Young researcher's poster mini-session:

Uncovering the driving mechanism of rotating spokes in partially magnetized plasmas

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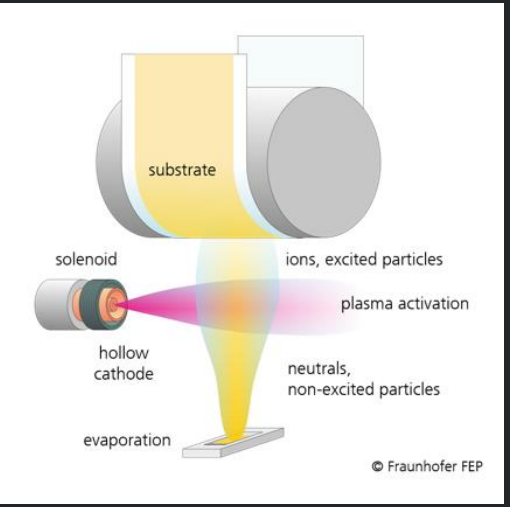
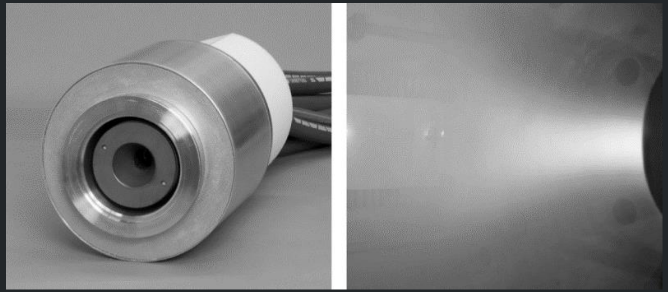
ExB Plasmas Workshop 2022

Madrid, online event

The Rotating Spoke under Conditions of Magnetically Enhanced Hollow Cathode Arc Discharge

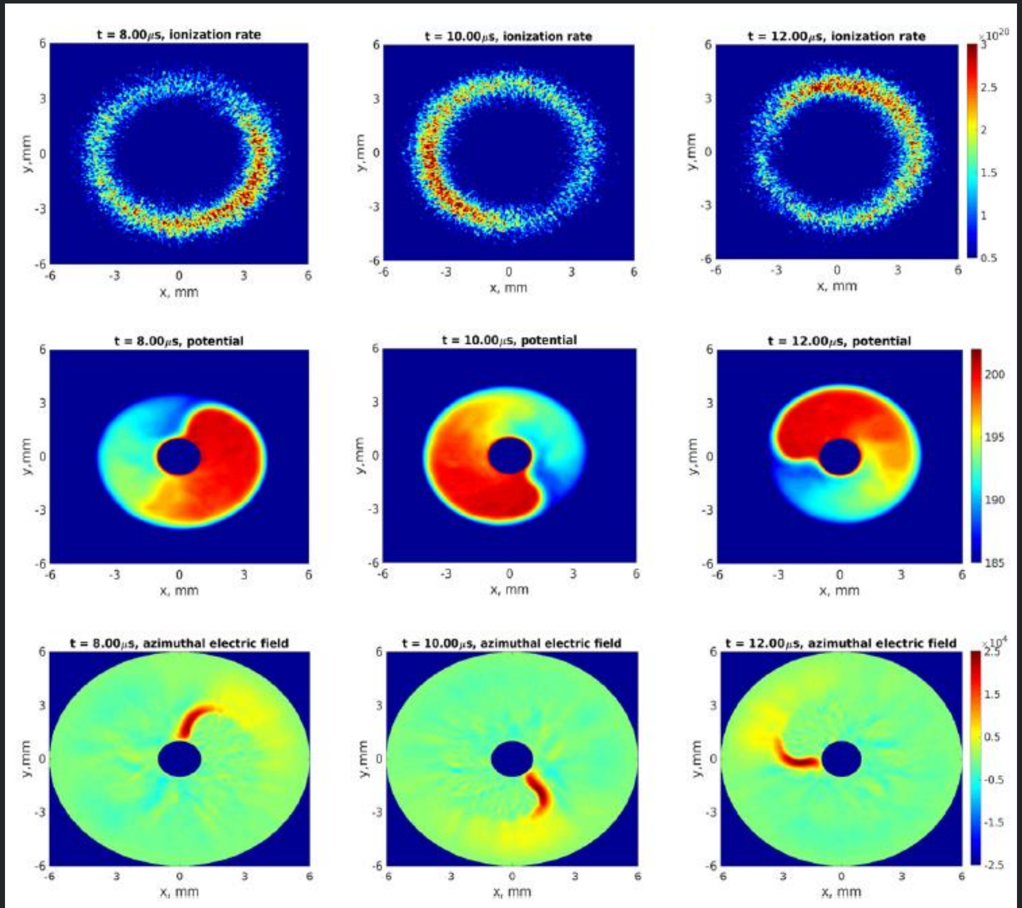


Schematic of magnetized enhanced hollow cathode arc discharge (ME-HCAD) for PEPVD

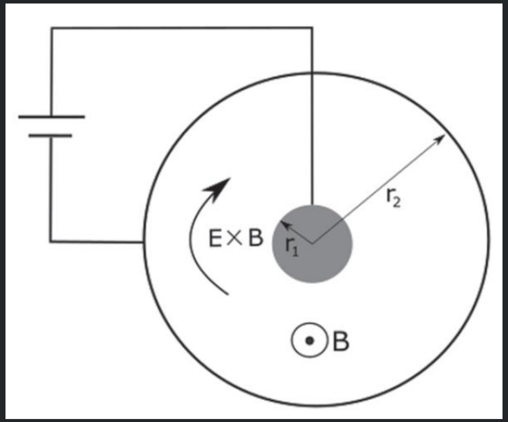


Prototype and operation

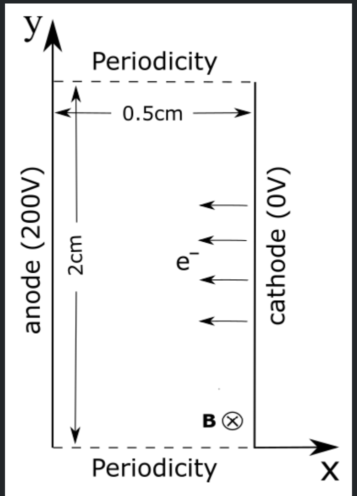
F. Fietzke et al. Plasma Processes and Polymers (2009)



2D cylindrical PIC/MCC (XPDC2 code) shows the rotating spoke with velocity v=4km/s. The model has uniform axial B= 60mT, P=10Pa, anode voltage U=200V, anode radius r_1=1mm and cathode r_2=6mm.



Cylindrical model



Planar model

Linear Theory of Gradient Drift Instability with Non-neutrality Considered

The dispersion relation of GDI including the non-neutrality:

$$k_y^2 \lambda_{De}^2 = \frac{\alpha k_y^2 c_s^2}{\omega^2} - \frac{\omega_d + k_y^2 \rho_e^2 (\omega - \omega_E + i\nu_{en})}{\omega - \omega_E + k_y^2 \rho_e^2 (\omega - \omega_E + i\nu_{en})}.$$

$$\omega_d = k_y v_d = k_\theta \frac{T_e}{eBL_n} (\mathrm{L}_n = \mathrm{n}_{e0} / \nabla \mathrm{n}_{e0}),$$

$$\omega_E = k_y v_E = k_y \frac{E_0}{B_0},$$

$$\alpha = \frac{n_{i0}}{n_{e0}}$$

α: non-neutrality coefficient

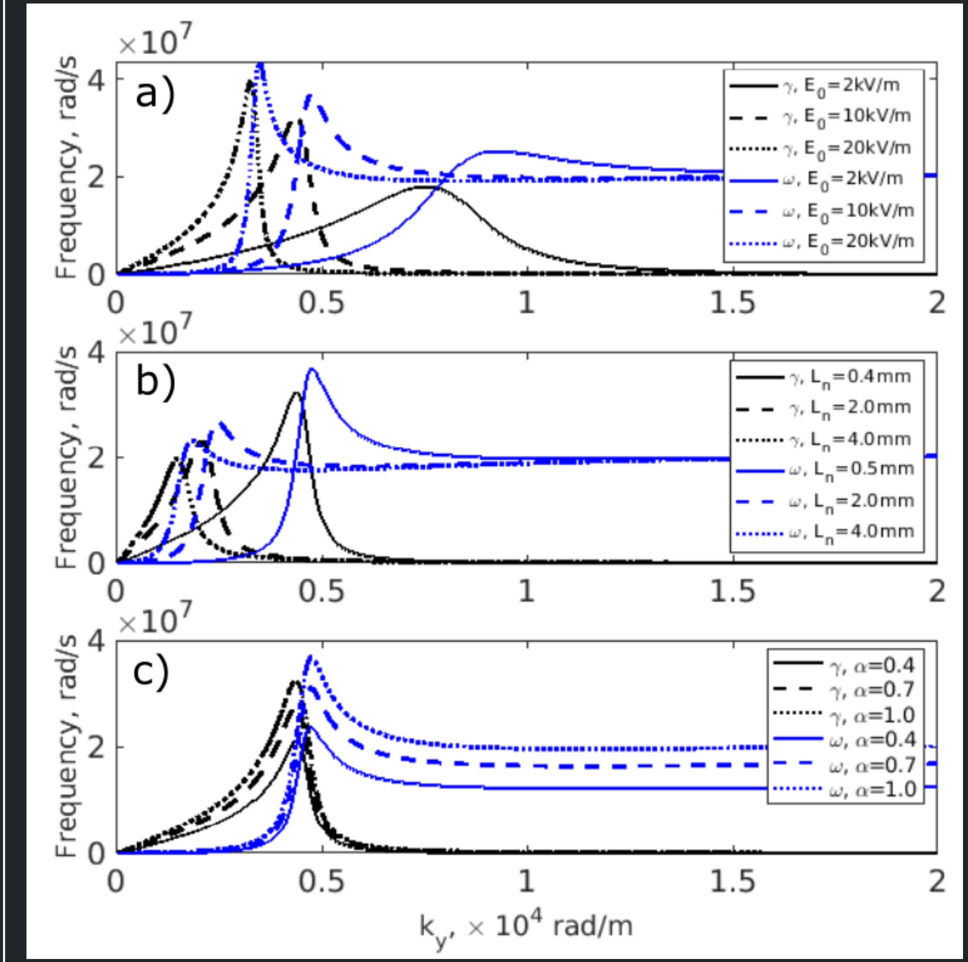
v_d: diamagnetic drift velocity

v_E: E × B drift velocity

n_{e0}: equilibrium electron density

n_{i0}: equilibrium ion density

- With increase of E_0 and L_n, the wave number k_{max} of the most unstable mode decreases
- Non-neutrality does not influence k_{max}
- The most unstable mode is the lower hybrid instability



Theoretical prediction of real frequency and growth rate with different values of electric field, density gradient length and non-neutrality coefficient.

Linear Analysis of the Spoke Instability Using the Cylindrical PIC Model

- **The instability is initiated in the anode sheath where $E \cdot \nabla n_0 > 0$**

- **The good agreement of dispersion relation between theory and PIC provides the evidence that the gradient drift instability drives the spoke formation in ME-HCAD.**

- **It is found that the most unstable mode is the lower hybrid type gradient drift instability .**

- **For the ω-k spectra, the MUSIC (multiple signal classification) method transforms time to ω and the FFT method is used to transform space to k.**

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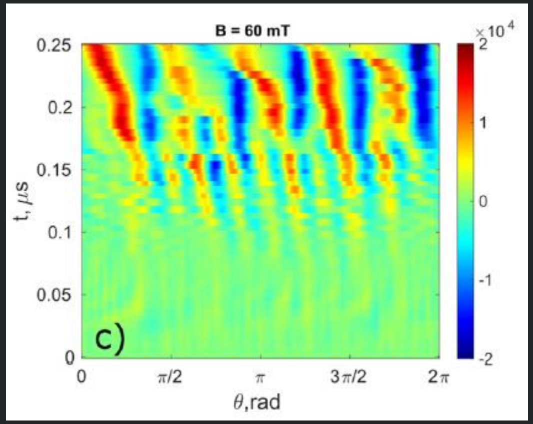
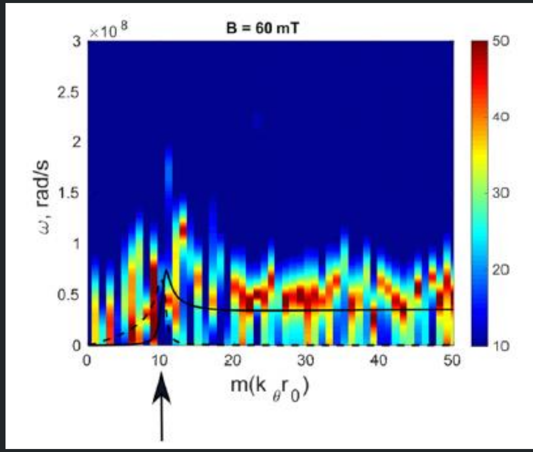
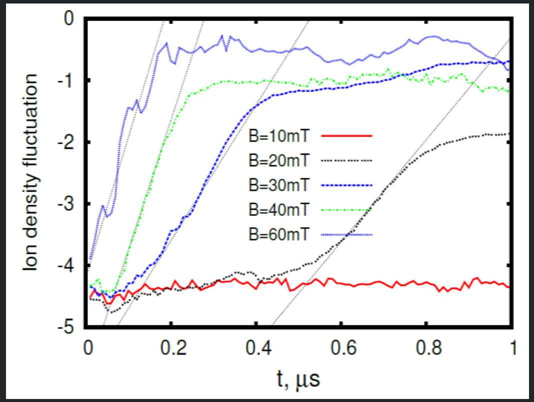


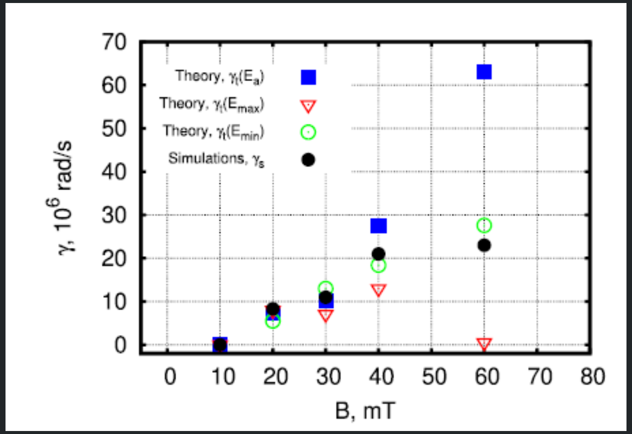
Temporal-azimuthal evolution of E_θ



ω-k spectra comparison between theory and simulation.



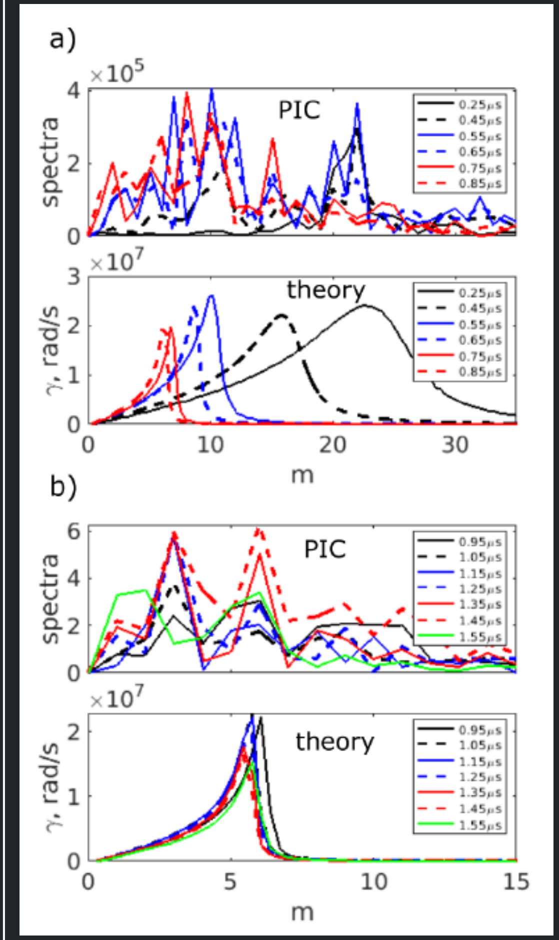
Ion density fluctuation as a function of time



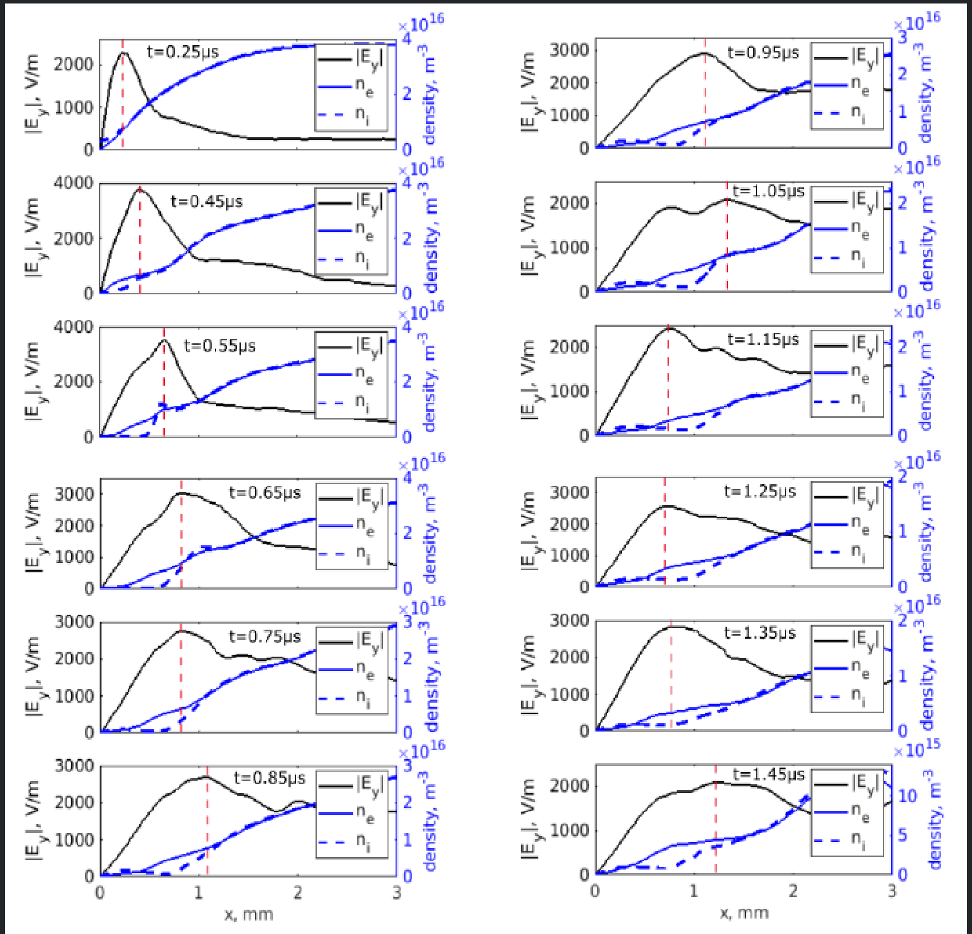
Mode growth rate comparison between theory and simulation.

Mode Transition in the Nonlinear Stage

- 2D Cartesian coordinate PIC/MCC simulations (2D-EDIPIC code) is used to study the nonlinear dynamics of spoke instability.
- The lower hybrid type instability takes place in the anode sheath where quasi-neutrality is violated.
- E_y spectra by FFT method in the azimuthal direction in the anode sheath shows the nonlinear transition from small wavelength modes to long wavelength modes.
- The comparison of the mode transition between theory and PIC shows a good agreement.
- The deviation between theory and PIC is attributed to the limitation of the linear theory in the nonlinear and nonlocal regime.



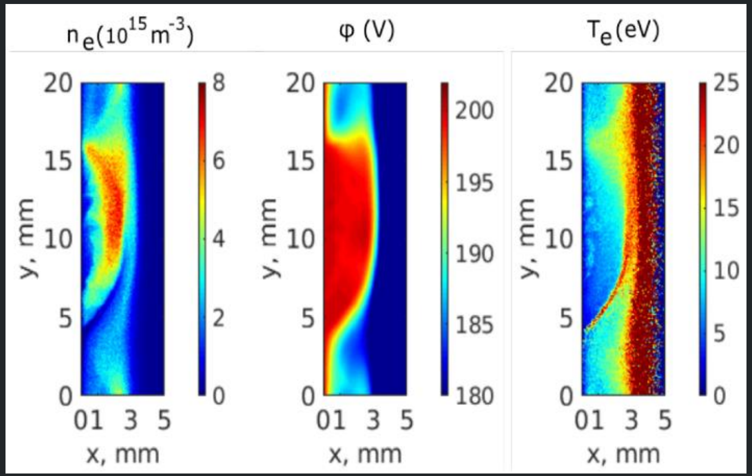
Mode transition comparison between theory and PIC



Radial (x) profiles of azimuthally (y) averaged n_e, n_i and azimuthal electric field.

Formation of the Spoke Potential Hump Region

The saturated spoke



- The lower hybrid instability triggers the anode sheath collapse resulting in the formation of the spoke potential hump region.
- The distortion of the electric potential at the edge of the potential hump region leads to the formation of the so-called double layer.

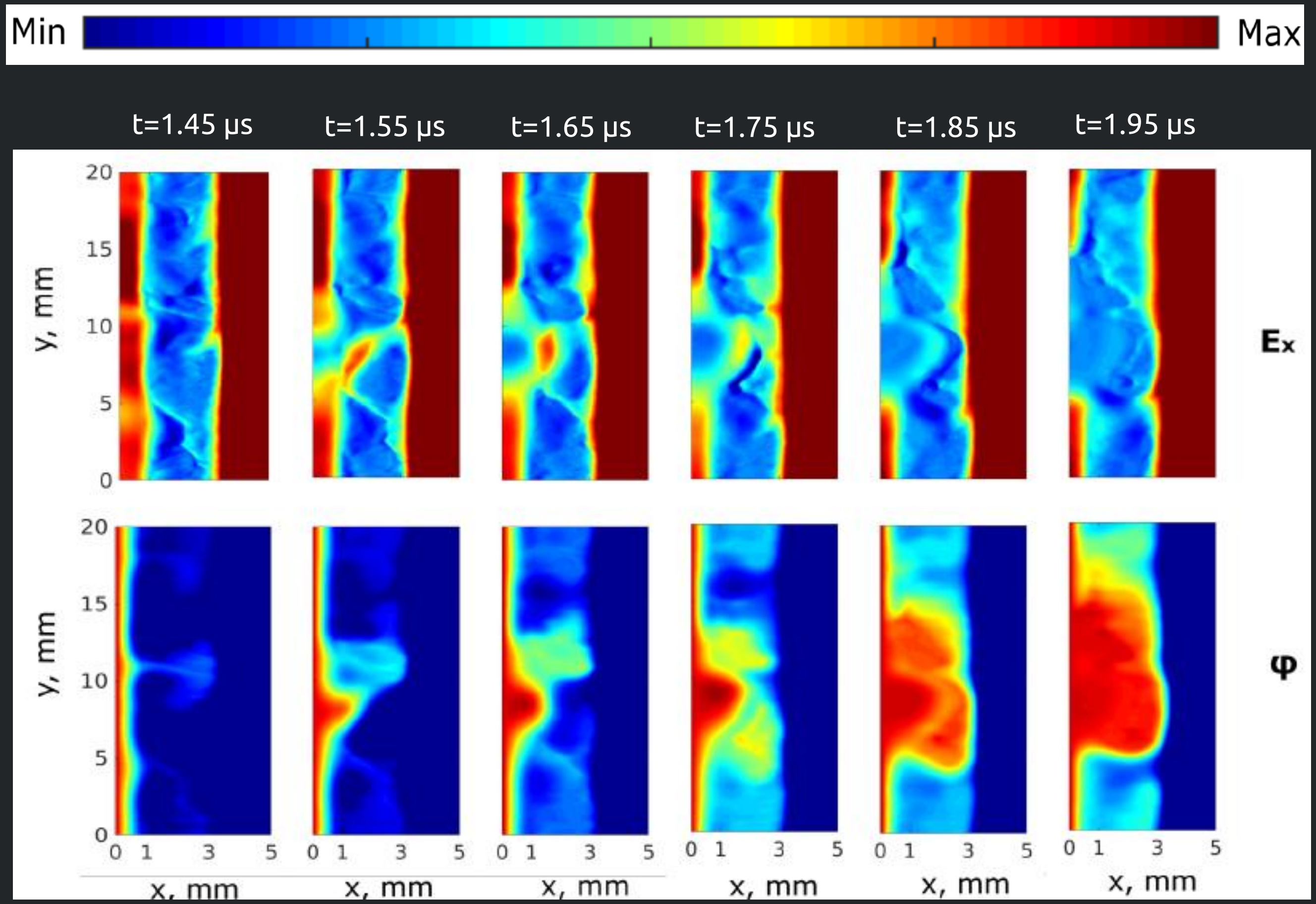


Fig. 2D PIC simulations show how the m=1 lower hybrid mode evolving into the spoke 'potential hump' with uniform B_z=40mT (anode: x=0; cathode: x=5mm, anode voltage U=200V).

Acknowledgments

The author A. Smolyakov was supported in part by NSERC Canada and the Air Force Office of Scientific Research FA9550-15-1-0226. Other authors have been supported by the German Science Foundation (DFG) within the SFB-TR 87 project framework.