

# New frontiers in Atomic, Molecular and Cluster Physics and Chemistry

ICTP, Adriatico Guesthouse  
Trieste, Italy  
14–15 November 2011



www.elettra.trieste.it/VAMC

## Invited Speakers

Nora Berrah (USA)  
Giovanni De Nino (Italy/  
Slovenia)  
Reinhard Dörner (Germany)  
Tim Laarmann (Germany)  
Peter Lambropoulos (Greece)  
Tobias Lau (Germany)  
Michael Meyer (Germany)  
Catalin Miron (France)  
Thomas Möller (Germany)  
M Novella Piancastelli (Sweden)  
Robert Richter (Italy)  
Jan-Michael Rost (Germany)  
Jan-Erik Rubensson (Sweden)  
Giuseppe Sansone (Italy)  
Toshinori Suzuki (Japan)  
Simone Techert (Germany)  
Kiyoshi Ueda (Japan)  
Joachim Ullrich (Germany)

## Organizing Committee

Carlo Callegari  
Kevin Prince  
Frank Stienkemeier  
Thomas Moeller  
Maria-Novella Piancastelli  
Marcello Coreno  
Lorenzo Avaldi  
Stefano Stranges

# Program

## MONDAY 14.11

8:30 8:50 Registration  
8:50 9:00 Welcome speech

*Chair: William M. Fawley*

### 1. Overviews: Science and machine global perspectives

9:00 9:35 Maria Novella Piancastelli  
*"Recent advances in atomic and molecular physics at the new synchrotron and free-electron laser sources"*

9:35 10:10 Jan-Michael Rost  
*"Massive parallel ionization through intense short wavelength light"*

10:10 10:45 Giovanni De Ninno  
*"Principles and performance of VUV/X-ray light sources"*

10:45 11:05 *COFFEE BREAK*

### 2. FEL Facilities

*Chair: Michael Meyer*

11:05 11:40 Nora Berrah  
*"Probing Molecules from Within using Ultra-Intense and Ultra-Fast X-Rays from the LCLS FEL"*

11:40 12:15 Joachim Ullrich  
*"Ultrafast Dynamics: Pump-Probe Experiments at Free Electron Lasers"*

12:15 12:50 Kiyoshi Ueda  
*"FEL experiments in Japan: from EUV to X-rays"*

12:50 14:05 *LUNCH*

### 3. Clusters, droplets, liquids, scattering

*Chair: Paolo Piseri*

14:05 14:40 Simone Techert  
*"Studies of the dynamics of bulk chemistry with FEL radiation - state of the art and perspectives"*

14:40 15:15 Thomas Möller  
*"Ultrafast processes and imaging of clusters"*

15:15 15:50 Tim Laarmann  
*"Coherent superposition of two rotational quantum states in the time domain: Microwave spectroscopy without microwaves"*

15:50 16:25 Tobias Lau  
*"X-ray magnetic circular dichroism spectroscopy of size selected cluster ions: From spin coupling and orbital quenching to magnetic phase transitions"*

16:25 16:45 *COFFEE BREAK*

#### **4. High fields**

*Chair: Paolo Decleva*

16:45 17:20 Peter Lambropoulos  
*"Multiple Ionization under Strong Short Wavelength Radiation"*

17:20 17:55 Giuseppe Sansone  
*"Molecular attosecond dynamics"*

17:55 18:30 Reinhard Dörner  
*"Multiparticle Coincidences Studies of Photoionization of Quantum Halos"*

18:30 19:30 Poster Session

19:30 *DINNER*

### **TUESDAY 15.11**

#### **5. Advanced applications of Synchrotron Radiation**

*Chair: Maria Novella Piancastelli*

9:00 9:35 Jan-Erik Rubensson  
*"Resonant Inelastic Soft X-ray Scattering Applied to Free Atoms and Molecules"*

9:35 10:10 Catalin Miron  
*"Electron spectroscopy – a probe for fundamental properties of isolated species"*

10:10 10:30 *COFFEE BREAK*

#### **6. Pump-probe**

*Chair: Marcel Drabbels*

10:30 11:05 Robert Richter  
*"Two-color experiments at the Gasphase beamline @ ELETTRA – CW and time-resolved studies"*

11:05 11:40 Toshinori Suzuki  
*"Time-Energy Mapping of Photoelectron Angular Distribution"*

11:40 12:15 Michael Meyer  
*"Atomic photoionization in intense XUV and optical laser fields"*

12:15 Closing speech

**VISIT TO Elettra/FERMI** (Schedule to be determined)

# **Recent advances in atomic and molecular physics at the new synchrotron and free-electron laser sources**

Maria Novella Piancastelli  
*Uppsala University, Sweden*

Recent years have witnessed a tumultuous development in the field of electronic structure and dynamics of isolated atomic and molecular species, mainly stimulated by the advent of new and more powerful light sources. I will review some of the latest breakthroughs which have taken place at the most recently operational synchrotron and free electron laser sources, together with the new research prospects now foreseeable.

# **Massive parallel ionization through intense short wavelength light**

Jan M Rost

*Max Planck Institute for the Physics of Complex Systems, Dresden*

We investigate multiphoton absorption by photons with frequencies in the XUV regime and higher.

Here, nonlinear photon absorption proceeds via many electrons absorbing one photon each which gives rise to a new kind of many electron dynamics in extended systems such as clusters and biomolecules. It does not occur with traditional intense infrared light, since there nonlinear photoabsorption typically couples many photons to only a few electrons.

# **Principles and performance of VUV/X-ray light sources**

G. De Ninno

*Sincrotrone Trieste and University of Nova Gorica*

We review the working principle, the performance and the perspectives of light sources built in the aim of generating VUV/X-ray radiation with laser-like properties (high brilliance, sub-picosecond pulse duration, transverse and longitudinal coherence, good shot-to-shot reproducibility). We will in particular consider the case of synchrotrons and free-electron lasers, and carry out a comparison between free-electron lasers based on self-amplified spontaneous emission and on high-gain harmonic generation.

# Probing Molecules from Within using Ultra-Intense and Ultra-Fast X-Rays from the LCLS FEL

Nora Berrah,  
*Physics Department, Western Michigan University*

The response of molecular systems to the ultra-intense, femtosecond x-ray radiation from the hard x-ray FEL, the Linac Coherent Light Source (LCLS), was investigated. Sequential multiphoton ionization, frustrated absorption [1] and double core hole production mechanisms [2,3] will be presented.

[1] M. Hoener *et al.*, *Phys. Rev. Lett.* **104**, 253002 (2010)

[2] L. Fang *et al.*, *Phys. Rev. Lett* **105**, 083005 (2010).

[3] N. Berrah L. Fang, B. Murphy, T. Osipov, K. Ueda, E. Kukk, R. Feifel, P. van der Meulen, P. Salén, H. T. Schmidt, R. D. Thomas, M. Larsson, R. Richter, K. C. Prince, J. D. Bozek, C. Bostedt, S. Wada, M. Piancastelli, M. Tashiro, M. Ehara, *PNAS*, (in press 2011)

# Ultrafast Dynamics: Pump-Probe Experiments at Free Electron Lasers

J. Ullrich

*Department for Experimental Many-Particle Quantum Dynamics  
Max-Planck Institute for Nuclear Physics, D-69117 Heidelberg, Germany*

One of the most exciting opportunities opened by Free Electron Lasers (FEL) is the feasibility of performing, for the first time, pump-probe experiments in the VUV, EUV and X-ray wavelength regimes with femtosecond time resolution or even below. Here, a first light pulse (IR, Vis, EUV, EUV or X-ray) initiates dynamics, like a chemical reaction, a phase transition, spin-, orbital, or charge-density waves in solids and a second pulse, impinging at a variable but well-defined time delay, probes the motion.

In the talk, a first series of such experiments, performed at the VUV-FEL in Hamburg, FLASH, the SCSS test facility in Japan as well as pioneering measurements at the LCLS X-ray FEL will be presented. At FLASH and SCSS the VUV-pulse has been split by a back-reflecting mirror that is cut onto two halves. One of the pulses can then be delayed by moving the two half-mirrors with respect to each other reaching sub-femtosecond accuracy. In a demonstration experiment the vibrational wave-packet motion in deuterium molecular ions with a round-trip time of about 22 fs could be traced, indicating a time-resolution of better than 10 fs. Moreover, the isomerization time in VUV-excited acetylene evolving into vinylidene cations proceeding within about 50 fs was measured for the first time, ending a 20 years controversial debate. More recently, the dynamics of a suite of other charge migration reactions was investigated via time-resolved many-particle fragment detection in a reaction microscope (REMI) watching atoms move in real-time. Using the CAMP instrument at LCLS first optical pump – X-ray probe experiments have been performed on aligned molecules, clusters and biological nano-crystals highlighting the rich future potential of these methods envisioning tracing Ångstrom spatial changes at femtosecond time resolution.

At the same time we witness tremendous technological progress at FELs: Non-linear autocorrelation traces showed sharp peaks with a FWHM in the order of the coherence length of the radiation (4 fs at FLASH and 10 fs at SCSS), explained by the statistical nature and coherence properties of the FEL pulses and pointing towards exciting possibilities to perform attosecond X-ray – X-ray pump-probe experiments at the LCLS. In addition, new machine developments, like “slotted spoilers”, “longitudinal space charge amplifiers” and high-harmonic generation or lasing in FEL-excited targets nurture the expectation to create attosecond pulses that might even be synchronized with an optical laser on a sub-femtosecond time-scale, which would open the door towards keV-attosecond science.

## **FEL experiments in Japan: from EUV to X-rays**

Kiyoshi Ueda

*IMRAM, Tohoku University, Sendai 980-8577, Japan*

In 2008, the SPring-8 Compact SASE Source (SCSS) test accelerator, started operation in Japan. It provides linearly polarized EUVFEL pulses in the wavelength region of 51-61 nm. We have been investigating multi-photon multiple ionization and subsequent relaxation processes in atoms, molecules, and clusters irradiated by EUVFEL pulses, using ion and electron momentum spectroscopy and pump-probe techniques. In June 2011, SCSS XFEL, nicknamed "SACLA" lased and started commissioning. Our scientific program with SACLA is largely based on research problems which constitute a bridge between atoms and small molecules and more complex systems. We plan to study, for example, light-induced phase transition in clusters and light-induced structural change of photo-reactive bio-molecules, using time-resolved coherent X-ray imaging combined with Coulomb-explosion ion imaging and photoelectron diffractions. The talk will describe current status of EUVFEL experiments as well as plans and preparations for experiments with SACLA, as well as the first commissioning experiment with SACLA.

# Ultrafast processes and imaging of clusters

Thomas Möller

*Institut für Optik und Atomare Physik, Technische Universität Berlin*

The understanding of the interaction of high intensity, short-wavelength, short-pulse radiation with matter is essential for virtually all experiments with new superintense X-ray sources, in particular for flash imaging of nm sized particles. Clusters as a form of matter intermediate between atoms and bulk solids are ideal samples to study fundamental light – matter interaction processes. They are finite systems with the density of bulk solids allowing the investigation of inner- and interatomic phenomena.<sup>1,2,3</sup> Very recently, initial experiments have shown that in nm-sized gas phase particles can be imaged by single shot scattering.<sup>4</sup> Upcoming X-ray lasers will allow improving the resolution and going to smaller particles. This will open new fields in cluster and nanometer-scale science. Ultrafast electron and ion dynamics can be studied with nm spatial resolution by means of time-resolved scattering using pump-probe techniques as well as time of flight spectroscopy. The talk will give an overview of recent results obtained at the FLASH facility in Hamburg and the LCLS in Stanford.

1 T. Ditmire, T. Donnelly, A.M. Rubenchik et al., *Phys. Rev. A* **53** (5), 3379 (1996).

2 H. Wabnitz, L. Bittner, R. Döhrmann et al., *Nature* **420**, 482 (2002).

3 C. Bostedt, H. Thomas, M. Hoener et al., *Physical Review Letters* **100** (13), 133401 (2008).

4 C. Bostedt, M. Adolph, E. Eremina et al., *Journal of Physics B-Atomic Molecular and Optical Physics* **43** (19), 194011 (2010).

**Coherent superposition of two rotational quantum states in the time domain:  
Microwave spectroscopy without microwaves**

T. Laarmann

*Photon Science, Deutsches Elektronen Synchrotron (DESY), Germany*

Femtosecond laser pulses in the near-infrared spectral range were used to excite a coherent superposition of two rotational quantum states of cold carbon monoxide in a non-resonant Raman process. The associated nuclear motion is followed in time by subsequent Coulomb explosion with soft X-ray FLASH pulses at high intensity in a pump-probe scheme. The coupling of  $J = 0$  and  $J = 2$  states results in an asymmetry of spatial fragmentation patterns detected parallel to the laser polarization axis. The observed wave packed oscillation prevails for at least 1 nanosecond covering more than 150 recurrences without dephasing. This observation can serve as a new route to disentangle complex rotational couplings and ultrafast decoherence phenomena that occur in complex systems and environments such as doped helium droplets in real time with a spectral and temporal resolution limited by the length of the delay scan and the femtosecond pulse duration, respectively.

# **X-ray magnetic circular dichroism spectroscopy of size selected cluster ions: From spin coupling and orbital quenching to magnetic phase transitions**

Tobias Lau

*Institut für Methoden und Instrumentierung der Synchrotronstrahlung, Helmholtz-Zentrum Berlin für Materialien und Energie GmbH*

X-ray spectroscopy of size-selected atomic, molecular, and cluster ions is challenging because of ultralow target densities. A viable approach is to perform X-ray spectroscopy in ion trap experiments [1–5] with sensitivity in the femtomol or  $10^{-6}$  monolayer equivalent range.

To study spin and orbital contributions to magnetic moments of size-selected ions via X-ray magnetic circular dichroism (XMCD) spectroscopy, we have upgraded our linear ion trap setup [1–5] with liquid helium cooling and a 5 T magnetic field. This setup allows us to explore magnetic coupling of model systems in the molecular limit, where we could demonstrate ferromagnetically coupled local high spin states in the archetypical bulk antiferromagnets chromium and manganese. Vice versa, we observed antiferromagnetic alignment of the central atom to the outer shell in iron, the archetypical bulk ferromagnet. In small iron clusters, we also followed the rapid quenching of the orbital magnetic moment [6].

- [1] J. T. Lau *et al.*, Phys. Rev. Lett. **101**, 153401 (2008).
- [2] J. T. Lau *et al.*, Phys. Rev. B **79**, 241102(R) (2009).
- [3] J. T. Lau *et al.*, Phys. Rev. A **79**, 053201 (2009).
- [4] K. Hirsch *et al.*, J. Phys. B: At. Mol. Opt. Phys. **42**, 154029 (2009).
- [5] J. T. Lau *et al.*, J. Chem. Phys. **134**, 041102 (2011).
- [6] M. Niemeier *et al.*, submitted for publication

# Multiple Ionization under Strong Short Wavelength Radiation

P. Lambropoulos

*IESL-FORTH and Physics Dept. University of Crete, Greece*

Strong, short wavelength radiation, of pulse duration in the range of few to tens of femtoseconds obtained in present day Free Electron Lasers (FEL) has ushered in a new era in laser-matter interactions. With photon energies ranging from the XUV to hard X-rays, various layers of new processes and phenomena are expected to emerge.

Although the hard X-ray machines have become operational only recently, in the XUV to soft X-ray range, a substantial body of experimental and theoretical work has already produced a variety of results, posing at the same time a number of questions for the future. Owing to the high intensity, the common feature of those processes is the non-linear dependence on the intensity of the radiation and the production of multiply ionized species, occasionally of quite high ionization stage. After a broad overview of the landscape of existing data and general understanding, I outline the underlying mechanisms and their dependence on the photon energy range, the present theoretical framework, as well as an attempt to identify crucial areas of experimental and theoretical investigations necessary for further progress.

# Molecular attosecond dynamics

G. Sansone<sup>1,2</sup>

<sup>1</sup>*Dipartimento di Fisica Politecnico, Piazza Leonardo da Vinci 32 20133 Milano Italy*

<sup>2</sup>*Max Planck Institut für Kernphysik, Saupfercheckweg 1, D-69117 Heidelberg Germany*

The generation and characterization of single attosecond pulses have been achieved through several efforts in the field of ultrafast intense laser sources over the last 20 years [1] and through theoretical developments on the interaction of intense light pulses with atomic and molecular systems [2]. The duration of attosecond pulses is rapidly approaching the atomic unit of time [3] that represents, in the classical description of the atomic model, the natural time scale of the electronic motion; also in quantum mechanics the attosecond regime is the relevant time domain for electrons as the inverse of the energy spacing among electronic levels, (that determines the time constant for non-stationary states), lies typically in this range. First applications of such pulses have been mainly focused on simple atoms or molecules to validate new experimental approaches and to gain first information on electron-electron correlation.

Experimental and theoretical results on the ultrafast dynamics initiated by single attosecond pulses in helium and H<sub>2</sub> and D<sub>2</sub> will be shown.

In hydrogen several states of the neutral molecule (autoionizing states) or of the molecular ion ( $1s\sigma_g$  and  $2p\sigma_u$ ) can be accessed due to the large bandwidth of the attosecond pulses. The electron dynamics can be probed and controlled using a synchronized infrared few-cycle pulse [4].

New directions for the investigation of attosecond dynamics in more complex molecular systems will be discussed. In particular the experimental challenges related to the complete characterization of complex dynamics involving electron and nuclear degree of freedom will be analyzed.

## References

- [1] T. Brabec and F. Krausz, *Rev. Mod. Phys.* **72**, 545 (2000).
- [2] M. B. Gaarde, J. L. Tate and K. J. Schafer, *J. Phys. B: At. Mol. Opt. Phys.* **41**, 132001 (2008).
- [3] H. Mashiko *et al.*, *Opt. Lett.* **34**, 3337 (2009).
- [4] G. Sansone *et al.*, *Nature* **465**, 763 (2010).

# Multiparticle Coincidences Studies of Photoionization of Quantum Halos

Reinhard Dörner  
*Frankfurt University, Germany*

We will discuss recent experiment on the most "quantum" of all molecules, the Helium Dimer. This super dilute system shows an extreme internuclear distance of 52 Angstrom and is bound by only neV.

We show how a single photon can lead to double ionization of the two distant centers.

# Resonant Inelastic Soft X-ray Scattering Applied to Free Atoms and Molecules

Jan-Erik Rubensson

*Department of Physics and Astronomy, Uppsala University, Sweden*

Resonant inelastic X-ray scattering (RIXS) reflects fine details in electronic structure and dynamics. The process is site specific on the atomic length scale (sub-nanometer) and time specific on the timescale for nuclear and electronic rearrangements (femto- to attoseconds). Consequently, RIXS spectroscopy has a tremendous potential in atomic and molecular, chemical and condensed matter physics. RIXS techniques have, however, suffered from the lack of adequate radiation sources. In practice this has limited the spectral quality and only a fraction of the inherent advantages have been exploited.

Here RIXS spectra of free molecules ( $O_2$  and  $CO_2$ ) with an energy resolution ( $E/\Delta E \sim 10000$ ) that allows for separation of individual vibrational excitations [1] are presented. This opens a wealth of new possibilities, provides detailed information about ultrafast dynamics, and facilitates accurate mapping of the final state potential surfaces.

The measurements were made with the SAXES spectrometer [2] at the ADDRESS beamline [3] at the Swiss Light Source of the Paul Scherrer Institut, using a gas/liquid cell with an ultrathin membrane. The data is discussed in terms of *ab-initio* multimode scattering calculations.

RIXS opportunities at soft X-ray free-electron-lasers are briefly discussed, with emphasis on non-linear processes such as multi-photon excitations, stimulated RIXS and four-wave mixing [4].

## References

- [1] F.Hennies, et al., PRL 104, 193002 (2010), A. Pietzsch et al. PRL 106, 153004 (2011), Y. Sun et al., J. Phys. B 44 161002 (2011), Y. Sun et al., PRB, in press.
- [2] G. Ghiringhelli, et al., Rev. Sci. Instrum. 77, 113108 (2006).
- [3] V. N. Strocov, et al., J. Synch. Rad. 17, 631 (2010).
- [4] Y. Sun et al., PRA 81, 013812 (2010).

## Electron spectroscopy – a probe for fundamental properties of isolated species

Catalin Miron

*Synchrotron SOLEIL, l'Orme des Merisiers, France*

Since many years, electron spectroscopy is an excellent analytical tool to characterize material's chemical composition or degree of oxidation [1]. When performed at ultra-high resolution inner-shell spectroscopies provide an accurate probe of ultrafast (fs) decay dynamics, in particular for isolated species [2]. Completely new scientific opportunities are being offered by the bright and highly monochromatic x-ray beams coupled to state-of-the-art instrumentation available at the newest facilities, such as the PLEIADES [3] beamline at SOLEIL (France), operated as a user facility since March 2010.

Selected examples will be shown from a panel where high-resolution spectroscopies have been employed to investigate fundamental properties of matter, such as the Vibrational Scattering Anisotropy (VSA) [4], the Auger-Doppler effect using circularly polarized light [5], or the rotational Doppler broadening of molecular electron spectra [6].

[1] K. Siegbahn *et al.*, *ESCA. Atomic, Molecular and Solid State Studied by Means of Electron Spectroscopy*, Almqvist and Wiksells, Uppsala (1967).

[2] C. Miron and P. Morin, "High-Resolution Inner-Shell Photoionization, Photoelectron and Coincidence Spectroscopy", in *Handbook of High-Resolution Spectroscopy*, **Vol 3**, Edited by M. Quack and F. Merkt, ISBN: 978-0-470-06653-9, John Wiley & Sons, Ltd, Chichester, UK, p. 1655-1689 (2011).

[3] C. Miron *et al.*, <http://www.synchrotron-soleil.fr/Recherche/LignesLumiere/PLEIADES>

[4] C. Miron *et al.*, *Phys. Rev. Lett.* **105**, 093002 (2010).

[5] O. Travnikova *et al.*, *Phys. Rev. Lett.* **105**, 233001 (2010).

[6] T.D. Thomas *et al.*, *Phys. Rev. Lett.* **106**, 193009 (2011).

## **Two-color experiments at the Gasphase beamline @ ELETTRA – CW and time-resolved studies**

Robert Richter  
*Sincrotrone Trieste S.c.p.A.*

Time resolved pump-probe experiments allow the determination of the energy and lifetimes of excited states, the study of internal and intra-molecular energy distribution after a photo-absorption process or the exploration of vibrational levels out of the Franck-Condon region. In addition the interaction of laser radiation with atoms and molecules is known to change their electronic structure and give rise to new physical phenomena. The relative importance of various effects depends on the intensity of the laser field and ranges from harmonic generation, the AC Stark effect, above threshold ionization to electromagnetically induced transparency. The understanding of such effects is also important for the development of new techniques and tools in optics. If appropriate conditions can be found, laser coupling offers the possibility of shortening synchrotron light pulses (in principle) even into the fs region, without any modification to the machine. In a first approximation, the duration of the light pulse is expected to be equal to the duration of the laser pulse.

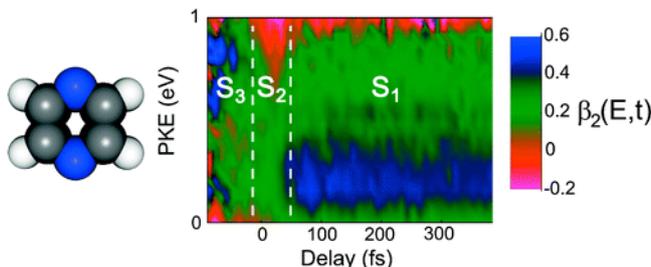
A mode-locked tunable Ti:Sapphire oscillator is synchronized with the time structure of the storage ring and can be used to study the photoionization dynamics. In multibunch operation of the ring the setup permits the direct observation of the dynamics from a few nanoseconds down to the 10's of picoseconds range. Experiments can be performed both in the frequency domain, taking advantage of the high energy resolution of the picosecond sources, and in the time domain. The characteristics of the setup are demonstrated by examining recent results on two-color ionization of noble gases and molecular nitrogen. Experiments on effects of laser-induced coupling between bound levels of noble gases on the length of the synchrotron radiation pulse will also be discussed.

# Time-Energy Mapping of Photoelectron Angular Distribution

Toshinori Suzuki

Kyoto University: CREST JST: RIKEN

Time-resolved photoelectron imaging allows accurate measurements of photoelectron kinetic energy and angular distributions with light sources such as femtosecond lasers, a VUV free electron laser, and a conventional He(I) light source. In my presentation, I introduce some important technical and scientific advancement we made in the past decade, and I discuss in particular non-adiabatic dynamics of polyatomic molecules studied by time-energy mapping of photoelectron angular distribution with 22 fs time-resolution.



## References

- “Probing ultrafast internal conversion through conical intersection via time-energy mapping of photoelectron angular anisotropy”, T. Horio et al., *J. Am. Chem. Soc.* **131**, 10392 (2009).
- “Time-resolved photoelectron imaging of ultrafast  $S_2 \rightarrow S_1$  internal conversion through conical intersection in pyrazine”, Y.-I. Suzuki et al., *J. Chem. Phys.* **132**, 174302 (2010).
- “Time-resolved photoelectron imaging of  $S_2 \rightarrow S_1$  internal conversion in benzene and toluene ” Y.-I. Suzuki et al., *J. Chem. Phys.* **134**, 184313 (2011).
- “Excited-State Dynamics of  $CS_2$  Studied by Photoelectron Imaging with a Time Resolution of 22fs” T. Fuji et al., *Chem. Asian. J.* DOI: 10.1002/asia.201100458 (2011) (Open access).
- “Molecular frame image restoration and partial wave analysis of photoionization dynamics of NO by time-energy mapping of photoelectron angular distribution”, Y. Tang et al., *Phys. Rev. Lett.* **104**, 073002 (2010).
- “Time-resolved photoelectron imaging using a femtosecond UV laser and a VUV free-electron laser”, S. Y. Liu et al., *Phys. Rev. A* **81**, 031403 (2010).
- “He(I) Ultraviolet Photoelectron Spectroscopy of Benzene and Pyridine in Supersonic Molecular Beams Using Photoelectron Imaging”, S. Y. Liu et al., *J. Phys. Chem. A* **115**, 2953 (2011).

## Atomic photoionization in intense XUV and optical laser fields

Michael Meyer

*European XFEL GmbH, Albert-Einstein-Ring 19, D-22761 Hamburg, Germany*

The combination of intense femtosecond X-ray and NIR pulses produced by Free Electron Lasers (FEL) and synchronized optical lasers, respectively, offers various new possibilities to investigate the dynamics of atomic photoionization. Some recent results obtained at the XUV-FEL FLASH in Hamburg and the first X-ray FEL, the LCLS in Stanford, will be presented.

In the experiments at FLASH, the strong dressing field ( $>10^{12}$  W/cm<sup>2</sup>) produced by the optical laser, give rise to the so-called two-color Above Threshold Ionization (ATI), which could be studied for the first time in a regime free from unwanted interference effects [1]. In addition, the NIR field can modify also the dynamics of the resonant Auger decay. For the resonant Kr 3d-5p excitation at 91.2 eV, we have investigated by electron spectroscopy the laser-induced shift of the resonance position and have observed competition between resonant and direct Auger decay caused by the ionizing of the excited 5p electron in the NIR field.

Recent experiments at LCLS have taken advantage of the very short (2-5 fs) pulse durations delivered by this FEL. The duration coincides with the lifetime of the Ne 1s core hole state and with the temporal width of one optical cycle of the 800 nm radiation from the NIR dressing laser. The analysis of the angle-resolved KLL Auger decay in atomic reveals strong interference effects, which result from the coherent emission of electrons produced during one cycle of the superimposed optical field. The experimental results are in excellent agreement with recent theoretical work [2].

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[2] A.K. Kazansky, N.M. Kabachnik, J.Phys.B **42**, 121002 (2009); **43**, 035601 (2010).

## Poster Session

## **TEM and HR-PES studies of Al and Au nanoparticles self-assembled in a wide-gap organic semiconductor**

I.M. Aristova<sup>1</sup>, O.V. Molodtsova<sup>2</sup>, O.Yu. Vilkov<sup>3</sup>, J. Viefhaus<sup>2</sup>, V.V. Kveder<sup>1</sup>,  
C. Laubschat<sup>4</sup>, M.Knupfer<sup>5</sup>, and V.Yu. Aristov<sup>1,2</sup>

<sup>1</sup> *ISSP, Russian Academy of Sciences, Chernogolovka, 142432, Russia*

<sup>2</sup> *HASYLAB at DESY, D-22607 Hamburg, Germany*

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Materials with a high on-off resistance ratio could become the basis for resistive random-access memory (RRAM). Such a “storage class memory” would revolutionize the information technology industry as outlined in [1-3]. One type of RRAM can be based on hybrid organic–inorganic systems, mainly consisting of inorganic nanoparticles (NP) blended into an organic matrix. The evolution of the morphology and the electronic properties of the hybrid organic-inorganic systems composed of aluminum and gold nanoparticles (NP’s) distributed in an organic matrix, copper phthalocyanine (CuPc), as a function of nominal metal content was studied by transmission electron microscopy and by surface- and bulk sensitive photoelectron spectroscopy. Gold atoms deposited onto the CuPc surface diffuse into the organic matrix and self-assemble to NP’s. There is no formation of a continuous metallic Au film on top of the CuPc film up to large nominal coverage of about 130 Å. Gold atoms are assembled to well defined NP’s with metallic properties. Strong difference in morphology and electronic properties were observed for aluminum nanoparticles formation. E.g., on the very first stage of aluminum deposition, aluminum atoms show strong chemical interaction with substrate atoms. The properties of the nano-composite thin-film are supposed to be significantly dependent on their microstructure, i.e. the size, concentration, bulk- and size-distribution of nanoparticles.

Acknowledgements: This work was supported by the RFBR under grant 10-02-00269.

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## Ideal Heisenberg coupling in small ferromagnetic manganese clusters

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X-ray magnetic circular dichroism (XMCD) measurements on manganese cluster cations in the gas phase ( $Mn_n^+$ ) provide for the first time a direct experimental proof for ferromagnetic coupling of localized high spin states in small clusters ( $n=2-4$ ) and a transition from a ferromagnetic to an antiferromagnetic phase for larger clusters ( $n>4$ ).

Due to strong localization of the d-electrons, X-ray absorption spectra (XAS) of the  $Mn_{1-4}^+$  clusters are identical to the spectrum of the monomer (fig.1 left), corresponding to local high-spin states ( $3d^5$ ) at the Mn atoms with a completely filled 3d majority spin subband for all these clusters.

For larger clusters ( $n>5$ ), d-electrons participate in bonding and delocalize, resulting in a broadening of the spectrum and gradual vanishing of the magnetic moment, visible in the XMCD signal (fig.1 right)

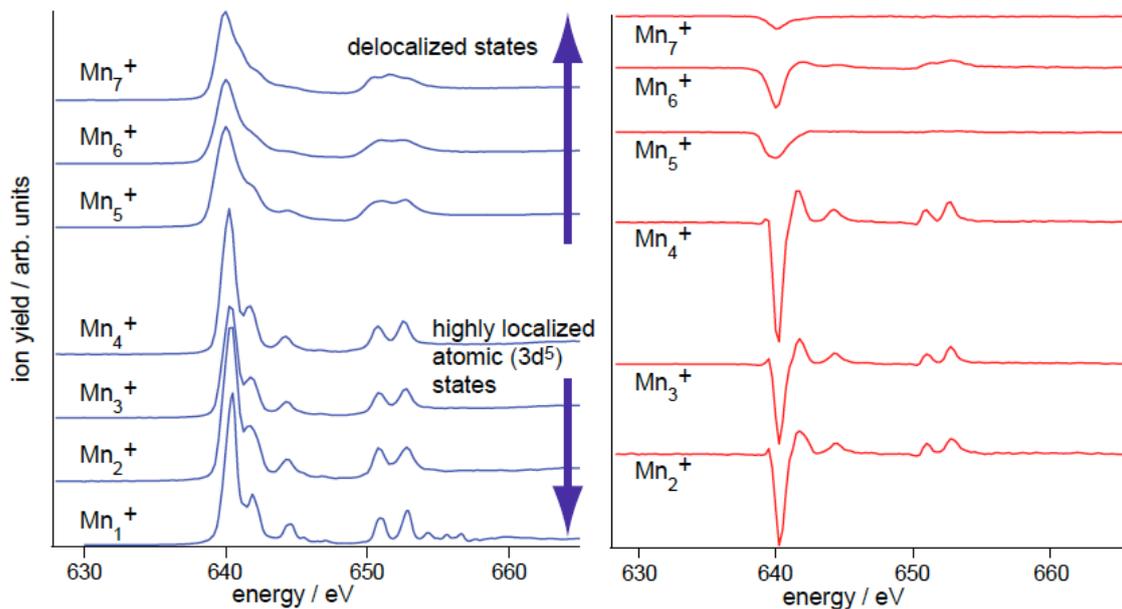


Figure 1: XAS spectra revealing transition from highly localized atomic  $3d^5$  states to delocalized states (left) and corresponding strong XMCD signal of the high spin states (right) of manganese cluster cations.

## **Detecting secondary structure changes in protein-NP systems by Diamond B23 SRCD beamline.**

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Until now not much is known about the effect of nanoscale materials on proteins. To understand both the effects of nanoparticles (NP) in biological systems and to design the next generation NP-based drug delivery systems, it is critical to be able to measure the structure and stability of the protein of interest upon interaction with NP. This information is very difficult to obtain due to the very nature of the system involving a solid/liquid interface<sup>1</sup> and low concentration of the proteins. We measured for the first time the secondary structure of proteins in low nanomolar concentration and in particular the structural and stability changes associated with proteins bound non covalently to silver and gold nanoparticles close to 1:1 particle ratios using Diamond B23 beamline for SRCD. The use of B23 beamline has allowed detailed structural information on protein-NP complexes that have been elusive until now.

# Comparison of mixed quantum-classical and full quantum results for the multiphoton dissociation of $\text{H}_2^+$ : Complete dynamics in strong laser fields

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We present a mixed quantum-classical approach for the time-dependent dynamics of para- $\text{H}_2^+$  exposed to short intense laser pulses with 800 nm wavelength including all nuclear as well as electronic degrees of freedom. Depending on the initial vibrational state, the angular distributions of photo fragments show characteristic shapes in very good agreement with our full quantum calculations. The results are interpreted in the framework of two-dimensional adiabatic Floquet surfaces which depend on the internuclear separation and the rotation angle [1], demonstrating that adiabatic light-dressed surfaces are a useful concept also for full dimensional nuclear dynamics.

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## 2p Core Level Binding Energy Spectra of Size Selected Silicon and Aluminum Cluster Cations: Chemical Shifts and Cluster Structure

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Experimental and theoretical 2p core level binding energies of size selected  $\text{Si}^+$  ( $n = 5-92$ ) and  $\text{Al}^+$  ( $n = 12 - 15$ ) clusters were obtained from soft X-ray photoionization efficiency curves and density functional calculations. In these free clusters, two size dependent contributions to the 2p electron binding energy can be distinguished: A macroscopic charging energy, which follows the well-known metallic sphere model, and a microscopic chemical shift due to the local geometric and electronic structure.

In small Al  $n^+$  clusters, 2p core level binding energies of surface and central atoms are separated by a large chemical shift of  $\approx 0.8$  eV that is reproduced by DFT calculations and can be attributed to initial state effects. This shift is larger than the 2p spin-orbit splitting in  $\text{Al}^+$ . In comparison, chemical shifts for  $\text{Si}^+$  clusters are significantly smaller and of opposite sign.

Because of the strong dependence of core level binding energy spectra on the specific cluster geometry, a joint experimental and theoretical approach allows for the determination of cluster structure. This is demonstrated for the case of  $\text{Si}^{12+}$ , for which no structure was assigned previously. The setup, results, and implications will be discussed in detail.

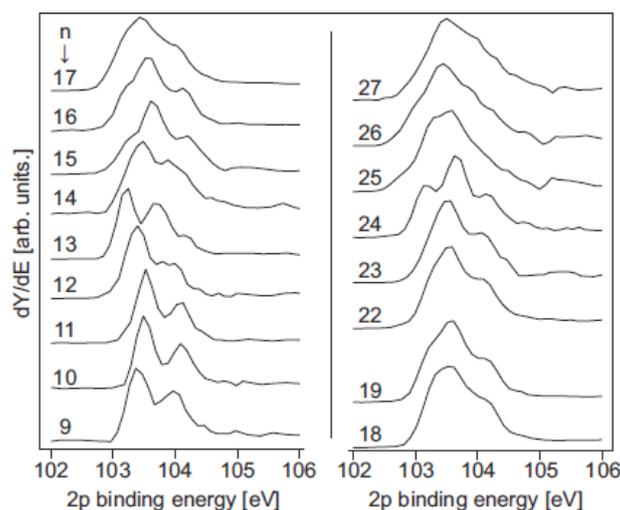


Figure 1: 2p binding energy spectra of size selected  $\text{Si}^+$  clusters, corrected for the macroscopic charging energy.

## Prediction of soft X-ray photo-electron/absorption spectra by *ab initio* calculations

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We present two different theoretical approaches used to predict the photoelectron and the photoabsorption and discuss their accuracy by comparison with new experimental data.

The first method has been developed specifically for molecular inner shell excitation and ionization by Nobuhiro Kosugi since 1980 and implemented in the GSCF3 code. [1] Here the core ionized states and core-to-excited states transitions are solved within the Hartree-Fock approximation by explicitly taking into account the core hole. The excited orbitals to be singly occupied by the core-electron excitations are optimized within the STatic EXchange (STEX) method by freezing the core and the occupied valence HF orbitals of the corresponding core hole state. The calculations have been run for several molecules of biological interest (tyramine, tryptamine, tryptophol, barbituric and thiobarbituric acid) and the obtained XPS and NEXAFS spectra have been compared with the experimental results. [2]

The second approach has been developed by Angela Acocella in order to investigate the onset of the ionization dynamics in photoelectron spectroscopy with a quantum-mechanical time-dependent propagator used to evolve the electronic wavefunction [3] with the aim to correlate it to the spectral analysis. In practice, the high energy of the incoming photon triggers a complicated re-organization of the wavefunction where the usually dominant one-photon contribution is combined with all the possible many-photon contributions of the same energy, together with the continuum states of the ionized electron. The presented model proved to reproduce with reasonable accuracy both XPS and UPS spectra of the coronene molecule. [4]

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# **Clocking ultrafast wave packet dynamics in molecules through UV-induced symmetry breaking**

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We investigate the use of UV pump - UV probe schemes to trace the evolution of nuclear wave packets in excited molecular states by analyzing the asymmetry of the electron angular distributions resulting from dissociative ionization. The asymmetry results from the coherent superposition of gerade and ungerade states of the remaining molecular ion in the region where the nuclear wave packet launched by the pump pulse in the neutral molecule is located. Hence, the variation of this asymmetry with the time delay between the pump and the probe pulses parallels that of the moving wave packet and, consequently, can be used to clock its field-free evolution. The performance of this method is illustrated for the H<sub>2</sub> molecule.

# Superexcited states observed in the photofragmentation of isoxazole and tetrahydrofuran molecules

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Dissociation and fragmentation of molecules may be produced by absorption of radiation or by collisions with charged particles. In the transfer of energy, the target molecule may be excited to a superexcited state, lying above the first ionization potential, which is a transient state in the fragmentation process.

In the communication we present studies of the superexcited states observed in the fragmentation processes of the isoxazole (C<sub>3</sub>H<sub>3</sub>NO) and tetrahydrofuran (C<sub>4</sub>H<sub>8</sub>O) molecules following absorption in the VUV region. The above cyclic molecules are built on furanose ring, which may be identified in the deoxyribose sugar of DNA helix. Thus, they are often considered to be simple analogues of building blocks of DNA for investigations of radiation interactions with DNA [1]. The experiment has been carried out at the Gas-Phase photoemission beamline of the Elettra storage ring, Trieste, using the photon induced fluorescence spectroscopy (PIFS) [2]. The studies of fluorescence of the excited fragments (Fig. 1) allow identification of the superexcited states and gives information on their dynamics and possible dissociation channels [3].

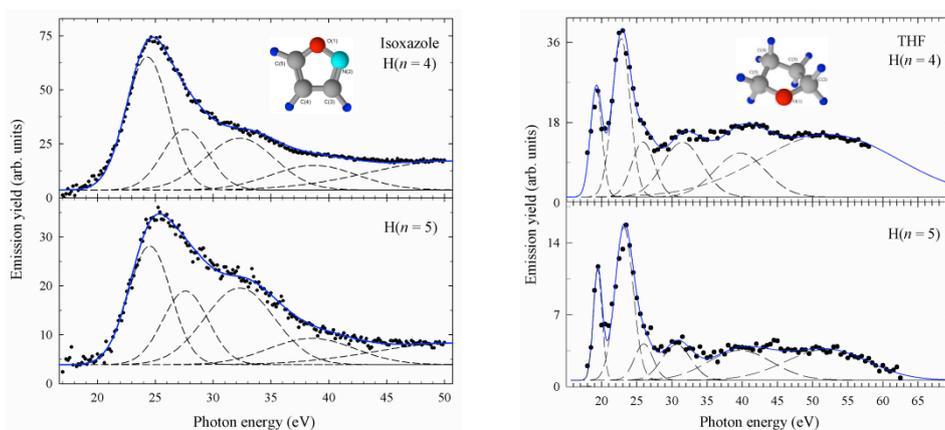


Fig. 1. Emission yields of the H( $n$ ),  $n = 4$  i 5 excited atoms, observed in the photofragmentation of isoxazole and tetrahydrofuran (THF) molecules. The dashed lines indicate positions and widths of the superexcited states of studied molecules.

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