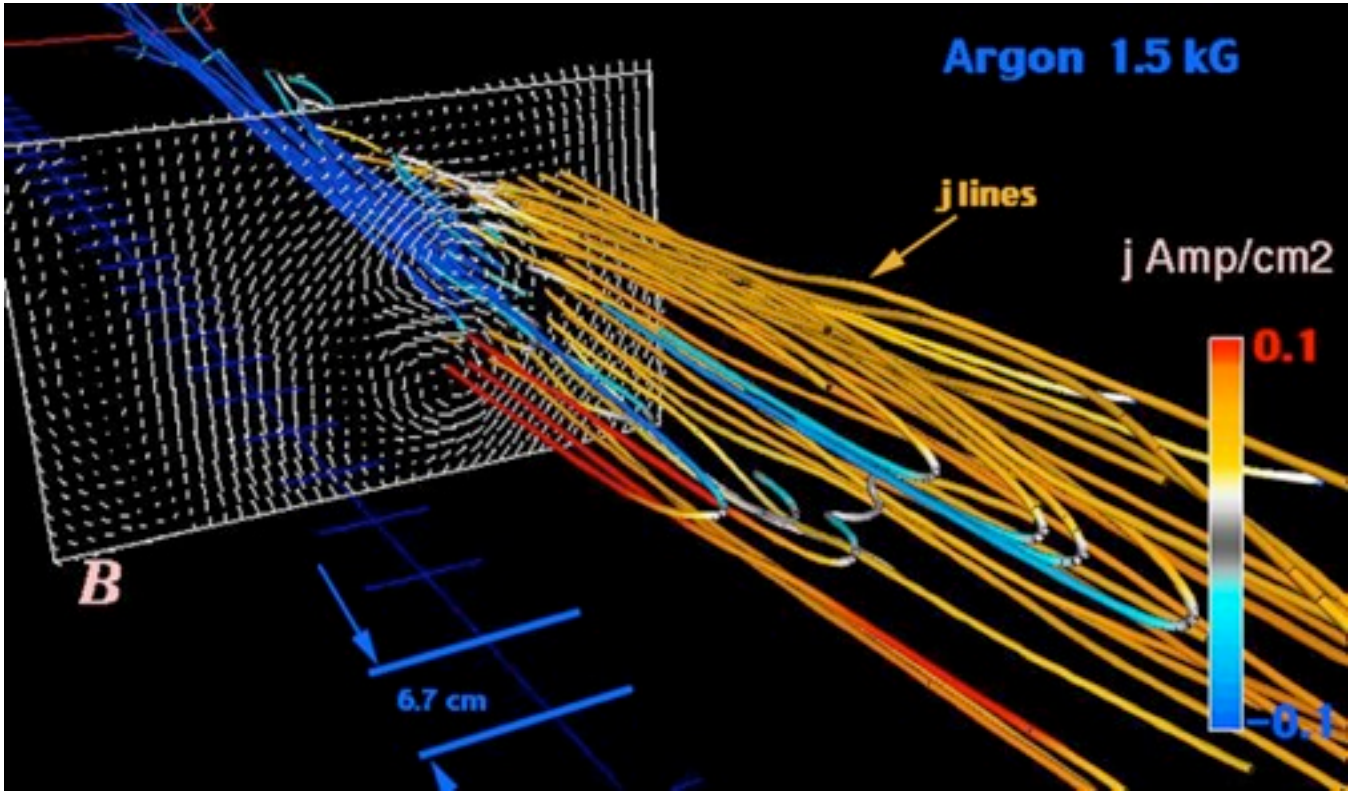
# Research Opportunities at the Basic Plasma Science Facility

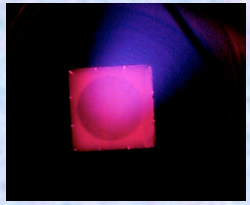
BaPSF

Jointly funded by NSF-DOE




Walter Gekelman Dept. of Physics University of California, Los Angeles

# Basic Plasma Science Facility



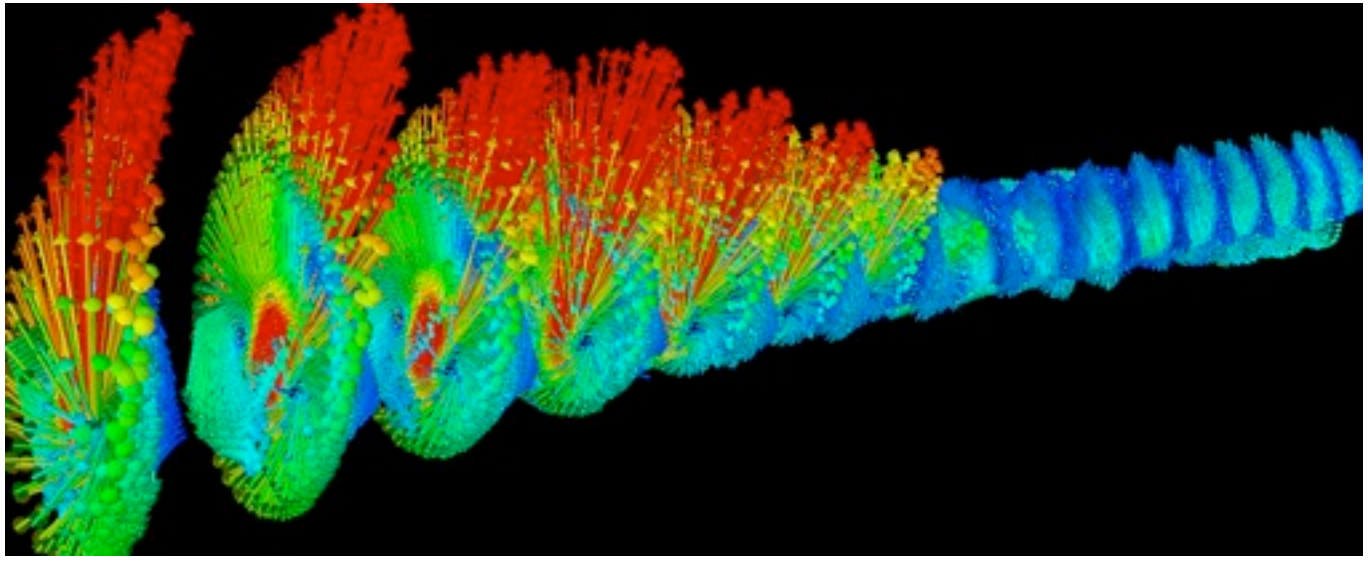
**Operational Requirements for a Basic Plasma Facility**

- Dependable, reproducible plasma.
- Quiescent, fully ionized (if required) plasmas.
- Ability to rapidly reconfigure experiments and device.
- Available diagnostics (probes, LIF, microwaves, etc, ).
- 24 hour operation.
- Many access ports for diagnostics, antennas, etc.
- Automated data acquisition (3 dimensional data if needed).
- Ability to rapidly process and visualize data.
- Available technical staff

## Research topics under investigation at the BaPSF

1) Resonant absorption of high-power electromagnetic waves,
2) Effects of electric fields on plasma confinement
3) Dynamics of magnetized plasma flows
4) Role of nonlinear Alfvén waves in MHD turbulence,
5) Interaction of laser–generated plumes with magnetized plasmas,
6) Magnetic Flux ropes and 3D reconnection
7) Dynamics and formation of filamentary structures
8) Auroral electron acceleration,
9) Electron heat transport in magnetized plasmas,
10) Plasma–edge turbulence and formation of streamers
11) Novel microwave diagnostics of plasma parameters,
12) Interaction of Alfvén waves with boundaries and plasma resonances,
13) Search for electron solitary structures using microprobes
14) Study of ion transport in Alfvénic turbulence,
15) Microwave generation by Langmuir Turbulence
16) Search for stationary Alfvén waves
17) Fast particle remediation by waves
18) Cherenkov radiation of Alfvén waves by fast ions
19) Wave propagation in multi-species plasmas

# Experiments on Alfvén waves



W. Gekelman, G. Morales, S. Vincena, J. Maggs, D. Leneman, N. Palmer, P. Pribyl, A. Gigliotti

# Behavior of the Shear Alfvén Wave

in a 'real' spatially uniform plasma

## Kinetic Wave

$$\frac{\omega^2}{k_\parallel^2} = V_A^2\left(1 - \frac{\omega^2}{\Omega_{ci}^2} + k_\perp^2 \rho_s^2\right)$$

$\rho_s$ ion sound gyroradius

$\varsigma << 1$

High β, β > $m_e/M_i$

$$\varsigma = \frac{\omega}{k_\parallel v_{th}}$$

$$Z'(\varsigma)\left[\frac{v_e^2}{V_A^2}\left(1 - \frac{\omega^2}{\Omega_{c1}^2}\right) - \varsigma^2\right] = k_\perp^2 \delta_e^2$$

## Inertial Wave

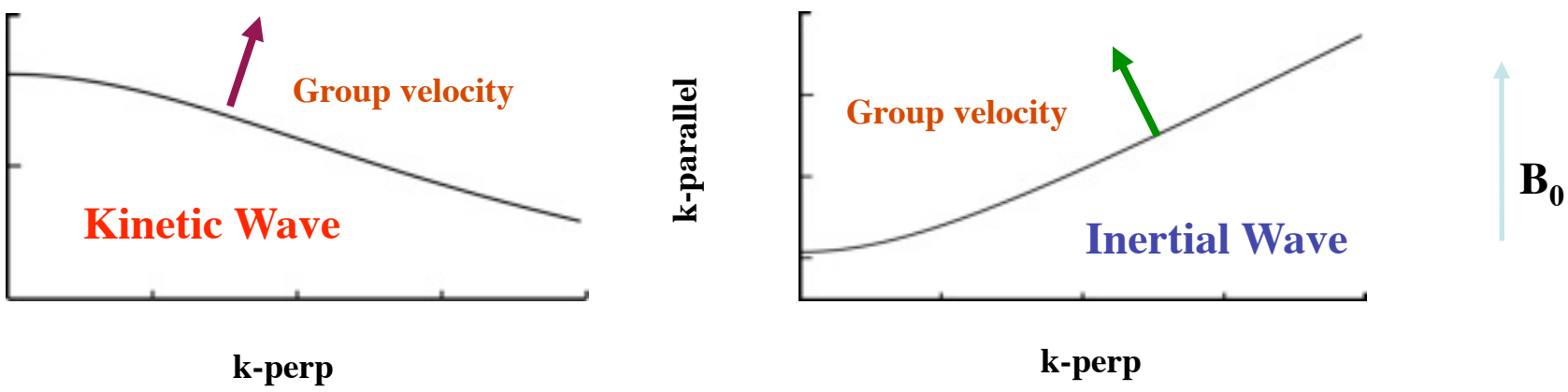
$$\frac{\omega^2}{k_\parallel^2} = \frac{V_A^2\left(1 - \omega^2/\Omega_{ci}^2\right)}{1 + k_\perp^2 \delta_e^2}$$

$\delta_e$ electron inertial length

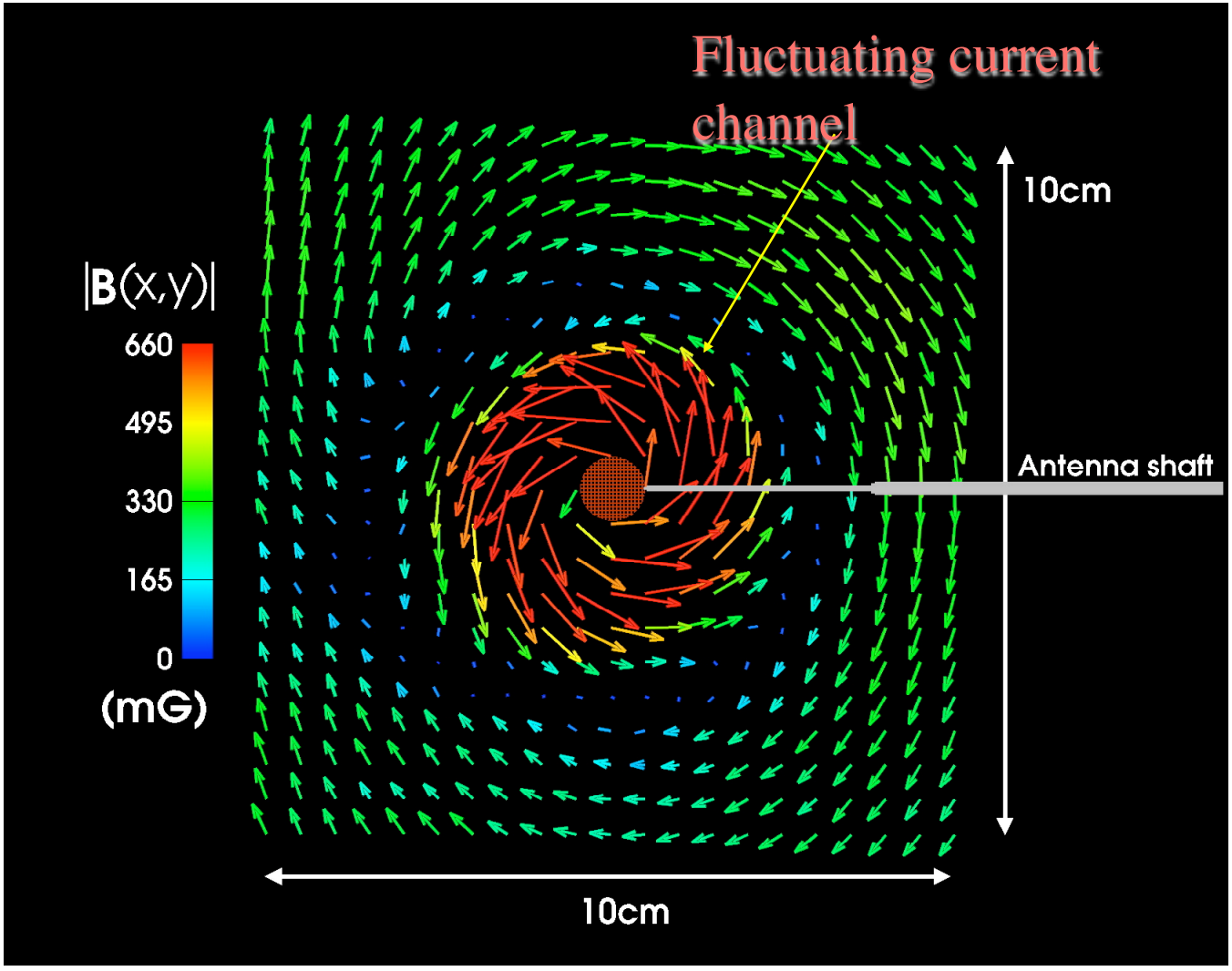
$\varsigma >> 1$

Low β, β < $m_e/M_i$

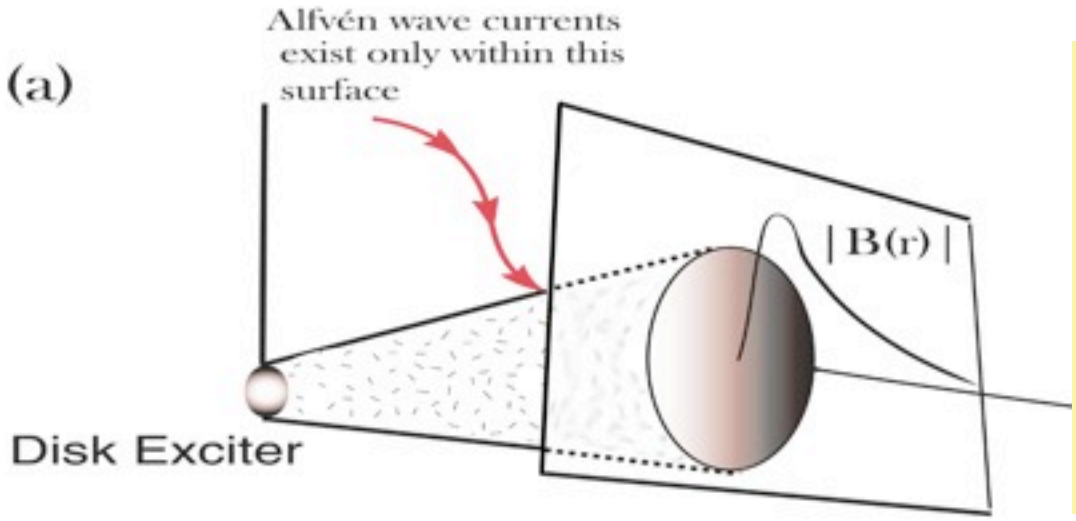
## Wave normal surfaces

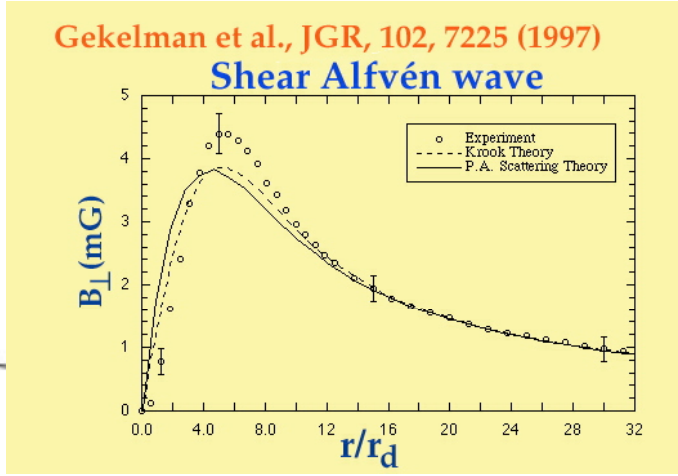


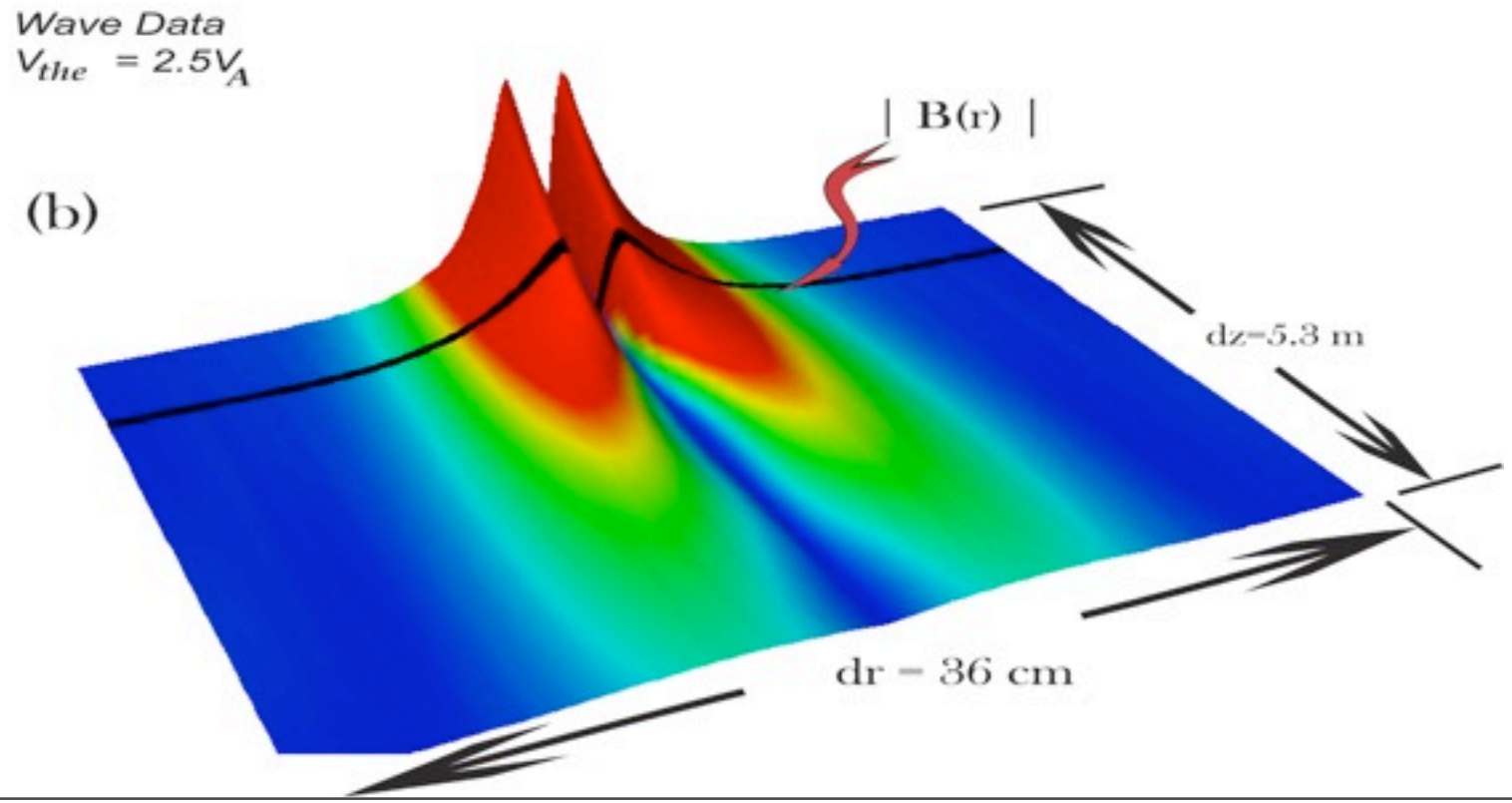
# wave data in a plane

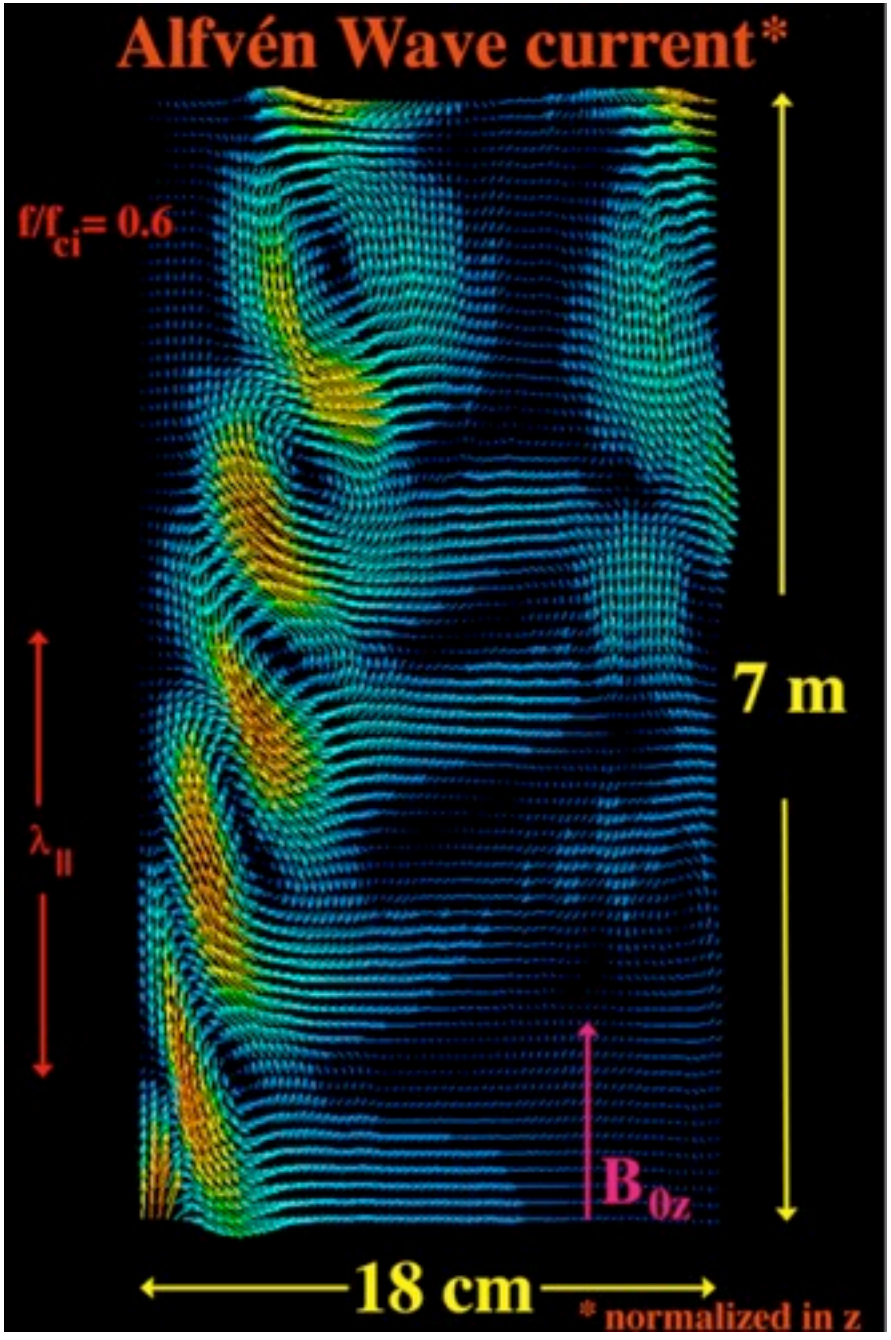



Antenna is 1.5 m out of this plane


(a)
Alfvén wave currents exist only within this surface
| B(r) |
Disk Exciter

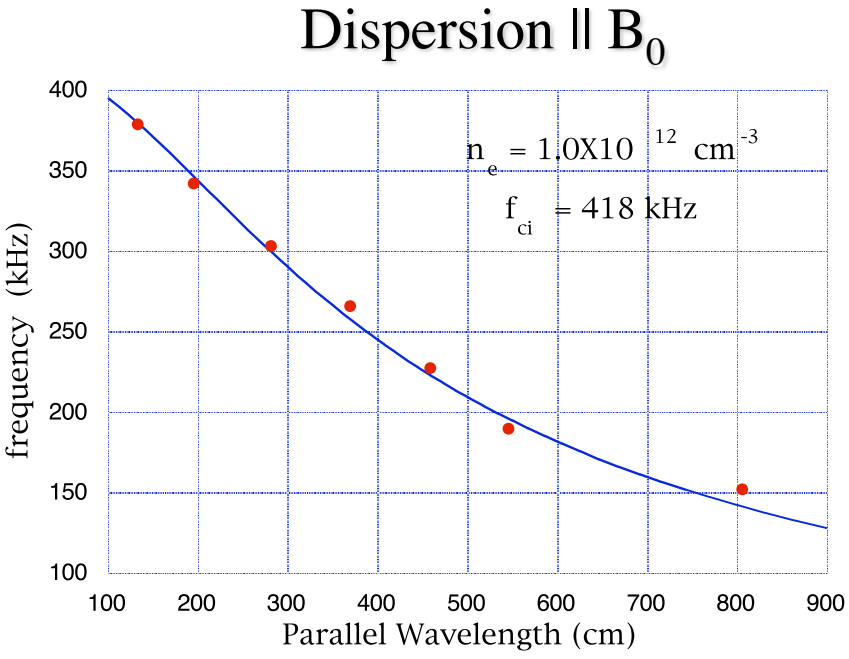

Gekelman et al., JGR, 102, 7225 (1997)
Shear Alfvén wave
Experiment
Krook Theory
P.A. Scattering Theory
B⊥ (mG)
r/rd
0
1
2
3
4
5
0.0
4.0
8.0
12
16
20
24
28
32


Wave Data
$V_{the} = 2.5V_A$
(b)
| B(r) |
dz=5.3 m
dr = 36 cm



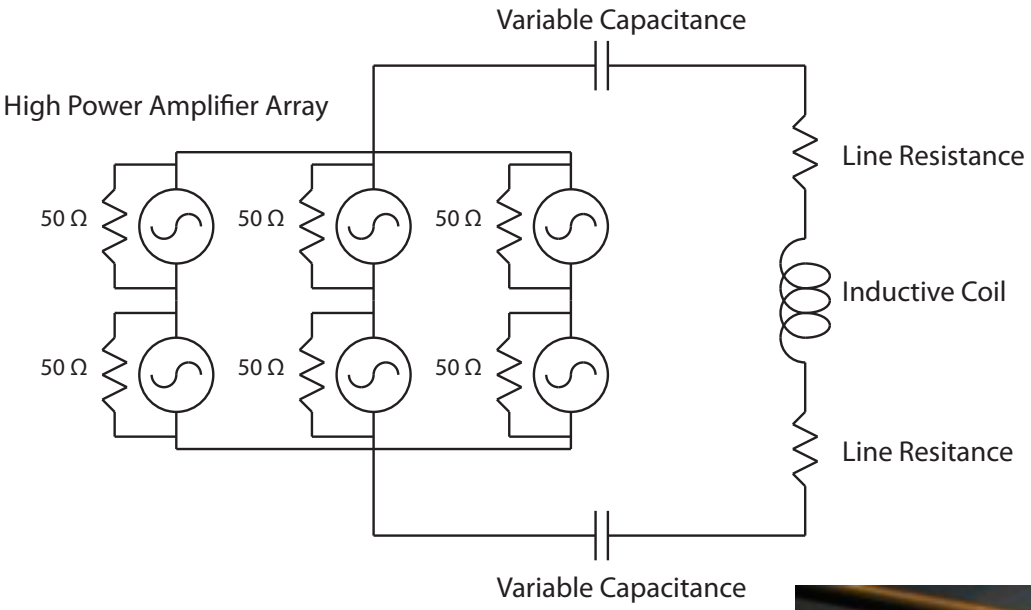

# Wave current...

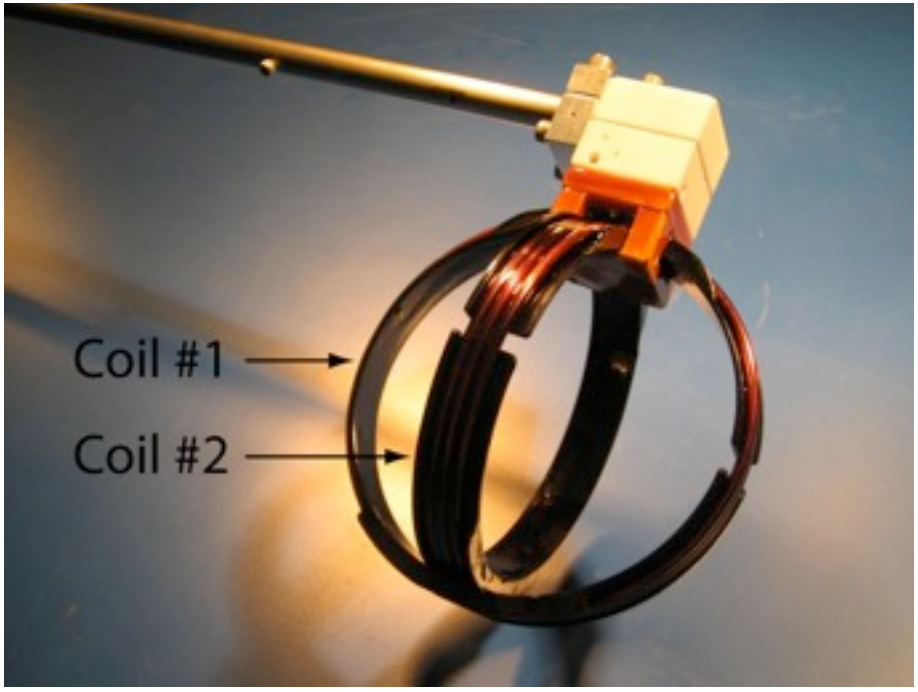
# perpendicular to B

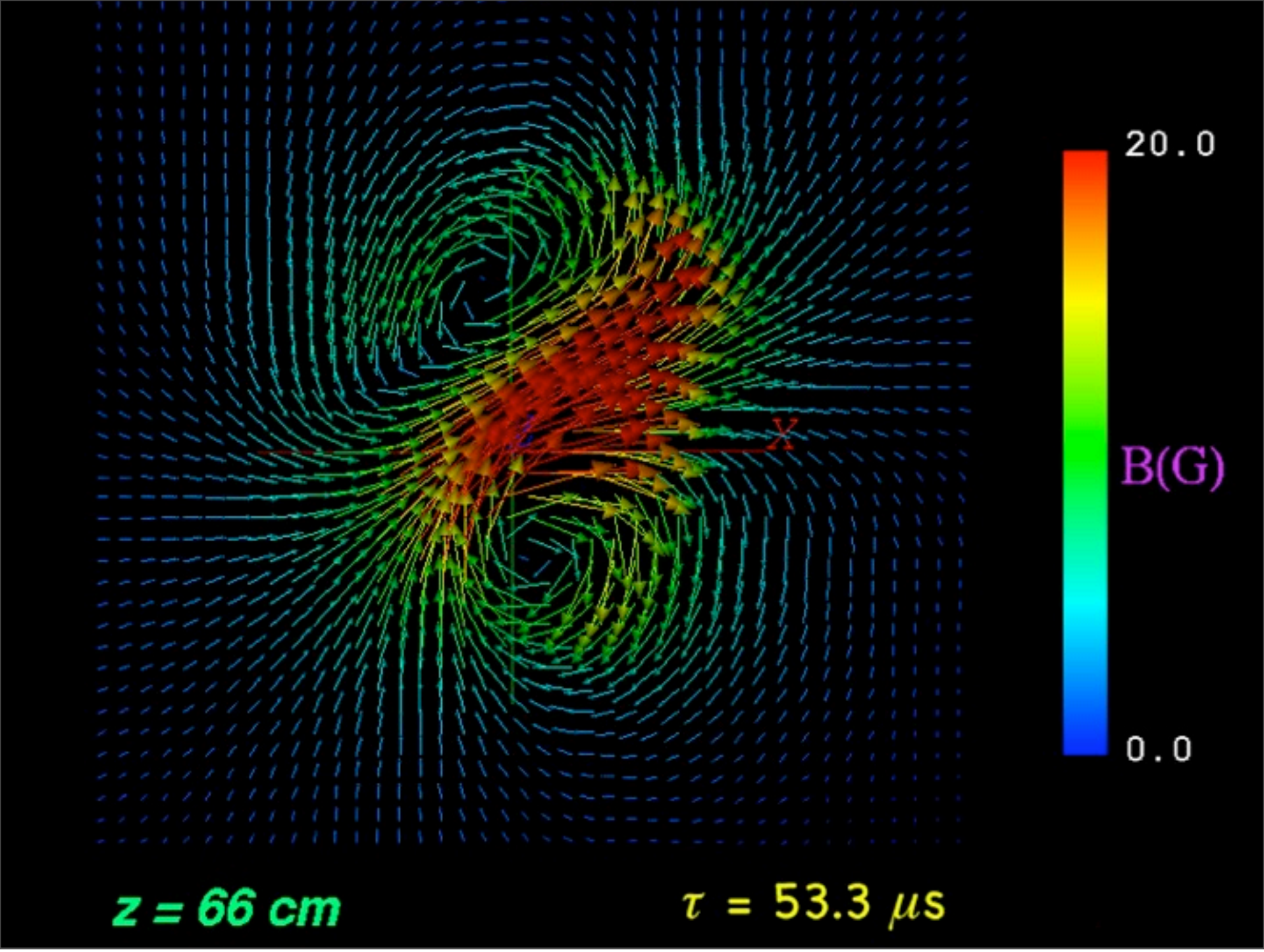



Disk exciter (kinetic regime)

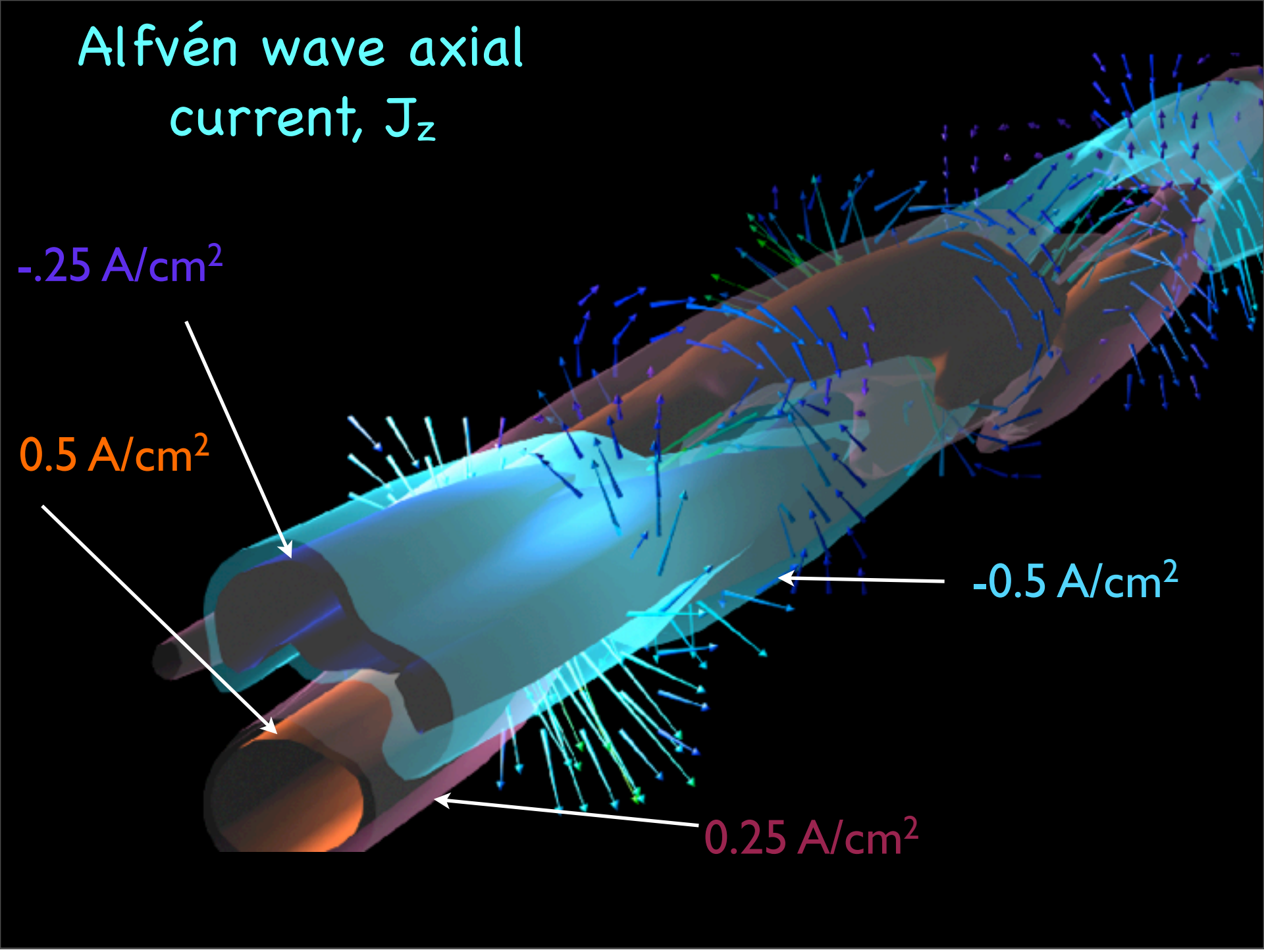
# Polarized Alfvén Wave Experiments

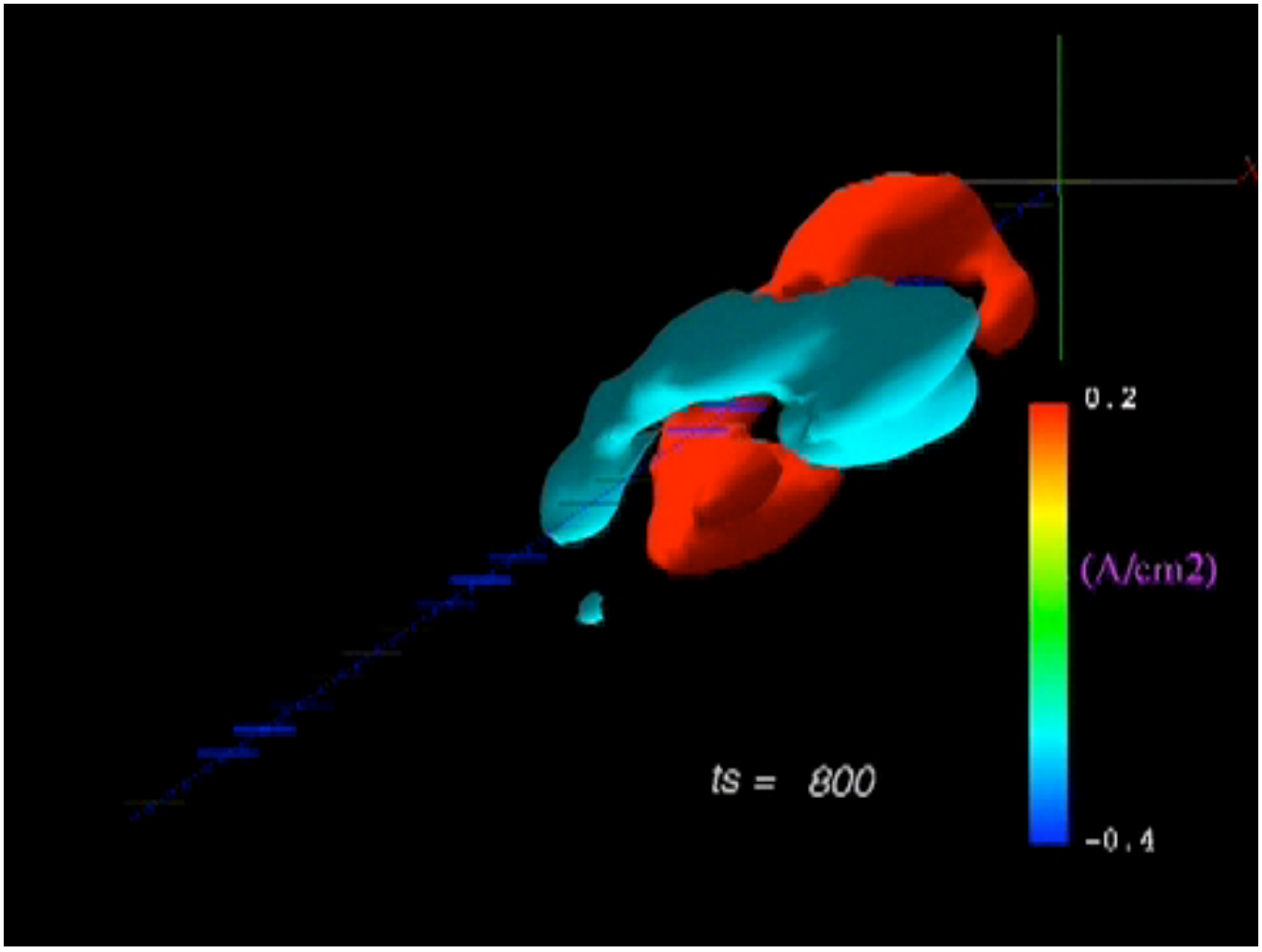

Variable Capacitance
High Power Amplifier Array
Line Resistance
50 Ω
50 Ω
50 Ω
Inductive Coil
50 Ω
50 Ω
50 Ω
Line Resitance
Variable Capacitance


Coil #1
Coil #2

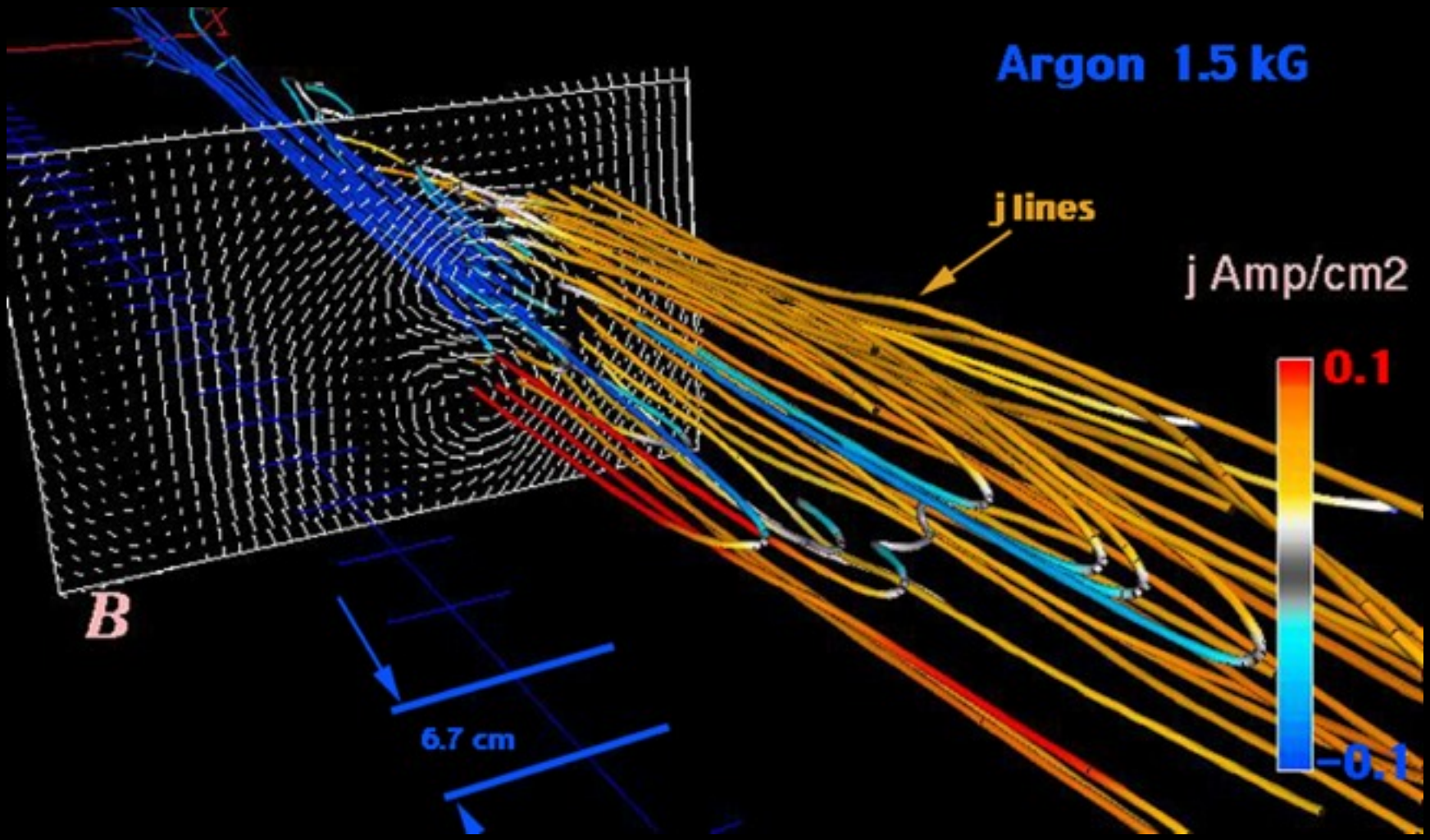

20.0
B(G)
0.0
X
z = 66 cm
τ = 53.3 μs

# Alfvén wave axial current, $J_z$




0.2
(A/cm2)
ts = 800
-0.4

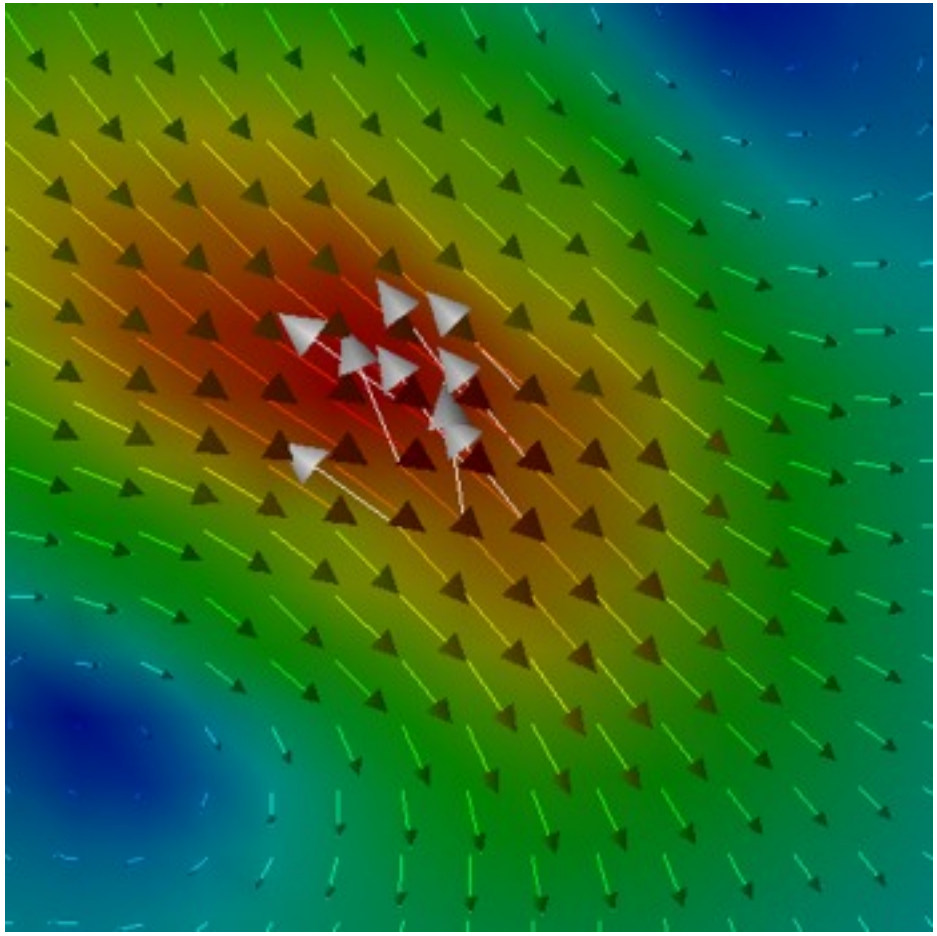
Wave current derived from $\Delta X B$

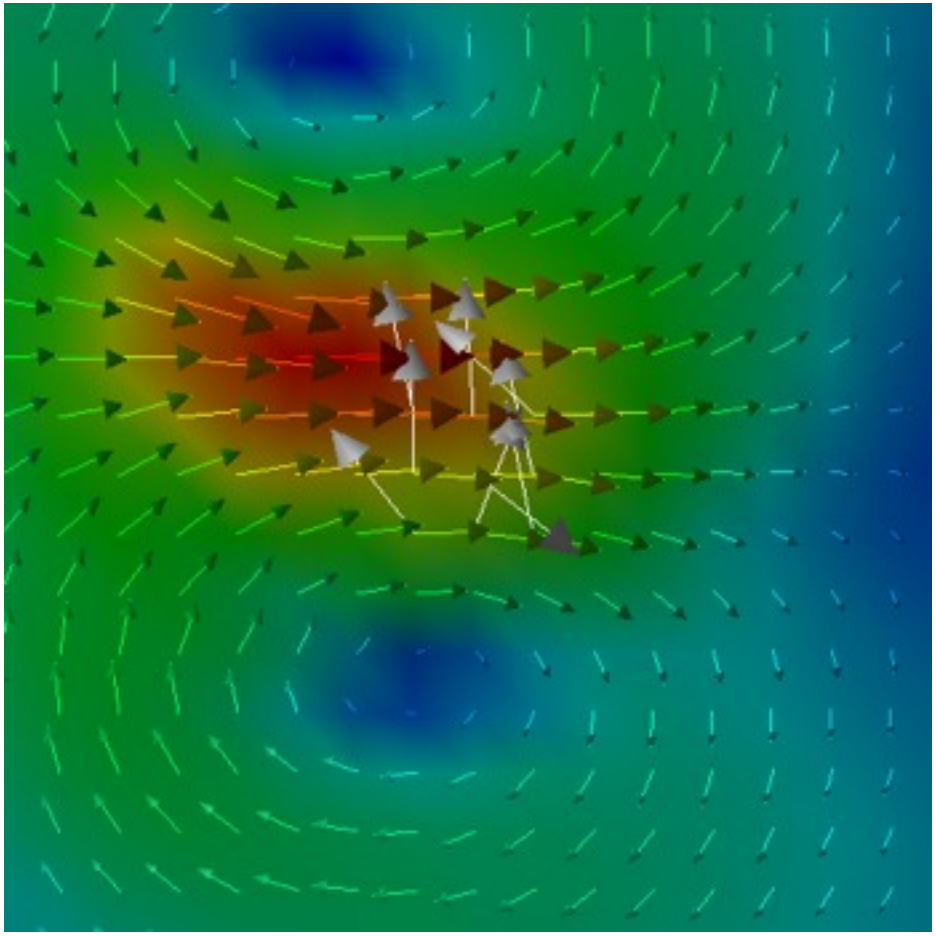


# Laser Induced Fluorescence Measurement

White arrows → normalized velocity

Colored arrows → Bwave





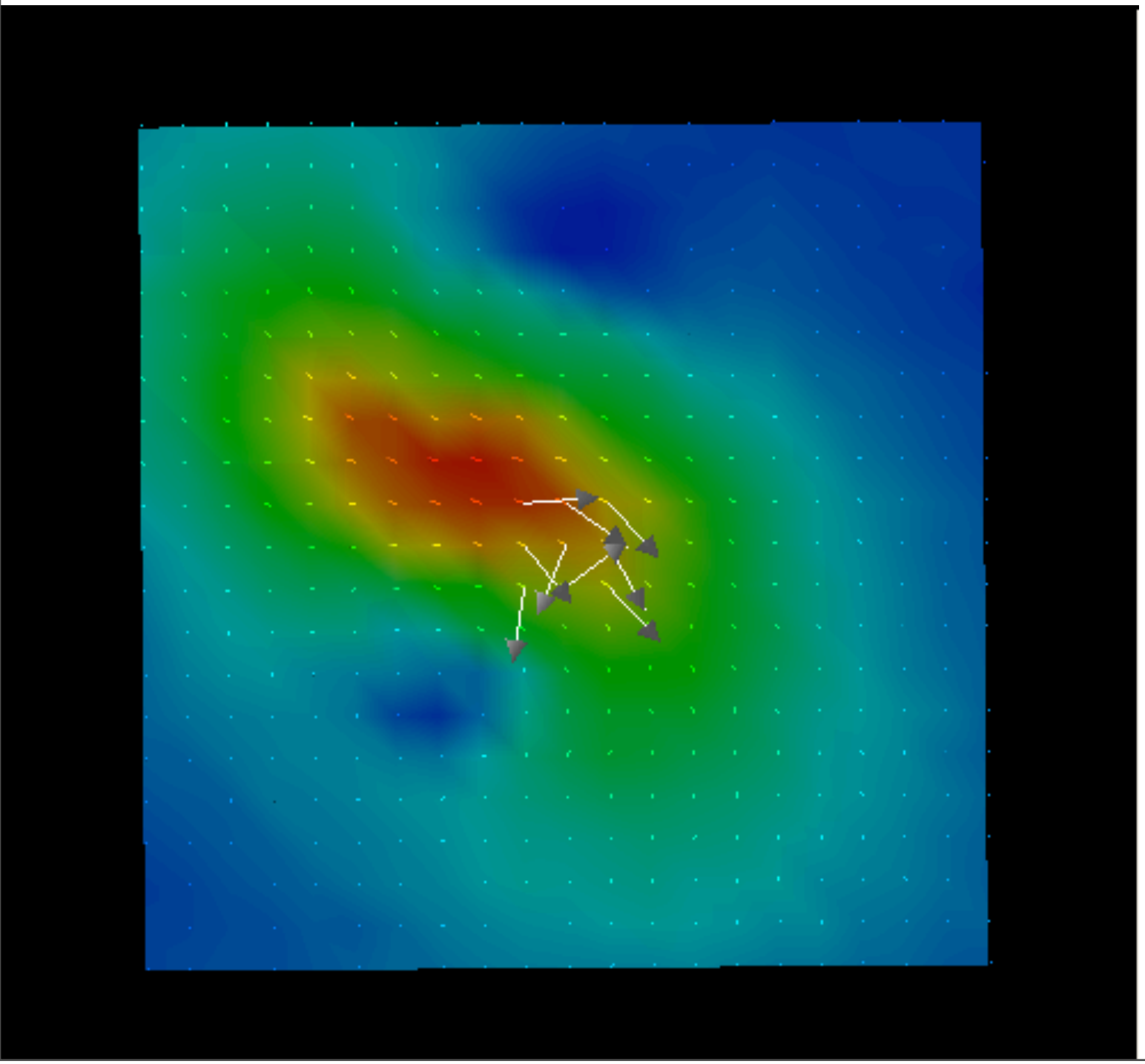
δt = 58 μs

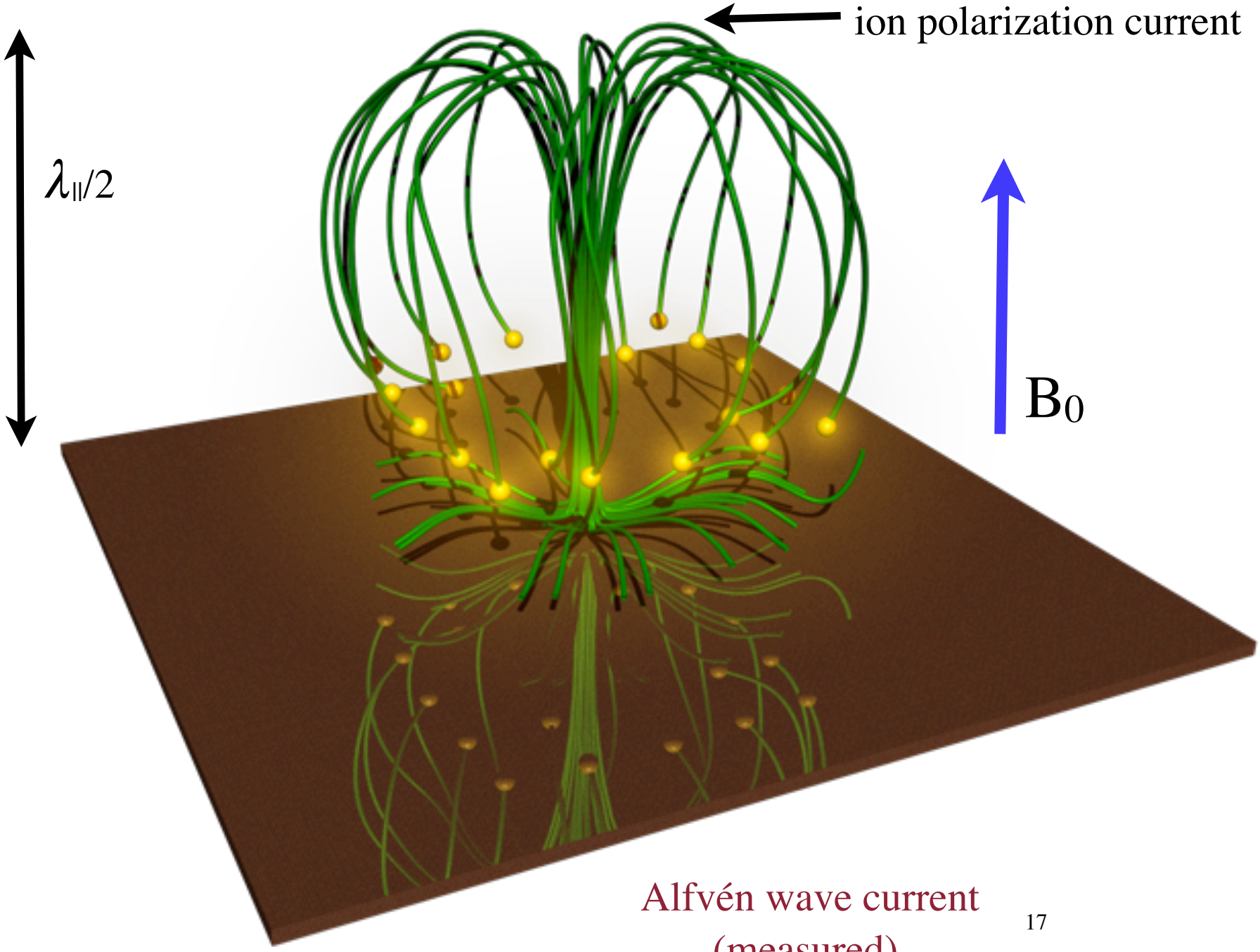
$$\bar{\omega} = \frac{\omega}{\omega_{ci}}$$

$$v_{Drift} = \frac{E_{\perp}}{B_0(1-\bar{\omega}^2)}$$

δt = 134 μs

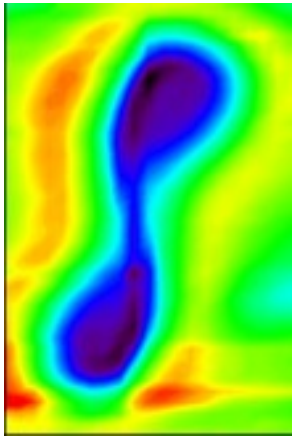
$$v_D = \frac{1}{\omega_c B_0(1-\bar{\omega}^2)} \frac{dE_{\perp}}{dt}$$

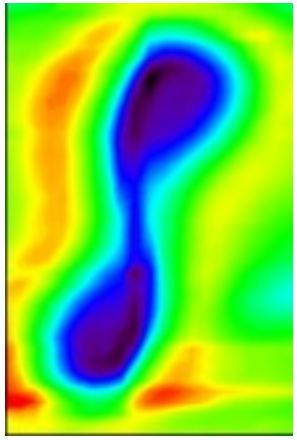




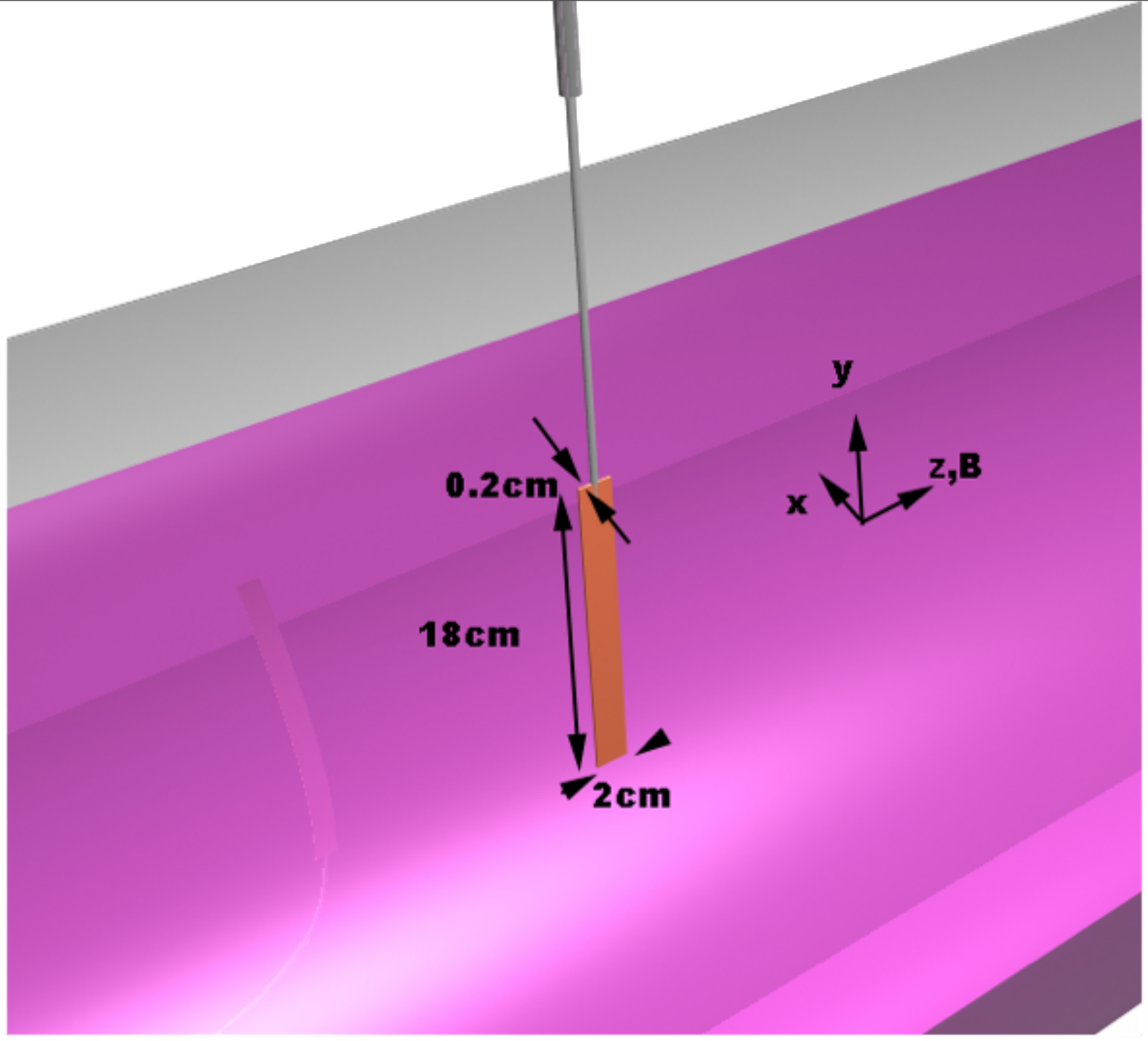

Alfvén wave current
(measured)

# Plasma flow, fluctuations, and transport associated with a thin current sheet

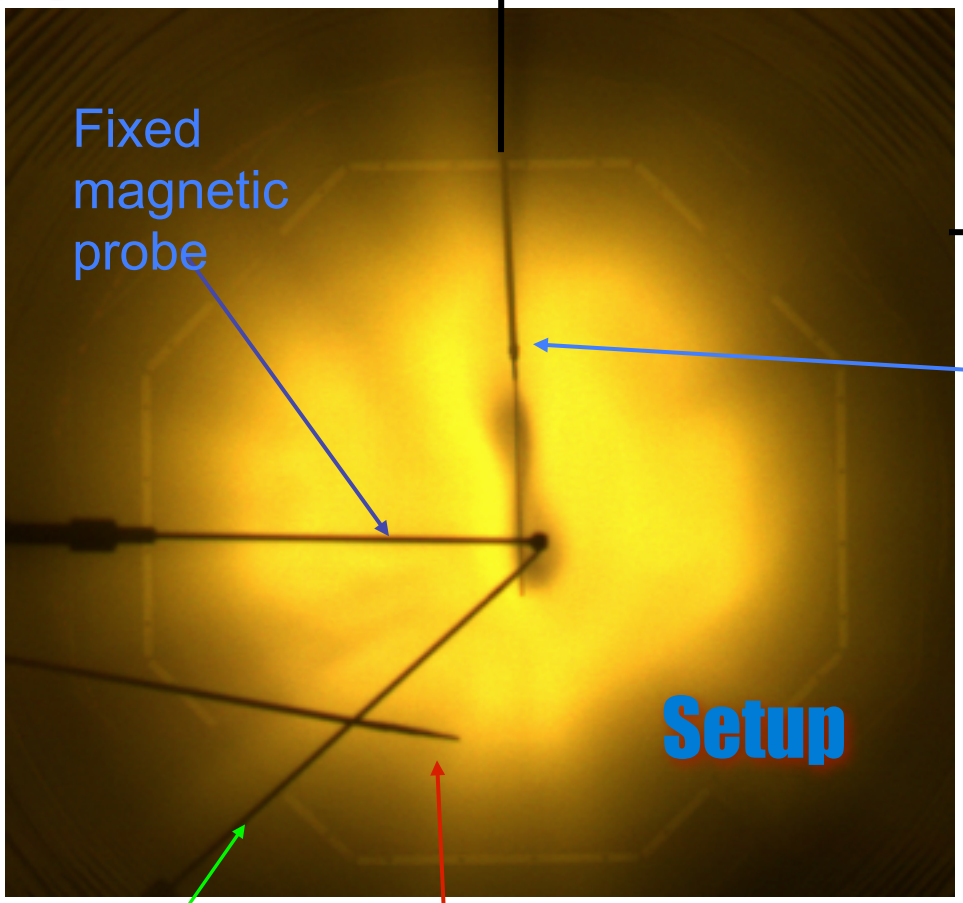




**Stephen Vincena,Walter Gekelman, Patrick Pribyl, & Troy Carter**


y
z,B
x
0.2cm
18cm
2cm

# Geometry and Philosophy of data collection




capacitors

Transistor switch

Fixed magnetic probe

Current sheet antenna $\delta x$ =2mm

Current = 70A

Voltage = 75 V

He, B=500G…1.5 kG

Photograph $T_{shutter}$ = 1 $\mu$s

View down axis of machine

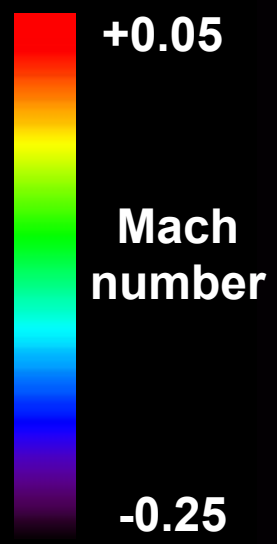
Fixed flow probe

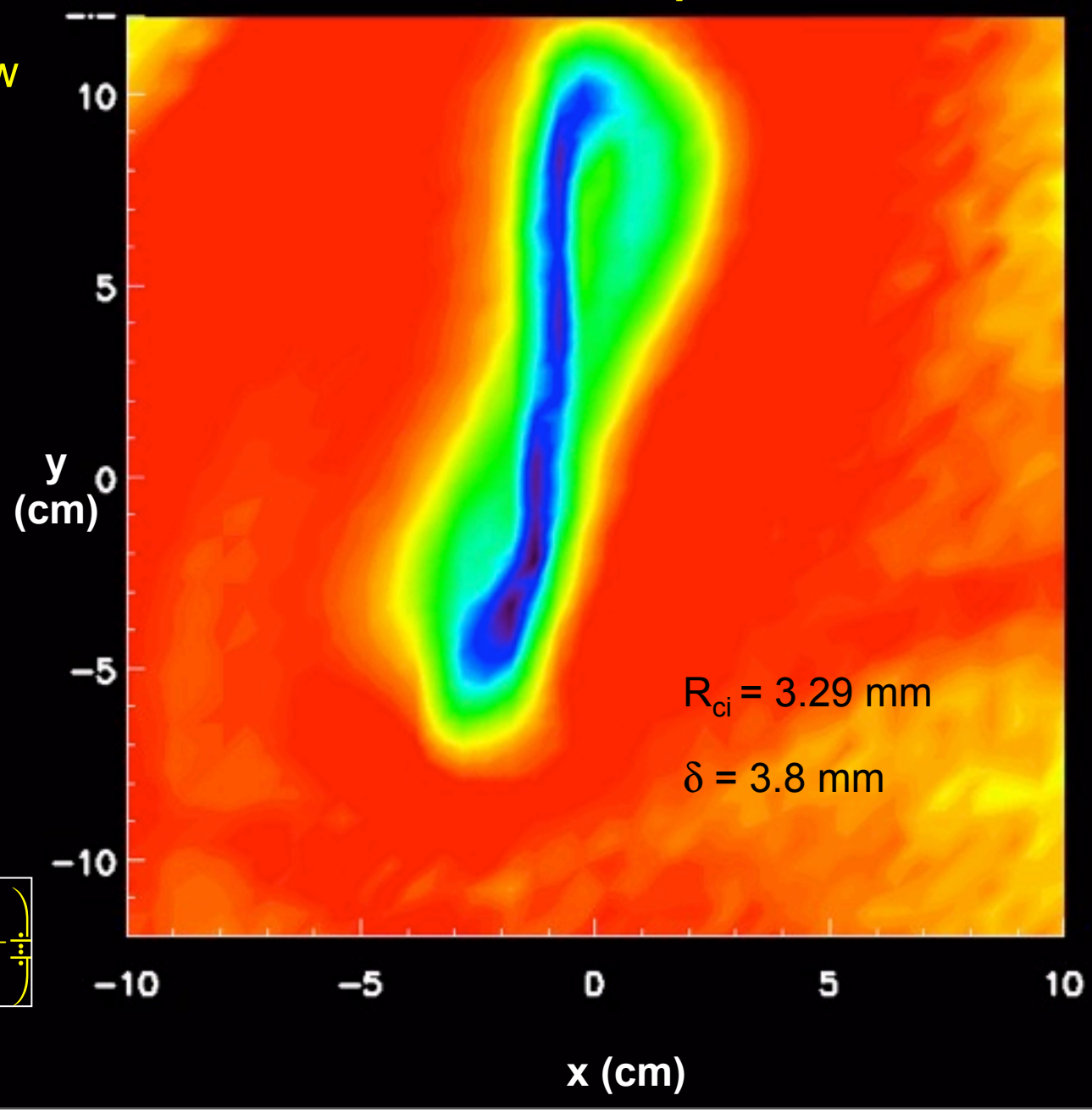
Movable flow probe

# Parallel Ion Flow in a Perpendicular Plane

T=690μsec

Time of peak flow

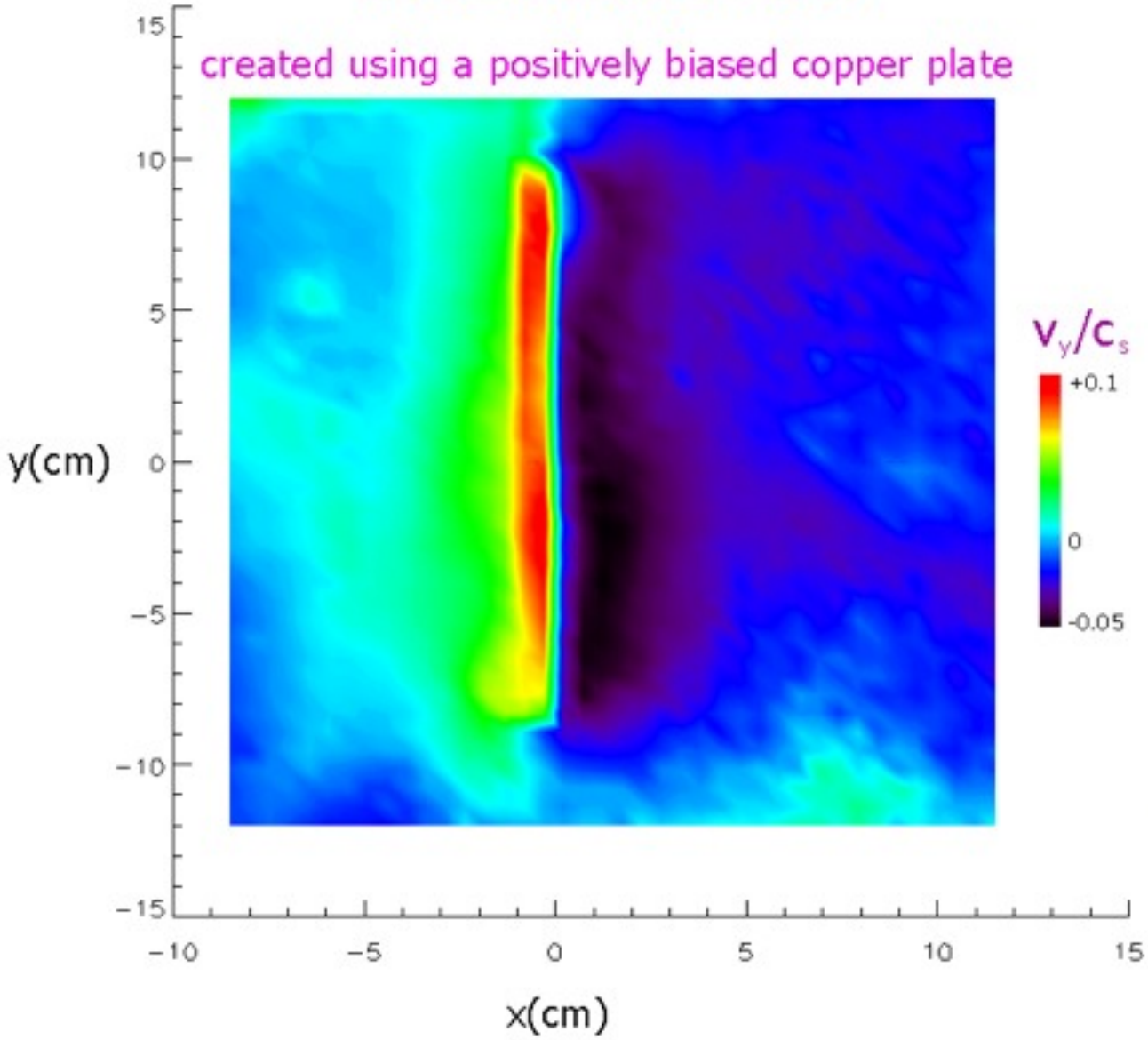


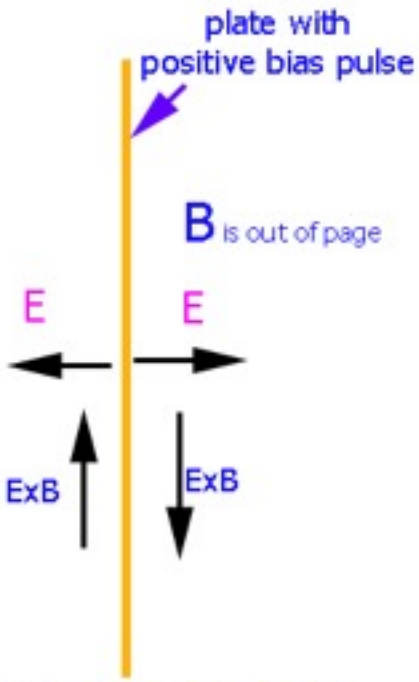




$$M_{\parallel} = \frac{1}{2}\ln\left(\frac{I_{Sat-Upstrem}}{I_{Sat-Downstream}}\right)$$

# E x B Plasma Flow

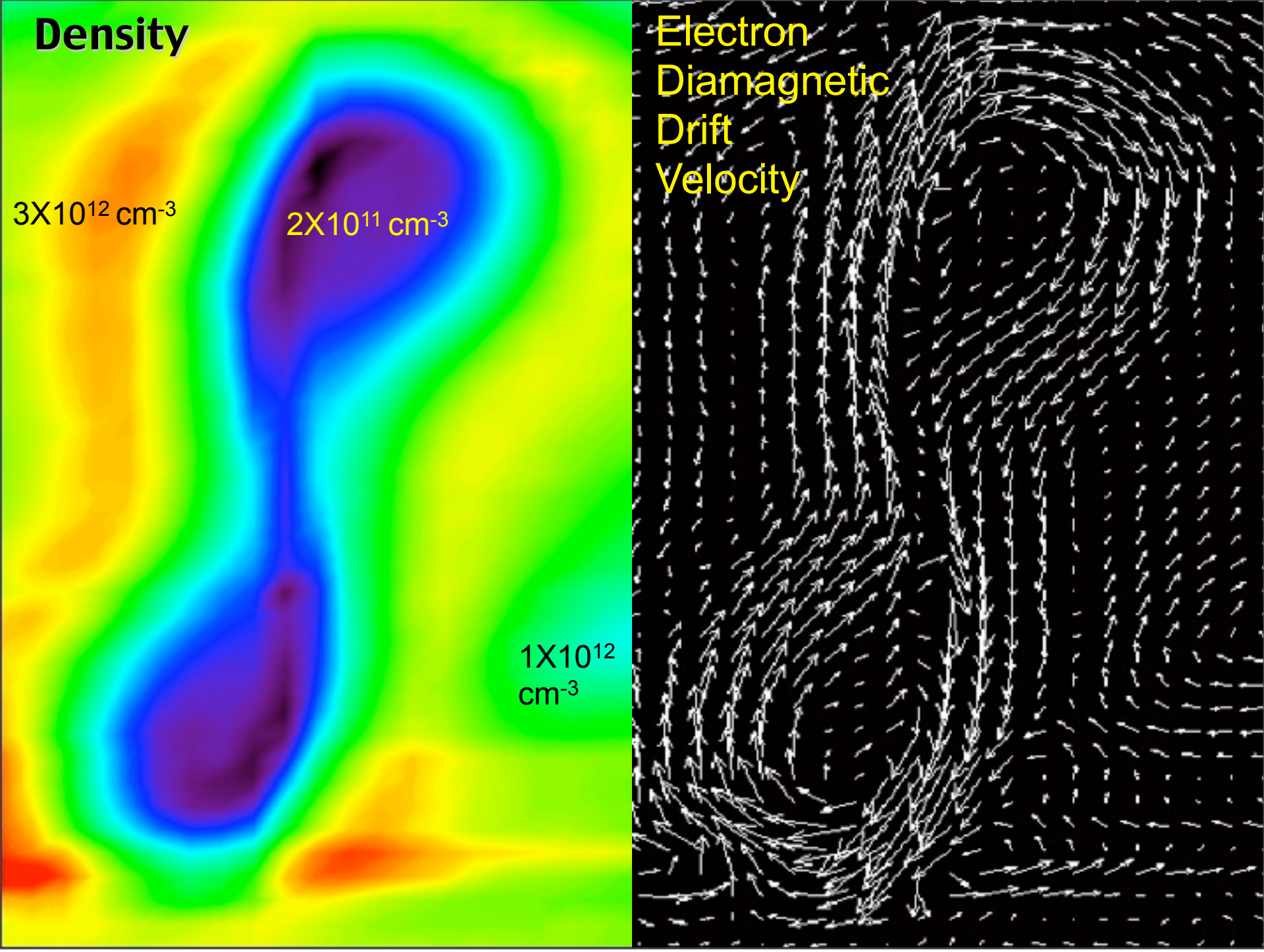
created using a positively biased copper plate



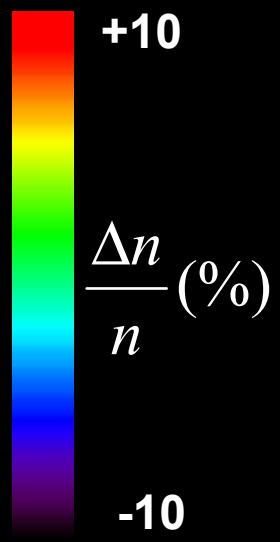




ions within a gyro-radius (0.4cm)
of the plate will spiral into
the sheath and drift in the ExB direction

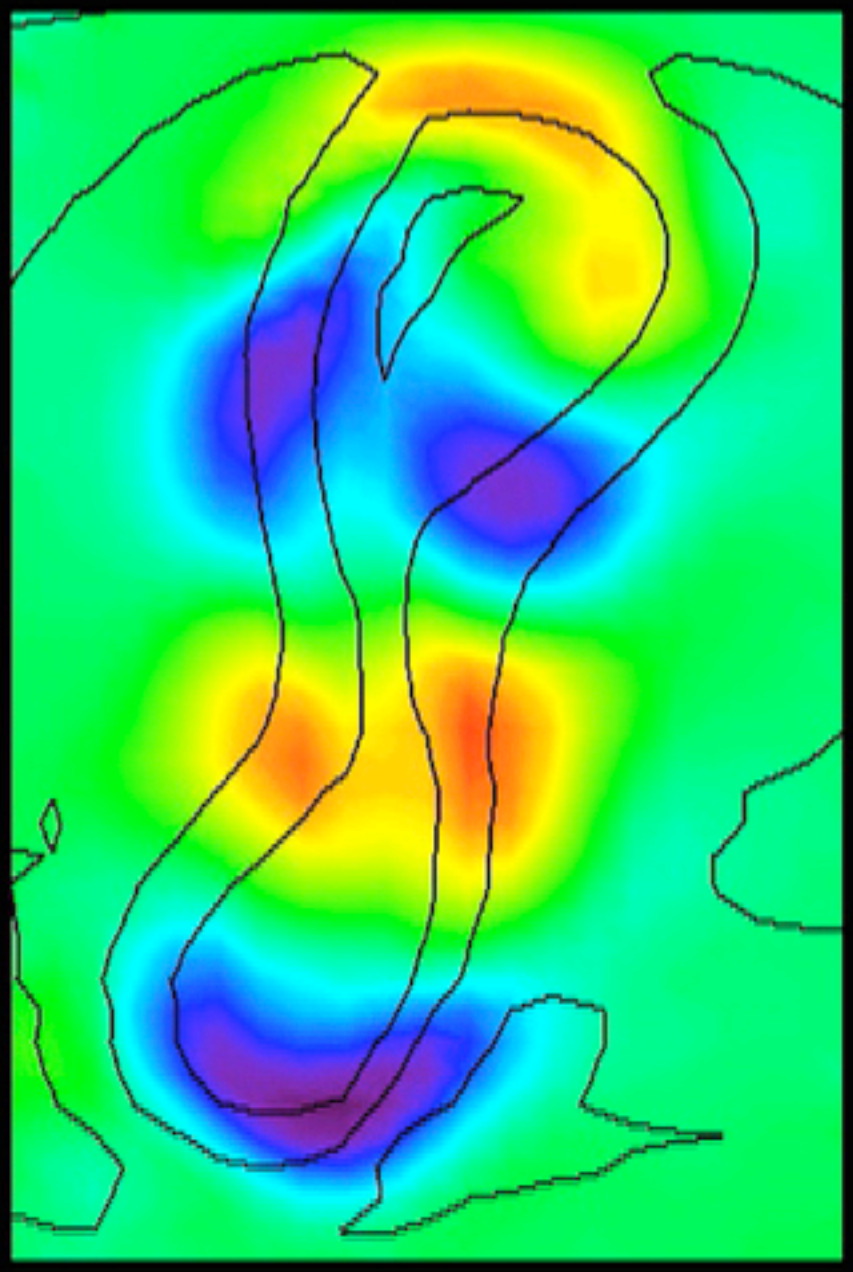
Perpendicular flow measured using a 4-sided mach probe at a distance of z=128cm


Density
3X10^12 cm^-3
2X10^11 cm^-3
1X10^12 cm^-3
Electron Diamagnetic Drift Velocity

# Density Fluctuations Due to Drift Waves




Frequency:
0.1Fci




We use a pair of ion-saturation probes to make correlation measurements of the density fluctuations.

Black lines are contours of the average density.

Colors are the reconstructed amplitude and phase information from the cross-correlation measurements.

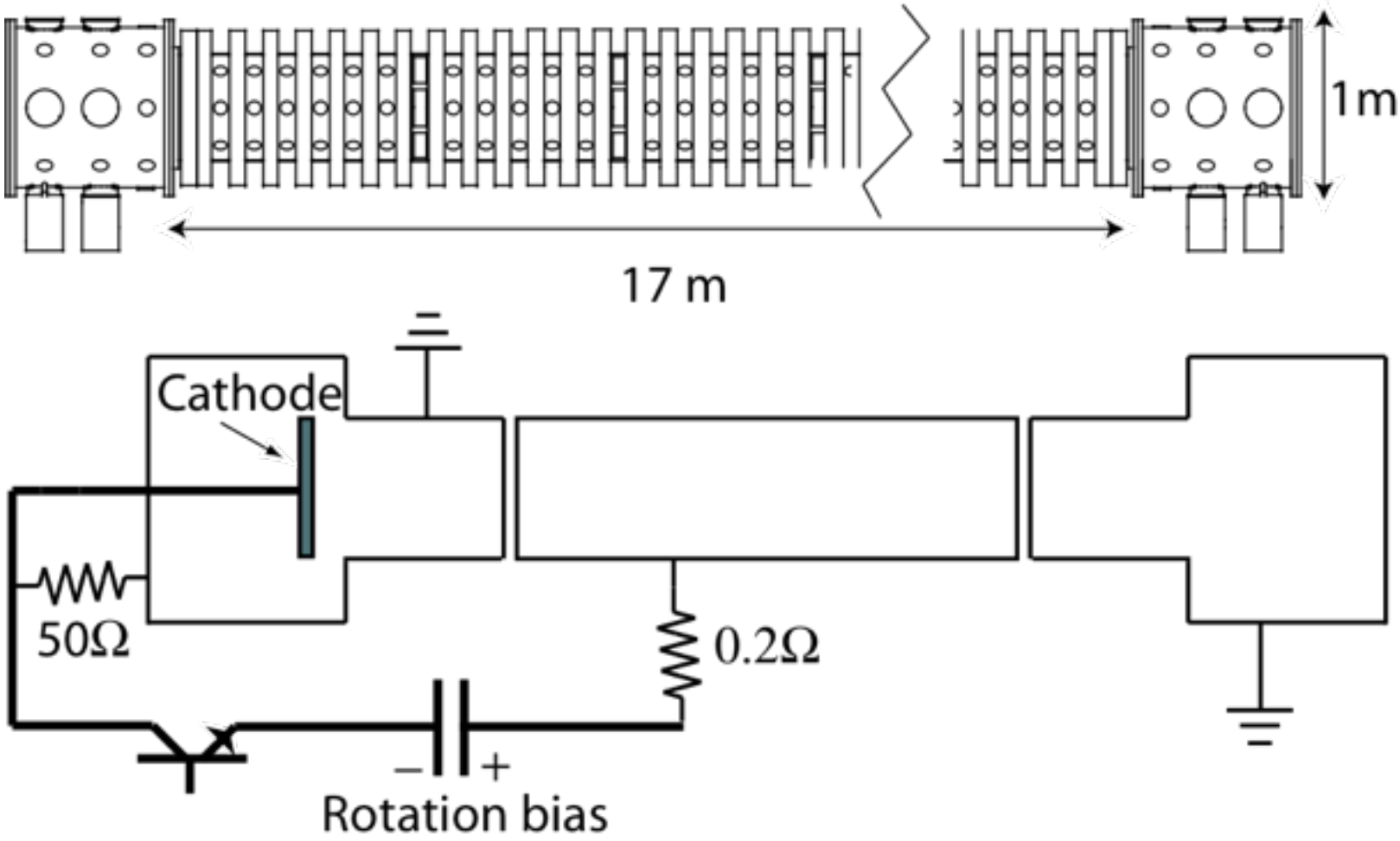
# Suppression of turbulent particle flux during biased rotation in LAPD

T.A. Carter, J.E. Maggs, and D.C. Pace
Dept. of Physics and Astronomy, UCLA

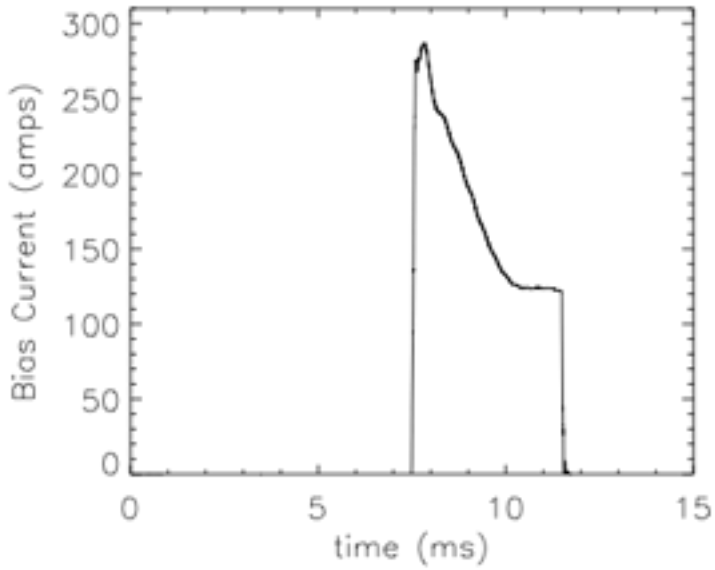
Acknowledgements: R.J. Taylor, P. Pribyl

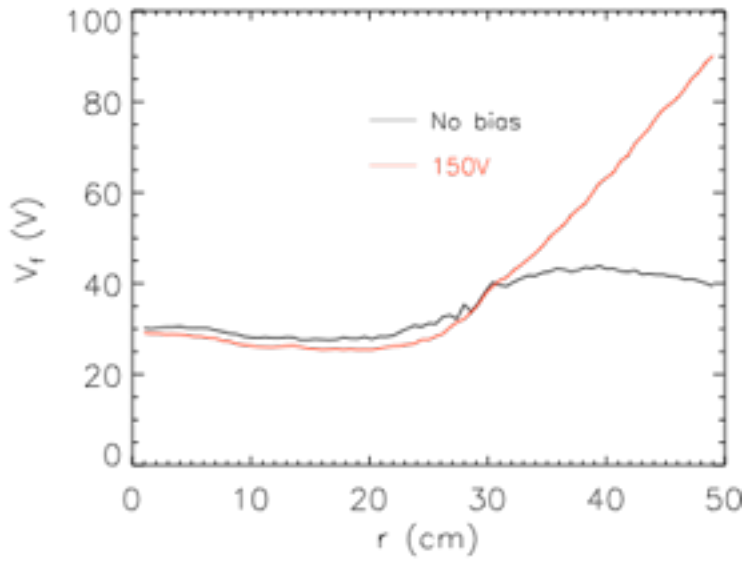
2005 Transport Task Force Meeting
Napa, CA

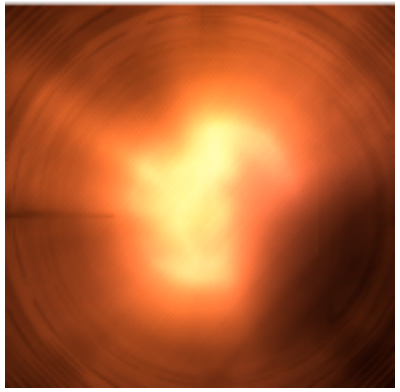
# Biased rotation in LAPD



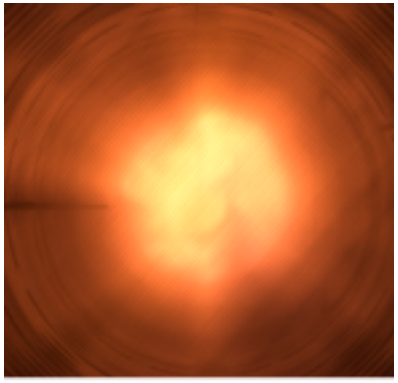
# Biasing creates electric fields in the edge and "cleans up" edge in visible images



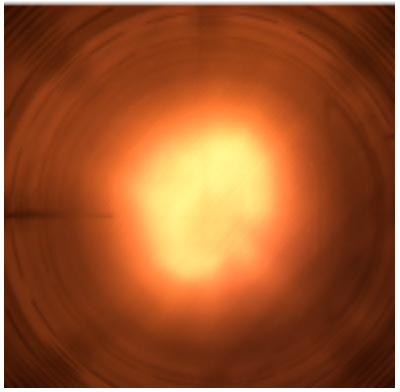



No bias

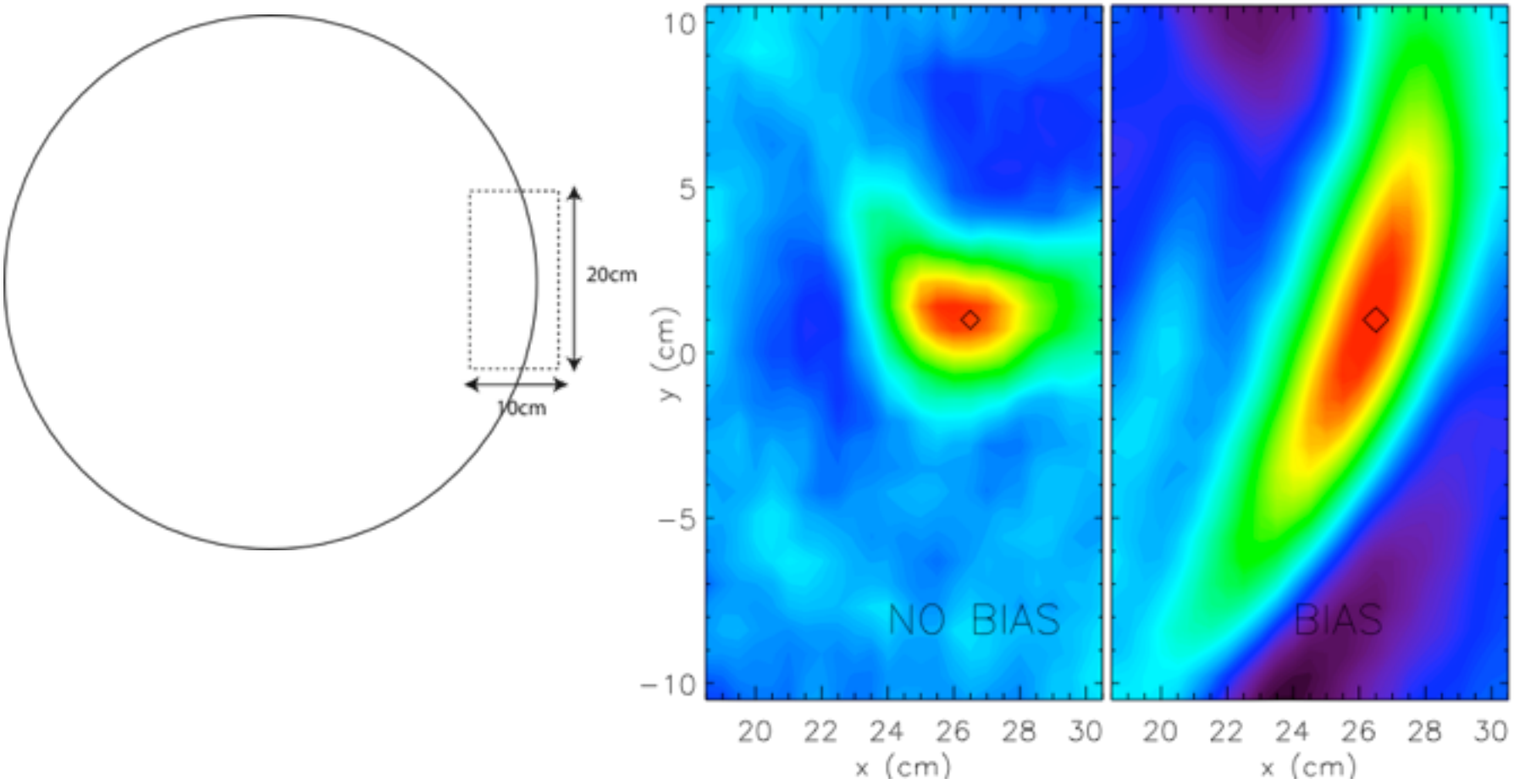


75V

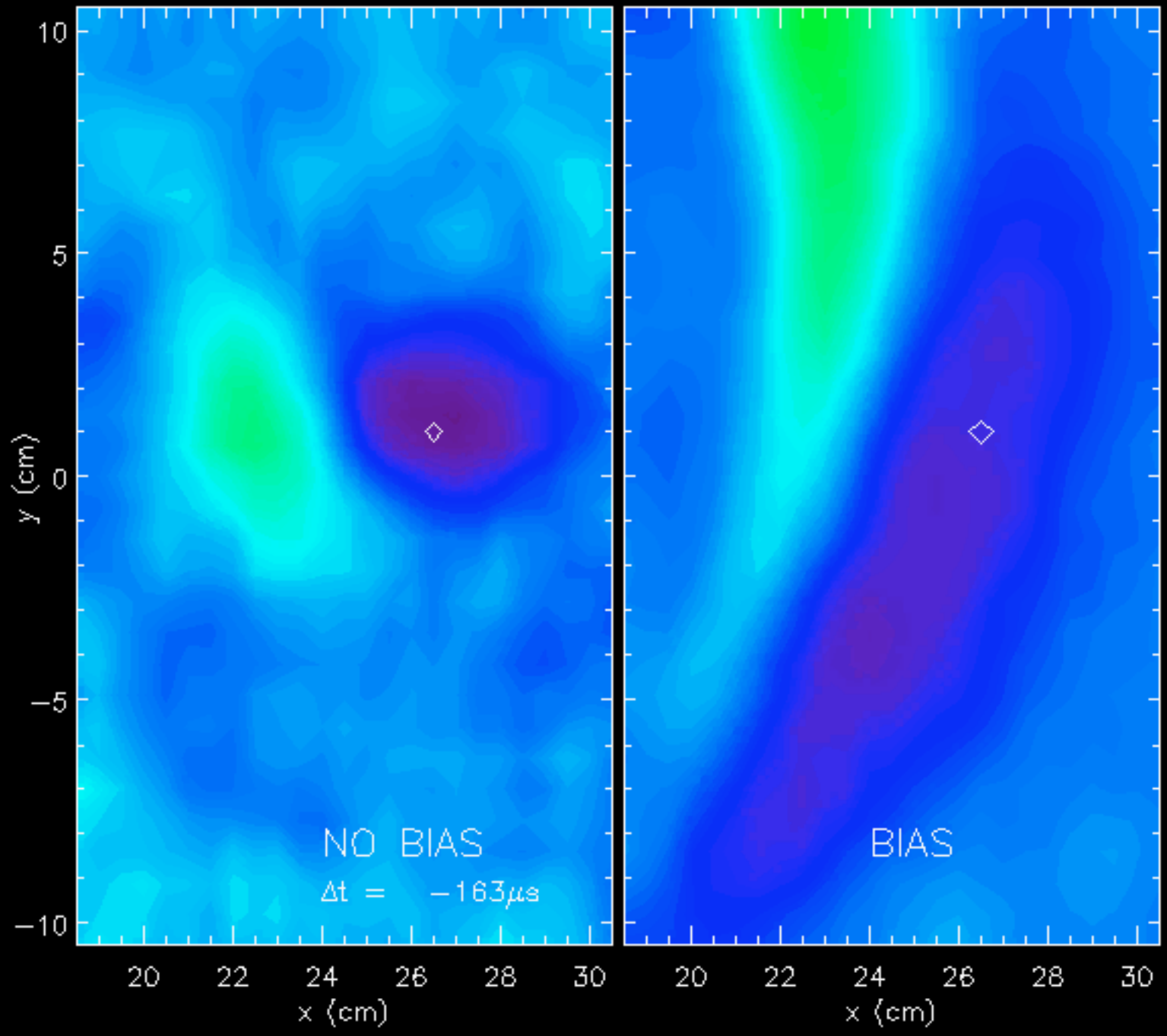


150V

# 2D correlation functions sheared during biased rotation



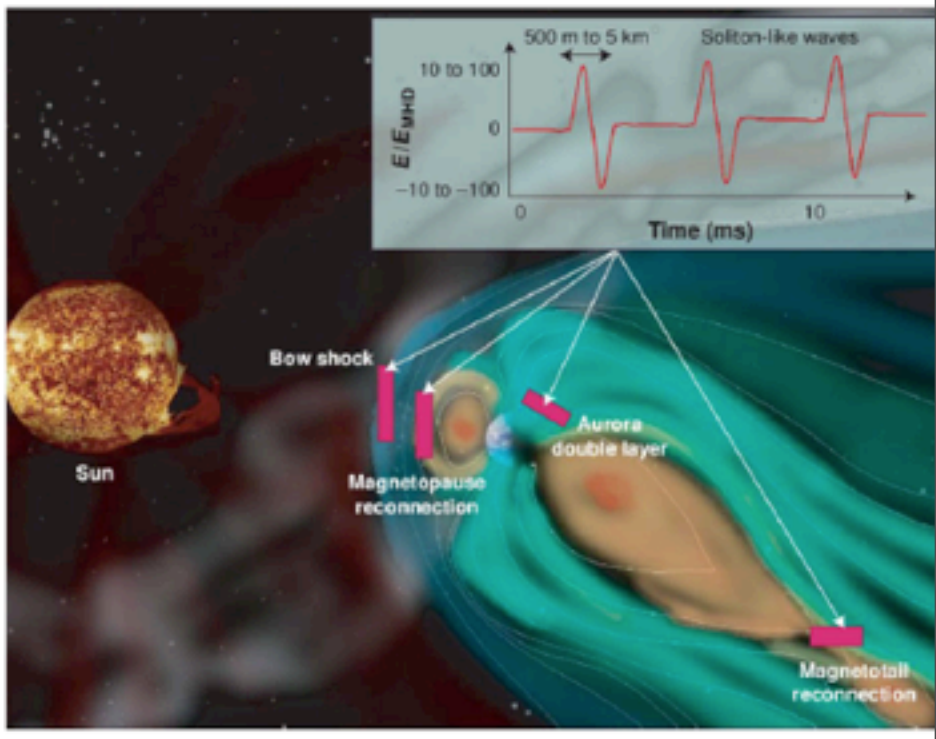

- Correlation function sheared, with significant azimuthal correlation
- Radial correlation length is reduced, but only slightly


10
5
0
−5
−10
y (cm)
20
22
24
26
28
30
x (cm)
NO BIAS
Δt = −163μs
BIAS
20
22
24
26
28
30
x (cm)

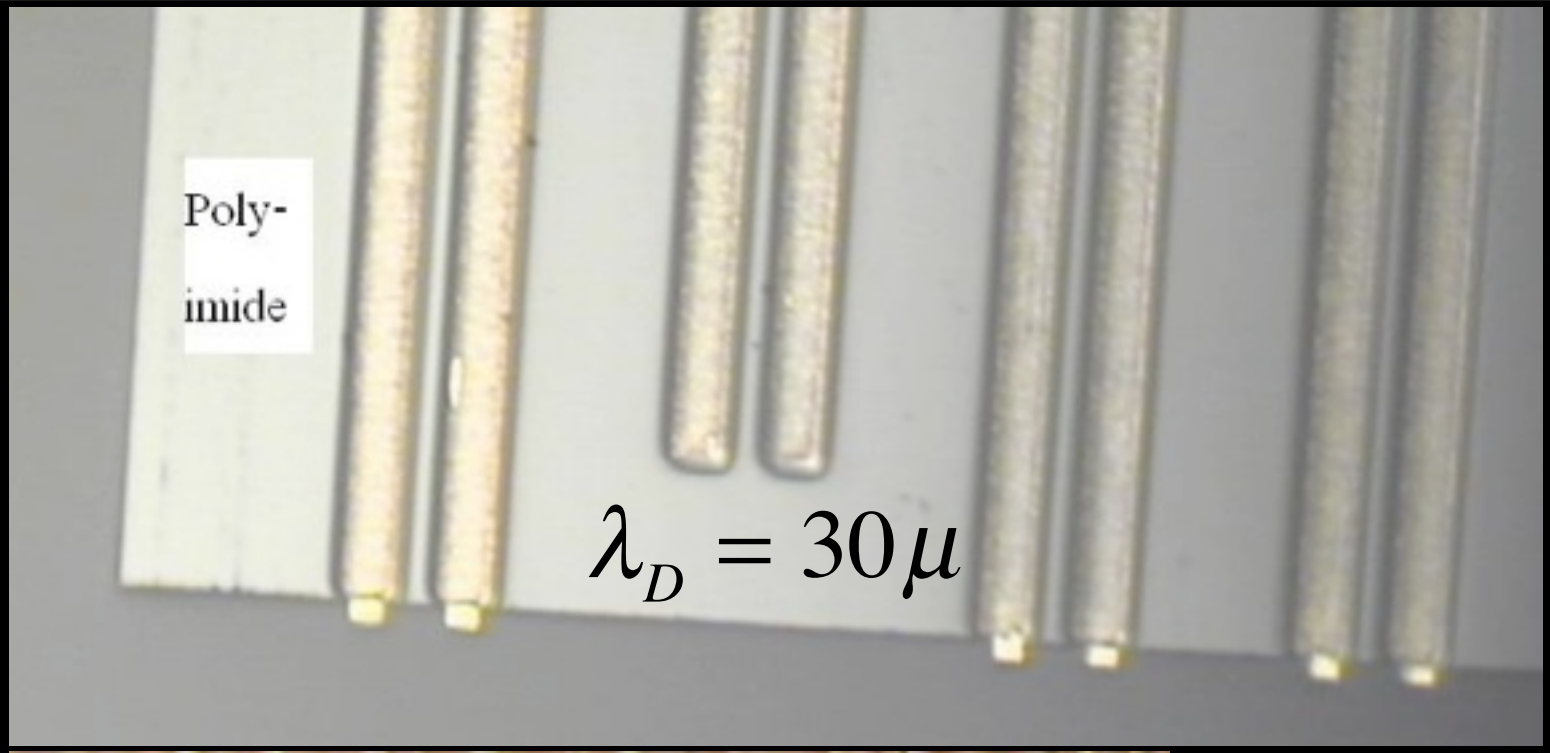
# Search for Electron Solitary Structures

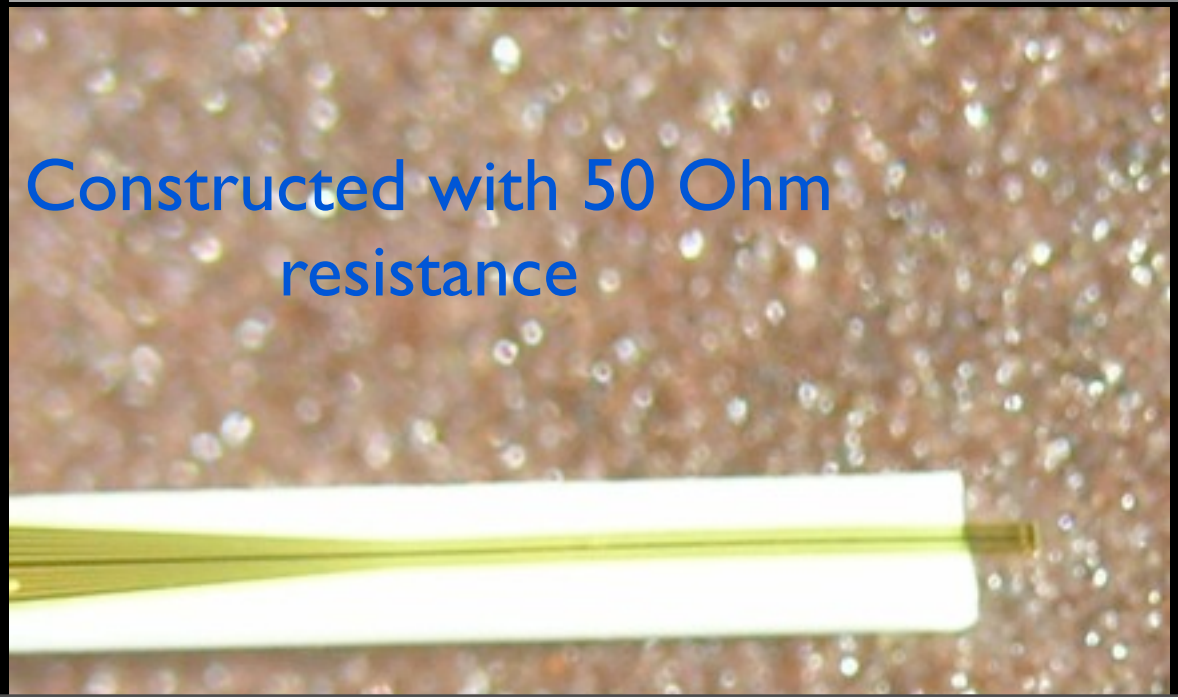
Li Jen Chen, J. Pickett, B. Lefebvre (U. New Hampshire), Paul Kintner (Cornell), Jack Judy, Franklin Chiang (UCLA EE),
W. Gekelman, P. Pribyl (UCLA Physics)

- Isolated Debye-scale structures with relatively large electric fields
- Seen in many contexts:
  - Plasma sheet, PSBL
  - Auroral acceleration region
  - Magnetopause
  - Bow shock
  - Magnetosheath, free solar wind
  - Laboratory reconnection experiments (Fox et al., PRL 08)
- BGK electron-holes? macroscopic role?




(From Hoshino, 2003)

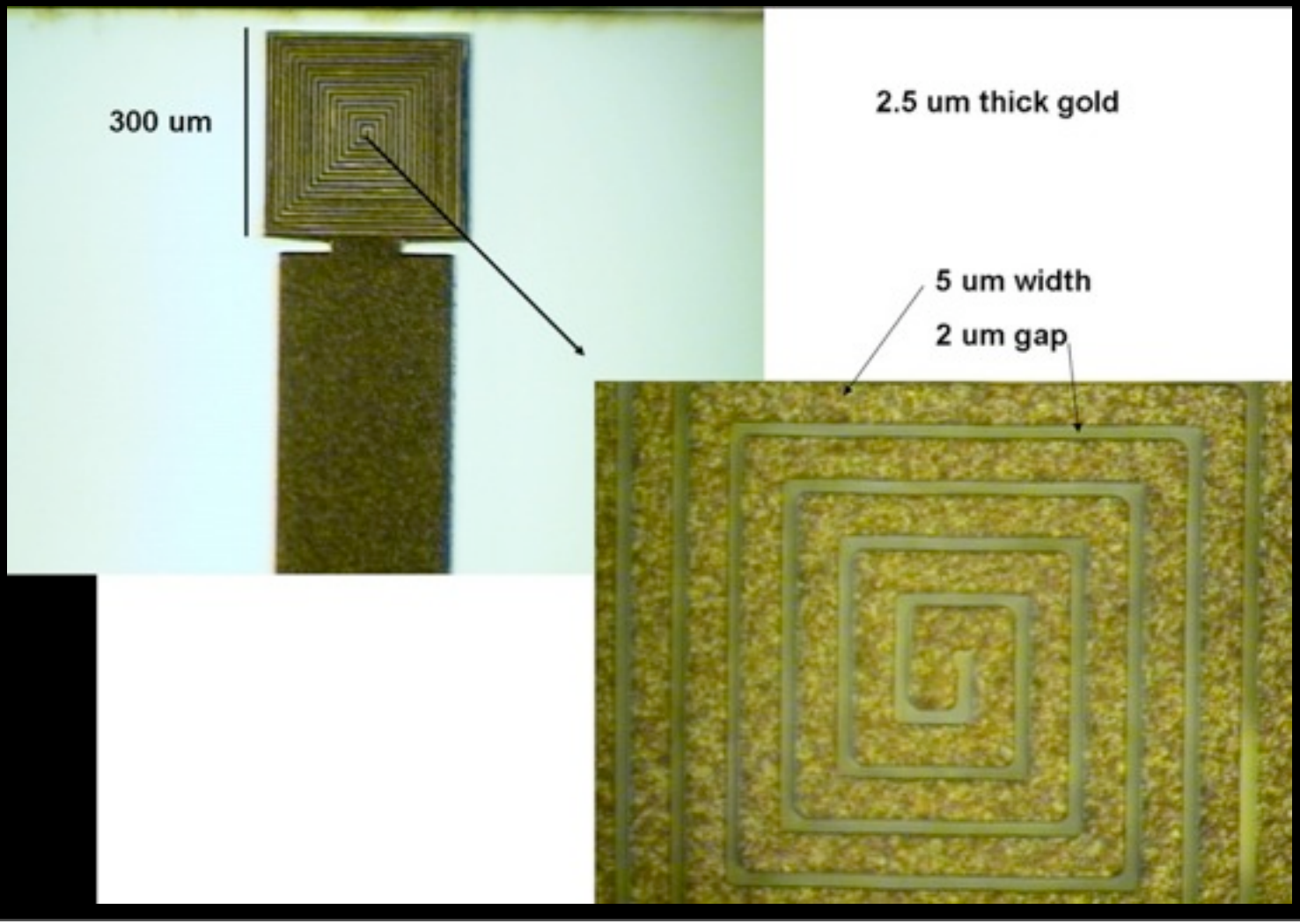


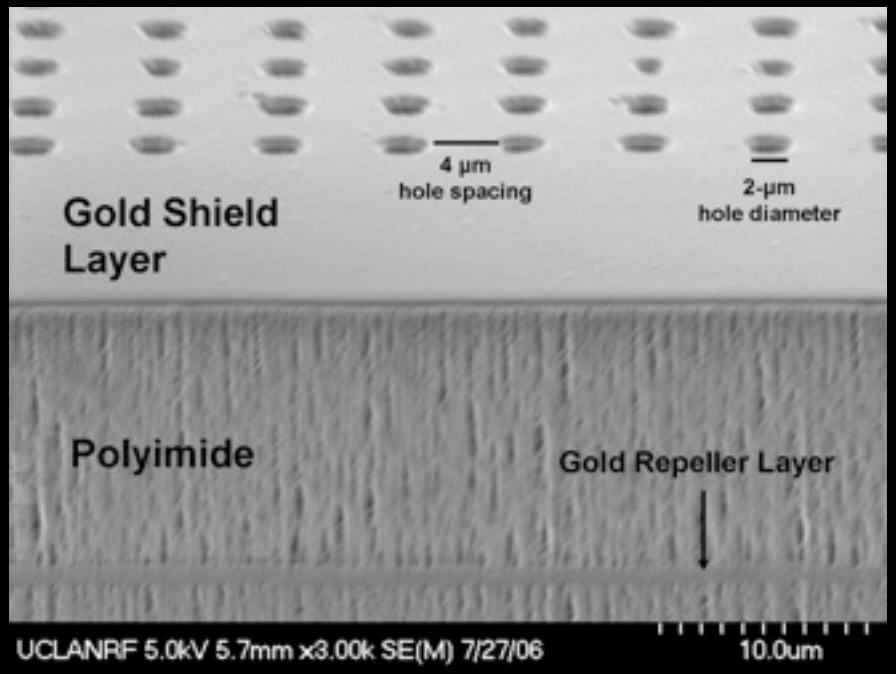

Probe tips are
15 $\mu$ square ,
20 $\mu$ apart
5 GHz

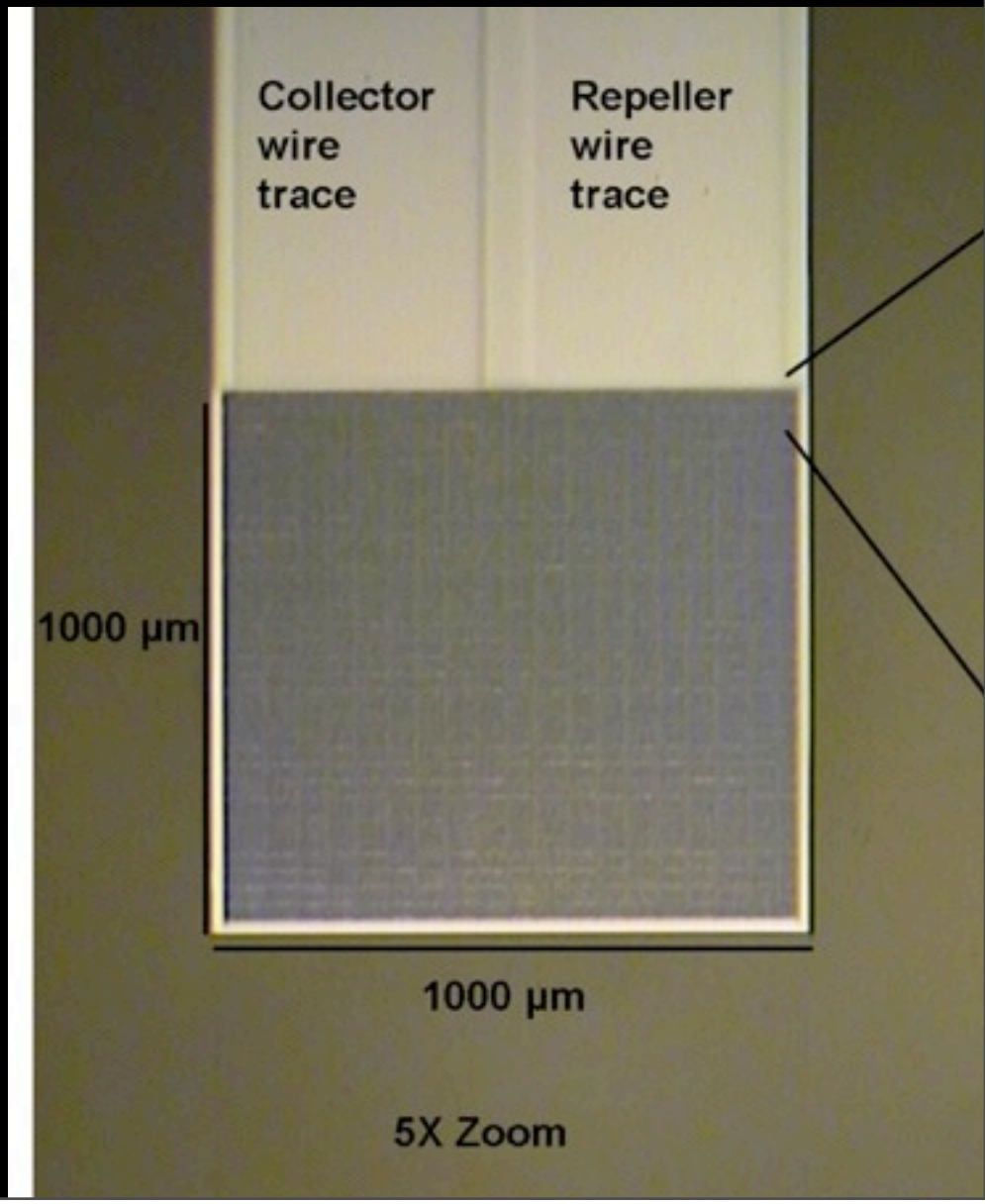
# Other microprobes

## B dot probe



# Velocity Analyzer

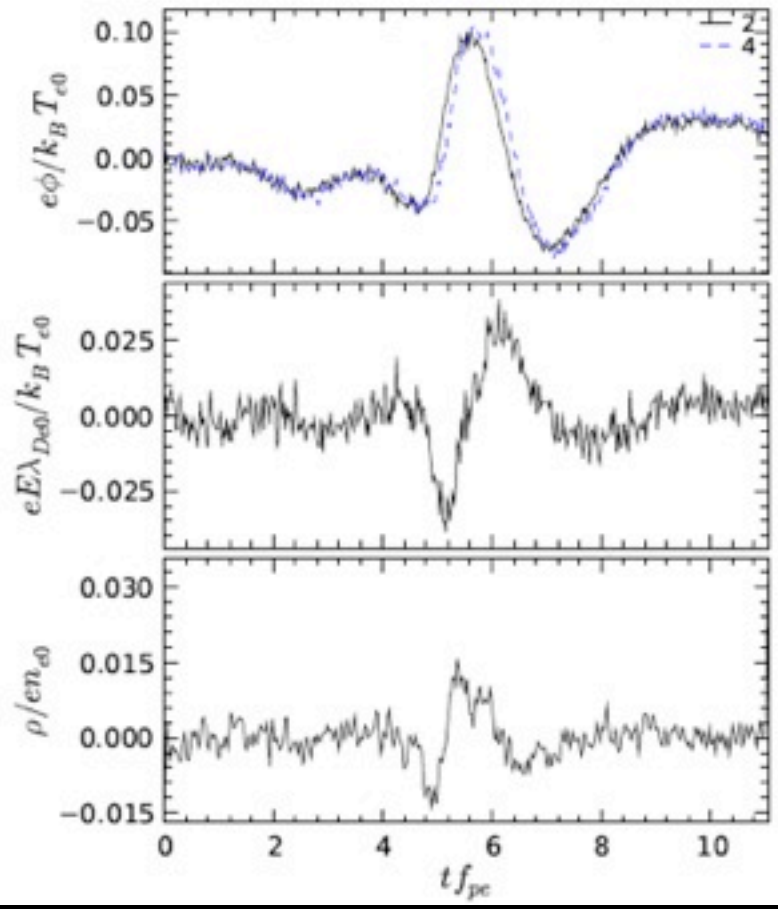


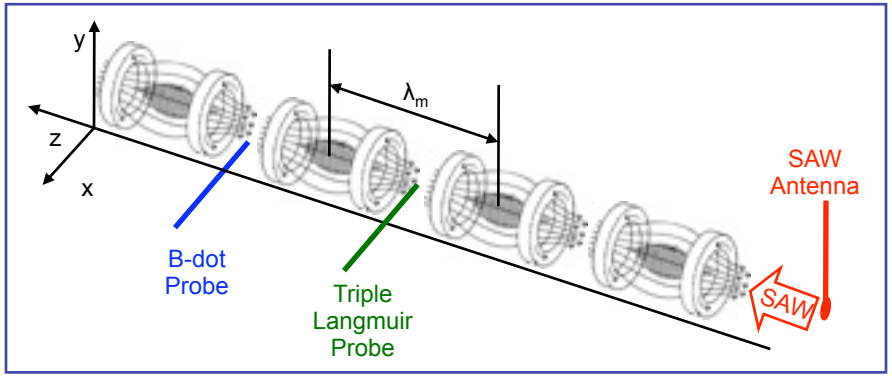
## Experimental Observations

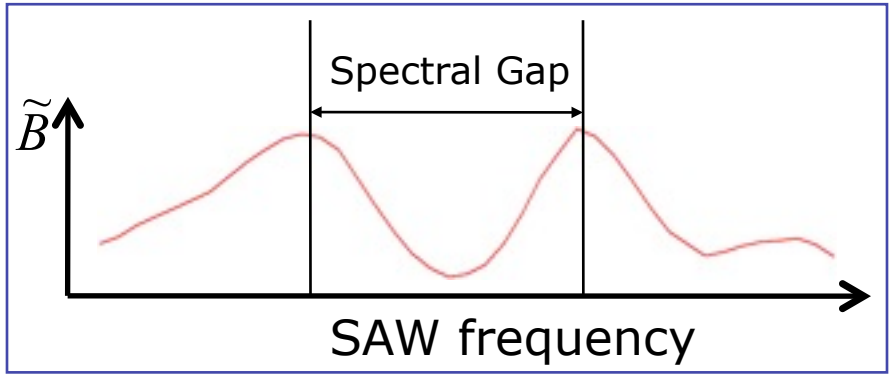
- Broadband signal $< f_{pe}$
- Positive potential hump, dipolar electric field, positive charge density (assuming slab)
  - $v = 240$ km/s
    $= 1.28 v_{Te} \ll v_b/2$
    $L_{\parallel} \approx 6.4 \lambda_{De}$
  - $v = 200$ km/s $= 1.07 v_{Te}$
    $L_{\parallel} \approx 5 \lambda_{De}$
    Hints of instability?

## Potential and E field



# Shear Alfvén Wave (SAW) Spectra in a Periodic Magnetic Mirror Array




**Y. Zhang, W.W. Heidbrink, H. Boehmer, R. McWilliams (UC Irvine)**

**Guangye Chen, Boris N. Breizman (UT Austin)**

**S. Vincena, T. Carter, D. Leneman, W. Gekelman, B. Brugman (UCLA)**

http://hal9000.ps.uci.edu/Presentations.htm

**Work supported by DOE DE-FG02-03ER54720**

UCIrvine THE UNIVERSITY OF TEXAS AT AUSTIN UCLA

# Periodic Structures Influence Wave Propagation in Many Physical Environments

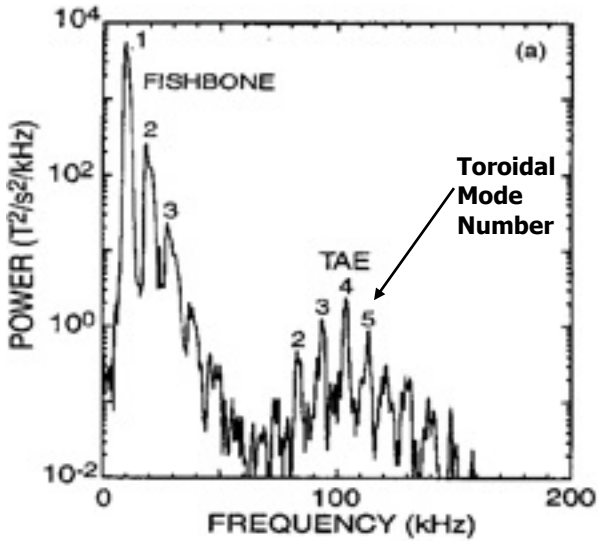



Fig. 1. TAE structure in DIIID
(E. M. Carolipio et. al. PoP 8(7) 3391, 2001)

$\omega_{TAE} \sim v_A / 2qR$, $L = qR$, $q(r_m) \sim m/n$

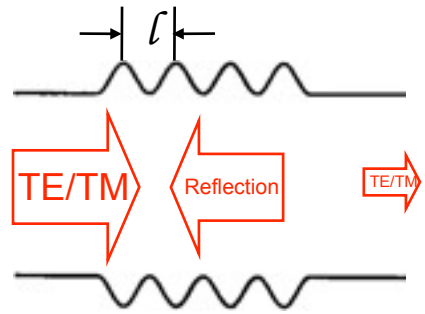



Fig. 2. Bragg Waveguide Reflector

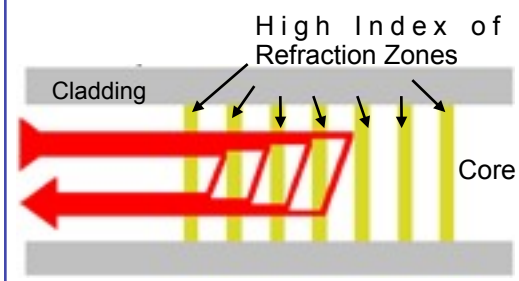



Fig. 3. Fiber Bragg Grating

$$\varepsilon = \varepsilon_0[1 + M\cos(\vec{K} \times \vec{r})]$$

Waves in a **periodic** medium (or boundary condition)

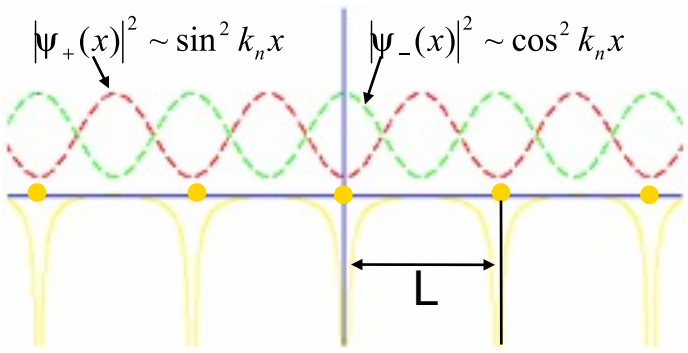
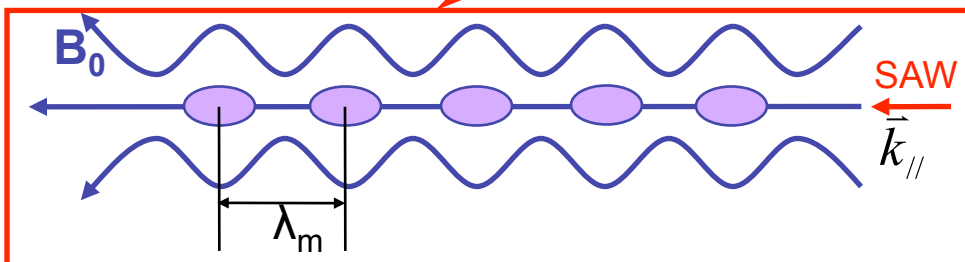


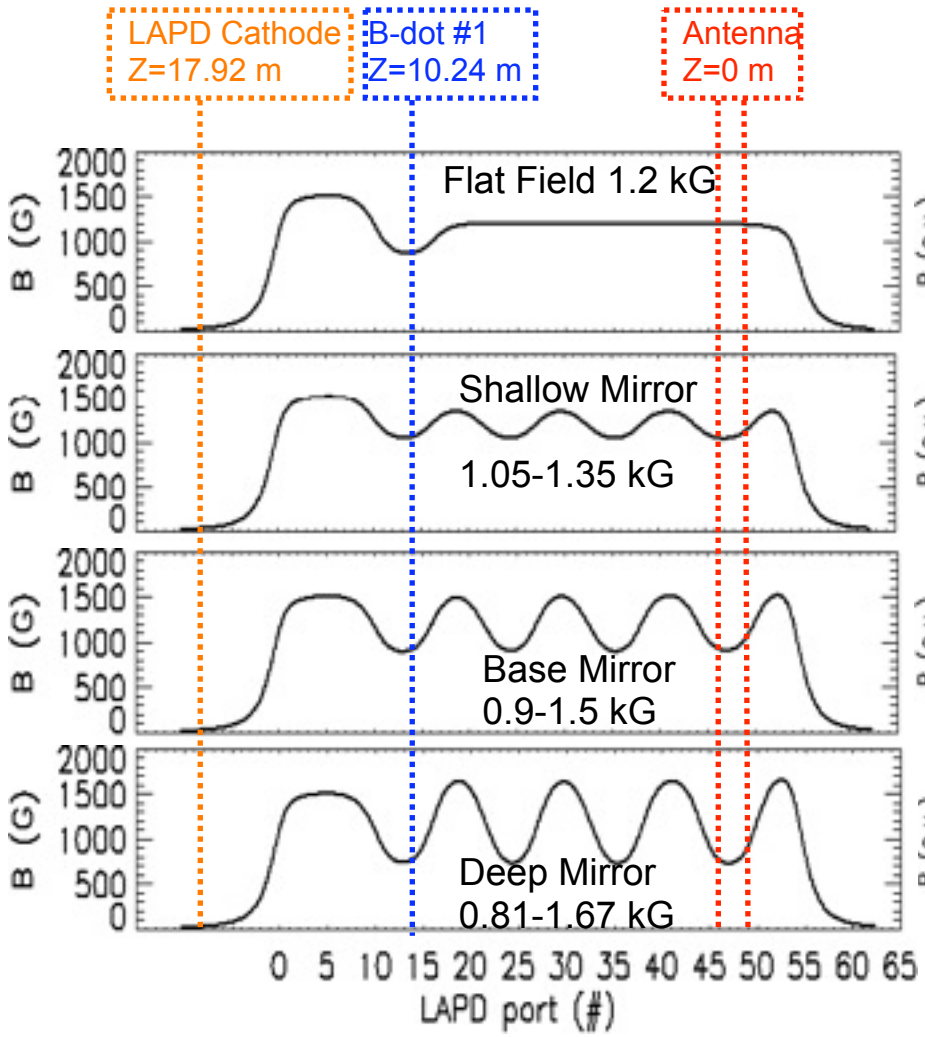

Fig. 4. Solid - state Electron Probability Density in Periodic Ion Core Potential



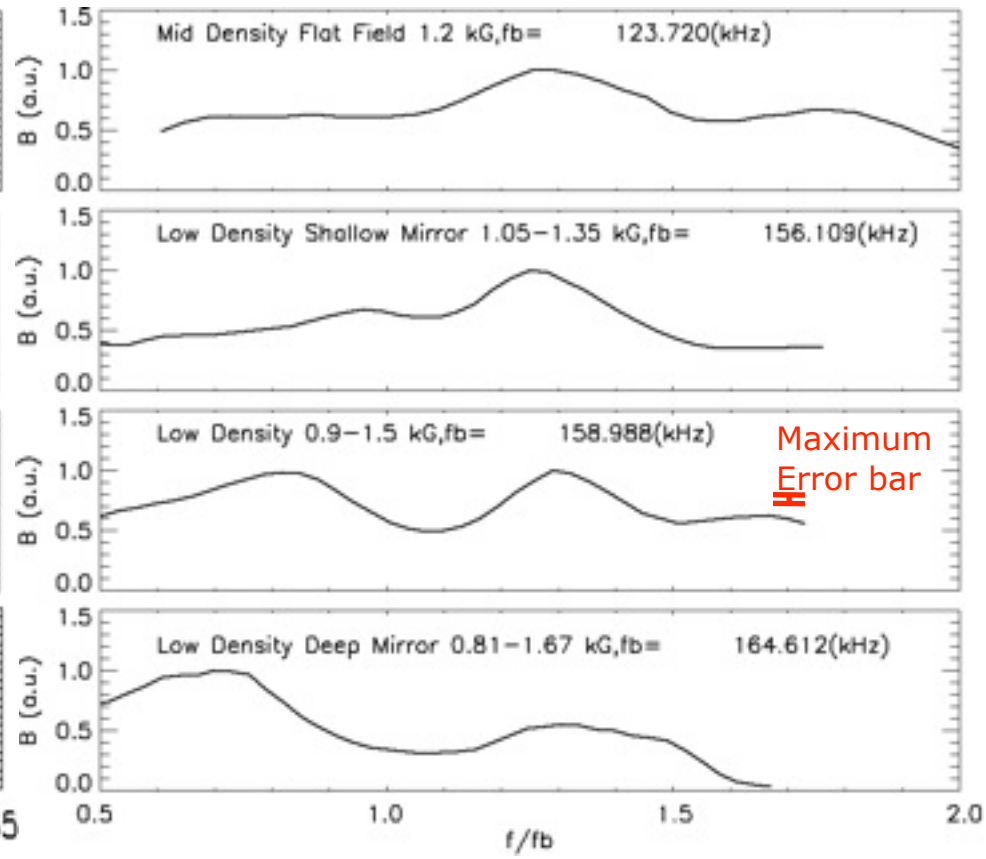

Given Bragg reflection condition $2k_{//} = k_m$ or $\lambda = 2\lambda_m$, a **propagation gap** is centered at $f_B = v_{A//}/2\lambda_m$

Fig. 5. Mirror Alfvén Experiment in LAPD

# Gap Width is Proportional to Mirror Depth ($B_{max}$-$B_{min}$/$B_{max}$+$B_{min}$)




Normalized $B_\theta$ Versus Normalized Frequency ($f/f_B$)




(Maximum Error of normalized B is ±0.04)

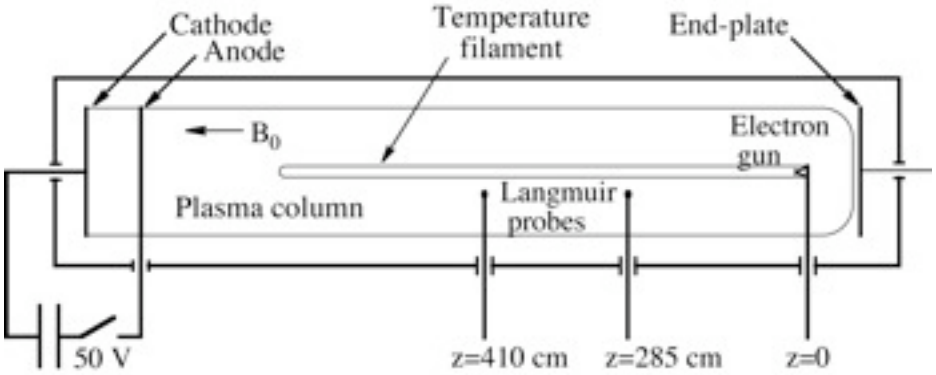
# Electron Heat Transport

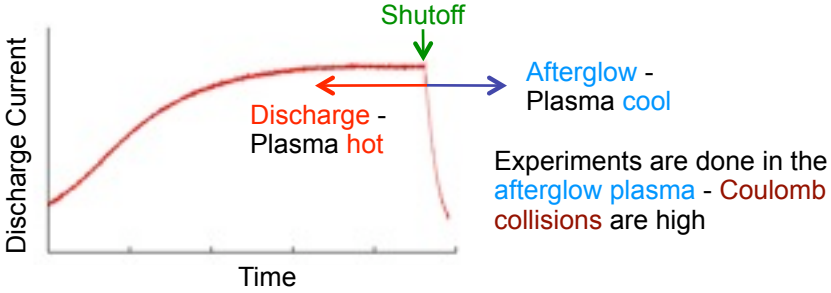
J. Maggs, A. Burke, G. Morales (UCLA)

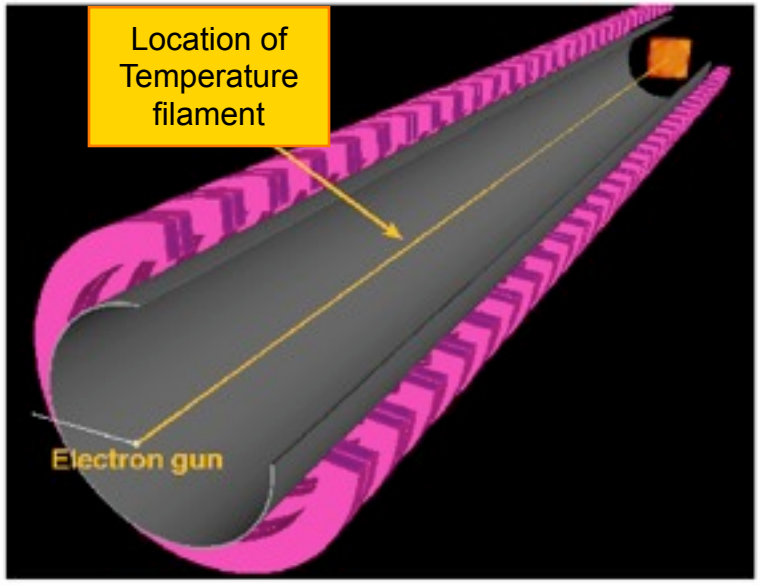
# Making a Temperature Filament in the Lab

Use a small (3 mm) electron gun to produce a low voltage electron beam

Beam produces an axial-elongated heat source and conduction leads to a field-aligned temperature filament



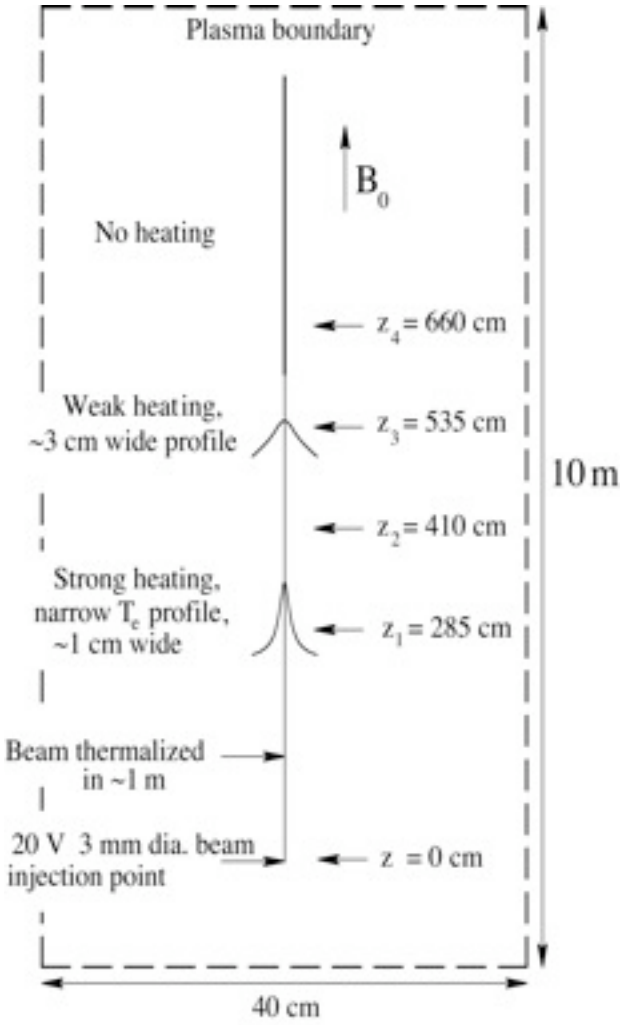




In a plasma, the cross-field thermal conductivity is much smaller than the field-aligned conductivity, but the large cross-field area and small field-aligned area in the long narrow filament balances this difference

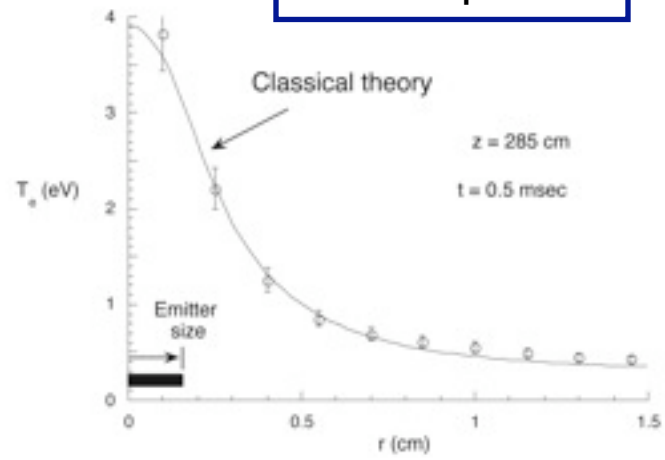
The end of the temperature filament does not extend to the machine wall so that the 'nose' of the filament is a free boundary

# Temperature profiles in the filament

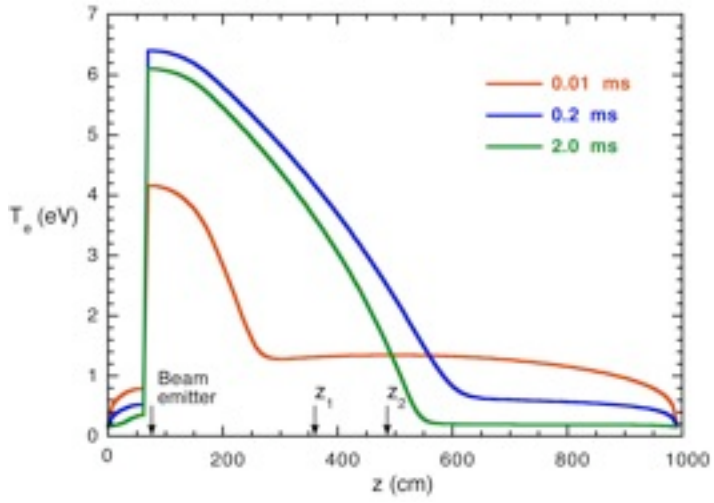
General morphology




Radial profile




Axial profile



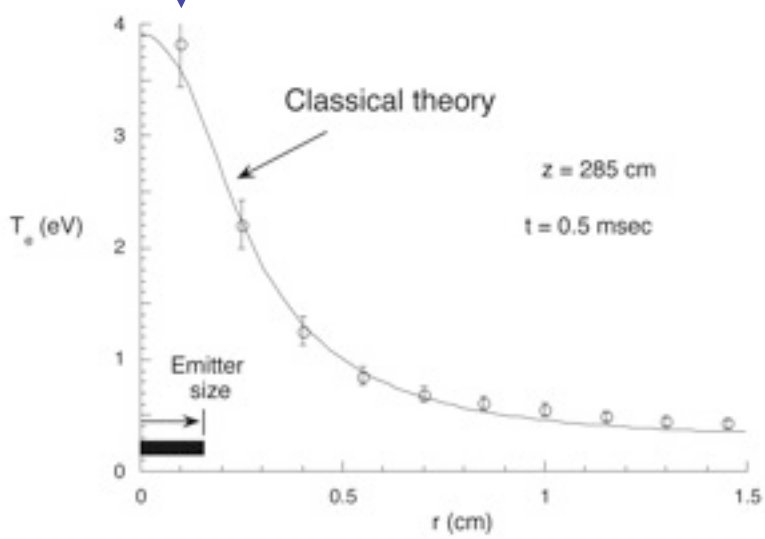

This result is from a computer code

# Drift-Alfvén waves in the temperature filament

Drift-Alfven waves are generated spontaneously - driven by radial gradients in electron temperature

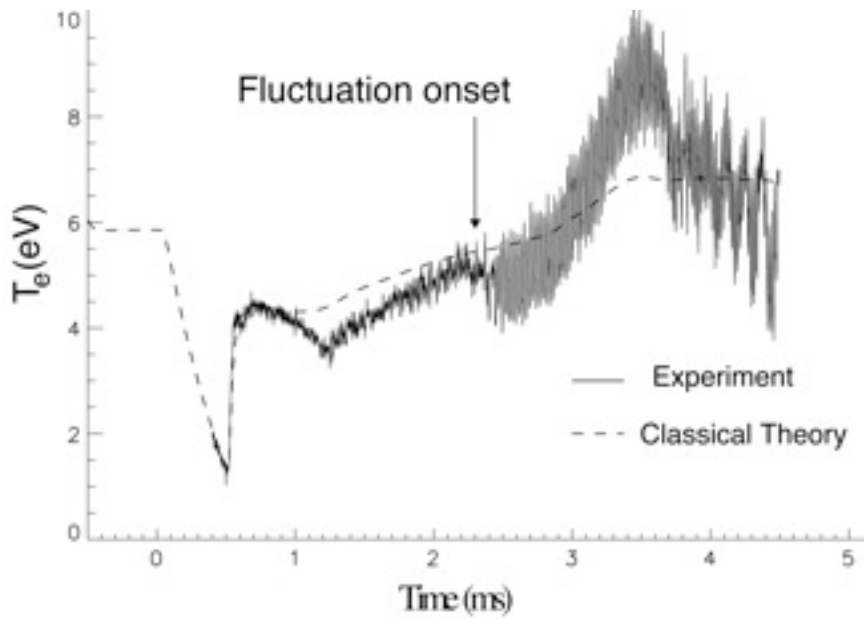
Waves effect heat transport in the plasma

Temporal evolution at this radial location




Radial Temperature Profile

Temporal Evolution

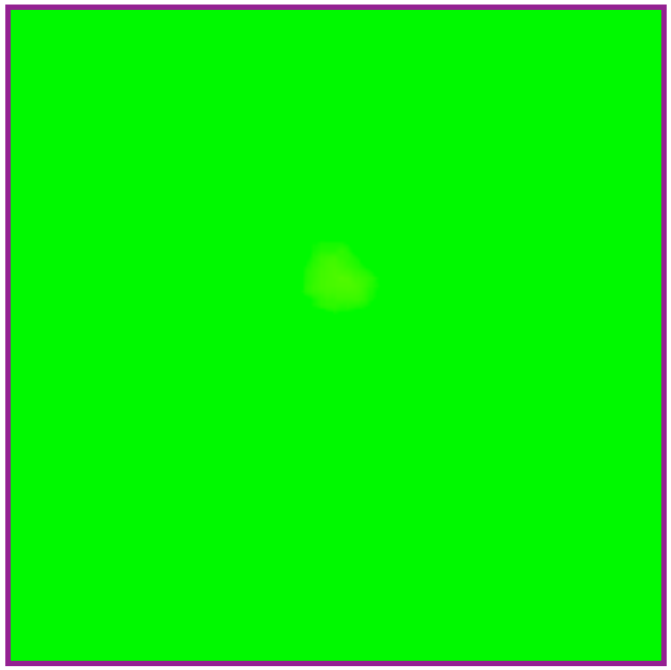


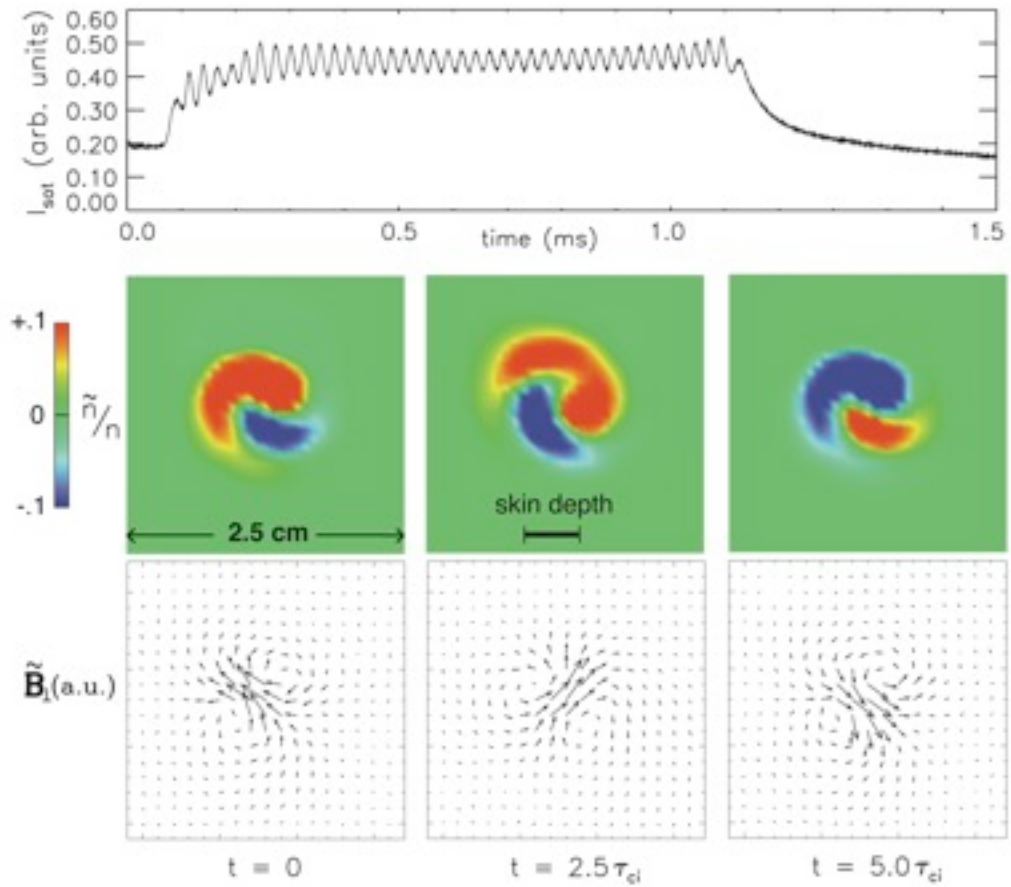
# Temporal and spatial behavior of drift-Alfvén waves

Drift-Alfvén waves have both density and magnetic fluctuations

$$I_{sat} \propto n\sqrt{T_e}$$

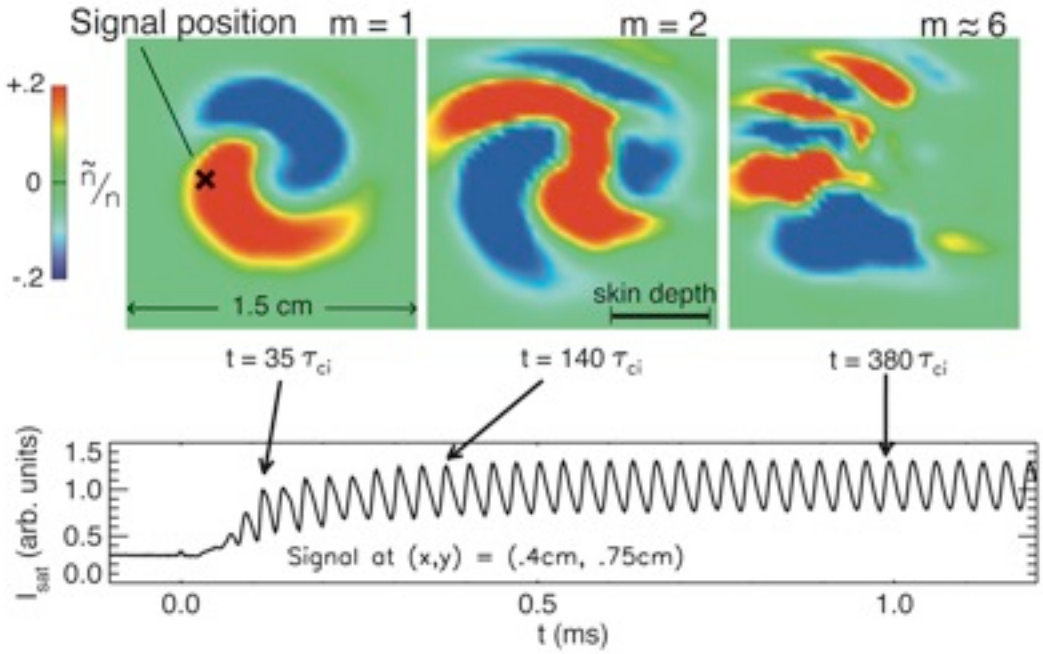
Data plane across $B_0$

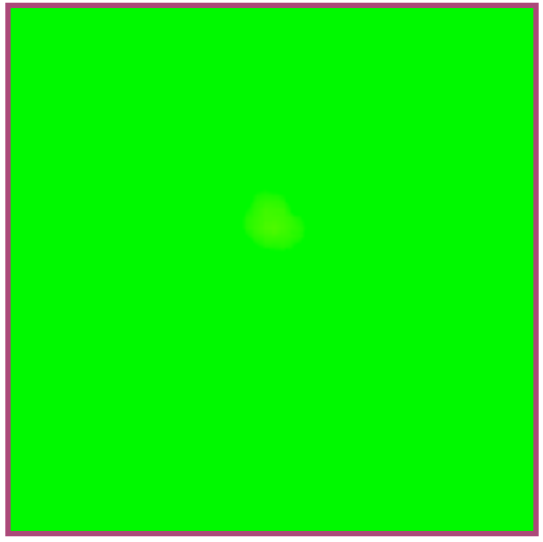





Period of the spiral is about ten gyro-periods

# Azimuthal mode number progression



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- This includes use of all existing diagnostics
- Full time staff assistance
- Use of all computers, software, and lab equipment
- BaPSF does not cover the costs of a user's transportation, accommodations, meals.
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Steve Spangler (U. Iowa)

Upon approvable of the white paper time on the machine is scheduled.

# *Interested?*

- gekelman@physics.ucla.edu
- http://plasma.physics.ucla.edu/bapsf

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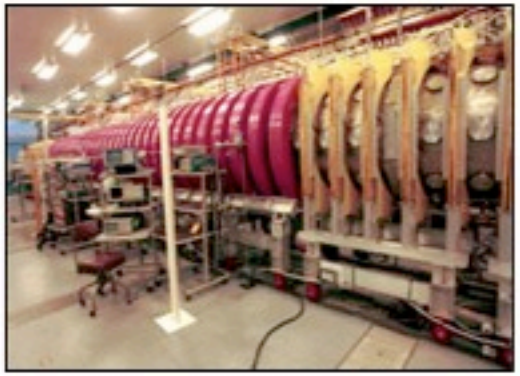

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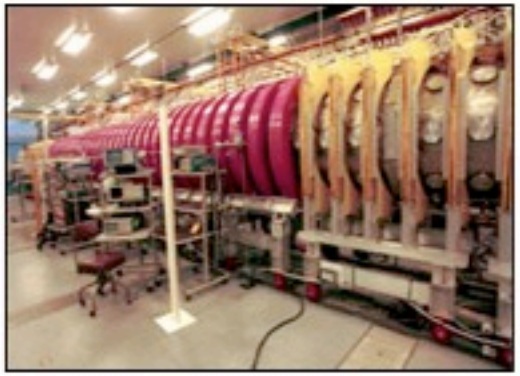

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