Overview of the Basic Plasma Science Facility

Troy Carter (on behalf of BaPSF local group and users)
Dept. of Physics and Astronomy, UCLA

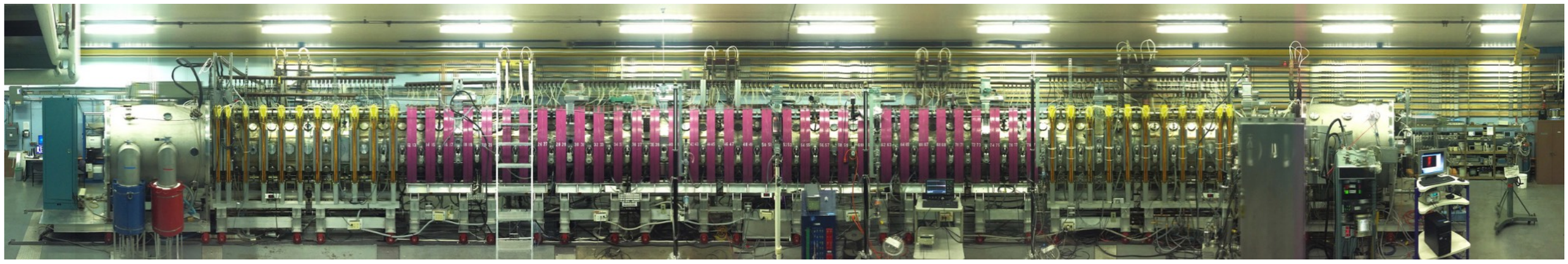
PSTI UCLA
Plasma Science and Technology Institute

UCLA

Summary

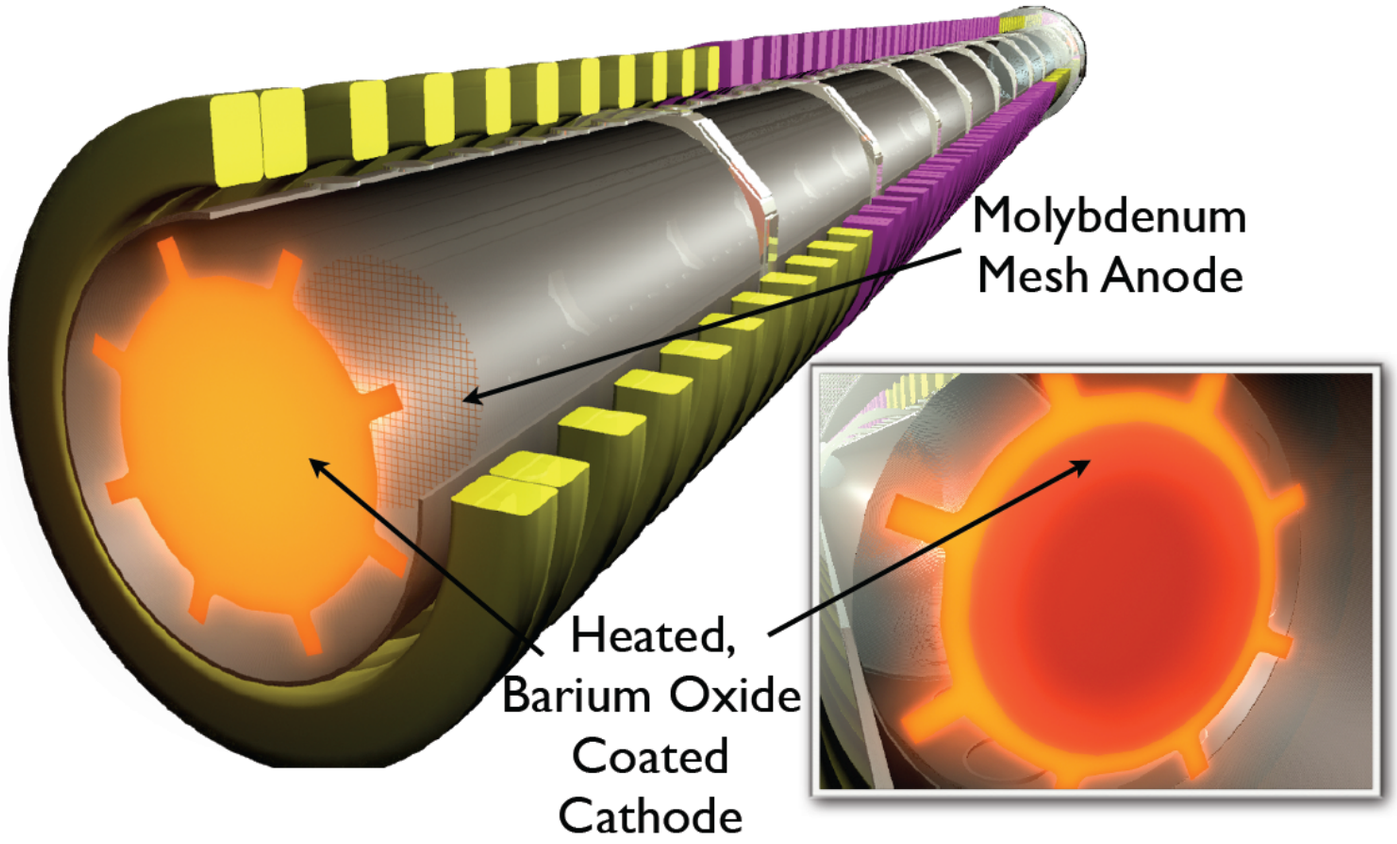
- Basic Plasma Science Facility: User facility for study of fundamental processes in magnetized plasmas (primary device: Large Plasma Device (LAPD))
- Example experiments of interest to this community:
  - Linear & Nonlinear (kinetic/inertial) Alfvén waves
  - Wave/particle interactions
    - Scattering of mirror-trapped energetic electrons by Alfvén waves
    - Excitation of whistler waves (hiss-like/chorus-like) by energetic electron beam
    - Excitation of Alfvén waves (EMIC) by energetic ion beam in multi-ion species plasma

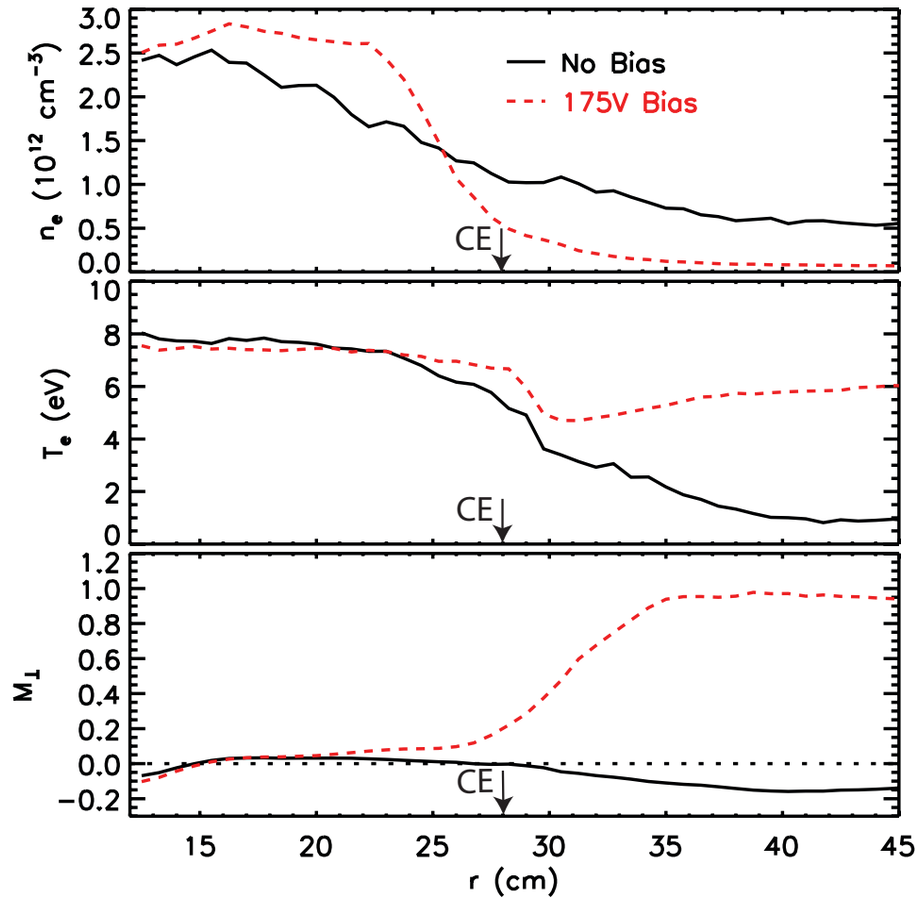
The LArge Plasma Device (LAPD)



- Solenoidal magnetic field, cathode discharge plasma (BaO and LaB_6)
- BaO Cathode: $n \sim 10^{12}$ cm^{-3}, $T_e \sim$ 5-10 eV, $T_i \lesssim 1$ eV
- LaB_6 Cathode: $n \sim 5 \times 10^{13}$ cm^{-3}, $T_e \sim$ 10-15 eV, $T_i \sim$ 6-10 eV
- B up to 2.5kG (with control of axial field profile)
- BaO: Large plasma size, ~20m long, D~60cm
- High repetition rate: 1 Hz
- US NSF/DOE Sponsored user facility: users from this community are welcome! (international users too)

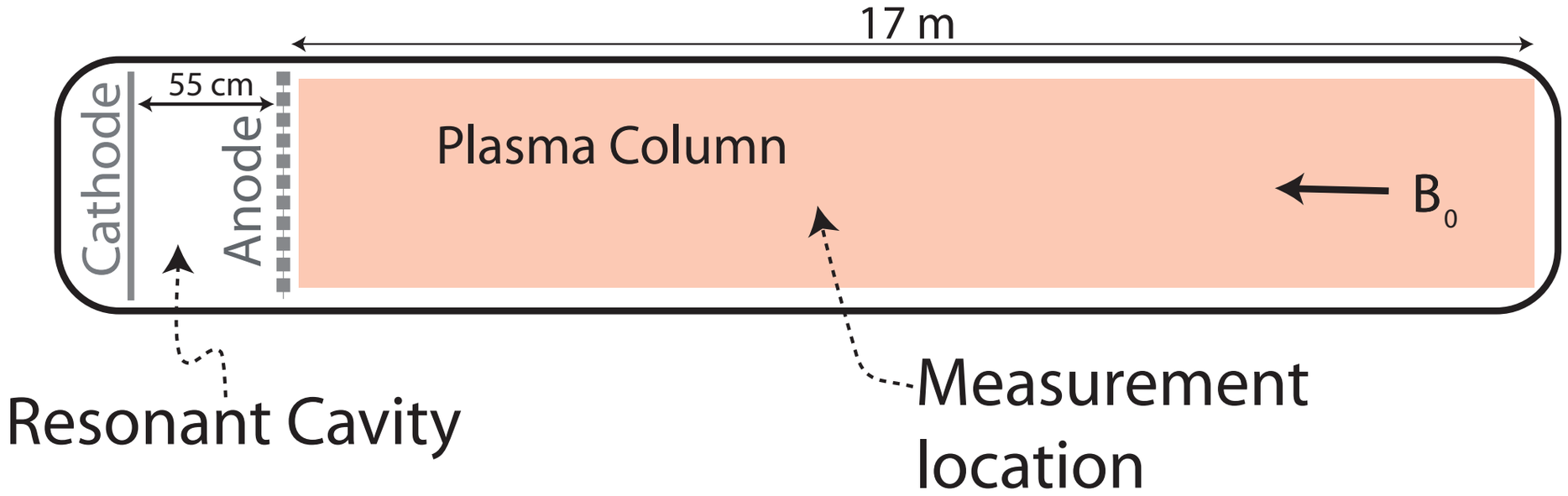
LAPD BaO Plasma source



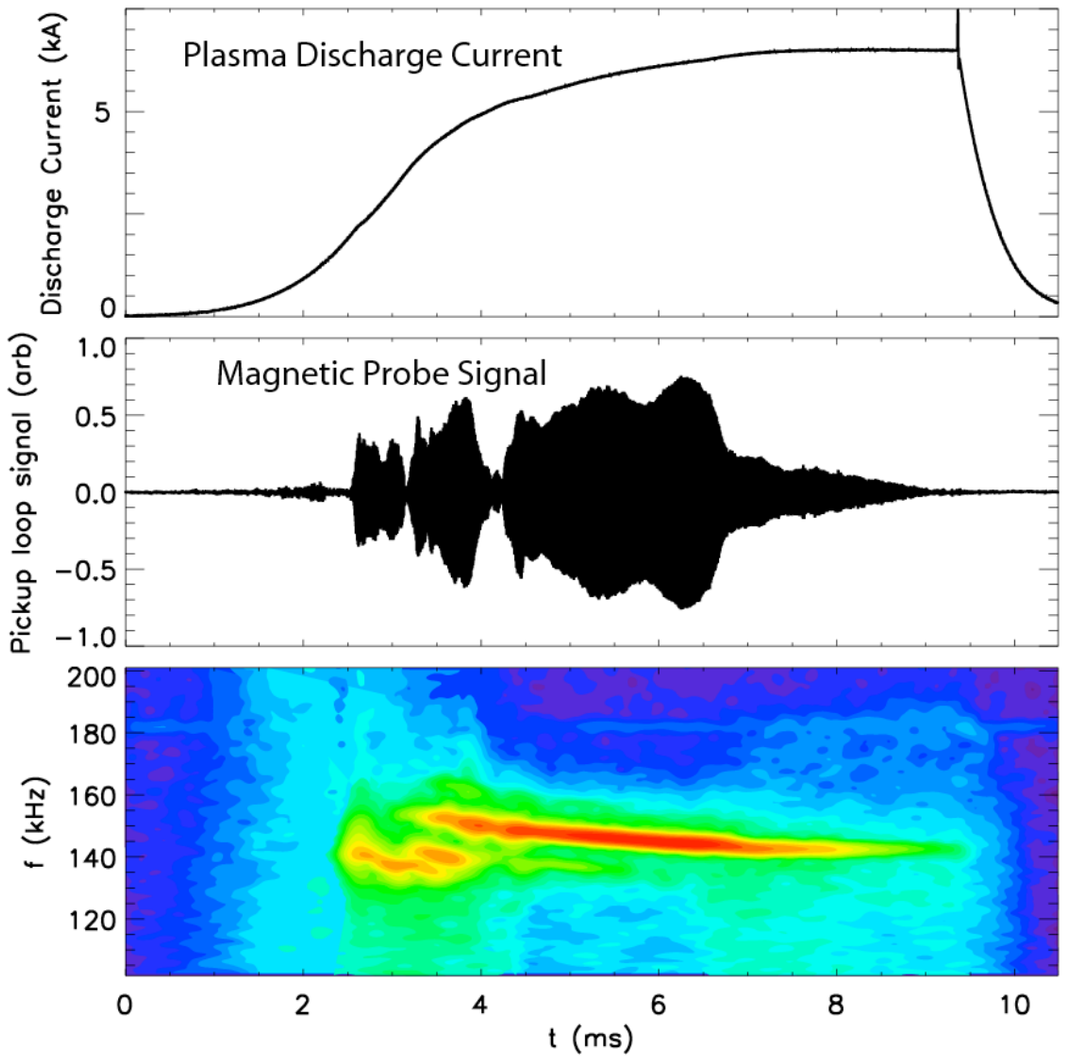


- Produces plasmas with 10-20 ms duration at 1 Hz rep rate
- $n \sim 10^{12}$ cm^{-3}, $T_e \sim$ 5-10 eV, $T_i \lesssim$ 1 eV
- Large quiescent core plasma (~60 cm diameter) for study of plasma waves, injection of ion/electron beams, etc.

Example data: Alfvén wave MASER



- Plasma source acts as resonant cavity for shear Alfvén waves
- Driven spontaneously by discharge current (thought to be inverse Landau damping on return current electrons)
- Alfvén wave "MASER"

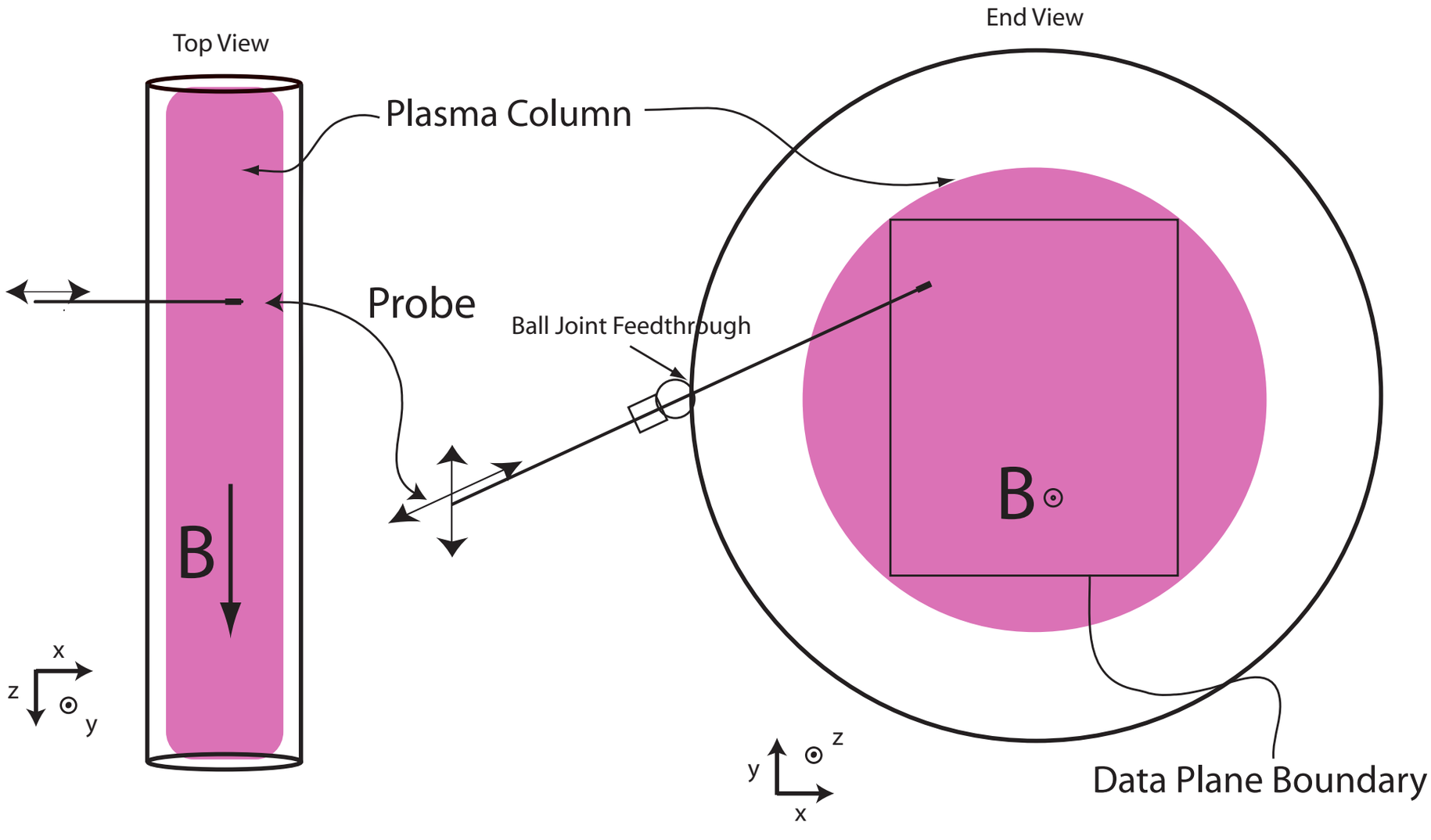


Maggs, Morales, PRL 91, 035004 (2003)

Maggs, Morales, Carter, PoP 12, 013103 (2005)

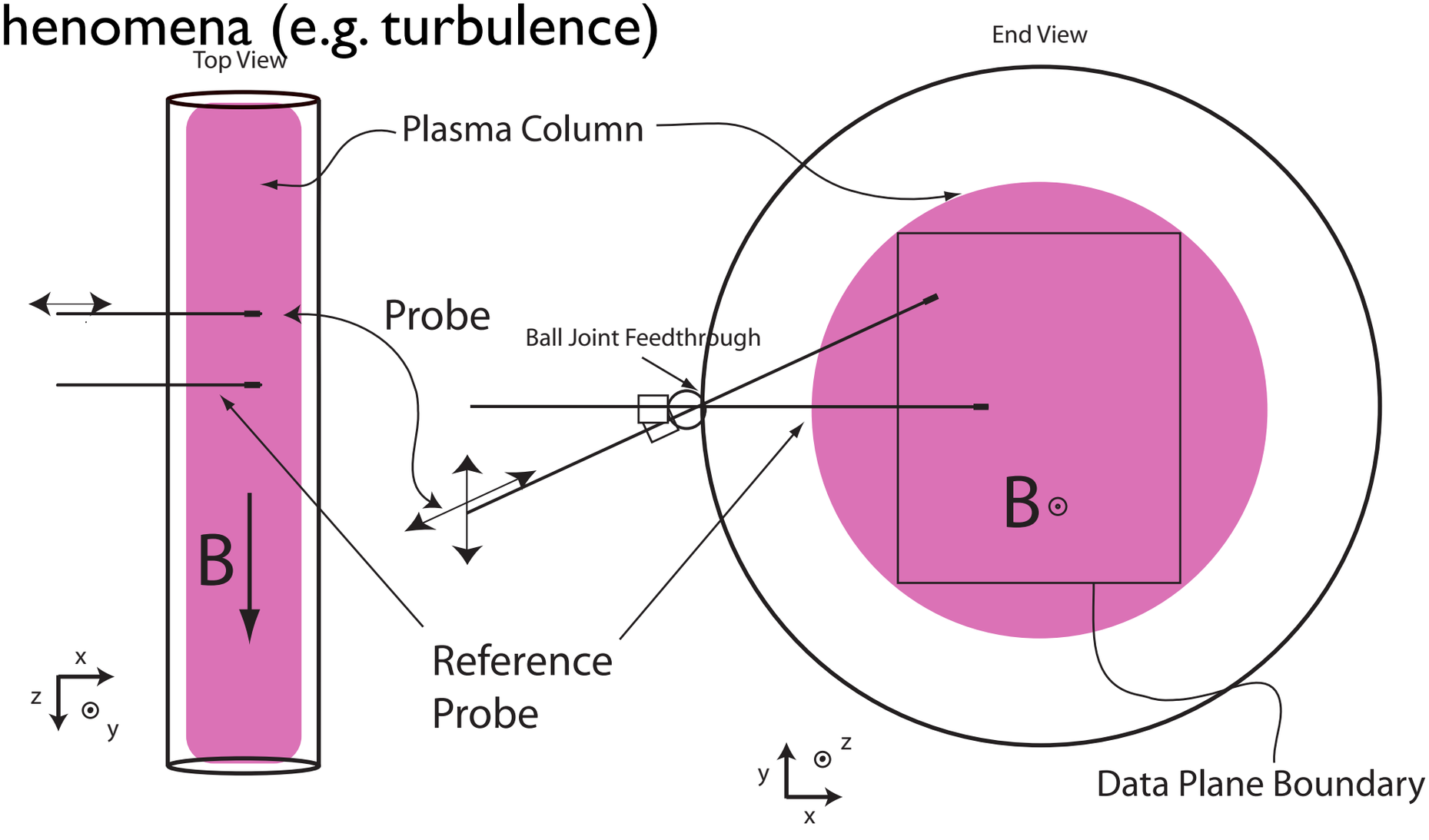
Measurement methodology in LAPD

- Use single probes to measure local density, temperature, potential, magnetic field, flow: move single probe shot-to-shot to construct average profiles

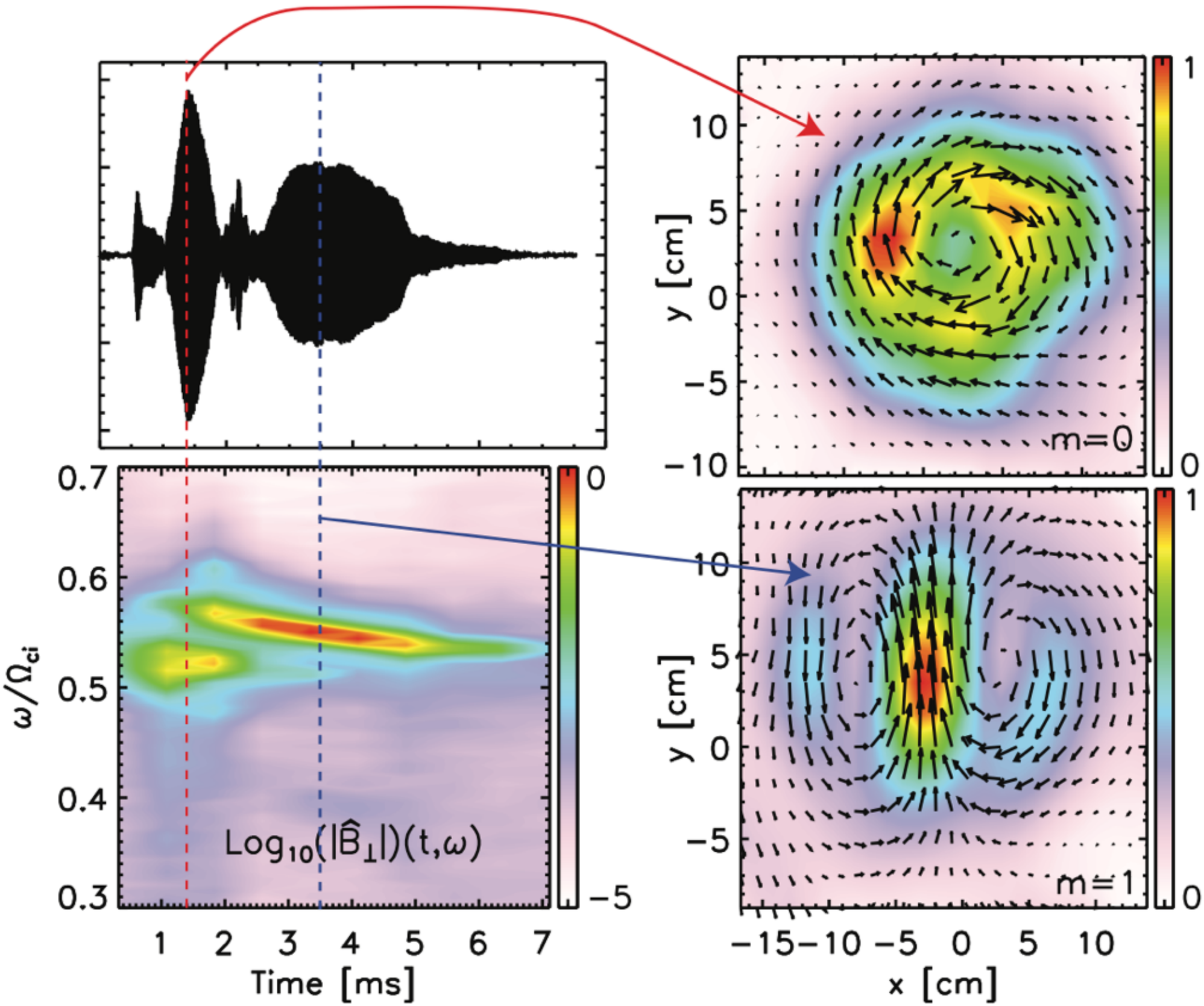


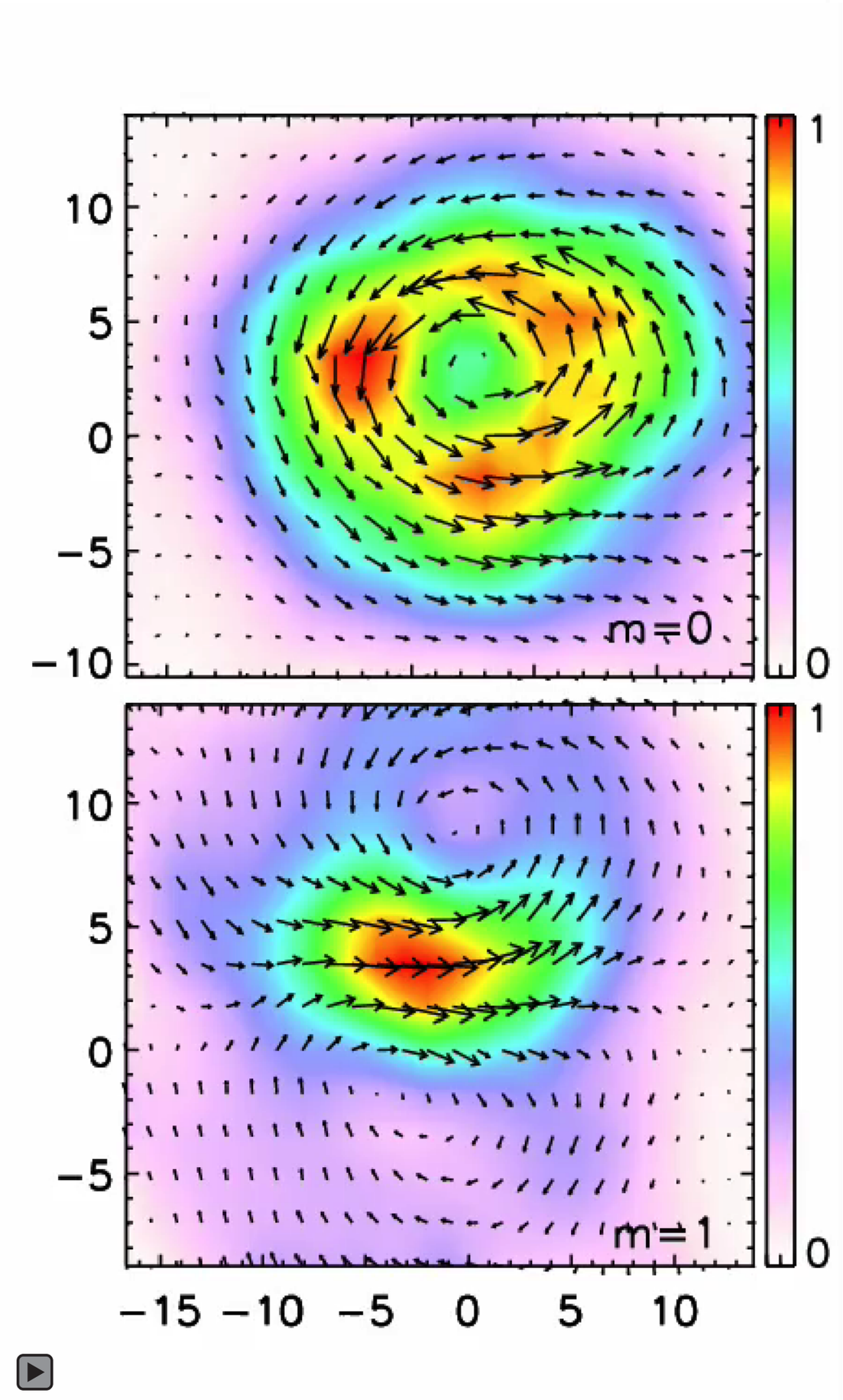
Measurement methodology in LAPD

- Use single probes to measure local density, temperature, potential, magnetic field, flow: move single probe shot-to-shot to construct average profiles
- Add a second (reference) probe to use correlation techniques to make detailed statistical measurements of non-repeatable phenomena (e.g. turbulence)



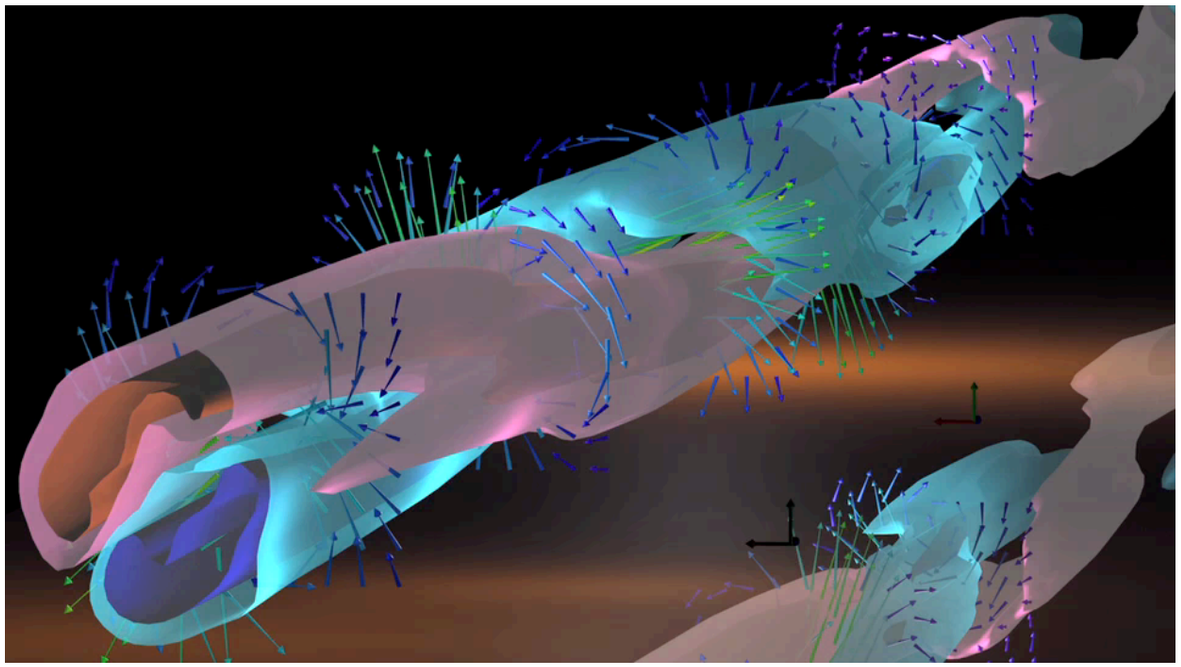
Measured structure of Alfvén eigenmodes in LAPD

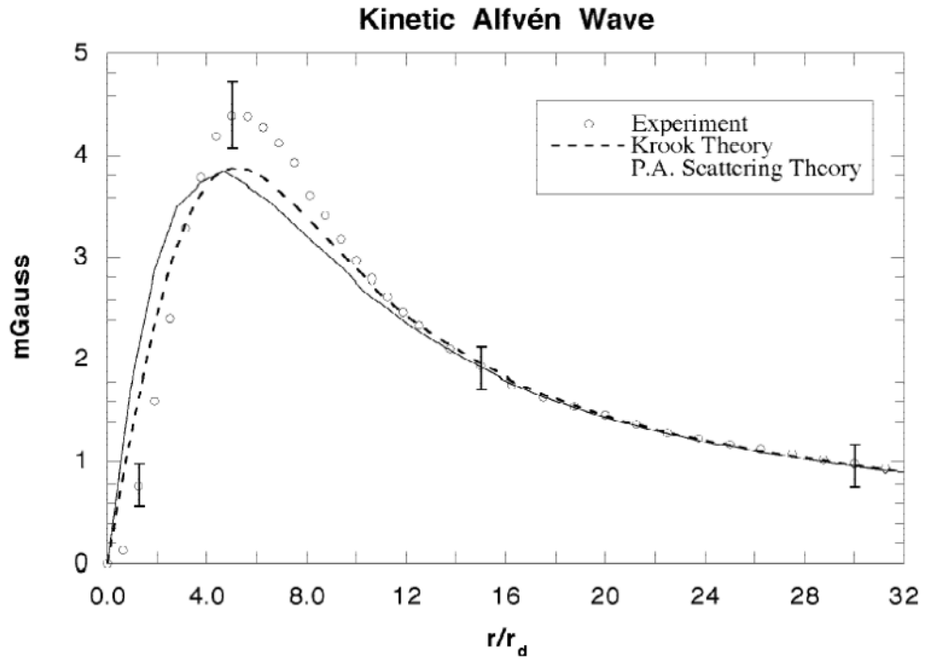



10
5
0
−5
−10
m=0
1
0
10
5
0
−5
m=1
1
0
−15 −10 −5 0 5 10

Alfvén wave studies in LAPD

- LAPD created to enable AW research need length to fit parallel wavelength (~few meters)
- Below: measured 3D pattern of wave current and magnetic field from a LHP kinetic shear Alfvén wave in LAPD



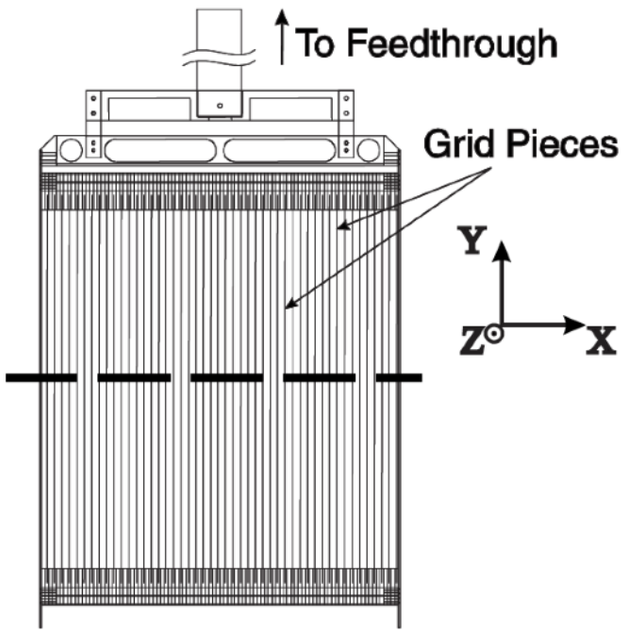


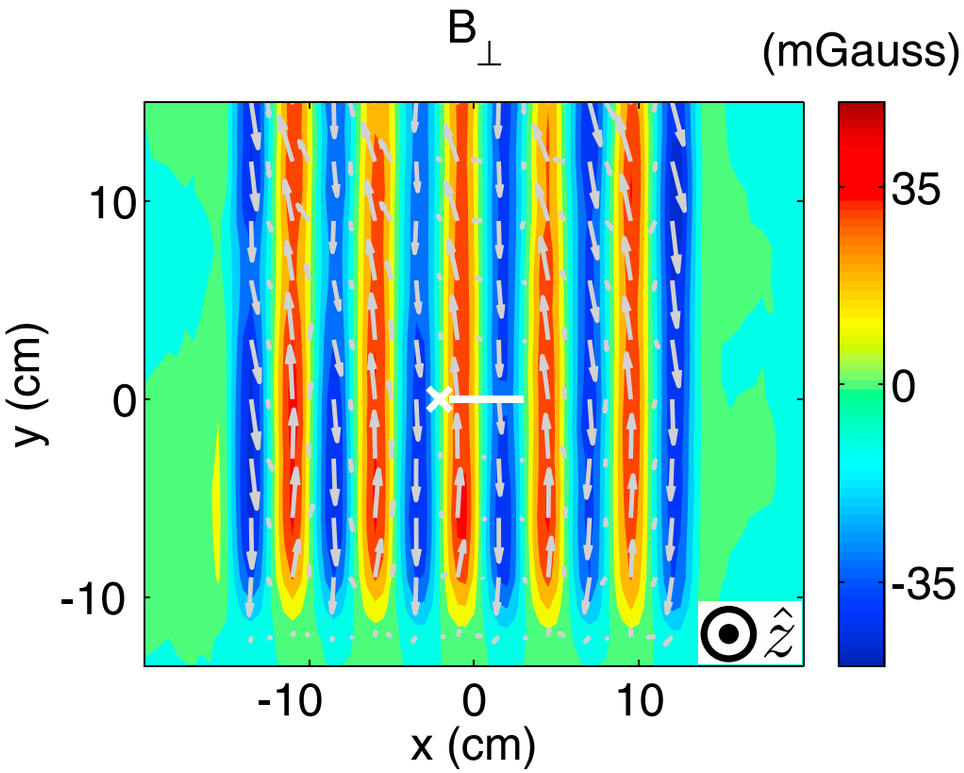
- A number of issues studied over the years: radiation from small source, resonance cones, field line resonances, wave reflection, conversion from KAW to IAW on density gradient… [UCLA LAPD group: Gekelman, Maggs, Morales, Vincena, Carter, et al]

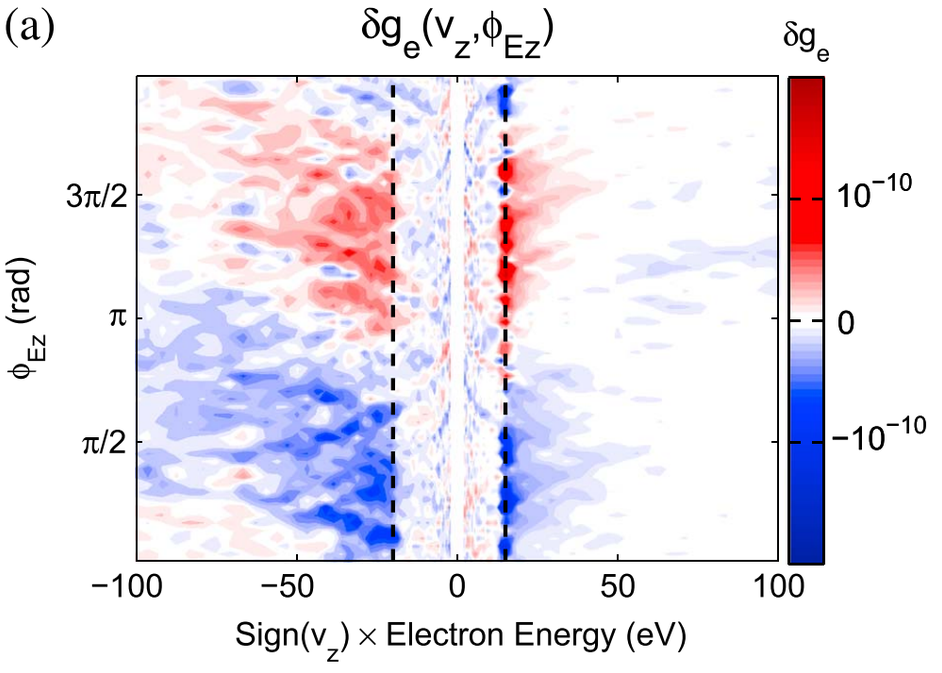
Review: Gekelman, et al., PoP 18, 055501, (2011)

Details, publication list at http://plasma.physics.ucla.edu

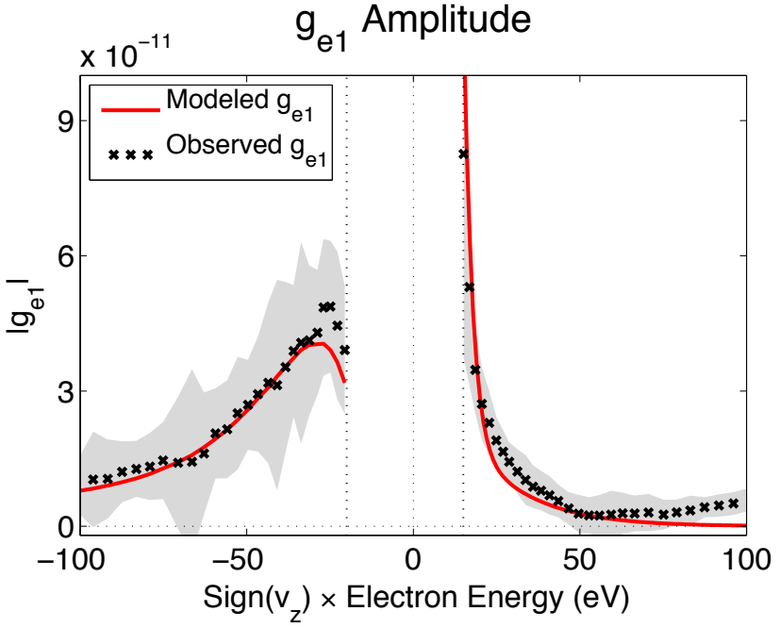
Electron acceleration/response to inertial Alfvén wave





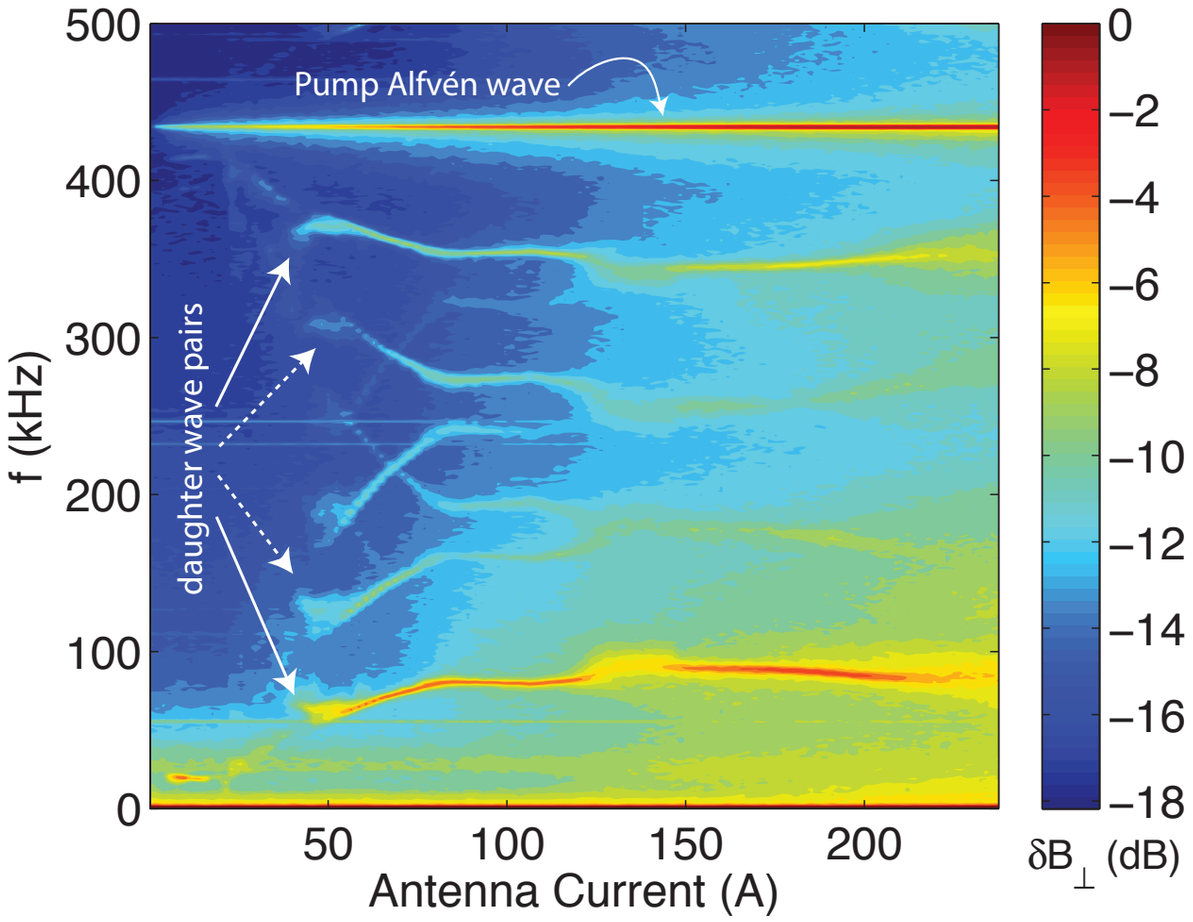


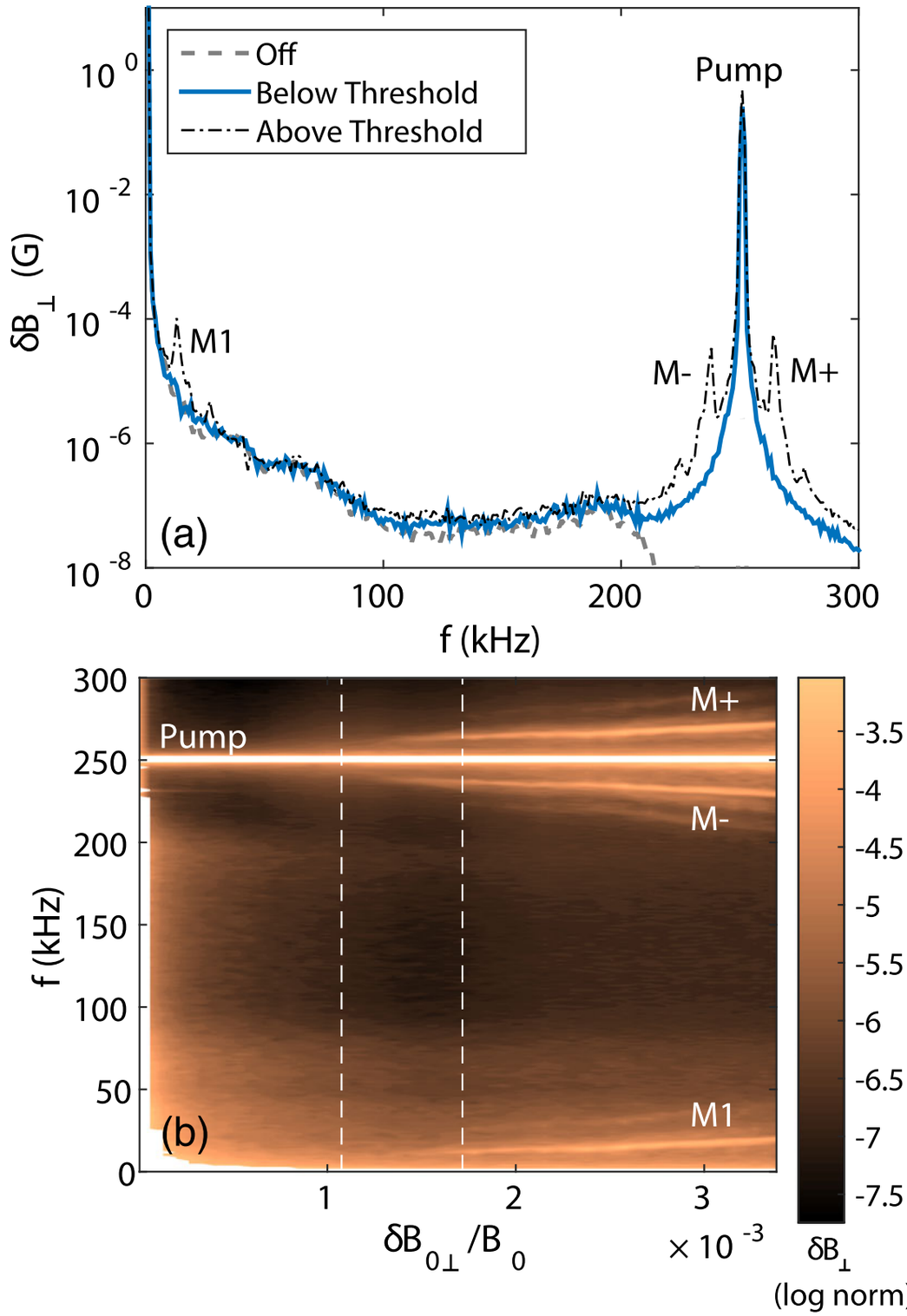
- Kletzing (Iowa): interest in understanding electron acceleration by Alfvén waves; relevance to generation of Aurora
- Used novel electron distribution diagnostic (whistler wave absorption (Skiff)) to study oscillation in electron distribution function in presence of inertial AW



Schroeder, et al., Geophys. Res. Lett. 43, 4701 (2016)

Parametric instability of kinetic Alfvén waves

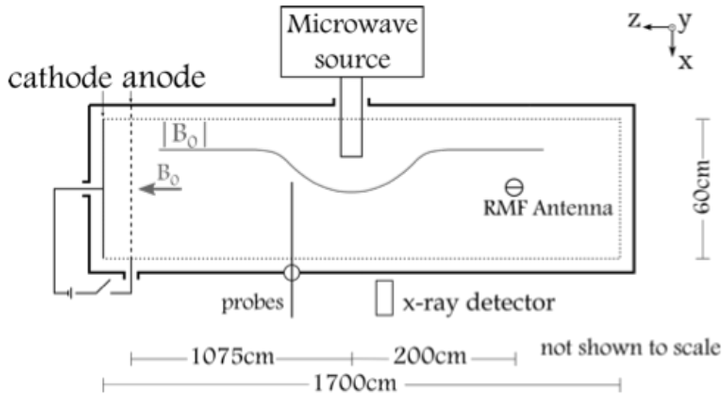


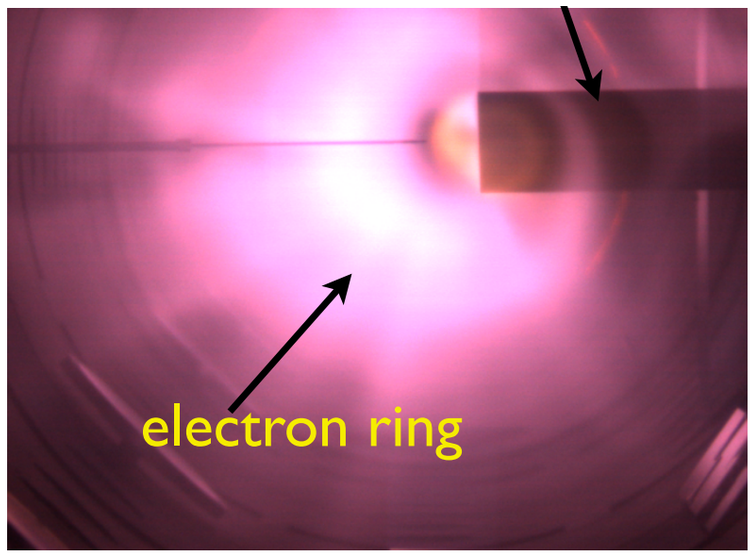


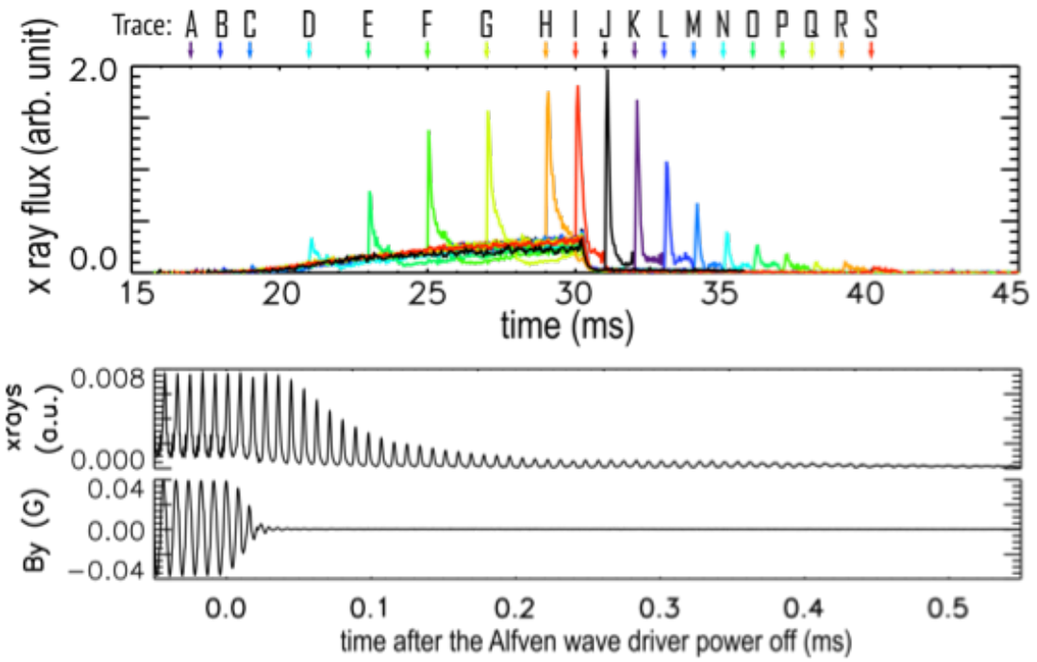
- First laboratory observation of a parametric instability of a shear Alfvén wave (consistent with "modulational decay" instability)

Dorfman and Carter, PRL 116, 195002 (2016)

Scattering of trapped, energetic electrons by shear waves





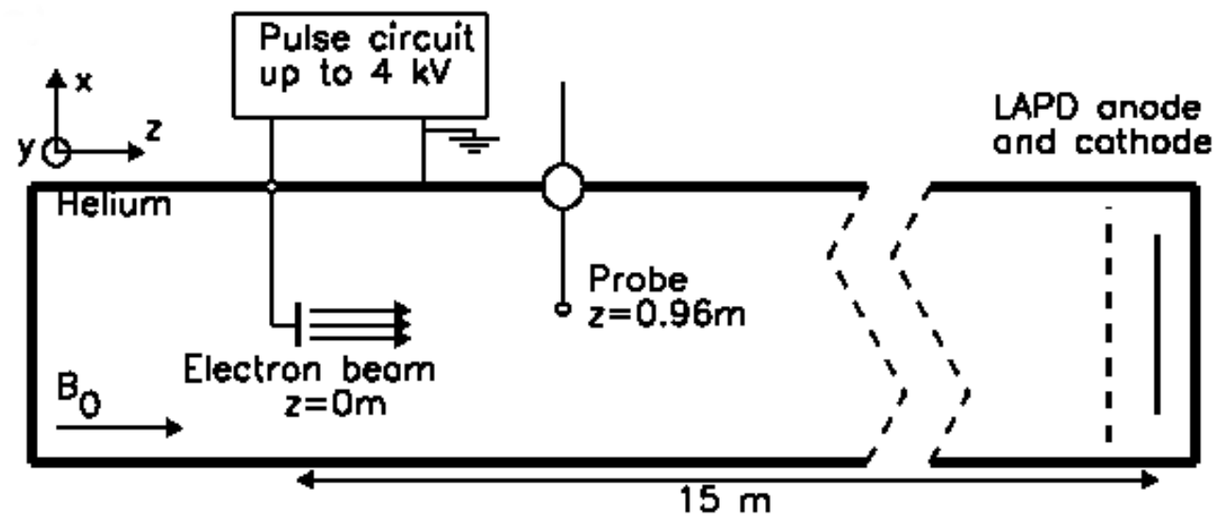


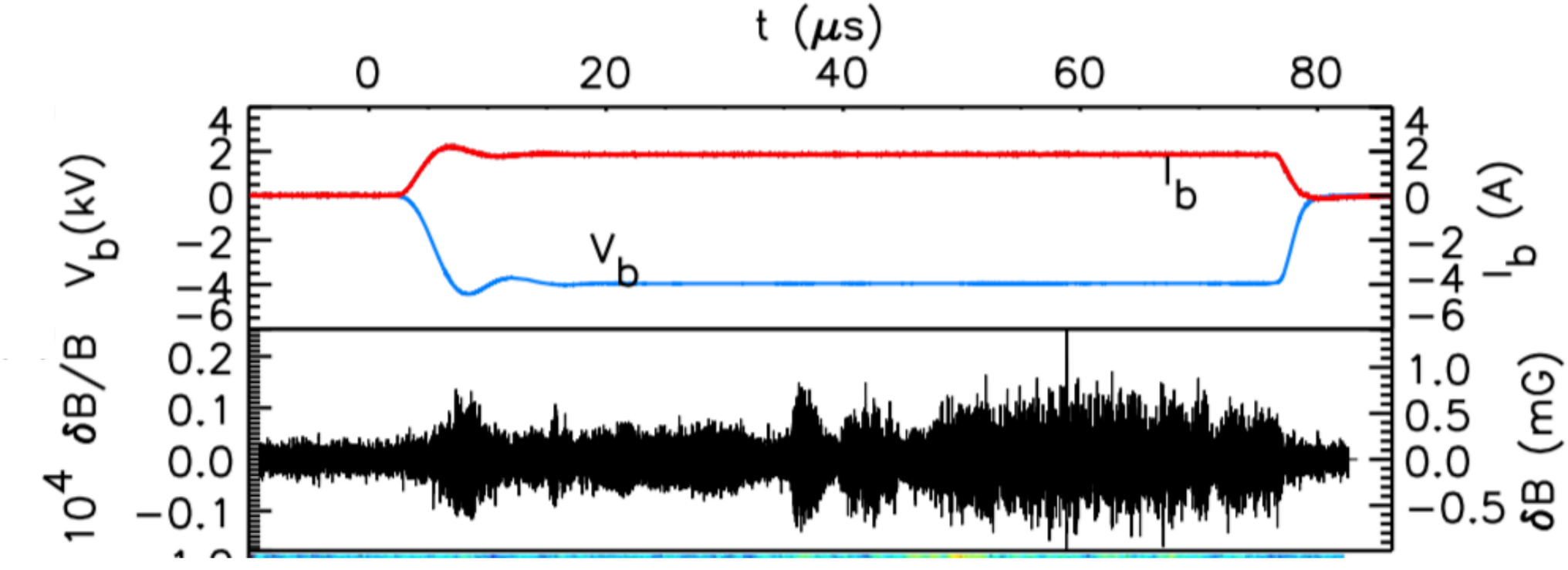
- Project led by D. Papadopoulos (UMd)
- High power microwaves used to generate mirror-trapped, energetic electron population (up to 1 MeV)
- Shear waves injected, de-trapping of electrons observed (x-ray generation) — surprisingly a non-resonant process, AWs of a range of frequencies are effective

Y. Wang, et al., PRL 108, 105022 (2012)

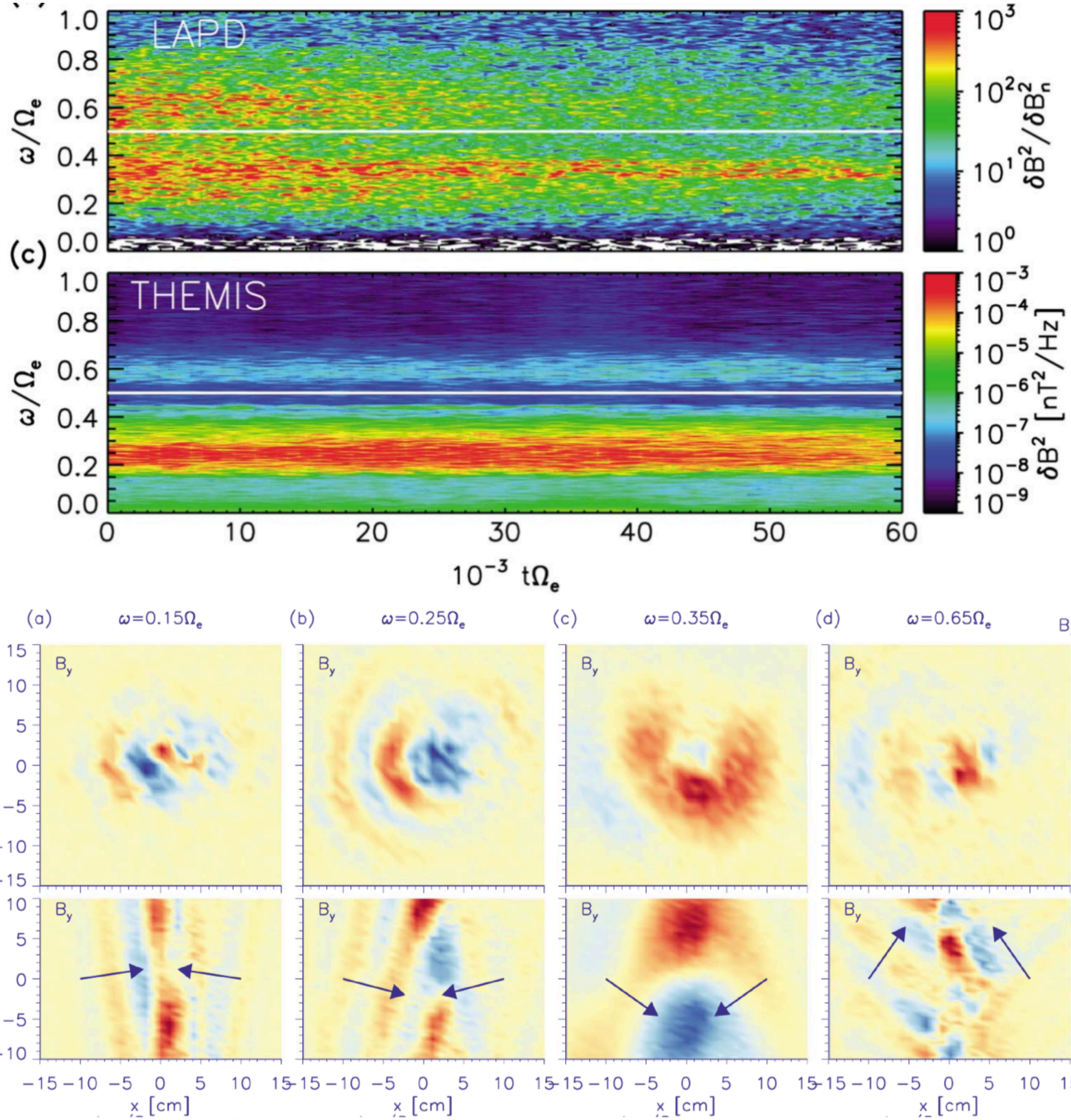
Production of whistler waves by energetic electrons in LAPD

- J. Bortnik (UCLA): Inject ~4 keV electron beam into LAPD plasma; whistler emission observed





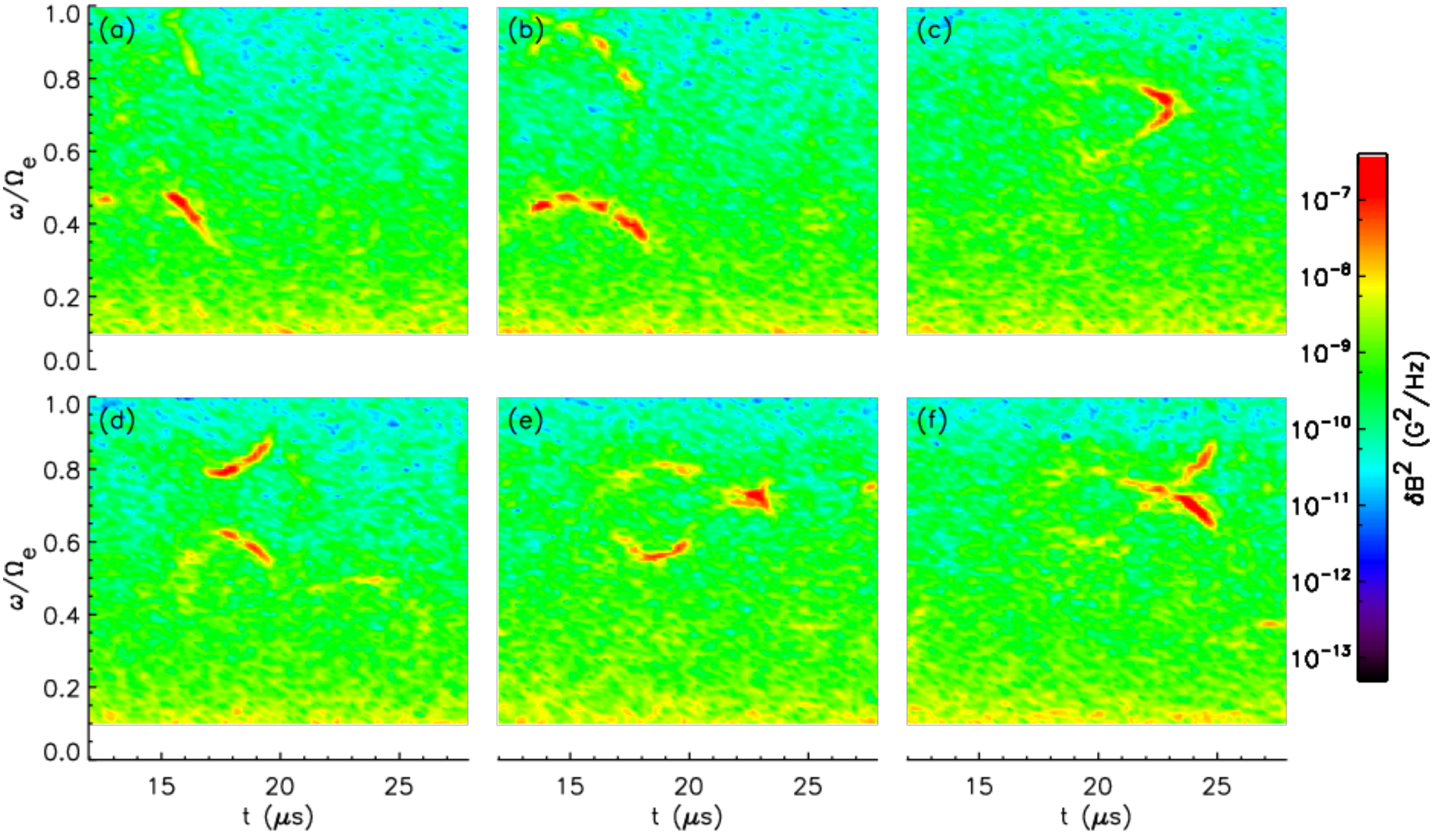
Broadband whistler emission observed (hiss-like)



- Two bands, with quiet region around 0.5 f_{ce}
- n_b/n_e ~ 0.1%, , f_{pe}/f_{ce} ~ 6-15
- Consistent with Landau & Doppler-shifted Cyclotron Resonance (normal and anomalous)

An, et al. Geophys. Res. Lett., 43, 2413–2421 (2016)

Chirping (chorus-like) emission observed at higher beam density

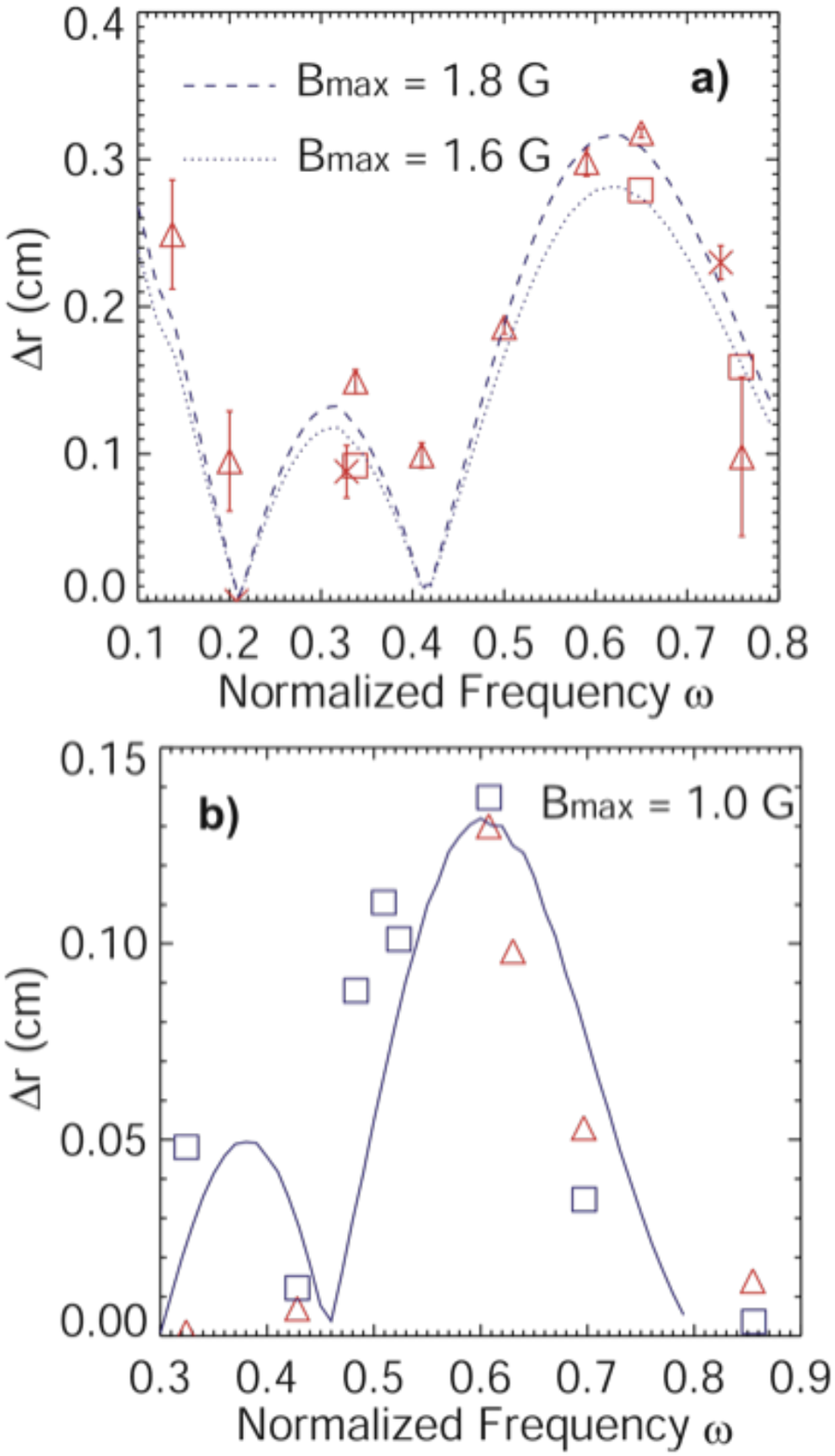


- Seen at higher beam current: $n_b/n_e \sim 1\%$, (also $f_{pe}/f_{ce} \sim 2\text{-}4$)

Van Compernolle, et al., Phys. Rev. Lett. 114, 245002 (2015)
Van Compernolle, et al., Plasma Phys. Contr. Fusion 59, 014016 (2017)

Interactions of SAWs with Energetic Ions

Spatial Spreading of Ion Beam

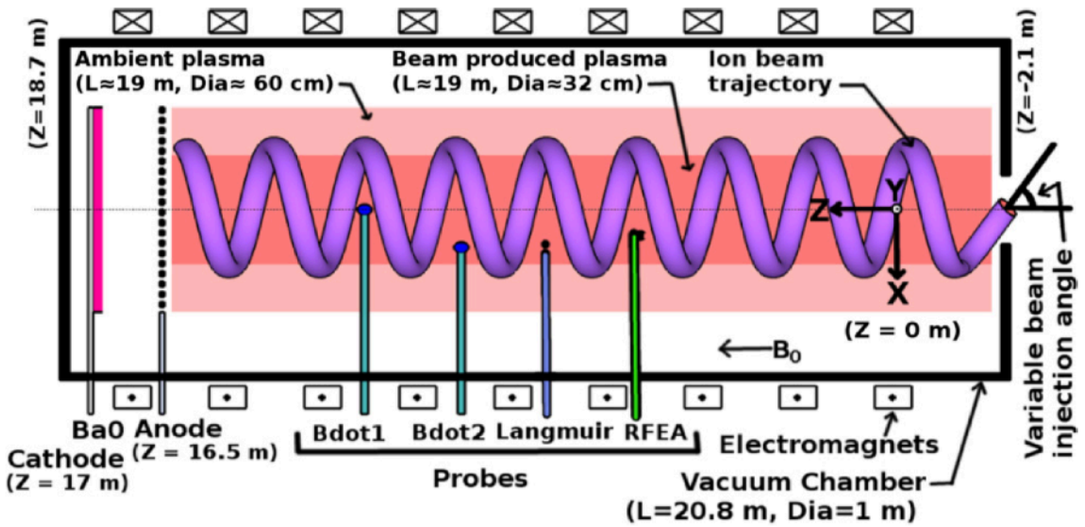


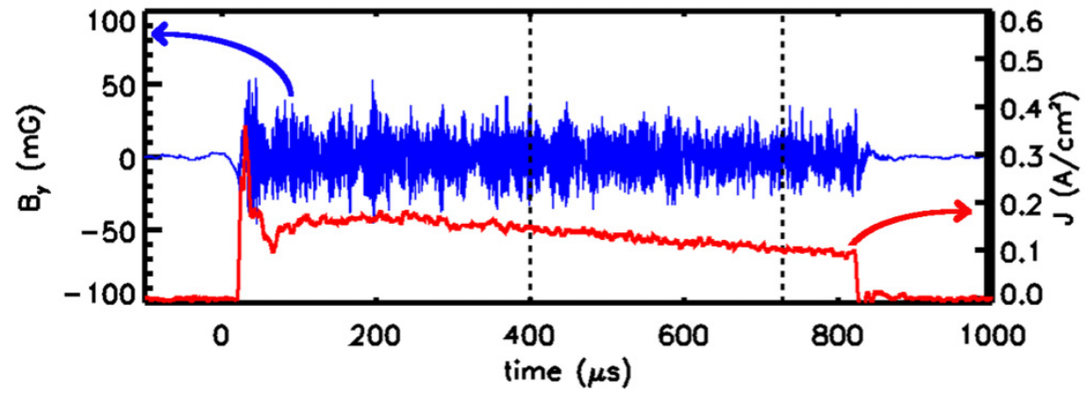
Wave Frequency

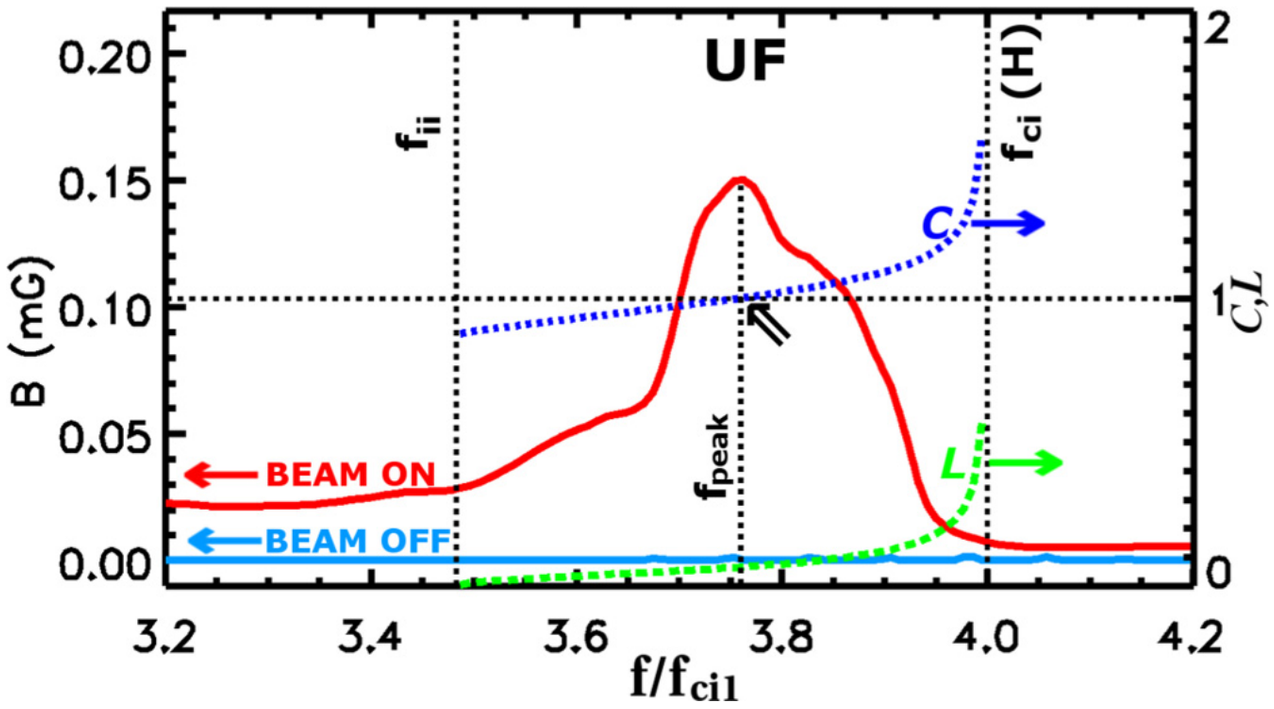
- Heidbrink (UCI): Fusion-motivated study of scattering/diffusion of fast ions by SAWs
- Low current (test particle) Lithium ion beam (~1 keV) interacts with antenna launched AWs
- Doppler-shifted cyclotron resonant interaction observed; interaction only observed with LHP waves

Y. Zhang et al., Phys. Plasmas 16, 055706 (2009)
Y. Zhang et al., Phys. Plasmas 15, 102112 (2008)

Excitation of Alfvén waves (EMIC) by intense ion beam







- Up to 25 keV, ~10A ion beam injected into H/He plasmas
- Waves seen at a range of frequencies (up to LH)
- SAW/EMIC excited in H+ band (due to Doppler-shifted cyclotron resonance)

Tripathi, et al., Phys. Rev. E., **91**, 013109 (2015)

Have an idea? Apply for run time!

- Yearly solicitation for LAPD runtime (just completed review for Calendar 2018 runtime). Next solicitation in the fall for 2019 runtime (stay tuned).
- Runtime, use of existing equipment/diagnostics, and staff support are free (you pay for travel)
- We welcome proposals from theorists, space observers (our group can assist with design & execution of experimental ideas). International proposals are welcome
- Please contact me if you are interested!

http://plasma.physics.ucla.edu
tcarter@physics.ucla.edu