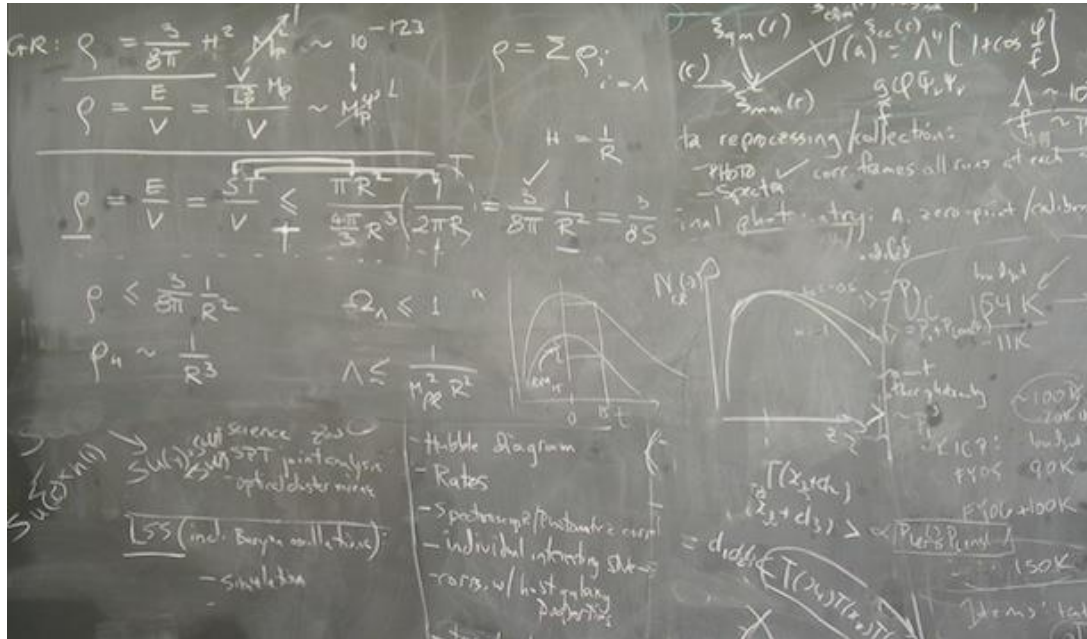


History of Science (Wissenschaftsgeschichte)



Prof. Dr. Thomas Jüstel

e-mail: tj@fh-muenster.de, skype: thomasjuestel

web: <https://www.fh-muenster.de/juestel>

**Department Chemical Engineering (CIW)
Institute for Optical Technologies (IOT)
FH Münster University of Applied Sciences**

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 artificial light sources

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



INTERNATIONAL
YEAR OF LIGHT
2015

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

Electricity
Magnetism

Chemistry
Biology

Driver of natural and cultural evolution

Historical Development of Light Sources

Prehistoric period

Antiquity

18th century

19th century

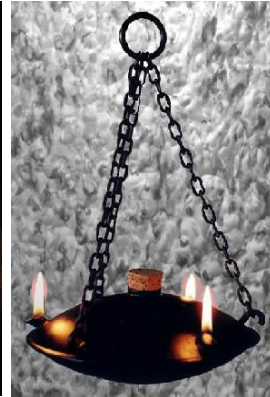
Access to suitable energy sources ↑



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

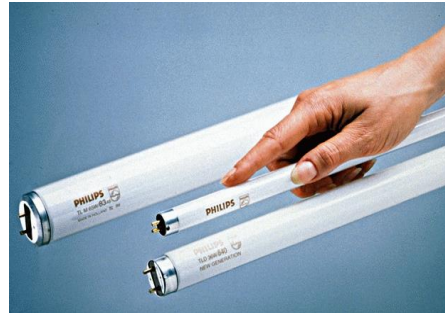
21st century

Lifetime, luminosity, luminous efficacy, Tc, light quality↑

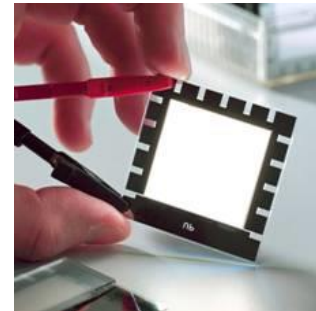
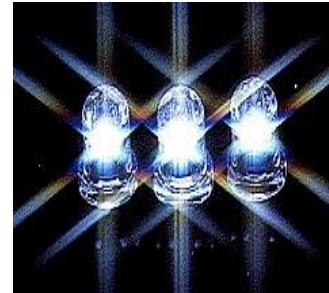
Incandescent and halogen lamps



Gas discharge lamps



Inorganic and organic LEDs



High brightness LEDs and laser diodes



Historical Development of Light Sources

History of non electric lighting

1.37·10¹⁰ years ago

1.3·10¹⁰ years ago

1·10⁹ years ago

400000 years ago

13000 years ago

5000 B.C.

1000 B.C.

600 B.C.

280 B.C.

1608

1668

1772

1783

1784

1826

Big bang

First stars and galaxies

Bioluminescence

Torches and open fire

Primitive stone lamps

Fat lamps with wick

Candles

Oil ceramic lamps

First lighthouse (Alexandria)

Telescope (refractor)

Newton telescope (reflector)

Gas lamps

Petroleum lamps

Argand lamp (lamp with a hollow wick)

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

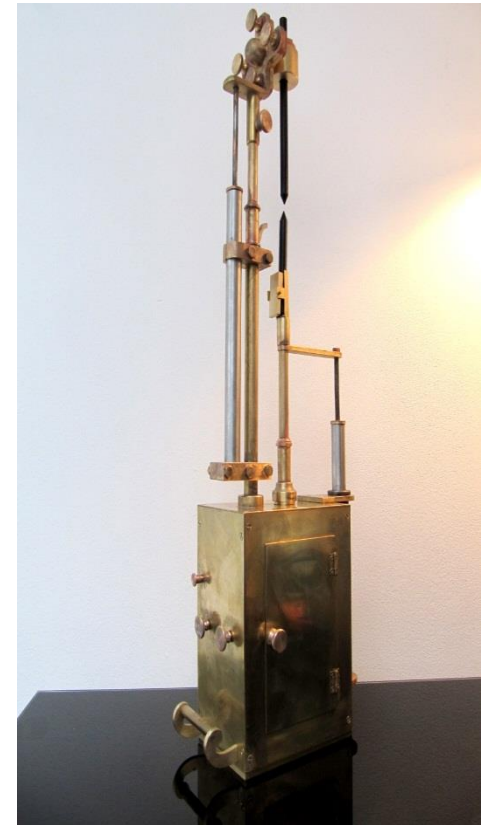
- In nature: Thunder & Lightning
- 17th and 18th century
 - Artificially made sparks by electrostatic charging
 - Electricity for social events & entertainment
- 1800: Development of the battery by Alessandro Volta
 - Voltaic columns mad from copper and zinc layers, separated by an electrolyte
 - continuous 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 adjustment of electrodes
- Advantage: High intensity and luminous flux
- Application in head lights and projection



Historical Development of Light Sources

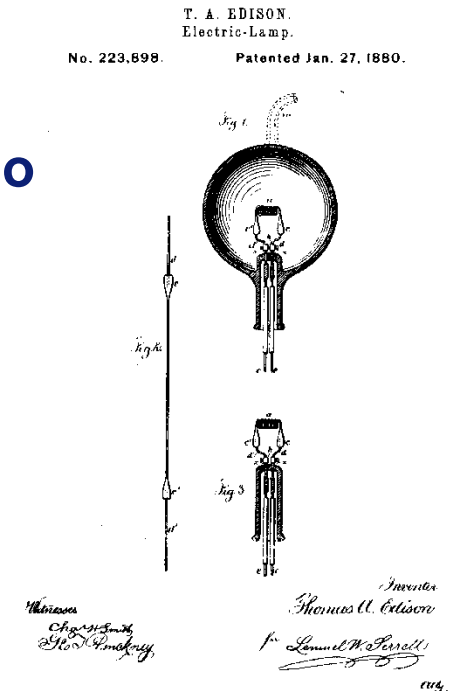
Experiment conducted by Thomas Alva Edison (1847-1931)



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

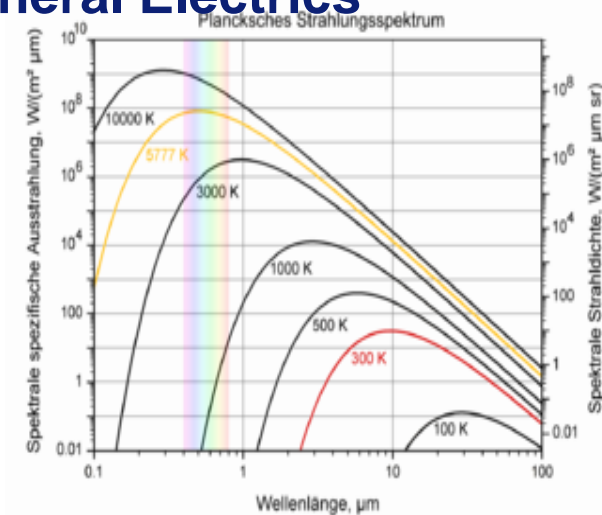
- Burns since 1901
- 4 Watts and 110 Volts
- Carbon filament
- Internet address:
<http://www.centennialbulb.org/>



Historical Development of Light Sources



Further development of incandescent lamps

- 1890: Conversion of the electrical grid to AC
- Coil material development:
 - Osmium ($T_m = 3130 \text{ °C}$) and Tantal ($T_m = 3017 \text{ °C}$)
 - 1904: Patent for tungsten coil
 - 1912: Use of tungsten ($T_m = 3422 \text{ °C}$) by General Electric
- 1911: Vacuum replaced by Argon-N₂ blend
- 1936: First use of a double coil
- 1959: Halogen cycle to reduce tungsten 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 on mercury vapour lamps	
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 $\text{CaWO}_4 + \text{Zn}_2\text{SiO}_4:\text{Mn}$	
1938	GE	Fluorescent lamp with $\text{MgWO}_4 + (\text{Zn},\text{Be})_2\text{SiO}_4:\text{Mn}$	
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	

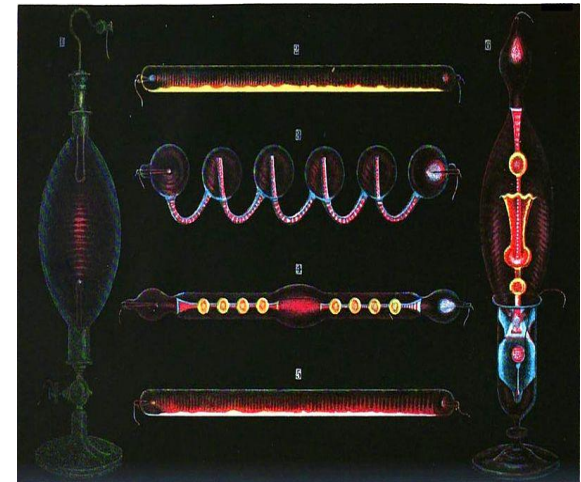
Historical Development of Light Sources

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

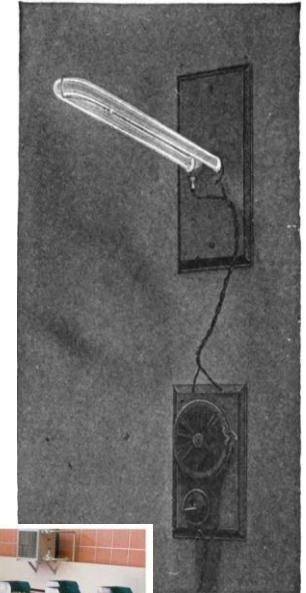
**Started development of many
types of gas discharge lamps**



Historical Development of Light Sources

Gas discharge lamps

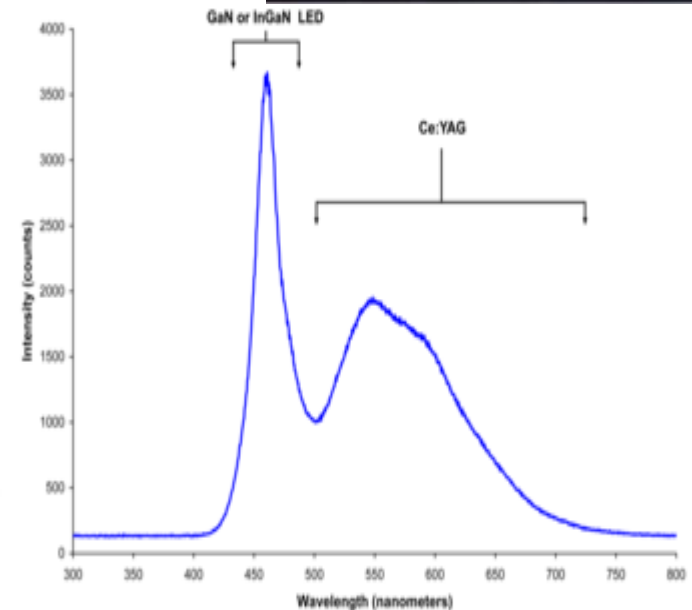
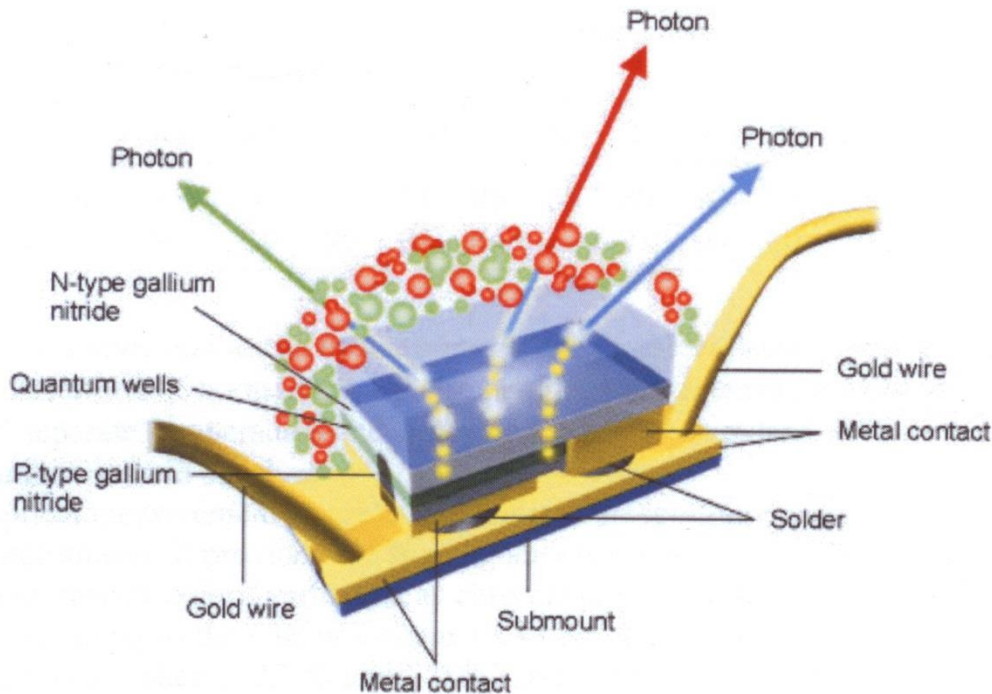
- 1900:** Hg vapour lamp by Cooper & Hewitt
No luminescent materials yet
→ Bluish green emission
- 1930ties:** Development of lamp phosphors for the conversion of Hg line at 254 nm
- 1938:** Start of commercial use
- 1948:** Begin of TL lamp production at Philips Lighting Roosendaal, NL
- 2015:** End 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 / $\text{Sr}_2\text{Si}_5\text{N}_8\text{:Eu}$
2004	Mitsubishi	Deep red emitting $\text{CaAlSiN}_3\text{:Eu}$
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 $\text{La}_3\text{Si}_6\text{N}_{11}\text{:Ce}$
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


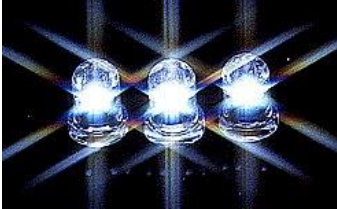


Nick Holonyak, jr. (2000)

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 $R_a = 0 \dots 100$
- ⇒ „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

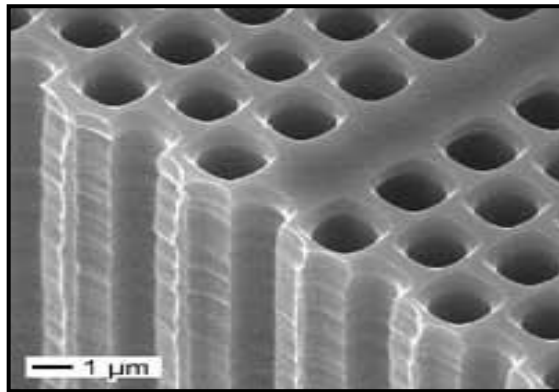
Historical Development of Light Sources

Recent improvement by photonic crystals

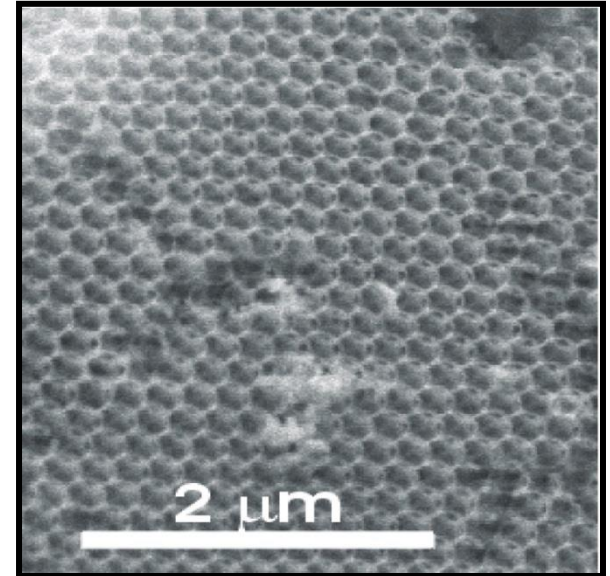
... to increase light outcoupling of light sources

... to reduce IR emission

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



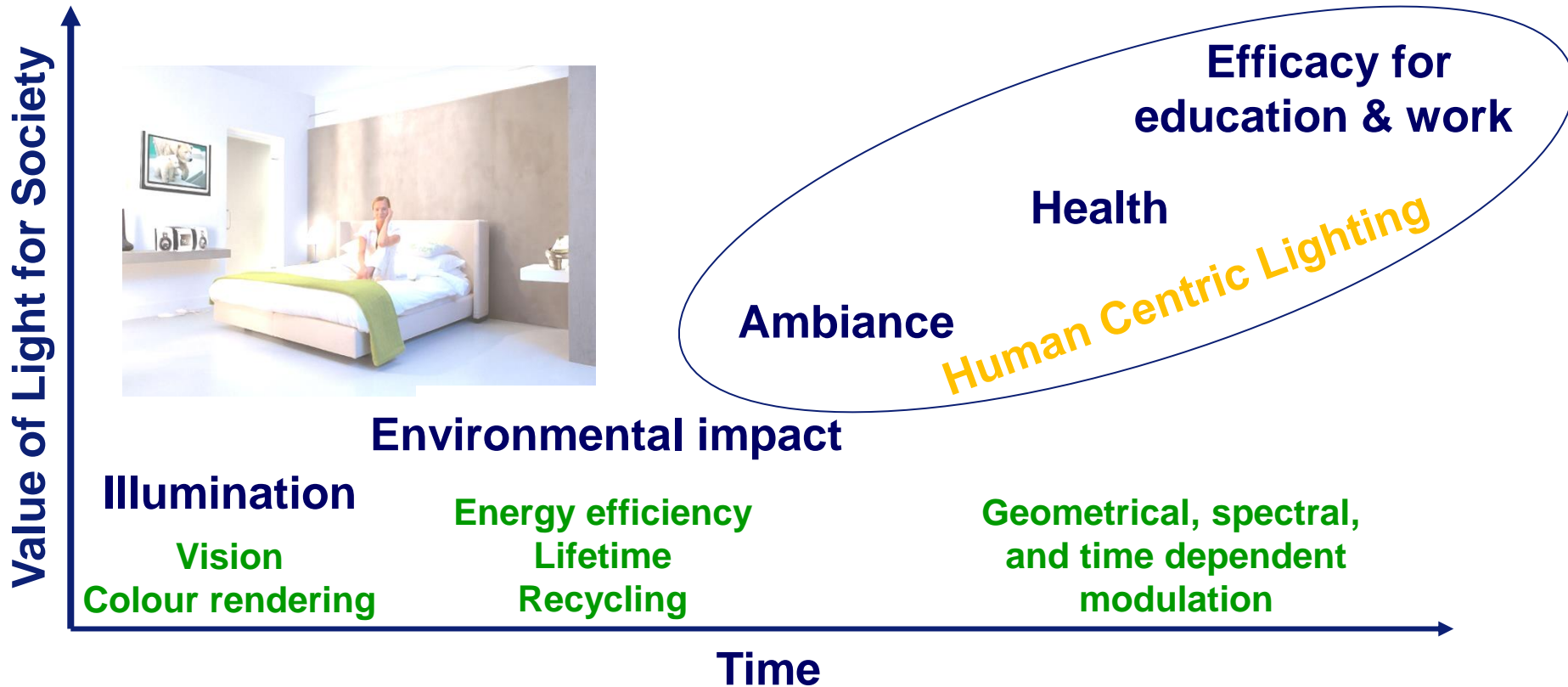
Tungsten filament with photonic
band structure via 3D-structuring



Inverse opal / TiO₂ basis

Historical Development of Light Sources

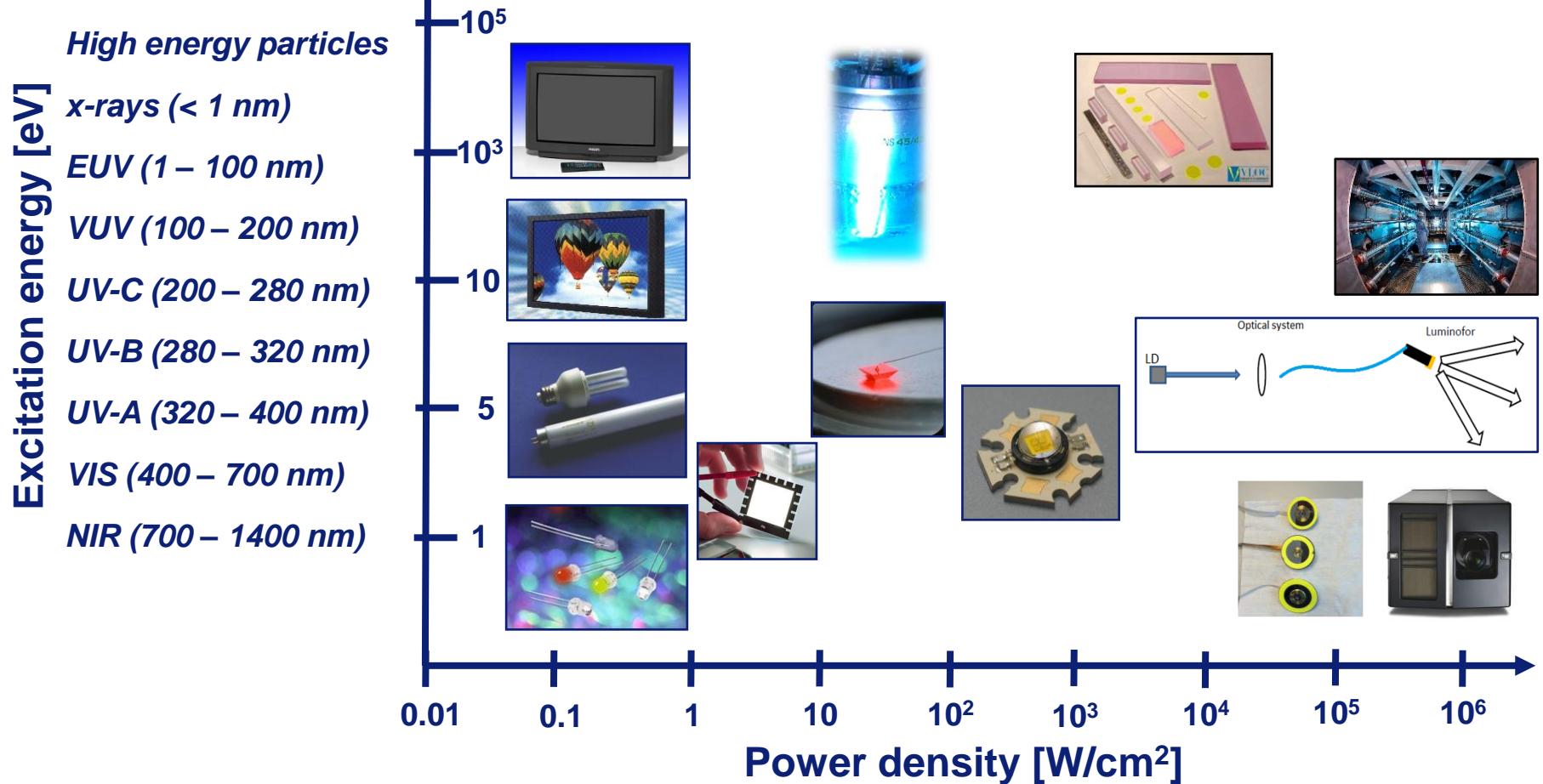
Future Trends: Human Centric Lighting (HCL)



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

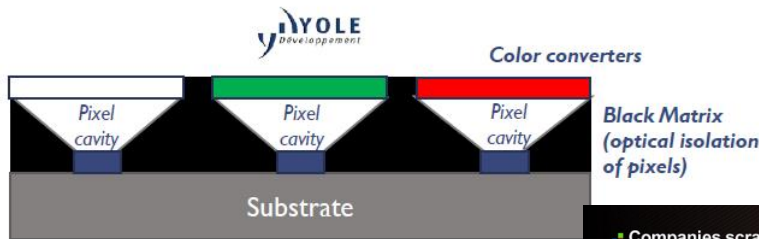
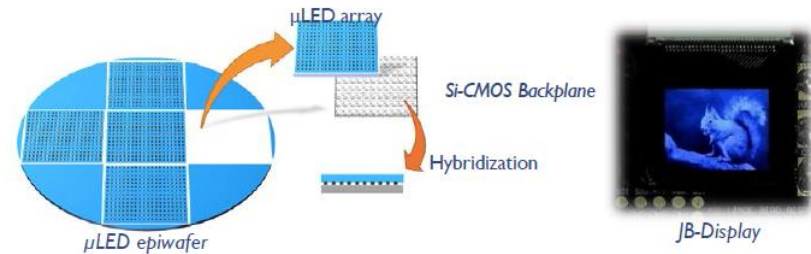
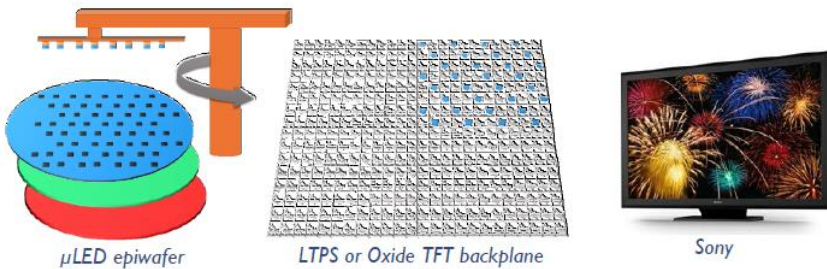


Historical Development of Light Sources

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):



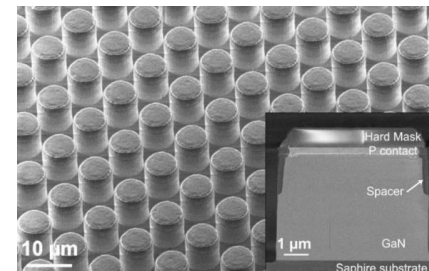
Source: Eric Virey, YOLE,
Phosphor Global Summit,
March 2018, San Diego, CA
μ-LEDs cinemas are under
construction worldwide

Companies scrambling for Micro LED patents

Micro LED supply chain

LED	Mass Transfer	Driver IC	Panel
EPSTAR	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.



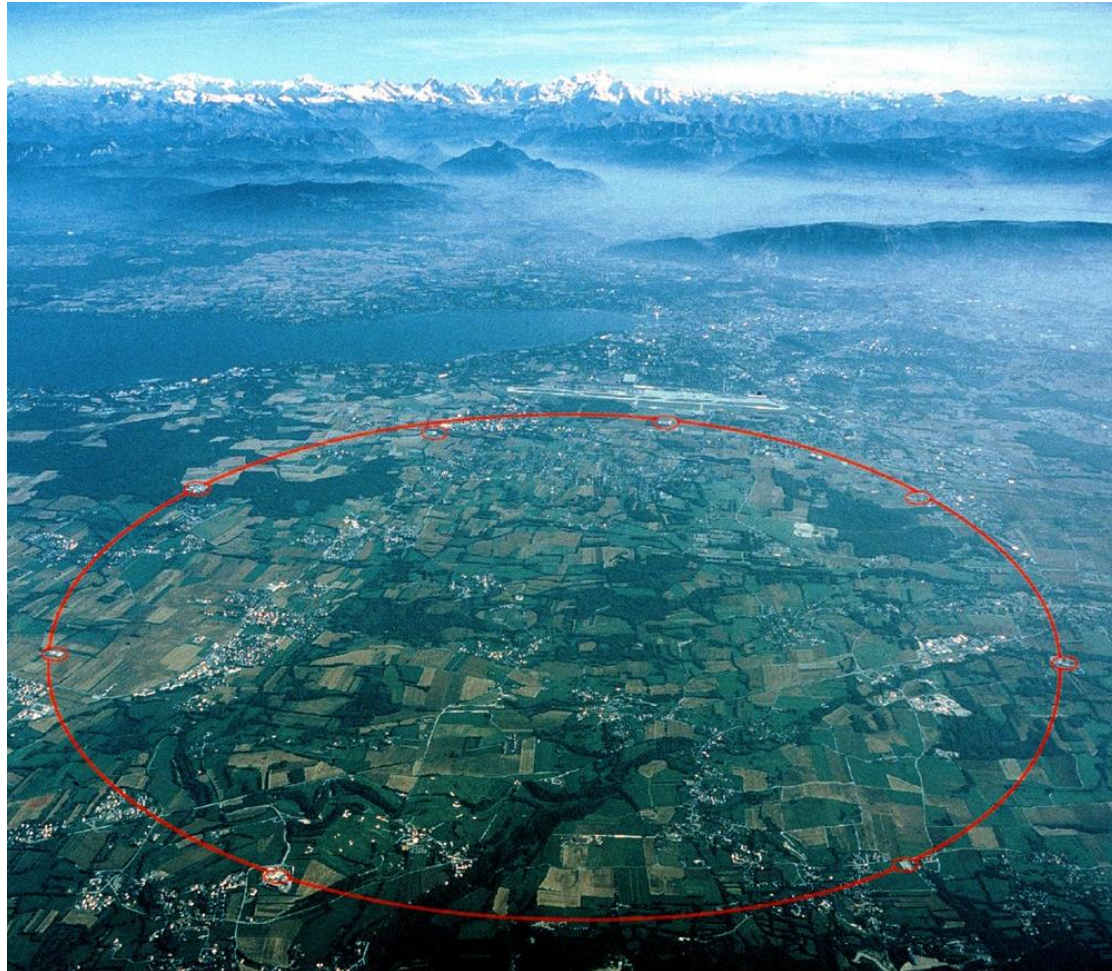
The Future of Science - Diversification and Globalisation

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

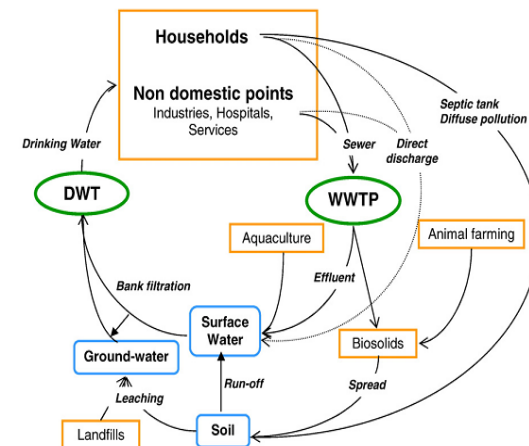


The Future of Science - Diversification and Globalisation

Globalisation

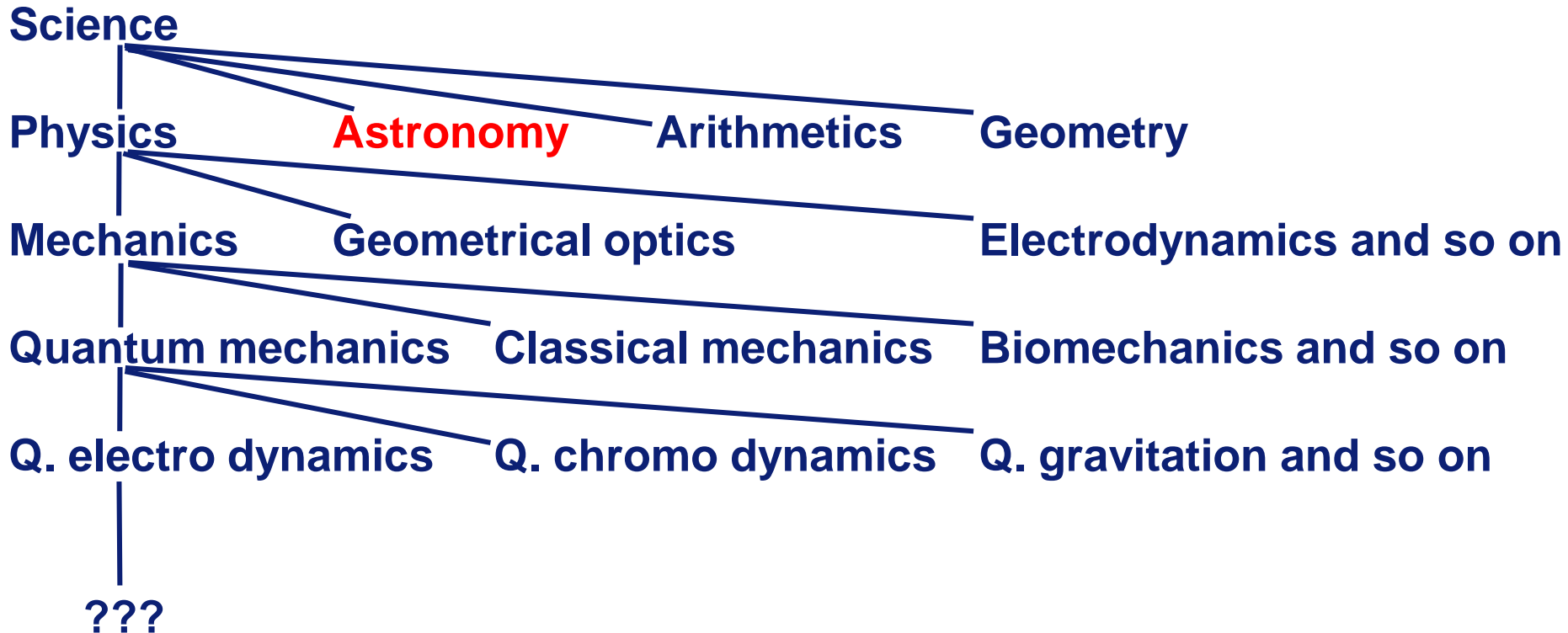
Problem areas of the 21st century are of global relevance

- Climate Change due to CO₂ 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)



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

**$\sim 10^{12}$ galaxies in the
observable universe**

**$\sim 10^{22}$ stars in the
observable universe**

**$\sim 10^{26}$ planets in the
observable universe**

**$\sim 10^{30}$ bacteria on
Earth**

**$\sim 10^{78} - 10^{82}$ atoms in the
observable universe**

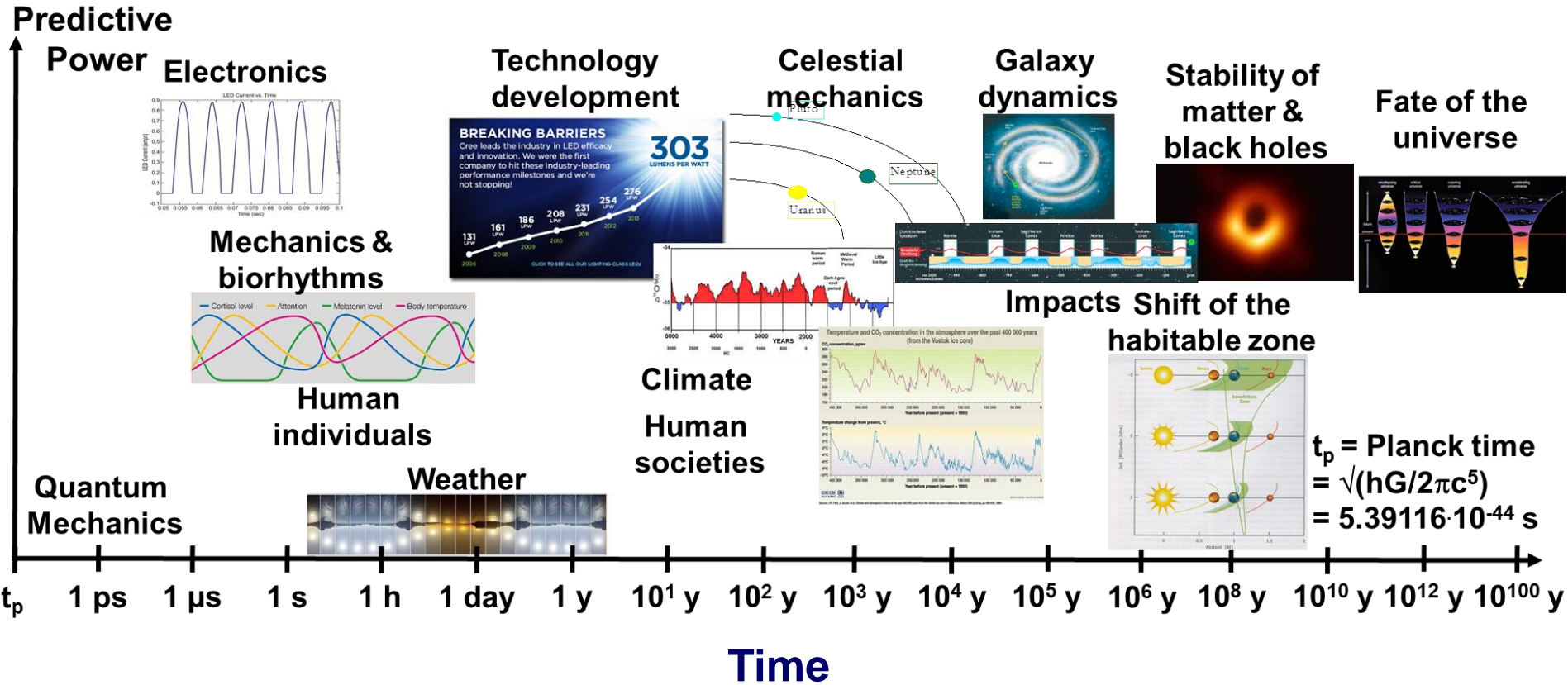
The Future of Science

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. Calvin, 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