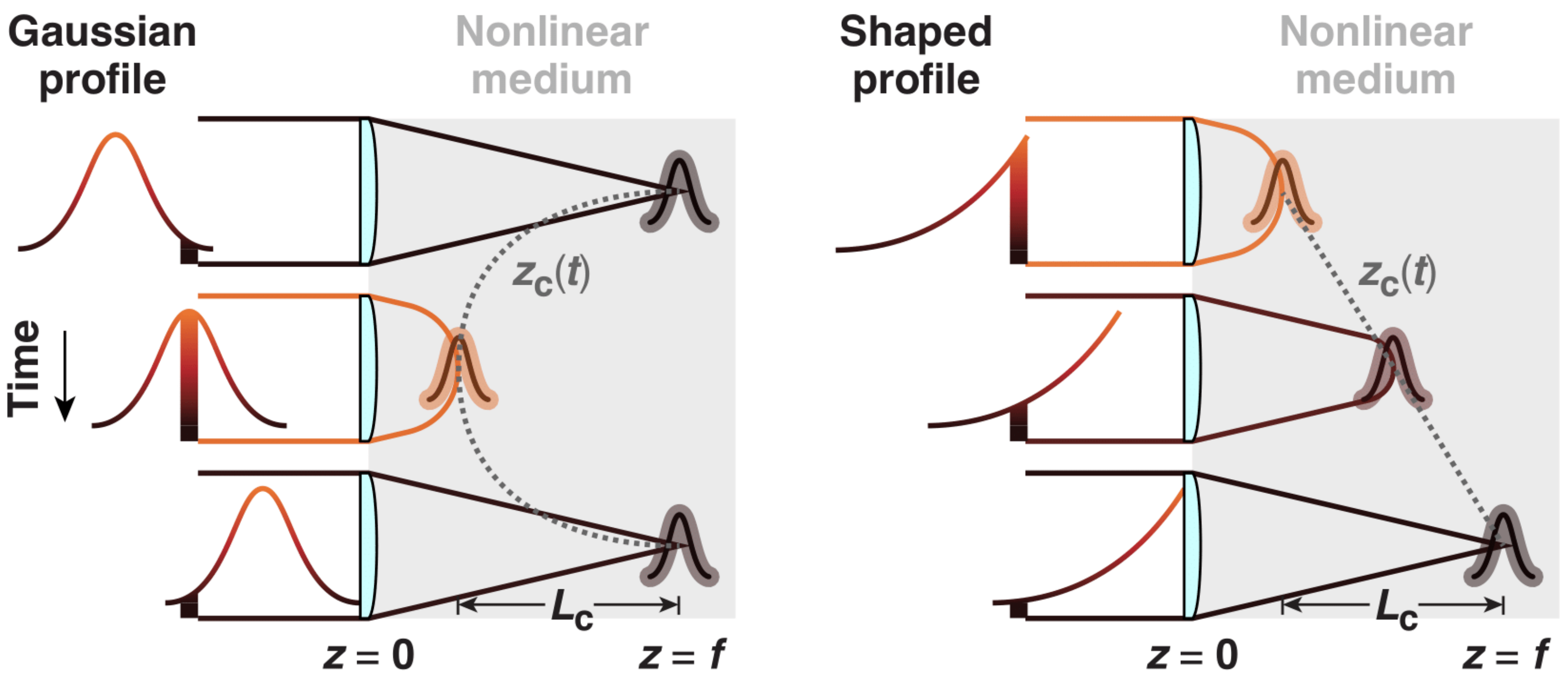
Nonlinear Spatiotemporal Control of Laser Intensity



TC15381b

Tanner Simpson
Ph.D. Student
Advised by John Palastro and Dustin Froula
Laboratory for Laser Energetics, University of Rochester

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Collaborators

Dillon Ramsey, Philip Franke, Manfred Virgil Ambat, David Turnbull, Dustin Froula, and John Palastro
University of Rochester, Laboratory for Laser Energetics

Navid Vafaei-Najafabadi
Department of Physics, Stony Brook University

Summary

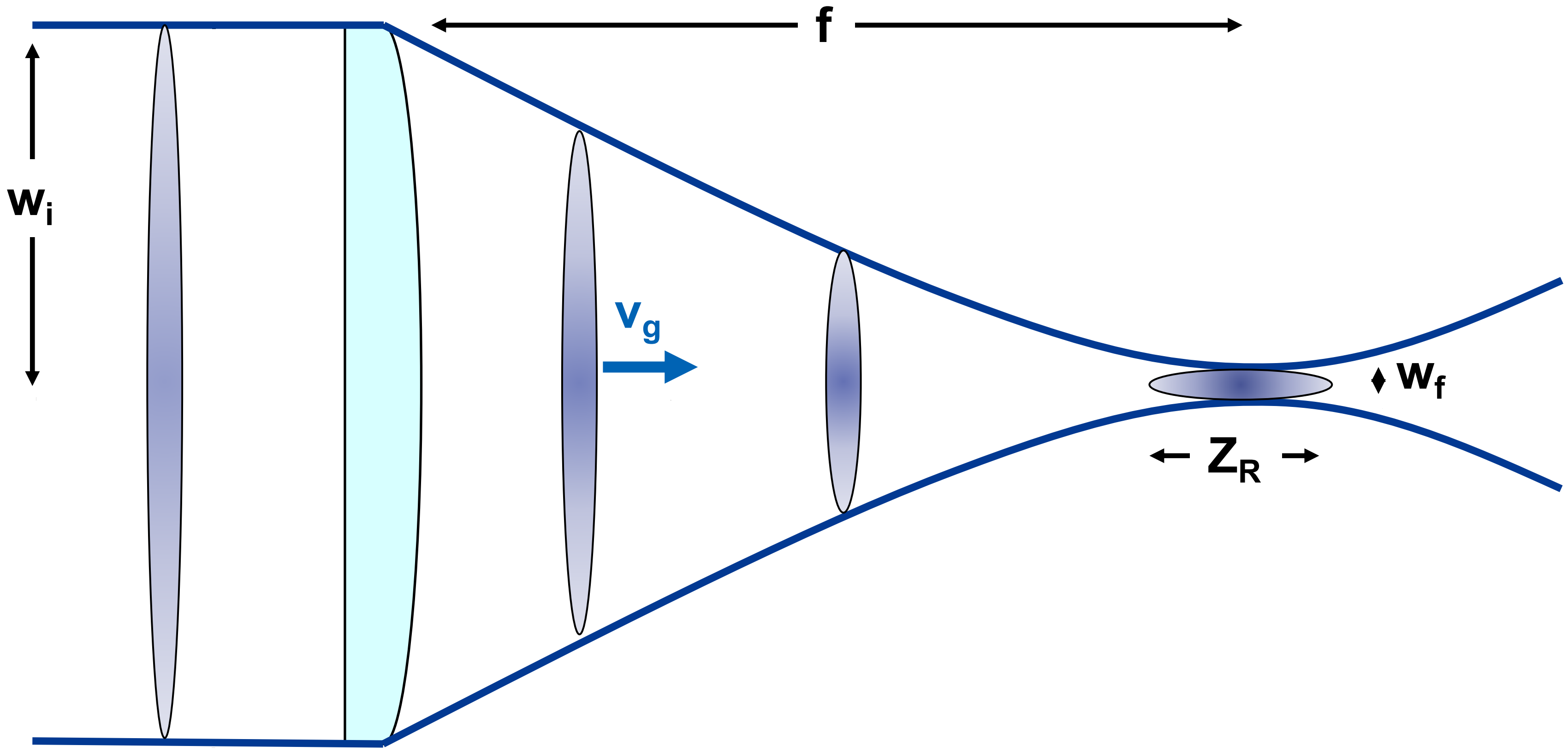
A novel technique called the ‘self-flying focus’ has been developed, enabling control of a laser intensity peak for distances comparable to a lens focal length

- **The self-flying focus combines temporal pulse shaping in the near field with nonlinear self-focusing in the far field to provide spatiotemporal control of laser intensity**
- **The technique does not require advanced focusing optics: the instantaneous power controls the intensity peak location and the shape (slope) controls the velocity**
- **The self-flying focus can utilize long, low power pulses where short, high power pulses are conventionally required**
- **The self-flying focus can produce a meter long, highly uniform plasma for advanced accelerator concepts, particularly the dephasingless laser wakefield accelerator****

*Simpson et al. submitted (2020)

**Palastro et al. PRL (2020)

For a focused laser beam, the region of high intensity is limited to the Rayleigh range, while the intensity peak moves at the group velocity



Many applications benefit from a sustained intensity or a more tunable intensity peak trajectory

Spatiotemporal couplings can structure a pulse to control the intensity peak velocity; more advanced schemes can also extend the region of high intensity

Tilted pulse front method for THz generation*

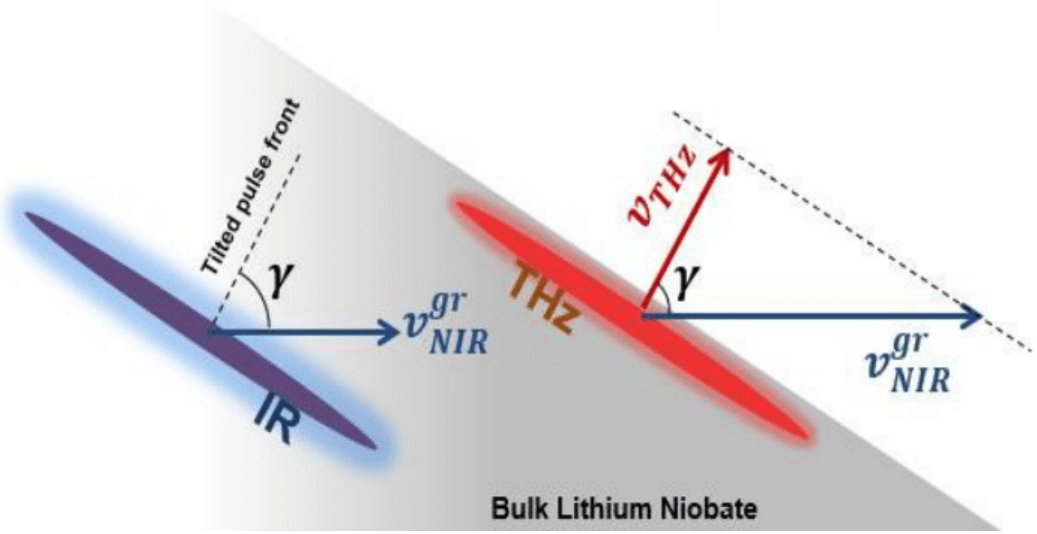
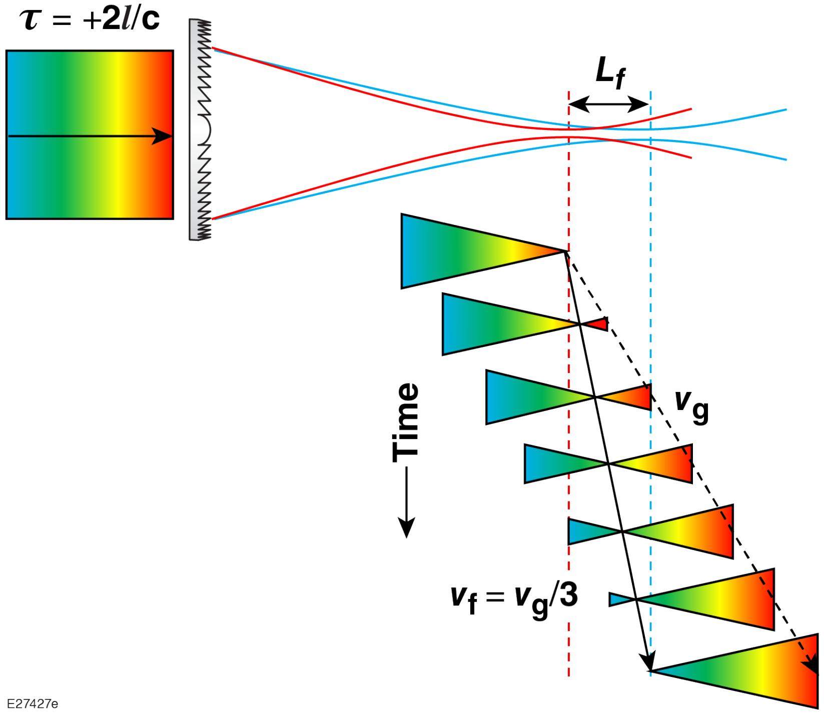


Figure from Franz Kartner website

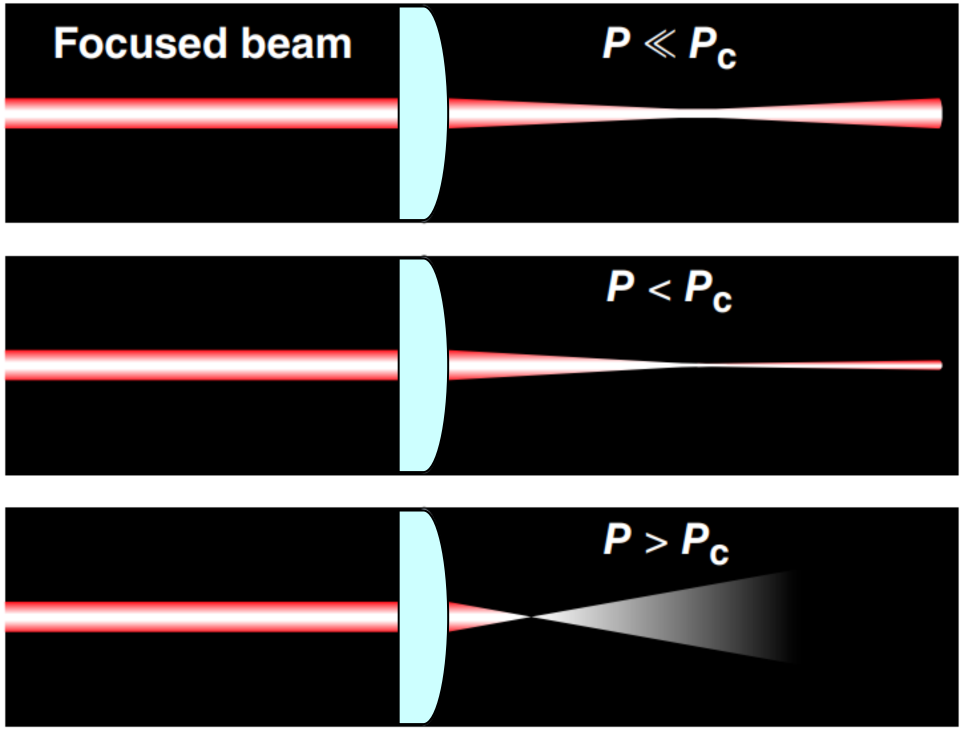
Original 'Flying focus' using chromatic aberration and temporal chirp**

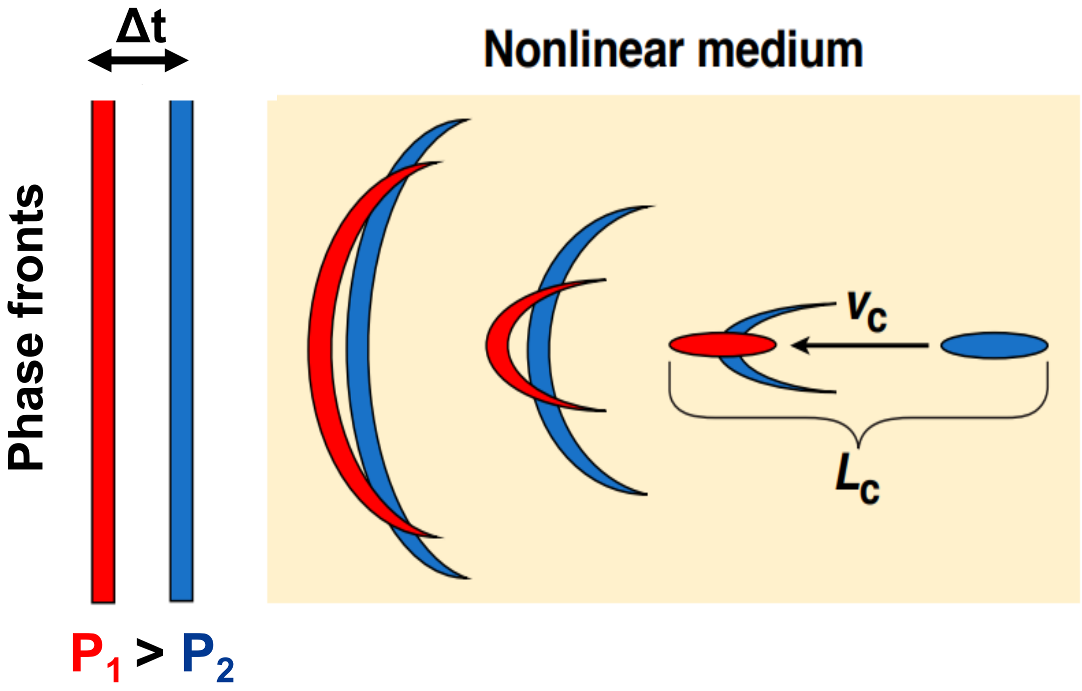


Current techniques achieve spatiotemporal control with linear optics, but couplings from nonlinear optics can also modify pulse propagation

*Hebling et al. Opt. Express (2002) **Froula et al. Nat. Photonics (2018)

Self-focusing will affect a laser pulse differently depending on its power relative to the critical power, P_c

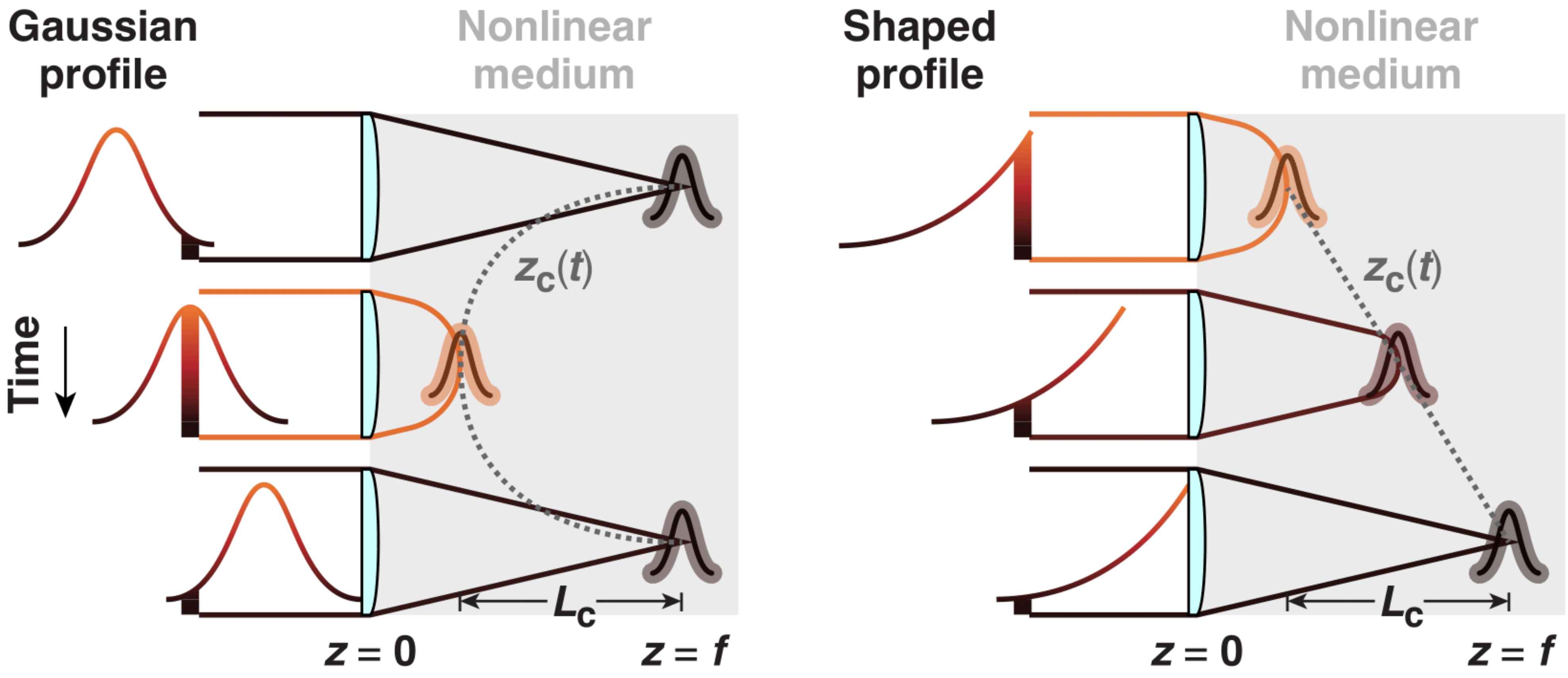




$$v_c \propto \frac{P_1 - P_2}{\Delta t}$$

Within a pulse, the instantaneous power controls the amount of self-focusing, while the shape controls the timing between adjacent foci

Each temporal slice composing a laser pulse will experience a focusing effect dependent on its power



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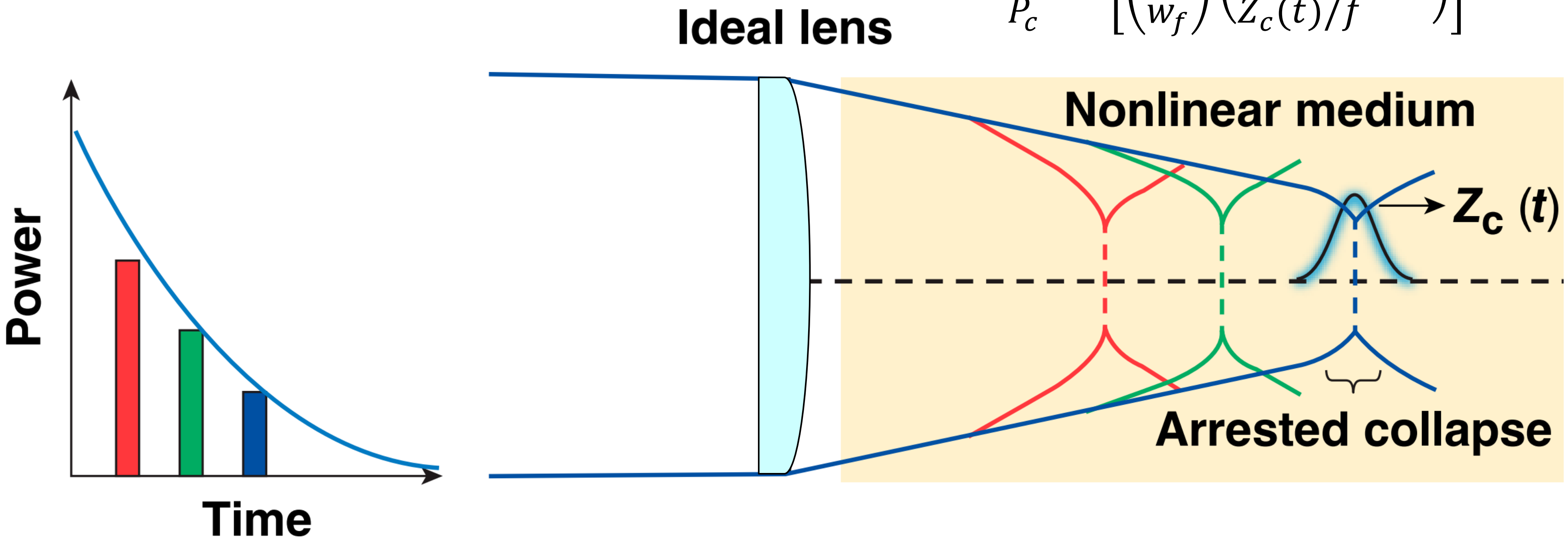
A shaped pulse, like those developed for inertial fusion, can drive an intensity peak at any velocity

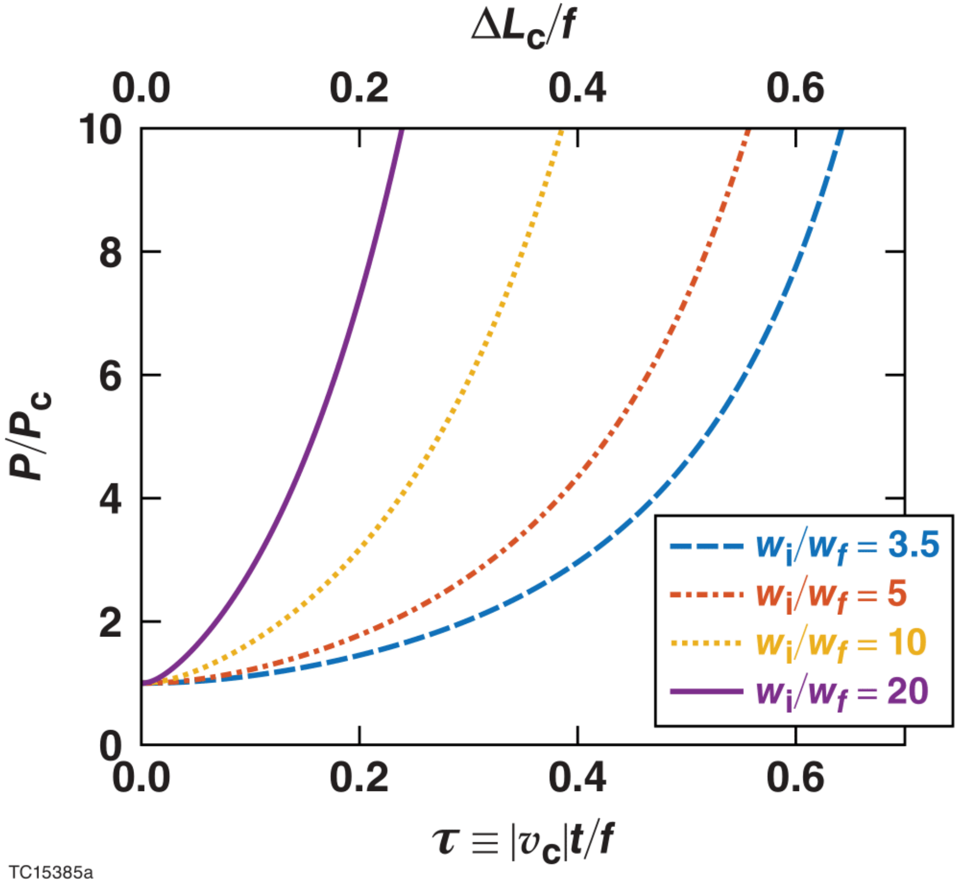
An arrest mechanism (e.g., ionization) halts self-focusing near the collapse point and ensures a nearly constant on-axis intensity

$$\frac{P(t)}{P_c} = \left[\left(\frac{w_i}{w_f}\right)\left(\frac{1}{Z_c(t)/f} - 1\right)\right]^2 + 1$$



As each slice reaches arrest at a different location, the intensity peak duration is much shorter than the overall pulse duration

The power and energy can be tuned to meet a wide range of laser requirements by adjusting the focal geometry



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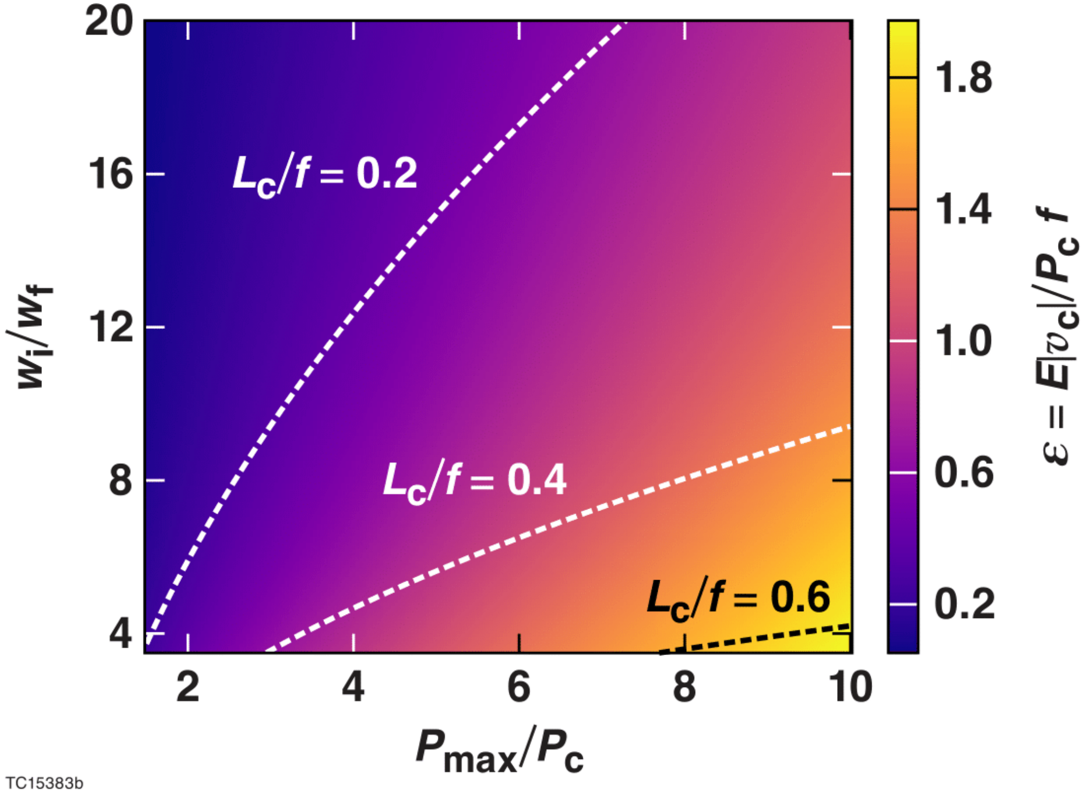

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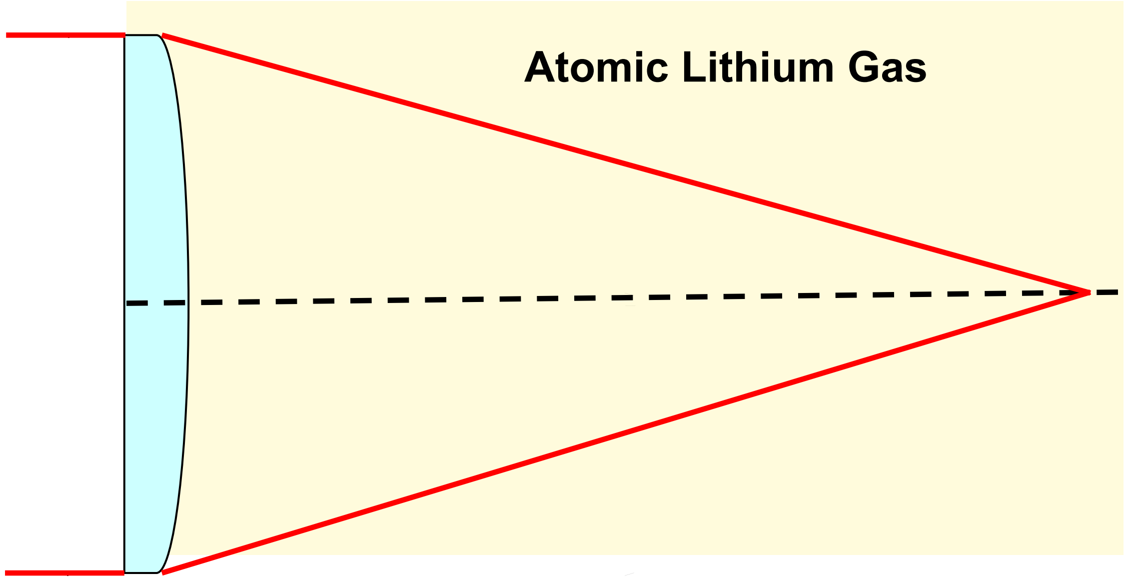
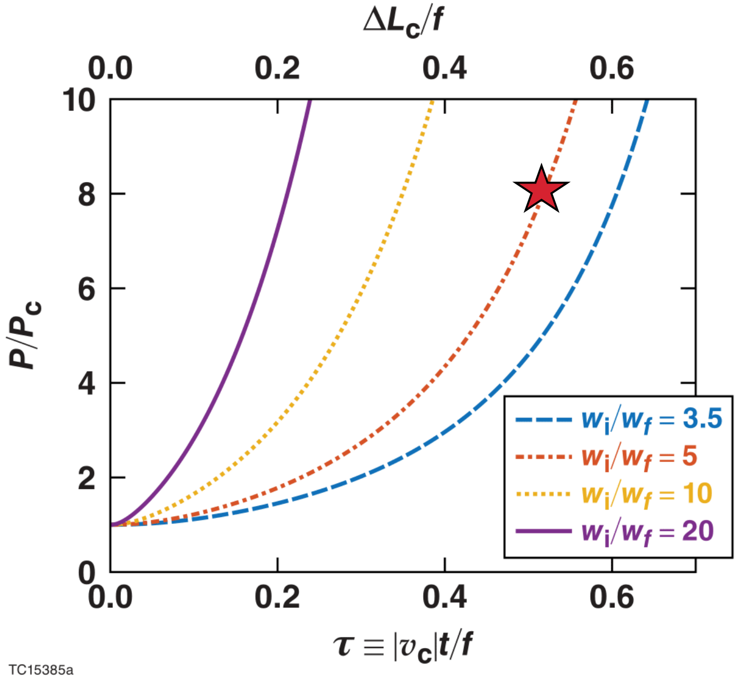
A large spot size ratio creates a steeper power profile, greater energy expenditure, and larger arrested spot size for the same L_c/f

The self-flying focus can drive an intensity peak over large distances, making it an obvious choice for producing long plasma channels



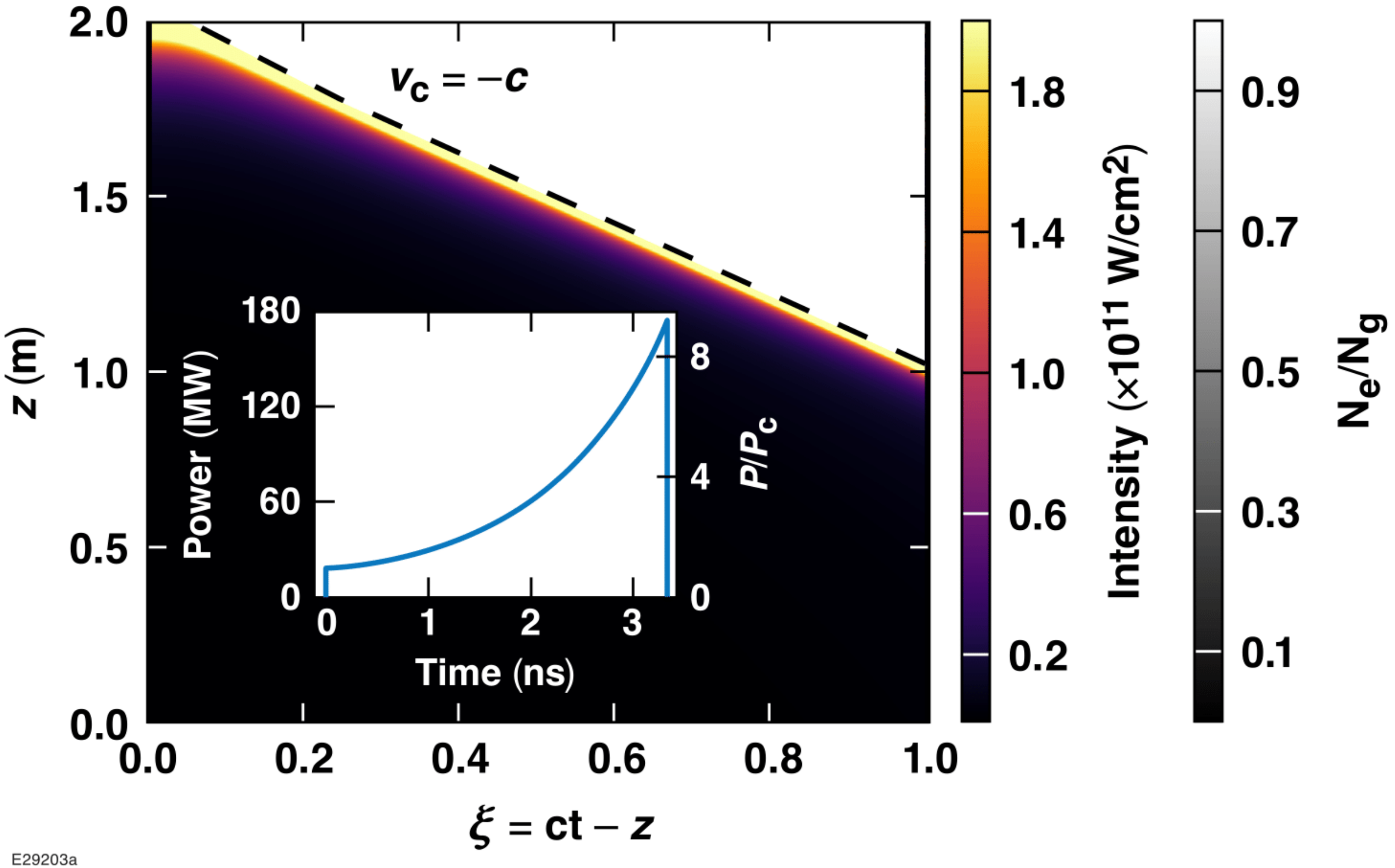


$$\left(\nabla_\perp^2 + 2ik_0\frac{\partial}{\partial z}\right)E_\perp(r,\xi) = \left(-2k_0^2 n_2 I + k_p^2\right)E_\perp(r,\xi) - Q_{FI} - Q_{IB}$$

Diffraction | **Propagation** | **Self-focusing** | **Plasma refraction** | **Field ionization Loss** | **Inverse Bremsstrahlung Loss**

Parameters are chosen to minimize the accelerator length of the recently proposed dephasingless laser wakefield accelerator*

The self-flying focus mitigates ionization refraction by propagating backwards and can create a plasma at the velocity of relativistic accelerated electrons



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