X-ray Diffraction Microscopy for Materials Science and Biology

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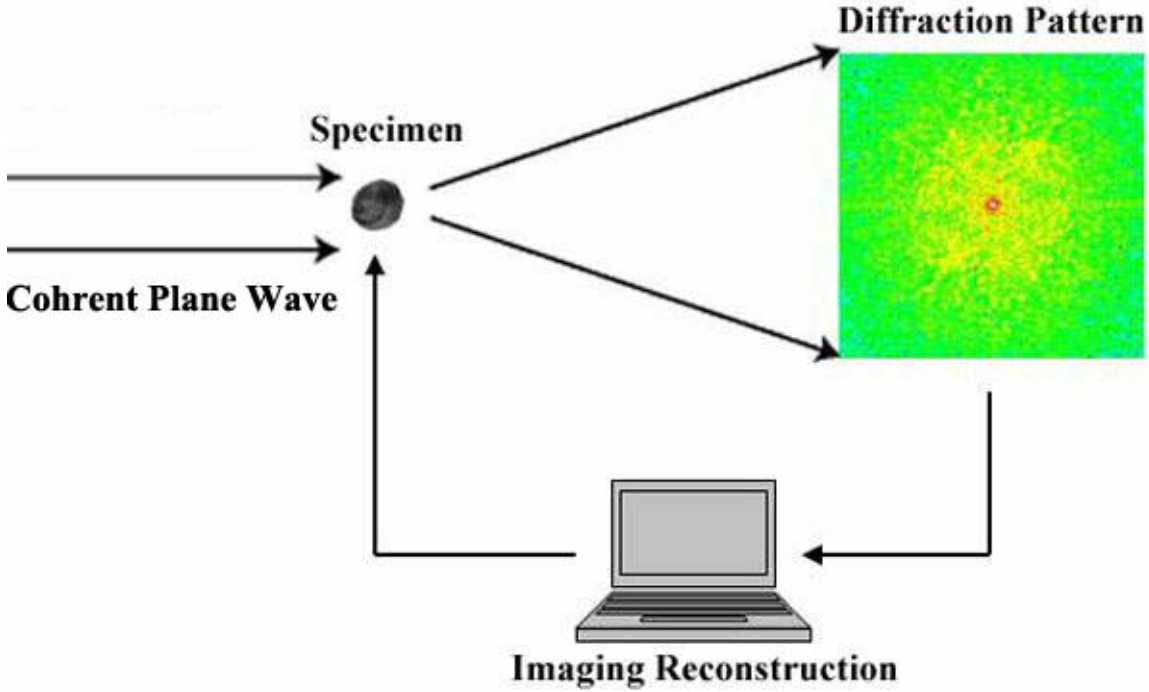
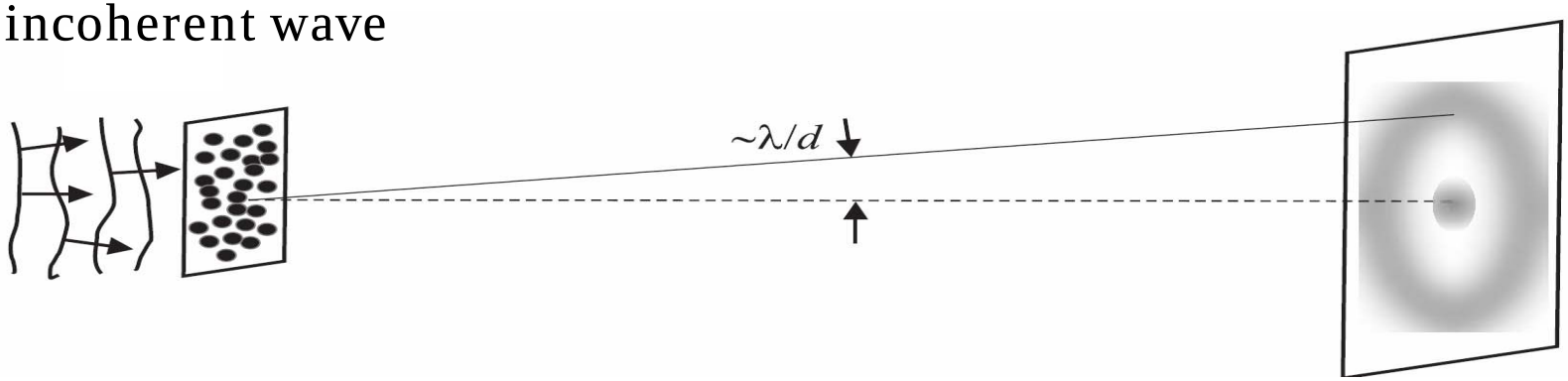
X-ray diffraction microscopy



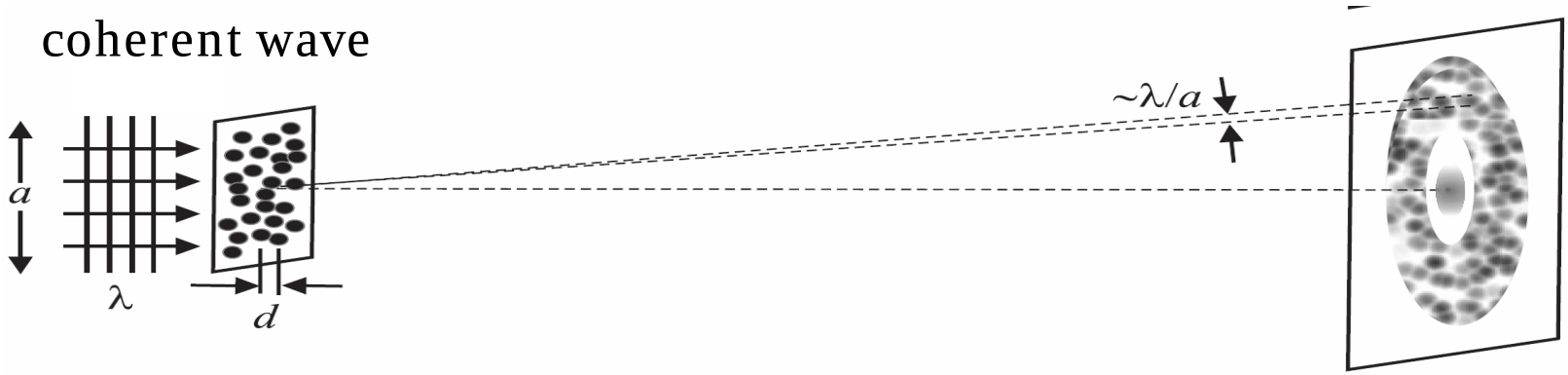
- spatially coherent x-ray beam
- noncrystalline (isolated) sample
- oversampled diffraction pattern
- computational image reconstruction

Coherent wave illumination

incoherent wave

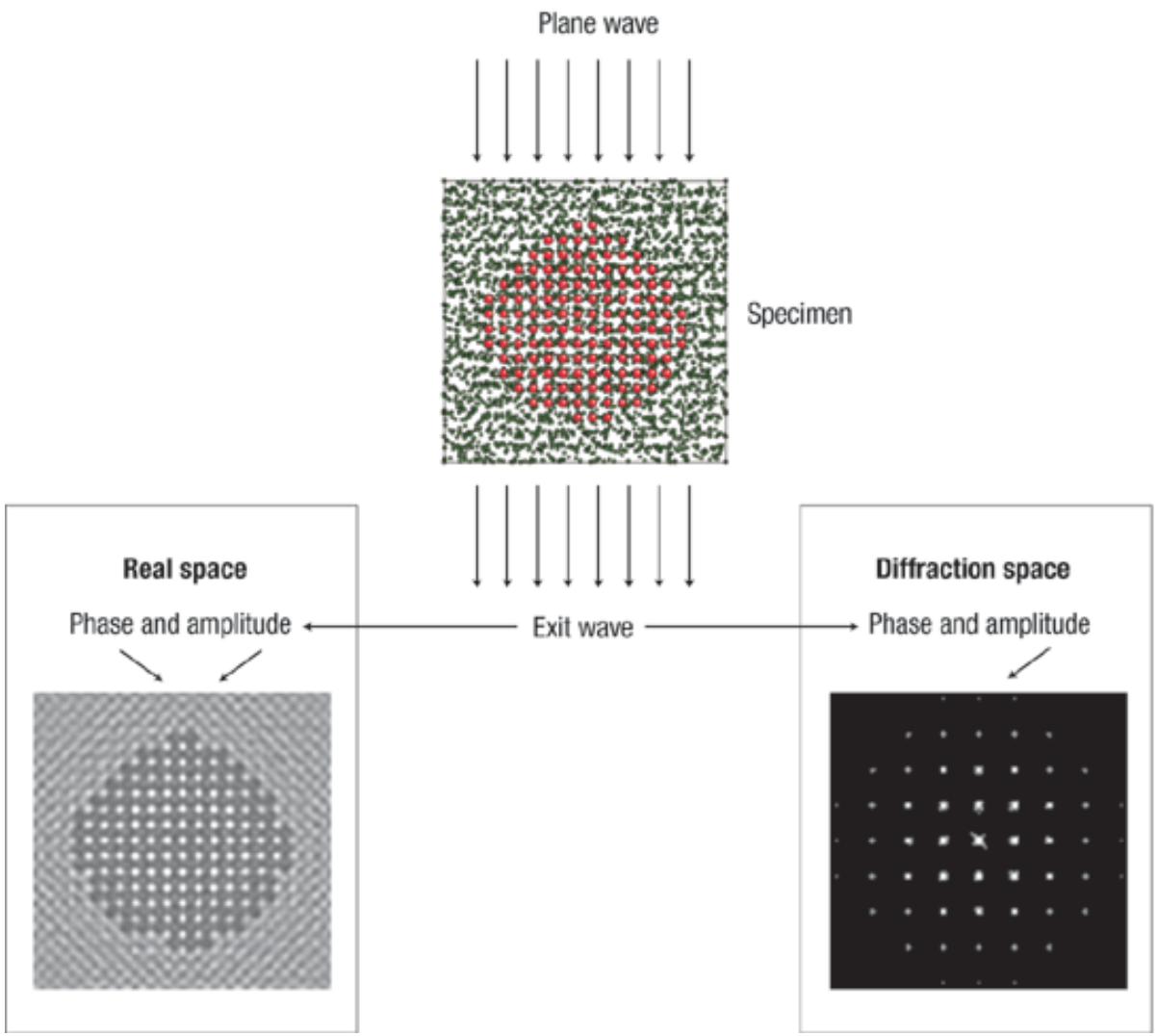


coherent wave



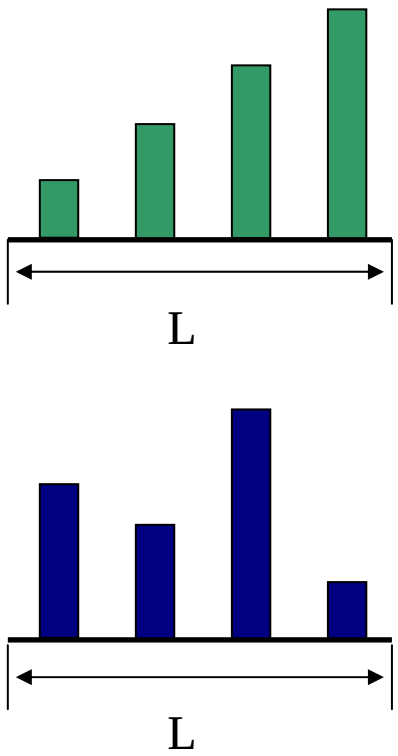
Picture from F. Veen, *JPCM* ('04)

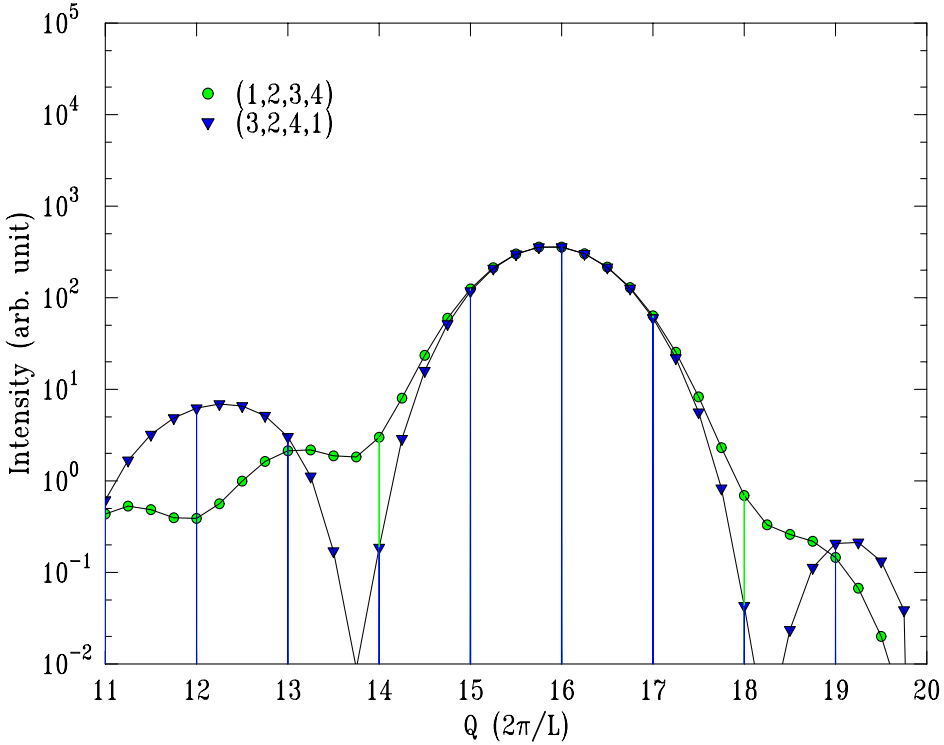
Diffraction: the phase problem



Picture from Koster and Zandbergen, *Nature Mater.* ('05)

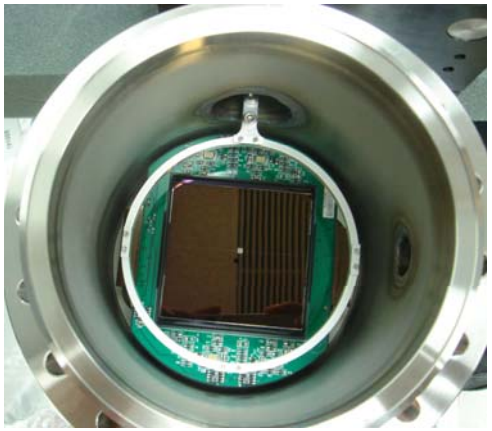
The phase: oversampling

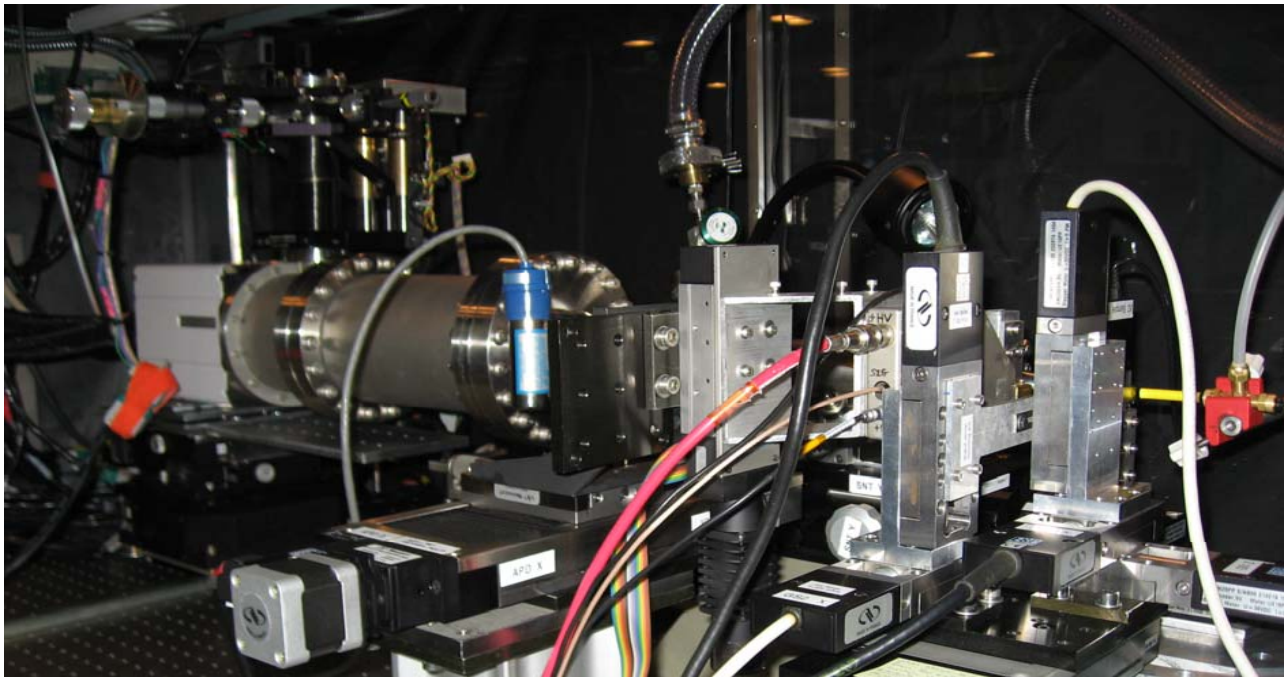




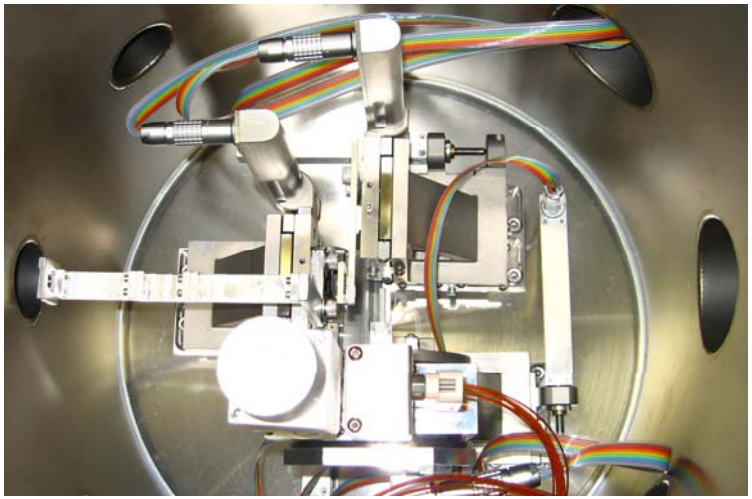
Acquiring diffraction pattern finer than the Bragg spacing:
Distinction between the two specimens becomes more obvious!

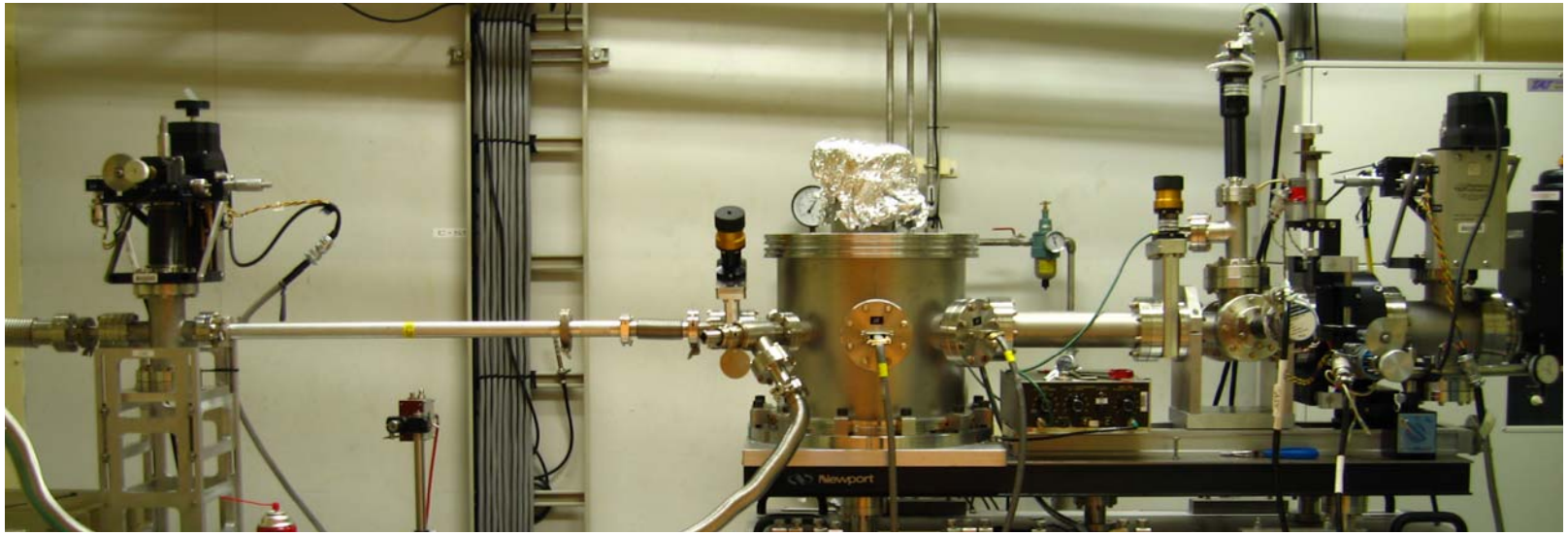
Synchrotron facilities: 2ID-B @ APS (1-3 keV)





Synchrotron facilities : 29 XUL @ SPring-8 (5 keV)

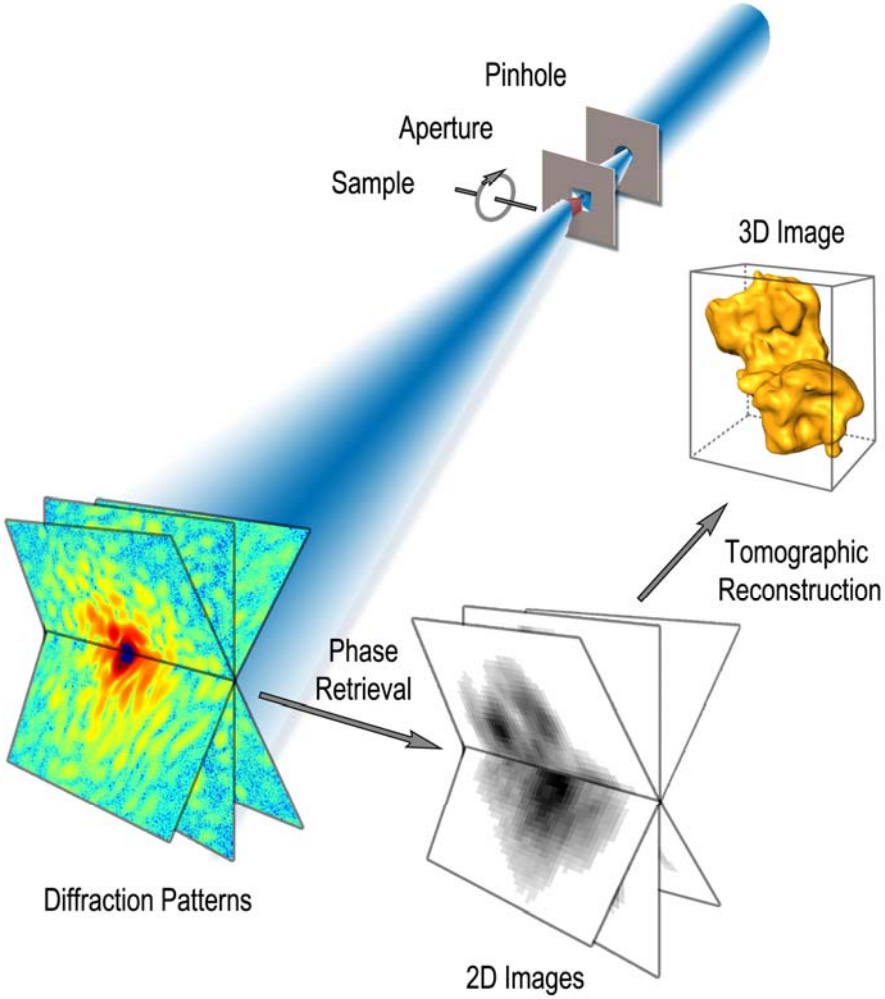


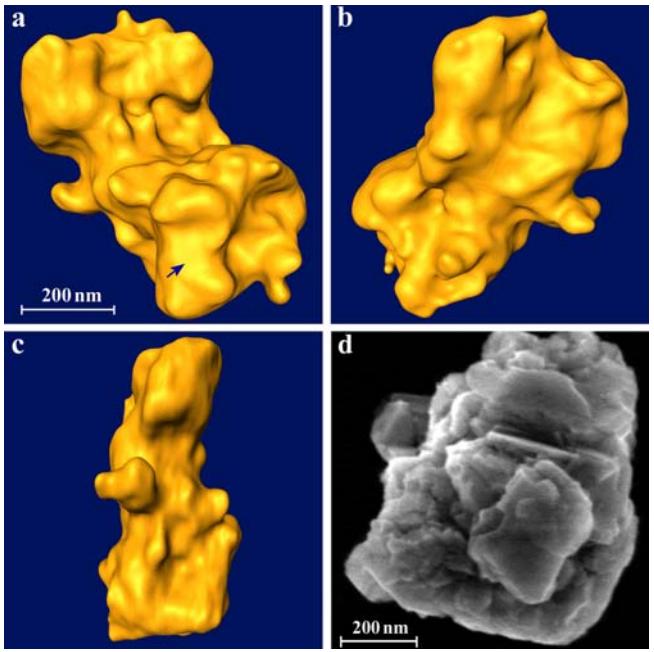


Applications

- nondestructive 3D imaging
- single cell imaging
- bio-minerals: bone particles

3D structure of a GaN nano-crystal (1)

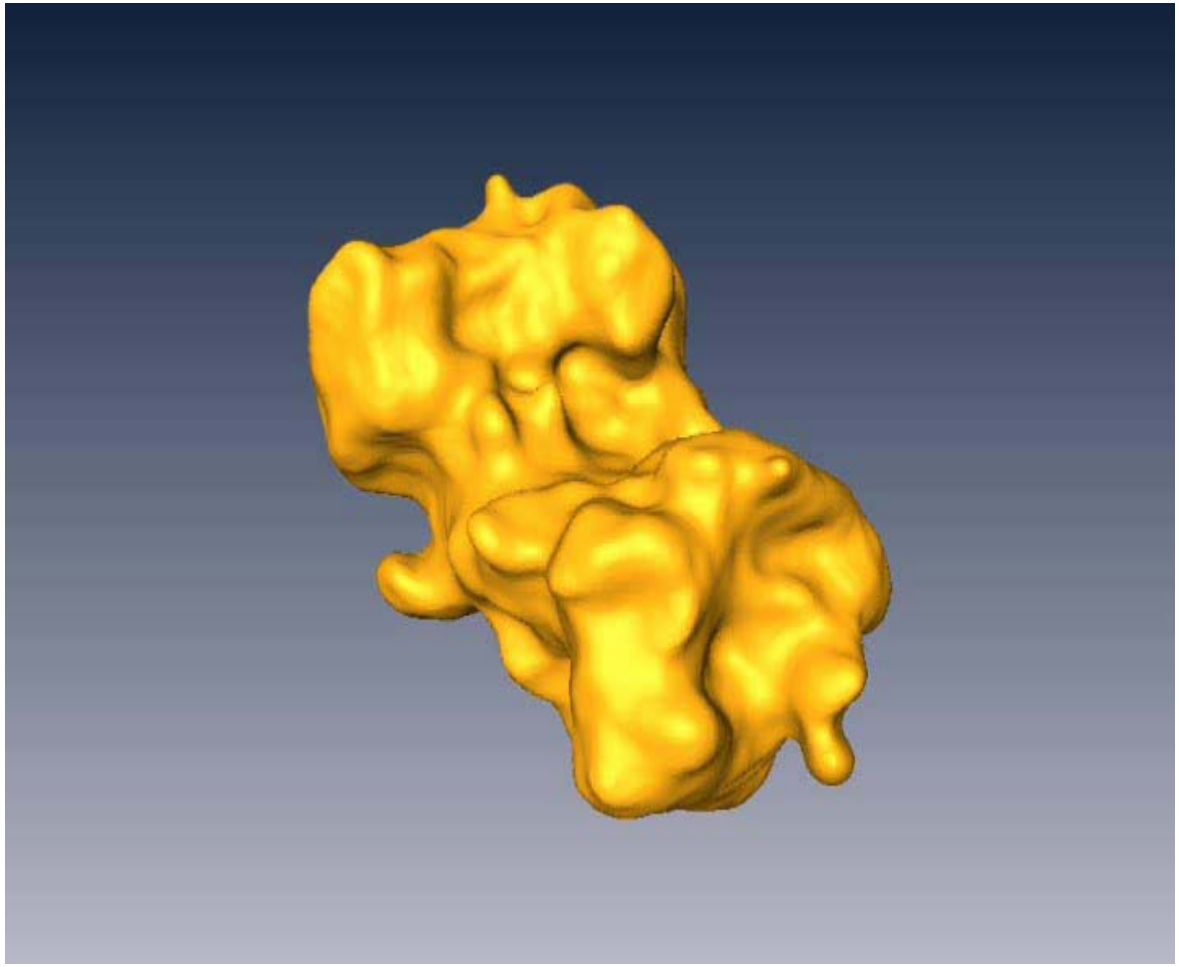




Tomographic 3D reconstruction

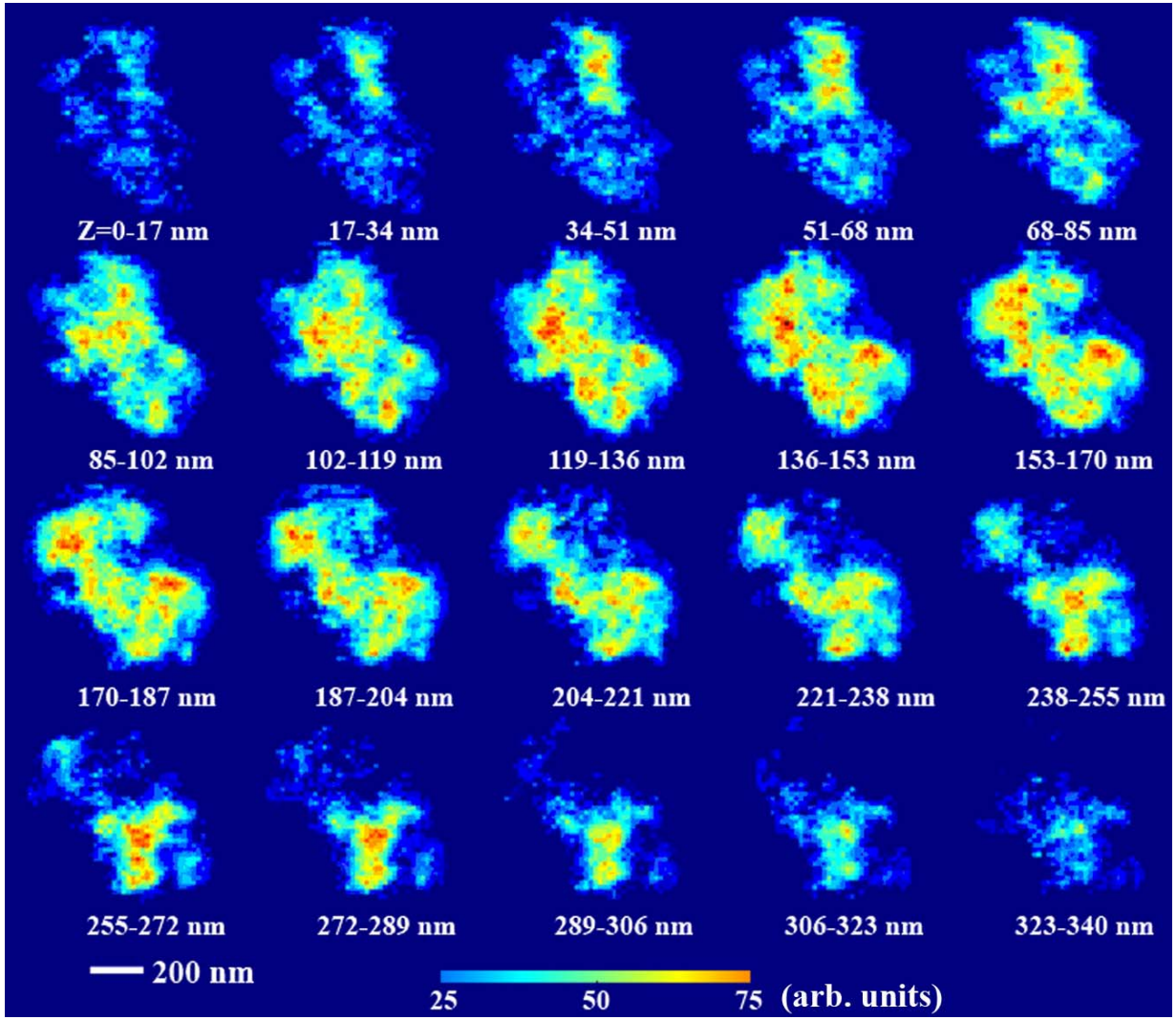
Miao et al., *PRL* ('06)

3D structure of a GaN nano-crystal (2)



Miao et al., *PRL* ('06)

3D structure of a GaN nano-crystal(3)

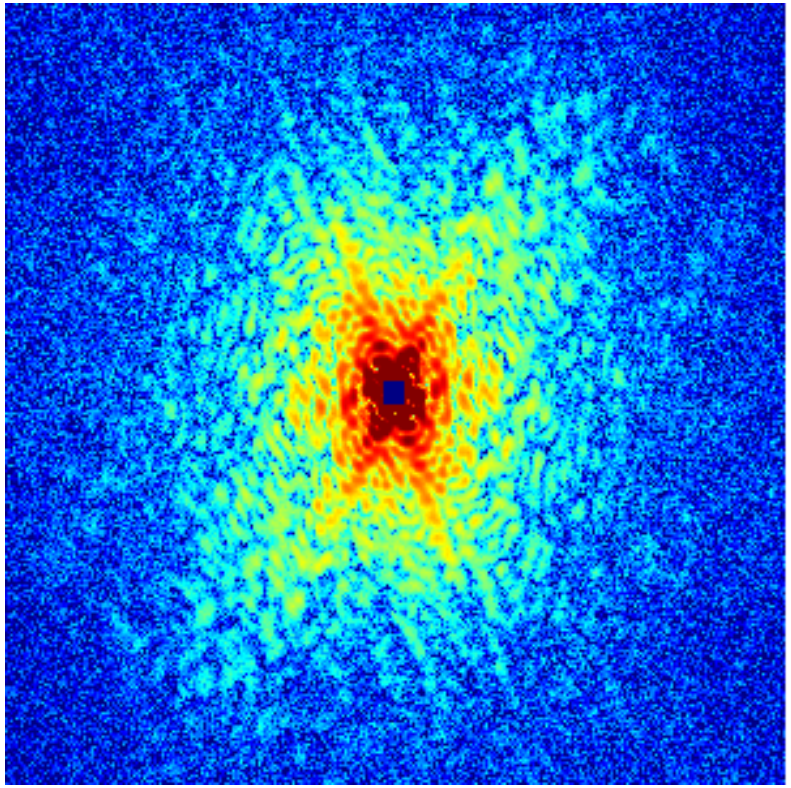


platelets and core-shell structure

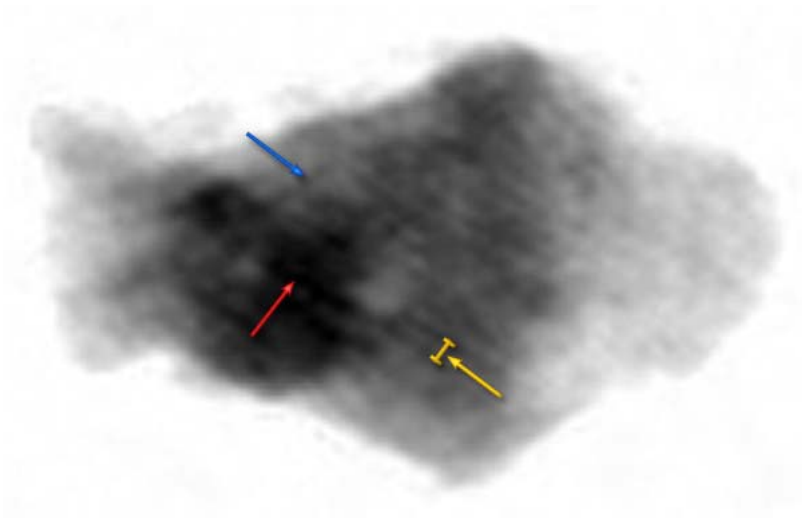
Miao et al., *PRL* ('06)

Imaging bio-minerals: fish bone particles

•diffraction imaging of a high degree mineralized fish bone particle



diffraction pattern



Reconstructed image displaying ~70nm periodicity as well as mineral aggregations

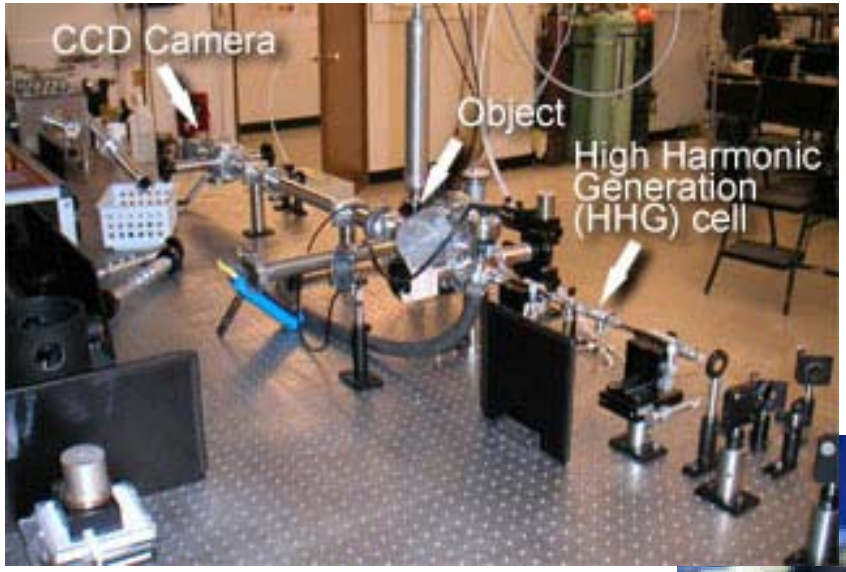
Diffraction microscopy now

resonant diffraction microscopy

table-top diffraction microscopy

Table-top imaging: EUV(1)

- table-top diffraction imaging in collaboration with Murane group @JILA



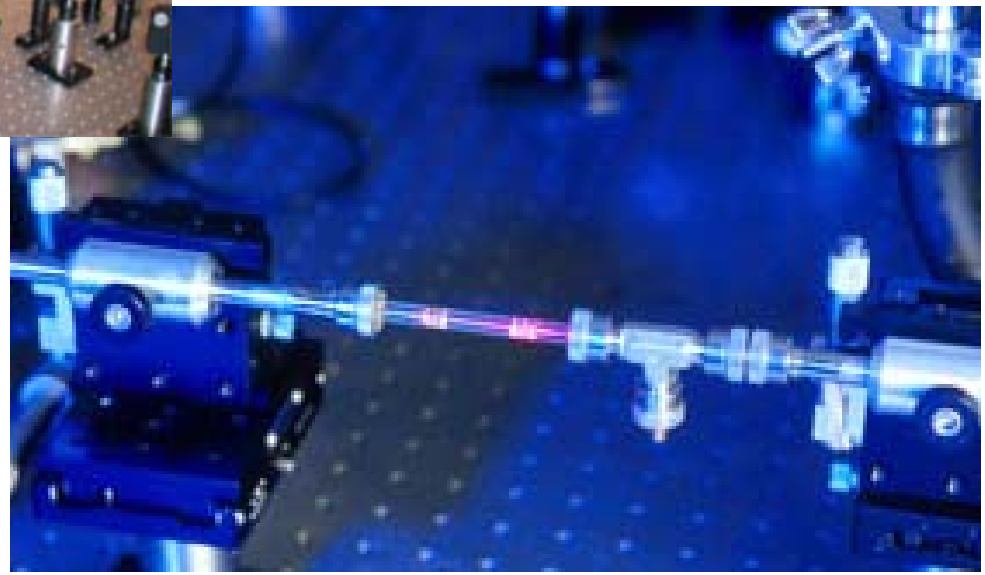
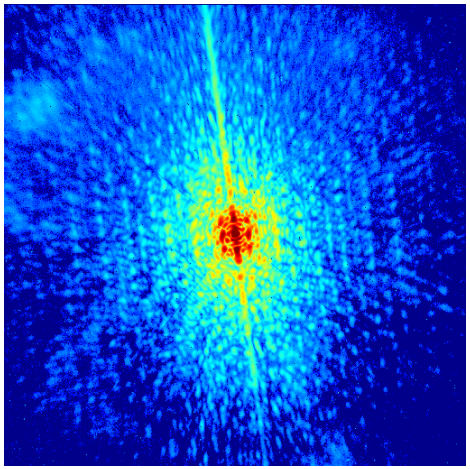
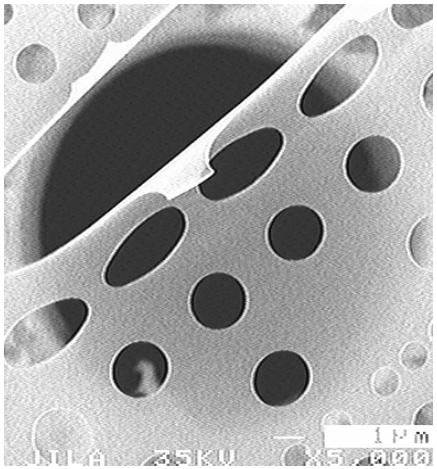


Table-top imaging: EUV(2)

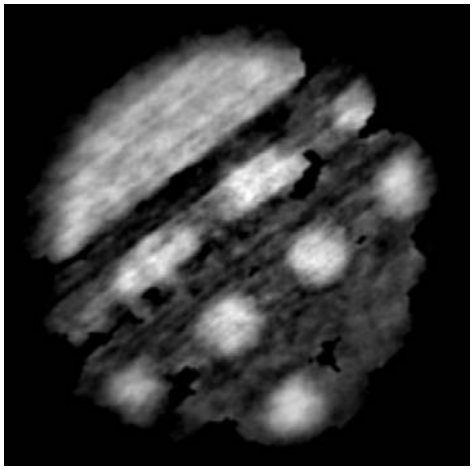
- first diffraction imaging by using EUV table-top light source



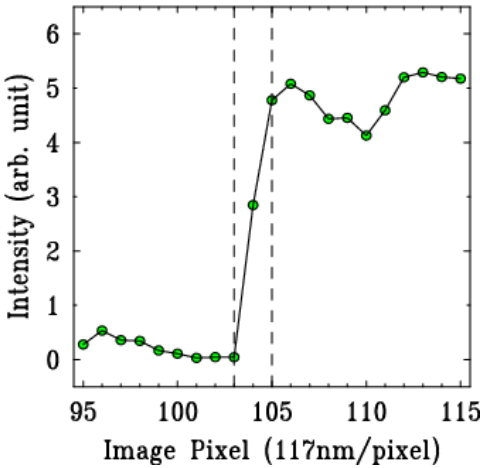
diffraction pattern



sample (SEM image)



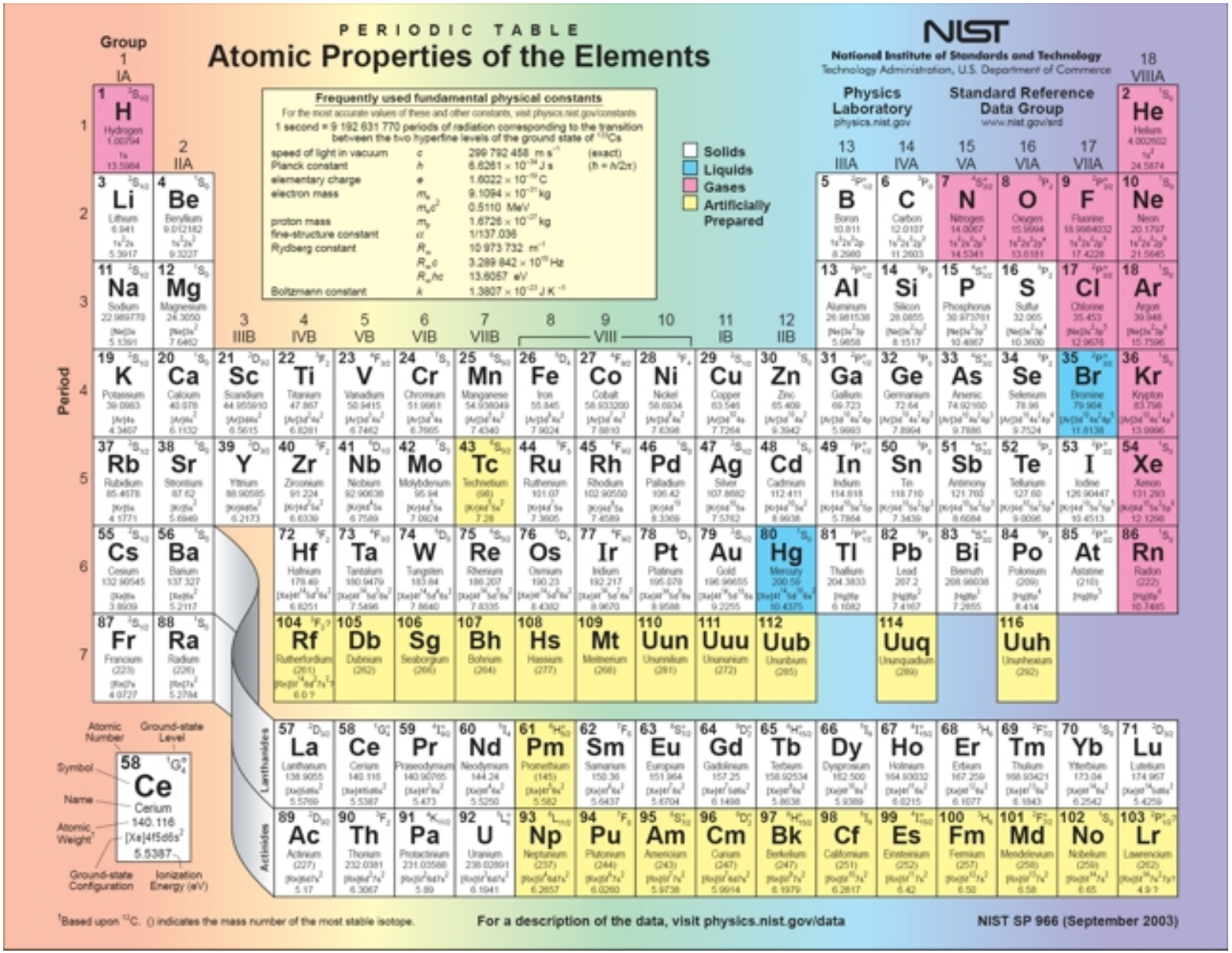
sample (reconstruction)



Science opportunity

- compositional analysis of bio-minerals
- multi-color imaging of cells: systems biology
- magnetic materials: DMS, etc
- correlated electrons: imaging electronic orbital
  nano-scale phase separations in CMR
  domain structures in multiferroics
- seeing in action

energy range	sample prep.	high flux
polarization	H, E, P, T	detector


PERIODIC TABLE
Atomic Properties of the Elements
NIST
National Institute of Standards and Technology
Technology Administration, U.S. Department of Commerce
Physics Laboratory
physics.nist.gov
Standard Reference Data Group
www.nist.gov/srd
Frequently used fundamental physical constants
For the most accurate values of these and other constants, visit physics.nist.gov/constants
1 second = 9 192 631 770 periods of radiation corresponding to the transition between the two hyperfine levels of the ground state of 133Cs
speed of light in vacuum c 299 792 458 m s−1 (exact)
Planck constant h 6.6261 × 10−34 J s (ħ = h/2π)
elementary charge e 1.6022 × 10−19 C
electron mass me 9.1094 × 10−31 kg
mec2 0.5110 MeV
proton mass mp 1.6726 × 10−27 kg
fine-structure constant α 1/137.036
Rydberg constant R∞ 10 973 732 m−1
R∞c 3.289 842 × 10^15 Hz
R∞hc 13.6057 eV
Boltzmann constant k 1.3807 × 10−23 J K−1
Solids
Liquids
Gases
Artificially Prepared
Group
Period
Lanthanides
Actinides
Atomic Number
Ground-state Level
Symbol
Name
Atomic Weight
Ground-state Configuration
Ionization Energy (eV)
[Based upon 12C. () indicates the mass number of the most stable isotope.
For a description of the data, visit physics.nist.gov/data
NIST SP 966 (September 2003)

Summary

" toward a single atom microscope"

1. Coherent x-ray diffraction microscopy

   non-invasive 3D imaging – GaN
   single cell imaging
   bio-minerals

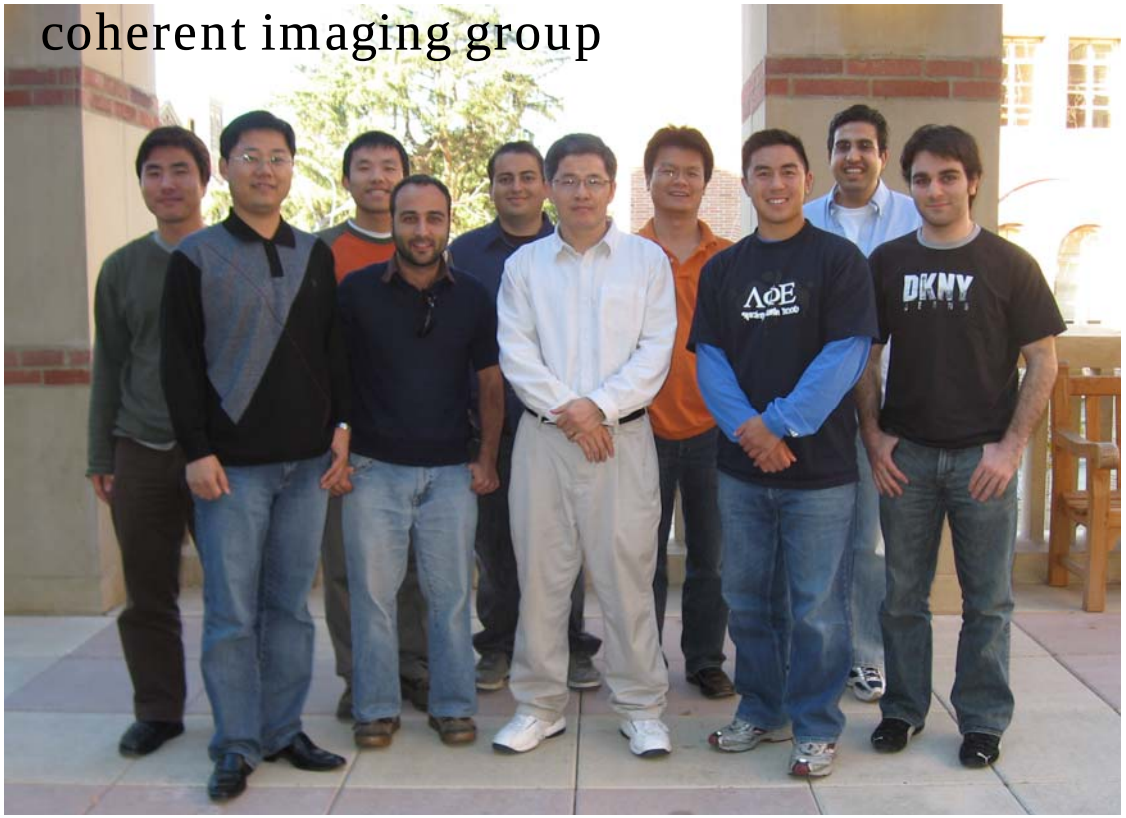
2. Resonant imaging

   elemental sensitivity in Au/Pt pattern
   elemental mapping of buried structures

3. Table-top diffraction microscopy: HHG

4. Science opportunity

Acknowledged to



- Materials science, UC Davis
  S. Risbud
- Microbio. Immuno.
  & Mol. Gen., UCLA
  F. Tamanoi & J. Jurano
- Children's hospital, Harvard
  M. Glimcher & L.Graham
- EE, UCLA
  J. Judy & K. Wang
- JILA, UC Boulder
  Murane's group

- APS : M. de Jonge, C. Rau, D. Paterson, I. McNulty
- SPring-8 : Y. Nishino, Y. Takahashi, Y. Kohumura & T. Ishikawa
- LBNL : C. Cork & T. Earnest