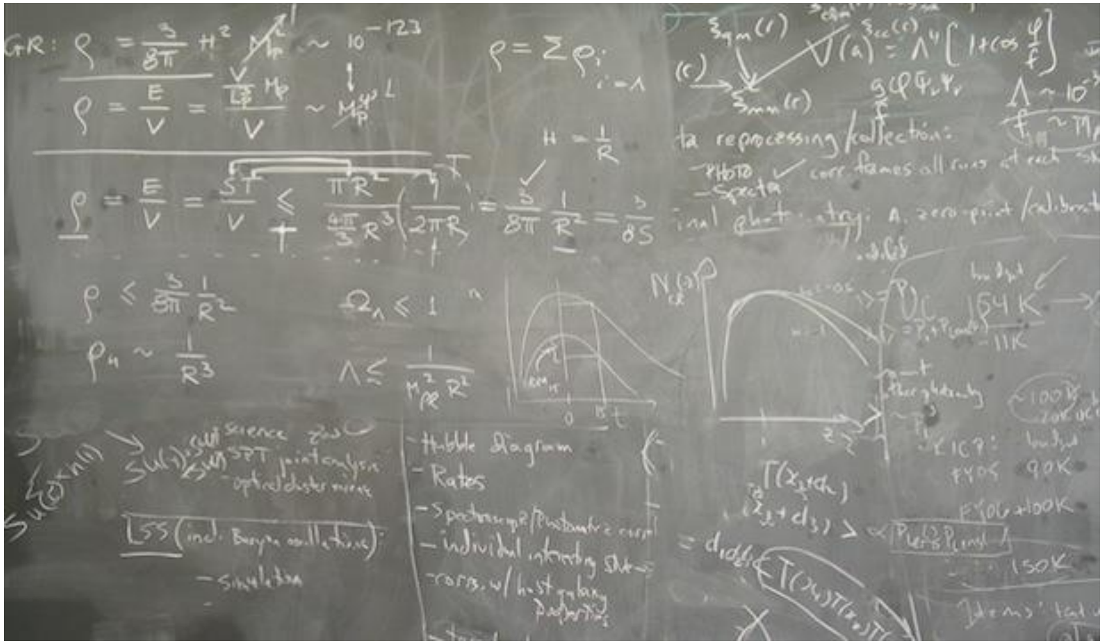
History of Science
(Wissenschaftsgeschichte)



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Contents

- The big picture - Science and human society development
- Science, religion and philosophy - Three ways of learning
- From early religions to modern astrophysics
  - Historical models of the universe
  - The cosmic architecture
  - Progress in observation techniques
- Major discoveries in physics
  - How quantisation developed
  - The standard model of matter
  - The road to nuclear fission and fusion
- Once alchemy - today chemistry
  - Discovery of the cosmic toolbox - The periodic table
  - Chemistry - Simply everything
  - 100 Million compounds and no end?
- Revolutions in biology
  - Darwin's evolution
  - Mendel's inherit laws
  - The molecule of life (Watson & Crick)
  - Biotechnology - Quo vadis?
- Historical development of light sources
  - Fire and lamps: Catalysts of human activity and development
  - Light as the carrier of interaction
  - Photonic devices as the origin of innovation
- The future of science
- Discussion

Historical Development of Light Sources

Strong Interaction

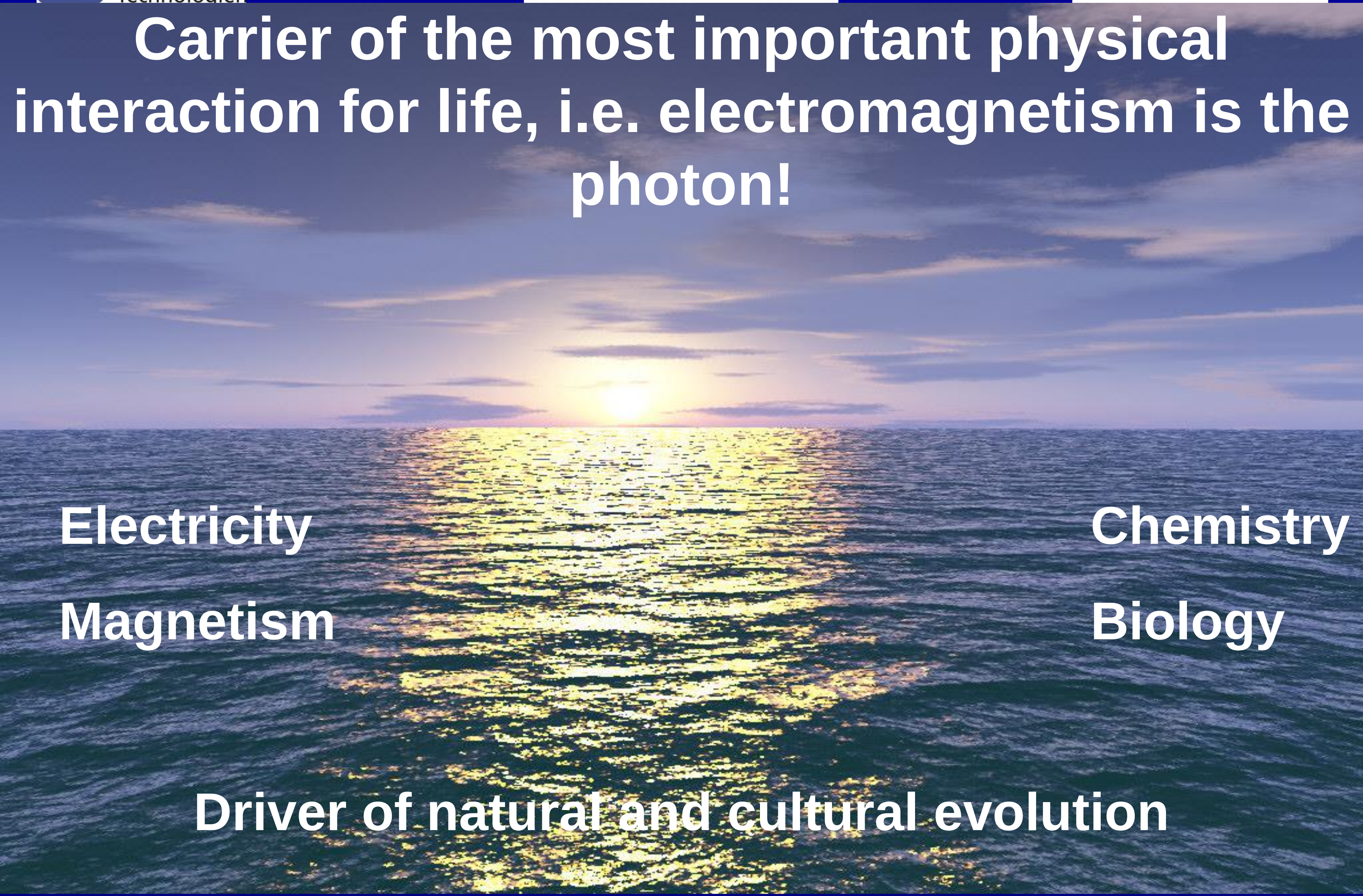
Human history ↔ Development of artifical light sources

INTERNATIONAL YEAR OF LIGHT 2015

Artificial light

- **supplies heat (health) and security**
- **enables human activity independent of daylight**
- **is a design element**
- **can be used for signalling and communication**
- **enables technical advances, e.g. in photochemistry & biology, material processing, medicine, IT, architecture and construction**

Carrier of the most important physical interaction for life, i.e. electromagnetism is the photon!



Electricity **Chemistry**

Magnetism **Biology**

Driver of natural and cultural evolution

Historical Development of Light Sources

Prehistoric period — **Antiquity** — **18^{th} century** — **19^{th} century** →

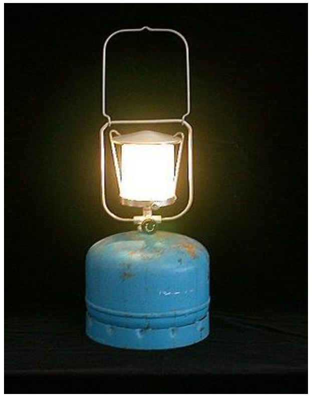
Access to suitable energy sources↑

open fire

torches

candles

oil lamps



Auer light

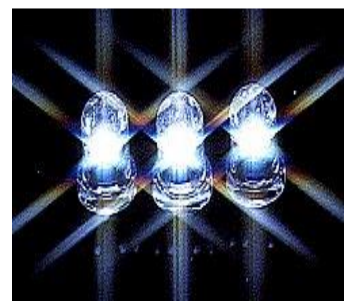
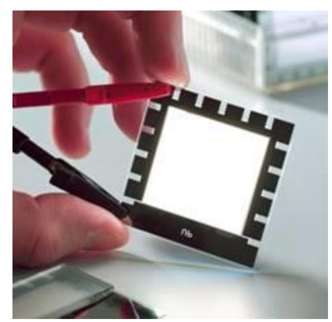
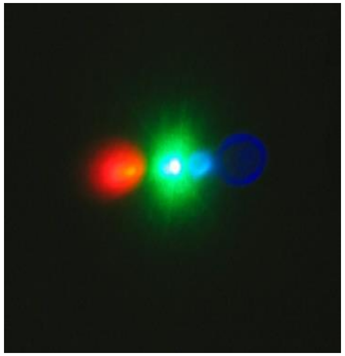
coal wire lamp

Chemical light sources → Electrical light sources

Historical Development of Light Sources

19th century — **20th century** — **21st century** →

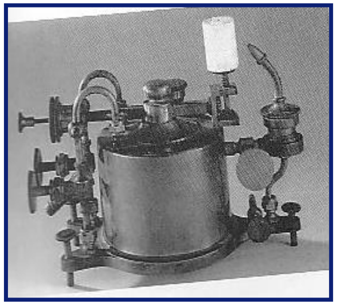
Lifetime, luminousity, luminous efficacy, light quality↑

Incandescent and halogen lamps	Gas discharge lamps	Inorganic and organic LEDs	High brightness LEDs and laser diodes
			
			

Historical Development of Light Sources

History of non electric lighting

$1.37 \cdot 10^{10}$ years ago	Big bang
$1.3 \cdot 10^{10}$ years ago	First stars and galaxies
$1 \cdot 10^{9}$ years ago	Bioluminescence
400000 years ago	Torches and open fire
13000 years ago	Primitive stone lamps
5000 B.C.	Fat lamps with wick
1000 B.C.	Candles
600 B.C.	Oil ceramic lamps
280 B.C.	First lighthouse (Alexandria)
1608	Telescope (refractor)
1668	Newton telescope (reflector)
1772	Gas lamps
1783	Petroleum lamps
1784	Argand lamp (lamp with a hollow wick)
1826	Limelight, CaO-Burner “Thermoluminescence”



Historical Development of Light Sources

Some Milestones concerning the development of incandescent lamps

- 1801 Louis J. des Thenard observes that metal glows when it is connected to current
- 1820 Electrified Platinum wire show visible glow
- 1854 Heinrich Göbel invents the first light bulb with a charred bamboo filament
- 1878 J.W. Swan invents carbon filament lamp (UK No 8 in 1880)
- 1879 Patent applied by T.A. Edison on incandescent lamp with cotton fiber (US 223,898 in 1880)
- 1880 A lot of metals and alloys are tested for filaments, e.g. W, Os, Ta, Re
- 1883 Edison and Swan establish a firm in London. First in Germany produced light bulb
- 1890 A.N. Lodygim tries to replace the bamboo filament by a metal wire
- 1890 Carl Auer von Welsbach gets patent for the production of Os and W. He founds the company Osram
- 1897 W. Nernst invents the „Nernst Stift“ (today IR-radiator)
- 1902 O. Feuerlein and W. von Bolton use Ta for their light bulbs
- 1903 W. Whitnew covers a carbon filament with metal to prevent the evaporation of the filament
- 1905 Light bulbs with Ta are produced, till 1st World War more than 50 Mio. pieces
- 1906 GE gets a patent for the production of W filaments
- 1910 W.D. Coolidge is able to produce cheap W
- 1911 I. Langmuir uses Ar-N2 for filling the glass bulb and increases the lifetime
- 1936 Krypton is used as filling gas. The so called “coiled coil” is invented
- 1958 Xenon is used as filling gas
- 1960 Halogen lamps were invented. First LEDs
- 1973 Halogen lamp with interference filter

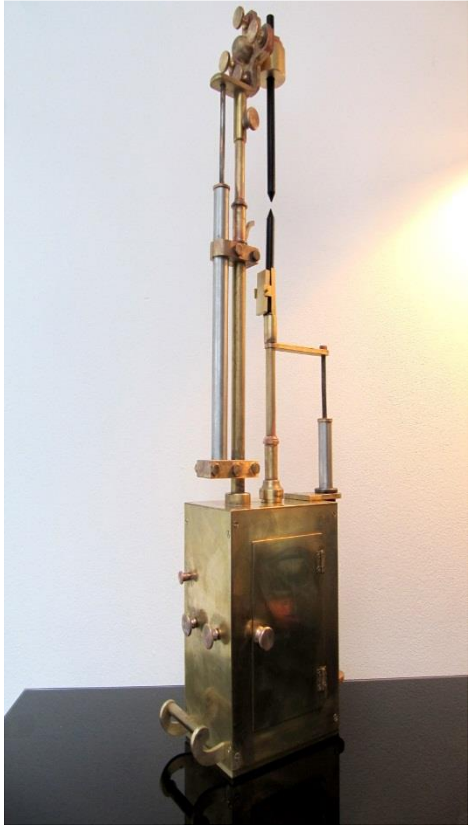
Historical Development of Light Sources

Observations of electricity

- In nature: Thunder & Lightning
- 17th and 18th century
  - Artificially made sparks by electrostatic charging
  - Electricity for social events & entertainment
- 1800: Development of the battery by Alessandro Volta
  - Voltaic columns mad from copper and zinc layers, separated by an electrolyte
  - continuous energy source available

Historical Development of Light Sources

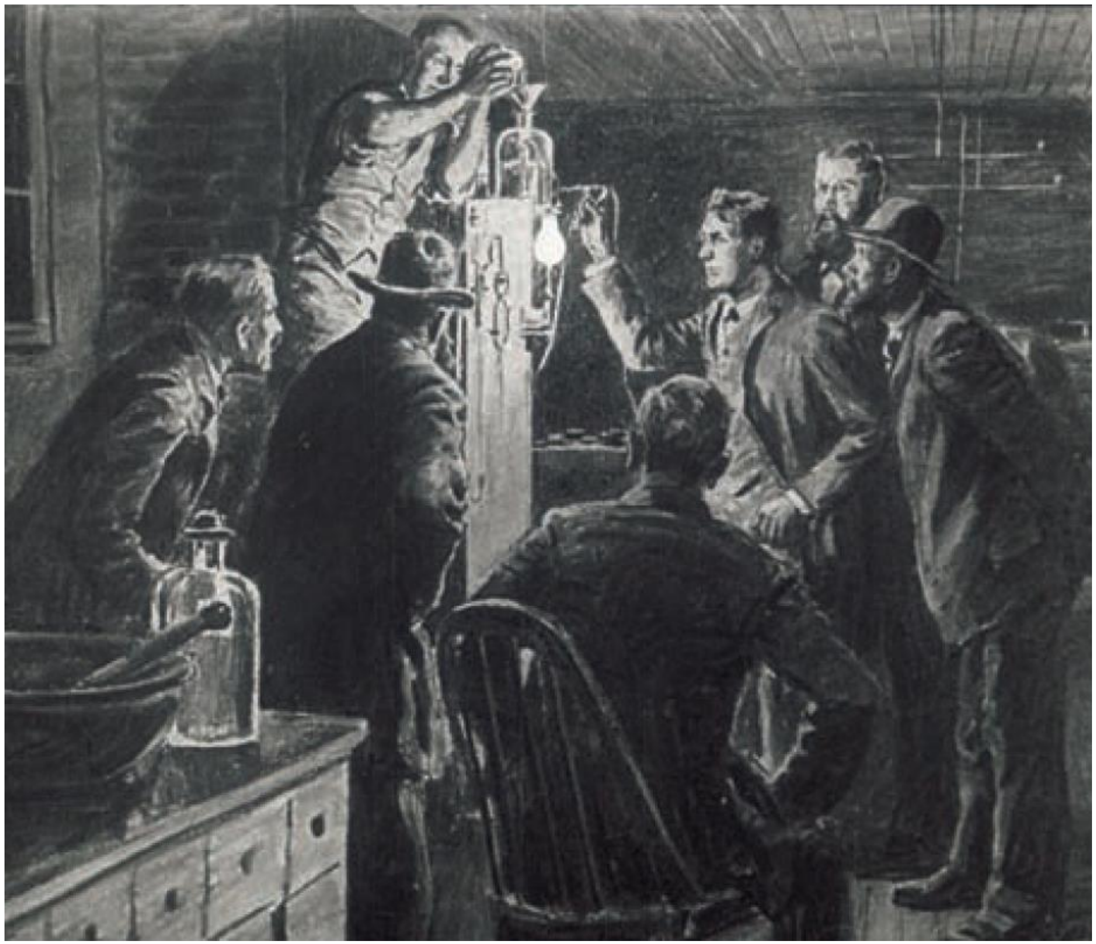
Carbon Arc Lamp



- Invented by Humphry Davy 1806
- Principle:
  - 2 Graphite electrodes separated by air
  - Application of a voltage
  - Discharge ignition
- Burn off of electrodes requires adjustement of electrodes
- Advantage: Hight intensity and luminous flux
- Application in head lights and projection

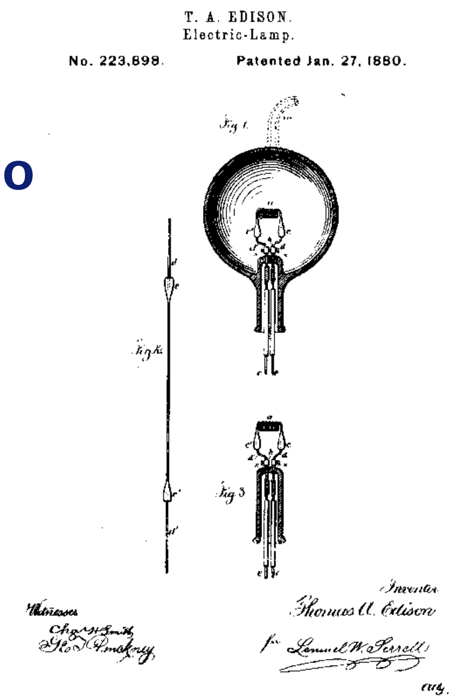
Historical Development of Light Sources

Experiment conducted by Thomas Alva Edison (1847-1931)



Historical Development of Light Sources

Breakthroughs in incandescent lamps



- 1879: Patent applied by Thomas Alva Edison, Menlo Park, NJ → US223,898

- Advantages
  - Carbon filament in improved vacuum enables higher lifetime
  - Higher resistance of the carbon filament
    - ➢ higher voltage possible (about 100 V)
    - ➢ transport of electricity over larger distance possible

- Distribution of the whole supply chain by Edison:
  - Lamps, electric grid, and dynamos

Historical Development of Light Sources

The Centennial Light

- Burns since 1901
- 4 Watts and 110 Volts
- Carbon filament
- Internet address: http://www.centennialbulb.org/

Historical Development of Light Sources

Further development of incandescent lamps

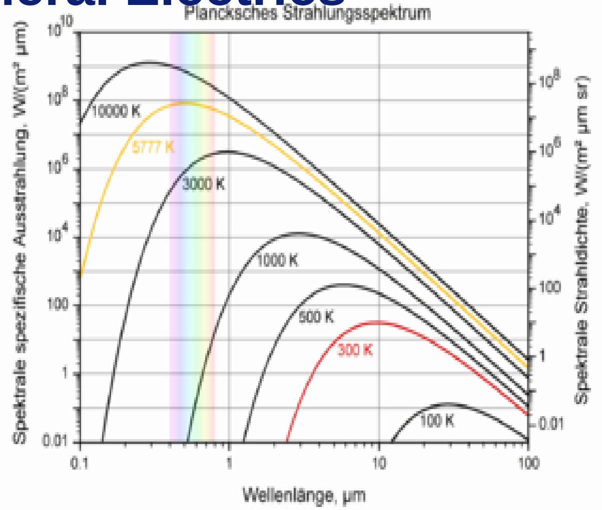
- **1890: Conversion of the electrical grid to AC**

- **Coil material development:**
  - **Osmium (T_m = 3130 °C) and Tantal (T_m = 3017 °C)**
  - **1904: Patent for tungsten coil**
  - **1912: Use of tungsten (T_m = 3422 °C) by General Electrics**

- **1911: Vacuum replaced by Argon-N_2 blend**

- **1936: First use of a double coil**

- **1959: Halogen cycle to reduce tungstan loss**



Historical Development of Light Sources

History of electric lighting

1854	Goebel	Incandescent lamp with bamboo fibres
1858	Geißler	Hg discharge
1859	Becquerel	Fluorescent lamp
1878/79	Swan&Edison	Incandescent lamp with carbon filament
1900	Cooper & Hewitt	Patent of mercury vapour lamp
1907	J.H. Round	Electroluminescence of SiC
1934	Germer	Low-pressure discharge lamp with luminescent screen
1936	Destriau	Indirect electroluminescence
1937	Claude	Ne-discharge lamp with $CaWO_4 + Zn_2SiO_4:Mn$
1938	GE	Fluorescent lamp with $MgWO_4 + (Zn,Be)_2SiO_4:Mn$
1948		Halophosphate lamp
1959	GE	Halogen lamp using I_2
1961	Biard & Pitman	Semiconductor LED
1971	Koedam & Opstelten	Tricolour concept
1980		Compact fluorescent lamp
1990	Friend & Burroughes	First organic LED

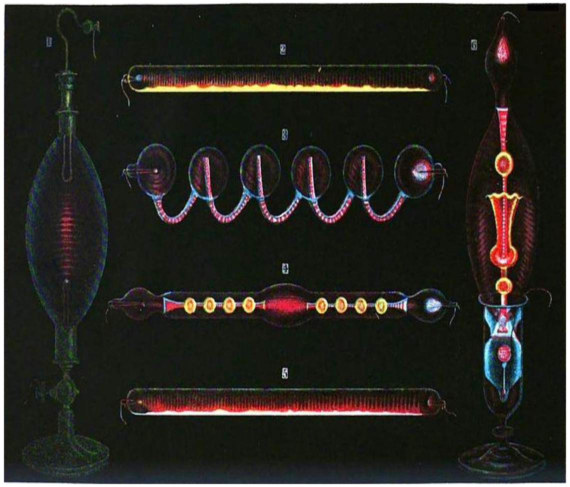
Historical Development of Light Sources

Gas discharge lamps

1858: Heinrich Geißler invents the Geißler tube
Glas cylinder with electrodes at both ends, which comprises different gases such as Argon, Neon, air, Hg vapour, or Sodium

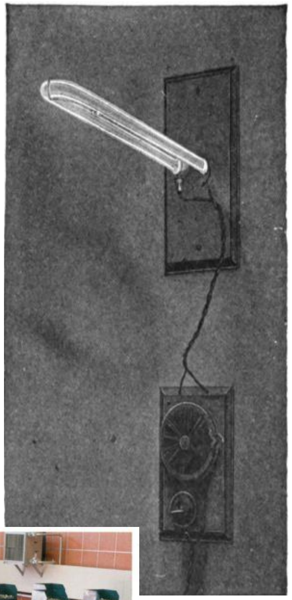
Application areas: Research and demonstration purposes

Started development of many types of gas discharge lamps



Historical Development of Light Sources

Gas discharge lamps



1900: Hg vapour lamp by Cooper & Hewitt
No luminescent materials yet
→ Bluish green emission

1930ties: Development of lamp phosphors for the conversion of Hg line at 254 nm

1938: Start of commercial use

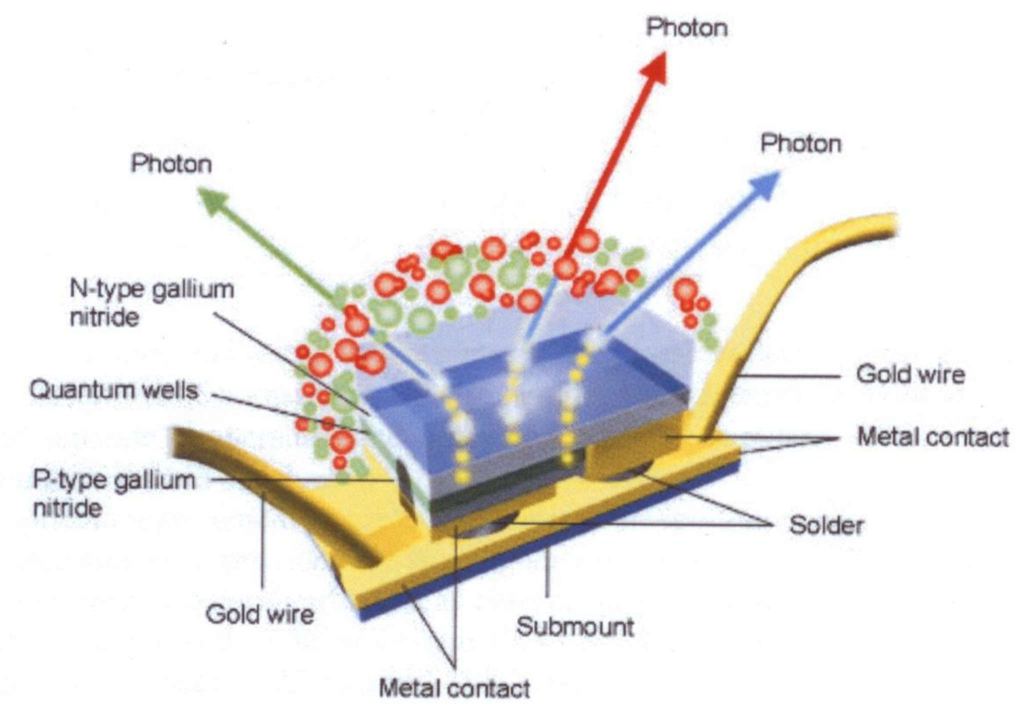
1948: Begin of TL lamp production at Philips Lighting Roosendaal, NL

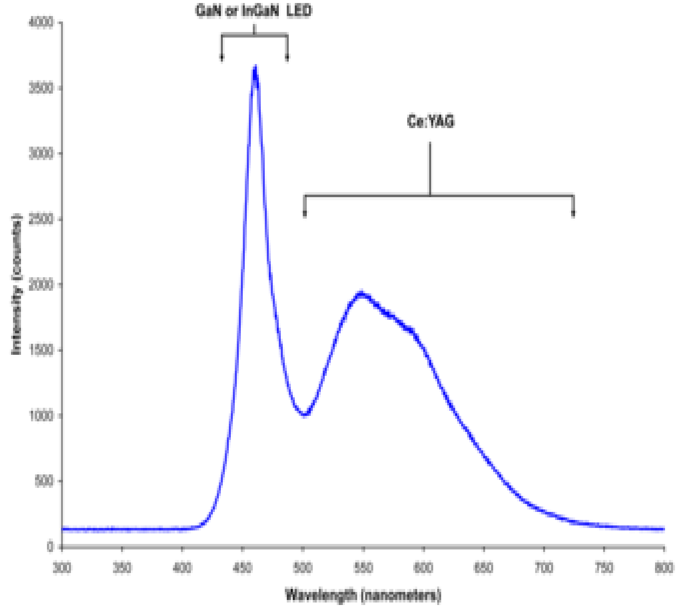
2015: End of TL lamp production at Philips Lighting Roosendaal, NL

Historical Development of Light Sources

1991: Discovery of UV/blue emitting LED (In,Ga)N

White light LED: Blue LED + Yellow phosphor





Historical Development of Light Sources

History of electric lighting

1993	**Nakamura**	**Highly efficient blue (In,Ga)N LED**
1995	**Schnick**	**Nitridic luminescent materials**
1996	**Nichia/Osram**	**White LED comprising (In,Ga)N LED + YAG:Ce**
2000		**White LEDs more efficient than incand. bulbs**
2004	**Nichia/Osram/Philips**	**Warm white LED with (Ca,Sr)S:Eu / $Sr_2Si_5N_8$:Eu**
2004	**Mitsubishi**	**Deep red emitting $CaAlSiN_3$:Eu**
2006	**Nichia**	**Cool white LED with 100 lm/W @ 20 mA**
2007	**Nichia**	**Cool white LED with 160 lm/W @ 20 mA**
2010	**CREE**	**Cool white LED with 208 lm/W @ 20 mA**
2011	**Mitsubishi**	**Yellow emitting nitride phosphor $La_3Si_6N_{11}$:Ce**
2012	**Epistar**	**Warm white LED with 216 lm/W @ 5 mA**
2013	**CREE**	**Cool white LED with 276 lm/W @ 20 mA**
2014	**CREE**	**Cool white LED with 303 lm/W @ 20 mA**
2015	**UNESCO**	**International Year of Light (IYL2015)**
2019	**UNESCO**	**International Year of Periodic Table (IYPT2019)**

Historical Development of Light Sources

21st century: LEDs dominate artificial lighting

Semiconductor material	Wavelength (range) [nm]	External quantum yield [%]	Application areas
(Al,Ga)N	210 - 365	10	Disinfection, photo-chemistry, purification
(In,Ga)N	365 - 500	80 (@ 410 nm)	Lighting, data storage
(Al,Ga)InP	650	55	Backlighting, signalling
(Al,Ga)As	720	40	Horticulture, biometric recognition, sensors
GaAs	850	55	Remote controls, sensors
(In,Ga)As	930	50	Biometric recognition, sensors

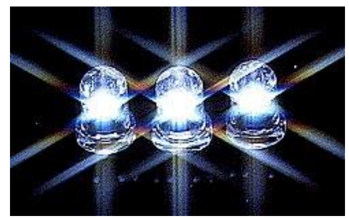
Nick Holonyak, jr. (2000)

It is vital to know that the LED is an ultimate form of light source, in principle and practice, and that its development indeed can and will continue until all power levels and colors are realized

Historical Development of Light Sources

What is it all about?

- **Lifetime:** EOL or reduction of luminosity down to 70% → L70
- **Luminosity in Lumen:** 10 lm → 100 lm → 1000 lm → 10000 lm

- **Luminous efficacy:** 0 … 683 lm/W
  - Dependent on type and spectrum of the light source
  - Dependent on receiver and lighting situation
- **Light colour:** Colour temperatur T_c = 2700 – 8000 K
- **Light quality:** Colour rendering index R_a = 0 …100

⇒ „5L“ of a light source

Historical Development of Light Sources

Will the Edison light bulb die out?

- In 2005 Fidel Castro asks to use lamps with a maximum of 15 W
- Ireland forbids incandescent lights from 2009 on.
- Australia forbids incandescent lights from 2010 on.
- Italia also plans to ban the incandescent lights
- Canada wants to change 2012
- USA wants to change between 2012 and 2014
- EU bans halogen lamps by the end of 2017

Likely YES, due to political decisions and the outstanding performance of ILEDs, OLEDs, PLEDs, and QLEDs

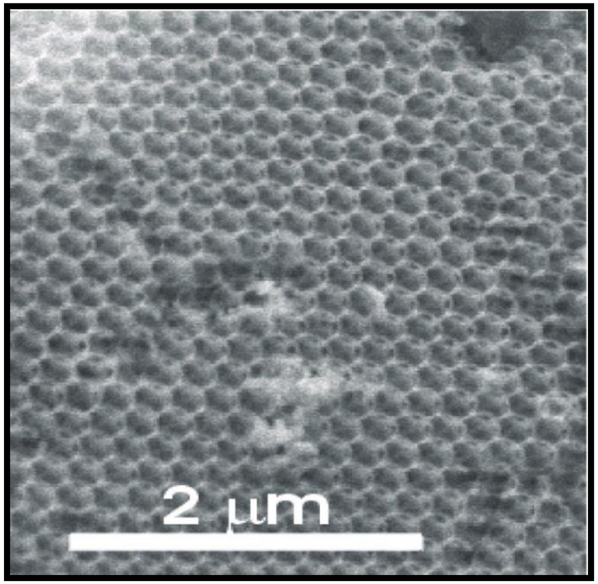
Historical Development of Light Sources

Recent improvement by photonic crystals

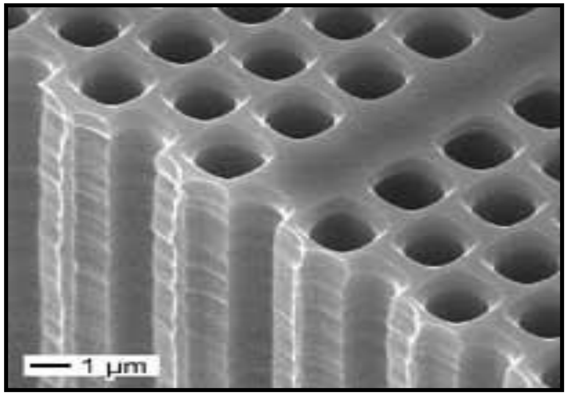
… to increase light outcoupling of light sources

... to reduce IR emission

Both measures can improve wall plug efficiency LEDs, OLEDs, and even thermal radiators



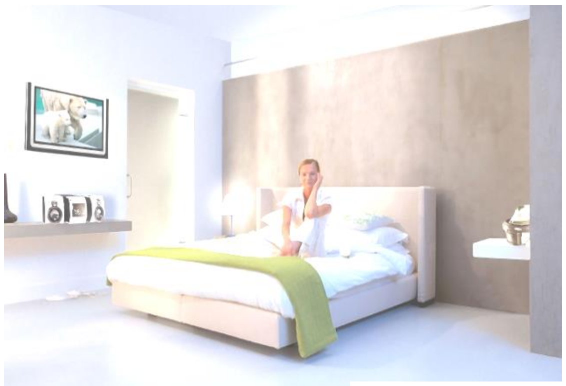
Inverse opal / TiO_2 basis



Tungsten filament with photonic band structure via 3D-structuring

Historical Development of Light Sources

Future Trends: Human Centric Lighting (HCL)



Value of Light for Society

Efficacy for education & work

Health

Human Centric Lighting

Ambiance

Environmental impact

Illumination

Vision
Colour rendering

Energy efficiency
Lifetime
Recycling

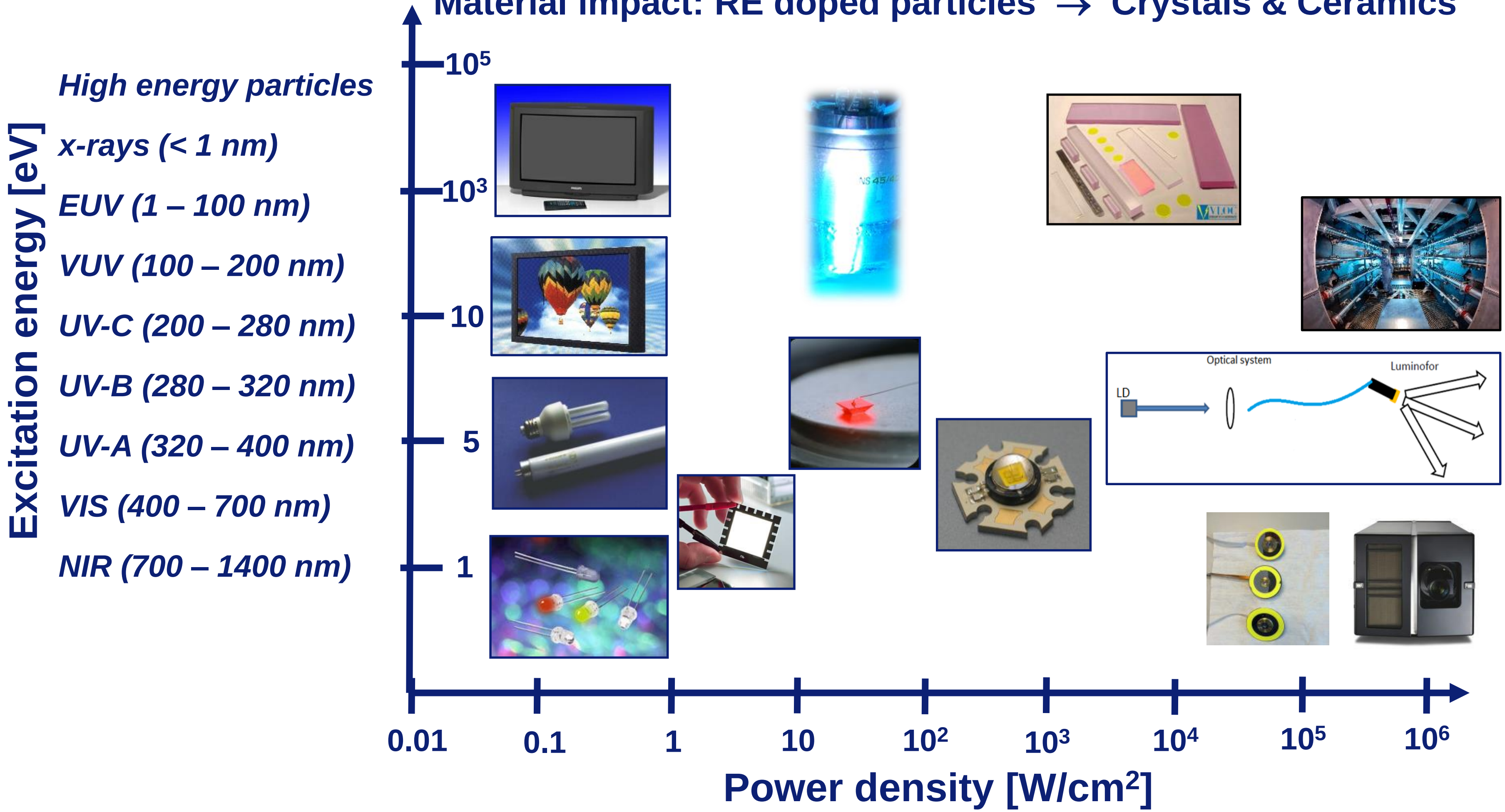
Geometrical, spectral, and time dependent modulation

Time

Historical Development of Light Sources

Future Trends: Power Density Increase

Material impact: RE doped particles → Crystals & Ceramics



Historical Development of Light Sources

History of display technology

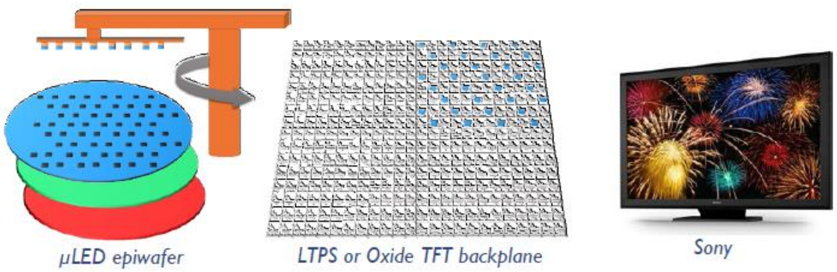
• 1875 George Carey	First TV concept
• 1884 Paul Nipkow	First practical TV
• 1897 Braun	Braun tube
• 1926 Philo Farnsworth	First official TV broadcast
• 1928 A. Hovhannes, J. Blaird	Colour TV
• 1971 James Fergason	LCDs
• 1977	Gas discharge displays (monochrome orange)
• 1999 Philips	Monochrome PolyLED Display
• 2000 iFire	17“ ACTFEL Display
• 2004 iFire	34“ ACTFEL Display
• 2006	200 und 300“ Plasma Displays
• 2008	LED Backlit LCDs
• 2009 Shinoda Plasma	Flexible 125“ Plasma Displays
• 2012 Sony	4K home projector (3840 x 2160 pixel)
• 2012 NHK/Panasonic	8K 145“ LCD-Display (7680 x 4320 pixel)
• 2015	OLEDs Displays
• 2016 Sony	40“ µ-LED Display (6,220,800 sub-pixel)
• 2019 Samsung	75“ µ-LED 4K Display
• 2021 Samsung	88“, 99“, and 111“ µ-LED

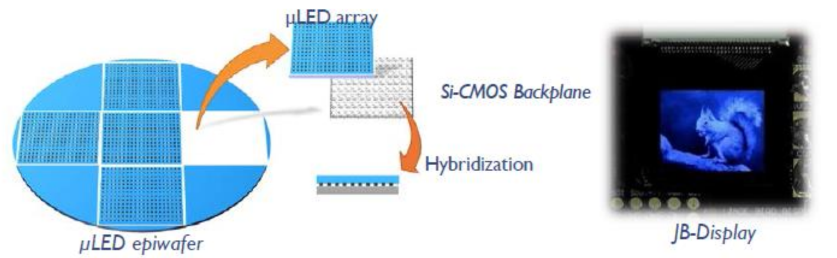
Historical Development of Light Sources

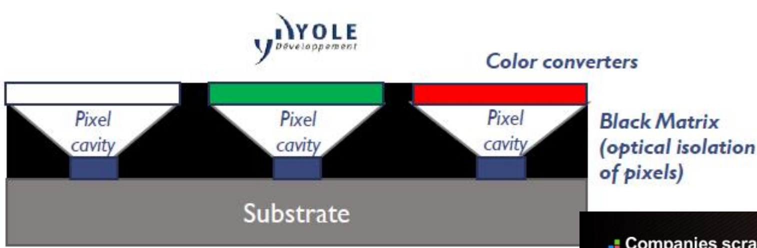
Since 2018: Micro-LED Displays as next generation displays?

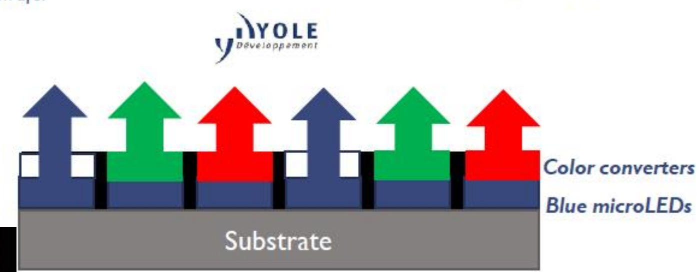
Large displays with low pixel densities (TV, smartphones…): R,G,B LED or Blue + color converter

High resolution/pixel density integrated arrays for microdisplays (AR/MR/VR):

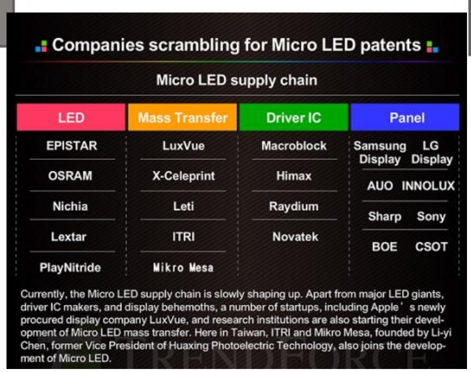








Source: Eric Virey, YOLE, Phosphor Global Summit, March 2018, San Diego, CA
µ-LEDs cinemas are under construction worldwide

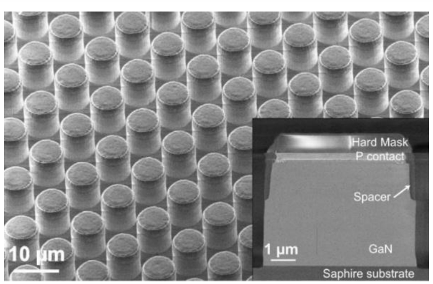

Companies scrambling for Micro LED patents

Micro LED supply chain

LED	Mass Transfer	Driver IC	Panel
EPISTAR	LuxVue	Macroblock	Samsung Display, LG Display
OSRAM	X-Celeprint	Himax	AUO, INNOLUX
Nichia	Leti	Raydium	Sharp, Sony
Lextar	ITRI	Novatek	BOE, CSOT
PlayNitride	Mikro Mesa		

Currently, the Micro LED supply chain is slowly shaping up. Apart from major LED giants, driver IC makers, and display behemoths, a number of startups, including Apple's newly procured display company LuxVue, and research institutions are also starting their development of Micro LED mass transfer. Here in Taiwan, ITRI and Mikro Mesa, founded by Li-yi Chen, former Vice President of Huaxing Photoelectric Technology, also joins the development of Micro LED.

TRENDFORCE



The Future of Science - Diversification and Globalisation

Globalisation

Present major experiments host international communities!

- **Space stations: Spacelab, MIR, ISS**
- **Neutrino detectors**
- **Gravitation waves detectors**
- **Large telescopes: VLT, ELT, …**
- **Particle accelerators: BESSY, DESY, SLAC, CERN, …**

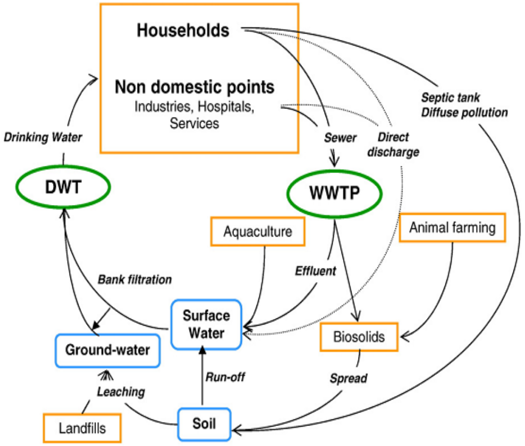
Large Hadron Collider
Proton - Proton Collisions
7 TeV vs. 7 TeV
d ~ 9 km, Ring ~ 27 km

The Future of Science - Diversification and Globalisation

Globalisation

Problem areas of the 21st century are of global relevance

- Climate Change due to CO_2 Emission
- Air, Soil and Water Pollution
- Demand for Strategic Metals
- Dissipation of Heavy Metals into the Environment
- Entry of Pharmaceuticals into the Aquatic System
- Demographic Development (Society ageing)
- Waste Disposal (Radioactive material, electronics, …)



The Future of Science

Diversification (an example)

Science

Physics — **Astronomy** — **Arithmetics** — **Geometry**

Mechanics — **Geometrical optics** — **Electrodynamics and so on**

Quantum mechanics — **Classical mechanics** — **Biomechanics and so on**

Q. electro dynamics — **Q. chromo dynamics** — **Q. gravitation and so on**

???

The ultimate goal of science is to understand completely how the universe works for which novel disciplines steadily develop …..

The Future of Science

Diversification of Astronomy

- Astrobiology
- Astrochemistry
- Astrometry
- Astrophysics
- Celestial mechanics
- Cosmology
- Didactics of astronomy
- Extrasolar planets and moons
- Extragalactic astronomy
- History of astronomy
- Nautical and aeronautical astronomy
- Neutrino astronomy
- Planetology
- Radio astronomy
- Stellar astronomy
- X-ray astronomy

~ 10^{12} galaxies in the observable universe

~ 10^{22} stars in the observable universe

~ 10^{26} planets in the observable universe

~ 10^{30} bacteria on Earth

~ 10^{78} – 10^{82} atoms in the observable universe

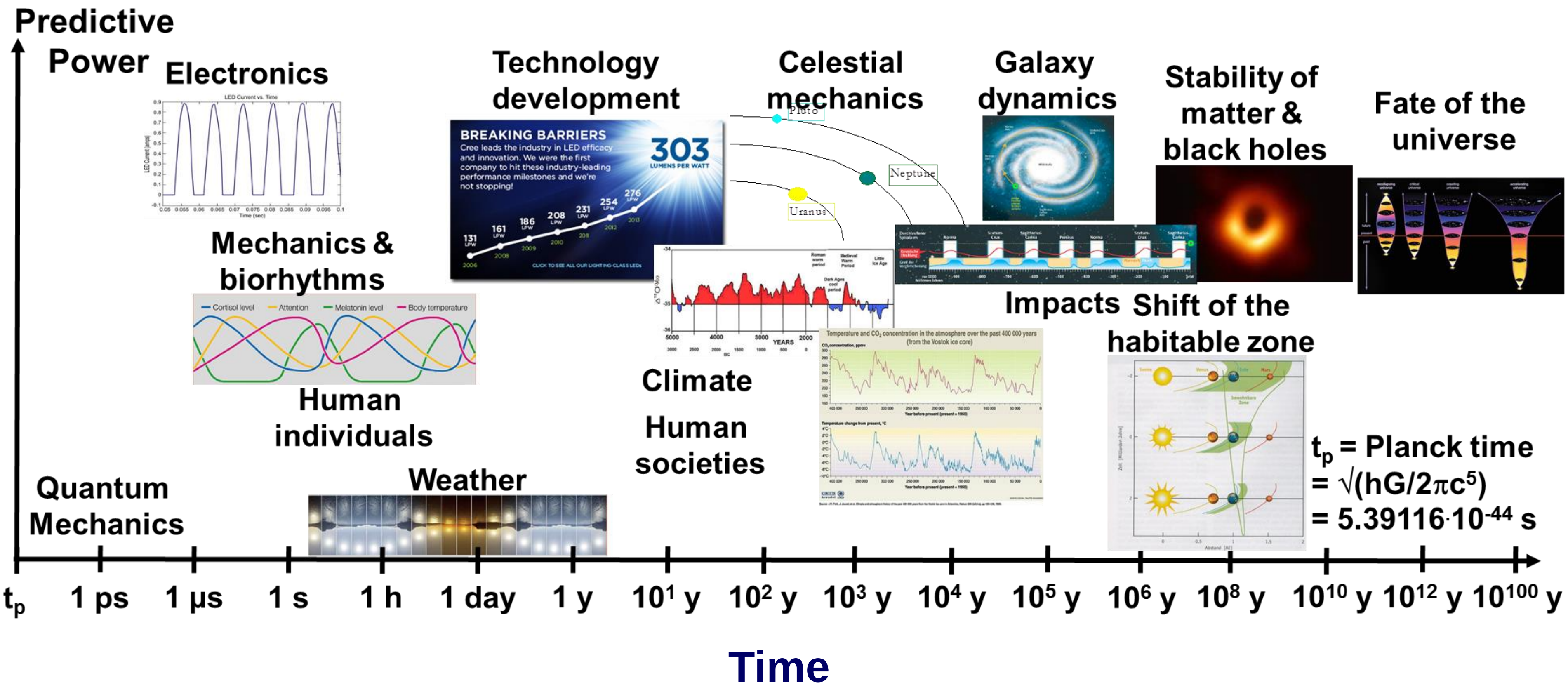
The Future of Science

Clarify the role of humans in the Universe

- Detection of exoplanets and life on other space bodies, formation of planetary systems (adaptive optics, space telescopes and probes)
- Physics of black holes, pulsars, magnetars, quasars (gravitation waves and neutrino detectors)
- Nature of dark matter and dark energy
- Detection of supersymmetric particles, GUT to join QM and GRT
- Are physical constants constant?
- Long-term stability of matter and black holes
- Fate of the observable universe

The Future of Science

Improve quality of scientific predictions, e.g. the weather forecast or climate change (to enable better business & political decisions)



The Future of Science

Main goal: Secure the future of humans on our planet Earth

Science for a sustainable development and for contributions to solve global challenges:

- Climate change
- Dissipation of metals and micro pollutants
- Plastic waste and micro plastics
- 6th mass extinction
- Antibiotics resistance
- Mass animal farming
- Limited phosphate sources
- Acidification of oceans
- Urbanization
- Renewable energy sources
- Desertification
- Rise of the sea level
- Extreme poverty
- Energy consumption and risks of digitalization
- Migration and growing mobility

What is the History of Science?

Origin

History of science developed late 19th to early 20th century, largely in tandem with the philosophy of science. Most practitioners are scientists themselves, reflexively interested in their fields. One goal is to define the nature of science.

Science is widely presented as the enterprise of producing universal truth. Assumption that the stock of known truth is, by definition, generally agreed on, and always increases whenever worthwhile research happens.

According to this vision, history of science is a tale of upward, cumulative progress:

- **William Whewell, *History of the Inductive Sciences*, 1847**
- **George Sarton, *Introduction to the History of Science*, 1927**
- **C. C. Gillispie, *The Edge of Objectivity*, 1960**

INTRODUCTION 9

which the mind of the philosopher employs itself;—the history of those branches of knowledge for the last three hundred years abundantly teaches us.

Accordingly, the existence of clear ideas applied to distinct facts will be discernible in the History of Science, whenever any marked advance takes place. And, in tracing the progress of the various provinces of knowledge which come under our survey, it will be important for us to see, that, at all such epochs, such a combination has occurred; that whenever any material step in general knowledge has been made,—whenever any philosophical discovery arrests our attention;—some man or men come before us, who have possessed, in an eminent degree, a clearness of the ideas which belong to the subject in question, and who have applied such ideas in a vigorous and distinct manner to ascertained facts and exact observations. We shall never proceed through any considerable range of our narrative, without having occasion to remind the reader of this reflection.

Successive steps in Science.—But there is another remark which we must also make. Such sciences as we have here to do with, are, commonly, not formed by one single act;—they are not completed by the discovery of one great principle. On the contrary, they consist in a long-continued advance; a series of changes; a repeated progress from one principle to another, different and often apparently contradictory. Now, it is important to remember

What is Science? Some Citations (in German)

Selected Aphorisms and Statements

- **Die Wissenschaft ist der auserlesenste Weg, um das Menschengemüt heroisch zu gestalten. (Giordano Bruno, ital. Astronom, 1548-1600)**
- **Wissenschaft ist das Wissen um Konsequenzen und um die Abhängigkeit einer Tatsache von einer anderen. (Thomas Hobbes, engl. Philosoph, 1588-1679)**
- **Wissenschaft ist das beste Gegengift gegen die Gifte der Inbrunst und des Aberglaubens. (Adam Smith, schott. Ökonom, 1723-1790)**
- **Wissenschaft ist das Bedürfnis, Ursachen herauszufinden. (William Hazlitt, engl. Essayist, 1778-1830)**
- **Wissenschaft ist organisiertes Wissen. (Herbert Spencer, engl. Philosoph und Soziologe, 1820-1903)**
- **Wissenschaft ist, was man weiß. Philosophie ist, was man nicht weiß. (Bertrand Russell, brit. Philosoph, 1872-1970)**
- **Wissenschaft ist ein fantastisches Abenteuer des Geistes, der in einer Welt voller Rätsel die Wahrheit sucht. (Cyril Herman Hinshelwood, engl. Chemiker, 1897-1967)**

What is Science? Some Citations (in German)

Selected Aphorisms and Statements

- Wissenschaft ist ein großes Spiel. Es ist inspirierend und erfrischend. Das Spielfeld ist das ganze Universum. (Isidor Isaac Rabi, US-amerik. Physiker, 1898-1988)
- Wissenschaft entsteht im Gespräch. (Werner Heisenberg, dt. Physiker, 1901-1976)
- Wissenschaft ist wie Sex. Manchmal kommt etwas Sinnvolles dabei raus, das ist aber nicht der Grund, warum wir es tun. (Richard Phillips Feynman, US-amerik. Physiker, 1918-1988)
- Wissenschaftlicher Fortschritt hängt teilweise von einem Prozess des nicht-inkrementellen oder revolutionären Fortschritts ab. (Thomas S. Kuhn, US-amerik. Physiker, 1922-1996)
- Wissenschaft macht die größten Fortschritte, wenn Beobachtungen uns dazu zwingen, unsere Annahmen zu überdenken. (Vera Rubin, US-amerik. Astronomin, 1928-2016)
- Wissenschaft ist die interesselose Suche nach der objektiven Wahrheit über die materielle Welt. (Richard Dawkins, brit. Evolutionsbiologe, 1941-)

Further Reading

Journals

- Angewandte Chemie
- Biologie in unserer Zeit
- Chemie in unserer Zeit
- Journal of Luminescence
- Light: Science & Applications
- Nature
- Nature Photonics
- Photonik
- Physik in unserer Zeit
- Science
- Sky & Telescope
- Spektrum der Wissenschaft
- Sterne und Weltraum

Books

- William H. Kalvin, Der Schritt aus der Kälte, Dtv 2000
- G.F. Miller, Die sexuelle Evolution, Spektrum akademischer Verlag 2001
- Gabrielle Walker, Schneeball Erde, Berlin-Verlag 2003
- B. Bryson, A Short History of Nearly Everything 2003
- J. Bennett, M. Donahue, N. Schneider, M. Voit, Astronomie, Pearson 2010
- P. Kunitzsch, Der Almagest, Springer 2011
- P.D. Ward, D. Brownlee, Unsere einsame Erde, Springer 2012
- N. Welsch, J. Schwab, C.C. Liebmann, Materie, Springer 2013