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Towards the development of an optical lattice clock using bosonic isotopes of mercury

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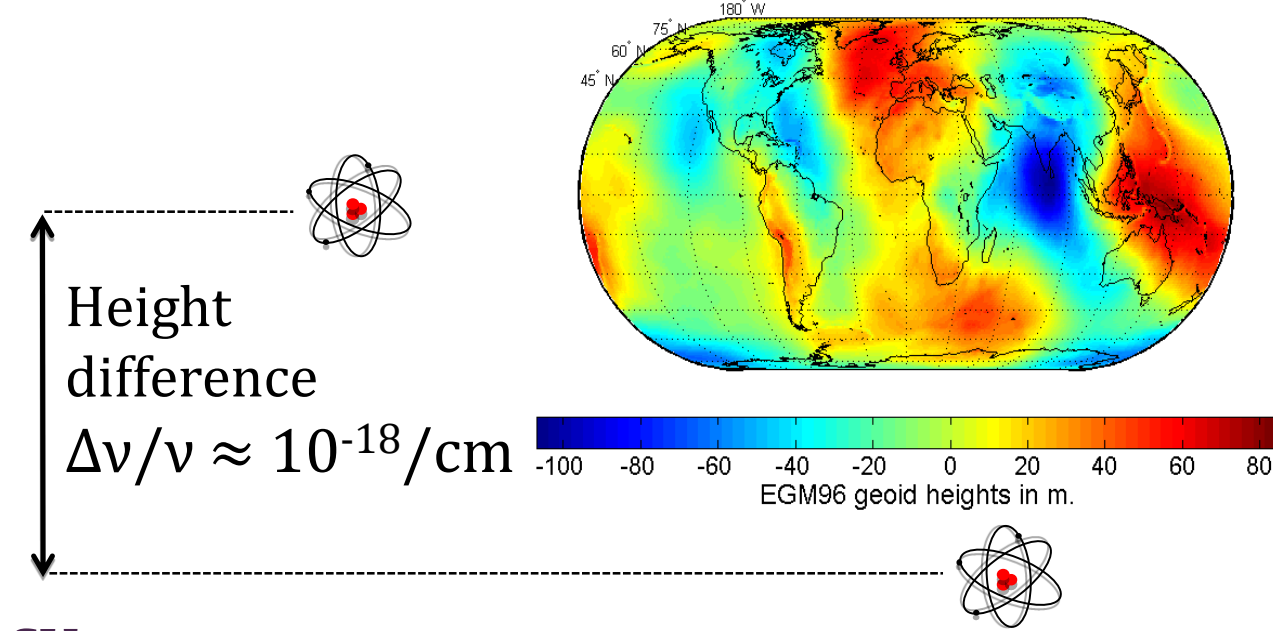
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Motivations and applications

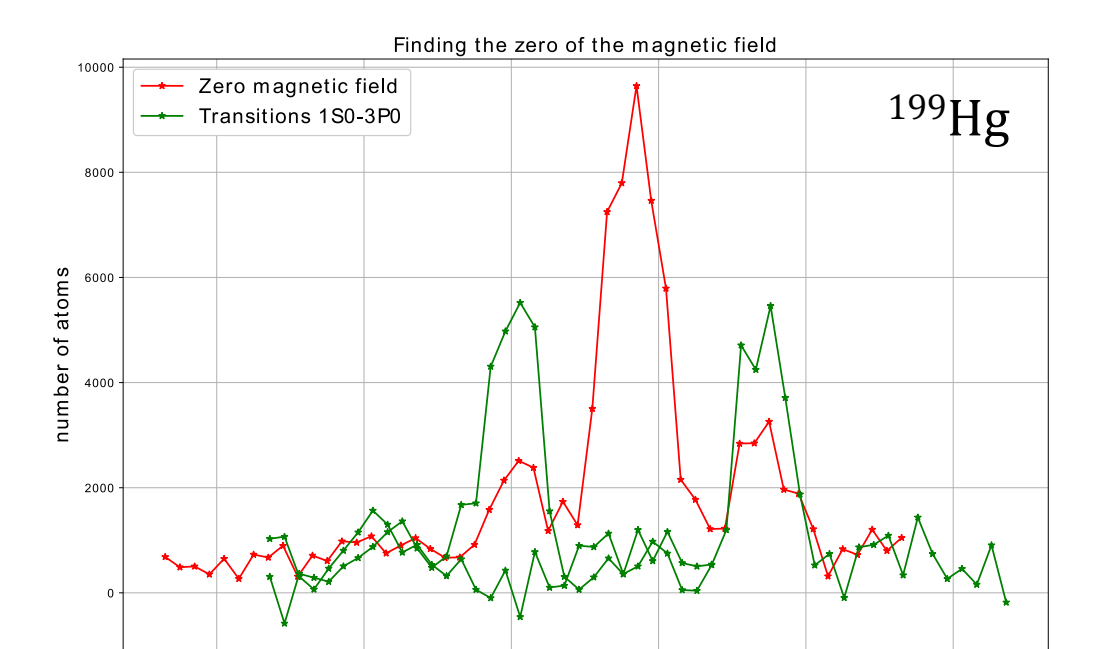
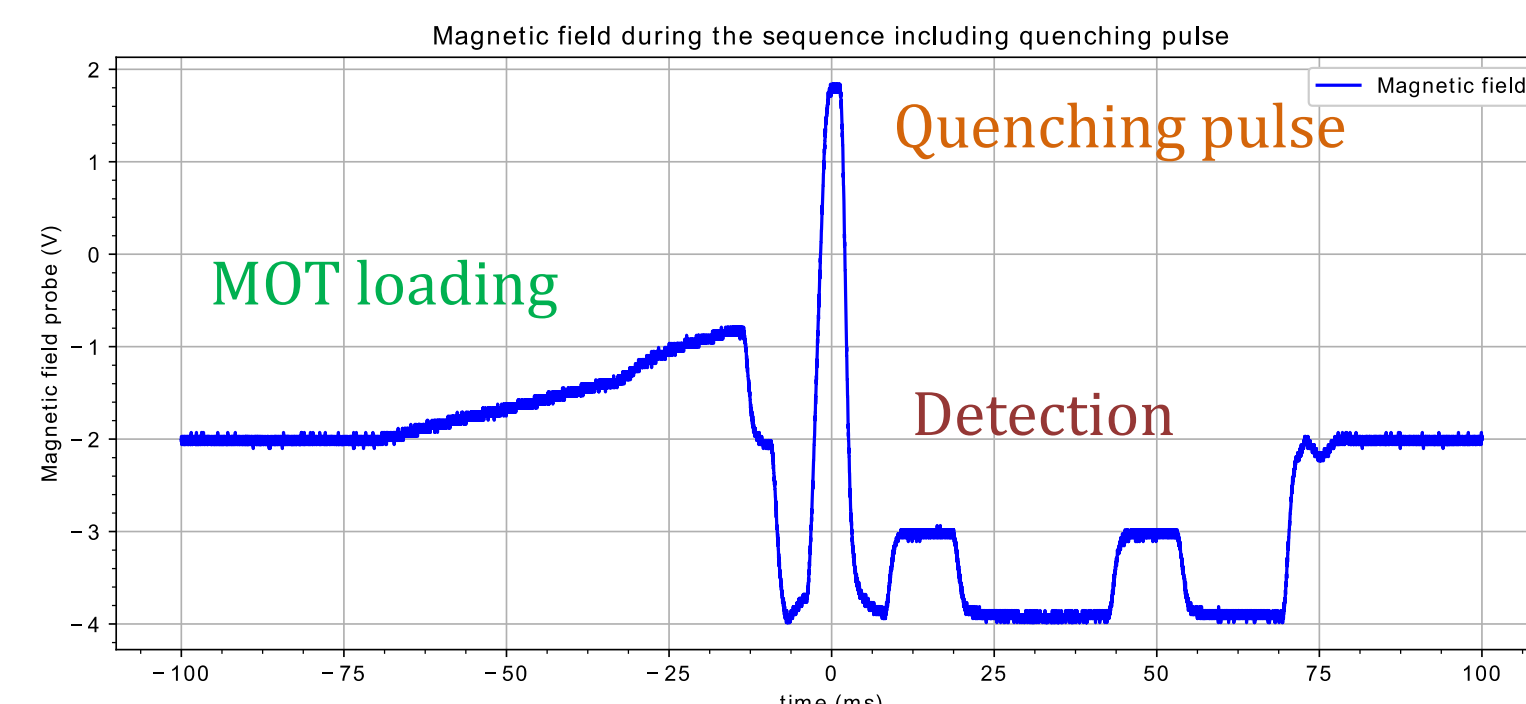
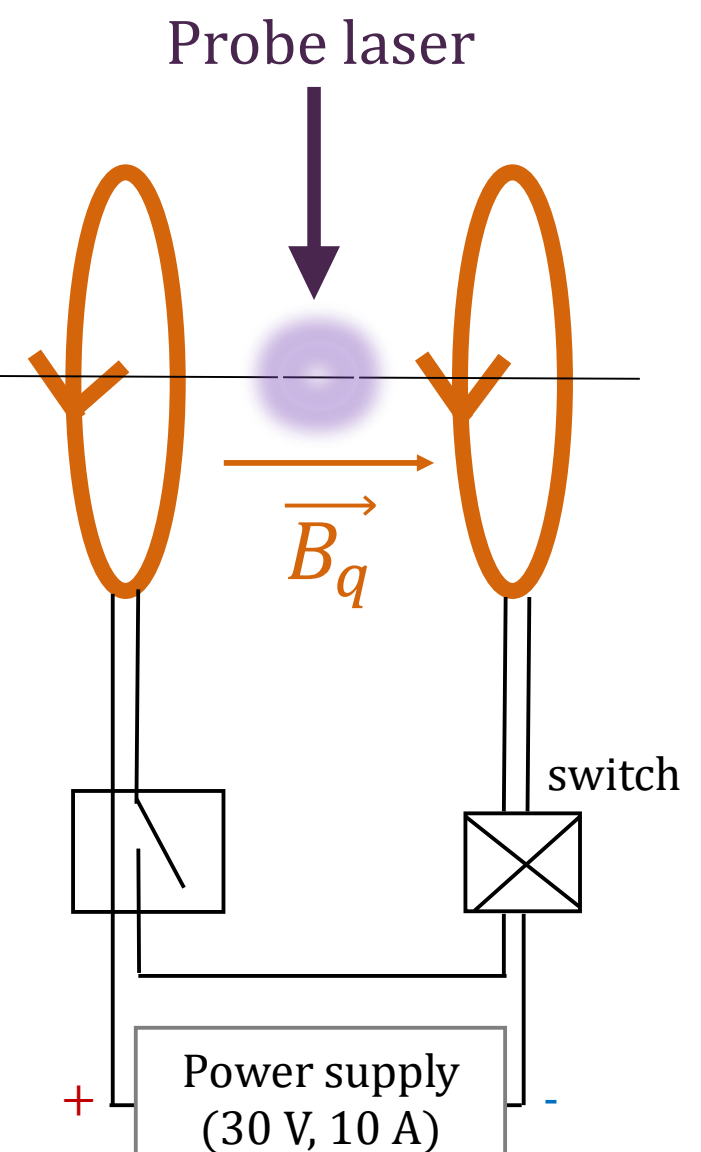
- Metrology (redefinition of the SI second)
- Study variations of fundamental constants (fine structure constant α)
- Search for physics beyond the standard model (Dark Matter)
- Tests of General Relativity (equivalence principle, gravitational redshift)
- Applications in the field of chronometric geodesy



Setup for quenching the bosonic transition

⇒ Goal : To produce high enough magnetic field to allow the bosonic transition with the highest coupling achievable

- External magnetic field \vec{B}_q obtained thanks to the 3D MOT coils in Helmholtz configuration and a switch mechanism to quickly reverse the current in one of the coils. Maximum field accessible in our setup : $B_q = 155 \times 10^{-4} T$
- Atoms are not ejected from the lattice when quenching is switched
- Residual magnetic field control system improved :
 - Zero of the magnetic field found and stable with a $1.5 \mu T$ precision
- Also an improved coupling between the probe laser and the atoms



The choice of mercury

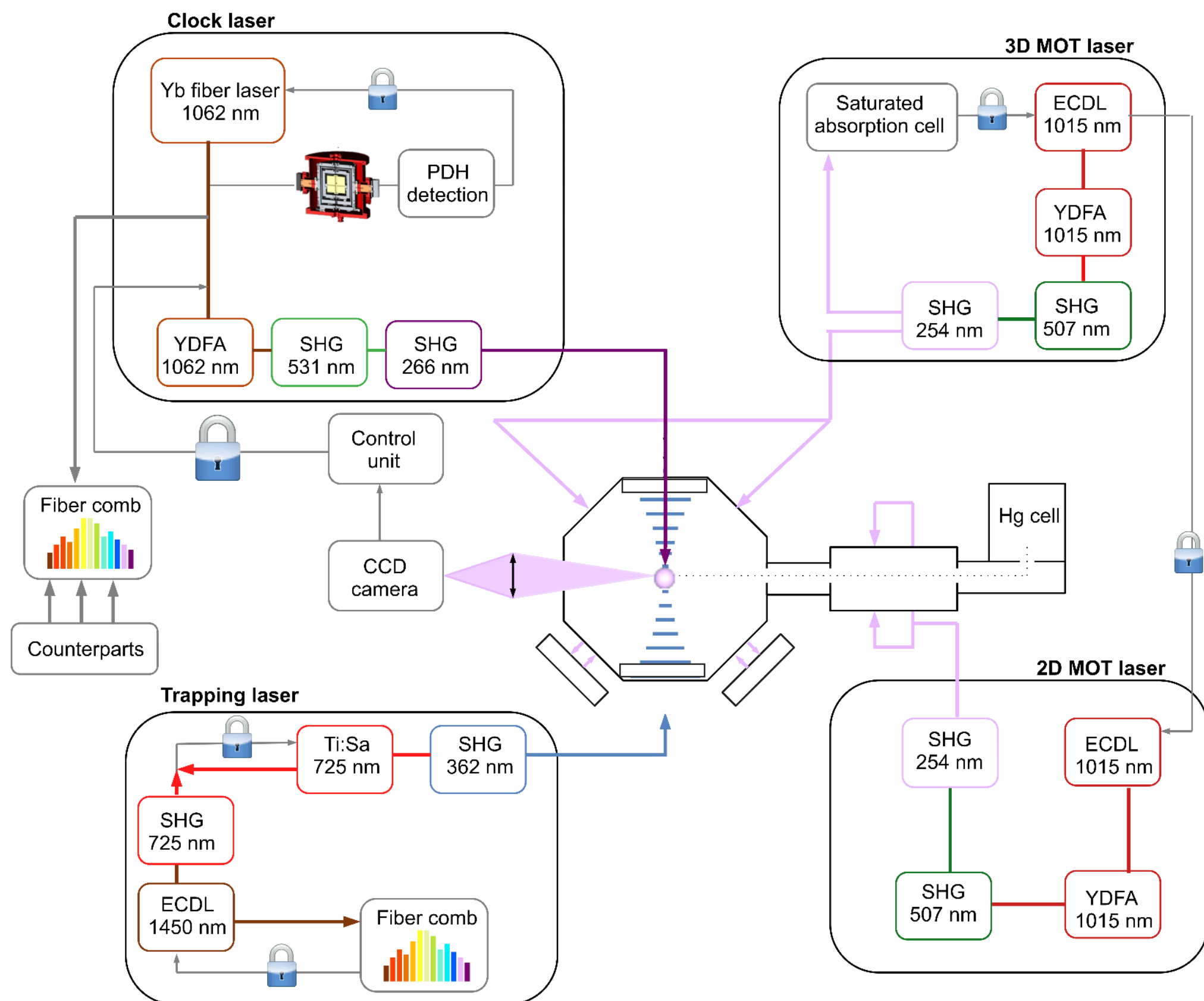
Exquisite properties for optical lattice clocks...

- Low sensitivity to black-body radiation shift (Yb/16, Sr/30)
 - Simple structure of the clock transition
 - High vapour pressure at room temperature (no oven, possibility for a 2D-MOT...)
 - 7 stable isotopes
 - Sensitive to variations of α
- ... that come at a price
- Deep-UV wavelengths hard to reach



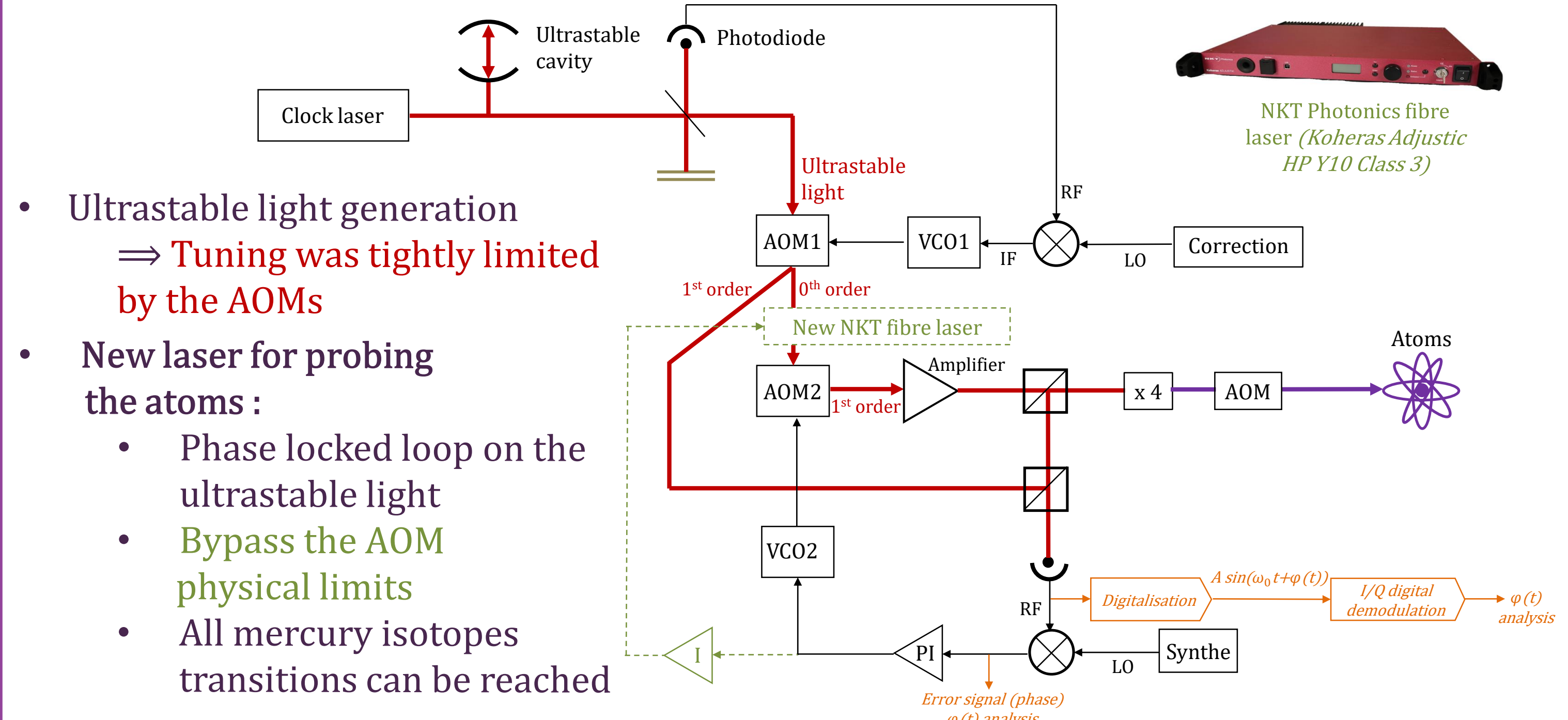
Experimental setup

- 10^6 atoms trapped in the 3D-MOT
- 1000 spin-polarised atoms in the lattice



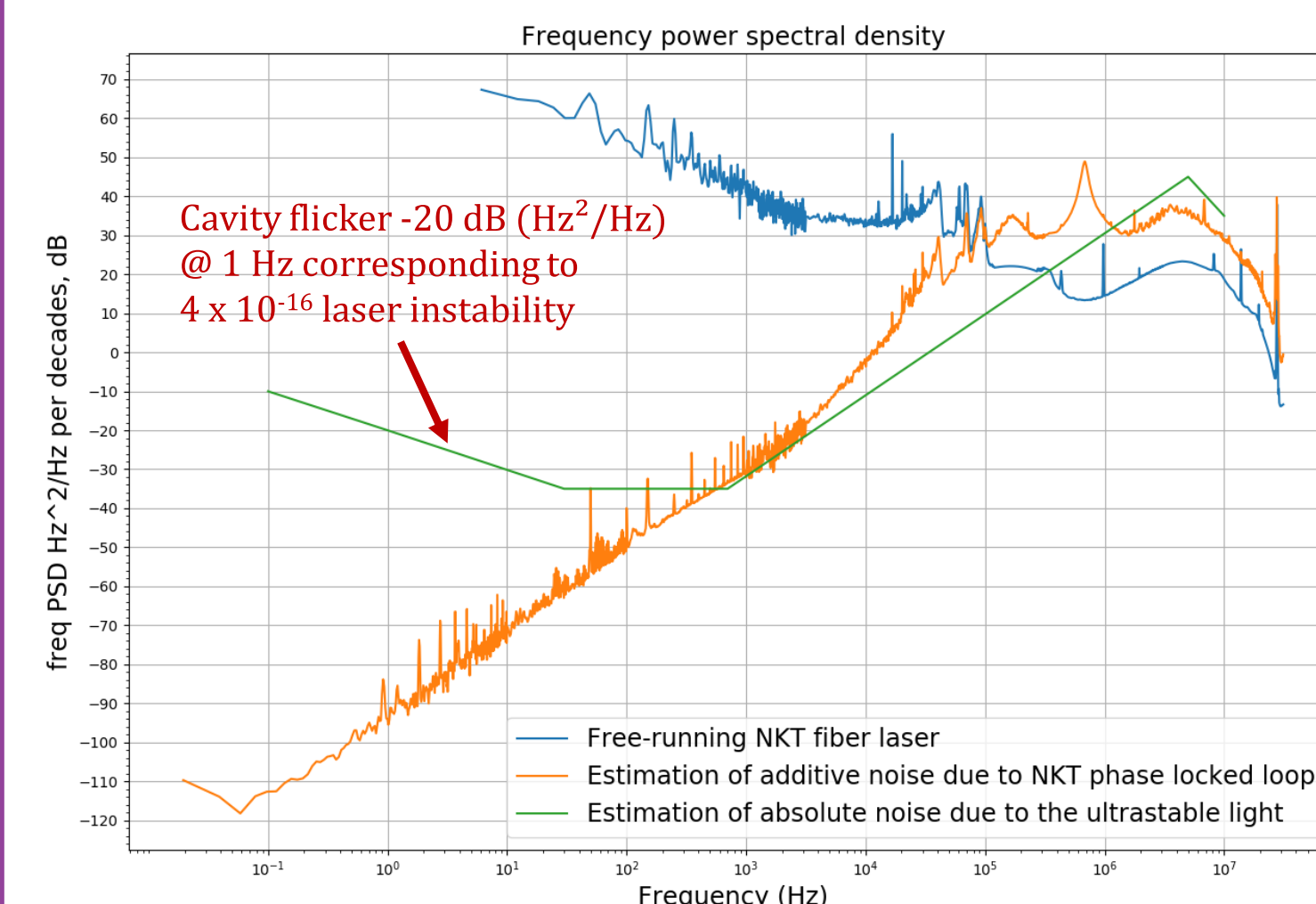
Setup to probe any of the mercury isotopes

⇒ Goal : To have a flexible ultrastable light which can probe any of the mercury isotopes (tuning of 10 GHz to access all transitions, fermions and bosons), with no additional noise



- Ultrastable light generation ⇒ Tuning was tightly limited by the AOMs
- New laser for probing the atoms :
 - Phase locked loop on the ultrastable light
 - Bypass the AOM physical limits
 - All mercury isotopes transitions can be reached

- New laser characterisation with 3 different methods :
 - Quasi free running laser and estimation of its linewidth is found to be 12.9 kHz
 - Error signal of the phase locked loop
 - Phase coherent analysis of optical beatnote

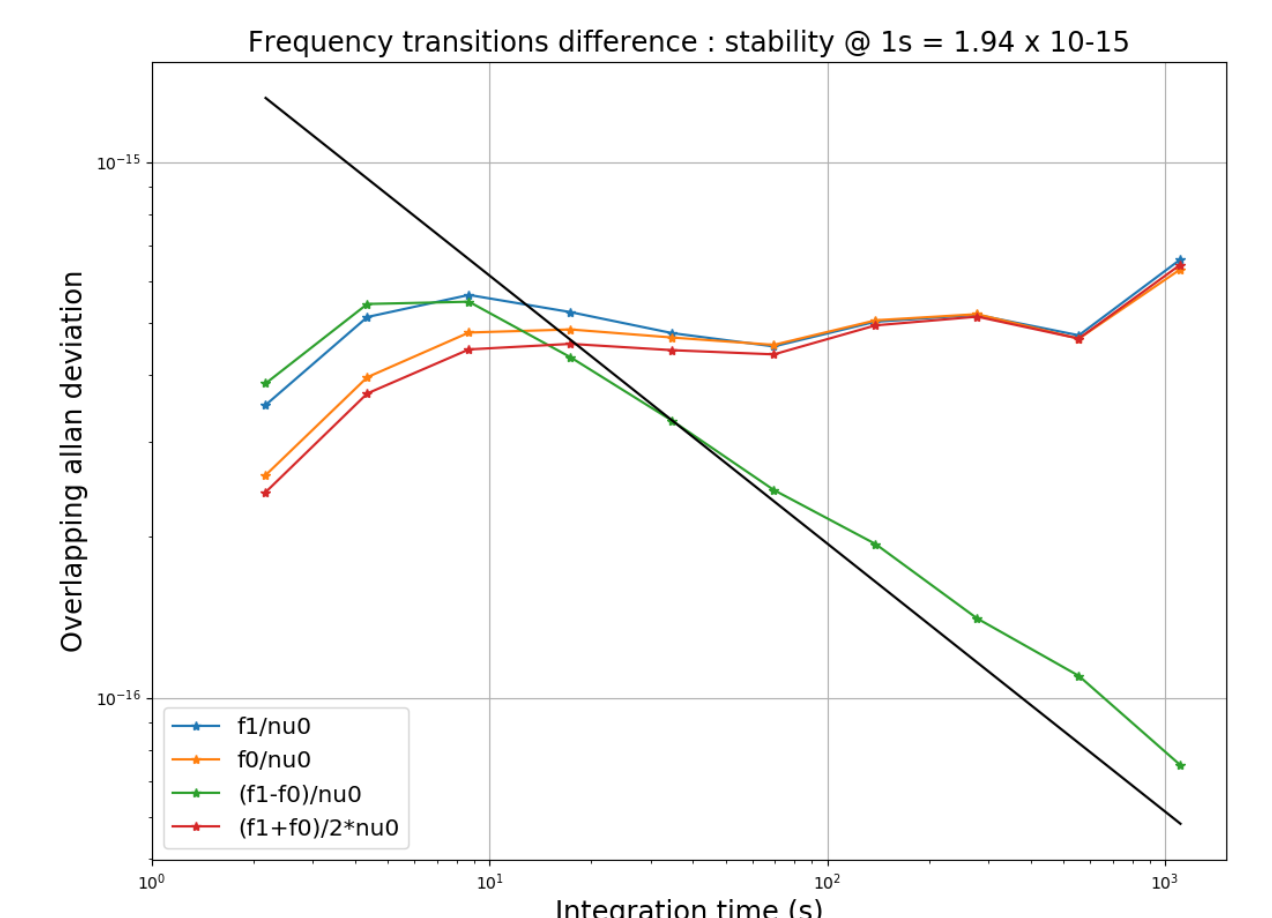


Green curve estimation of ultrastable light noise from [13].

- No significant additional noise at low frequencies for the new NKT fibre laser
 - Additive noise impact on clock is at the level of about 10^{-18} @1s via the Dick effect
- Power spectral density in range 1-100 Hz still defined by the cavity flicker noise

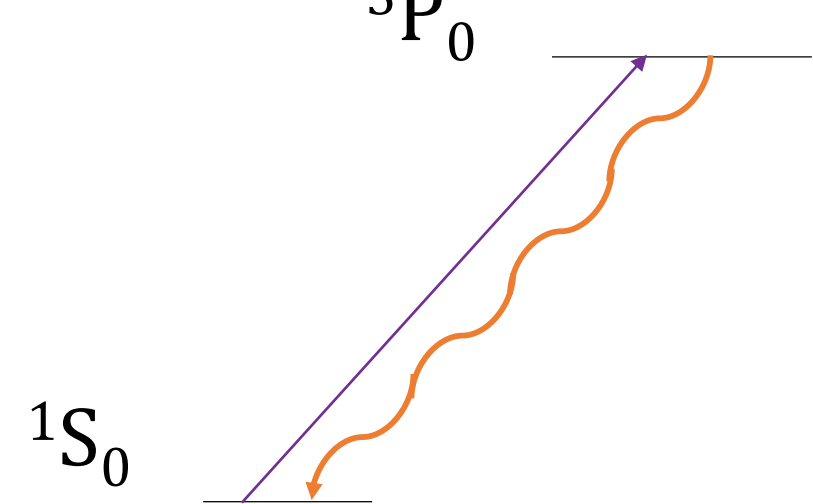
- Clock measurements with ^{199}Hg is giving good stabilities :

⇒ We can infer a stability @1s of about $8-9 \times 10^{-16}$ from curves on the right
 ⇒ Similar stabilities with the previous ultrastable laser scheme

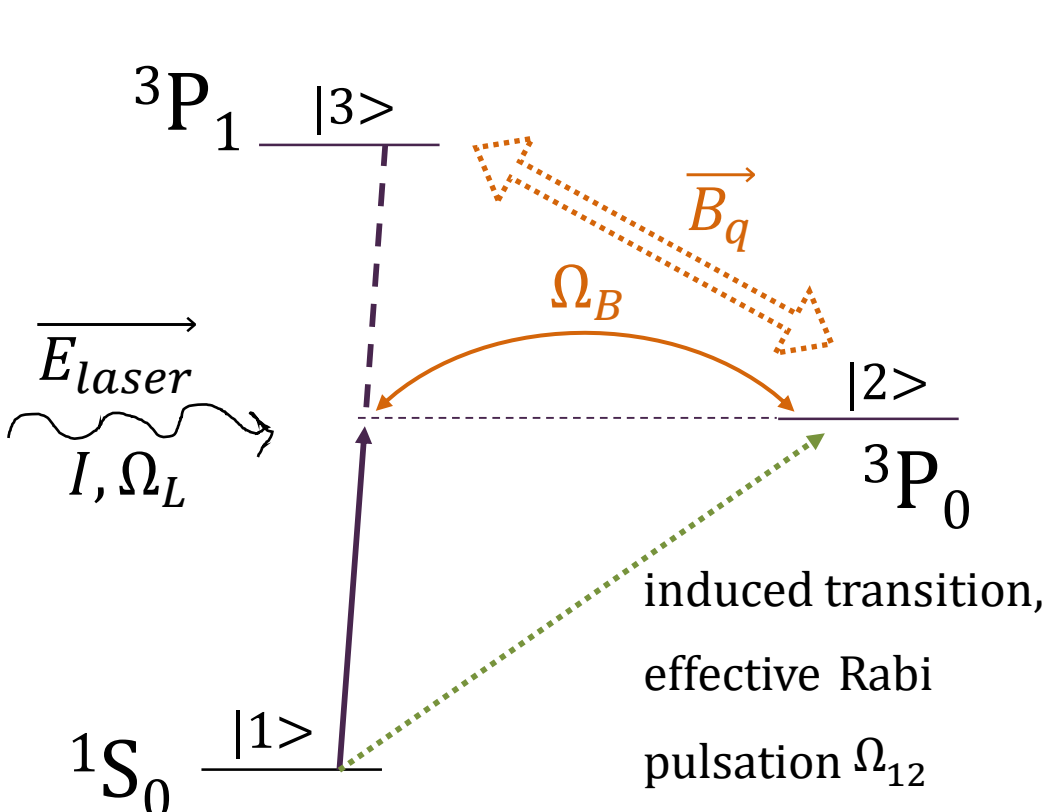


From fermionic isotopes to bosonic isotopes

Fermionic isotope ^{199}Hg



Bosonic isotope Ex : ^{198}Hg



- Non zero nuclear spin
- Transition naturally allowed thanks to hyperfine mixing
- *But 3P_0 lifetime of $\sim 1,5 s$*
- *A limit to exploit new ultrastable lasers*
- Zero nuclear spin
- Forbidden transition but can be induced by an external magnetic field \vec{B}_q : « quenching »
- *Lifetime potentially unlimited and adjustable*
- *To be studied : High second order Zeeman shift and light shift*
- *Hyper Ramsey probing to circumvent them ?*

- Finding the bosonic clock transition (after [6])
 - High effective Rabi pulsation Ω_{12} needed ⇒ high magnetic field \vec{B}_q
 - Current experimental uncertainty for ^{198}Hg : 10.3 MHz [11]

^{198}Hg	Power [mW]	Intensity I [W/cm ²]	Magnetic field B [10 ⁻⁴ T]	Second order Zeeman shift $\frac{\Delta E}{2\pi}$ [10 ⁻¹⁴]	Rough estimate of the light shift $\frac{\Delta_L}{2\pi}$ [10 ⁻¹⁴]	Effective Rabi pulsation (low estimate) $\frac{\Omega_{12}}{2\pi}$ [Hz]
High coupling	1	1.59	155	-52.5	1.6	38.0
	0.1	0.159	155	-52.5	0.16	12.0

Figure of merit : $\xi = \frac{\Omega_{12}}{\sqrt{\Delta_L \Delta_B}}$
 ⇒ characterises the strength of the excitation compared to the field shifts

	Yb	Sr	Ca	Mg	Hg (estimation)
ξ	0.60	0.30	0.28	0.28	0.36

References

- [1] W.F. McGrew et al., *Nature*, p.1, 11 (2018)
- [2] A. D. Ludlow et al., *Review of Modern Physics*, 87, 7(2015)
- [3] S. Bize, *Comptes Rendus Physique*, 20, 1 (2019)
- [4] R. Tyumenov et al., *New Journal of Physics*, 18, 11 (2016)
- [5] K. Yamanaka et al., *Physical Review Letters*, 114, 238001 (2015)
- [6] A. V. Taichenachev et al., *Physical Review Letters*, 96, 3,(2006)
- [7] S. Origlia et al., *Physical Review A*, 98, 11 (2018)
- [8] S. Falke et al., *New Journal of Physics*, 16, 073023 (2014)
- [9] J. Lodewyck et al., *Metrologia*, 53, 1123,(2016)
- [10] N. Huntemann et al., *Physical Review Letters*, 116, 063001 (2016)
- [11] A. Kramida, *J. Res. Natl. Inst. Stand. Technol.*, 116, 599-619 (2011)
- [12] M. Andia et al., *Presentation at IFCS, 2020.*
- [13] S.T. Dawkins et al., *Appl Phys B*, 99, 41-46 (2010)
- [14] C. Guo et al., *Physical Review A*, 107, 033116 (2023)