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Are resonance phenomena creating instabilities in the magnetic filter region in a low-temperature plasma?

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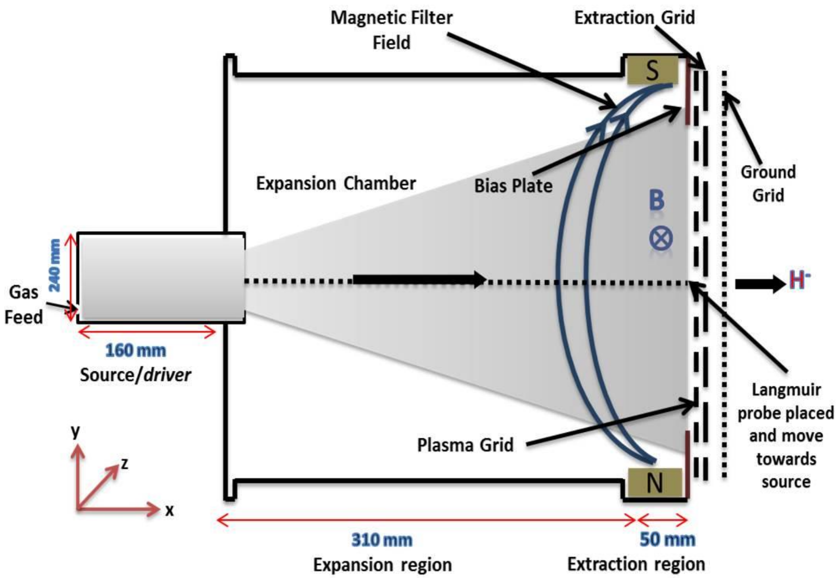
Outline

- Problem statement
- Length and time scales
- 2D-3V PIC-MCC kinetic model
- Case-studies
- Results and discussion

Problem Statement

- Plasma transport across the magnetic filter is complex to understand due to different drifts and instabilities.
- In partially magnetized plasmas, only electrons are magnetized (not ions).
- Presence of potential gradient with magnetic field, density and temperature gradients introduce drifts and instabilities in the plasma.

Motivation



- **Heating of ITER plasma by injection of neutral beam at 1 MeV.**
- **Neutral beam generated by neutralization of negative ion beam.**
- **Negative ions generated in a low temperature plasma source.**

Length and Time Scales

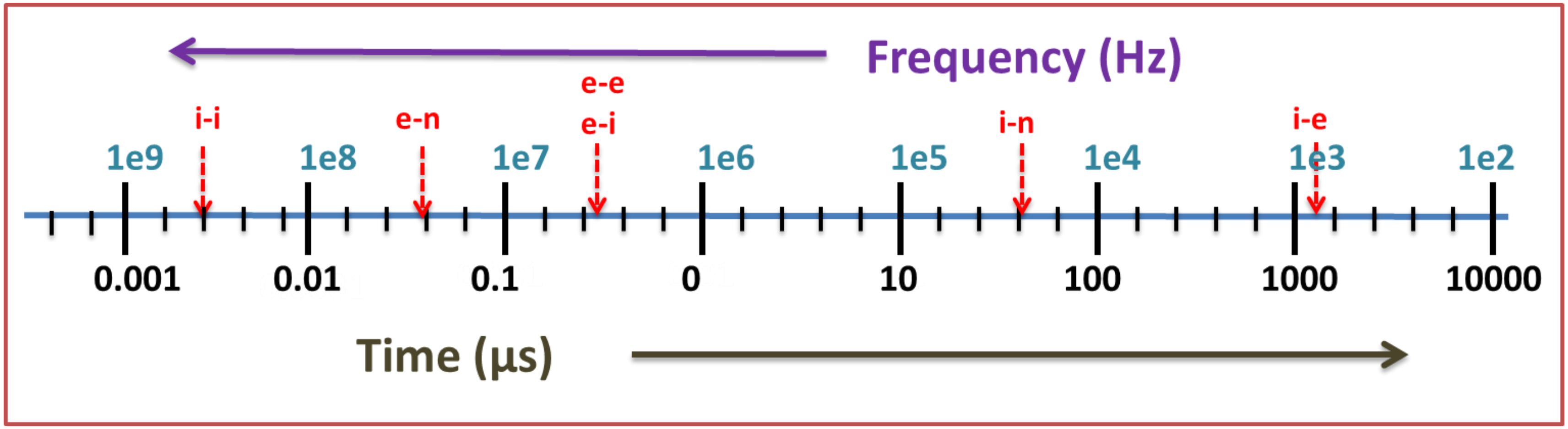
Physical parameter	Equations	Value
debye length λ_d	$(\epsilon_0 kT/n_e e^2)^{1/2}$	$7.43 \times 10^{-6} m$ (Te=1 eV) $2.35 \times 10^{-5} m$ (Te=10 eV)
electron larmor radius R_{Le}	$\frac{0.0238 T_e^{1/2}}{B}$	$3.40 \times 10^{-6} m$ (Te=1 eV) $1.08 \times 10^{-5} m$ (Te=10 eV)
ion larmor radius R_{Li}	$\frac{(1.02 \times m_i/m_p)^{1/2} Z^{-1} T_i^{1/2}}{B}$	$2.35 \times 10^{-5} m$ (B=70 Gauss, $T_i = 0.026 eV$)
Sheath thickness s	$\lambda_D (2U_b/T_e)^{1/2}$ [29]	4.70×10^{-5} m (T_e=1eV) 4.70×10^{-5} m (T_e=10eV)

Table 1. Different length scale using electron temperature Te = 10 eV, Ion temperature Ti = 0.026 eV, and B = 7 mT.

Physical parameter	Equations	Value
plasma frequency ω_p	$(n_e e^2/m\epsilon_0)^{1/2}$	5.64×10^{10} Hz
electron cyclotron frequency ω_{ce}	$\frac{eB}{m_e}$	1.231×10^9 Hz
ion cyclotron frequency ω_{ci}	$\frac{eB}{m_i}$	0.335×10^6 Hz
ele-ion Coul. colli. freq.	$2.9 \times 10^{-12} n_i ln\Lambda (kT_e/e)^{-3/2}$ [12]	Te=1 eV $2.79 \times 10^7 Hz$ Te=5 eV $2.49 \times 10^6 Hz$ Te=10 eV $8.81 \times 10^5 Hz$
ele.-neutral colli. freq.	$n_o \sigma_{en} \frac{kT_e}{m_e}^{1/2}$	Te=1 eV $6.08 \times 10^6 Hz$ Te=5 eV $1.36 \times 10^7 Hz$ Te=10 eV $1.92 \times 10^7 Hz$
ion-neutral collision frequency	$n_o \sigma_{in} \frac{kT_i}{m_i}^{1/2}$	$2.29 \times 10^4 Hz$

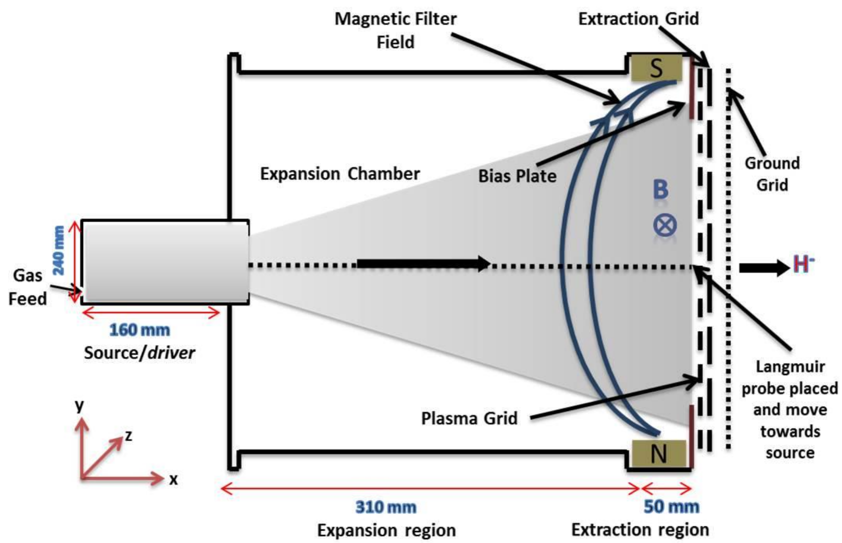
Table 2. Different time scale using electron temperature Te = 10 eV, Ion temperature Ti = 0.026 eV, and B = 7 mT. Electron and ion collision cross-section = 1.00 x 10^{-19} m^2

Time Scales

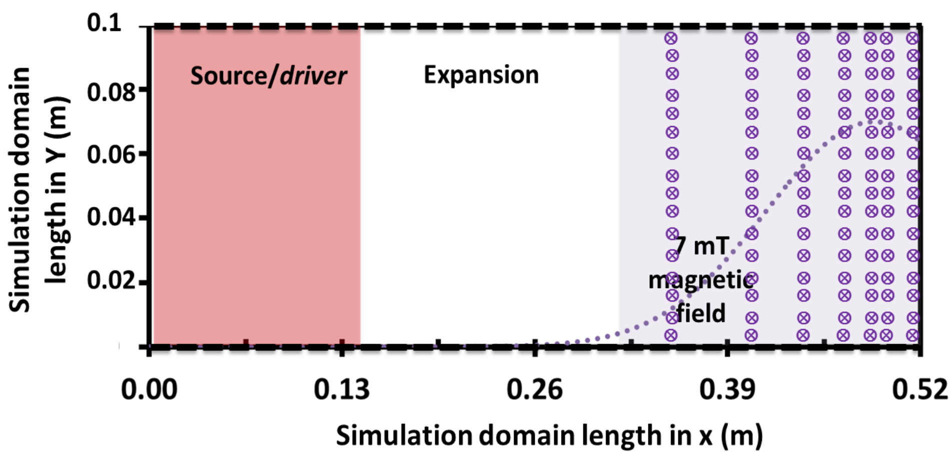

Frequency (Hz)
i-i
e-n
e-e
e-i
i-n
i-e
1e9
1e8
1e7
1e6
1e5
1e4
1e3
1e2
0.001
0.01
0.1
0
10
100
1000
10000
Time (µs)

ROBIN

(RF-Operated Beam source in INdia)[1]



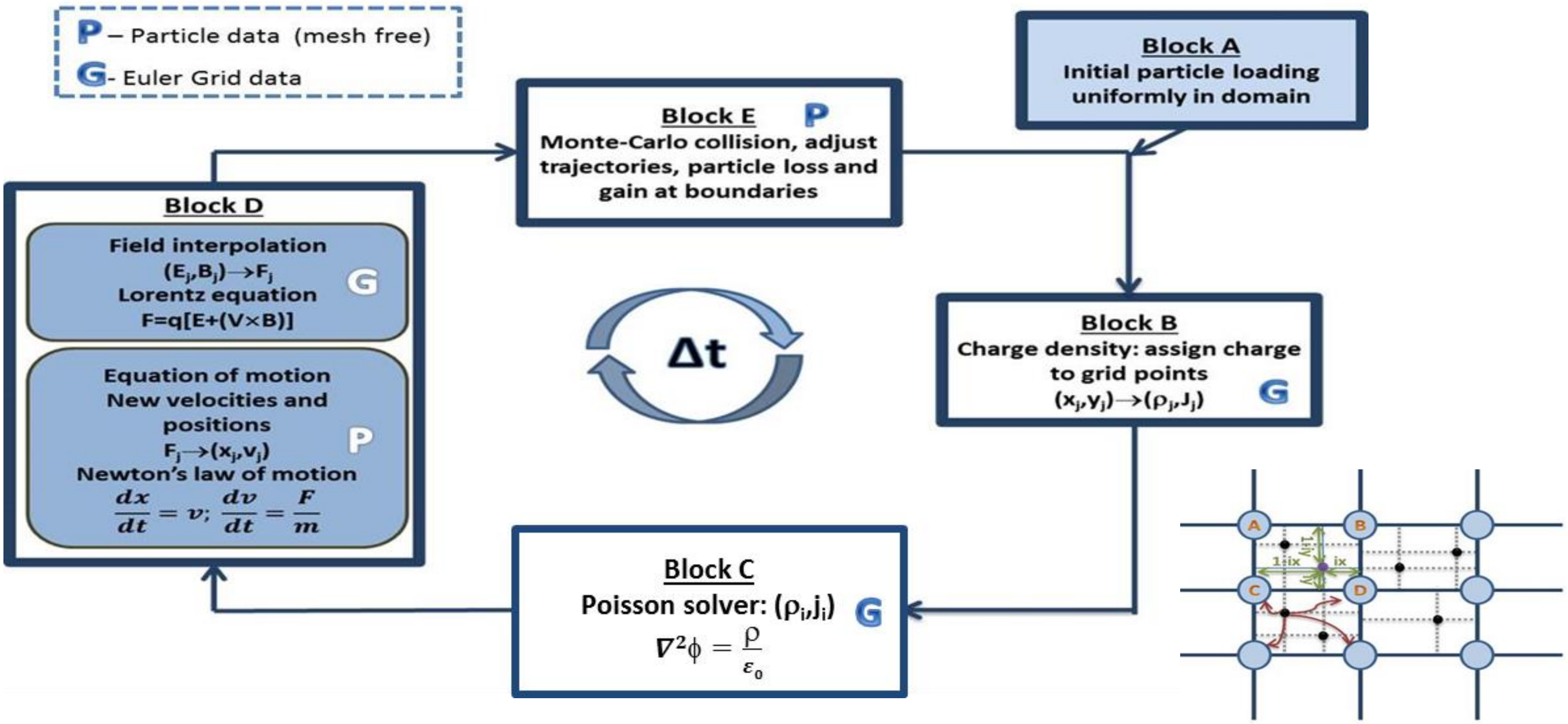
Experimental Setup



Simulation Domain

[1] G. Bansal et al., "Negative ion beam extraction in ROBIN," Fusion Eng. Des., vol. 88, no. 6–8, pp. 778–782, 2013.

2D-3V PIC-MCC kinetic model



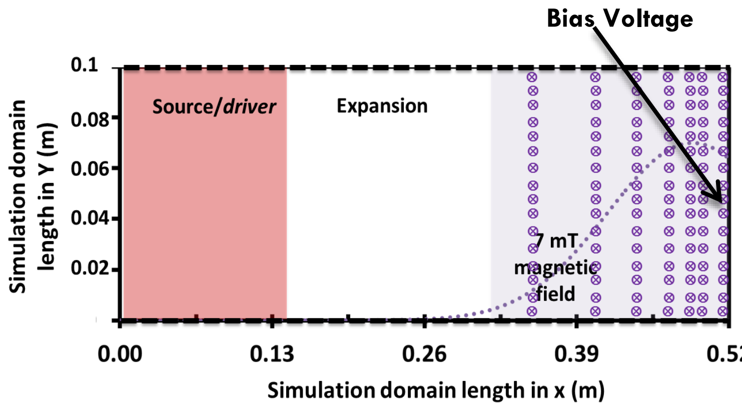
Case-studies

Case:1 B =0 mT, V_{bias} = 0V

Case:2 B =0 mT, V_{bias} = 20V

Case:3 B =7 mT, V_{bias} = 0V

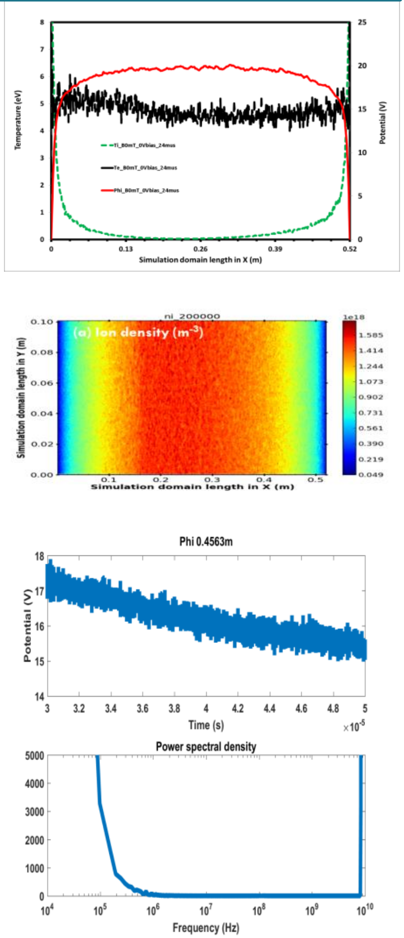
Case:4 B =7mT, V_{bias} = 20V



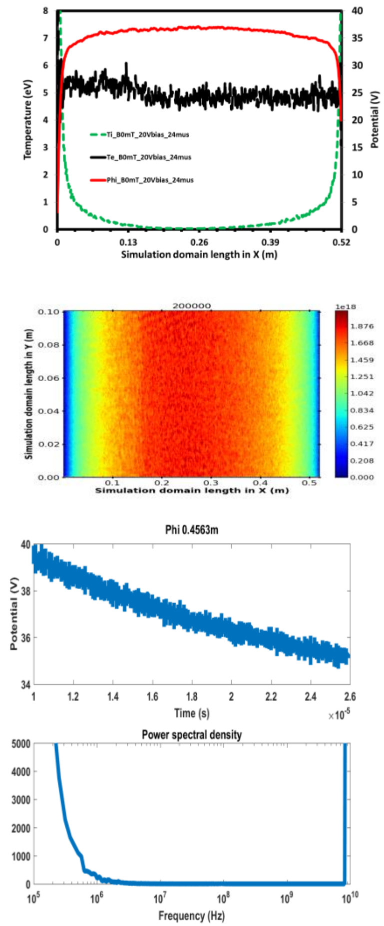
Case-studies

Changing Magnetic field and Bias voltage

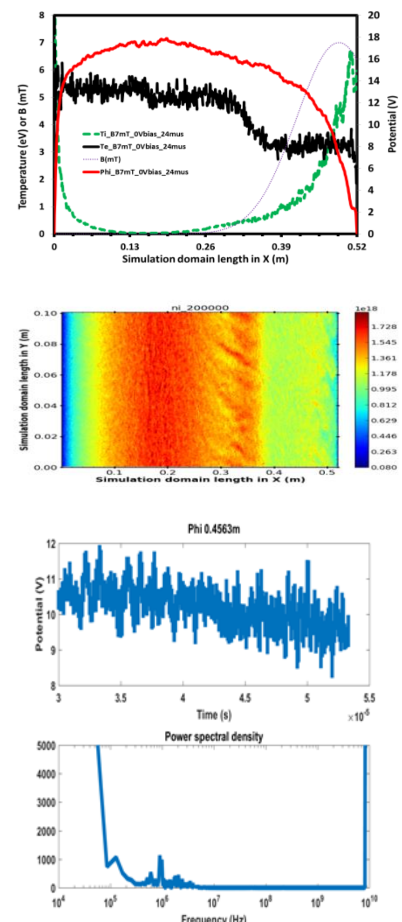
Case 1:
B 0 mT – 0 Vbias



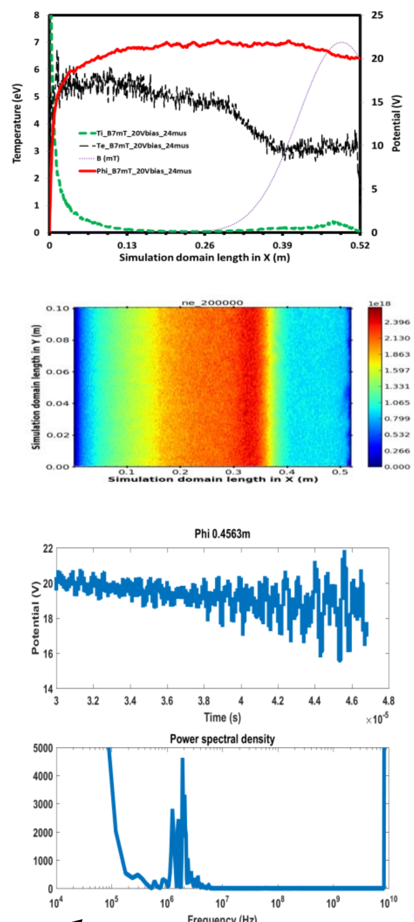
Case 2:
B 0 mT- 20 V bias

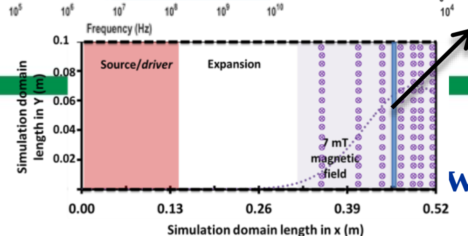


Case 3:
B 7 mT – 0 Vbias



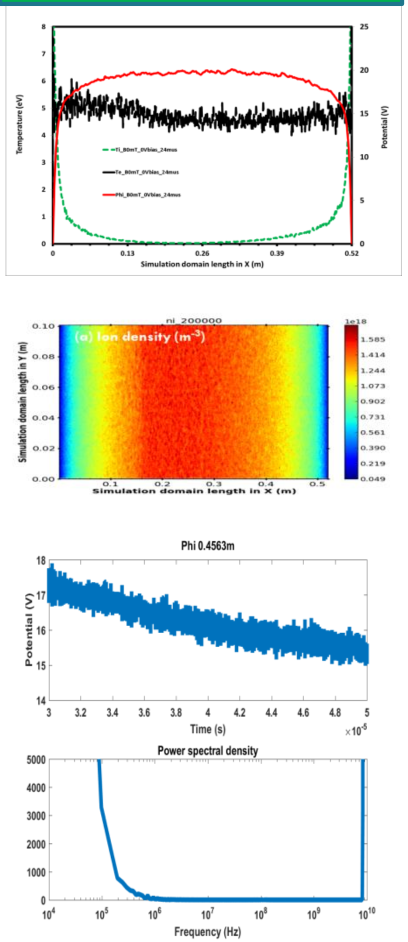
Case 4:
B 7 mT- 20 V bias



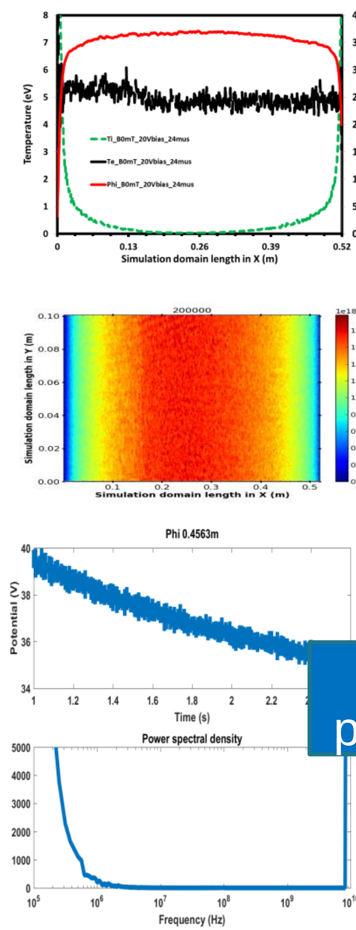


Case-studies

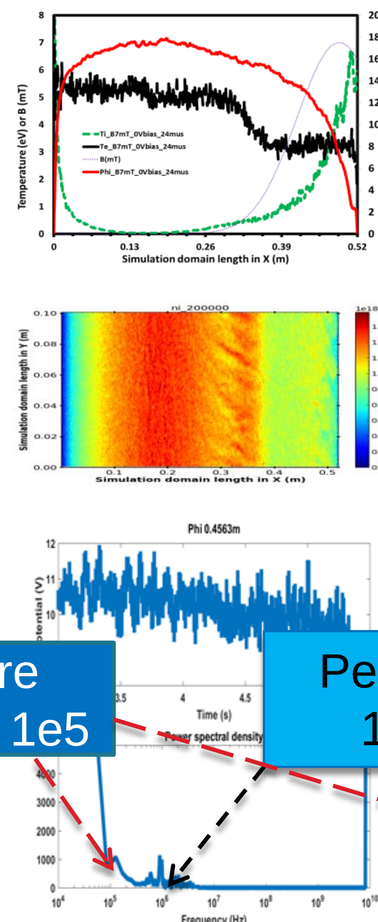
Case 1: B 0 mT – 0 Vbias



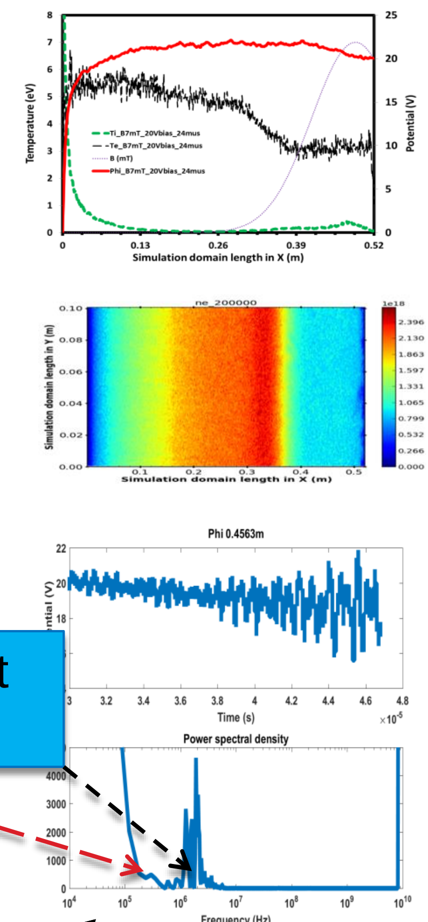
Case 2: B 0 mT- 20 V bias



Case 3: B 7 mT – 0 Vbias

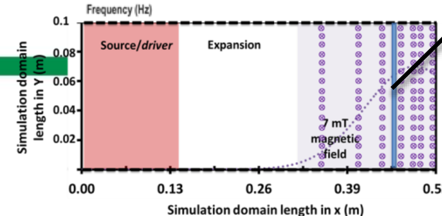


Case 4: B 7 mT- 20 V bias



1 more peak at 1e5

Peak at 1e6

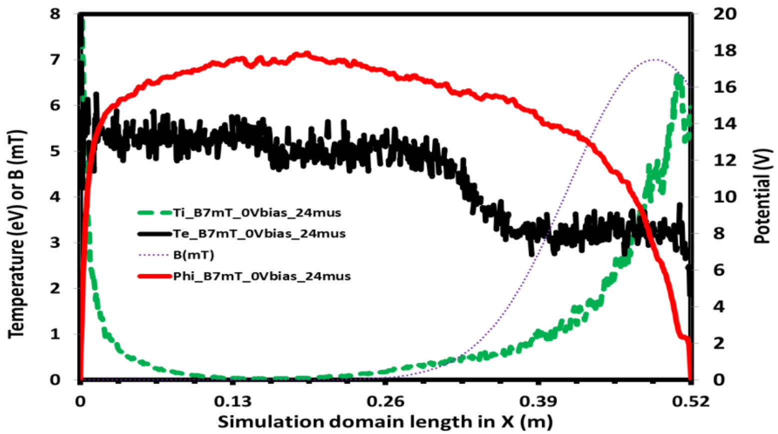


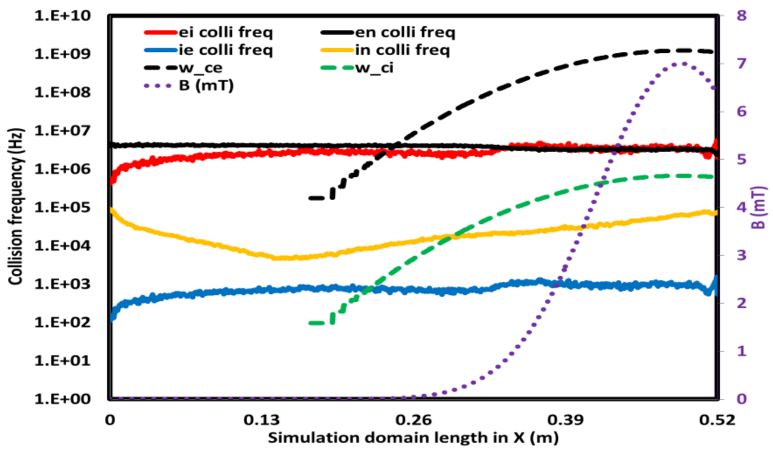
Observation from FFT analysis

- FFT analysis shows that in case of 0 mT magnetic field, no frequency peak observed.
- In case of 7 mT, two peaks are observed at 10^5 Hz and 10^6 Hz, but amplitude of peaks are different.
- In case of 7 mT 0 V bias (case-3), 10^5 Hz peak is stronger than 10^6 Hz.
- In case of 7 mT 20 V bias (case-4), 10^6 Hz is stronger.
- In Case 3, E and B both fields are present.

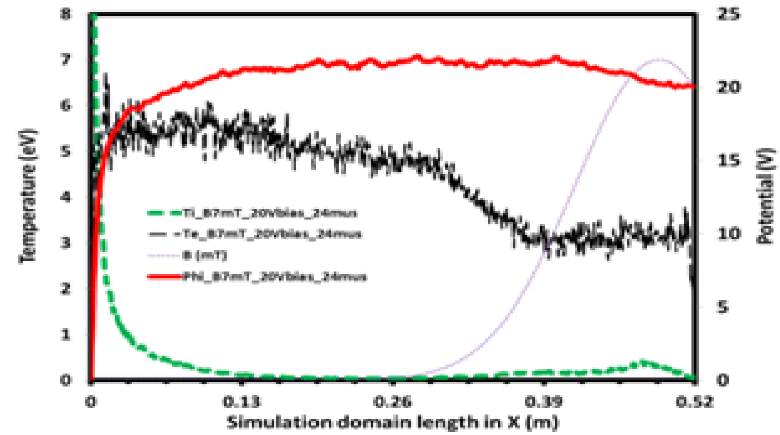
Case-studies

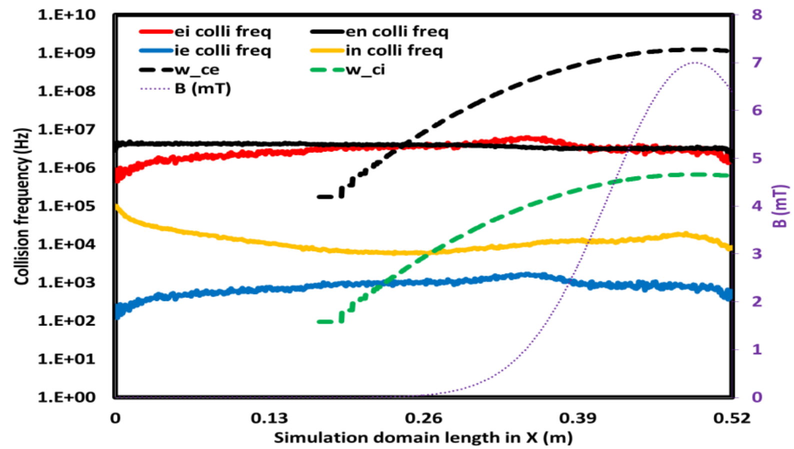
Case 3: B 7 mT – 0 Vbias





Case 4: B 7 mT- 20 V bias





Ion-acoustic wave past work

Evidence for neutrals carrying ion-acoustic wave momentum in a partially ionized plasma

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ABSTRACT

An experimental study of Ion Acoustic (IA) wave propagation is performed to investigate the effect of neutral density for Argon plasma in an unmagnetized linear plasma device. The neutral density is varied by changing the neutral pressure, which, in turn, allows the change in ion-neutral, and the electron-neutral collision mean free path. The collisions of plasma species with neutrals are found to modify the IA wave characteristics such as the wave amplitude, the velocity, and the propagation length. Unlike the earlier reported work where neutrals tend to heavily damp the IA wave in the frequency regime $\omega < \nu_{in}$ (where ω is the ion-acoustic mode frequency and ν_{in} is the ion-neutral collision frequency), the experimental study of the IA wave presented in this paper suggests that the collisions support the wave to propagate for longer distances as the neutral pressure increases. A simple analytical model is shown to qualitatively support the experimental findings.

Ion-acoustic wave past work

Linear ion acoustic waves in a density gradient

The Physics of Fluids 17, 1738 (1974); https://doi.org/10.1063/1.1694964

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more...

PDF ABSTRACT CITED BY TOOLS SH

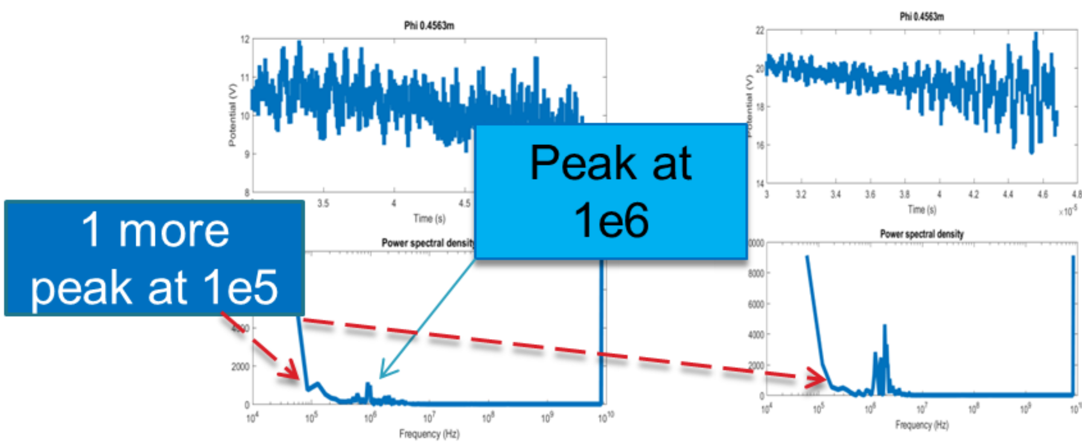
TOPICS
- Plasma waves
- Plasma properties and parameters

ABSTRACT

Both the experimental and theoretical behavior of linear ion acoustic waves in density gradients formed in a collisionless discharge plasma have been studied. The experiment and the theory both show a strong spatial growth of the density perturbation produced by the wave when the wave propagates in the direction of increasing density and a damping when the wave propagates in the direction of decreasing density. Theoretically, the growth and damping rates are found to be proportional to $n_0^{1/2}$, where n_0 is the local unperturbed density. By using the measured density profile, good agreement is found between experiment and the linearized fluid theory. Although the wave amplitude n_1, itself, decreases as the wave propagates into a region of lower density, the *relative* amplitude n_1/n_0 increases. This can be expected to lead to wave steepening and shock-like behavior, as noted previously by others. The work reported here is mainly concerned with the range where the wavelength is smaller than the characteristic length of variation of the plasma density.

Summary

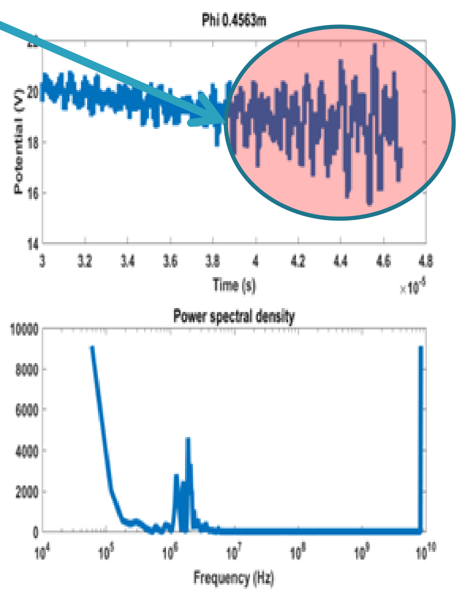
- In absence of magnetic field (with and without bias voltage Case-1 and Case-2), no frequency found in FFT analysis.
- 10^5 Hz and 10^6 Hz frequencies are observed on case -3 and case-4 (with B).
- Strong E and B both are present in case -3 (with B=0 mT, 0 Vbias), but in case-4, weak E and B field present.
- 10^5 Hz suggest to frequency related to EXB drifts instabilities.
- 10^6 Hz is due to lower hybrid.



REQUIRES BRAINSTORMING

- **Potential time series plot shows enhancement in potential structure (B 7 mT 20 Vbias) –**

Is that any resonance effect?



More detail about work can be found from

1. Miral Shah, Bhaskar Chaudhury, Mainak Bandyopadhyay, Arun Chakraborty, *Computational characterization of plasma transport across magnetic filter in ROBIN using PIC-MCC simulation*, **Fusion Engineering and design**, vol. 121,111402, **2020.**
2. Harshil Shah, Siddharth Kamaria, Riddhesh Markandya, Miral Shah, Bhaskar Chaudhury, *A novel implication of 2D3V PIC algorithm for Kepler GPU architectures*, **Proceedings of 24th IEEE International conference of high performance computing, data, and analytics (HIPC-2017)**, Jaipur, India, page no-378, 18-21 Dec, 2017.
3. Chaudhury B. et al. *Hybrid Parallelization of Particle in Cell Monte Carlo Collision (PIC-MCC) Algorithm for Simulation of Low Temperature Plasmas. Software Challenges to Exa-scale Computing*, **Second workshop on Software Challenges to Exascale Computing (SCEC 2018), Communications in Computer and Information Science**, Springer, Singapore, vol. 964, page no – 32, 13-14 Dec, 2018.

THANK YOU

#	Reaction	Energy	Type
1	$H_2 + H_2$	-	Momentum transfer
2	$H_2(J=0) \rightarrow H_2(J=2)$	0.044 eV	Rotational excitation
3	$H_2(J=1) \rightarrow H_2(J=3)$	0.073 eV	Rotational excitation
4	$H_2 \rightarrow H_2(v=1)$	0.516 eV	excitation
5	$H_2 \rightarrow H_2(v=2)$	1.000 eV	excitation
6	$H_2 \rightarrow H_2(v=3)$	1.500 eV	excitation
7	$H_2 \rightarrow H_2(b3)$	8.900 eV	excitation
8	$H_2 \rightarrow H_2(b1)$	11.300 eV	excitation
9	$H_2 \rightarrow H_2(c3)$	11.750 eV	excitation
10	$H_2 \rightarrow H_2(a3)$	11.800 eV	excitation
11	$H_2 \rightarrow H_2(c1)$	12.400 eV	excitation
12	$H_2 \rightarrow H_2(d3)$	14.000 eV	excitation
13	$H_2 \rightarrow H + H(n=2)$	15.000 eV	dissociative excitation
14	$H_2 \rightarrow H_2$	15.200 eV	sum of excitation of Rydberg levels
15	$H_2 \rightarrow H + H(n=3)$	16.600 eV	dissociative excitation to Balmer alpha (N=3)
16	$H_2 \rightarrow H_2^+$	15.400 eV	Ionization