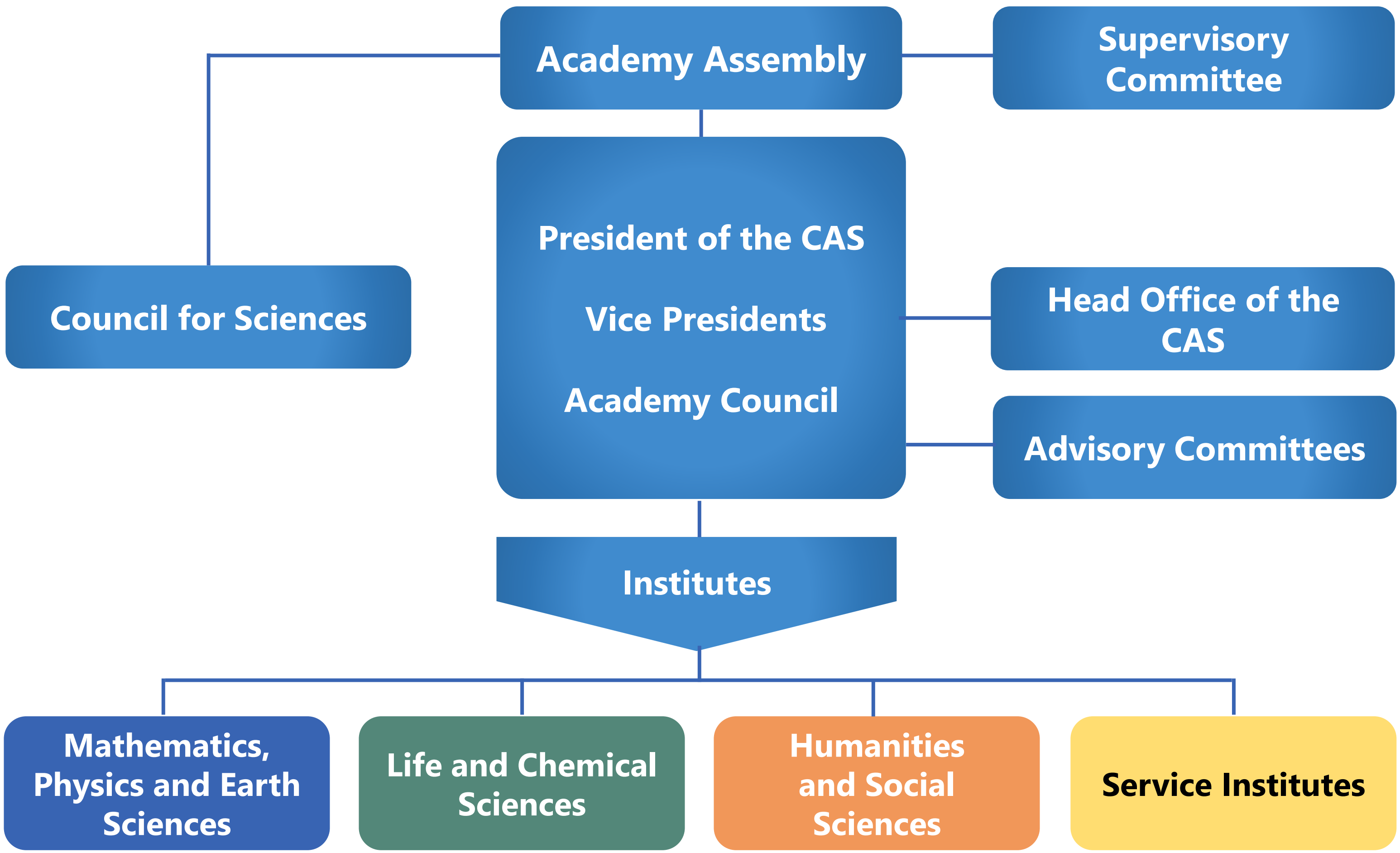
INSTITUTE OF SCIENTIFIC INSTRUMENTS
The Czech Academy of Sciences

The Czech Academy of Sciences

Ondřej Číp

Activities of the Institute of Scientific Instruments of the Czech Academy of Sciences in the field of optics and optical quantum clocks

Structure of the CAS



ISI in outline

ISI is located at Brno www.isibrno.cz
ISI founder: Czech Academy of Sciences of Czech Republic
ISI is one of 53 institutes of CAS
ISI is a public research institution

ISI size:
270 employees total (FTE):

- 78 research scientists
- 36 PhD students
- 98 technicians and admin.
- + workshop personnel, servicemen, etc.

Our mission

ISI CAS

Research of **methods, techniques and tools** for diagnostics, metrology, imaging and analysis in both life and non-living nature including development of technologies

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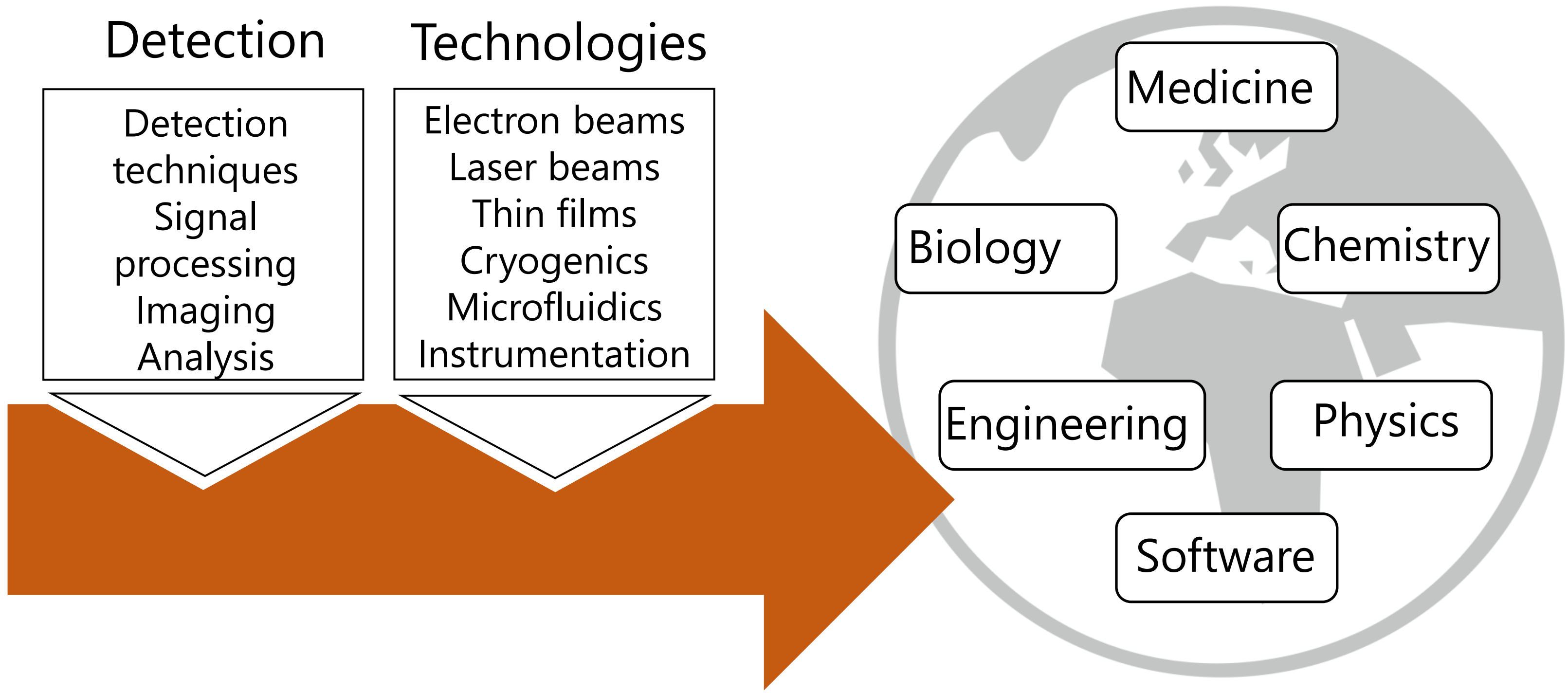
Partners and users
in the field:



Coherence Optics and the ISI

ISI CAS

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- **Applied and Integrated Photonics** – Ing. Mojmír Šerý, Ph.D.

Coherence Optics – Ing. Ondřej Číp, Ph.D.
- **Coherent Lasers and Interferometry** – Ing. Ondřej Číp, Ph.D.
- **Laser Technology** – doc. RNDr. Libor Mrňa, Ph.D.

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Key research fields of Coherence Optics

1. Lasers and light sources for length metrology

- primary laser standards for length, stabilized lasers for interferometry and industrial metrology, laser with controlled coherence, two-frequency DBR stabilized laser, absorption cells

2. Optical measuring techniques

- coordinate interferometry, long-distance absolute interferometry, fibre sensors, measurement of hollow cylindrical surfaces, all-photonic length sensor, nanocomparators for calibration of length sensors, methodology of surface diagnostic in optics and precision engineering

3. Laser technologies

- monitoring and control of the laser welding process, hybrid welding techniques, micromachining with picosecond laser

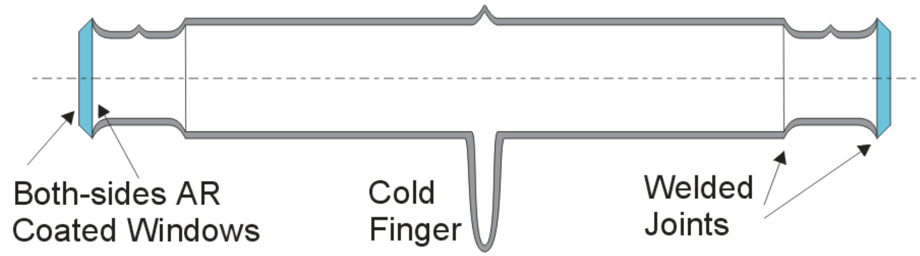
4. Spectroscopy of trapped ions and optical ion clocks

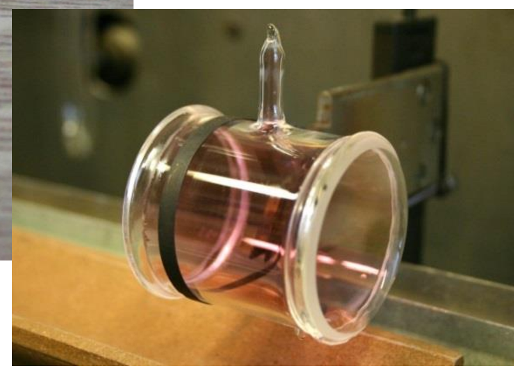
- Ramsey spectroscopy on the quadrupole transition, ion optical clock experimental operation, non-classical multi-phonon states of a single atom, non-classical light emitted from ensembles of cooled ions, study of interference of the light emitted from linear Coulomb crystals

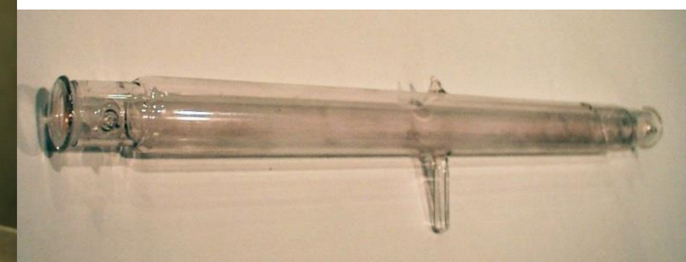
5. Transfer of optical frequencies over fibre networks

- photonic network of phase-coherent links in Central Europe (1400 km of coherent links), instrumentation for coherent links, participation on the building of pan-European infrastructure for T/F transfer

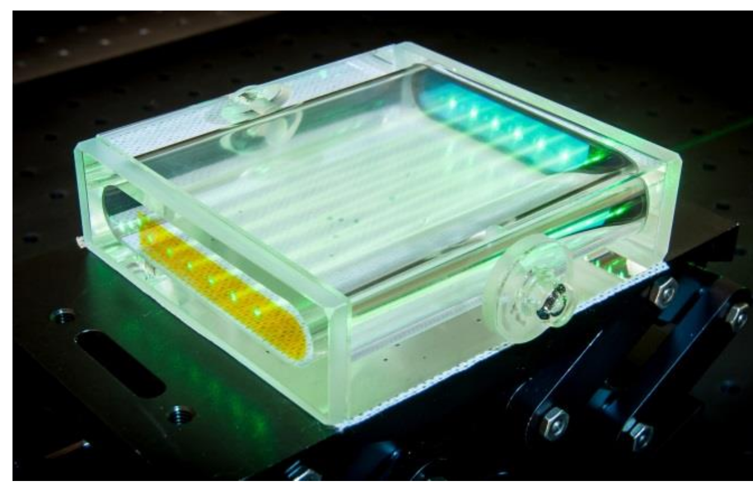
1. Lasers and light sources for length metrology







- The cell tube and windows are from quartz glass, windows are slightly tilted (~1^{O}) and AR coated on both sides, the cover layer of SiO_2 inside has no influence on the gas purity
- **Available gases: Iodine, Acetylene, Methane, Rubidium, Cesium, noble gases (Xe), and others.**
- The cell tube is evacuated and degassed at temperature up to 400^{O}C for 100 hours and filled with super-pure iodine or other gases.
- Cells up to 1 m in length were made.
- The results: reference iodine cells – various research and national metrology laboratories in the world operate them.



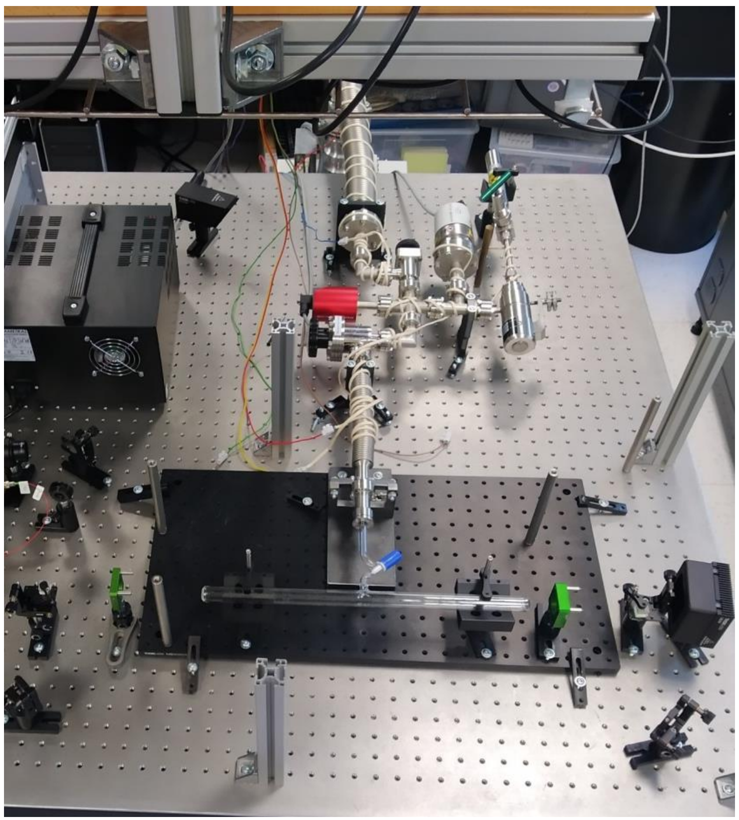
1. Lasers and light sources for length metrology

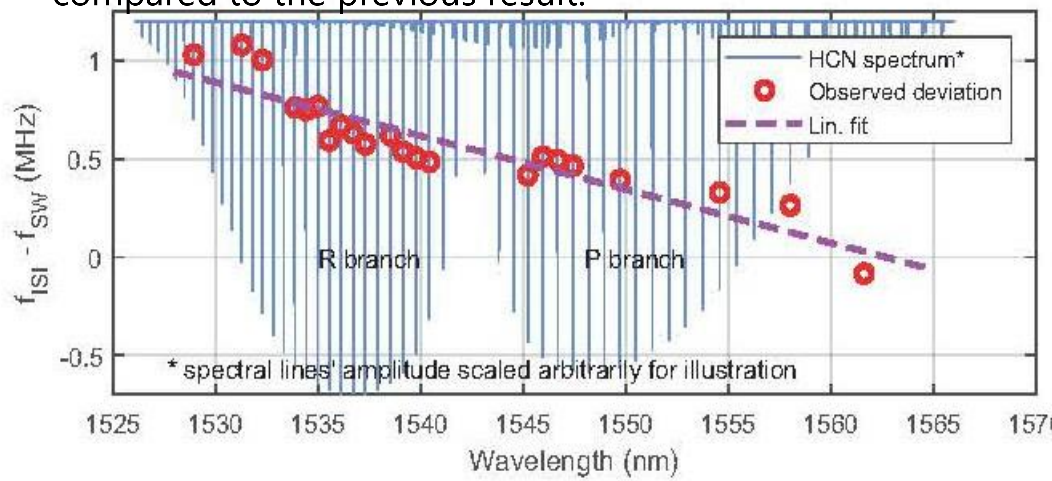
ISI CAS

Stabilized laser systems for fundamental metrology of lengths and interferometry

New spectroscopy reference (HCN) for stabilization of telecom lasers has been investigated with the pressure and temperature effects and achievable stability of locked lasers within H2020 project LaVA

We demonstrated an approach to stabilize the operational conditions needed to maintain the constantly low pressure of the hydrogen cyanide to carry out the saturated spectroscopy with the third-harmonic synchronous demodulation. We demonstrated approximately a **fourtyfold improvement** in the line centers' resolution compared to the previous result.





J. Hrabina at al.: Absolute frequencies of $H^{13}C^{14}N$ hydrogen cyanide transitions in 1.5 µm region with saturated spectroscopy and sub-kHz scanning laser. Optics Letters, 47, 5704-5707 (2022)

LaVA EMPIR
Horizon 2020
European Union Funding
for Research & Innovation

2. Optical measuring techniques

A number of interferometric systems built for various applications

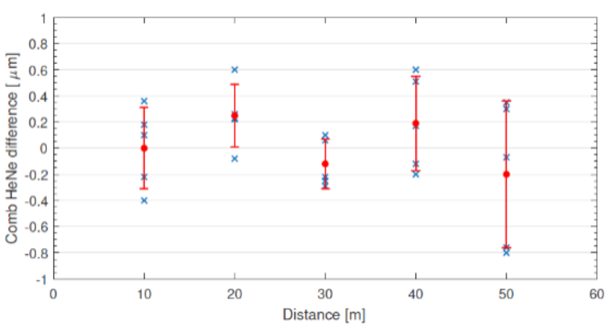
System for TESCAN, designed for e-beam writer, IR, fiber-based, differential interferometer

Interferometer setup mounted on the flange of a vacuum chamber

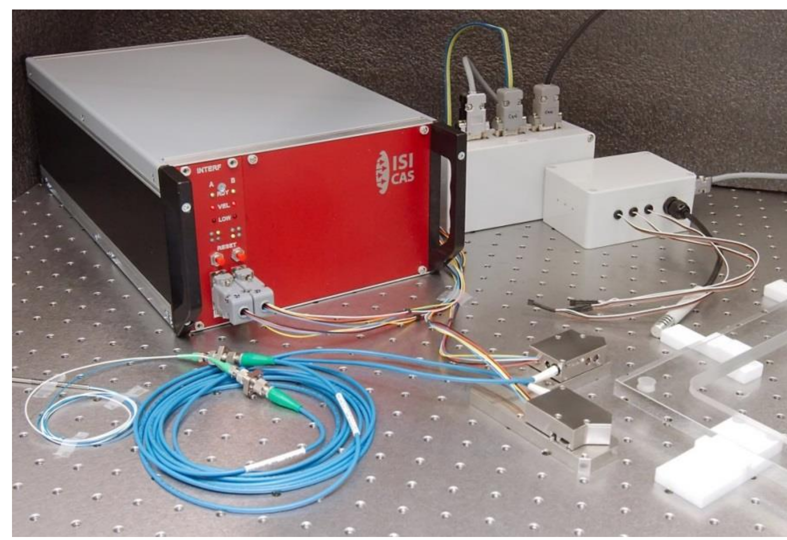
Similar systems developed for other producers of e-beam writers

Coordinate measurement for two-axis (x-y) and three axis (x-y-yaw)

Absolute scale interferometer based on femtosecond comb for long distance measurement



Complete system with control electronics, signal processing, compensation of refractive index – system developed for Meopta-Optika for calibration of lens systems

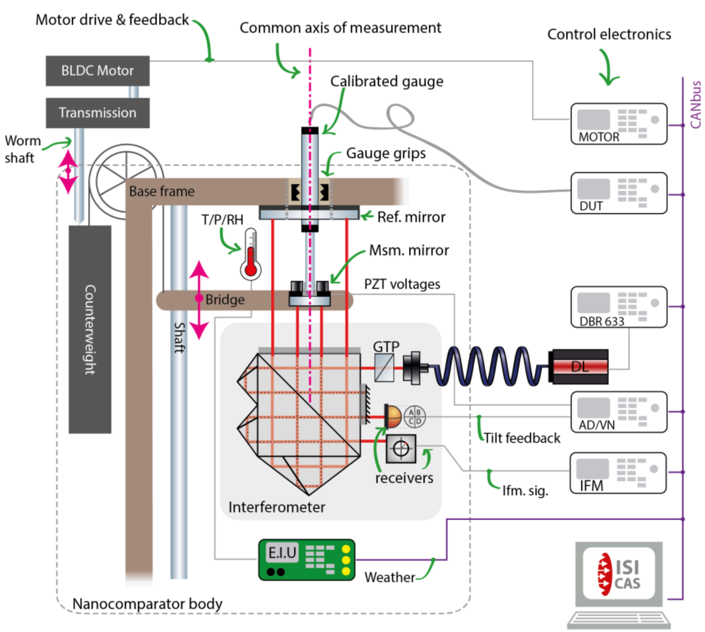


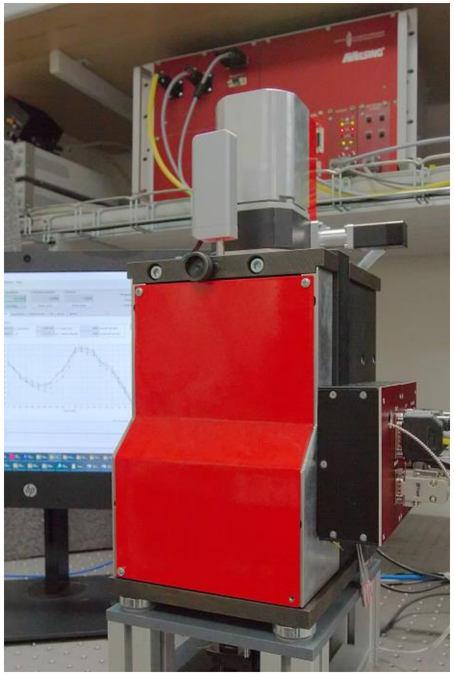
Research within EU EMRP project "Long Distance Surveying" SIB60

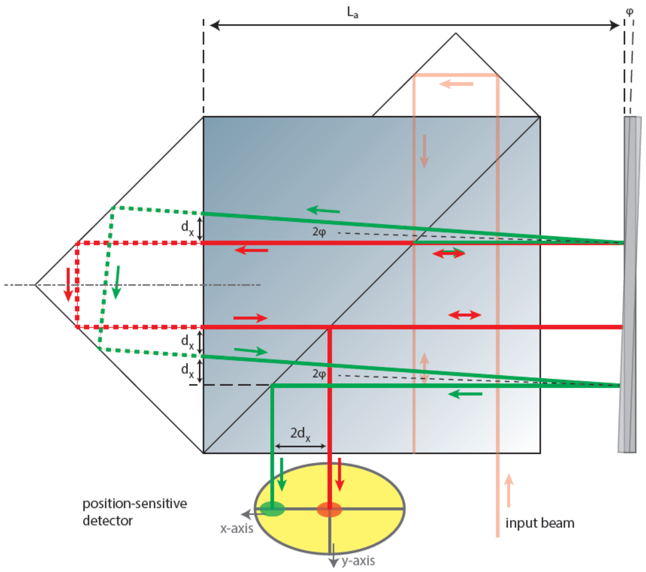
2. Optical measuring techniques

We developed nano-calibration gauge with laser interferometer as a length reference

- new configuration of fully differential interferometer arrangement
- collaborative research with company MESING Czech Republic
- pilot operation of the calibration of LVDT and ruler based optical length sensors
- planned installation in MESING calibration service laboratory and Czech Metrology Institute





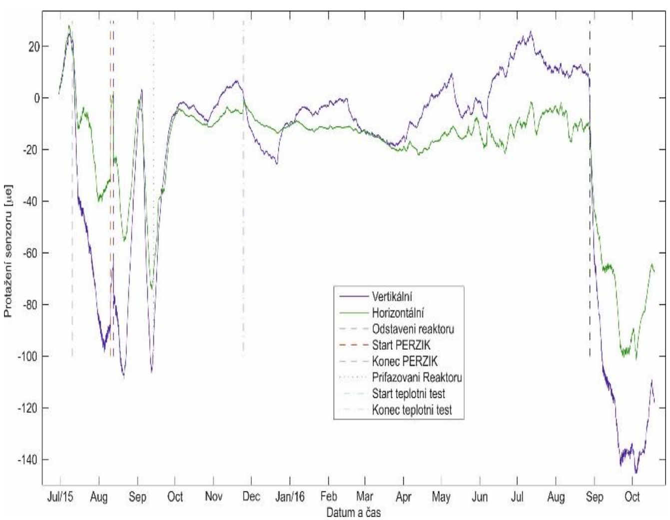


S. Rerucha et al. Compact differential plane interferometer with in-axis mirror tilt detection, Optics and Lasers in Engineering 141, 2021. doi: 10.1016/j.optlaseng.2021.

2. Optical measuring techniques

Optical sensors and interferometers for deformation measurement

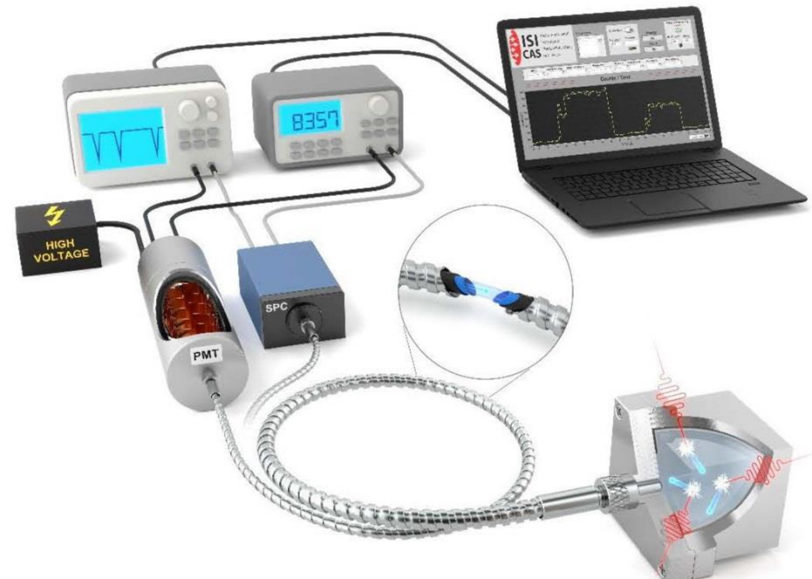
We developed a unique fiber optic system – network of strain gauges with fiber Bragg gratings for monitoring of containments and measurement of cable strain



A year-round measurement of the containment with reactor shutdown, temperature and pressure test.

Optical fibre radiation sensor

We designed and test fiber optic sensors for measurement of ionizing Gamma radiation



M. Jelinek at al: Design and Characterisation of an Optical Fibre Dosimeter Based on Silica Optical Fibre and Scintillation Crystal, Sensors, 2022, 22, 7312. ttps://doi.org/10.3390/s22197312

3. Laser technologies – fundamentals of laser welding

Research area

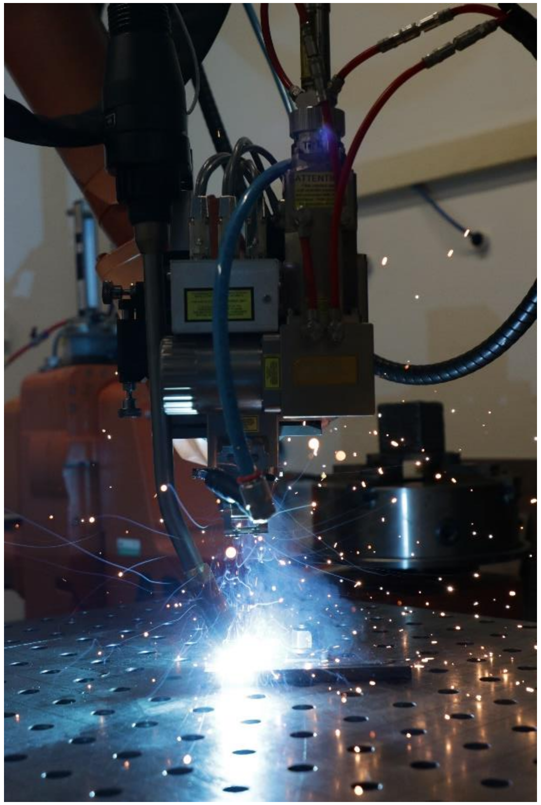
- Laser welding including wobbling, hybrid welding
- Laser - 2D/3D cutting
- Process diagnostics
- Micromachining with a picosecond power laser
- WAAM (Wire Arc Additive Manufacturing)– 3D metal printing
- Numerical simulations of laser welding and WAAM
- Optical layers

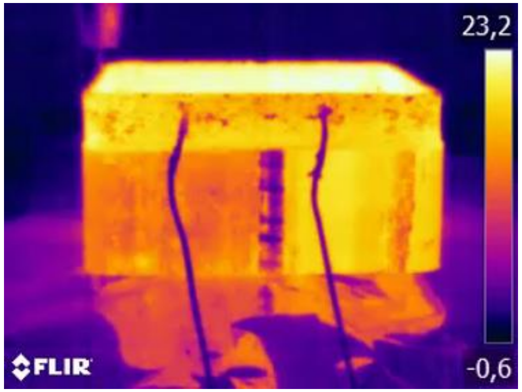
Excellence

– Diagnostics of laser welding process

– Numerical simulations

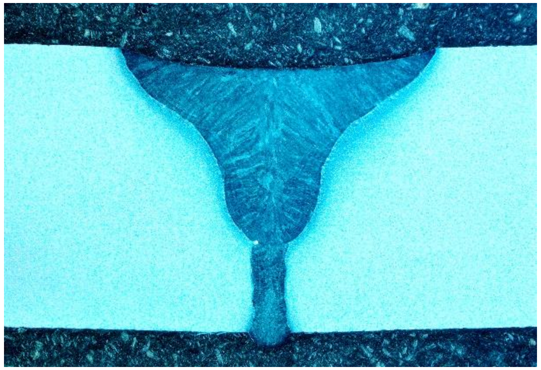
– Micromachining with IR, VIS and UV laser wavelengths





WAAM monitoring

Picosecond micromachining microlens array

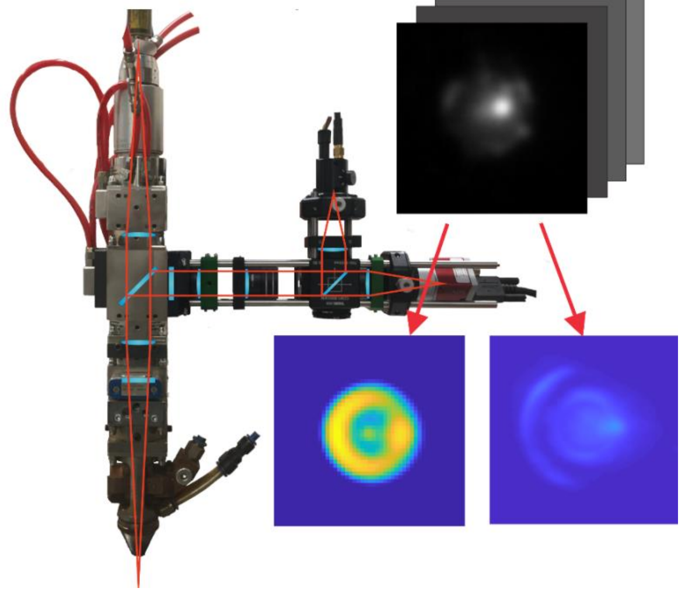


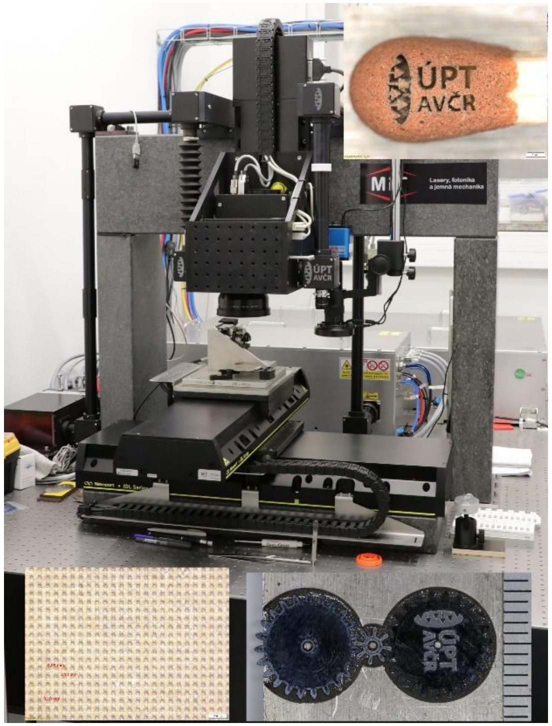
3. Laser technologies – advanced welding methods

Mission

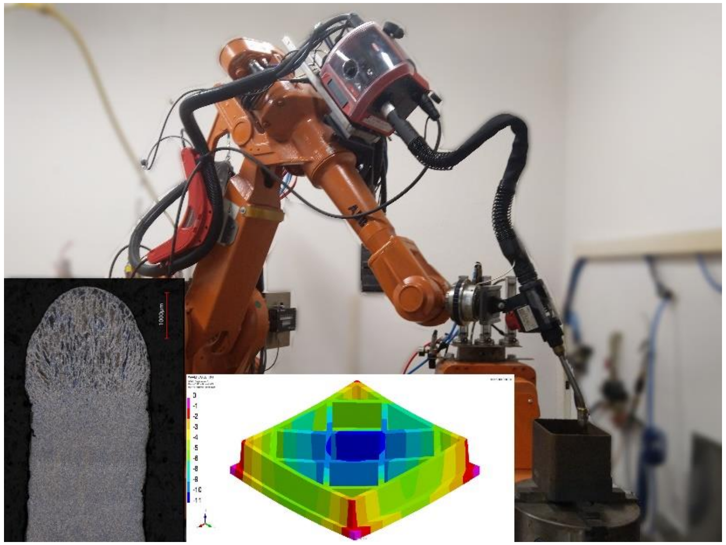
- Theoretical and experimental research of laser welding process
- Study, monitoring and control of the laser welding process
- Application of laser welding technology for the high-tech industry and green technology
- Application of picosecond micromachining for optical elements

Laser process monitoring

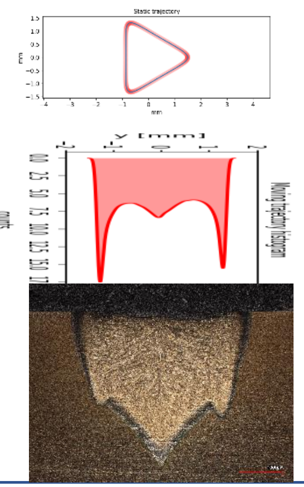




3D metal printing WAAM



Wobble welding



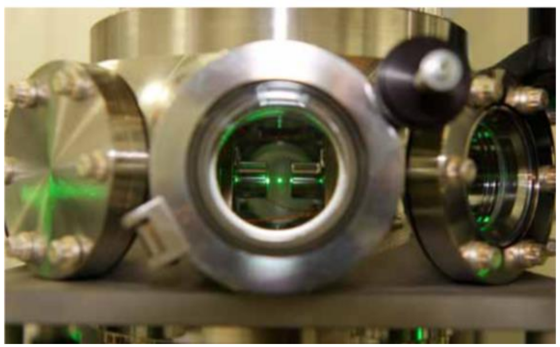
New topic – Quantum Technologies

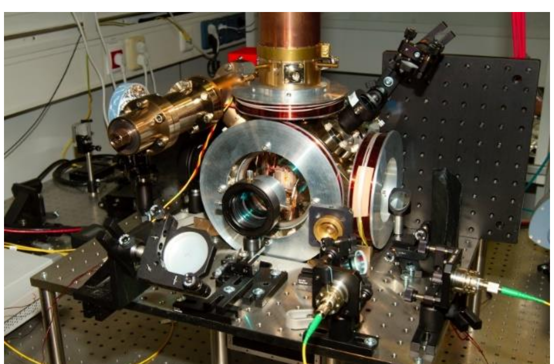
2nd wave of quantum revolution – present day of quantum technologies – quantum networks, communication, computing, measurement …

The basis are two principles:

- **superposition –** objects may be in more quantum states at the same moment
- **entanglement –** objects may be interlinked without physical interaction

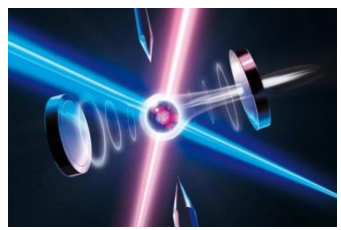
on the level of individual quantum objects



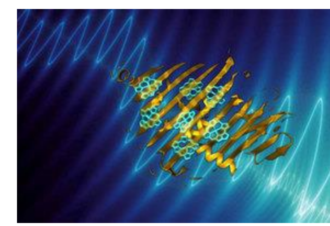


Initiative joins 6 topics …

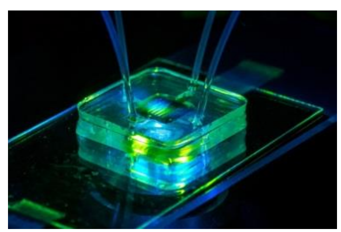
… and these are ours



Atomic quantum clocks



Quantum simulators



Quantum sensors

Quantum cryptography

Quantum communications

Quantum computing

4. Spectroscopy of trapped ions and optical ion clocks

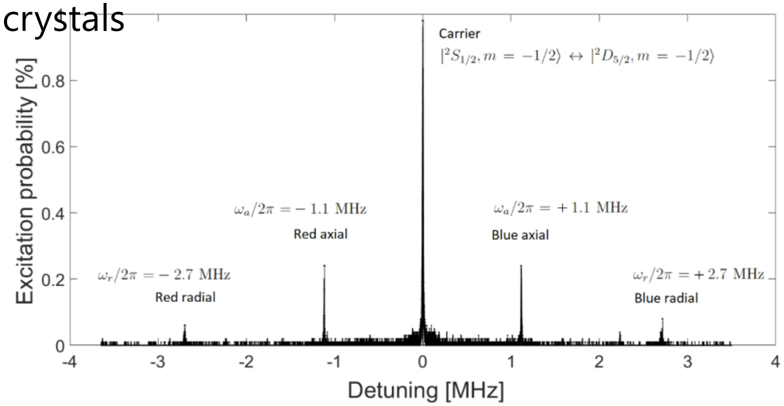
ION1 - experimental setup for laser cooling of trapped ions (cooperation ISI and Palacky University of Olomouc)

Our goals:

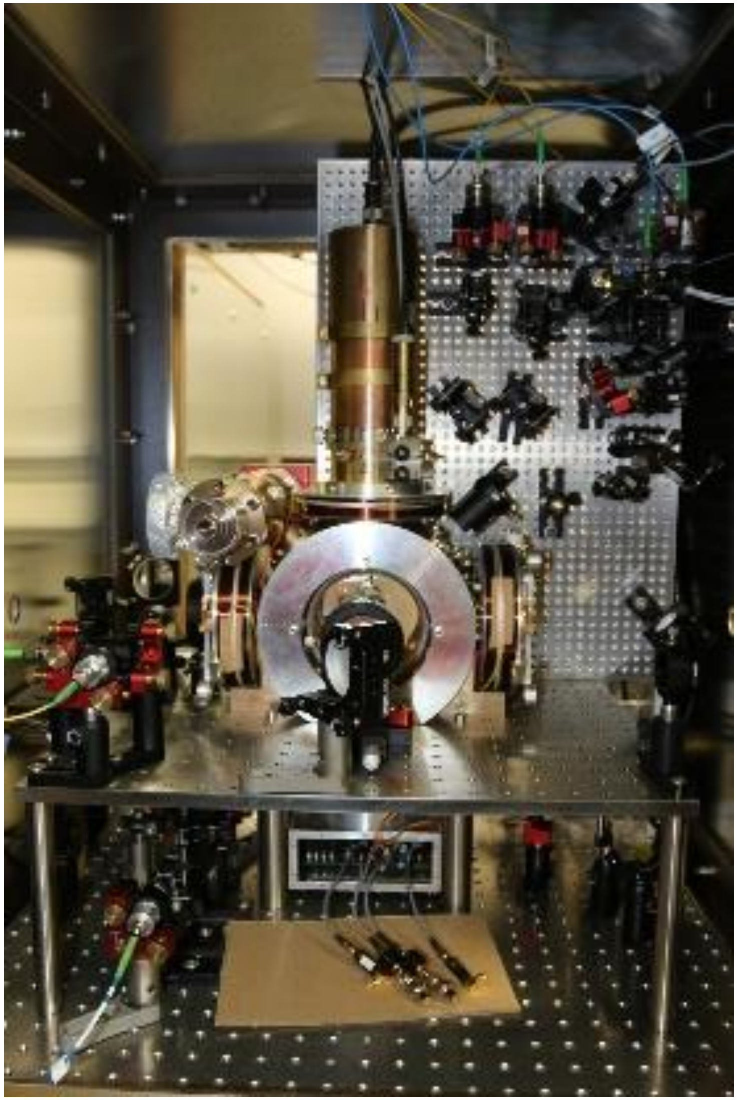
- optical quantum clock – optical frequency reference with $^{40}Ca^+$
- infrastructure for quantum optics experiments

We do:

- Ramsey spectroscopy on the quadrupole transition
- ion quantum clock experimental operation
- non-classical multi-phonon states of a single atom
- non-classical light emitted from ensembles of cooled ions
- interference of the light emitted from linear Coulomb crystals



ALISI infrastructure of ISI (2009 - 2012)
Centre of Excellence (2014 - 2018)
mQ-net - Cold Quantum Objects (2019 - 2023)



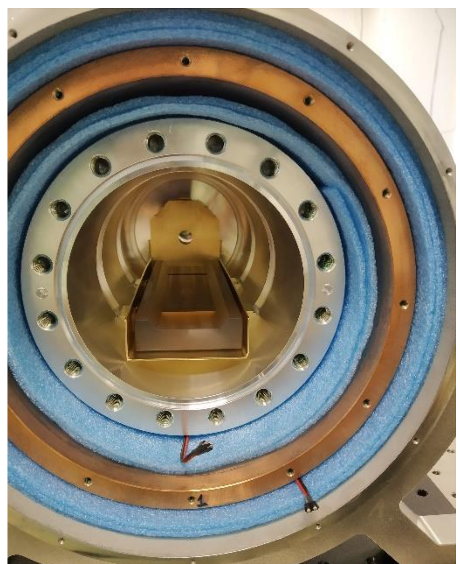
Vacuum chamber with ion trap for $^{40}Ca^+$ laser cooling

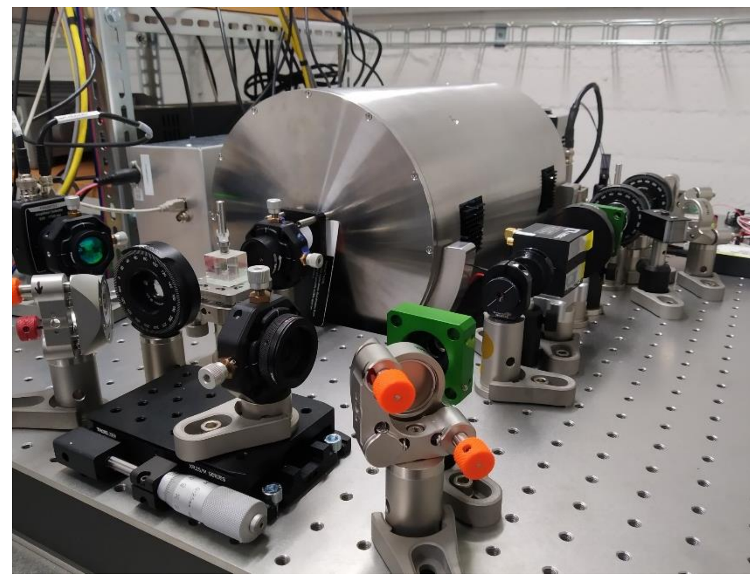
4. Spectroscopy of trapped ions

C1540-2 - new high-finesse optical cavity for a clock laser

We do:

- design of the optical cavity configuration – 18 cm long ☺
- vacuum chambre design and assembling
- complex electronics for the cavity temperature control (3 stages)
- phase locking electronics with PDH technique
- put into operation with fibre laser NKT at 1540 nm
- testing the operation against C1540-1 based clock laser



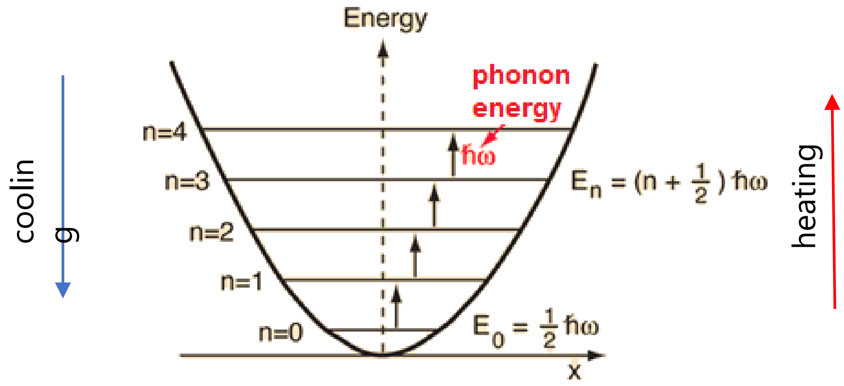


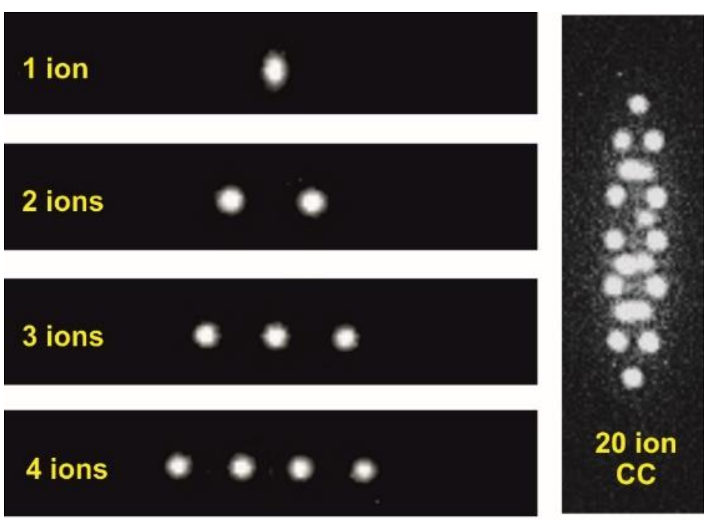
Cooperation with Institute of Plasma Physics CAS – centre TOPTEC under the project Centre of Electron and Photon Optics

4. Spectroscopy of trapped ions

Thermal states control – heating-rate of ion

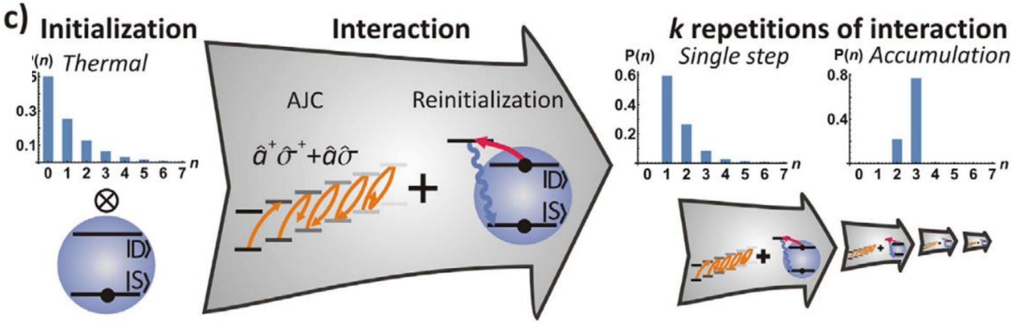
Heating-rate – the rate of increase in the temperature of the ion due to the excitation of motional modes by the environment (especially by the electric field)





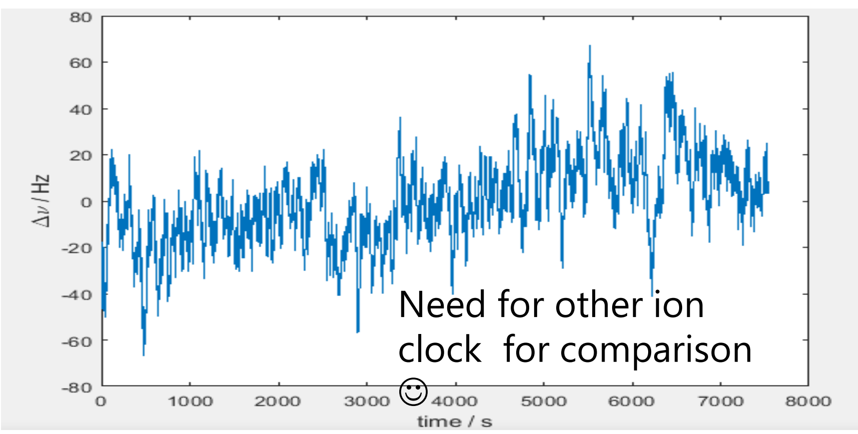
Non-classical light from large ensembles of ions

We demonstrated accumulation and control of non-classical motional states in a single-atom mechanical oscillator



L. Podhora, L. Lachman, T. Pham, A. Lešundák, O. Číp, L. Slodička, R. Filip, Quantum non-Gaussianity of multiphonon states of a single atom, Phys. Rev. Lett. 129, 013602 (2022)

Optical ion clock experimental operation



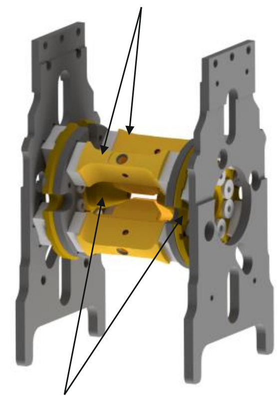
4. Spectroscopy of trapped ions

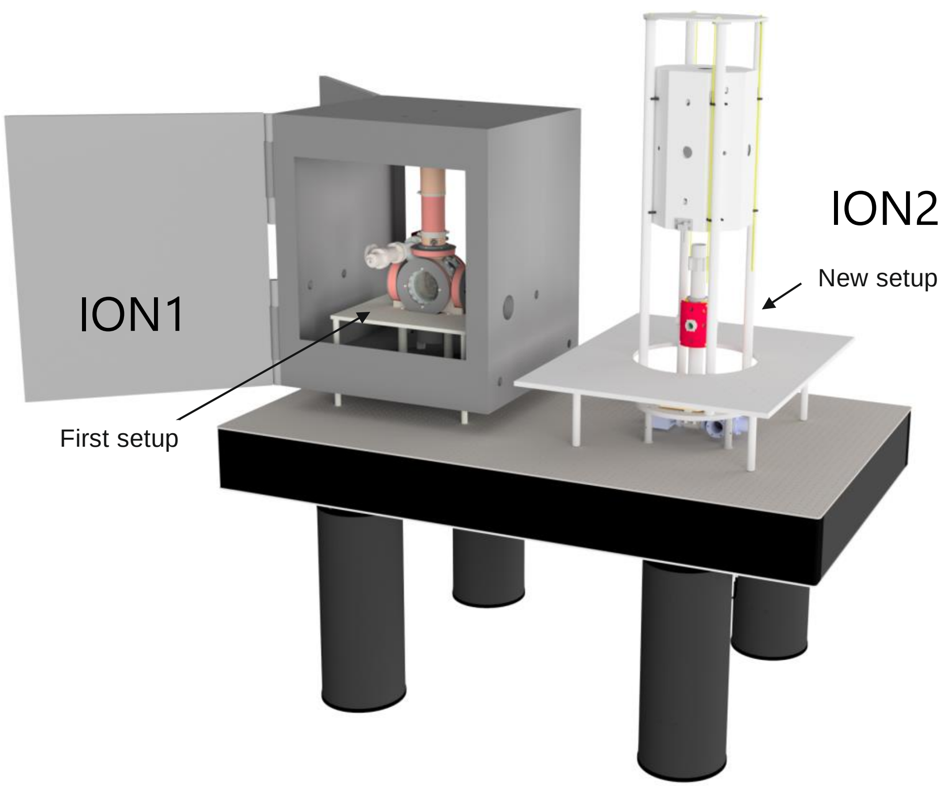
ION2 – new experimental setup for cooling of $^{40}Ca^{+}$ and $^{27}Al^{+}$

Our goals:

- quantum logic in a two-species ionic Coulomb crystal
- optical ion clock – optical frequency reference with $^{27}Al^{+}$
- infrastructure for quantum optics experiments

Our design of a modified Innsbruck's style linear Paul trap





We do:

- homogeneous B-field in the Coulomb crystal area
- compact magnetic shielding
- good optical access for fluorescence collection
- components are in the production process

Since 2021 – the work supported by the project TSCAC (Two-species composite atomic clocks)

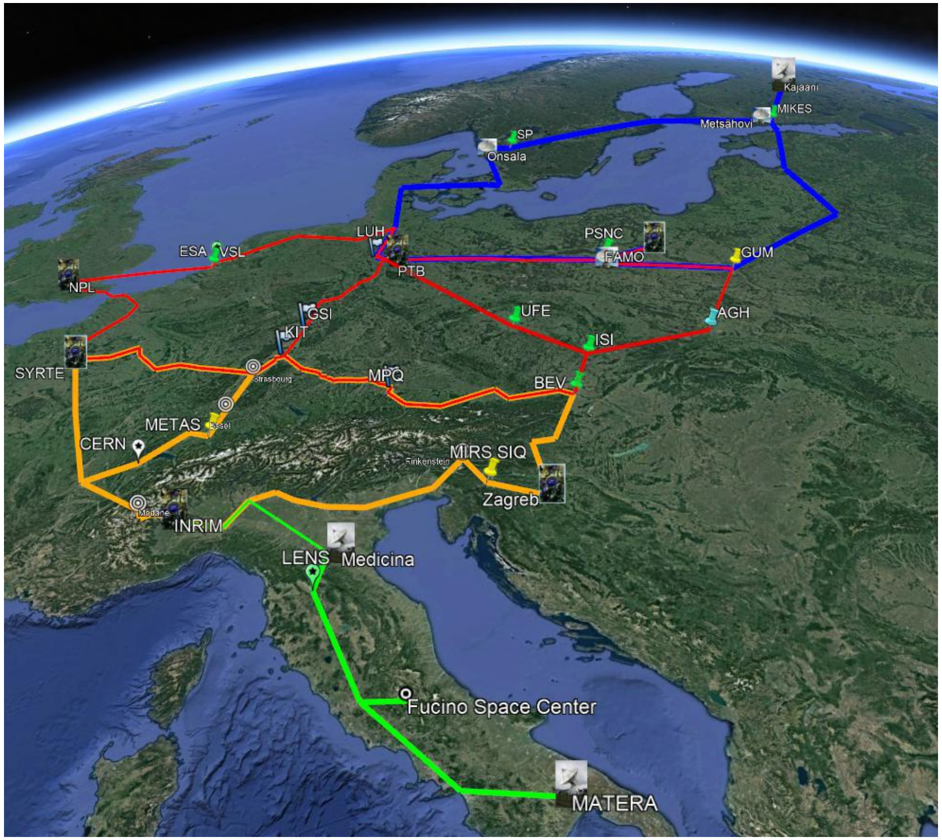
TSCAC EMPIR

Horizon 2020
European Union Funding
for Research & Innovation

5. Transfer of optical frequencies over fibre networks

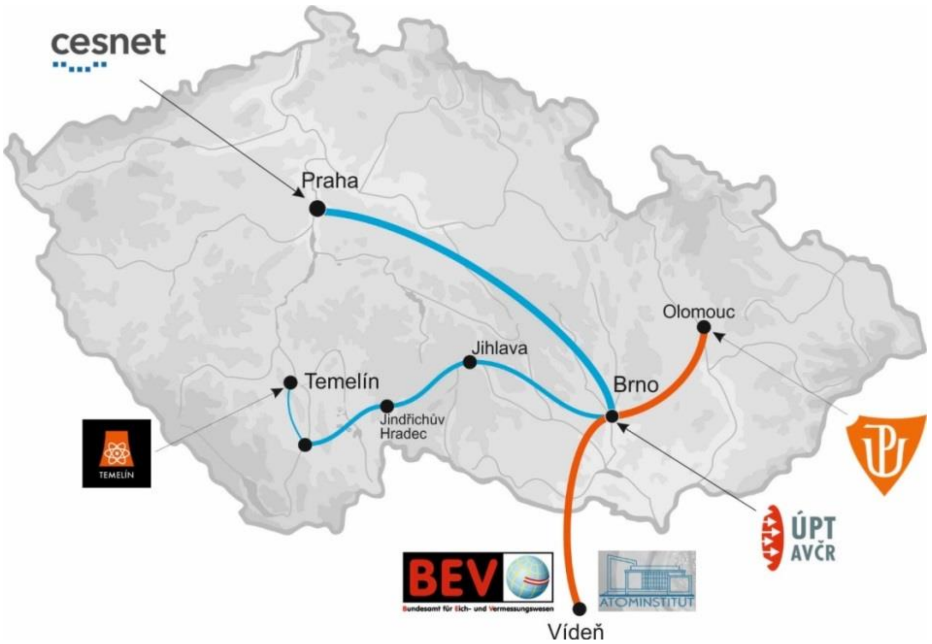
Our goal:

We build a pan-European network for transfer of precise time and frequencies from optical atomic clocks to stakeholders



We do:

- complex electronics and optics for coherent transfer
- 1500 km of phase-coherent optical fibre links in the Central Europe
- cooperation with CESNET – Czech NREN



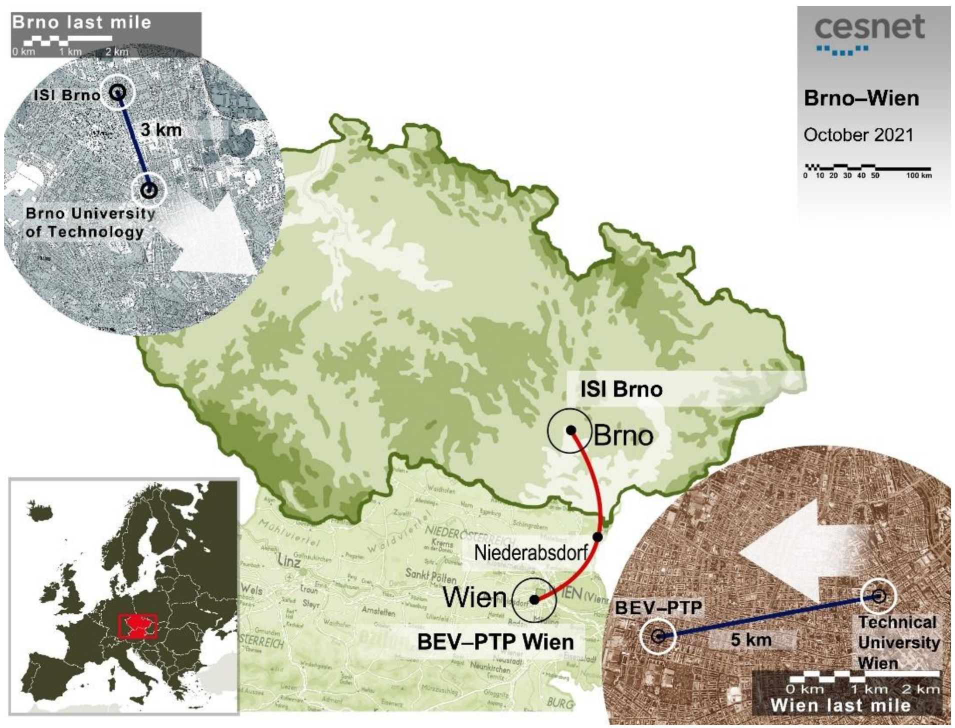
Horizon 2020
European Union Funding
for Research & Innovation

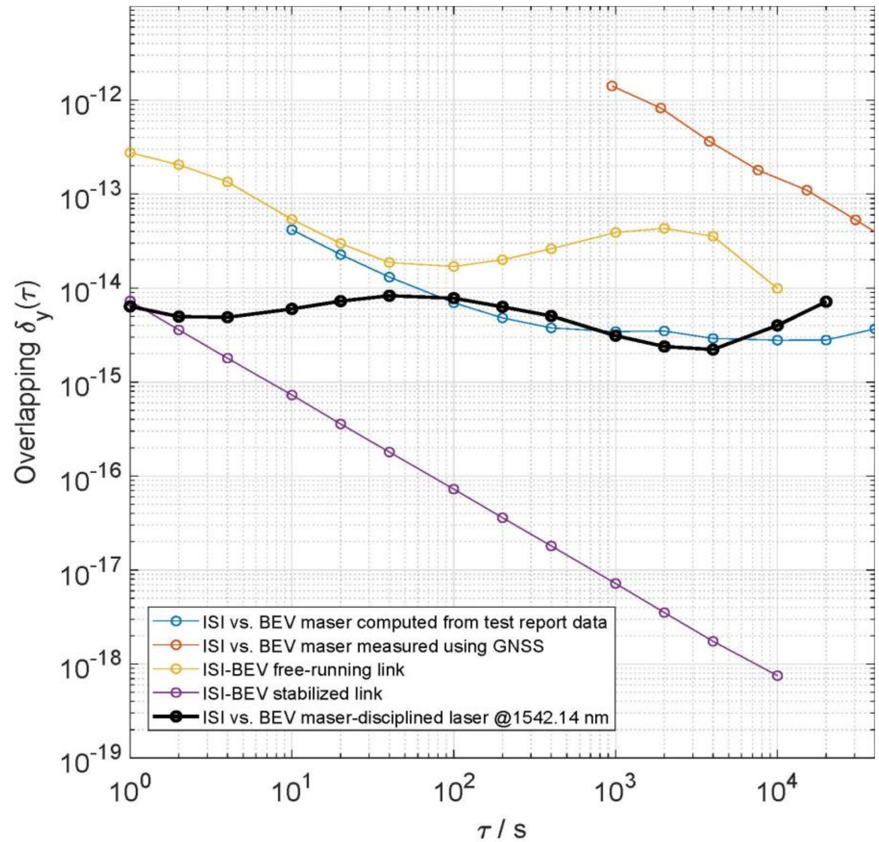
TiFOON

CloNetS DS
Clock Network Services Design Study

6. Transfer of optical frequencies over fibre networks

Comparison of the stabilities of two Hydrogen masers via phase locked lasers through a 235 km optical fiber and GNSS satellite system – fundamental experiment for future optical quantum clock (ISI – BEV) comparisons





M. Cizek at al.: Coherent fibre link for synchronization of delocalized atomic clocks, Optics Express 30, 5450 (2022)

EMPIR
Horizon 2020
European Union Funding
for Research & Innovation

Collaboration in research and applications

Involvement in international projects:

1. Metrology for movement and positioning in six degrees of freedom (IND58 REG1), EURAMET, EC
2. Long Distance Surveying (SIB60), EURAMET, EC
3. Clock Network Services - Design Study, EC, 951886, INFRADEV H2020
4. Coulomb Crystals for Clocks, EURAMET, 17FUN07 CC4C, EMPIR H2020
5. Large Volume Metrology Applications, EURAMET, 17IND05 LaVA, EMPIR H2020
6. Advanced time/frequency comparison and dissemination through optical telecommunication networks, EURAMET, 18SIB06 TiFOON, EMPIR H2020
7. Two-species composite atomic clocks, 20FUN01 TSCAC EMPIR H2020
8. Transportable Optical Clock for Key Comparisons, SRT-S03 TOCK EPM Horizon Europe

Key international partners:

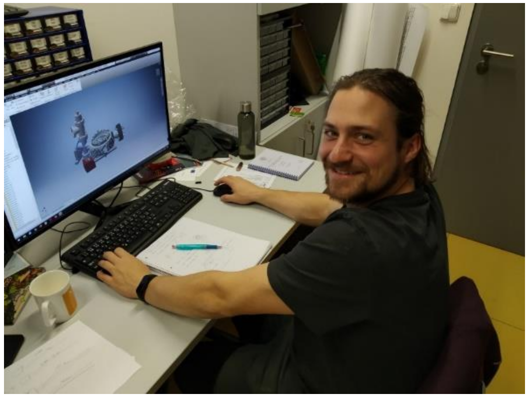
- NPL Teddington, UK
- PTB Braunschweig, Germany
- LUH Hannover, Centre of Excellence for Quantum metrology, Germany
- BEV, Austria
- TU Wien – Atom Institute, Austria
- INRIM Turin, Italy
- LNE-SYRTE Paris, France

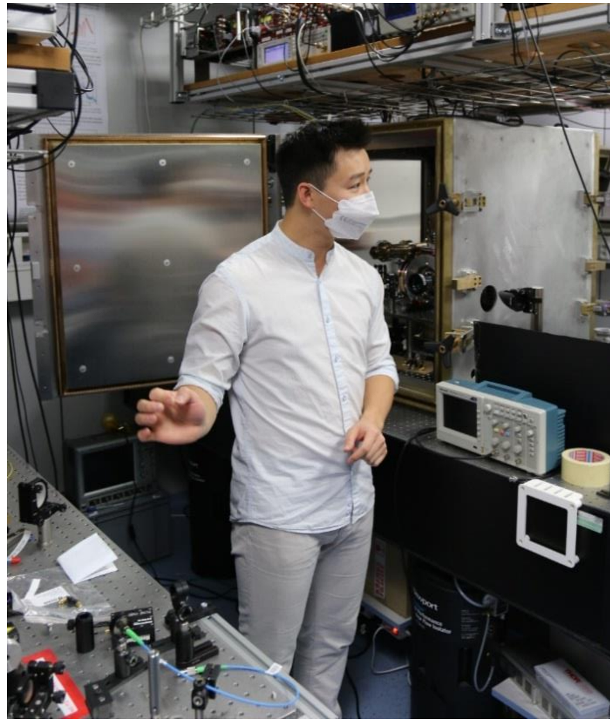
Industrial application partners:

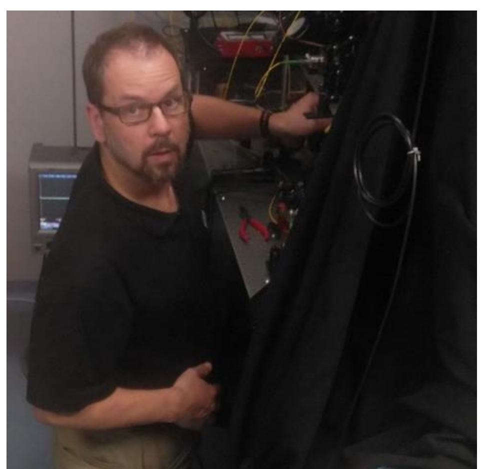
- Tescan Orsay Holding
- Meopta – Optika
- Mesing
- Siemens Energy
- Proficomms
- Nuclear Power Plant Temelín
- Aquadem
- EBZ Hoffmann

Our team

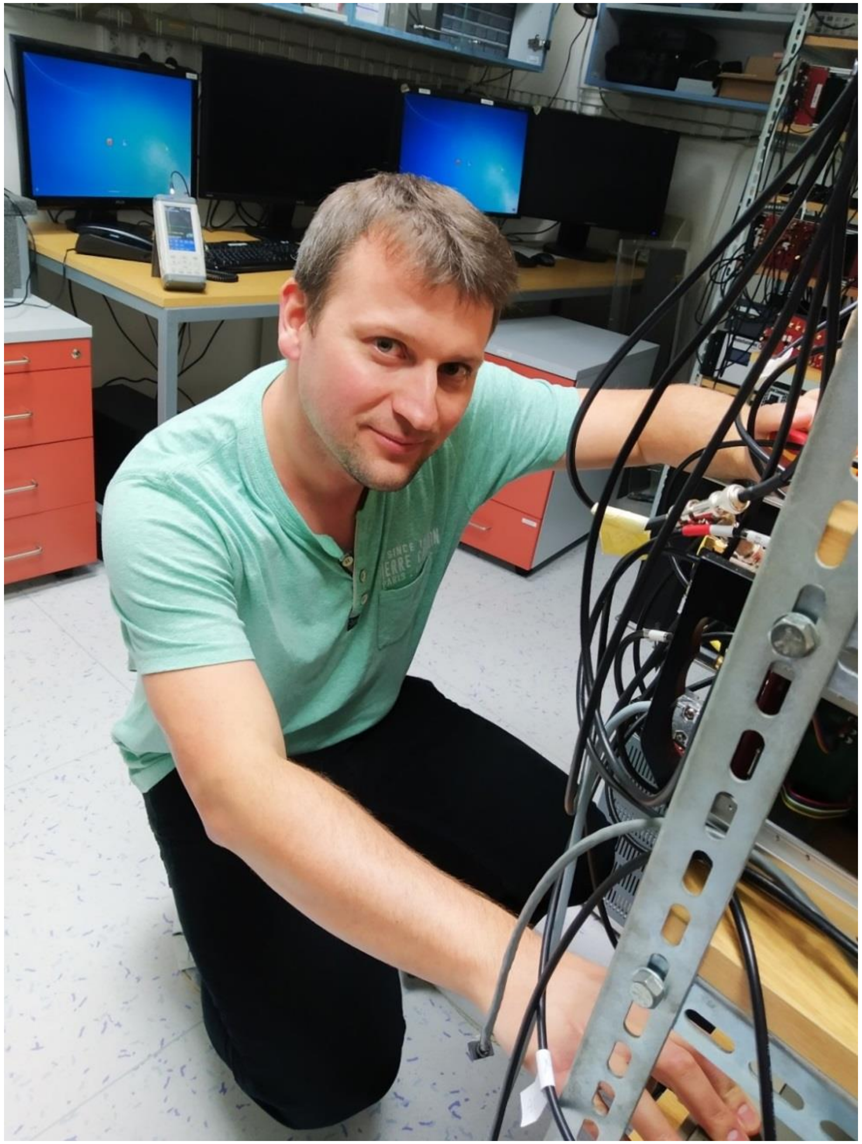
ISI CAS







Our team



Thank you for your attention