UNOOSA Hypergravity/Microgravity Webinar

2021-06-02

# Scientific experiments of ultra-cold atom and quantum simulation in Chinese Space station


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**Institute of Quantum Electronics, Peking University**

# Outline

1. Introduction to the International Space Ultra-cold Atomic Physics Experiment

2. The scientific missions of the space station's ultra-cold atomic experiment rack

3. The experimental principle of obtaining 100pK temperature

4. Progress of ultra-cold atomic physics rack for Chinese space station

5. Scientific experiments in the ultra-cold atomic laboratory rack

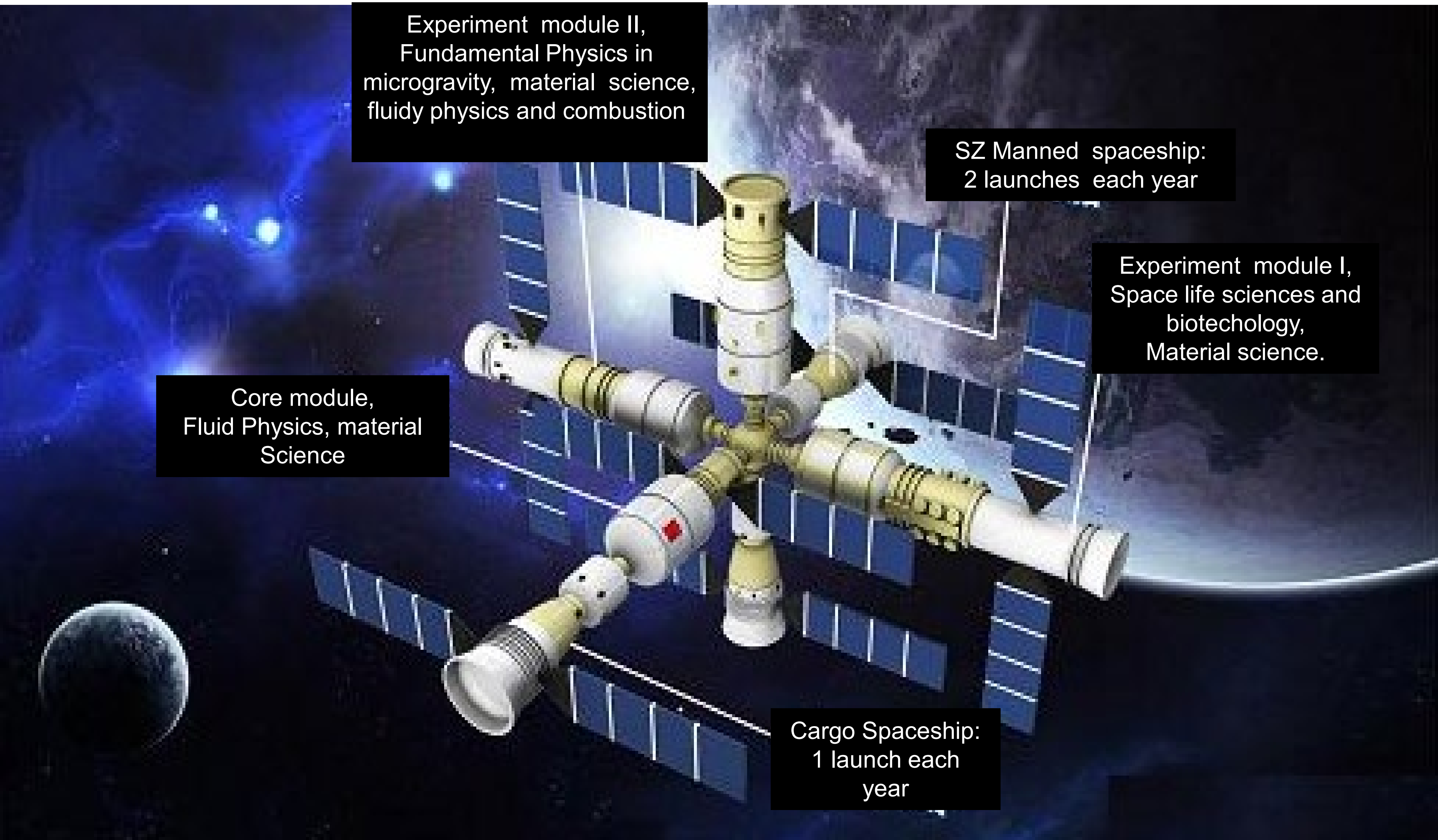
6. Summary

# China space station launch

Core module launch April 29, 2021

# Chinese Space Station

## Core module launch in 2021, Science II module launch in 2022




- 2006-2009
  - Demonstration of Manned Space Development Strategy
  - Demonstration of the space station project implementation plan

- 2009.12-2010.8
- More than 30 seminars held
- 148 units, 304 experts and 45 academicians across the country

- 2010.09-2011.3
- Invite 107 experts to establish 7 field demonstration working groups
- Nearly 30 seminars have resulted in 8 field demonstration reports and 7 field task guides

- 2012.1.-2013.4
- Confirm 14 platforms

**Historical argumentation**

**The first round of deepening demonstration of space station applications**

**The second round of deepening demonstration of space station applications**

**Demonstration of Space Station Application Platform**

***Nearly 1,000 domestic experts in various fields have participated in the application task demonstration work.***

# Goals and Missions for Chinese Space station

**The overall goal: to build a national-level space laboratory, and strive to make major breakthroughs in science and technology.**

**Space science research goals: In the key areas of frontier exploration of space science, we will obtain a number of major discoveries with international influence, enter the world's advanced ranks, and improve the overall level of space science in my country.**

- **Space Life Science and Biotechnology**
  - Space Basic Biology Research
  - Space Radiation Biology Research
  - Frontier and Interdisciplinary Research of Space Life Science
  - Space Biotechnology and Application Research
  - Basic Research on Space Ecological Life Support System
- **Microgravity Fluid Physics and Combustion Science**
  - Research on Microgravity Fluid Dynamics and Its Application
  - Two-phase flow, phase change heat transfer and its application research
  - Combustion Science and Its Application Research
- **Space Materials Science**
  - Mechanism of Material Preparation Process in Microgravity Environment
  - Preparation and research of important application background materials
  - Research on Material Service Behavior in Space Environment
- **Basic Physics of Microgravity**
  - Space Cold Atom Physics
  - Relativity and Gravitational Physics
  - High-precision time-frequency system and its application
  - Low temperature condensed matter physics experiment
- **Space Astronomy and Astrophysics**
  - Multi-color high-precision photometry and spectral survey
  - Dark matter particles and cosmic ray detection
  - Celestial Variation and Outburst Phenomenon Detection
  - Space Astronomy New Technology Experiment
- **Space Environment and Space Physics**
  - Space environmental forecasting and monitoring
  - Space Physics Exploration Research

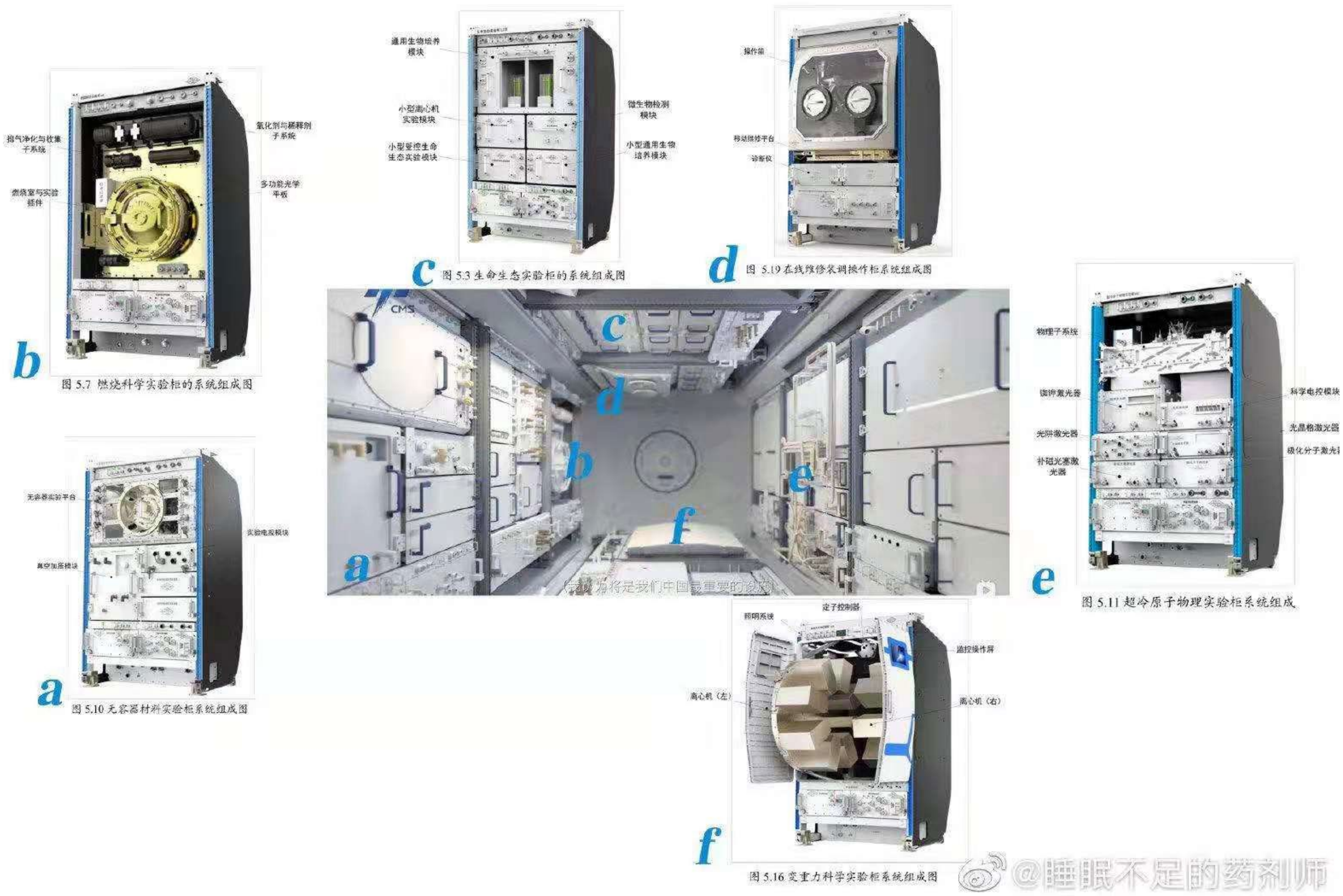
# Scientific experiment platform planning

1. Life Ecological Experiment Platform
2. Biotechnology Experimental Platform
3. Online operation and cryogenic storage platform
4. Fluid physics experiment platform
5. Two-phase system experiment platform
6. Combustion experiment platform
7. High-temperature material science experiment platform
8. Non-container material experiment platform
9. Ultra-cold atomic physics experiment platform
10. High-precision time-frequency system
11. High and microgravity experiment platform

12. Variable gravity experimental platform
13. Modular general experiment platform
14. Science popularization youth scientific experiment platform

# China Space Station-Ultra-cold Atomic Physics Experiment Platform

Science Capsule II will be launched in 2022



2018-5-20 launch



# NASA's Cold Atom Laboratory to Create 'Coolest Spot in Universe'

Mar 8, 2017 by News Staff / Source

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Bose-Einstein condensate
Cold Atom Laboratory
Dark energy
International Space Station
Matter
NASA

**Follow**

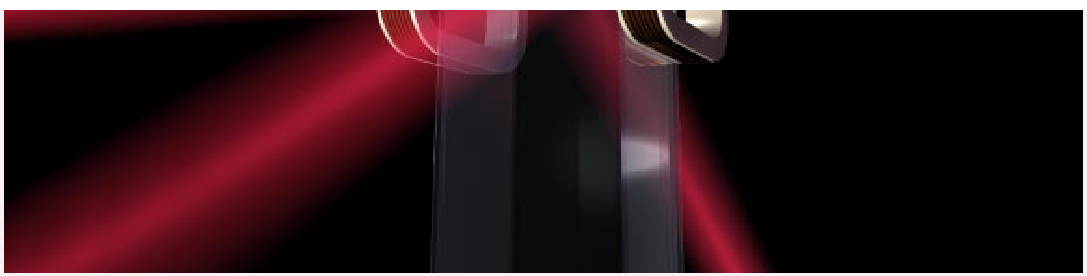
This summer, a suite of instruments called the Cold Atom Laboratory (CAL)

-- At super-low temperatures, atoms behave in surprising ways.

-- NASA has never before created or observed this behavior in space.

-- A Nobel Prize winner and other scientists will conduct experiments on this behavior using new technology.

-- This technology might one day lead to improved sensors, quantum computers, and atomic clocks used in spacecraft navigation.



Artist's concept of a magneto-optical trap and atom chip to be used by NASA's Cold Atom Laboratory aboard the International Space Station. CAL will provide an opportunity to study ultra-cold quantum gases in the microgravity environment of the space station — a frontier in scientific research that is expected to reveal interesting and novel quantum phenomena. Image credit: NASA / JPL-Caltech.

CAL, developed by NASA's Jet Propulsion Laboratory (JPL), is in the final stages of assembly, ahead of a ride to space this August on SpaceX CRS-12.

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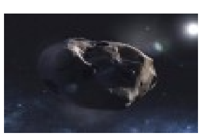
Extraterrestrials May Be More Like Us than We Think, Say Biologists



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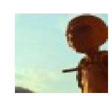
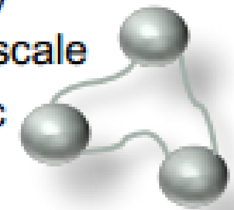


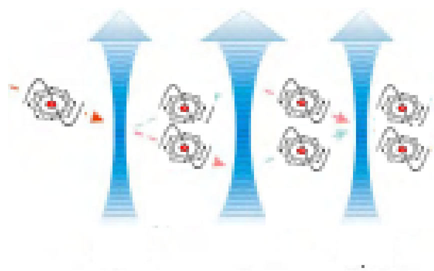
Extraterrestrials May Be More Like Us than We Think, Say Biologists
Nov 1, 2017 | Astrobiology

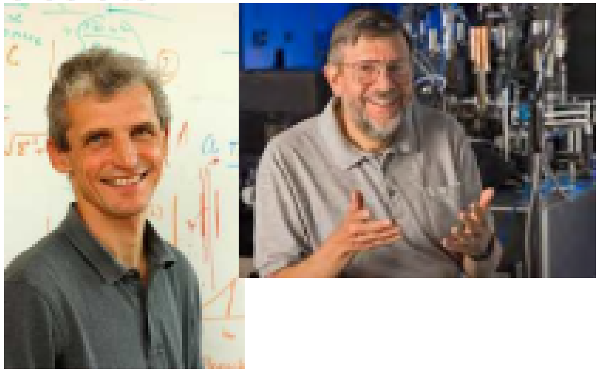
Jupiter's Northern and Southern X-Ray Auroras Pulse Independently
Oct 31, 2017 | Astronomy

# CAL1 5 Flight Investigations and Minor Facility Modifications Needed by PIs



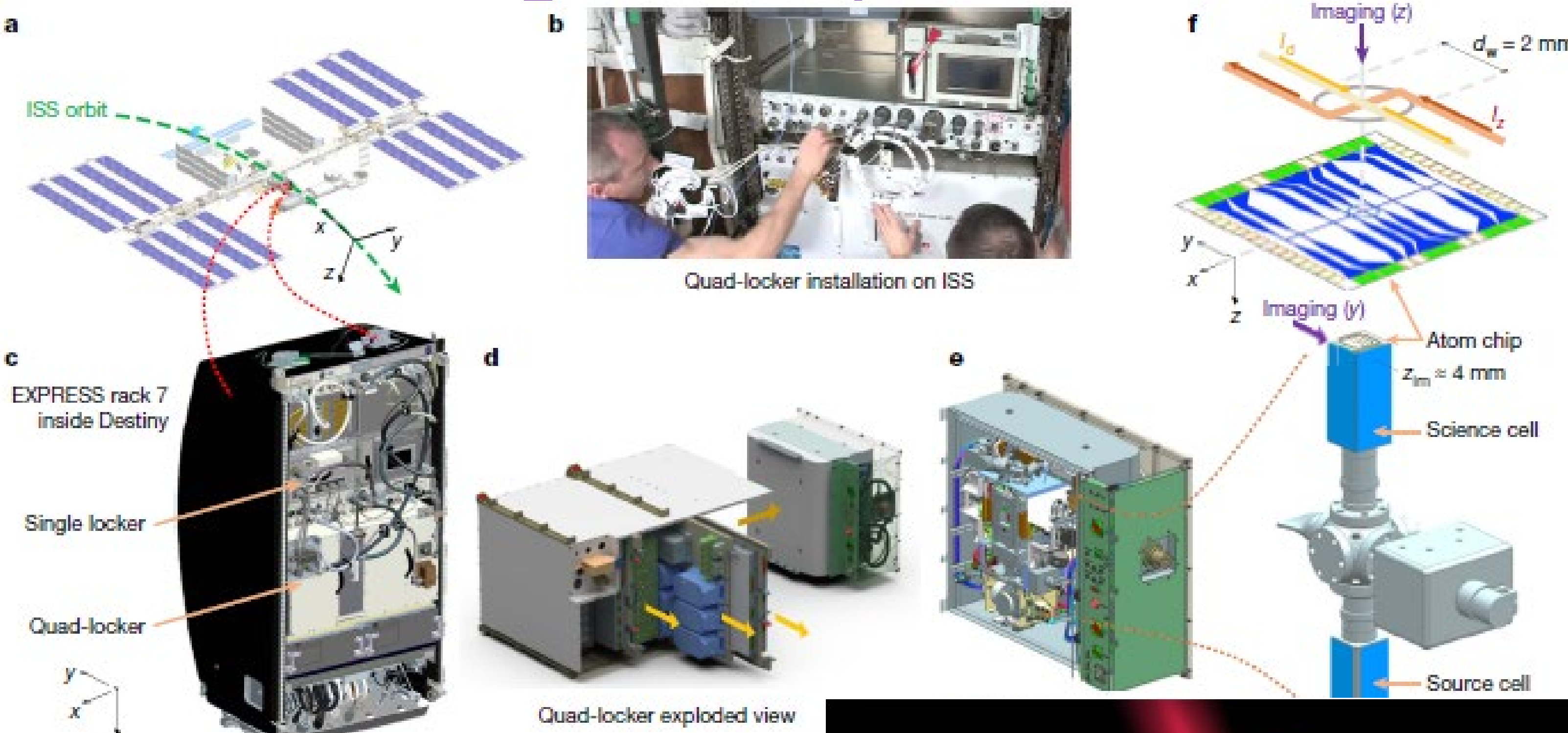
- Zero-G Studies of Few and Many Body Physics (PI E. Cornell)
  - How complexity of the universe evolves from subatomic scale
  - Incorporation of Potassium 39 and a fast tuning magnetic field into CAL instrument
- Atom interferometry will pave the way for definitive space-based tests of Einstein's Theory of General Relativity (PI N. Bigelow, Co-PI W. Ketterle, Co-I W. Phillips)
  - Holy grail of theoretical physics probing deep into Planck-scale physics
  - Incorporation of Bragg scattering beam for two species atom interferometry

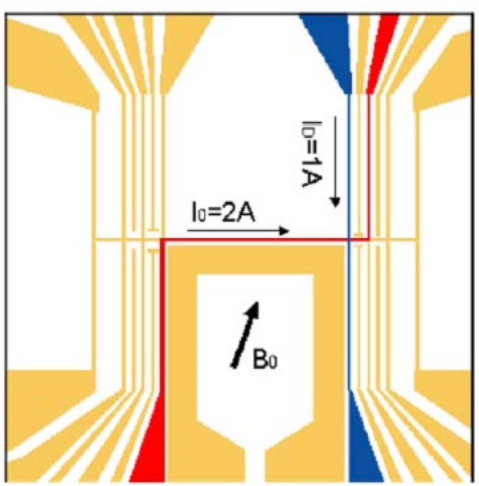




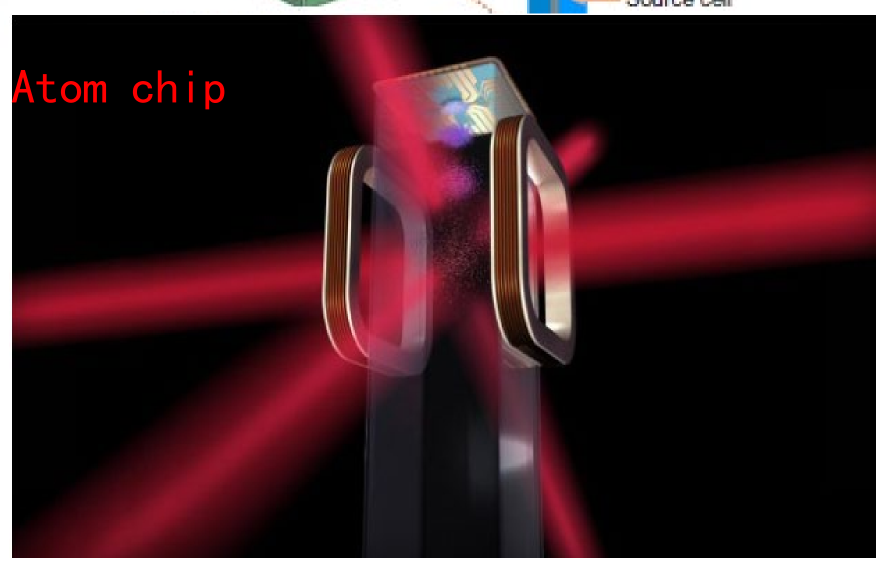
- Microgravity dynamics of bubble-geometry Bose-Einstein condensates (PI Nathan Lundblad)
- Fundamental Interactions for Atom Interferometry with Ultracold Quantum Gases in a Microgravity Environment (PI Jason Williams)
- Development of Atom Interferometry Experiments for the International Space Station's Cold Atom Laboratory (PI Cass Sackett)

# CAL (Cold Atom Laboratory) —— Design and implementation



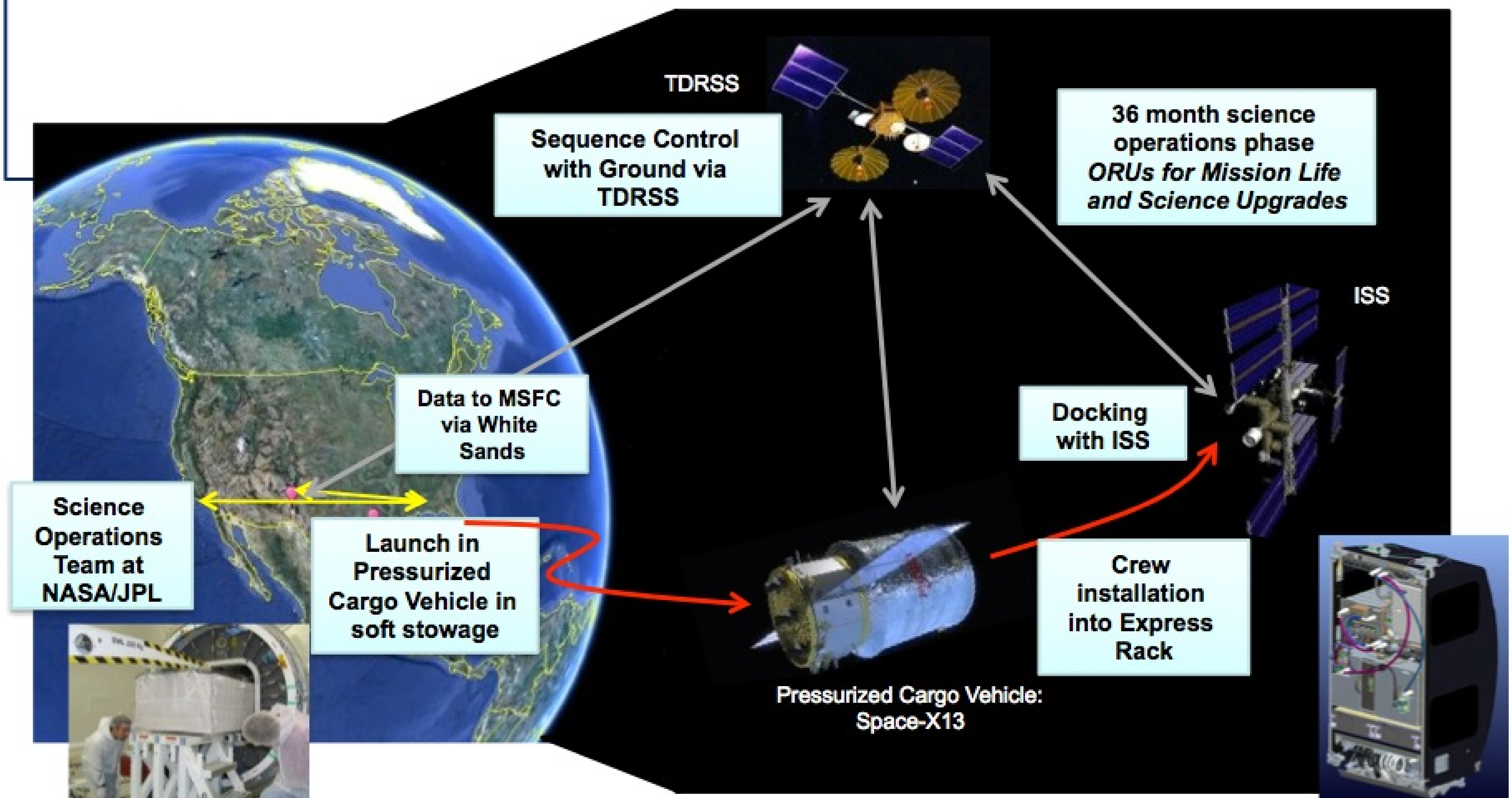




Atom chip



# CAL Mission Overview

Science Definition Sept 2012 → Development 2012-2017 → Delivery Apr 2017 → Target Launch Aug 2017 → Mission Operations Aug 2017-2020



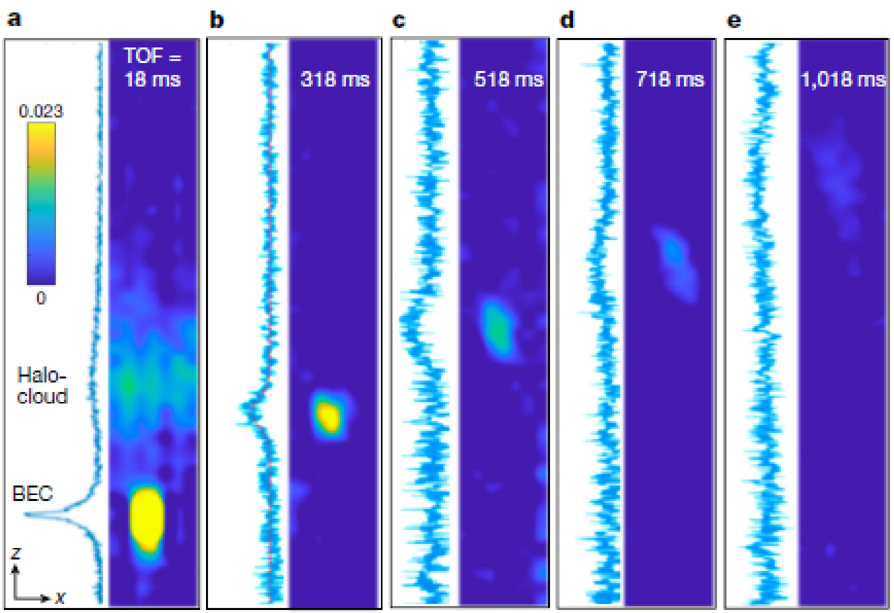
Article

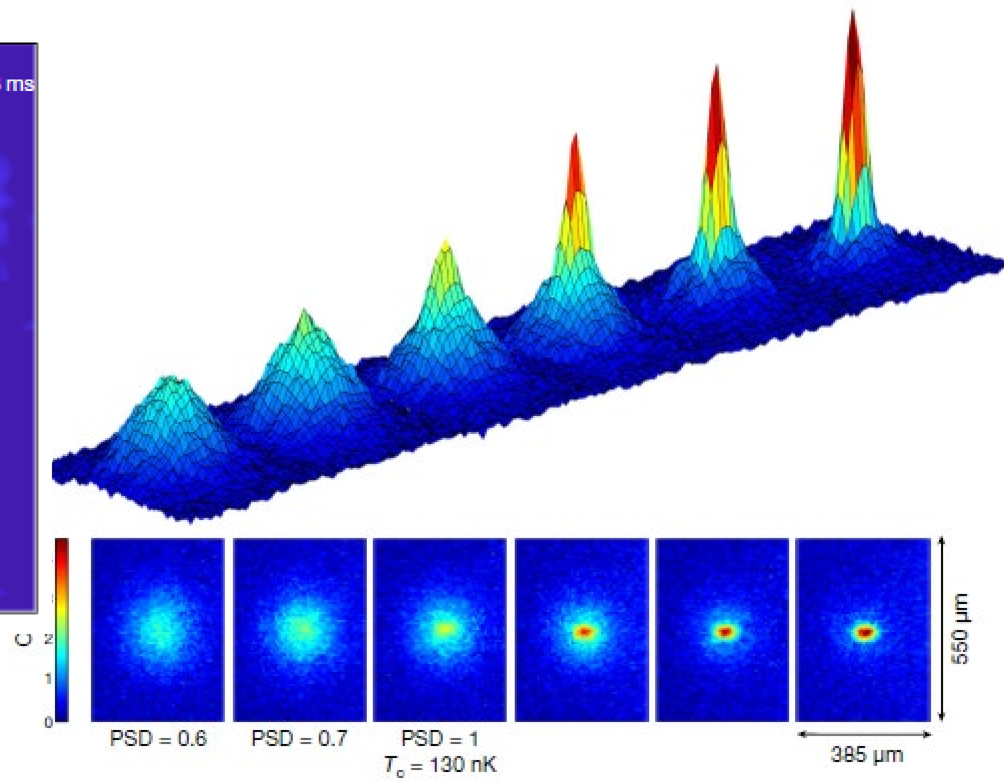
# Observation of Bose–Einstein condensates in an Earth-orbiting research lab

https://doi.org/10.1038/s41586-020-2346-1
Received: 30 October 2019
Accepted: 26 March 2020
Published online: 11 June 2020

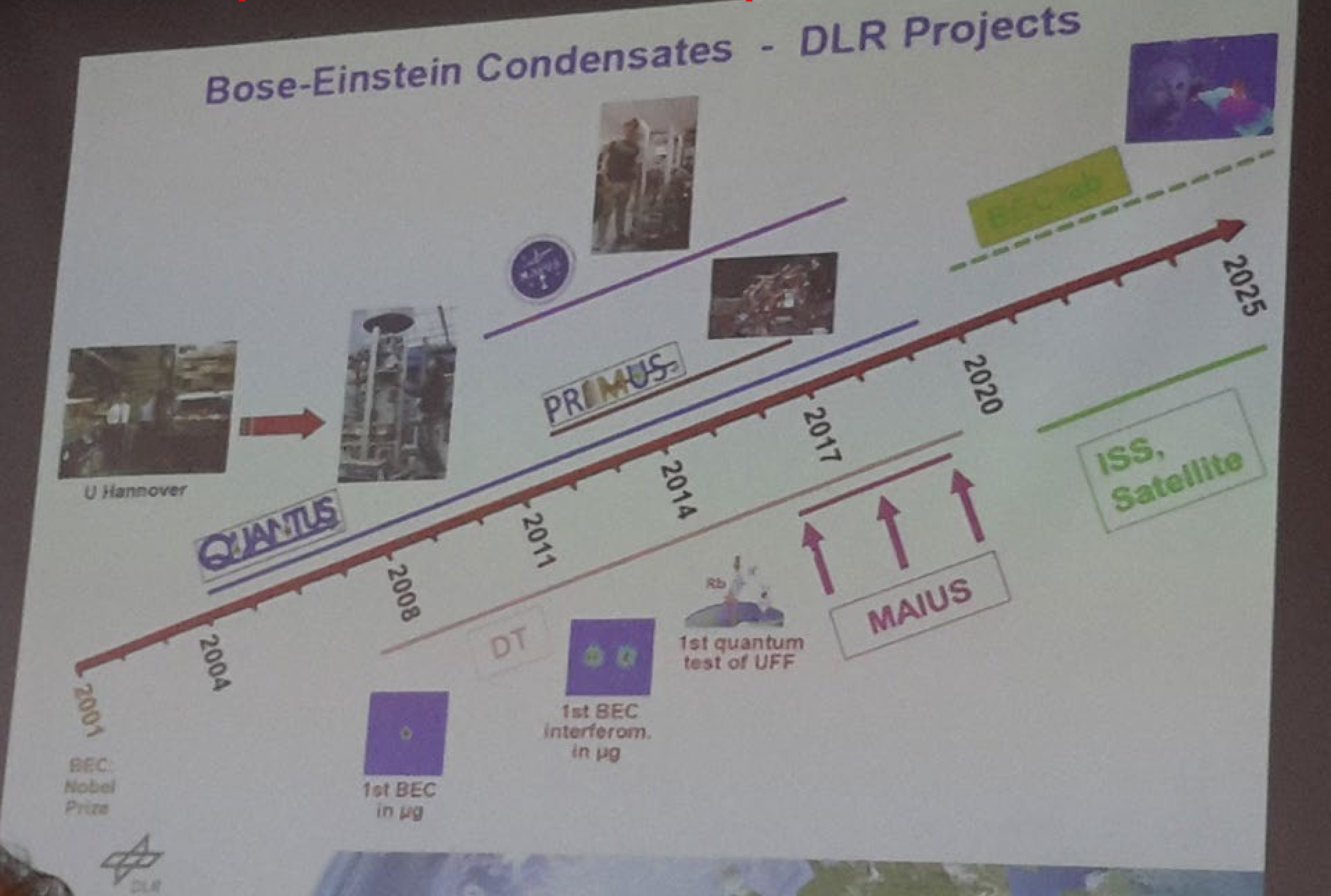
David C. Aveline[1,2]✉, Jason R. Williams[1,2], Ethan R. Elliott[1,2], Chelsea Dutenhoffer[1], James R. Kellogg[1], James M. Kohel[1], Norman E. Lay[1], Kamal Oudrhiri[1], Robert F. Shotwell[1], Nan Yu[1] & Robert J. Thompson[1]✉

Quantum mechanics governs the microscopic world, where low mass and momentum

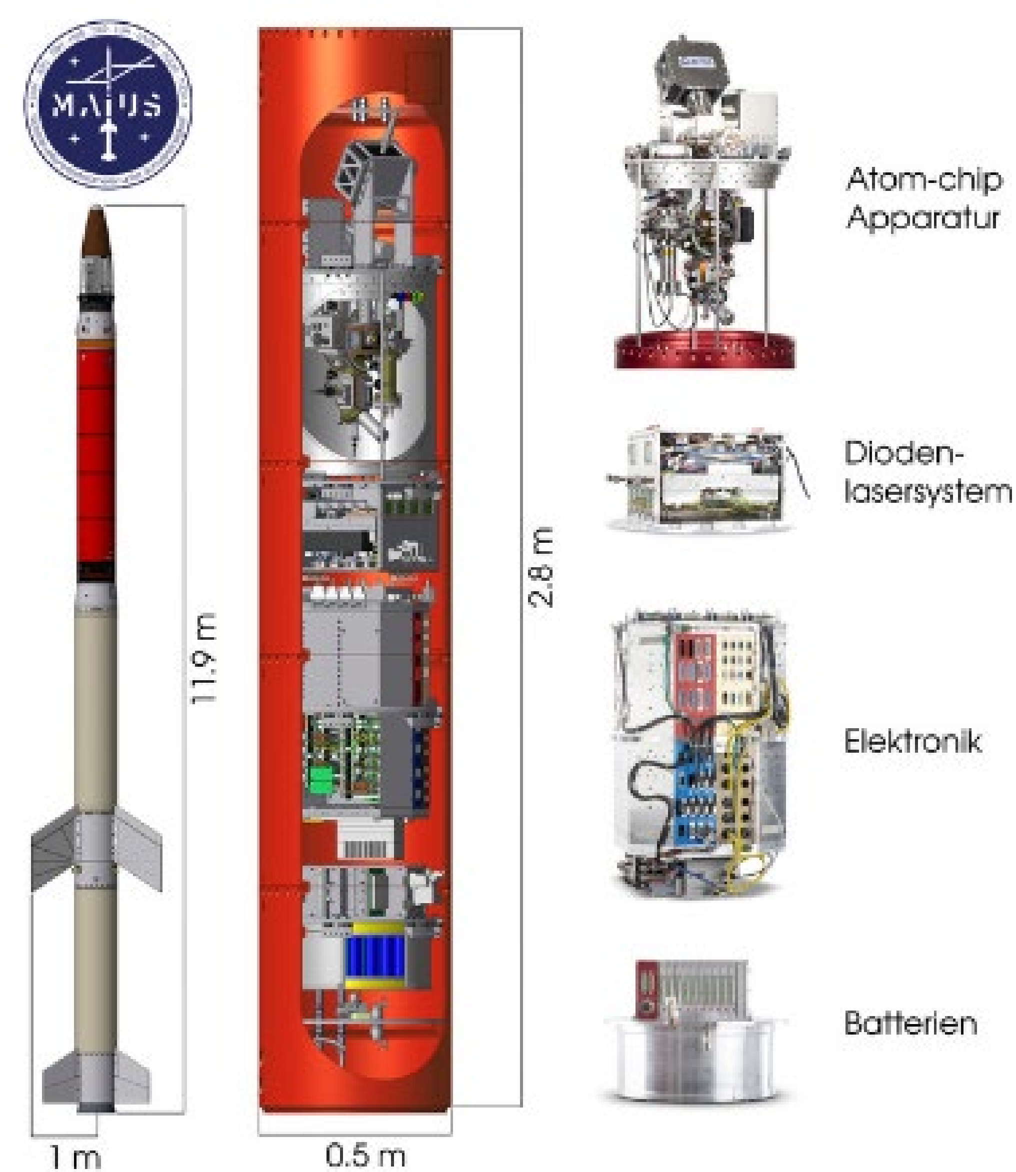


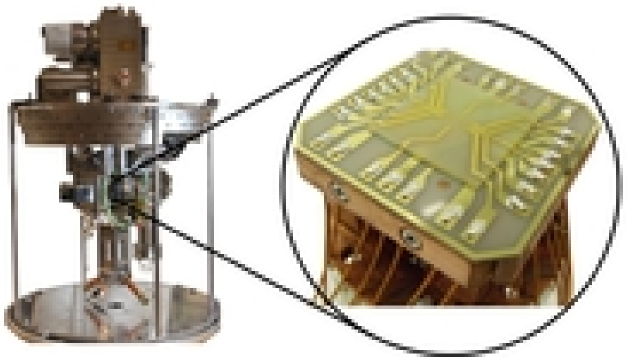



# ESA Space Cold Atom Experiment



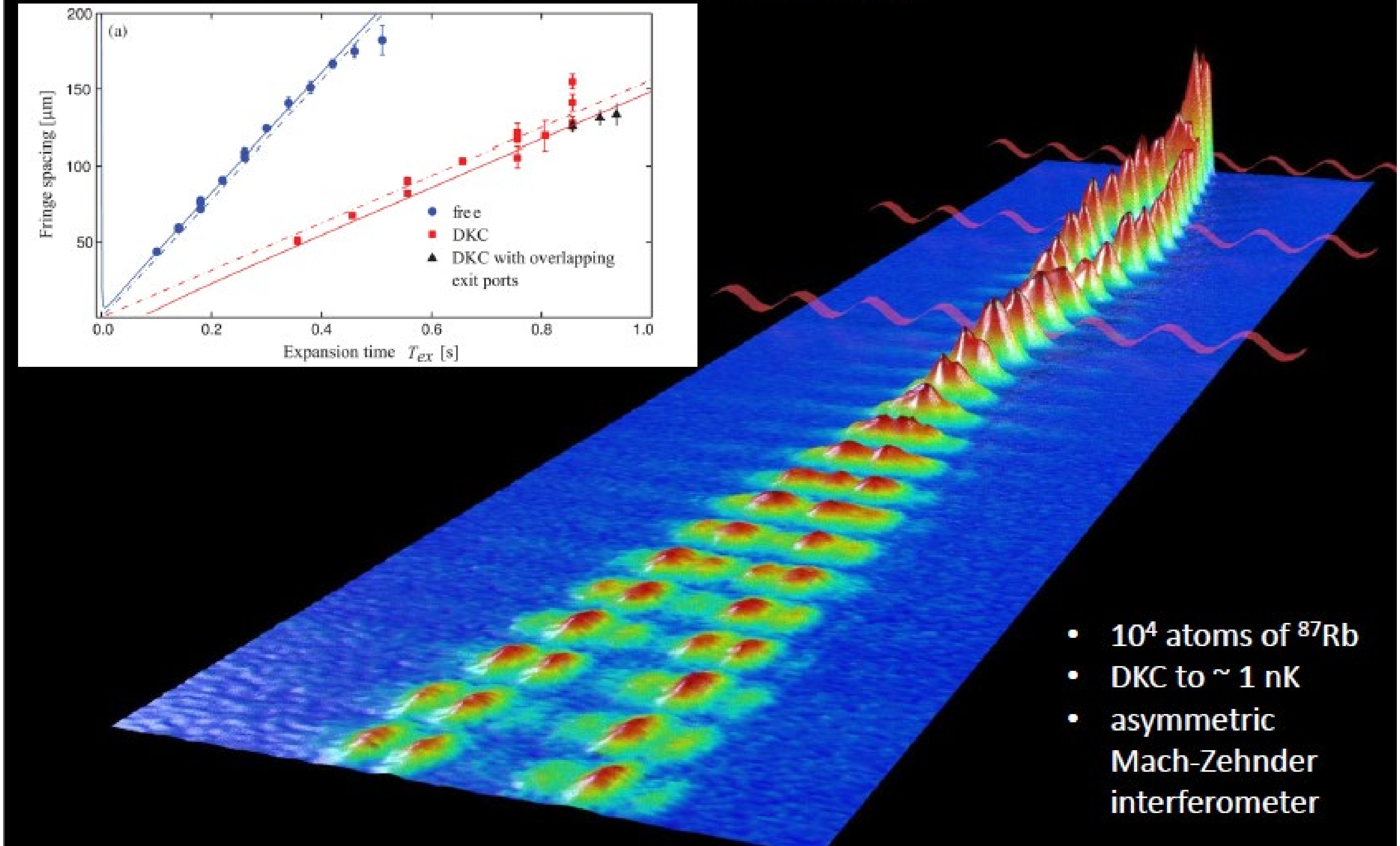
# MAIUS(I) Rocket-University of Hannover, Germany-January 23, 2017



Atom chip

# QUANTUS I – $^{87}$Rb BEC, DKC & AI in µg

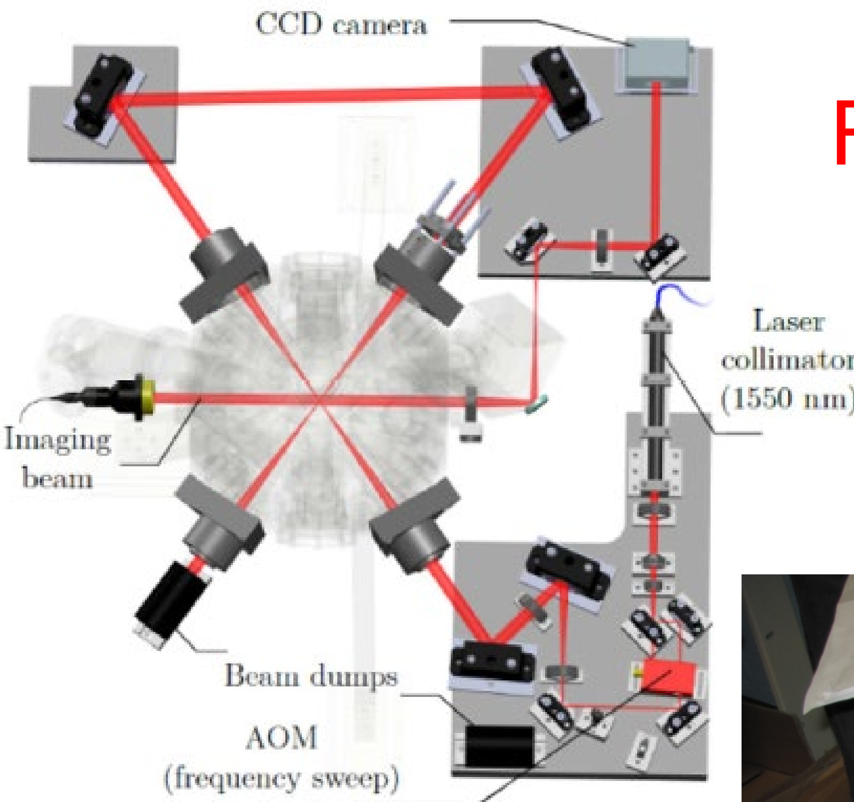


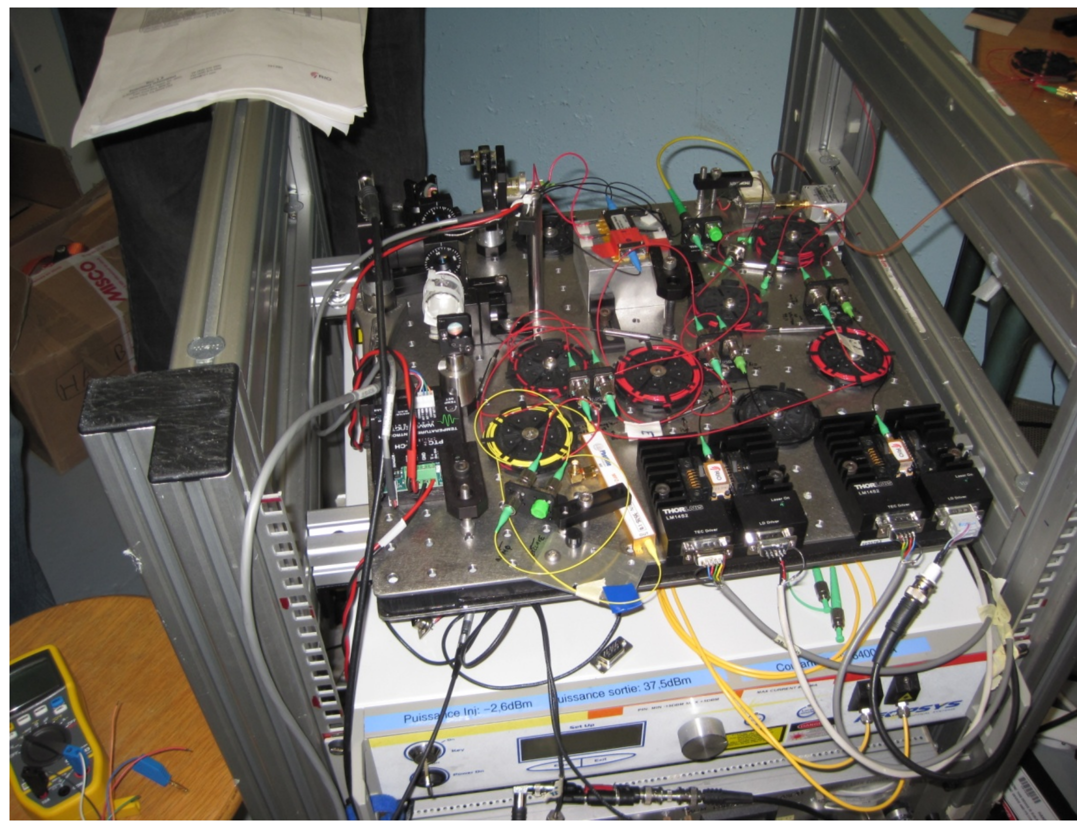

- $10^4$ atoms of $^{87}$Rb
- DKC to ~ 1 nK
- asymmetric Mach-Zehnder interferometer

[Physik Journal 05/2013; Müntinga et al., PRL 110, 093602 (2013)]

NATURE COMMUNICATIONS | DOI: 10.1038/ncomms1479

# Fiber laser solution



# Comparison of space cold atom platforms in four countries:

| Country | United States | Germany | France | China |
|---|---|---|---|---|
| Platform | Space station | Drop Tower\Rocket | Parabolic plane | Space station |
| Potential well | Atomic chip | Atomic chip | Three-dimensional optical trap | Three-dimensional optical rap |
| $^{87}Rb$ atomic number | $2\times10^5$ | QuantusI: $1\times10^4$, QuantusII: $4\times10^5$ | $5\times10^5$ | $1\times10^5$ |
| $^{41}K$ atomic number | $1\times10^5$ | $4\times10^4$ | | |
| $^{40}K$ atomic number | $5\times10^4$ | | | $1\times10^4$ |
| $^{39}K$ atomic number | | | $5\times10^4$ | |
| Temperature | 100pK | 10nK | 300nK | 100pK |
| lifetime | 10s | 3s | 3s | 10s |
| Deep cooling method | Delta kick cooling | Delta kick cooling | optical trap evaporative cooling | Two-stage cooling |
| wavelength<br>Dimension<br>well depth | 852nm<br>Three-dimensional<br>0-10Er | None | None | 1064nm<br>Three-dimensional<br>0-30Er |
| Bias magnetic field | 0-235Gauss | None | None | 0-600Gauss |
| Imaging resolution | 2um | 7um | 7um | 5.4um |
| Degenerate gas preparation | Achieve BEC and Fermi degeneration in the micro-magnetic trap of the atom chip | Obtain $^{87}Rb$、$^{41}K$ quantum degenerate gas in atomic chip micro magnetic trap | Obtain $^{87}Rb$、$^{39}K$ quantum degenerate gas in the optical trap | Obtain $^{87}Rb$、$^{39}K$ quantum degenerate gas in the optical trap |
| Degenerate gas type | Bose-Fermi Mix | Double Bose Deg. Gas | Double Bose Deg. Gas | Bose-Fermi Mix |

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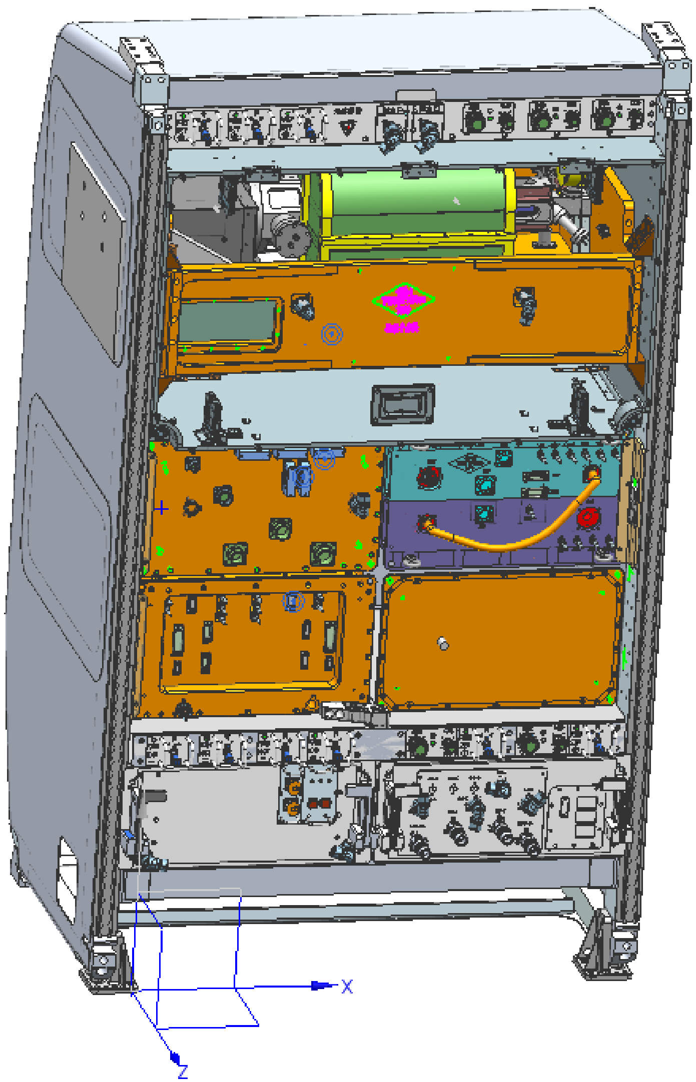
# China Space Station-Ultra-cold Atomic Physics Experiment Platform




# Ultra-cold Atomic Physics Platform Project

**The establishment of the ultra-cold atomic physics platform will carry out research on world-class problems and is expected to achieve major basic scientific breakthroughs.**

**Four types of challenging experiments can be carried out:**

I. **Quantum states of matter:** (1) Ideal quantum gas statistical physics; (2) Quantum magnetism; (3) Quantum new states of matter; (4) Heteronuclear polarized molecules;

II. **Celestial body simulation:** (5) Acoustic black hole; (6) Bose explosion

III. **Quantum computing:** (6) Quantum topology;

IV. **Frontier exploration category:** (7) Quantum measurement theory test; (8) The relationship between quantum mechanics and gravity; (9) Standard model test.

北京大学 PEKING UNIVERSITY

SIOM 中国科学院上海光学精密机械研究所 SHANGHAI INSTITUTE OF OPTICS AND FINE MECHANICS,CHINESE ACADEMY OF SCIENCES

中国科学院武汉物理与数学研究所 wuhan Institute of Physics and Mathematics ,Chinese Academy of Sciences

中国科学院物理研究所 INSTITUTE OF PHYSICS CHINESE ACADEMY OF SCIENCES

中国科学技术大学 University of Science and Technology of China

山西大学 Shanxi University

華東師範大學 EAST CHINA NORMAL UNIVERSITY

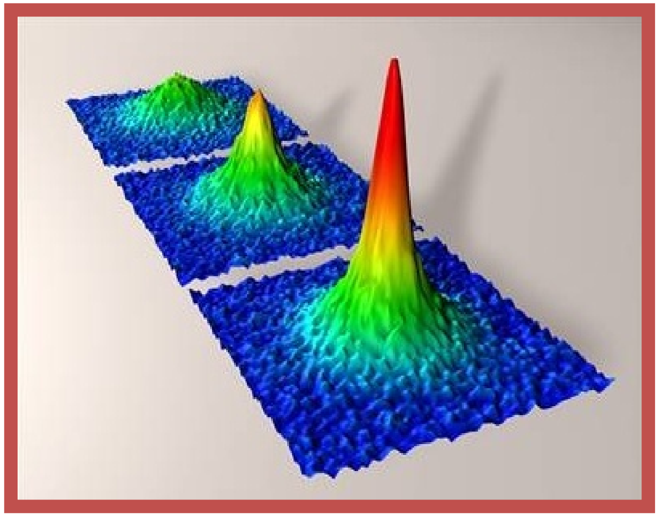
# Advantages for Cold Atom Physics in Space

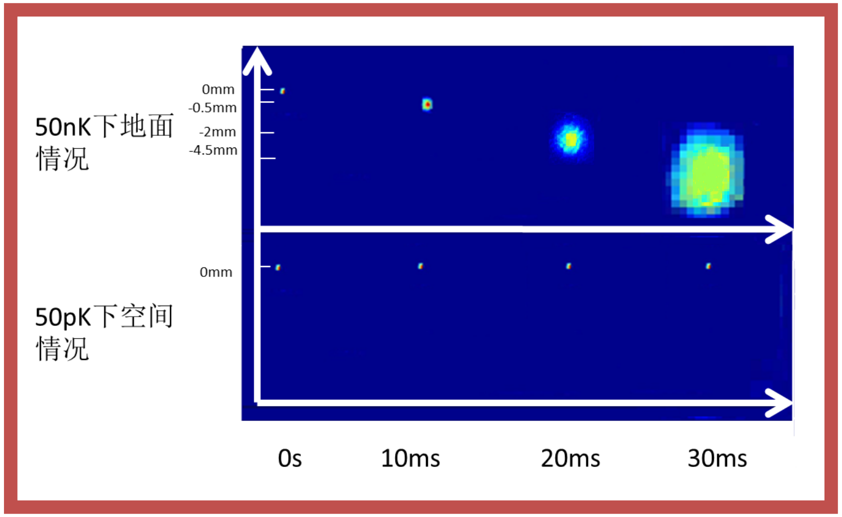
- Low temperature: $10^{-12}$ K（pK, 0.000000000000K）, three order lower than on the earth (nK)

Absolute temp.: 0K=-273.15°C

Room temp.: 300K=26.85°C

- Longer observation time (20s) , three order longer than on the earth (20ms),
- Space uniform, no gravity potential.





## The Nobel Prize in Physics 1997

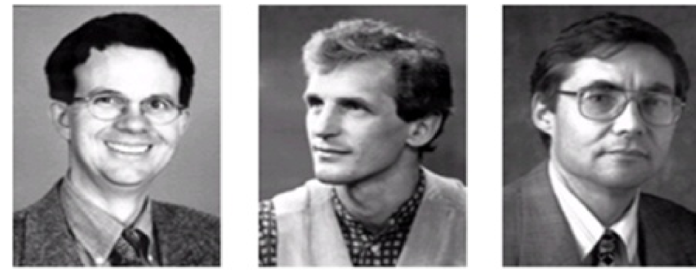
"for development of methods to cool and trap atoms with laser light"

Steven Chu | Claude Cohen-Tannoudji | William D. Phillips

**Laser cooling**

## The Nobel Prize in Physics 2001

"for the achievement of Bose-Einstein condensation in dilute gases of alkali atoms, and for early fundamental studies of the properties of the condensates"



Eric A. Cornell | Wolfgang Ketterle | Carl E. Wieman

**Bose-Einstein Condensation**

## The Nobel Prize in Physics 2005

"for his contribution to the quantum theory of optical coherence"

"for their contributions to the development of laser-based precision spectroscopy, including the optical frequency comb technique"


Roy J. Glauber | John L. Hall | Theodor W. Hänsch

**Precision Measurement based on cold atom**

## The Nobel Prize in Physics 2012

Serge Haroche, David J. Wineland

The Nobel Prize in Physics 2012

Serge Haroche

David J. Wineland

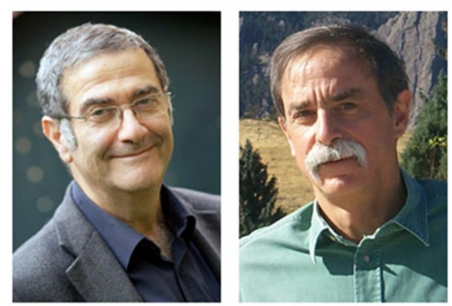


Photo: © CNRS Photothèque/Christophe Lebedinsky

Serge Haroche

Photo: © NIST

David J. Wineland

**Quantum Manipulation based on cold atom**

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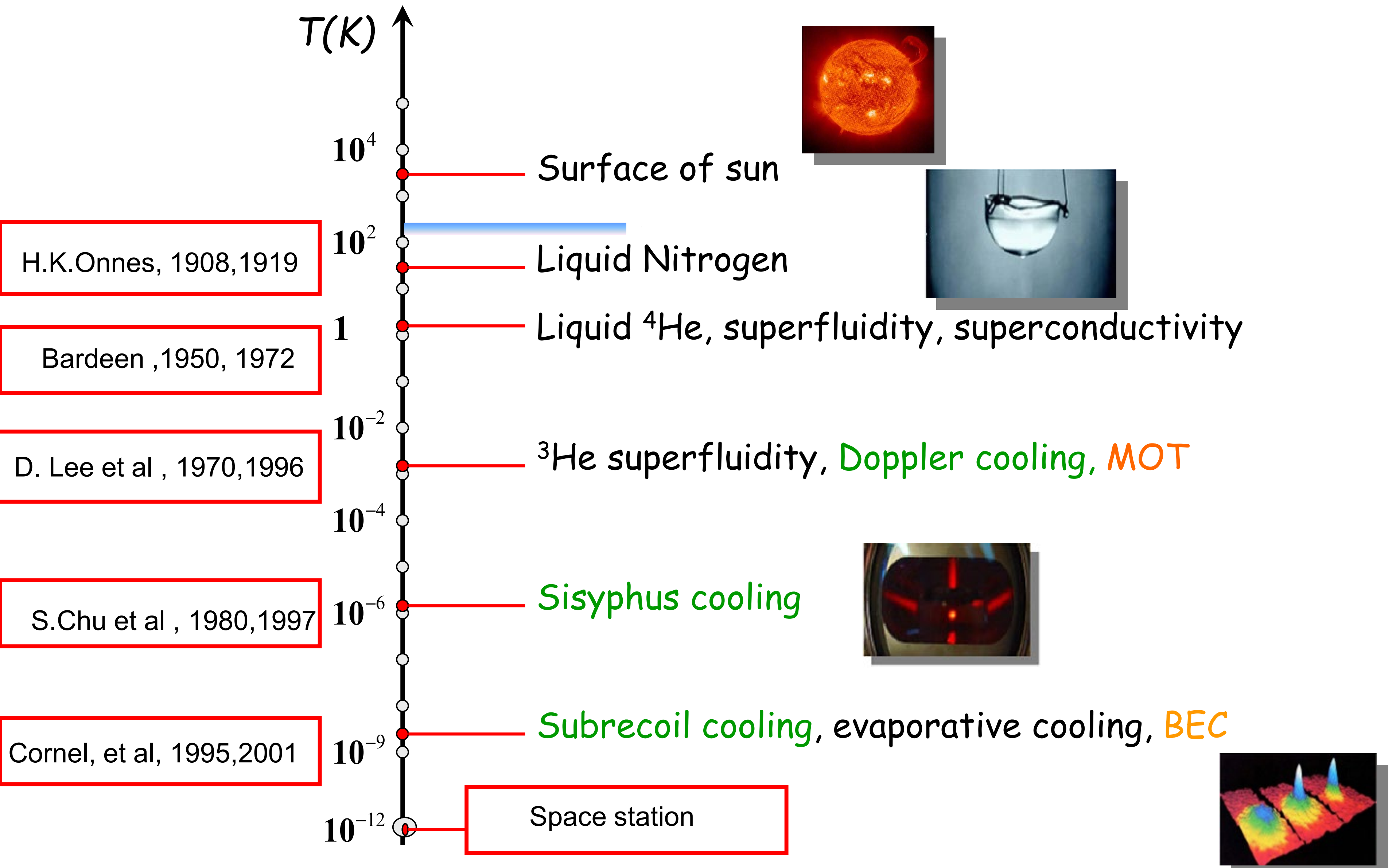
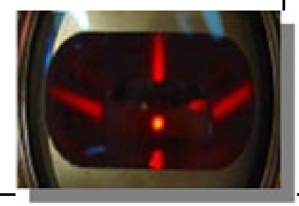
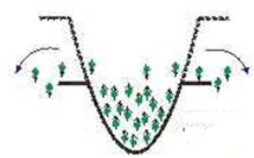
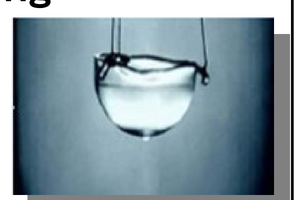
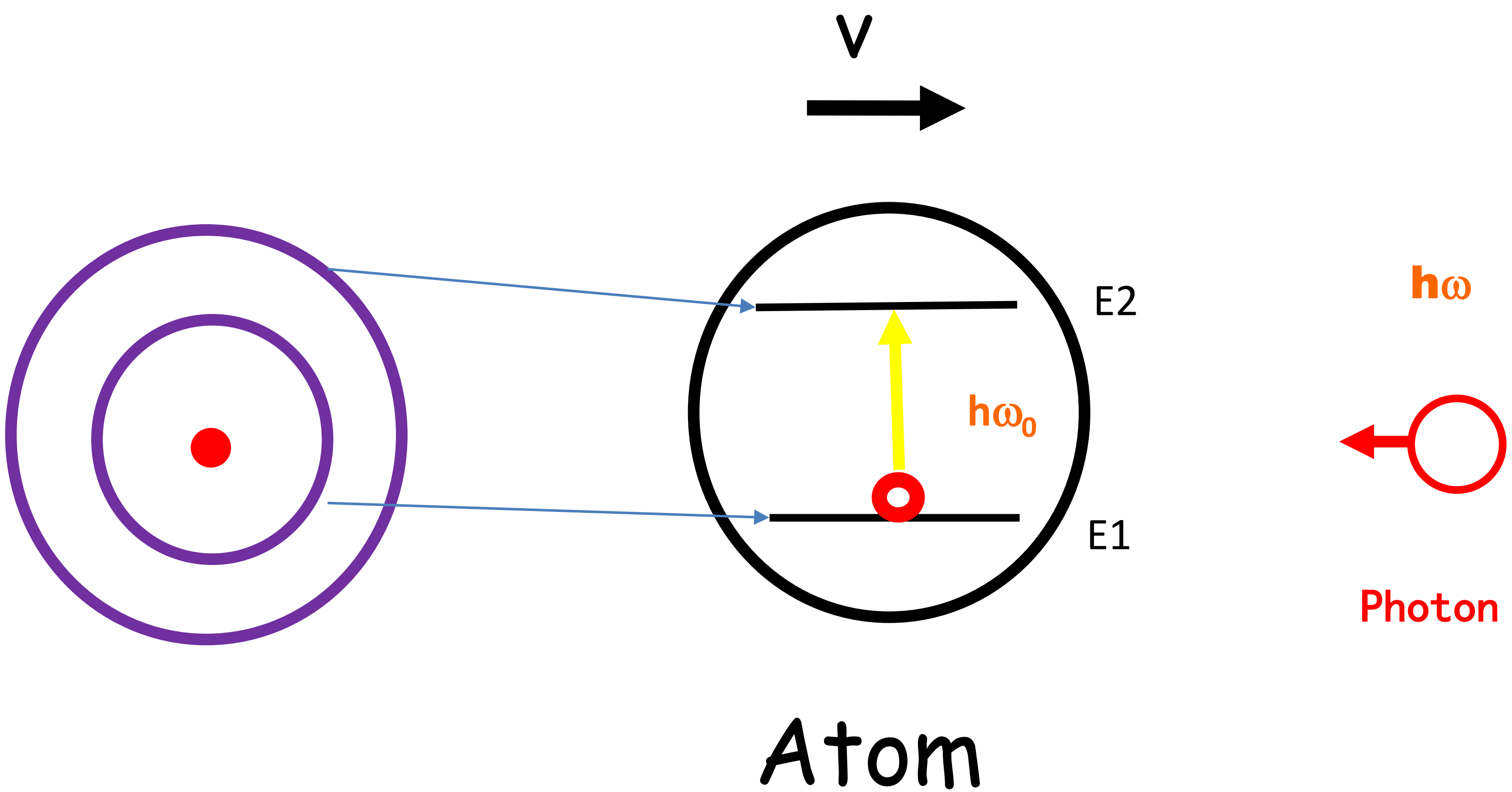
# Cooling Roadmap for Cooling of Matter



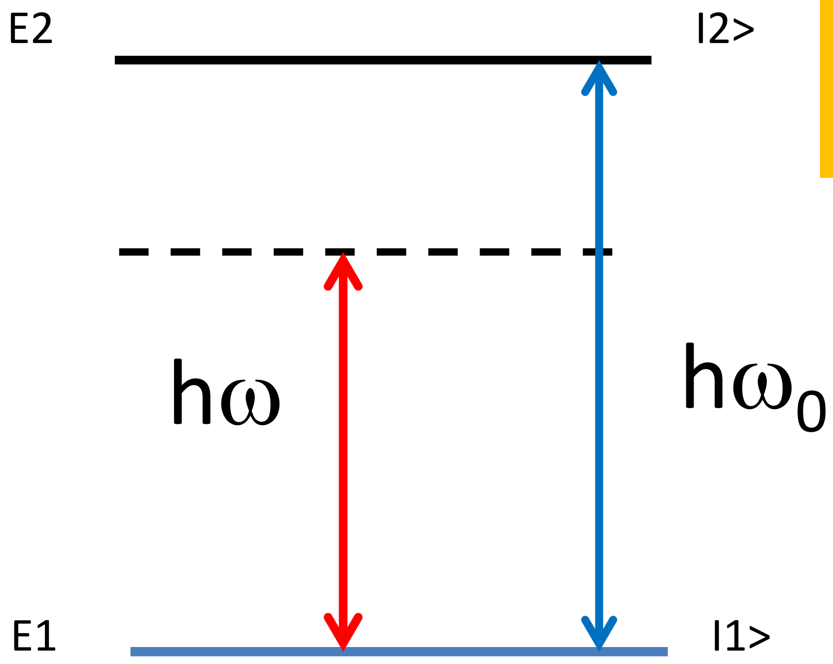
# Comparison of cooling methods

| Method | Material | Principle | Loading Method | Speed | Temperature |
|---|---|---|---|---|---|
| Laser cooling | Gas: atoms and molecules | Laser radiation pressure | Magnetic field + laser  | Fast | $10^{-6}$K μK |
| Evaporative cooling | Gas: atom and molecule | Evaporation + collision | Magneto-optical or laser  | Fast | $10^{-9}$K nK |
| Cryogenic cooling | Liquid, solid | Collision, | Container loading  | Slow | $10^{-3}$K mK |

# Doppler laser cooling



# Principle for laser cooling




$$absorption: \hbar\omega + Kv = \hbar\omega_0$$

$$emssion: \hbar\omega_0$$

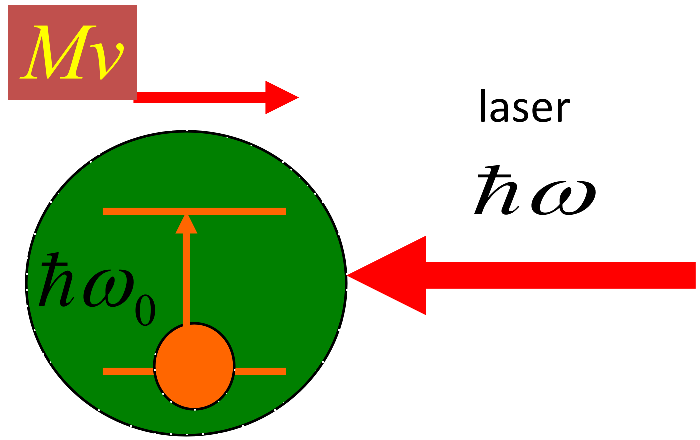
The frequency of absorbing photons : ω

Less than

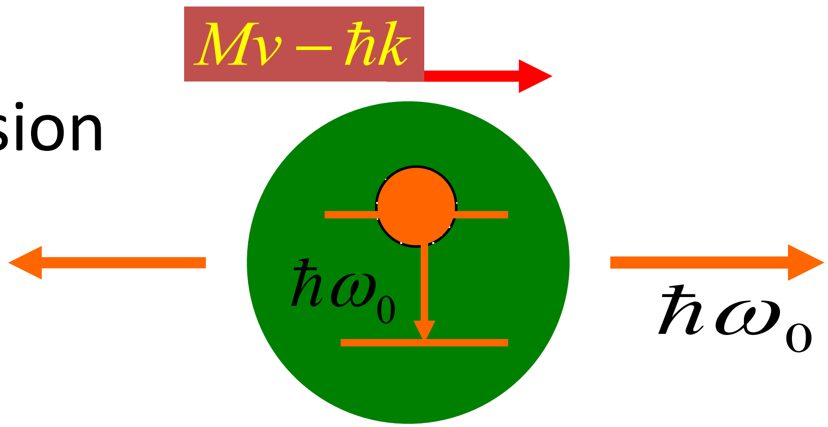
The frequency of photons radiated by atoms : $\omega_0$

# The laser cools the temperature of atoms down

absorption




emission




The momentum change of one photon absorbed by an atom:

$$\Delta Mv = \hbar k$$

Atomic momentum change:

$$\Delta v = \frac{\hbar k}{M} \approx 3cm/s$$

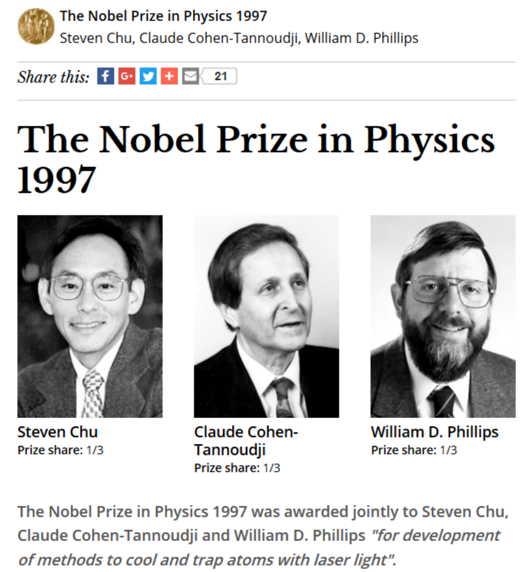
Spontaneous emission rate:

$$\Gamma = 10^8 / s$$

# Laser cooling: high-efficiency cooling

Acceleration:

$$a = \Delta v / \tau$$
$$= 3\times10^{-2} / 10^{-8}$$
$$= 3\times10^{6} m/s^{2}$$
$$= 3\times10^{5} g$$




**From 300K to 300uK**

**Decrease by 6 orders of magnitude!**

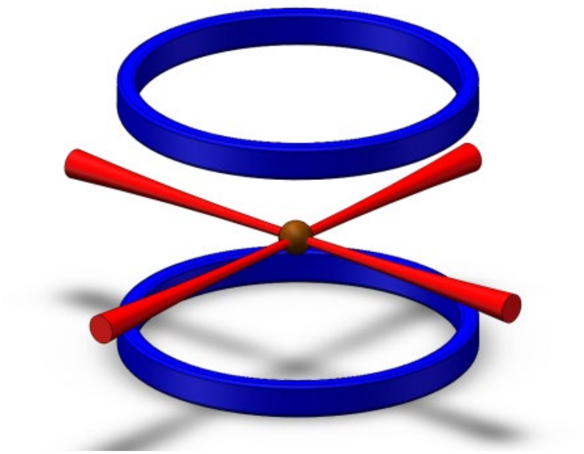
**Cool the speed of the atom from 1000m/s to 0,**
**It takes 300,000 jumps and only 3ms!**

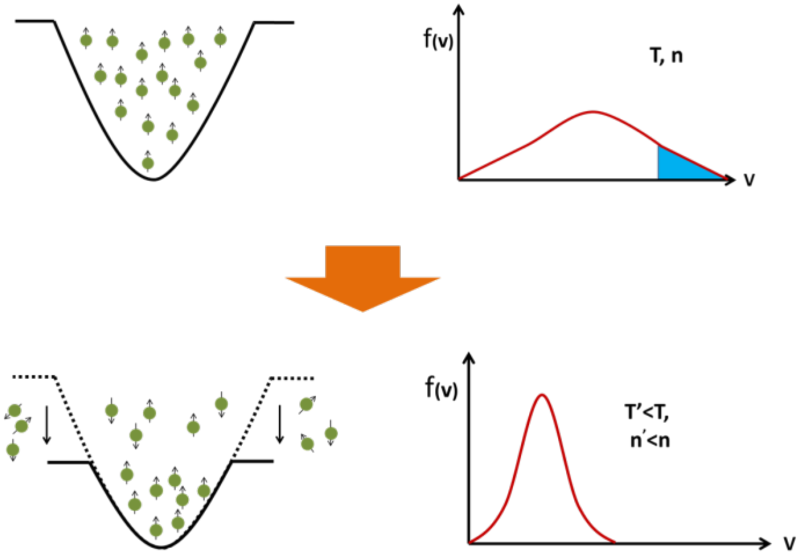
$\boxed{\text{Actual temperature: } 100\mu K\text{–}0.0001K}$

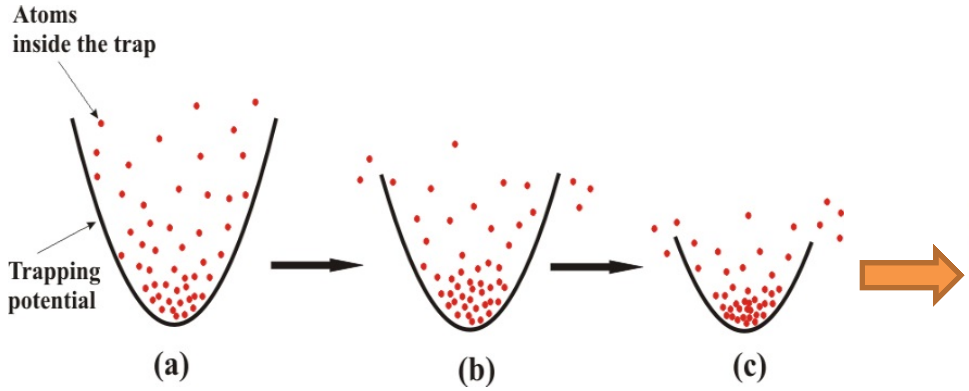
# Evaporative cooling

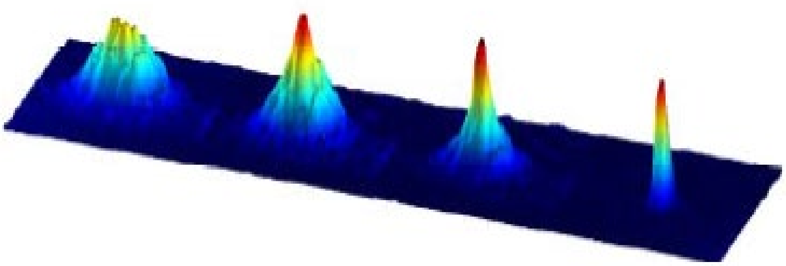
# Schematic diagram of evaporative cooling process

- **Principle of evaporative cooling:**





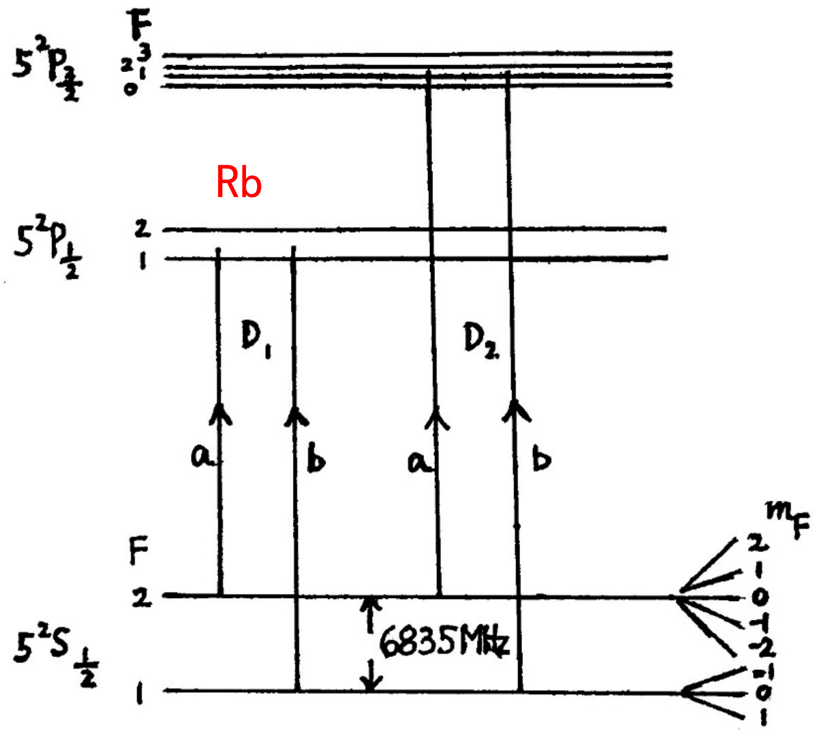



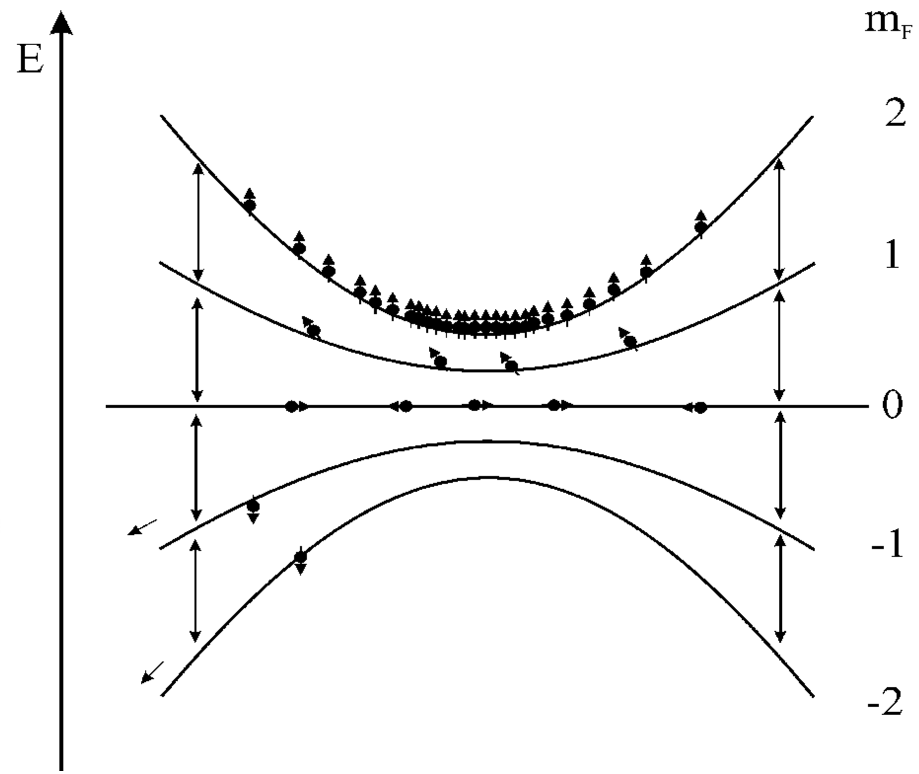



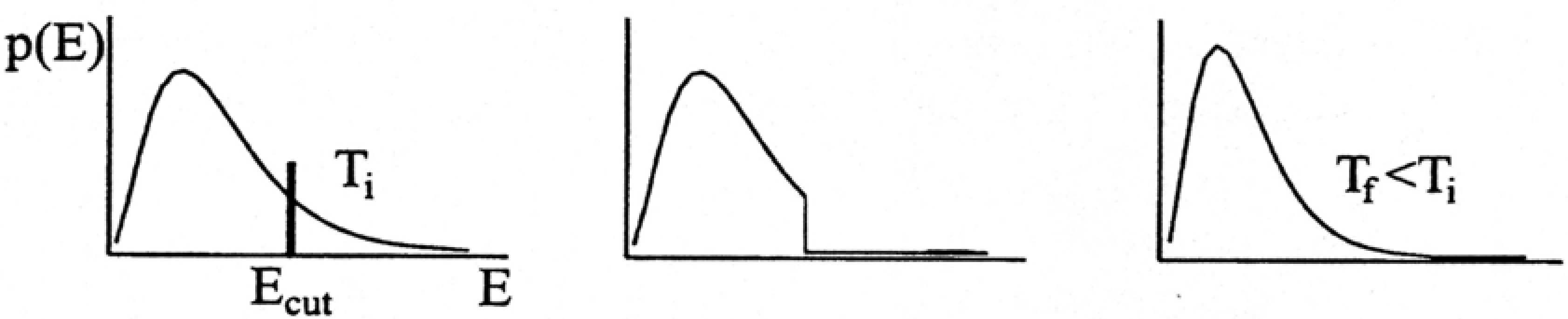
**Traditional evaporative cooling technology**

**Bose-Einstein Condensation (BEC)**

# Forced evaporative cooling



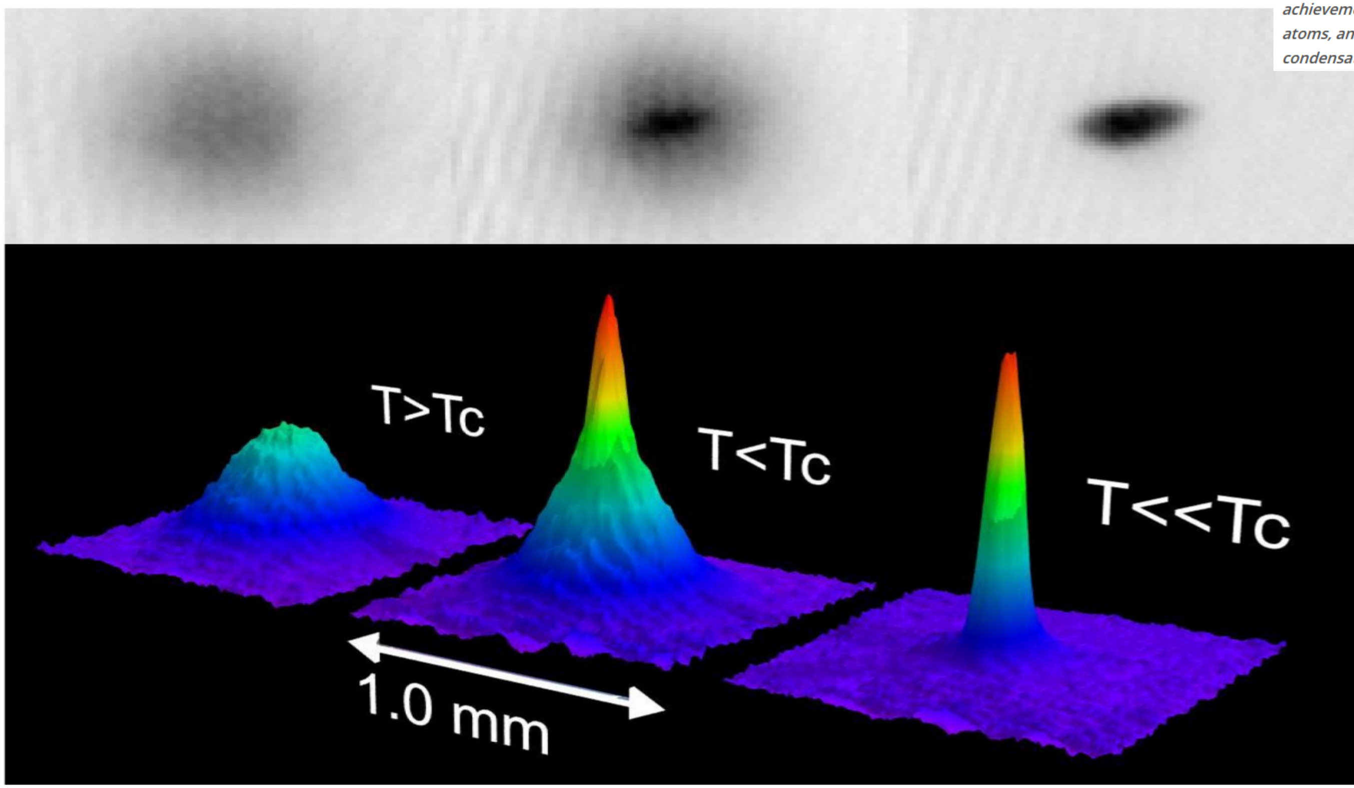



# Bose-Einstein Condensation (BEC)

Temperature up to 50 nanoKelvin

——0.000000005k

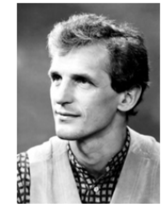



The Nobel Prize in Physics 2001
Eric Cornell, Wolfgang Ketterle, Carl Wieman

Share this: 0

## The Nobel Prize in Physics 2001

Eric A. Cornell
Prize share: 1/3



Wolfgang Ketterle
Prize share: 1/3

Carl E. Wieman
Prize share: 1/3

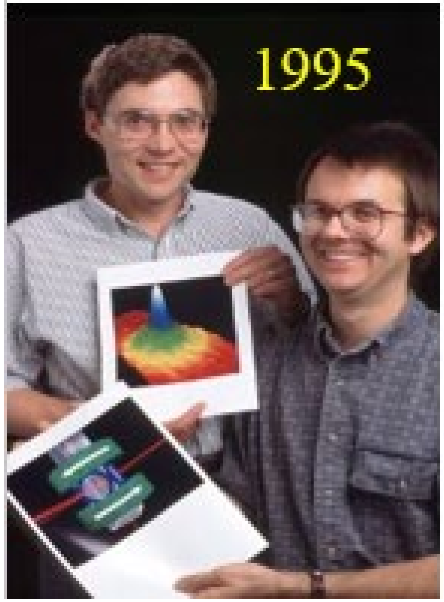
The Nobel Prize in Physics 2001 was awarded jointly to Eric A. Cornell, Wolfgang Ketterle and Carl E. Wieman *"for the achievement of Bose-Einstein condensation in dilute gases of alkali atoms, and for early fundamental studies of the properties of the condensates".*

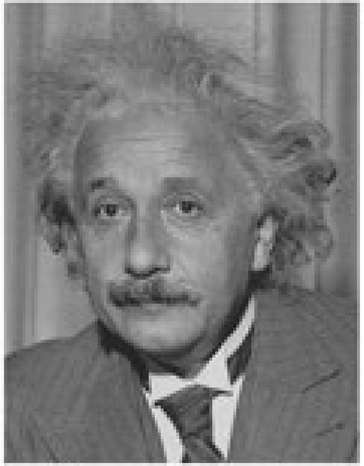
# Bose-Einstein Condensation

**Atoms and molecules**

$$n(\varepsilon) = \begin{cases} \dfrac{1}{e^{(\varepsilon-\mu)/k_B T} - 1} \\[2ex] \dfrac{1}{e^{\varepsilon/k_B T} - 1} \end{cases}$$

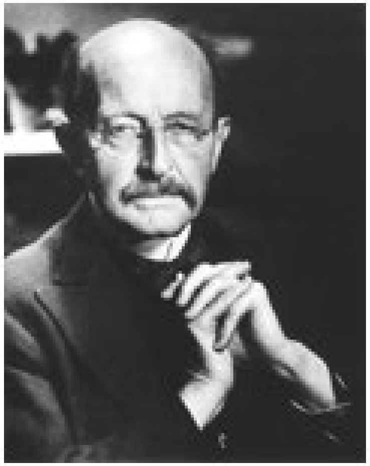
Black-Body Radiation
"Photons"



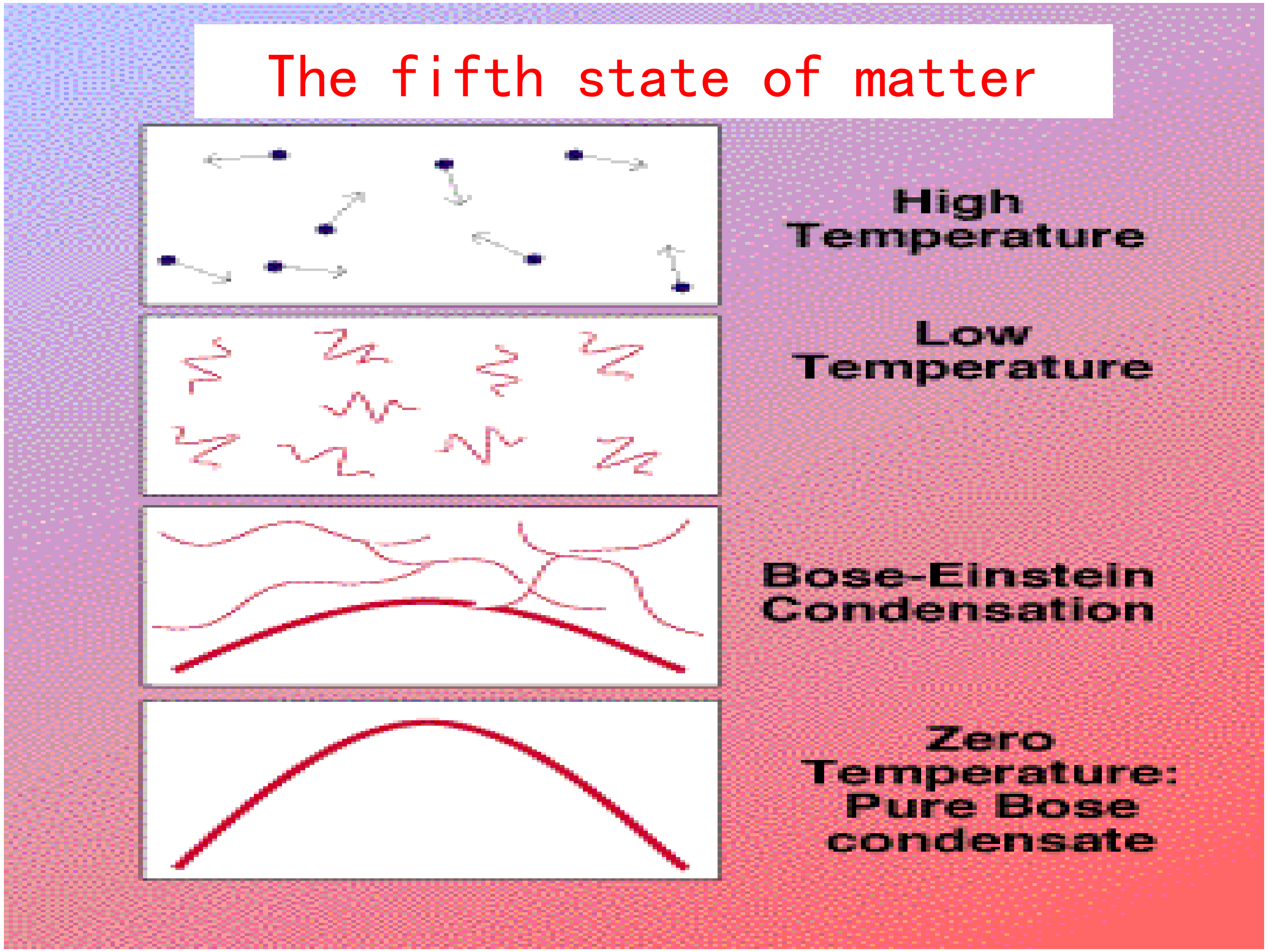
Albert Einstein

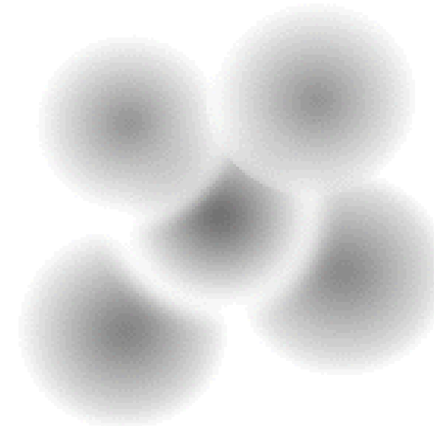
**Predication in 1924, Bose and Einstein**



Max Planck

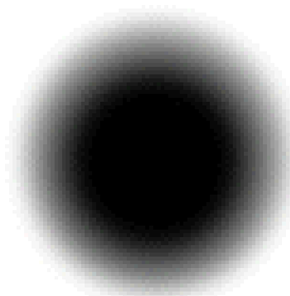
Satyendra Nath Bose



Some very cold atoms

T>Tc , λD<La



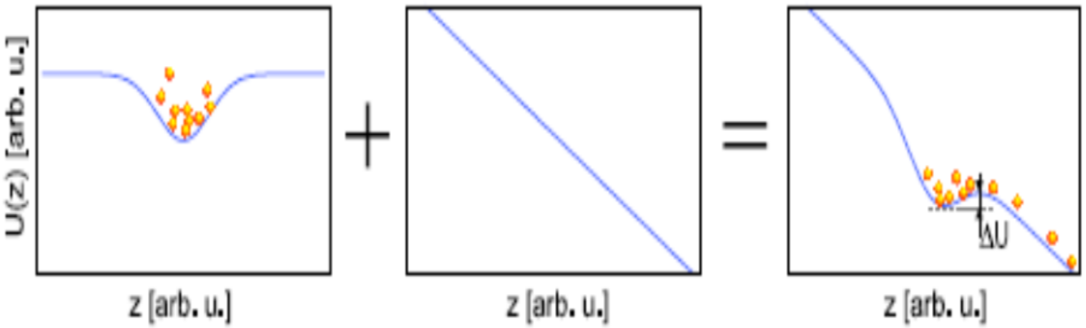
Some atoms in a BEC condensate

T<Tc, λD>La

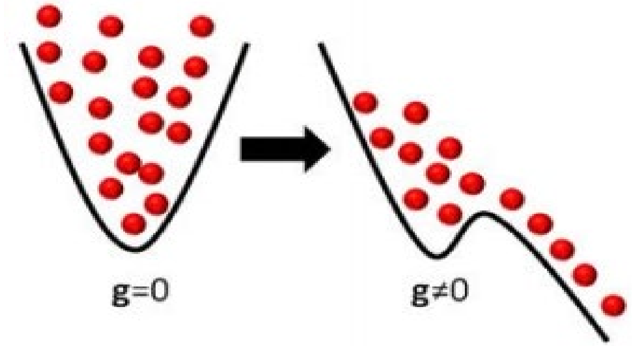
De Broglie wavelength

$$\lambda_{dB} = h / \sqrt{2\pi M K_B T}$$

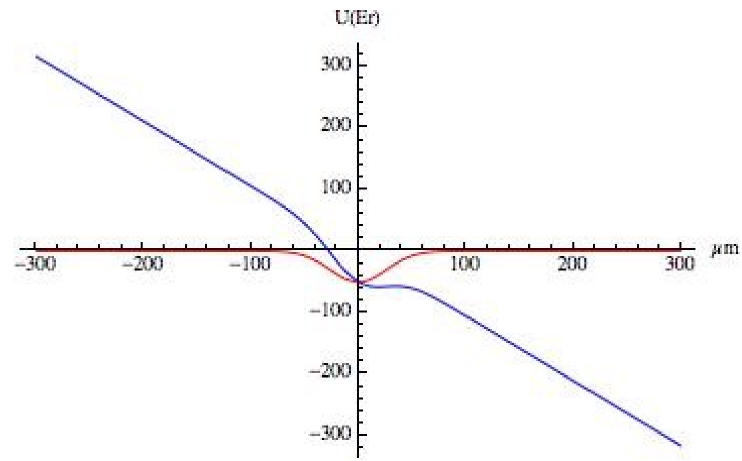
# The effect of gravity on temperature




（a） (b) (c)

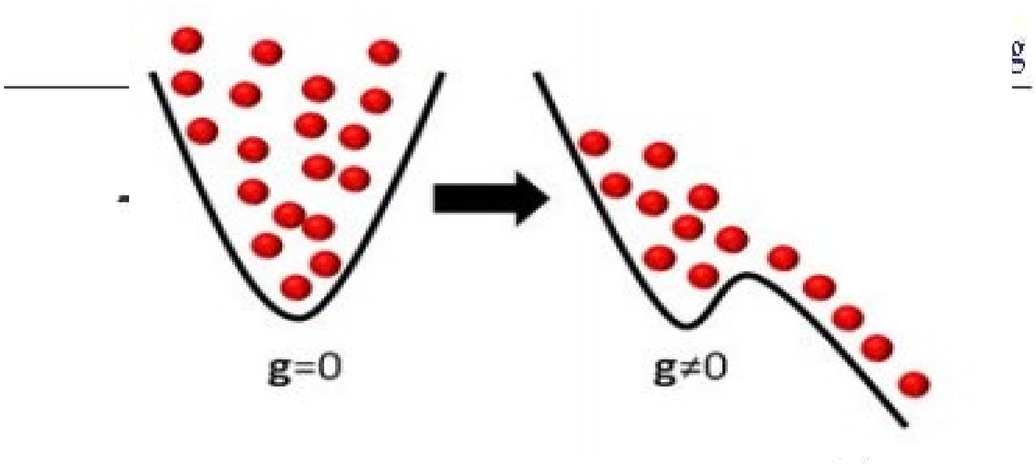



$$E = -mgz + \frac{1}{2}m\omega^2 z^2$$

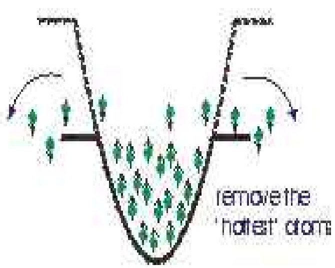


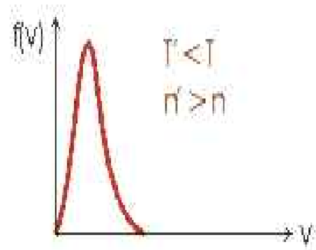

The effect of gravity on the potential well

# Temperature vs trap frequency




Evaporation and (Re-) Thermalization




Phase transition temperature:

$$T_c = 0.94 \frac{\hbar}{k} \varpi N^{1/3}$$

$$= \varpi(nk)$$

Critical temperature in different traps

$\varpi = 100Hz$ $\quad T_c = 100nk$ gound

How to find a fast cooling approach to pK?

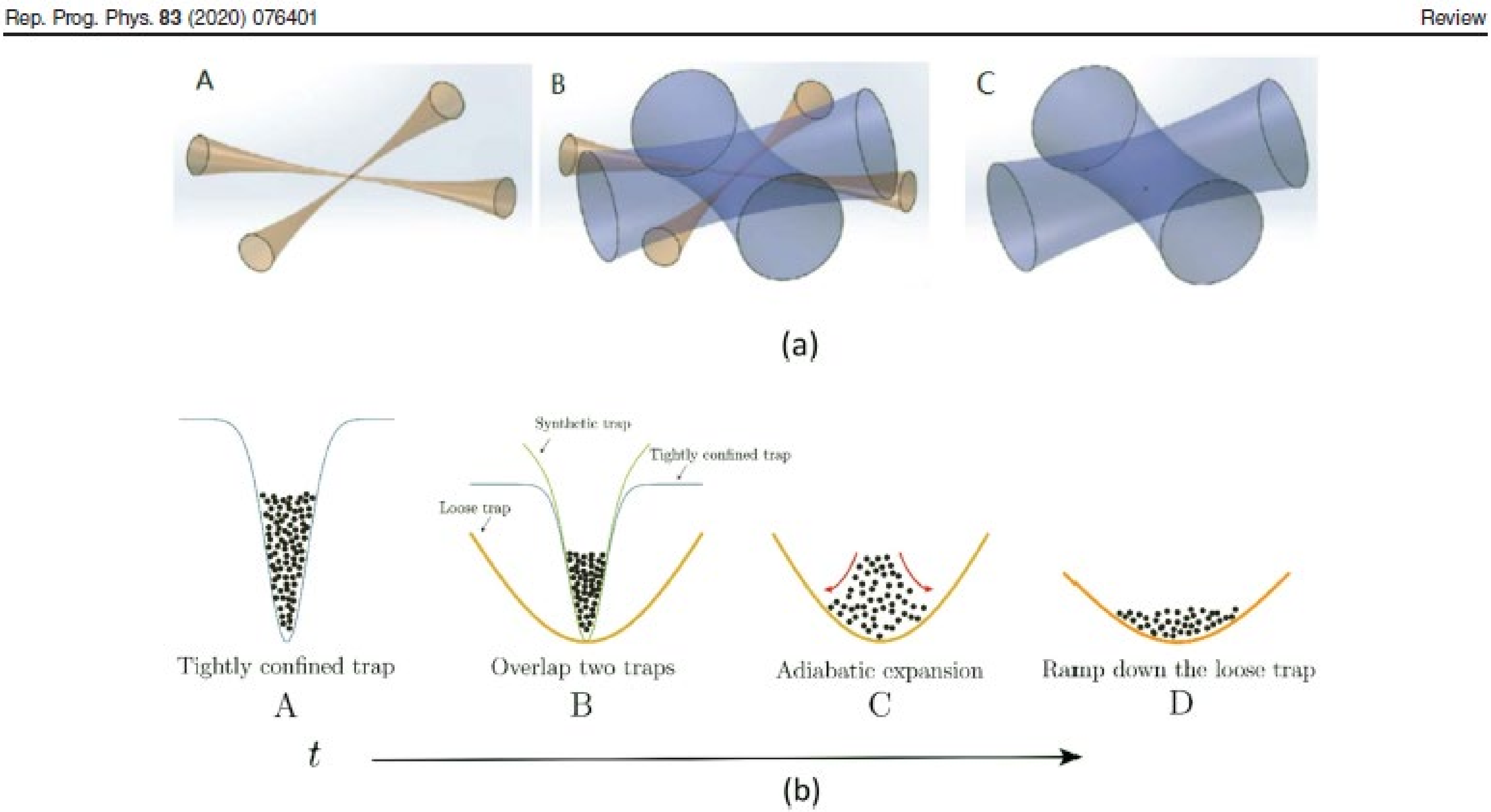
$\varpi = 0.001Hz$ $\quad T_c = 1pk$ space

Collision rate:

$$r \propto \varpi$$

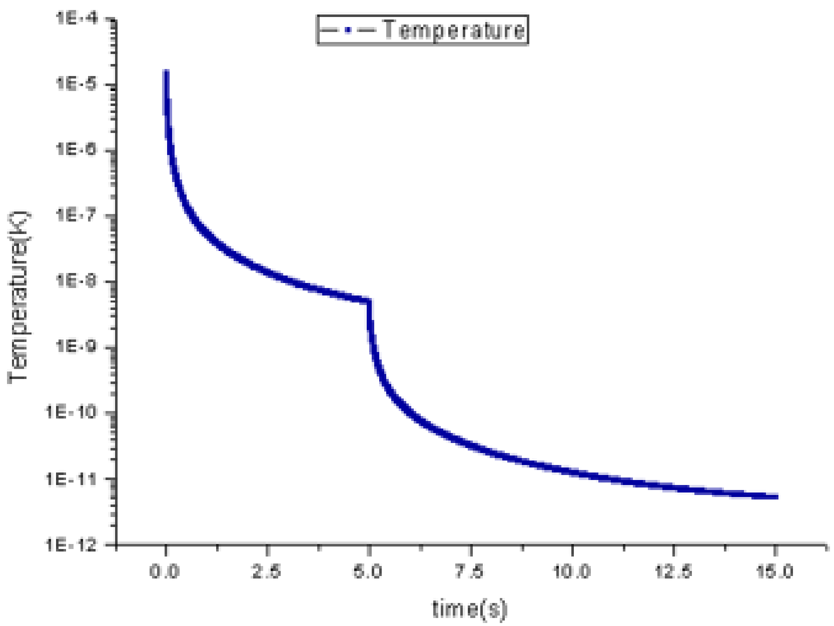
$$T_c \to pK \quad \text{needs } 1000s$$

# Two-stage evaporative cooling (TSC) theory in microgravity environment

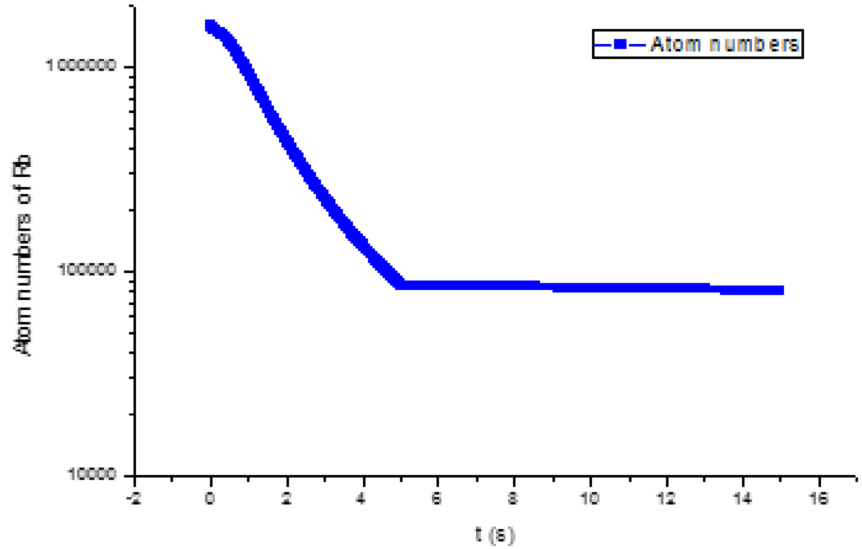



The emergence of picokelvin physics， Xuzong Chen and Bo Fan， Rep. Prog. Phys. 83, 076401 (31pp)， (2020)

# Break through the ground limit and get a theoretical prediction of pK-level temperature




(A) The relationship between rubidium 87 atomic gas temperature and time



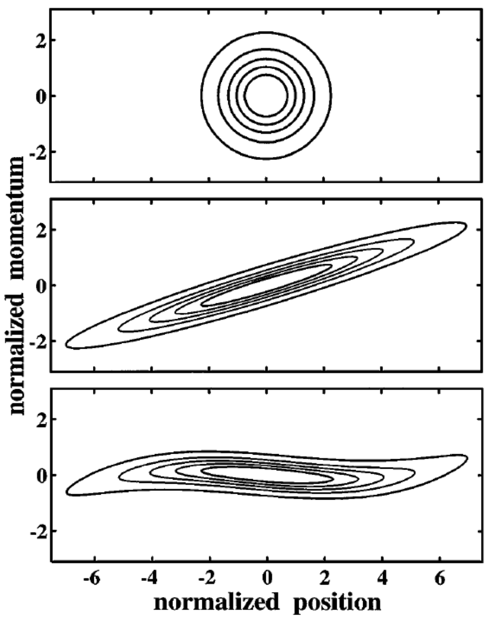

(b) The relationship between rubidium 87 atomic number and time

Within 15 seconds, the atom can theoretically be cooled to 7pK

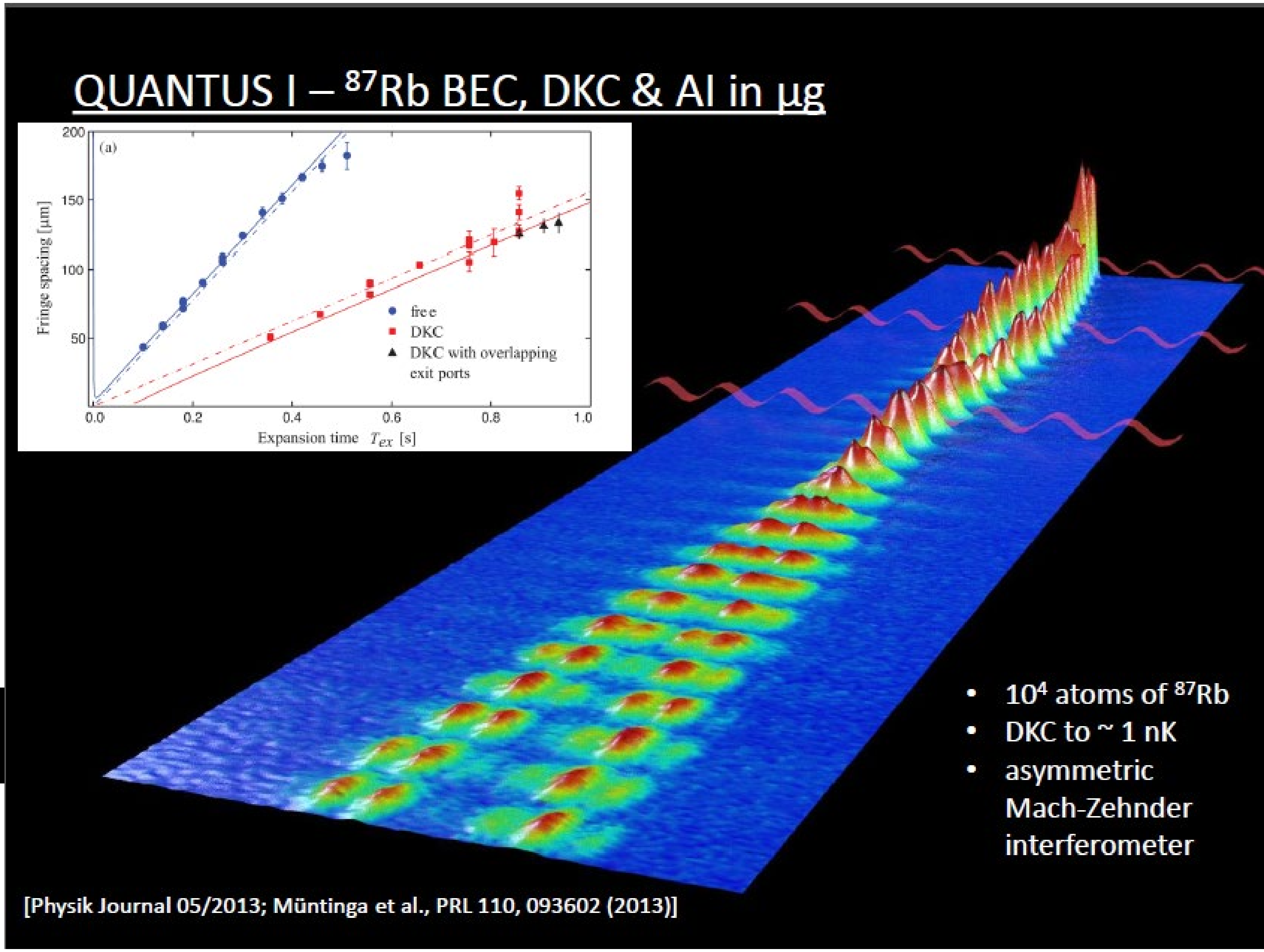
# Cooling methods in Germany and the United States: pulse impulse cooling

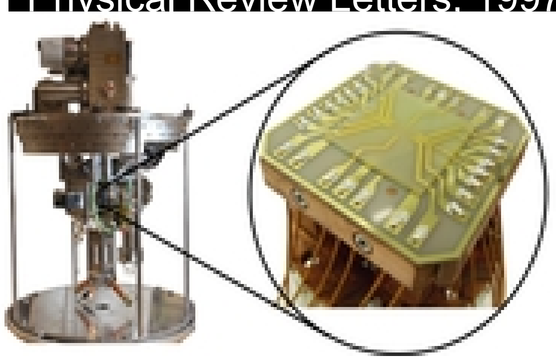
DKC（Delta Kick cooling），

（DKC）

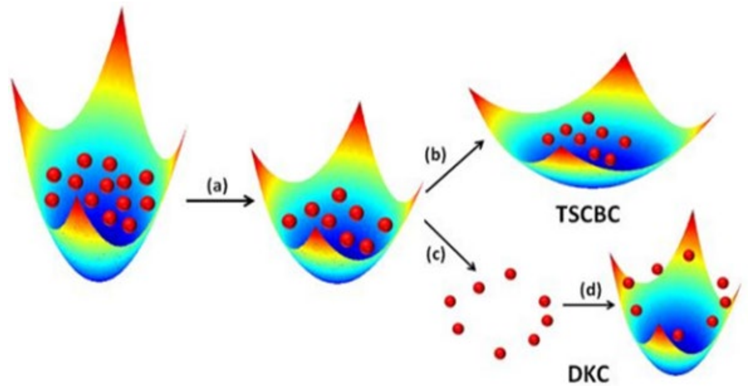


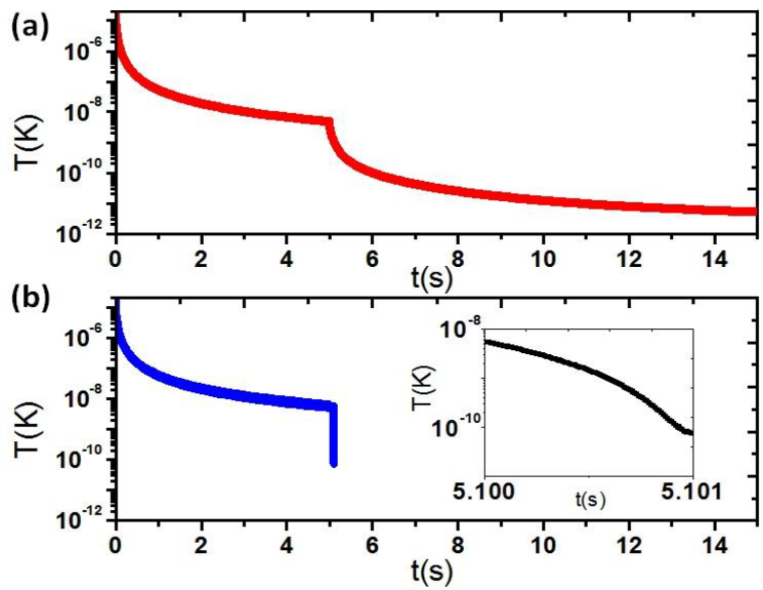

Ammann H, Christensen N. Physical Review Letters, 1997.



# Simulation comparison of two cooling methods in microgravity environment




**TSC cooling method and pulse impulse cooling method (DKC) comparison**

| 物理量 | TSCBC | DKC |
|---|---|---|
| $T_{Rb}$ | 7pK | 75pK |
| $t_{Rb}$ | 10s | 0.1s |
| $r_{Rb}$ | 300μm | 100μm |
| $PSD_{Rb}$ | 3.70 | 3.57 |
| $(\Delta P/P)_{Rb}$ | $10^{-4}$ | $10^{-3}$ |
| $T_K$ | 51.2 | 388 |
| $t_K$ | 10s | 5s |

- It can be preliminarily drawn that, compared with the two cooling methods, the two-step cross-cooling method can obtain a lower temperature of 7pK (pulse impact method 75pK), but the pulse impact method requires a shorter time for continuous preparation of cold atoms, about 5.1s (two-step cross cooling for 15s).

# Analysis of the influence of gravity on two cooling methods

| g | $10^0$ | $10^{-1}$ | $10^{-2}$ | $10^{-3}$ | $10^{-4}$ | $10^{-5}$ |
|---|---|---|---|---|---|---|
| Temperature | 5.2nk | 770pK | 91pK | 25pK | 7.2pK | 7pK |

The influence of gravity on two-stage optical trap evaporative cooling (TSCBC)

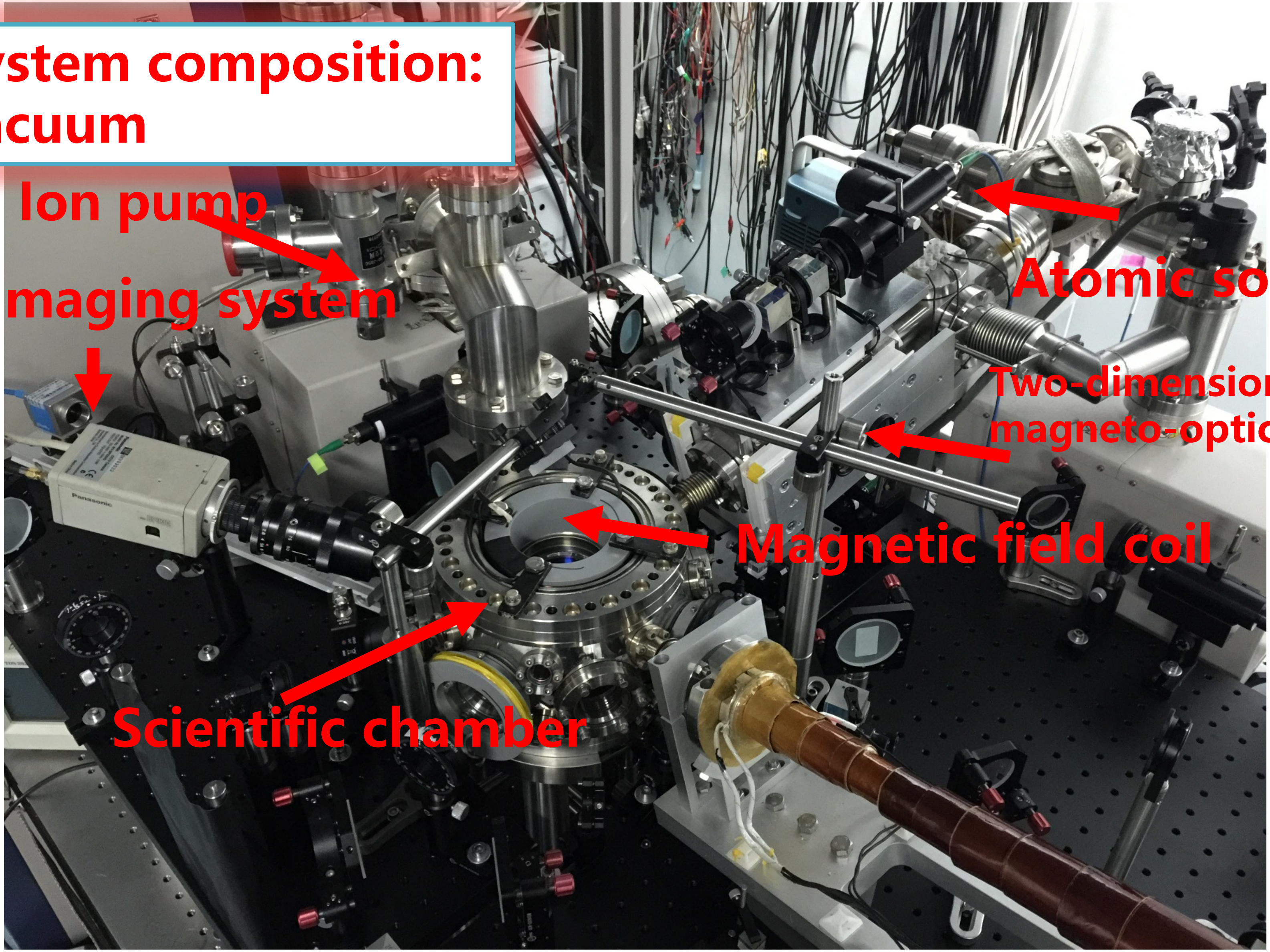
| g | $10^0$ | $10^{-1}$ | $10^{-2}$ | $10^{-3}$ | $10^{-4}$ | $10^{-5}$ |
|---|---|---|---|---|---|---|
| Temperature | 112nK | 14nK | 2.2nK | 601pK | 76pK | 70pK |

The effect of gravity on pulse impact cooling (DKC)

The yellow highlight is the gravitational condition for two methods to reach a temperature of the order of 100pK.

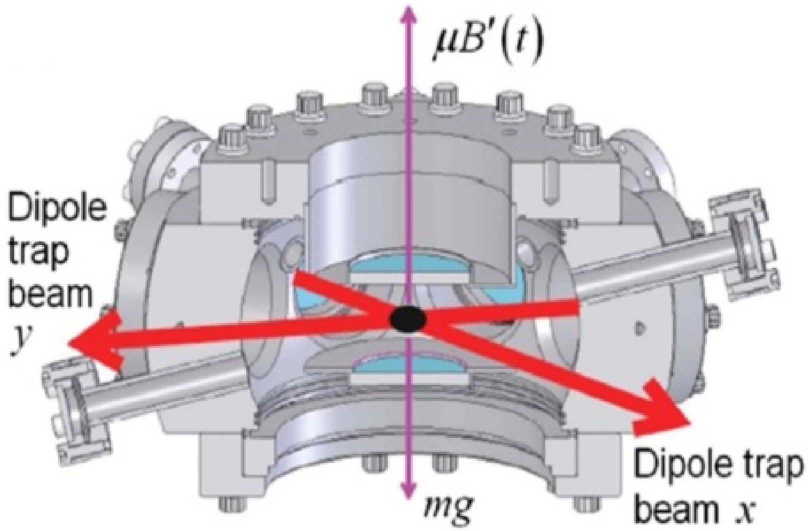
Comparison of different techniques in optical trap for generating picokelvin 3D atom cloud in microgravity, Hepeng Yao, Tian Luan, Chen Li, Yin Zhang, Zhaoyuan Ma, Xuzong Chen， **Optics Communications**, 359 (2016) 123–128

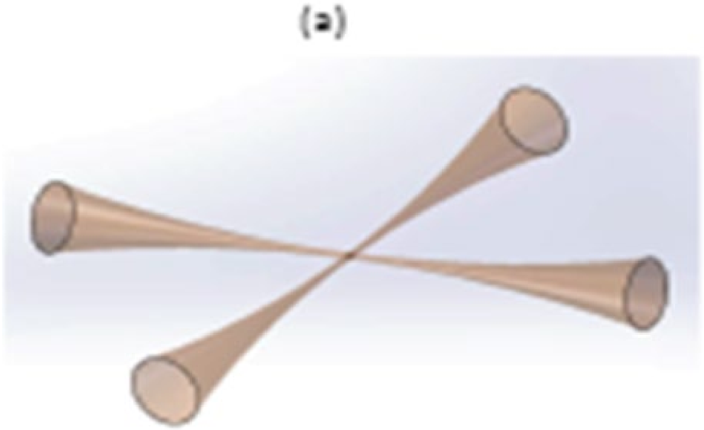
# Ground cooling experiment verification system



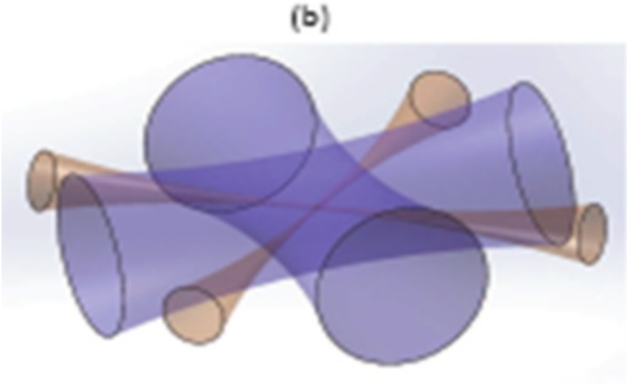
# Evaporative cooling experiment program

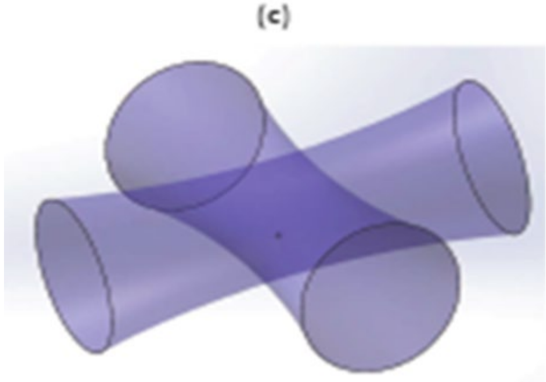
Two Stage Cross Beam Cooling， TSCBC



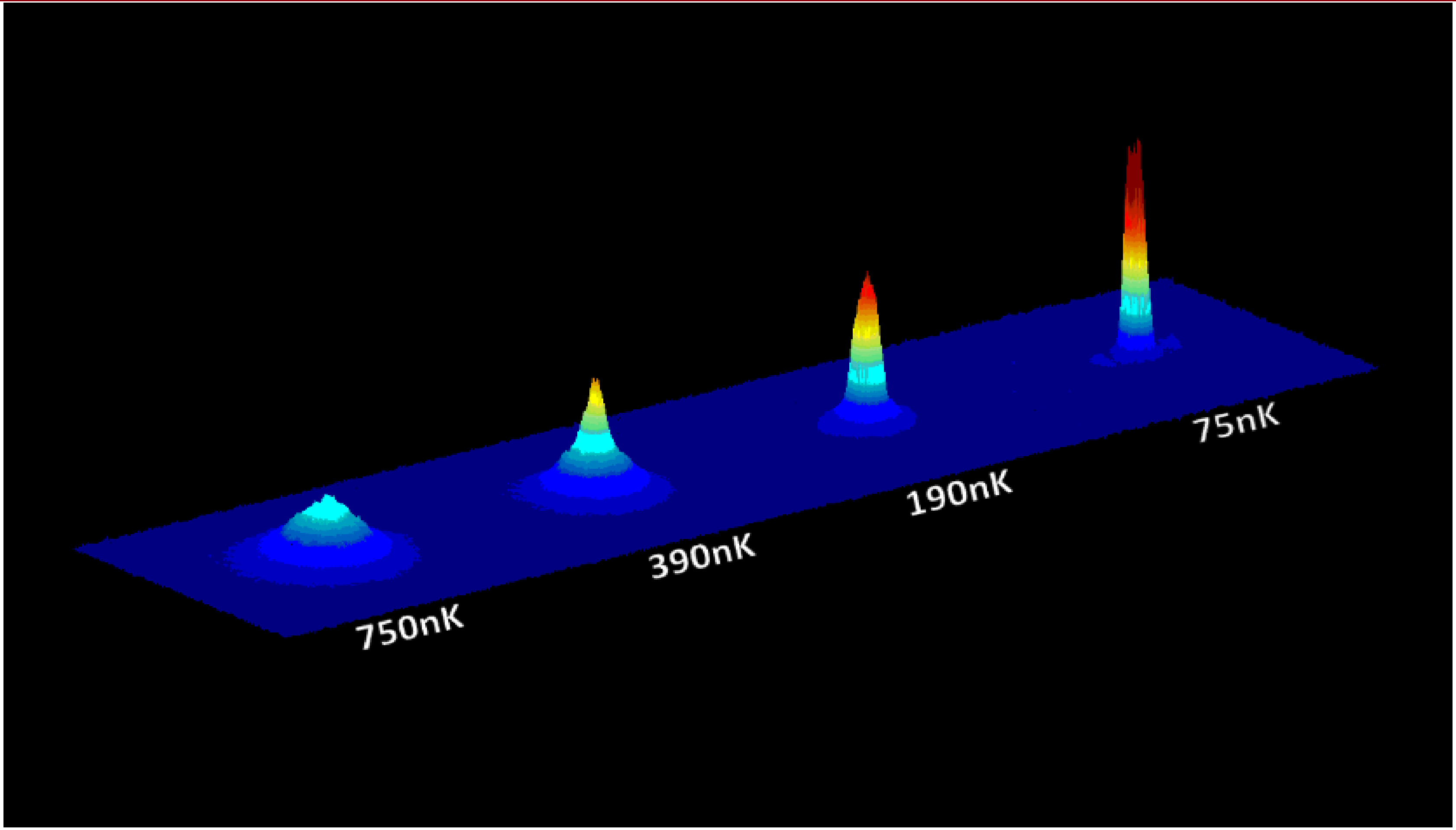

Luminous flux diameter: 60um, wavelength: 1064nm.




Luminous flux diameter: 3mm
wavelength: 1064nm

# Principle prototype preparation degenerate gas results

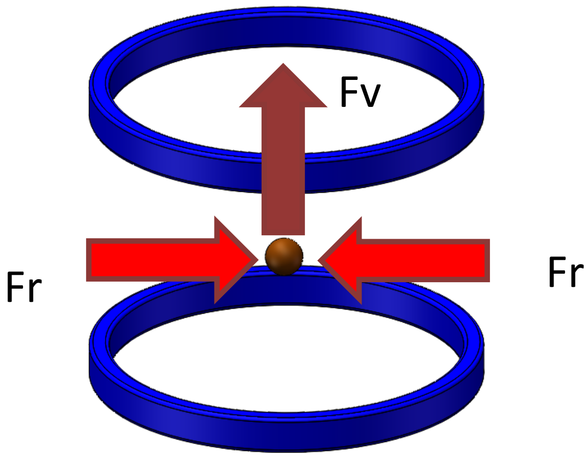



| N=5.85e5 | N=5.09e5 | N=2.5e5 | N=2e5 |
|---|---|---|---|
| T=750nK | T=390nK | T=190nK | T=75nK |
| η=0% | η=16% | η=51% | η=78% |
| PSD=9.13E-2 | PSD=4.88E-1 | PSD=6.34E-1 | PSD=15E0 |

# Experimental design of cooling of two-stage optical well on the ground

## Limitation analysis of evaporative cooling on the ground

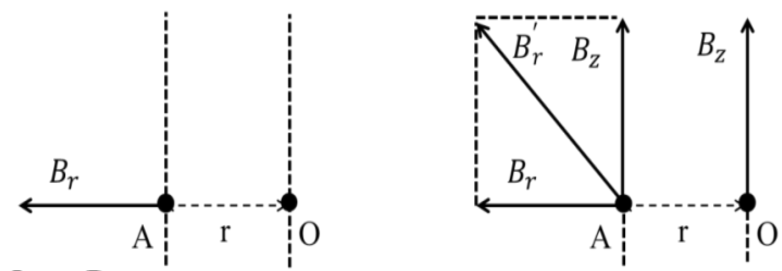
**The side effects of magnetic suspension balance gravity**




$$U_B(x,y,z) = \mu_B B_z' \sqrt{\frac{x^2}{4} + \frac{y^2}{4} + \left(z - \frac{B_z}{B_z'}\right)^2}$$


$$\omega_x = \omega_y = \sqrt{\frac{\partial^2 U_B(x,y,z)/\partial x^2 \,|_{x=0}}{m}} = \sqrt{\frac{B_z'^2}{4mB_z}}$$

**The compensate magnetic field compensates for the limitation of lateral binding**




(a) (b)

Limitation of magnetic field noise

$$\mu_B \Delta B = 1\mathrm{Er} = \frac{h^2 k^2}{2m}$$

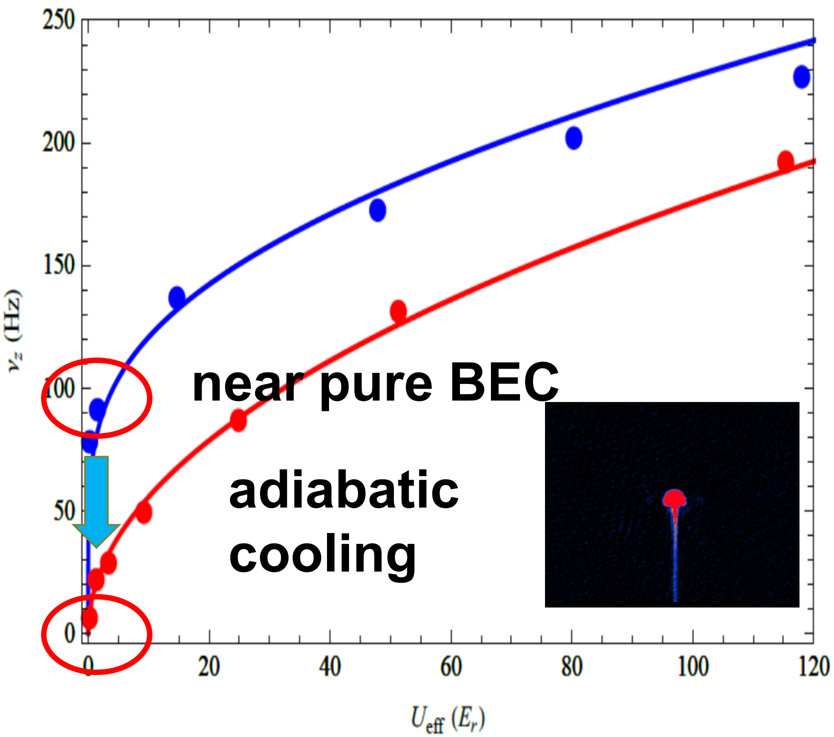
$\omega_0 = \gamma \Delta B$ $\quad \Delta B \approx 10$ mG

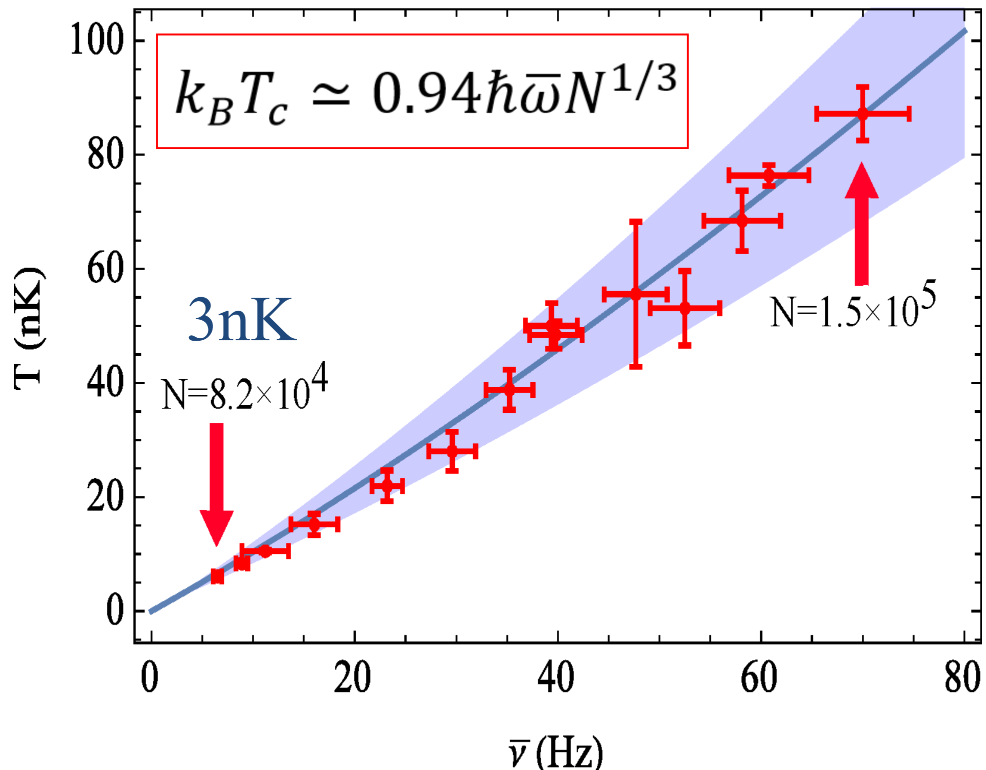
$\Delta T \approx 3$ nK $\quad \Delta B \approx 10\ \mu G$

$\omega_0 \approx 700$ Hz $\quad \Delta T \approx 3$ pK

**The magnetic field noise has a great influence!**

# Results for two stages cooling




Trap frequency v.s. laser power:

- : gravity-tilted trap (exp.)
- : magnetic levitation (exp.)
- : gravity-tilted trap (theory)
- : magnetic levitation (theory)

① Levitation: using gradient magnetic field 30.5G/cm for |1,-1>

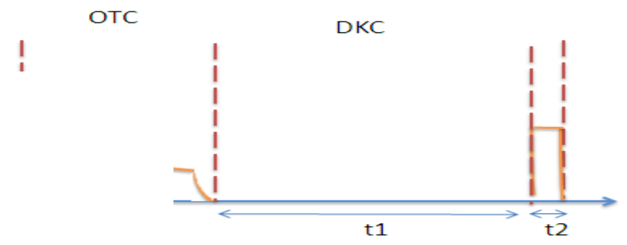
② Adiabatic expansion of optical trap

Chen Li, Tianwei Zhou, Yueyang Zhai, Jinggang Xiang, Tian Luan, Qi Huang, Wei Xiong, and **Xuzong Chen**, Rev. Sci. Instrum. **88**, 053104 (2017)

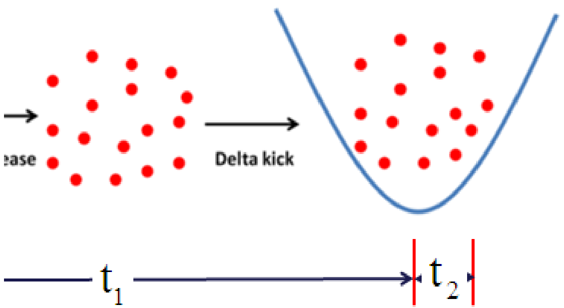
# Delta kick cooling, DKC

（1） after trap being turned off:

- $\omega^2 t_1 t_2 = 1$
- $t_1 t_2 = 1/\omega^2 = 1/(4\pi^2 * 10 * 10)$




- 0.01Hz T=7pK $t_1$=10s $t_2$ = 20s
- 0.1Hz T=0.07nK $t_1$ =1s $t_2$ = 2s
- 1Hz T=0.7nK $t_1$ =100ms $t_2$ = 200ms




- 10Hz T=7nK $t_1$=10ms $t_2$ = 20ms
- 100Hz T=70nK $t_1$ =1ms $t_2$ = 2ms
- 1000Hz T=700nK $t_1$ =0.1ms $t_2$ = 0.2ms
- 10000Hz T=7uK $t_1$ = 10us $t_2$ = 20us
- 100000Hz T=70uK $t_1$ = 1us $t_2$ = 2us

$$: \quad \omega^2 t_1 t_2 = 1$$

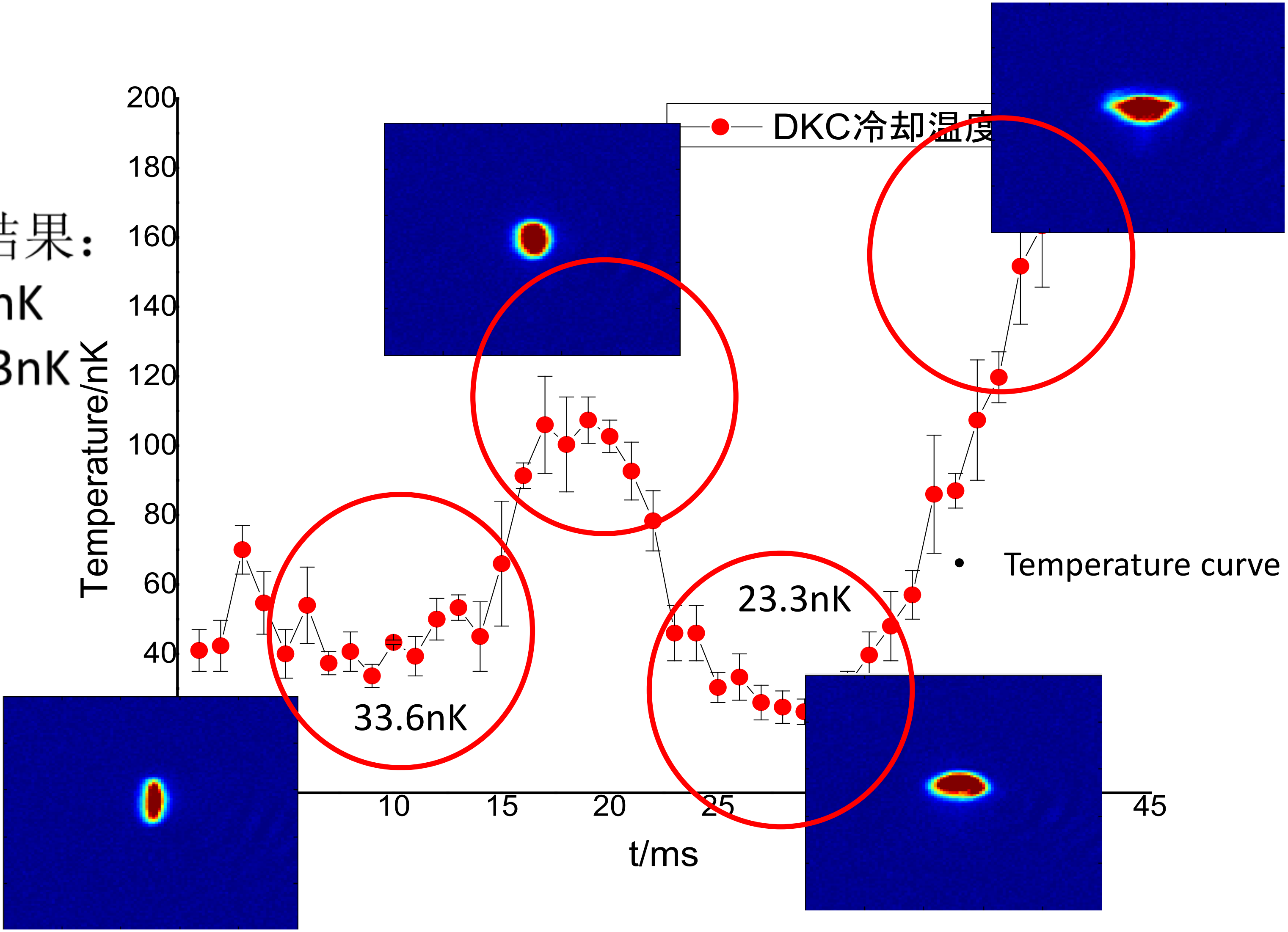
$$v = 0$$

# Ground pulse impulse cooling test results

- 温度测量结果：

$t_1$=9 ms, 33.6nK

$t_1$=29 ms, 23.3nK




- Temperature curve

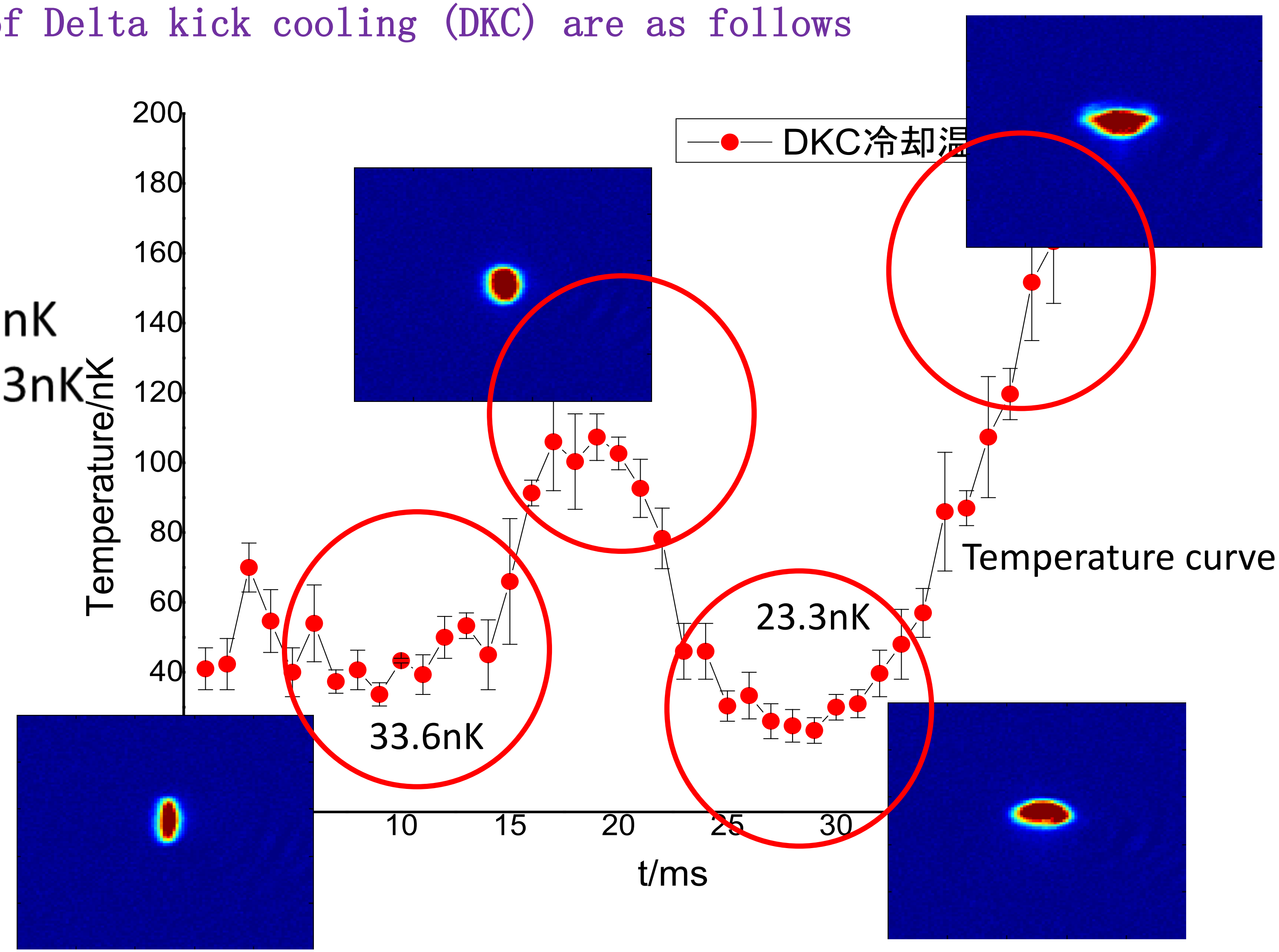
# Experimental results of ground DKC

The results of Delta kick cooling (DKC) are as follows

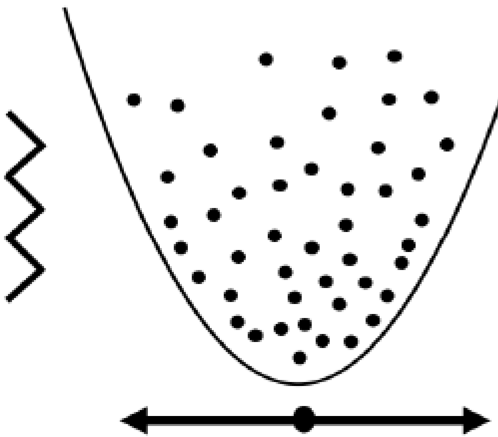
Temperature measurement

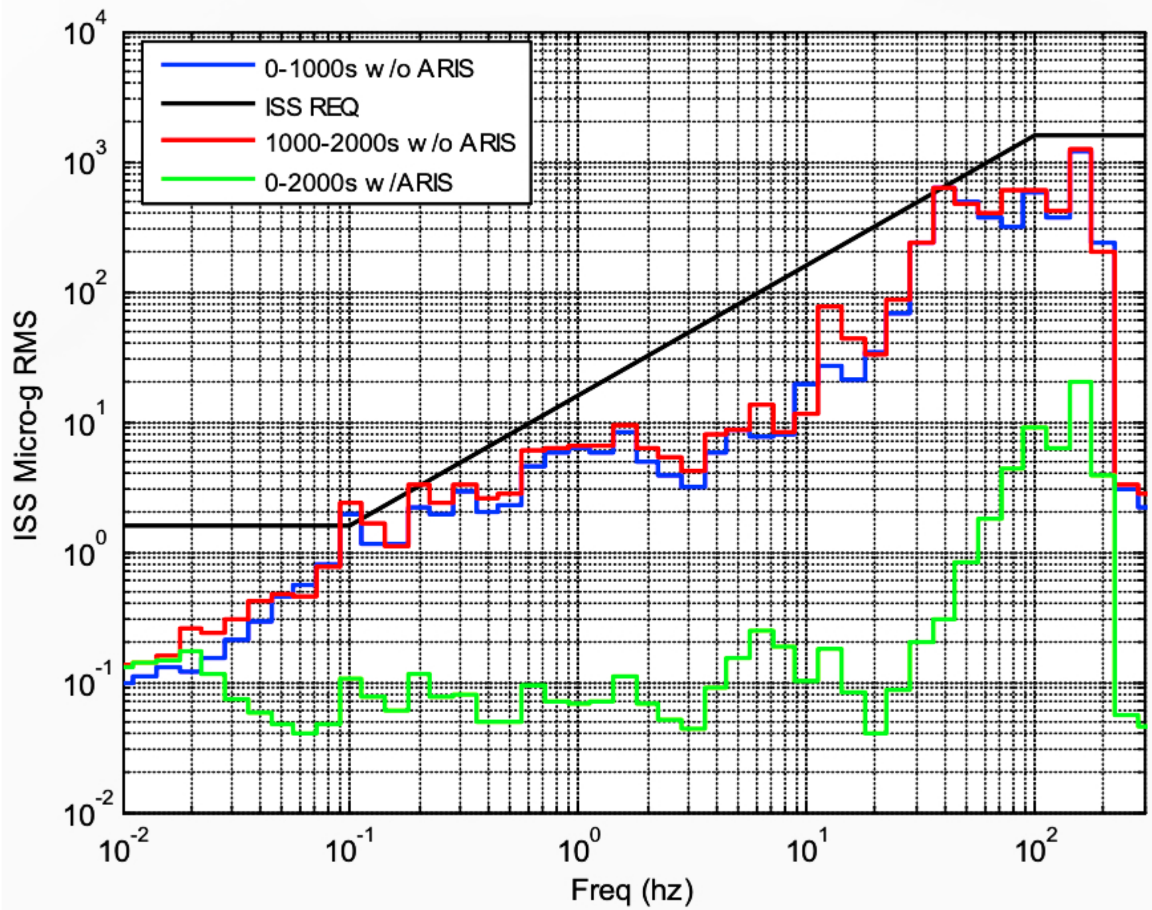
$t_1$=9 ms, 33.6nK

$t_1$=29 ms, 23.3nK



# The new challenge of space station cooling: the impact of vibration on cooling



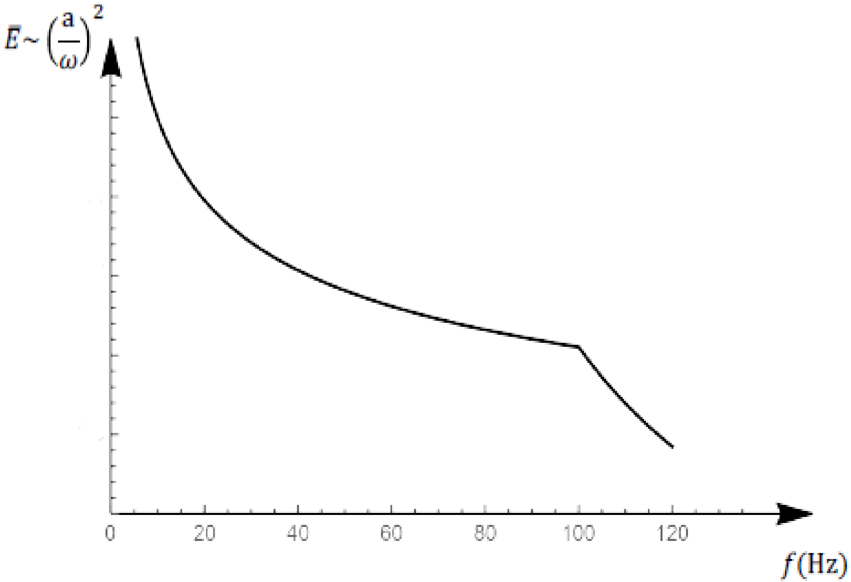


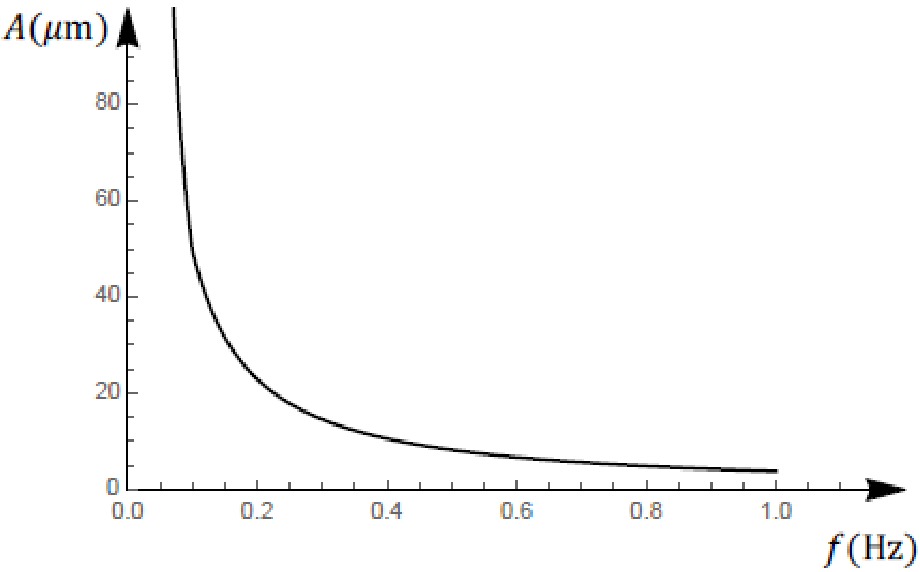

原国际空间站振动加速度与频率的关系

# Deep cooling technology under spatial vibration conditions

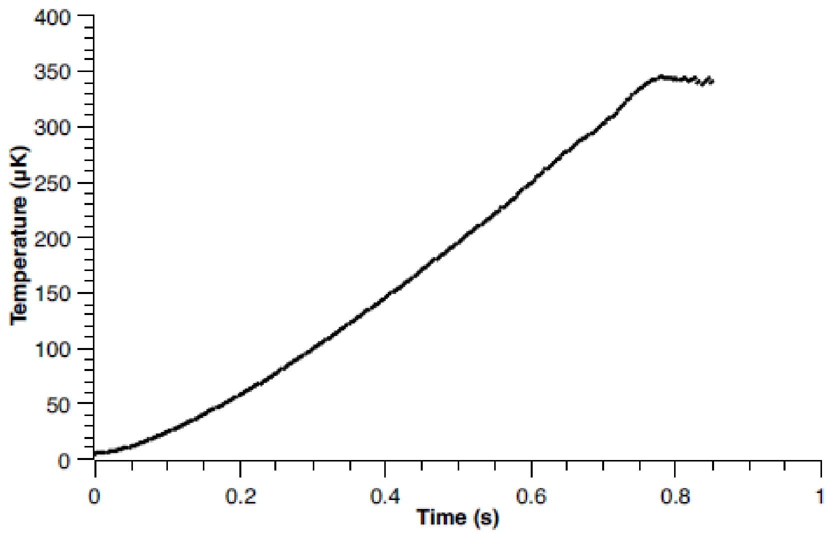
- The method of this numerical simulation adopts the "direct Monte Carlo simulation" or DSMC method.
- The DSMC method is derived from the numerical simulation of fluid problems and is usually used in aeronautical engineering. It can handle the dynamic evolution of large particle systems. We use this method to simulate the cooling process of the boson ultra-cold gas system until the quantum phase transition occurs.
- This numerical simulation can give key physical parameters such as temperature, particle number, number density, phase space density, etc. of the total cooling process.
- The impact of mechanical vibration is a typical forced vibration problem, which specifically belongs to Base exited Forced Vibration.
- We study the cooling problem under single-frequency continuous vibration. Second, study the vibration problem under the vibration acceleration spectrum of the International Space Station.

# Numerical simulation of vibration heating process

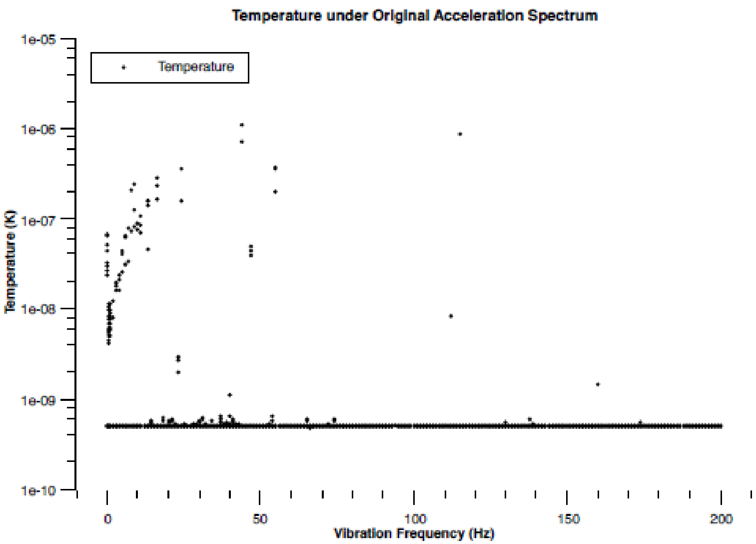


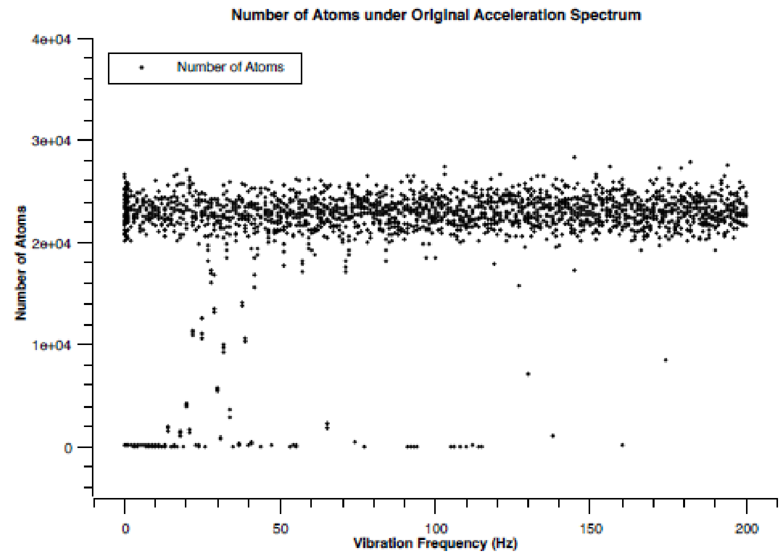

Hea



# Numerical simulation of vibration heating process




(a) final temperatures

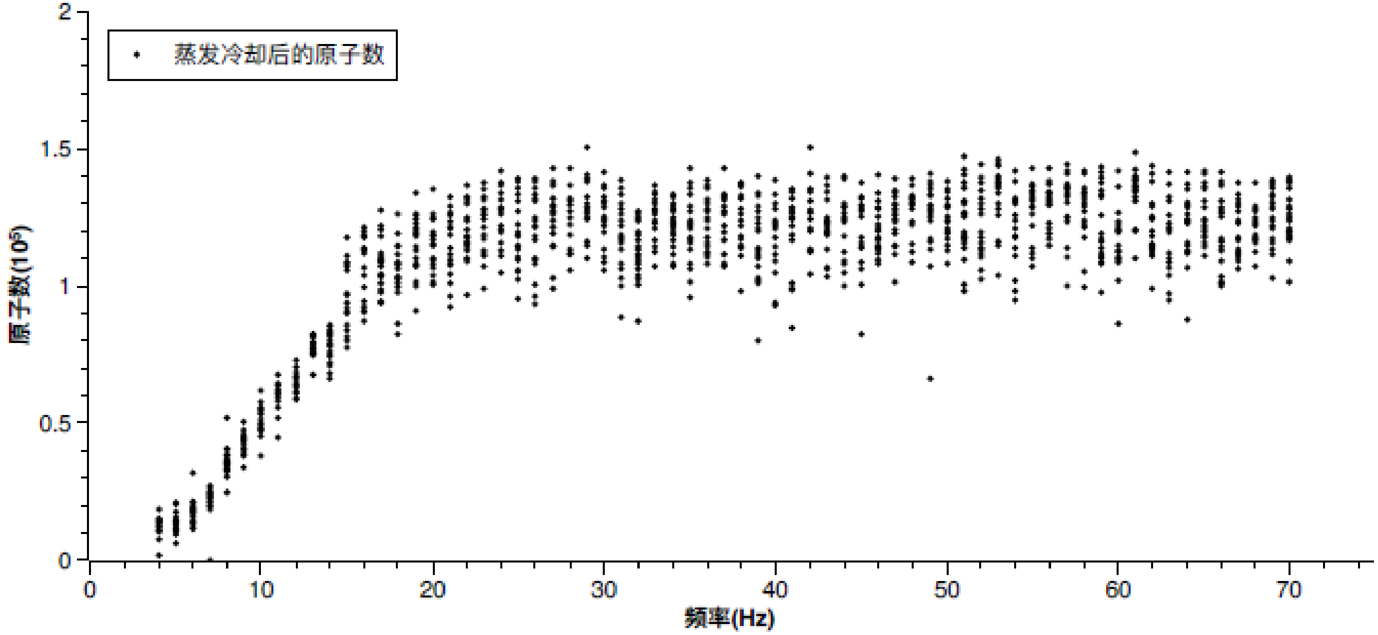


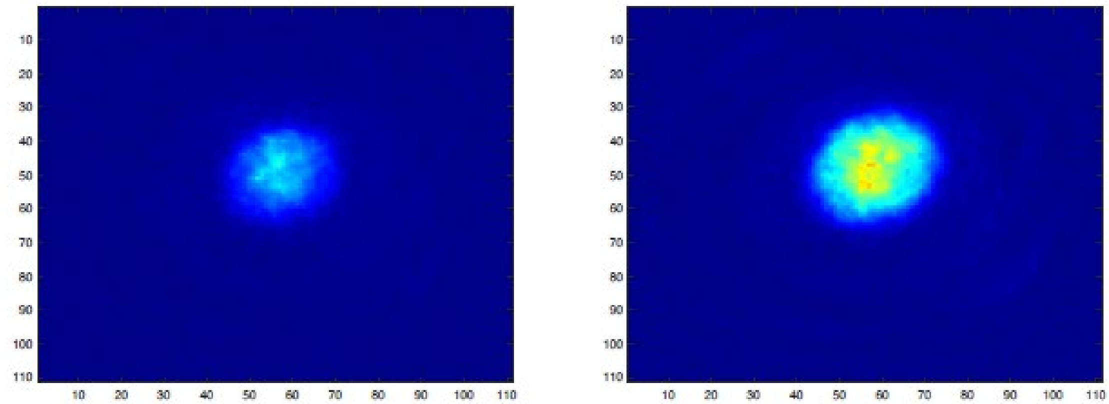

(b) final number of atoms

| 频率 (Hz) | 概率 (%) @1X[a] | 概率 (%) @0.1X[b] | 概率 (%) @0.01X[c] |
|---|---|---|---|
| 0.1 ~ 0.9 | 27 | 29 | 22 |
| 1 ~ 10 | 27 | 21 | 7 |
| 11 ~ 20 | 27 | 6 | 2 |
| 21 ~ 30 | 27 | 0 | 0 |
| 31 ~ 40 | 25 | 0 | 0 |
| 41 ~ 50 | 10 | 0 | 0 |
| 51 ~ 60 | 11 | 2 | 0 |
| 61 ~ 70 | 0 | 1 | 0 |
| 71 ~ 80 | 6 | 1 | 0 |
| 81 ~ 90 | 0 | 1 | 0 |
| 91 ~ 100 | 7 | 1 | 0 |
| 101 ~ 200 | $< 2$ | 0 | 0 |

[a] ‘1X’ 为国际空间站 (ISS) 振动谱
[b] ‘0.1X’ 为 0.1 倍的国际空间站 (ISS) 振动谱
[c] ‘0.01X’ 为 0.01 倍的国际空间站 (ISS) 振动谱

# Numerical simulation of vibration heating process



( a ) ( b )

(a). 5 Hz 振动, $0.157\times10^5$ 个原子; (b). 65 Hz 振动, $1.369\times10^5$ 个原子, 温度为 T = 29 nK 的 BEC;

# Outline

1. Introduction to the International Space Ultra-cold Atomic Physics Experiment

2. The scientific goals of the space station's ultra-cold atomic experiment rack

3. The experimental principle of obtaining 100pK temperature

4. Progress of ultra-cold atomic experiment rack for space station

5. Scientific experiments in the ultra-cold atomic laboratory rack

6. Summary

**Peking University is institution of scientific PI, one of the pioneer of cold atom in china**

CHIN.PHYS.LETT. Vol.13, No.11 (1996) 821

# Magneto-Optical Trap of Cesium Atoms *

GAN Jian-hua, LI Yi-min, CHEN Xu-zong, LIU Hai-feng[1],
YANG Dong-hai, WANG Yi-qiu
*Department of Electronics, Peking University, Beijing 100871*
[1] *Permanent address: Shaanxi Astronomical Observatory, Chinese Academy of Sciences, Lintong 710600*

First cesium MOT in china

(Received 24 April 1996)

*We have trapped a cold sample of cesium atoms in a magneto-optical trap. The damped harmonic force of magneto-optical trap was used to capture and trap the cesium atoms directly from*

PHYSICAL REVIEW A **73**, 013624 (2006)

# Population oscillation of the multicomponent spinor Bose-Einstein condensate induced by nonadiabatic transitions

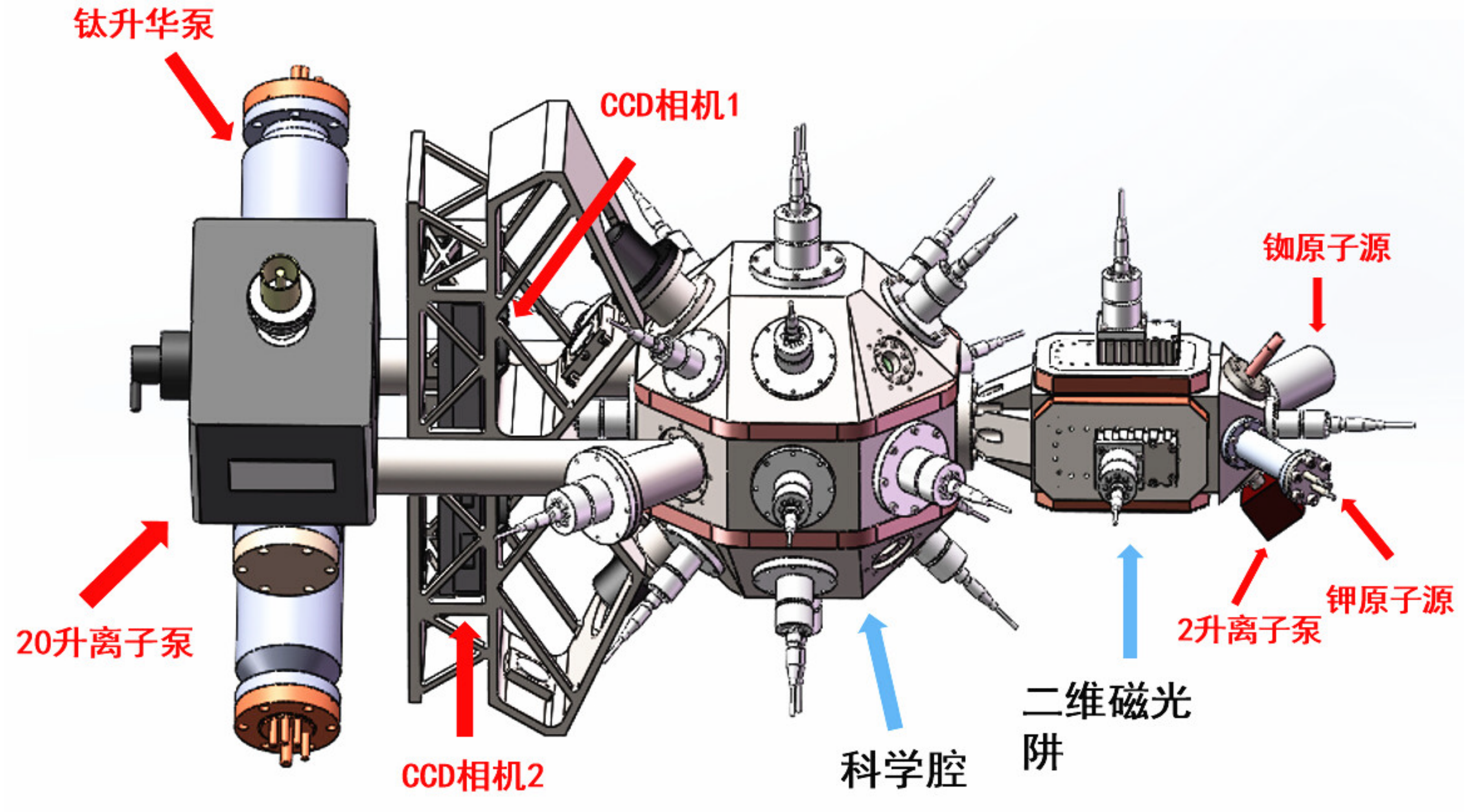
Xiuquan Ma, Lin Xia, Fang Yang, Xiaoji Zhou, Yiqiu Wang, Hong Guo,* and Xuzong Chen†
*Key Laboratory for Quantum Information and Measurements, Ministry of Education, School of Electronics Engineering and Computer Science, Peking University, Beijing 100871, Peoples Republic of China*

(Received 1 October 2005; published 24 January 2006)

First atom laser and first BEC paper published in international journal in china

The generation of the population oscillation of the multicomponent spinor Bose-Einstein condensate is demonstrated in this paper. We observe and examine the nonsynchronous decreasing processes of the magnetic fields generated between quadrupole coils and Ioffe coils during the switch-off of the quadrupole-Ioffe-configuration trap, which is considered to induce a nonadiabatic transition. Starting from the two-level

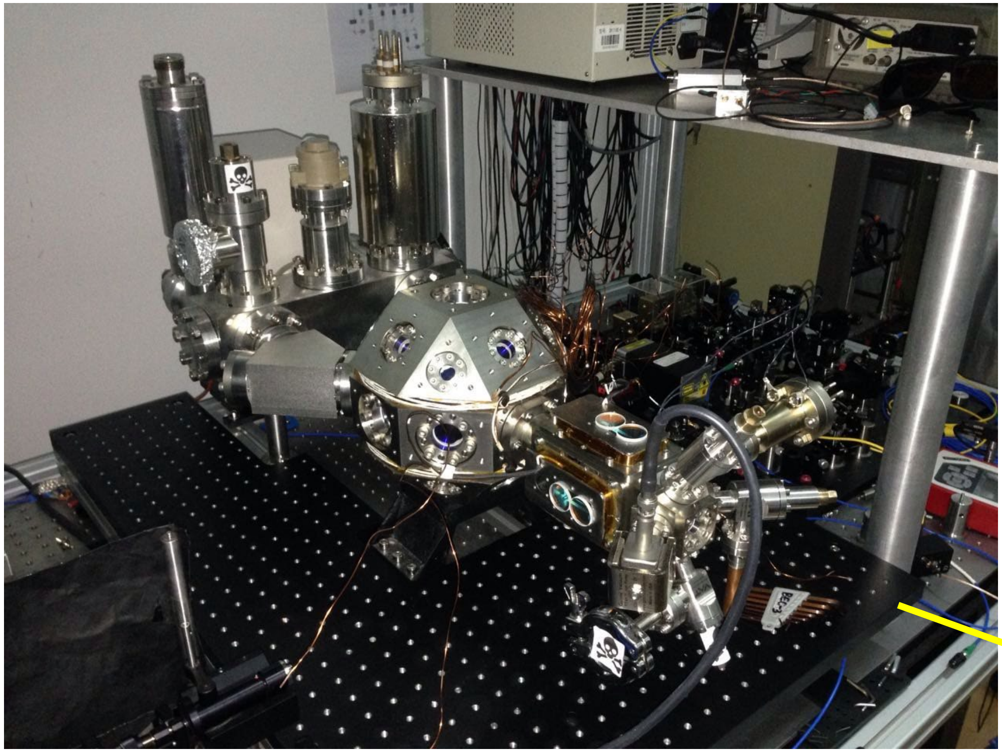
# Ground prototype of space ultra-cold atomic experiment system



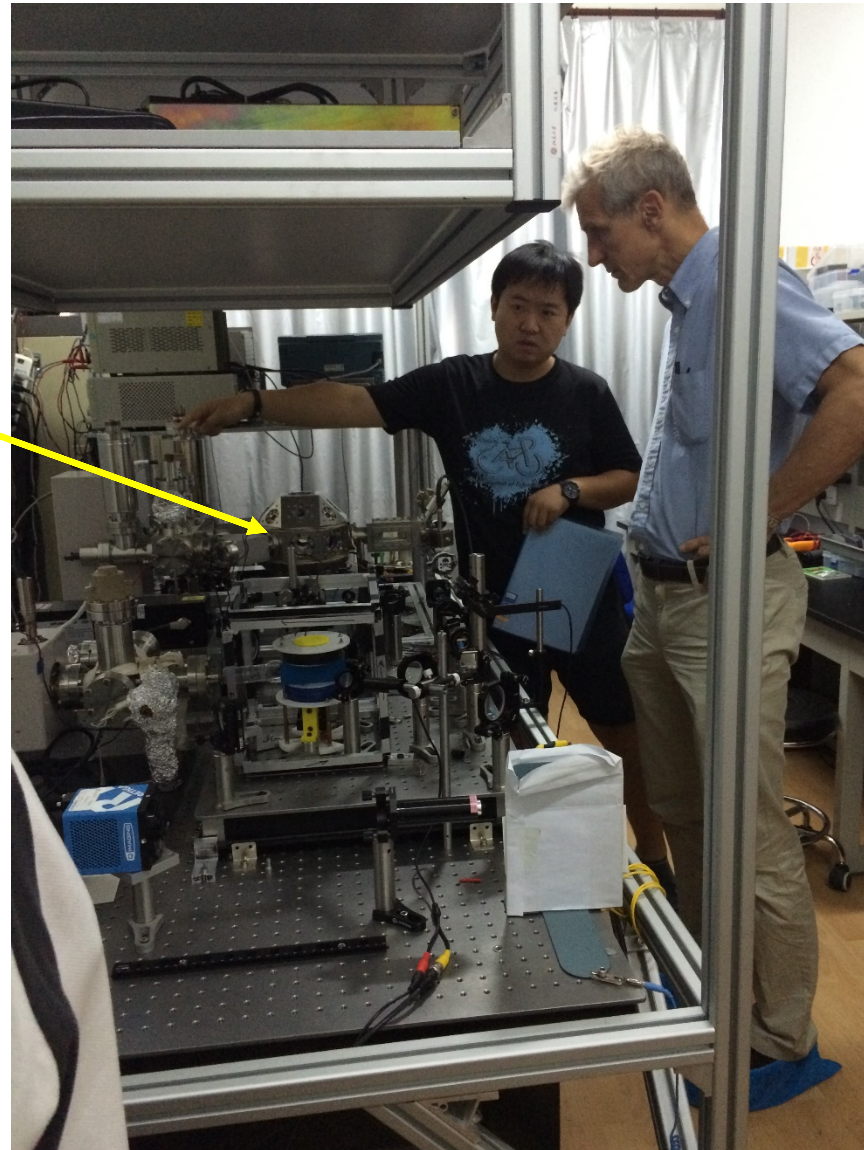

Experimental System-B

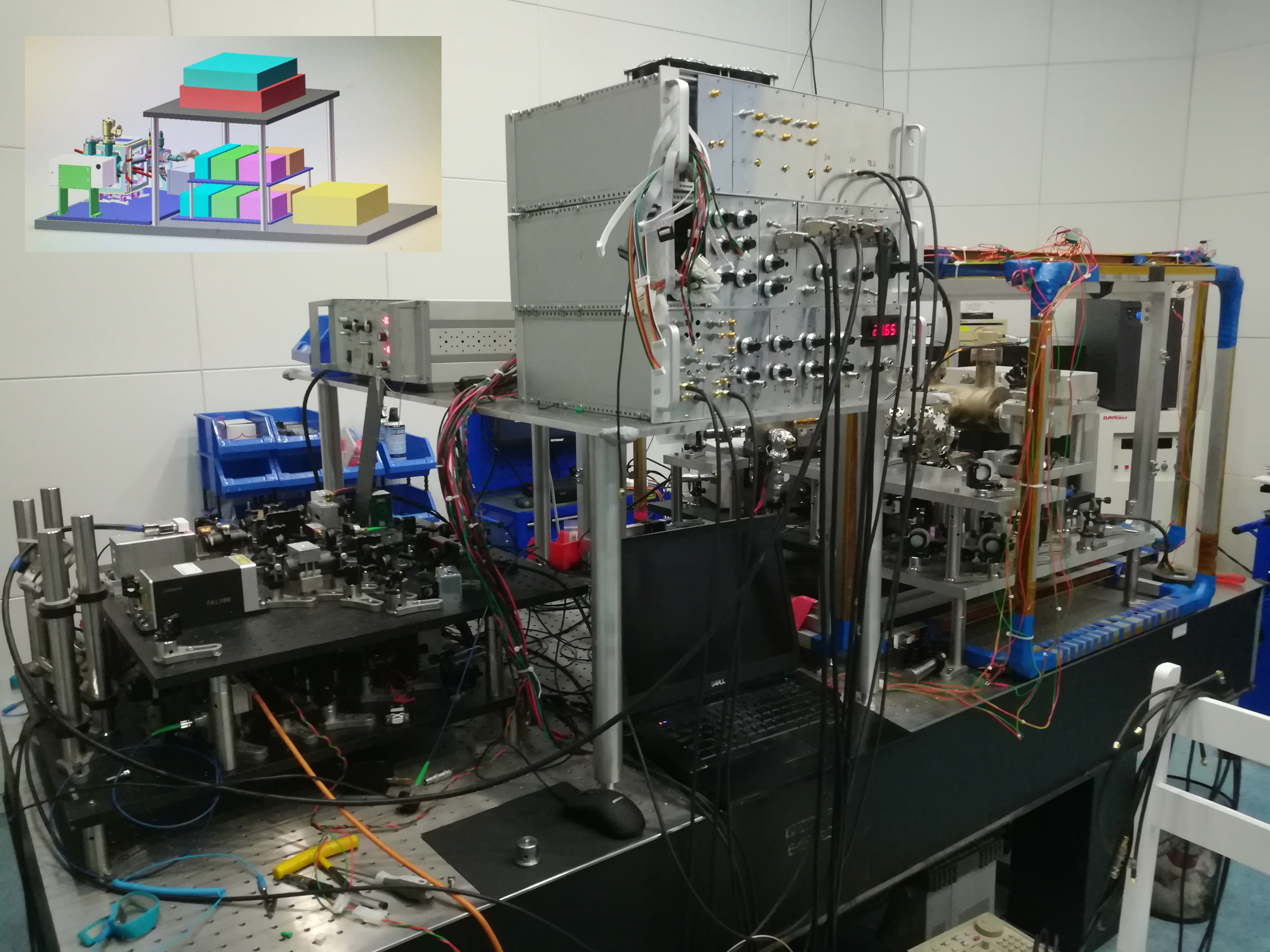
- Normal working vacuum pressure: <$3X10^{-9}$Pa
- Experiment content:
  - Rubidium atom degenerate gas experiment, potassium atom degenerate gas experiment, ground scientific experiment verification, vacuum holding experiment without power supply

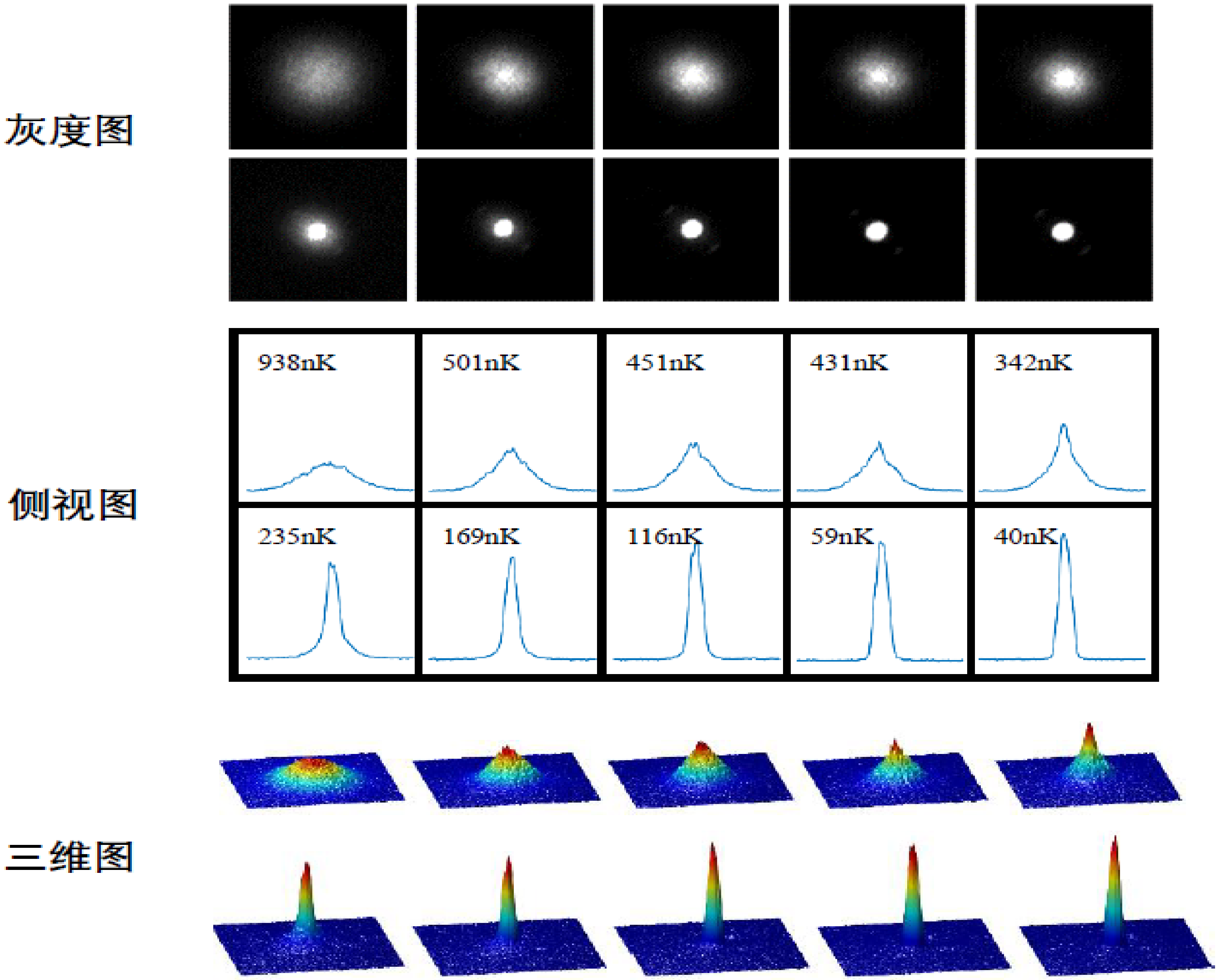
# Prototype of space ultra-cold atomic experiment system



Nobel Prize winner Wolfgang Ketterle visited the prototype of the space ultra-cold atomic experiment system August 3, 2016






灰度图
侧视图
938nK
501nK
451nK
431nK
342nK
235nK
169nK
116nK
59nK
40nK
三维图

**Shanghai Institute of Optics and Fine Mechanics is institution of Project PI, the pioneer of cold atom in china**

ELSEVIER

Optics Communications

Volume 70, Issue 6, 15 April 1989, Pages 462-466

# Collimation of an atomic beam using retarded dipole force

Yuzhu Wang [1], Yudan Cheng, Weiquan Cai

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https://doi.org/10.1016/0030-4018(89)90365-9

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First laser cooling paper and temperature lower than Doppler limit

## Abstract

We report the experimental study of collimation of an atomic beam using retarded dipole force. The transverse velocity of the atomic beam has been reduced from 50 to 15 cm/s, which corresponds to decrease in transverse efficient temperature from 350 to 33 μK. It has been found that a good collimation of the atomic beam can not be obtained at small detuning

CHIN.PHYS.LETT. Vol. 20, No. 6 (2003) 799

# Evidence for a Bose–Einstein Condensate in Dilute Rb Gas by Absorption Image in a Quadrupole and Ioffe Configuration Trap *

First BEC in china

WANG Yu-Zhu(王育竹), ZHOU Shu-Yu(周蜀渝), LONG Quan(龙全),
ZHOU Shan-Yu(周善钰), FU Hai-Xiang(付海翔)

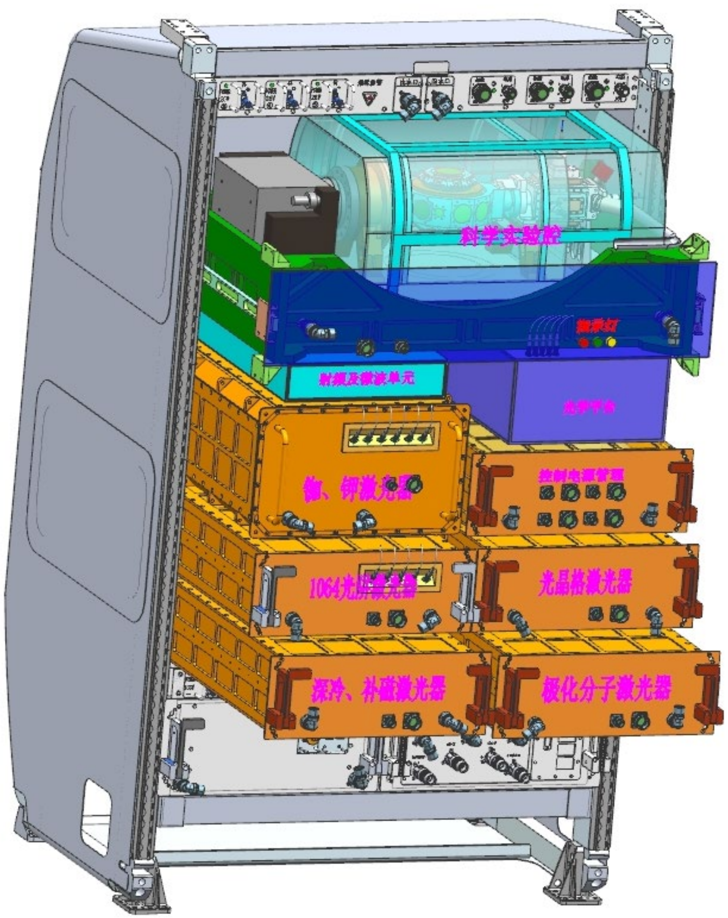
*Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences, Shanghai 201800*

(Received 21 February 2003)

*We report the realization of Bose–Einstein condensation (BEC) in dilute rubidium gas. The BEC was achieved in a quadrupole and Ioffe configuration trap. The number of condensed atoms is around $4 \times 10^4$ in total $5 \times 10^5$, and the transition temperature is 250 nK. We have studied the light scattering of the atom cloud and the condensate in a tightly confined magnetic trap. We show that it is possible to use the diffraction patterns in the near-resonant imaging of the trapped cold atomic samples to give the information of the BEC phase transition.*

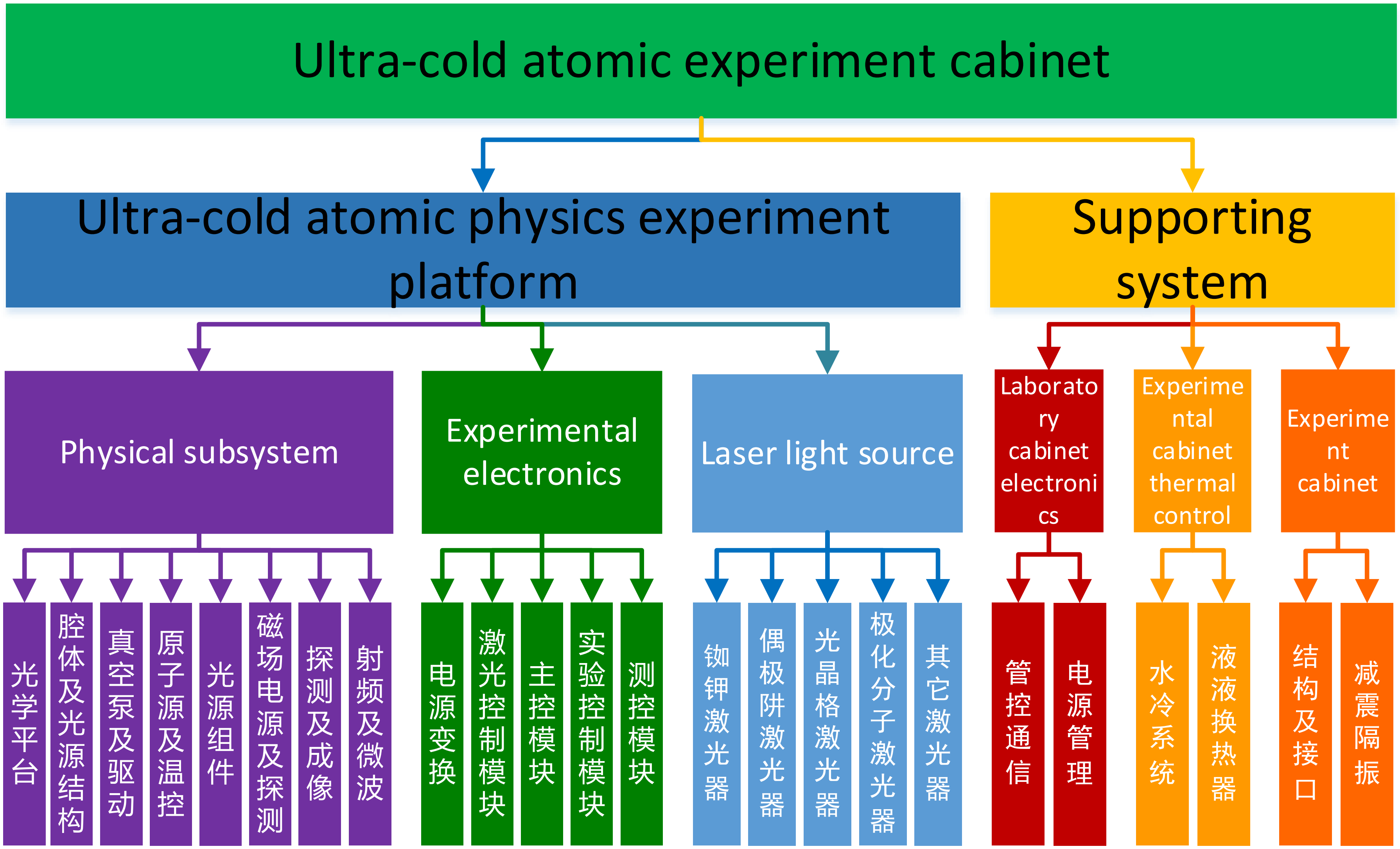

3

# Introduction of ultra-cold atomic experiment rack

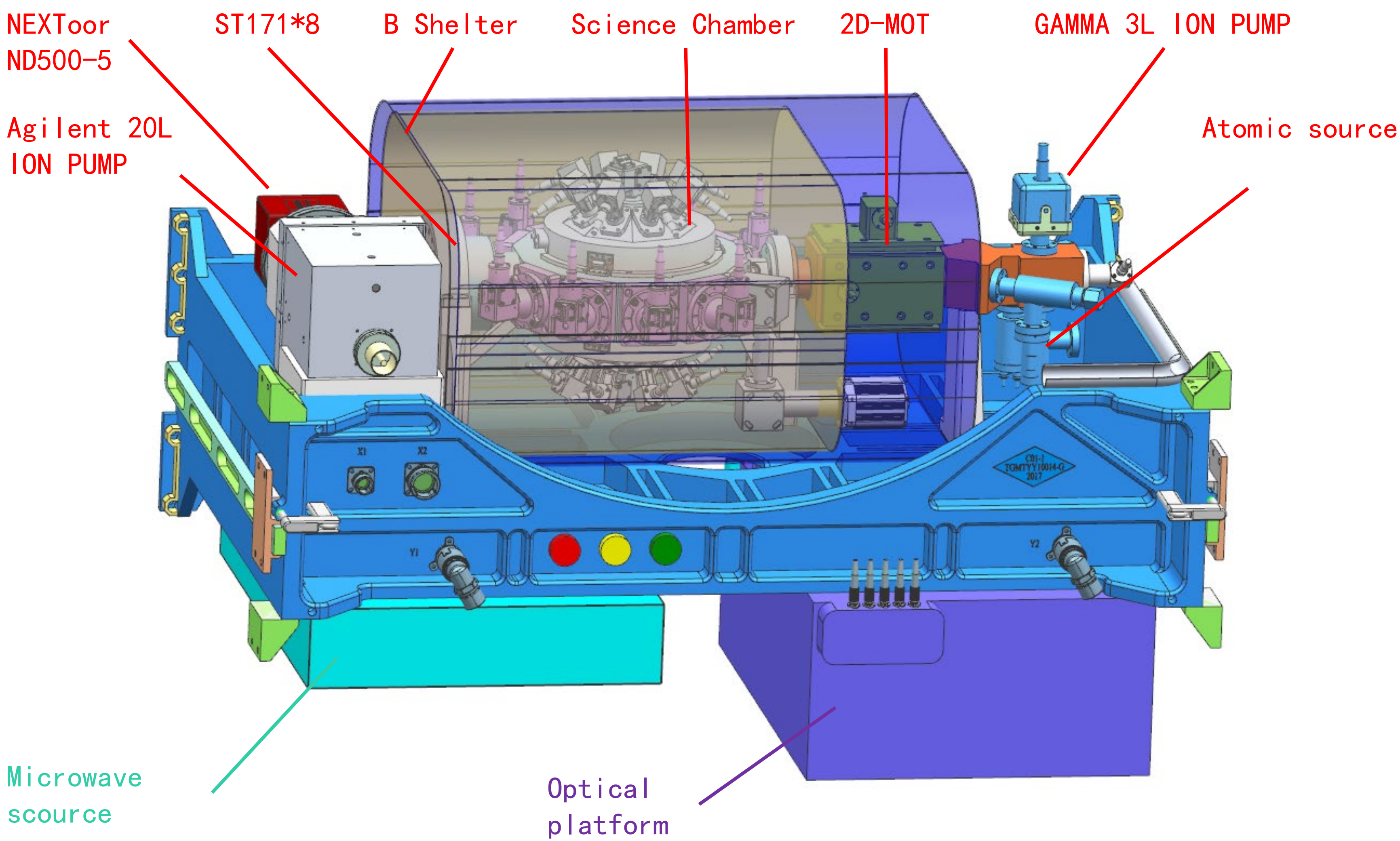



- **Advance**: to ensure that the space ultra-cold atomic platform established represents the international advanced level and meets the goals of forward-looking scientific experiments.
- **Safety**: Fully consider the safety of the space station and the safety of astronauts;
- **Scalability**: The platform adopts a modular design, the size of each module meets the specifications of the experimental cabinet, and the communication and power supply adopt the standard of the experimental cabinet, which is versatile and expandable, and is easier to replace and upgrade to meet the needs of future space science experiments.

# System composition of ultra-cold atomic physics rack (CAPR)

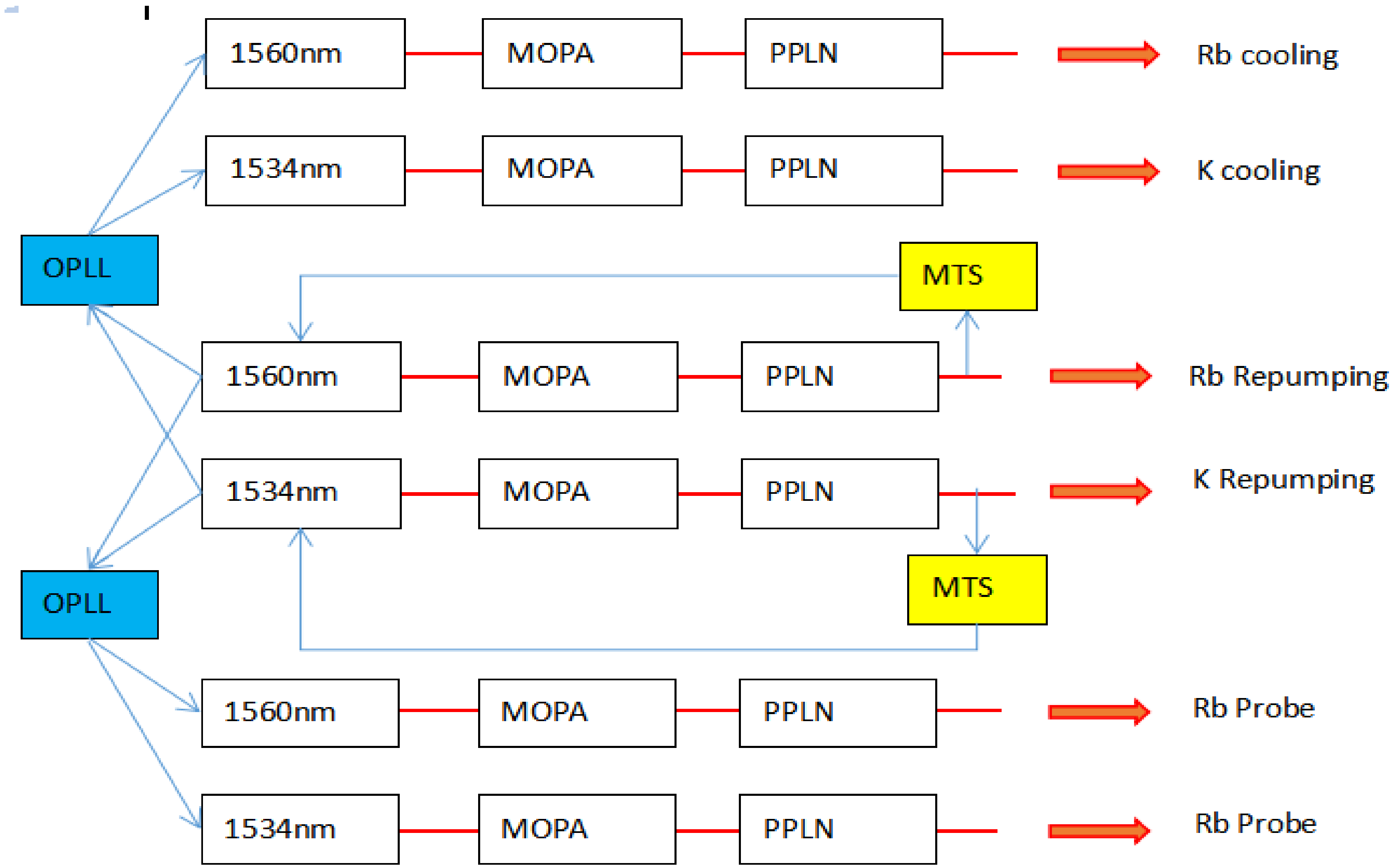


# Physical Unit



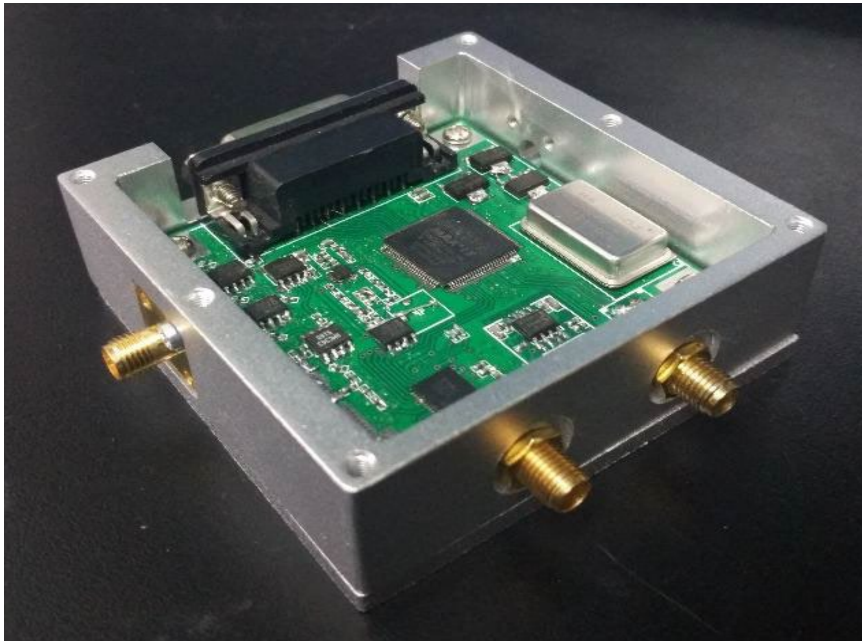
Test of the system by the team of Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences, and Peking University

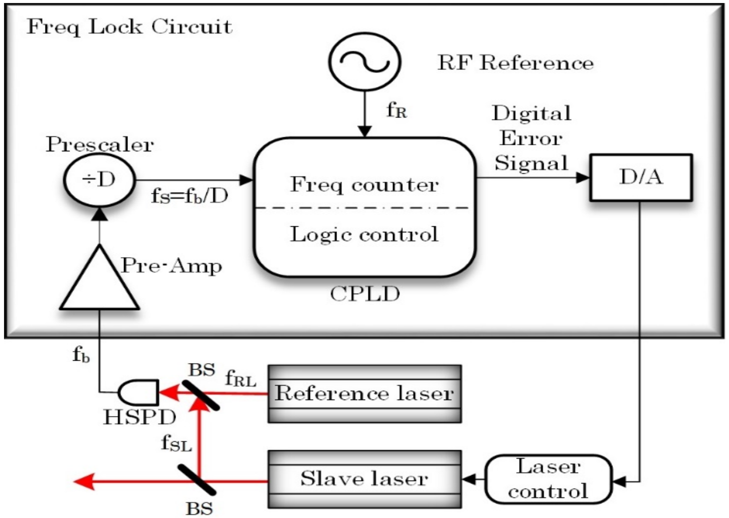
# Key technology (1): all-fiber laser technology



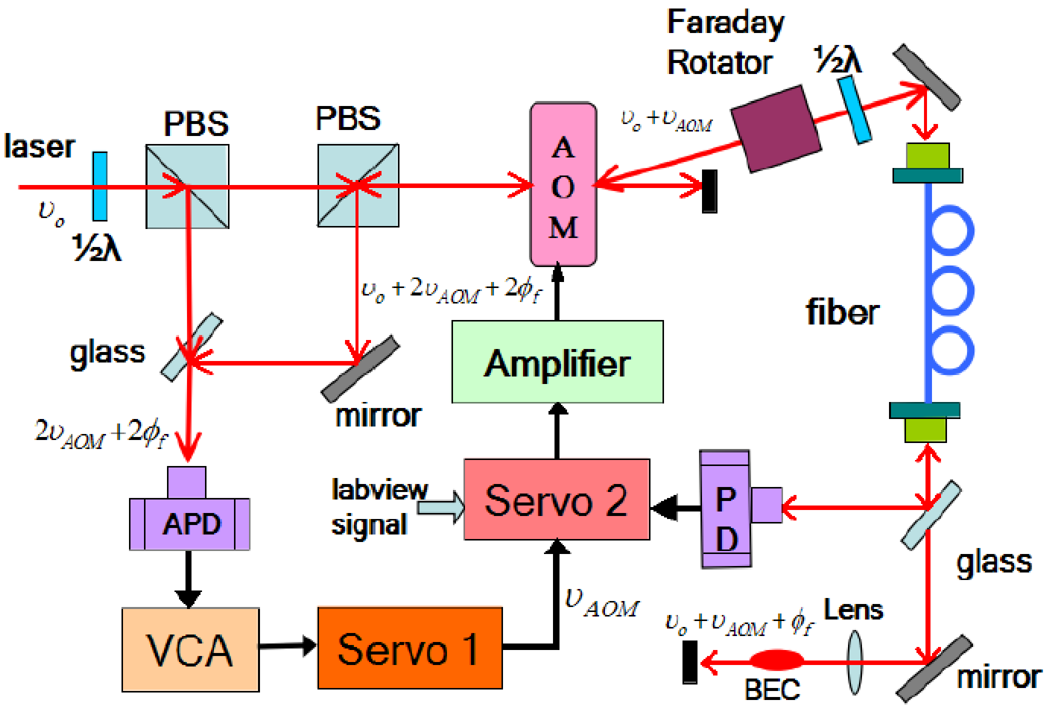
# Key technology (2): high frequency laser phase lock technology

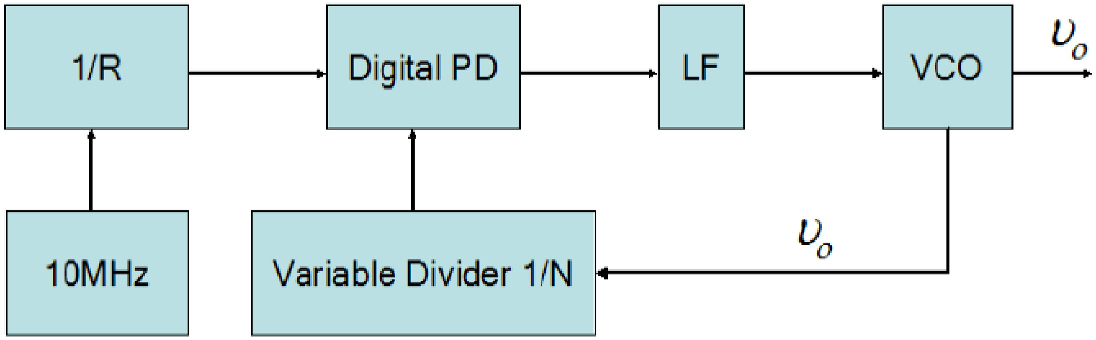
- In the process of laser cooling atoms, a tunable frequency-stabilized laser is required
- Traditional AOM + Double Pass method: complex optical path, large volume, high power consumption
- The new system uses beat frequency locking
- The circuit is realized based on CPLD: highly integrated, PCB area is only 6cm×6cm
- The beat frequency signal line width is 22MHz, and the lock frequency is set to red detune 6.57GHz
- The frequency lock and phase lock modules cooperate with each other to complete the laser lock, and the lock line width is 10MHz
- Tuning range ±12GHz, dynamic range 500MHz

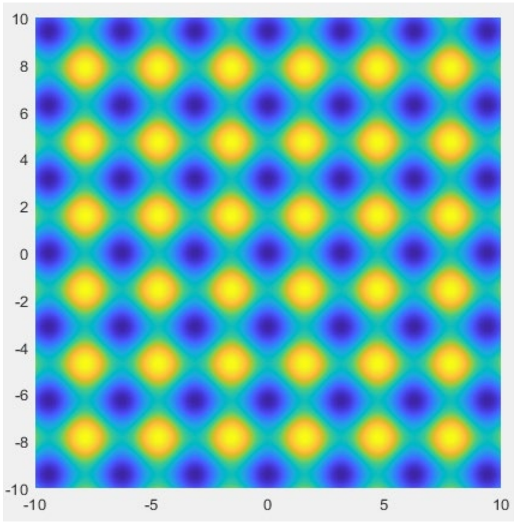




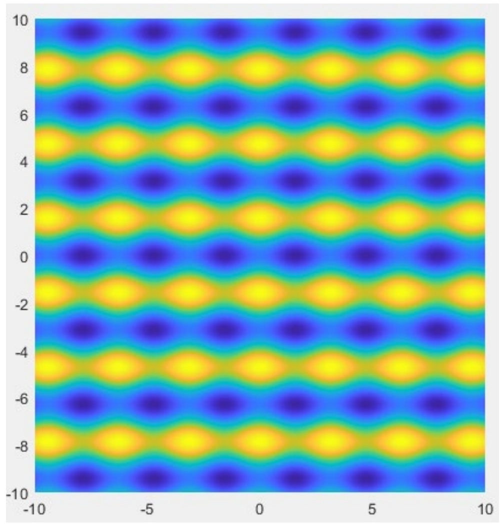
# Key technology (3): laser power stabilization and laser phase lock



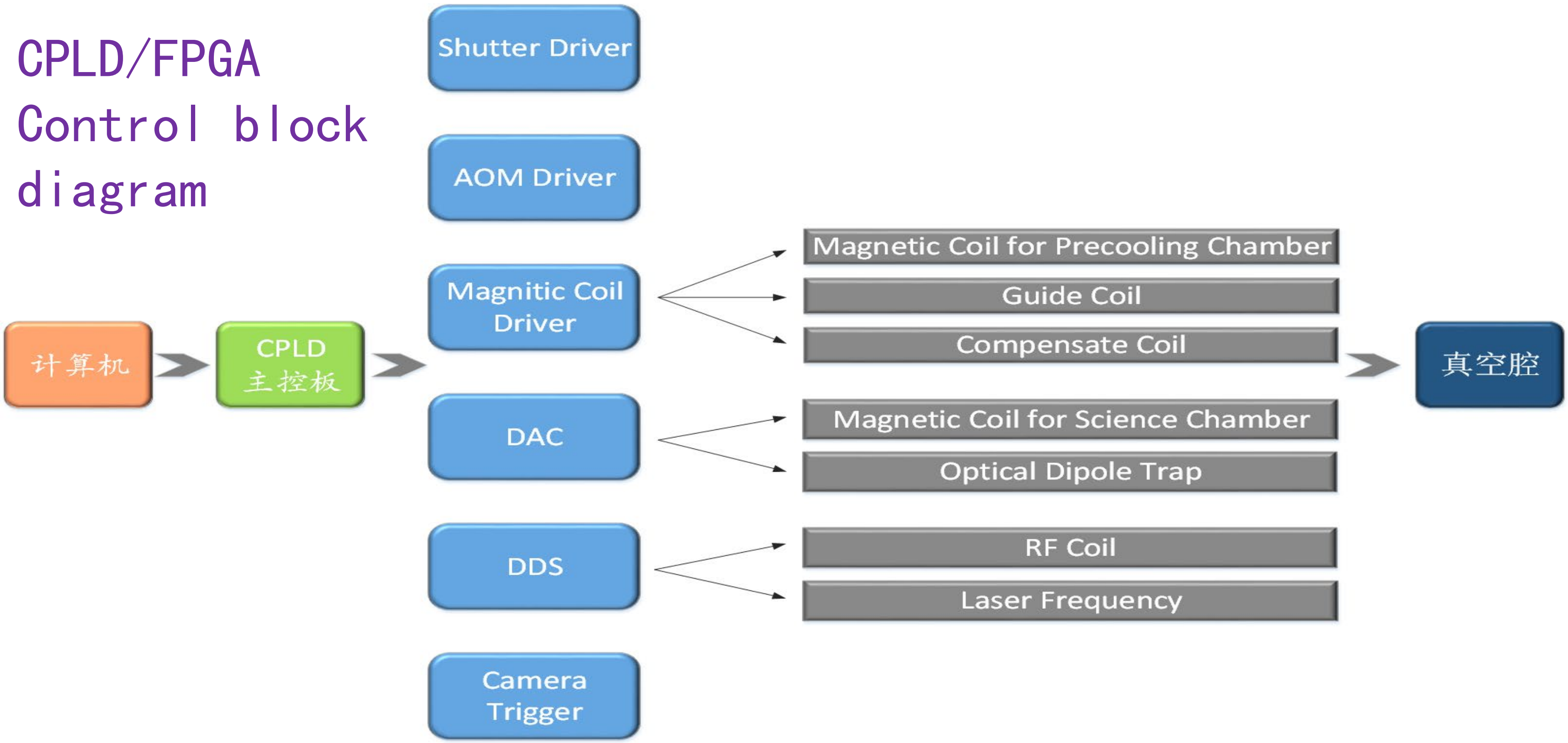
φ=0

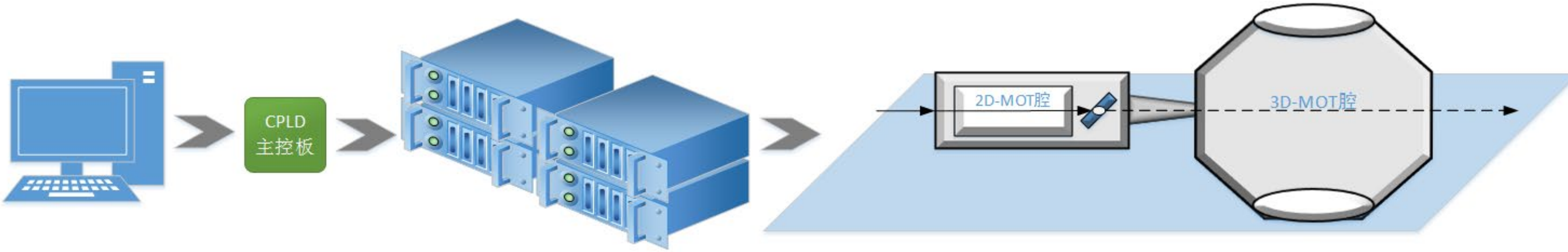


φ=π

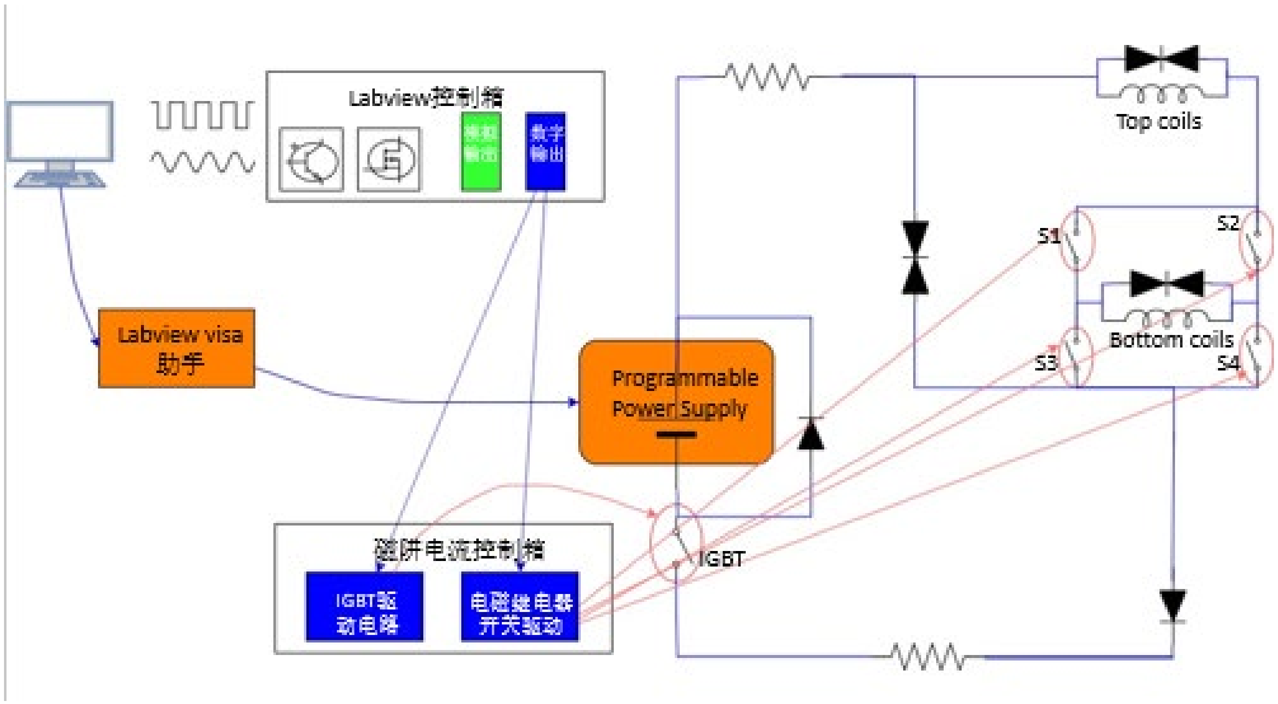
# Key technology (4): CPLD/FPGA control circuit

CPLD/FPGA Control block diagram



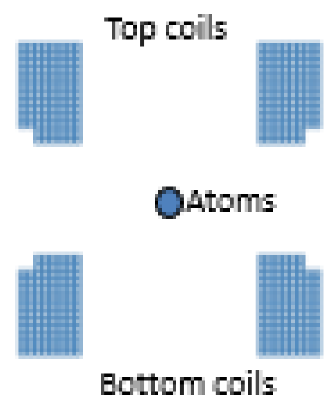



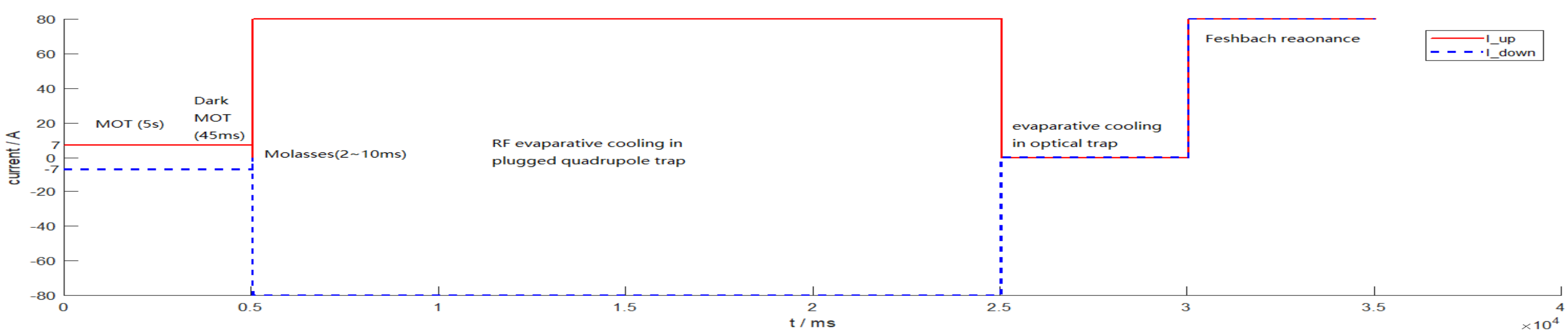
# Key technology (5): high current magnetic trap control technology



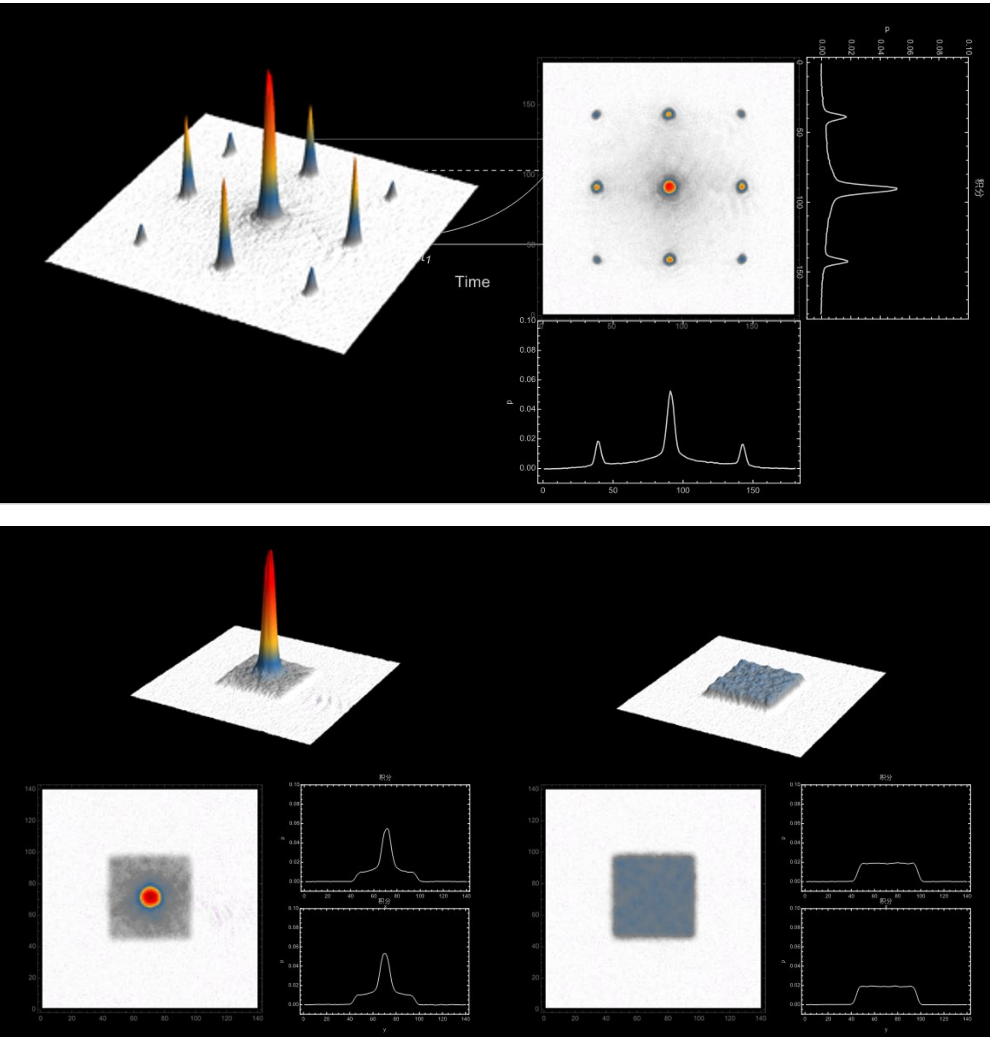

磁场：600Gs

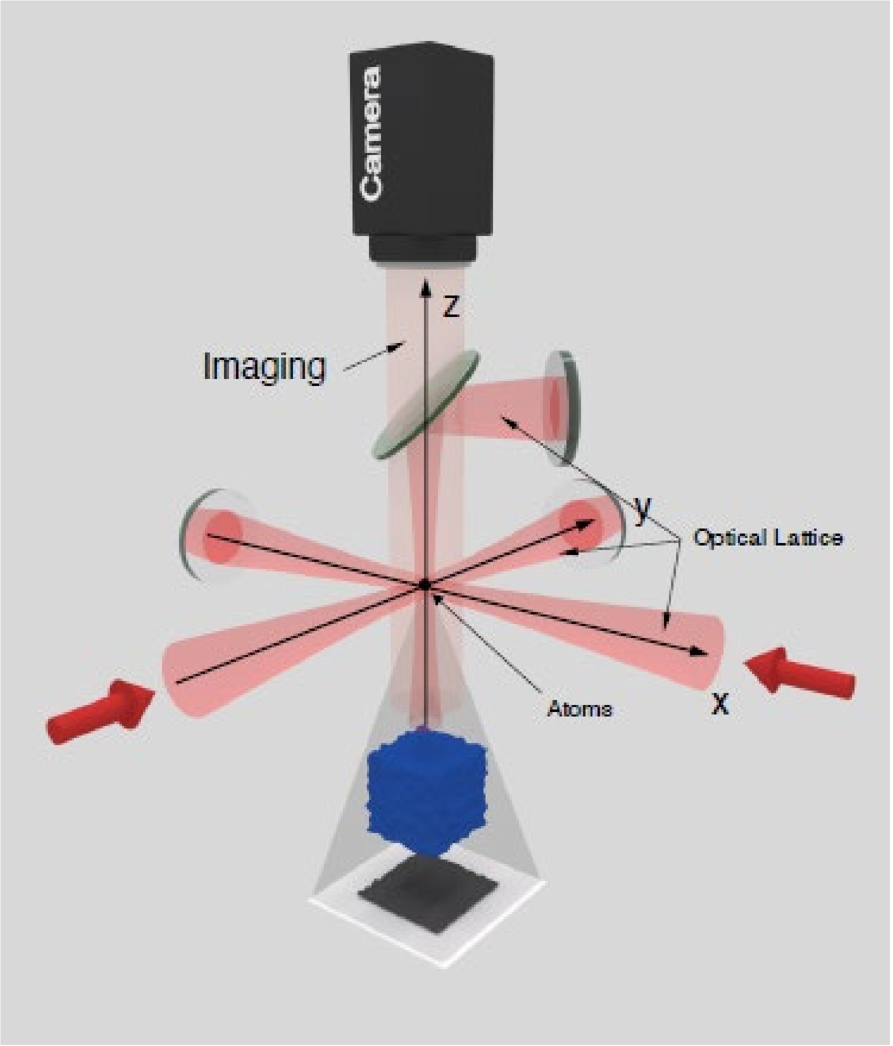
电流：500A



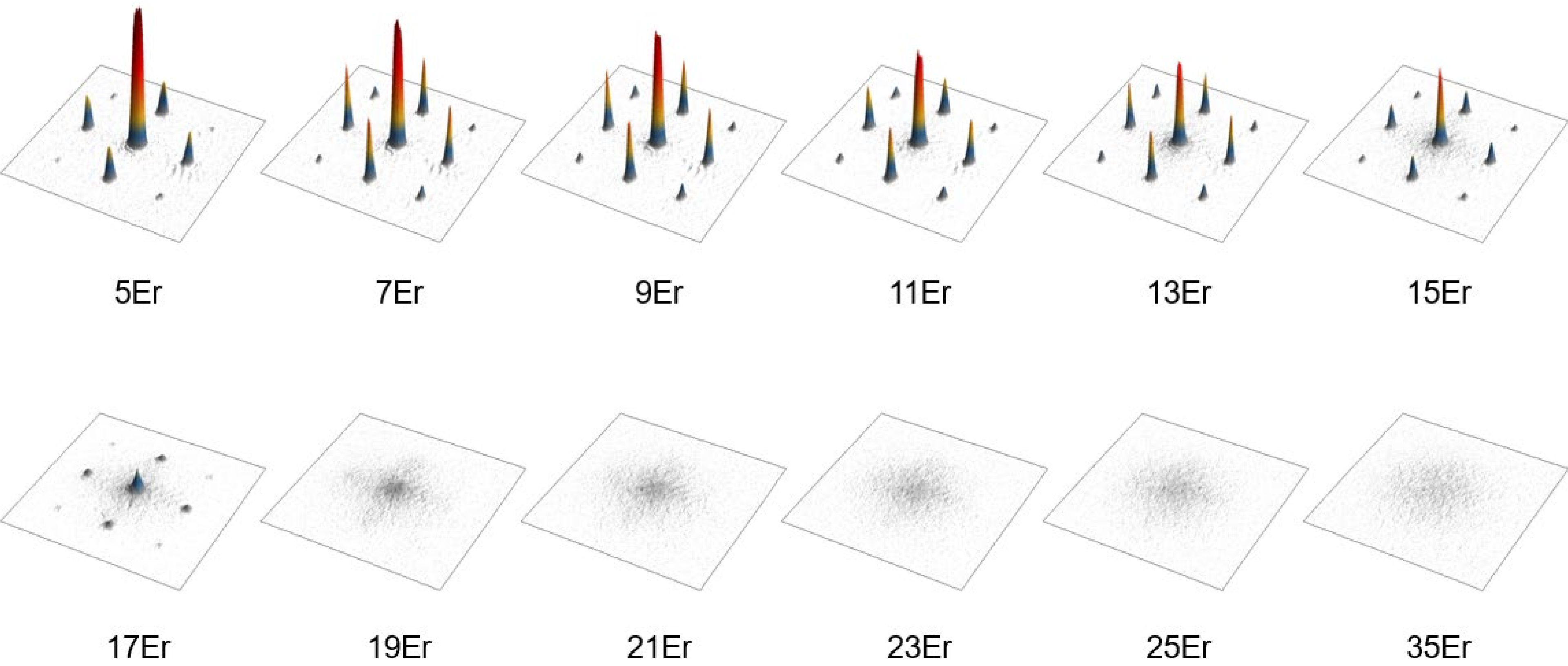
# (6) The key technology of scientific experiment: optical lattice technology




**A three-dimensional light lattice can be formed by adding a third pair of lights in the vertical direction**

# (6) The key technology of scientific experiment: optical lattice technology



# Outline

1. Introduction to the International Space Ultra-cold Atomic Physics Experiment

2. The scientific goals of the space station's ultra-cold atomic experiment rack

3. The experimental principle of obtaining 100pK temperature

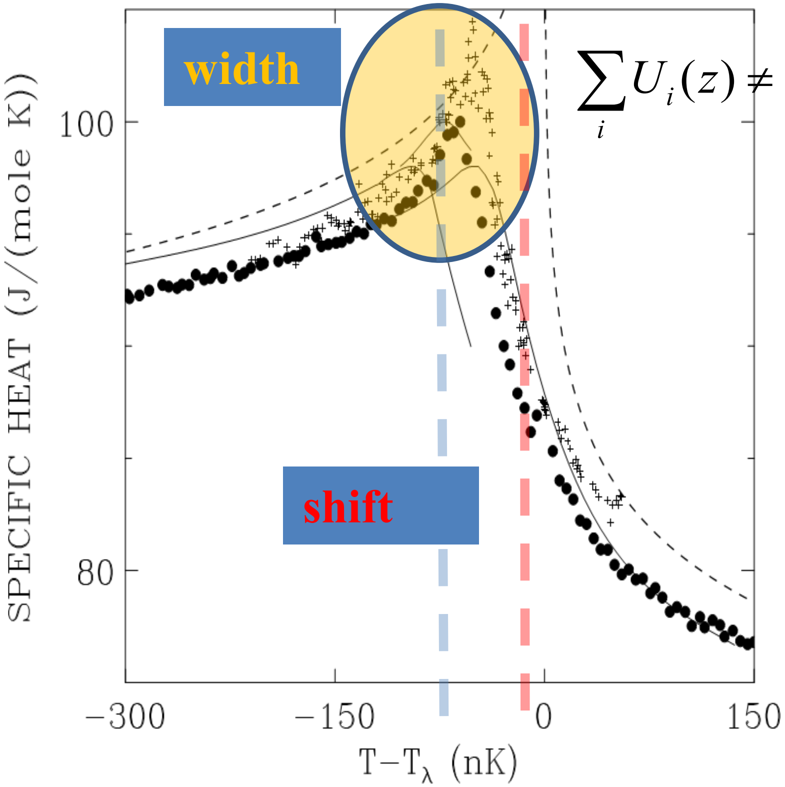
4. Progress of ultra-cold atomic experiment cabinet for space station

5. Scientific experiments in the ultra-cold atomic laboratory rack

6. Summary

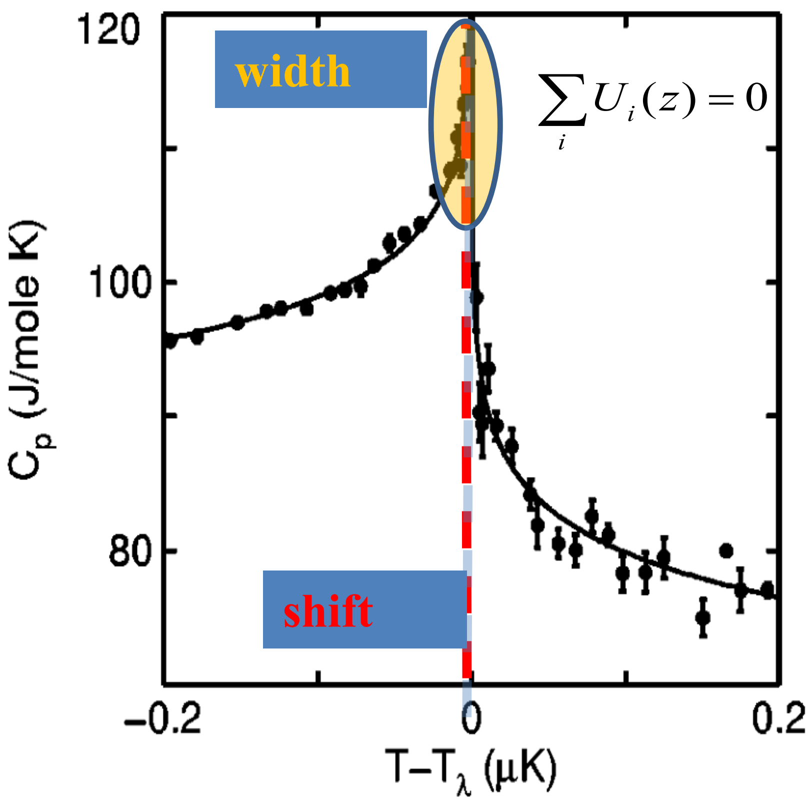
# Famous scientific experiments on the International Space Station ——Measurement of critical phase transition characteristics of $^4$He between the space station and the ground

$$\hat{H} = \sum_i \left[ -\frac{\hbar^2}{2m_i}\Delta_i + U_i(z) + V_i(x,y,z) \right]$$




Phys. Rev. Lett. Vol. 84, p. 4894, 2000

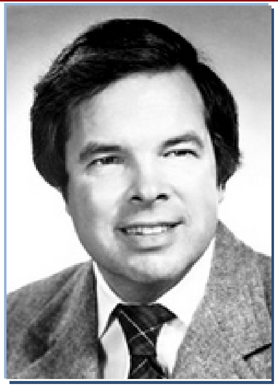
$^4$He superfluid lambda transition in earth gravity




Phy. Rev. B Vol. **68**, p. 174518 , 2003

$^4$He superfluid lambda transition in microgravity in ISS

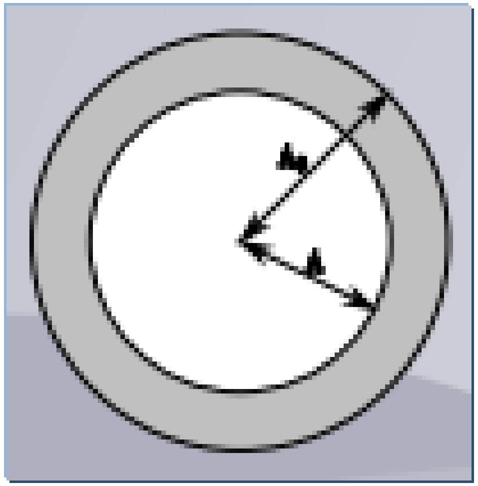
# Famous scientific experiments on the International Space Station ——Measurement of critical phase transition characteristics of $^4He$ between the space station and the ground



**K. G. Wilson**
**1982 Nobel Prize**

Wilson proposed the renormalization group theory:

- Consider the fluctuations in the phase change region
- Remove the high-energy mode integrals, leaving the low-energy mode



$$\boxed{Z = \int D[\varphi] e^{-S_{\Lambda_0} - S_1} = \int D\left[\varphi^<\right] \int D\left[\varphi^>\right] e^{-S_{\Lambda_0} - S_1}}$$

$$S_{\Lambda_0}[\varphi] = \frac{1}{2} \int_{\vec{k}} \left[r_0 + c_0 \vec{k}^2\right] \varphi(-\vec{k}) \varphi(\vec{k})$$

$$S_1 = \frac{n_0}{4!} \int_{\vec{k}_1} \ldots \int_{\vec{k}_4} \delta(\vec{k}_1 + \ldots + \vec{k}_4) \varphi(\vec{k}_1) \varphi(\vec{k}_2) \varphi(\vec{k}_3) \varphi(\vec{k}_4)$$

Cutoff

$$\left|\vec{k}\right| < \Lambda_0$$

$\xi = e^l$

The critical exponents obtained by the renormalization group method agree well with the experiments!

# The critical index of critical behavior is compared with experimental results

TABLE I. Comparison of predicted and observed values of universal quantities near the lambda point.

| Quantity | Predicted | Reference | Observed | Reference |
|---|---|---|---|---|
| $\alpha$ | $-0.01126 \pm 0.0010$ | 7 | $\sim -0.022 \pm 0.006$ | 15, 16, 17 |
| $\alpha$ | $-0.0146 \pm 0.0008$ | 8 | $-0.0105 \pm 0.00038$ | 10, 11 |
| $\zeta$ ($\nu$) | $0.67155 \pm 0.00027$ | 8 | $0.6705 \pm 0.0006$ | 18 |
| $3\zeta + \alpha - 2$ | 0(exact) | 20 | $-0.0012 \pm 0.0027$ | 5, 18 |
| $\Delta$ | $0.529 \pm 0.009$ | 25 | $0.5 \pm 0.1$ | 22 |
| $P$ | $4.433 \pm 0.077$ | 9 | $4.2 \pm 0.1$ | 23 |
| $a_c^+/a_c^-$ | $1.6 \pm 1.0$ | 24 | $1.0 \pm 0.3$ | 23 |
| $a_c^-/\alpha a_\rho$ | $3.4 \pm 0.1$ | 24 | $4.1 \pm 0.2$ | 23 |

$$\boxed{C_p \sim |t|^{-\alpha}} \qquad \boxed{\xi \sim |t|^{-\nu}} \qquad t \equiv \frac{T - T_c}{T_c}$$

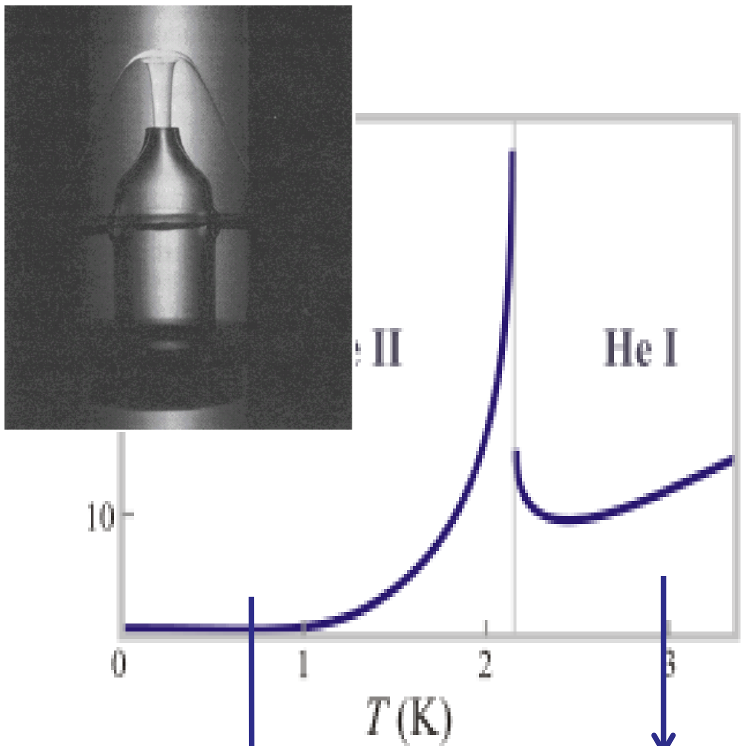
PHYSICAL REVIEW B **68**, 174518 (2003)

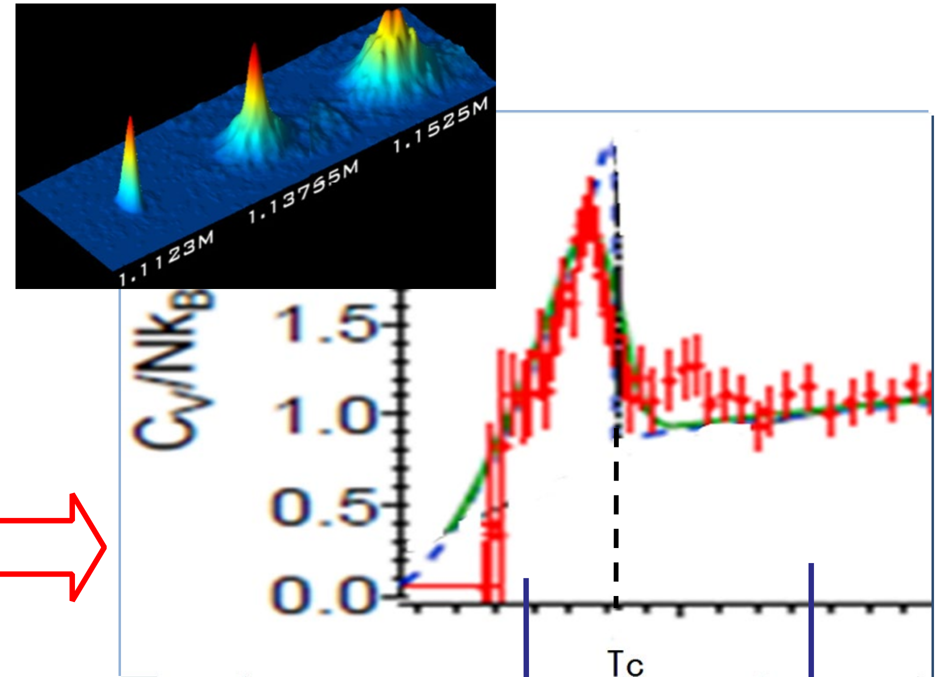
$$\boxed{\alpha = \frac{1}{2} - \frac{3\tau}{10} - 0.129777778\tau^2 - 0.039547352\tau^3 - 0.02432025\tau^4 - 0.00324983\tau^5 - 0.0121092\tau^6}$$



RG

# Comparison of He$^4$ and Bose gas




Quantum Liquid

Normal Liquid

Quantum gas

Normal gas

(1) Multi-body interaction system
(2) H4 Bose system, H3 Fermi system,
(3) 87Rb Bose, 40K Fermi system;

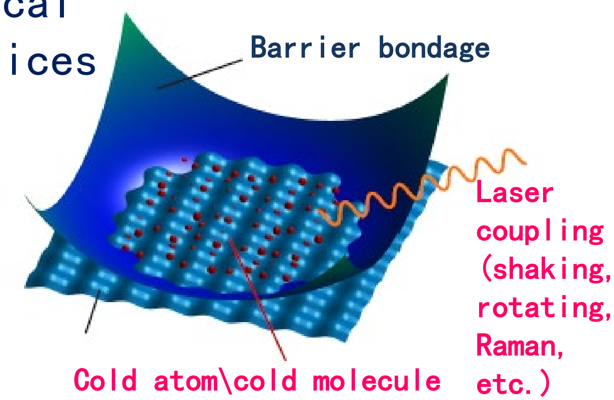
(4) superfluid T<Tc
(5) $\lambda$ phase change
(6) critical temperature: Tc;

# Quantum simulation experiments based on ultra-cold atoms optical lattices


2001 Nobel Prize winner Wolfgang Ketterle: "Quantum simulation of quantum gases in optical lattices can help people understand the properties of matter on a larger scale. Usually, the distance between atoms is on the order of nanometers. On the order of micrometers, this makes it easier to prepare and observe microscopic substances."

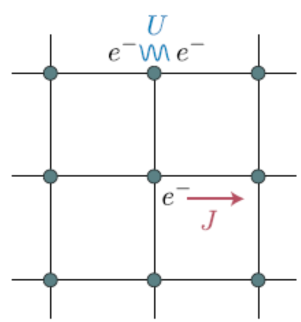
Application prospects: precision quantum measurement, quantum sensors, quantum computers, quantum multi-body physics

## Optical lattices




- Control geometric configuration: potential barrier V(r)
- Control microscopic parameters: J, U
- Clean: no impurities, no phonons
- Ingredients: Fermi, Bose, Molecule

## Theoretical model

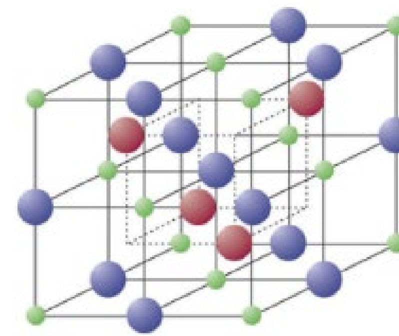



$$\hat{H}_{model} = -J\sum_{link}\hat{a}_j^\dagger\hat{a}_j + 1$$

$$+U\sum_{sites}\hat{a}_j^\dagger\hat{a}_j^\dagger\hat{a}_j\hat{a}_j$$

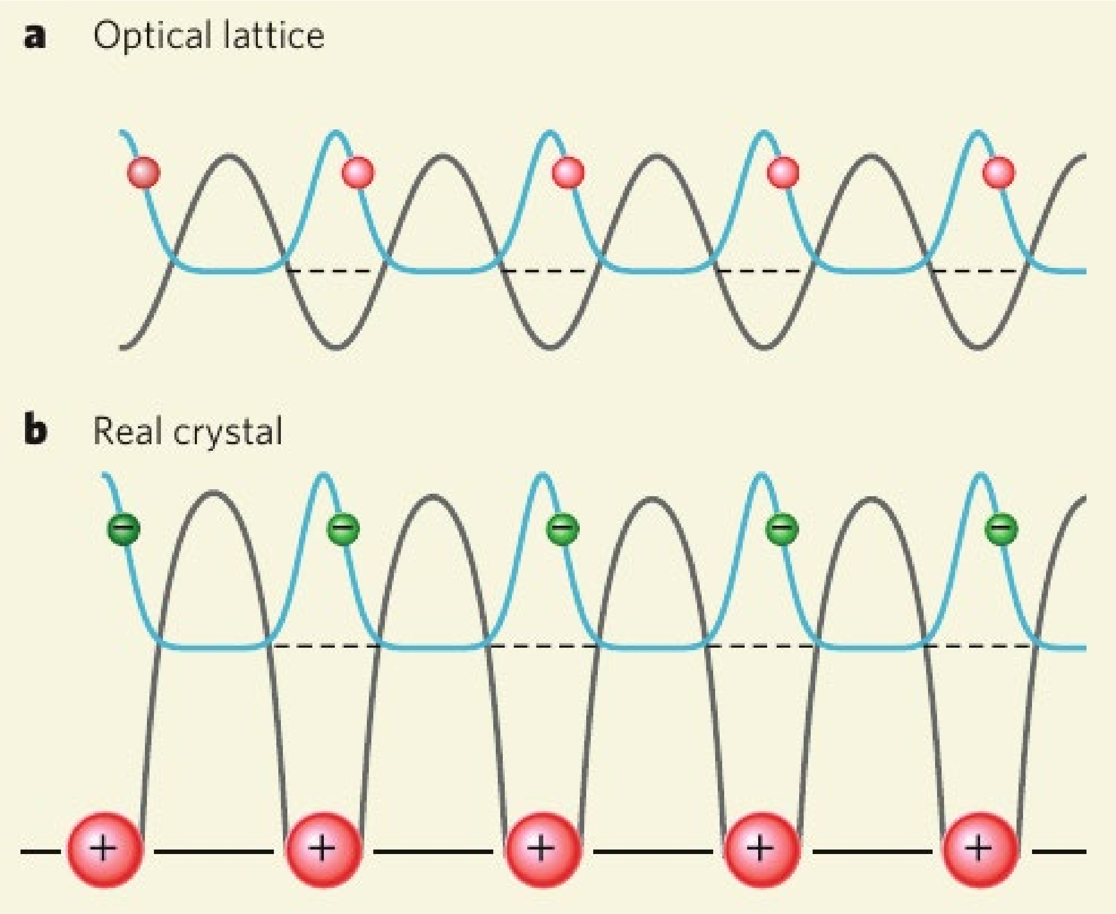
$$+\,ingredient\ \ldots$$

## Lattice



- High temperature superconductor
- Graphene
- Topological insulators
- Topological superfluid
- Weir Semimetal

# Quantum simulation



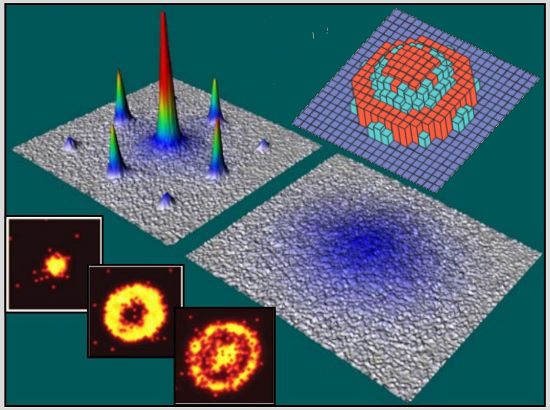

(1) Multi-body system;
(2) Periodic
(3) Bose-Hubbard model

$$\hat{H} = -J\sum_{\langle i,j\rangle}\hat{a}_i^{\dagger}\hat{a}_j + \sum_i \varepsilon_i \hat{a}_i^{\dagger}\hat{a}_i + \frac{1}{2}U\sum_i \hat{a}_i^{\dagger}\hat{a}_i^{\dagger}\hat{a}_i\hat{a}_i$$

$$= -J\sum_{\langle i,j\rangle}\hat{a}_i^{\dagger}\hat{a}_j + \sum_i(\varepsilon_i - \mu)\hat{n}_i + \frac{1}{2}U\sum_i \hat{n}_i\left(\hat{n}_i - 1\right)$$

# Optical lattice and quantum simulation

## Bose-Hubbard Model：SF-MI transition



Nature (2002)　　Science (2010)

**1998**

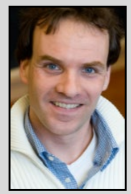
**P. Zoller (Innsbruck)**

**2002**

**I. Bloch (Max Planck)**

**2010**

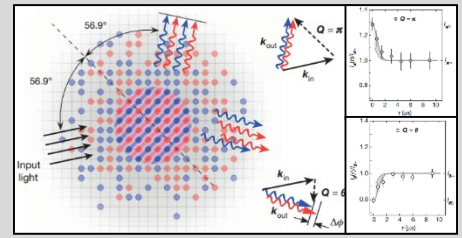
**S. Kuhr (Strathclyde)**



**M. Reiner (Harvard)**

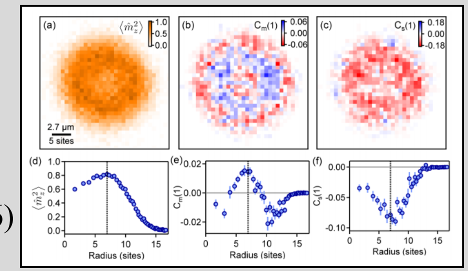
## Fermi-Hubbard Model：Antiferomagnetism

Nature (2015)




$$\hat{H} = -J\sum_{<ij>\sigma}\hat{c}_{i\sigma}^{\dagger}\hat{c}_{j\sigma} + U\sum_{i}\hat{n}_{i\uparrow}\hat{n}_{i\downarrow} - \mu\sum_{i}\hat{n}_{i}$$

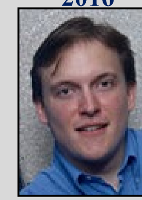
Science (2016)




**2015**

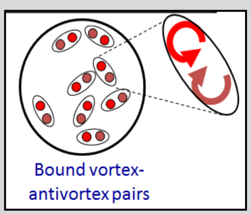
**R. G. Hulet (Rice University)**

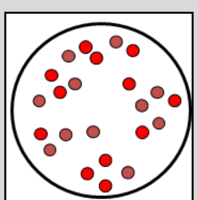
**2016**



**M. Zwierlein (MIT)**

## KT- transition



1972

**1972**

**D. J. Thouless (Univ of Washington)**

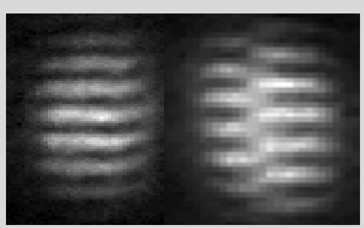
**1972**

**J. M. Kosterlitz (Brown Univ)**

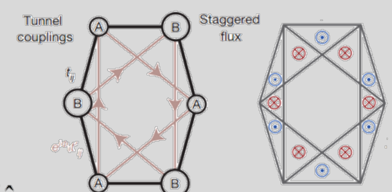
**2006**

**Jean Dalibard (COF)**

Nature ( 2006 )



## Haldane Model



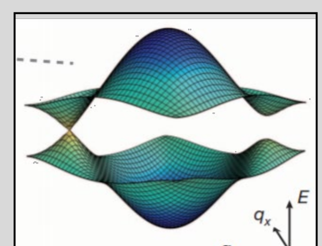

$$\hat{H} = \sum_{<ij>} t_{ij}\hat{c}_i^{\dagger}\hat{c}_j + \sum_{<<ij>>} e^{i\Phi_{ij}} t_{ij}^{'}\hat{c}_i^{\dagger}\hat{c}_j + \Delta_{AB}\sum_{i\in A}\hat{c}_i^{\dagger}\hat{c}_j$$

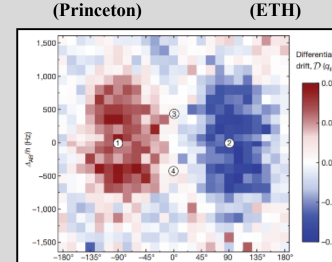
**1988**

**D. Haldane (Princeton)**

**2014**

**T. Esslinger (ETH)**




Nature ( 2014 )

# 2016 Nobel Prize in Physics

KUNGL.
VETENSKAPS-
AKADEMIEN
THE ROYAL SWEDISH ACADEMY OF SCIENCES

4 OCTOBER 2016

Scientific Background on the Nobel Prize in Physics 2016

## TOPOLOGICAL PHASE TRANSITIONS AND TOPOLOGICAL PHASES OF MATTER

compiled by the Class for Physics of the Royal Swedish Academy of Sciences

In a 2014 experiment, the group led by Immanuel Bloch managed to design a lattice with topologically non-trivial bands, similar to the ones studied in the famous paper by Thouless *et al.* [51]. These bands were then populated by a gas of cold bosonic $^{87}$Rb atoms, and using an intricate measuring procedure, they could experimentally determine the Chern number for the lowest band to $C_1^{exp} = 0.99(5)$ [3].

Also in 2014, the group led by Tilman Esslinger made an experiment with cold $^{40}$K atoms in an optical lattice to simulate the precise model proposed by Haldane in 1988 [29]. This shows that reality sometimes surpasses dreams. At the end of his paper Haldane wrote: "While the particular model presented here, is unlikely to be directly physically realizable, it indicates . . .". What he could not imagine was that 25 years later, new experimental techniques would make it possible to create an *artificial state of matter* that would indeed provide that "unlikely" realization.

### 6.2 Quantum simulations, and artificial states of matter

In our discussion of the KT phase transition, we stressed universality, meaning that the same model Hamiltonian describes critical phenomena in very different physical systems. This universality is however to a very small *critical region* in the vicinity of the transition temperature. There is however another strategy that allows the use of the same Hamiltonian for different systems in wider parameter ranges. The basic idea goes back to Feynman, who pointed out that one could hope to solve very hard quantum problems by designing a *quantum simulator*.

Such a simulator is itself a quantum system with many degrees of freedom, but it should be well controlled and designed to embody the important aspects of the physical system one is attempting to simulate. More precisely, this means having the correct degrees of freedom and the correct interactions. Cold atomic gases have turned out to provide a perfect platform for obtaining this [11]. An important tool in these experiments is the optical lattices that are formed as an interference pattern by intersecting laser beams.

An example of this is the observation of the KT-transition in a layered Bose-Einstein condensate of $^{87}$Ru atoms. At low temperatures one observes coherence effects characteristic of the phase with power law correlations, and at higher temperatures one sees free vortices [20].

## The Nobel Prize in Physics 2016

Photo: A. Mahmoud
**David J. Thouless**
Prize share: 1/2

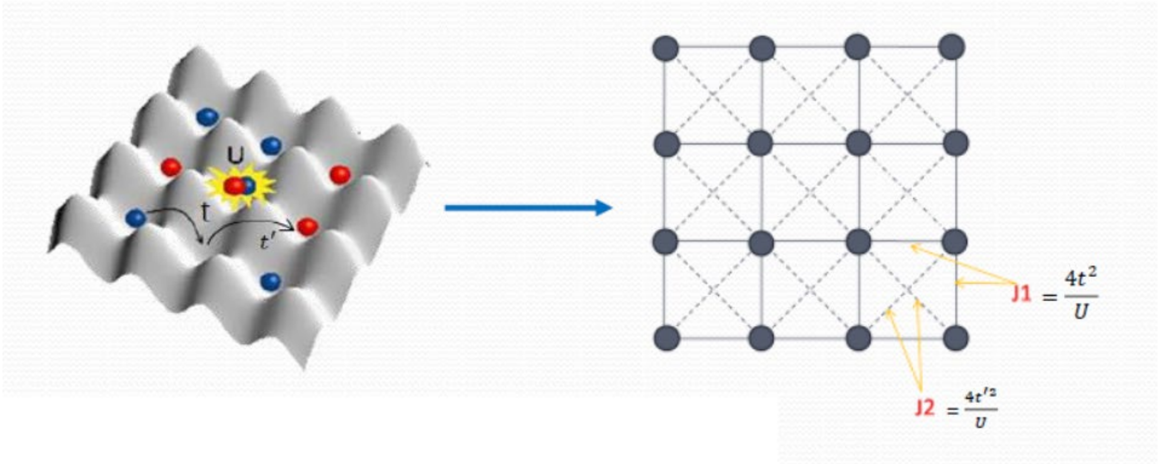
Photo: A. Mahmoud
**F. Duncan M. Haldane**
Prize share: 1/4

Photo: A. Mahmoud
**J. Michael Kosterlitz**
Prize share: 1/4

# Advantages of space quantum simulation platform

Bose-Hubble Model $H = -J\sum_{\langle i,j\rangle} a_i^\dagger a_j + \frac{U}{2}\sum_i n_i(n_i - 1) + \sum_i W_i n_i$

(1) Theoretical simulation of the Bose Hubble model
(2) Gutzwiller mean field theory;
(3) Quantum model Carlo simulation;
(4) Calculation of renormalization group.




Ultra-low temperature provides new possibilities for precision quantum simulation

# Advantages of space quantum simulation platform

Low temperature: 100pK, long observation time: 10s.

IOP Publishing Reports on Progress in Physics

Rep. Prog. Phys. **83** (2020) 076401 (31pp) https://doi.org/10.1088/1361-6633/ab8ab6

Review

## The emergence of picokelvin physics

**Xuzong Chen and Bo Fan**

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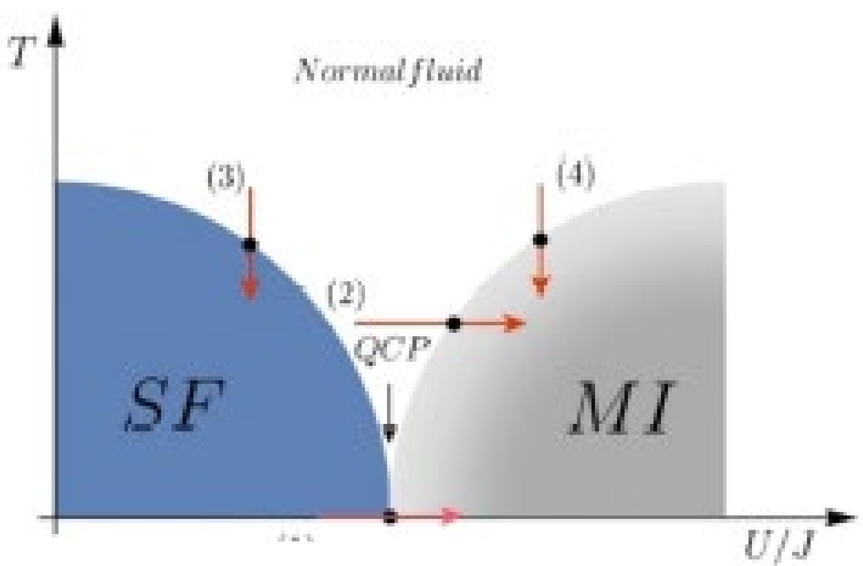
Rep. Prog. Phys. **83** (2020) 076401 Review

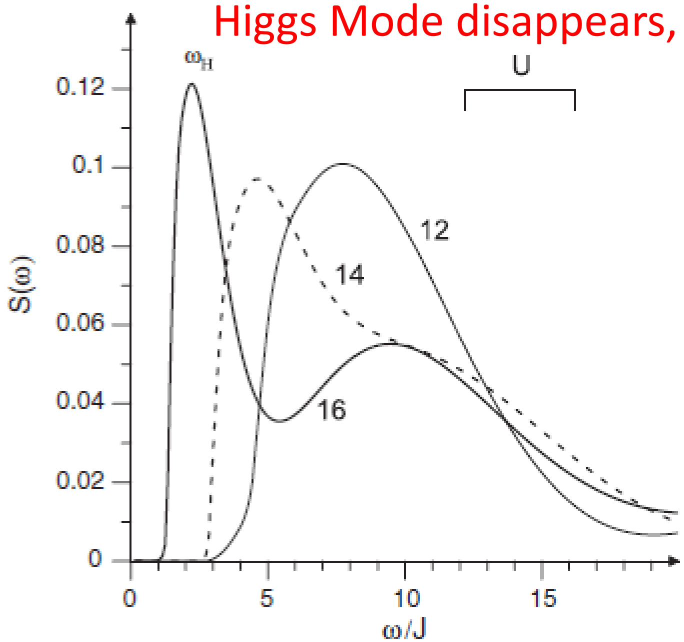
**Table 2.** Parameters with relative energy (temperature).[a]

| Optical trap depth $U_0$ | $10E_r$ | $15E_r$ | $20E_r$ |
|---|---|---|---|
| $T$ (tunneling) | $0.02E_r = 2.2k_B$ nK | $0.007E_r = 0.7k_B$ nK | $0.003E_r = 0.3k_B$ nK |
| $U$ (interaction) | $0.28E_r = 27k_B$ nK | $0.38E_r = 37k_B$ nK | $0.47E_r = 46k_B$ nK |
| $J = \frac{4t^2}{U}$ (tunneling in Heisenberg model) | $0.007E_r = 0.7k_B$ nK | $5.8 \times 10^{-4}\ E_r = 0.056k_B$ nK | $6.6 \times 10^{-5}\ E_r = 0.006k_B$ nK |

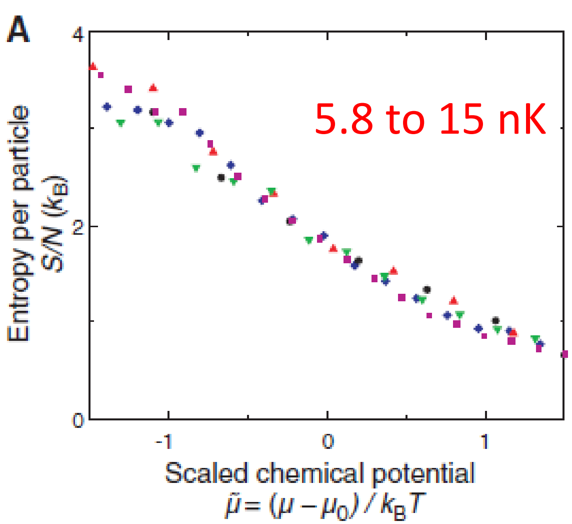
# Advantages of space quantum simulation platform




Higgs Mode disappears, T>J




PRL **109**, 010401 (2012)




5.8 to 15 nK

Provides a new way for quantum simulation precision measurement

2 MARCH 2012 VOL 335 **SCIENCE**

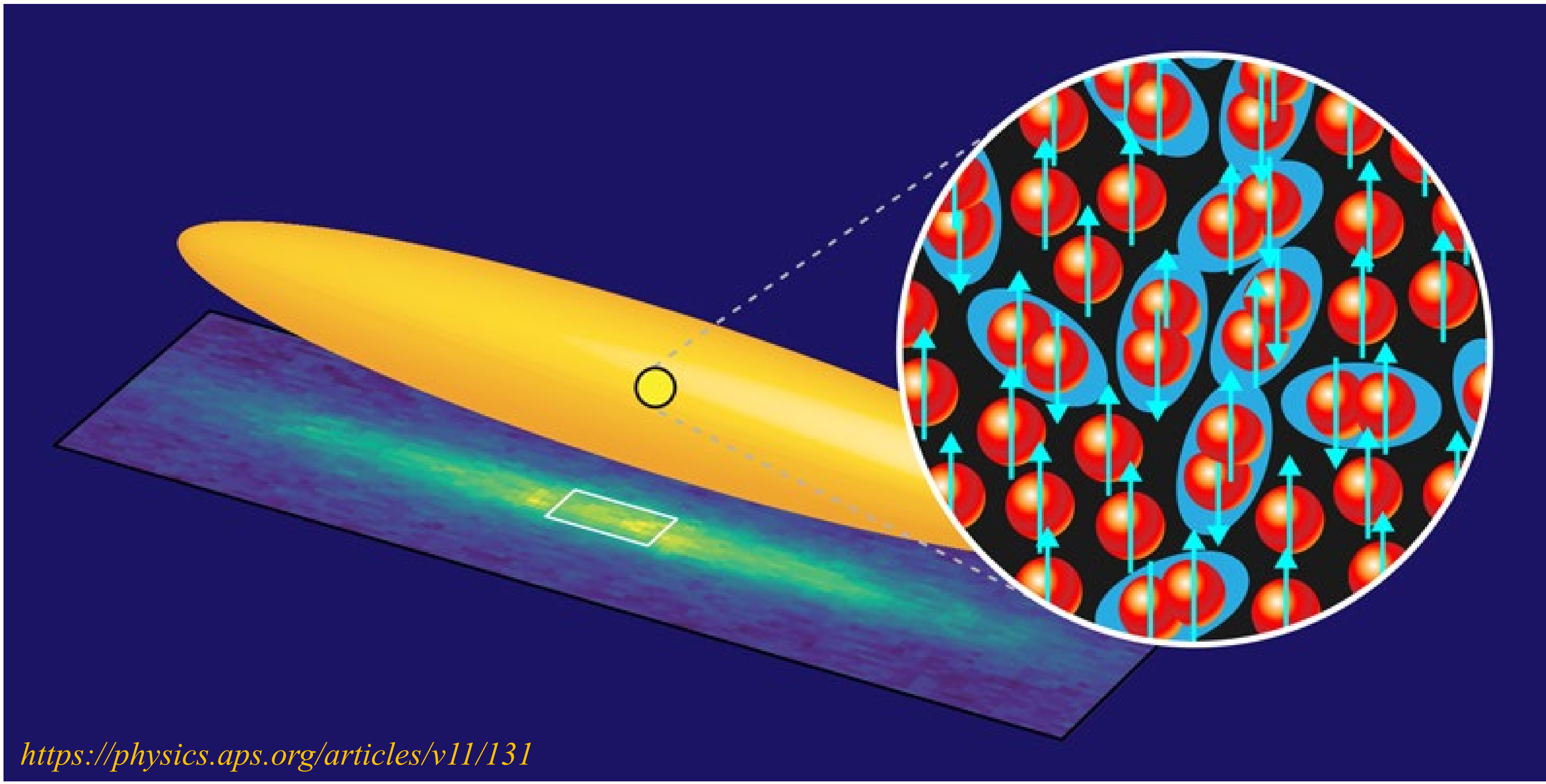
# Experiments for construction period

- Quantum simulation category:
  - Quantum magnetism ($^{87}Rb$);
  - Quantum new state of matter ($^{87}Rb$);
  - Effimov effect ($^{87}Rb+^{40}K$);
- Black hole exploration category:
  - Acoustic black hole ($^{87}Rb$).

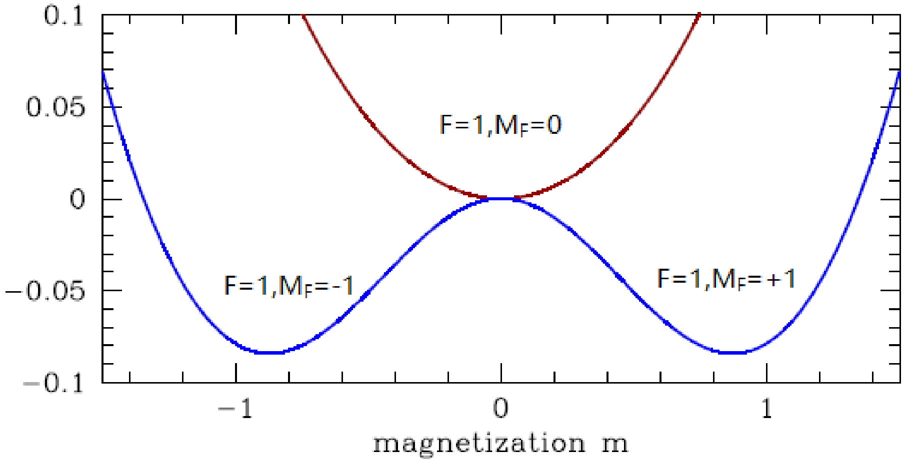
After two and three rounds of discussions, the four scientific experiment schemes, key technology design, optical path design, timing design, and acceptance of experimental results were basically determined, and the input conditions for the four experiments were determined together with the Shanghai Institute of Optics and Mechanics.

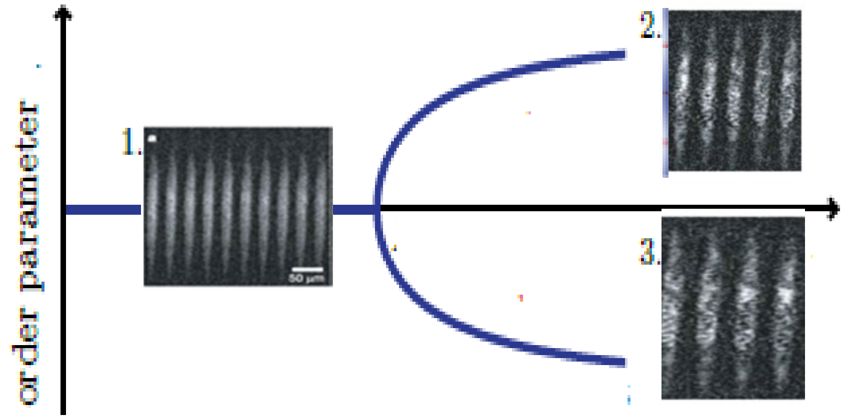
# Experiment 1: Quantum Magnetism

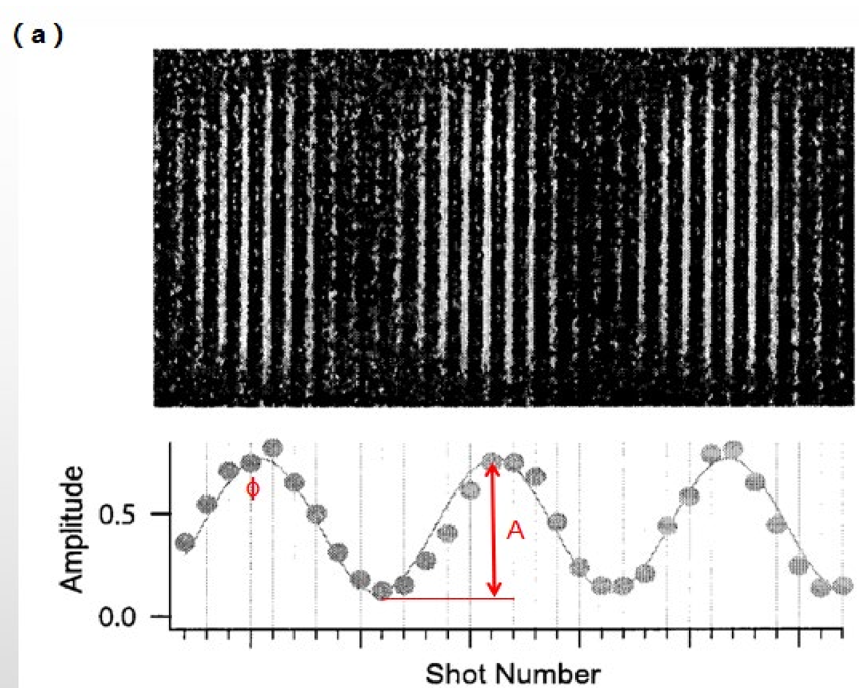
Liu Wuming, Institute of Physics, Chinese Academy of Sciences

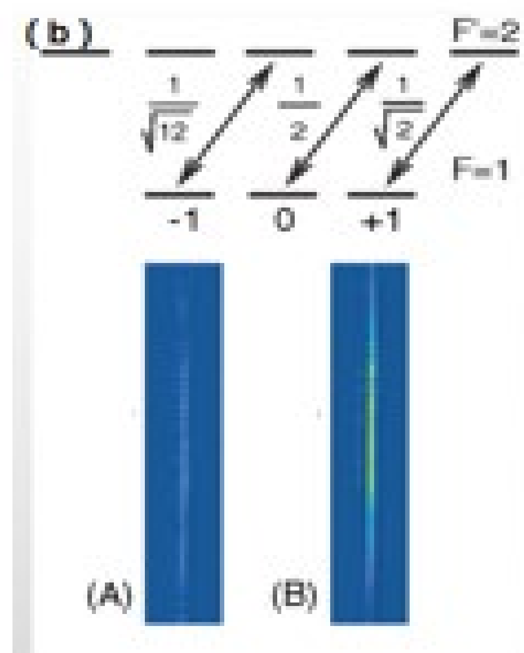


# Rb Quantum Magnetism



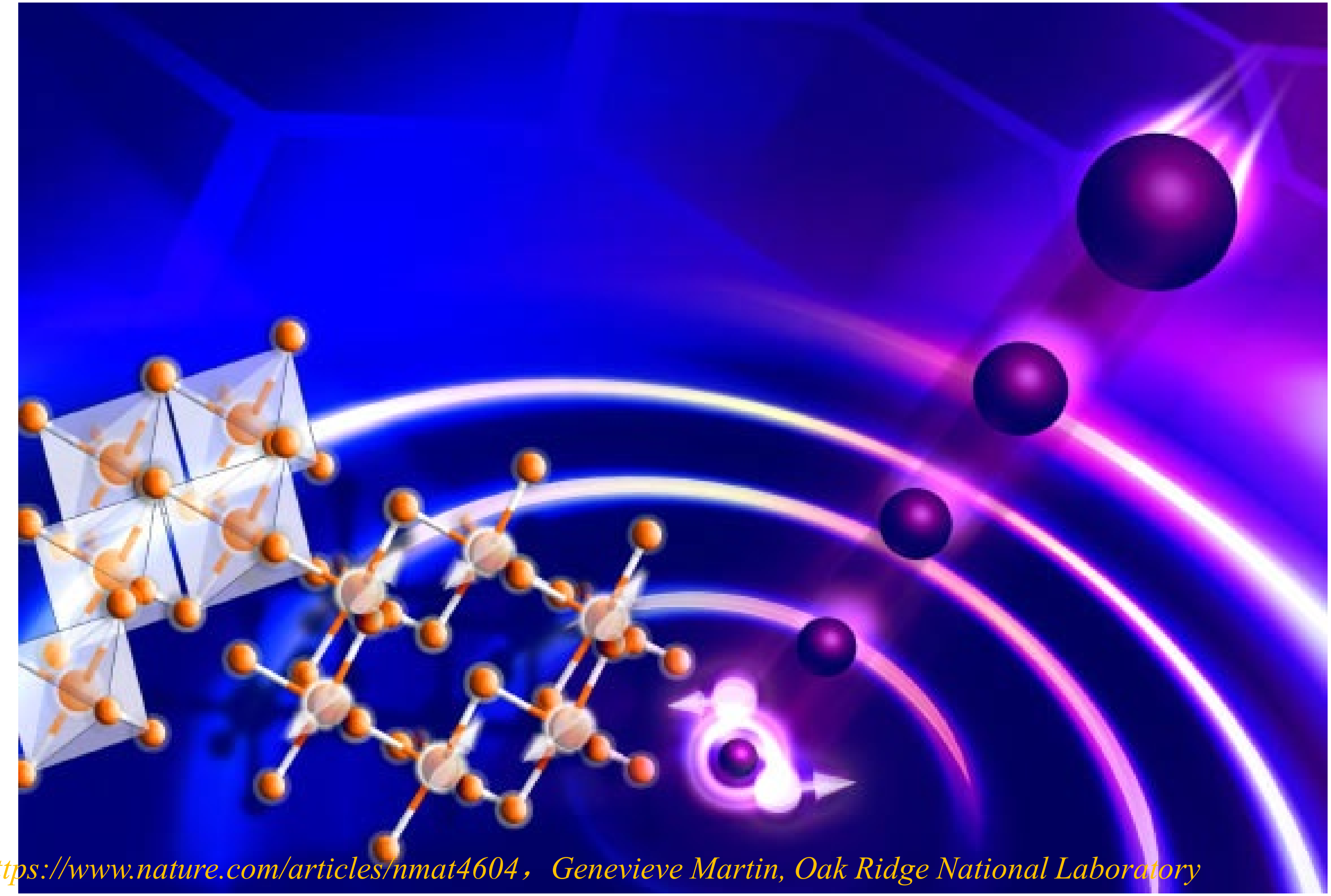



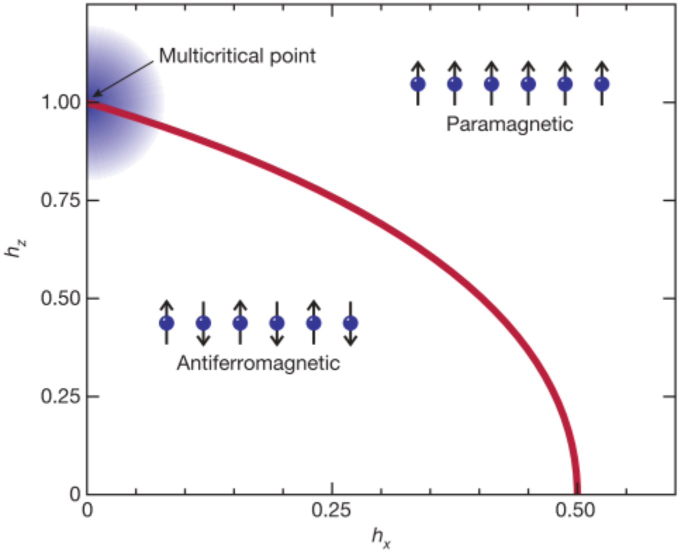
# Experiment 2: Novel Quantum State

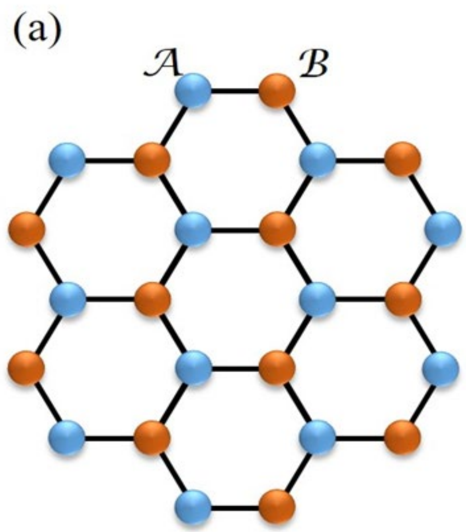
Zhou Xiaoji, Peking University,

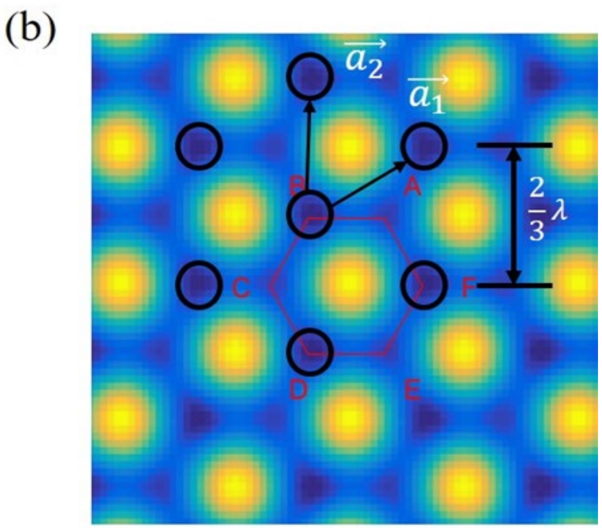


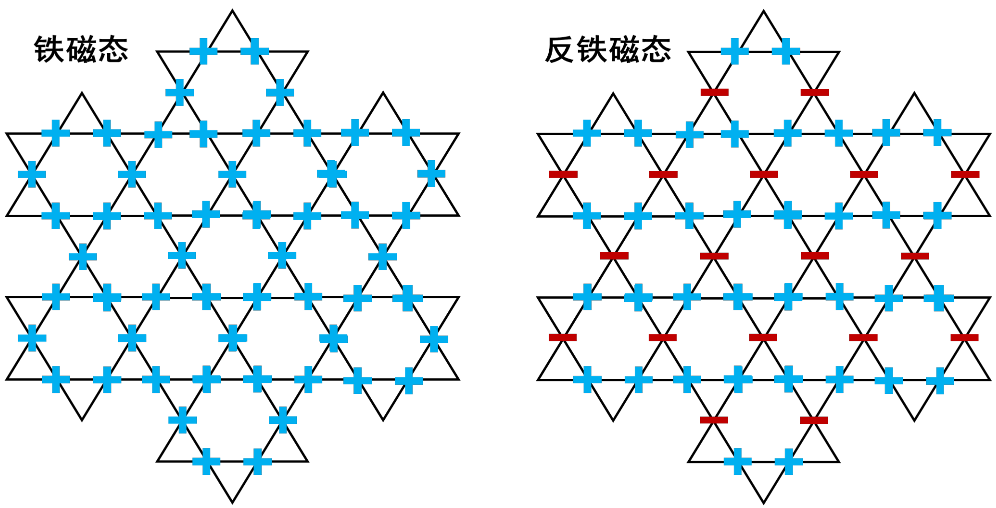
https://www.nature.com/articles/nmat4604， Genevieve Martin, Oak Ridge National Laboratory

# Kagome lattice magnetic quantum simulation



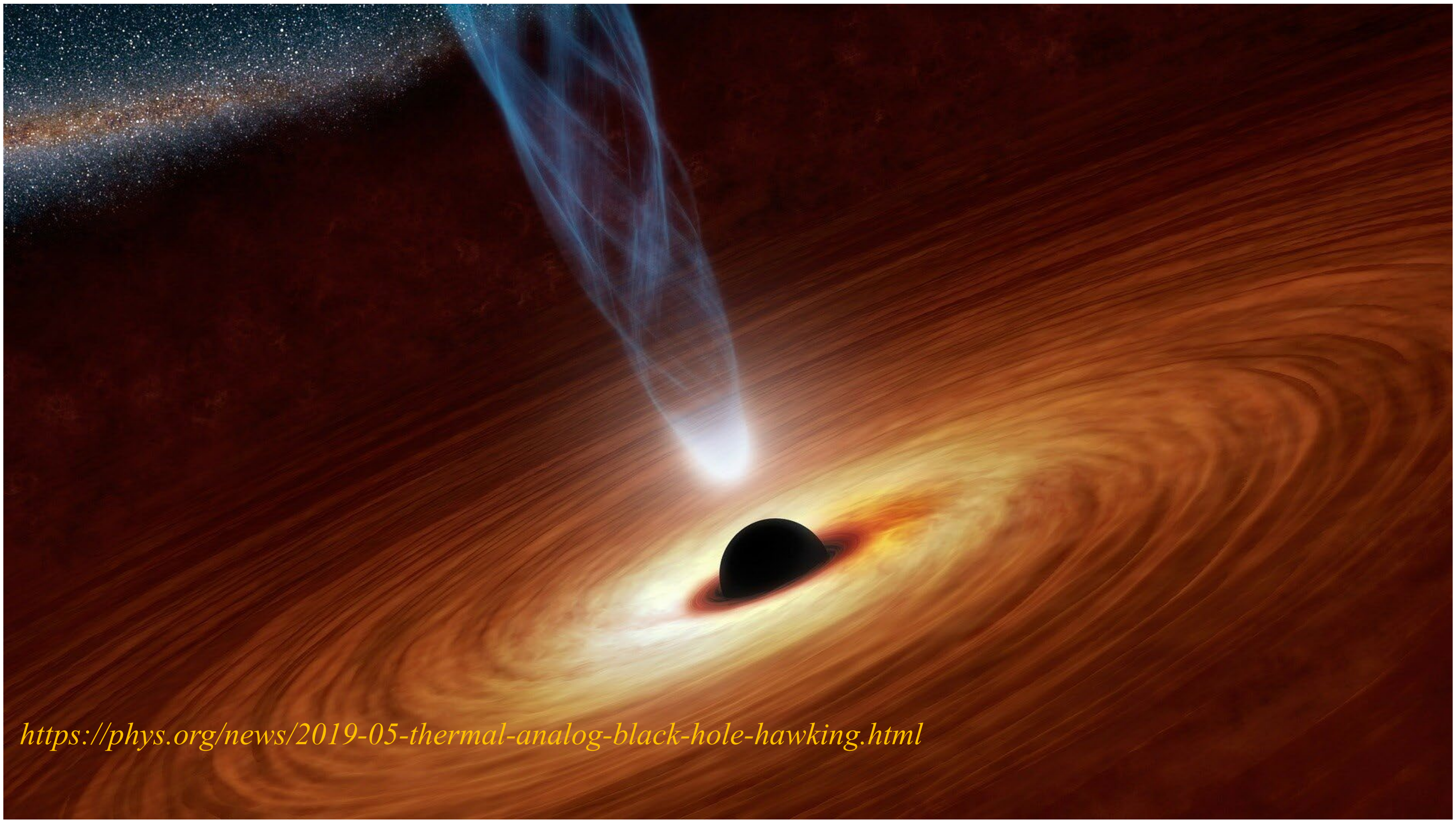



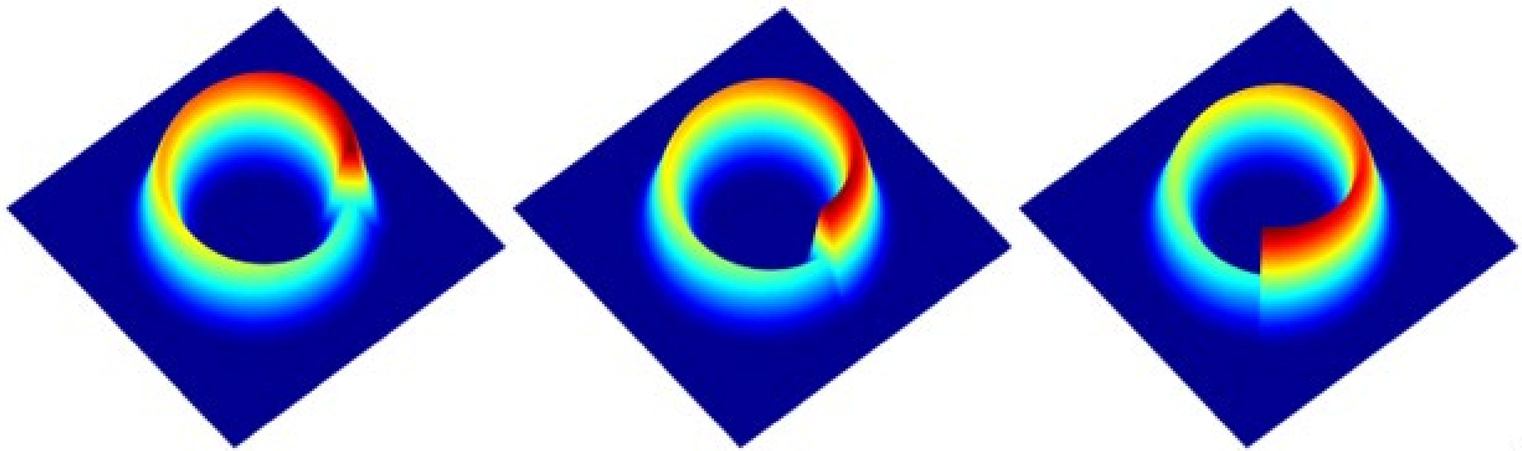



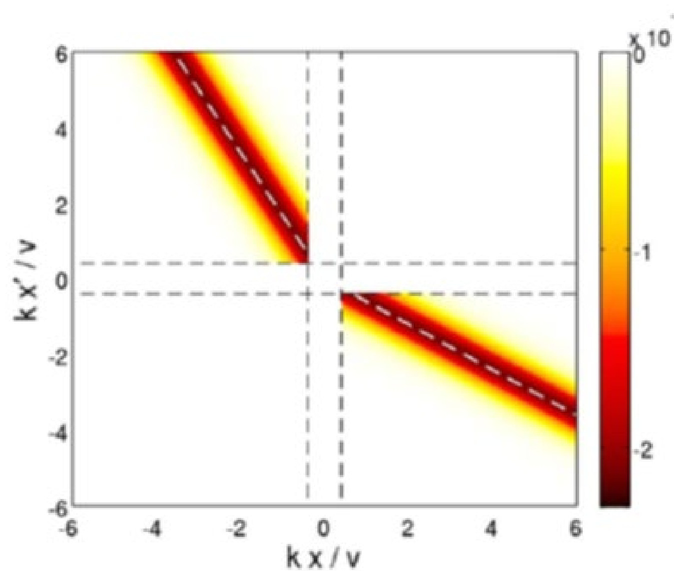
# Experiment 3: Acoustic Black Hole

Lv Baolong, Wuhan Institute of Precision Measurement Science and Technology Innovation, CAS



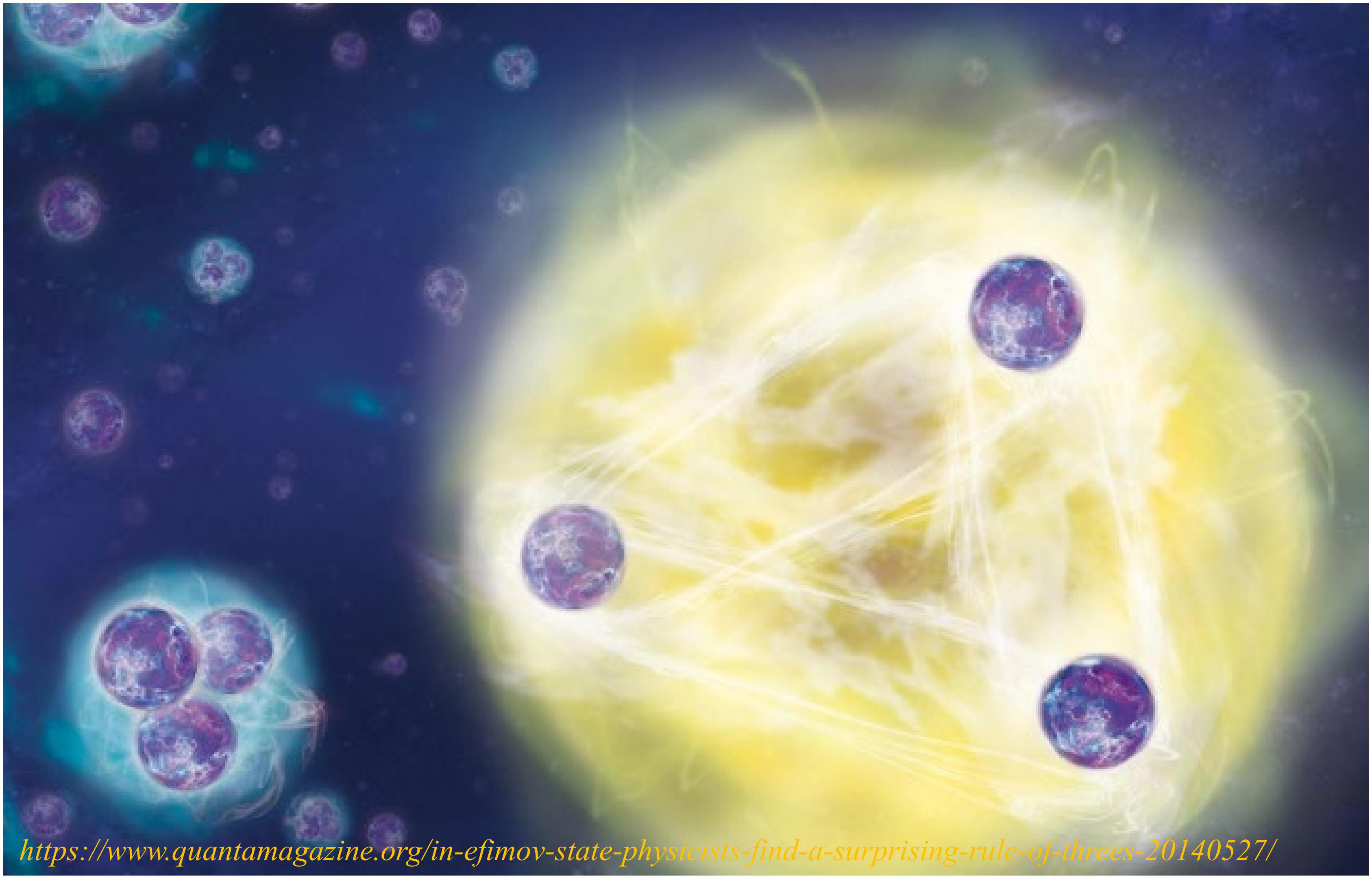
# The creation of acoustic black holes



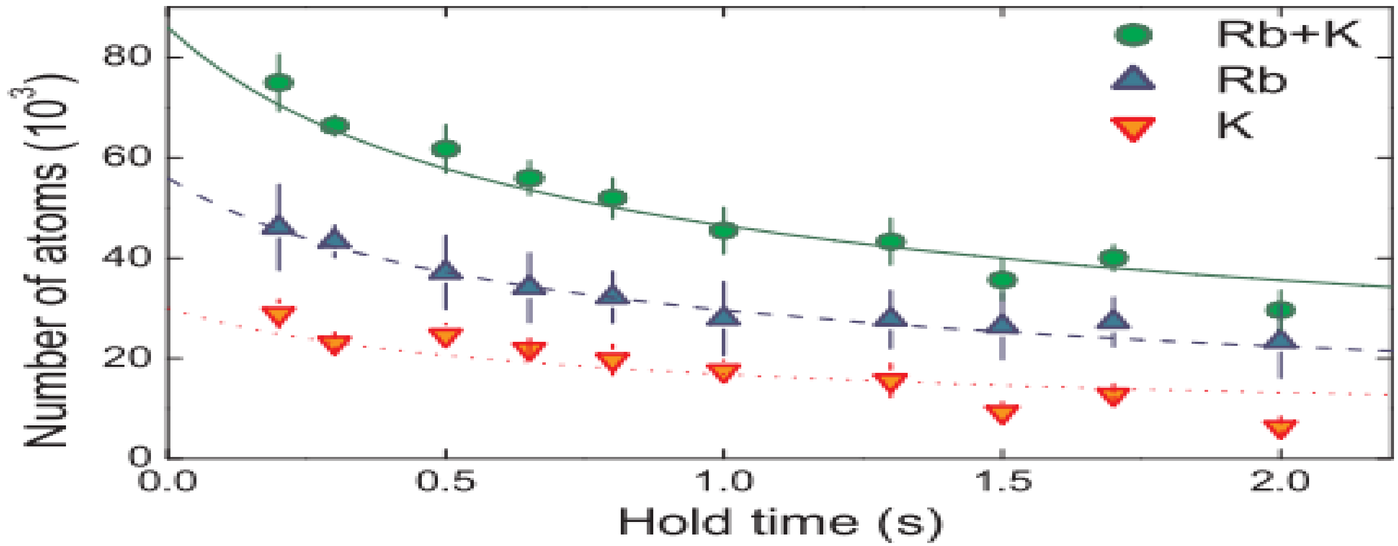


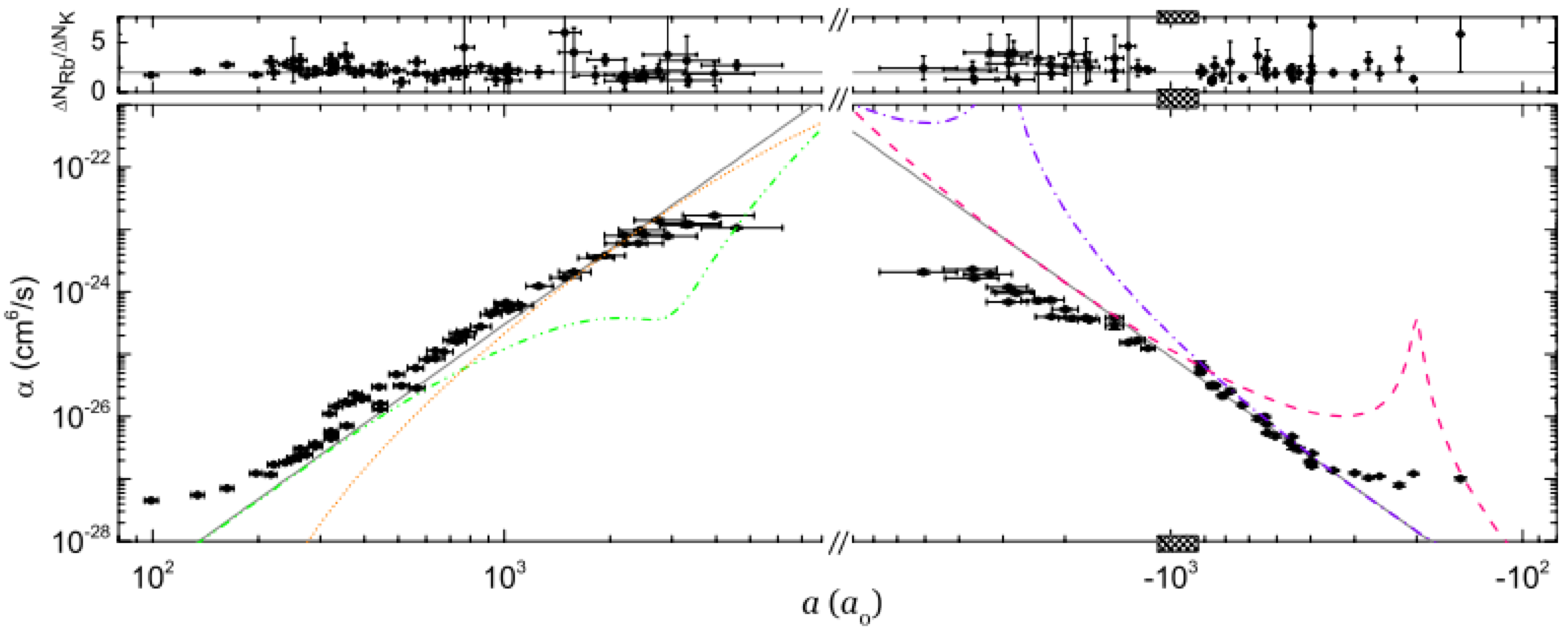
# Experiment 4: Effimov effect

Zhou Shuyu, Shanghai Institute of Precision Optics and Mechanics,



# Rb-K heteronuclear Effimov effect



# On-orbit experiment

Four types of experiments are planned (January 2023-December 2032): (1) Quantum simulation; (2) Quantum new state of matter; (3) Test of basic physical theories; (4) Dark matter, Higgs model Wait for measurement.

- The first category: quantum simulation
  - Highly excited state new optical lattice phase transition (87Rb)
  - Quantum Hall effect on the "Haldane sphere" of cold atoms in space (87Rb)
  - Research on Super Solid State and Topological Super Solid State (87Rb)
  - Quantum simulation of spin polarization induced by chiral structure (87Rb)
  - Three-dimensional Anderson localization (87Rb)
- The second category: quantum state of matter
  - Preparation and detection of Majorana fermions in cold 40K atoms (40K)
  - Deep degeneracy of ultra-cold Bose-Fermi mixed gas (87Rb+40K)
  - Study on Excitation Properties of Cold Atomic Element under Special Shape External Potential (87Rb)
  - Excellent fluid physics research under microgravity conditions: shock waves and turbulence under quantum viscous forces(87Rb)

# On-orbit experiment

- The third category: precise examination of physical theories
  - The precise inspection of the renormalization group of the ideal optical lattice quantum phase transition (87Rb)
  - Research and application of one-dimensional quantum system under microgravity conditions (Yang-Bax equation test) (87Rb)
  - Test General Relativity Based on the Gravitational Electromagnetic Effect of Space Cold Atoms (87Rb)
- The fourth category: dark matter, Higgs mode, etc. measurement
  - Develop coherent matter wave optics and interferometer (measurement of dark matter gauge field and density distribution) in a microgravity environment (87Rb)
  - Ideal optical lattice Higgs-type excitation measurement (87Rb)
  - pK BEC interferometer (UFF/WEP test) (87Rb)
  - Quantum simulation based on complex cold atom optical lattice and its microgravity precision measurement (derived gauge field in curved space and its physical effects) (87Rb)

# Outline

1. Introduction to the International Space Ultra-cold Atomic Physics Experiment

2. The scientific goals of the space station's ultra-cold atomic experiment rack

3. The experimental principle of obtaining 100pK temperature

4. Development of ultra-cold atomic experiment cabinet for space station

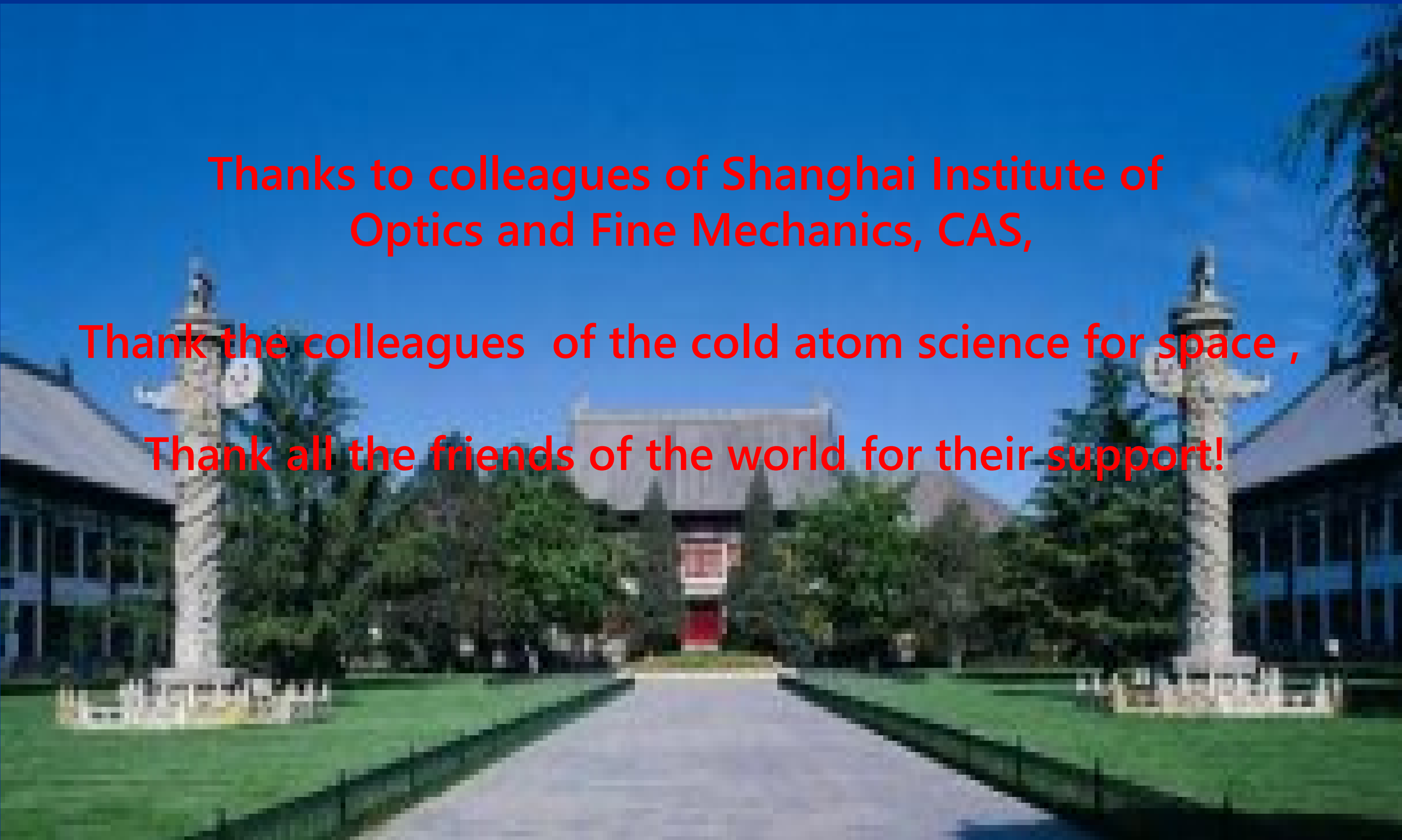
5. Scientific experiments in the ultra-cold atomic laboratory rack

6. Summary

# Conclusion

- **Excellent ultra-cold atomic physics experiments require extreme conditions of microgravity, and the space ultra-cold atomic experiment cabinet will become an ideal platform to provide such extreme conditions.**
- **Space ultra-cold atomic physics is an important result of the combination of basic research and aerospace engineering, and it is also a good opportunity for the simultaneous development of Chinese aerospace science and technology with the world's aerospace science and technology.**
- **The ultra-cold atomic physics experimental platform is currently the most complex scientific research system on the space station. The successful development has played an important role in promoting the development of chinese aerospace science and ultra-cold atomic physics.**
- **The team of scientists in China's ultra-cold atomic physics experiments has matured and will show our important role in the future international ultra-cold atomic physics and space science experiments.**

# Ultracold Atomic Physics Research Team at Peking University



Thanks to colleagues of Shanghai Institute of Optics and Fine Mechanics, CAS,

Thank the colleagues  of the cold atom science for space ,

Thank all the friends of the world for their support!

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