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

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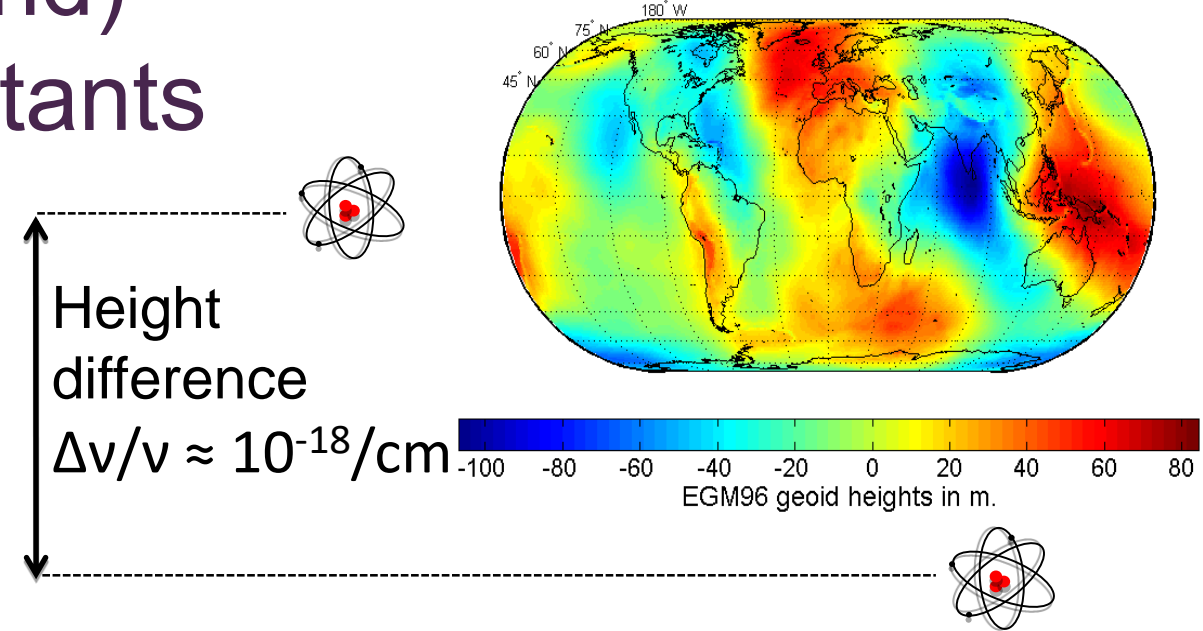
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Motivations and applications

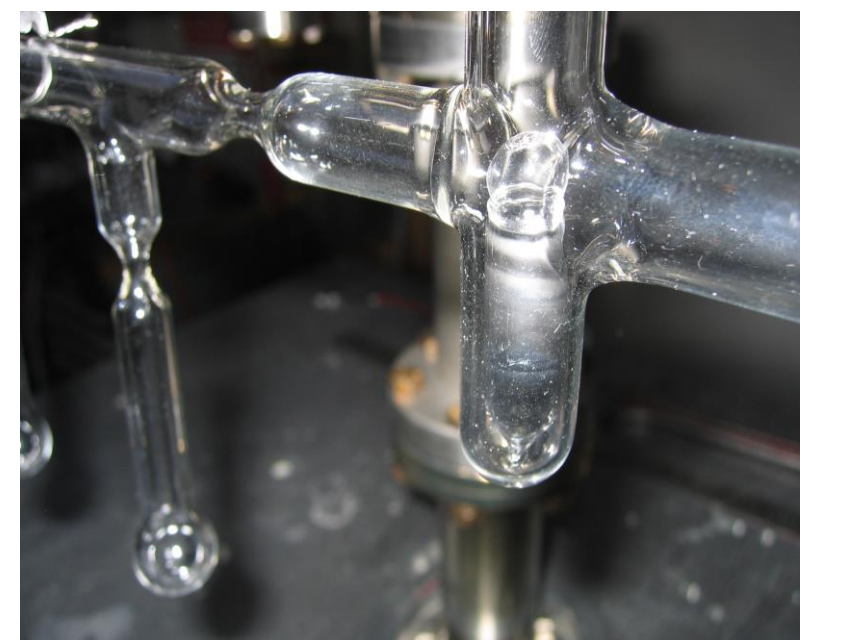
- Metrology (redefinition of the SI second)
- Study variations of fundamental constants (fine structure constant α)
- Search for physics beyond the standard model (Dark Matter)
- Tests of General Relativity (equivalence principle, gravitational redshift)
- Applications in the field of chronometric geodesy



The choice of Mercury

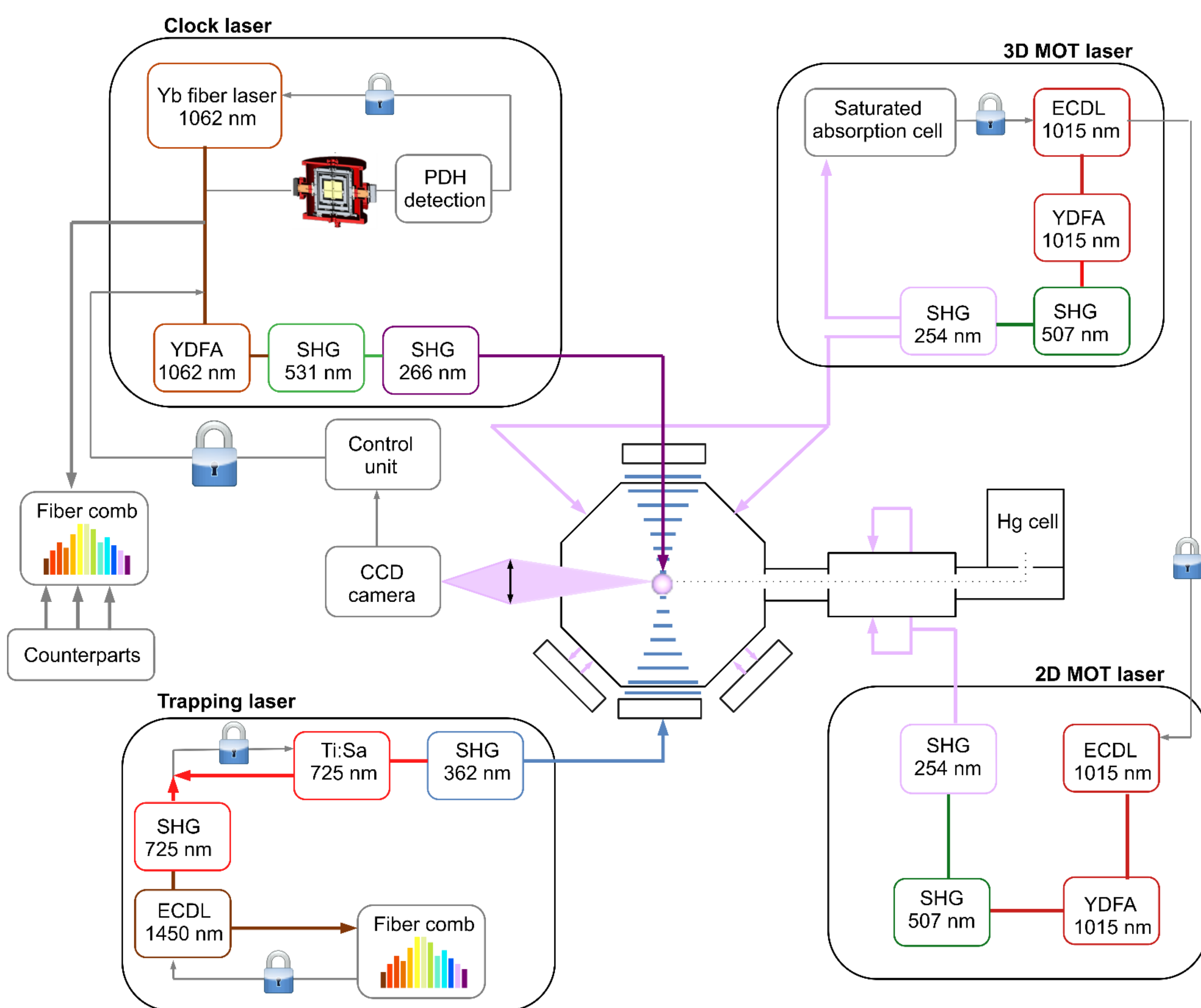
Exquisite properties for optical lattice clocks...

- 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

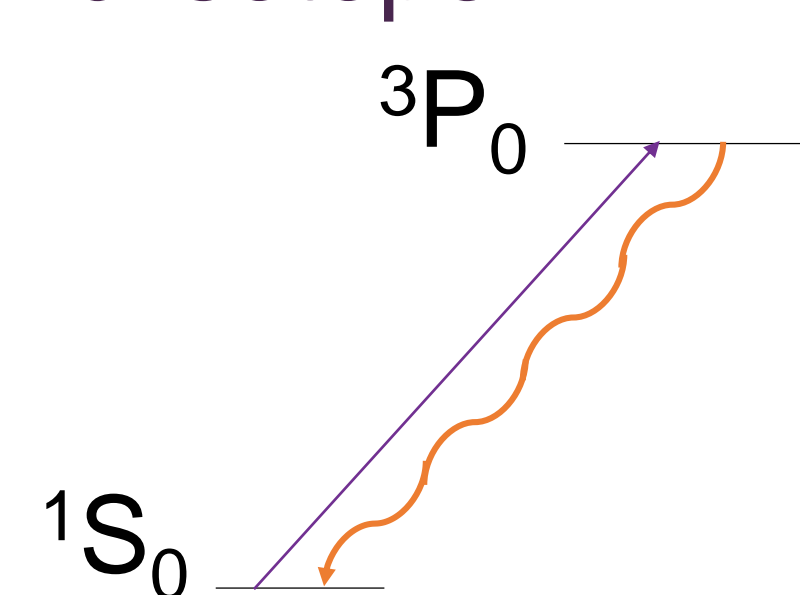
- 10^6 atoms trapped in the 3D-MOT
- 1000 spin-polarised atoms in the lattice



From fermionic isotopes to bosonic isotopes

Fermionic isotope

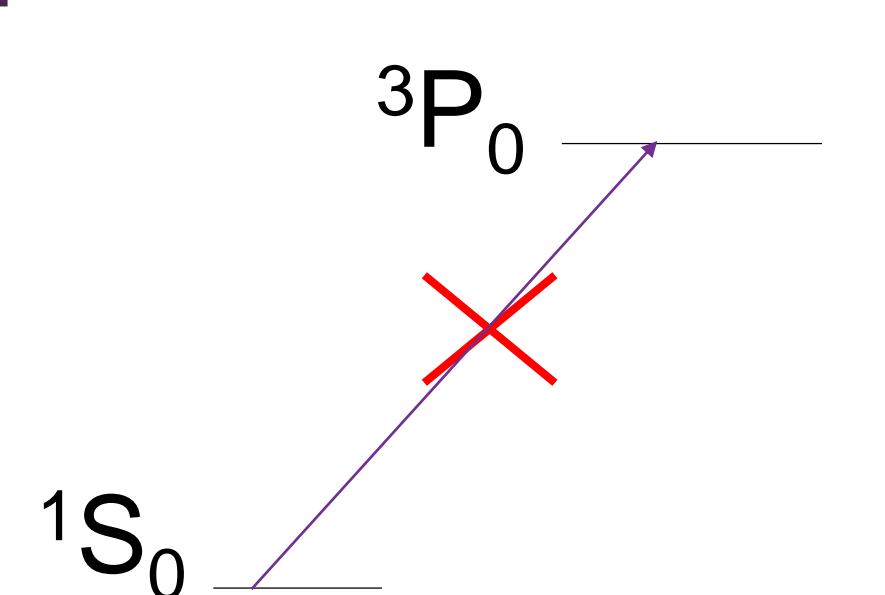
^{199}Hg



- Non zero nuclear spin
- Transition naturally allowed thanks to hyperfine mixing
- **But 3P_0 lifetime of ~ 1.5 s**
- **A limit to exploit new ultrastable lasers**

Bosonic isotope

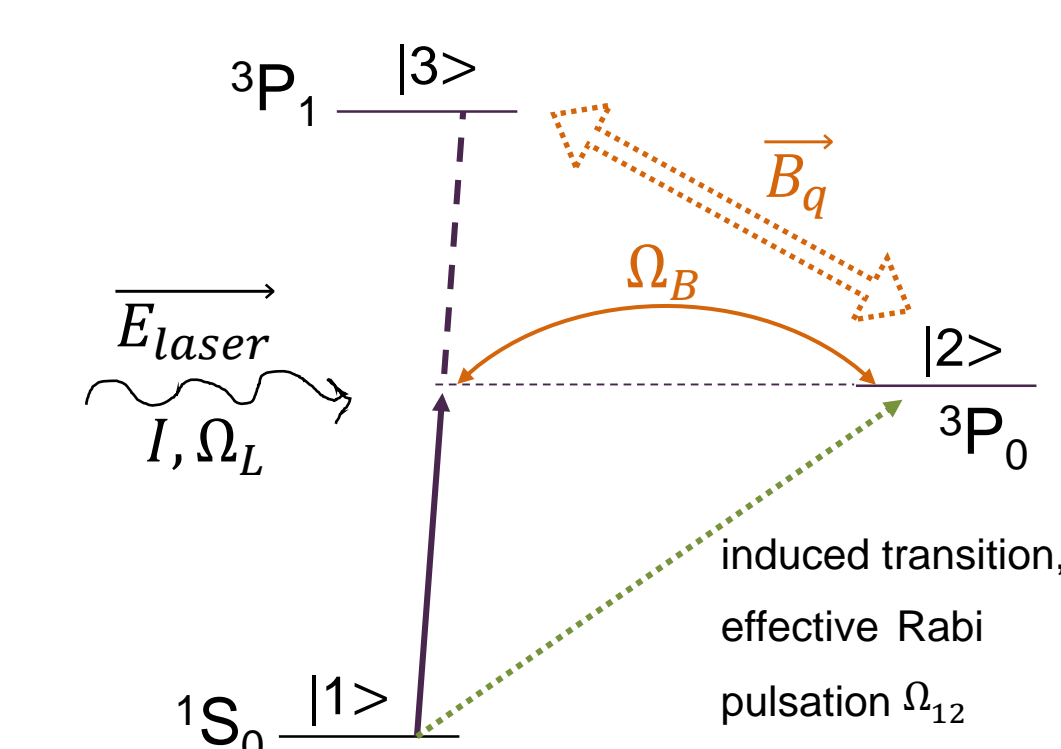
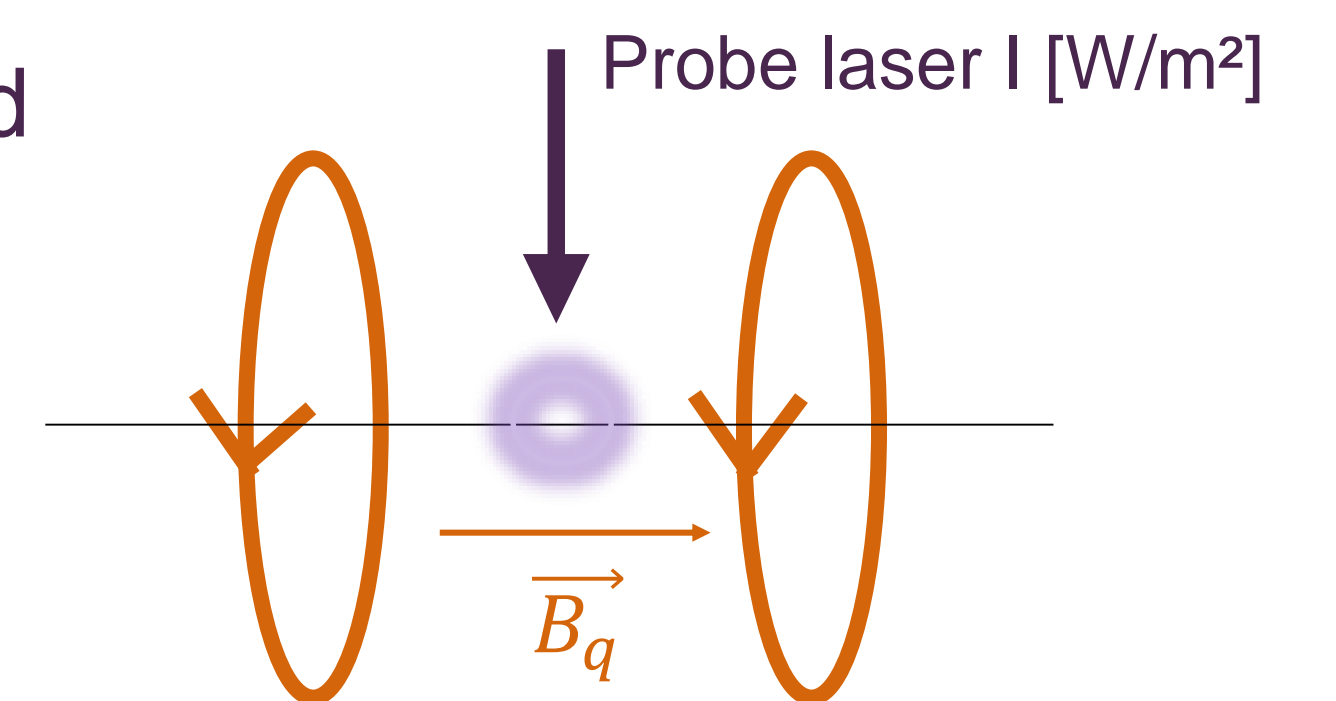
Ex : ^{198}Hg



- 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 interrogation to circumvent them ?**

Quenching calculations (after [6])

- External magnetic field \vec{B}_q obtained thanks to the 3D MOT coils in Helmholtz configuration.
- Maximum field accessible in our setup : $B_q = 155 \times 10^{-4} \text{ T}$



- Finding the bosonic clock transition
 - High effective Rabi pulsation Ω_{12} needed \Rightarrow high magnetic field B_q .
 - Current experimental uncertainty for ^{198}Hg : 12 MHz [11].

^{198}Hg	Power [mW]	Intensity I [W/cm ²]	Magnetic field B [10 ⁻⁴ T]	Second order Zeeman shift $\frac{\Delta_B}{2\pi}$ [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
Low coupling	1	1.59	15.5	-0.52	1.6	3.8
	0.1	0.159	15.5	-0.52	0.16	1.20

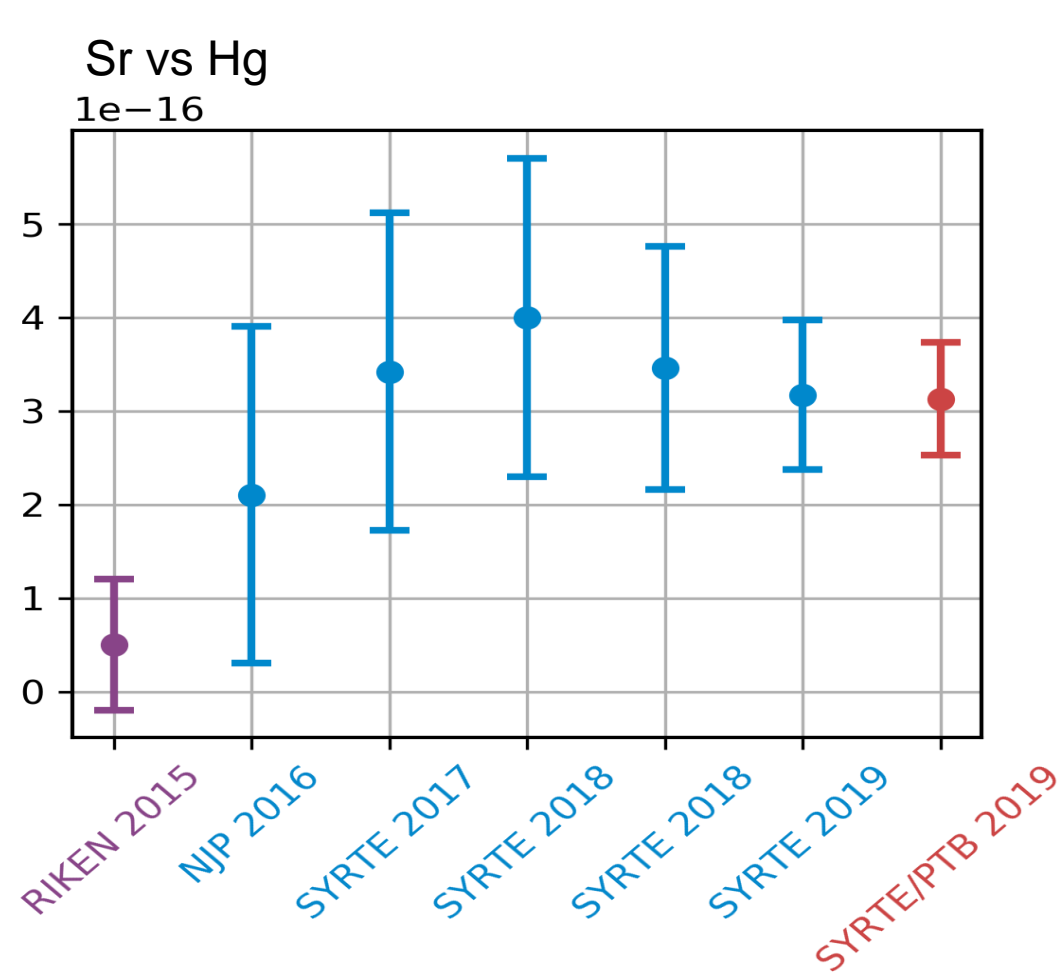
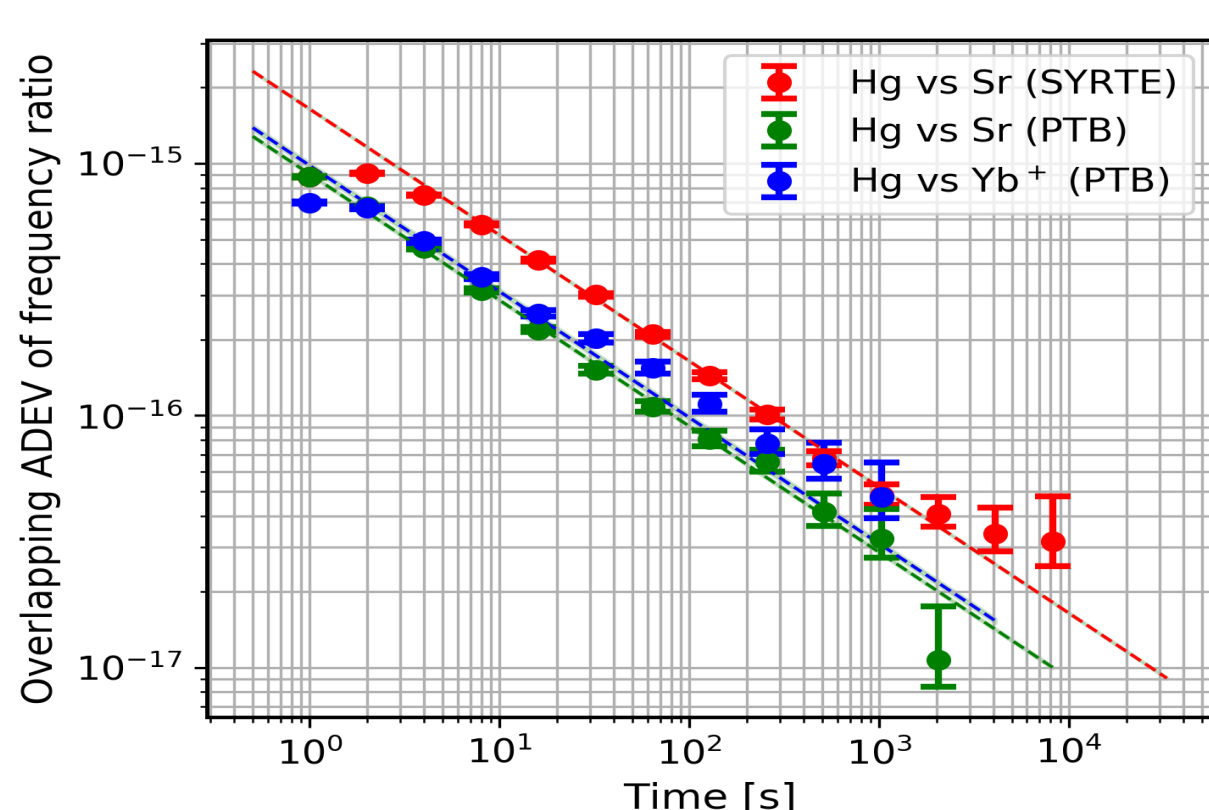
Figure of merit :

$$\xi = \frac{\Omega_{12}}{\sqrt{\Delta_L \Delta_B}}$$

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

\Rightarrow characterises the strength of the excitation compared to the field shifts

Latest measurement campaigns ^{199}Hg (local and optical fiber links)



Systematic effect	Correction (10 ⁻¹⁷)	Uncertainty (10 ⁻¹⁷)
Linear lattice light shift	-3	2.1
Quadratic Zeeman effect	1.3	0.2
Collisional shift	2.6	1.5
Nonlinear lattice light shift	-3	3
Black-body radiation	15.1	2
Background gas collisions	0	2
Probe light shift	0	0.1
Probe laser AOM phase transient	0.2	0.4
TOTAL	14.2	4.8

- Lattice light shifts are dominant
- Some systematics are limited by statistics
- For a few effects only theoretical estimates available
- BBR shift is manageable at room T with almost no effort
- Total uncertainty for the mercury clock : **4.8×10^{-17}** below the SI second
- See [12]

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