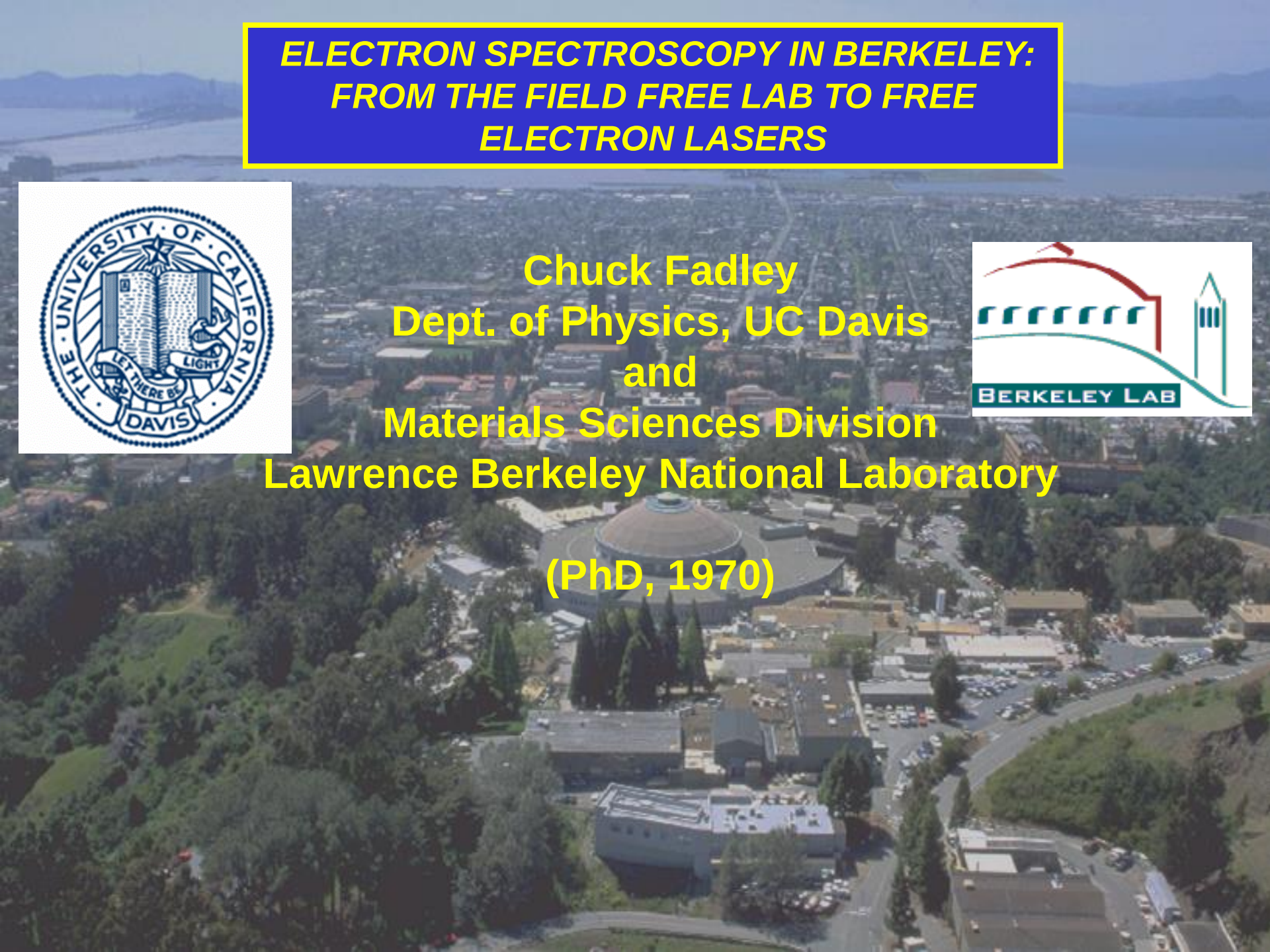
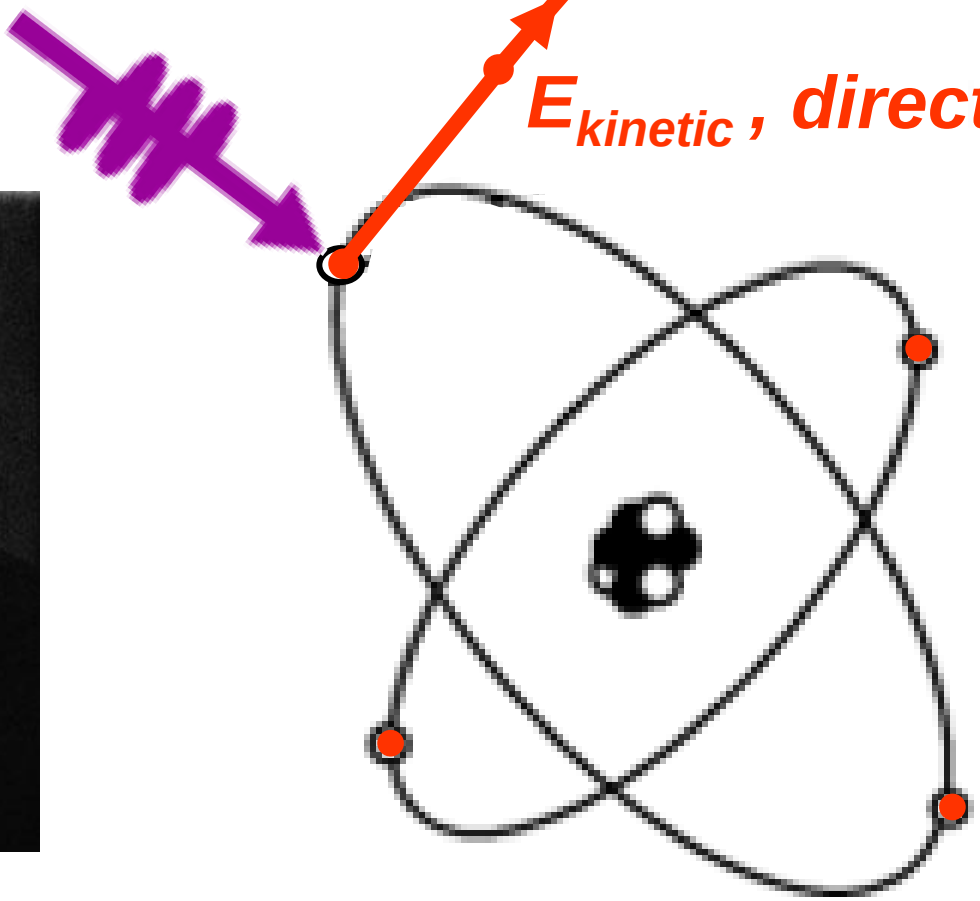
ELECTRON SPECTROSCOPY IN BERKELEY: FROM THE FIELD FREE LAB TO FREE ELECTRON LASERS



Chuck Fadley
Dept. of Physics, UC Davis
and
Materials Sciences Division
Lawrence Berkeley National Laboratory

(PhD, 1970)

The Photoelectric Effect, Einstein, 1905
Light can behave like a Particle!



$$h\nu = E_{initial} - E_{final} = E_{binding} + E_{kinetic}$$

From 1960s→Photoelectron Spectroscopy = Photoemission

The first spectrometer in the U.S.—Made in Sweden

NUCLEAR INSTRUMENTS AND METHODS 27 (1964) 173–189; © NORTH-HOLLAND PUBLISHING CO.

A 50-CM DOUBLE FOCUSING BETA SPECTROMETER OF THE CURRENT SHEET TYPE

K. SIEGBAHN, C. NORDLING, S.-E. KARLSSON, S. HAGSTRÖM, A. FAHLMAN and I. ANDERSSON

Institute of Physics, University of Uppsala, Sweden

Received 26 March 1964

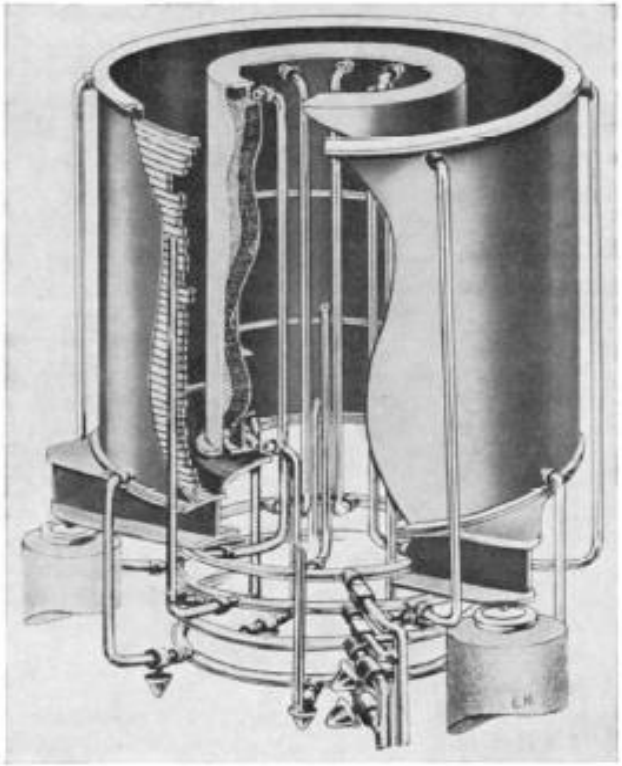
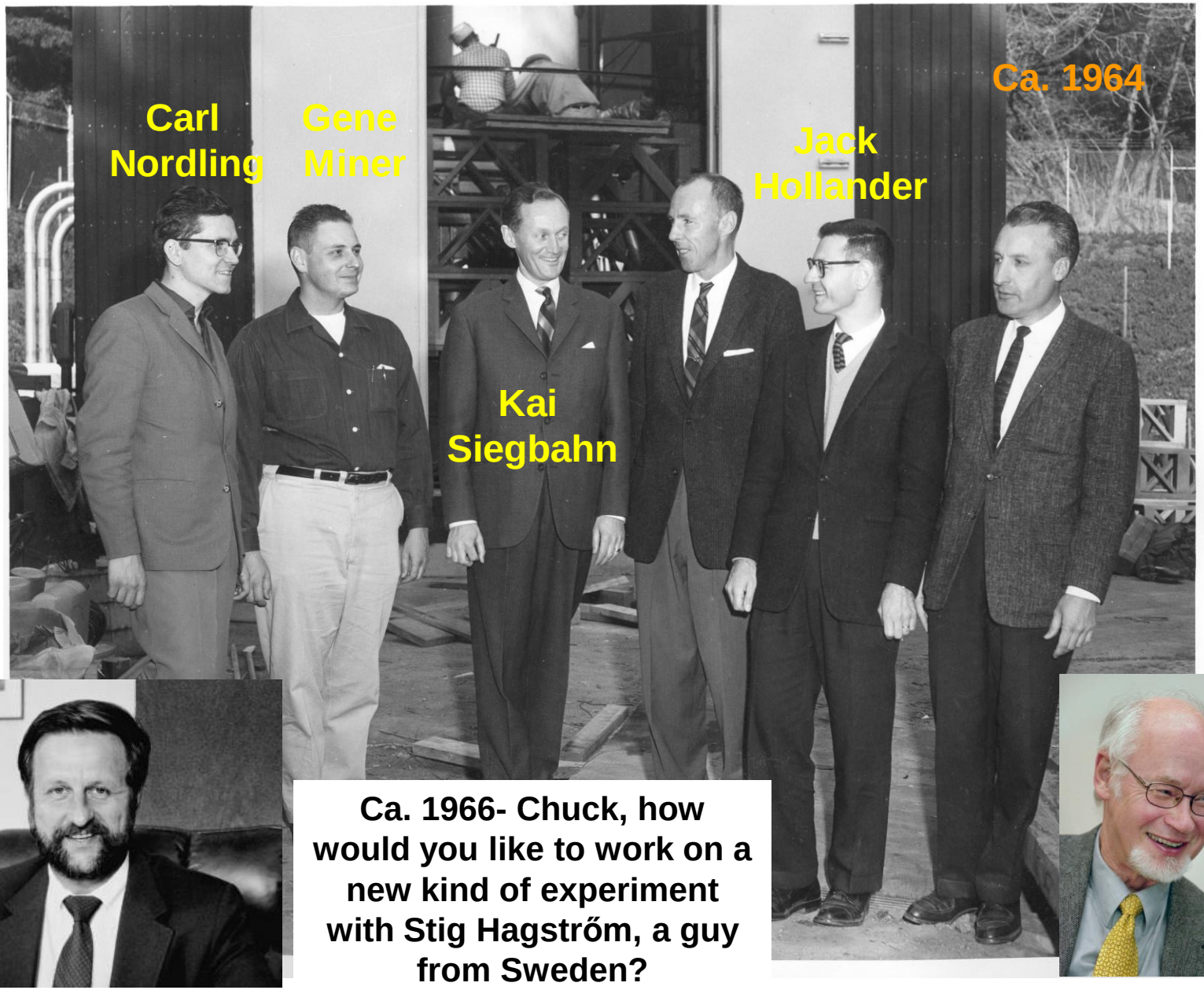


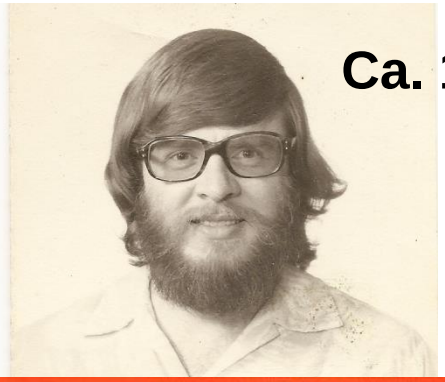
Fig. 1. Cut-away view of the spectrometer coils and cooling manifold. This is an artist's view and was made before the manufacturing of the coils.



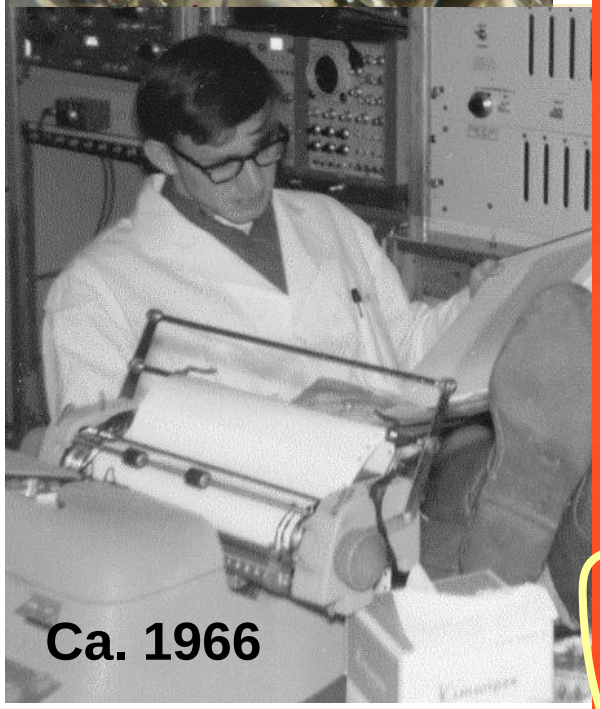
Dave Shirley

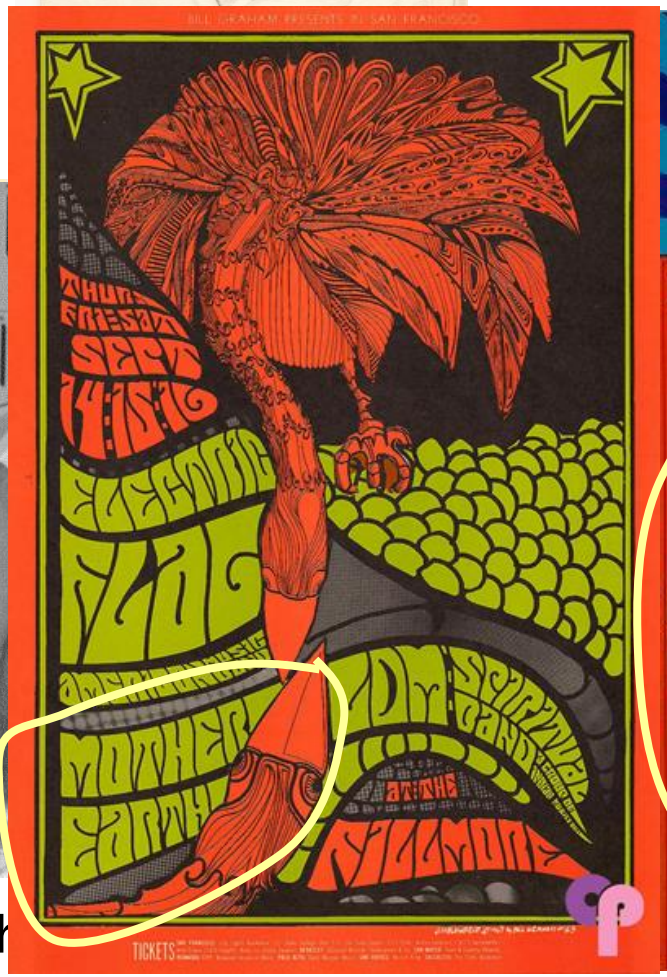
Ca. 1966- Chuck, how would you like to work on a new kind of experiment with Stig Hagstrőm, a guy from Sweden?

Stig Hagström
1932-2011



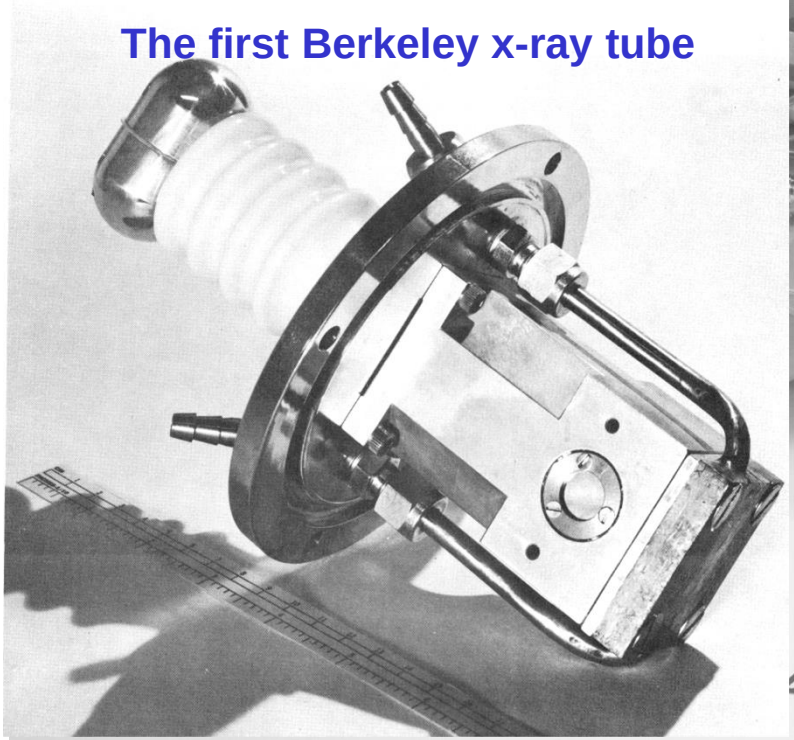
The “group bands” from my apt.



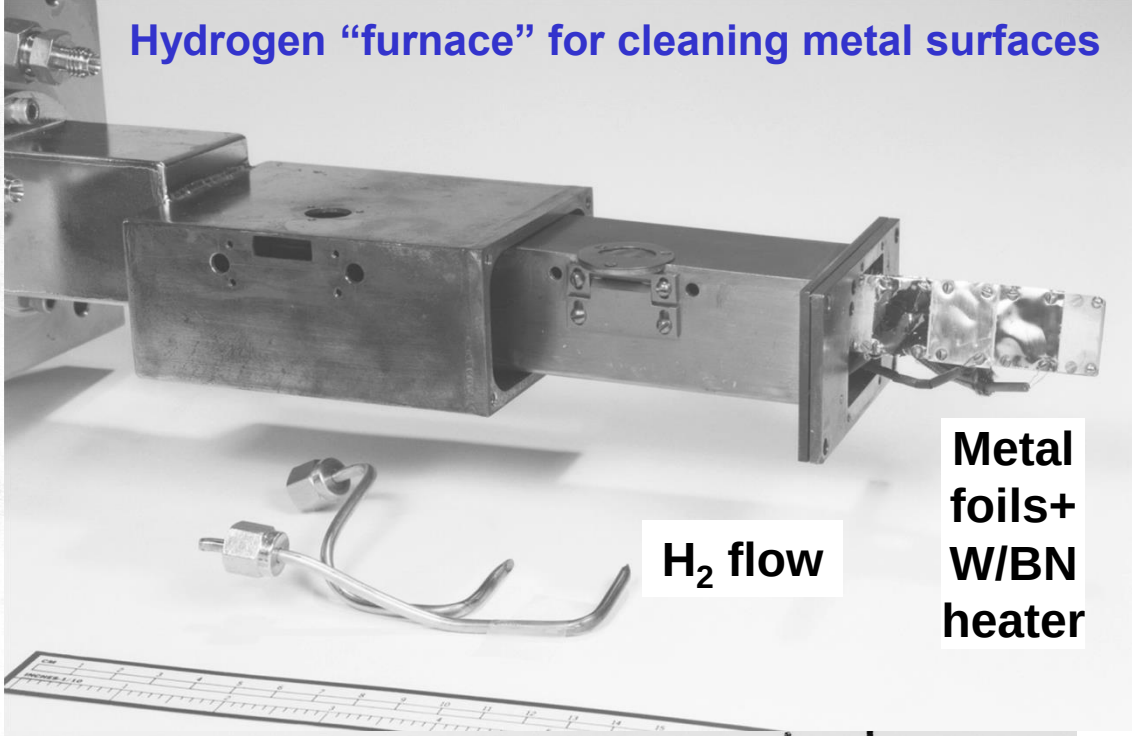


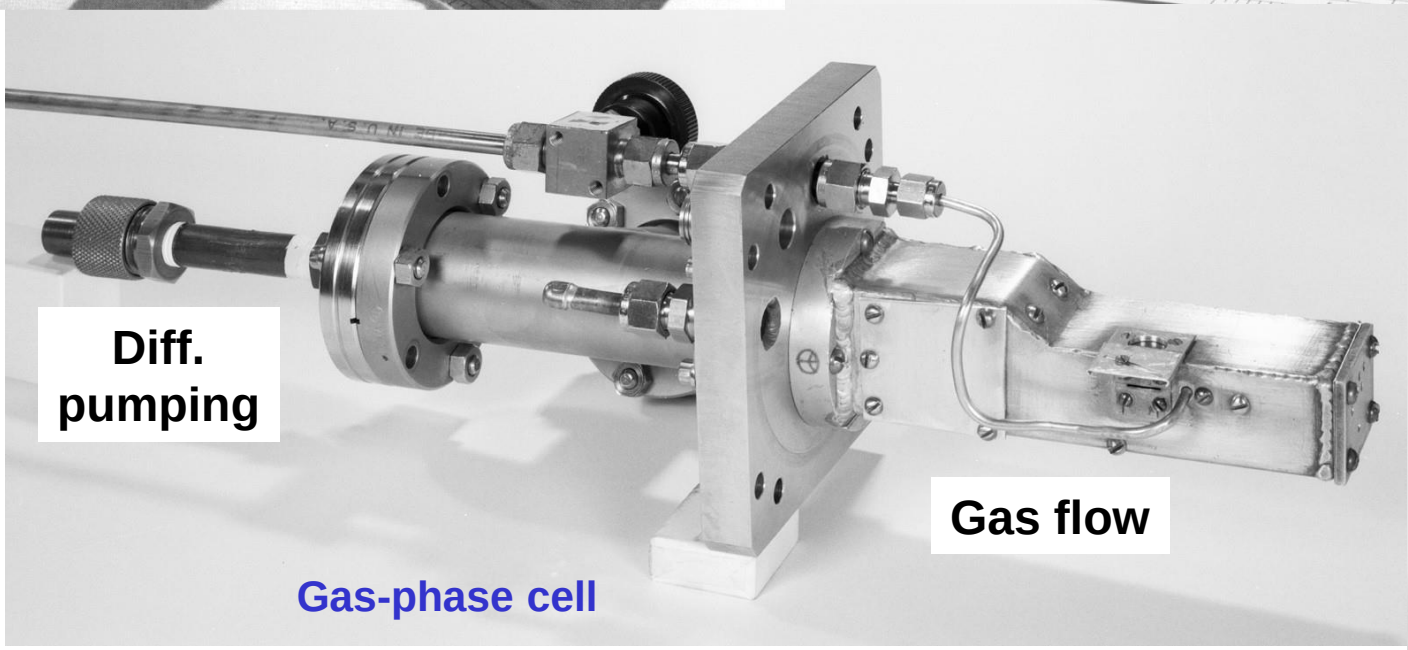
Typewriter for output, th

The first Berkeley x-ray tube

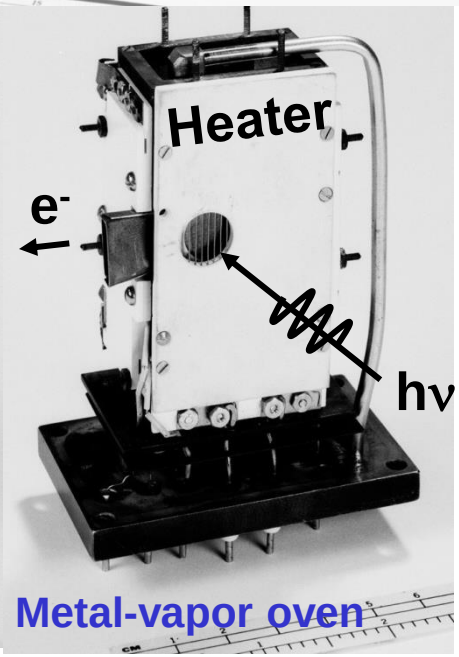


Hydrogen “furnace” for cleaning metal surfaces



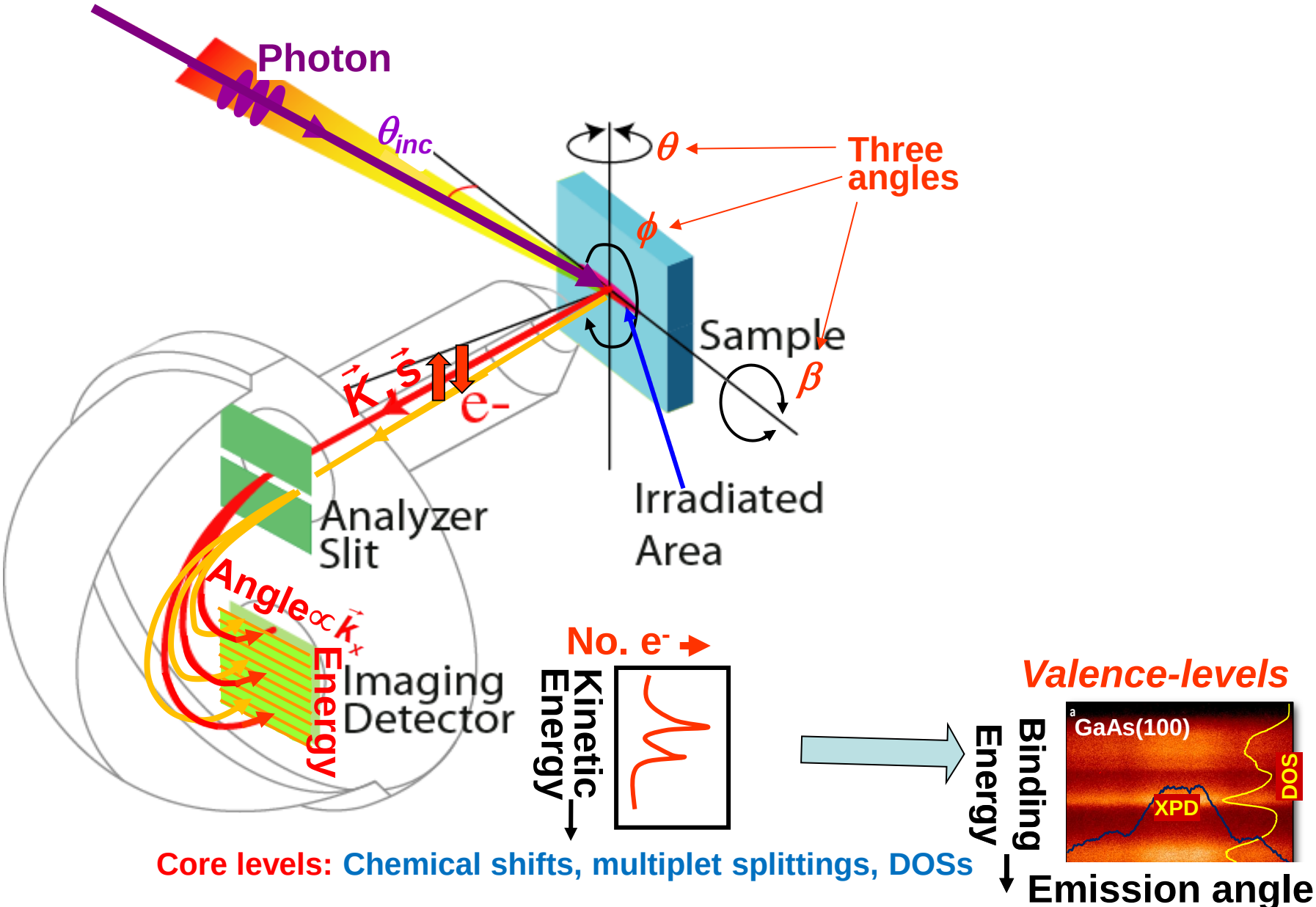


Gas-phase cell

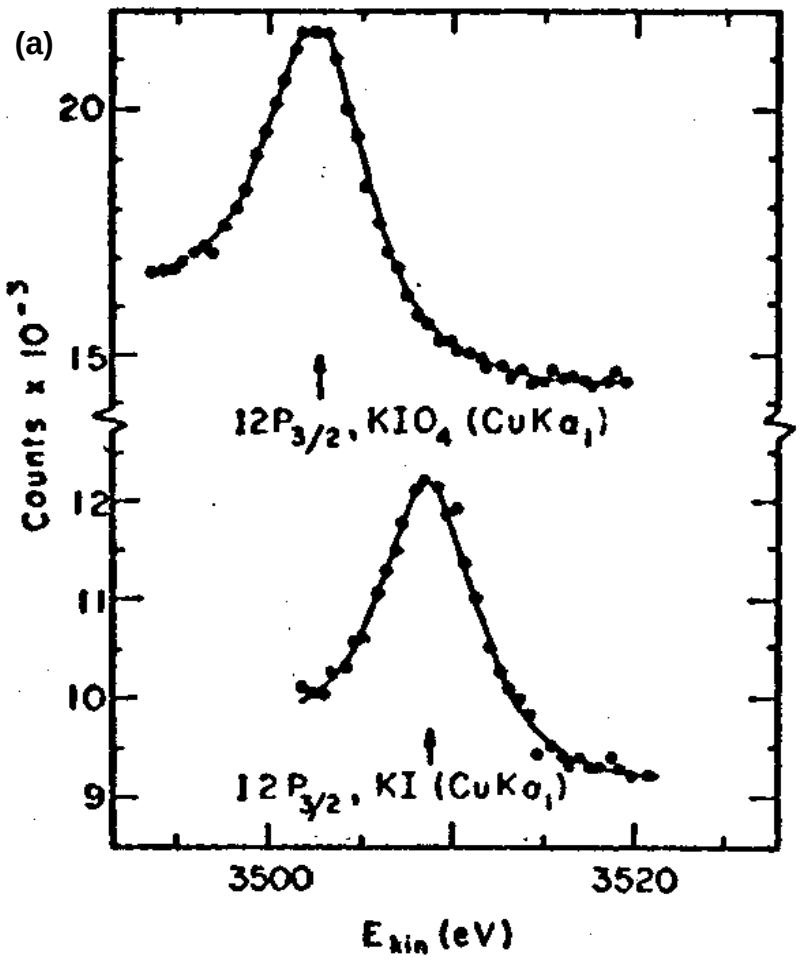


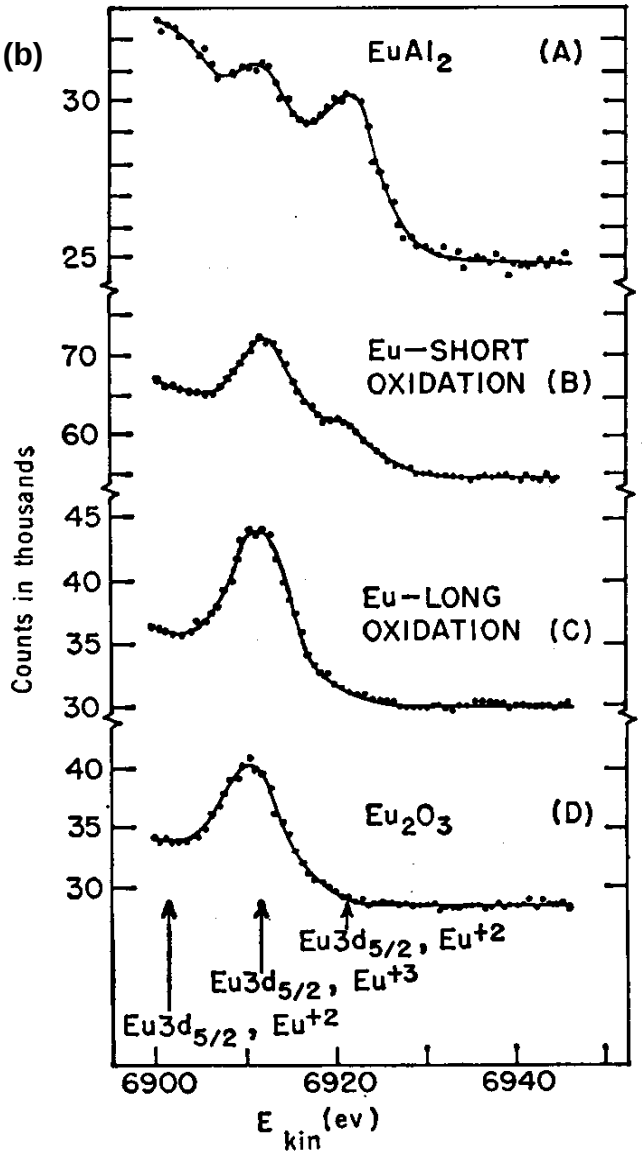
Metal-vapor oven

Photoelecton spectroscopy: the various dimensions



Chemical shifts





Potential model for chemical shifts

Fadley, Hagstrom, Hollander, Klein, Shirley, Science 157, no. 3796, 1571 (1967)

Multiplet splittings in molecules and solids → Net spin moment

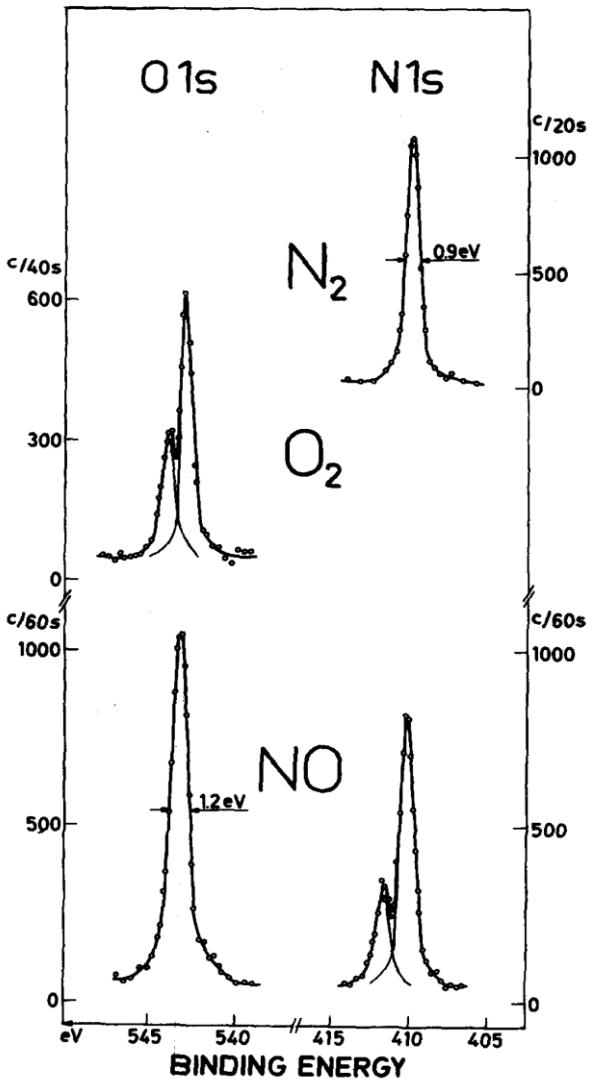
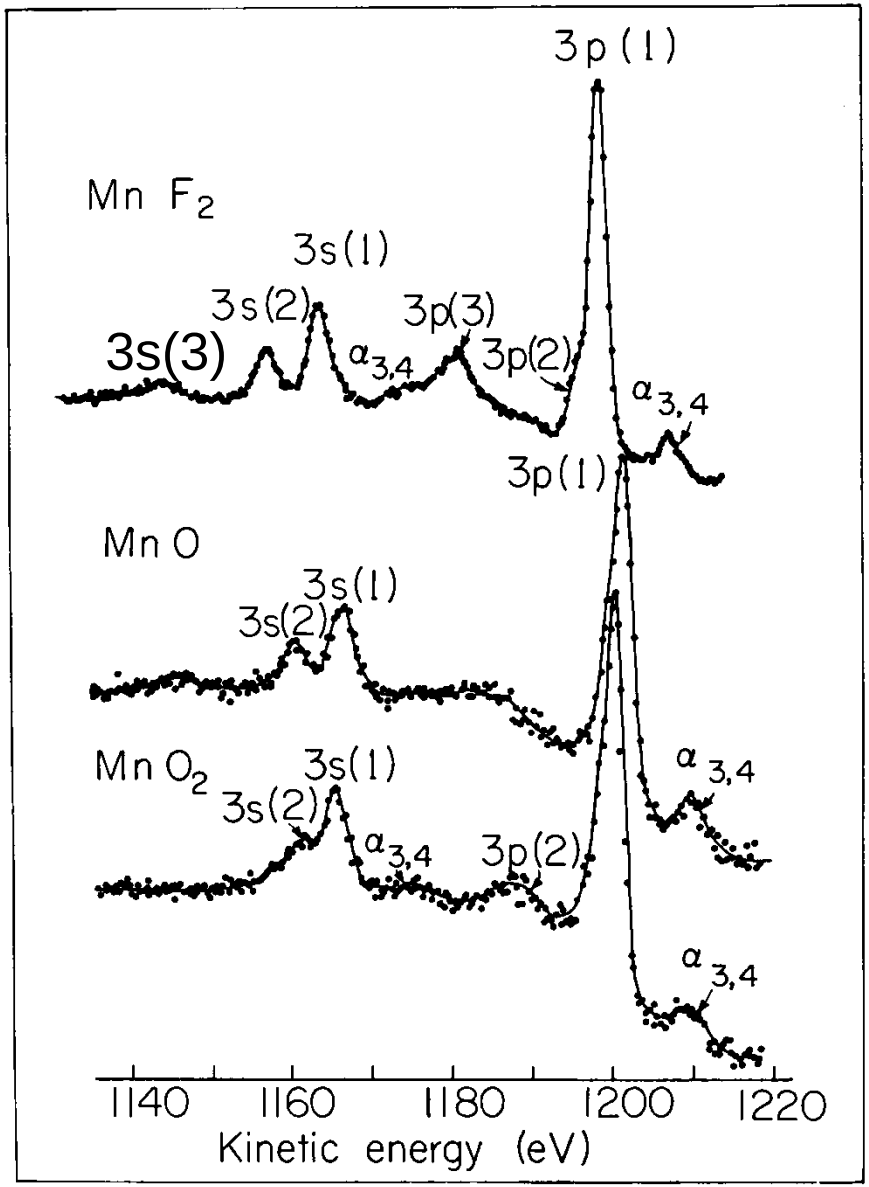
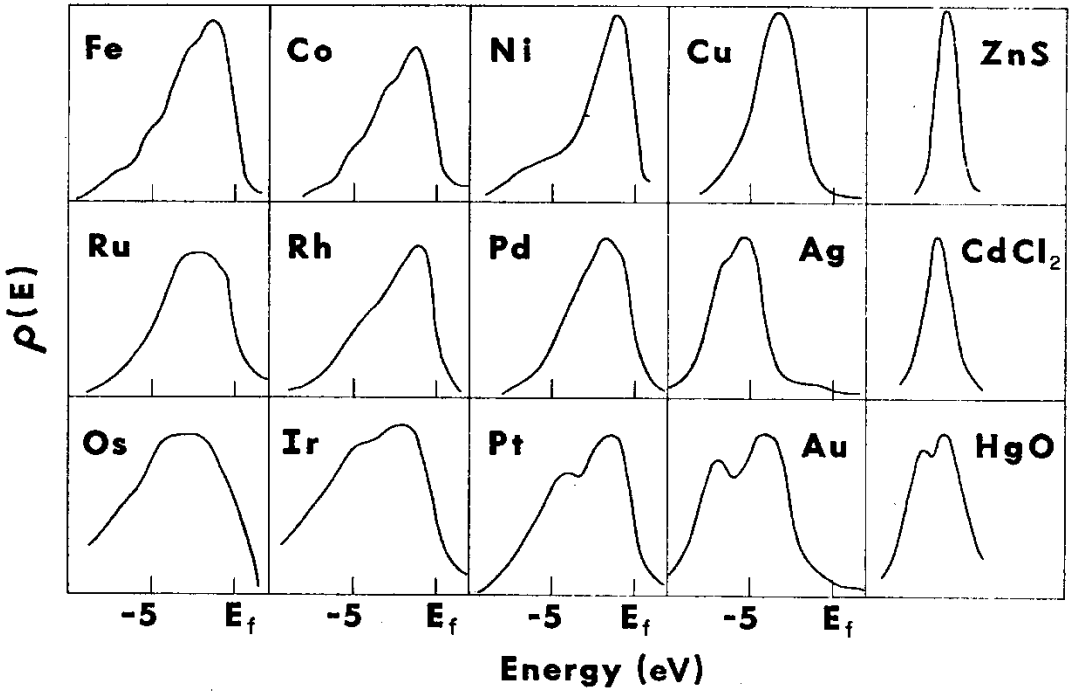


Fig. 1. ESCA spectra of core electron levels in N_2, O_2, and NO. Paramagnetic splitting is observed for the 1s levels in the O_2 and NO molecules.



Hedman, Heden, Nordling, Siegbahn, Physics Letters 29A, 178 (1969) /// Fadley, Shirley, et al., Phys. Rev. Lett. 23, 1397 (1969)

Densities of state of solids



Fadley, Shirley, Phys. Rev. Letters,
Phys. Rev. Letters 21, 980 (1968)

“ICESS-1”--Asilomar, 1971

Fred Grimm
Oak Ridge

Dave Shirley
Berkeley

Don Hammond
HP Labs.

Kai Siegbahn
Uppsala

The HP 5950 Spectrometer

The Berkeley electron spectroscopy lab. -ca. 1972

Reed McFeely

HP 5950A

Steve Kowalczyk

Rotary-motion drive

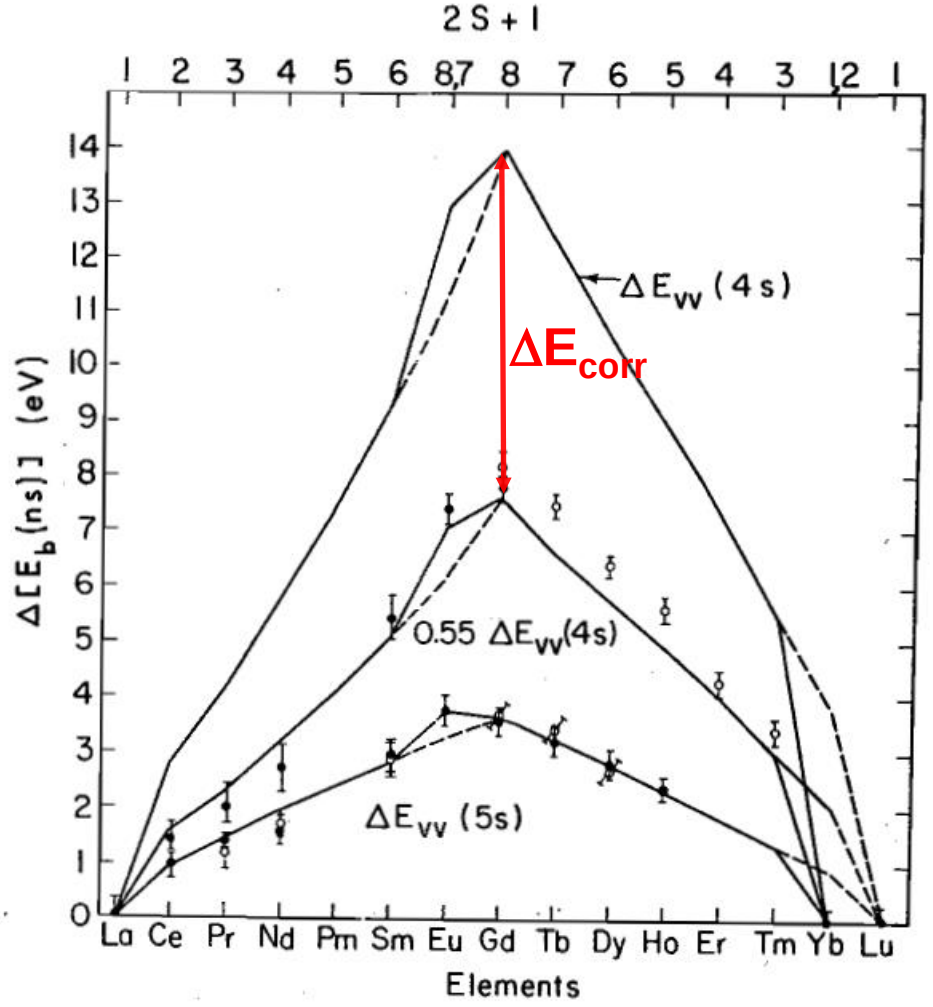
CMA

Cryopump

Linear-motion drive

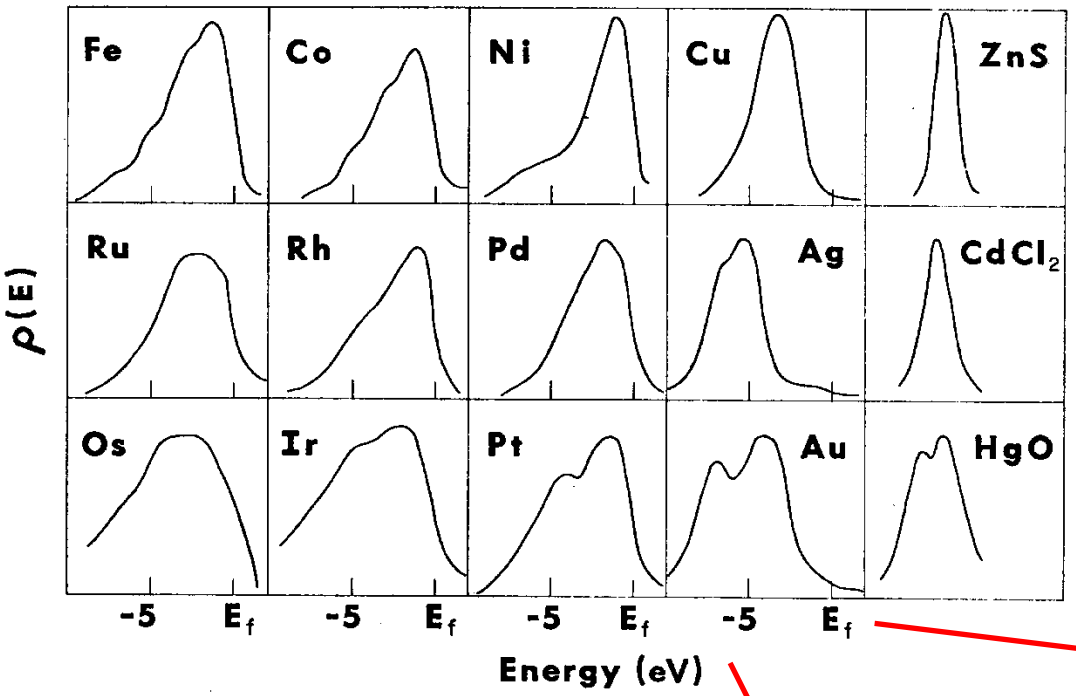
500 l/s ion pump

Multiplet splittings and intrashell correlation effects



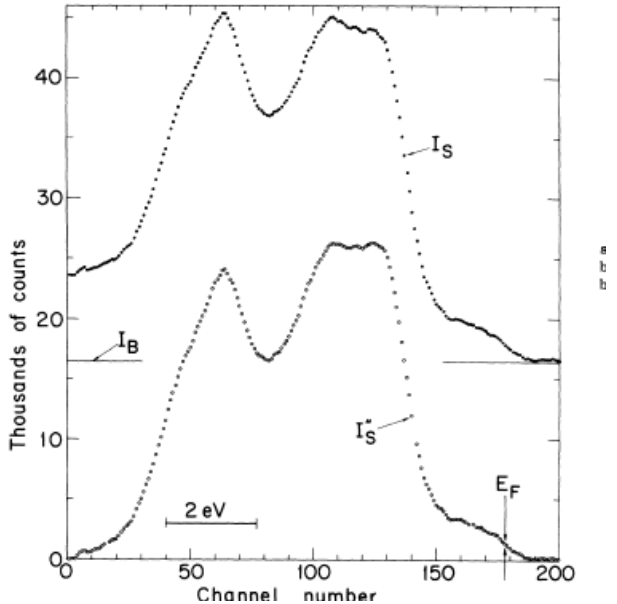
F.R. McFeely, S.P. Kowalczyk, L. Ley, D.A. Shirley, Physics Letters A4 49, 301 (1974)

Densities of state of solids

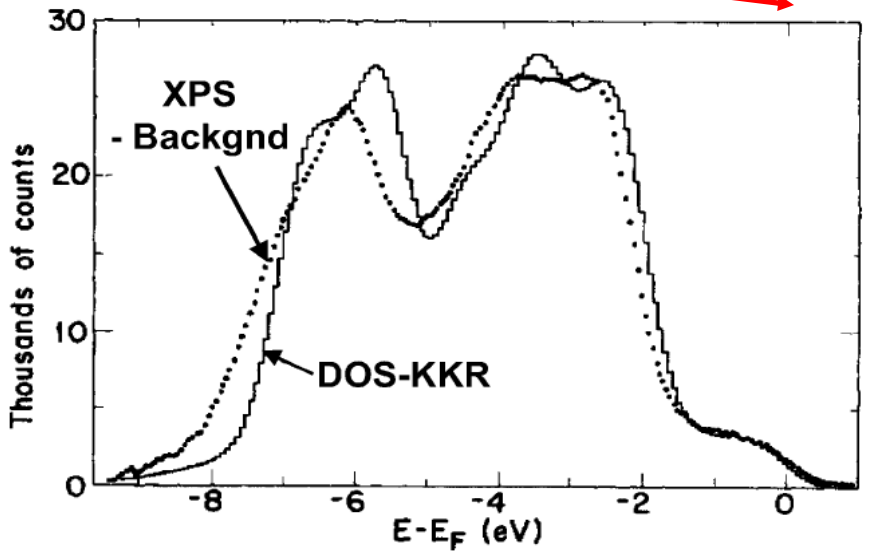


Fadley, Shirley, Phys. Rev. Letters,
Phys. Rev. Letters 21, 980 (1968)

The Shirley Background

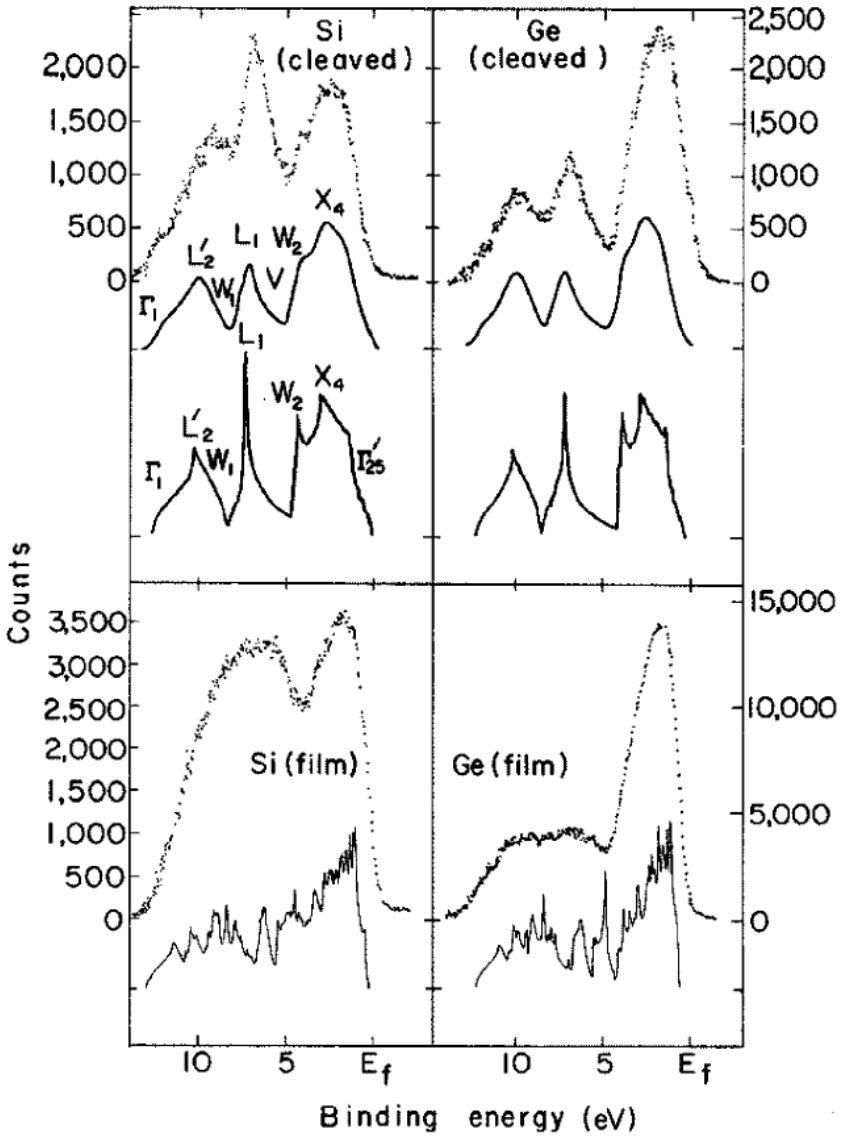


$$I_S''(N) = I_S'(N) - I_S''(0)\left(\sum_{N'>N} I_S'(N') \Big/ \sum_{N'>0} I_S'(N')\right)$$

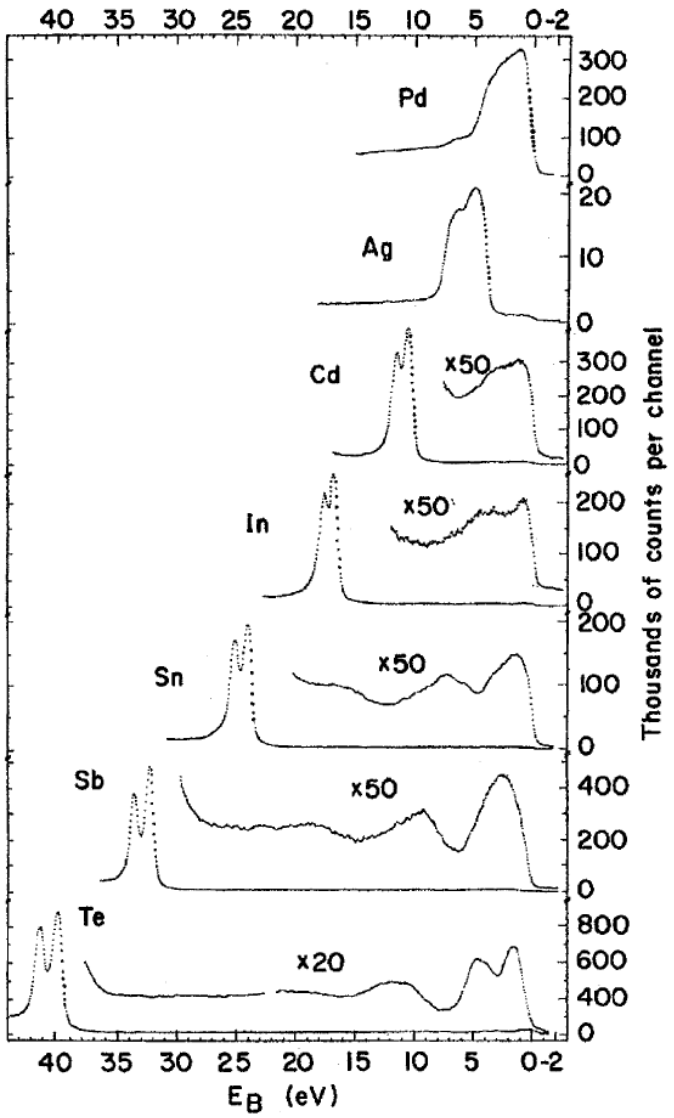


D.A. Shirley, Phys. Rev. B5 (1972) –3308 citations!

Densities of state of solids



L. Ley, S. Kowalczyk, R. Pollak, and D. A. Shirley, Phys. Rev. Lett. 29, 1088 (1972)



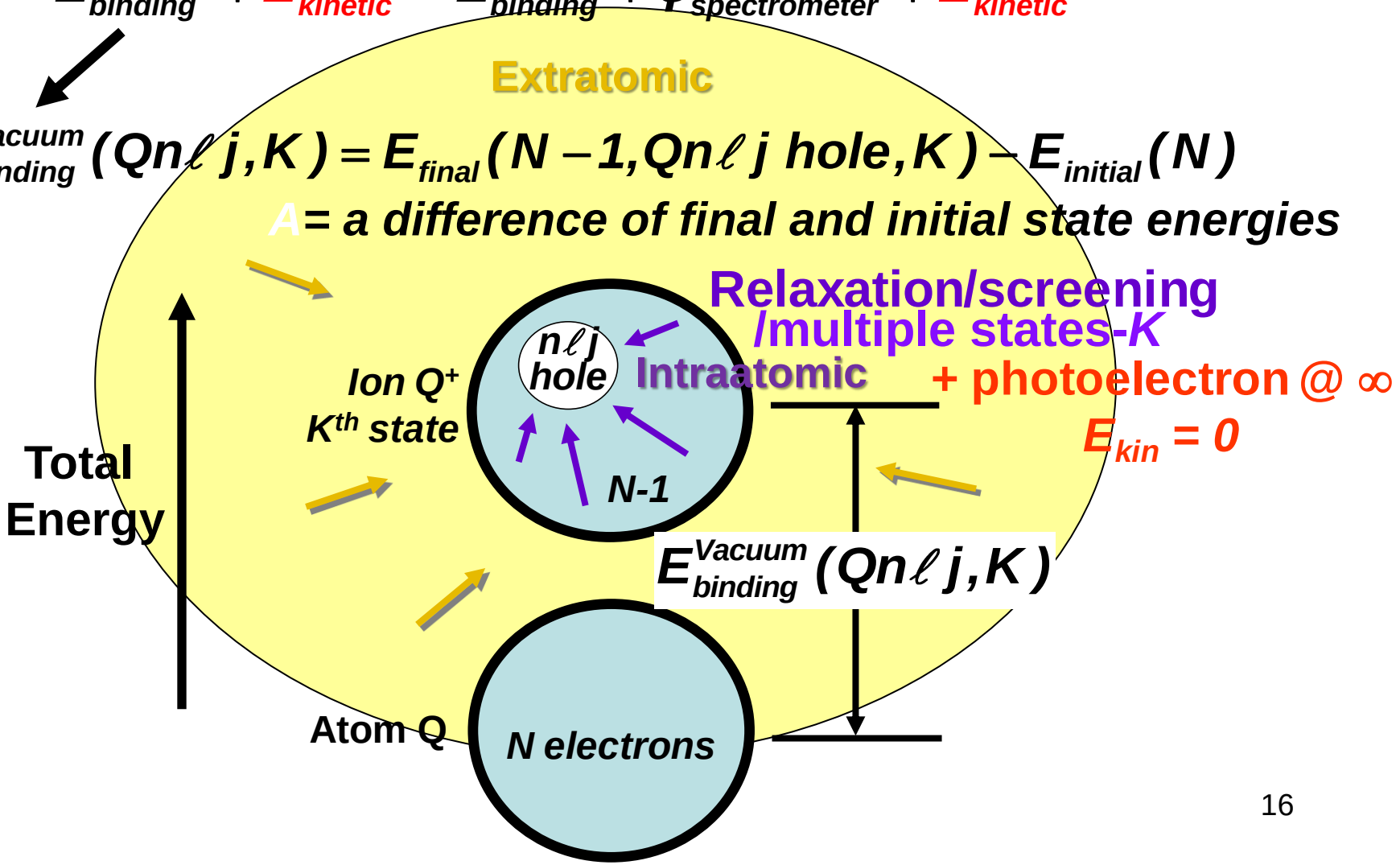
R. A. Pollak, S. Kowalczyk, L. Ley, and D. A. Shirley., Phys. Rev. Lett. 29, 274 (1972)

Photoemission: The correct energy picture

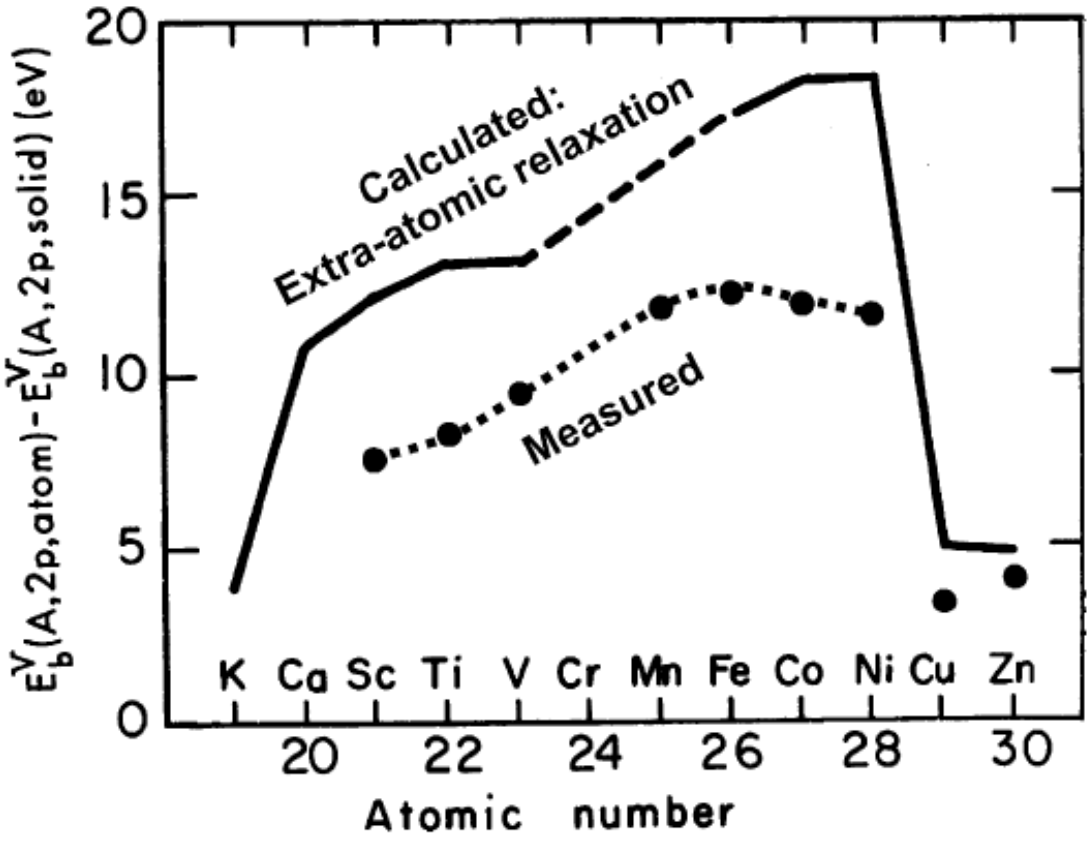
$$h\nu = E^{Vacuum}_{binding} + E_{kinetic} = E^{Fermi}_{binding} + \varphi_{spectrometer} + E_{kinetic}$$

$$E^{Vacuum}_{binding}(Qn\ell j, K) = E_{final}(N-1, Qn\ell j\ hole, K) - E_{initial}(N)$$

A = a difference of final and initial state energies

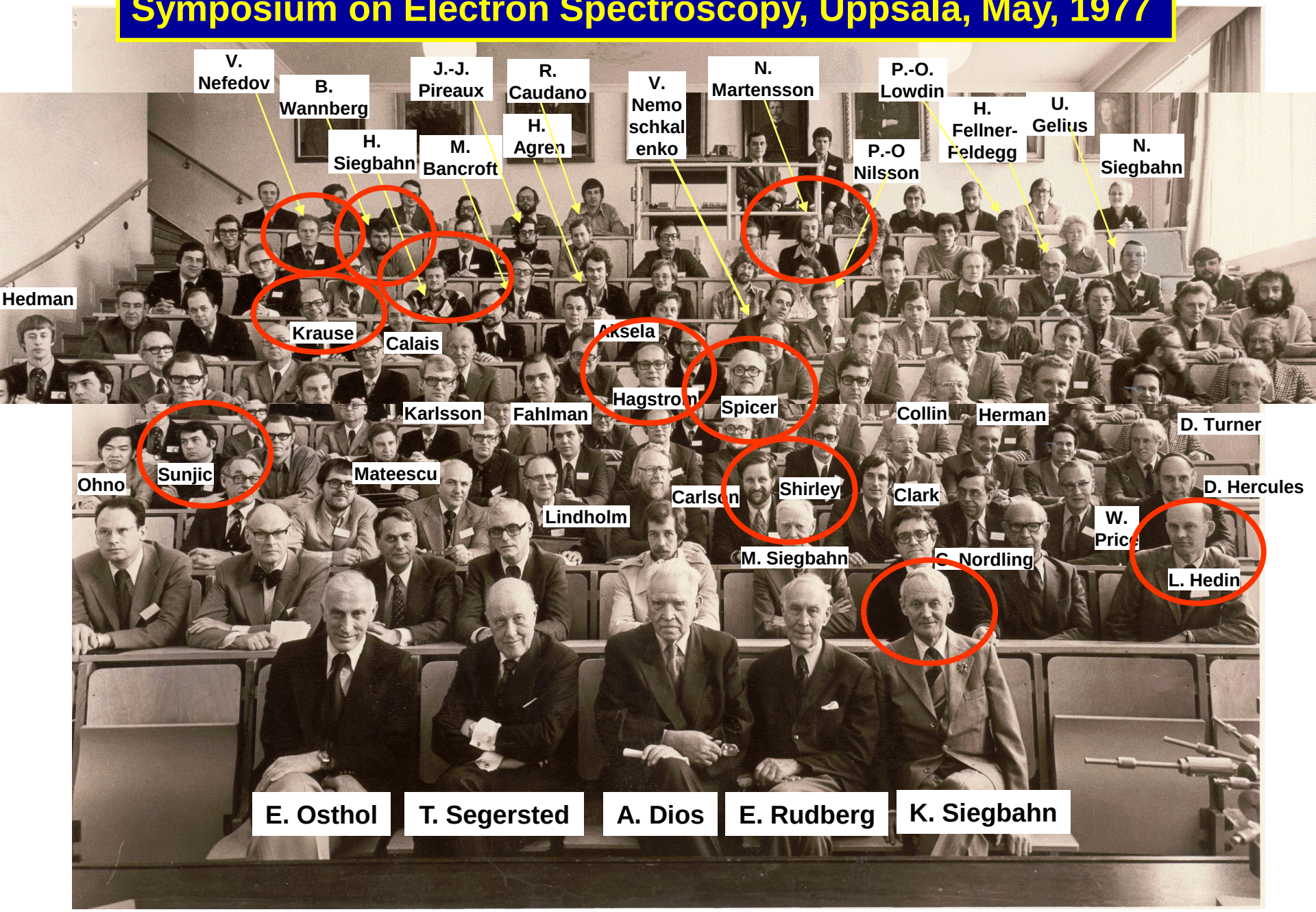


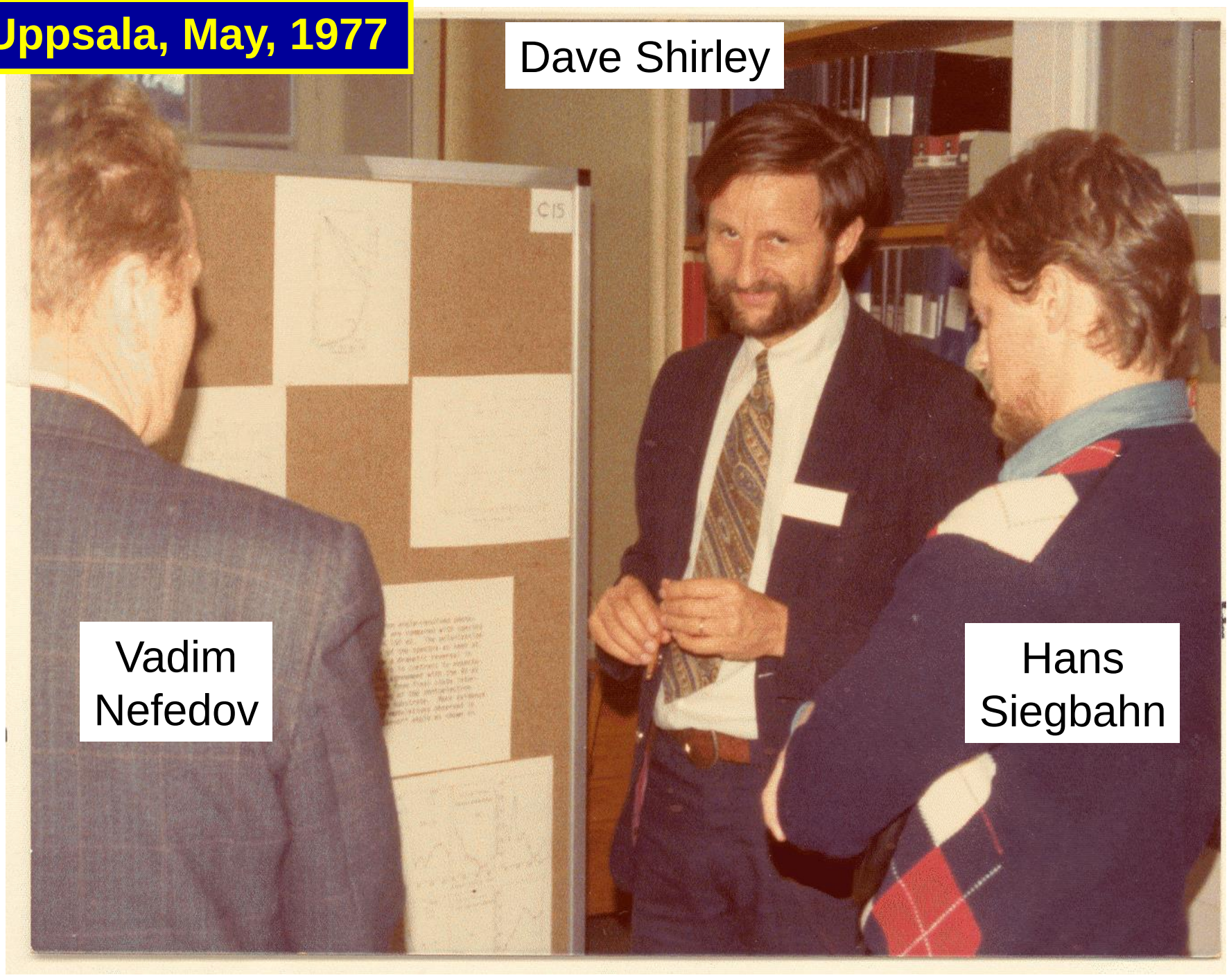
Final-state relaxation/screening around a hole

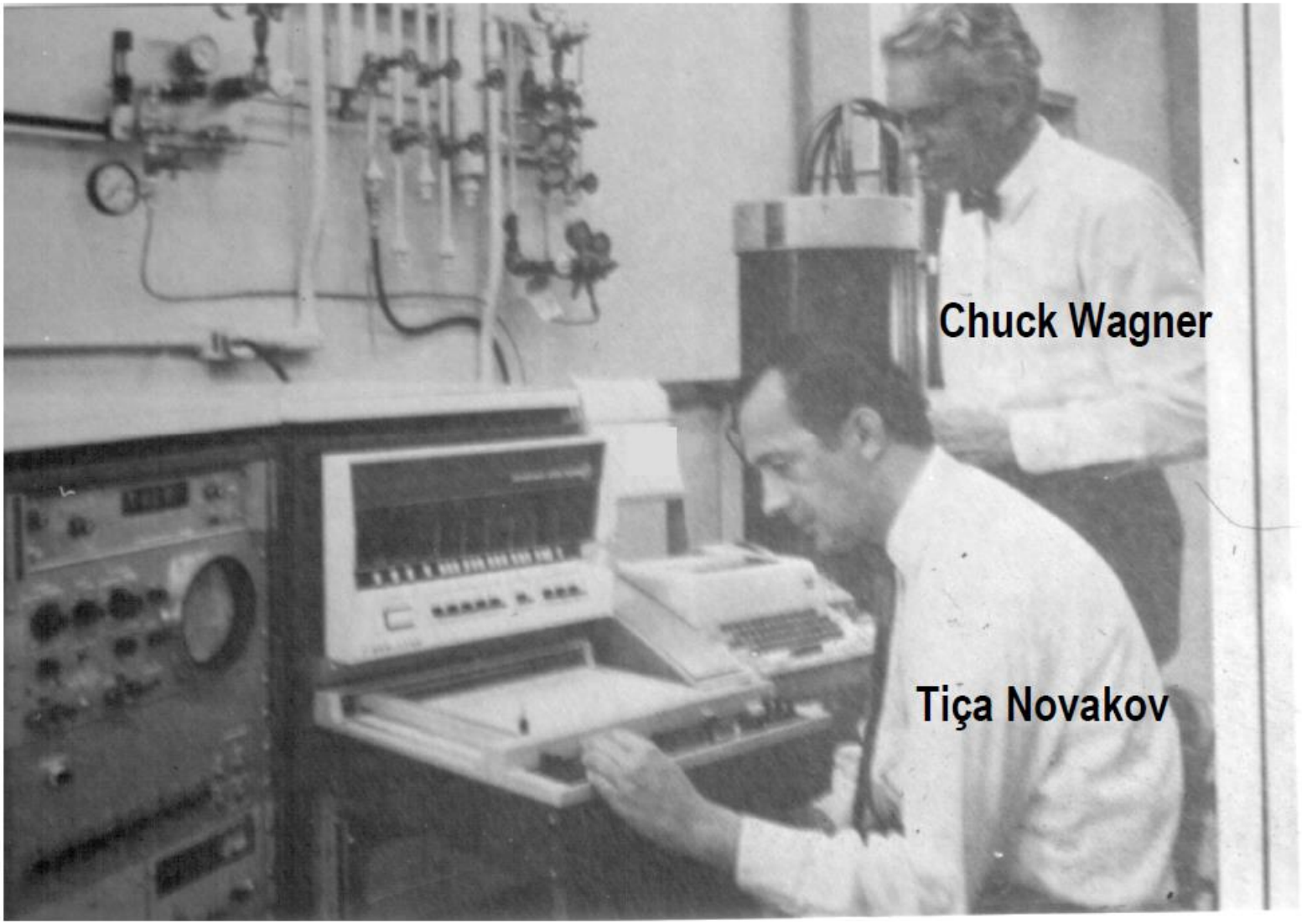


L. Ley, S. P. Kowalczyk, F. R. McFeely, R. A. Pollak, and D. A. Shirley
Phys. Rev. B8 (1973) 2392

Symposium on Electron Spectroscopy, Uppsala, May, 1977

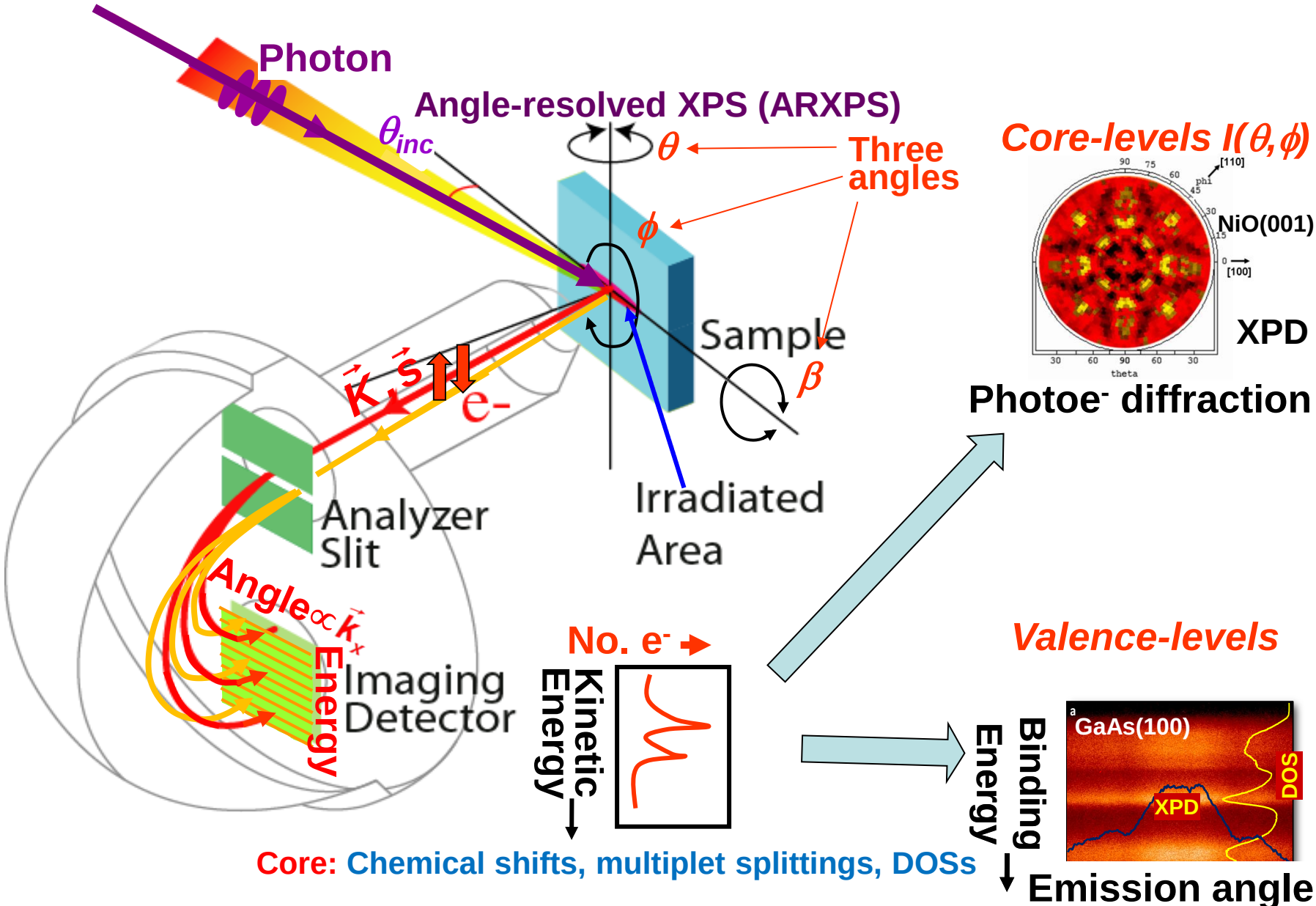



Uppsala, May, 1977
Dave Shirley
Vadim Nefedov
Hans Siegbahn


Chuck Wagner
Tiça Novakov

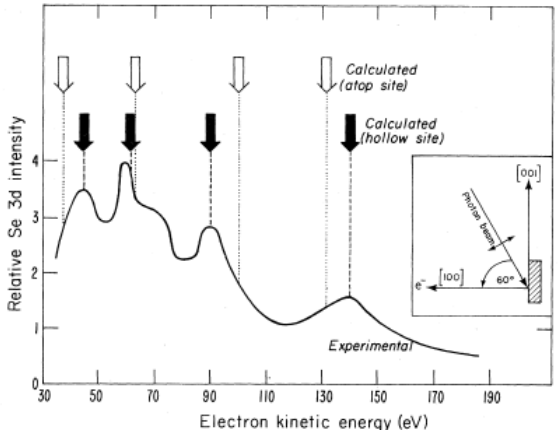
The Stanford Synchrotron Radiation Lightsource
Ca. 1974 to 1993

Photoelecton spectroscopy: the various dimensions

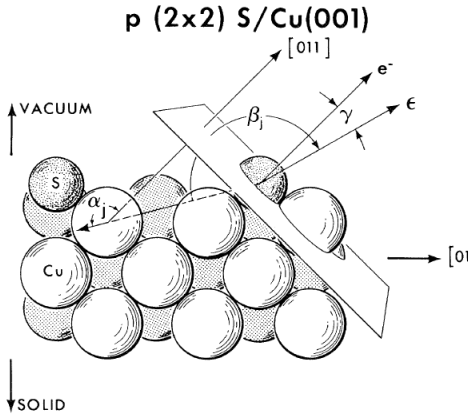


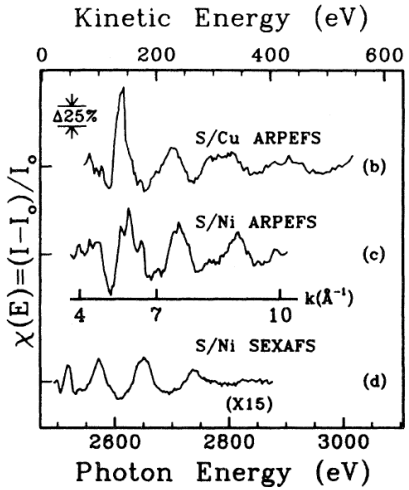
Surface atomic structures from photoelectron diffraction and photoelectron holography

Se on Ni(001):

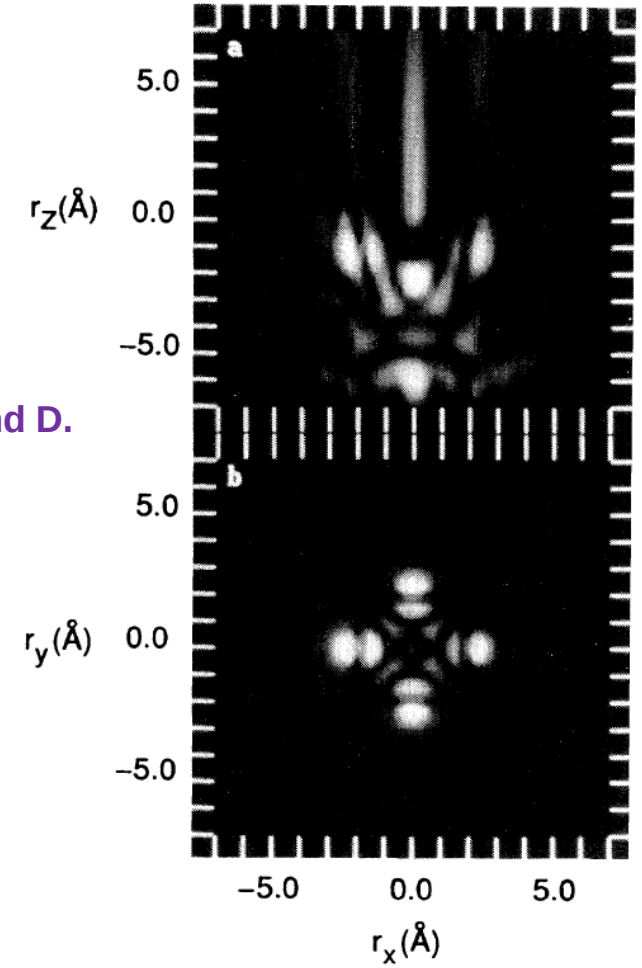


S. D. Kevan, D. H. Rosenblatt, D. Denley, B.-C. Lu, and D. A. Shirley, Phys. Rev. Lett. 41, 1566 (1978)



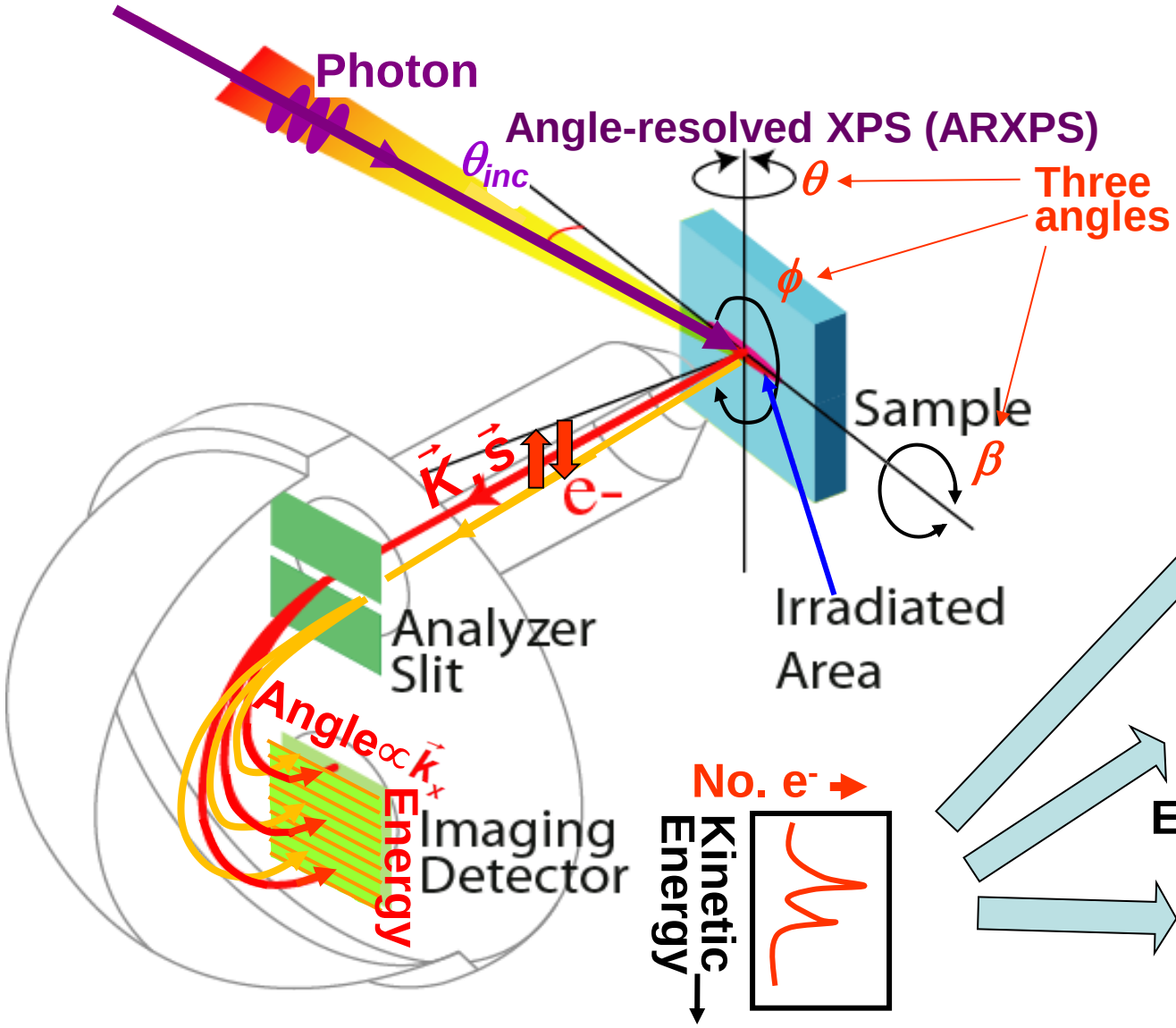


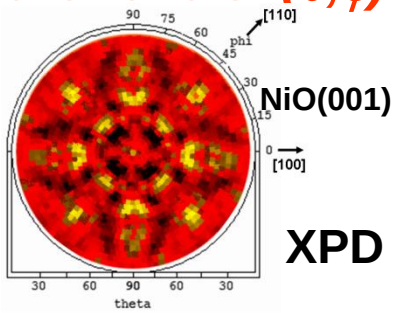
J. J. Barton, C. C. Bahr, Z. Hussain, S. W. Robey, J. G. Tobin, L. E. Klebanoff, and D. A. Shirley, Phys. Rev. Lett. 51, 272 (1983)



J. J. Barton, Phys. Rev. Lett. 67, 272 (1991) (By then at IBM Watson)

Photoelecton spectroscopy: the various dimensions

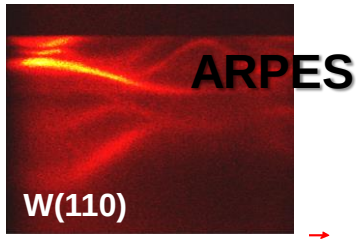




Core-levels I(θ,ϕ)

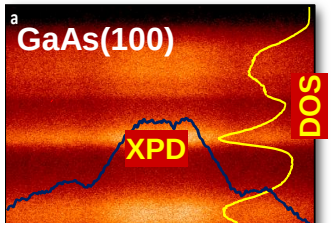
Photoe- diffraction

Valence-levels



Binding Energy

Emission angle→ $\vec{k}_x$

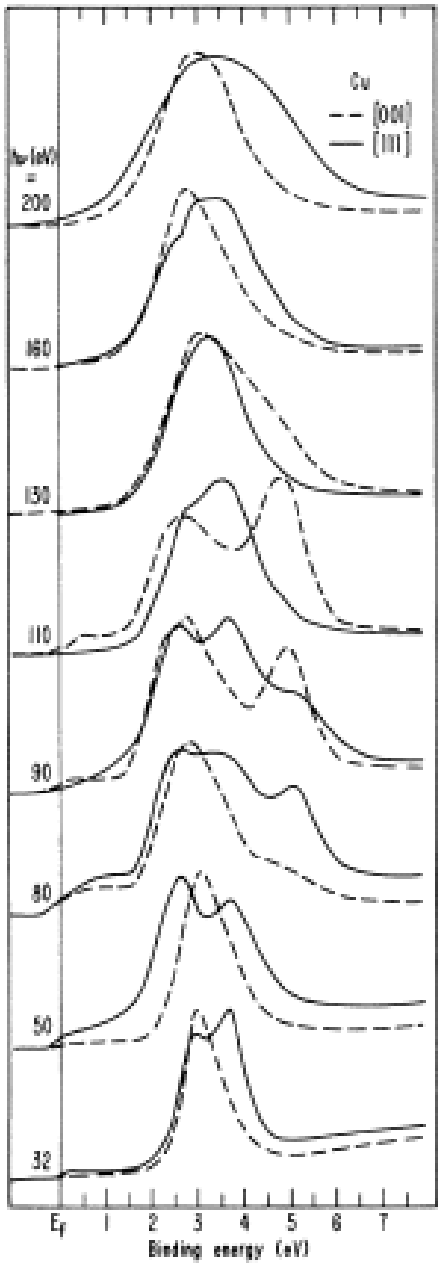


Binding Energy

Emission angle

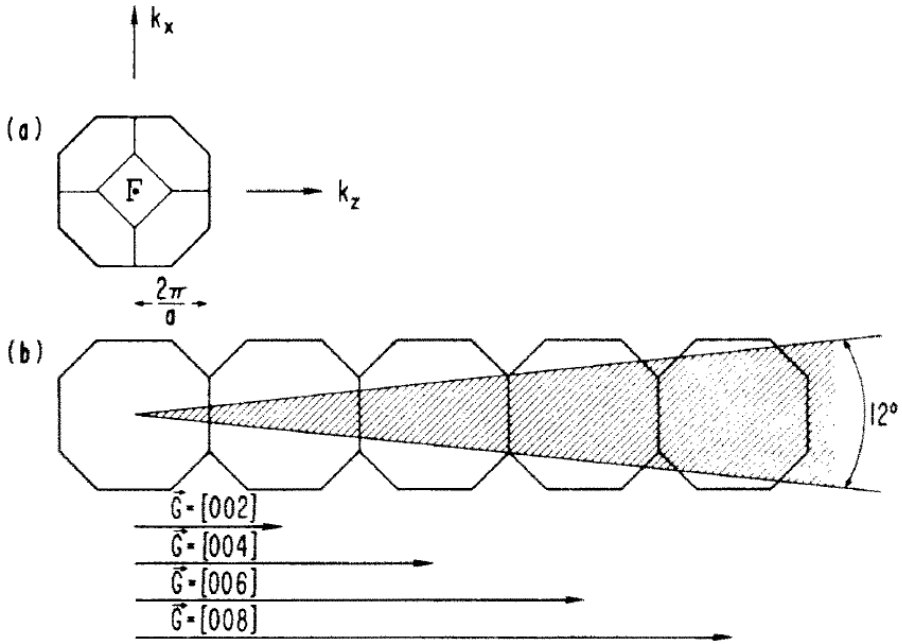
Core: Chemical shifts, multiplet splittings, DOSs

Angle-resolved photoemission from valence bands: Cu



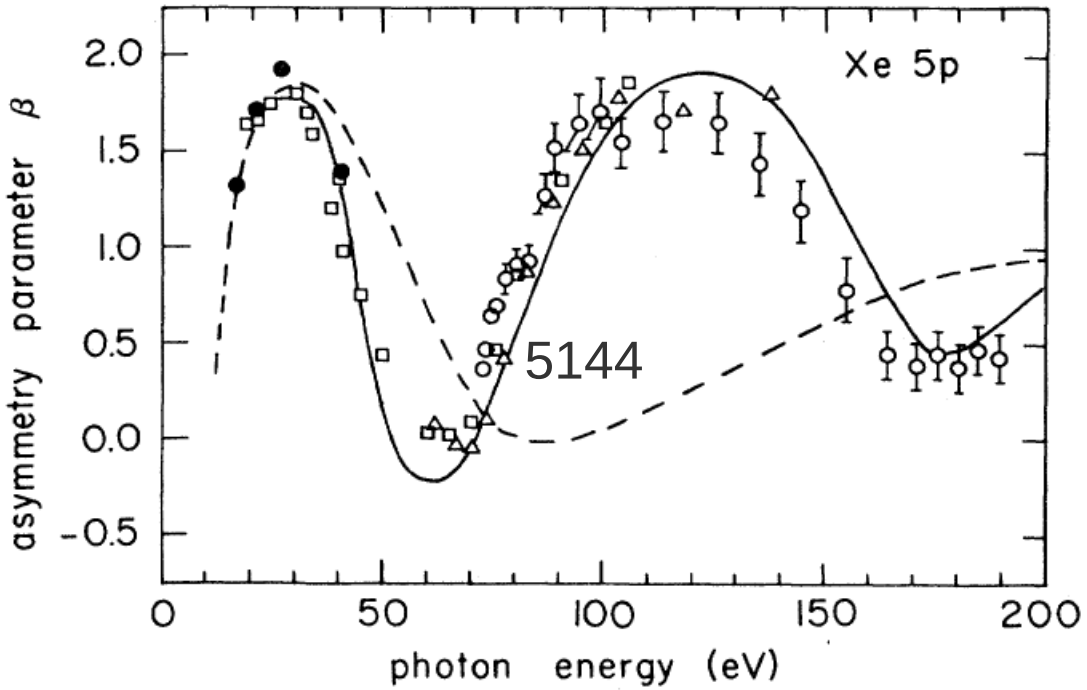
Increasing photon energy→

Moving through k-space



J. Stöhr, G. Apai, P. S. Wehner, F. R. McFeely, R. S. Williams, and D. A. Shirley, Phys. Rev. B 14, 5144 (1976)

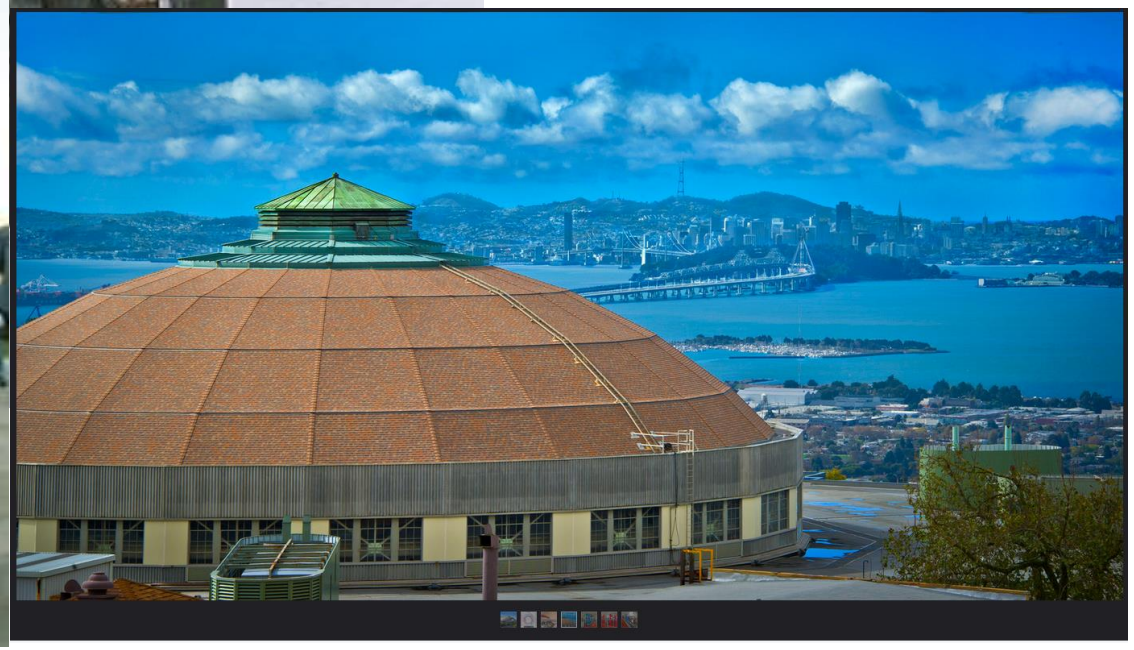
And gas-phase atomic and molecular studies: Differential photoelectric cross sections, the asymmetry parameter



S. Southworth, U. Becker, C. M. Truesdale, P. H. Kobrin, D. W. Lindle, S. Qwaki, and D. A. Shirley
Phys. Rev. A 28, 261-279 (1983)

LBNL Director, 1980-89

The Advanced Light Source-1993 to present

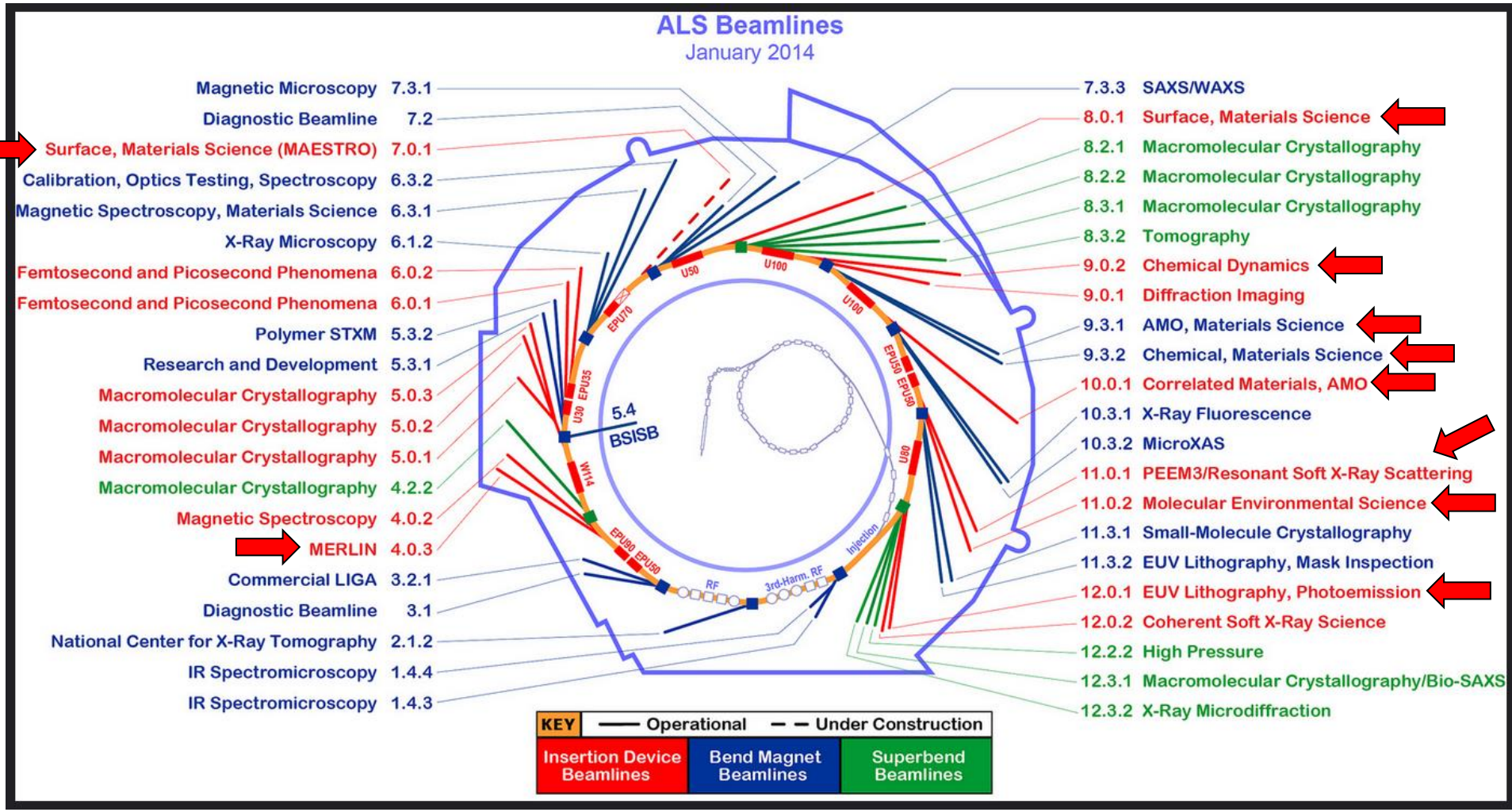


The National Center for Electron Microscopy

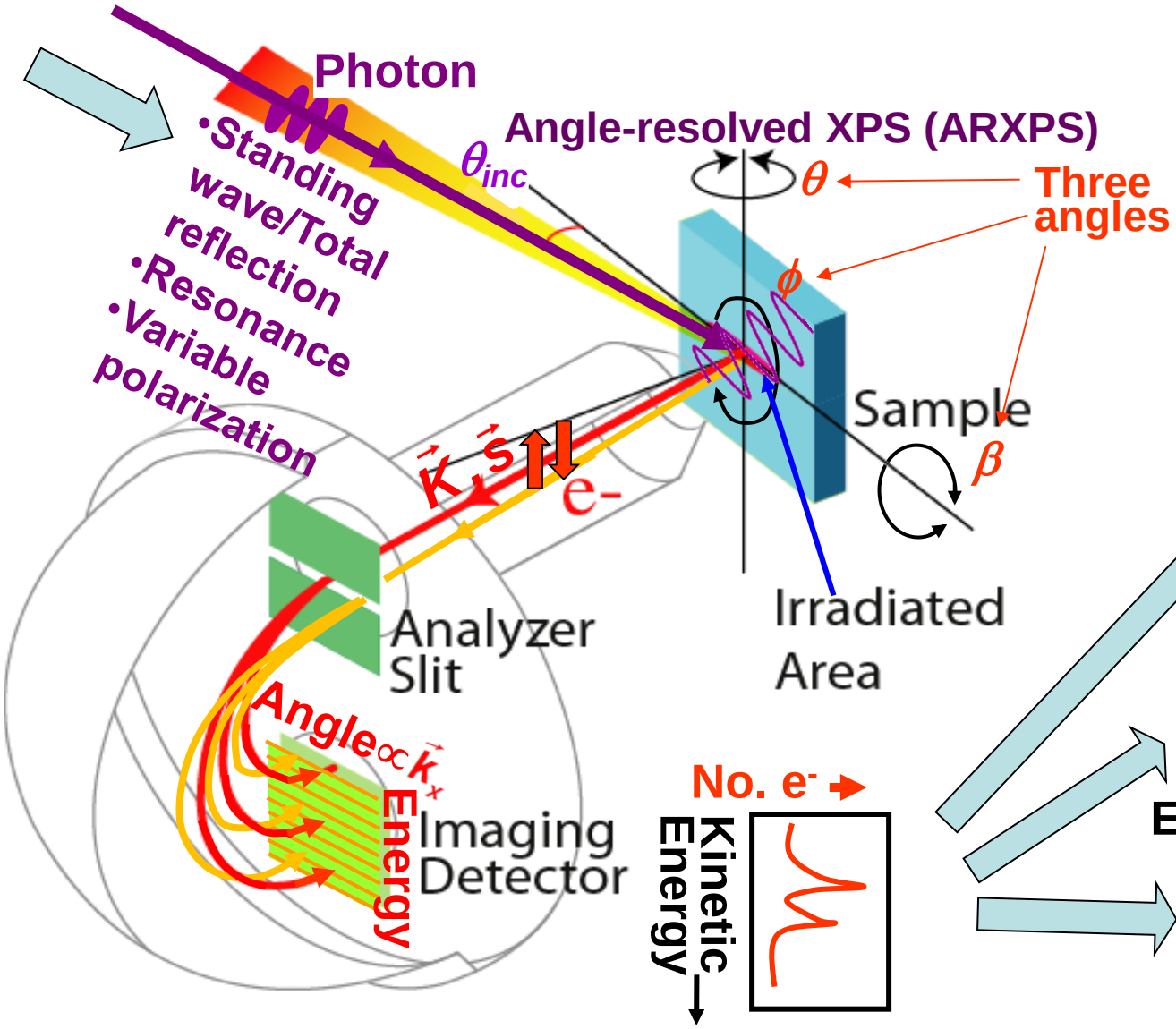
The Center for X-Ray Optics

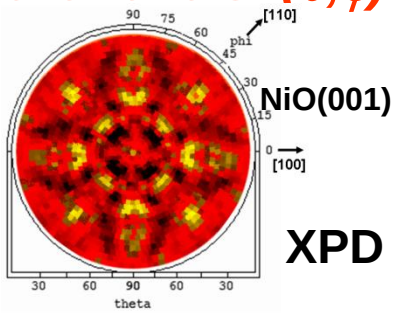
The Advanced Light Source at 20 years

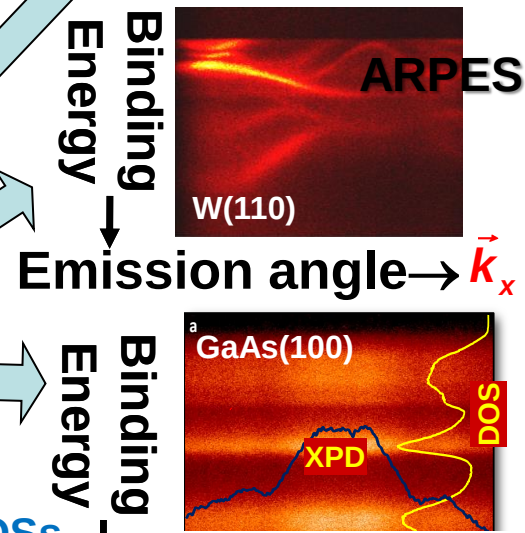
➡ = photoelectron spectroscopy/photoemission



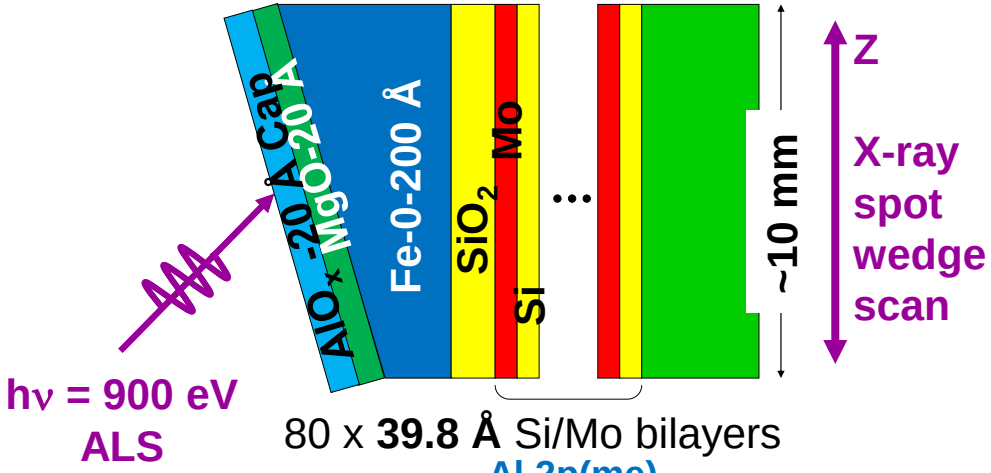
Photoelecton spectroscopy: the various dimensions

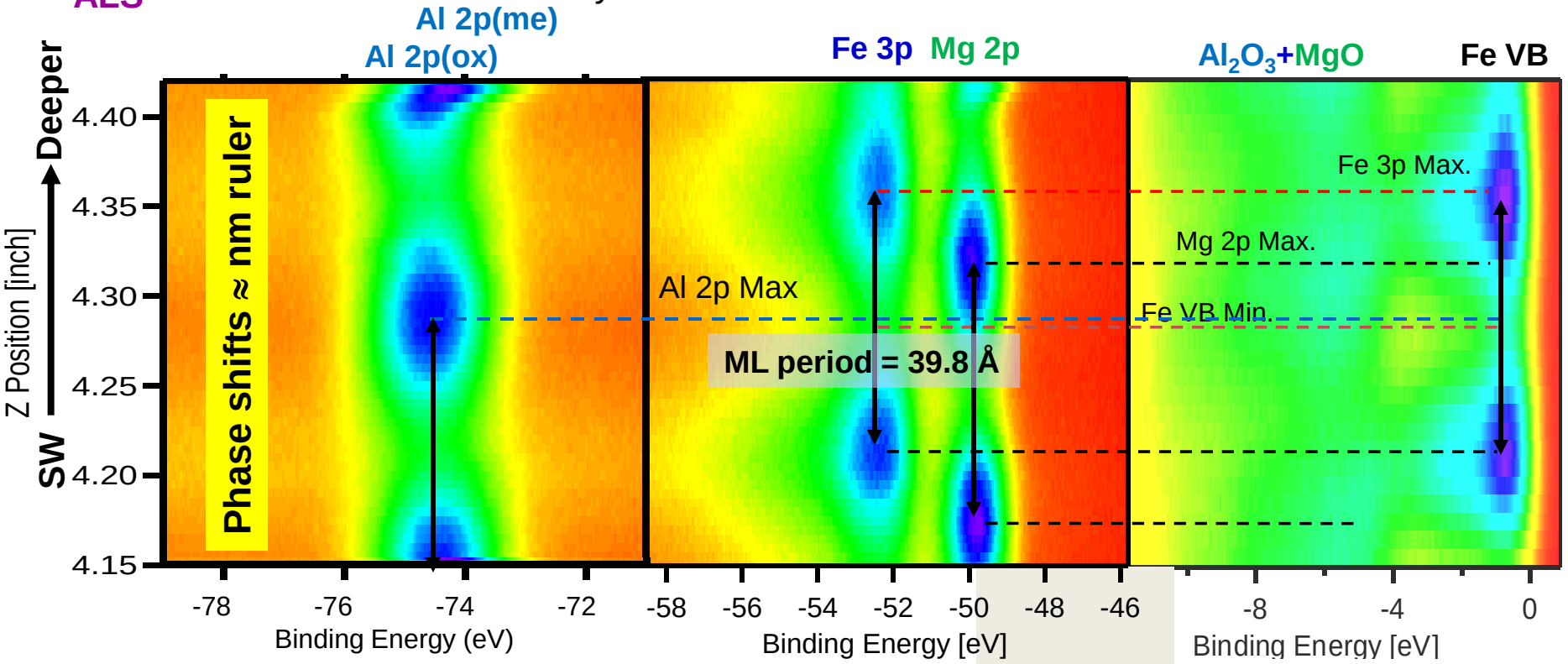






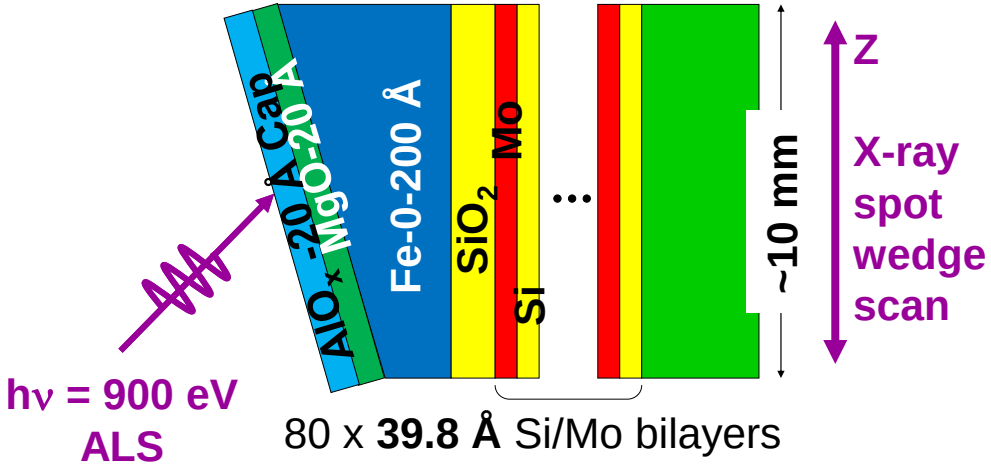
Soft x-ray standing-wave wedge scans through a magnetic tunnel junction



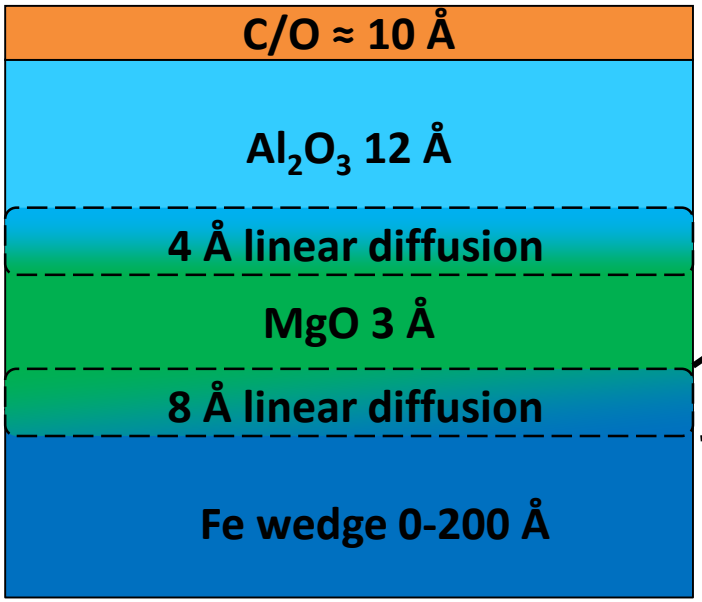


Balke, Yang et al., Phys. Rev. B 84, 184410 (2011)

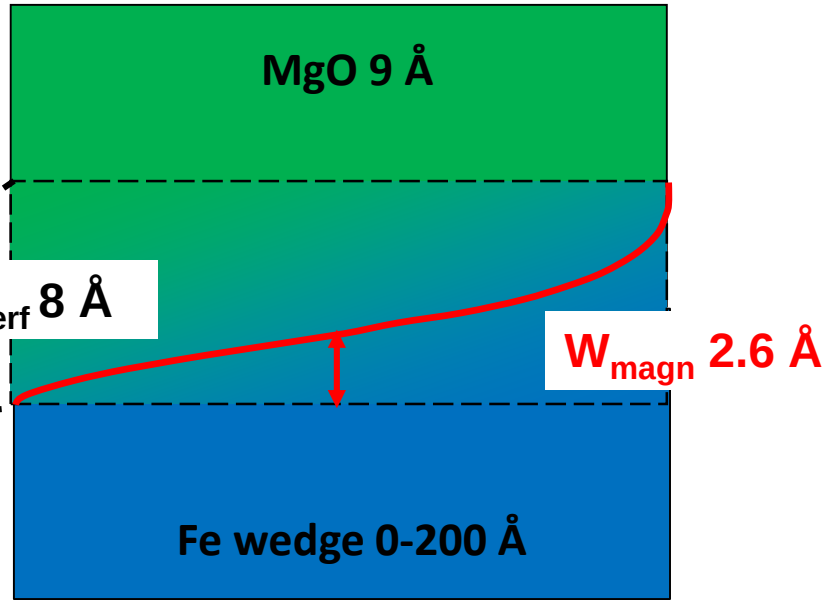
Soft x-ray standing-wave wedge scans through a magnetic tunnel junction



Concentration

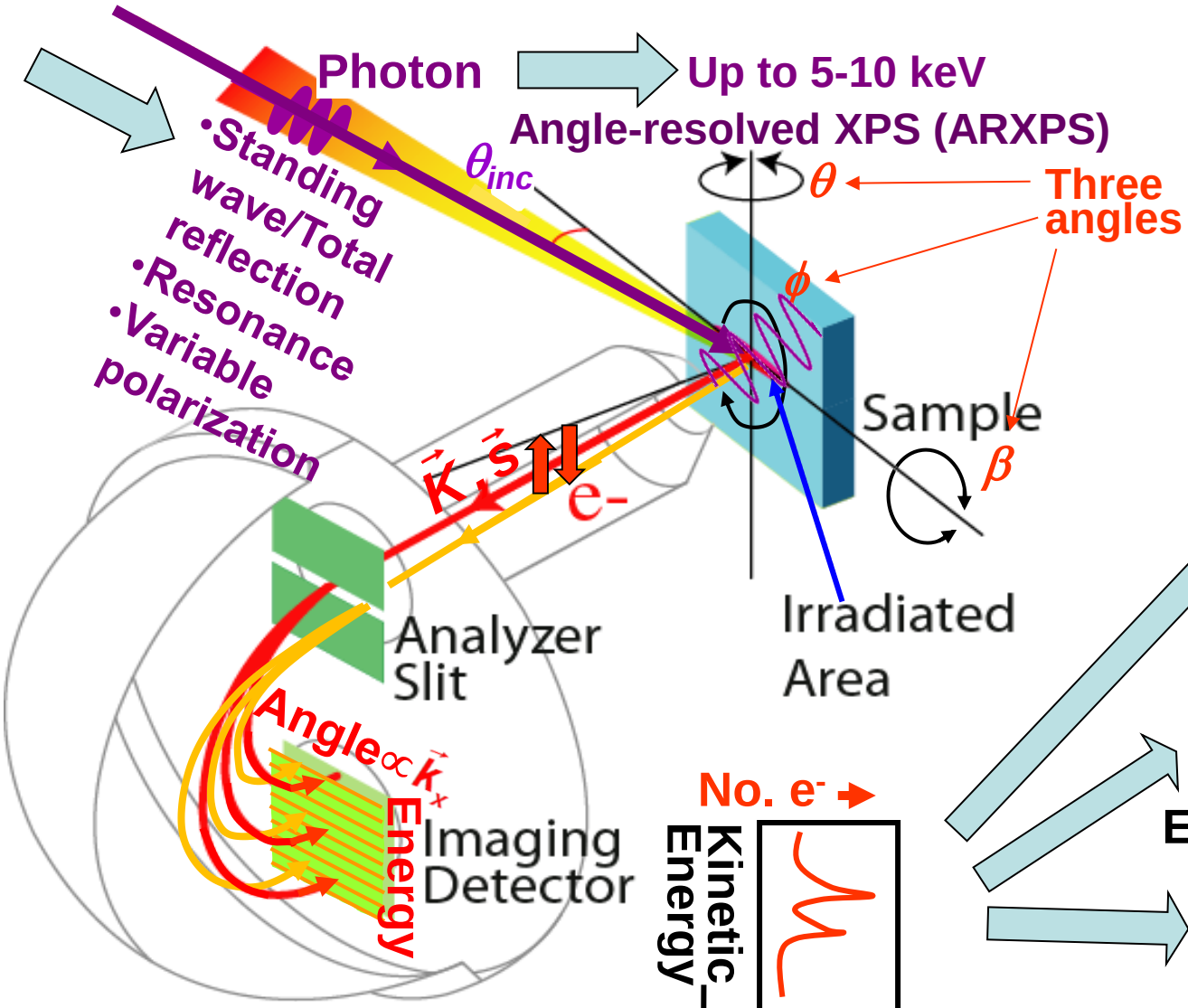


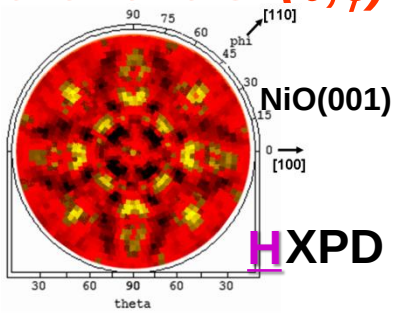
Magnetization

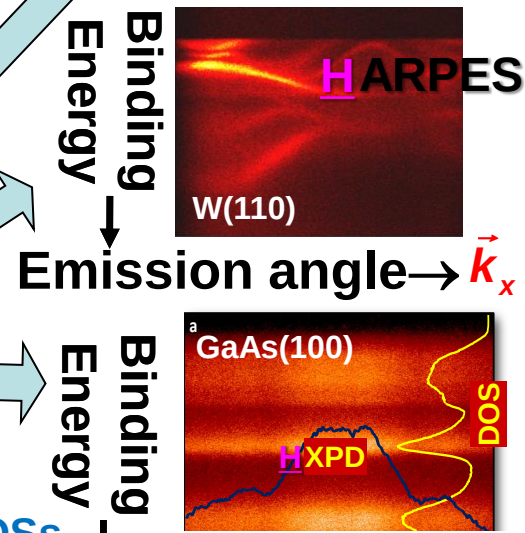


Balke, Yang et al., Phys. Rev. B 84, 184410 (2011)

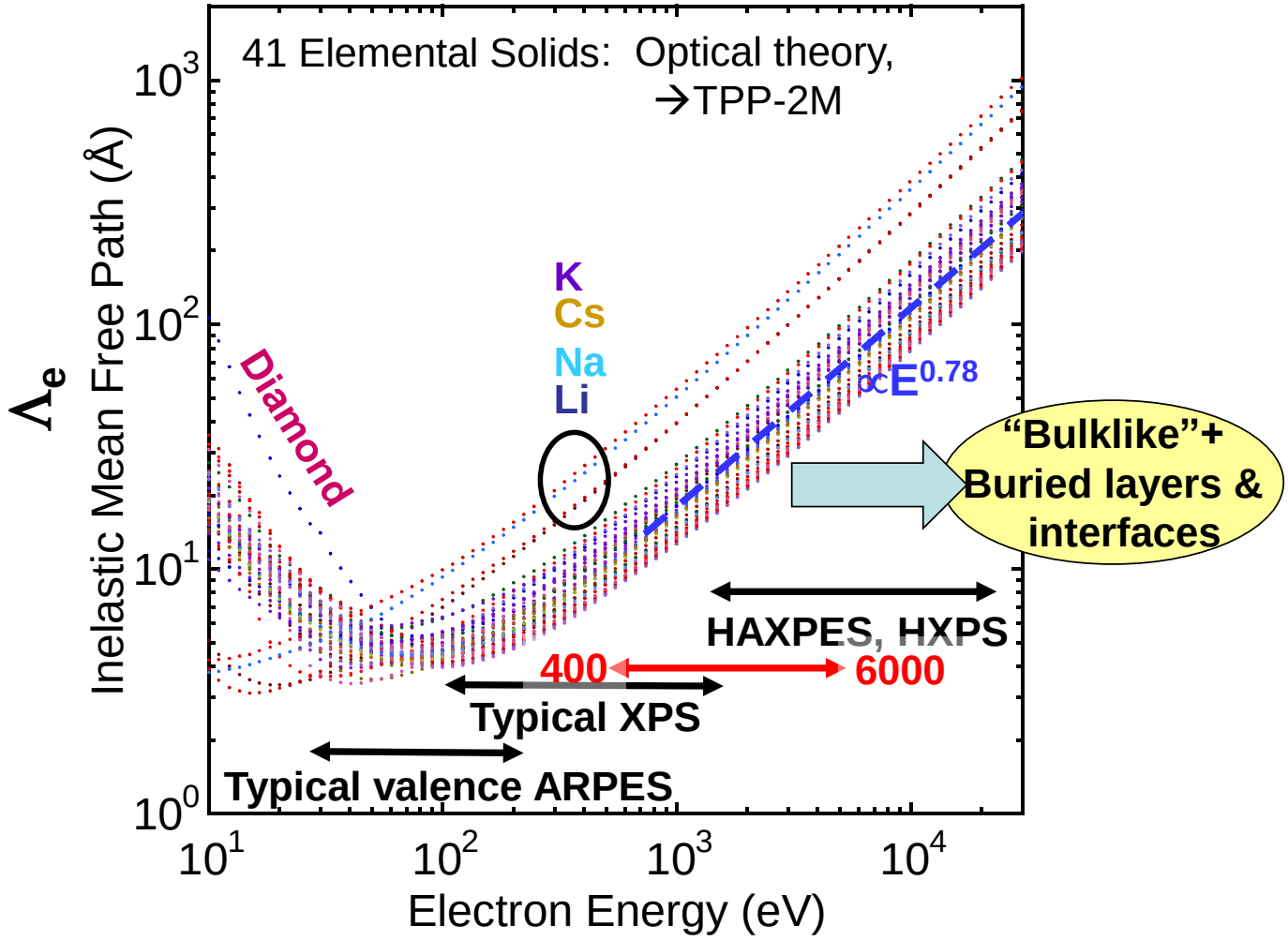
Photoelecton spectroscopy: the various dimensions







The reason for higher photon energies

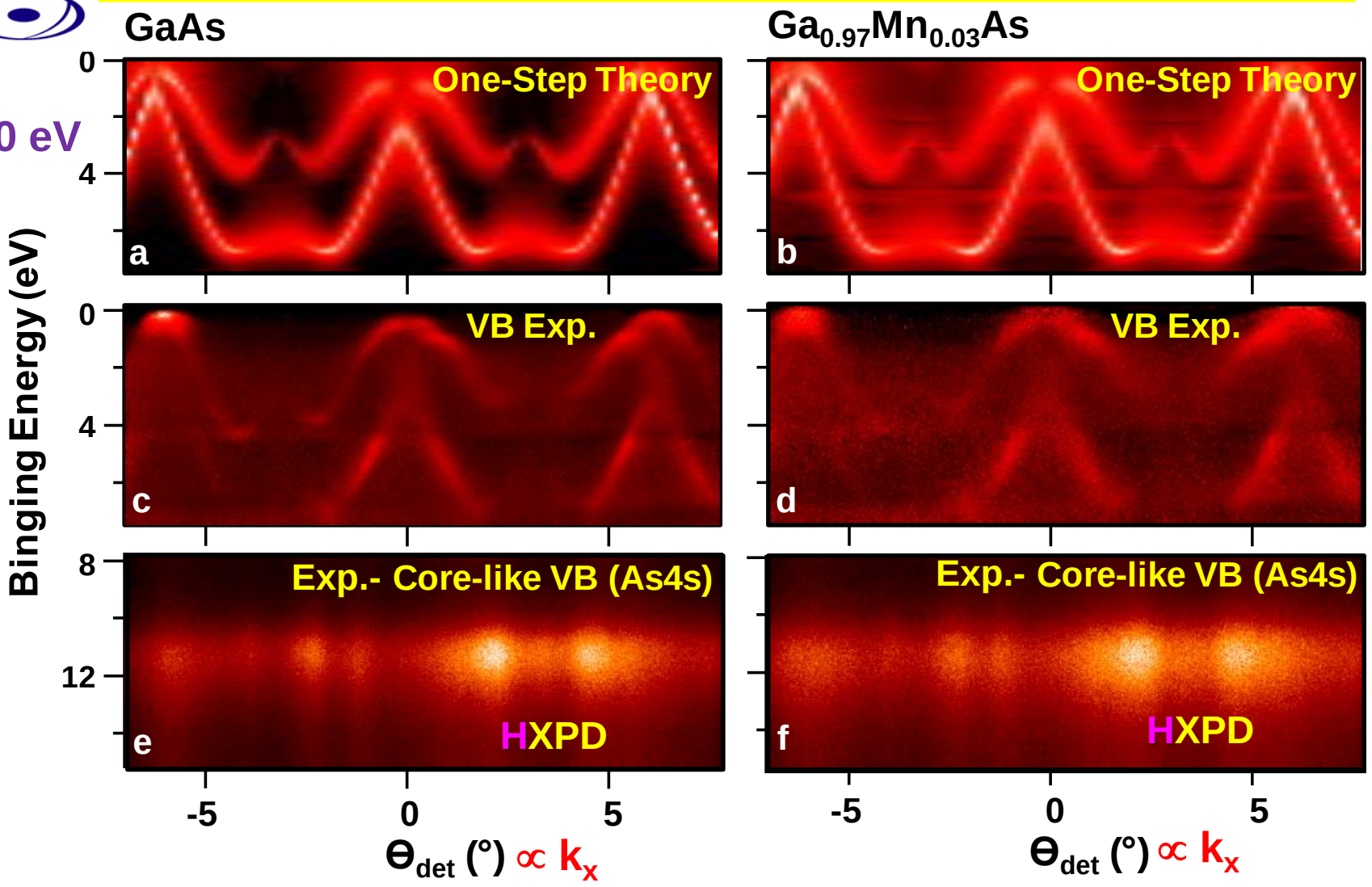


Tanuma, Powell, Penn, Surf. and Interf. Anal. 43, 689 (2011)

Hard x-ray ARPES--GaAs and DMS $Ga_{0.97}Mn_{0.03}As$ Comparing Experiment and One-Step KKR Theory

SPring-8

3,200 eV



Gray et al., Nature Materials 11, 957 (2012)

Photoelecton spectroscopy: the various dimensions

From UHV to multi-Torr
The Real World! (Hussain)

Space (PEEM) &
Time resolution (lasers,
FELs, Molodtsov)

Photon

Up to 5-10 keV

Angle-resolved XPS (ARXPS)

•Standing wave/Total reflection
•Resonance
•Variable polarization

θ_{inc}

θ Three angles

ϕ

β

Sample

$\vec{K}, \vec{S}$ e-

V

New detectors (e.g. delay-line, integrated circuit; spin); Other spectrometers (e.g. time-of-flight) (Hussain)

Analyzer Slit

(Suzer) Irradiated Area

Angle$\propto \vec{k}_x$

Energy

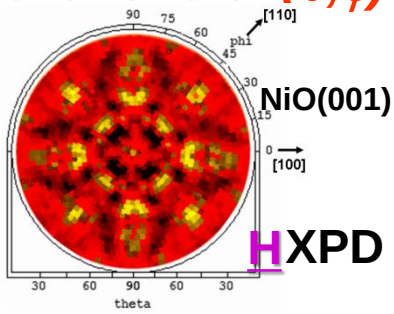
Imaging Detector

No. e-

Kinetic Energy

Core: Chemical shifts, multiplet splittings, DOSs

Core-levels I(θ,ϕ)

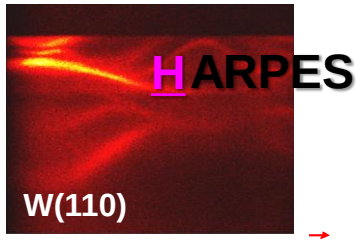


HXPD

Photoe- diffraction

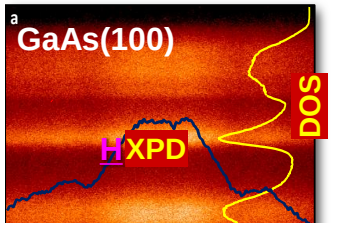
Valence-levels

Binding Energy



Emission angle→ $\vec{k}_x$

Binding Energy



Emission angle

Thank you Dave, for many creative ideas, your vision of the future, your good advice on many matters, and all that you have contributed to us, to UCB, LBNL, FUB, and the scientific community at large.