Frontiers of Ultracold Atoms and Molecules

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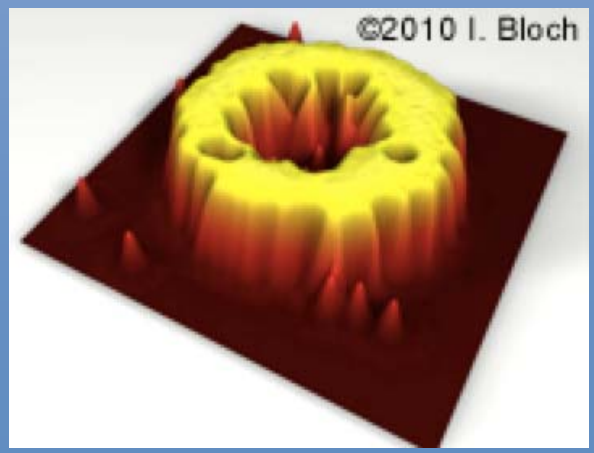
11-15 October 2010

the focus week of the KITP Program:
"Beyond Standard Optical Lattices"

Coordinators: E. Altman, M. Lewenstein, W. V. Liu



Opening Remarks

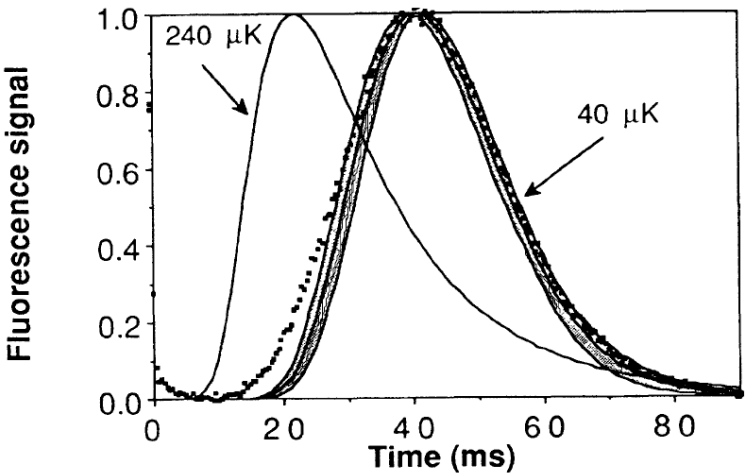
W. D. Phillips

Joint Quantum Institute

National Institute of Standards and Technology
and
University of Maryland

Some history and some perspectives on optical lattices, cold atoms, and all that

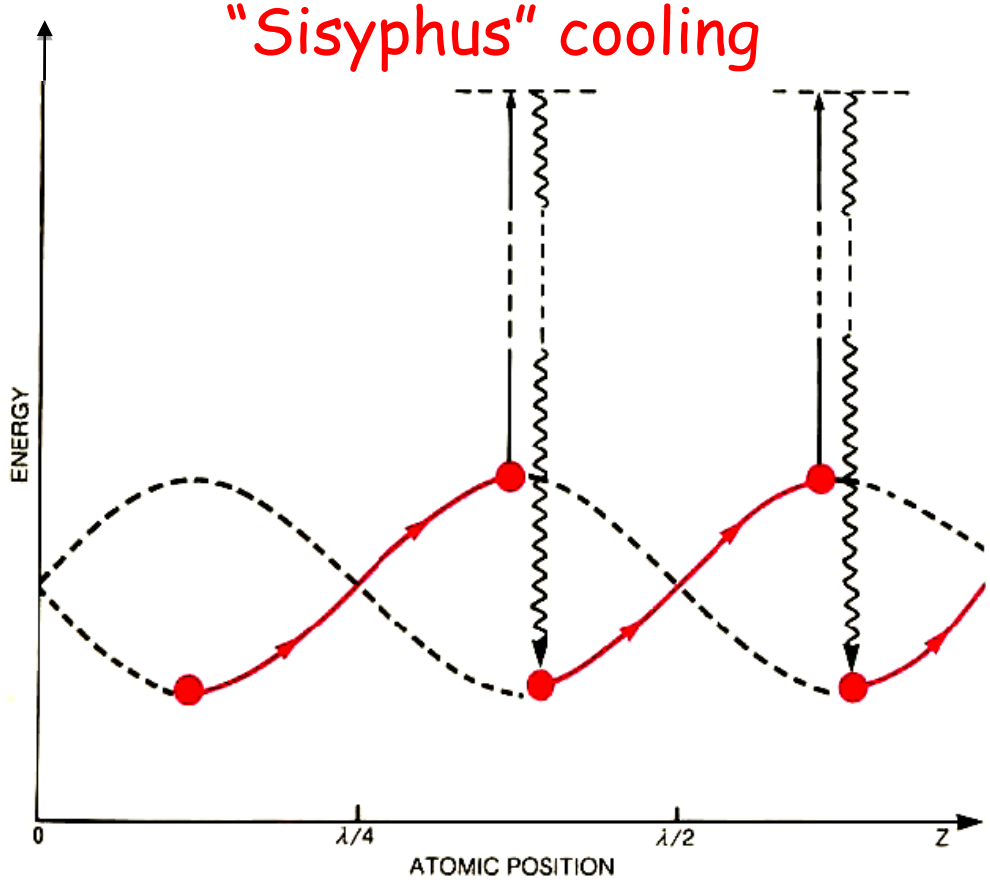
The Pre-History of Optical Lattices



Lett et al. PRL 1988

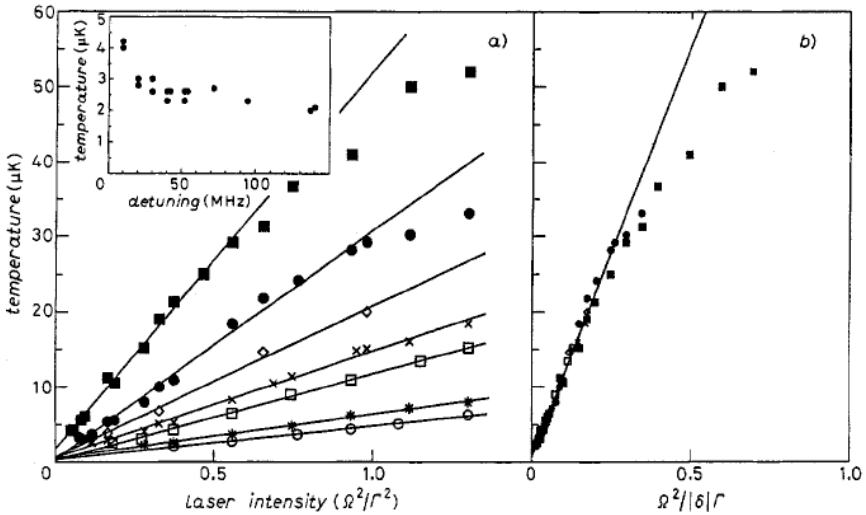
In 1988 we learned that laser cooling could produce temperatures much lower than the accepted lower limit.

"Sisyphus" cooling



Cohen-Tannoudji and Phillips, Phys. Today 1990

Soon, **Steve Chu**'s group at Stanford and **Dalibard and Cohen-Tannoudji** in Paris had explained why:



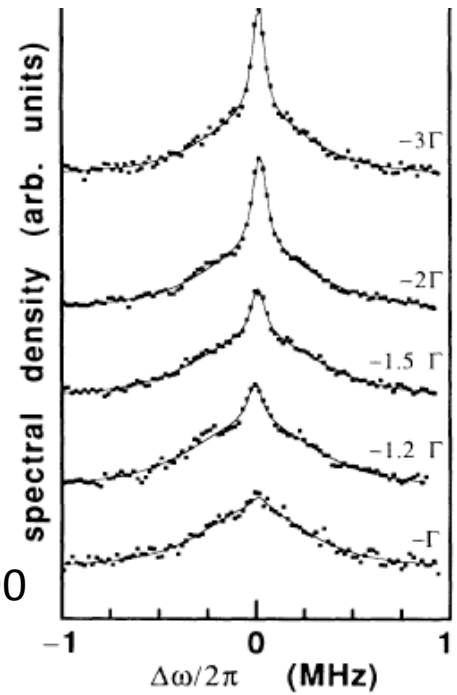
The atom kinetic energy being lower than the well-depth implied that the atoms should have been held in a lattice…

Salomon et al. 1990

EUROPHYSICS LETTERS

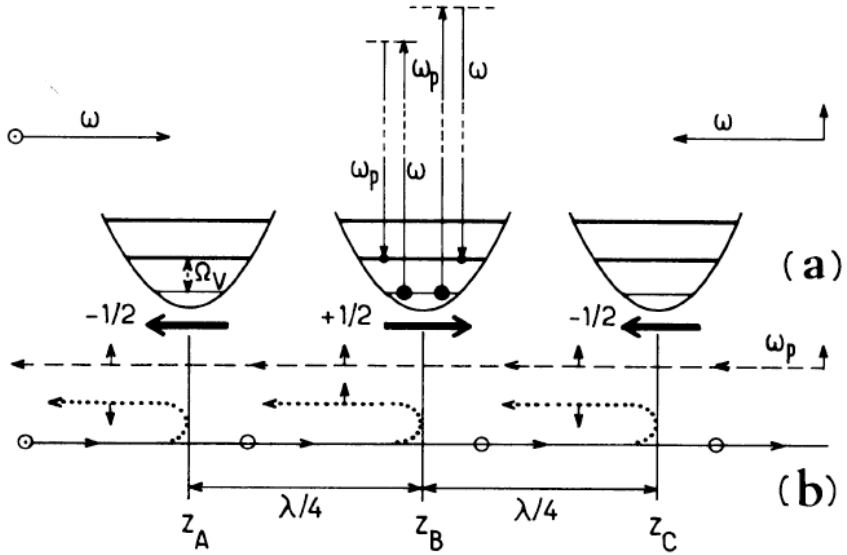
Let us also point out that the average kinetic energy of the atoms is on the order of the light shifts of the atomic energy levels. Thus a significant fraction of the atoms may be trapped in the wells formed by the spatial modulation of these shifts. Such trapping may well have already been seen in Na molasses [11].

The sharp peak in the emission spectrum was a Lamb-Dicke narrowing that indicated the atoms were localized sub-wavelength in the 3-D standing wave.

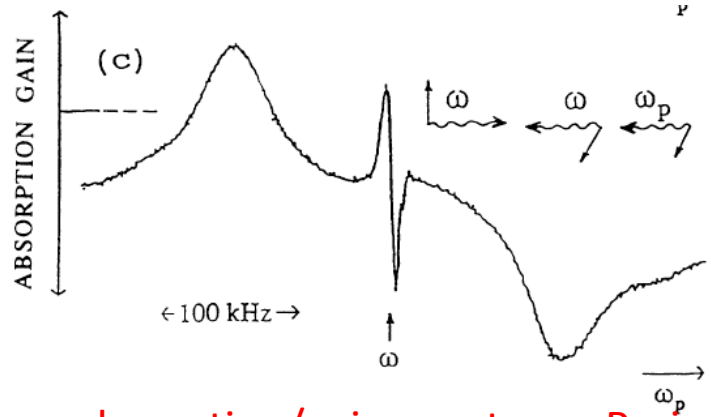


Westbrook et al. PRL 1990

Soon, groups in Paris, Munich/Garching, and Gaithersburg had seen energy-quantization for atoms trapped in such lattices.



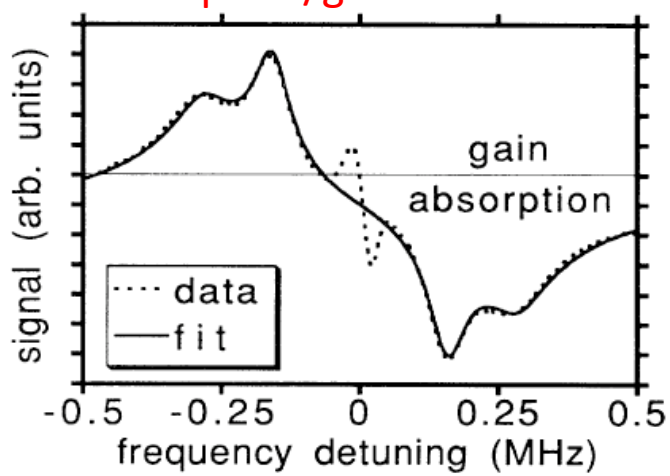
Raman transitions in lattice sites

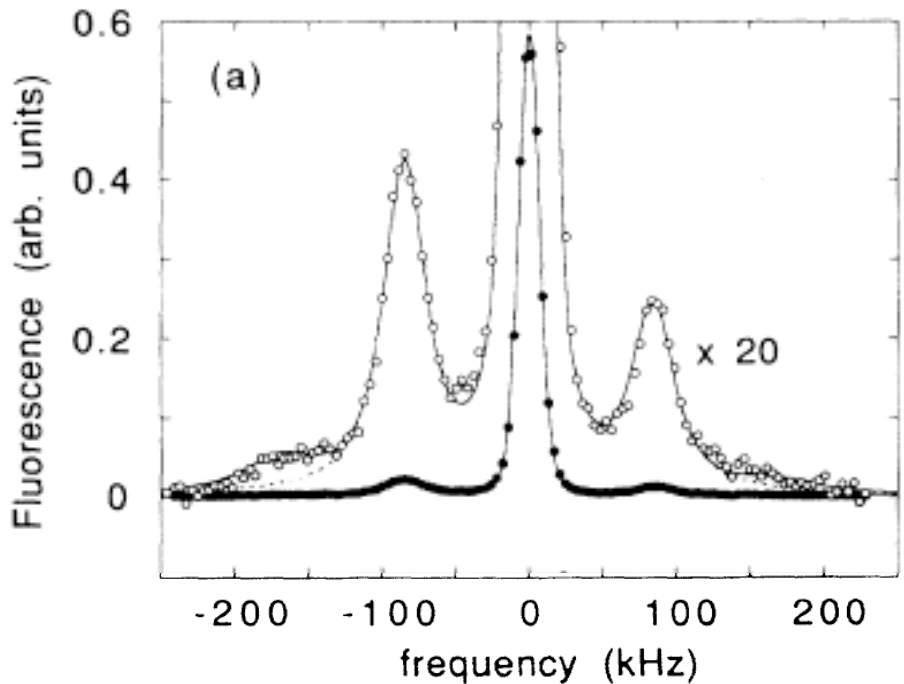


absorption/gain spectrum, Paris

emission spectrum in Gaithersburg

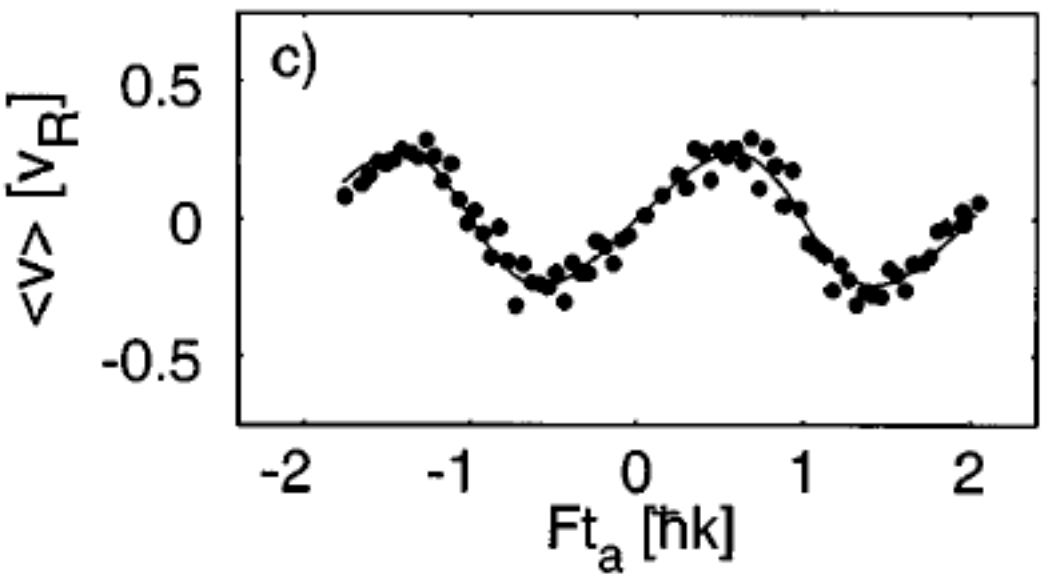
absorption/gain in Munich



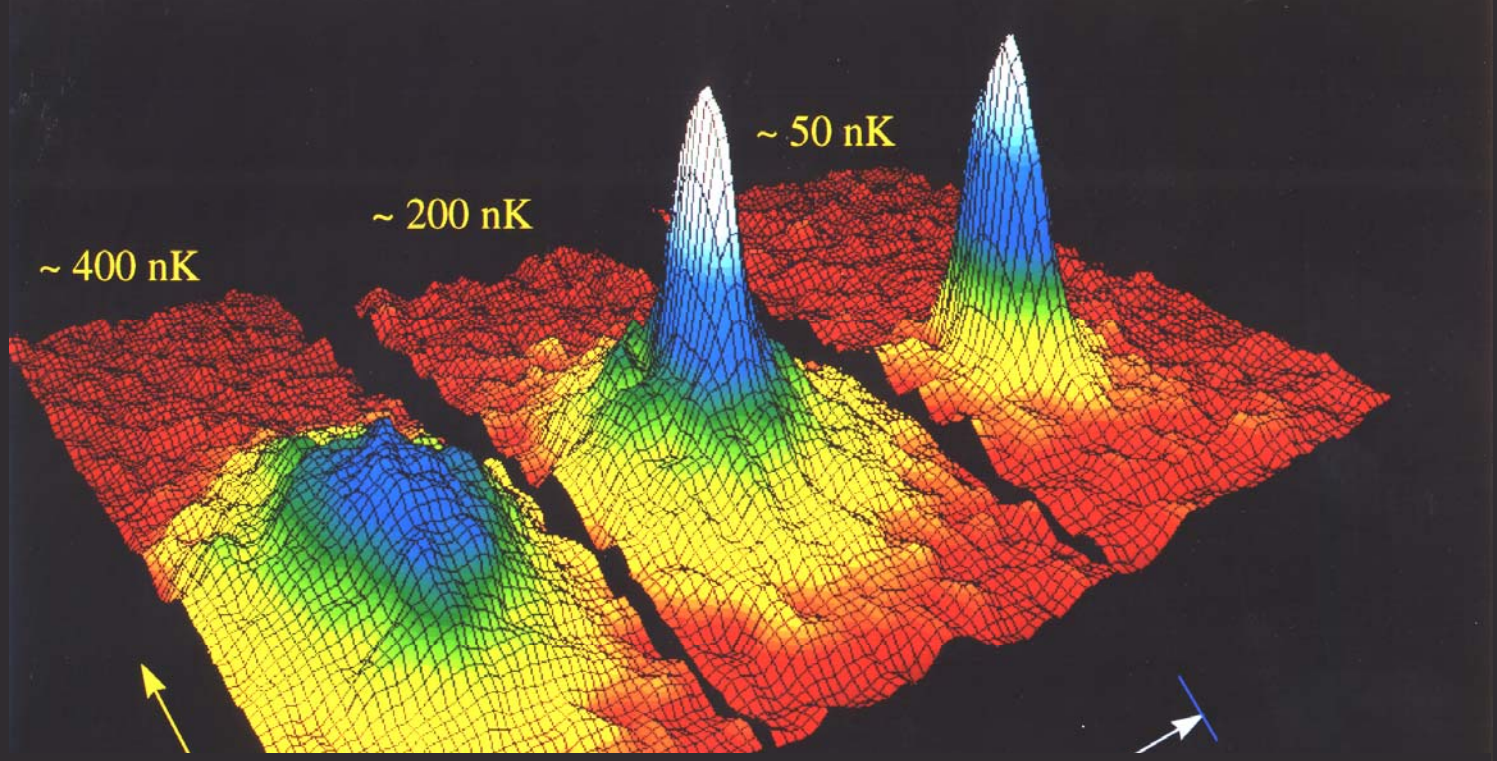


These experiments and many others like them studied the behavior of atoms in *dissipative* lattices. The lattice that held the atoms was also damping and cooling them.

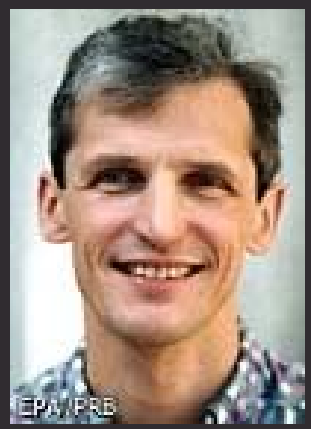
The beginning of the "modern" era of optical lattices began at nearly the same time BEC was first achieved:

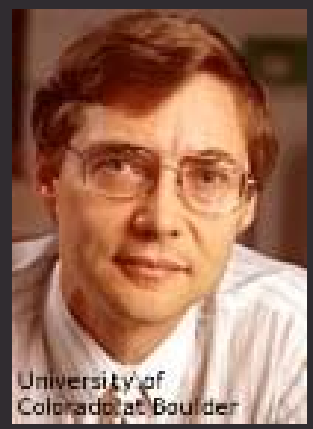


Starting with sub-Doppler cooling, then applying sub-recoil Raman cooling, then a *non-dissipative* lattice, far from resonance, the Paris group observed Bloch oscillations.

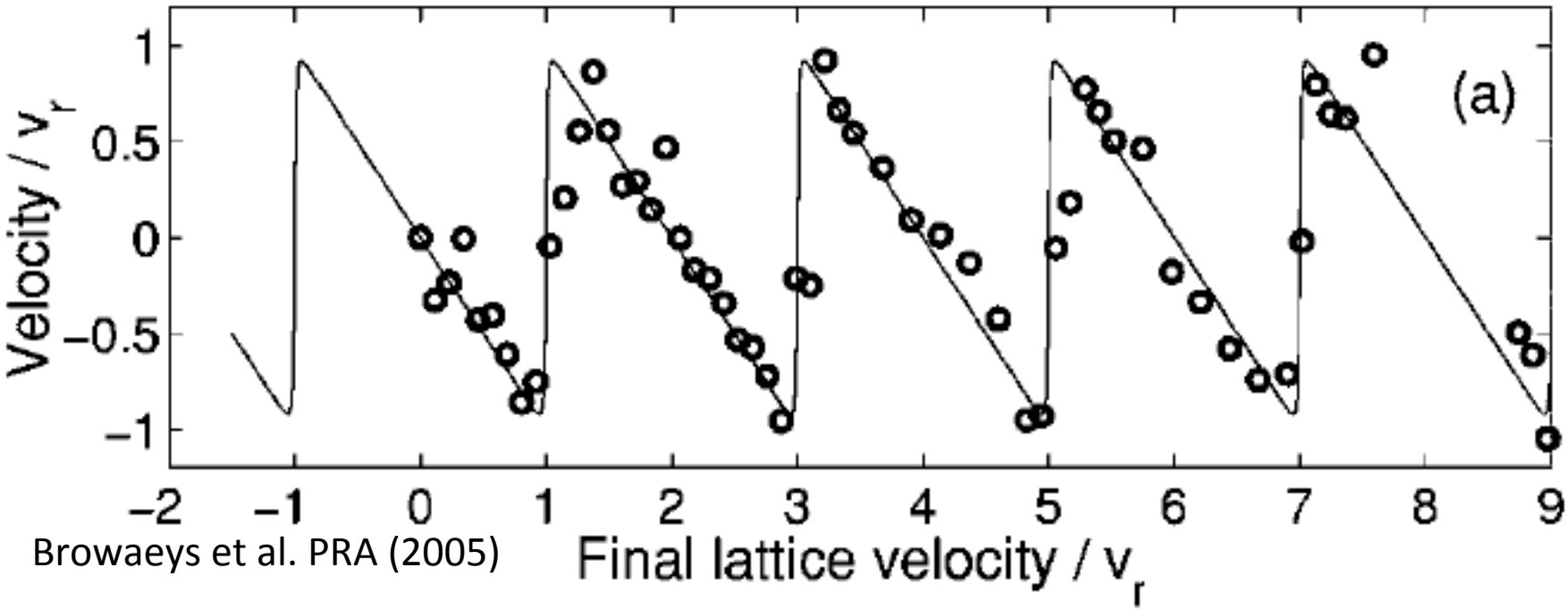


With BECs loaded into very-far-off-resonant lattices, the modern era fully arrived and the experimental and theoretical acitivity exploded.





Experiments with BECs in lattices repeated the Bloch oscillation experiments done earlier with laser-cooled atoms. The ease with which this phenomenon is observed underscores a key feature of cold atoms in optical lattices:

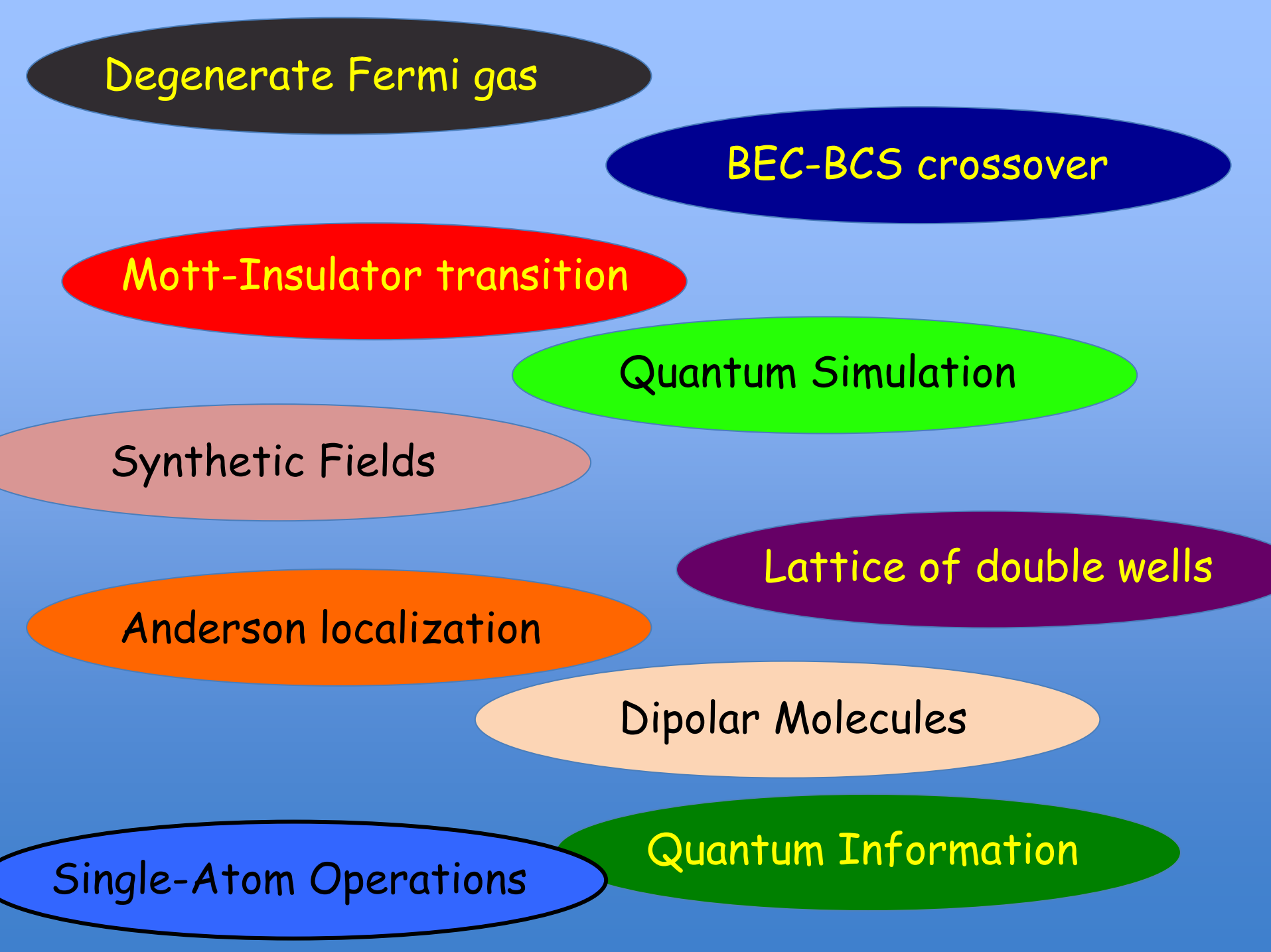


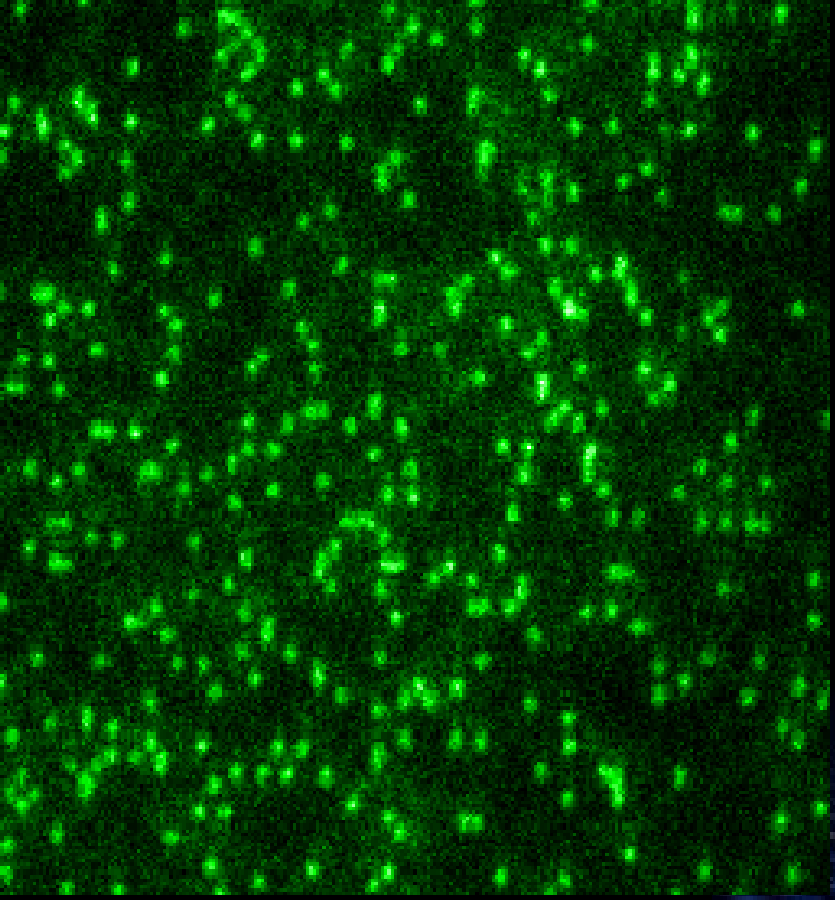
Browaeys et al. PRA (2005)

Phenomena difficult or impossible to see in condensed matter are sometimes easy with cold atoms. Among the key features are cleanliness of the system and different possibilities for measurement.

Optical lattice vs. crystal lattice

- **The optical lattice is essentially free of dislocations, impurities (although defects and disorder might be added, and the lattice potential is not perfectly uniform).**
- **Atoms can be Bosons as well as Fermions.**
- **No coulomb (long-range) interaction. (but $1/R^3$ dipole is possible)**
- **There are no traditional phonons (but we might engineer them).**
- **The lattice constant is variable, upwards of 100s of nanometers.**
- **The lattice geometry can be chosen (even quasi-periodicity is possible)**
- **The potential is exactly known and controllable. It can be switched on and off and modulated.**
- **Different kinds of control and measurement are possible with atoms compared to electrons (e.g., momentum distributions are easy to measure, but conductivity is not so easy).**
- **….**


Degenerate Fermi gas
BEC-BCS crossover
Mott-Insulator transition
Quantum Simulation
Synthetic Fields
Lattice of double wells
Anderson localization
Dipolar Molecules
Quantum Information
Single-Atom Operations



Dreams of quantum information processing with cold atoms in optical lattices projects some possible results of single atom manipulation and measurement.

Marcus Greiner lab: single atom imaging and dynamics; now, Mott-insulator state of extremely low entropy.

The End

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