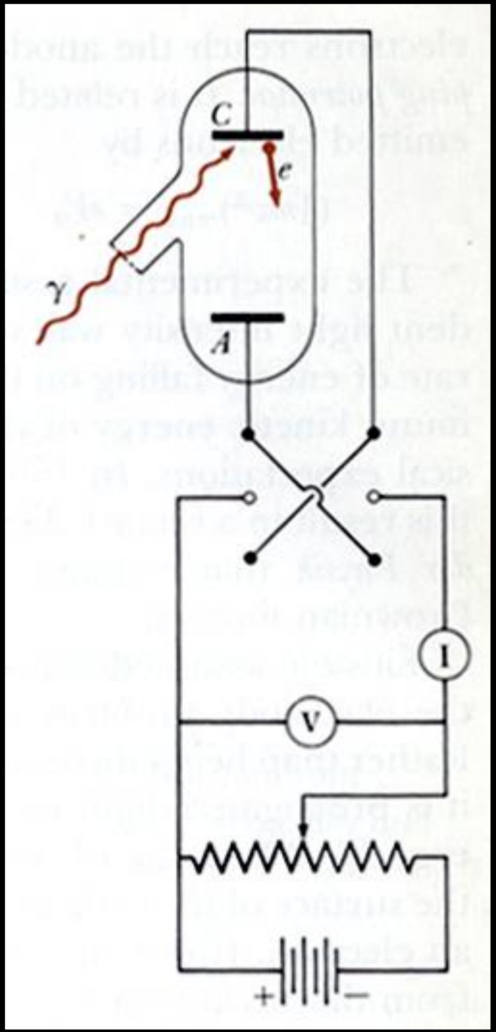
Atoms in Intense Laser Fields: Classical Models and Bicircular Light

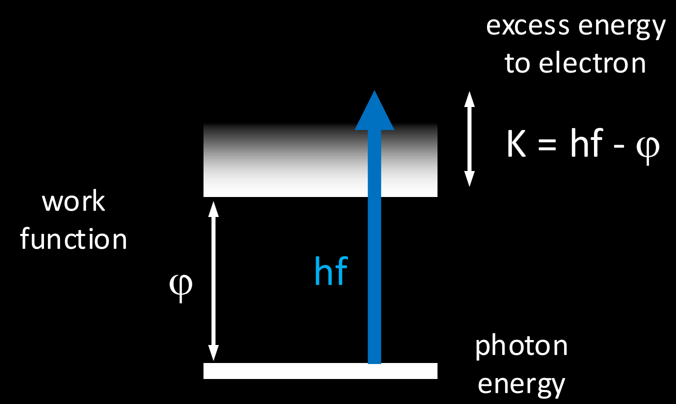
APS-4CS
Greeley, CO
10 October 2025

Jan L. Chaloupka
Department of Physics & Astronomy
University of Northern Colorado

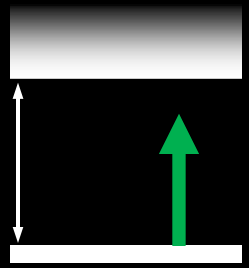
Photoelectric Effect

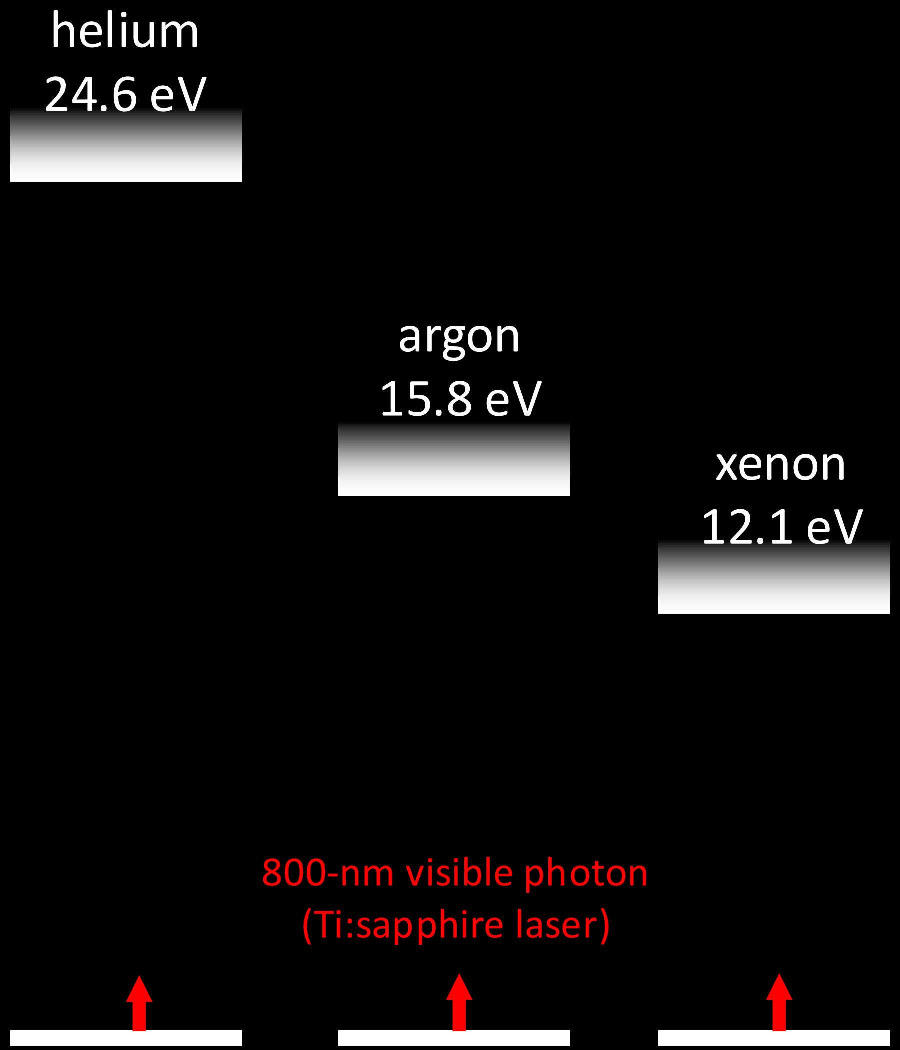


(Tippler, Modern Physics)



No ionization for hf < φ :





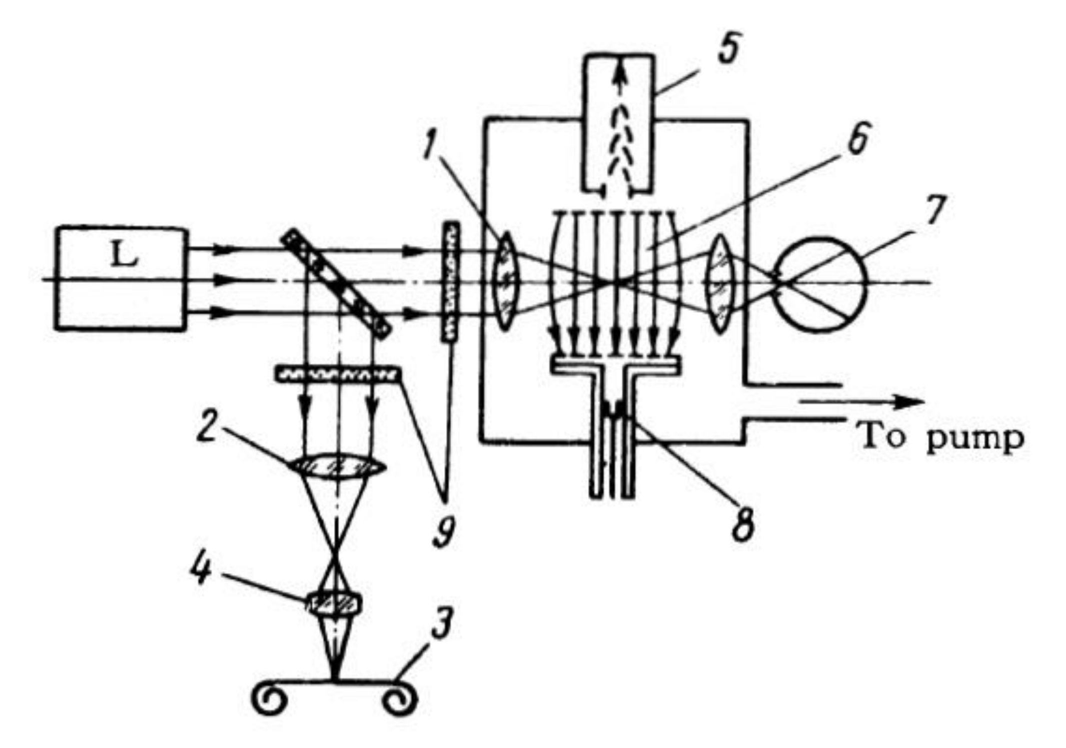
Many-Photon Ionization

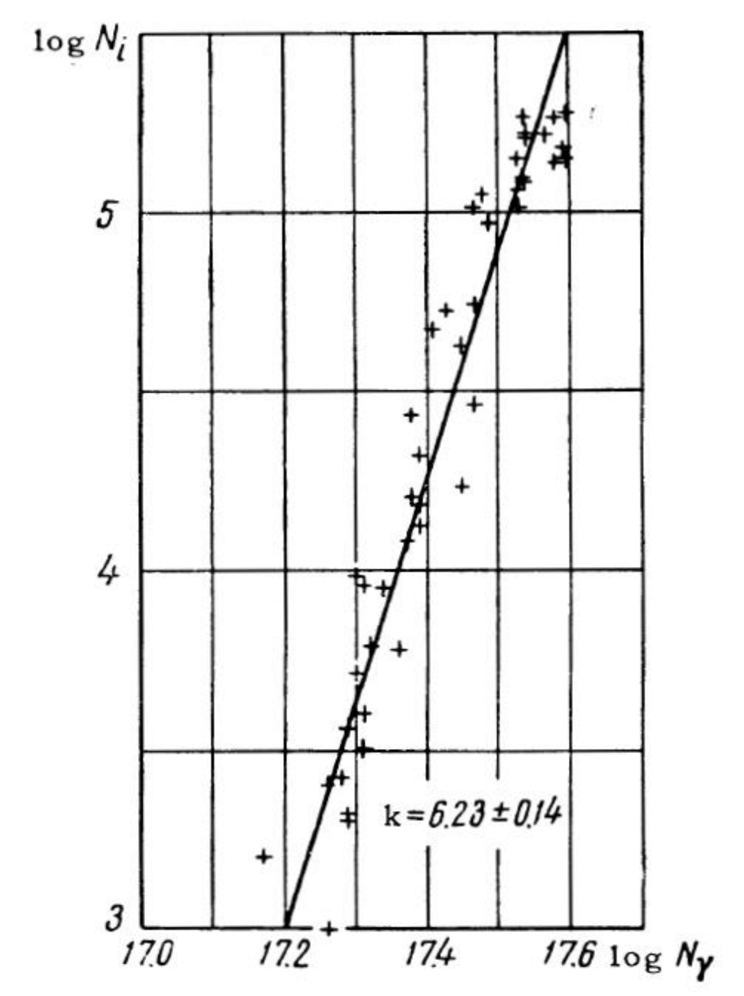
SOVIET PHYSICS JETP VOLUME 23, NUMBER 1 JULY, 1966

MANY-PHOTON IONIZATION OF THE XENON ATOM BY RUBY LASER RADIATION

G. S. VORONOV and N. B. DELONE

P. N. Lebedev Physics Institute, Academy of Sciences, U.S.S.R.





Above-Threshold Ionization

Free-Free Transitions Following Six-Photon Ionization of Xenon Atoms

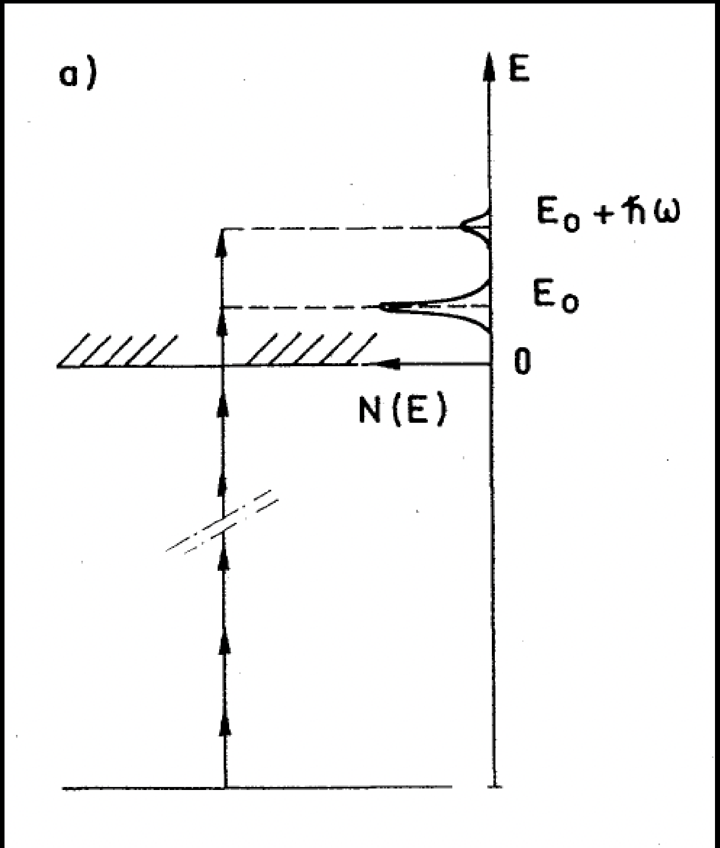
P. Agostini, F. Fabre, G. Mainfray, and G. Petite
Centre d'Etudes Nucléaires de Saclay, Service de Physique Atomique, 91190 Gif-sur-Yvette, France

and

N. K. Rahman
Laboratorio di Chimica Quantistica ed Energetica Molecolare del Consiglio Nazionale delle Ricerche, 56100 Pisa 35, Italy

(Received 29 January 1979)

The energy spectrum of electrons produced by multiphoton ionization of xenon atoms has been analyzed with a retarding potential technique. We have shown that the discrete absorption of photons above the six-photon ionization threshold was observable under specified conditions. A simple model based upon inverse bremsstrahlung gives a resonable agreement with the experiments.

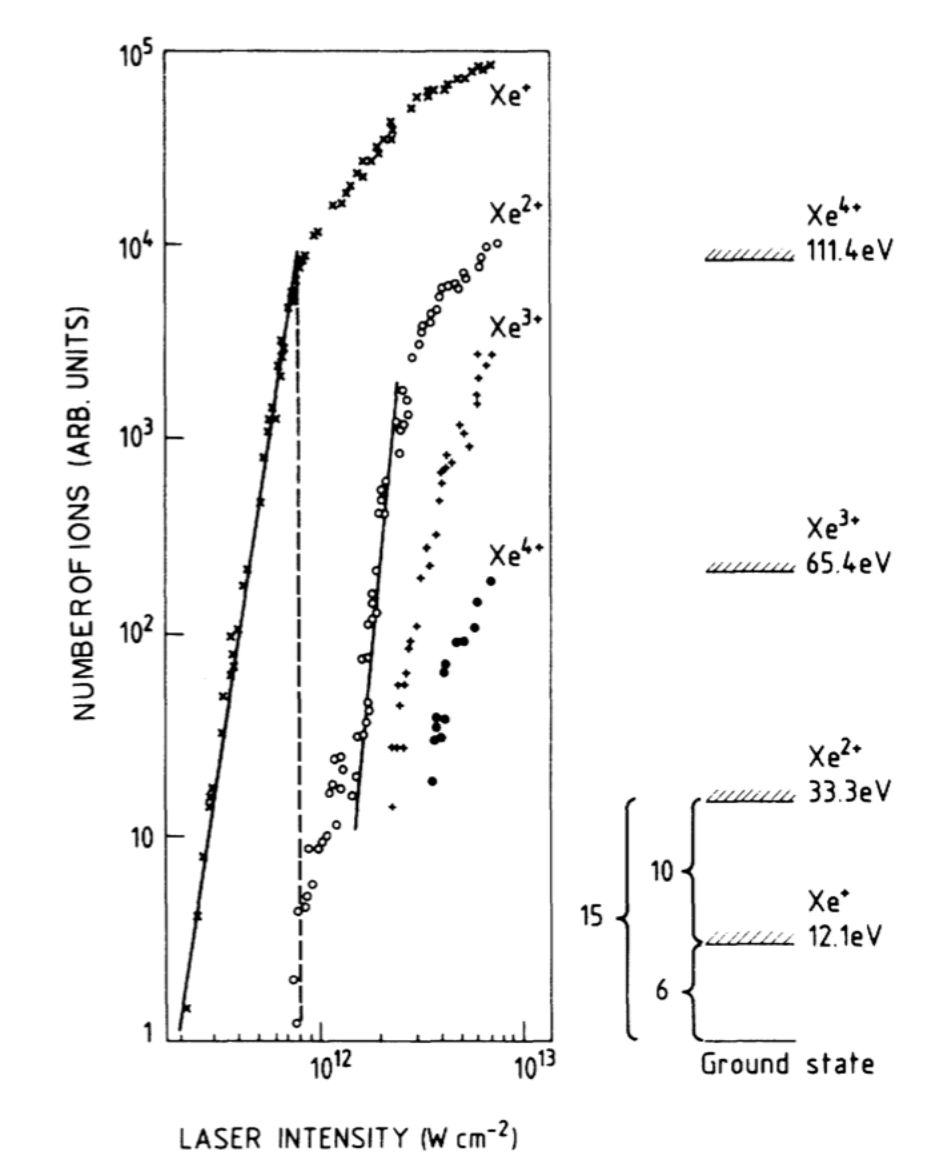


Multiply Charged Ions

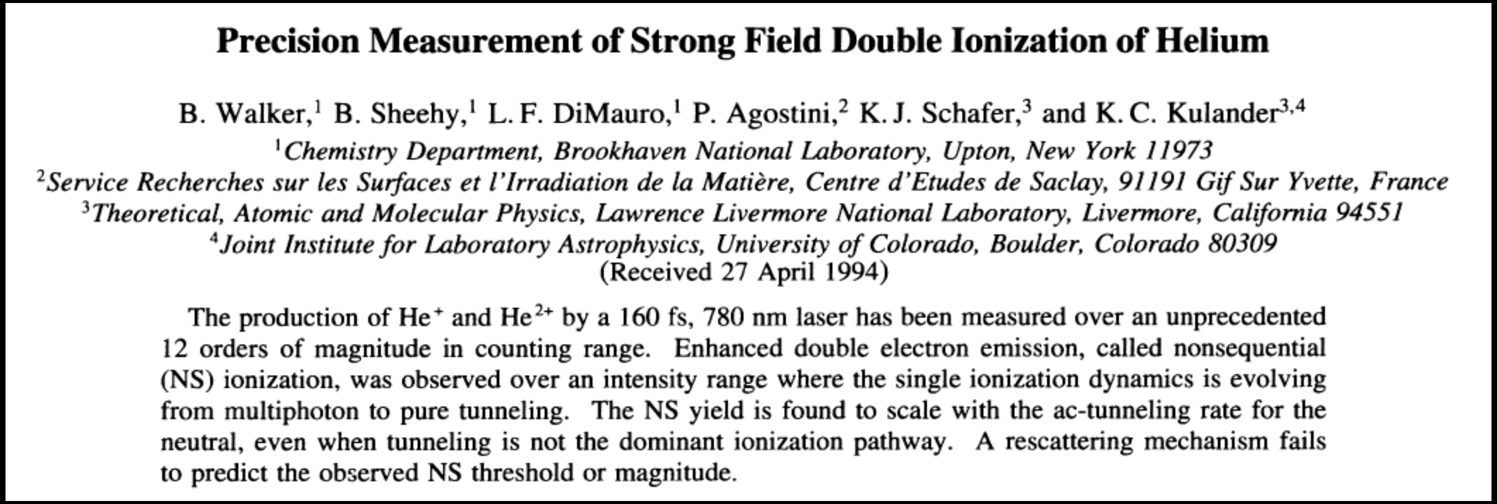
Multiply charged ions induced by multiphoton absorption in rare gases at 0.53 μm

A. l'Huillier, L. A. Lompre, G. Mainfray, and C. Manus
Centre d'Etudes Nucléaires de Saclay, Service de Physique des Atomes et des Surfaces,
F-91191 Gif-sur-Yvette Cedex, France
(Received 20 December 1982)

Up to quadruply charged ions are induced in Xe atoms by a 50-psec laser pulse at 0.53 μm in the 10^{12} W cm^{-2} range. The mechanism of the formation of Xe^{2+} ions is elucidated. In the lowest intensity range, Xe^{2+} ions are produced by direct 15-photon absorption from the ground state of the atoms, while at a higher intensity Xe^{2+} ions are produced by a stepwise process via Xe^{+} ions. These two processes take place at distinctly different intensities. A kinetic model using rate equations affords a good fit with experimental results. Moreover, for the first time it was possible to obtain the multiphoton ionization cross sections related to the two-electron removal from Xe atoms, as well as the one-electron removal from Xe^{+} ions.



Multiply Charged Ions (NSDI)



Precision Measurement of Strong Field Double Ionization of Helium

B. Walker,[1] B. Sheehy,[1] L. F. DiMauro,[1] P. Agostini,[2] K. J. Schafer,[3] and K. C. Kulander[3,4]

[1]*Chemistry Department, Brookhaven National Laboratory, Upton, New York 11973*

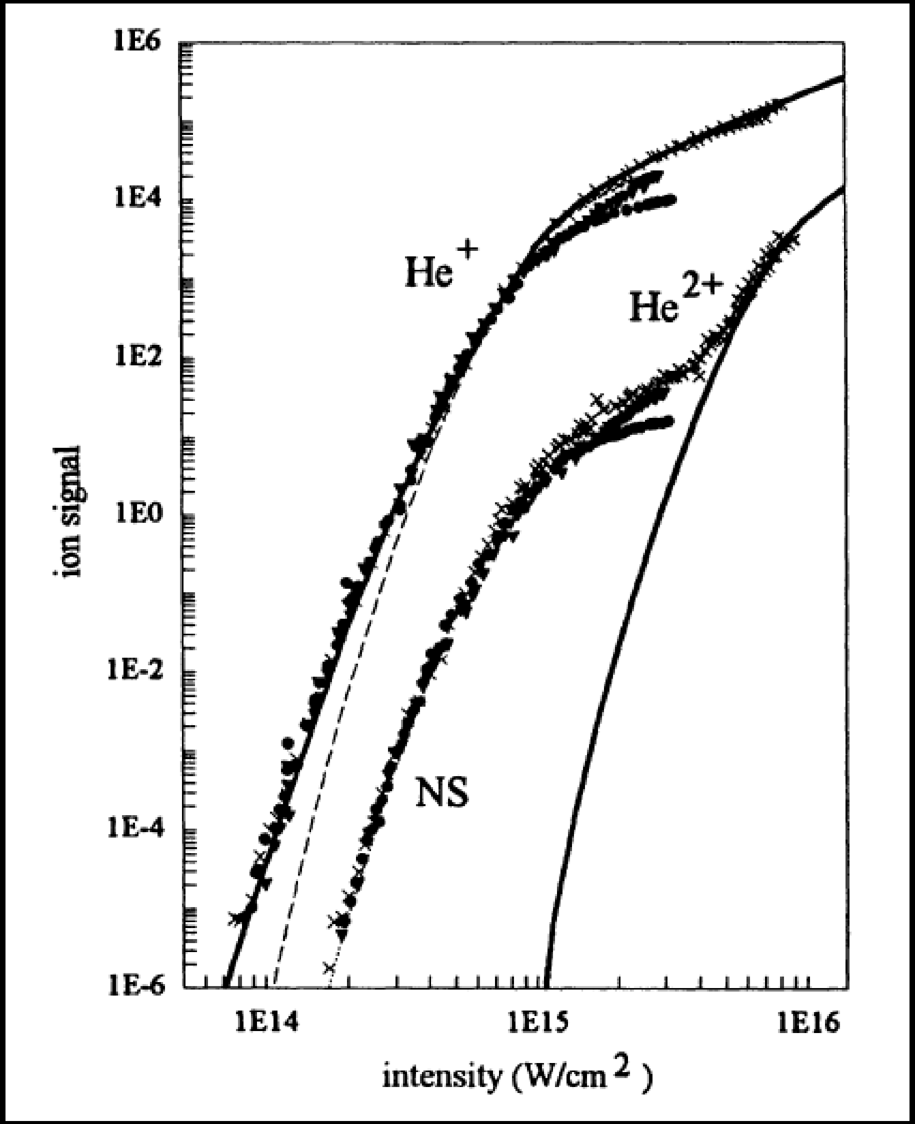
[2]*Service Recherches sur les Surfaces et l'Irradiation de la Matière, Centre d'Etudes de Saclay, 91191 Gif Sur Yvette, France*

[3]*Theoretical, Atomic and Molecular Physics, Lawrence Livermore National Laboratory, Livermore, California 94551*

[4]*Joint Institute for Laboratory Astrophysics, University of Colorado, Boulder, Colorado 80309*

(Received 27 April 1994)

The production of He^+ and He^{2+} by a 160 fs, 780 nm laser has been measured over an unprecedented 12 orders of magnitude in counting range. Enhanced double electron emission, called nonsequential (NS) ionization, was observed over an intensity range where the single ionization dynamics is evolving from multiphoton to pure tunneling. The NS yield is found to scale with the ac-tunneling rate for the neutral, even when tunneling is not the dominant ionization pathway. A rescattering mechanism fails to predict the observed NS threshold or magnitude.



Atomic Antenna

Atomic antenna

M. Yu. Kuchiev

A. F. Ioffe Physicotechnical Institute, Academy of Sciences of the USSR, Leningrad

(Submitted 26 December 1986; resubmitted 2 March 1987)

Pis'ma Zh. Eksp. Teor. Fiz. **45**, No. 7, 319–321 (10 April 1987)

A new mechanism for the absorption of photons of a low-frequency field by an atom is proposed: an "atomic antenna." This mechanism raises the intensity of multiphoton processes by many orders of magnitude. This is true in particular of multiple ionization and of ionization far from the threshold.

Rescattering

VOLUME 71, NUMBER 13 PHYSICAL REVIEW LETTERS 27 SEPTEMBER 1993

Plasma Perspective on Strong-Field Multiphoton Ionization

P. B. Corkum

National Research Council of Canada, Ottawa, Ontario, Canada K1A 0R6

(Received 9 February 1993)

During strong-field multiphoton ionization, a wave packet is formed each time the laser field passes its maximum value. Within the first laser period after ionization there is a significant probability that the electron will return to the vicinity of the ion with very high kinetic energy. High-harmonic generation, multiphoton two-electron ejection, and very high energy above-threshold-ionization electrons are all consequences of this electron-ion interaction. One important parameter which determines the strength of these effects is the rate at which the wave packet spreads in the direction perpendicular to the laser electric field; another is the laser polarization. These will be crucial parameters in future experiments.

VOLUME 70, NUMBER 11 PHYSICAL REVIEW LETTERS 15 MARCH 1993

Above Threshold Ionization Beyond the High Harmonic Cutoff

K. J. Schafer,[1] Baorui Yang,[2] L. F. DiMauro,[2] and K. C. Kulander[1]

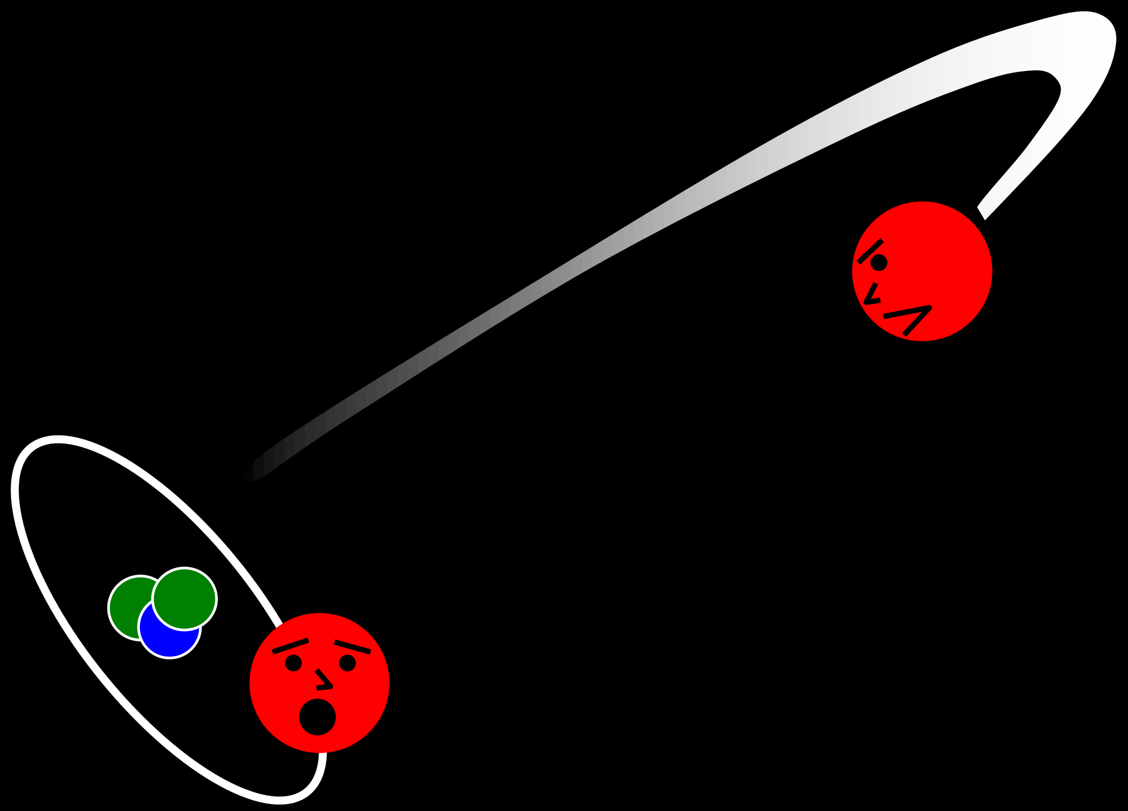
[1] *Lawrence Livermore National Laboratory, Livermore, California 94550*

[2] *Chemistry Department, Brookhaven National Laboratory, Upton, New York 11973*

(Received 2 December 1992)

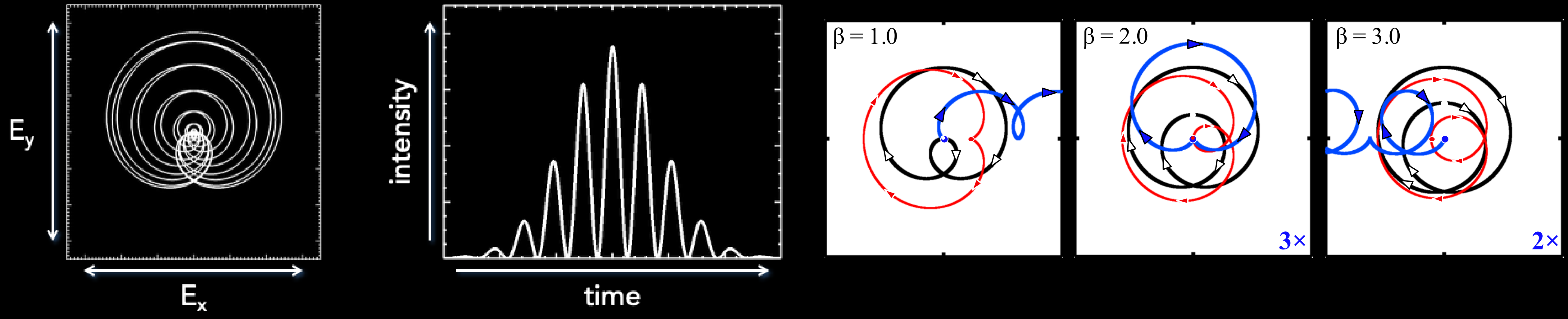
We present high sensitivity electron energy spectra for xenon in a strong 50 ps, 1.053 μm laser field. The above threshold ionization distribution is smoothly decreasing over the entire kinetic energy range (0–30 eV), with no abrupt changes in the slope. This is in direct contrast to the sharp cutoff observed in xenon optical harmonic generation spectra. Calculations using the single active electron approximation show excellent agreement with the observed electron distributions. These results directly address the unresolved relationship between the electron and photon emission from an atom in an intense field.

Rescattering

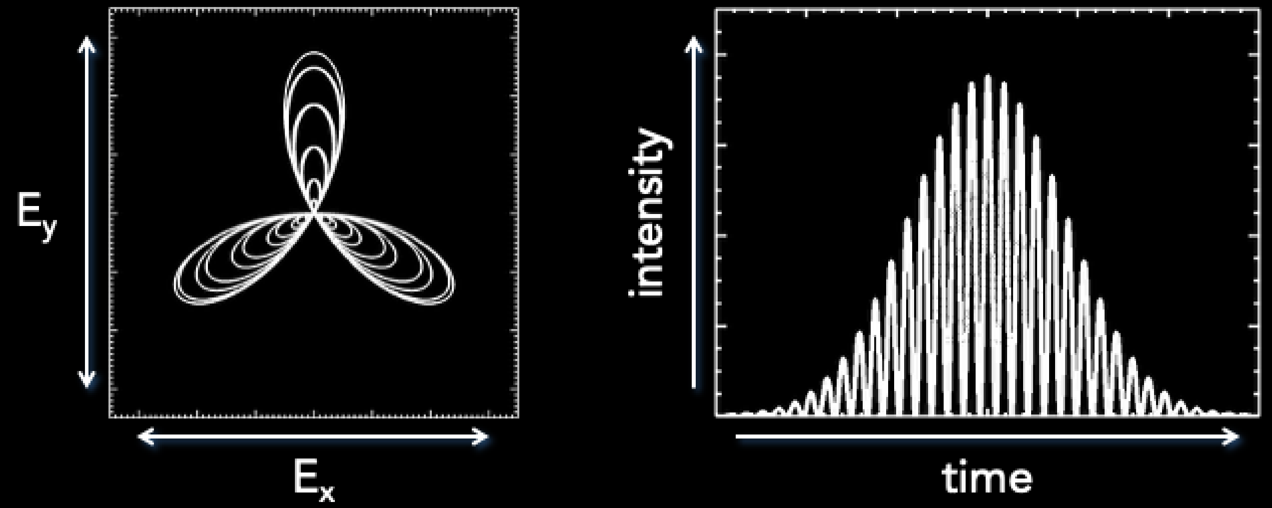


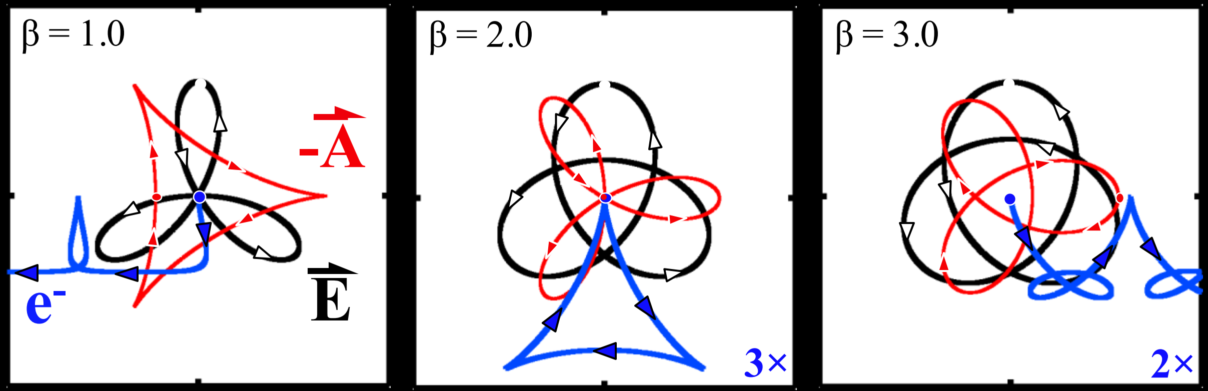
Bicircular Laser Pulses

Corotating Fields



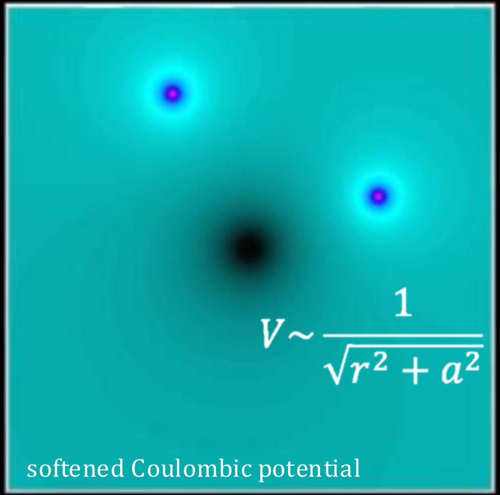
Counter-rotating Fields

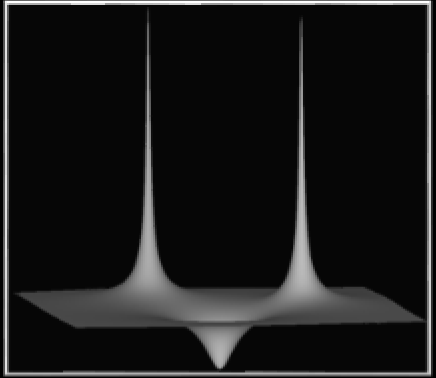


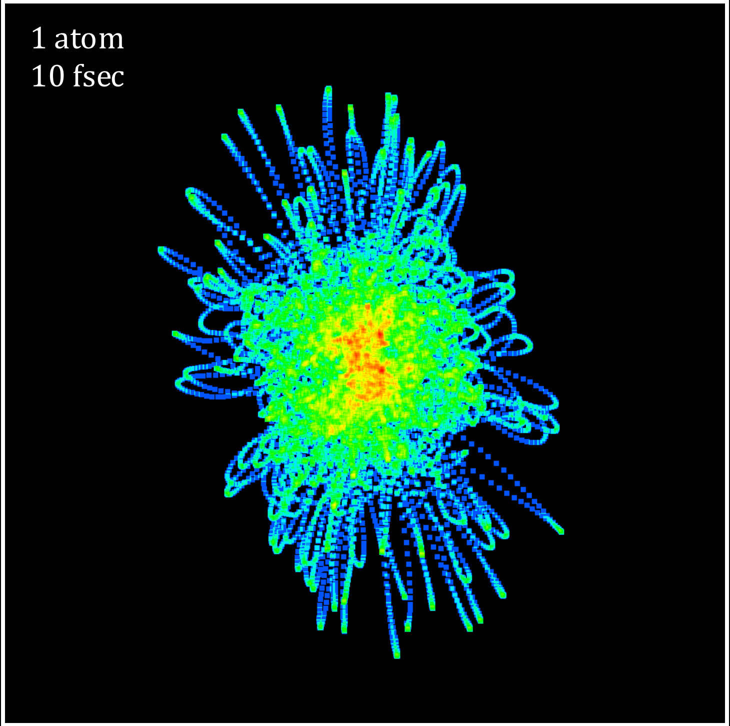


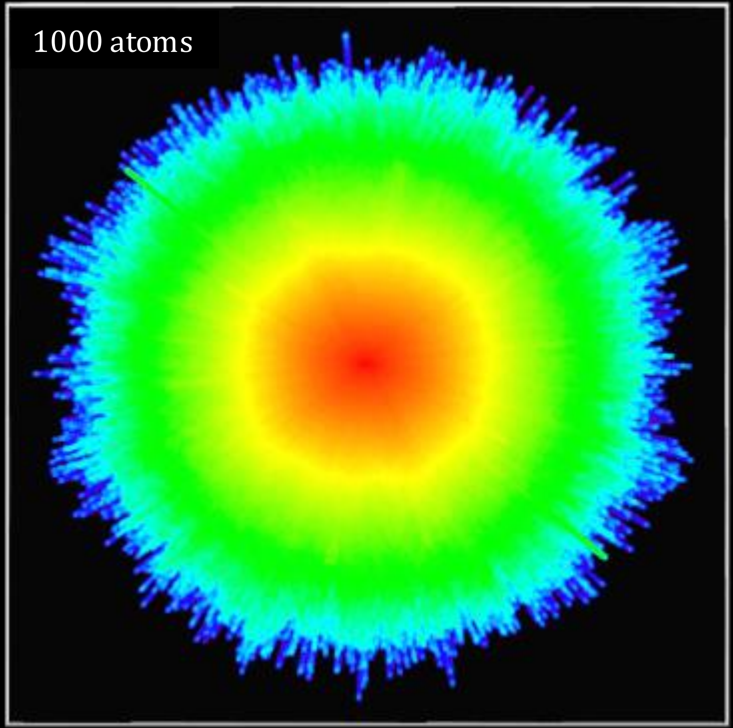
β = amplitude ratio of $2\omega:\omega$ (400nm:800nm)

Classical Model Atom

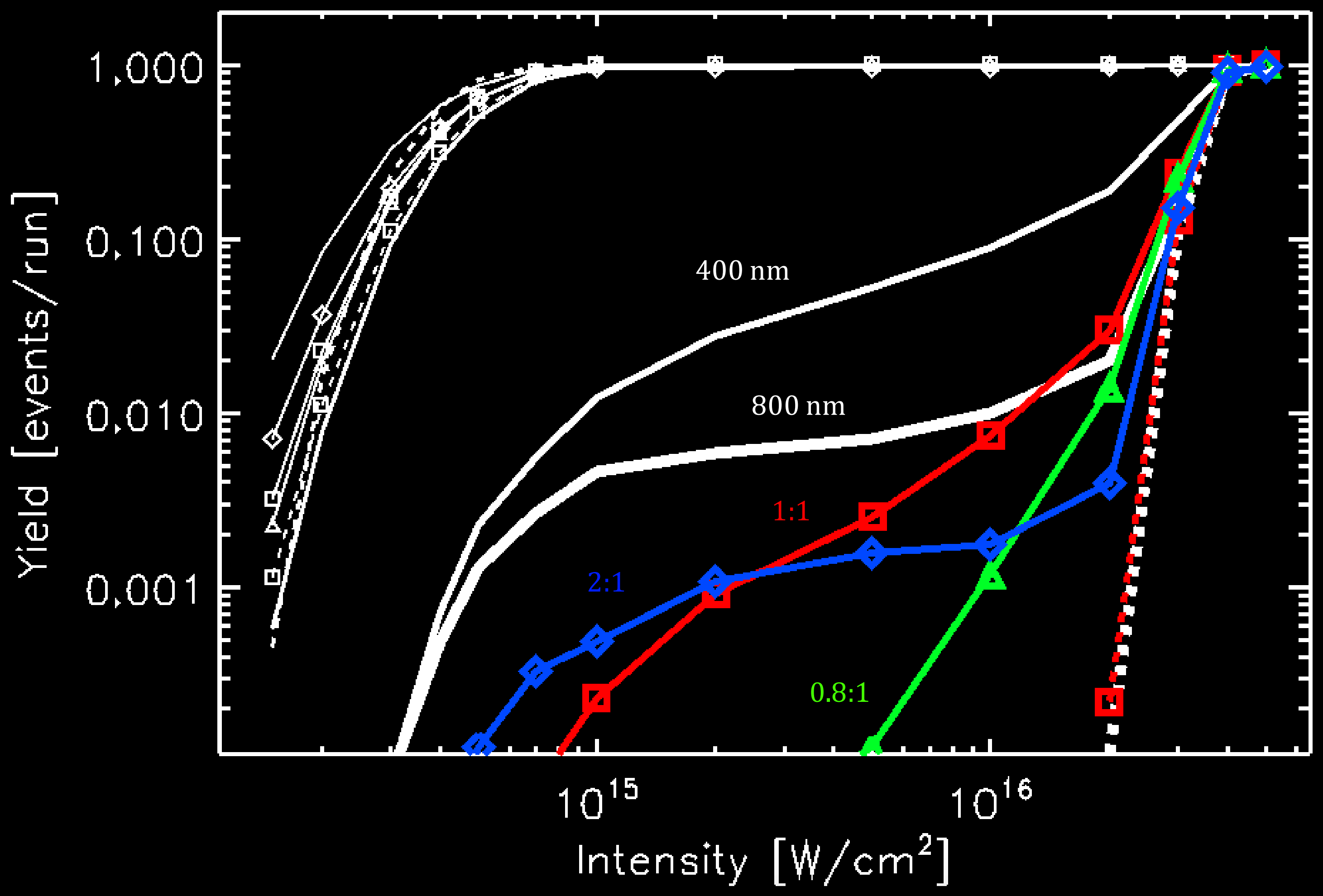








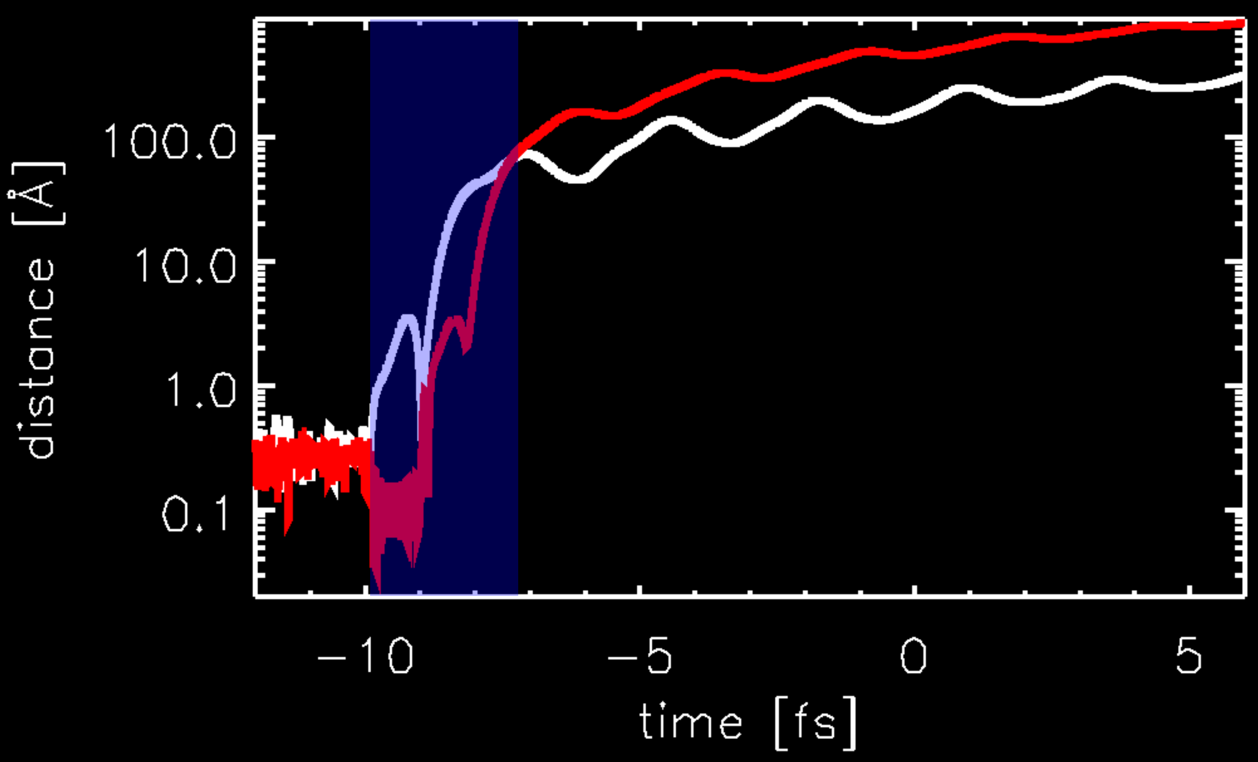
Helium Double Ionization Yields

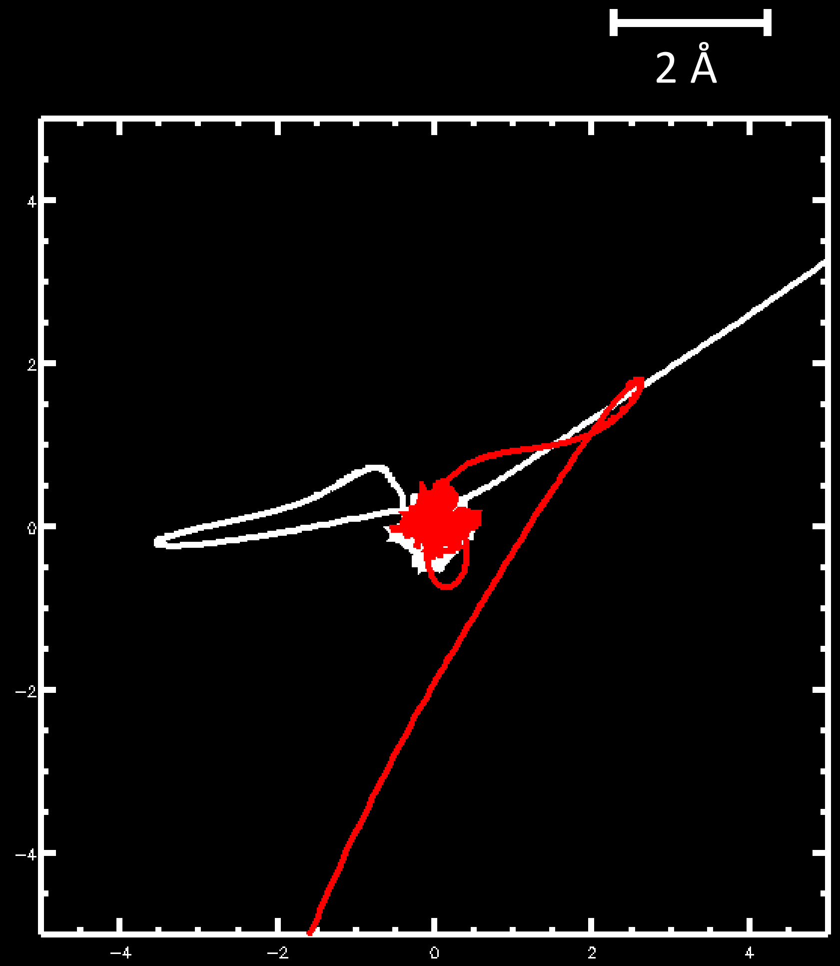


10^5 runs/point
1.4×10^6 runs/curve
9.8×10^6 runs total

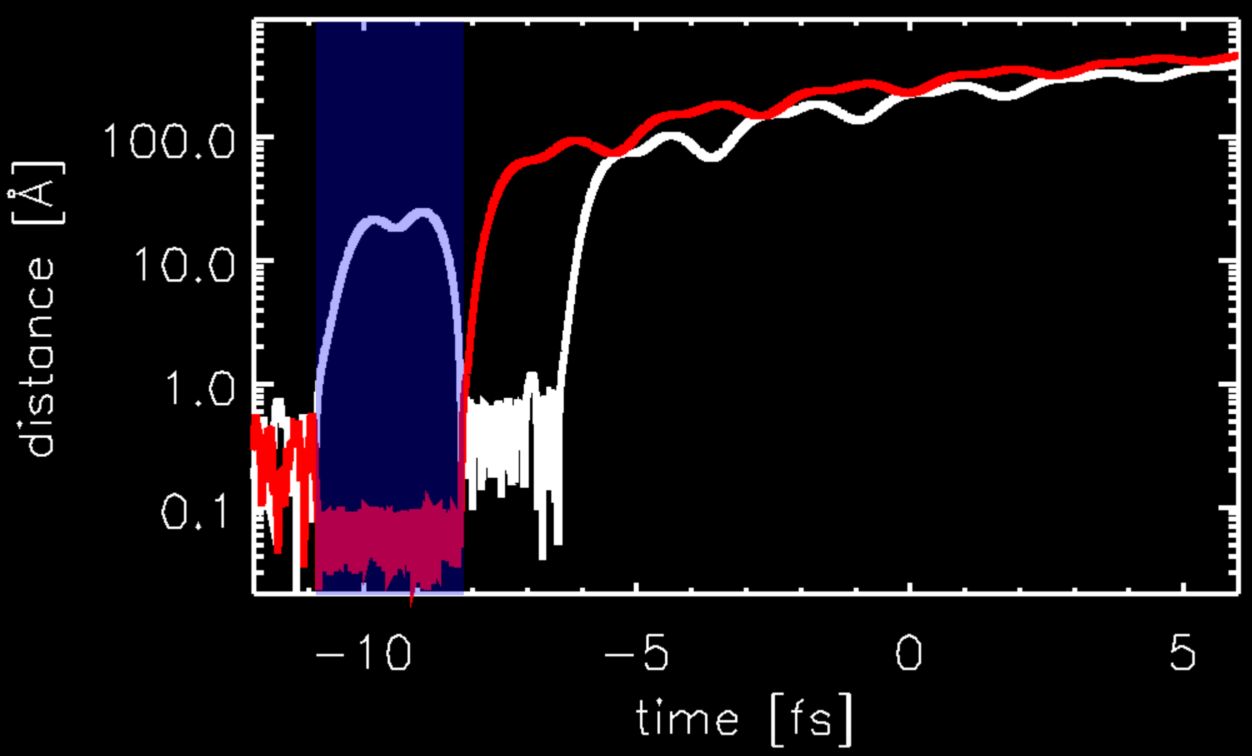
J. L. Chaloupka & D. D. Hickstein, Physical Review Letters (2016)

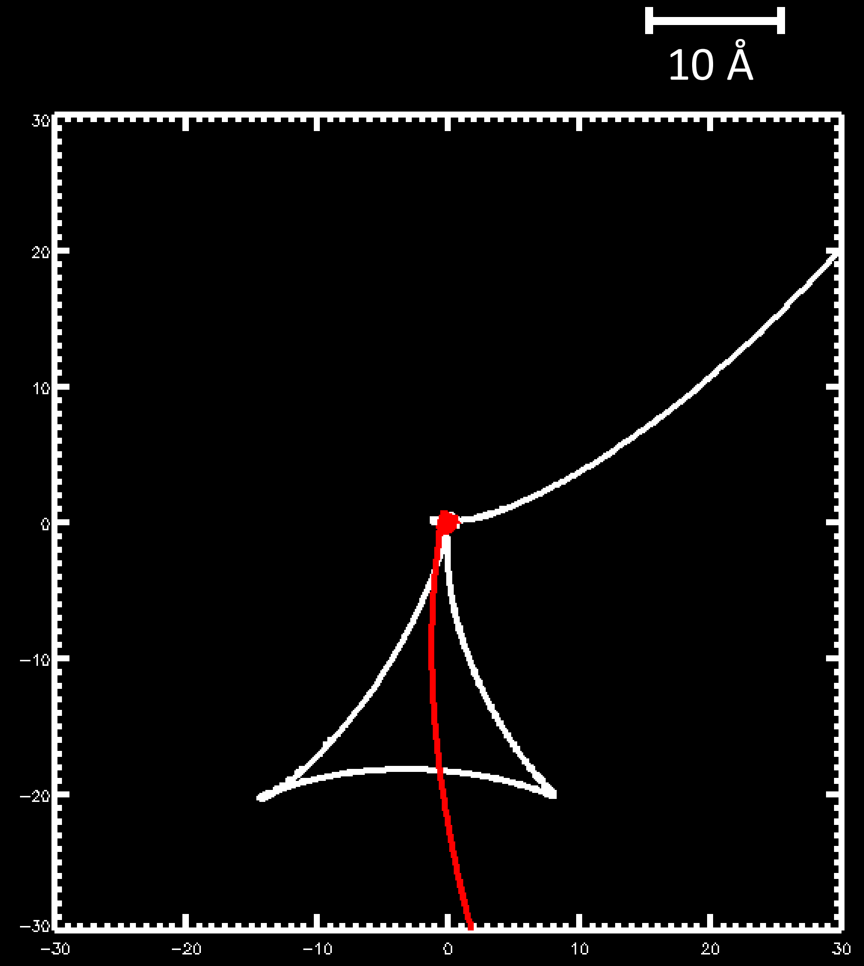
Sample DI Event (β=1)



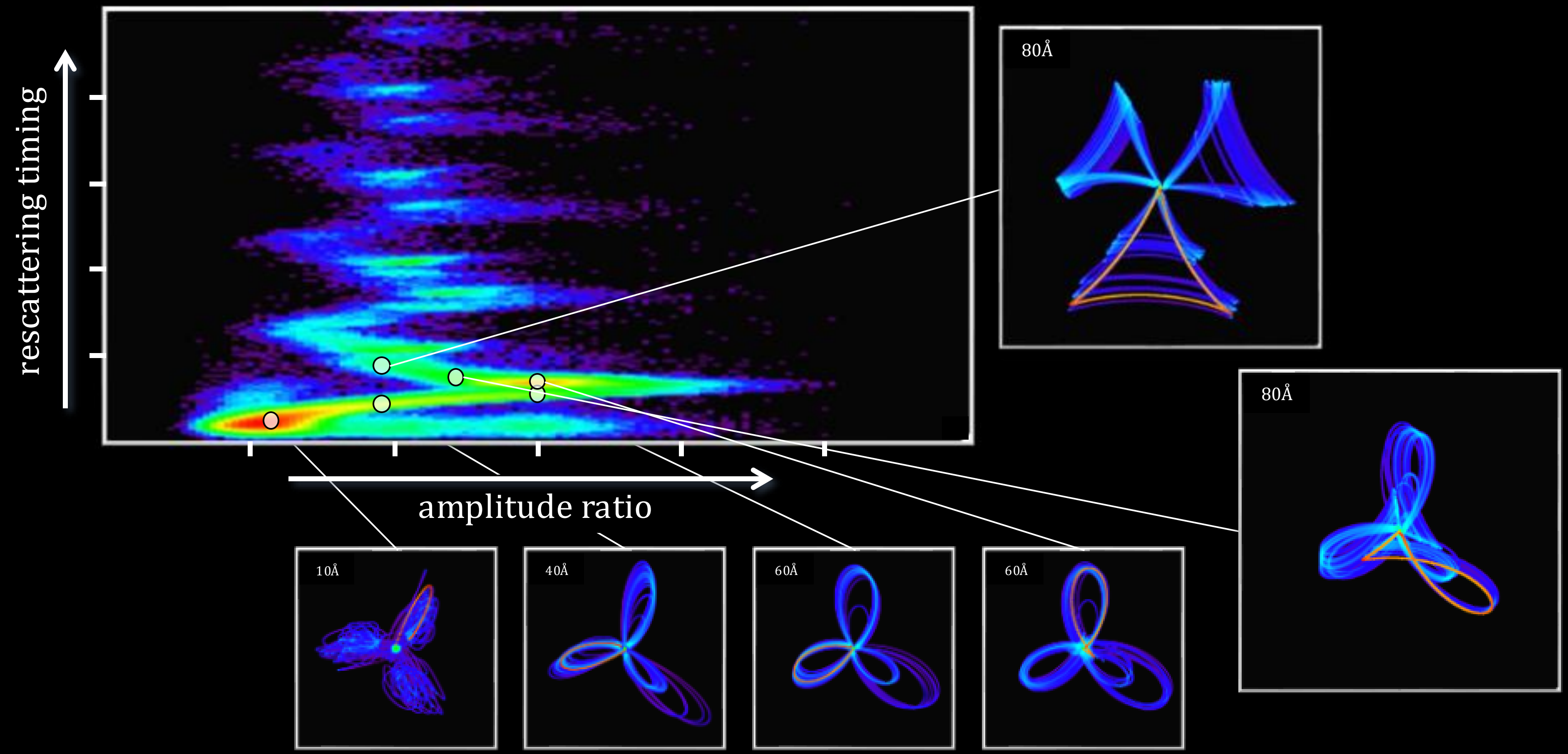


Sample DI Event (β=2)



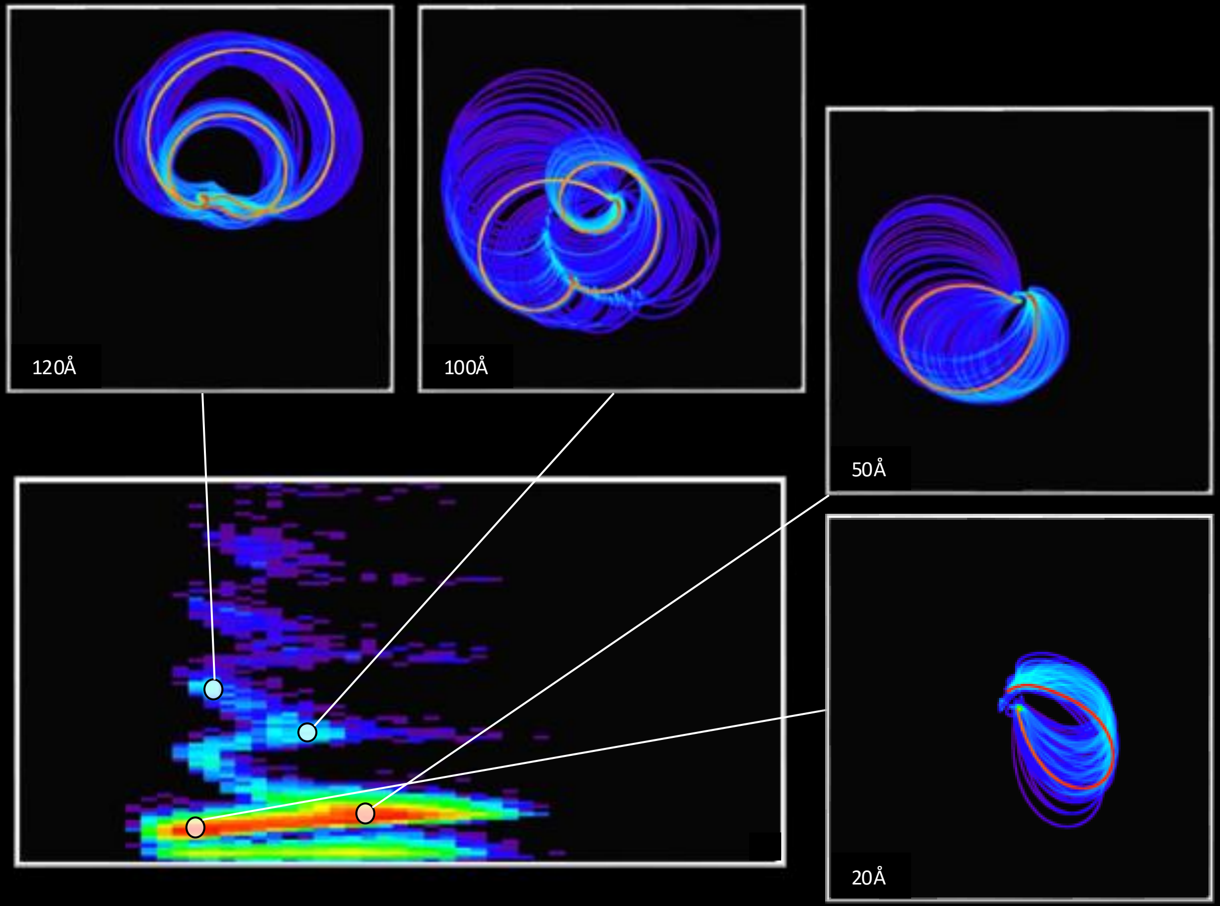


Ionization Dynamics vs β (counter-rotating)



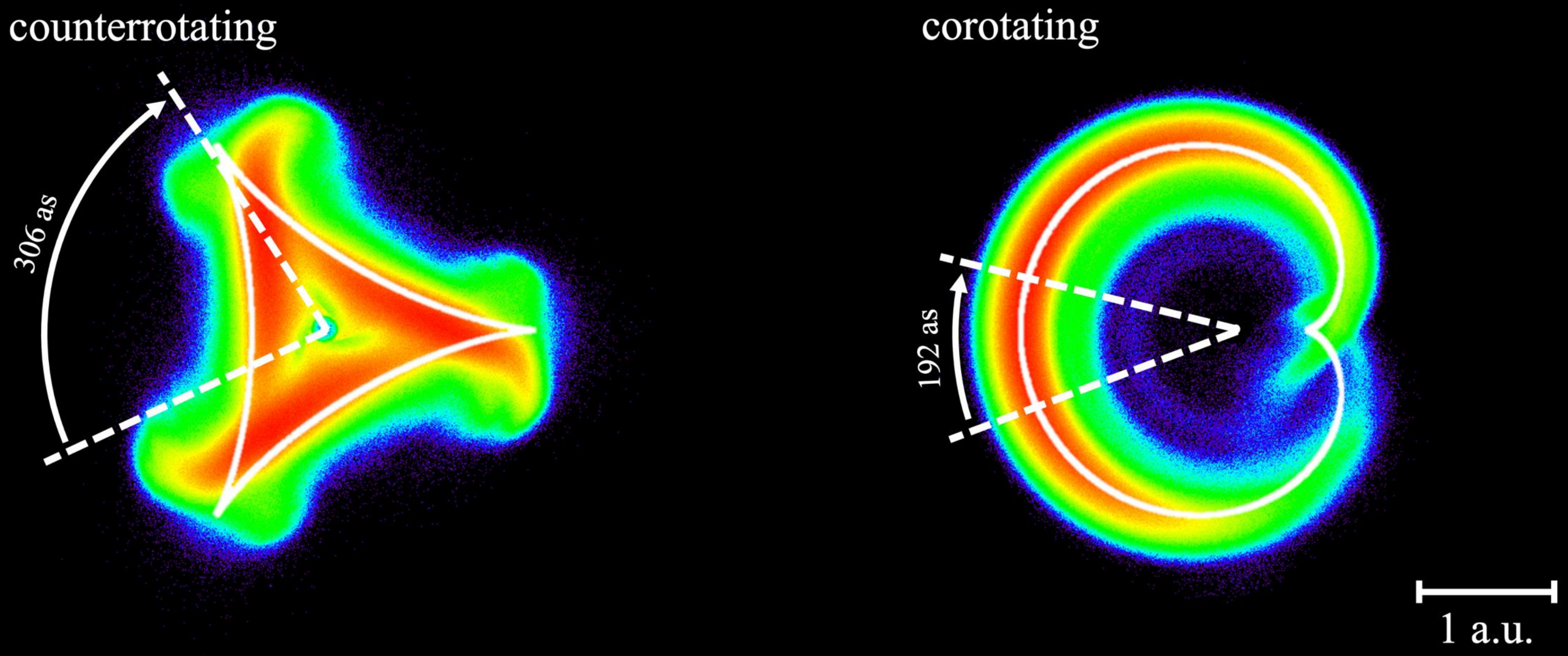
10^{16} W/cm^2
3.6×10^8 runs total

Ionization Dynamics vs β (corotating)



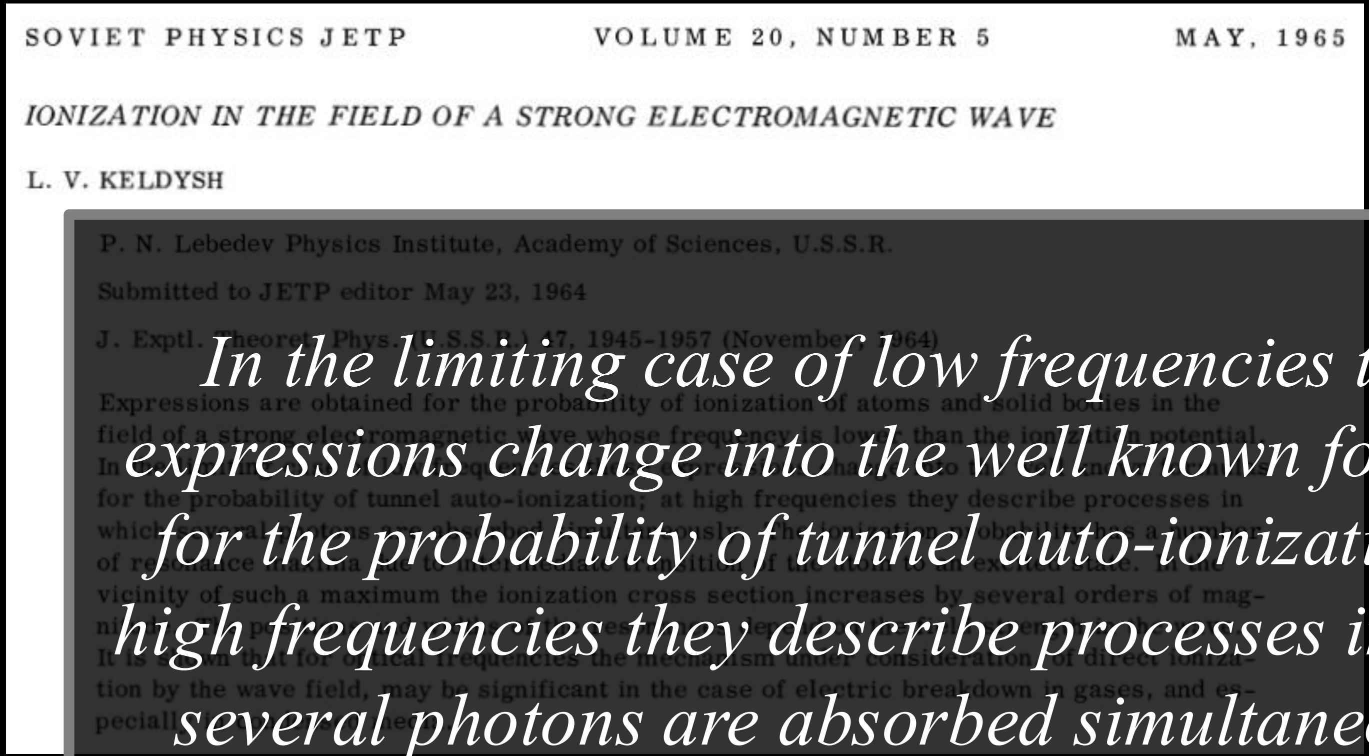
10^{16} W/cm^2
1.9×10^9 runs total

Atomic Physics Attosecond Stopwatch



J. L. Chaloupka, Journal of Physics B: Atomic, Molecular and Optical Physics 53 (18), 185601 (2020)

Keldysh Parameter


SOVIET PHYSICS JETP VOLUME 20, NUMBER 5 MAY, 1965

IONIZATION IN THE FIELD OF A STRONG ELECTROMAGNETIC WAVE

L. V. KELDYSH

P. N. Lebedev Physics Institute, Academy of Sciences, U.S.S.R.

Submitted to JETP editor May 23, 1964

J. Exptl. Theoret. Phys. (U.S.S.R.) 47, 1945-1957 (November, 1964)

In the limiting case of low frequencies these expressions change into the well known formulas for the probability of tunnel auto-ionization; at high frequencies they describe processes in which several photons are absorbed simultaneously.

$$\gamma = \sqrt{\frac{I_p}{2U_p}}$$

Ionization Potential

Pondermotive Potential

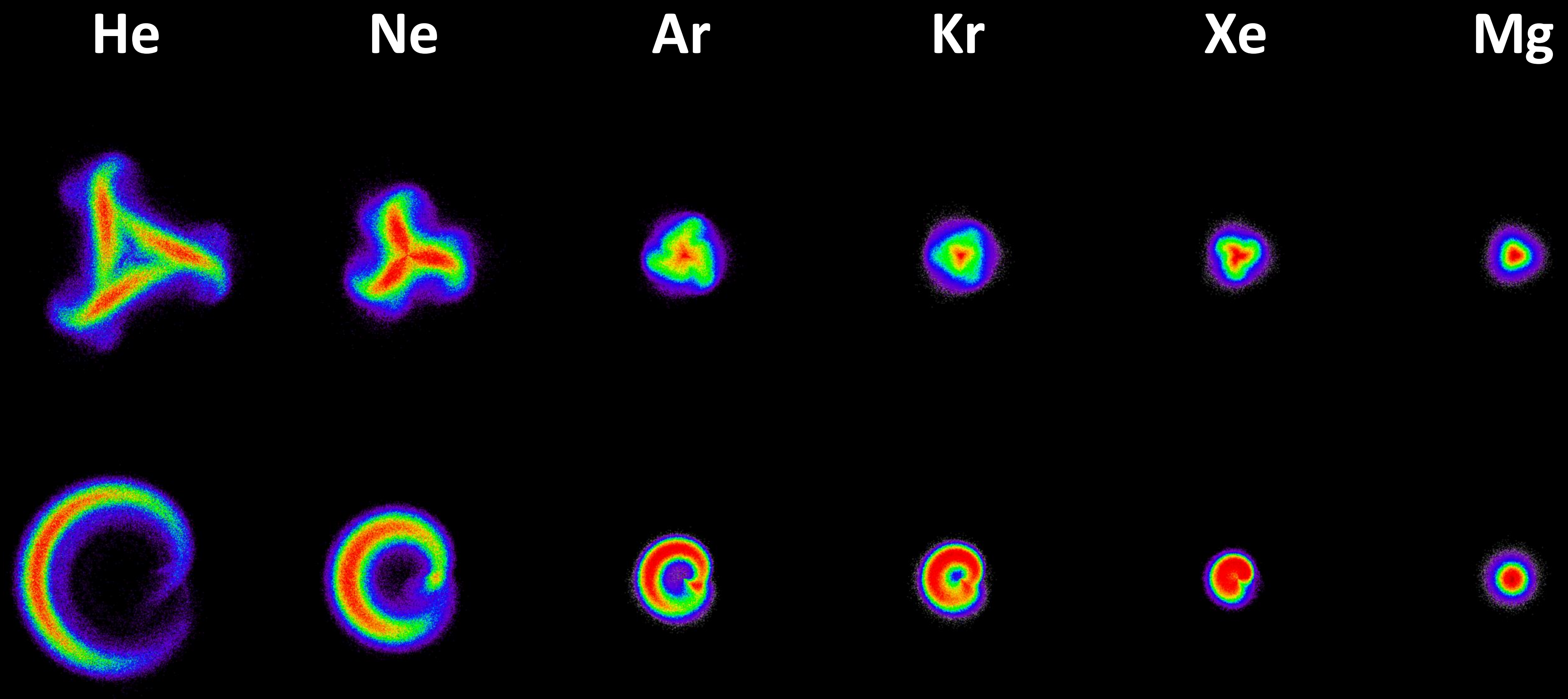
Coulomb vs Laser

Tunneling → Multiphoton

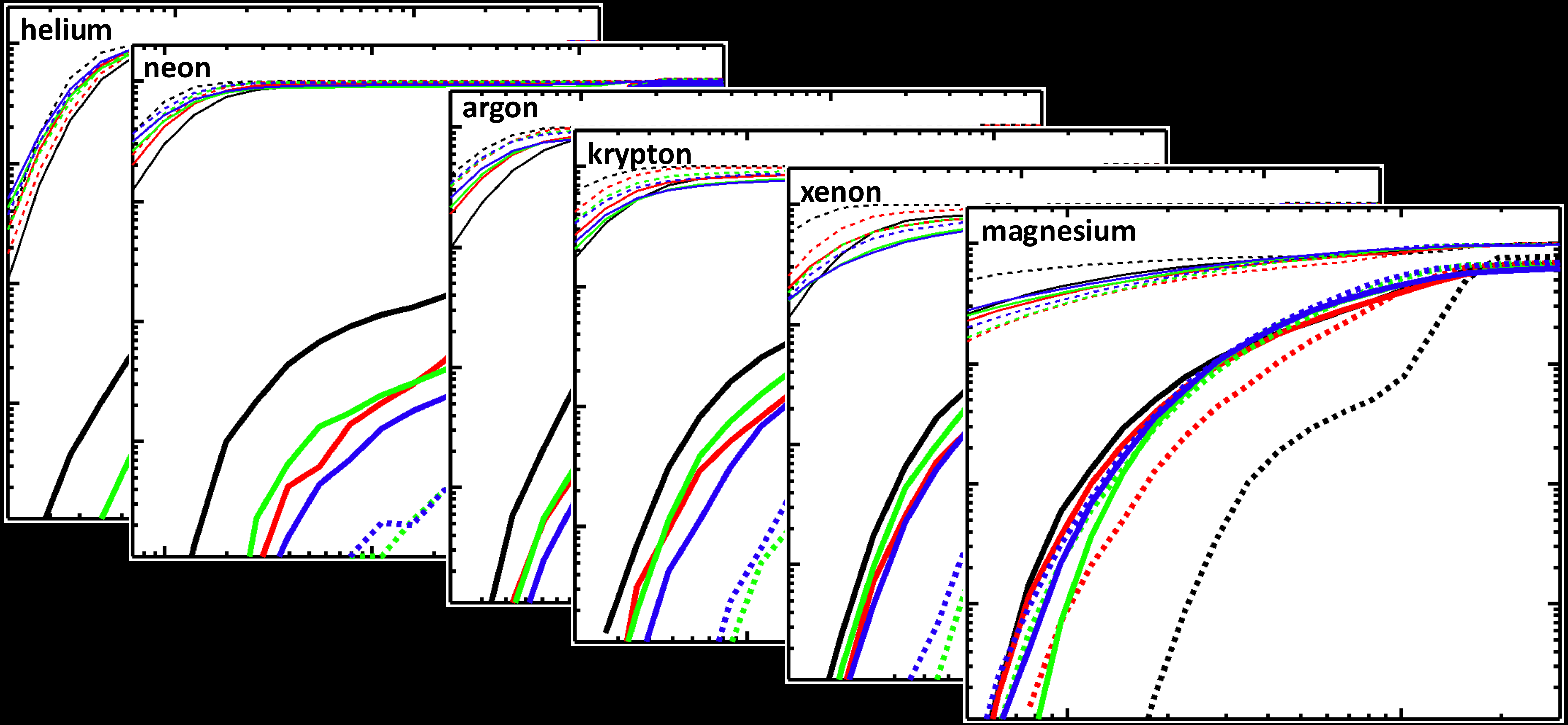
increasing *relative* strength of the Coulomb potential

Helium	Neon	Argon	Krypton	Xenon	Magnesium
γ=0.64	**γ=0.95**	**γ=1.48**	**γ=1.71**	**γ=2.25**	**γ=2.83**

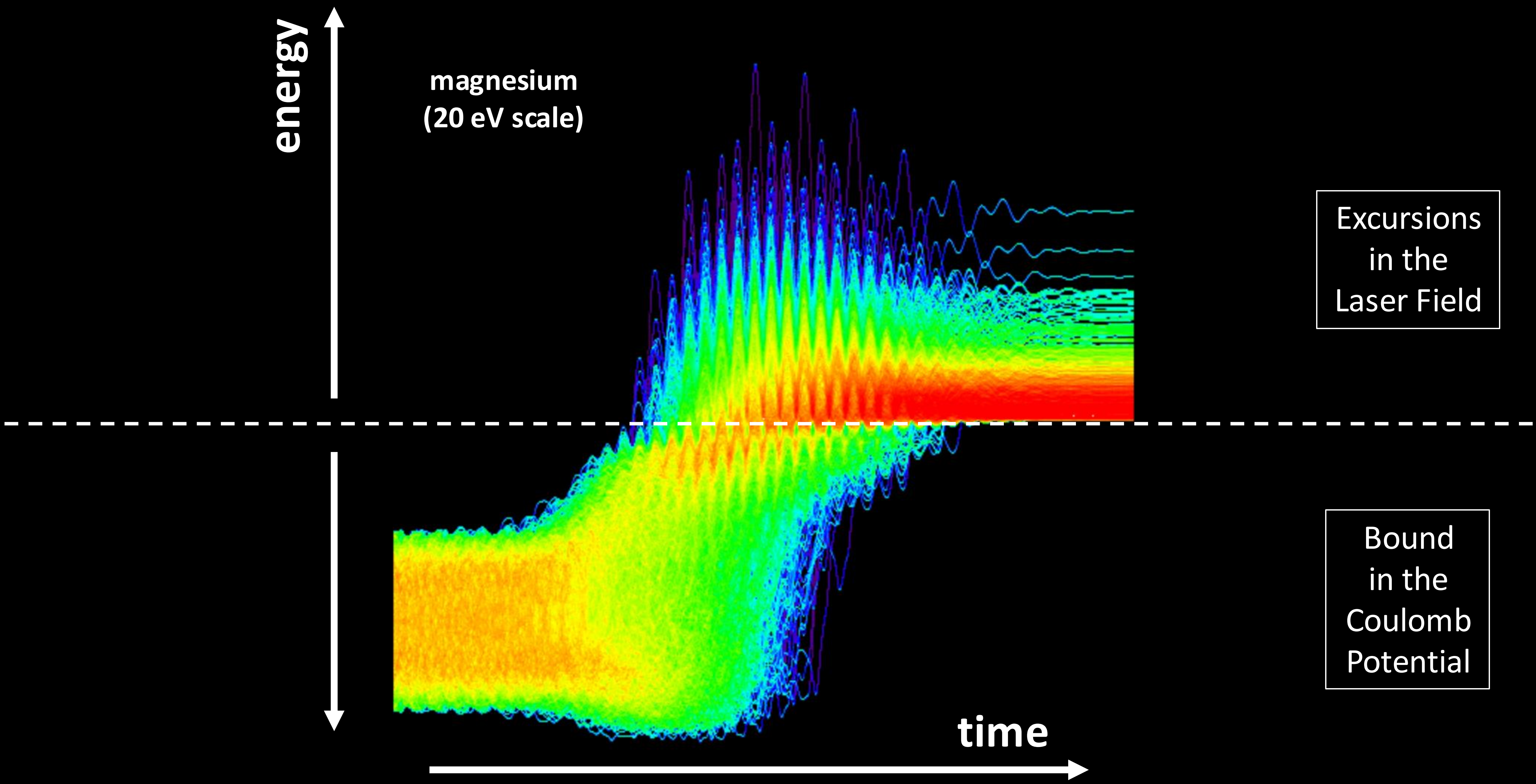
Single Ionization Momentum Distributions



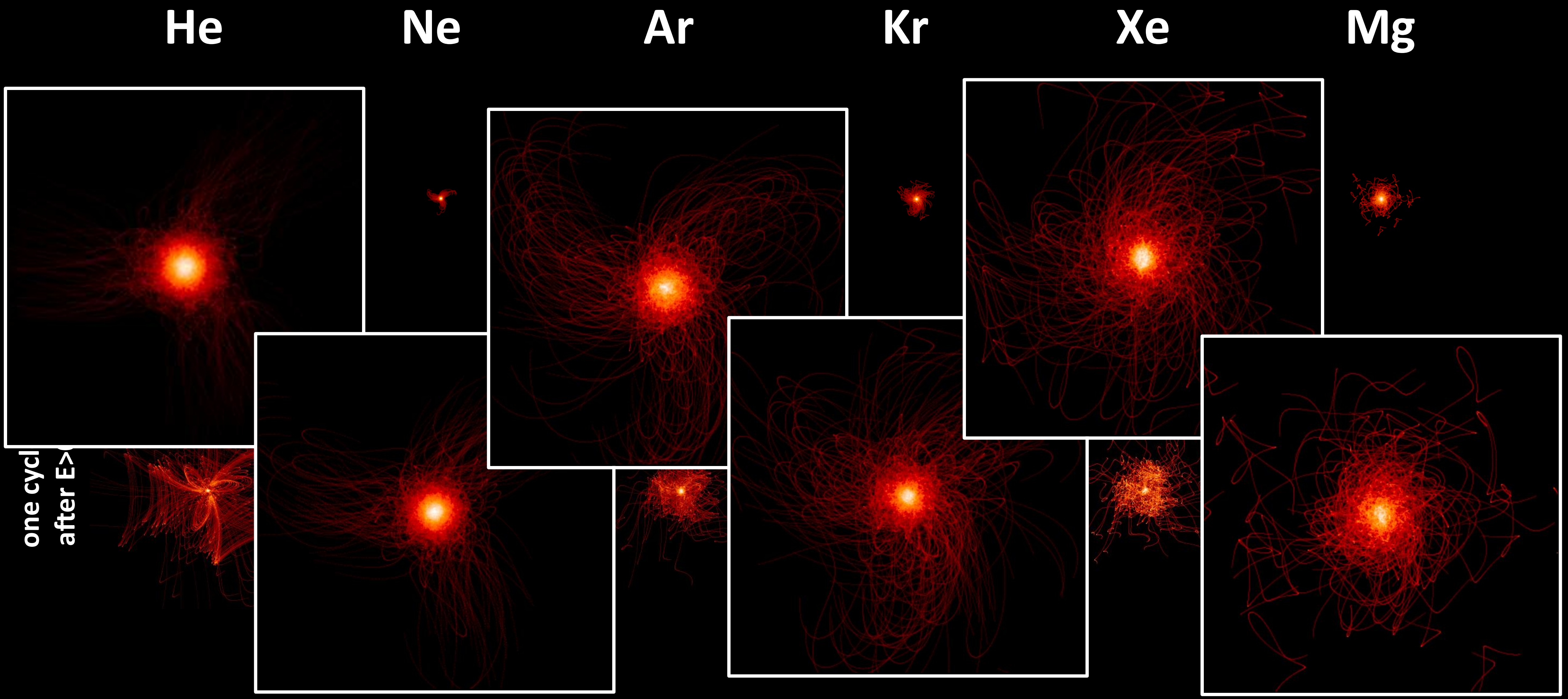
Double Ionization Yields



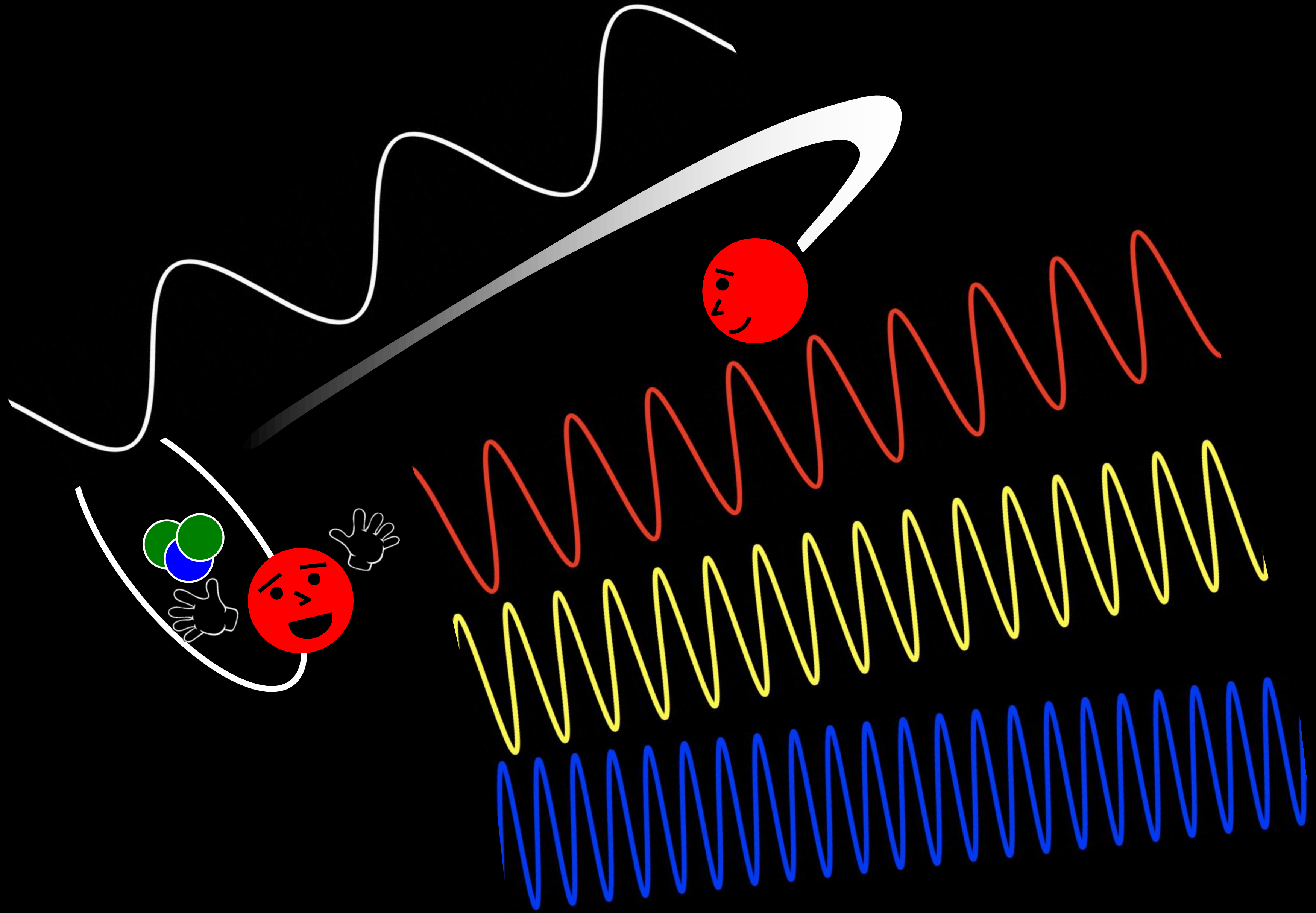
NSDI Electron Energy vs Time (β=2)



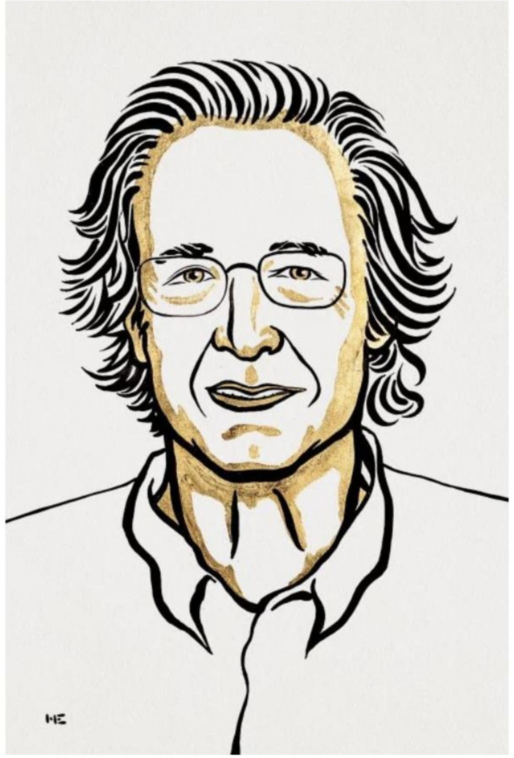
NSDI Electron Trajectories (β=2)



High Harmonic Generation



2023 Nobel Prize in Physics



Ill. Niklas Elmehed © Nobel Prize Outreach

Pierre Agostini

Ill. Niklas Elmehed © Nobel Prize Outreach

Ferenc Krausz

Ill. Niklas Elmehed © Nobel Prize Outreach

Anne L'Huillier

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

Quantum Optics V, Zakopane, Poland, June 2001

Thank You!