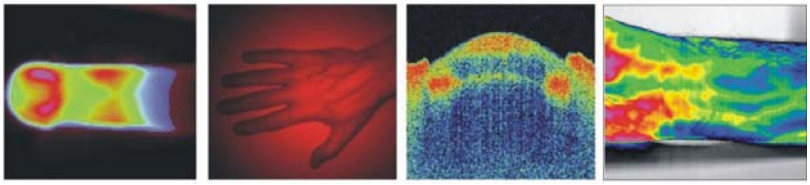
Applied Optoelectronics in Medicine

Aplikovaná optoelektronika v lékařství

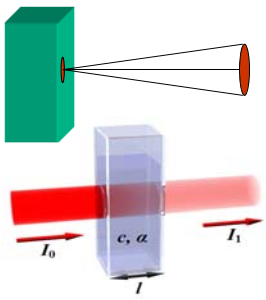
Interdisciplinary course at the CTU Prague (P317APL-E, W, 4 credits)



2. Light and life - ecological and biophysical aspects
2. Světlo a život – ekologické a biofyzikální aspekty

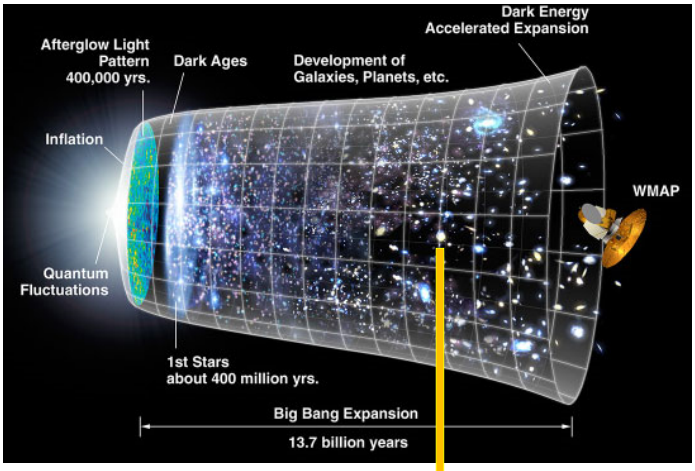
Learning aims of the second AOM lecture

- Cosmic timeline, the earth in optical radiation field of the sun
- Energetic drive of the earth
- Basic radiation laws
- What is light?



The age of universe: The Big bang theory

As the founder of the theory is the theologian and physicist Georges Lemaître, who in 1931 called for the initial state of the universe, the term "primordial atom" (Uratom) used. The term Big Bang was coined by Sir Fred Hoyle



Georges H.J.E. LEMAITRE
(1894 – 1966)

Age of our Earth: 4.600 Millions of years

"The Universe in One Year" was inspired by Carl Sagan. He was the first person to explain the history of the universe in one year-as a "Cosmic Calendar"

Imagine that the entire history of the universe is compressed into one year - with the Big Bang corresponding to the first second of the New Year's Day, and the present time to the last second of December 31st (midnight).
Using this scale of time, each month would equal a little over a billion years.

Formation of the Earth: Sept. 14
Origin of life on Earth: Sept. 25
First humans on Earth: Dec. 31
1:30 p.m.

Carl SAGAN
(1934 – 1996)

To the Earth dwellers origin: before first men and first women

"If we compare the Earth life to a human life, then the Earth, 4.600 million years old, could be seen as a 46 year old man …

Retarded child .....
About first 7 years we know actually nothing .....
About next 35 years only fragmentary information exists .....
First, the Earth from 42 year of life began to flourish .....
Dinosaurs vanished before 45 year of the Earth life .....
Mammals entered first on the Earth before 8 months .....

In the middle of the last week monkeys like man and then men like monkeys were evolving .....

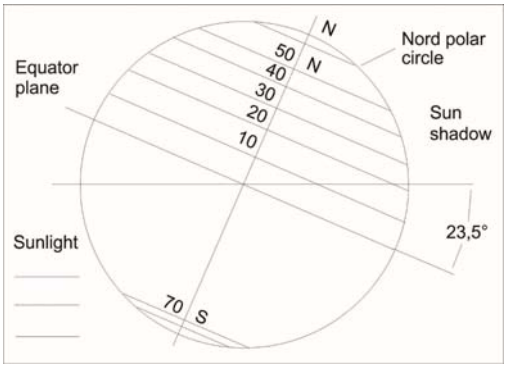
Last weekend the Earth was enveloped by the last Ice Age .....
Present people exists about 4 hours .....
Last hour man invented agriculture .....
The industrial revolution began just 1 minute ago ....."

www. greenpeace.at

Our solar system and the planet earth

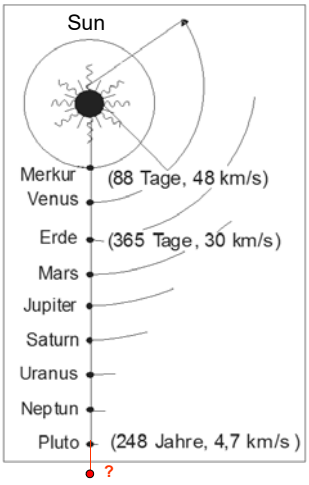
"E pur si muove ..." G. Galilei (1564 - 1642)

Constellation of the earth at winter solstice



The best way to approximate the Planet Earth geometrically is to look at a rotation ellipsoid with flat poles, which real shape differs with 80 m from the ideal shape.
This does not include the different mountains.

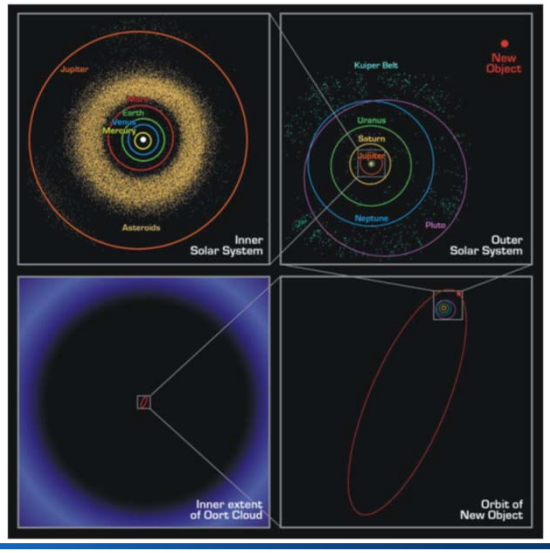
Our solar system



Mysterious planetoid

2003 VB 12 (SEDNA)

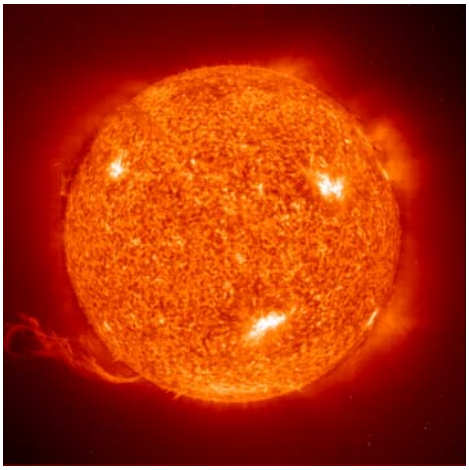
Self rotation: 40 days
Diameter: ca 1.600 km
Surface temperature: ca. -240 °C



Sun as radiation source for the earth

Macrophysics

Mass	:	2.10^{30} kg (98% of the whole mass of the solar system)
Diameter	:	1.390.000 km
Mean density	:	1,3 g/cm^3
Density in the centre:		160 g/cm^3



Nuclear physics

Temperature	: 5.800 K (surface)
Centre of the sun	: 35% H, 63% He, 2% rest
Nuclear fusion	: 700.000.000 t (H) in 695.000.000 t (He)
Energy production	: 5.000.000 t/s
Age	: ca 4.7 billion years

„Completed service life“: ca 5 billion years

Solar energy of the earth, earth's energetic drive, solar constant

The Sun's whole radiated power P_S is 3,9 ·10^{26} W, the Sun emittance S_S on the surface is (assuming isotropic emission):

$$S_S = \frac{P_S}{4\pi r_S^2} = 1.58 \cdot 10^7 \frac{W}{m^2}$$

The Sun radiation part before the access into the Earth's atmosphere (extraterrestial solar constant) is (assuming a mean distance between Sun and Earth of 150 Million km):

$$S_E = \frac{P_S}{4\pi d_{S-E}^2} = 1.38 \cdot 10^3 \frac{W}{m^2} \approx 2 \frac{cal}{cm^2 \cdot \min}$$

Numerical aperture of the Earth's illumination: N.A.= n_o . sin α = 0,004

In direction of the Earth the Sun radiates with the power (Earth's energetic drive):

$$P_E = S_E \cdot A_{proj} = 1.78 \cdot 10^{17} W$$

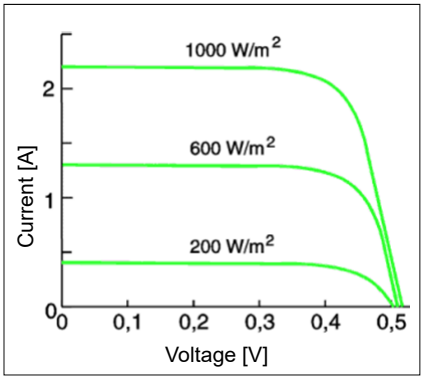
The mean transmission factor of the Earth's atmosphere is about 54% (ca. 34% are reflected and scattered ("Albedo") and ca. 12% absorbed (Energy consumption for movement of air mass and hating of the gas mantle)). Assuming these parameters and vertical solarisation the power density on the Earth's surface is about

745 W/m².

Solar energy of the earth, earth's energetic drive, solar constant

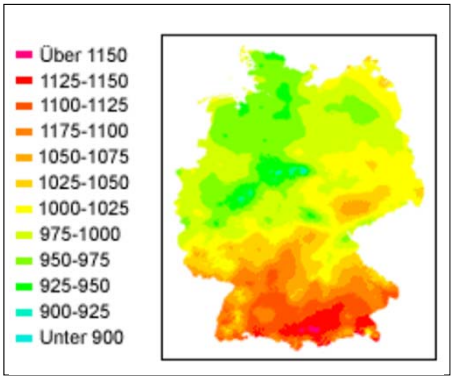
Practical solar power calculation:

Electrical current – voltage characteristic of the Si-Solarpanel (A=10x10cm=100cm²)



10 W/m²

Global radiation - average per Year (1981-2000) in kWh/m²

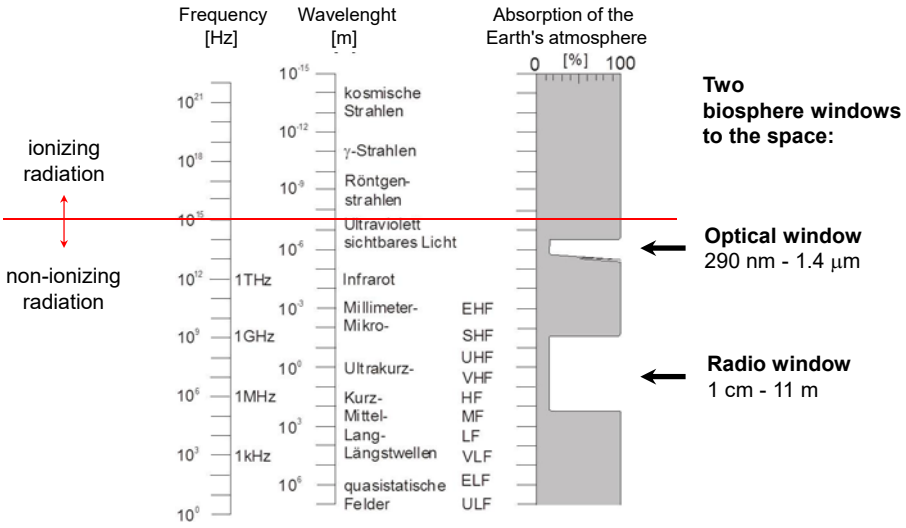


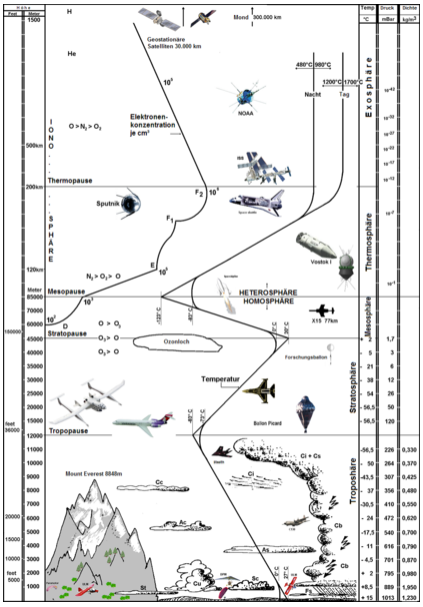
114 W/m²

Solar energy of the Earth, Earth´s energetic drive, solar constant:

Proposal for 5 GW solar power satellite station
(Prof. Brand, Univ. of Erlangen)

Frequency range of the electromagnetic spectrum





Kennelly-Heaviside layer

(also known as the E layer), is one layer of the Ionosphere.
The E layer is the middle layer, 90 km to 120 km above the surface of the Earth.
It reflects short-radiowaves and such, plays an important role in radiowave propagation.

Ozon layer

is a layer in Earth's atmosphere from about 10 to 50 kilometers, which contains high concentration of ozone (O3). This layer absorbs 97–99% of the Sun's high frequency ultraviolet light.
The ozone layer was discovered in 1913 by the French physicists Charles Fabry and Henri Buisson.

Oliver HEAVISIDE
(1850 - 1925)
British physicist

Arthur Edwin KENNELLY
(1861 - 1939)
American electrical engineer

Charles FABRY (1867 - 1945)
and
Henri BUISSON (1873 - 1944)
Both french Physicists

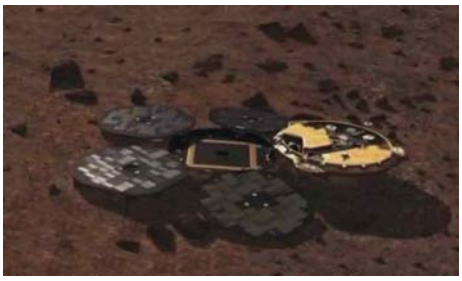
Source:
American Institute of Physics

Example “Radio window”

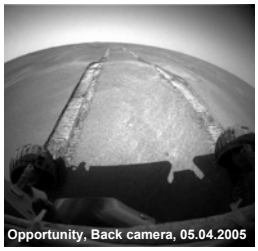
NASA PATHFINDER MISSION
Start 04.12.1996, landing 04.07.1997

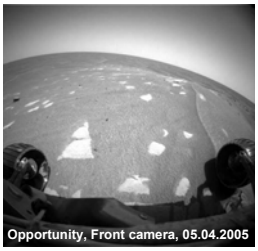
Next Mars-Missions:

- ESA MARS EXPRESS
  Start: June 2003
  Landing: December 2003
  Rover: Beagle 2



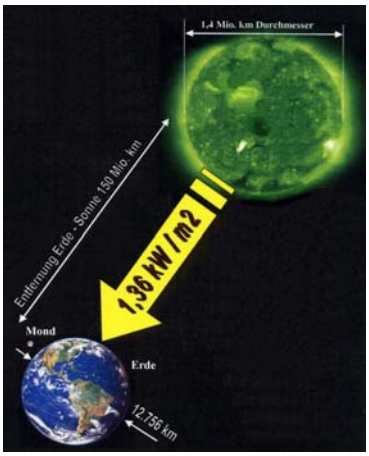
- NASA MARS EXPLORATION
  Start: July 2003
  Landing: January 2004
  Rover: Spirit and Opportunity



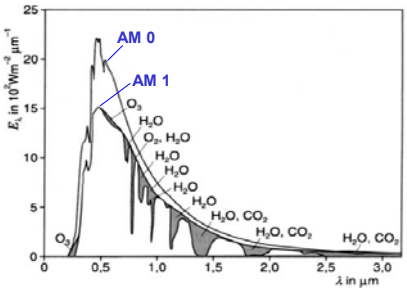


Example “Optical window”

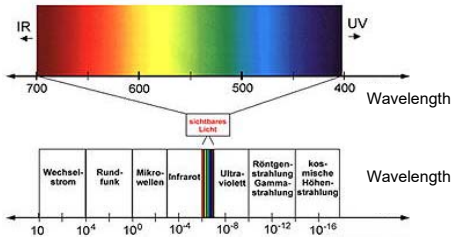
Planet Earth in the radiation of the Sun



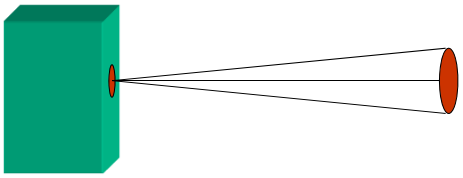
Sun radiation spectrum 5800 K outside and in the Earth's atmosphere (AM 0) and on the Earth (AM 1).



Optical Spectrum of light



Important radiation laws in optics



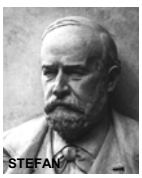
- **BEER-LAMBERT law** — August Beer (1825 – 1863), German physicist and mathematician
  Johann H. Lambert (1728-1777), Swiss mathematician and astronomer
- **PLANCK´s radiation law** — Max Planck (1858 - 1947), German physicist
- **WIEN´s displacement law** — Wilhelm Wien (1864 - 1928), German physicist
- **STEFAN-BOLTZMANN law** — Jožef Stefan (1835 - 1893), Slovene physicist
  Ludwig Boltzmann (1844 - 1906), Austrian physicist


BEER


LAMBERT


PLANCK


WIEN


STEFAN

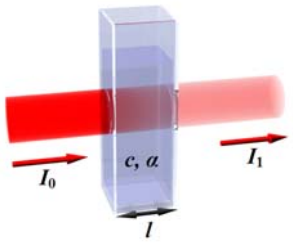

BOLTZMANN

BEER - LAMBERT law

$$T = \frac{I}{I_0} = 10^{-\alpha \ell} = 10^{-\varepsilon \ell c}$$

$$A = -\log_{10}\left(\frac{I}{I_0}\right)$$

$$A = \varepsilon \ell c = \alpha \ell$$



T … Transmission (or transmissivity);
A … Absorption (or absorbance)
I_0 and I … Intensity (or power) of the incident and the transmitted light;
α … absorption coefficient; ε … extinction coefficient of the absorber;
c … concentration of absorbing species, l … path length,

Remember:

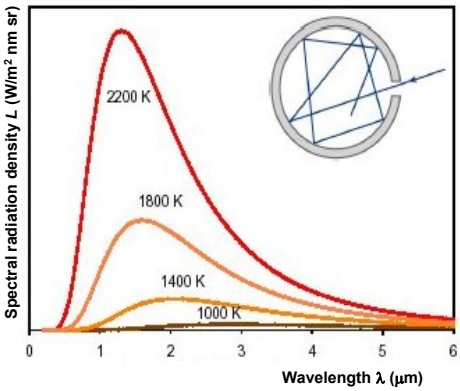
- *The absorption of light relates to the properties of the material through which the light is travelling*
- *There is logarithmic dependence between the transmission of light and the product of the absorption coefficient and the distance the light travels through the material*
- *The absorbance becomes linear with the concentration (or number density of absorbers)*

PLANCK´s radiation law

$$L_{e,f}(f,T)df = \frac{2hf^3}{c^2\Omega_0}\cdot\left(e^{\frac{hf}{kT}}-1\right)^{-1} df$$

h = 6,63 x 10^{-34} Js … Planck's constant

k = 1,38 x 10^{-23} J/K … Boltzmann constant

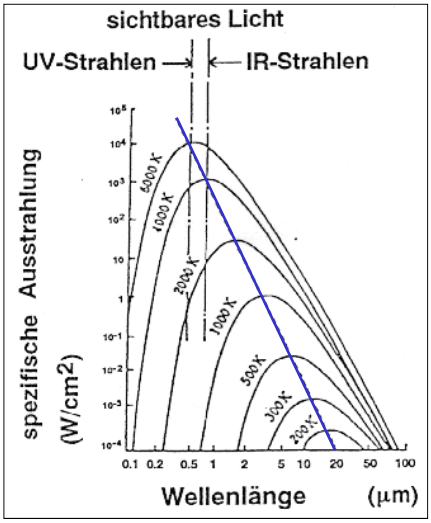


Remember:

Spectral radiation density in interval df is depend from frequency, radiation angle and temperature

WIEN's displacement law

$$\lambda_{max} = 2898 / T \; [\mu mK]$$

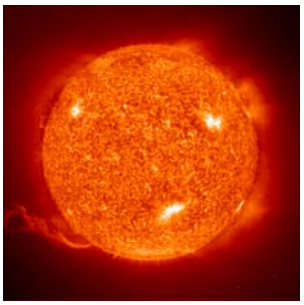


Remember:

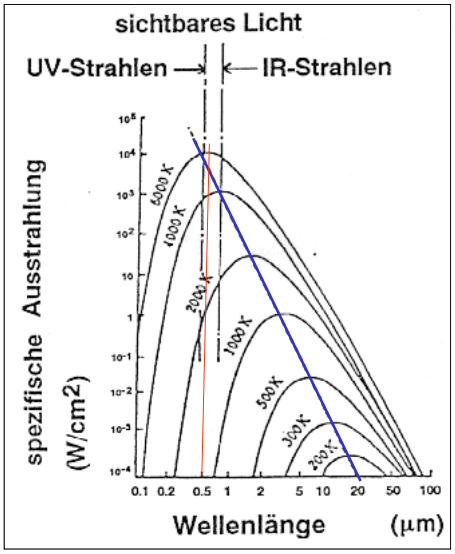
Radiation power of the light source is strongly dependent from it's temperature.

WIEN´s displacement law

Example 1:
Sun (T = 5.800 K)

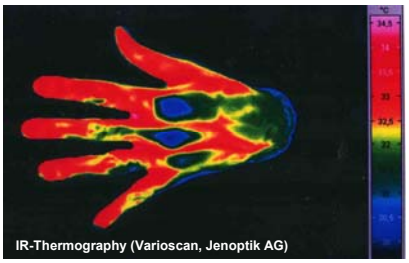


λ_{max} **= 500 nm**

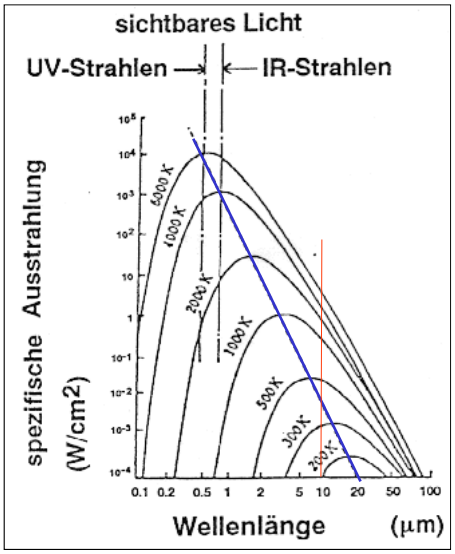


WIEN´s displacement law

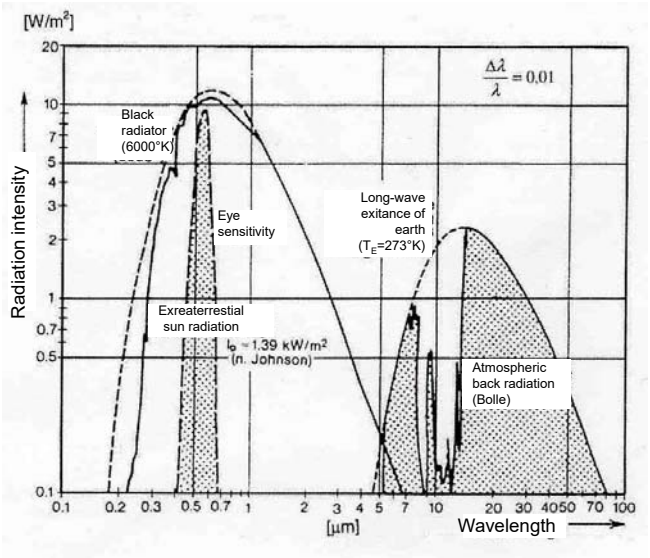
Example 2:
Human Body (T = 305 K)



λ_{max} = 9.5 µm



The earth as an IR radiation source / Greenhouse effect



STEFAN-BOLTZMANN law

$$M_e(T) = \sigma T^4$$

$$\sigma = \frac{2\pi^5 k^4}{15 h^3 c^2} = 5.670 \cdot 10^{-8}\ W/(m^2 K^4)$$

σ … *Stefan-Boltzmann constant (constant of proportionality);*
k … Boltzmann constant; h … Planck's constant

Remember:

The total energy radiated per unit surface area specific emission of a black body (known variously as the body irradiance, energy flux density, radiant flux or the emissive power) is directly proportional to the fourth power of the body's temperature.

Example "Sun": **$M_{e,S}$ = 6,42 x 10^7 W/m²**

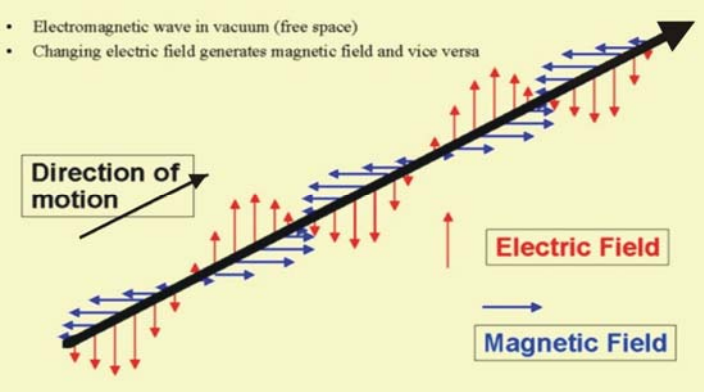
Example "Human body": **$M_{e,B}$ = 490,5 W/m²**

Example "Earth": **$M_{e,E}$ = 314,7 W/m²**

Example "Cosmic background": **$M_{e,C}$ = 3,01 x 10^{-6} W/m²**

Dual character of light

• electromagnetic wave (oscillating electric and magnetic field)



• photon particles

Remember:

- *Light is characterized by the wavelength λ or by the frequency $\nu = c/\lambda$ (c … speed of light in vacuum).*
- *Electromagnetic waves transport energy.*
- *The energy of electromagnetic waves is quantized; it exists in packages of the size*

$$E_{Ph} = h\nu = (hc)/\lambda$$

- *These packages are called photons or light quanta (h = 6,63 x 10^{-34} Js, Planck´s constant)*

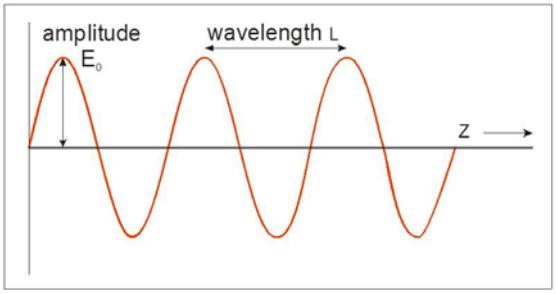
Propagation of light as waves

Most of the interactions between light and molecules of biological interest are electrical in nature. Therefore, the description of a light wave focuses on the nature of the oscillating electric field ***E***, which has both a direction and an amplitude.

$$\vec{E}(z,t) = \vec{E}_0 \cos(\omega t - kz)$$

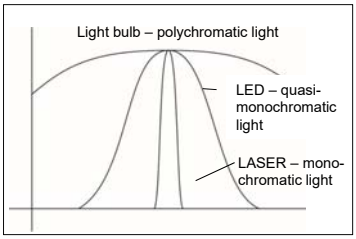
$k = \frac{2\pi}{\lambda}$ … wave number

ω … angular frequency

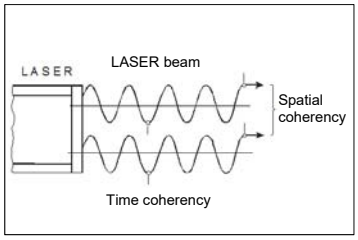


Important properties of optical radiation

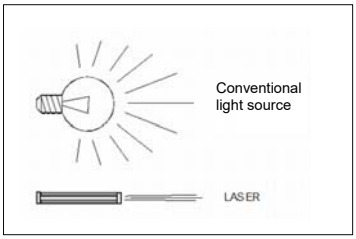
Monochromacy



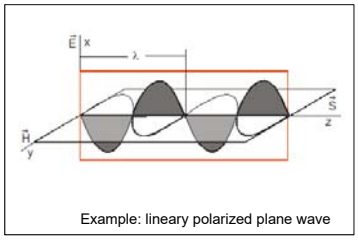
Coherency



Collimation



Polarization



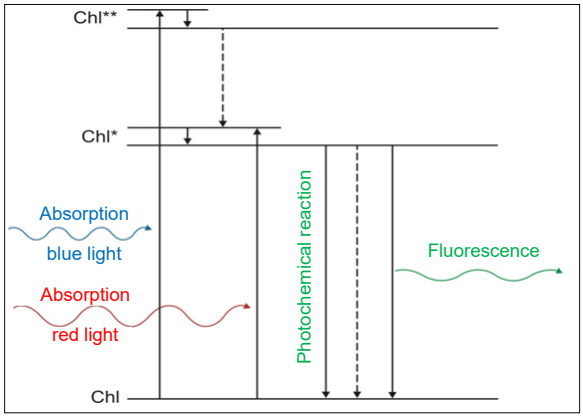
Light as energy source for life processes

Photosynthesis in Chlorophyll – containing plants and bacteria.

Anorganic substances + Sunshine

↓

Plant matter + Oxygen



Energy levels in Chlorophyll molecule.
After absorbing a blue light photon, the Chlorophyll molecule switches from the ground to the „second excited energy state Chl**“. Through energy losses and heat, it drops to the lower energy level “first excited level Chl*”. This level can be also reached after absorption of a red light photon.
On the way back to the ground state level, energy is produced, which is transformed through the photochemical reaction or released as heat and fluorescence.

Significance of light in formation and development of life

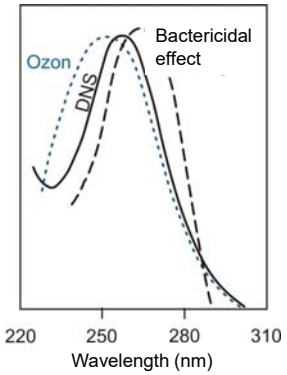
1) Formation of air oxygen and photosynthesis
2) Incurrence of Ozone layer in the atmosphere
3) Modifications of DNA in cells through UV - radiation

The **Desoxyribonucleic acid (DNA)**
is the carrier of genetic information (Genom).

Ozone absorbs radiation almost the same way as the DNA does. In this way it protects the DNA and the life on Earth.

At the time of life formation, there must be lack of Ozone in the Earth atmosphere. One may speculate, that the first life developed under protective shield of water layer.

Absorption spectra of Ozone, DNA and
(activity spectrum) bactericidal effect of the UV- radiation.



Natural light sources and light sensitivity of some biological processes

(Excluding photosynthesis, we understand the values as lower boundaries for the biological effect)

Radiant power in [Watt/m2]	
1000	Sunshine at lunchtime in Summer
200	Light saturation of photosynthesis in wheat
100	Daylight, clouded sky
10	Photosynthesis compensation balance (Breathing and Photosynthesis)
1	Photoperiodic flowering control
0,1	Late twilight, seed germination
0,01	Moonlight
0,001	Human colour vision
0,0001	Perceptible Chlorophyll formation (red light)
0,0000001	Black – white vision
0,000000000001	Light from a star of 6th order of magnitude, perceptible by eye (2x10^{-9} Lux)
0,00000000000000001	Light from a weak Star , which is observable with the largest Telescope

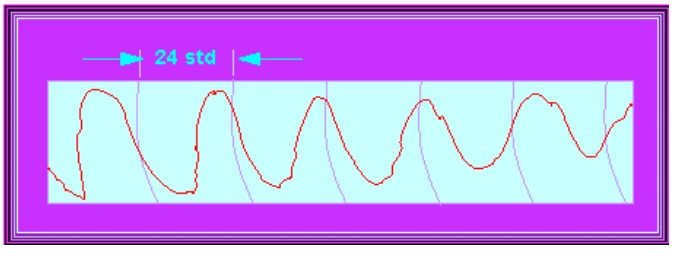
Light, life and sun worship

Sun worship was a traditional act in many population groups all over the world, especially by culturally high rated nations (Inca, Egypt etc.). Obvious evidence of sun worship can be found also in Bible.
The light was, since ever, an indispensable element for human beings.

Pharao ECHNATON, Egyptian Regent (1370 – 1352 v. Chr.), with queen NOPHRETETE. The sunshine "Hands" symbolizing blessing and protection. Relief from Tell el Amarna

Alternations in light and darkness, photoperiodism and circadian rhythms in humans, animals and plants

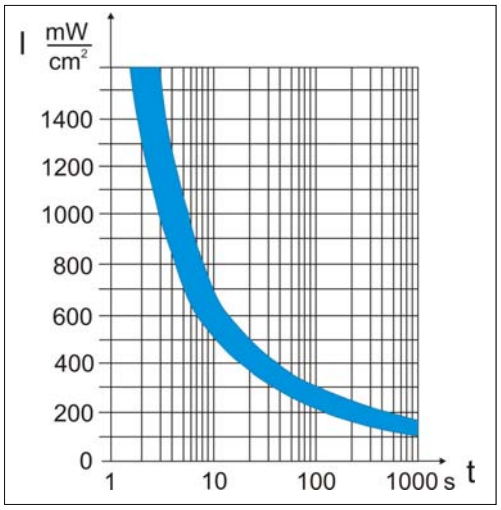
- Since ancient times, we know that physiological activities follow the circadian rhythm ...
- Since the 18 Century, these phenomena were investigated experimentally ...
- 1729 the Parisian astronom De Mairan observed, that the movements of plants continue with uninterrupted darkness ...
- The final proof provided BUNNING E. and K. STERN, by 1930, when analyzing reactions of *Phaseolus multiflorus* under constant thermodynamic laboratory conditions and according to a predetermined program of light (light-dark phases).



Typical course of circadian leaf movements under continuous light conditions. Within 6 days, it develops a phase shift of around 17 hours compared to a normal day period. The period length of this endogenous rhythm was around 27 hours (Bünning and Tazawa, 1957).

Optical radiation & human skin

- erythema
- pigmentation
- short time damage (pain)
- long time damage (carcinoma)



LEITGEB, N.: Strahlen, Wellen, Felder. Thieme Verlag, Stuttgart, 1990

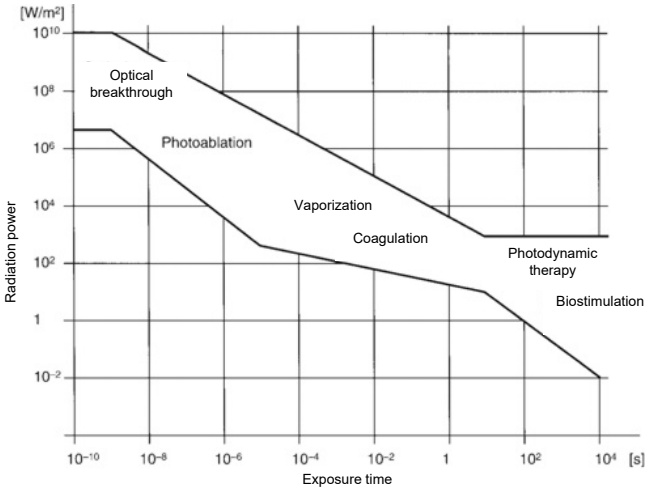
Optical radiation and the eye

Important radiation protection: Sunglasses are not only a fashion fad

Fotos: dpa

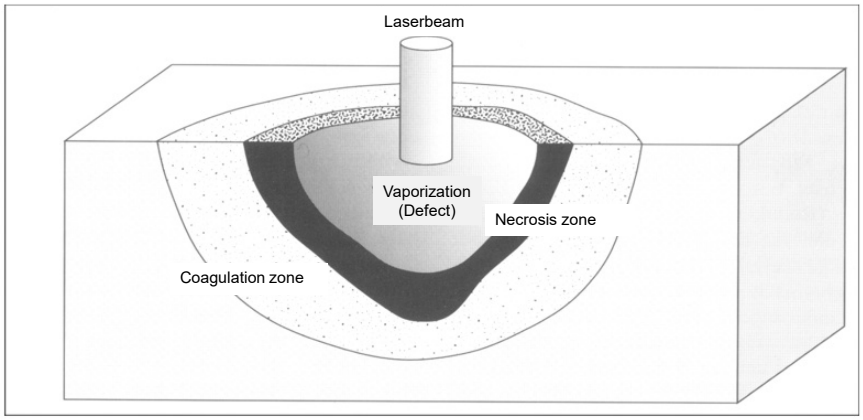
Interaction of light – skin

- Photochemical processes (bio-stimulation, photodynamic tumor therapy)
- Thermal changes (coagulation, vaporization)
- Nonlinear effects (non - thermal changes: photoablation, photodisruption)



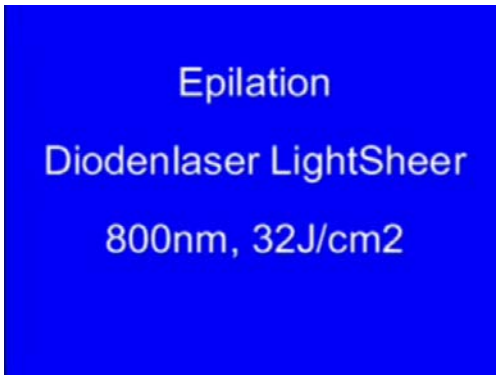
Scheme of the thermal laser "action zones" on tissue

- 37 ° C Warming only, no tissue damage
- 45 ° C Depending on the duration - cell death, membrane damage, edema
- 60 ° C Denaturation of proteins, coagulation, necrosis (whitish discoloration)
- 150 ° C Tissue carbonization (black color)
- 300 ° C Evaporation or combustion, thereby ablation (vaporization)



The applications of laser in medicine and biology
are diverse, sometimes even controversial …

Source: Wikipedia, ein „gelasertes" Logo auf einem Apfel



Source: Ästhetische Medizin, St. Josef-Hospital, Uni Bochum

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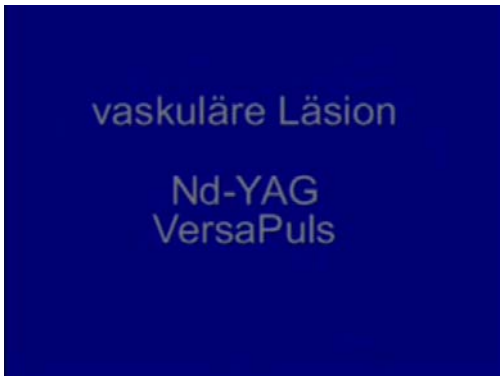

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Information transfer between living cells by UV - light (Biophotons*)?

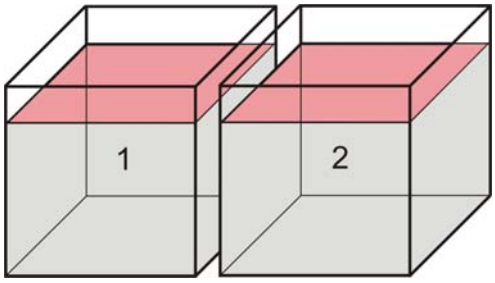
Experiment acc. Kaznacheev et al .**:
Two similar jars, made of quartz-glass (UV transparent) , two identical cultures of living cells in suitable culture media.

Action in Jar 1:
Test 1: viral infection
Test 2: cell poisoning with corrosive sublimate
Test 3: cell killing with high-dose UV

Result:
each time, found diseased cells in the neighbor jar

Repetition of the test series, but with
"normal glass" jars.

Result:
No cell damage in the neighboring jar.



Hypothesis of the group Kaznacheev:
Photons in the UV region are able to transfer metabolic regulatory information from cell to cell.

* **Biophotons** (formerly referred to as "mitogenetic radiation" or "ultra weak cell radiation") are photons of a R´radiation that comes from living cells.
** Kasnatschejew, W.P., Schurin, S.P., Michailowa, L.P.: Kommunikation zwischen Zellen durch Strahlung? Naturwissenschaftliche Rundschau 26 (1973), S. 444

Citát pro druhou přednášku / Quotation of the lecture 2:

On the question of one of his students:

„How to be successful in science ?“

the teacher answered:

„To work, finish, publish“

M. Faraday (1791 – 1867)
the English chemist and physicist,
world wide known for his pioneering experiments in electricity and magnetism