Science with X-rays and Neutrons

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UCSD

PAC-11 NYC 2011

What are particle accelerators good for?

- Solving the structure of the atom and the nucleus
- Unraveling the secrets of the Universe
- Finding the Higgs Boson
- Transmuting radioactive materials
- Medical applications
- Providing Neutron and X-ray Beams for studying the properties of materials !!!

Partnerships

- IPNS   Bob Kustom,Yang Cho, Bob Martin, Charlie Potts, Frank Brumwell, Jack Carpenter, David Price
- NSLS Ken Green, Rena Chasman, Ari van Steenburgen, Martin Blume
- APS John Galayda, Rod Gerig,Mike Borland, Glenn Decker, David Moncton, Gopal Shenoy
- LCLS John Galayda, Keith Hodgson

Yes I Do Smile on Occasion

$$S(\mathbf{Q}, \omega) \sim [1-\exp(-\beta\,\omega)]^{-1}\, \mathrm{Im}\, \chi(\mathbf{Q}, \omega)$$

$$S(\mathbf{Q}) = \int d\omega\, S(\mathbf{Q}, \omega) = \left| \langle \rho\, (\mathbf{Q}) \rangle \right|^2$$

Brightness & Fluxes for Neutron & X-Ray Sources

	Brightness $(s^{-1}m^{-2}ster^{-1})$	dE/E (%)	Divergence $(mrad^2)$	Flux $(s^{-1}m^{-2})$
Neutrons	10^{15}	2	10×10	10^{11}
Rotating Anode	10^{20}	0.02	0.5×10	5×10^{14}
Bending Magnet	10^{27}	0.1	0.1×5	5×10^{20}
Undulator (APS)	10^{33}	10	0.01×0.1	10^{24}

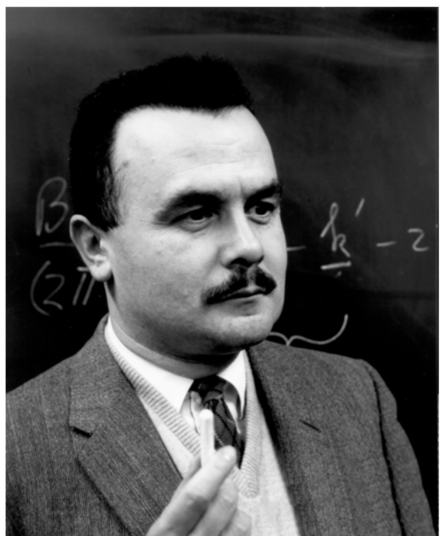
Neutron Advantages

- Penetrating, but does no damage to sample
- H/D contrast matching can be used to study macromolecules in solution, polymers, etc.
- Strongly interacts with magnetic moments
- Energies match those of phonons, magnons,rotons, etc.

Nobel Prize in Physics, 1994

Awarded for “pioneering contributions to the development of neutron scattering techniques for studies of condensed matter”

Bertram N. Brockhouse

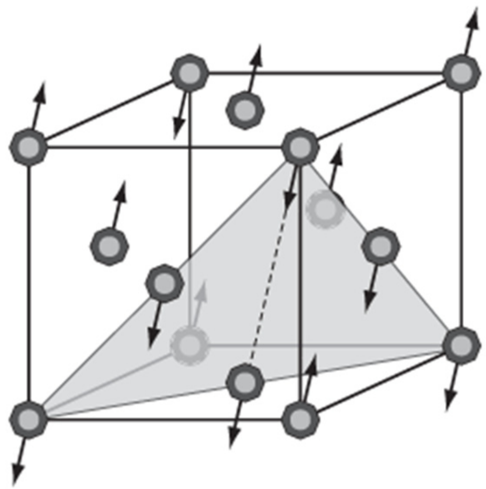


Development of
neutron spectroscopy

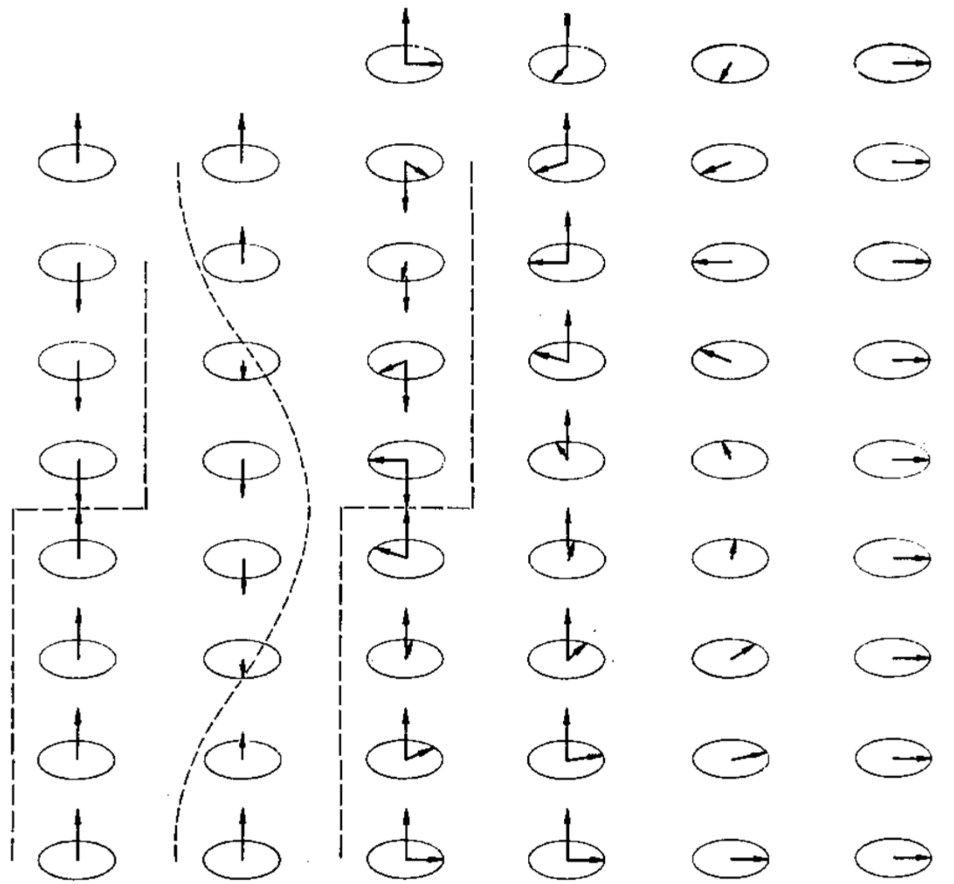
Clifford G. Shull

Development of the
neutron diffraction technique

First Study of an Antiferromagnetic Structure



Antiferromagnetic Structure of MnO
(Shull and Wollan Phys. Rev. 83, 333 (1951)



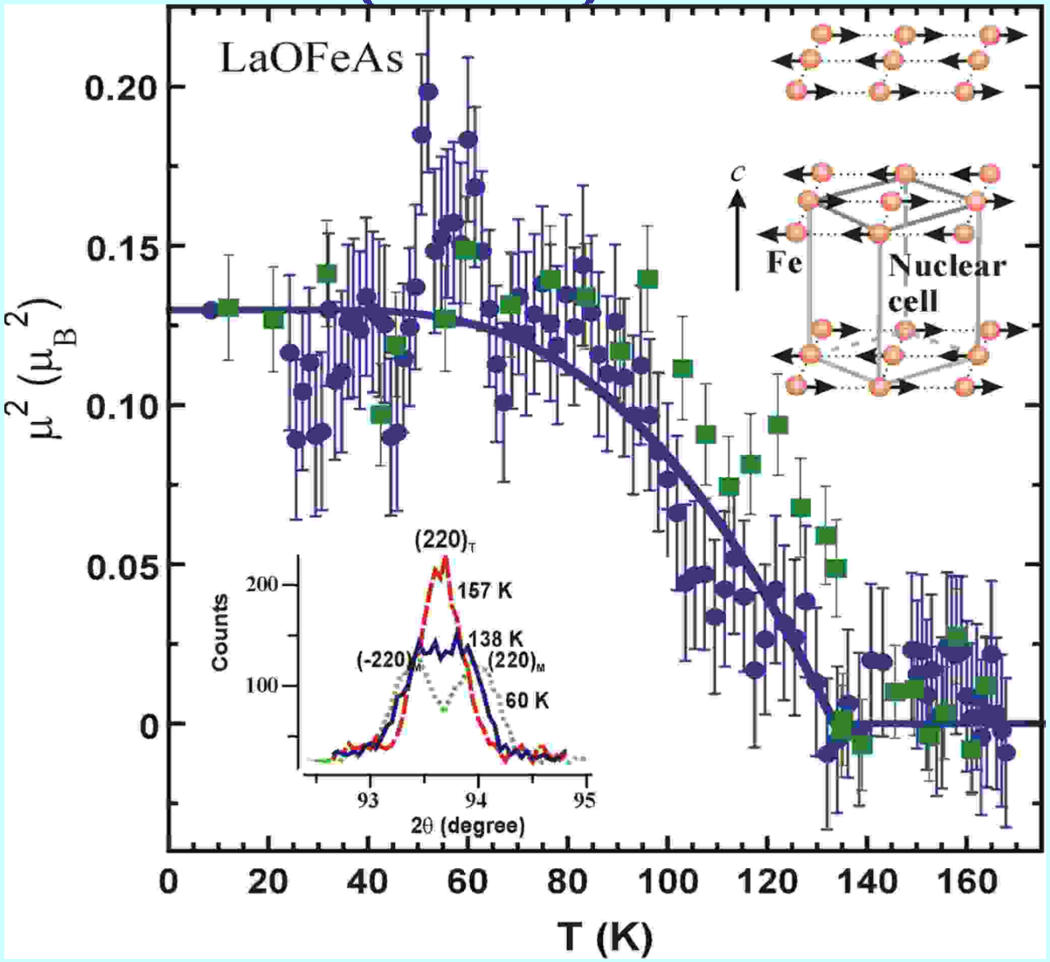
Magnetic Structure of the Rare Earth Metals
(W.C. Koehler (1965))

QuickTime™ and a
decompressor
are needed to see this picture.

Spin Structure of Cu ions in La2CuO4

Vaknin et al., PRL 1987

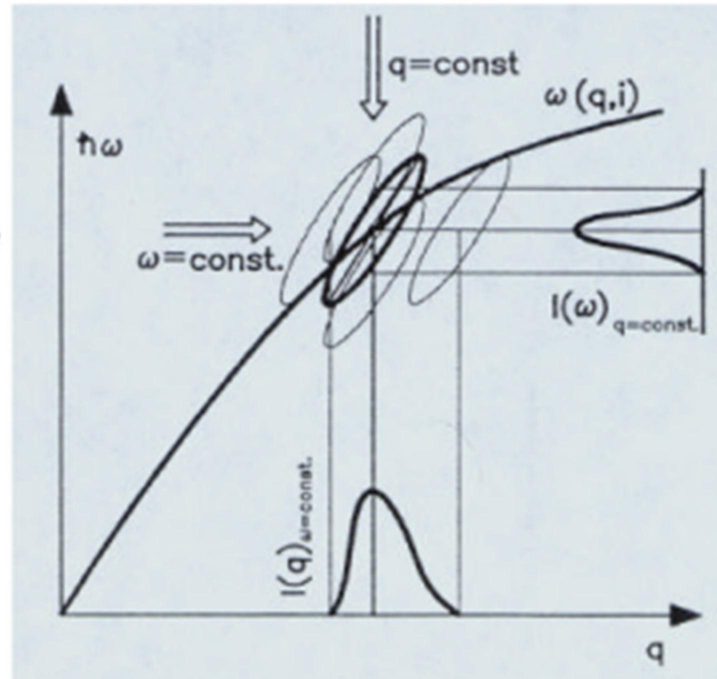
Magnetic Structure La(O,F)FeAs

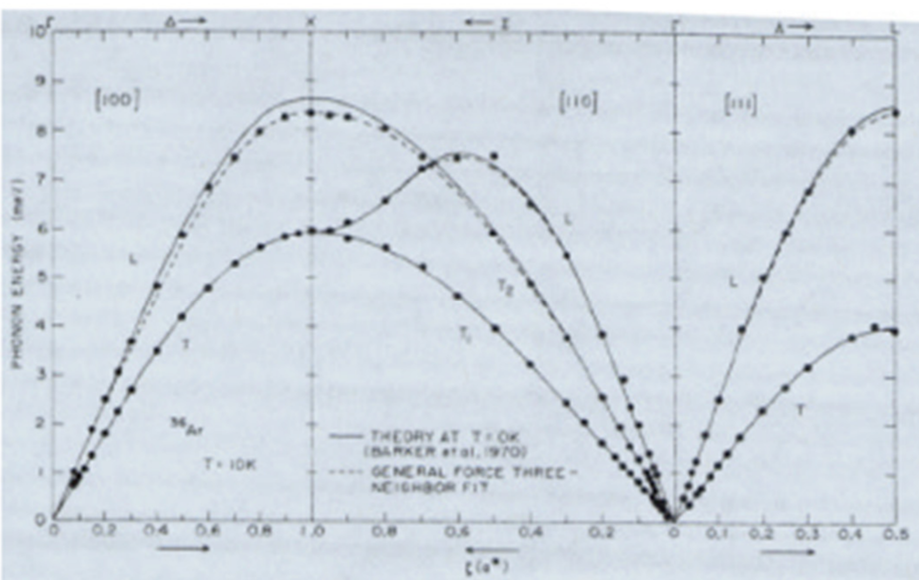


Magnetic Order Close to Superconductivity in the Iron-based Layered La($O_{1-x}F_x$)FeAs systems, C. de la Cruz, Q. Huang, J. W. Lynn, J. Li, W. Ratcliff II, J. L. Zarestky, H. A. Mook, G. F. Chen, J. L. Luo, N. L. Wang, and P. Dai, P. Dai, *Nature* **453**, 899 (2008).

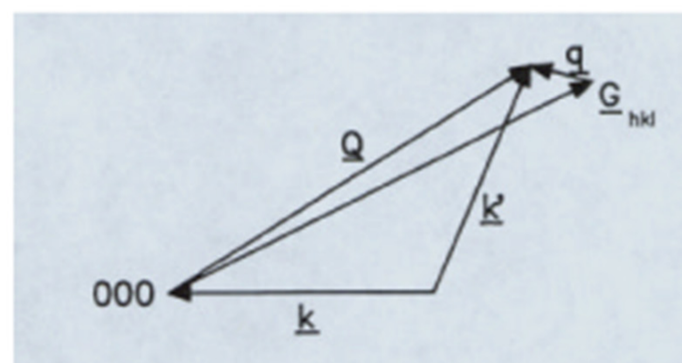
Triple Axis Spectrometers Have Mapped Phonons Dispersion Relations in Many Materials

- Point by point measurement in (Q,E) space
- Usually keep either k_I or k_F fixed
- Choose Brillouin zone (I.e. G) to maximize scattering cross section for phonons
- Scan usually either at constant-Q (Brockhouse invention) or constant-E

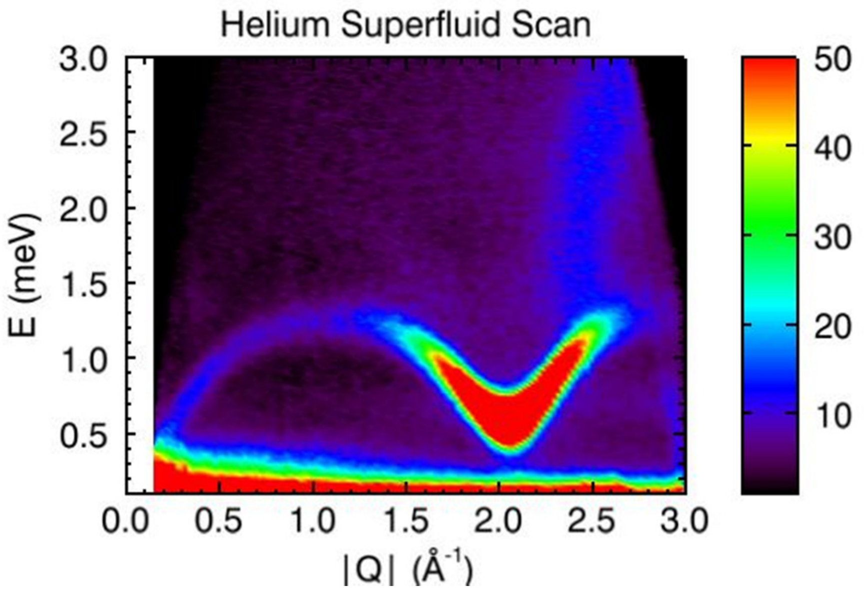




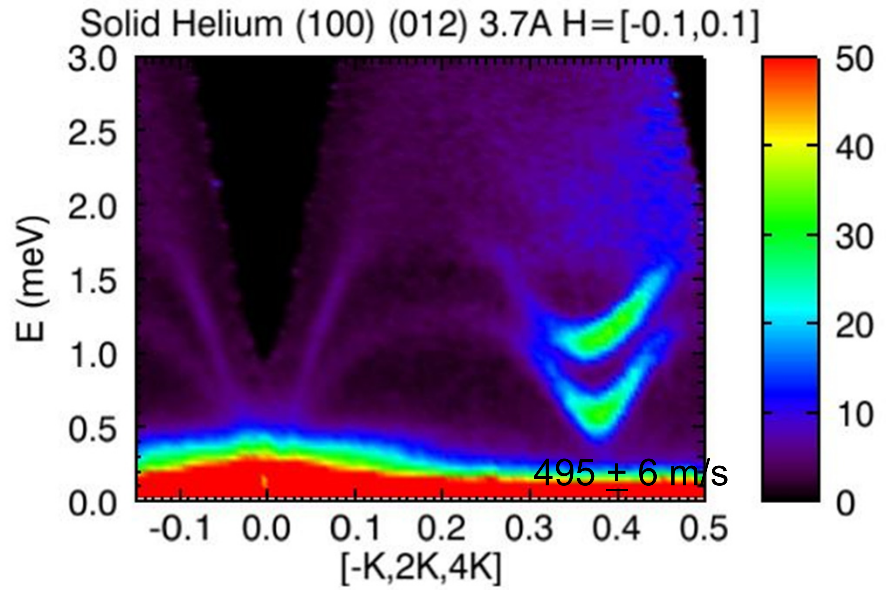
Phonon dispersion of ^{36}Ar

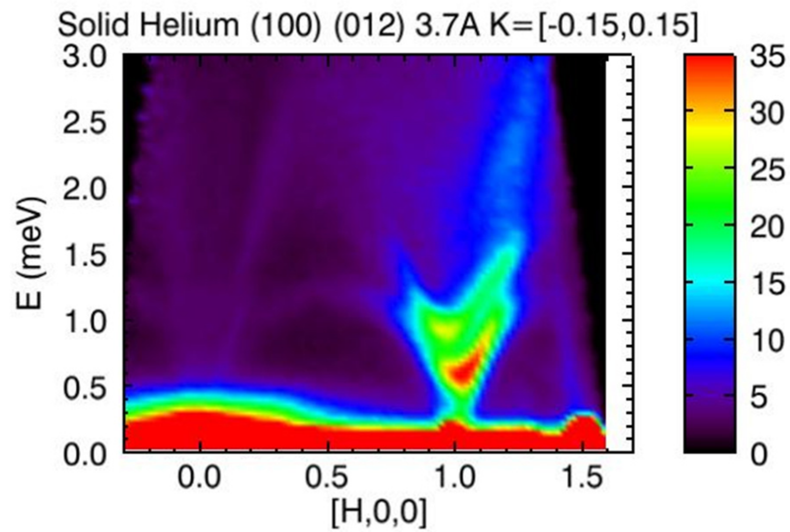


Superfluid at melting Point

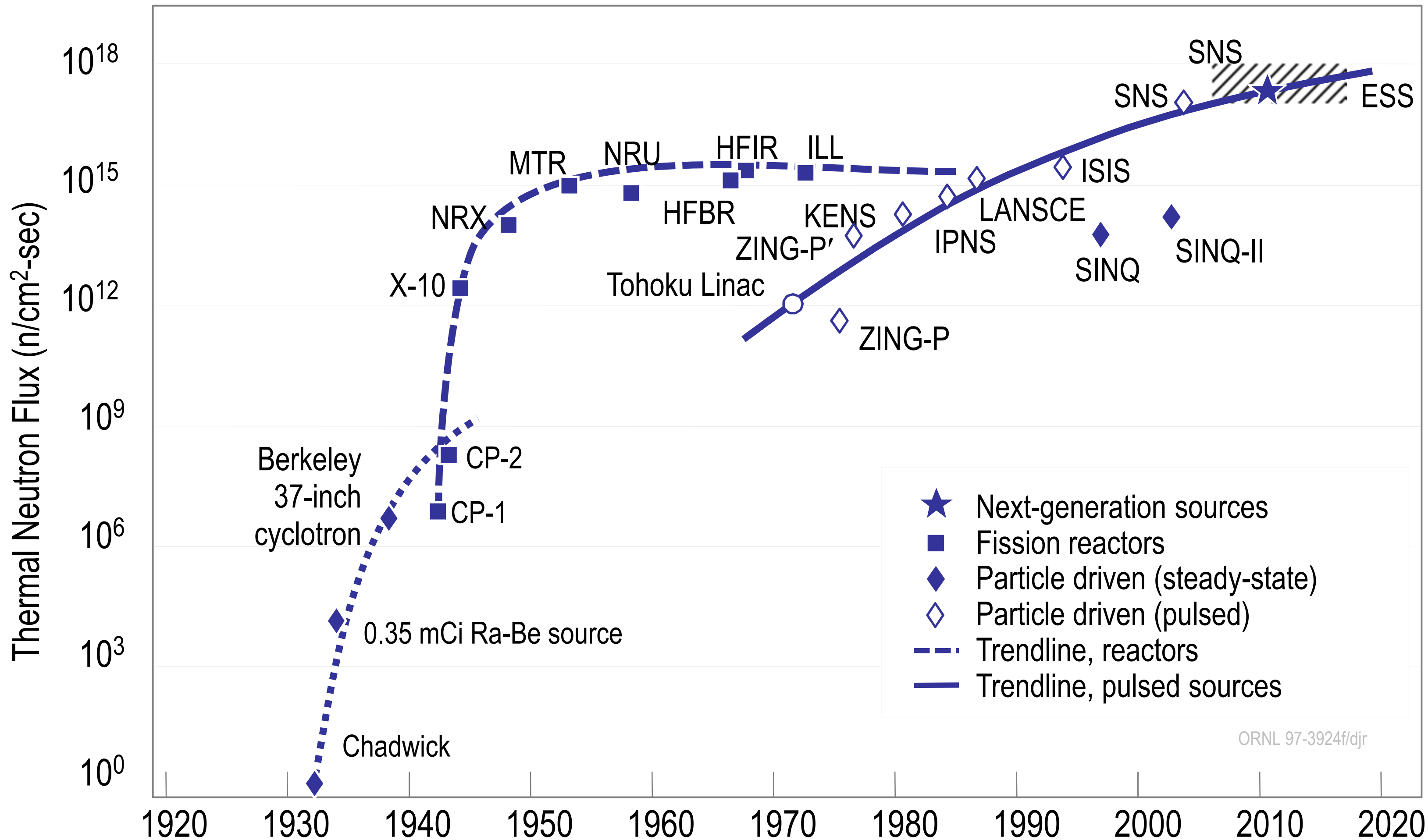


Solid and liquid at melting



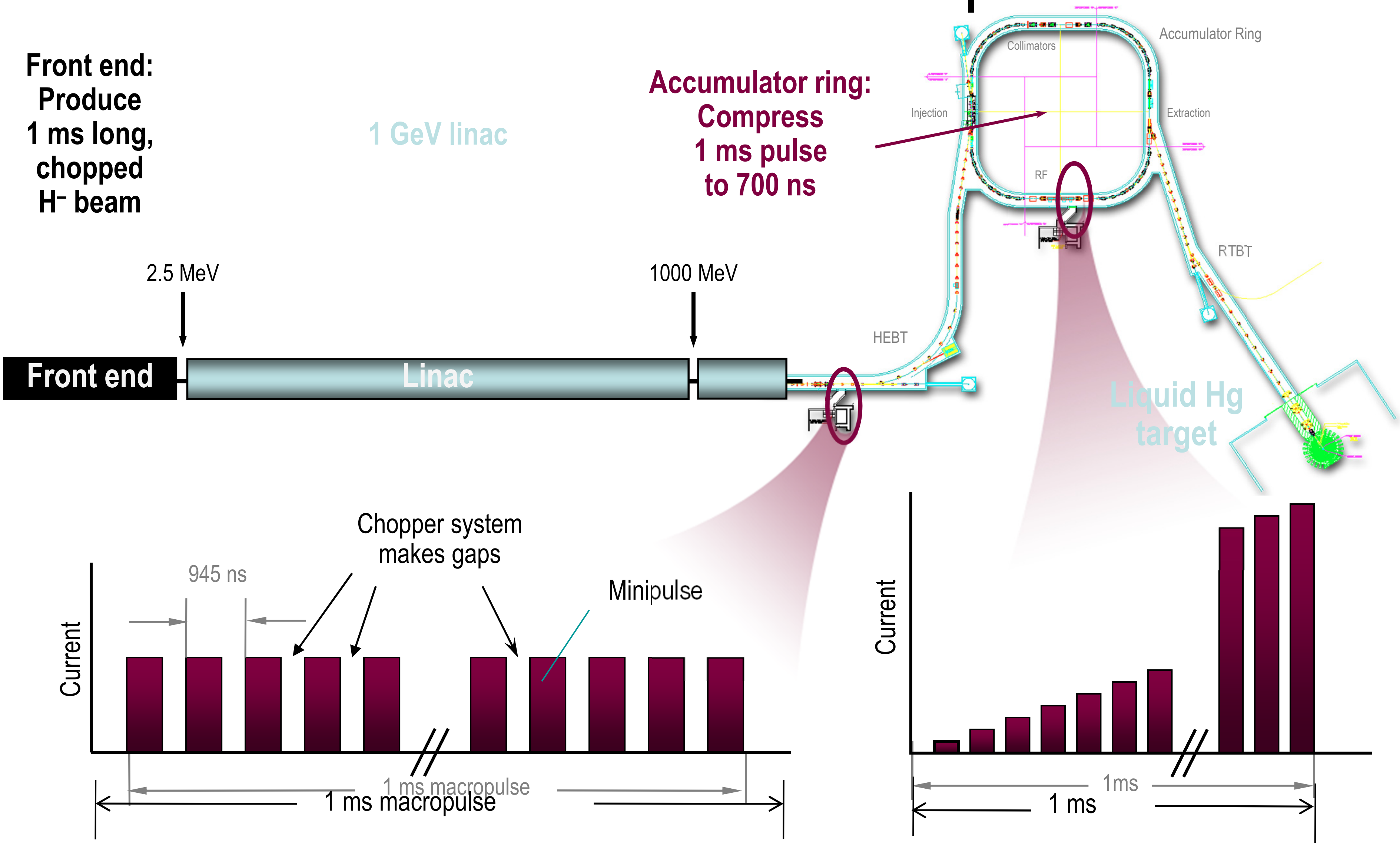


We have come a long way since 1932

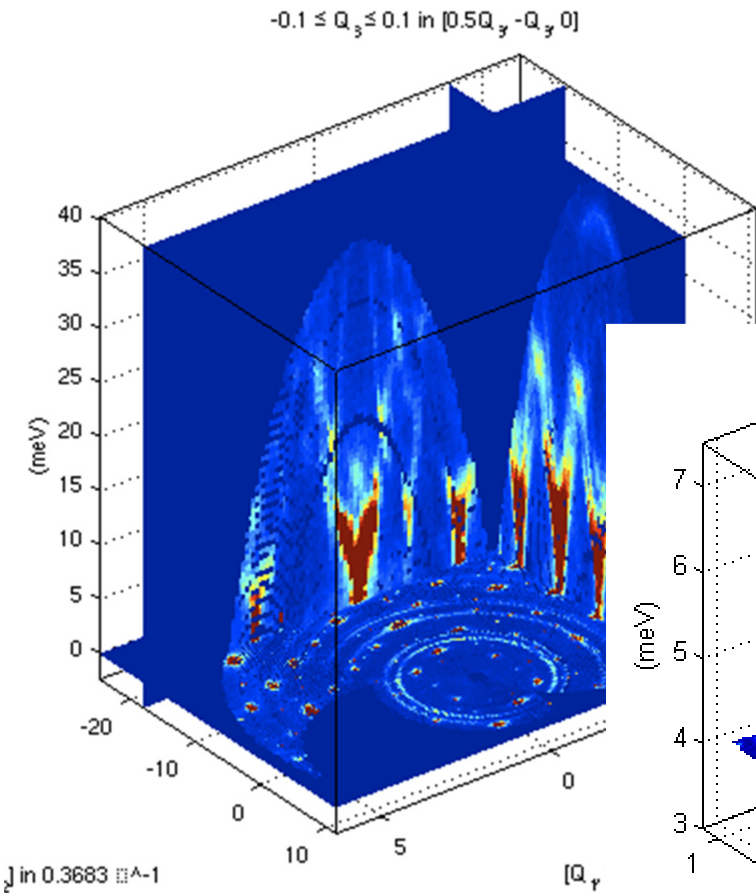


(Updated from *Neutron Scattering,* K. Skold and D. L. Price: eds., Academic Press, 1986)

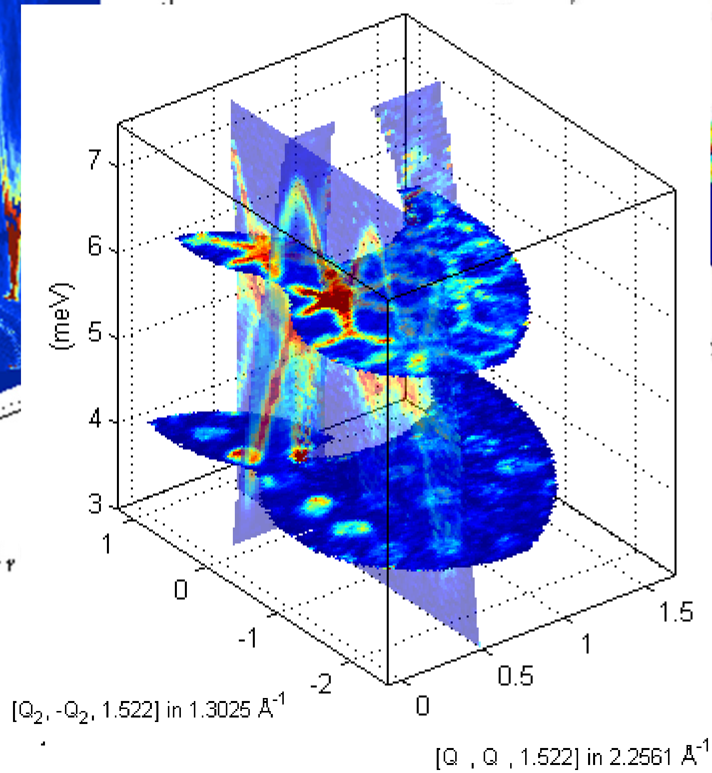
SNS Accelerator Complex



Complete measurements of S(Q,ω) measurements on MERLIN spectrometer at ISIS

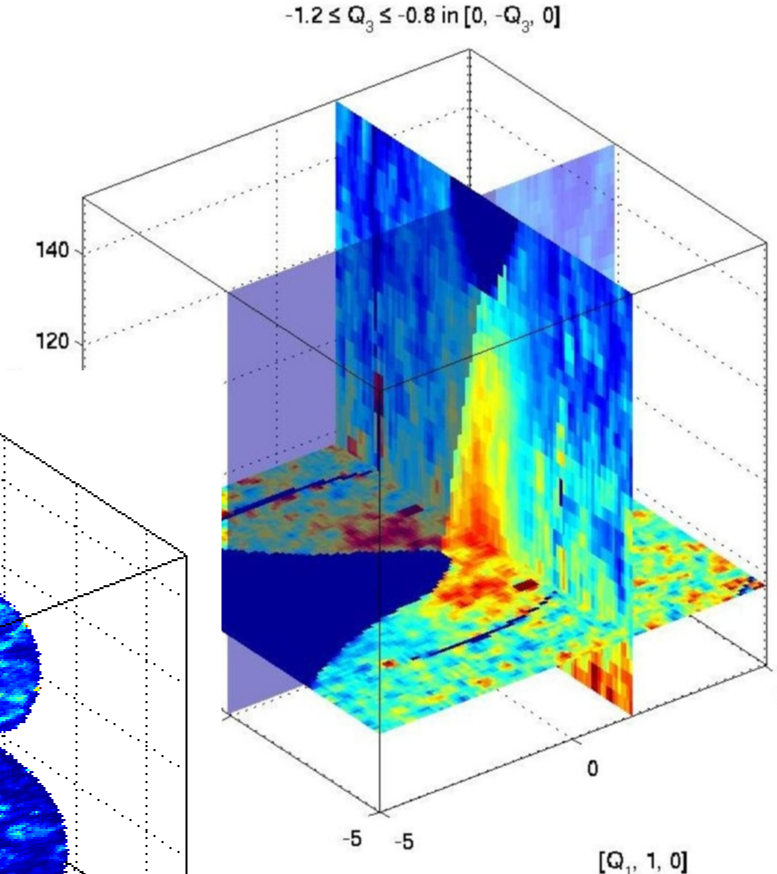


Calcite
(Dove, Cope)



$Sr_3Cr_2O_8$
(Lake)

6g crystal S=1/2

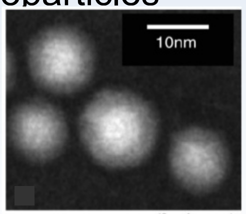


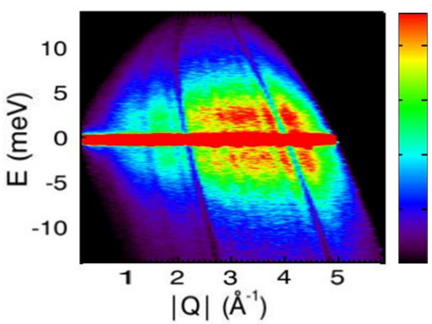
MnSi
(Perring, Ewings)

Impacting a broad range of science

Nanoscience

First observations of conventional spin waves in nanoparticles

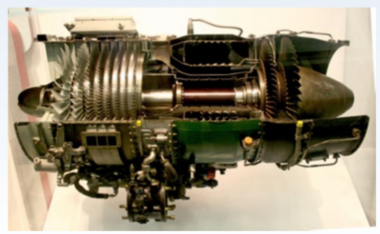


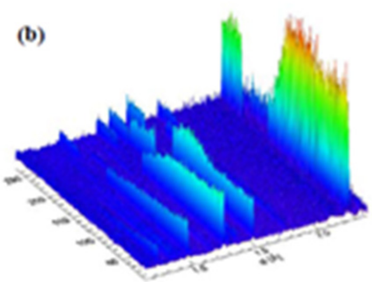


Feygenson et al.,
Phys. Rev. Lett. (submitted)

In situ imaging for industry

Providing industry with a look inside real materials

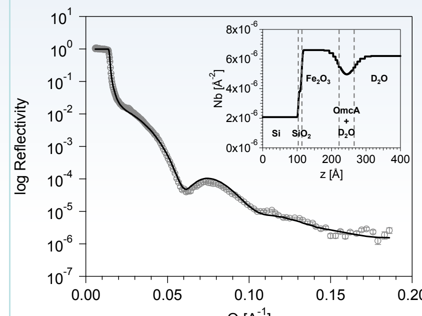


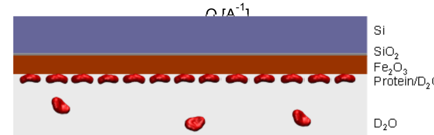


Ma et al.,
Scripta Mat. (submitted)

Bioremediation

Probing molecular interactions between microbial-cell protein and mineral surfaces

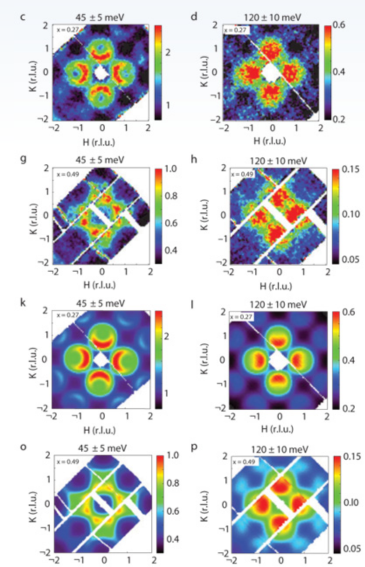




Johs et al., *Biophys. J. 98, 3035* (2010)

Superconductivity

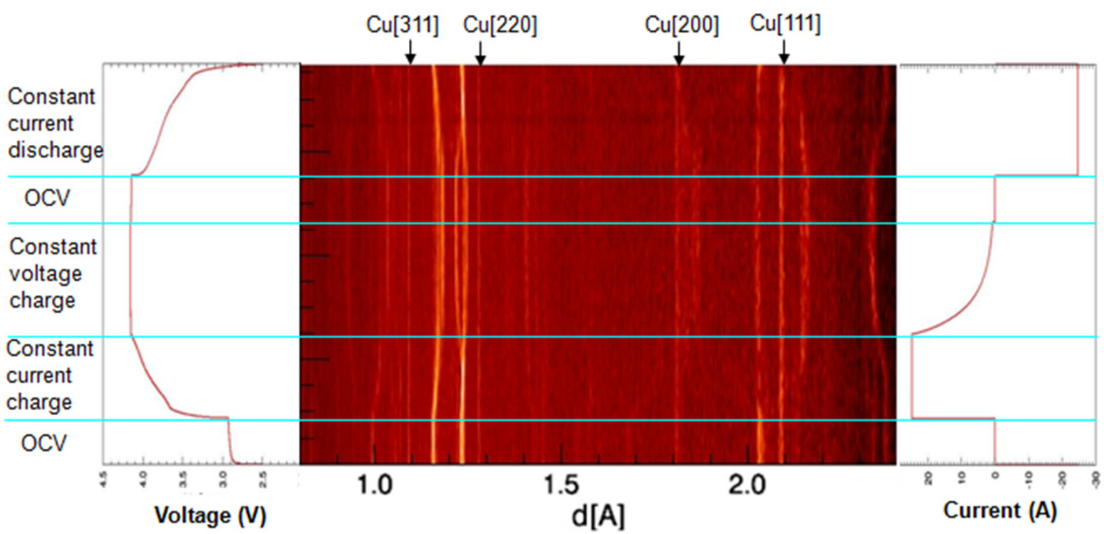
Evolution of spin excitations in superconductors: Strong evidence that superconductivity is related to magnetic interactions

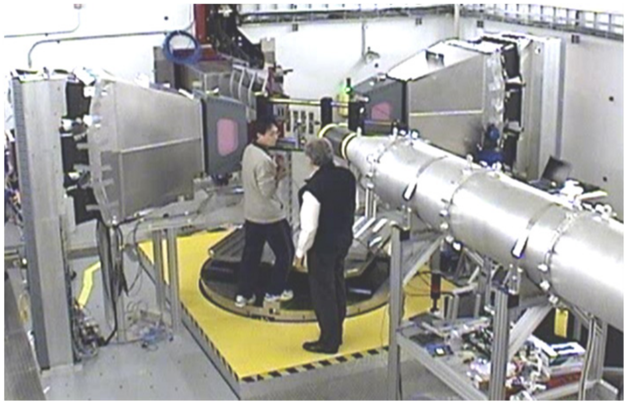


Lumsden et al, *Nature Phys.* 6, 182 (2010)

Pushing the limits: Single pulse diffraction

- In-situ study of structure evolution of Li-ion battery
  - Structure changes are clearly established
  - Time resolution for the present data ~ 2 min, but this could easily be reduced to seconds
  - A new phase forms and dissolves during charge-discharge; more detailed analysis is under way
  - Time-resolved spatial mapping is possible

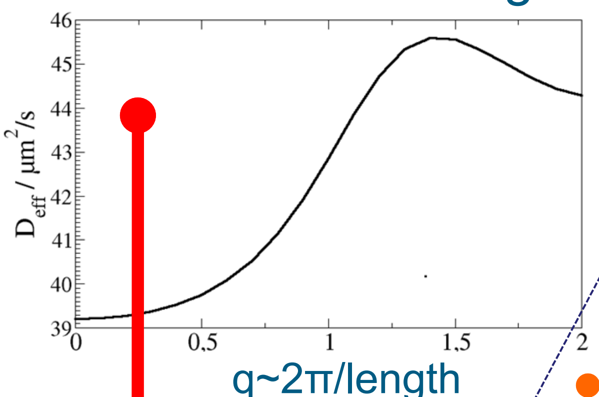


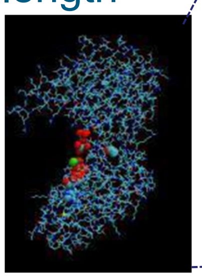


Functional domain dynamics in proteins

NSE

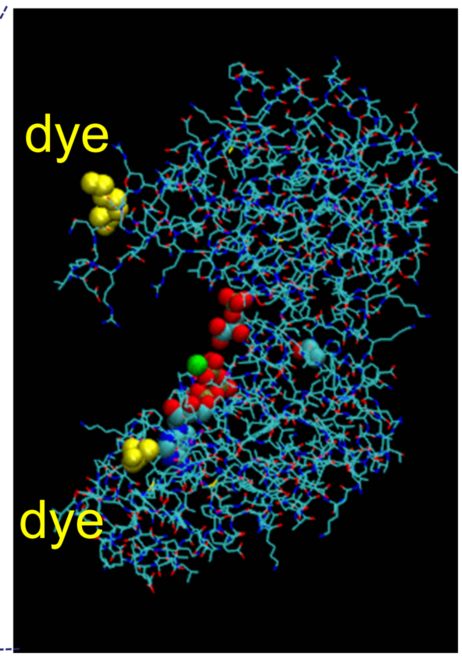
0.5-50 nm length scale
ps - µs time scale
orientational average





FRET

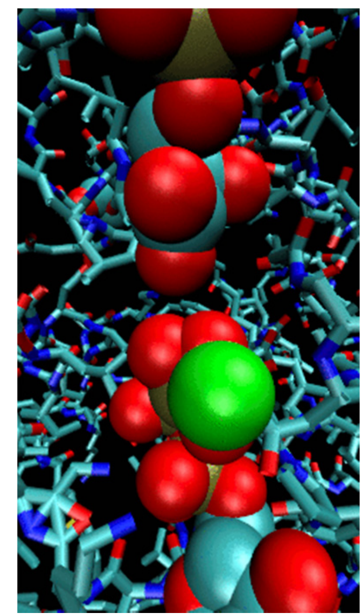
fixed defined position
> µs timescale



phosphoglycerate kinase

NMR

ps - ms timescale
small proteins



Science with X-Rays

- Diffraction and crystal structures
- Structure Factors of liquids and glasses
- Structures of Thin Films
- ARPES
- EXAFS, XANES
- Studies of Magnetism with resonant XMS
- Inelastic X-ray scattering: phonons, electronic excitations
- X-ray Photon Correlation Spectroscopy
- Microscopy
- Imaging/Tomography

Compare the evolution of high intensity optical and x-ray sources

Hign-intensity at optical wavelengths

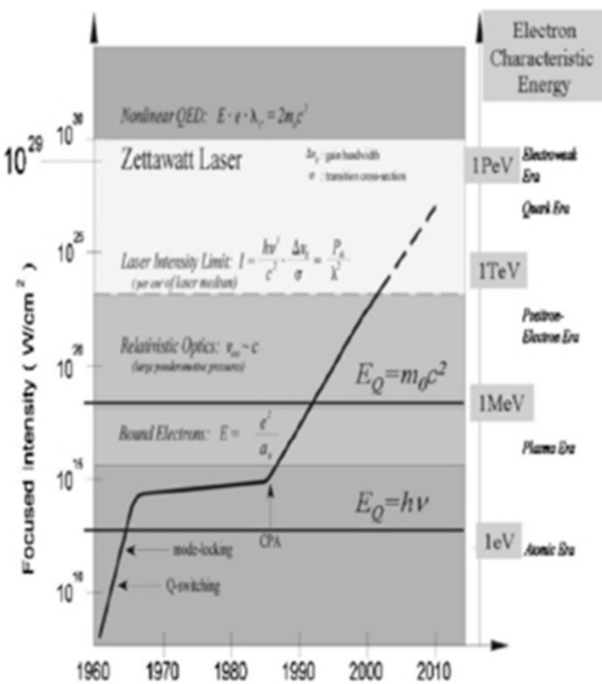
- high harmonic generation
- tabletop coherent x-ray radiation
- attosecond pulses

High-intensity at x-ray wavelengths

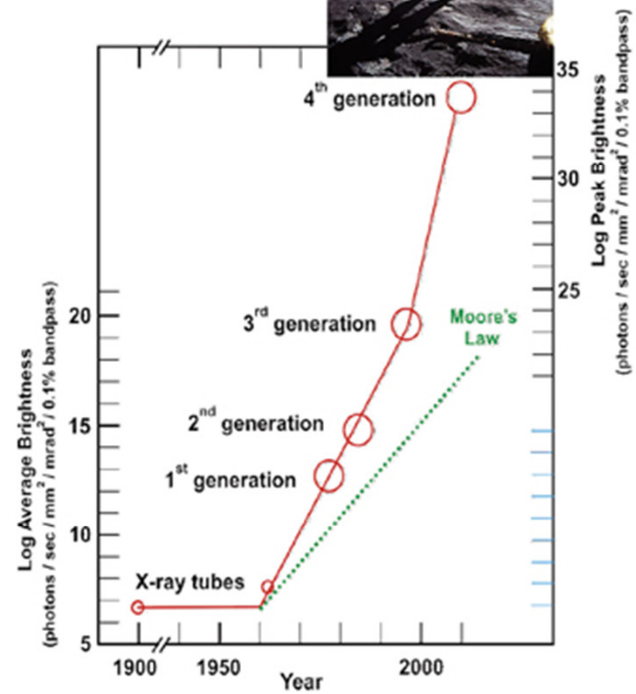
?

?

?



G. Mourou RMP 2006



D. Moncton, George Brown

Example 1: X-Ray Diffraction & structural biology

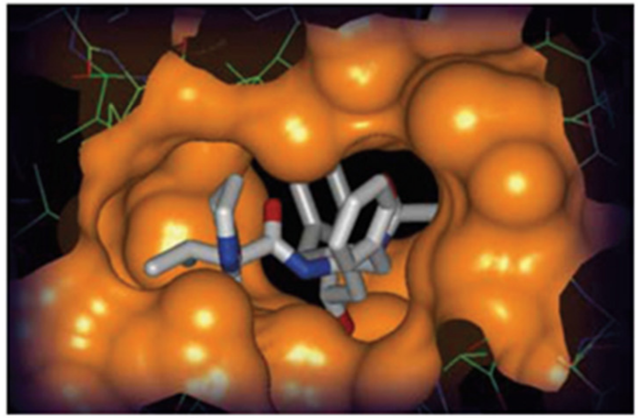
- D.C. Phillips presents the 3-D structure of lysozyme to the Royal Society in **1965**
- Linear polypeptide chain
- Folded model of the same amino acid sequence
- July 2009: 58,588 structures in Protein Data Bank

A single protein structure used to be the project of a scientific lifetime

Synchrotron Radiation - 8301 structures solved in 2009

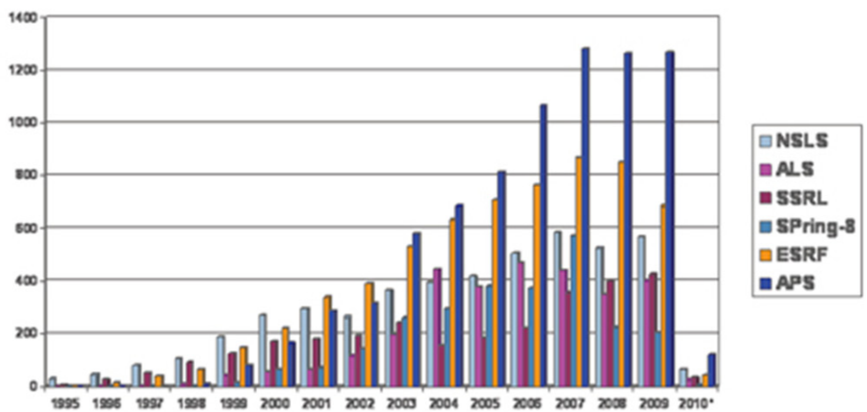
Synchrotron research on proteins has led to major advances in drugs to battle infection, HIV, cancer

Renal cancer drug pazopanib™ developed in part based on APS research (GlaxoSmithKline)



Close-up view of the drug binding site within HIV protease (Kaletra®, Abbott).

Ramakrishnan, Steitz and Yonath
2009 Chemistry Nobel Laureates



APS protein structure output is almost twice that of any other light source

X-rays dominant in protein structure determinations

WORLDWIDE PDB PROTEIN DATA BANK

Snapshot: July 1, 2009

58,588 released atomic coordinate entries

Molecule Type

54,141	proteins, peptides, and viruses
2,033	nucleic acids
2,381	protein/nucleic acid complexes
33	other

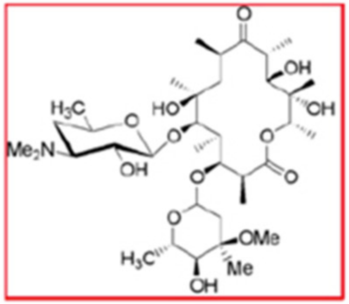
Experimental Technique

50,284	X-ray
7,914	NMR
243	electron microscopy
17	hybrid
130	other

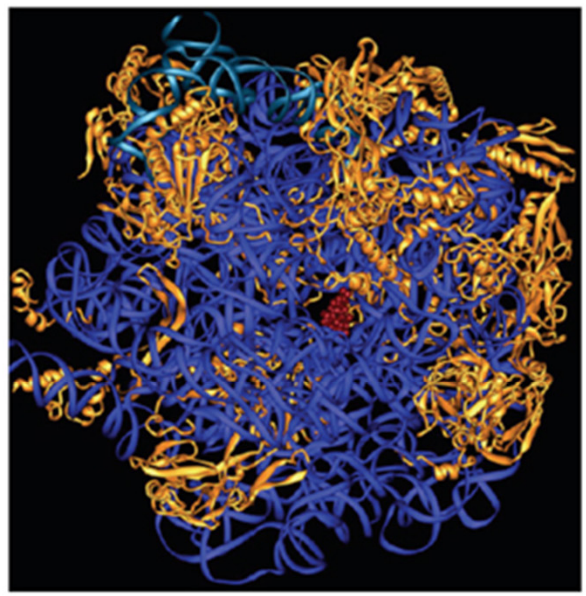
Year	Total Depositions
2000	2983
2001	3286
2002	3563
2003	4830
2004	5508
2005	6678
2006	7282
2007	8130
2008	7073
2009	8301
2010	1952
TOTAL	59586

Designing antibiotics –

difference between bacterial and eukaryotic ribosomes is one amine group in the 2.5MD ribosome

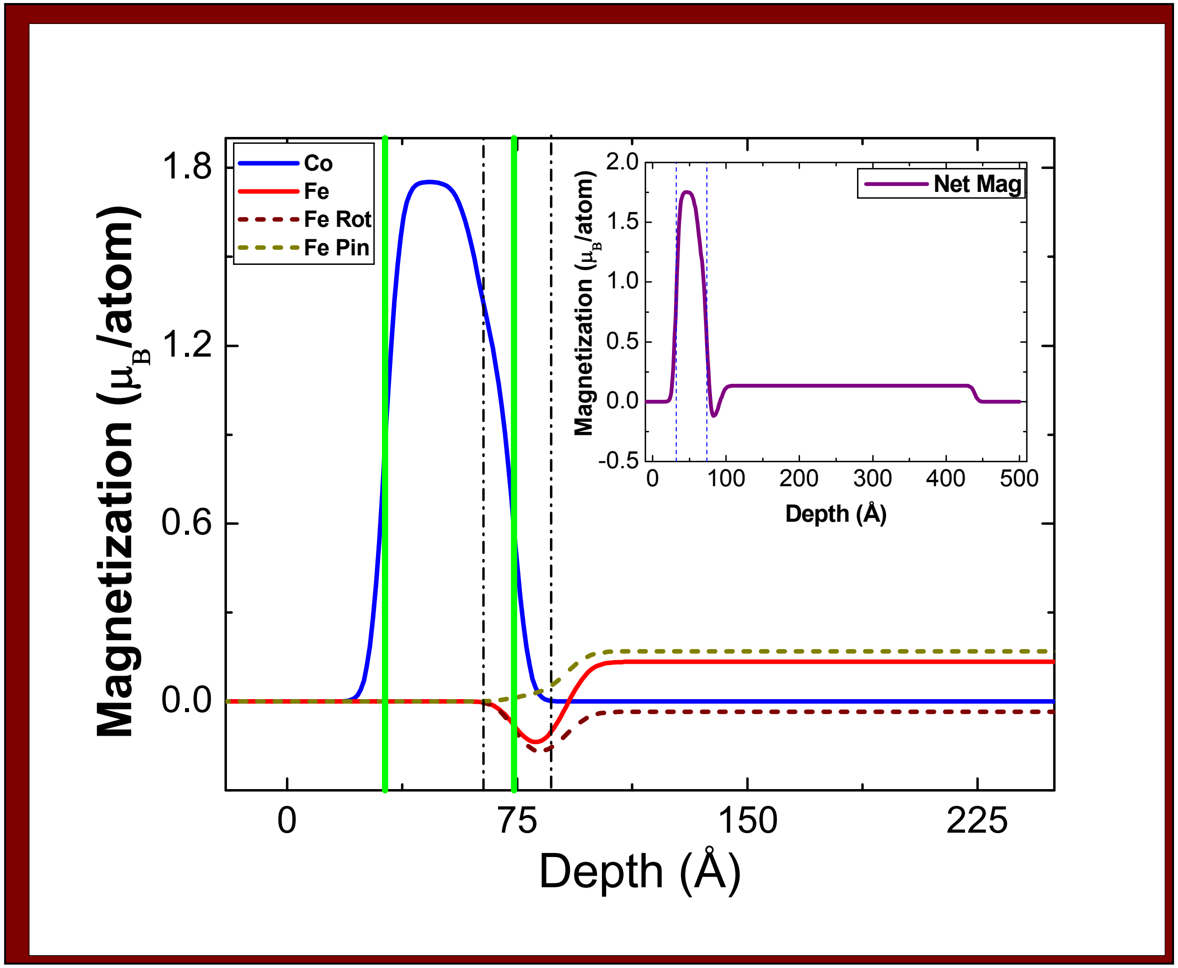


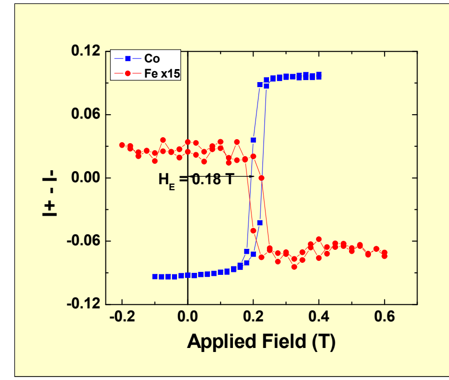
Erythromycin – a macrolide antibiotic that blocks protein synthesis by binding to bacterial ribosomes but not to eukaryotic ribosomes

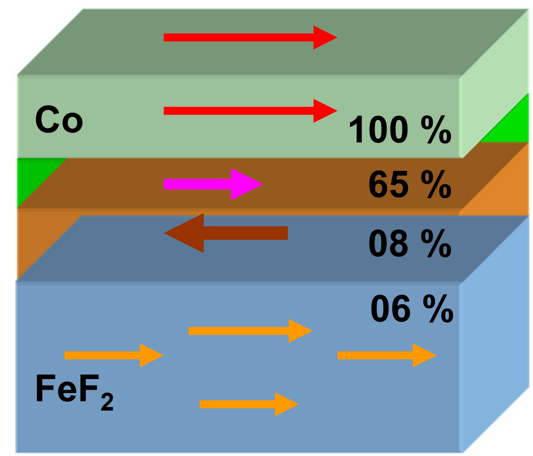


www.molgen.mpg.de

Depth Dependent Magnetic Density Profile

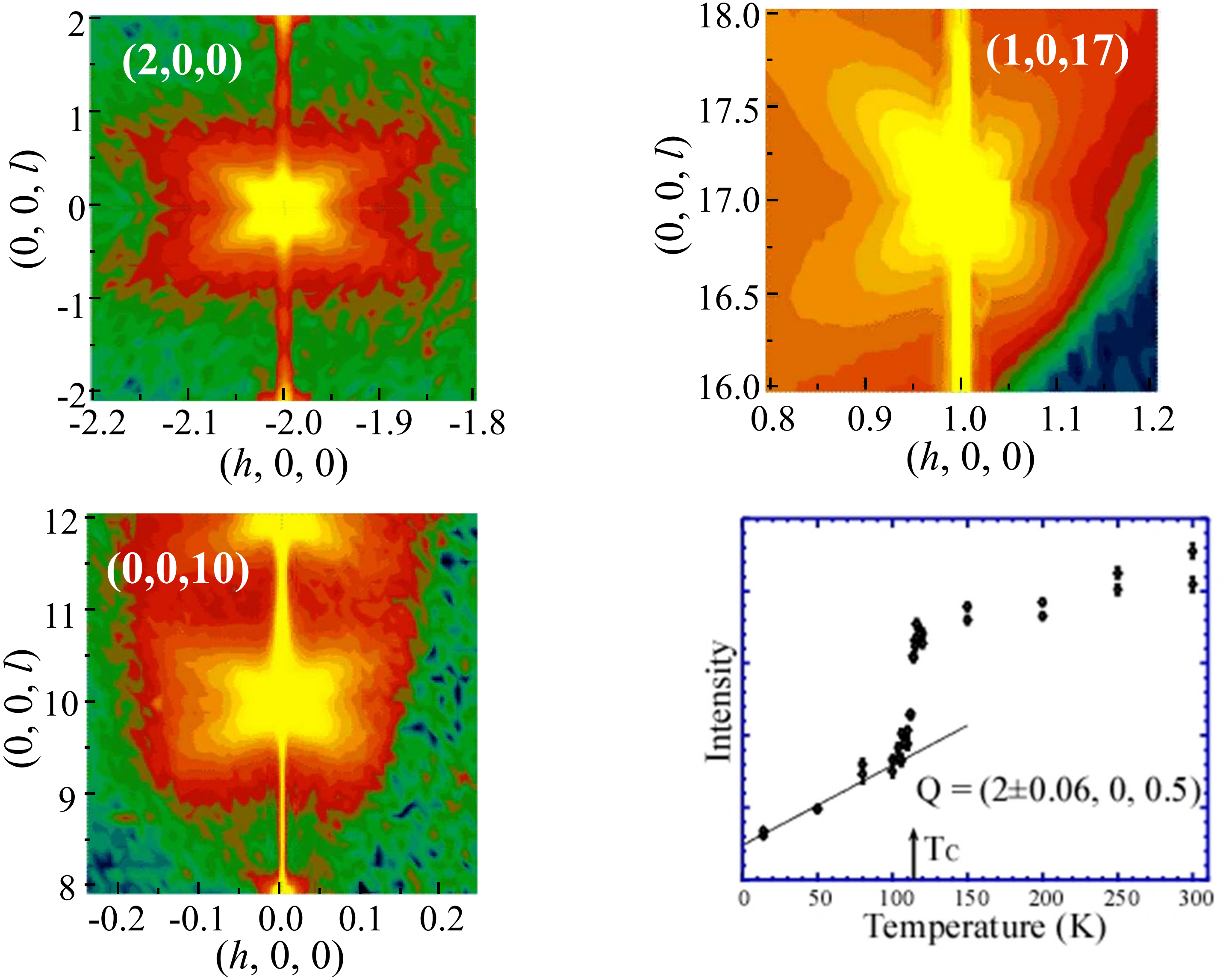




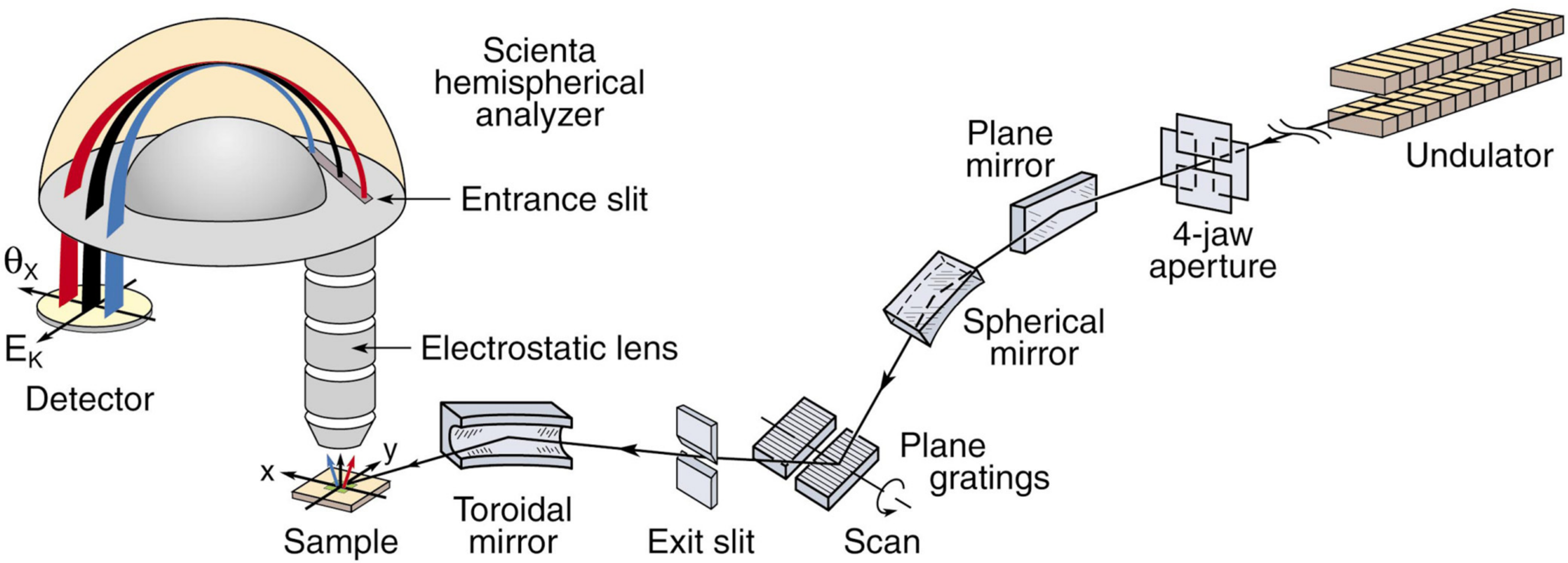


Exchange bias due to exchange interaction between Fe pinned and Fe rotating moments which is then mitigated across the Co/FeF_2 interface
Decreasing field is favorable to reversal and hence positive EB effect

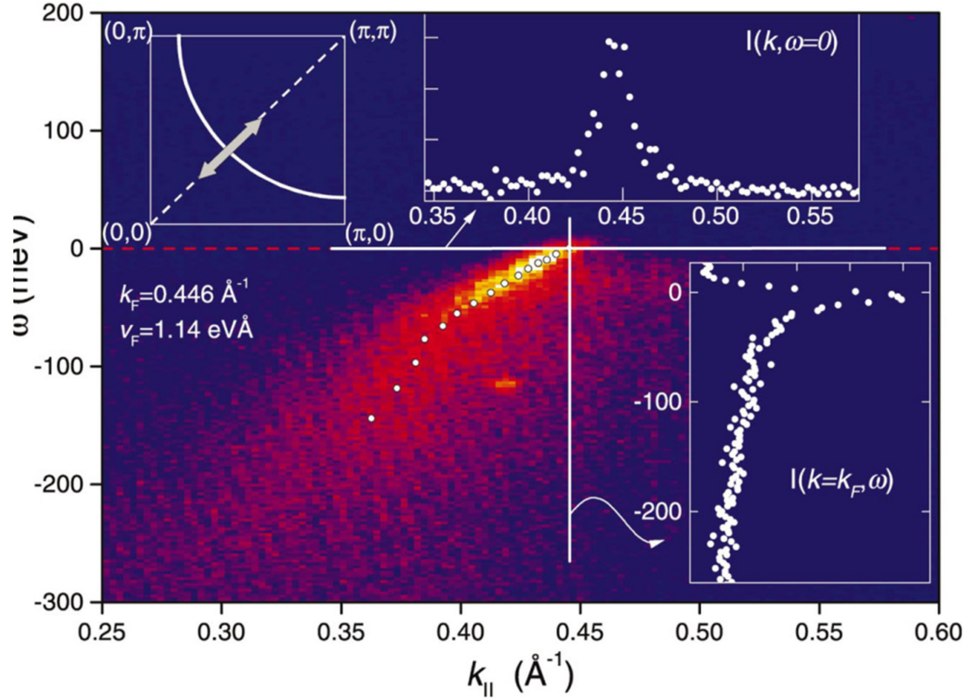
Polarons via single-crystal diffuse scattering



L. Vasiliu-Doloc *et al.*, PRL **83**, 4393 (1999).



IG. 6. Generic beamline equipped with a plane grating monochromator and a Scienta electron spectrometer (Color).

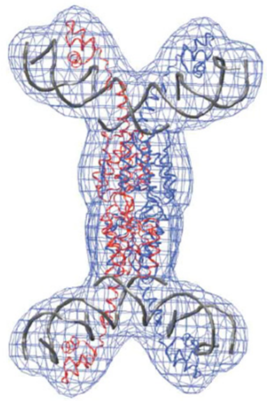


IG. 7. Energy (ω) vs momentum ($\mathbf{k}_{\|}$) image plot of the pho- ›emission intensity from $Bi_2Sr_2CaCu_2O_{8+\delta}$ along (0,0)-(π,π). his k-space cut was taken across the Fermi surface (see ketch of the 2D Brillouin zone upper left) and allows a direct sualization of the photohole spectral function $A(\mathbf{k},\omega)$ (al- 10ugh weighted by Fermi distribution and matrix elements). he quasiparticle dispersion can be clearly followed up to E_F, ; emphasized by the white circles. Energy scans at constant 10mentum (right) and momentum scans at constant energy 1pper right) define *energy distribution curves* (EDC's) and *omentum distribution curves* (MDC's), respectively. After alla, Fedorov, Johnson, Wells, *et al.*, 1999 (Color).

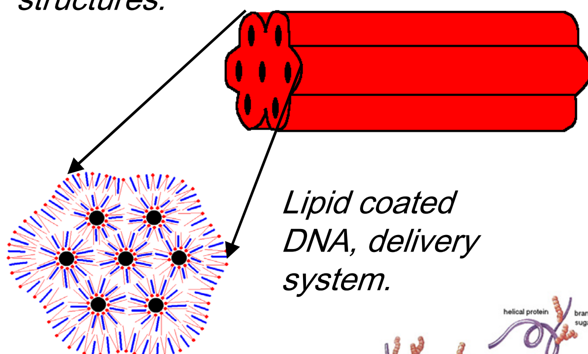
People want pretty pictures (in Space and Time!)

The TS2 Science Case

- Bio-Science

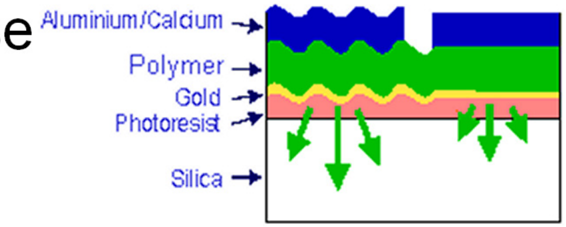


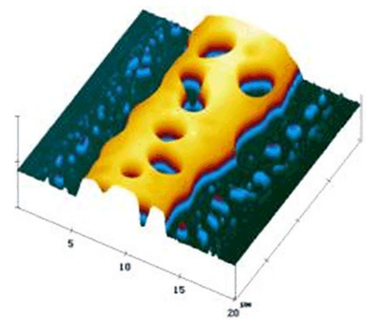
Overall size & shape of Tn3 resolvase (protein) – DNA complex, using neutron & X-ray contrasts plus known crystal structures.

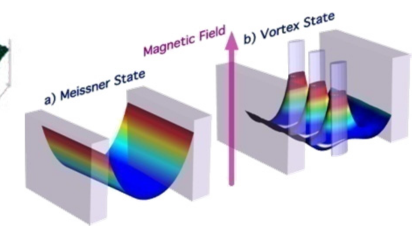


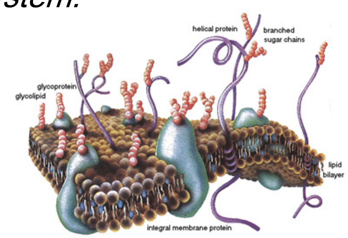
Lipid coated DNA, delivery system.

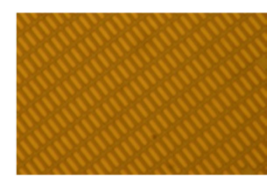
- Advanced Materials

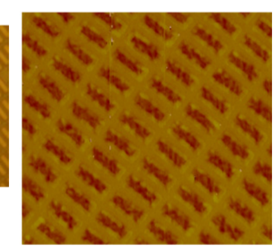


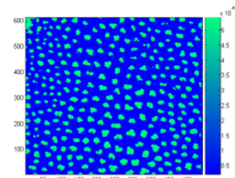


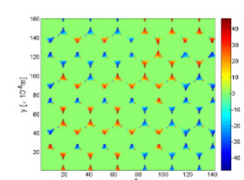


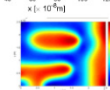




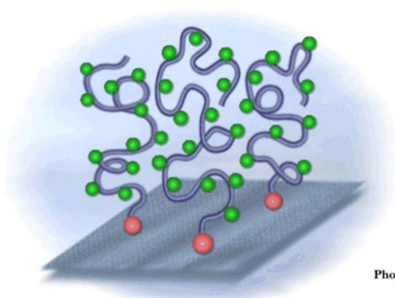


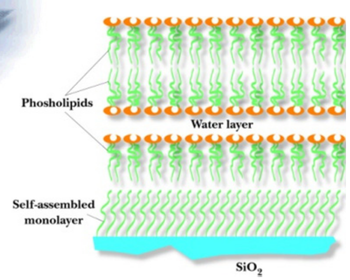






- Soft Matter



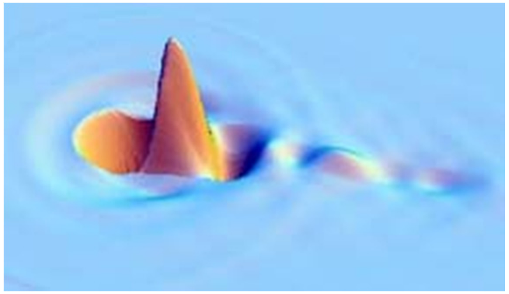


X-Rayed Movie http://focus.aps.org/files/18925_vid_v13_st25_1.mov

P. Abbamonte/Brookhaven National Lab Phys. Rev. Lett. **92**, 237401

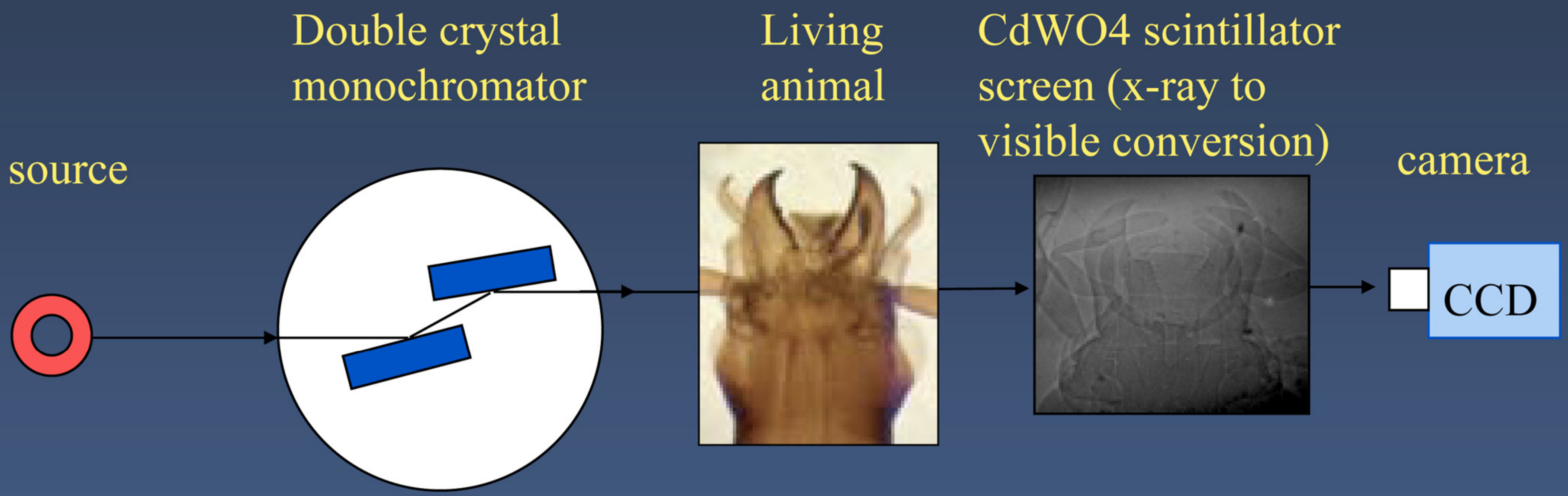
Ripple effect. Researchers used x rays to visualize the sloshing of electrons in water molecules. They then calculated the wake of electron motion that would surround a gold ion moving through the fluid (above, click to see larger view).

See animation below.A research team has produced the fastest movies ever made of electron motion. Created by scattering x rays off of water, the movies show electrons sloshing in water molecules, and each frame lasts just 4 attoseconds (quintillionths of a second). The results, published in the 11 June *PRL*, could let researchers "watch" chemical reactions even faster than those viewable with today's "ultrafast" pulsed lasers.



Phase Contrast Imaging
PEEM
X-ray tomography
X-ray Microscopy/Fluorescence microscopy
X-Ray Holography
Phase retrieval imaging

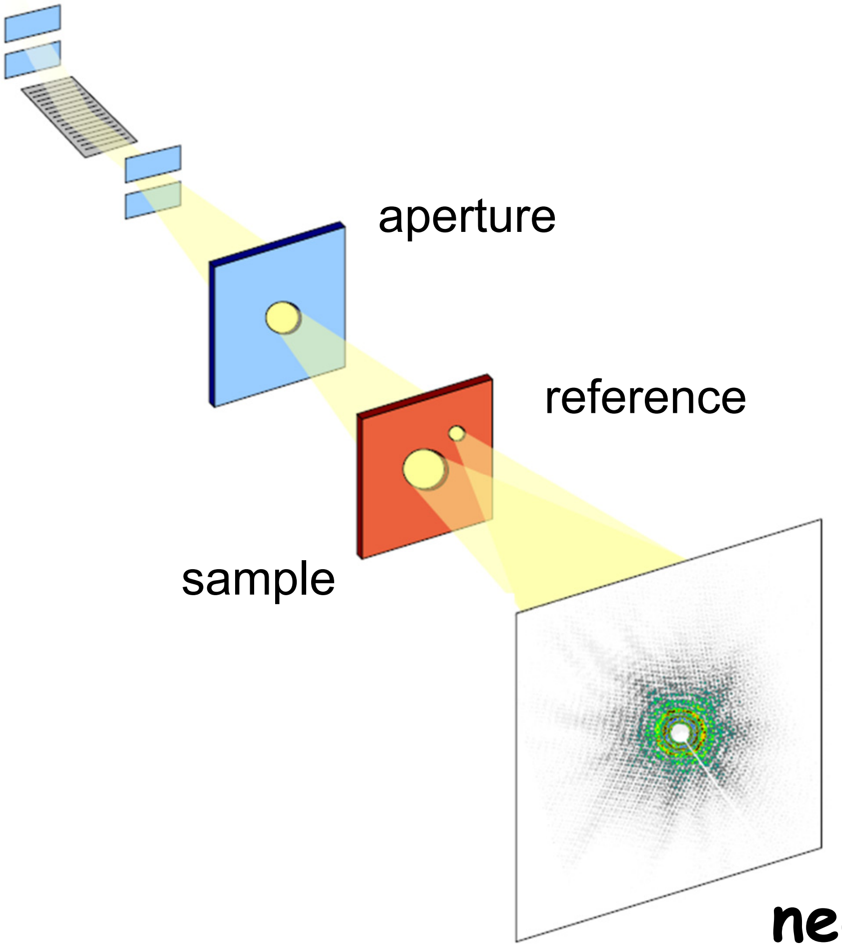
Phase enhanced x-ray imaging:

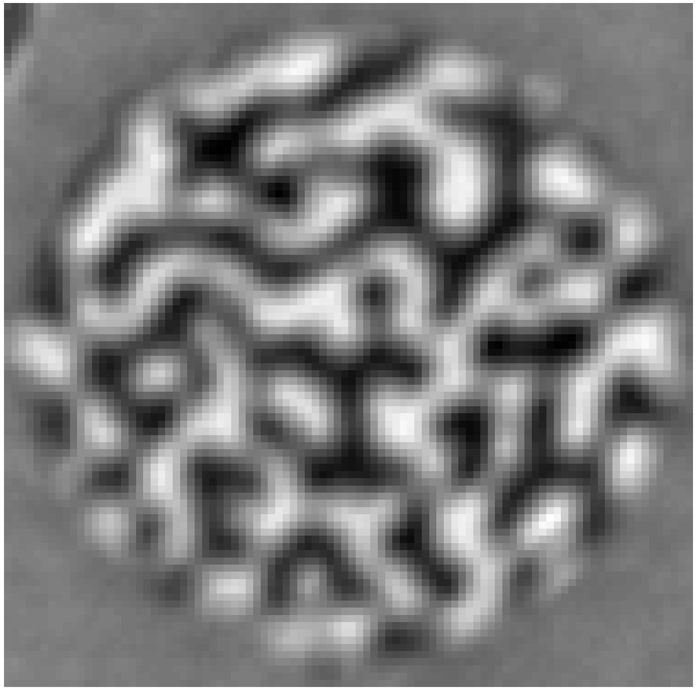


X-ray images depend on differences in density within the sample.

Also: Beam coherence produces interference fringes (edge enhancement effects).

Imaging via Soft X-ray Fourier Transform Holography





needs circular polarized x-rays

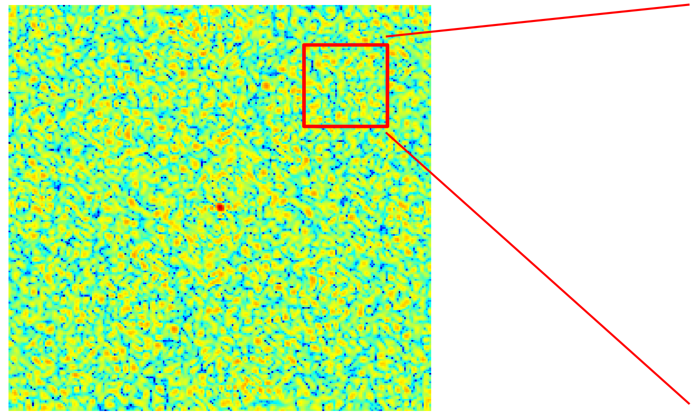
Method : S. Eisebitt et al. Nature 432, 885 (2004)
Resolution: L. M. Stadler et al. PRL, 100, 245503 (2008)

Photon Correlation Spectroscopy

Brownian Motion of 100 particles

QuickTime™ and a
Video decompressor
are needed to see this picture.

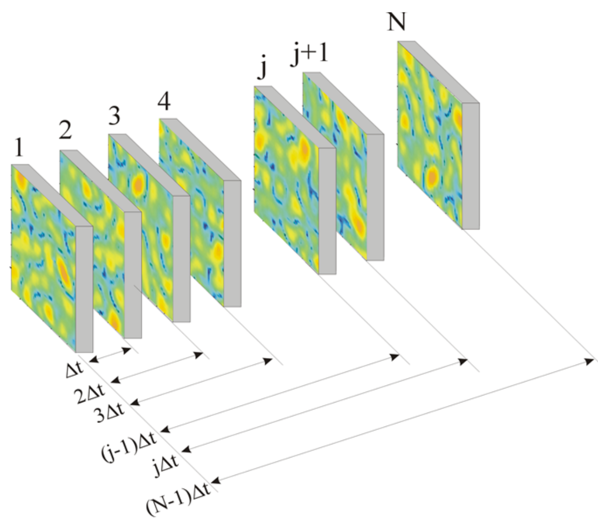
Diffraction Pattern



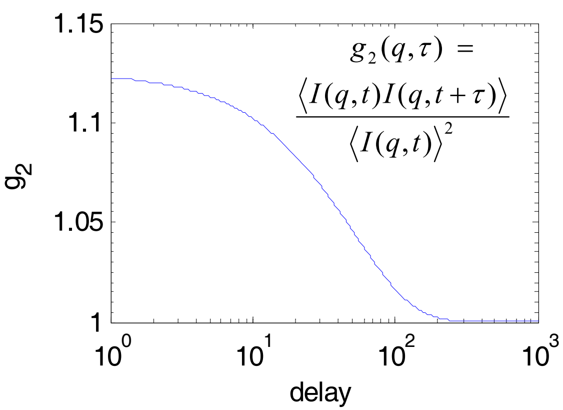
Speckles

QuickTime™ and a
Video decompressor
are needed to see this picture.

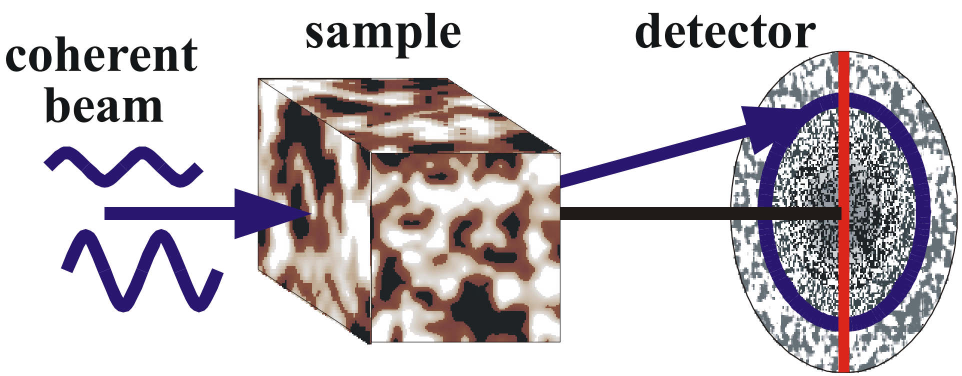
QuickTime™ and a
Video decompressor
are needed to see this picture.



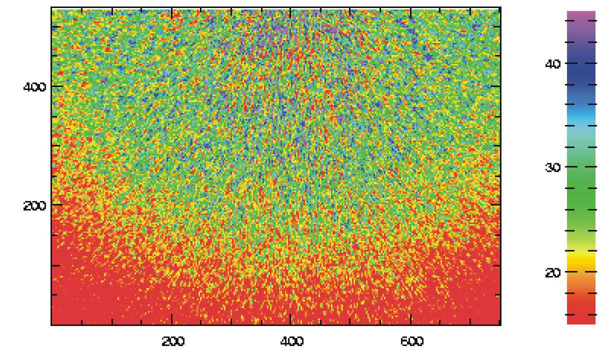
Intensity-intensity auto correlation

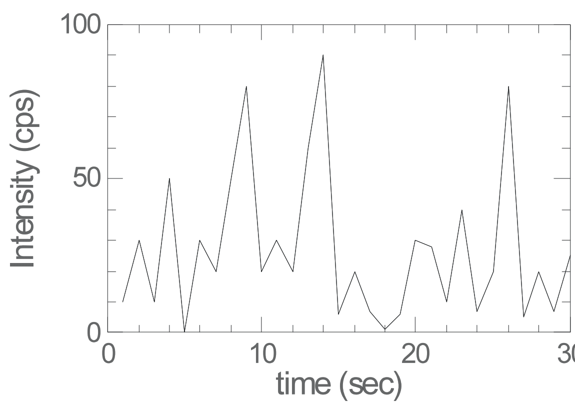


Photon Correlation Spectroscopy

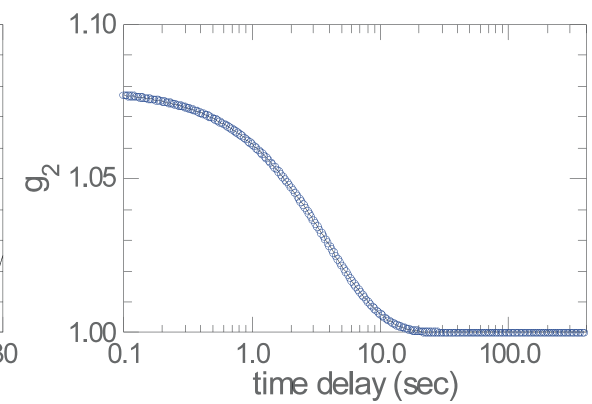


X-ray speckle pattern from a static silica aerogel





$$g_2(\boldsymbol{q},t) = \frac{\langle I(\boldsymbol{q},t')I(\boldsymbol{q},t'+t)\rangle}{\langle I(\boldsymbol{q},t')\rangle^2}$$



$$g_2(t) = 1 + \beta \exp(-2\Gamma t)$$
$$= 1 + \beta \exp(-2t/\tau)$$

β:speckle contrast

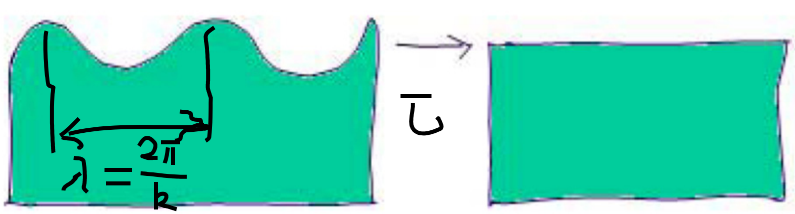
Siegert Reln.

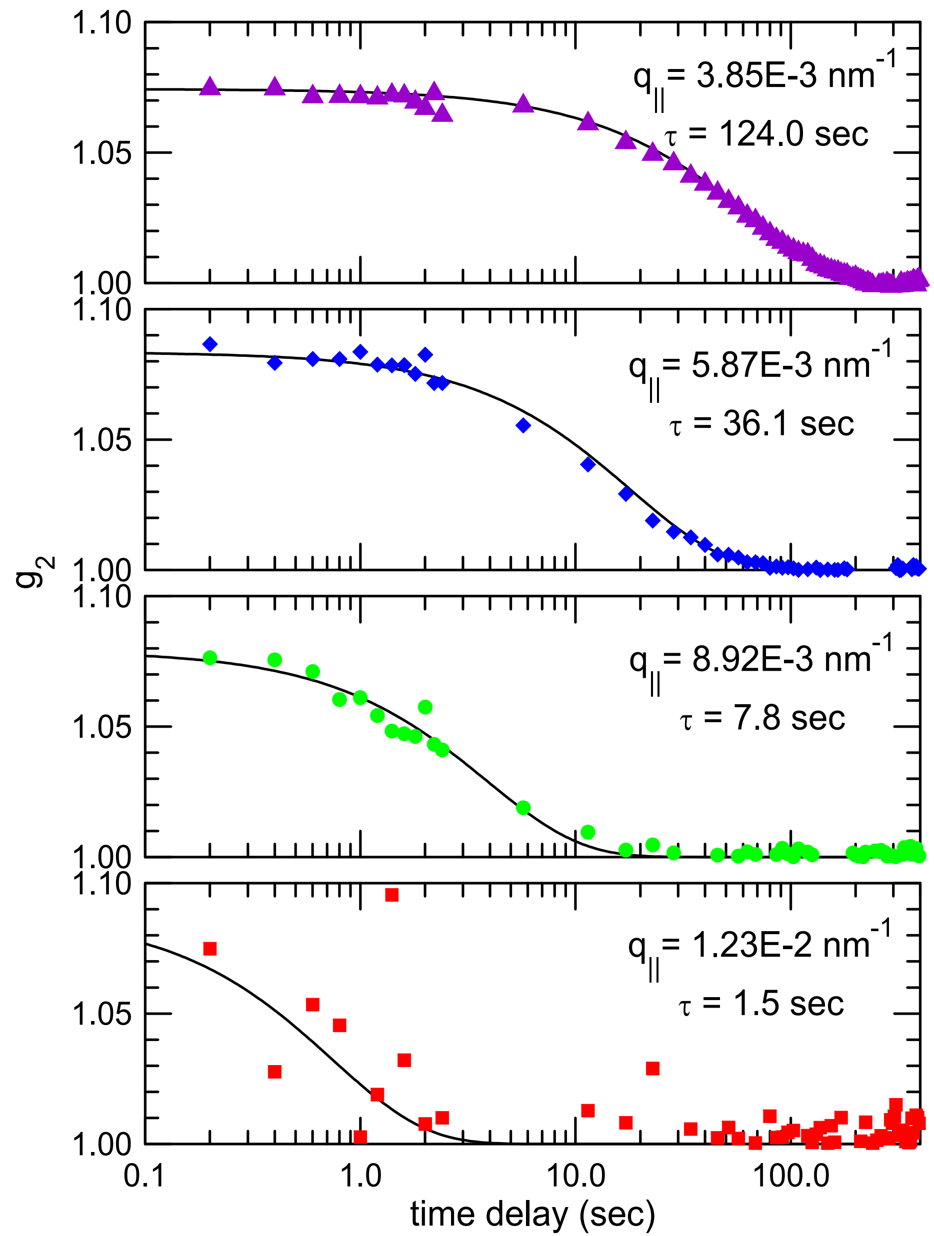
$g_2(\mathbf{q},t) = |g_1(\mathbf{q},t)|^2$

Intensity Autocorrelation

$$g_2(q,\tau) = \frac{\langle I(q,t)I(q,t+\tau)\rangle}{\langle I(q,t)\rangle^2}$$

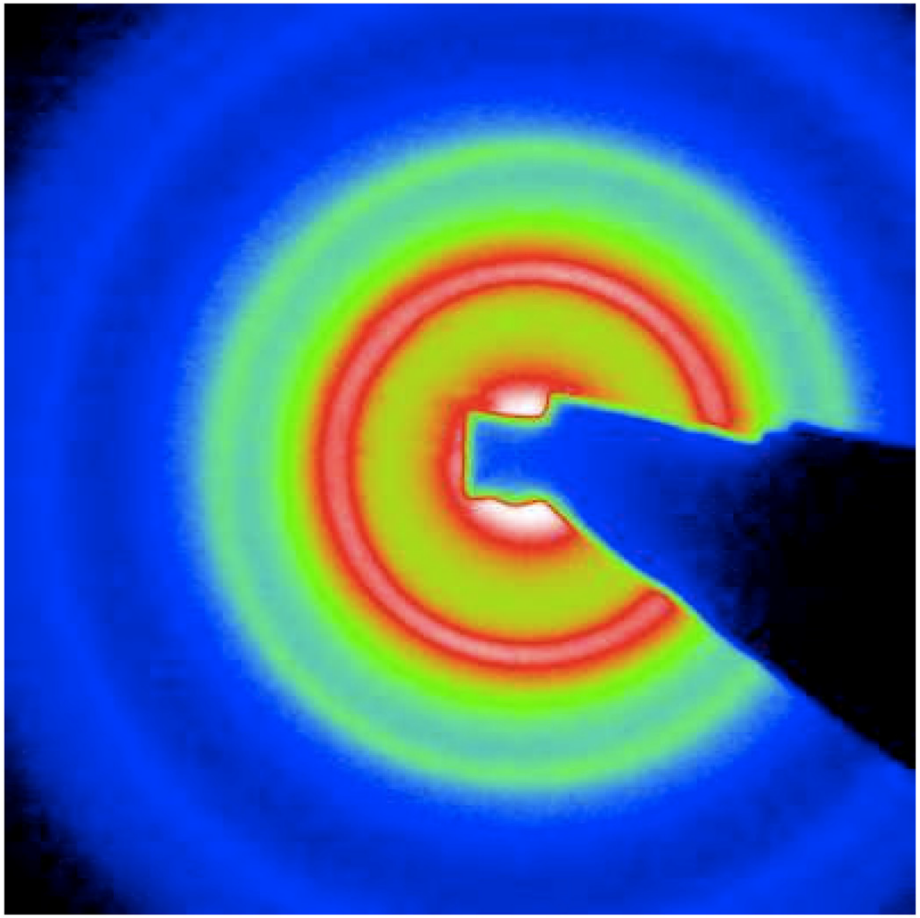
$$g_2(q,\tau) = 1 + \beta e^{-2t/\tau}$$

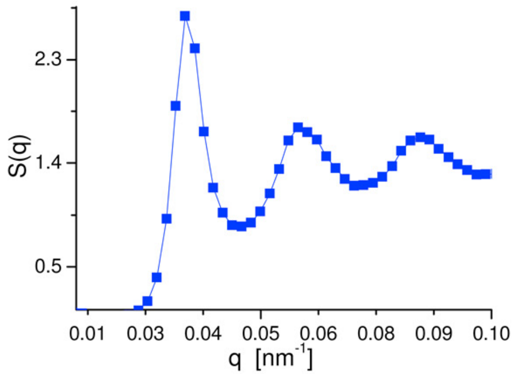




Hyunjung Kim, et.al., PRL 90, 68302 (2003)

Incoherent SAXS





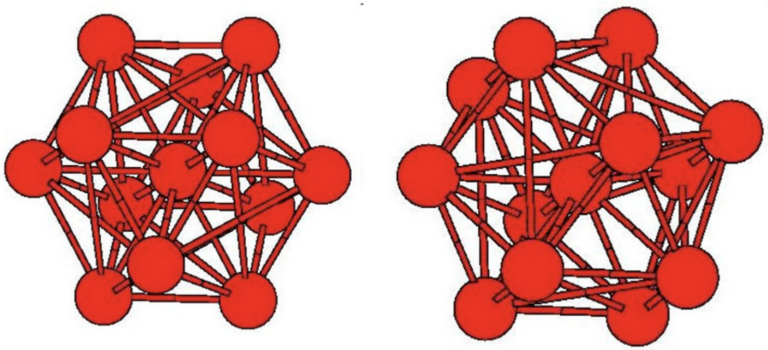
ensemble averaged structure factor

$$< S(Q) > = 1 + n_0 \int (g(r) - 1) e^{iQr} dr$$

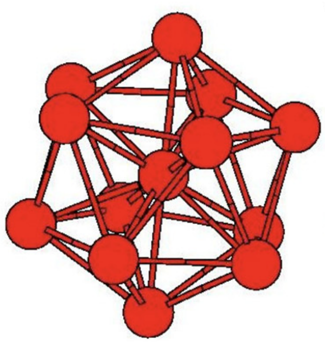
radial distribution function

$$g(r) = 4\pi r^2 n_0^{-2} < \rho(0)\rho(r) >$$

information on local symmetries is lost



fcc and hcp structures can fill up space
and form crystals



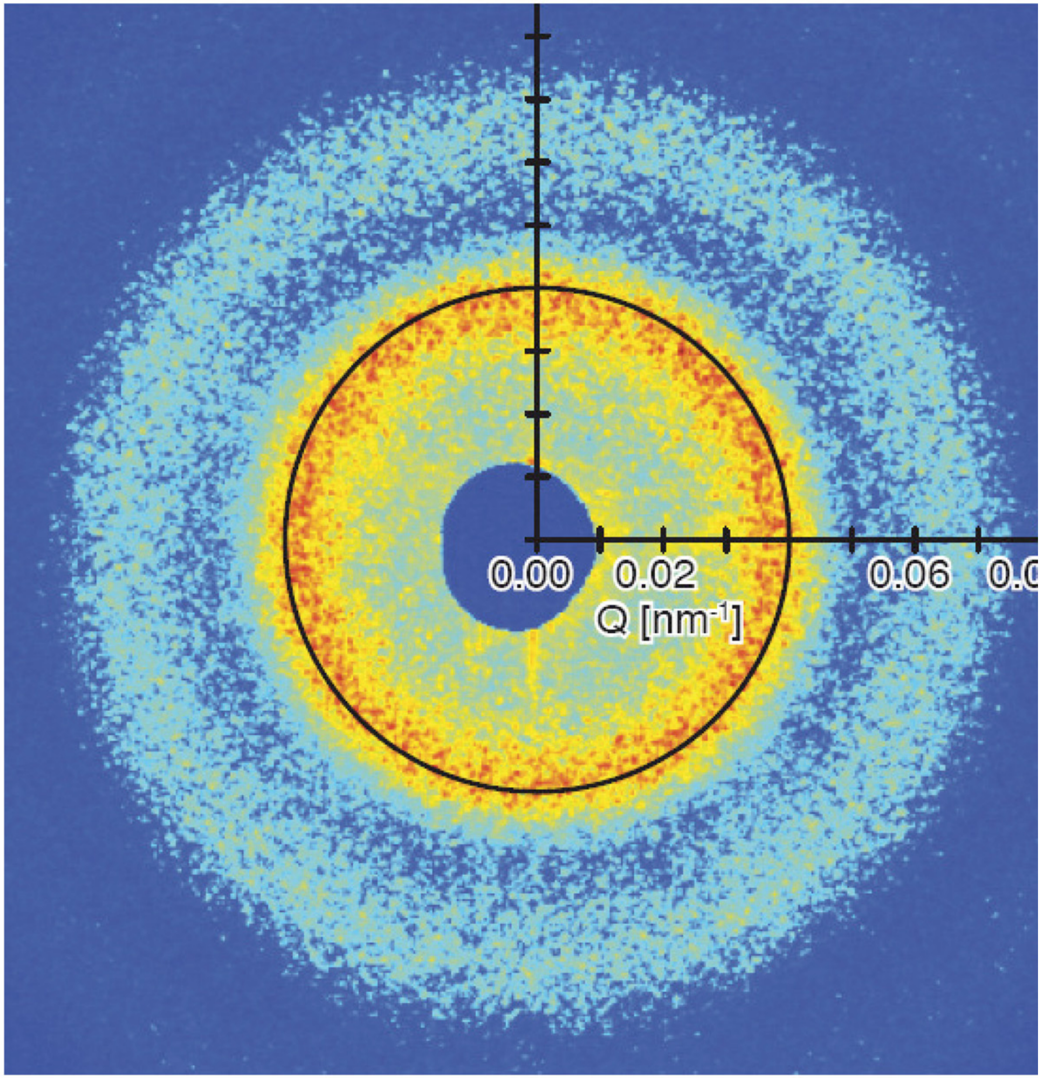
icosahedral structures can not fill space
but may be energetically favored in liquids
“locally favored structures (lsf)”

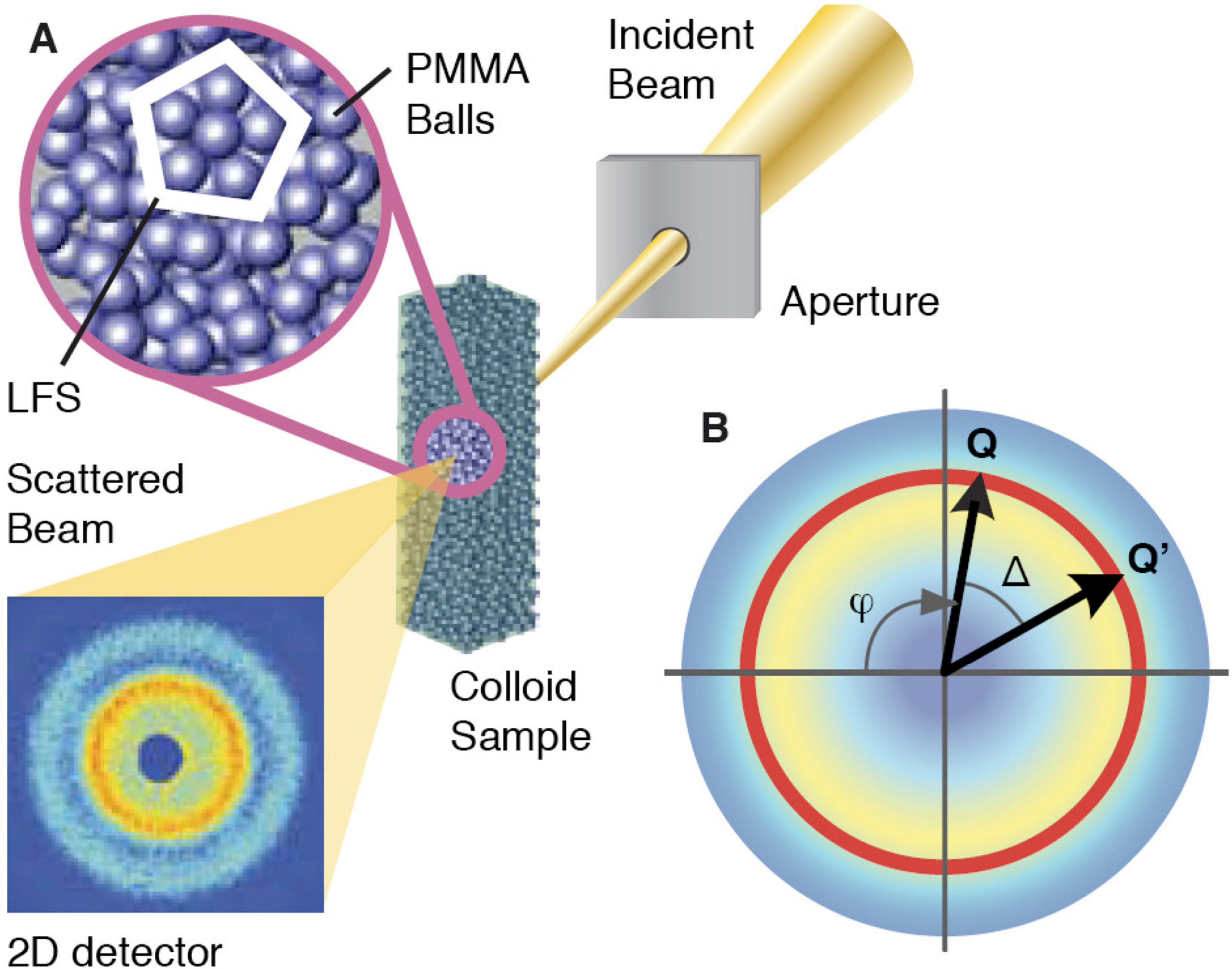
F. C. Frank, Proc. R. Soc. London A 215, 43 (1952).
P. J. Steinhardt, D. R. Nelson, and M. Ronchetti, Phys. Rev. B 28, 784 (1983)

Hard sphere systems – speckle pattern

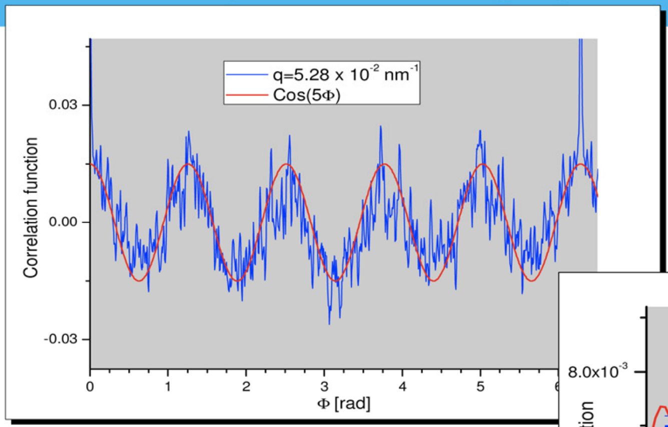
P.Wochner et al.

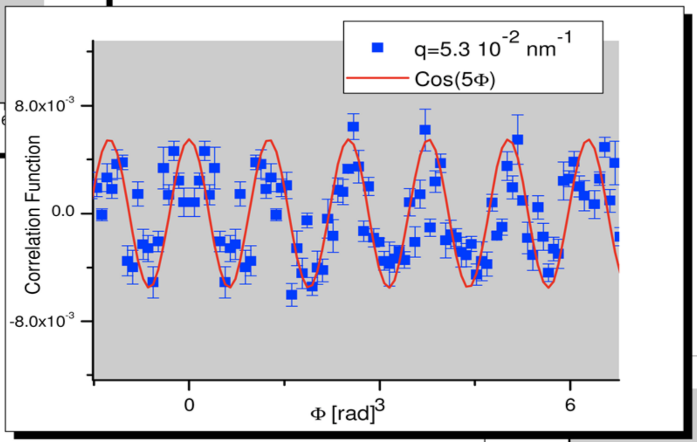
PNAS 2009

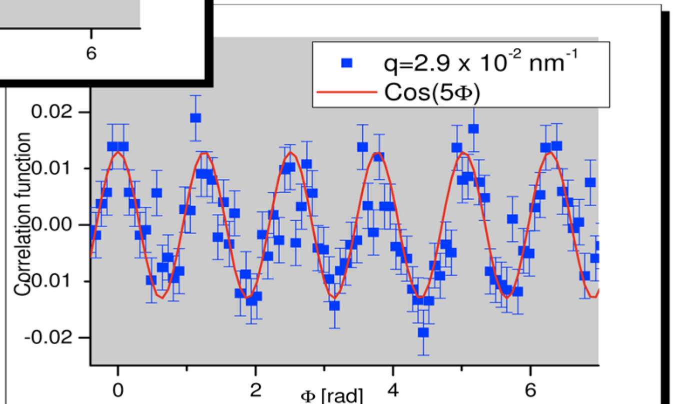


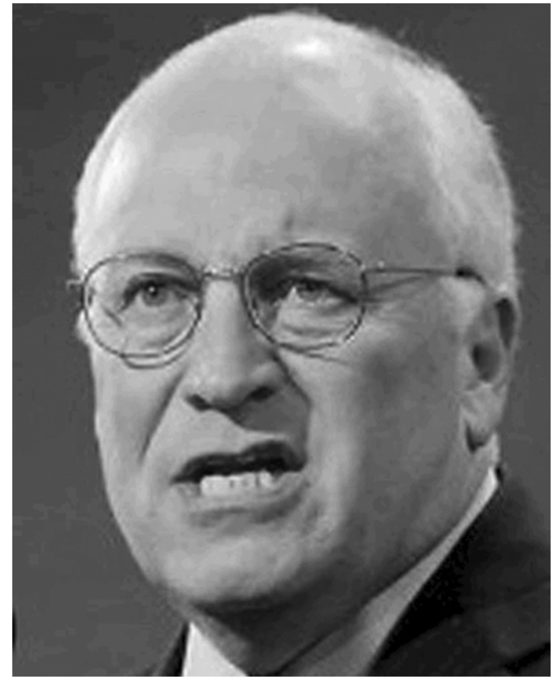

A
PMMA
Balls
Incident
Beam
Aperture
LFS
Scattered
Beam
Colloid
Sample
2D detector
B
Q
Q’
Δ
φ

5-fold symmetry present in all hard sphere systems

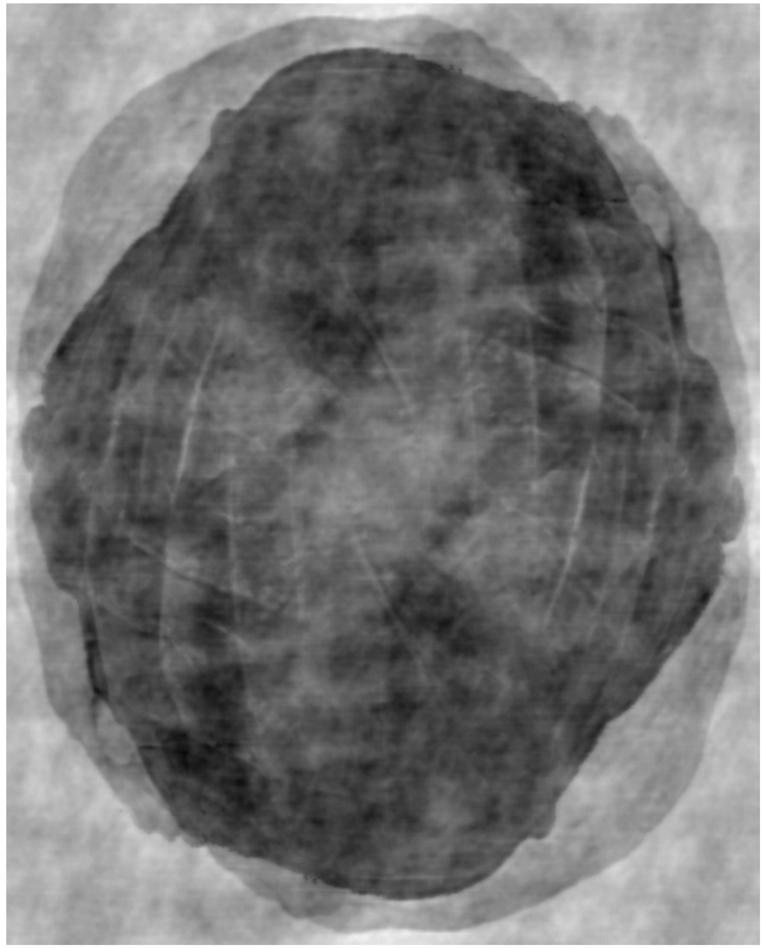


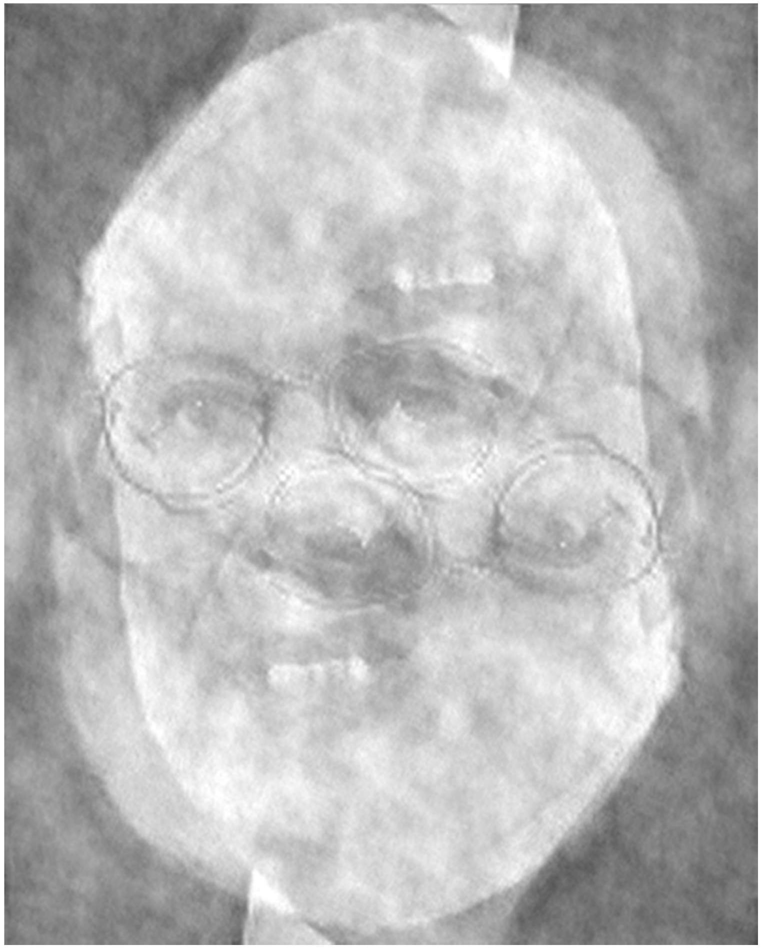






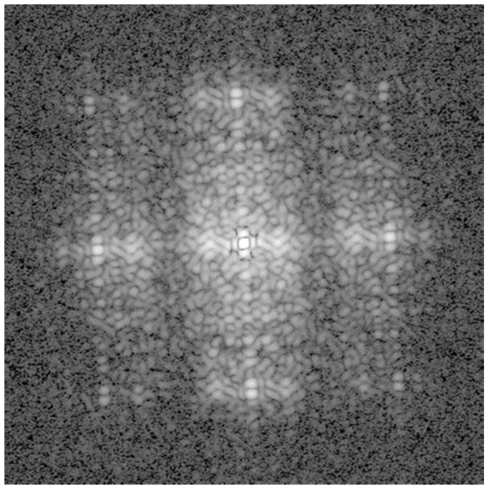
The "Phase Problem"

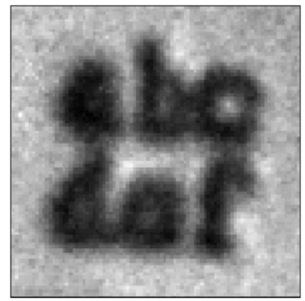




Miao, Charalambous, Kirz, Sayre, *Nature* **400**, 342 (1999).

λ=1.8 nm
soft x-ray
diffraction
pattern





Low angle data
From optical
micrograph

Scanning
electron
micrograph
of object

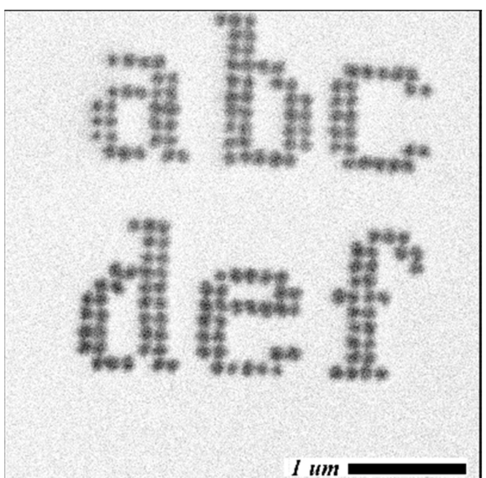


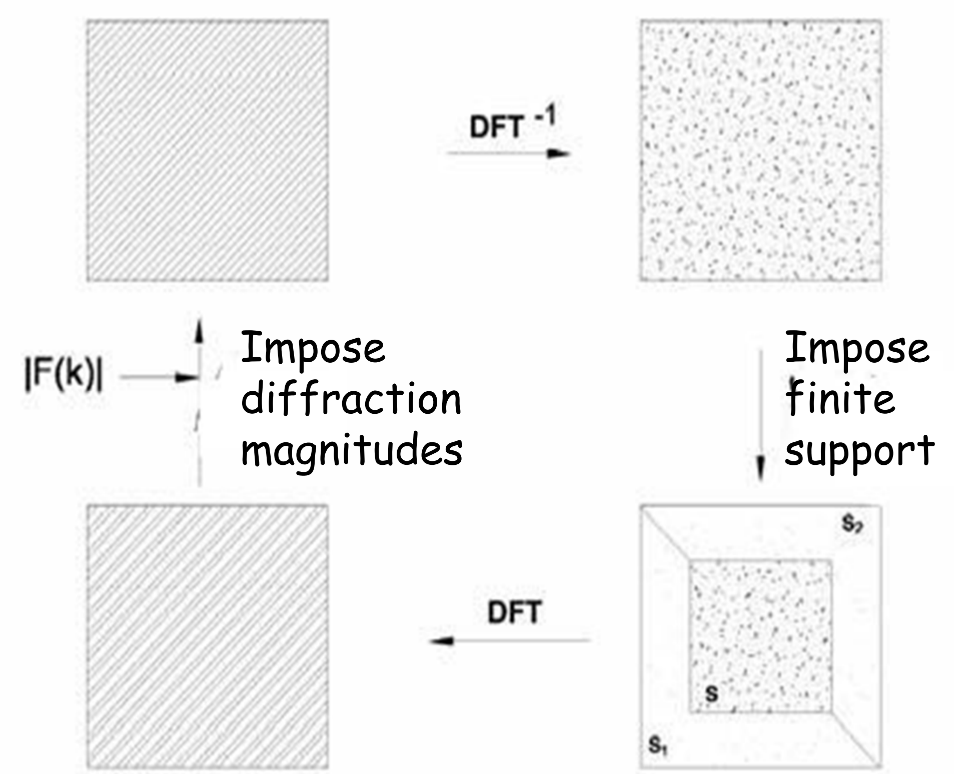
Image reconstructed from diffraction pattern (θ_{max} corresponds to 80 nm). Assumed positivity

Reconstruction

Equations can still not be solved analytically

Fienup iterative algorithm

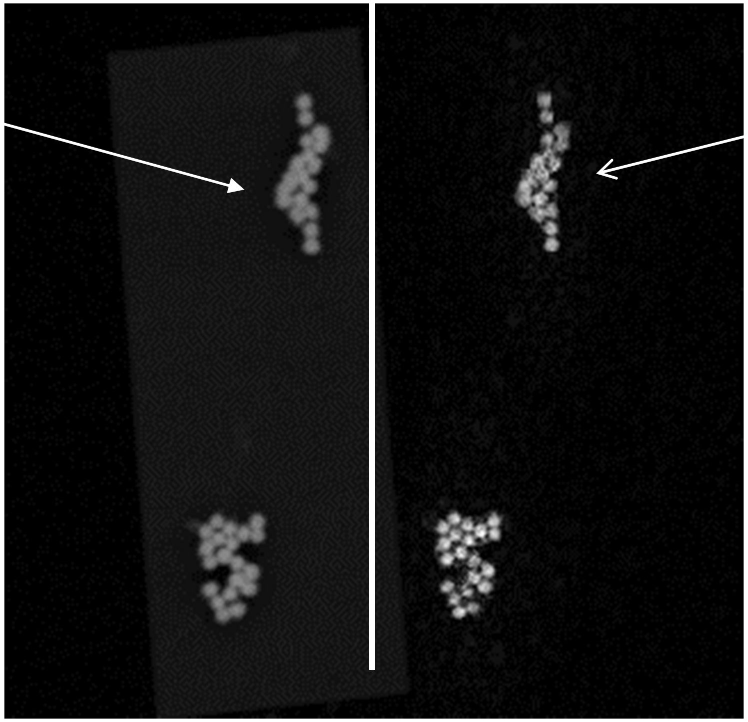
Reciprocal space Real space



•Positivity of electron density helps!

Successful reconstruction of image from soft X-ray speckle alone.

SEM Image



X-ray reconstruction

50 nm diameter Gold Balls on transparent SiN membrane.

No "secondary image" was used

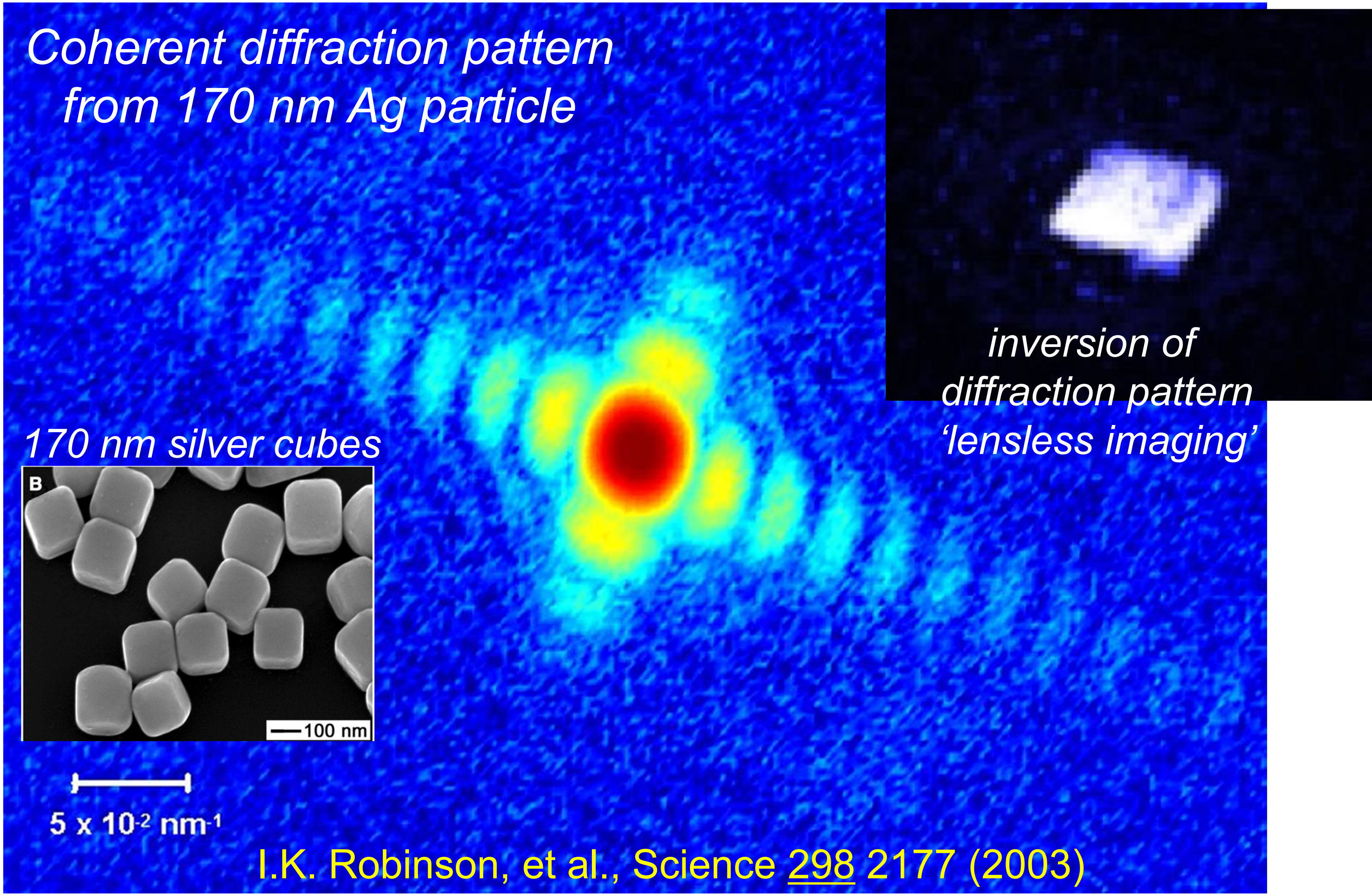
Approximate object boundary obtained from autocorrelation fn.

*How to make an isolated object ? Use AFM to remove unwanted balls.

He, Howells, Weierrstall, Spence Chapman, Marchesini et al. Phys Rev B In press. 03, Acta A.59, 143 (2003).

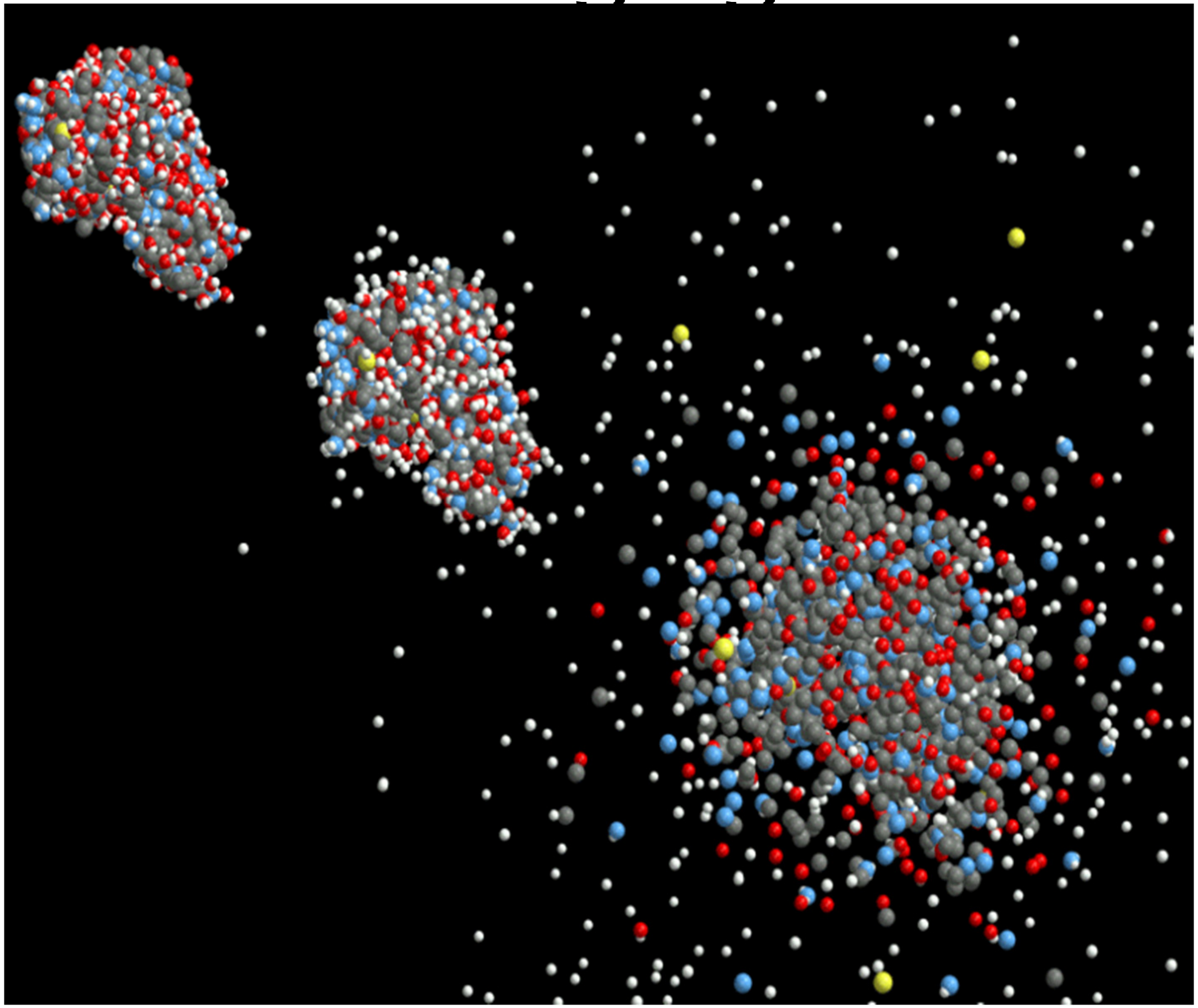
Imaging of individual nanoparticles at the APS

Ross Harder, University of Illinois, Champaign



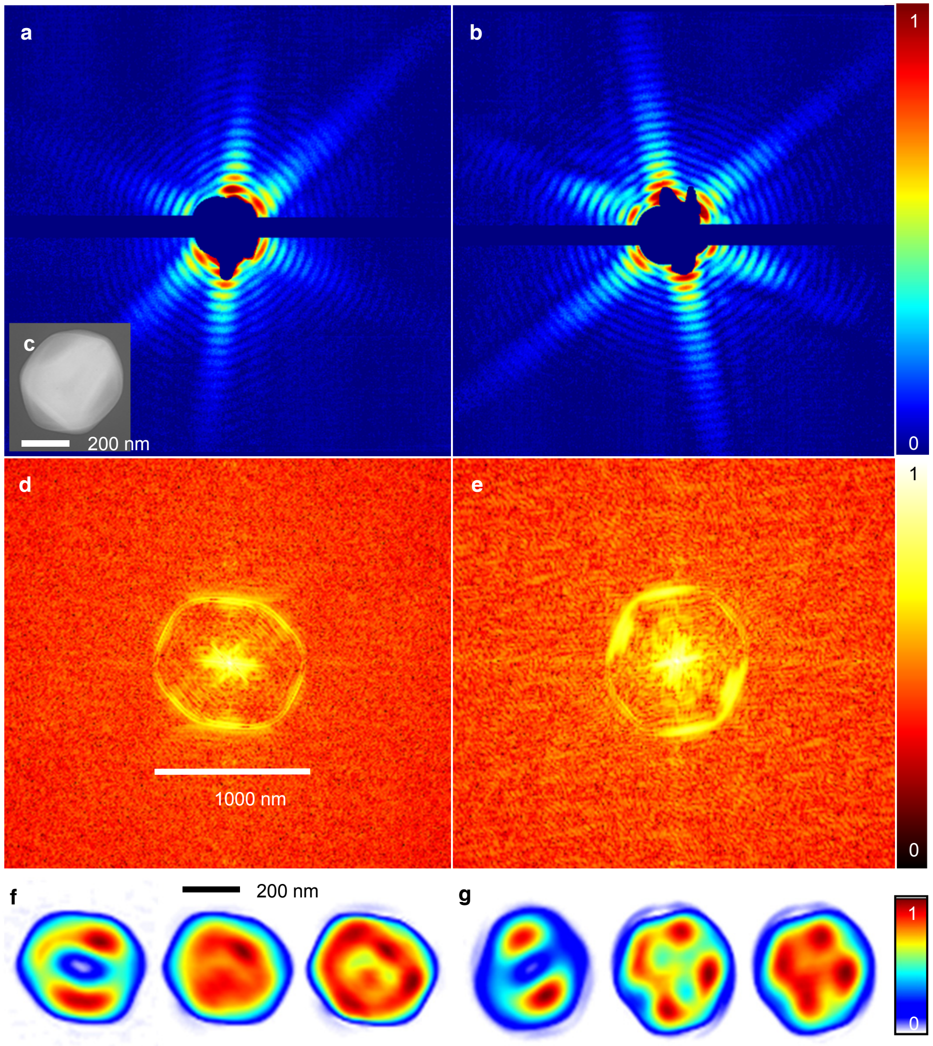
Single molecule imaging?

- Atomic resolution structures known for *few* mammalian membrane proteins!
- Collect many single molecule diffraction patterns from fast x-ray pulses, and reconstruct?
- Lysozyme explodes in ~50 fsec
- R. Neutze *et al*., *Nature* **406**, 752 (2000)



Single mimivirus particles intercepted and imaged with an X-ray laser

Beyond crystallography: A new world in structural sciences

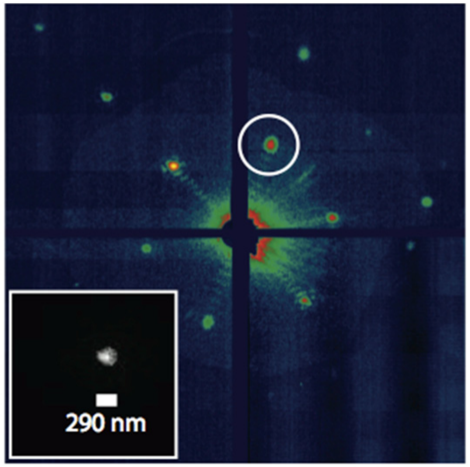


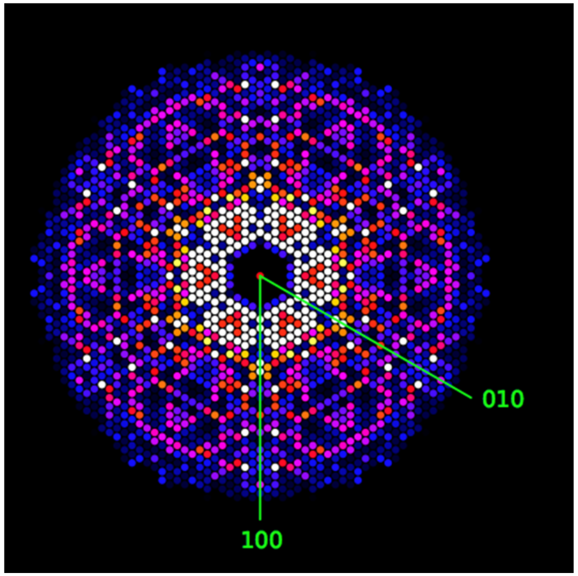
- A very short and extremely bright coherent X-ray pulse can be used to outrun key damage processes and obtain a single diffraction pattern from a large macromolecule, a virus, or a cell *without the need for crystalline periodicity.*
- Mimivirus is the largest known virus, *comparable in size to a small living cell*. It is too big for structure determination by electron microscopy and it cannot be crystallised.
- The structure of the intact virus was recovered from the flash diffraction pattern alone.
- There was no measurable sample deterioration.
- Death-rays: We expect high-resolution structures in such experiments with shorter and brighter photon pulses focused to a smaller area.
- Resolution can be further extended by averaging for samples available in multiple identical copies.

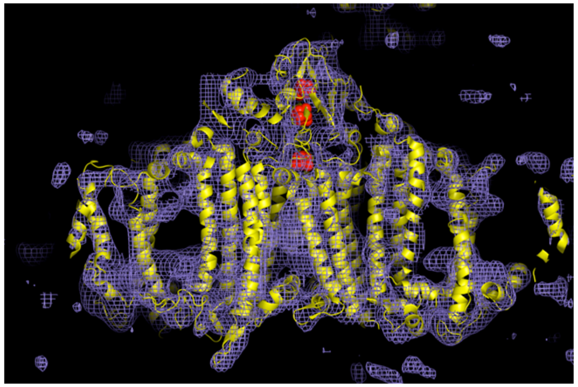
M.M. Seibert, T. Ekeberg, F.R.N.C Maia et al., *Nature* **470**, 78–81 (2011)

Femtosecond x-ray nanocrystallography overcomes limitations of radiation damage

A new paradigm opens up macromolecular structure determination to systems too small or radiation sensitive for synchrotron studies, and may save years of effort in crystallization trials





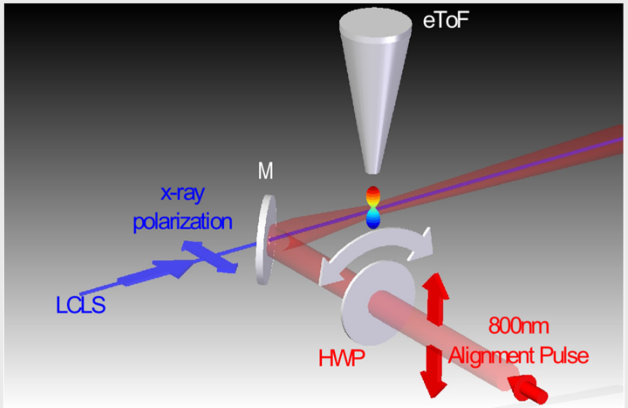


Single-shot diffraction patterns are recorded with 70 fs pulses. Coherent diffraction shows the crystal size is sub-micron (top left) and that the crystal has a perfect lattice. Individual shots are oriented in 3D and combined to build up the full information content of the underlying macromolecule (top right). This first demonstration was carried out at 2 keV photon energy, limiting the resolution to about 9 Å. (This will be improved with the dedicated CXI instrument.) The quality of the data are demonstrated by carrying out molecular replacement refinement (right). Structural details such as helices can be observed.

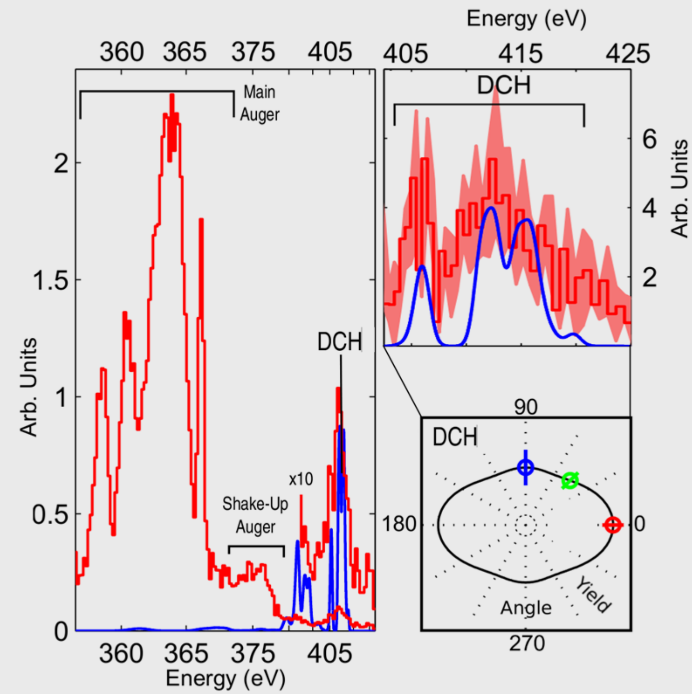
- The ultrafast LCLS x-ray pulses allow us to record "diffraction before destruction" where information is obtained before the onset of structural damage.
- Diffraction can be measured from sub-micron crystals containing less than a thousand molecules.
- Demonstrated using Photosystem I, a membrane protein, key to photosynthesis, that is extremely difficult to grow into large crystals.
- 30 single-crystal patterns per second were recorded from a liquid stream carrying a suspension of nanocrystals. 15,000 of these were indexed and combined into a full diffraction pattern which was analyzed with standard tools.
- Data are collected at room temperature. No cryogenic cooling or stabilization required.

 H.N. Chapman et al., Nature **470,** 73 (2011)

Femtosecond time-resolved x-ray experiments study aligned "hollow" molecules

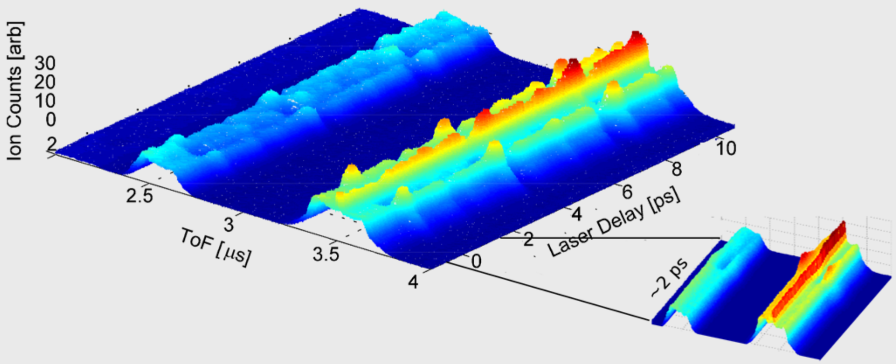


"Hollow" molecule Auger spectrum in the molecular frame



Measurement in red
Ab initio calculation in blue

Laser pump/x-ray probe ion time of flight spectra



- **10 fsec x-ray pulse arrives within 150 fsec of peak in alignment**
- **X-ray pulse produces molecules with a hollow atom (double core hole)**
- **First spectra of intramolecular dynamics...**
  - **in strong x-ray fields in the molecular frame**

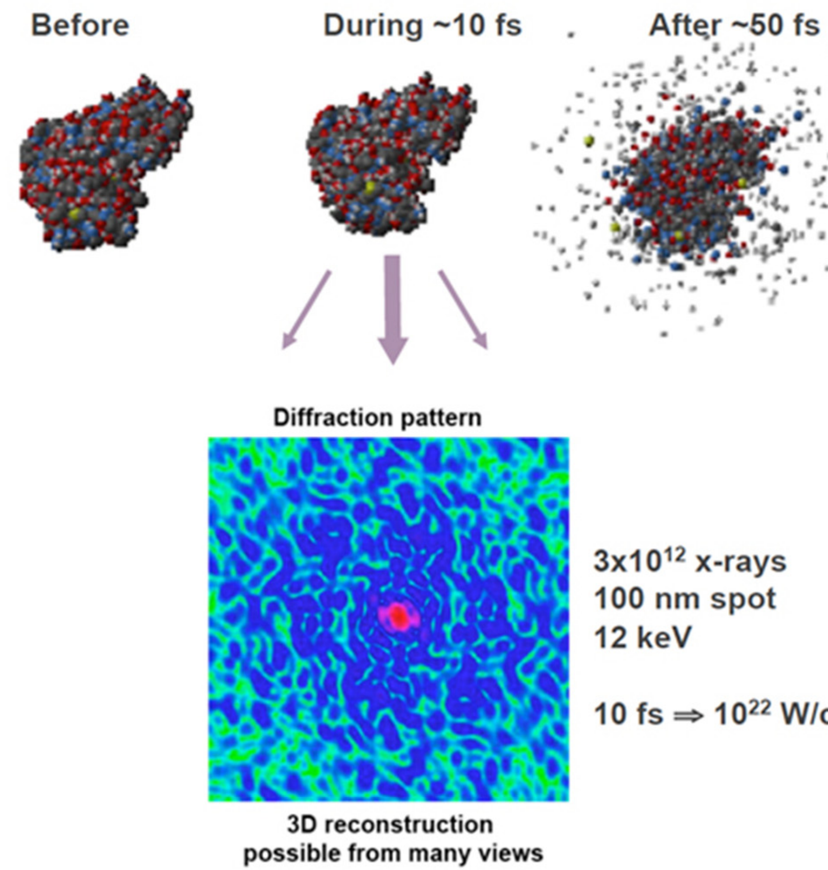
J. Cryan, J. Glownia, P. Bucksbaum, R. Coffee, *et al.*, Phys. Rev. Lett., **105**, 083004 (2010); Opt. Exp. **18**, 17620 (2010)

AMO questions at the ultraintense x-ray frontier

- fundamental nature of x-ray damage at high intensity
  - -Coulomb explosion
  - -electronic damage
  - -behavior at 10^{22} W/cm^2 - 1Å

- nonlinear x-ray processes
  role of coherence

- quantum control of inner-shell processes



3x10^{12} x-rays
100 nm spot
12 keV

10 fs ⇒ 10^{22} W/cm^2

Neutze, Wouts, van der Spoel, Weckert, Hajdu Nature 406, 752 (2000)

LCLS Experiment 1 - Oct 1, 2009

Nature of the electronic response to

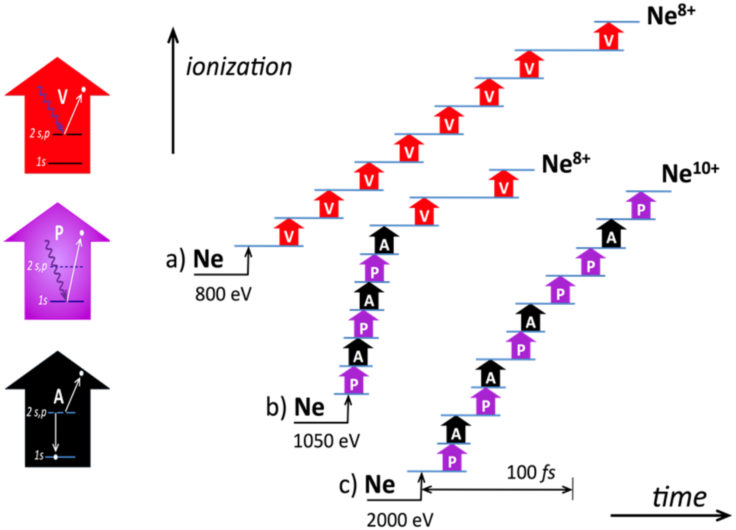
10^5 x-rays/Å^2
80 - 340 fs
800 - 2000 eV

~10^{18} W/cm^2

Original single molecule imaging parameters, Neutze et al. Nature (2000)
3 x 10^{12} x-rays/(100 nm)^2 = 3 x 10^6 x-rays/Å^2
10 fs
~10^{22} W/cm^2

Femtosecond electronic response of atoms to ultraintense x-rays

Understanding the response of matter to ultraintense x-ray irradiation is vital for LCLS applications

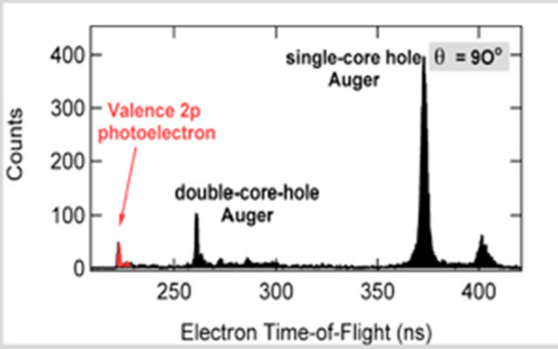


Multiphoton ionization of atoms occurs within a single LCLS pulse of ~100 fs duration and fluence of ~10^{12} x-rays per square micron. The multiple ionization proceeds through a sequence of single electron ejections. Three types of electrons are ejected, valence (V), inner-shell (P) and Auger (A),as depicted on the left of the diagram. One can control the ionization mechanism. Studying the prototypical neon atom: at photon energies below the K-edge (870 eV) the outer electrons are stripped (VVV… process), whereas at photon energies above the K-edge the inner electrons are initially ejected, followed by femtosecond Auger decay (PAPA… process). At very high intensity, both 1s core electrons can be removed prior to refilling by Auger decay to produce exotic hollow atoms.

- LCLS provides x-ray pulses with peak intensities more than a billion times greater than those from any existing synchrotron source. Understanding the electronic response at extreme x-ray intensities is fundamental.
- By studying a simple target, neon, where the dominant interaction changes as a function of photon energy from outer- to inner-shell absorption, a general understanding can be achieved.
- Observe full stripping of neon via a six-photon, ten-electron process within a single ~100 fs x-ray pulse – the first observed multiphoton x-ray process.
- Observe x-ray induced transparency via hollow atom formation at high x-ray intensities – predict this phenomenon will be generally observed in molecules, solids – allowing one to control the penetration depth in matter with pulse duration.
- Straightforward rate equation model reproduces the observed trends – suggesting that more complex systems may be modeled.

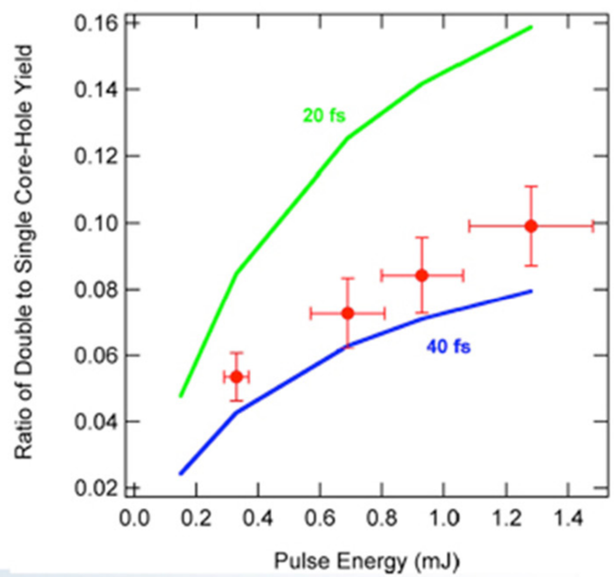
L. Young et al., Nature **466**, 56 (2010)

Hollow atom production: deliberate, huge and an a an indicator of x-ray pulse duration



Hollow atom yield
@ LCLS ~10%
@ synchrotron ~0.3%
due to electron correlation

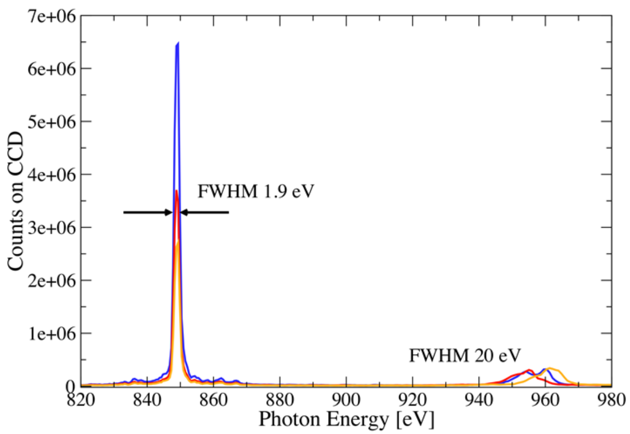
1050 eV,
nominal electron bunch duration ~80 fs



Summary of ultra-intense x-ray interaction phenomena

- Target changes during a single 100 fs x-ray pulse at fluences similar to that for single molecule imaging
  - six-photon, ten-electron stripping of neon ($\sim 10^{12}/\mu m^2$)
  - multiphoton absorption probability high when fluence > $1/\sigma$
- Intensity-induced x-ray transparency – a general phenomena
  - transient x-ray transparency caused by formation of hollow atoms
  - hollow atoms $\sigma_{scatt}/\sigma_{abs}$ is increased – advantageous for imaging
- Straightforward rate equation calculations capture essential physics
- Femtosecond time-scale atomic processes provide FEL diagnostics

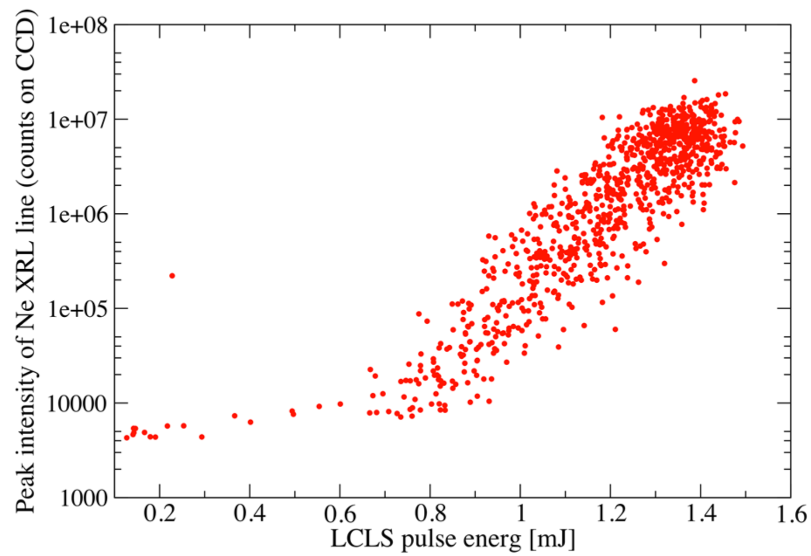
First realization of an atomic inner-shell x-ray laser at 850 eV, by ultrafast photoionization of Neon with the LCLS



Single shot spectra of the transmitted LCLS line at around 960 eV and the Ne K-a line at 850 eV (1.9 eV instrument-limited width). The brightest shot resulted in 2×10^9 photons in the Ne K-a line, with a conversion efficiency of 10^{-3}.

- Focusing LCLS pulses of 960 eV into a Neon gas sample to a spot size of ~1.5 mm, a long narrow plasma column is produced on a femtosecond timescale by photoionization of the K-shell, resulting in a population inversion of the Ne K-a transition.
- Fluorescence photons of the front-end of the plasma column get amplified by stimulated emission, resulting in ultrabright, fs x-ray pulses at 850 eV
- The photoionization-based atomic x-ray lasing scheme was first proposed in 1967 (Duguay and Renzepis)
- Due to requirement of an extremely fast and intense x-ray pump source, it could never be realized so far.
- The experiment is a first step in the virtually unexplored field of non-linear quantum optics with x-rays and opens the pathway to new, non-linear spectroscopic methods in the x-ray regime

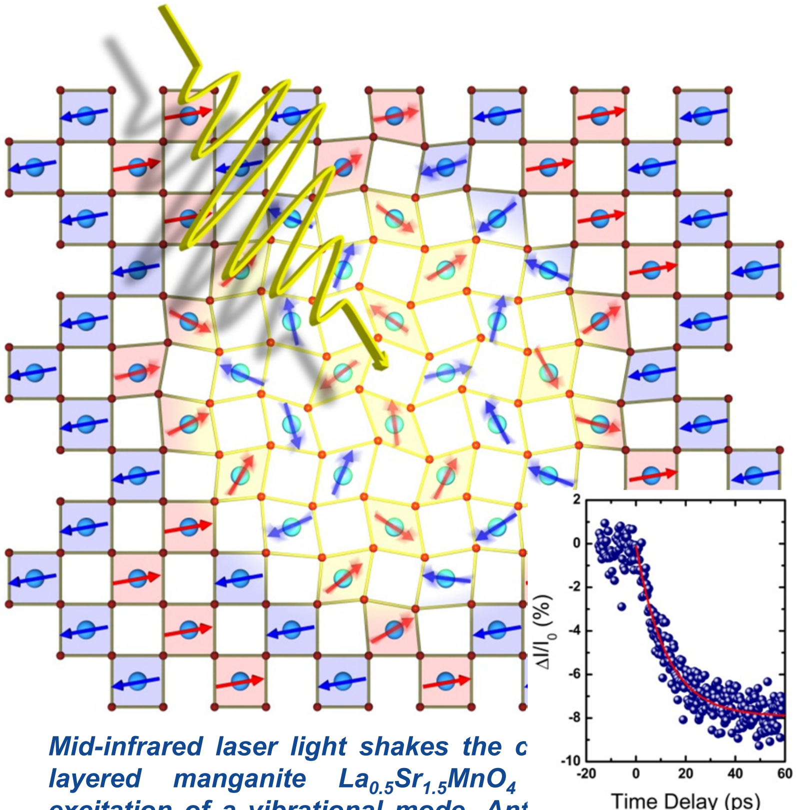
Peak intensity of the Ne K-a line as a function of the pumping power of the LCLS. Doubling the pumping intensity gives a rise in the peak power of four orders of magnitude.



N. Rohringer et al., manuscript in preparation

Controlling magnetism in complex oxide with lattice excitation

New approach for magnetic switching disclosed at the LCLS Free Electron Laser



Mid-infrared laser light shakes the c… layered manganite $La_{0.5}Sr_{1.5}MnO_4$ … excitation of a vibrational mode. Ant… is in this way perturbed, as viewed by time-resolved resonant soft X-ray diffraction from the magnetic superlattice.

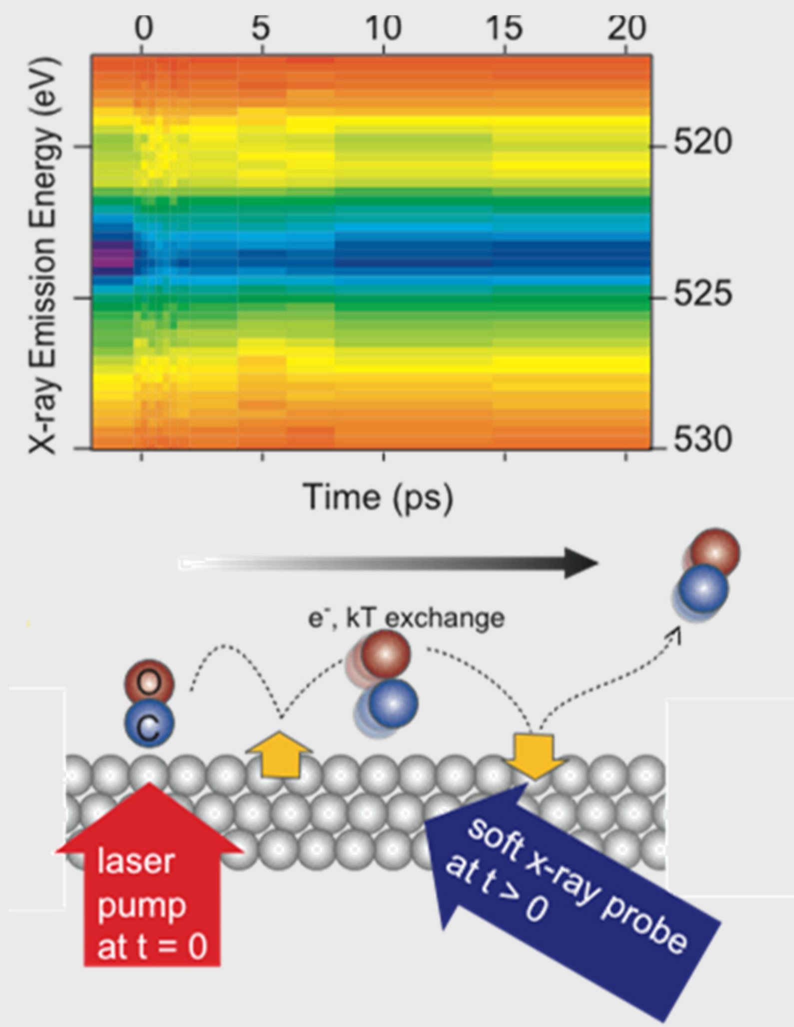
- To date, light control of magnetization has always been induced by near-infrared light. This type of stimulation is associated with large dissipation, as eV-photon energies are used to drive the rearrangement of the microscopic order on the meV energy scale.
- Electronic properties of complex oxides can be controlled by optical excitation of lattice vibrations in the mid infrared, providing an alternate path to steer condensed matter on ultrafast timescales.
- Recent experiments at the LCLS Free Electron Laser utilizing time-resolved resonant soft X-ray diffraction demonstrate that the magnetic order in complex oxides can be disordered through optical lattice manipulation.
- The magnetic response time is 12ps, likely dictated by spin-lattice relaxation rates.

LCLS | CFEL SCIENCE Center for Free-Electron Laser Science | BROOKHAVEN NATIONAL LABORATORY | BERKELEY LAB | ALS

M. Först, R.I. Tobey, S. Wall et al., to be published

LCLS pump-probe experiments: CO on Ru(001)

- Nearly all chemical reactions of importance to society occur at interfaces
- Catalysis is a trillion dollar industry and is also at the core of chemical energy transformations
- The first pump probe experiment at LCLS investigated a simple reaction step involving breaking of the CO-metal bond
- The experiments use a 400 nm optical laser pump pulse, and a LCLS pulses to probe the CO electronic structure state though O K-emission spectroscopy as a function of time delay.
- The results shows the time evolution of a transient CO state where the chemical bond strength to the surface is reduced



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Conclusion

Much of the most exciting recent science with Neutrons and X-rays has resulted from fruitful collaborations between accelerator physicists and CM and Materials Scientists and Crystallographers and Biologists

Hopefully, this will continue, leading to more exciting science over the next decade,
So, this is not……………..

THE END