Matter in Extreme Condition at X-ray Free-Electron Lasers

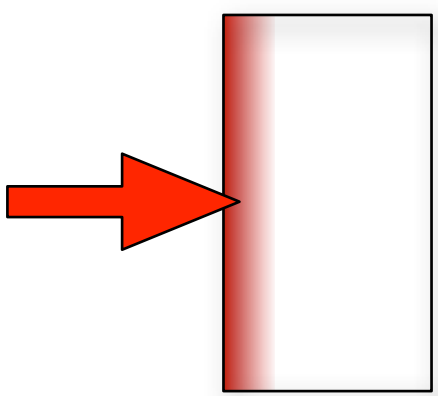
Bob Nagler

Bob.Nagler@slac.stanford.edu

MEC studies with XUV and X-ray FEL radiation

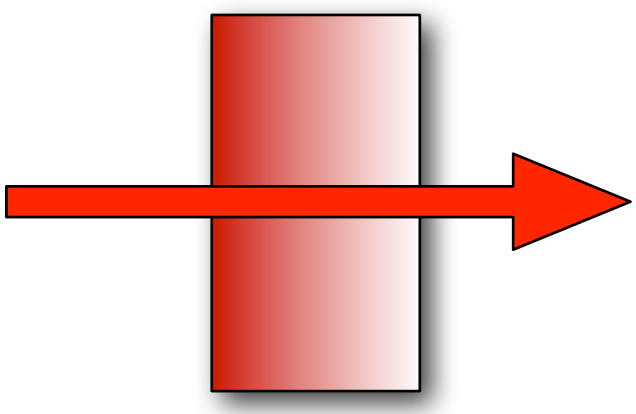
Optical laser excitation

$\omega < \omega_p$



XUV and X-ray laser excitation

$\omega > \omega_p$



ω_p is typically 10-15 eV (UV)

Requirements

1. XUV or X-ray wavelength

2. Short pulses, sub-ps

3. Lots of photons

HEDS instrument at the European X-FEL

Experiments at other Facilities:

FLASH: WDM creating

Thomson Scattering on Dense He

At LCLS

SXR:

solid density Al Plasma

Plasma kinetics in Al Plasma

XPP:

Diffraction on Shocked Iron

Fourier Domain Interferometry on X-ray heated matter

CXI:

Diffraction on Shocked Iron

MEC:

Phase Contrast Imaging of Shocks

Diffraction on Shocked nanocrystals

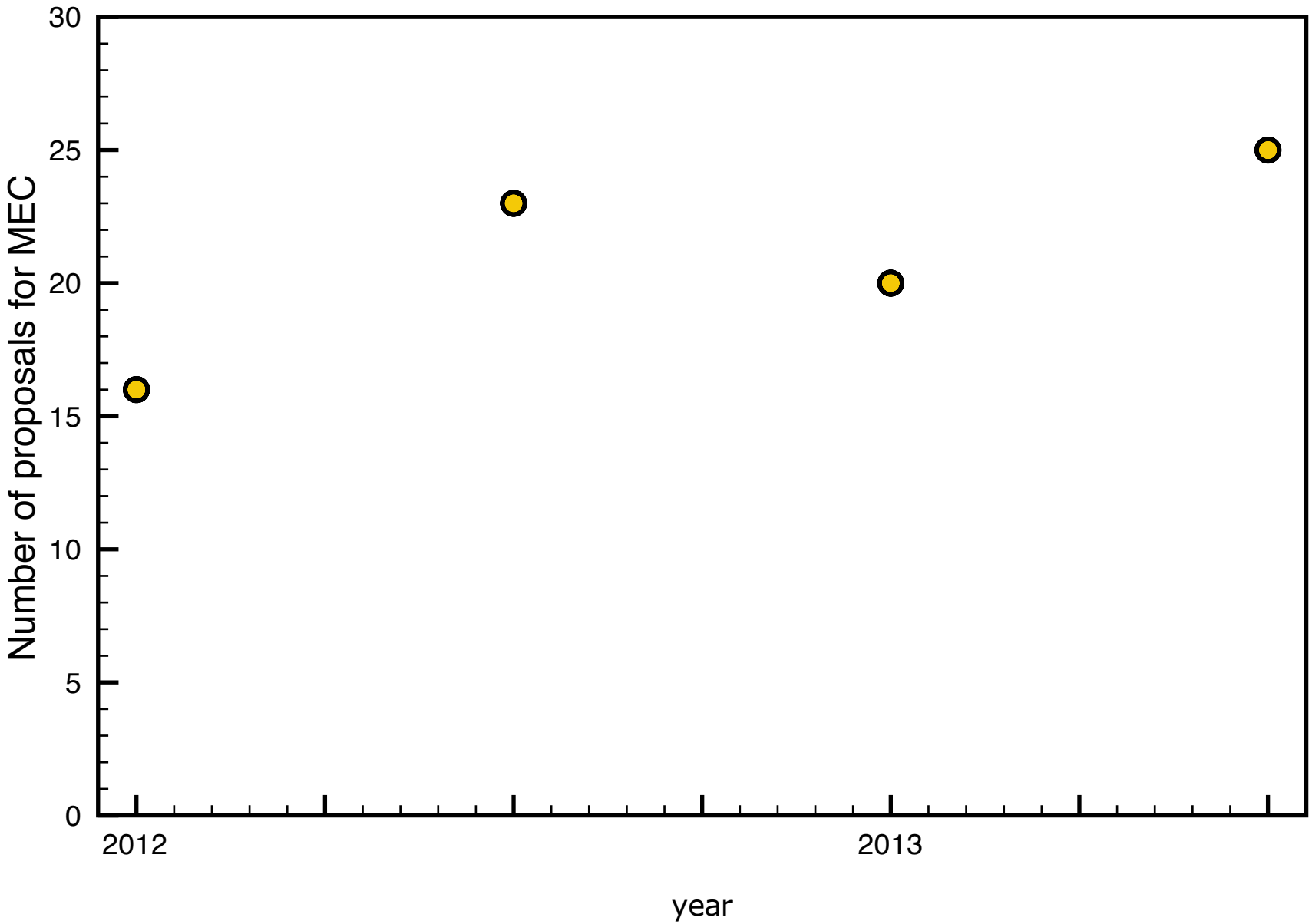
Structural transition in shocked SiO_2

XANES in Warm Dense Ag and Mb

Quasi-elastic scattering Dense Plasmas

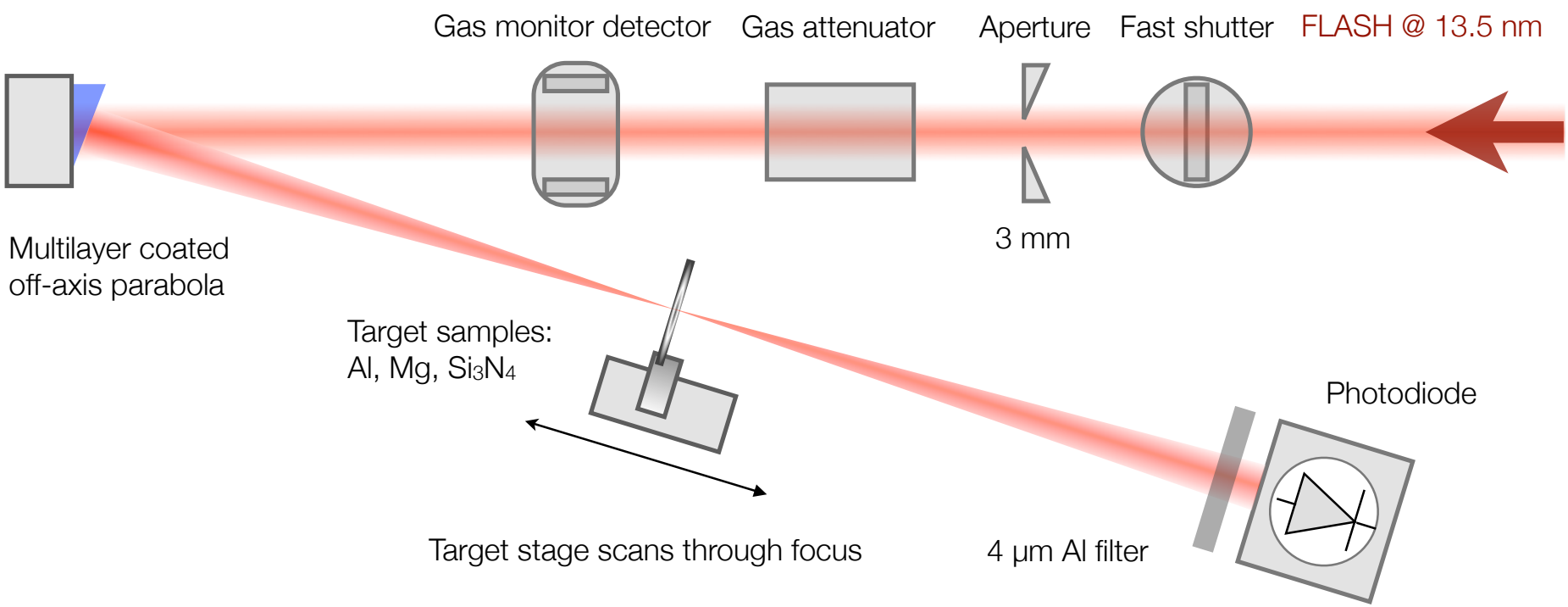
Upcoming experiments at MEC:

Phase transition in shocked Bi
Compression measurement using inelastic X-ray scattering
Phase transition of Fe using XANES
Ion-Ion scattering feature in WDM
Complex refractive index measurement of WDM using HHG


30
25
20
15
10
5
0
Number of proposals for MEC
2012
2013
year

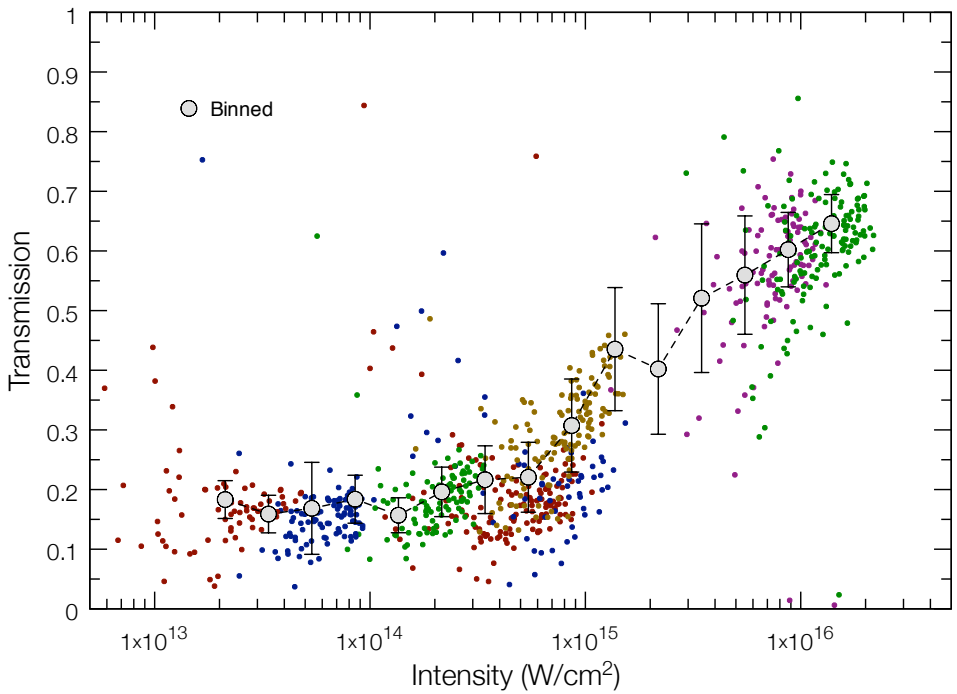
- Creating Transparent Aluminum in Flash
- Measuring highly ionized charge states in solid Al (SXR)
- Phase contrast imaging of shocked solids
- Structural transition in shocked quartz
- Inelastic scattering on dense plasmas
- XANES in Warm Dense Ag and Mb

Creating WDAluminum at FLASH

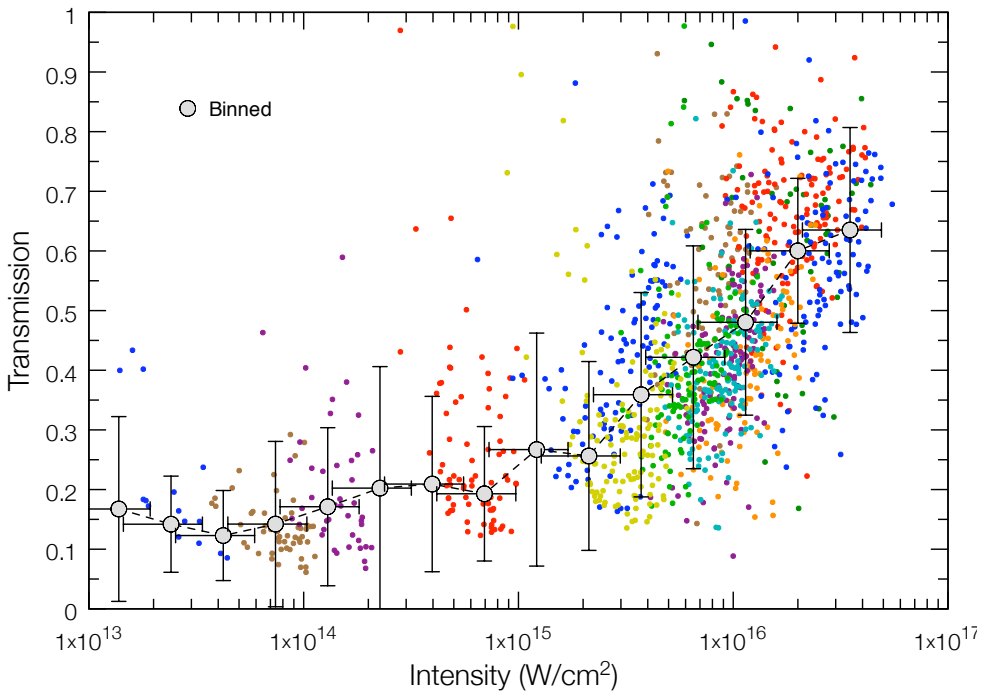


large collaboration: Oxford University, DESY, SLAC, LBNL, LLNL, Rostock Univerity, U. Jena, etc.
(see Nagler et al. Nature Physics 5, 1341 (2009))

Aluminium



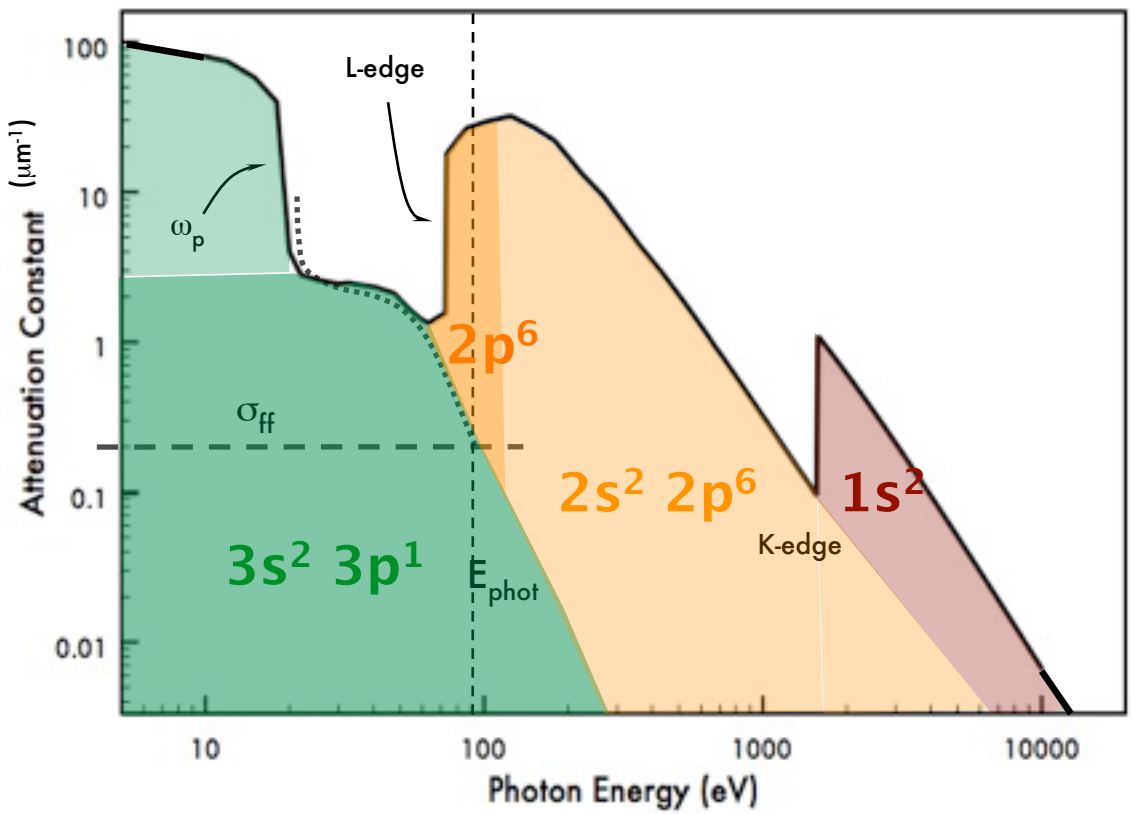
Magnesium



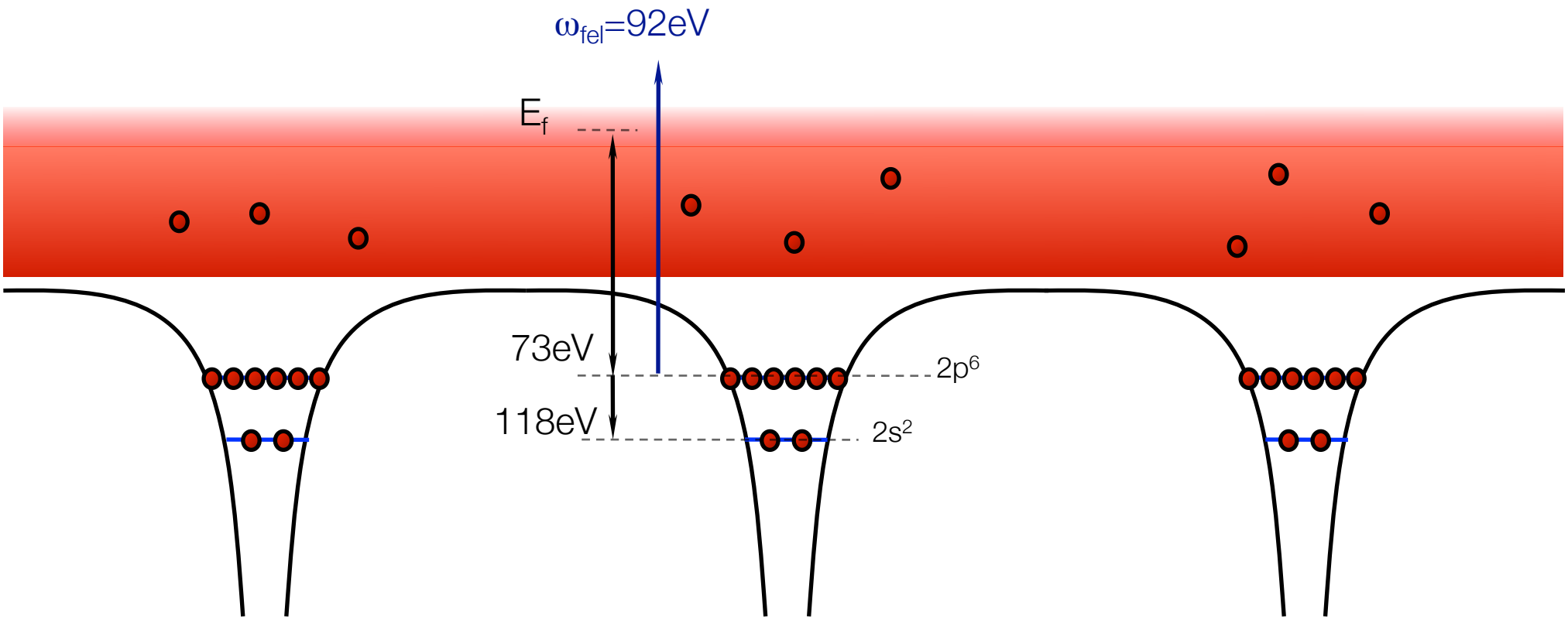
Saturable absorption in Aluminium

Electron configuration in atomic aluminium:

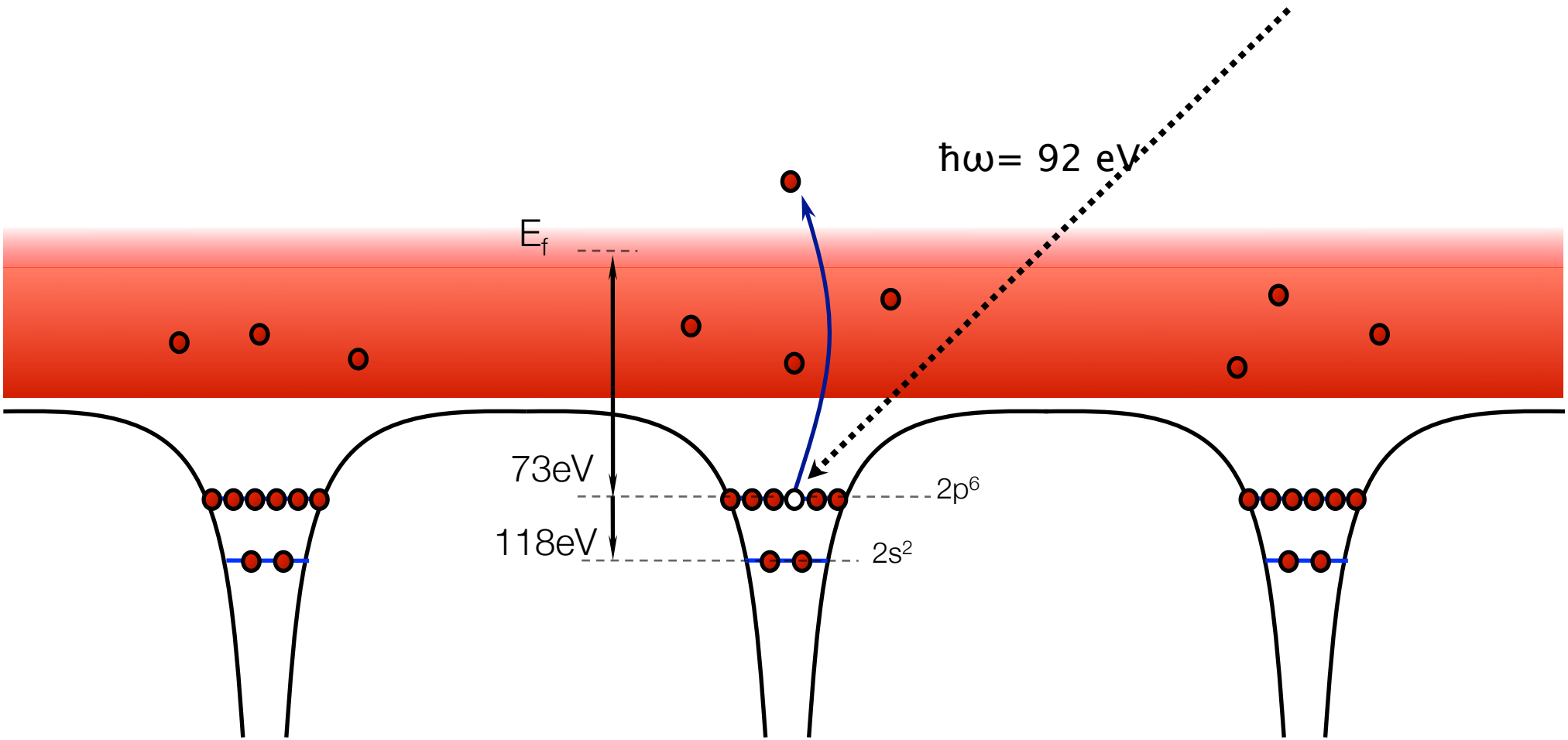
$1s^2$	$2s^2\ 2p^6$	$3s^2\ 3p^1$
K	L	M



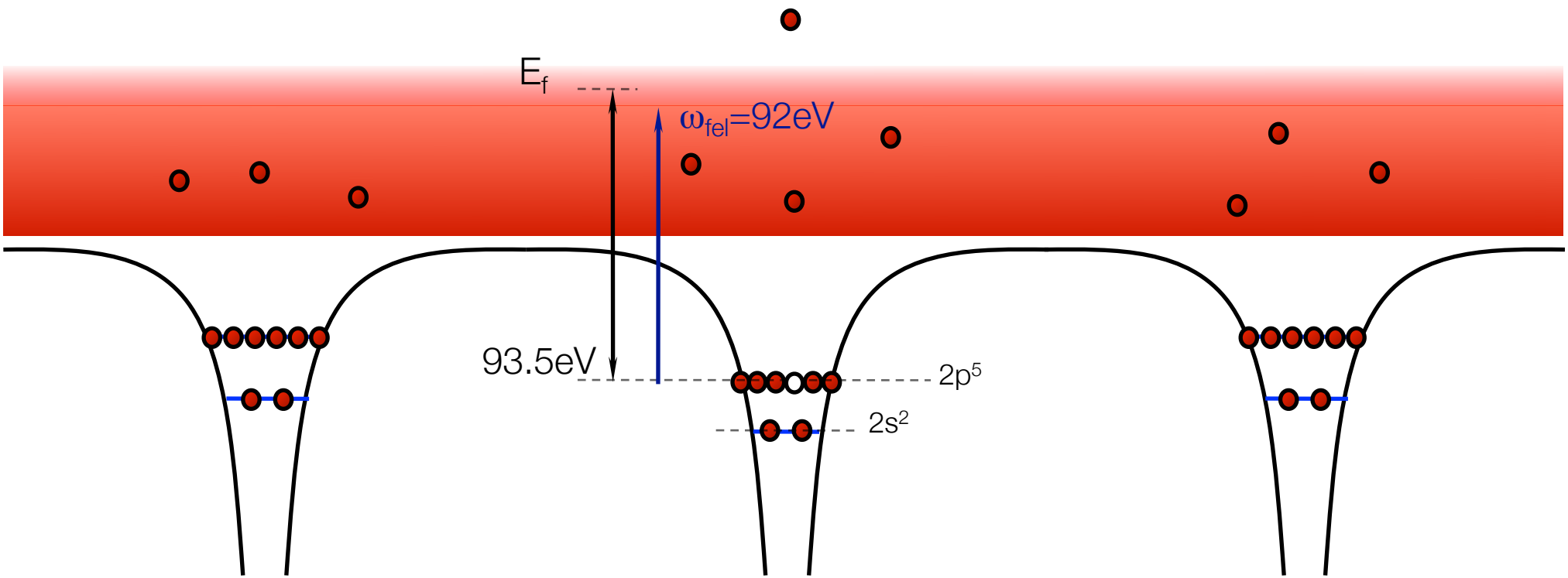
L-edge shift

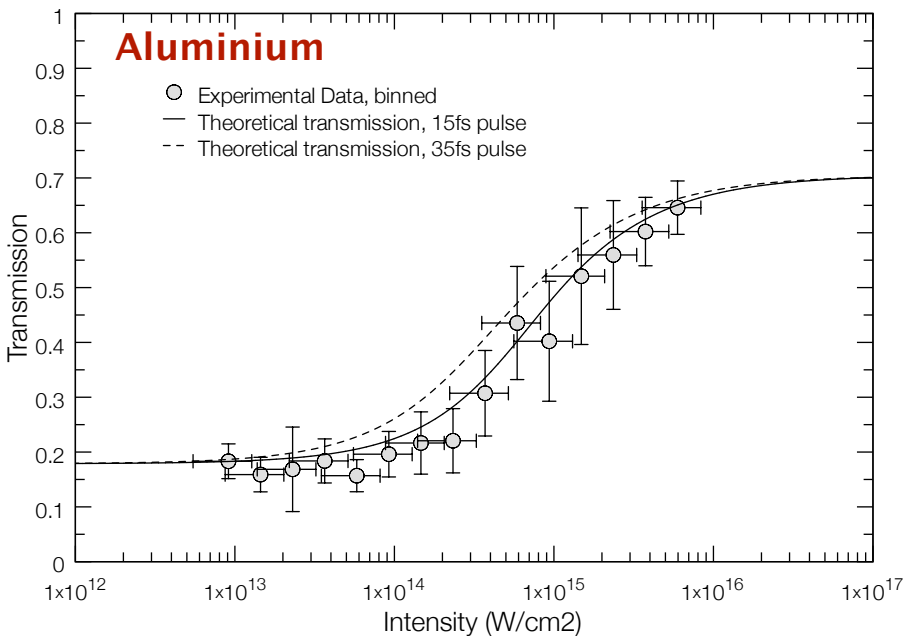


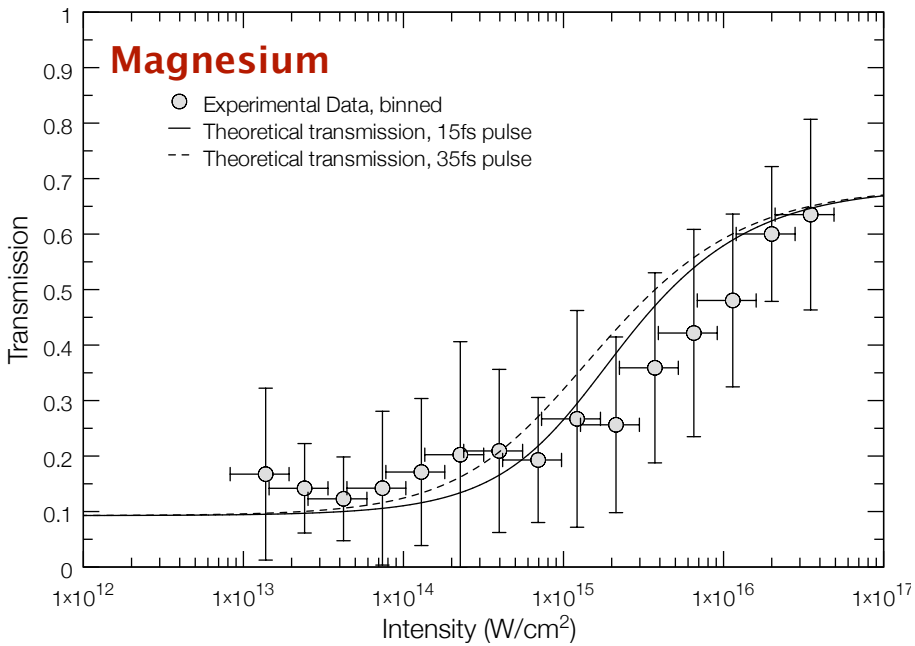
L-edge shift



L-edge shift



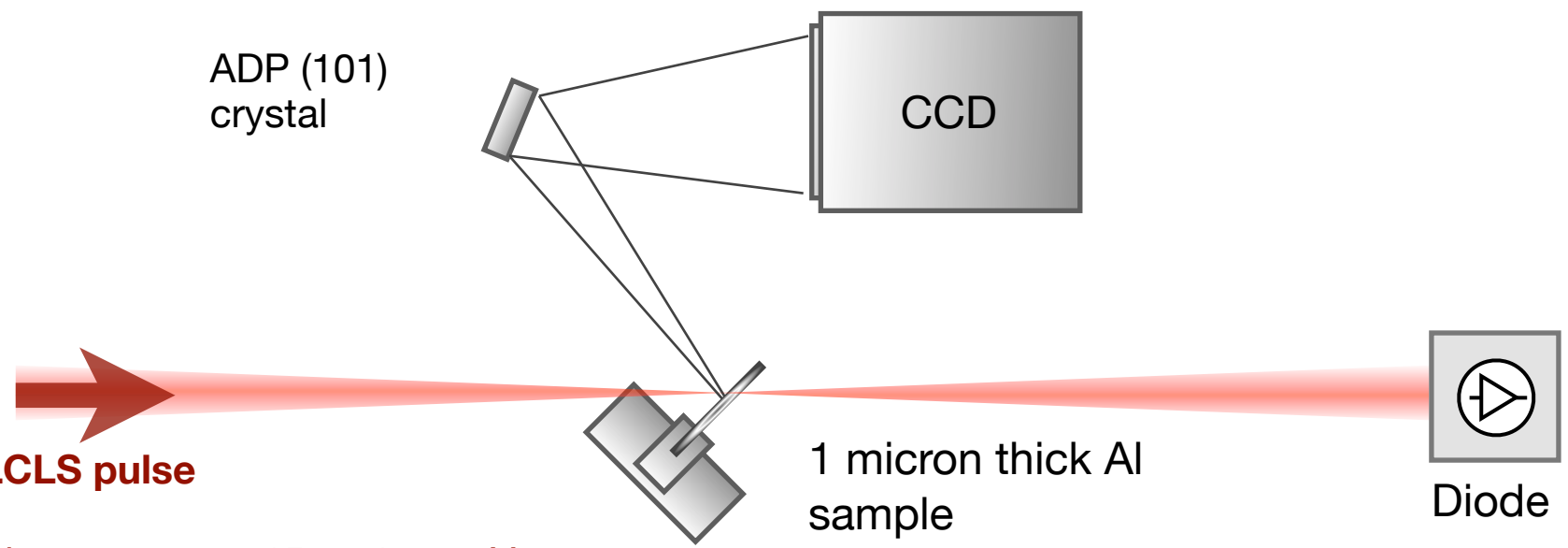




Nagler et al. Nature Physics 5, 1341 (2009)

Measuring highly ionized charge states in solid Al (SXR)

X-ray spectrometer: Al K-alpha emission **1460–1680 eV**



Photon energy: 1560–1830 eV

Pulse length < 80 fs

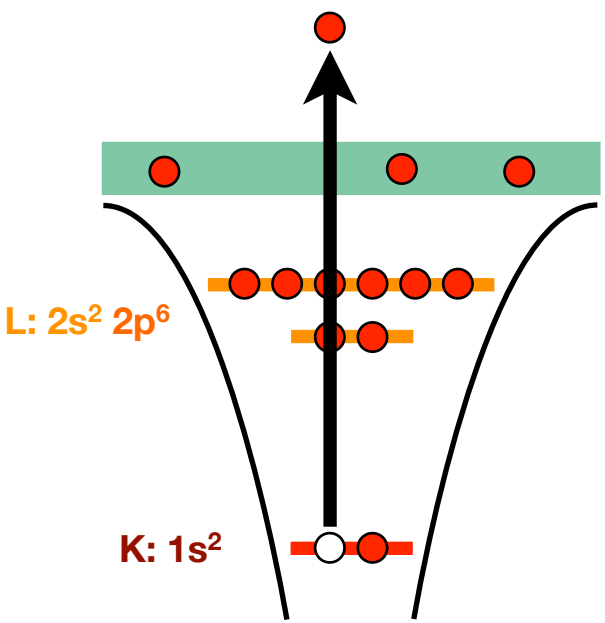
Peak Intensity ~10^{17} W cm^{-2}

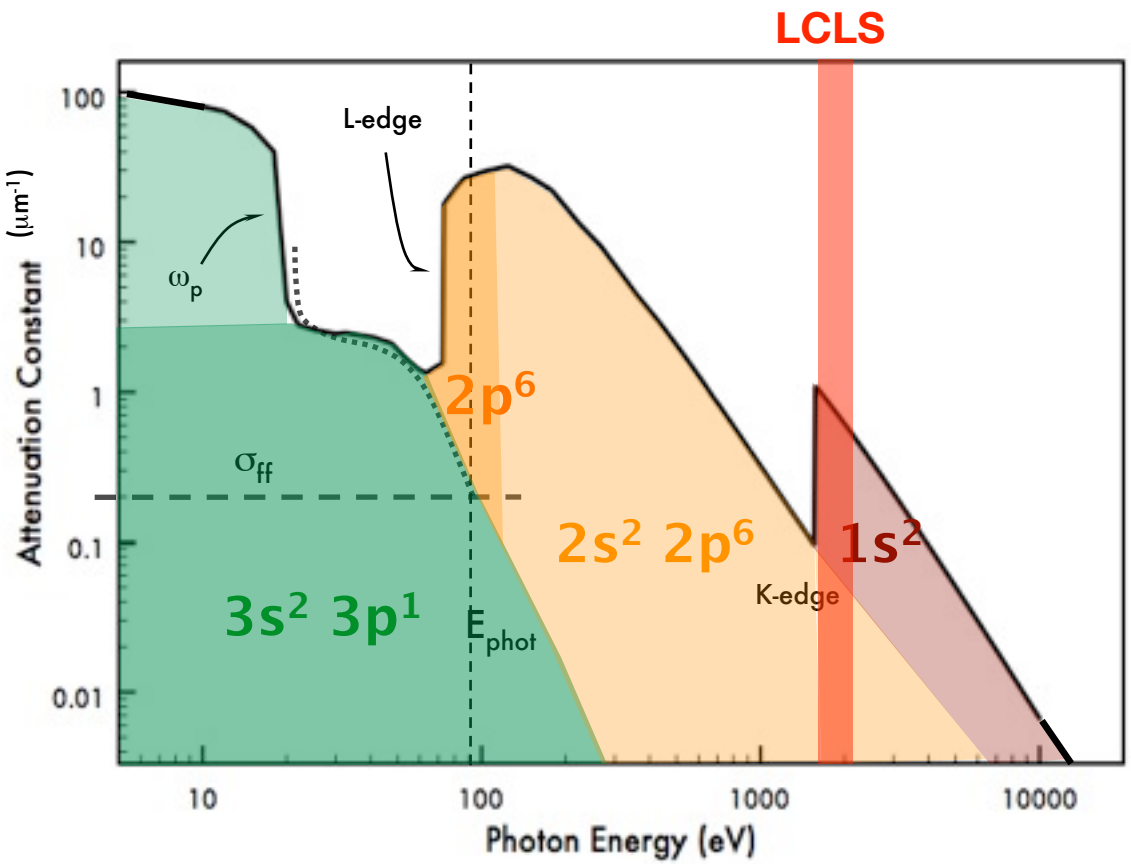
S. M. Vinko[1], O. Ciricosta[1], B. I. Cho[2], K. Engelhorn[2], H.-K. Chung[3], C. R. D. Brown[4], T. Burian[5], J. Chalupsky´[5], R. W. Falcone[2,6], C. Graves[7], V. Ha´jkova´[5], A. Higginbotham[1], L. Juha[5], J. Krzywinski[7], H. J. Lee[7], M. Messerschmidt[7], C. D. Murphy[1], Y. Ping[8], A. Scherz[7], W. Schlotter[7], S. Toleikis[9], J. J. Turner[7], L. Vysin[5], T. Wang[7], B. Wu[7], U. Zastrau[10], D. Zhu[7], R. W. Lee[7], P. A. Heimann[2], B. Nagler[7] & J. S. Wark[1]

Electronic structure of Aluminium

Neutral Al

Photo-excitation





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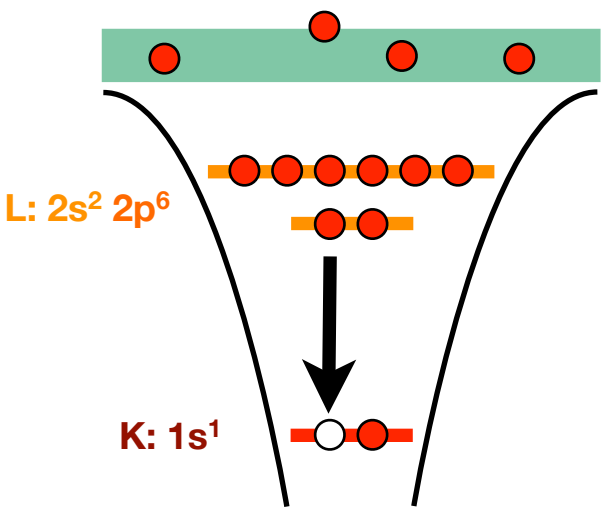
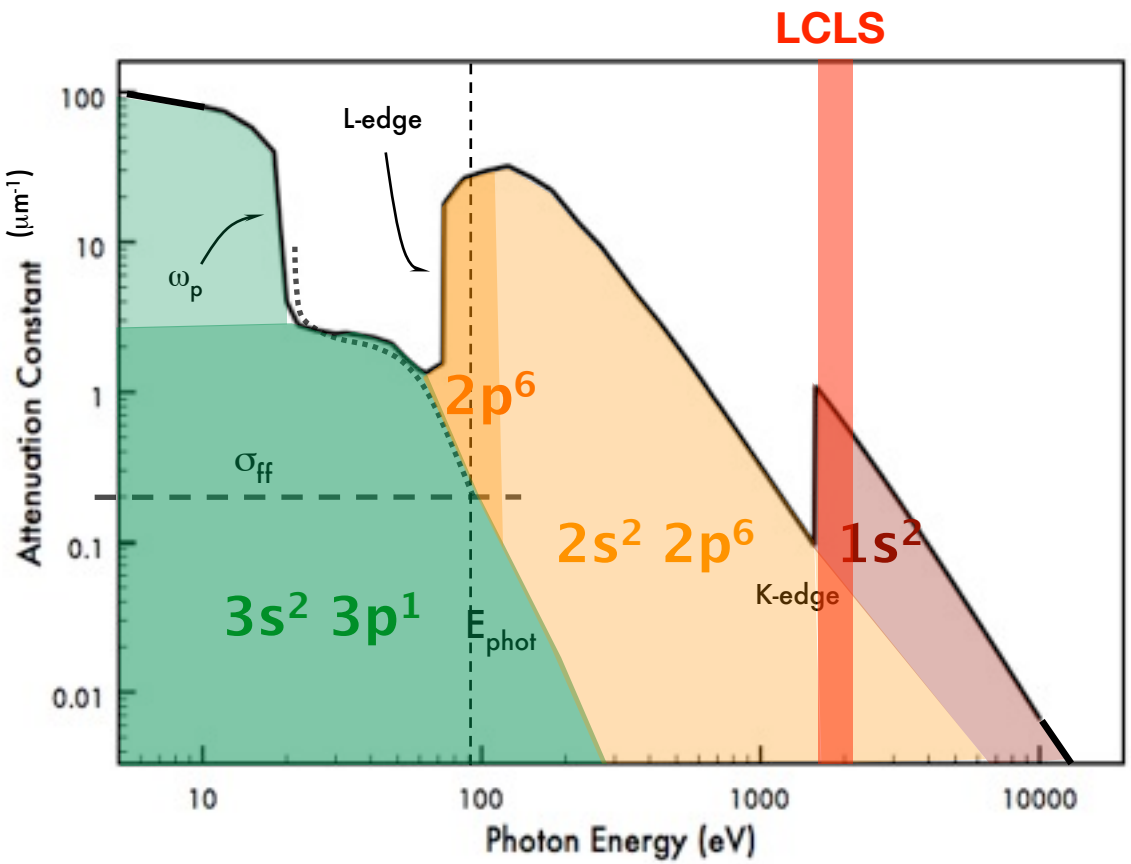
K-alpha emission





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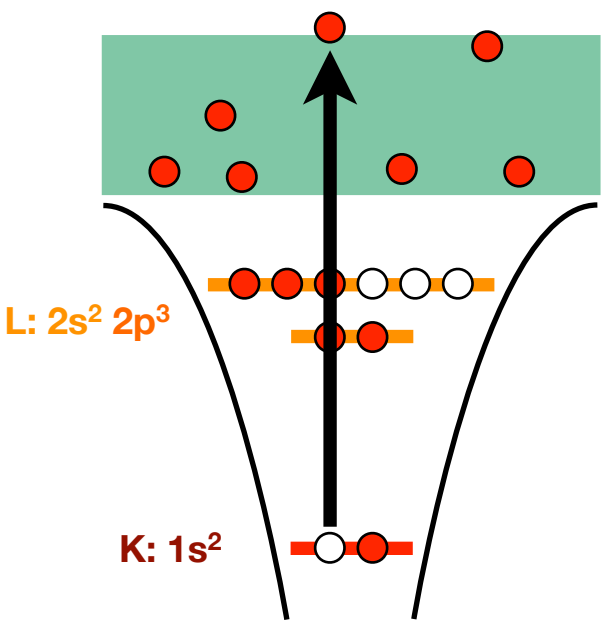

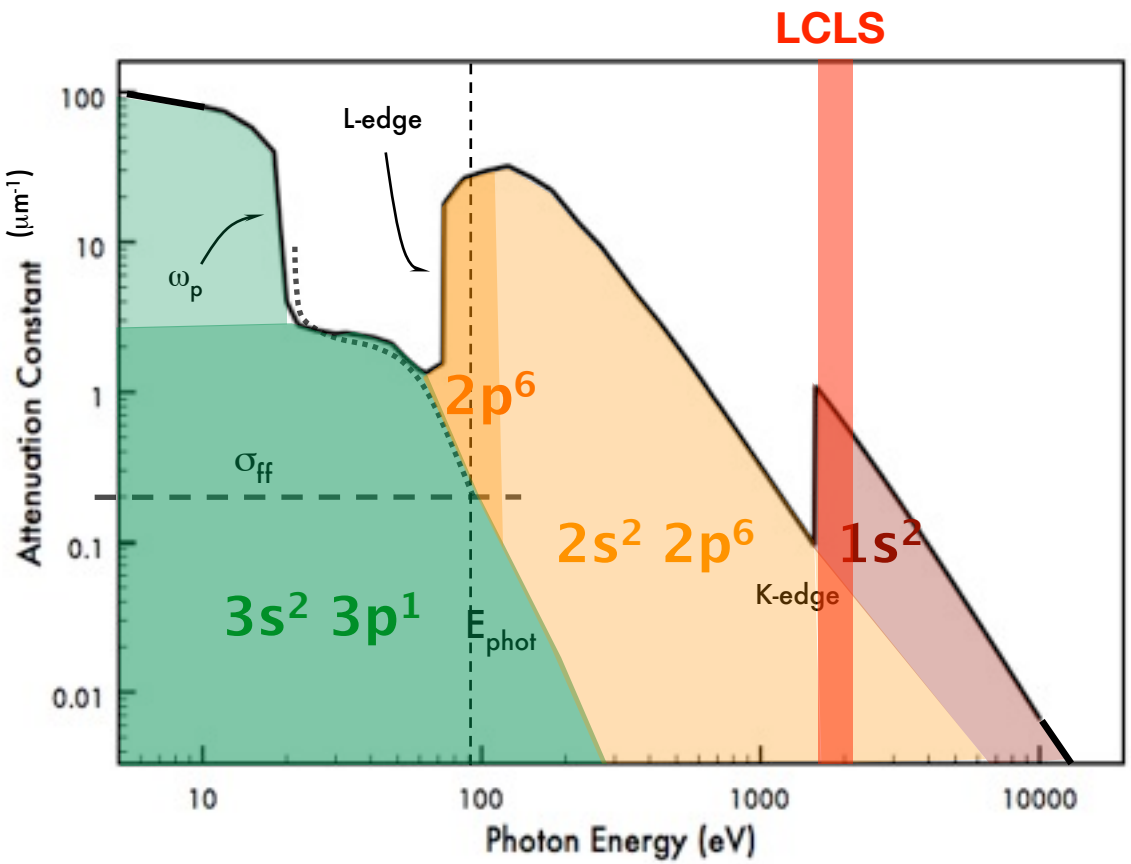

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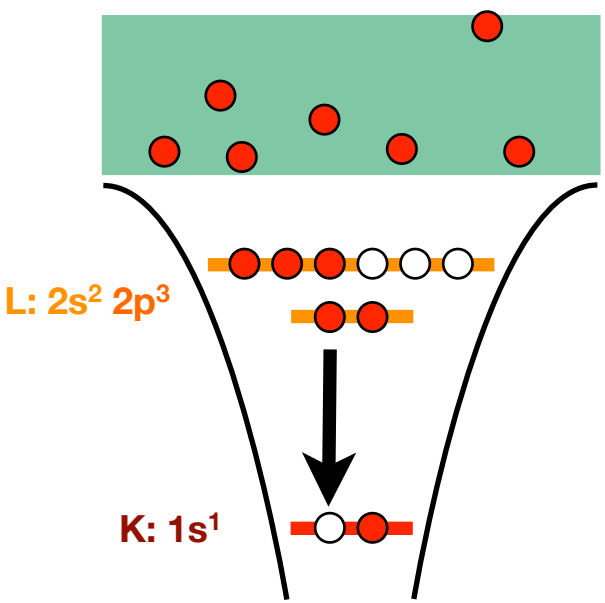
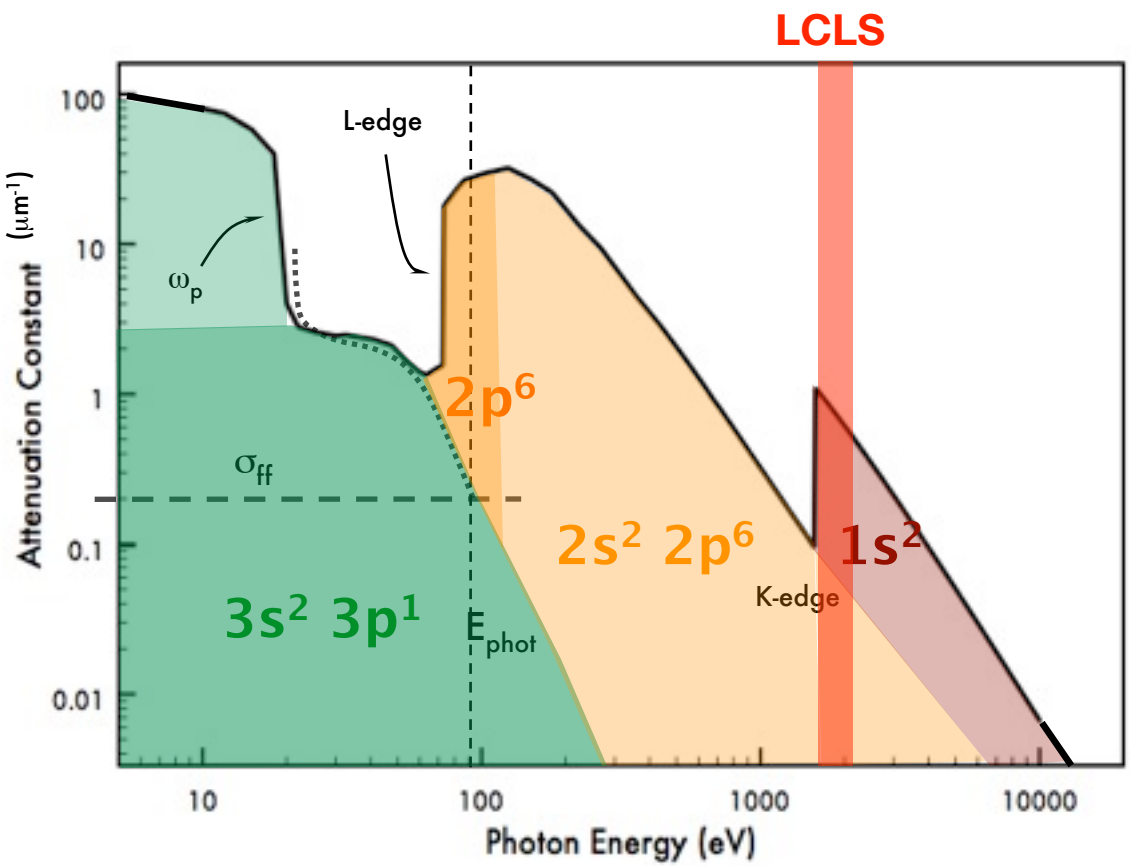
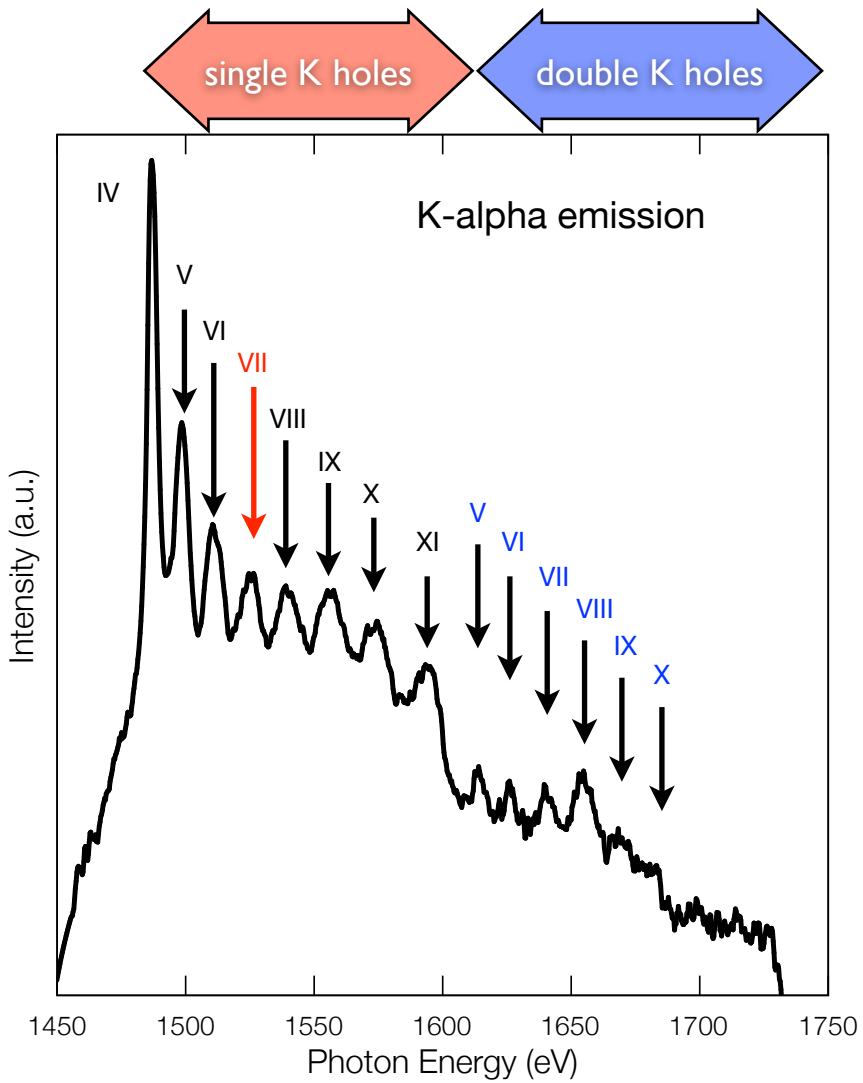
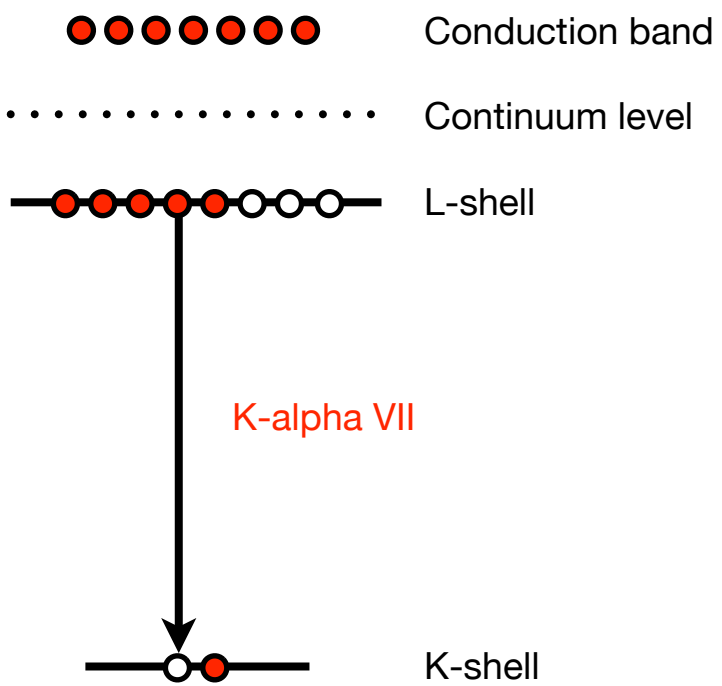




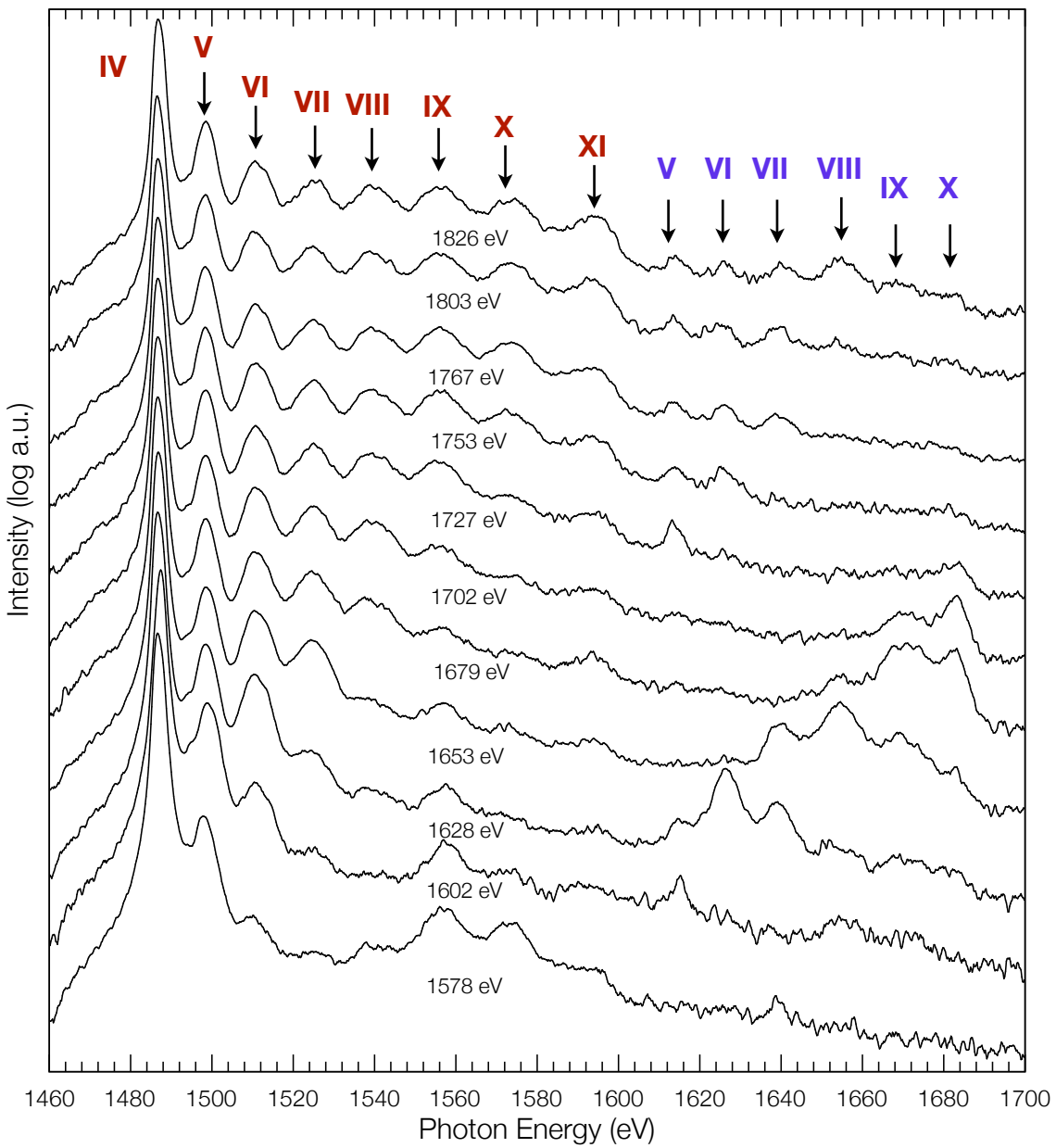


FEL photon energy: 1830 eV

Physical recombination process



K-shell spectroscopy of Hot Dense Aluminium



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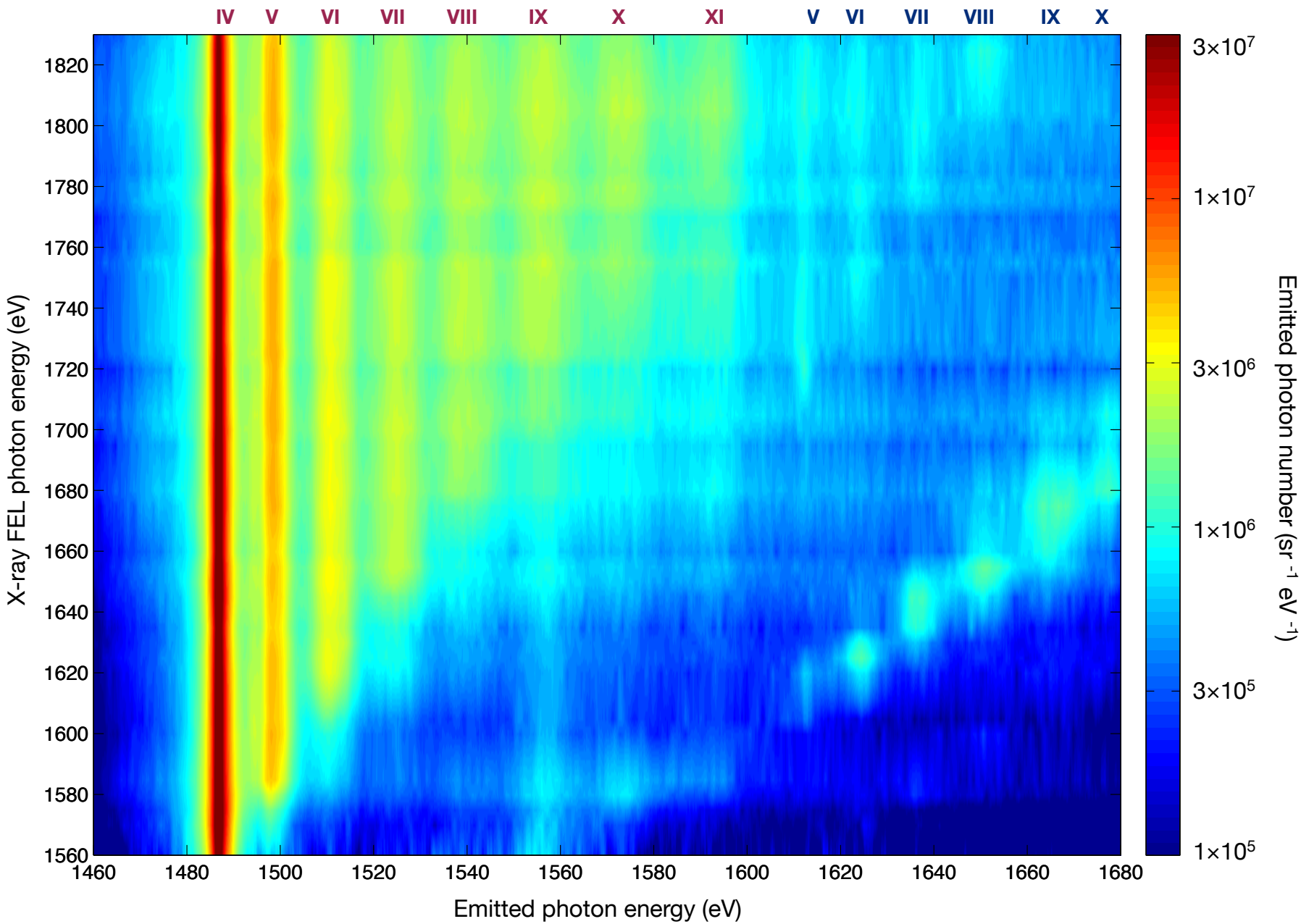
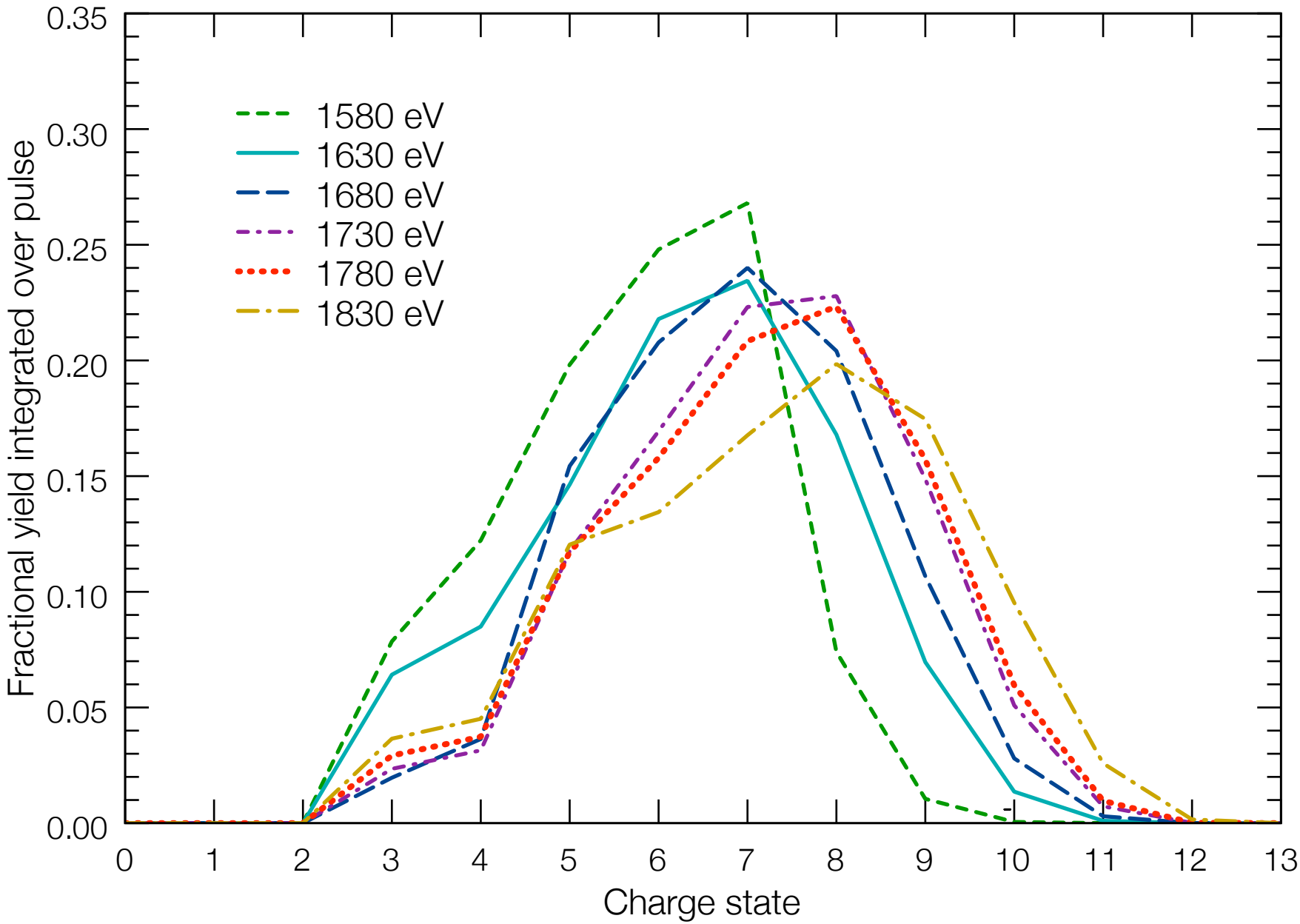
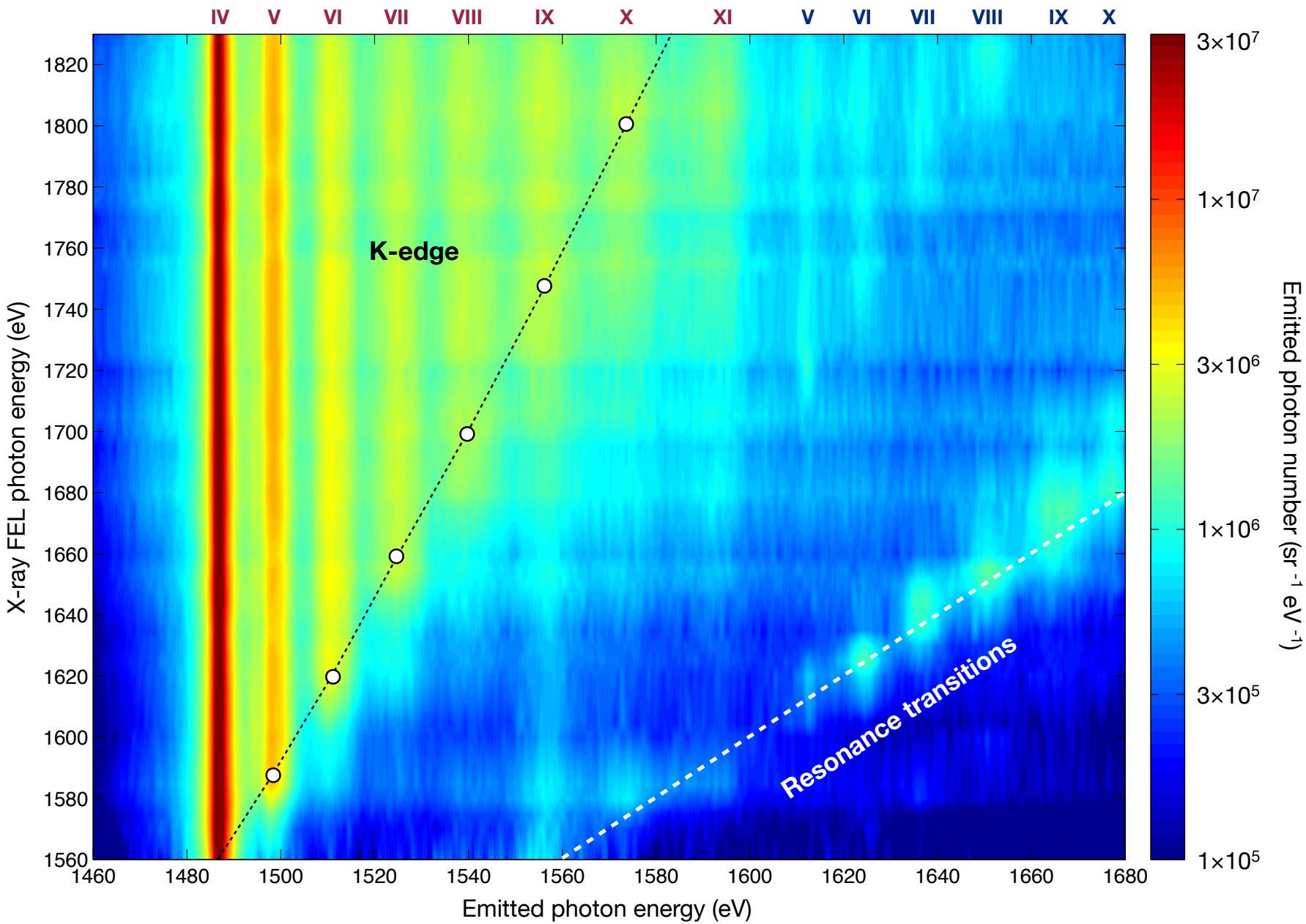



0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Fractional yield integrated over pulse
1580 eV
1630 eV
1680 eV
1730 eV
1780 eV
1830 eV
0
1
2
3
4
5
6
7
8
9
10
11
12
13
Charge state


IV
V
VI
VII
VIII
IX
X
XI
V
VI
VII
VIII
IX
X
K-edge
Resonance transitions
X-ray FEL photon energy (eV)
Emitted photon energy (eV)
Emitted photon number (sr -1 eV -1)
1820
1800
1780
1760
1740
1720
1700
1680
1660
1640
1620
1600
1580
1560
1460
1480
1500
1520
1540
1560
1580
1600
1620
1640
1660
1680
3×10^7
1×10^7
3×10^6
1×10^6
3×10^5
1×10^5

Phase Contrast imaging of Shockwaves is solids

At TUD

Andreas Schropp
Christian Schroer
Robert Hoppe
Vivienne Meier
Jens Patommel
Dirk Samberg
Frank Seiboth

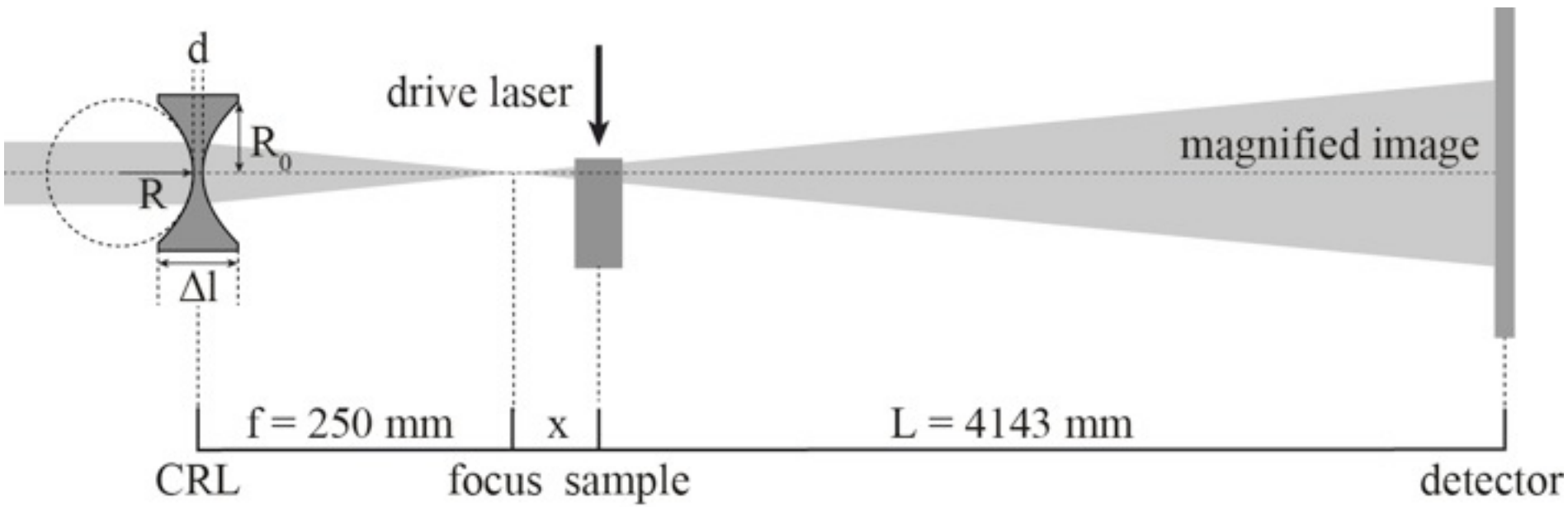
At SLAC

Jerry Hastings
Brice Arnold
Eric Galtier
Hae Ja Lee
Bob Nagler

At LLNL

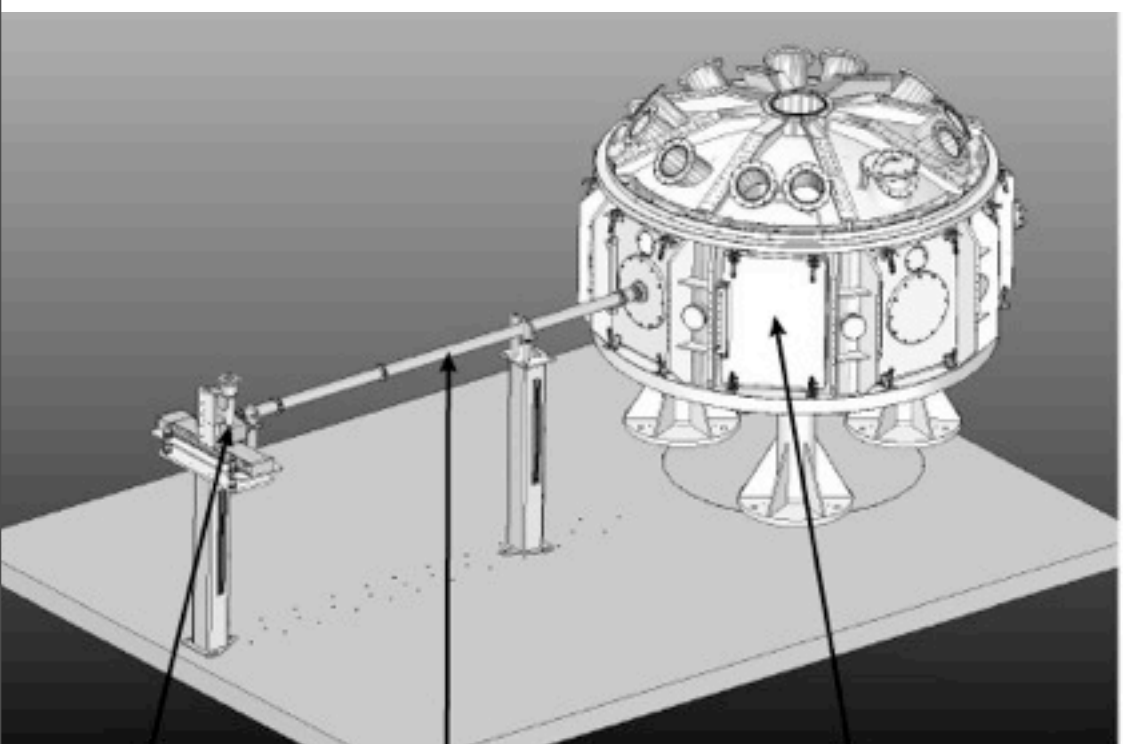
Rip Collins
Damian Hicks
Yuan Ping

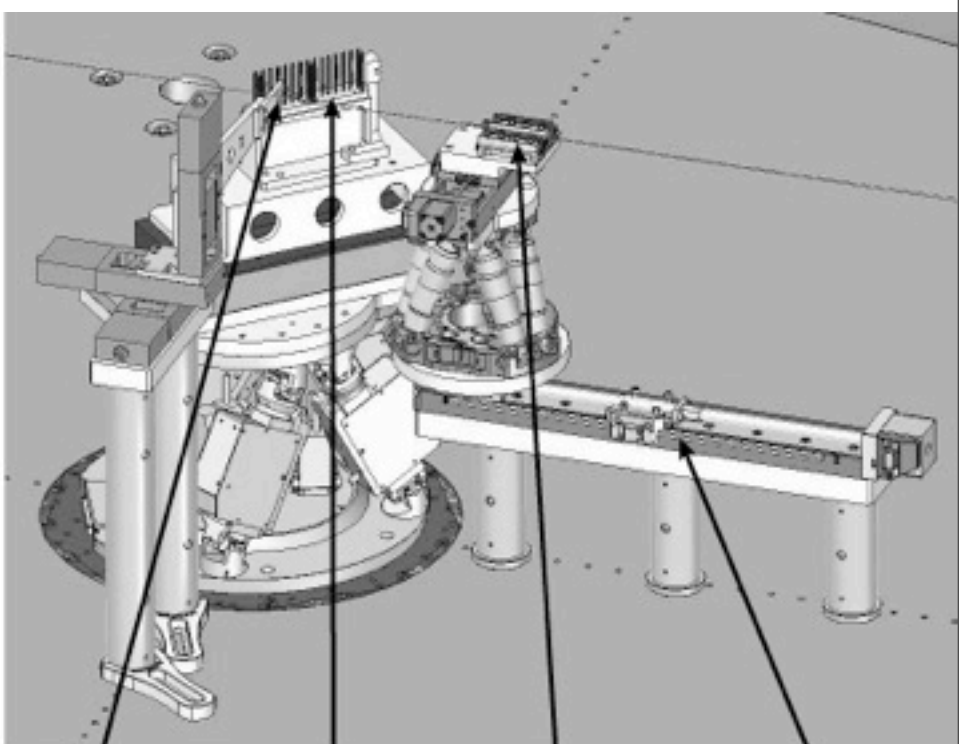
High-Resolution X-Ray Phase Contrast Imaging



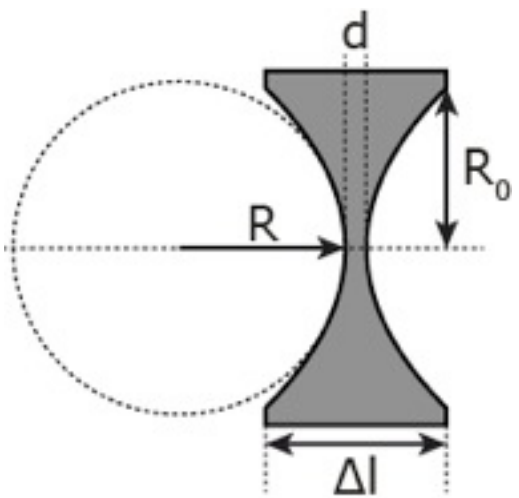
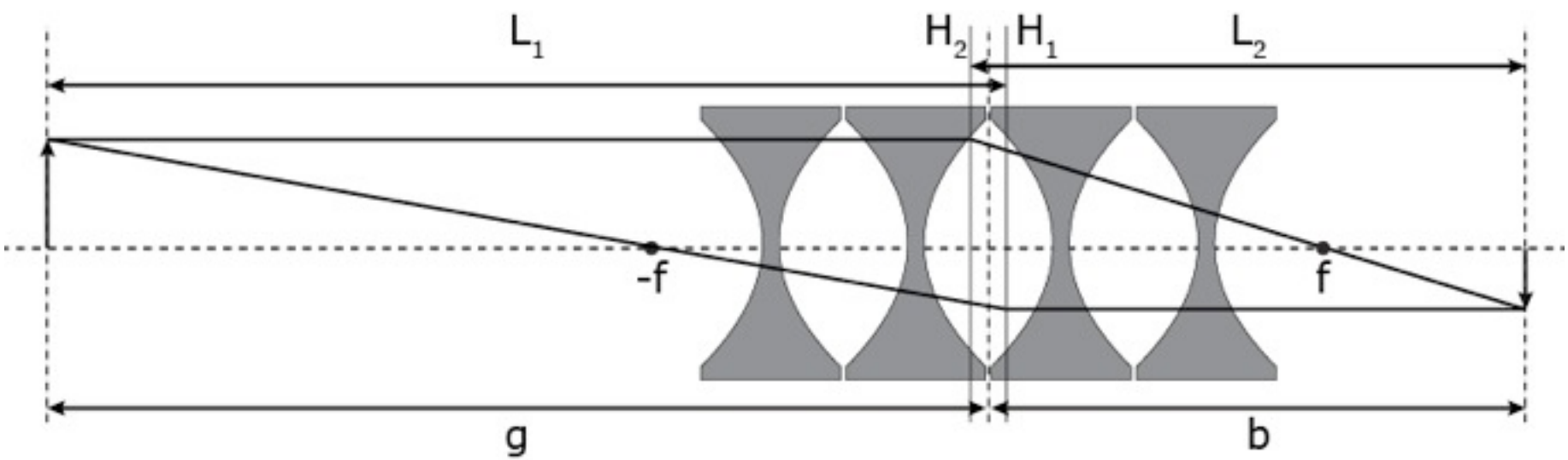
- imaging with secondary point source: efficient use of fluence
- phase contrast: for quantitative results, phase retrieval required

MEC Setup


detector
flight tube
MEC-vacuum chamber


pinhole
sample
Be-CRLs
linear stage

Focusing by Be-CRLs

Stack of N=20 Be-CRLs (R = 50µm, R_0=150µm):

- f = 250mm (~L_2)
- diffraction limited spot size of d_t = 114nm
- FOV ~ 100µm