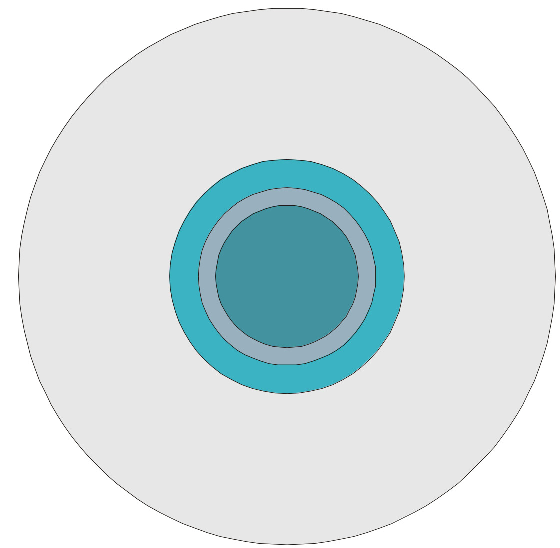


Laser eye surgery

Side view



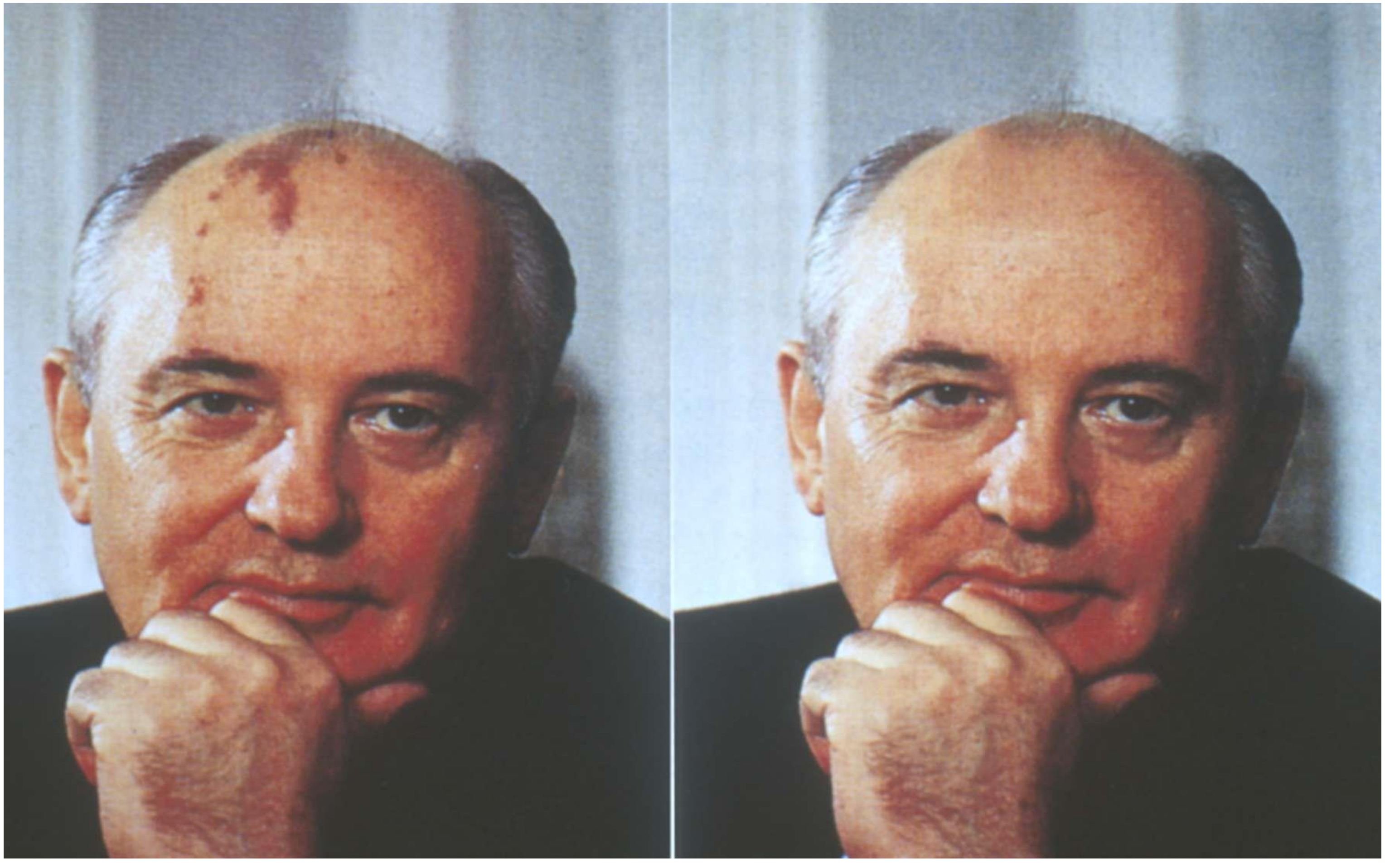
Face view



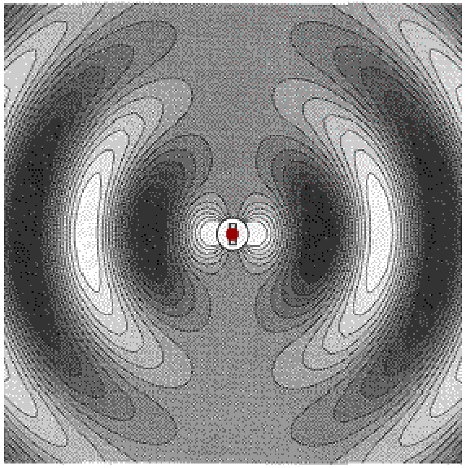
Concentric rings expand as the iris opens up to cover the entire area

Laser cosmetic surgery

Laser cosmetic surgery



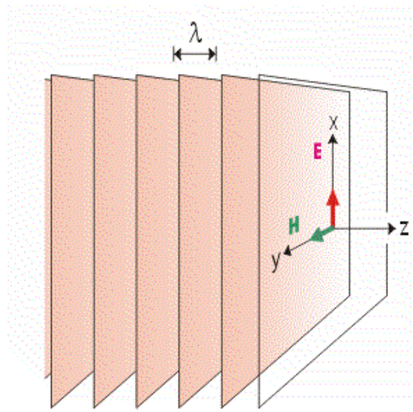
0.1 Electromagnetic Waves

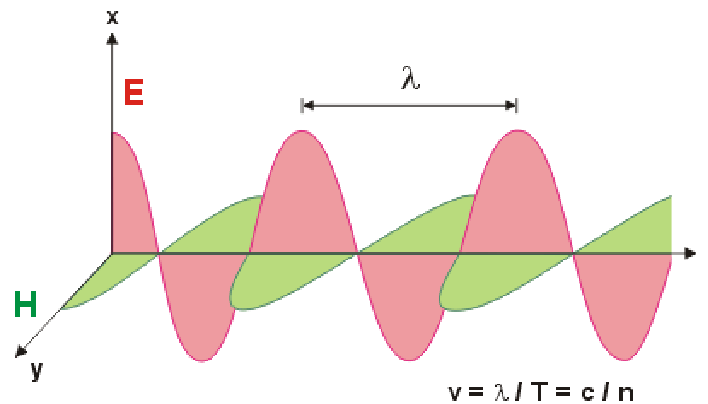


An oscillating electric charge creates oscillating variation of the electric (and also magnetic) field. The oscillations spread away as an electromagnetic wave propagating at the speed of light.

In a uniform dielectric medium with permittivity $\varepsilon = \varepsilon_r \varepsilon_0$ and permeability $\mu = \mu_0$, Maxwell's equations yield simple solutions for the vector fields of electric intensity E and magnetic intensity H.

$$\mathbf{E} = \mathbf{E}_0 \cos(\boldsymbol{\omega t} - \boldsymbol{\beta z})\, \mathbf{a}_x \quad \text{and} \quad \mathbf{H} = \mathbf{H}_0 \cos(\boldsymbol{\omega t} - \boldsymbol{\beta z})\, \mathbf{a}_y$$

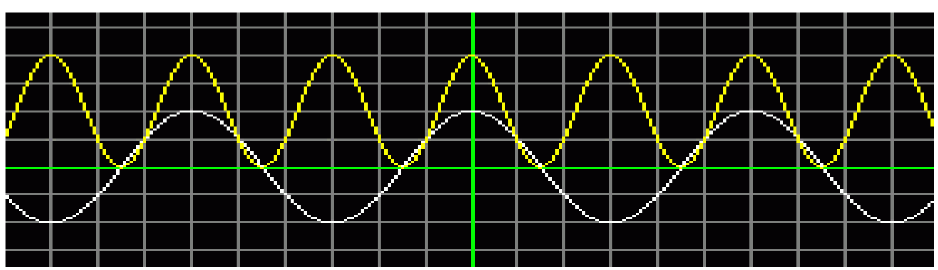




These two equations represent plane wavefronts (x-y plane) moving in the z direction with speed $v = \omega/\beta = 1/\mathrm{sqrt}\,(\mu_e) = c/n$, where c is the speed of light in free space and $n = \mathrm{sqrt}\,(\varepsilon_r)$ is the refractive index of the dielectric medium. There is sinusoidal variation of magnitude of the E and H vector fields which are aligned at the right angles to each other, and the direction of propagation.

Power Intensity

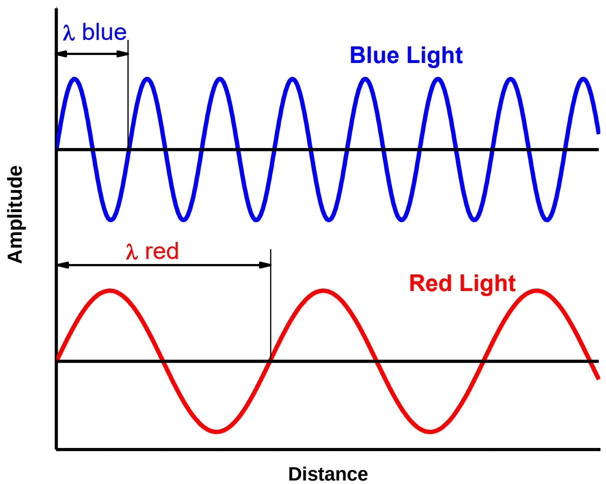
$I = (1/2)\, c\, \varepsilon\, E_0^2$



Electric field E

1.1 Monochromaticity

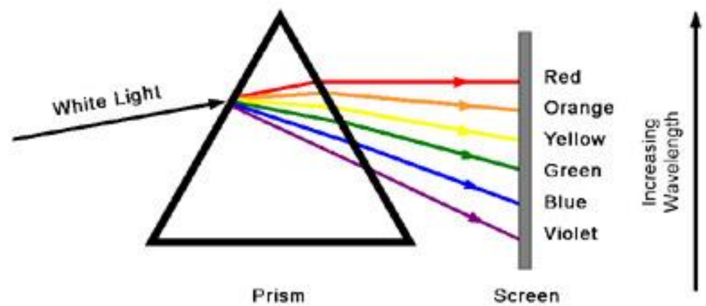
The light emitted by lasers is different from that produced by more common light sources such as incandescent bulbs, fluorescent lamps, and high-intensity arc lamps. An understanding of the unique properties of laser light may be achieved by contrasting it with the light produced by other, less unique sources.

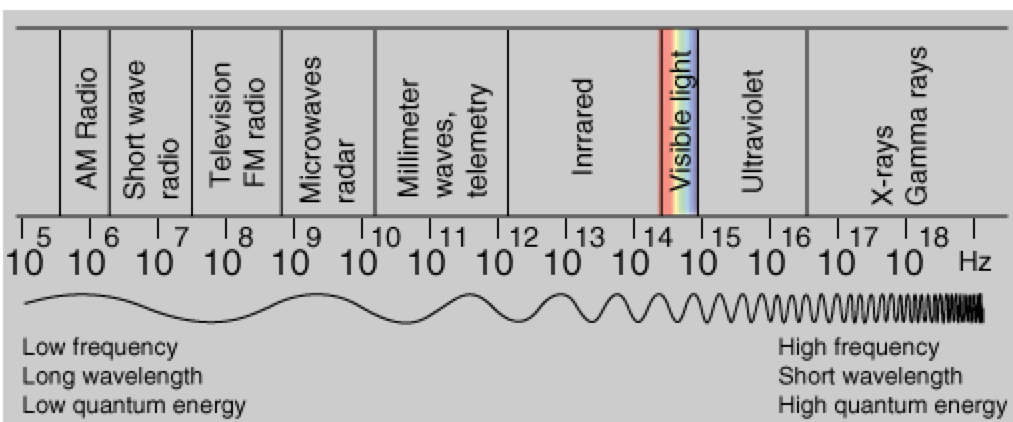


Comparison of the wavelengths of red and blue light

All light consists of waves traveling through space. The color of the light is determined by the length of those waves, as illustrated in Figure.

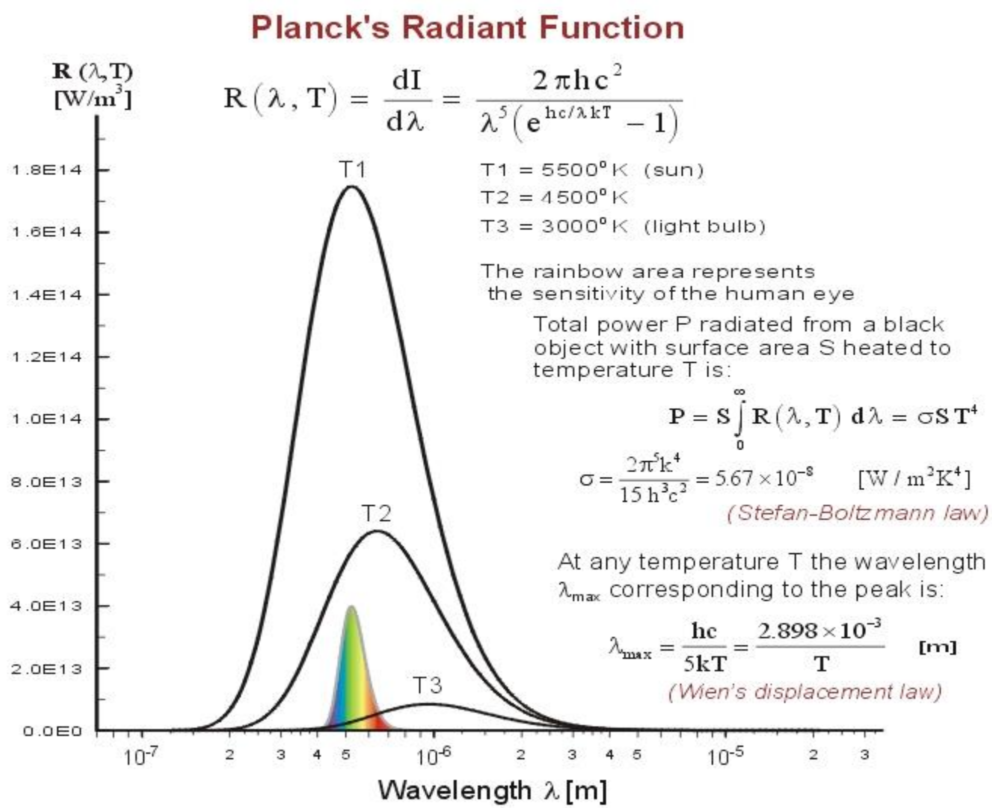
Wavelength is the distance over which the wave repeats itself and is represented by the Greek letter λ (lambda). Each color of visible light has its own characteristic wavelength.



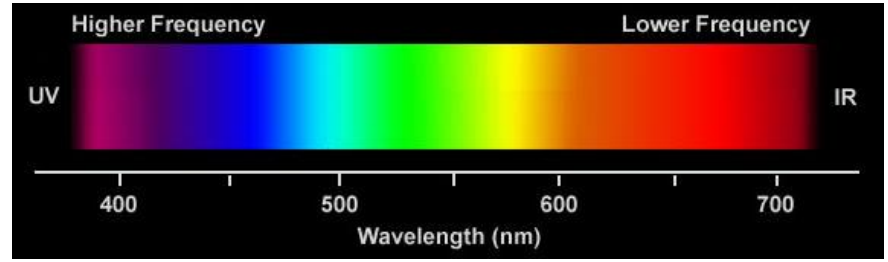


The Electromagnetic Spectrum

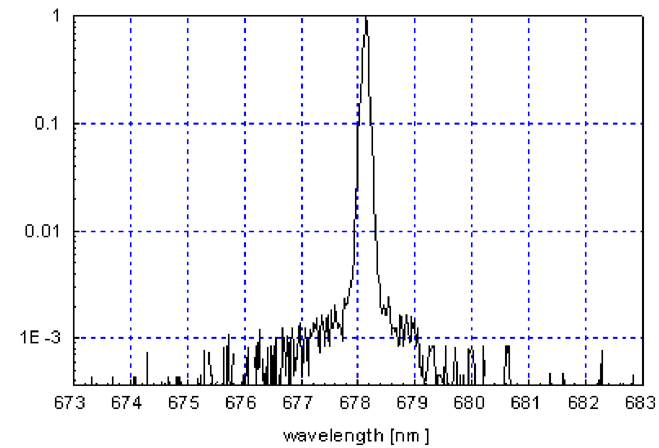
Monochromaticity



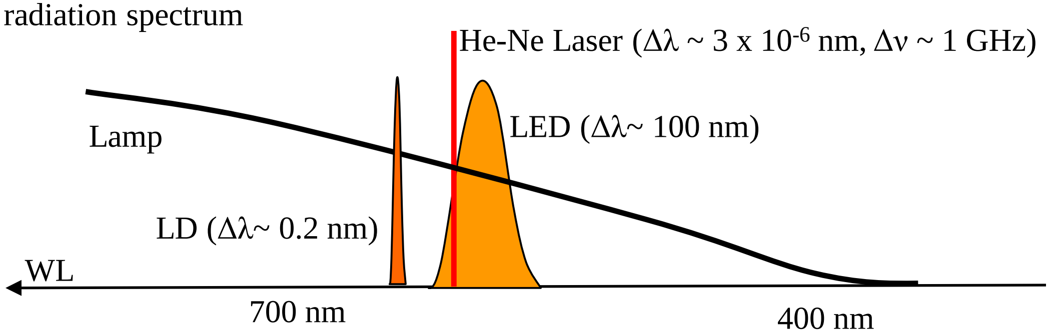
Black body radiation spectrum



Visible part of the spectrum



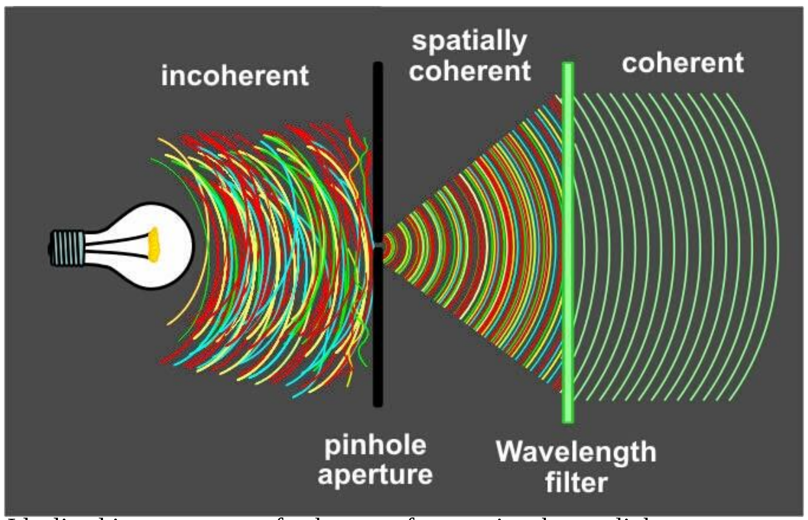
The spectrum of a typical laser diode



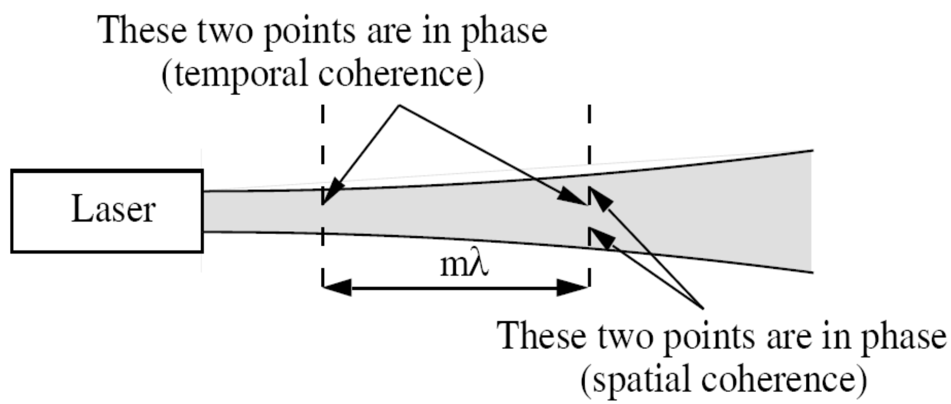
The beam of a helium-neon gas laser is a very pure red color (~ 632.8 nm). It consists of an extremely narrow range of wavelengths within the red portion of the spectrum. It is said to be nearly ”monochromatic”, or nearly "single-colored“. Near-monochromaticity is a unique property of laser light, meaning that it consists of light of almost a single wavelength.

Spatial coherence

Spatial coherence is determined by the coherence width $W_c = k\,(\lambda/D)\,R$,
where k is a constant dependent on the shape of the source (for a circular source k = 1.22), D is the approximate diameter of the source and R is the distance from the source. Coherence width is the distance along the wavefront (perpendicular to the direction of propagation), within which the amplitude and phase of the wave can be considered well defined and therefore predictable. An ideal light source would be a point (D = 0) generating ideal spherical wavefronts. An ideal point source would have infinite coherence width.



Idealized improvement of coherence from an incoherent light source



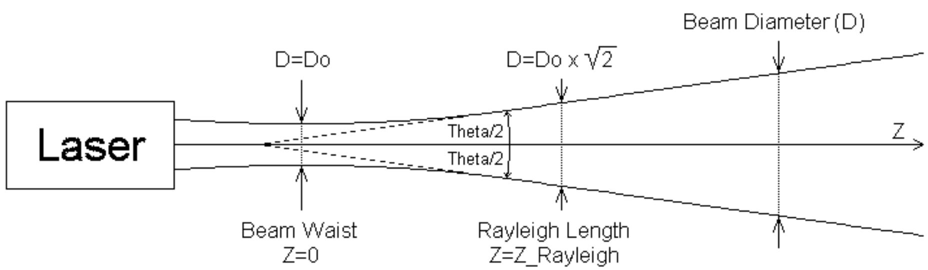
Temporal and spatial coherence for laser beam

1.3 Spatial and spectral brightness

	Light Bulb (100 W)	**The Sun**	**He-Ne Laser**
Full power	1 W (1 % efficiency)	1.9×10^{26} W	1 mW (1 mm beam diam)
Number of photons/sec per m²	6×10^{16} At a distance of 2 m	2×10^{21}	9×10^{20}
Intensity of light	0.02 W/m² At a distance of 2 m	700 W/m²	300 W/m²

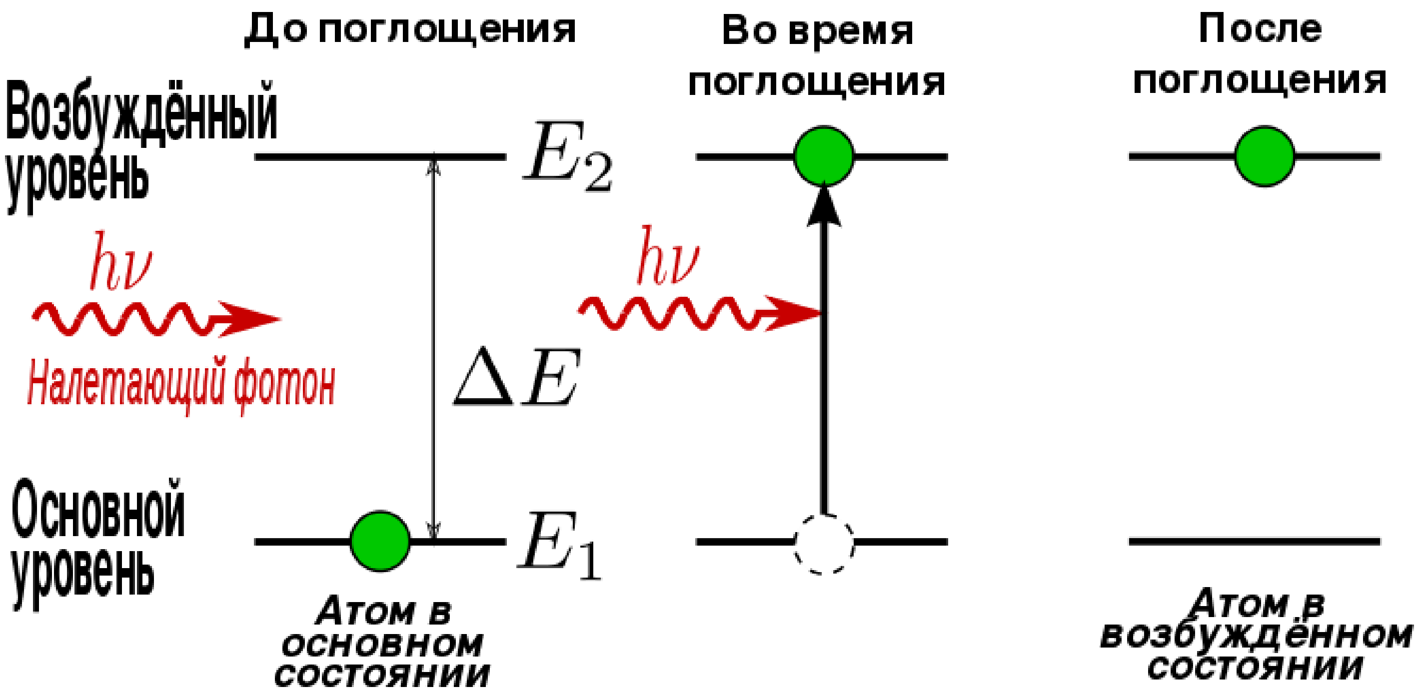
We note that the sun is twice as bright as a typical He-Ne laser, and 35,000 times brighter than a 100 W light bulb at 2m distance.

The intensity of the HeNe is about half that of the Sun, but the energy density per unit frequency, $\rho(\omega)$, is of order 10^7 larger. This high energy density per unit frequency is one of the distinguishing marks of a system that is producing light by stimulated rather than spontaneous emission, and is rarely found in anything other than laser systems.

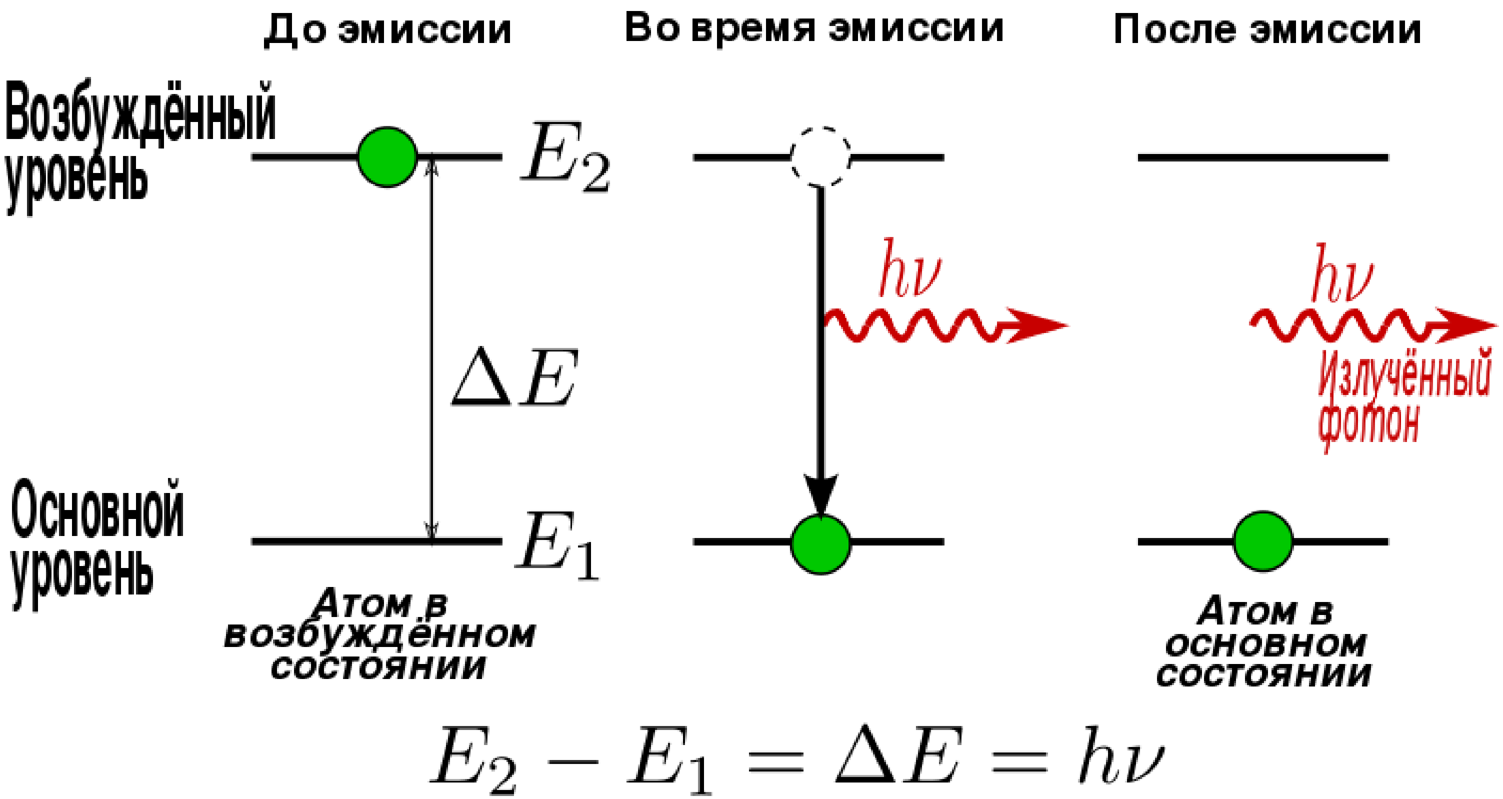


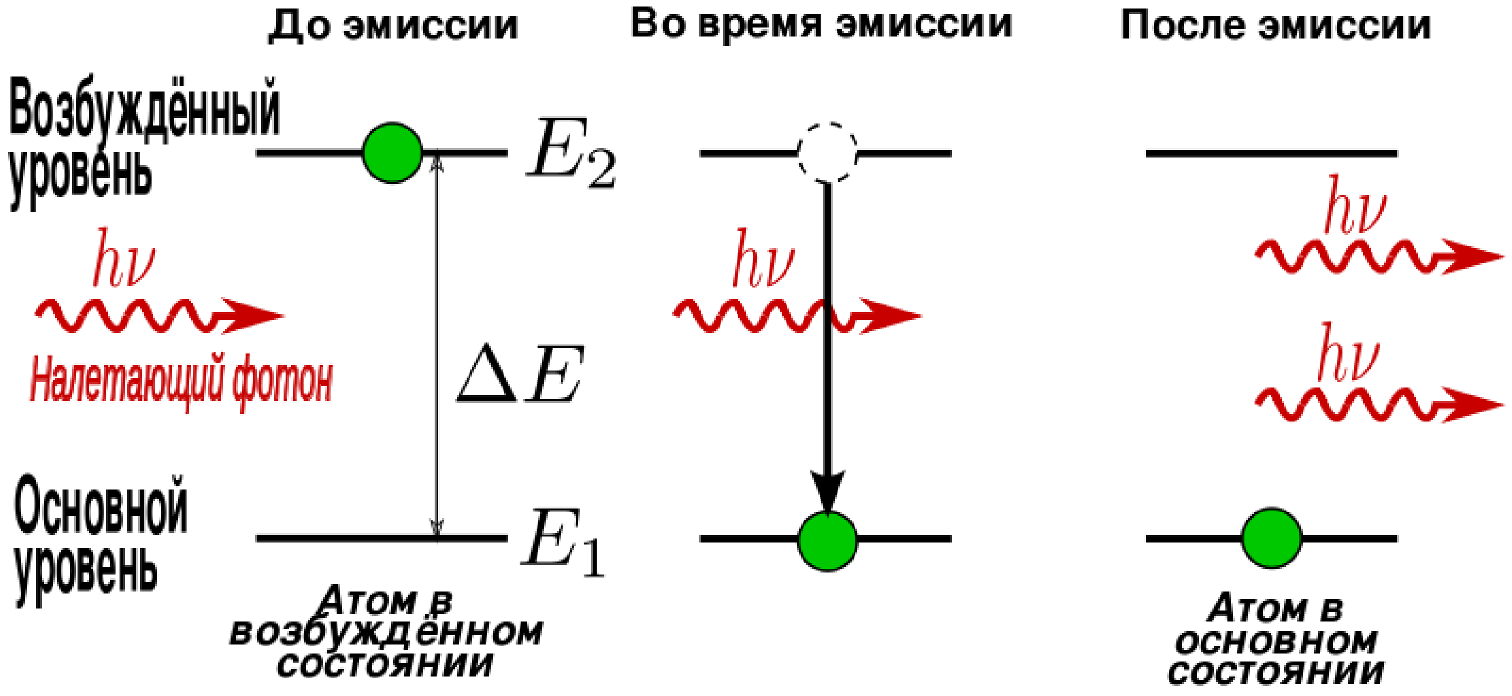
Divergence, Beam Waist, Rayleigh Length

$$\text{Brightness} = \frac{\text{Power [W]}}{\text{Beam Diameter [mm]} \times \text{Beam Divergence [mRad]}}$$



$$E_2 - E_1 = \Delta E = h\nu$$


До эмиссии
Во время эмиссии
После эмиссии
Возбуждённый уровень
Основной уровень
E_2
E_1
ΔE
$h\nu$
$h\nu$
Излучённый фотон
Атом в возбуждённом состоянии
Атом в основном состоянии
$E_2 - E_1 = \Delta E = h\nu$



$$E_2 - E_1 = \Delta E = h\nu$$