QuNu交叉前沿讲习班@SCNU，2022-11-16

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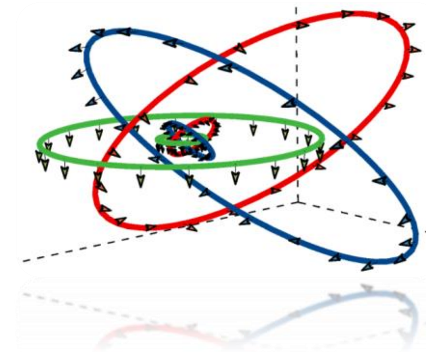
Synthetic topological Yang-Mills vacua in ultracold atomic Bose Einstein condensates



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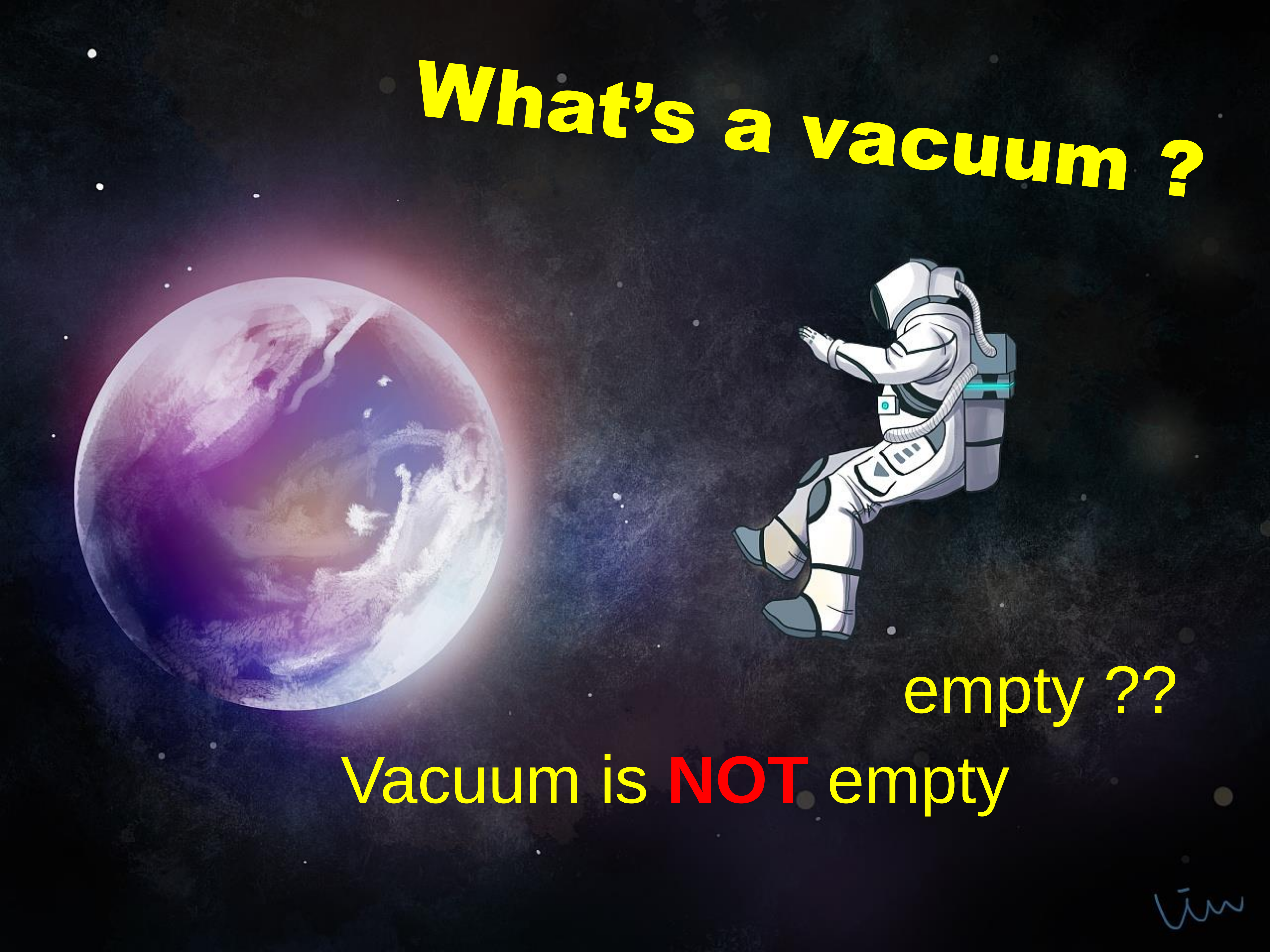
Outline

- Introduction
- Topology of SU(2) gauge field: Winding
- Simulating topological SU(2) vacua
- Experimental realizaiton using a BEC
- Outlook

What's a vacuum ?

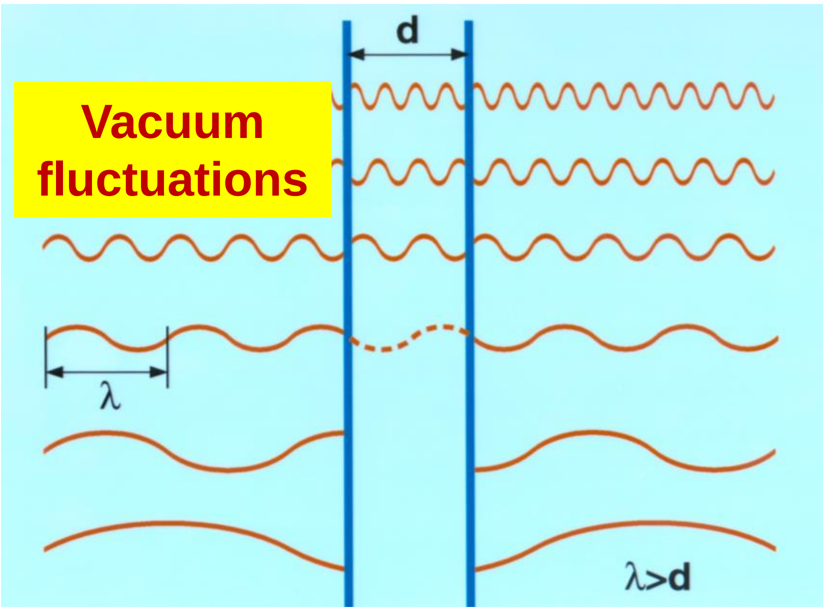


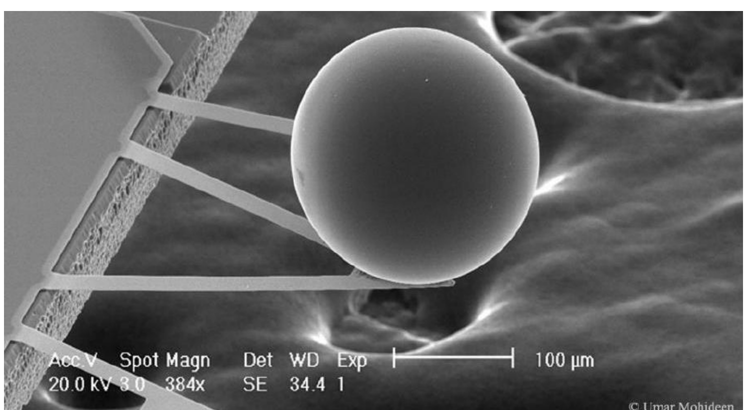
empty ??

Vacuum is **NOT** empty

QED Vac: Local Effect

Casmir Effects





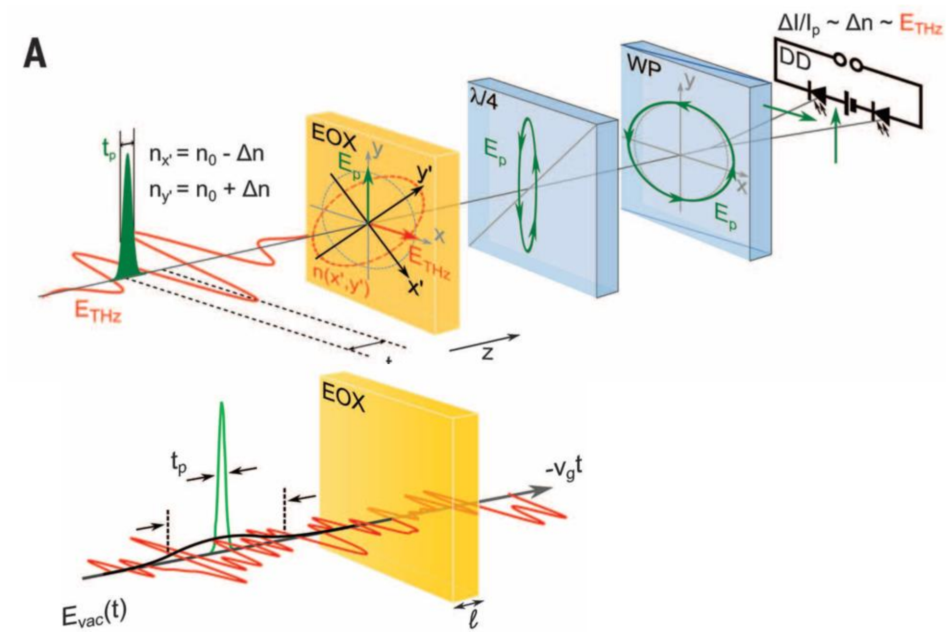
Pic: Nothing But Net | by Brian Koberlein

QUANTUM OPTICS

Direct sampling of electric-field vacuum fluctuations

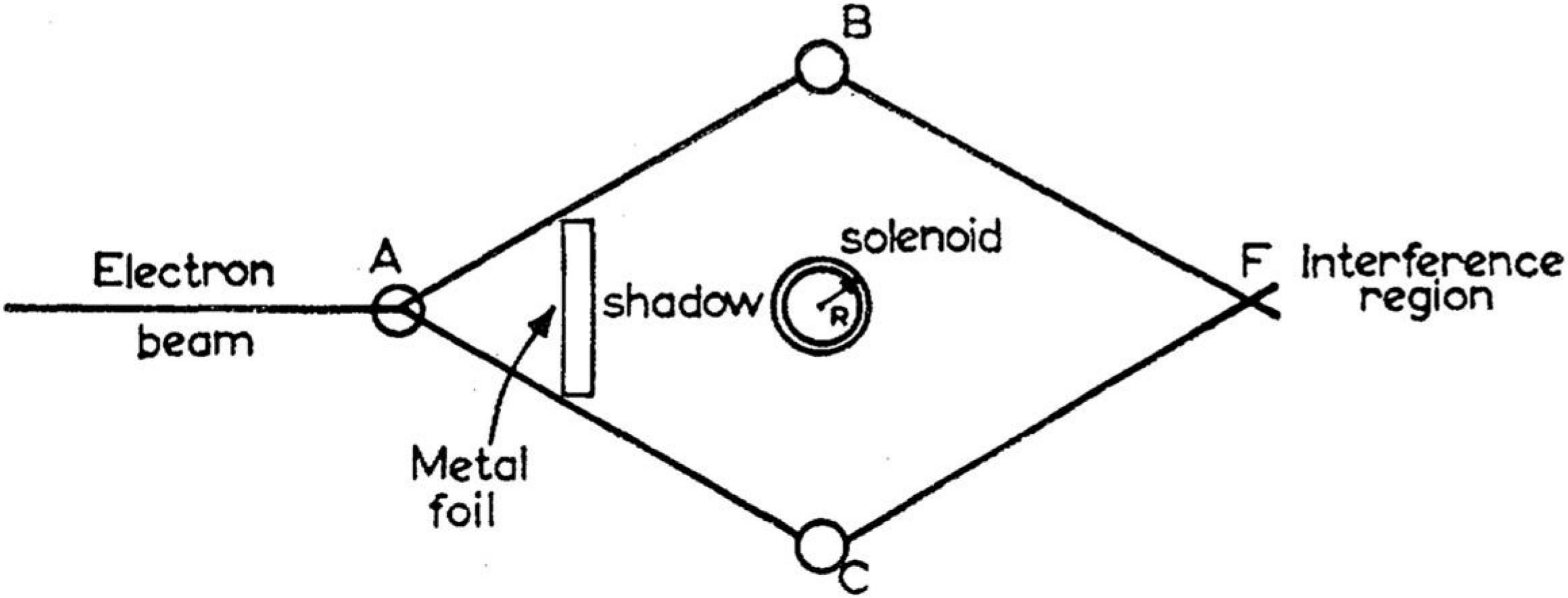
C. Riek, D. V. Seletskiy, A. S. Moskalenko, J. F. Schmidt, P. Krauspe, S. Eckart, S. Eggert, G. Burkard, A. Leitenstorfer*

The ground state of quantum systems is characterized by zero-point motion. This motion, in the form of vacuum fluctuations, is generally considered to be an elusive phenomenon that manifests itself only indirectly. Here, we report direct detection of the vacuum fluctuations of electromagnetic radiation in free space. The ground-state electric-field variance is inversely proportional to the four-dimensional space-time volume, which we sampled electro-optically with tightly focused laser pulses lasting a few femtoseconds. Subcycle



Science 350.420 (2015)

QED Vac: Global Effect

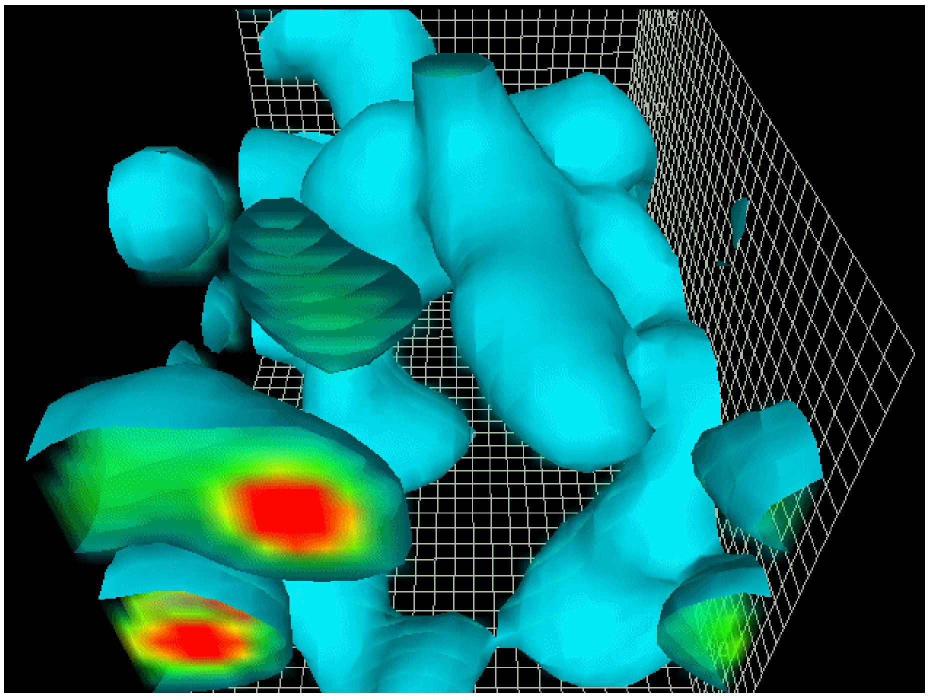


electron interference: Electromagnetic waves show **global geometric effects**

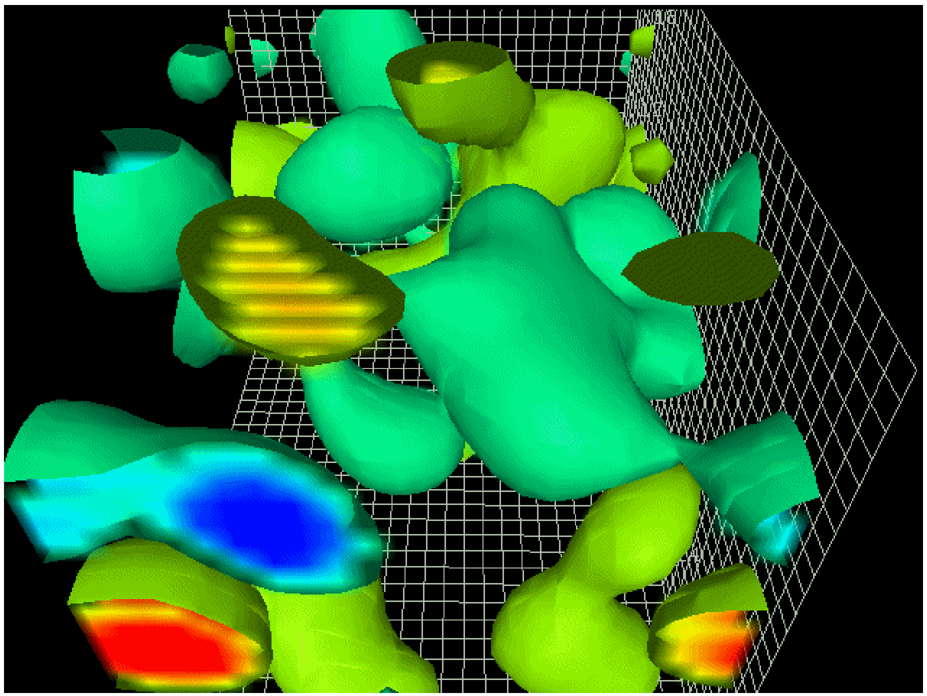
[1] *T. Maudlin, Entropy* 2018, *20*(6), 465; https://doi.org/10.3390/e20060465

QCD vacuum

Action Density



Topological Charge Density



[1] Animation from: Derek Leinweber (adelaide.edu.au)

Vacuum structure matters !

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Geometry of non-perturbative vacuum

- *Electromagnetic vacuum*
  - ✓ space-time "stratified" structure is charge-neutral;
  - ✓ can be in a *non-deformed state*;
  - ✓ delocalized zero-point fluctuations fill up the whole space-time

- *"Weak" vacuum* **(Higgs condensate)**
  - ✓ space-time "stratified" structure is *spontaneously deformed*;
  - ✓ layers are "weakly" charged;
  - ✓ deformations (shifts) are regular and *continuous*;
  - ✓ is *classically determined* and zero-point fluctuations is only slightly disturb it

- *"Strong" or QCD vacuum* (**Quark-Gluon condensate**)
  - ✓ space-time "stratified" structure is *spontaneously deformed;*
  - ✓ layers carry different "color" charges;
  - ✓ deformations are *localized* and determined totally by quantum effects;
  - ✓ such a structure is *not classically determined*

Physical Vacuum is the quantum superposition of substructures (vacuum condensates) constantly transforming one into another

Properties of matter are totally determined by properties of vacuum structures! 11

[1] Talk by R. Pasechnik (Lund Univ.), " The Physical Vacuum: Where Particle Physics Meets Cosmology"

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EM waves: Vector potential matters

Maxwell Eqs: Coupled **Field** Eqs.

$$\nabla \cdot \boldsymbol{E} = \frac{\rho}{\varepsilon_0}$$
$$\nabla \cdot \boldsymbol{B} = 0$$
$$\nabla \times \boldsymbol{E} = -\frac{\partial \boldsymbol{B}}{\partial t}$$
$$\nabla \times \boldsymbol{B} = \mu_0 \boldsymbol{J} + \mu_0 \varepsilon_0 \frac{\partial \boldsymbol{E}}{\partial t}$$

Potentials: Scalor and Vector

$$\boldsymbol{B} = \nabla \times \boldsymbol{A}$$
$$\boldsymbol{\nabla} \times \left(\boldsymbol{E} + \frac{\partial \boldsymbol{A}}{\partial t} \right) = 0$$
$$\Leftrightarrow \boldsymbol{E} = -\boldsymbol{\nabla} \boldsymbol{\Phi} - \frac{\partial \boldsymbol{A}}{\partial t}$$

How to determine $(\boldsymbol{A}, \boldsymbol{\Phi})$

Gauge choices: ***Gauge** transformation*

Field $(\boldsymbol{B}, \boldsymbol{E})$ ***are gauge invariant***

$$\mathbf{A} \to \mathbf{A}' = \mathbf{A} + \boldsymbol{\nabla}\Lambda$$
$$\Phi \to \Phi' = \Phi - \frac{\partial \Lambda}{\partial t}$$

e.g. Coulomb gauge: $\boldsymbol{\nabla} \cdot \boldsymbol{A} = 0$

also transverse/radiation gauge

Lorentz condition: $\boldsymbol{\nabla} \cdot \boldsymbol{A} + \frac{1}{c^2}\frac{\partial \Phi}{\partial t} = 0$

Classcial: local field strength (E, B) + charge+ Maxwell Eq.

Quantum: nonlocal $\varphi_D = \frac{e}{\hbar c} \oint \mathcal{A} d\mathbf{r}$ (Dirac Phase) e.g. AB effect

Gauge Symmetry

Noether theorem

$$\frac{dL}{ds} = 0 \quad \Rightarrow$$

$$\frac{d}{dt}\left[\frac{\partial L}{\partial \dot{x}}\frac{dx}{ds}\right] = 0 \quad \Rightarrow$$

$$C = \frac{\partial L}{\partial \dot{x}}\frac{dx}{ds} = \text{常数}$$

All Gauge theories are based upon charge conservation.

↓

The continuous symmetry that leads, by Noether's Theorem, to charge conservation is called Local Gauge Invariance

↓

Local Gauge Invariance defines the full structure of electrodynamics

[1] From: gauge symmytry charge conservation

U(1) Group: Abelian

EM waves

Potentials $(\boldsymbol{A}, \boldsymbol{\Phi})$:

$$\boldsymbol{B} = \nabla \times \boldsymbol{A}$$

$$\boldsymbol{E} = -\boldsymbol{\nabla\Phi} - \frac{\partial \boldsymbol{A}}{\partial t}$$

Observable:

Gauge invariant

In Minkowski space: 4-vector $(t, x, ..) = (r_0, r_1, ..)$

QM under local GT: $\boldsymbol{U} = \boldsymbol{exp}(\boldsymbol{i}\phi(r_\alpha)) \in \boldsymbol{U}(1)$

$\psi \to \boldsymbol{exp}(\boldsymbol{i\phi})\psi$ while $\mathbf{A} \to \boldsymbol{U}\mathbf{A}\boldsymbol{U}^{-1} + \boldsymbol{i}\boldsymbol{U}^{-1}\partial_\alpha \boldsymbol{U}$

$$\mathcal{A}^\alpha \to \mathcal{A}^\alpha - \partial_\alpha \phi, \ \mathcal{F}^{\alpha\beta} = \partial_\alpha \mathcal{A}^\beta - \partial_\beta \mathcal{A}^\alpha$$

Vacuum: $\mathcal{F}^{\alpha\beta} = \partial_\alpha \mathcal{A}^\beta - \partial_\beta \mathcal{A}^\alpha = 0 \Rightarrow \mathcal{A}^\beta = 0$

$$\varphi_D = \frac{e}{\hbar c}\oint \mathcal{A} d\mathbf{r} = \frac{e}{\hbar c}\int \mathcal{B} d\mathbf{s} = \frac{e}{\hbar c}\Phi$$ (Observable)

$T.T.Wu$ & $Ch.N.Yang$ [PRD1975]: EM theory ⇔ gauge invariance of φ_D

$\boldsymbol{U}(1)$ determines the **EM properties**

U(n>1) Group: Non-Abelian

Multi-component wavefunctions $\vec{\psi}$ ($n \geq 2$) $\Leftrightarrow$ $\hat{\boldsymbol{A}}$ gauge potential

Gauge transformation group $\boldsymbol{U(n)}$: Non-Abelian

Gauge potential $\hat{\boldsymbol{A}}$: local $\hat{\boldsymbol{U}}(\boldsymbol{\mu}) \in \boldsymbol{U(n)}$

$$\vec{\psi} \to \hat{\boldsymbol{U}}\vec{\psi},\ \ \hat{\boldsymbol{A}} \to \hat{\boldsymbol{U}}^{-1}\hat{\boldsymbol{A}}\hat{\boldsymbol{U}} + \boldsymbol{i}\hat{\boldsymbol{U}}^{-1}\partial_{\boldsymbol{\mu}}\hat{\boldsymbol{U}}$$

$$\mathcal{F}^{\alpha\beta} = \partial_\alpha \mathcal{A}^\beta - \partial_\beta \mathcal{A}^\alpha - ig[\mathcal{A}^\alpha, \mathcal{A}^\beta]$$

In certain initial frame: $\hat{\boldsymbol{A}}(\boldsymbol{\mu}) = \boldsymbol{0}$ → Pure gauge potential: $\hat{\boldsymbol{A}} = \boldsymbol{i}\boldsymbol{g}^{-1}\hat{\boldsymbol{U}}^{-1}\partial_{\boldsymbol{\mu}}\hat{\boldsymbol{U}}$

Zero Field strength (vacuum): $\mathcal{F}^{\alpha\beta} = 0$ (no force)

Non-Abelian $\hat{\boldsymbol{U}} \to \varphi_B = \hat{\boldsymbol{P}} \oint \hat{\boldsymbol{A}} d\boldsymbol{\mu} \neq 0$ (Wilson-Loop)

[1] Spin Gauge Fields, K.Y. Bliokh, Y. P. Bliokh; [2] R. Jackiw, RMP(1980)

Topology of Vacuum

Yang-Mills Field – Non-Abelian gauge field $\hat{\boldsymbol{U}}(\vec{x}) \in \boldsymbol{U}(\boldsymbol{n})$

$\vec{\psi}(\vec{x}) \to \hat{\boldsymbol{U}}(\vec{x})\vec{\psi}(\vec{x})$ → Pure gauge: $\hat{\boldsymbol{A}} = \boldsymbol{i}\boldsymbol{g}^{-1}\hat{\boldsymbol{U}}^{-1}\partial_{\boldsymbol{\mu}}\hat{\boldsymbol{U}}$ → $\mathrm{L} = \frac{1}{4}Tr(F_{uv}F^{uv}) = 0$

Ground state of Yang-Mills Gauge Field → Vacuum

Topological invariant (winding number) $w = \frac{1}{24\pi^2}\int d^3x\, \epsilon_{ijk} Tr(A_{\boldsymbol{i}}A_{\boldsymbol{j}}A_{\boldsymbol{k}})$

e.g. $\hat{\boldsymbol{U}}(\vec{x}) \in \boldsymbol{SU}(\boldsymbol{2})$

$$\hat{U}^{(1)}(\vec{x}) = \frac{\vec{x}^2 - \eta^2}{\vec{x}^2 + \eta^2} + \frac{2i\eta\vec{\sigma}\cdot\vec{x}}{\vec{x}^2 + \eta^2}$$

$\hat{U}^{(n)}(\vec{x}) = \left[\hat{U}^{(1)}(\vec{x})\right]^n$ → $w = \mathrm{n}$, w -fold degenerate vacua

PRL 37,8(1976); PRL 37,172(1976); Dr. Yan-qing Zhu's internal talk

Emergent Synthetic Gauge Field

Schrödinger equation for the motion of an atom:

$$i\hbar\frac{\partial\psi}{\partial t}=\left(-\frac{\hbar^2}{2m}\nabla^2+\hat{H}_s(\vec{\boldsymbol{r}})\right)\psi$$

$$\hat{H}_s(\vec{\boldsymbol{r}})=\mu_B g_s\hat{\boldsymbol{B}}(\vec{\boldsymbol{r}})\cdot\hat{\boldsymbol{S}}+\mu_N g_I\hat{\boldsymbol{B}}(\vec{\boldsymbol{r}})\cdot\hat{\boldsymbol{I}}+\alpha_{hf}\hat{\boldsymbol{J}}\cdot\hat{\boldsymbol{I}}$$

introduce a unitary matrix $\hat{\boldsymbol{U}}(\vec{r})\rightarrow\hat{\boldsymbol{U}}^{+}(\vec{r})\hat{H}_s(\vec{\boldsymbol{r}})\hat{\boldsymbol{U}}(\vec{r})=\hat{\Lambda}(\vec{r})$ and $\tilde{\psi}=\hat{\boldsymbol{U}}^{+}\psi$

$$i\hbar\frac{\partial\tilde{\psi}}{\partial t}=\left(-\frac{1}{2m}(-i\hbar\nabla-\hat{\boldsymbol{A}}(\vec{\boldsymbol{r}}))^2+\hat{\Lambda}(\vec{r})\right)\tilde{\psi}$$

where $\hat{\boldsymbol{A}}=\boldsymbol{i}\hbar\hat{\boldsymbol{U}}^{+}\nabla\hat{\boldsymbol{U}}\Leftrightarrow\hat{\boldsymbol{A}}=\boldsymbol{ig}^{-1}\hat{\boldsymbol{U}}^{-1}\partial_{\mu}\hat{\boldsymbol{U}}$

Emergent synthetic gauge field $\hat{\boldsymbol{A}}(\vec{r})$ is determined by $\hat{\boldsymbol{U}}(\vec{r})$

[1] Ultracold atomic physic, Zhai Hui, Tsinghua Univ.

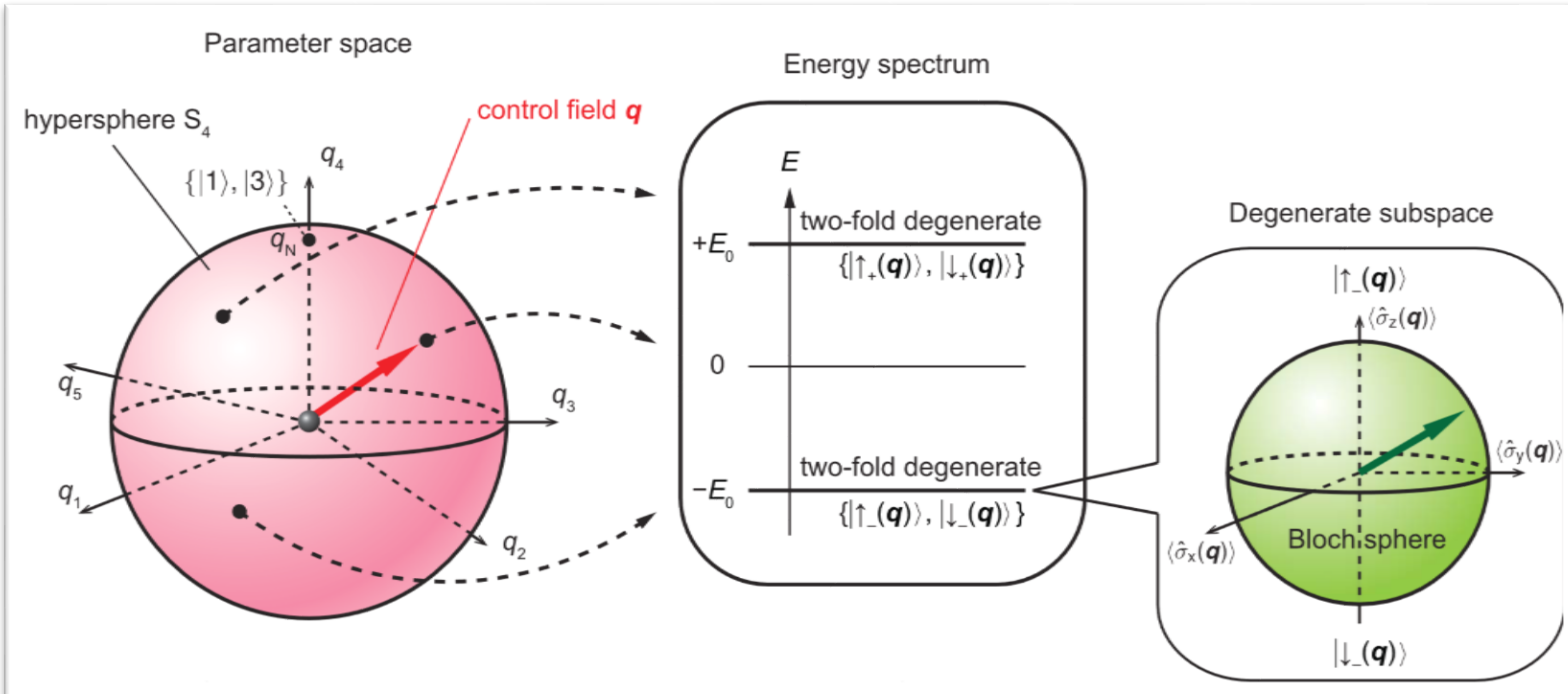
Artificial gauge field in cold atoms

$\hat{H} = \hat{H}(\boldsymbol{\mu})$ depends on parameter $\boldsymbol{\mu}$: eigenvector adiabatically moves in **μ**-space

Berry connection: $\hat{\boldsymbol{A}} = \hat{\boldsymbol{A}}(\boldsymbol{\mu})$ is **nontrivial** when space contains ***degenerate point***

Berry phase $\varphi_B \neq 0$ (Observable)： $\varphi_B = \int \hat{\boldsymbol{A}} d\boldsymbol{\mu}$, topological effects

Berry curvature $\hat{\boldsymbol{F}}$ (Observable)： $\mathcal{F}^{\alpha\beta} = \partial_\alpha \mathcal{A}^\beta - \partial_\beta \mathcal{A}^\alpha$, non-zero dynamical effects



[1] Science 360, 1429–1434 (2018); npj Quantum Information (2021) 144; …

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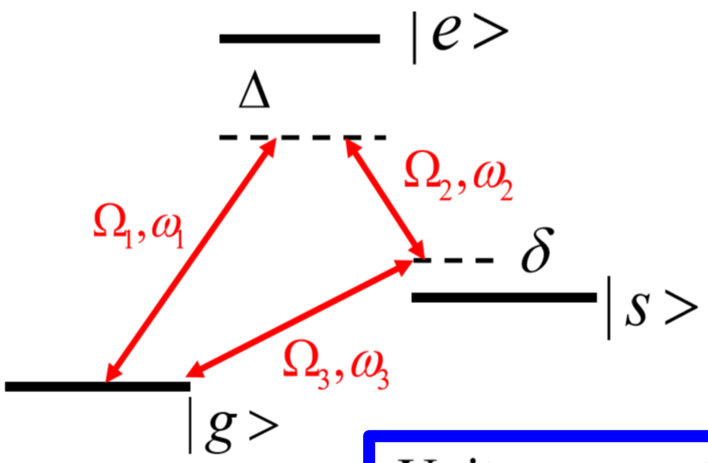
Theoretical Scheme

$$H=\begin{pmatrix} 0 & \Omega_3^* & \Omega_1^* \\ \Omega_3 & -\alpha\delta & \Omega_2^* \\ \Omega_1 & \Omega_2 & \alpha\Delta \end{pmatrix} \qquad \alpha=\mathrm{sign}(r-\eta)$$



$$\Omega_3=\sqrt{\frac{\delta}{\Delta}}\Omega_1 e^{-i\frac{\pi}{2}}=-i\Omega_1\sqrt{\frac{\delta}{\Delta}}(\delta,\Delta>0) \ll 1\ \mathrm{Hz}$$

For $\Delta >> \delta,\Omega$ (Large detuning)

$$H\rightarrow H_r=\begin{pmatrix} \frac{|\Omega_1|^2}{-\Delta} & \frac{\Omega_1^*\Omega_2}{-\Delta}+i\Omega_1^*\sqrt{\frac{\delta}{\Delta}} \\ \frac{\Omega_1\Omega_2}{-\Delta}-i\Omega_1\sqrt{\frac{\delta}{\Delta}} & \frac{|\Omega_2|^2}{-\Delta}-\delta \end{pmatrix}$$

Unitary matrix

$$U=\left(|\psi_+\rangle,|\psi_-\rangle\right)$$

$$H_r|\psi_n\rangle=E_n|\psi_n\rangle$$

$$E_+=0,\ E_-=-\alpha\delta-\frac{\Omega^2}{\alpha\Delta}$$

$$\Omega=\sqrt{|\Omega_1|^2+|\Omega_2|^2}$$

w = Hopf index χ

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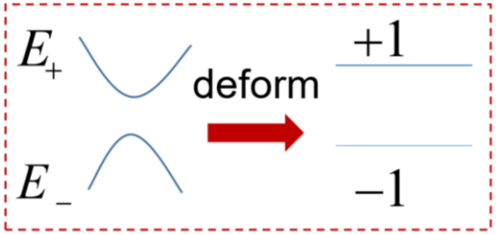
Flattened Hamiltonian

$$H = U(r)\begin{pmatrix} E_+ & 0 \\ 0 & E_- \end{pmatrix} U(r)^{-1}$$



$$\tilde{H} = \Pi_+ - \Pi_- = |+\rangle\langle+| - |-\rangle\langle-| = U(r)\sigma^3 U(r)^{-1}$$

Winding number:

$$w = \frac{1}{24\pi^2}\int dr\,\varepsilon^{ijk}\,tr\left(U^{-1}\partial_i U U^{-1}\partial_j U U^{-1}\partial_k U\right)$$

Equivalent

Hopf index:

$$\chi = -\frac{1}{4\pi^2}\int d^3r\,\varepsilon_{ijk}a_i\partial_j a_k$$

Berry connection: $a_\mu = \langle - | \partial_\mu | - \rangle$

$$f_{uv} = \partial_u a_v - \partial_v a_u$$

Topological quantum matter with cold atoms
D.W. Zhang, ***Y. Q. Zhu***, Y.X.Zhao, S. L. Zhu, Adv. Phys. 67(4), 253-402(2018).

$$\chi = -\frac{1}{4\pi^2}\int d^3r\,\varepsilon_{ijk}a_i\partial_j a_k = -\frac{1}{4\pi^2}\int d^3r\,\vec{a}(\vec{r})\cdot\vec{f}(\vec{r})$$

Detection $f_{uv}(\vec{r})$

f_{uv} gauge invariant, a_u gauge dependent: $\vec{f}(\vec{r}) = \nabla \times \vec{a}(\vec{r})$

$$\chi = -\frac{1}{4\pi^2}\int d^3r \varepsilon_{ijk} a_i \partial_j a_k = \int d^3r \vec{a}(\vec{r}) \cdot \vec{f}(\vec{r})$$

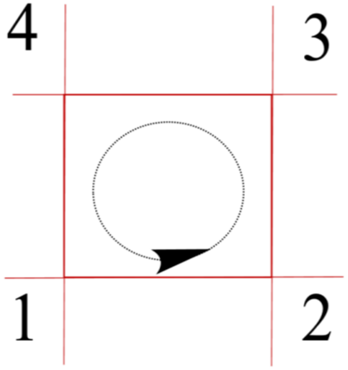
$$a_\mu = \langle \psi(\vec{r}) \mid \partial_\mu \psi(\vec{r}) \rangle = (\langle \psi(\vec{r}) \mid \psi(\vec{r} + \delta\vec{\mu}) \rangle - 1)/\delta\vec{\mu}, \delta\vec{\mu} \to 0$$

$\boldsymbol{U(1)link}$: $U_\mu(\vec{r}) = \langle \psi(\vec{x}) \mid \psi(\vec{x} + \delta\mu) \rangle \approx e^{a_\mu \delta\mu} \to a_\mu \delta\mu = \ln U_\mu(\vec{r})$

Check: $C(\vec{r}) = \delta x \delta y f_{xy} = lnTr\big(\rho(\vec{r} + \delta\vec{x})\rho(\vec{r} + \delta\vec{x} + \delta\vec{y})\rho(\vec{r} + \delta\vec{y})\rho(\vec{r})\big)$

$\Rightarrow f_{xy} = C(\vec{r})/\delta x \delta y$ With $\rho(\vec{r}) = |\psi(\vec{r})\rangle\langle\psi(\vec{r})|$

Gauge invariants



Detection $a(\vec{r})$?

$\vec{a}(\vec{r})$ gauge dependent➔ Find $\vec{a}(\vec{r}_0)$ from $\vec{f}(\vec{r}_0)$?

Choose Coulomb gauge

$$\nabla \cdot a = 0$$

$$\because f = \nabla \times a$$

$$\therefore \nabla \times f = \nabla(\nabla \cdot a) - \nabla^2 a$$

Introduce effective current density

$$j = -\nabla^2 a$$

$$a_\mu(r) = \int_{V'} \frac{\nabla \times f(r')dV'}{4\pi|r - r'|}$$

$$j_\mu = (\nabla \times f)^\mu = \partial_\nu f^\lambda - \partial_\lambda f^\nu$$

⟷

Review the magnetostatic equation in electrodynamics.

$$\vec{B} = \nabla \times \vec{A}, \ \nabla \cdot \vec{A} = 0$$

$$\nabla \times \vec{B} = \mu \vec{J} = \nabla(\nabla \cdot \vec{A}) - \nabla^2 \vec{A} = -\nabla^2 \vec{A}$$

$$\vec{A}(r) = \frac{\mu}{4\pi} \int_V \frac{\vec{J}(r')dV'}{|r - r'|} \approx \sum_i \frac{\mu \vec{J}(r')\delta V}{4\pi \, r_i}$$

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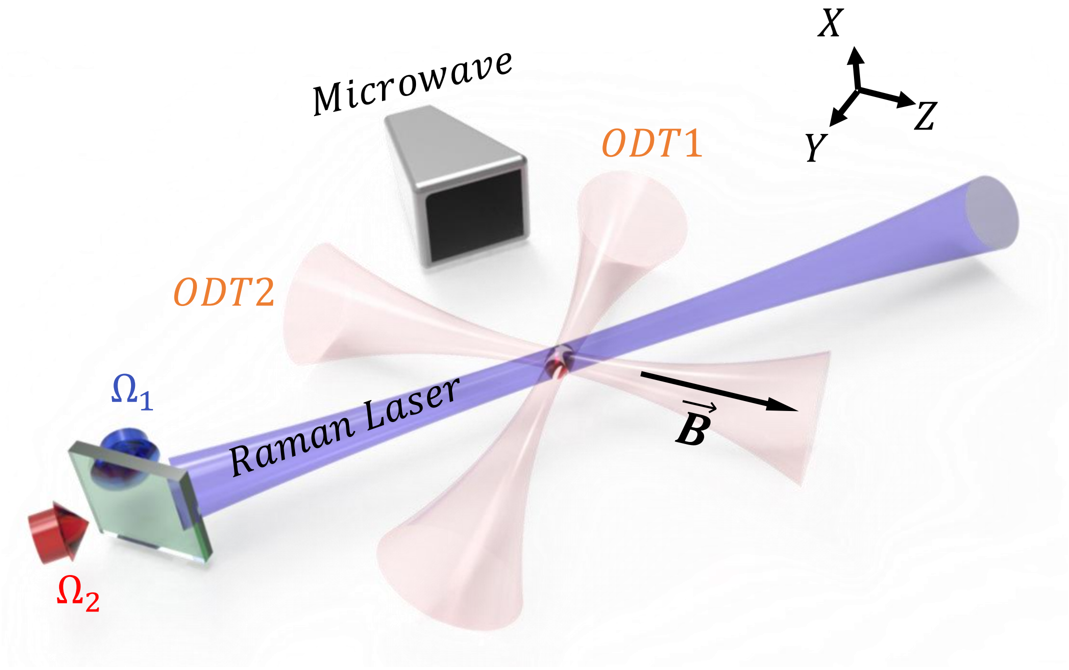
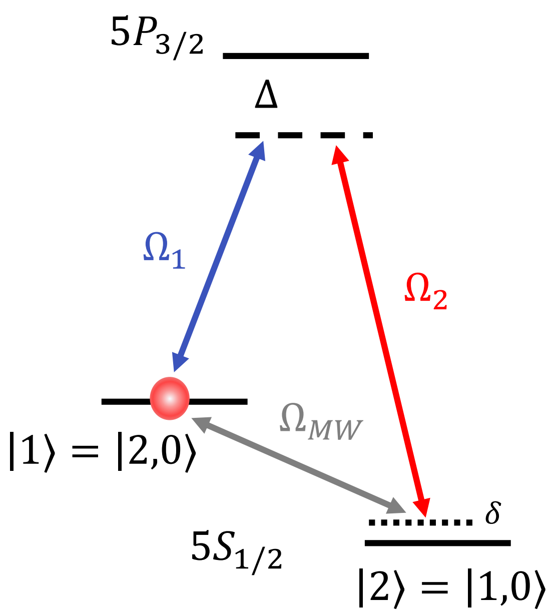
Experimental Setup





Initial state preparation

$|F = 2, m_F = 0\rangle$

Adiabatic state preparation

$|\Psi_\pm\rangle = \begin{bmatrix} \cos(\theta/2) \\ \pm \sin(\theta/2)\, e^{i\varphi} \end{bmatrix}$

Quantum state tomography

$\hat{\rho} = \begin{pmatrix} \rho_{00} & \rho_{10} \\ \rho_{01} & \rho_{11} \end{pmatrix}$

Quantum state manipulation

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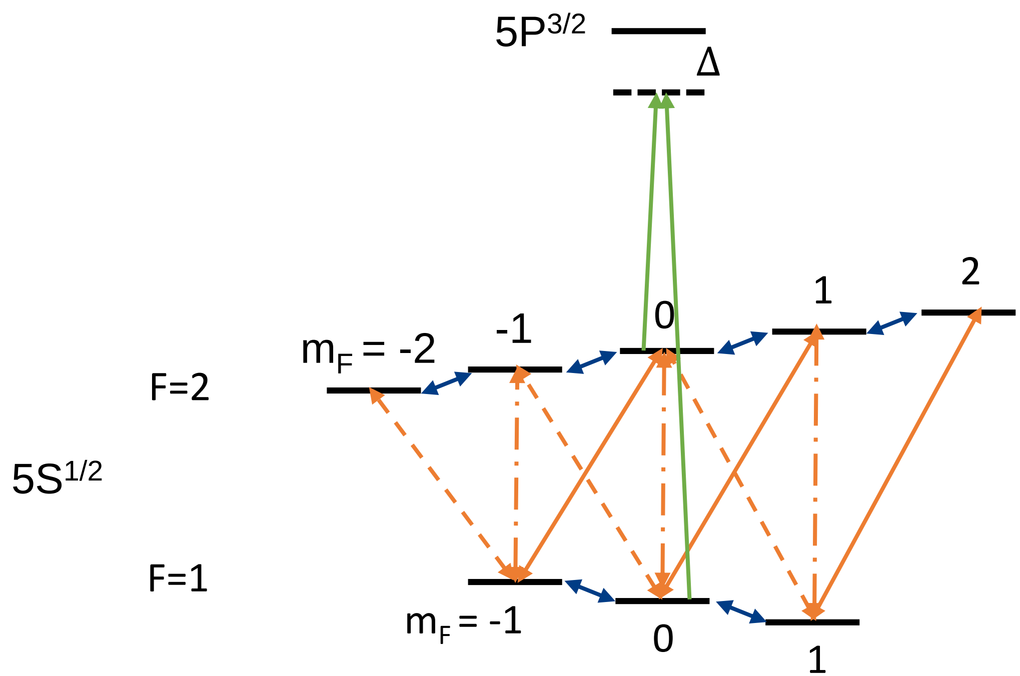
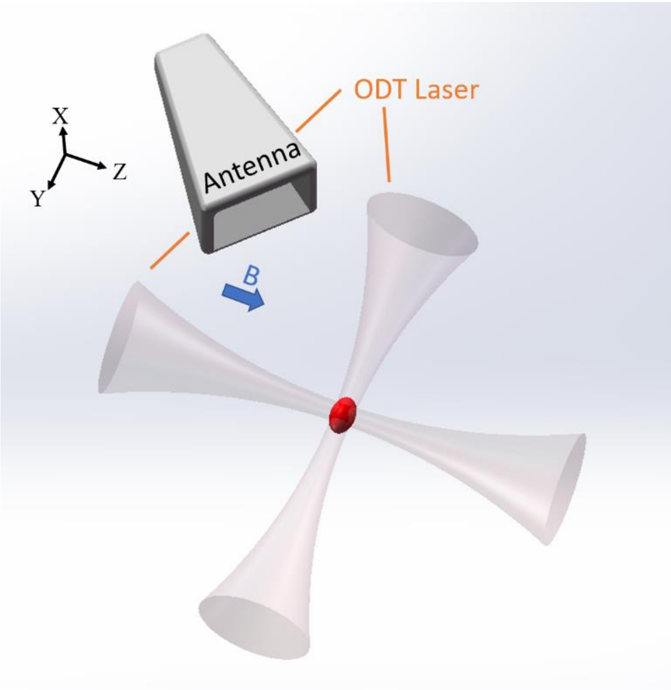
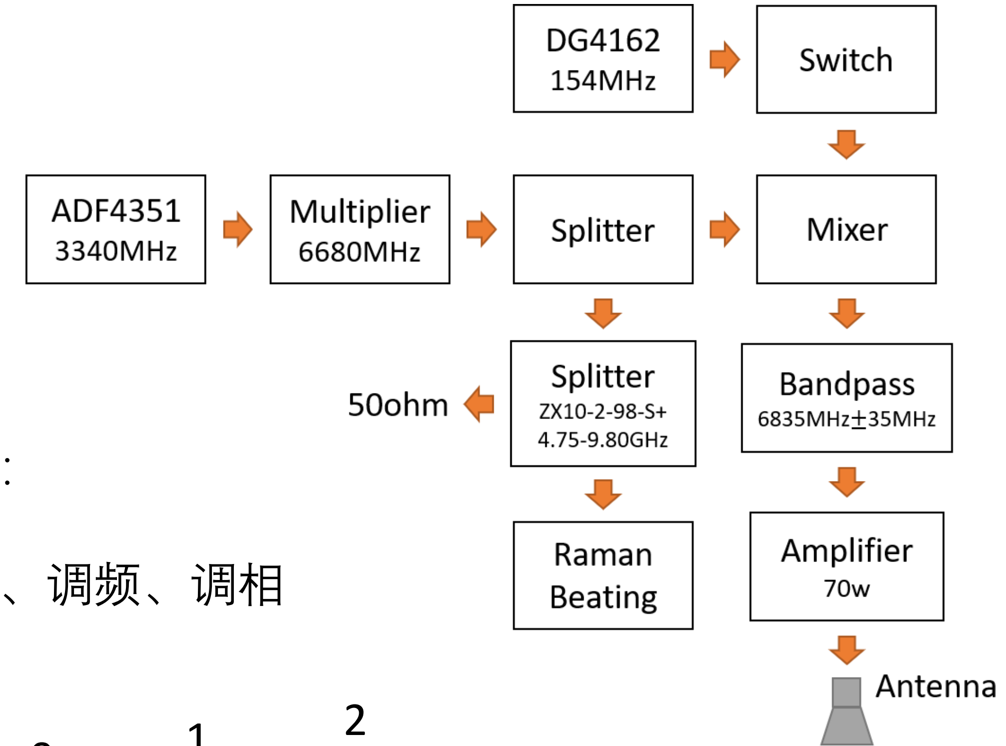
量子态 ➡ 电磁场

- 射频场: 300KHz~300GHz
- 微波场: 300MHz~300GHz
- 激光场: 300nm ~1500nm



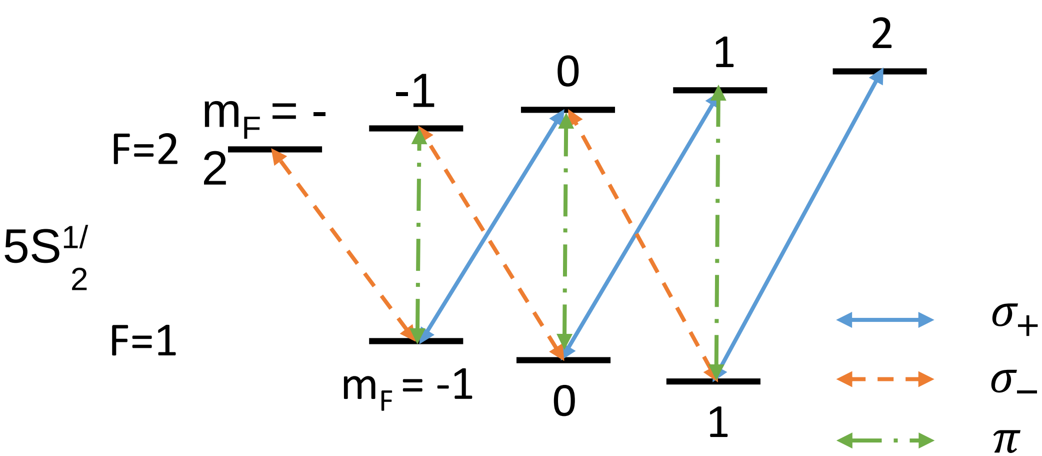
Microwave and RF



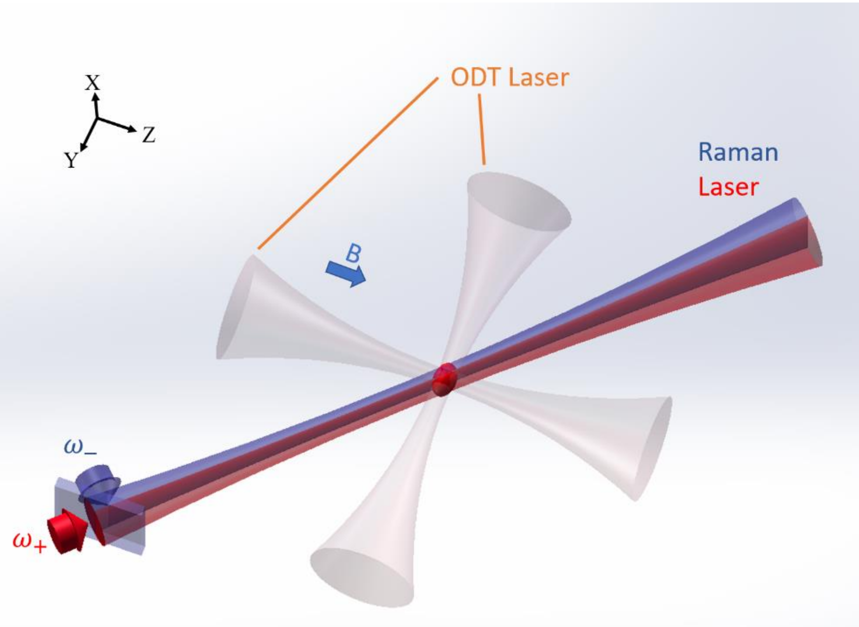


微波：

调幅、调频、调相

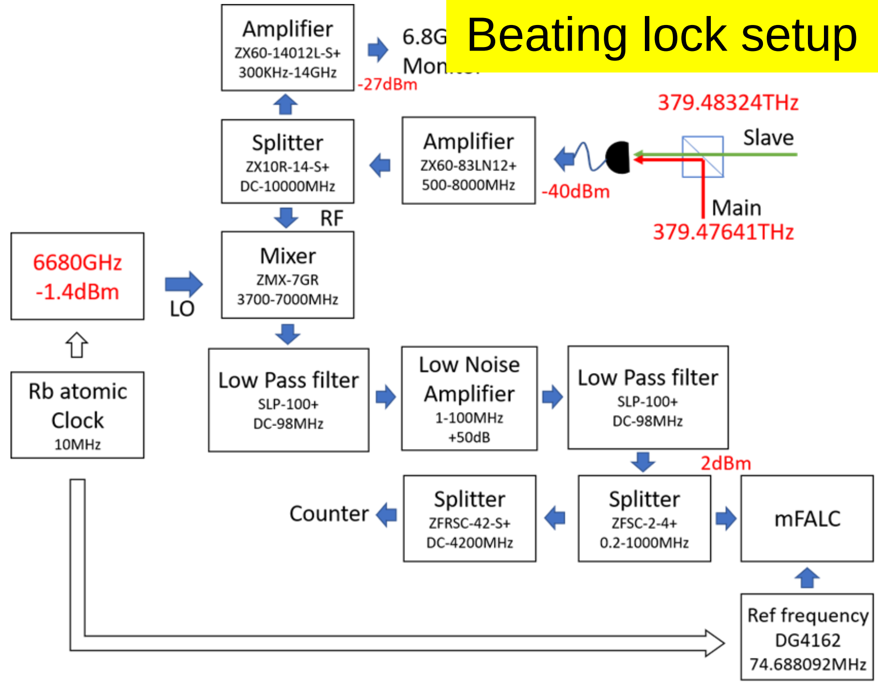


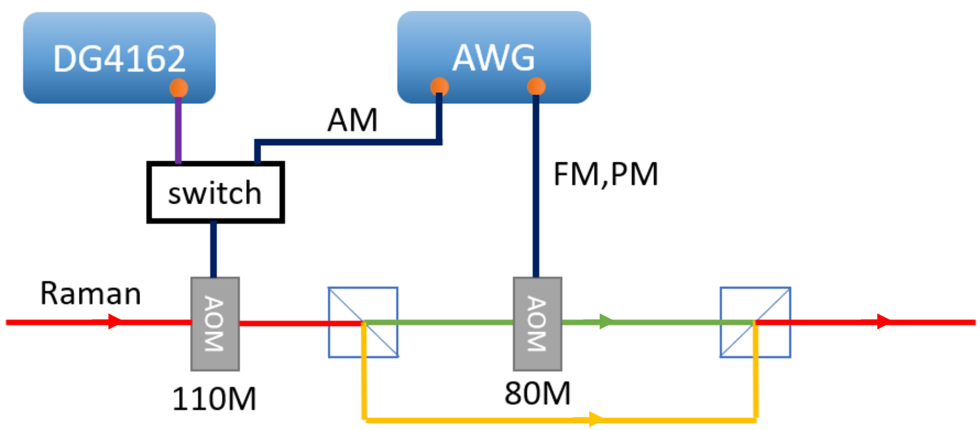
Raman Laser



Raman laser： intensity, phase, frequency

Beating lock setup





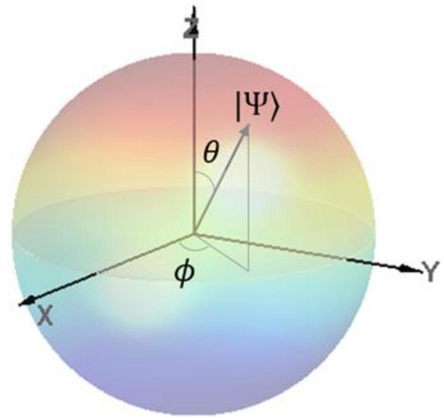
Quantum state tomography

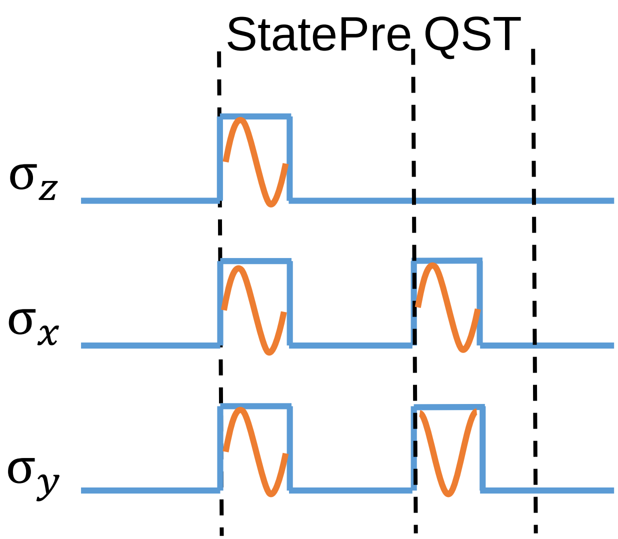
$$\hat{\rho} = |\Psi\rangle\langle\Psi|$$

$$= \begin{pmatrix} \rho_{00} & \rho_{10} \\ \rho_{01} & \rho_{11} \end{pmatrix}$$

$$= \frac{1}{2}\hat{\sigma}_0 + \frac{1}{2}\left(v_x\hat{\sigma}_x + v_y\hat{\sigma}_y + v_z\hat{\sigma}_z\right)$$

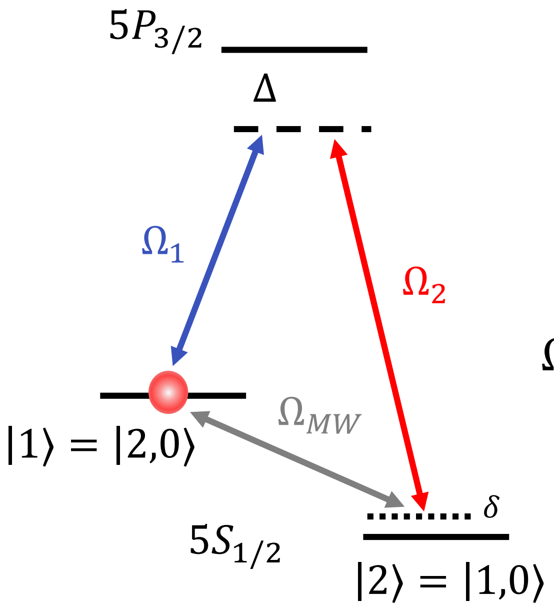
$$|\Psi\rangle = \cos\frac{\theta}{2}|0\rangle + \sin\frac{\theta}{2}e^{i\phi}|1\rangle$$





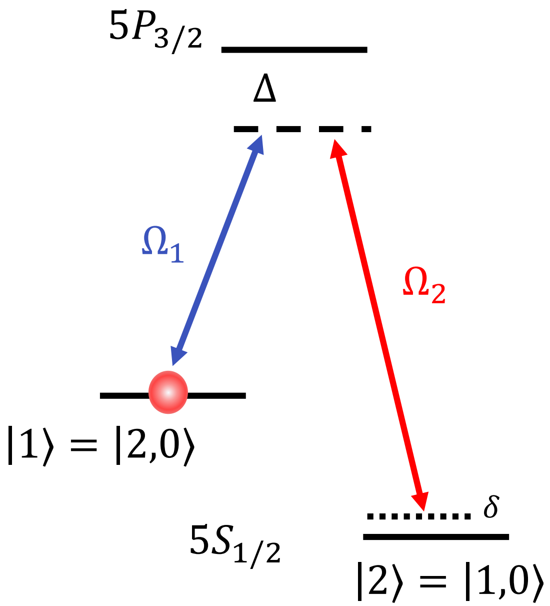
- 最大似然估计→符合物理性质的最有可能的密度矩阵

Energy level scheme



$$\Delta \gg \delta, \Omega_i$$

$$\Omega_{MW} = -i\Omega_1\sqrt{\frac{\delta}{\Delta}} \sim 0 \ll 1Hz$$



$$H = U(r)\begin{pmatrix} E_+ & 0 \\ 0 & E_- \end{pmatrix}U(r)^{-1}$$

$$E_+ = 0, E_- = -\alpha\delta - \frac{\Omega^2}{\alpha\Delta} \ll E_{excited} \sim \Delta$$

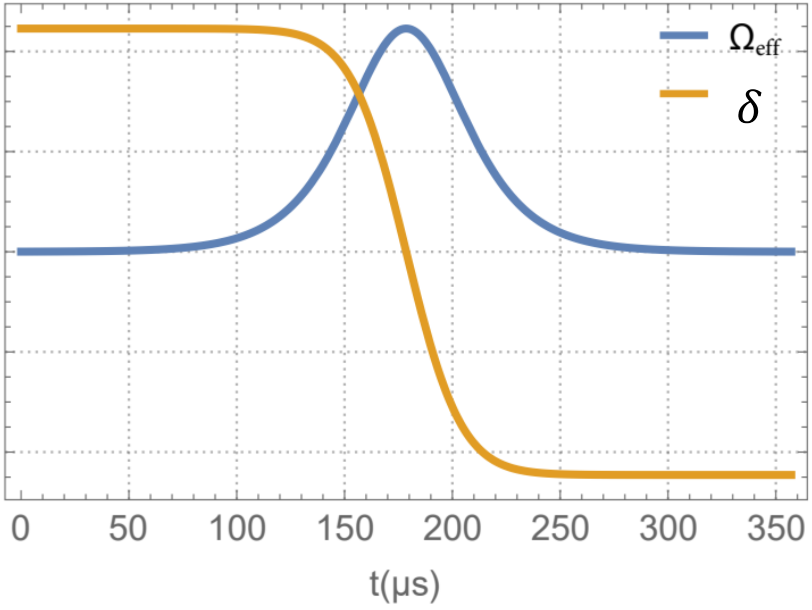
$$H = \frac{\hbar}{2}\begin{bmatrix} \delta_{exp} & \Omega e^{-i\varphi_{exp}} \\ \Omega e^{i\varphi_{exp}} & -\delta_{exp} \end{bmatrix}$$

$$E_\pm = \pm\frac{\hbar}{2}\sqrt{\Omega^2 + \delta_{exp}{}^2} \ll E_{excited} \sim \Delta$$

Quantum state preparation

$$|\Psi(0)\rangle = \begin{pmatrix}1\\0\end{pmatrix} \rightarrow adiabatic \rightarrow \begin{pmatrix} cos\frac{\theta}{2}e^{-i\phi} \\ sin\frac{\theta}{2} \end{pmatrix}$$

$$\hat{H} = \frac{\hbar}{2}\begin{pmatrix} \delta & \Omega e^{-i\phi} \\ \Omega e^{i\phi} & -\delta \end{pmatrix} = \frac{\hbar}{2}\Omega_0 \begin{pmatrix} cos\theta & sin\theta e^{-i\phi} \\ sin\theta e^{i\phi} & -cos\theta \end{pmatrix}$$



Single photon detuning:

$\Delta = -3904GHz$

Raman power:

$P_1 = 45mW, P_1 = 53mW$

Raman size:

$r_1 = 375\mu m, r_2 = 150\mu m$

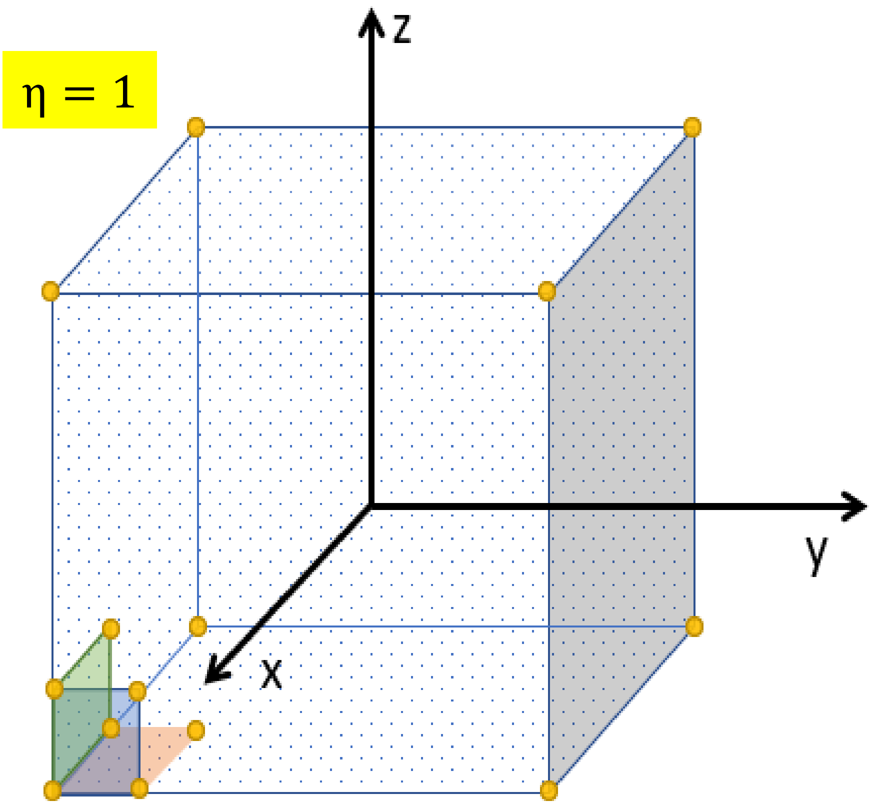
Controlled parameter: $\theta = \arctan(\Omega/\delta)$

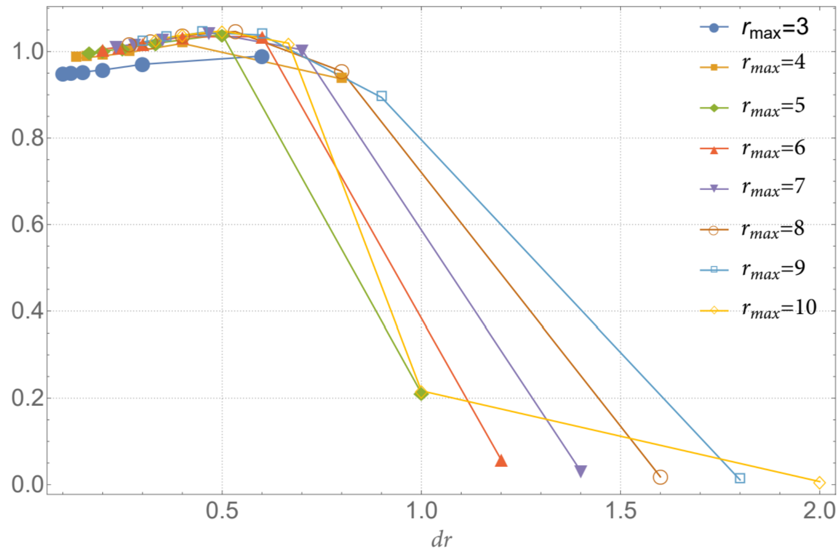
pulse: $\Omega t = 20\pi \sim 350us$

Grid size

$$U^{(1)}(\vec{x}) = \frac{\vec{x}^2 - \eta^2}{\vec{x}^2 + \eta^2} - \frac{2i\eta\vec{\sigma}\cdot\vec{x}}{\vec{x}^2 + \eta^2}$$

$$\chi = -\frac{1}{4\pi^2}\int d^3r\,\vec{a}(\vec{r})\cdot\vec{f}(\vec{r})$$

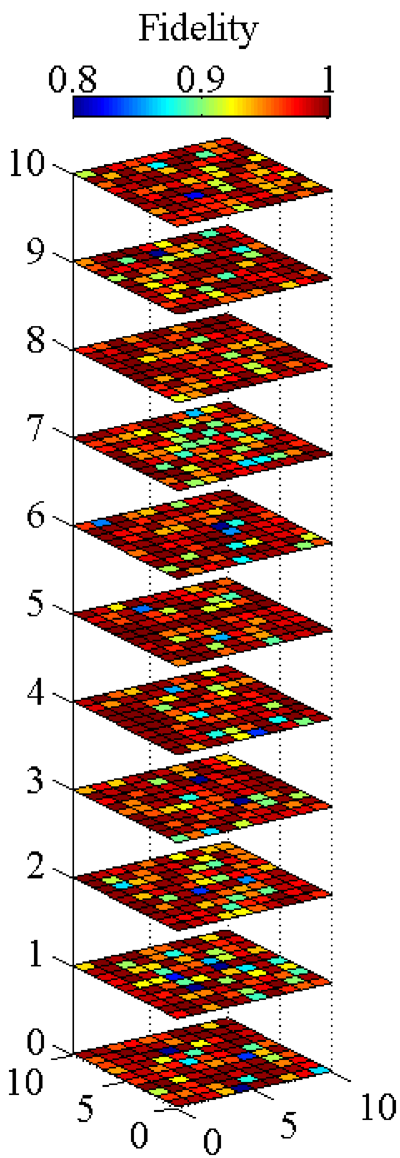




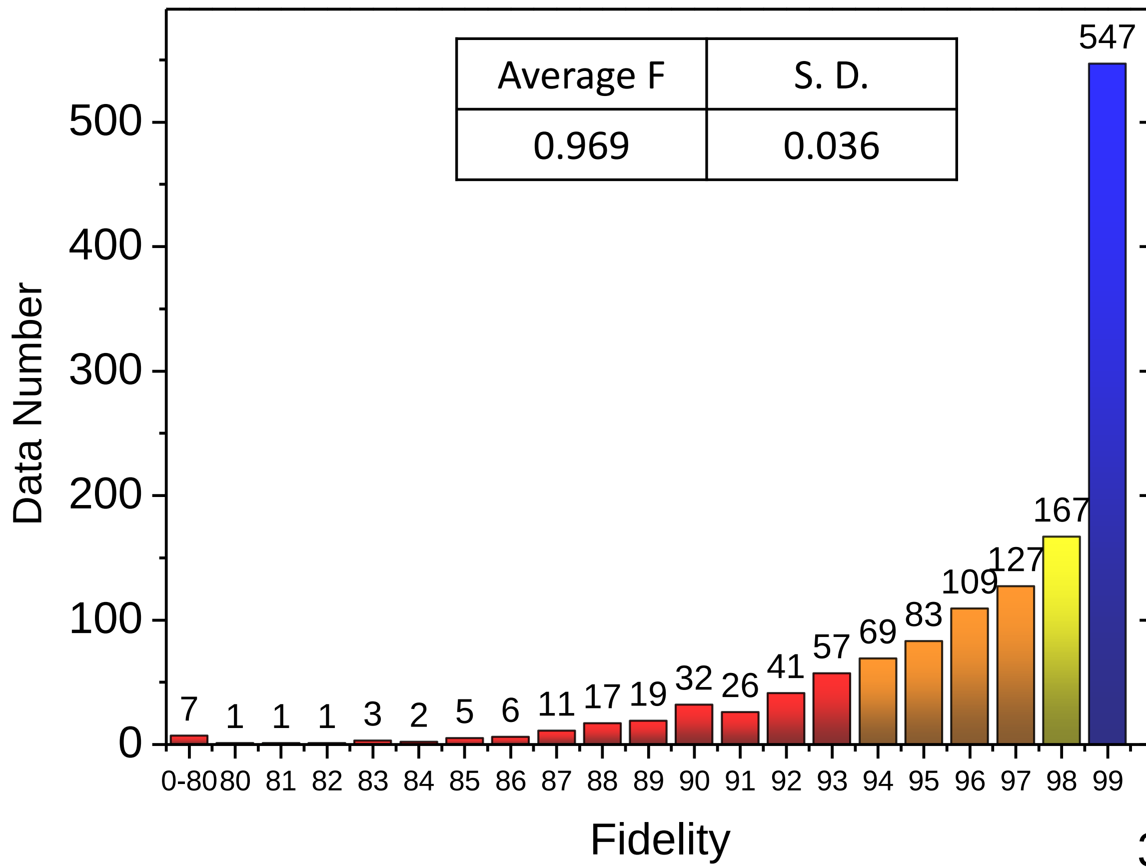
Grid size: 10x10x10

$L = [-3.3, 3.3]$

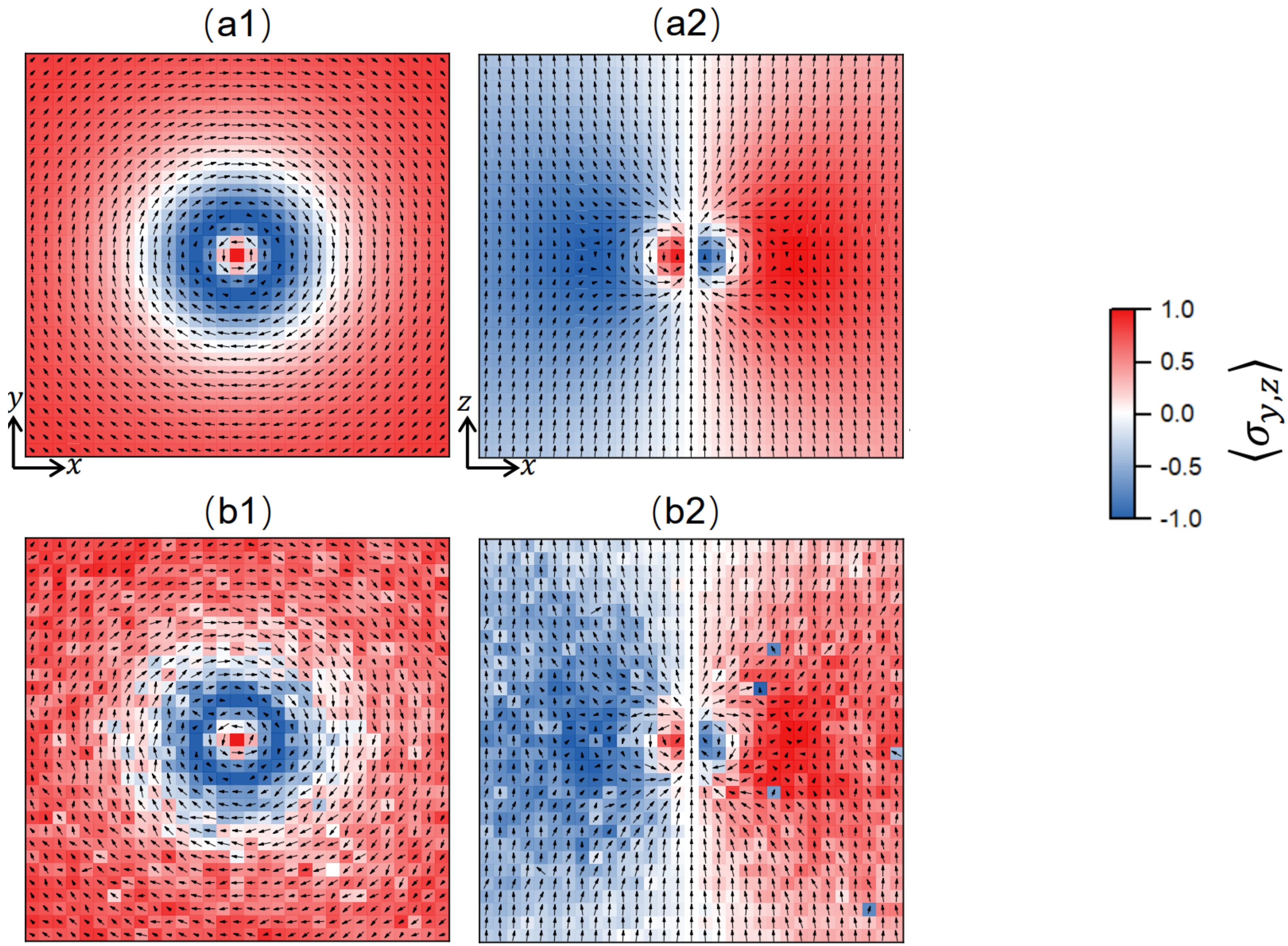
Quantum state fidelity



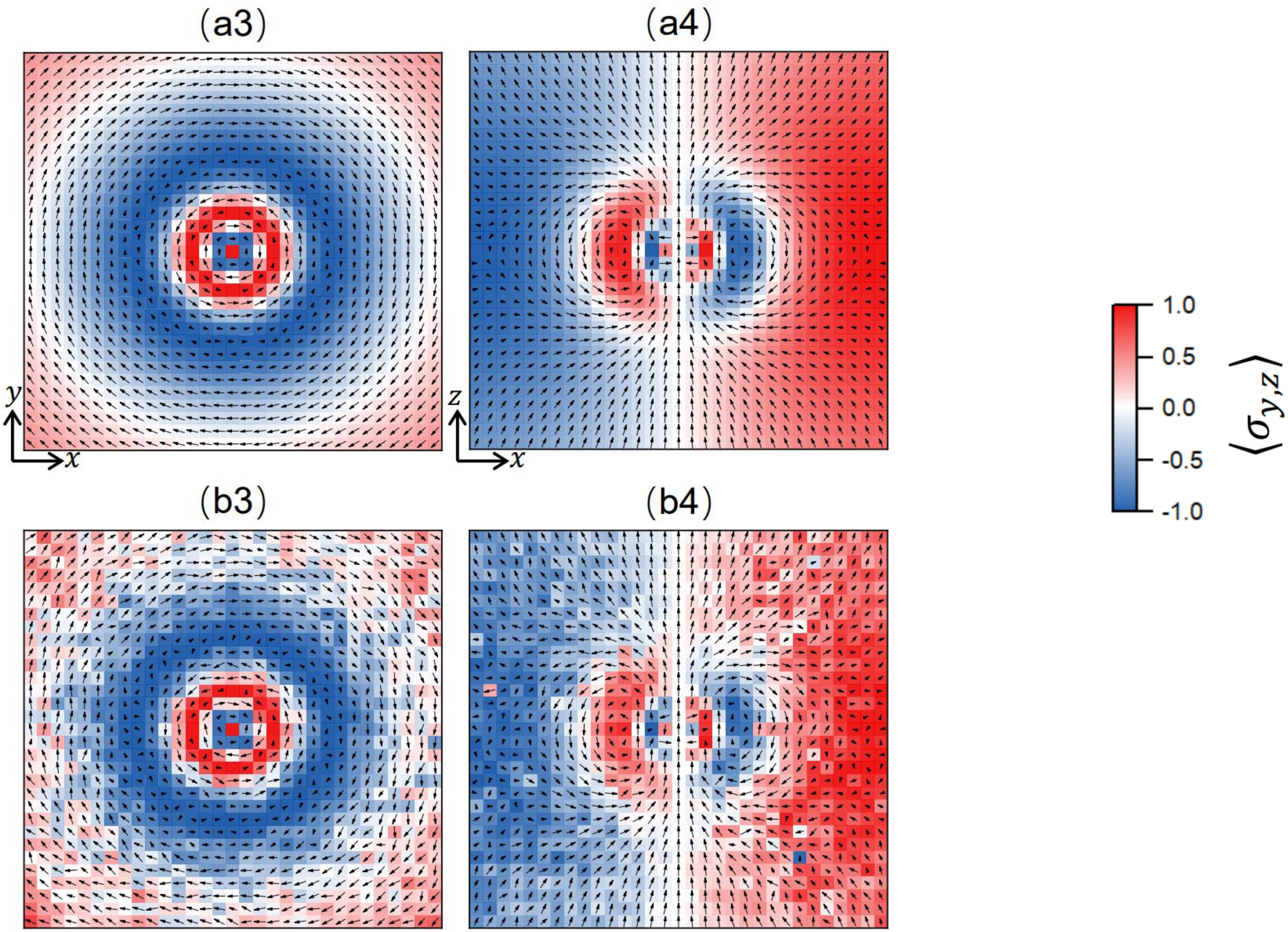
	Theory	Experiment	Using Data F>95%	Using Data F>99%
χ	0.986	0.912	0.955	0.980



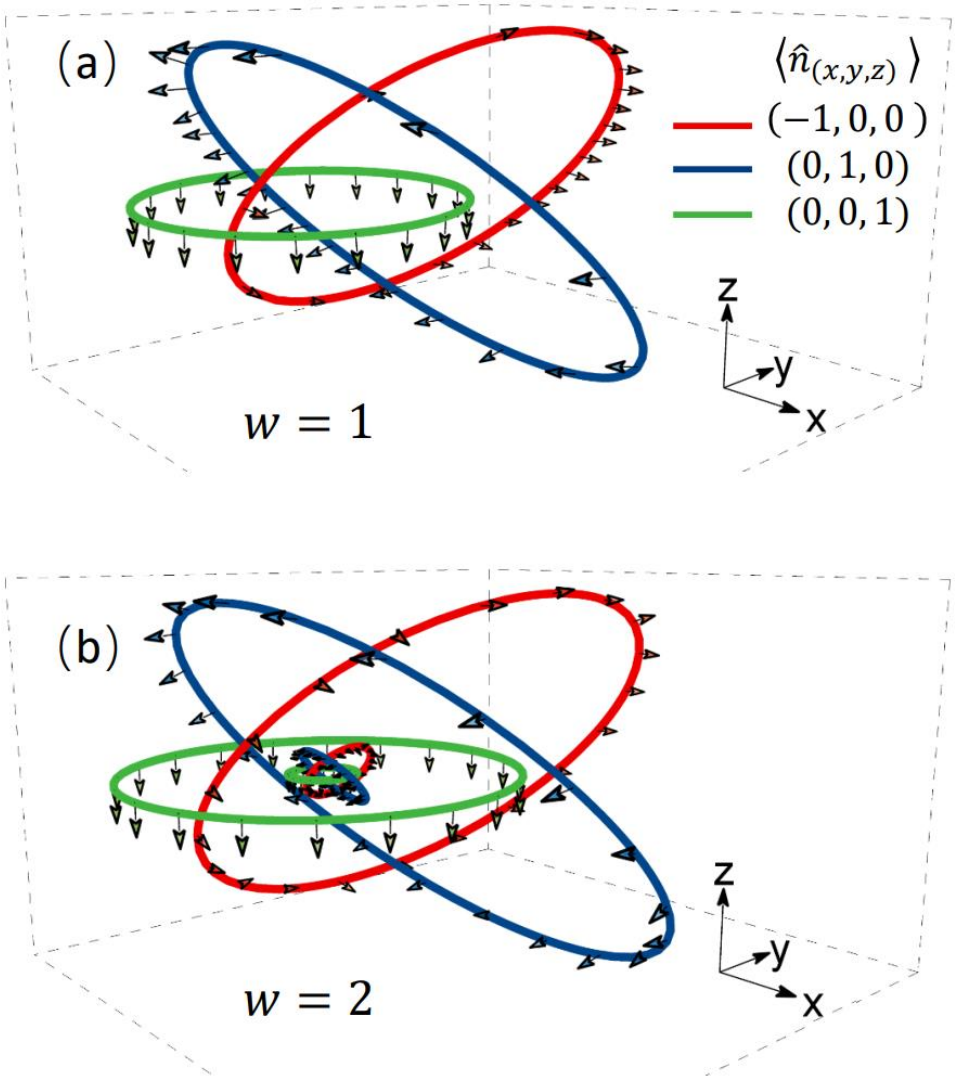
Spin Texture of $w = 1$



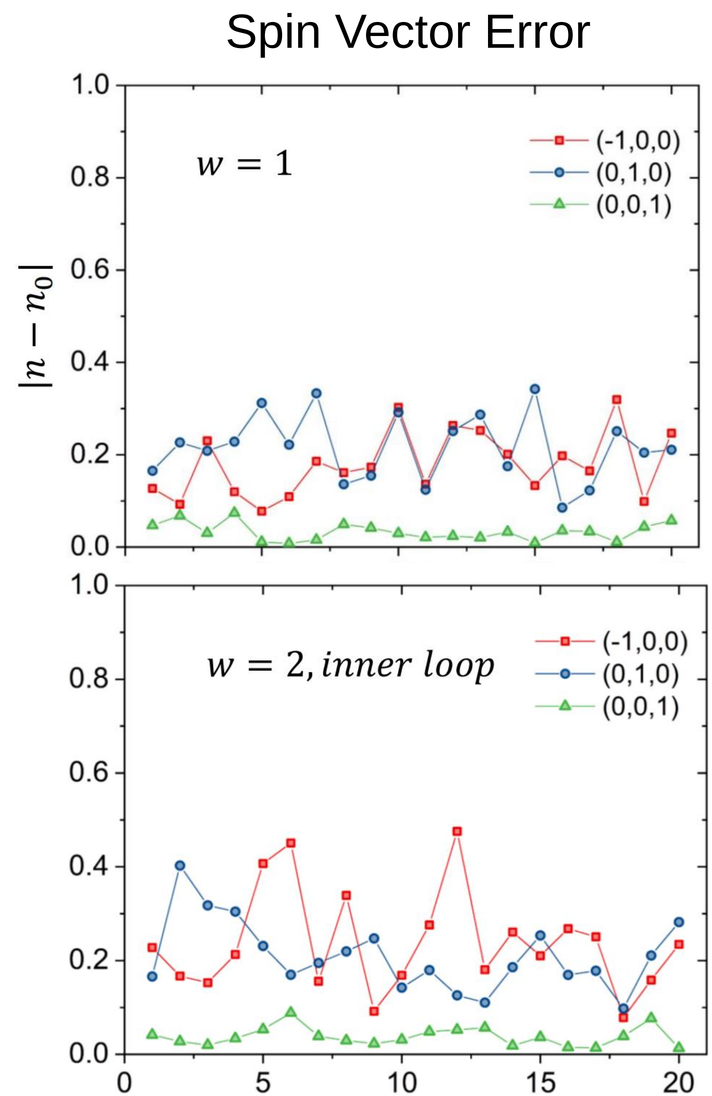
Spin Texture of $w = 2$



Hopf Link



(a)
$\langle \hat{n}_{(x,y,z)} \rangle$
(−1, 0, 0)
(0, 1, 0)
(0, 0, 1)
z
y
x
$w = 1$
(b)
z
y
x
$w = 2$

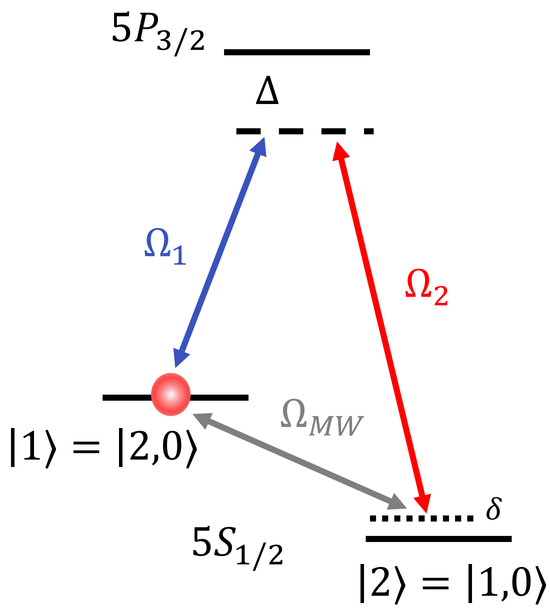


Spin Vector Error
$|n - n_0|$
$w = 1$
(-1,0,0)
(0,1,0)
(0,0,1)
$w = 2, inner\ loop$
(-1,0,0)
(0,1,0)
(0,0,1)
1.0
0.8
0.6
0.4
0.2
0.0
0
5
10
15
20

Summary

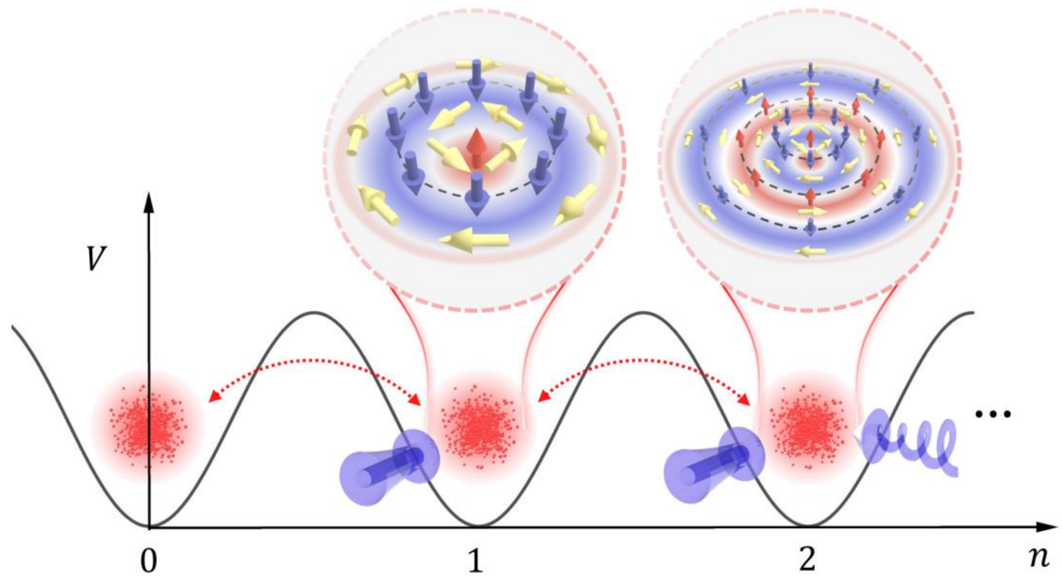
- Introduction
- Topology of SU(2) gauge field: Winding
- Simulating topological SU(2) vacua
- Experimental realizaiton using a BEC
- Outlook

Real Space Non-Abelian Vacua



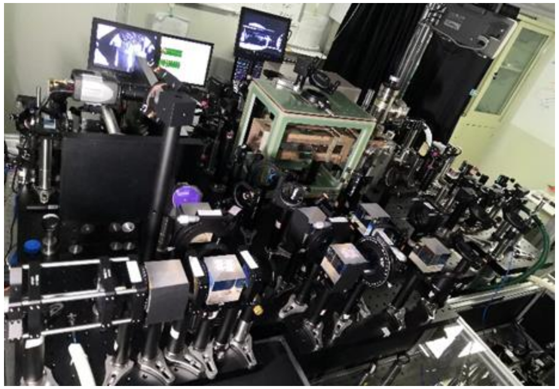
$$H_{exp}(r) = \hbar \begin{pmatrix} 0 & 0 & \Omega_1^* \\ 0 & -\alpha\delta & \Omega_2^* \\ \Omega_1 & \Omega_2 & \alpha\Delta \end{pmatrix}$$

Vacuum tunneling- Instantons

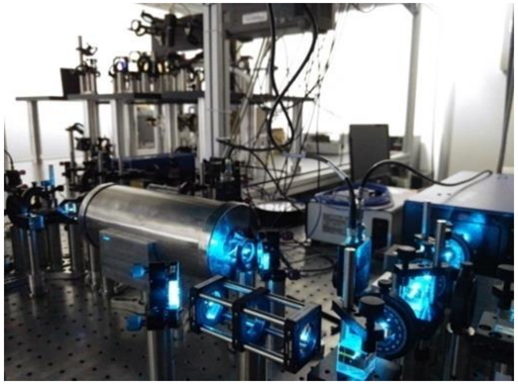


Platforms @SCNU

Quantum control

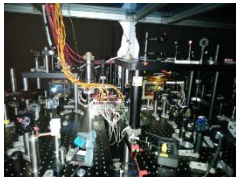


Quantum Memory

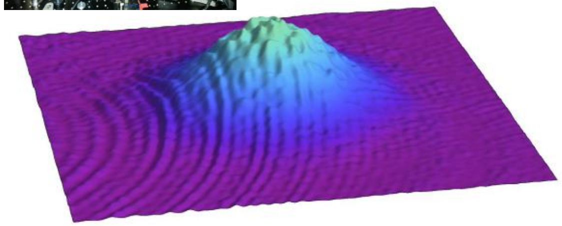


Cold Rydberg atom

Hybrid cold system



2019-July-24
Rb BEC



Rb BEC: SOC,OL

Yb Quantum gas

Team and Funding

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PhD Congjun Zou

Dr. Wei Huang

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……

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Prof. Yan-Xiong Du

Dr. Qing-Xian Lv、Zhen-Tao Liang

PostDoc position opening