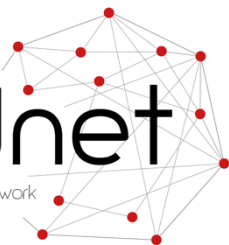


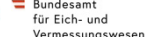
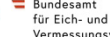
AQUnet

Austrian Quantum Fiber Network



Funded by the Austria
Research Promotion Agency

Infrastructure project 884678



Th

Thorium clocks and fiber networks

AQUclock

Austrian Quantum Clock



Bundesamt
für Eich- und
Vermessungswesen



Funded by the Austria
Research Promotion Agency

AQUnet

connect



Bundesministerium
Bildung, Wissenschaft
und Forschung

Thorsten SCHUMM

Vienna University of Technology

Atominstytut

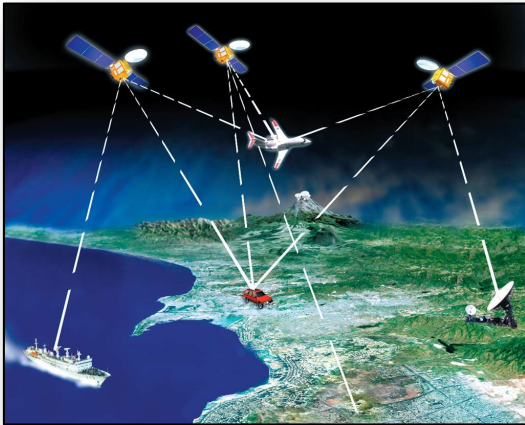
Vienna, 29.01.2025



WHY we want a Thorium nuclear clock?



Better clocks for applications

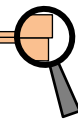


Atomic clocks for satellite-based navigation:
GPS, Galileo, GLONASS, BDS...

**Aim: Field applications,
compact, robust, lightweight, low energy...**



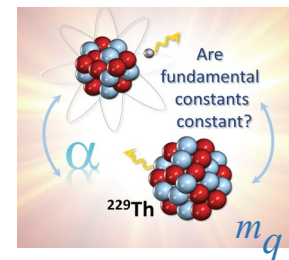
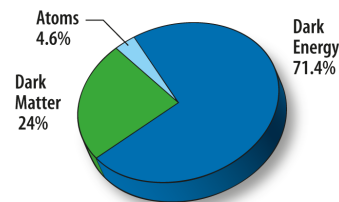
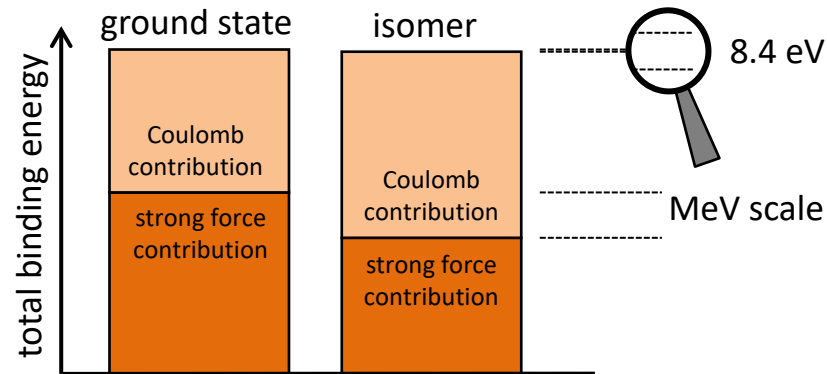
WHY we want a Thorium nuclear clock?



Better clocks for applications ... and fundamental research



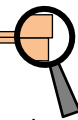
Atomic clocks for satellite-based navigation: GPS, Galileo, GLONASS, BDS...



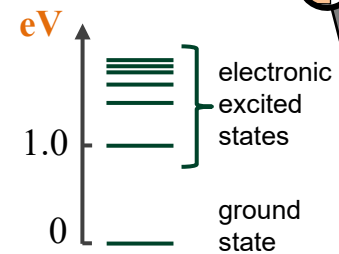
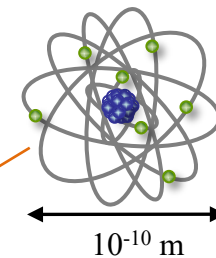
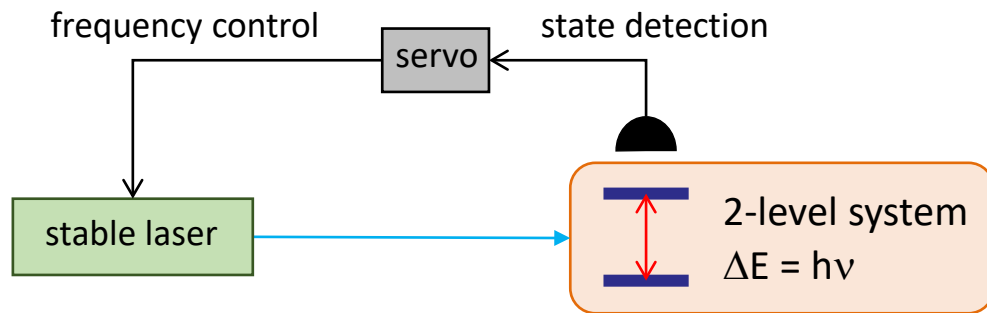
Aim: Field applications, compact, robust, lightweight, low energy...

Aim: Lab applications, Ultimate performance, comparison with other clocks...

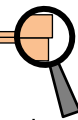
WHAT is a Thorium nuclear clock?



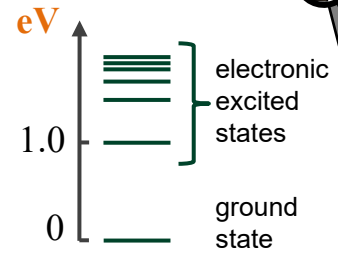
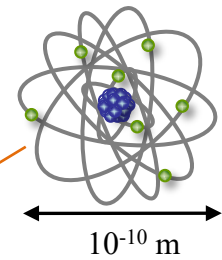
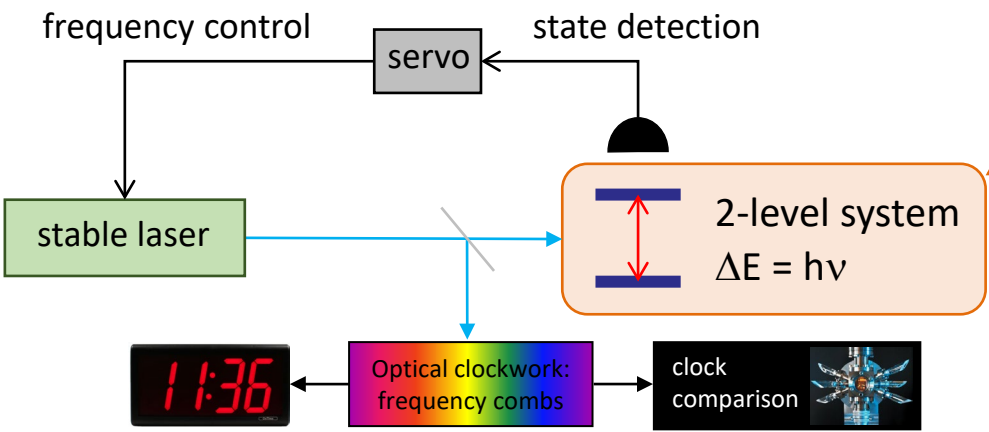
scheme of an atomic clock



WHAT is a Thorium nuclear clock?



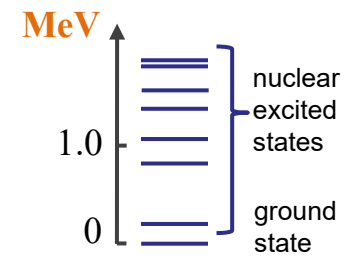
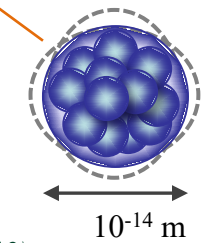
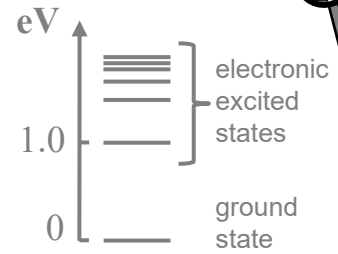
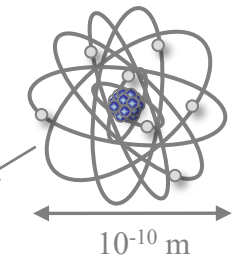
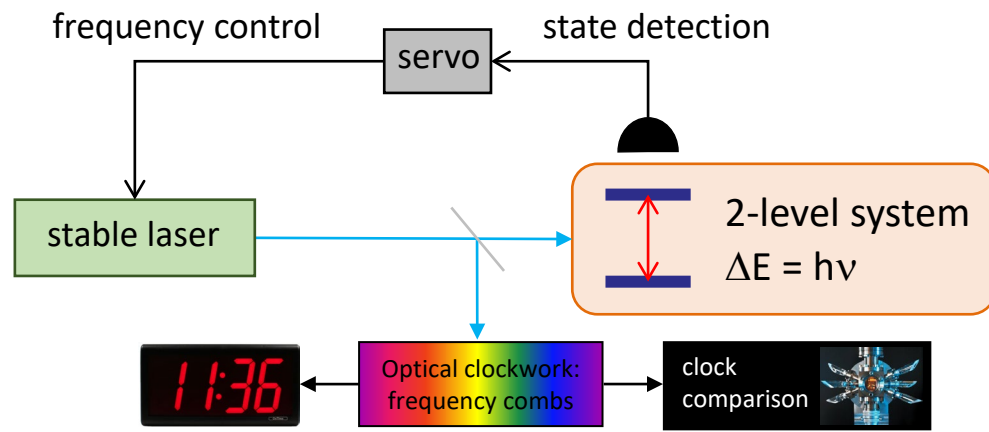
scheme of an atomic clock



WHAT is a Thorium nuclear clock?

scheme of an atomic clock

scheme of a **nuclear clock**

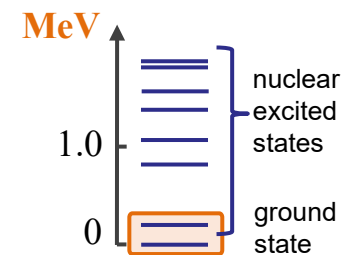
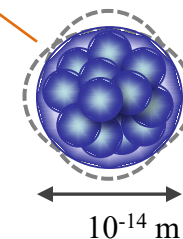
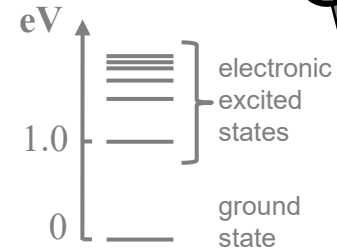
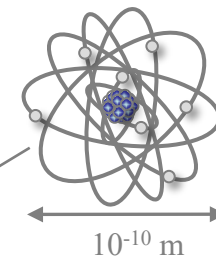
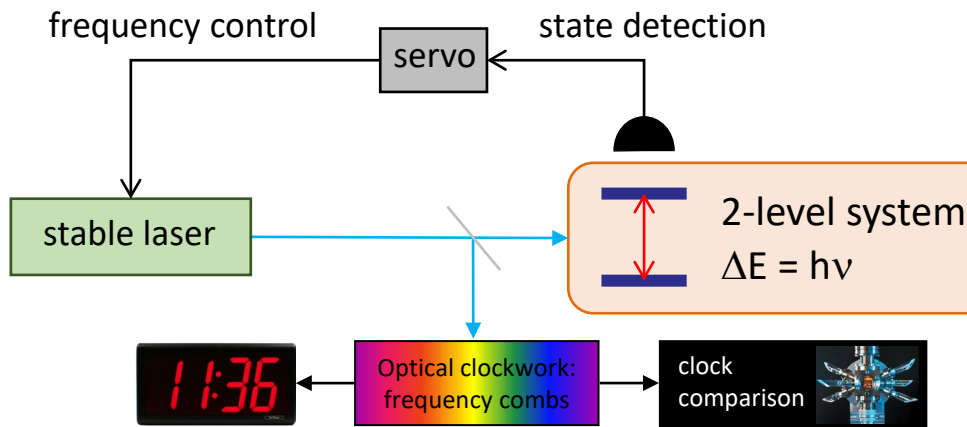


Nuclear clock proposal: E. Peik and Chr. Tamm, Europhys. Lett. 61, 181-186 (2003)
 10^{-19} performance estimate of ^{229}Th ion clock: C. J. Campbell, et al., PRL 108, 120802 (2012)
Performance estimate of ^{229}Th solid-state clock: G. Kazakov, et al., New Journal of Physics 14, 083019 (2012)

WHAT is a Thorium nuclear clock?

scheme of an atomic clock

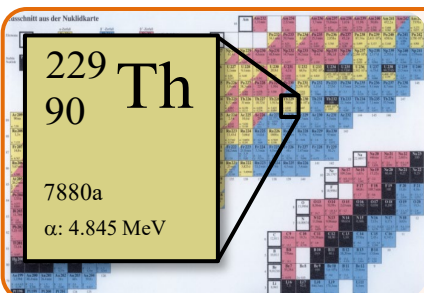
scheme of a **nuclear clock**



Nuclear clock proposal: E. Peik and Chr. Tamm, Europhys. Lett. 61, 181-186 (2003)

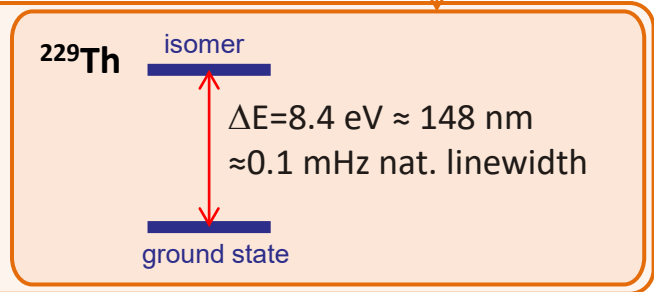
10⁻¹⁹ performance estimate of ²²⁹Th ion clock: C. J. Campbell, et al., PRL 108, 120802 (2012)

Performance estimate of ²²⁹Th solid-state clock: G. Kazakov, et al., New Journal of Physics 14, 083019 (2012)



²²⁹Thorium properties:

- lowest excitation energy of all nuclides: 8.4 eV
- half life: ≈ 7900 yr (α-decay)
- produced in α-decay of ²³³U or β-decay of ²²⁹Ac
- **nuclear transitions robust against perturbations**

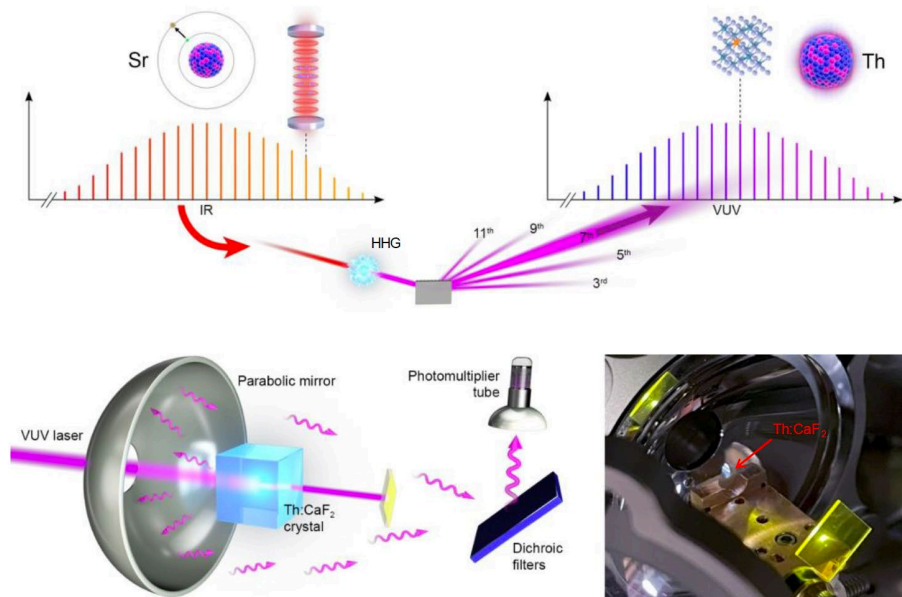




YES we can! (since 2024)



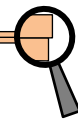
First Laser excitation of an atomic nucleus, first realization of a nuclear clock, comparison with Sr clock



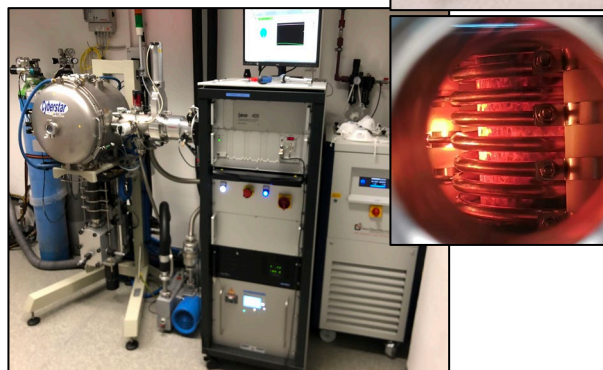
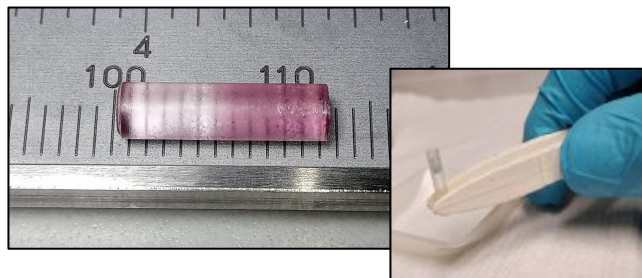
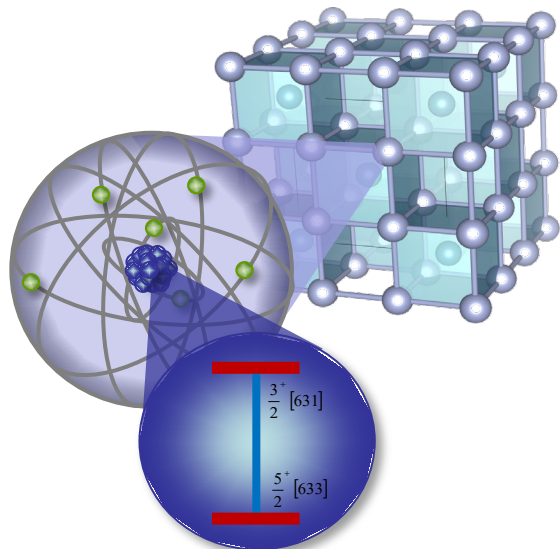
$$\frac{\nu_{229\text{Th}}}{\nu_{87\text{Sr}}} = 4.70707238097(2)_{\text{stat}}(2)_{\text{sys}}$$



Where will it go? A solid-state optical clock



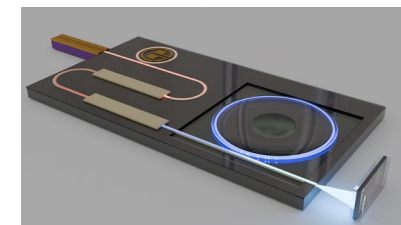
The nuclear transition works as a clock even when placed into a solid



In-house growth of ^{229}Th -doped crystals



microdisc resonator

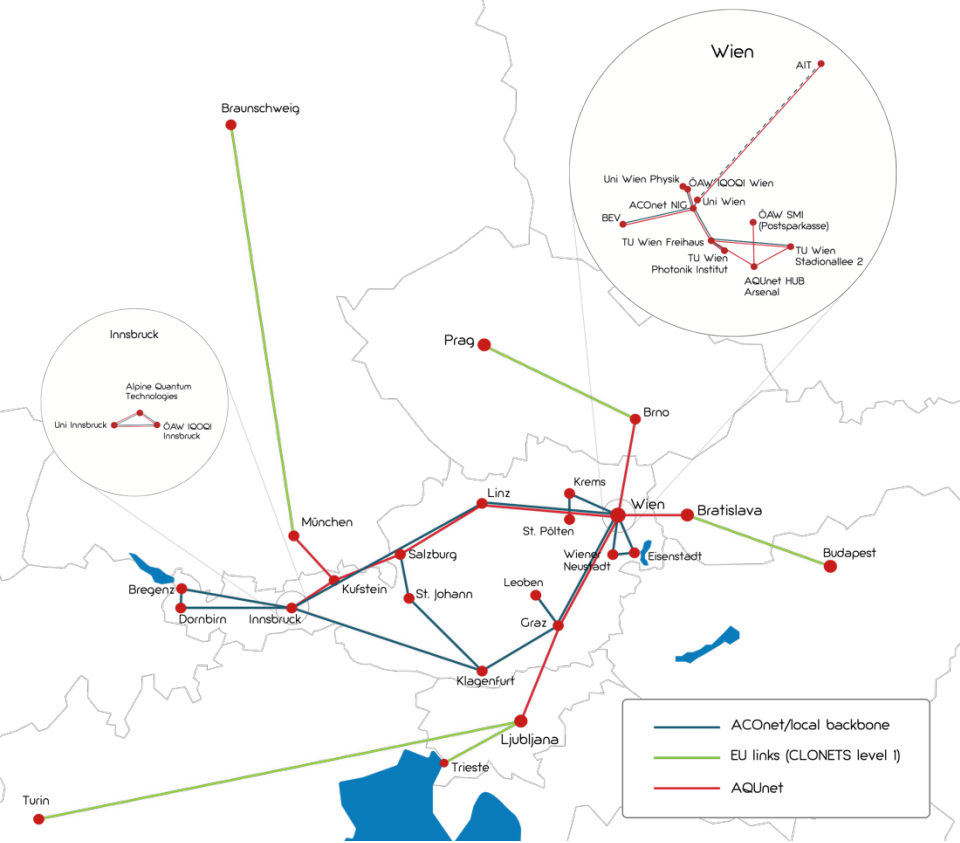


integration with laser sources and detectors

Worldwide unique expertise at TU Wien



But how to compare? AQUnet – Project



FFG-funded infrastructure project

- 3rd call R&D infrastructure, non-economic use
- 7 out of 54 funded
- start may 2021, duration 5(6) years
- Volume 2.4 Mio €, mainly for fiber backbone

Project coordinator

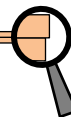
- Bernd Logar (ACONET assoc.)

Project Partners

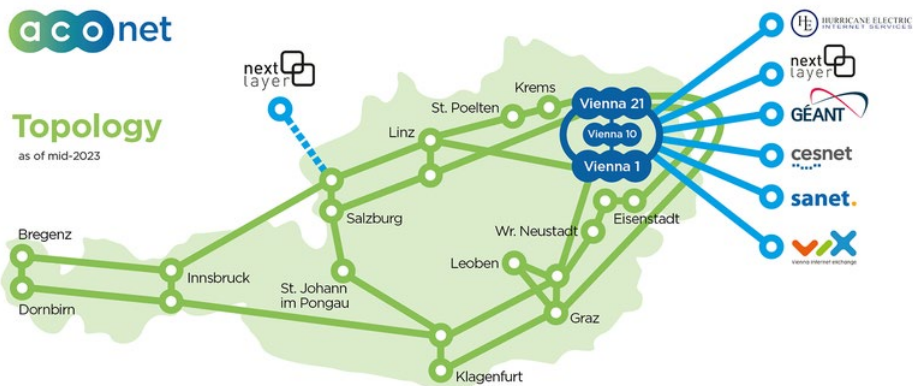
- TU Wien (T. Schumm)
- Uni Wien (P. Walther)
- Uni Innsbruck (T. Northup)
- BEV (P. Milota)



Funded by the Austria Research Promotion Agency



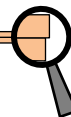
Using the academic fiber backbone for quantum...



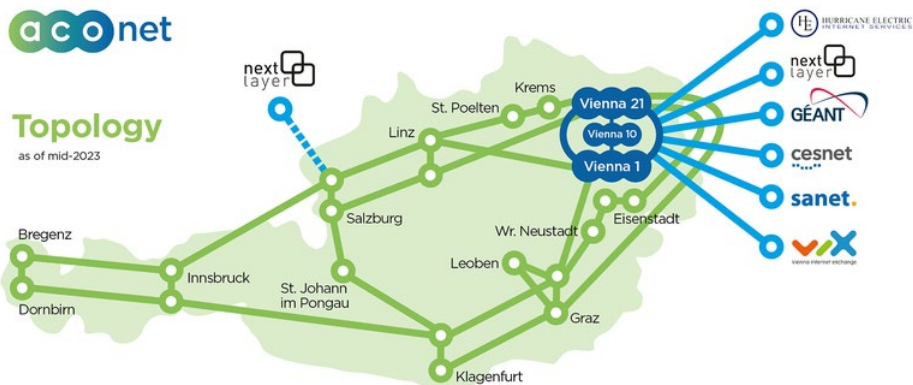
operated through framework contract with with **A1** Telekom Austria Group

Renewed 2021, specifically considering „quantum applications“:

- providing dark fibers
- providing joint use for classical + metrology
- access to intermediate stations + equipment deployment
- remote access to deployed equipment



Using the academic fiber backbone for quantum...



operated through framework contract with



Renewed 2021, specifically considering „quantum applications“:

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- remote access to deployed equipment

2 main activity pillars

Quantum communication

- mainly dark fibers
- distances <100 km

Frequency metrology / „clock signals“

- dark and operative fibers
- amplification every 100 km (needs access)

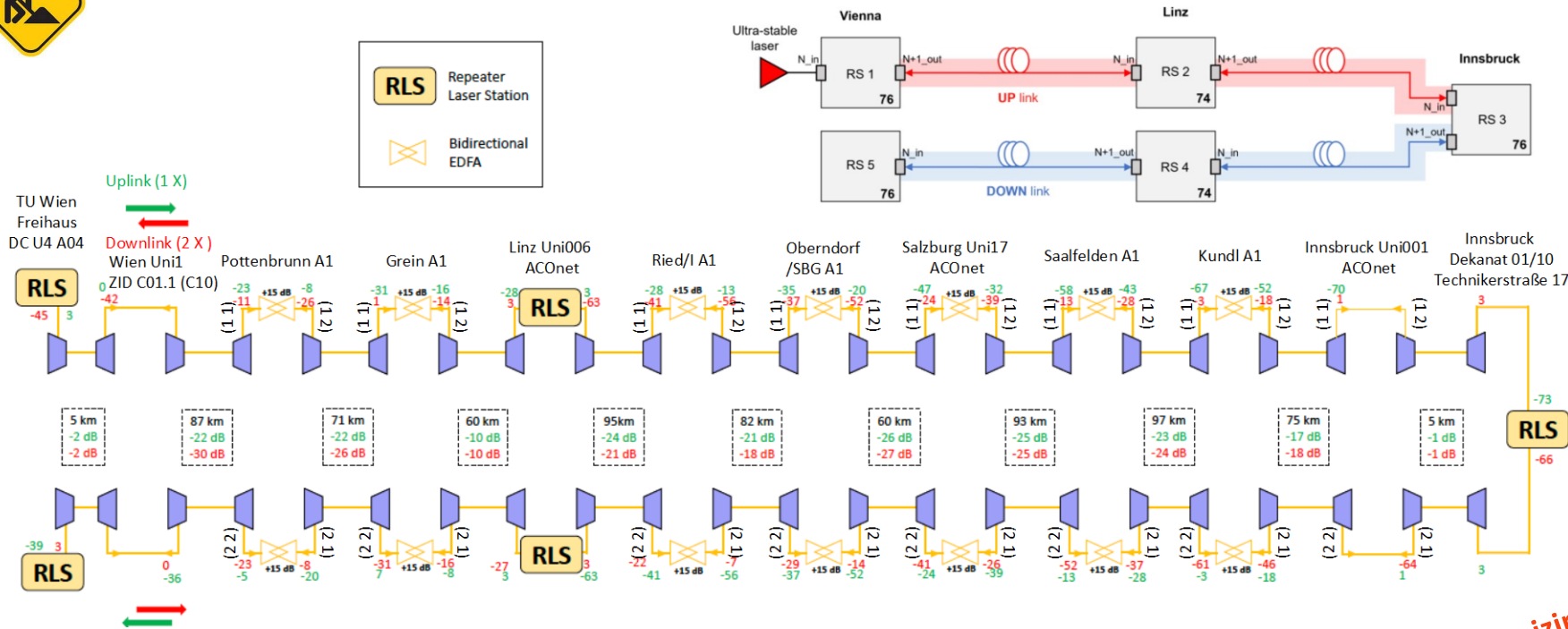
Service to the community! contact me...

Long-term goal: integration into ACOnet services





Example 1 : Vienna-Innsbruck-link



- self-monitoring link, can be used for seismic monitoring
- signal extraction (only) at RLS stations: Linz + Innsbruck

Link is online, optimizing...



Along the link...fiber amplifiers (EDFAs)

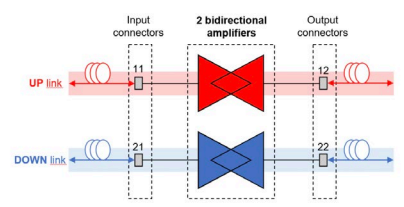
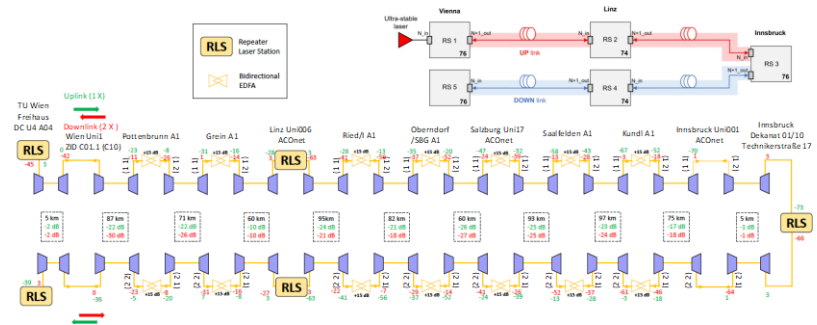
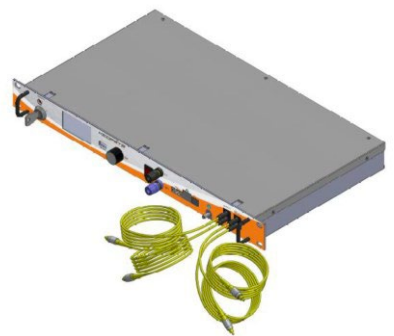
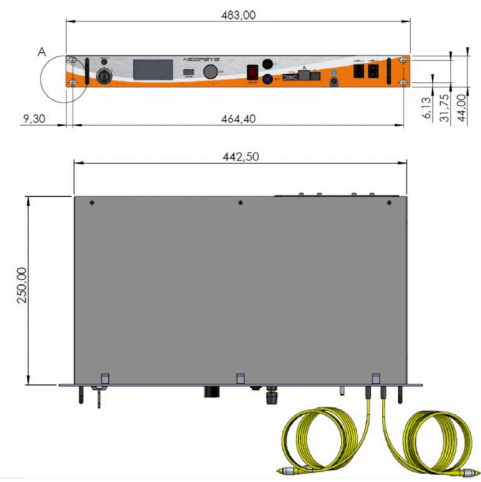


Fig.1 Scheme of the optical design inside an EDFA rack. It contains 2 bidirectional amplifiers. The optical connectors for amplifier 1 are labeled 11/12 and 21/22 for amplifier 2.

2.2 MECHANICAL DESIGN



7 units, currently deployed by A1 teams
+ out of band management on ALL sites



Along the link...regenerator laser stations (RLS)

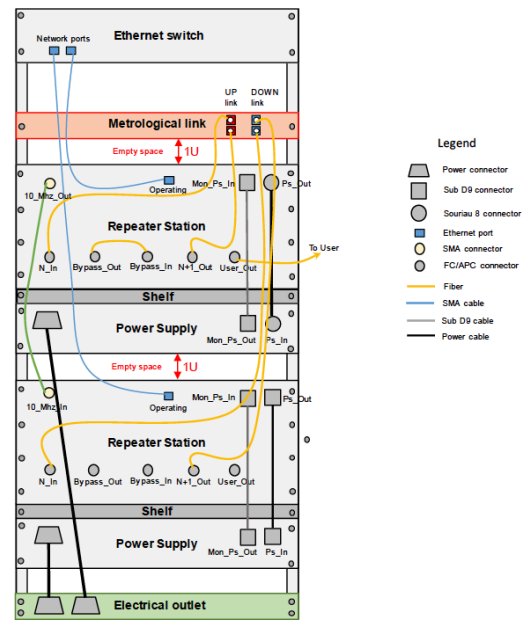
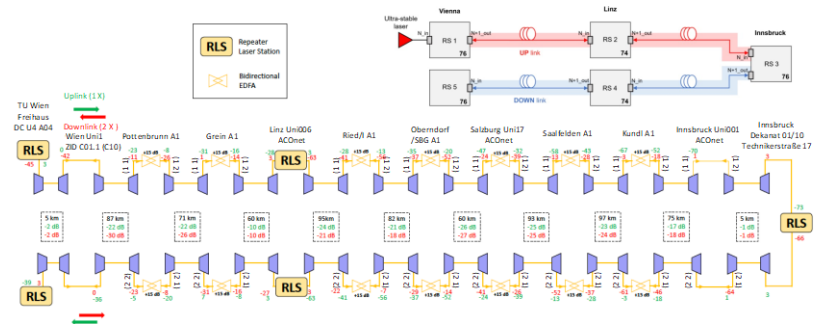
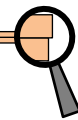


Fig.8 Scheme of a typical configuration of the rack cabinet in a node with all the connections (electrical, optical, RF, network) between the RS and the other devices. In this example, 2 RLS are installed for noise compensation of the upward and downward fibers respectively.

All units deployed (Vienna, Linz, Innsbruck)
 Need to establish remote monitoring system



BEV-TU Wien-Brno link already operational



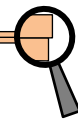
Inter-Wien link using operative data fibers

Online since 12/2022





BEV-TU Wien-Brno link already operational



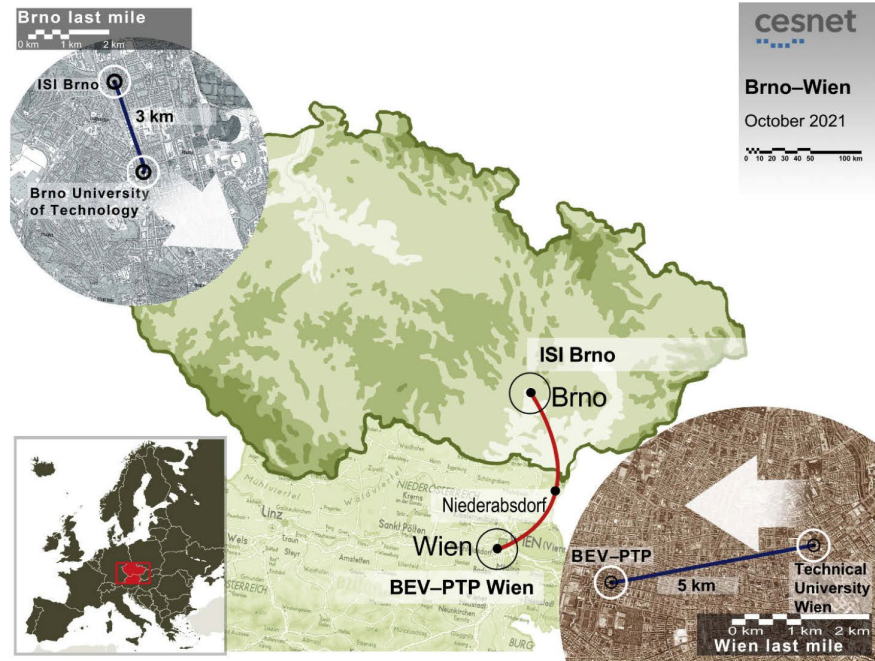
Inter-Wien link using operative data fibers

Online since 12/2022



Wien-Brno link using dark fibers

Online since 01/2022





BEV-TU Wien-Brno link already operational



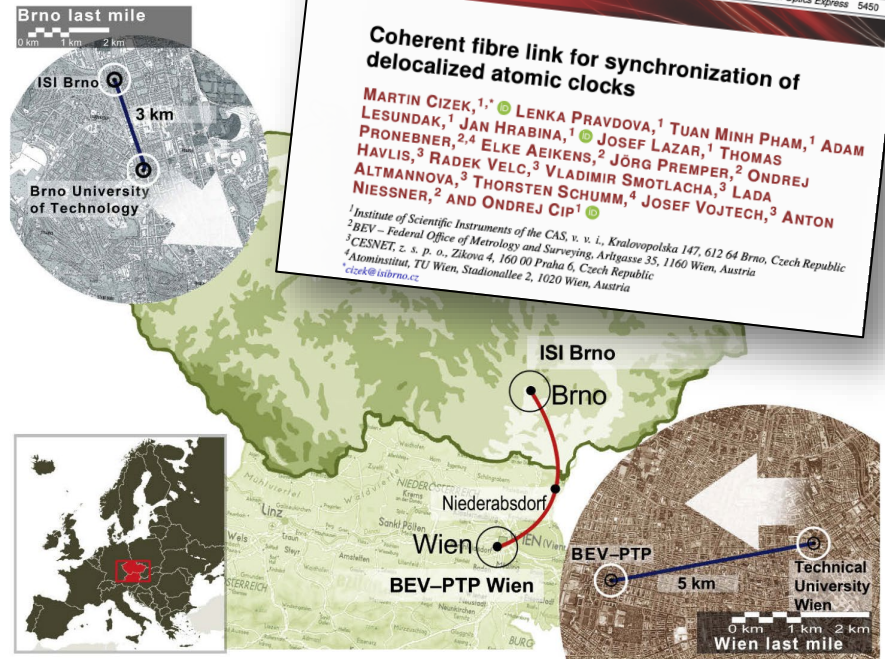
Inter-Wien link using operative data fibers

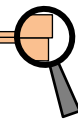
Online since 12/2022



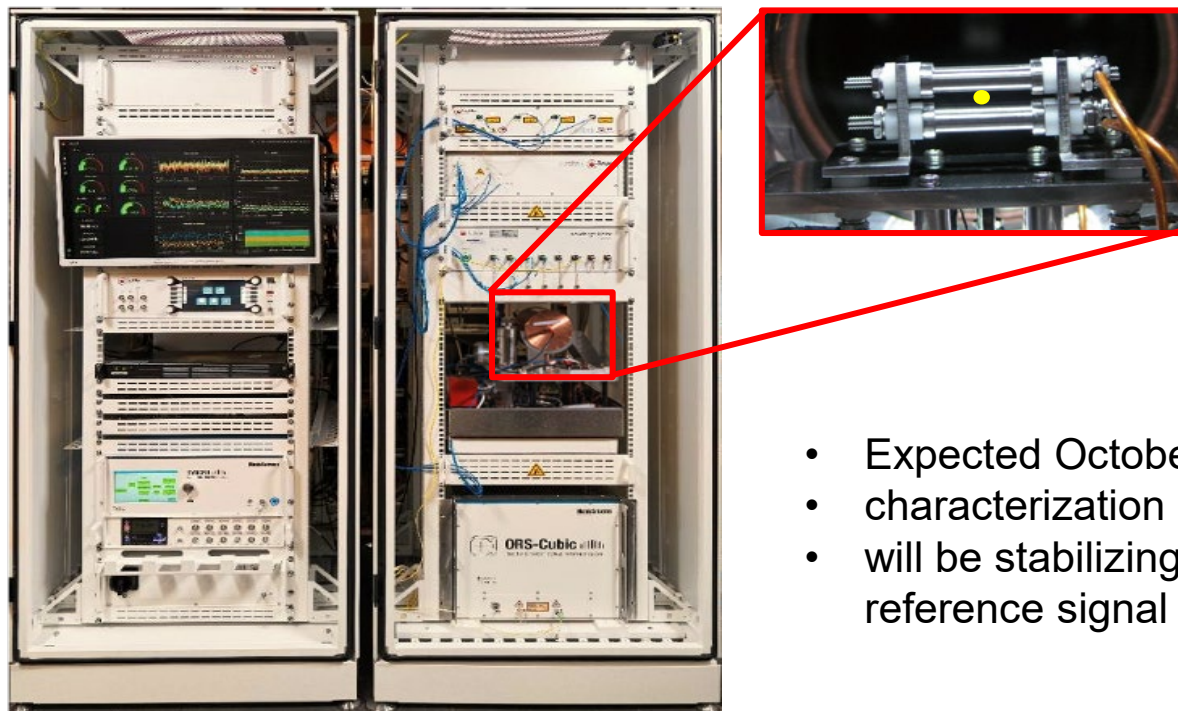
Wien-Brno link using dark fibers

Online since 01/2023





Yb⁺ (T)optiClock, to be installed at BEV



- Expected October 2025
- characterization and benchmarking @PTB before
- will be stabilizing (dedrifting) the national 1542 nm reference signal

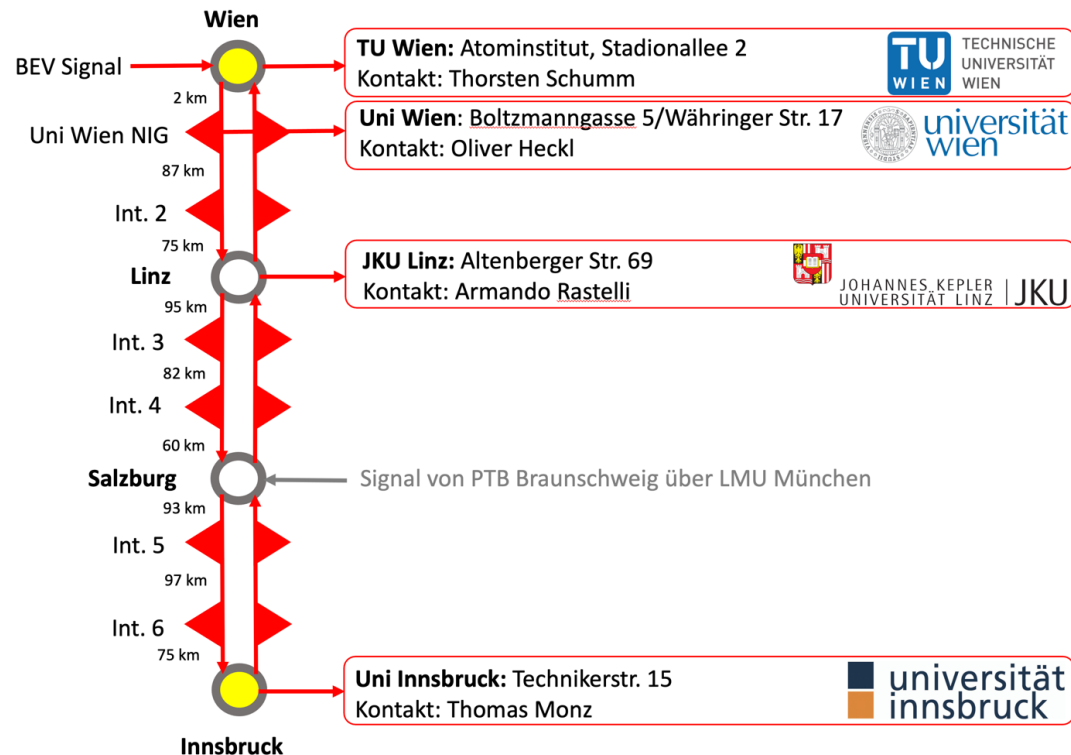
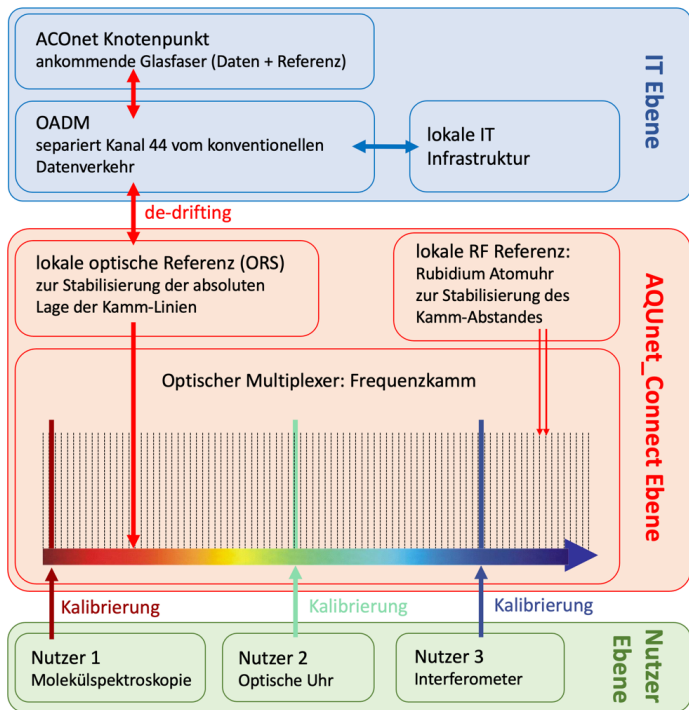


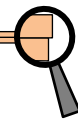
AQUnet_connect: multiplexing into labs



Converting the 1452 nm reference signal to lab-relevant wavelength

Bundesministerium Bildung, Wissenschaft und Forschung





thorsten.schumm@tuwien.ac.at