Construction of an absolute gravimeter using atom interferometry with cold ^{87}Rb atoms

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Summary

- Use of the gravimeter: The Watt Balance
- Principle of our gravimeter, atom interferometry
- Lasers frequency locks…
- Sensitivity to phase noise
- Sensitivity to vibrations and rejection method
- Advancement : the traps
- Conclusion

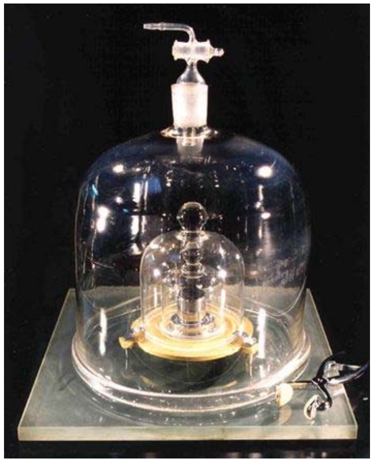
The Watt Balance project

Objective : replace the standard Kg with a definition linked to the Planck's constant *h*

Why : the standard Kg is the last artifact of the international system, observed drift on the primary and secondary standards of 5.10^{-8} Kg over 30 years

Mass metrology: goal of 10^{-8} of relative precision

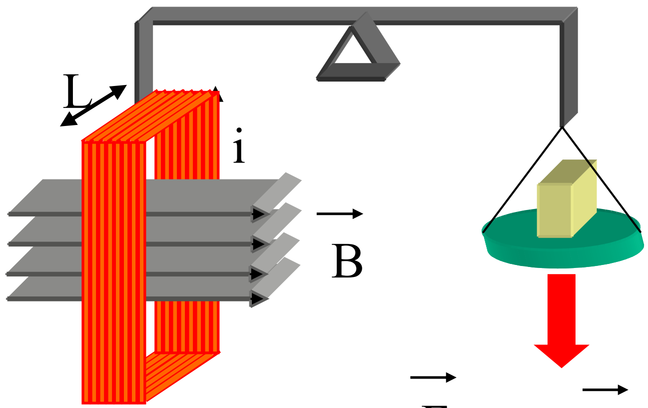
Principle : Balance a mechanical power with an electrical power



BIPM standard Kg

The Watt Balance project

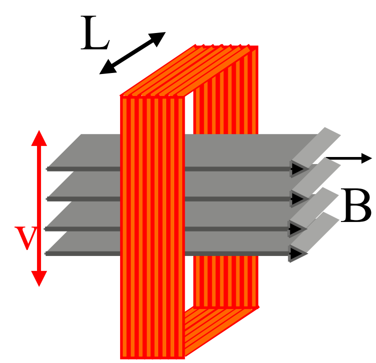
statical Phase



$\vec{F}_g = m \times \vec{g}$

$\vec{F}_{Laplace} = i\,\vec{L} \times \vec{B}$

Dynamical Phase constant speed motion



$E = B \times L \times v$

$B \times i \times L = m\,g$

$m\,g\,v = E\,i$

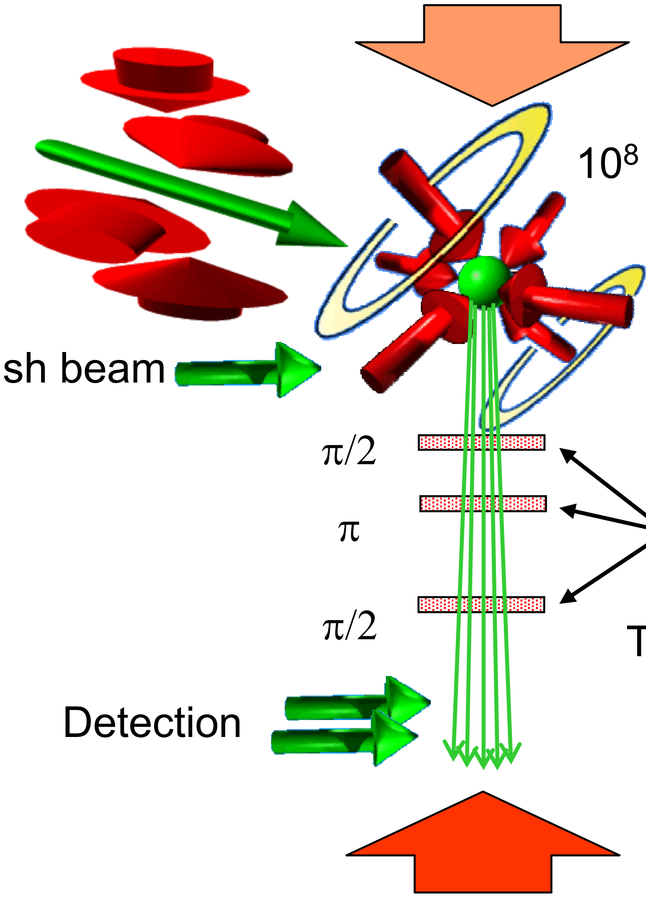
Josephson Frequency

Planck's Constant

$$m = k\,\frac{f_J^{\,2}}{g \times v}\,h$$

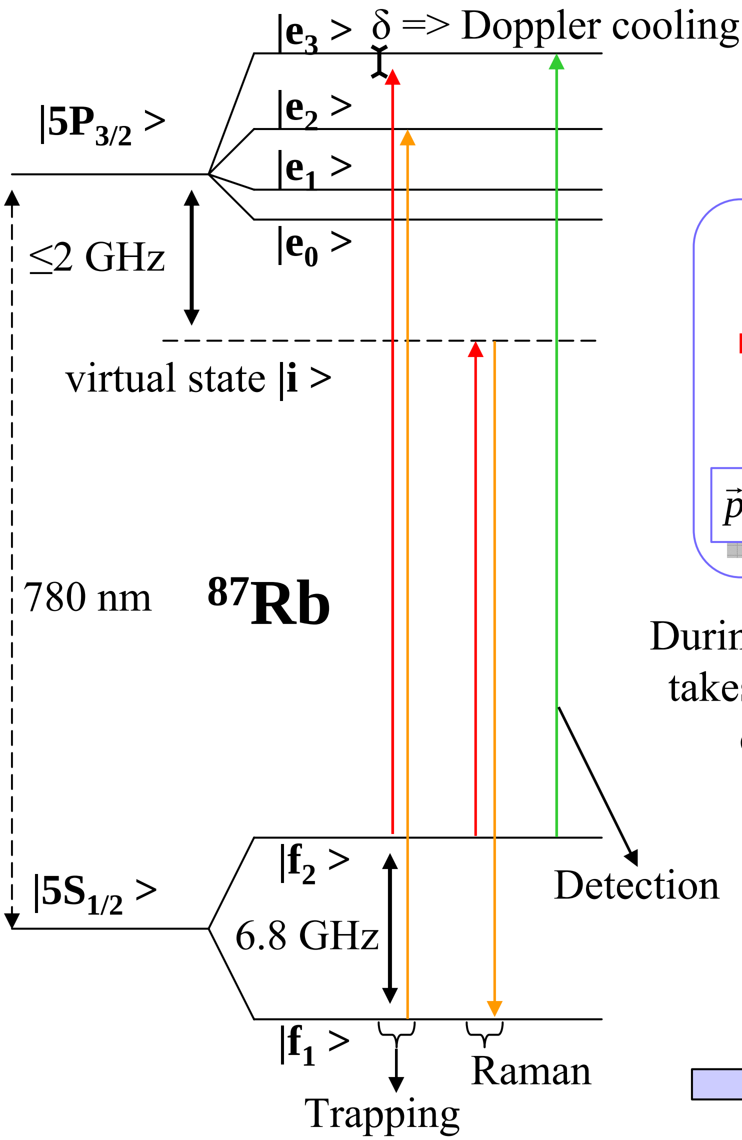
Necessity of a precise *g* mesurement

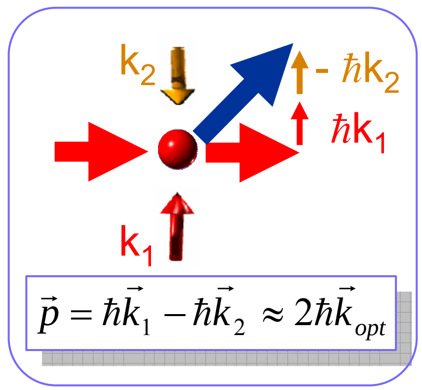
General Principle



$$\Delta\Phi = k_{eff}.g.T^2$$

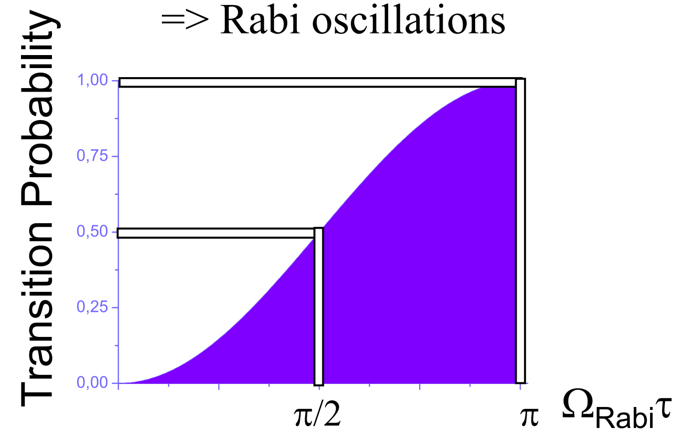
Stimulated Raman Transitions





During the transition, the atom takes two photon recoils and change its trajectory

The lasers couple the $|f_1>$ and $|f_2>$ states in a quantum superposition => Rabi oscillations



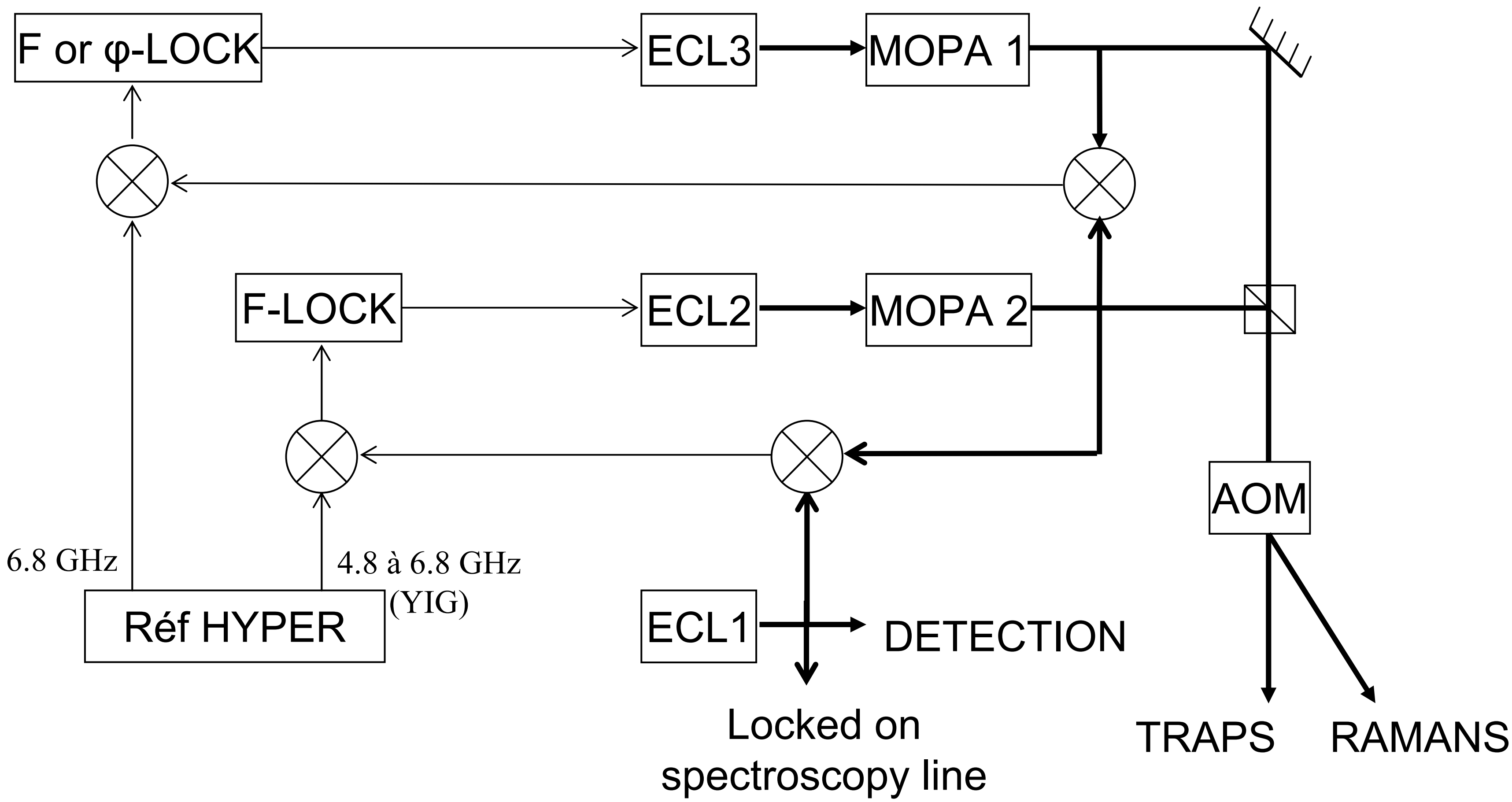
π pulse : Atomic mirror

π/2 pulse : Atomic beam Splitter

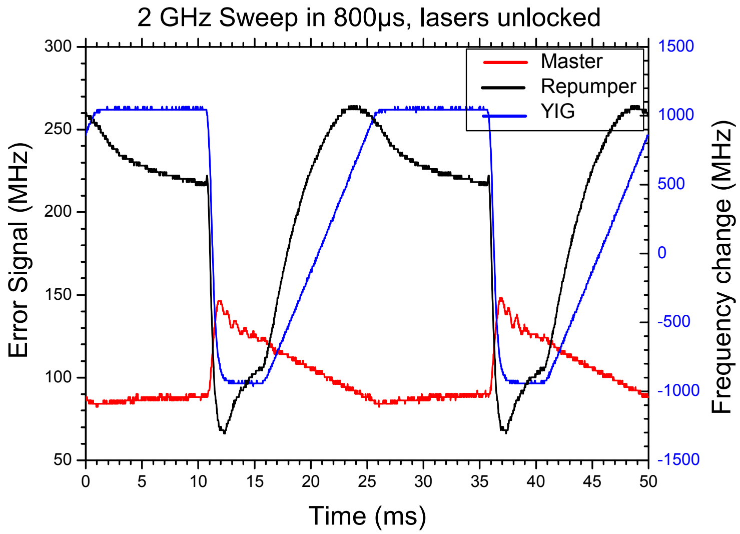
⇨ same lasers for trapping and Raman

Optical Bench

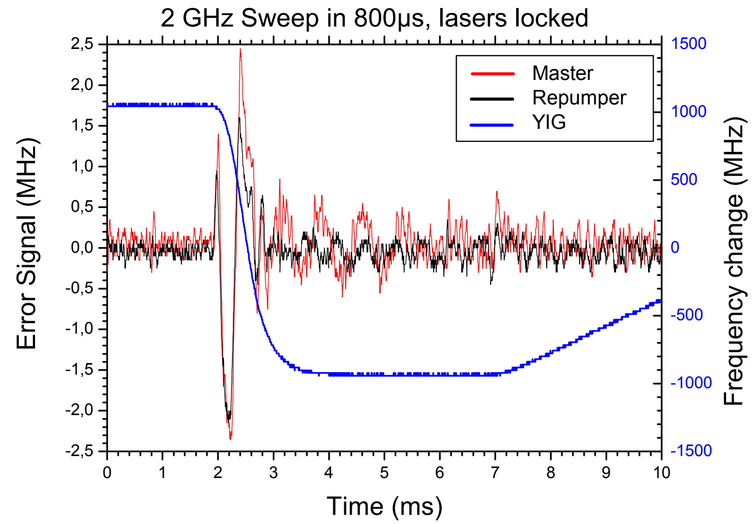
1 single bench for cooling and Raman pulses

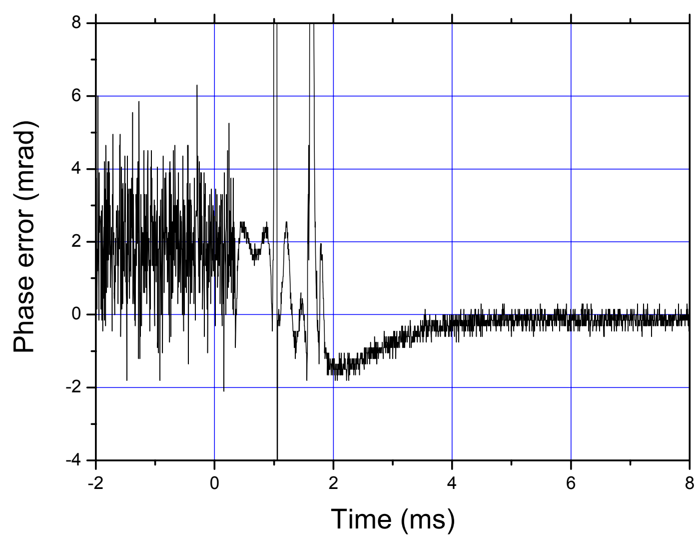


Transition to φ-lock



Fixed ramps applied on lasers controls

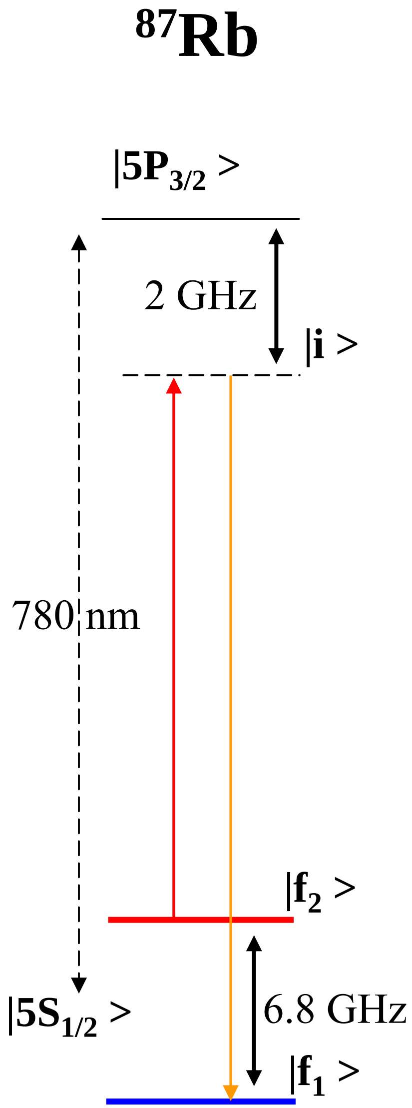




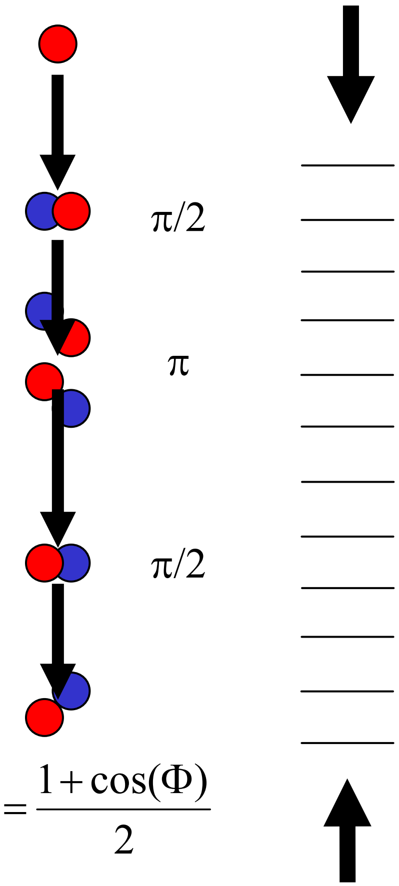
0.8 ms to sweep by 2 GHz

3 ms to reach the 1 mrad level

Atomic interferometer



$$\varphi_1(t) = k_1 z(t) + \varphi_1{}^0(t)$$



$$P_{\bullet} = \frac{1+\cos(\Phi)}{2}$$

$$\varphi_2(t) = -k_2 z(t) + \varphi_2{}^0(t)$$

$$\phi(0) = 0$$

$$\phi(T) = \frac{1}{2} k_{eff}\, g T^2$$

$$\phi(2T) = 2 k_{eff}\, g T^2$$

$\phi(t) = \varphi_2(t) - \varphi_1(t)$ is printed on the atomic phase

Interferometer's phase shift

$$\Phi = \phi(0) - 2\phi(T) + \phi(2T)$$

$$\Phi = k_{eff}\,.g.T^2 + \phi^0(0) - 2\phi^0(T) + \phi^0(2T)$$

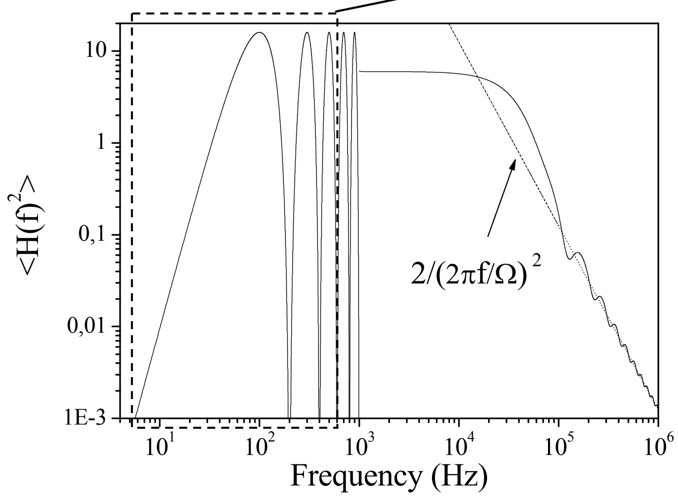
T=50ms => ~10^6 rad

Transfer function H(ω) for laser phase noise

$$\sigma_{\Phi}^{2} = \int H(\omega)^{2} S_{\varphi}(\omega) d\omega$$

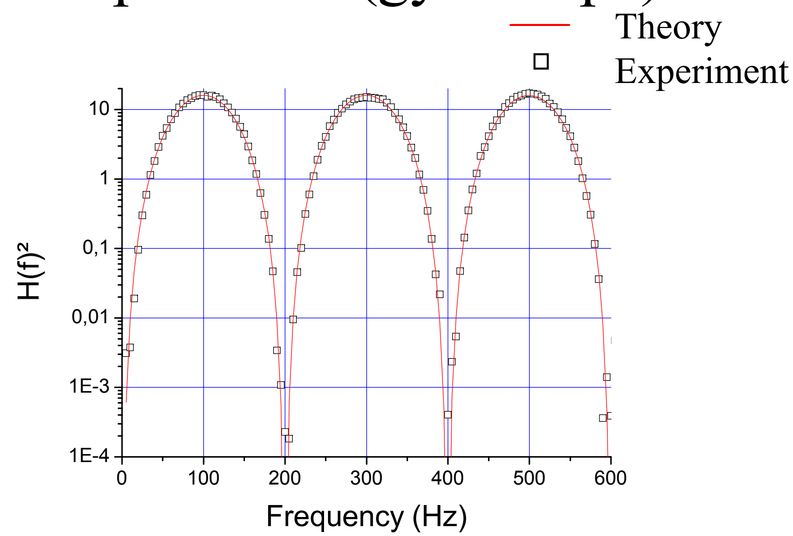
$S_{\varphi}(\omega)$ Phase power spectral density

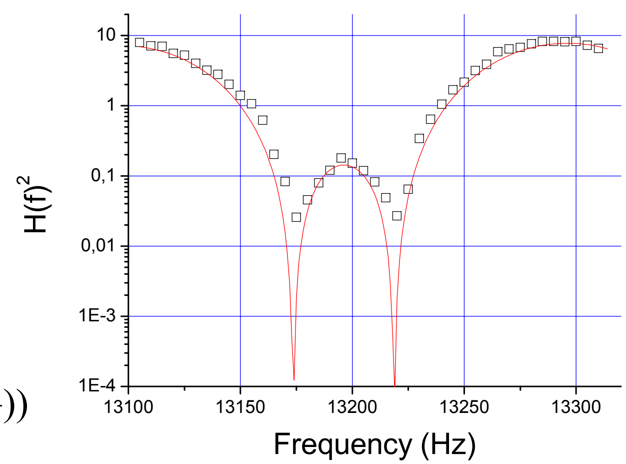
Theory (T=5ms):



$$H(\omega) = -\frac{4i\omega\Omega}{\omega^{2} - \Omega^{2}} \sin\left(\frac{\omega(T+2\tau_R)}{2}\right)\left(\cos\left(\frac{\omega(T+2\tau_R)}{2}\right) + \frac{\Omega}{\omega}\sin\left(\frac{\omega T}{2}\right)\right)$$

Experiment (gyroscope)





Raman laser phase noise

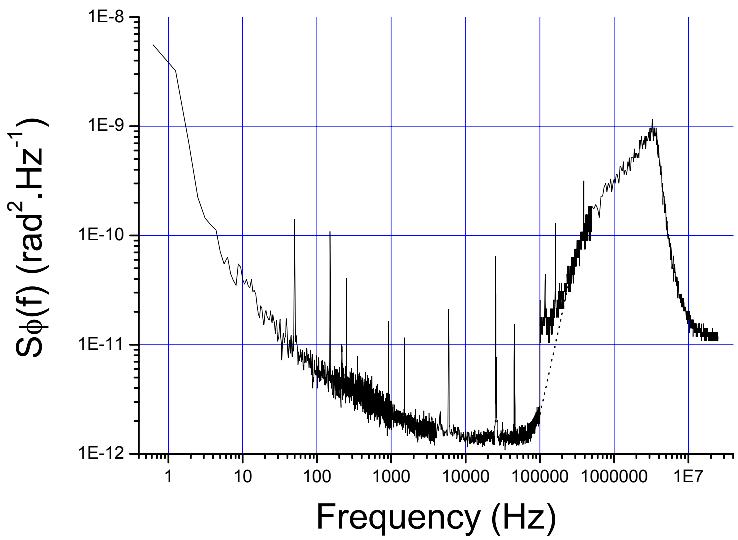
Two possible sources:

→ Reference frequency phase stability: $\sigma_\Phi = 1.2$ mrad

Estimated for state of the art quartz oscillator

→ Residual noise of the Phaselock loop:

Experimental result →



Weighted with H(ω):
2T=100ms and τ=10 µs

$\sigma_\Phi = 1.3$ mrad

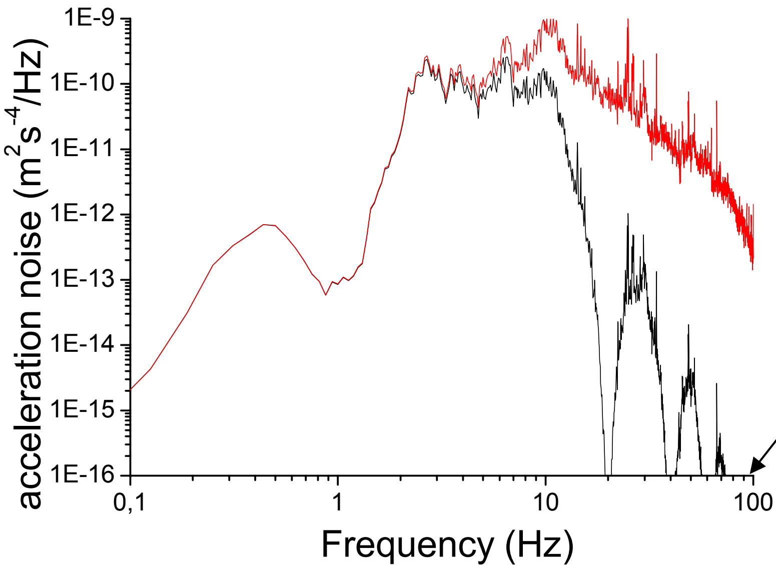
Total contribution: $\sigma_\Phi = 1.75$ mrad => 9 ng/shot

Sensitivity to vibrations

phase/position
$\delta\phi \Leftrightarrow k_{eff}\delta z$

$$\sigma_{\Phi}^{2} = k_{eff}^{2} \int \frac{H(\omega)^{2}}{\omega^{4}} S_a(\omega) d\omega$$

— Noise level in the lab
— Weighted noise



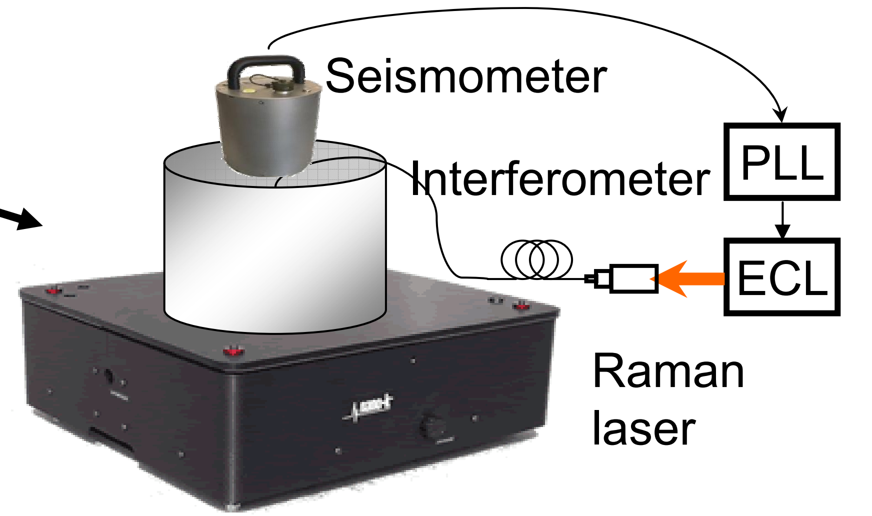
Required vibration noise level (>0.3 Hz) : 1 $ng/Hz^{1/2}$

Up to 80 Hz :

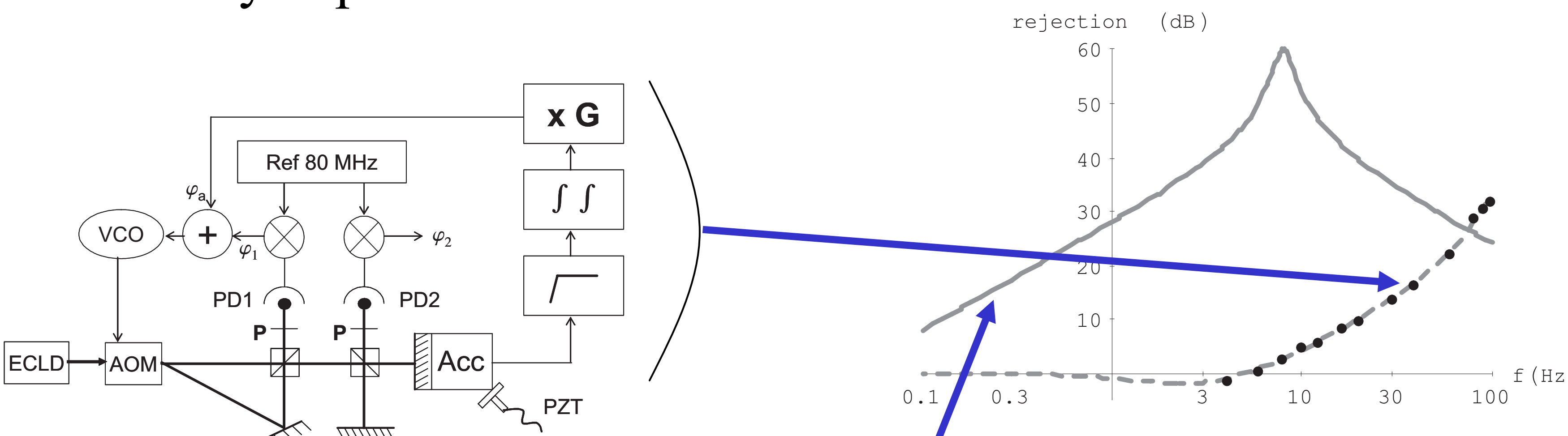
Need for vibration isolation and compensation

Vibration rejection

Act on the Raman phase difference to compensate for vibrations



Method tested on auxiliary experiment



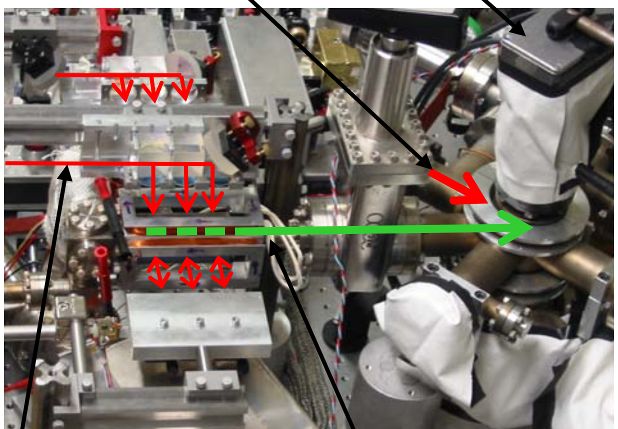
With a seismometer

Progress report

2D-MOT

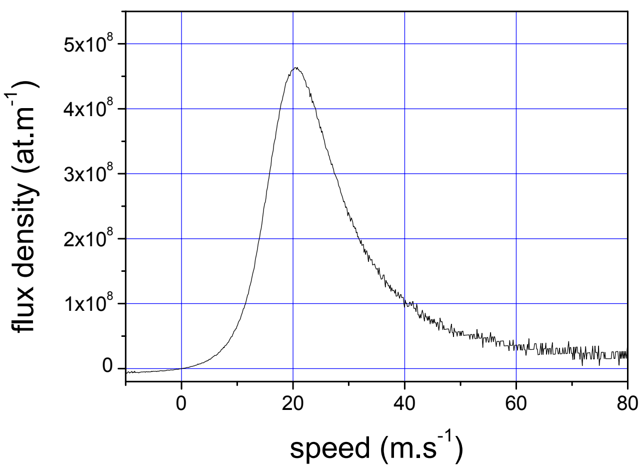
Detection

Photodiode



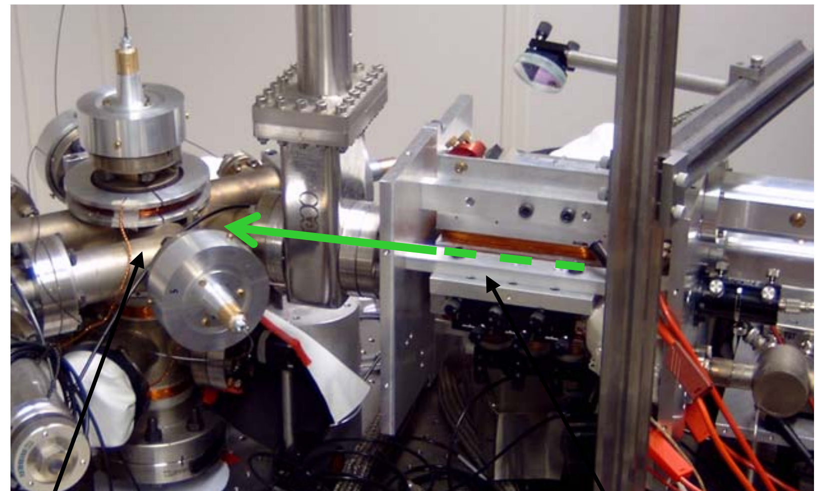
trapping lasers

Cold atoms



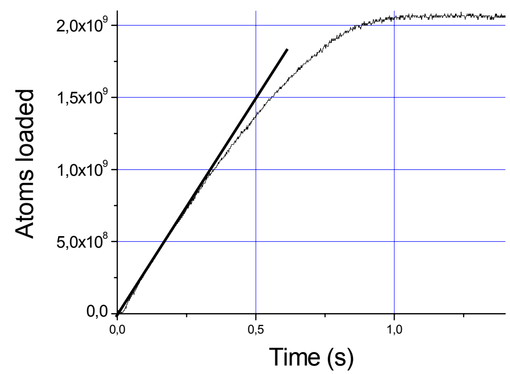
2D-MOT total flux $=10^{10}$ atoms.s^{-1}

3D-MOT



3D-MOT

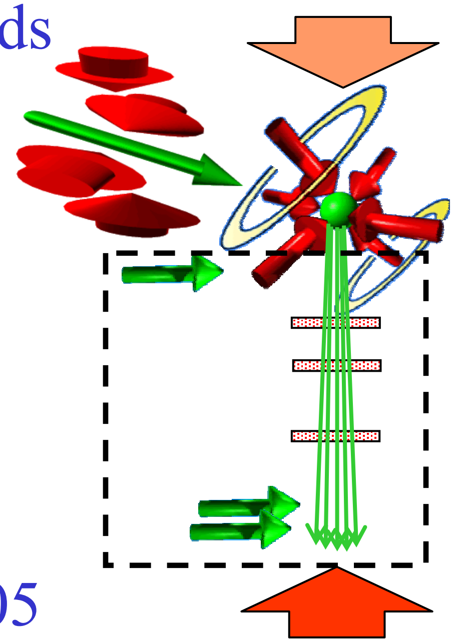
2D-MOT



3D-MOT loading rate = 3.10^9 atoms.s^{-1}

Conclusion

Expected sensitivity : 10^{-9} g after a few seconds
Expected accuracy : 10^{-9} g



- Cold atom sources obtained
- Raman lasers phase-locked

-First atom interferometry signals: early 2005

Limited by vibrations

Preliminary vacuum chamber => test the system

-Implement the vibration isolation platform

and the vibration rejection