Trapped Ion Frequency Standards With Yb^+

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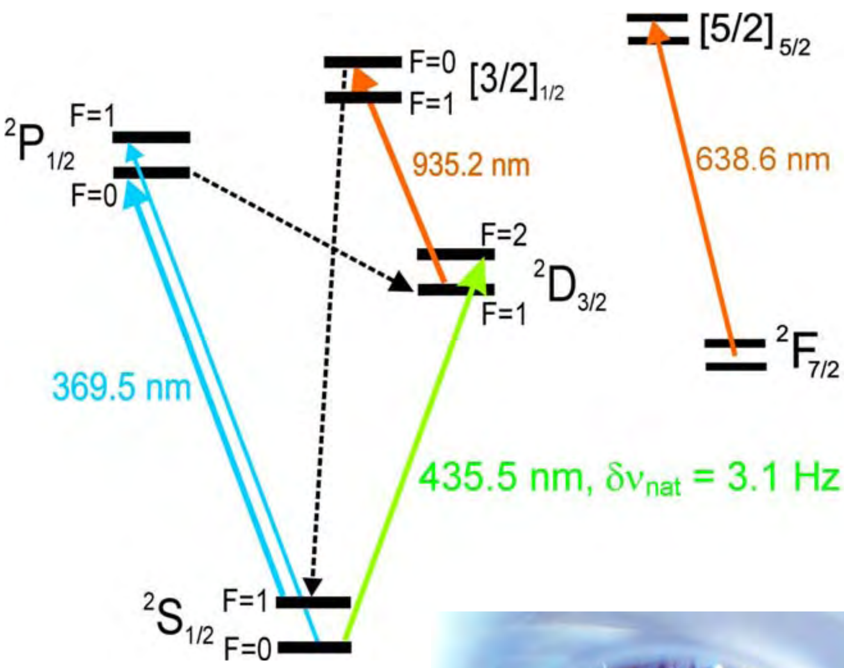
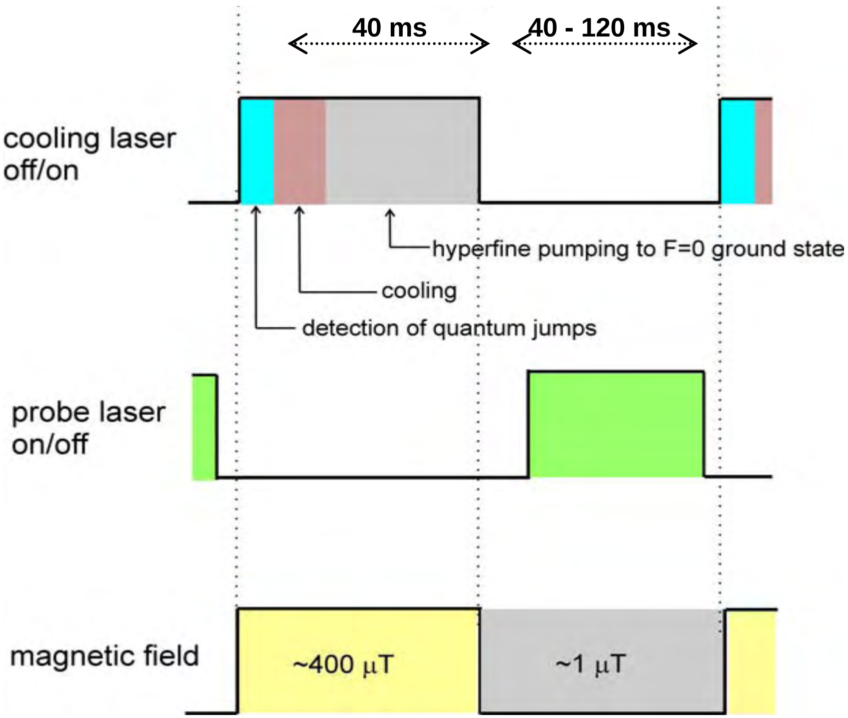
Support: DFG, FQXI

Yb+ single-ion optical frequency standard

$^{171}Yb^+$ level scheme

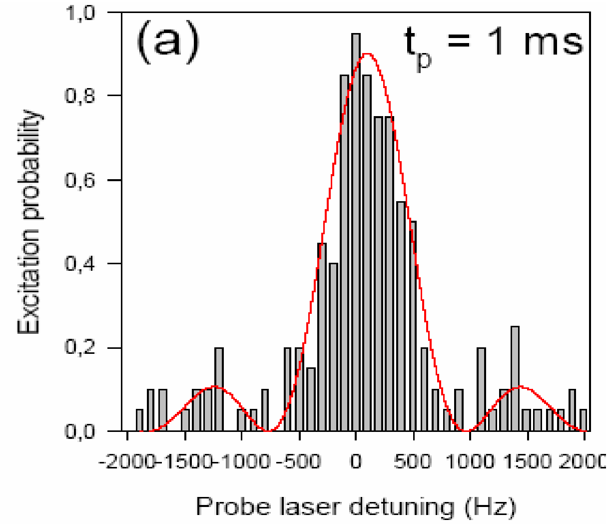


Measurement cycle

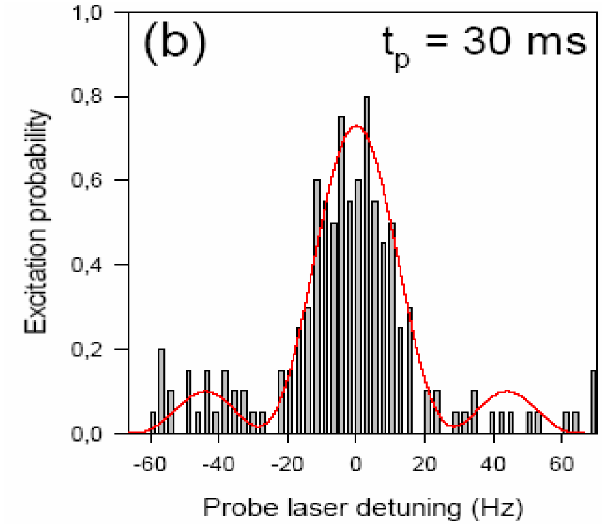


High resolution spectroscopy of the quadrupole transition at 688 THz

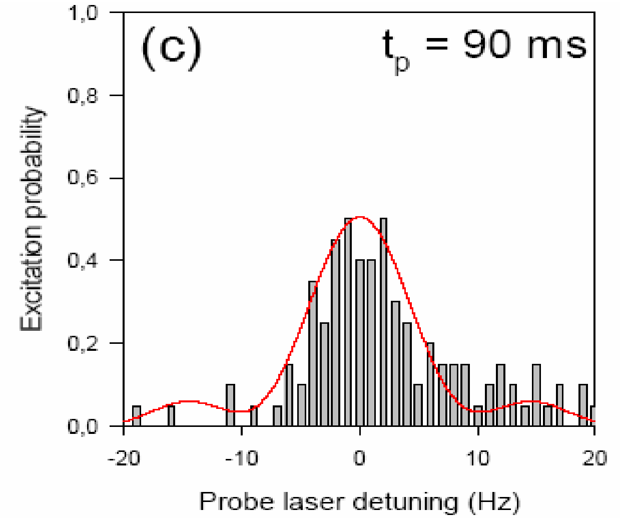
Pi-Pulse
τ(pulse) = 1 ms
1 kHz linewidth



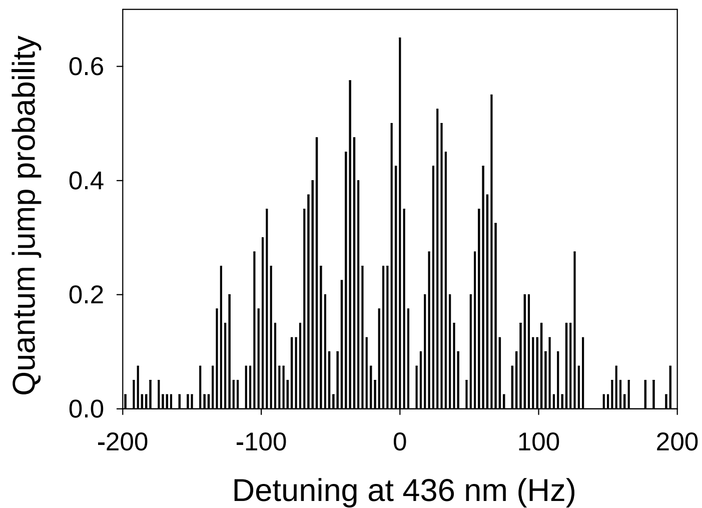
„standard operation“
τ(pulse) = 30 ms
30 Hz linewidth



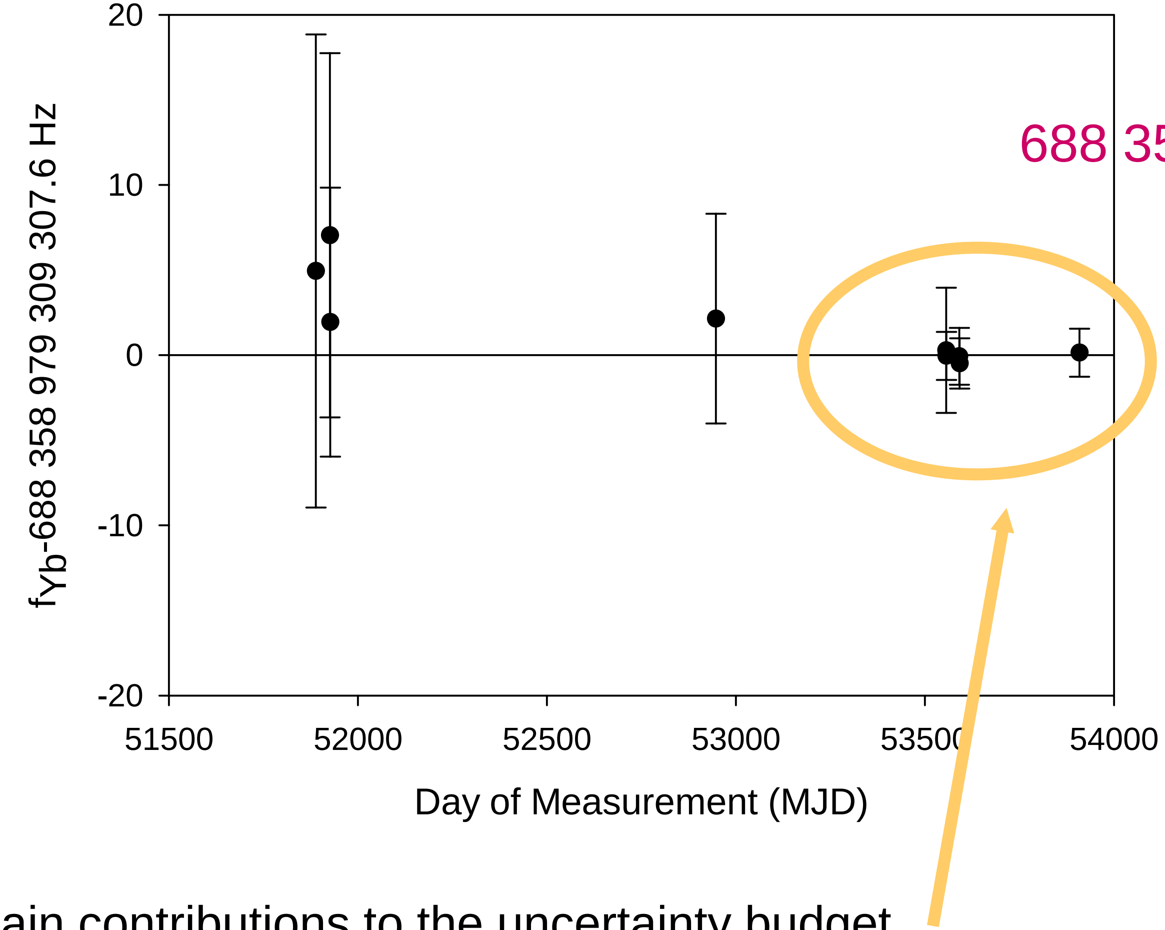
Close to the resolution lim
τ(pulse) = 90 ms $\approx 2 \cdot \tau(Yb^+)$
10 Hz linewidth



Ramsey excitation
with 30 ms pulse separation



Results of absolute frequency measurements 2000-2006



$^{171}Yb^{+}$ $S_{1/2}$ - $D_{3/2}$:
688 358 979 309 307.5(1.4) Hz

Main contributions to the uncertainty budget
of the measurements in 2005 and 2006:

u_A=0.40 Hz (continuous measurements up to 36 h)
u_B(Cs)=0.83 Hz
u_B(Yb^+)=1.05 Hz (quadrupole shift, blackbody AC Stark shift)

New Limits for Temporal Variations of Fundamental Constants

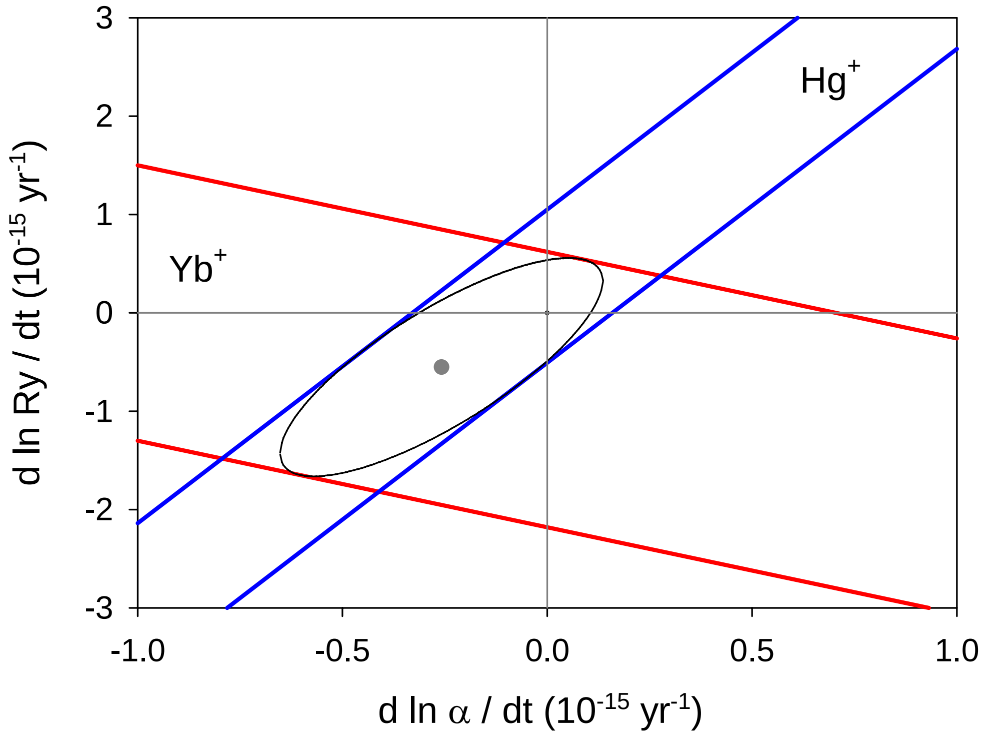
Combining the data from Yb^+ with those from the Hg^+ frequency standard at NIST, W. H. Oskay et al., Phys. Rev. Lett. **97**, 020801 (2006), yields

For the fine structure constant:

$$\frac{d \ln \alpha}{dt} = (-0.26 \pm 0.39) \cdot 10^{-15}\ \mathrm{yr}^{-1}$$

For the Rydberg frequency:

$$\frac{d \ln Ry}{dt} = (-0.55 \pm 1.11) \cdot 10^{-15}\ \mathrm{yr}^{-1}$$



E. Peik et al., physics/0611088

See also:
T. Fortier et al., PRL 98, 070801 (2007)

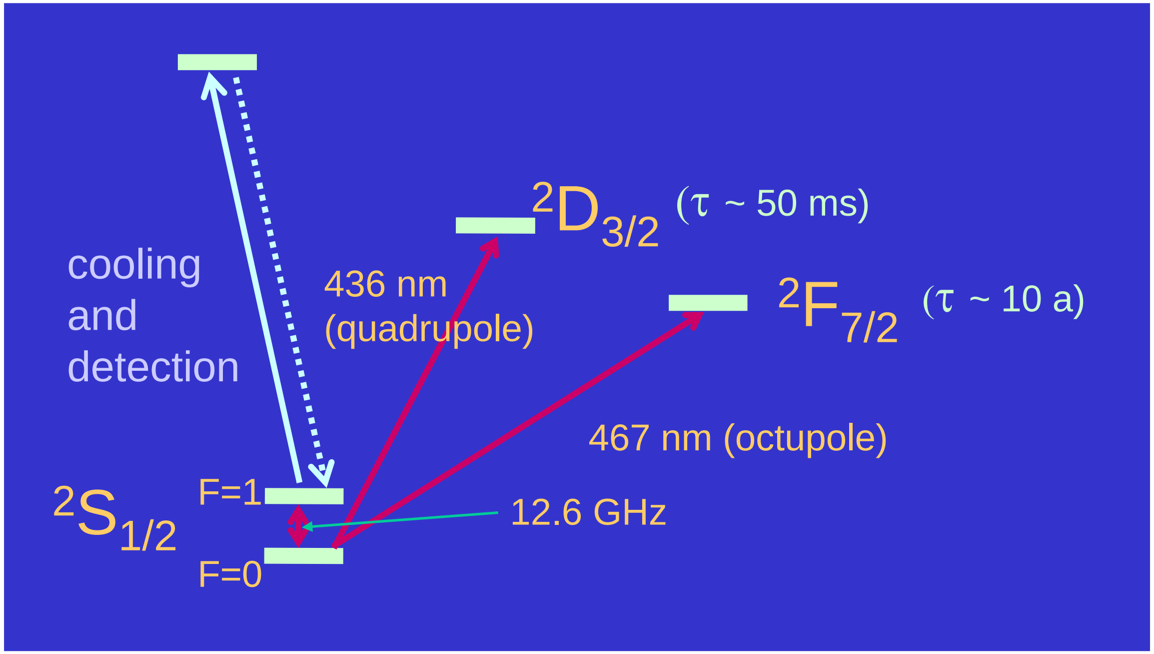
Future Possibilities:

Direct optical frequency ratio measurements with a frequency comb: avoid uncertainty contributions from cesium clocks

- PTB/NPL: Yb^+ octupole vs. quadrupole: $|\Delta A=6.2|$

$$Y = \frac{f_{Quad}}{f_{Okt}} \qquad \frac{d\ln Y}{dt} = 6,2\,\frac{d\ln\alpha}{dt}$$

Level scheme of $^{171}Yb^+$

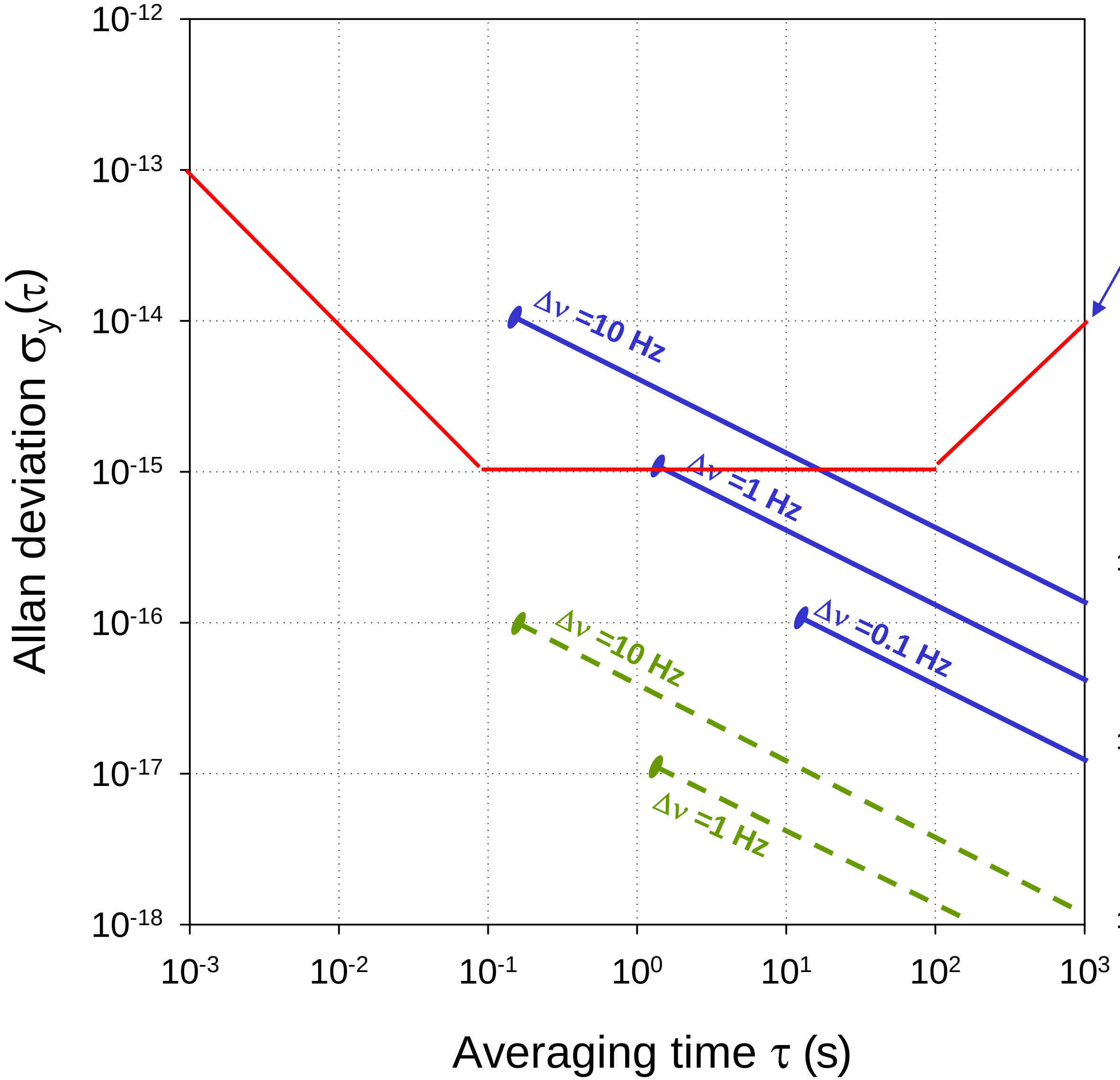


Quantum and laser limits on stability

PTB

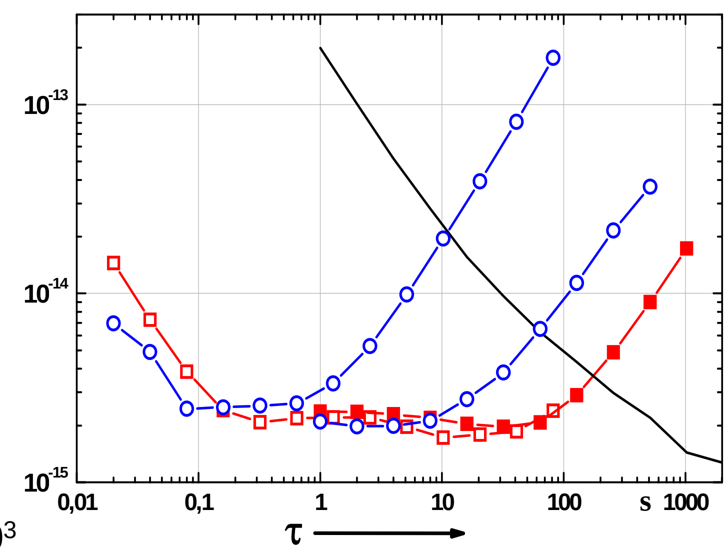
assumed: $\nu_0 = 10^{15}$ Hz, C=1, SNR=1 (N=1) and SNR=100 (N=10^4),

Fourier limit $\Rightarrow t_c \approx 1/\Delta\nu\,,\ \tau \geq 2/\Delta\nu$



Good clock laser,
short-time linewidth ~0.6 Hz,
1/f thermal length noise

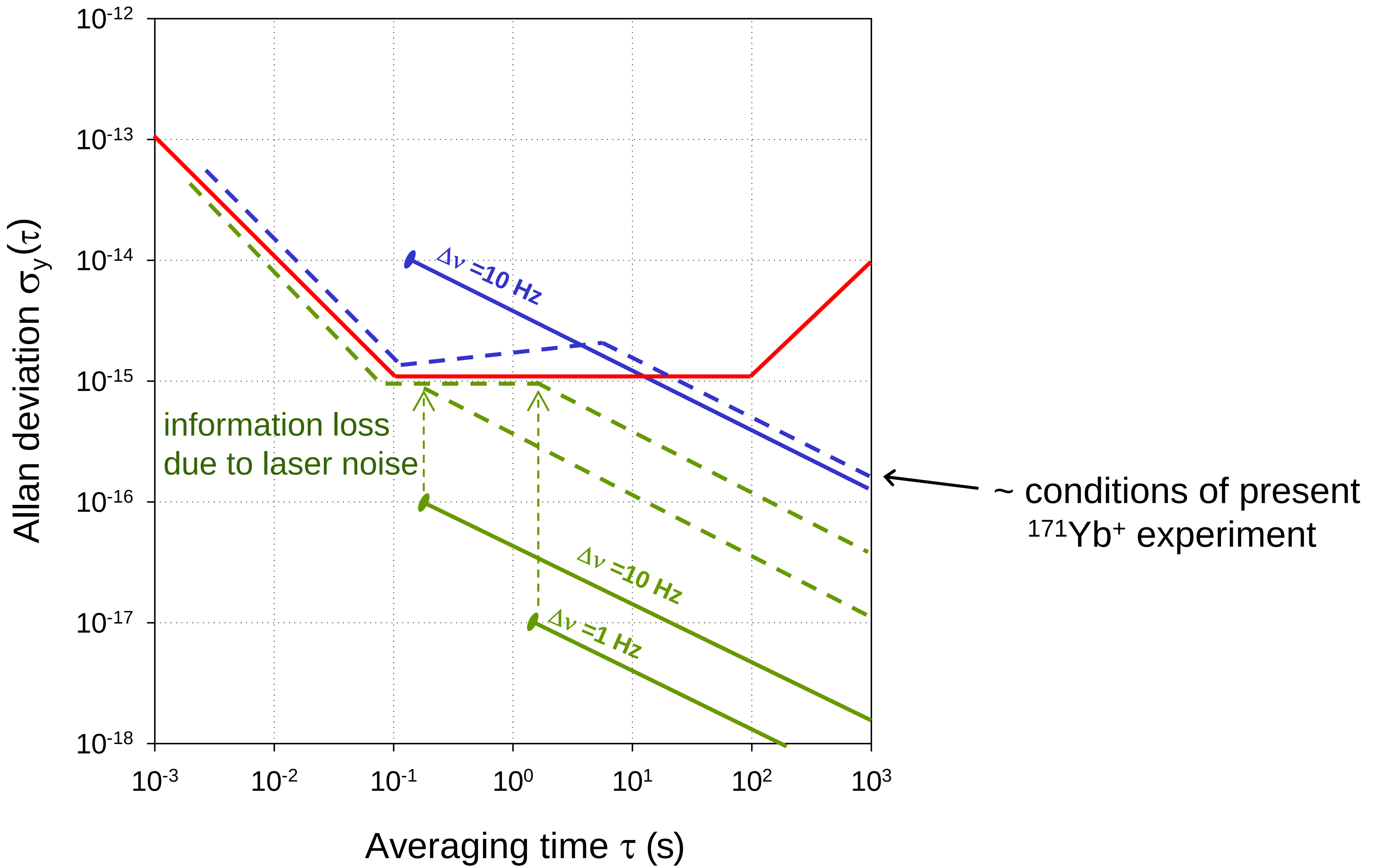
PTB measurement of combined instability of Ca and Yb^+ clock lasers (Uwe Sterr's talk):



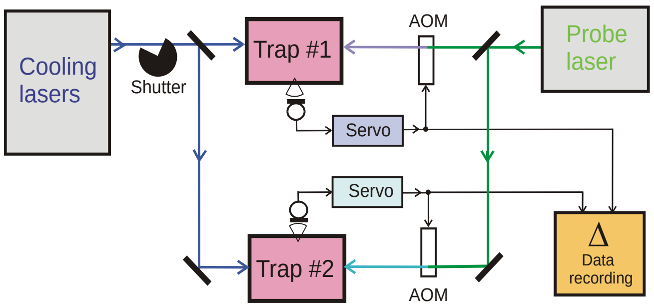
Stability of controlled laser frequency

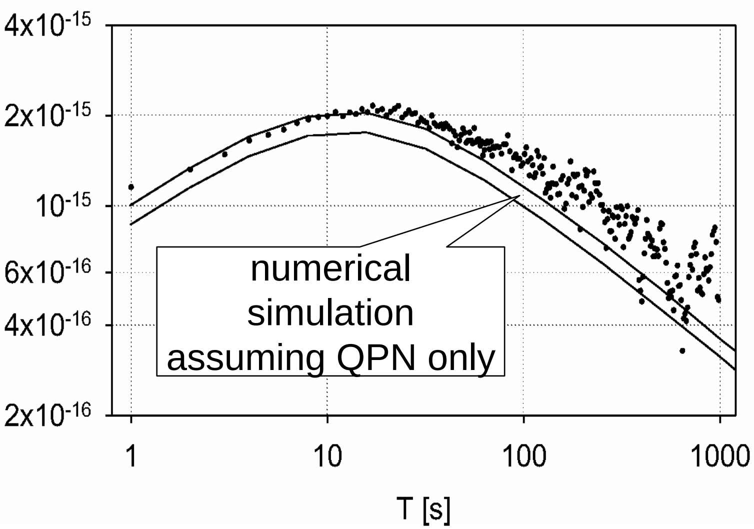
assumed: $\nu_0 = 10^{15}$ Hz, C=1, SNR=1 (N=1) and SNR=100 ($N=10^4$),

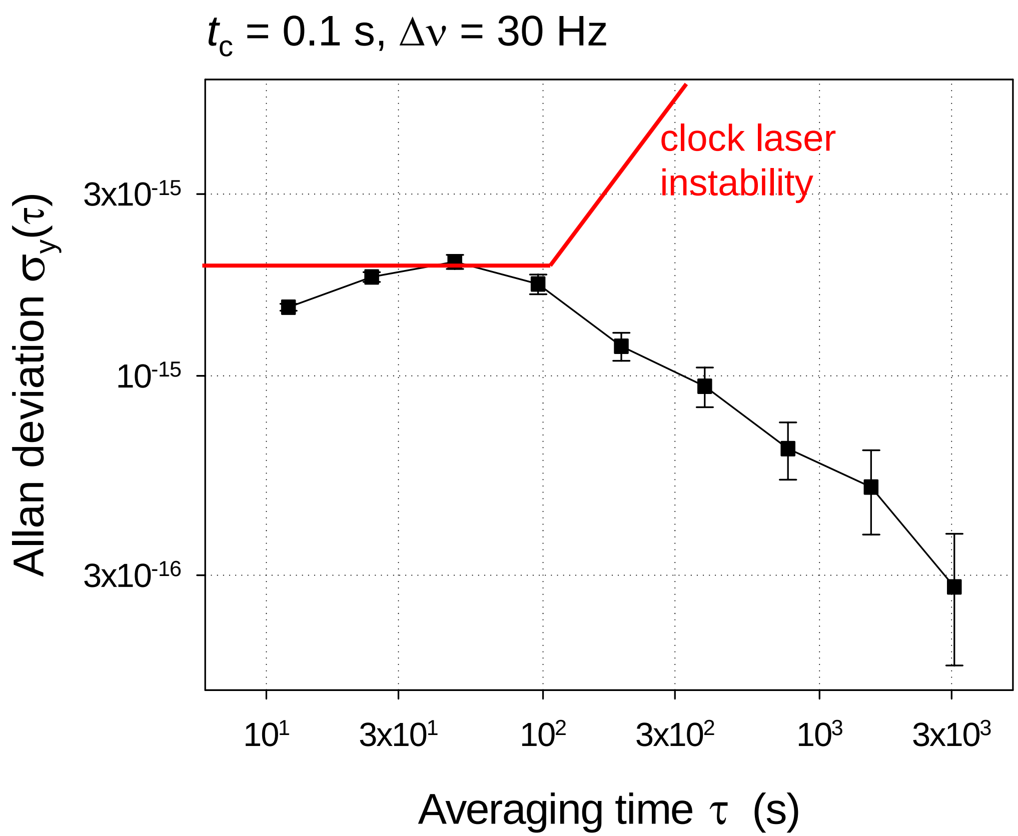
Fourier limit $\Rightarrow t_c \geq 1/\Delta\nu,\ \tau \geq 2/\Delta\nu$



Comparison between two traps: instability







Comparison simulation ↔ experiment, optimization:

E. Peik, T. Schneider, Chr. Tamm, J. Phys. B: At. Mol. Opt. Phys. 39, 145 (2006)

Outlook: $^{171}Yb^{+}$ Optical Frequency Standards

- New trap: better control of systematic shifts

- Direct optical frequency ratio measurement of two forbidden transitions in one ion

- Higher resolution, lower instability: requires progress with laser frequency stabilization