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

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► **To cite this version:**

Clara Zyskind, Manuel Andia, Changlei Guo, S. Bize. Towards the development of an optical lattice clock using bosonic isotopes of mercury. IEEE IFCS-EFTF 2023, Jun 2023, Toyama, Japon, Japan. hal-04505900

HAL Id: hal-04505900

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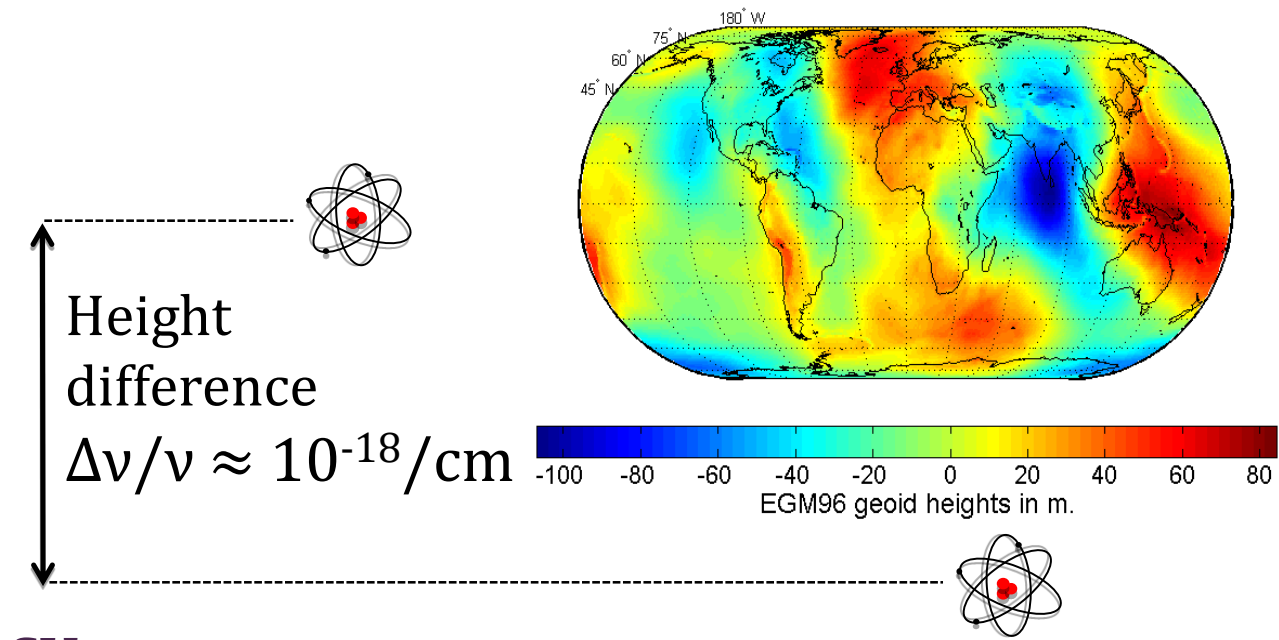
Submitted on 15 Mar 2024

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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...

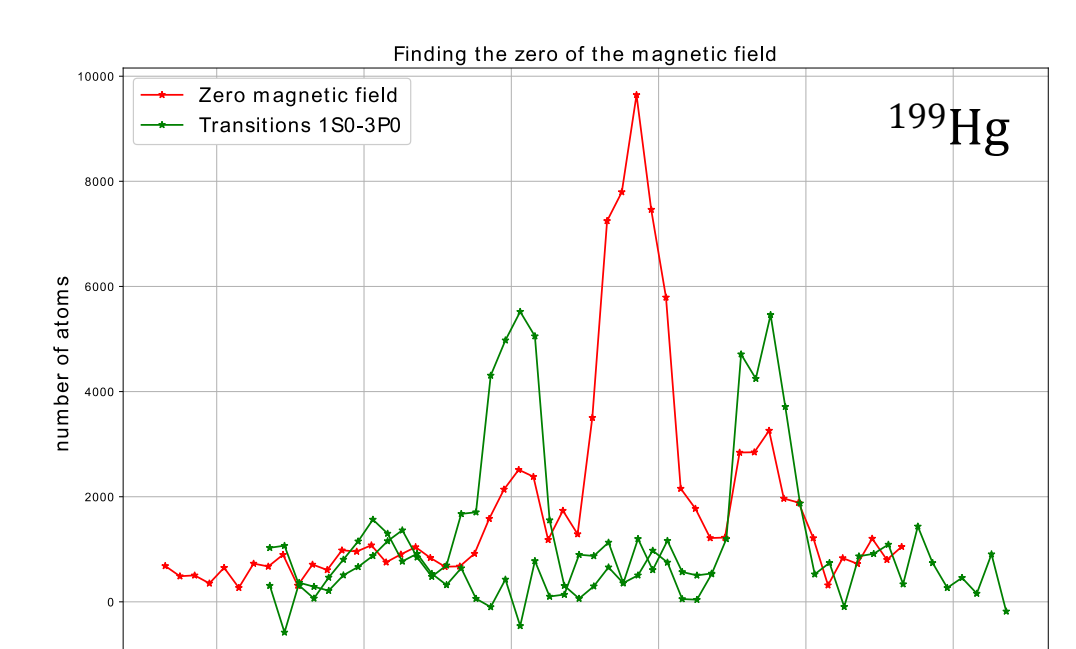
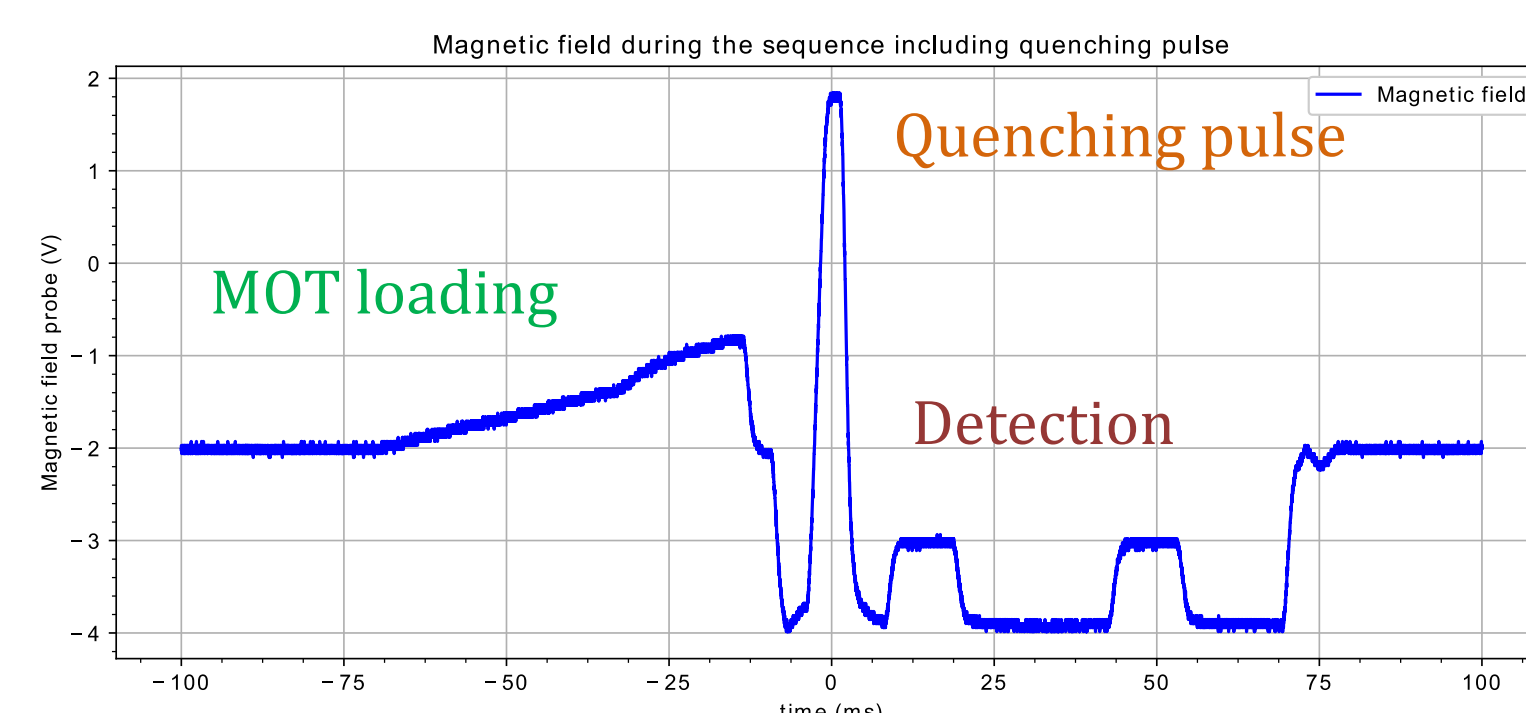
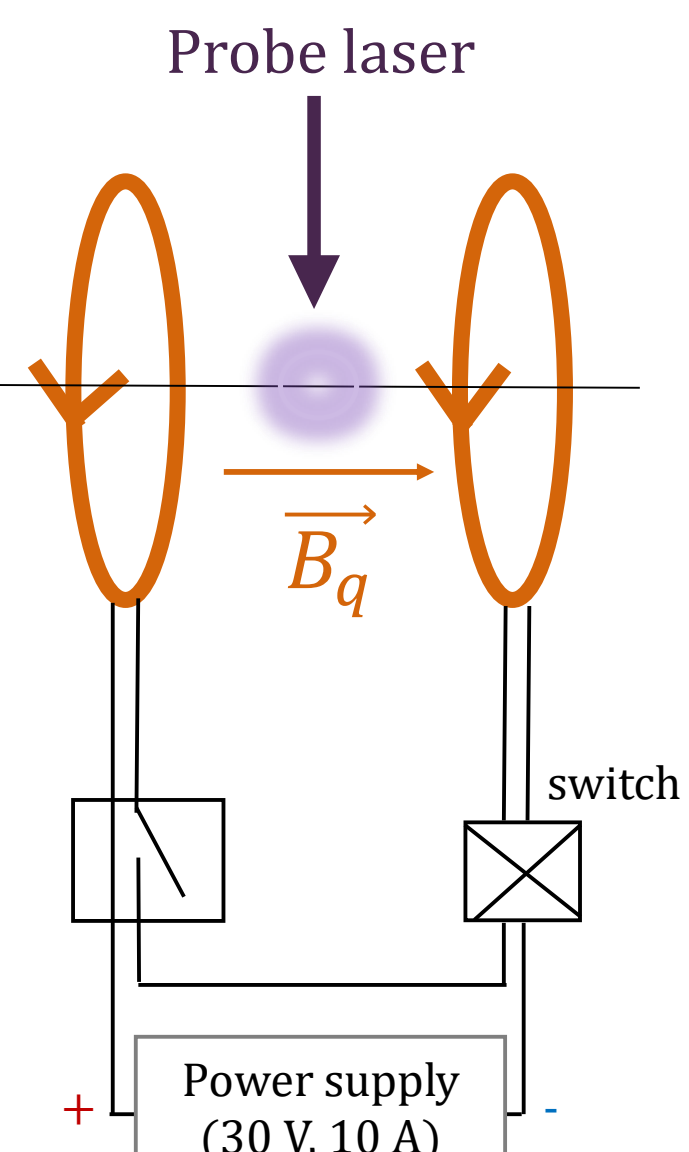
- Low sensitivity to black-body radiation shift (Yb/16, Sr/30)
 - Simple structure of the clock transition
 - High vapour pressure at room temperature (no oven, possibility for a 2D-MOT...)
 - 7 stable isotopes
 - Sensitive to variations of α
- ... that come at a price
- Deep-UV wavelengths hard to reach



Setup for quenching the bosonic transition

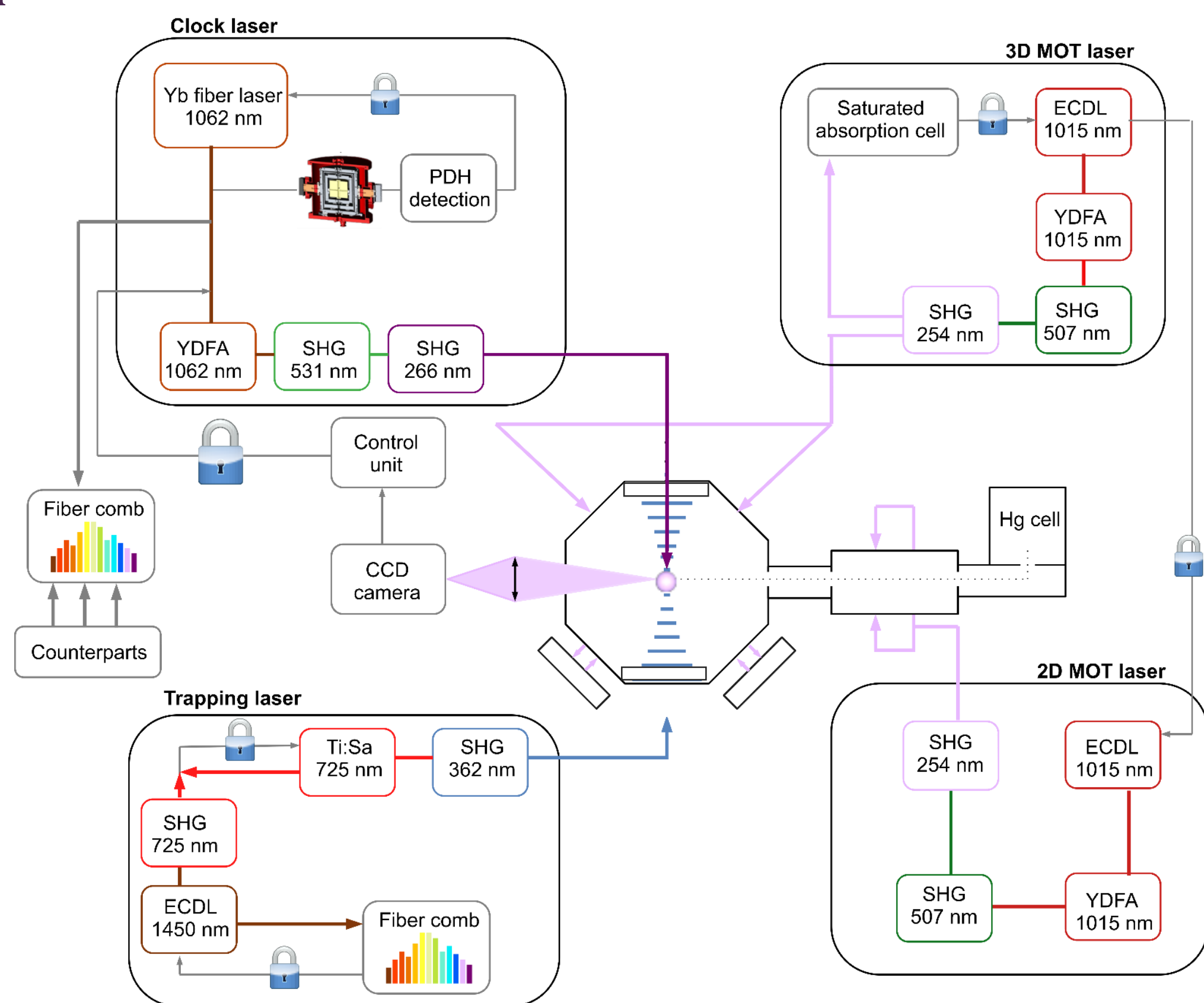
⇒ Goal : To produce high enough magnetic field to allow the bosonic transition with the highest coupling achievable

- 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



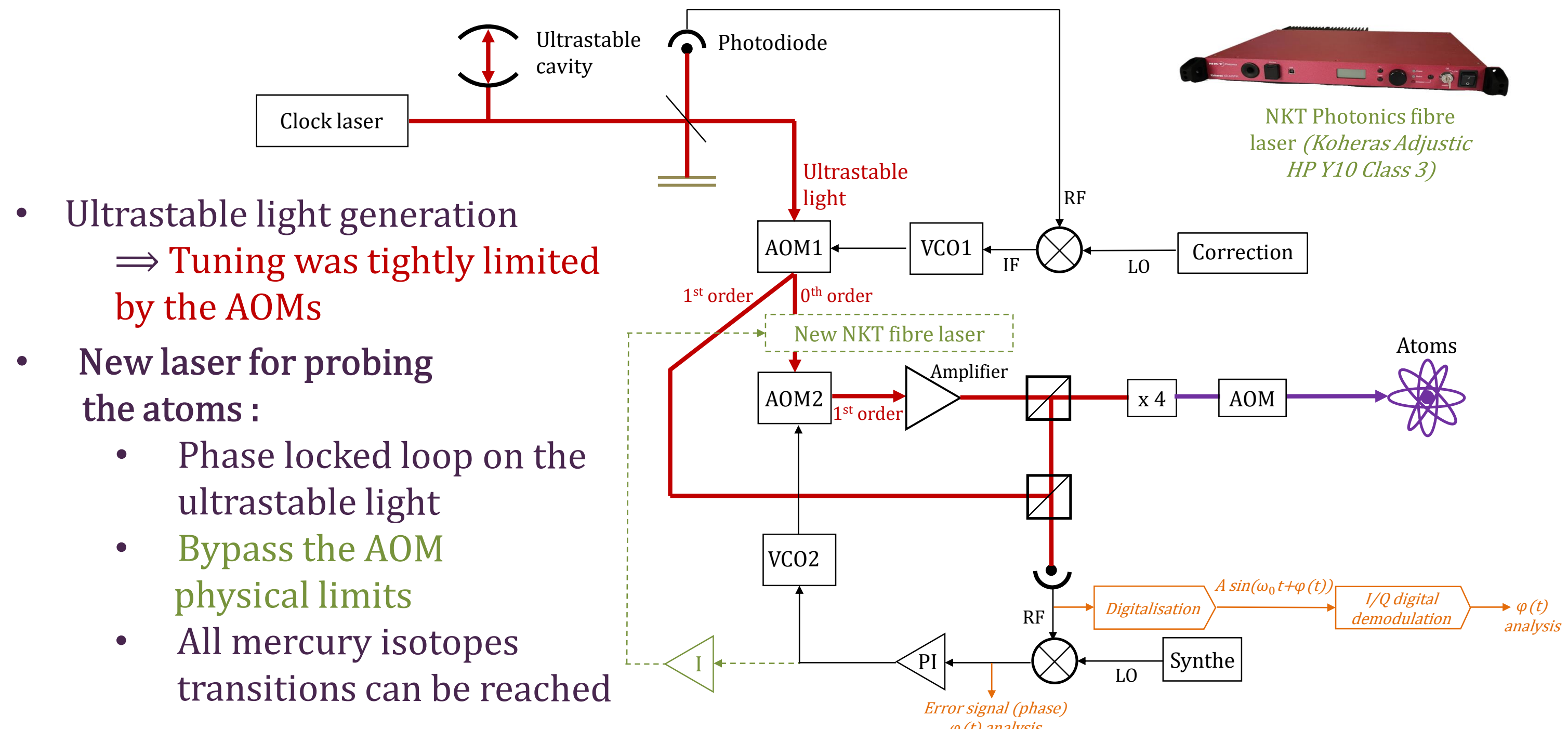
Experimental setup

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



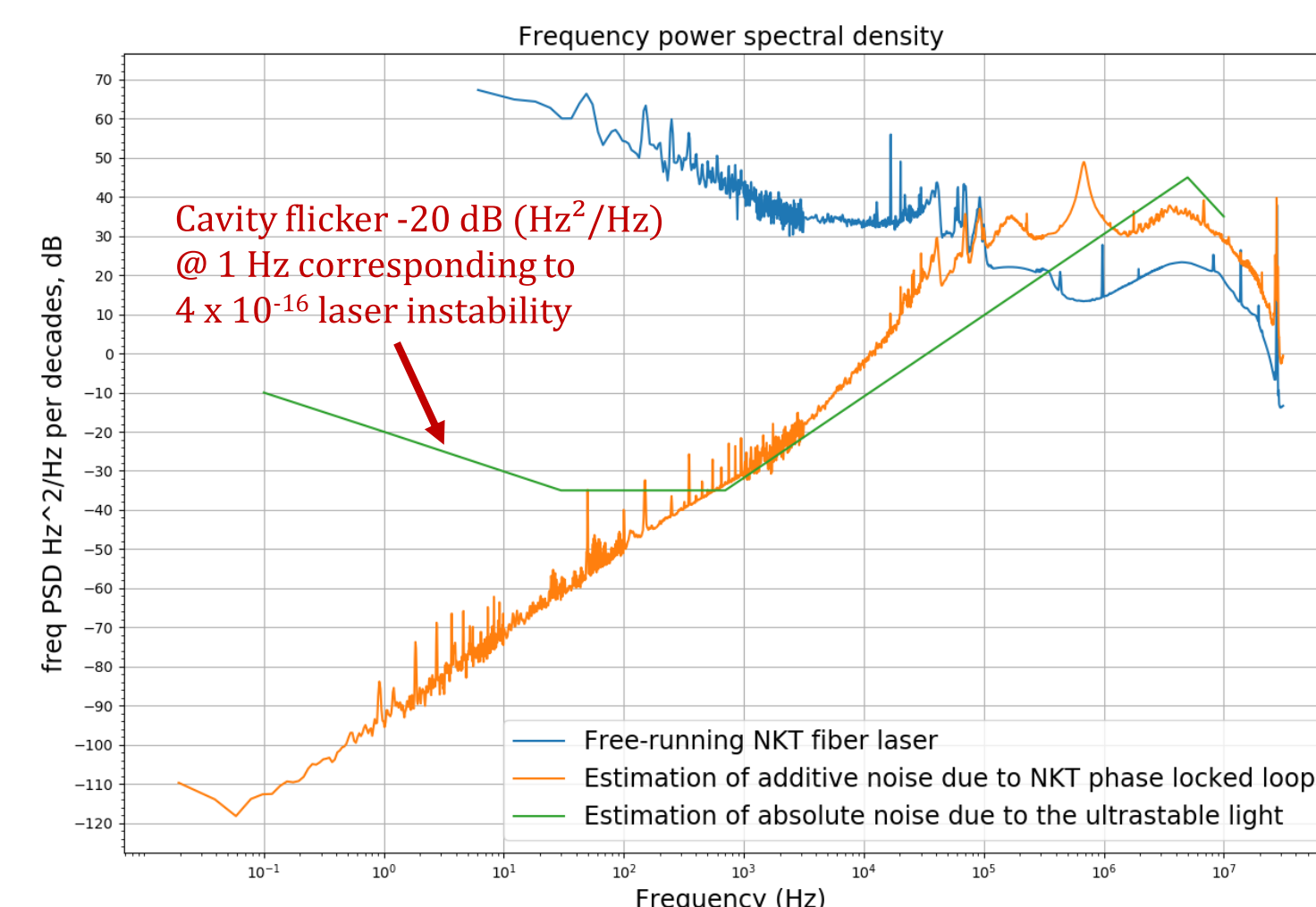
Setup to probe any of the mercury isotopes

⇒ 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

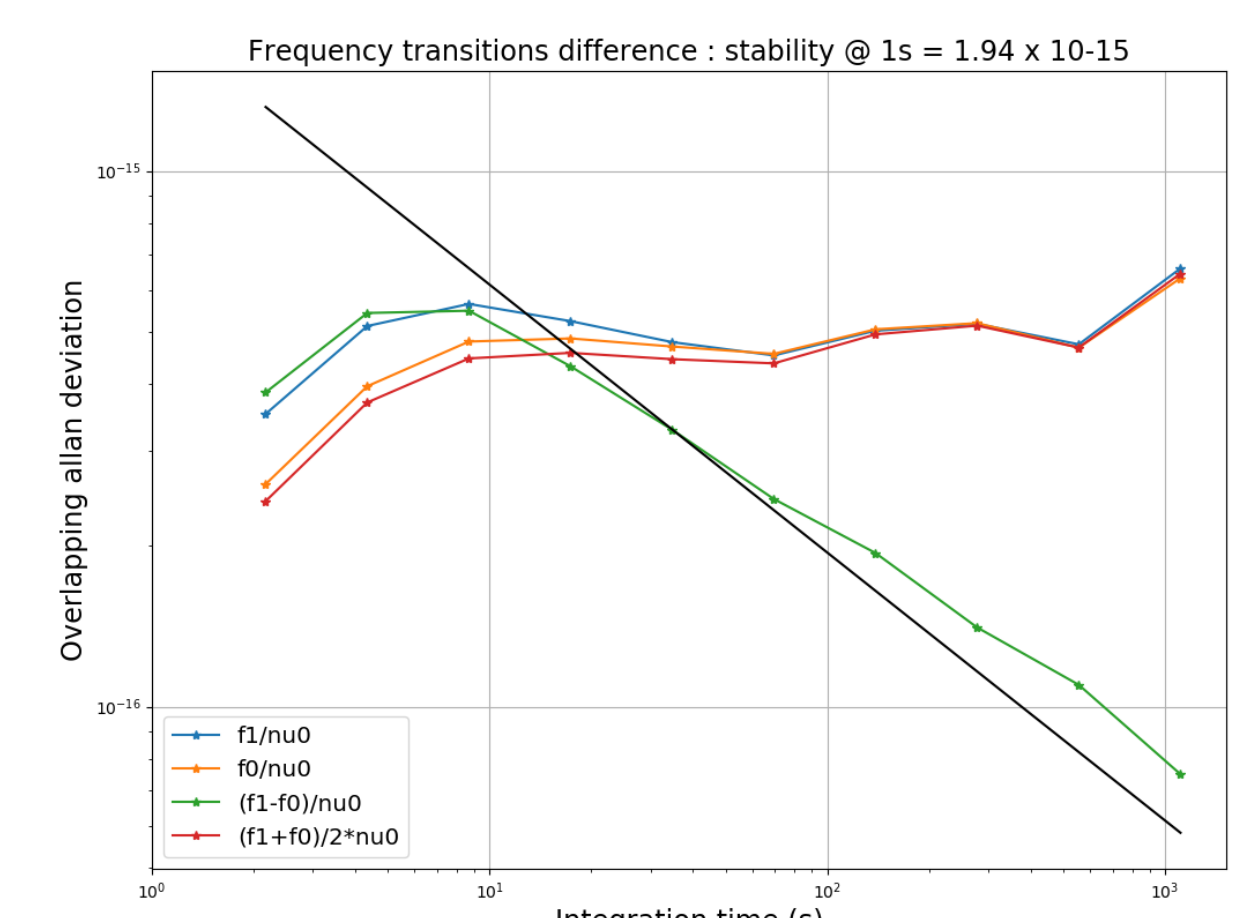


Green curve estimation of ultrastable light noise from [13].

- 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

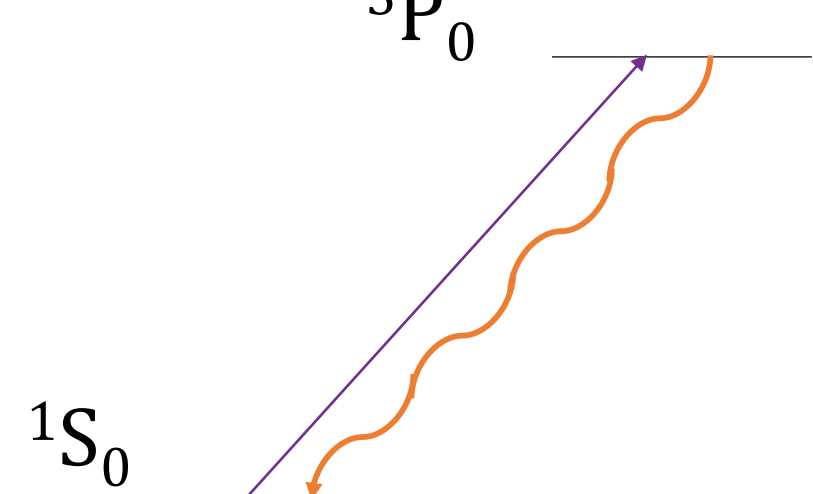
- Clock measurements with ^{199}Hg is giving good stabilities :

⇒ 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

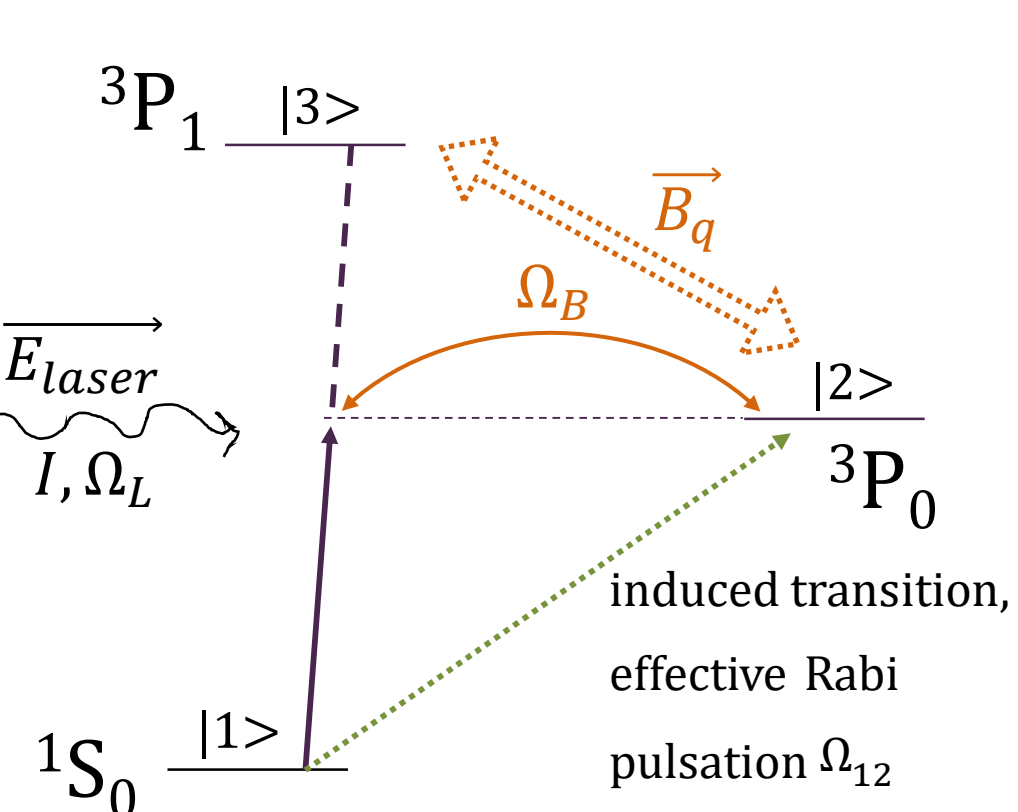


From fermionic isotopes to bosonic isotopes

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

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