- Organization
- General objectives
- A variety of platforms
- Highlights

Office members of the Quantum Sensors and Metrology Area

Quantum sensors and Metrology	
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Number of groups involved : 32

Do not hesitate to contact us
if you have any question related to the calls for projects, the evaluation …

Objectives of the Quantum Sensors and Metrology area

Scope of the area

- Study quantum properties of matter and light to realize sensors
- Measure physical quantities to probe the environment
- Realize standards for these measurements

How to ?

By exploiting the principles of quantum mechanics

Central to our field is the quantum superposition, the question of the coherence and the use of non classical states and entanglement as a resource

Goals :
Beat the classical limits, reach the quantum limit, go beyond …
Quantum limit ? Could be defined as « a limit for noise levels set by quantum mechanics »

Technological aspects:
How to use these sensors? How to deploy them ? What level of integration can be reached ? For which applications?

A variety of platforms and status of advancement

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Different platforms

Atoms/molecules/artificial atoms/photons/optomechanical devices/mesoscopic systems
Different levels of maturity, different enabling technologies, different measurement principles

A few examples

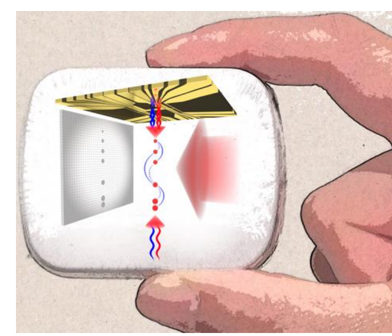
Atomic sensors:

MW clocks and inertial sensors in differential mode at the QPN
Optical clocks/inertial sensors still limited by « classical » noise (laser / vibration noise)
Demonstration of optical magnetometers below the SQL

Maturity: technology transfer

Deployment: underway

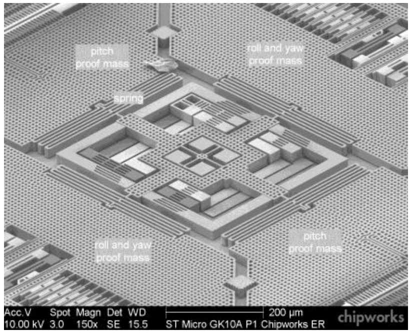
Integration:
still requires efforts

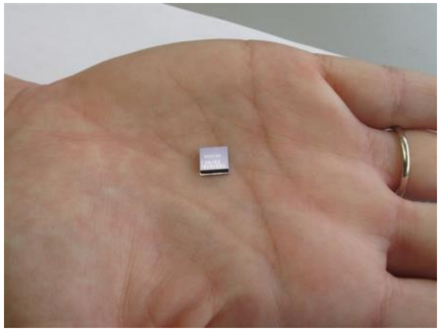


A few examples

Optomechanical sensors: SQL reached recently (Peterson et al., PRL 116, 063601 (2016))
With a very strong optomechanical coupling, fluctuations are imposed by the quantum fluctuations of light (rather than by thermal noise)
Key: very low T … but should be possible at high temperature if increasing the coupling.

Integration: OK (nano-objets). **Deployment**: targeted / projects ongoing



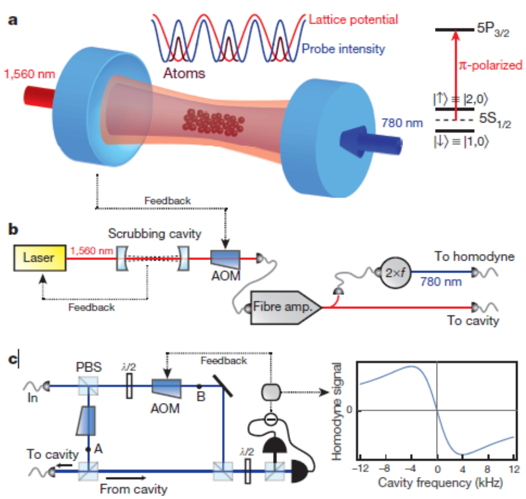


Artificial atoms: N/V centers in diamond, vacancies in SiC, dopants in crystals …
Temperature sensors, magnetometers, electrometers, strain sensors at the nanometer scale
Detection of spins by ESR with sensitivity limited by quantum fluctuations of the electromagnetic field instead of thermal or technical noise. Requires amplifiers at very low T.
Challenge: « high temperature » materials

Squeezing the collective spin of an ensemble of 5 10^5 atoms via an optical-cavity-based measurement

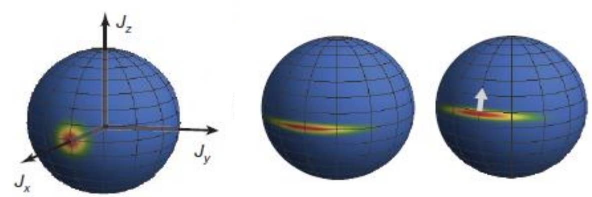
(Hosten et al., Nature (2016) « Measurement noise 100 times lower than the quantum-projection limit using entangled atoms »)

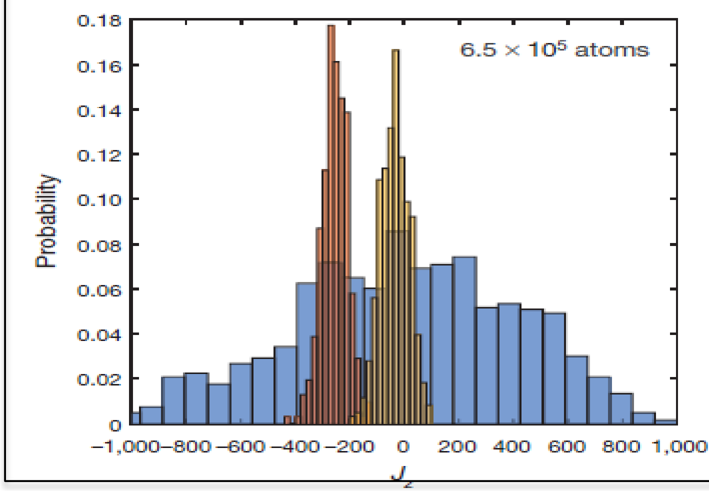
Preparation of a spin squeezed state through a collective population difference measurement



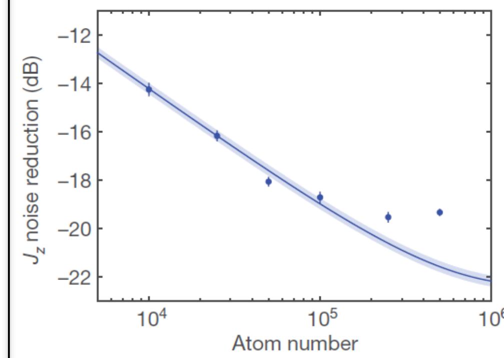
A Jz measurement projects the quantum state into one with a narrower distribution of Jz than a coherent spin state (CSS)

(CSS) (Spin squeezed state)





Demonstrated: 20 dB squeezing



Proof of principle experiment in clock configuration : 10.5 dB gain

Remains to be implemented in a state of the art interferometer (clock, inertial sensor)

Similar setups currently developed/under development on clocks at SYRTE

A sensitive electrometer based on a Ry atom in a Schrondiger-cat state

A. Facon, E.-K. Dietsche, D. Grosso, S. Haroche, J.-M. Raimond, M. Brune & S. Gleyzes, Nature 18335 (2016)

Measurement of the electric field using a large angular momentum (quantum number J≈25) with a single atom in a high energy Ry state

Atoms prepared in |J,J>

Standard Ramsey interferometer

$$\phi = (\omega(F) - \omega_{\rm rf})\tau$$

Probability to find the atoms in |J,J>

$$P(\varphi_{\rm rf}) = |\langle\theta, \varphi_{\rm rf}|\theta, \phi\rangle|^2 = \exp(-J\sin^2\theta(\phi - \varphi_{\rm rf})^2/2)$$

$$\langle J, J|\psi_f\rangle = |\langle J, J|\psi_f\rangle| e^{-i\Phi} \qquad \Phi = J\left[\phi - \varphi_{\rm rf} - 2\arctan\left[\cos\theta\tan\left(\frac{\phi - \varphi_{\rm rf}}{2}\right)\right]\right]$$

Add MW pulses, coupling to reference state

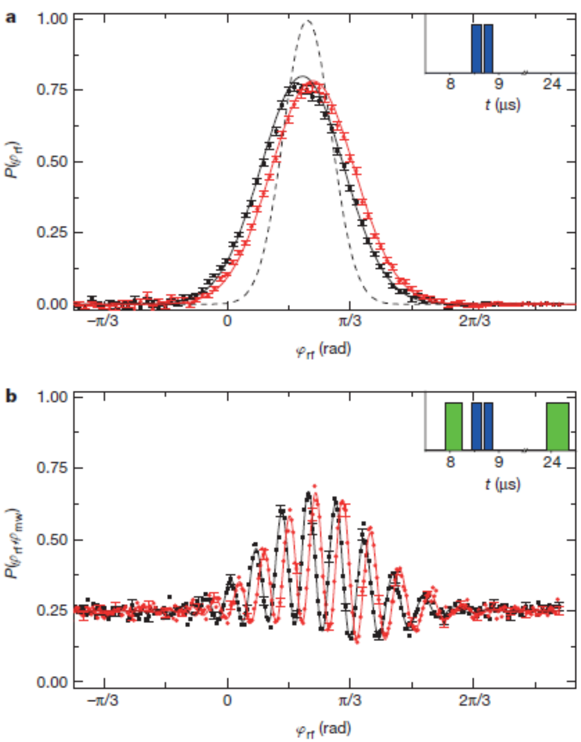
(|J,J>+|R>)/$\sqrt{2}$

Make them interfere

Probability to find the atoms in |J,J>

$$P(\varphi_{\rm rf}, \varphi_{\rm mw}) = \frac{1}{4} + \frac{1}{4}P(\varphi_{\rm rf}) + \frac{1}{2}\sqrt{P(\varphi_{\rm rf})}\,\cos(\Phi - \varphi_{\rm mw})$$

RF pulses at $\omega_{\rm rf}$



$$\sigma^1_{F,\rm SQL} = \frac{1}{\tau\sqrt{2J}}\left|\frac{\partial\omega}{\partial F}\right|^{-1}$$

1/J^1/2 scaling (CSS)

$$\sigma^{1,\rm th}_F = \frac{1}{\tau J(1-\cos\theta)}\left|\frac{\partial\omega}{\partial F}\right|^{-1}$$

1/J scaling

Finally, sensitivity outperforms the SQL by a factor of up to 2