PhD Open Days

*chamzkoti.zahra34@tecnico.ulisboa.pt

Towards Efficient Generation of Intense Ultrashort Pulses via Plasma

Zahra M. Chamazkoti*, L. O. Silva

Motivation

- ✦ Attosecond pulses open access to the subatomic frontier, enabling the observation of electron dynamics.
- ✦ Applications: from ultrafast phenomena to nuclear physics, biomolecular studies, and astrophysics.
- ✦ Challenge: low intensity; the strongest ultrashort pulses are generated within plasma.
- ✦ Findings: enhance plasma mirror reflectivity and identify the optimal capture point for detecting high-intensity attosecond pulses in modern laser facilities.

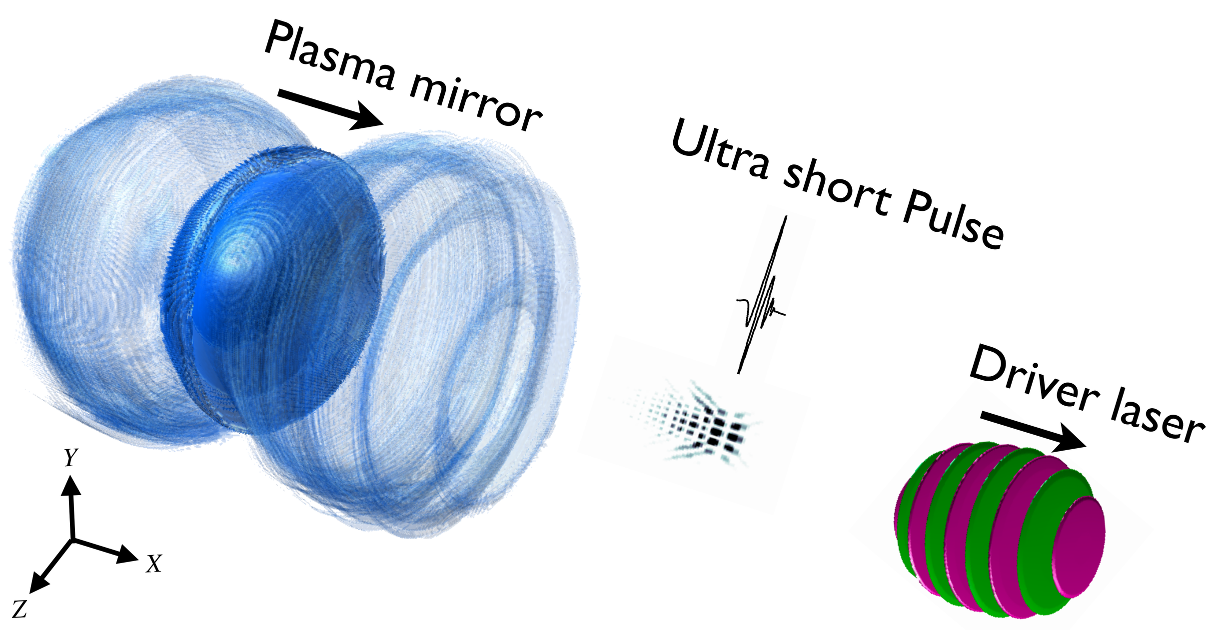

Figure 1: Schematic of Ultrashort Pulse Generation via the Flying Mirror: A driver laser excites a relativistic electron layer in underdense plasma. The source pulse reflects from this layer and is compressed [1] to attosecond duration by the double Doppler effect.

What Is the Reflection Coefficient of a Relativistic Plasma Mirror?

Reflection coefficient for flattop, parabolic and Dirac delta density profile:

$$R'_{flat} = \frac{\Gamma^2\omega^2_{\text{cut-off}} - \omega^2_{p0}}{\Gamma^2\left(2\omega_0^2 - \omega^2_{\text{cut-off}}\right) - \omega^2_{p0} + 2i\chi\, n\sqrt{1 - \frac{\omega^2_{p0}}{\Gamma^2\omega_0^2}}\,\Gamma^2\omega_0^2\cot\left(\chi\, n\gamma^2(1+n\beta)k_0\, l\right)}$$

$$R'parabolic = 1 - \frac{F\left(\frac{\mu'_+}{4}\right)}{F\left(\frac{\mu'_+}{4}\right) - i\frac{l'k'_b}{2}G\left(\frac{\mu'_+ + 2}{4}\right)} + \frac{F\left(\frac{\mu'_+}{4}\right) - \mu'_+ G\left(\frac{\mu'_+}{4}+1\right)}{\mu'_+ G\left(\frac{\mu'_+}{4}+1\right) - F\left(\frac{\mu'_+}{4}\right) + i\left[\frac{l'k'_b}{2}G\left(\frac{\mu'_+ + 2}{4}\right) + \frac{\omega'_0 n'}{\Delta}F\left(\frac{\mu'_+ + 2}{4}\right)\right]}$$

$$R'_{dirac} = -\frac{1 - \frac{\omega^2_{p0}}{\omega^2_{p\,\max}}}{1 + \frac{\omega^2_{p0}}{\omega^2_{p\,\max}} - \frac{2i\sqrt{1 - \frac{\omega^2_{p0}}{\Gamma^2\omega_0^2}}(1+n\beta)\,\omega_0^2}{k_0\, l\,\omega^2_{p\,\max}}}$$

$$R = R'\gamma^2(1+n\beta)^2$$

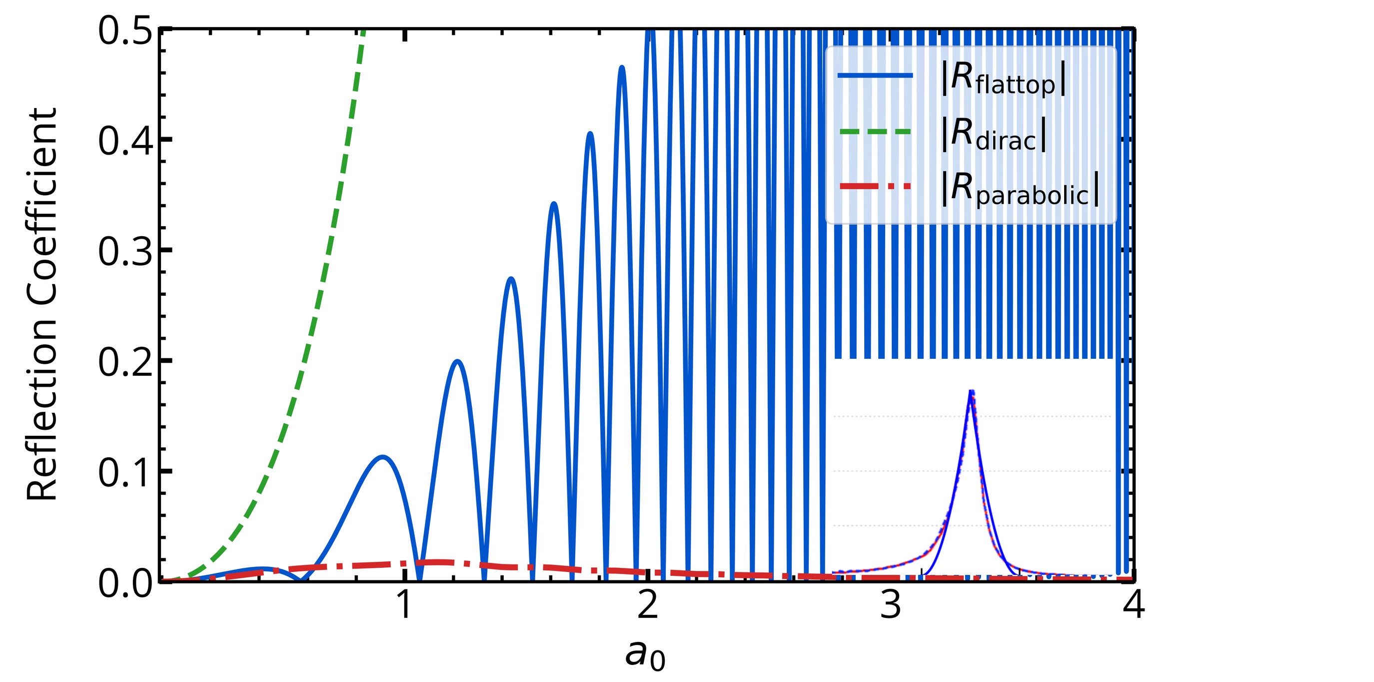

Figure 2: Reflection Coefficient as a function of a_0 for three density profiles. Osiris Simulations [2] indicate the driven plasma mirror exhibits a parabolic density profile.

Which Strategies Can Improve Plasma Mirror Efficiency?

Osiris

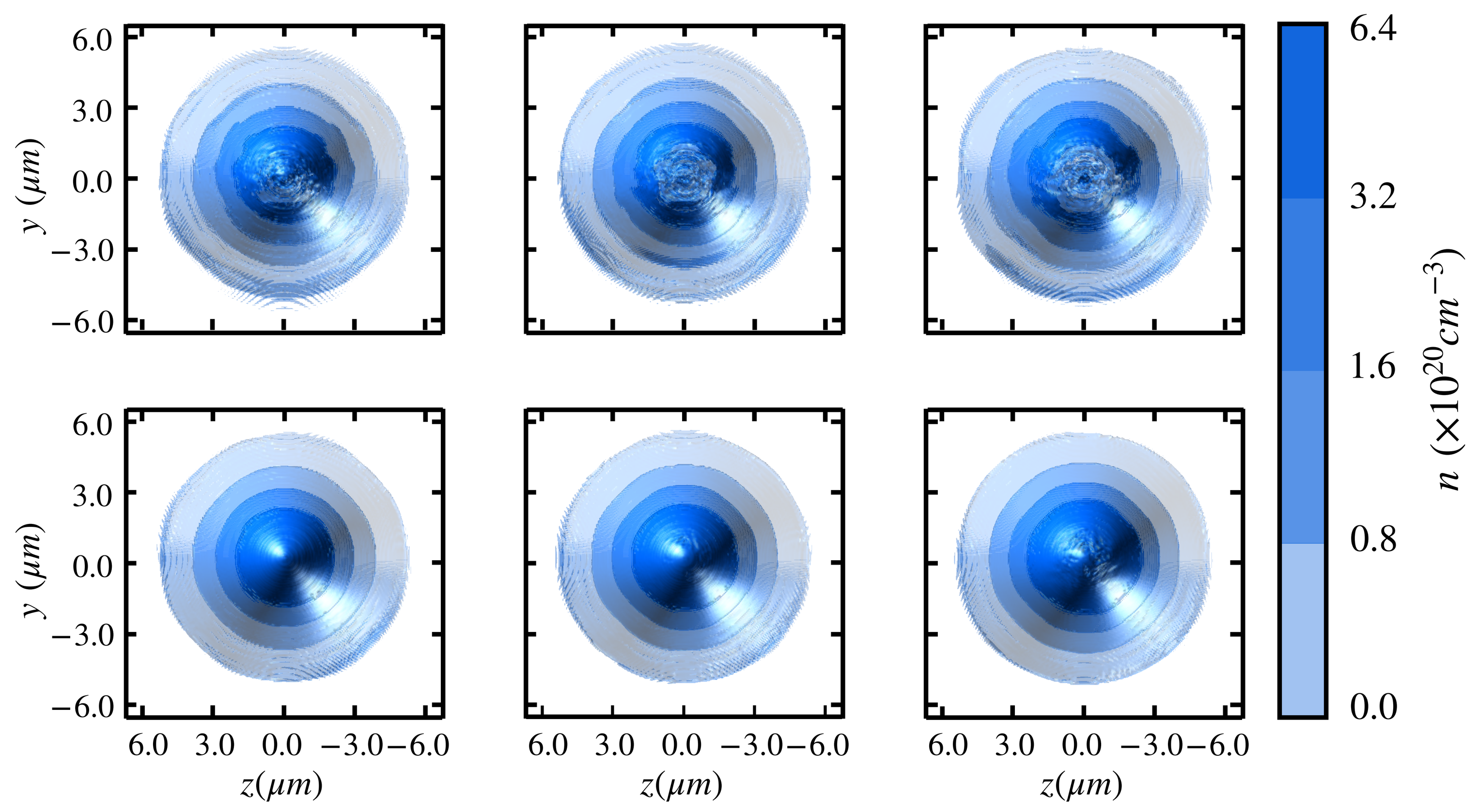

Figure 3: 3D density profile of the driven plasma mirror from OSIRIS simulations with linear (top) and circular (bottom) polarization, viewed from the mirror front. Circular polarization produces a cleaner and more stable mirror, leading to up to thirtyfold higher efficiency.

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

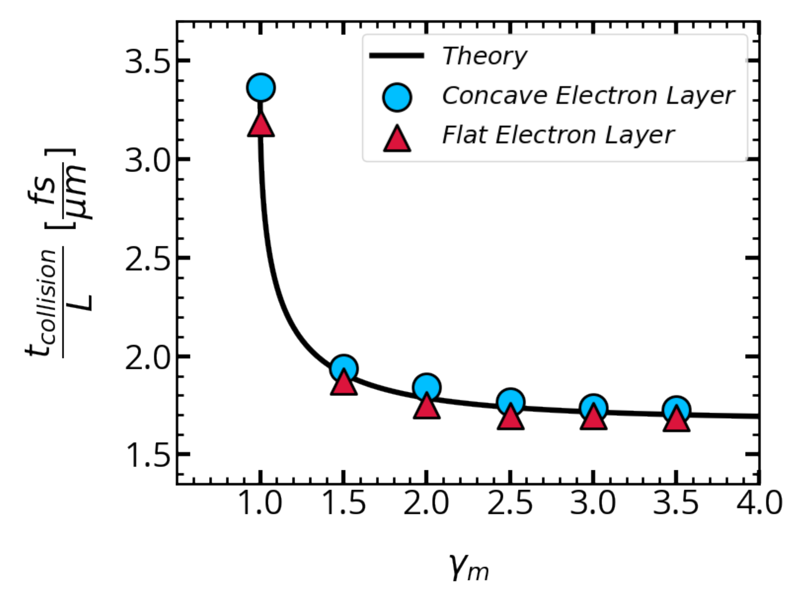

Figure 4: OSIRIS simulations confirming our theoretical prediction that the ultrashort electron-layer detachment time $t_{collision} = L/c(1+\beta)$ depends on the mirror velocity and source pulse duration.

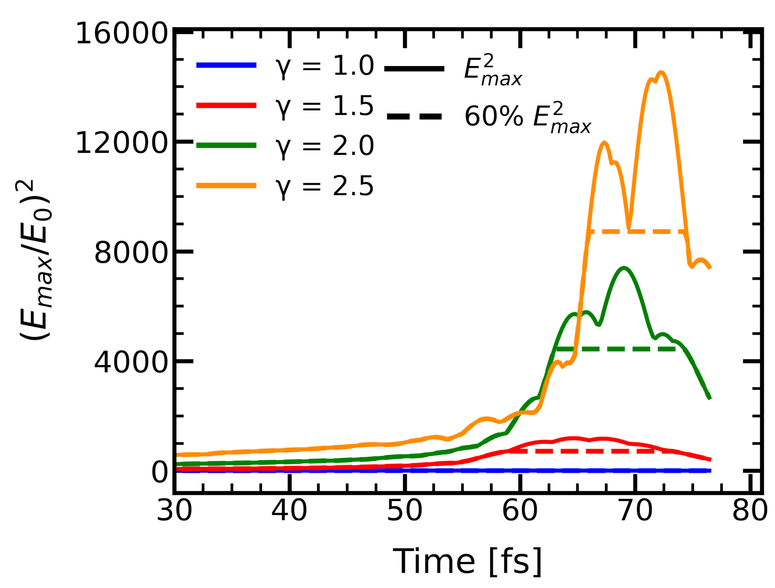

Figure 5: The focal spot shifts due to the relativistic motion of the mirror and expands over the $f_1 = f(1+\beta)$ and $f_2 = f_1 + L\beta/(1+\beta)$ ranges. OSIRIS simulations for various mirror velocities show excellent agreement with our theoretical predictions.

➡Harmony between plasma density, driver pulse spot size and time duration, and a_0 are important to achieve a stable mirror [2, 3]:

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

Conclusions

- ✦ Using a circularly polarized laser pulse in the bubble regime, achievable with modern laser facilities, ensures excellent density uniformity and leads to an ultrashort pulse with an enhancement on the order of ten.
- ✦ OSIRIS simulations fully confirm our theoretical predictions on collision time and the optimal position for capturing a strong attosecond pulse.
- ✦ This achievement opens the way for further advances in experimental research, ultrafast science, subatomic physics, and astrophysics.

References

[1] A. Einstein, Annalen der Physik, 17.10, 891-921(1905).

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

[3] W. Lu et al. Physical Review Special Topics-Accelerators and Beams, 10, 061301 (2007.)

[4] R. A. Fonseca, et al., in P.M.A. Sloot et al., editors, ICCS (2002), LNCS 2331, 342-351 (2002).

This work is supported by the Portuguese FCT– under project UID/50010– Instituto Plasmas e Fusão Nuclear.

TÉCNICO LISBOA

Supervisor: Luís O. Silva
GoLP/INFN, IST

fct Fundação para a Ciência e a Tecnologia

phdopendays.tecnico.ulisboa.pt