Insights into quantum matter from new experiments

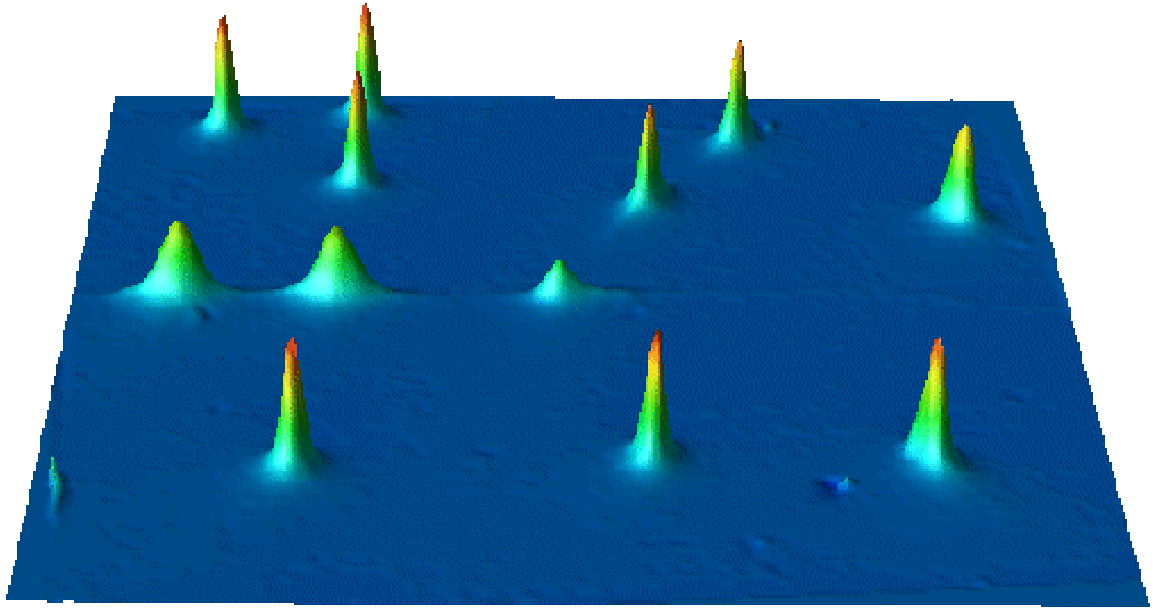
Detecting new many body states will require:

- Atomic scale resolution of magnetic fields
- Measuring and manipulating electron spins
- Spatially resolved spectral information on charge dynamics

I will mention some state-of-the-art experiments and speculate on the future

Resolving magnetic fields

$YBa_2Cu_3O_{6+x}$



↔ 10μm

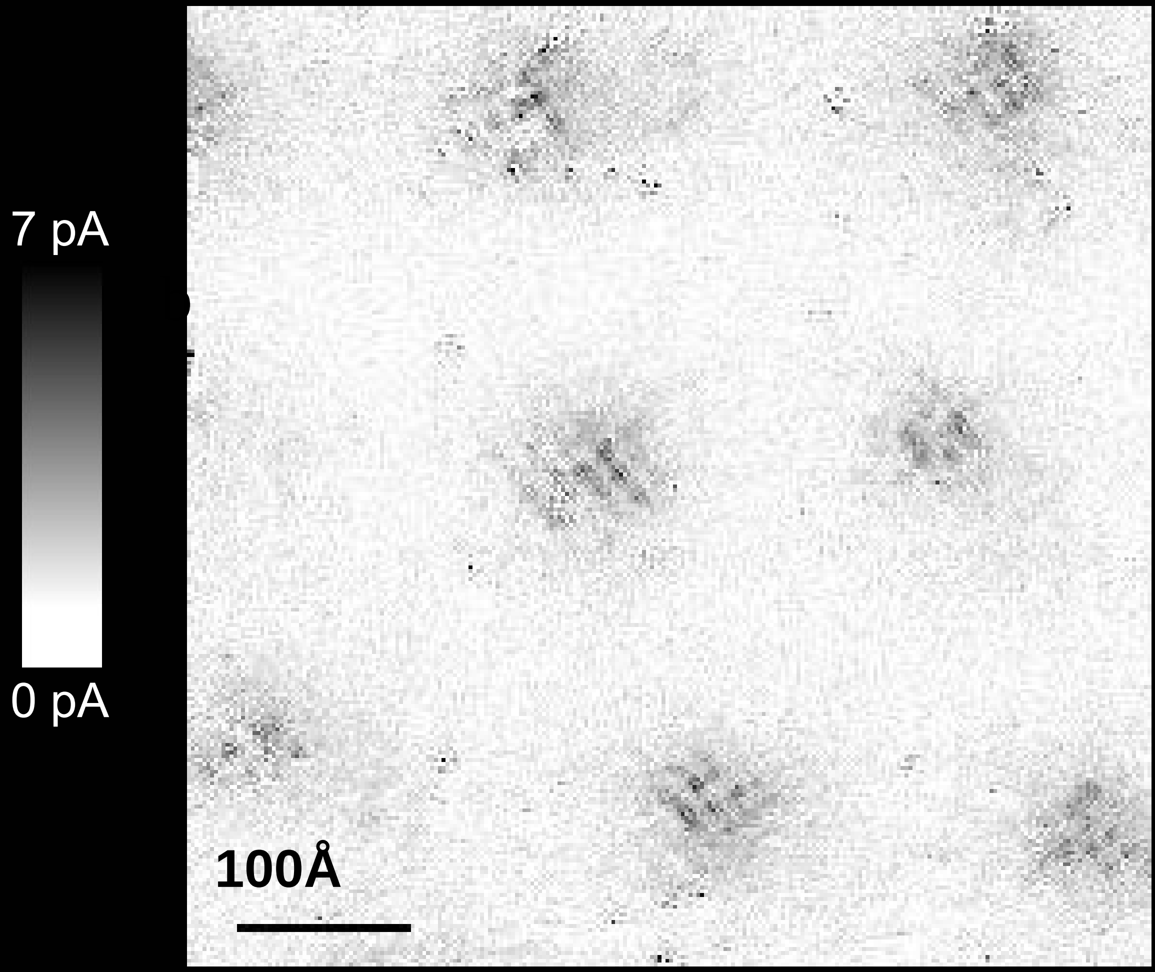
The spontaneous generation of flux at the tricrystal point occurs independent of the how the high-T_c film is patterned. This is an image of an unpatterned YBCO film on a tricrystal substrate. There are 7 conventional Abrikosov vortices in the grains, 4 conventional Josephson vortices in the grain boundaries, and a half-quantum Josephson vortex as the tricrystal point.

J.R. Kirtley, C.C. Tsuei, Martin Rupp, J.Z. Sun, Lock See Yu-Jahnes, A. Gupta, M.B. Ketchen, K.A. Moler, and M. Bhushan, Phys. Rev. Lett. ***76****,1336(1996).*

Flux quanta on the surface of a cuprate superconductor: evidence for *d*-wave pairing

Future: higher atomic scale resolution ?

Atomic scale resolution of "charge"



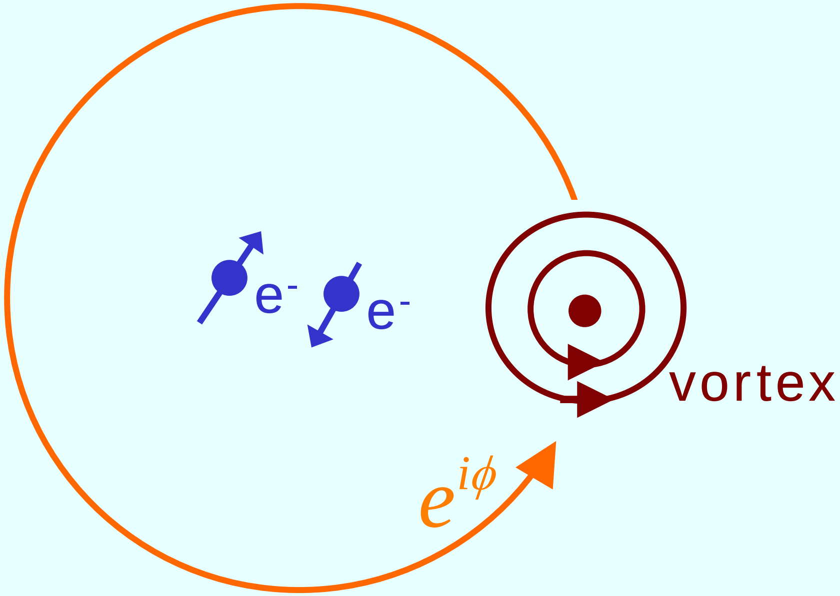
Scanning tunneling microscopy

Vortex-induced LDOS modulations (≈ 4 lattice spacings) of $Bi_2Sr_2CaCu_2O_{8+\delta}$ integrated from 1meV to 12meV at 4K

J. Hoffman E. W. Hudson, K. M. Lang, V. Madhavan, S. H. Pan, H. Eisaki, S. Uchida, and J. C. Davis, *Science* 295, 466 (2002).

Future: dynamic information from "noise" measurements ?

Commercial break: novel many body effects in STM measurements



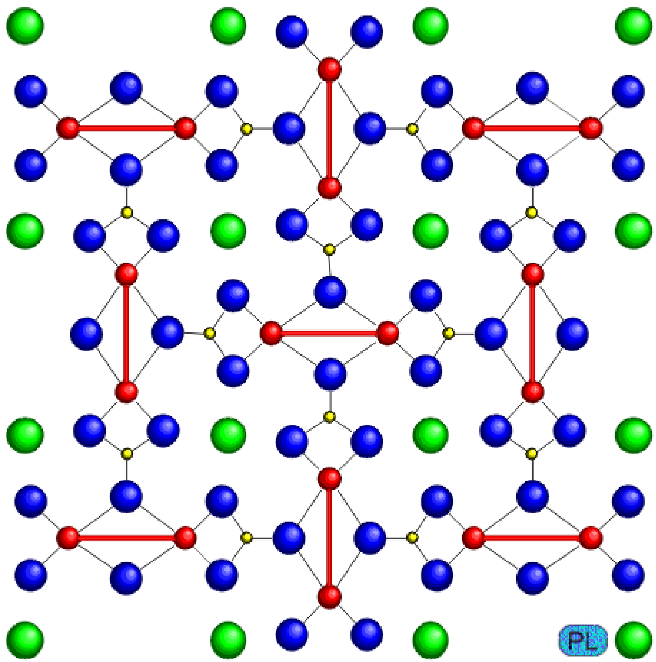
The wavefunction of a vortex acquires a phase factor each time the vortex encircles a Cooper pair or an electron—this phase is responsible for the quantum interference effects.

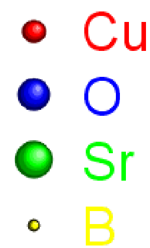
Vortices come in multiple flavors, with the number of flavors determined by the average density of electrons. The periodic density modulations at the core of each vortex are then an **interference pattern** between the different flavors of vortices, as they undergo quantum zero-point motion.

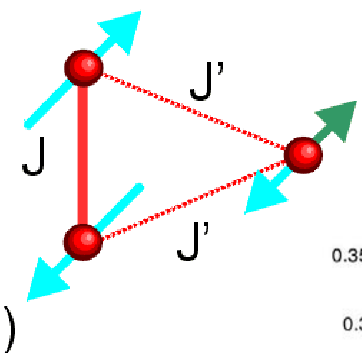
L. Balents, L. Bartosch, A. Burkov. S. Sachdev, K. Sengupta, cond-mat/0408329

Detecting and manipulating spins

Magnetization plateau in a spin gap insulator

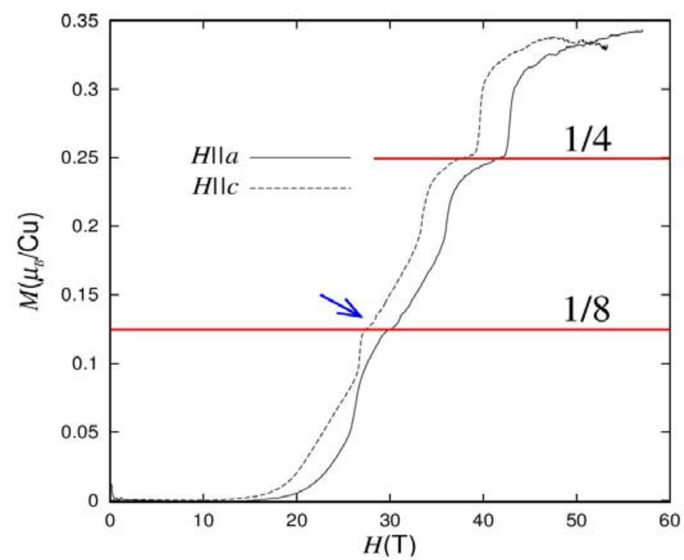






Up spin bosons form a Mott insulator at rational filling

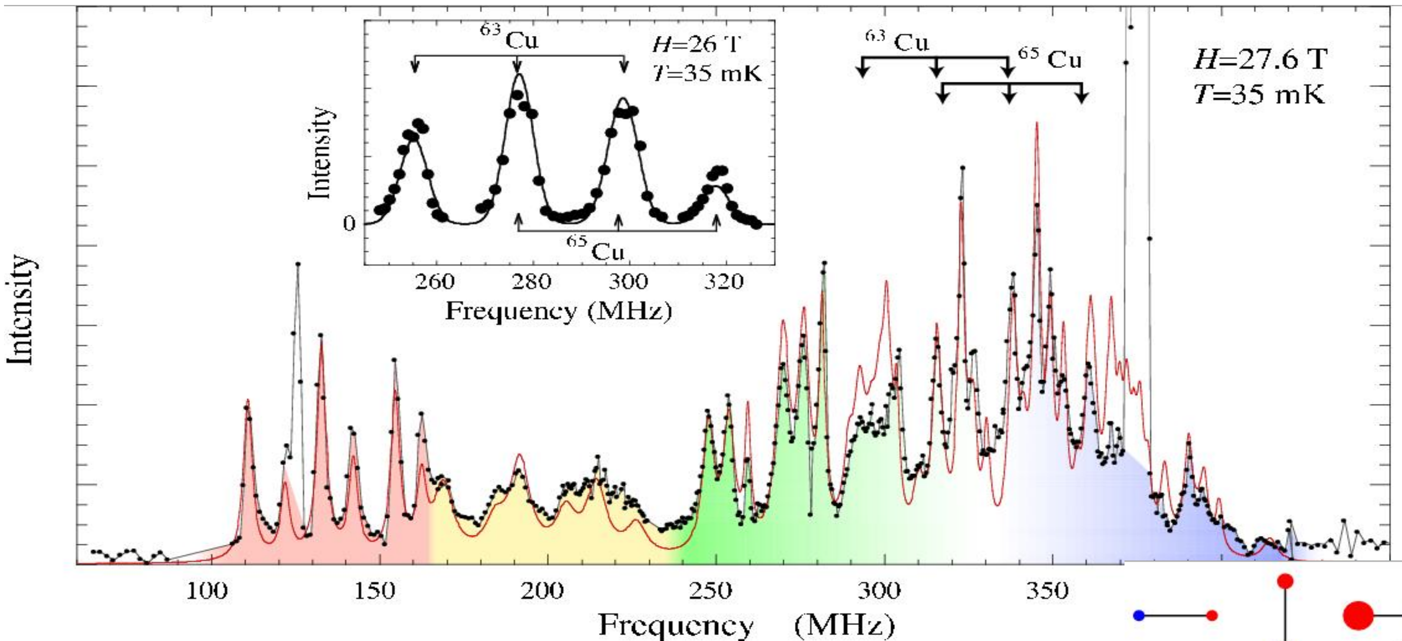
$SrCu_2(BO_3)_2$



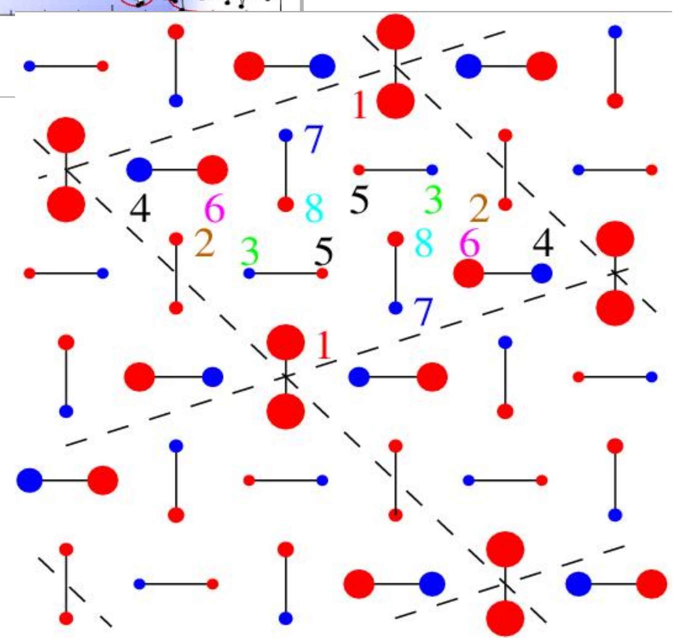
K. Kodama, M. Takigawa, M. Horvatic, C. Berthier, H. Kageyama, Y. Ueda, S. Miyahara, F. Becca, and F. Mila, *Science* **298**, 395 (2002).

Detecting and manipulating spins

Nuclear magnetic resonance



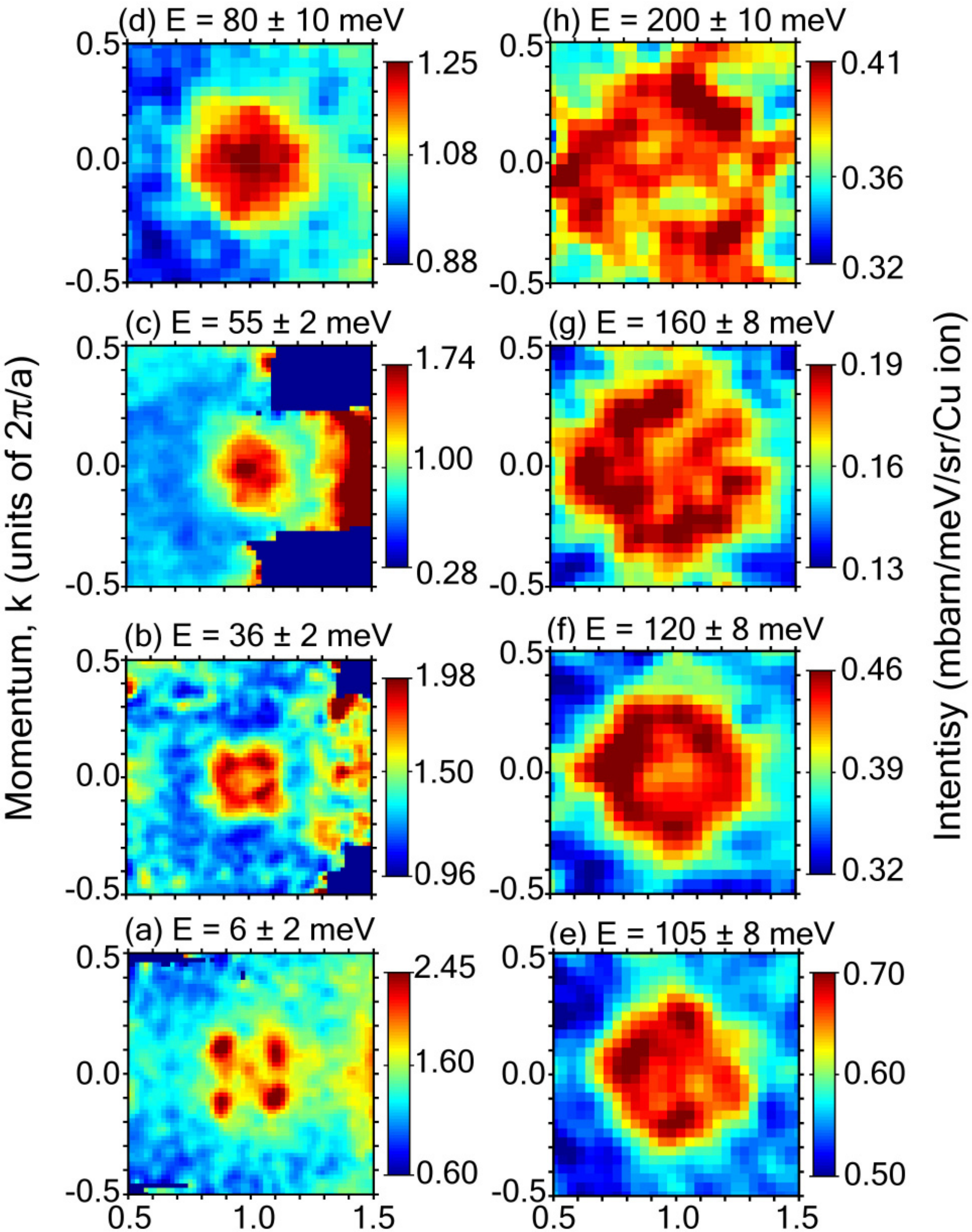
$SrCu_2(BO_3)_2$



K. Kodama, M. Takigawa, M. Horvatic, C. Berthier, H. Kageyama, Y. Ueda, S. Miyahara, F. Becca, and F. Mila, *Science* **298**, 395 (2002).

Future: moving spins around and measuring spin transport

Detecting and manipulating spins



Neutron scattering

High energy spin excitations in the cuprate superconductors

J. M. Tranquada *et al.*, *Nature* **429**, 534 (2004)

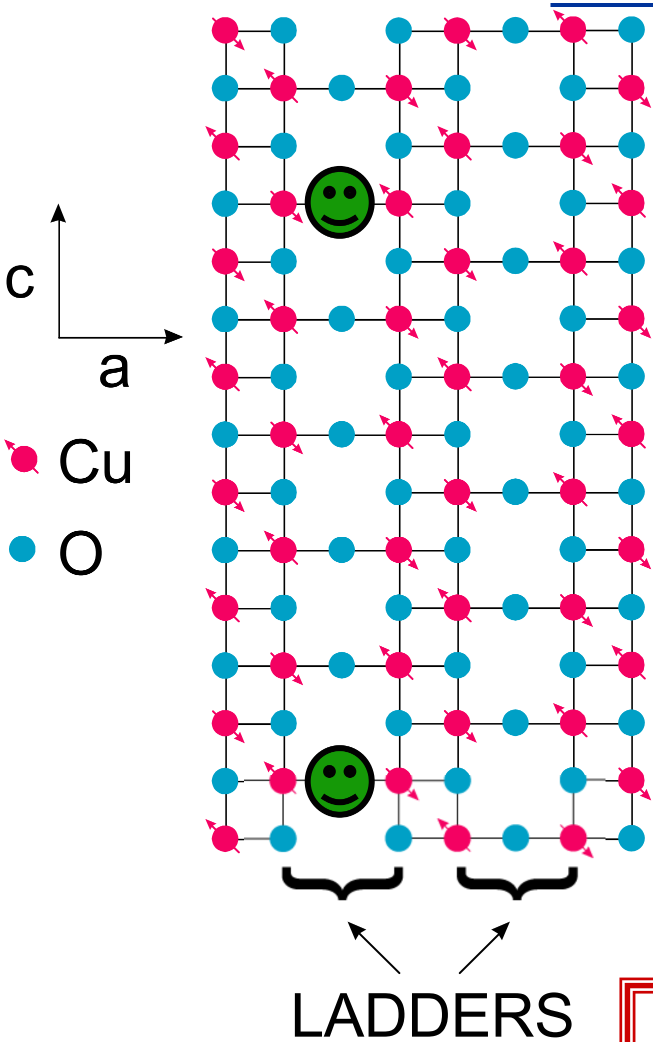
Detecting and manipulating spins

Spallation Neutron Source, Oak Ridge, Tennessee (2006)

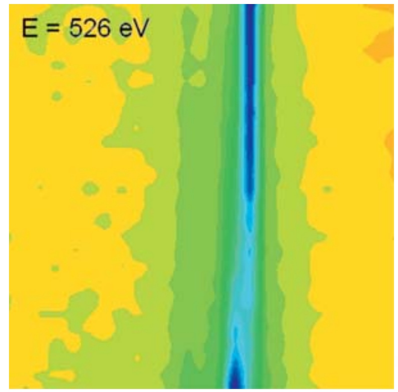
Future: better resolution will help distinguish distinct quantum paramagnets (spin liquids)

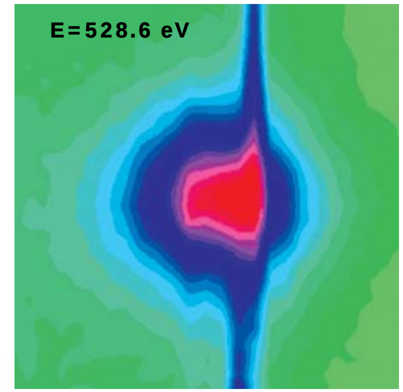
Detecting only the correlated electrons

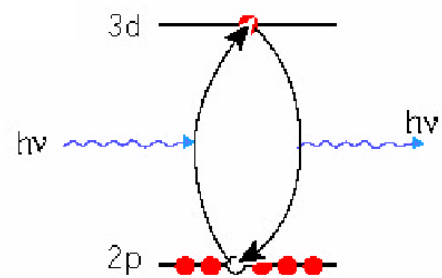
$Sr_{14}Cu_{24}O_{41}$



Resonant Soft X-ray Scattering (RSXS)







P. Abbamonte, G. Blumberg, A. Rusydi, A. Gozar, P. G. Evans, T. Siegrist, L. Venema, H. Eisaki, E. D. Isaacs, & G. A. Sawatzky, *Nature* (2004).

Future: Dynamic information rivaling that of neutron scattering

Insights into quantum matter from new experiments

Detecting new many body states will require:

- Atomic scale resolution of magnetic fields
- Measuring and manipulating electron spins
- Spatially resolved spectral information on charge dynamics

Future: New experiments will illuminate subtle quantum correlations in many body states, yield new surprises, and keep theorists honest.