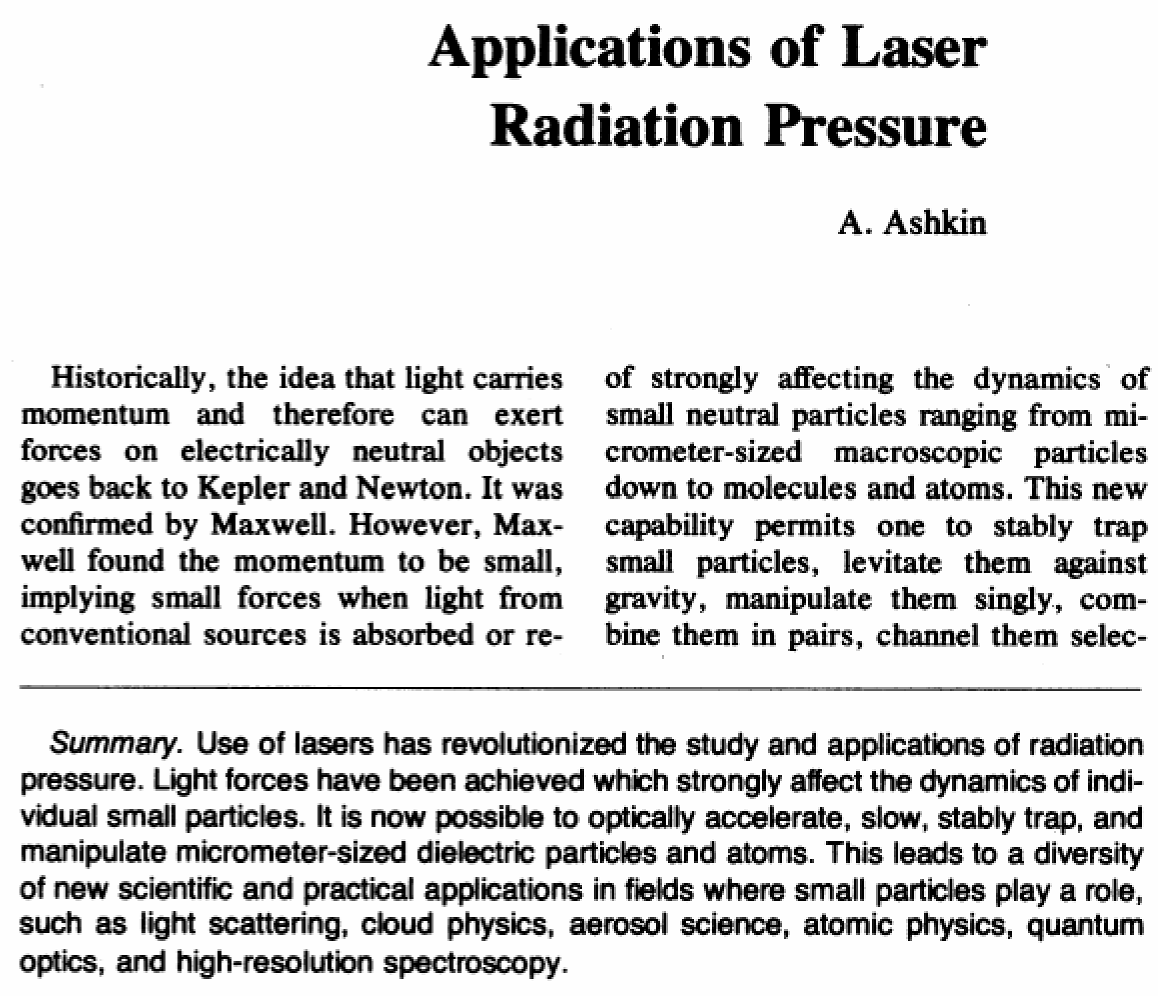
AC Stark shift and optical trapping

Optical trapping

The first “laser-trapping” was not performed on atoms, but rather dielectric objects



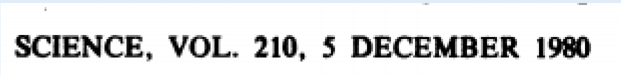
Applications of Laser Radiation Pressure

A. Ashkin

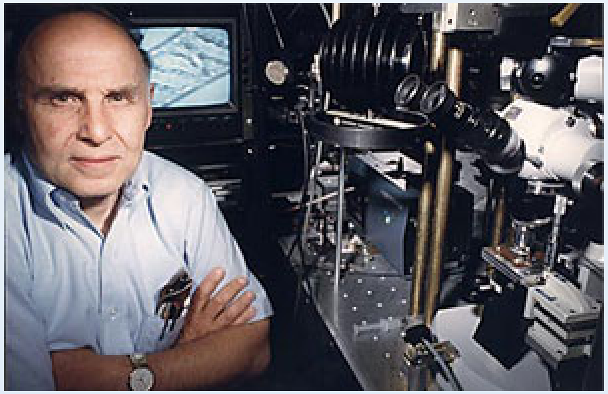
Historically, the idea that light carries momentum and therefore can exert forces on electrically neutral objects goes back to Kepler and Newton. It was confirmed by Maxwell. However, Maxwell found the momentum to be small, implying small forces when light from conventional sources is absorbed or re- of strongly affecting the dynamics of small neutral particles ranging from micrometer-sized macroscopic particles down to molecules and atoms. This new capability permits one to stably trap small particles, levitate them against gravity, manipulate them singly, combine them in pairs, channel them selec-

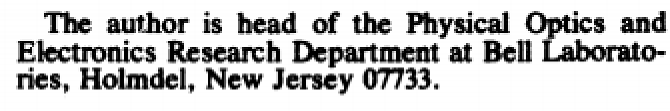
---

Summary. Use of lasers has revolutionized the study and applications of radiation pressure. Light forces have been achieved which strongly affect the dynamics of individual small particles. It is now possible to optically accelerate, slow, stably trap, and manipulate micrometer-sized dielectric particles and atoms. This leads to a diversity of new scientific and practical applications in fields where small particles play a role, such as light scattering, cloud physics, aerosol science, atomic physics, quantum optics, and high-resolution spectroscopy.



SCIENCE, VOL. 210, 5 DECEMBER 1980





The author is head of the Physical Optics and Electronics Research Department at Bell Laboratories, Holmdel, New Jersey 07733.

Optical trapping

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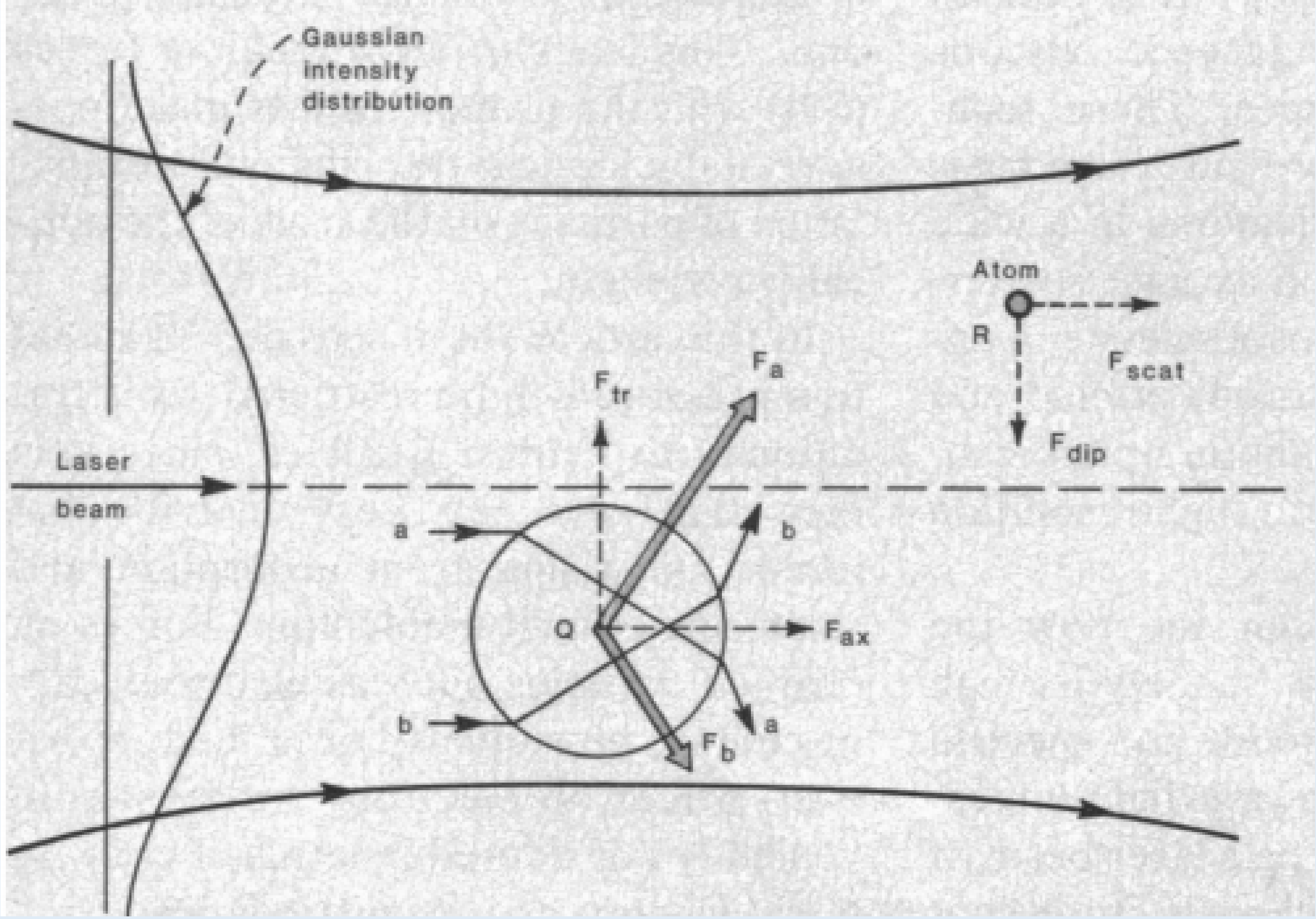

SCIENCE, VOL. 210, 5 DECEMBER 1980

Optical trapping

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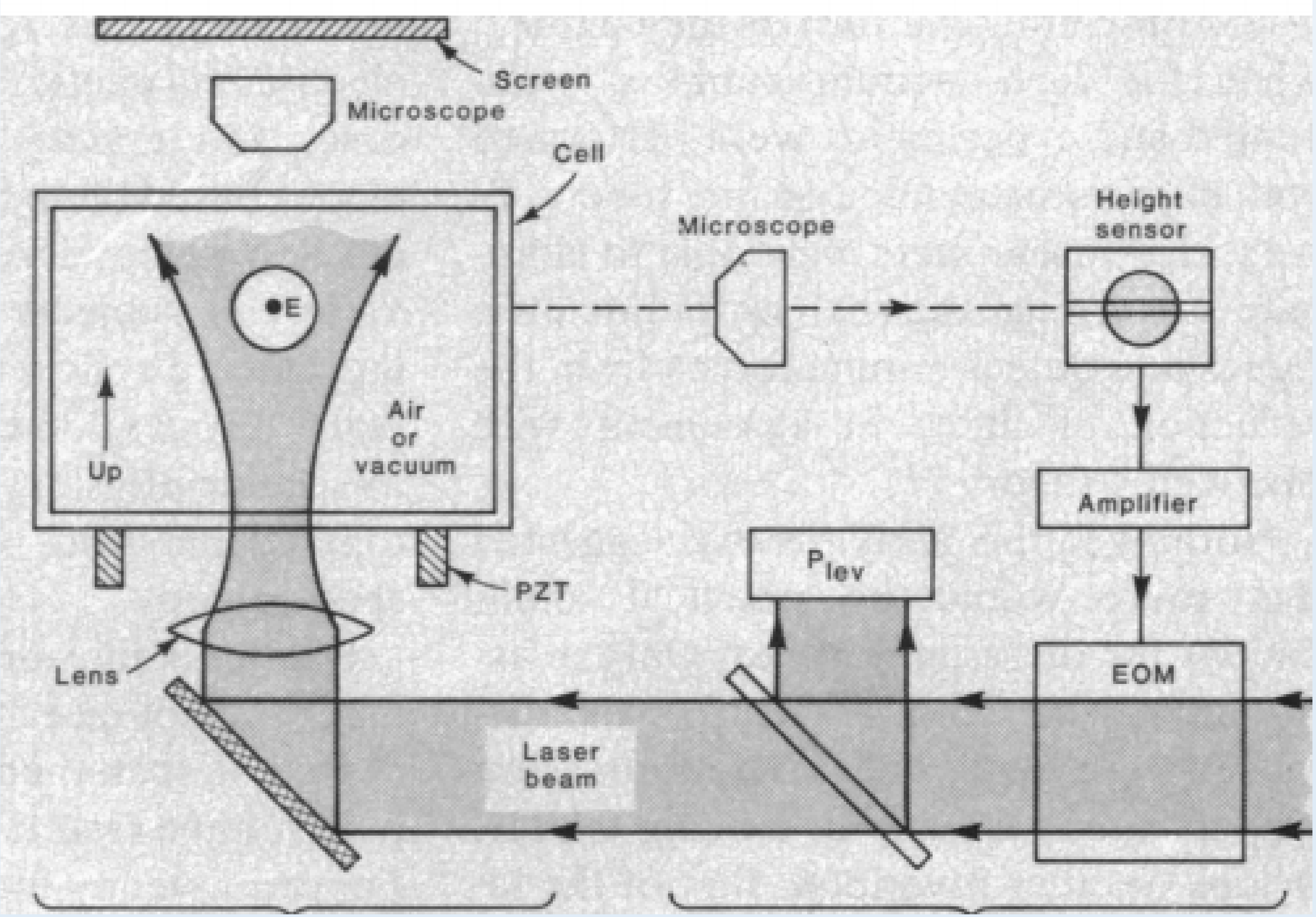
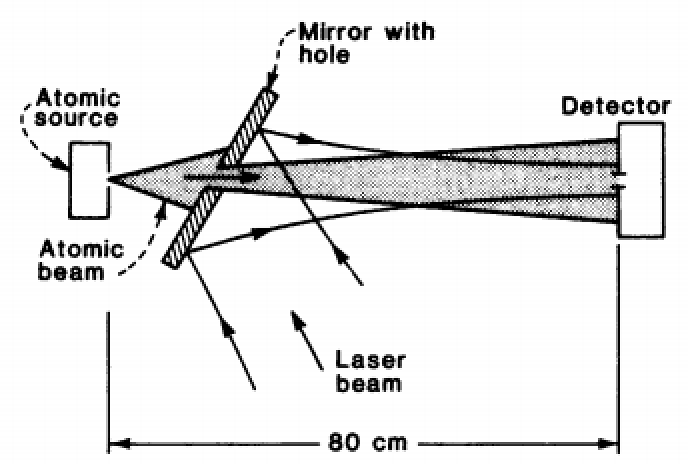


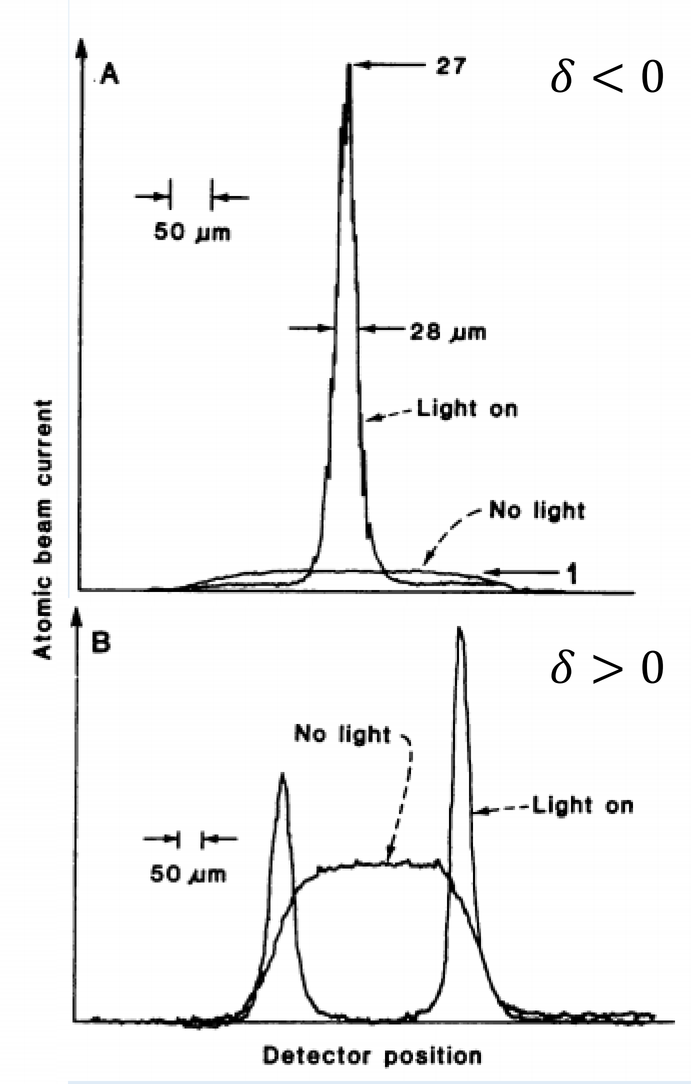
SCIENCE, VOL. 210, 5 DECEMBER 1980

Optical trapping

Also demonstrated a laser “lens” for neutral atoms

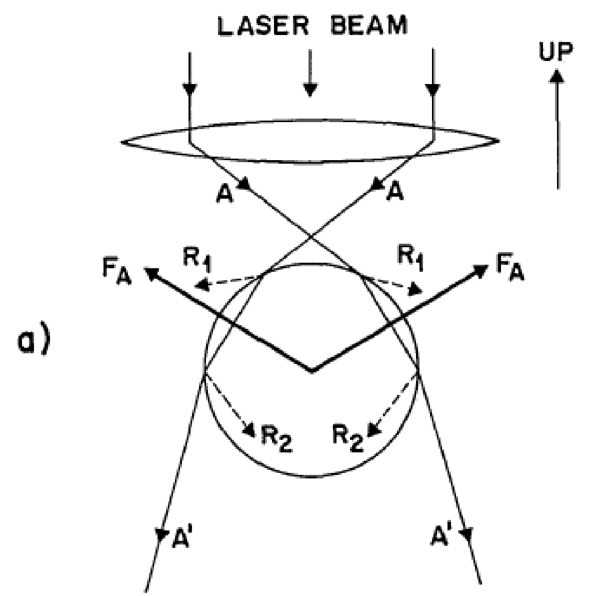


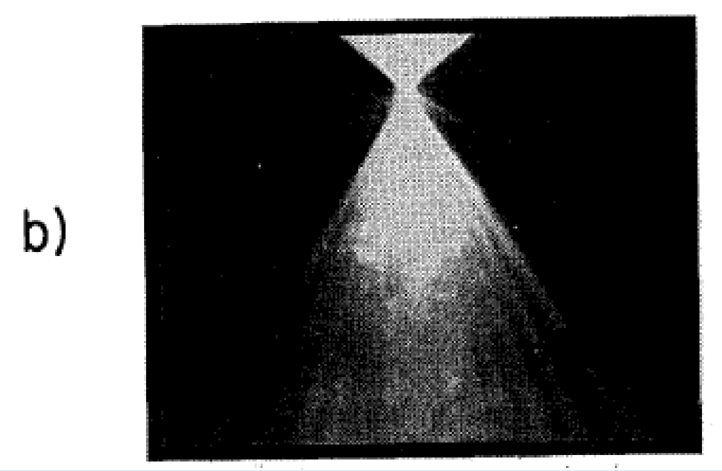
SCIENCE, VOL. 210, 5 DECEMBER 1980

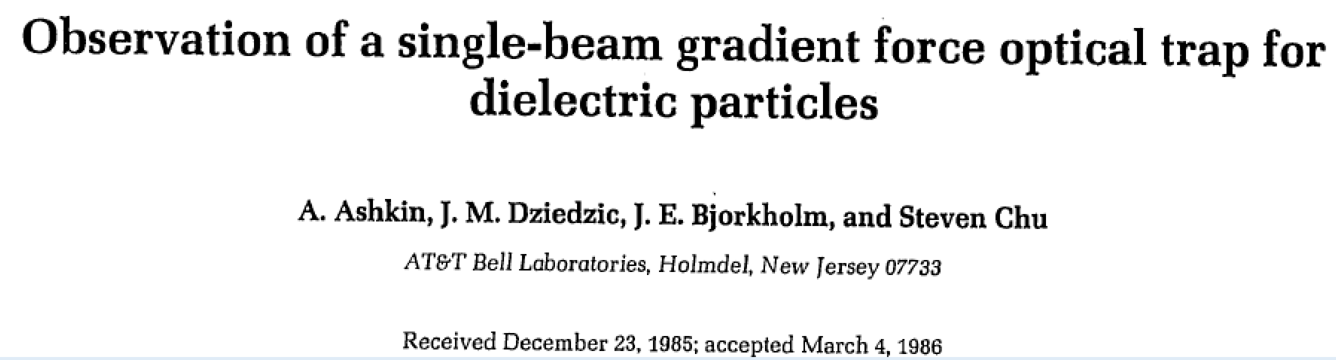


Optical trapping

More-tightly focused, trapped against gravity by gradient force (not scattering)





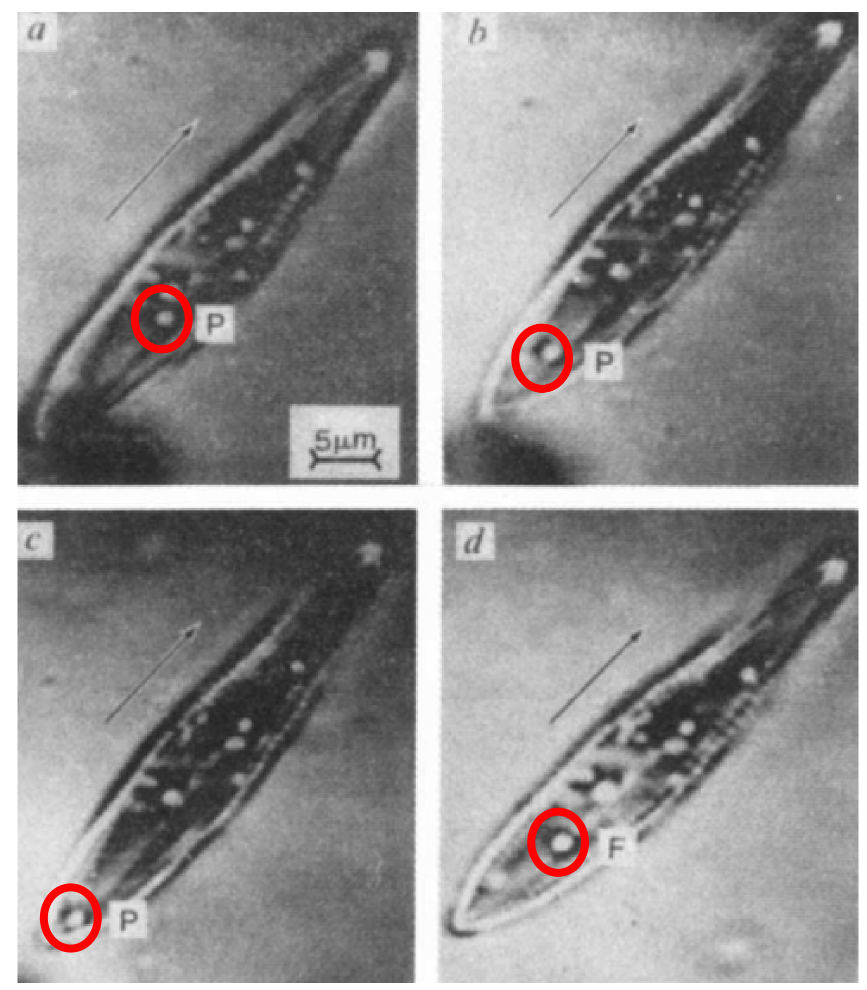


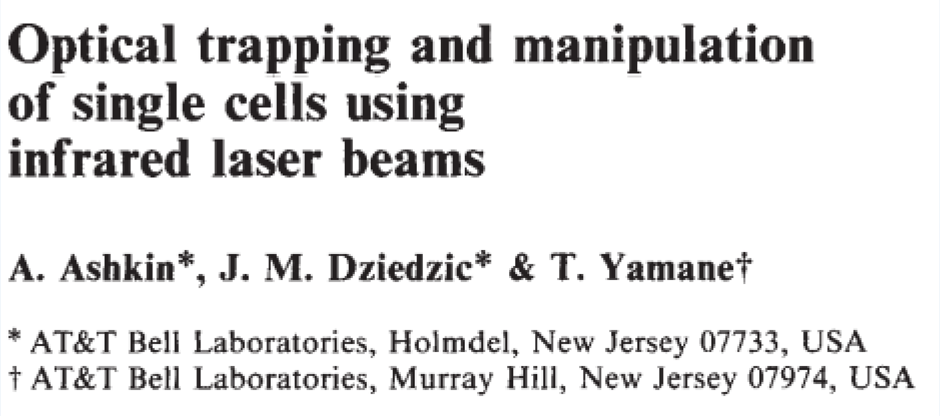
Observation of a single-beam gradient force optical trap for dielectric particles

A. Ashkin, J. M. Dziedzic, J. E. Bjorkholm, and Steven Chu
AT&T Bell Laboratories, Holmdel, New Jersey 07733

Received December 23, 1985; accepted March 4, 1986

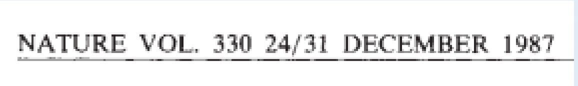
Aside – applications to biology/biophysics



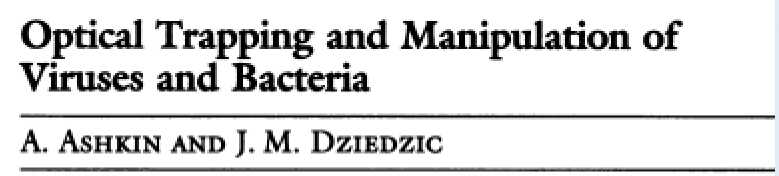

Optical trapping and manipulation of single cells using infrared laser beams

A. Ashkin*, J. M. Dziedzic* & T. Yamane†

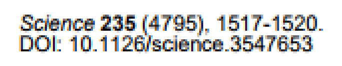
* AT&T Bell Laboratories, Holmdel, New Jersey 07733, USA
† AT&T Bell Laboratories, Murray Hill, New Jersey 07974, USA


NATURE VOL. 330 24/31 DECEMBER 1987

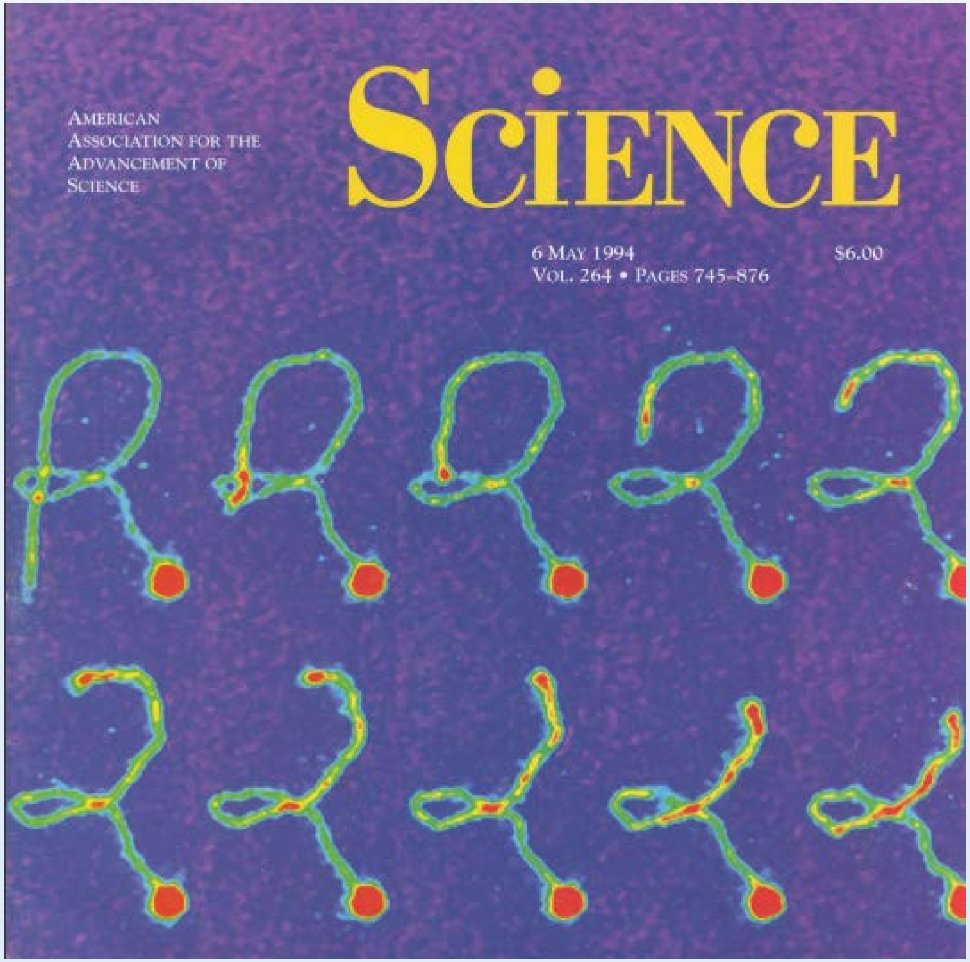
Also that year:


Optical Trapping and Manipulation of Viruses and Bacteria

A. Ashkin and J. M. Dziedzic


Science **235** (4795), 1517-1520.
DOI: 10.1126/science.3547653

Aside – applications to biology/biophysics



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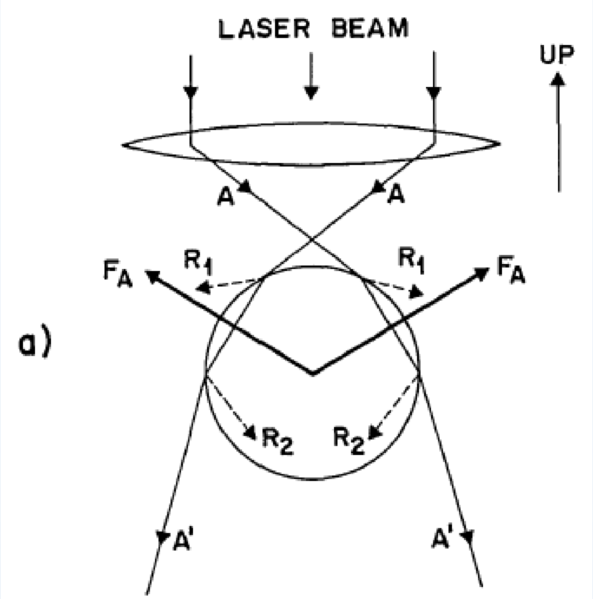
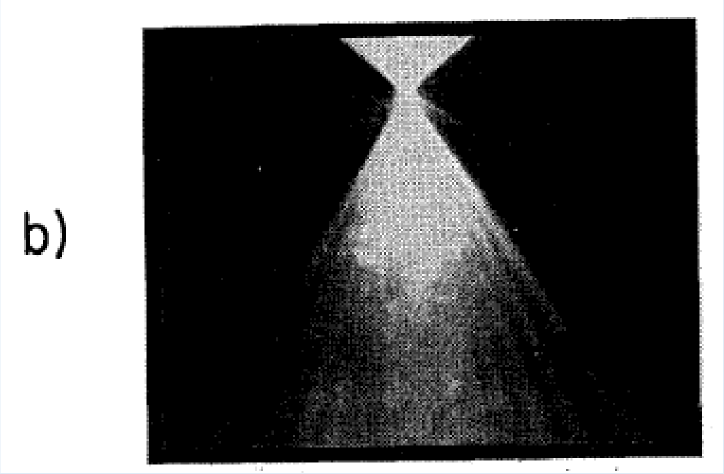
Chu group, 1994

Optical trapping

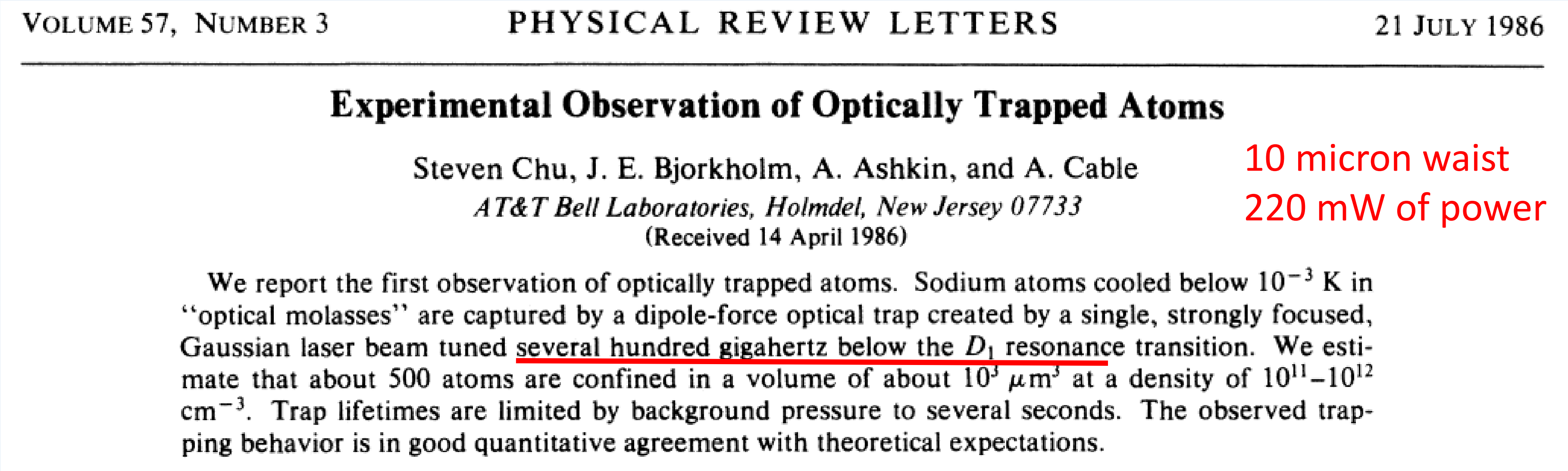
More-tightly focused, trapped against gravity by gradient force (not scattering)





This force depends on the index of refraction --- related to polarizability / dipoles

Back to 1986 – optical trapping of atoms



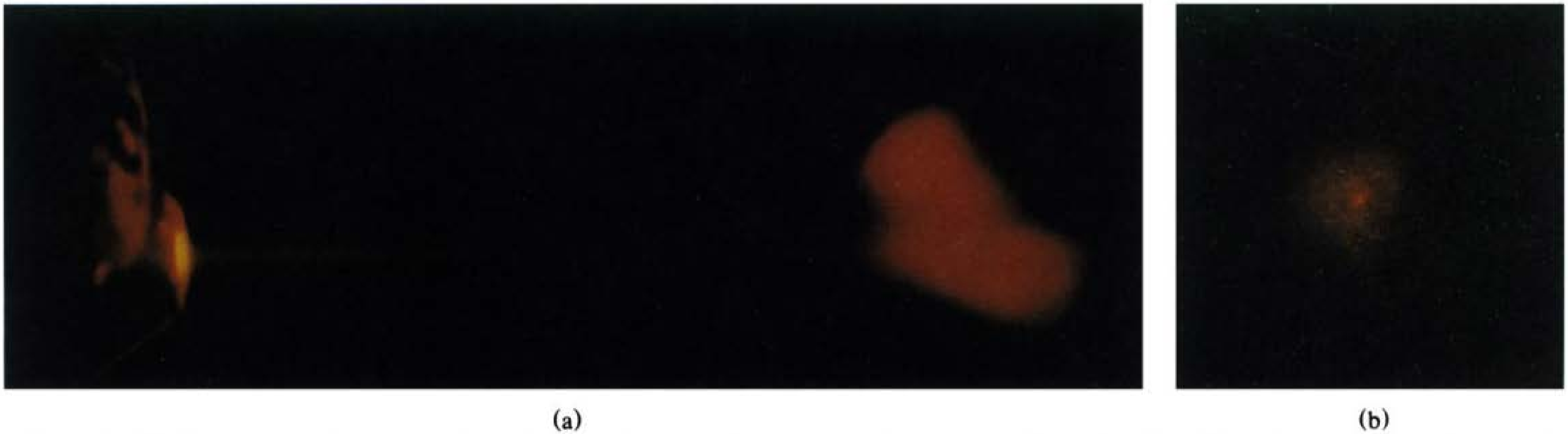
VOLUME 57, NUMBER 3 PHYSICAL REVIEW LETTERS 21 JULY 1986

Experimental Observation of Optically Trapped Atoms

Steven Chu, J. E. Bjorkholm, A. Ashkin, and A. Cable
AT&T Bell Laboratories, Holmdel, New Jersey 07733
(Received 14 April 1986)

10 micron waist
220 mW of power

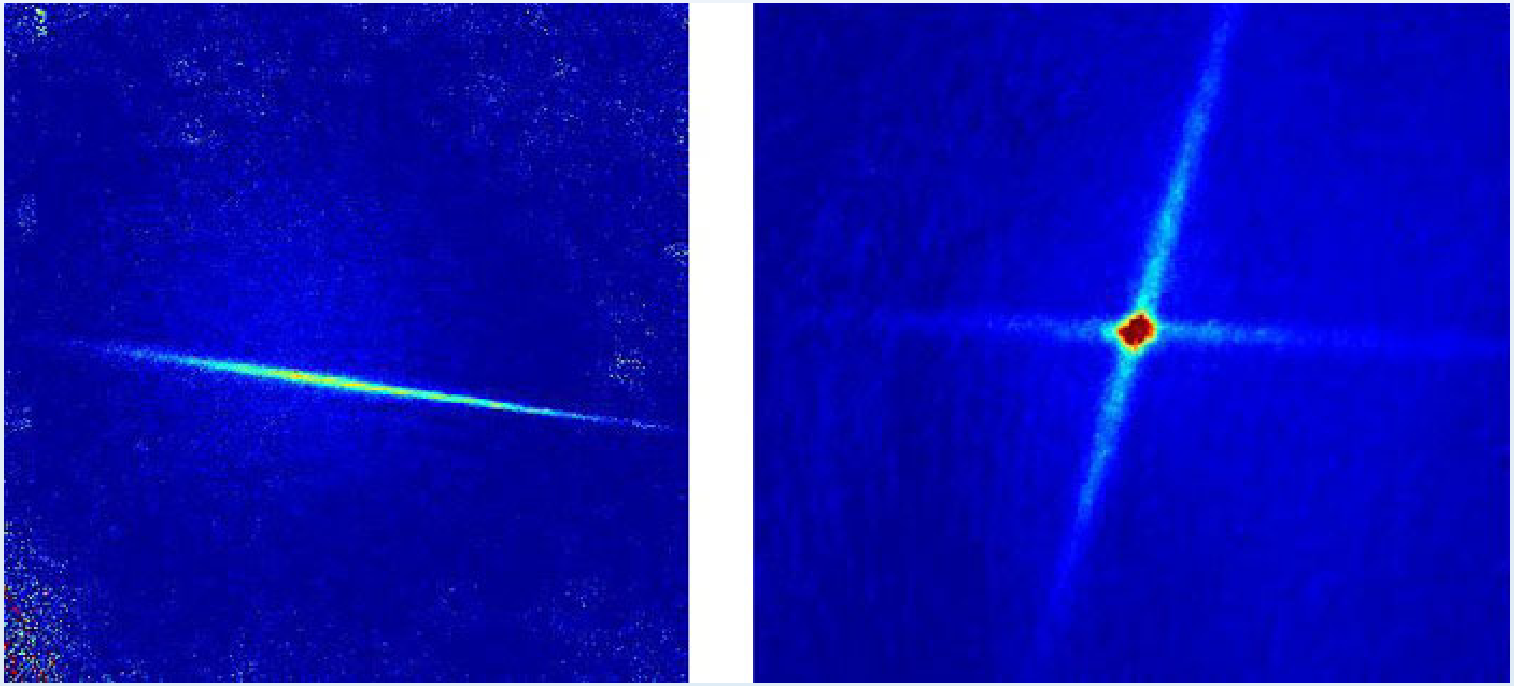
We report the first observation of optically trapped atoms. Sodium atoms cooled below 10^{-3} K in "optical molasses" are captured by a dipole-force optical trap created by a single, strongly focused, Gaussian laser beam tuned several hundred gigahertz below the D_1 resonance transition. We estimate that about 500 atoms are confined in a volume of about $10^3\ \mu\mathrm{m}^3$ at a density of 10^{11}–10^{12} cm^{-3}. Trap lifetimes are limited by background pressure to several seconds. The observed trapping behavior is in good quantitative agreement with theoretical expectations.



(a) (b)

FIG. 2. (a) Photo showing the collimating nozzle, atomic beam, and atoms confined in OM. The distance from the nozzle to the OM region is 5 cm. (b) Photo taken after the atomic source and the slowing laser beam have been turned off, showing trapped atoms.

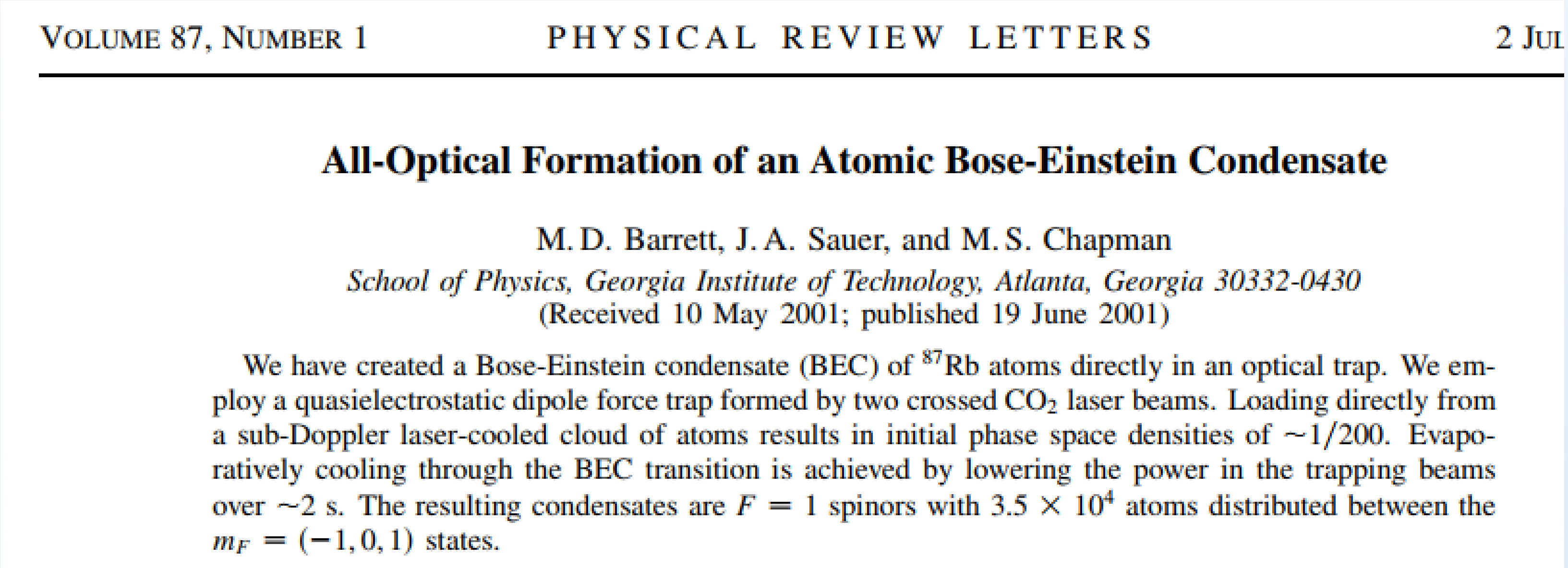
Crossed-beam dipole traps



Number of considerations w.r.t.

- Volume
- Depth
- Stability
- Trapping Frequencies

Really far-detuned traps



VOLUME 87, NUMBER 1 PHYSICAL REVIEW LETTERS 2 JUL

All-Optical Formation of an Atomic Bose-Einstein Condensate

M. D. Barrett, J. A. Sauer, and M. S. Chapman
School of Physics, Georgia Institute of Technology, Atlanta, Georgia 30332-0430

(Received 10 May 2001; published 19 June 2001)

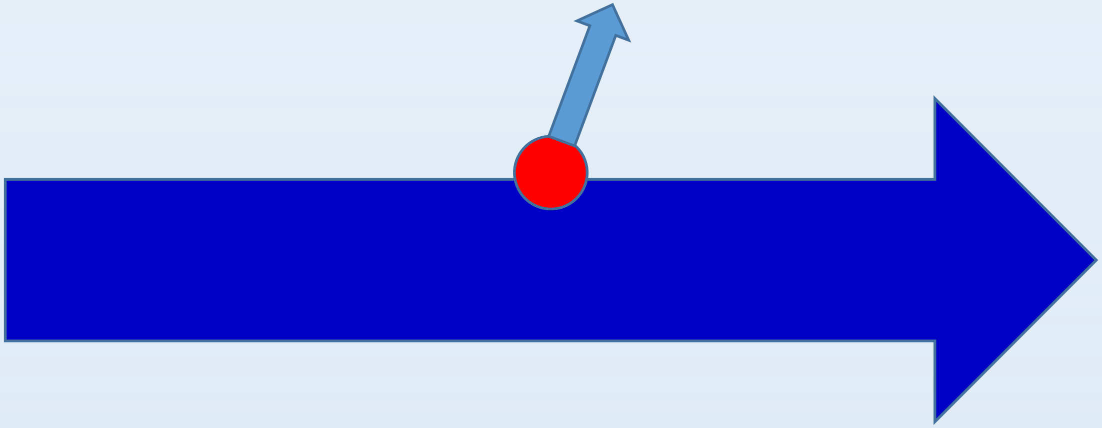
We have created a Bose-Einstein condensate (BEC) of ^{87}Rb atoms directly in an optical trap. We employ a quasielectrostatic dipole force trap formed by two crossed CO_2 laser beams. Loading directly from a sub-Doppler laser-cooled cloud of atoms results in initial phase space densities of $\sim 1/200$. Evaporatively cooling through the BEC transition is achieved by lowering the power in the trapping beams over ~ 2 s. The resulting condensates are $F = 1$ spinors with 3.5×10^4 atoms distributed between the $m_F = (-1, 0, 1)$ states.

“QUEST” -- QUasiElectroStatic Trap

Interesting trap – very low scattering and counter-rotating term roughly as important as co-rotating term

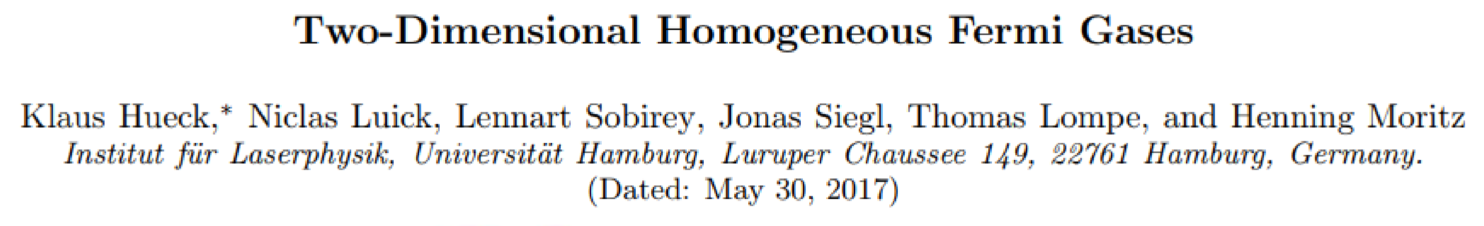
$$\omega \ll \omega_{eg} \quad \rightarrow \quad |\omega - \omega_{eg}| \approx |\omega + \omega_{eg}| \approx \omega$$

Blue-detuned dipole traps



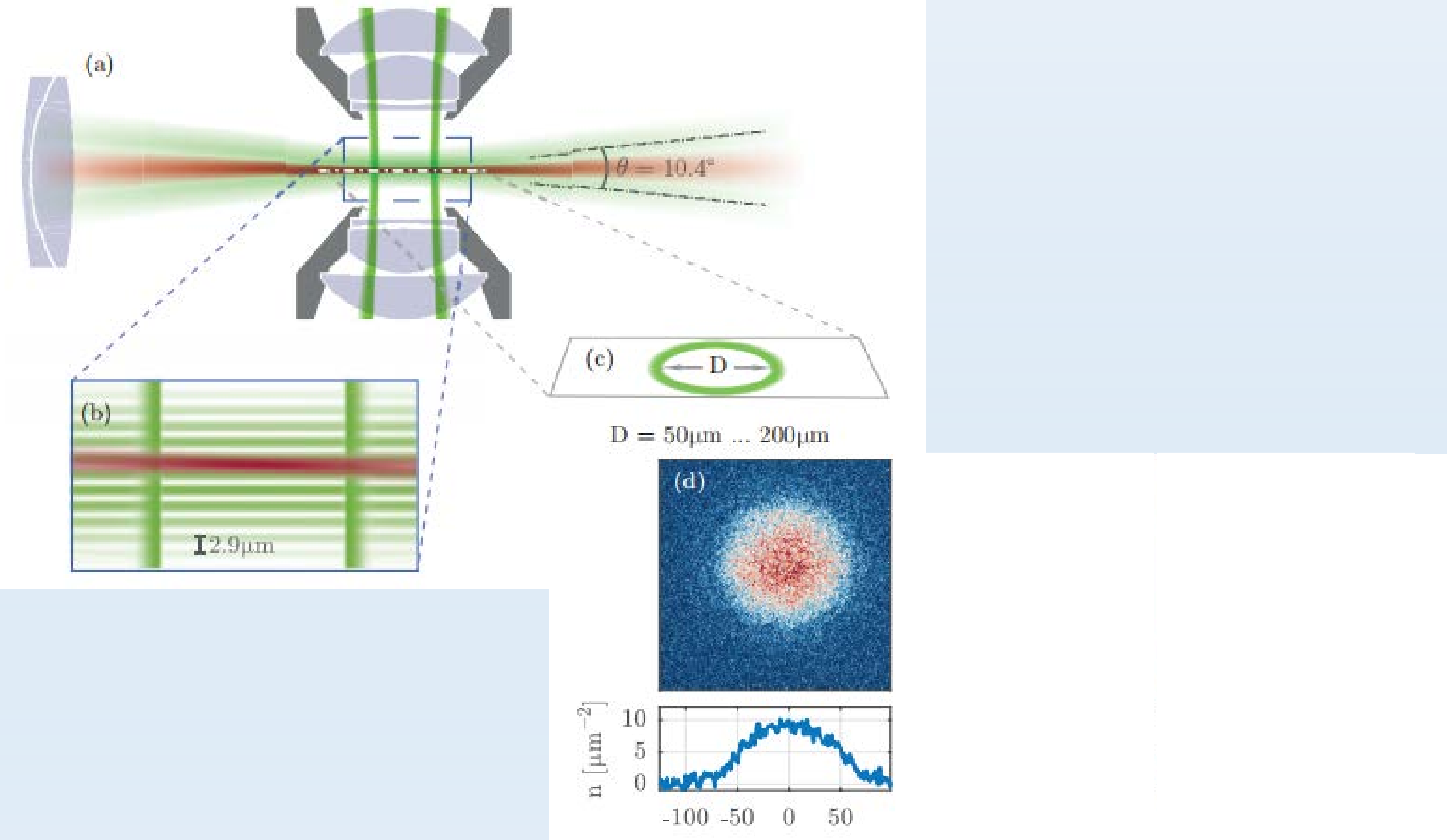
Atoms are repelled from points of high intensity --- stable trapping with repulsive potentials requires some care and has some subtleties

Blue-detuned dipole traps



Two-Dimensional Homogeneous Fermi Gases

Klaus Hueck,* Niclas Luick, Lennart Sobirey, Jonas Siegl, Thomas Lompe, and Henning Moritz
Institut für Laserphysik, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany.
(Dated: May 30, 2017)



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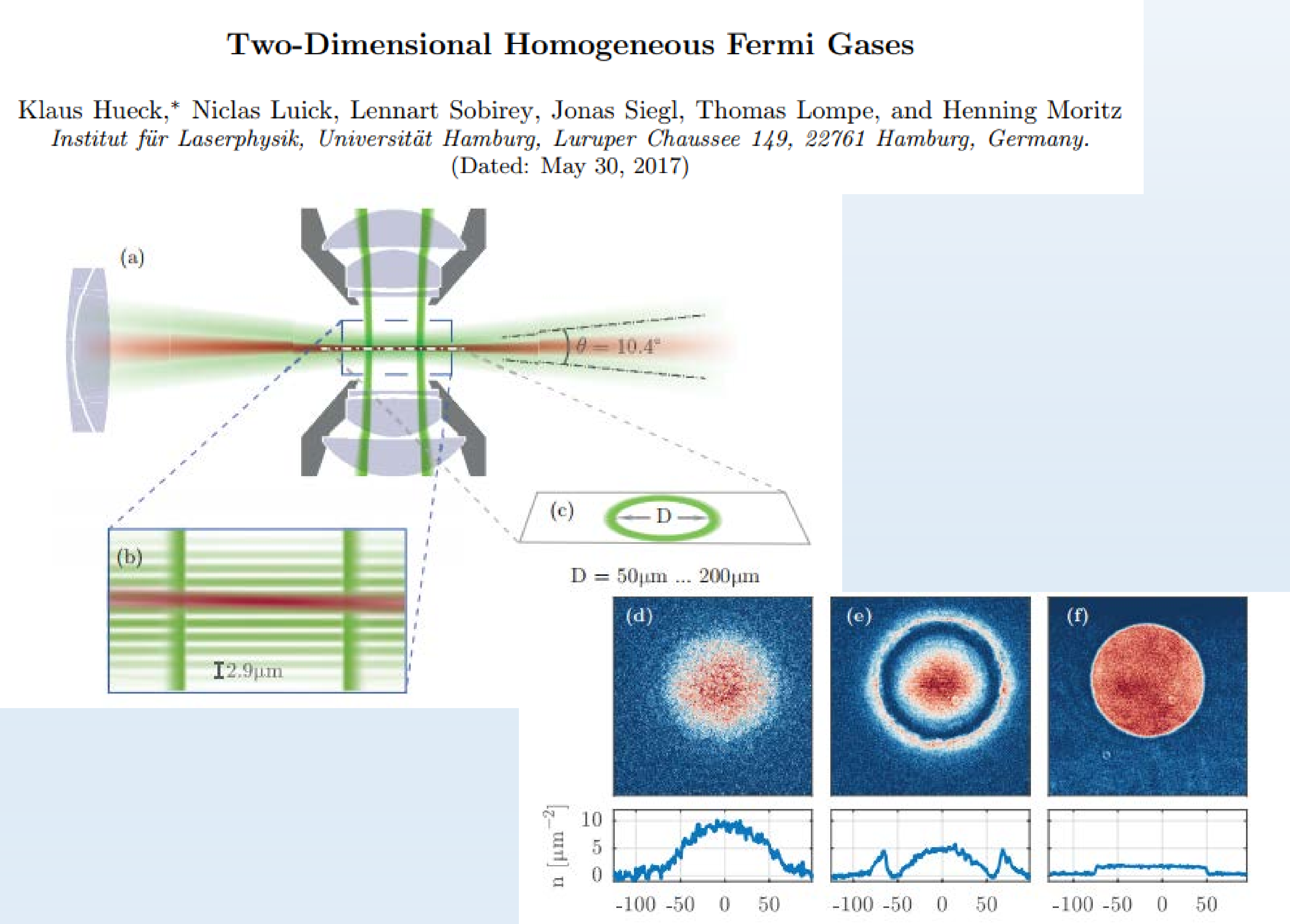

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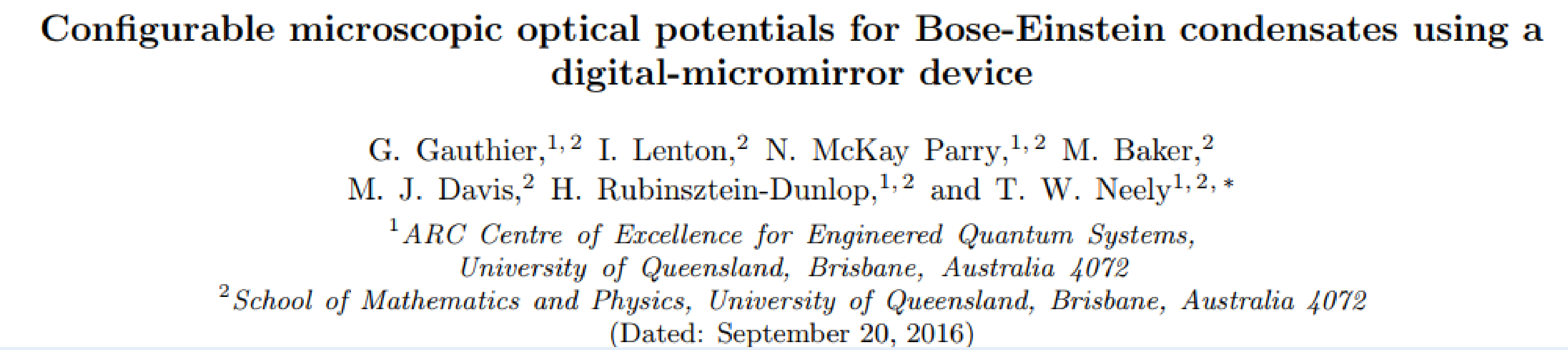
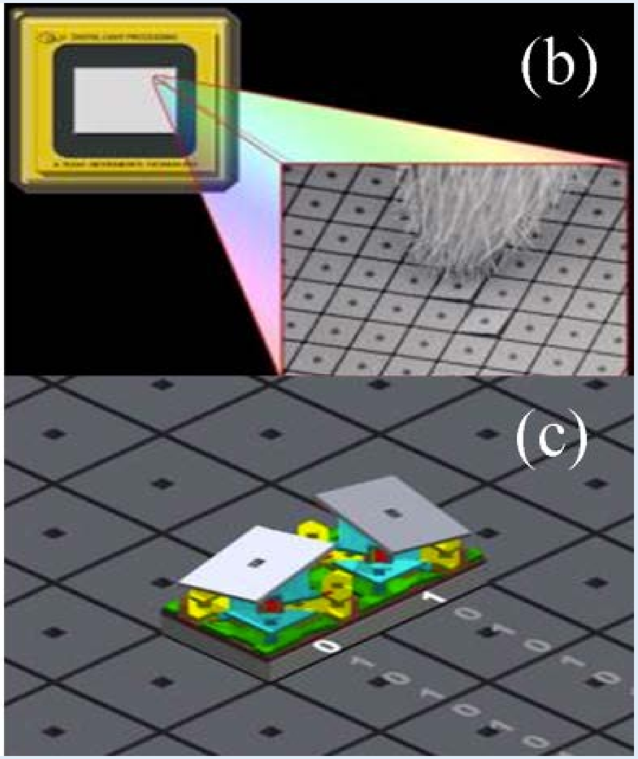


Configurable microscopic optical potentials for Bose-Einstein condensates using a digital-micromirror device

G. Gauthier,[1,2] I. Lenton,[2] N. McKay Parry,[1,2] M. Baker,[2]
M. J. Davis,[2] H. Rubinsztein-Dunlop,[1,2] and T. W. Neely[1,2,*]
[1] *ARC Centre of Excellence for Engineered Quantum Systems, University of Queensland, Brisbane, Australia 4072*
[2] *School of Mathematics and Physics, University of Queensland, Brisbane, Australia 4072*
(Dated: September 20, 2016)



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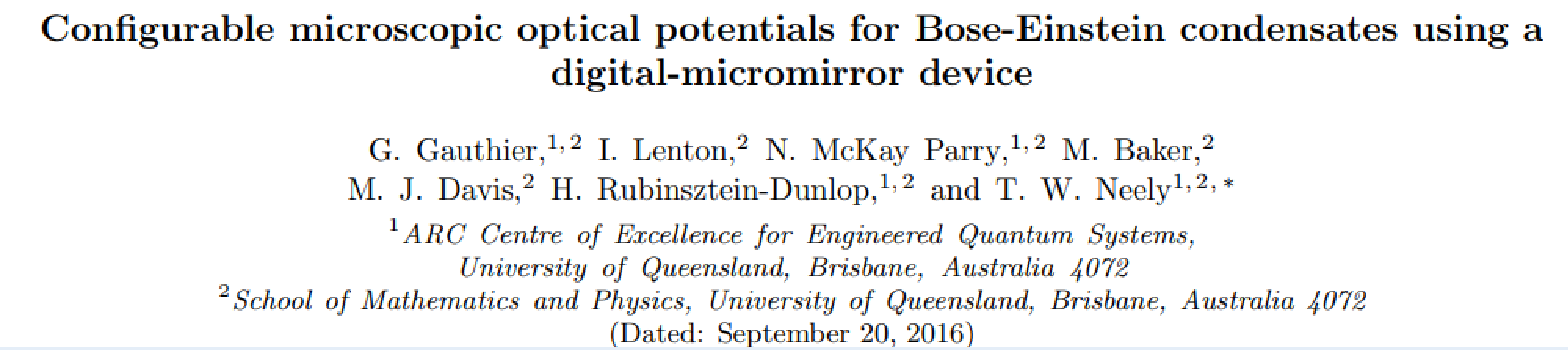

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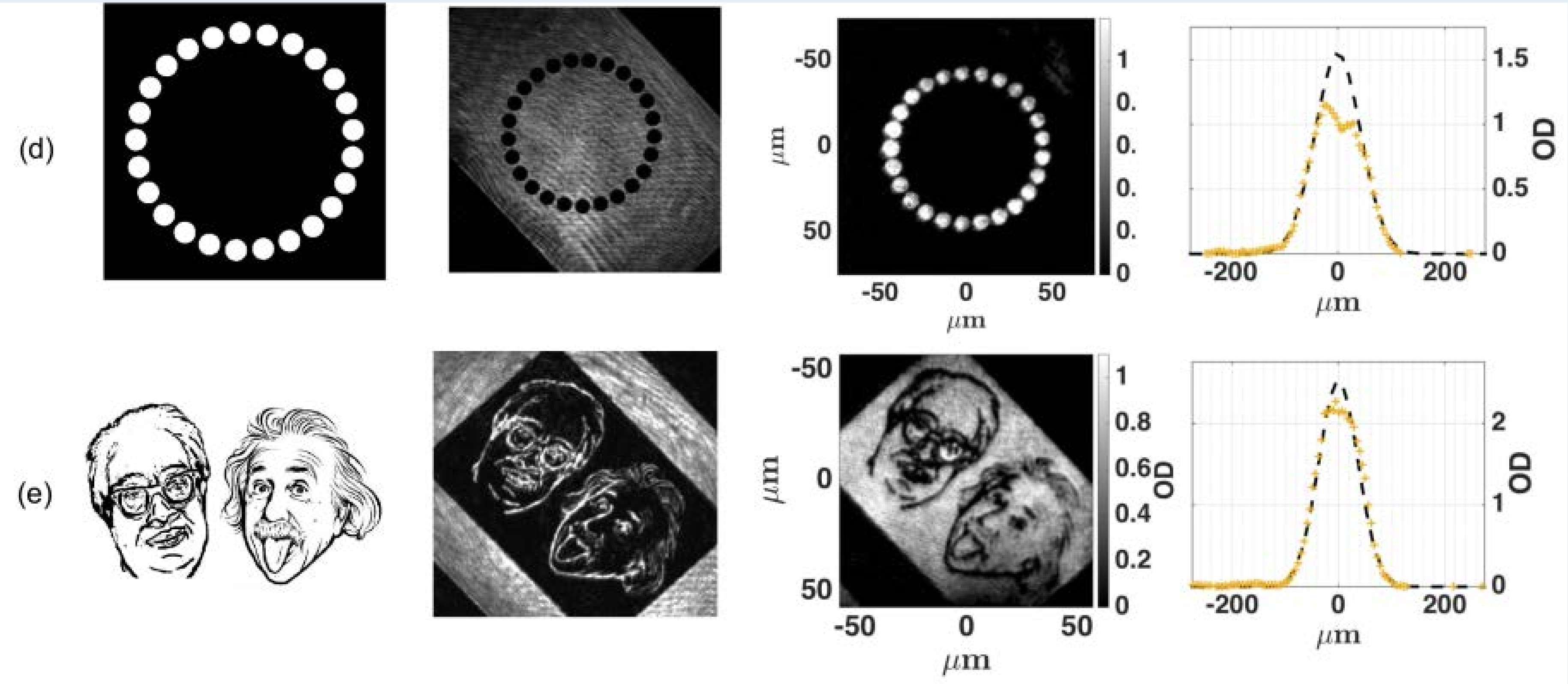
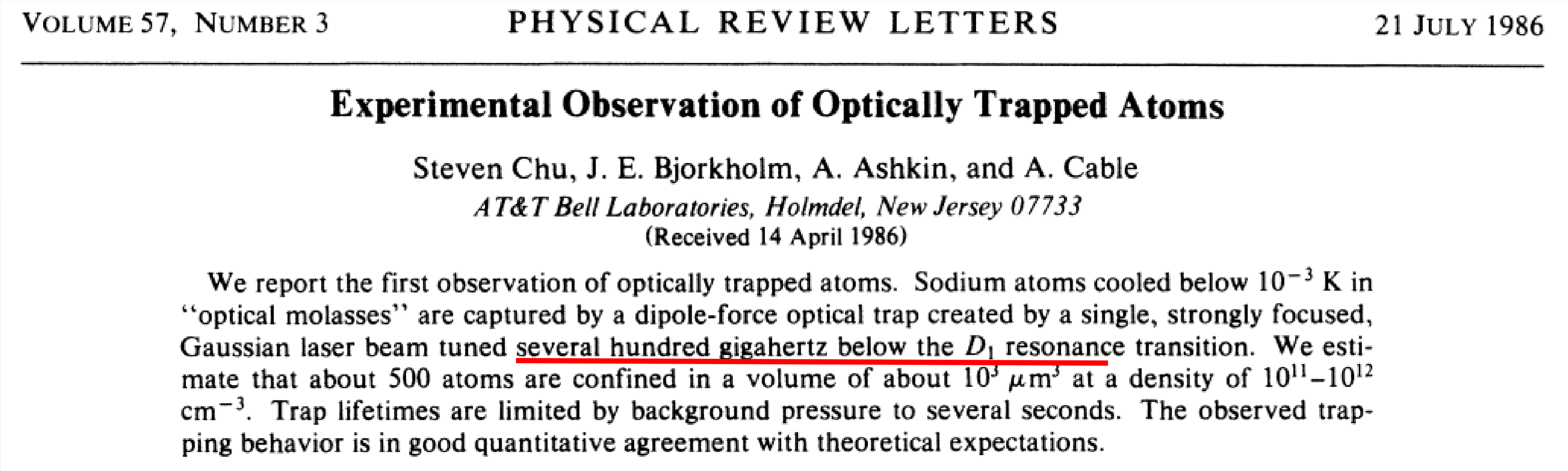


Back to 1986 – optical trapping of atoms



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Experimental Observation of Optically Trapped Atoms

Steven Chu, J. E. Bjorkholm, A. Ashkin, and A. Cable
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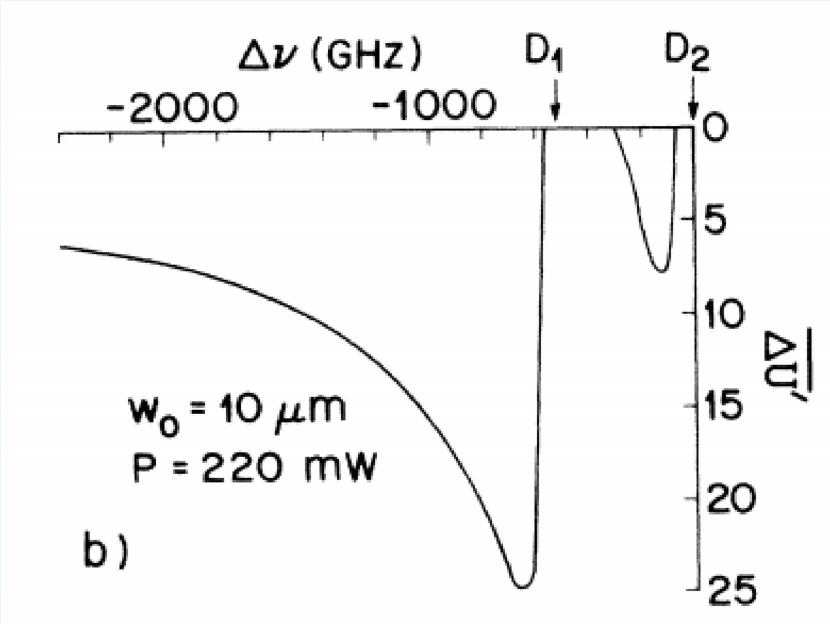
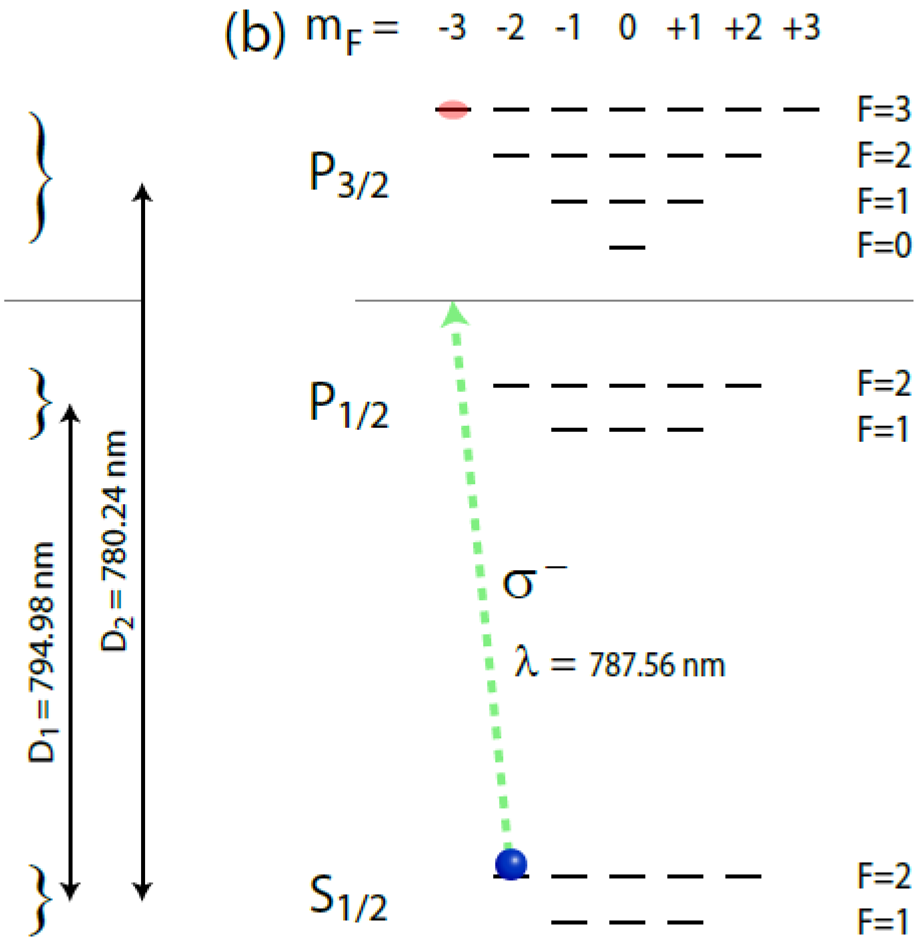
We report the first observation of optically trapped atoms. Sodium atoms cooled below 10^{-3} K in "optical molasses" are captured by a dipole-force optical trap created by a single, strongly focused, Gaussian laser beam tuned several hundred gigahertz below the D_1 resonance transition. We estimate that about 500 atoms are confined in a volume of about 10^3 μm^3 at a density of 10^{11}–10^{12} cm^{-3}. Trap lifetimes are limited by background pressure to several seconds. The observed trapping behavior is in good quantitative agreement with theoretical expectations.



Interesting frequency dependence
Between two strong transitions

State-dependent potentials

Can make traps that depend on atomic state, due to AC Stark shifts of allowed transitions for a given polarization



State-dependent potentials

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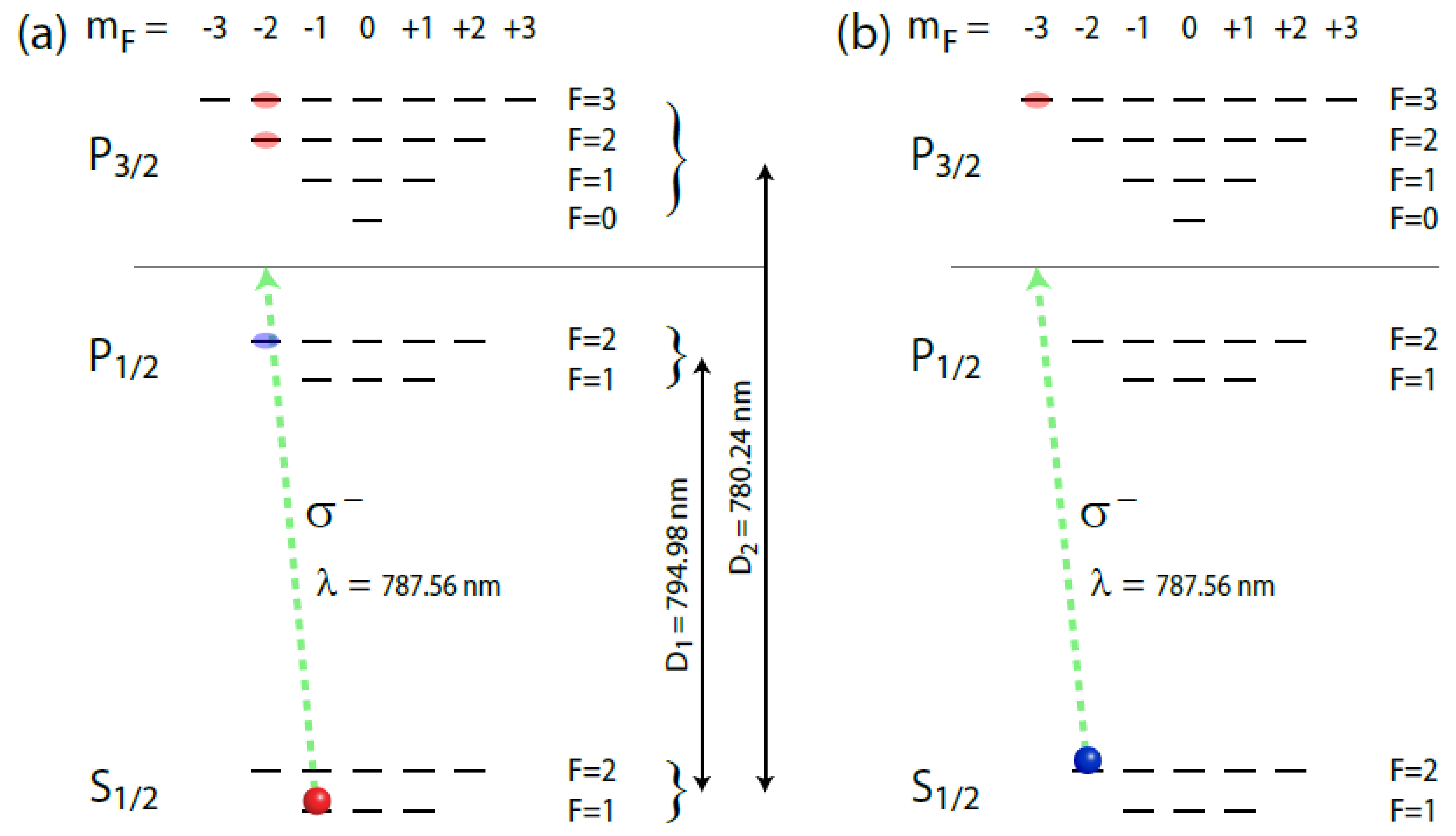

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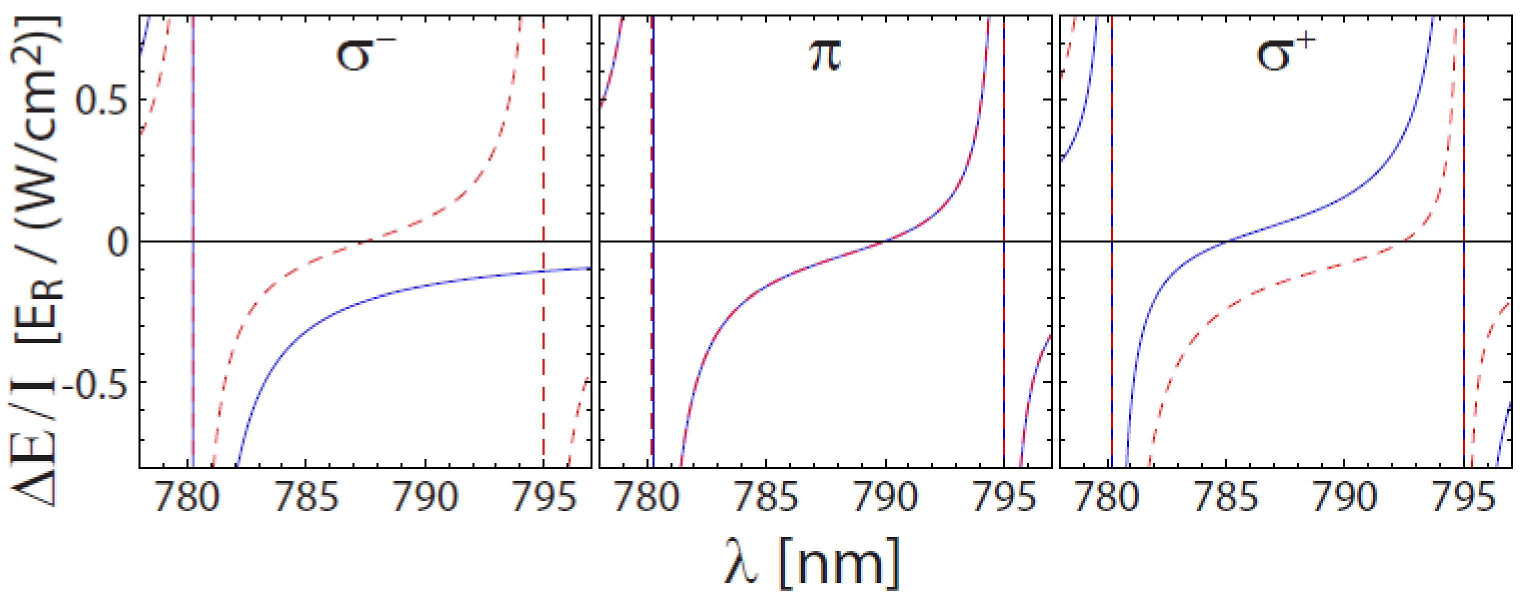
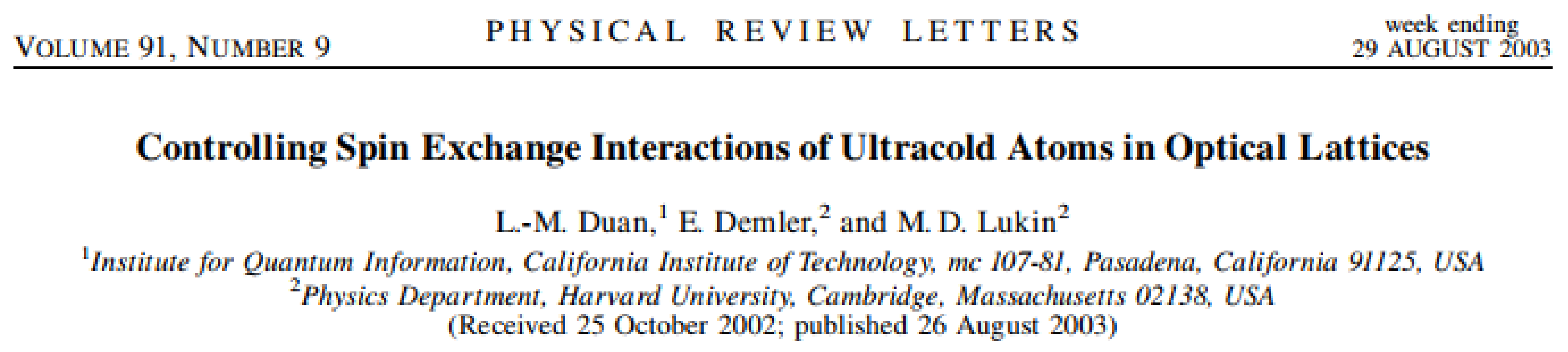


$$U_i(\mathbf{r},t) = \frac{3\pi c^2}{2}\left[\frac{\Gamma_{\mathrm{D}_1}}{\omega_{\mathrm{D}_1}^3}\sum_{j\in{}^2\mathrm{P}_{1/2}}\frac{|c_{ji}|^2}{\omega-\omega_{ji}} + 2\frac{\Gamma_{\mathrm{D}_2}}{\omega_{\mathrm{D}_2}^3}\sum_{j\in{}^2\mathrm{P}_{3/2}}\frac{|c_{ji}|^2}{\omega-\omega_{ji}}\right]I(\mathbf{r},t)$$

State-dependent potentials

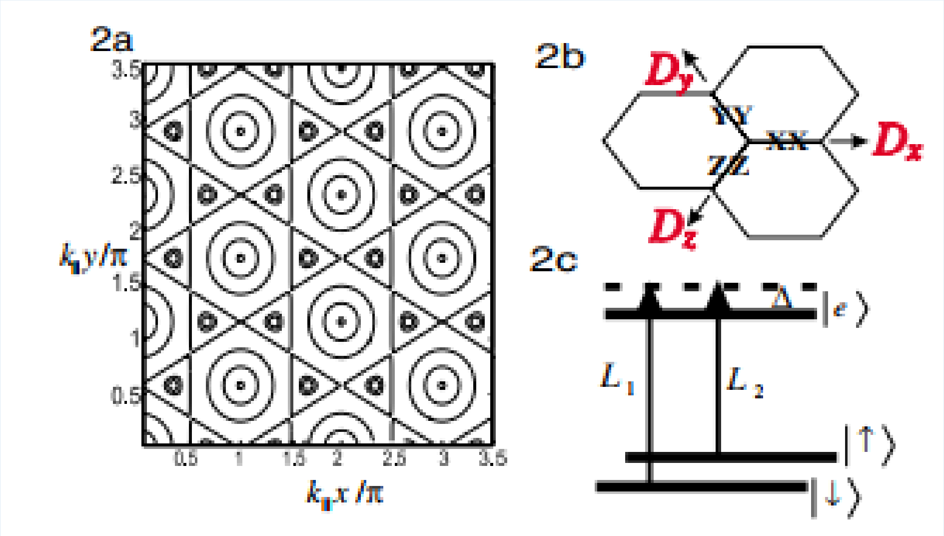


VOLUME 91, NUMBER 9 PHYSICAL REVIEW LETTERS week ending 29 AUGUST 2003

Controlling Spin Exchange Interactions of Ultracold Atoms in Optical Lattices

L.-M. Duan,[1] E. Demler,[2] and M. D. Lukin[2]
[1]*Institute for Quantum Information, California Institute of Technology, mc 107-81, Pasadena, California 91125, USA*
[2]*Physics Department, Harvard University, Cambridge, Massachusetts 02138, USA*

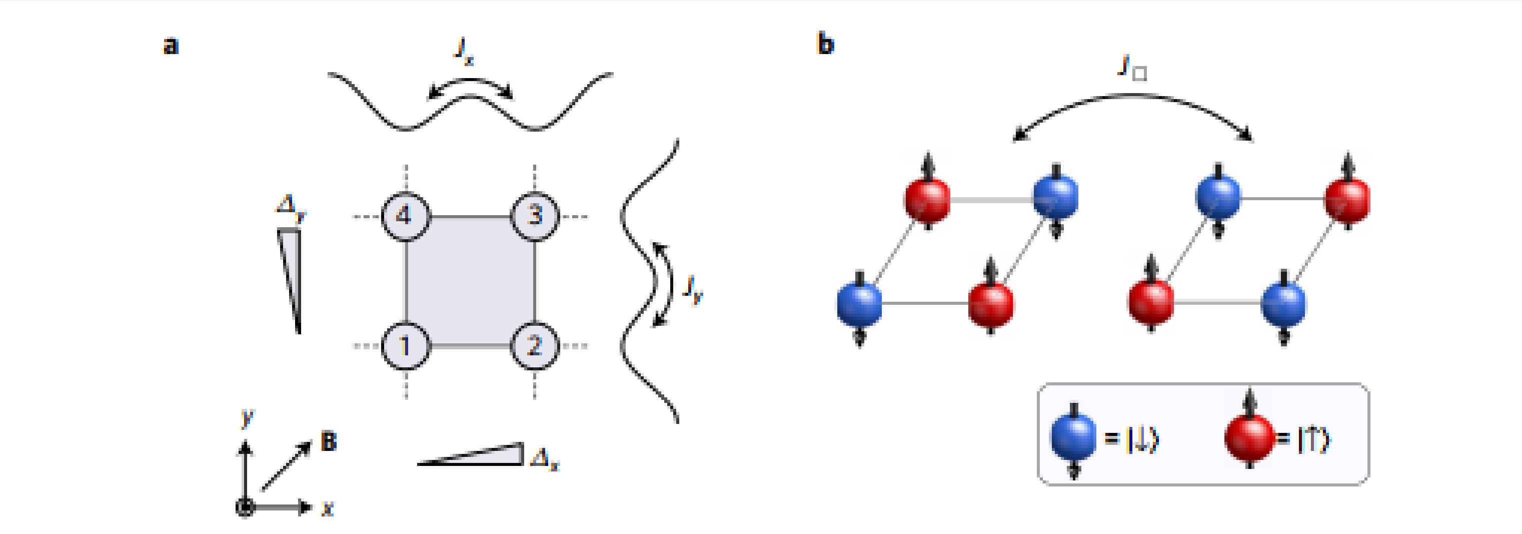
(Received 25 October 2002; published 26 August 2003)



State-dependent potentials

Four-body ring-exchange interactions and anyonic statistics within a minimal toric-code Hamiltonian

Han-Ning Dai[1,2,3†], Bing Yang[1,2,3†], Andreas Reingruber[2,4], Hui Sun[1,3], Xiao-Fan Xu[2], Yu-Ao Chen[1,3,5], Zhen-Sheng Yuan[1,2,3,5★] and Jian-Wei Pan[1,2,3,5★]



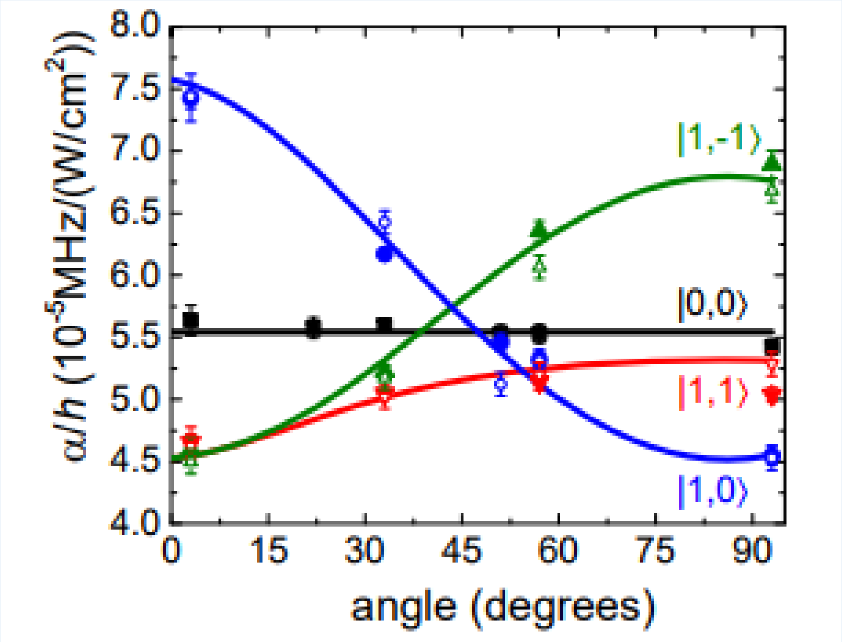
State-dependent potentials

Can make traps that depend on atomic state, due to AC Stark shifts of allowed transitions for a given polarization

For particles with anistropic valence electron density, get state dependence due to coupling with light’s polarization

→ true for some lanthanides, etc.

→ Especially true for molecules!



Neyenhuis, et al. PRL 2012