Atom chips for inertial sensors

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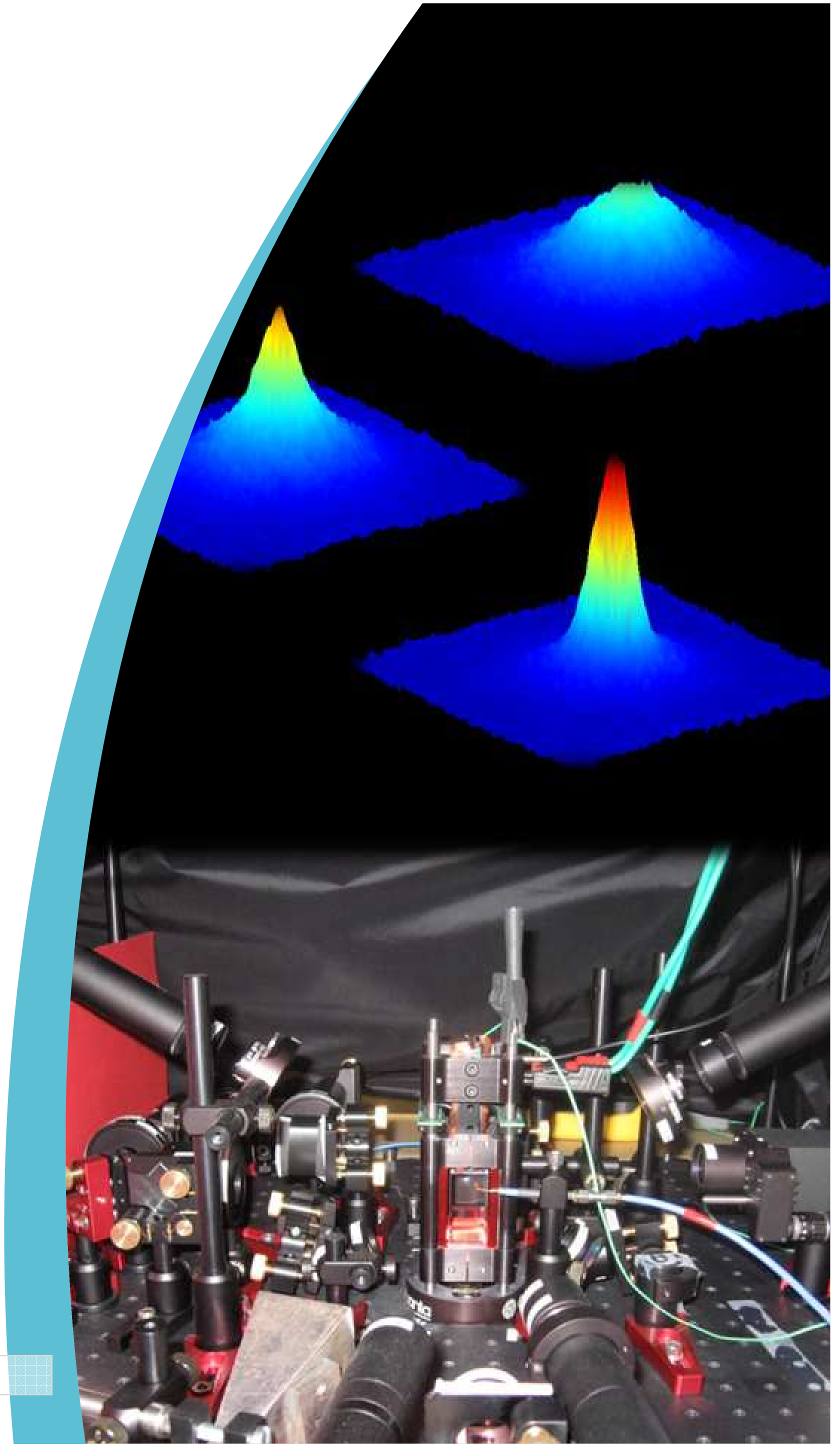


Outline

Introduction

- Why cold atoms in Thales ?
- Sensors with ultimate precision *(long coherence time)*

Chose of atom chips

- Compactness, on-board applications

Atomic clocks

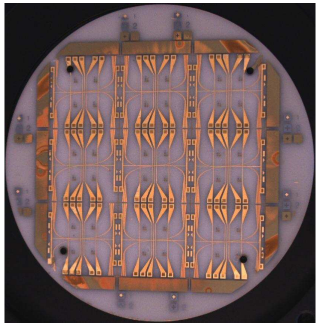
- Principle
- Ramsey interferometer

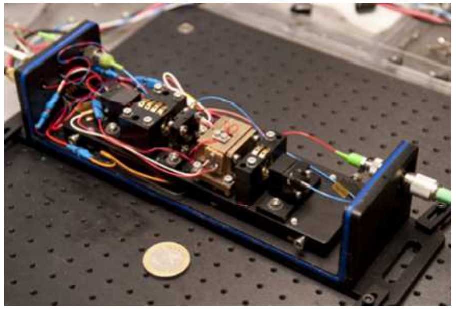
Accelerometer – gravimeter

- Principle
- Spatial splitting

Gyroscope

Activities on development of laser source for atomic sensors





Applications - Why cold atoms in Thales ?

Clocks

- Navigation
- GNSS
- Telecom networks synchronization

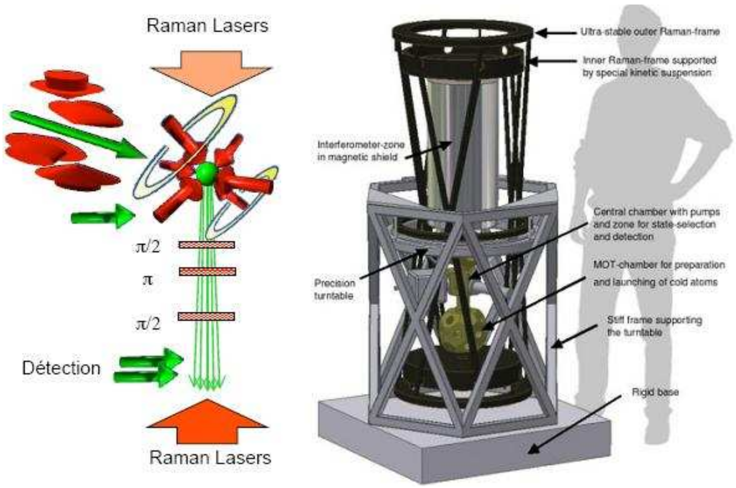
Accelerometers

- Navigation
- Gravimeter
  - Mass detection
  - Terrain aided navigation
  - Space instruments

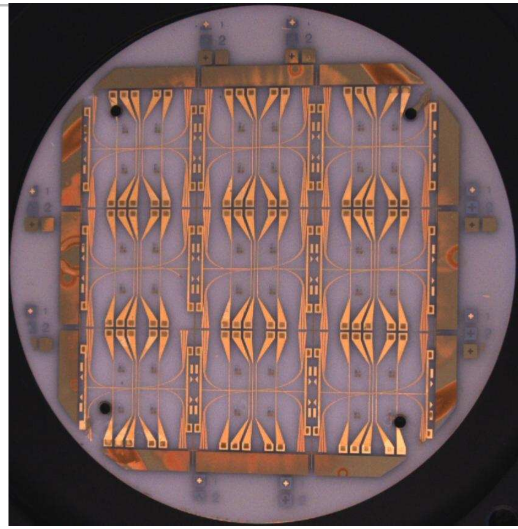
Gyroscopes

High performance inertial measurement units

Atom chips



Source : SYRTE (left) & Berlin university (right)



Atom chip (TRT / III-V Lab)

First generation atomic gravimeter

Atoms are free falling

On-chip atomic accelerometer

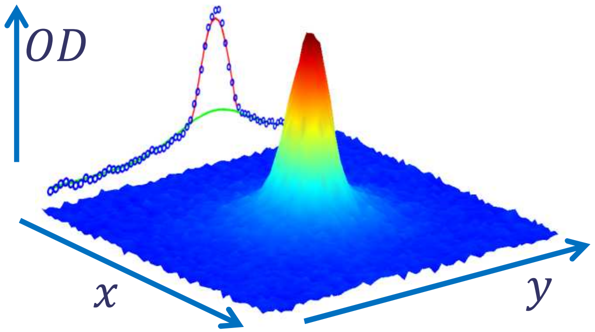
Atoms are trapped in the vicinity of a chip

Main advantages of atom chips :

- Low-energy device
- Compact
- Integration of advanced function on the same chip (microwave, optics, …) + sensors multiplexing

On chip Bose-Einstein condensate in TRT

- $\sim 10^4$ atoms @ $\sim$ 100 nK

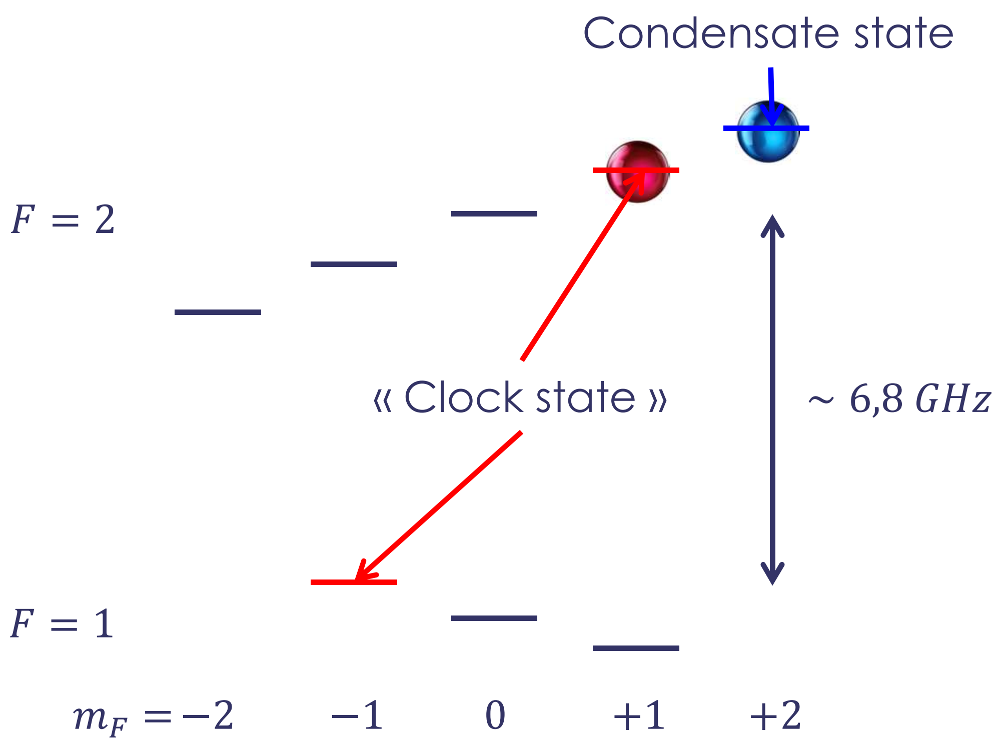


STIRAP transfer – on a chip

STIRAP : STImulated Raman Adiabatic Passage

- Condensate in $|2,2>$: higher magnetic moment (than |1,-1> or |2,1>), easier to trap/evaporate

- Transfer to one of the state $|2,1>$ or $|1,-1>$: good coherence properties

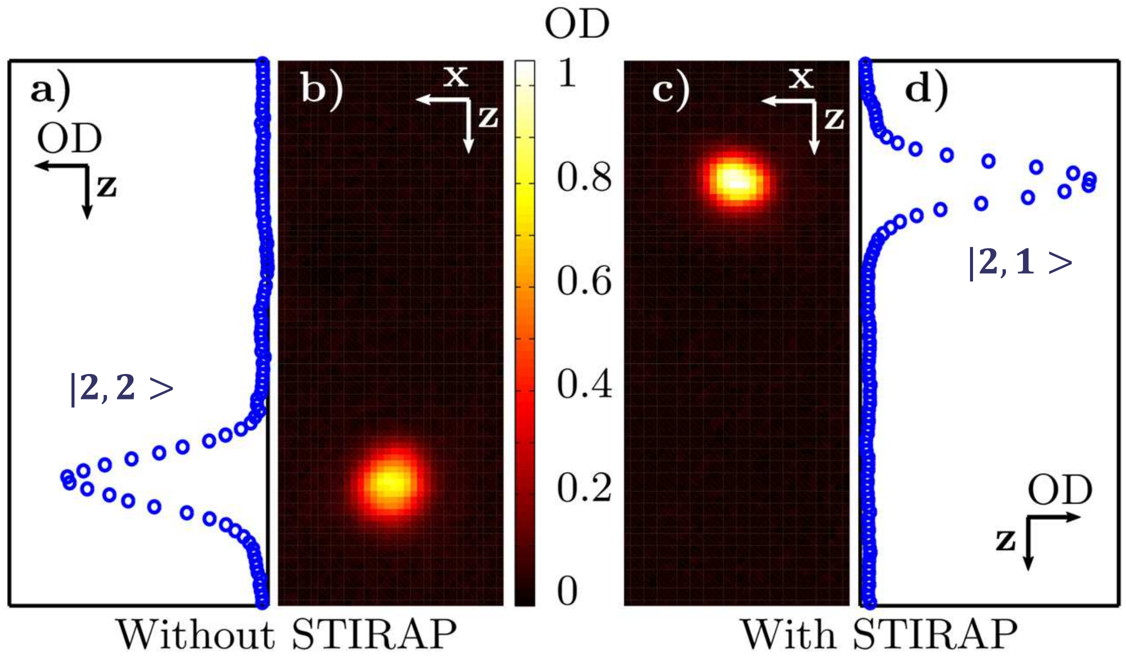


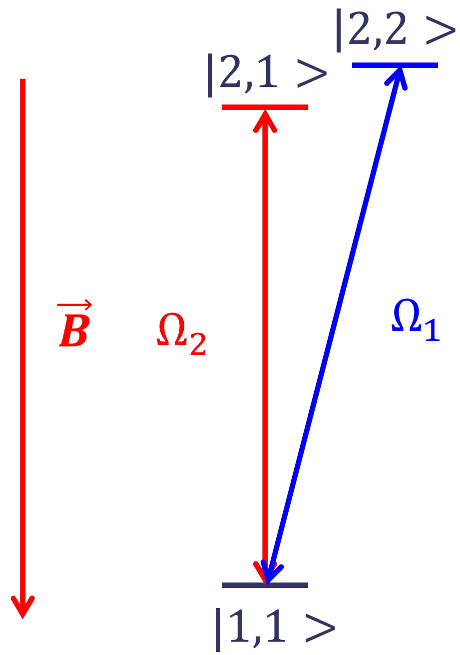
Hyperfine levels of ^{87}Rb

M. Dupont-Nivet, et al. Phys. Rev. A 2015, 91, 053420

STIRAP transfer – on a chip

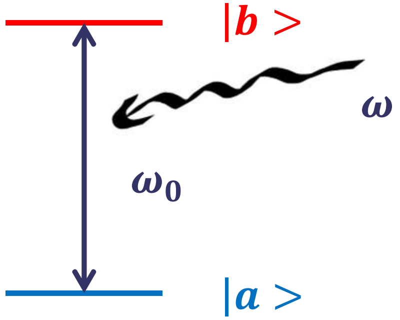
STIRAP : STImulated Raman Adiabatic Passage

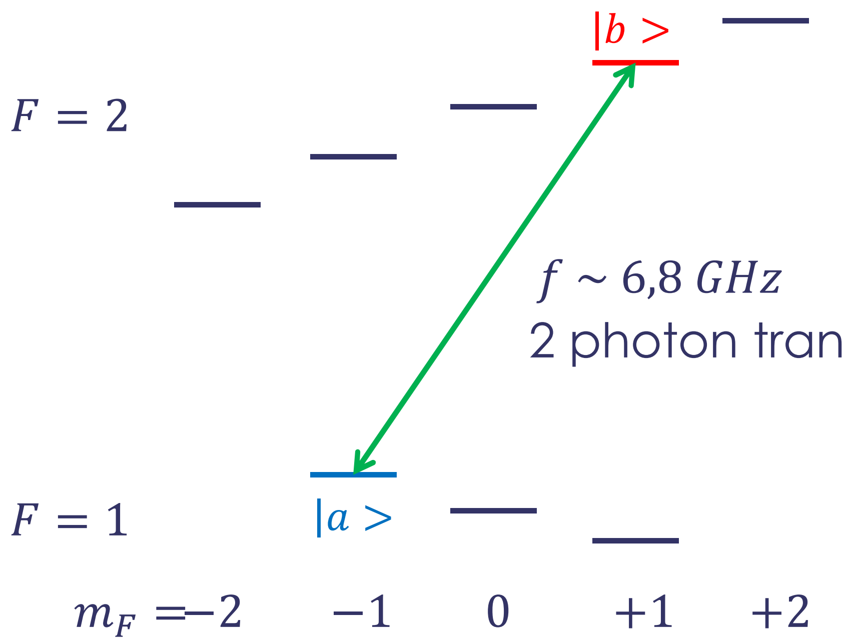




M. Dupont-Nivet, et al. Phys. Rev. A 2015, 91, 053420

Atomic clock – trapped on a chip





Hyperfine levels of ^{87}Rb

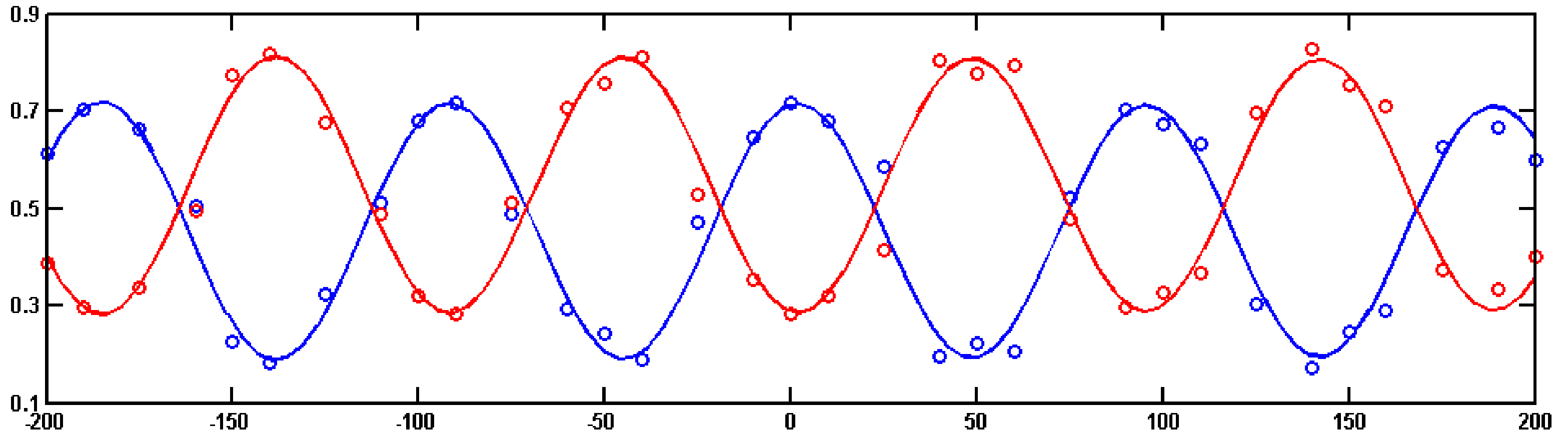
Main advantages :

- Magnetically trappable
- Same magnetic moment
- Weak sensitivity of the transition frequency to magnetic field fluctuations

Ramsey Interferometer – Atomic clock – trapped on a chip

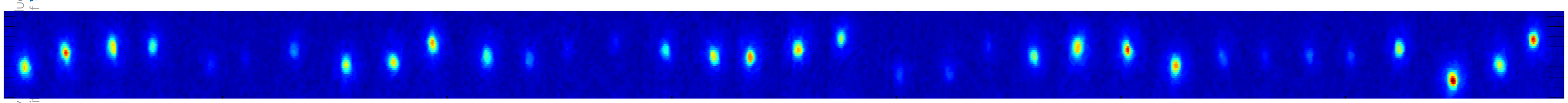
- Difference between two phases:
  - The oscillator one (in the microwave range)
  - Phase evolution of the atoms

- Translation of this phase difference on atomic populations of two electronic states

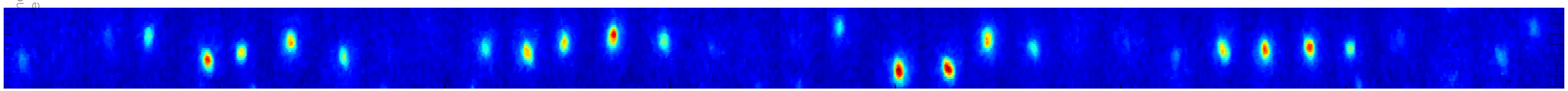


$\omega - \omega_0\ [Hz], \quad T = 10\ ms$

$|a>$



$|b>$



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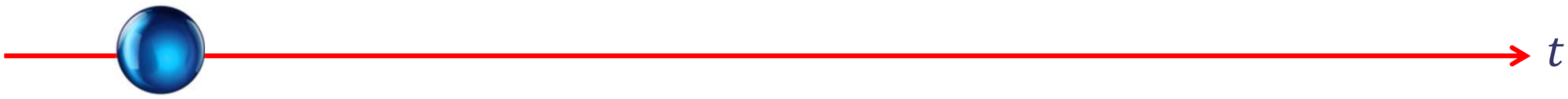
Towards an accelerometer on an atom chip



Atomic state $|a>$

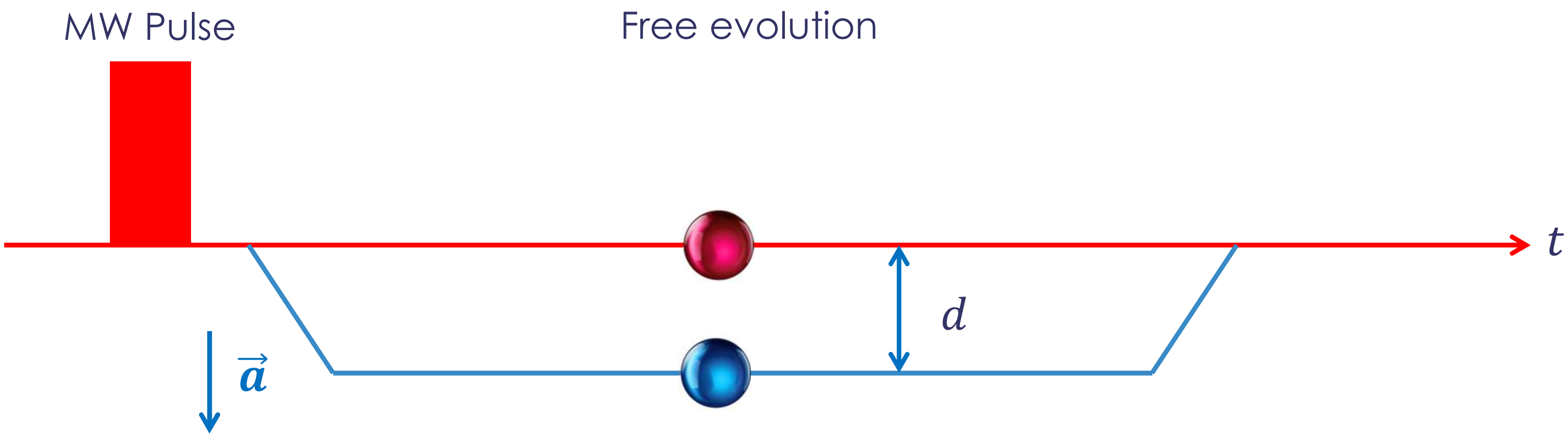
MW phase

Towards an accelerometer on an atom chip

Atomic state $\frac{|a> + e^{i\phi}|b>}{\sqrt{2}}$

MW phase ϕ

Towards an accelerometer on an atom chip



Atomic state $\frac{|a> + e^{i\phi - i\omega_0 t - i\phi_a(t)}|b>}{\sqrt{2}}$

MW phase $\phi + \omega t$

$$\phi_a(t) = \frac{m\,a\,d\,t}{\hbar} + \cdots$$

a : acceleration along the splitting axis

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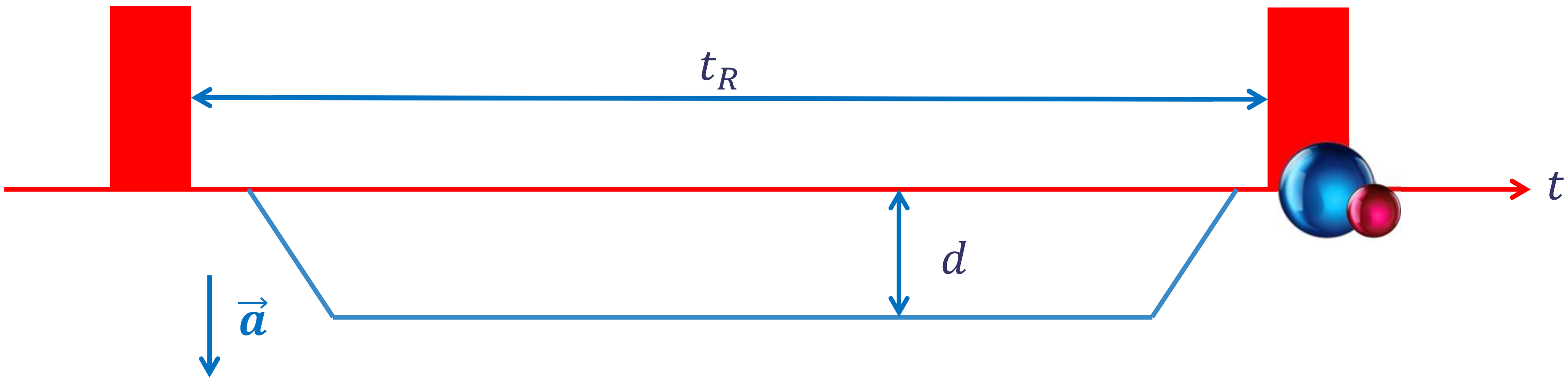
Towards an accelerometer on an atom chip



Atomic state $\quad p_a|a> + p_b|b> \quad p_a \propto 1 - \cos\big((\omega - \omega_0)t_R - \phi_a(t_R)\big)$

MW phase $\quad \phi + \omega t_R \quad \phi_a(t) = \frac{m\,a\,d\,t}{\hbar} + \cdots$

a : acceleration along the splitting axis

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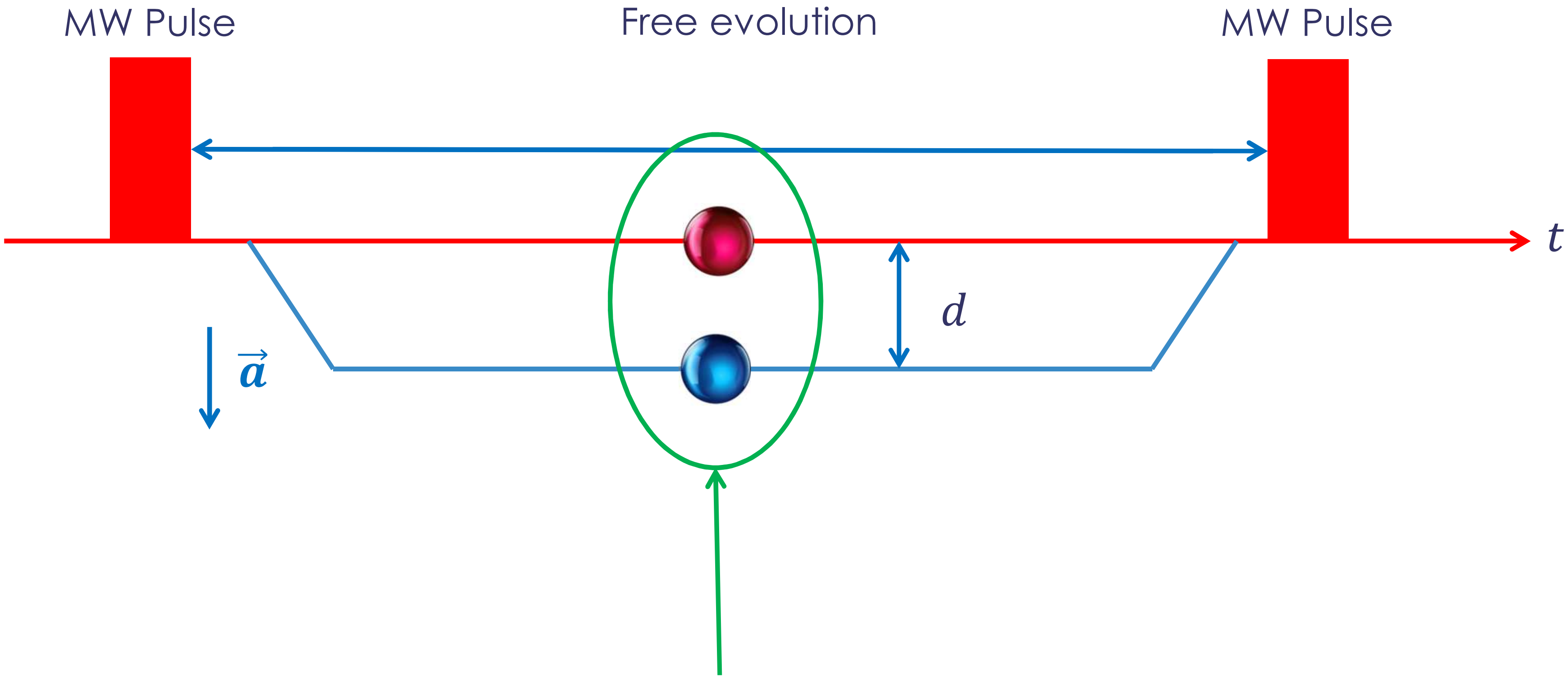
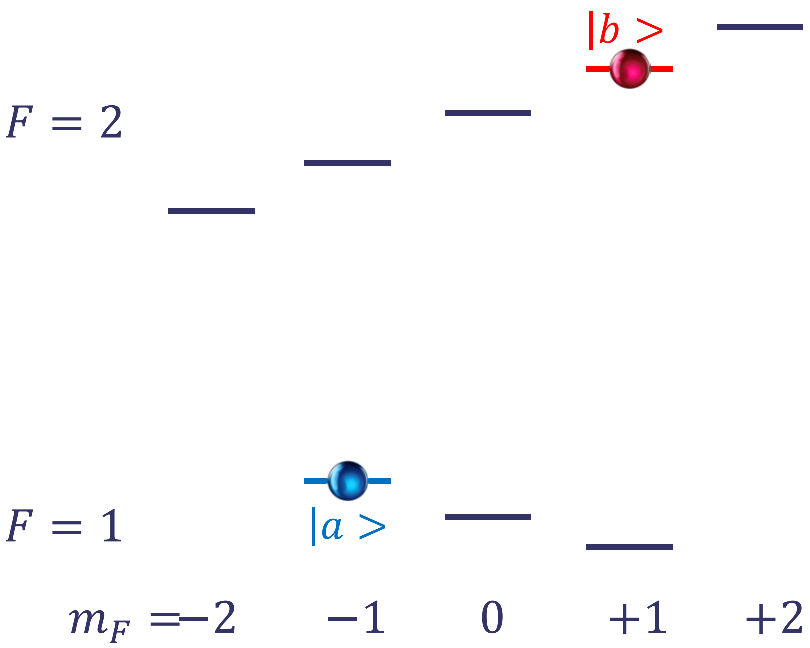
Towards an accelerometer on an atom chip



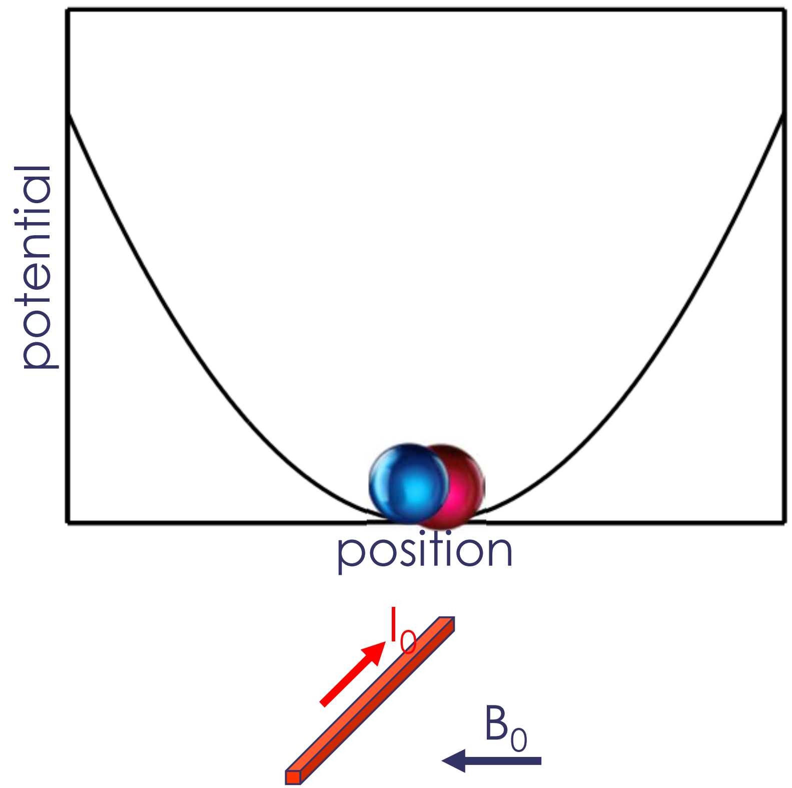
How to do it in the experiment ?

Towards an accelerometer on an atom chip

Commun magnetic trap



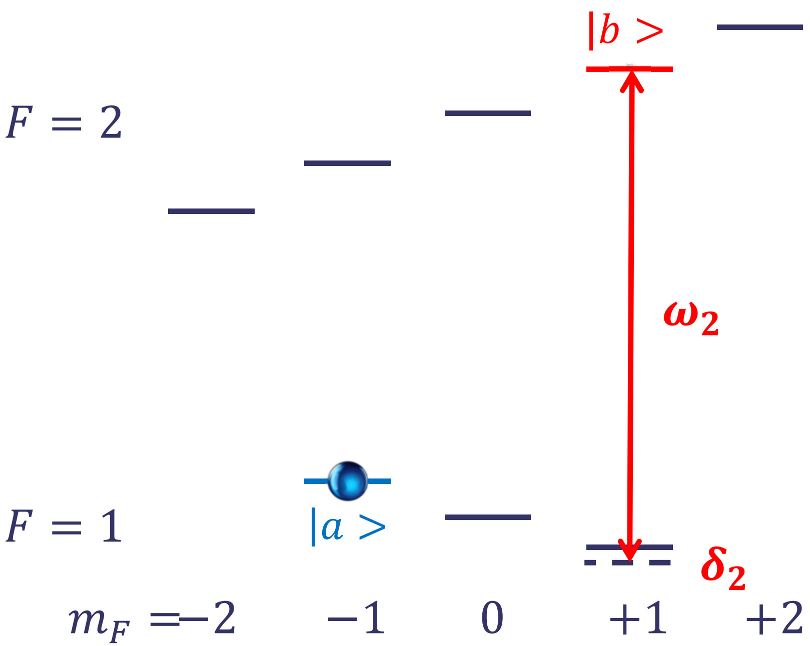
Hyperfine levels of ^{87}Rb



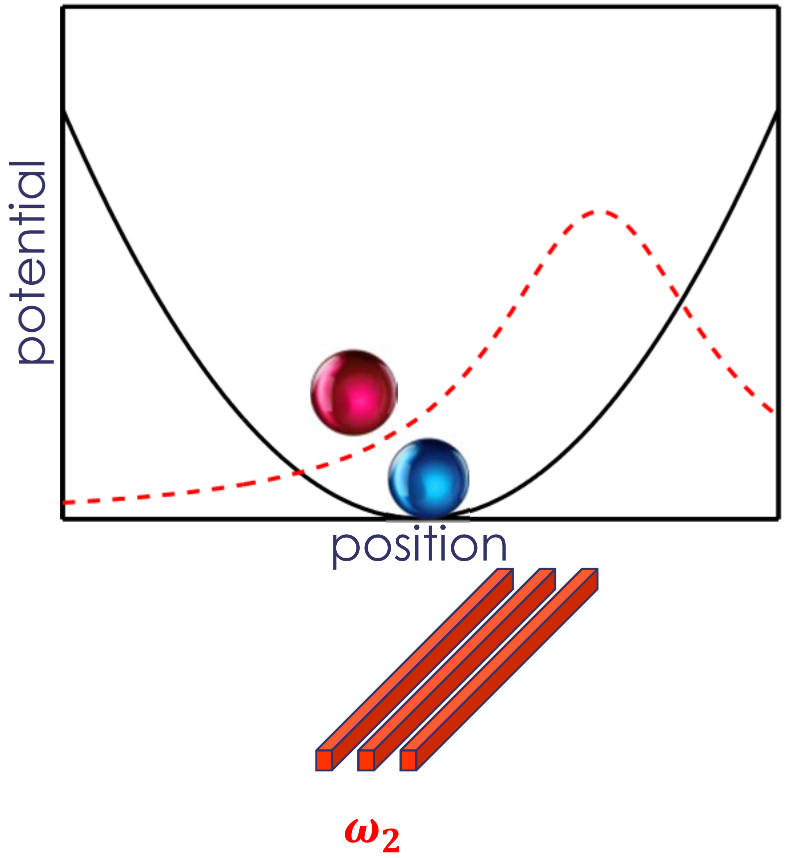
One waveguide : P. Bohi et al., Nat. Phys., 2009, 5, 592-597
Two waveguides : M. Ammar, M. Dupont-Nivet et al., PRA, 2015, 91, 053623

Towards an accelerometer on an atom chip

A trap for $|b>$



Hyperfine levels of ^{87}Rb



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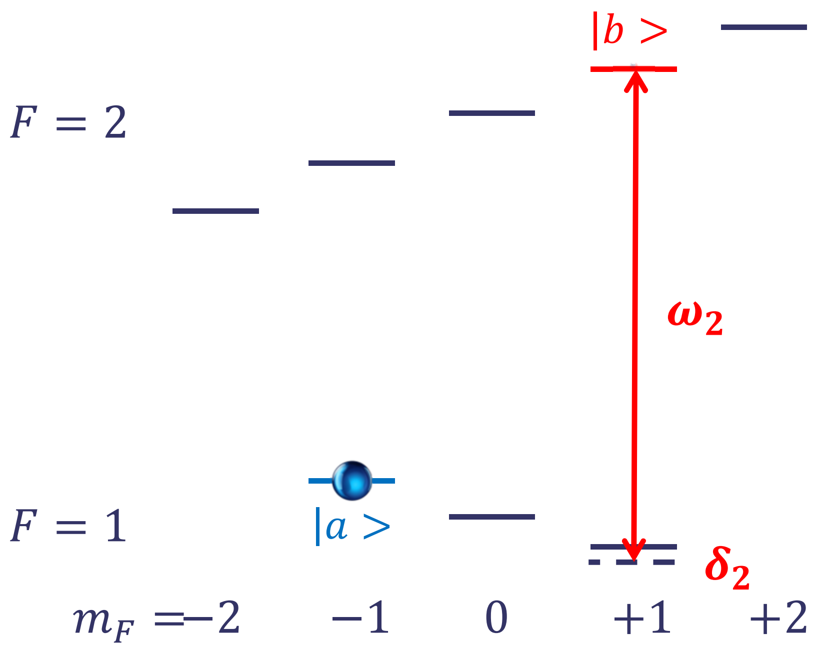
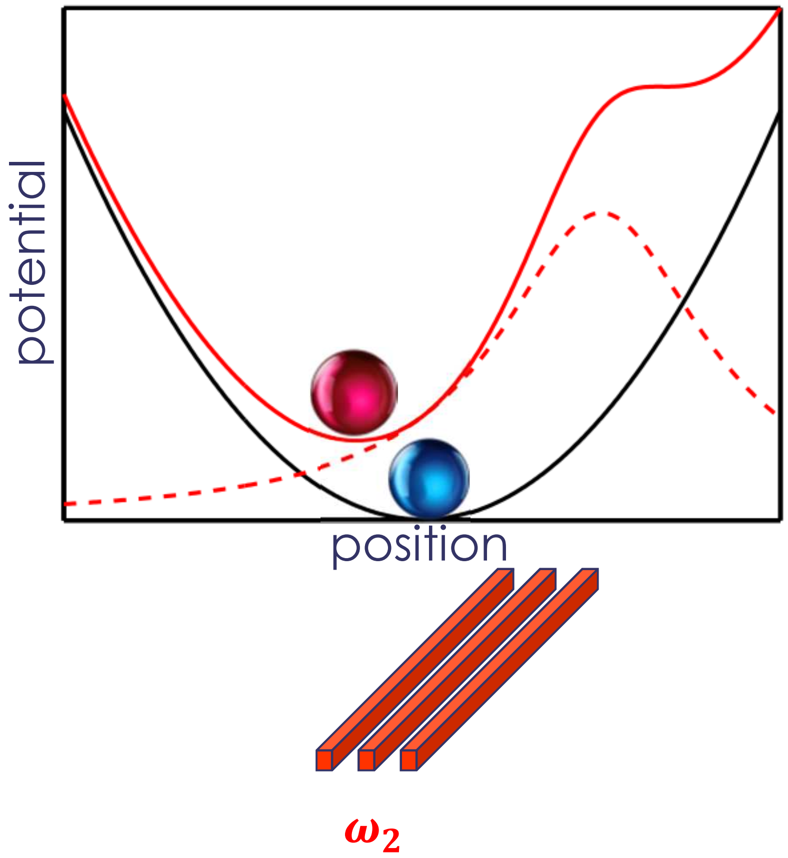


Hyperfine levels of ^{87}Rb



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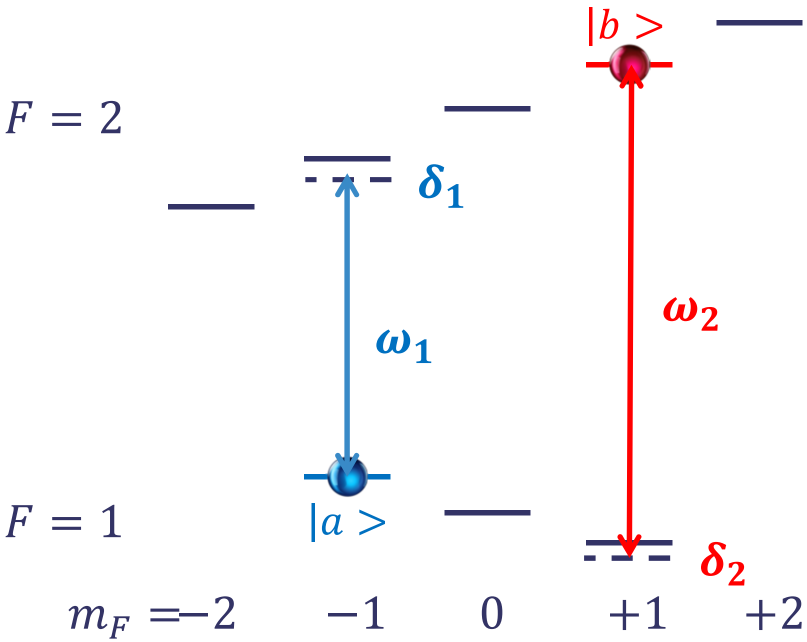
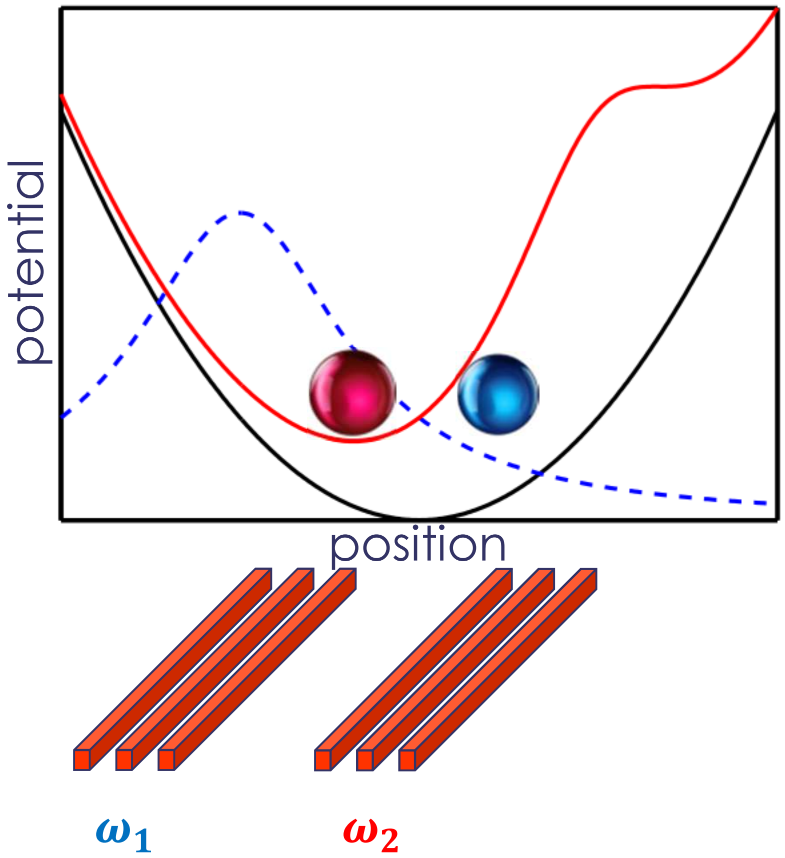
Towards an accelerometer on an atom chip

A trap for $|a>$



Hyperfine levels of ^{87}Rb



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Towards an accelerometer on an atom chip

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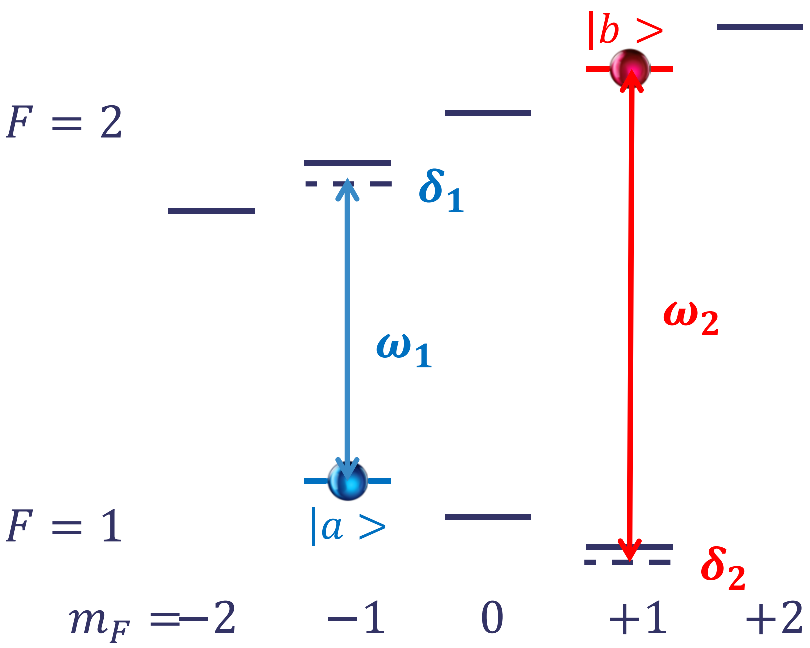

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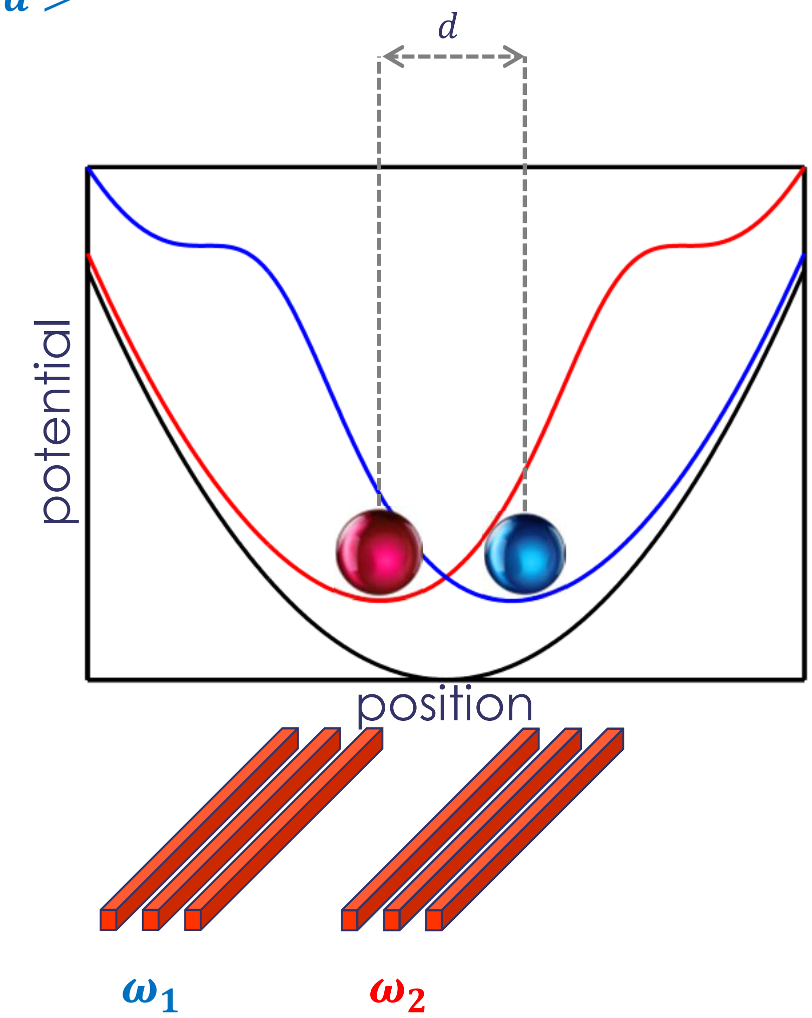

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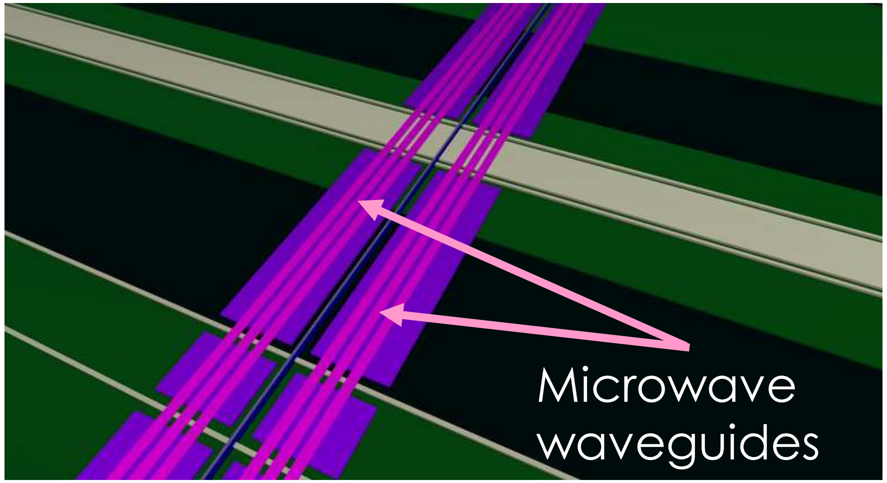
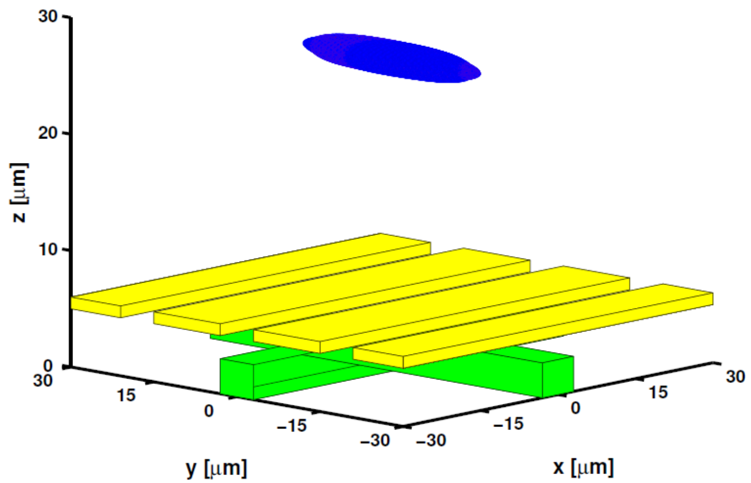
Towards an accelerometer on an atom chip

Geometric design



Equipotential simulation

$\vec{a}$



$|a>$ $|b>$ $P_{mw} = 0\ mW$

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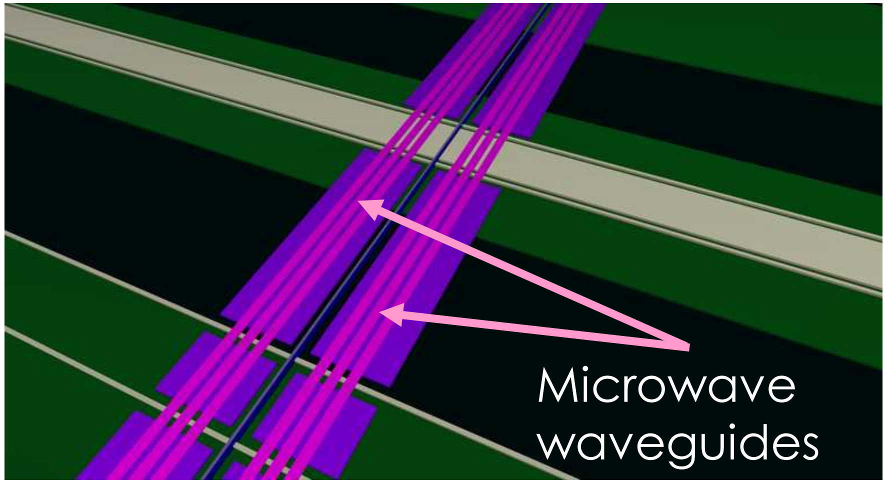
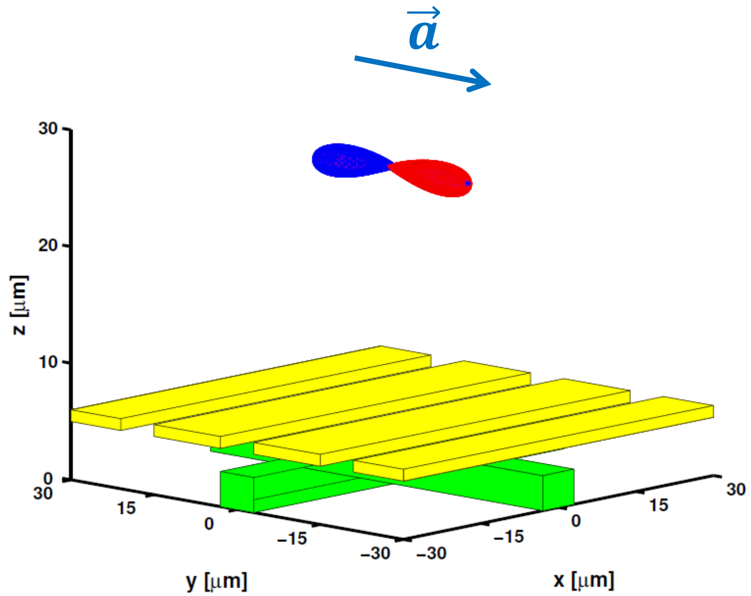
Towards an accelerometer on an atom chip

Geometric design



Equipotential simulation



$|a>$ $|b>$ $P_{mw} = 50\ mW$

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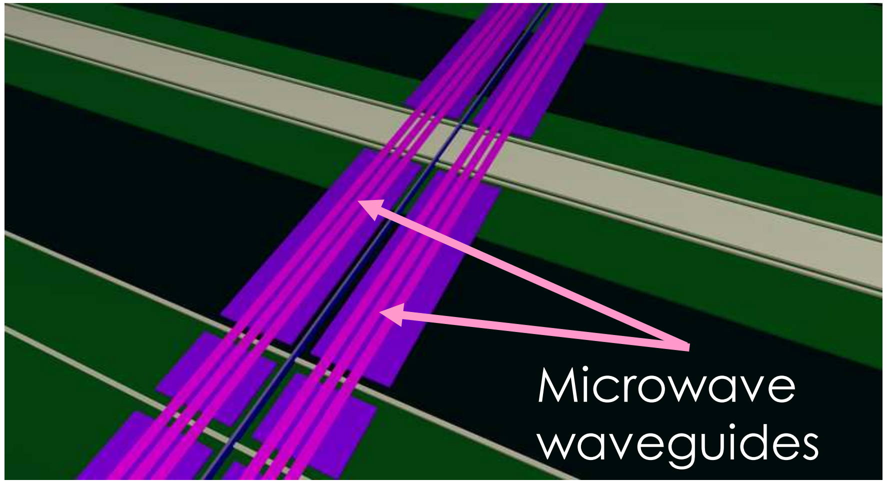
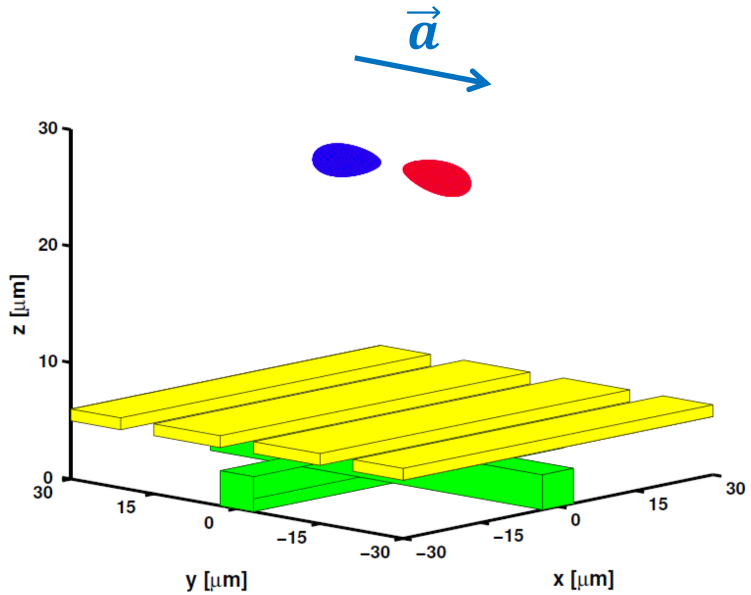
Towards an accelerometer on an atom chip

Geometric design



Equipotential simulation



$|a>$ $|b>$ $P_{mw} = 60\ mW$

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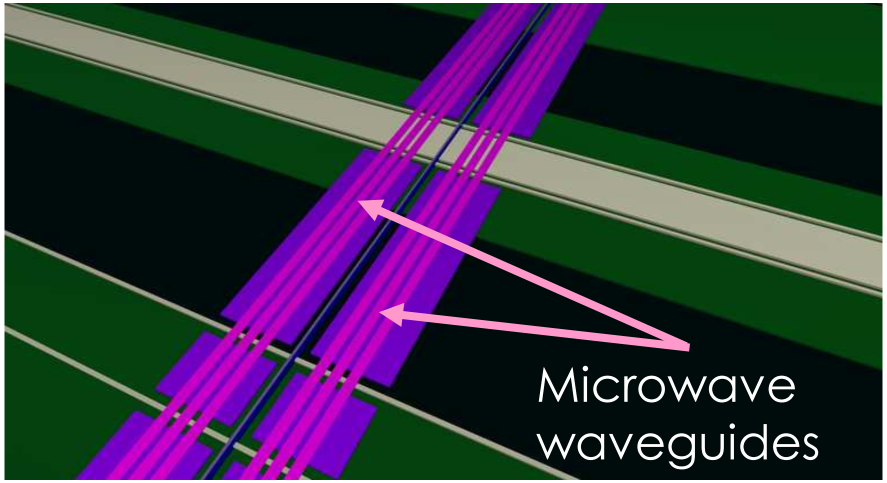
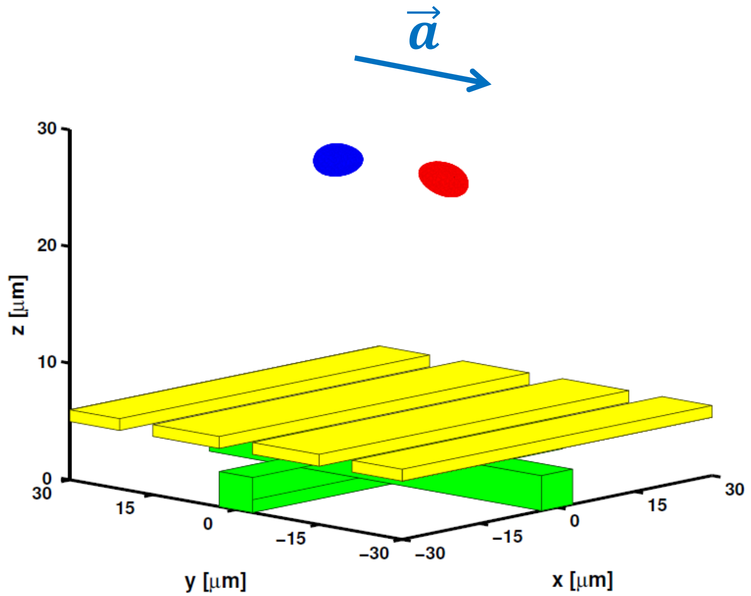
Towards an accelerometer on an atom chip

Geometric design



Equipotential simulation



$|a>$ $|b>$ $P_{mw} = 120\ mW$

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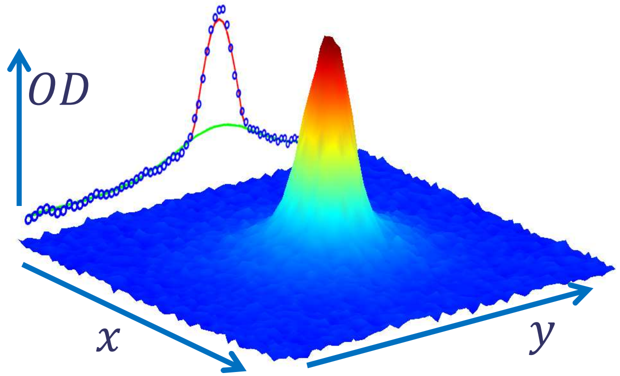
To BEC or not to BEC ?

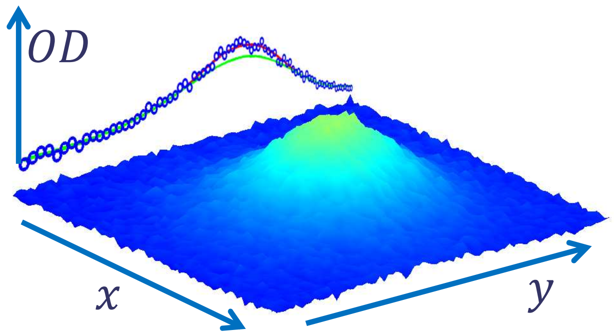
Bose Einstein Condensate

- Coherent atomic source
- Strong amplitude-phase couplings due to atom-atom interactions
  - Schumm *et al.*, Nature Physics (2005), 1, 57-62
  - Böhi *et al.*, Nature Physics (2009), 5, 592-597



Interferometry with thermal atoms

- Less interactions than BEC
- Already used for trapped atomic clocks
  - P. Treutlein *et al.*, PRL (2004), 92 ,203005
  - C. Deutsch *et al.*, PRL (2010), 105, 020401
- Atomic equivalent of « white light » interferometry
- A high level of symmetry is required



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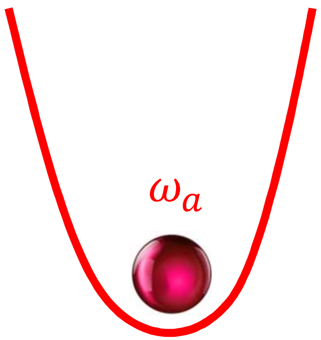
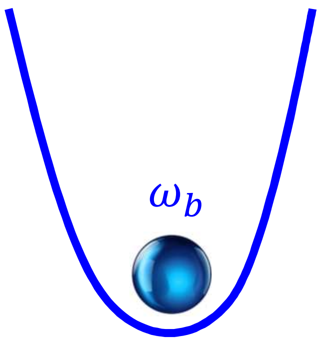
Importance of symmetry for thermal atoms

Symmetry-limited coherence time





$$\delta\omega = |\omega_a - \omega_b|$$

$$\delta\omega \ll \omega_a \sim \omega_b \sim \omega_m$$

$$\hbar\omega_m \ll k_B T$$

T : temperature

$$t_c = \frac{\omega_m}{\delta\omega}\frac{\hbar}{k_B T}$$

Simulation of the potentials :

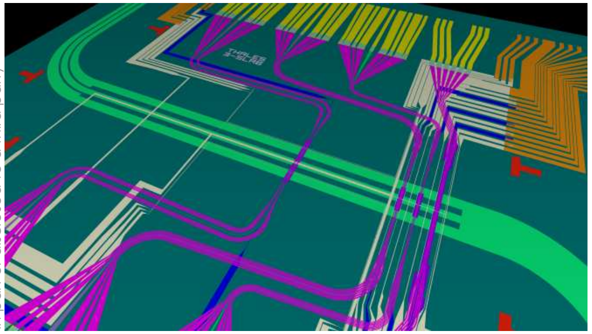
$$\frac{\delta\omega}{\omega_m} = 0.03\ \% \qquad \text{and} \qquad T = 370\ nK$$

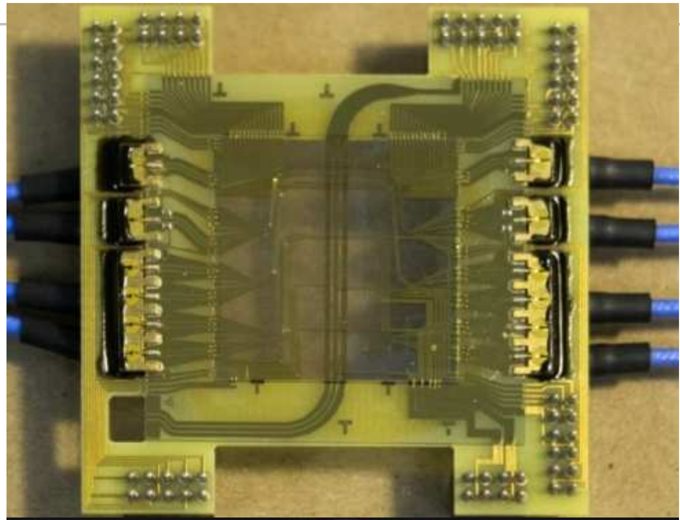
Expected coherence time :

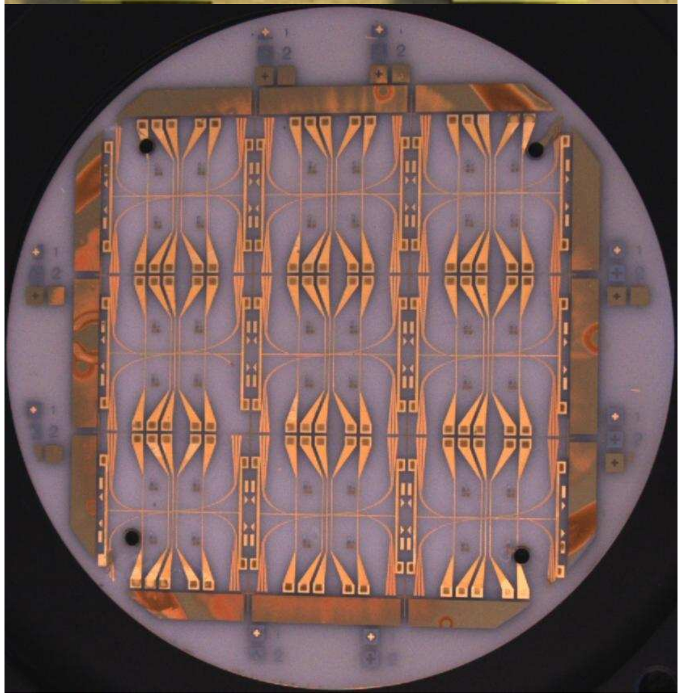
$$t_c = 60\ ms$$

M. Ammar, M. Dupont-Nivet et al., PRA, 2015, 91, 053623

Next step – atomic interferometer with spatial splitting

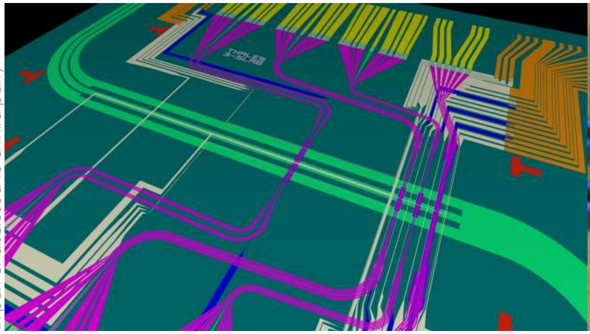


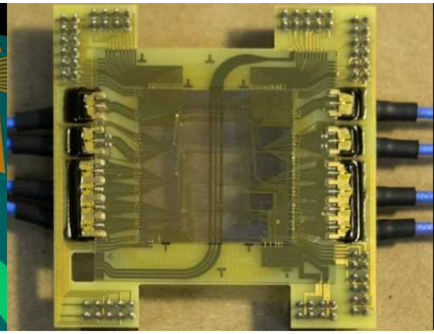


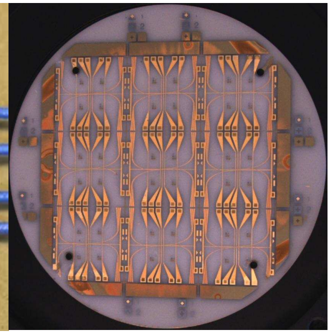


Atom chips (III-V Lab, TRT)

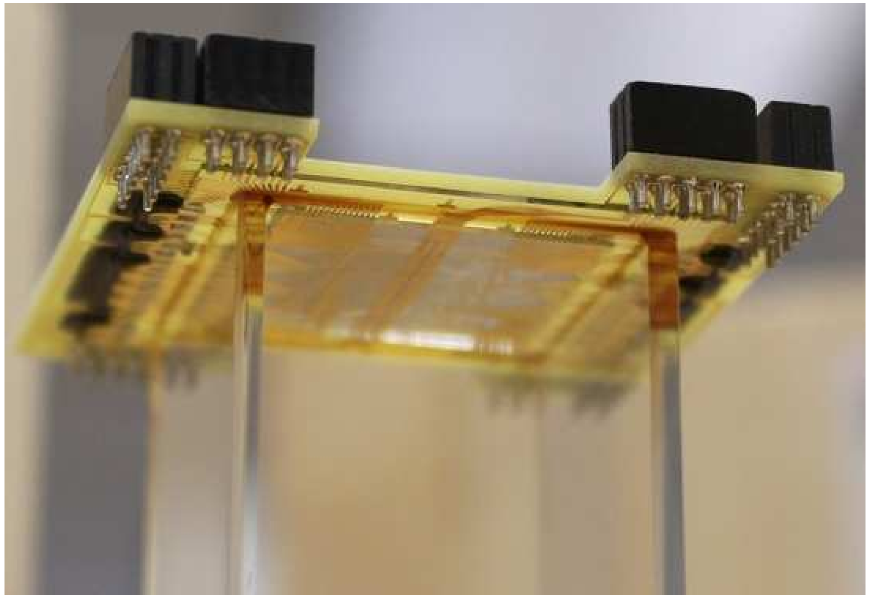
Next step – atomic interferometer with spatial splitting







- Atom chips (III-V Lab, TRT)
- Gluing on a vacuum chamber



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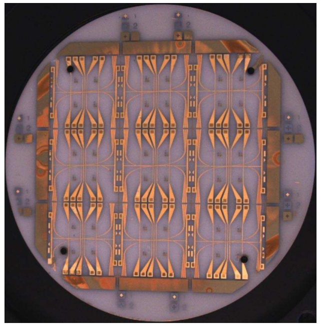
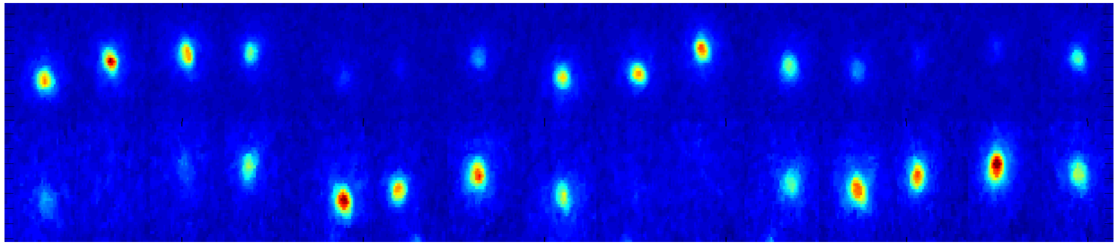
Conclusions

Design of a trapped atomic accelerometer

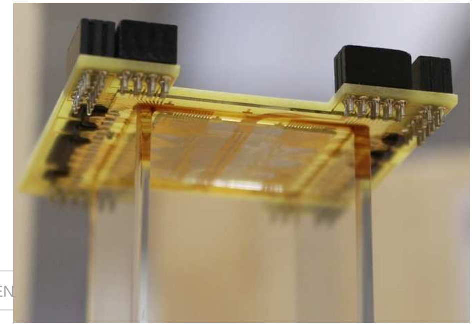


Progress in the realization of the accelerometer (Astrid OnAcis, coll. SYRTE, TAV)

- Ramsey sequence with high coherence time



- Building of a new experiment for the accelerometer in progress



Merci !

ONACIS (Astrid)
On a chip inertial sensors (2014-2017)

CATS (ANR)
Integrated atomic sensors on an atom chips
(2009-2014)

Former members :
- S. Schwartz
- M. Ammar
- L. Huet
- T. Laudat
- M. Casiulis
- R. Demur
- C. Guerlin
- J.-P. Pocholle

GTM :
- M. Carbonnelle
- G. Lehoucq

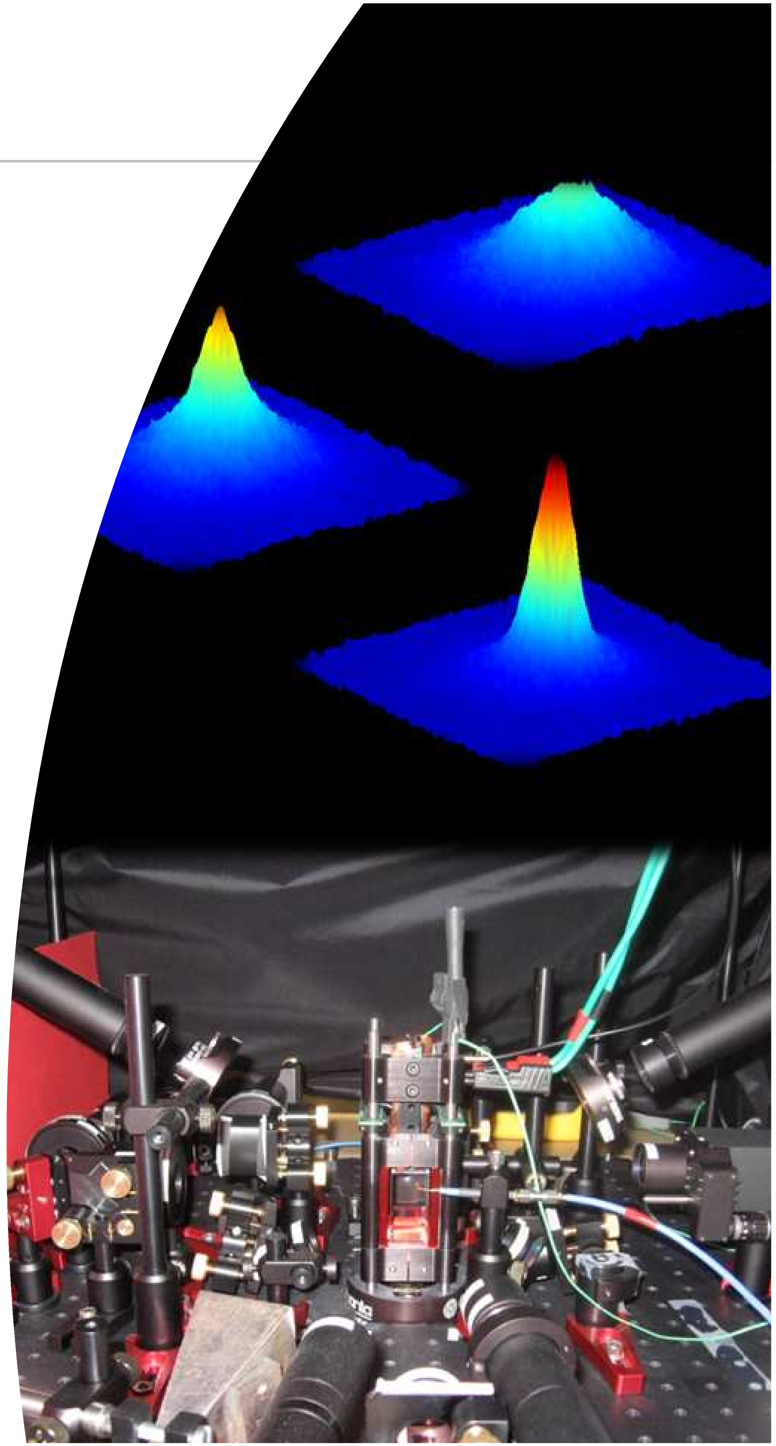
Syrte :
- C. Garrido-Alzar
- P. Rosenbusch

III-V Lab
- O. Patard
- R. Aubry
- S. Piotrowicz
- N. Sarazin
- E. Morvan
- S. Delage

LCFIO :
- C. Westbrook
- I. Bouchoule

LKB :
- J. Estève
- J. Reichel

DGA - MRIS :
- Ph. Adam



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