Electronic properties of solids excited with intermediate laser power densities

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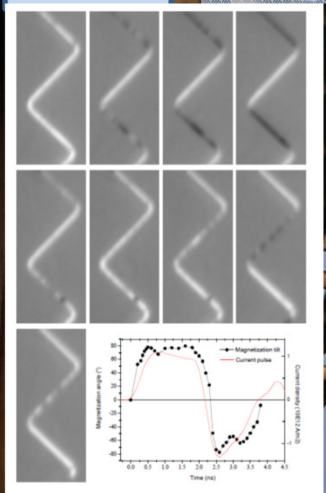
UR1 - CNRS - SOLEIL Synchrotron

TEMPO
Beamline

1ère rencontre des utilisateurs Attolab 19-20/11/2015

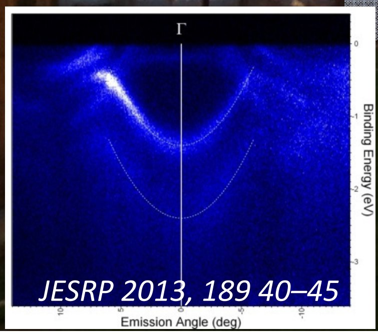
Time resolved Experiments

- Time resolved electronic structure:
  - Real time experiments
    - Annealing processes
    - Phase transitions
    - Adsorption and desorption
  - Pump Probe experiments
    - Spin injection & Magnetization dynamics
    - Device operation
    - Surface photovoltage
    - Laser induced magnetization dynamics

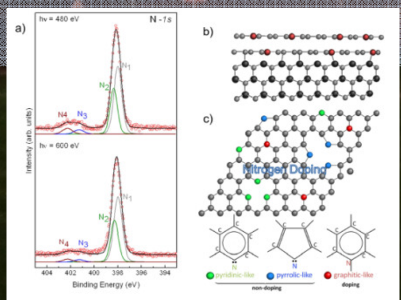


PRB, 2011, 83(2): art.n°020406

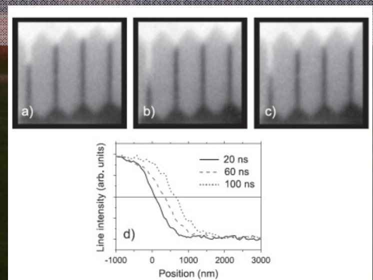
ACSNano 6,6075 (2012)



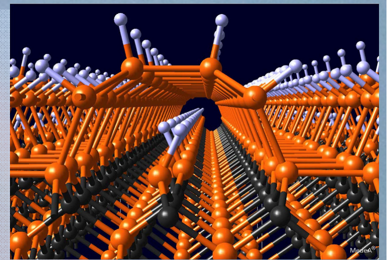
JESRP 2013, 189 40–45

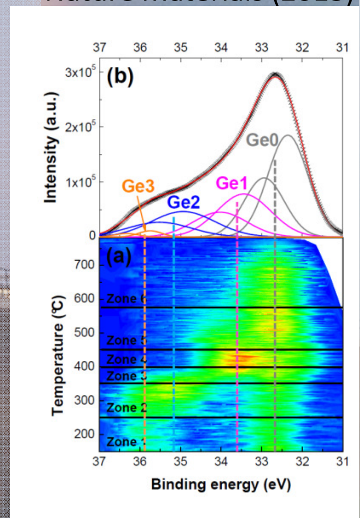


ACS Nano, 2012, 6(12): 10893

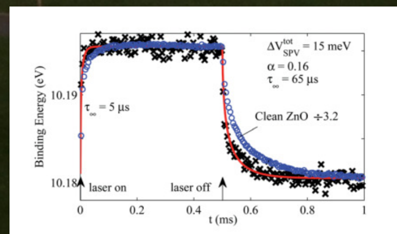


PRL 108, 247202(2012)





JAP, 2012, 112(9), 093508



Faraday Discuss. 2014, 171, 275

Laser installation

Fs Pulsed laser

Coherent REGA 9040

- **282 KHz synchronized**
- **40 fs, 6μJ/pulse**
- **OPA 800 – 400 nm**

M. Silly

fs laser excitations in solid state

- Surface Chemical reactions
- Phase transitions
- Magnetization dynamics

Pump/probe experiments:
Enough power to induce modification of physical properties

But the solid sample is still there

Photoelectron spectroscopy

- Electronic structure =>
- all properties
    - physical, chemical, magnetic,

- Element and site specific
- Basis for all time resolved studies
    - In all phase transitions electrons, more mobile than nuclei could drive the observed behavior

Laser power density

Needed several mJ/cm^2

REGA : 6μJ/pulse
with a focal spot of about 200 microns

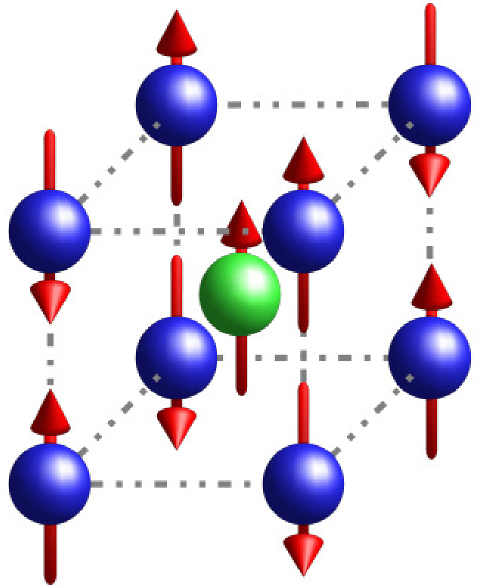
5 mJ/cm^2 @ 25 degrees incidence

High stability needed for both synchrotron and laser beamlines

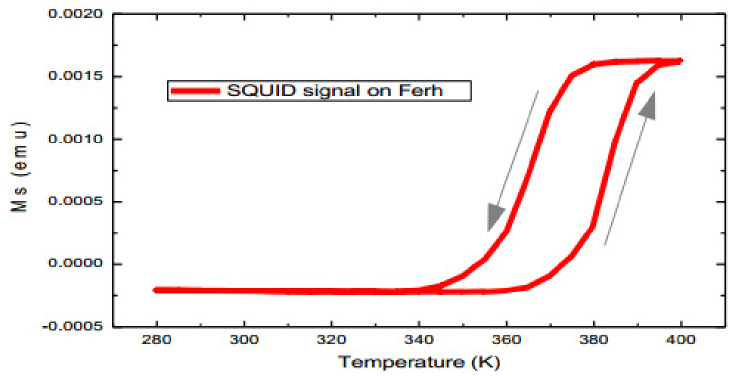
M. Silly

The phase transition in FeRh

In FeRh the transition involves both the Magnetic Order and the Lattice Structure;



Below T_c	Above T_c
$Fe=\pm 3.3\,\mu_B$	$Fe=3.1\,\mu_B$
$Rh=0\,\mu_B$	$Rh=0.9\,\mu_B$

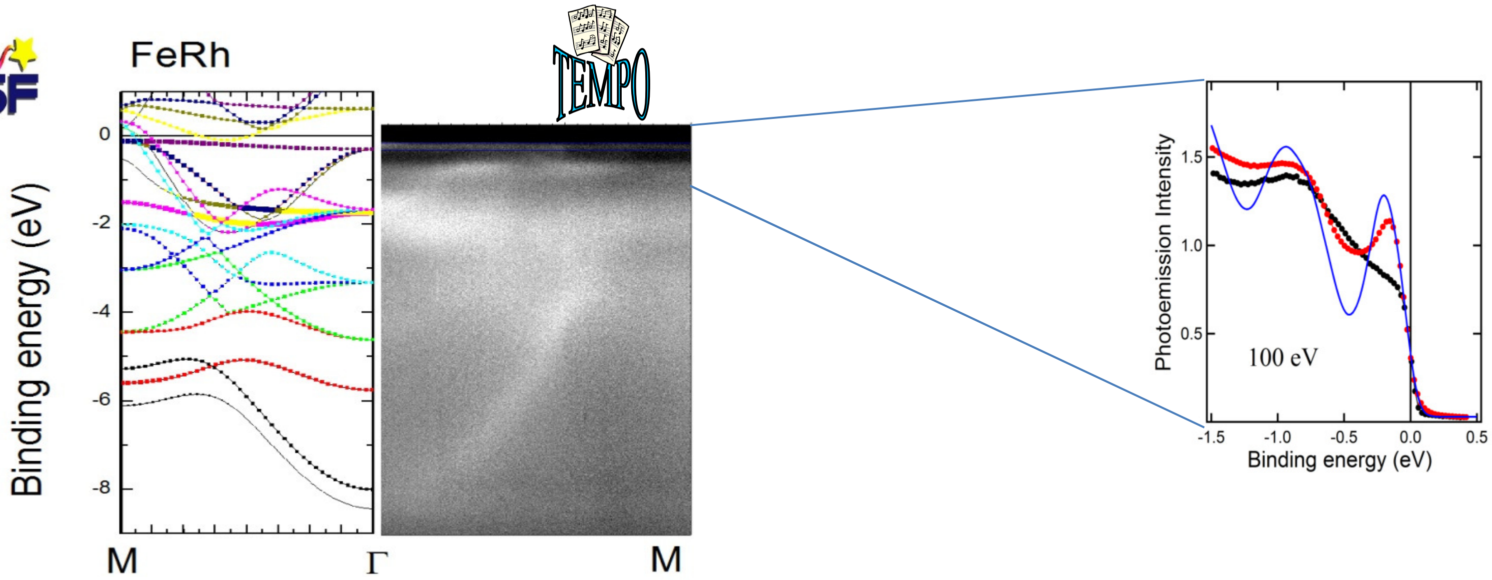


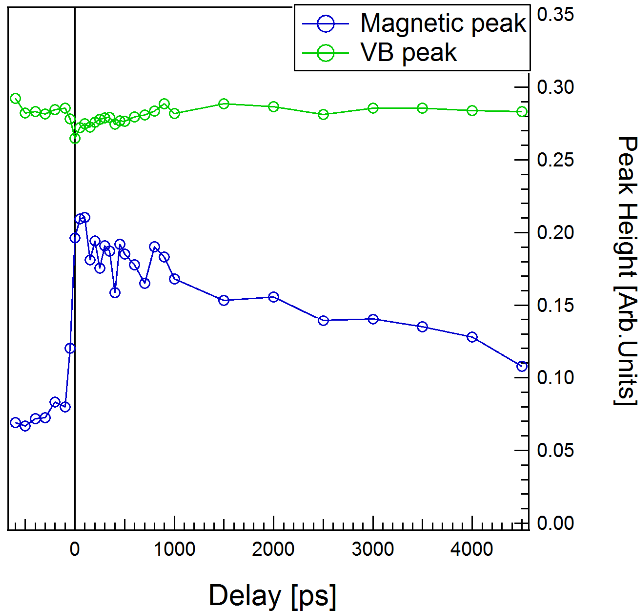
The volume is expanded of about 1% bulk samples or in thick films;

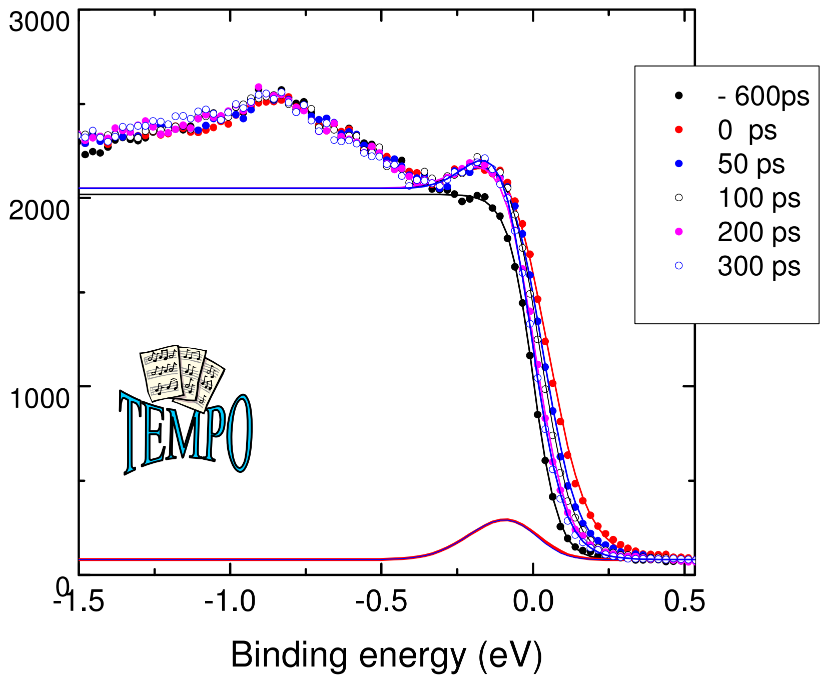
- Isotropically in bulk or in thick films;
- Along the out of plane direction for thin films

$T_{FM\rightarrow AFM}=385\,K \quad T_{AFM\rightarrow FM}=395\,K$

FeRh : electronic structure -> + laser induced phase transition



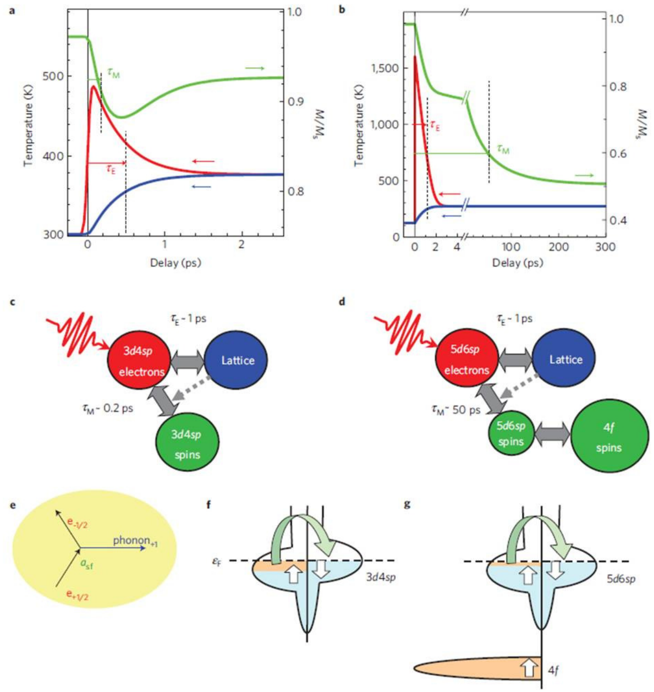




(F. Pressacco, M. Gatti, A. Nicolaou,D.Krizmancic)

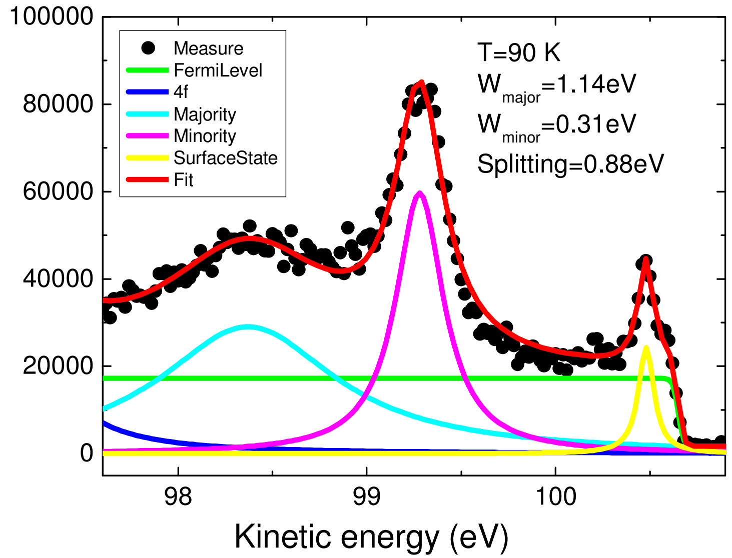
Magnetization dynamics

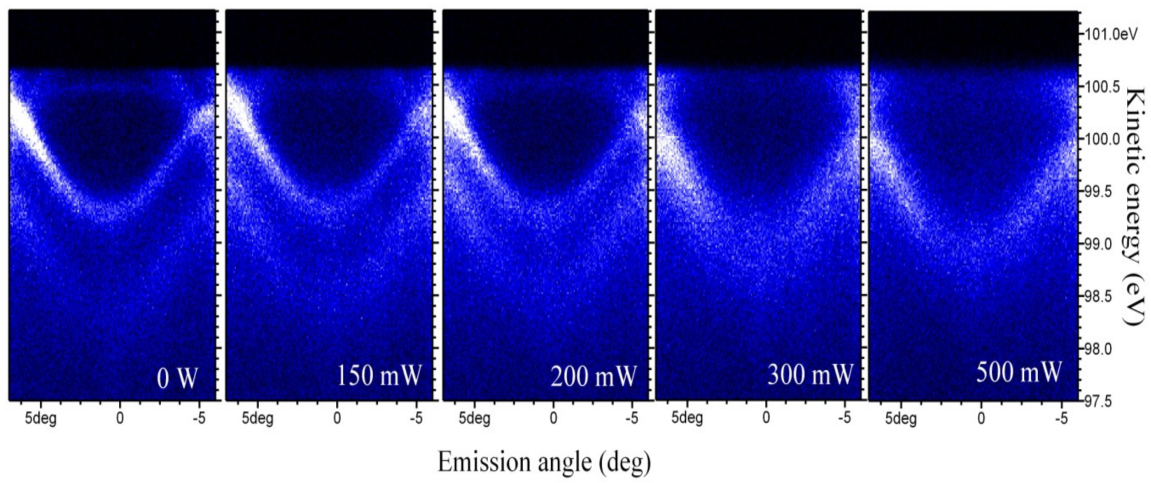
- Three temperature model
- Role of hot electrons
- IR laser excitation

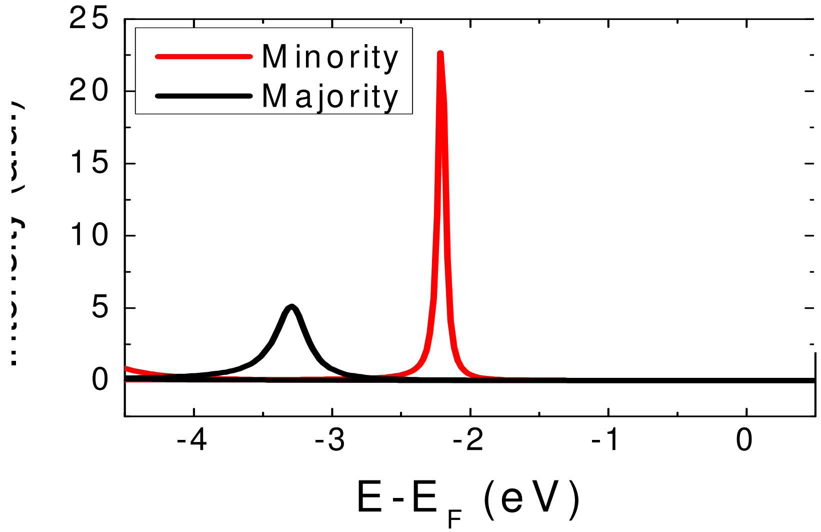


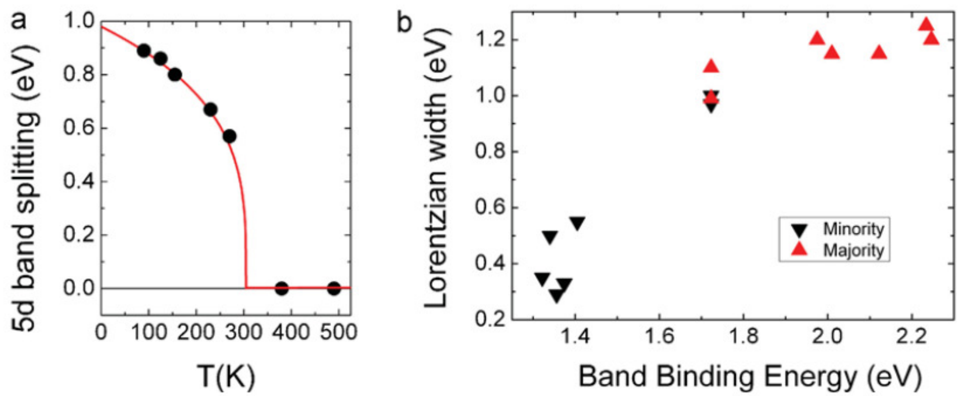
extracted form [Nature Materials Vol: 9, Pg: 259–265 (2010)].

Gd: Temperature dependence of magnetization



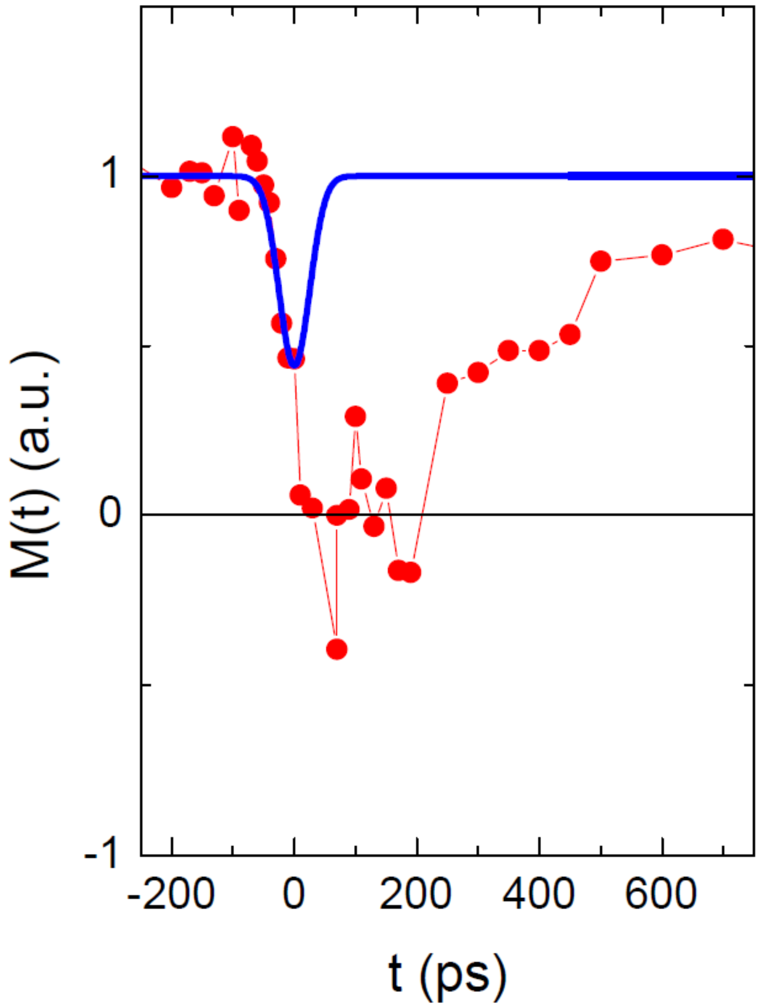


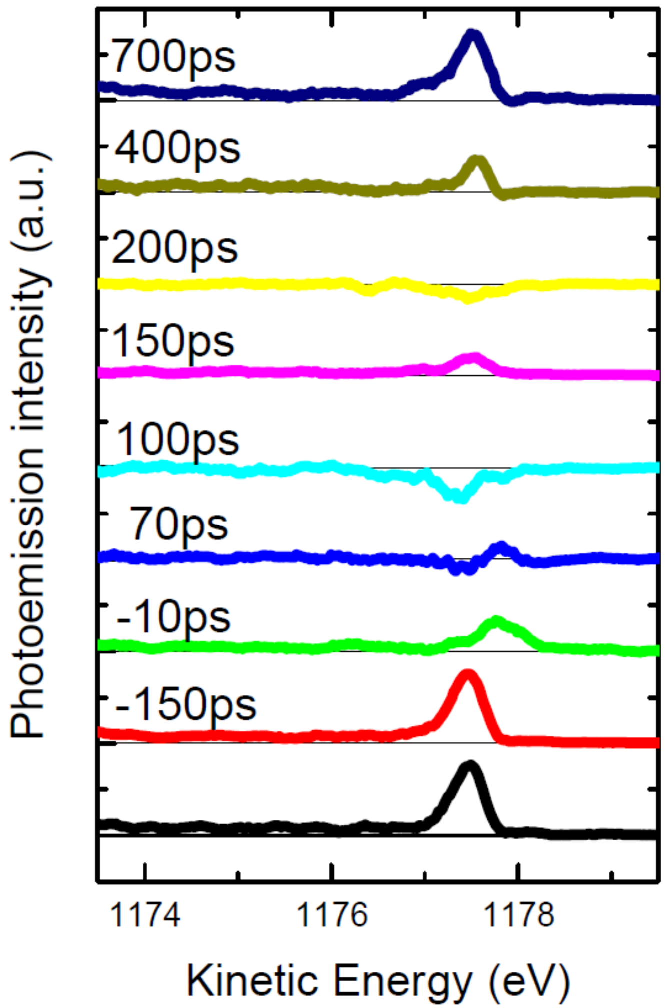




N. Beaulieu et al. J*ESRP, 2013, 189 Supp: 40–45*

Laser induced Fast demagnetization





Femtosecond Laser Excitation Drives Ferromagnetic Gadolinium out of Magnetic Equilibrium

Robert Carley,[1,2] Kristian Döbrich,[1] Björn Frietsch,[1,2] Cornelius Gahl,[2] Martin Teichmann,[1,2] Olaf Schwarzkopf,[3]
Philippe Wernet,[3] and Martin Weinelt[2,*]

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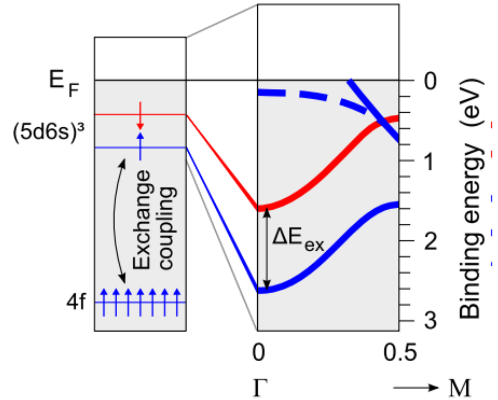
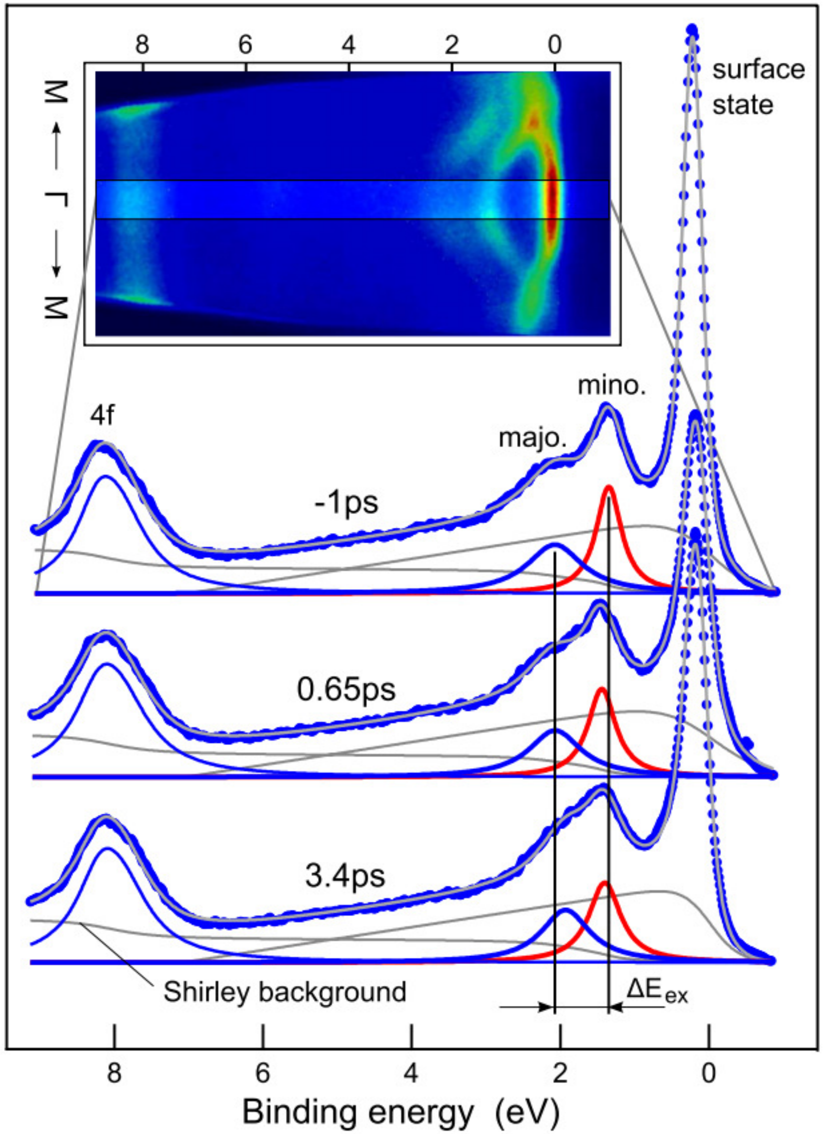
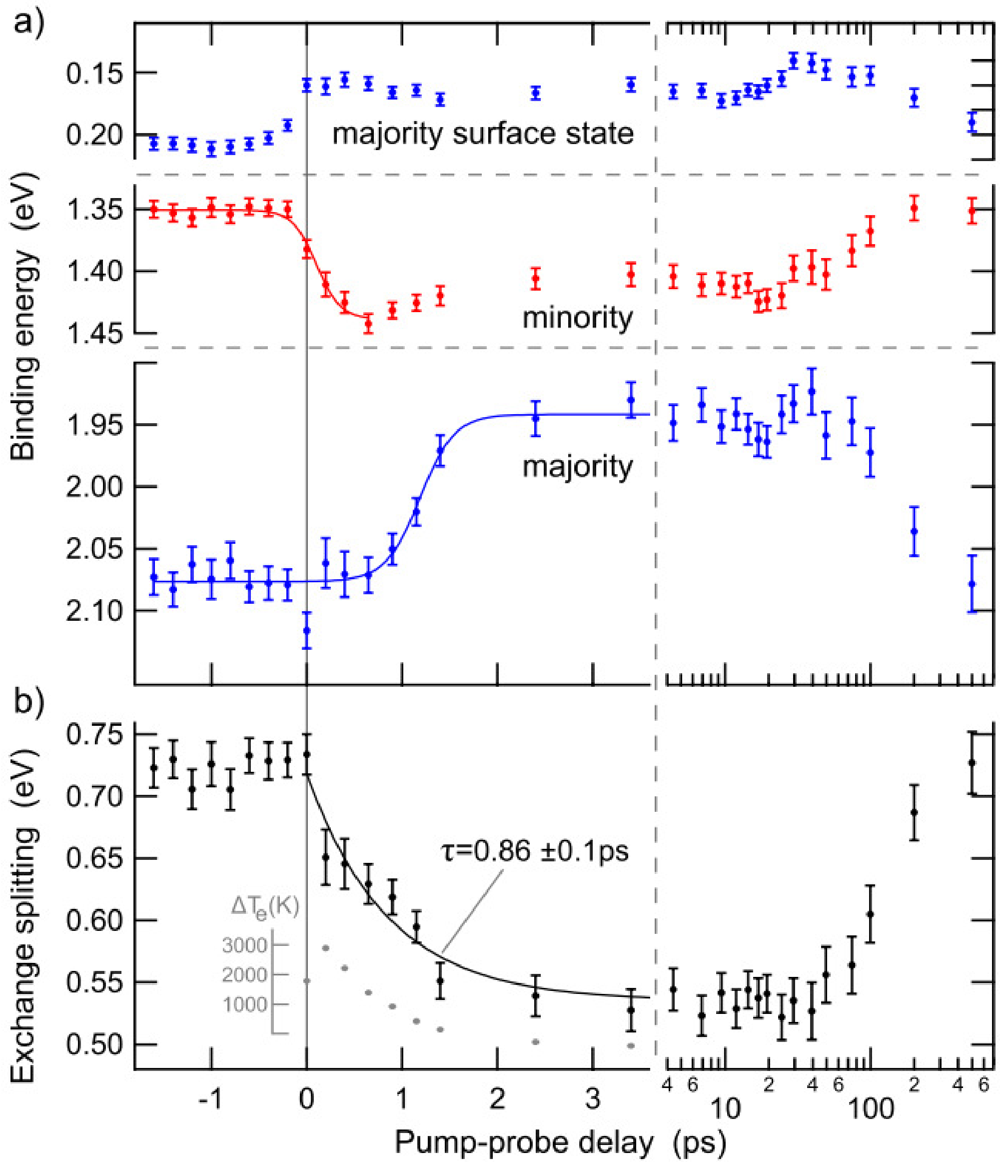


FIG. 1 (color online). Magnetic coupling (left) and calculated exchange-split valence band structure [31] of gadolinium (right). Majority spin band: blue, up arrows. Minority spin band: red, down arrows. The dashed line is the $5d_{z^2}$ majority spin surface state. Bands not seen in ARPES at 36 eV photon energy have been omitted.



HHG source

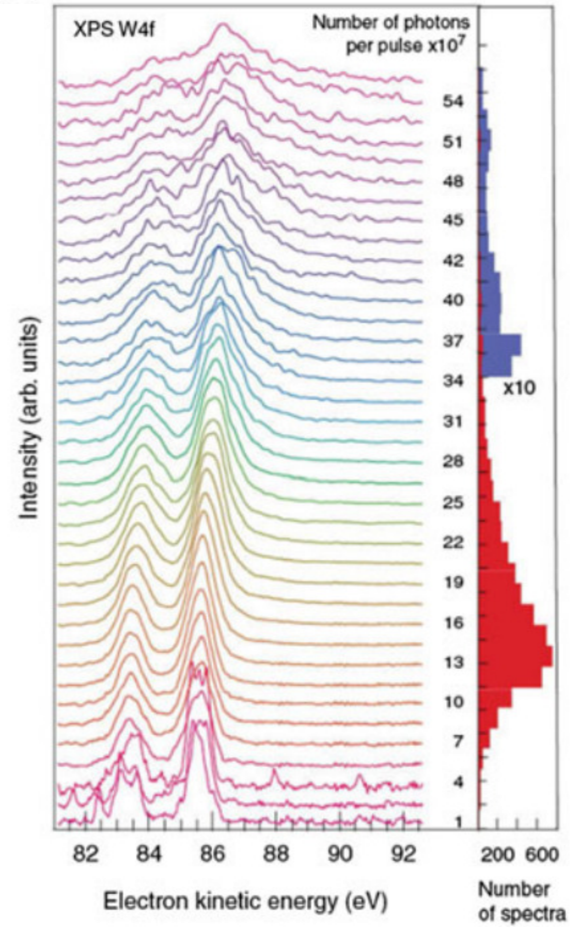


a)
b)
majority surface state
minority
majority
Binding energy (eV)
Exchange splitting (eV)
τ=0.86 ±0.1ps
ΔTe(K)
3000
2000
1000
0.15
0.20
1.35
1.40
1.45
1.95
2.00
2.05
2.10
0.75
0.70
0.65
0.60
0.55
0.50
-1
0
1
2
3
10
100
Pump-probe delay (ps)

Relatively high power density
Space charge created by pump pulse.

Beamline

Photoemission as a function of the photons per pulse

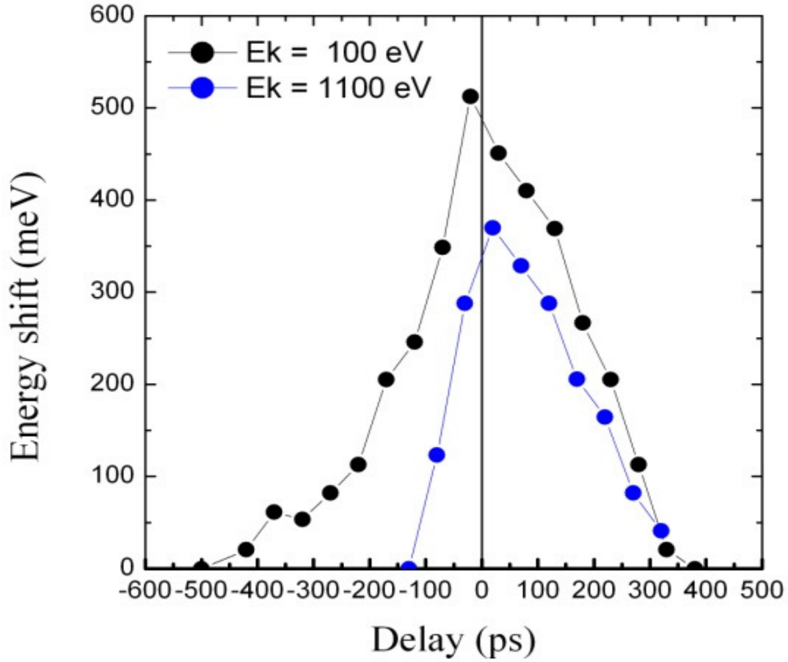


A. Pietzsch et al., *Towards time resolve core level photoelectron spectroscopy with femtosecond x-ray free-electron lasers.* New J. Phys. **10**, 033004 **(2008)**

FLASH

N. Beaulieu, G. Malinowski, A. Bendounan, M. Silly, C. Chauvet, D.Krizmancic, F. Sirotti

Space charge effects occurring during fast demagnetization processes.



In Ultrafast Magnetism I , vol.159, pp. 313-316. Springer, 2015

Multiphoton Photoemission

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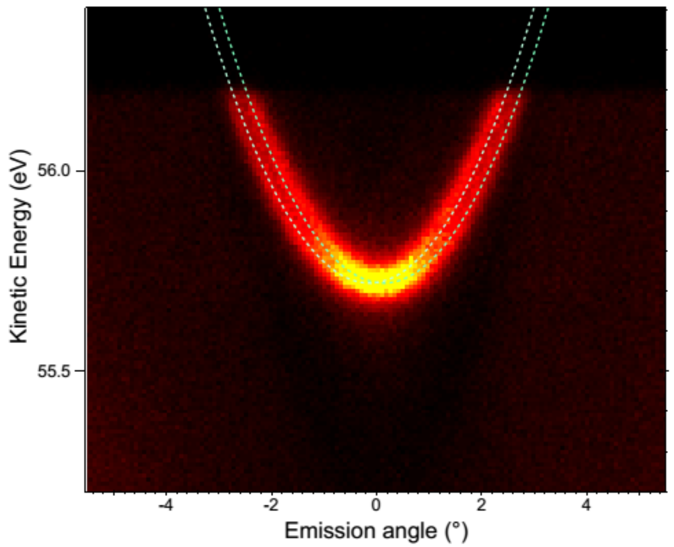
G. Malinowski Université de Lorraine, Nancy
G. Fratesi CNISM U. Milano-Bicocca, Italy & ETSF
G. Onida Dip. Fisica, U. Milano,Italy & ETSF
Valerie Veniard, LSI Palaiseau & ETSF

Synchrotron radiation
60 eV photon energy

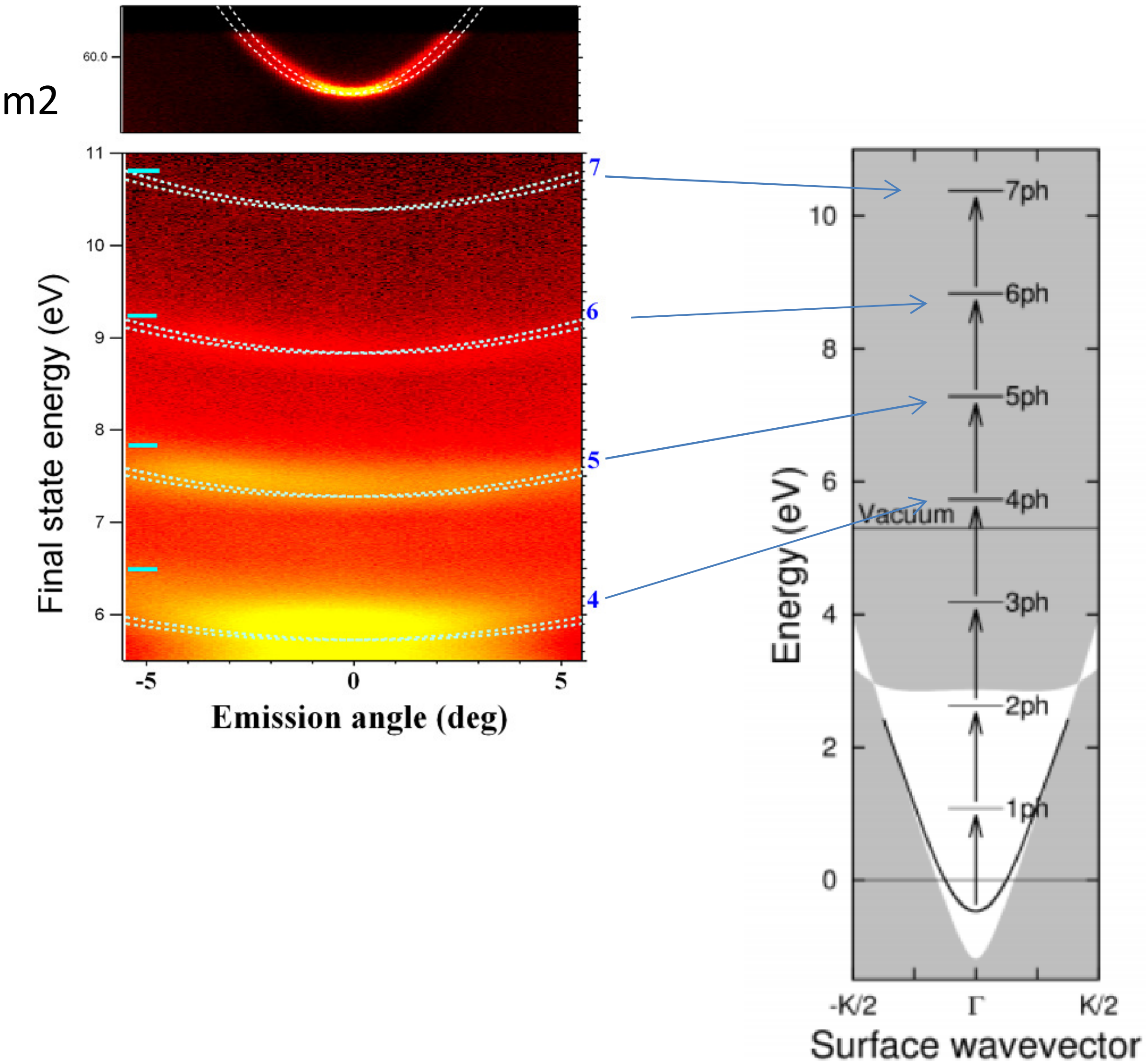


Au(111) - 90 K

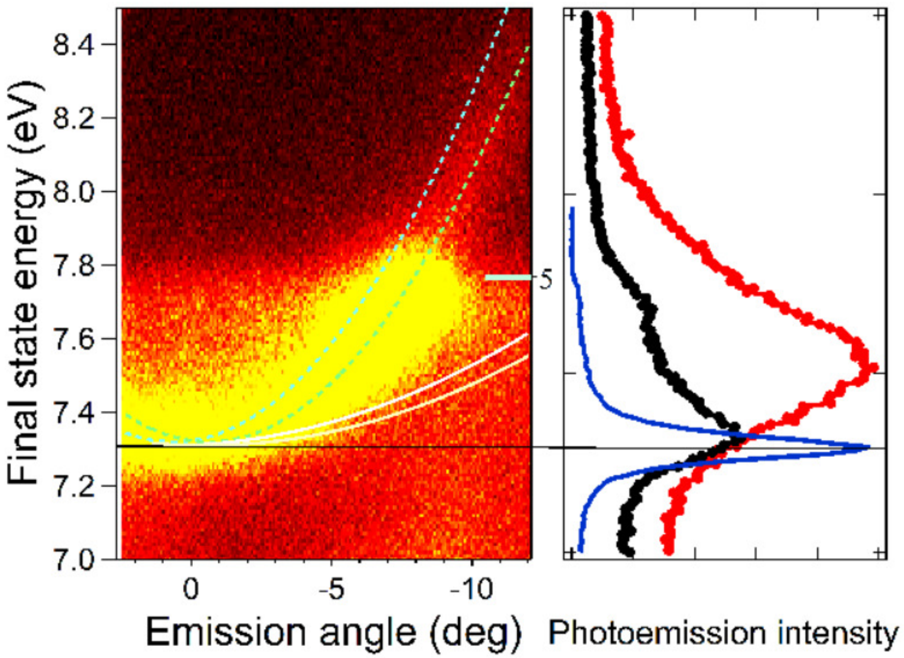
Phys Rev B 90, 035401 (2014)

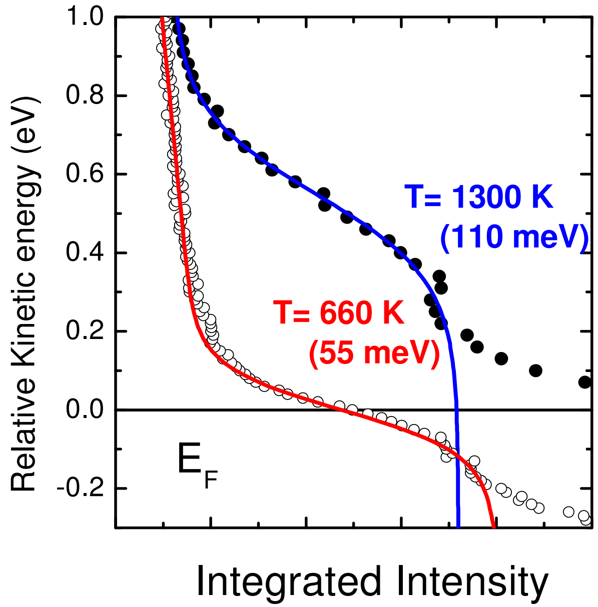
Multiphoton photoemission

REGA : 2mJ/cm2
800 nm



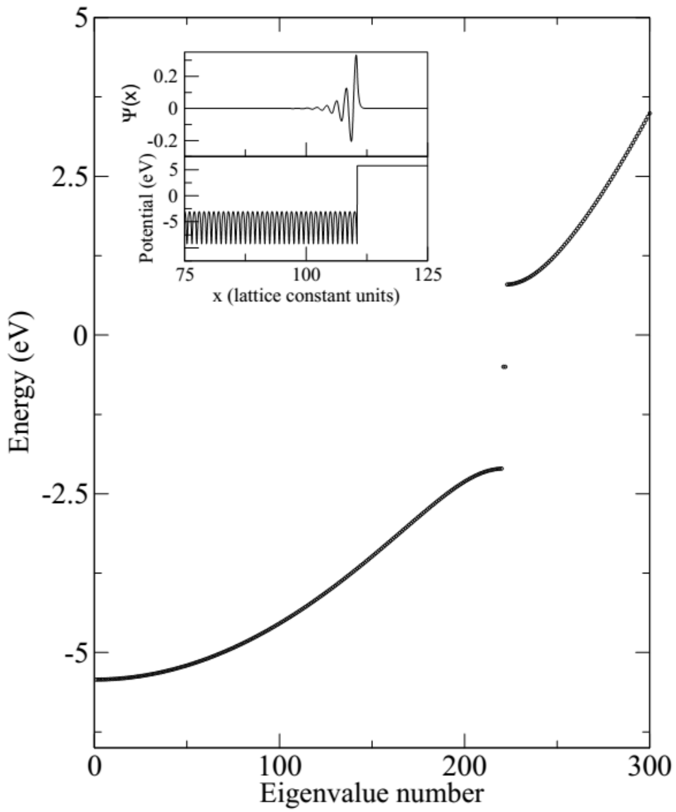
Multiphoton photoemission





Multiphoton photoemission

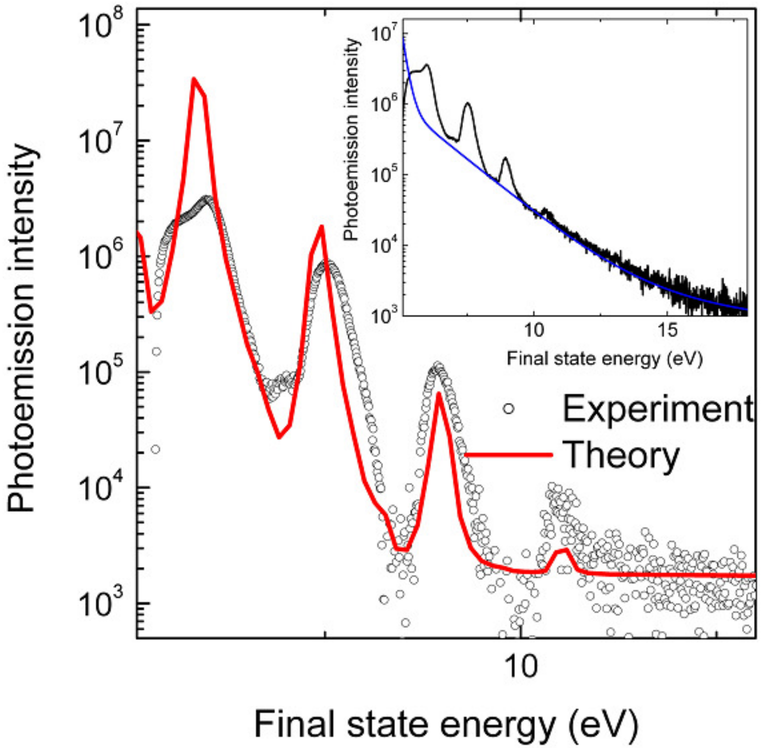
Simple model to describe the excitation of the electron in the surface state



$$V(x) = \sum_n \frac{V_0}{\sqrt{(x - na_0)^2 + 1}} exp(-k_{scr}|x - na_0|).$$

Time dependent Schrödinger equation →

Multiple electronic excitations with laser pulses at high power densities



Good description of the
Electronic excitation

Good agreement of laser power density

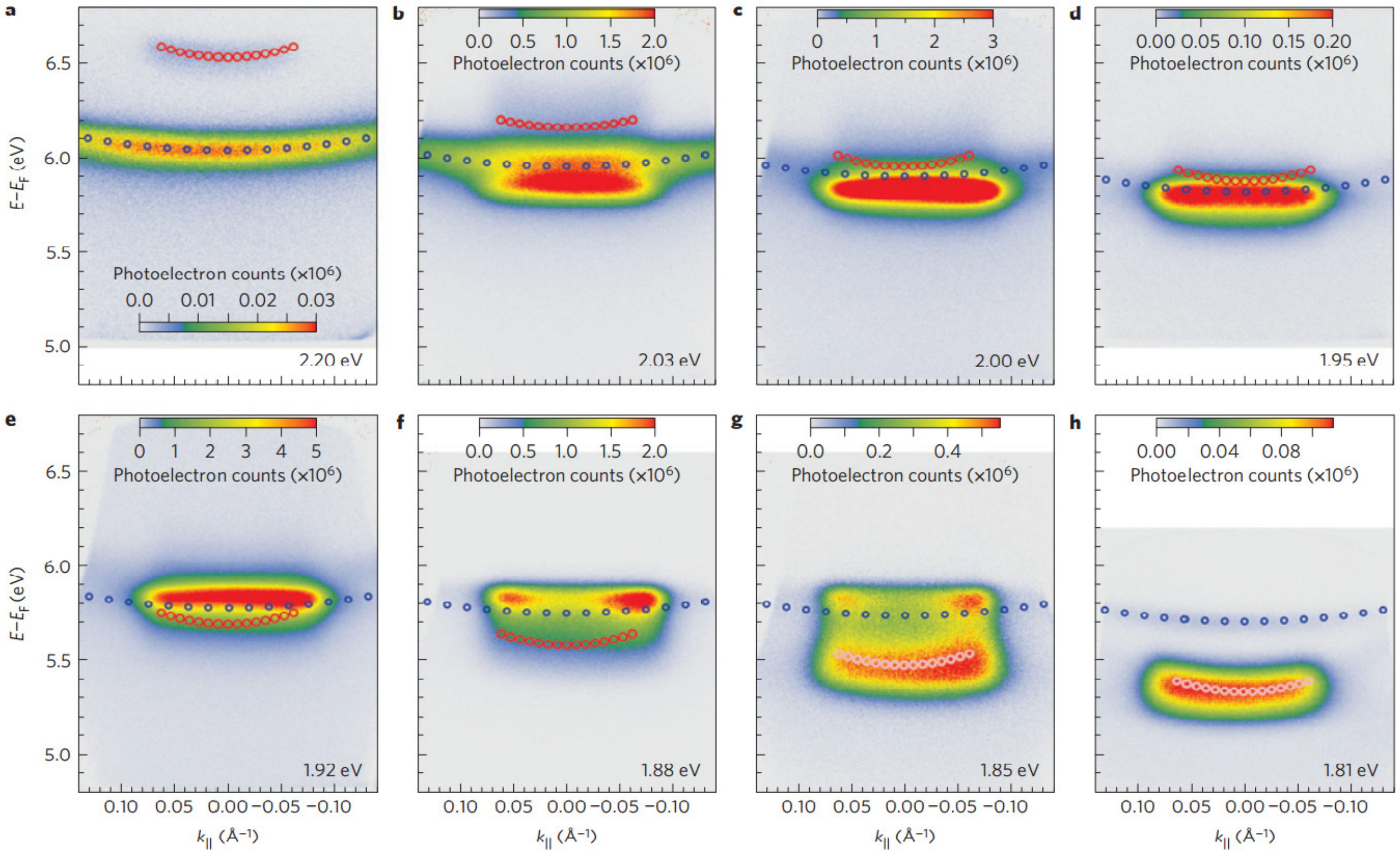
nature physics

LETTERS

PUBLISHED ONLINE: 1 JUNE 2014 | DOI: 10.1038/NPHYS2981

Transient excitons at metal surfaces

Xuefeng Cui[1], Cong Wang[1], Adam Argondizzo[1], Sean Garrett-Roe[2], Branko Gumhalter[3] and Hrvoje Petek[1]*



Conclusion:

electronic structure:
photon energies in the range up to 100 eV

No need to destroy samples

- High repetition rate fs pulses
- Continuous reliable operation
- Dedicated optimized exp. stations

Thanks to

M. Silly
A. Bendounan
C. Chauvet
F. Pressacco
N. Beaulieu

Theory
LSI Palaiseau & ETSF

M.Gatti
V. Veniard
G. Onida
G. Fratesi