UNIVERSITÀ DEGLI STUDI FIRENZE

Atom interferometry with the ^{88}Sr optical clock transition

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- Experimental setup
- Experimental results
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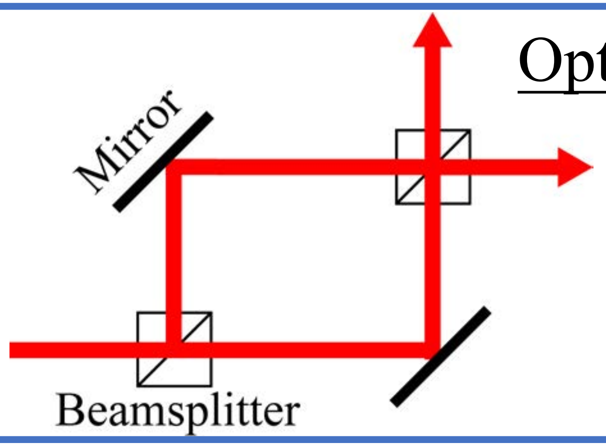
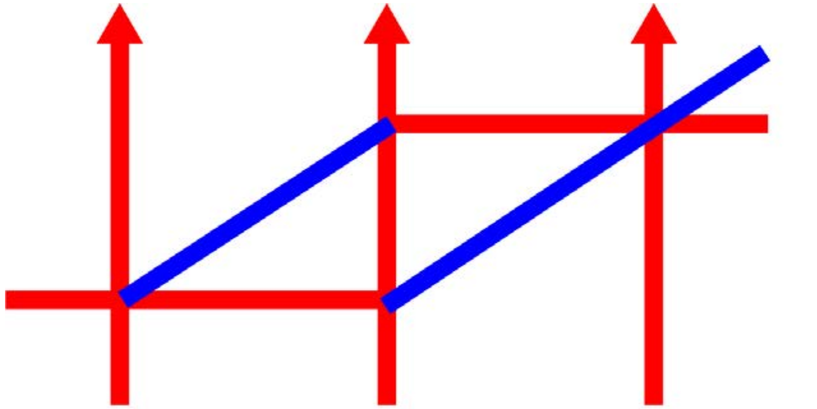
Atom interferometry

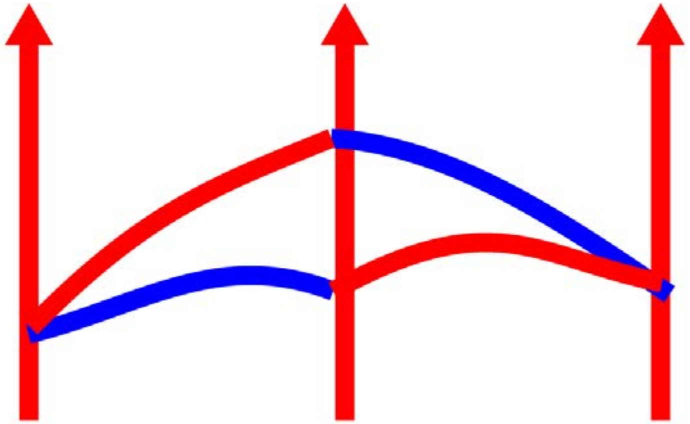


Optical interferometer (MZ)

Interference fringe

Atom interferometer (MZ)



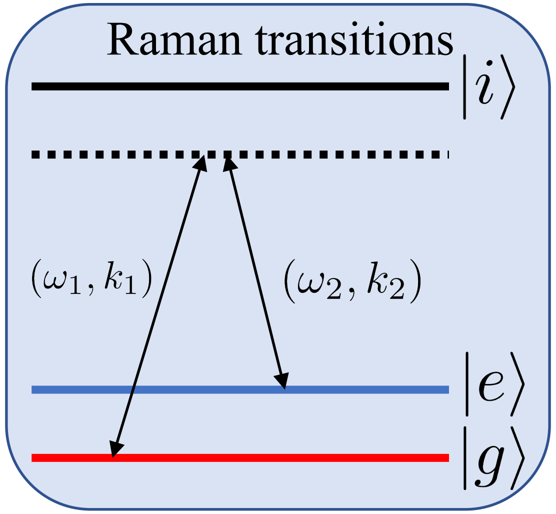


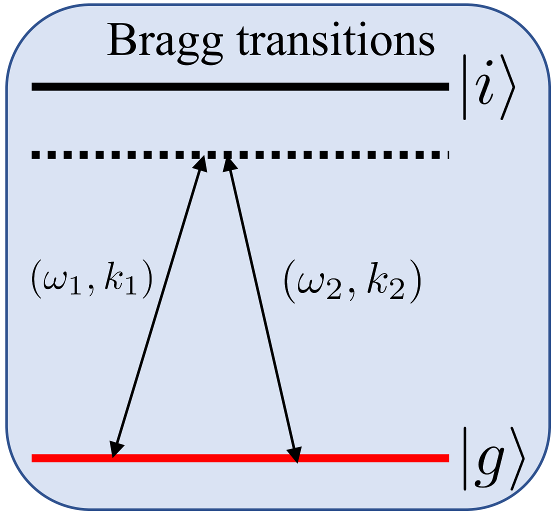
$$P = \cos(\Delta\Phi)$$

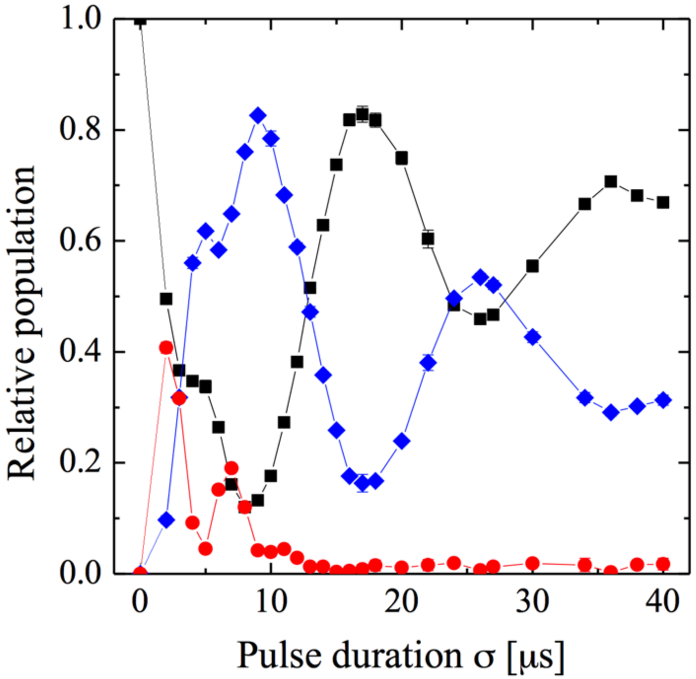
$$\Delta\Phi = (\alpha - g)kT^2 + (\phi_1 - 2\phi_2 + \phi_3)$$

Atomic beam splitter (multi-photon)

- Absorption a photon from one laser and stimulated emission to the counter-propagating beam
  - Rabi oscillations between 2 (or more) states
  - Different state has different momenta since photons carry momentum





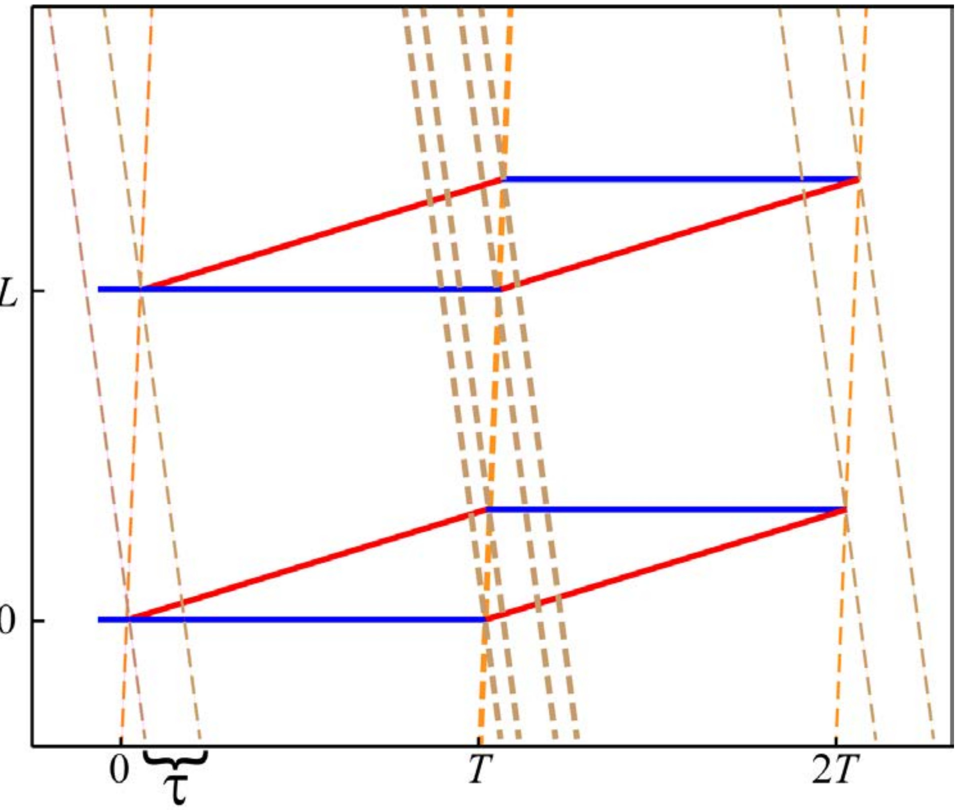


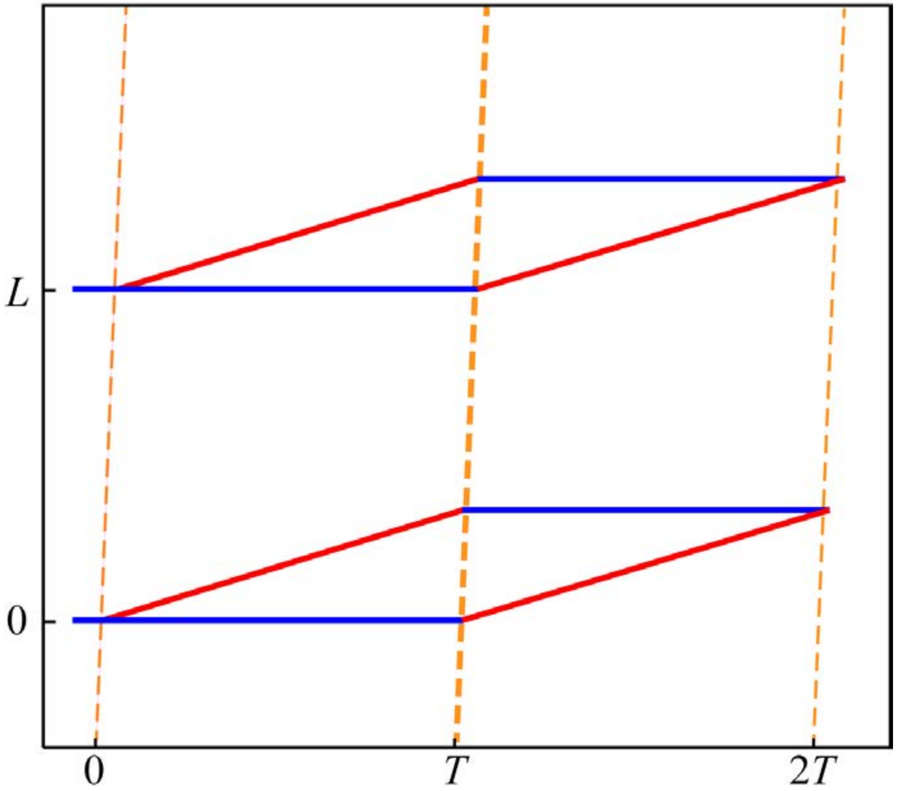
second order Bragg diffraction

$\Omega t = \pi/2$ ——– beamsplitter

$\Omega t = \pi$ ——– mirror

Multi-photon to single-photon interferometer





Main difference:

$$\Delta\Phi = kgT^2$$

$$\Delta\Phi = \frac{\omega_a}{c} gT^2$$

$$k \text{ vs } \frac{\omega_a}{c}$$

Phase error:

$$\delta\phi_L = \delta\omega\tau \sim \delta\omega L/c$$

GW:

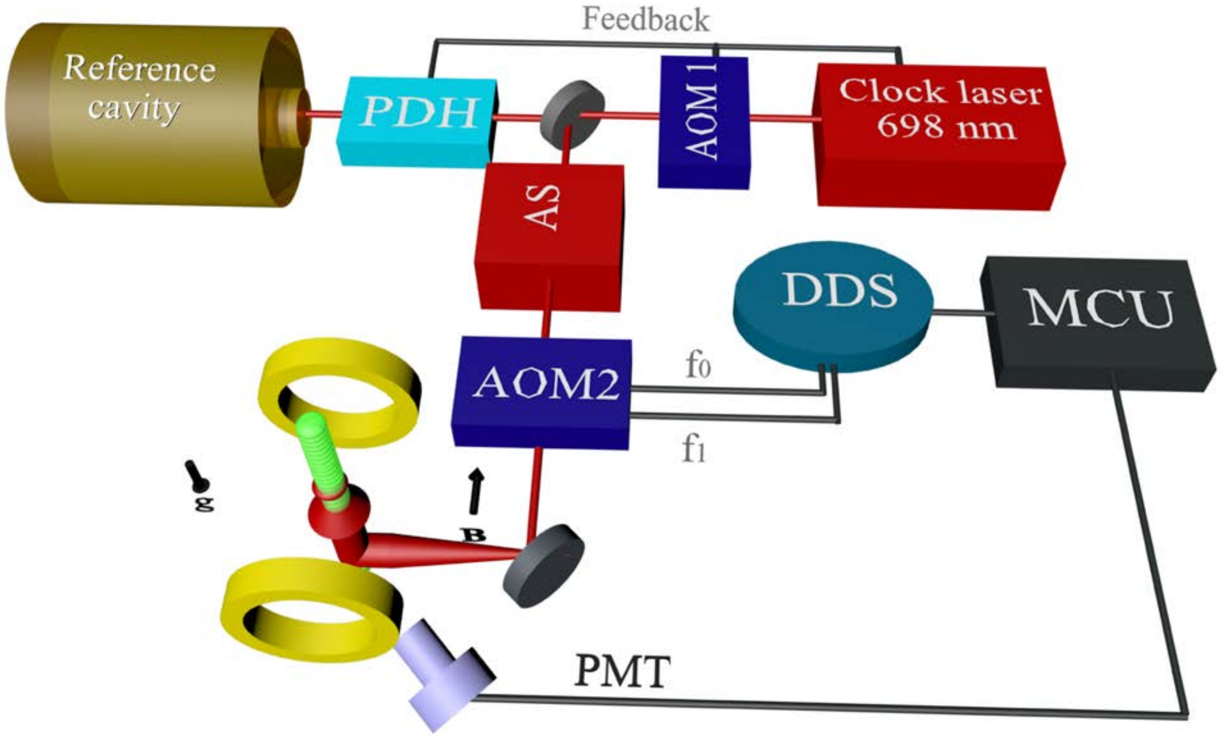
$$\Delta\Phi_{GW} \sim k\delta L \sim khL$$

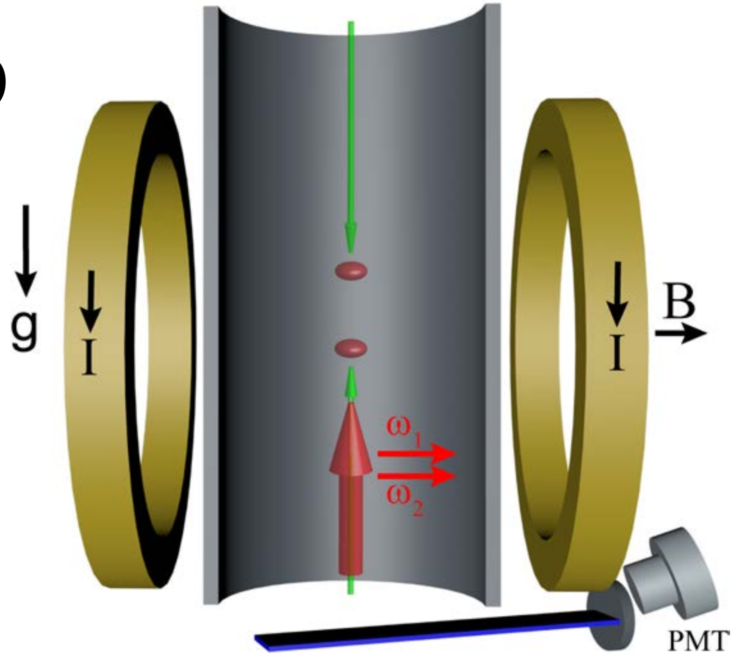
Requirement:

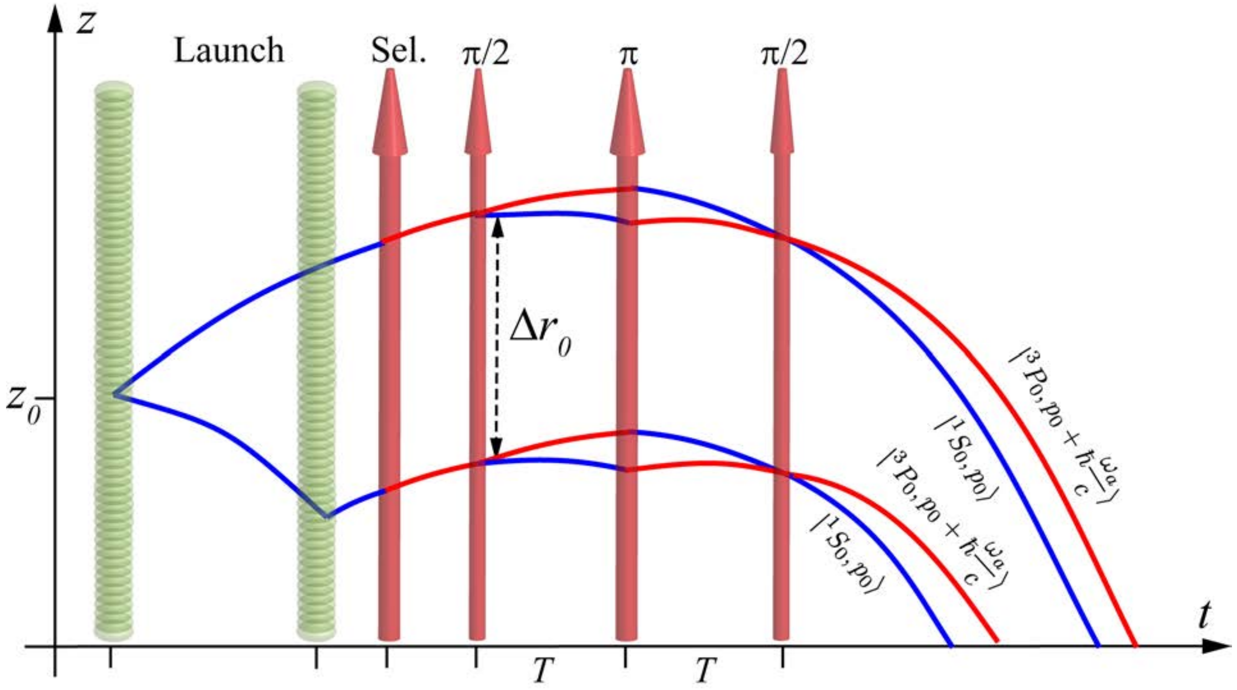
$$\frac{\delta\omega}{\omega} \ll h \sim 10^{-20}$$

N. Yu, and M. Tinto, Gen. Rel. Gravit. **43**, 1943 (2011)
P. W. Graham, J. M. Hogan, M. A. Kasevich, and S. Rajendran, Phys. Rev. Lett. **110**, 171102 (2013)

Experimental setup

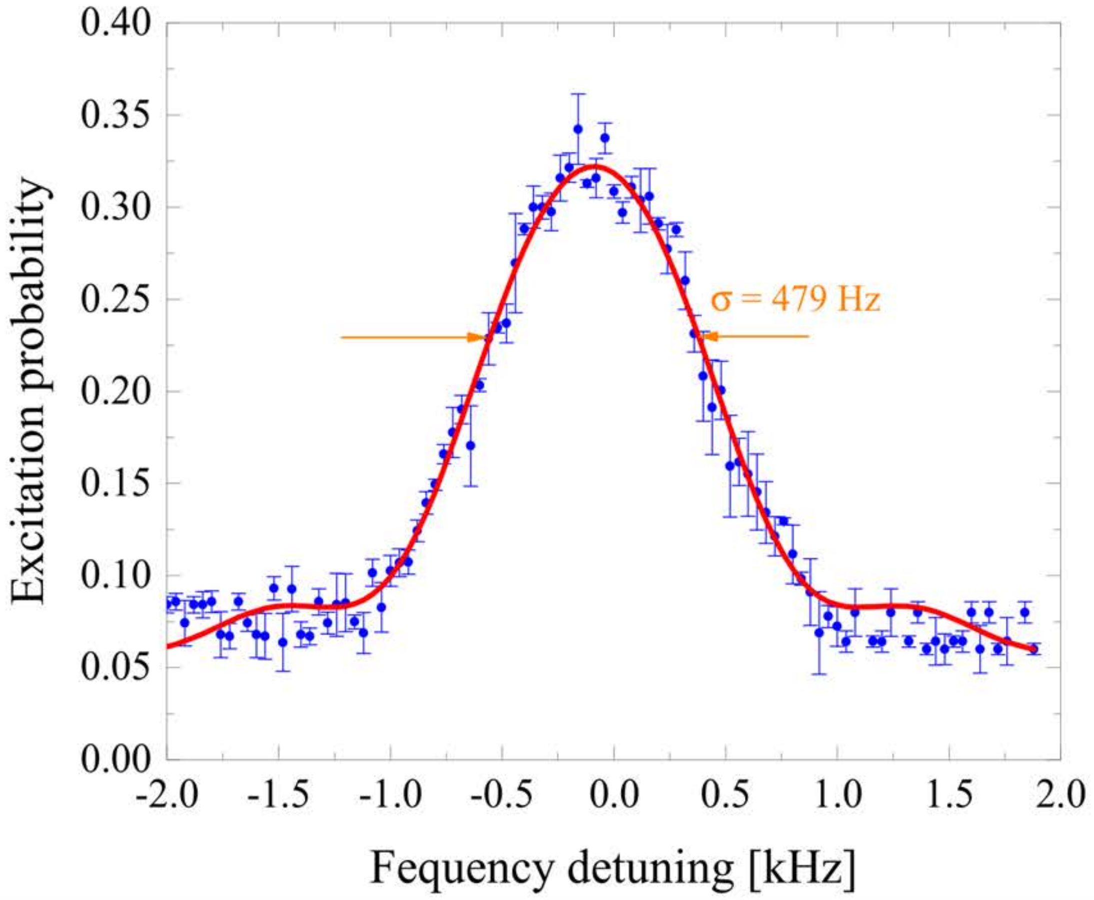


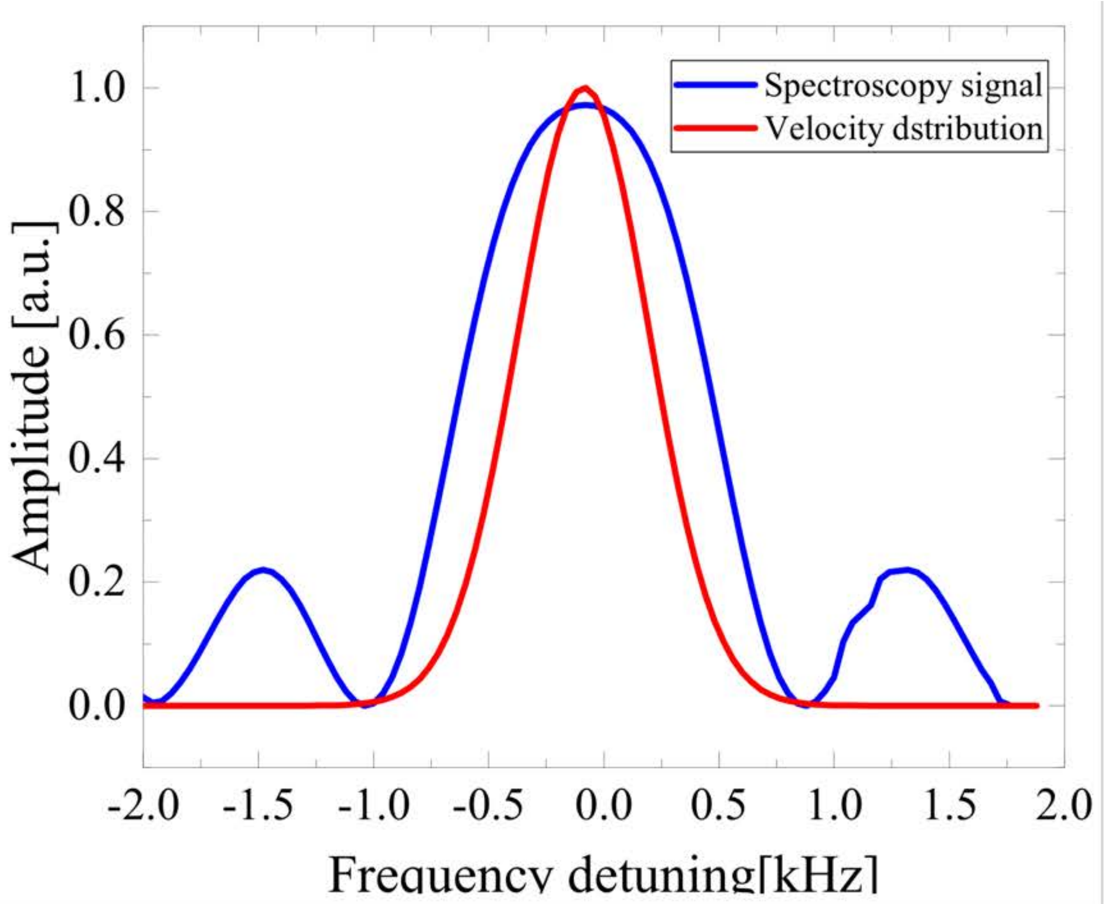




- Clock laser is locked to a high-finesse cavity (500, 000) via PDH technique.
- Power is amplified by amplifier setup (slave + tapered amplifier)
- Two clouds are developed by a double-launch technique

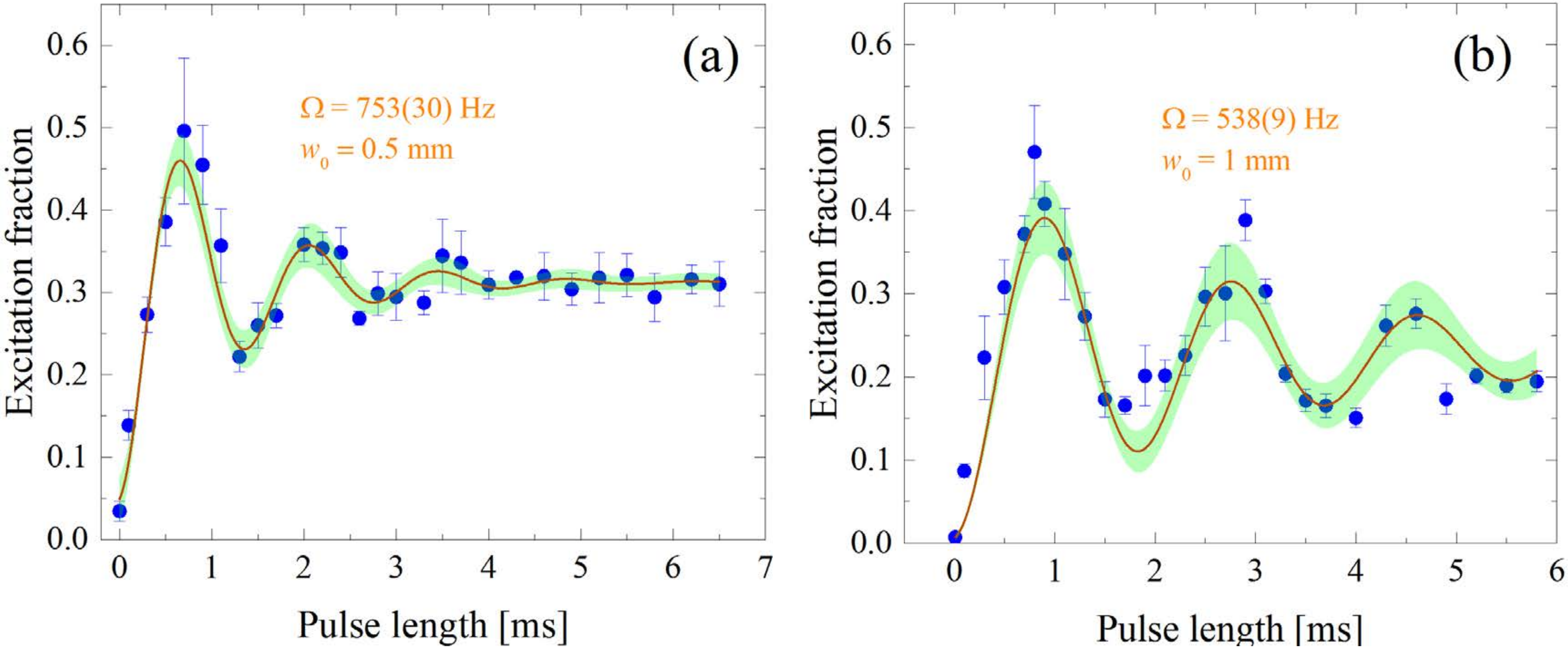
Momentum selection





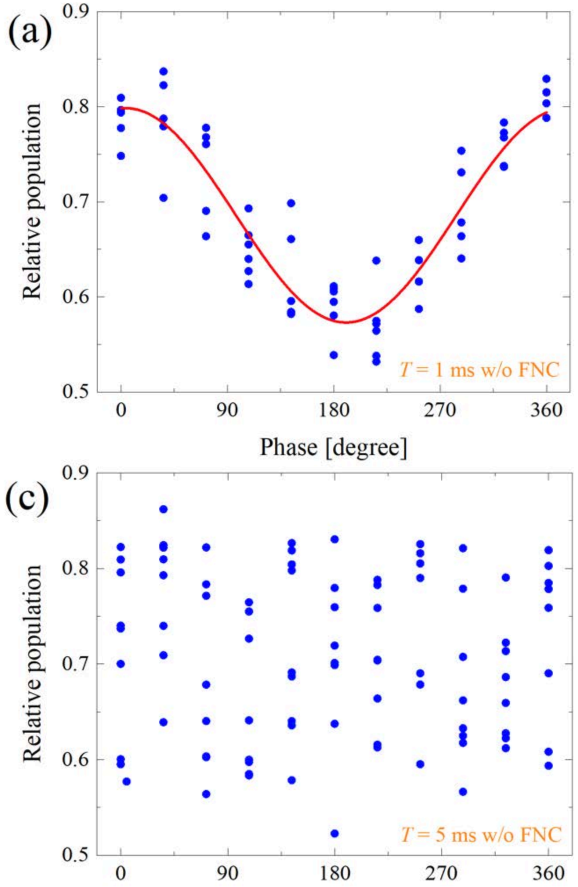
- Temperature of the selected cloud as cloud as ~ 450 pK

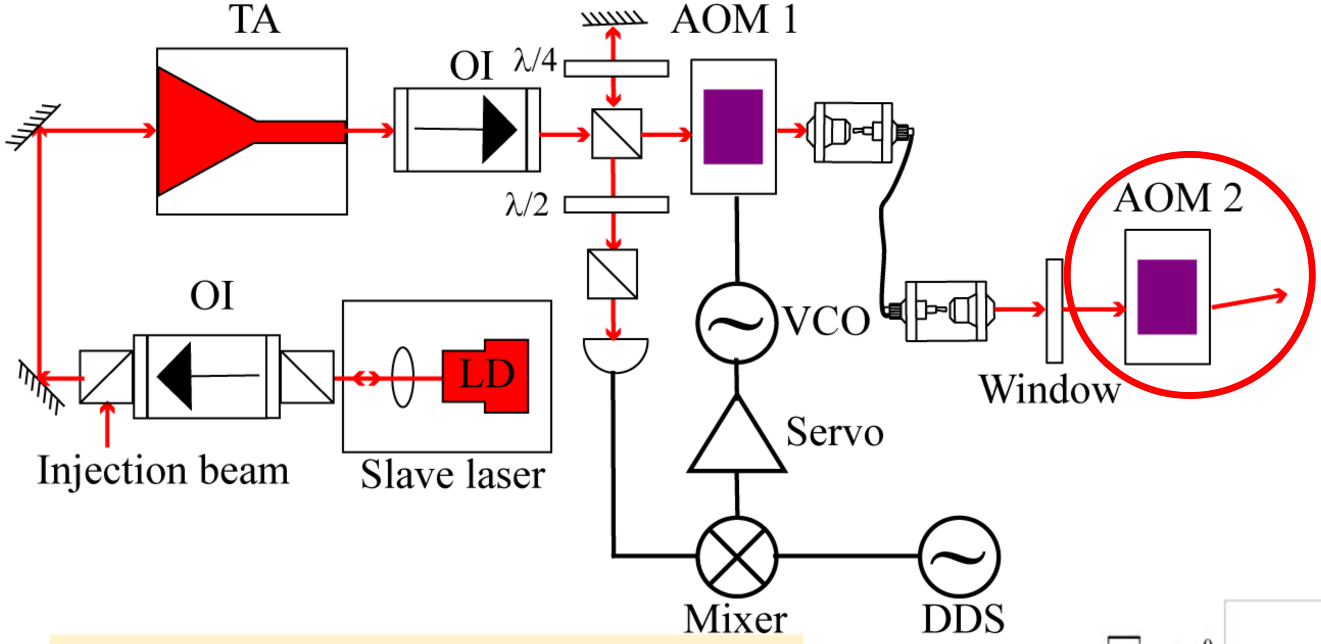
Rabi oscillations



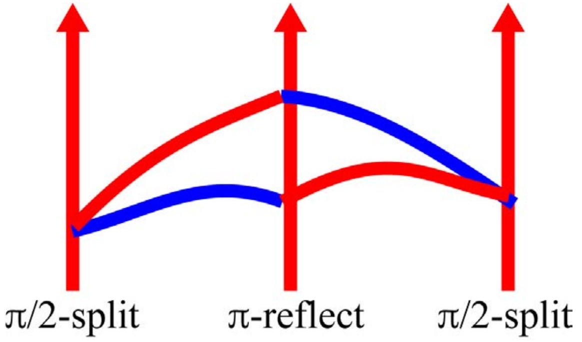
- We observed the highest Rabi frequency on $^1S_0$-$^3P_0$ clock transition reported ~ 753 Hz;
- The fast damping time 1.2 ms in (a) is due to the small beam waist;
- The Rabi frequency ^{87}Sr can be increased to 5 kHz with the same beam intensity 20 W/cm^2 ;

Gravimeter

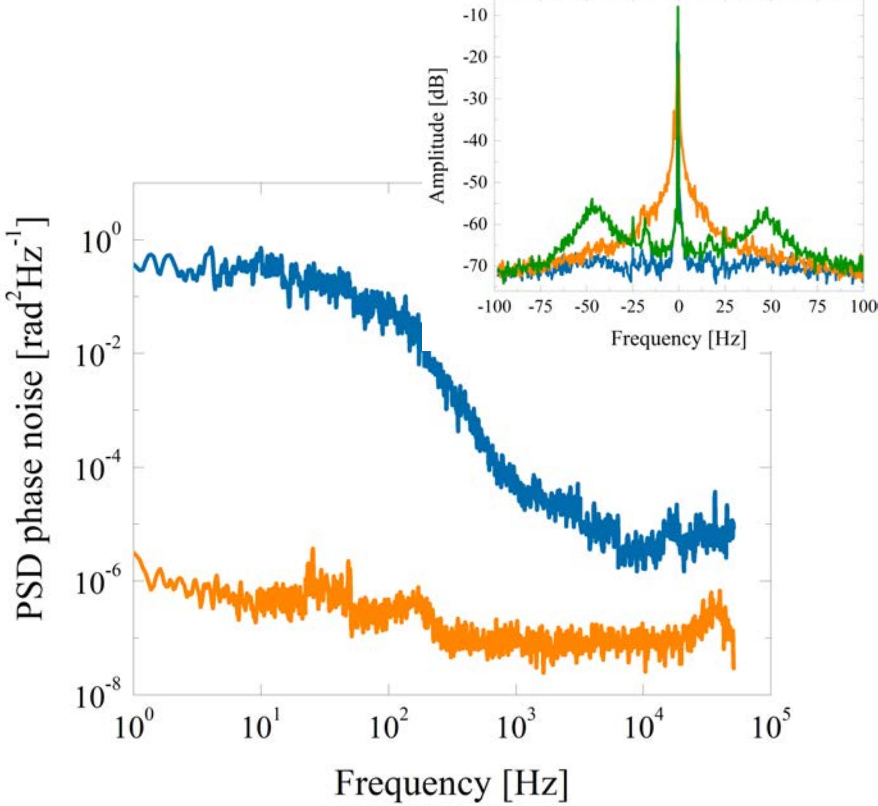




Fiber phase cancellation (FNC) setup

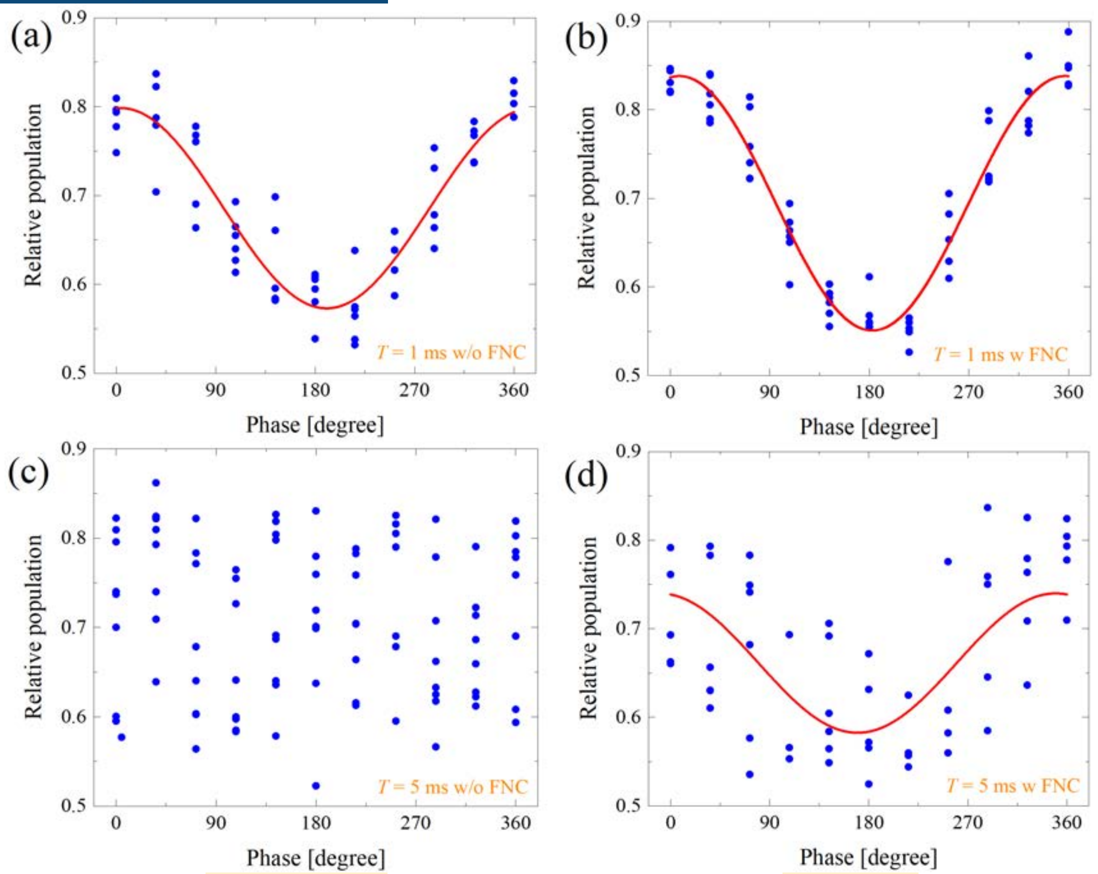


- Add one more AOM after the fiber for avoiding the random phase when the FNC setup relock the phase after interruption;
- Phase locking bandwidth 50 kHz;
- Suppress the noise induced by the fiber about 50 dB up to frequency of 100 Hz
- Outside of the loop is not compensated;



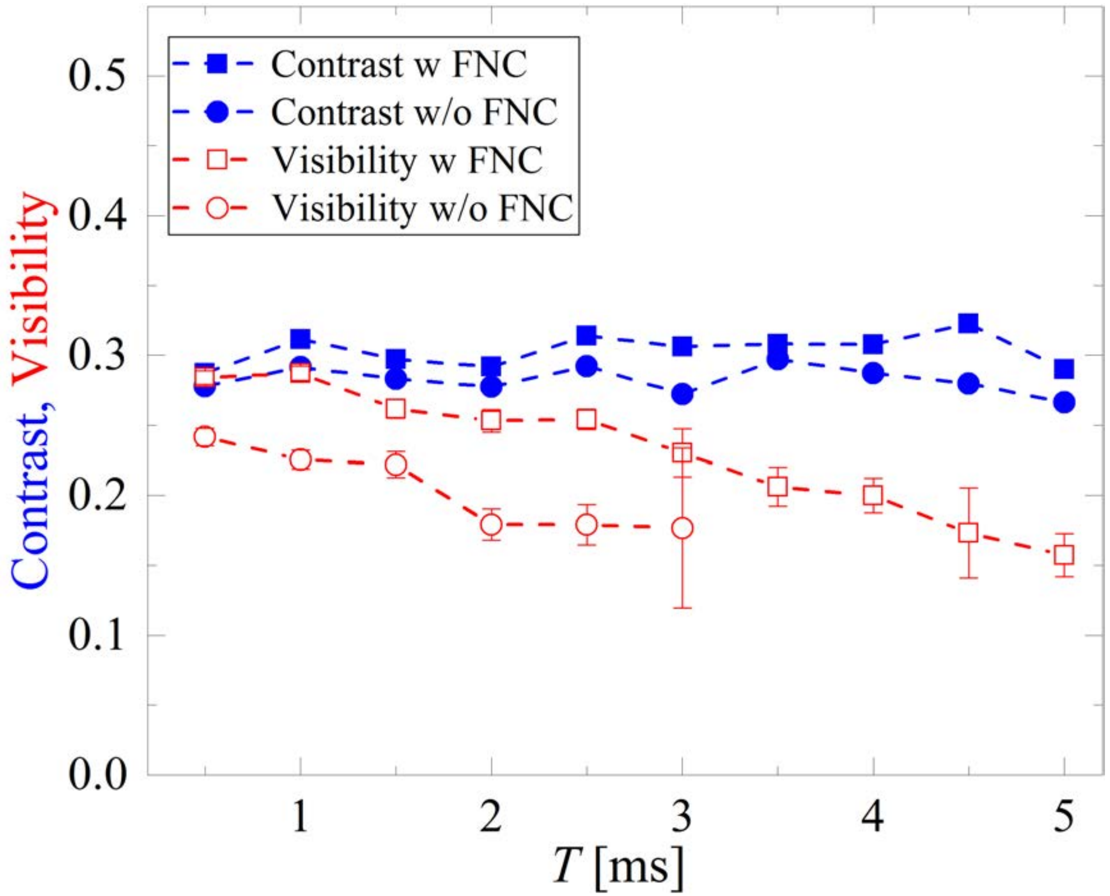
Fiber phase cancellation (FNC) performance

Gravimeter



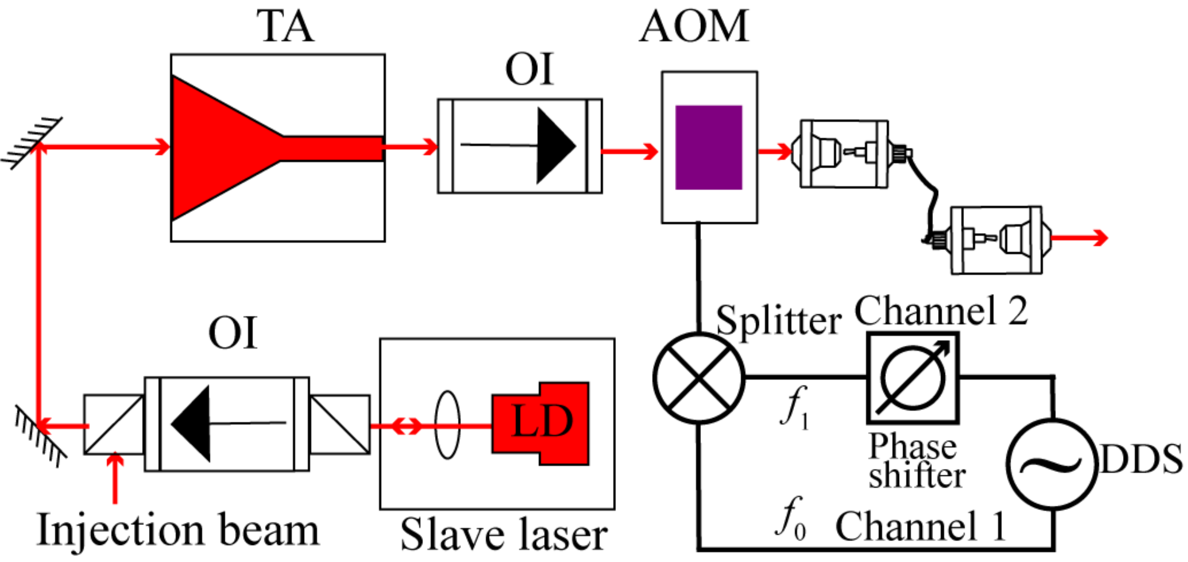
w/o FNC

w FNC



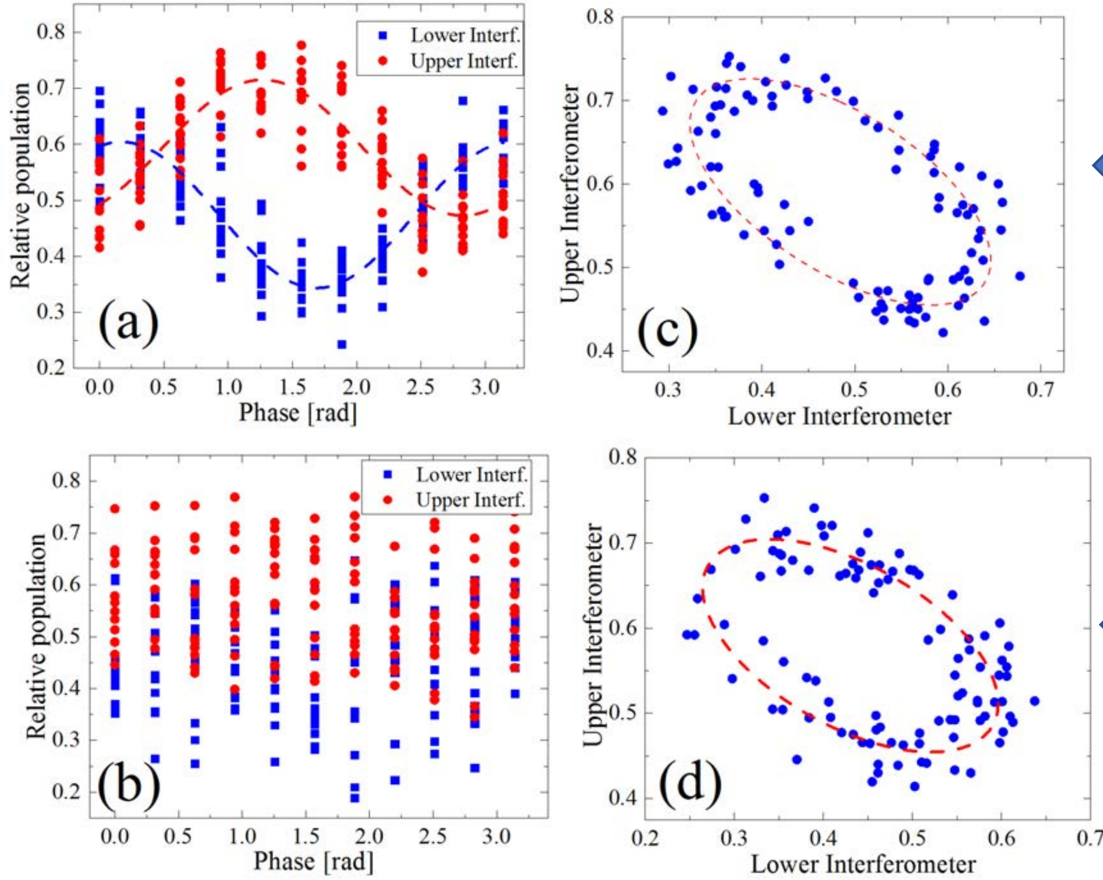
- We can clearly see the difference between with and without the FNC setup;
- No contrast loss observed up to $T = 5$ ms which is limited by fountain size;
- With fiber noise cancellation (FNC) setup, the fringe visibility can be partially recovered, but the fringe visibility is still going down up to $T = 5$ ms;
- The difference between the laser phase and the atomic phase.

Gravity gradiometer



- Gradiometer setup

$$\delta\phi \approx \frac{\omega_a}{c}(\Gamma T^2)\delta r_0 + \frac{\omega_a}{c}(\Gamma T^2)\delta v_0 T + \delta\phi$$



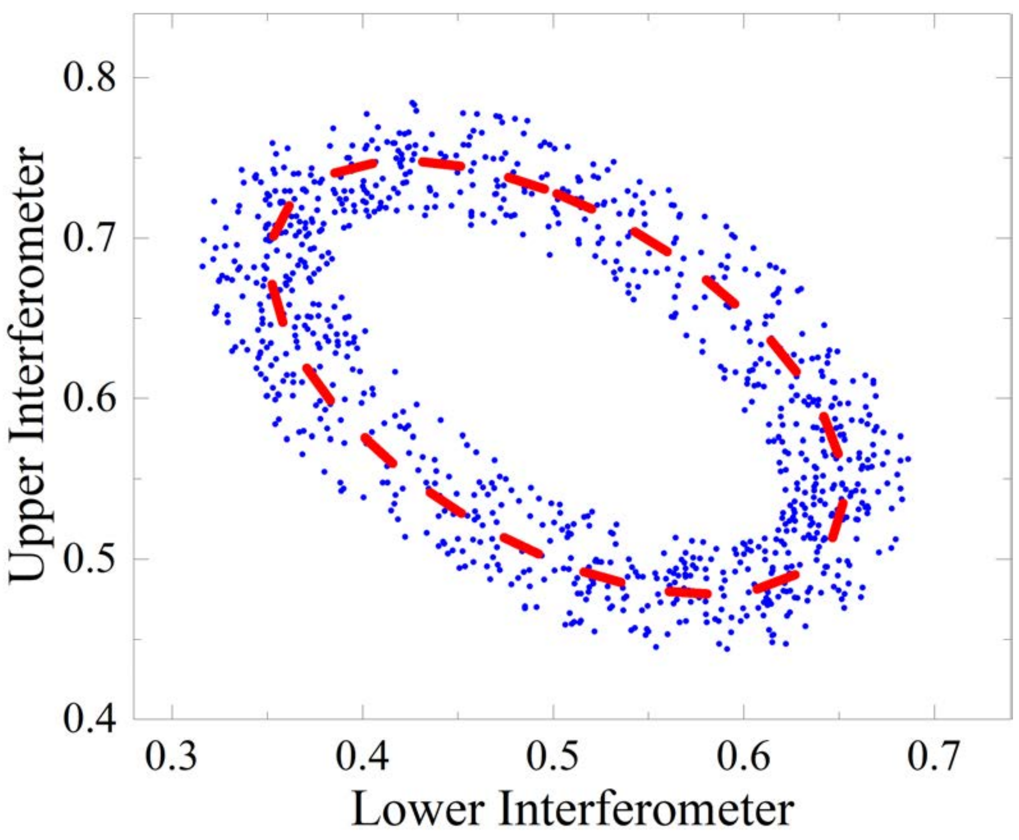
T = 1 ms

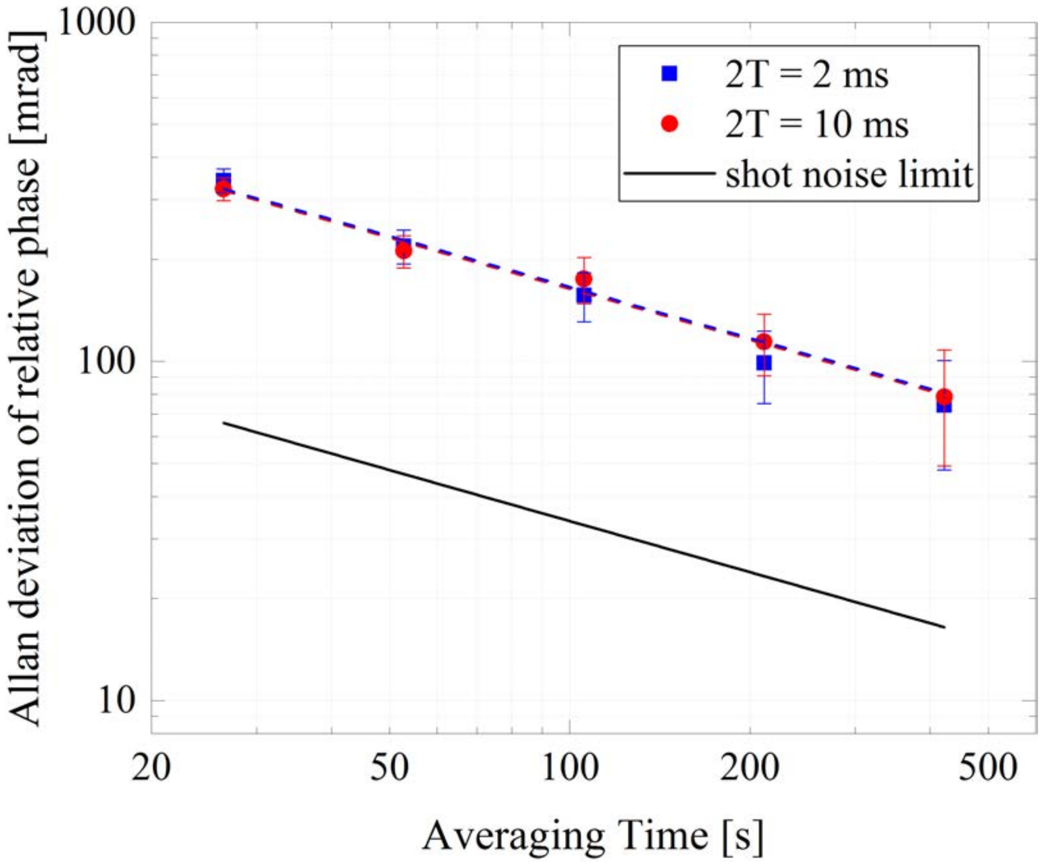
T = 5 ms

- New method for adding a relative phase shift between two AIs;
- Phase noise destroys the fringe visibility, but the ellipse is preserved.

- Typical ellipses at T= 1 ms and T = 5 ms with the relative phase shift of 3π/4

Gravity gradiometer





- 5 times higher than the shot noise limit;
- No decoherence is observed up to $T = 5$ ms;
- Common-mode noise rejection 1 ms at 400 s;

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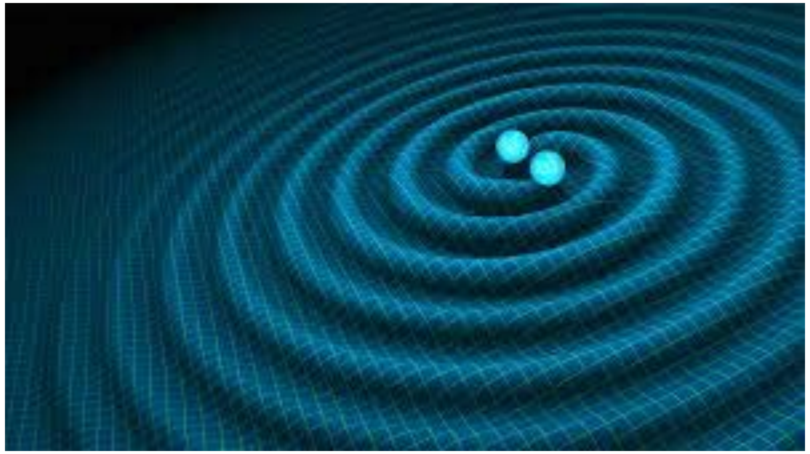
Applications

- Accurate determination of fundamental constants
- Test of Einstein equivalence principle
- Detection gravitational waves
- Interplay between Quantum Mechanics and General Relativity



Conclusion

- Demonstrate a proof-of-principle atom interferometr with the optical clock transition of strontium atoms;
- Provide a new method for add a relative phase shift between two AIs
- Illustrate a fundamental limitation of single-photon interferometers: the phase difference between the internal atomic phase and laser field;
- By compensating the phase noise induced by the fiber, the fringe visibility can partially be recovered;
- With the gradiometic configuration, the phase noise can be well rejected.

Thank you for your attention