IOCAT 2026 Conference

The 1st International Online Conference on Atoms

29–30 January 2026 | Online

MDPI

Nondipole laser-assisted photoionization: the streaking regime

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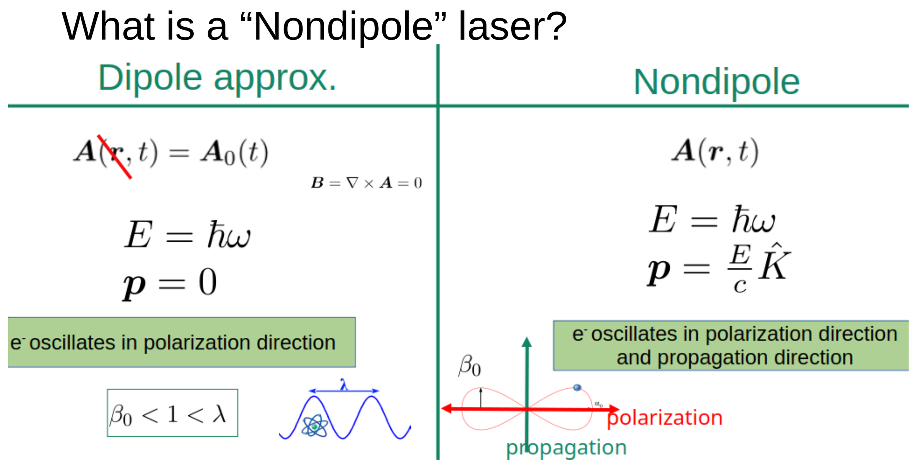
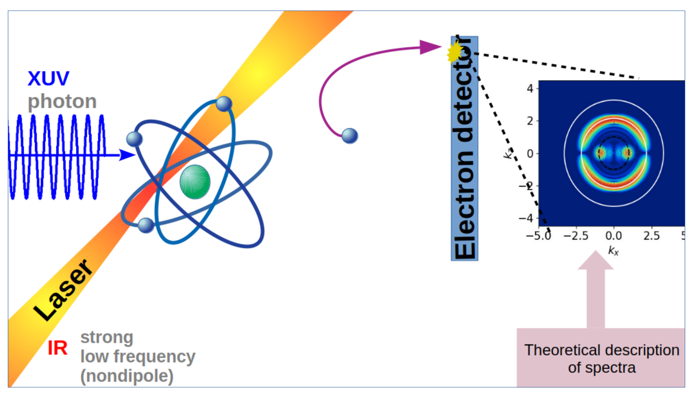
INTRODUCTION & AIM

What is a "Nondipole" laser?



Laser-assisted photoionization

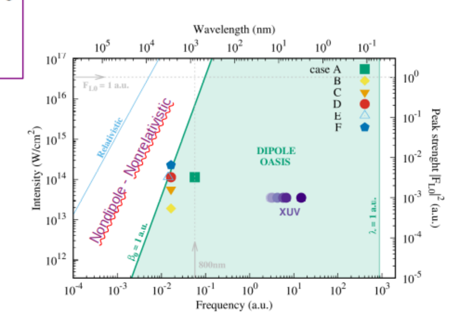


Let us consider a space-dependent **IR** laser field at the lowest order in 1/c,

$$A(\eta) \simeq A(\eta)|_{r=0} + \left[(r\cdot\nabla)A(\eta)\right]\Big|_{r=0} \simeq A_0(t) + \frac{\hat{z}\cdot r}{c}E_0(t),$$

DIPOLE approximation (1st term only)

NONDIPOLE nonrelativistic approximation: both terms



$$\chi_f^{VND}(\mathbf{r},t) = (2\pi)^{-3/2}\exp\{i\,\mathbf{\Pi}(\mathbf{k},t)\cdot\mathbf{r}\} \times \exp\left\{\frac{i}{2}\int_t^\infty \mathbf{\Pi}^2(\mathbf{k},t')\mathrm{d}t'\right\}$$

Nondipole Gordon Volkov wave function describes a free electron in a **nondipole IR** laser field

$$\Pi(k,t) = k + A_0(t) + \left[k\cdot A_0(t) + \frac{1}{2}A_0^2(t)\right]\frac{\hat{z}}{c}.$$

METHOD

XUV + IR LAPE

Laser Assisted Photoionization Emission

$$T_{\rm if} = -i\int_{-\infty}^{+\infty} \mathrm{d}t\,\langle\chi_f^-(r,t)|H_{\rm int}(r,t)|\phi_i(r,t)\rangle,$$

$$T_{if} = T_{if}^{IR}(\text{Direct Ioniz}) + T_{if}^{XUV}(\text{LAPE})$$

XUV ionization assisted by IR

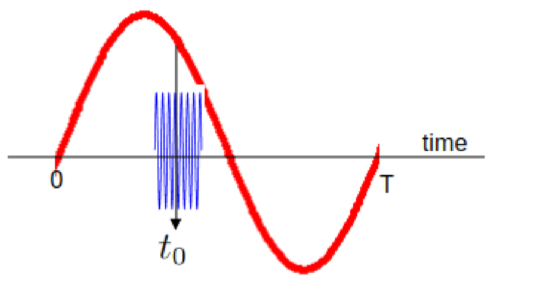
See Candelaria Migliaro Poster!

Flash poster session: 10.25hs CET

$$T_{\rm if}^{\rm st} = \int_{t_0-\tau_X/2}^{t_0+\tau_X/2} \ell(t)\,e^{iS(t)}\,\mathrm{d}t \simeq \ell(t_0)\,e^{i(S(t_0)+\frac{\pi}{4}\ddot{S}(t_0))}\sqrt{\frac{2\pi}{|\ddot{S}(t_0)|}},$$

Semi Classical Model (SCM) saddle point approximation (SPA)

$$\Pi^2(k,t_0) = v_0^2$$



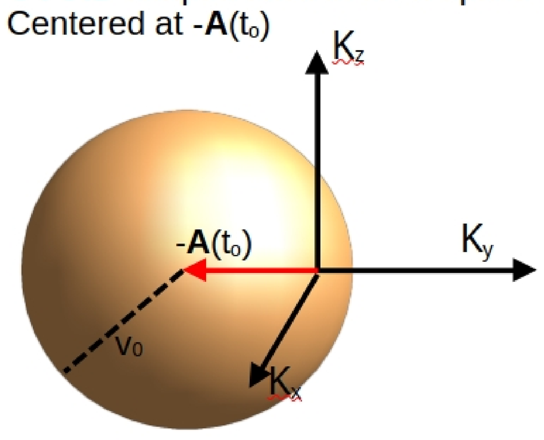
- delay between IR and XUV
- single saddle point
- ionization time

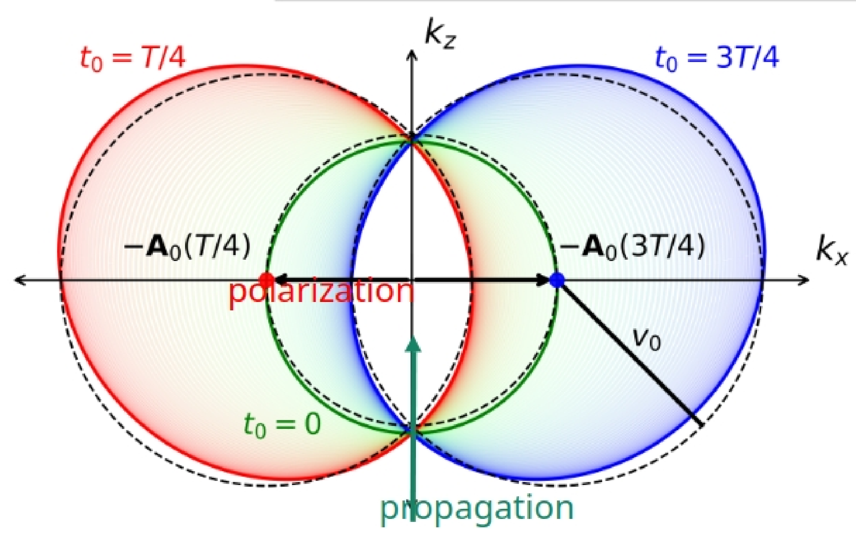
SPA $\Pi^2(k,t_0) = v_0^2$ → Nondipole → $\left[k + A(t_0) + (\cdots)/c\right]^2 = v_0^2$

$v_0^2 = 2(\omega_X - I_p)$

Nondipole: forward-deformed spheres

Semiclassical allowed momenta **OVOID**-shaped shell in 3D k-space Centered at -**A**(t_0)





In streaking conditions the stationary time t_s is the same as t_0, the delay between the IR and the short pulse XUV.

Those values of ***k*** satisfying its equation for real values of t_s define a quasi-sphere [centered at -**A**(t_0) and radius v_0], of classically allowed momenta

Dipole approximation: dashed lines determine the spheres centered at -**A**(t_0).

As it rotates for circularly polarizaed IR laser, the sphere also rotates in the plane perpendicular to z axis.

REFERENCES

Phys. Rev. A 112, 023111 (2025)

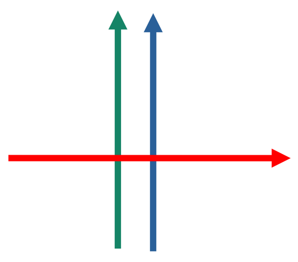
Reiss JPB 47 204006 (2014)

RESULTS & DISCUSSION

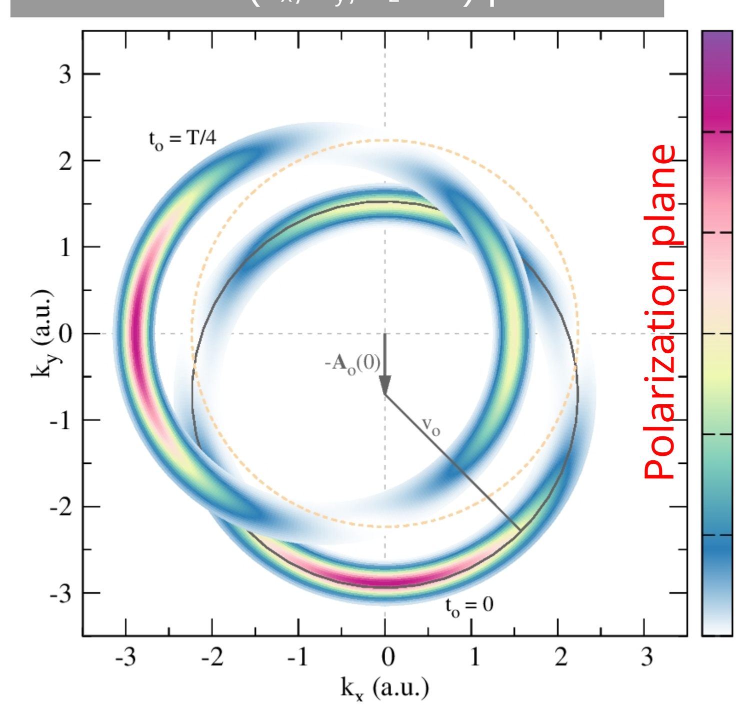
Streaking H(1s)

XUV sin² envelope

Circular IR



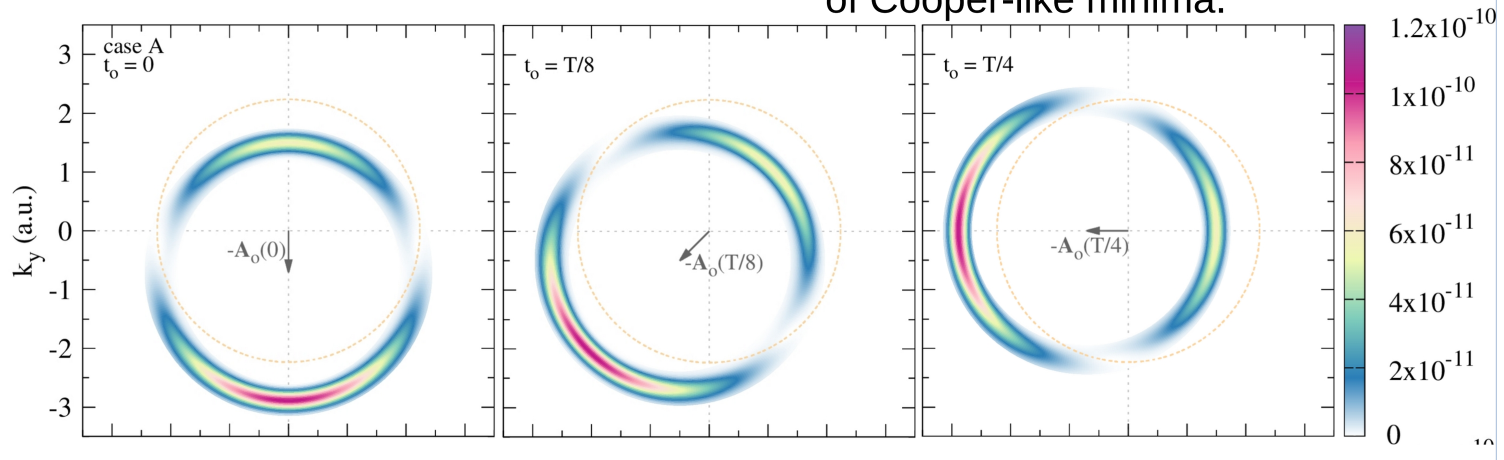
Polarization (k_x, k_y, k_z = 0) plane



Streaking PMD for H(1s) in the k_z=0 plane, where the dipole approximation predicts null emission.

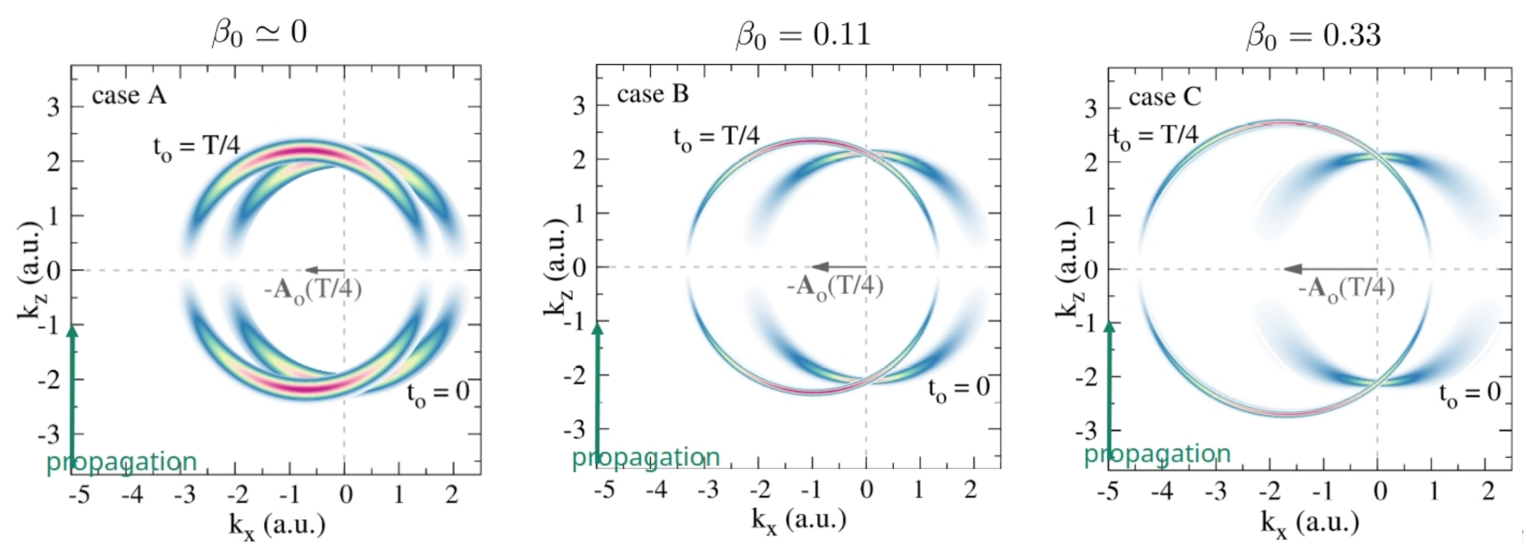
Electrons with energy: $E = v_0^2/2 = \omega_X - I_p$

behave as " dipole" electrons, whit null PMD, leading the appearance of Cooper-like minima.



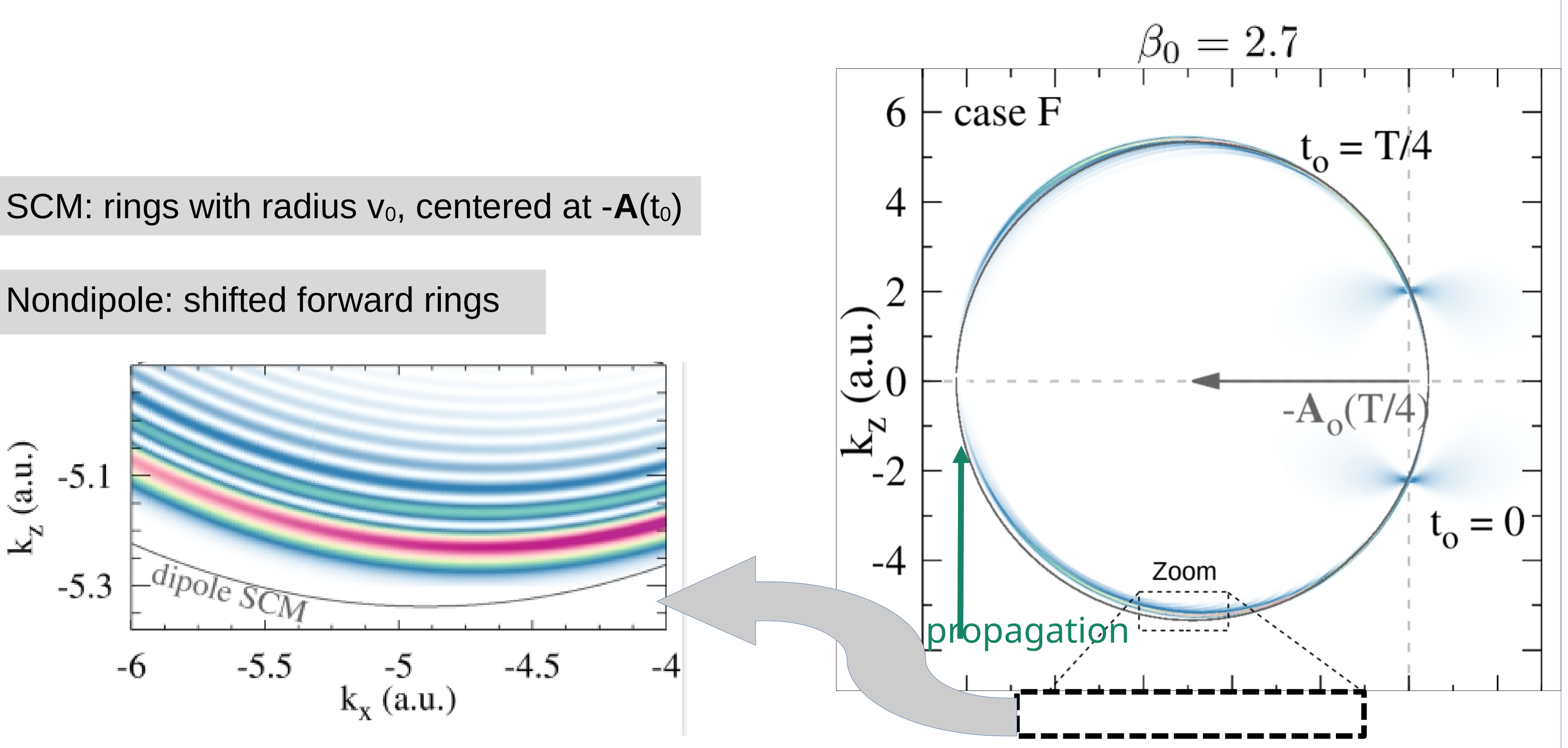
Changing the ionization times t_0, the PMD rotates as in attoclock process.

Propagation (k_x, k_y = 0, k_z) plane



SCM: rings with radius v_0, centered at -**A**(t_0)

Nondipole: shifted forward rings



CONCLUSION

We have studied LAPE process in a nondipole nonrelativistic SFA description. As particular case, we consider H(1s) ionizated by circularly polarized IR laser and train of short XUV pulses.

The STREAKING PMD is predominantly distributed on a surface predicted by the semiclassical model in momentum space.

PMD is non-zero in the dipole forbiden k_z=0 plane; where Cooper-like minima are observed along the E = v_0^2 / 2 line.

STREAKING pattern shifts in the direction opposite to the instantaneous IR polarization vector; changing the ionization times t_0, the PMD rotates as in attoclock process.