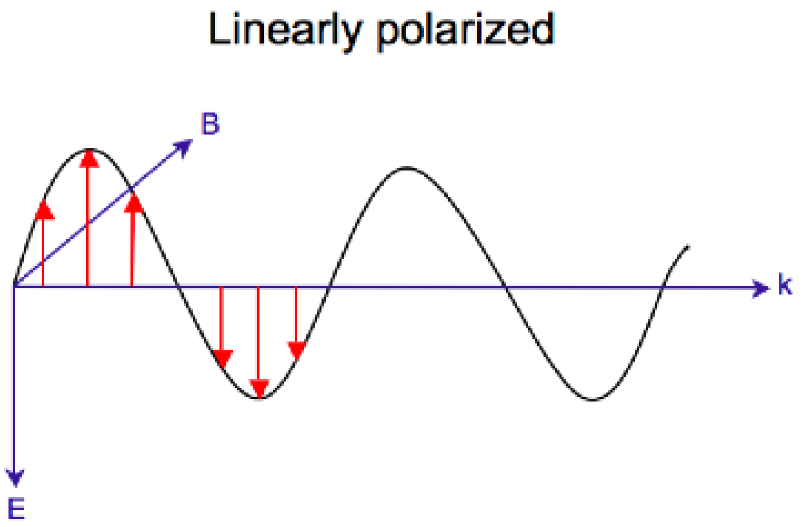
X-ray magnetic circular dichroism (XMCD)

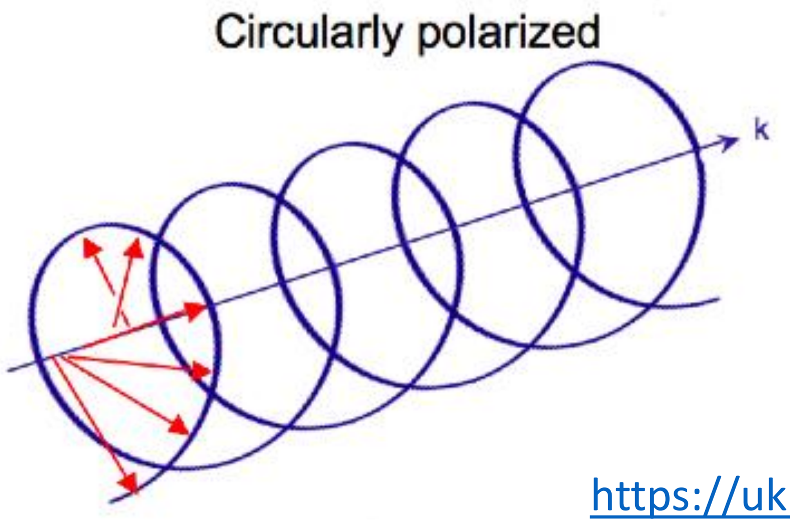
Дихроїзм / Dichroism

— різне поглинання світла речовиною залежно від його **поляризації** (анізотропія поглинання).

Оскільки поглинання світла залежить і від довжини хвилі, дихроїчні речовини по-різному забарвлюються при спостереженні з різних напрямків.

Розрізнюють **лінійний**, **круговий** (еліптичний) дихроїзми.



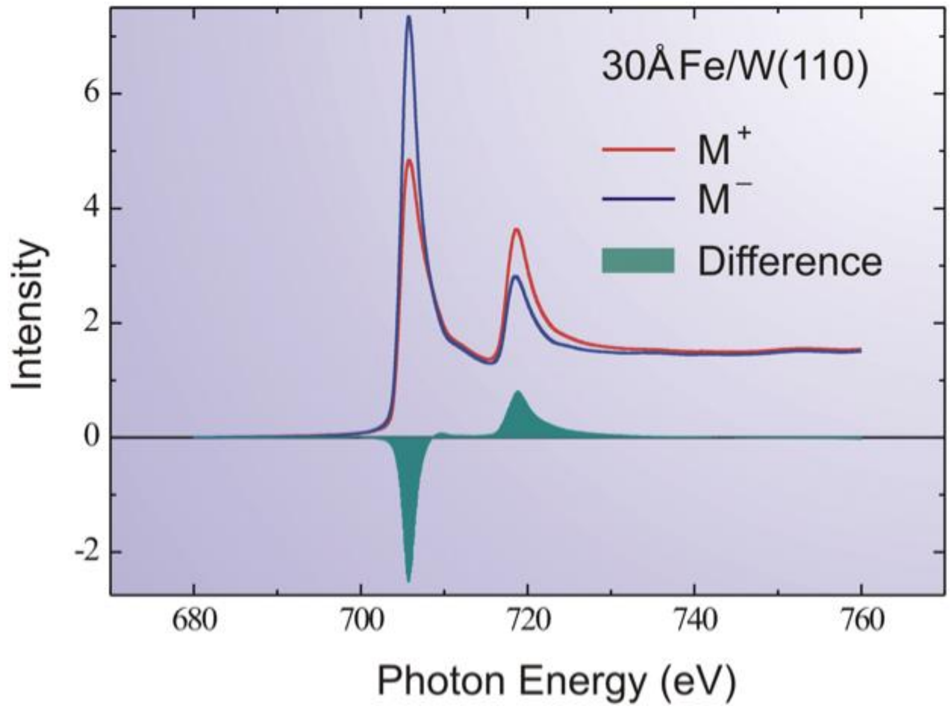


https://uk.wikipedia.org/wiki/Дихроїзм

To read

- Joachim Stohr. NEXAFS spectroscopy https://www-ssrl.slac.stanford.edu/stohr/nexafs.htm
- Joachim Stohr. Magnetic Dichroism Spectroscopy and Micrpscopy https://www-ssrl.slac.stanford.edu/stohr/xmcd.htm / *IBM J. Res. Develop.* **44**, 535 (2000) / *JMMM* **200**, 470 (1999).

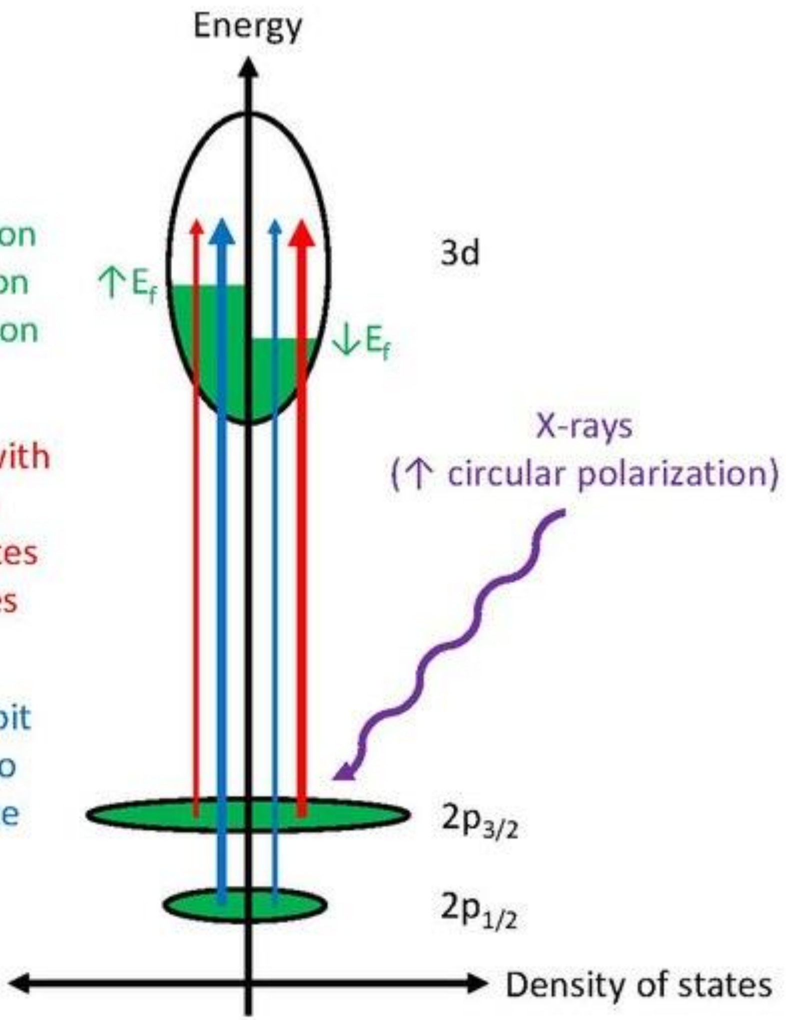
X-ray magnetic circular dichroism (XMCD)



A magnetic field applied in the ↑ direction aligns valence electrons in the ↑ direction leaving more hole states in the ↓ direction

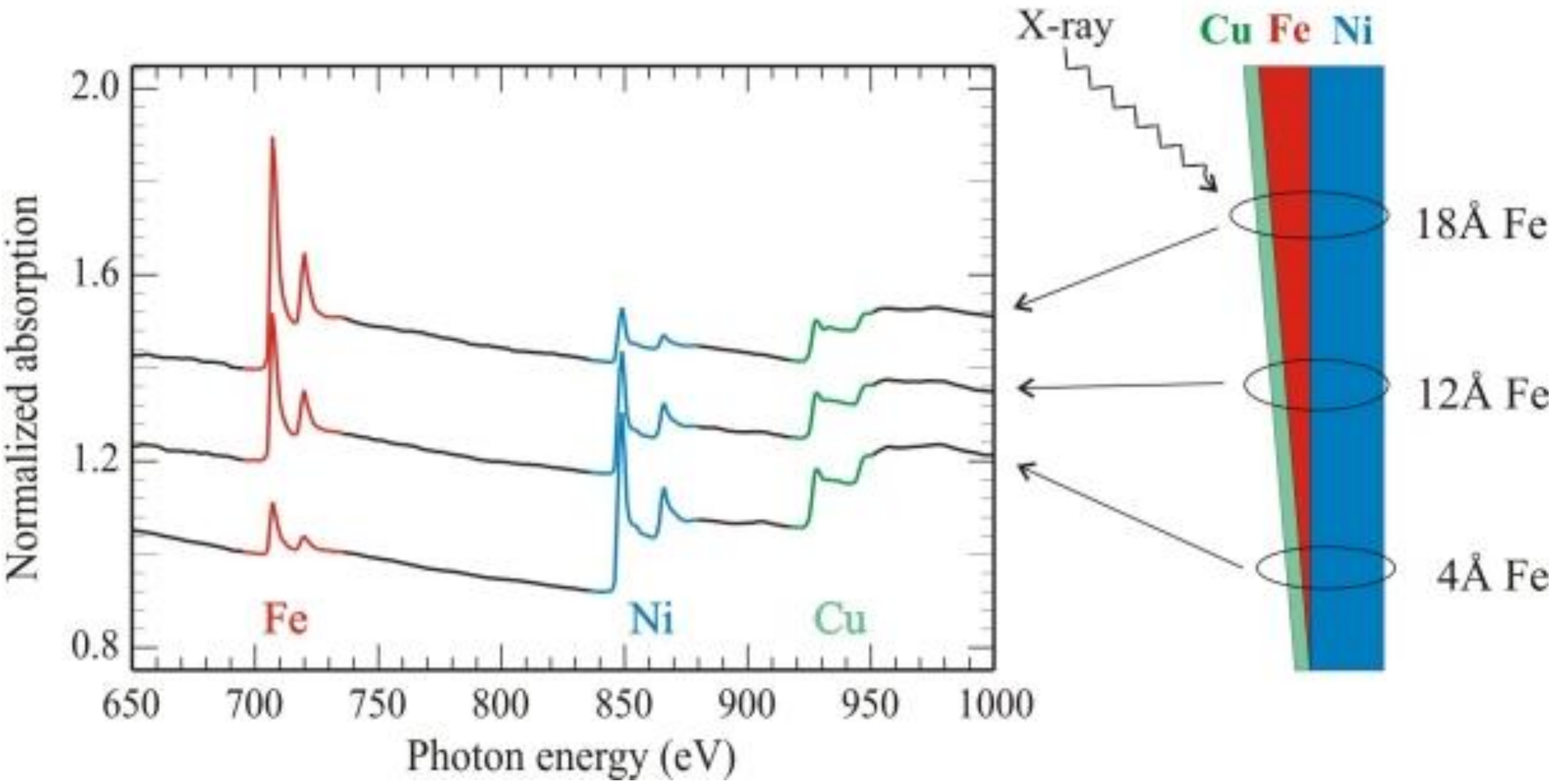
For the L_3 transition ($2p_{3/2}$→3d), X-rays with ↑ circular polarization are more likely to excite spin ↓ electrons into the hole states than spin ↑ electrons into the hole states

For the L_2 transition ($2p_{1/2}$→3d), spin-orbit coupling is opposite (l-s instead of l+s), so the excitation's spin sensitivity is opposite



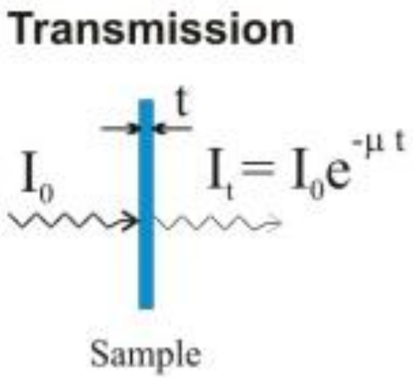
https://en.wikipedia.org/wiki/X-ray_magnetic_circular_dichroism

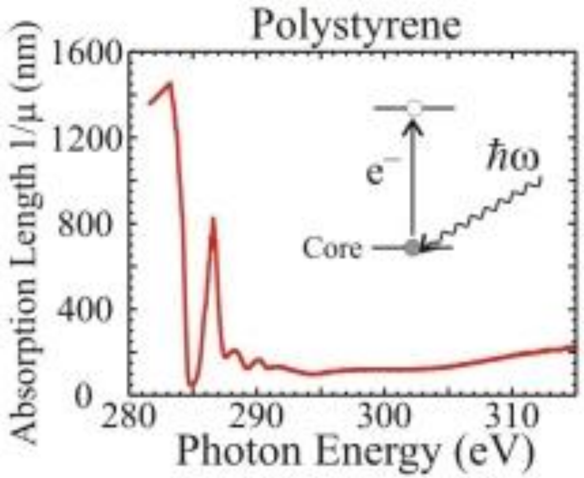
X-ray absorption spectroscopy

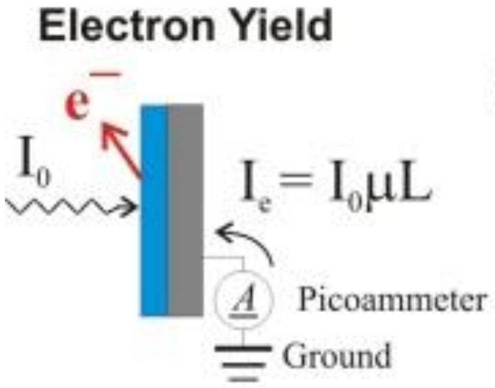


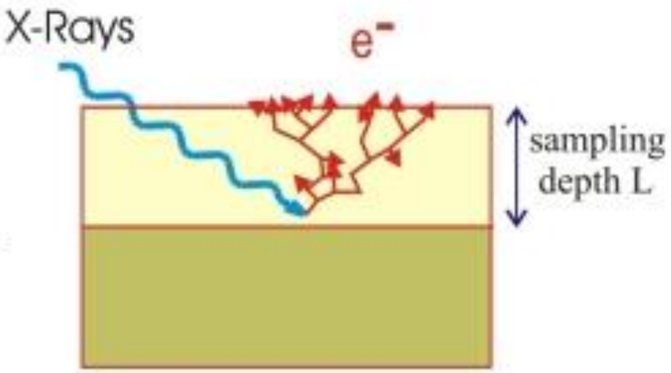
https://www-ssrl.slac.stanford.edu/stohr/xmcd.htm

Near Edge X-Ray Absorption Fine Structure spectroscopy (NEXAFS) / X-Ray Absorption Near Edge Structure (XANES)



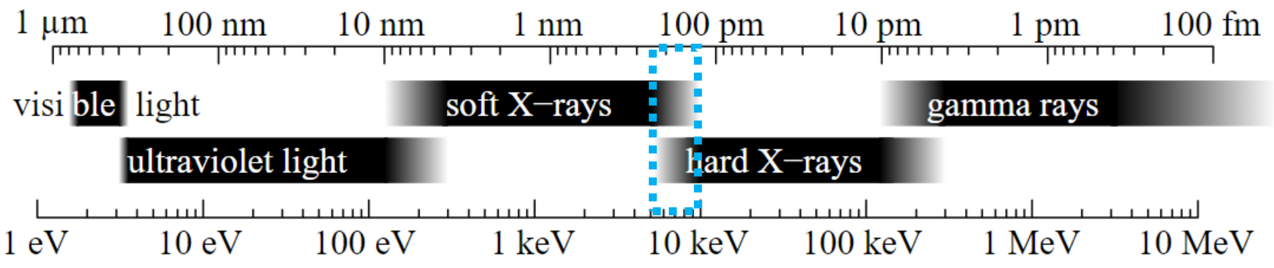




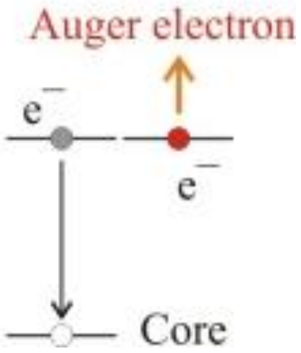


NEXAFS - soft x-ray

XANES - hard x-ray

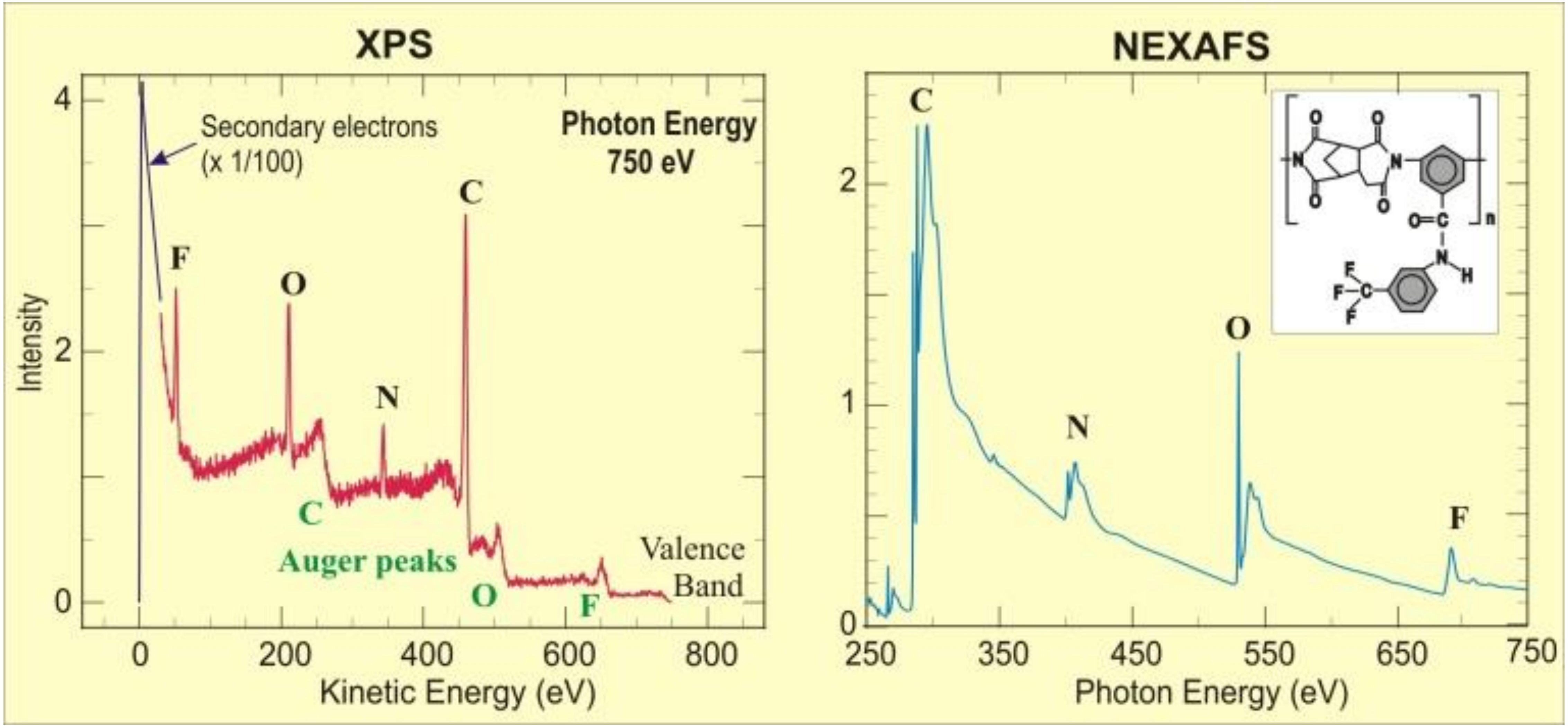


5–10 keV



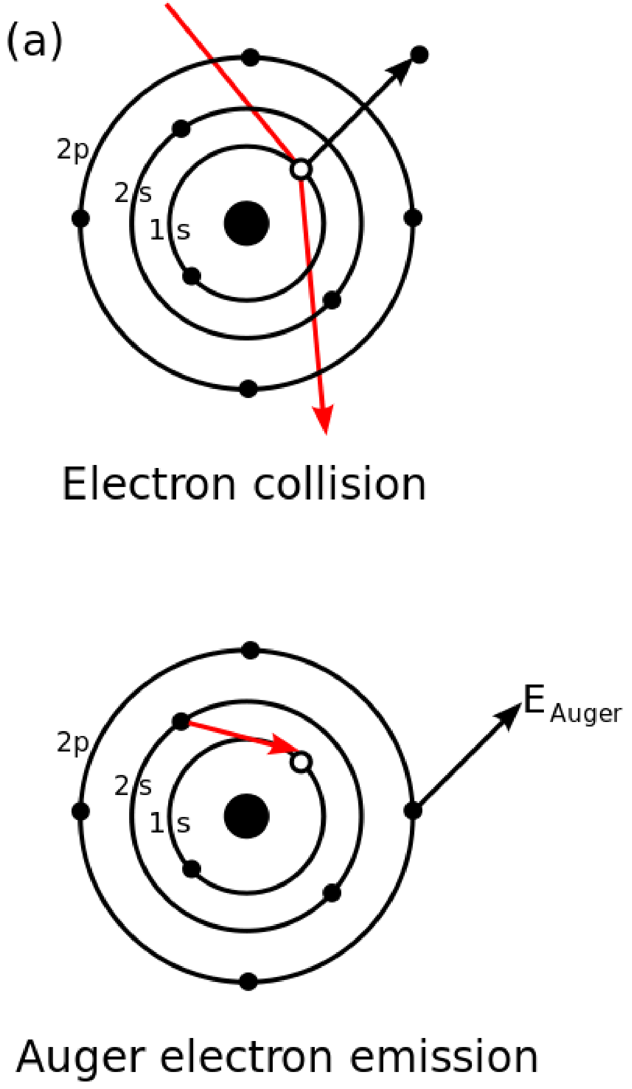
https://www-ssrl.slac.stanford.edu/stohr/nexafs.htm

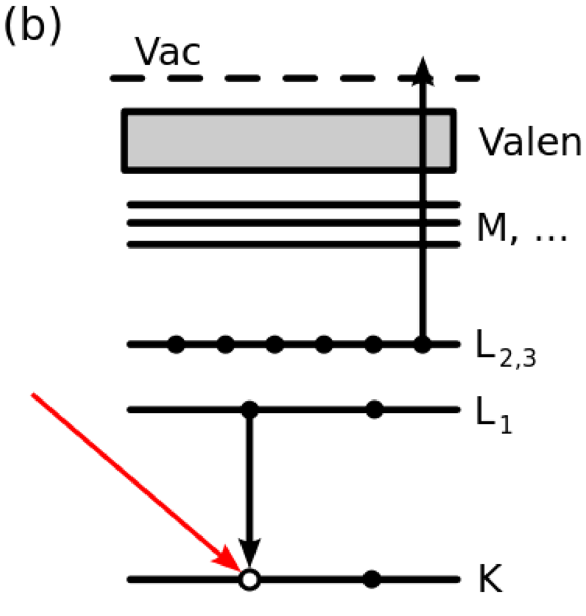
Near Edge X-Ray Absorption Fine Structure spectroscopy



https://www-ssrl.slac.stanford.edu/stohr/nexafs.htm

to remind: Auger electron spectroscopy





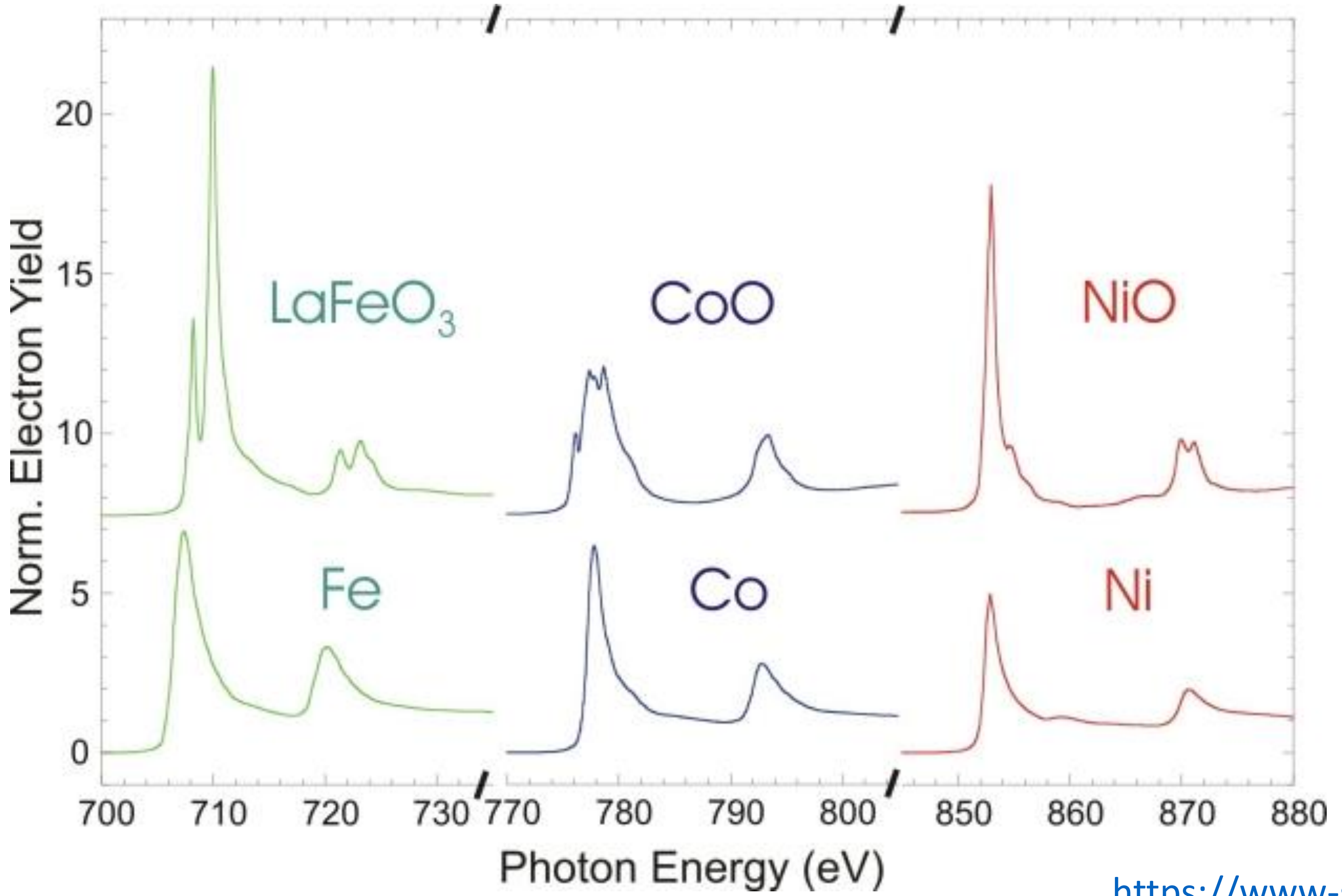
$$KL_1L_{2,3}$$

X-ray notation

Quantum numbers				Atomic notation	X-ray notation
n	ℓ	s	j		
1	0	1/2	1/2	$1S_{1/2}$	K_1
2	0	1/2	1/2	$2S_{1/2}$	L_1
2	1	1/2	1/2	$2P_{1/2}$	L_2
2	1	1/2	3/2	$2P_{3/2}$	L_3
3	0	1/2	1/2	$3S_{1/2}$	M_1
3	1	1/2	1/2	$3P_{1/2}$	M_2
3	1	1/2	3/2	$3P_{3/2}$	M_3
3	2	1/2	3/2	$3D_{3/2}$	M_4
3	2	1/2	5/2	$3D_{5/2}$	M_5

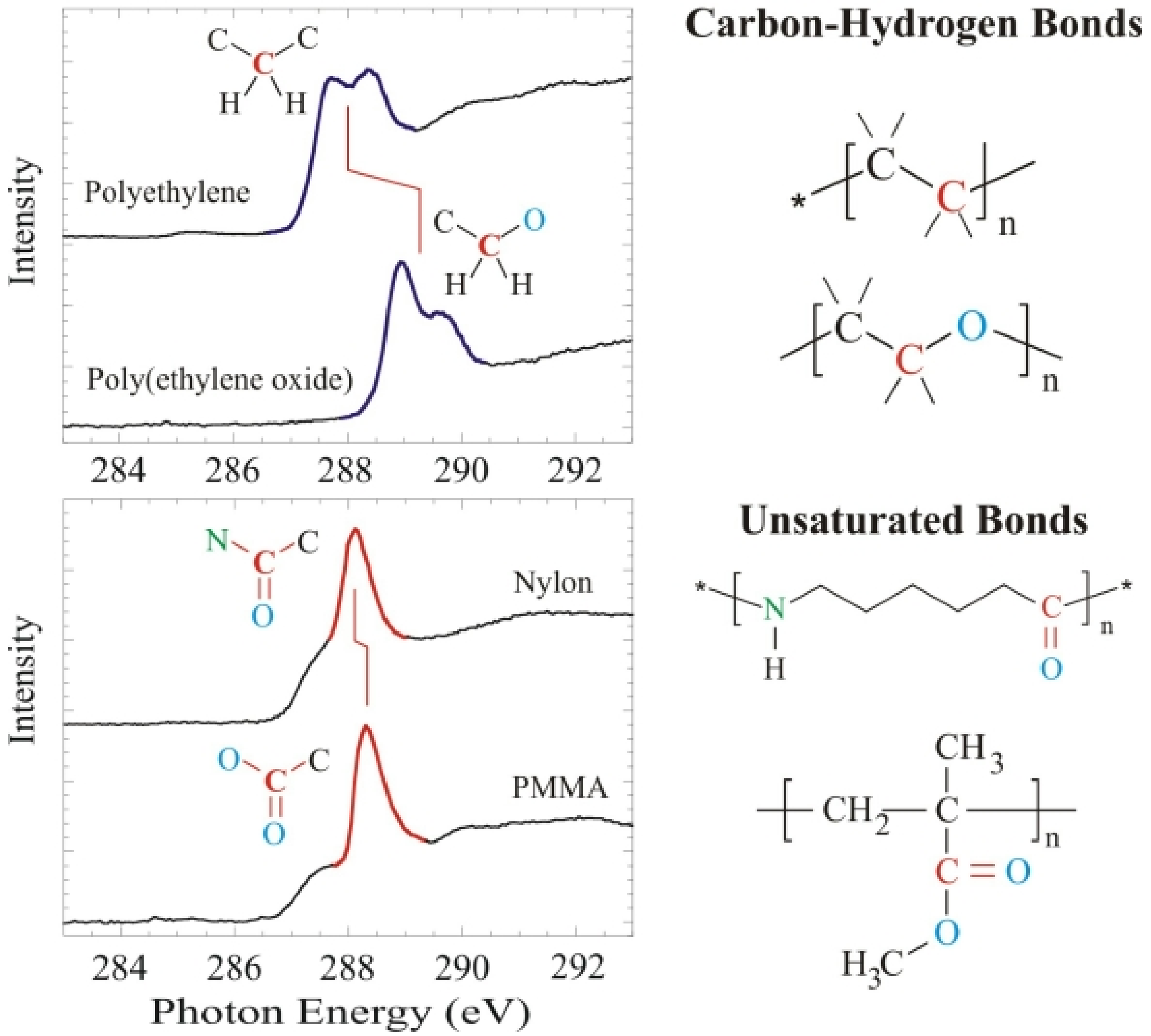
https://en.wikipedia.org/wiki/Auger_electron_spectroscopy

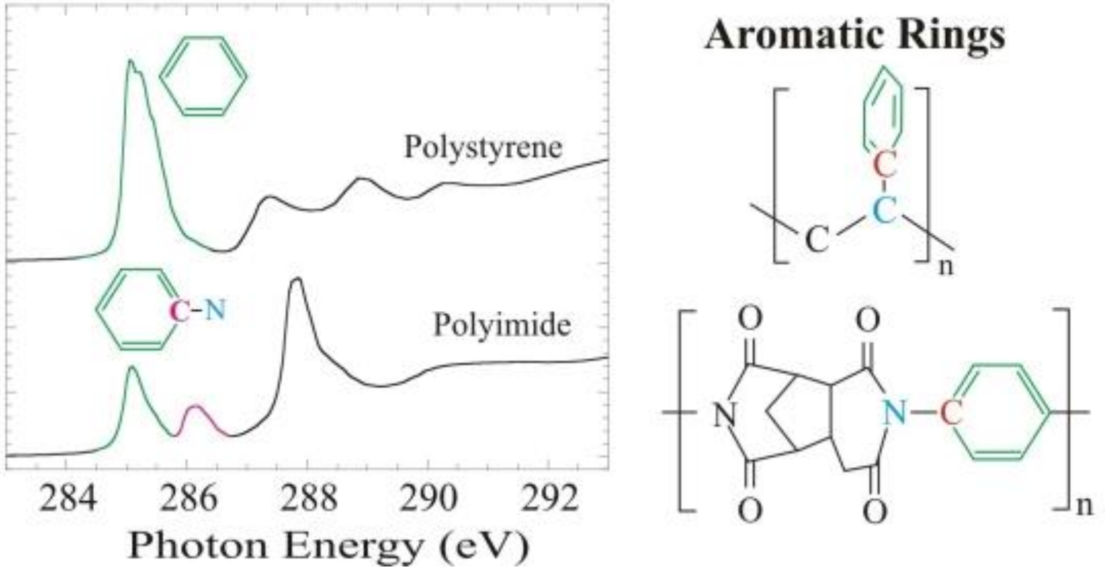
X-ray magnetic circular dichroism (XMCD)



https://www-ssrl.slac.stanford.edu/stohr/xmcd.htm

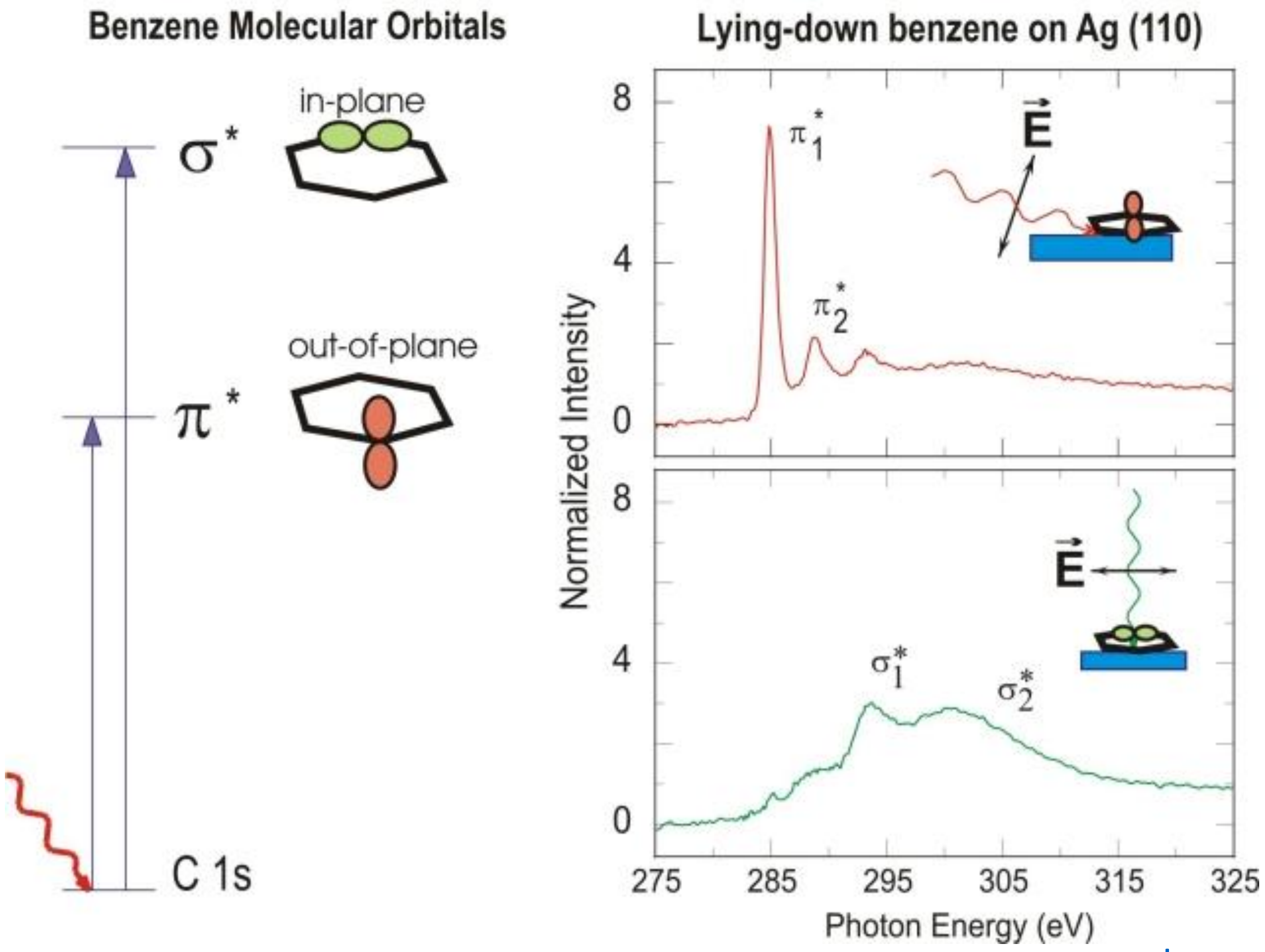
Carbon K-edge NEXAFS spectra





https://www-ssrl.slac.stanford.edu/stohr/nexafs.htm

Polarization dependent NEXAFS spectra of benzene chemisorbed on Ag(110)

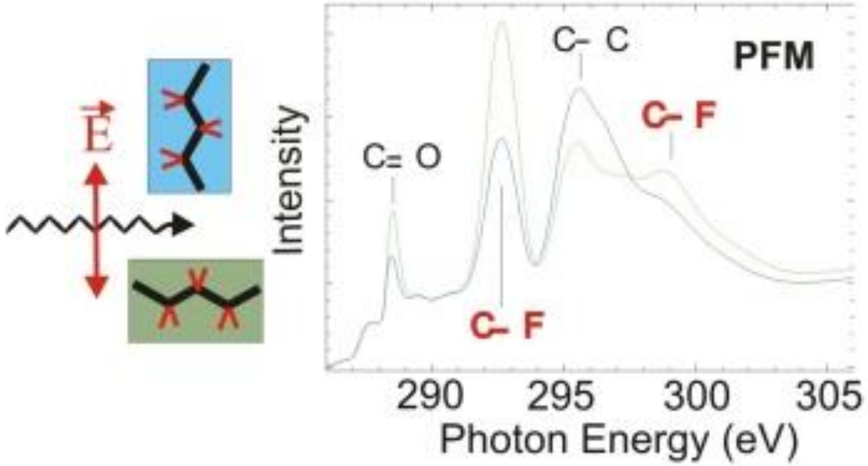


https://www-ssrl.slac.stanford.edu/stohr/nexafs.htm

XLD

X-ray Linear Dichroism

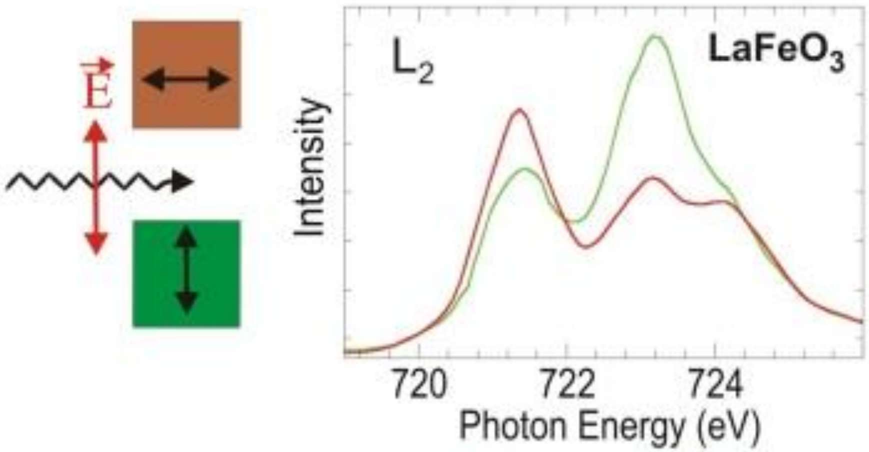
Stöhr *et al.*, Phys. Rev. Lett. **47**, 381 (1981)



XMLD

X-ray Magnetic Linear Dichroism

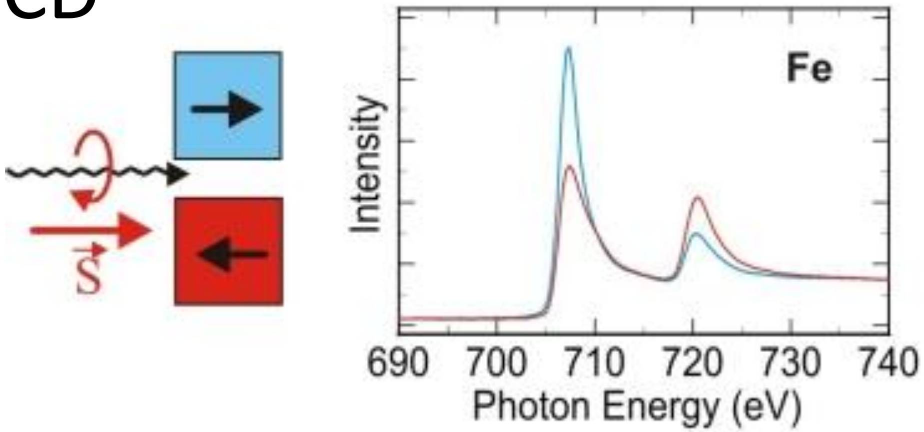
Van der Laan *et al.*, Phys. Rev. B **34**, 6529 (1986)



XMCD

X-ray Magnetic Circular Dichroism

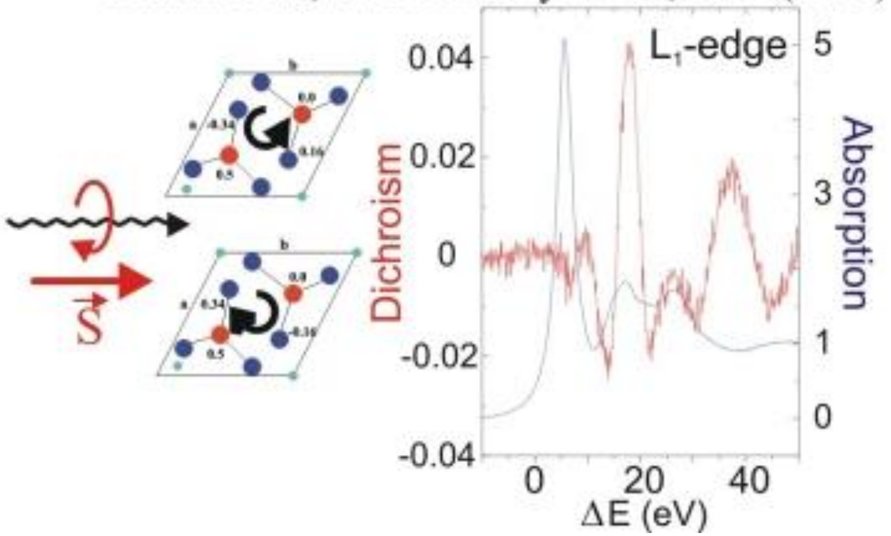
Schütz *et al.*, Phys. Rev. Lett. **58**, 737 (1987)



XCD

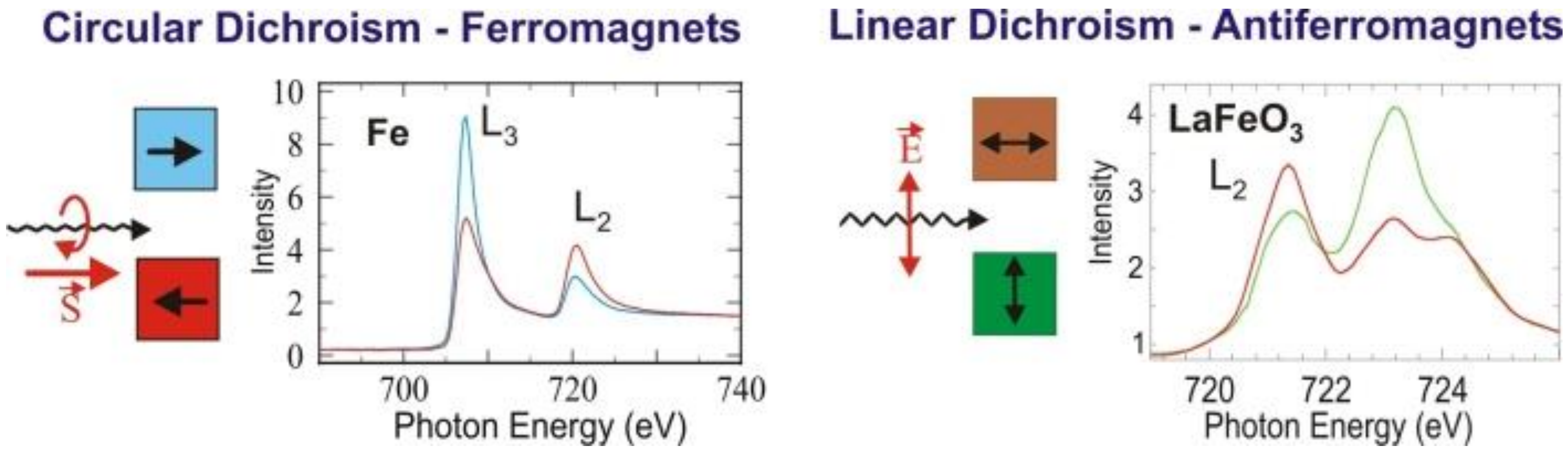
X-ray Natural Circular Dichroism

Goulon *et al.*, J. Chem. Phys. **108**, 6394 (1998)



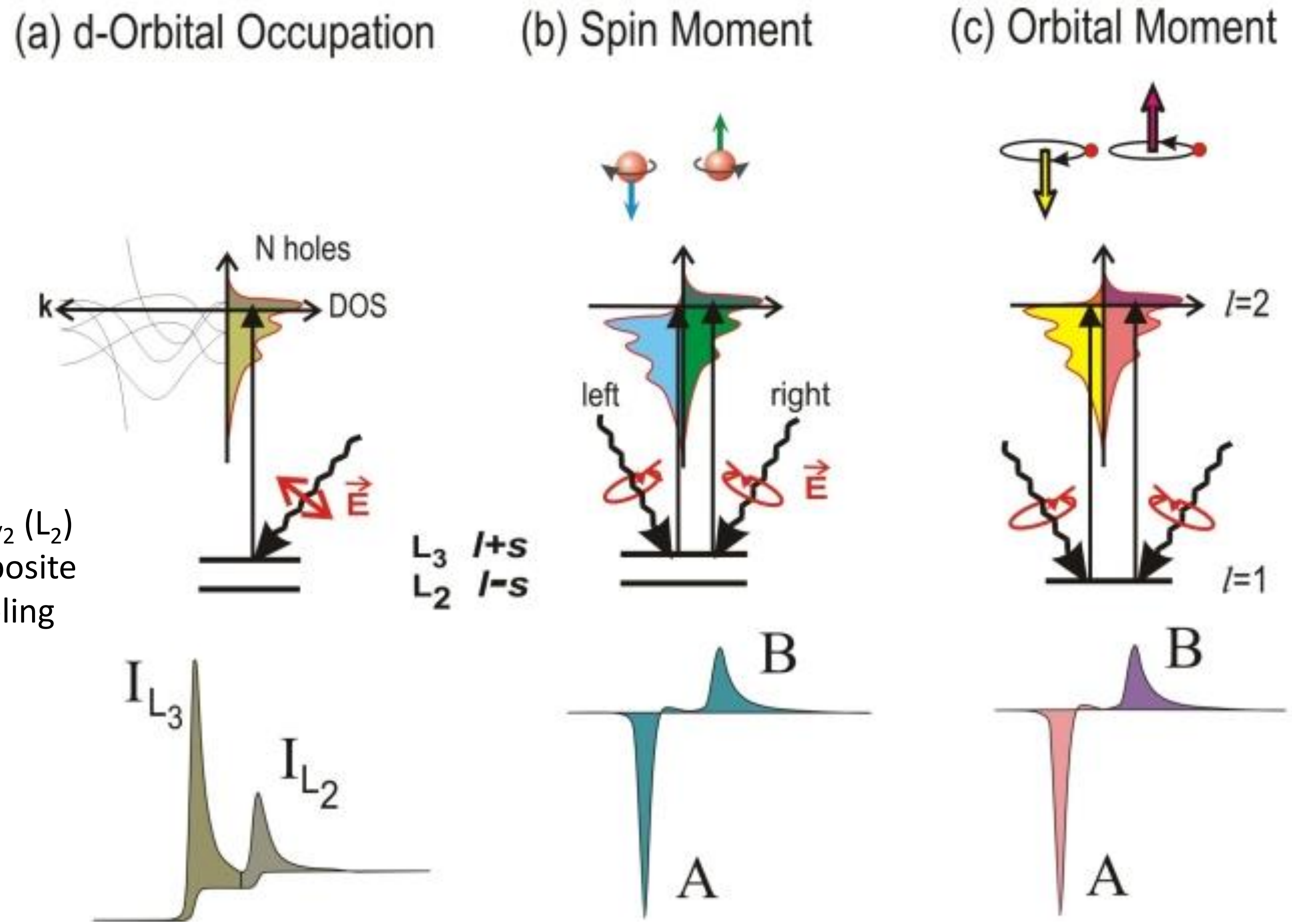
https://www-ssrl.slac.stanford.edu/stohr/nexafs.htm

X-ray magnetic circular dichroism (XMCD)



https://www-ssrl.slac.stanford.edu/stohr/xmcd.htm

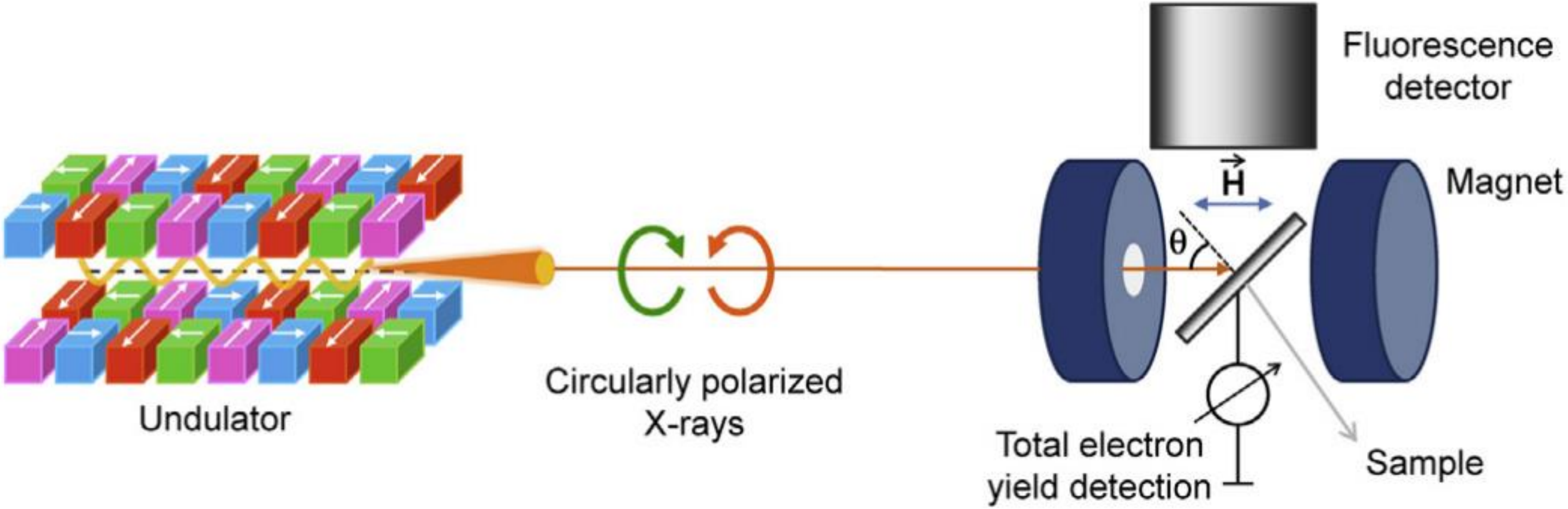
XMCD



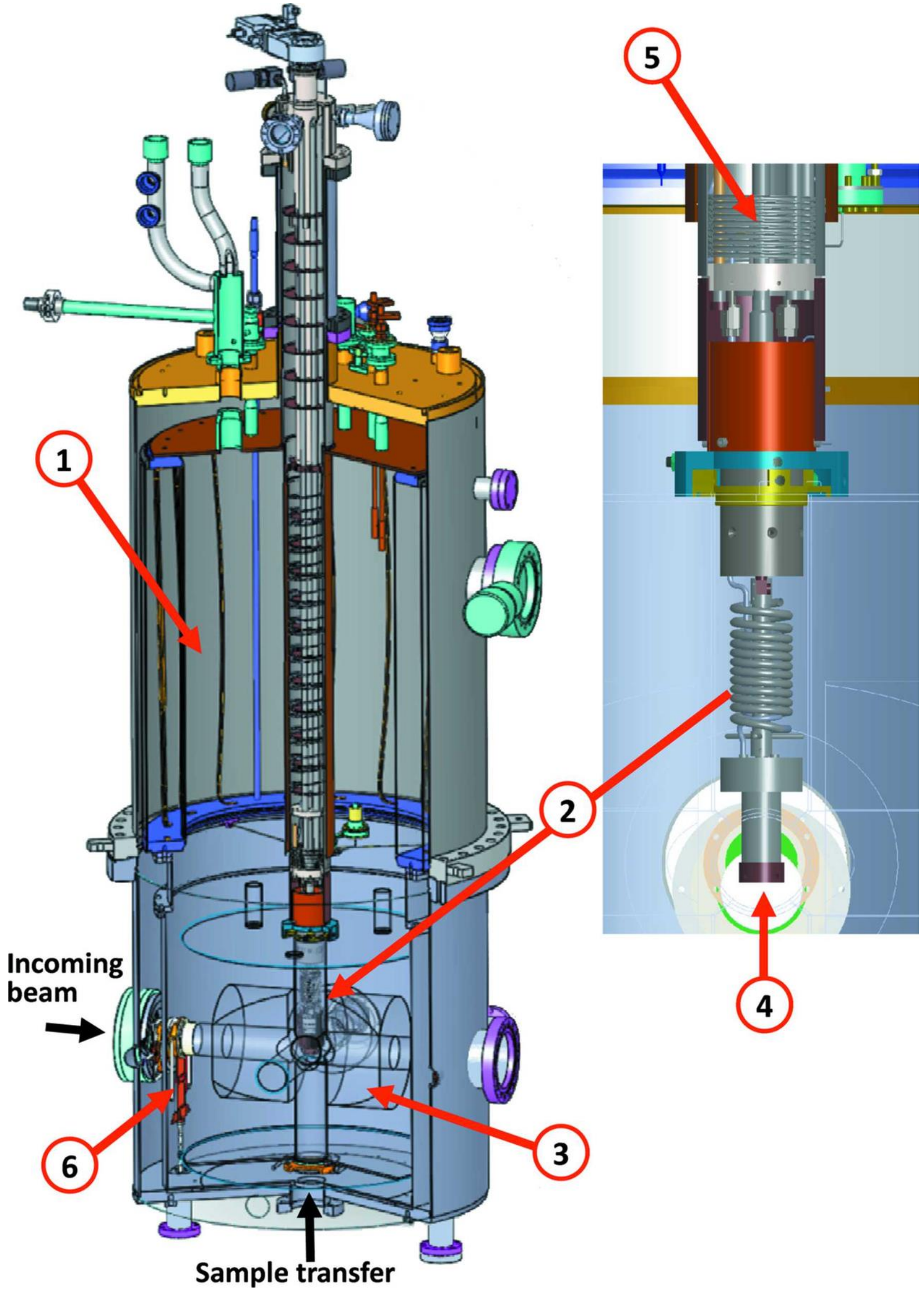
$p_{3/2}$ (L_3) and $p_{1/2}$ (L_2) levels have opposite spin-orbit coupling

https://www-ssrl.slac.stanford.edu/stohr/xmcd.htm

XMCD



https://doi.org/10.1016/j.ccr.2014.03.018



XMCD at ultralow temperature

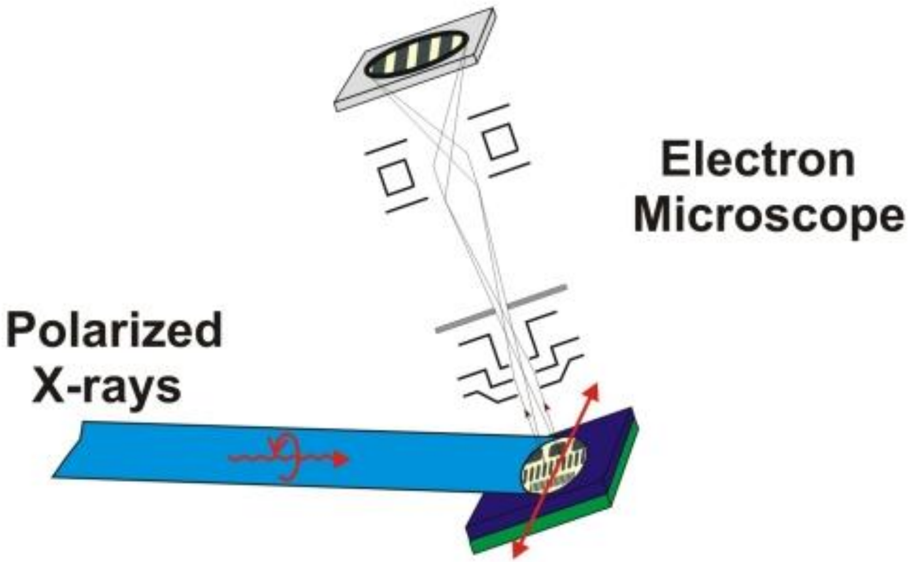
A new ultralow-temperature setup dedicated to soft X-ray absorption spectroscopy and XMCD on the DEIMOS beamline (SOLEIL synchrotron). T = 220 mK.

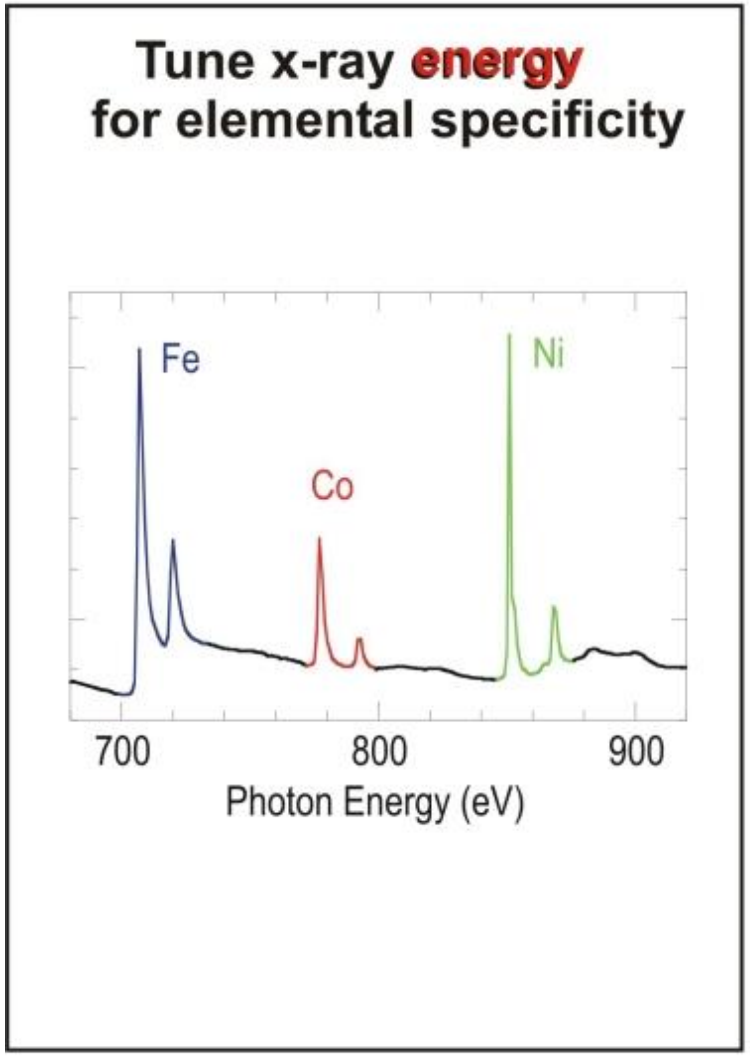
(1) main He_{liq} tank, (2) ^3He–^4He dilution refrigerator, (3) cryomagnet, (4) sample, (5) 4 K tank used for pre-cooling and (6) 4 K thermal retractable shield. Black arrows: the sample-transfer and incoming beam axes. The total height is around 200 cm and the diameter is 60 cm. The diameter of the bottom part of the refrigerator is ∼50 mm.

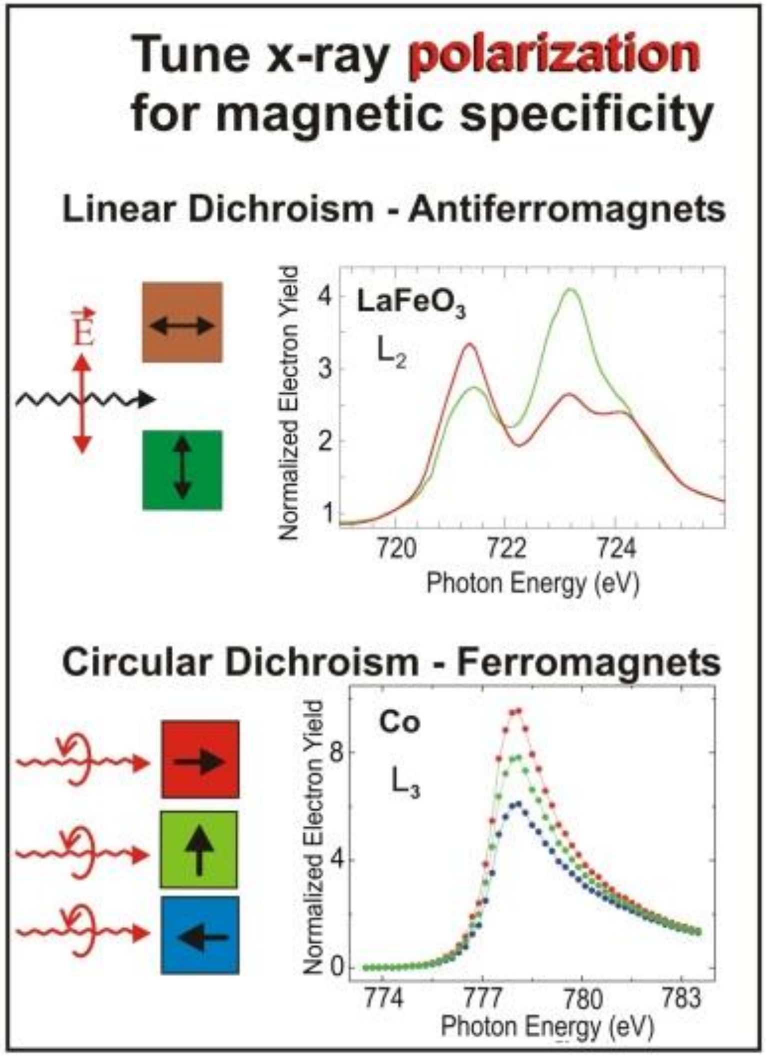
- **Kappler *et al.***
- **25** | 2018 | 1727–1735 | [10.11107/S1600577518012717](10.11107/S1600577518012717)

JSR Synchrotron JOURNAL OF SYNCHROTRON RADIATION

XMLD and XMCD by photoemission electron microscopy (PEEM)

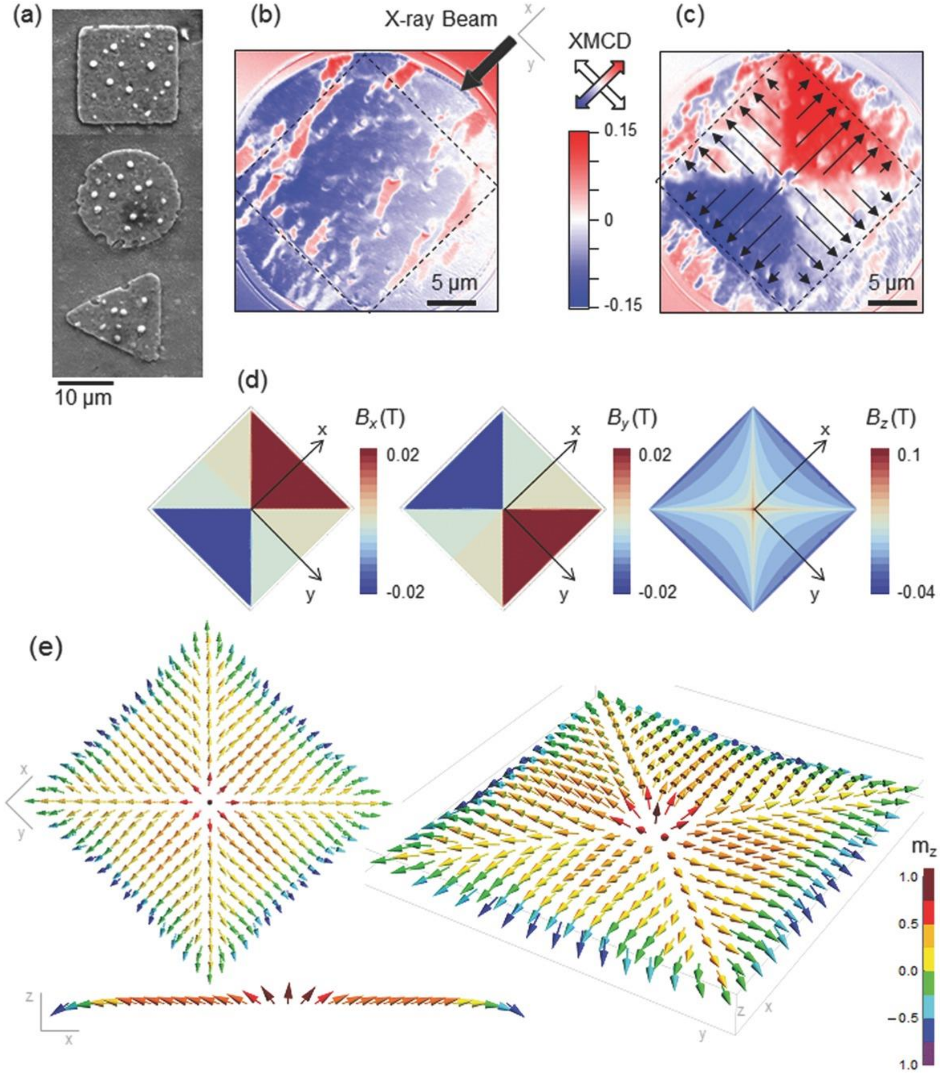


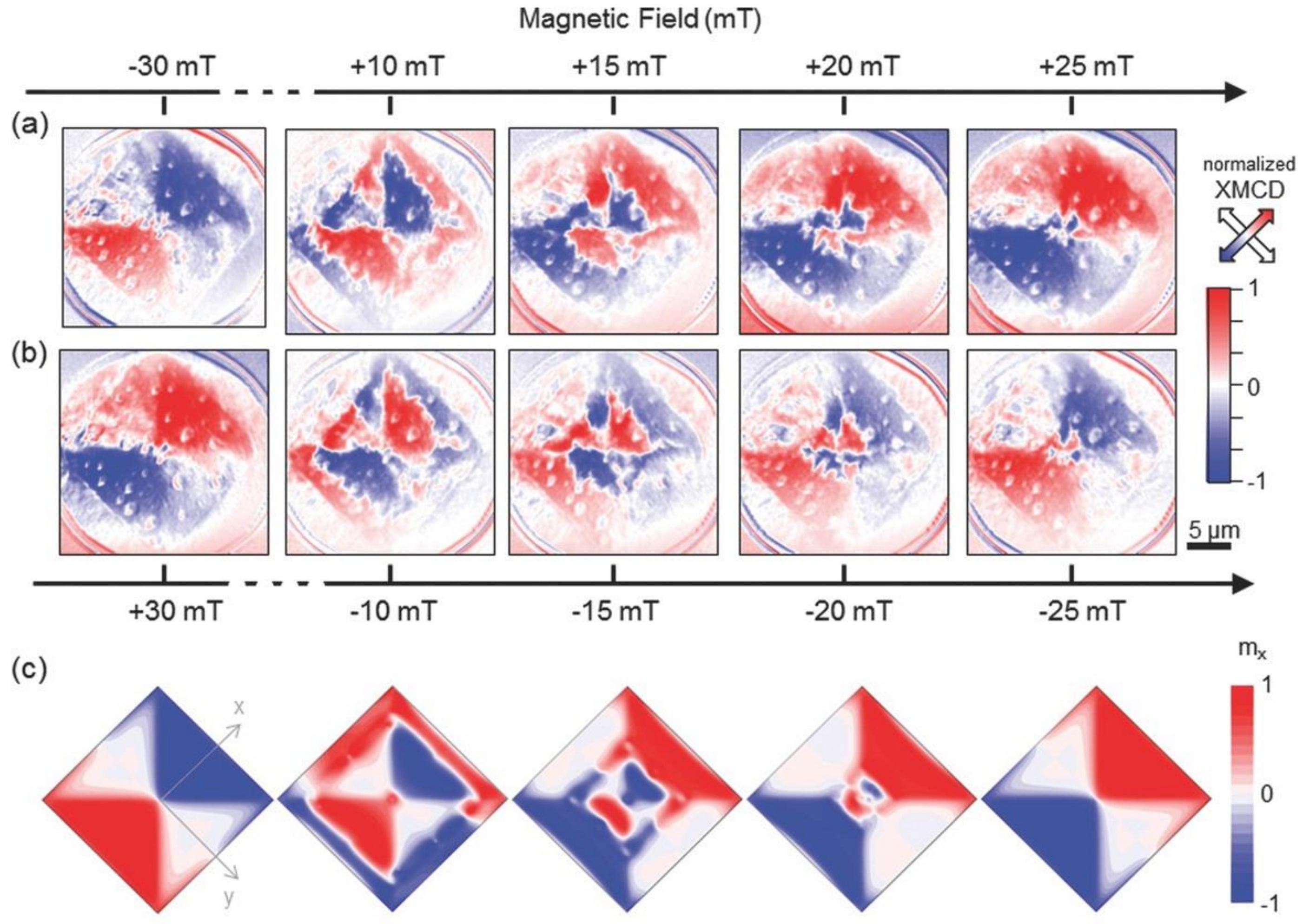




https://www-ssrl.slac.stanford.edu/stohr/xmcd.htm

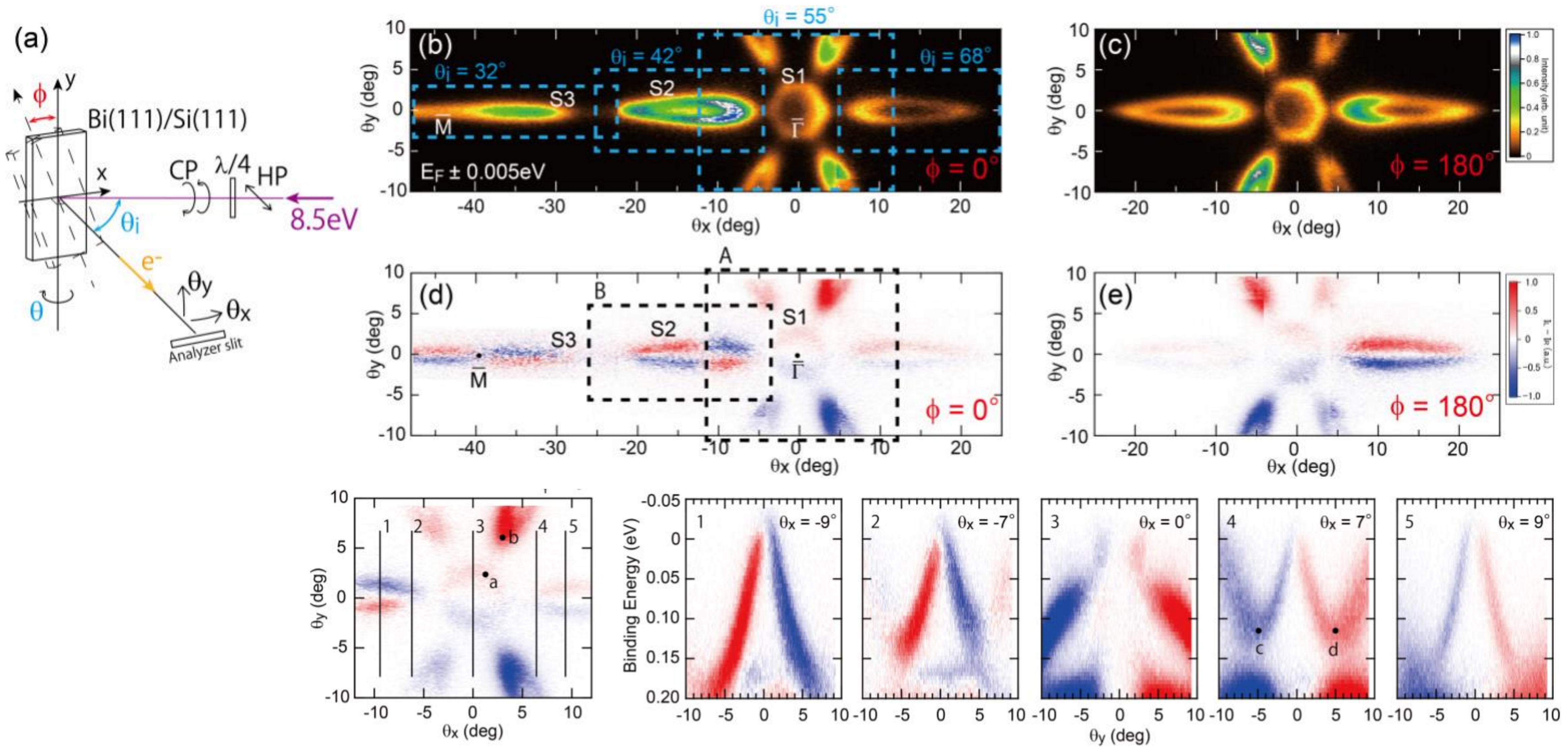
Encoding Magnetic States in Monopole-Like Configurations Using Superconducting Dots



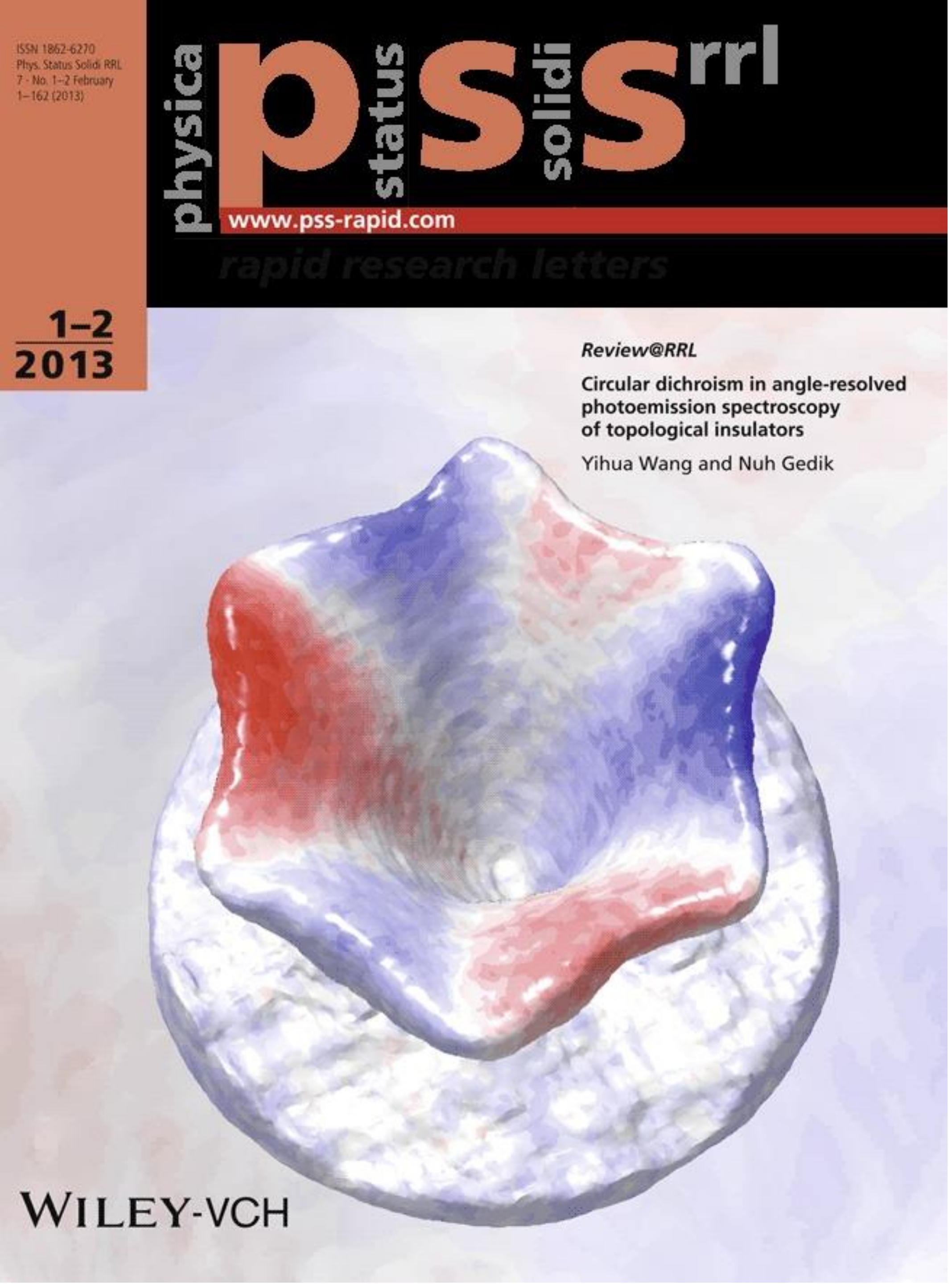


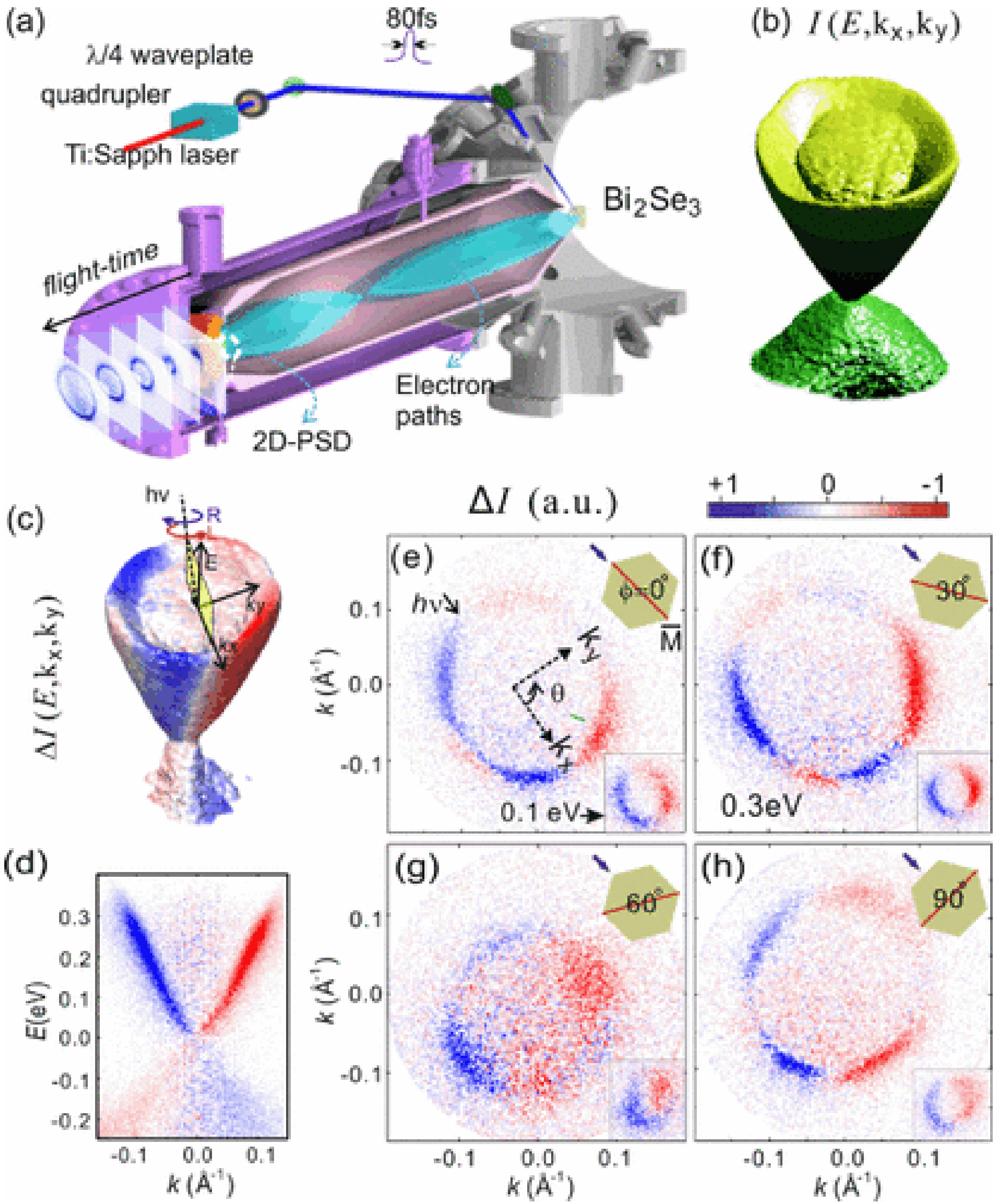
Advanced Science, 3, Issue: 11 (2016), DOI: (10.1002/advs.201600207)

Circular dichroism in ARPES mapping of surface state on Bi(111)

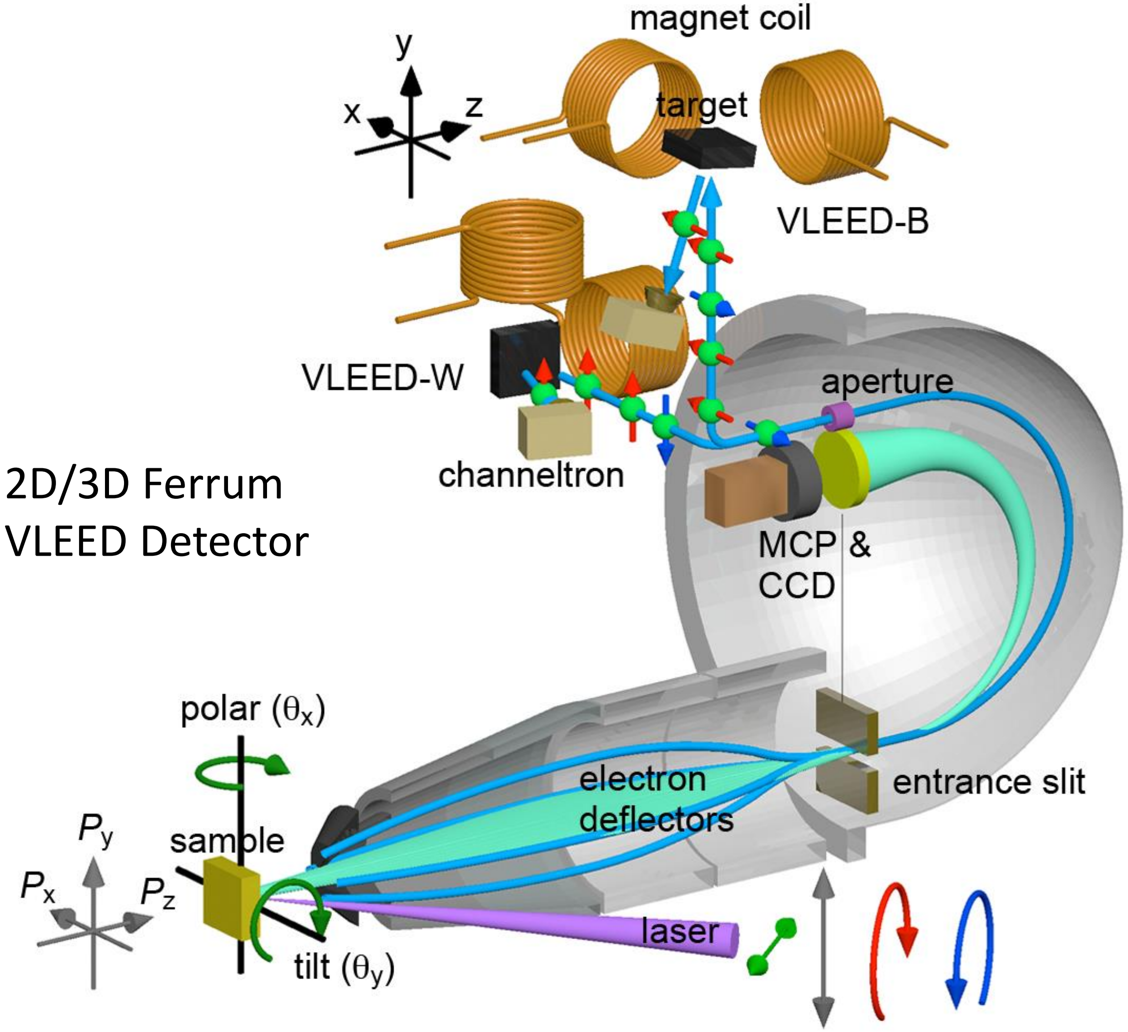


AIP Conference Proceedings 2054, 040011 (2019); https://doi.org/10.1063/1.5084612

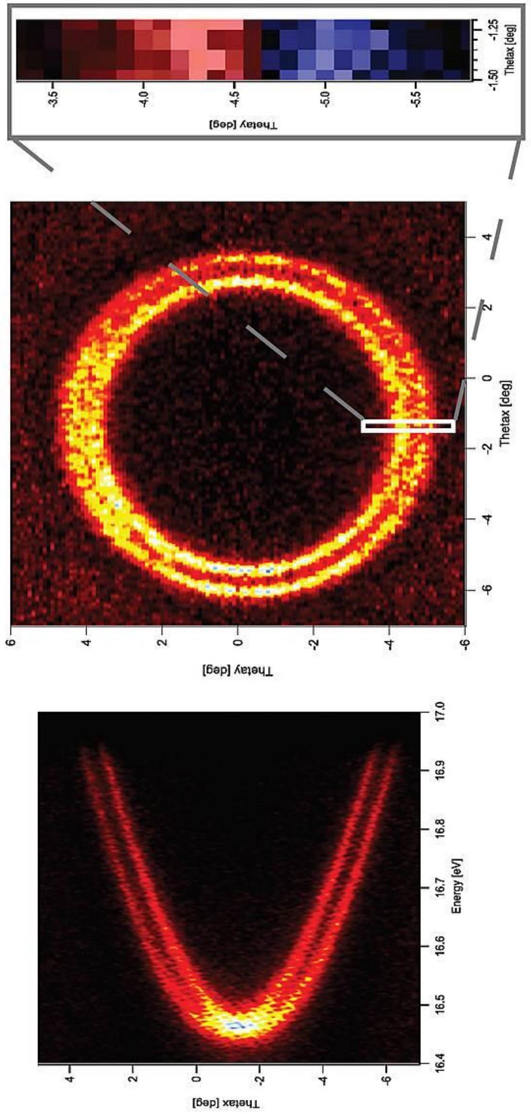

ISSN 1862-6270
Phys. Status Solidi RRL
7 · No. 1–2 February
1–162 (2013)
physica status solidi rrl
www.pss-rapid.com
rapid research letters
1–2
2013
Review@RRL
Circular dichroism in angle-resolved photoemission spectroscopy of topological insulators
Yihua Wang and Nuh Gedik
WILEY-VCH

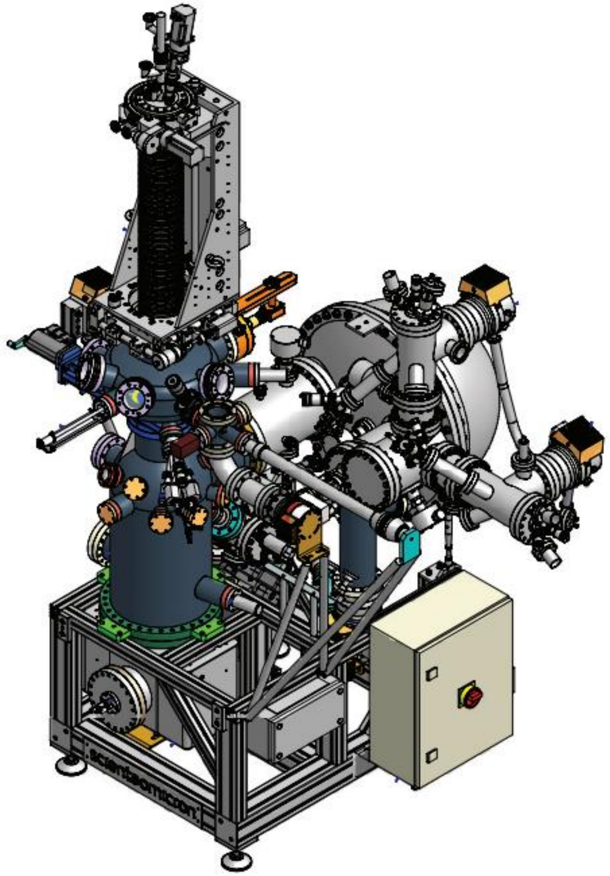

(a)
80fs
λ/4 waveplate
quadrupler
Ti:Sapph laser
Bi2Se3
flight-time
Electron paths
2D-PSD
(b) I (E,kx,ky)
(c)
hν
R
L
ΔI (E,kx,ky)
ΔI (a.u.)
+1
0
-1
(e)
(f)
(g)
(h)
hν
θ
0.1 eV
0.3eV
M
(d)
E(eV)
k (Å-1)

Spin- and Angle-Resolved Photoemission Spectroscopy



2D/3D Ferrum
VLEED Detector

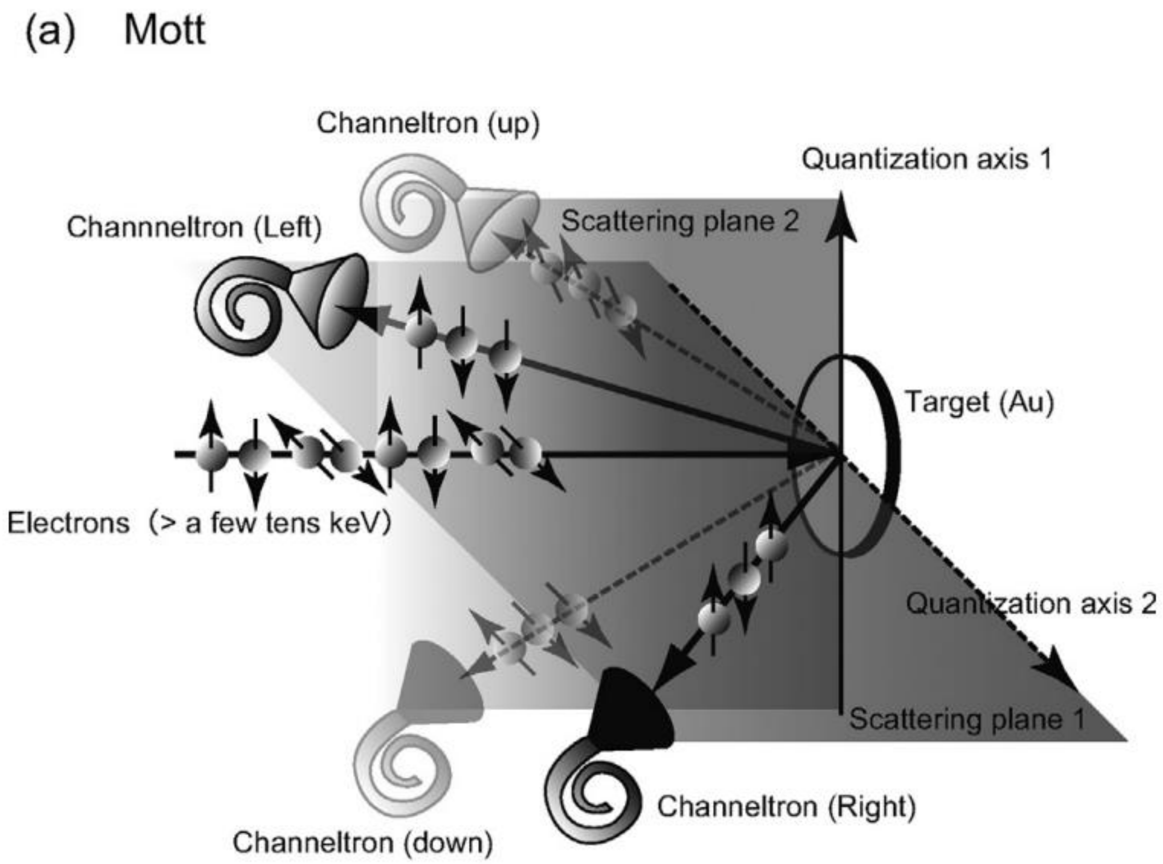


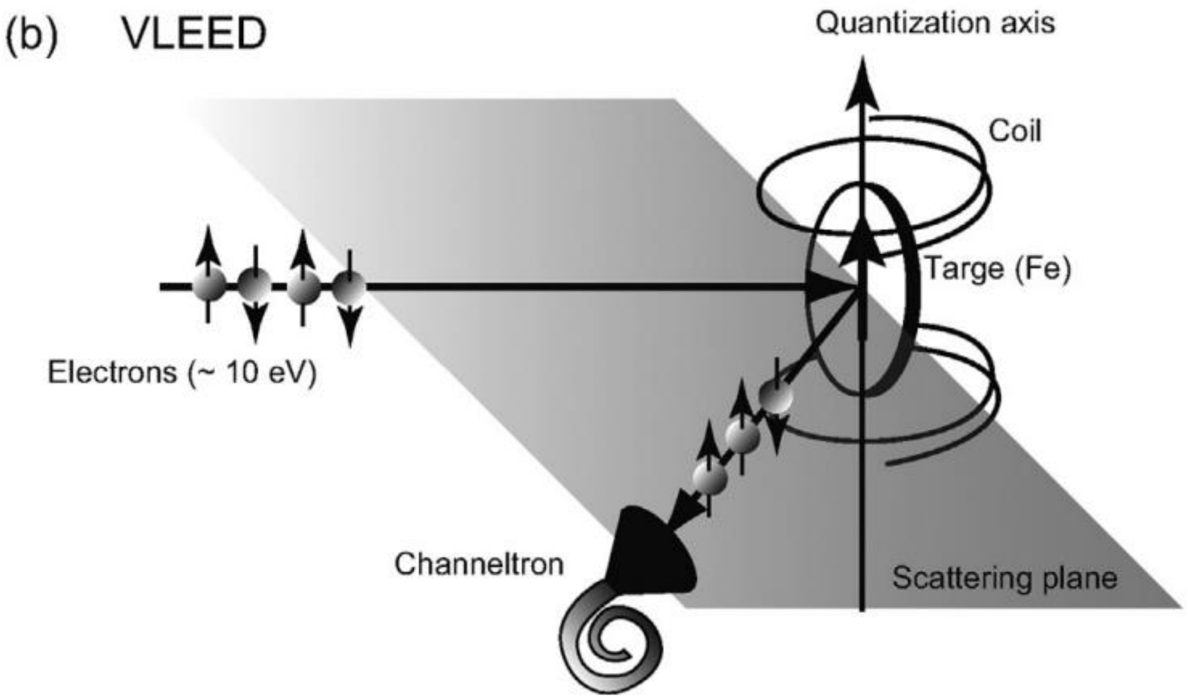


https://dx.doi.org/10.3791/57090

https://scientaomicron.com/Downloads/Brochures/ESPEC/VLEED_Ferrum_DA30L_SO_Brochure.pdf

Mott and VLEED spin detectors

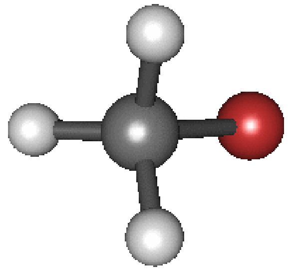


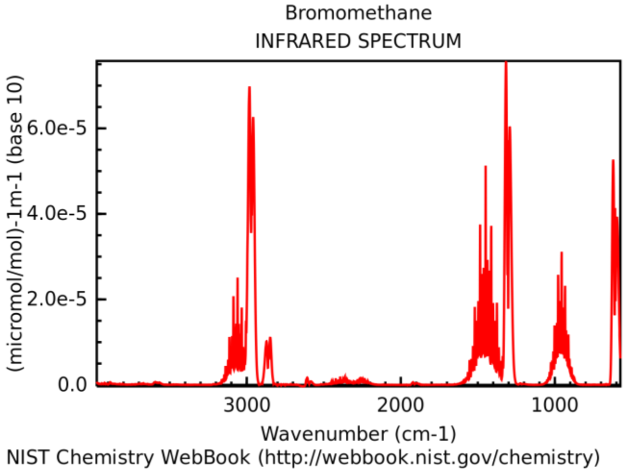


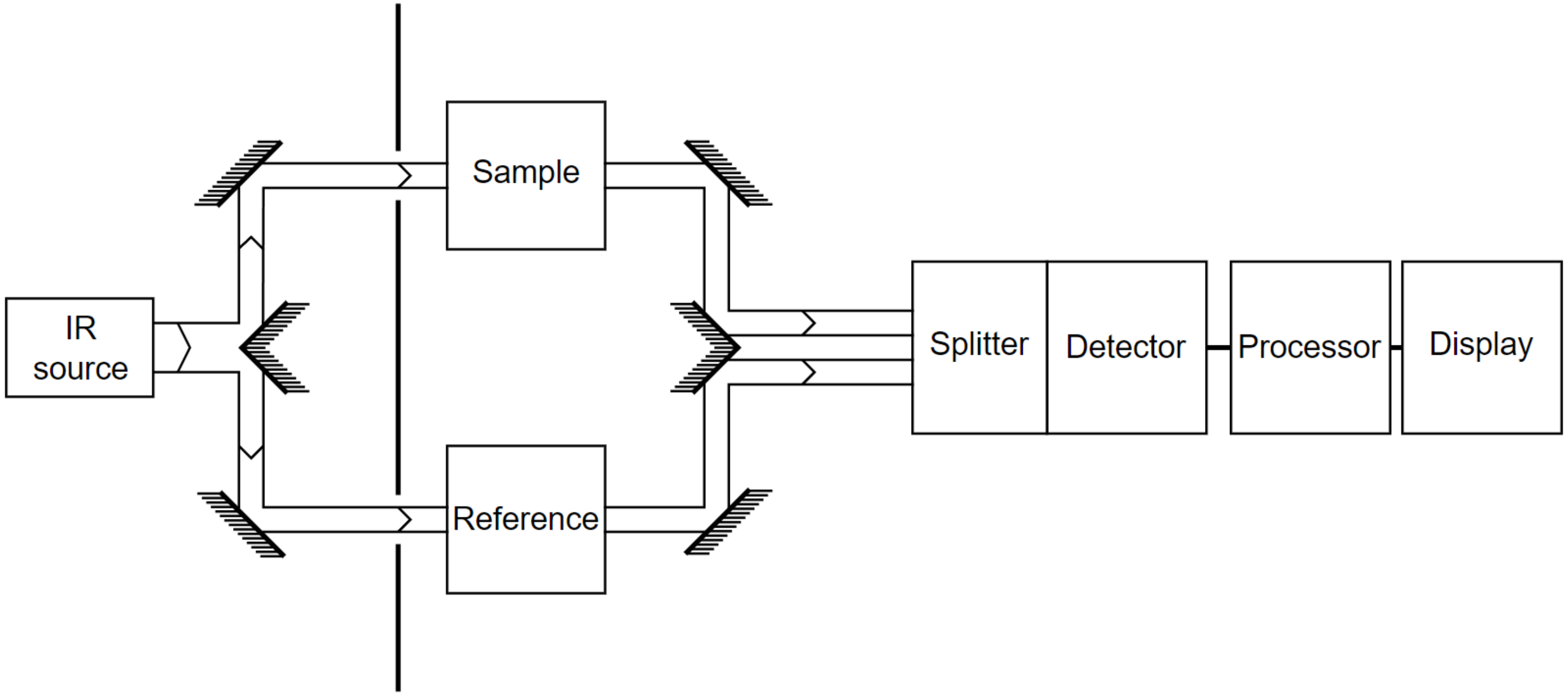
https://doi.org/10.1016/j.elspec.2014.10.010

Infra-red (IR) spectroscopy

IR spectroscopy





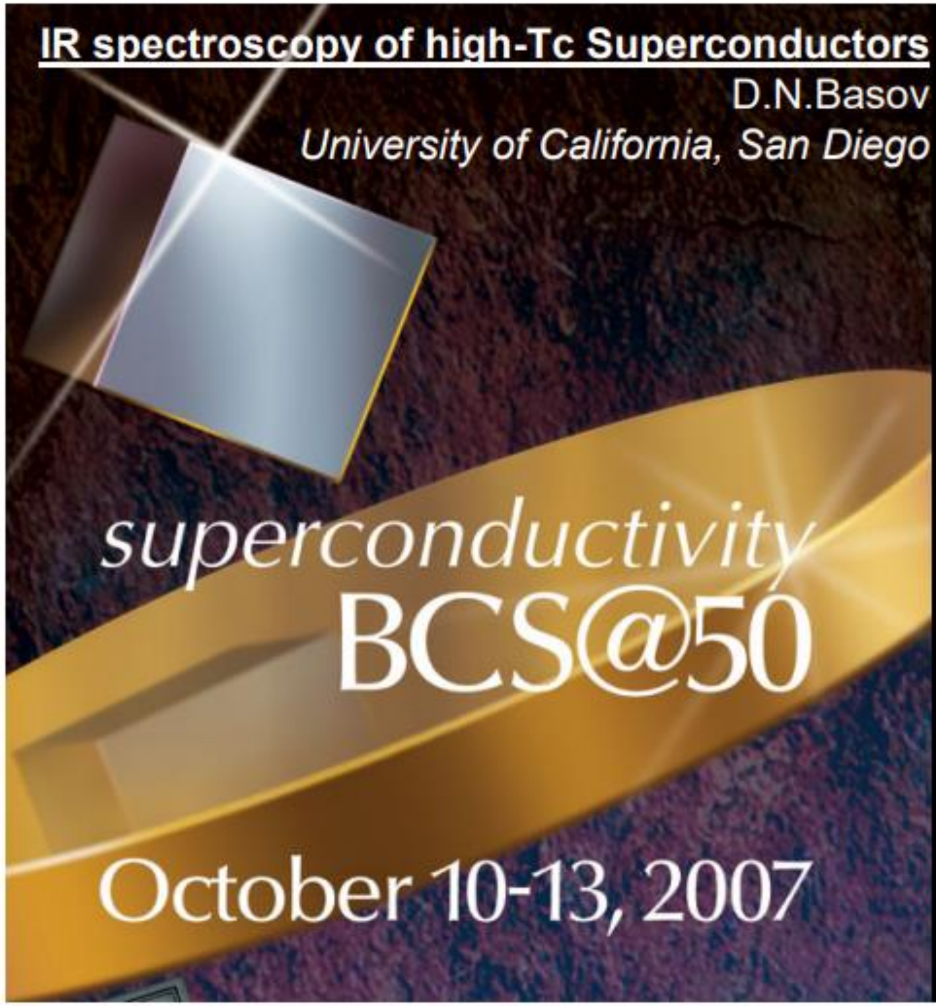


A beam of infrared light (passed through an interferometer) split into two separate beams. One is passed through the sample, the other passed through a reference. The beams are both reflected back towards a detector, however first they pass through a splitter, which quickly alternates which of the two beams enters the detector. The two signals are then compared and a printout is obtained. This "two-beam" setup gives accurate spectra even if the intensity of the light source drifts over time.

https://commons.wikimedia.org/wiki/File:IR_spectroscopy_apparatus.svg
https://en.wikipedia.org/wiki/Infrared_spectroscopy

To read

- D.N. Basov. IR spectroscopy of high-Tc Superconductors http://conferences.illinois.edu/bcs50/pdf/basov.pdf /
- D.N. Basov and T. Timusk *Reviews of Modern Physics* **77**, 721 (2005) http://infrared.ucsd.edu/basov_pubs/basov76.pdf
- P. Grosse; V. Offermann. Analysis of reflectance data using the Kramers-Kronig Relations. *Appl. Phys. A* **52**, 138 (1991). doi:10.1007/bf00323731
- Bo Xiang et al. Two-dimensional infrared spectroscopy of vibrational polaritons. *PNAS* **115,** 4845 (2018); https://doi.org/10.1073/pnas.1722063115



Energy Gap Interpretation of Experiments on Infrared Transmission through Superconducting Films*

M. Tinkham
Department of Physics, University of California, Berkeley, California

(Received September 4, 1956)

PHYSICAL REVIEW LETTERS
APRIL 15, 1959

DETERMINATION OF THE SUPERCONDUCTING SKIN DEPTH FROM THE ENERGY GAP AND SUM RULE*

M. Tinkham
Department of Physics, University of California, Berkeley, California
and
R. A. Ferrell
Physics Department, University of Maryland, College Park, Maryland

(Received March 11, 1959)

PHYSICAL REVIEW VOLUME 108, NUMBER 2 OCTOBER 15, 1957

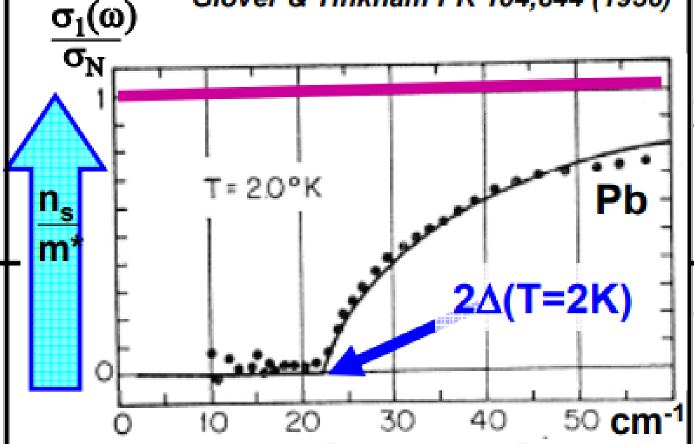
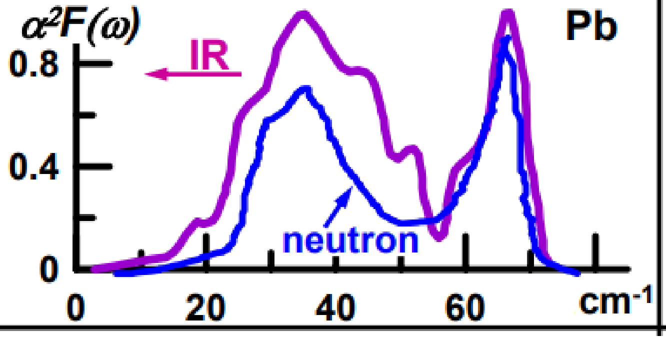
Conductivity of Superconducting Films for Photon Energies between 0.3 and 40kT_c*

R. E. Glover, III,† *University of California, Berkeley, California and University of North Carolina, Chapel Hill, North Carolina*
AND
M. Tinkham, *University of California, Berkeley, California*

(Received May 17, 1957)

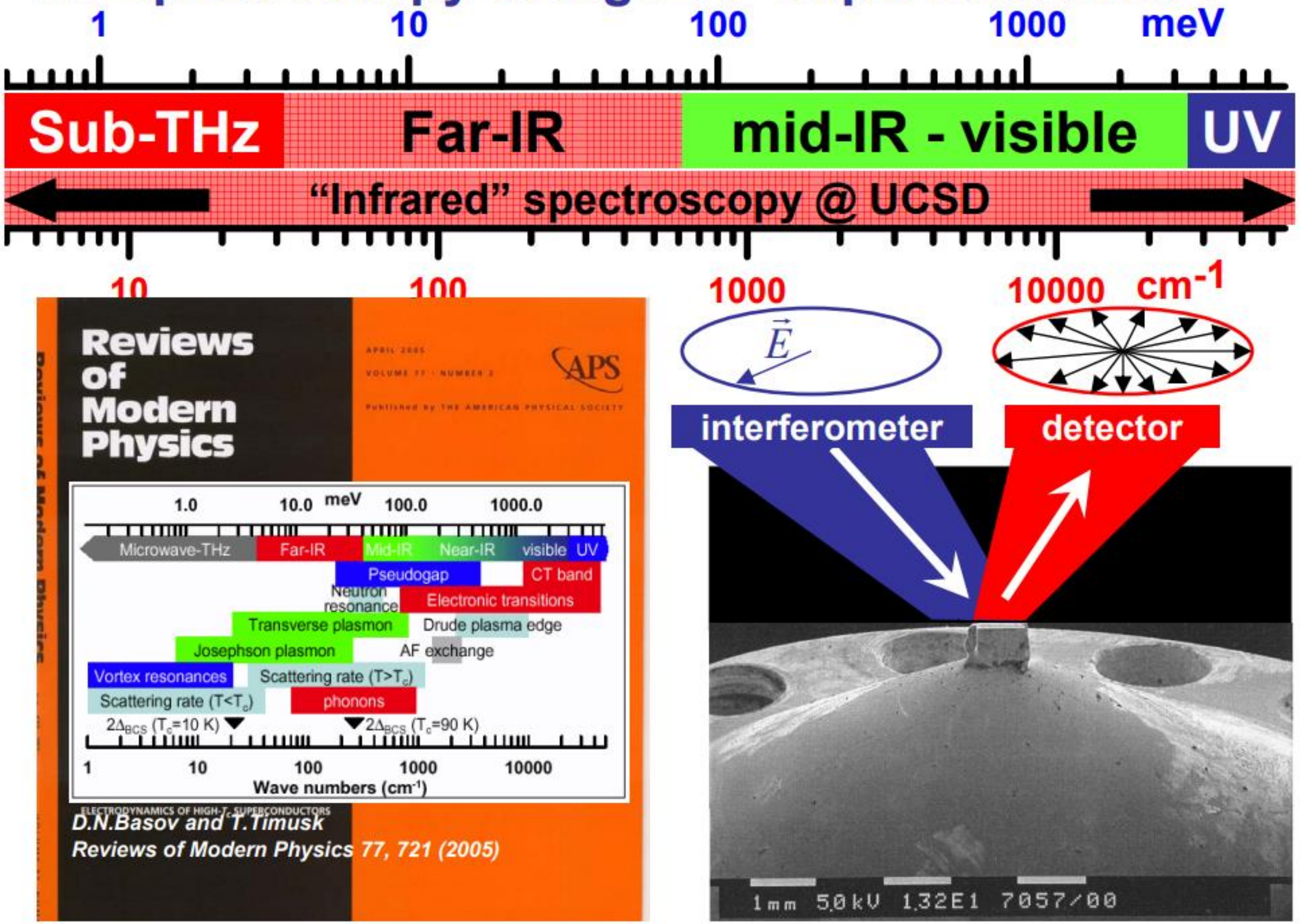
http://conferences.illinois.edu/bcs50/pdf/basov.pdf

Shedding Infrared Light on Superconductivity

	Elemental superconductors	High-T_c cuprates
Normal state	Fermi liquid	1. Doped Mott insulators
Energy gap	*Glover & Tinkham PR 104,844 (1956)* 	2. pseudogap
Superconducting condensate, penetration depth & sum rules	$\rho_s = \frac{n_s}{m^*} = \int d\omega \left[\sigma_1^N - \sigma_1^{SC}\right]$ *Ferrell-Glover-Tinkham sum rule*	3. Energy scales: > 10^2-10^3 kT_c $\rho_s = \int_{0+} d\omega \left[\sigma_1^N - \sigma_1^{SC}\right] + \Delta K$
Pairing "glue"	*R.R.Joyce and P.L. Richards PRL 24, 1007 (67)* *Farnworth and Timusk PRB10, 2799 (76)* 	4. Phonons? Magnetic excitations? Both/Neither? "modes"? No glue is needed/wanted?

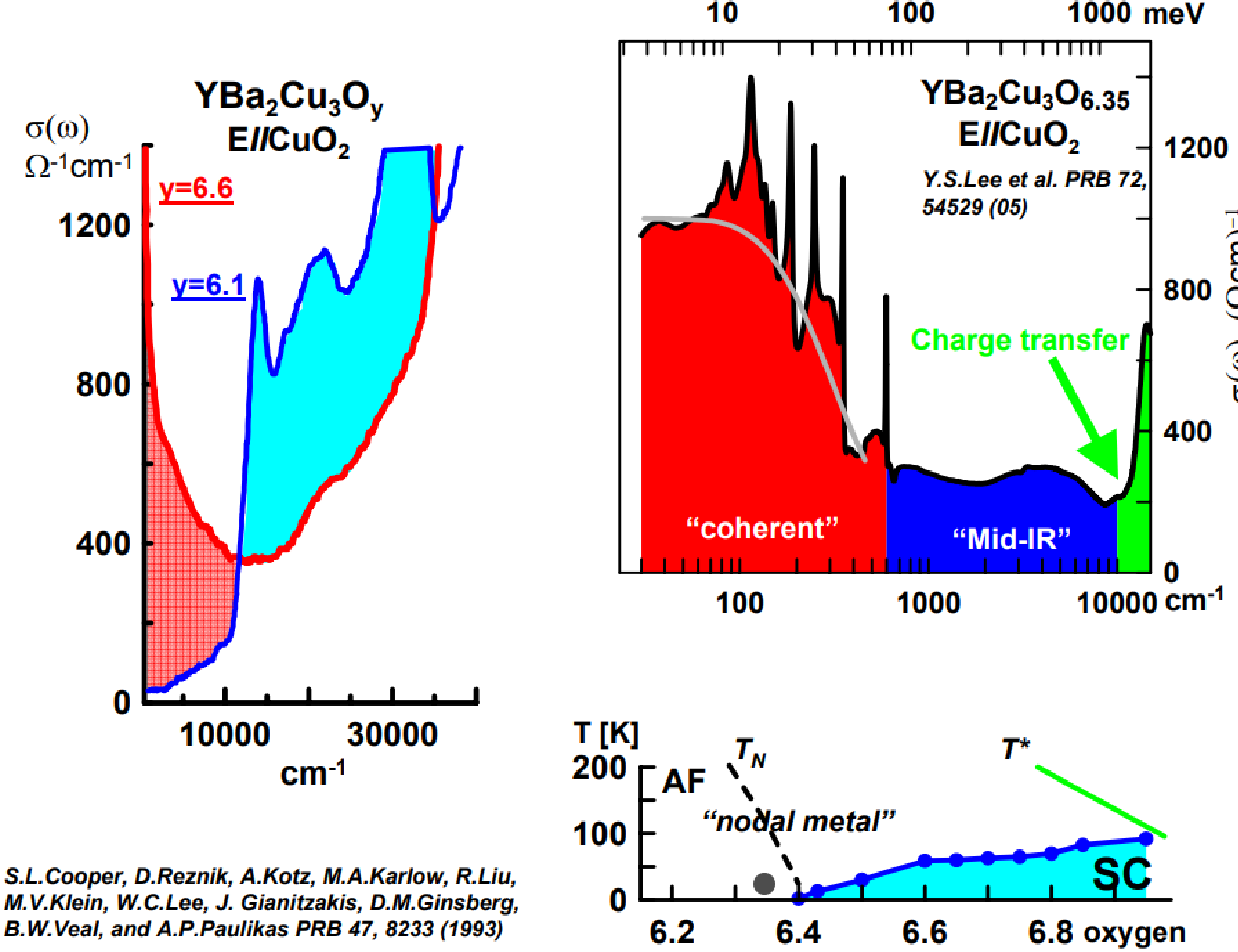
http://conferences.illinois.edu/bcs50/pdf/basov.pdf

IR spectroscopy of high-Tc superconductors



http://conferences.illinois.edu/bcs50/pdf/basov.pdf

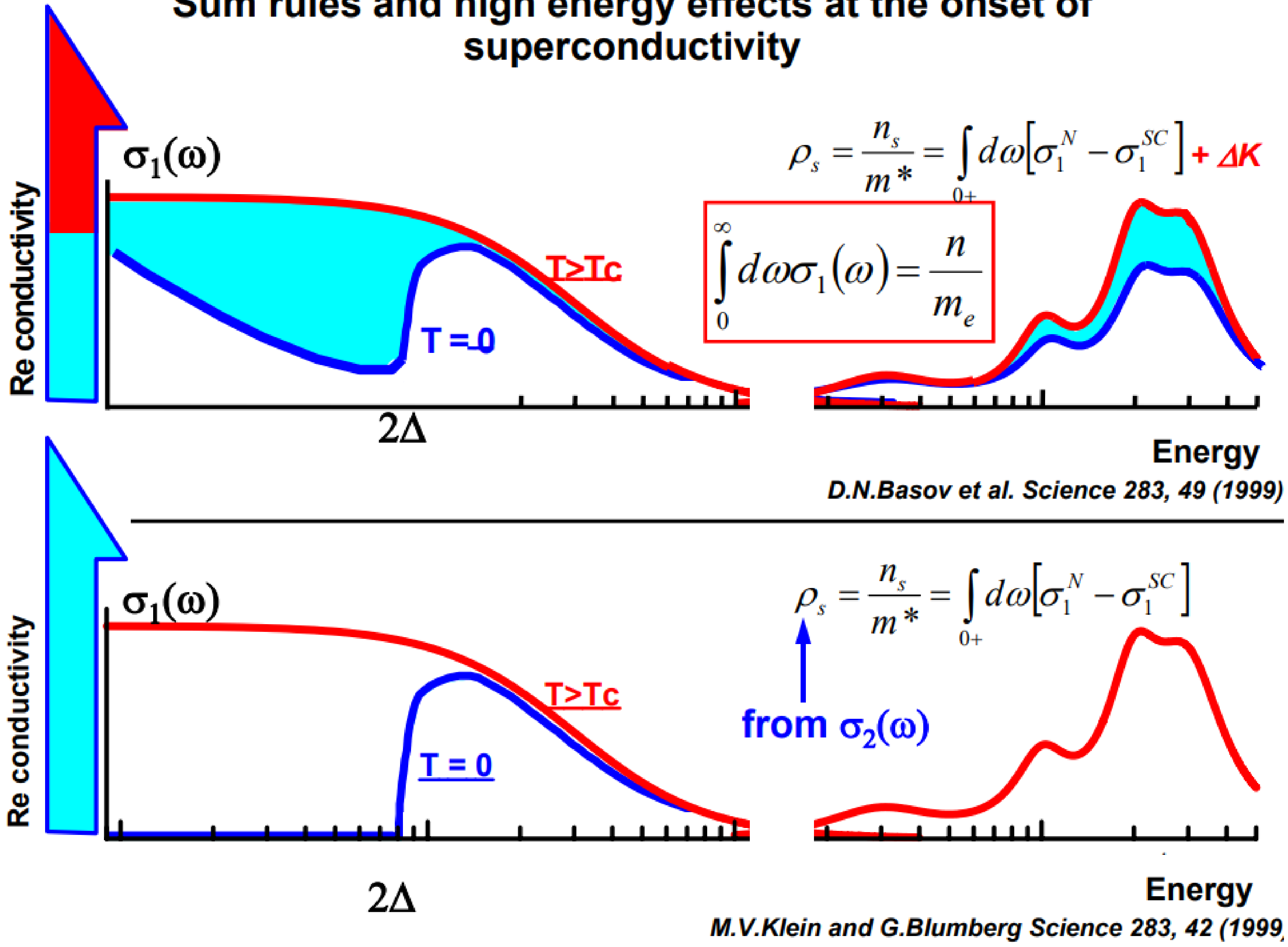
Charge dynamics in weakly doped CuO_2 planes



S.L.Cooper, D.Reznik, A.Kotz, M.A.Karlow, R.Liu, M.V.Klein, W.C.Lee, J. Gianitzakis, D.M.Ginsberg, B.W.Veal, and A.P.Paulikas PRB 47, 8233 (1993)

http://conferences.illinois.edu/bcs50/pdf/basov.pdf

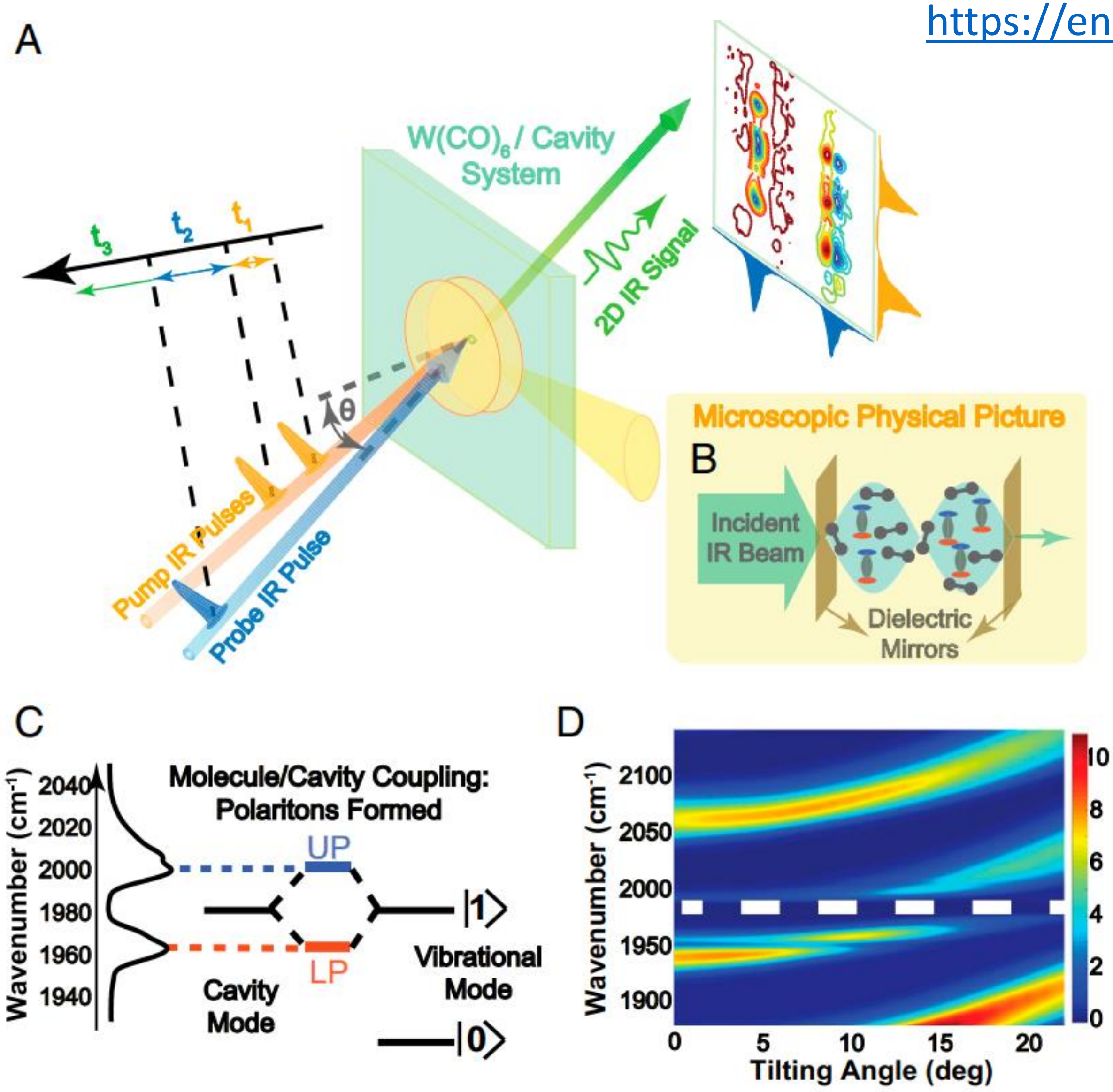
Sum rules and high energy effects at the onset of superconductivity

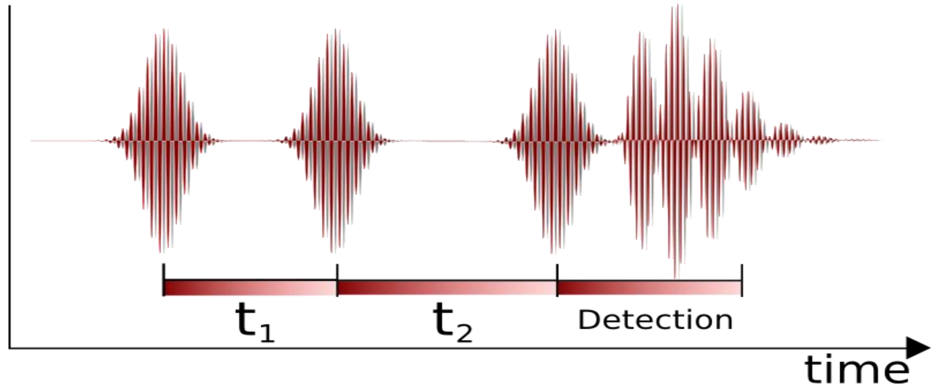


http://conferences.illinois.edu/bcs50/pdf/basov.pdf

Two-dimensional infrared spectroscopy (2DIR)

https://en.wikipedia.org/wiki/Two-dimensional_infrared_spectroscopy





(A) Scheme of vibrational polariton 2D IR spectroscopy setup. Pump and probe IR incident beams are symmetric with respect to the normal plane with the same tilting angle, θ.
(B) Illustration of the microscopic physics of molecules inside of a microcavity.
(C) Formation of vibrational polaritons by strongly coupled molecular vibration and cavity modes. (Left) vibrational polariton FTIR spectrum of W(CO)6.
(D) Dispersion of IR transmission of a microcavity filled with a nearly saturated W(CO)6 in hexane solution, white dashed line indicates the vibrational frequency of W(CO)6

https://www.pnas.org/content/115/19/4845