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Investigating a Transition in the Dynamics of Strong-Field Double Ionization in an Intense Bicircular Laser Pulse

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

Abstract: Using a classical ensemble method, we probe the double ionization of rare gases in intense bicircular laser pulses across a range of intensities and ionization potentials. We uncover a dramatic transition in the dynamics that lead to non-sequential double ionization, and establish a classical interpretation of the well-known Keldysh parameter.

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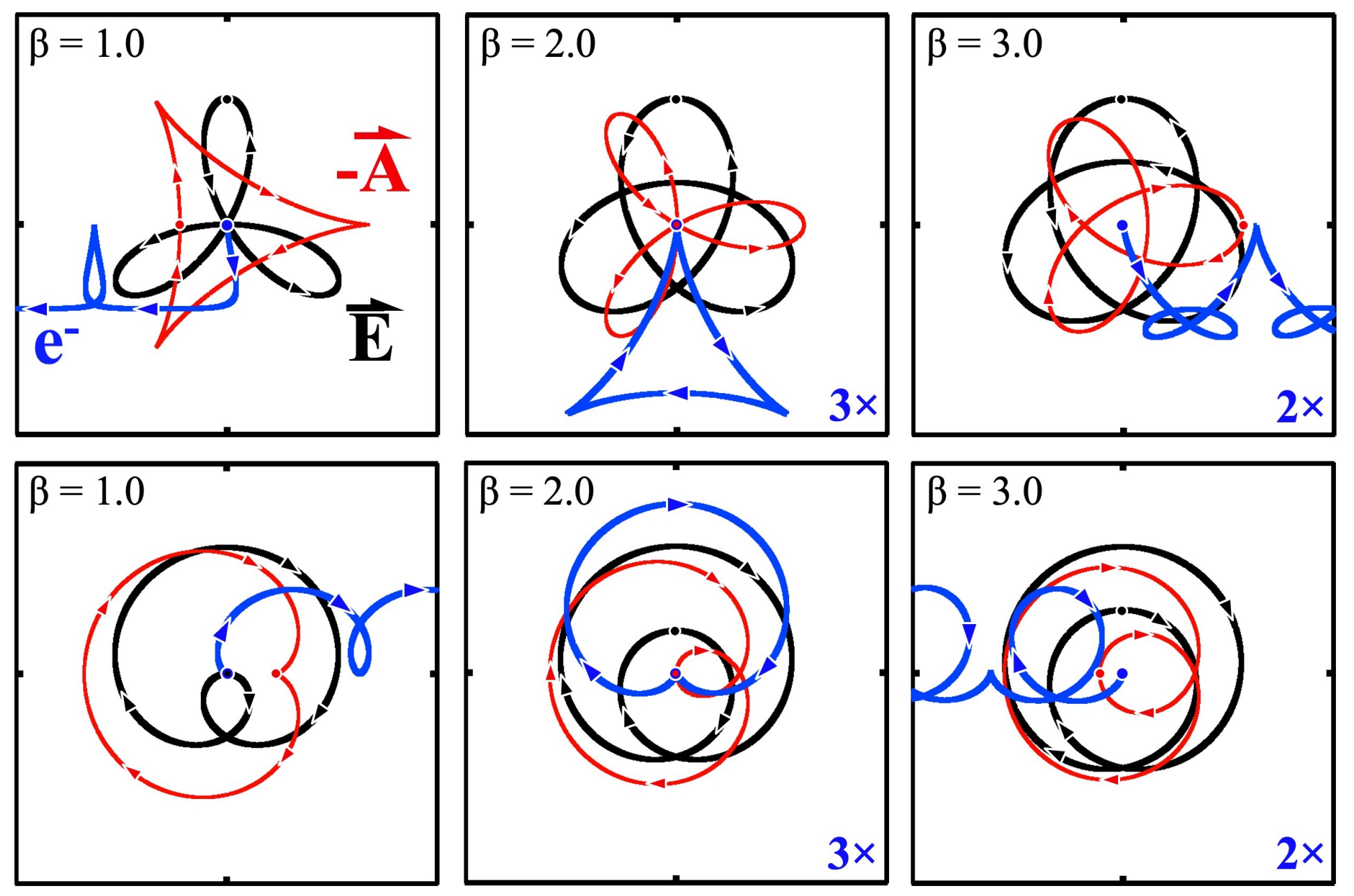
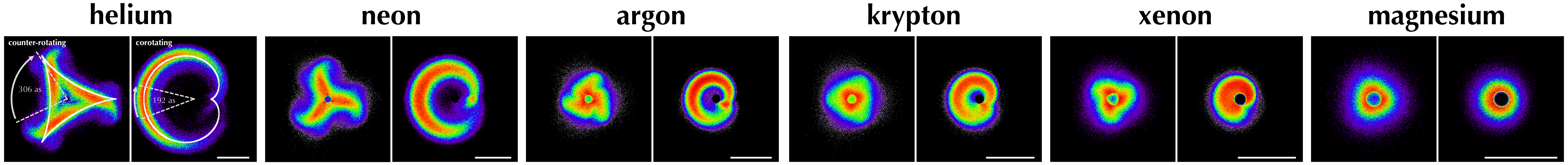
In this study, a completely classical model atom [1-4] is used, and established softening parameters for the atomic potential are employed for the various atomic species [5]. A realistic, three-dimensional laser pulse (τ=10 fs, ω_0=10 μm) [6] interacts with the model atoms for large ensemble sizes to generate ionization yield curves, electron momentum distributions, and rescattering electron trajectories. Throughout this work, “normalized intensity” is used, where the peak electric field amplitude is fixed, allowing for direct comparison between the different field conditions [3-4].

The Keldysh parameter $\gamma=(I_p/2U_p)^{1/2}$ is typically used to describe tunneling vs multiphoton behavior (small vs large γ). Here we also use it to indicate the relative strength of the Coulomb potential. For small γ, we can expect Coulomb effects to be small, giving rise to behavior closest to that predicted by the “simpleman” model, while for large γ, the effect of the Coulomb potential will become more significant. A larger Keldysh parameter signifies an effectively stronger Coulomb potential *relative to the laser field*, but at the same time, the weaker Coulomb potential *in absolute terms* means the electron-electron repulsion has a bigger influence. These effects act together to enhance the efficiency of double ionization for large γ for all pulse configurations, even reproducing the NSDI of Mg with circular polarization [13].

Intense bicircular fields [7-11] are generated through the linear combination of two laser pulses of circularly polarized light, typically at the fundamental and second harmonic frequencies. In this study, 400nm:800nm fields are used in both counter-rotating and corotating superpositions, and the 2ω:ω amplitude ratio (β) is varied to generate different field shapes. Electric field patterns are shown for counter-rotating (upper panels) and corotating (lower panels) fields. The negative vector potential shows the electron momentum distributions expected from the “simpleman” model [12], where the electron is released with zero initial velocity and the effect of the Coulomb potential is ignored. A simple electron trajectory is shown for release at the peak of the field (counter-rotating, upper panels), showing a perfect returning trajectory for a 2:1 amplitude ratio. For corotating fields (lower panels), the electron must be released at the null of the field in order to be driven back towards the parent ion. As a result, rescattering is much more effective with counter-rotating fields than with corotating pulses. However, the effect of the Coulomb potential can help improve corotating rescattering by 1) effectively delaying the release of the electron into the laser field and 2) significantly distorting electron trajectories.



SI electron momenta



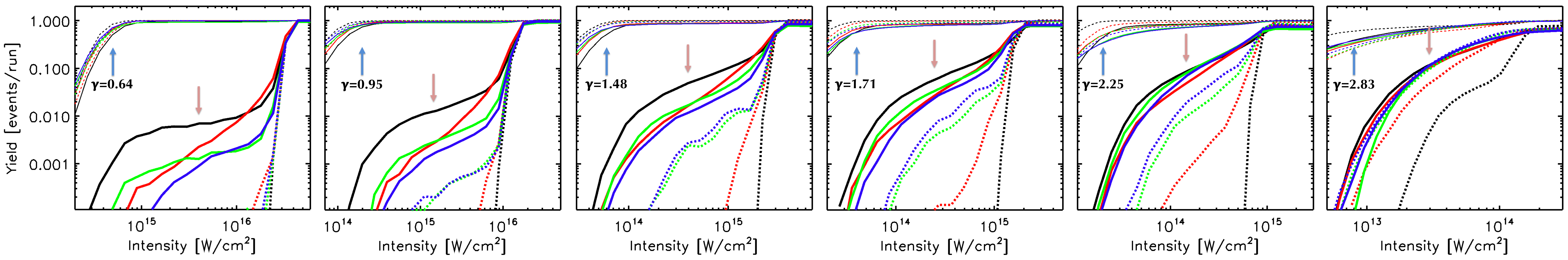
transverse electron momenta from single ionization

counter-rotating (left panel)
corotating (right panel)

1:1 400nm:800nm
intensity at blue arrow
one atomic unit scale indicated

image ensemble size of 10^6

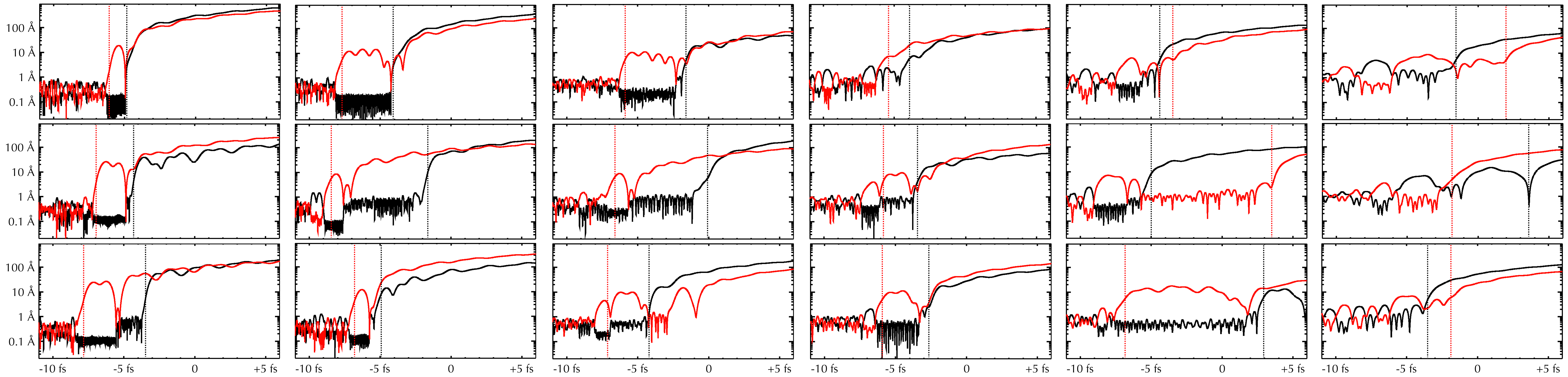
ionization yields



▬	**800nm linear**
🟥	**1:1 counter**
🟩	**2:1 counter**
🟦	**3:1 counter**
······	**800nm circular**
······	**1:1 co**
······	**2:1 co**
······	**3:1 co**

each graph is the result of
1.6×10^7 simulation runs
(8 curves, 20 intensities,
10^5 runs per intensity)

sample DI events



sample double ionization events

distance from nucleus vs time for each electron

2:1 400nm:800nm
intensity at red arrow

the first instance of positive energy for each electron indicated by dashed line