CHESS, the Synchrotron X-ray Radiation Facility at Cornell University

by Ernie Fontes[1] & Donald Bilderback[1,2]

[1]CHESS (Cornell High Energy Synchrotron Source)

[2]School of Applied & Engineering Physics

1. Overview

2. Science Experiments & Technology

3. Vision for the Future with an ERL machine

Acknowledgements: B. Batterman, J. Brock, K. Finkelstein, S. Gruner, R. Huang, A. Kazimirov, C. Sinclair, Q. Shen, M. Tigner

What is CHESS?

CHESS

Cornell High Energy Storage Synchrotron (CHESS, http://www.chess.cornell.edu) is an NSF/NIH user facility with an annual budget of $7M that supports research using high intensity X-ray beams. CHESS provides state-of-the-art synchrotron facilities for research in physics, chemistry, biology, environmental and materials sciences to between 600 and 1000 researchers per year, including Cornell faculty members on its 12 x-ray stations supported by a staff of nearly 60 individuals. MacCHESS, a facility supported by the National Institutes of Health National Center for Research Resources (NCRR), focuses on macromolecular crystallography and is included in the above numbers. G-line division is for CU faculty & students.

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Nature's Dimensions

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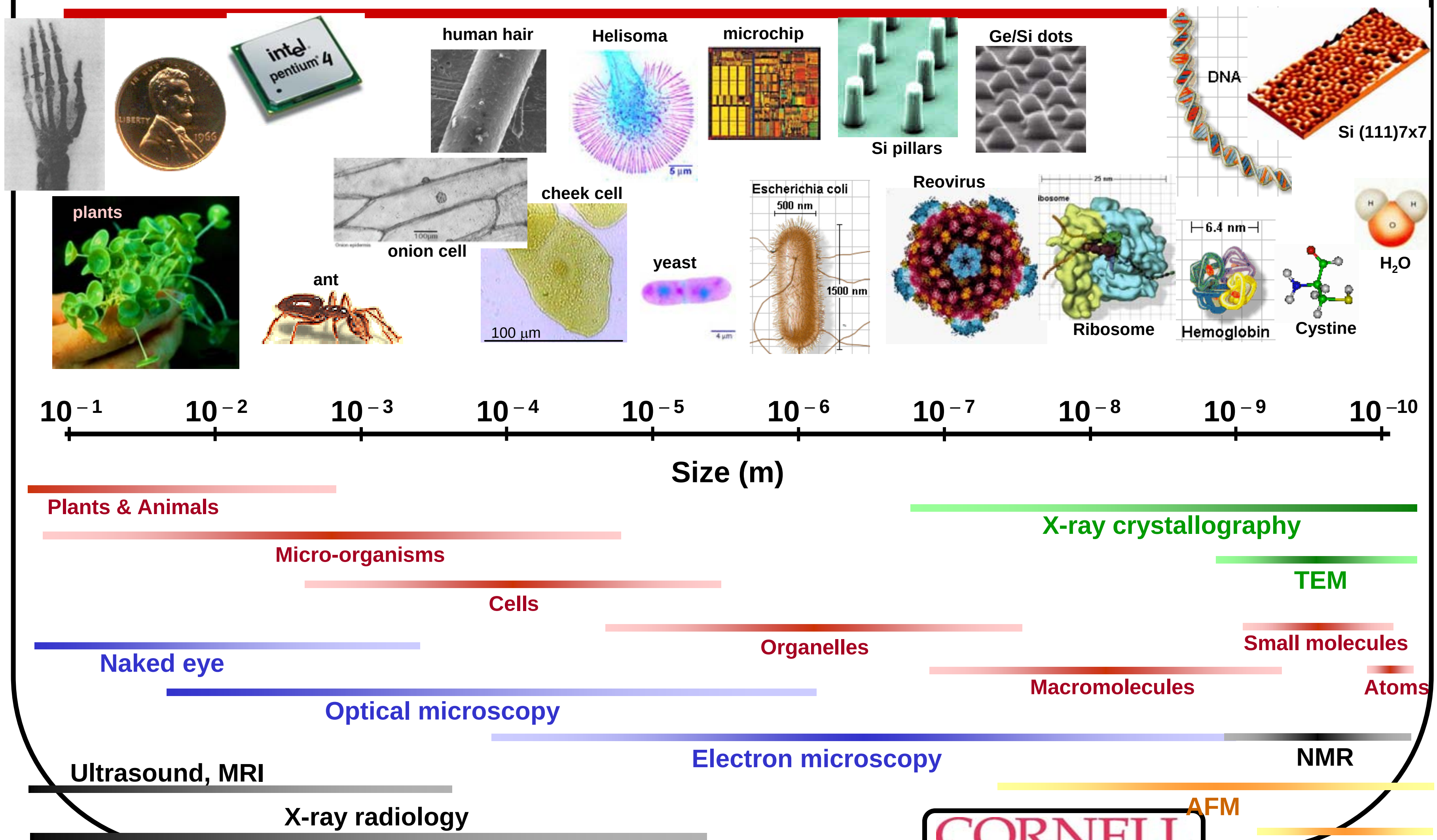

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What is Synchrotron Radiation?

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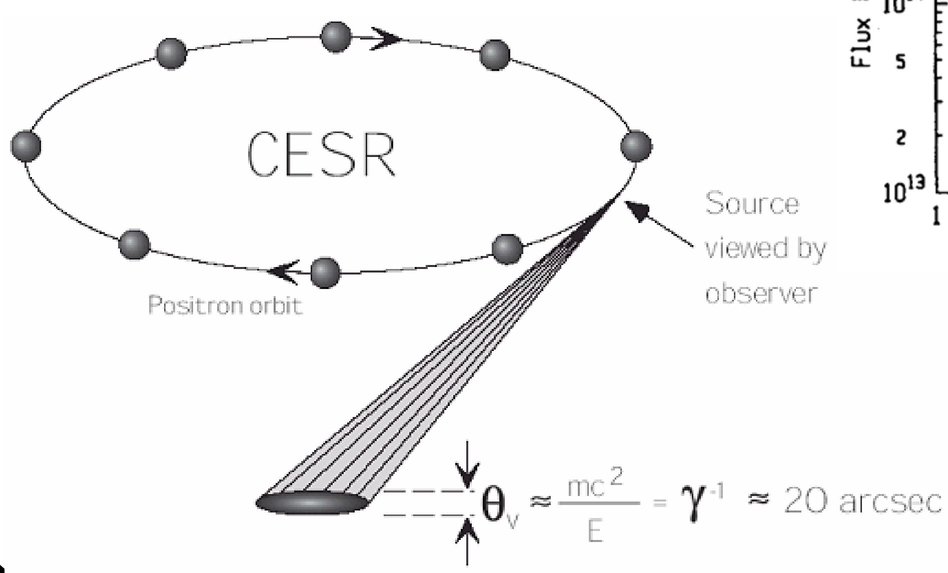
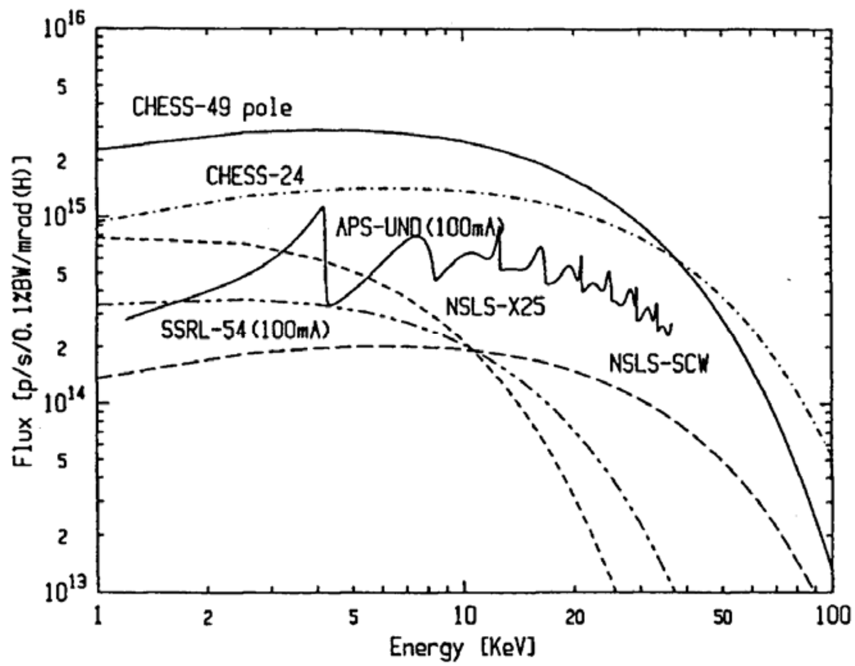
15 to 25 KW of power
in an x-ray wiggler beam
thus heat loading on components
is an issue!

polarized in plane of orbit, etc.





CHESS EAST & WEST

We build all equipment

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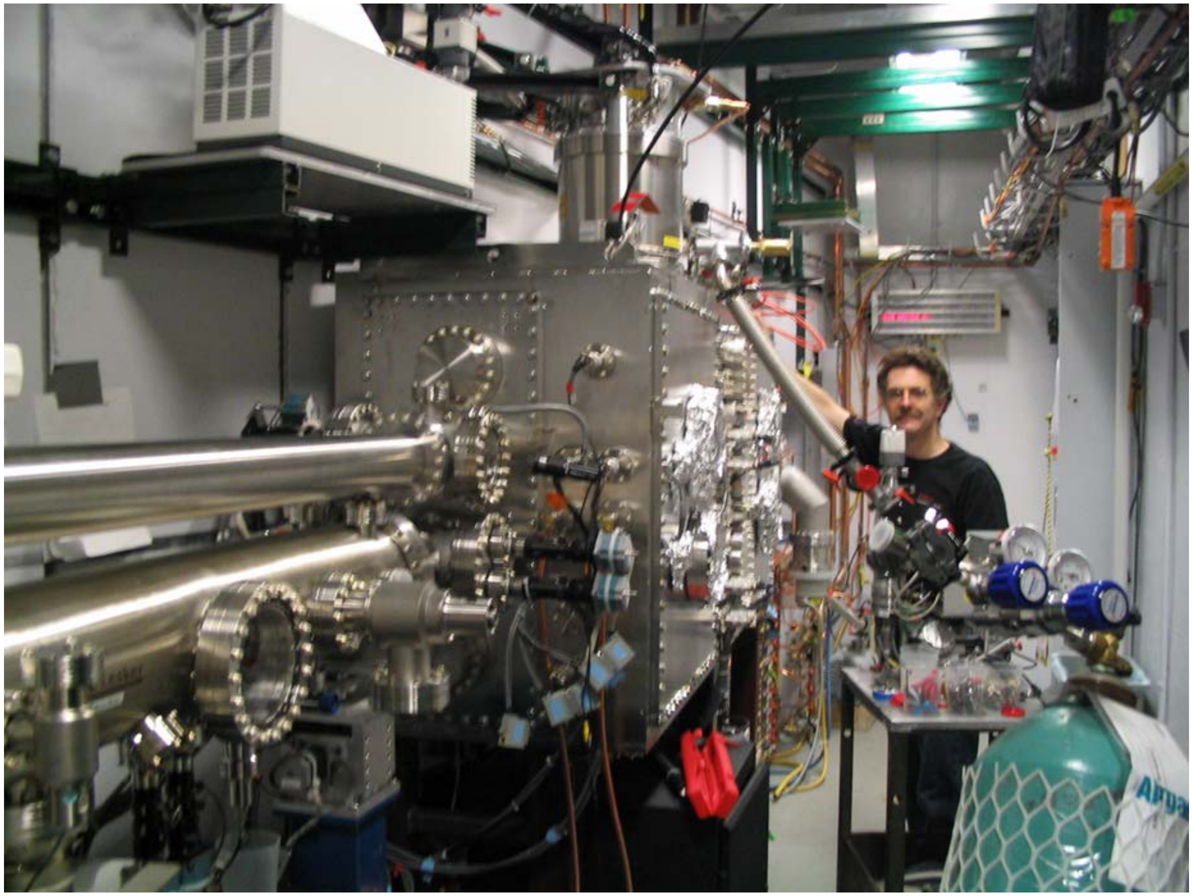
X-ray optics and stations are very special and specific to the needs of the experimental groups

many hands design & construct....

Bob Seeley, head of CHESS vacuum team is leak testing the G-line optics box.



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X-ray optics deflect beams

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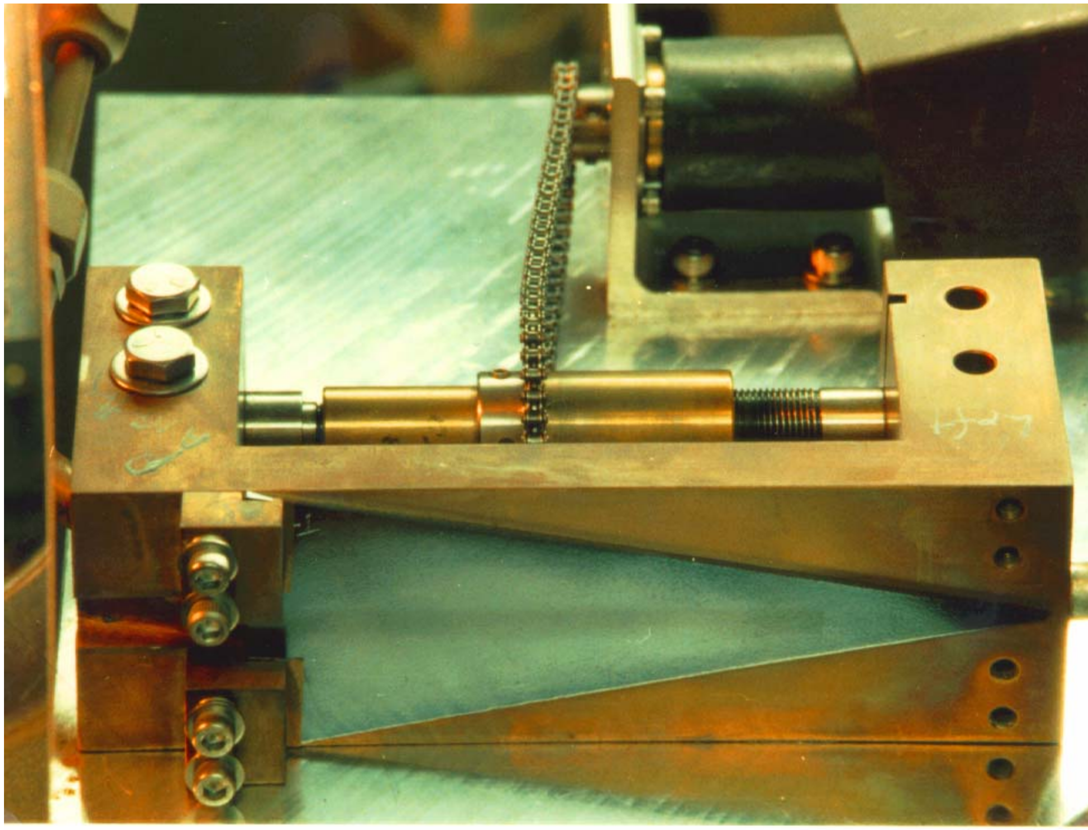

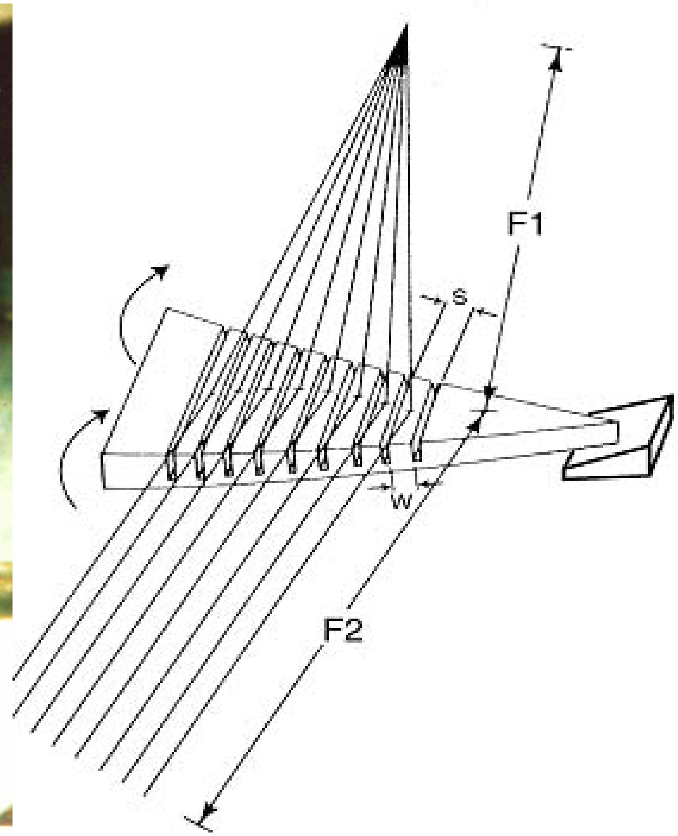

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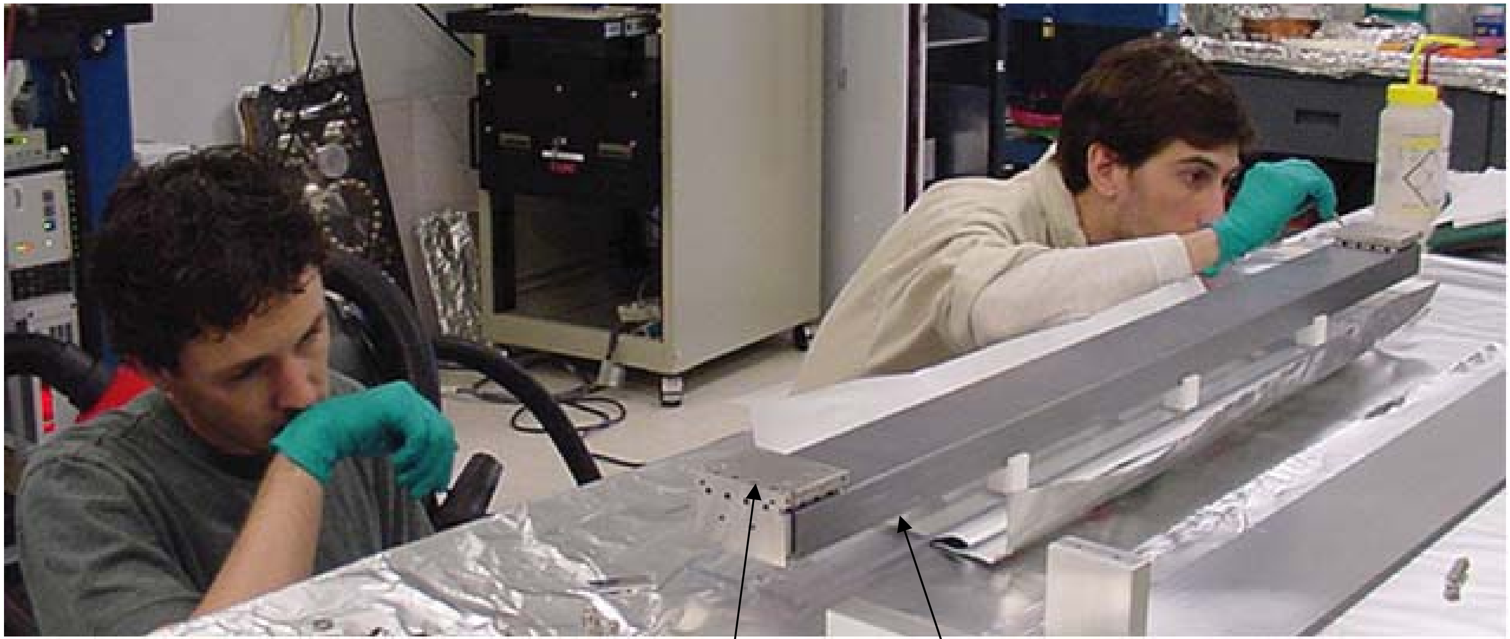
Undergraduate and graduate students help with construction

CHESS

Darin Dale, grad student (now Chess Scientist)

Chris Conolly, CHESS Operations Mgr.



Bending pads to curve mirror to R=few hundred meters

Silicon x-ray mirror surface polished to 3 Angstrom finish

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Who uses CHESS?

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The facilities are open to anyone (academic, corporate & industrial users, national laboratories, etc.)

•Submit a brief proposal that passes outside peer review and who agrees to publish their results.

•No charge for beam time except when performing proprietary research that will not be published. (In this case, full cost recovery of running the accelerator will apply.)

The result of all this activity? About a paper/day is published in the journals for each day of beamtime!

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Industrial Use of CHESS

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21 Industrial institutions use CHESS (60 users).

- Pharmaceutical industries for protein crystallography, semiconductor industries for materials science, and scientific supply industries for instrumentation development.

Direct facility-industrial collaborations include:

- Osmic, to develop x-ray optics
- Janis Research, to develop cryogenics
- Agere Systems, to develop semiconductors
- ADSC, to develop x-ray detectors

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X-ray Absorption

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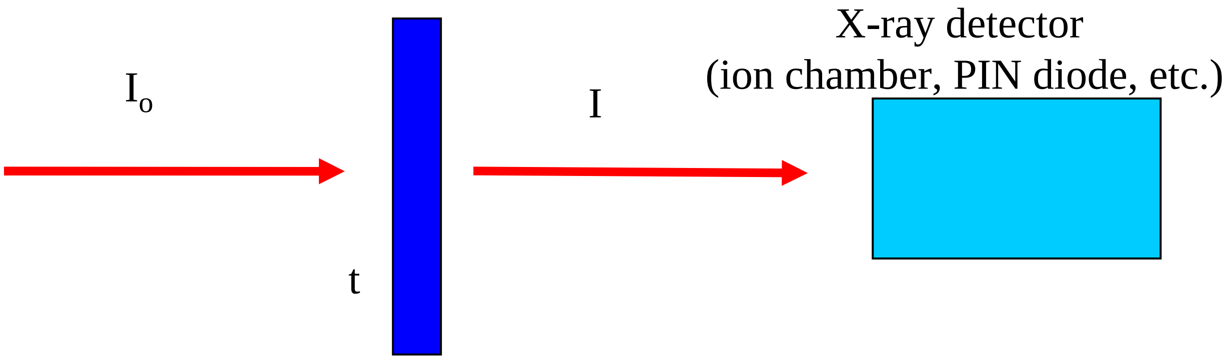

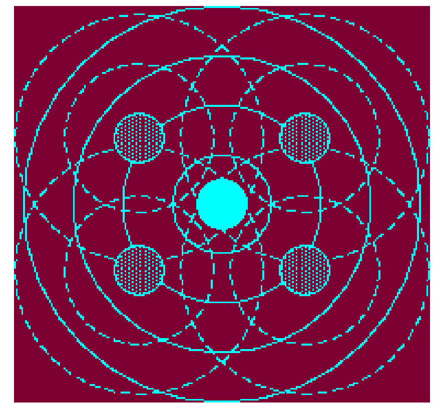

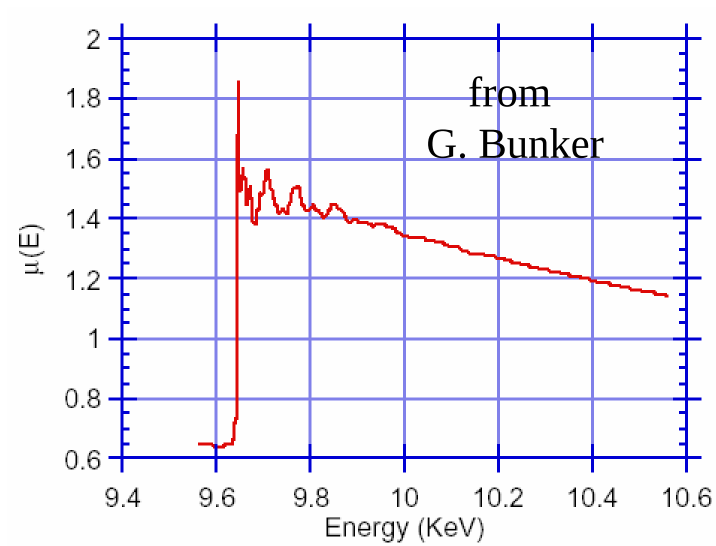

XAFS of ZnS (Sphalerite)

$I = I_o * \exp(-\mu t)$

1. **contrast in radiographs**
2. **near neighbor distances in EXAFS**
3. **X-ray fluorescent imaging**

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X-ray Crystallography

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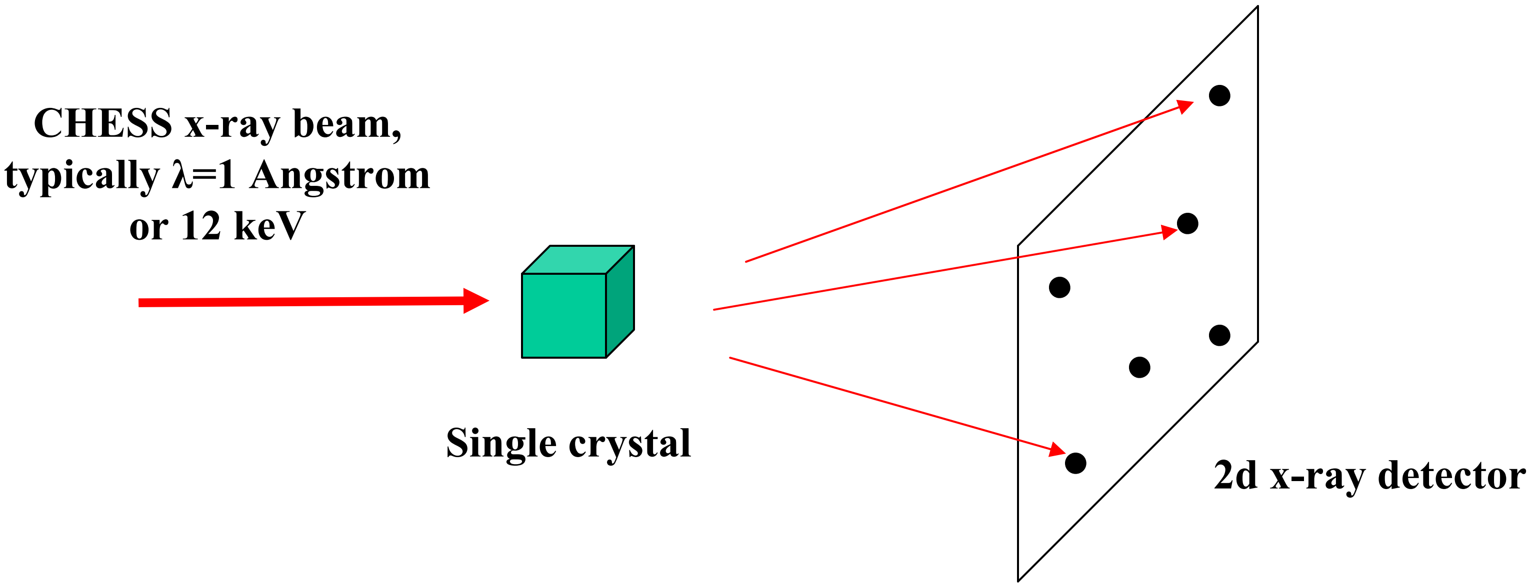

Constructive Interference when $n\lambda = 2\ d * \sin(\theta)$
d = spacing of the diffraction planes

Allows you to reconstruct the crystal on an atom-by-atom basis in 3-dimensions

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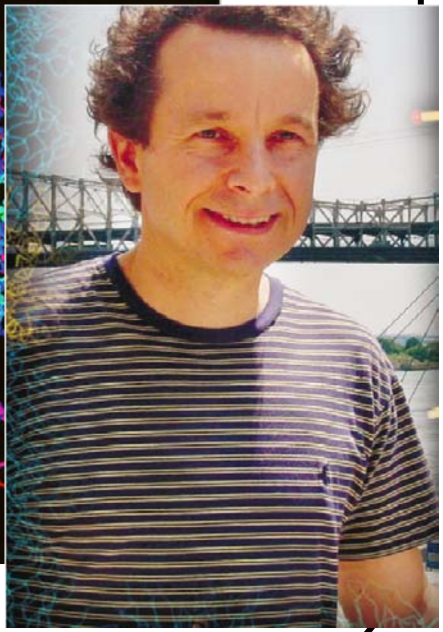
Prof. Rod MacKinnon
Nobel Prize in Chemistry, 2003

Faithful CHESS User Rod MacKinnon shares the 2003 Nobel Prize in Chemistry for determining the beautiful structure and function of ion channels. MacKinnon says "Our research aims to understand the molecular mechanisms of a class of integral membrane proteins known as ion channels. By catalyzing the rapid and selective flow of inorganic ions across cell membranes, these proteins generate electrical signals in cells. Among their many biological functions, ion channels control the pace of the heart, regulate hormone secretion and generate the electrical impulses underlying information transfer in the nervous system. Central questions in the field of mechanistic ion channel studies include: How do their pores discriminate between very similar ions such as those of sodium and potassium, and how does neurotransmitter binding or a change in a cell's membrane voltage control the gating (opening and closing) process?"



Rod MacKinnon "Shaky on the keys"

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Determining the structure of cell-membrane ion channels was thought to be mission impossible. Alison Abbott meets the researcher who proved the doubters wrong, opening new windows on cellular function.

Rod MacKinnon woke up on 1 January 1998 with a sickening feeling that his eureka moment had been a dream. Late into the night, at Cornell University's synchrotron light source in Ithaca, New York, he had been processing data on the structure of a crystallized potassium-ion channel from a cell membrane. Eventually, his colleagues left to join the New Year celebrations, and MacKinnon worked on alone.

Midnight passed, and with each iteration of the data, the image of the channel on his computer screen became clearer. Then, in the channel, shadows of multiple potassium ions began to emerge, lined up like pinballs, exactly as had been predicted some 50 years earlier. "I became so shaky I couldn't hit the keys, and I had no one to tell," MacKinnon recalls. Eventually he went to bed, the excitement of his discovery still buzzing round his head.

Fortunately for MacKinnon, this was no dream. It was, in fact, a stunning highlight among a series of revelations about ion channels to emerge from his lab. And it was all the more remarkable for the fact that, when MacKinnon embarked on his quest to unveil the channels' structures just a few years before, many structural biologists had regarded him as foolhardy. Didn't he realize that ion channels were almost impossible to crystallize for X-ray structural analysis?

Ion channels are proteins embedded in cell membranes. They act as extremely selective gateways, allowing specific ions to pass in and out of the cell in response to various signals. Most dramatically, they mediate the electrical impulses known as action potentials that are the basis of communication in the nervous system.

> I became so shaky I couldn't hit the keys, and I had no one to tell.

MacKinnon didn't start out obsessed with ion channels. After gaining a biochemistry degree, he studied medicine, but soon found that his enquiring mind required a tougher challenge. "I needed to do a real science," he says. So in 1986, MacKinnon returned to Chris Miller's laboratory at Brandeis University in Boston, where he had worked on an undergraduate project, to retrain as an electrophysiologist. This soon lured him towards the mysteries of potassium-channel function.

These puzzles had their roots in the pioneering studies of Alan Hodgkin and Andrew Huxley at the University of Cambridge, UK, who in 1952 showed that a nerve cell's membrane becomes transiently, and very rapidly, permeable to sodium at the start of an action potential[1]. Sodium ions rush into the cell, causing the voltage across the membrane to drop. The membrane then becomes permeable to potassium ions, which flow out of the cell, allowing it to return to its resting potential.

Three years later, Hodgkin, with his col-

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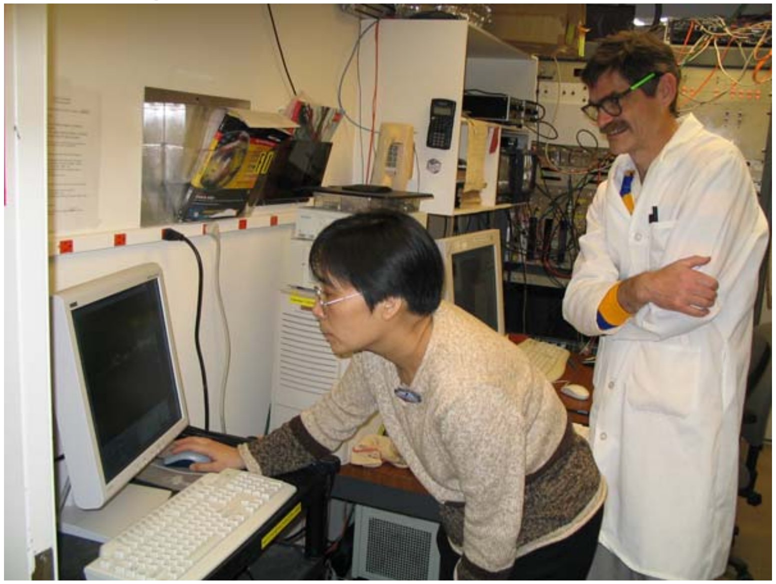
Adeno-associated Virus
Florida State, EM 596

CHESS

The aim of the projects on the ssDNA viruses is to identify structural determinants of receptor attachment, tissue tropism and in vivo pathogenicity between highly homologous Parvoviridae strains and serotypes and to elucidate the structural nature of the unique Geminiviridae capsid. Our structural studies so far indicate that slight capsid surface alterations, resulting from amino acid differences, are associated with pronounced differences in biological properties during the viral life cycle of parvoviruses. ....

Michael Chapman

Quing Xie and Michael Chapman



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Pulsed Laser Deposition at G3

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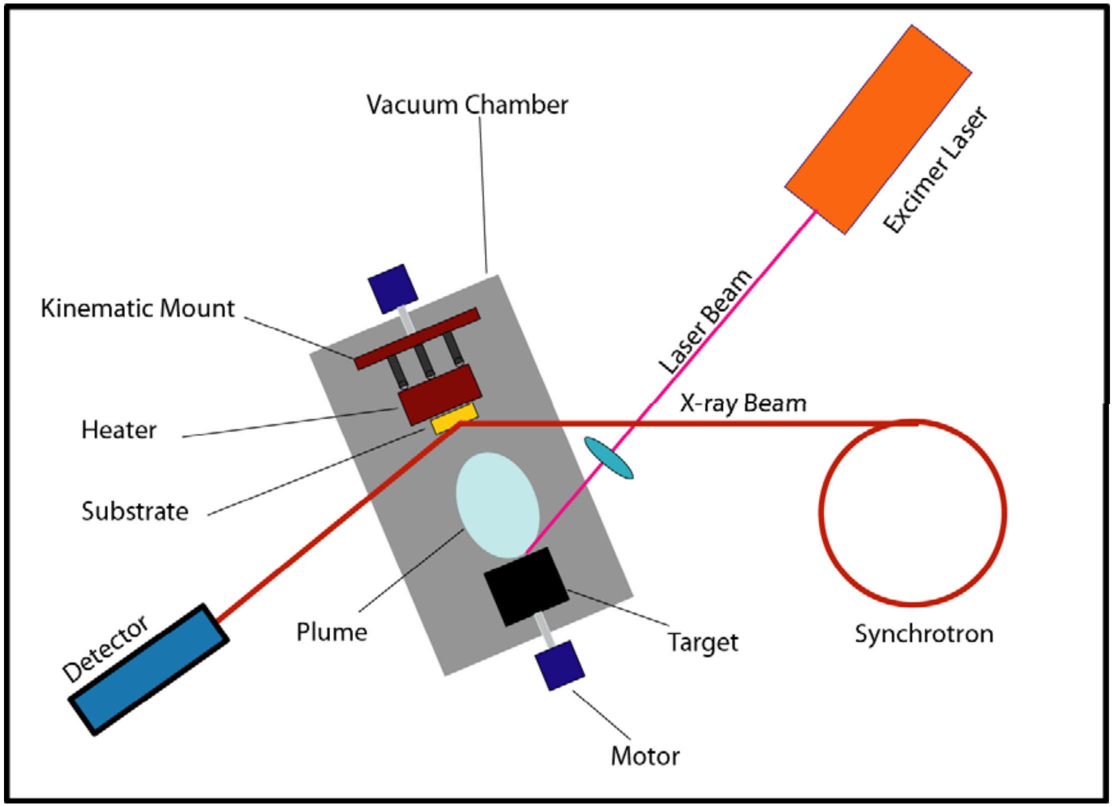

Aaron Fleet,
Yuri Suzuki,
Joel Brock

Darren Dale,

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Homoepitaxy of $SrTiO_3$ via PLD

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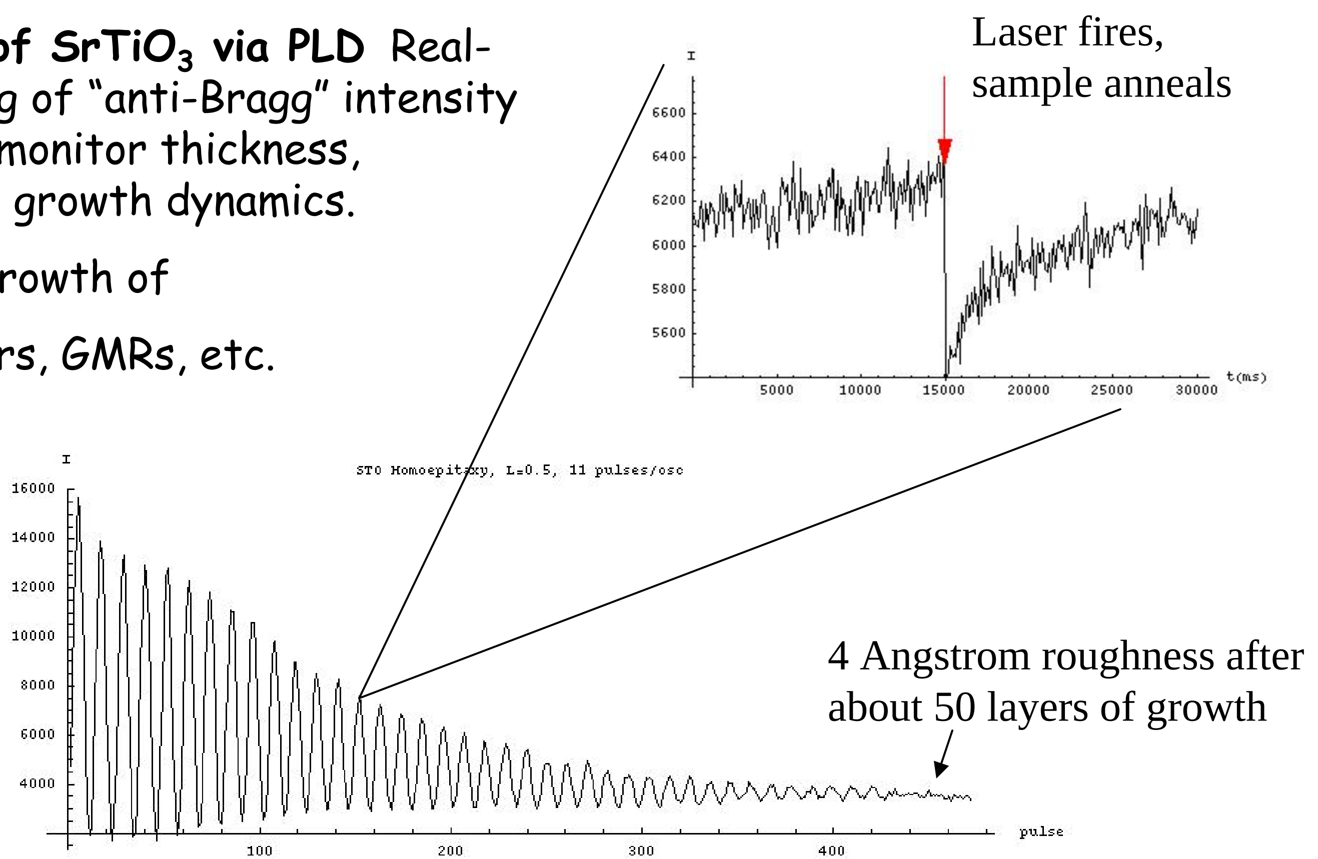
Homoepitaxy of $SrTiO_3$ via PLD Real-time monitoring of “anti-Bragg” intensity oscillations to monitor thickness, roughness, and growth dynamics.

Applications: growth of

superconductors, GMRs, etc.



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High Pressure X-ray Science in Diamond Anvil Cells

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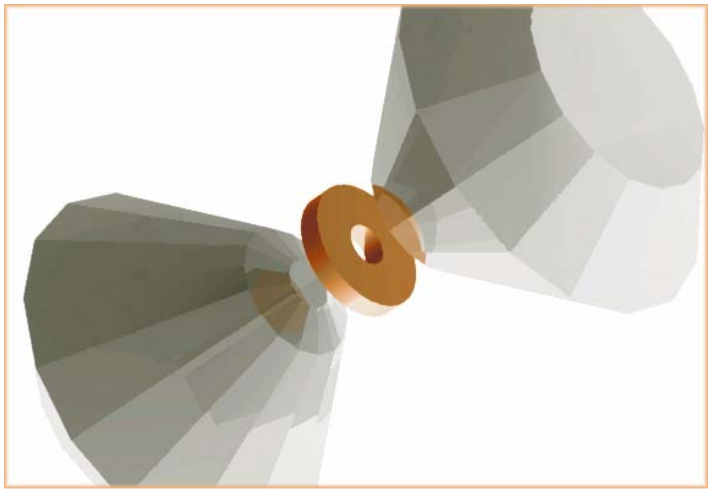
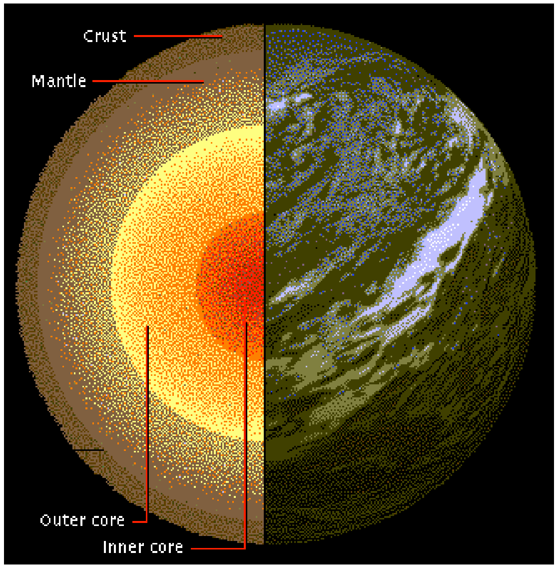
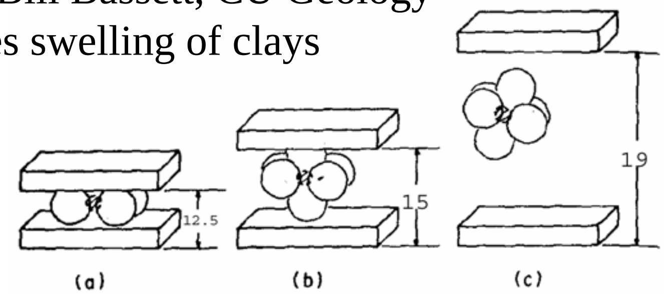




Prof. Arthur Ruoff - CU MSE High-Pressure expert has made center-of-earth pressures (380 GPa or 3.8 Mbar) at CHESS B1 station

Prof. Bill Bassett, CU Geology studies swelling of clays



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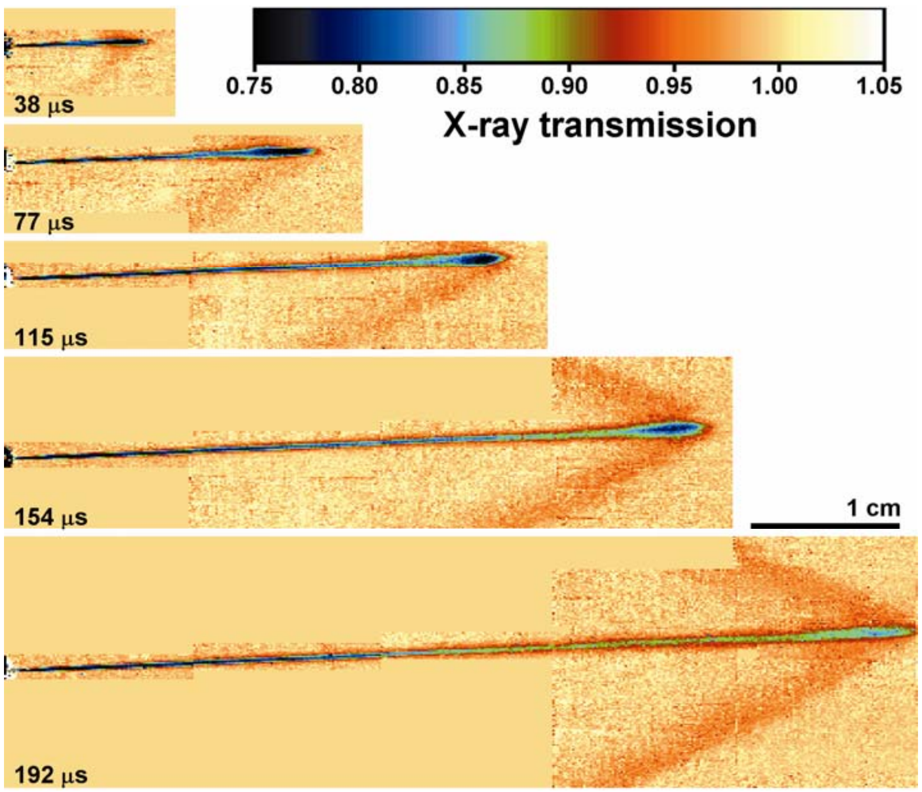
Microsecond Radiography of Diesel Fuel Injection Sprays



CHESS D-line + Prof. Sol Gruner group makes Pixel Array Detectors

A. MacPhee, M. Tate, C. Powell, Y. Yue, M. Renzi, A. Ercan, S. Narayanan, E. Fontes, J. Walther, J. Schaller, S. Gruner, J. Wang "*X-ray Imaging of Shock Waves Generated by High-Pressure Fuel Sprays*", Science **295**:1261, (2002).

movie

Gasoline Fuel Injection

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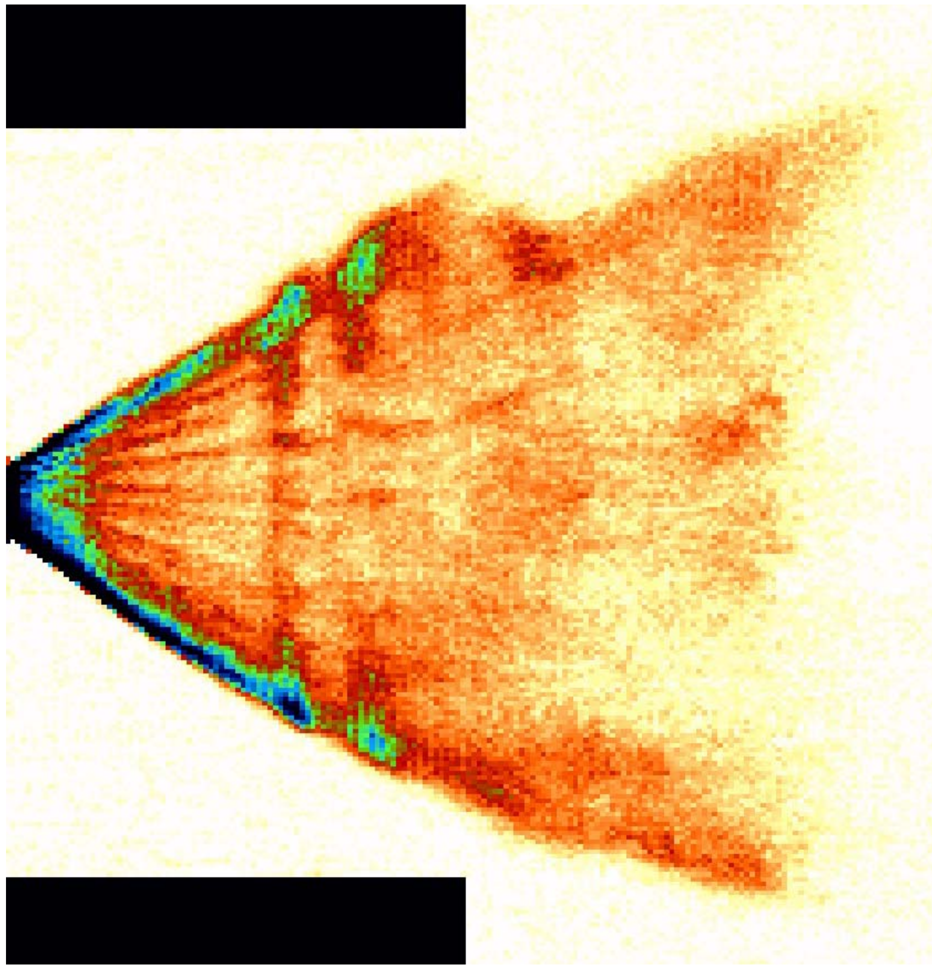

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Confocal X-ray Fluorescence (XRF) Microscopy for the Nondestructive Compositional Depth Profiling of Paintings

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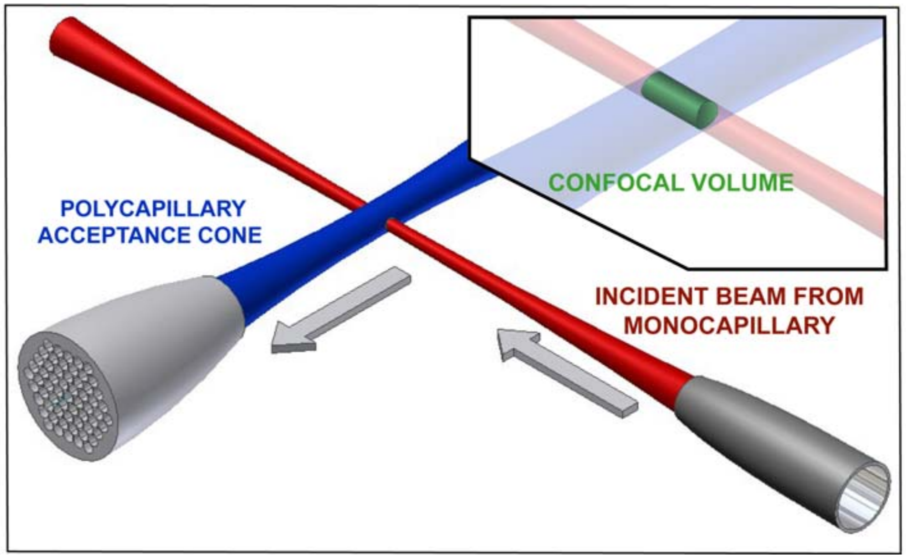
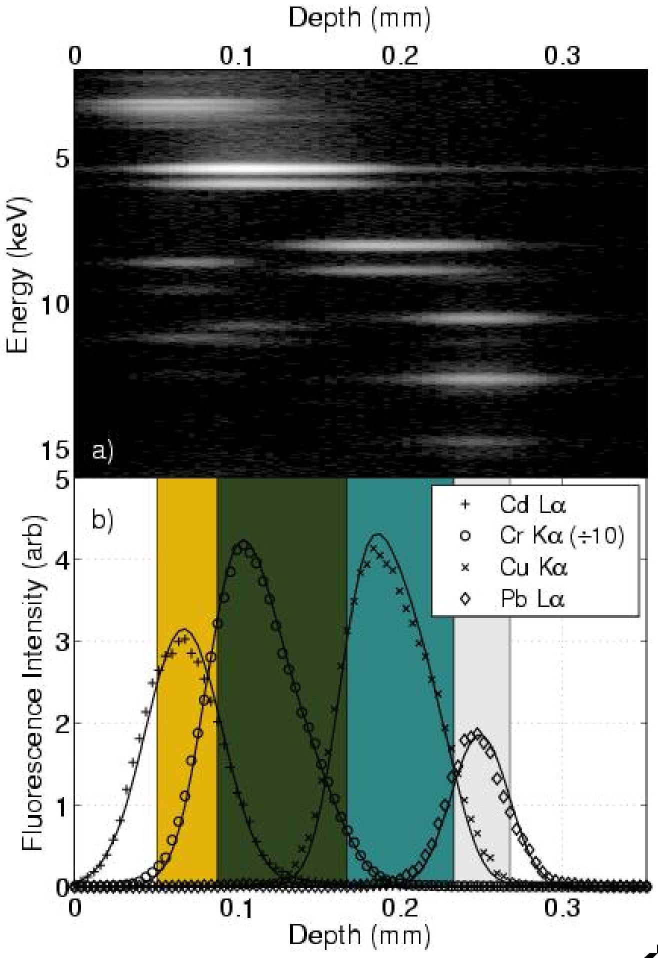
Winterthur Museum: Jennifer Mass and Christina Bisulca
Cornell: Arthur Woll, R. Huang, D. Bilderback, S. Gruner
X-ray Optical Systems: Ning Gao,



Geometry of the confocal XRF. The incident beam is focussed by a monocapillary lens to approximately 20x20 μm^2. Fluorescence is collected by a polycapillary, with a minimum collection area of 20-60 μm^2, depending on photon energy.



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Art History & Authentication of 17th Century Flemish artist David Teniers, "*The Armorer's Shop*"

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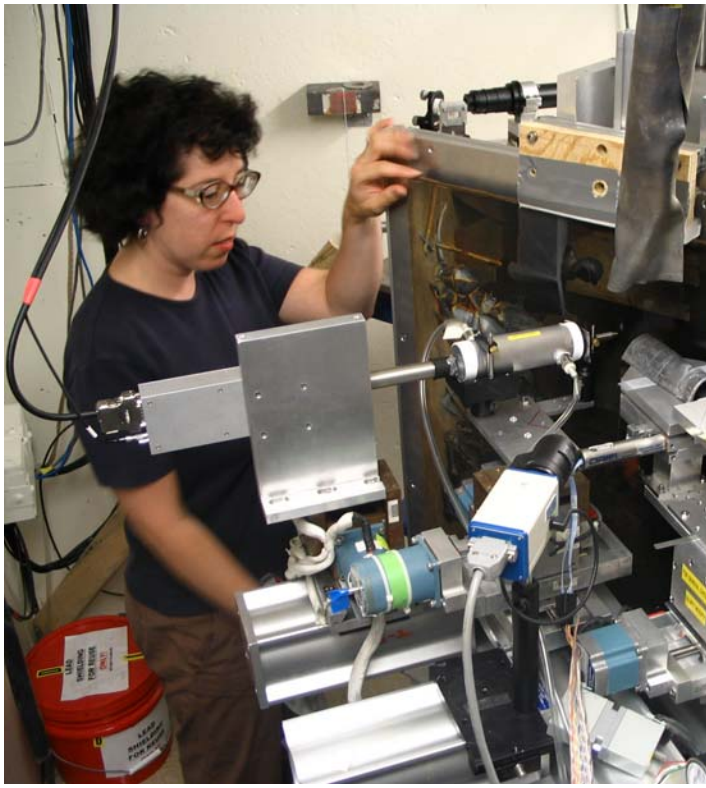

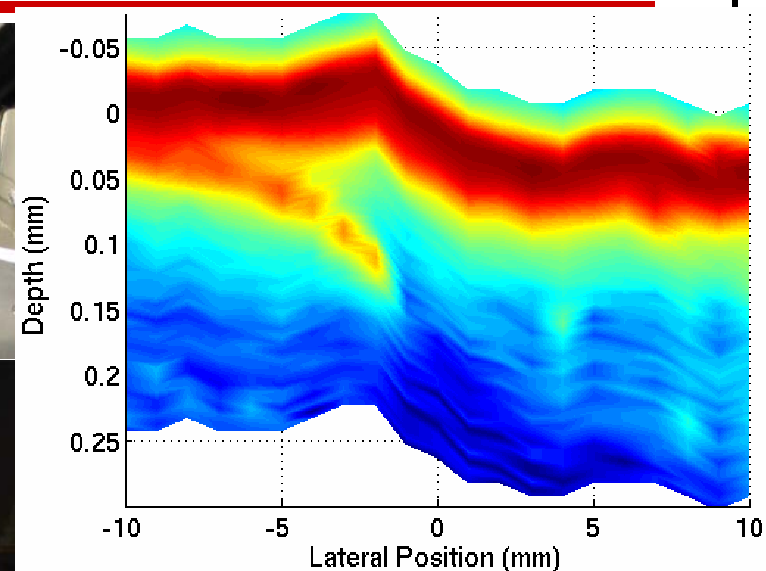

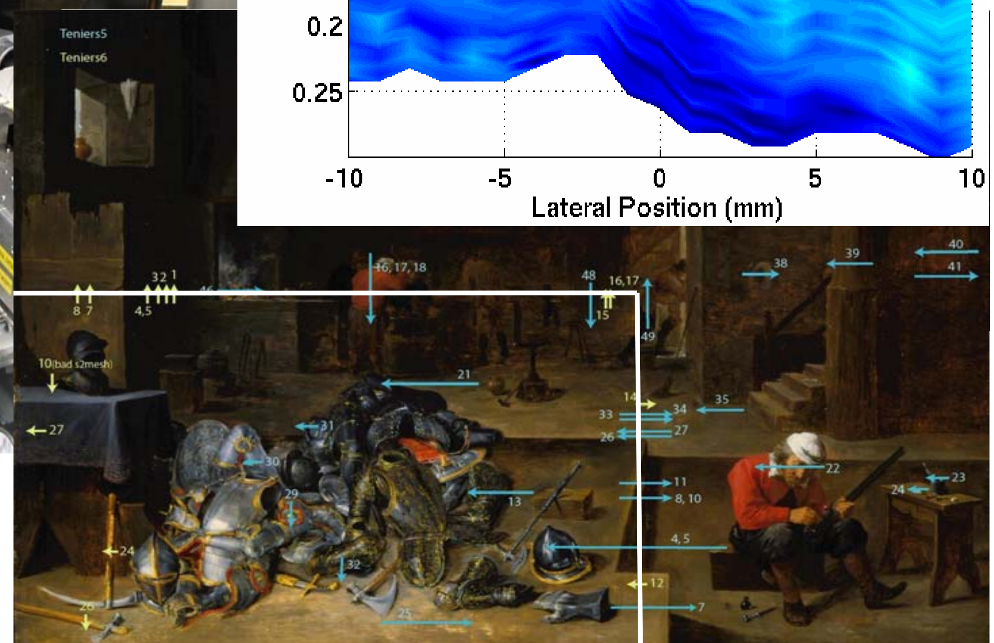

Arthur R. Woll1, Jennifer Mass2,3 Christina Bisulca2, Matthew Cushman2, Noelle Ocon3, and Bill Brown3

1Cornell High Energy Synchrotron Source, Cornell University, Ithaca, NY, 2University of Delaware, Newark, DE, 3Winterther Museum, Garden and Library, Winterthur, DE, 4North Carolina Museum of Art, Raleigh, NC

What is a block copolymer?

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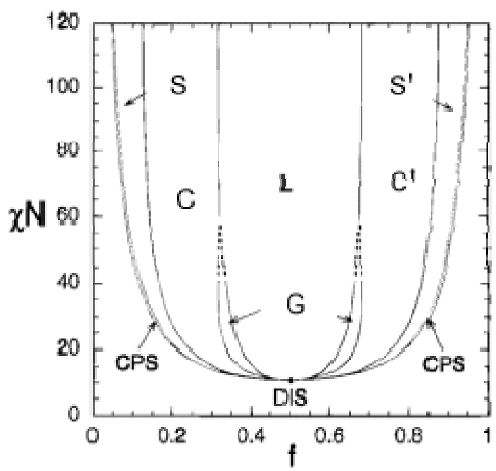
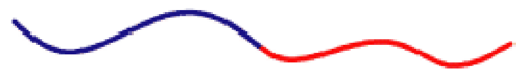
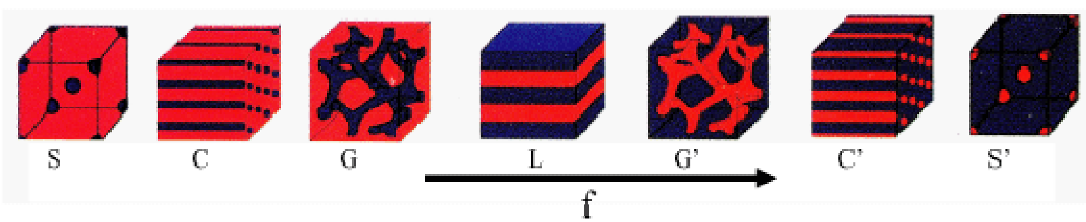
taken from Cornell Center for Materials Research webpage





χ: interaction parameter
N: degree of polymerization
f: volume fraction



Small Angle X-ray Scattering from Block Copolymer, D-line

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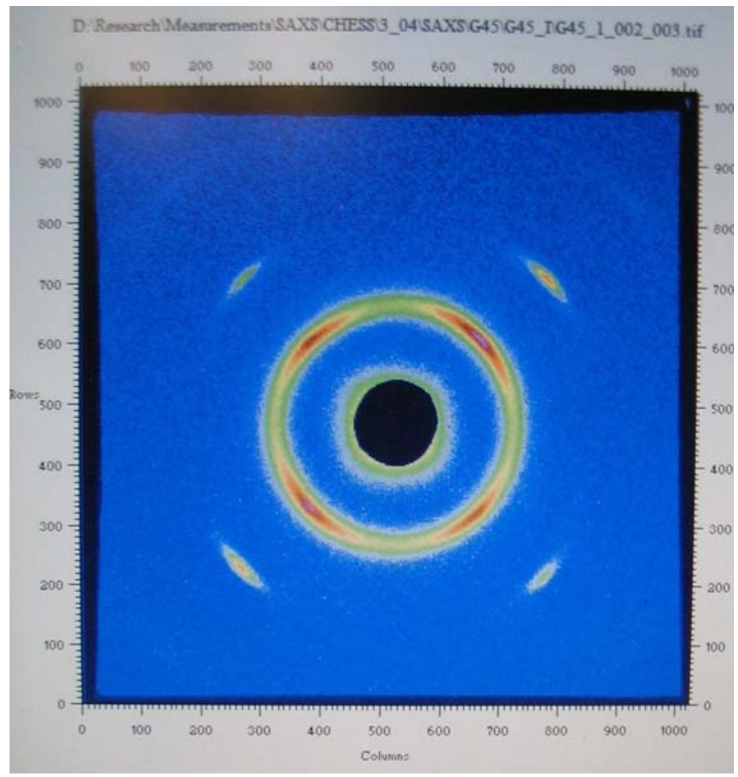
Styren-b-Isoprene-b-Styrene Block Copolymer from Net Thomas group, MSE at MIT

Steve Kooi & Panitarn Wanakamol



0.5 x 10 x 4 mm films, 3 sec x-ray exposure

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Lysozyme at 7000 psi at F2

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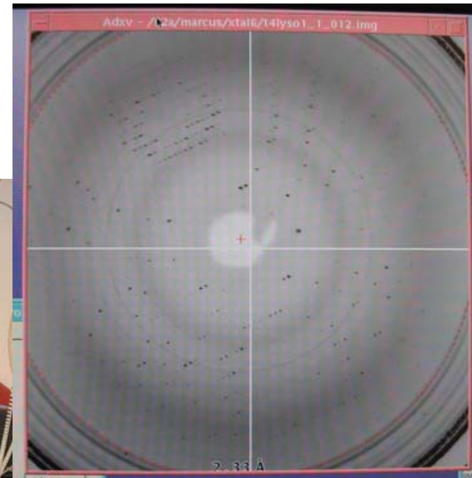
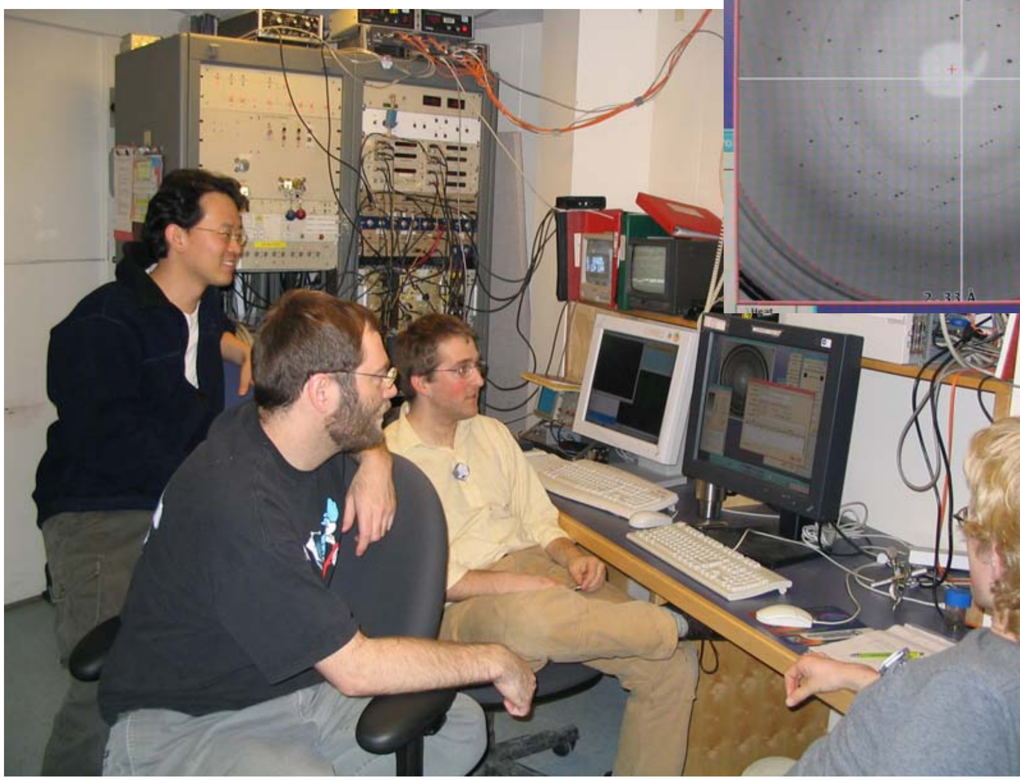
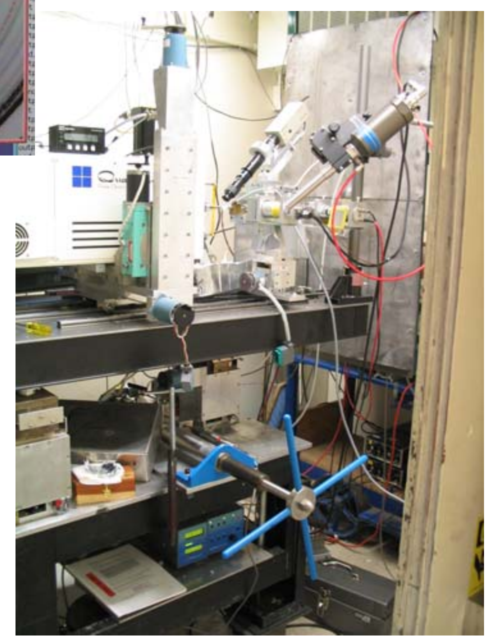


Chae Un Kim
Dave Schuler
Markus Collins
Buz Barstow
(Gruner group)





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CHESS Future: Energy Recovery Linac!

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- CHESS shares the CESR storage ring with HEP. In 2008 it can become a fully dedicated x-ray source.
- Cornell is developing a next generation Energy Recovery Linac (ERL) source as an upgrade to CESR – opens many new possibilities in biology and the physical sciences.
- A successful ERL provides a relatively low-cost pathway for future upgrades of other synchrotron storage rings.
- Plausible time-line:
  - 2006 - 2008: CESR shared between CHESS and High-Energy Physics, ERL prototyping
  - 2008 - 2011: CESR as fully dedicated machine & ERL prototyping, preparation for construction
  - 2015 and on: Dedicated ERL source

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ERL Upgrade to CESR

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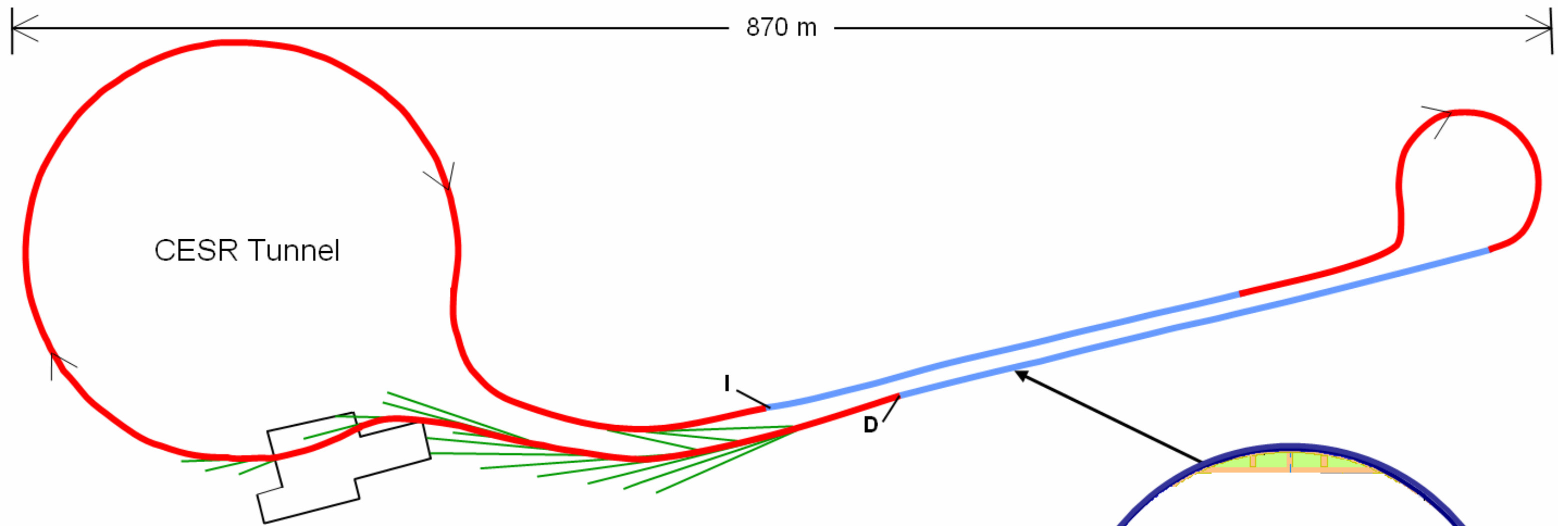
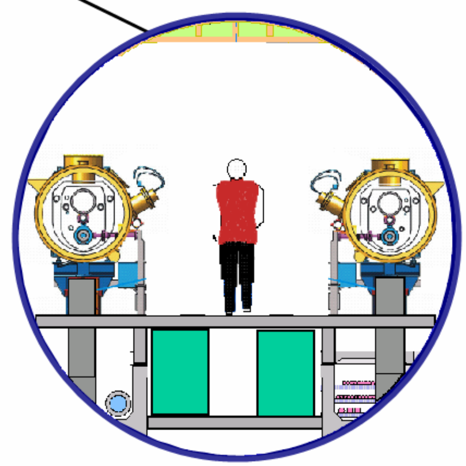


Preliminary layout view of an ERL upgrade to CHESS in the present CESR tunnel. A new tunnel with a return loop will be added to CESR. Electrons are injected into superconducting cavities at (I) and accelerated to 2.5 GeV in the first half of the main linac, then to 5 GeV in the second half. The green lines show 18 possible beamline locations. Electrons travel around the CESR magnets clockwise and re-enter the linac out of phase. Their energy is extracted and the spent electrons are then sent to the dump (D).



Two superconducting linacs in one tunnel accelerate the electrons to 5 GeV. Person shown for scale.

Spectacular new kind of x-ray source:

1. Ultra-high brightness/flux
2. Will focus an x-ray beam onto a single atom
3. Ultra-fast experiments on 50 fs scale

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ERL Microbeam Applications

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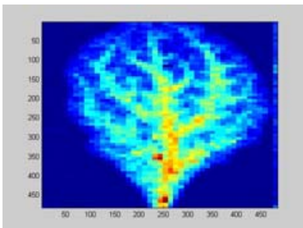
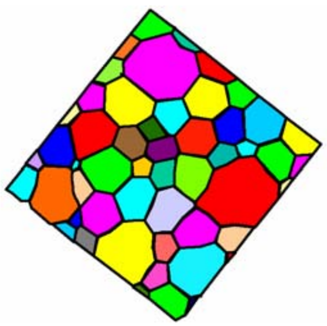


Zinc distribution in plant leaf by SR x-ray fluorescence

few cm scale object (CHESS data)

Centimeter scale

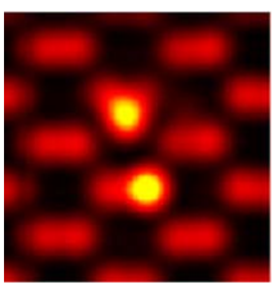


Hot-rolled Aluminum

SR x-ray diffraction. Map grain orientation and stress in real samples of 10^4 cubic microns at 1 micron resolution (APS data)

Micron scale

Nanometer scale



Two impurity atoms (yellow dots) in silicon crystal

TEM with 200 keV electrons can see individual atoms on samples a few atoms thick (Voyles, Lucent Technologies)

Atomic scale

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END