Fusion Science and Technology Studies using the Basic Plasma Science Facility

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BaPSF

UCLA

PSTI UCLA
Plasma Science and Technology Institute

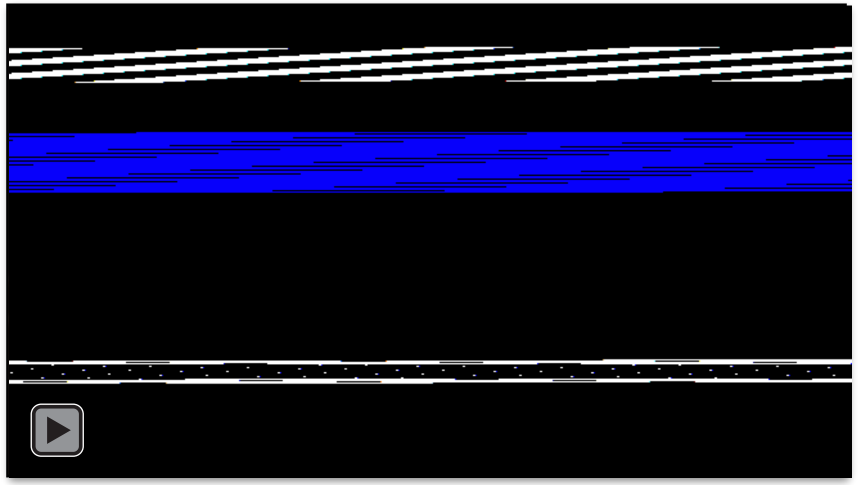
NSF

Summary

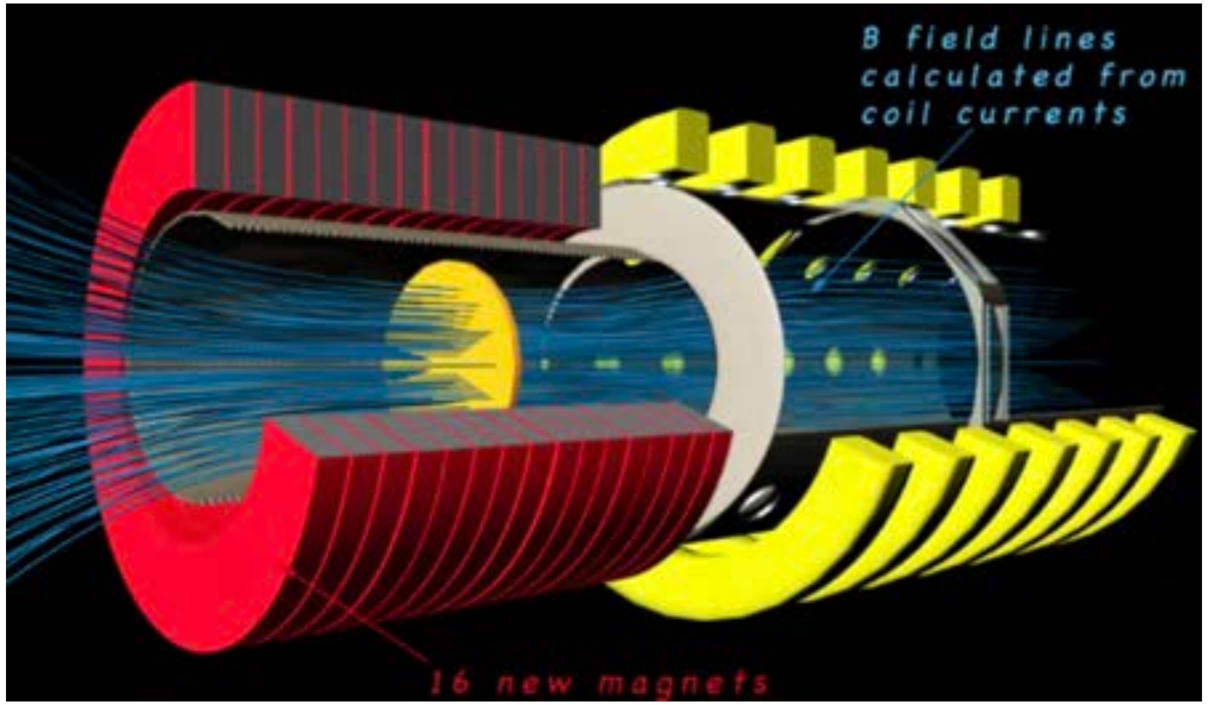
- Basic Plasma Science Facility: US DOE and NSF sponsored collaborative research facility for study of fundamental processes in magnetized plasmas. Primary device is Large Plasma Device (LAPD).
- Wide range of studies performed: waves, instabilities, turbulence & transport, shocks, reconnection. Will cover recent work relevant to fusion science and technology:
  - **ICRF Campaign**: Mitigation of RF sheaths using insulating antenna enclosure [Bal et al., NF (2022)], parasitic coupling to slow mode, HHFW/Helicon wave coupling and propagation
  - **Plasma-materials interaction studies:** Testing novel materials (VCMs) in LAPD: significantly decreased arcing/sputtering in VCM versus flat W targets

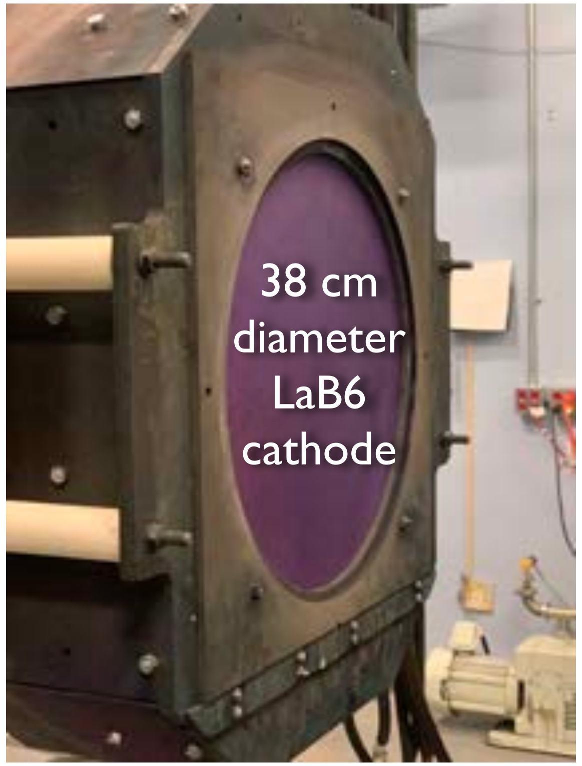
The Large Plasma Device (LAPD): a flexible experimental platform

- 20m long, 1m diameter vacuum chamber; emissive cathode discharge
- LaB_6 Cathode: $n \sim 1 \times 10^{13}\ cm^{-3}$, $T_e \sim 10$–15 eV, $T_i \sim 6$–10 eV
- B up to 3.5kG (with control of axial field profile)
- High repetition rate: 1 Hz
- US DOE & NSF Sponsored Collaborative Research Facility (international users welcome!)



Plasma Source Upgrade: large-area LaB_6

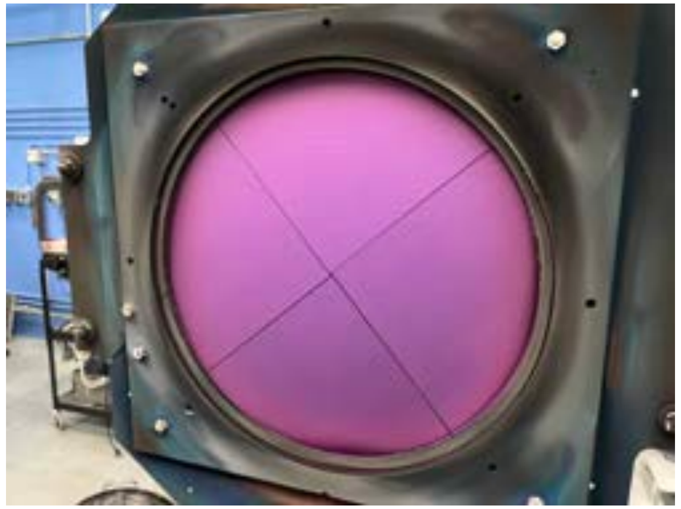




- New large-area LaB_6 emissive cathode source provides higher power density; access to higher density, higher pressure plasmas

- New magnet section, up to 0.9T, to allow magnetic expansion of plasma source region

- Additionally, installed capability for gas-puffing to fuel discharge to access improved operational regimes

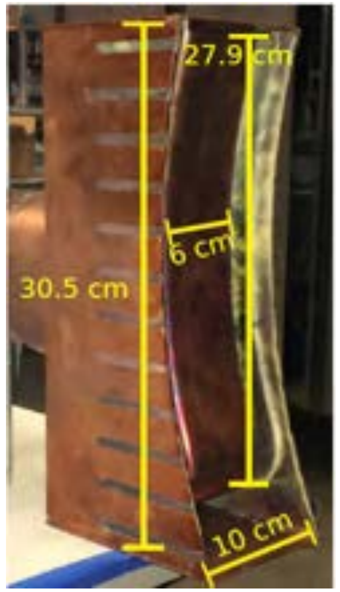


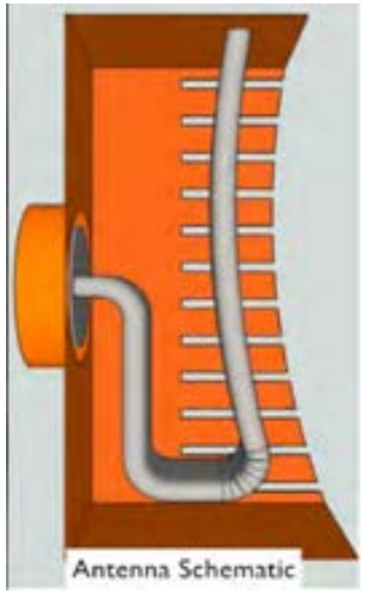
Y. Chen, et al., Rev Sci Instrum., 94, 085104 (2023)

ICRF Physics and Technology Studies on LAPD

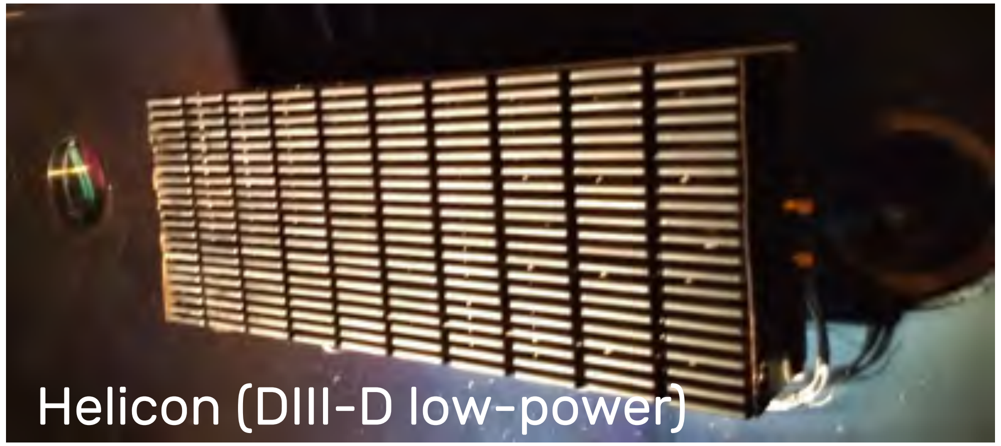
- Studies of Ion Cyclotron Range of Frequencies (ICRF) waves used to heat ions and electrons and drive current in fusion experiments
- Campaign participation from scientists & engineers at ORNL, MIT, PPPL, General Atomics, TAE Technologies, ASIPP, Max Planck IPP, U. Ghent…
  - Parasitic processes and their mitigation: **RF sheaths, coupling to slow mode,** parametric instabilities.
  - Helicon waves: **studying wave coupling and $n_\parallel$ control with DIII-D low-power Helicon antenna**
  - Mirror relevant studies: **cyclotron absorption of shear waves in strong magnetic field gradients** ("magnetic beach" geometry)

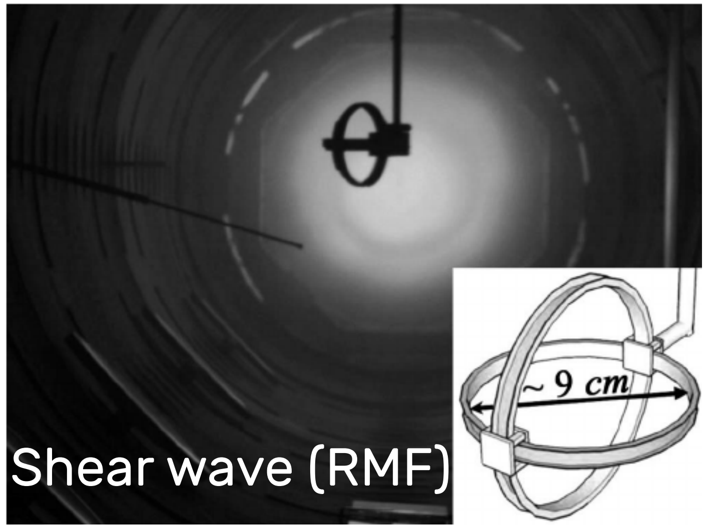
Infrastructure for exciting shear, fast, Helicon waves





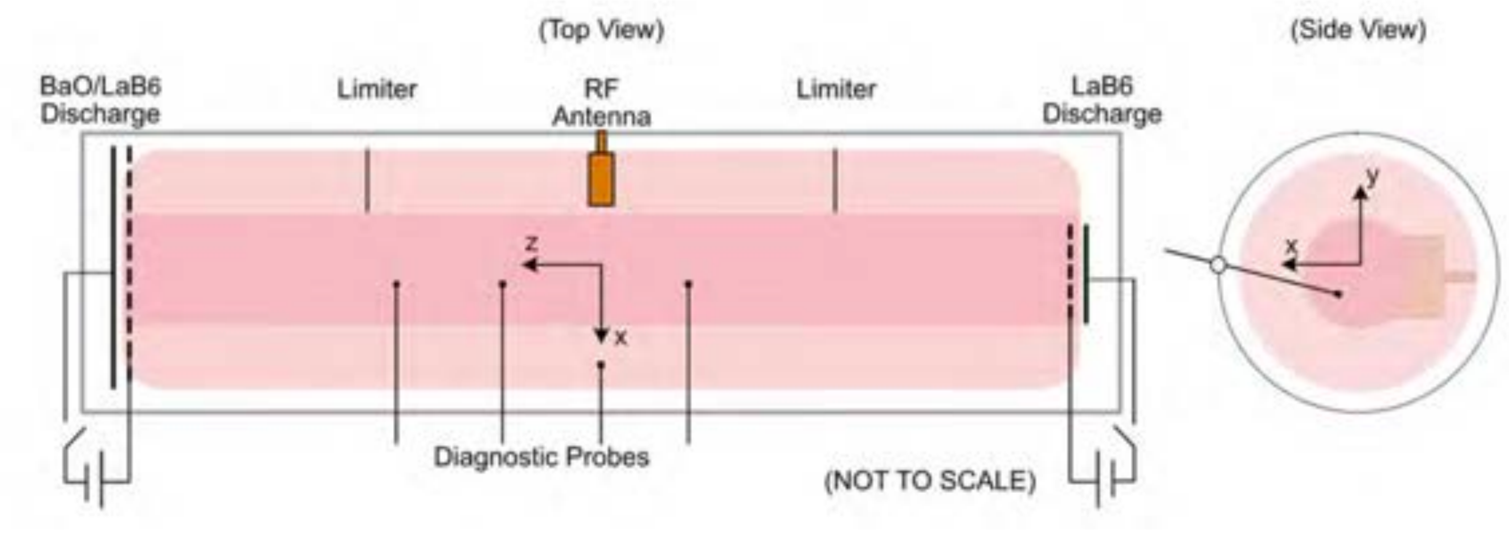
Single-strap ICRF
insertable, rotatable





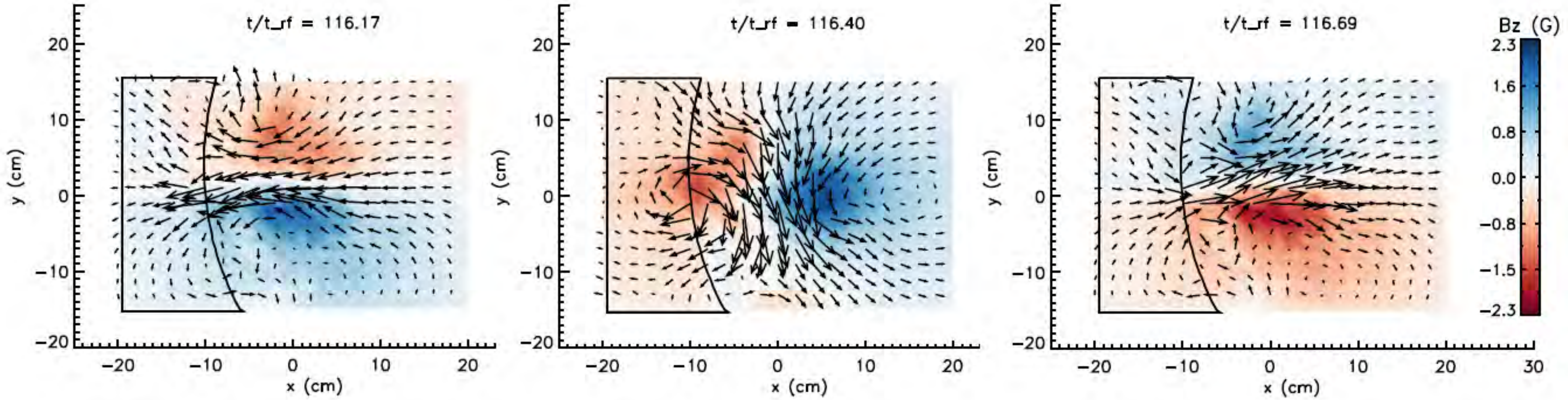
- Multiple high and low-power antennas available
- High power triode source: ~2.5MHz, f=1-10 fci, ~200 kW
- High power solid state sources: up to 1MHz, ~100kW+
- Low power (~400W) sources up to 600MHz+

Large amplitude fast waves excited using single-strap antenna

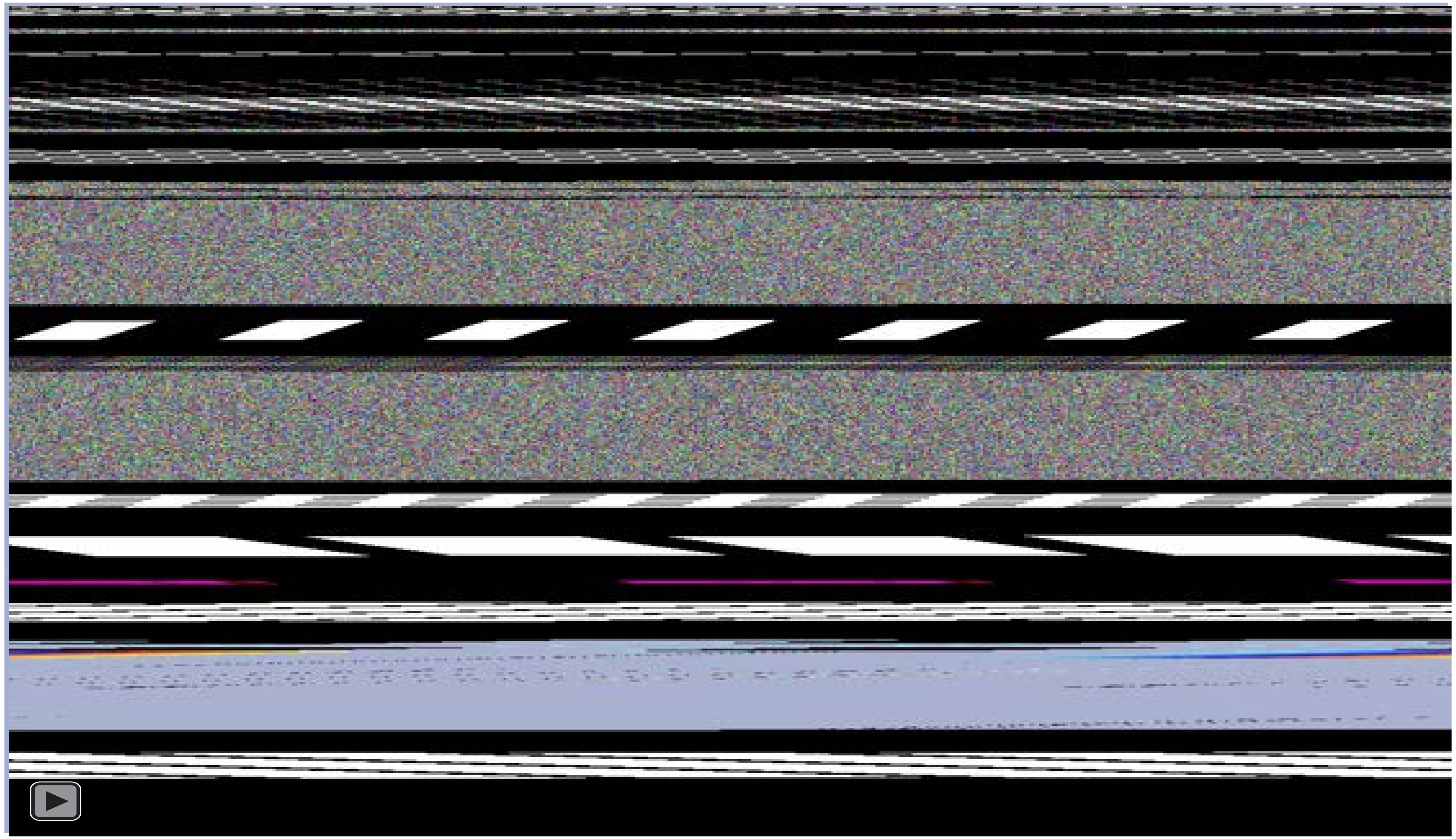


- High power (triode) source: f=1-10 fci, ~200 kW
- Coupled fast wave: m=1 mode structure observed

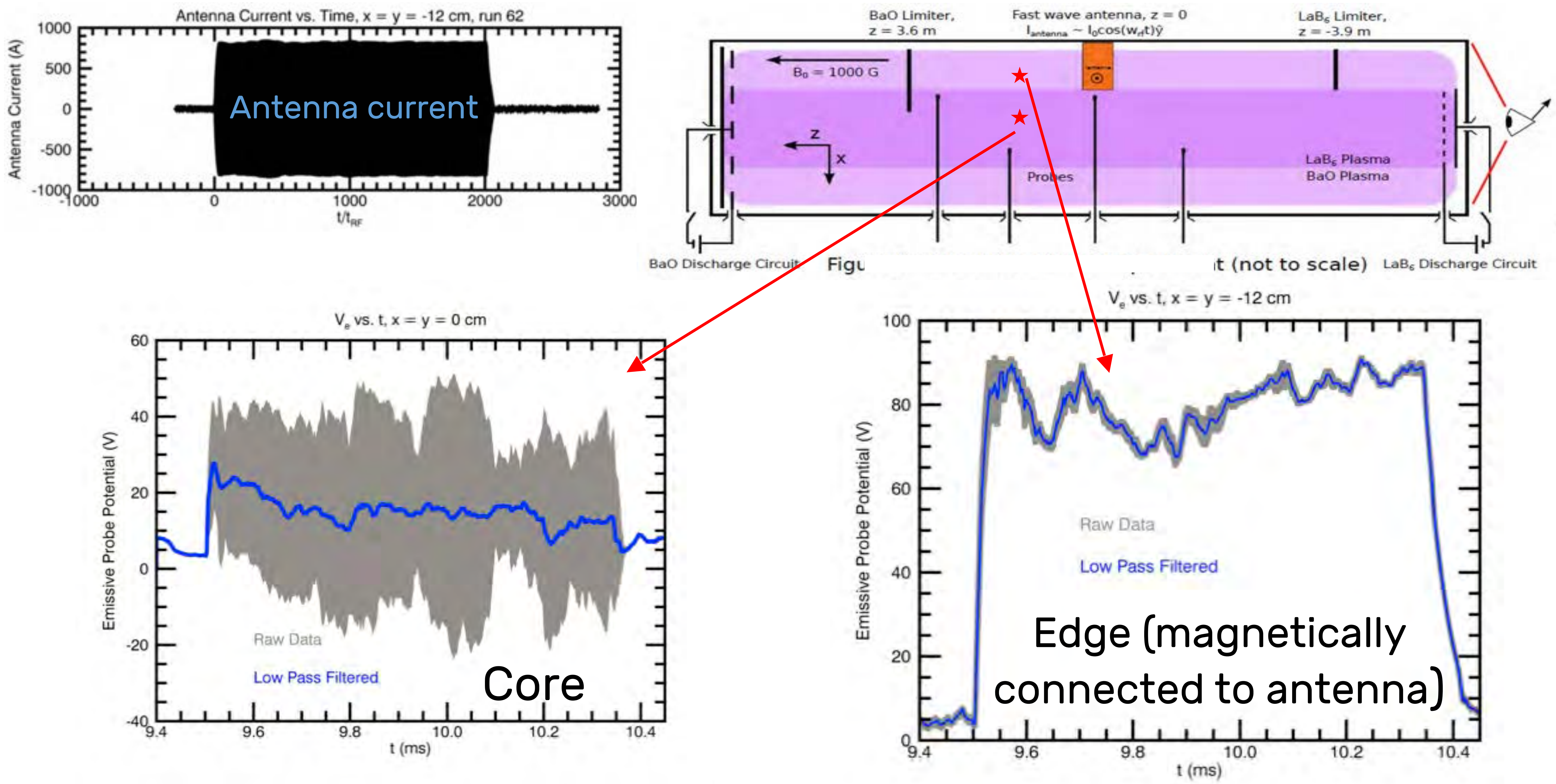
magnetic fluctuations



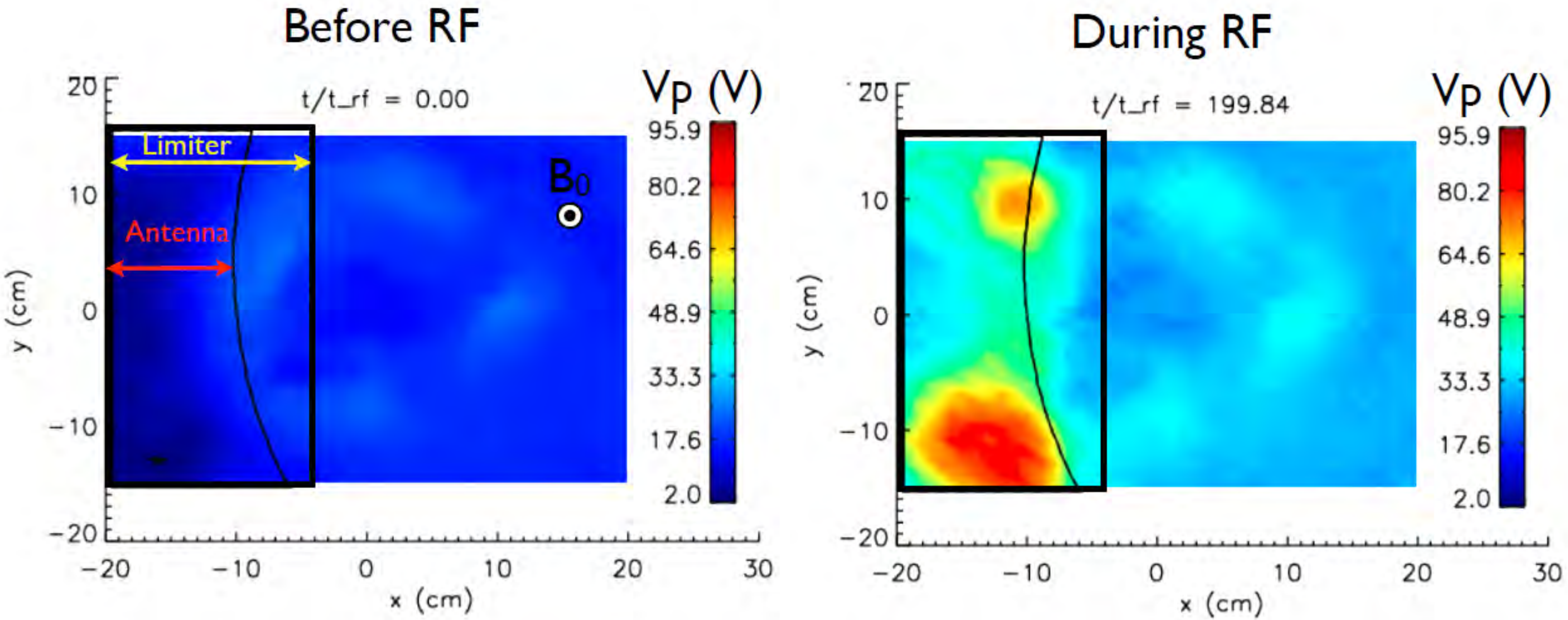
3D wave measurements: m=1 fast wave eigenmode excited by single-strap antenna



Plasma potential measurements show evidence of RF rectification

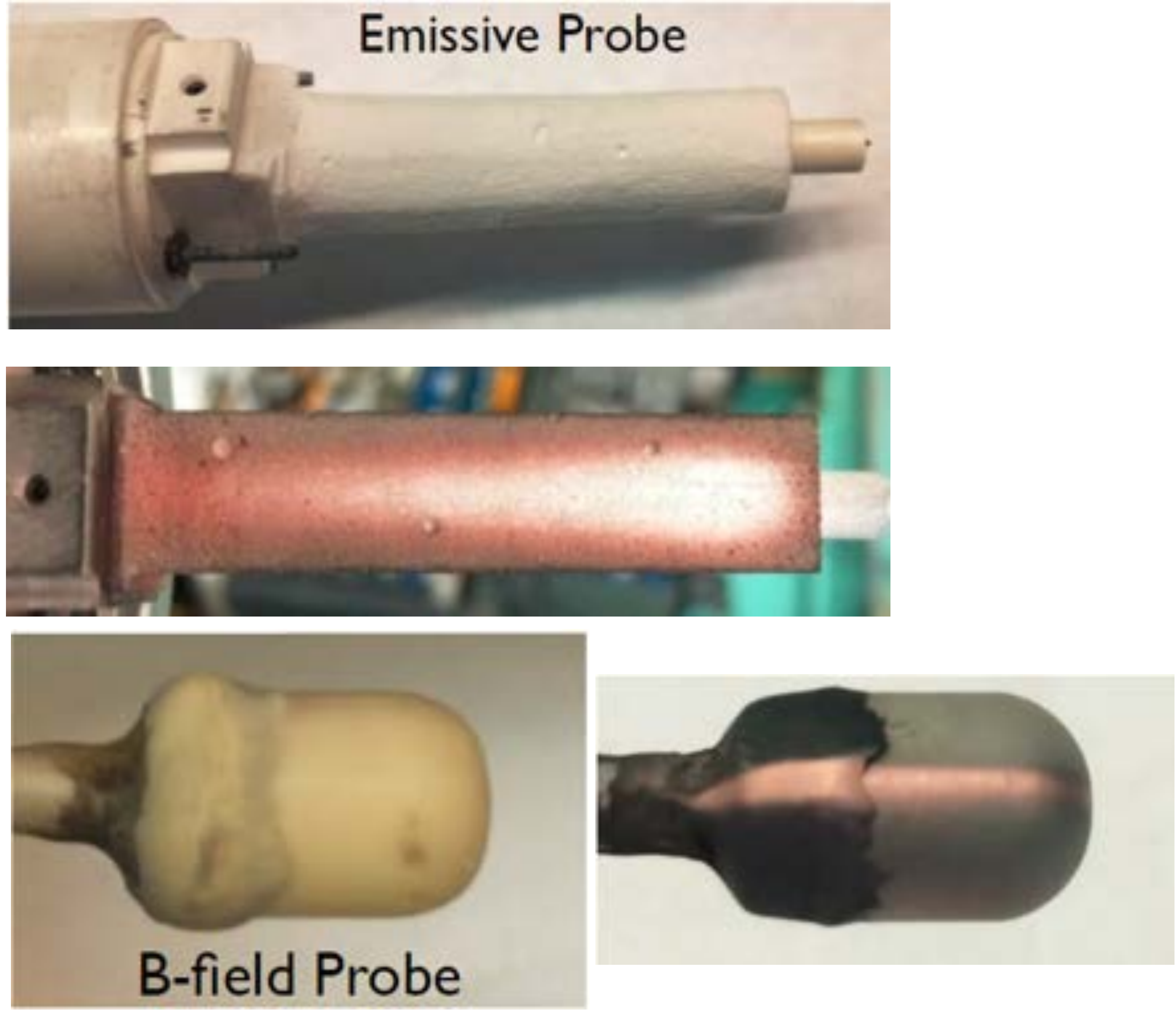


2D Potential measurements: Near-field RF sheaths localized on antenna structure

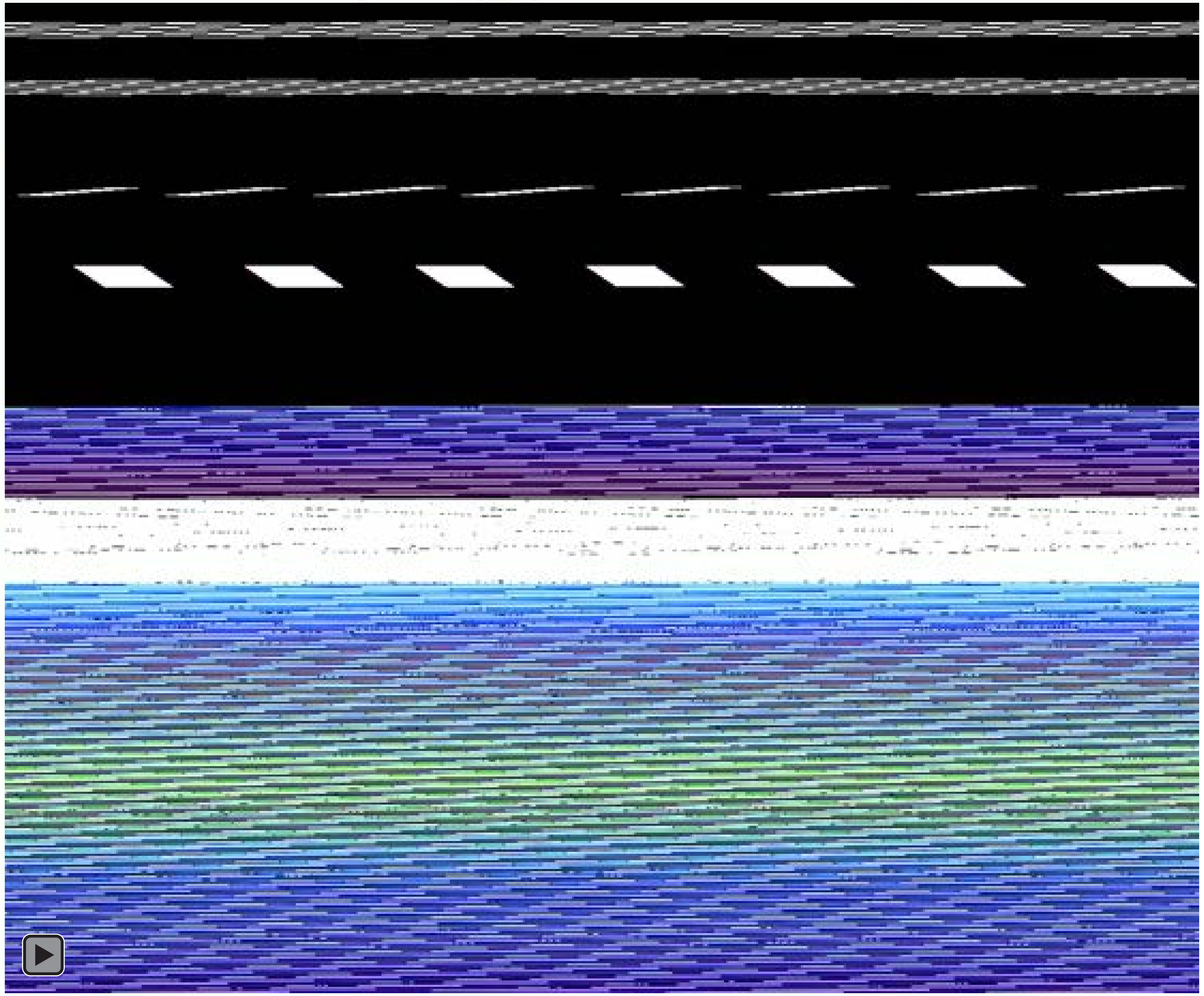


Martin, et al. PRL 119, 205002 (2017)

Impacts of RF Sheaths: sputtering and density modification

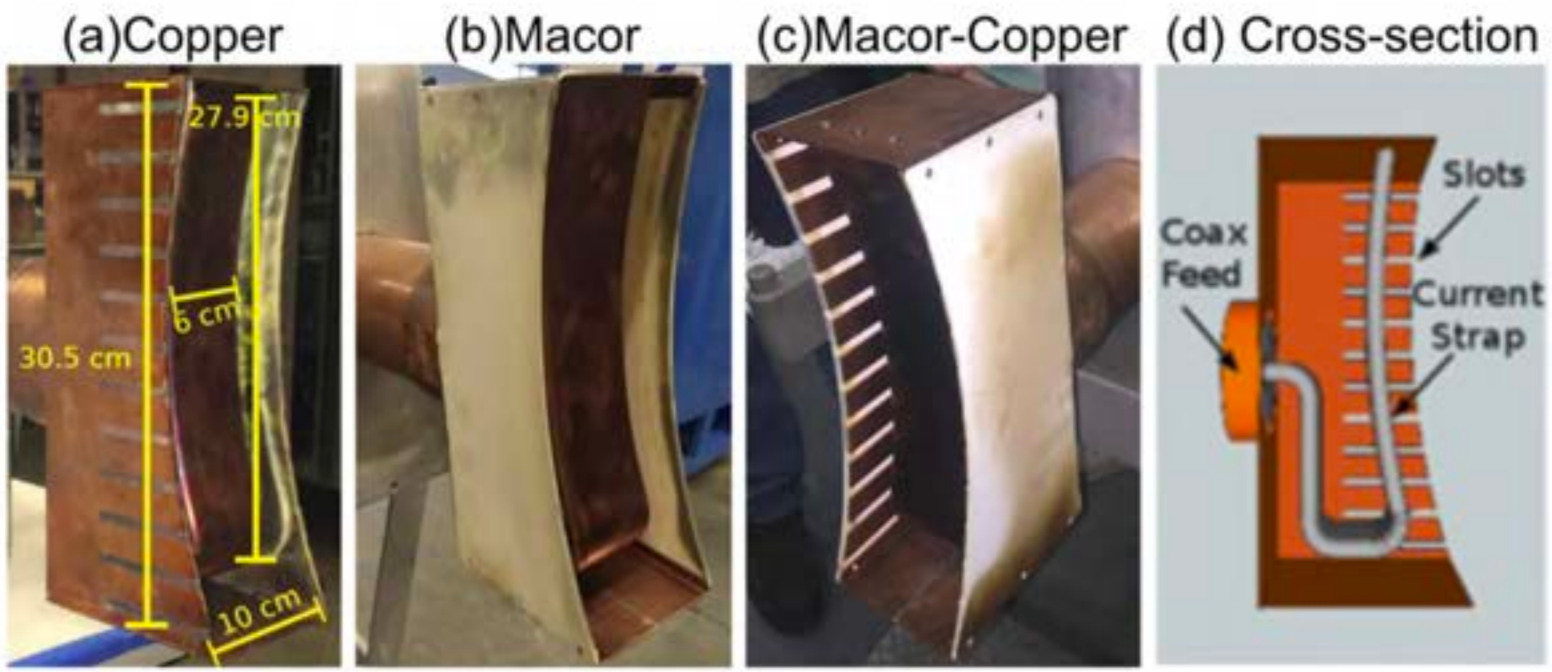


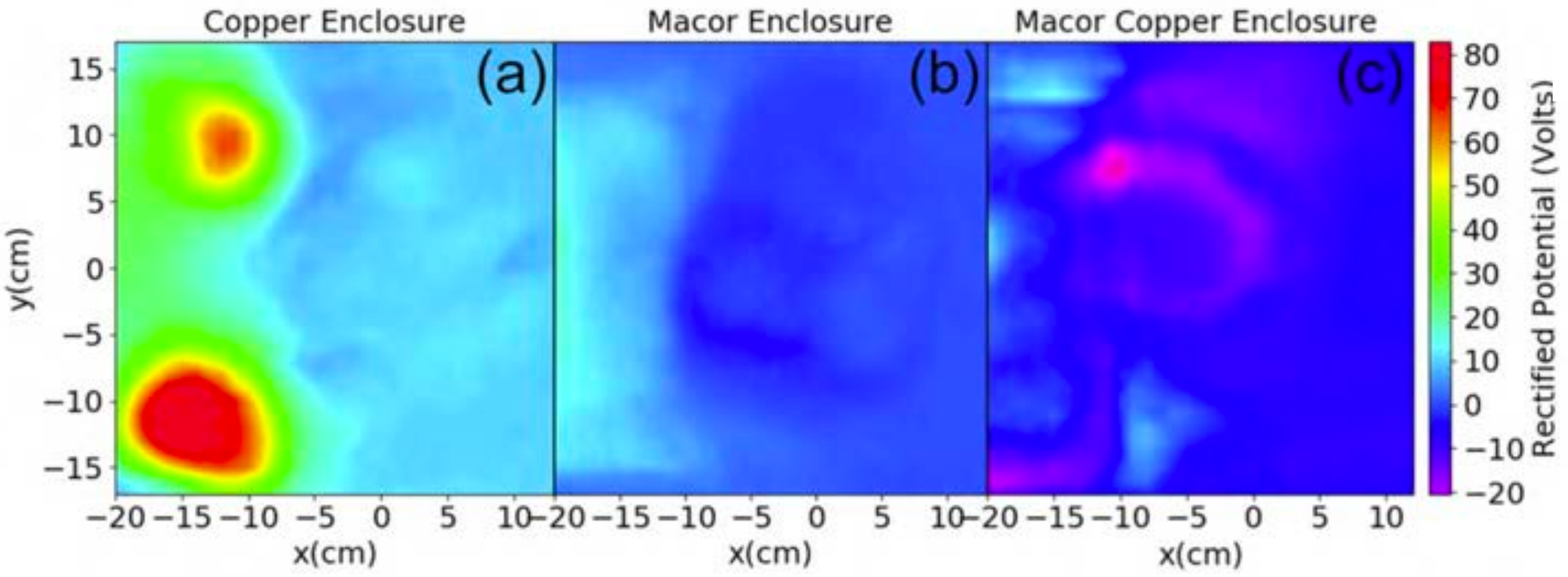
- Copper coatings on probes following high-power RF run: sputtering from copper antenna enclosure

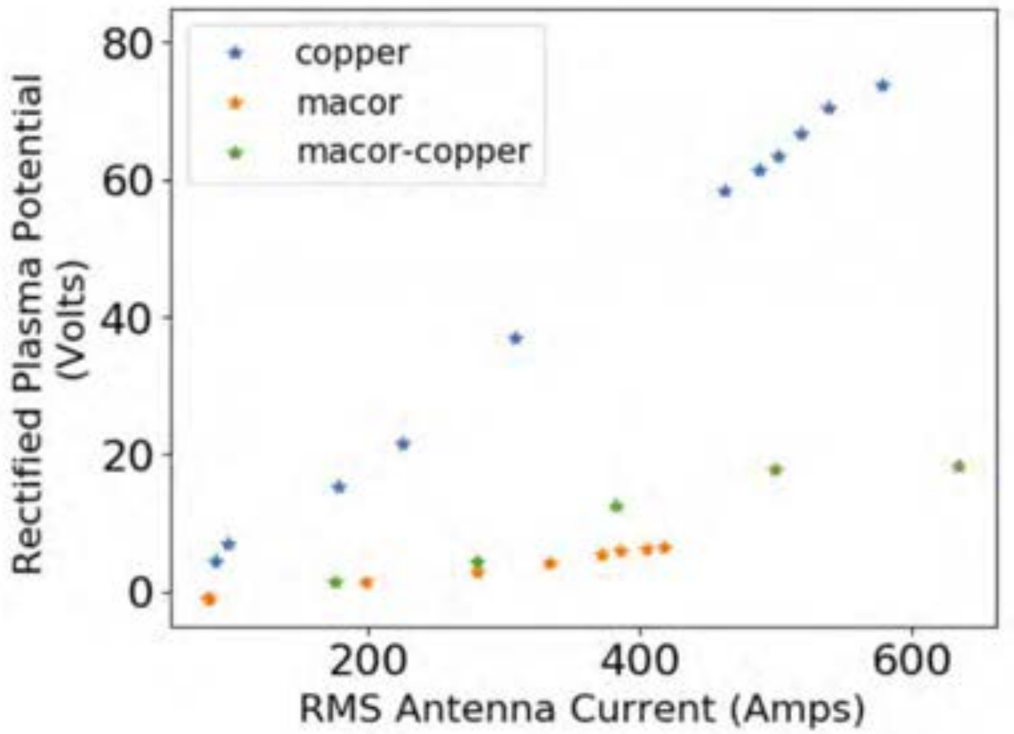


Colors: Ion saturation current ~ density
Vectors: ExB flow, deduced from V_p

Insulating antenna sidewalls mitigate RF sheath



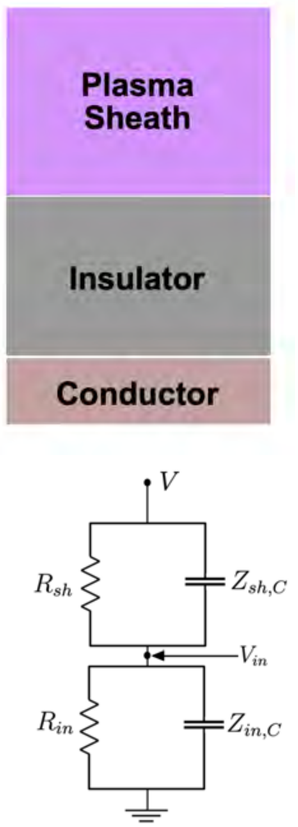


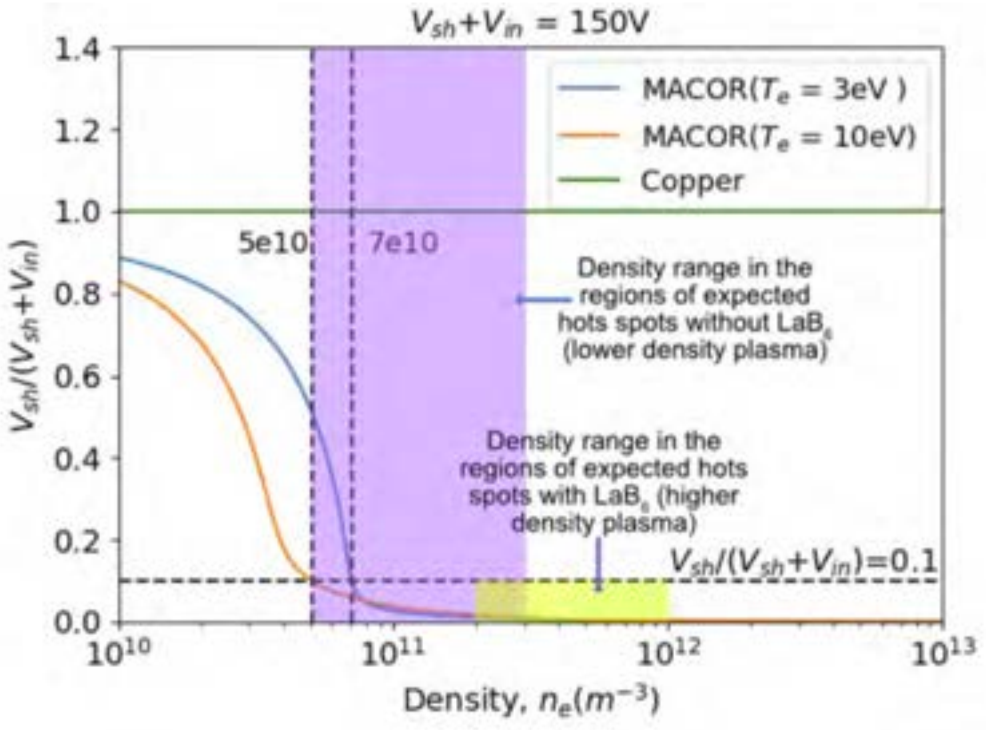


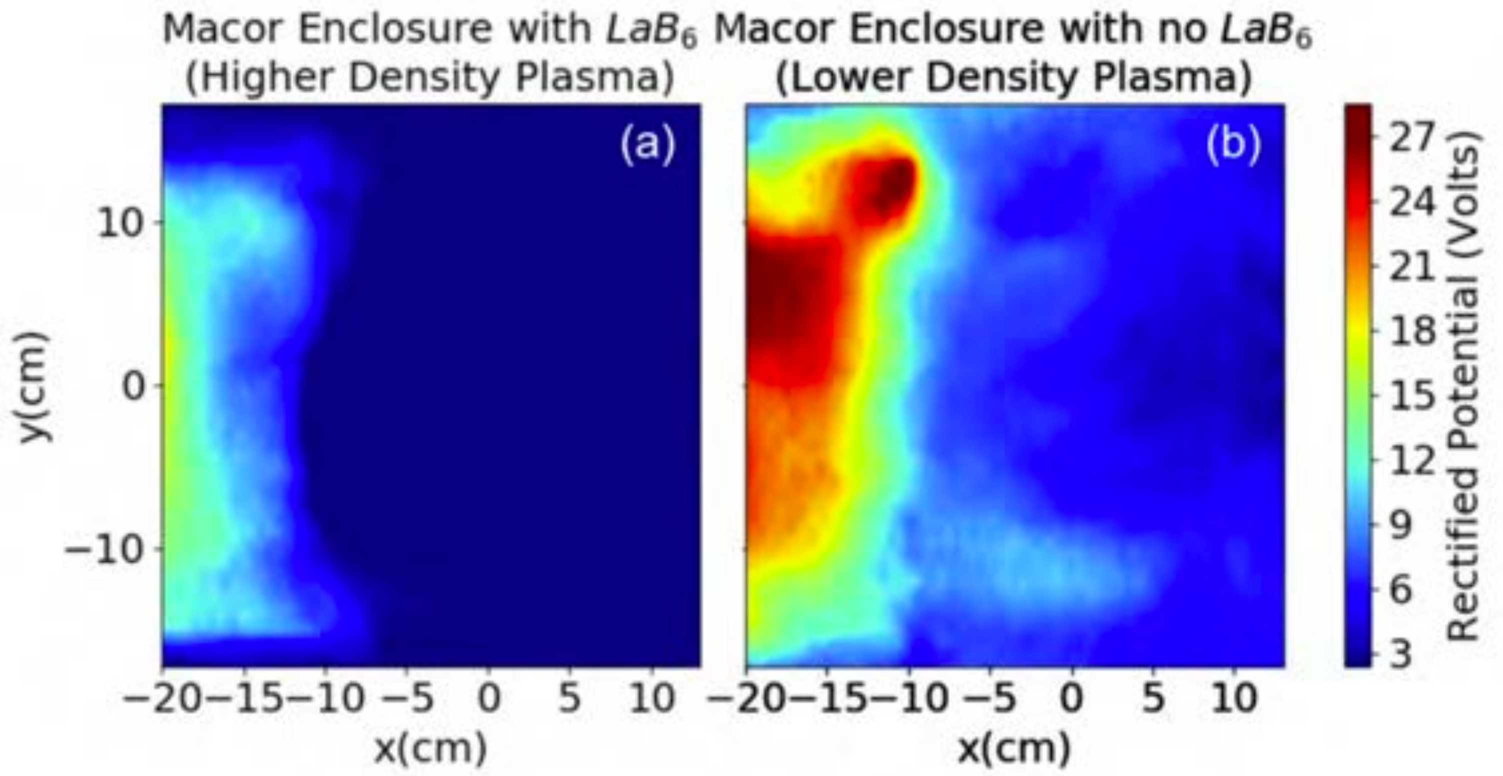
G. Bal, NF 62 086043 (2022)

Consistent with Phaedrus-T results (Majeski)

Mitigation consistent with model predictions





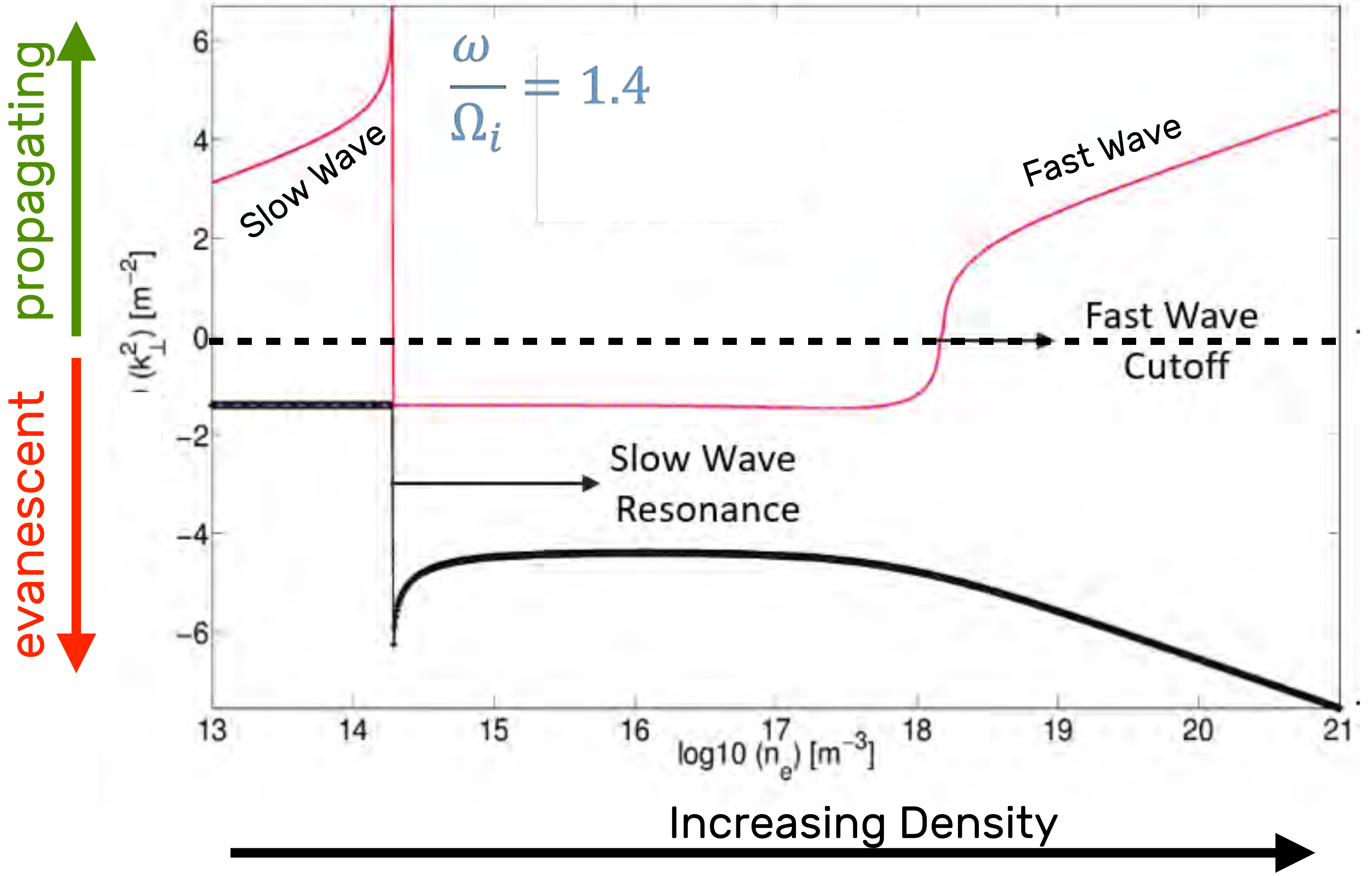


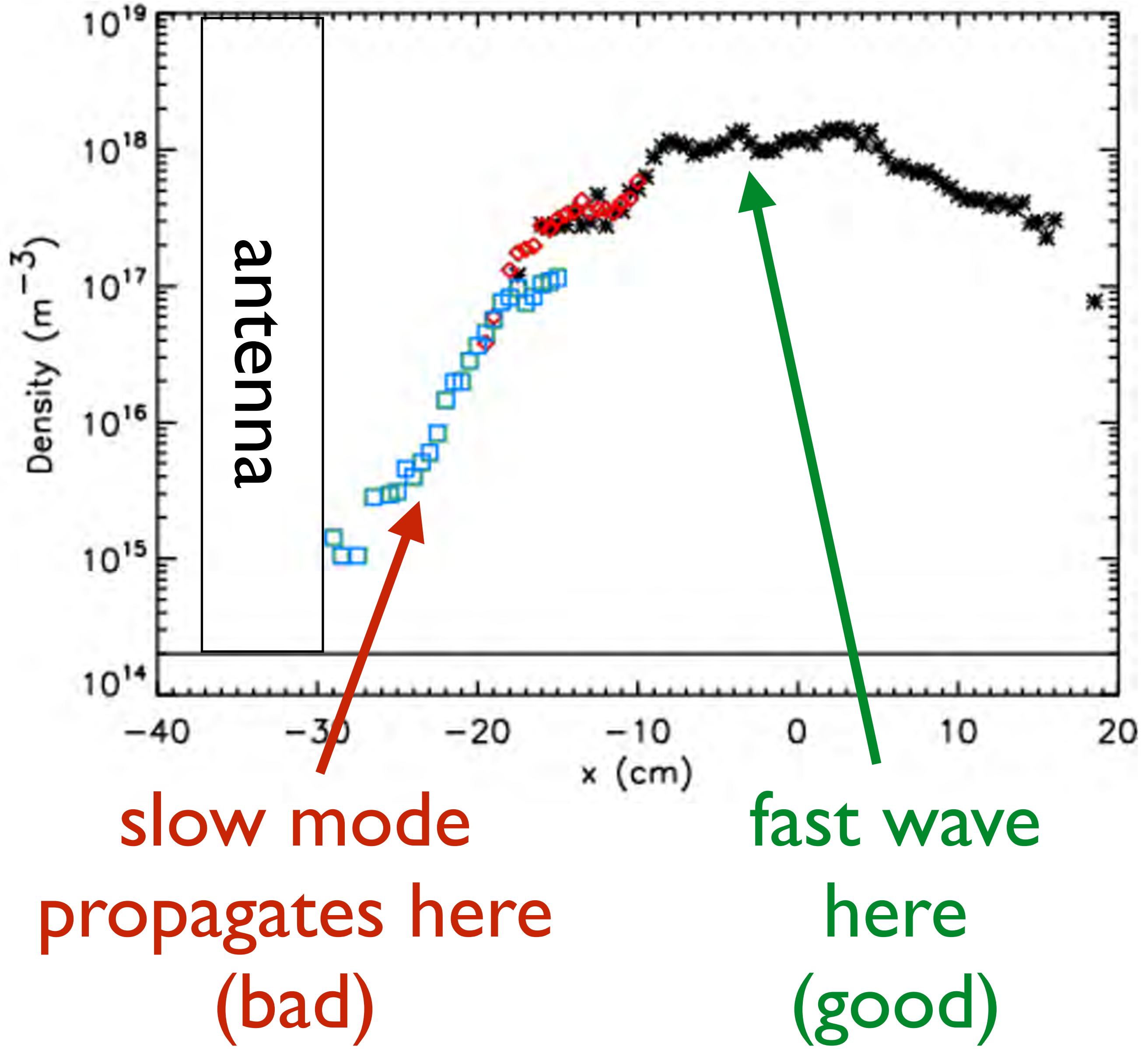
- Myra/D'Ippolito model: Insulator effectively forms voltage divider with plasma sheath. RF Sheath mitigation when insulator impedance is much larger than plasma sheath impedance

- Increased RF rectification seen in lower-density plasmas, consistent with model

Parasitic coupling to slow mode in LAPD

If density at antenna is low enough, unwanted coupling to slow mode (LH wave) is possible, leading to lost power, far-field sheaths, etc.

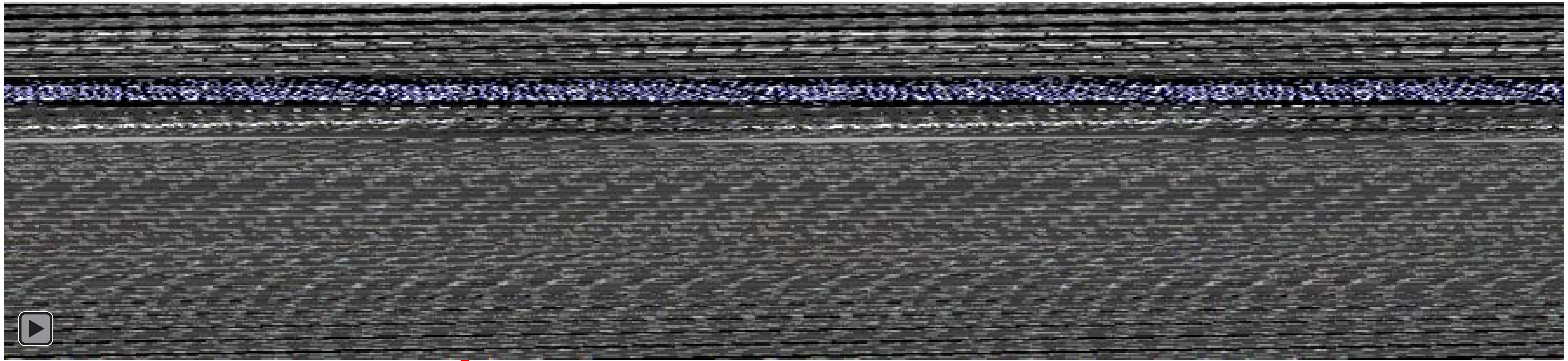




Parasitic coupling to slow mode observed in low density plasma near antenna

Lower hybrid wave near antenna, backward propagation

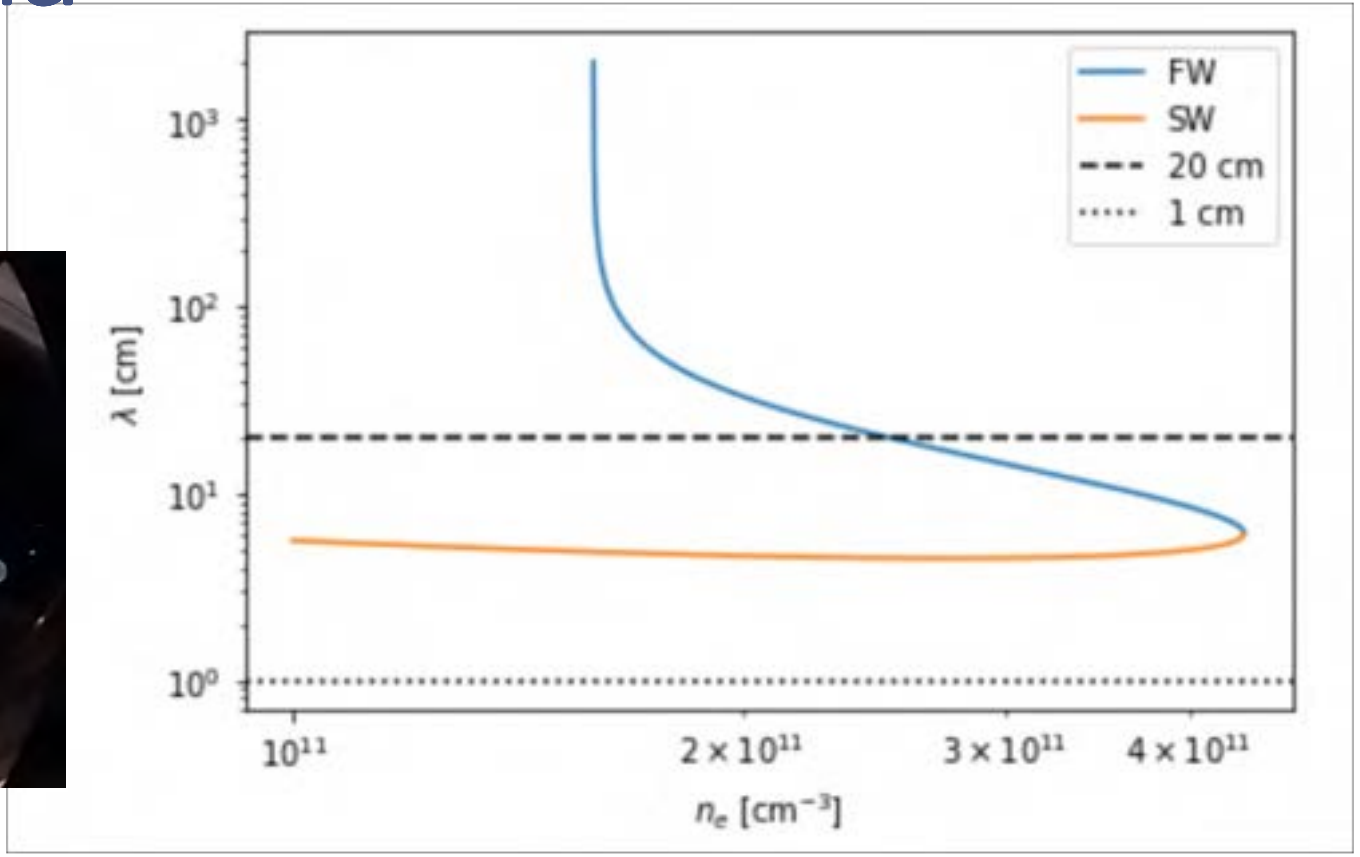
Fast wave in high density core plasma, m = 1 mode as before



Radial position of antenna aperture

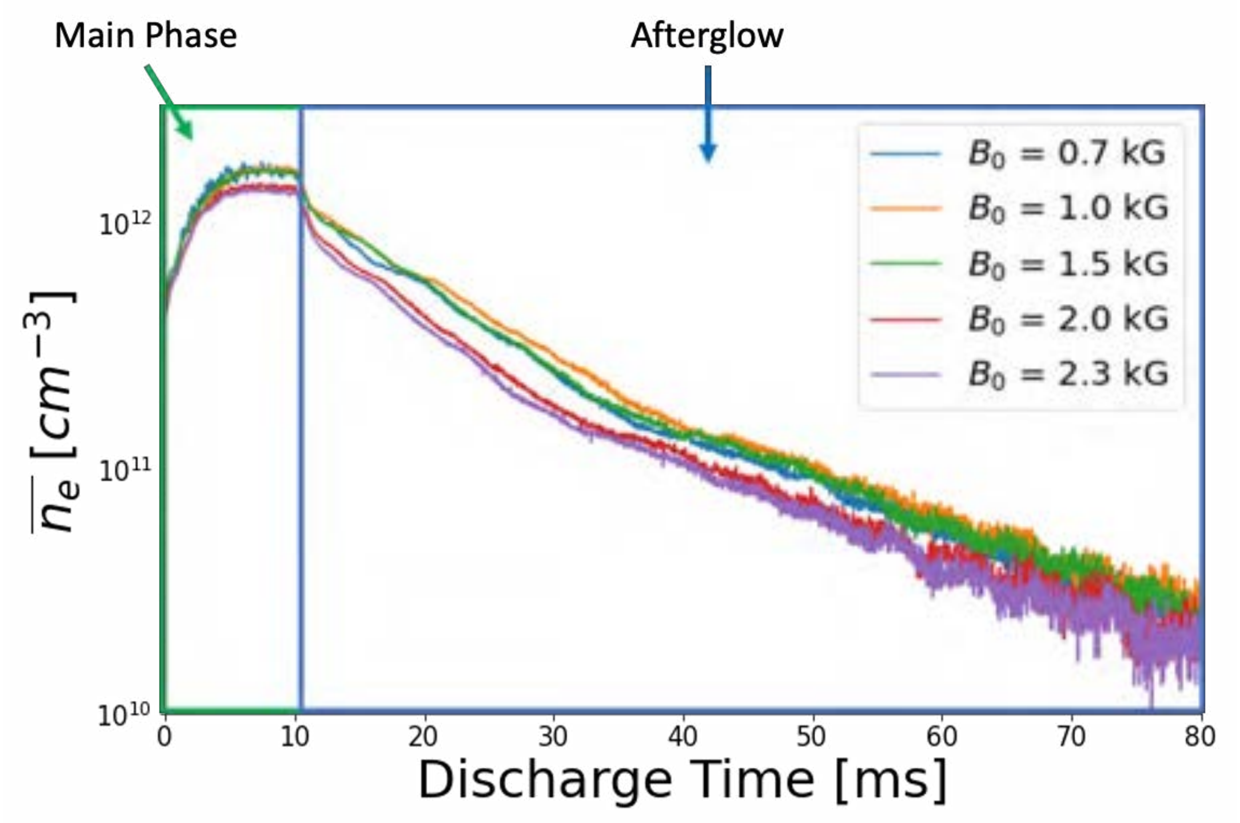
G. Bal, B. Van Compernolle, et al. in prep.

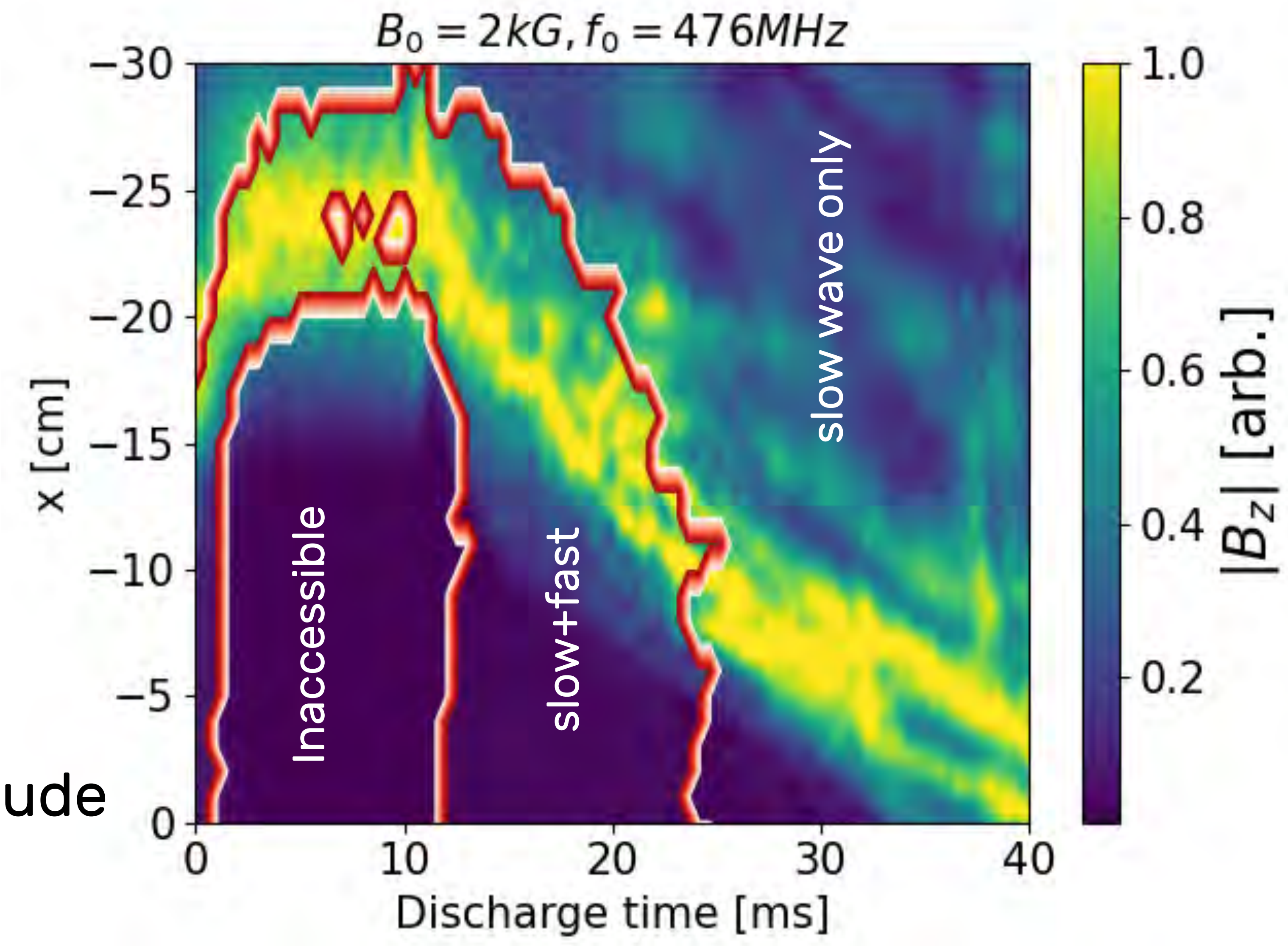
Helicon wave studies on LAPD using DIII-D prototype antenna



- Helicon antenna designed to launch fast waves in lower hybrid range of frequencies for off-axis current drive in DIII-D; low power prototype antenna installed in LAPD
- Operating at ~500MHz, can couple to both Fast Wave and Slow Wave in LAPD density/magnetic field conditions

Coupling/Propagation observed in expected density regimes

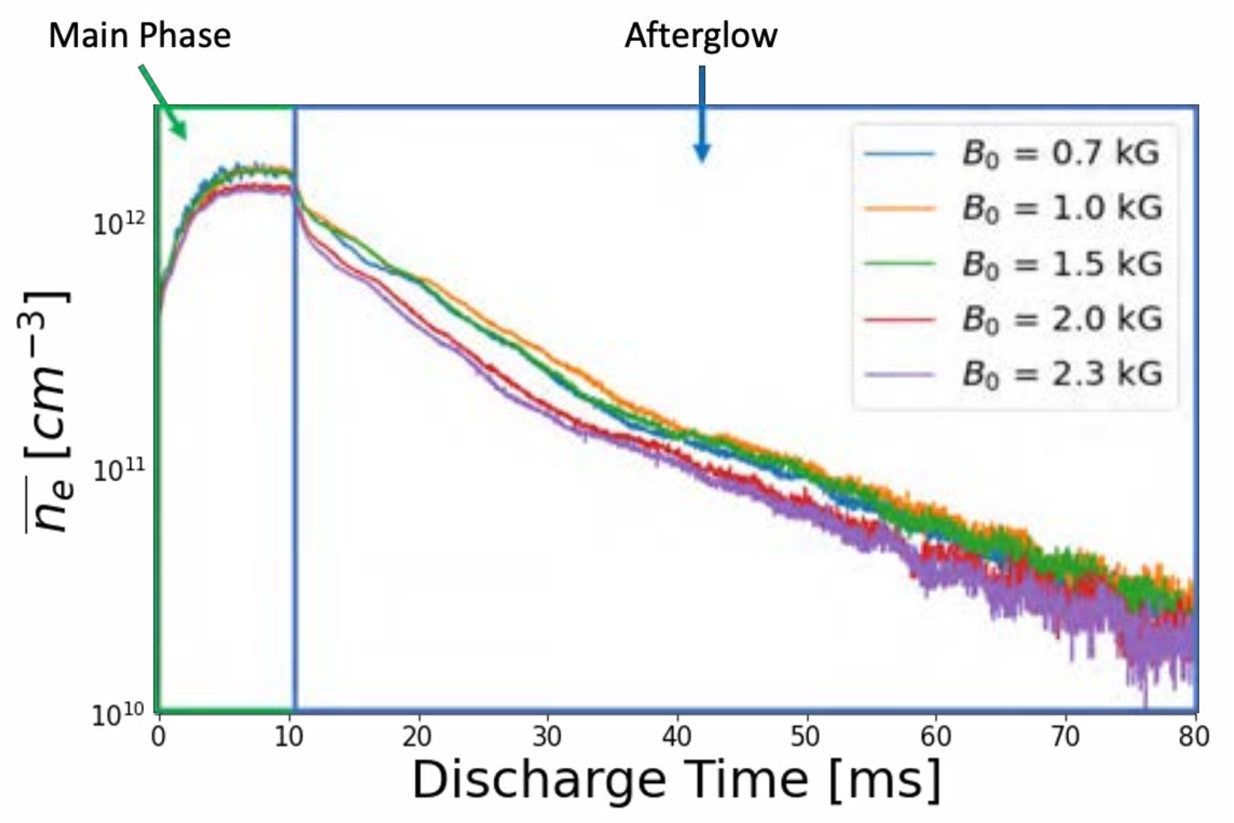




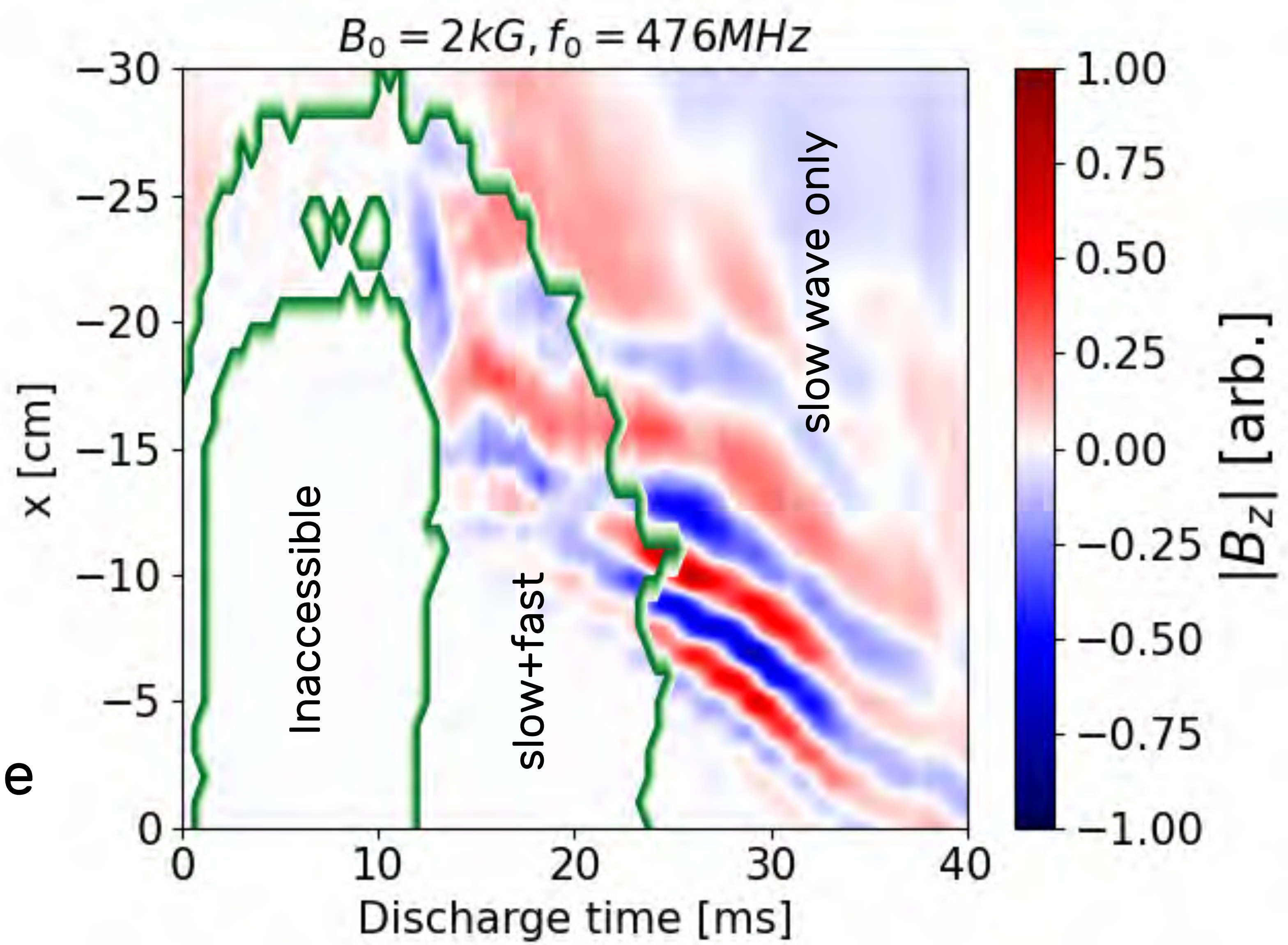
Wave amplitude

- Propagation in low-density edge during "main phase", penetrates into core as density drops during afterglow

Coupling/Propagation observed in expected density regimes



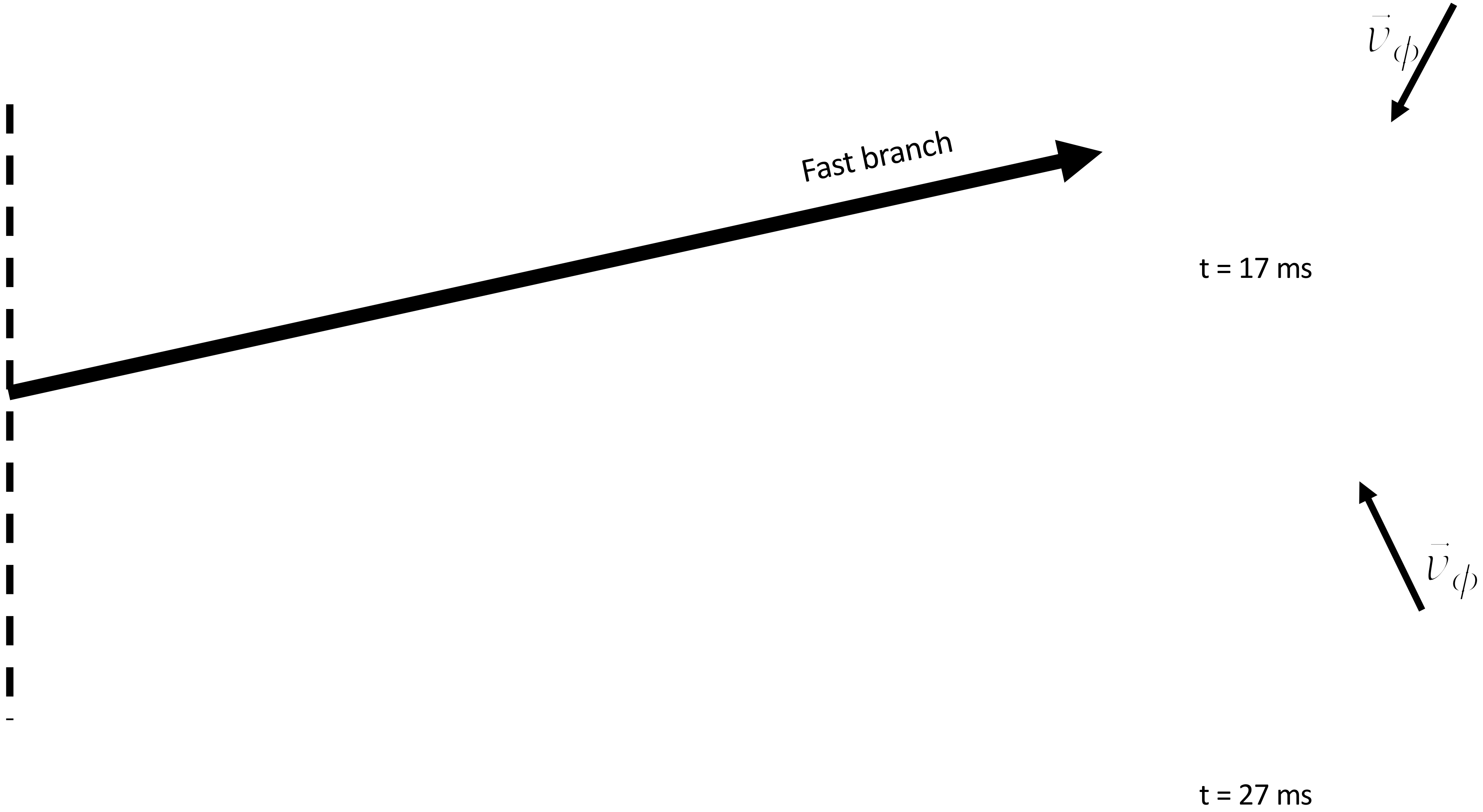
Wave phase



- Propagation in low-density edge during “main phase”, penetrates into core as density drops during afterglow

Coupling to both fast wave and slow wave observed

Antenna at x,z = (-30,0) cm



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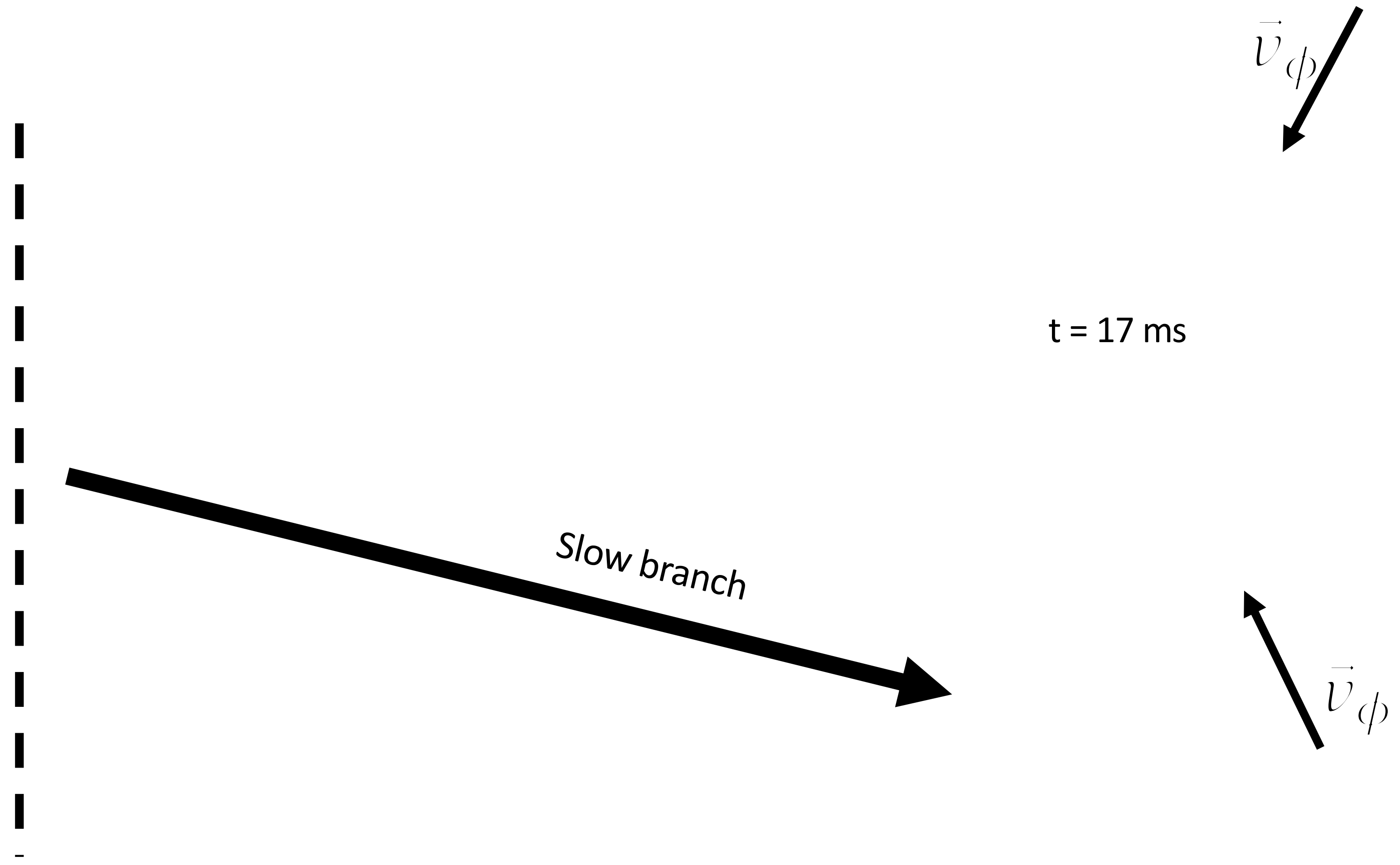
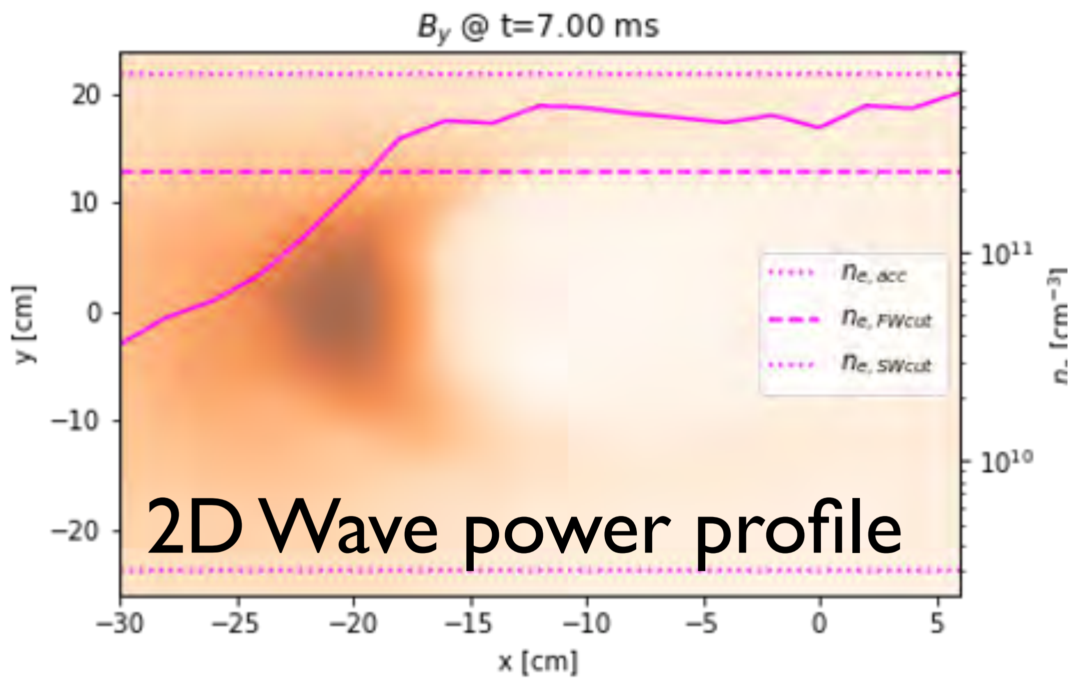
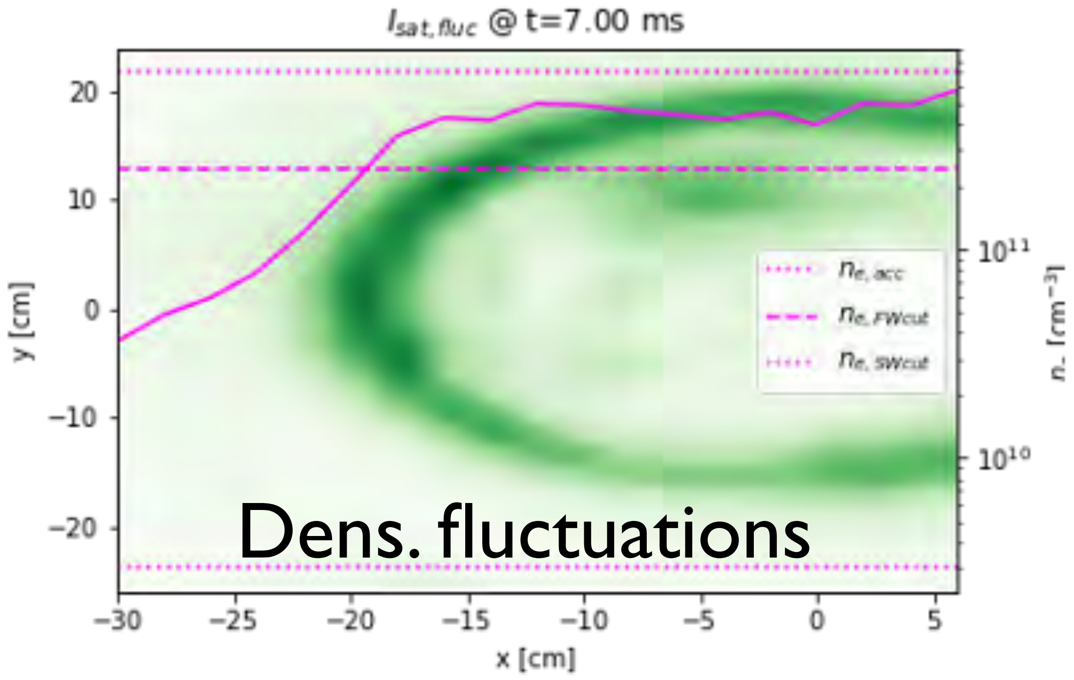


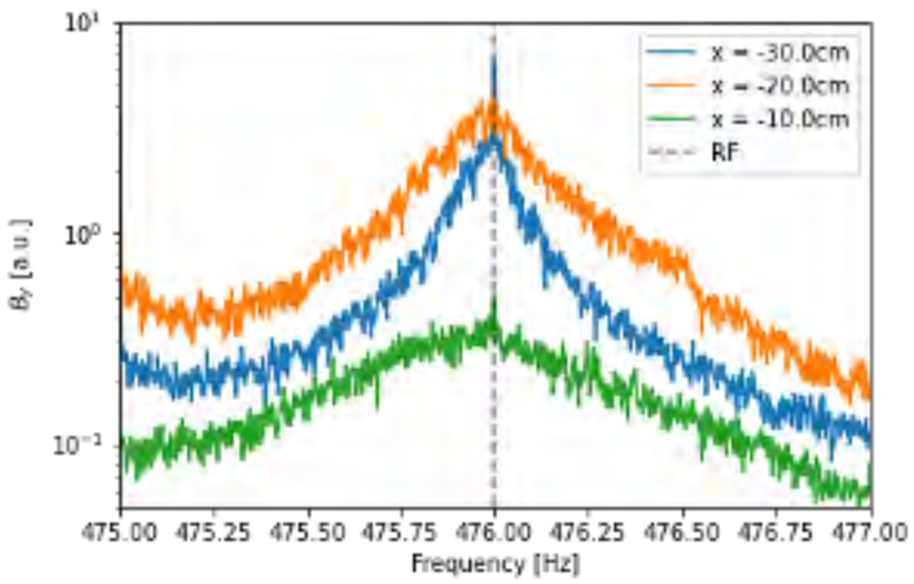
t = 17 ms

t = 27 ms

Ongoing work: wave interaction with turbulence, scattering, mode conversion to SW

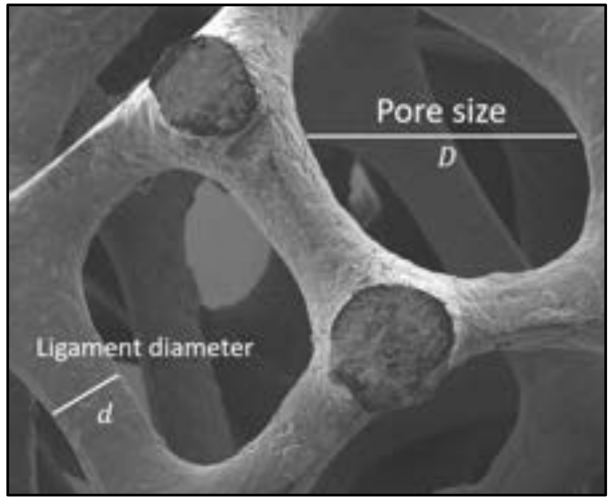


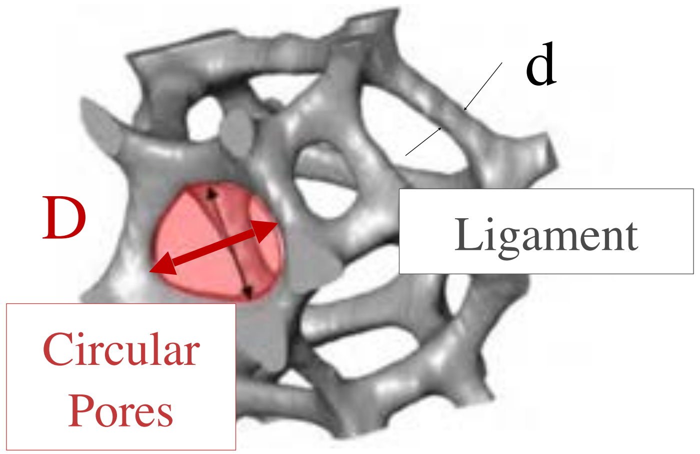


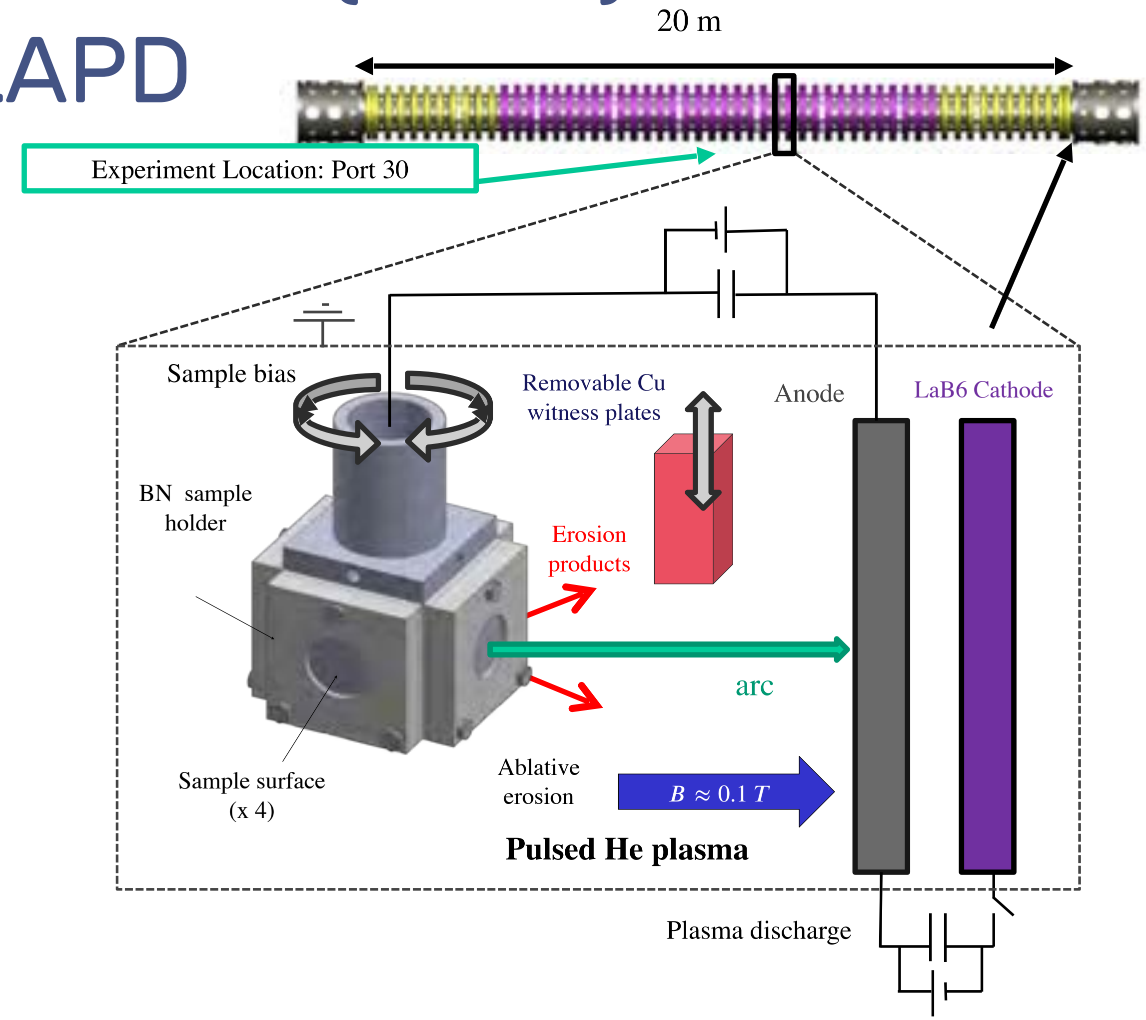


- In presence of drift-wave turbulence, see spectral broadening, wave power confined to edge region
- Possible scattering/mode conversion by turbulent filaments? (C. Lau et al., NF 2021, W. Tierens PoP 2020)

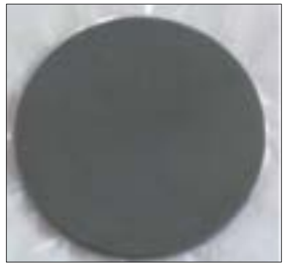
Tests of Volumetrically Complex Materials (VCMs) as PFCs/ Electrodes in LAPD



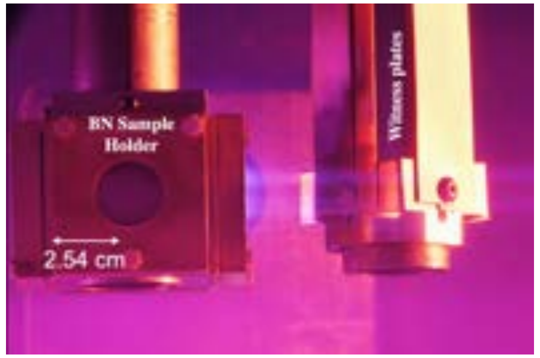




- VCMs including metal foams: reduction in sputtering/secondary emission via geometric trapping & recapturing
- Additional improvements from "plasma infusion" of the material
- Testing of sputtering/arcing performance via plasma exposure/biasing in LAPD


Flat W


VCM W

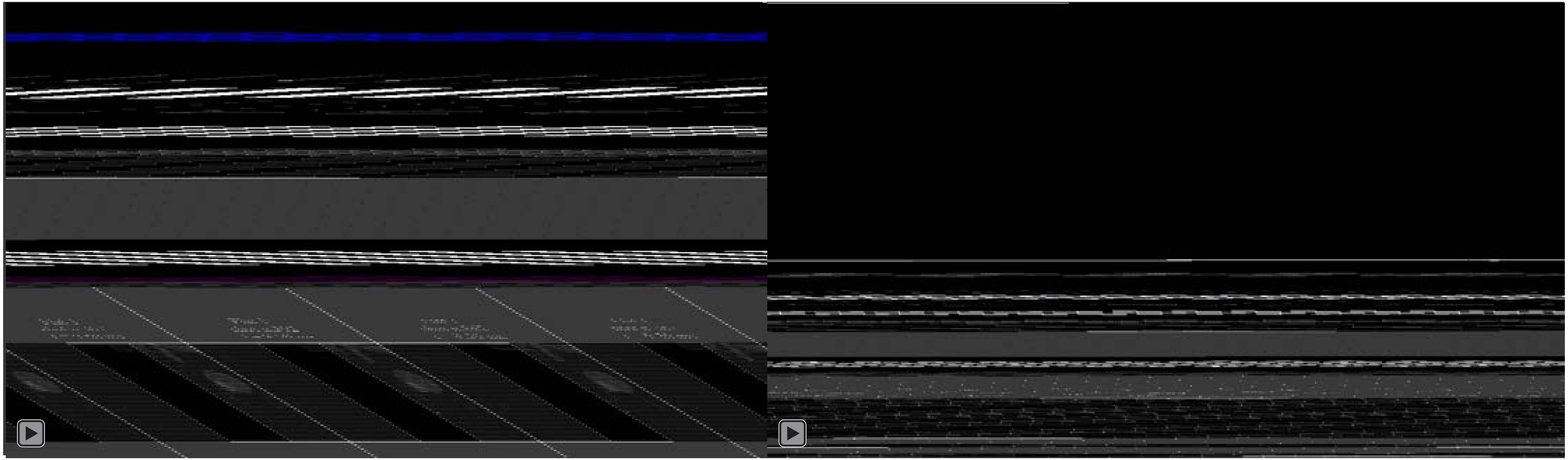


CHANGING WHAT'S POSSIBLE

AMPERE
Advanced Materials for Plasma-Exposed Robust Electrodes

A. Ottaviano PhD thesis

VCM have lower sputtering, mitigate arc impacts in LAPD tests



- Fast framing camera imaging: saw far fewer arcs, more arc movement on surface, and less sputtering with VCM (W Foam) compared to flat W target

A. Ottaviano, et al., in prep

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