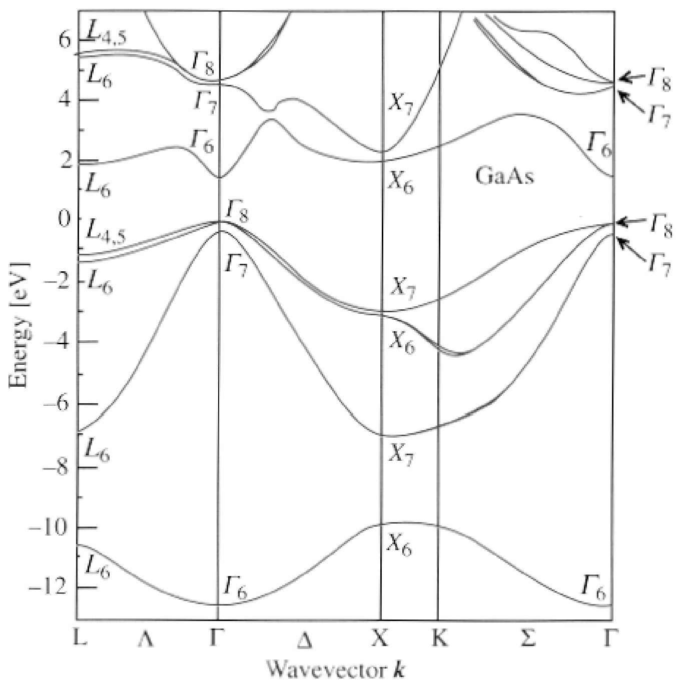
Strongly correlated many-body systems: from electrons in solids to ultracold atoms

Eugene Demler

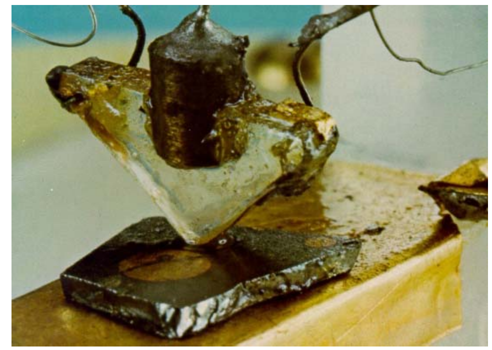
“Standard” model of electrons in solids

High density of electrons. Band theory. Description in terms of weakly interacting Landau electrons.

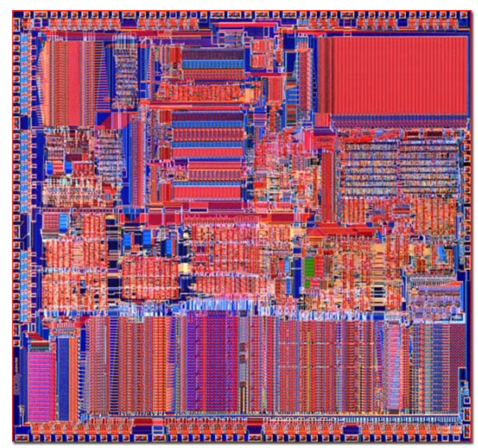
Au, Cu, Si, GaAs, …



Electronic band structure of GaAs



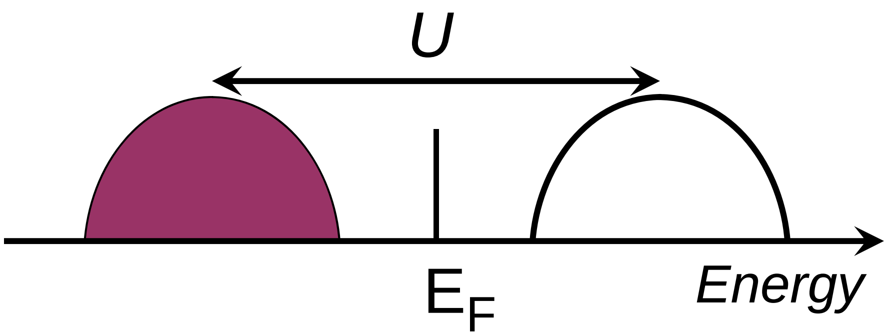
First semiconductor transistor



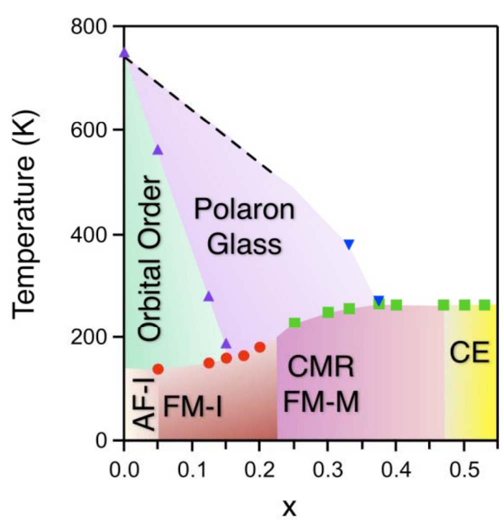
Intel 386DX microprocessor

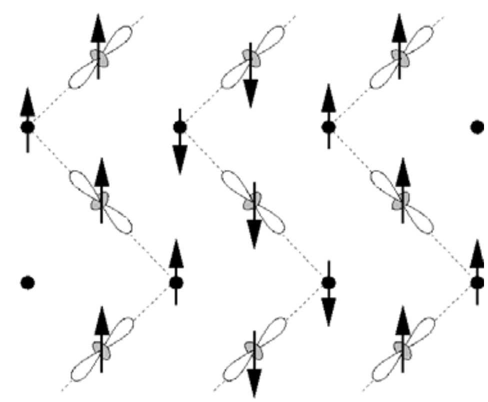
Strongly correlated electron systems

Low density of electrons. Interactions localize electrons. Hubbard bands. Unusual thermodynamic and transport properties. Spin and orbital ordering. Quantum magnetism.



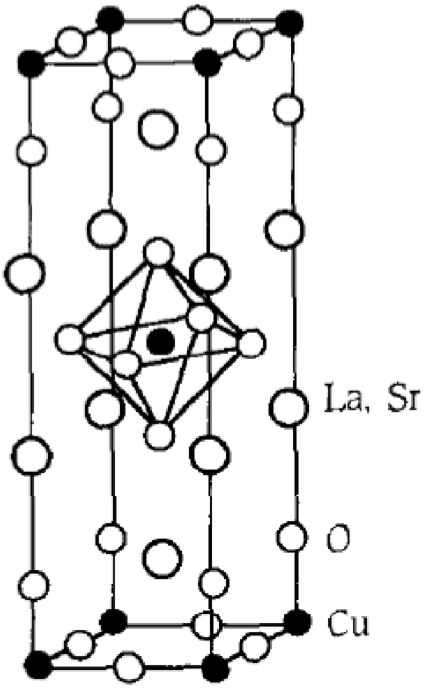
Phase diagram
of $La_{1-x}Ca_xMnO_3$



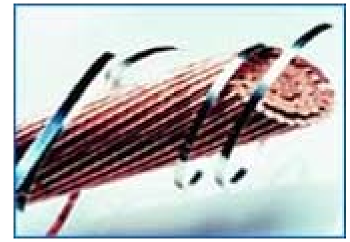


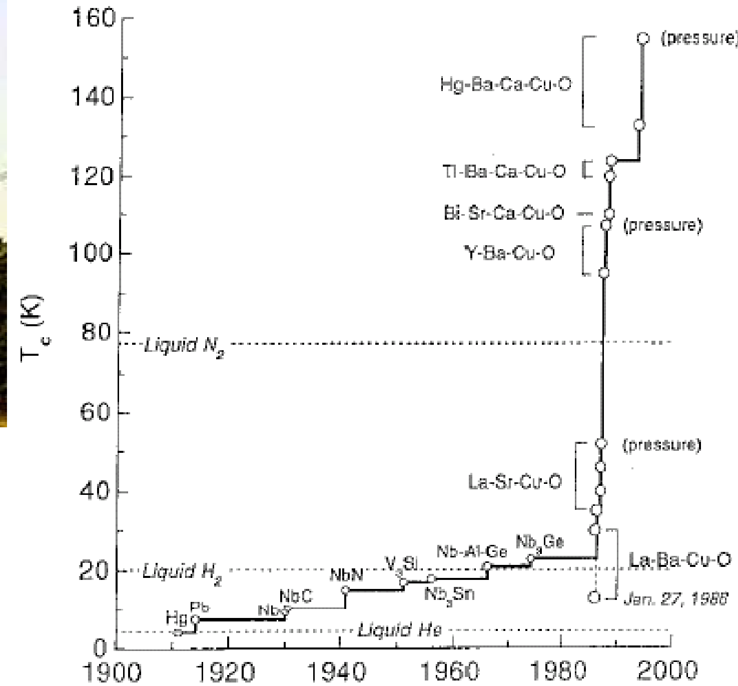
Ordered state for x=0.5

High Tc superconductors

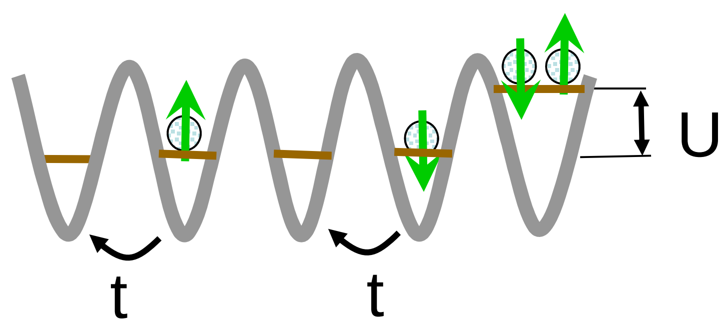


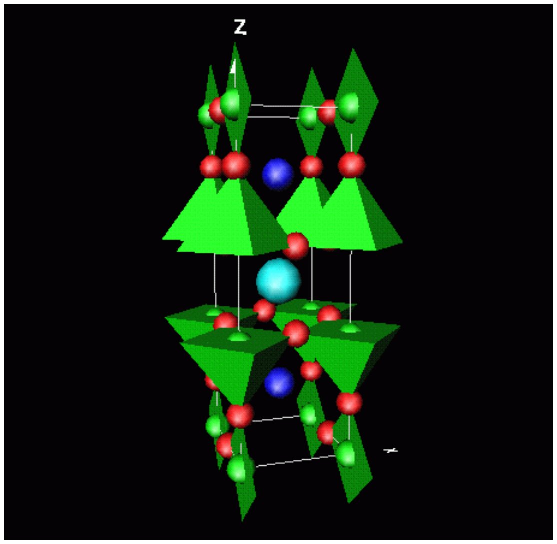
The structure
of La2CuO4



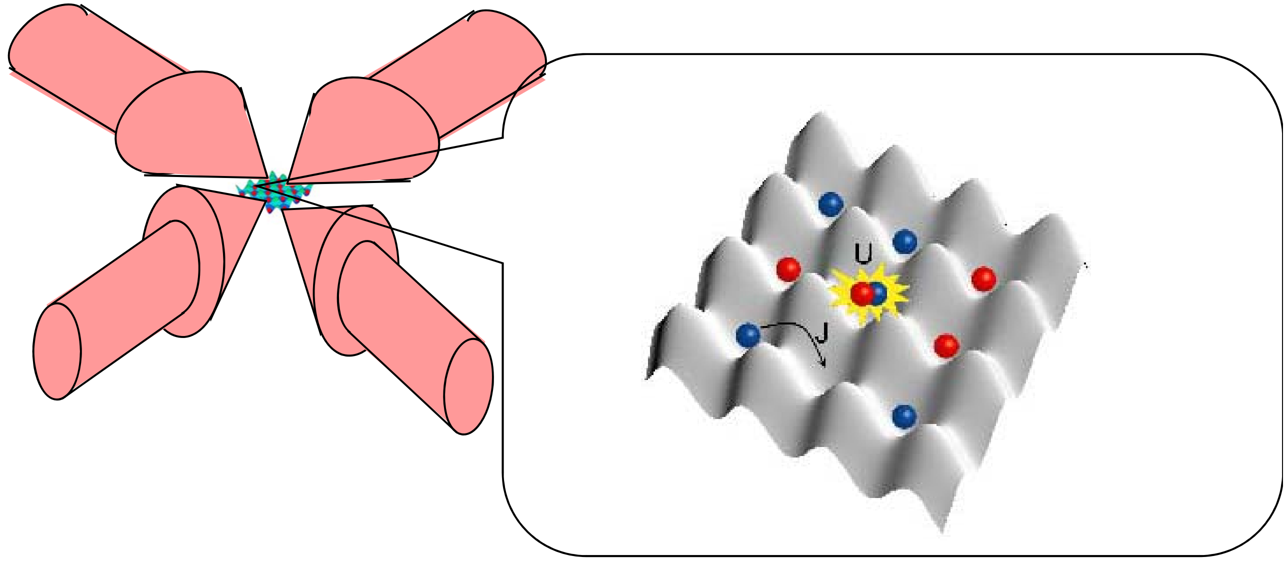


Microscopic description:
Hubbard model





$YBa_2Cu_3O_7$

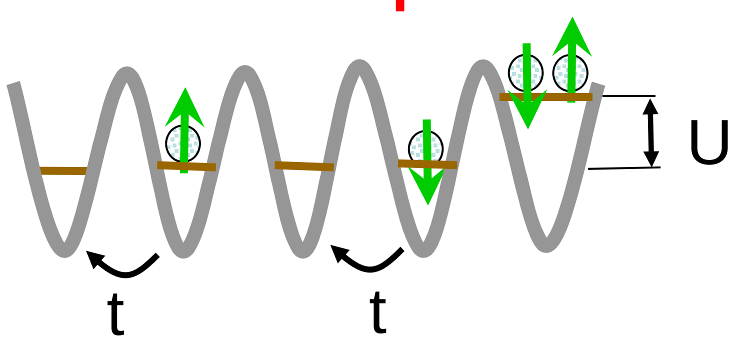


Atoms in optical lattice

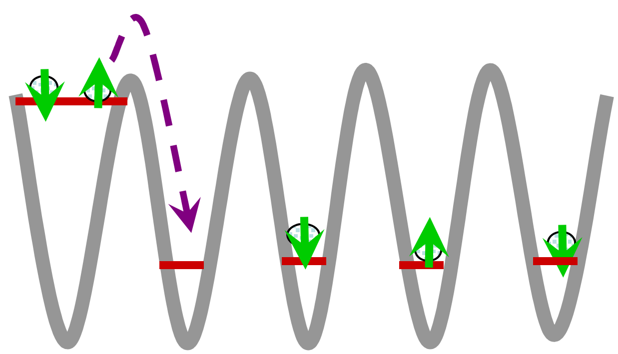
Antiferromagnetic and
superconducting Tc
of the order of 100 K

Antiferromagnetism and
pairing at sub-micro Kelvin
temperatures

Same microscopic model

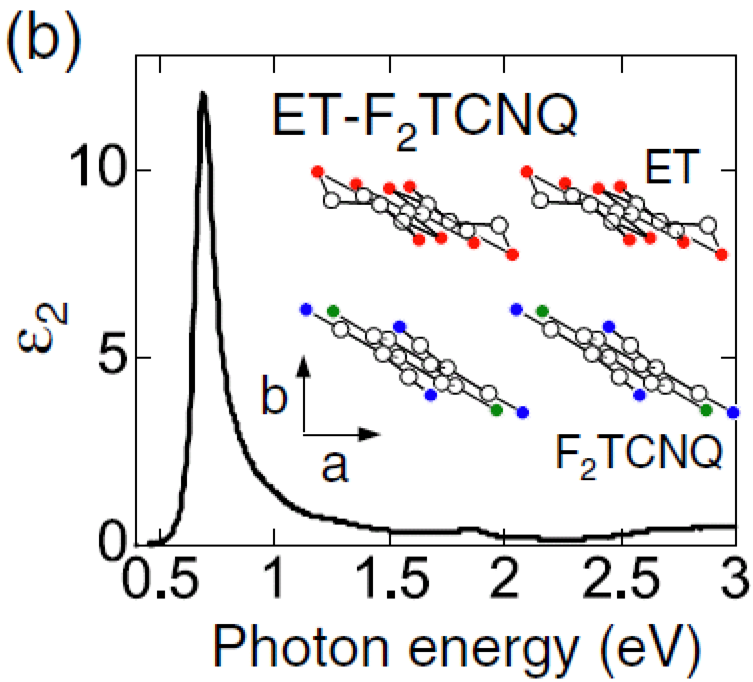


Doublon relaxation in organic Mott insulators

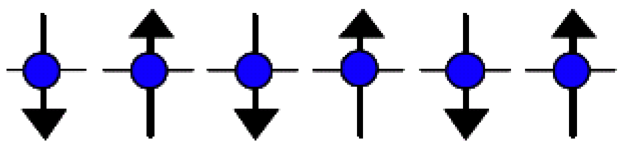


One dimensional Mott insulator ET-F_2TCNQ

bis(ethylenedithio)tetrathiafulvalene difluorotetracyanoquinodimethane



Mott-insulator state



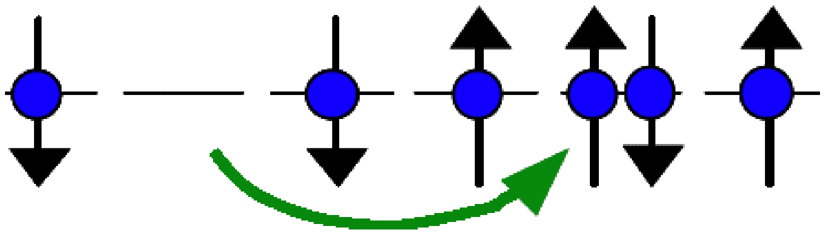
t=0.1 eV

U=0.7 eV

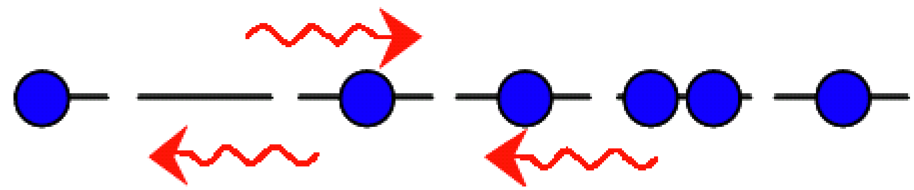
Photoinduced metallic state

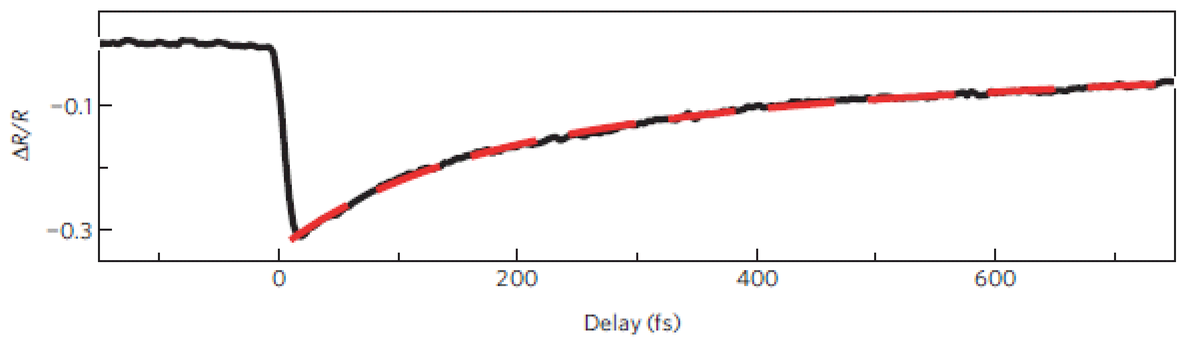
H. Okamoto et al., PRL 98:37401 (2007)
S. Wall et al. Nature Physics 7:114 (2011)

Photoexcitations



Conducting state by photo-doping

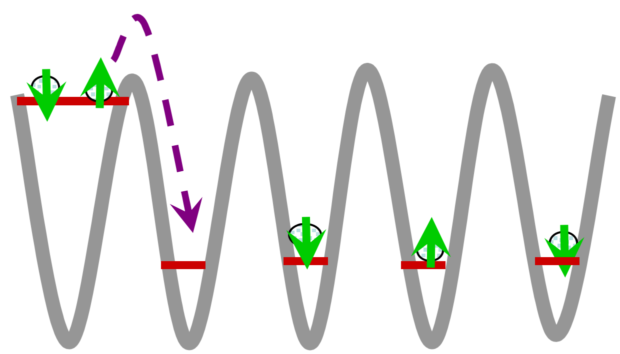




Surprisingly long relaxation time 840 fs

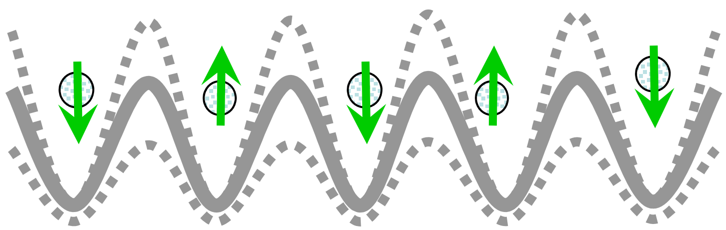
h/t = 40 fs

Doublon relaxation in ultracod Fermi gases

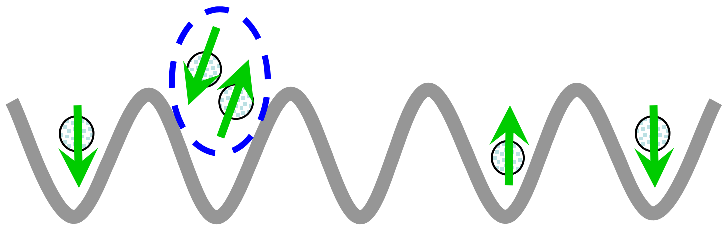


Lattice modulation experiments

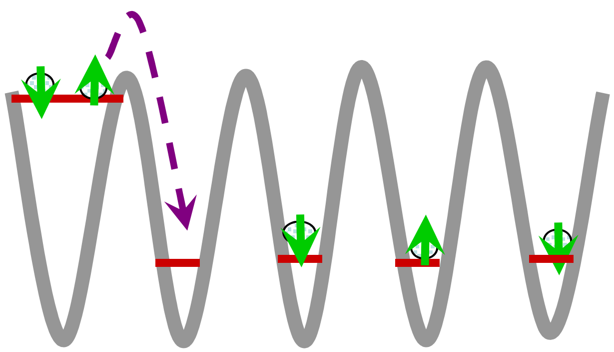
Probing dynamics of the Hubbard model



Modulate lattice potential V_0



Measure number of doubly occupied sites

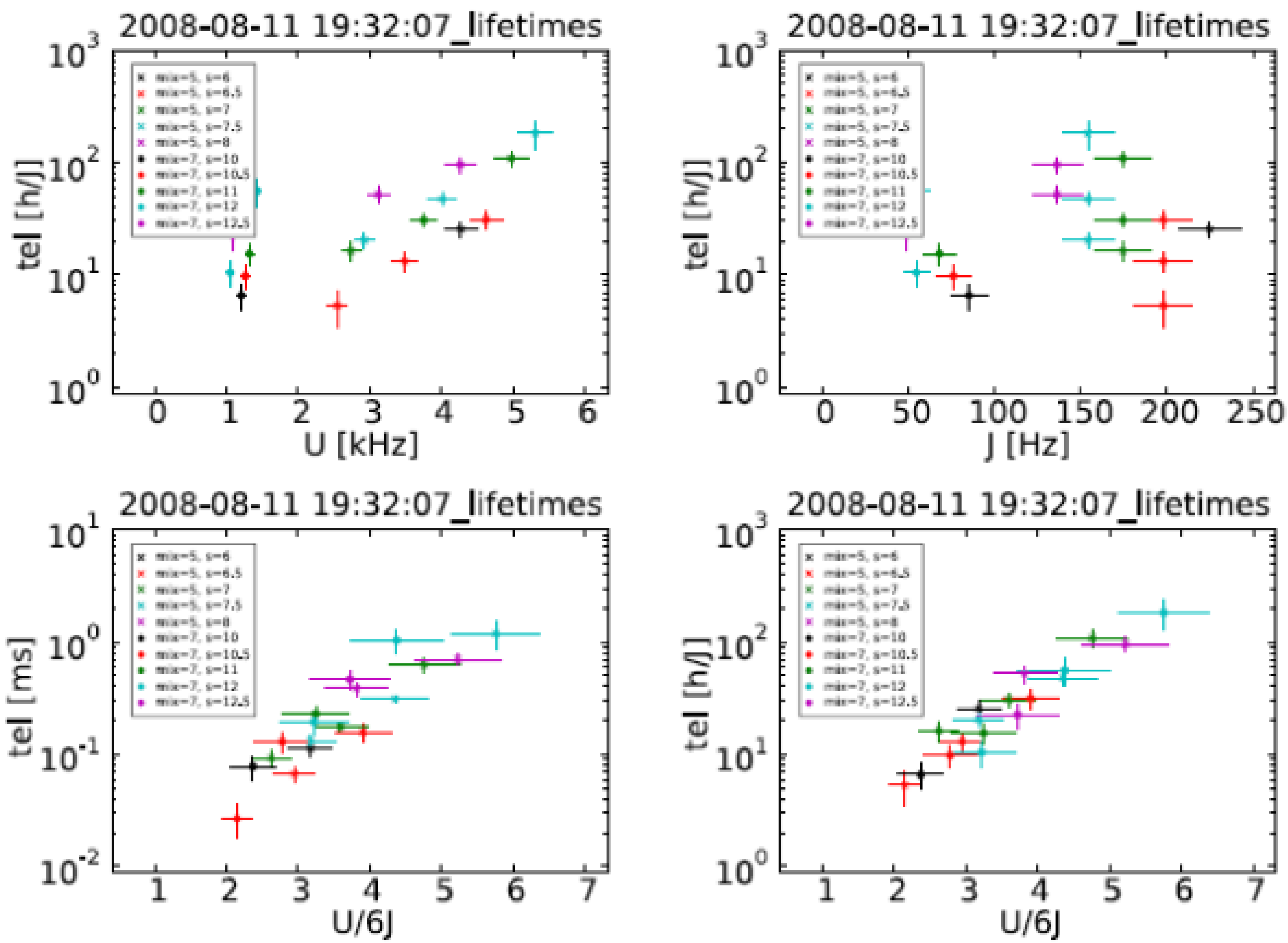


Measure how long it takes for doublons to decay

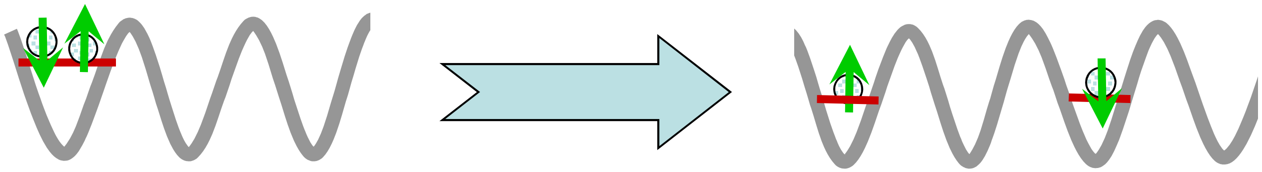
Ref: N. Strohmaier et al., PRL 104:80401 (2010)
Experiment: T. Esslinger's group at ETH
Theory: Pekker et al., Harvard

Fermions in optical lattice. Decay of repulsively bound pairs

Experiments: N. Strohmaier et. al.



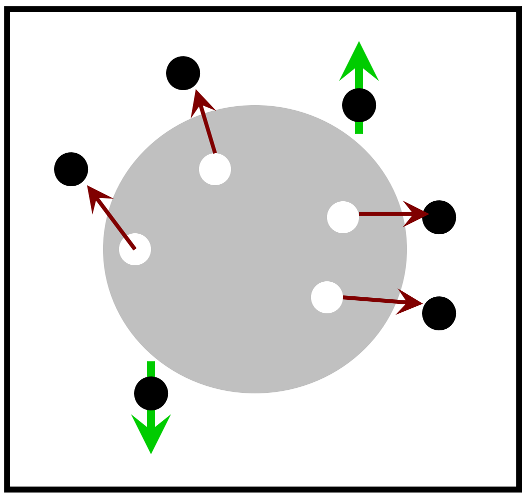
Doublon decay in a compressible state



Compressible state: Fermi liquid description

Excess energy U is converted to kinetic energy of single atoms
Kinetic energy scale set by bandwidth

$$\mathrm{w} = 12\,t$$



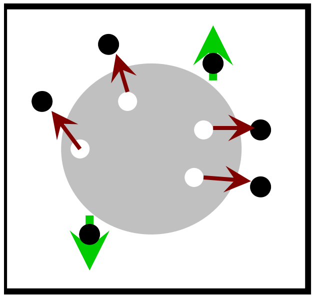
Perturbation theory to order n=U/w
Decay probability

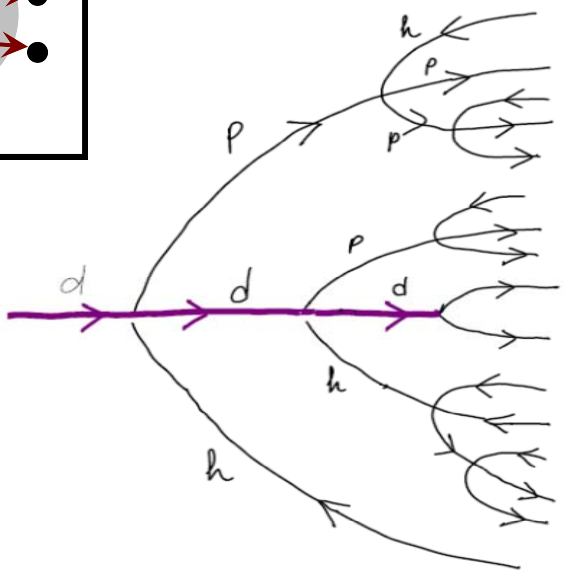
$$\frac{1}{\tau} \sim \left(\frac{t}{U}\right)^{\mathrm{const} \times \frac{U}{\mathrm{w}}}$$

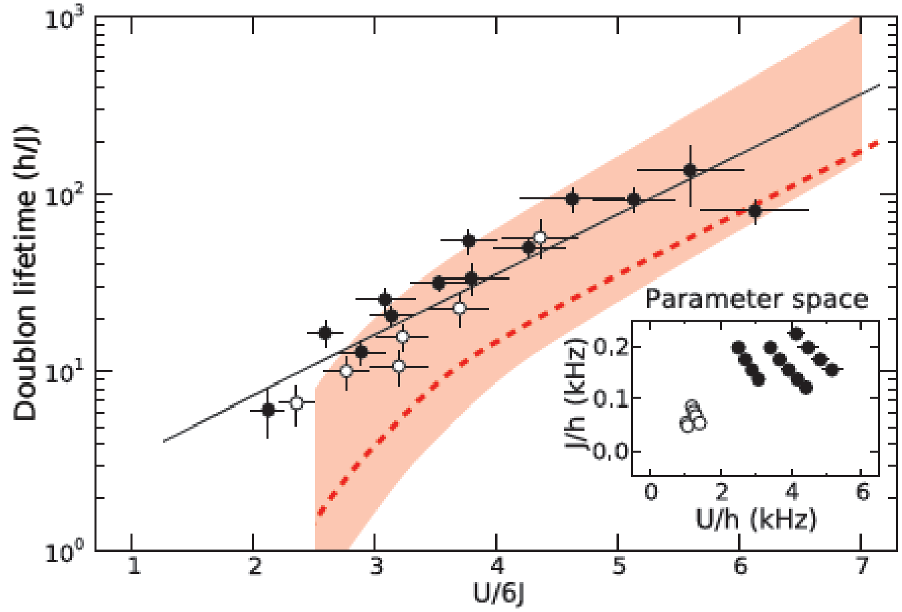
$$e^{-\mathrm{const}\, \times\, \frac{U}{\mathrm{w}} \times \log \frac{U}{\mathrm{t}}}$$

Doublon can decay into a pair of quasiparticles with many particle-hole pairs

Doublon decay in a compressible state





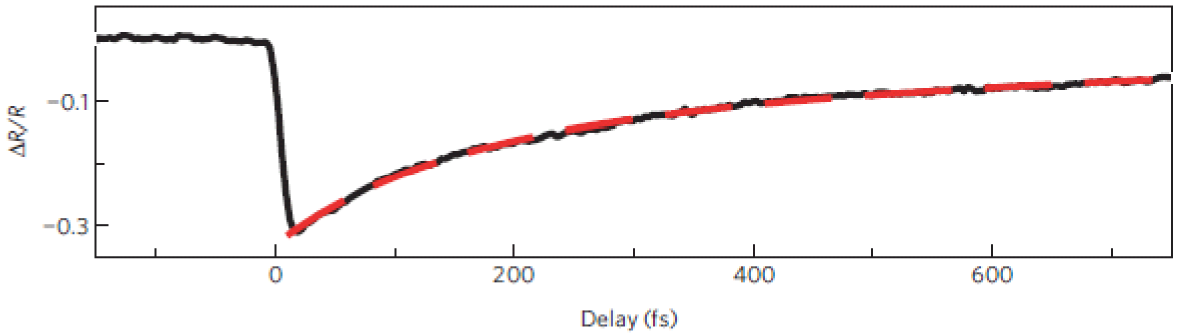


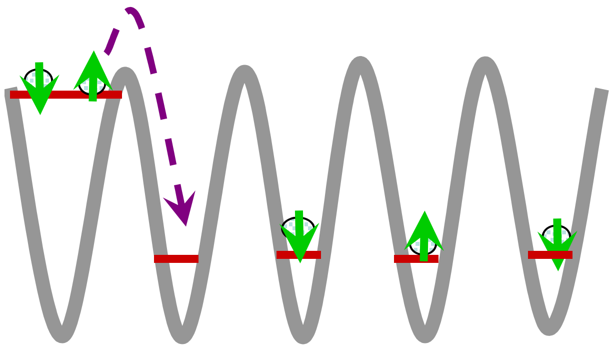
To calculate the rate: consider processes which maximize the number of particle-hole excitations

$$\tau \sim \frac{2\,h}{\mathrm{t}}\; e^{1.6\,\frac{U}{\mathrm{w}}}$$

Photoinduced metallic state

H. Okamoto et al., PRL 98:37401 (2007)
S. Wall et al. Nature Physics 7:114 (2011)

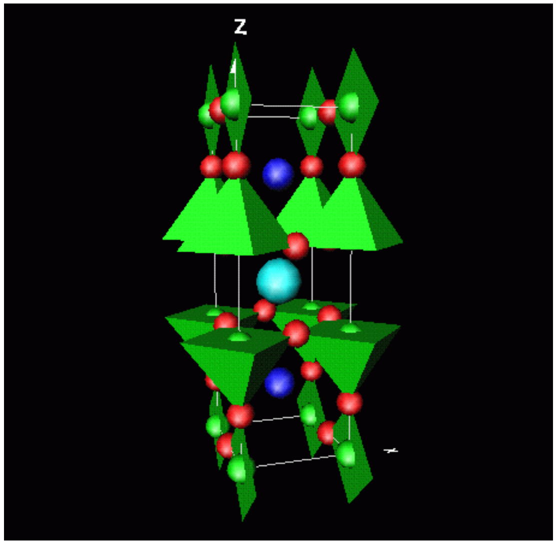




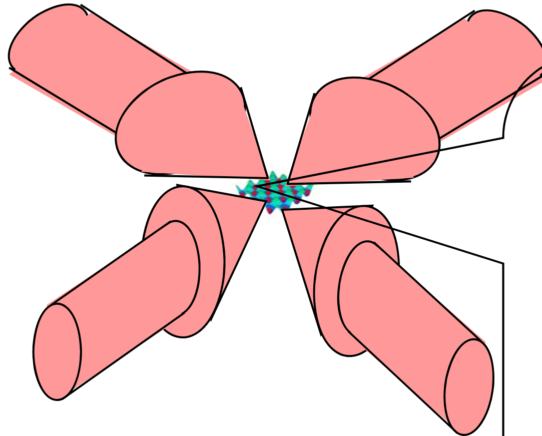
$$\tau \sim \frac{2\,h}{\mathrm{t}}\; e^{1.6\,\frac{U}{\mathrm{w}}}$$

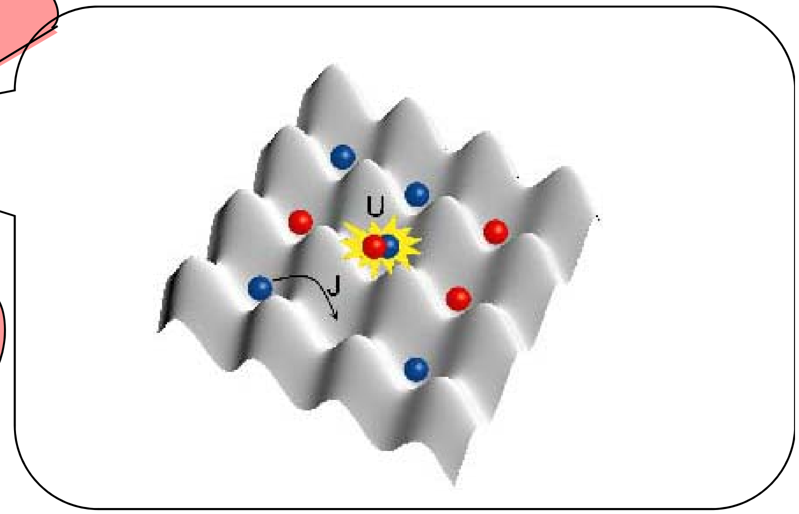
$\sim$1400 fs

t=0.1 eV
w=4t=0.4eV
U=0.7 eV



$YBa_2Cu_3O_7$





Atoms in optical lattice

Antiferromagnetic and
superconducting Tc
of the order of 100 K

Antiferromagnetism and
pairing at sub-micro Kelvin
temperatures

Same microscopic model