Centre for Quantum Engineering and Space-Time Research

Physikalisch-Technische Bundesanstalt Braunschweig und Berlin

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Progress on PTB's transportable Al^+ ion clock

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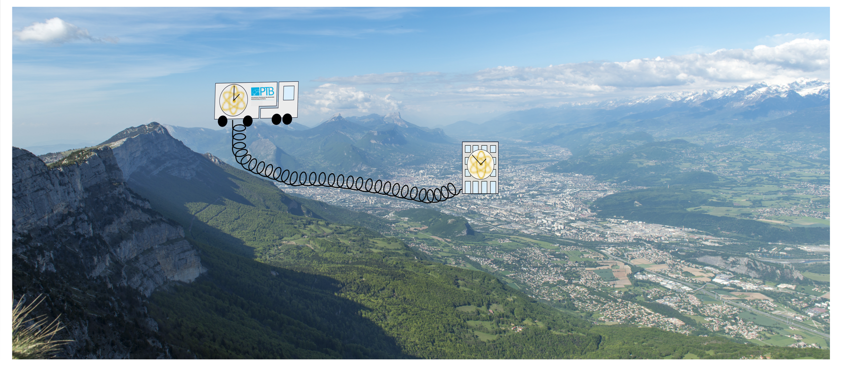
Background information

Motivation: Chronometric levelling

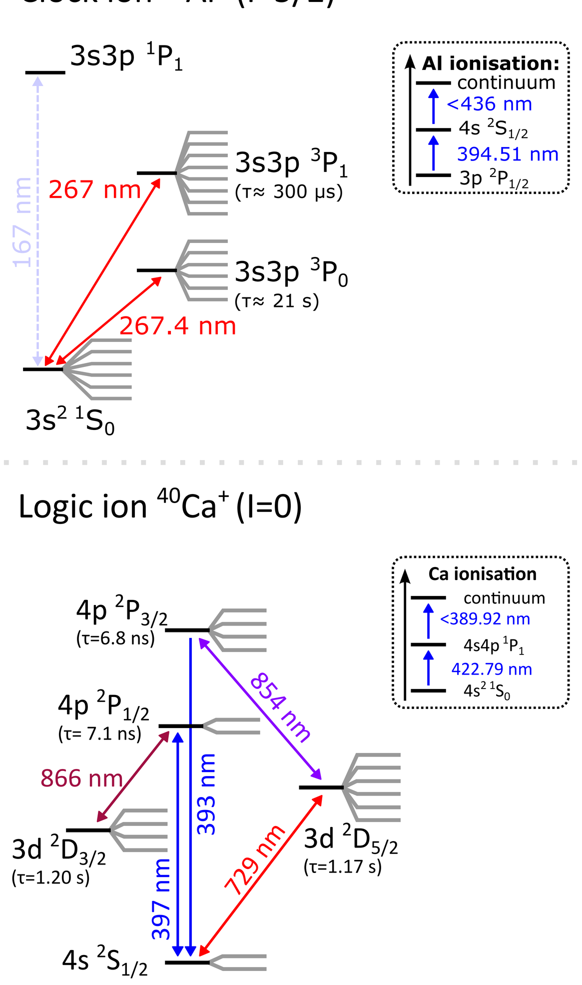
- Optical clocks provide low systematic fractional frequency uncertainties on the order of 10^{-18}
- Highly accurate transportable optical clocks allow side-by-side clock comparisons
- Applications of transportable optical clocks:
  - High accuracy tests of fundamental physics
  - Clock calibration among national metrology institutes
  - Possible future redefinition of the SI second
  - Height measurements based on gravitational redshift of two optical clocks



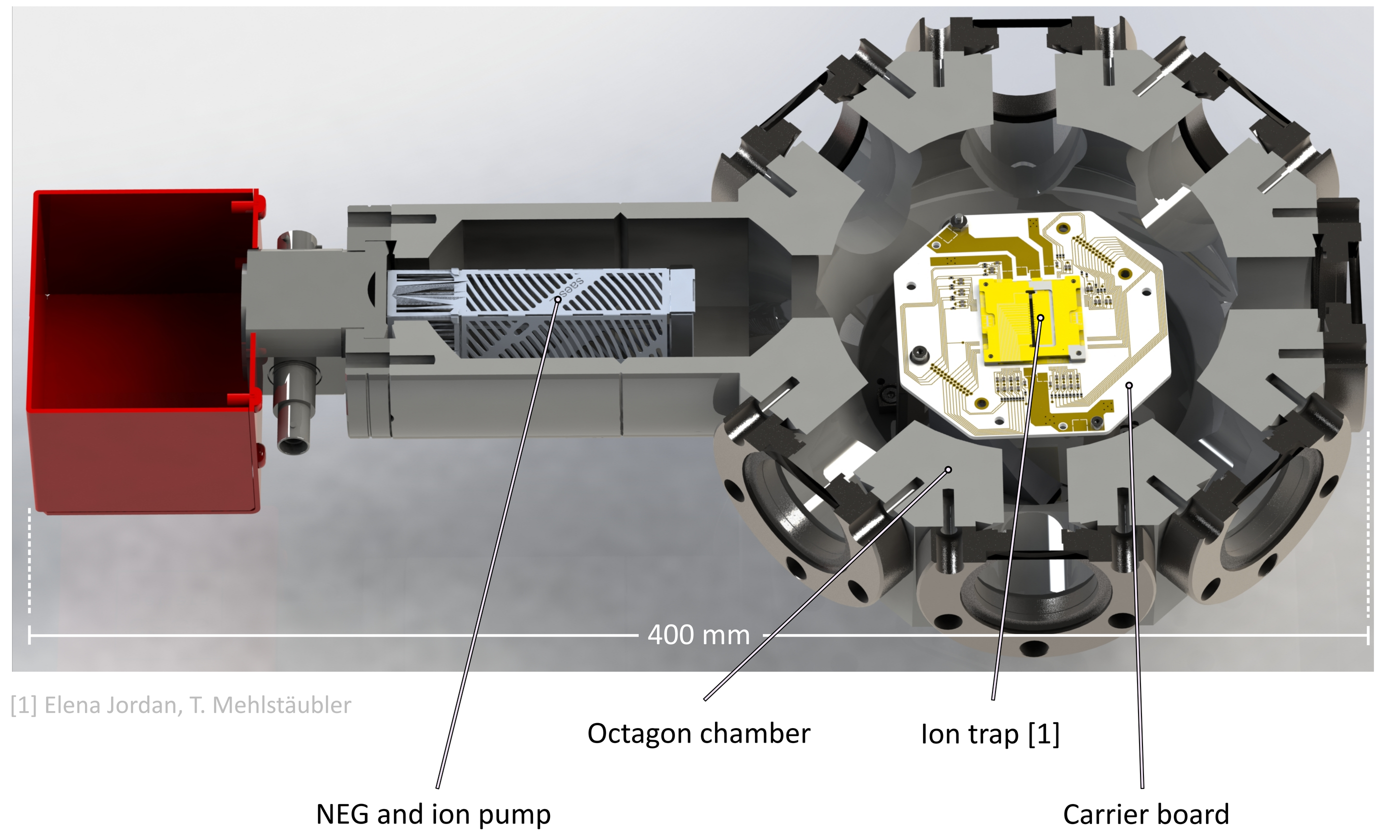
Ions' level schemes

Clock ion $^{27}Al^+$ (I=5/2)

Logic ion $^{40}Ca^+$ (I=0)



Vacuum package and trap assembly



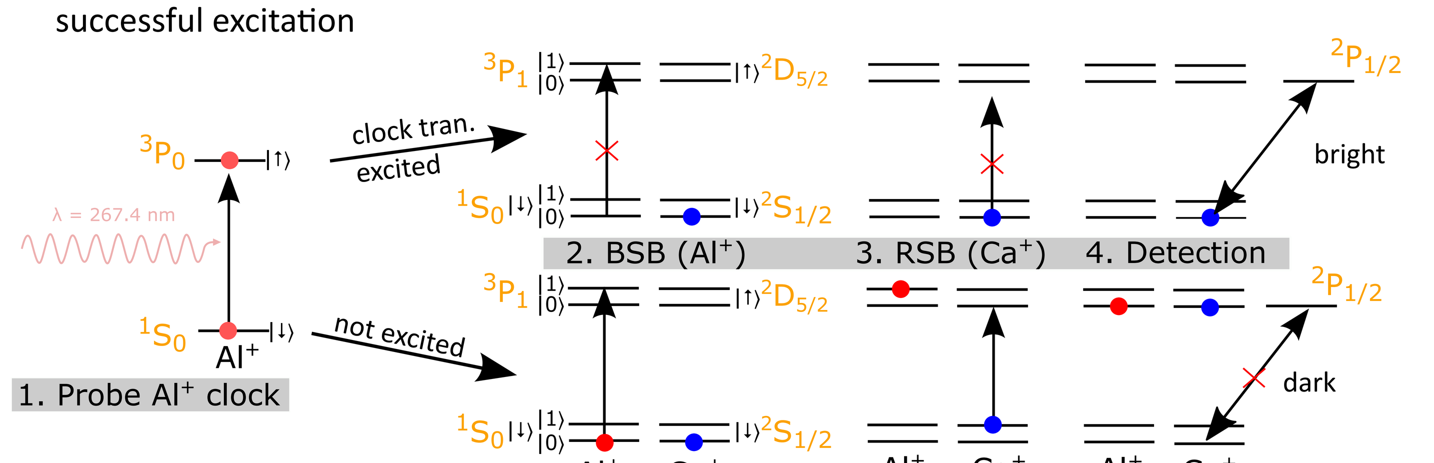
- Low-outgassing & non-magnetic aluminium octagon chamber with titanium viewports
- Thermal conductive AlN carrier board
- 4-layer stacked multi-segmented ion trap including compensation electrodes and temperature sensors [1]

Technique: Quantum logic spectroscopy

The Al^+ clock ion has very small electromagnetic shifts. Blackbody radiation, linear and quadratic Zeeman as well as quadrupole shifts were already shown to be very small or negligable which mark Al^+ to be an excellent clock species.
However, cooling and state readout is challenging as no transition is accesible, respectively.
Instead, a co-trapped Ca+ ion provides control on the clock ion via the Coulomb-determined shared motional state in the harmonic potential.

Typical clock sequence:

1. Probe the Al^+ clock transition
2. Probe the Al^+ logic state, adding one quantum of motion to Coulomb crystal for successful excitation
3. Probe the Ca^+ quantum logic state
4. Probe Ca^+ ion and detect if initial clock transition was successfully interrogated



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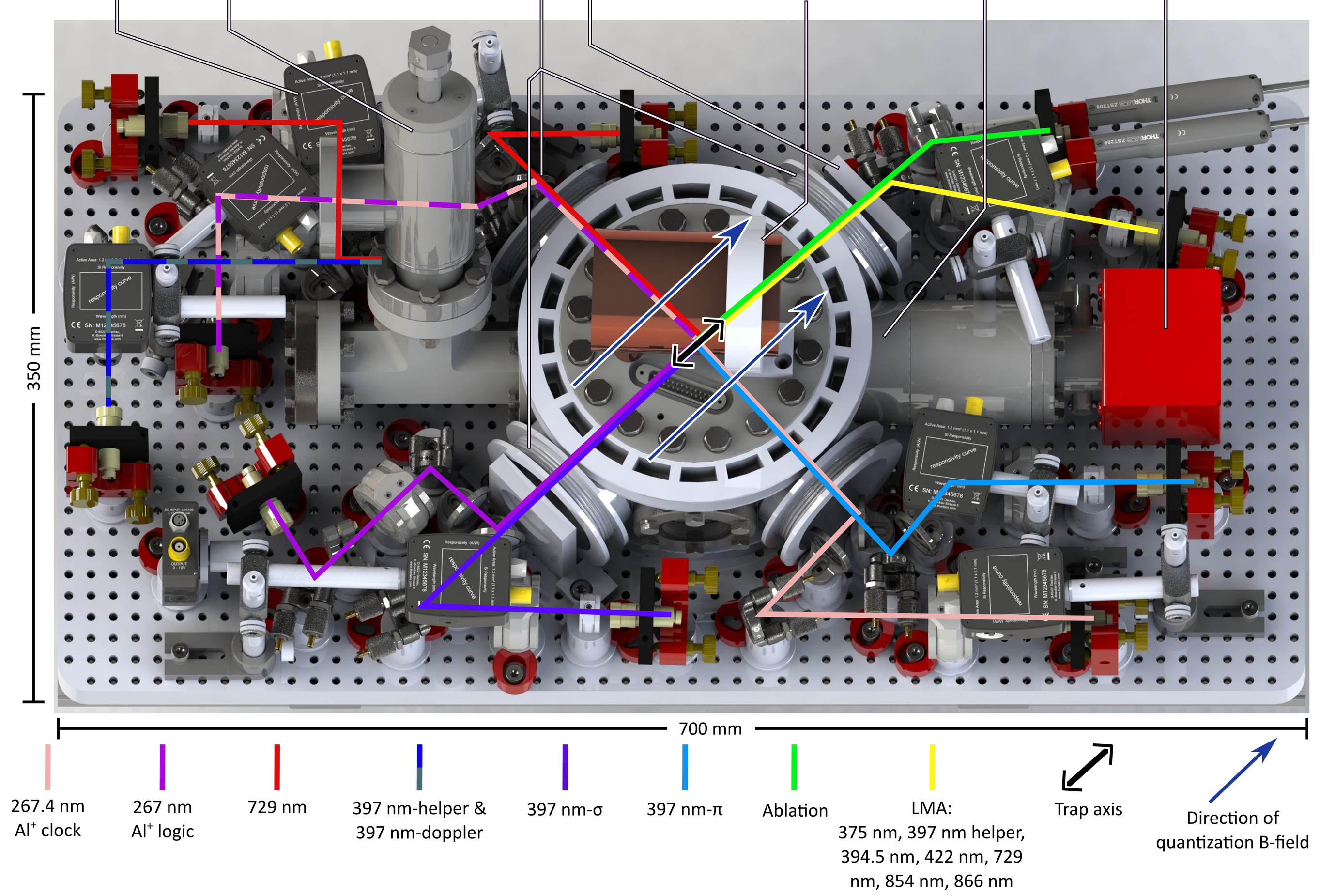
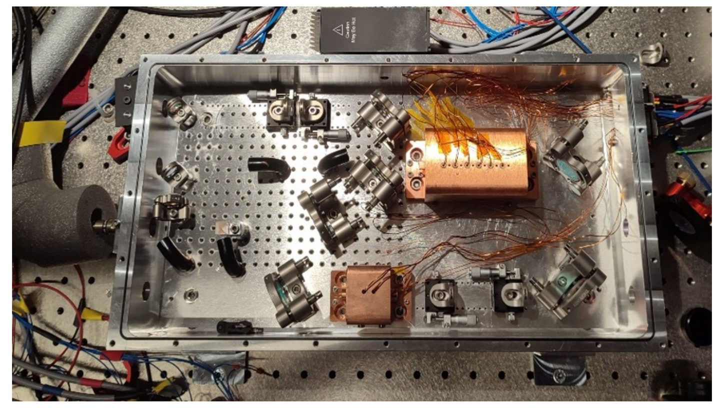
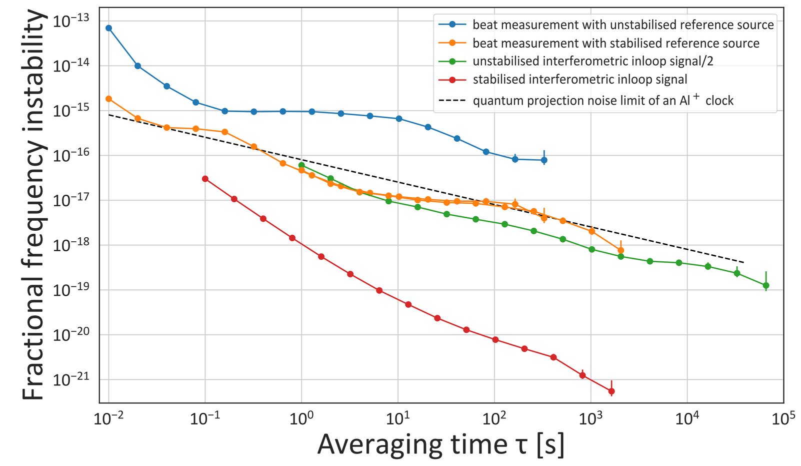
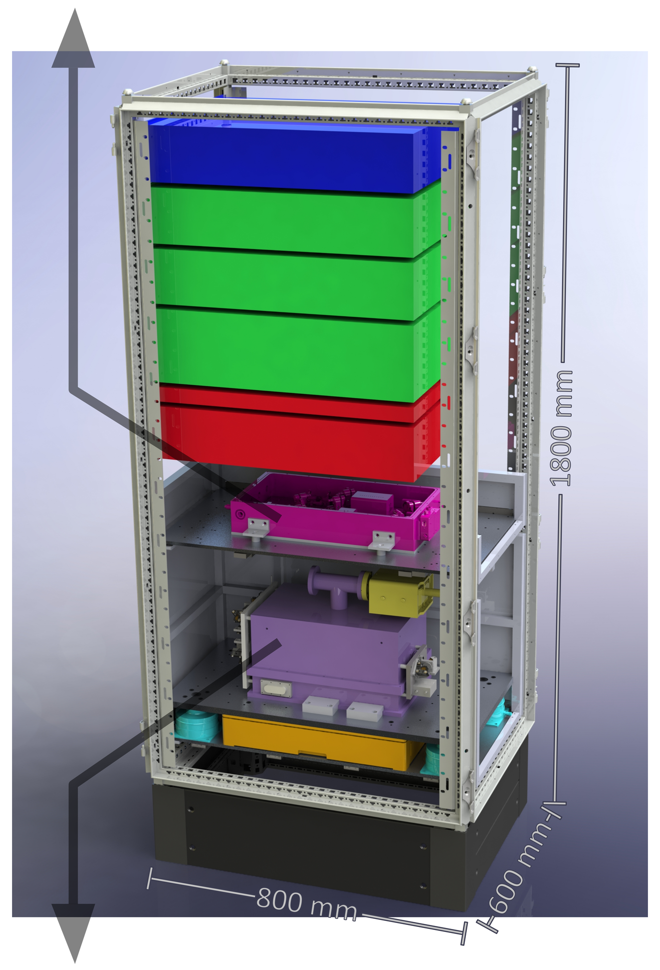
Physics package: QUIDICH breadboard



The clock laser







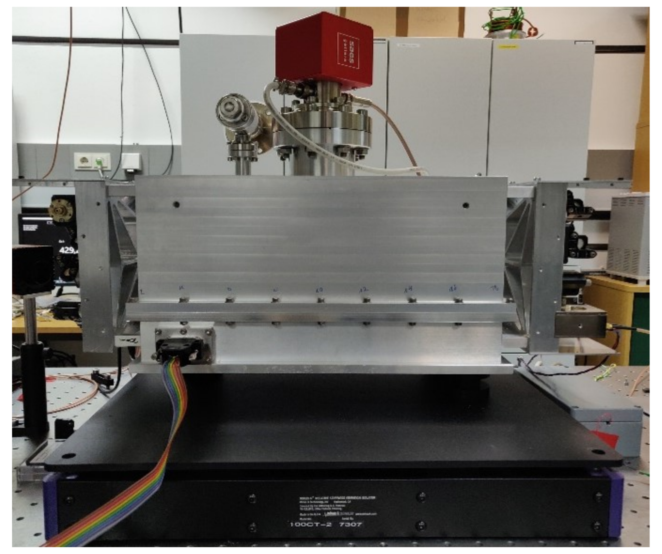
The clock laser setup:

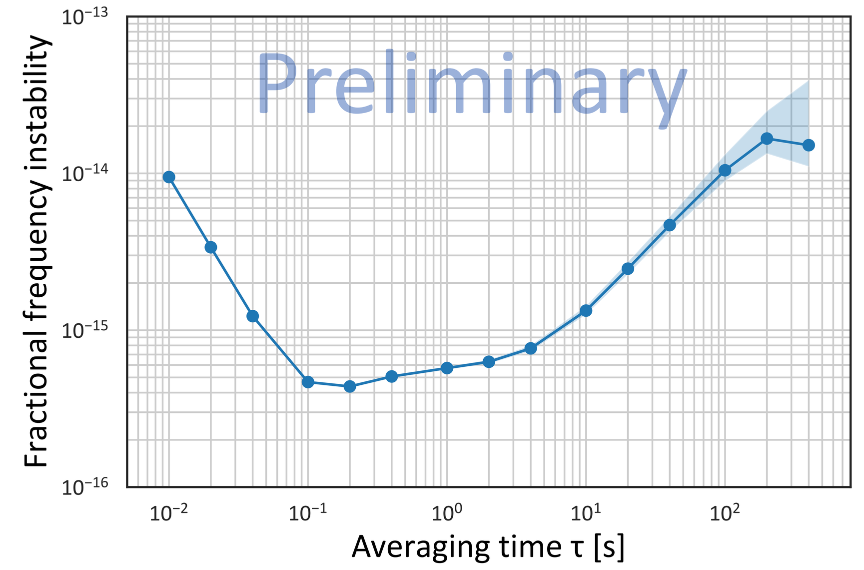
Fully rack-mounted clock laser apparatus comprising

- Experimental control computer (blue)
- Electronic devices (green)
- Laser source and amplifier (red)
- Single-pass frequency quadrupling system (magenta)
- Highly-stable reference cavity for fundamental IR light at 1069.6 nm (purple)
- Active vibration isolation platform (yellow)

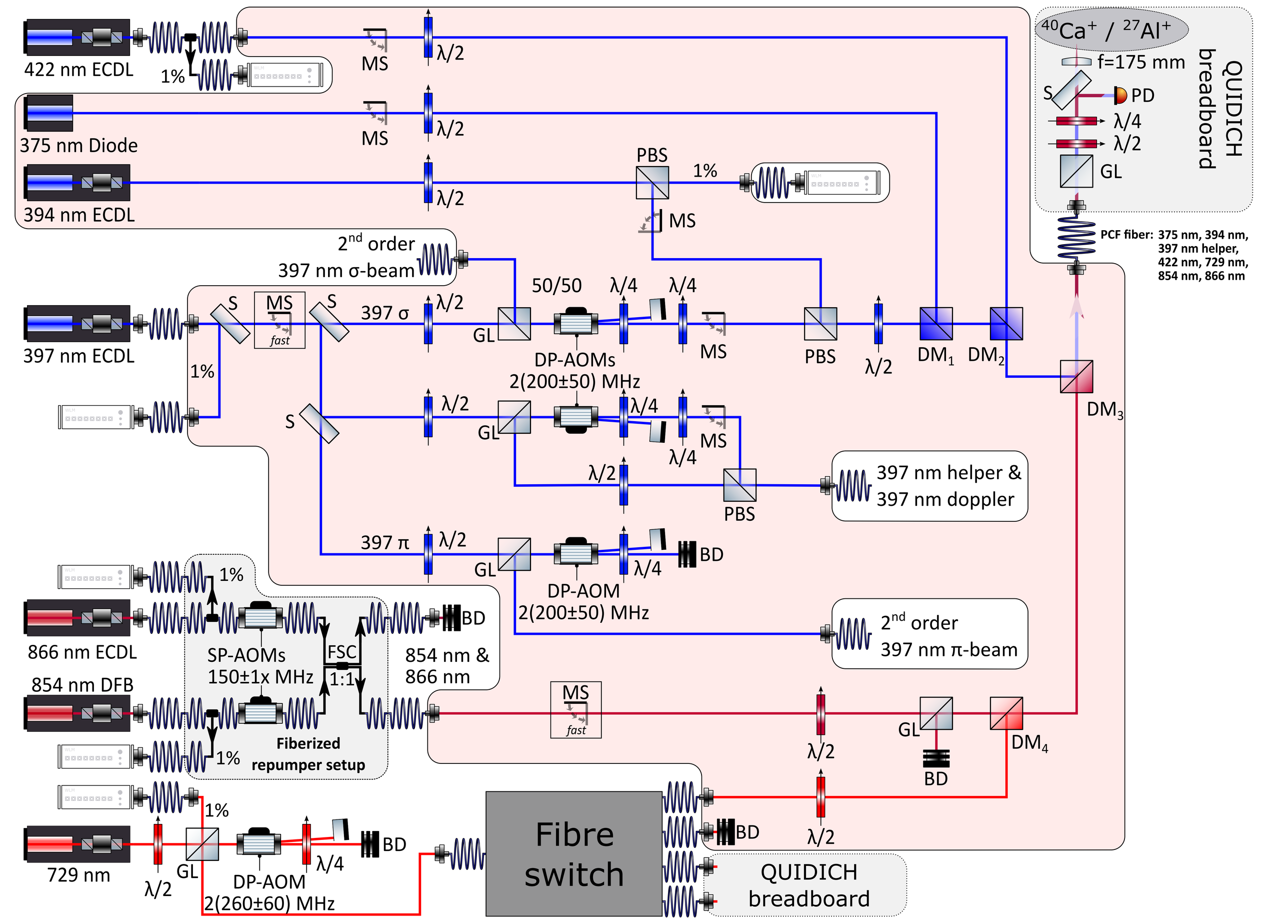
Characterization:

- Fractional frequency instability below 10^{-16} for quadrupling system
- The reference cavity proofs pre-stabilization of the fundamental frequency below $5 \cdot 10^{-16}$ at 1 second





Development of Ca^+ - laser system



Design:

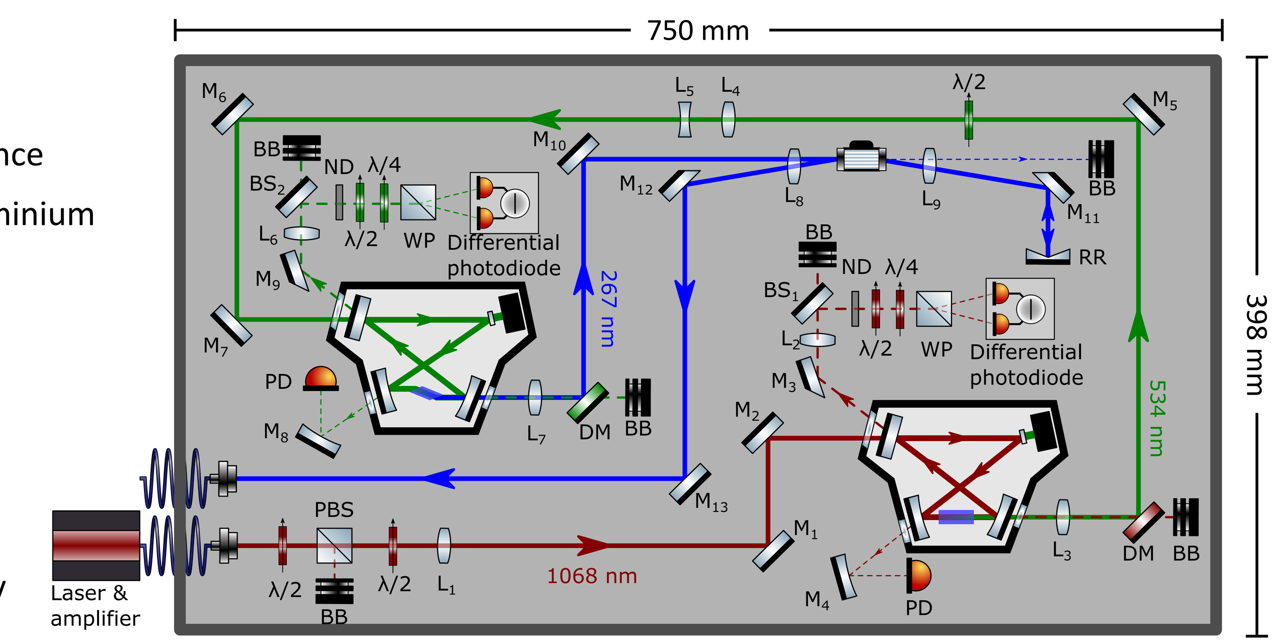
- Combining Ca^+-cooling laser (397 nm) with IR-repumper (866 nm), clear-out (854 nm) and Ca^+-logic (729 nm) lasers together with (partially resonant) ionization lasers for Ca (422 nm & 375 nm) and Al (394 nm) into one common LMA fibre (yellow path on QUIDICH board).
- The LMA fibre provides light on the trap axis containing all wavelengths necessary to load and capture ions.
- Splitting the 397 nm laser path thrice: Independent σ, π and doppler beams are provided using frequency shifters, respectively.
- Additional outputs for light-ion interactions on radial and diagonal axes are provided.
- Implementation of light pick-offs for frequency stabilization on wavelengthmeter.

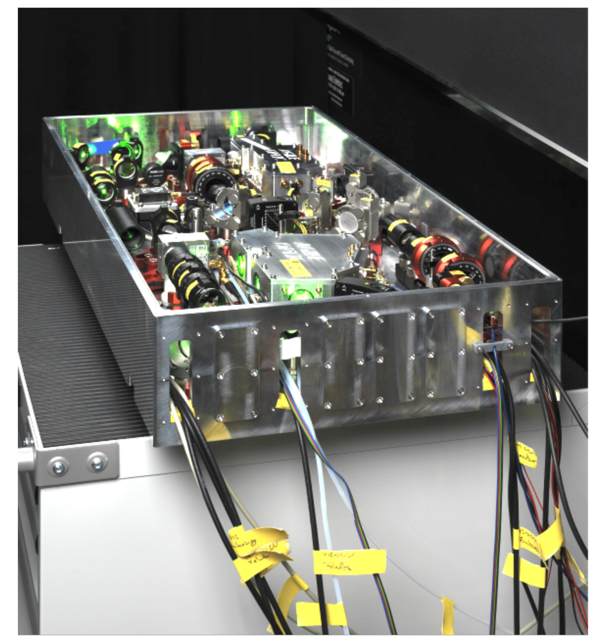
Next steps:

- Developing a compact design which fits into one 19" rack drawer. Prior planning with CAD software.
- Set up the laser system inside the highly-stable monolithic drawer.
- Capture the first ions within 2023!

Compact, rack-integrated Al^+ logic laser system

- Designed to address the $^3P_1$ state of Al^+ (I=5/2)
- Important for state preparation of Al^+ (I=5/2)
- Enables electron shelving on Al^+ as part of quantum logic sequence
- Implementaton of optical setup in highly-stable, monolithic aluminium drawer
- Frequency quadrupling based on two resonant frequency doubling cavities (Hänsch-Couillaud locking scheme)
- Setup includes double-pass UV-AOM for power stabilization, shutter and frequency control
- 1.4 mW UV output behind double pass AOM and UV-fiber
- **Next steps:** Stabilize IR fundamental to logic cavity for frequency stabilization and implement UV polarization & power control





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