Multi-photon Atom Interferometry via cavity-enhanced Bragg Diffraction

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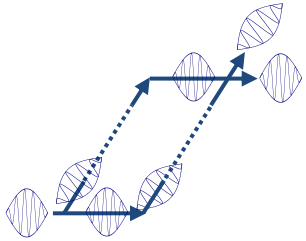
LSBB CNRS/UAR 3538



Increasing the sensitivity of atom interferometry:

why and how?

Why?

Further development of quantum technologies and fundamental physics experiments based on cold atoms.

Improving the sensitivity of atom interferometry for:

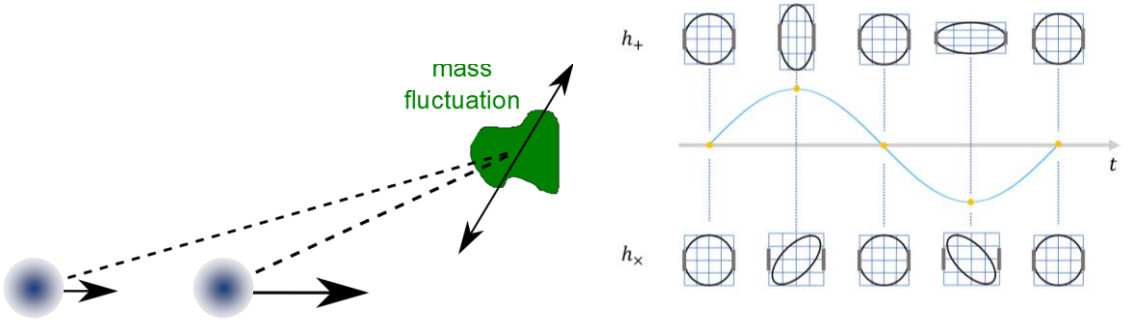
EP and general relatively tests

Tests of gravity and quantum gravity

Limits on Dark matter and energy theories

Observation of Lense-Thirring effect?

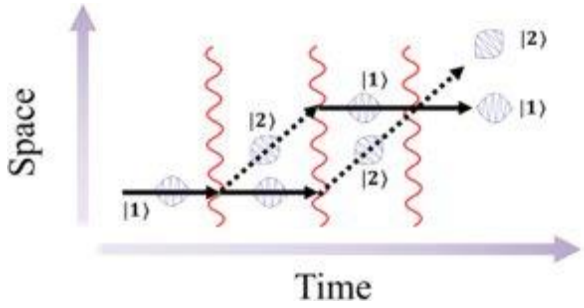
Prospective gravitation wave detectors



How?

Increase the space-time area of the interferometer with scalable techniques.

In essence, we increase the space time area of the interferometer (on the order of cm^2):



How to improve the scale factor? T or momentum.

More generally:

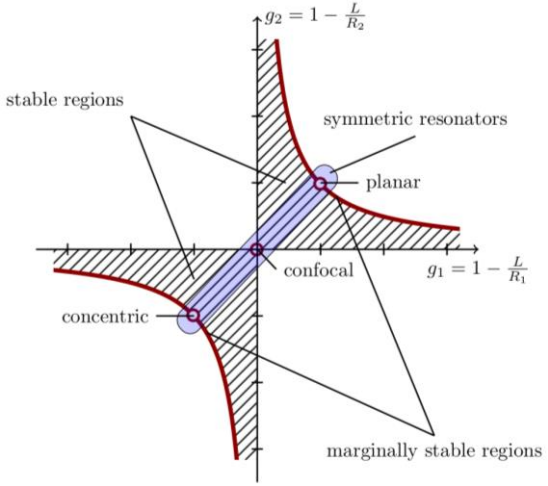
Sensitivity	Noise	Systematics
Large momentum transfer atom optics	Spin squeezing	Multiple atomic isotopes / species
Ultracold samples / continuous cooling	Spin entanglement	Measurement correlation
Bright atomic flux	Non-demolition	-

A *marginally stable* cavity for multi-photon interactions

Marginally stable? Do you mean semi-degenerate?

Why bother with this complication?

1. Optical gain can be significant – relaxes power requirements for Bragg diffraction

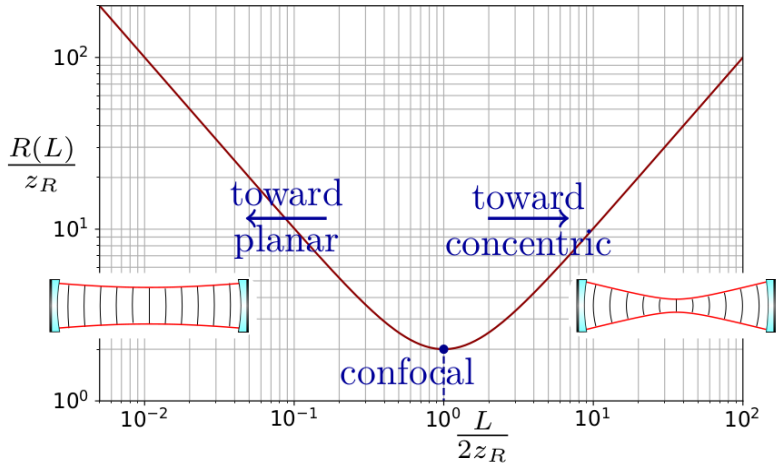


Stability diagram for a two curved mirrors optical cavity

2. Centimetric beam diameter for 1 m cavity

3. Propagates any beam shape that is injected, like a flat top!

arXiv: 2009.00941

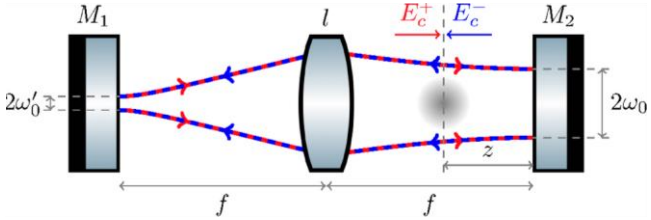


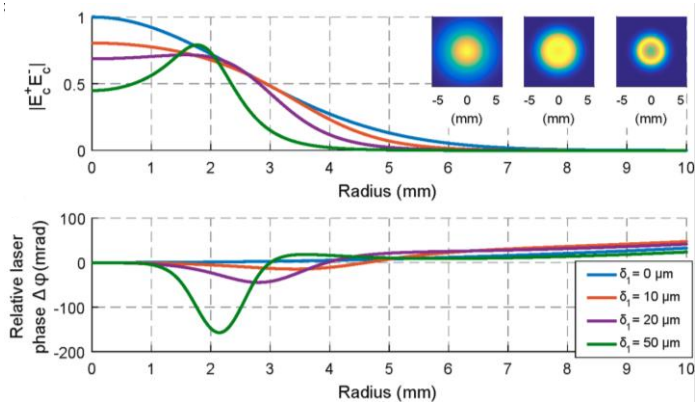
Radius of Curvature for a symmetric two mirror cavity as a function of distance between mirrors

...yes.

$$G = \frac{r_2(1-r_1^2)(1-r_L^2)}{[1-r_1 r_2(1-r_L^2)]^2}. \qquad \mathcal{F} = \frac{\pi\sqrt{r_1 r_2(1-r_L^2)}}{1-r_1 r_2(1-r_L^2)}.$$

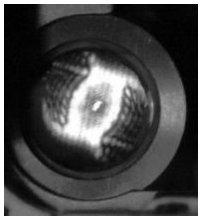
Theory (and hopes):
arXiv: 1701.01473

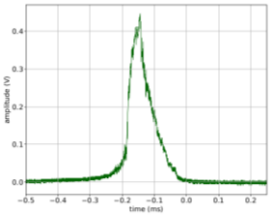




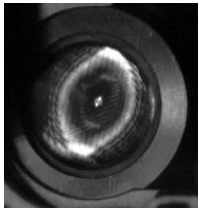
Experiment (in UHV):

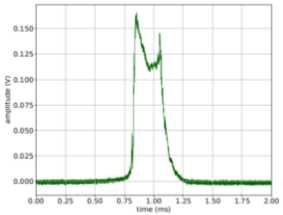
How it started:
Astigmatism, elliptical mode, due to lens and injected beam not centered



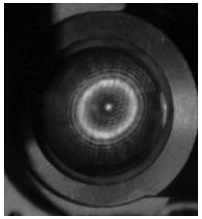


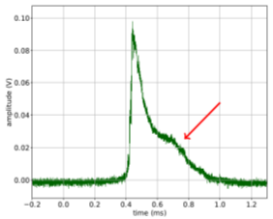
Reduced astigmatism, elliptical mode



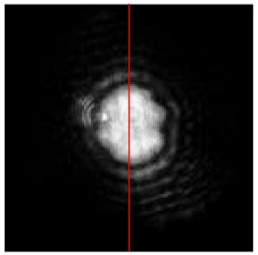


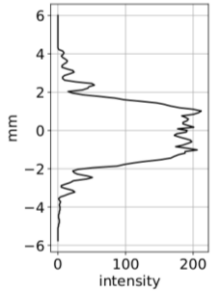
Ring mode, red arrow: clipping by piezo-stack @ diameter of 19 mm.



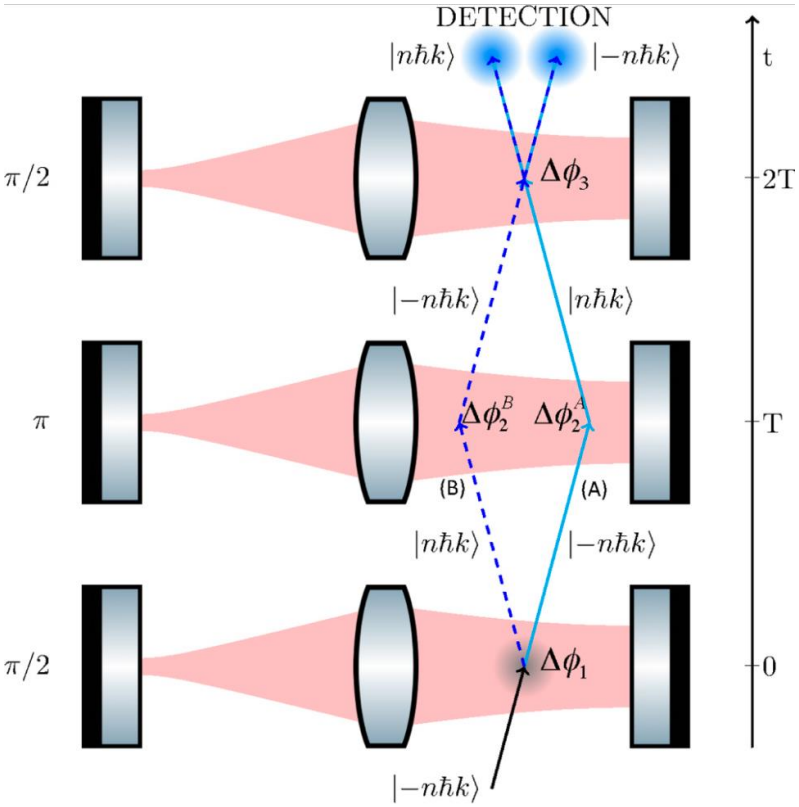


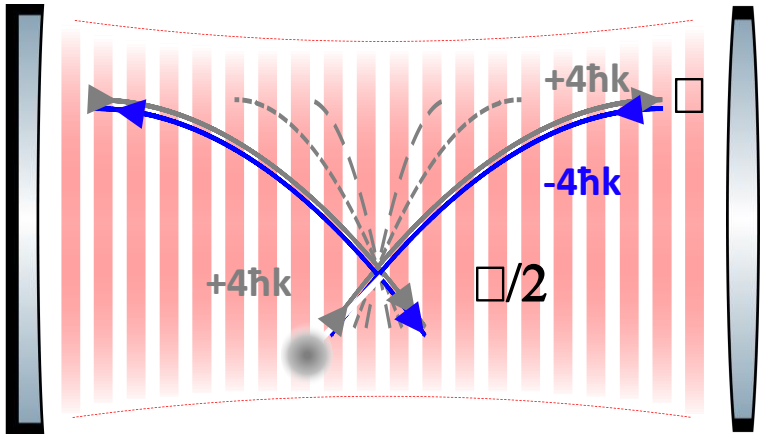
Eventually:
Resonant mode, ok alignment



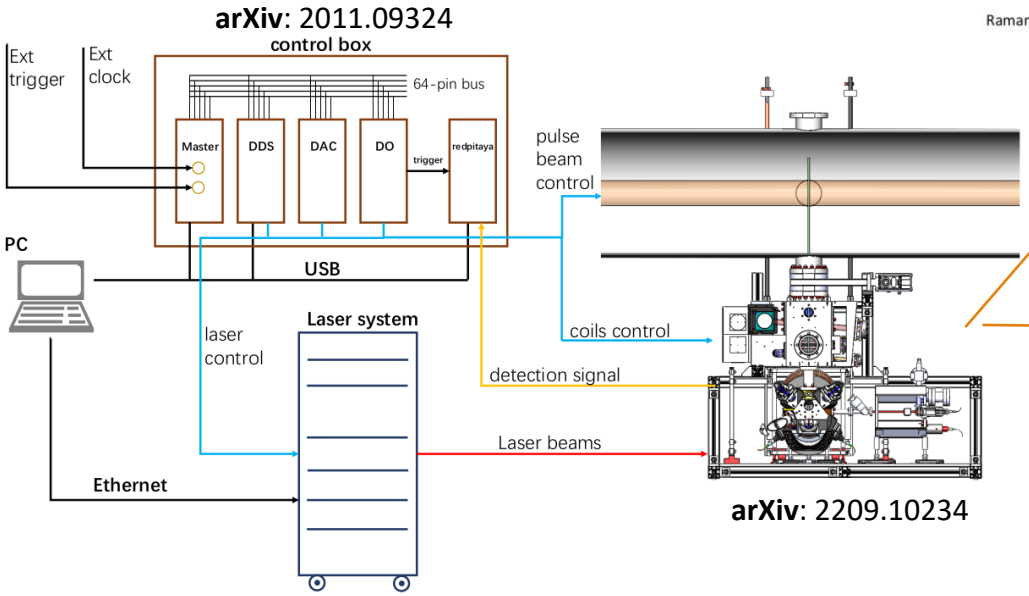


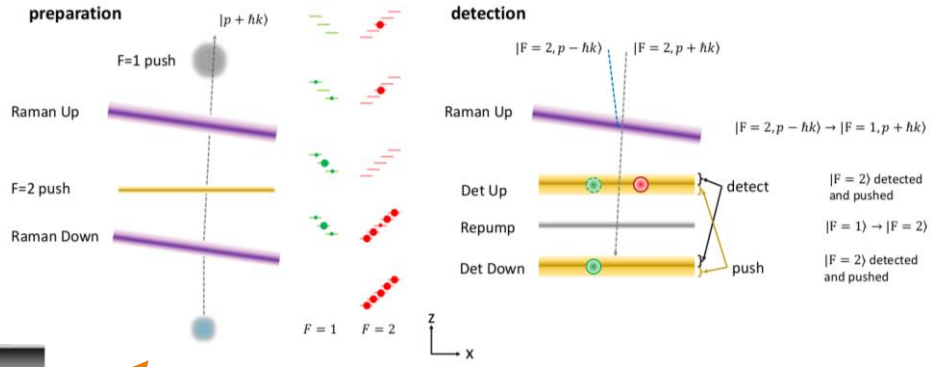
The hope:

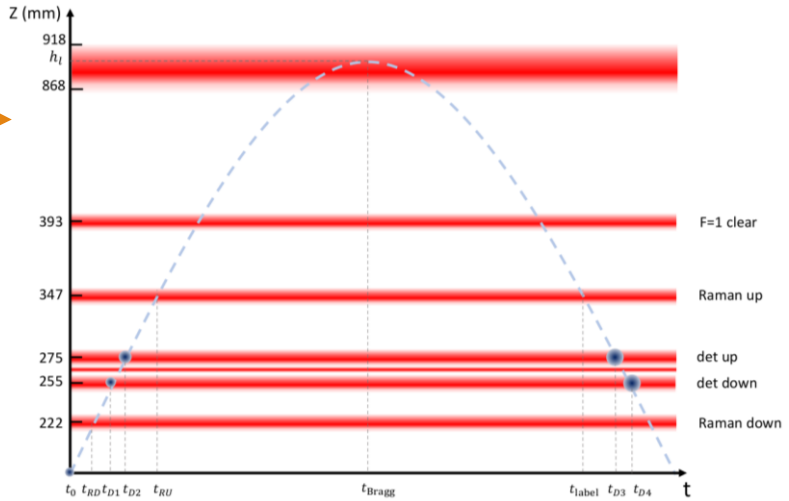

DETECTION
$|n\hbar k\rangle$
$|-n\hbar k\rangle$
t
$\pi/2$
$\Delta\phi_3$
2T
$|-n\hbar k\rangle$
$|n\hbar k\rangle$
π
$\Delta\phi_2^B$
$\Delta\phi_2^A$
T
(B)
(A)
$|n\hbar k\rangle$
$|-n\hbar k\rangle$
$\pi/2$
$\Delta\phi_1$
0
$|-n\hbar k\rangle$


+4ħk
-4ħk
+4ħk
□/2

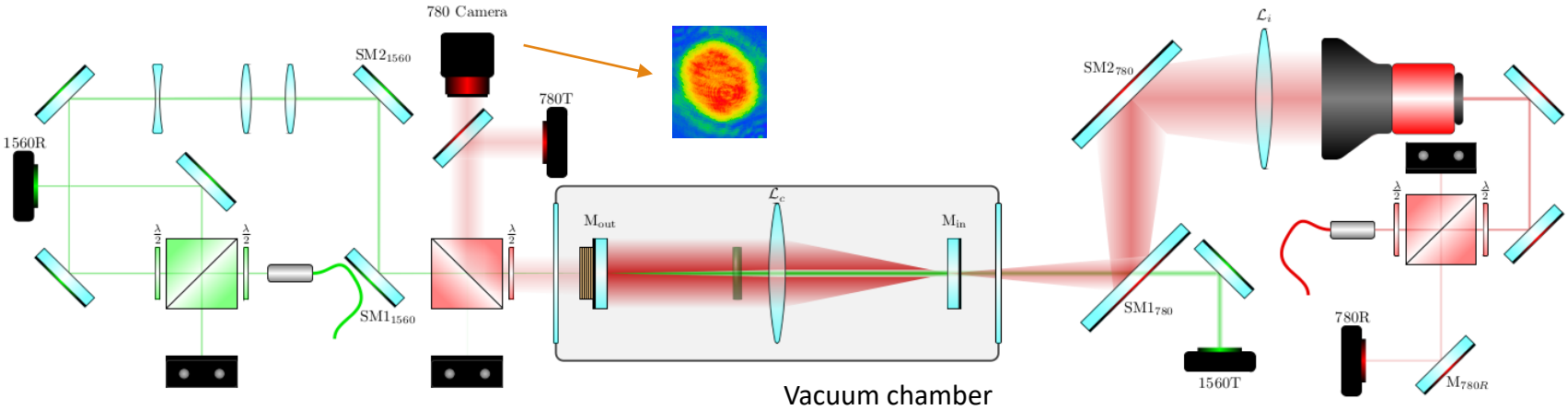
How does it work?





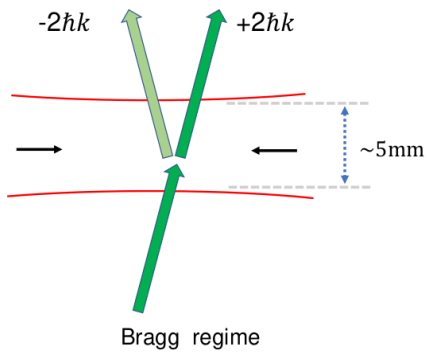


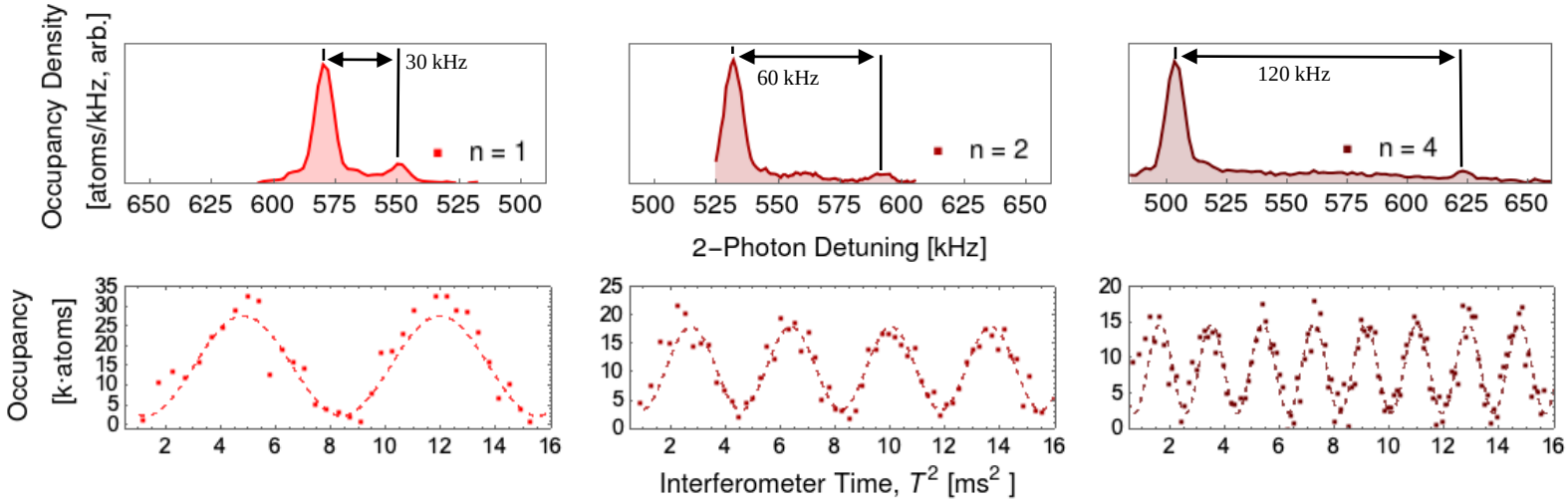
The cavity-enhanced Bragg diffraction bench



Diffraction and interference

arXiv: 2201.11693

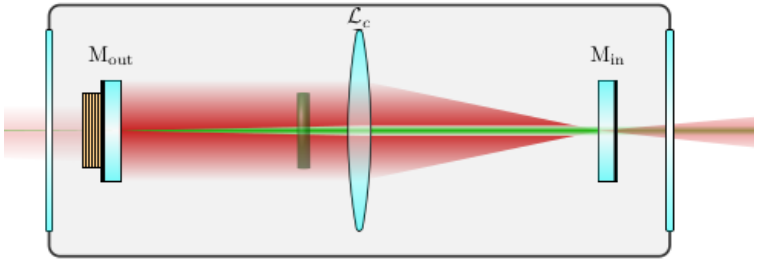




Demonstrating inertial sensitivity

We tried:

- Scanning the piezo (kind of worked)



We considered:

-An EOM for two frequency Bragg

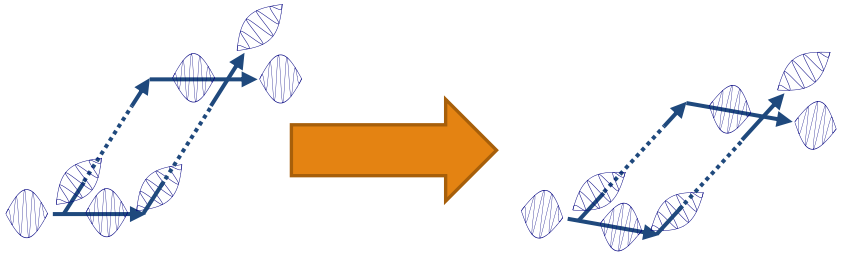
We ended up:

-Tilting the entire experiment

How?

The experiment rests on a multi-ton concrete block on compressed air active-vibration isolation...

Literally (small angle):



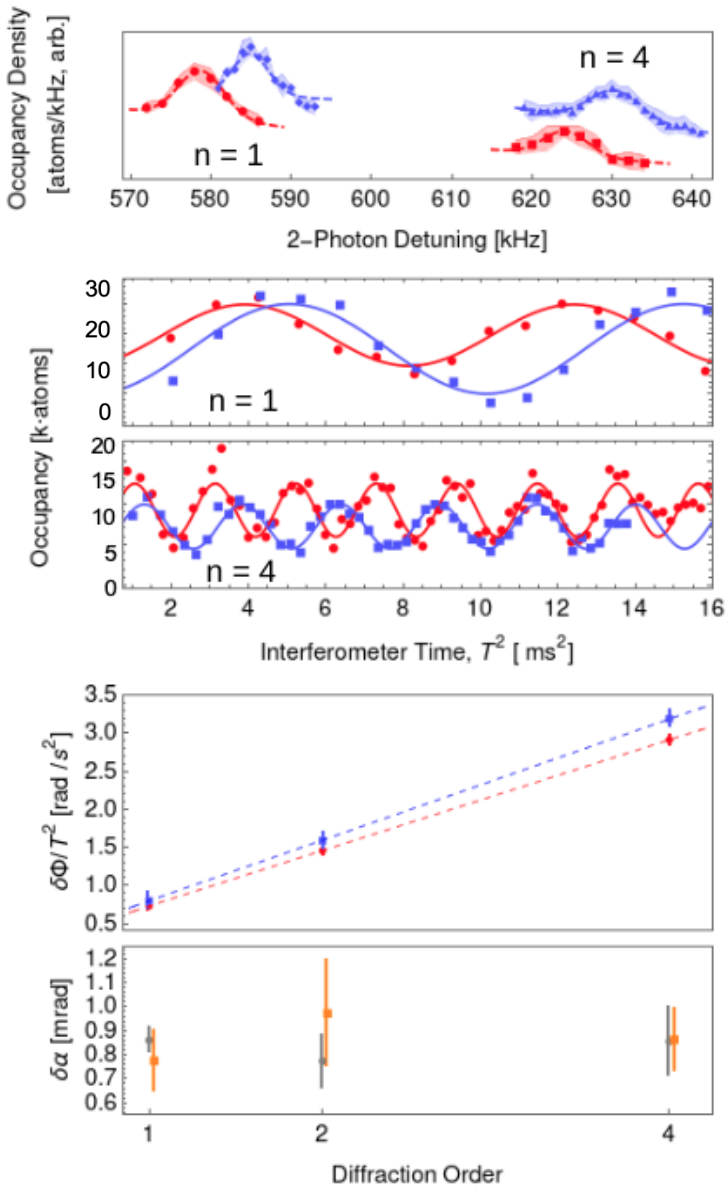
Tilt tests

I. Spectroscopic data

II. Interferometer data

III. Inclinometer data

<<All match>>

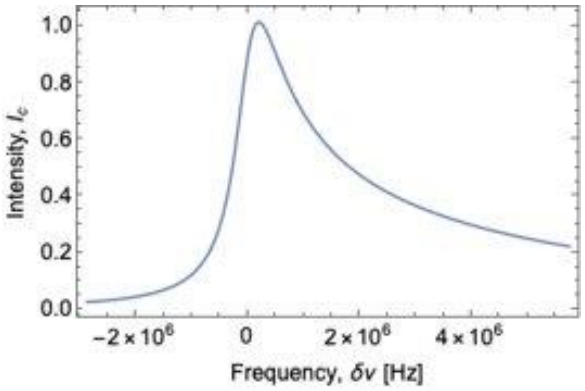


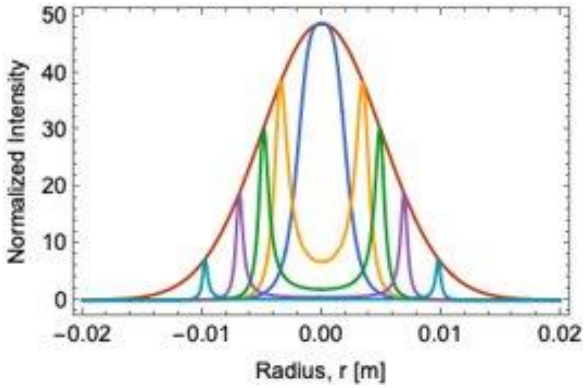
Spectroscopic shift matches interferometer cantilever effect across diffraction orders

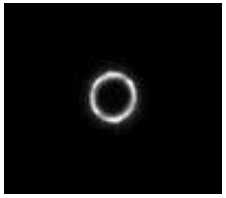
Comparing multiple beam sizes over multiple tilts, we find **no deviation** from the expected linear scale factor increase

A curious phenomena is observed

More application to atom interferometry via enhancing Bragg diffraction.







<u>This theoretical plot implies</u>:

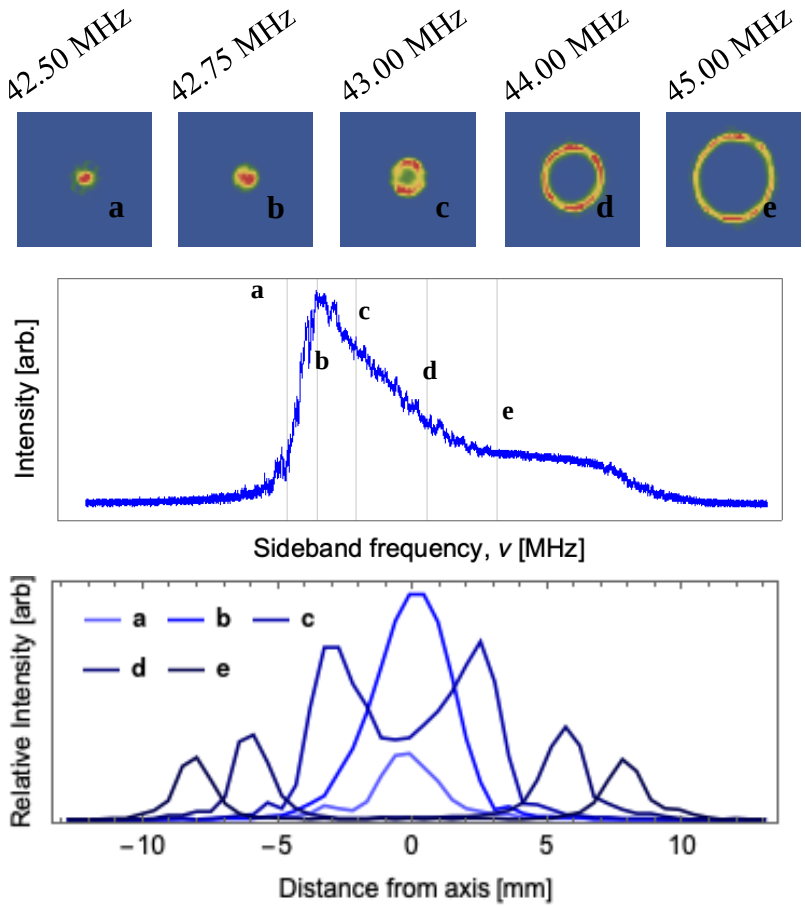
As we scan the laser frequency through the cavity resonance, we observe a *spatial variation* of the beam.

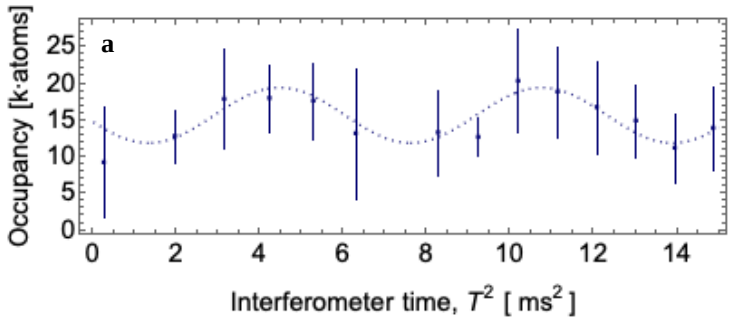
It is a ring mode, whose position of maximal intensity is controllable.

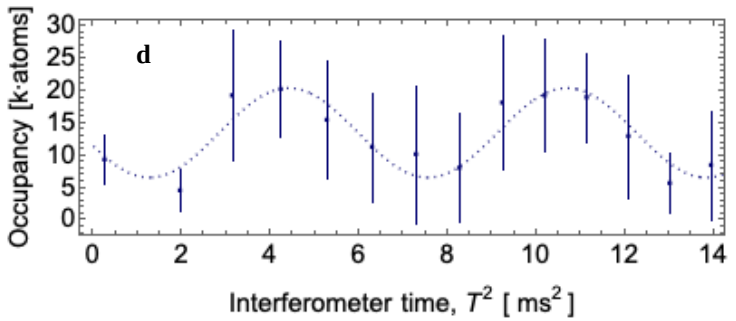
As it so happens, we observed this in the lab for some time...

Does it work for interferometry?

(...yes.)

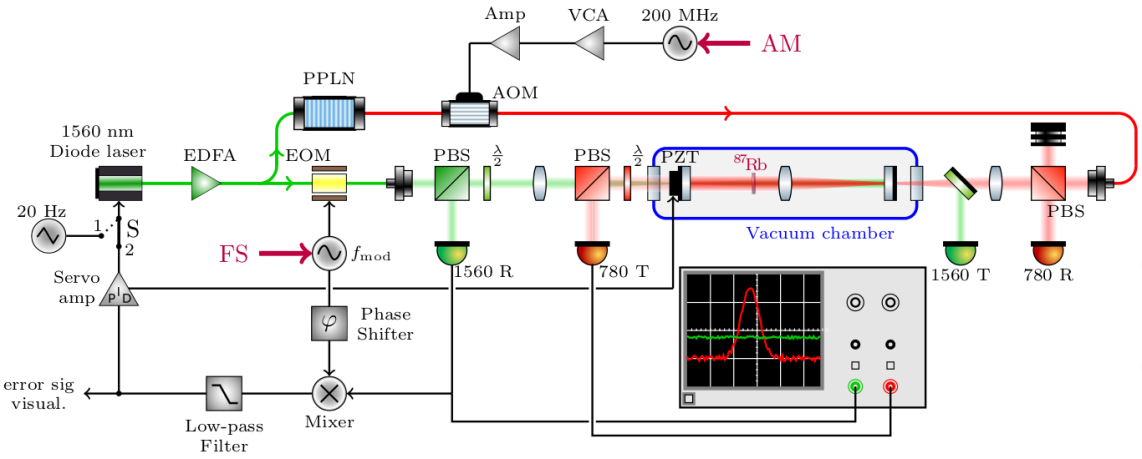


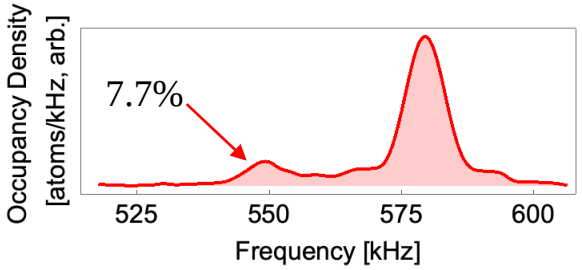


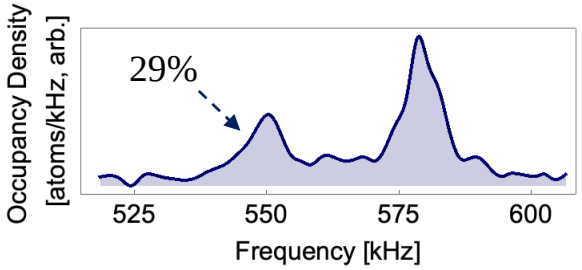


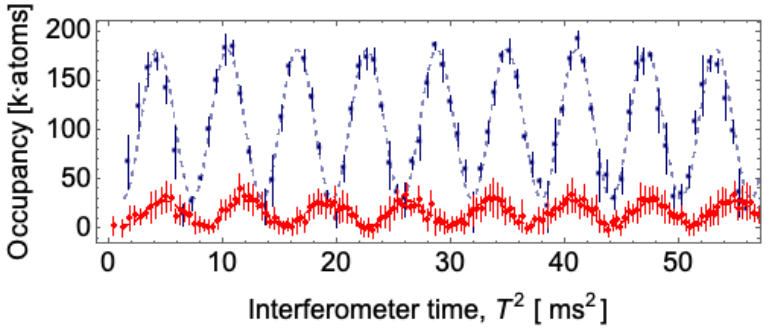
...but there's more!

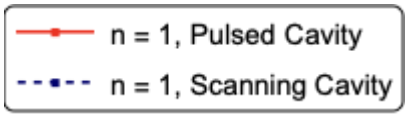
Scanned Cavity Interferometry











We apply:

- a linear frequency sweep
- a Gaussian amplitude modulation

We observe:

- a large increase in spatial selectivity, more atoms participate
- Unexpected coherence!

In summary

- Working toward LMT atom optics for µrad sensitivity in a horizontal configuration

- Used a marginally stable resonator for cavity-enhanced Bragg diffraction

- Multi-photon exchange and interference observed

- Applicability to inertial sensors demonstrated

- Construction of MIGA ongoing!

Message from the Director of LSBB

The LSBB is *open to collaborations* and to hosting any project that respects the low noise environment.

This includes seismic, chemical, electromagnetic, thermal, and radiative (pending the depth) studies.

Contact can be made via:

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Low Noise Inter-Disciplinary Underground Science & Technology