Optical Shock-Enhanced Self-Photon Acceleration

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63rd Annual Meeting of the American Physical Society Division of Plasma Physics
Pittsburgh, PA 8–12 November 2021
A photon accelerator driven by a pulse with spatiotemporal and transverse intensity profile shaping generates extreme ultraviolet attosecond pulses

- A “structured flying focus” pulse overcomes the limitations of a conventional photon accelerator

- Velocity control enables a positive feedback loop between intensity self-steepening, sharpening accelerating gradients, and increasing rates of spectral broadening, forming an optical shock

- Multi-octave spectra extending from 400 nm – 60 nm wavelengths, which support near-transform limited 350 as pulses, are generated over 90 μm of interaction length
Photon accelerators increase the frequency of a laser pulse in a moving electron density gradient, but they are limited by dephasing, refraction and diffraction.

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\[ \omega_{max} \propto \sqrt{\frac{\partial n_e}{\partial z}} \]
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[Diagram showing electron density over time and space with \( \omega_{\text{max}} \) proportional to the square root of the gradient of electron density.]
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\[ v_g \]
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2. Diffraction and refraction limit the gradient and its propagation length

Rayleigh length

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2. Transverse intensity control mitigates the effects of diffraction and refraction

T. T. Simpson et al. In Review (2021).

P. Franke et al. Phys. Rev. A 104, 043520 (2021).
2D finite-difference time-domain simulations were used to investigate shaped laser pulses interacting with gas-density plasma.

**Laser parameters:**

- $\lambda_0 = 400\text{nm}$
- $F/# = 6$
- $\tau_{\text{tot}} = 12\text{fs}$
- $E = 53\mu\text{J}$
- $v_f/v_{g0} = 1.015$
- $I = 4.8 \times 10^{16}\text{W/cm}^2$

**Material parameters:**

Nitrogen: $n_{e0} = 4.5\times 10^{20}\text{cm}^{-3}$

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P. Franke *et al.* Phys. Rev. A *104*, 043520 (2021).
The inside pulse is guided over 5 Rayleigh lengths, leading to a concentration of energy in time and space.
Extreme spectral broadening of the pump pulse occurs over only 90 μm of interaction length.
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A 1.3\( \times \) transform limited, focusable, 350 as pulse can be isolated using a 200 nm thick Mg-film (short-pass filter cut on 124 nm)*

*G. D. Tsakiris et al. New J. Phys. 8, 19 (2006).

P. Franke et al. Phys. Rev. A 104, 043520 (2021).
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Summary/Conclusions

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