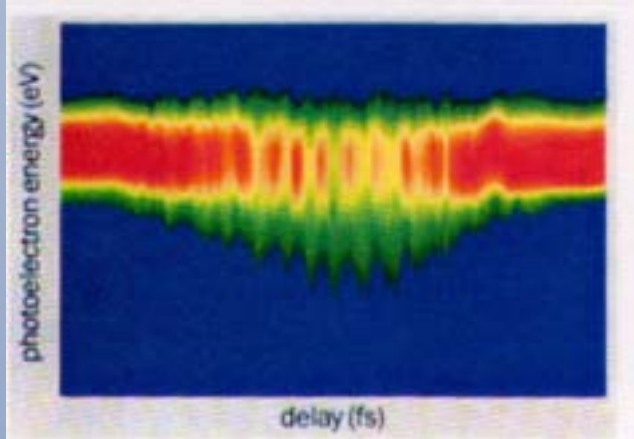


# Generation and Measurement of Isolated Attosecond Light Pulses

or

## A History of Brief Time

Michael Hentschel





Quantum Day 4 Students

April 12 2024

## About me:

*Dr. Michael Hentschel*

- 1998 MSc Electrical Engineering, Vienna University of Technology
- 2001 PhD Photonics Institute, Vienna University of Technology  
Post-Doc with Ferenc Krausz
- 2003 Researcher at Femtolasers  **Nobel Prize Physics 2023**  
Femtosecond Amplifiers
- 2006 Post-Doc with Anton Zeilinger, University of Vienna  
Entangled Photon Sources  **Nobel Prize Physics 2022**
- 2009 Researcher at Austrian Institute of Technology  
Quantum Key Distribution (aka Quantum Cryptography)



## Electrons in pulses of light

Through their experiments, this pair's laureates have created flashes of light that are brief enough to take snapshots of electrons' extremely rapid movements. Anne L'Huilier discovered a new effect from laser light's interaction with atoms in a gas. Pierre Agostini and Ferenc Krausz used this effect to demonstrate that they could create shorter pulses of light than were previously possible.

The faster an insect, the faster it perceives nearly its full range of frequencies. A fly captures the entire 100-hertz-to-10,000-hertz range. A wing beats 100 times per second. We can only perceive those in a select range around and a few hundred movements. The human ear, too, finds sounds that go together, and we find patterns as important to perception. A single focused photograph of a hummingbird in flight requires an exposure time that is much shorter than a single wingbeat.

This year's lectures have conducted experiments that show how to produce pulses of light that are short enough to depict the processes occurring inside atoms and molecules.

In the world of electrons, positrons and energies change at speeds of femtoseconds and a few hundred attoseconds, where an attosecond is one billionth of a billionth of a second.



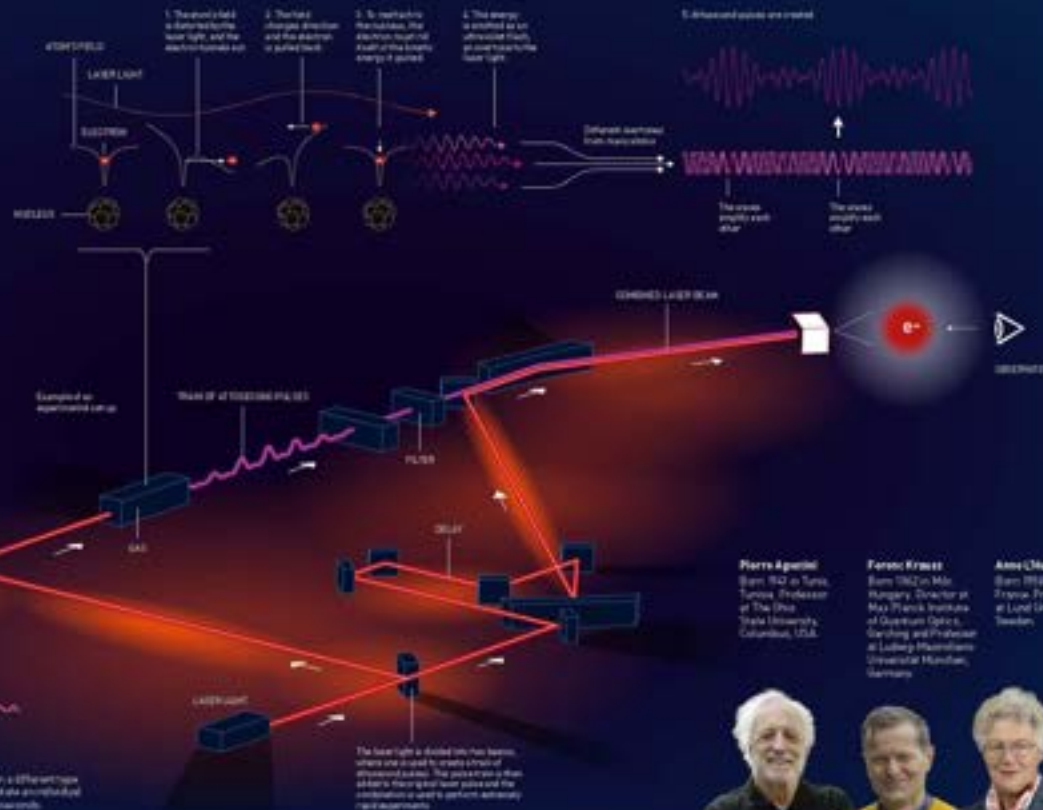
The trick to making shorter pulses is combining more and shorter wavelengths of light. The key is the spectrum of laser light – red lasers have several cycles for every cycle in the original wave.



In 1912 Anna L. Millner and her colleagues were able to produce and demonstrate overtones in infrared light transmitted through various noble gases. The experiment showed there was a plasma with many molecules of about the same intensity.

In 2009, Tierra Aquatica succeeded in producing and manipulating a series of light pulses. Each pulse was just 200 attoseconds long.

In 2004, Caron-Frantz worked on a little over two years of experience. She managed to find the appropriate value with a duration of 450 seconds.



**Harry Agard**  
Born 1942 in Tulsa, Oklahoma  
Turner Professor  
of Theology  
Tulsa University

**Ferenc Krausz**  
Born 1962 in Munkacs, Hungary. Doctor Max Planck Institute of Quantum Optics

**Anne C. Mueller**  
Born 1954 in Paris  
Fragrances Professor  
at Lund University  
Sweden

The laser light is divided into two beams, where one is used to create a field of attenuated neutrons. The polarizer is the other's focusing and laser pulse and the combination is used to perform neutron rapid depolarization.

LEARN MORE ABOUT THE NOBEL PRIZES AT [WWW.KVA.SE](http://WWW.KVA.SE)

[illegible]

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**Anne L'Huillier**  
born 1958 in Paris (France)  
Lund University (Sweden)

“Discovery of overtones when shining light on nobel gases (1987)”



**Pierre Agostini**  
*born 1941 in Tunis (Tunisia)*  
CEA Saclay (France) and  
Ohio State University (USA)

“Generation and measurement of a train of 250 attosecond pulses (2001)”

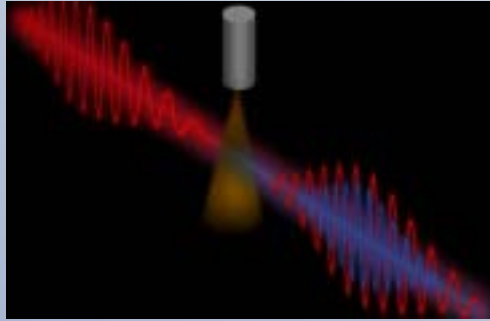


**Ferenc Krausz**  
*born 1962 in Mór (Hungary)*  
TU Wien (Austria) and  
MPQ Garching (Germany)

“Generation and measurement of isolated 650 attosecond pulses (2001)”



# What is an Attosecond?



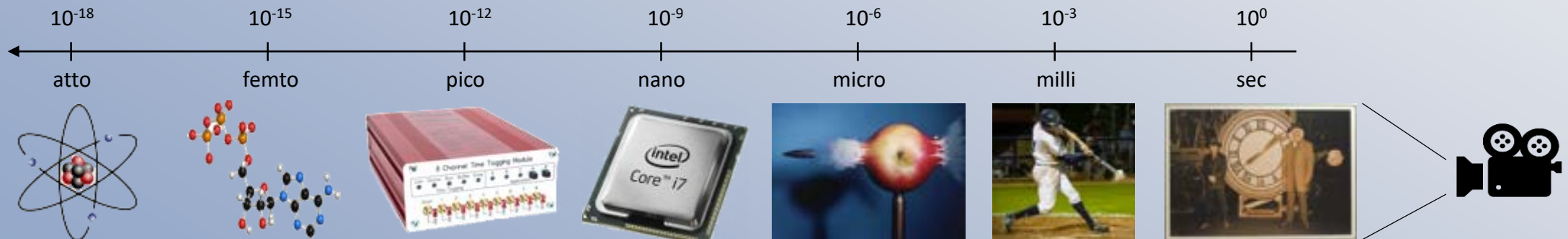
Attosecond



Second



Age of the universe (~30 billion years)



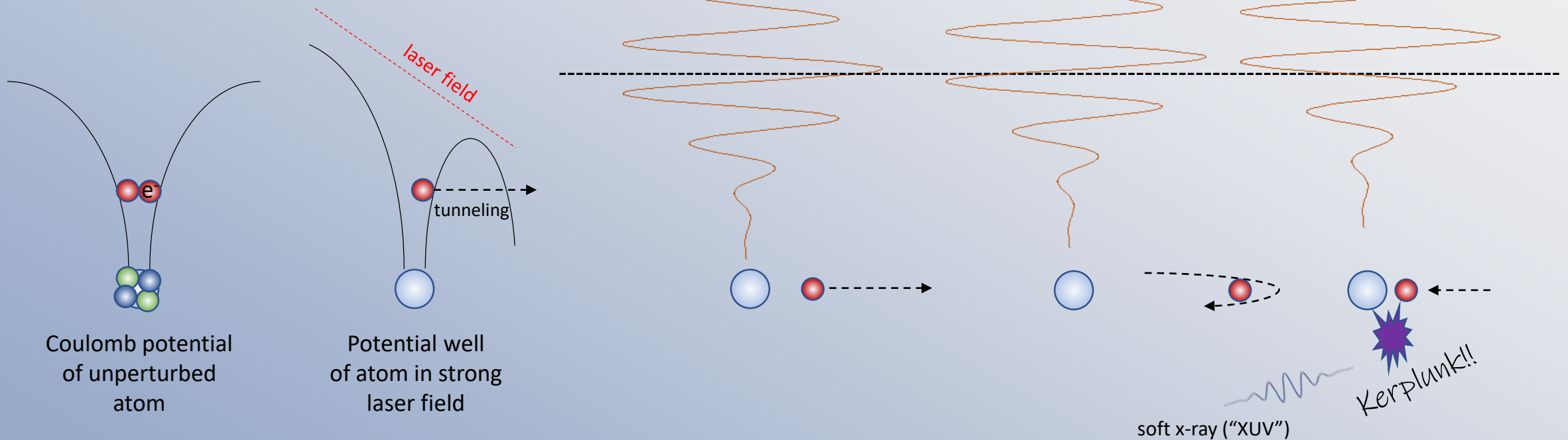
# High-Harmonic Generation

## L'Huillier's discovery 1987

Anne L'Huillier et al.

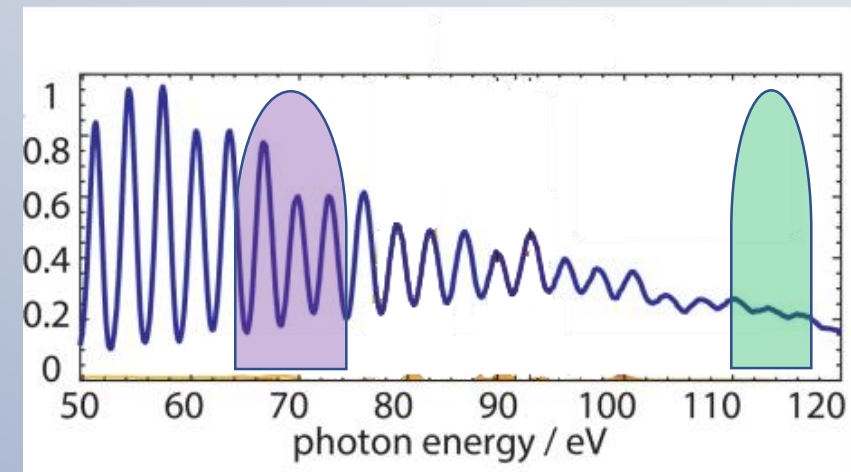
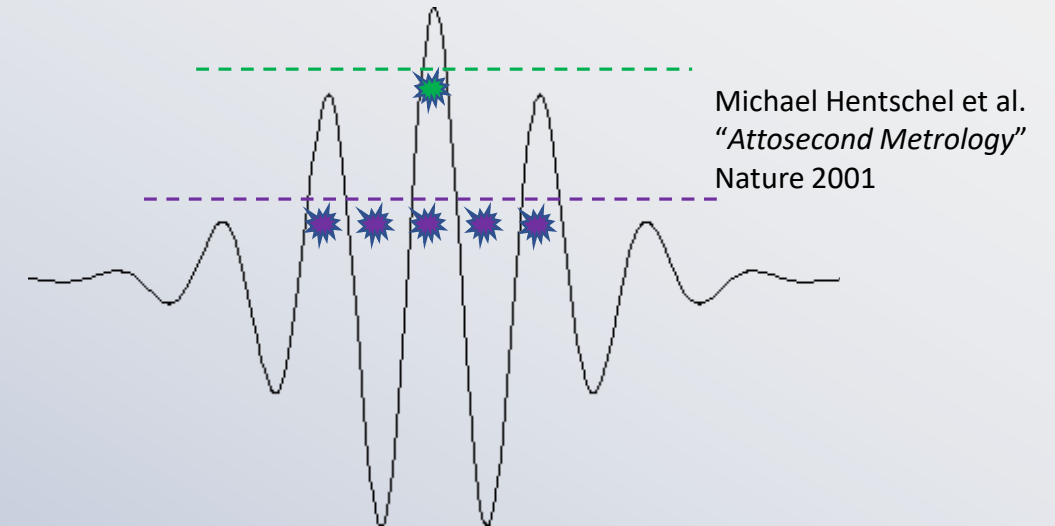
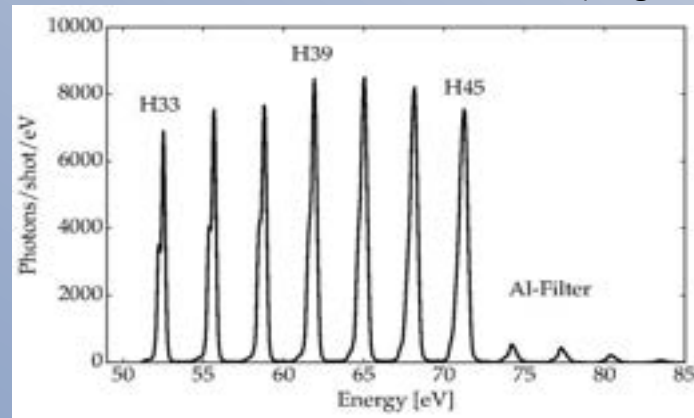
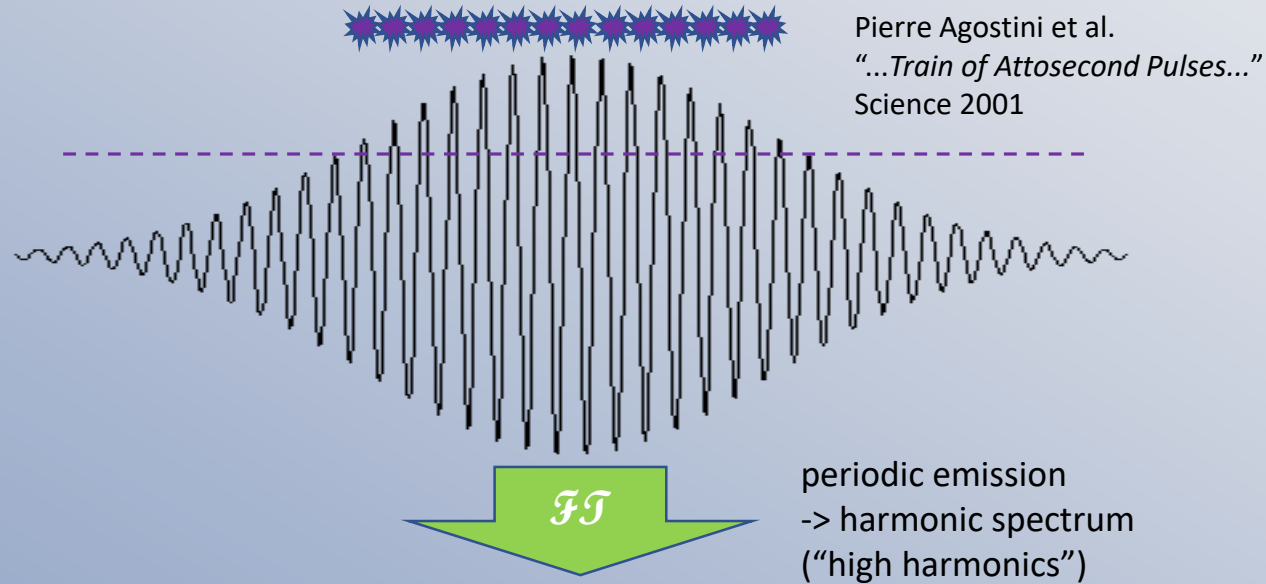
*"Multiple-Harmonic Conversion ... in Rare Gases"*

Molecular and Optical Physics 1988



# Attosecond Pulse Generation

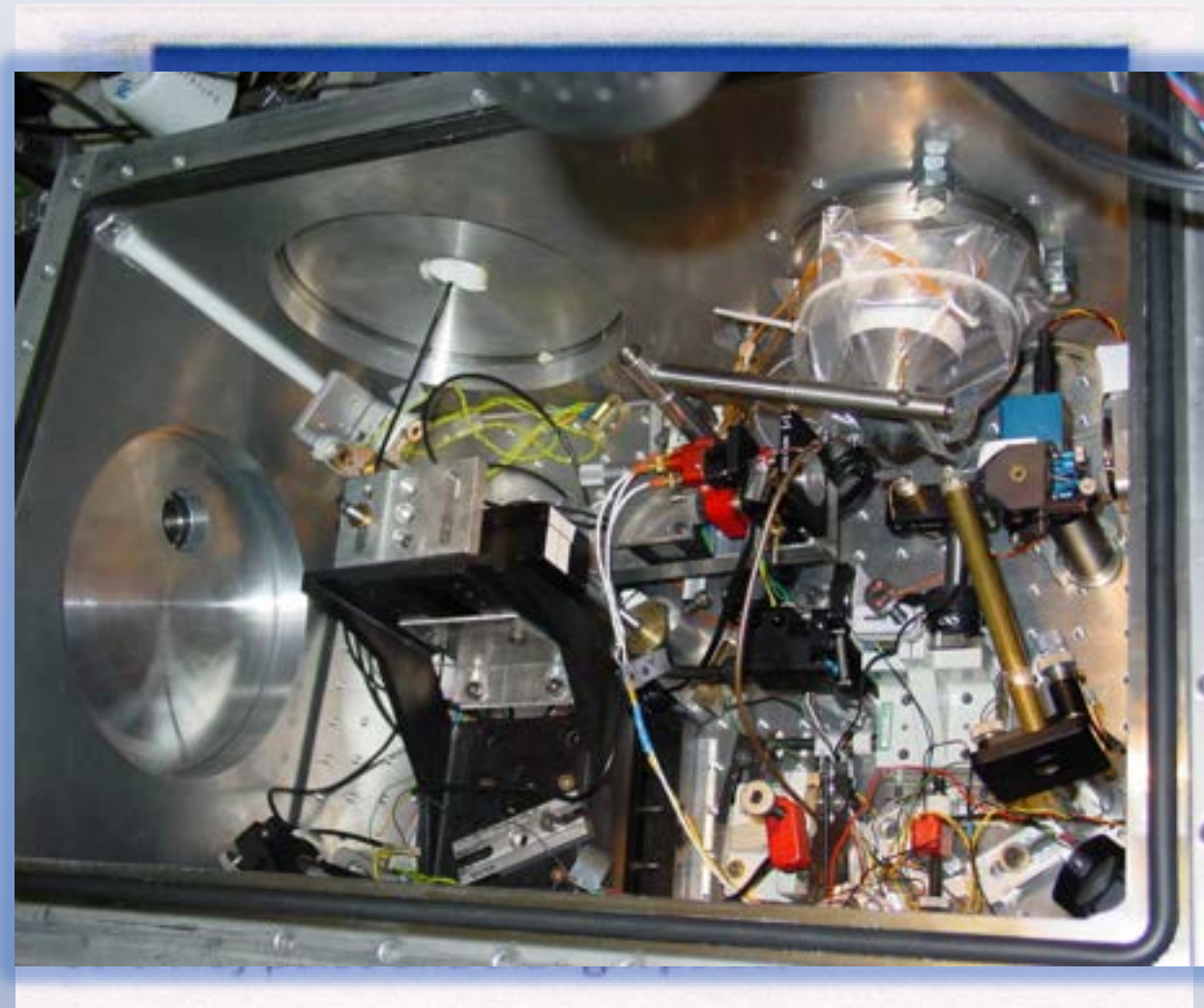
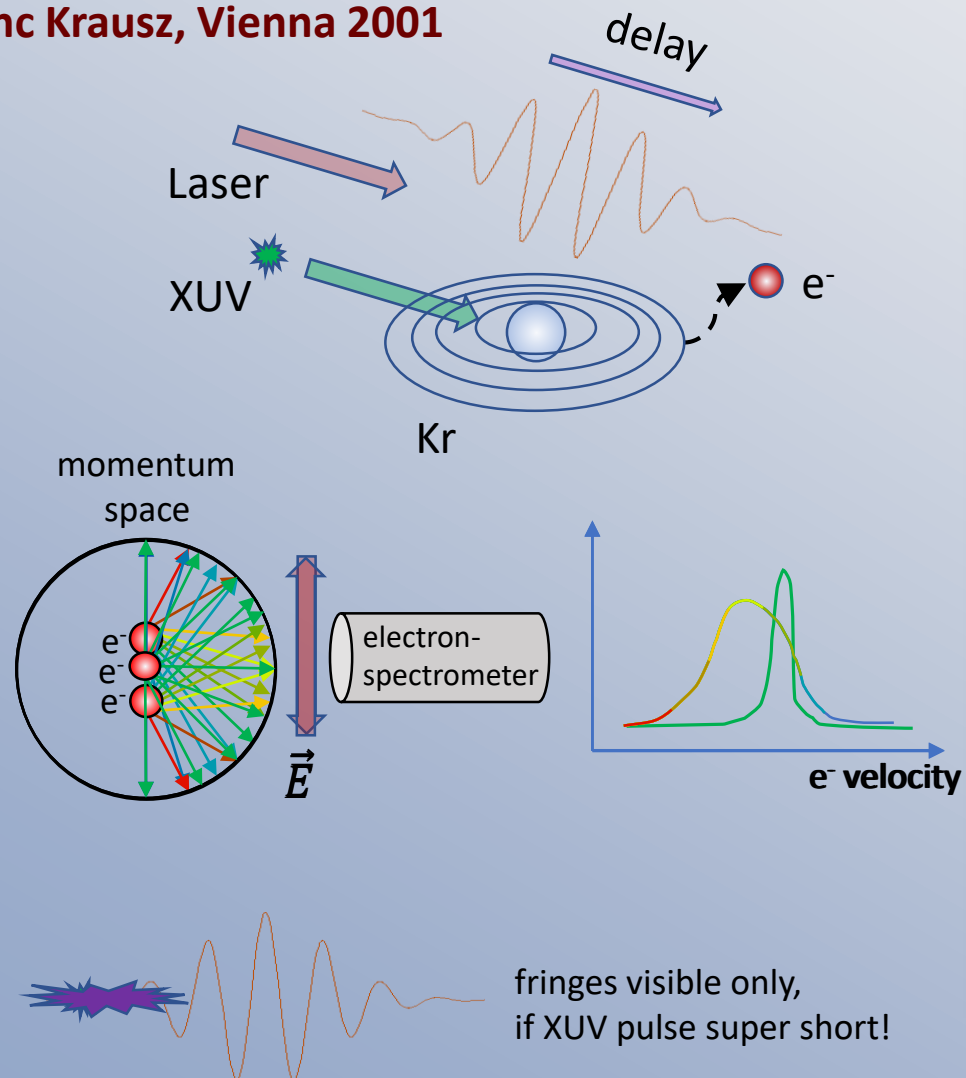
## The race between Agostini and Krausz 2001





# The Measurement

Ferenc Krausz, Vienna 2001



# Attosecond Pulses – In the Media





# The Nobel Week

Nobel lectures



# The Nobel Week

German embassy &  
BBC recording of  
“Noble Minds”





# The Nobel Week

Award ceremony &  
Student's Nobel NightCap

