Electron heating in magnetized capacitively coupled discharges

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Outline

- Introduction
- PIC simulation
- Electron power absorption in capacitively coupled discharges with a uniform magnetic field
- Electron power absorption in radio-frequency magnetron discharges
- Conclusions

Introduction

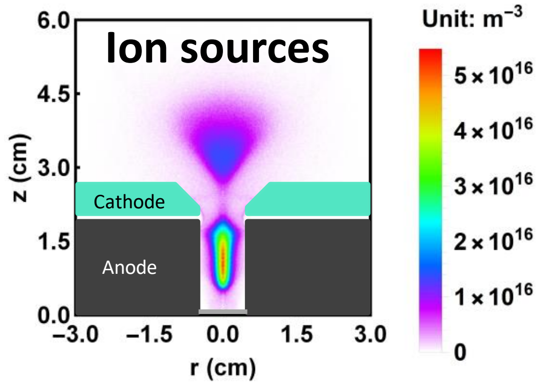
- Capacitively coupled discharges
  - Mechanism of electron power absorption
  - Ohmic heating and collisionless heating [1]
  - Heating mode transition with a transverse magnetic field [2]
- Motivations
  - Self-consistent investigation of electron heating in magnetized CCPs

[1] V.A. Godyak, and R.B. Piejak, Phys. Rev. Lett. 65, 996 (1990).
[2] M.M. Turner, D.A.W. Hutchinson, R.A. Doyle, M.B. Hopkins, Phys. Rev. Lett. 76, 2069 (1996).

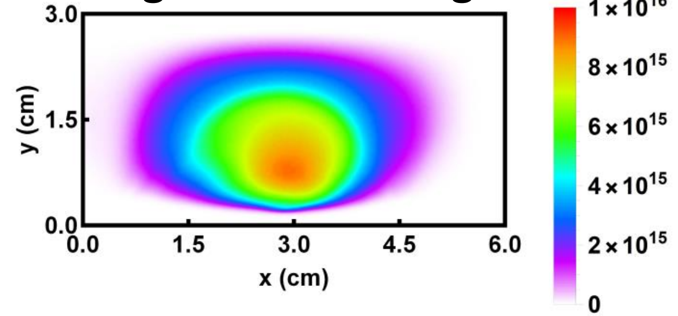
PIC simulation

ASTRA

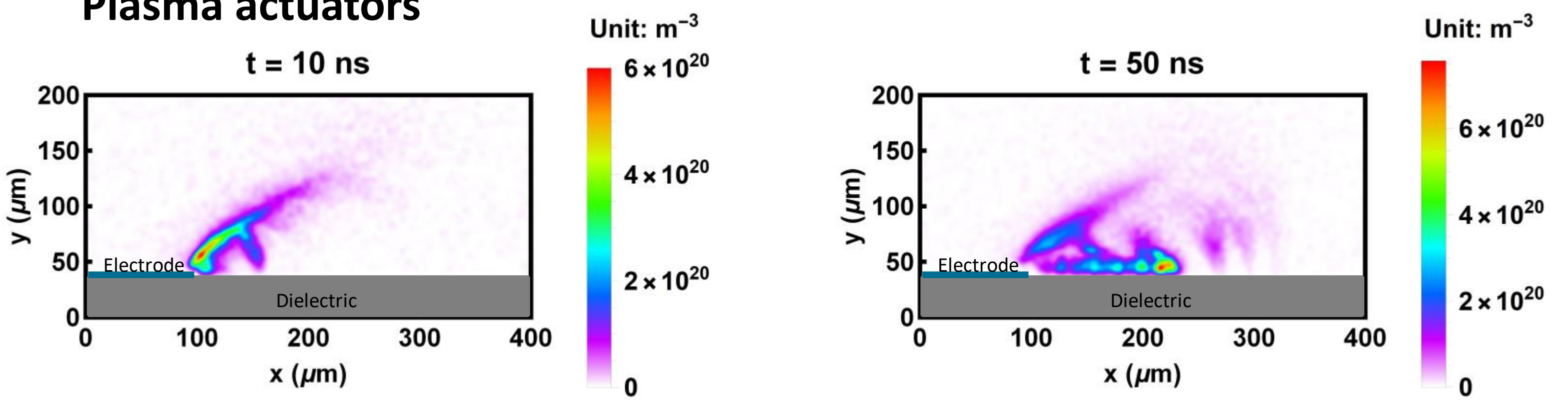
- 1d3v/2d3v object-oriented particle-in-cell (code)
- Multi-platform: Windows, Linux, Mac
- Benchmarked against Turner et al. [1]



Magnetron discharges



Plasma actuators

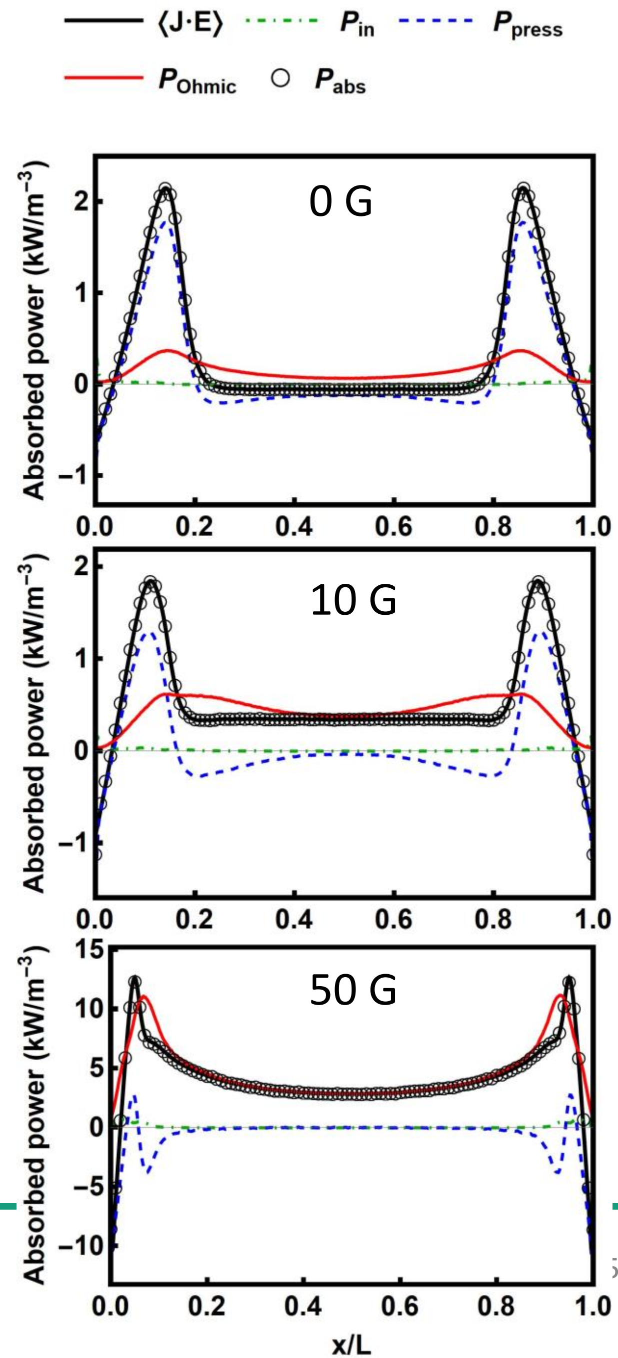


[1] M.M. Turner, A. Derzsi, Z. Donkó, D. Eremin, S.J. Kelly, T. Lafleur, T. Mussenbrock, Phys. Plasmas 20, 013507 (2013).

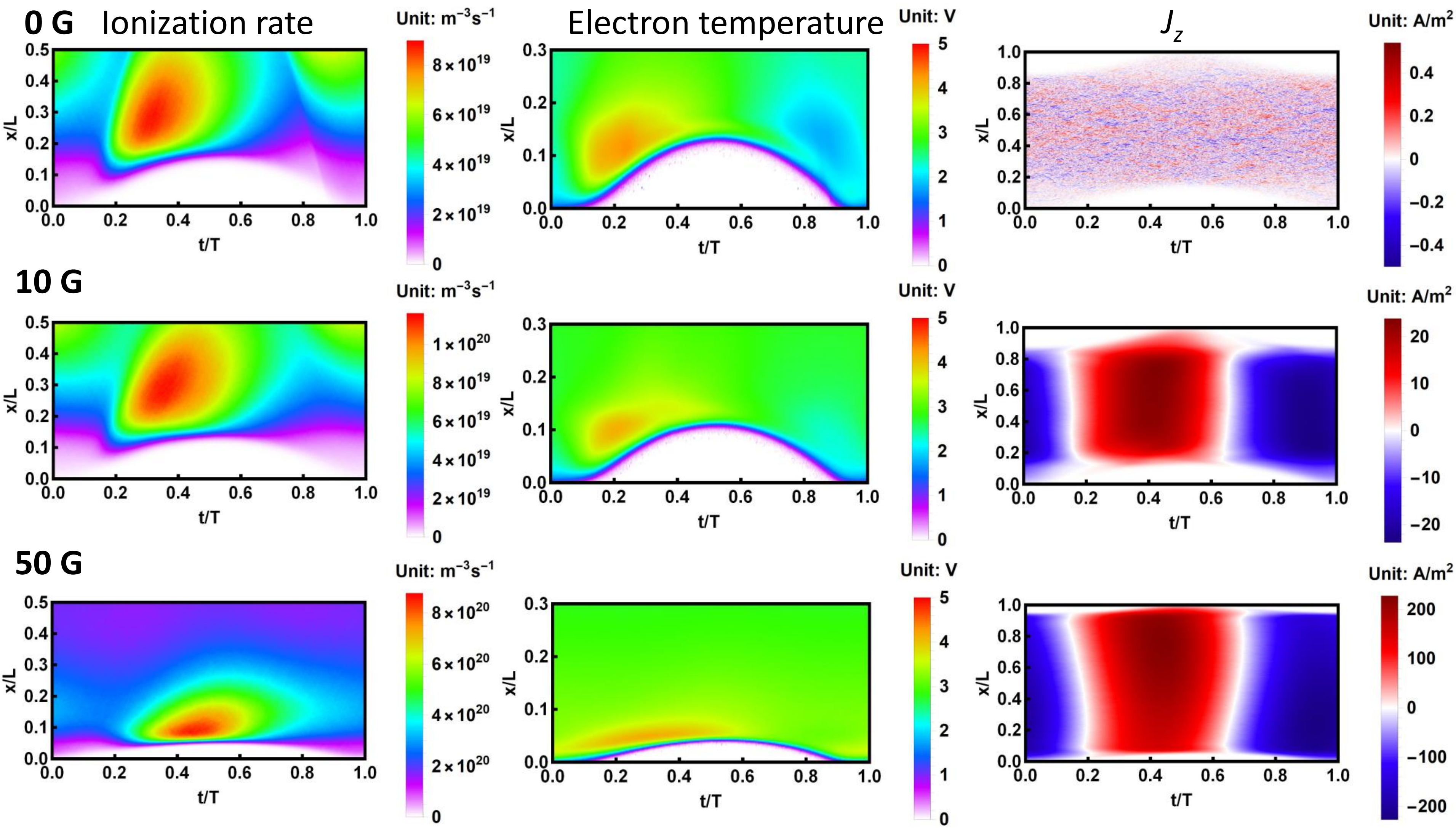
1d magnetized CCP discharges

- Parameters
  - Working gas: argon
  - Gas pressure: 10 mTorr
  - Gas temperature: 300 K
  - Gap length: 5 cm
  - frequency: f = 15 MHz
  - Voltage: 150 V
  - Magnetic fields: 0, 10 and 50 G
  - Grid points: 500
  - Time step: 2000 per rf period
  - Super particle number: 100,000—200,000
- Electric field along x-direction
- Magnetic field along y-direction
- Moment analysis of Boltzmann equation [1-3]

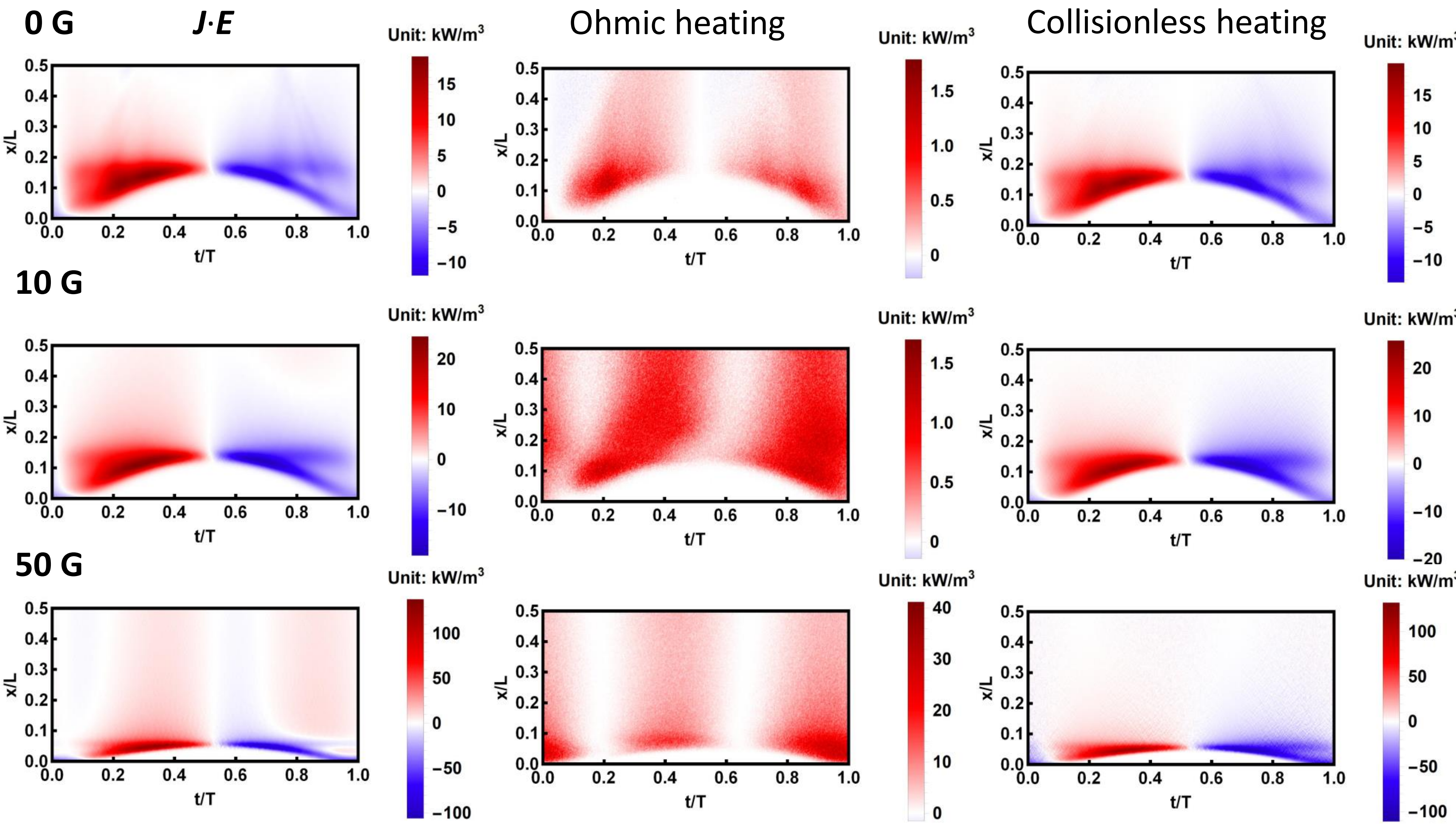
[1] M. Surendra et al., Phys. Rev. E 48, 3914 (1993).
[2] T. Lafleur et al., Plasma Sources Sci. Technol. 23, 035010 (2014).
[3] J. Schulze et al., Plasma Sources Sci. Technol. 27, 055010 (2018).



1d magnetized CCP discharges

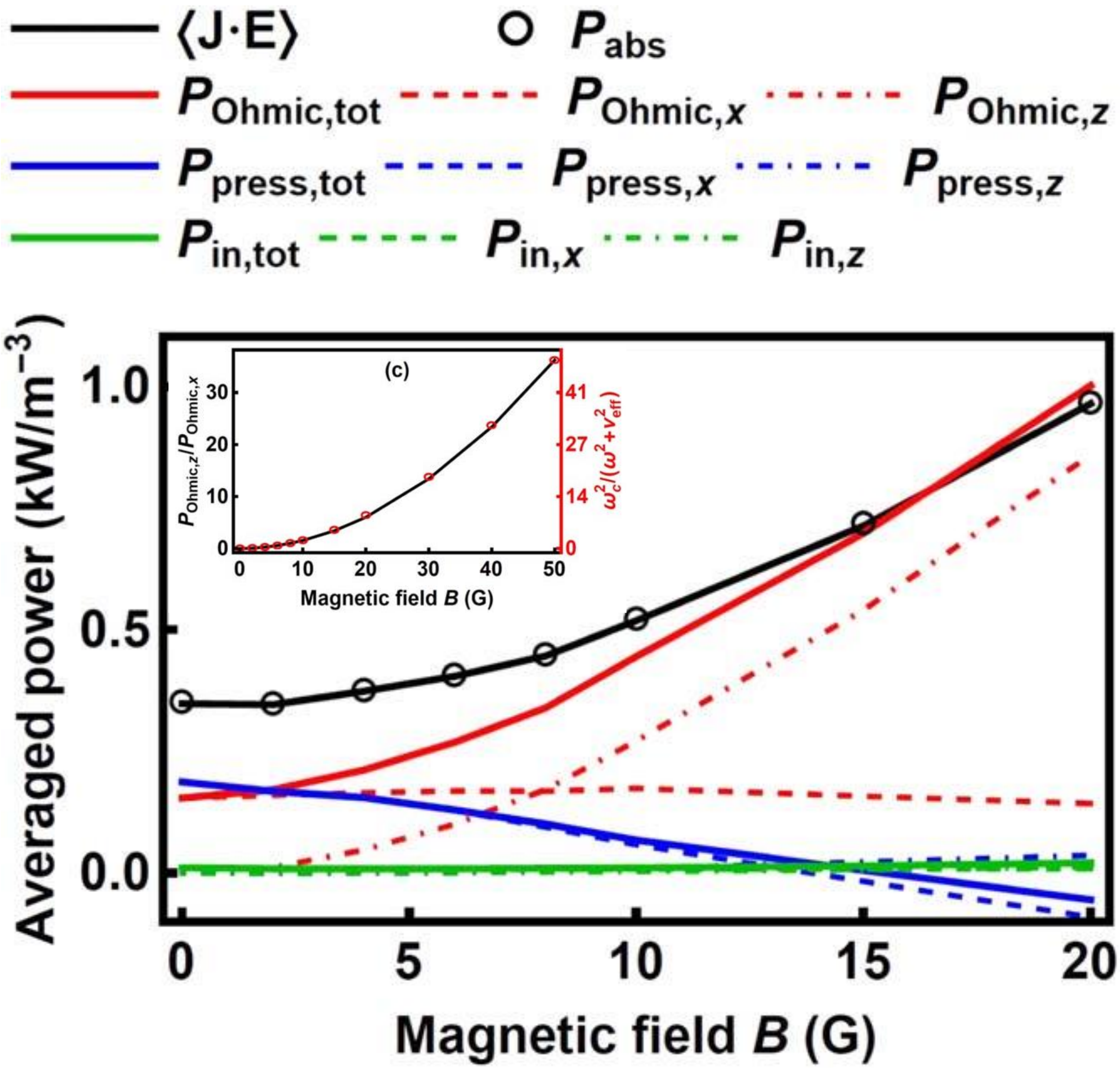


1d magnetized CCP discharges

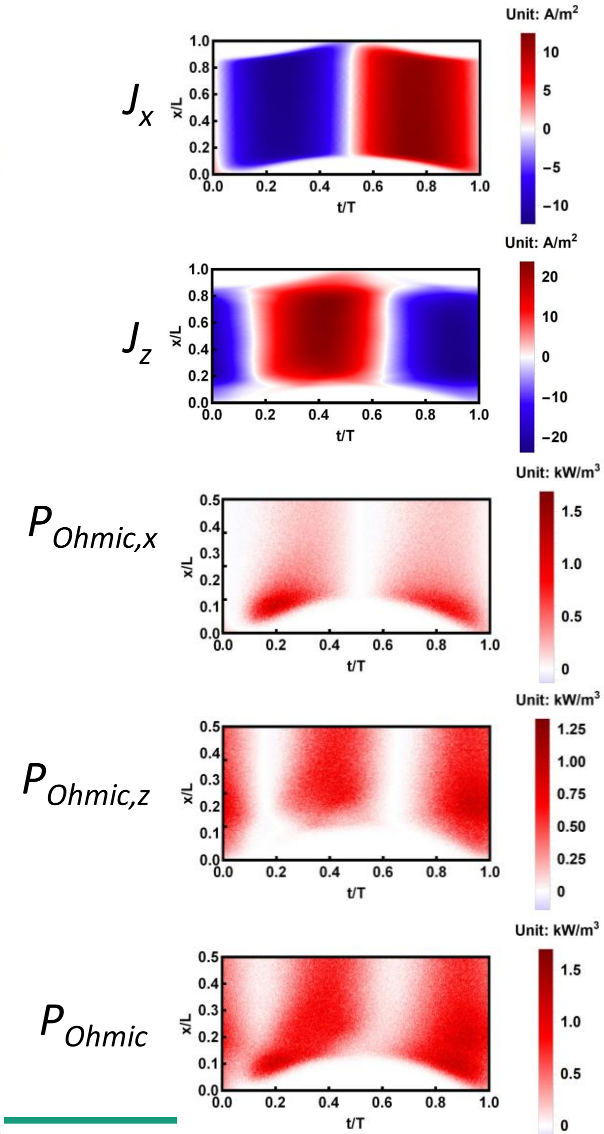


1d magnetized CCP discharges

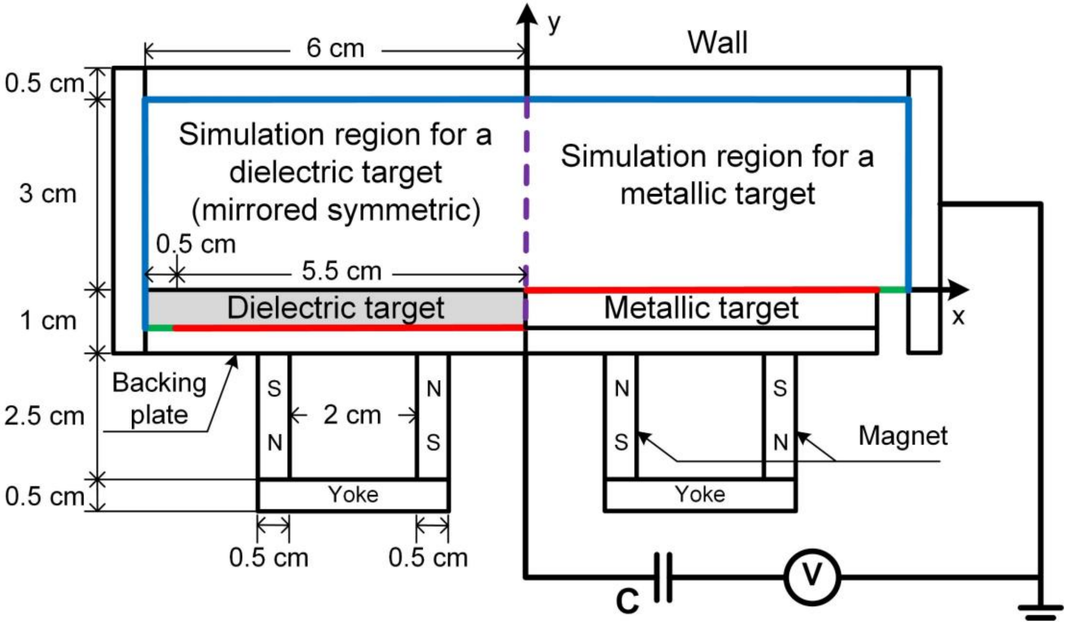
B.C. Zheng et al., Plasma Sources Sci. Technol. 28, 09LT03 (2019).

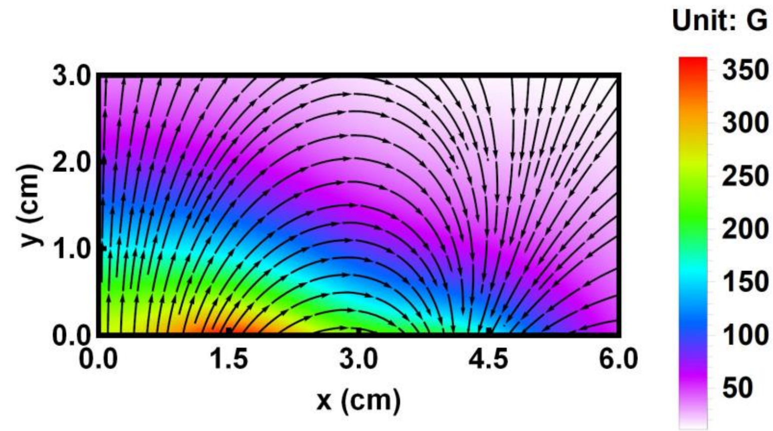


10 G



2d RFMS discharges

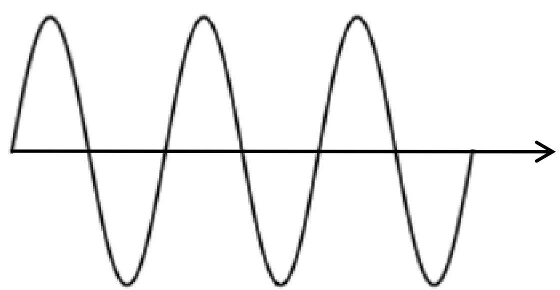




Schematic of a planar RF magnetron sputtering set-up

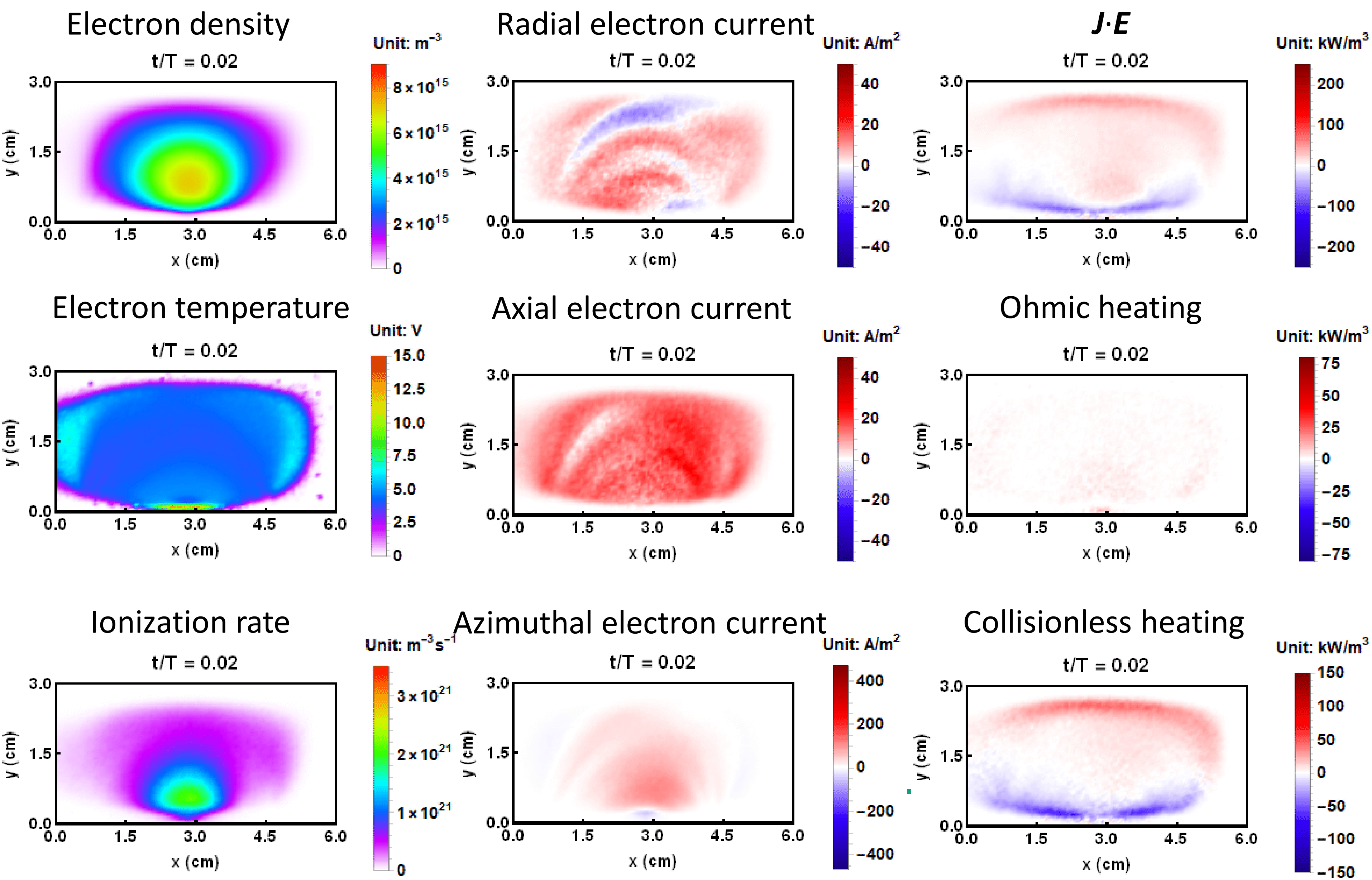
Magnetic field flux in the simulation region

Sinusoidal voltage waveform



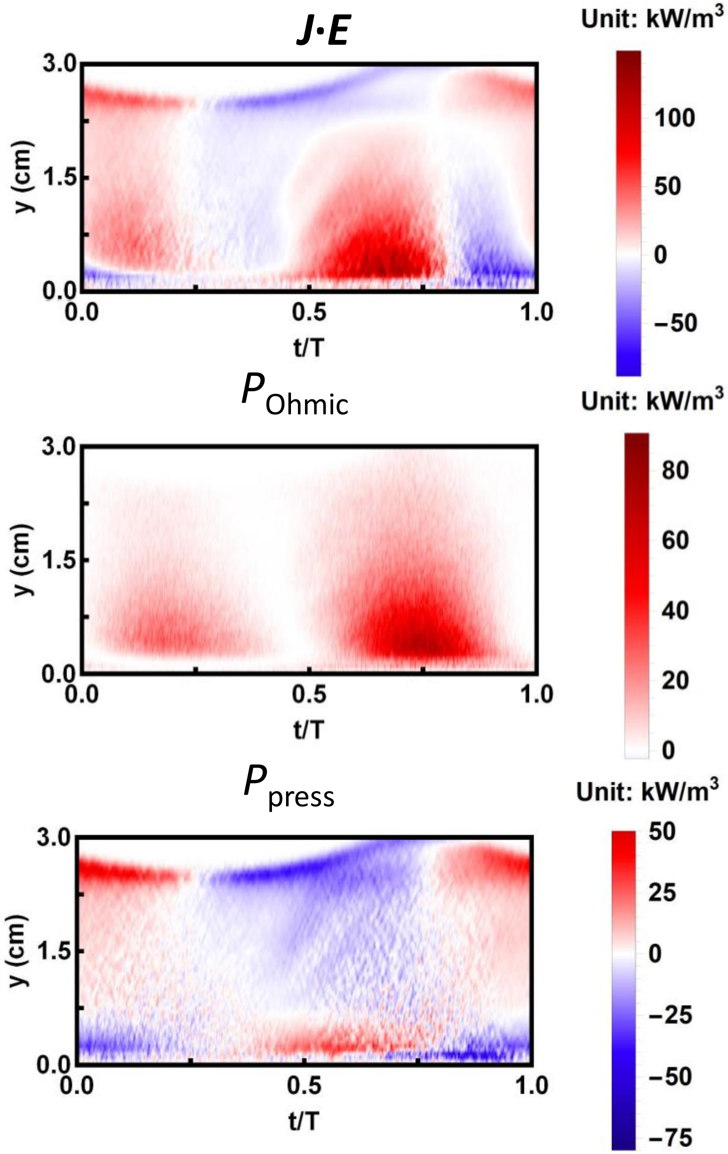
2d RFMS discharges

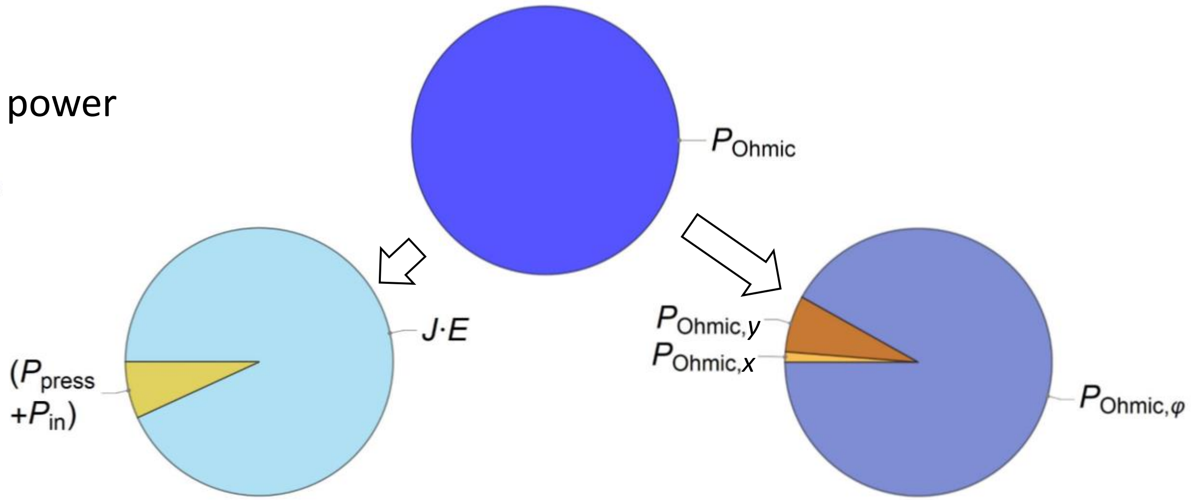
Animations not supported in PDF



2d RFMS discharges

Spatiotemporal distribution of electron power deposition at x = 3 cm



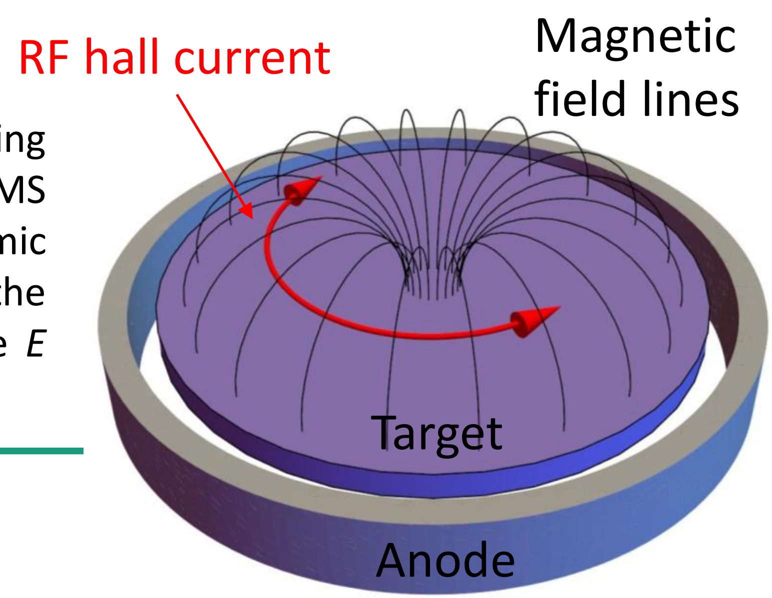


$$P_{abs} = \boldsymbol{J}\cdot\boldsymbol{E} = P_{Ohmic} + P_{press} + P_{in}$$

$$P_{Ohmic} = \boldsymbol{J}\cdot\boldsymbol{E} - (P_{press} + P_{in})$$

$$= P_{Ohmic,r} + P_{Ohmic,z} + P_{Ohmic,\varphi}$$

The primary heating component in RFMS discharges is the Ohmic heating induced by the RF Hall current in the $E \times B$ direction



Thank you

for your

attention