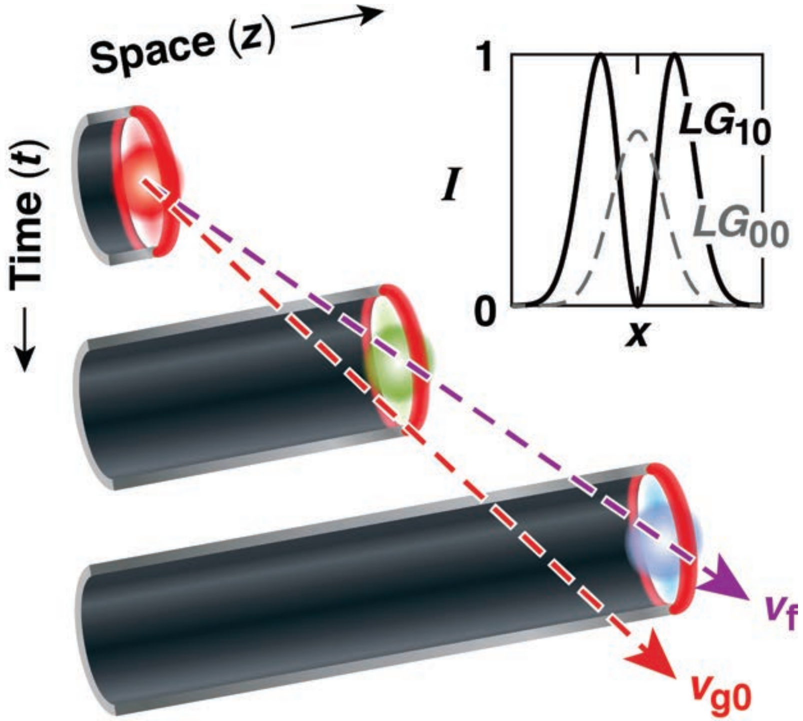
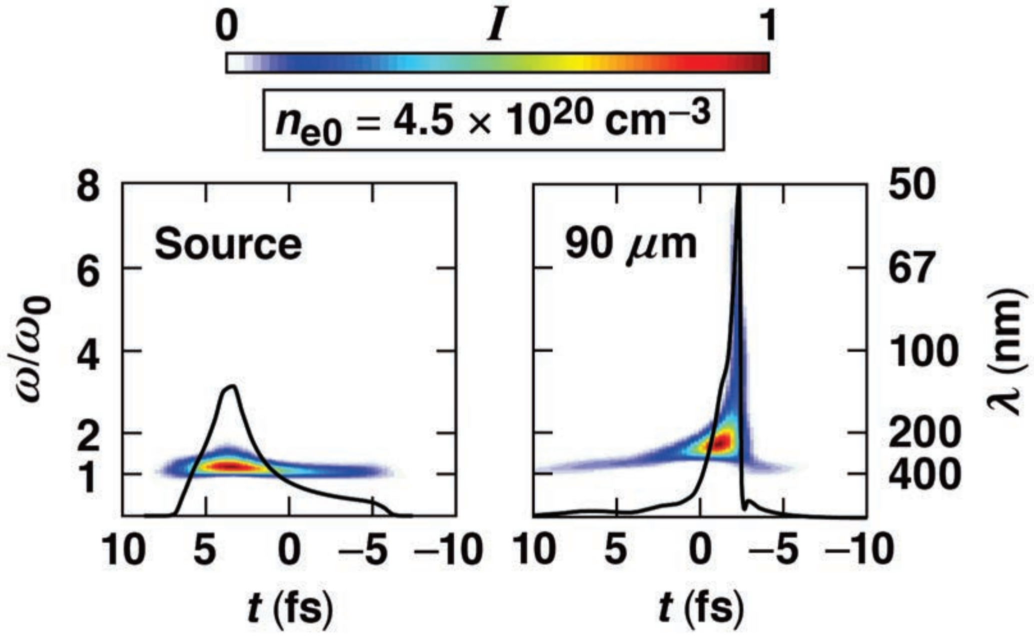
Optical Shock-Enhanced Self-Photon Acceleration





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D. Turnbull, D. H. Froula, and J. P. Palastro
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Division of Plasma Physics
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Summary

A photon accelerator driven by a pulse with spatiotemporal and transverse intensity profile shaping generates extreme ultraviolet attosecond pulses

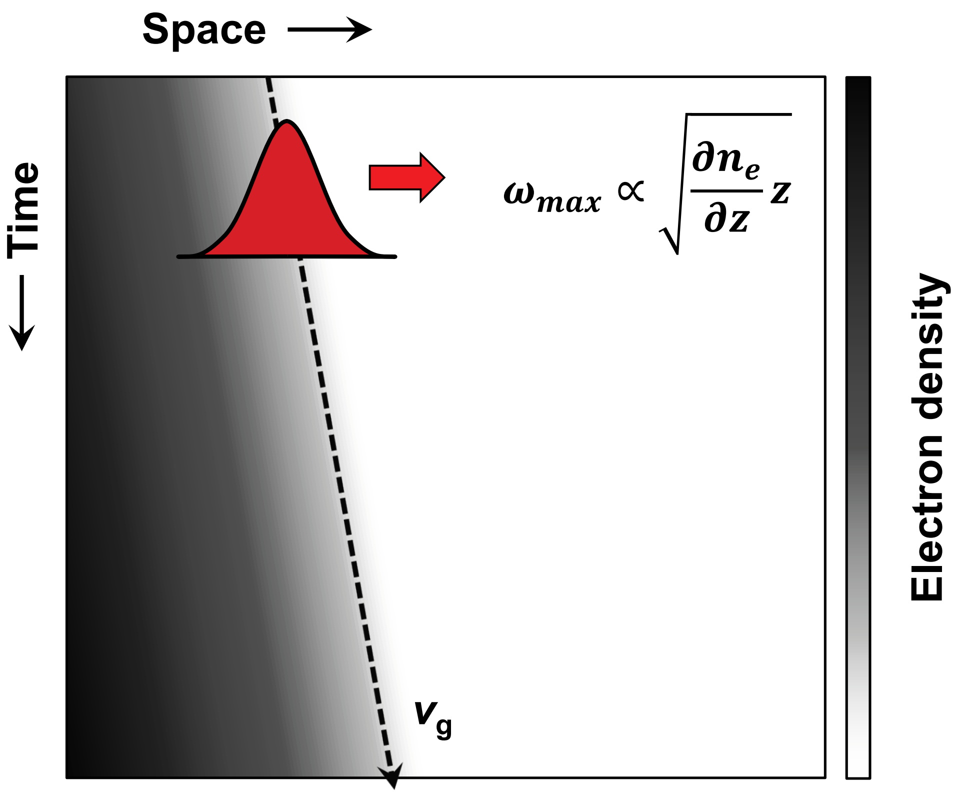
- **A "structured flying focus" pulse overcomes the limitations of a conventional photon accelerator**

- **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

1. Photons outrun the accelerating gradient ("dephasing")



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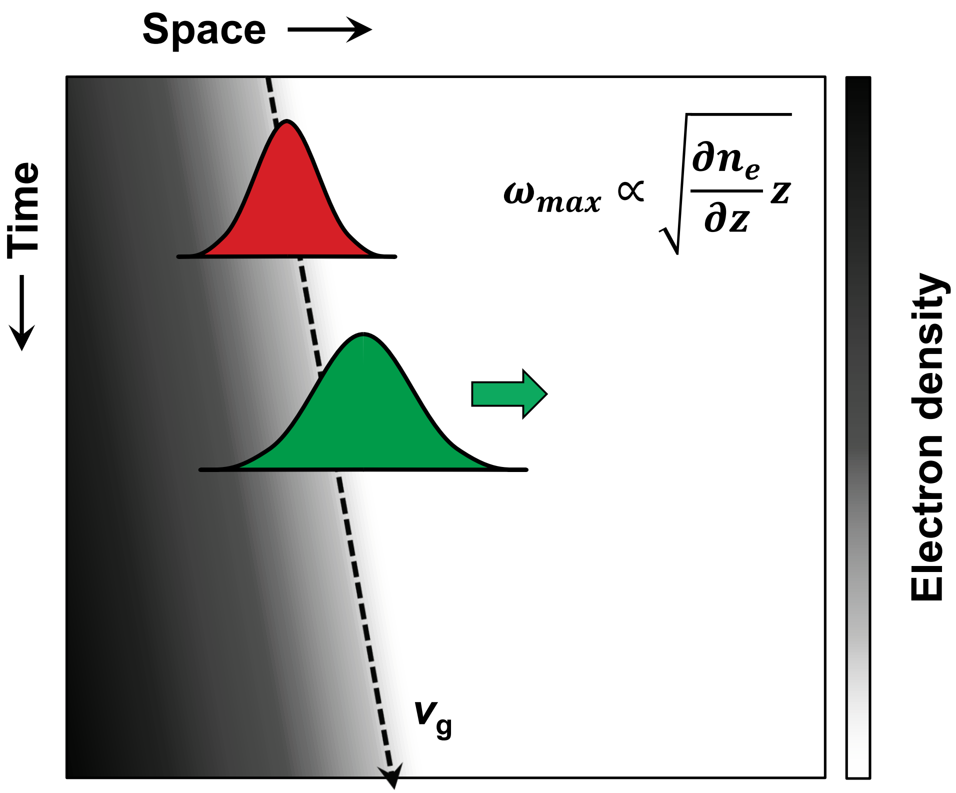

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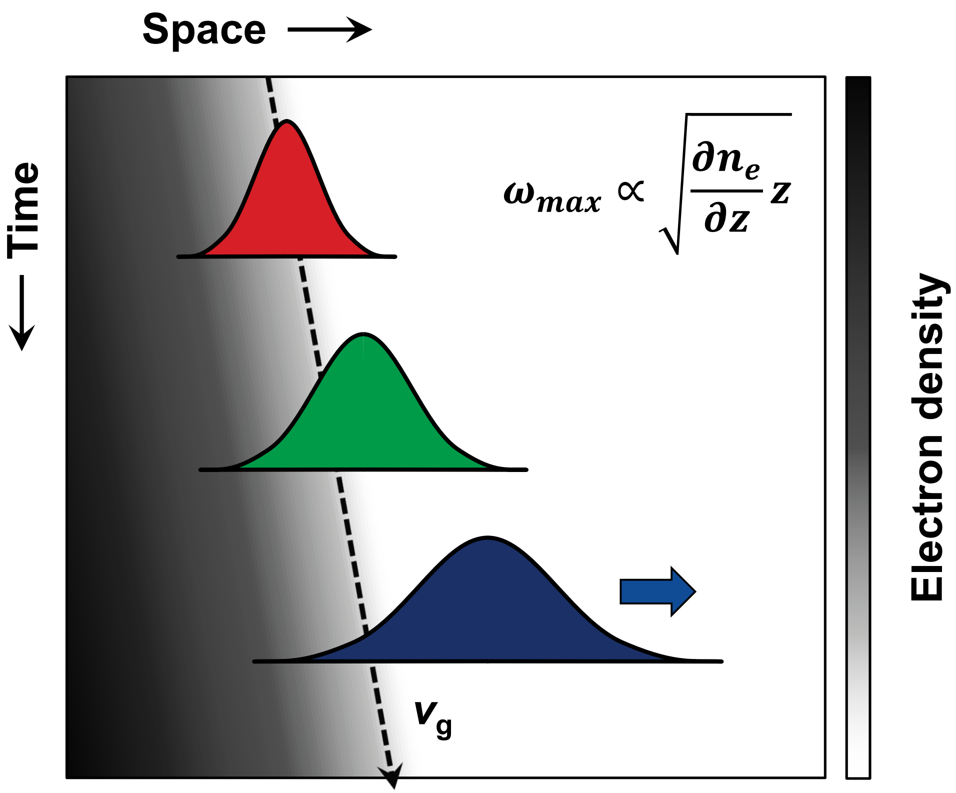

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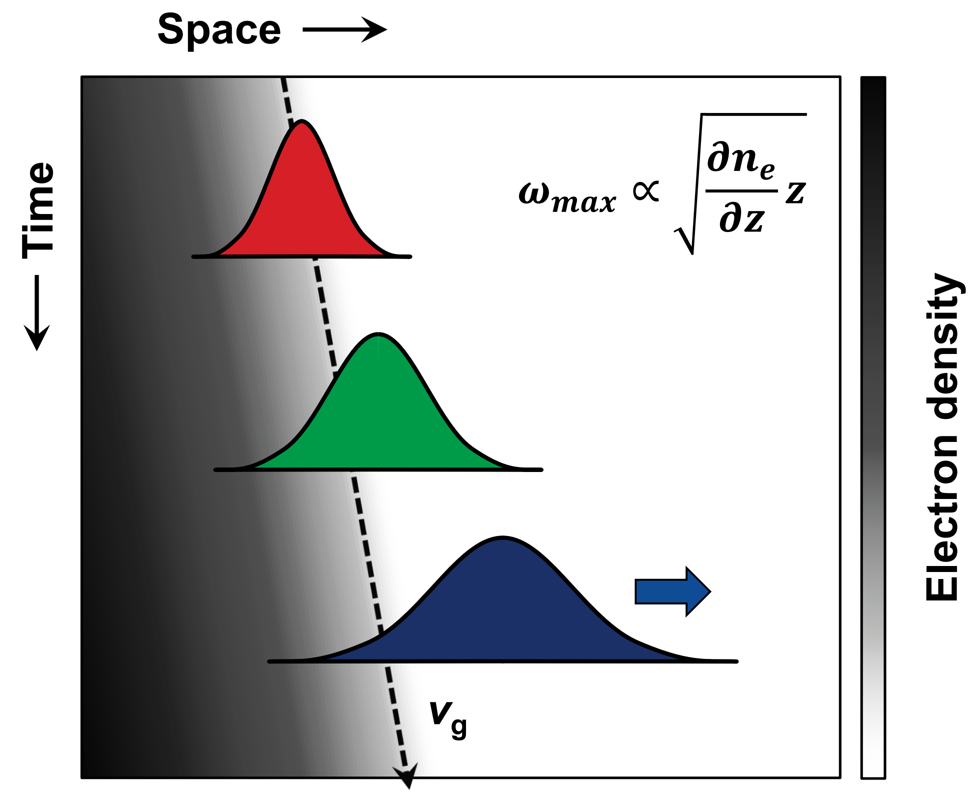
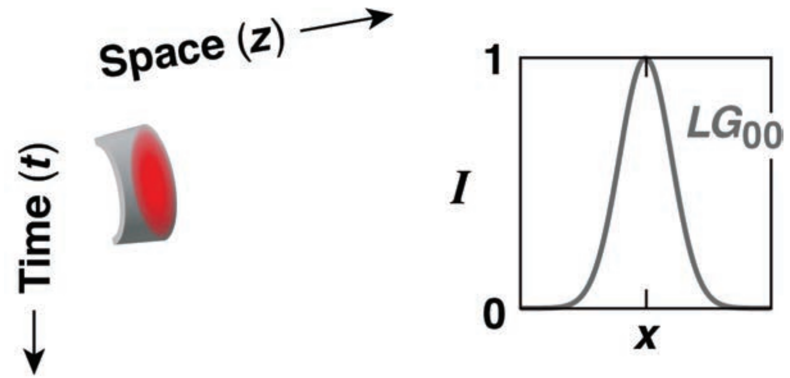


2. Diffraction and refraction limit the gradient and its propagation length

Rayleigh length

$$Z_R = 4\lambda_0 F_{\#}^2/\pi$$



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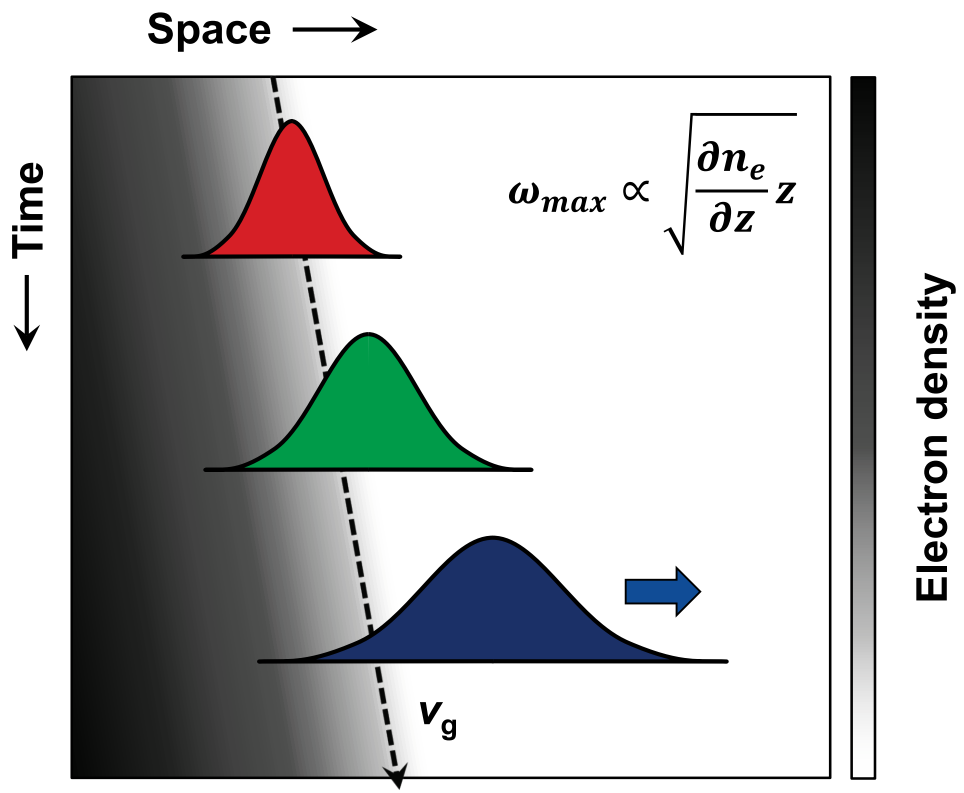

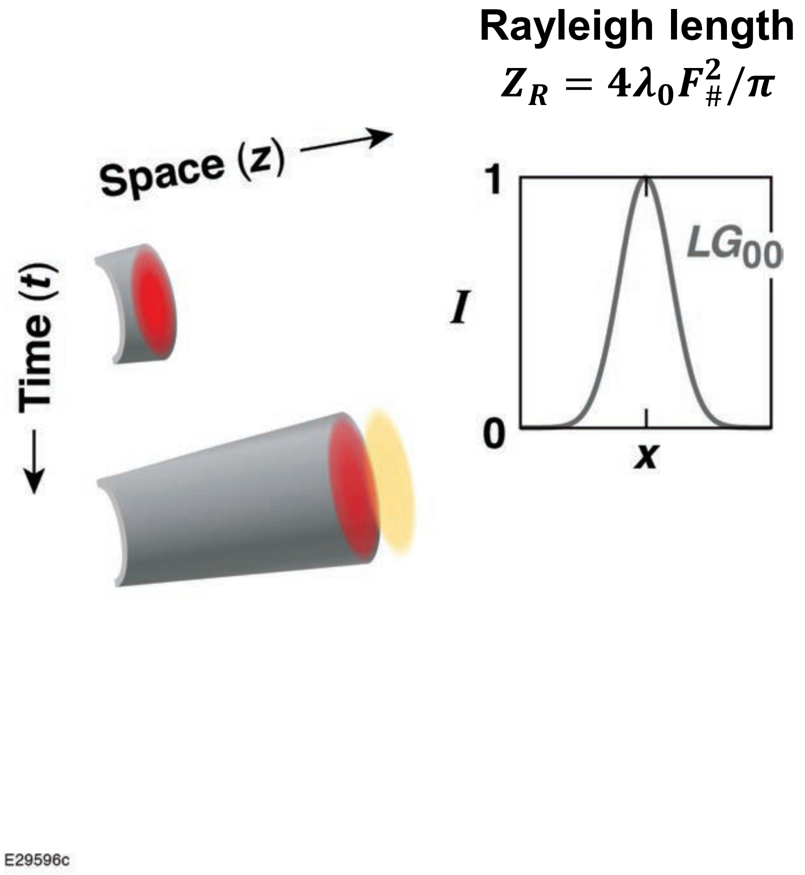

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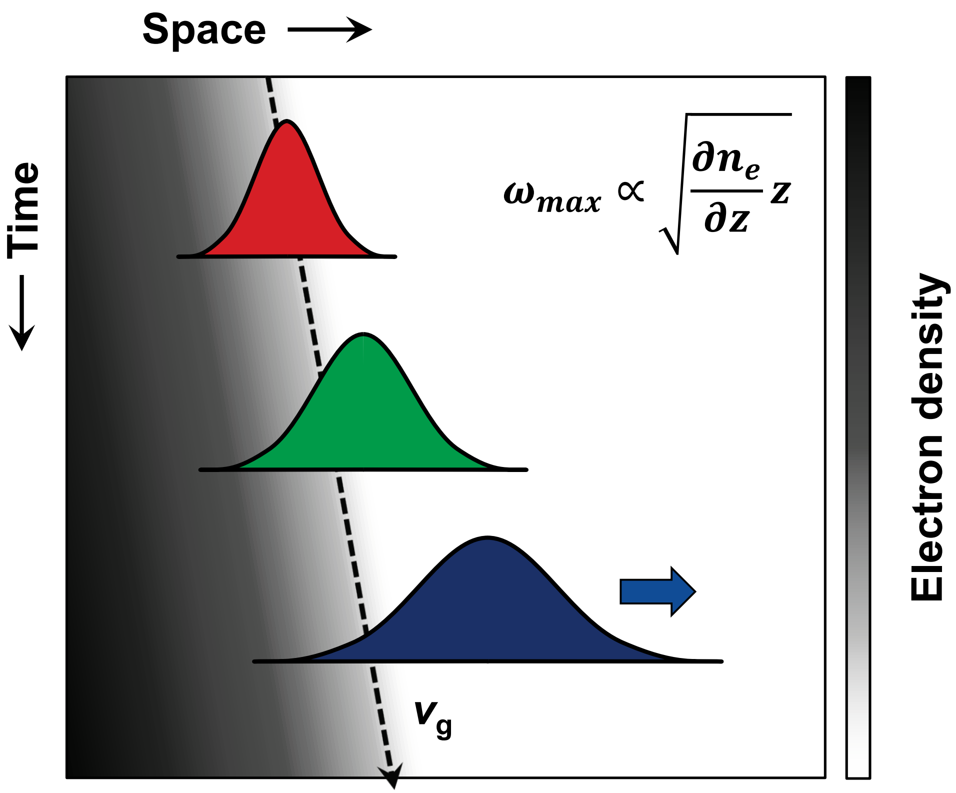

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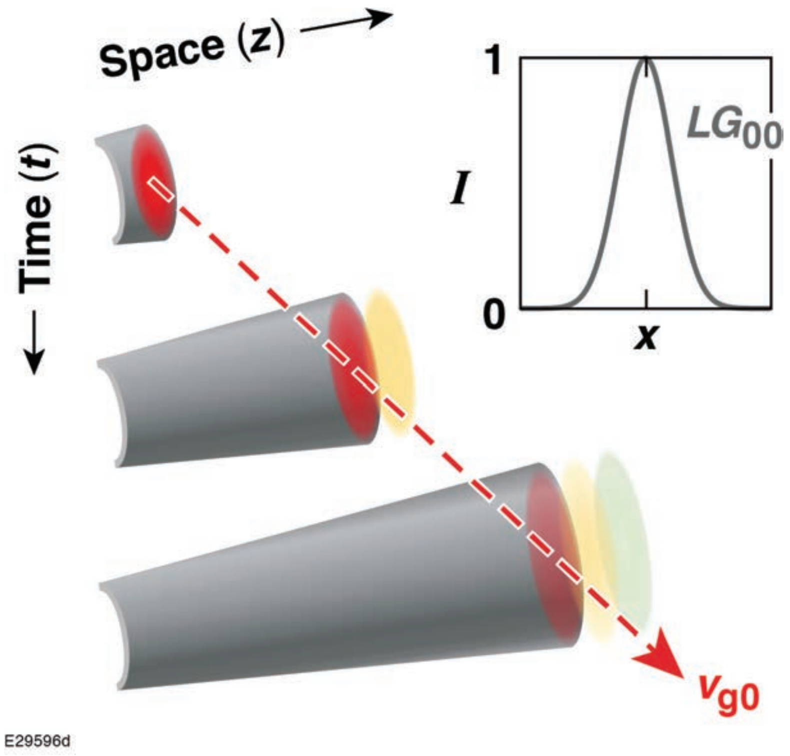
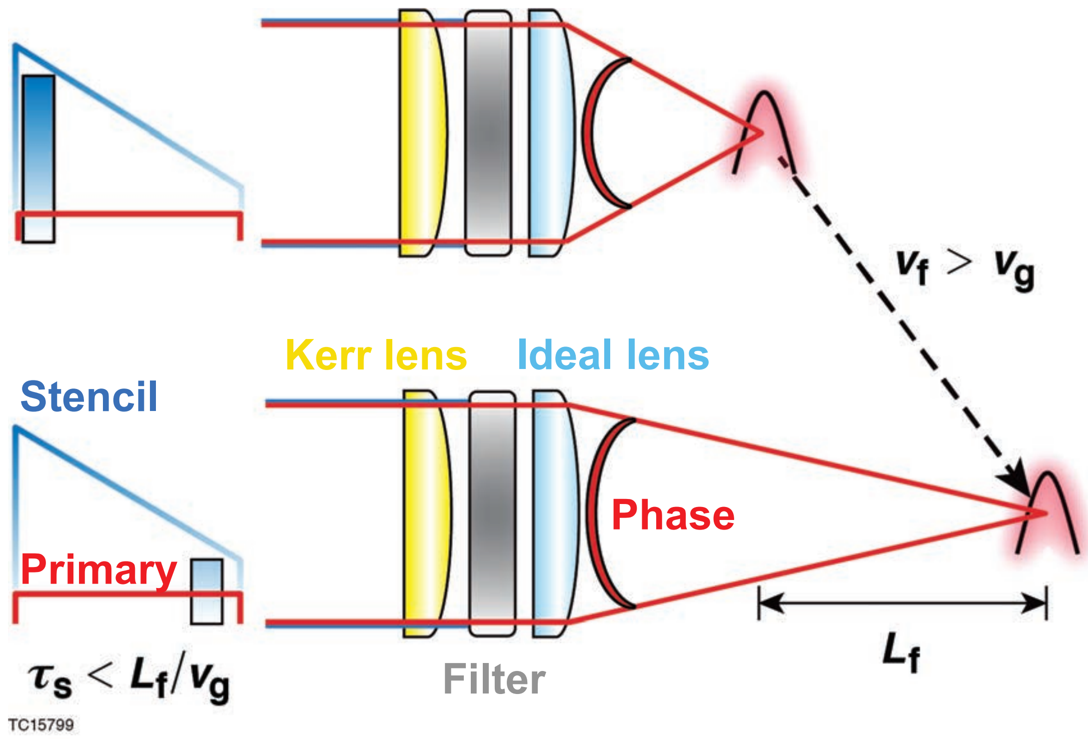


A "structured flying focus" pulse can overcome the limitations of a conventional photon accelerator

1. Spatiotemporal control mitigates the effects of dephasing and diffraction



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

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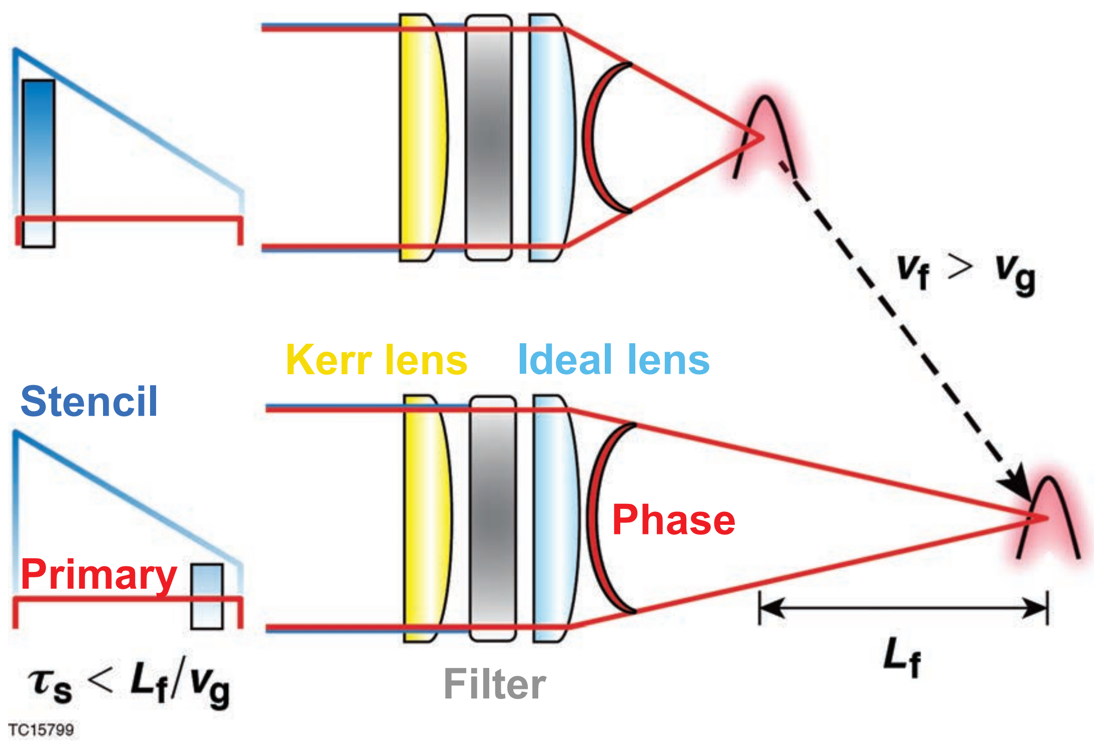
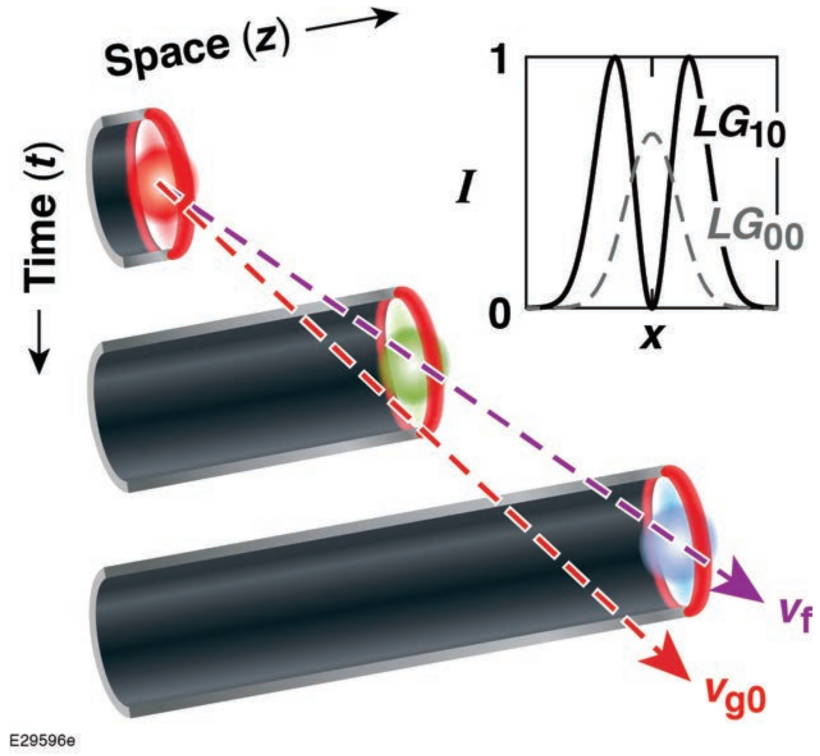


2. Transverse intensity control mitigates the effects of diffraction and refraction



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

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Laser parameters:

$\lambda_0 = 400\text{nm}$

$F/_{\#} = 6$

$\tau_{tot} = 12 \text{ fs}$

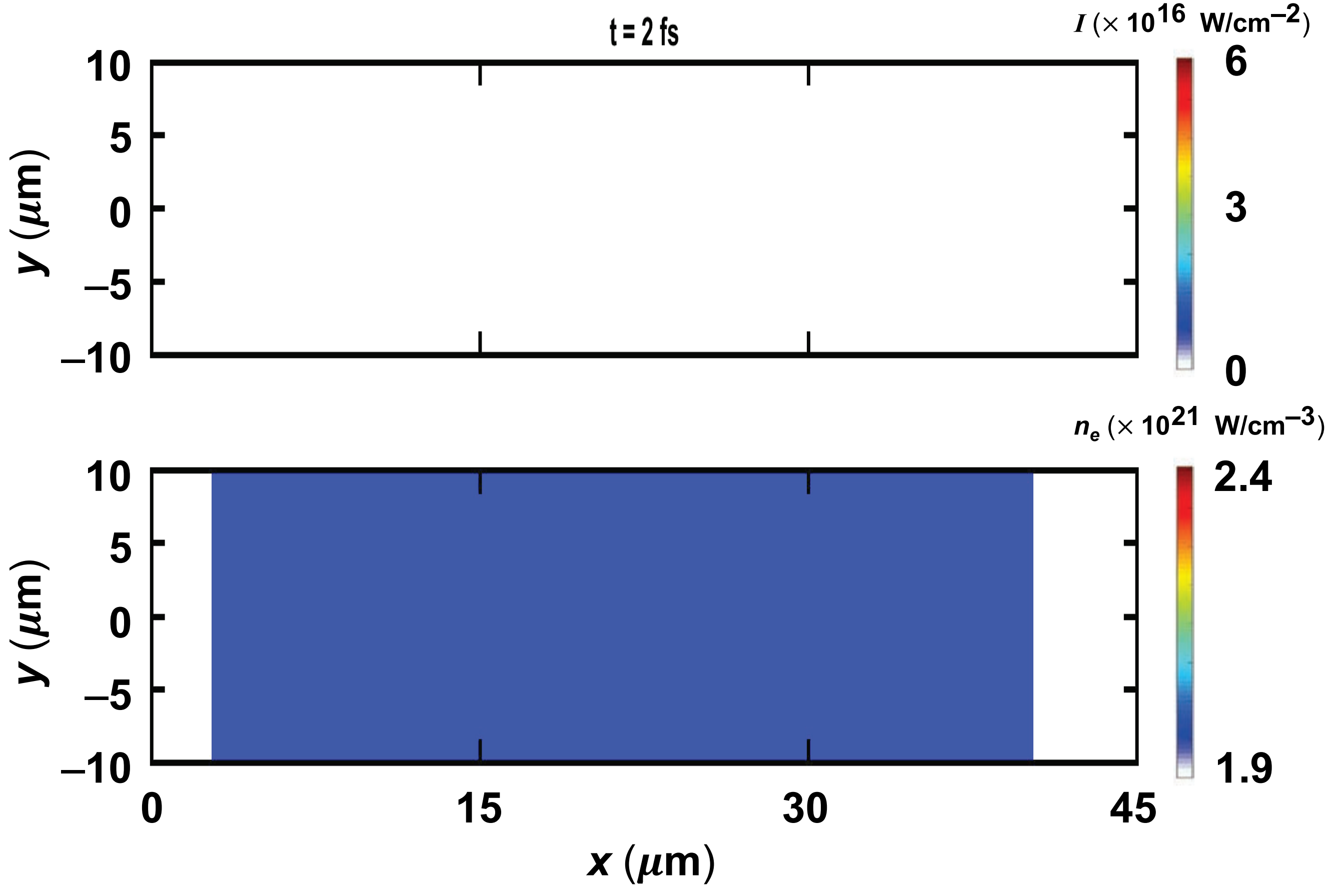
$E = 53\mu J$

$^{v_f}/_{v_{g0}} = 1.015$

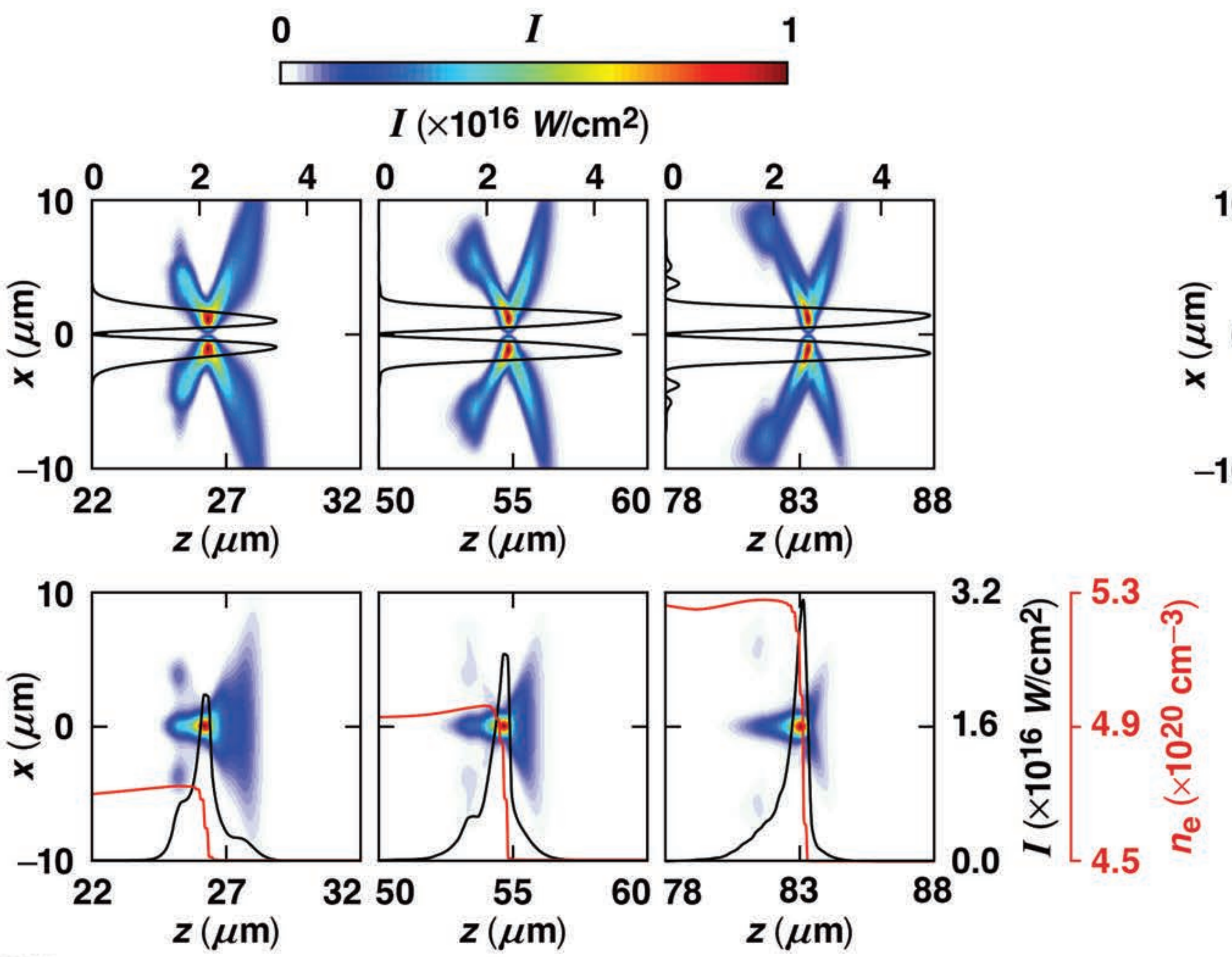
$I = 4.8 \times 10^{16} W/cm^2$

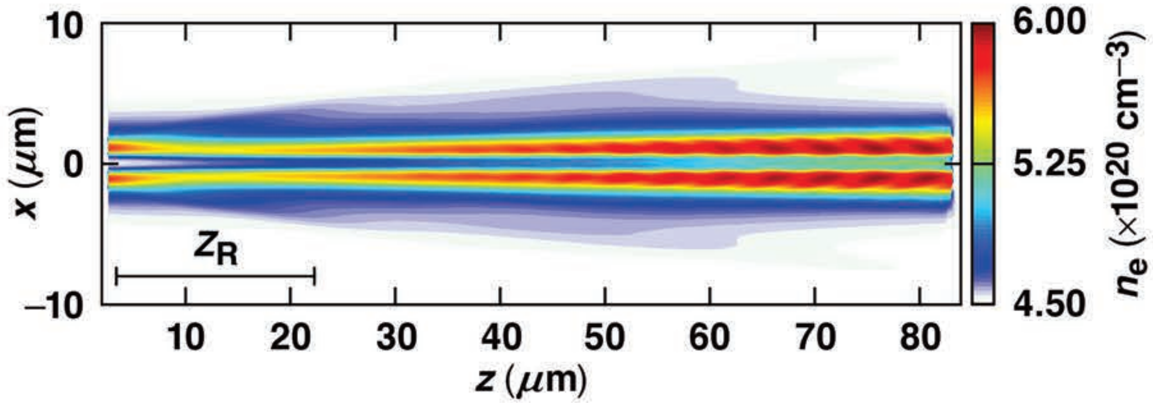
Material parameters:

Nitrogen: $n_{e0} = 4.5e20 \text{ cm}^{-3}$



The inside pulse is guided over 5 Rayleigh lengths, leading to a concentration of energy in time and space





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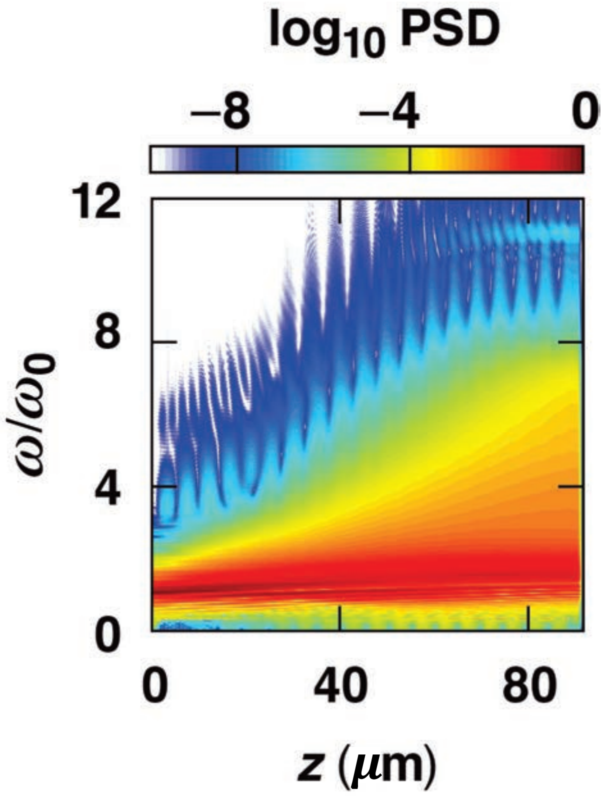
P. Franke *et al.* Phys. Rev. A **104,** 043520 (2021).

Extreme spectral broadening of the pump pulse occurs over only 90 μm of interaction length



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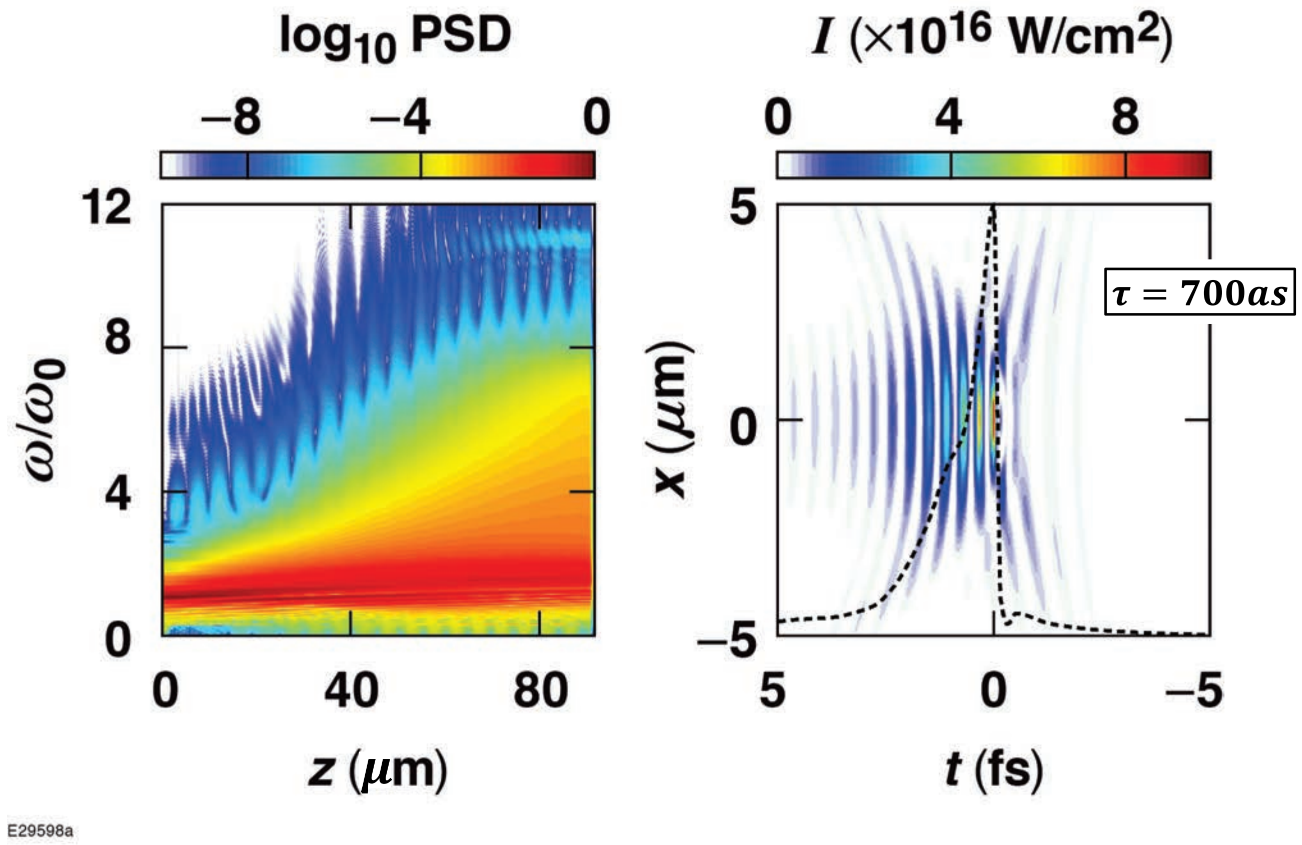

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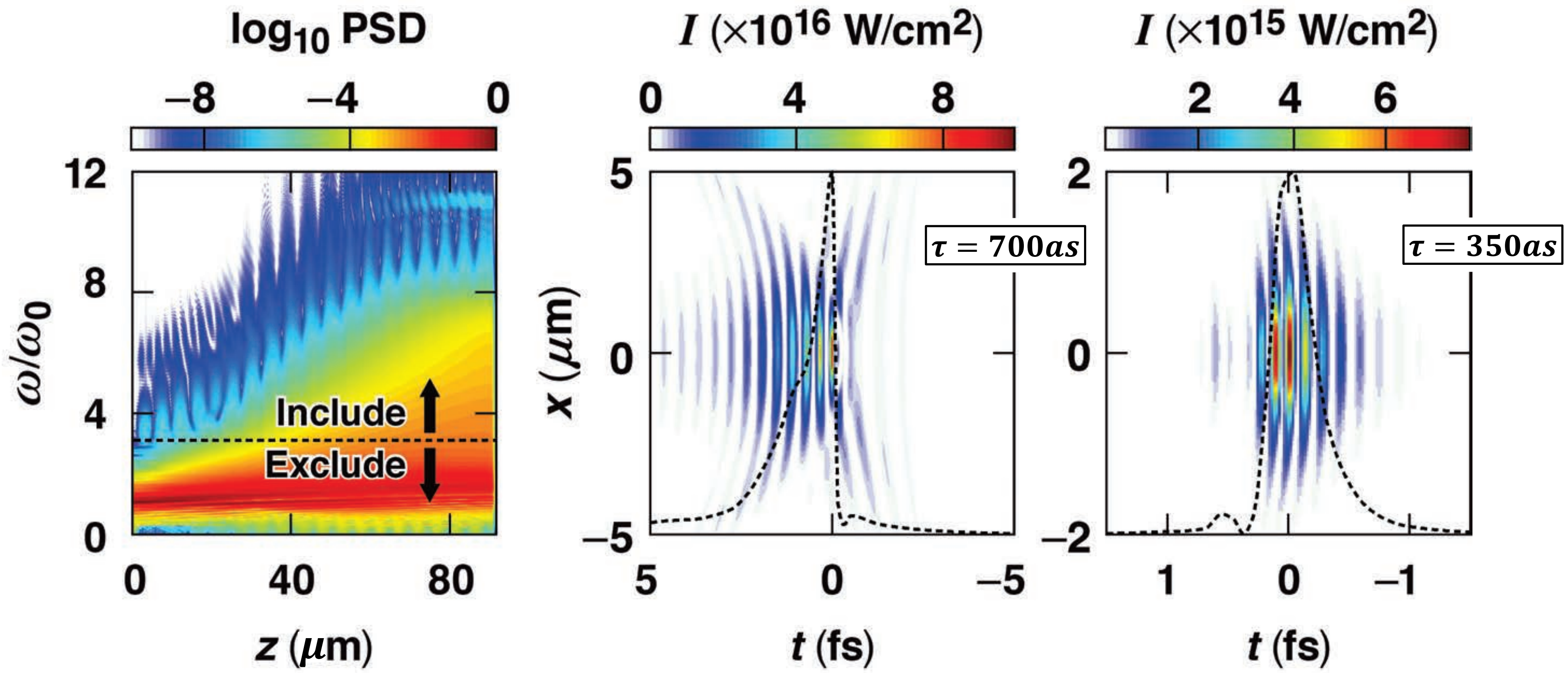
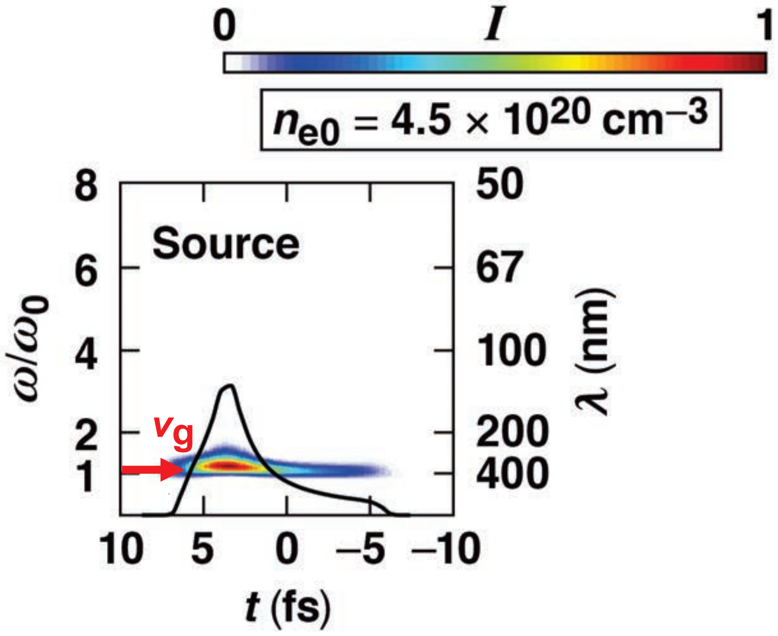


A 1.3× transform limited, focusable, 350 as pulse can be isolated using a 200nm thick Mg-film (short-pass filter cut on 124 nm)*

*G. D. Tsakiris *et al.* New J. Phys. **8**, 19 (2006). P. Franke *et al.* Phys. Rev. A **104,** 043520 (2021).

Photon acceleration, dispersion and velocity control cooperate to self-steepen the pulse, increasing the rate of spectral broadening



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P. Franke *et al.* Phys. Rev. A **104,** 043520 (2021).

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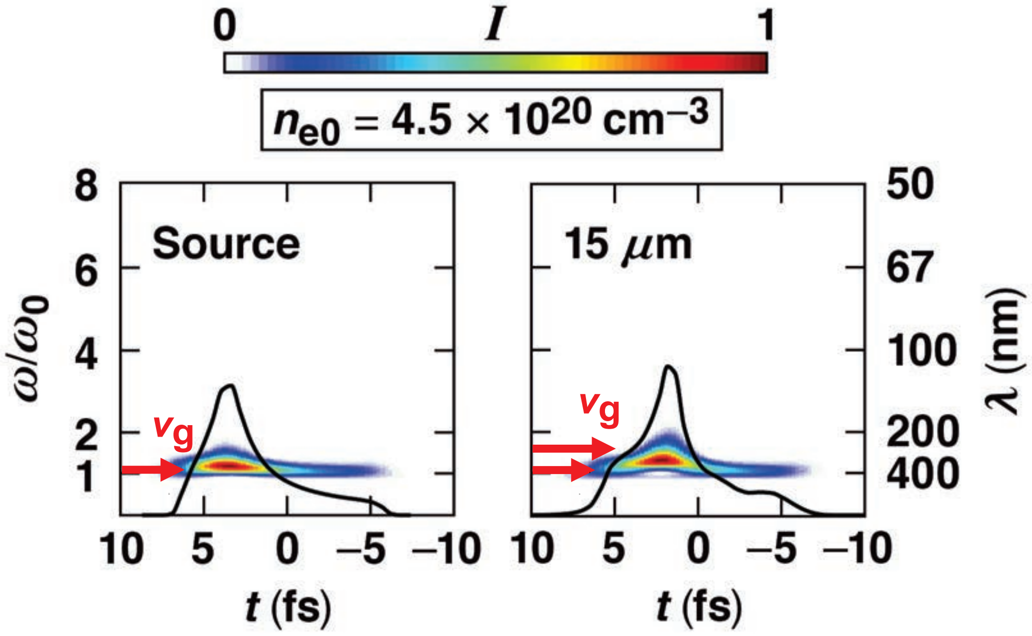

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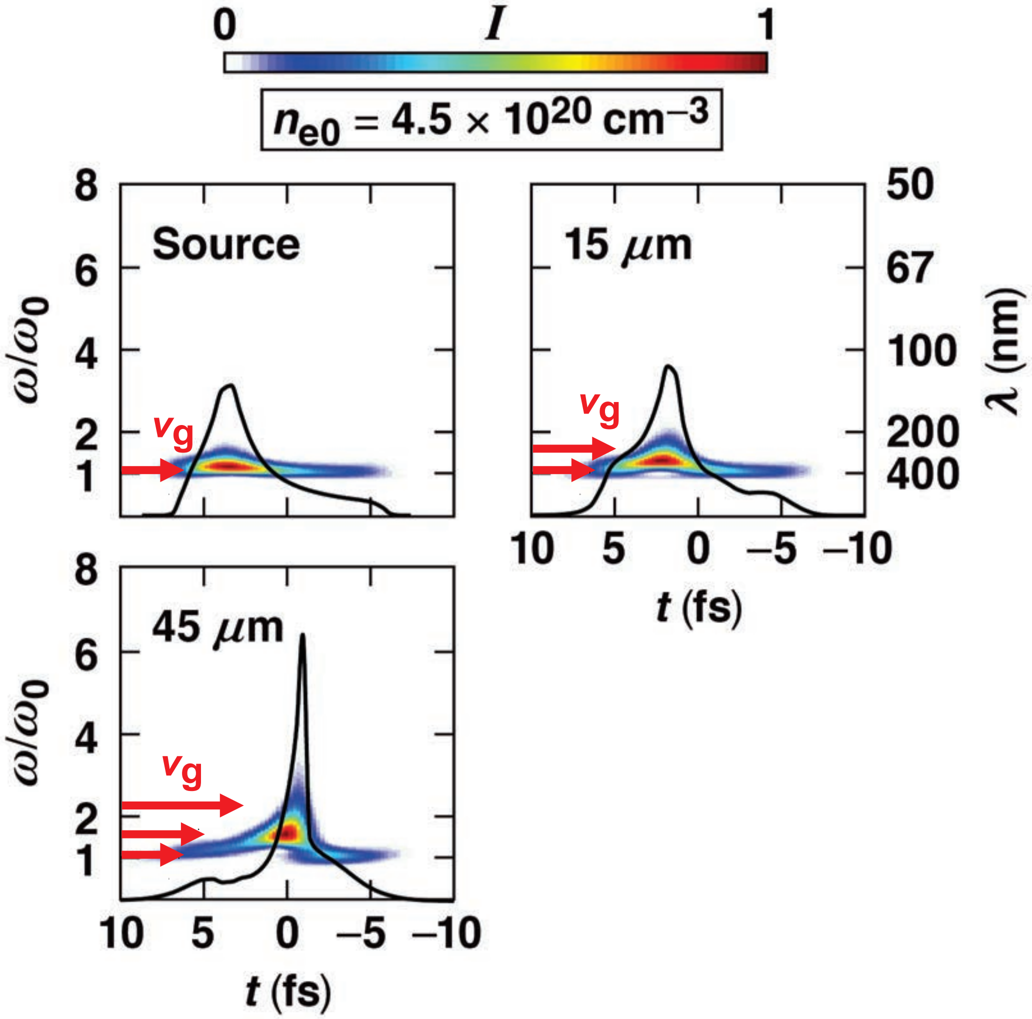

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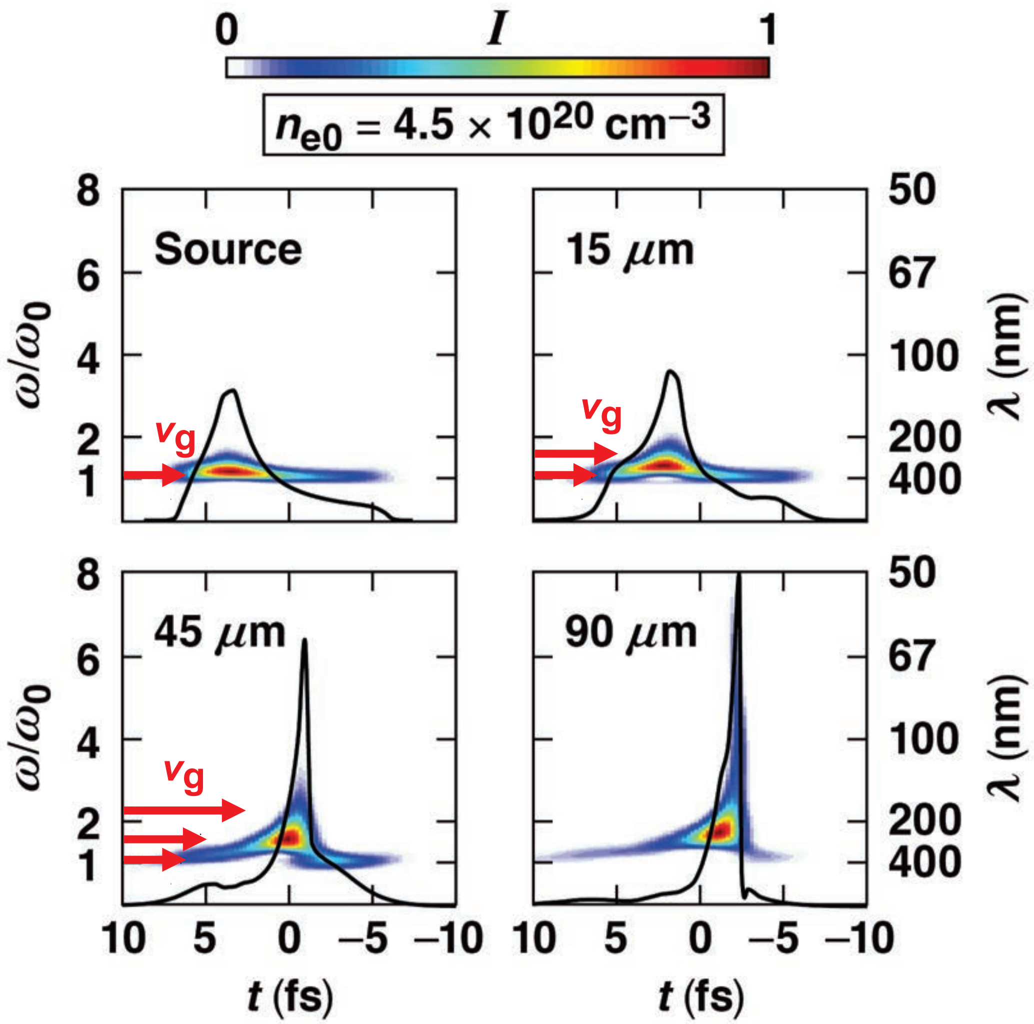

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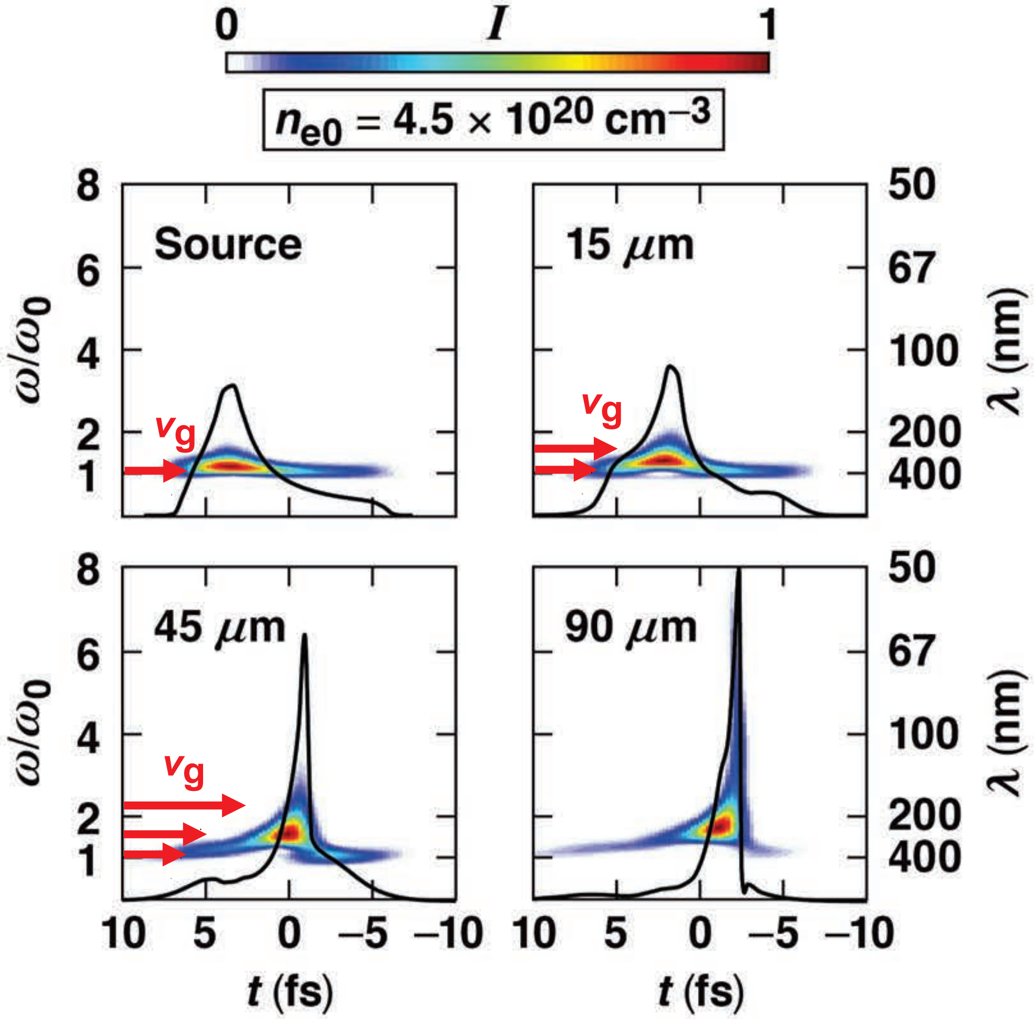

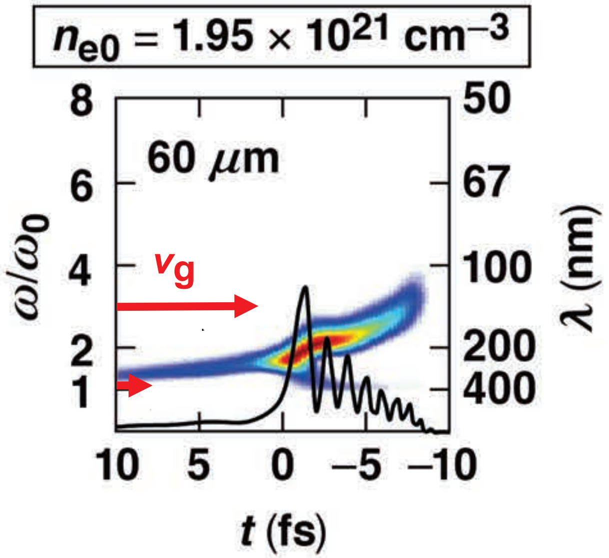

Optical wave-breaking ultimately limits the maximum frequency shift

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