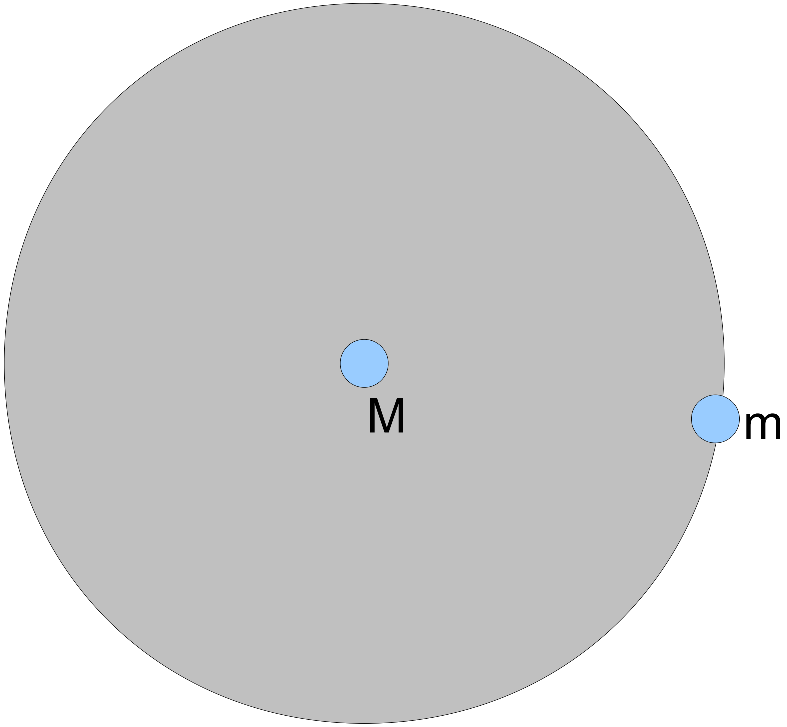


M stationary.
m moving in a circle of radius r
with velocity v

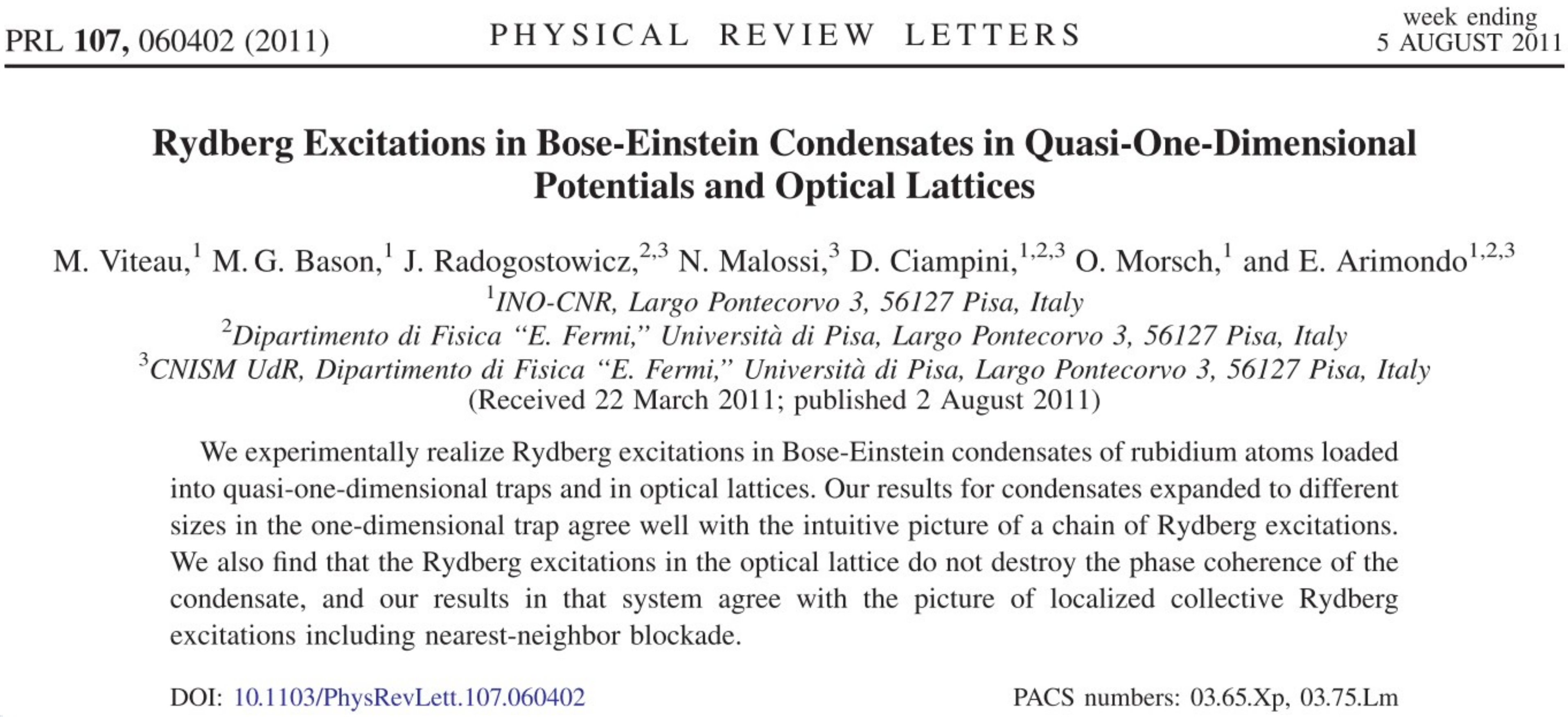
Mass M increased very slowly.
What happens to m?

r decreases, v increases?

Rydberg Excitations in BECs in 1D Potentials

Shreyas Potnis
QO Group meeting
17th August 2011

Outline



PRL **107,** 060402 (2011) PHYSICAL REVIEW LETTERS week ending 5 AUGUST 2011

Rydberg Excitations in Bose-Einstein Condensates in Quasi-One-Dimensional Potentials and Optical Lattices

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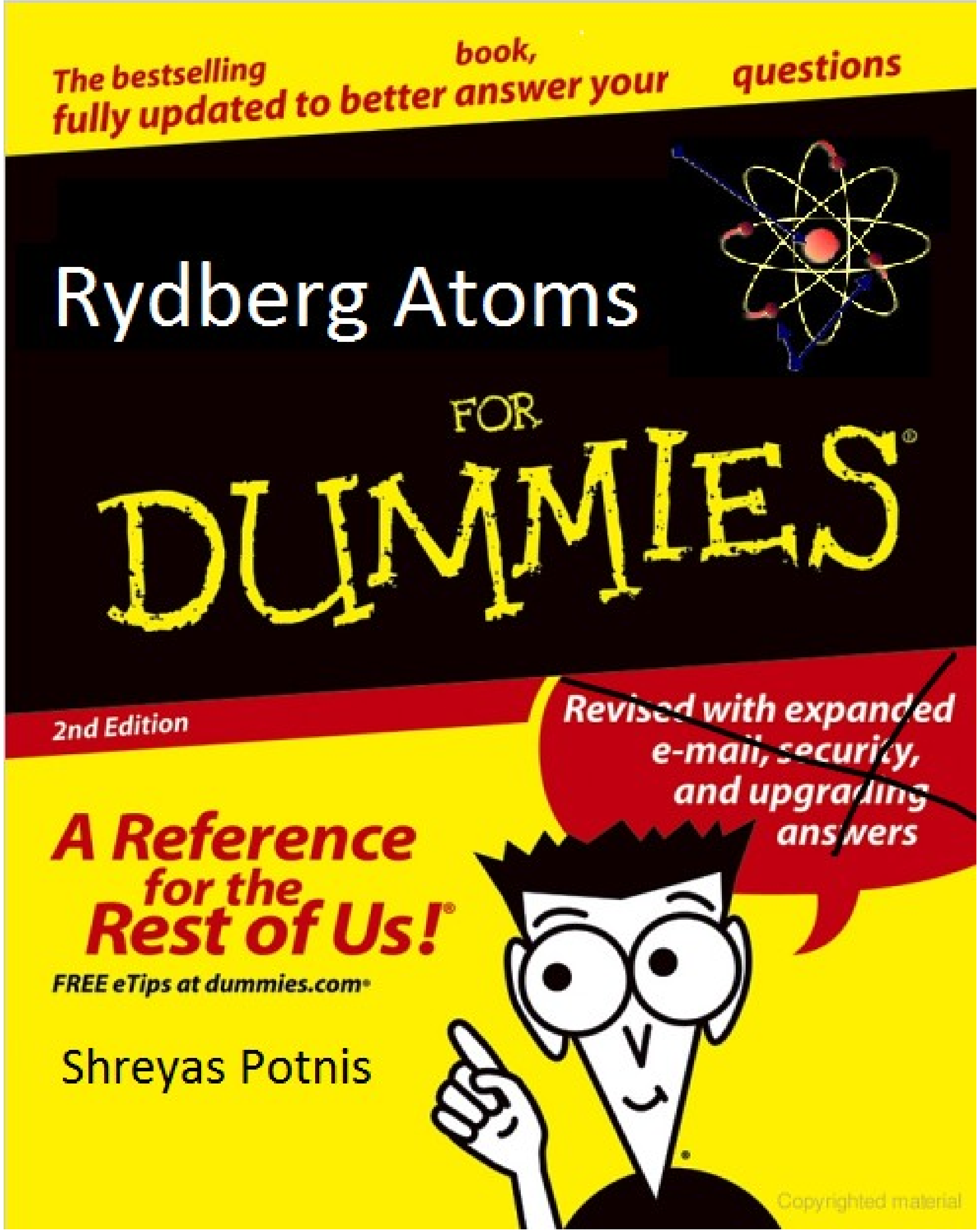
We experimentally realize Rydberg excitations in Bose-Einstein condensates of rubidium atoms loaded into quasi-one-dimensional traps and in optical lattices. Our results for condensates expanded to different sizes in the one-dimensional trap agree well with the intuitive picture of a chain of Rydberg excitations. We also find that the Rydberg excitations in the optical lattice do not destroy the phase coherence of the condensate, and our results in that system agree with the picture of localized collective Rydberg excitations including nearest-neighbor blockade.

DOI: 10.1103/PhysRevLett.107.060402 PACS numbers: 03.65.Xp, 03.75.Lm

- Made Rydberg atoms
- Probed Rydberg atoms
- Understood Rydberg atoms? Somewhat...



Rydberg Atoms FOR DUMMIES®

Shreyas Potnis

Crash course on Rydberg atoms

- Large Size
- Low Binding energies
- Large Dipole moments
- Radiative lifetimes are long!

$$r \propto n^2$$

$$E = \frac{1}{2}mv^2 - \frac{e^2}{r^2} \propto \frac{1}{n^2}$$

$$p \propto n^2$$

$$P = \frac{p_0^2\omega^4}{12\pi\epsilon_0 c^3}$$

Interacting Rydberg atoms

- Permanent dipoles in the presence of an external E

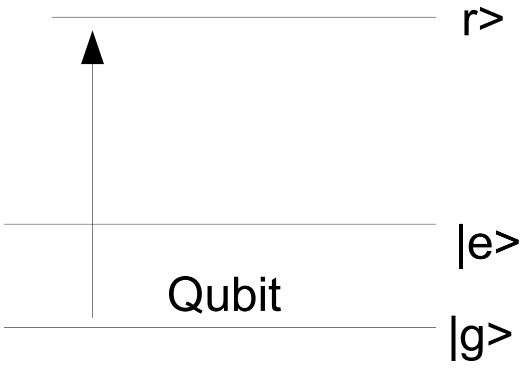
$$V_{\mathrm{dip}}(\mathbf{r}) = \frac{1}{4\pi\epsilon_0}\left[\frac{\mu_1 \cdot \mu_2}{|\mathbf{r}|^3} - 3\frac{(\mu_1 \cdot \mathbf{r})(\mu_2 \cdot \mathbf{r})}{|\mathbf{r}|^5}\right]$$

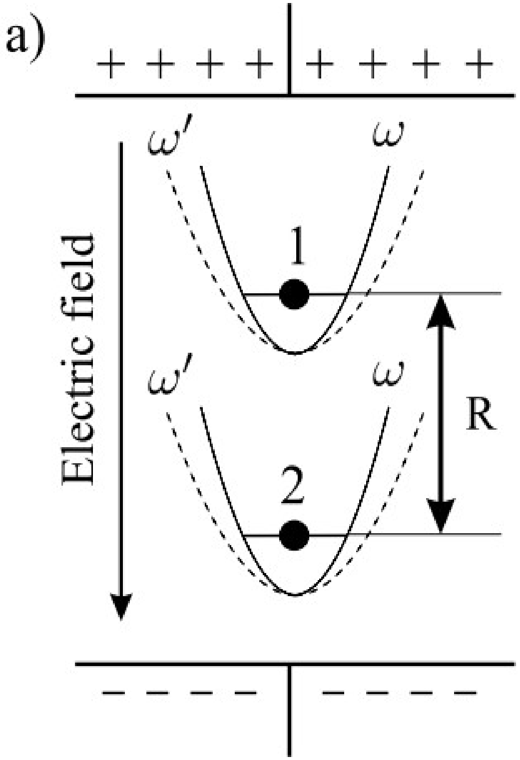
$$U \propto n^4/r^3$$

- Induced dipole-dipole interactions in absence -London forces

$$U \propto n^{11}/r^6$$

Controlled Phase gate



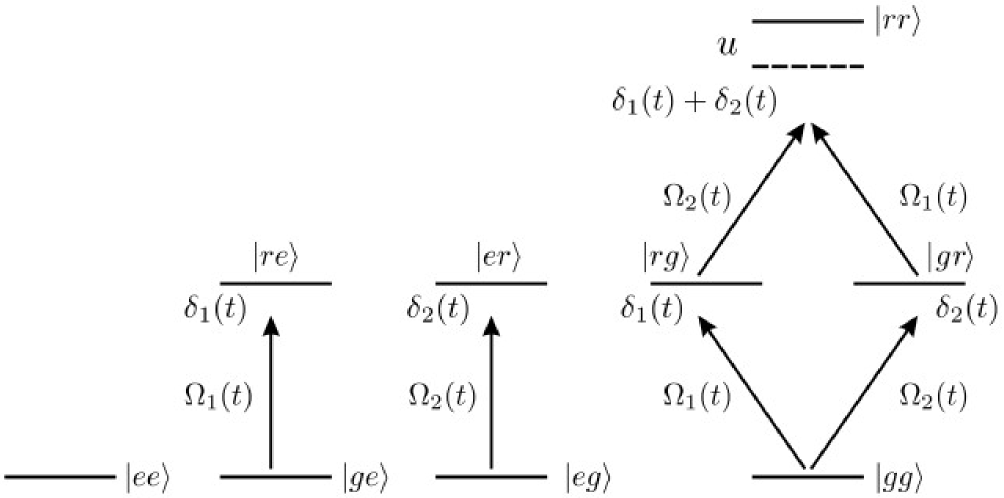


- Apply Pi pulse to both atoms so that they are in the rydberg state
- Wait for some time - Due to dipole interaction they will pick up a phase
- Apply Pi pulse again
- Depends on exactly what the interaction strength is

Phys. Rev. Lett. 85, 2208–2211 (2000)

Controlled Phase gate

- Pi pulse on the first atom
- 2Pi pulse on the second atom
- Pi pulse again on the first atom



Phys. Rev. Lett. 85, 2208–2211 (2000)

Superatoms

- Dipole Blockade
- Excitation shared amongst a collection
- A single excitation blocks out other atoms from being excited within a radius
- Each site can have many atoms
- However, Rabi Oscillation frequency changes? Can Pi pulses be applied without knowing number of atoms?

Collective and Conditional Excitation

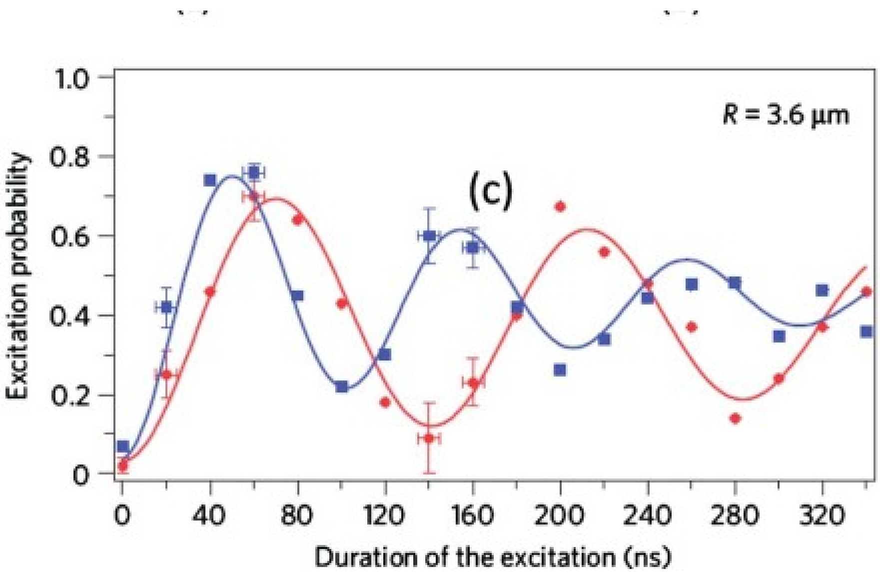


Fig. 8. (Color online) Principle and experimental realization of the Rydberg blockade. (a) Principle of the blockade between two atoms, in the regime of conditional excitation. When both atoms are simultaneously excited in the blockade regime, the symmetrical state $|\Psi_+\rangle$, described in the text, is only coupled to the ground state $|g,g\rangle$ with a strength $\sqrt{2}\Omega$ while the state $|\Psi_-\rangle$ is not coupled by the laser to the states $|g,g\rangle$ and $|r,r\rangle$. (c) Collective excitation of the two atoms separated by 3.6 μm. The circles represent the probability to excite one atom when the second atom is absent. The squares represent the probability to excite only one atom when the two atoms are trapped and are exposed to the same excitation pulse. From [20].

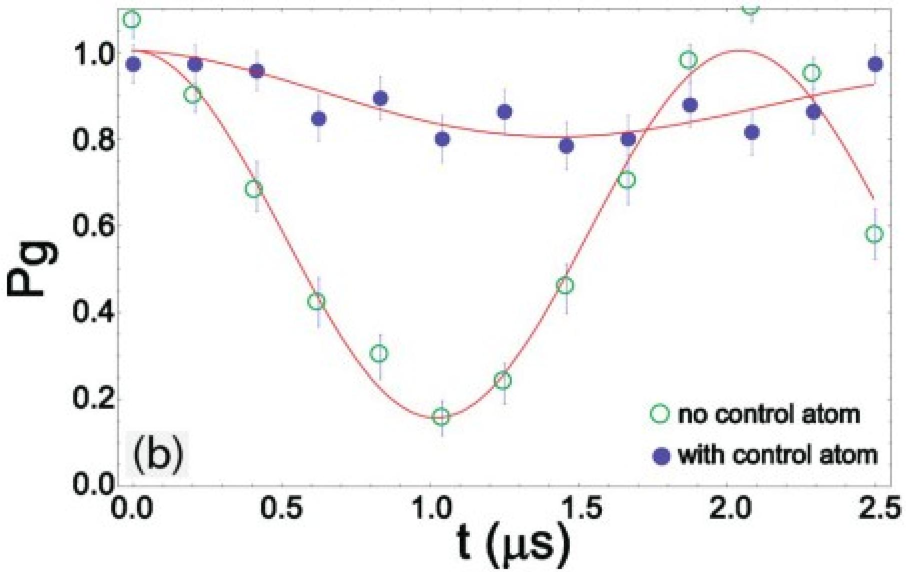


Fig. 7. (Color online) Single atom Rabi oscillation and evidence for blockade of the Rydberg excitation when a second atom is present. Experimental data for Rydberg excitation of the target atom with and without a second (control) atom present. From [55].

Nat. Phys. 5, 115–118 (2009)
Nat. Phys. 5, 110–114 (2009).

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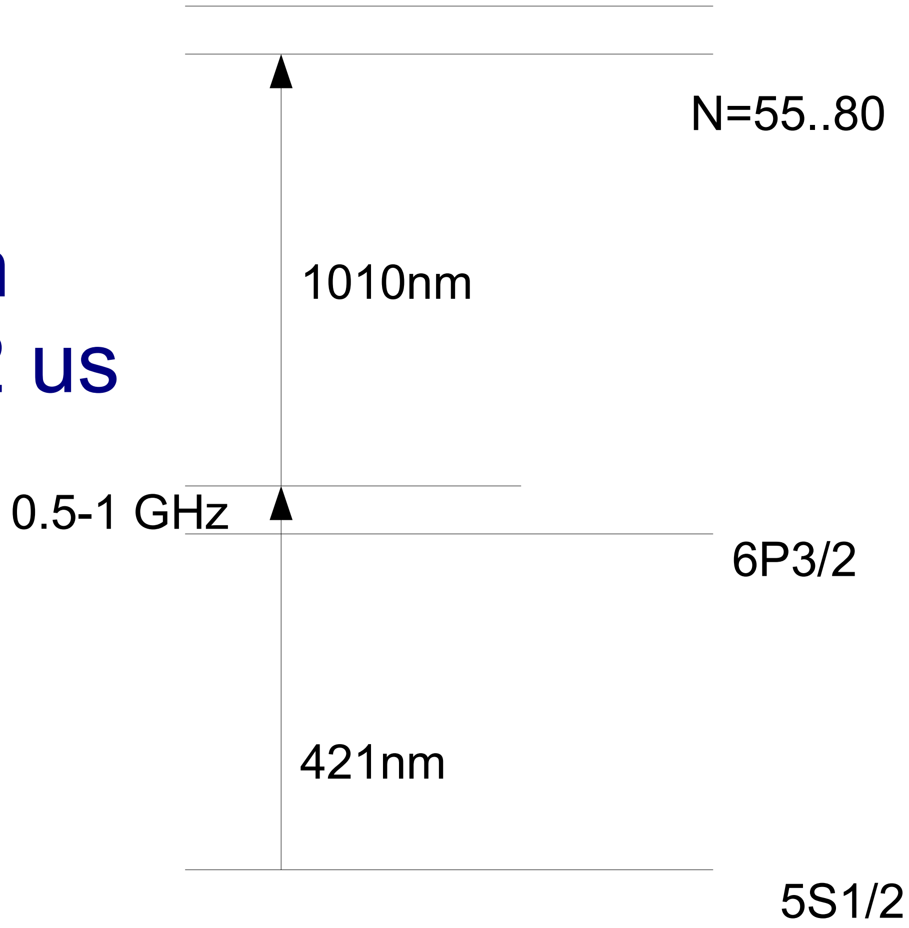
Making Rydberg atoms in a BEC

- Make a BEC – 10^5 87RB atoms, loaded into a 1D optical dipole trap – length ~ 500 um
- Add 1D lattice by intersecting two beams (840nm) at an angle. Lattice spacings up to 13um. For spacing of .42um, depth is 20Er; for 13um depth is 5000Er
- Radial size – 1-2 um

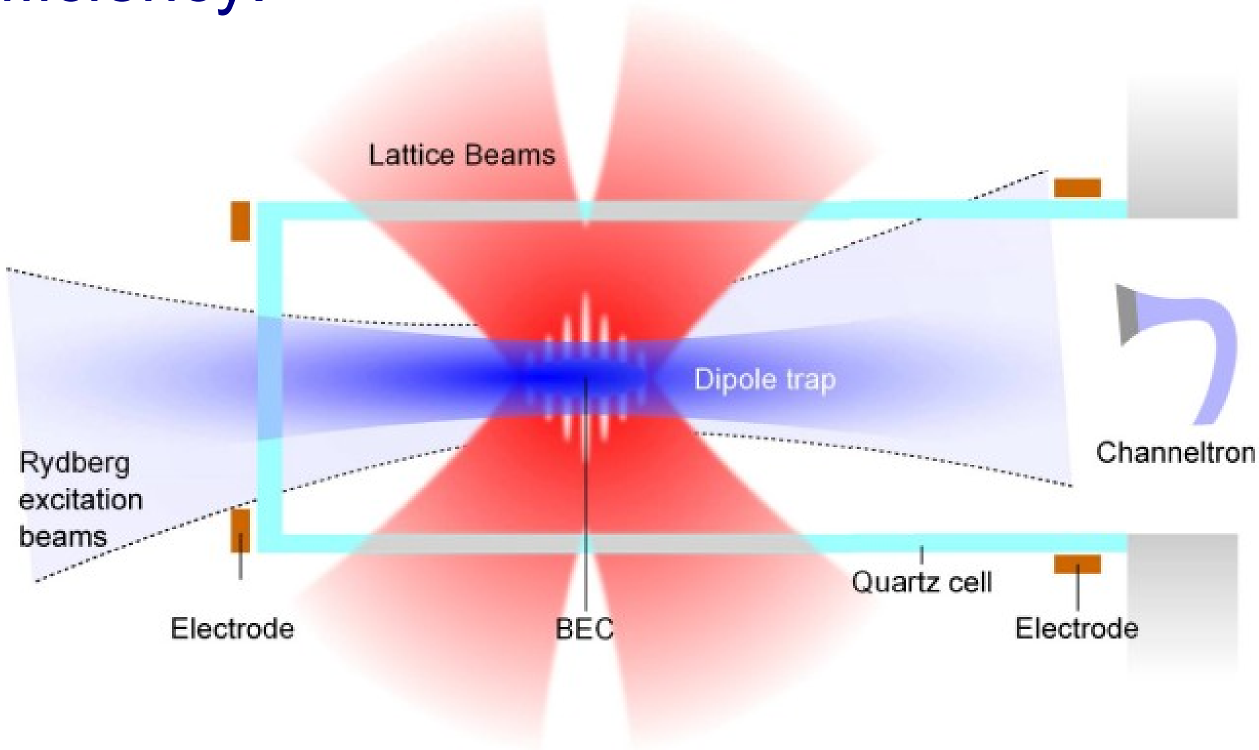
Making Rydberg atoms in a BEC

- Two-colour coherent excitation.
- 420 nm, 1010-1030nm lasers, pulsed for 1-2 us



Detecting Rydberg atoms

- Ionize them!
- Accelerate towards a channeltron
- Electrodes placed outside the quartz cell
- 35% detection efficiency.



1D Chain of Rydberg excitations

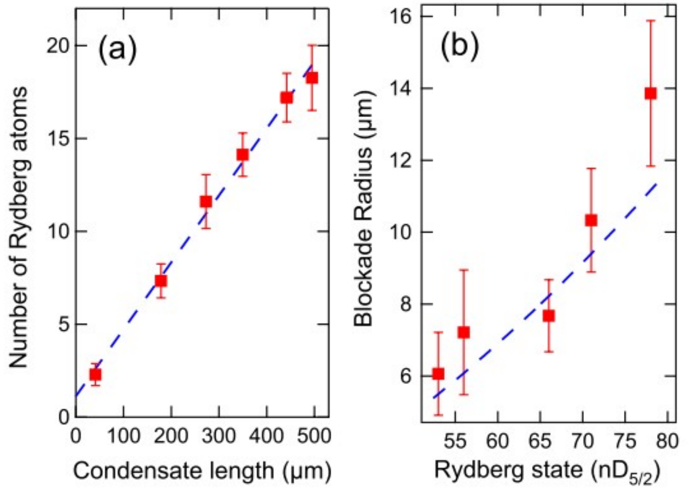


FIG. 2 (color online). Rydberg excitation in an expanded condensate. (a) Number of $66D_{5/2}$-Rydberg excitations (derived from the number of detected ions and the detector efficiency) for an excitation pulse of 1 μs duration as a function of the condensate length. The error bars indicate the standard deviation of the mean. (b) Measured blockade radius r_b as a function of the principal quantum number n. The dashed line is the theoretically predicted value assuming a total laser linewidth of 300 kHz.

- Sub-poissonian counting statistics
- If detection efficiencies are taken into account,

$$\Delta N \sim 0$$

Rydberg excitations in 1D lattice

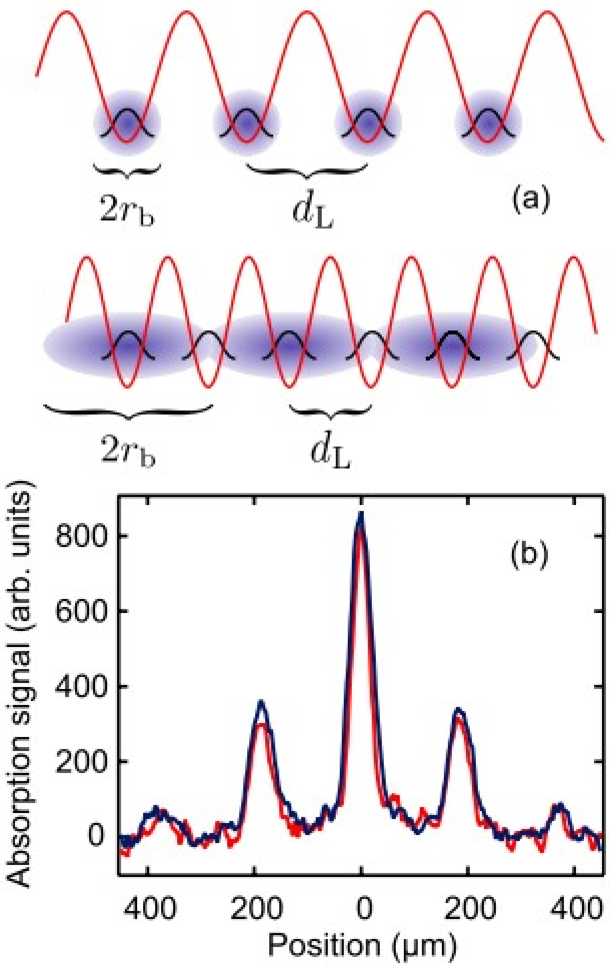


FIG. 3 (color online). Rydberg excitation in an optical lattice. (a) Schematic representation of the experiment. Depending on the lattice spacing d_L and the blockade radius r_b, a collective Rydberg excitation (indicated by the blue spheres) can either be confined to a single lattice site (above) or extend over several lattices sites (below). (b) Time-of-flight profile of a condensate released from an optical lattice with $d_L = 0.42\ \mu\mathrm{m}$, $V_0/E_\mathrm{rec} \sim 10$, and $r_b \approx 6\ \mu\mathrm{m}$ before (blue line) and after ten cycles of Rydberg excitation to the $53D_{5/2}$ state (pulse duration $1\ \mu\mathrm{s}$) and subsequent detection of the Rydberg atoms by field ionization (red line). The virtually identical interference profiles show that the overall phase coherence of the condensate is not affected by the collective Rydberg excitations.

Dipole Blockade in lattices

- Lattice spacing ~ blockade radius.
- 100 filled lattice sites
- 50-100 atoms per site

$$\alpha = r_b/d_L$$

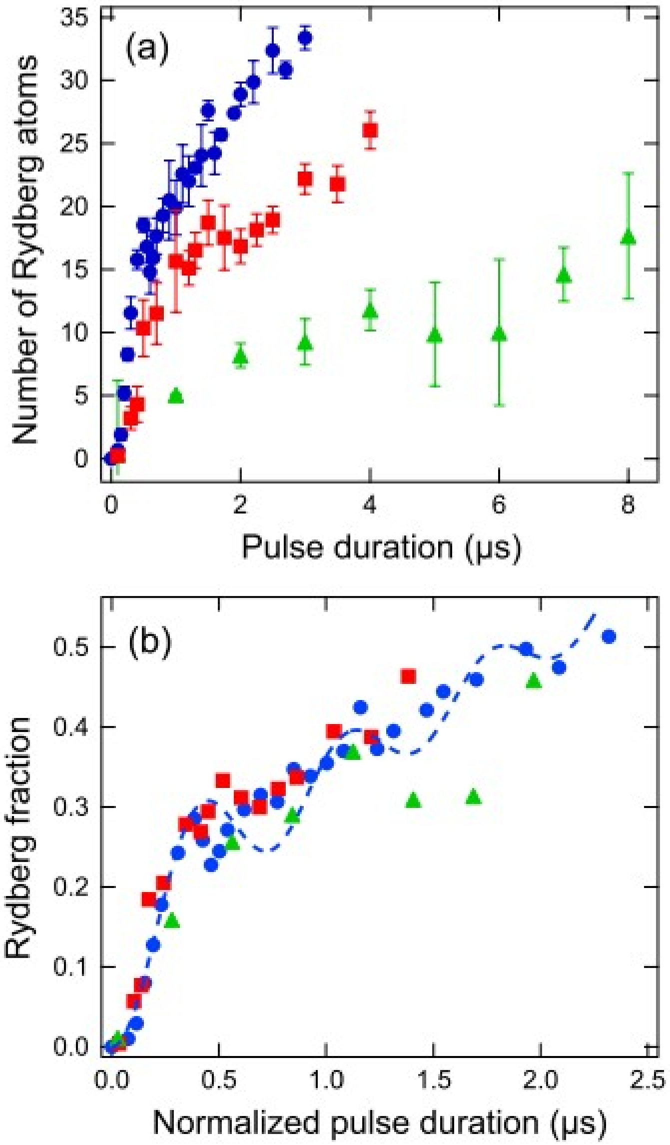


FIG. 4 (color online). Dynamics of Rydberg excitations in an optical lattice. (a) Number of $53D_{5/2}$ Rydberg excitations as a function of the pulse duration τ_p for different average atom numbers per lattice site: $\langle N_i \rangle = 500$ (filled circles), $\langle N_i \rangle = 200$ (open squares), and $\langle N_i \rangle = 50$ (filled triangles). (b) Here the experimental results of (a) are plotted against the renormalized pulse duration $\tau\sqrt{\langle N_{\max}\rangle/\langle N_i\rangle}$, with $\langle N_{\max}\rangle$ the largest atom number. The vertical axis is scaled in terms of the fraction of lattice sites containing a collective excitation. For clarity, in (b) error bars have been omitted. The dashed line is the numerical simulation for $\alpha = 2$ (see the text).

Summary

- Created and detected Rydberg atoms in BECs in 1D lattices
- Phase coherence of the BEC maintained over many excitation-detection cycles.
- Dipole blockade demonstrated