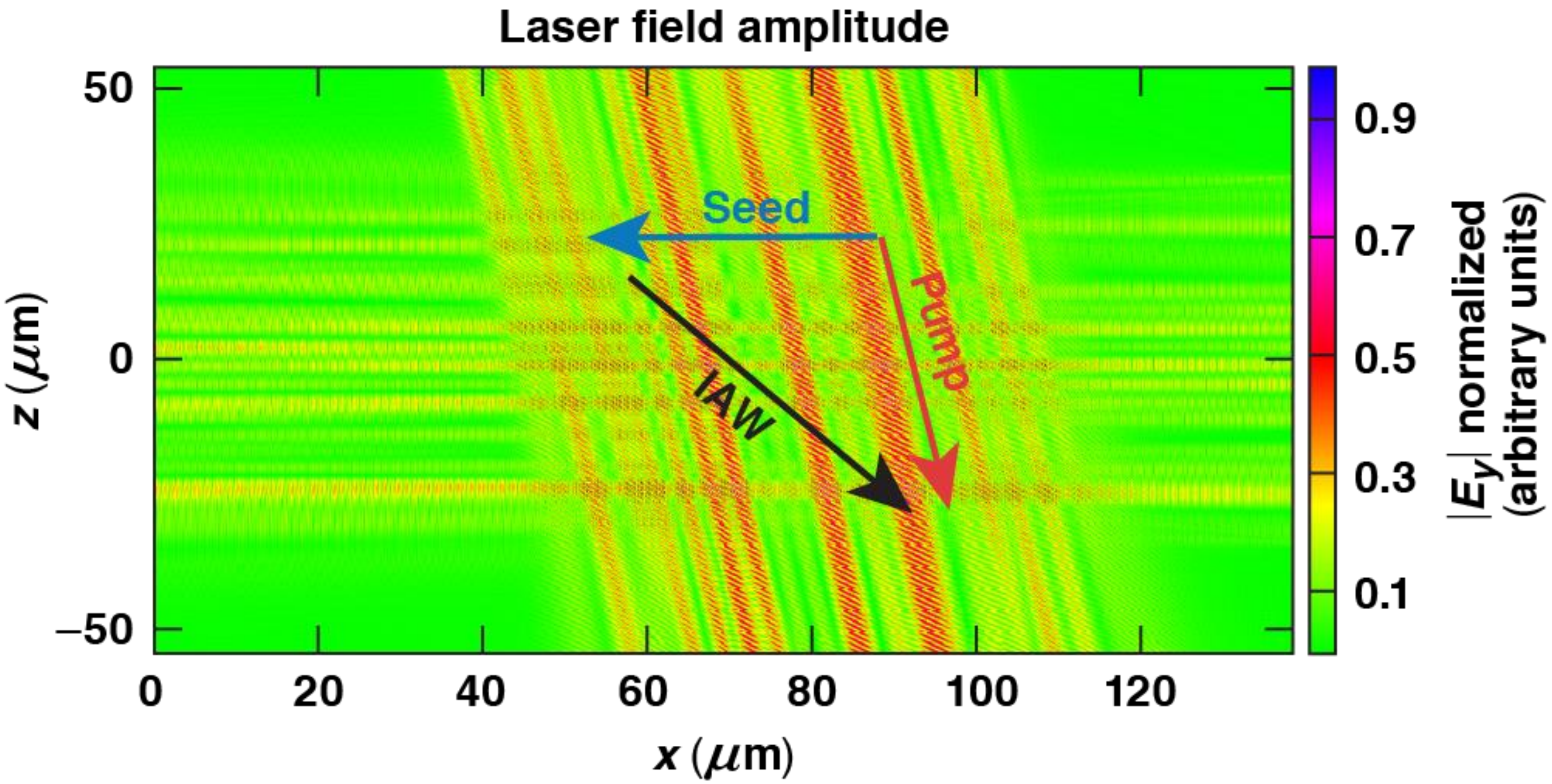
NONLINEAR SATURATION OF CROSS-BEAM ENERGY TRANSFER



TC15512

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Summary

Ion trapping results in two mechanisms for CBET saturation that occur over different time scales

- The nonlinear evolution of CBET predicted by collisional PIC simulations is in qualitative agreement with focused experiments in implosion relevant conditions (i.e. OMEGA TOP9)

- For the experimental conditions, CBET evolves through three stages:
  - Linear growth of IAW (0 – 12 ps)
  - Fast saturation (12 ps – 50 ps)
  - Slow saturation (>50 ps)

- On the fast time scale, CBET saturates dues to transverse breakup of the ion-acoustic waves (i.e. trapped particle modulational instability)

On the long time scale, collisional thermalization of trapped ions leads to a loss of resonance that saturates CBET

Collaborators

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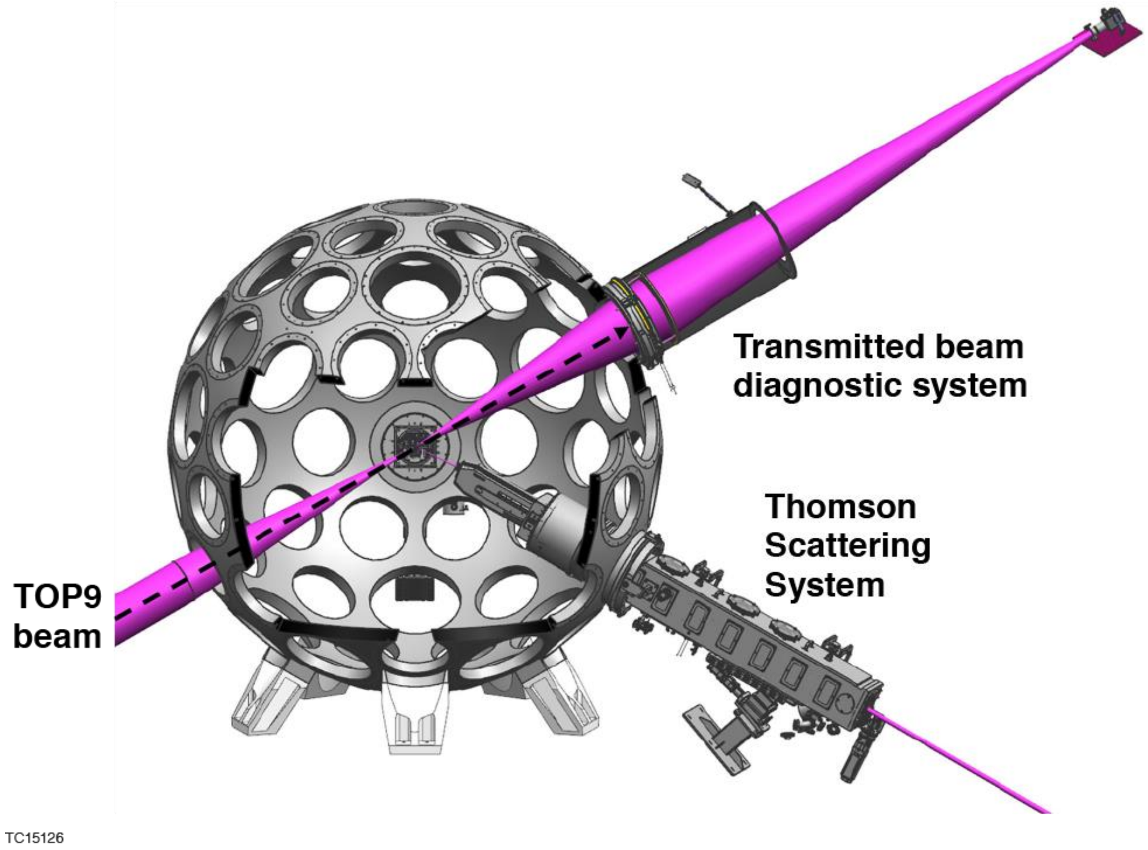
Cross-beam energy transfer (CBET) is the exchange of energy between electromagnetic waves mediated by their mutually driven ion acoustic wave (IAW)

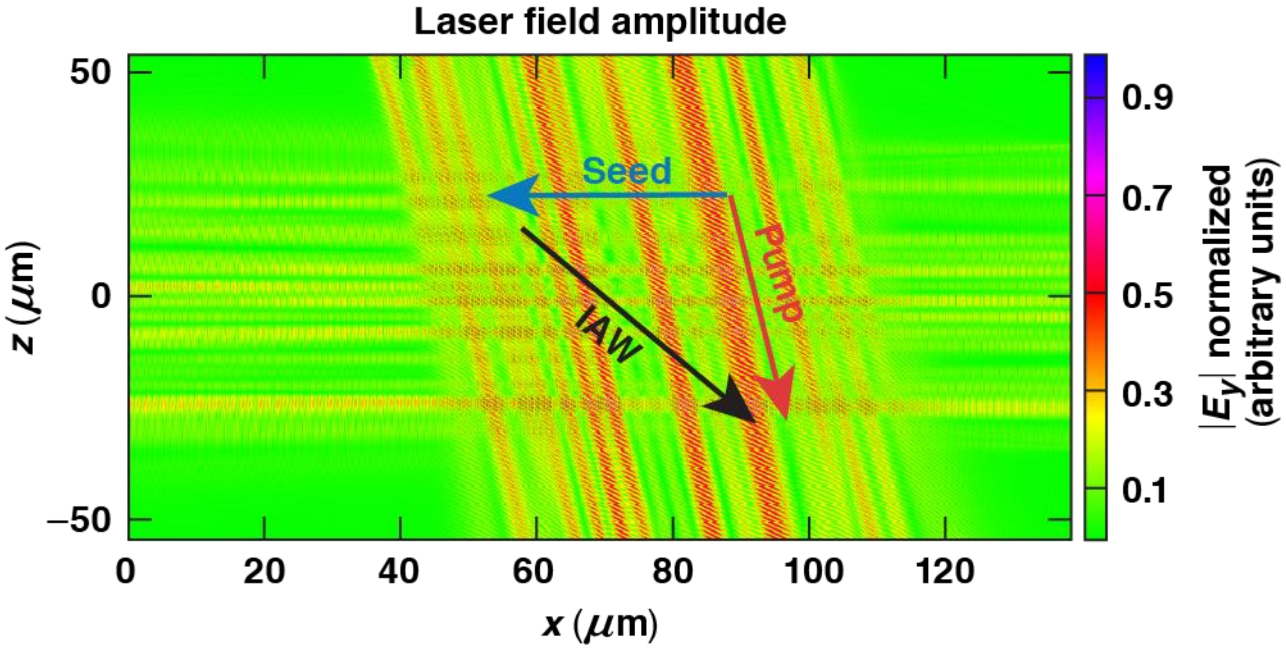
- CBET plays a critical role in laser-based inertial confinement fusion (ICF)
    - In direct drive: CBET scatters laser light away from the target, thus reducing absorption
    - In indirect drive: CBET can be used to tune the symmetry of the implosion
- The TOP9* (Tunable OMEGA Port 9) platform has been developed at the LLE for focused studies of CBET in ICF relevant plasmas



*B.E. Kruschwitz et al. *Proc. SPIE* 10898, 108904 (2019)

Collisional VPIC(*) simulations were performed to model the focused CBET experiments conducted on the OMEGA TOP9 platform

Plasma parameters
T_e = 600 eV and T_i = 150 eV
n_{e0} = 6.0e19 cm^{-3}
Ion species: H (55%) and N (45%)
Laser parameters
λ = 351 nm
Detuning: $\Delta\lambda$ = 2.800 A
I_{pump} = 2.2e15 W/cm^2



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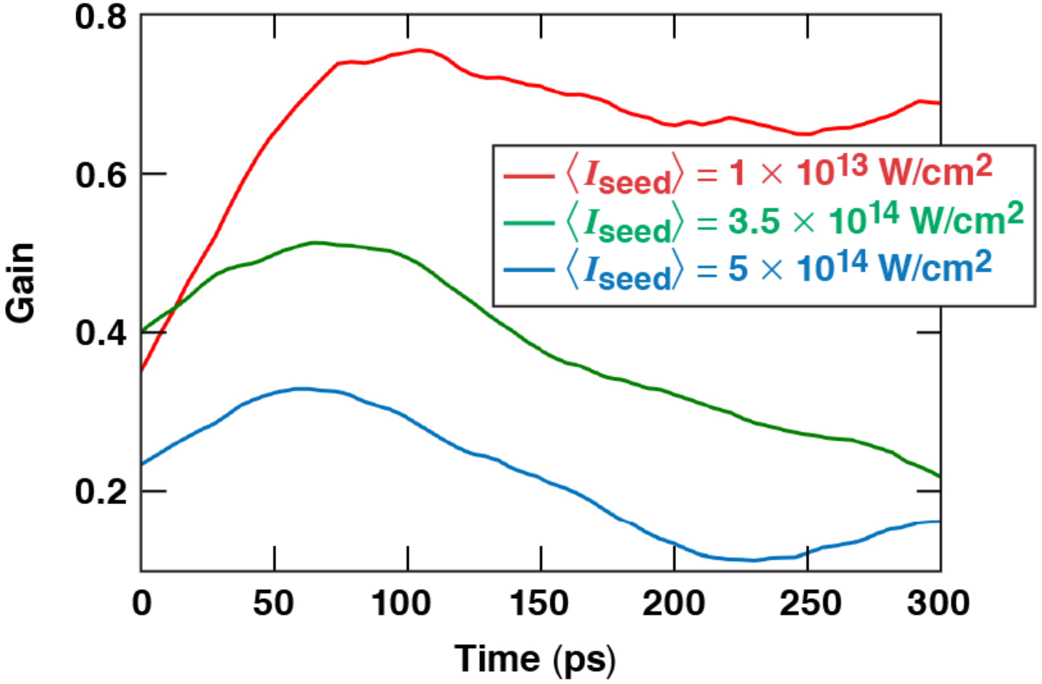
Each simulation used up to ~2x10^6 core-hours

*K.J. Bowers et al. *Phys. Plasmas* 15, 055703 (2008)

The nonlinear evolution of CBET predicted by the simulations is in qualitative agreement with the experiments

Experimental Measurements



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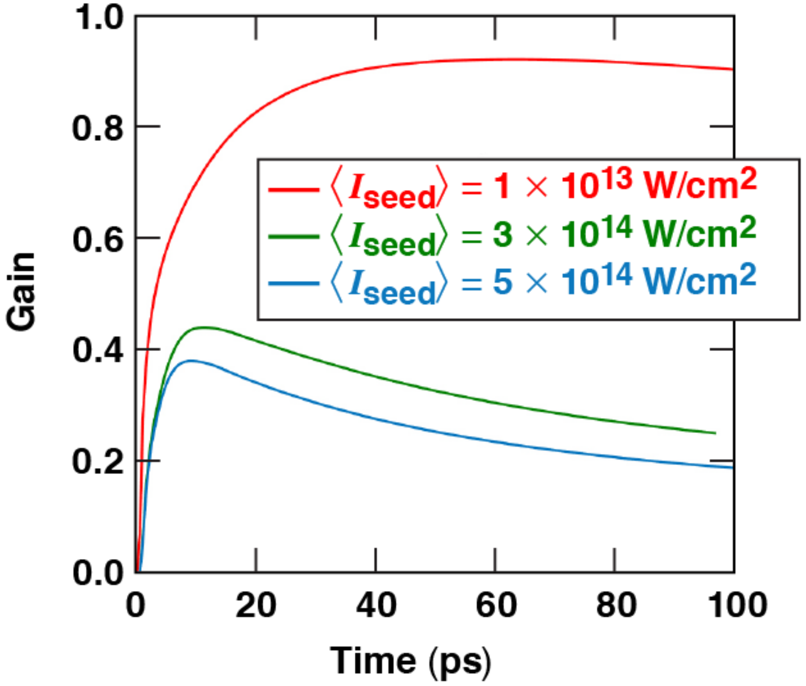
Simulations



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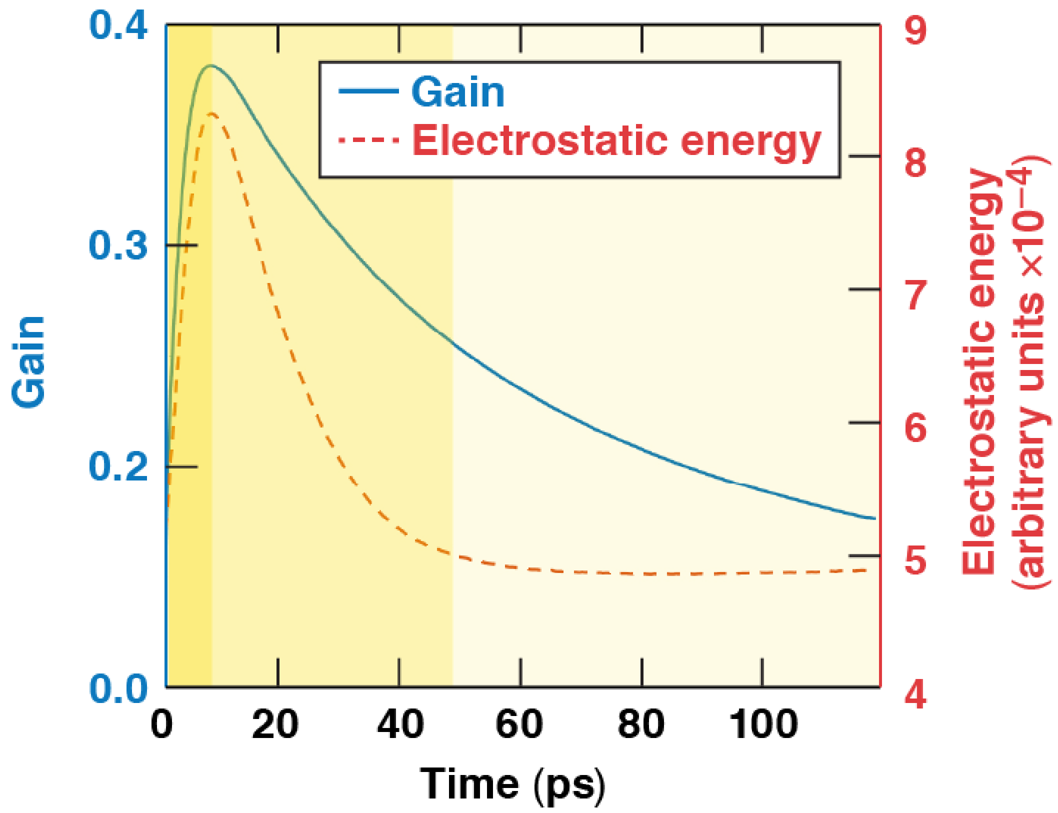
- For the lowest seed intensity (1e13 W/cm^2), the CBET gain is relatively constant over time
- For the higher seed intensities, the gain is reduced and decreases in time over ~ 100 ps

The decrease in CBET gain over time tracks the evolution of the energy in ion-acoustic waves

Simulation results at $\langle I_{seed} \rangle$ = 5e14 W/cm^2



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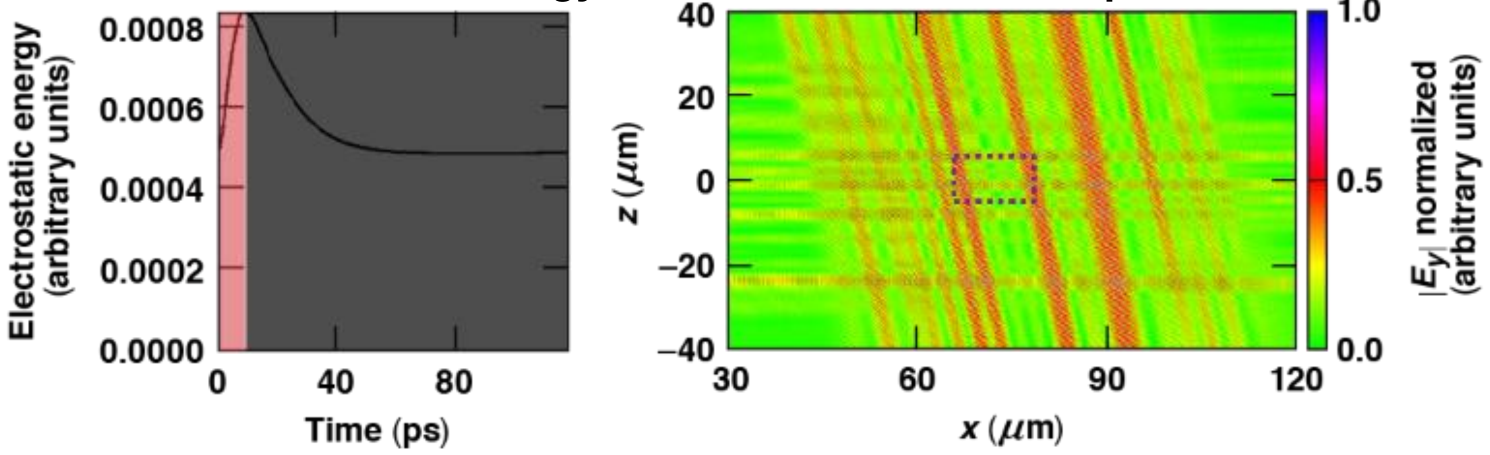
- The evolution of CBET occurs in three stages:
  - Linear growth of IAW (0 – 12 ps)
  - Fast saturation (12 ps – 50 ps)
  - Slow saturation (> 50 ps)

During the first stage (linear growth), the IAWs have a coherent structure



Electrostatic Energy

Laser field amplitude

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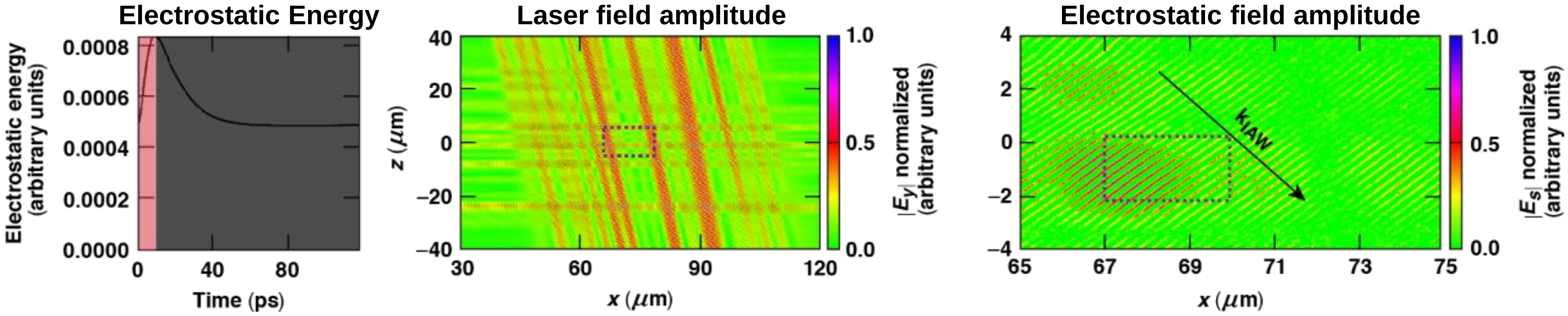

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- Higher intensity speckles drive the IAWs to larger amplitudes

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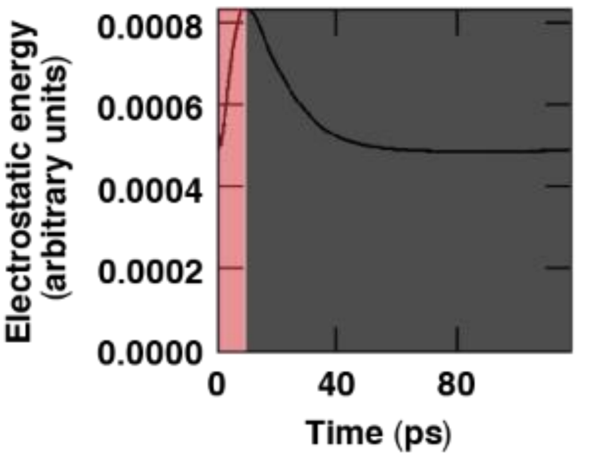
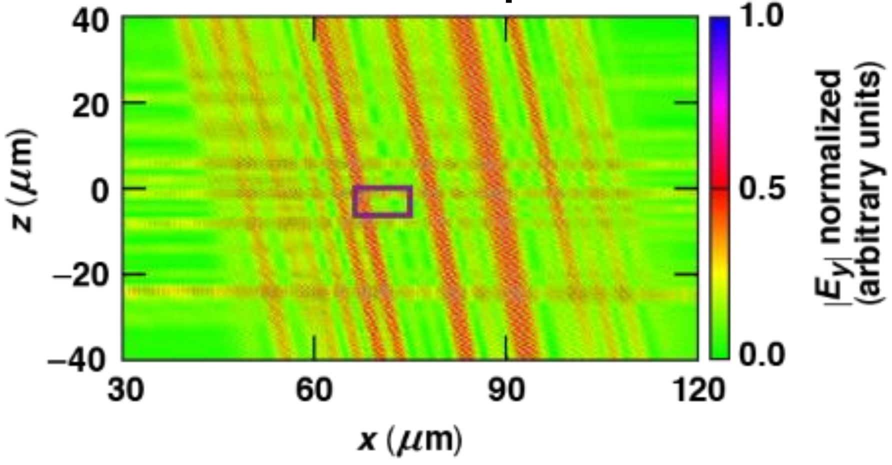
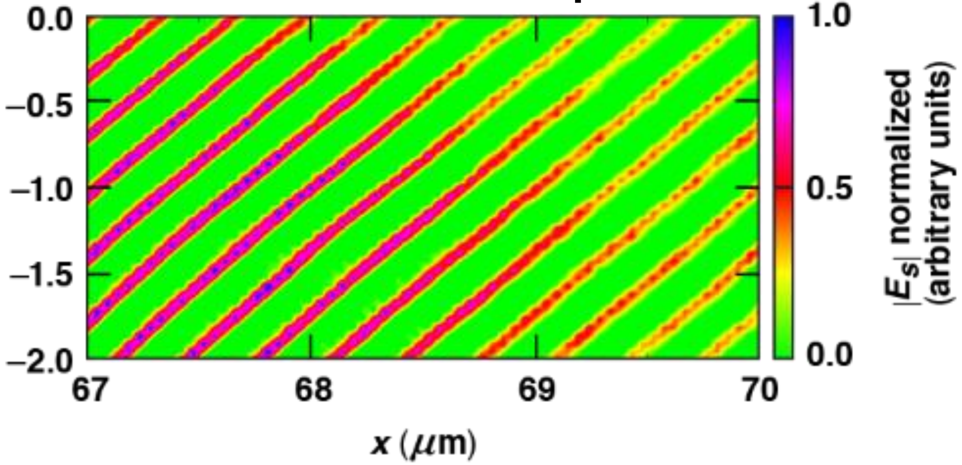

Electrostatic Energy


Laser field amplitude


Electrostatic field amplitude

- Higher intensity speckles drive the IAWs to larger amplitudes
- The IAWs exhibit coherent (flat) phase fronts

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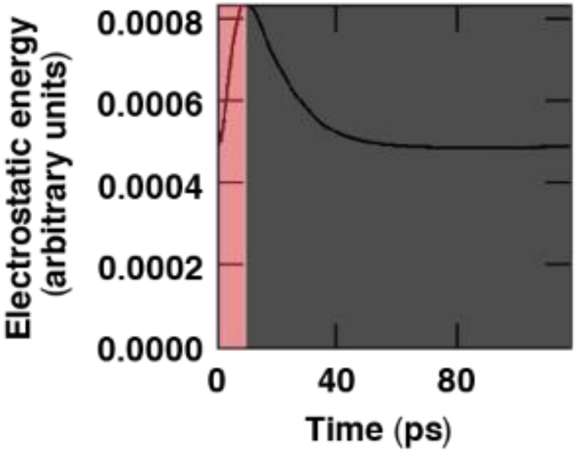
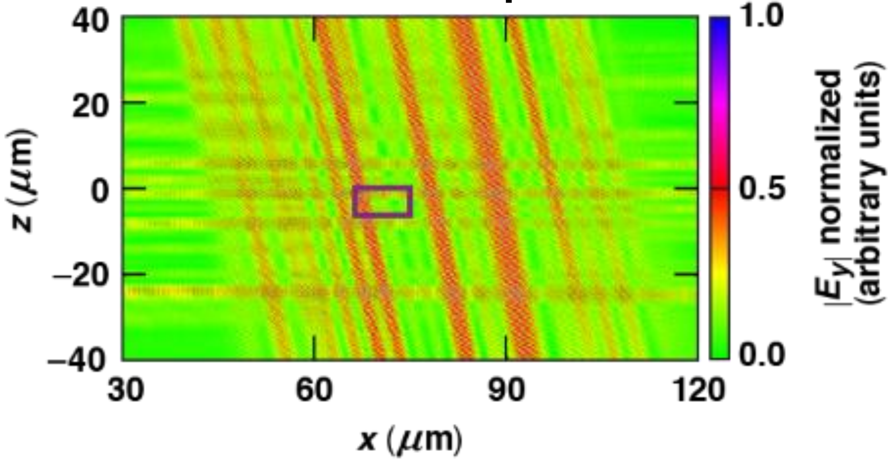
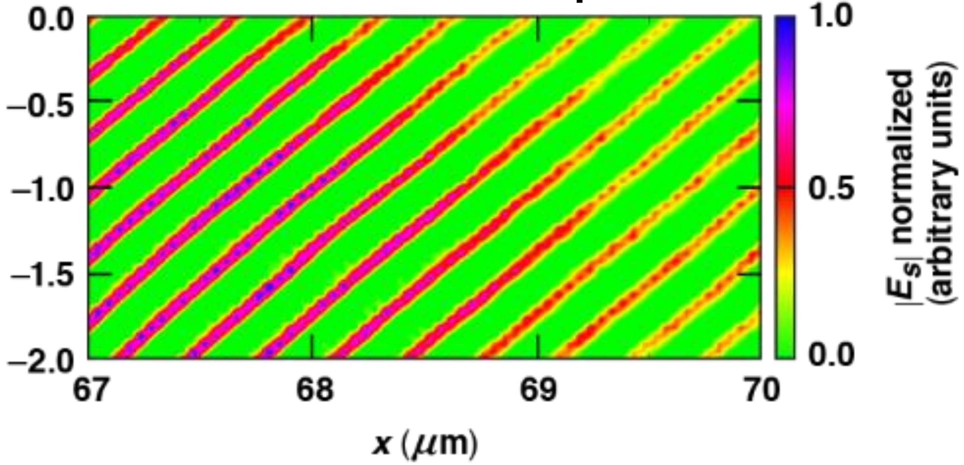
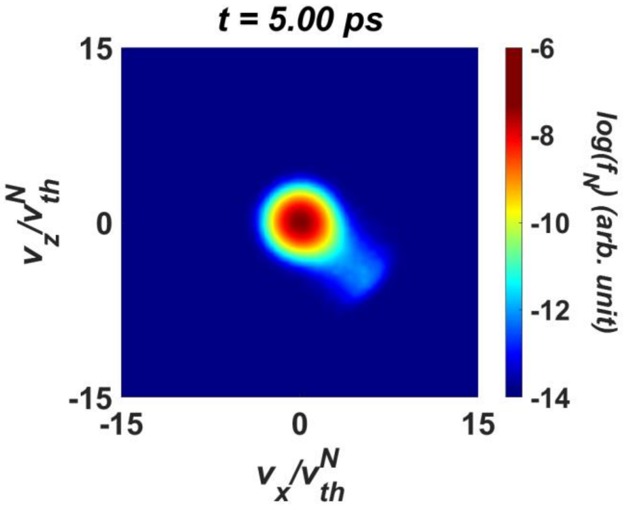
During the first stage (linear growth), the IAWs have a coherent structure


Electrostatic Energy


Laser field amplitude

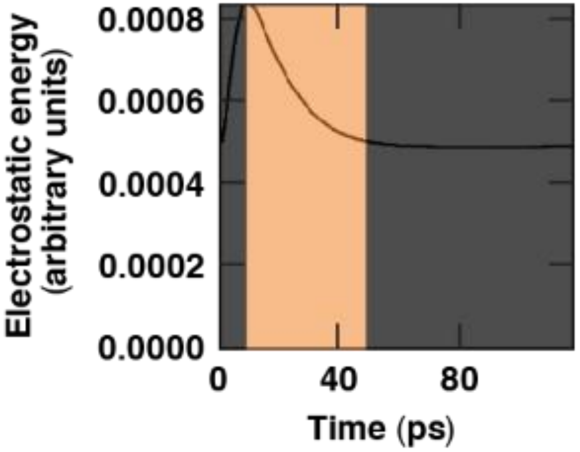

Electrostatic field amplitude

- Higher intensity speckles drive the IAWs to larger amplitudes
- The IAWs exhibit coherent (flat) phase fronts
- The ion distribution develops a tail along the direction of the IAW due to trapping

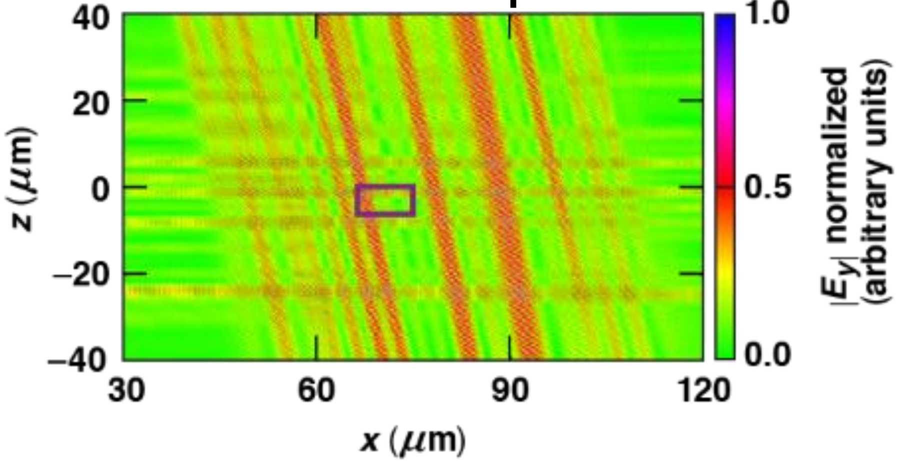


In the fast saturation stage, the IAW breaks up in the direction transverse to its propagation (*)

Electrostatic Energy



Laser field amplitude



(*) L. Yin et al. *Phys. Rev. Lett.* 99, 265004 (2007)

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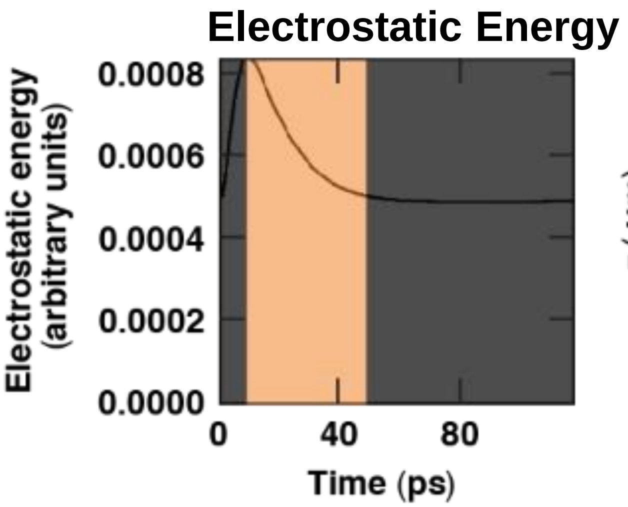
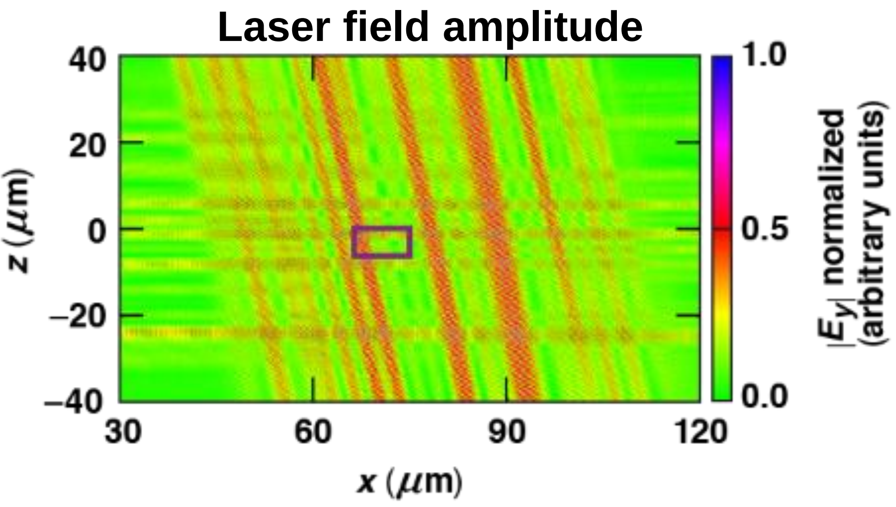
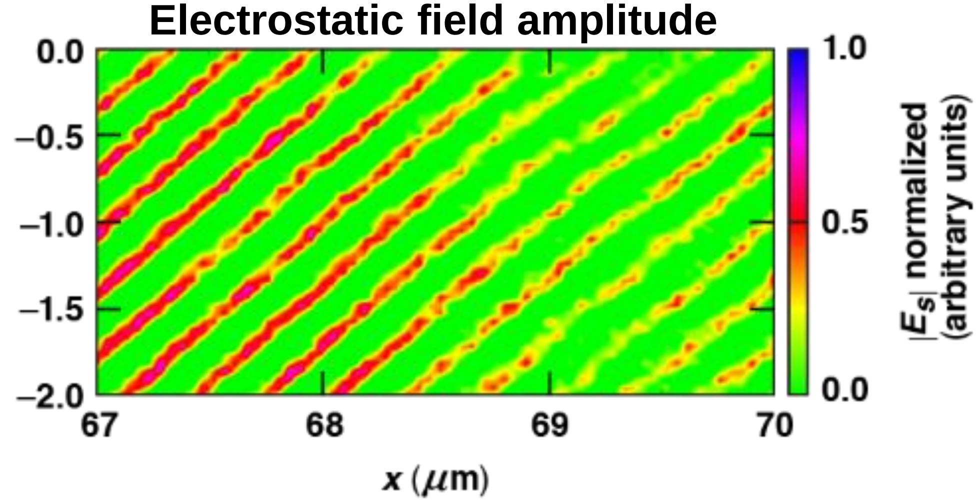

Electrostatic Energy


Laser field amplitude


Electrostatic field amplitude

- IAW undergoes transverse breakup around ~ 12 ps – 50 ps (trapping → bowing → filaments)

- The breakup allows for rapid side loss of trapped ions, dissipating the electrostatic wave energy

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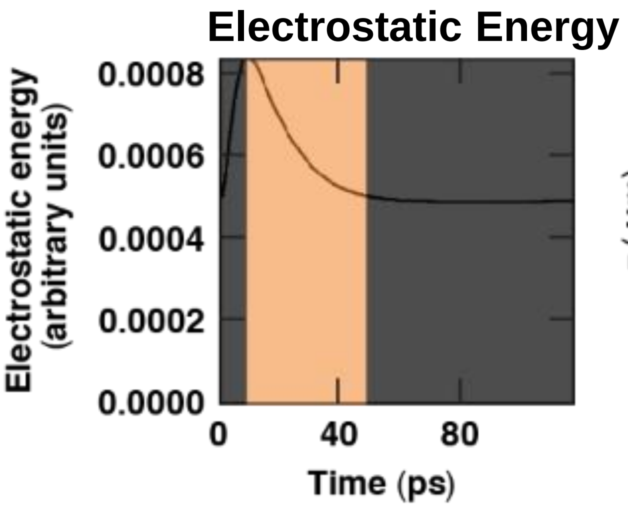
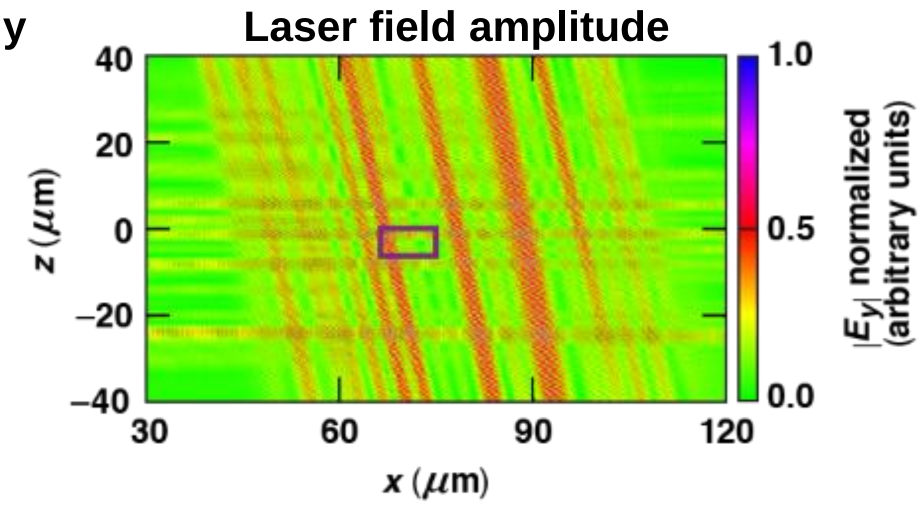
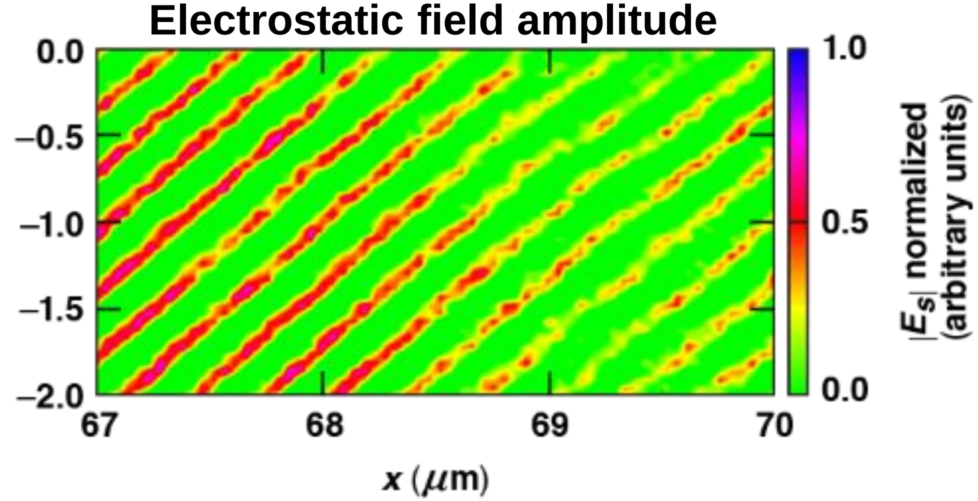
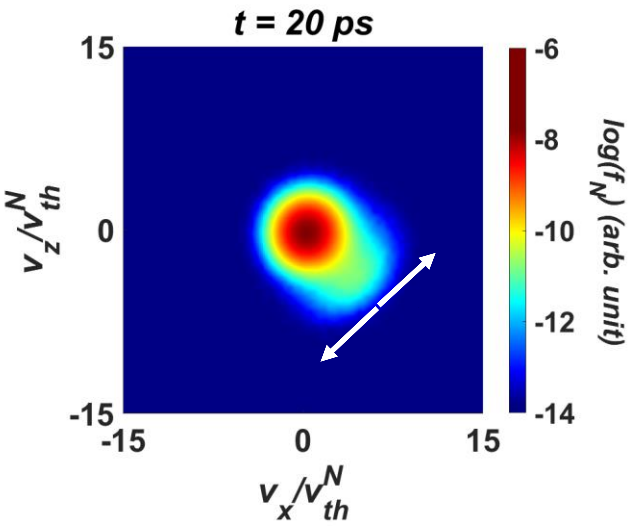






- IAW undergoes transverse breakup around ~ 12 ps – 50 ps (trapping → bowing → filaments)
- The breakup allows for rapid side loss of trapped ions, dissipating the electrostatic wave energy
- Side loss and pitch-angle collisions widen the trapping tail



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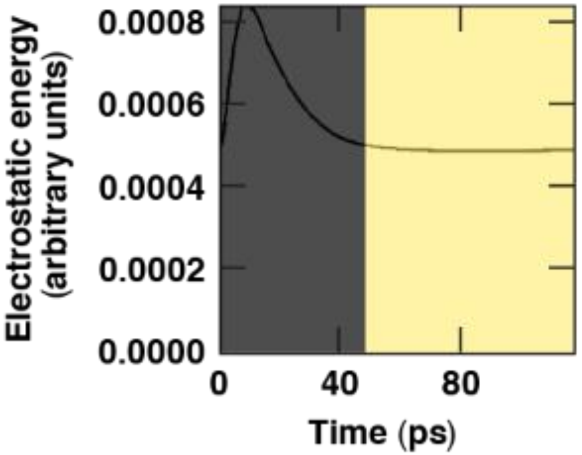
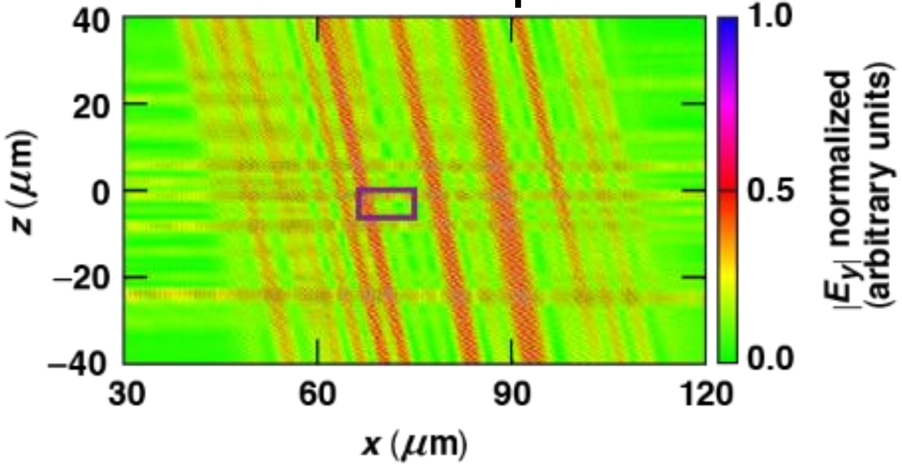
(*) L. Yin et al. *Phys. Rev. Lett.* 99, 265004 (2007)

Over longer time scales, ion-ion collisions isotropize the distributions, leading to an increased ion temperature

Electrostatic Energy



Laser field amplitude



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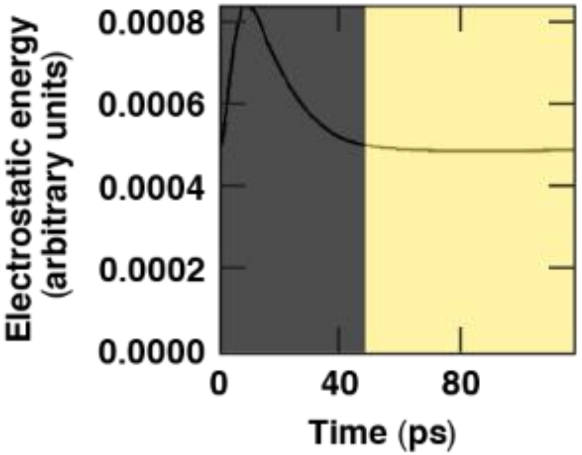
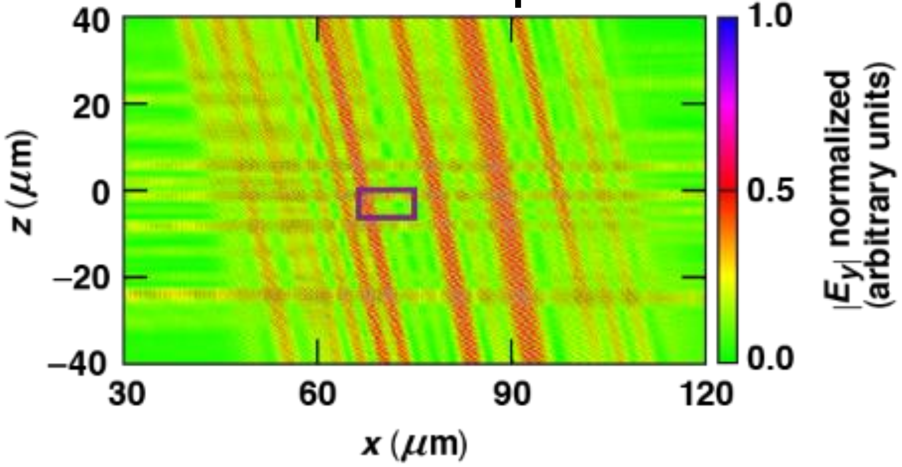
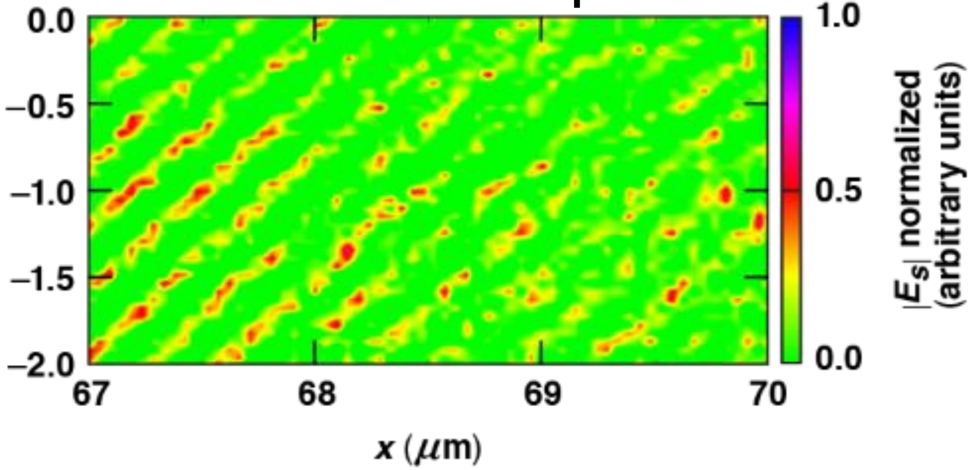
Over longer time scales, ion-ion collisions isotropize the distributions, leading to an increased ion temperature



Electrostatic Energy



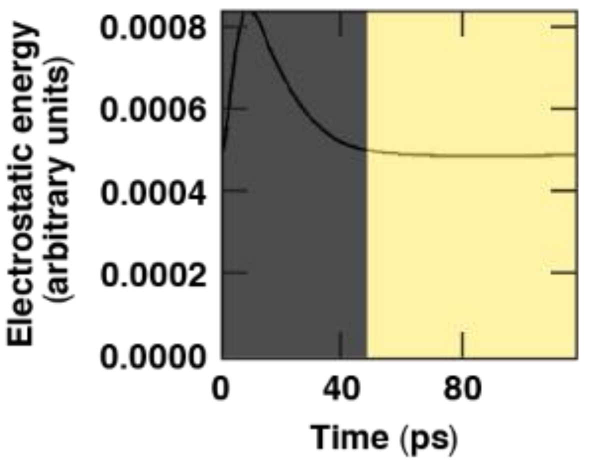
Laser field amplitude

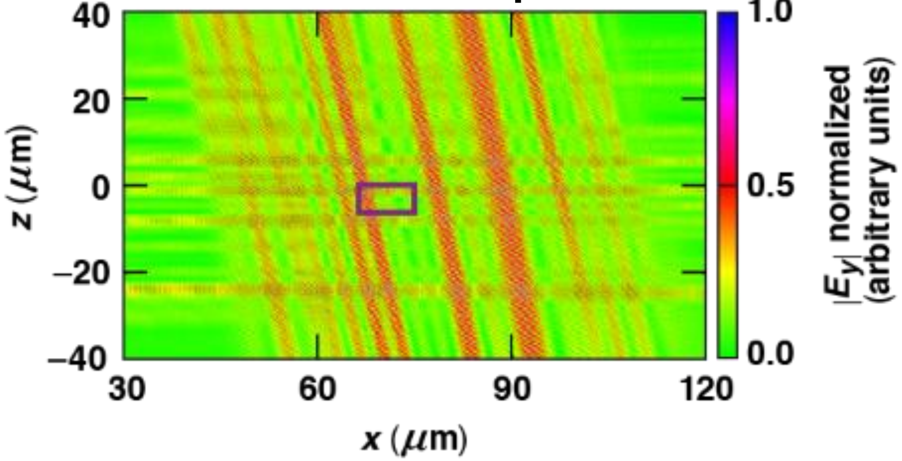


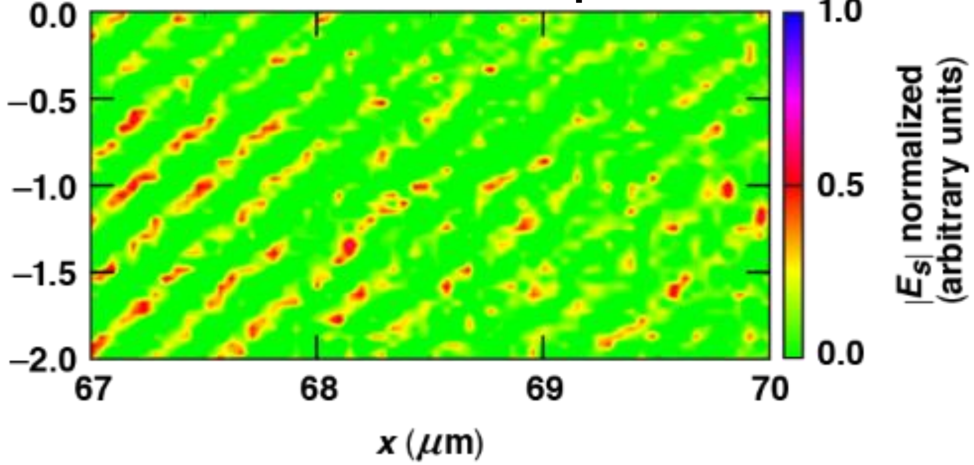
Electrostatic field amplitude

- The planar-like IAW has transitioned to localized electrostatic fluctuations

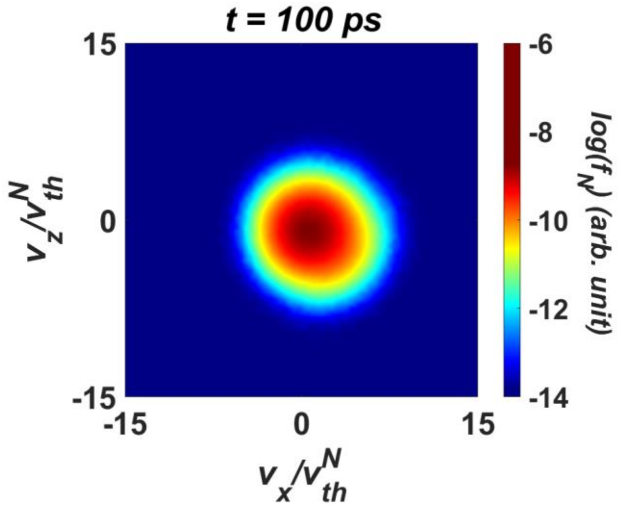
Over longer time scales, ion-ion collisions isotropize the distributions, leading to an increased ion temperature


Electrostatic Energy


Laser field amplitude


Electrostatic field amplitude

- The planar-like IAW has transitioned to localized electrostatic fluctuations
- The ion distribution recovers a near-Maxwellian shape with an elevated temperature (ion-ion collisions transfer energy from the tail to the bulk)



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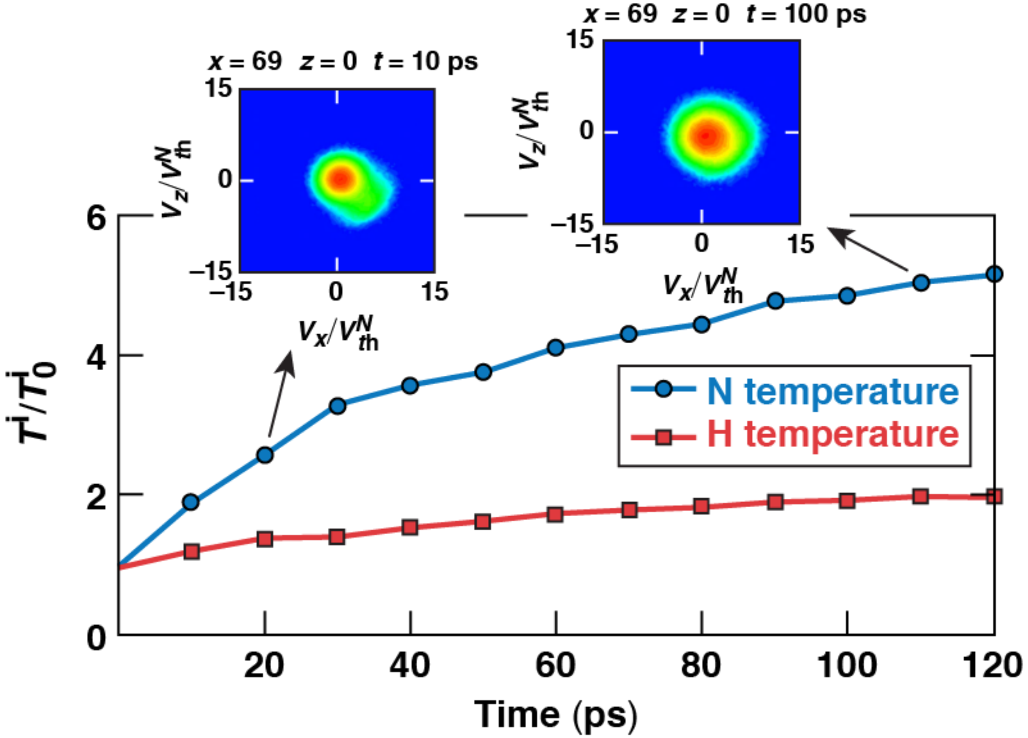
In strong speckles, the increase in ion-temperature shifts the resonant IAW frequency, resulting in a reduced gain



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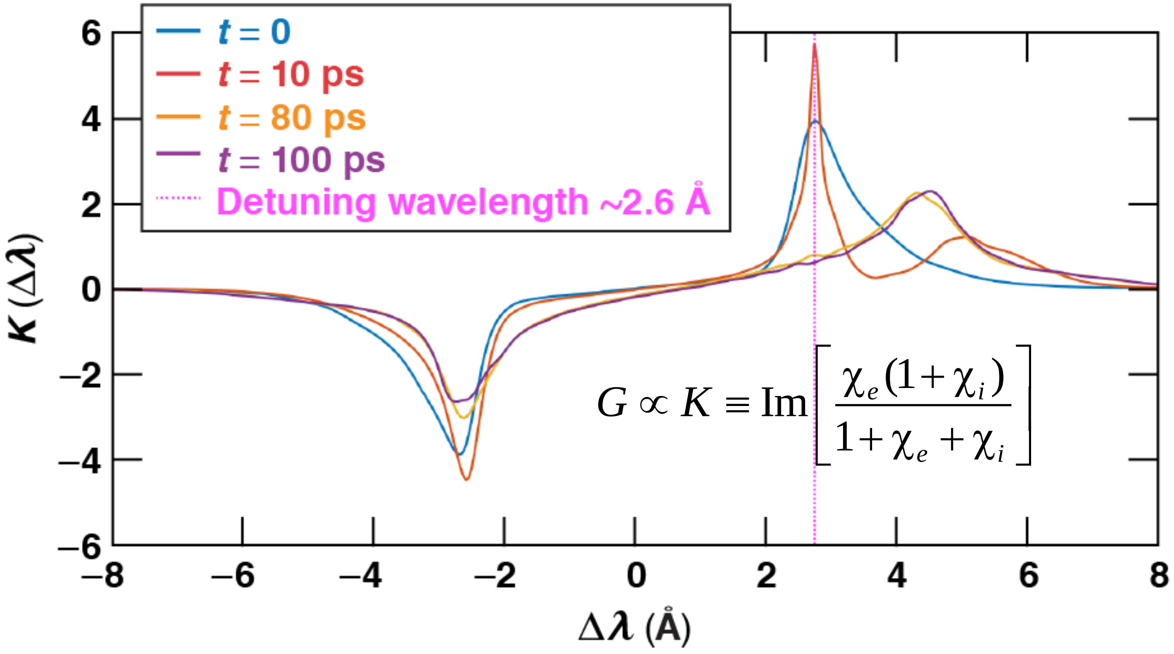

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On the long time scale, the detuning between the pump and seed beams no longer satisfies the matching condition for resonant excitation of the IAW with heated ions

Summary

Ion trapping results in two mechanisms for CBET saturation that occur over different time scales

- The nonlinear evolution of CBET predicted by collisional PIC simulations is in qualitative agreement with focused experiments in implosion relevant conditions (i.e. OMEGA TOP9)
- For the experimental conditions, CBET evolves through three stages:
  - Linear growth of IAW (0 – 12 ps)
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  - Slow saturation (>50 ps)
- On the fast time scale, CBET saturates dues to transverse breakup of the ion-acoustic waves (i.e. trapped particle modulational instability)

On the long time scale, collisional thermalization of trapped ions leads to a loss of resonance that saturates CBET

Questions?