Stability Analysis of Magnetized Plasma Flows For Space Propulsion

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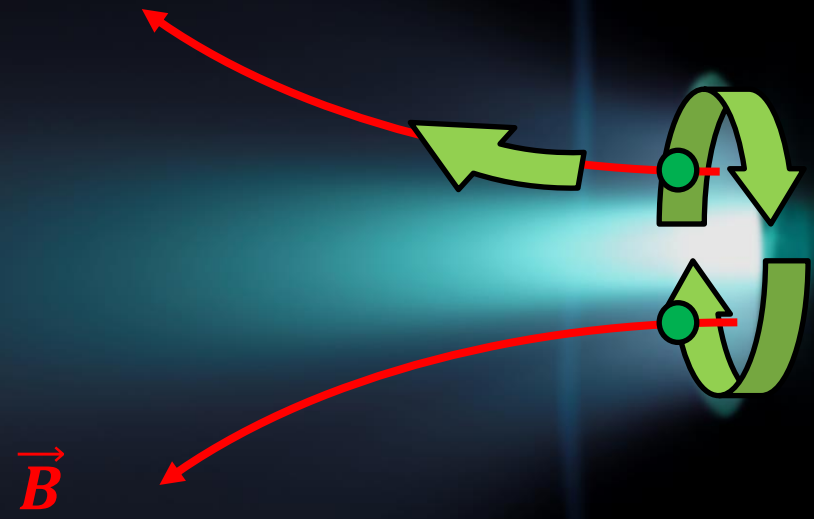
Supervisors: Mario Merino, Eduardo Ahedo

Doctoral Meetings 2025 - PhD in Aerospace Engineering

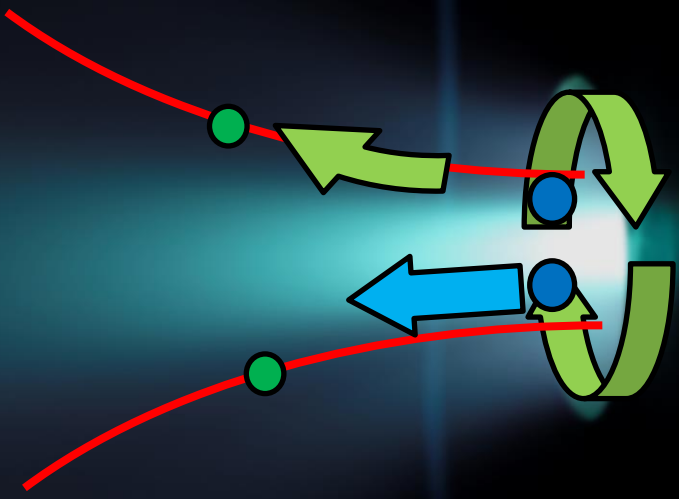
Instabilities in Magnetic Nozzles

- Acceleration Devices of EPTs
- Partially magnetized $E \times B$ plasmas
- Magnetized Electrons



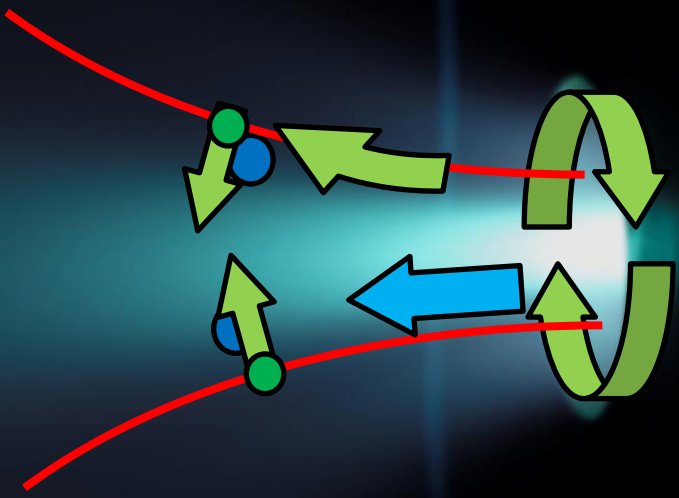
Instabilities in Magnetic Nozzles

- Acceleration Devices of EPTs
- Partially magnetized $E \times B$ plasmas
- Magnetized Electrons
- Weakly magnetized Ions

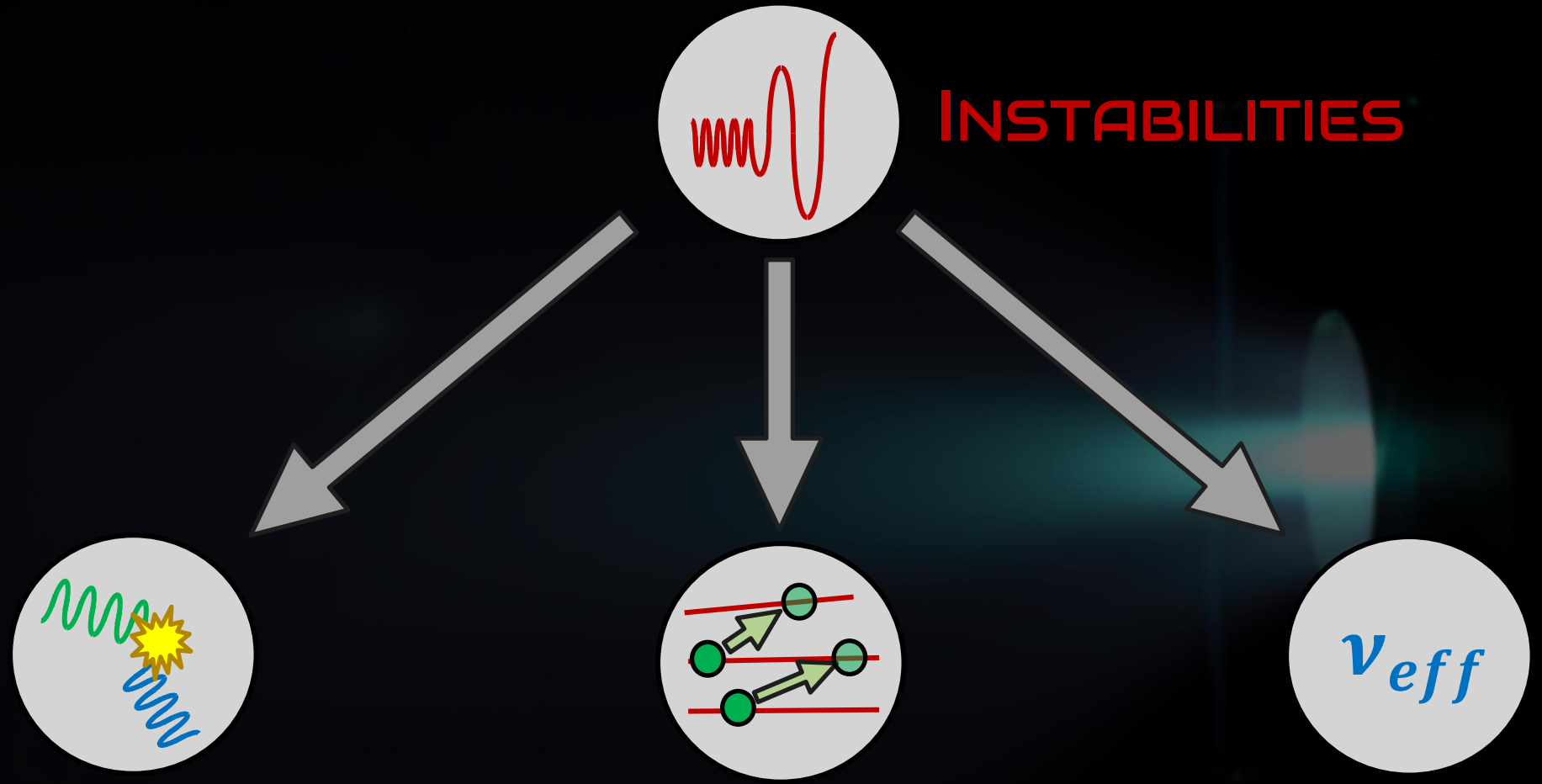


Oscillations in Magnetic Nozzles

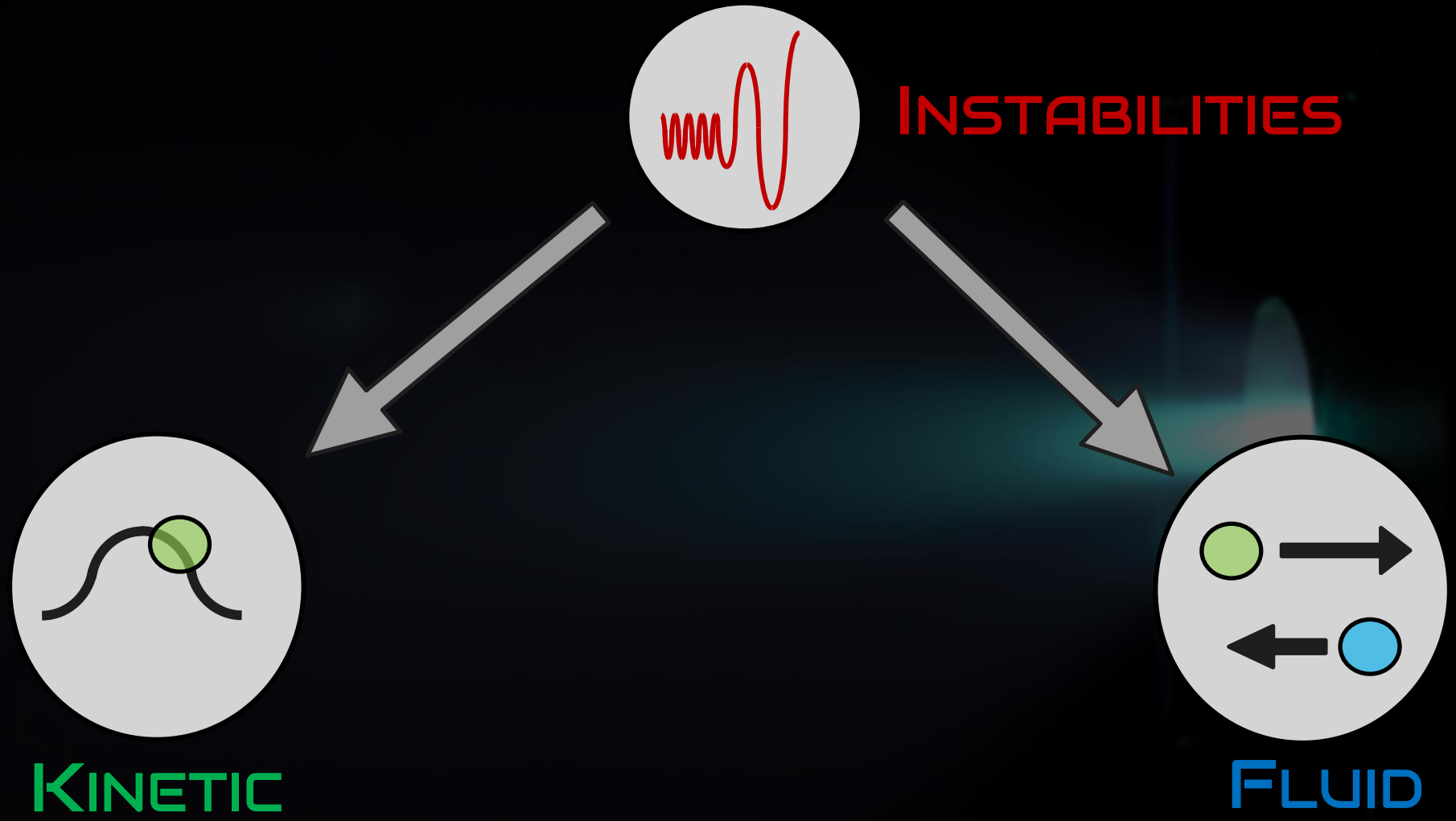
- Acceleration Devices of EPTs
- Partially magnetized $E \times B$ plasmas
- Magnetized Electrons
- Unmagnetized Ions
- Cross-Field Transport
  - Collisions, Instabilities



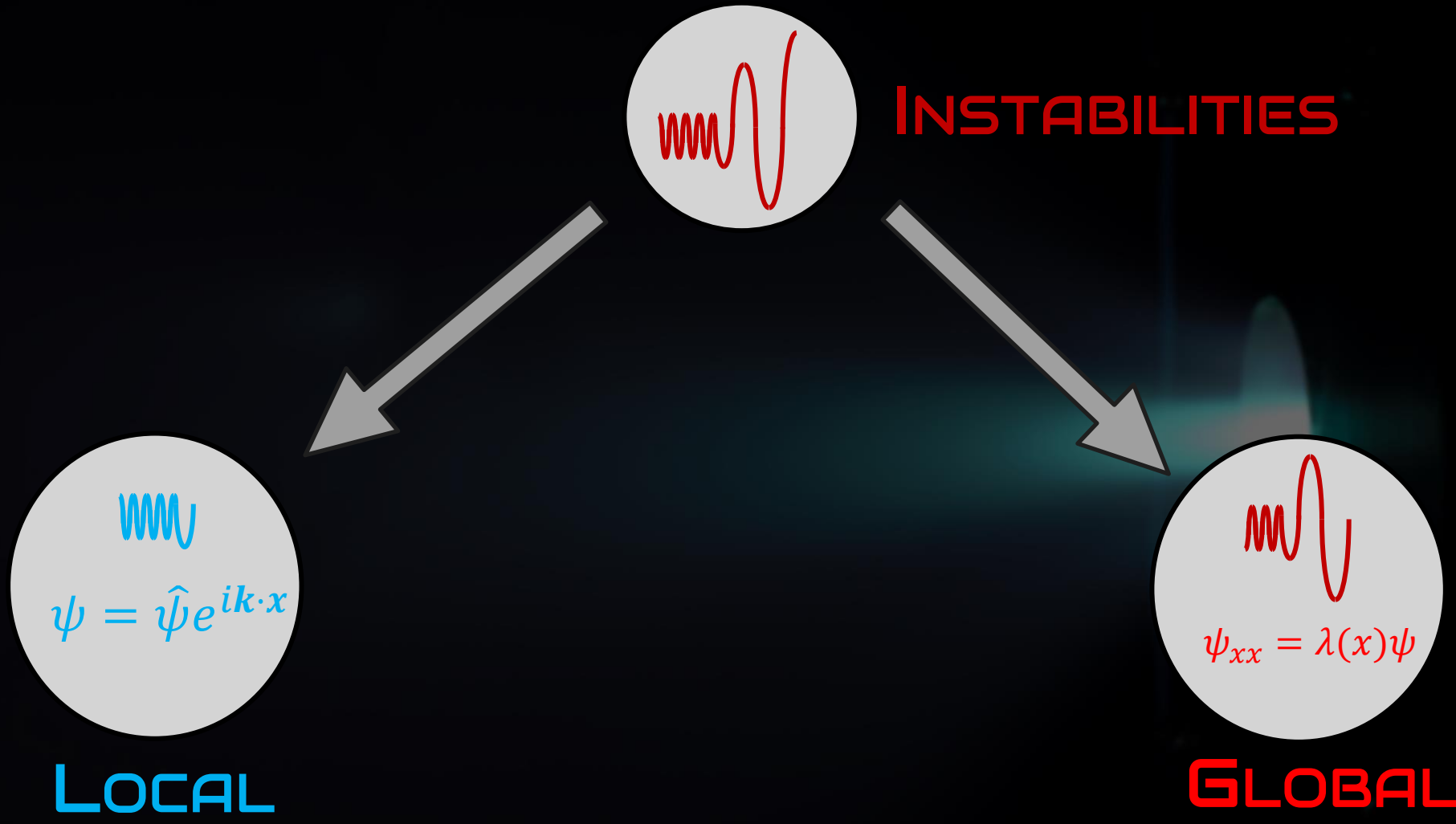
Instabilities in Magnetic Nozzles



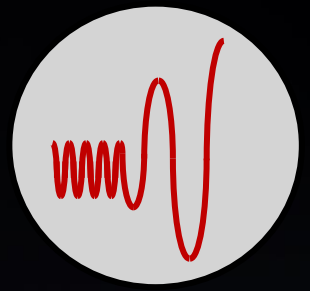
Drift-Driven Instabilities



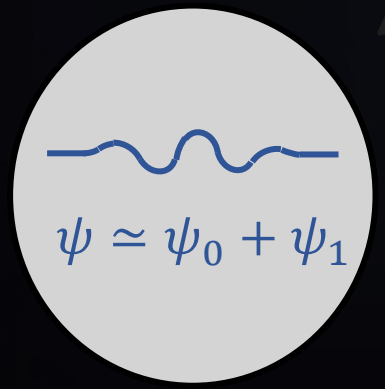
Drift-Driven Instabilities



Drift-Driven Instabilities



Instabilities

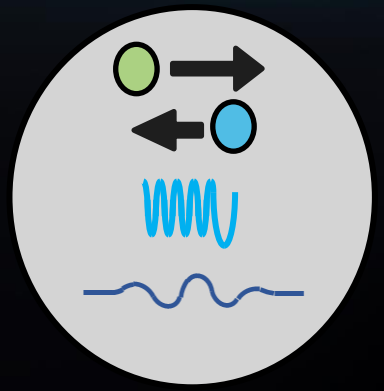


Linear

Non-Linear

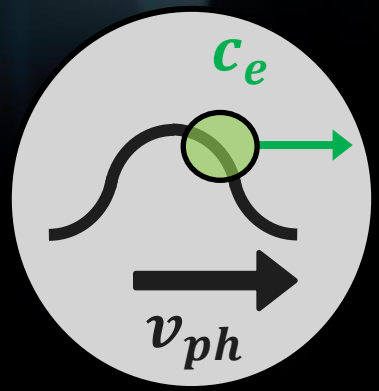
1° Step:

Fluid Local Linear Analysis



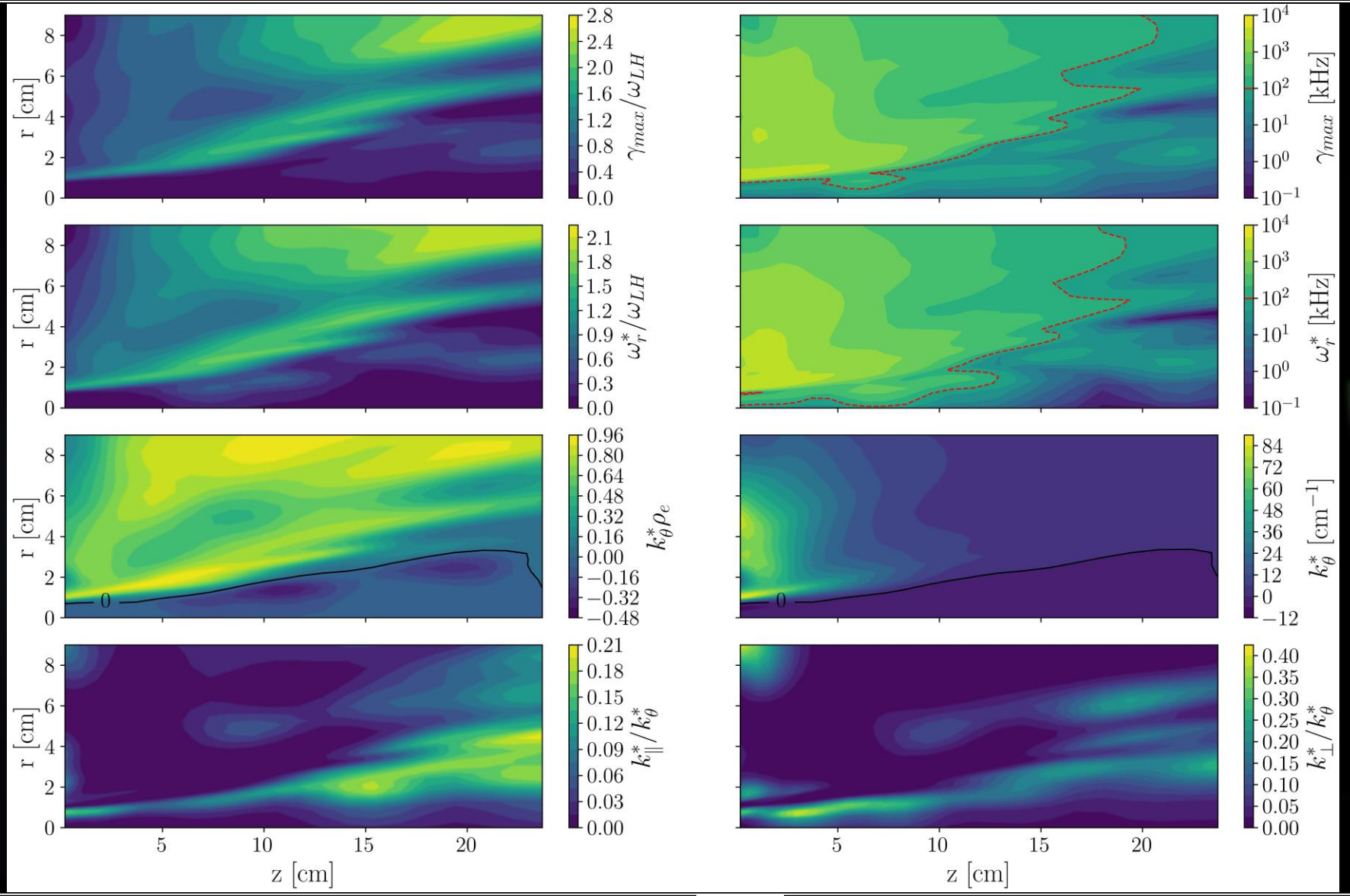
Fluid Local Linear Analysis

- Reduced complexity
- Long wavelength $k\rho_e < 1$
- Large parallel phase velocty $\left|\frac{\omega}{k_\parallel}\right| > c_e$



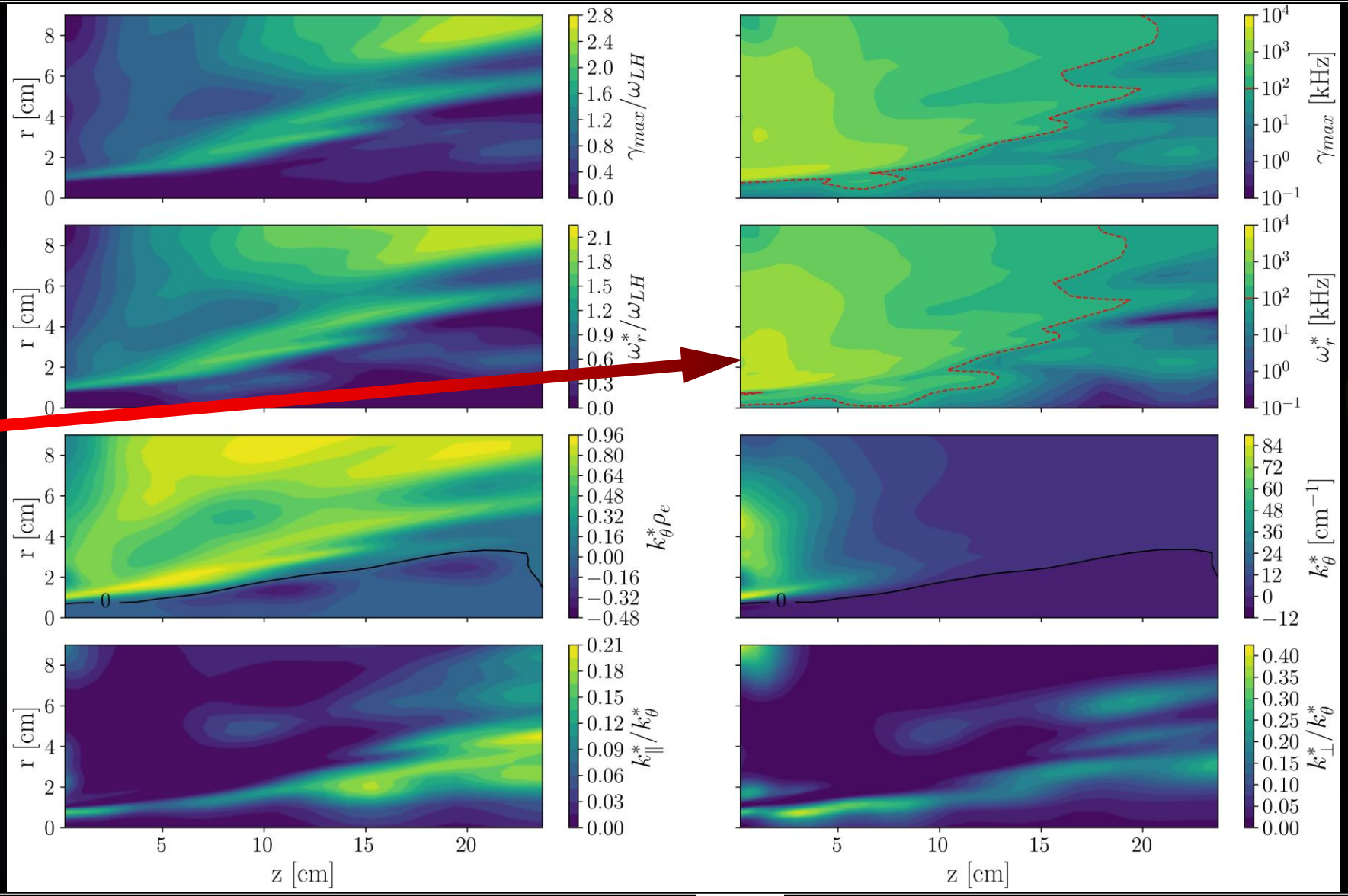
Fluid Local Linear Analysis

- Applied model to a Magnetic Nozzle



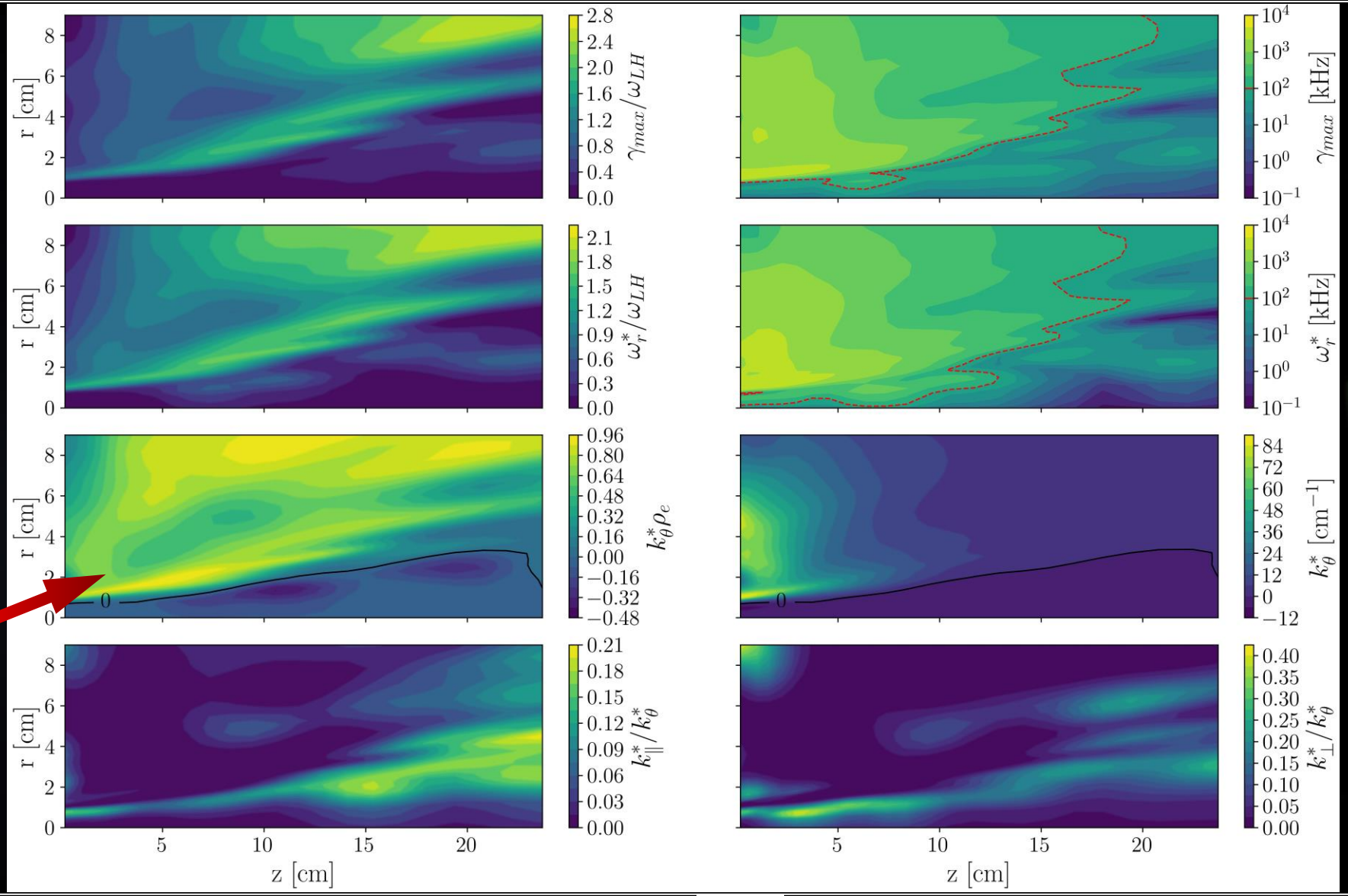
Fluid Local Linear Analysis

- Applied model to a Magnetic Nozzle
  - 100 kHz – 1 MHz



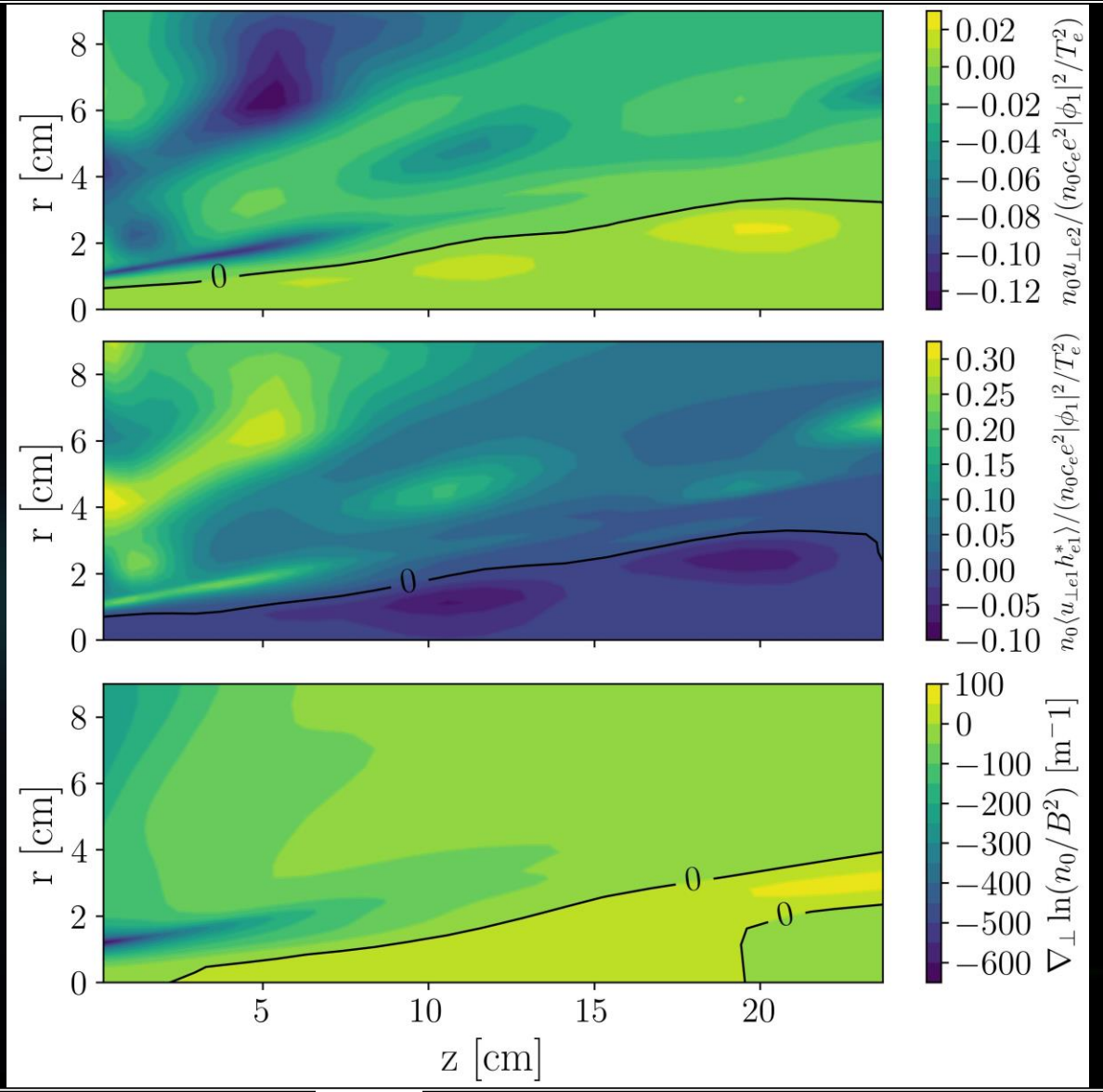
Fluid Local Linear Analysis

- Applied model to a Magnetic Nozzle
  - 100 kHz – 1 MHz
  - Mainly aziumthal waves



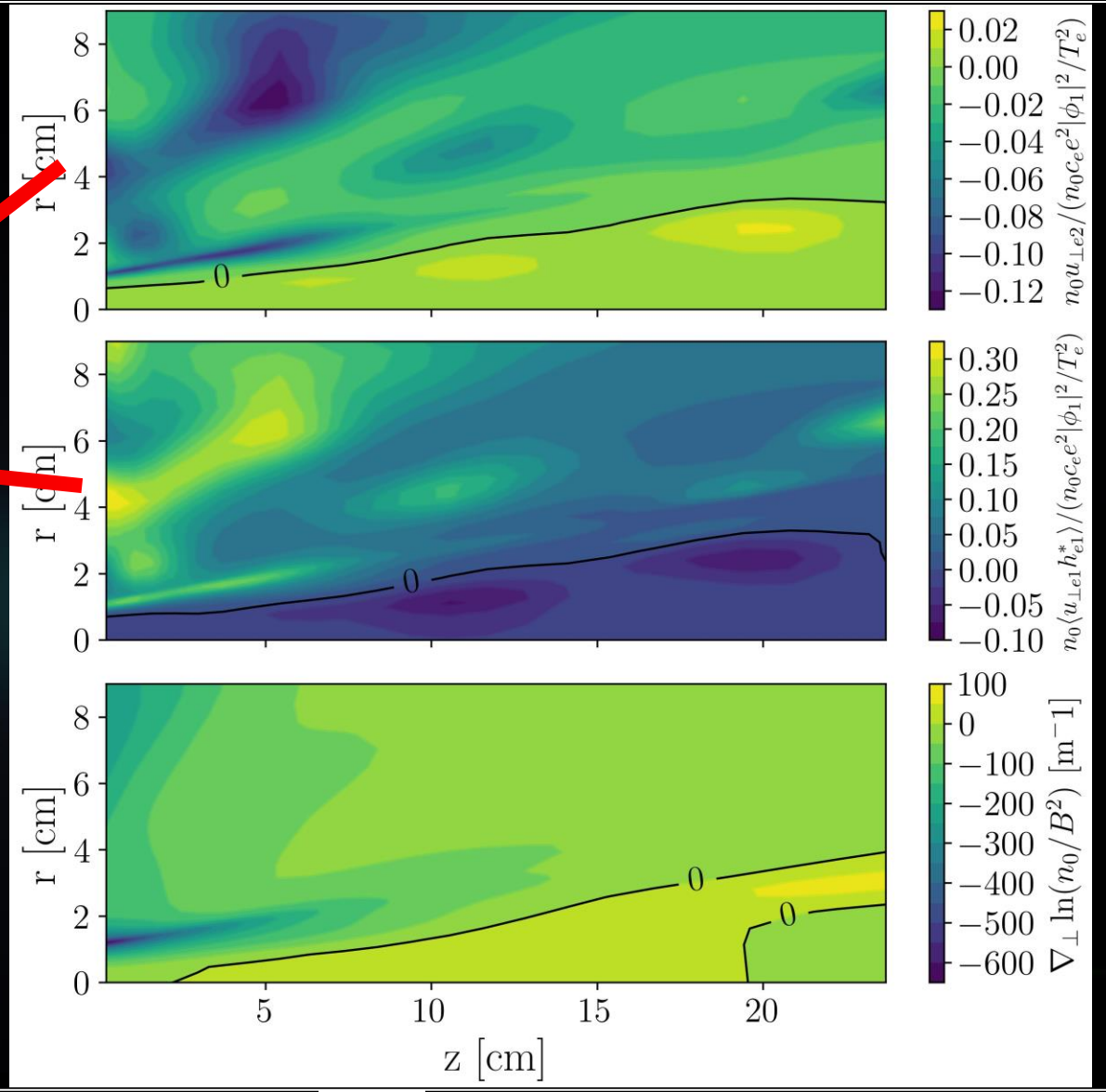
Fluid Local Linear Analysis

- Applied model to a Magnetic Nozzle
- Effect of instabilities on quasilinear transport



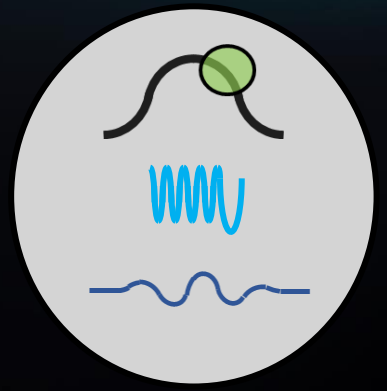
Fluid Local Linear Analysis

- Applied model to a Magnetic Nozzle
- Effect of instabilities on quasilinear transport
  - Outward electron flux



1.5° Step:

Kinetic Local Linear Analysis



Kinetic Local Linear Analysis

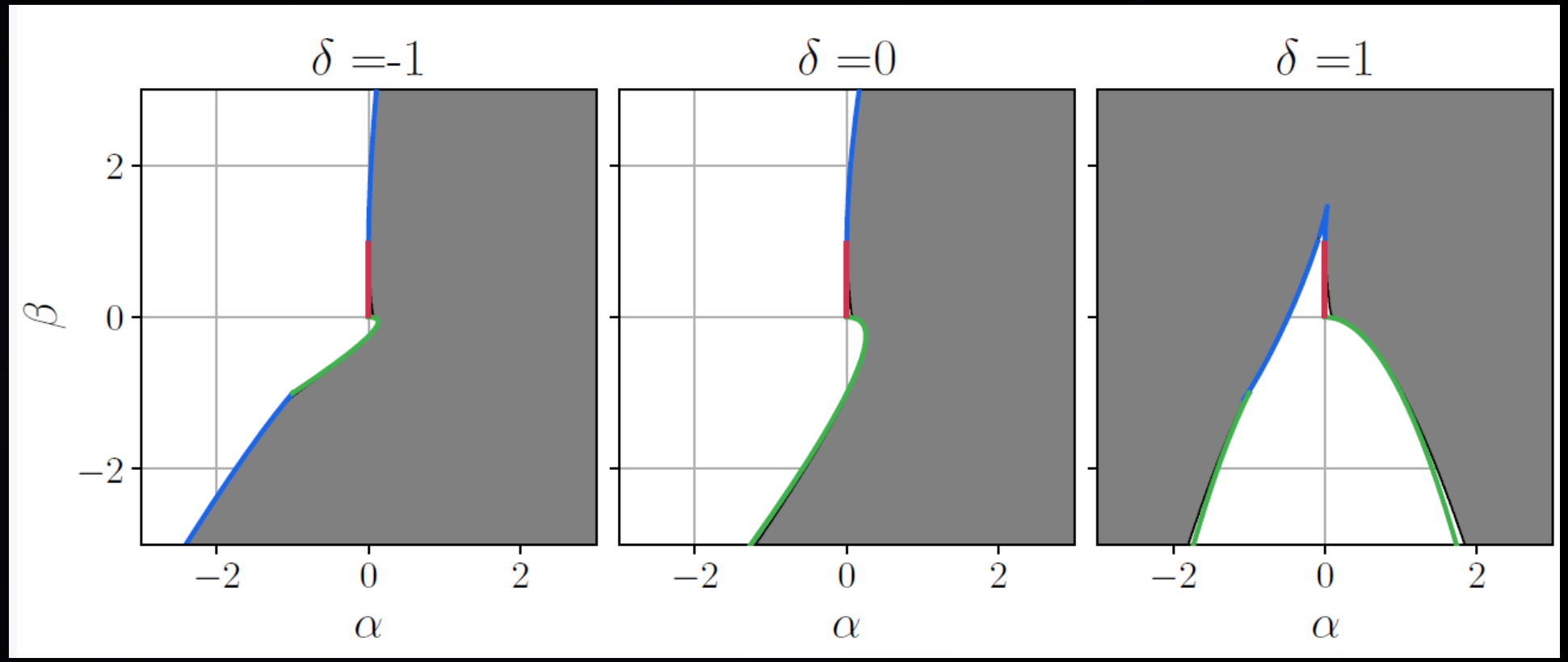
- Fluid ions
  - $\frac{\partial n_i}{\partial t} + \nabla \cdot (n_i \boldsymbol{u}_i) = 0$
  - $\frac{\partial \boldsymbol{u}_i}{\partial t} + (\boldsymbol{u}_i \cdot \nabla)\boldsymbol{u}_i = -e\nabla\phi$

- Drift-Kinetic Electrons
  - $\frac{\partial f_e}{\partial t} + \left(\boldsymbol{u}_E - \frac{m_e w_\perp^2}{2eB}\boldsymbol{e}_x \times \nabla \ln B\right) \cdot \nabla f_e - \frac{w_\perp}{2}(\nabla \cdot \boldsymbol{u}_e)\frac{\partial f_e}{\partial w_\perp} = 0$

- Dependence on 3 parameters:
  - $\alpha = \alpha(\nabla B, \nabla n)$ $\beta = \beta(\nabla B, \nabla T)$ $\delta = \delta(\nabla B, \nabla \phi)$

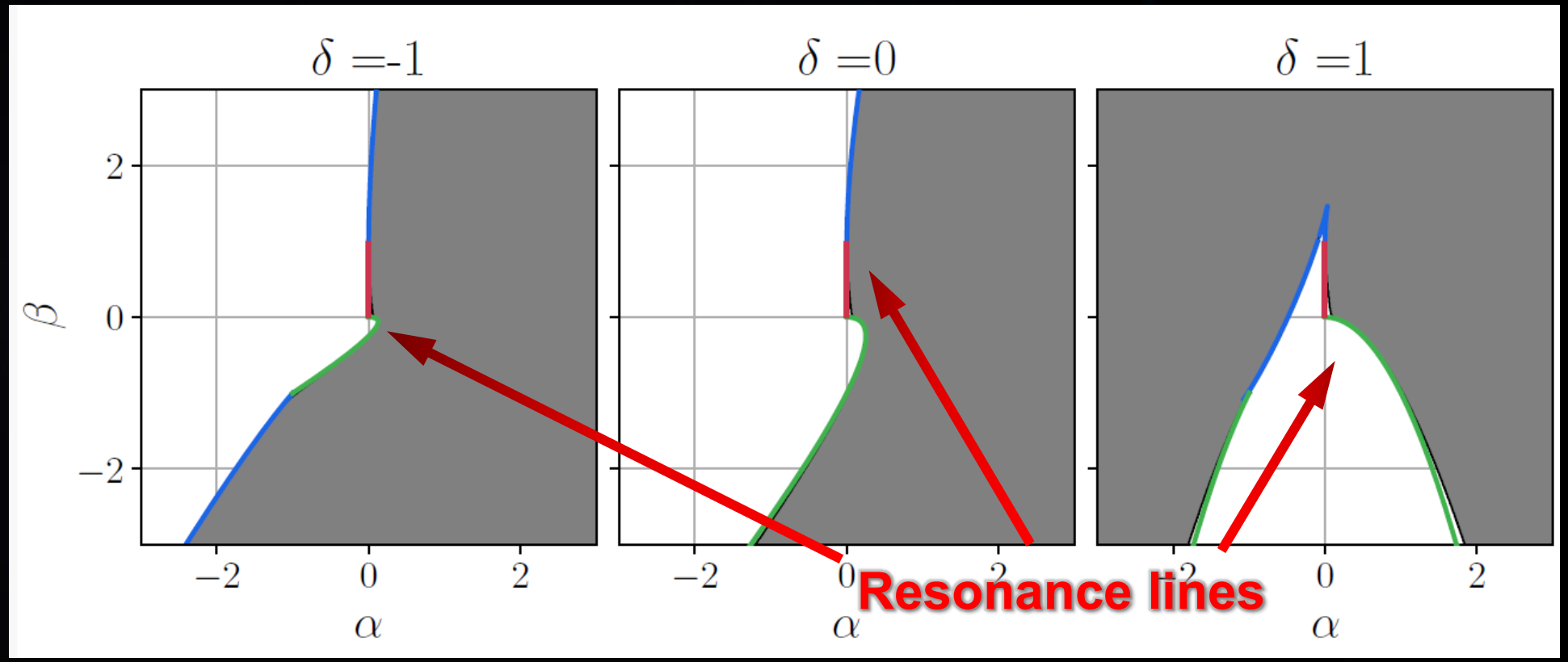
Kinetic Local Linear Analysis

- More comples marginal stability thresholds



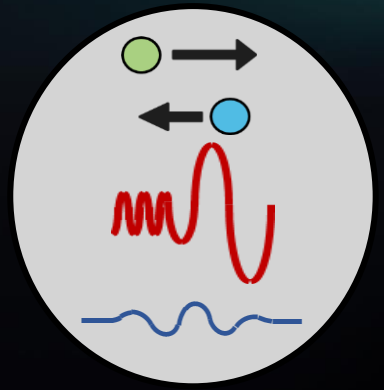
Kinetic Local Linear Analysis

- More comples marginal stability thresholds



1.75° Step:

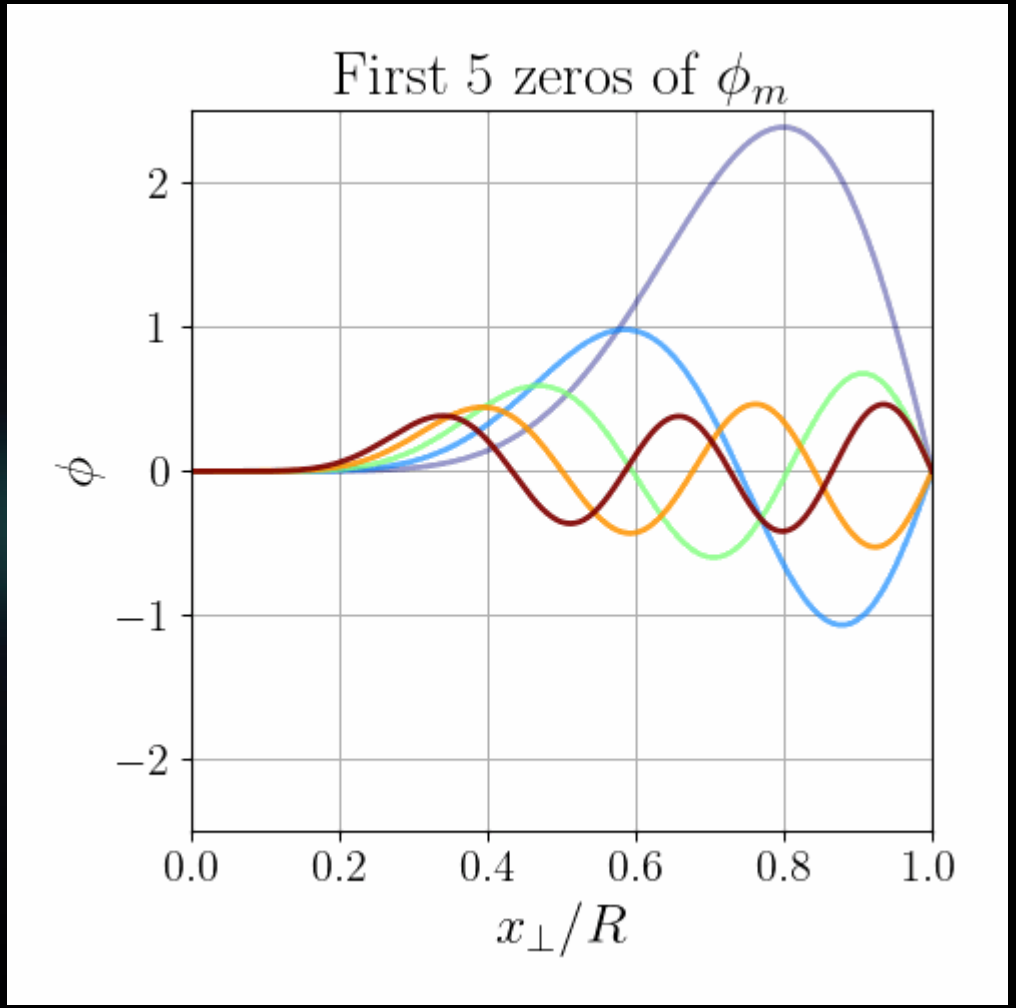
Fluid Global Linear Analysis



Fluid Global Linear Analysis

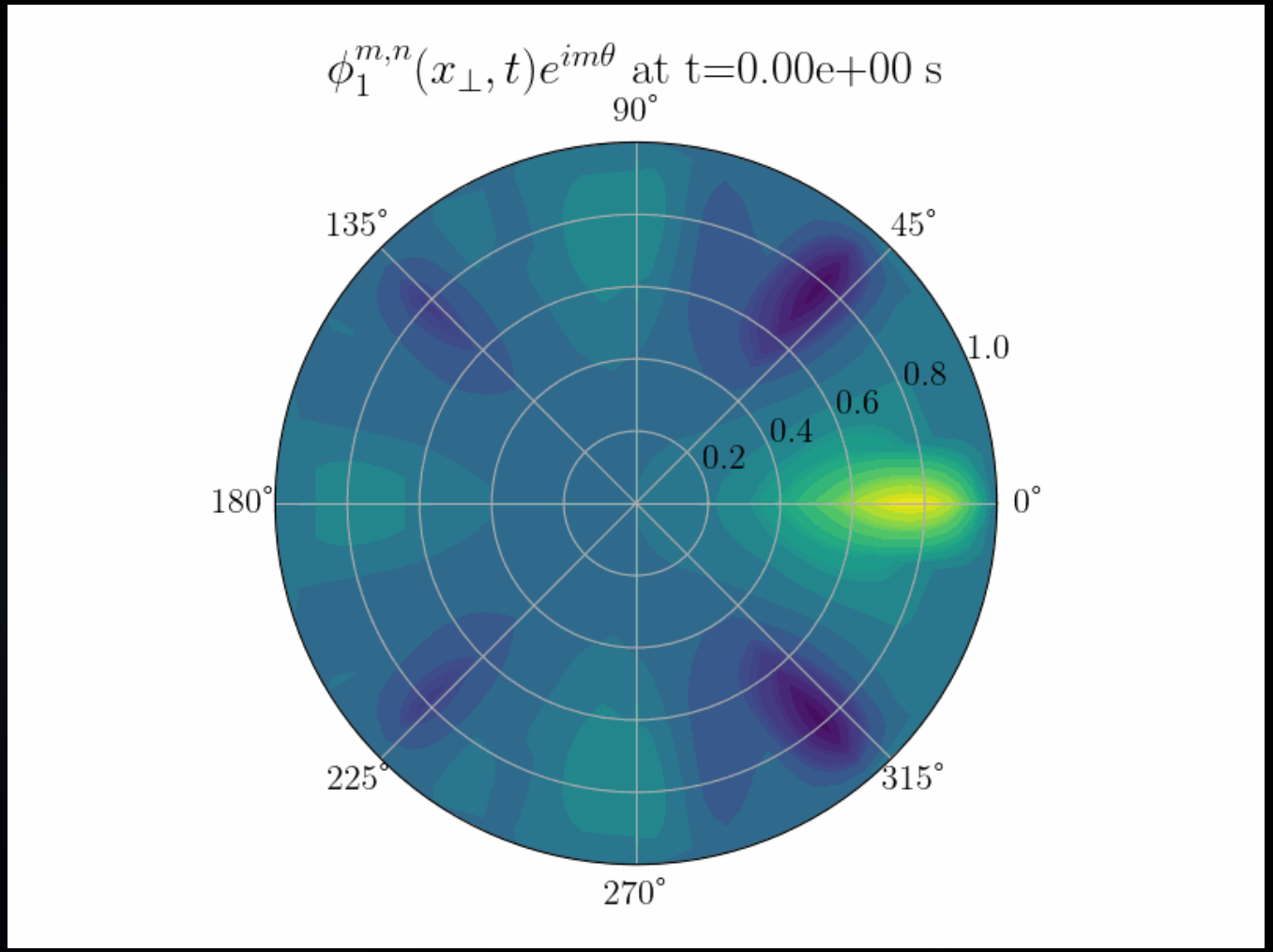
- Find Eigenfunctions
  - $(\nabla_{\perp}^2 + \nabla_{\parallel}^2)\psi = -k^2(x_{\perp}, x_{\parallel}, \omega, m)\psi$
- Plasma column
  - Gaussian $n_0(r)$
  - Parabolic $\phi_0(r)$
  - ϕ_m is the superposition of **Kummer**'s Functions

$m = 7$



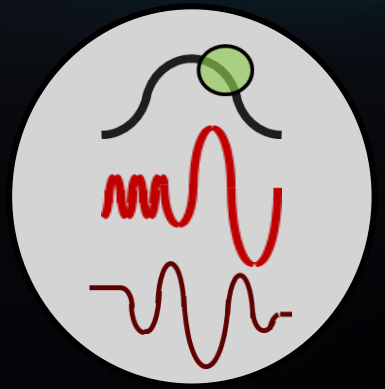
Fluid Global Linear Analysis

- Plasma column
  - Gaussian $n_0(r)$
  - Parabolic $\phi_0(r)$



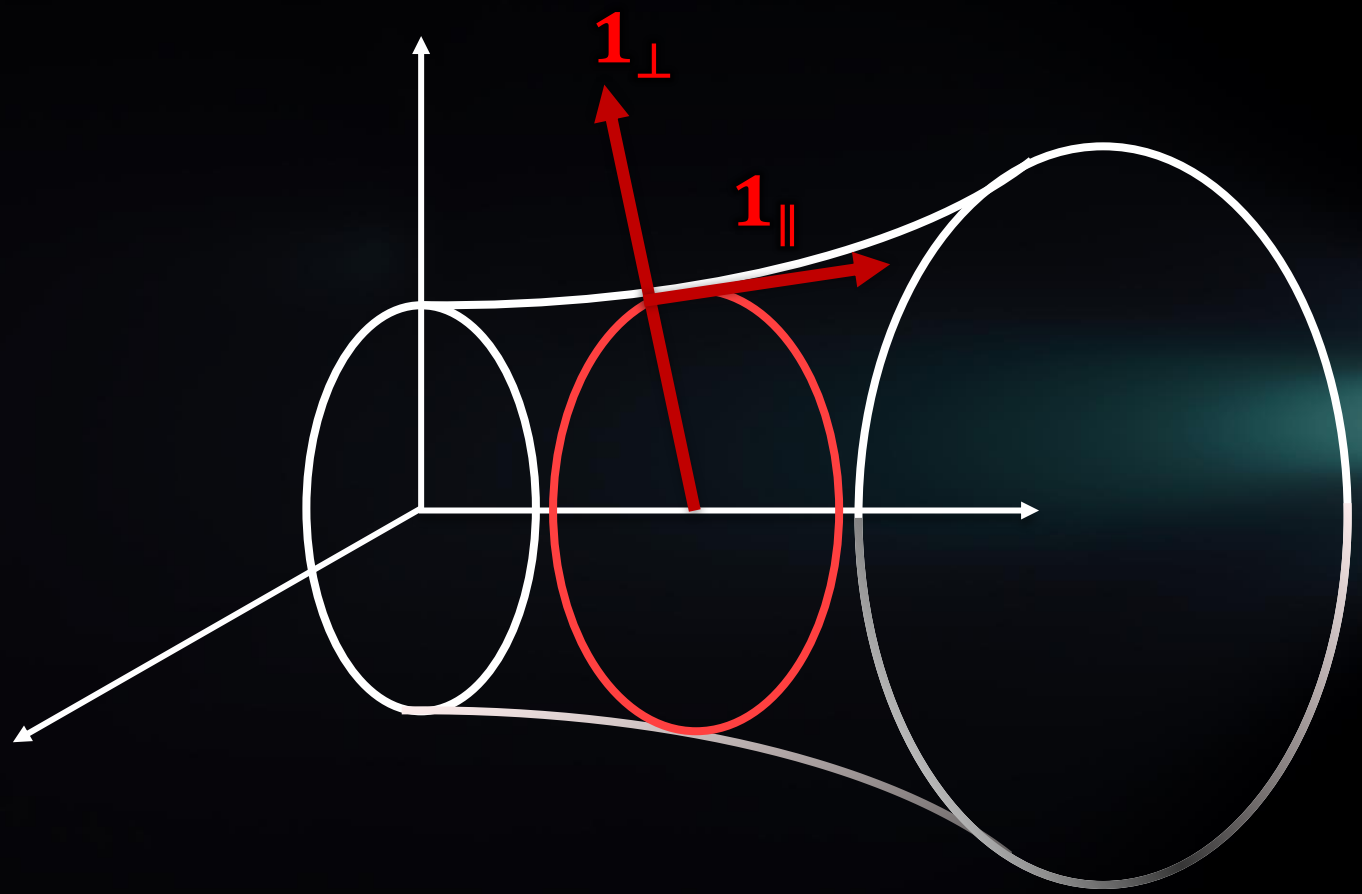
2° Step:

Kinetic Global Non-Linear Analysis



Kinetic Global Non-Linear Analysis

- Extension to 3D of in-house PIC model



Kinetic Global Non-Linear Analysis

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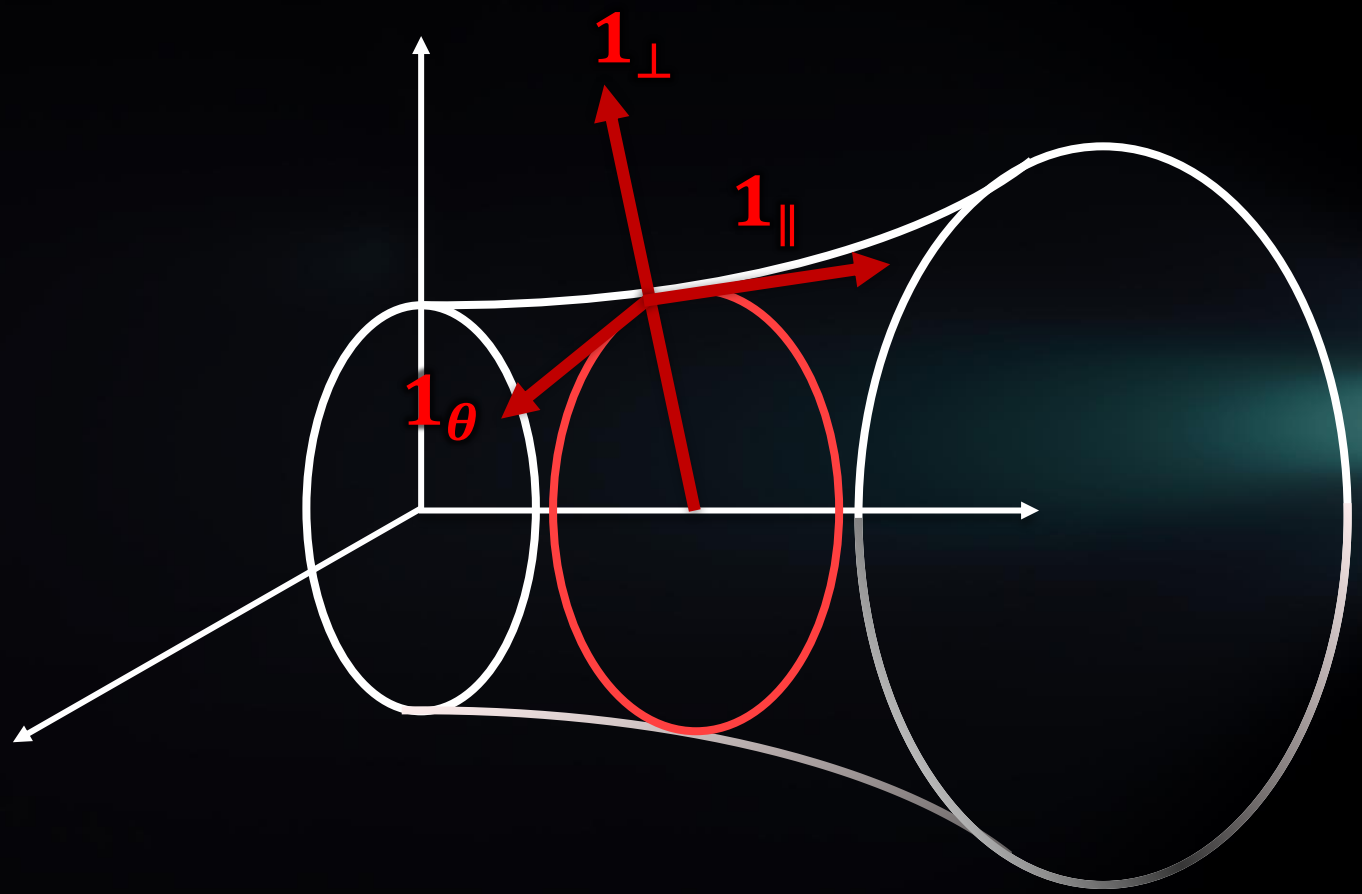

Kinetic Global Non-Linear Analysis

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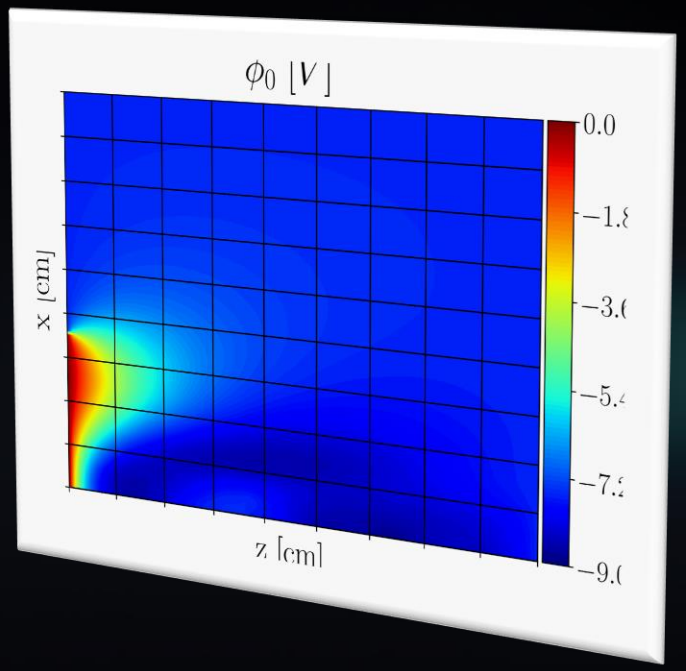

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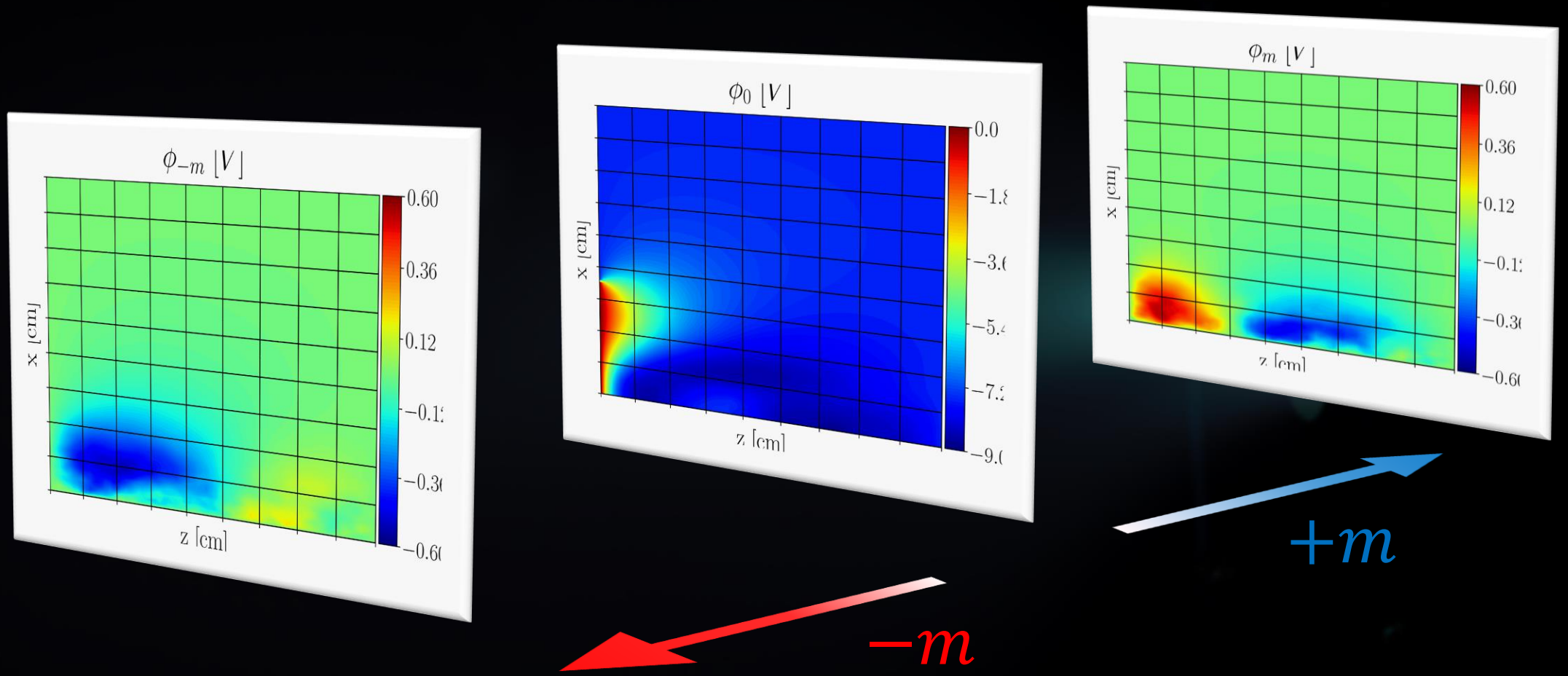

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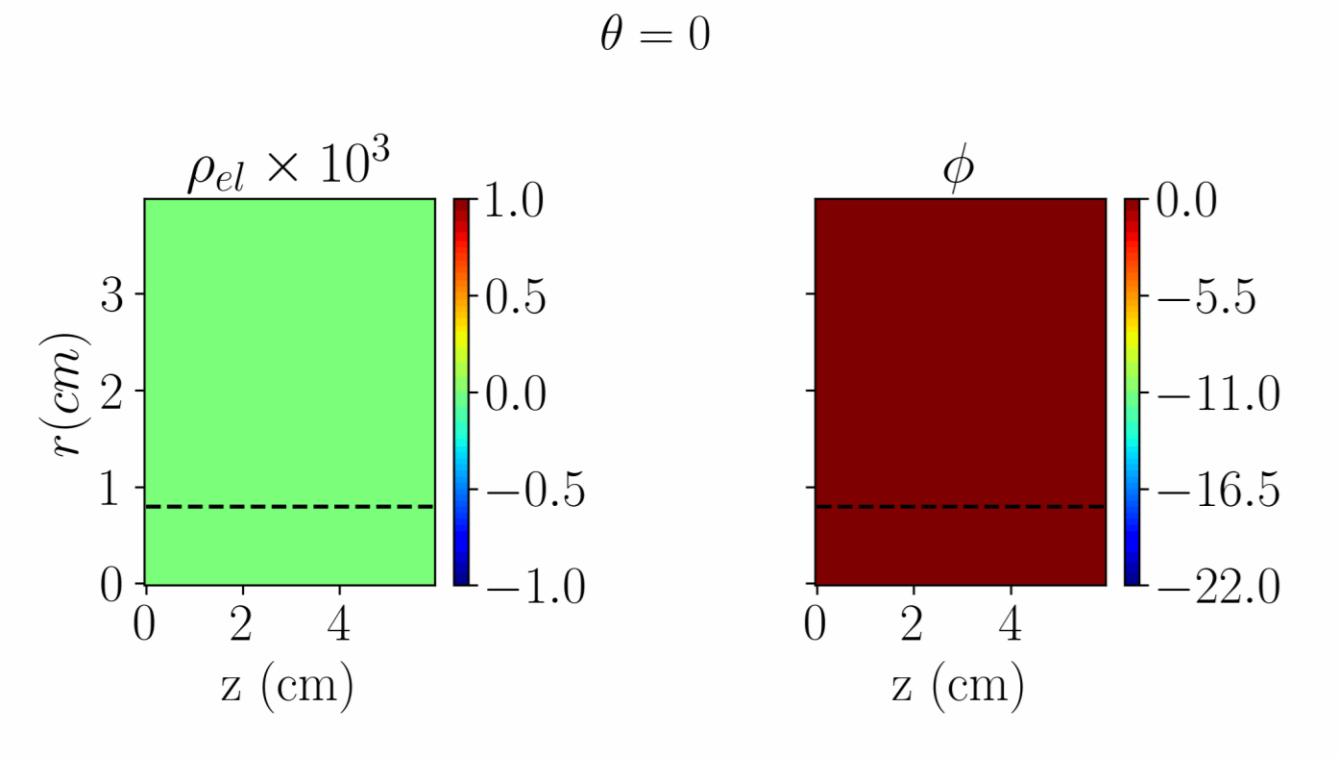

Kinetic Global Non-Linear Analysis

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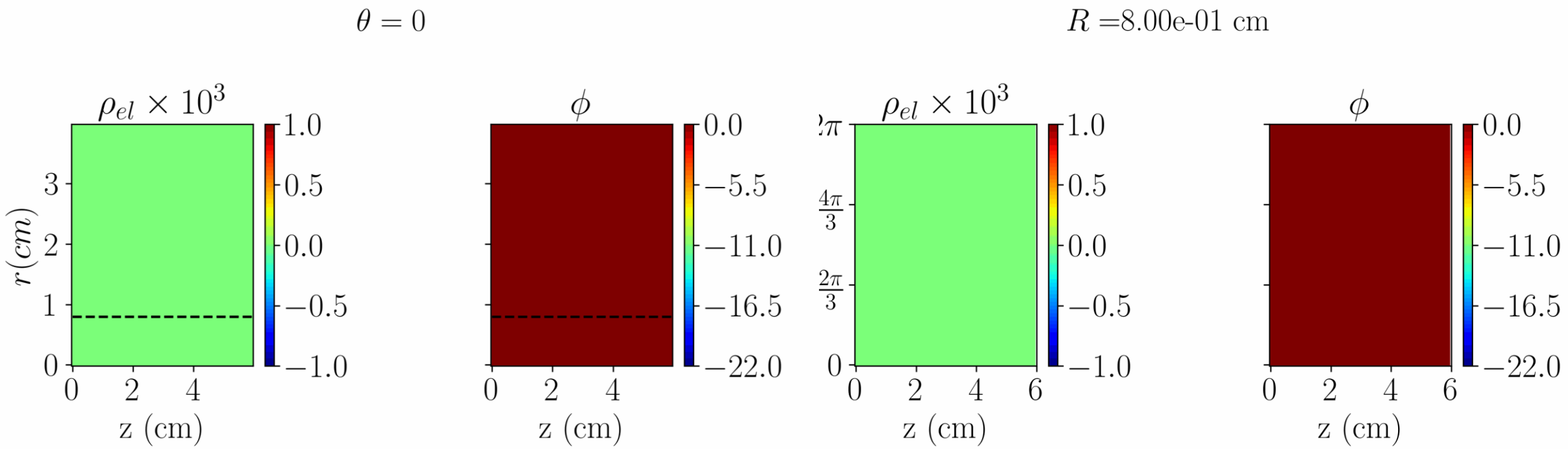

Achievements

- Journal papers
  - Published:
    -
  - Under review:
    - *Local Analysis of Lower-Hybrid Drift Instabilities in a magnetic nozzle*, Physics of Plasmas
  - To be sent:
    - Collaboration with J.J. Ramos, *Kinetic Effects on Drift Gradient modes in Hall Thrusters*

- Conferences:
  - *Analysis of Drift Instabilities in Magnetic Nozzles*, 39° IEPC, Tolouse, France

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- Dissemination:
  - *Pintura Acustica: Convertir Imagenes en Musica*, Semana de la Ciencia 2024

- Athletic Achievements:
  - Navier-Stokes City, Liga interna de Futbol Sala 2024/2025

Acknowledgments

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Thank you!

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Extra Slides