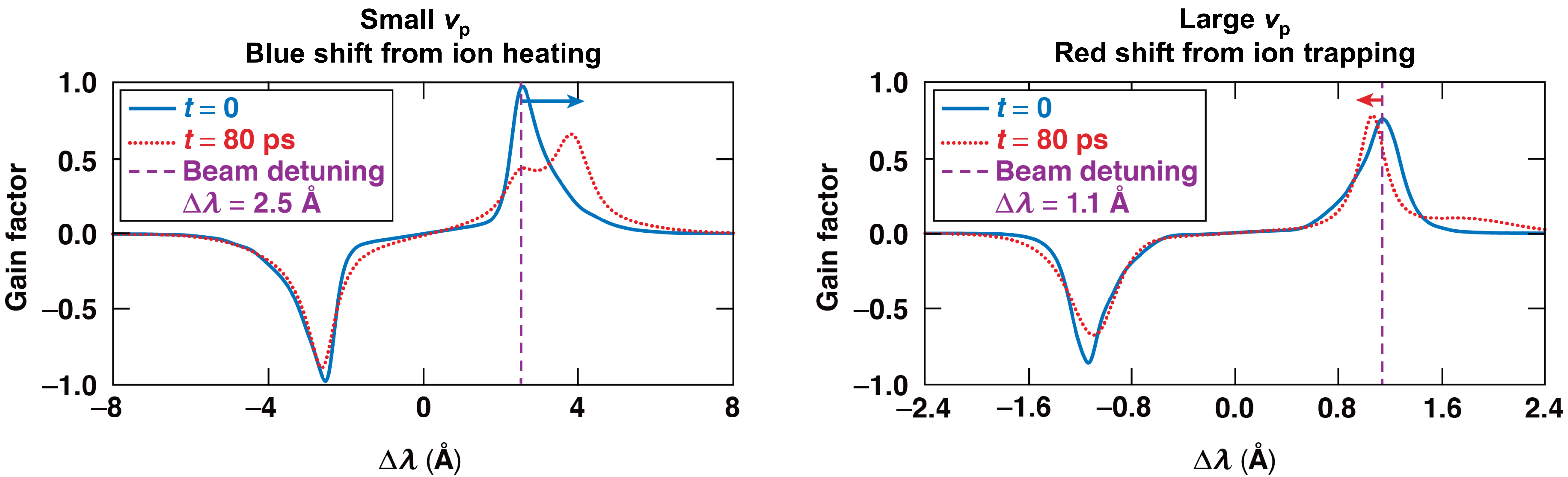
# Cross-beam energy transfer saturation by ion trapping-induced detuning




TC15656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Summary

# CBET can saturate through two types of resonance detuning, both of which result from ion trapping-induced modifications to the ion distribution functions (*)

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- Cross beam energy transfer (CBET) is the exchange of energy between two electromagnetic waves mediated by their ponderomotively driven ion acoustic wave (IAW)
- Collisional VPIC simulations were performed to model the focused CBET experiments conducted on the OMEGA TOP9 platform
- The phase velocity of the driven IAW determines the source of detuning:
  - For small IAW phase velocity, the rapid thermalization causes the resonant IAW frequency to blueshift
  - For large IAW phase velocity, persistent trapping-induced tails in the ion distribution functions result in a small redshift to the resonance IAW frequency

*Nguyen, Khanh Linh, et al. Physics of Plasmas 28.8 (2021): 082705

# Collaborators

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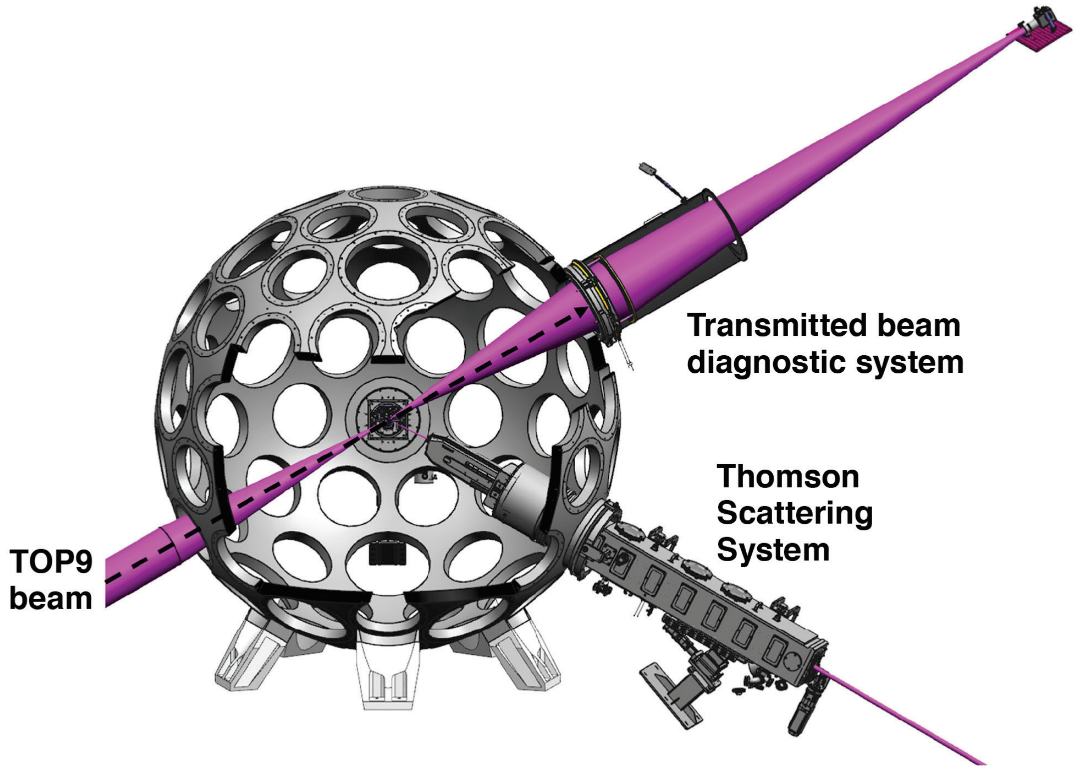
# Cross-beam energy transfer (CBET) is the exchange of energy between electromagnetic waves mediated by their mutually driven ion acoustic wave (IAW)

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

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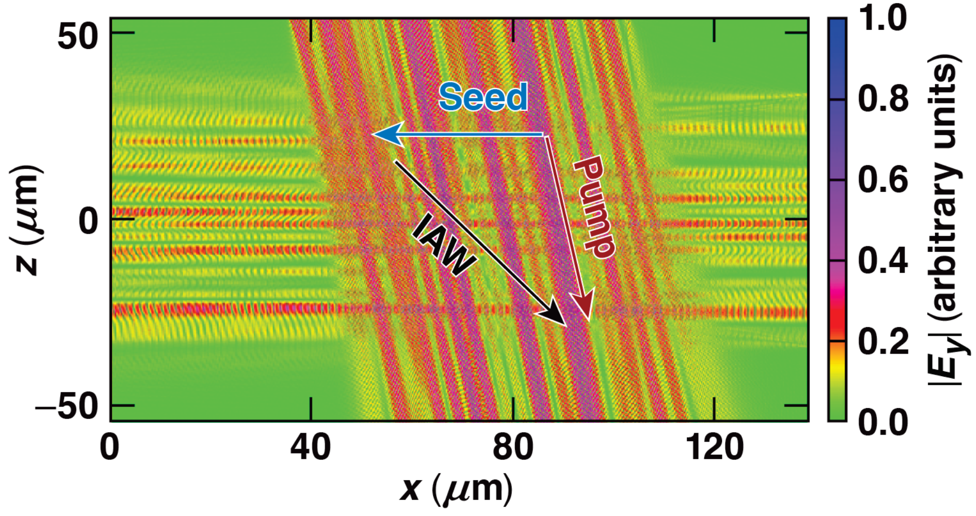
# Collisional VPIC simulations were performed to model CBET experiments on TOP9 for two configurations: (1) Small IAW $v_p$

| Plasma parameters (*) |
|---|
| $n_{e0}$ = 6.0e19 cm$^{-3}$ (0.6% $n_{cr}$) |
| H (55%) and N (45%) |
| $T_e$ = 600 eV and $T_i$ = 150 eV |
| **Laser parameters (*)** |
| Crossing angle = 99$^o$ |
| λ = 351 nm (pump wavelength) |
| Detuning: $\Delta\lambda$ = 2.500 A |
| $I_{pump}$ = 2.2e15 W/cm$^2$ $I_{seed}$ = 5.0e14 W/cm$^2$ |

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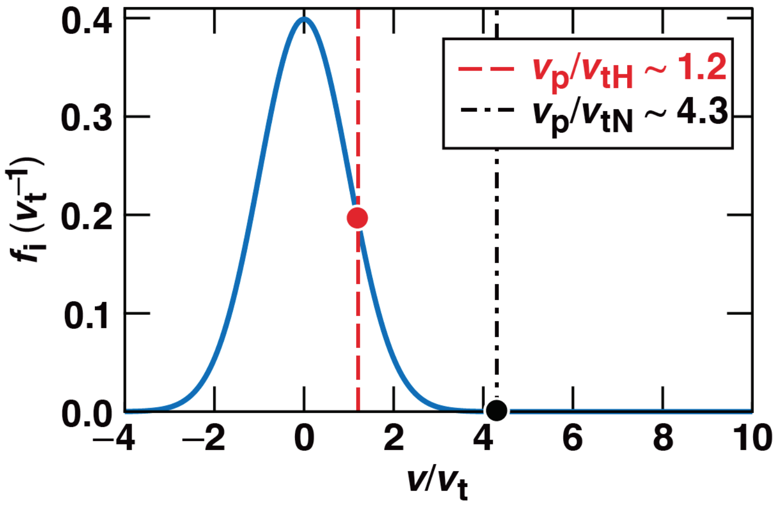


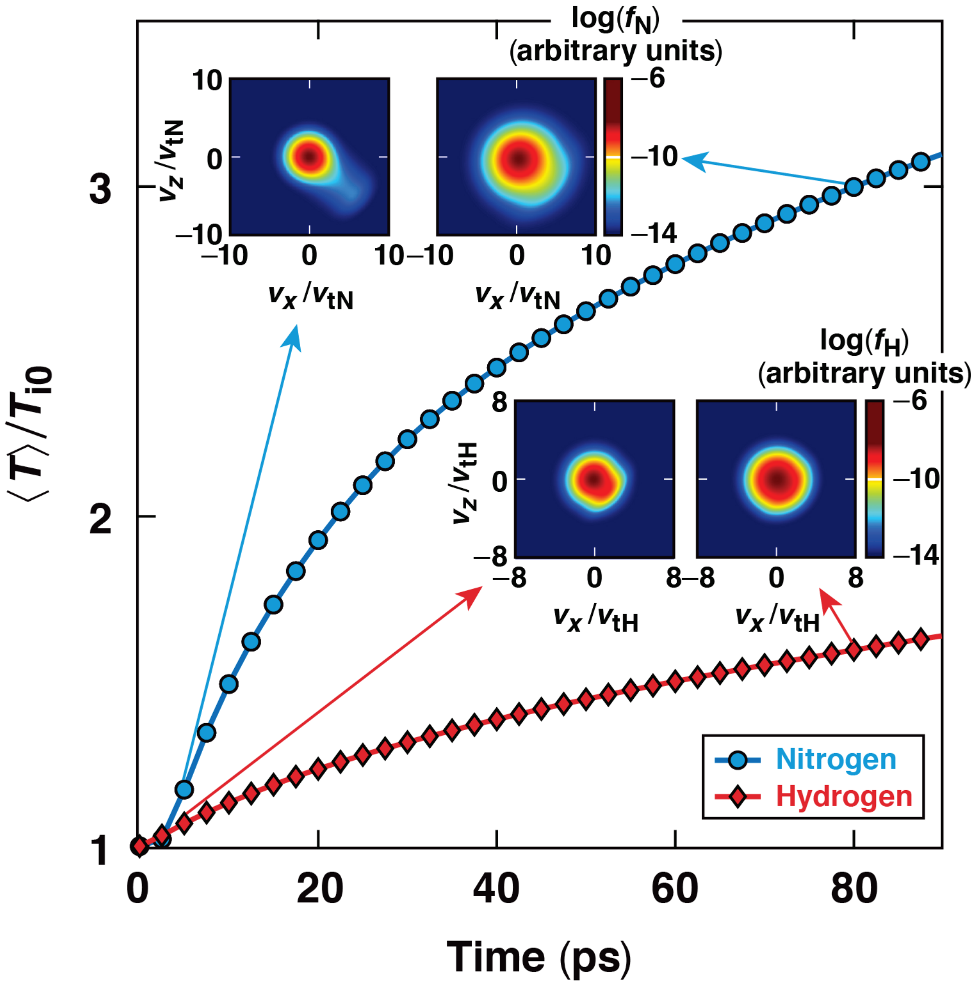

The large crossing angle and low plasma density result in a “small” IAW phase velocity ($v_p \approx 0.54\ c_s$)

Here, $c_s = \sqrt{\frac{\overline{ZT_e + 3T_i}}{\overline{M_i}}}$ is the sound speed




*Hansen, A. M., et al. Physical Review Letters 126.7 (2021): 075002.)

# Ion-ion collisions rapidly thermalize the trapping-induced modifications to the ion distribution function

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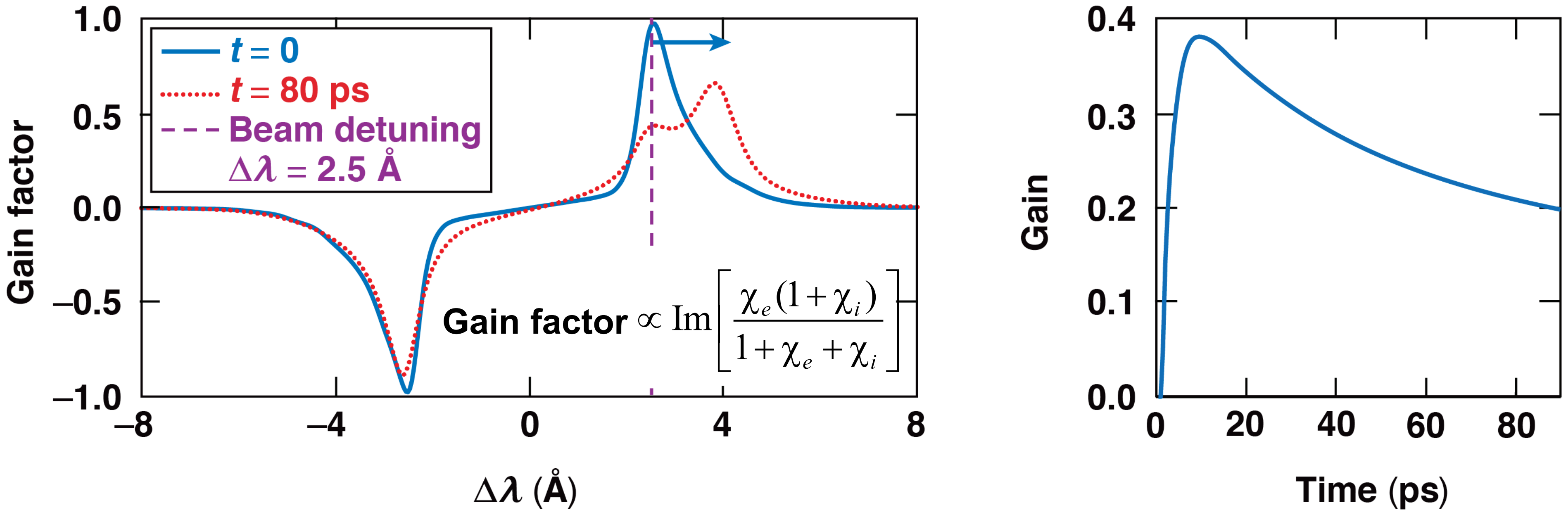
- The IAW traps many more H ions than N ions
- Nevertheless, the N temperature increases by a factor of 3.2, while the H temperature only increases by a factor of 1.6
- Rapid H-N collisions allow the H ions to quickly transfer energy to the N ions, while the slower N-H collisions inhibit the N ions from giving energy to H ions

# The rapid thermalization causes the resonant IAW frequency to blueshift

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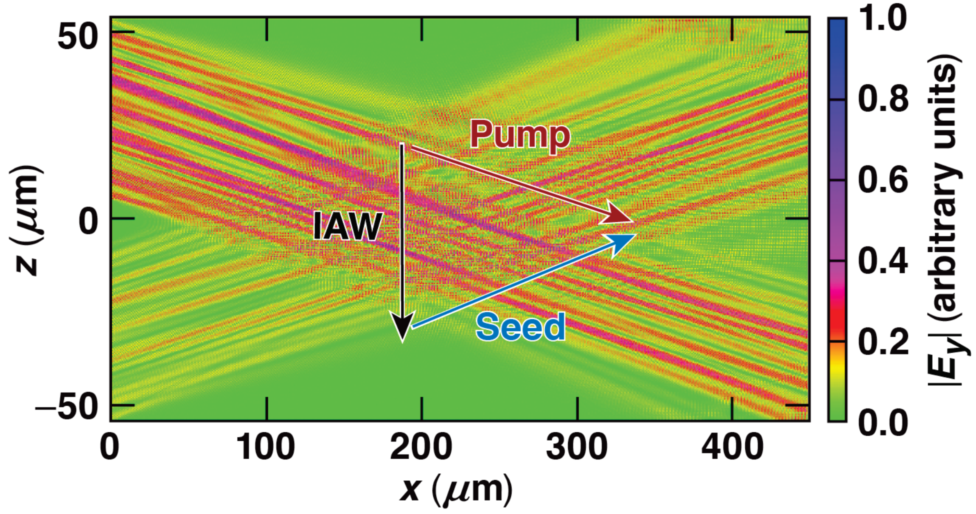
The gain drops over time as the resonant frequency continues to blueshift

# Collisional VPIC simulations were performed to model CBET experiments on TOP9 for two configurations: (2) Large IAW $v_p$

| Plasma parameters (*) |
|---|
| $n_{e0}$ = 1.10e20 cm$^{-3}$ (1.2% $n_{cr}$) |
| H (55%) and N (45%) |
| $T_e$ = 840 eV and $T_i$ = 130 eV |
| **Laser parameters (*)** |
| Crossing angle = 21.4$^o$ |
| $\lambda$ = 351 nm |
| Detuning: $\Delta\lambda$ = 1.100 A |
| $I_{pump}$ = 2.2e15 W/cm$^2$ <br> $I_{seed}$ = 5.0e14 W/cm$^2$ |

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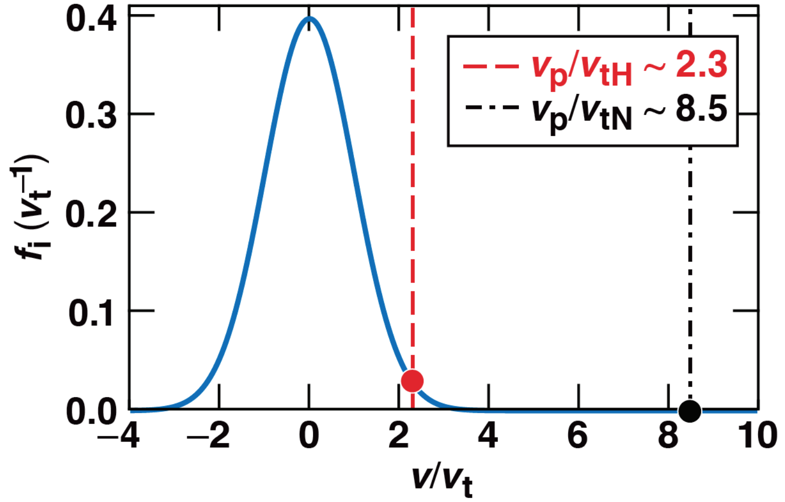


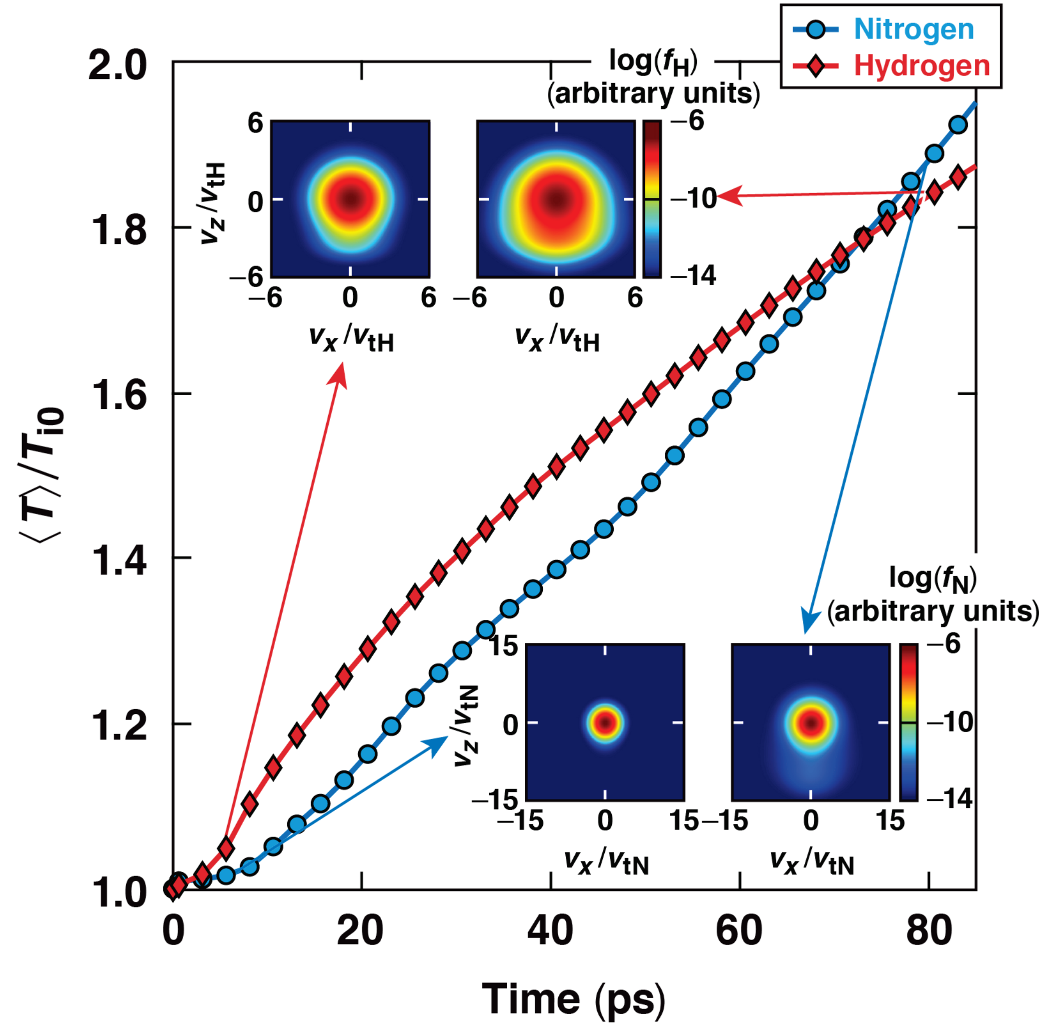

The small crossing angle and high plasma density result in a "large" IAW phase velocity ($v_p \approx 0.85\ c_s$)

Here, $c_s = \sqrt{\dfrac{\overline{Z}T_e + 3T_i}{\overline{M}_i}}$ is the sound speed



*Hansen, A. M., et al. Physical Review Letters 126.7 (2021): 075002.)

# The larger velocity of trapped ions weakens the collisionality and slows thermalization

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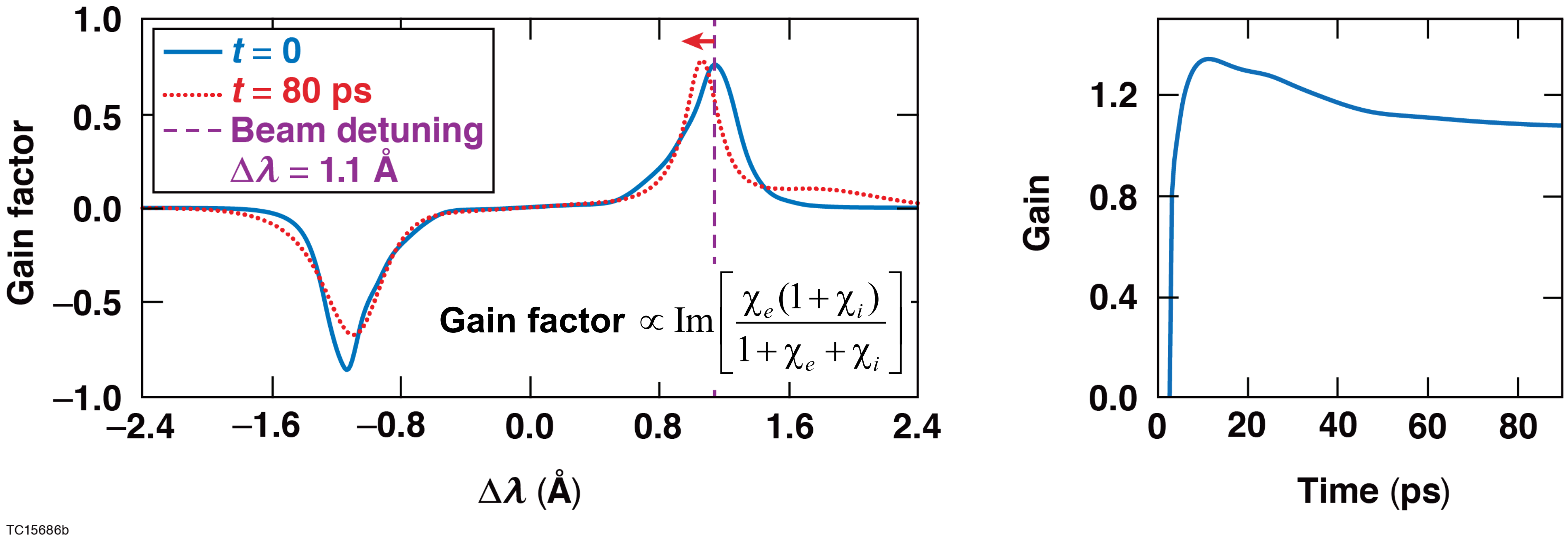
- The H and N temperatures increase nearly in unison by a factor of ~2.0
- The energy exchange rates between the H and N are nearly equal ($\nu_\varepsilon^{HN} \approx \nu_\varepsilon^{NH}$)
- The weak collisionality allows the trapping induced modifications to the distribution functions to persist over longer time scales

# The persistent trapping-induced tails in the ion distribution functions result in a small redshift to the resonance IAW frequency




Redshifting of the resonant frequency causes a slight drop in the gain over the interaction time

Summary

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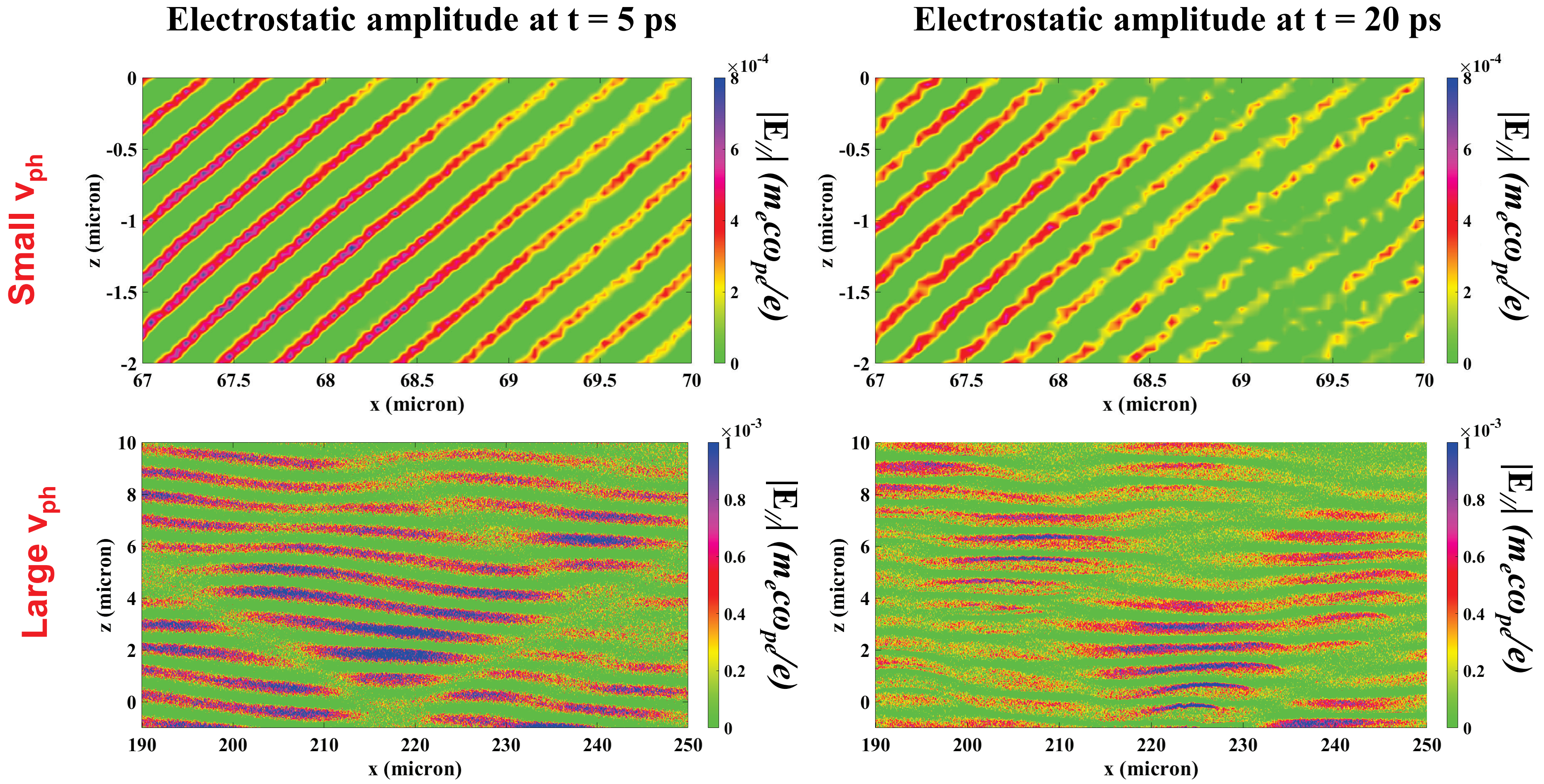
UNIVERSITY of ROCHESTER

*Nguyen, Khanh Linh, et al. Physics of Plasmas 28.8 (2021): 082705.)

# Additional slides

# On the fast-time scale, CBET saturate due to transverse breakup of the ion-acoustic wave




- Transverse breakup of IAW is caused by trapped particle modulational instability (TPMI) (*)
- Transverse breakup allows for quick dissipation of IAW energy
- IAW damping increases as transverse breakup occurs, leading to a saturation of CBET

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