

# ZAIGA

Terrestrial Very-Long-Baseline Atom Interferometry Workshop  
August 20-22, 2025, Leibniz University - Hannover

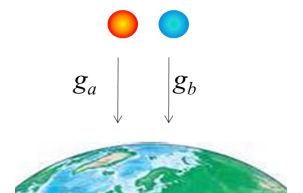


# Large Momentum Transfer(LMT) with Double-Diffraction Raman Transition for Dual-Species Atom Interferometer(AI)

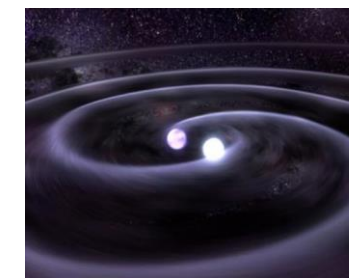
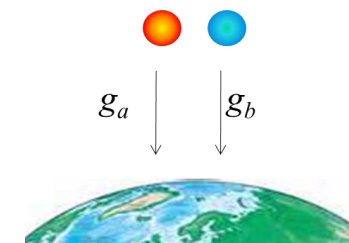
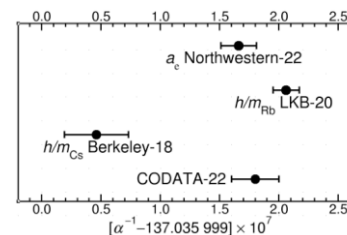
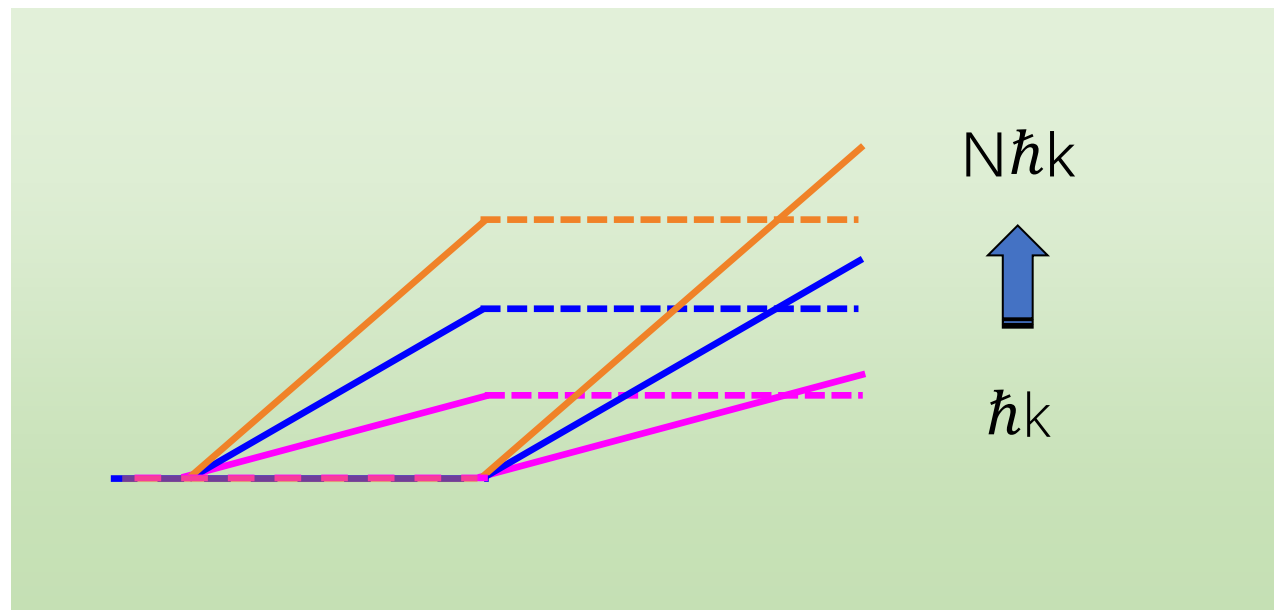
Lin Zhou

Innovation Academy for Precision Measurement Science and Technology,  
Chinese Academy of Sciences, China

August 20, 2025



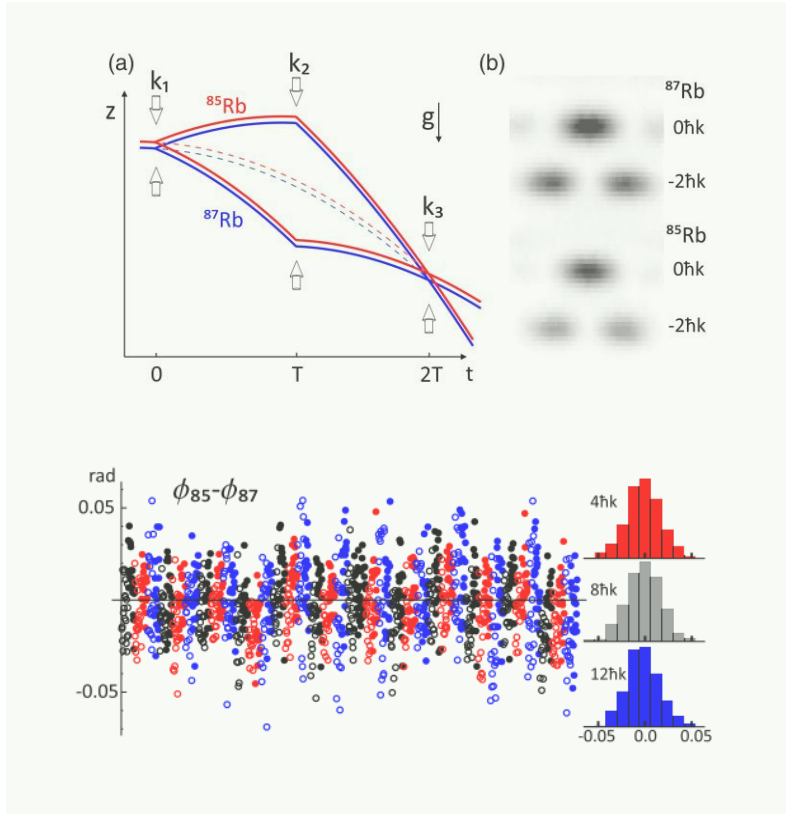
# Large momentum transfer (LMT)



**Stimulated Raman transitions**  
**Multi-photon Bragg Scattering**  
**Bloch oscillations**  
**Single photon transitions**

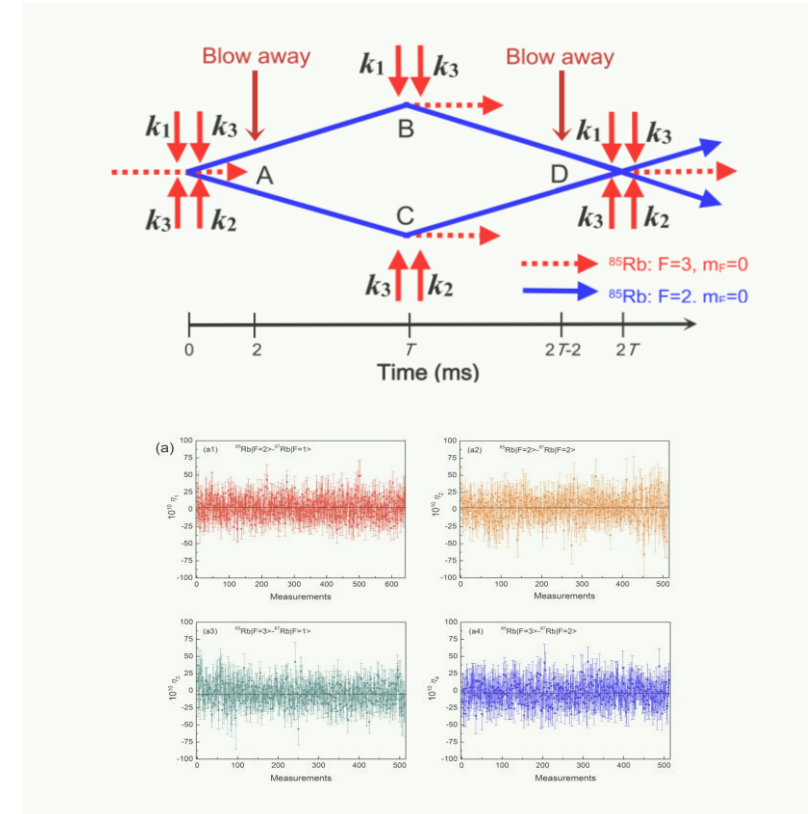
S. Abend *et al.*, *AVS QuantumSci.* **6**, 024701(2024)  
J. M. McGuirk *et al.*, *Phys. Rev. Lett.*, **85**,4498(2000)  
H. Müller *et al.*, *Phys. Rev. Lett.* **100**, 180405 (2008)  
P. Cladé *et al.*, *Phys. Rev. Lett.* **102**, 240402 (2009)  
J. Rudolph *et al.*, *Phys. Rev. Lett.* **124**, 083604 (2020)

# LMT for the dual-species atom interferometers



4, 8, 12  $\hbar k$   
**Bragg Scattering**

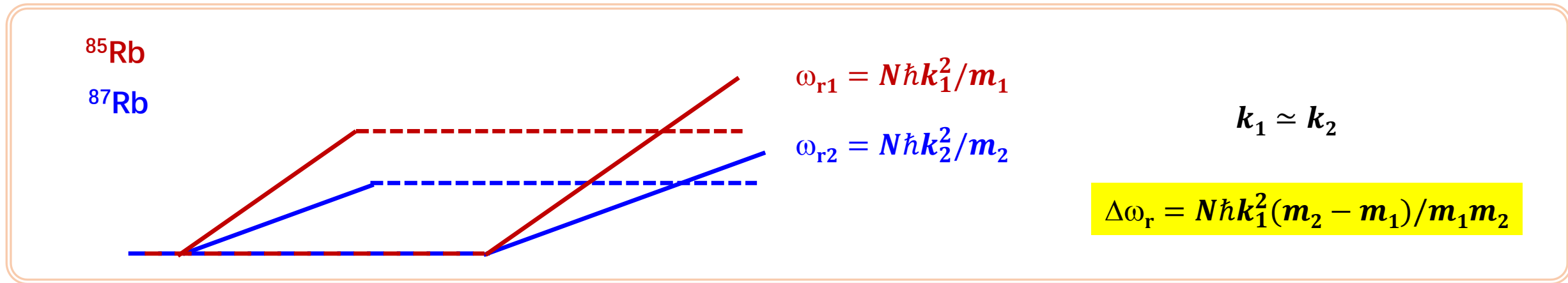
P. Asenbaum *et al.*, *Phys. Rev. Lett.* **125**, 191101 (2020)



4  $\hbar k$   
**Raman Transitions**

L. Zhou *et al.*, *Phys. Rev. Lett.* **115**, 013004 (2015)

# The challenges and applications



## Key points of dual-specie AI:

1. Using the same laser to obtain high common-mode noise rejection ratio
2. The Rabi frequencies of different species' AIs are the same
3. The ac Stark shift caused by laser beams is zero for both AIs

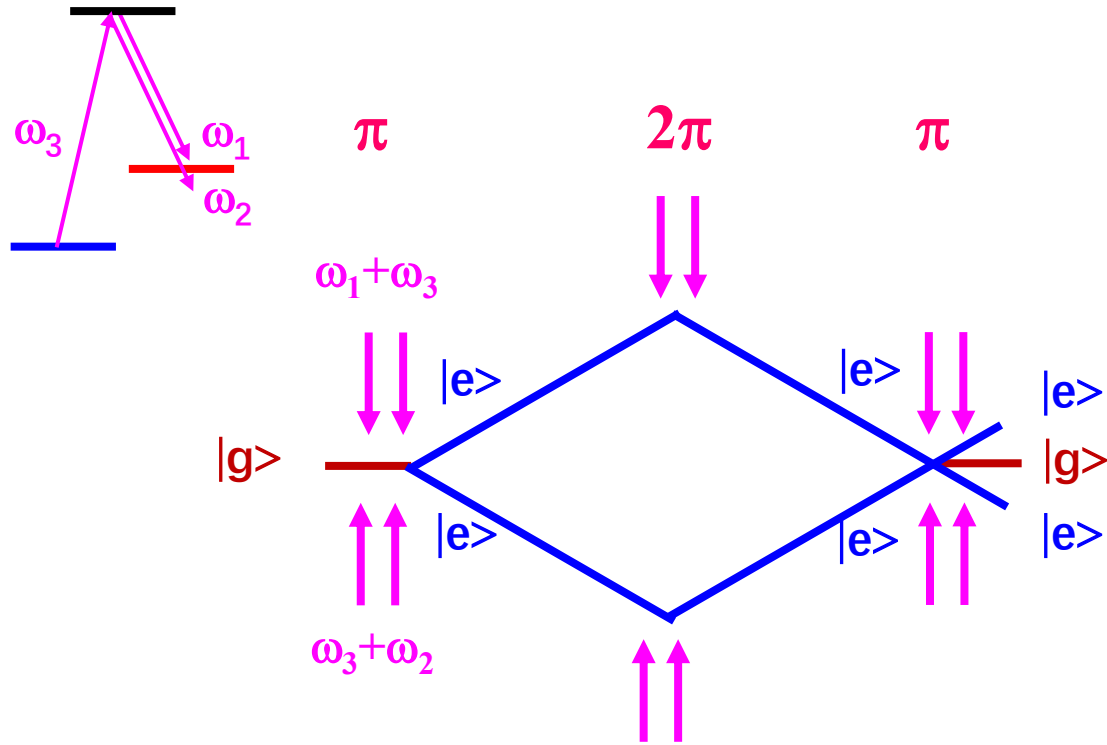
...

## The challenges faced by dual-species LMT AI:

1. Under the requirement of common-mode noise rejection, the compatibility of dual-species atom interferometer limits the optimization of experimental parameters.
2. A recoil-induced Doppler shift difference exists between LMT dual-species AIs.

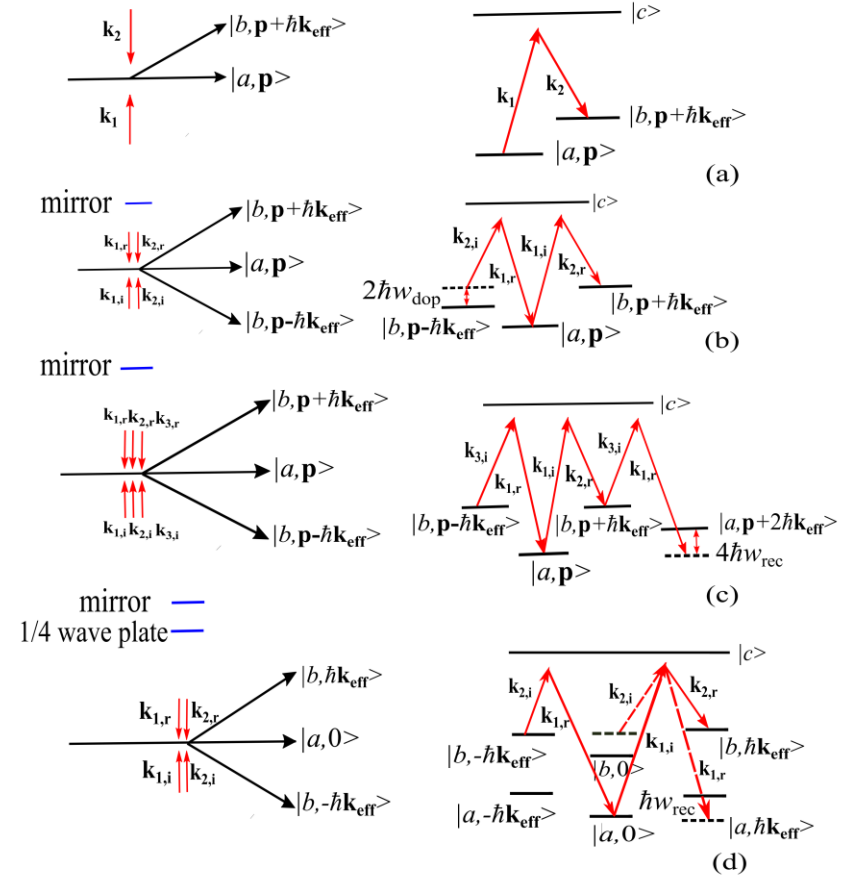
**Potential applications: WEP tests, large dynamic range AIs**

# Double-diffraction Raman atom interferometer



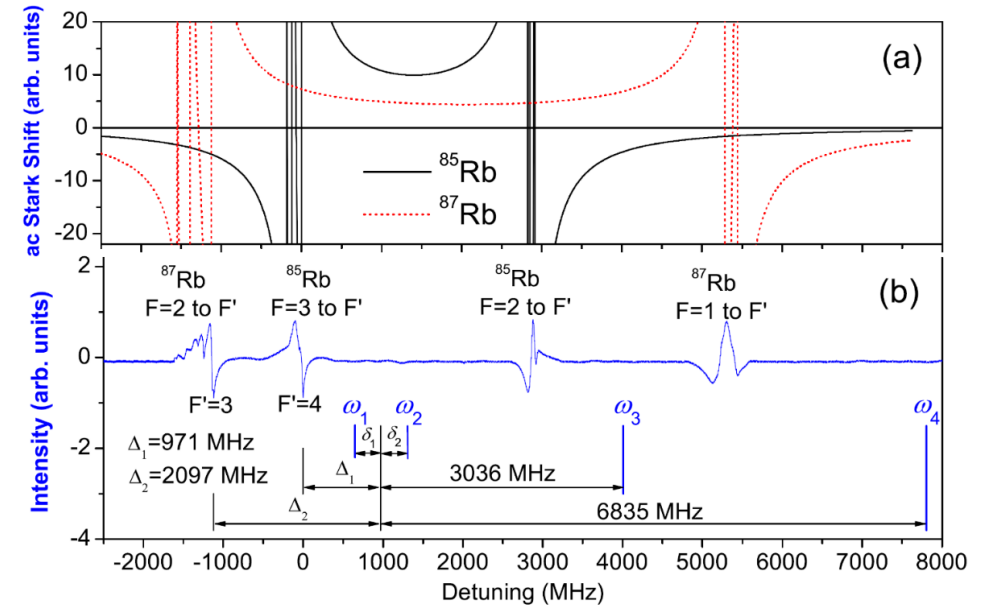
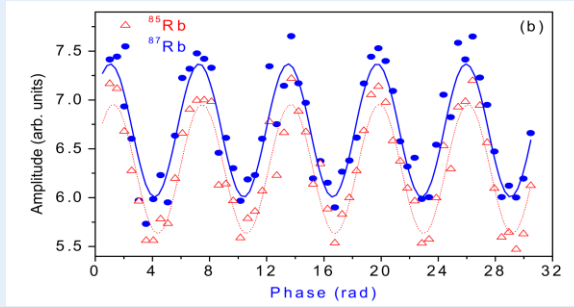
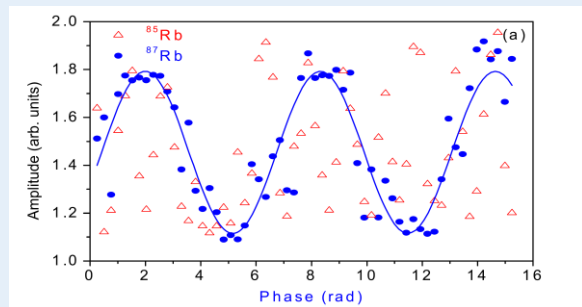
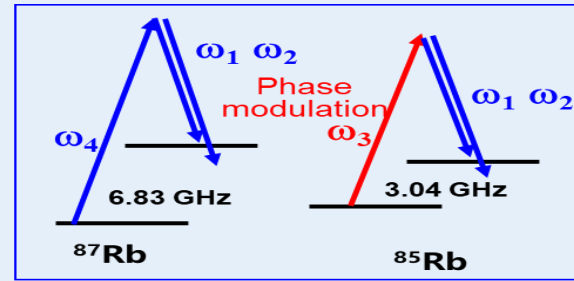
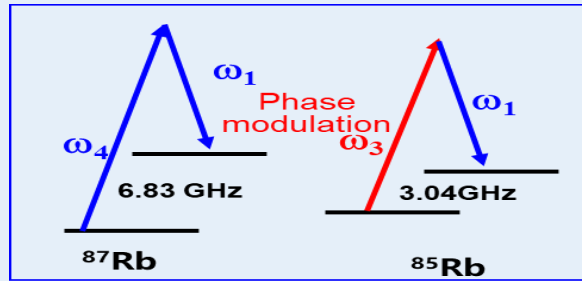
**Symmetric interference loop**  
**Identical internal states interference**  
**State selective detection**

T. Lévêque *et al.*, *Phys. Rev. Lett.* **103**, 080405 (2009)  
 N. Malossi *et al.*, *Phys. Rev. A* **81**, 013617 (2010)  
 H. Ahlers *et al.*, *Phys. Rev. Lett.* **116**, 173601 (2016)



M. He *et al.*, *Phys. Rev. A* **103**, 063310 (2021)  
 L. Zhou *et al.*, *Phys. Rev. A* **104**, 022822 (2021)

# 4-wave double-diffraction Raman transition (4WDR)



$$\omega_1:\omega_2:\omega_3:\omega_4 = 1.0:1.0:3.1:14.3$$

$$\phi_{85} \propto \omega_1 - \omega_3$$

$$\phi_{87} \propto \omega_1 - \omega_4$$

$$\phi_{85} \propto \omega_1 - \omega_2$$

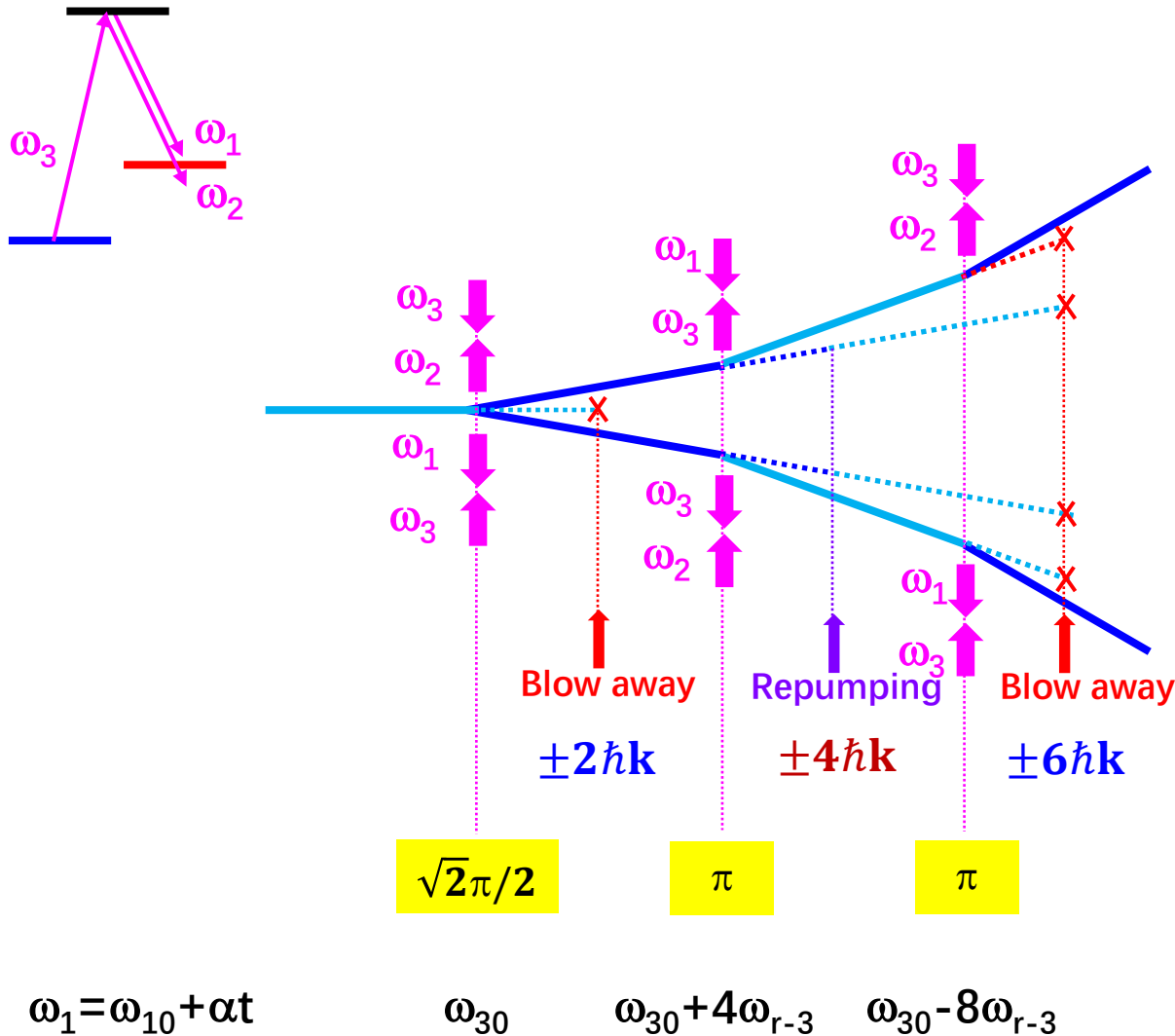
$$\phi_{87} \propto \omega_1 - \omega_2$$

**4WDR method:**

$$^{85}\text{Rb}: \omega_1 / \omega_2 / \omega_3$$

$$^{87}\text{Rb}: \omega_1 / \omega_2 / \omega_4$$

# Independent compensation of the recoil frequency



The frequency compensation scheme:

**$^{85}\text{Rb}$**

$$\Delta\omega_3^m = (-1)^m \times (4\omega_{r-3} \times (m-1)) ,$$

$$\omega_{r-3} = 2\pi \times 15.439 \text{ kHz}, m \in \{1, 2, \dots, n\}$$

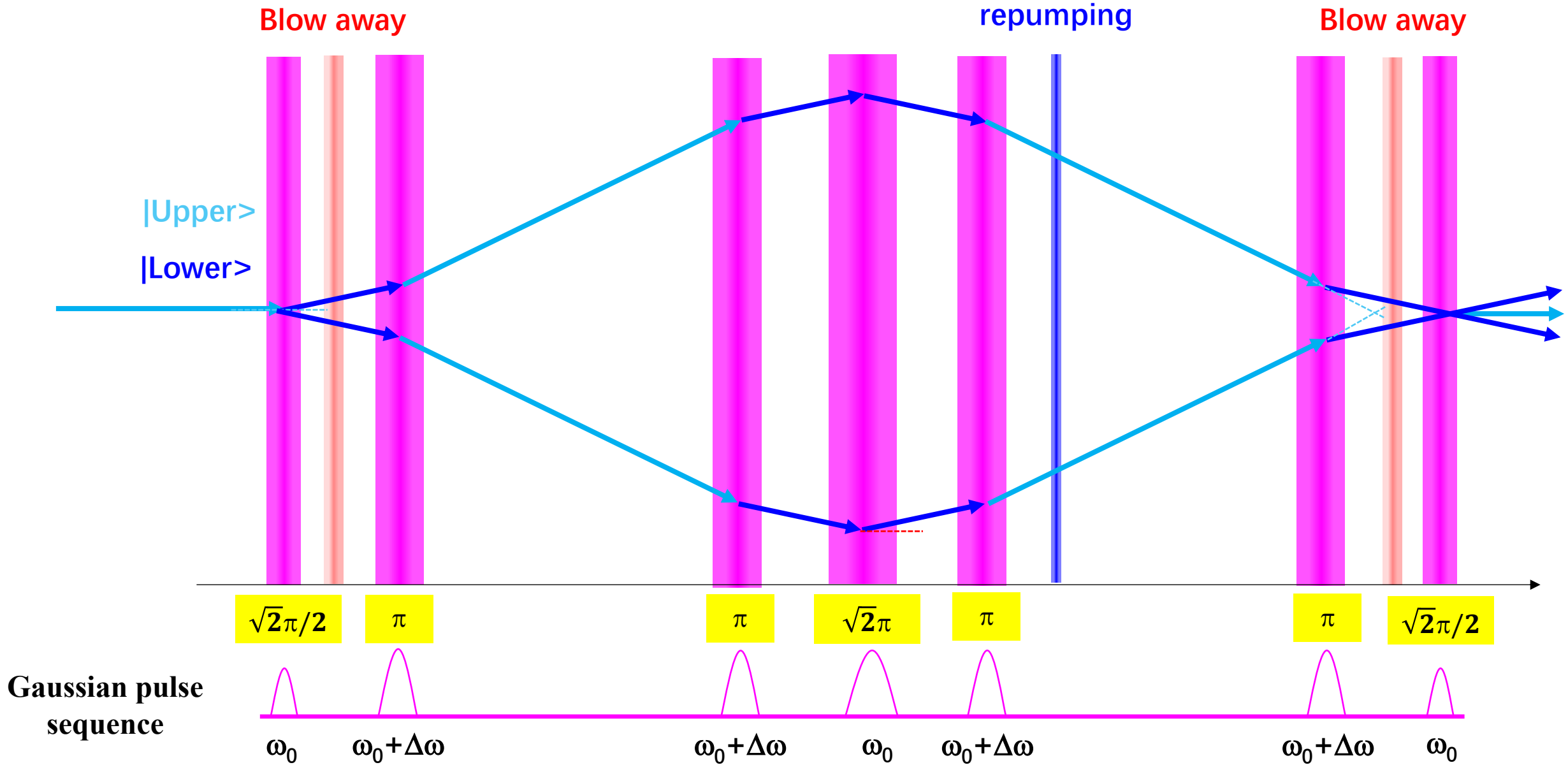
**$^{87}\text{Rb}$**

$$\Delta\omega_4^m = (-1)^m \times (4\omega_{r-4} \times (m-1)) ,$$

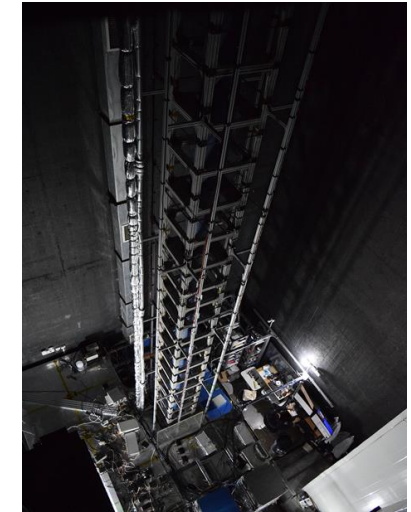
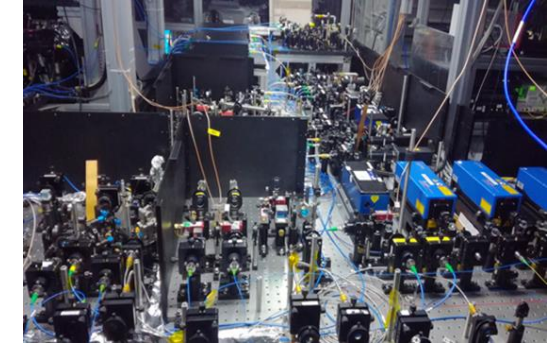
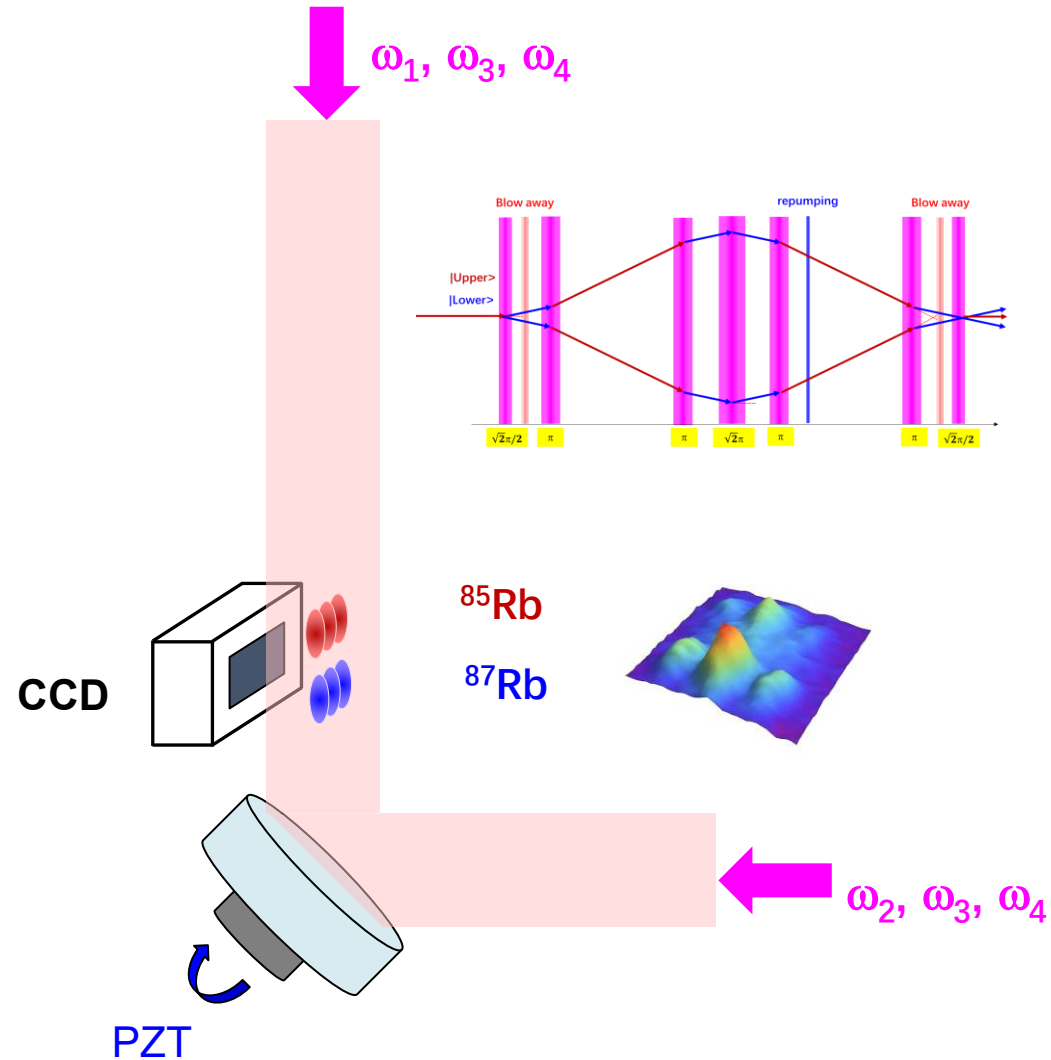
$$\omega_{r-4} = 2\pi \times 15.084 \text{ kHz}, m \in \{1, 2, \dots, n\}$$

$$\Delta\omega_r = 360 \text{ Hz}$$

# LMT with $8\hbar k$



# Experimental setup



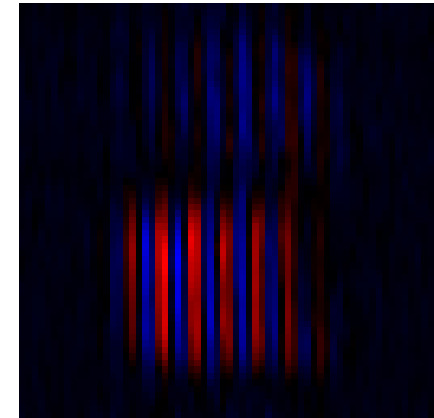
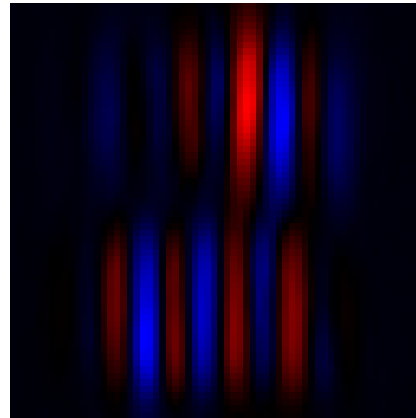
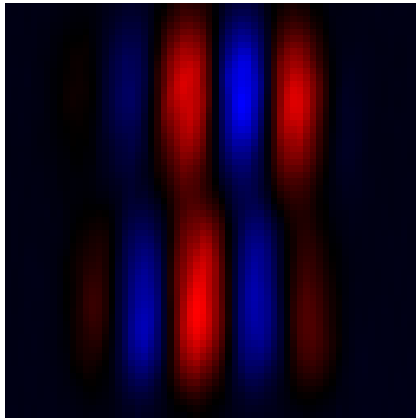
**10 m AI in Wuhan**

$\delta g/g \sim 8.6\text{E-}12$  g (with cold atoms)

# Experimental results

$^{85}\text{Rb}$

$^{87}\text{Rb}$



$4\hbar k$

$8\hbar k$

$16\hbar k$

22%

6%

1%

Contrast

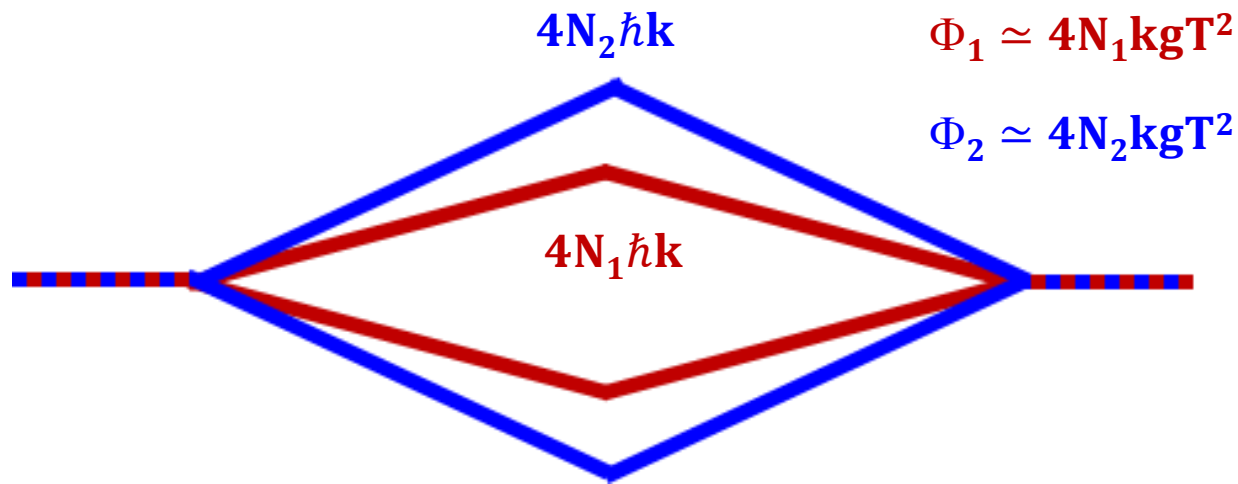
18%

5%

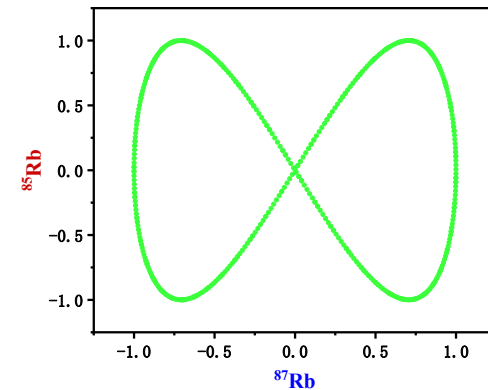
3%

$T=90\text{ms}$ , transfer efficiency : 75%

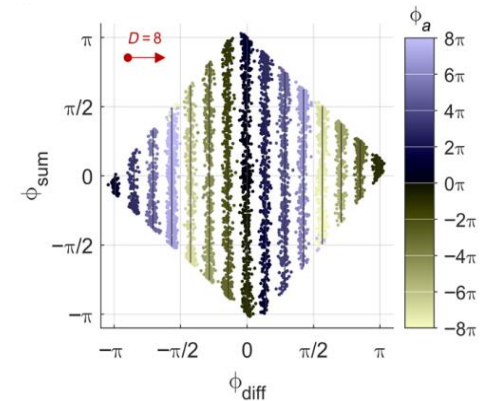
# Method: Dual-species AIs with different LMT orders



Phase shift ratio of AIs:  $\Phi_1/\Phi_2 \simeq N_1/ N_2$



Lissajous curve  
( $\Phi_1 : \Phi_2 = 1 : 2$ )



AIs + Moiré effect  
( $N_1(N_1 + 1) * 2\pi$ )

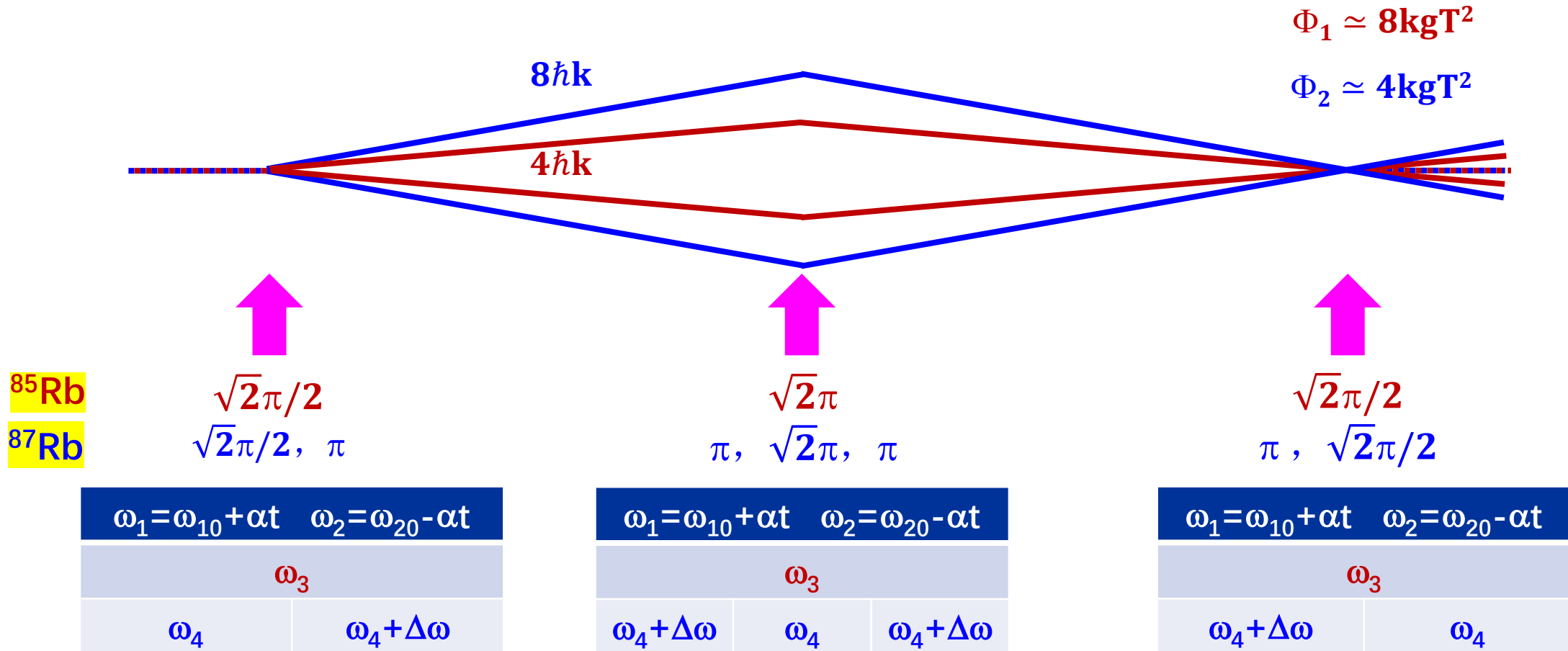
Dynamic range :  $(0, 2\pi)$   $\xrightarrow{N_2 = N_1 + 1}$   $N_1(N_1 + 1) * 2\pi$

**AI×1** **AI×2**

D. Yankelev *et al.*, *Sci. Adv.* **6** : eabd0650 (2020)

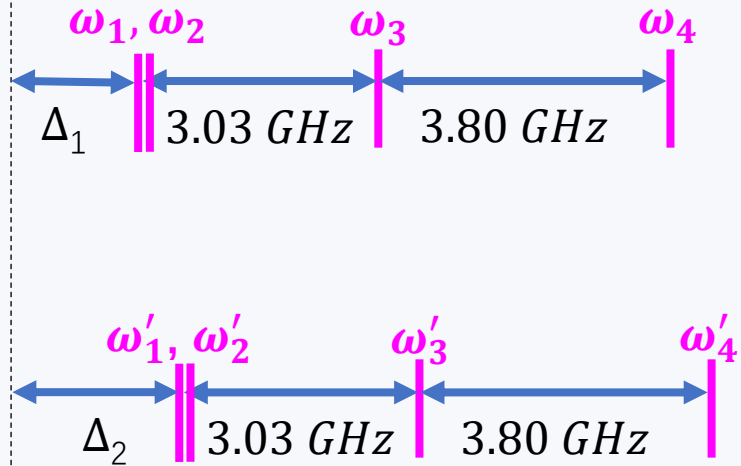
X. Chen *et al.*, *Phys. Rev. A* **90**, 023609 (2014)

# Scheme for laser pulses sequence



Phase shift ratio of AIs:  $\Phi_1/\Phi_2 \approx 2:1$

# Scheme for Raman lasers



$$\Delta_2, I'_1, I'_2, I'_3, I'_4 \rightarrow \Omega_{eff}^{87} = 2\Omega_{eff}^{85}$$

$$\Delta_2 - \Delta_1 \simeq 100 \text{ MHz}, \quad \Delta I \simeq 10 \sim 100 \text{ mW}$$

Change the detuning and intensity of lasers



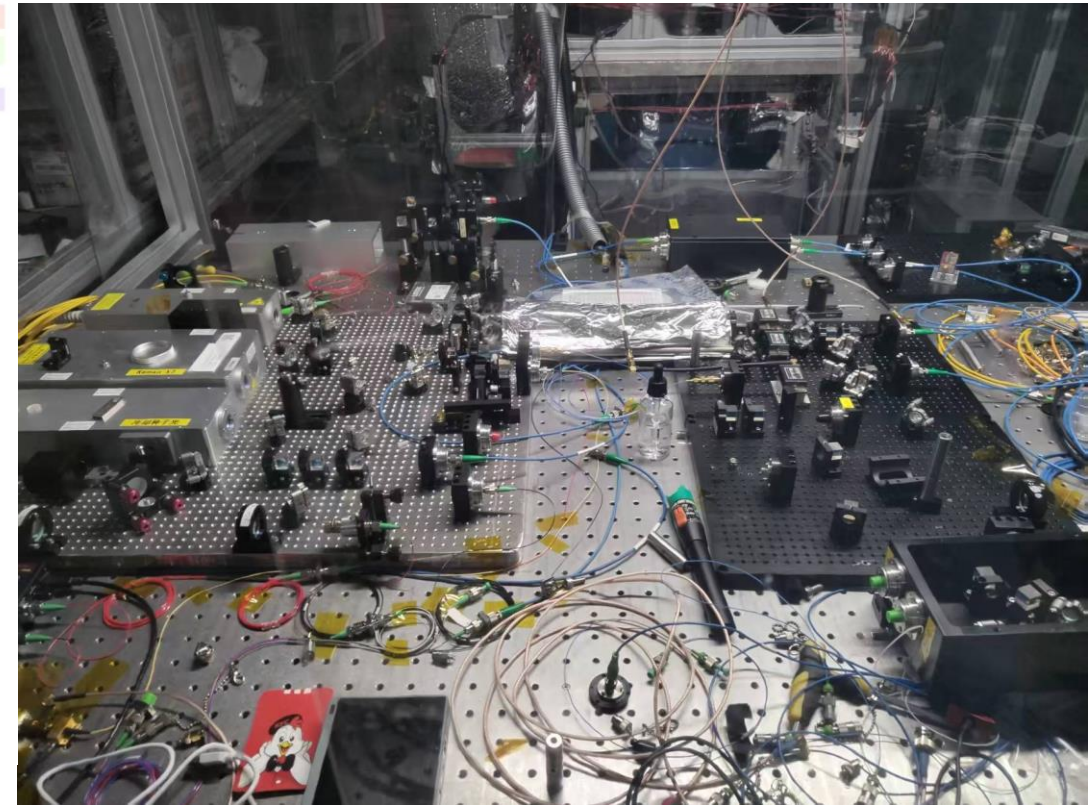
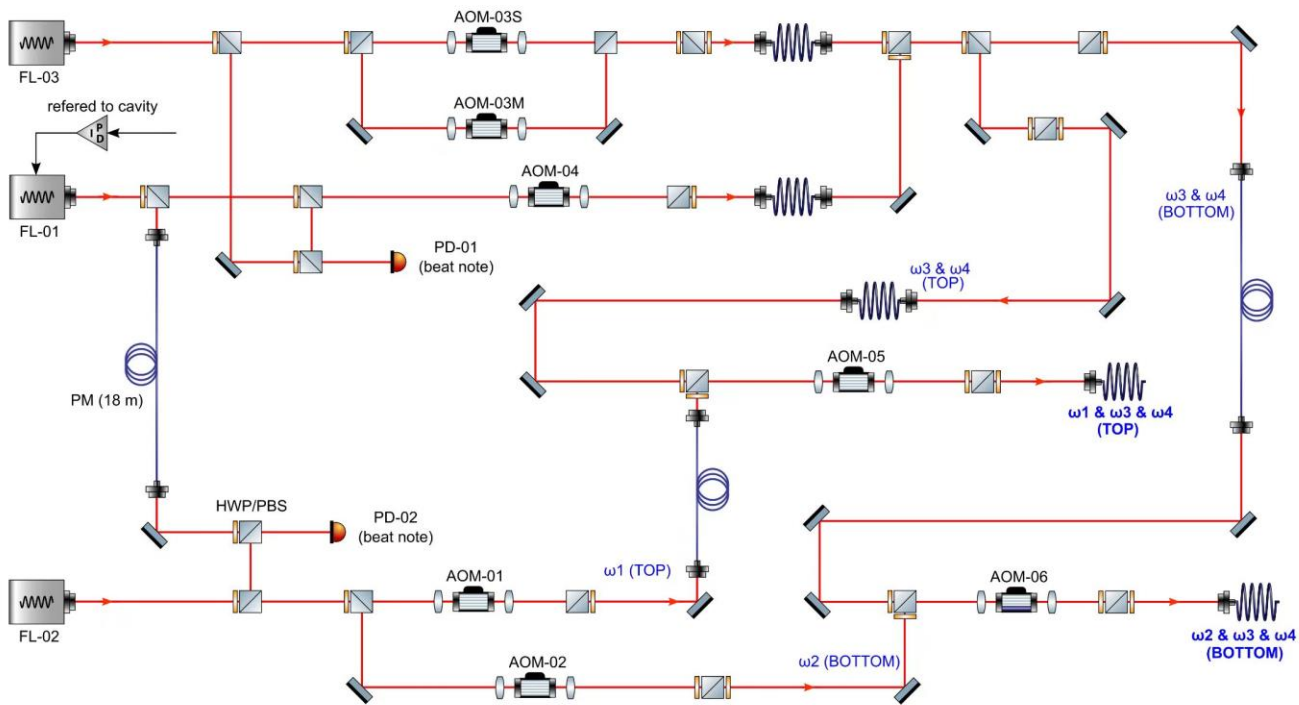
$$\Delta_1, I_1, I_2, I_3, I_4 \rightarrow \Omega_{eff}^{87} = \Omega_{eff}^{85}$$

$$\Delta_1, I_1, I_2, (I_3 + I'_3), I_4 \rightarrow \Omega_{eff}^{87} = 2\Omega_{eff}^{85}$$

$$I_3 : I'_3 \quad (1 : 0) \rightarrow (0.17 : 0.83)$$

Compensation laser  $\omega'_3$  + change the intensity ratio of laser beams

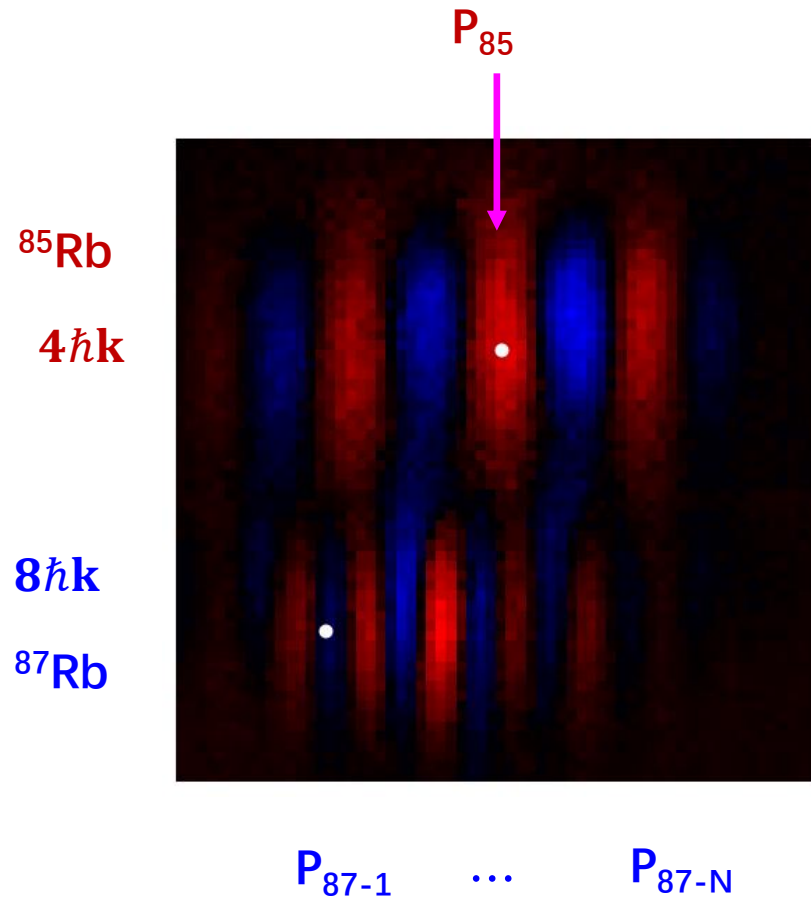
# Laser system



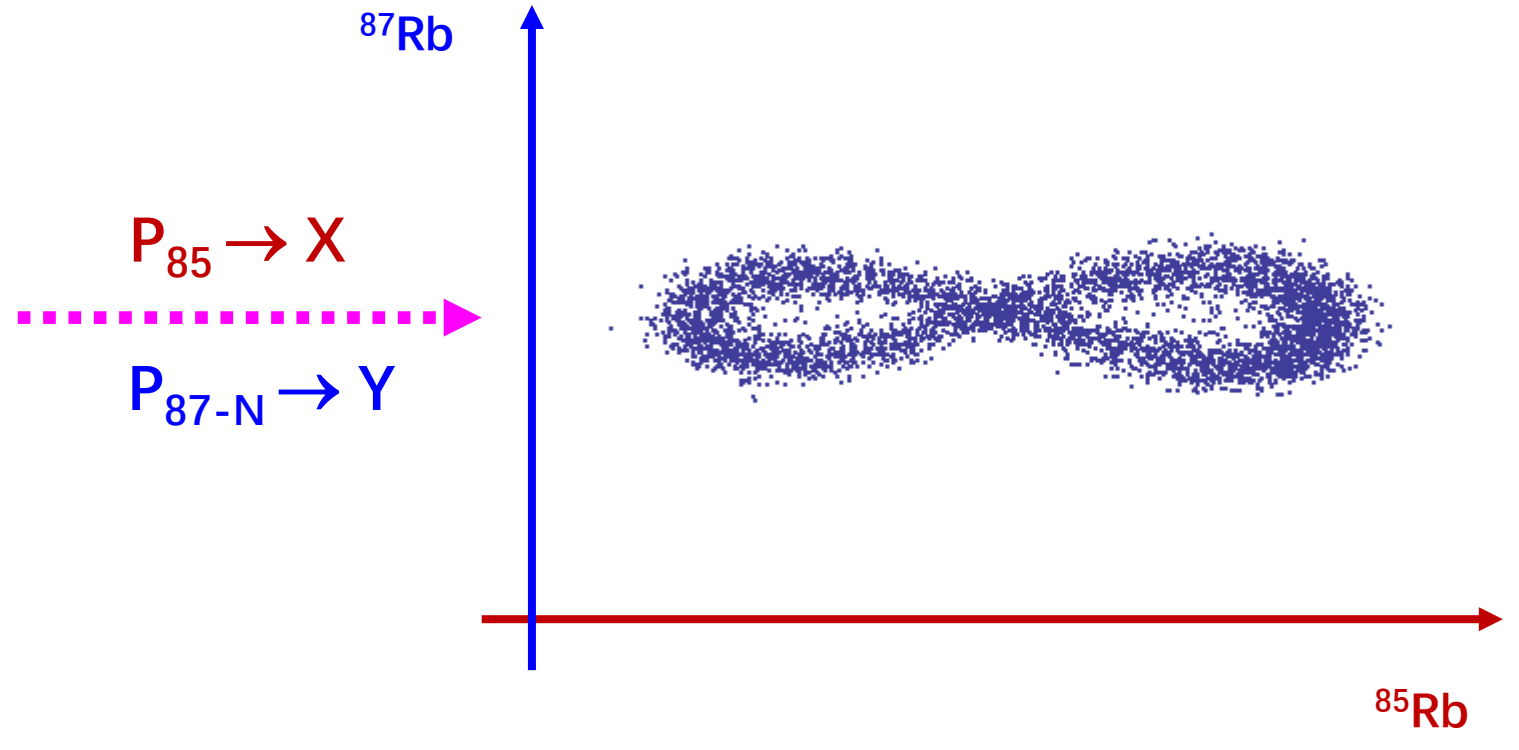
Fiber laser  $\times$  3

FL-01:  $\omega_4$   
FL-02:  $\omega_1$  &  $\omega_2$   
FL-03:  $\omega_3$  &  $\omega'_3$

# Experimental results



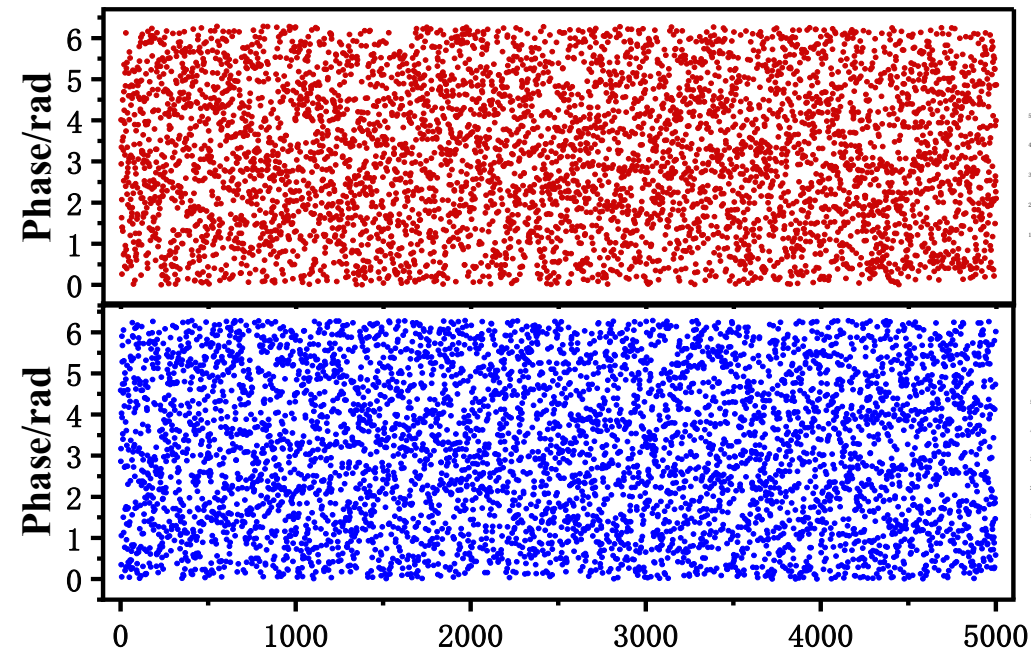
Shearing interference fringes



Lissajous curve (5000 data points)

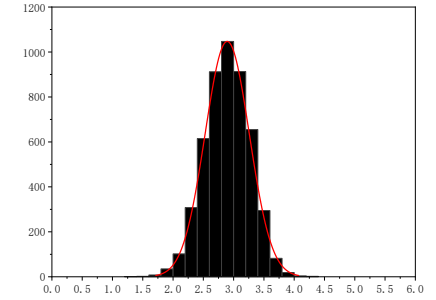
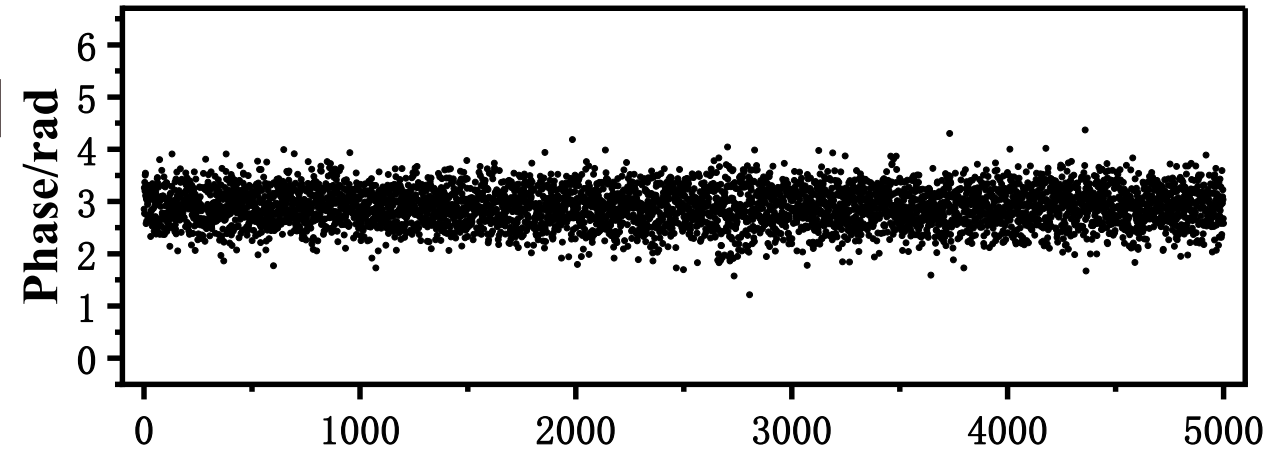
# Experimental results

$$\phi_{85} = 4kg(t)T^2 = n\pi + \phi_{85-0}$$



$$\phi_{87} = 8kg(t)T^2 = 2n\pi + \phi_{87-0}$$

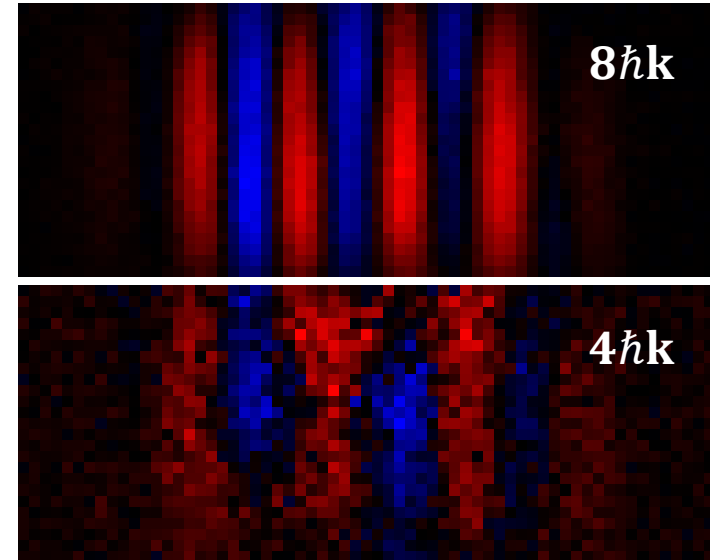
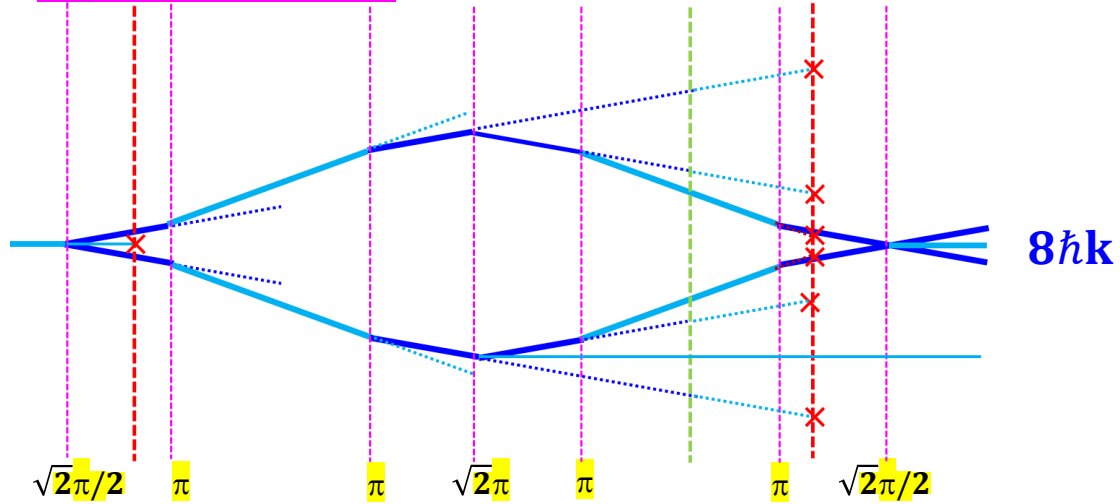
$$T = 100\text{ms} \quad \delta\phi > 20\pi$$



$$\begin{aligned} \Delta\phi &= \phi_{87} - 2\phi_{85} \\ &= \phi_{87-0} - 2\phi_{85-0} \\ \Delta\phi &\in (0, 2\pi) \end{aligned}$$

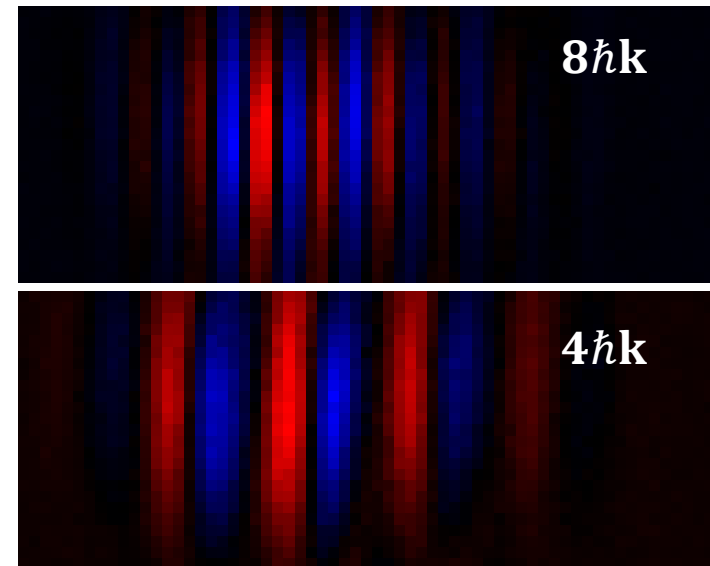
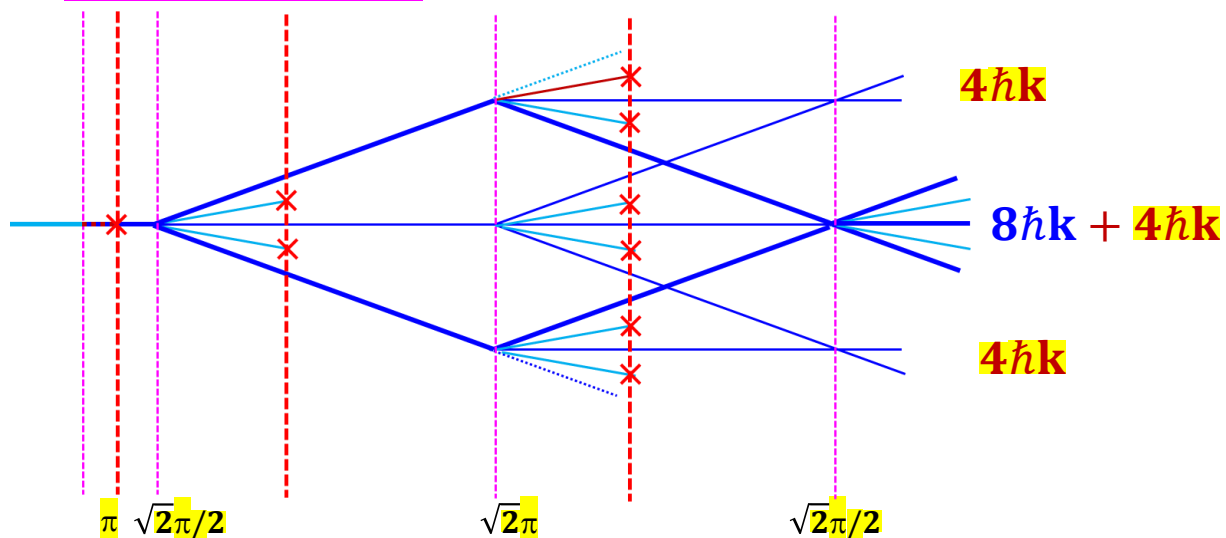
# Parasitic interferometers

## 7 pulses scheme



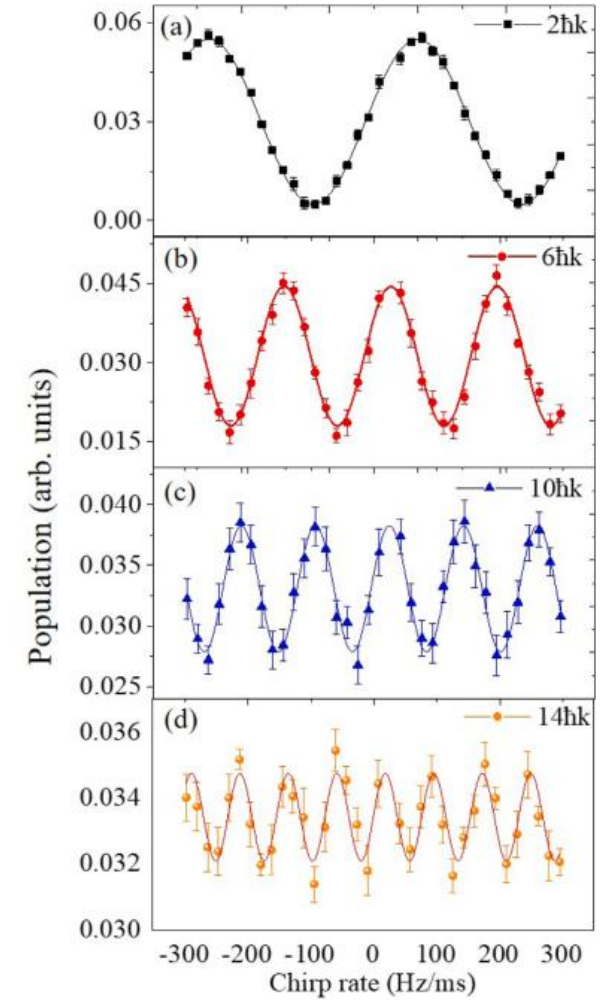
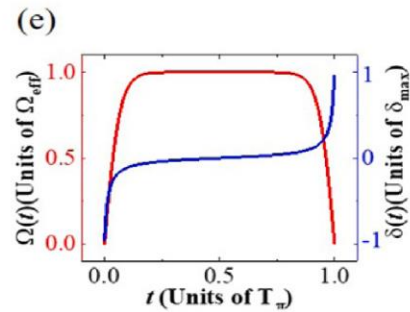
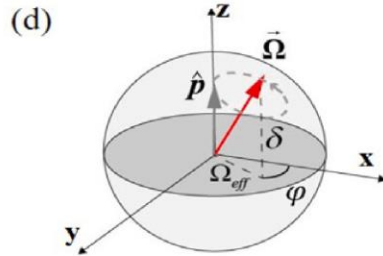
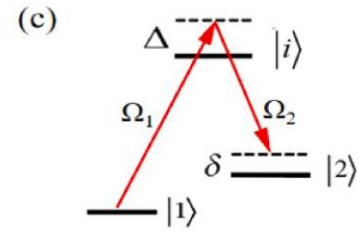
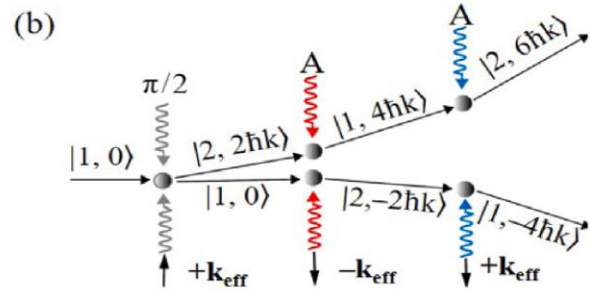
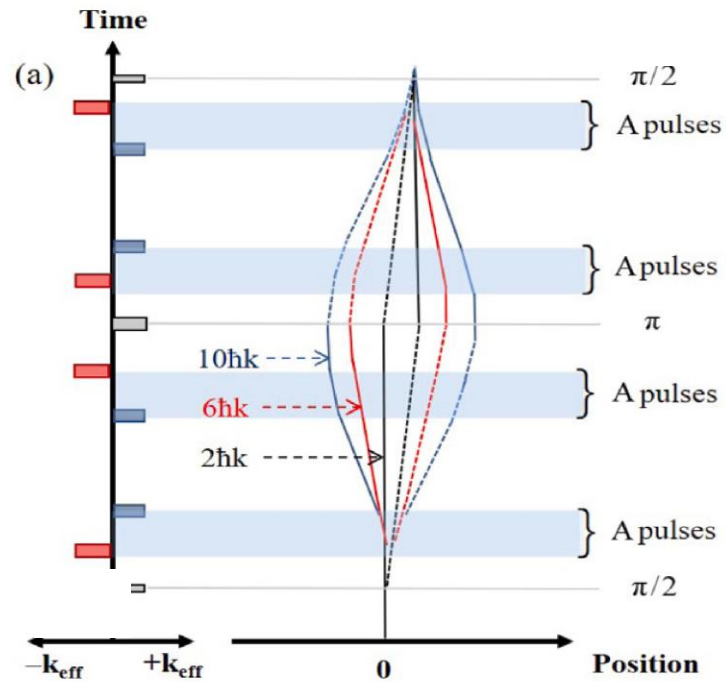
$^{87}\text{Rb}$   
 $8\hbar k$ : 5.7%  
 $4\hbar k$ : 0.8%

## 3 pulses scheme



$^{87}\text{Rb}$   
 $8\hbar k$ : 2.6%  
 $4\hbar k$ : 2.1%

# Raman adiabatic rapid passage (RARP)



# 4 Summary and discussion

1. We have developed a large momentum transfer technique for dual-species atom interferometers that is insensitive to the differential recoil frequency.
2. We have implemented dual-species atom interferometers with different LMT orders and demonstrated their common-mode rejection capability under high-phase-noise conditions.

Next steps:

1. Improve atomic state transfer efficiency of Raman pulses (ultracold atomic sources, Raman adiabatic rapid passage techniques)
2. Perform large-dynamic-range gravity measurements using LMT dual-species atomic interferometers.

# Acknowledgments

**Group members:** Ming-Shen Zhan, Jin Wang, Chuan He , Si-Tong Yan, Run-Dong Xu, Dong-Feng Gao, Xi Chen, Wei-Tou Ni

**Graduate students:** Jun-Jie Jiang, Zhuo Hou, Zhi-Xin Li, Jia-Qi Lei, Lu Zhou, You-Meng Hu, Jia-Ming Wei.

**Funding:**

Ministry of Sci & Tech of China (MOST)  
Chinese Academy of Sciences (CAS)  
Natural Science Foundation of China (NSFC)



**Thank you for your attention!**