Dark State Optical Lattice with a Subwavelength Spatial Structure

180319

Group Intro.

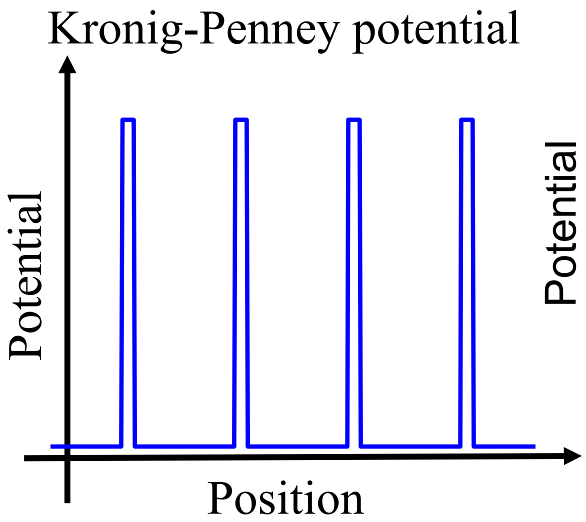
- James V. Porto
- Ph. D: Cornell University
  - Superfluidity of ^{3}He in aerogel
- University of Maryland, NIST
- Research Areas
  - Cold Atoms in Optical Lattices
  - Interacting Photons
  - Ultracold Rb/Yb Mixtures

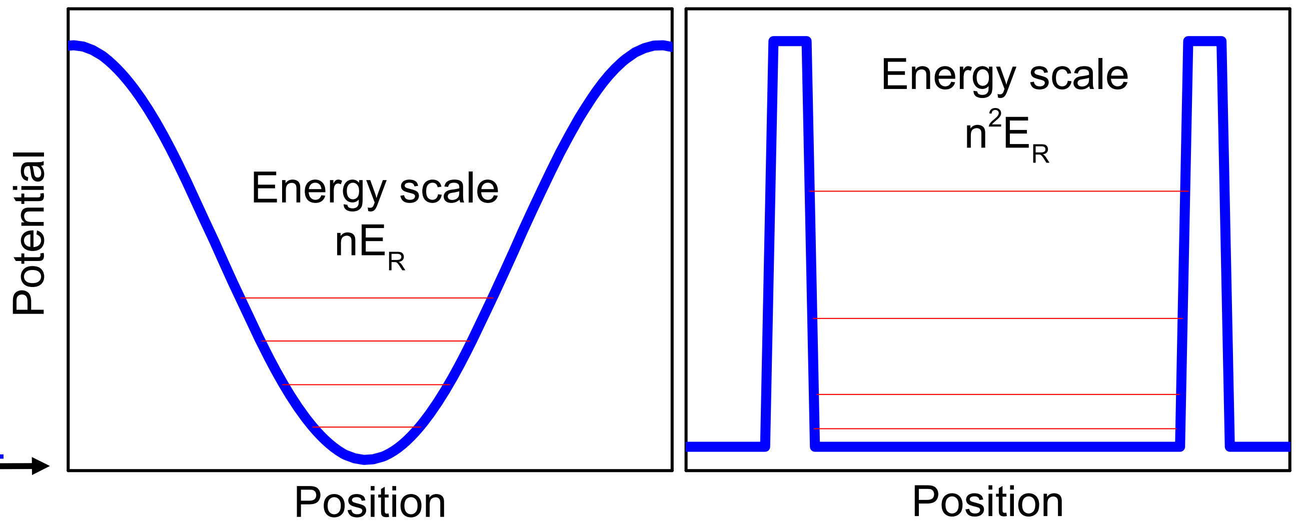
Publication

Dark State **Optical Lattice** with a Subwavelength Spatial Structure ← Today's paper
Dissipation induced dipole blockade and anti-blockade in driven **Rydberg** systems
Spontaneous avalanche dephasing in large **Rydberg** ensembles
Anomalous Broadening in Driven Dissipative **Rydberg** Systems
Nonlinear looped band structure of Bose-Einstein condensates in an **optical lattice**

What they did

- Optical potentials with subwavelength spatial structure
- Kronig-Penney potential(widths below $\lambda/50 \sim 10$ nm)
- Study the band structure
- Subwavelength motional control of atoms
  - creation of narrow tunnel junctions for quantum gases
  - building sharp-wall box-like traps
  - studying Anderson localization with random strength in the barrier height

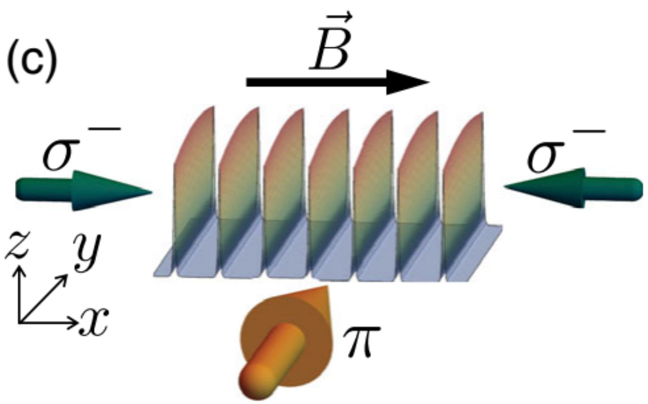


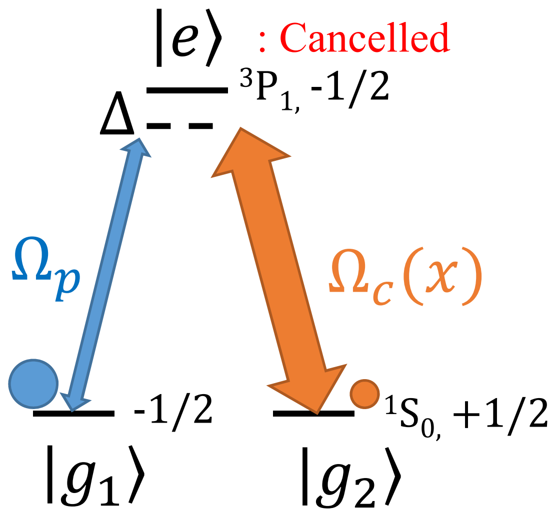


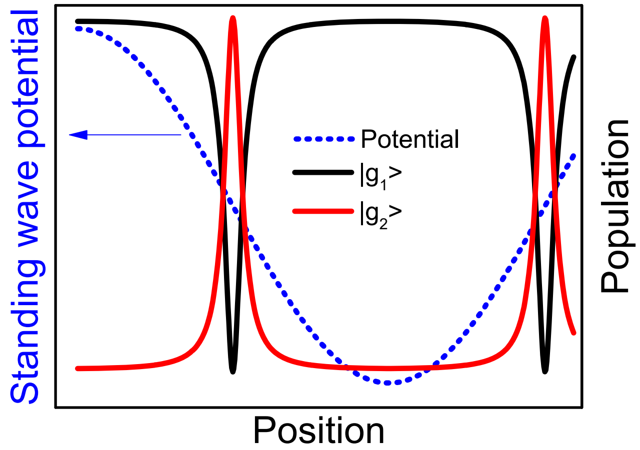
Schematics

- Standing wave light along x axis(Ω_c), traveling wave light along y axis(Ω_p)
- Dark state: $|E_0(x)\rangle = \sin(\alpha(x))\,|g_1\rangle - \cos(\alpha(x))\,|g_2\rangle$ → Eigenstate of internal state basis for fixed x

  where $\alpha(x) = \arctan[\Omega_c(x)/\Omega_p]$
- If $\Omega_p/\Omega_c = \epsilon \ll 1$, dark state changes composition over a narrow region.
- Atoms remain in the dark state under a adiabatic approx.(slowly moving atom)







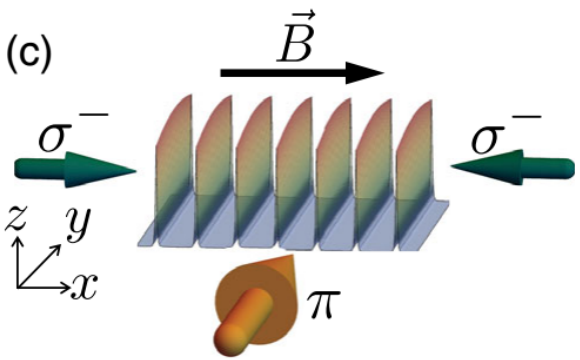
Schematics

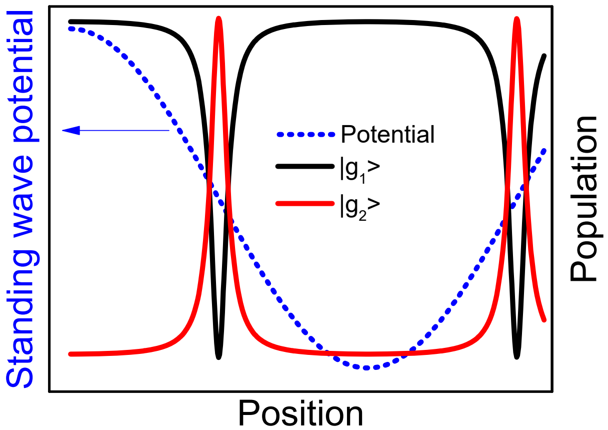
- Atoms remain in the dark state under a adiabatic approx.(slowly moving atom)
- $\langle x|H|E_0(x)\rangle = \langle x|\left(\frac{\boldsymbol{P}^2}{2M} + U\right)|E_0(x)\rangle \Rightarrow \left(\frac{(\boldsymbol{P}-\boldsymbol{A})^2}{2M} + U(x) + V(x)\right)\psi_{E_0}(x)$
- For example, $\boldsymbol{P}|E_0(x)\rangle = -i\hbar\nabla|E_0(x)\rangle$

$$= -i\hbar\nabla\sin(\alpha(x))\,|g_1\rangle + i\hbar\nabla\cos(\alpha(x))\,|g_2\rangle + \sin(\alpha(x))\,\boldsymbol{P}|g_1\rangle - \cos(\alpha(x))\,\boldsymbol{P}|g_2\rangle$$

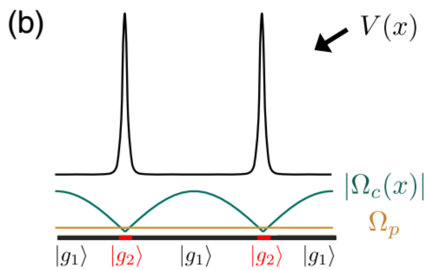
Momentum term due to the state composition change — Usual momentum term

- Kinetic energy associated with large gradient($\boldsymbol{P} = i\hbar\boldsymbol{\nabla}$) in the wave function gives rise to a potential. => Artificial scalar gauge potential



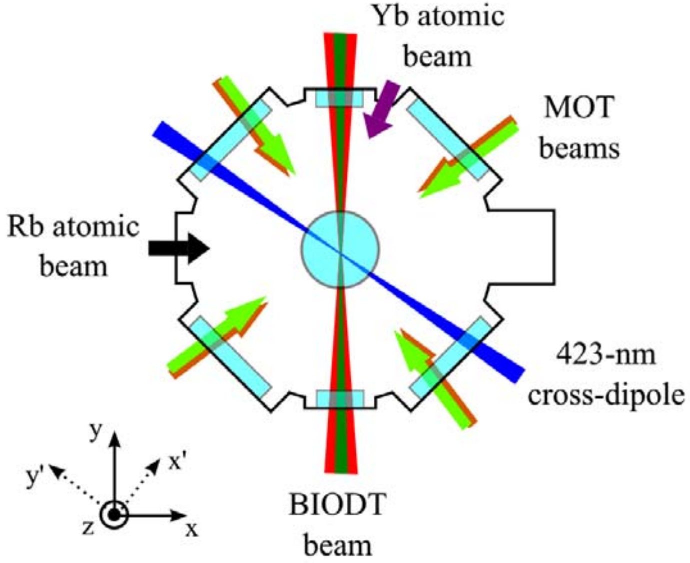


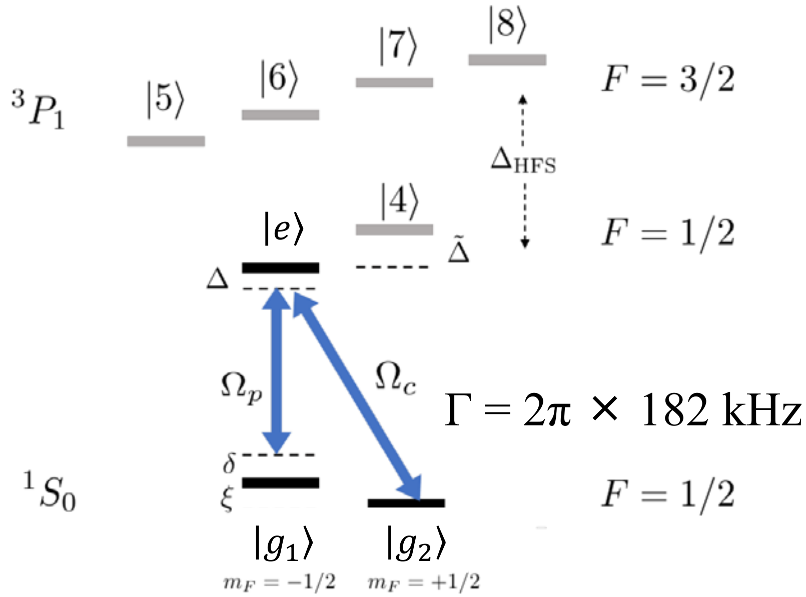
$$V(x) = \frac{\hbar^2}{2m}\left(\frac{d\alpha}{dx}\right)^2 = E_R\frac{\epsilon^2\cos^2(kx)}{[\epsilon^2 + \sin^2(kx)]^2},$$



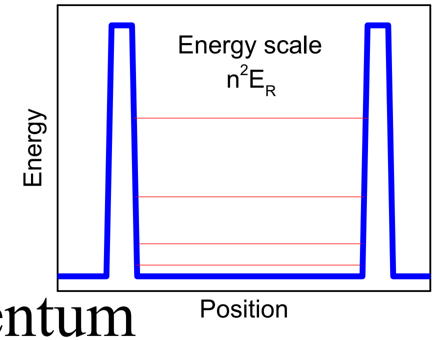
Experimental details

- Atom: ^{171}Yb
- Sympathetic cooling with ^{87}Rb atoms
- Yb MOT – Rb MOT – RF evaporation – load Rb – Dipole evaporation – remove Rb (T ~ 300 nK)
- Optically pump to $|g_1\rangle$ state and populate dark state by turning on Ω_{c1}, Ω_p, and Ω_{c2}, one by one.

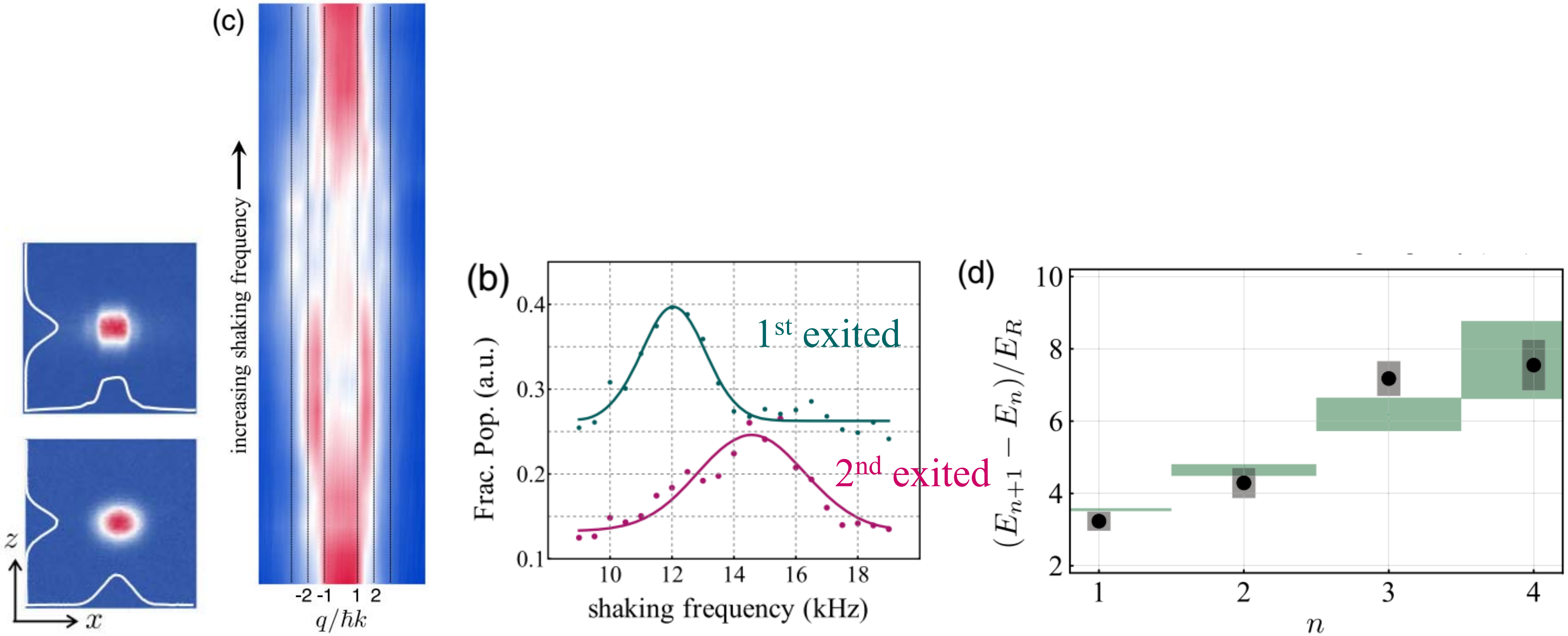




Band mapping



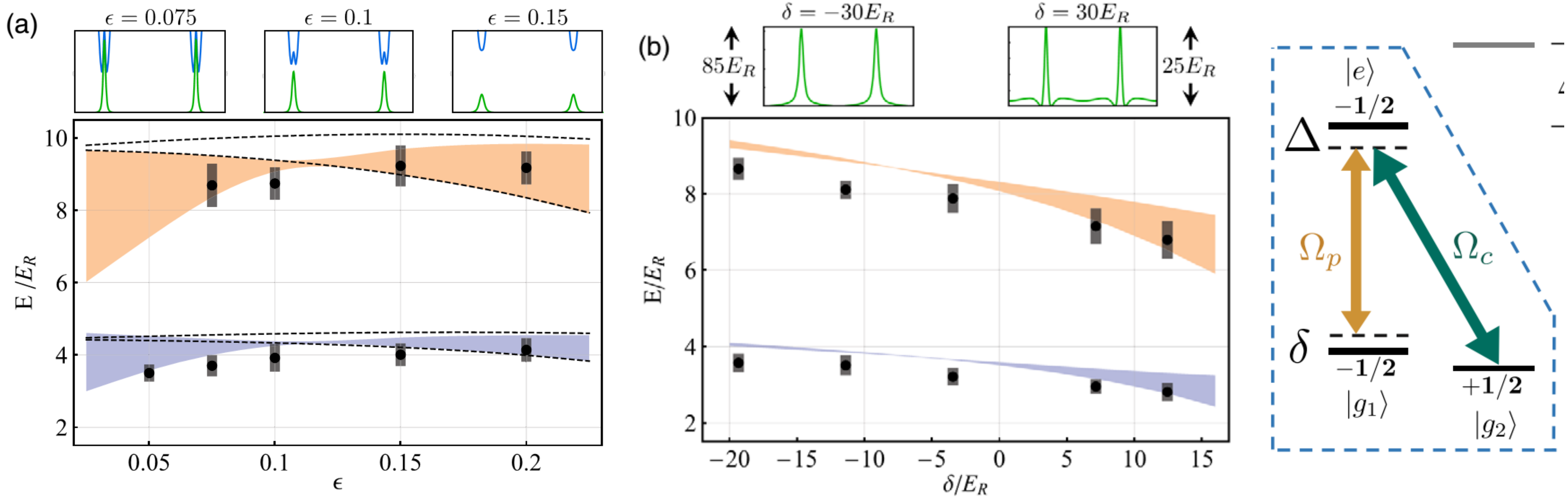
- Use time-of-flight (TOF) images to measure the momentum
- Excite atoms to higher bands by shaking the lattice
- Excitation depends on shaking frequency
- Energy spacing increases as n increases (E_n scales as $n^2 E_R$)



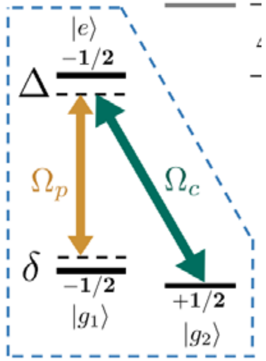
Barrier strength and perturbation

- Energy of KP lattice is independent of barrier strength
- By varying $\Omega_p(\epsilon)$, measured energy spacing
- When $\delta \neq 0$, the state experience additional potential and band structure changes

$$V(x) = \frac{\hbar^2}{2m}\left(\frac{d\alpha}{dx}\right)^2 = E_R \frac{\epsilon^2 \cos^2(kx)}{[\epsilon^2 + \sin^2(kx)]^2},$$



Dissipation



- Dark state lifetime is significantly longer for $\Delta > 0$.
- When $\Delta < 0$, exiting into the energy allowed E_{-} state via nonadiabatic bright state coupling
- Nonadiabatic bright state coupling also leads to dissipation dependence on the laser power.