Strong interplay between superluminosity and radiation friction during direct laser acceleration of electrons within a magnetic filament

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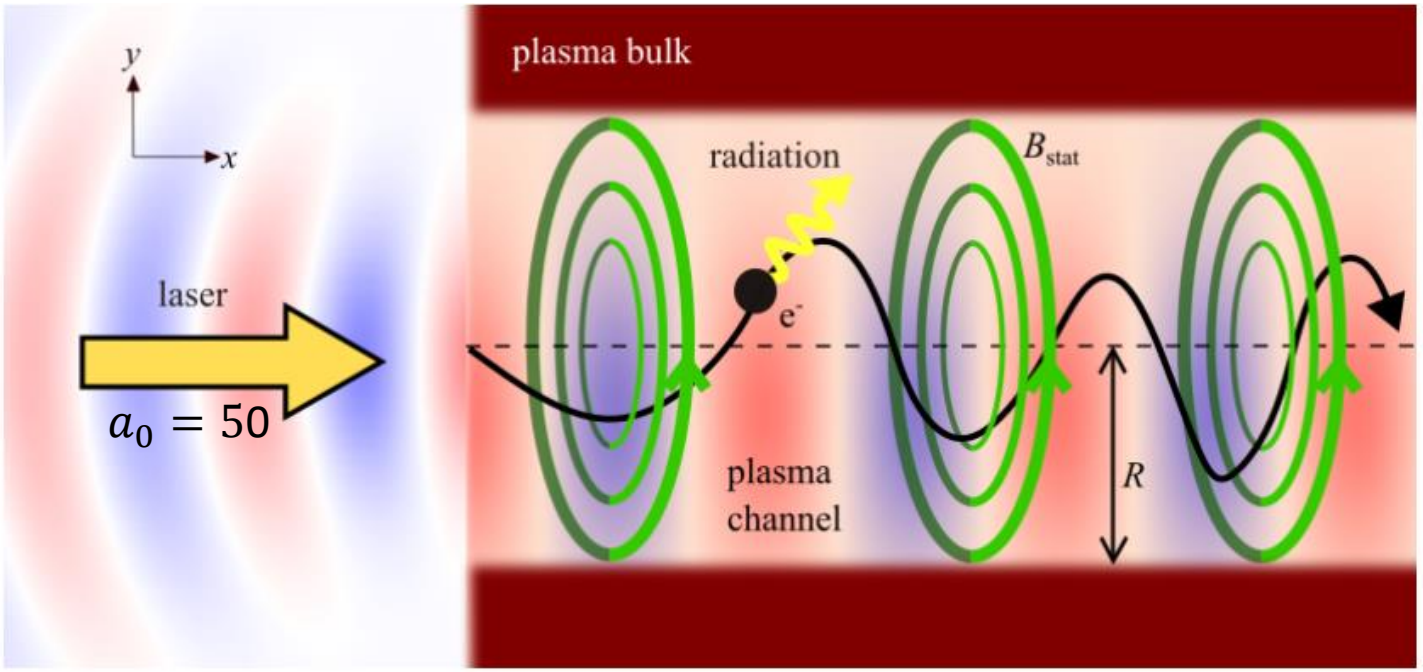
Background

- We studied the direct laser acceleration of electrons within a self-generated magnetic filament that has been observed in PIC simulation.
- The electron emits the radiation and experiences the radiation friction force.
- Laser wavefronts are superluminal due to the presence of plasma.
- We studied it using test-particle model.



Z. Gong et al, PRE **102**, 013206 (2020)
D. Stark et al, PRL **116**, 185003 (2016)

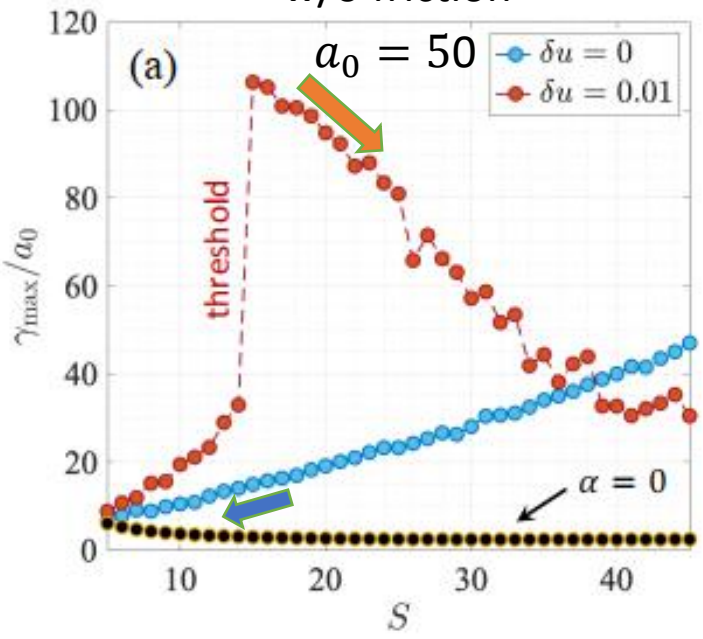
Energy gain w/o friction

- Superluminosity $\delta u = (v_{ph} - c)/c$ can enhance the energy gain.
- It can be shown that, w/o friction, there's a constant of motion

$$S = \gamma - \frac{v_{\mathrm{ph}}}{c}\frac{p_x}{m_e c} + \frac{v_{\mathrm{ph}}}{c}\alpha\frac{y^2}{{\lambda_0}^2}.$$

- $S = \gamma_i$ assuming electron is initially at rest and on axis.

w/o friction



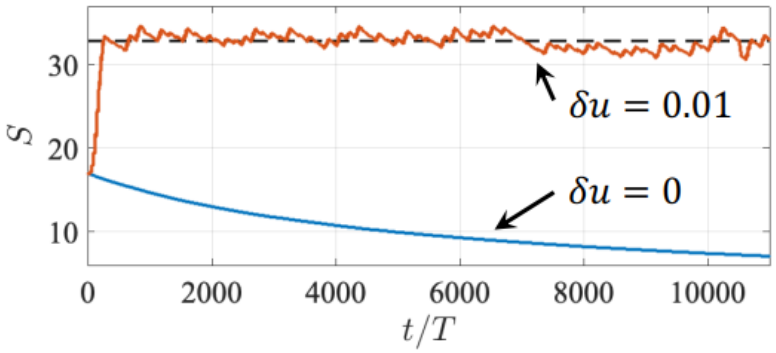
With friction

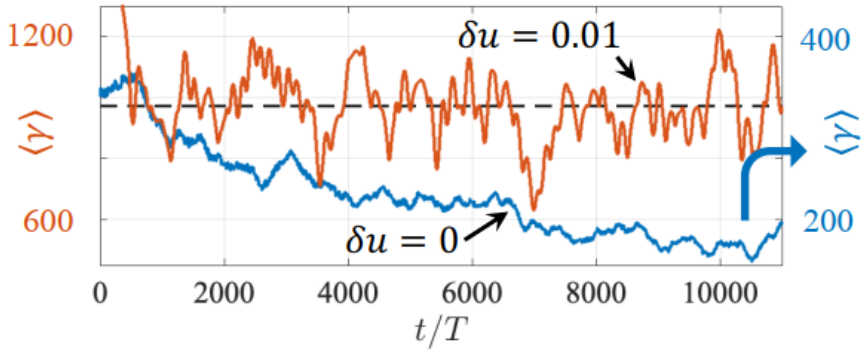
- S will change, resulting in the change of energy gain.
- For S starting at 17, S will increase in superluminal case but decrease in luminal case.

Z. Gong et al, Sci. Reports **9**, 17181 (2019)
V. Khukik et al, POP **23**, 103108 (2016)

Interplay between friction and superluminosity

- Overall, S can increase in superluminal case, but not in luminal case.
- We showed that the maximum increasing rate dS/dt is $\gamma^2 \delta u$ larger in the superluminal case than in luminal case.
  - $\gamma = 100, \delta u = 0.01 \Rightarrow \gamma^2 \delta u = 100$
- $\delta u = 0$: S keeps decreasing, γ keeps dropping
- $\delta u = 0.01$: S increases and stays constant, γ decreases and then stays constant.

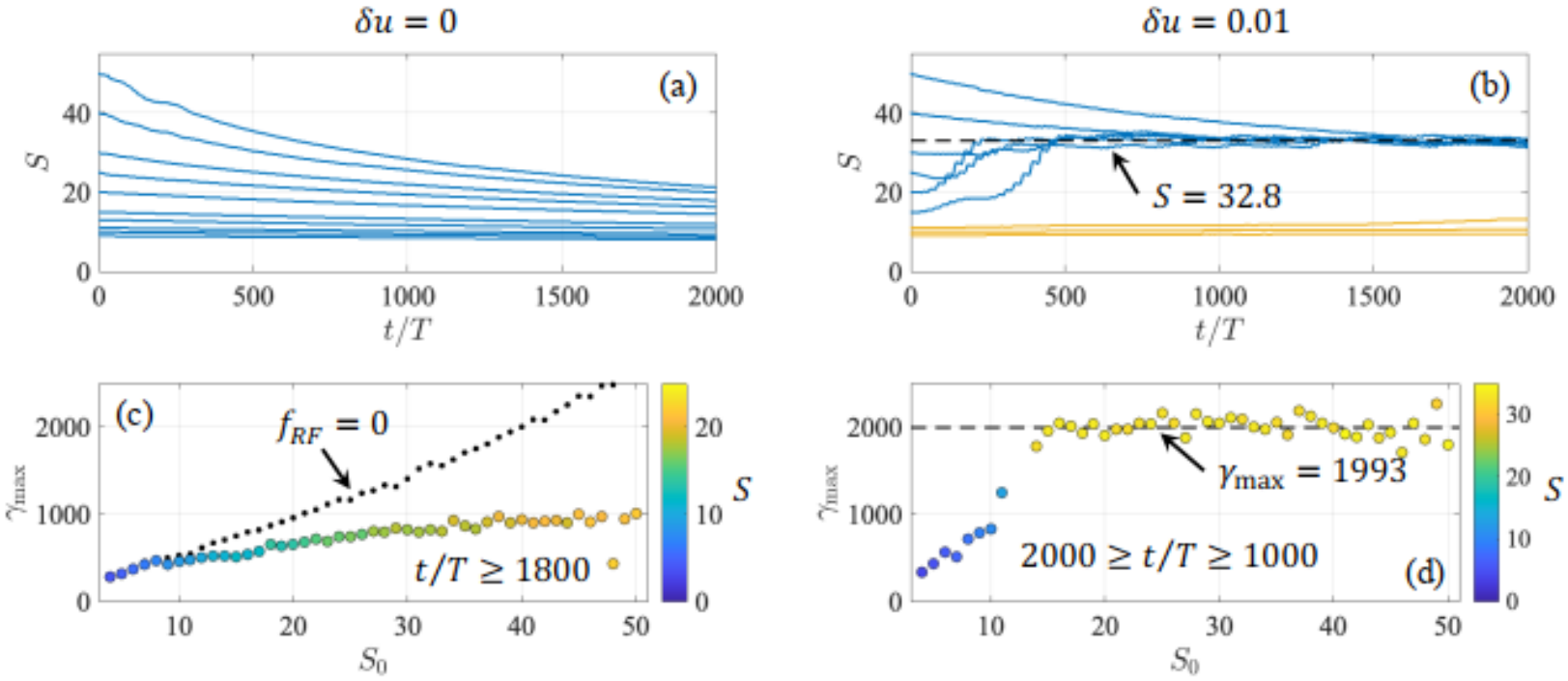




Attractor behavior

- The interplay between superluminosity and radiation friction will manifest the “attractor” behavior.

- The electrons with various initial energies reach roughly the same maximum energy and radiation power.

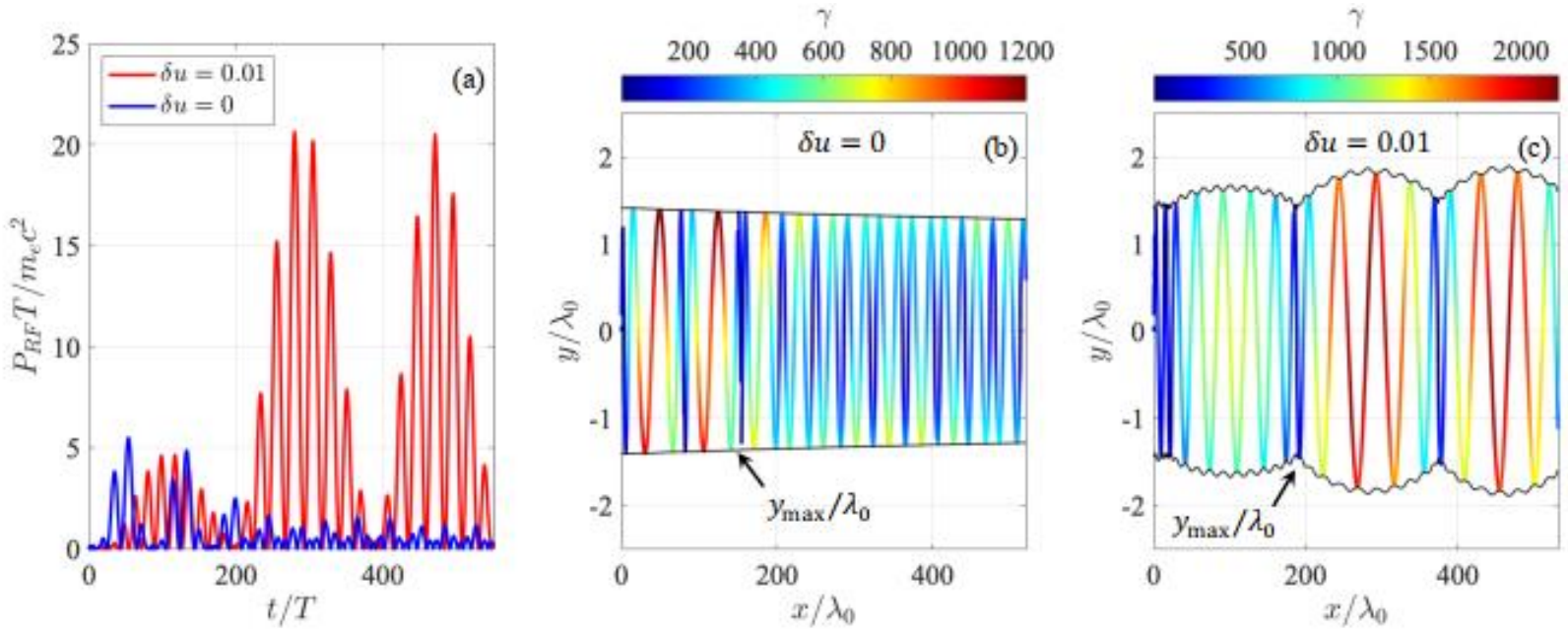


Superluminosity effect on x-ray emission

- We found that the radiation power scales as $P_{\mathrm{rad}} \propto \gamma^2 \mathrm{B}_{stat}{}^2 \propto \gamma^2\, y_{max}^2$
- The maximum transverse displacement expand due to superluminosity.

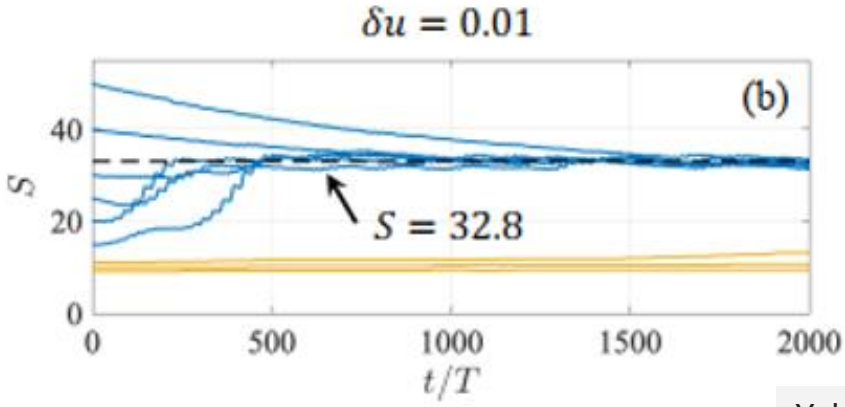
$$\mathrm{y}_{\mathrm{max}} \propto j_0^{-1/2}[(S + \gamma\delta\mathrm{u})\,]^{1/2}$$

- Due to the larger γ and y_{max}, the radiation power is larger in superluminal case than in luminal case.



Summary

- We studied the direct laser acceleration of electrons within a self-generated static magnetic filament.
- Small superluminosity ($v_{ph} = 1.01\ c$) has a profound impact on electron dynamics.
- The interplay of superluminosity and radiation friction manifests as an attractor effect. The electrons with various initial energies will reach roughly the same maximum energy and emit the same power.



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