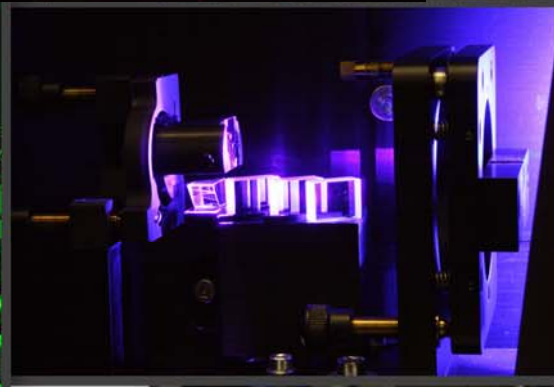
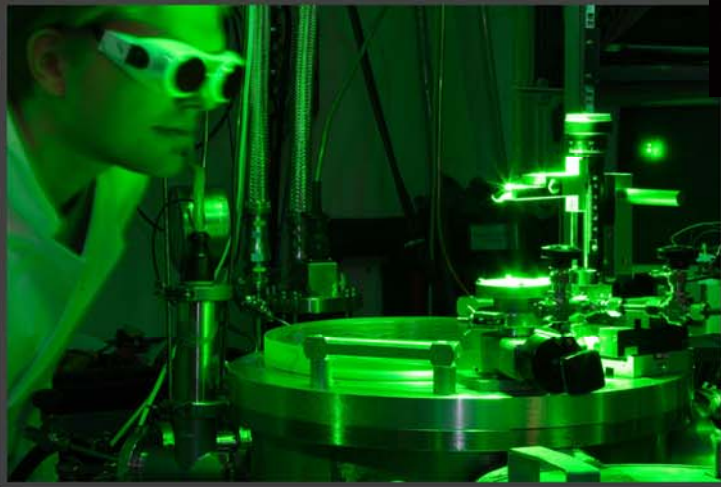
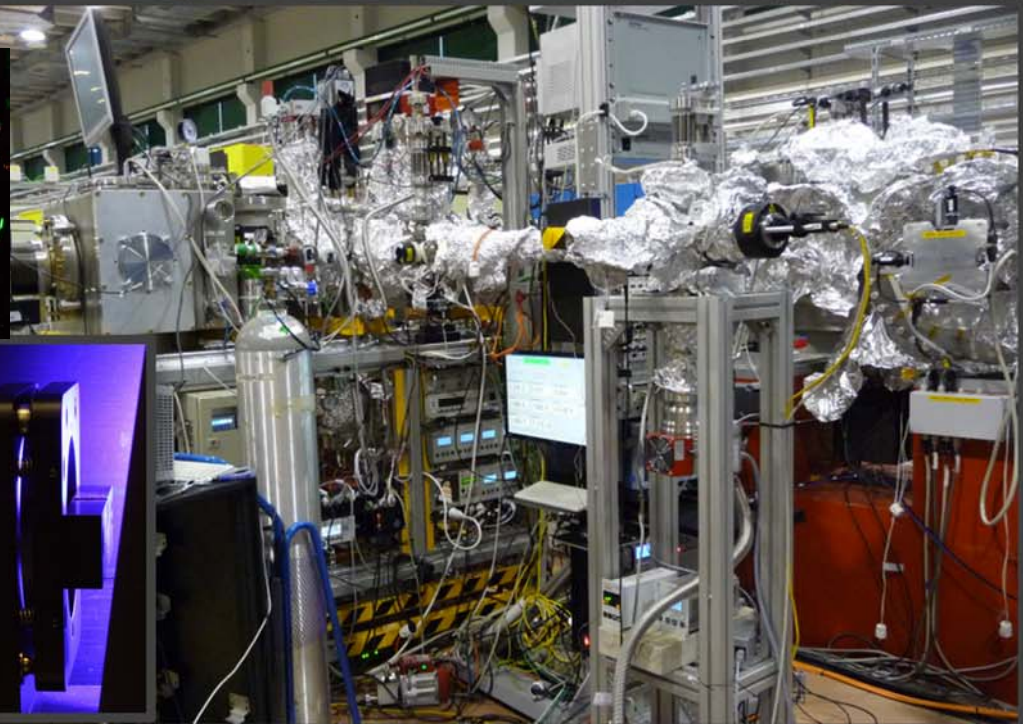
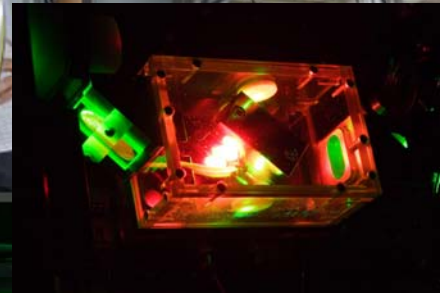
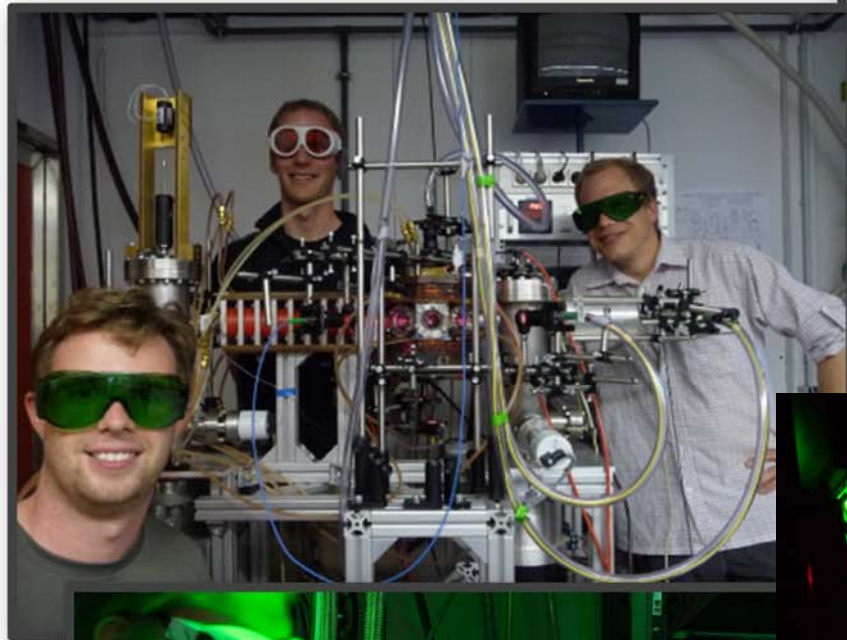




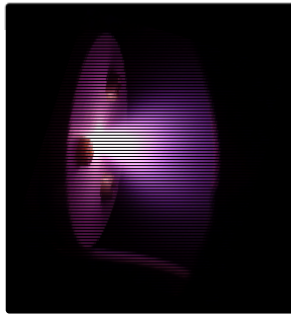
Frank Stienkemeier
Marcel Mudrich
Aaron LaForge

University of Freiburg (FREIB)



Large quantum clusters and cold molecules

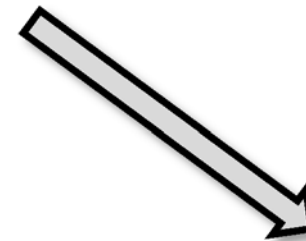
Supersonic Molecular Beams



Rare Gas
Clusters

Helium
Nanodroplets

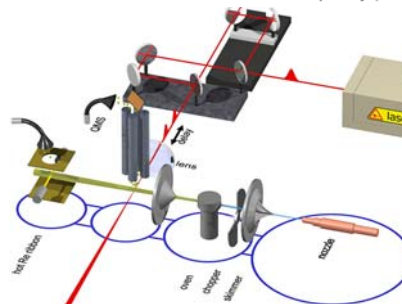
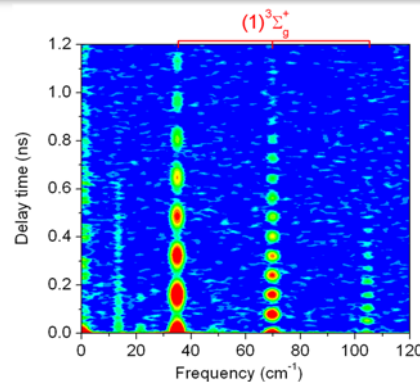
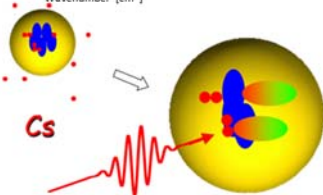
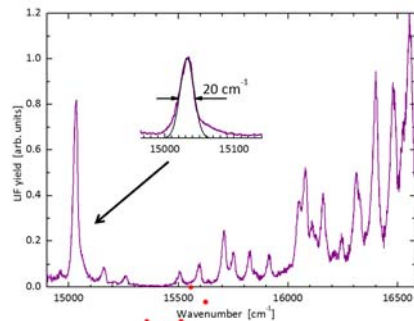
H₂-Clusters



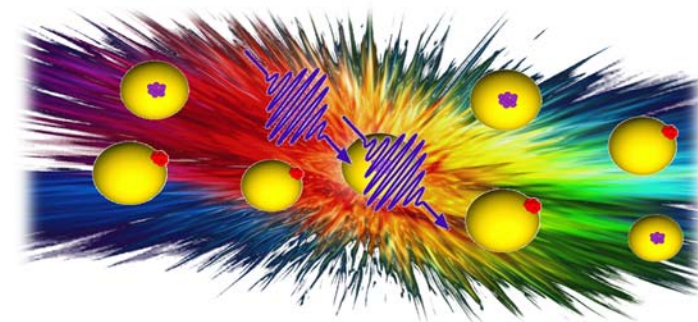
Isolation of molecules and
molecular complexes at low
temperatures

Dynamics

Special properties of
clusters as size-limited bulk
matter

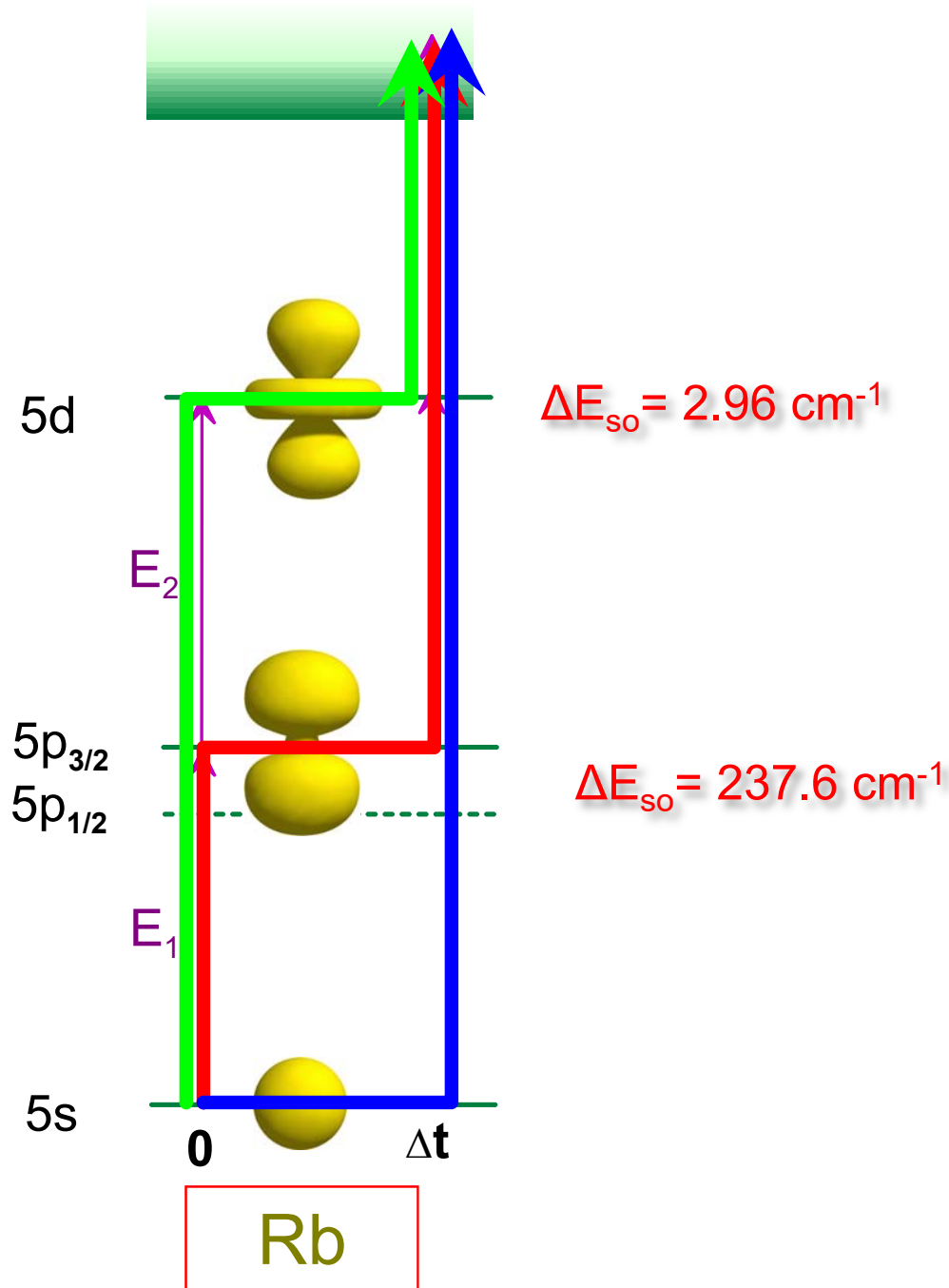


Nanoplasmas



Electron Dynamics

Quantum Interferences – Level scheme of Rb



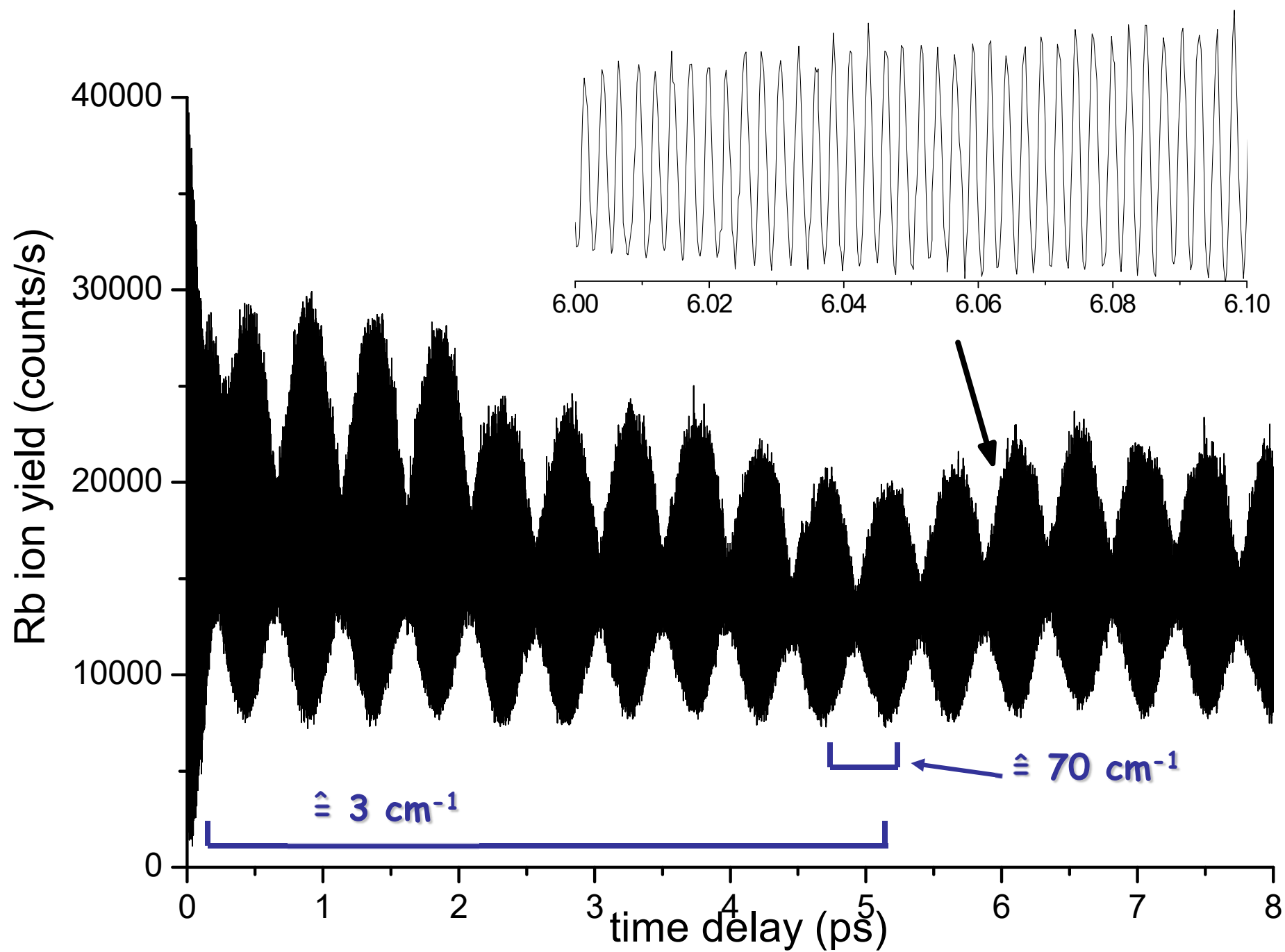
$$5d \leftarrow 5p:$$

$$E_2 = 12885.78 \text{ cm}^{-1}$$

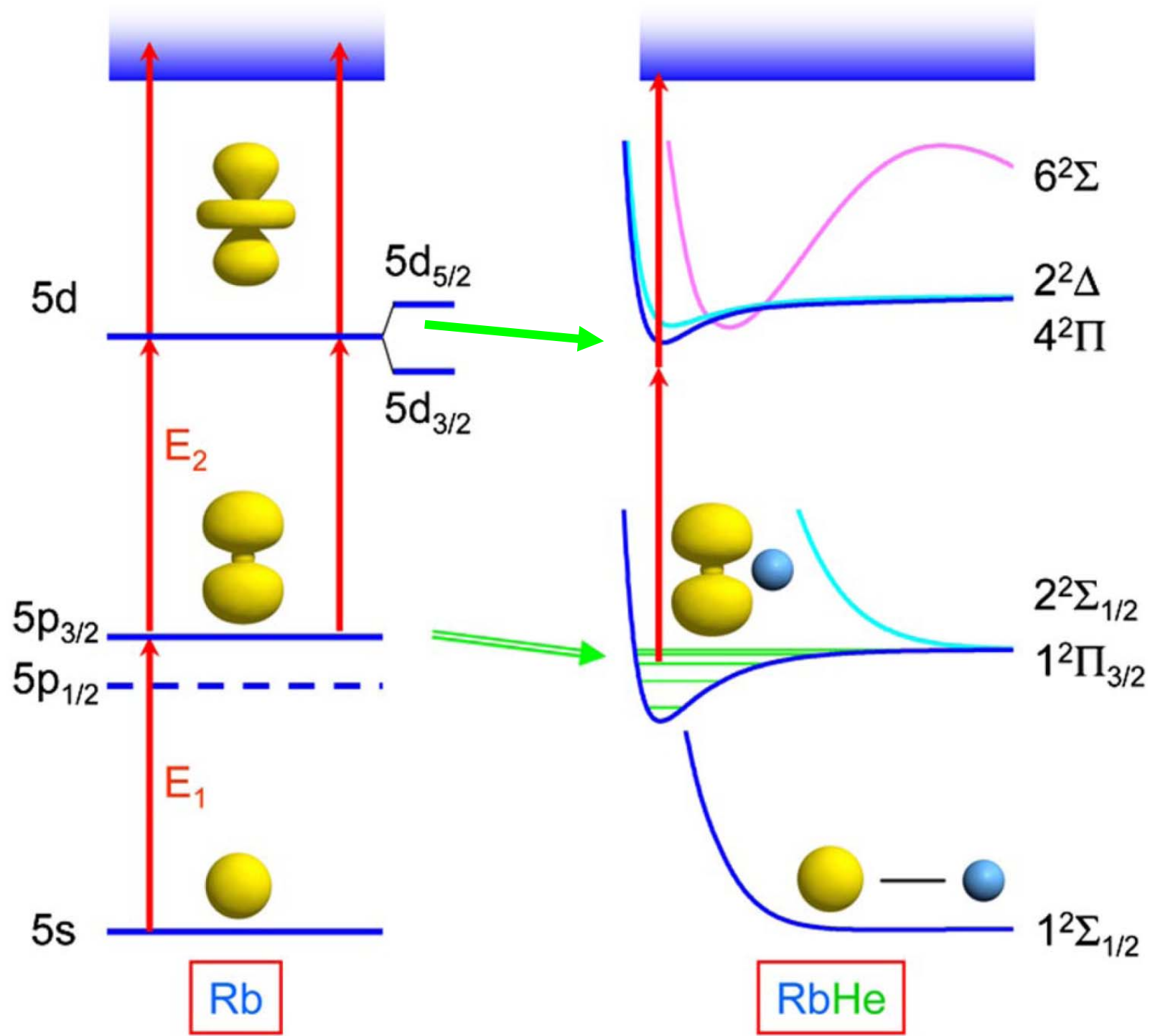
$$5p \leftarrow 5s$$

$$E_1 = 12816.56 \text{ cm}^{-1}$$

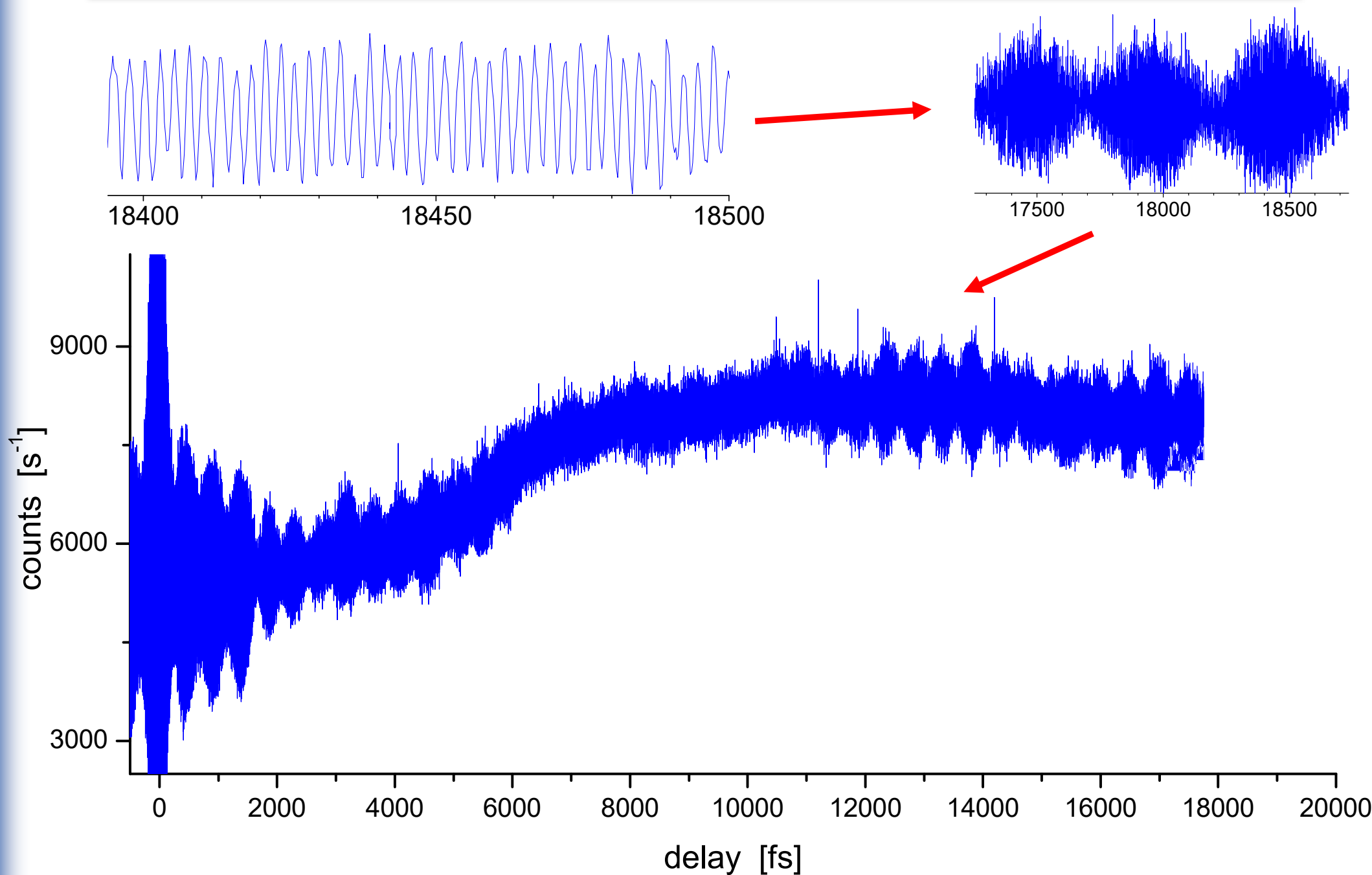
$$\Delta E_{1,2} = 69.22 \text{ cm}^{-1}$$

Ionization of Rb on He_N 

Level scheme of Rb / RbHe

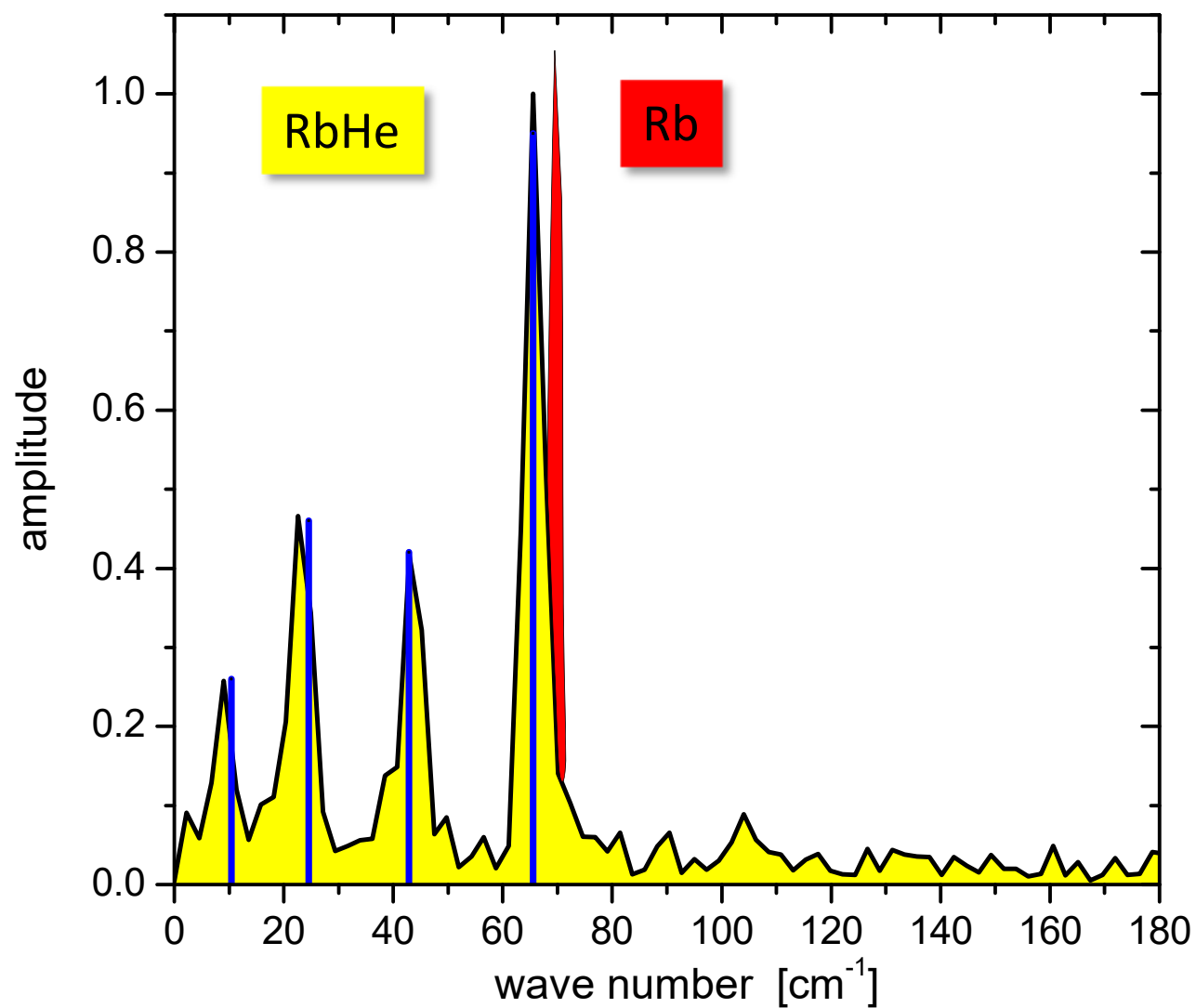


Pump-probe spectrum of RbHe exciplexes

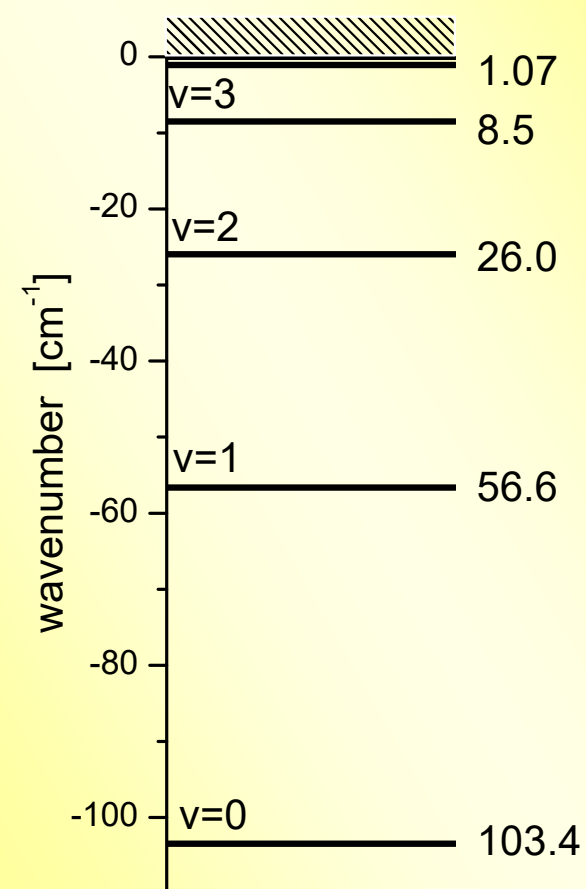


M. Mudrich, P. Claas, G. Droppelmann, C.-P. Schulz, and F. Stienkemeier, Phys. Rev. Lett. **100**, 023401 (2008)

Comparison with vibrational levels from potentials

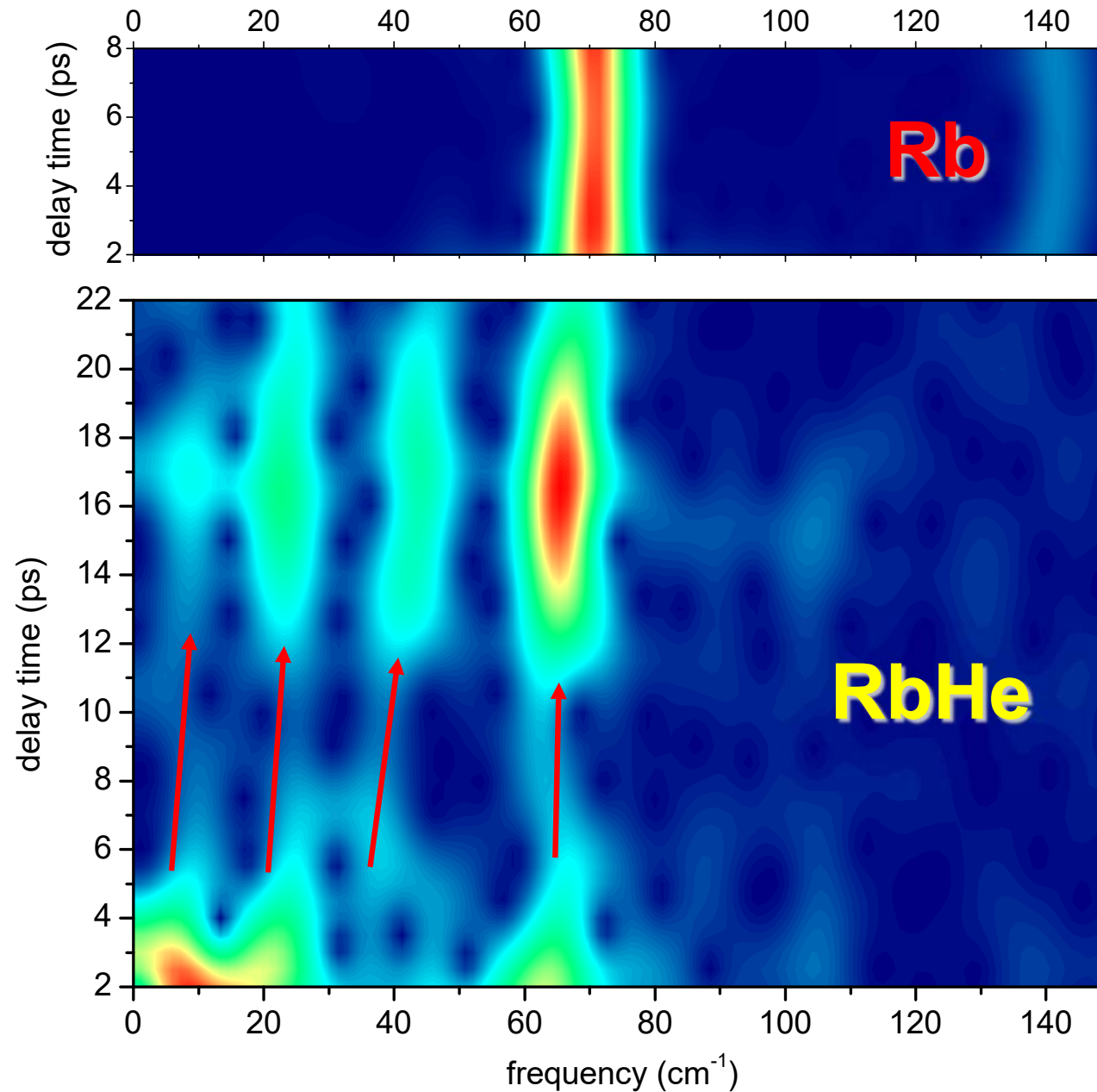


RbHe: vib. levels



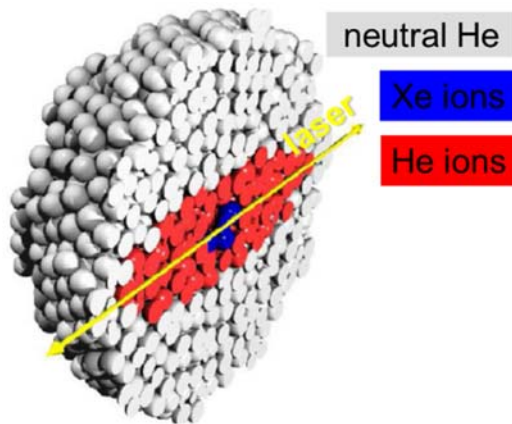
RbHe potential:
J. Pascale, Phys. Rev. A **28**, 632

Spectrogram analysis of envelope



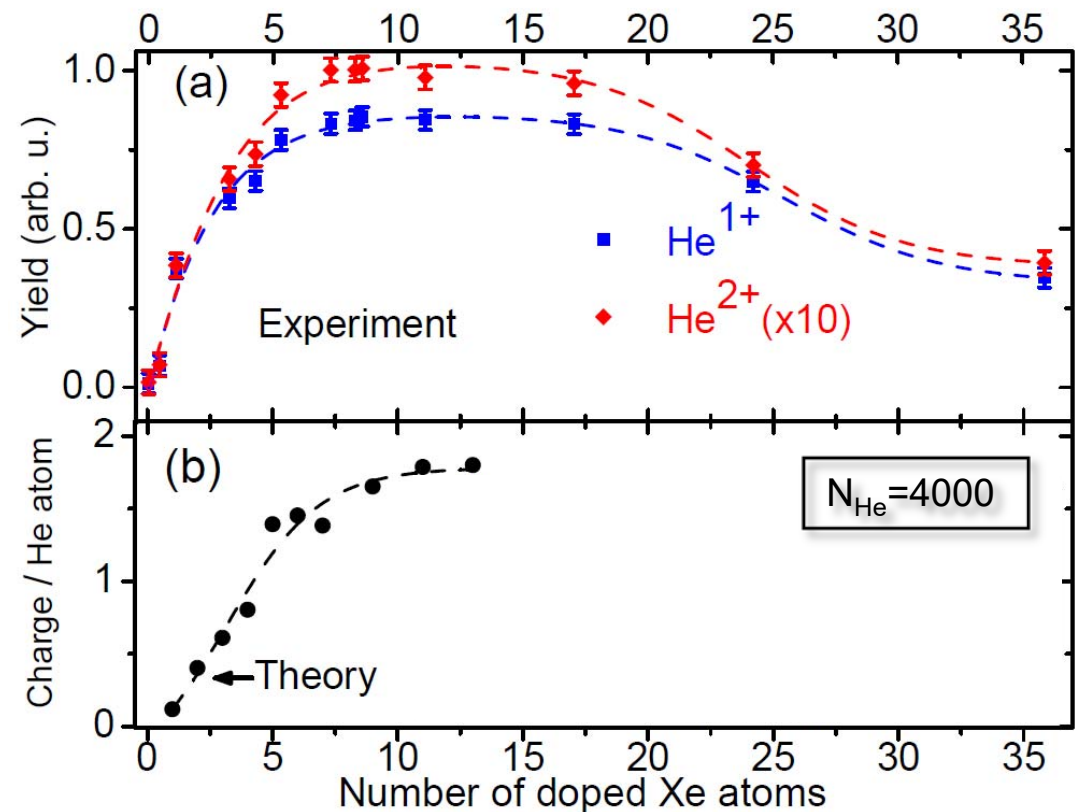
High Fields (IR)

Seeded ignition of nano plasmas



„4 Xe atoms are enough to fully double-ionize even large droplets!“

Mikaberidze et al., PRL **102**, 128102 (2009)

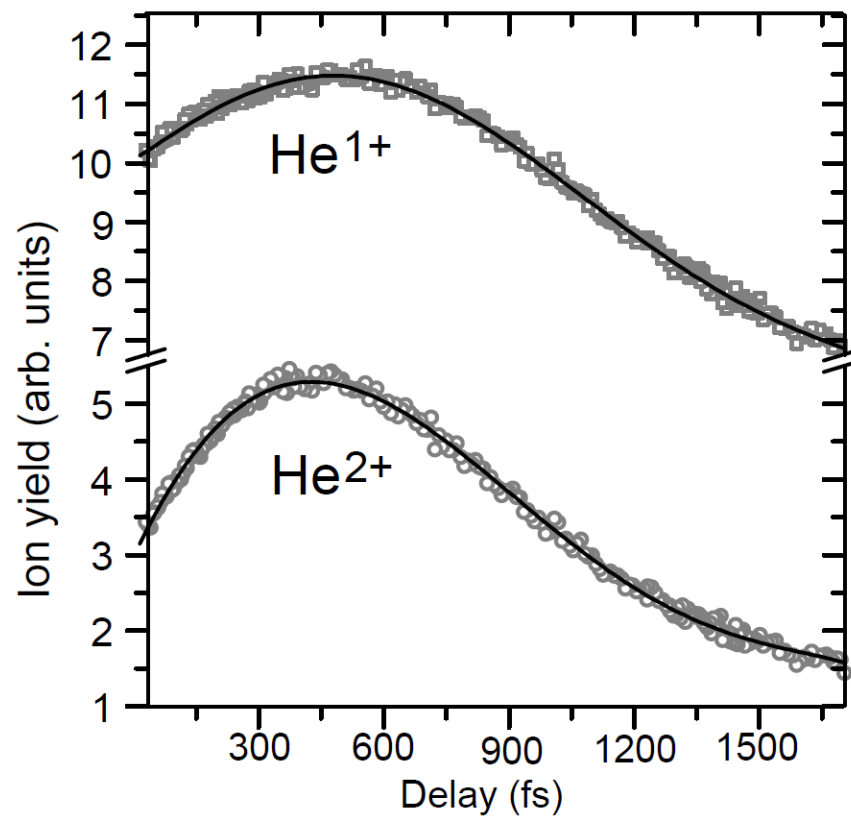


- o High-field IR pulses, few cycle IR pulses
- o Pump-Probe experiments → expansion of cluster, helium plasmon resonance
- o Different location of dopants

Collaboration with R. Moshhammer, et al., MPIK Heidelberg

S. R. Krishnan, et al., Phys. Rev. Lett. **107**, 173402 (2011)
S. R. Krishnan, et al., New J. Phys. **14**, 075016 (2012)
S. R. Krishnan et al., chapter 64 in *Multiphoton Processes and Attosecond Physics*, Springer Verlag (2012)

Probing „longer“ times: Pump-probe dynamics of He ions



Plasmon resonance feature
at 200fs – 1000fs

- Fast/narrow resonance at low doping levels
- Very similar dynamics irrespective of species
- Strong dependence of resonance position / width on droplet size

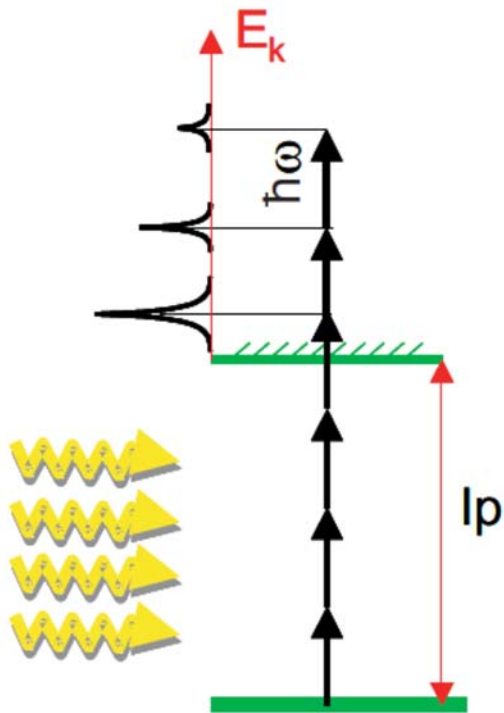
Helium plasma resonance !

High Photon Energies (XUV)

Laser - atom interaction in the IR

Weak field: Multiphoton regime

$$I \leq 10^{14} \text{ W/cm}^2$$



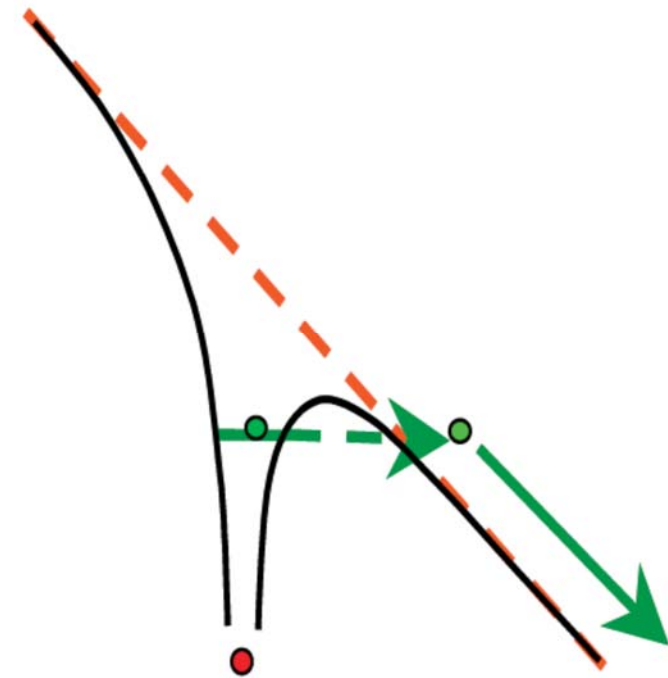
Keldysh parameter $\gamma_K = \sqrt{\frac{I_P}{2U_P}}$

$\gamma_K > 1$: Multiphoton

$\gamma_K < 1$: Tunneling

Strong field: Tunneling / Over-barrier regime

$$I \geq 10^{14} \text{ W/cm}^2$$



Ponderomotive potential: Average kinetic energy of electrons oscillating in the laser field

$$U_P \propto I \lambda^2$$

New femto/attosecond light sources



Elettra and FERMI lightsources



Low Density Matter Beamline

FEL Experiments with Beams of Molecules, Clusters,
Molecular Complexes and Nanostructures

Collaborators located in:

Freiburg	Raphael Katzy Aaron LaForge Viktor Lyamayev (now XFEL, Hamburg) Marcel Mudrich Frank Stienkemeier (Coordinator)
Berlin	Maria Krikunova Thomas Möller (Coordinator Detectors) Yevheniy Ovcharenko
Lausanne	Nils B. Brauer Marcel Drabbels
Milan	Michele Devetta Tommaso Mazza (now XFEL, Hamburg) Paolo Piseri
Trieste	Michele Alagia Carlo Callegari (Local Coordinator) Marcello Coreno Michele Di Fraia Paola Finetti Cesare Grazioli Oksana Plekan Kevin Prince Robert Richter
Rome	Lorenzo Avaldi Patrick O'keeffe Stefano Stranges

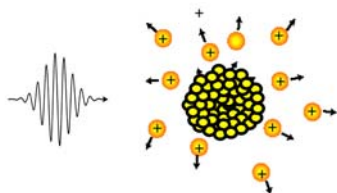


SAPIENZA
UNIVERSITÀ DI ROMA

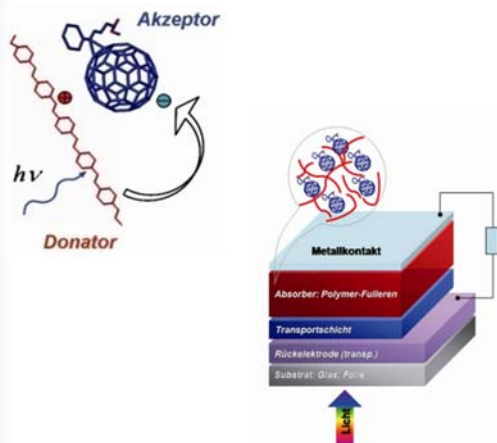


The Low Density Matter Beamline

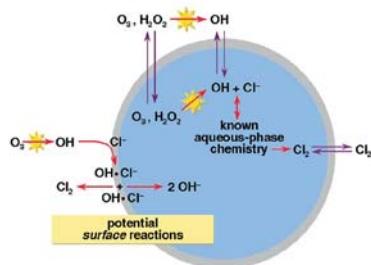
Fundamental physics



Material science



Chemistry/Biochemistry

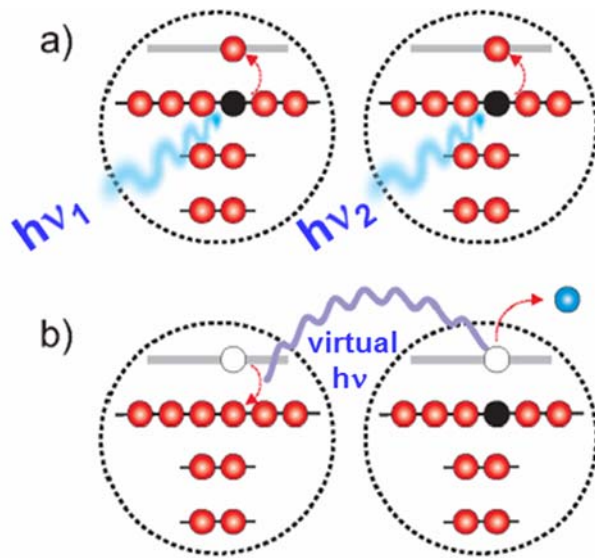


Aerosol / Atmospheric chemistry



V. Lyamayev, Y. Ovcharenko, R. Katzy, M. Devetta and L. Bruder et. al, J. Phys. B **46** 164007 (2013)

Collective Autolionization – Interatomic Coulombic Decay



ICD electron:

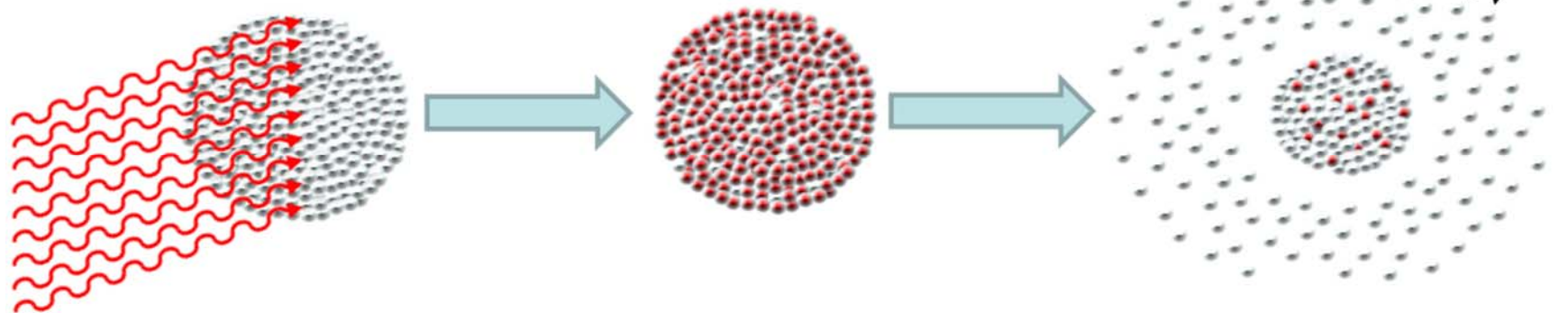
$$\text{KER} = 2 \times E_{\text{He}^*} - \text{IP}_{\text{He}}$$

He(1s2p ¹P): 17.8eV

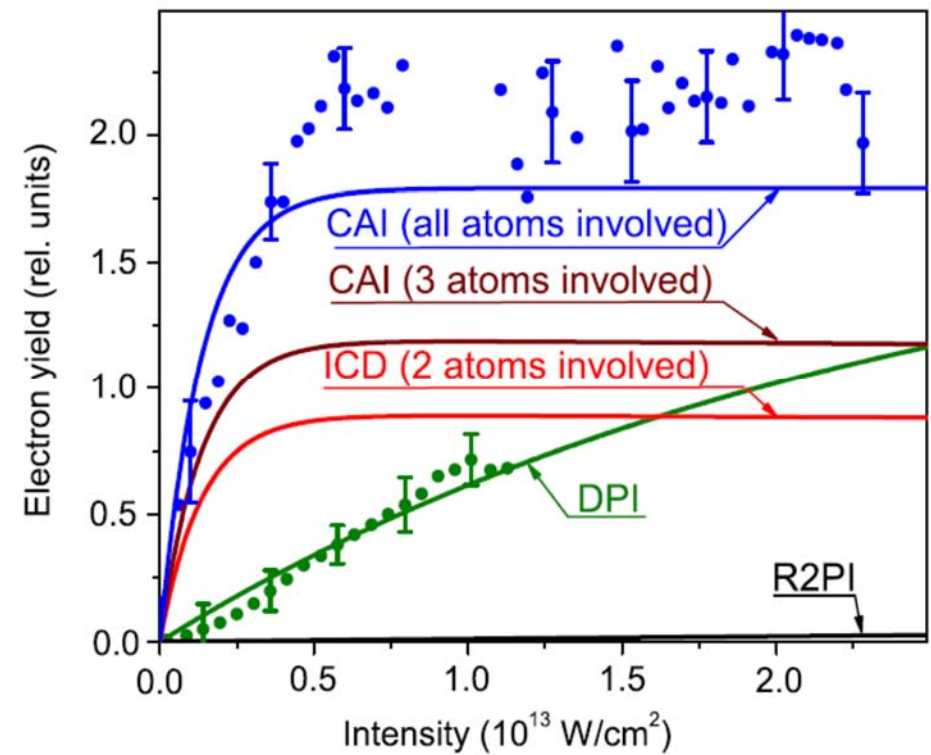
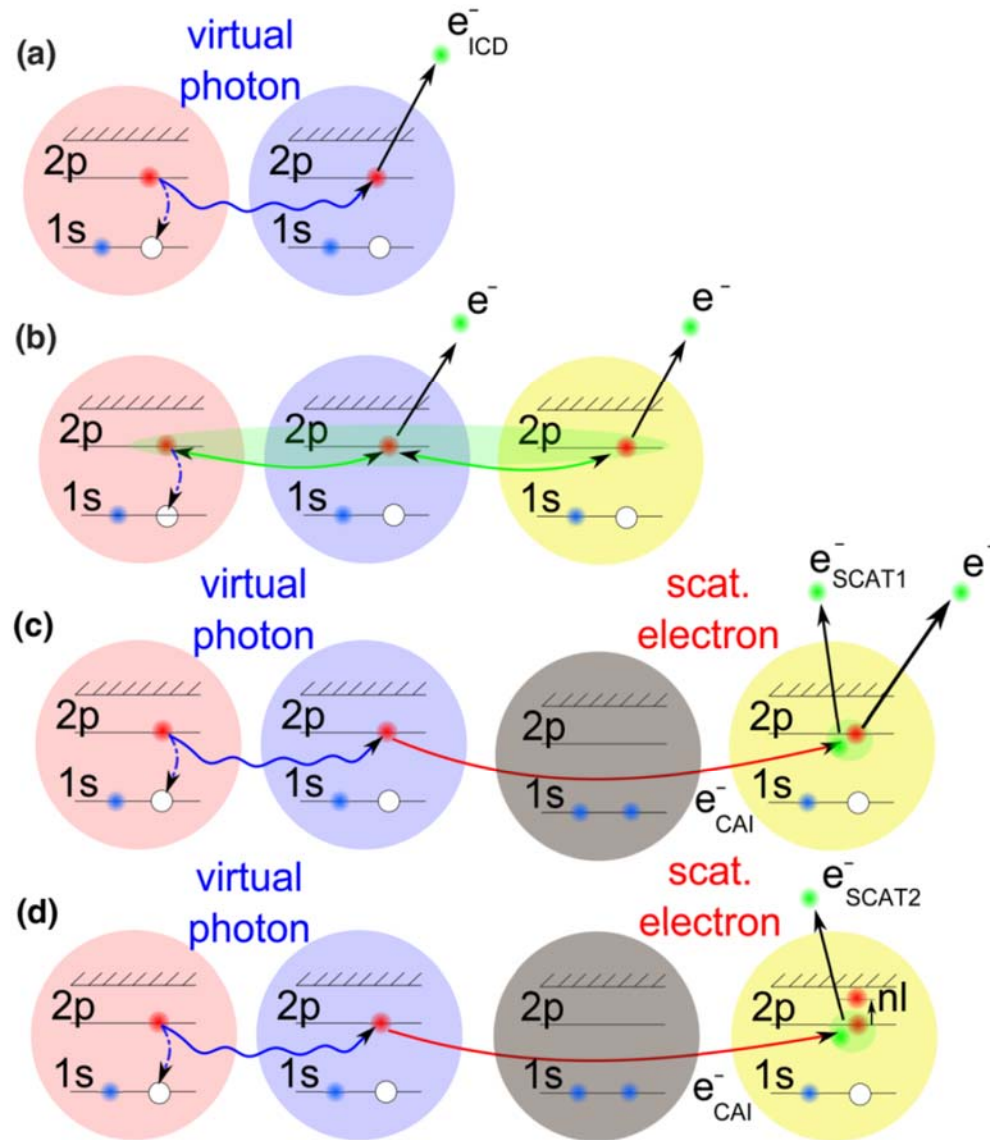
He(1s2s ¹S): 16.6eV

Nanoplasma formation!

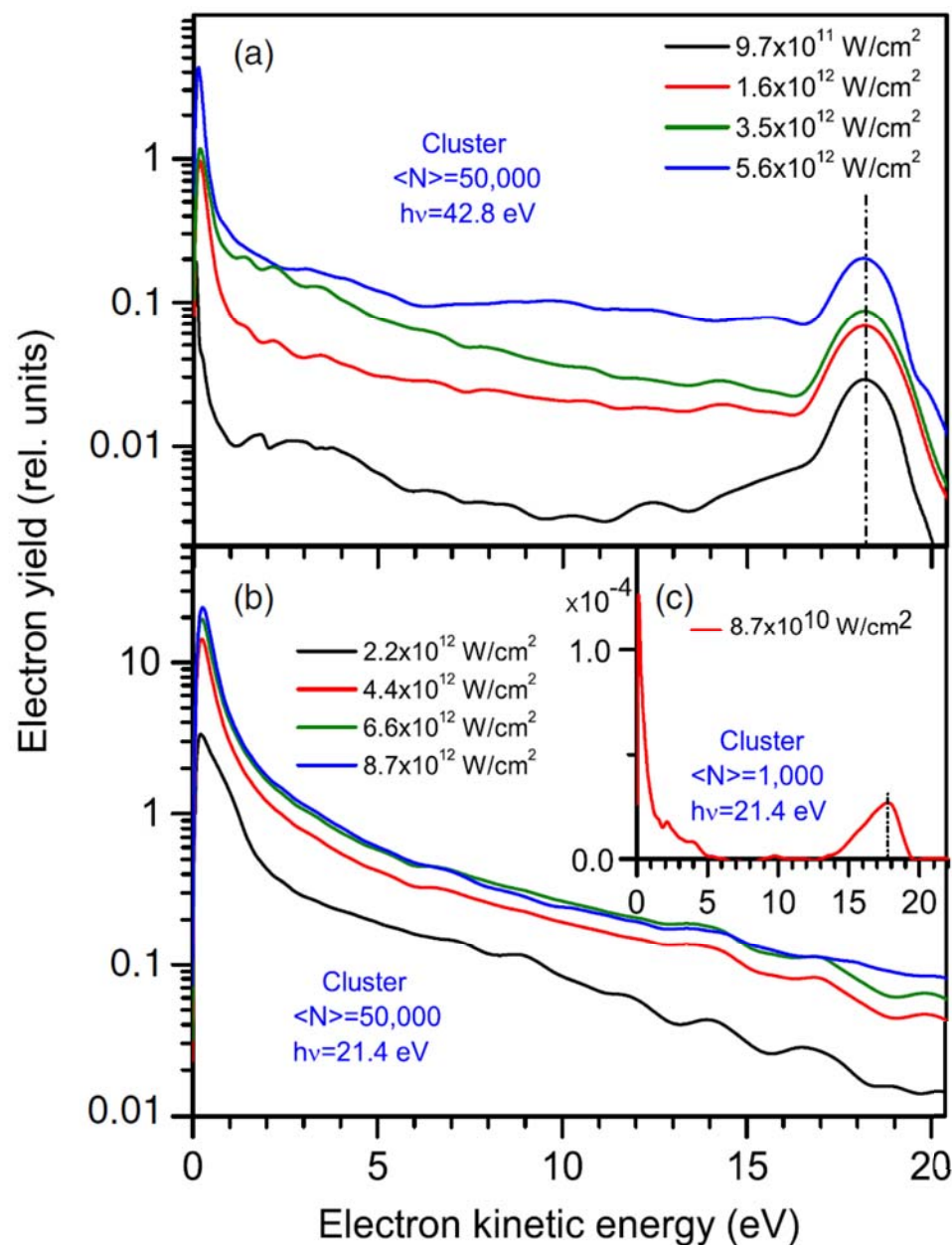
Coulomb explosion of the cluster



Collective manybody autoionization dominates

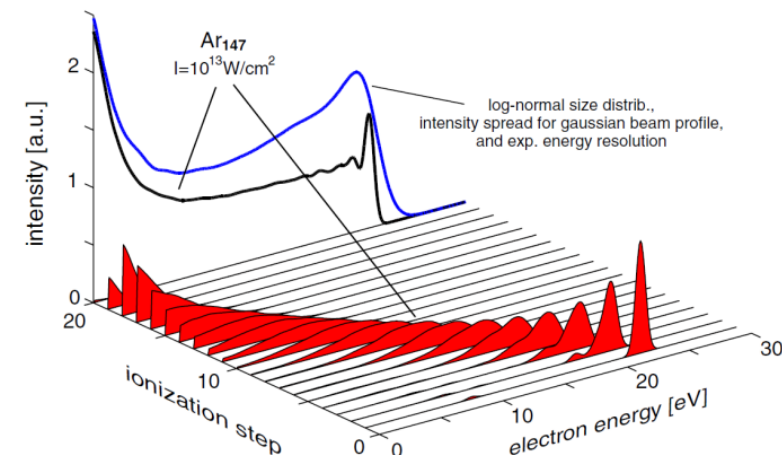


Photoelectron spectra



$h\nu = 42.8$ eV

$h\nu = 21.4$ eV



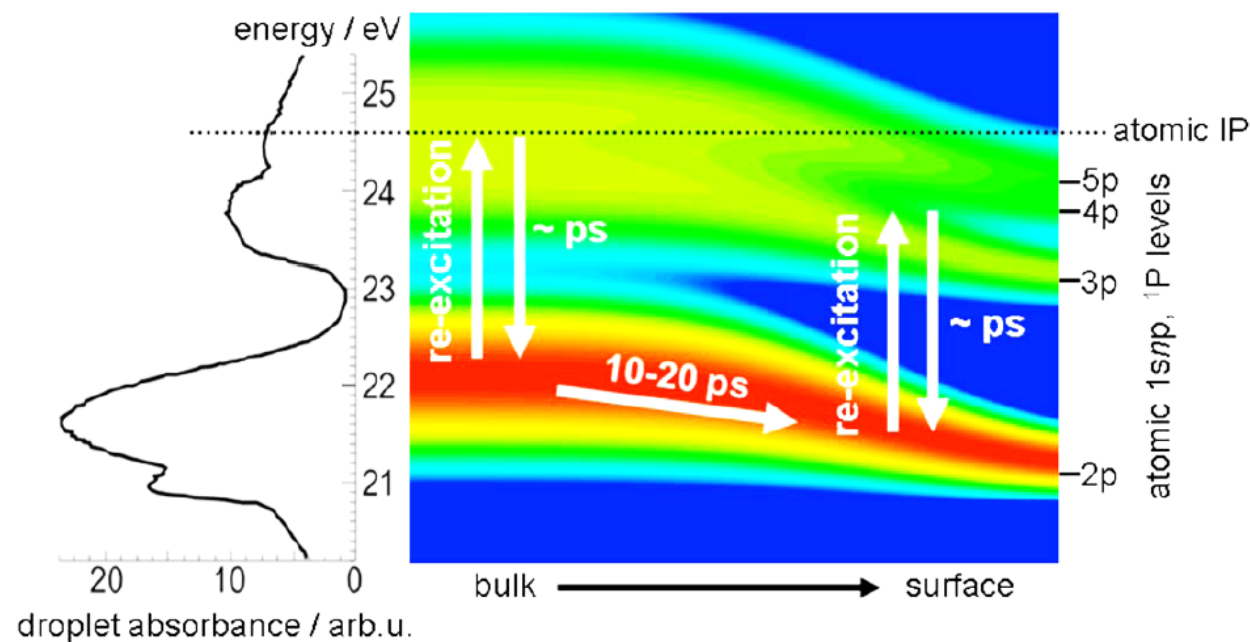
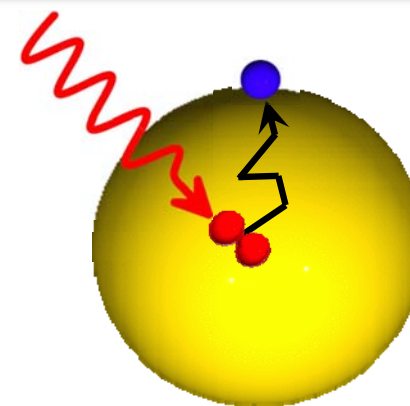
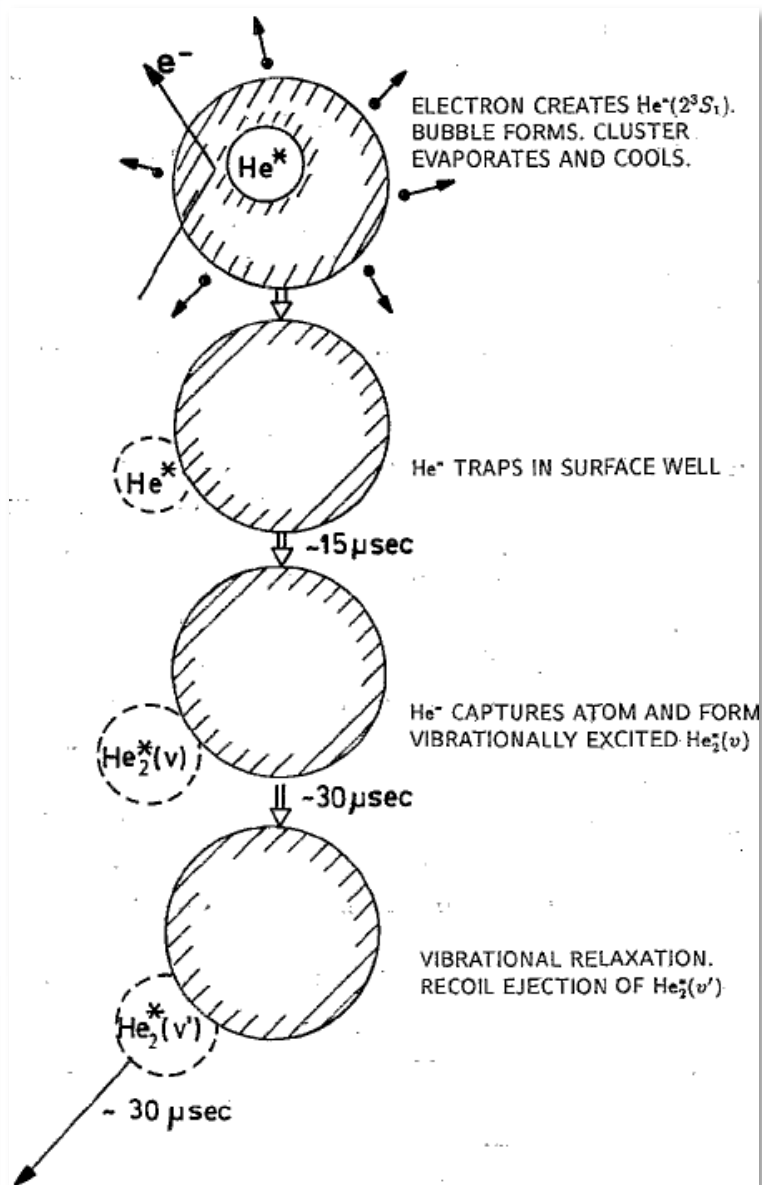
Ar clusters

C. Bostedt et al., PRL **100**, 133401 (2008);

Photoelectron Spectra: kinetic energies of electrons identify different processes!

Ovcharenko Y, et al., Phys. Rev. Lett. **112**, 073401(2014)

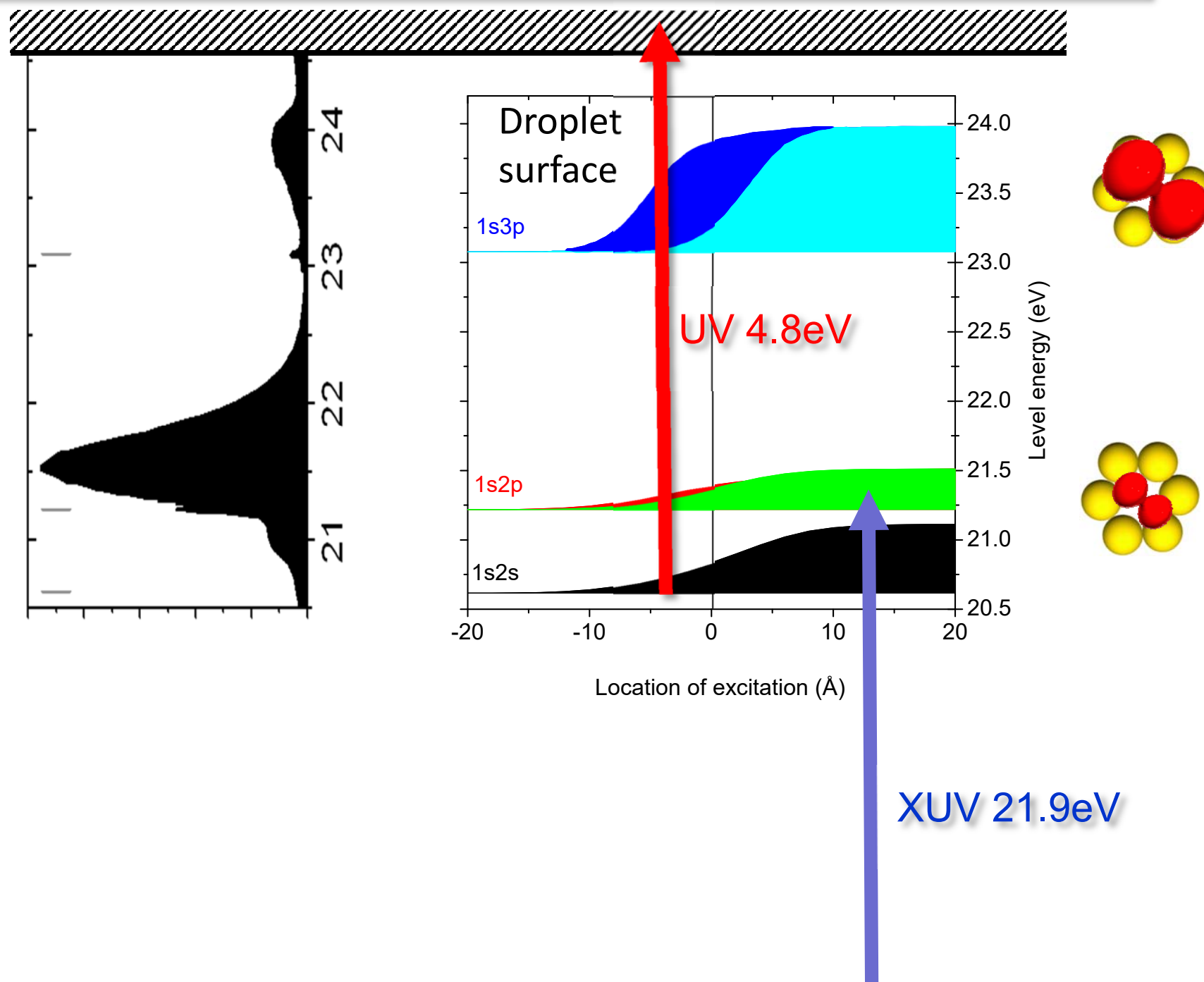
Dynamics



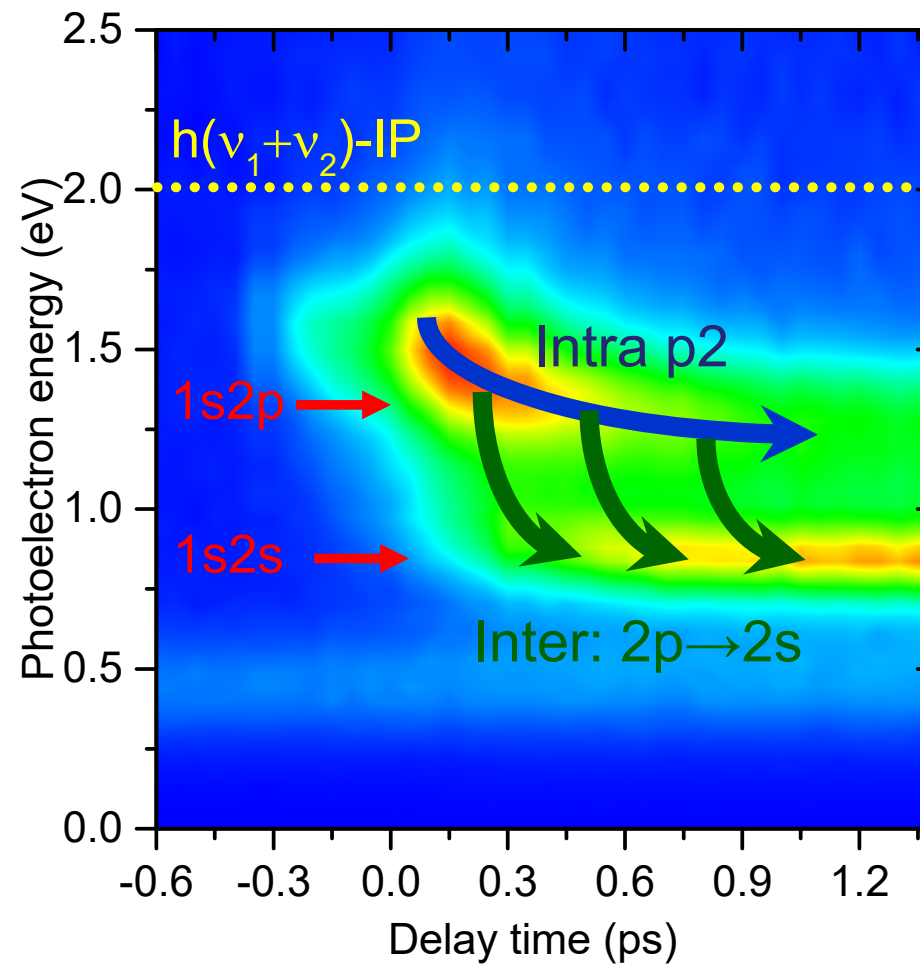
Buchenau, Toennies et al.,
J. Chem. Phys. **95**, 8134 (1991)

O. Bünermann, O. Kornilov, S. Leone, D. Neumark, and O. Gessner., IEEE J. Sel. Top. Quantum Electron. **18**, 308 (2012)

XUV – UV pump-probe experiment



Relaxation upon 2p excitation



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Ingo Hügel
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Aaron LaForge
Marcel Mudrich

Heinz-Peter Breuer
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Thomas Fennel

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EPFL Lausanne

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Milan

Giuseppe Sansone

Paolo Piseri

XFEL Hamburg

Viktor Lyamayev

Tommaso Mazza

Trieste

Michele Alagia

Carlo Callegari

Marcello Coreno

Michele Di Fraia

Paola Finetti

Oksana Plekan

Kevin Prince

Robert Richter

Rome

Patrick O'keeffe
Stefano Stranges

Low Density Matter Collaboration

Last helium and water runs:

Carlo Callegari

Alessandra Ciavardini

Michele Di Fraia

Paola Finetti

Aaron LaForge

Patrick O'Keeffe

Yevheniy Ovcharenko

Oksana Plekan

Robert Richter

Stefano Stranges

Marcel Drabbels

Marcello Coreno

Michele Devetta

Raphael Katzy

Marcel Mudrich

Arek Mika

Paolo Piseri

Kevin Prince

Frank Stienkemeier

Micheal Ziemkiewicz

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Trieste

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Michele Di Fraia

Paola Finetti

Cesare Grazioli

Oksana Plekan

Kevin Prince

Rome

Lorenzo Avaldi

Patrick O'keeffe

Stefano Stranges

FERMI machine team

€€€: DFG