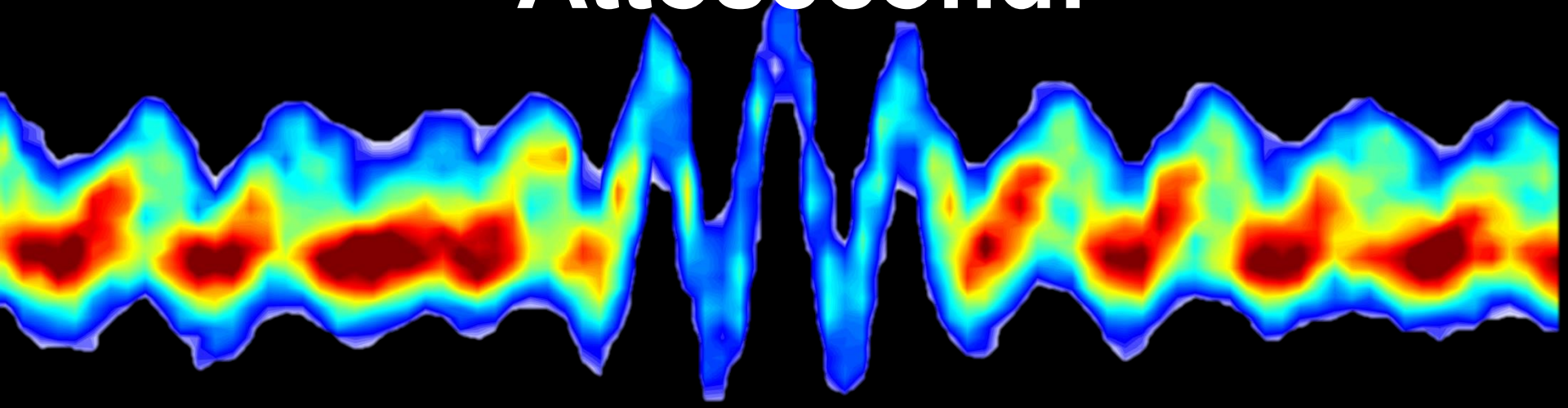
Women in Science and my Career Journey in More Than an Attosecond!



Francesca Calegari
Center for Free Electron Laser Science, DESY, Universität Hamburg

EPACE kick-off, Hamburg 15.12.2025

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

History of Female Nobel Laureates in Physics

Marie Curie, née Sklodowska

Marie Curie Sklodowska

The Nobel Prize in Physics 1903

Prize motivation: "in recognition of the extraordinary services they have rendered by their joint researches on the radiation phenomena discovered by Professor Henri Becquerel."

Also awarded: the Nobel Prize in Chemistry in 1911

60 years

Photo from the Nobel Foundation archive.

Maria Goeppert Mayer

Maria Goeppert Mayer

The Nobel Prize in Physics 1963

Prize motivation: "for their discoveries concerning nuclear shell structure."

55 years

Photo: A. Mahmoud

Donna Strickland

The Nobel Prize in Physics 2018

Prize motivation: "for their method of generating high-intensity, ultra-short optical pulses."

2 years!

© Nobel Prize Outreach. Photo: Annette Buhl

Andrea Ghez

The Nobel Prize in Physics 2020

Prize motivation: "for the discovery of a supermassive compact object at the centre of our galaxy."

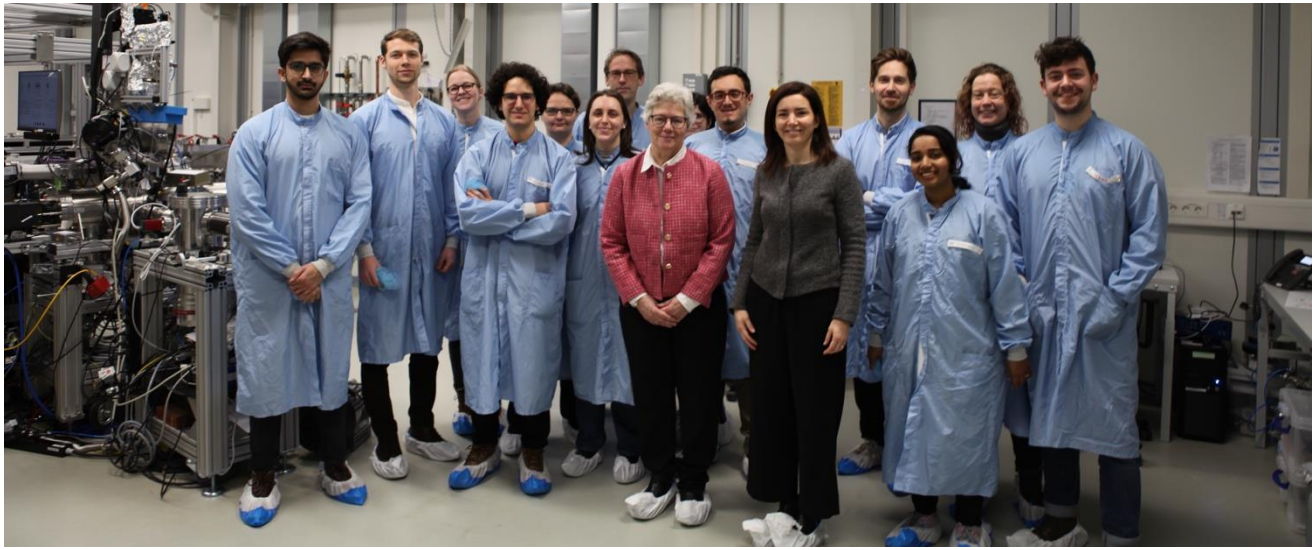
History of Female Nobel Laureates in Physics

Anne L'Huillier

3 years!

The Nobel Prize in Physics 2023

Prize motivation: "for experimental methods that generate **attosecond pulses** of light for the study of electron dynamics in matter"



Anne L'Huillier visiting the CFEL-ATTO group @ DESY in January 2024

Why gender is an issue in Science?

TROY VETTESE

Sexism in the Academy

Women's narrowing path to tenure

Ceal Floyer, *Ladder*. 2019, aluminum ladder. 109 5/8 × 14 3/4". Photo by Ken Adlard. Courtesy of Lisson Gallery. © Ceal Floyer.

Issue 34, n+1, Head Case

Key gender issues:

- The leaky pipeline
- Two tenured men for every tenured woman
- „Girls grow up in a world hostile to female intelligence“
- Geder bias in reviewing proposals and papers
- The „prove it again“ mechanism: skepticism about women‘s abilities
- Careers of husbands tend to come first
- Dual career problem
- Difference in salaries
- The “mother figure“
- Sexual harassment

And many more…

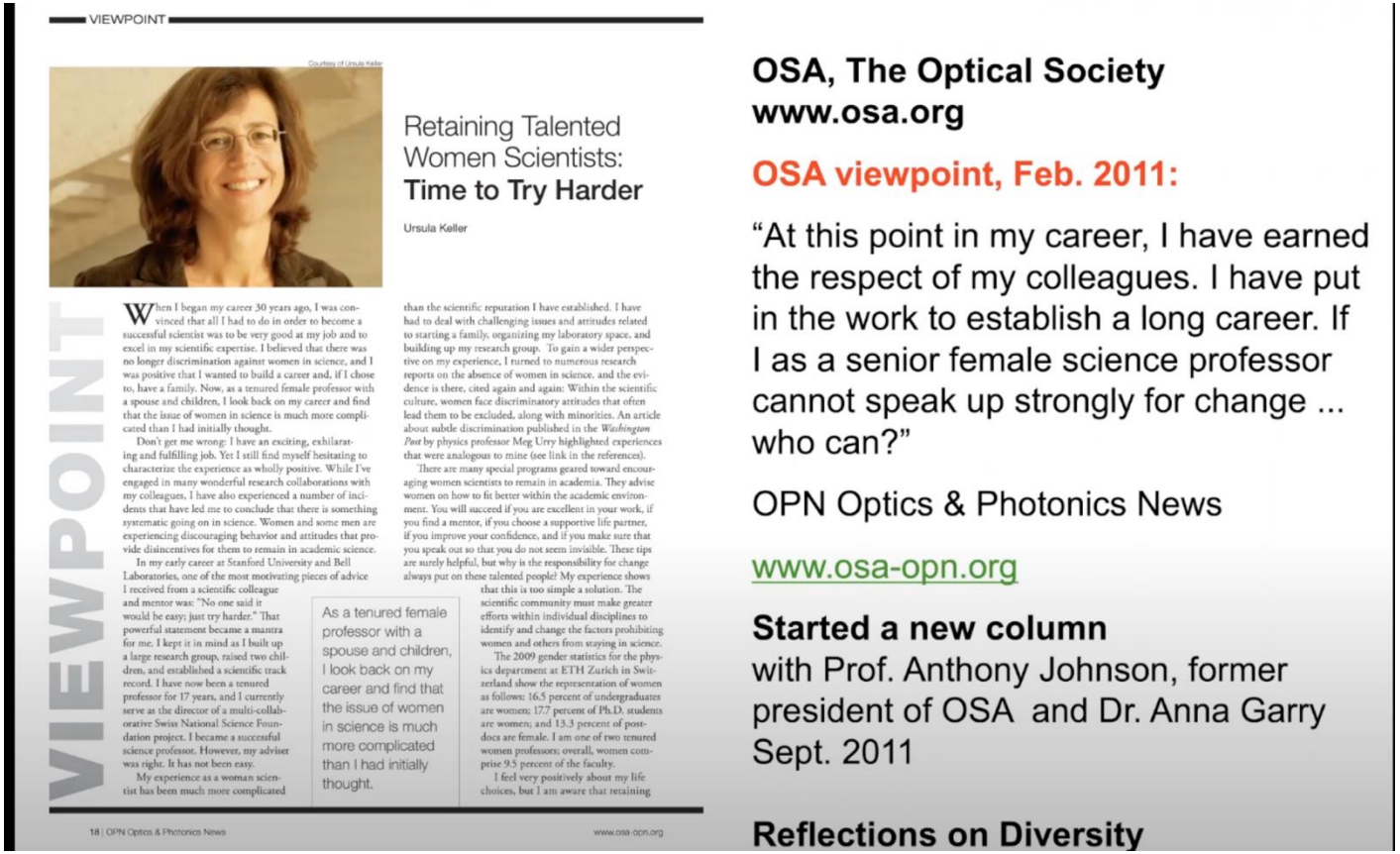
The leaky pipeline

Women in science: Clogging the leaky pipeline, Naturejobs, 23 Mar 2016
Philipp Gramlich and Karen Bodewitz

Instead of injecting more diversity at the bottom we should try to plug the pipeline by focussing on the many women that are already present at graduate and postgraduate stages. Give them, and particularly young mothers, the flexibility, infrastructure and confidence to live their passion for science and break through the glass ceiling. Give them the chance to pull the balance right!

Retaining Talented Women Scientists

Prof. Dr. Ursula Keller, ETH Zürich



VIEWPOINT

Courtesy of Ursula Keller

Retaining Talented Women Scientists: **Time to Try Harder**

Ursula Keller

VIEWPOINT

When I began my career 30 years ago, I was convinced that all I had to do in order to become a successful scientist was to be very good at my job and to excel in my scientific expertise. I believed that there was no longer discrimination against women in science, and I was positive that I wanted to build a career and, if I chose to, have a family. Now, as a tenured female professor with a spouse and children, I look back on my career and find that the issue of women in science is much more complicated than I had initially thought.

Don't get me wrong: I have an exciting, exhilarating and fulfilling job. Yet I still find myself hesitating to characterize the experience as wholly positive. While I've engaged in many wonderful research collaborations with my colleagues, I have also experienced a number of incidents that have led me to conclude that there is something systematic going on in science. Women and some men are experiencing discouraging behavior and attitudes that provide disincentives for them to remain in academic science.

In my early career at Stanford University and Bell Laboratories, one of the most motivating pieces of advice I received from a scientific colleague and mentor was: "No one said it would be easy; just try harder." That powerful statement became a mantra for me. I kept it in mind as I built up a large research group, raised two children, and established a scientific track record. I have now been a tenured professor for 17 years, and I currently serve as the director of a multi-collaborative Swiss National Science Foundation project. I became a successful science professor. However, my adviser was right. It has not been easy.

My experience as a woman scientist has been much more complicated than the scientific reputation I have established. I have had to deal with challenging issues and attitudes related to starting a family, organizing my laboratory space, and building up my research group. To gain a wider perspective on my experience, I turned to numerous research reports on the absence of women in science, and the evidence is there, cited again and again: Within the scientific culture, women face discriminatory attitudes that often lead them to be excluded, along with minorities. An article about subtle discrimination published in the *Washington Post* by physics professor Meg Urry highlighted experiences that were analogous to mine (see link in the references).

There are many special programs geared toward encouraging women scientists to remain in academia. They advise women on how to fit better within the academic environment. You will succeed if you are excellent in your work, if you find a mentor, if you choose a supportive life partner, if you improve your confidence, and if you make sure that you speak out so that you do not seem invisible. These tips are surely helpful, but why is the responsibility for change always put on these talented people? My experience shows that this is too simple a solution. The scientific community must make greater efforts within individual disciplines to identify and change the factors prohibiting women and others from staying in science.

> As a tenured female professor with a spouse and children, I look back on my career and find that the issue of women in science is much more complicated than I had initially thought.

The 2009 gender statistics for the physics department at ETH Zurich in Switzerland show the representation of women as follows: 16.5 percent of undergraduates are women; 17.7 percent of Ph.D. students are women; and 13.3 percent of postdocs are female. I am one of two tenured women professors; overall, women comprise 9.5 percent of the faculty.

I feel very positively about my life choices, but I am aware that retaining

18 | OPN Optics & Photonics News www.osa-opn.org

OSA, The Optical Society
www.osa.org

OSA viewpoint, Feb. 2011:

"At this point in my career, I have earned the respect of my colleagues. I have put in the work to establish a long career. If I as a senior female science professor cannot speak up strongly for change ... who can?"

OPN Optics & Photonics News

www.osa-opn.org

Started a new column
with Prof. Anthony Johnson, former president of OSA and Dr. Anna Garry
Sept. 2011

Reflections on Diversity

YouTube: DynaMENT - Plenary Talk by Ursula Keller - 10 September 2021

What about me and my career in photonics?

As of today…

Got the titles: Prof. Dr.
Joint appointment between Hamburg Universität and DESY
Full Pofessor of Physics and Leading Scientist

Got the "bold" publications
Science, Nature, Nature Physics, Nature Photonics, etc…

Got the grants and the awards
ERCs, ICO Prize and Ernst Abbe Medal, OSA Fellow

Got fundings, labs, institutional roles and a large group of young and motivated students and scientists

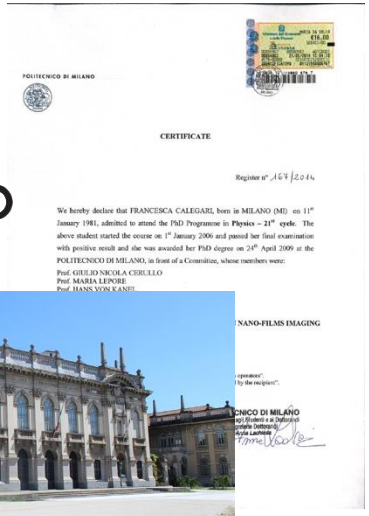
But…was it easy at all?

A good start in Physics and Photonics

Master in Physics, 2005
Università Statale di Milano
Summa cum Laude

PhD in Physics, 2009
School of Photonics
Politecnico di Milano

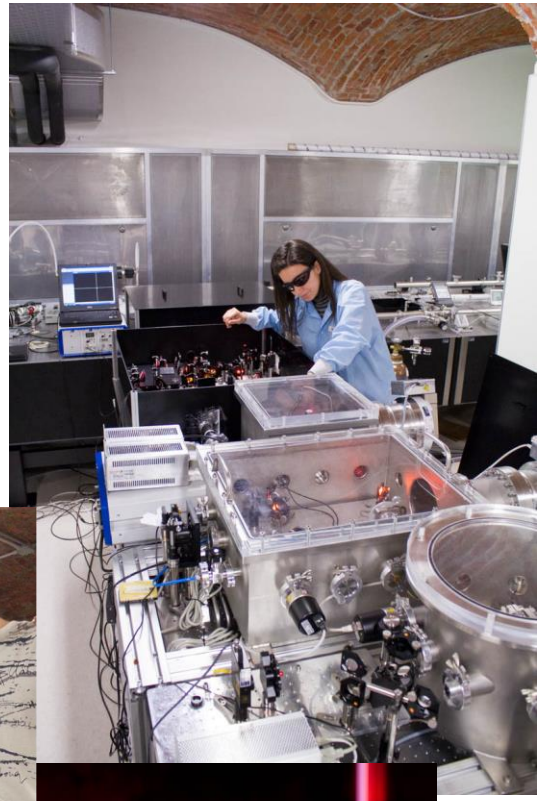
POLITECNICO
MILANO 1863

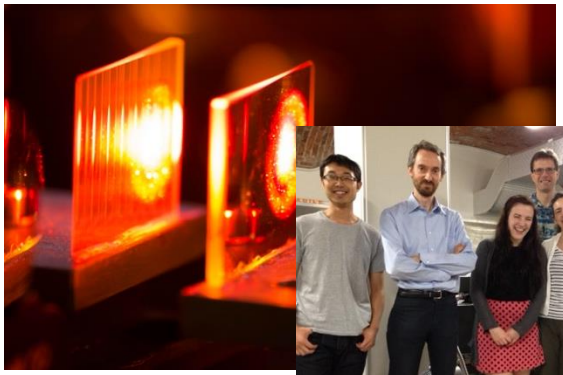


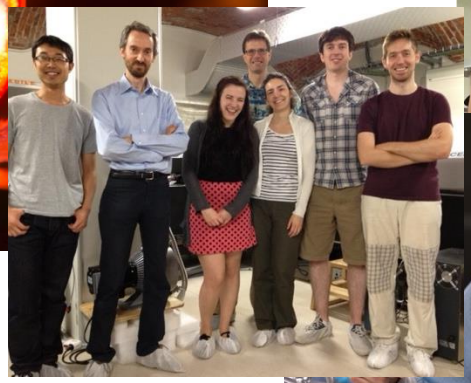
At this time I thought science had no gender and I could not foresee any obstacles

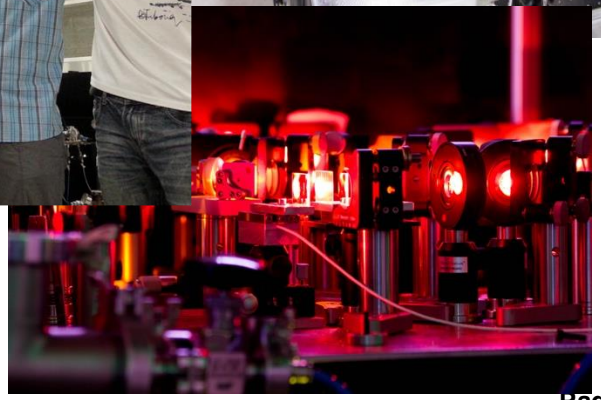
Trained to study the smallest and the fastest

- Studied in an excellent reserach group
- Followed my passion for light and lasers
- Had a lot of fun (and pizza) in the lab!
- Found excellent mentors who motivated me to pursue a career in science
- Found my role models

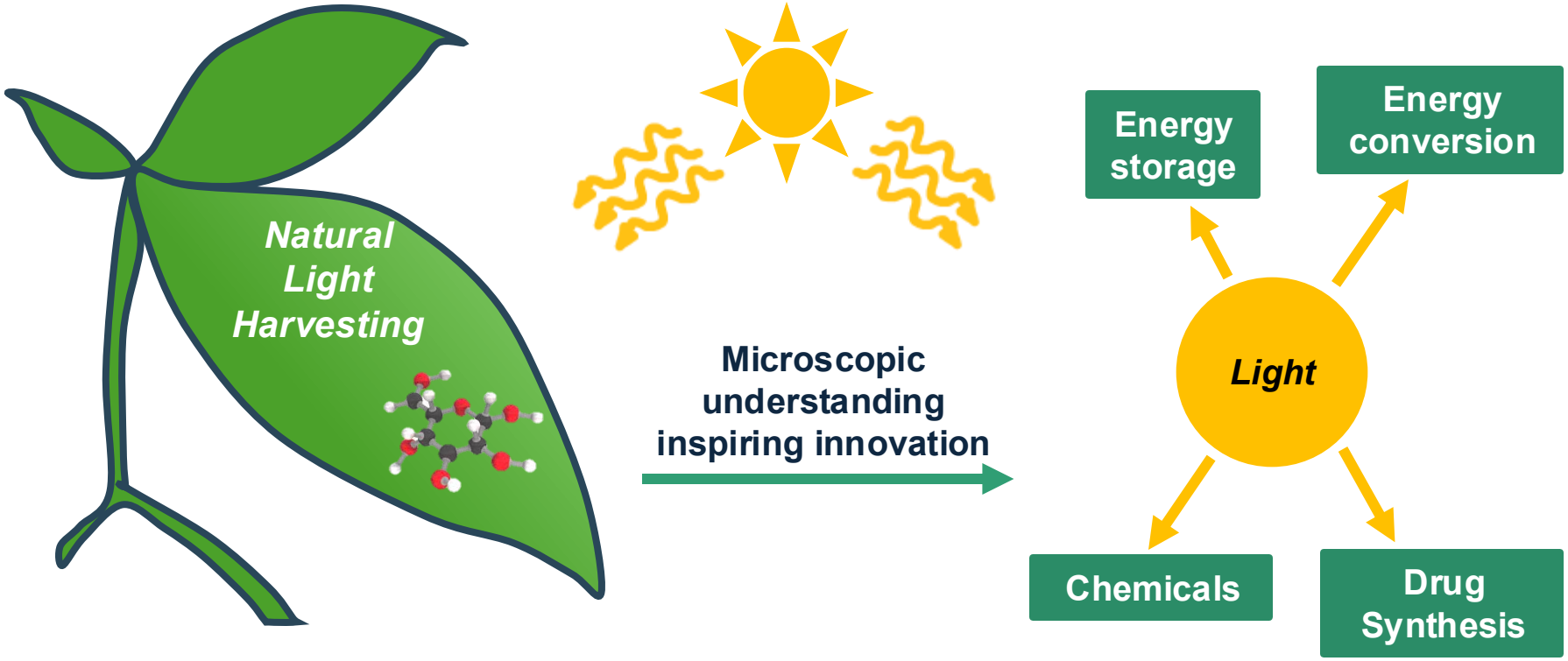








Understand ultrafast molecular dynamics for engineering light harvesting



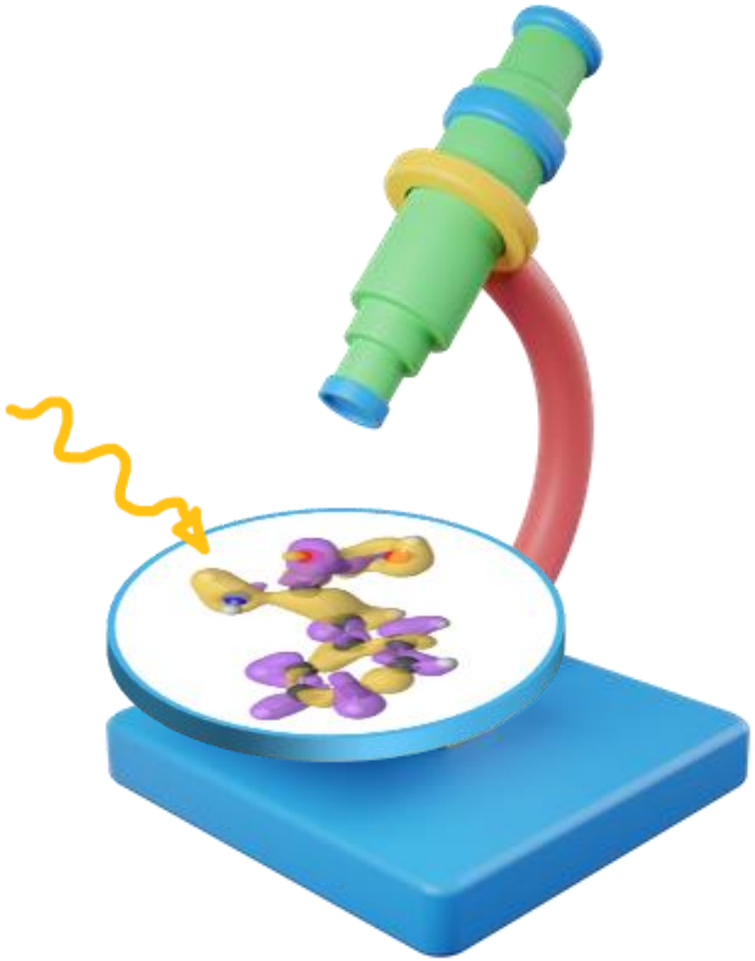
Lv, J., et al. Nat Rev Chem ***7****, 91–105 (2023)*

Image and control photochemical processes

Motivation:

Understand the light-molecule interaction & the mechanisms relevant for photochemistry

Image electrons at the relevant time and length scales



Time scales in matter

Matter is often driven by external stimuli out of equilibrium!

MeV

meV

Energy

10^{6}

10^{-3}

Nucleonic motion

Atomic motion

zepto

pico

10^{-21}

10^{-12}

Time [s]

Inner sh

ction band

1

10

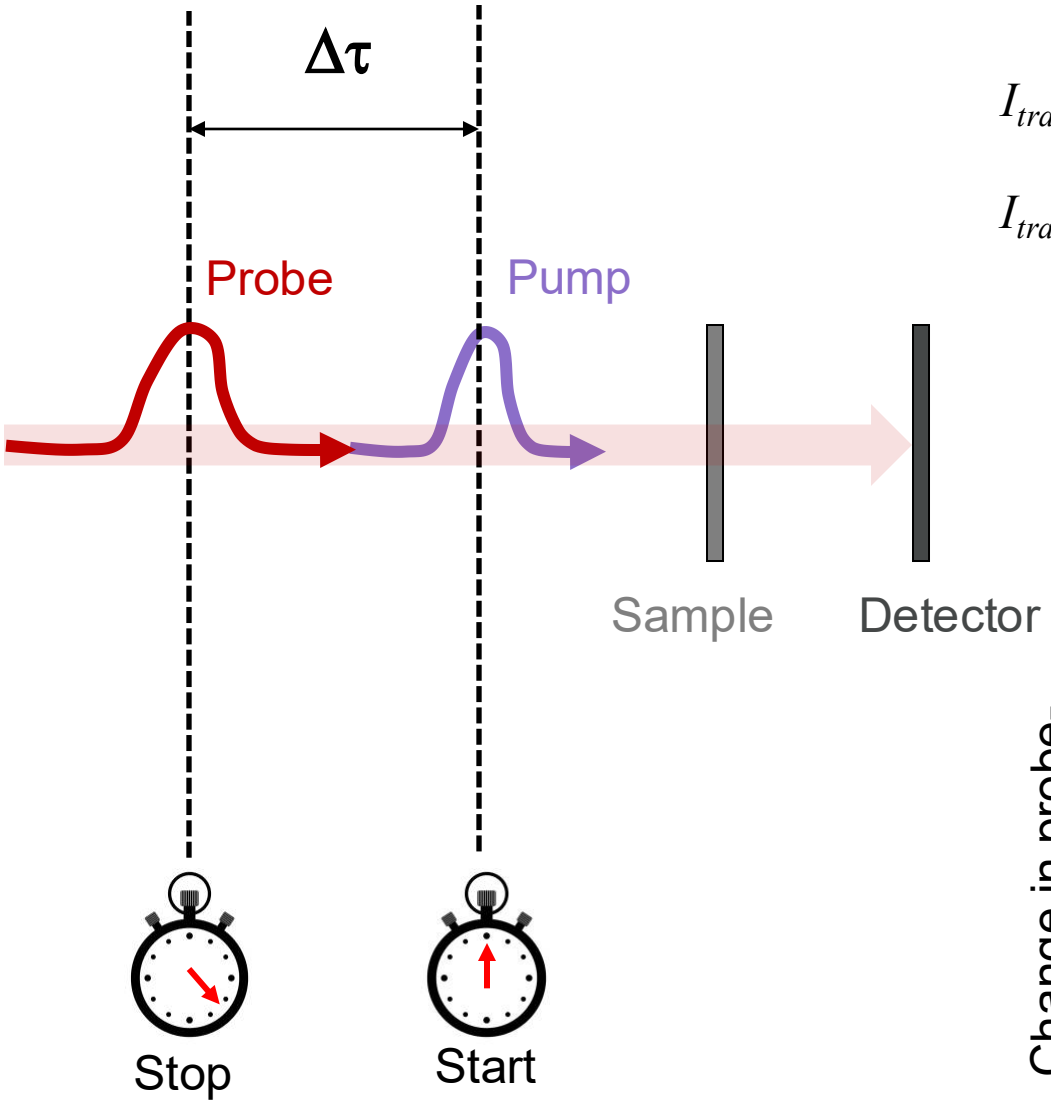
100

1000

10000

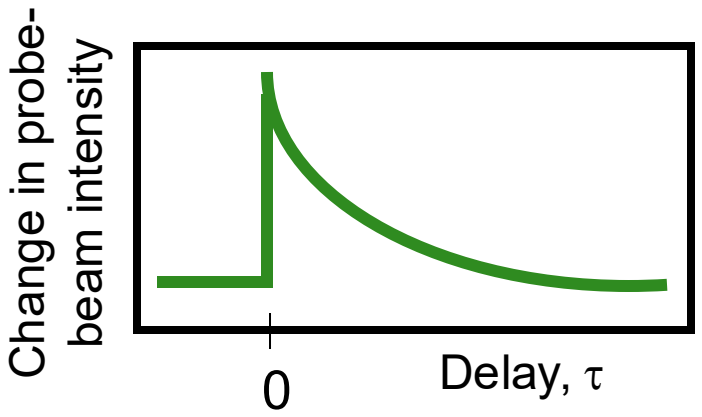
Time [as]

Time-resolved measurement: “pump & probe”



$$I_{transmitted} = I_{incident} \exp\{-\alpha_0 L\}$$

$$I_{transmitted}(\tau) = I_{incident} \exp\{-[\alpha_0 - \Delta\alpha(\tau)]L\}$$



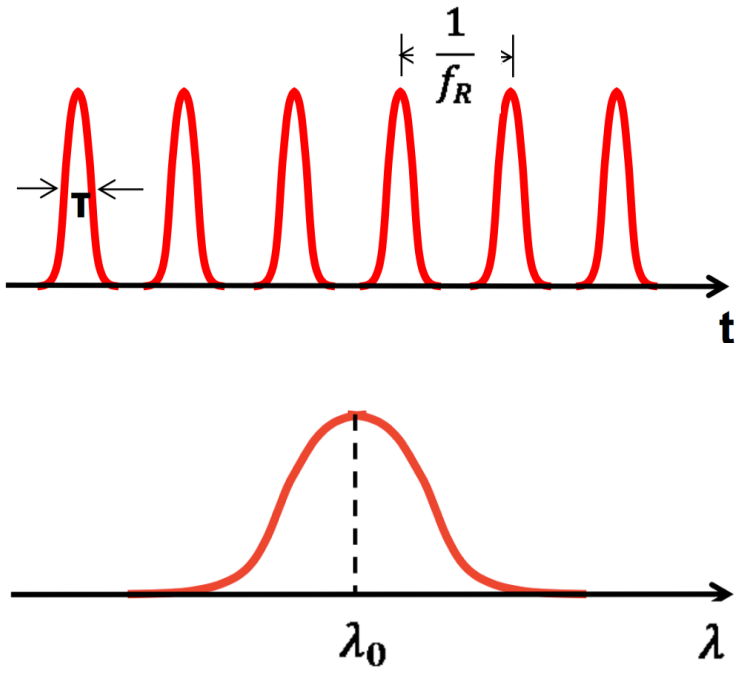
Pulsed Lasers: short light pulses to image matter

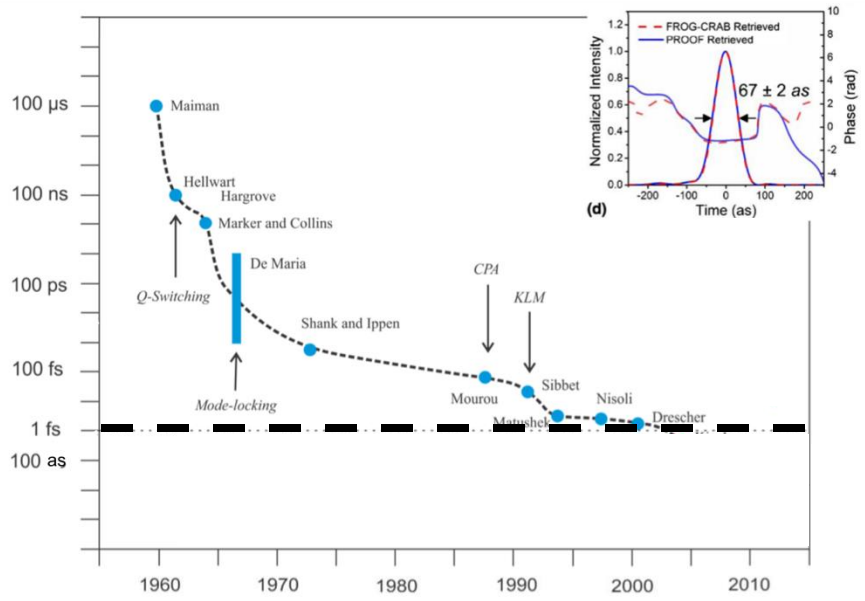
Laser pulses:

T= duration

λ_0= carrier wavelength

f_R = repetition rate





Femtosecond pulses can be produced by conventional lasers

The Nobel Prize in Physics 2023

Ill. Niklas Elmehed © Nobel Prize Outreach

Pierre Agostini

Prize share: 1/3

Ill. Niklas Elmehed © Nobel Prize Outreach

Ferenc Krausz

Prize share: 1/3

Ill. Niklas Elmehed © Nobel Prize Outreach

Anne L'Huillier

Prize share: 1/3

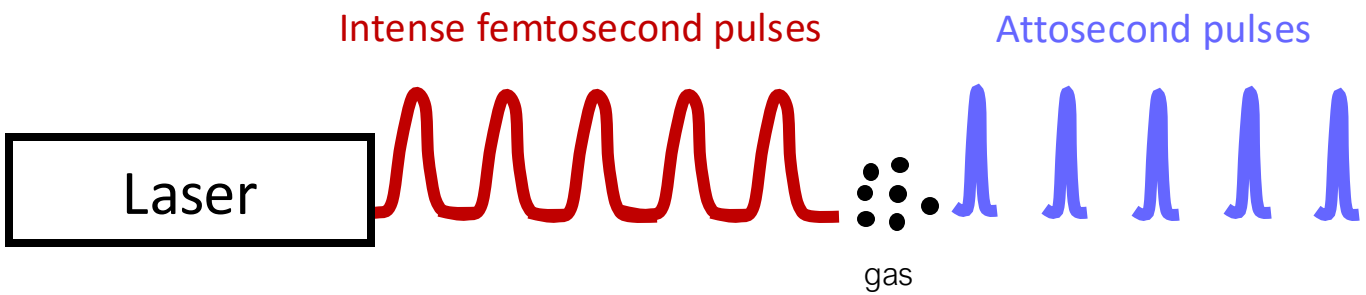
"for experimental methods that generate attosecond pulses of light for the study of electron dynamics in matter"

Experiments with light capture the shortest of moments

The three Nobel Laureates in Physics 2023 are being recognised for their experiments, which have given humanity new tools for exploring the world of electrons inside atoms and molecules. Pierre Agostini, Ferenc Krausz and Anne L'Huillier have demonstrated a way to create extremely short pulses of light that can be used to measure the rapid processes in which electrons move or change energy.

Extreme nonlinear optics: non-perturbative regime

When a laser is focused on a target medium with peak intensity above 10^{14} W/cm^2 a frequency conversion to higher order harmonics can be achieved via a non-perturbative interaction and shorter pulses are produced.



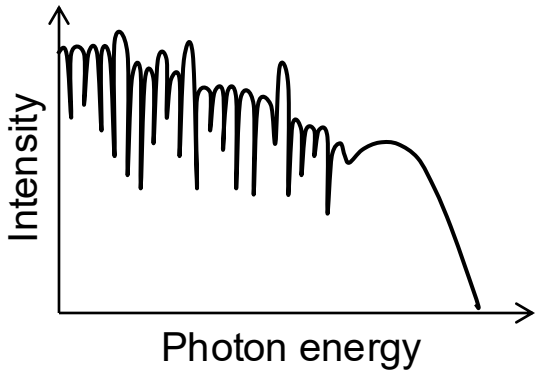
$\lambda_n = n\,\lambda_1$

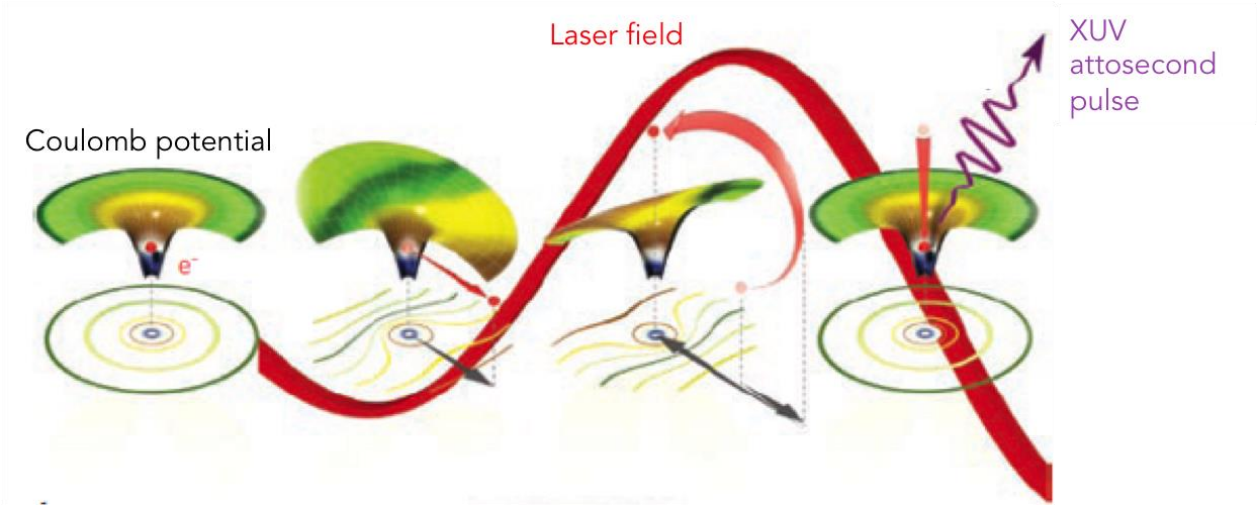
n = 7,9,11,13,…

High-order Harmonic Generation

Three-step model

1. Tunnel ionization
2. Acceleration
3. Recollision

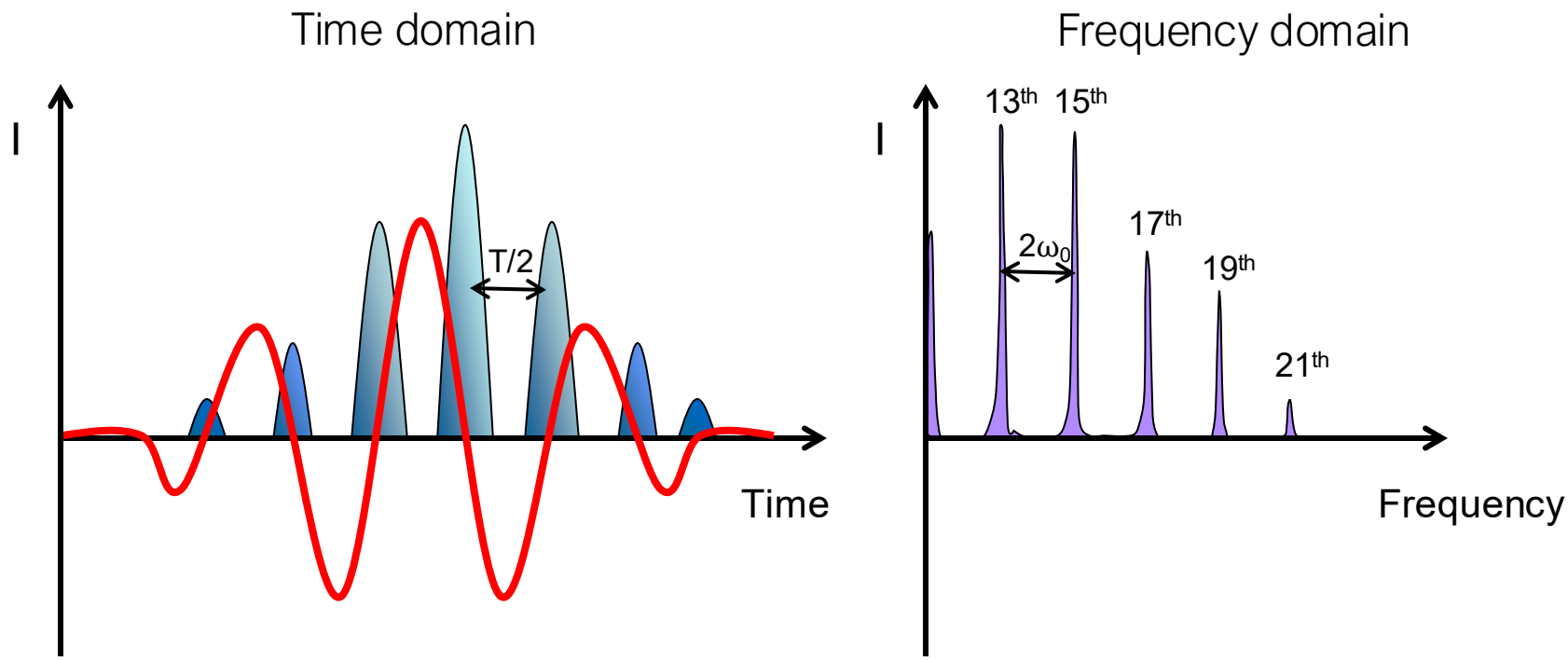




K.J. Schafer et al, Phys. Rev. Lett. 70, 1599 (1993)

P. B. Corkum, Phys. Rev. Lett. 71, 1994 (1993)

The attosecond pulse train



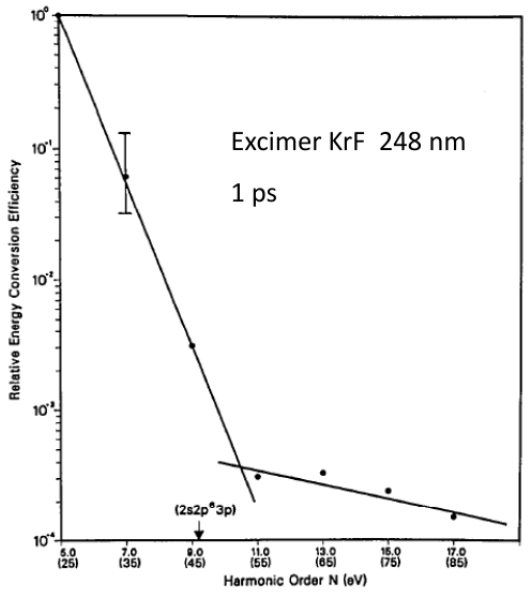
HHG every half cycle of the driving laser: attosecond pulse train

The interference between attosecond pulses separated T/2 gives rise to odd order harmonics of the fundamental frequency (spaced 2ω)

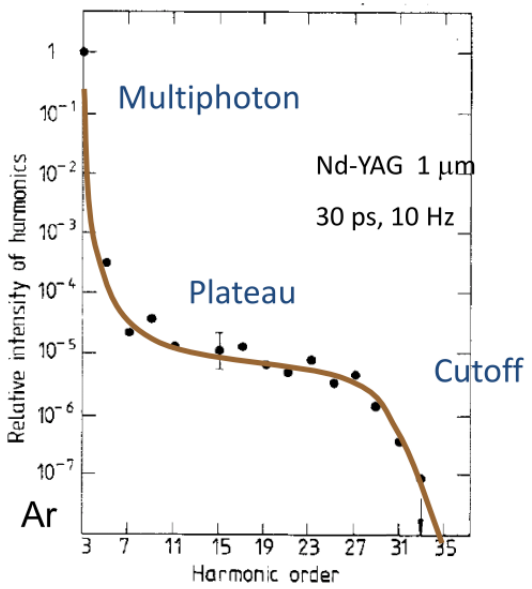
First observation of HHG

High-order Harmonic Generation - HHG

In the late 90's scientists observed frequency conversion of laser pulses to the XUV at orders incompatible with a perturbative multi-photon picture



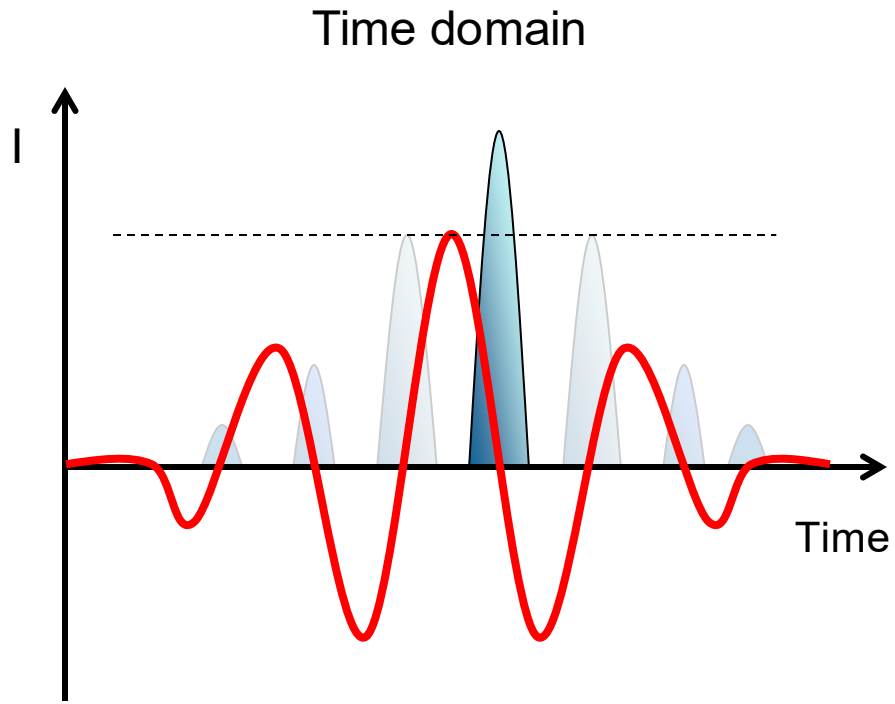
McPherson et al, JOSA B (1987)

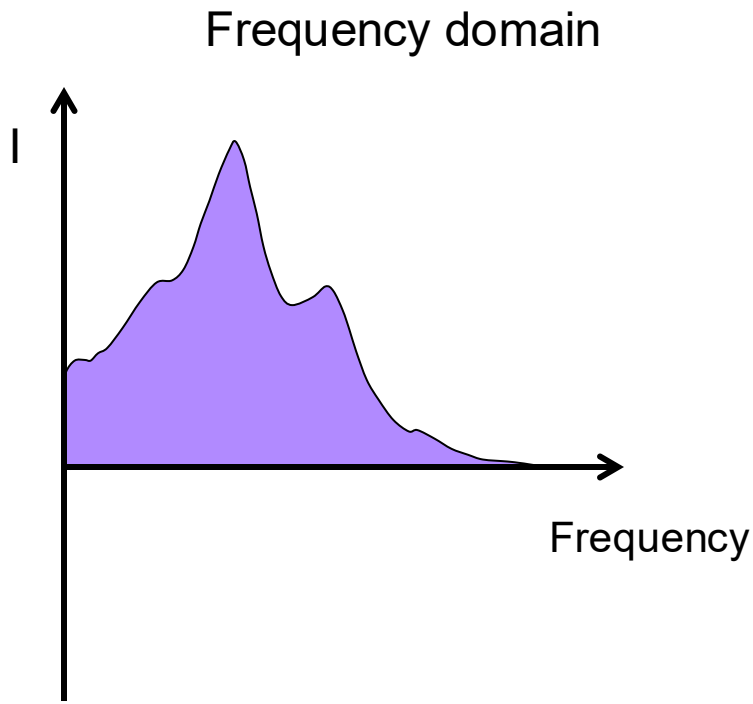


J Ferray et al, J. Phys. B (1988)

Ill. Niklas Elmehed © Nobel Prize Outreach
Anne L'Huillier
Prize share: 1/3

Isolated attosecond pulses





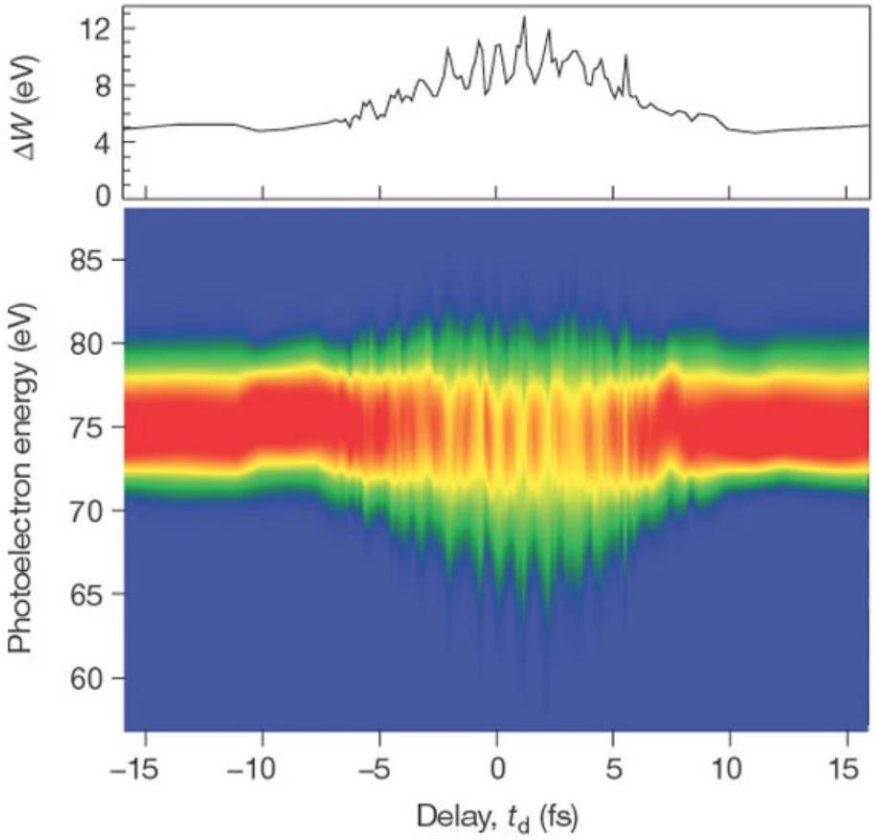
Spectral and temporal gating methods on HHG enable the generation of an isolated attosecond pulse

G. Sansone et al., Science 314, 443 (2006)
F. Ferrari et al., Nat. Photonics 4, 875 (2010)
F. Calegari et al., J. Phys. B 45, 074002 (2012)

Shortest attosecond pulse 43 as!

T Gaumnitz et al, Optics Express 25 (2017)

First measurement of isolated attosecond pulses



Ill. Niklas Elmehed © Nobel Prize Outreach

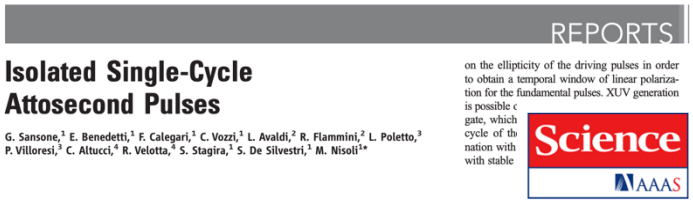
Ferenc Krausz

Prize share: 1/3

Hentschel, M. et al. Attosecond metrology. Nature 414, 509–513 (2001)

Beginning of my PhD studies: exciting times for ultrafast and attosecond science

Participated in the first demonstration of the generation of isolated attosecond pulses:
We measured 130 as!

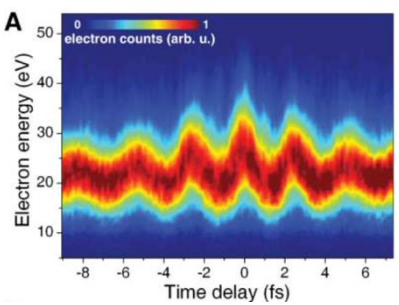

REPORTS

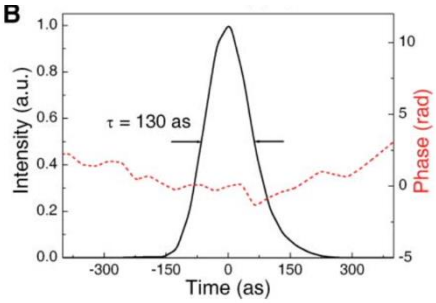
Isolated Single-Cycle Attosecond Pulses

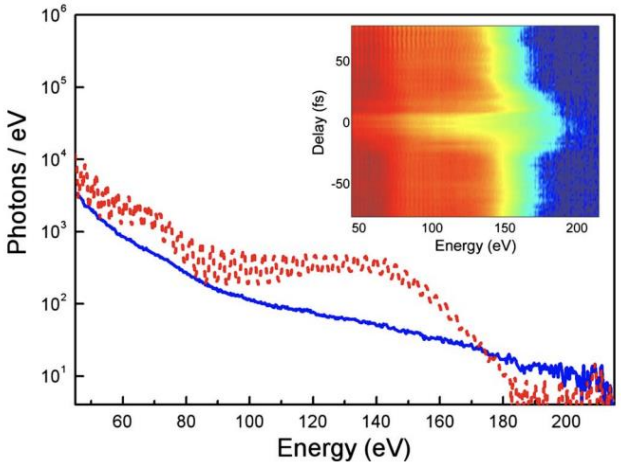
G. Sansone,[1] E. Benedetti,[1] F. Calegari,[1] C. Vozzi,[1] L. Avaldi,[2] R. Flammini,[2] L. Poletto,[3] P. Villoresi,[3] C. Altucci,[4] R. Velotta,[4] S. Stagira,[1] S. De Silvestri,[1] M. Nisoli[1]*

on the ellipticity of the driving pulses in order to obtain a temporal window of linear polarization for the fundamental pulses. XUV generation is possible gate, which cycle of th nation with with stable

Science
AAAS







During my PhD I worked for pushing the generation towards higher photon energies:
we reached 200 eV!

October 15, 2009 / Vol. 34, No. 20 / OPTICS LETTERS

Efficient continuum generation exceeding 200 eV by intense ultrashort two-color driver

F. Calegari,[1,*] C. Vozzi,[1] M. Negro,[1] G. Sansone,[1] F. Frassetto,[2] L. Poletto,[2] P. Villoresi,[2] M. Nisoli,[1] S. De Silvestri,[1] and S. Stagira[1]

Decided to learn molecular imaging techniques to combine laser science and molecular physics

In 2009 learned about Reaction Microscope
Visiting Scientist at Max Planck Institut für Kernphysik, Heidelberg, Germany
Prof. J. Ullrich

In 2010 learned about VMI
Postdoc at FOM institute AMOLF, Amsterdam, The Netherlands
Prof. M. Vrakking

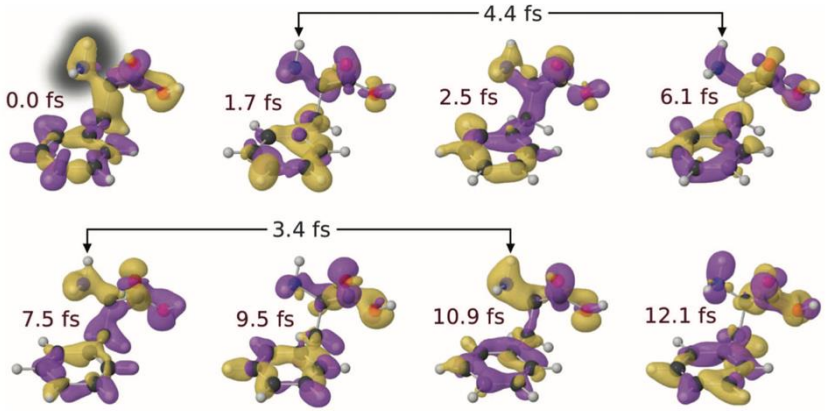
Expanding knowledge pays off!

ATTOSECOND DYNAMICS

Ultrafast electron dynamics in phenylalanine initiated by attosecond pulses

Science
AAAS

F. Calegari,[1] D. Ayuso,[2] A. Trabattoni,[3] L. Belshaw,[4] S. De Camillis,[4] S. Anumula,[3] F. Frassetto,[5] L. Poletto,[5] A. Palacios,[2] P. Decleva,[6] J. B. Greenwood,[4] F. Martín,[2,7]* M. Nisoli[1,3]*



In 2014 I obtained the most important scientific result of my career:
I successfully demonstrated that attosecond pulses can be used to obtain a „molecular movie“ of the charge migrating in a bio-relevant molecule

- Invited to many conferences
- Invited to write follow up works and review papers
- Motivated further research in many groups around the world
- I also got a permanent position as staff scientist at the National Research Council and as assistant professor at Politecnico di Milano

Femtochemistry: coherent control of chemistry by light

Classical forces on the atomic nuclei

Using **femtosecond pulses**:

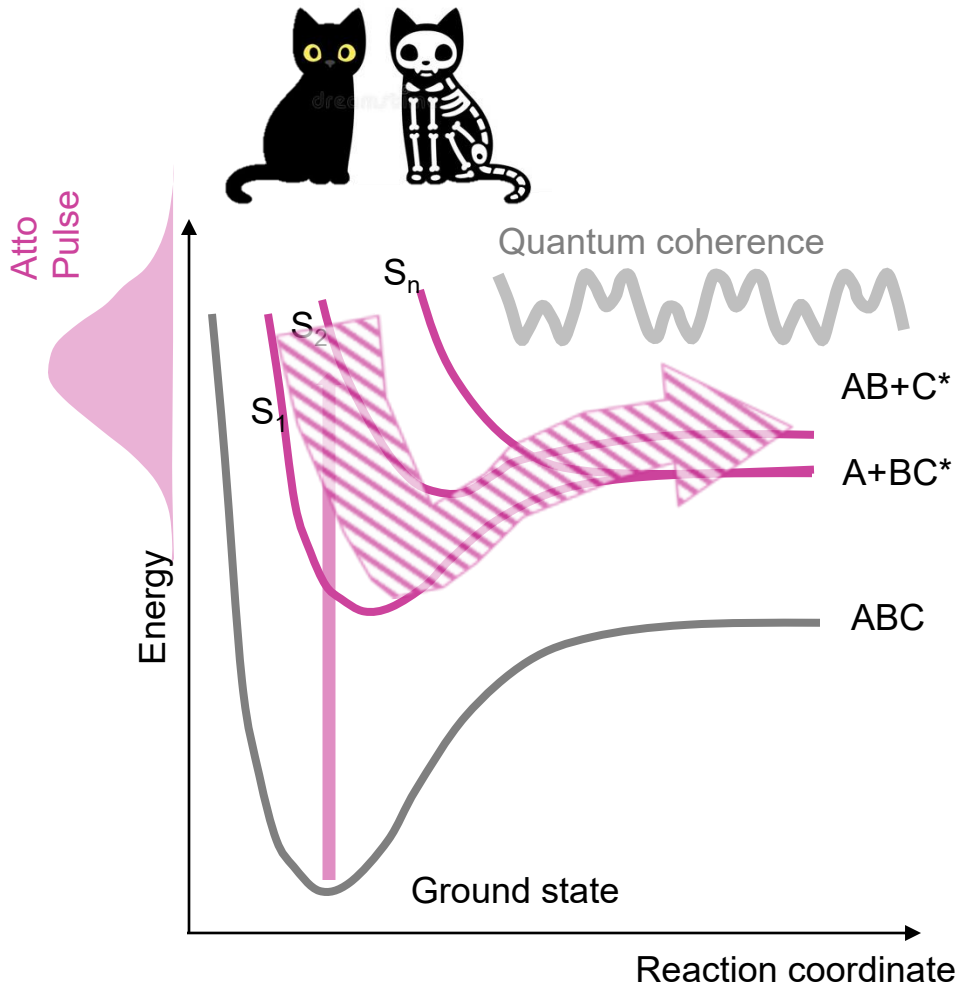
The coherent excitation of a specific electronic state efficiently creates specific photoproducts.

Vibrational coherences can be populated.

$|\Psi> = c_1 |v_1> + c_2 |v_2> \ldots + c_n |v_n>$

A. H. Zewail, J. Phys. Chem. A, 104, 24, 5660 (2000)

Attochemistry: new quantum landscape



M. Cardosa-Gutierrez et al, J. Phys. B, 57 133501 (2024)

F. Calegari & F. Martin, Commun Chem 6, 184 (2023)

Quantum forces on the atomic nuclei

Using **attosecond pulses broadband and sudden excitation (fixed nuclei)**:

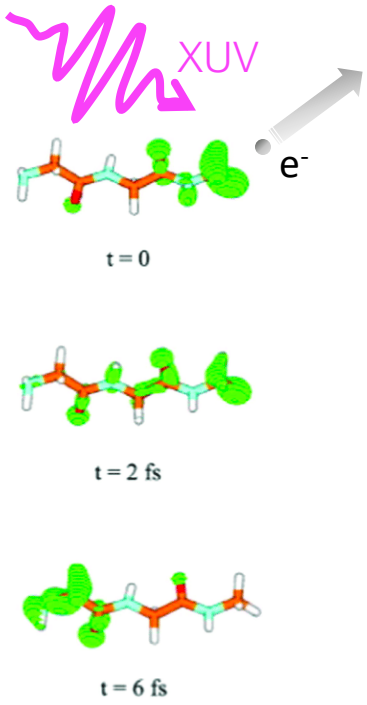
An electronic wavepacket (EWP) is created.

$|\Psi\rangle = c_1 |S_1\rangle + c_2 |S_2\rangle \ldots + c_n |S_n\rangle$

The quantum correlation between electron and nuclei creates new terms in the total force field → **shaping EWP allows to engineer the force.**

Charge directed reactivity!

Charge migration



GlyGlyNHCH$_3$
Small peptide

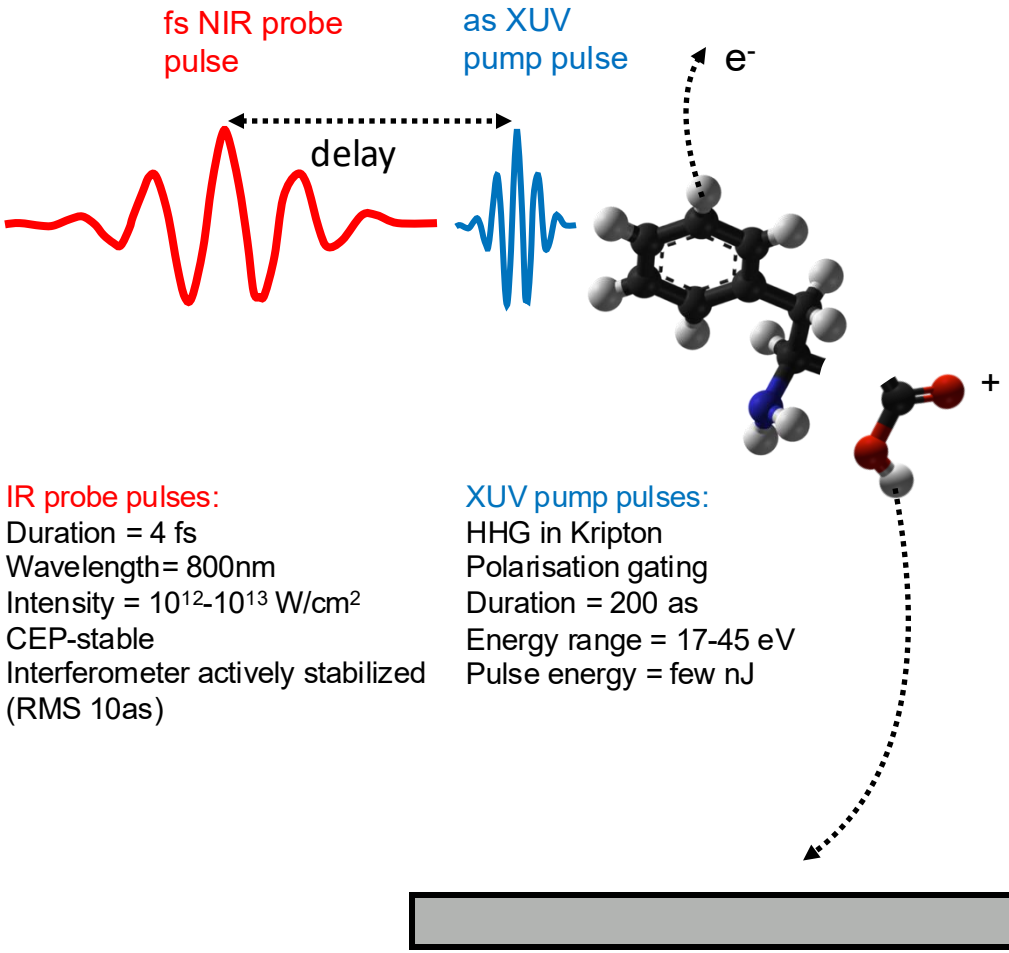
Sudden ionization/electronic excitation leads to a non-stationary charge density distribution: charge migration.

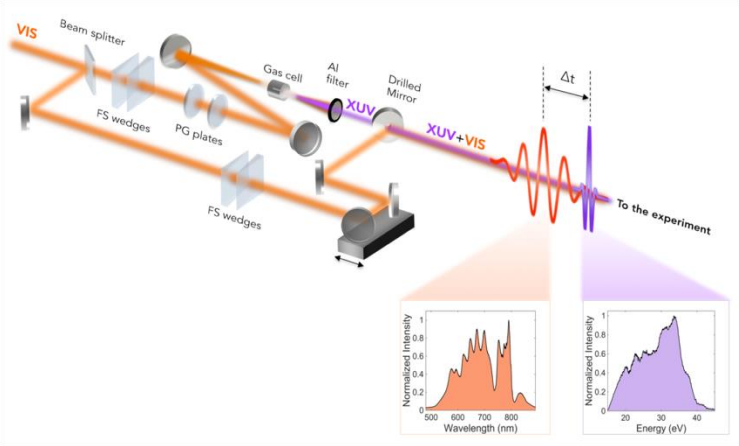
- How can we initiate charge migration?
- How can we observe charge migration?
- Can we take advantage of the emergent quantum force field acting on the atomic nuclei to control the chemistry?

S. Lünnemann et al., Chem. Phys. Lett. 450, 232 (2008)
L. Cederbaum et al, Chem. Phys. Lett. 307, 205 (1999)
F. Remacle, R. Levine, PNAS 103, 6793 (2006)
A. Kuleff, L. Cederbaum, Chem. Phys. 338, 320 (2007)

Detecting charge migration

Attosecond time resolved photofragmentation

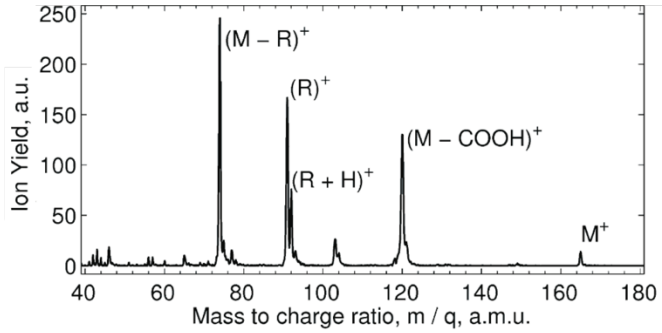




IR probe pulses:
Duration = 4 fs
Wavelength= 800nm
Intensity = 10^{12}-10^{13} W/cm^2
CEP-stable
Interferometer actively stabilized (RMS 10as)

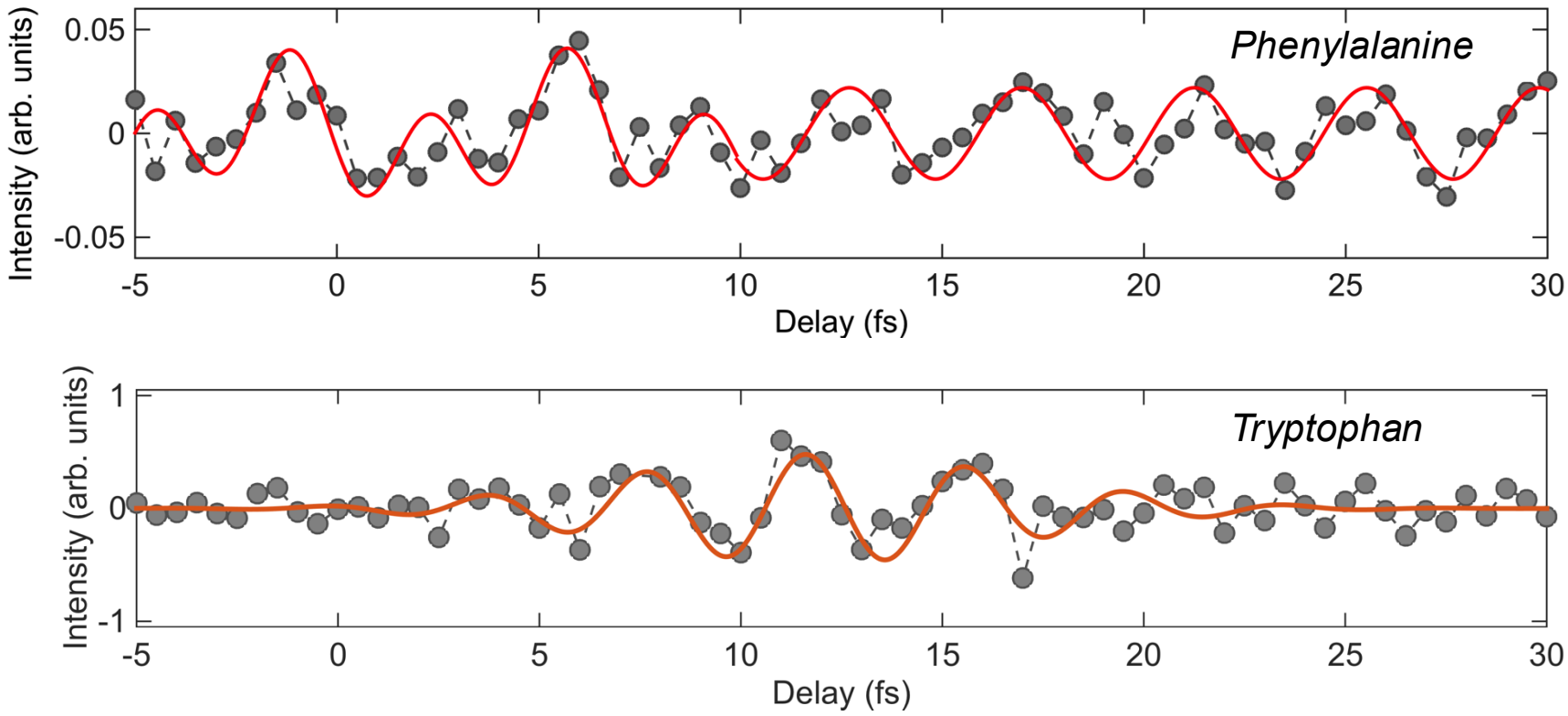
XUV pump pulses:
HHG in Kripton
Polarisation gating
Duration = 200 as
Energy range = 17-45 eV
Pulse energy = few nJ

MASS SPECTRUM



Charge migration in aromatic amino acids

Dication yield after subtraction of the 25-fs decay

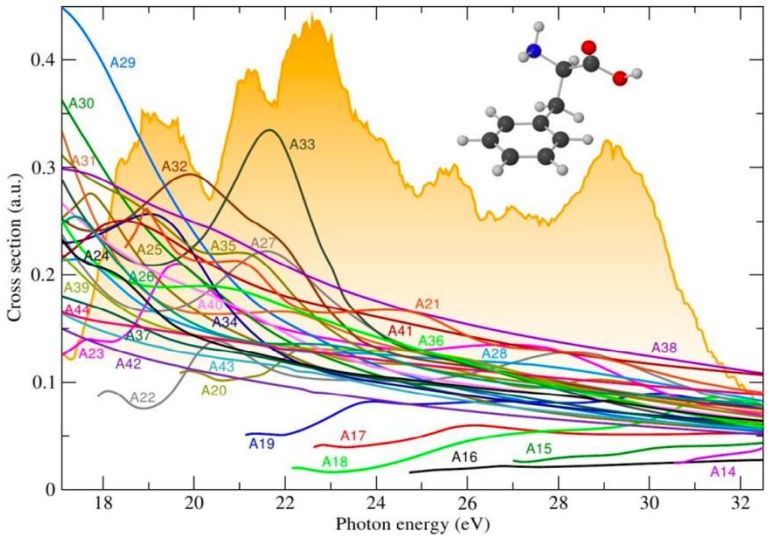


Sub 4.5 fs oscillations

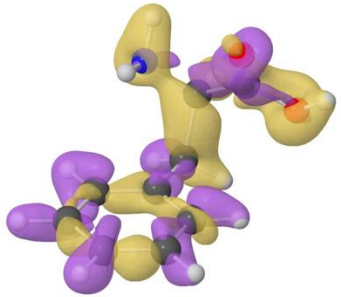
F. Calegari et al., Science 346, 336 (2014)
M. Lara-Astiaso et al, The journal of physical chemistry letters 9 (16), 4570-4577, (2018)

Charge migration in aromatic amino acids

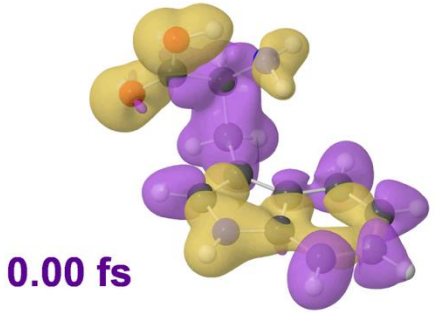
- Manifold of 1h states included
- Frozen nuclei
- 2h1e not included (no CC expansion)



Phenylalanine

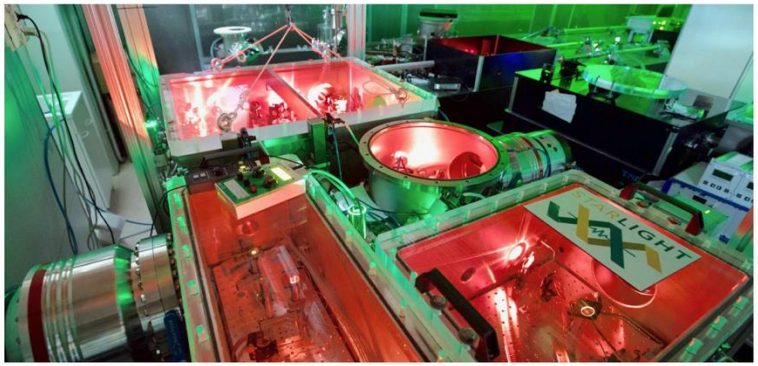


Tryptophan



F. Calegari et al., Science 346, 336 (2014)

Grants and progress in the career



In 2015, I proposed a new idea to study the UV-photochemistry of DNA with extreme time resolution

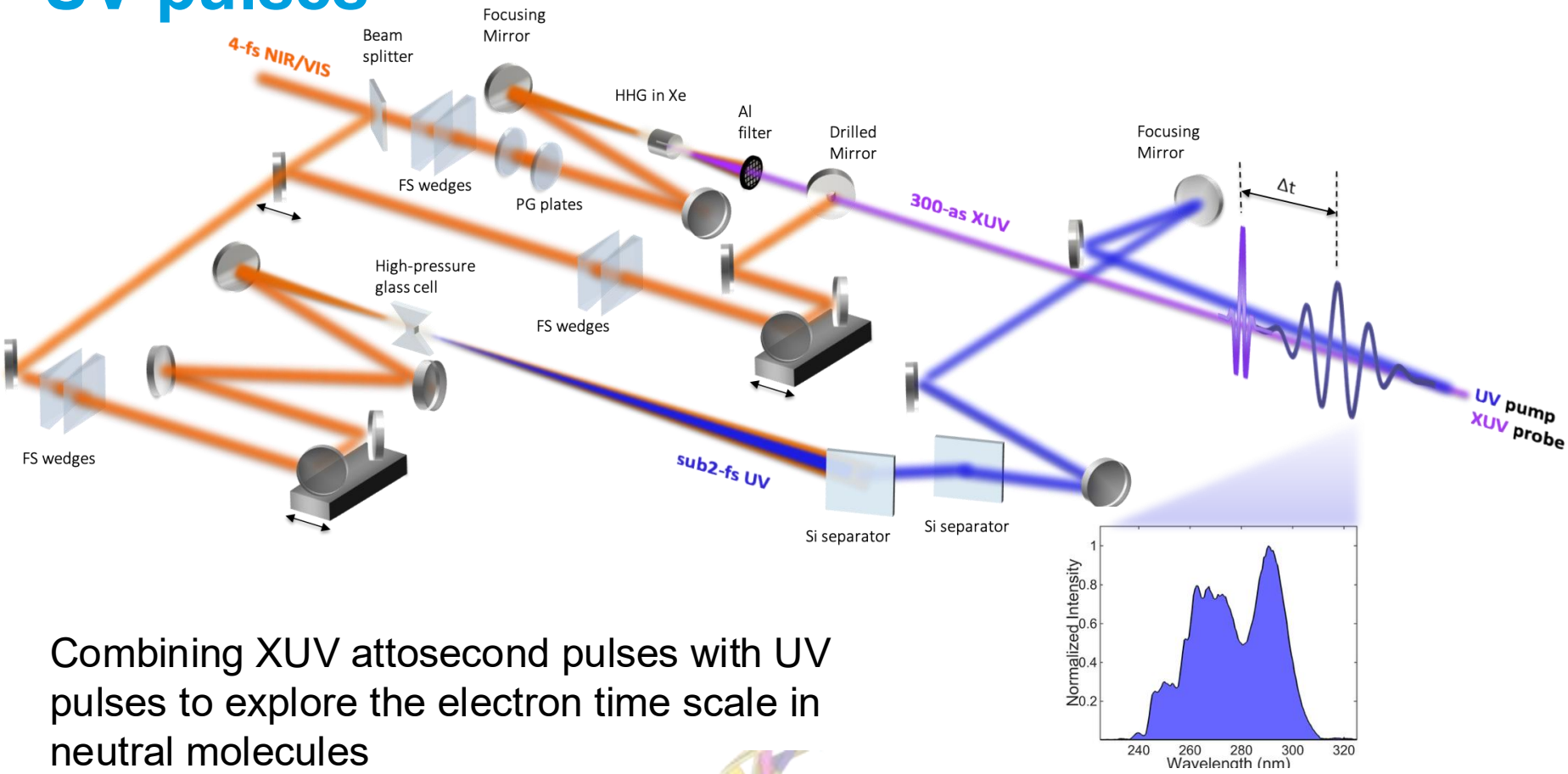
ERC StG STARLIGHT, 1.5 Millions Euro

- Started my own group
- Learned about managing people and budget

In 2016, I have been successfully selected in the Helmholtz Distinguished Professorship program for **female scientist**

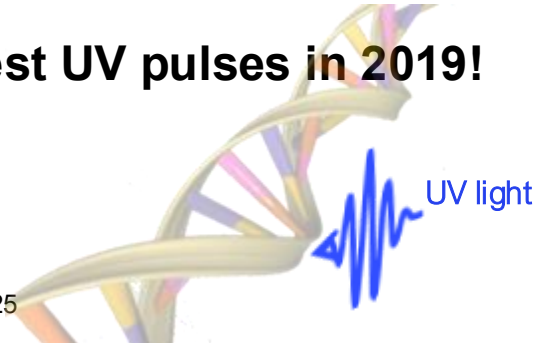
- Moved to Hamburg on a **„quota“ program**
- Built new labs and established a new group for attosecond science

Novel attosecond approaches: ultrashort UV pulses



Combining XUV attosecond pulses with UV pulses to explore the electron time scale in neutral molecules

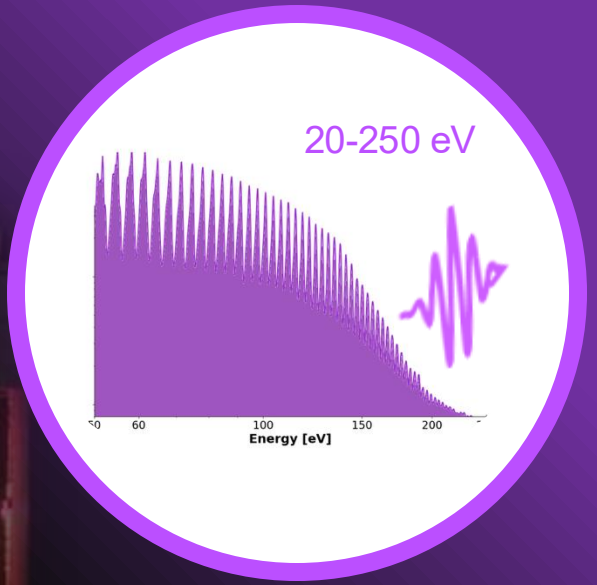
World-record shortest UV pulses in 2019!

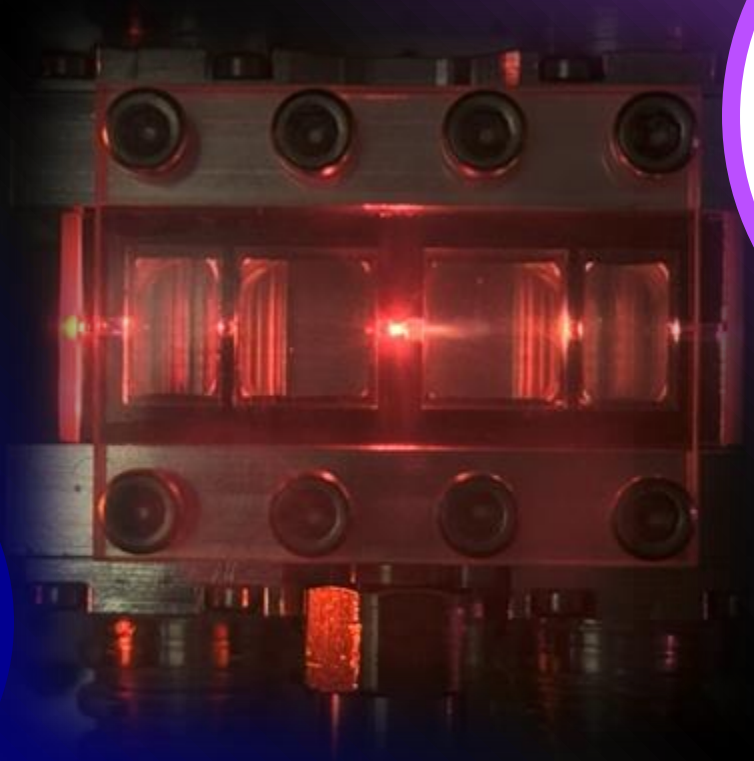


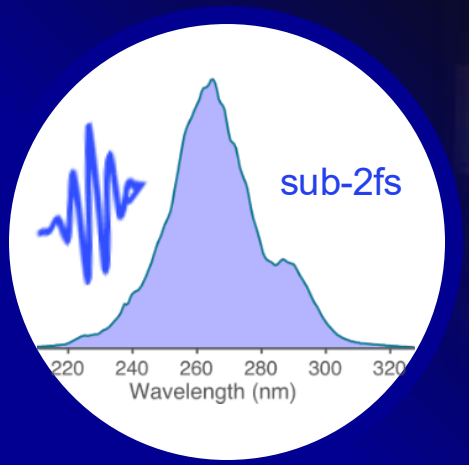
M. Galli et al, Optics letters 44 (6), 1308-1311 (2019)

Ultrafast light sources

VUV-soft X







A. Azzolin et al,
arXiv :2510.09496

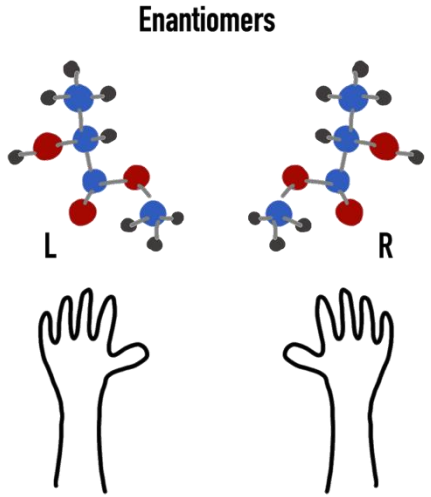
UV

M. Galli et al, Optics letters 44 (6), 1308-1311 (2019)
V. Wanie et al, J. Phys Photonics 6, 025005 (2023)
L. Silletti et al, Optics Letters 48, 1842-1845 (2023)
L. Silletti et al, APL Photonics 10, 070801 (2024)

Applications: chirality

Concept

- Non-superimposable mirror images
- Handedness defines the interaction with another chiral object



Chiral molecules = enantiomers

Chiral recognition

- Homochirality of all living organisms (l - amino acids)
- Pharmacology → healing vs toxic effect

l-methamphetamine

Nasal decongestant

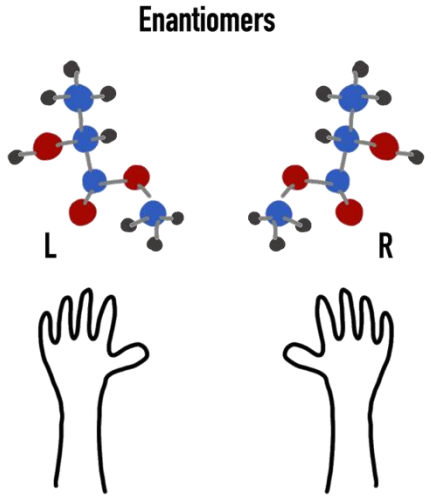
d-methamphetamine

Recreational drug

Applications: chirality

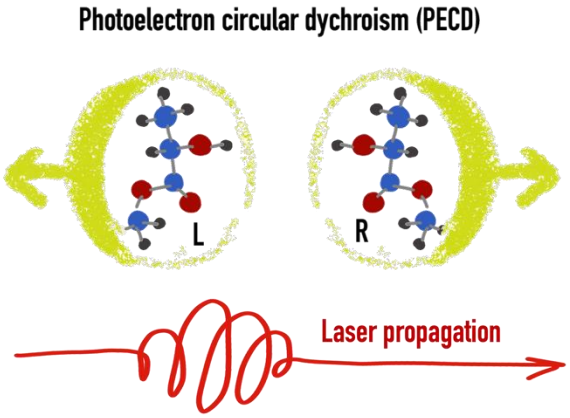
Concept

- Non-superimposable mirror images
- Handedness defines the interaction with another chiral object



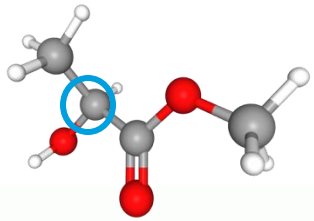
Chiral molecules = enantiomers

Probing chirality

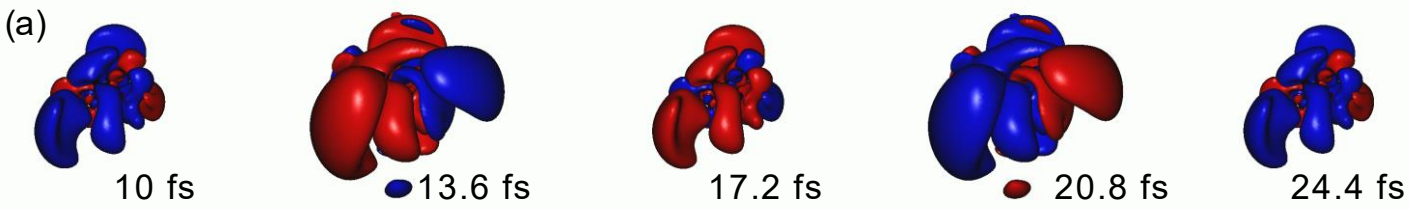


S. Beaulieu et al, Faraday Discuss., 194, 325 (2016)

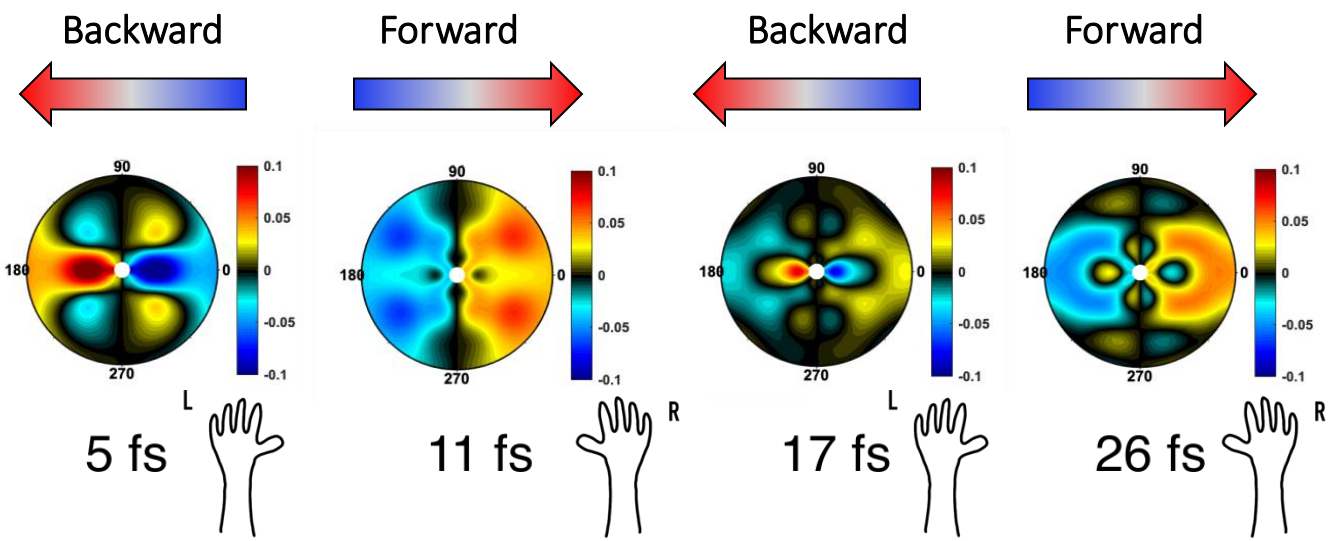
Time-dependent PECD

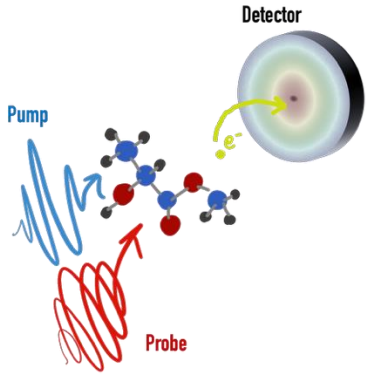


UV-activated Charge migration



Ultrafast inversion of PECD

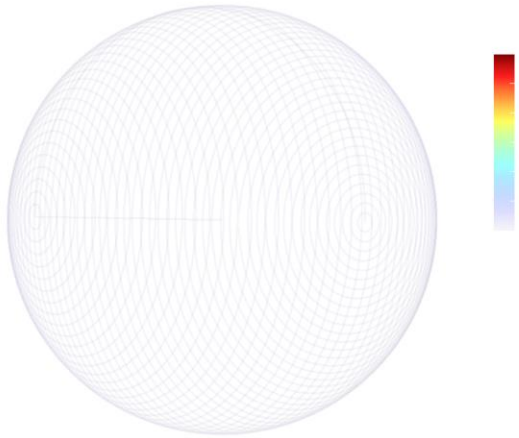


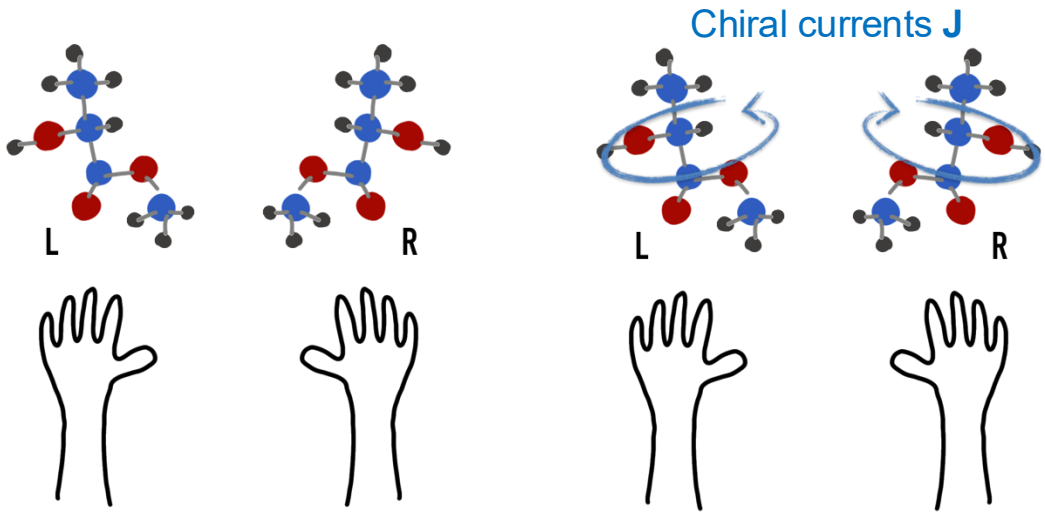


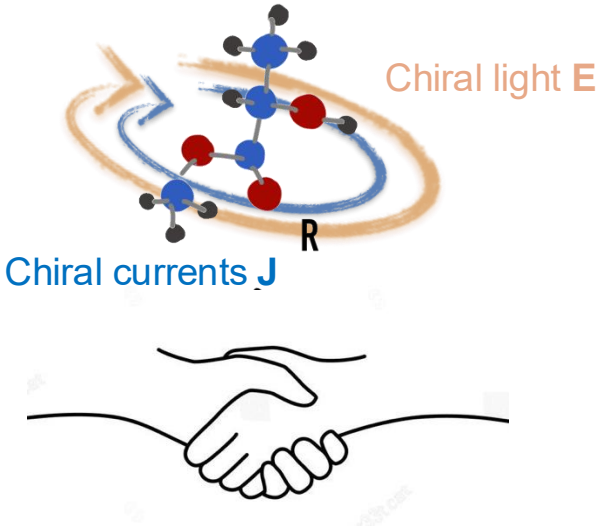
V. Wanie et al, Nature 630, 109 (2024)

Chiral currents

Charge migration results in chiral currents switching sign with the periodicity of the electronic beatings.



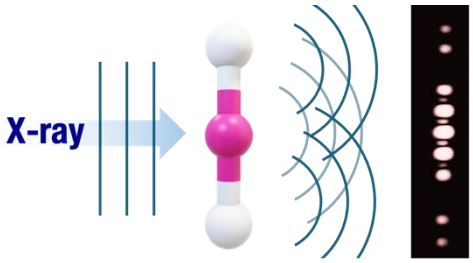


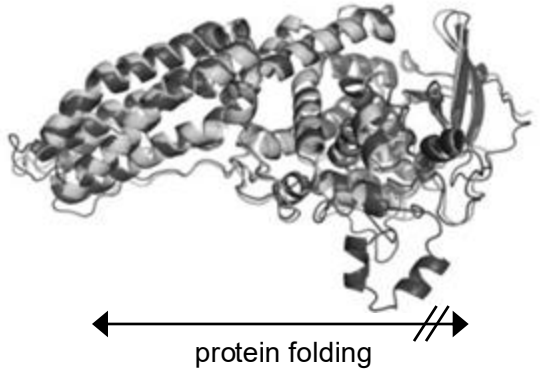


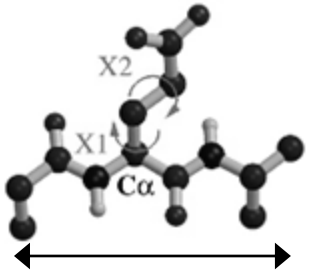
Transient chiral currents enable **control of enantio-selective interactions.**

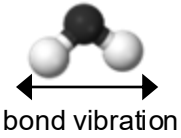
Dynamics on multiple time and length scales

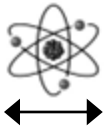
Length: X-ray Crystallography



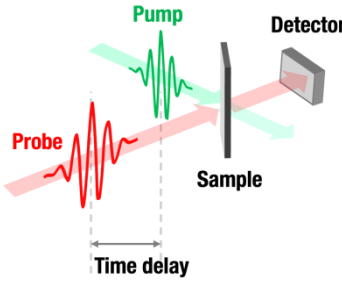








Time: ultrafast light sources



µm

nm

Å

Time

attoseconds
10^{-18} s

femtoseconds
10^{-15} s

picoseconds
10^{-12} s

…

microseconds
10^{-6} s

The fastest and the shortest

µm

nm

Å

+

electronic motion

Missing → a technological challenge

Time

attoseconds
10^{-18} s

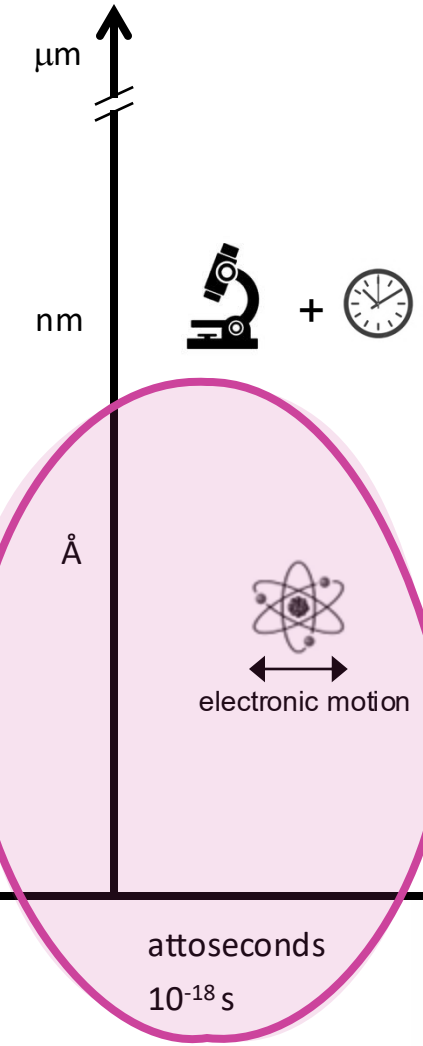
femtoseconds
10^{-15} s

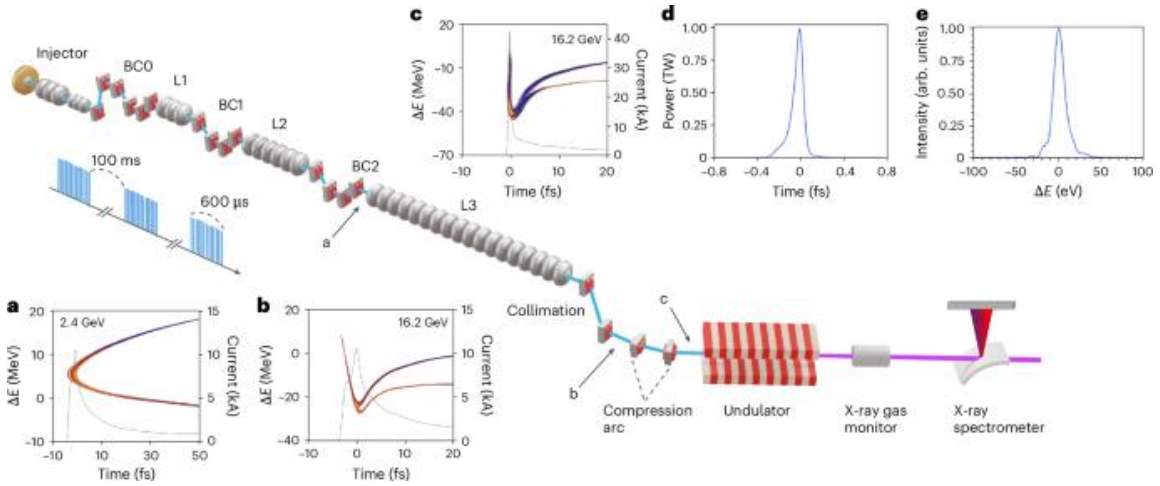
picoseconds
10^{-12} s

…

microseconds
10^{-6} s

The fastest and the shortest





Recent demonstration of *attosecond* hard X-ray pulses at Eu XFEL

Yan, J., et al. Nat. Photon. ***18****, 1293–1298 (2024)*

Missing → a technological challenge

Time

attoseconds
10^{-18} s

femtoseconds
10^{-15} s

picoseconds
10^{-12} s

…

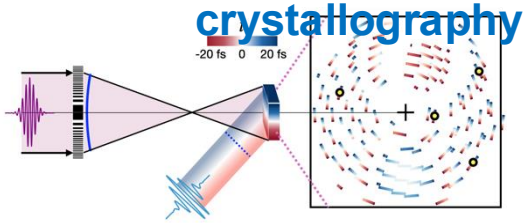
microseconds
10^{-6} s

The ultimate microscope for capturing electrons in action

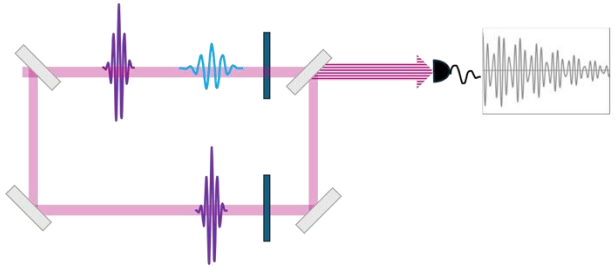
ERC Synergy Grant

IDEAA: Imaging the Dynamics of Electrons with Atto and Å resolution

Convergent beam atto x-ray crystallography



Attosecond interferometry

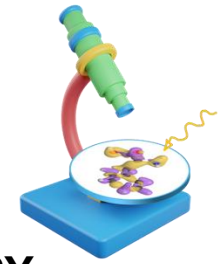


Structure

Optical response

IDEAÅ

Dynamic quantum crystallography



Saša Bajt – DESY
Francesca Calegari – DESY, UHH
Henry Chapman – DESY, UHH
Nina Rohringer – DESY,

What else happened?

In 2019 I became a mother!

So far so good…but then which were the obstacles?

There were many closed doors…

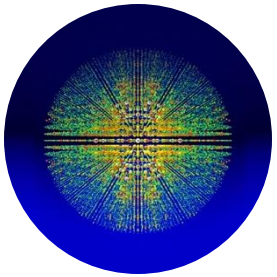
Looking back, I now changed my mind.

A job in Science (as many other jobs) is not gender neutral: being a minority is challenging…you simply have to work harder, to fight more and to be more persistent.

- I had to fight more than my male colleagues to have my contribution recognised
- I have been taken as a mother figure, making my role as a leader more difficult
- I had to postpone quite a lot the idea of being a mother. I felt societal pressure.
- I witnessed discrimination and mobbing of dear friends and colleagues (female professors)
- I had to negotiate harder for my salary and resources
- **I always have the doubt of being chosen for my gender more than my skills… remember I am here on a QUOTA program!**

…but I am very optimistic

I believe excellence is above all
I believe in role models
I believe we can do more for equity
I believe there are still obstacles but there has been progress



CLUSTER OF EXCELLENCE
CUI: ADVANCED IMAGING OF MATTER

DESY · UH · European XFEL · mpsd Max-Planck-Institut für Struktur und Dynamik der Materie

Speaker of Cluster of Excellence Advanced Imaging of Matter

More than 50% female postdoc

More than 30% female PhD students

Coordinating the call for the Mildred Dresselhaus program: we invite distinguished visiting female professors in Hamburg (role models)

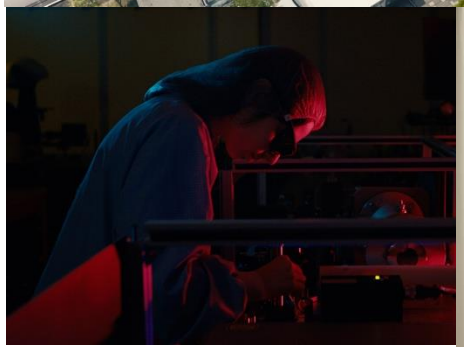
dynaMENT Mentoring for women in natural sciences

Mentor for female PhD students and post docs

Thanks a lot!

- One more (and most important tip) –

When facing failure, the key is persistence. As Thomas Edison said, "I have not failed. I've just found 10,000 ways that won't work"



https://atto.cfel.de