Towards Intense and Controlled Ultrashort Pulse Generation via Plasma

Z. M. Chamazkoti*[1], L. O. Silva[1]

[1]GoLP/Instituto de Plasmas e Fusão Nuclear, Universidade de Lisboa, Lisbon, Portugal

*mohamadzade.zahra34@tecnico.ulisboa.pt

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Motivation

- ✦ Attosecond Pulses: Gateway to the Subatomic Frontier, Revealing Electron Dynamics,
- ✦ Exciting Applications: From Ultrafast Phenomena to Nuclear Physics, Biomolecular Studies, and Astrophysics,
- ✦ Challenge: Low-Intensity Attosecond Pulses; Strongest Ultrashort Pulses Generated is located Inside Plasma,
- ✦ Overcoming Limitations: Enhancing Reflectivity and Proposing Experimental Setups Relevant to Modern Laser Facilities.

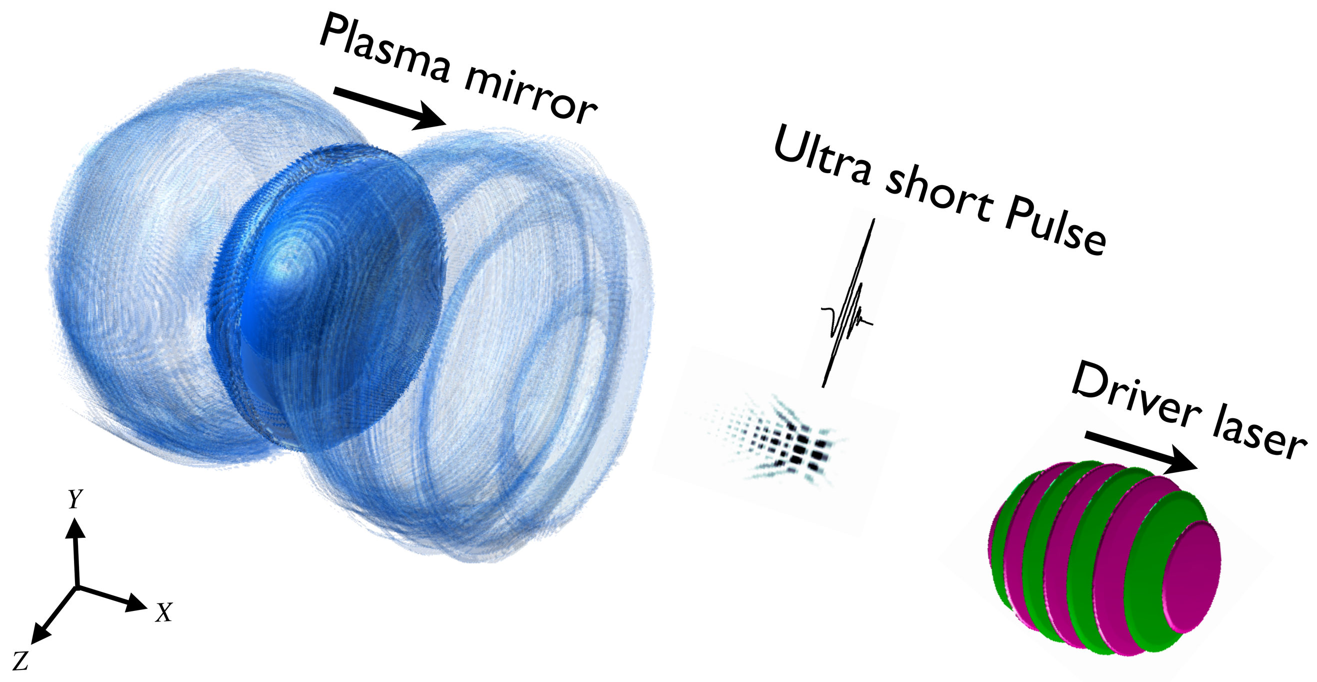

Figure 1: Schematic of Ultrashort Pulse Generation via the Flying Mirror: A driver laser excites a relativistic electron layer in underdense plasma. The source pulse reflects from this layer and is compressed to attosecond duration by the double Doppler effect.

Reflection Coefficient o Relaativistic plasma mirror

➡Reflection coefficient for flat top density profile [2]:

$$R_{flat} = \frac{E_r}{E_0} = \gamma^2(1+\beta)^2 \times \frac{\omega^2_{cut-off}}{(2\omega_0^2 - \omega^2_{cut-off}) + 2i\chi\omega_0^2 \cot(\chi\gamma^2(1+\beta)k_0 l_{mirror})}$$

➡and where density profiles become Dirac delta functions:

$$R_{dirac} = -\frac{\gamma^2(1+\beta)^2}{1 - \frac{2\, i\, \gamma\, \omega_0}{k_0\, l_{mirror}\, \omega^2_{pmax}}}$$

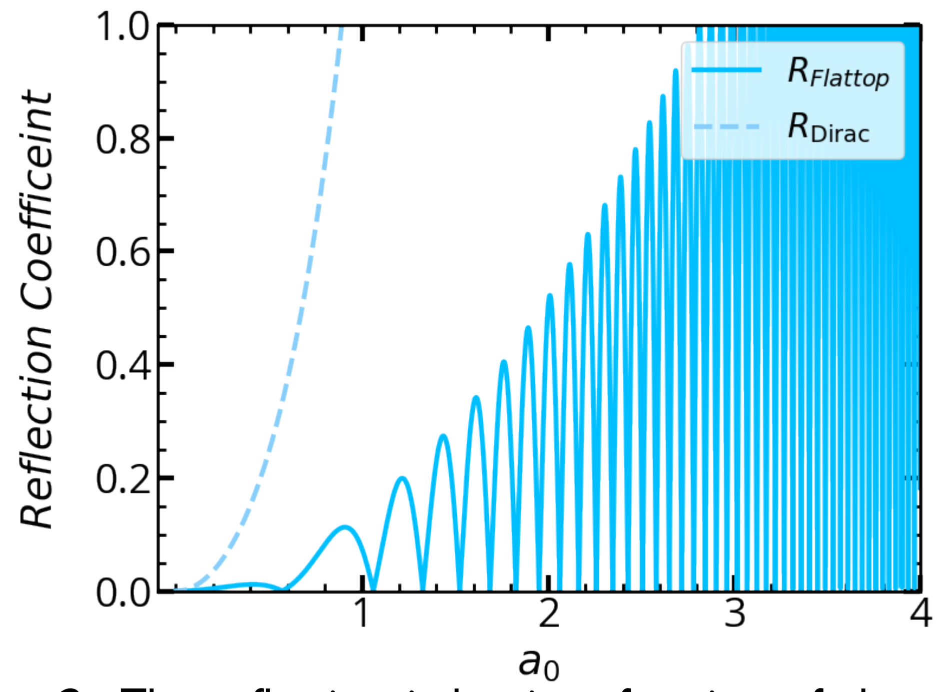

Figure 2: The reflection index is a function of the gamma factor, mirror density and thicness, all of which depend on a_0.

Employing Circularly Polarized vs. Linearly Polarized as Driver Pulse

Osiris

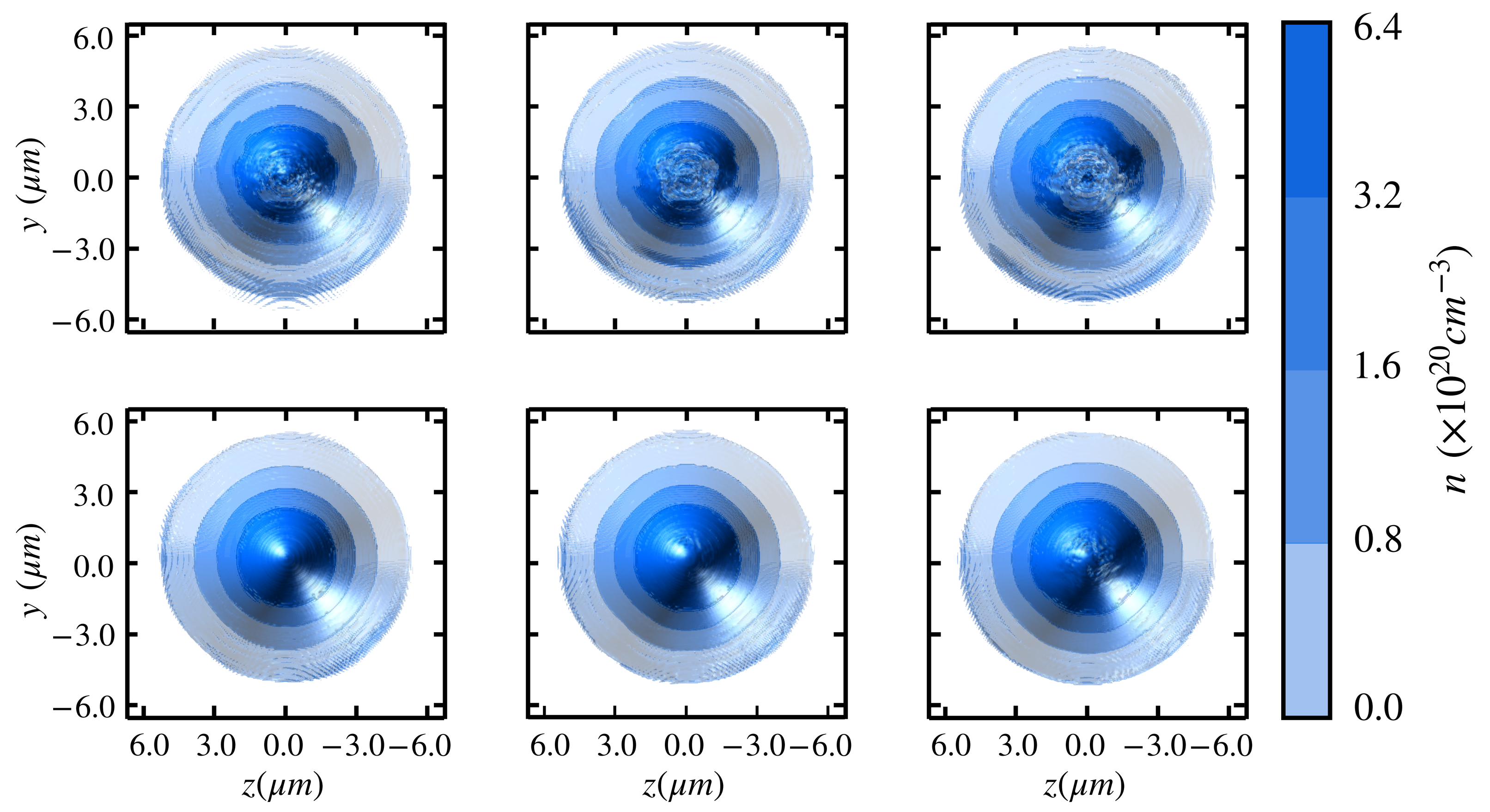

Figure 3::3D density profile of the relativistic electron layer driven by a laser pulse with linear (top) and circular (bottom) polarization, viewed from the mirror front. Circular polarization produces a cleaner and more stable mirror, resulting in up to tenfold higher efficiency.

	LP		CP
	$\tau_r = 550\ as$		$\tau_r = 400\ as$
LP	$I_r/I_s = 1.4$	CP	$I_r/I_s = 56.2$
	$\gamma \sim 2.6$		$\gamma \sim 3$

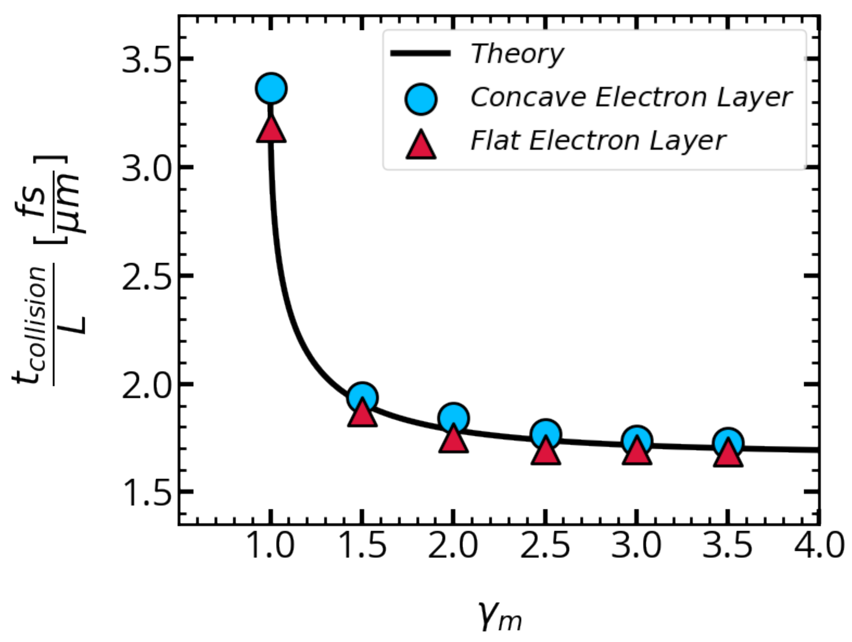

Figure 4: OSIRIS simulations confirm our theoretical prediction of ultrashort electron layer separation times. The collision time is dependent to the gamma factor of mirror and the length of source pulse.

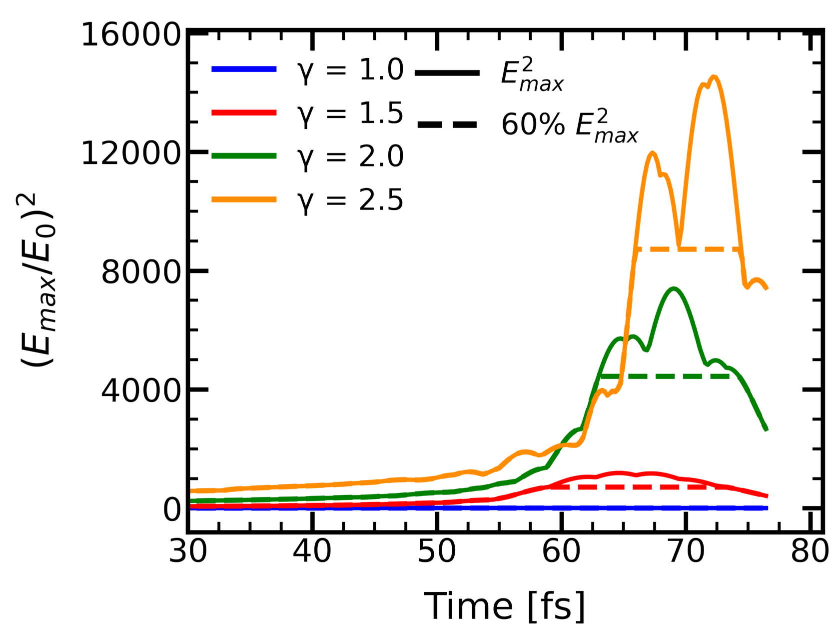

Figure 5: In relativistic mirrors, the focal point expands in addition to the relativistic Doppler shift. The results from OSIRIS simulations for different mirror velocities are in good agreement with our theoretical predictions.

$$t_{collision} = \frac{L}{c}\frac{1}{(1+\beta)}$$

$$f_1 = f(1+\beta)$$

$$f_2 = f(1+\beta) + \frac{L\beta}{1+\beta}$$

➡Harmony between plasma density, driver pulse spot size and time duration, and also a_0 are important to achieve a stable mirror [3, 4]:

$a_0 \simeq 3$	$W_d = 6\lambda$
$n_p = 0.01\ n_{cr}$	$P \simeq 6.7\ TW$
$\tau_d = 6T$	$\lambda_d = 0.75\ \mu m$

Conclusions

- ✦ Employing a circularly polarized laser pulse as the driver in the bubble regime, supported by modern laser facilities, provides excellent uniformity and higher density, resulting in a stronger ultrashort pulse.
- ✦ OSIRIS simulations fully confirm our theoretical predictions on collision time and identify the optimal position for capturing a strong attosecond pulse.
- ✦ This achievement paves the way for significant advancements in experimental research, ultrafast science, subatomic physics, and astrophysics.

References

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[3] L. O. Silva et al., Comptes Rendus Physique, 10, 167-175 (2009).
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