X-ray Fluorescence Imaging Following Synchrotron Beam Excitation

Uwe Bergmann

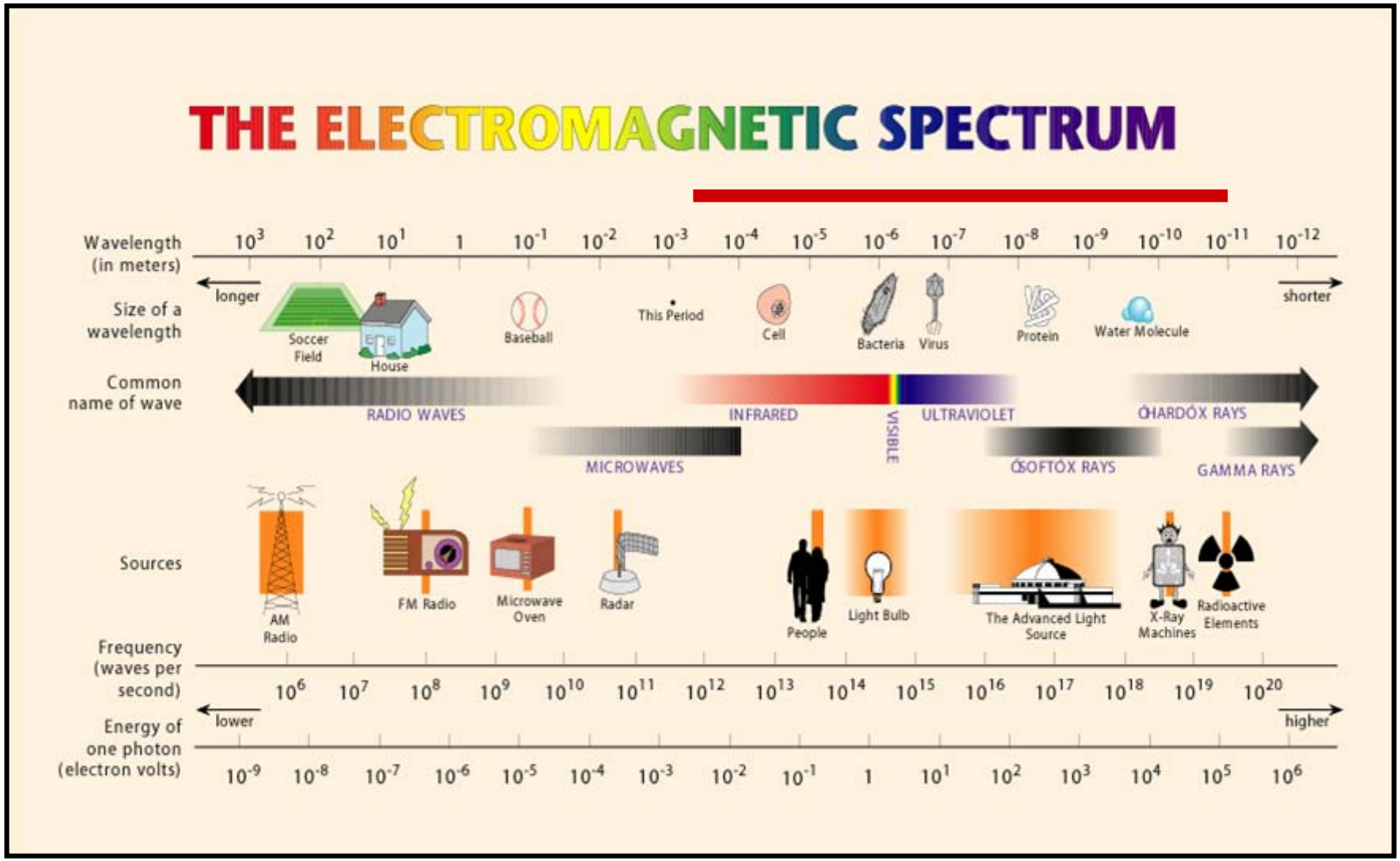
Stanford Synchrotron Radiation Laboratory
Stanford Linear Accelerator Center

April 1-4, 2004 Walters Art Museum Baltimore, Maryland

Outline

- introduction to synchrotron radiation (SR)
- x-ray transmission imaging
- x-ray fluorescence (XRF) imaging
- examples of SR based XRF imaging
- details and numbers
- proposed plan

Synchrotron Radiation Spectrum



SR Facilities Around the World

- 54 operational light source rings in 19 countries
- 8 rings in construction
- 11 in advanced stages of design/planning

For a list of SR facilities around the world see:

http://ssrl.slac.stanford.edu/SR_SOURCES.HTML

Four Largest US Synchrotron Sources

Stanford Synchrotron Radiation Laboratory (SSRL)
Stanford Linear Accelerator Center (1974)

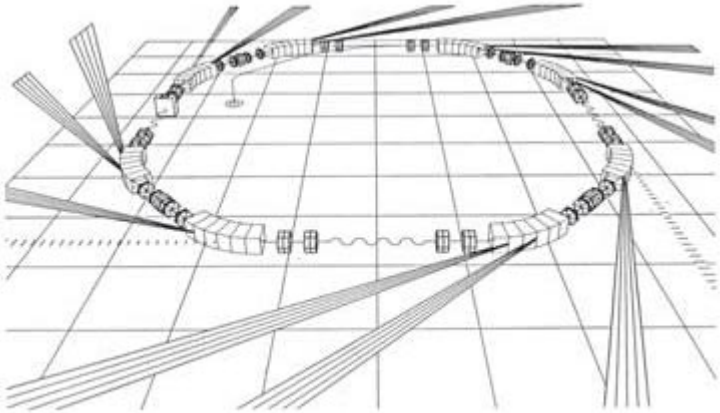
National Synchrotron Light Source (NSLS)
Brookhaven National Laboratory (1982)

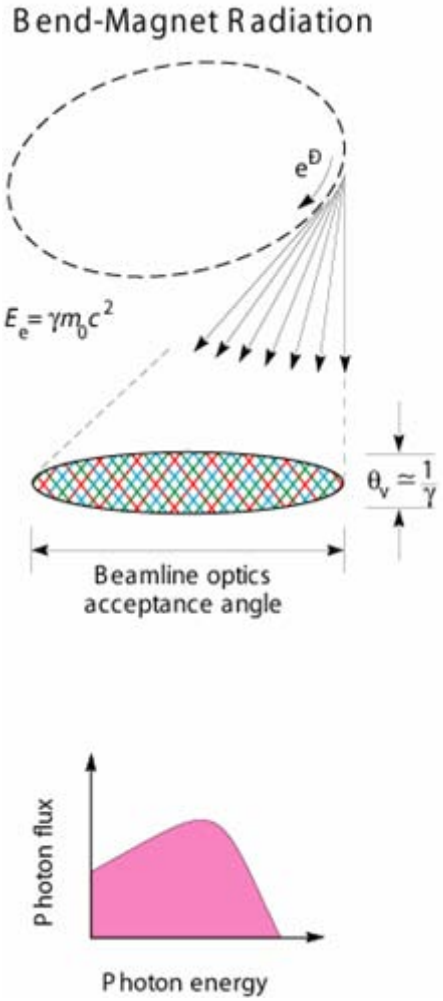
Advanced Light Source (ALS),
Lawrence Berkeley National Laboratory (1993)

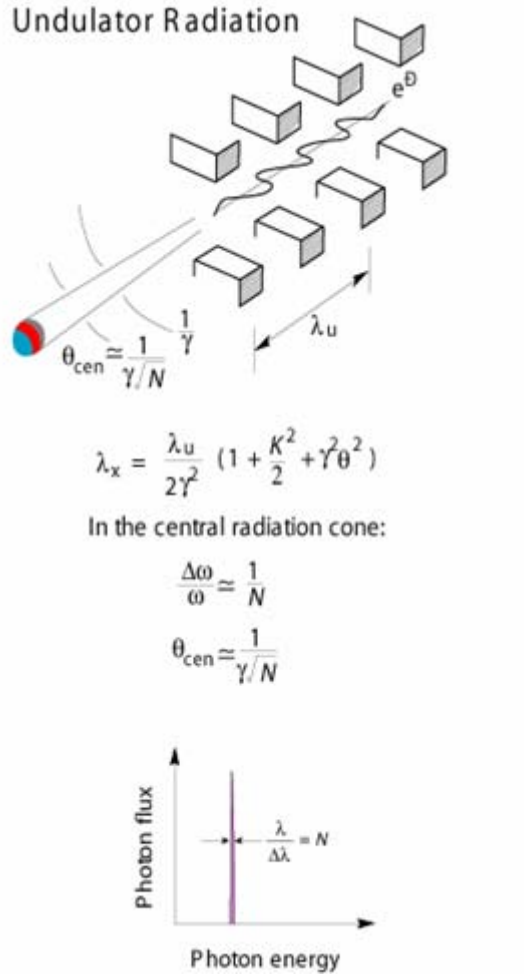
Advanced Photon Source (APS),
Argonne National Laboratory (1996)

Different Types of Synchrotron Sources

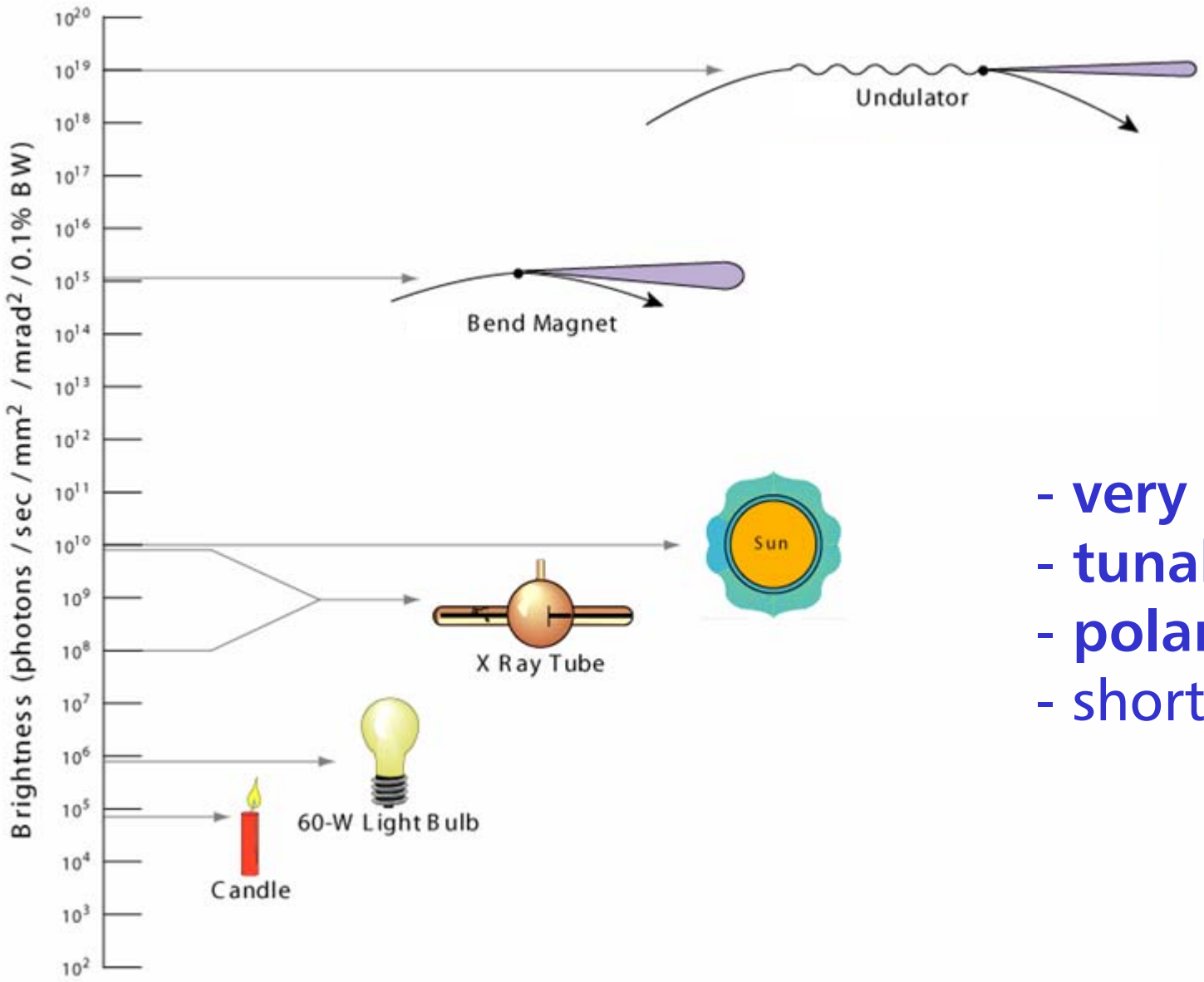
schematics of a synchrotron lab







Properties of Synchrotron Sources?



- very intense
- tunable
- polarization
- short pulses

Concept of X-ray Transmission Imaging

- measure transmission at two energies: below and above absorption edge of element of interest

- take difference to enhance contrast

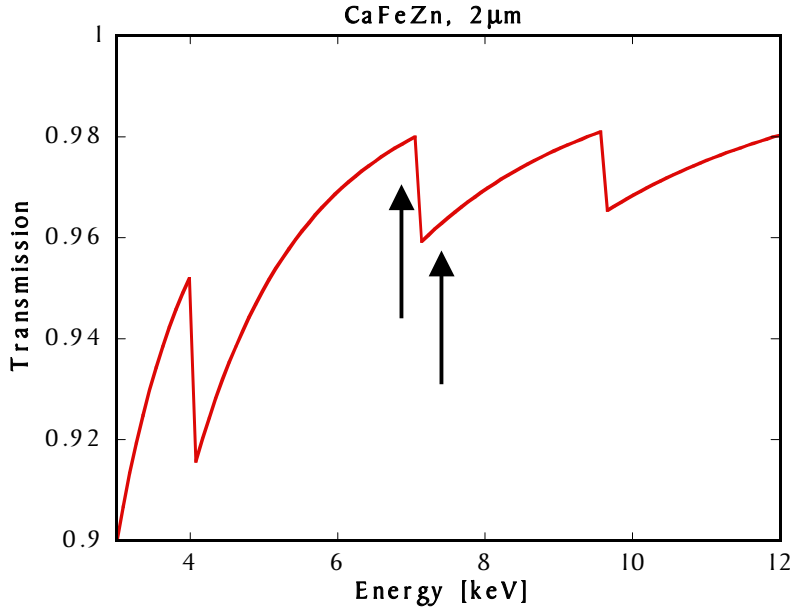
- chemical dependence

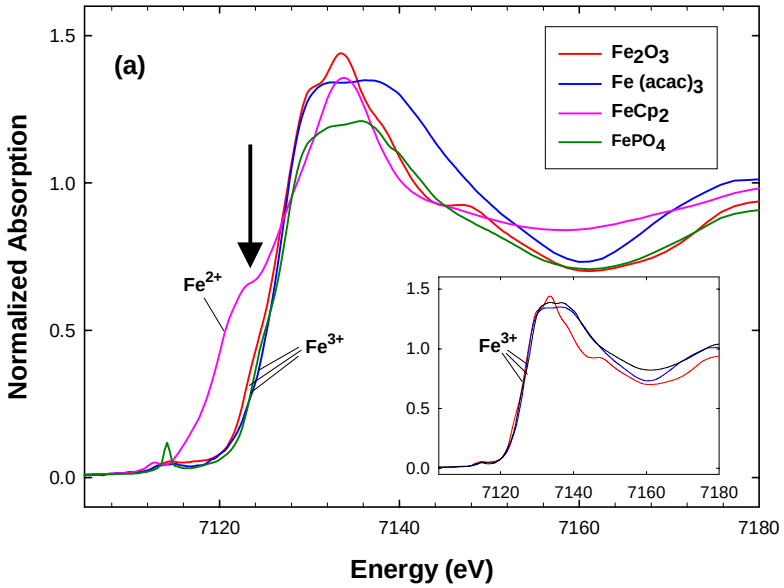
plus:

- stereographic imaging is possible
- line sources: faster imaging

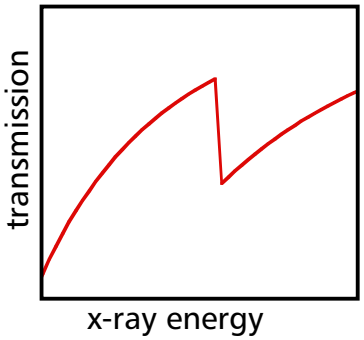
minus:

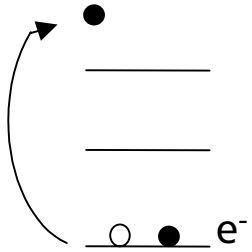
- large ink concentration necessary
- sample has to be sufficiently transparent to x-rays

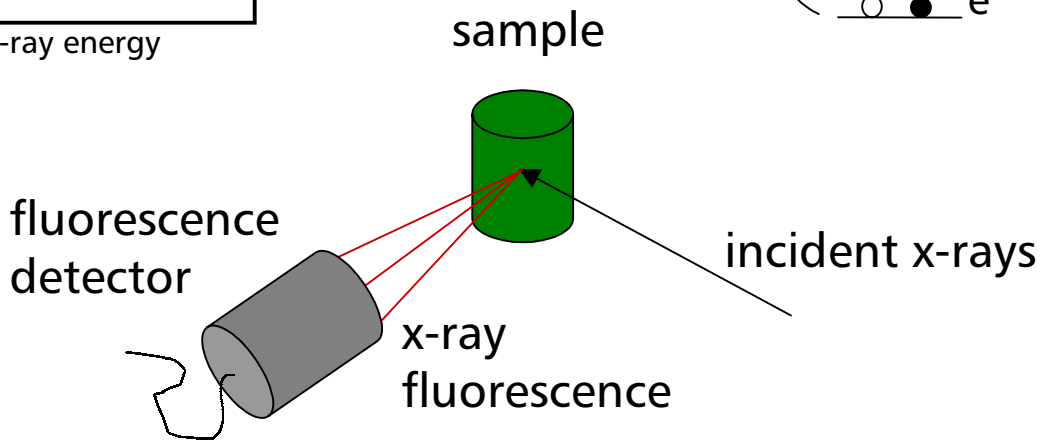




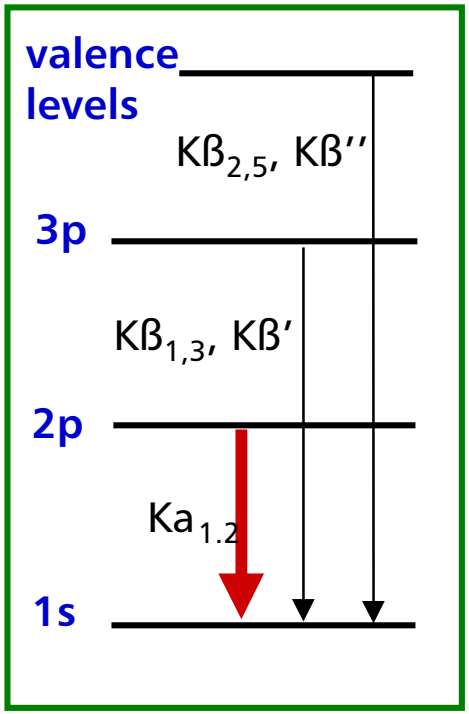
Concept of X-ray Fluorescence Imaging







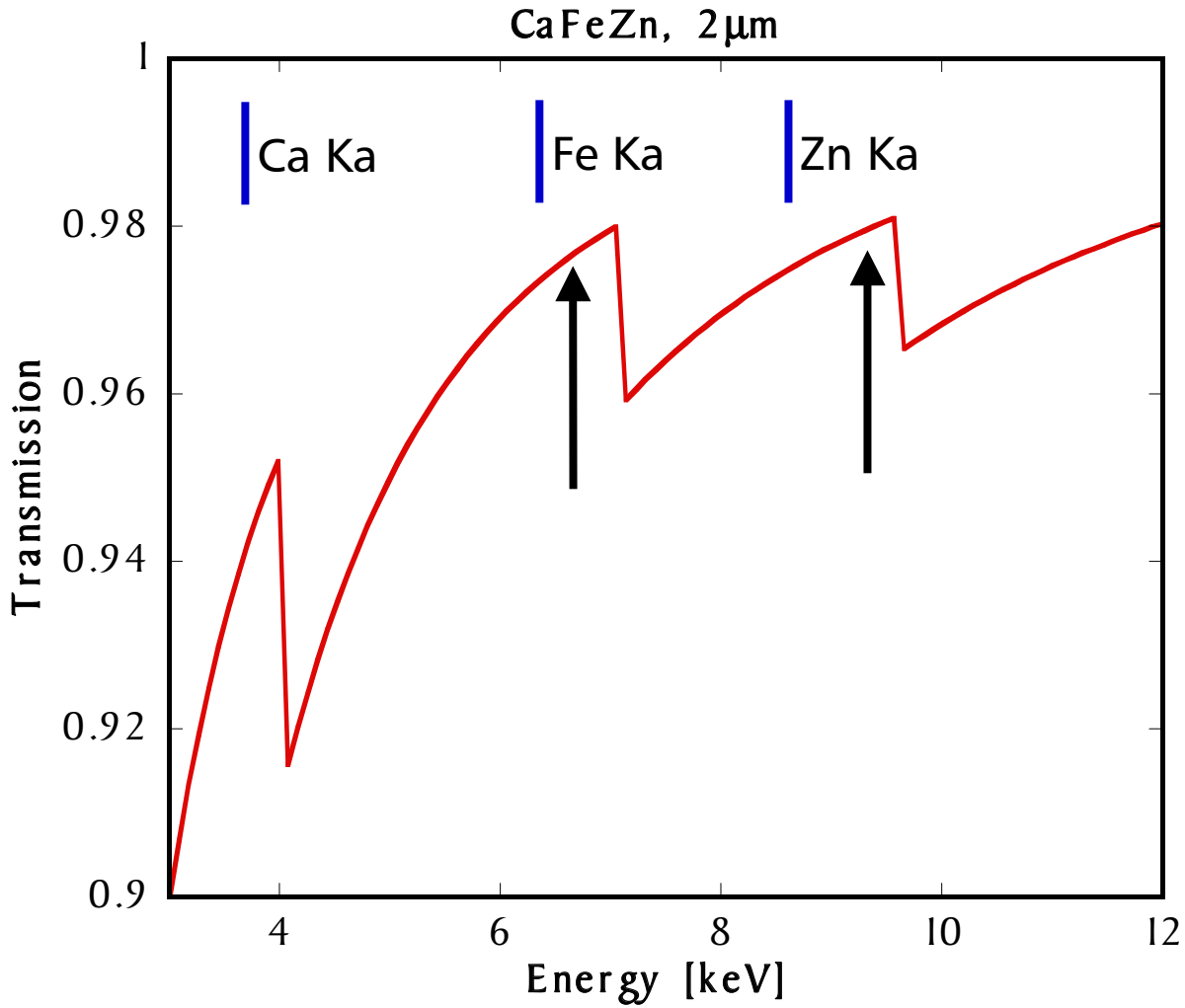
level diagram Fe



- incident x-ray photon knocks out inner-shell electron
- hole is immediately filled from electron in outer shell
- fluorescence photon is emitted, predominantly Ka radiation
- fluorescence is detected for imaging

plus: greatly enhanced sensitivity compared to transmission imaging

Choice of X-ray Energy



Examples of XRF Imaging with SR

Investigation of calcifications in breast tissue using EXAFS and XRF

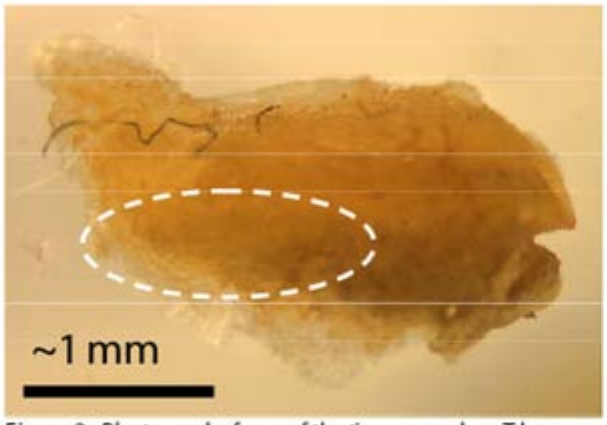


Figure 2. Photographof one of the tissue samples. The dashed lines enclose the region of the calcification

Sayers et al

Examples of XRF Imaging with SR

X-Ray Fluorescence Studies of Elements in Human Lung Tissue

M.Z. Kiss, D.E. Sayers, A.C. Thompson, S.A. McHugo, P. Pleshanov, E. Pleshanova1, Yu. A. Bykovsky

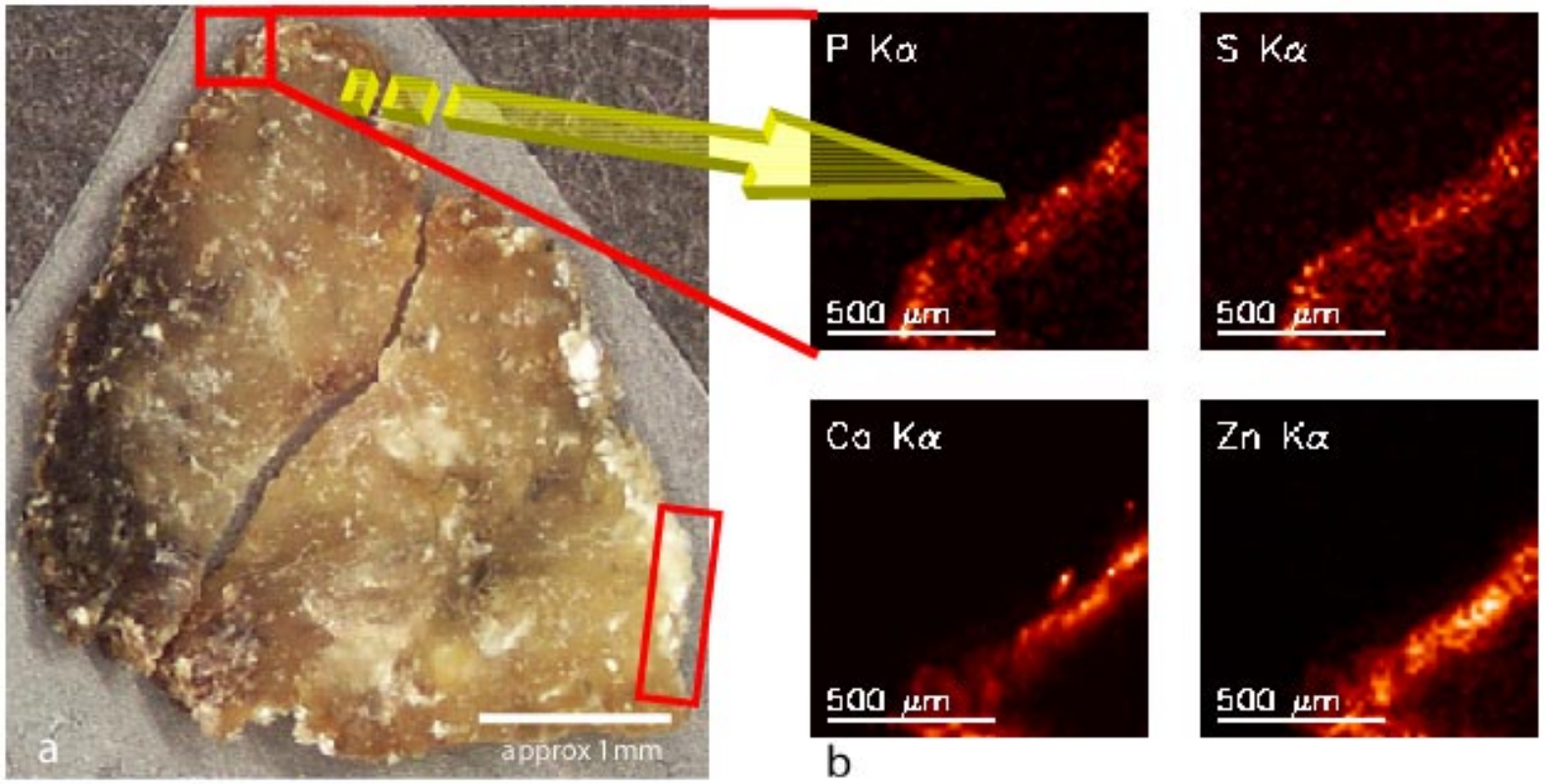
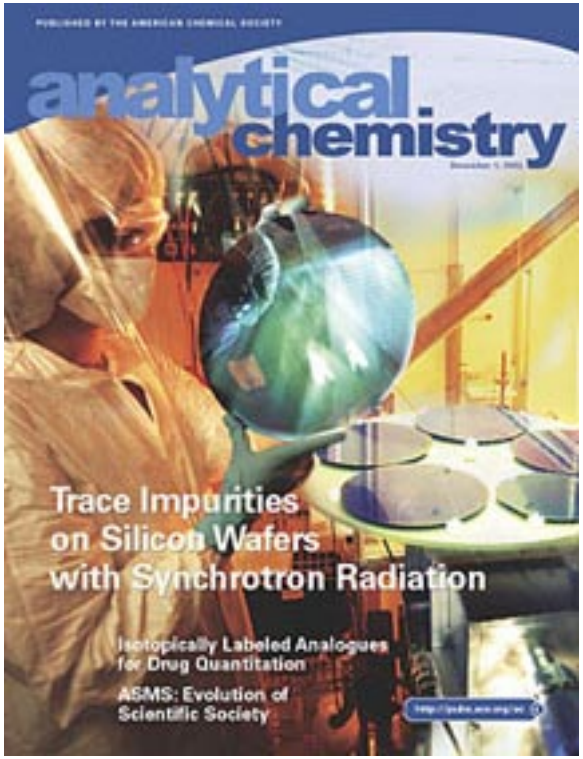
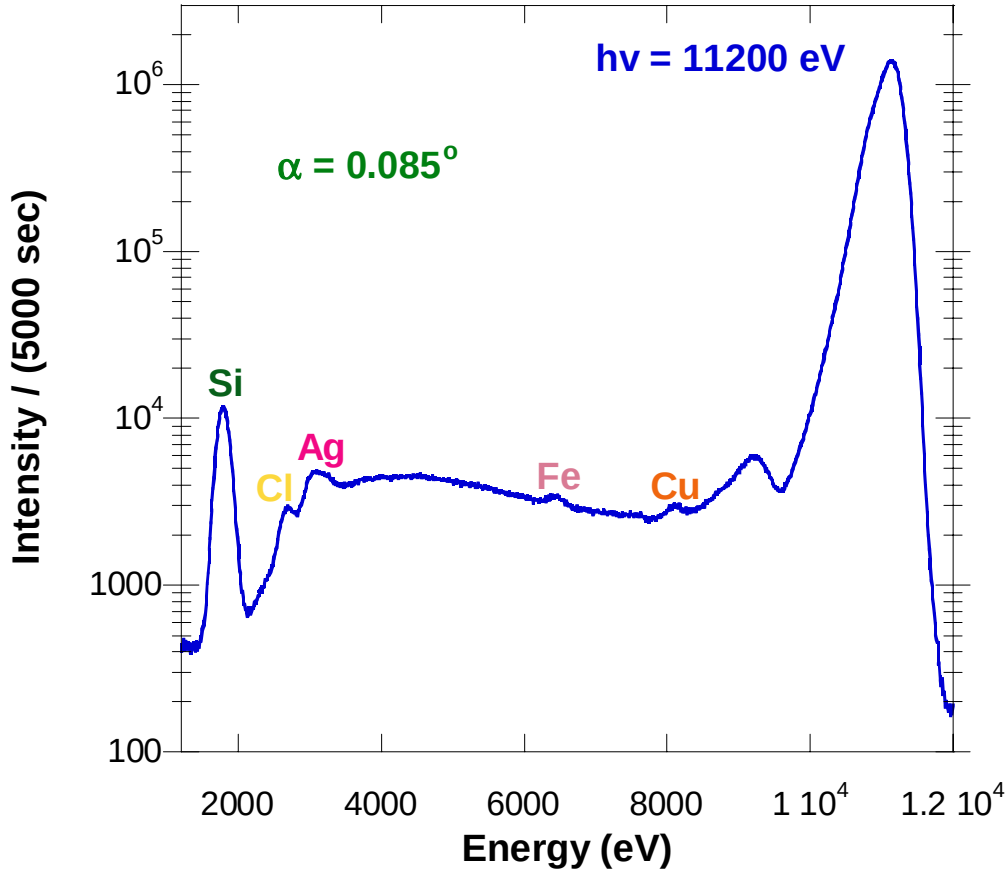


Figure 1. a) Photomicrograph of lung tissue sample from a worker at the radiochemistry factory in Chelyabinsk. b) Elemental distribution maps of P, S, Ca, and Zn.

Detection of Trace Impurities

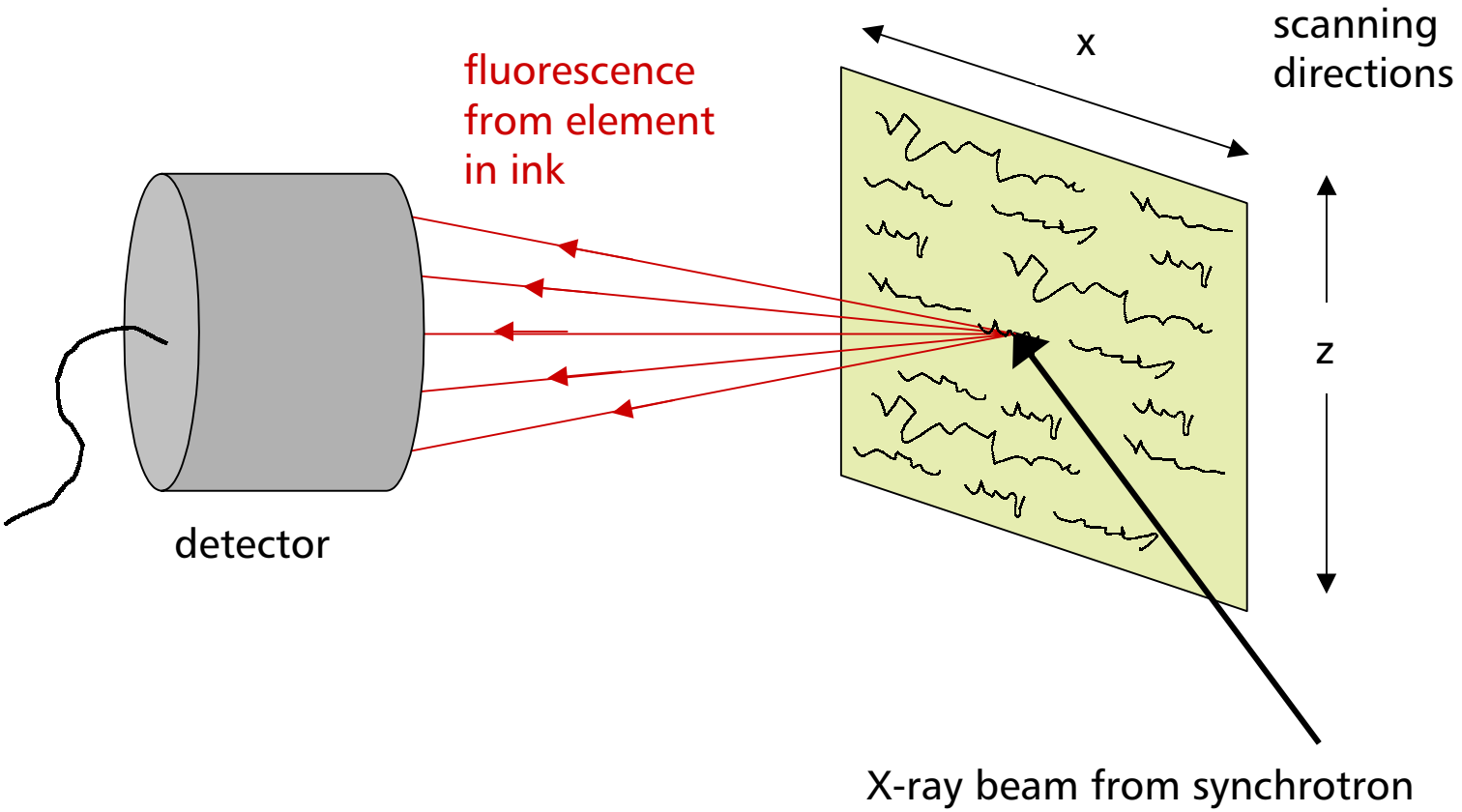


Baur et al

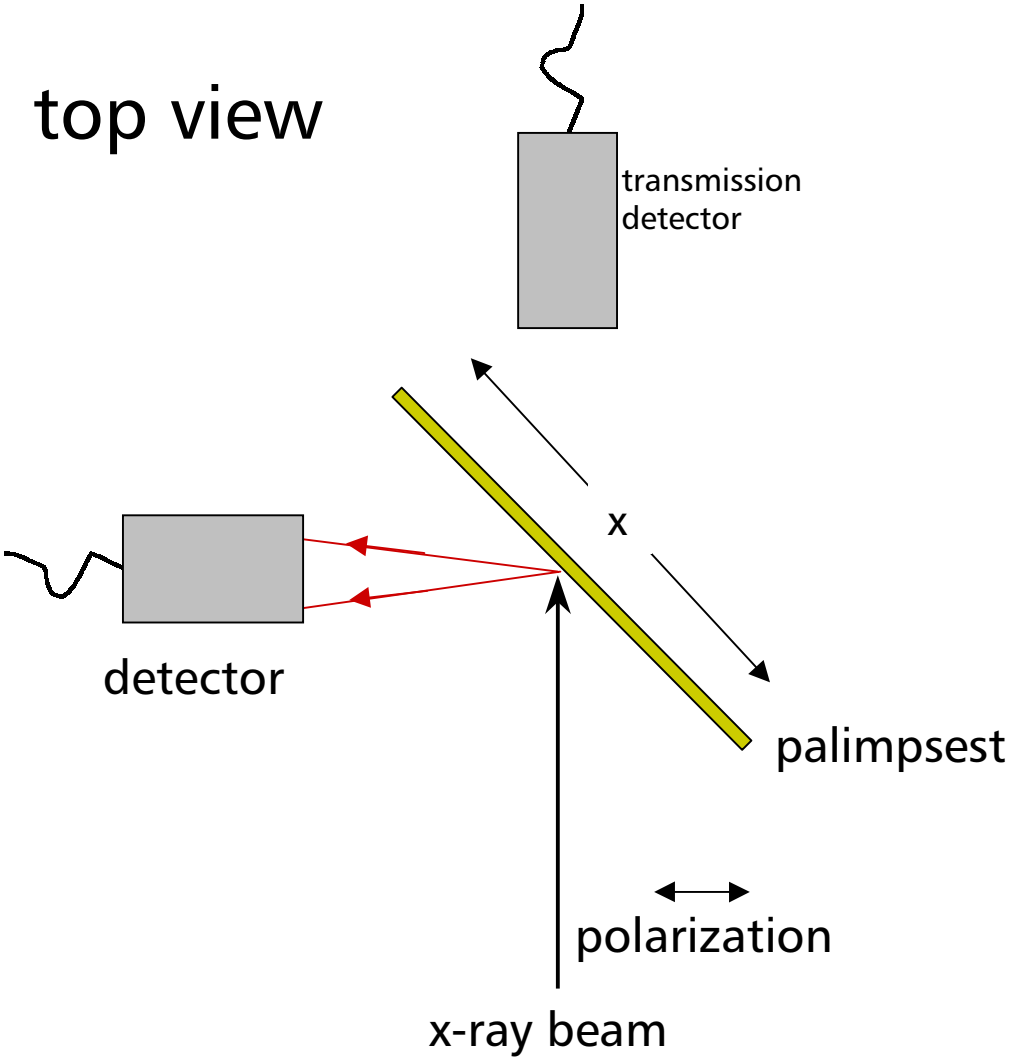


sensitivity to extremely low concentrations
much less than millionth of a mono layer!

Schematic Experimental Setup

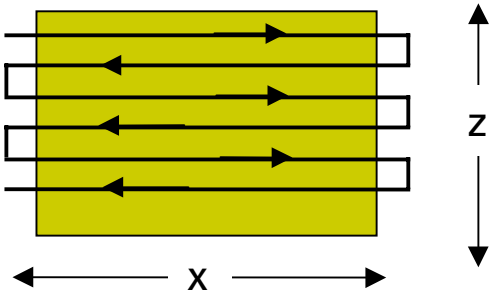


Schematic Experimental Setup



front view

- continuous x-scans
- steps in z-direction



example:

10 * 10 cm^2 scanning area,
100 μm resolution
1/100 sec illumination per data point

10 seconds/line, 1000 lines
~ 3 hours total scanning time

intense x-ray beam is important

Some Details

- scans are performed with high precision computer-controlled translation stages (Huber)

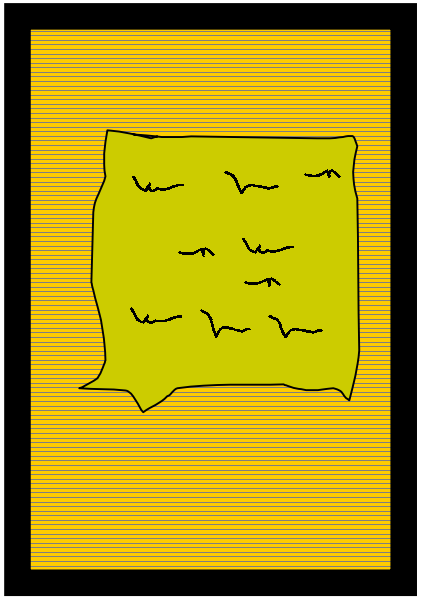
-fast scan ability *

- large area Ge detector for fluorescence detection available

- incident intensity is recorded for normalization

- automated system that closes beam shutter if scanning gets interrupted

- tests on sample texts for best x-ray parameters and potential radiation damage



- palimpsest can be placed in airtight frame (glove box for loading available)

- data analysis programs are available (e.g. Matlab)

blue = available now green = still to be done

Proposed Plan

- build and test all the scanning/imaging hardware
- identify one or several elements for imaging (e.g. Fe, Ca)
- study a test object of composition similar to the original text
- test for appropriate sample protection, X-ray energy, beam size and exposure times (radiation damage)
- study the original text