NONLINEAR DYNAMICS OF NONNEUTRAL PLASMAS

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WHAT IS PLASMA?

Neutral plasma: \[ \sum Q_i = 0 \]

Nonneutral plasma: \[ \sum Q_i \neq 0 \]
1) EXPERIMENTS AND THEORETICAL MODELIZATION OF RADIOFREQUENCY GENERATION TECHNIQUE AND PLASMA DYNAMICS UNDER RF EXCITATION

2) FLUID INSTABILITIES AND COHERENT STRUCTURES IN NONNEUTRAL PLASMAS (E.G. DIOCOTRON WAVES AND THEIR DECAY)
PLASMA CONFINEMENT PRINCIPLE

→ Cyclotron and E×B drift single particle orbit

$\nu_{ExB} \ll \nu_{lon} \ll \nu_{cyc}$
ELTRAP

- $L < 1 \text{ m}$
- $\varnothing = 90 \text{ mm}$
- $B < 0.2 \text{ T}$
- $V_{\text{con}} = \pm 100 \text{ V}$
- $p \approx 10^{-8} \text{ mbar}$
- $T \approx 300 \text{ K}$
PLASMA FORMATION

Radiofrequency excitation
- $\nu_{RF} \sim$ MHz
- $V_{pp} \sim$ V
- Excitation time $\sim$ s

Electron plasma
- $n_e \sim 10^6$ cm$^{-3}$
- $Q \sim 10^2$ pC
- $T_{||} \sim$ eV
- $N_i/N_e < 0.1$
RF GENERATION SYSTEMATIC ANALYSIS
1D SINGLE PARTICLE HEATING MODEL

\[ e_{n+1} = e_n \]
\[ \phi_{n+1} = \phi_n + 4M / e_{n+1}^{1/2} \mod (2\pi) \]
\[ e_{n+1} = e_n - \sin(\phi_n + \phi_n') + \sin(\phi_n + \phi_n' + 2i\phi_n'') \]
\[ \phi_{n+1} = \phi_n + \phi_n' + 2i\phi_n'' + 2M / e_{n+1}^{1/2} \mod (2\pi) \]

with \[ e_n = E_n / V_1, \quad M = L_1 v / \sqrt{2V_1 / m} \]
<table>
<thead>
<tr>
<th><strong>2D Ideal Fluid</strong></th>
<th><strong>2D Electron Plasma</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>$\frac{\partial \zeta}{\partial t} + \mathbf{v} \cdot \nabla \zeta = 0$</td>
<td>$\frac{\partial n}{\partial t} + \mathbf{v} \cdot \nabla n = 0$</td>
</tr>
<tr>
<td>$\nabla^2 \psi = \zeta$</td>
<td>$\nabla^2 \phi = 4\pi en$</td>
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<tr>
<td>$\mathbf{v} = \mathbf{e}_z \times \nabla \psi$</td>
<td>$\mathbf{v} = \frac{\mathbf{e}_z \times \nabla \phi}{B} c$</td>
</tr>
<tr>
<td>$\zeta = (\nabla \times \mathbf{v}) \cdot \mathbf{e}_z$</td>
<td>$\zeta = \frac{c}{B} \nabla^2 \phi = \frac{4\pi ec}{B} n$</td>
</tr>
<tr>
<td>$\psi(\text{wall}) = \text{constant}$</td>
<td>$\phi(\text{wall}) = \text{constant}$</td>
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</tbody>
</table>
FLUID STRUCTURES IN NATURE AND IN LABORATORY
DIOCOTRON MODE

\[
n_e(r, \theta, t) = n_e^0(r) + \sum_{l=-\infty}^{\infty} \delta n^l_e(r) \exp(i l \theta - i \omega t)
\]

\[
\phi(r, \theta, t) = \phi^0(r) + \sum_{l=-\infty}^{\infty} \delta \phi^l(r) \exp(i l \theta - i \omega t)
\]

\[
\Omega_l = \frac{n_e e}{2 \varepsilon_0 B} \left( l - 1 + \left( \frac{R_p}{R_w} \right)^{2l} \right)
\]
\[ \delta \phi(r = R_w, \theta, t) = \sum_{m=0}^{N_s-1} V_m(t) [H(\theta - 2m\pi / N_s) - H(\theta - 2(m+1)\pi / N_s)] \]

\[ V_m = V_d \cos \left( \omega_d t + \frac{2\pi \sigma mj}{N_s} \right) \]

- \( m = 0, \ldots, N_s - 1 \)
- \( j = 1, \ldots, N_s / 2 \)
- \( N_s = 8 \)
Complete theoretical modelization and experimental characterization of RF-generation technique and plasma dynamics (formation, stationary states, modulation, bifurcation) under RF excitation.

Systematic studies on higher diocotron mode excitation and waves decay, corroborated by pic 2D simulations, and theory development for linear and nonlinear case.

Improvement of manipulation techniques of RF generated plasma for a better control of the quantities in interest (e.g. charge and density profile) in order to have a better shot-to-shot repeatability (feedback damping technique, plasma longitudinal squeezing).

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