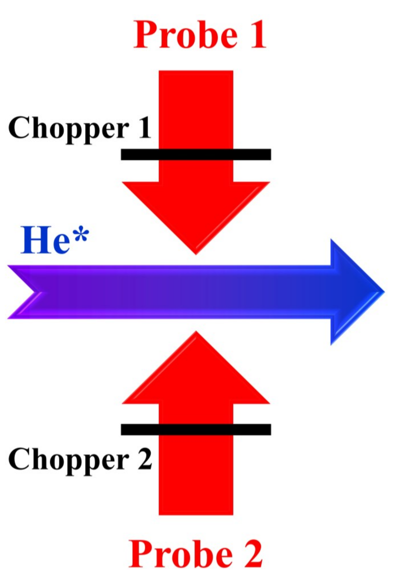
Doppler-free spectroscopy of an atomic beam probed in traveling-wave fields

Jin-Lu Wen[1], Jia-Dong Tang[2], Jun-Feng Dong[1], Xiao-Jiao Du[3], Y. R. Sun[3], Shui-Ming Hu[1,2]

[1] Department of Chemical Physics, University of Science and Technology of China, Hefei 230026, China
[2] Hefei National Research Center of Physical Sciences at the Microscale, University of Science and Technology of China, Hefei 230026, China
[3] Institute of Advanced Science Facilities, Shenzhen 518107, China

Experimental Method

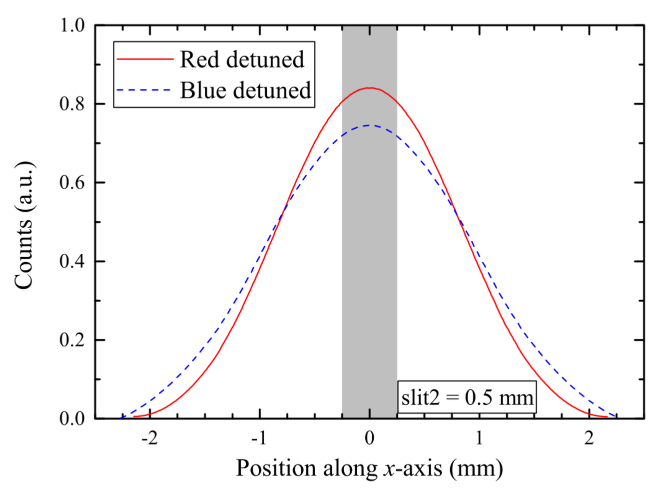


Background

- Common methods: Prism reflection, Interferometric, Cat's Eye, Active Fiber-based Retroreflector (AFR)
- Both the Cat's Eye and the AFR method could adjust the deviation angle ξ less than 10 μrad

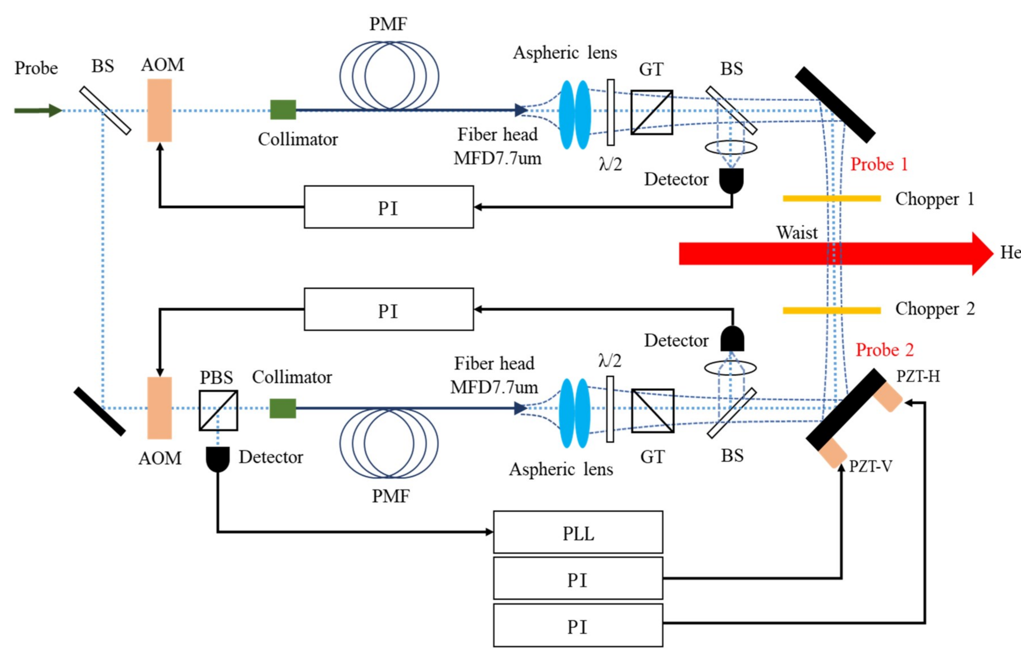
Challenges of Standing-Wave

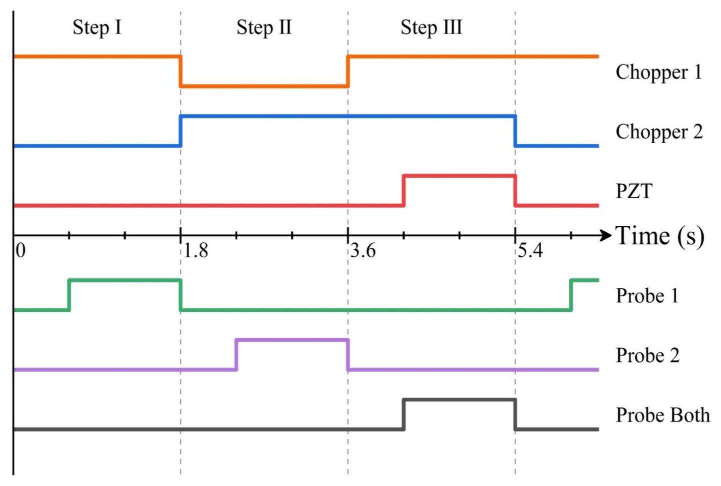
- Incident angle should be close to $\pi/2$
- Differences in parameters of laser beams may lead to systematic error
- Big dependence of laser power
- Detectable laser-cooling effect

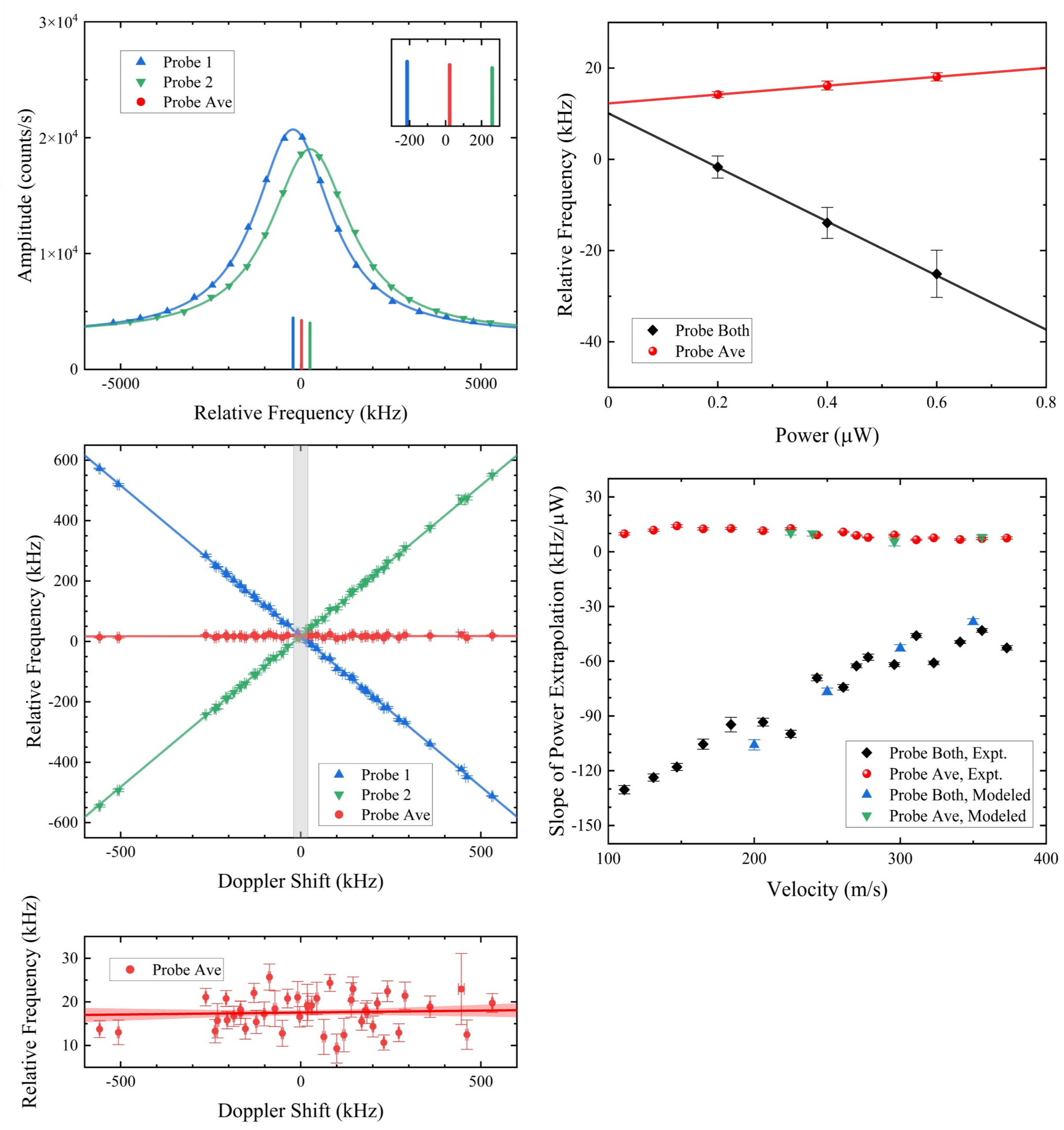


X. Zheng et al. Phys. Rev. A 99, 032506 (2019)

Sequential Counterpropagating Traveling-Wave Optical Pulses Method (SCTOP)







- Detect with traveling-wave on both sides separately
- Couple laser from one fiber to the other to overlap
- Could be measured with any incident angle between ± 3.5 mrad
- Less power dependence

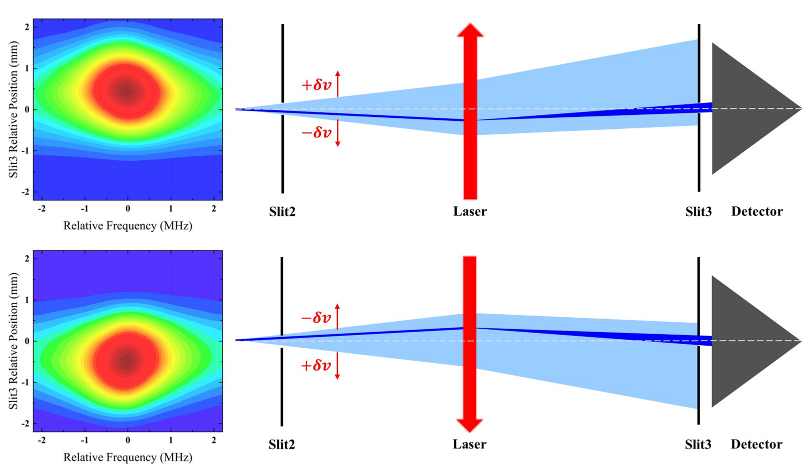
> **Read more: Phys. Rev. A 107, 042811 (2023)**

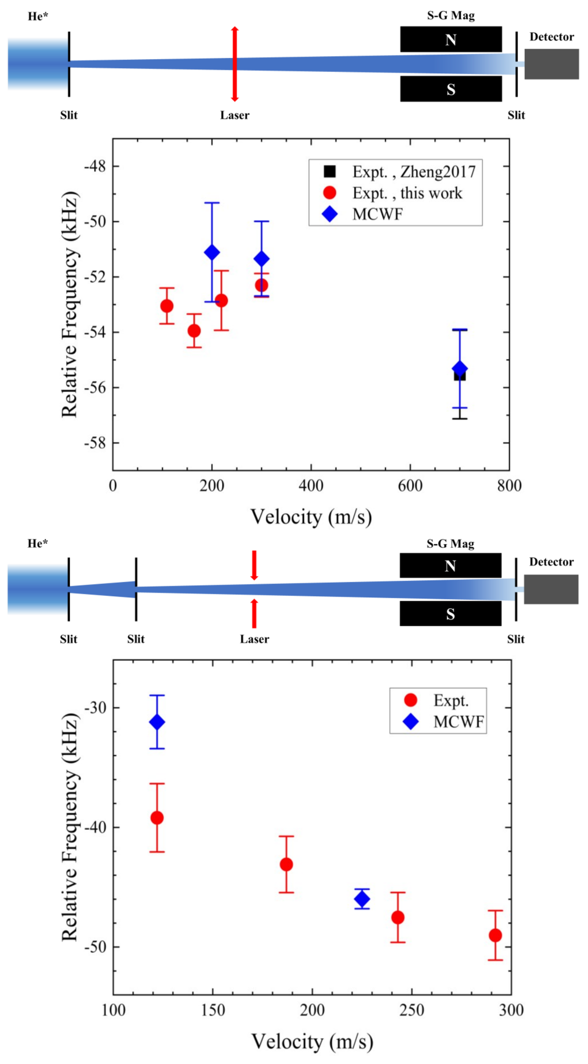
> **Contact: wjl14@mail.ustc.edu.cn**

New Systematic Shift

Postselection Shift

We detected the distribution after interaction with the laser and found that the slit before the detector would select some part of the atomic beam with transverse velocity, and this postselection effect could induce systematic shift



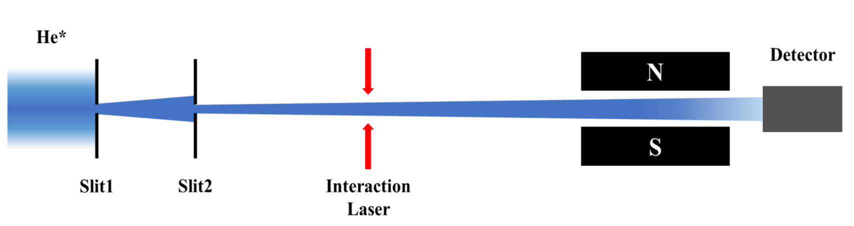


At a high beam speed, the shift could be simply expressed as $\Delta f = \frac{h}{m\lambda^2}\frac{l_f}{l}$, here l is the distance between two slits and l_f is the distance from laser to the slit before detector

While the transverse distribution of velocity and location couldn't be ignored when the beam velocity is slow, especially in a narrow beam. We used the Monte Carlo Wave Function (MCWF) method to simulate, and the results are consistent with what we see in the experiment

The correction for Zheng2017 is + 55.3 (1.4) kHz

How to Avoid This



- A sufficiently narrow beam
- Detect all
- No postselection slit or an equivalent slit

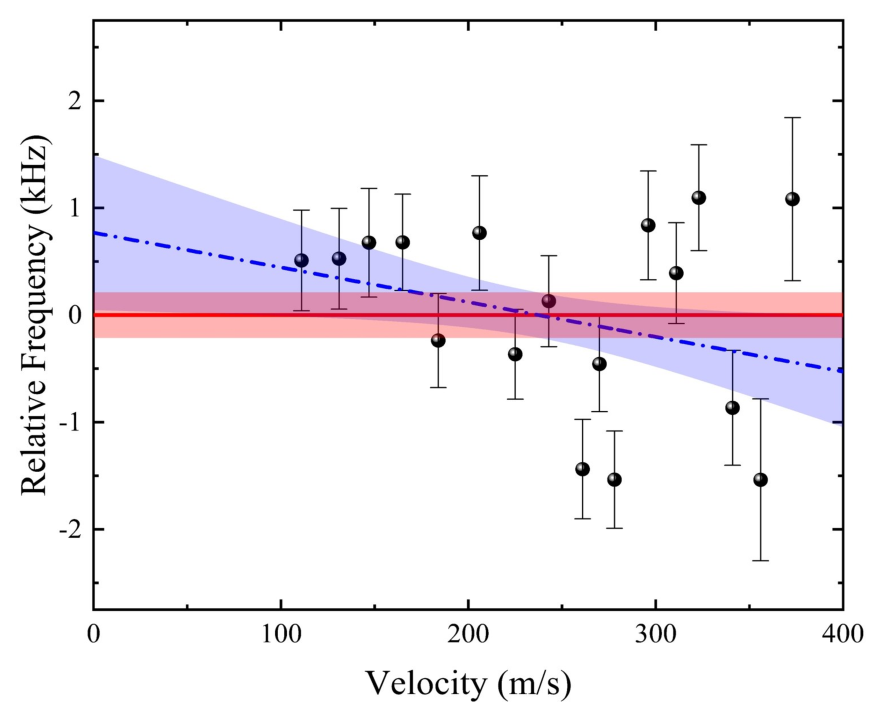
† Unpublished result

† See more about postselection effect: Rev. Mod. Phys. 86, 307 (2014)

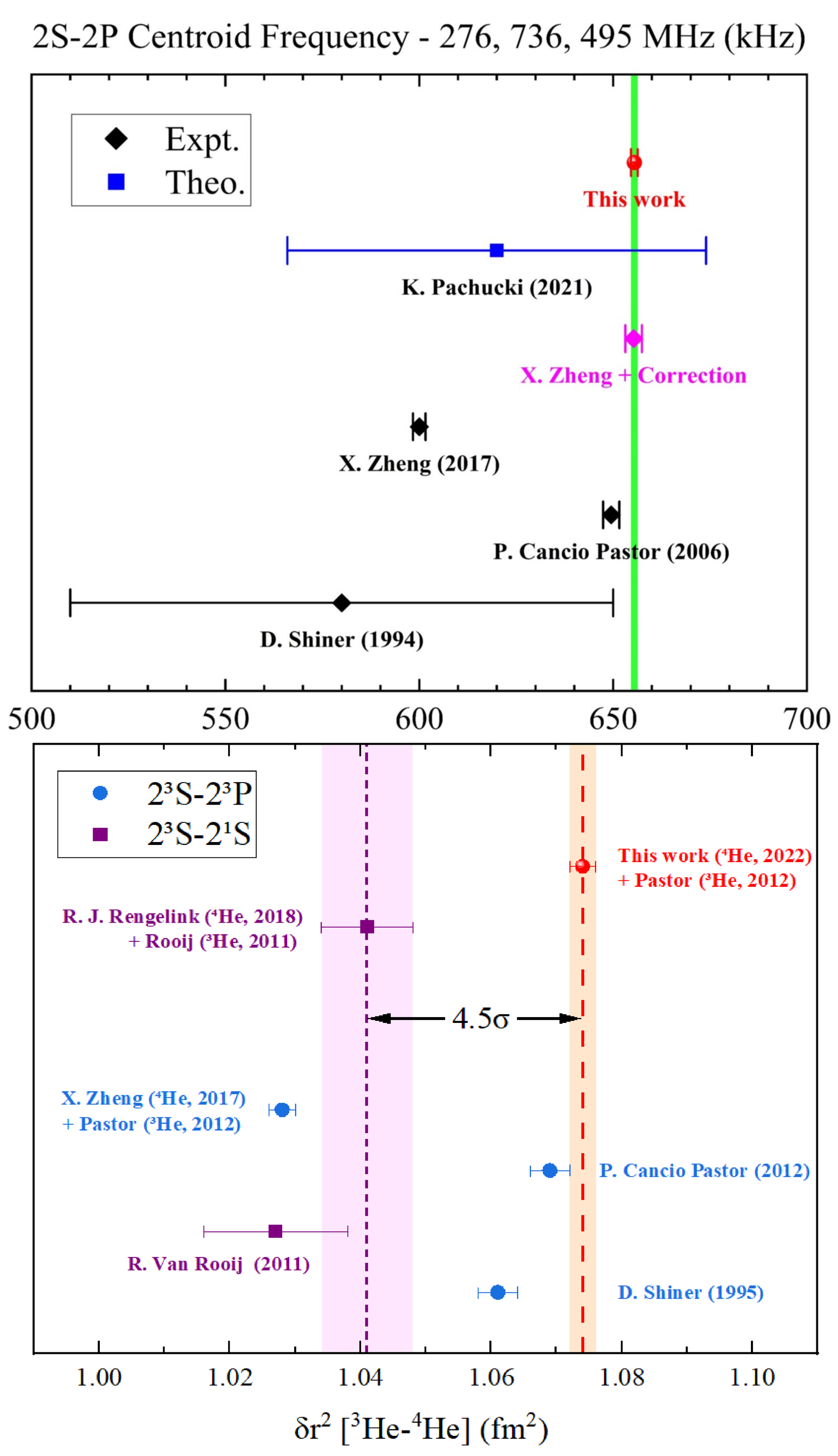
Preliminary Result

^{4}He 2^3S-2^3P

With the SCTOP method and a configuration without postselection effect, we measured the frequency of $2^3S_1 - 2^3P_0$ transition of ^{4}He, and the final accuracy could be less than 1 kHz



Δf(1σ)	X. Zheng	This work
Statistics	0.45	0.22
1st Doppler	1.1	0.82
2nd Doppler	0.15	0.01
Frequency calibration	0.55	0.05
Line profile	0.3	
Quantum interference	0.1	0.1
Zeeman effect	0.01	0.01
Laser power	0.1	0.1
Light-force shift	0.8	
Total	1.6	**0.86**



New ^{3}He measurement is undergoing at Hefei!

Acknowledgment

中国科学院 CHINESE ACADEMY OF SCIENCES
NSFC National Natural Science Foundation of China
中华人民共和国科学技术部 Ministry of Science and Technology (MoST)