EPIC Meeting on New Space at European Space Agency

Lasers for quantum optics: From laboratory into real life – and into space?

Dr. Thomas Renner, CSO TOPTICA Photonics AG

13.9.2019

All Wavelengths.

190 nm - 0.1 THz

TOPTICA Group: Key Figures

Key Figures

Employees	300
Revenues	70 Mio €
Founded	1998
HQ	Munich/Germany

Technology

Diode Laser Systems
Ultrafast ps/fs Fiber Lasers
Frequency Combs
eagleyard Laser Diodes

Markets

Quantum Technologies
Biophotonics & Microscopy
Materials inspection & processing

Science: Industry = 50/50

Visions of Quantum Optics for Commercial Applications

Quantum Computing

New Drugs

Ca^+ Yb^+ Sr JJ Rb Yb QD Sr^+ Mg^+ K hν Na Cs Li Ba^+

Quantum Sensing

Map Earth and Brain

Rb NV K Sr Yb Cs Li Xe Hg He Yb^+

Quantum Communication

Secure Cryptography

NV Rb hν Ca^+ Yb^+ QD Cs Pr^{3+} Eu^{3+} SiV Er^{3+} Tm^{3+} Nd^{3+}

Quantum Metrology

Navigation Accuracy

Sr Hg Yb Ca+ Yb^+ Ca Hg^+ Al^+ Sr^+ H Cd Th^{3+} In^+

Example 1: Clock – Real life point of view

Mantle Clock, around 1900

accuracy: seconds per day (10^{-4})

accuracy of the best mechanical clocks: seconds per year (10^{-7})

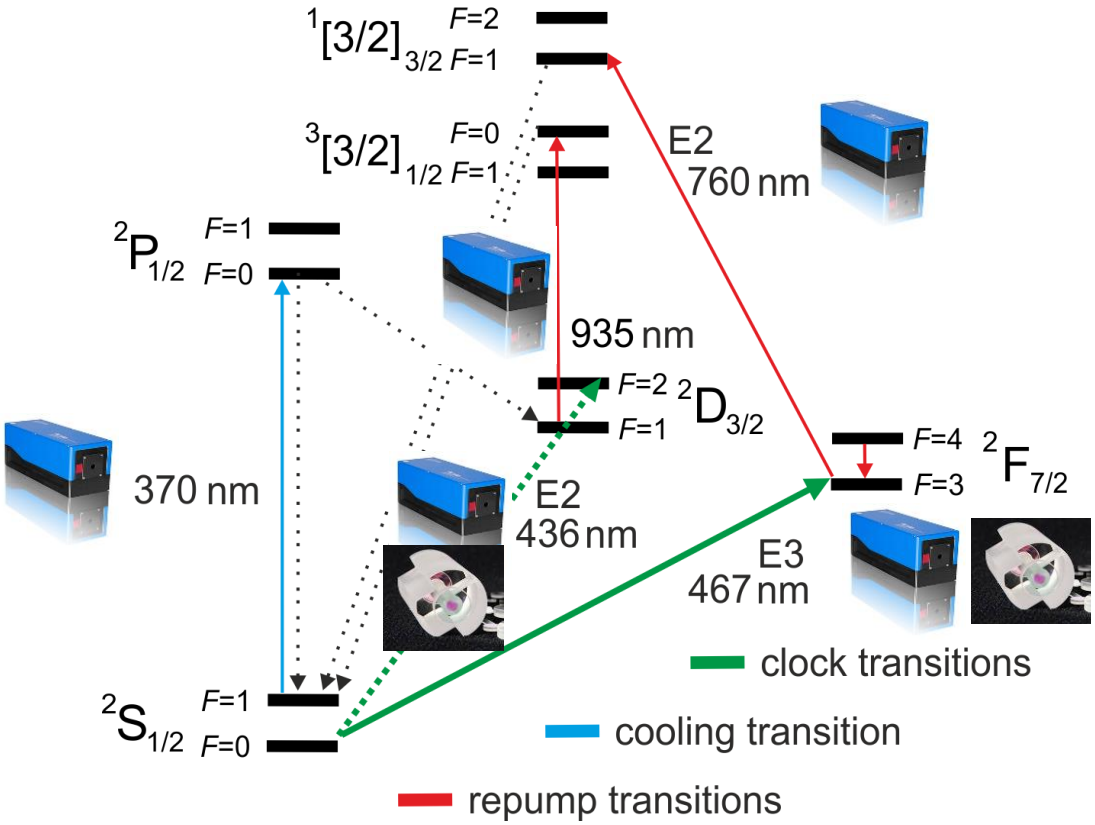
Example 1: Optical Clock – Laboratory point of view

Modern Optical Atomic Clock

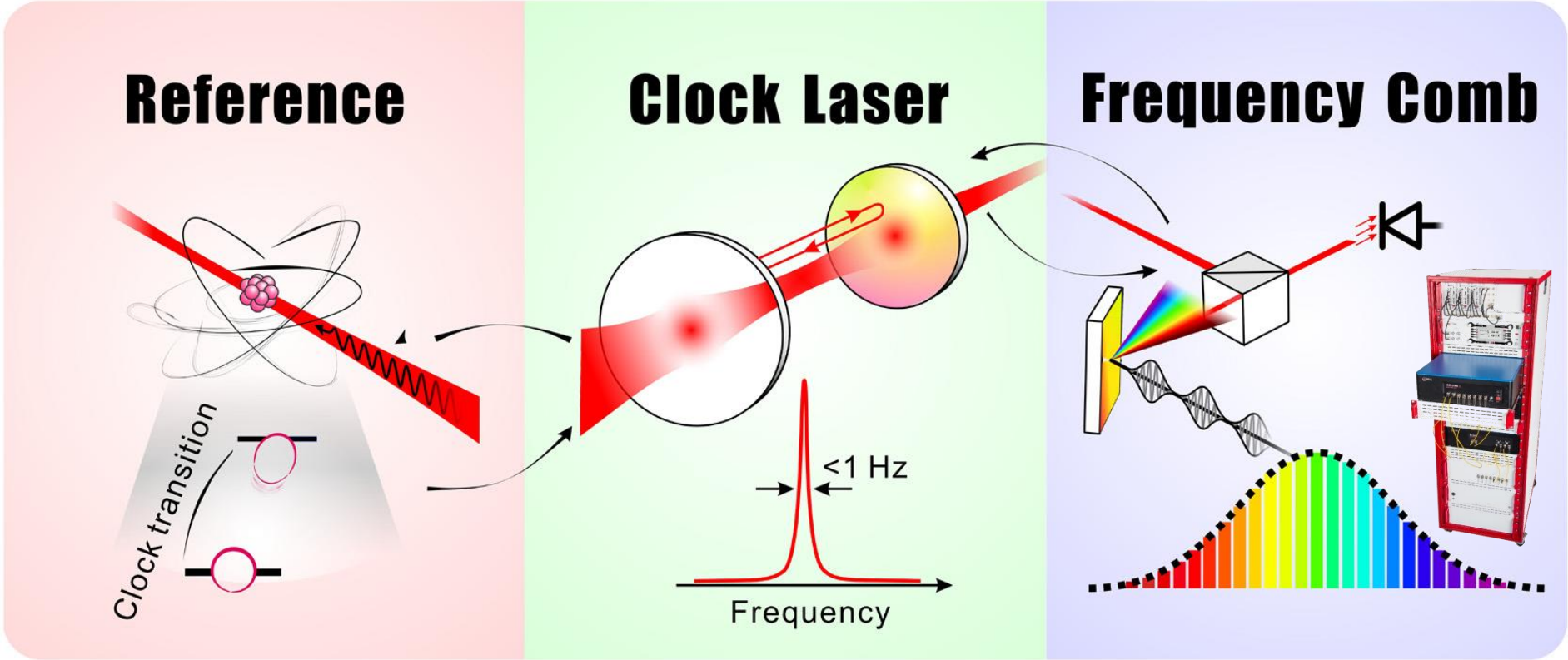
here: Yb ion clock @ PTB

accuracy: seconds in the age of the universe ($3 \cdot 10^{-18}$)

Example 1: Optical Clock (Yb+) – Physicist point of view



Example 1: Optical Clock – Laser point of view (state of the art)

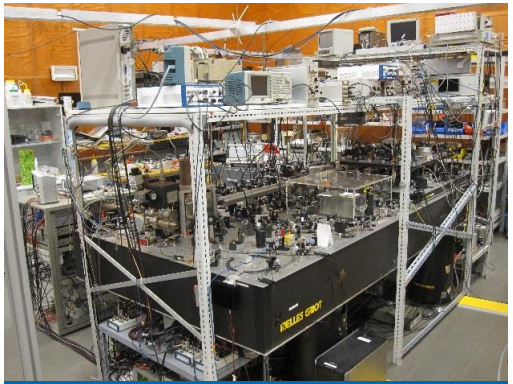


Atomic Transition (+ Preparation Lasers)	Clock Laser	Frequency Comb (= Freq. Translator)

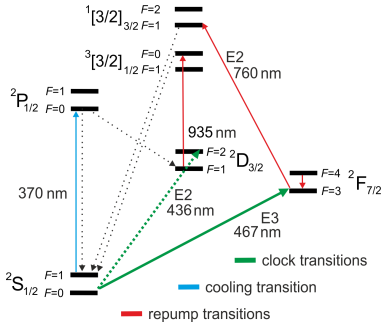
taken from Dumke et al., Journal of Optics 18, 093001 (2016)

Summary: Optical Clock from different points of view

Real Life



Laboratory



Physics

Laser

Example 2: Computer – same story

Mechanical calculator (1940)

basic arithmetics

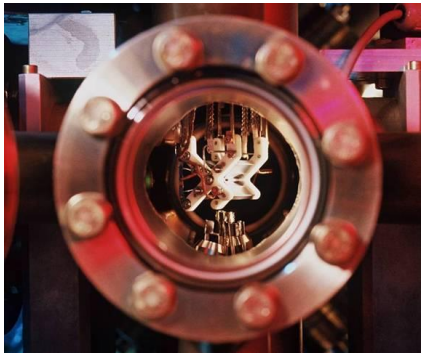
13 digits

Quantum Computer

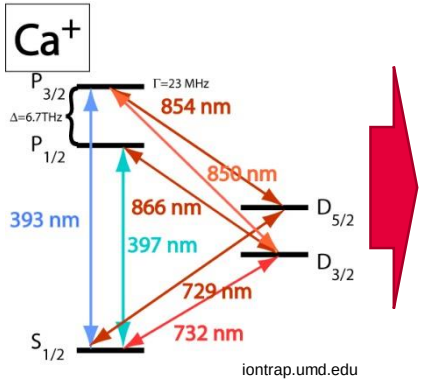
here: ion-trap, IQOQI Innsbruck,
20 qubits

300 qubits can represent more values than there are atoms in the observable universe.

Real Life



Laboratory



Physics

Laser

Example 3: Scale (nano-gravitation) – same story

Precision Balance

principle used since >4000 years

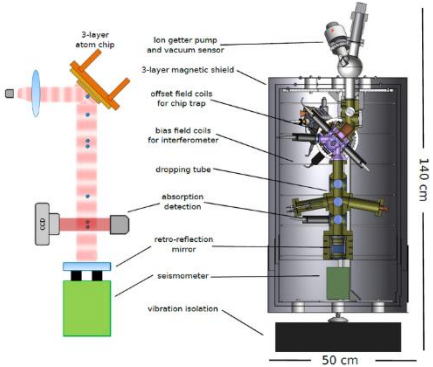
gravity is measured using falling masses

Modern Quantum Sensor

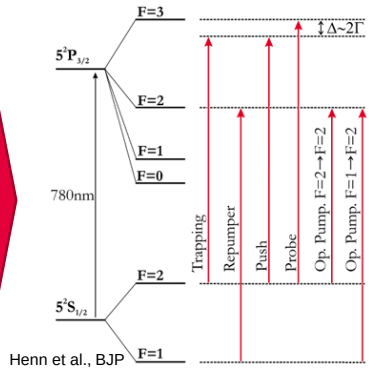
here: quantum gravimeter, falling atoms
Leibniz Universität Hannover

absolute gravity measurements $<10^{-9}$ g

Real Life

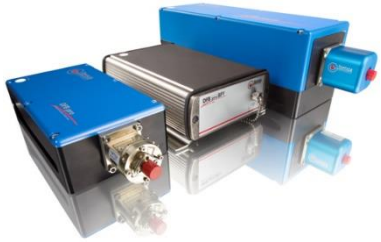


Laboratory



Henn et al., BJP

Physics



Laser

Example 4: Communication – same story

Telephone, before 1945

first “call” in 1876

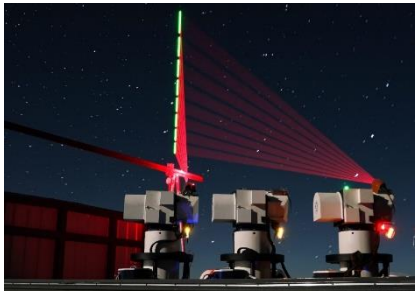
digital communication since 1980

Quantum Cryptography

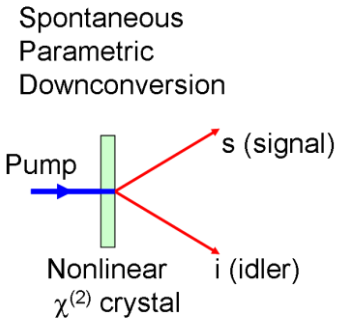
here: parametric downconversion,
quantum satellite Micius

physically secure communication

Real Life



Laboratory

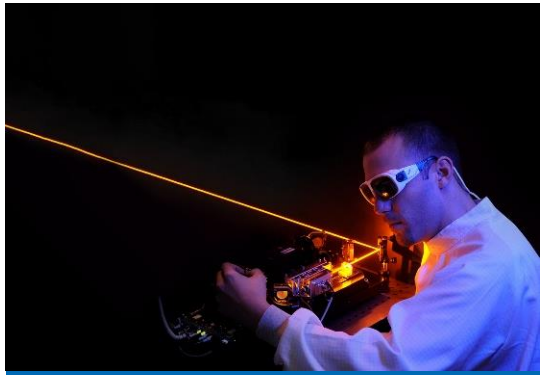


Wikipedia.org

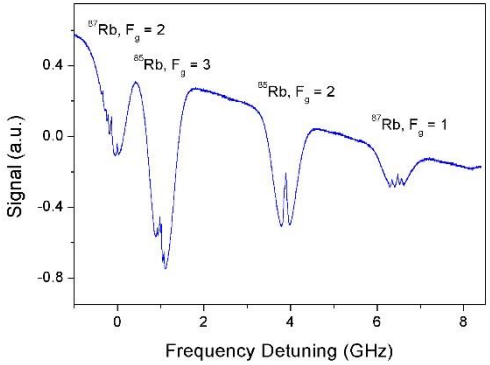
Physics

Laser

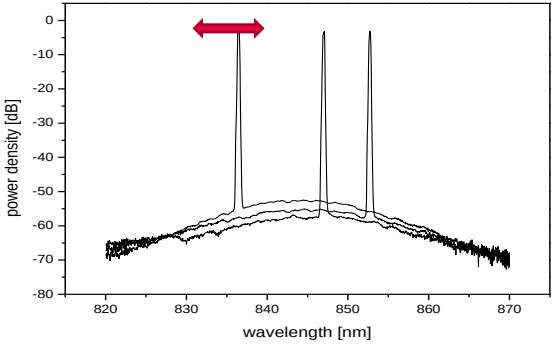
Common requirements of all applications for the lasers



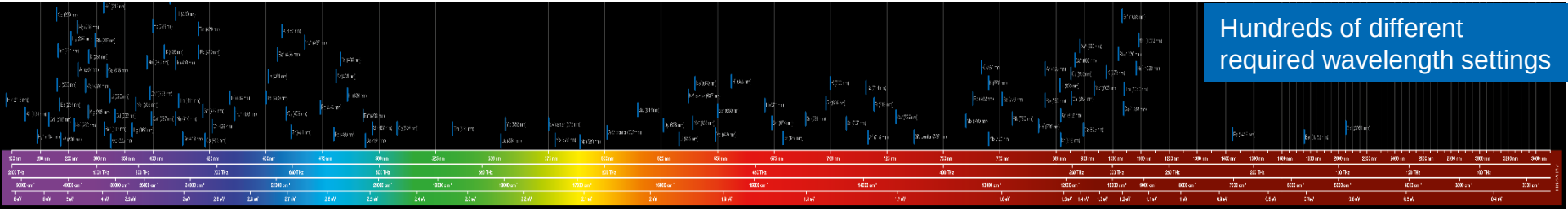
Laser power
(100 mW .. 10 W)



Laser line width << atomic transition linewidth (Hz .. MHz)

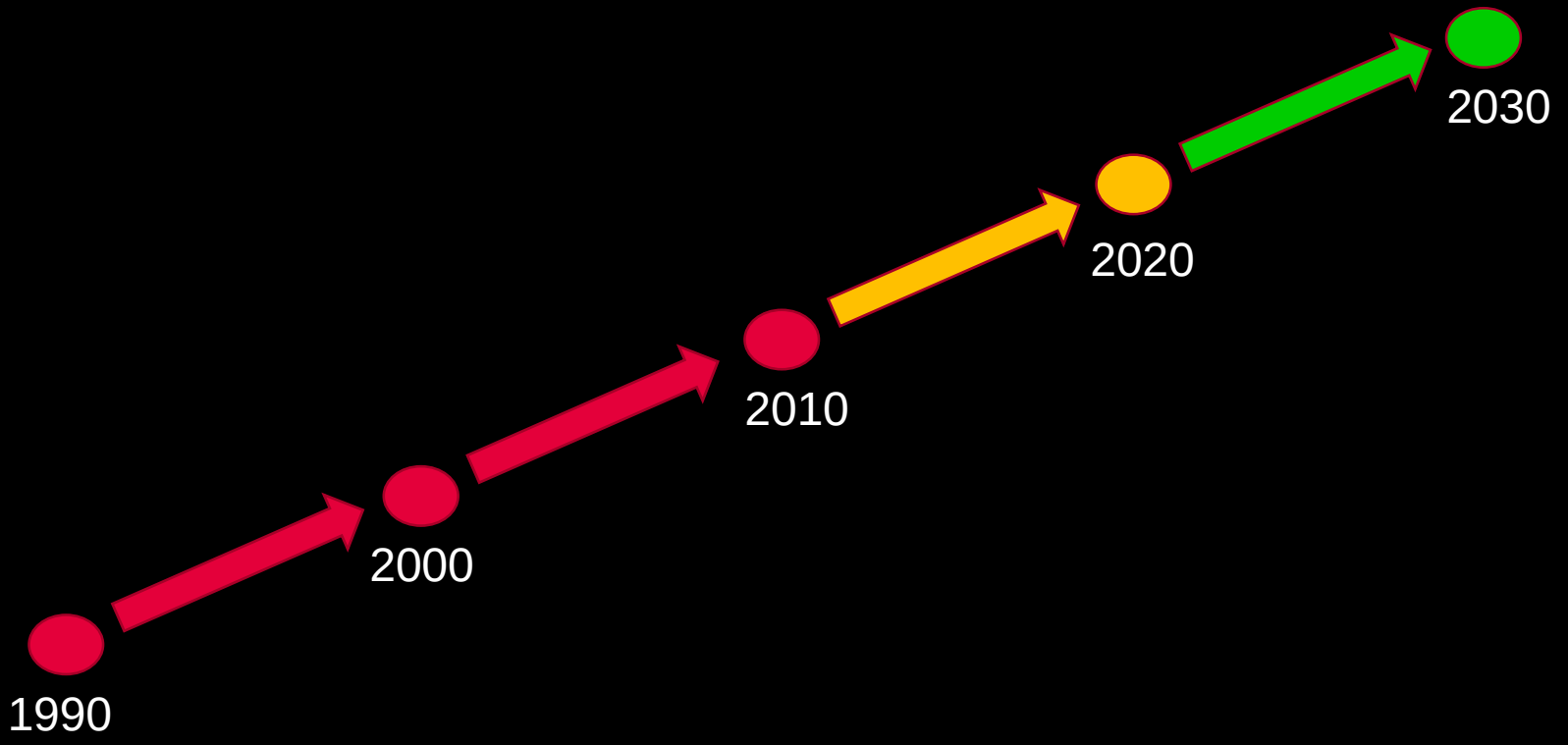


Resonant with atomic transition
→ Tunable (50 GHz)



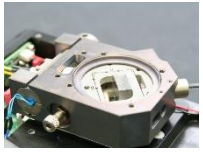
Hundreds of different required wavelength settings

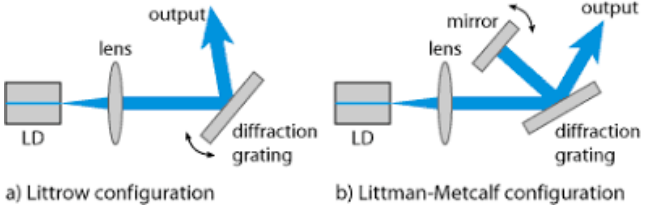
Lasers in QT: History & Future



1990: Dye Lasers -> ECDL Diode Lasers

Up to now:
>10.000 TOPTICA ECDL installed

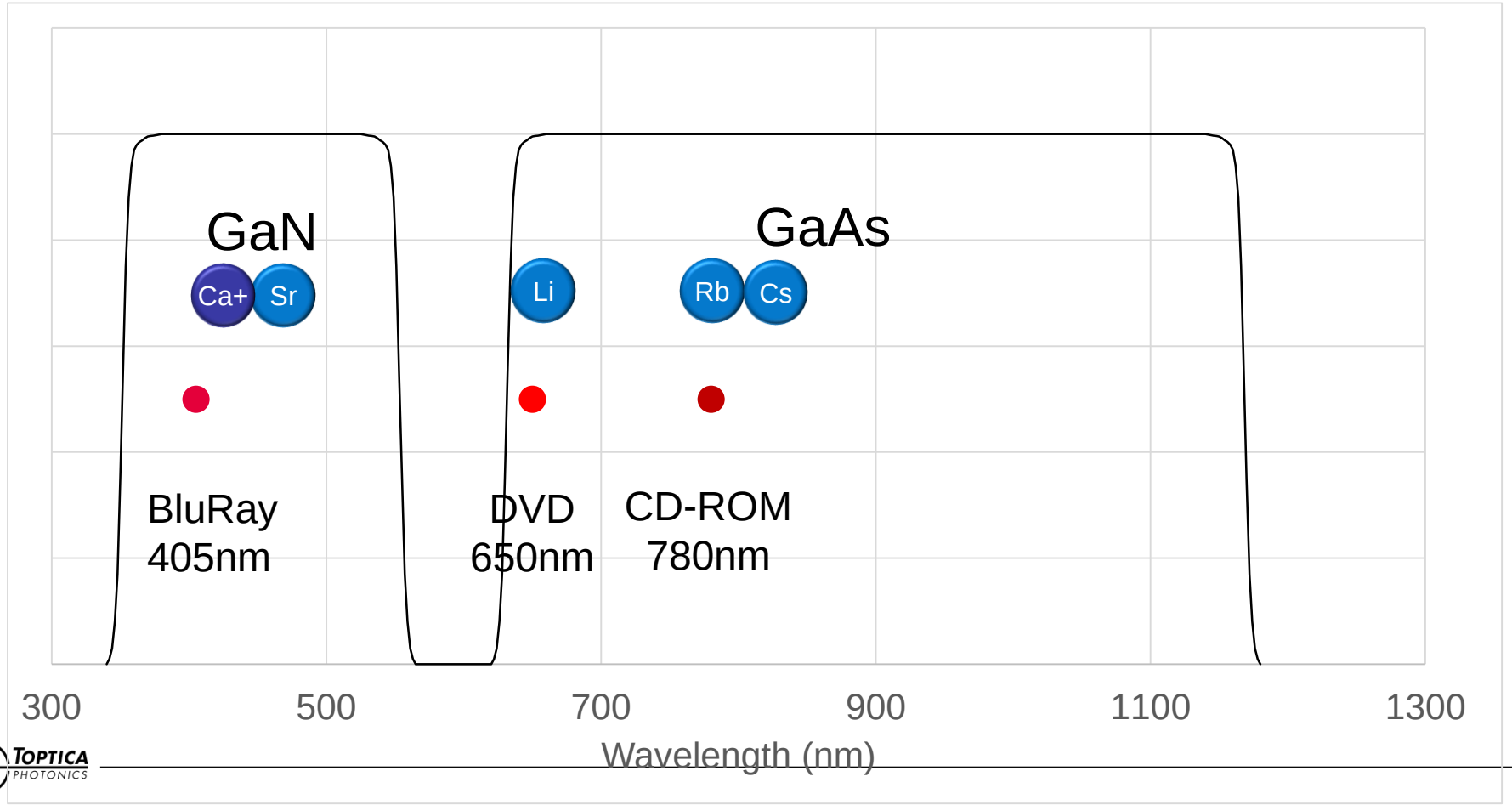




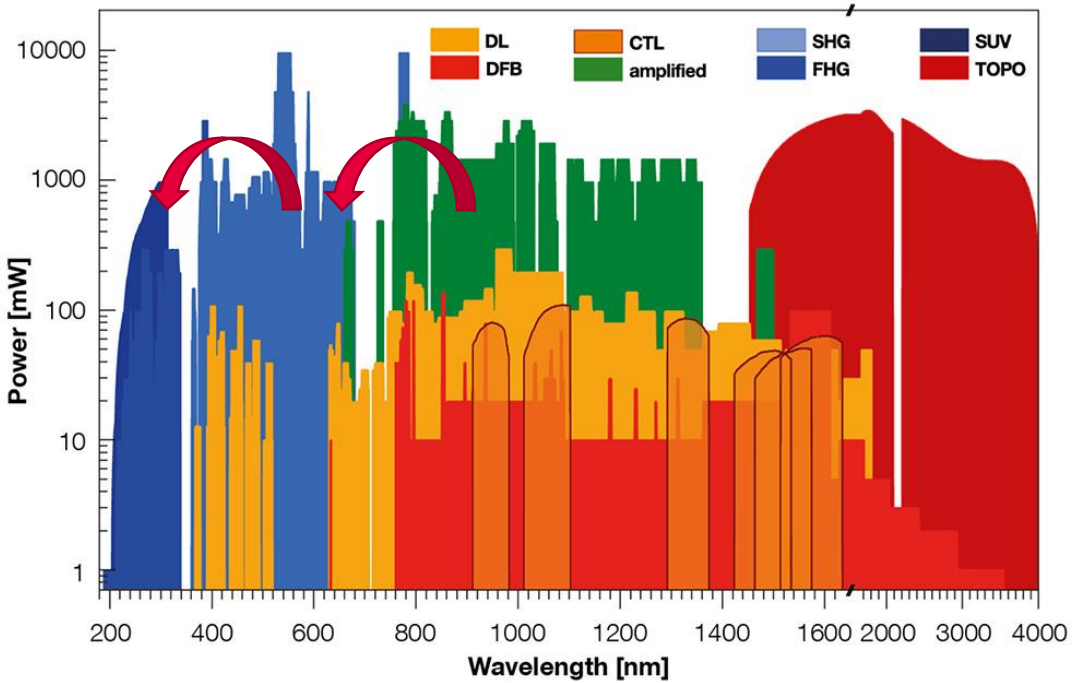
Tunable diode lasers (> 1990)

Tunable dye lasers (< 1990)

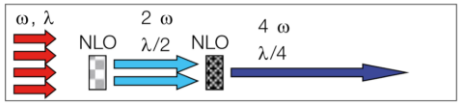
1990 ff:CD/DVD/blue-ray were the drivers for optical diode development



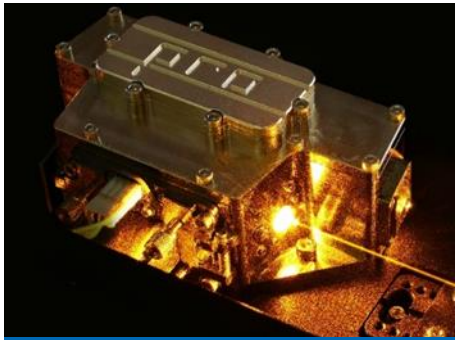
2000: „All Wavelengths“



Filling all spectral gaps by frequency conversion



NLO principle



Bow tie NLO module

2010: Digital Control

Analog Control

Digital Control

Remote Control

2020: Transportable Racks (status quo)

MDL pro:
4 ECDL lasers in 1 rack

DFC Core:
Transportable Frequency Comb

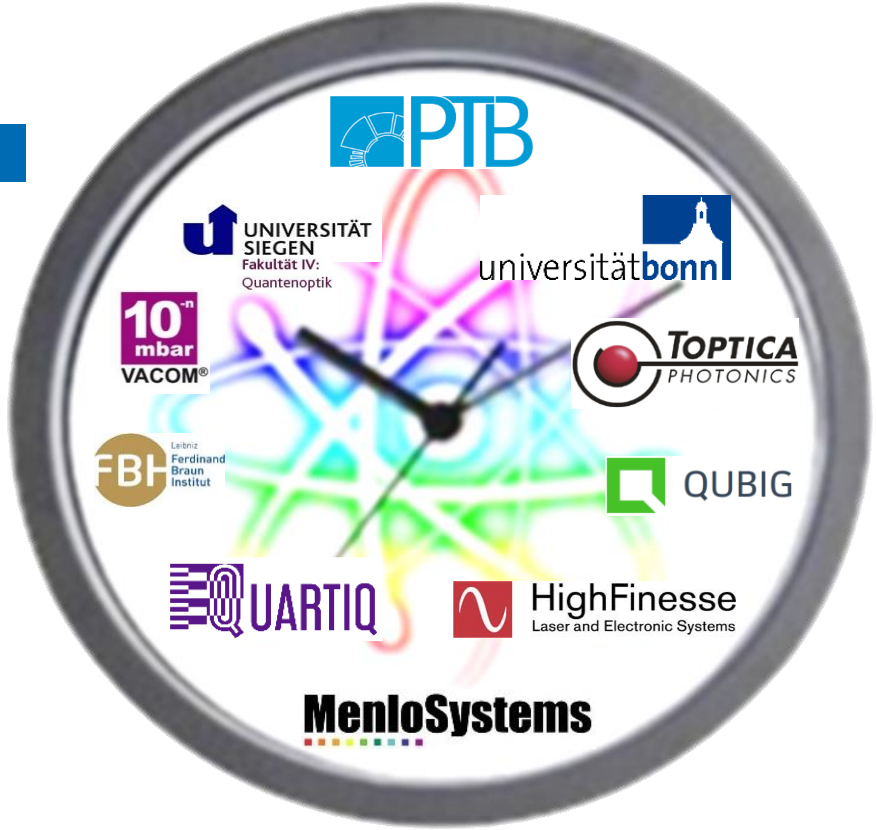
Opticlock:
Transportable Yb+ clock (PTB)

Status quo of Lasers in QT: 2020 → Transportable Racks: Opticlock

opticlock

Key facts

- first of three QUTEGA pilot projects
- development of a **transportable** high-availability and **easy-to-use optical single** $171Yb^+$ **ion clock** that can be operated outside a specialized laboratory
- 10x better than H-maser
- Realization of the SI-second with $6x10^{-16}$ uncertainty
- 19” rack-style, office environment
- QT product developments
- transfer of scientific research results into industry
- project duration: 2017-2020
- ~ 6 M€ project (~75% funded)
- www.opticlock.de



6 Companies

2 Universities

1 Research Institute

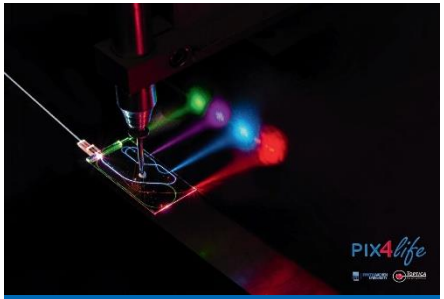
1 Federal Institute

Sensing/Metrology

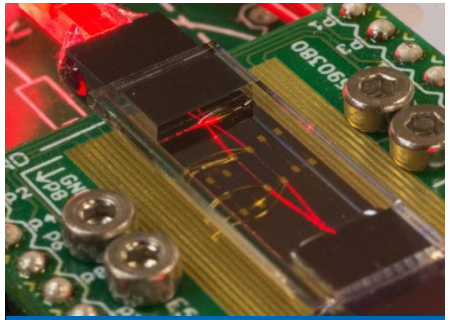
2030: Miniaturization, minimum power consumption, extended environment

???

How will it be done? (major challenges)

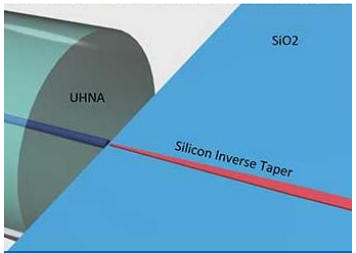


All-on chip lasers
(all wavelengths?)



PIC for lasers & secondary optics (Lionix)

Next generation tunable diode laser for „all wavelengths“



Fiber chip connectors

Single purpose compact electronics

Lasers in QT: History & Future

1990

2000

2010

2020

?

2030

Thank you for
your attention

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