Streaking time delay in laser assisted photoionization by intense XUV pulse

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Date: 19/01/2022

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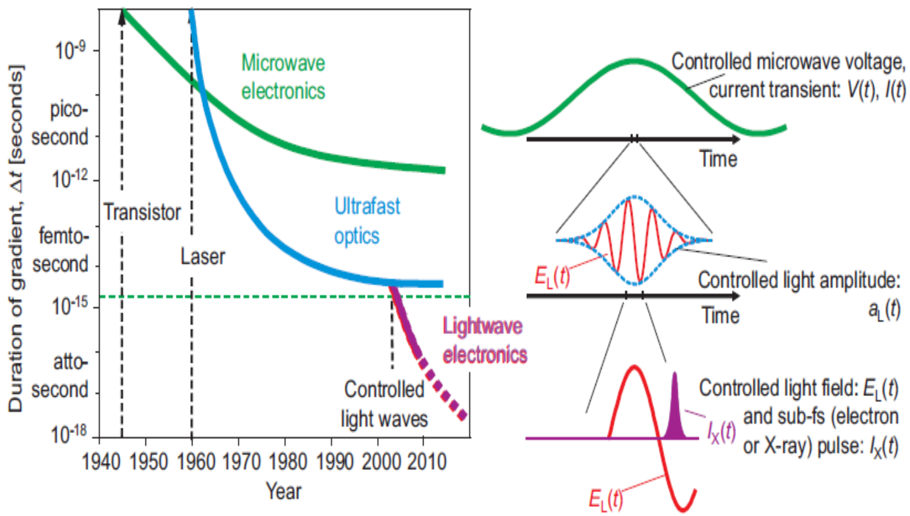
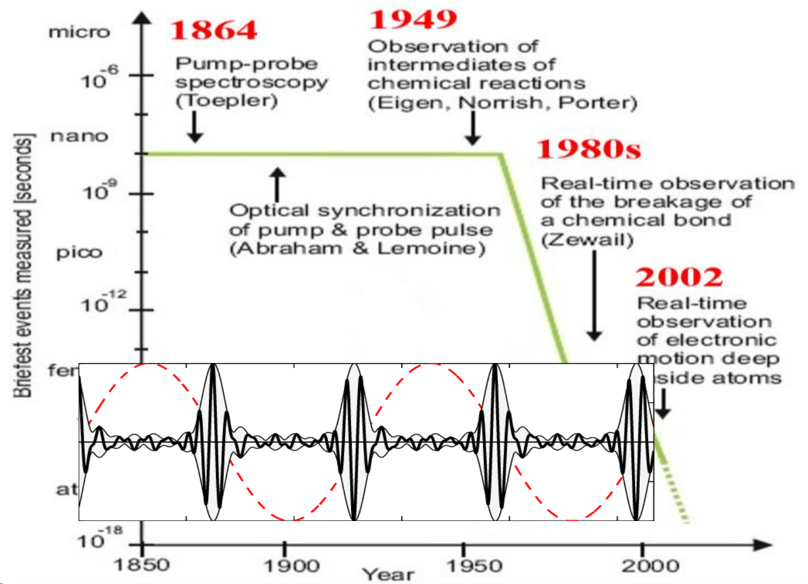
EVOLUTION OF ULTRAFAST SCIENCE





microcosm

Physics

Biology

Chemistry

Electronic dynamics on the molecular scale is responsible for the transport of bioinformation and initiates changes in the chemical composition and function of biological systems.

Rev. Mod. Phys. (2009)

What are the most efficient ways of putting atoms into highly excited states that allow x-ray light amplification and thus creation of compact x-ray lasers?

Can the function of biomolecules be manipulated and novel molecular structures be formed by steering electrons in chemical bonds?

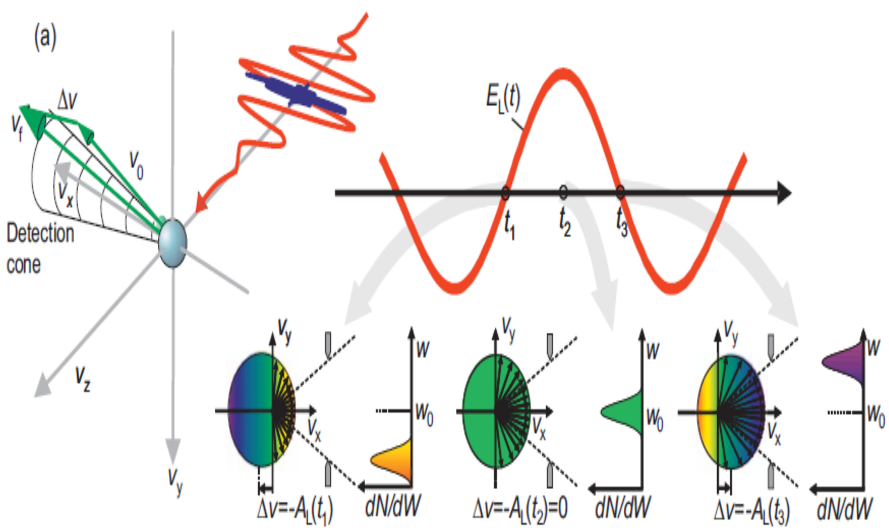
How does charge transfer occur in molecules assembled on surfaces and how can it be optimized for more efficient solar cells or for fighting radiation damage during biological imaging?

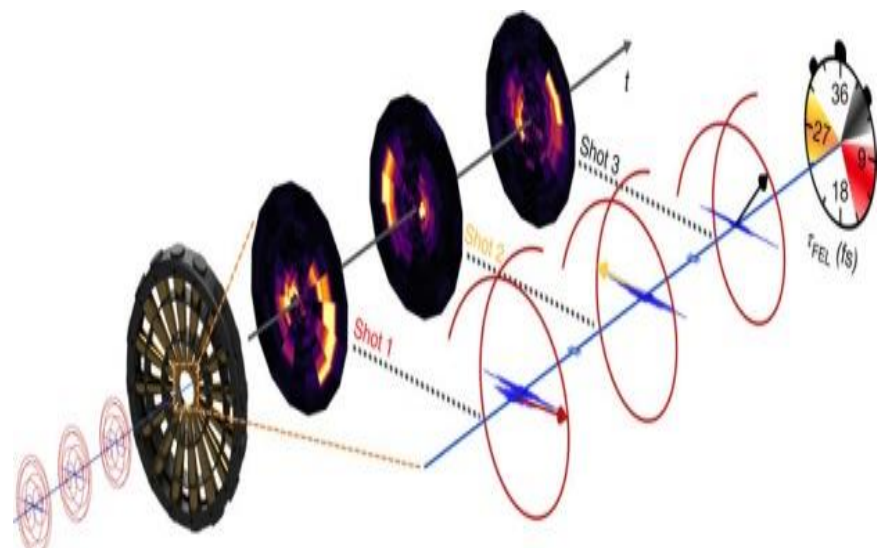
What are the ultimate size and speed limits of electronic information processing and magnetic information storage, and how can we approach these limits?

How can energy be most efficiently transported into high-density matter to ignite nuclear fusion?

ATTOSECOND CONTROL AND METROLOGY

- **Light-field-controlled attosecond metrology(Linear attosecond streaking)**
- **Field-controlled attosecond metrology(Angular attosecond streaking or Attoclock)**





$T_{XUV} = 100 - 500\ as$
$I_{XUV} = 10^{12} - 10^{15}$W/cm^2

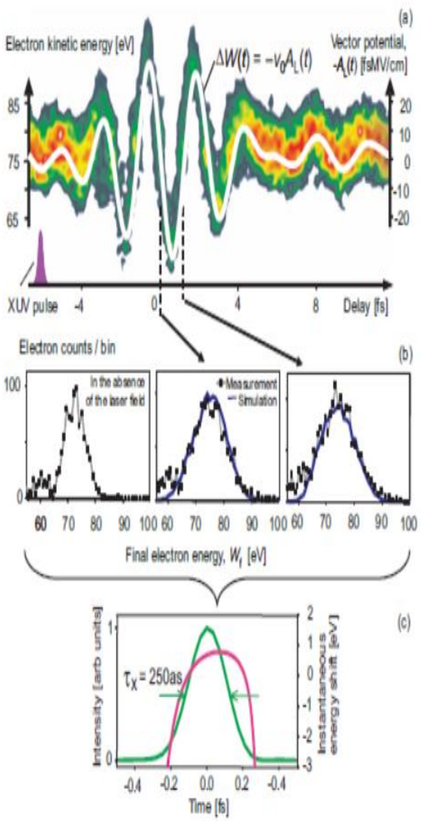
$T_{IR} = 5 - 10\ fs$
$I_{IR} = 10^{10} - 10^{12}$W/cm^2

$I_{IR} = 10^{13} - 10^{14}$W/cm^2

Science. (2001), Science, (2004), PRL, 2002

Science, (2008), Rev. Mod. Phys. (2009)

MILESTONES OF ATTOSECOND PHYSICS



Sub-fs laser pulses

Auger decay

Attosecond streaking

Tunneling dynamics

80as pulses

Photoionization time-delay

Tunneling time

Nature, 414, 509 (2001).
Science, 292, 1869 (2001).
Nature, 419, 803 (2002).
Nature, 421, 611 (2003).
Nature, 427, 817 (2004).
Science, 305, 1267 (2004).
Nature, 446, 627 (2007).
Nature, 449, 1029 (2007).
Science, 320, 1614 (2008).
Science, 328, 1658 (2010).
Nature, 466, 739 (2010).
Science, 334, 195 (2011).
Nature, 485, 343 (2012

Science. (2001), Science, (2004), PRL, 2002

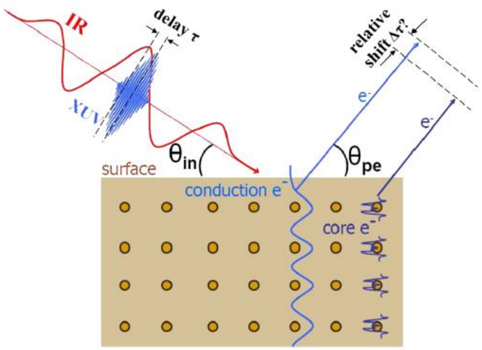
EWS time delay and Streaking time delay

❑ **Eisenbud-Wigner-Smith (EWS) time delay**

➢ The variation of the spectral phase with energy of the electron

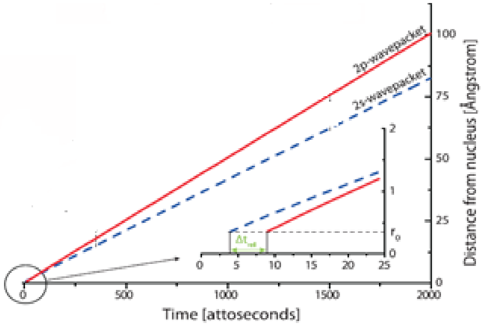
$$t_{EWS} = \frac{\partial}{\partial E} arg < \Psi(E)|z|\Phi_0 >$$

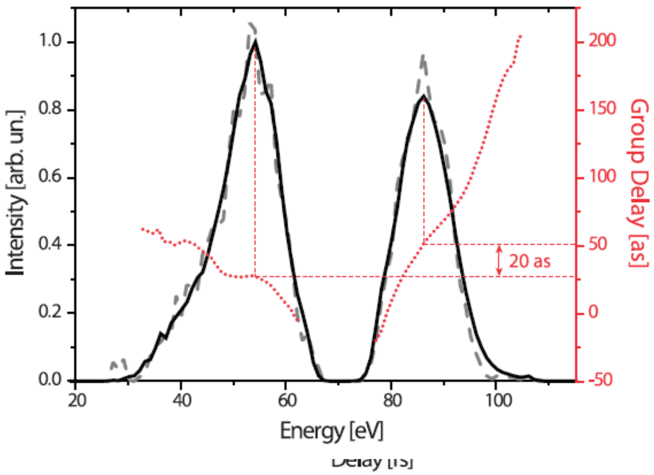
➢ How much more or less time an electron take to move in a potential V with moment $p(r) = \sqrt{(2E - V(r))}$ compared to a free particle with moment $p = \sqrt{2E}$.

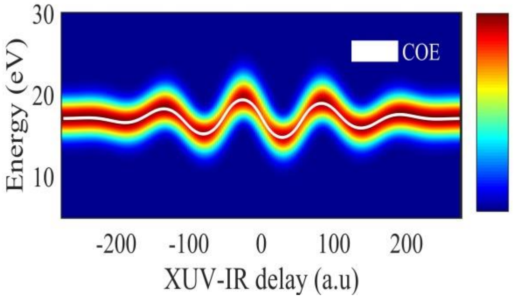


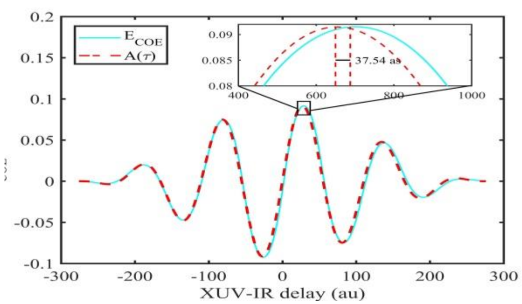
❑ **Streaking time delay**

$$\delta p = -\alpha A_{IR}(t + \tau_S)$$



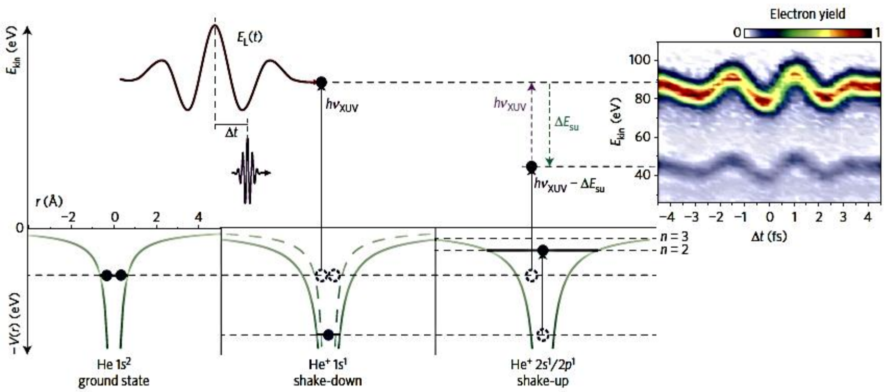


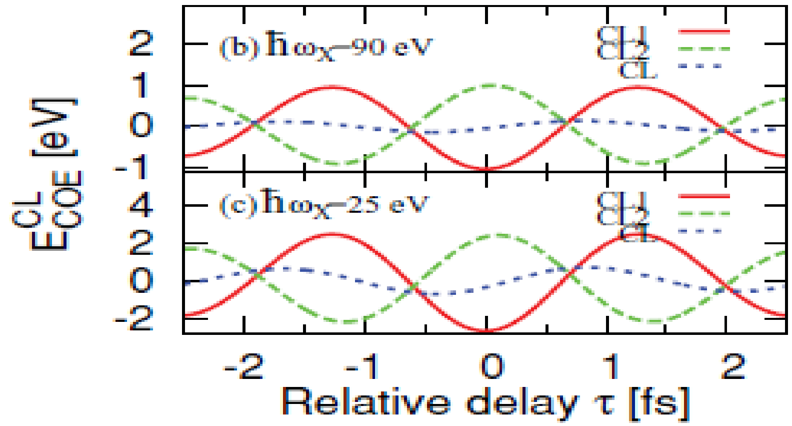




PRL, 2009, Science. (2010)

Contributions to streaking time delay

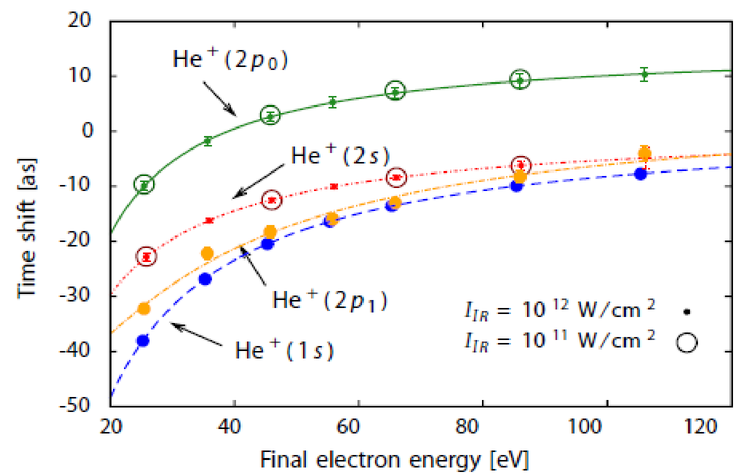




$$E_{COE}{}^{CLC} = -\frac{1}{p}\int_x^\infty F(x')A_{IR}\left(\frac{x'-x}{p} - \tau\right)dx'$$

$$t_S = t_{EWS} + t_{CLC} + t_{dLC} + t_{e-e}$$

$$lim_{\omega\to 0} t_S = t_{EWS}$$



PRA, 2010, J. Phys. B, 2011, Rev. Mod. Phys. 2015, Nat. phys. 2017, PRL, 2020

Model

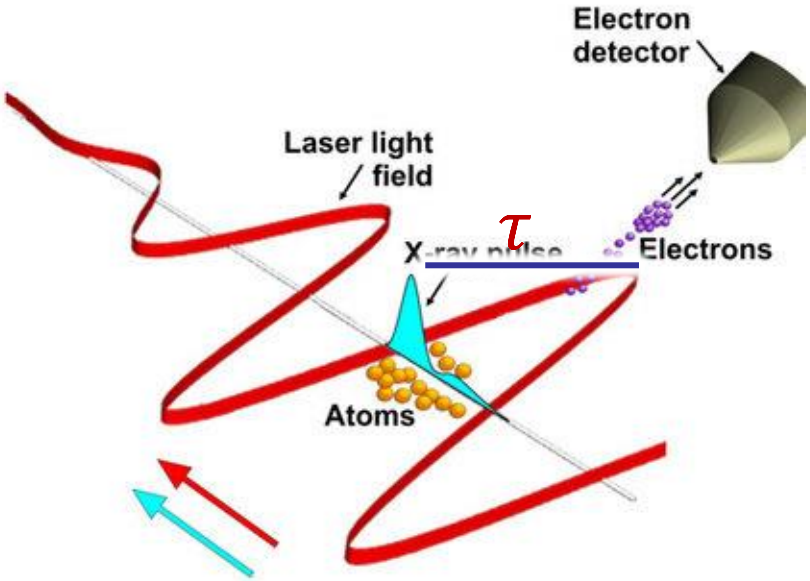
$$i\frac{\partial}{\partial t}\Psi(x,t) = [-\frac{\partial^2}{\partial x^2} + V(x) + U(x,t)]\ \Psi(x,t)$$

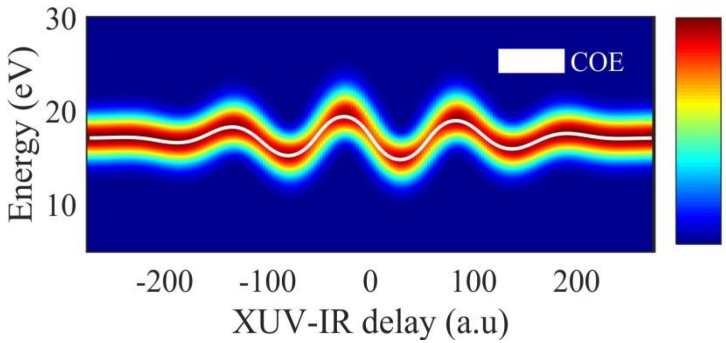
$$V(x) = -\frac{1}{\sqrt{x^2+a}}$$

$$U(x,t) = -A_X(t)\frac{\partial}{\partial x} - A_{IR}(t)\frac{\partial}{\partial x}$$

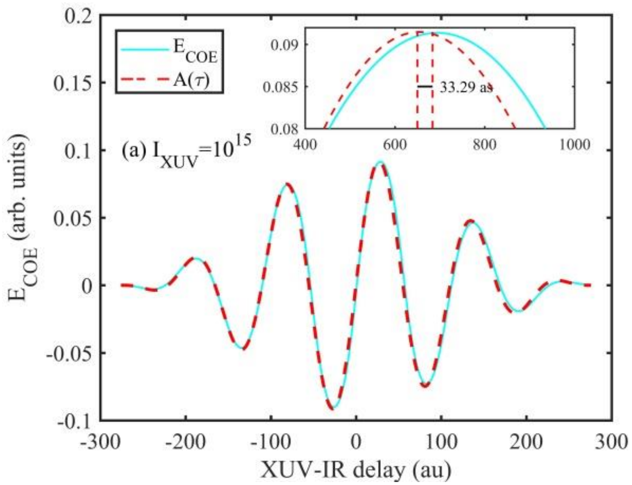
$$f(p,\tau)=|\Psi(p,\tau)|^2$$

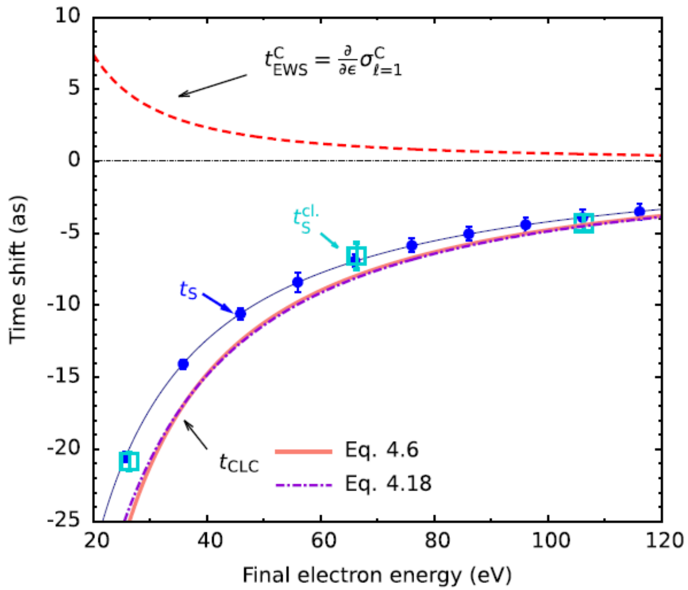
$$I_{XUV} = 10^{15} - 10^{17}\ W/cm^2$$

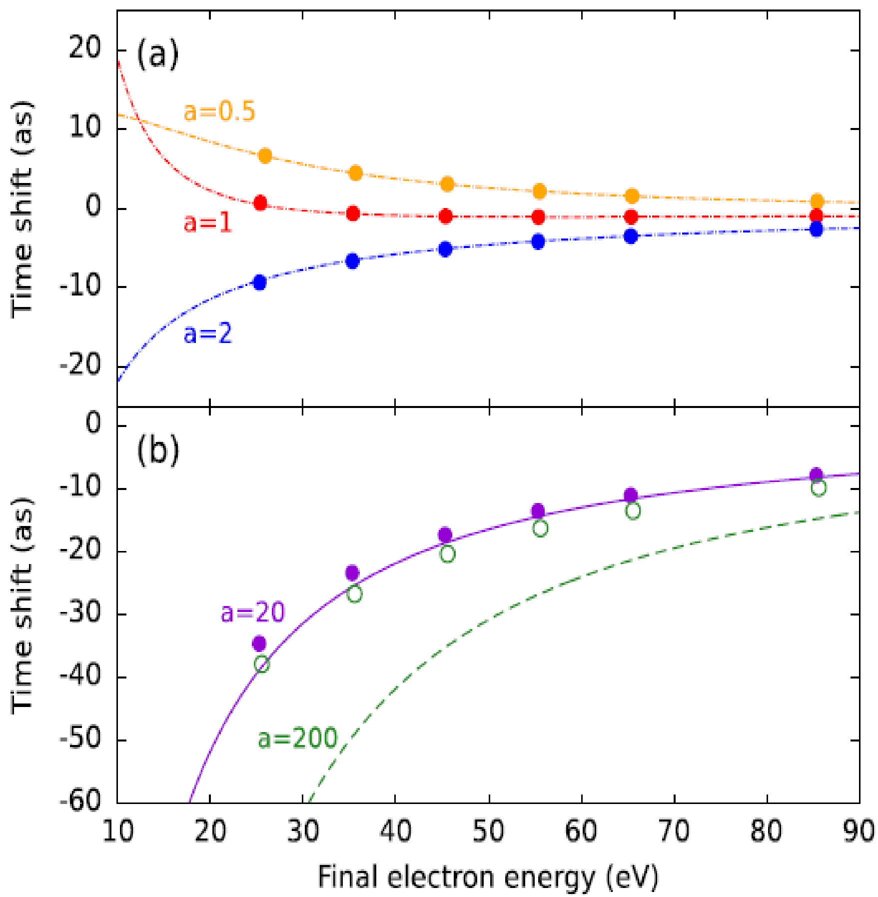




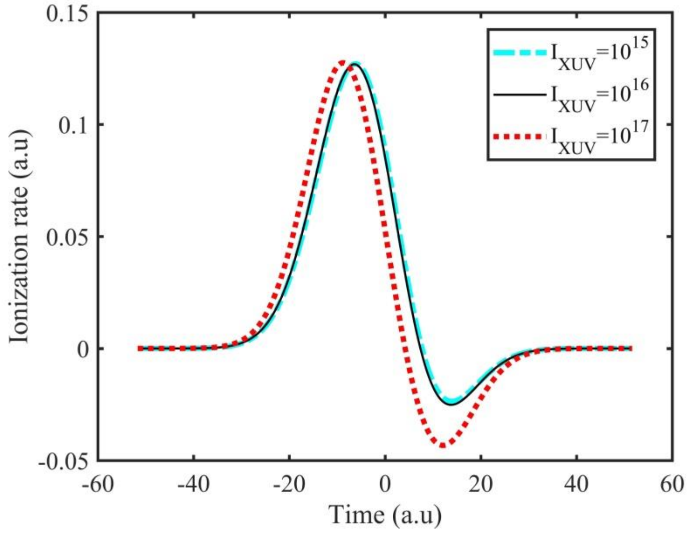
Numerical Results

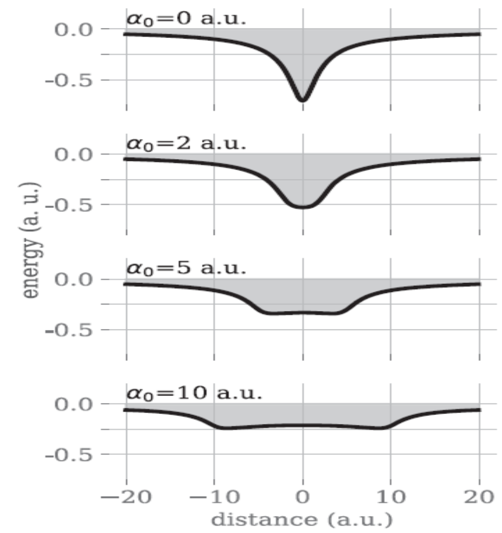






Semiclassical Reuslts





$$\Psi(x,t) = a(x,t)e^{-i(p+A_{IR}(t))x}e^{-i\left[\frac{p^2}{2}t+S_p(x,t)\right]}$$

$$S_p^{EA}(x,t) = S_p^{SFA}(t) + \int_t^{\infty} U(x_L(t',t,x))dt'$$

$$\delta E_{COE}^{EA}(x',\tau) = -pA_{IR}(\tau) + \frac{V(x)A_{IR}(\tau)}{p} + \frac{1}{p}\int_x^{\infty} dx'V'(x')A_{IR}\left(\frac{x'-x}{p}-\tau\right).$$

J. Phys. B, 2017

Conclusions

- The streaking time delay shifts to larger negative values with increasing the intensity of the attosecond XUV pulse.

- In higher energy region of the photoelectron, the streaking time delay converge in a single line as for the low intensity of the XUV pulse.

- The shift in the streaking delay with the intensity of the XUV pulse is attributed to the distortion of the potential and the strong oscillations of the COW in the ground state.

Thank You for the attention