Development of a cold-atom inertial measurement unit

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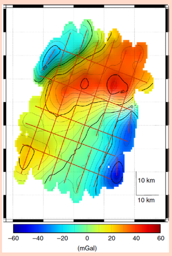
Applications to inertial sensing



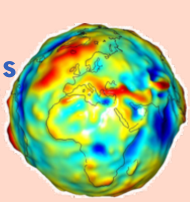
Navigation

Inertial navigation, gravity field mapping

Field map realised with an onboard cold atom gravimeter[1]

Geophysics

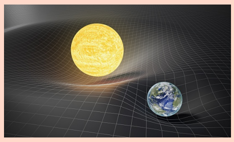
Internal structure of Earth, seismology



Géoide

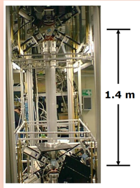
Fundamental Physics

Determination of G



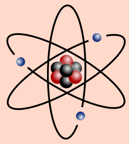
G.M. Tino, LENS

Equivalence principle



M. Kasevich, Standford

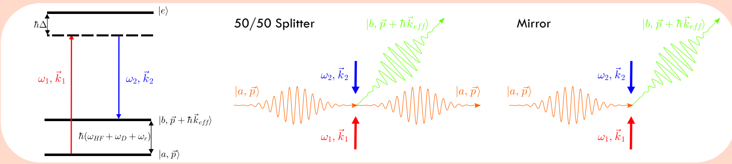
Measurement of h/m



LKB

Atom interferometry

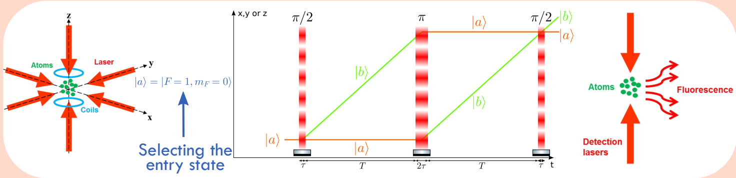
Stimulated Raman transitions



2 atomic states a and b — $\pi/2$ pulse : beamsplitter — π pulse : mirror

Analogue to Mach-Zehnder optical interferometer :
matter waves ⟷ light ; $\pi/2$ and π pulses ⟷ beamsplitter and mirrors

Atom interferometry principle



Cooling and trapping the atoms

10^7 atoms of ^{87}Rb

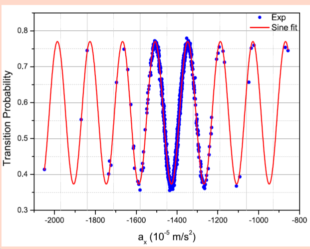
T = 2 μK

Mach-Zehnder light-pulse atom interferometer

Detection of the interference fringes

Interference fringes

Correlation fringes for the horizontal accelerometer[2]



Fringes pattern : $\mathcal{P} = \mathcal{P}_0 - \frac{\mathcal{C}}{2}\cos(\Delta\Phi)$

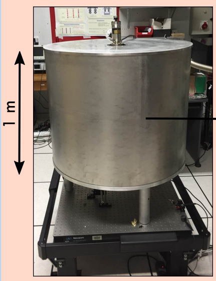
Phaseshift : $\Delta\Phi = \vec{k}_{eff}.\left(\vec{a} - 2\vec{\Omega} \times \vec{v}_0\right)T^2$

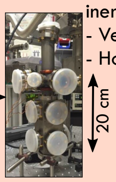
effective laser wave-vector — set the direction of the measurement

acceleration

rotation — Coriolis acceleration

Cold-atom inertial measurement unit





Actual progress towards the development of the inertial measurement unit :
- Vertical accelerometer already studied
- Horizontal accelerometer : 2 techniques developed

Future developments :
- atomic gyroscope : use of large momentum transfer pulses
- increasing the operating range in rotation
- combination of the atomic accelerometers and gyroscope previously developed in a single sensor

Goal

To measure the 3-axis components of acceleration and rotation in a compact inertial sensor for onboard applications

Hybridization with a classical sensor

Quantum sensor: Dead times, Limited dynamic range / Accuracy, Sensitivity, Long term stability

Classical sensor: Bias, Long term drifts / Continuous measurement, High dynamic range

Avoid dead times

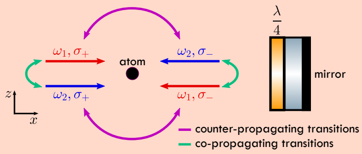
Corrects the bias and drifts

The inertial component is measured by the classical sensor and periodically corrected by the quantum sensor measurement

Horizontal accelerometer

Lift of the degeneracy

Two-photons stimulated Raman transitions :
4 possible transitions



Detuning from the two-photons resonance :

$$\delta = \omega_1 - \omega_2 - (\omega_{HF} + \omega_D + \omega_r)$$

ω_{HF} : hyperfine transition

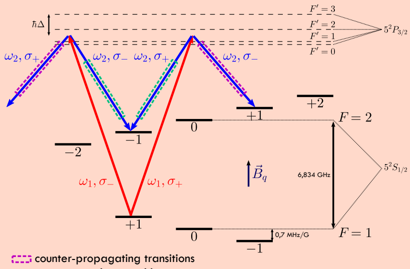
$\omega_D = \pm\vec{k}_{eff}.\vec{v}$: Doppler effect

$\omega_r = \frac{\hbar k_{eff}^2}{2m}$: recoil frequency shift

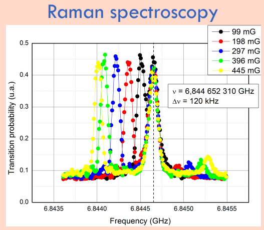
For horizontal measurement : no Doppler effect ⟶ 2 pairs of Raman lasers degenerated

2 methods to lift the degeneracy : - frequency chirped Raman lasers[2] : $\beta = \frac{1}{2\pi}\frac{d\omega_{1/2}}{dt}$

- σ_+/σ_- transition using magnetic sub levels[3]

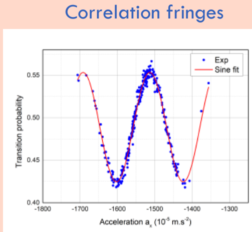


Raman spectroscopy



Results[3]

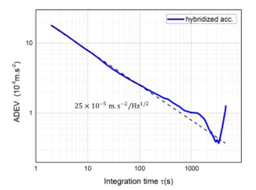
Correlation fringes



Magnetic field B = 400 mG

Contrast of 13%

Sensitivity and stability



Short term sensitivity : $25.10^{-5} m.s^{-2}/\sqrt{Hz}$

Best resolution at 3300s integration time : $3,8.10^{-6} m.s^{-2}/\sqrt{Hz}$

References :

[1] Y. Bidel *et al.* Nat. Commun. 9, 627 (2018)

[2] I. Perrin *et al.* Phys. Rev. A 100, 053618 (2019)

[3] J. Bernard *et al.* Arxiv:2111.05642 (2021)