ISSS-15+IPELS-16 Presentation
Max Planck Institute, Garching, Germany, Aug. 7, 2024

Turbulence and Transport from Multiple Entangled Plasma Pressure Filaments in a Magnetized Plasma

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***Acknowledgement*: Faculty and Staff, Basic Plasma Science Facility (BaPSF), UCLA:**
Troy Carter, Walter Gekelman, George Morales
Steve Vincena, Shreekrishna Tripathi, Pat Pribyl & Technical staff

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OUTLINE

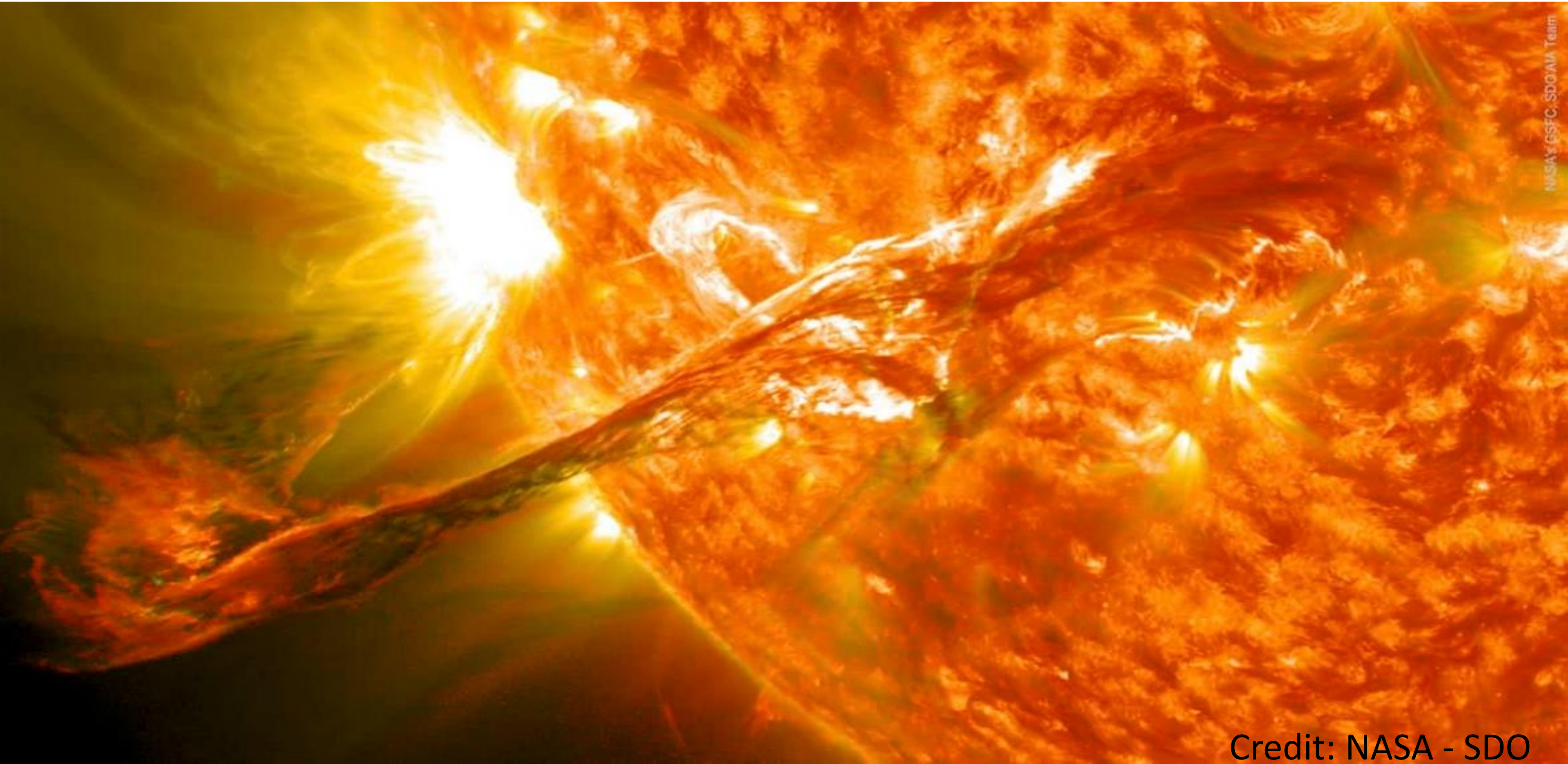
- **Introduction to “blob-filament” structures in magnetized plasma environments**
- **Overview and results from controlled “seeded” filament experiments**
  - **Experiment setup using the Large Plasma Device (LAPD) at BaPSF, UCLA**
  - **Results 1 – Filament-Filament interaction - wave mode structure and self-organization**
  - **Results 2 – 3D gyrokinetic plasma simulations**
  - **Results 3 (New) – Turbulent mixing in a filament lattice**
- **Summary**

RD Sydora, S Karbashewski, B Van Compernolle, MJ Poulos, J. Loughran, *Jour. Plasma Physics*, **85**, 905850612 (2019).

S. Karbashewski, R.D. Sydora, B. Van Compernolle, T. Simala-Grant, M.J. Poulos, *Phys. Plasmas*, **29**, 112309 (2022).

RD Sydora, T Simala-Grant, S Karbashewski, F Jimenez, B Van Compernolle, MJ Poulos, *Phys Plasmas*, **31**, 082304 (2024)

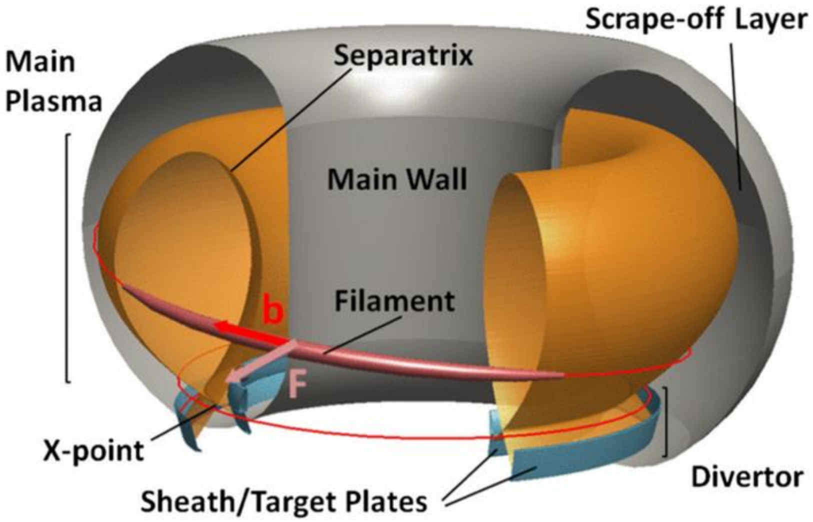
Filamentary Structures in Magnetized Plasmas



Credit: NASA - SDO

INTRODUCTION

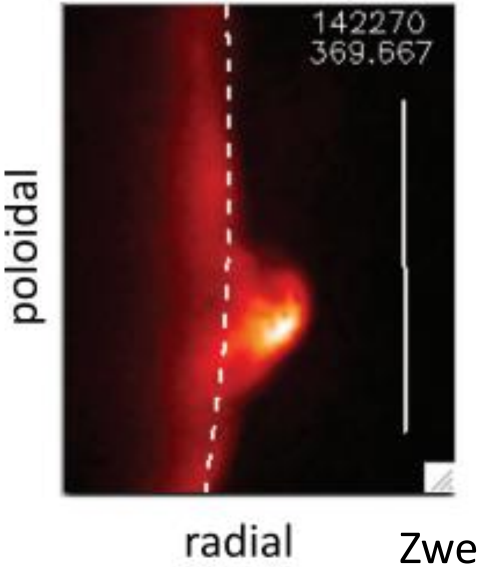
- Motivation for this work partly comes from extensive research in the last two decades on “blobs” or “blob-filament” transport in edge region of toroidal, magnetized plasmas



Carralero et al, 2015

Blob image – Gas puff imaging (GPI)

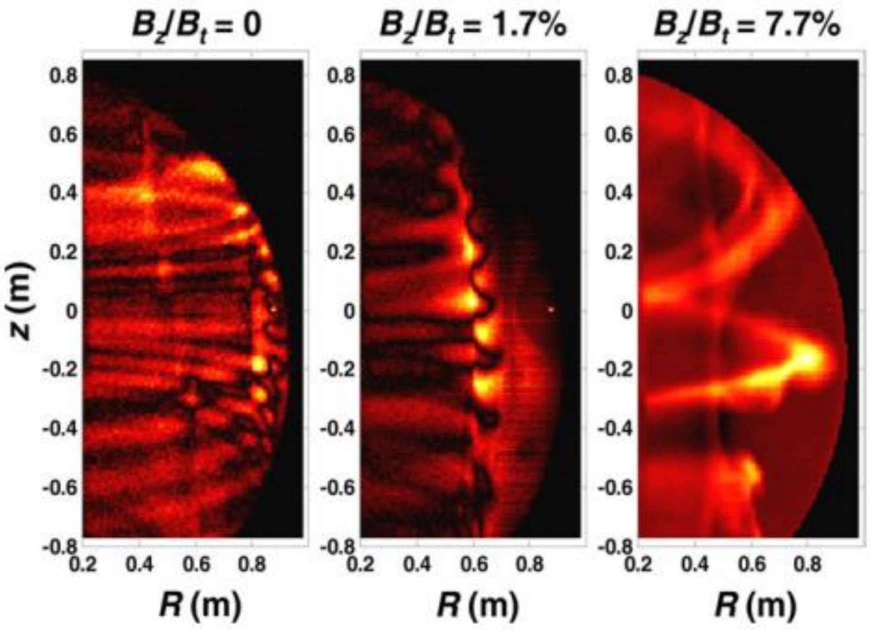
NSTX



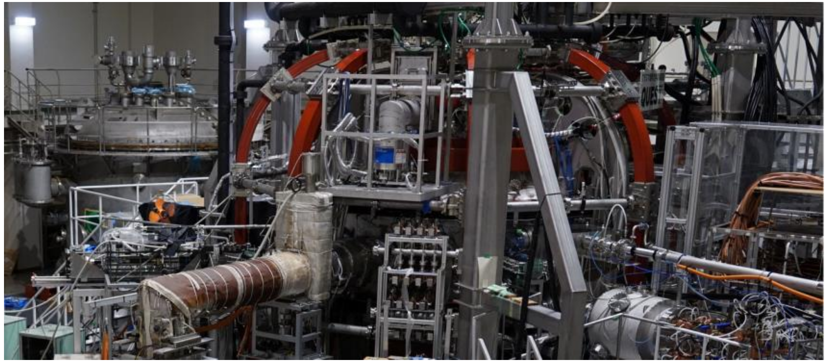
Zweben et al, 2022

INTRODUCTION

➢Further observations of filamentary structures in toroidal plasmas



QUEST Plasma Experiment, Japan



Banerjee et al, 2012

INTRODUCTION

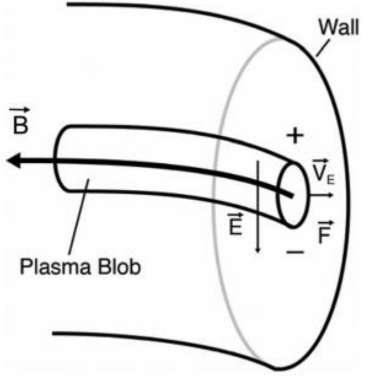
- Cross-field transport of particles and energy is enhanced through blob-filaments.
- Blob transport is *intermittent* rather than a purely diffusive process.
- The blob-like structure forms as a result of instabilities, either in the core or the edge region of the toroidal plasma (active research area).

INTRODUCTION

- Cross-field transport of particles and energy is enhanced through blob-filaments.
- Blob transport is *intermittent* rather than a purely diffusive process.
- The blob-like structure forms as a result of instabilities, either in the core or the edge region of the toroidal plasma (active research area).
- Physical mechanism of radial motion of blob-filaments is quite well understood through action of gradient-B and curvature drifts of charged particles in the blob, which polarize it, leading to radial **E**x**B** motion (S. Krasheninnikov, 2001).

Gradient drift $\mathbf{V_B} = \frac{\mathbf{mv_\perp^2}}{\mathbf{2qB^3}}(\mathbf{B} \times \nabla \mathbf{B})$ → polarization

ExB drift $\mathbf{V_E} = \frac{\mathbf{E \times B}}{\mathbf{B^2}}$ → cross-field drift



D'Ippolito, Myra, Zweben, PoP, 2011

INTRODUCTION

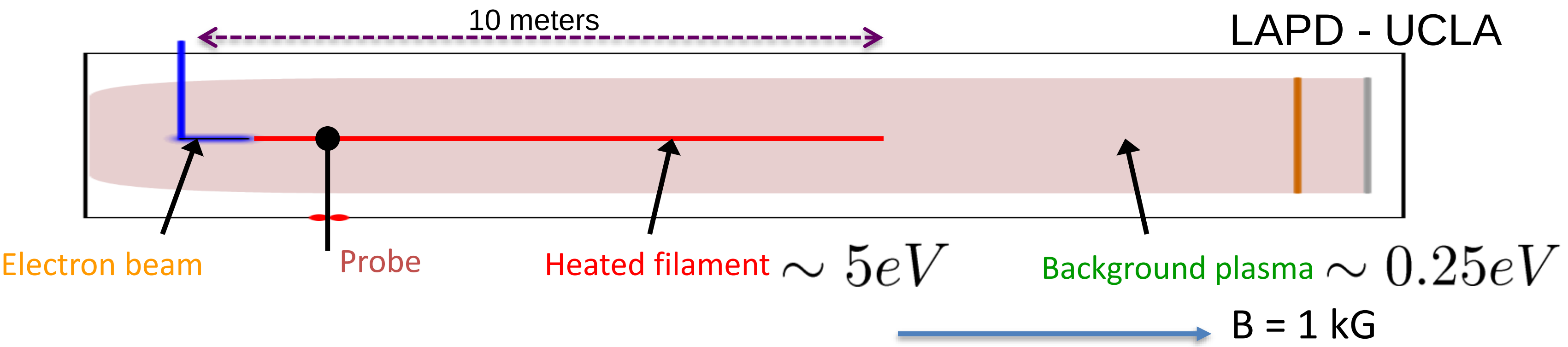
Main questions addressed in this work:

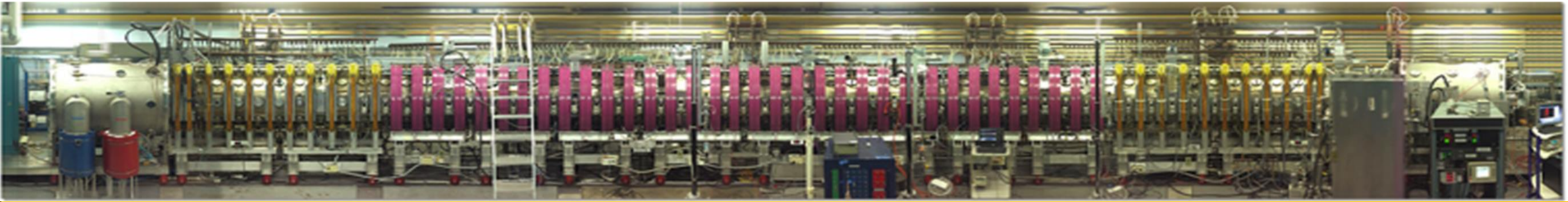
- *Internal instabilities* in coherent blob-filament structure – the question of lifetime?
- What is the *range of interaction* in cases of multiple blob-filaments in close proximity? Properties of filament-filament interaction.

EXPERIMENT SETUP

Making "blob-filaments"

A long, narrow temperature filament in an afterglow plasma

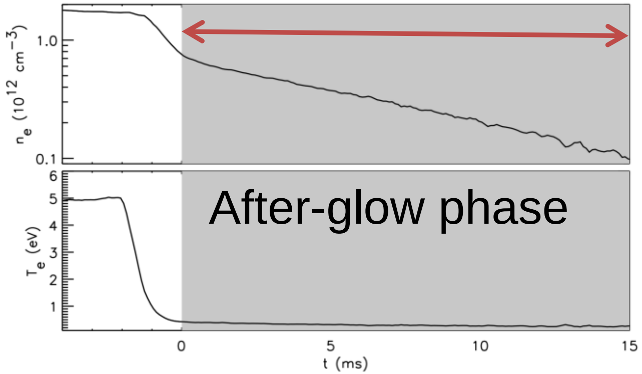




W. Gekelman *et al.*, Rev. Sci. Instruments **87**, 025105 (2016), A.T. Burke et al, Phys. Plasmas 7 (5), 1397, 2000.

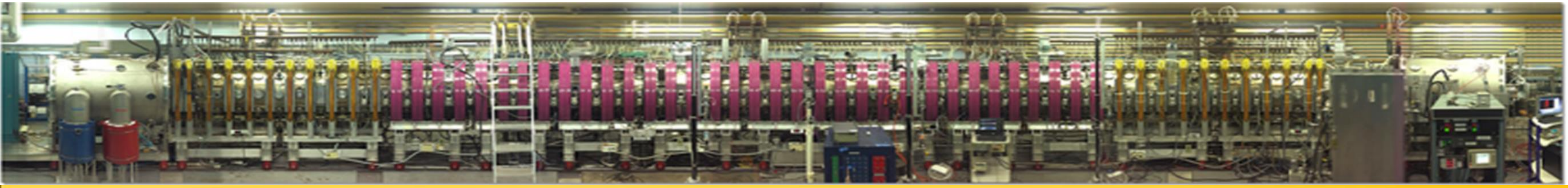
Experiment Setup

- The experiments take place in the Large Plasma Device (LAPD) at the Basic Plasma Science Facility (BaPSF) at UCLA.



➢ *Afterglow Plasma Parameters:*

- **Helium plasma**
- **Background Magnetic Field, $B_0 = 1000$ G**
- **Density, $n \sim 1 \times 10^{12}$ cm^{-3}**
- **Background electron temperature, $T_e < .5$ eV**
- **Alfvén Speed, $V_A \sim 10^8$ cm/s**
- **Ion Sound Speed, $c_s < 10^6$ cm/s**
- **Ion Cyclotron Frequency, $\Omega_i \sim 380$ kHz**



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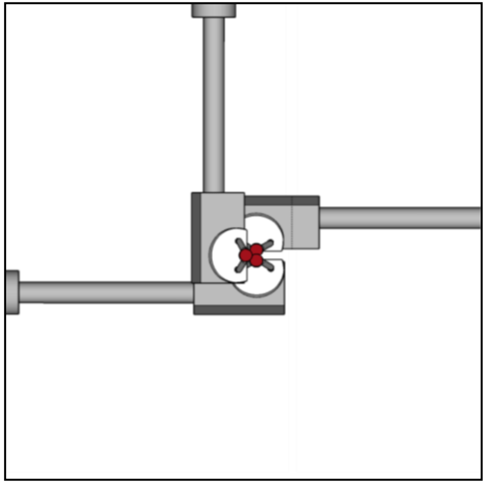
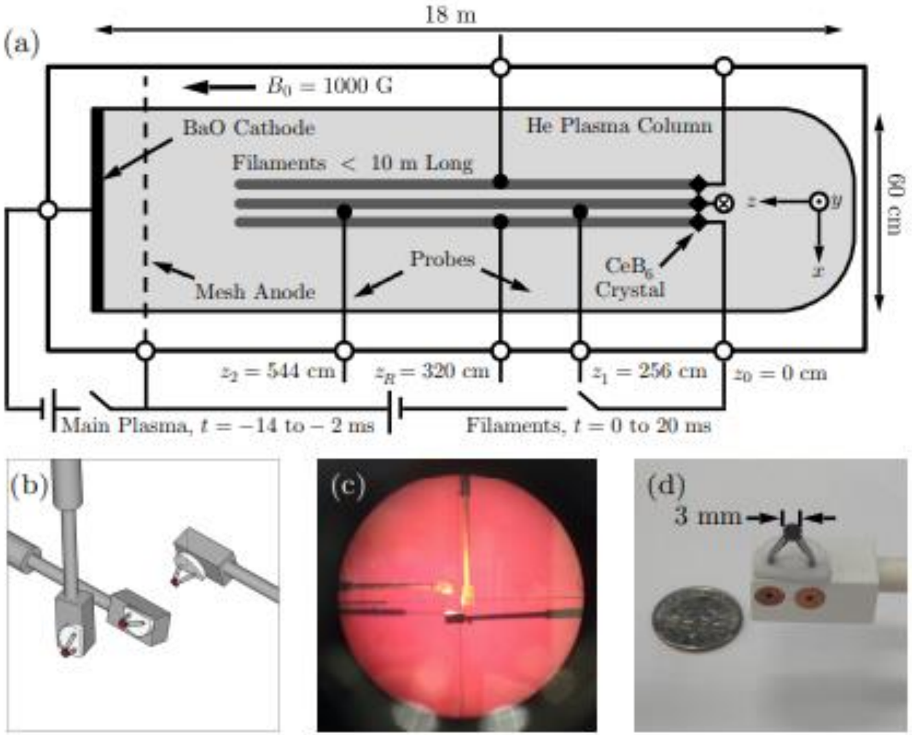
EXPERIMENT SETUP

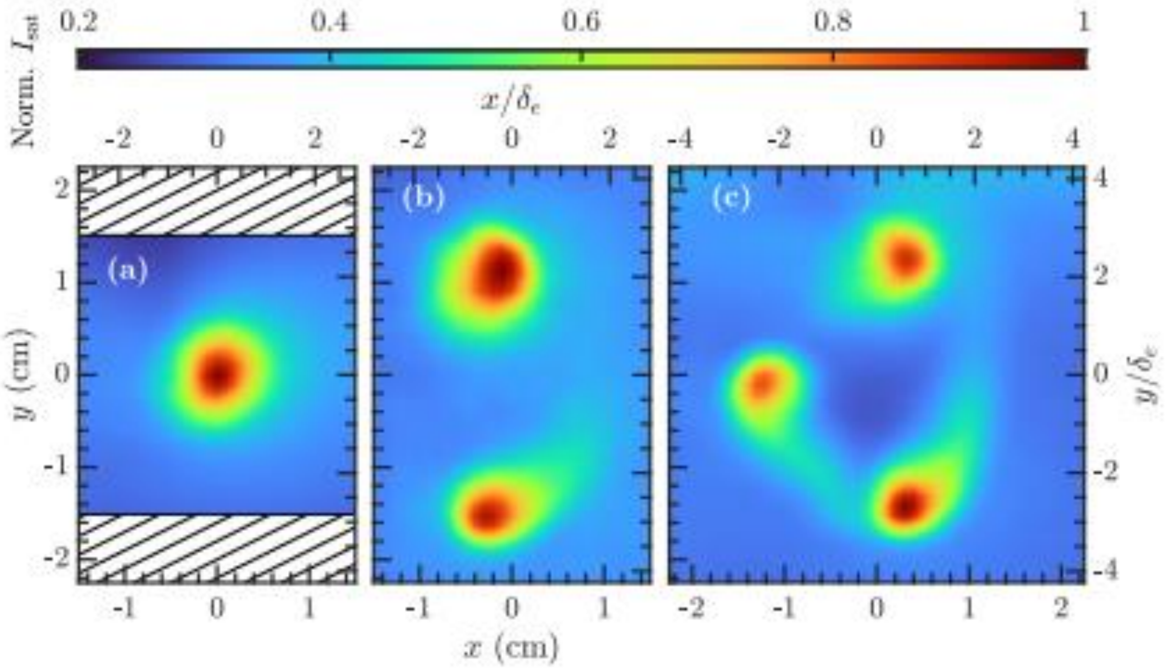




R.D. Sydora, S. Karbashewski, B. Van Compernolle, M.J. Poulos, J. Loughran, *Jour. Plasma Phys.* (2019)

CROSS-FIELD ION SATURATION CURRENT (I_{SAT}) PLANES: 1, 2 AND 3 FILAMENTS

Planes take at axial location z_1 = 256cm



S. Karbashewski, R.D. Sydora, B. Van Compernolle, T. Simala-Grant, M.J. Poulos, *Phys. Plasmas*, **29**, 112309 (2022).

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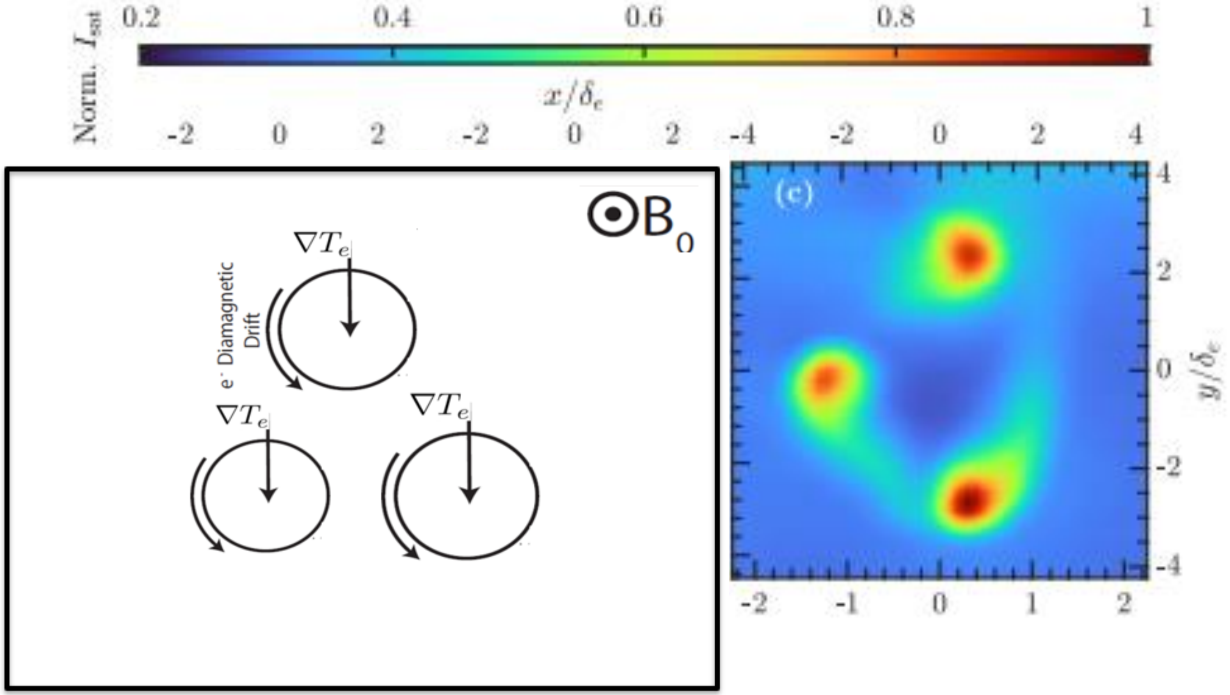

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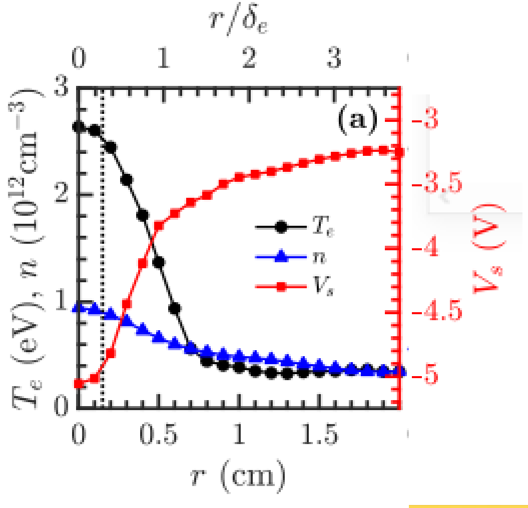

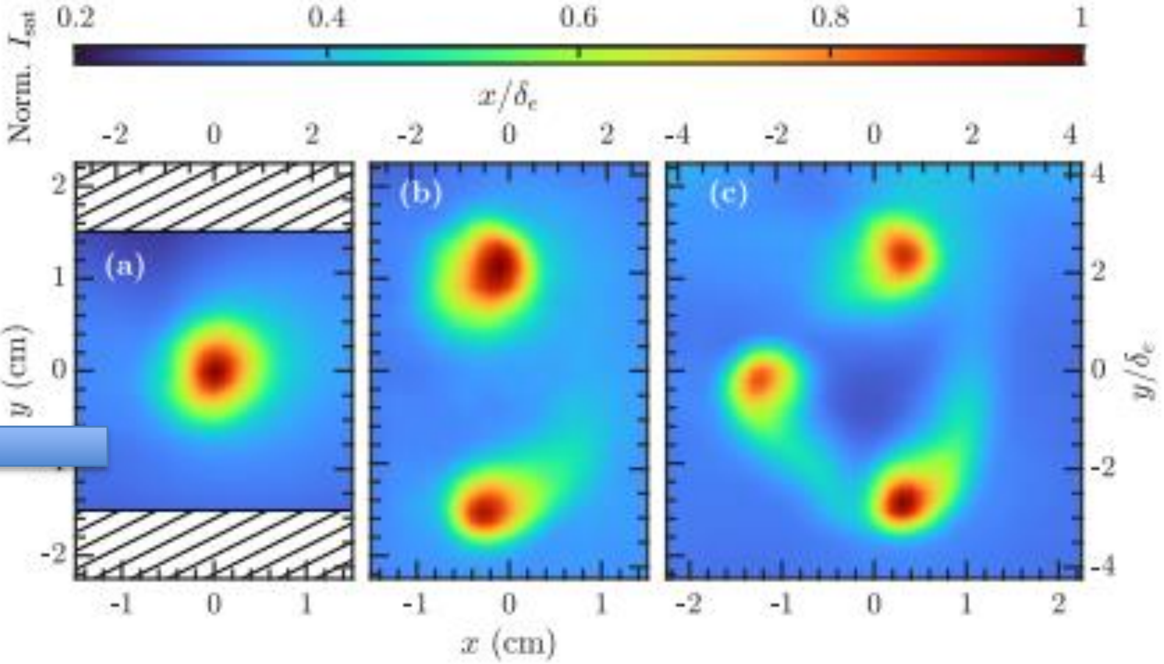

S. Karbashewski, R.D. Sydora, B. Van Compernolle, T. Simala-Grant, M.J. Poulos, *Phys. Plasmas*, **29**, 112309 (2022).

Cross-field Ion Saturation Current (I_{SAT}) Planes: 1, 2 and 3 filaments

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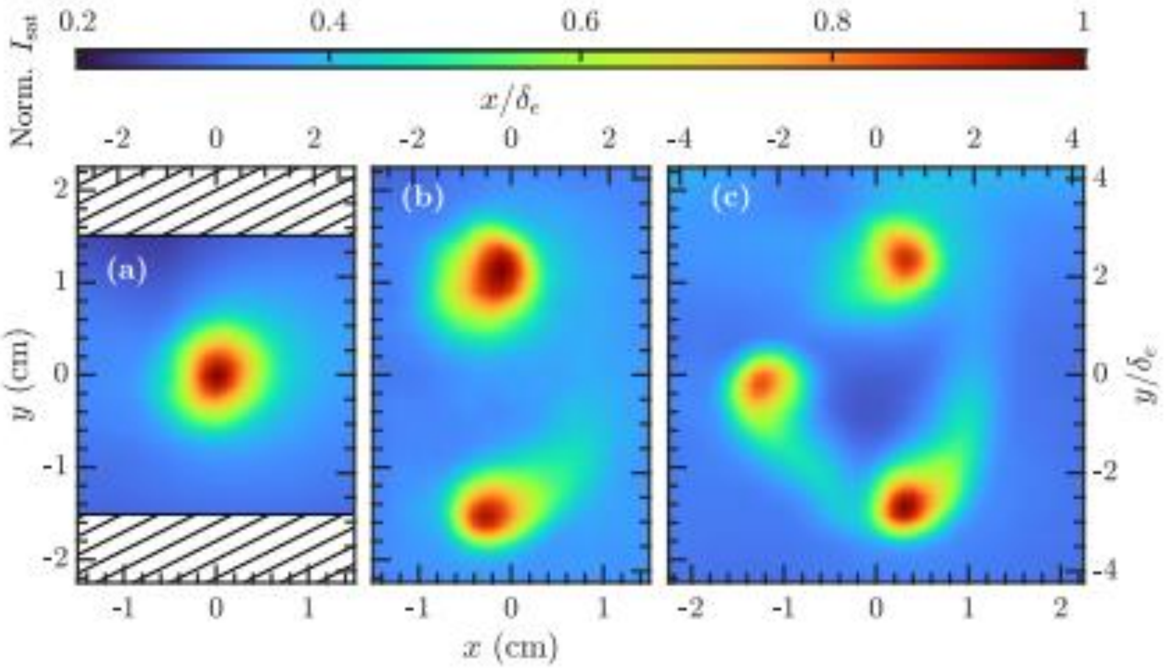

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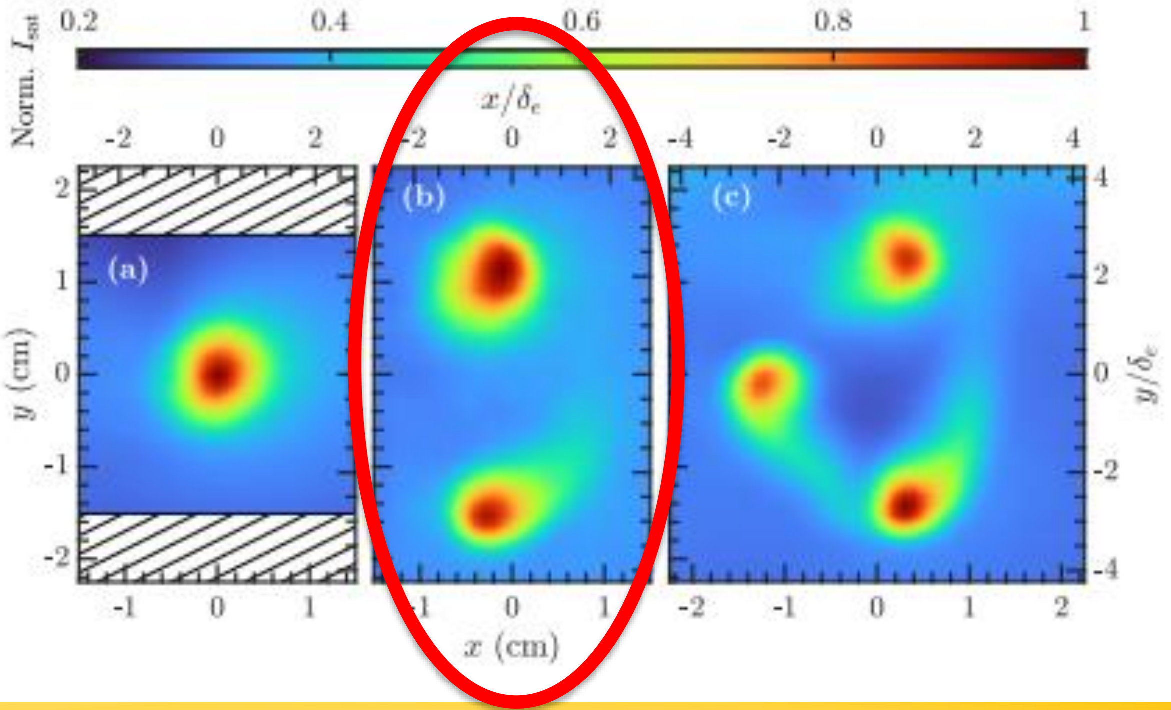

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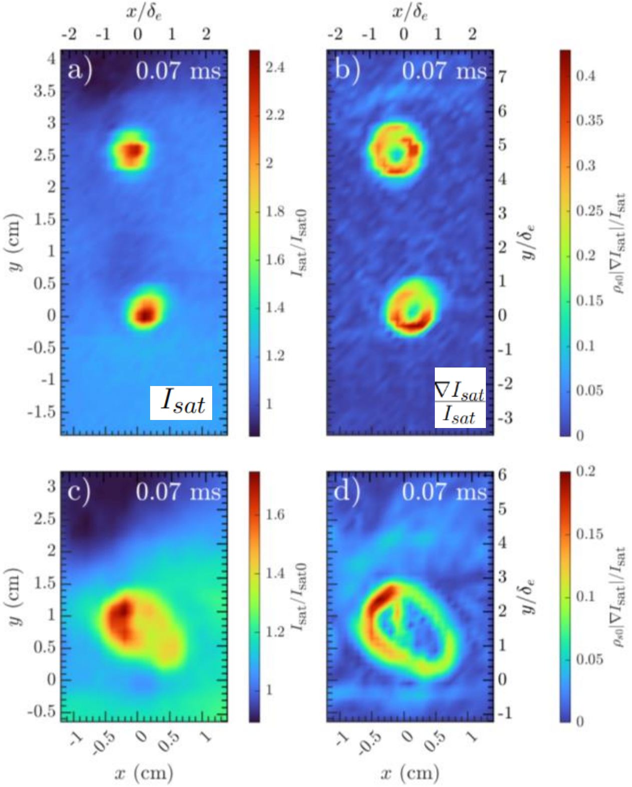
Cross-field Ion Saturation Current (I_{SAT}) Planes, z_1=256cm: 2-Filament Case



RD Sydora, T Simala-Grant, S Karbashewski, F Jimenez, B Van Compernolle, MJ Poulos, *Phys Plasmas*, **31**, 082304 (2024)

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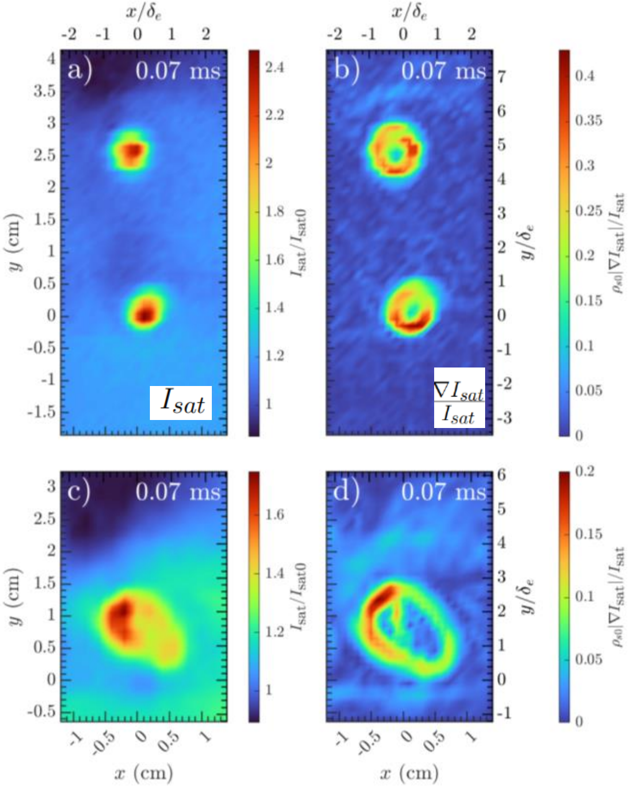

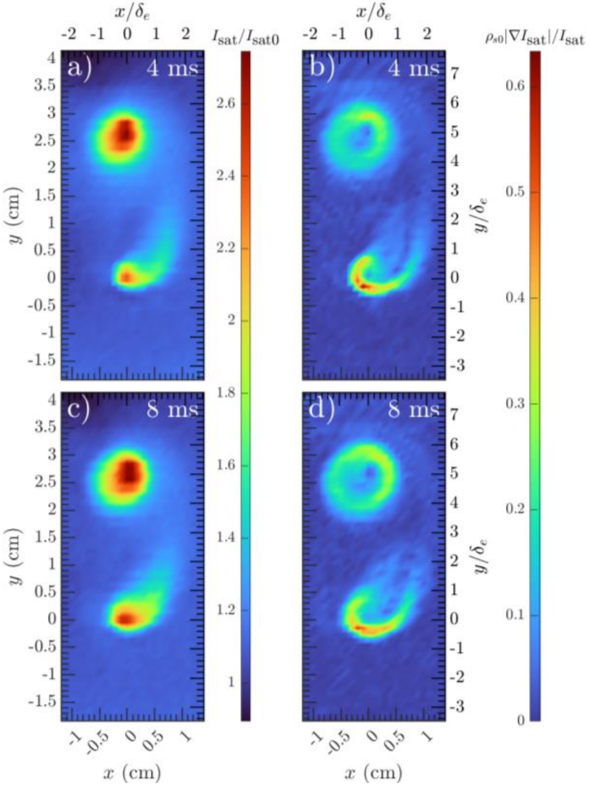

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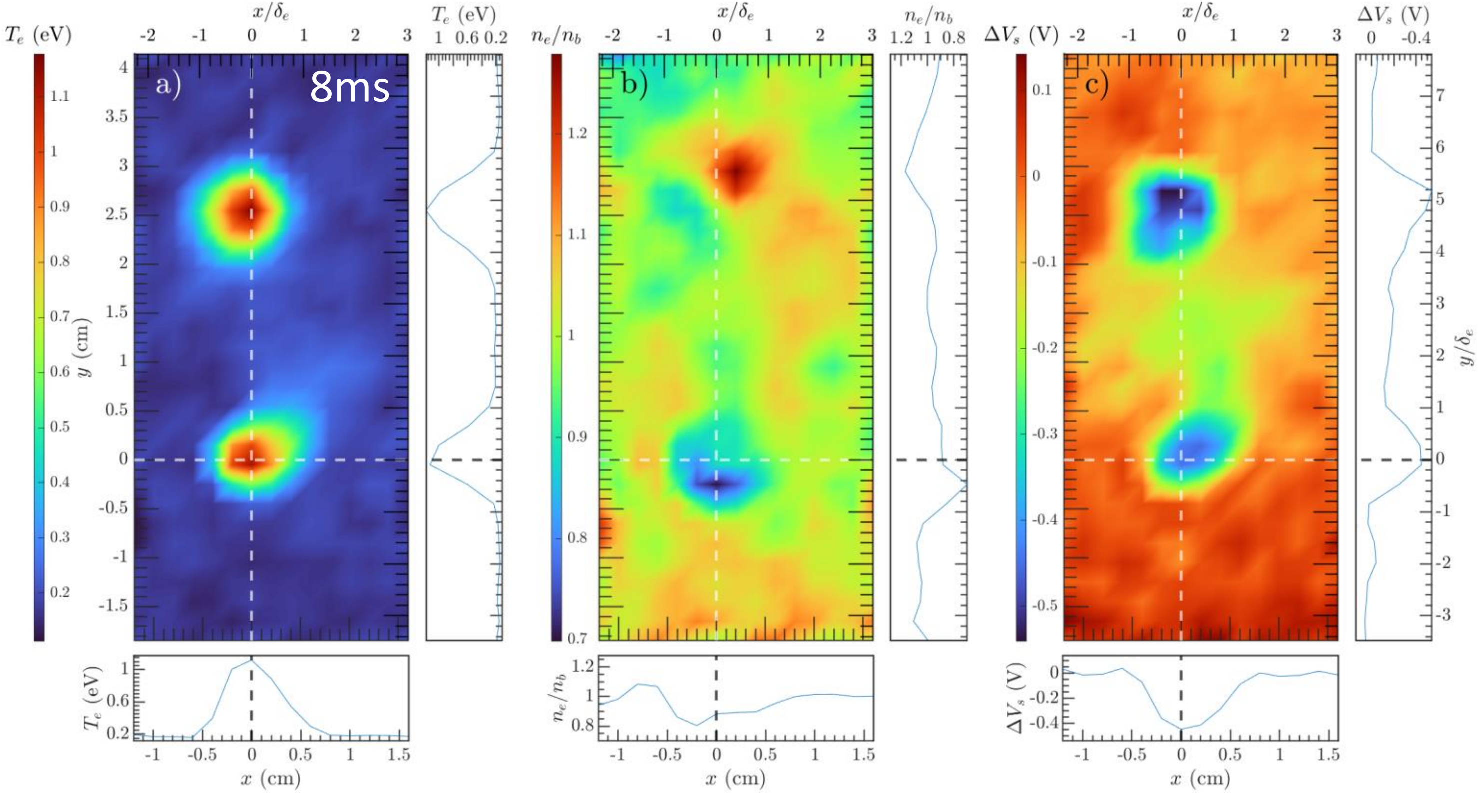
CROSS-FIELD PLANES – TEMPERATURE, DENSITY, POTENTIAL, z_1=256CM: 2-FILAMENT CASE



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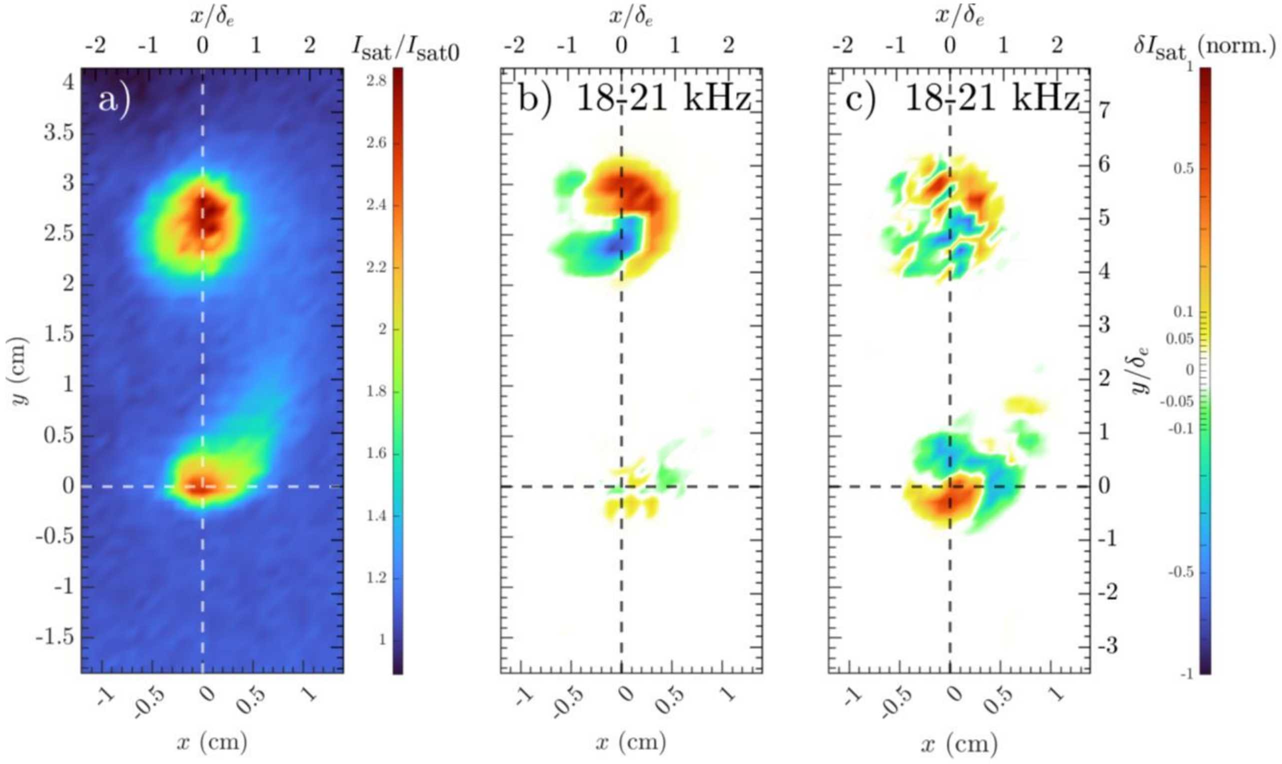
Cross-field Planes – Mode Structure, z_1=256cm: 2-Filament Case



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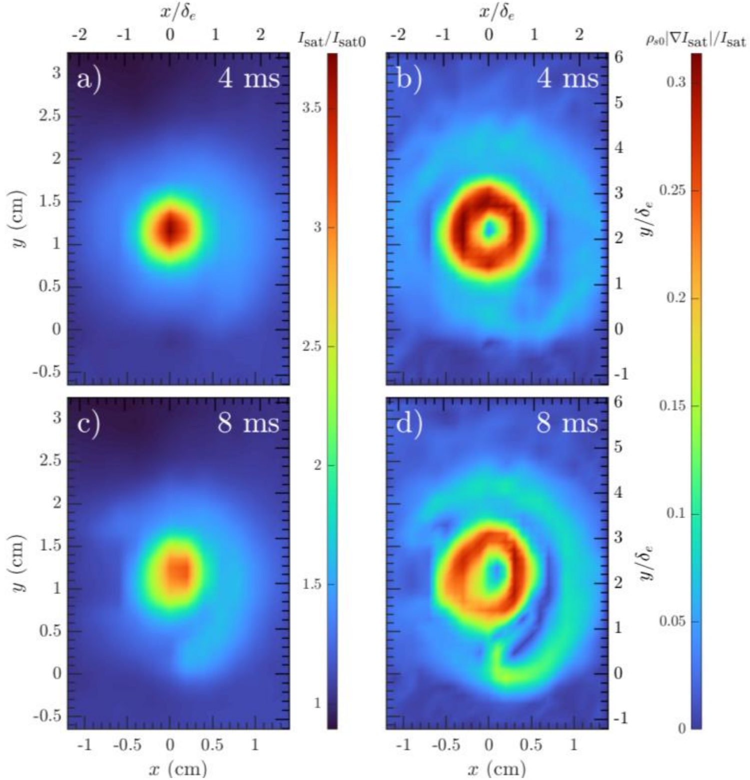

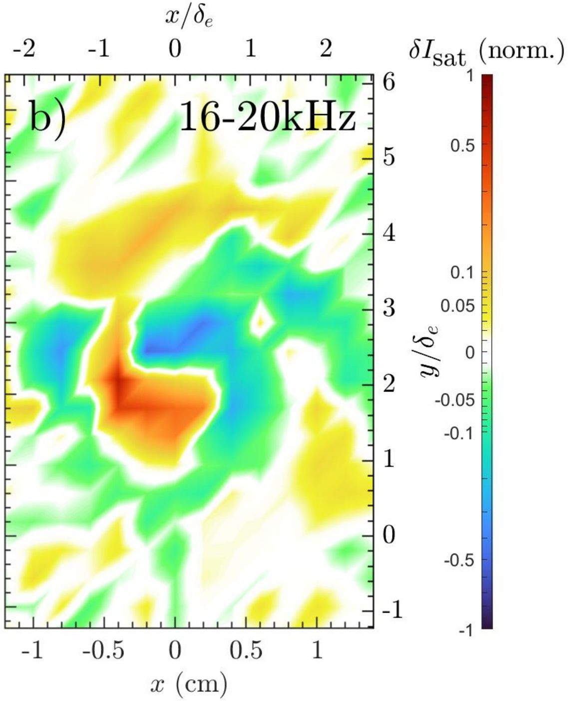

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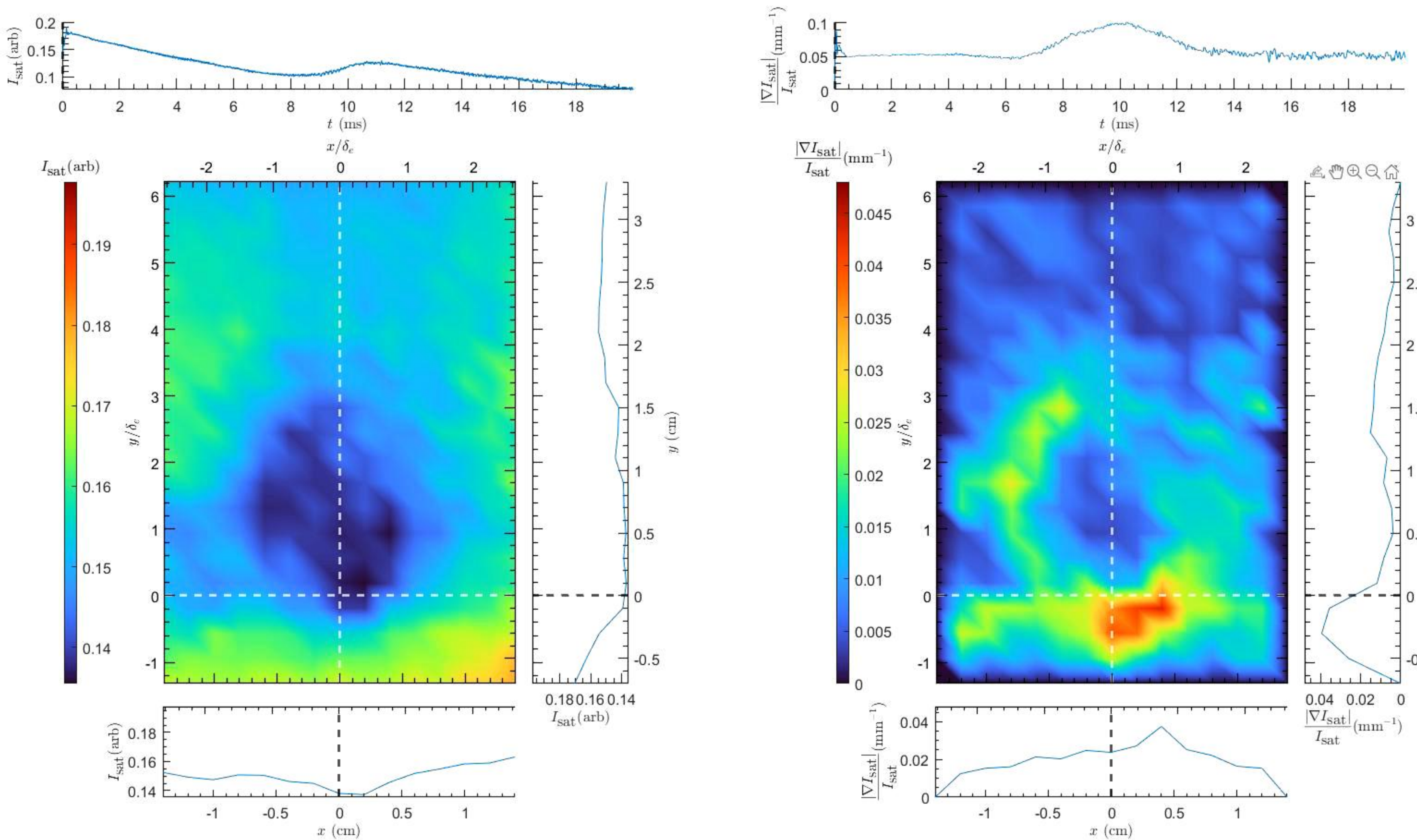

$I_{\rm sat}$(arb)
t (ms)
$\frac{|\nabla I_{\rm sat}|}{I_{\rm sat}}$(mm^{-1})
t (ms)
x/δ_e
$I_{\rm sat}$(arb)
y/δ_e
y (cm)
$I_{\rm sat}$(arb)
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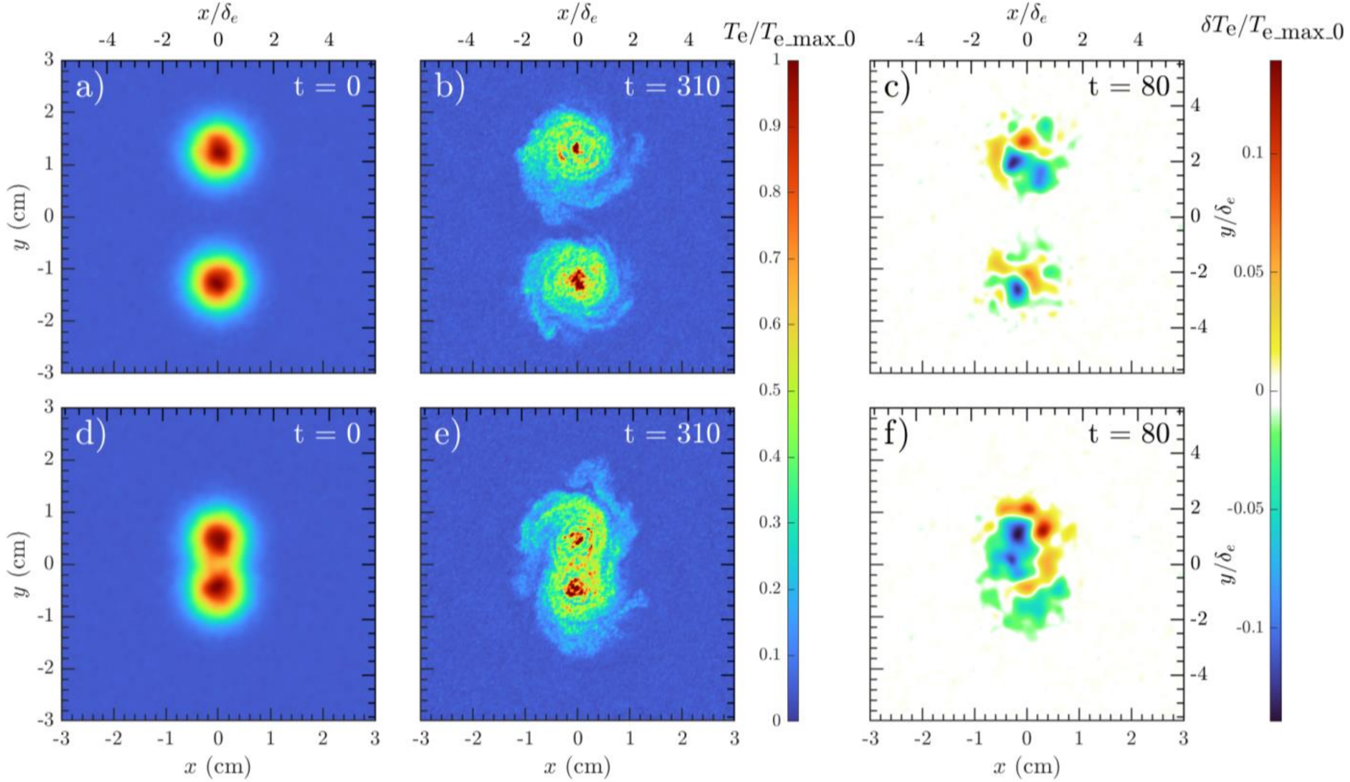
x (cm)

CROSS-FIELD δT_E PLANES – 3D GYROKINETIC SIMULATIONS: 2-FILAMENT CASE



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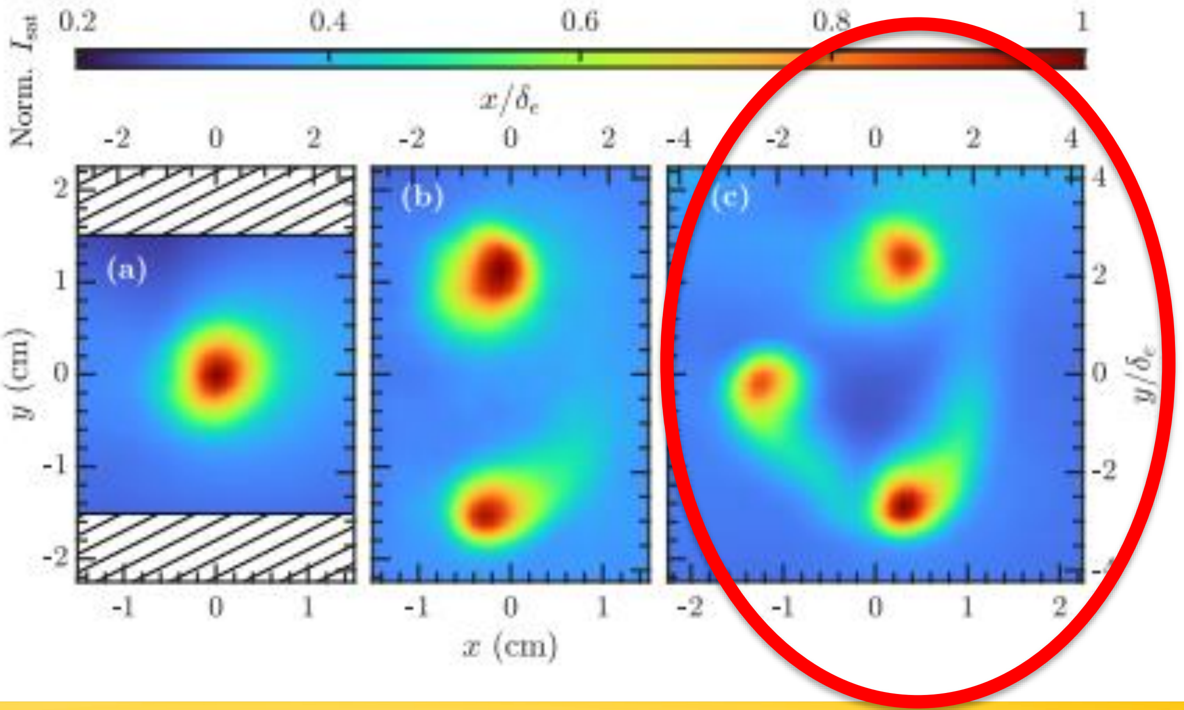

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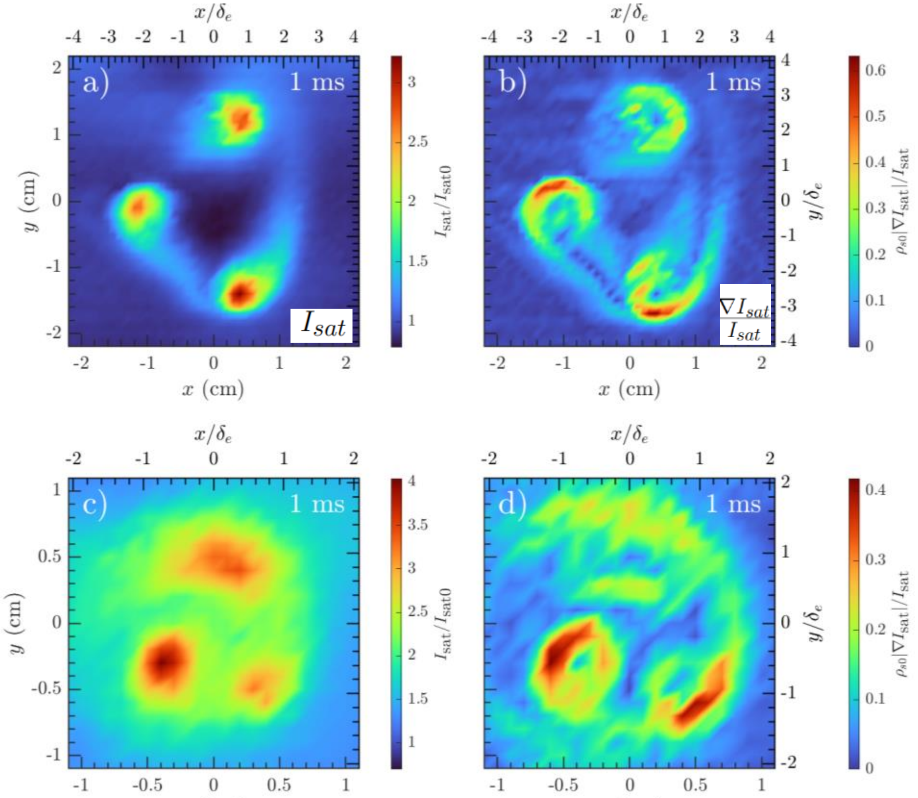
CROSS-FIELD ION SATURATION CURRENT (I_{SAT}) PLANES, z_1=256CM: 3-FILAMENT CASE



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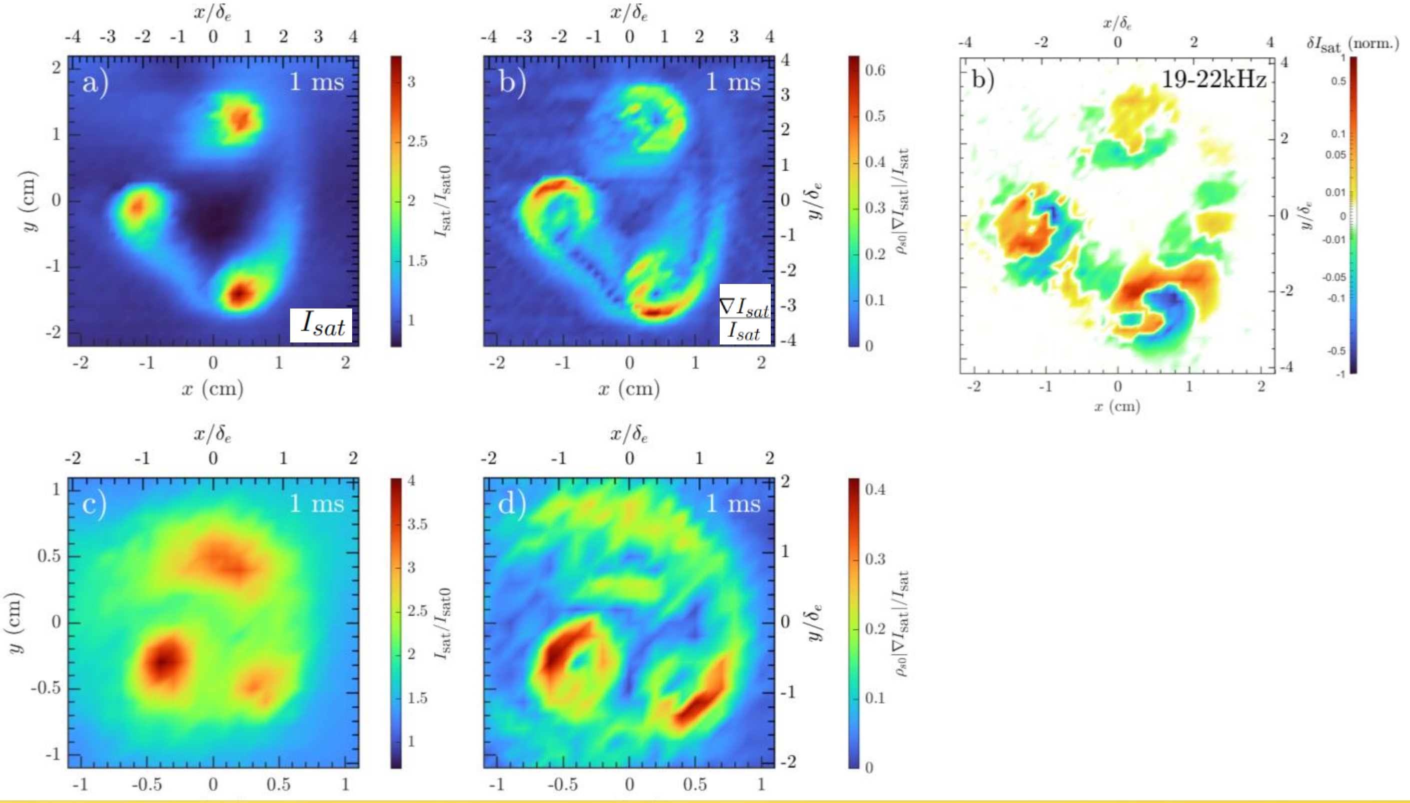
Cross-field Ion Saturation Current (I_{SAT}) Planes, z_1=256cm: 3-Filament Case



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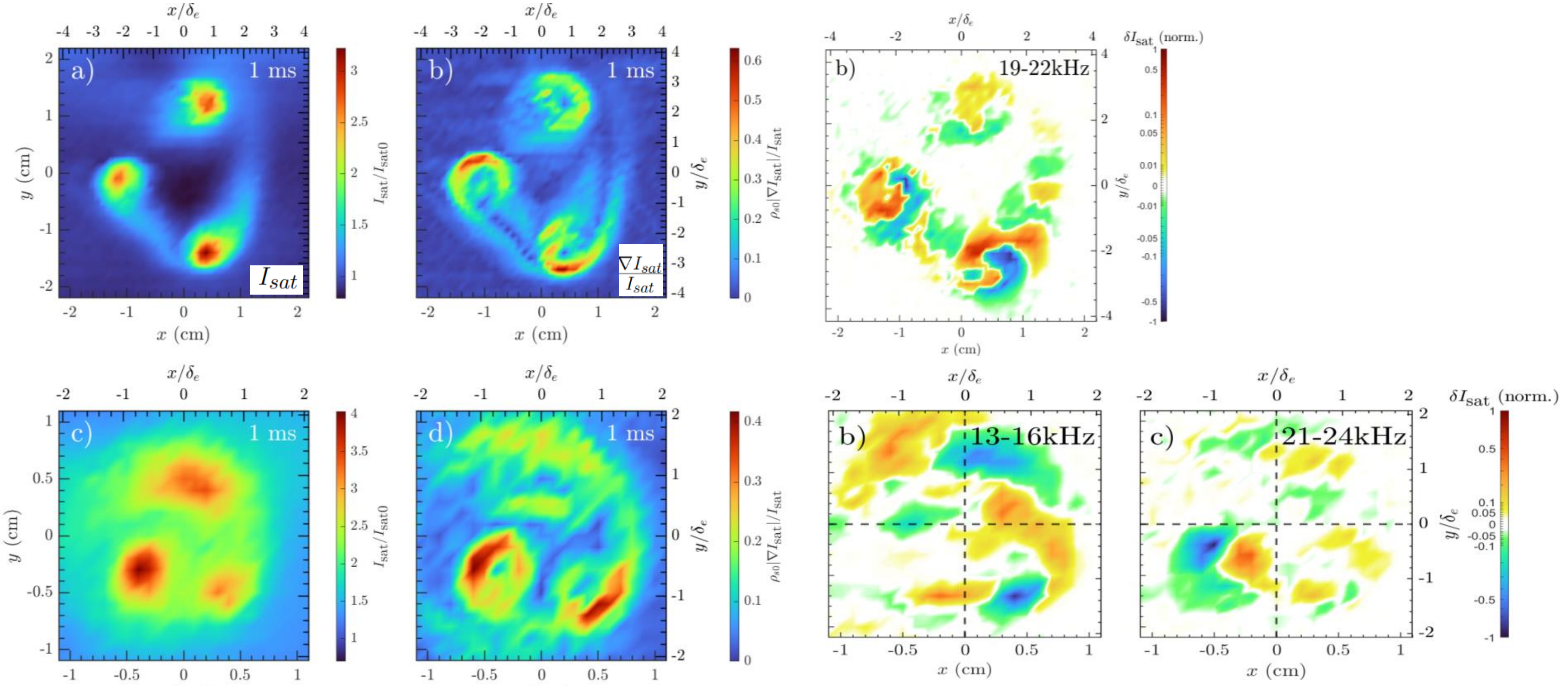

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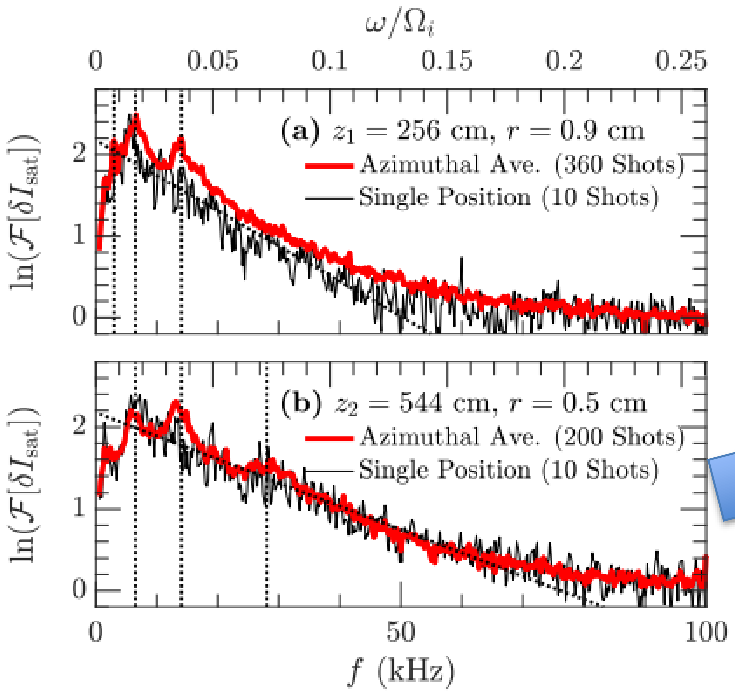
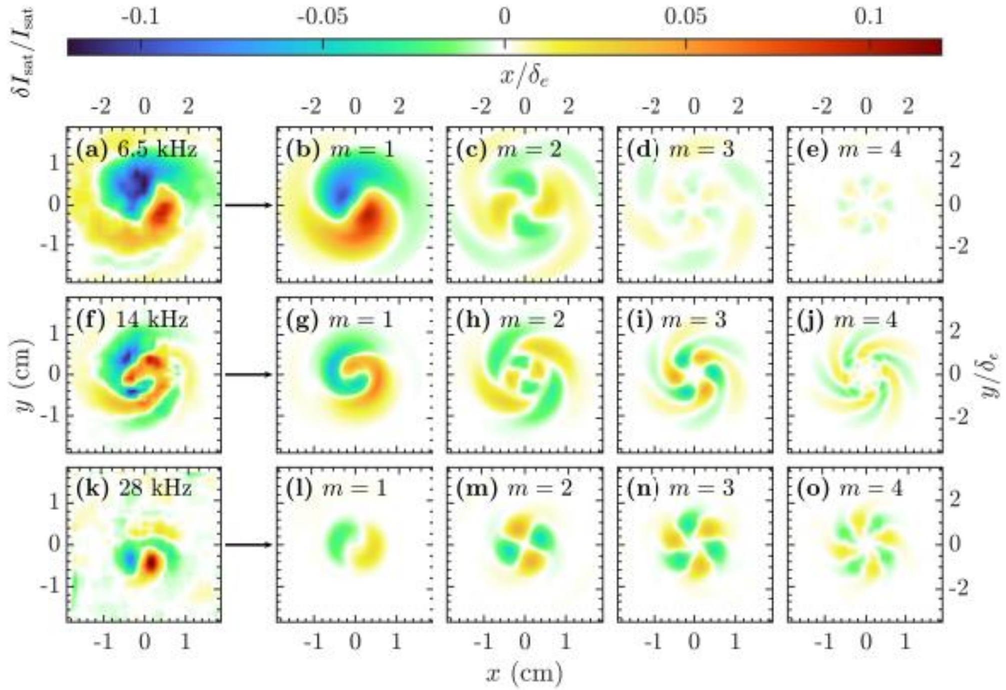
Drift-Alfven Modes





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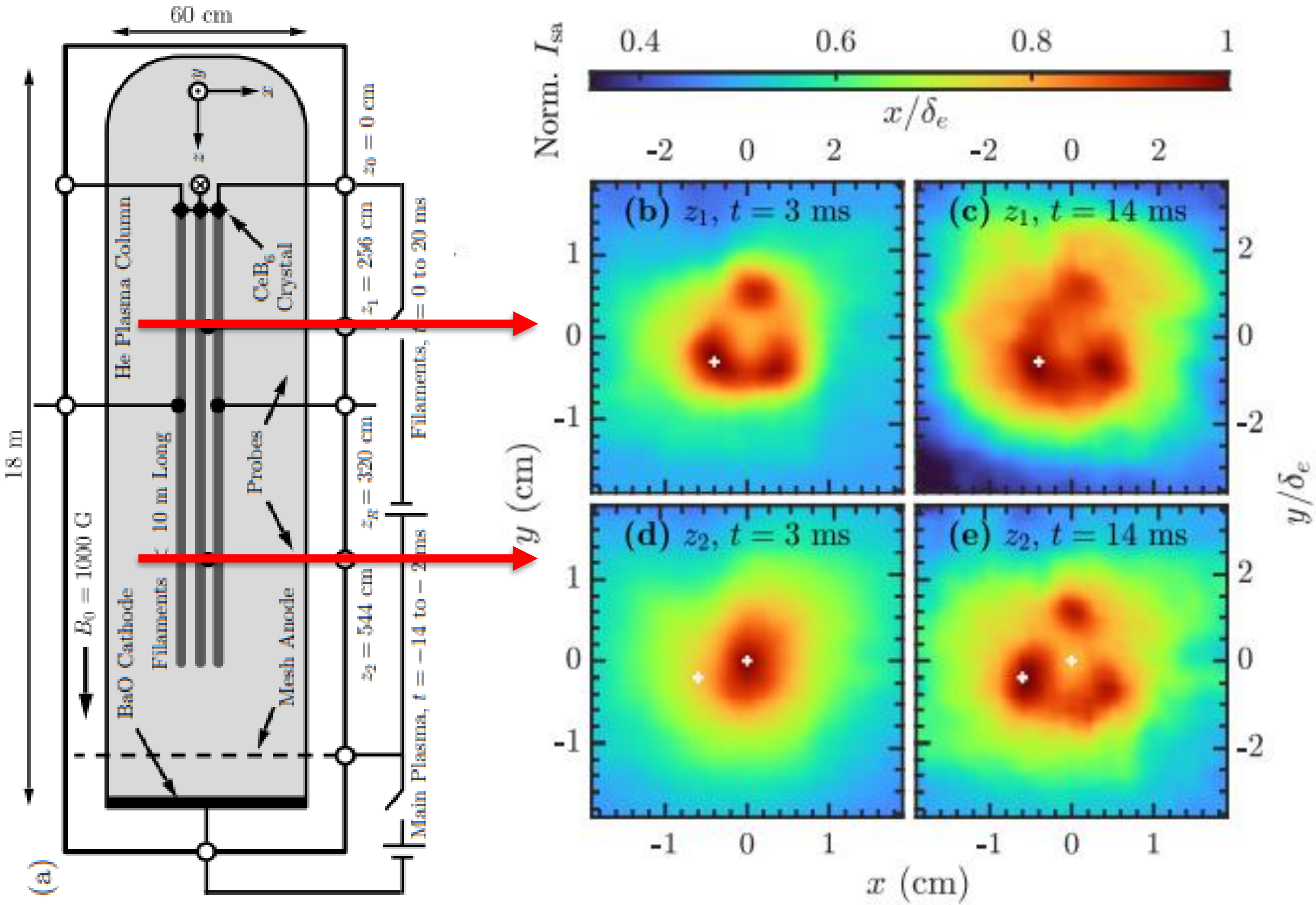
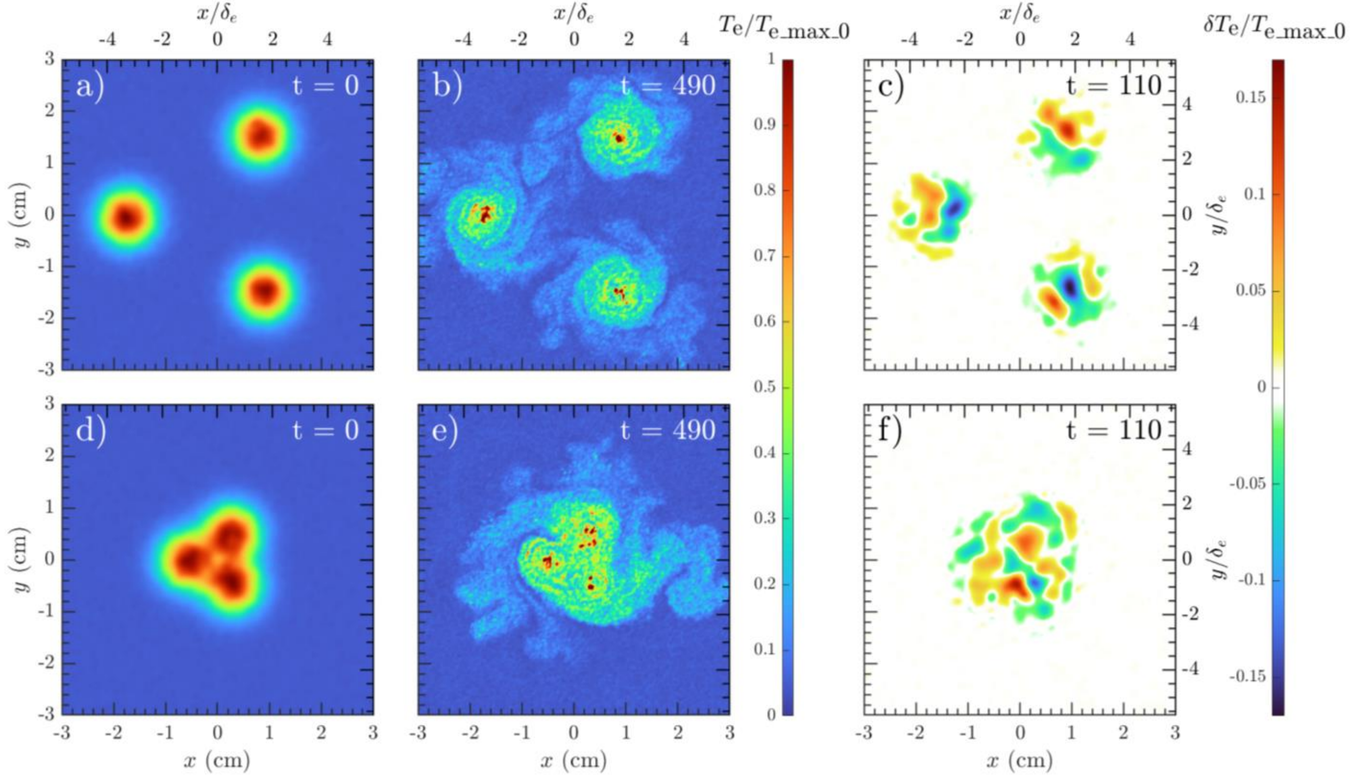
Axial variation



Cross-field δT_E Planes – 3D Gyrokinetic Simulations: 3-Filament Case



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SUMMARY

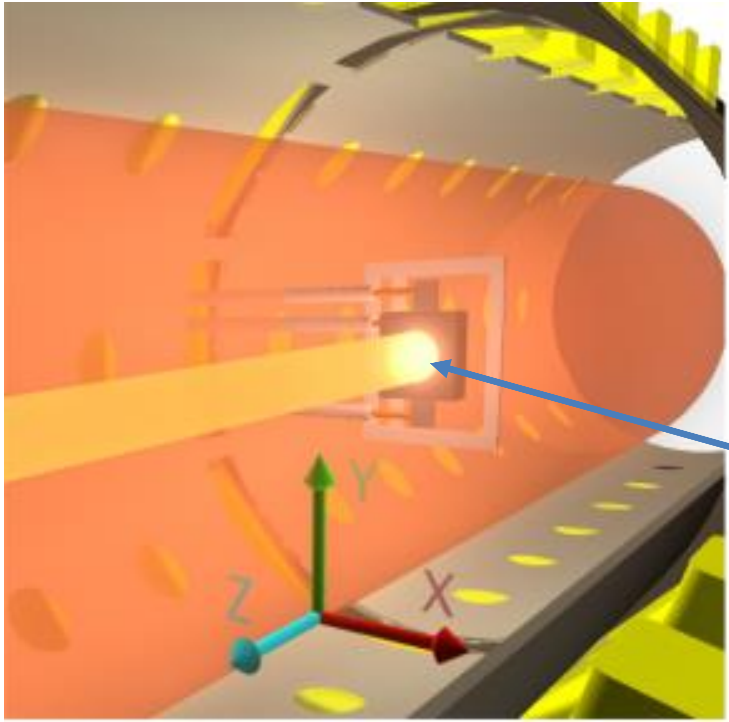
- For sufficiently steep pressure gradients filaments have internal instabilities (drift-Alfven modes) that have extended radial structure which cause filament-filament interactions at distances several times their diameter. Verified through nonlinear gyrokinetic simulations.

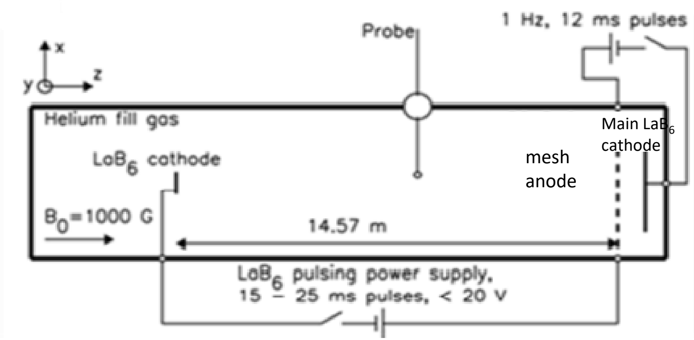
- For magnetized plasma pressure filaments in close proximity, we have characterized the nonlinear drift wave mode structure. Symmetry breaking of the gradients leads to non-symmetric mode structure initially. Azimuthal ExB flows tend to re-organize the pressure gradients to form on the outside of the filament bundle.

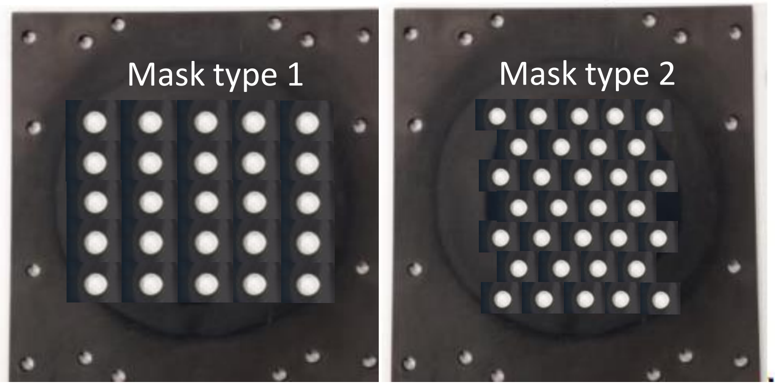
- New experiments on the self-organization of multiple filaments arranged in a lattice-pattern exhibit the evolution to a rotating layered state, currently under study.

Work in Progress: Filament Lattice

(Collaboration with F. Ramirez, P. Diamond, UCSD)

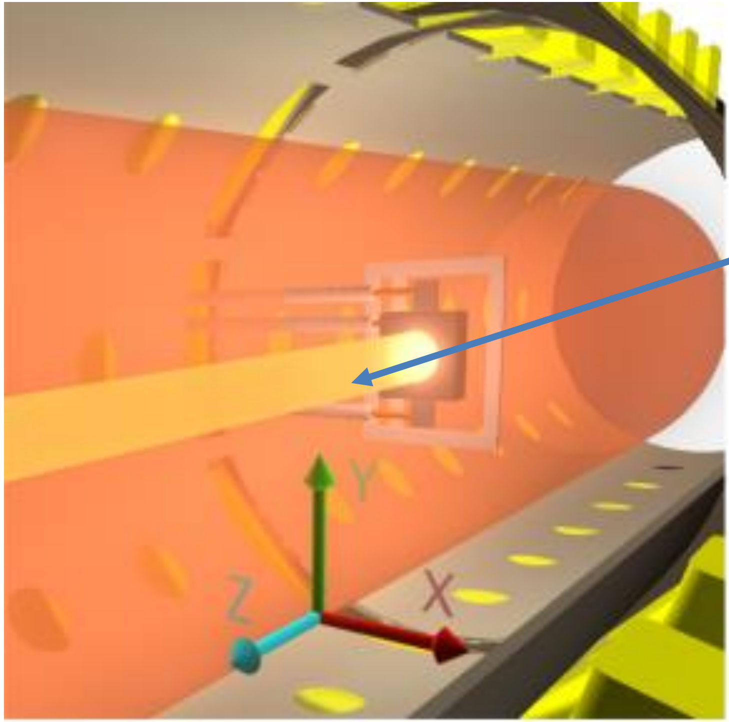


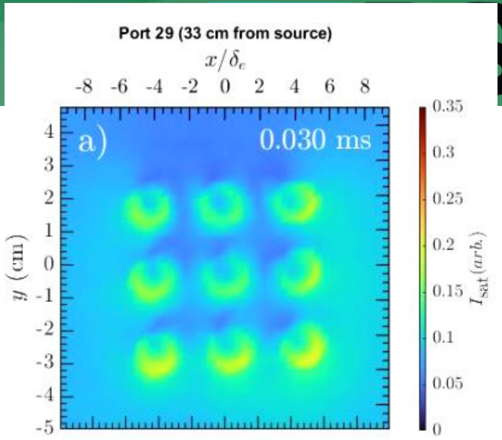




UNIVERSITY OF ALBERTA

FILAMENT LATTICE





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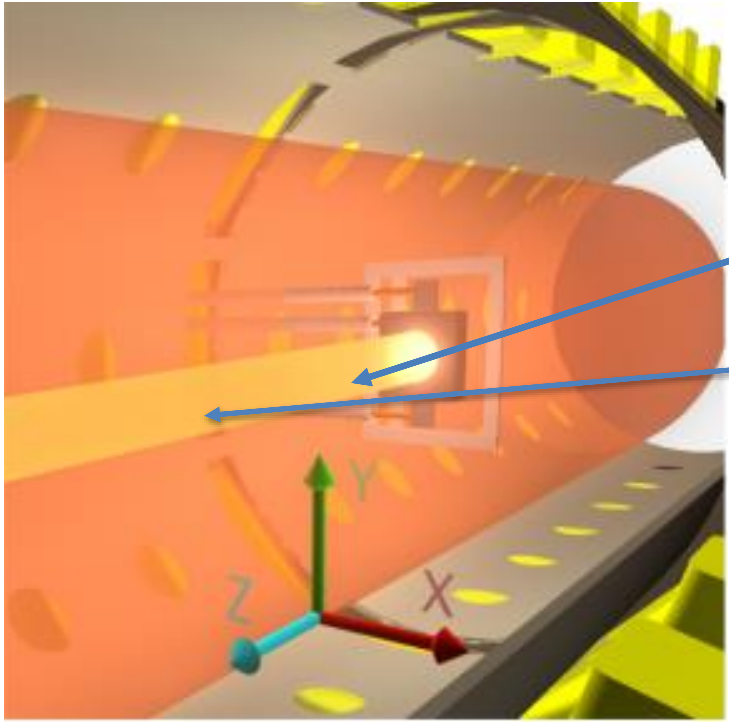
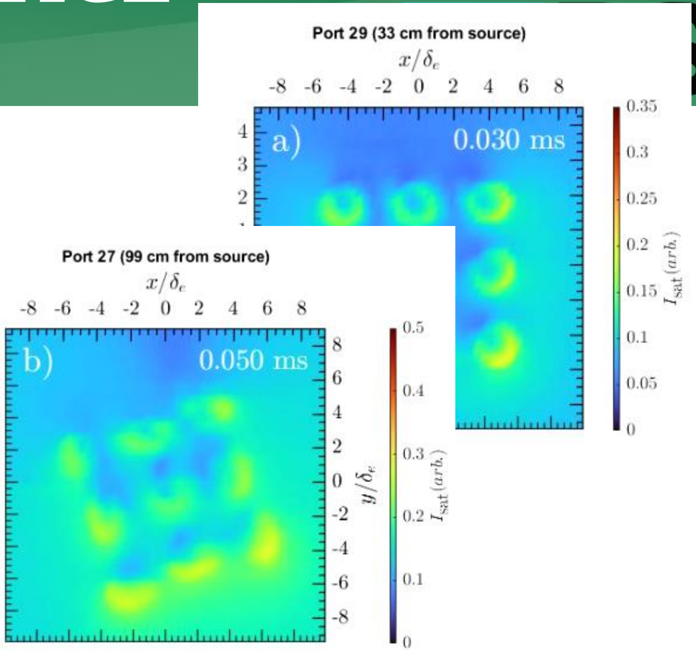
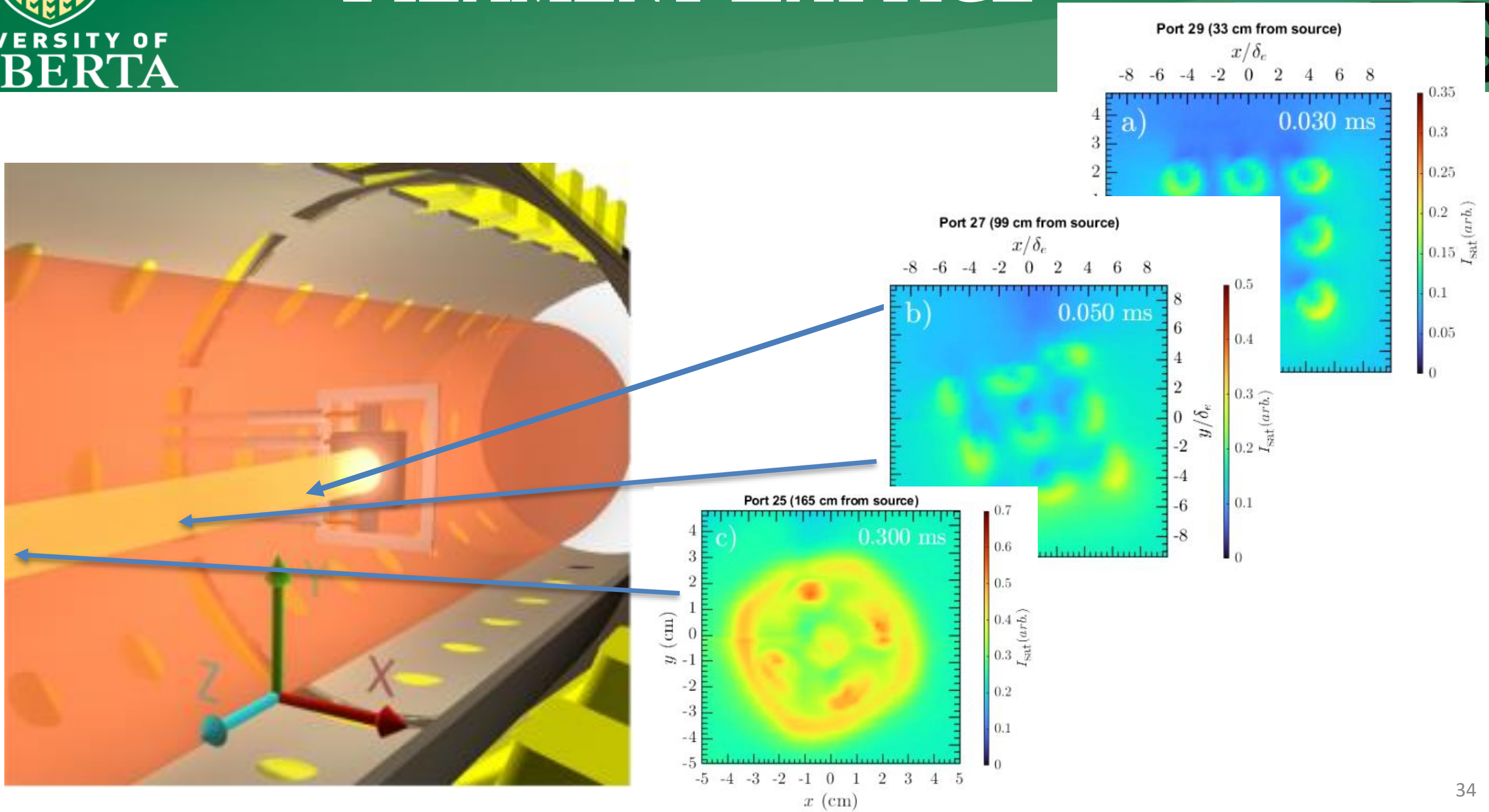




Filament Lattice



VORTEX LATTICE DYNAMICS

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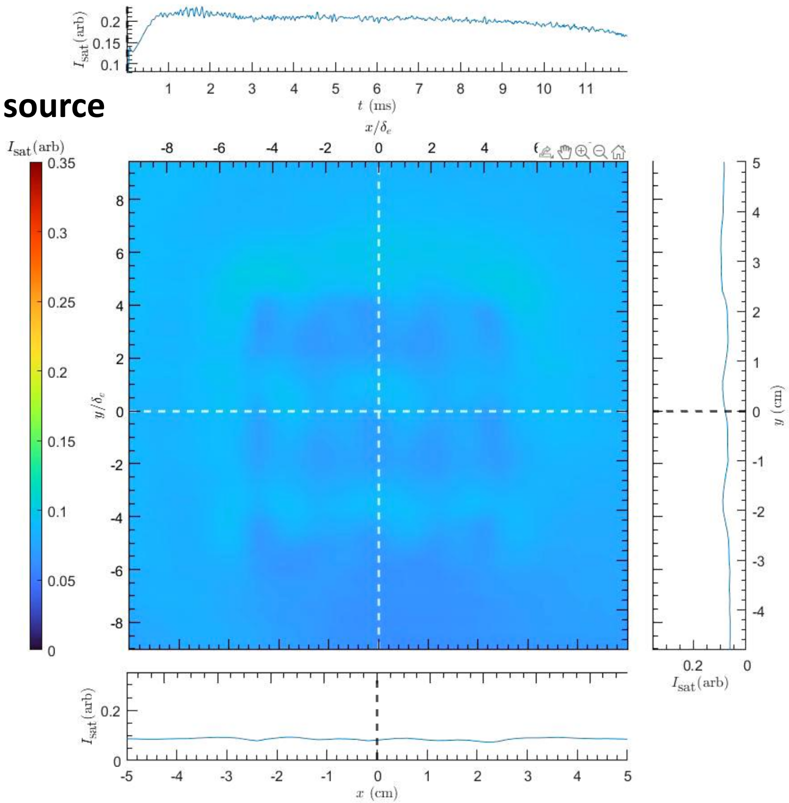
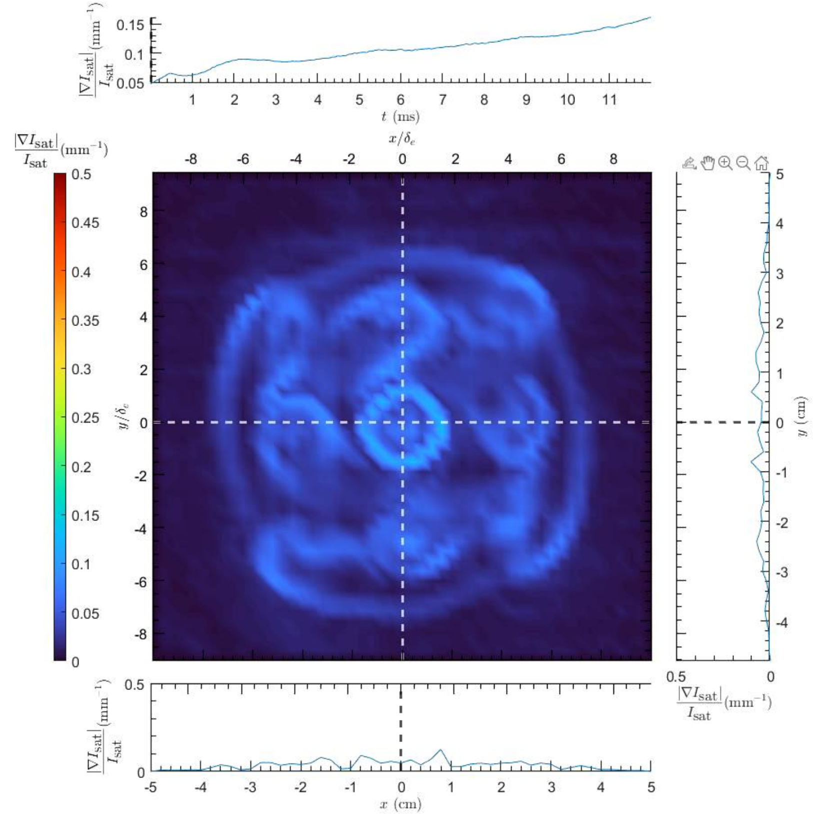
BaPSF

33cm from source





Thank you

Questions?