

Optical Clocks and Frequency Standards

– present research at PTB

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State-of-the-art clocks with Cs

- since 1967: SI-second defined through ^{133}Cs
- best Cs-clocks today: fountains based on laser-cooled atoms
- accuracy: $\delta v/v_0 = 3\text{-}5 \times 10^{-16}$ (limits: high collisional shift, Blackbody shift)
- short term instability: 2×10^{-14} (with cryo-sapphire)
 1.4×10^{-13} (with quartz)

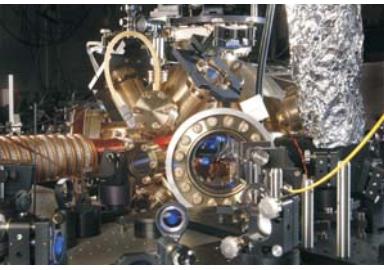
New concepts with optical clocks

- short term instability of a frequency standard scales like:
- with quality factor:
- systematic shifts contribute less at higher frequencies
- latest results (Al^+ / Hg^+): accuracy = 3×10^{-17}
 $\sim 3 \times 10^{-15}$ in 1 s

Goals & Applications

- geodetic measurements: clock probes local gravity potential
- ultra-stable frequency standard for navigation
- tests of fundamental physics:
 - Lorentz invariance
 - change of fundamental constants
 - local position invariance
- possible new definition of SI-second

Neutral atom standard: Strontium



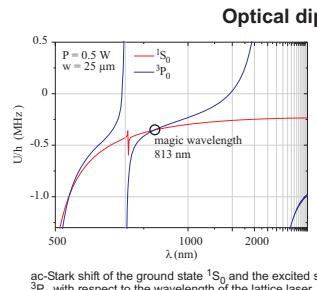
Isotopes
 ^{84}Sr : 0.56%
 ^{86}Sr : 9.86%
 ^{87}Sr : 7.00% I = 9/2
 ^{88}Sr : 82.58%

Cooling transitions

- first cooling stage: $^1\text{S}_0 \rightarrow ^1\text{P}_1$ @ 461 nm
 $T = 2 \text{ mK}$
 second cooling stage: $^1\text{S}_0 \rightarrow ^3\text{P}_1$ @ 689 nm
 $T = 3 \mu\text{K}$

Clock transition

- $^1\text{S}_0 \rightarrow ^3\text{P}_0$ @ 698 nm (429 THz)

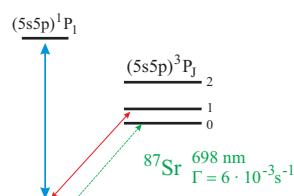


Quantum projection noise with 10^4 Sr atoms:

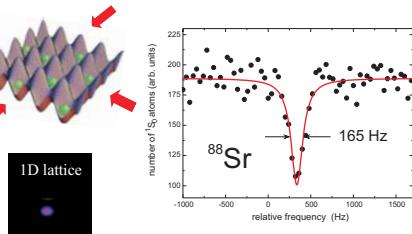
$$S/N \sim \sqrt{N}$$

- mHz linewidth of the clock transition limit: probe laser
- $Q = 2.4 \times 10^{14}$ realized!

$$= 4 \times 10^{-17} \text{ in 1 s possible}$$

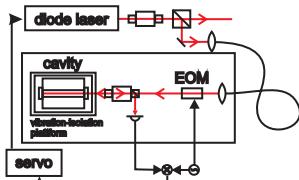


Optical dipole trap without net lightshift

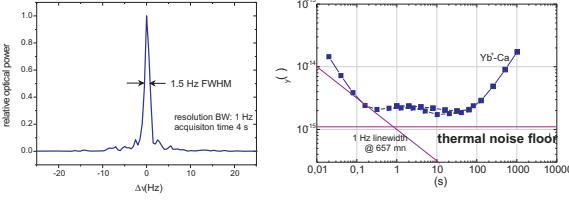


Clock laser

Diode laser locked onto ULE-cavity:

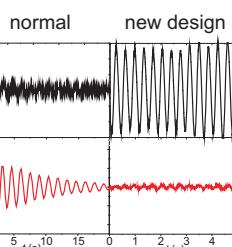
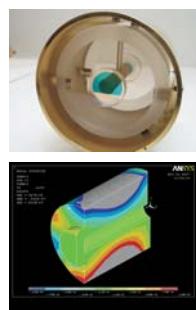


Clock laser line width & stability:



New designs

Vibration insensitive mounting of a cavity:

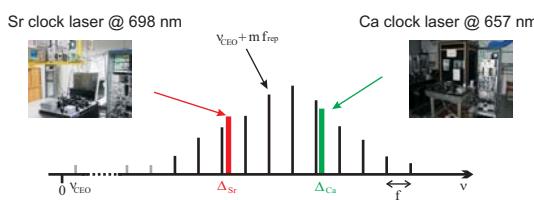


Femto second comb: clockwork

Counting of optical frequencies

$$v_{\text{opt}} = v_{\text{ceo}} + m f_{\text{rep}} - \Delta$$

Transfer scheme with frequency comb:



FUTURE

- Portable optical frequency standards
- Frequency comparison via optical fiber networks
- New cavity concepts: LN-cooled, whispering gallery mode...
- New concepts for laser stabilization!

Support:

