Progress on Atom Interferometer (AI) in BUAA

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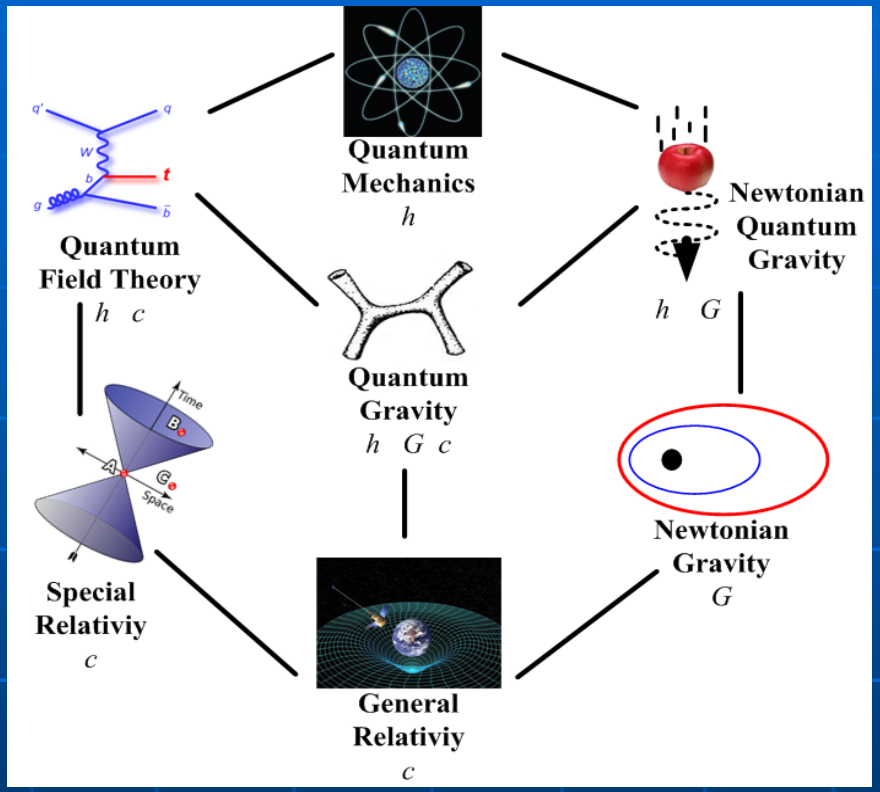
01.09.2011

7th UK-China Workshop on Space Science and Technology

Outline

- Fundamental science in space exploration and atom interferometers
- Introduction to Atom interferometers
- Progress on atom interferometer in BUAA

Fundamental Science in Space Exploration



Platform

Application

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Precision Measurement with Atom Interferometer in Space Exploration

- Measurement of fundamental constants such as ♋ and G
- New definition of unit Kg
- Test of equivalence principle
- Test of general relativity
- Test Newton's law at short distances
- Development of new detectors for gravitational wave
- Development of transportable sensors for geophysics and space

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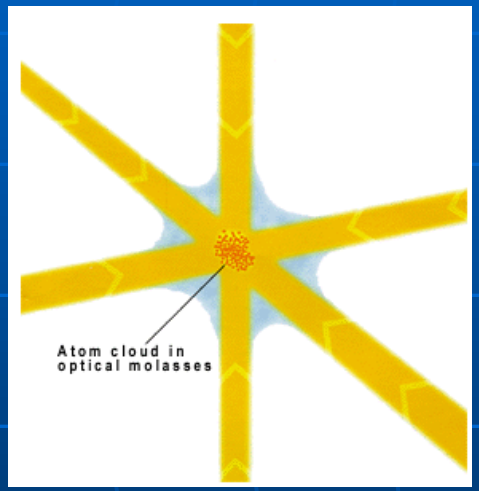
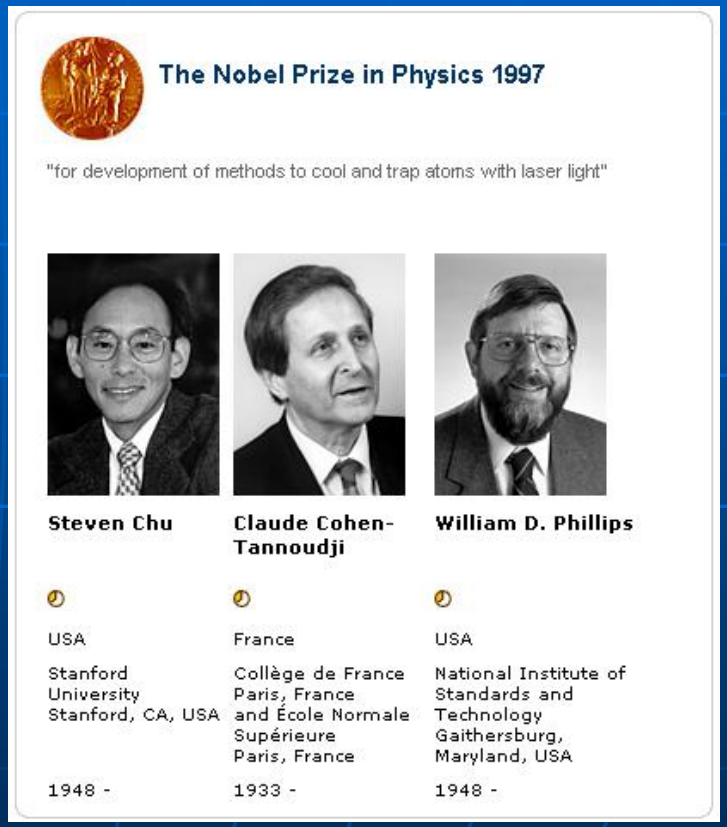
Laser Cooling Technology

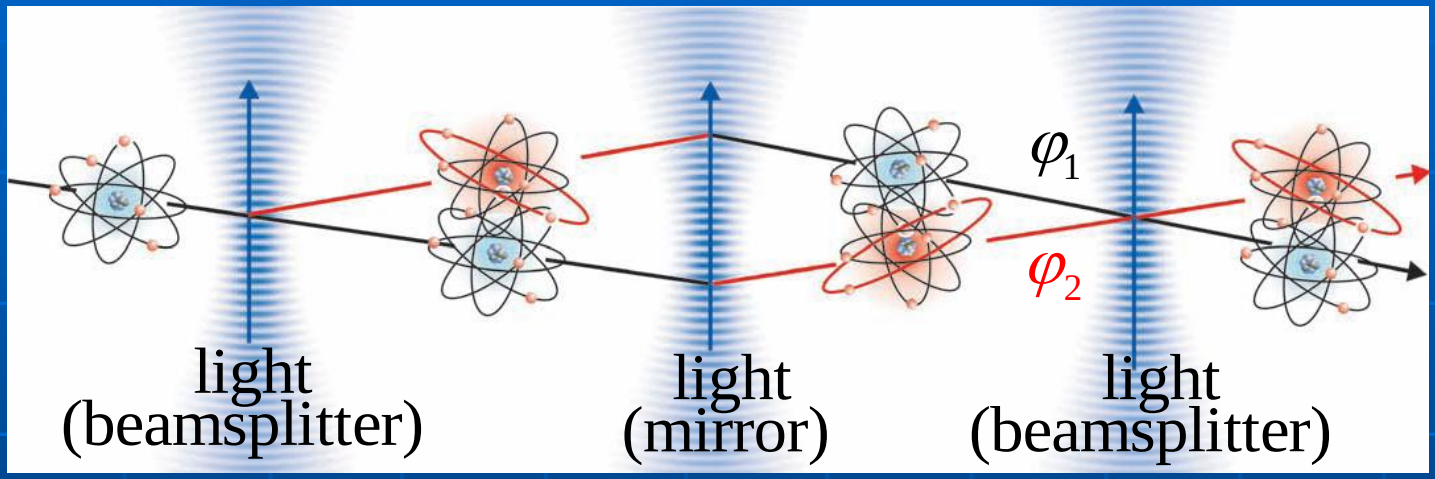


Laser cooling: Laser light is used to cool atomic vapors to temperatures of ~10^{-6} Kelvin.

Laser cooling techniques are used to achieve the required velocity (wavelength) control for the atom source.



Principle of Atom interferometer

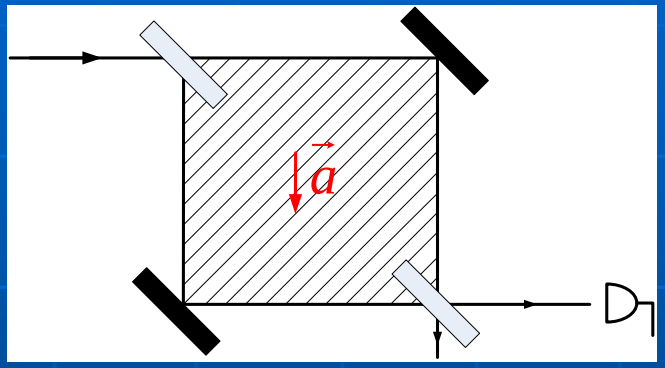


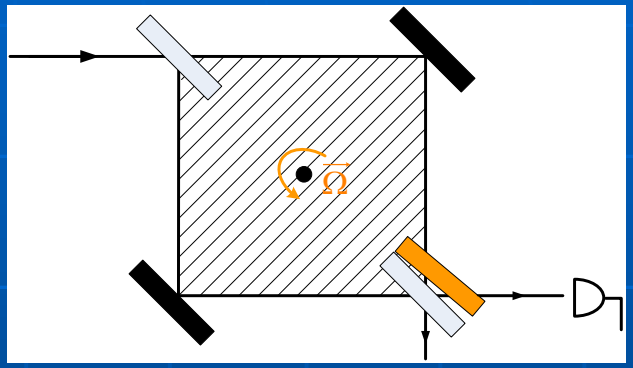
phase difference:

$$\Delta\varphi=\varphi_1-\varphi_2=\frac{1}{\hbar}\left(\int_1 U_1 \mathrm{d}t-\int_2 U_2 \mathrm{d}t\right)$$

The energy U can be different for the two partial waves as a result of the interaction with external potentials or because of the difference in atomic internal ernergy.

Sensitivity of Atom Interferometry





Phase shift:

$$\Delta\Phi = \frac{2\pi}{\lambda} T_{drift}^2 \cdot \vec{a}$$

$$\Delta\Phi = \frac{4\pi\vec{\Omega}\cdot A}{\lambda\upsilon}$$

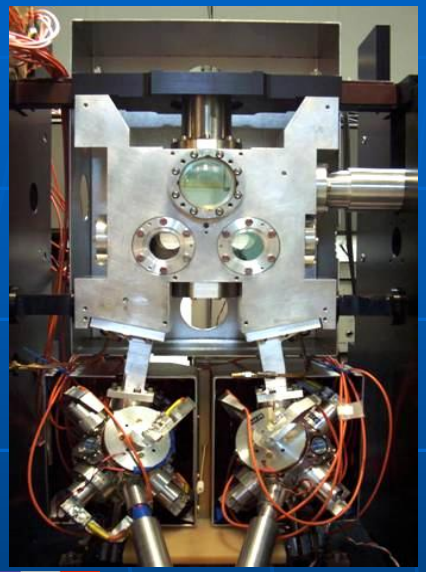
Sensitivity:

$$\frac{\Delta\Phi_{mat}}{\Delta\Phi_{ph}} \sim \left(\frac{c}{\upsilon_{at}}\right)^2 \approx 10^{11} - 10^{17}$$

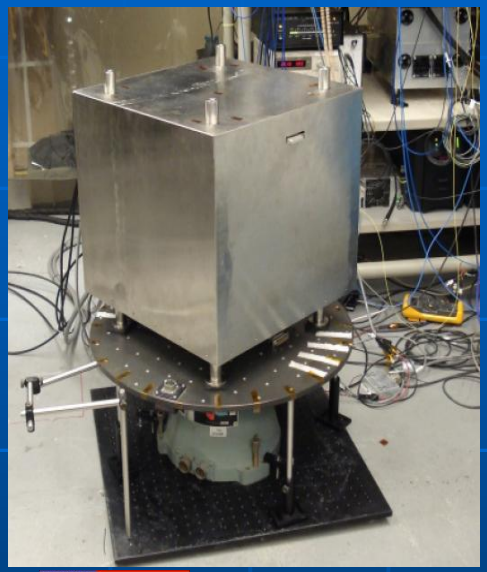
$$\frac{\Delta\Phi_{^{133}\mathrm{Cs}}}{\Delta\Phi_{633\mathrm{nm}}} = \frac{M_{^{133}\mathrm{Cs}} c^2}{\hbar\omega_{633\mathrm{nm}}} \approx 6.3\times 10^{10}$$

optical field: $\lambda = \frac{2\pi c}{\omega}$; atoms: $\lambda = \frac{h}{M\upsilon}$

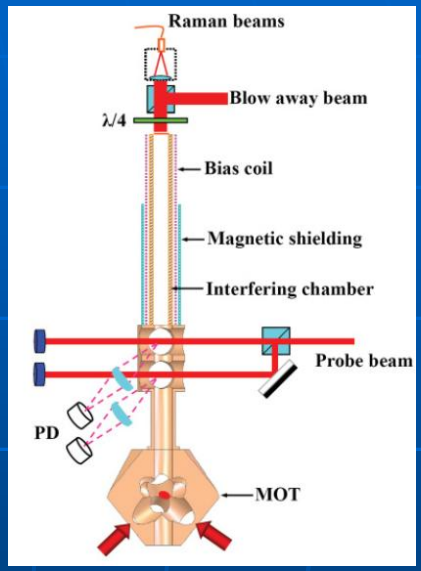
Atom Interferometers without Guide



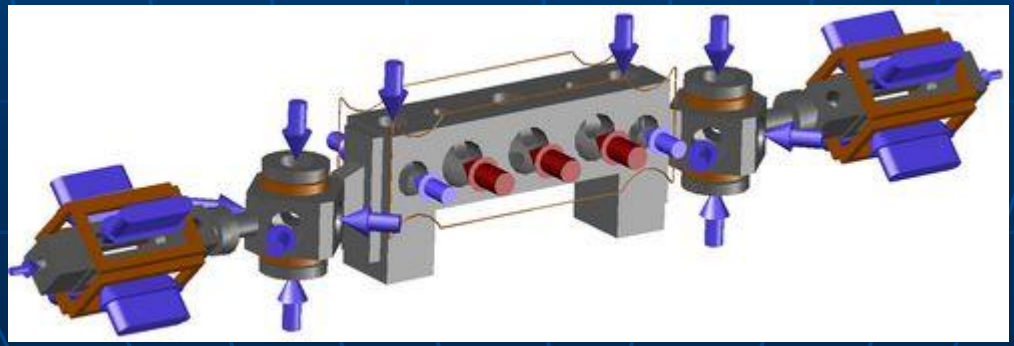
LNE-SYRTE
6-axis inertial sensor



Stanford
atom gyroscope



HUST
atom interferometry



IQO
Cold Atom
Sagnac Interferometer

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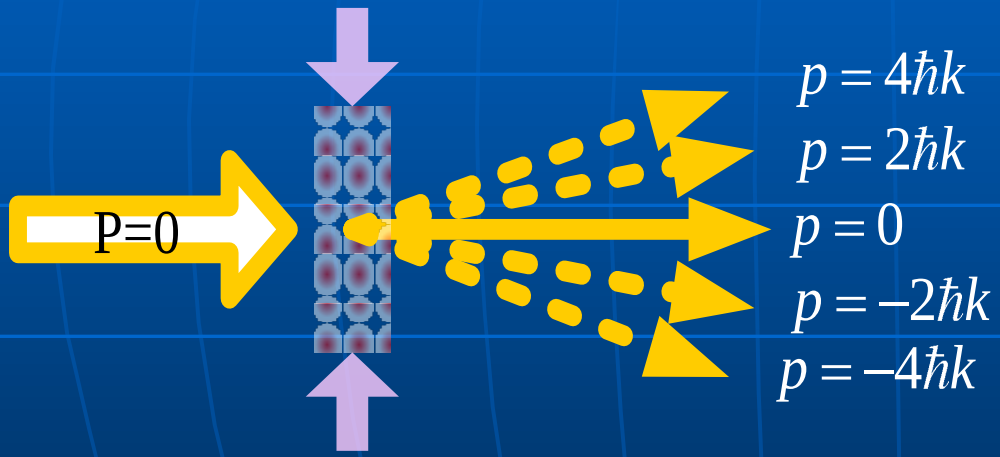
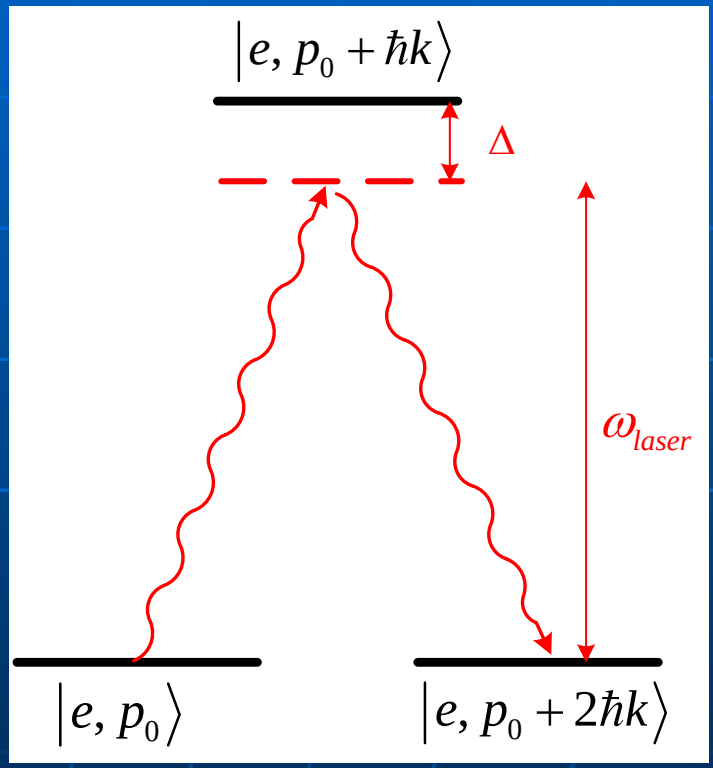
Beamsplitter and Mirror for Atoms

- **Kapitza-Dirac Diffraction**

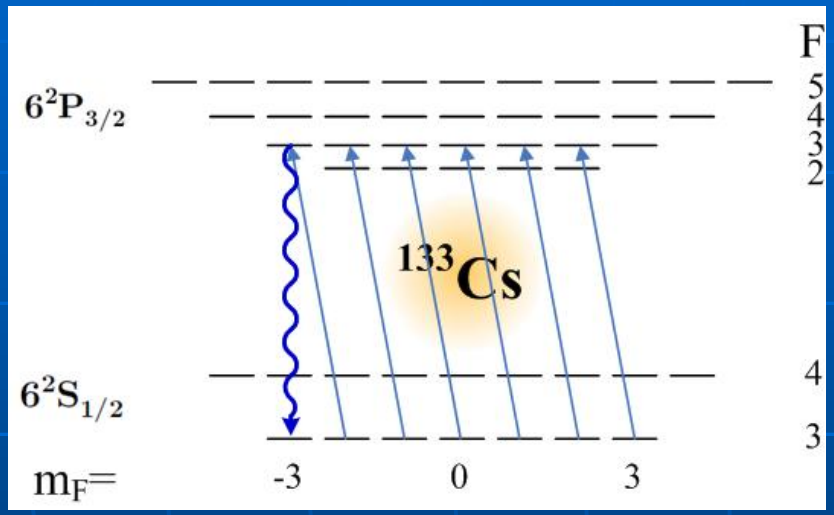


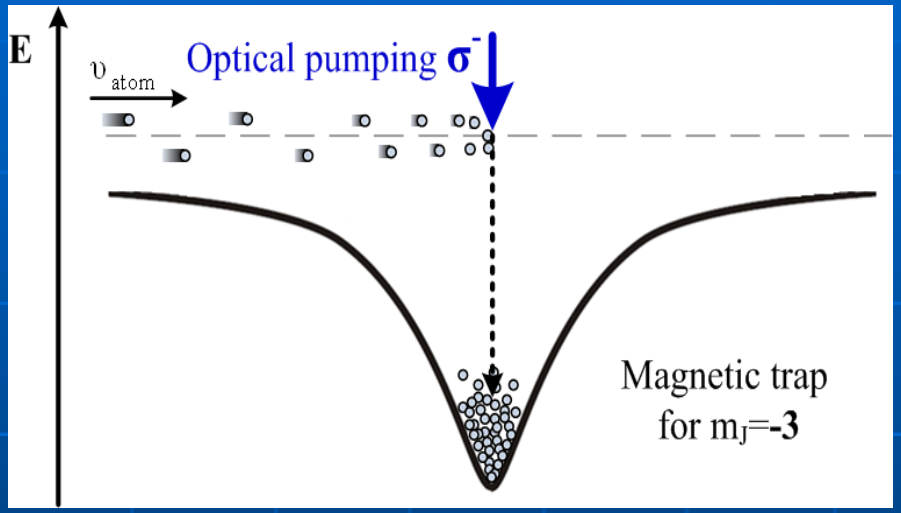
Standing Light wave field is used for splitting/combining and reflecting the atoms, just like beamsplitters and reflector mirrors in optics.



Laser field is far off-resonant to reduce the spontaneous decay of atoms from the excited state.

Magnetic Waveguide for Atoms



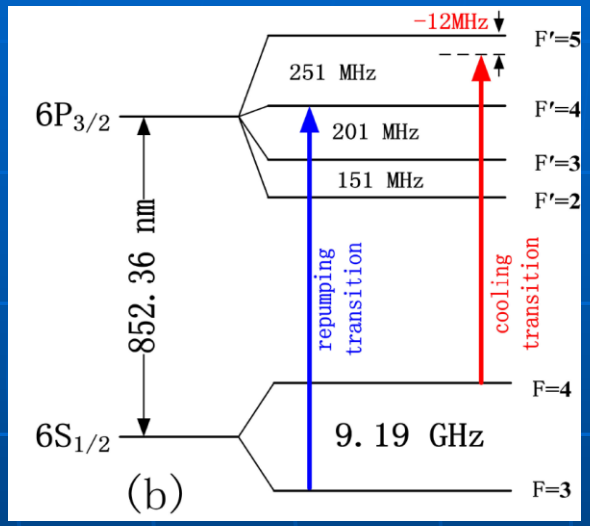


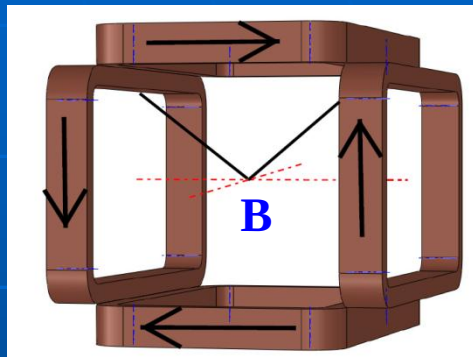
Optical pumping

Optical pumping + Magnetic trap

- Cold atoms can be trapped in magnetic trap with the optical pumping process.
- The trapped atoms can be moved with the control of the magnetic trap.

Transverse Laser Trapping





$B_{x,y} \sim 10$ Gauss/cm

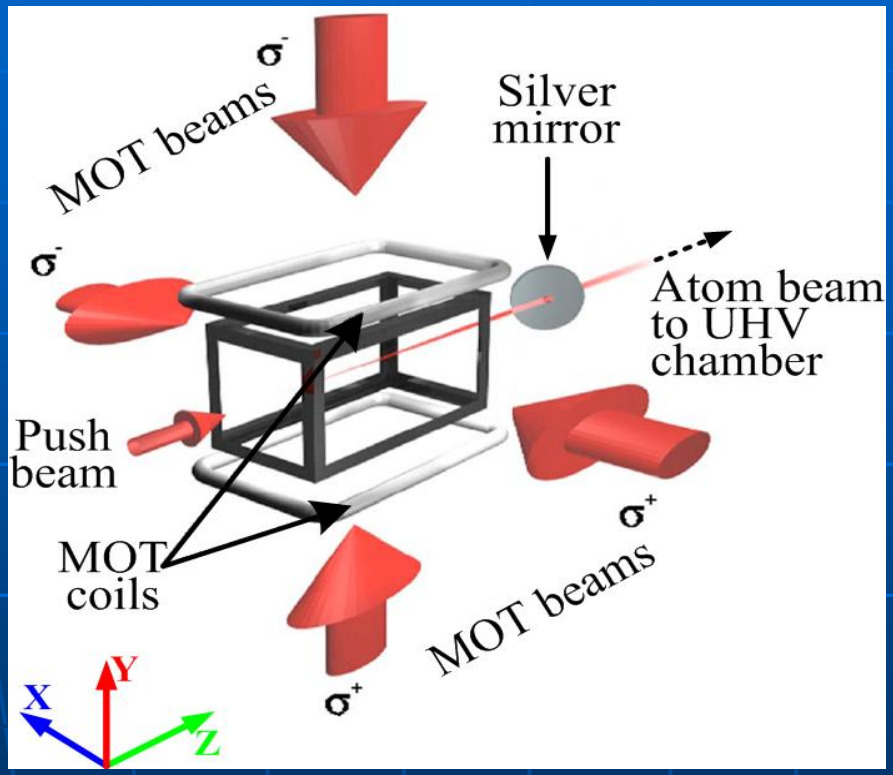
$B_z \sim 0$ Gauss/cm

- ^{133}Cs atoms in the first vacuum chamber was laser cooled and magneto-Optical trapped (MOT) in two dimensions .
- A cigar-shaped optical molasses is achieved in the center of the vacuum chamber.

$$\vec{F}_{\mathrm{OM}}\big|_{z} = -\beta \vec{v}_{\mathrm{atom}}\big|_{z}$$

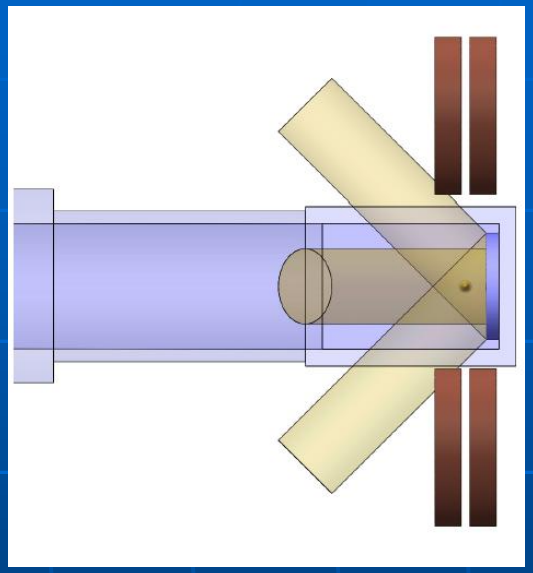
$$\vec{F}_{\mathrm{MOT}}\big|_{x,y} = -\beta \vec{v}_{\mathrm{atom}}\big|_{x,y} - \kappa \vec{r}$$

Moving Optical Molasses

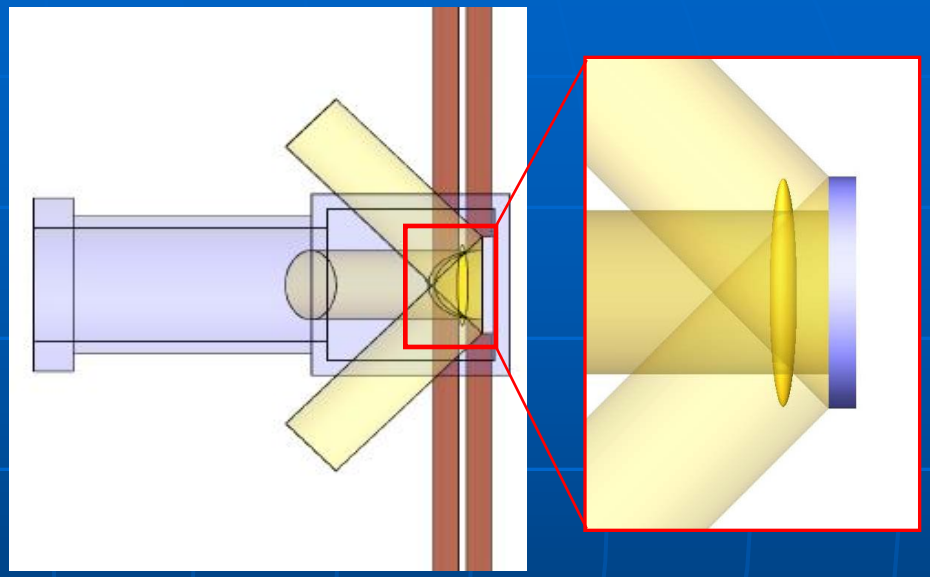


- Optimization of various parameters to enhance the atomic flux, including the push laser power and polarization, transverse gradient of quadrupole magnetic field, laser detuning, and Caesium vapor pressure.

Mirror MOT in Ultra-high Vacuum



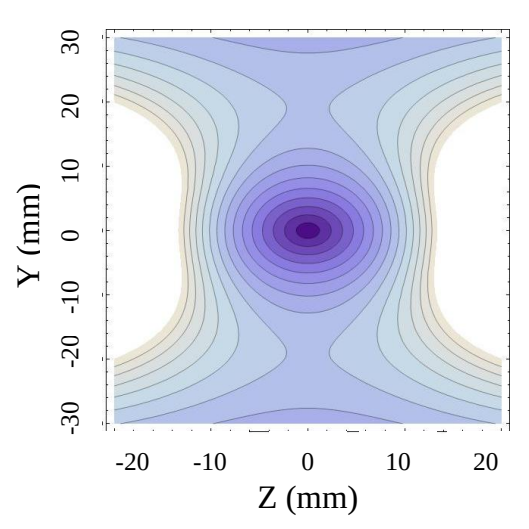
Side view

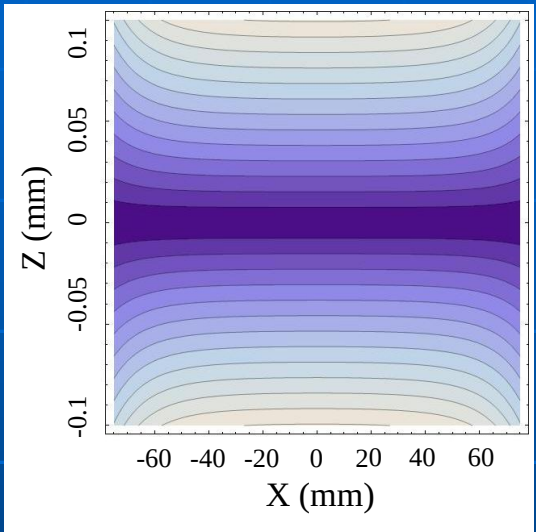


Top view

- Mirror MOT in the UHV cell recaptures the cold Caesium atoms transported from the 2D+ MOT.
- Mirror MOT is also a 2D MOT
- Field gradient of 2D quadrupole magnetic trap in x- and y- directions: 10 Gauss/cm, in z-direction is nearly zero Gauss/cm.

Magnetic Waveguide





Field gradient:

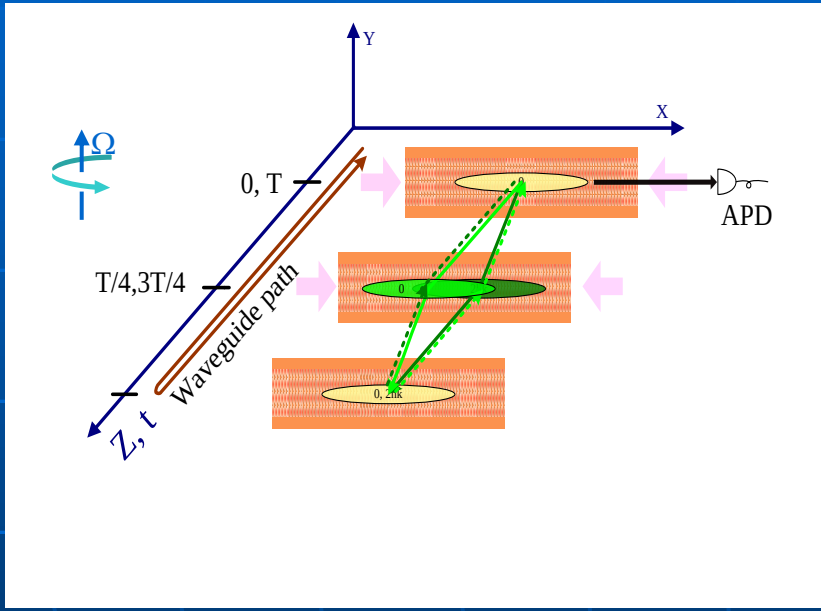
Z direction: 133 Gauss/cm

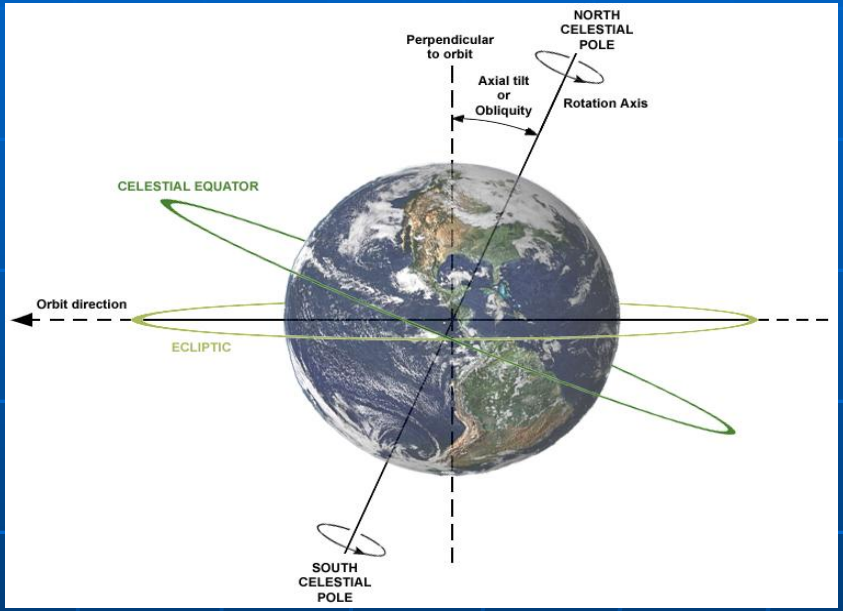
Y direction: 127 Gauss/cm

X direction: $< 5 \times 10^{-10}$ Gauss/cm

The resulting radius of curvature of the guide is estimated to be about 400m at point 10 mm far from the center of the guide in x direction.

Guide-based Atom Gyroscope





- Using Figure-8 path to compensate the difference of magnetic waveguide to achieve long atomic coherence times.
- Control the guide's motion accurately to ensure the enclosed area exactly.

- Latitude of Beijing: 39° 56′
- Waveguide (oscillation period 0.1s): 8mm back and forth, 12 times
- Area enclosed: 21 mm^2
- Phase shift: Pi

summary

- Acquired 2D Caesium MOT
- To transport cold Caesium atoms to AI chamber efficiently
- To load recaptured cold atoms into magnetic waveguide
- To measure the earth's rotation with guide-based atom interferometer
- Strengthen the collaboration with RAL


Thanks