NCCR MUST

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Co-Directors NCCR MUST

SNF National Center of Competence in Research
Molecular Ultrafast Science and Technology

nccr-must.ch
NCCR MUST / SNF
16 groups
ETH, EPFL, U Basel, U Bern, U Geneva, U Zurich
Duration: 12 years in 3 Phases
Phase 1: 2010 – 2014, 17 Mio CHF
Our motivation

• Fast processes are important in engineering, physics, chemistry and biology

• Examples:
  - high-speed electronics, high data-rate communication
  - important biological reactions such as respiration, photosynthesis …
  - energy conversion and storage, artificial photosynthesis, fuel cells …

  all involve ultrafast time-space events that enable and initiate the process
  – we do not understand fully
  – nor can we copy them all

• We need to better understand, model and control atomic and molecular chemical reactions and energy transfer processes on an atomic and molecular level.

• Time scale: picosecond – femtosecond and even attosecond regime
Length scale: micrometer to sub-nanometer regime
Time and length scales

- 1 picosecond = 1 ps = \(10^{-12}\) s = 0.000’000’000 ‘001 s
- 1 femtosecond = 1 fs = 1 ps / 1000 = \(10^{-15}\) s = 0.000’000’000’000’001 s
- 1 attosecond = 1 as = 1 fs / 1000 = \(10^{-18}\) s = 0.000’000’000’000’000’001 s

Fast processes are important in engineering, physics, chemistry and biology: We need to better understand, model and control atomic and molecular chemical reactions and energy transfer processes on an atomic and molecular level.
Time and length scales

- Measurements with attosecond resolution isolates purely electronic dynamics on short time scales.
- We can study time-dependent electronic and atomic structure for the first time.
Scientific questions addressed by SLS

Francis Crick (1962):
“if you want to understand function, study structure”

Synchrotron Light Source (SLS)
(PSI in Villigen)
time “slow” 100 ps = 100’000 fs
length “fine” 20 nm – 0.1 nm

http://www.psi.ch/
Scientific questions addressed

Francis Crick (1962) – updated
“if you want to understand function, study time-dependent structure”
... how a structure evolves in time during a process (e.g. chemical reaction)

How do we do this?

... with ultrafast science and technology

*New tools that allow us to clearly see a process in real-time, always bring real progress both in theory and application*
Flash photography with 1-μs time exposure

Harold E. Edgerton
MIT, USA
1903-1990
How to access the fast time scales?

Example:

**Fast process: balloon explosion**

Fast process started with a “bullet”

Explosion observed with flash photography after a time delay $\Delta t$ following the gun shot.

*(photo showing balloon with a hole)*

How do I do this with ultrafast lasers?

*first pulse “bullet”*
Example:

**Fast process: balloon explosion**

Fast process started with a “bullet”

Explosion observed with flash photography after a time delay $\Delta t$ following the gun shot.

( photo showing balloon with a hole)

How do I do this with ultrafast lasers?

$\Delta z = 1 \, \mu m \Leftrightarrow \Delta t \approx 2 \times 3.3 \, \text{fs}$
How to access the fast time scales?

\[ t = 1 \mu m \approx 3.3 \text{ fs} \]

\[ \Delta z = 1 \mu m \Leftrightarrow \Delta t \approx 2 \times 3.3 \text{ fs} \]
How to access the fast time scales?

Structure on atomic scale: flash photo replaced by **diffraction patterns**

\[ \Delta t \approx 2 \times 3.3 \text{ fs} \]

\[ \Delta z = 1 \mu m \]
Scientific questions addressed

- Francis Crick (1962) – updated
  “if you want to understand function, study time-dependent structure”

One approach: diffraction

We want to follow the movements of atoms

Atoms are small (<nm) and move very fast (fs)
1 nm = 0.000 000 001 m
1 fs = 0.000 000 000 000 001 s

- chemical reactions
- magnetic properties
- nanostructures
- biomolecules
Scientific questions addressed

• Francis Crick (1962) – updated
  “if you want to understand function, study time-dependent structure”

One approach: diffraction

We want to follow the movements of atoms

Atoms are small (<nm) and move very fast (fs)

1 nm = 0.000 000 001 m
1 fs = 0.000 000 000 000 001 s

SwissFEL (PSI in Villigen)
Time “fast” ≈ fs
Space “ultrafine” 20 nm – 0.1 nm

• chemical reactions
• magnetic properties
• nanostructures
• biomolecules
MUST brings additional tools and techniques

Ultrafast lasers in the UV, visible, IR, mid-IR, THz spectral regime with femtosecond pulses

**Ultrafast lasers**
- “fast” ≈ 5 fs
- “rough” > 100 nm

Attoclock at ETH: “ultra-ultrafast” ≈ 1 as
- single atom or molecule

Attoline at ETH: “ultrafast” ≈ 100 as
- “fine” > 10 nm (> 1 nm)

attohand: 1 revolution per fs
Scientific questions addressed

Groups
- Paul Beaud
- Majed Chergui
- Thomas Gerber
- Peter Hamm
- Matthias Hengsberger
- Ursula Keller
- Markus Meuwly
- Ursula Röthlisberger

Scientific Questions
- Protein Dynamics
- Biological Water
- First Principle MD Simulations
- Valence Order in Strongly Correlated Systems

Structural Dynamics
Visualization of electronic and atomic motion within molecules and solids

Supporting Technologies
- UV-VIS-IR MultiD Spectroscopy
- Electron Diffraction
- X-Ray Diffraction
- X-Ray Absorption
Scientific questions addressed

**Groups**
- Thomas Feurer
- Matthias Hengsberger
- Ursula Keller
- Jacques Moser
- Markus Meuwly
- Ursula Röthlisberger
- Jiri Vanicek
- Eric Vauthey

**Scientific Questions**
- Vibrational control of electron transfer
- Bimolecular electron transfer
- Time-resolved fundamental QM processes (tunneling, ionization, photoemission ...)

**Charge, Energy, and Signal Transfer**
Visualization of charge, energy, or ligand transfer within molecules

**Supporting Technologies**
- Attosecond Spectroscopy
- Attosecond Rescattering
- UV-VIS-IR MultiD Spectroscopy
- Electron Diffraction
- X-Ray Diffraction
- X-Ray Absorption
- Transient Absorption
- Photoelectron Spectroscopy
Attoclock resolves tunneling time

Attosecond electron tunneling time revealed with the attoclock 2013: it is real, not instantaneous and has a probability distribution (submitted to Nature, 11. March 2013)
Scientific questions addressed

Groups
- Thomas Feurer
- Hubert Girault
- Jacques Moser
- Bruce Patterson
- Eric Vauthey
- Jean-Pierre Wolf

Scientific Questions
- Molecules at surfaces and interfaces
- Controlling the properties of molecules and solids with light

Control
- Control of electronic and atomic motion within molecules

Supporting Technologies
- Catalysis
- Surface- and nano-science
- Interfaces
- Pulse shaping
- THz driver
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Total 15 PI groups funded in Phase I

Total 19 PI groups for Phase II

5 new PIs
NCCR MUST – outreach projects

• Structural changes within the leading houses:
  
  **FAST Initiative** not only because of “fast processes”
  **Femtosecond and Attosecond Science and Technology**

• Advancement of women:

  **ETH WPF**
  **ETH Women Professor Forum**
ETH FAST Initiative: current members

4 Departments ETH Zurich with 9 Professors
PSI
Interest from Uni Bern and Zürich
Centers and Strategic Partnerships

**FAST Initiative**

center of excellence

currently a “virtual” center of ETH and PSI (Phase 1, 1.2 Mio CHF)

support joint projects and interdisciplinary education (FAST Fellows, lectures)

4 departments and with 9 professors

Physics (3+2PSI), Biology (1), Chemistry (2), and Material Science (1)

Increasing interest, especially with newly hired professors

Director of NCCR MUST: initiated FAST with the vision that FAST is broader than MUST

Research platform

benefits from common interest of the ultrafast laser technology

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For a world leading effort a “virtual” center is not enough.
We need a “real” interdisciplinary research space (FAST Lab)
FAST Initiative responds to global trends in scientific practice

- Global trends
  - Integration of different disciplines
  - Integration of various groups (e.g. PULSE at Stanford, focus on professors)
  - Integration of different institutes (e.g. CFEL in Hamburg, national focus)
  - ... more in Japan, China ...

- PULSE: independent laboratory at Stanford University
  - established in 2004
  - partnership of professors at Stanford
  - Scientific focus: Ultrafast dynamics in magnetism, molecular dynamics, chemistry
  - Shared laser technology will bring students and scientists from all departments to talk and interact
  - Infrastructure/technology: high power optical lasers, Linac Coherent Light Sources (LCLS)

- CFEL: Center for Free Electron Laser, Hamburg
  - established in 2006
  - Partners: Max Planck Society, DESY, University of Hamburg
  - Scientific focus: Ultrafast dynamics in nanocrystallography, materials in general, single molecule imaging, theory of correlated systems, imaging
  - Infrastructure/technology: high power optical lasers, electron microscopy, European XFEL

- We can learn from their experience and make it better for our FAST center.
Added value for a “real” FAST center (FAST Lab)

• **Complements and enhances SwissFEL**
  A “real” FAST center allows ETH to leverage on SwissFEL investment and effectively address future challenges in high-speed electronics, communication, energy sources, health ... No single department can do this!

• **FAST center is more accessible and flexible** than large centralized SwissFEL
  - FAST provides a larger spectral range, faster time resolution, but not the better spatial resolution (“ultrafine”)
  - FAST and SwissFEL complement each other, offer new synergies, and some pre-characterization studies
  - Additional space for PSI researchers supporting better synergies and collaborations with ETH

• **A “real” FAST center should be on ETH Hönggerberg**
  - ETH is a world-leading university that can attract the best minds
  - Easy access for students and for many departments at ETH is critical for the interdisciplinary nature of the FAST center

• **Shared laser technology**
  - will bring students and scientists from all departments to talk and interact
  - will be enhanced with interdisciplinary education
  - a research center with added benefits and beyond departmental structure
  - no permanent membership, evaluation based on continued excellence and return of investment
  - new laser development also be driven by the scientific questions
  - will more effectively use future investments

• **New investment of laser development is beyond a single professor group**

• **FAST Lab infrastructure and single professors with a specific quest will need more than one expensive laser!**
Added value for a “real” FAST center (FAST Lab)

- **Incubator space for young scientists (SNF ass. Prof., ERC grants)**
  - currently we have to turn away young people because of limited space
  - not enough resources and time to first build a larger laser infrastructure for their experiments

- **Public outreach**
  - integration of a public visiting and interaction center
  - Science city can help to get more people excited about science: “laser fascinates people”
  - show them how fast processes affect our life and technology
  - interaction center for school classes and “corporate outings”

- **Industrial laser user facility:**
  - ultrafast lasers are increasingly important for industrial applications in electronics, computing and material processing
Applications of ultrafast lasers

- **Good time resolution (short laser pulses)**
  Measurements of fast processes

- **High pulse repetition rates**
  Optical communication
  Interconnect
  Optical clocking

- **High peak intensity**
  Nonlinear Optics
  Precise material processing
  New energy sources (Laser fusion)

- **Broad optical spectrum**
  Frequency metrology (frequency comb)
  Optical clocks
  Optical coherence tomography (OCT)
Applications of ultrafast lasers

Photonik - Umsatz Unternehmen Standort Schweiz, 2011
Total: 4.1 Milliarden CHF

- Lasermaterialbearbeitung
- Optische Messtechnik und Bildverarbeitung
- Optische Medizintechnik und Life Science
- Optische Informationstechnik
- Photovoltaik, erweitertes Produktionspektrum
- Optische Komponenten und Systeme
Applications of ultrafast lasers

- **Good time resolution (short laser pulses)**
  - Measurements of fast processes

- **High pulse repetition rates**
  - Optical communication
  - Interconnect
  - Optical clocking

Optical interconnects in servers, data centers, supercomputers . . .

Future Application:

Intra-board & intra-chip interconnects
Applications of ultrafast lasers

• Good time resolution (short laser pulses)
  Measurements of fast processes

• High pulse repetition rates
  Optical communication
  Interconnect
  Optical clocking

• High peak intensity
  Nonlinear Optics
  Precise material processing
  New energy sources (Laser fusion)

• Broad optical spectrum
  Frequency metrology (frequency comb)
  Optical clocks
  Optical coherence tomography (OCT)

Precise material processing (cold ablation)
long pulse short pulse

Precision
High surface quality
Functional surfaces
Inner glass micro marking
3D printing ...
FAST Initiative with a “real” research center

- **Scientific driver**: time-dependent structure and energy transfer

  *Embedded in the vision* that we can contribute to important challenges such as **alternative energy sources and improving health** …

- We need expertise in physics, chemistry, engineering, and biology

- FAST Initiative with a “real” research center. Why?
  “When we can combine these people under one roof, make it beneficial for them to talk to each other, we then can achieve a strong push forward in our research”

  A short summary also:
  Globe, Nr. 1, March 2013, p. 24
NCCR MUST – outreach projects

• Structural changes within the leading houses:
  
  **FAST Initiative**
  not only because of “fast processes”
  **Femtosecond and Attosecond Science and Technology**

• Advancement of women:
  
  **ETH WPF**
  ETH Women Professor Forum
Gender monitoring 2011/12, equal
Gender monitoring 2011/12, equal
Gender monitoring 2011/12, equal

Professuren nach Geschlecht und Nationalität 2011

AProf
- 24.9% Ausl_Fr
- 3.5% CH_Fr
- 47.6% Ausl_M
- 23.9% CH_M

o+aProf
- 6.6% Ausl_Fr
- 1.7% CH_Fr
- 61.3% Ausl_M
- 30.4% CH_M
Gender Analysis two examples at ETH
(ETH Equal Office, Gender Monitoring Report, 2009/2010, ETH Zurich)
Prof Dr Renate Schubert and Kristin Hoffmann, www.equal.ethz.ch

Gender stats Physics ETH Zurich

Gender stats Chemistry and Applied Biology ETH Zurich
**ETH Women Professors Forum (ETH WPF)**

The ETH Women Professors Forum was established in March 2012 and formally became an association/verein in May 2012. The seven member Executive committee was voted into office by a group of 20 professors at the first Assembly Meeting. The Forum aims to develop collegiality, make visible the scientific excellence of ETH women professors, organize scientific and social events, and gain influence within the ETH environment.

Of the 484 professors working at ETH, 56 are female professors (tenured, assistant professors and SNSF professors) - 12% of the population (April 2012 figures). The WPF aims to contribute to ETH Zurich’s ongoing efforts to attract, recruit, promote and retain female professors in our university.

**History, Philosophy and Strategy of ETH WPF**

The members of the Executive Board are as follows:

- **Ursula Keller**, Physics (President)
- **Janet Herling**, Director of EAWAS (Vice President)
- **Marcella Carillo**, Physics
- **Silvia Dorn**, Environmental Systems Science
- **Gudula Grote**, Management, Technology and Economics
- **Renate Schuert**, Delegate for Equal Opportunities to ETH President, Humanities, Social and Political Sciences
- **Vivien Vogel**, Health Sciences and Technology

**Activities in 2012 - 2013**

**Scientific Lunch Program 2012 - 2013**

**ETH WPF Executive Board Meetings**

- ETH Women Professors Forum Retreat, April 8th, Uto Kulm, 9am - 6pm, 2013
- ETH WPF Executive Board meeting with ETH Schulleitung, May 28th, 2013
ETH WPF Executive Board (Elected during first assembly meeting, 7 March 2012):

- Ursula Keller, Physics, President
- Janet Hering, EAWAG Director, Vice President
- Marcella Carollo, Physics
- Silvia Dorn, Environmental Systems Science
- Gudela Grote, Management Sciences
- Renate Schubert, Delegate for Equal Opportunities to ETH President, Humanities, Social and Political Sciences
- Viola Vogel, Health Sciences and Technology

ETH Zurich
61 women Prof.
as of Feb. 2013
75% are members
(i.e. 45 Profs.)
ETH WPF Goals

• to become the advisory board for the ETH “Schulleitung” for women in leadership position
• building membership and collegiality between ETH women professors: monthly scientific lunches, social events, etc.
• networking, support, exchange of experience, inter-disciplinary and inter-departmental information flow
• to nurture and promote excellence of women scientists
• to provide successful role models for our students and to encourage our mostly Swiss undergraduates to set and achieve higher goals for their careers
• to help to develop working “structures” for more diversity, for dual career couples and families
• to reach out to Swiss industry: board members, consultants
• to collaborate with other networks for women in leadership positions
About NCCR MUST

The NCCR MUST is an interdisciplinary research program launched by the Swiss National Science Foundation in 2010. It brings together 16 Swiss research groups working in Ultrafast Science across the fields of physics and chemistry.

The focus in MUST (Molecular Ultrafast Science and Technology) is to create new experimental and theoretical tools and to apply them to unravel the fastest processes in the physics and chemistry of natural and manmade matter. Experimental tools rely on ever-shofter sources of electromagnetic radiation, be it ultraviolet, visible, infrared or even bursts of X-rays. Currently, we are witnessing further huge steps forward in these technologies. New sources of femtosecond X-ray pulses, such as the slicing scheme at synchrotrons, or the X-ray free electron laser (XFEL), are built or planned - one of them at the PSI (SwissFEL). Electron diffraction reaches ultrafast time scales, techniques similar to NMR are extended into the IR and UV/VIS spectrum. Attosecond pulses of light bring us to the time scales of electron motion, and intense THz pulses allow for direct excitation of structural modes. Improved, and even novel, theoretical tools emerge from constantly growing computational capabilities, which in turn enable us to tackle previously unsolved problems.

In Switzerland every modern aspect of Ultrafast Science is covered by the MUST network and Swiss researchers are among the leaders in the field. The research goals of MUST include...

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16 groups
ETH, EPFL, U Basel, U Bern, U Geneva, U Zurich
Duration: 12 years in 3 Phases
Phase 1: 2010 – 2014, 17 Mio CHF
Scientific questions addressed

- **Scientific driver:** time-dependent structure and energy transfer

- To understand how matter functions at the electronic, atomic, and molecular level:
  - how matter changes its structure during a reaction
  - how quanta of energy are transported on a microscopic spatial and ultrafast time scale

- **Embedded in the vision** that we can contribute to important challenges such as **alternative energy sources and improving health** …

We address these challenges through basic research which we believe is essential for breakthrough progress in these areas.
History: ETH WPF

18. July 2011  8 senior women Professors – first meeting
   (including Heidi Wunderli and Sarah Springman)
2011  3 consultation lunches with 25 ETH women professors
Dec. 2011  Presidents Apero announced ETH WPF creation and
   ETH Schulleitungsbeschluss gave permission for ETH logo
7. March 2012  First Assembly Meeting:  20 attendees (with written support
                  from  36 out of 52 women professors)
8. April 2013  2. Assembly Meeting and first one day retreat on Uto Kulm

First year activities: building up membership and collegiality
- organized scientific lunches
- social activities
- getting women professors into important leadership positions within ETH
  (e.g. Forschungskommission ...)
- first meeting with ETH president (getting to know each other ...)
- One day retreat meeting 8. April 2013 to develop recommendations for
  ETH executive meeting on 28. May 2013
Why so few women in high academic positions?

- Complicated ...
- Many studies done ... with well documented reasons
- This is also well documented by independent studies:
  
  LERU Report, **Women research and universities: excellence without gender bias**, July 2012


 Selected feature

Women's work
Why is science still institutionally sexist? A special section of Nature confronts the issues.
Why so few women in high academic positions?

- Mother
- Mate
- Daughter
- (Intellectual Spinster)
- Female-colleague

How the men in Ann’s lab see her.