

Electron cyclotron drift instability : influence of electron properties in CTS measurement

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**ExB Plasmas
Workshop
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Madrid, online event

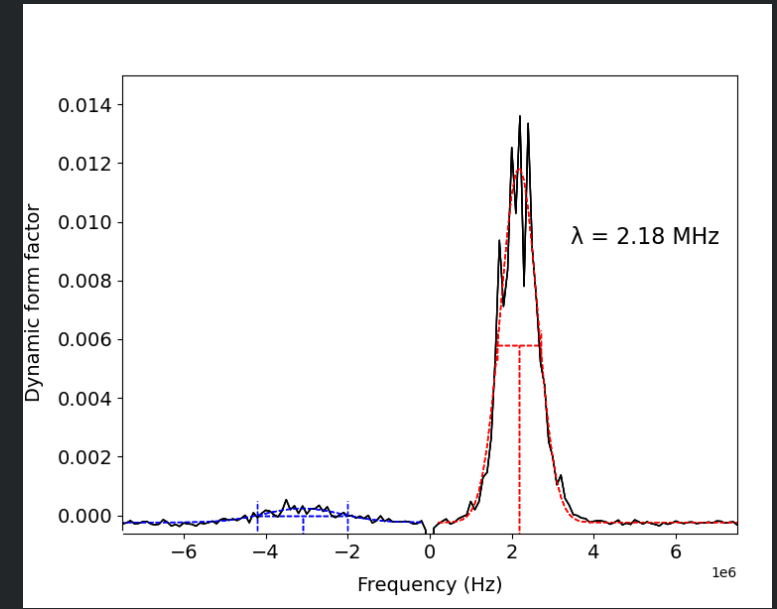
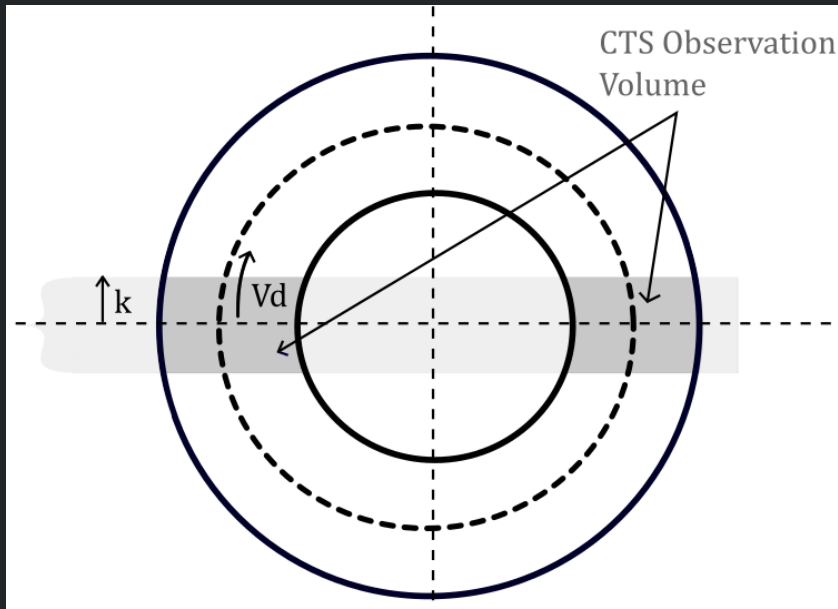
Context and objectives

The electron cyclotron drift instability (ECDI) is an important actor in the anomalous transport of electrons in ExB sources :

- First evidence for existence and for role in transport in thrusters in 2D PIC simulations in 2004 ¹
- Experimental confirmation in 2009 by coherent Thomson scattering²
- Many numerical and theoretical studies conducted since, in several teams, including Refs 3 - 9:

1. Adam, J. C., Héron, A., & Laval, G. (2004) *Phys. Plasmas*, 11(1), 295-305
2. Tsikata, S., Lemoine, N., Pisarev, V., & Gresillon, D. M. (2009) *Phys. Plasmas*, 16(3), 033506
3. Coche, P., & Garrigues, L. (2014) *Phys. Plasmas*, 21(2), 023503
4. Cavalier, J., Lemoine, N., Bonhomme, G., Tsikata, S., Honoré, C., & Grésillon, D. (2013) *Phys. Plasmas*, 20(8), 082107
5. Boeuf, J. P., & Garrigues, L. (2018) *Phys. Plasmas*, 25(6), 061204
6. Lafleur, T., Baalrud, S. D., & Chabert, P. (2017) *Plasma Sources Sci Technol*, 26(2), 024008
7. Janhunen, S., Smolyakov, A., Sydorenko, D., Jimenez, M., Kaganovich, I., & Raitses, Y. (2018) *Phys. Plasmas*, 25(8), 082308
8. Kaganovich, I. D., Smolyakov, A., Raitses, Y., Ahedo, E., Mikellides, I. G., Jorns, B., ... & Fruchtman, A. (2020) *Phys. Plasmas*, 27(12), 120601
9. Taccogna, F., Minelli, P., Asadi, Z., & Bogopolsky, G. (2019) *Plasma Sources Sci Technol*, 28(6), 064002

ECDI measurement in experiments



- ECDI detection made possible by coherent Thomson scattering (CTS)
- Ability to measure small-scale electron density fluctuations at different wavenumbers, in different directions: determination of the dispersion relation
- Measurement over the entire width of the channel : scan over a range of plasma parameters

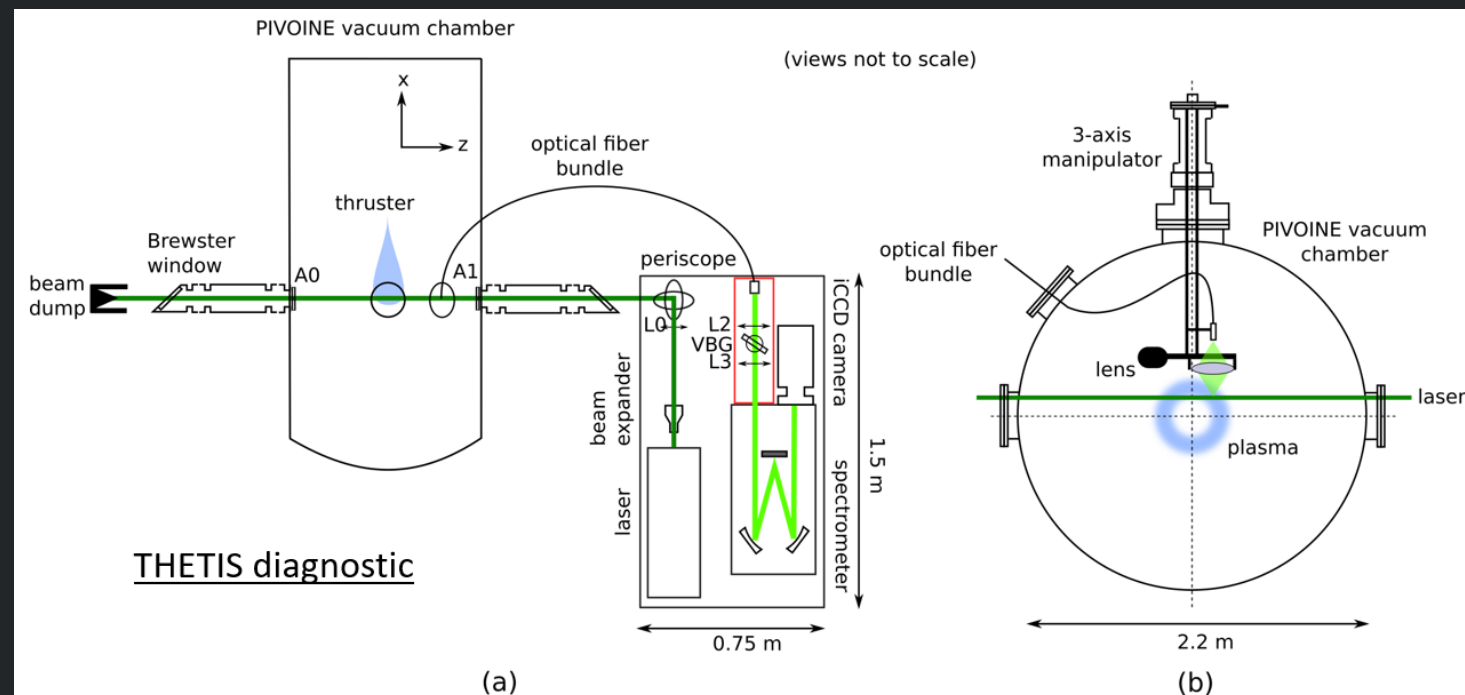
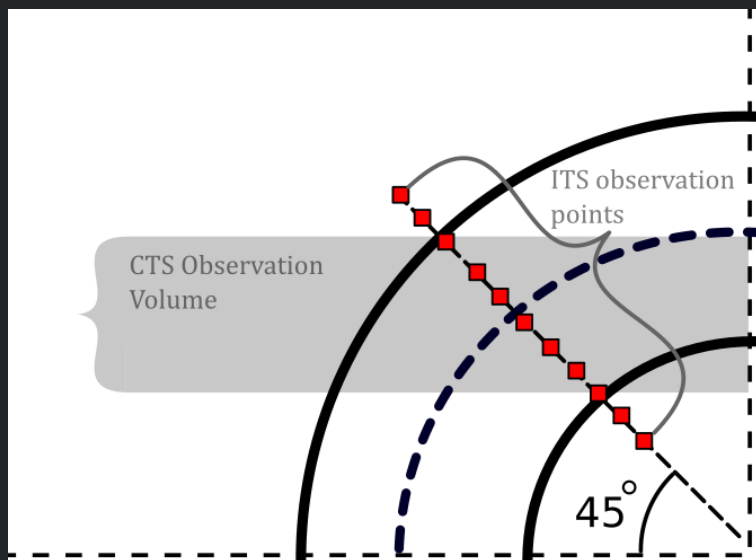
Objective of study

- CTS experiments have shown key features of the ECDI:
 - (i) linear, continuous dispersion relation
 - (ii) presence of a non-zero wave vector component (k_z) along the magnetic field
- The dispersion relation obtained in experiments differs somewhat from that seen in linear kinetic theory:
 - theory: persistence of unstable lobes, only smoothed for large k_z
- The differences may lie in the plasma properties seen by the observation volume in experiments
 - Question: how do these electron properties affect the dispersion relation solutions ?
- Proposed investigation
 - Non-invasive measurement of electron properties (density, temperature) using recently-developed incoherent Thomson scattering diagnostic (THETIS)¹
 - Examination of dispersion relation solutions for these measured plasma conditions

1. Vincent, B., Tsikata, S. et al (2018) Plasma Sources Sci. Technol. 27 055002

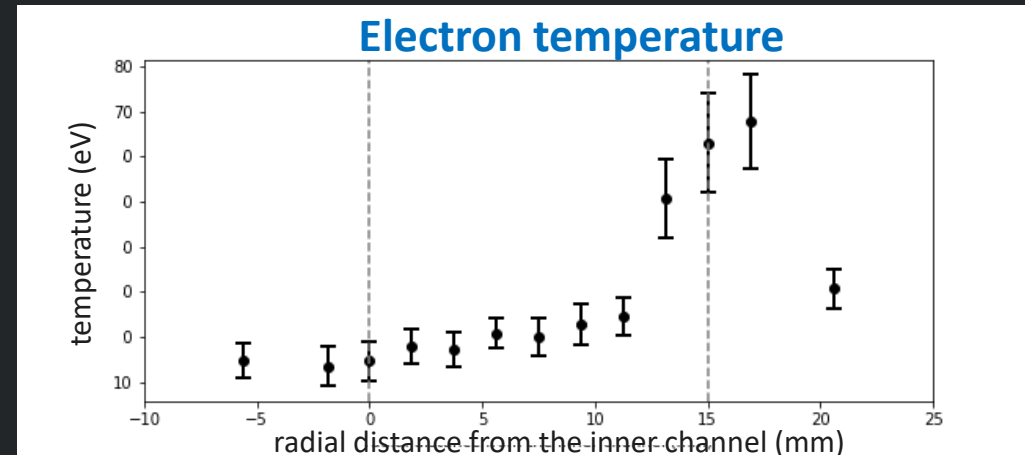
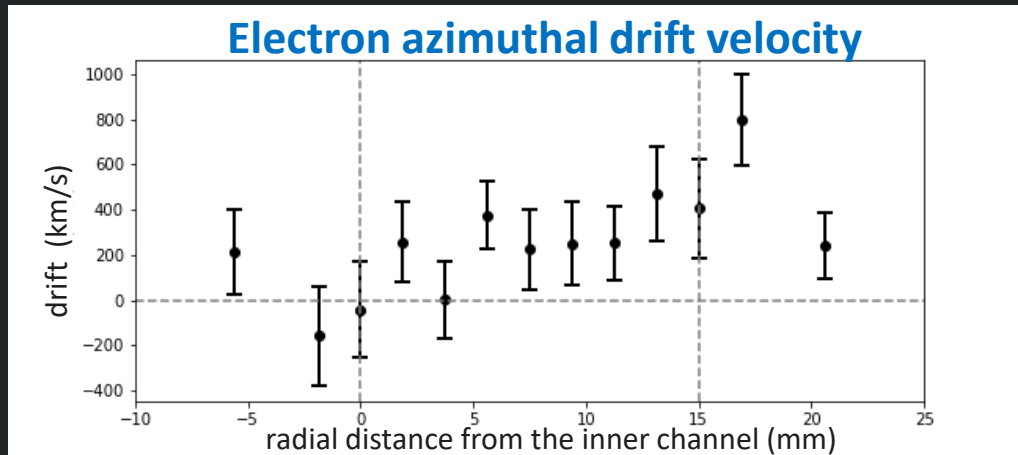
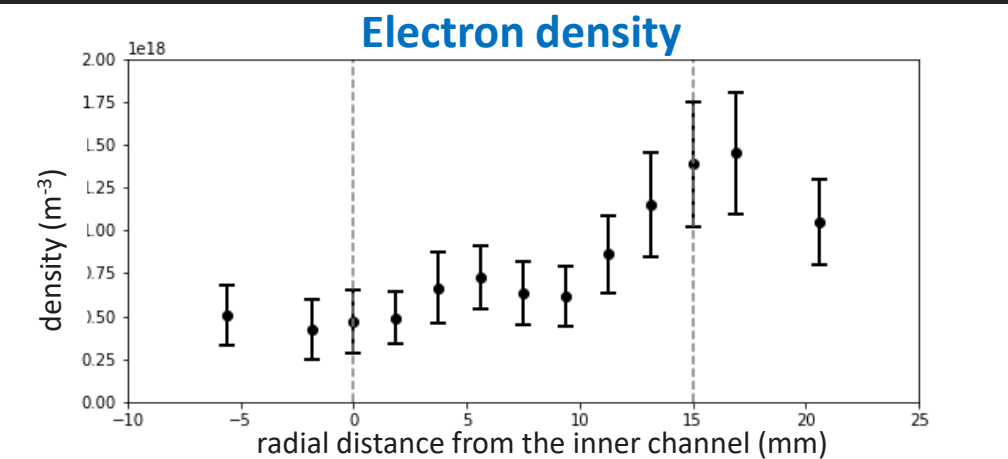
Measurement of electron properties using ITS

- ITS enables the direct and non-perturbative recovery of the electron properties : n_e , T_e and drift velocity
- The diagnostic implementation achieved allows for investigations in plasma environments of densities as low as 10^{16} m^{-3}
- The high spatial resolution makes it possible to scan different points separately over the entire width of the channel, directly in the ionization and acceleration zone



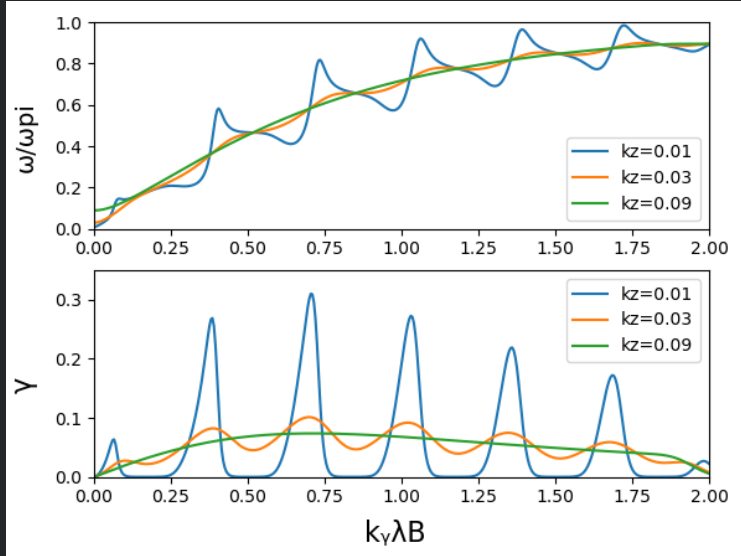
Radial variation in electron properties from ITS

- Large variation of the plasma properties between the inner and outer edge of the channel
- ECDI will develop under different plasma conditions

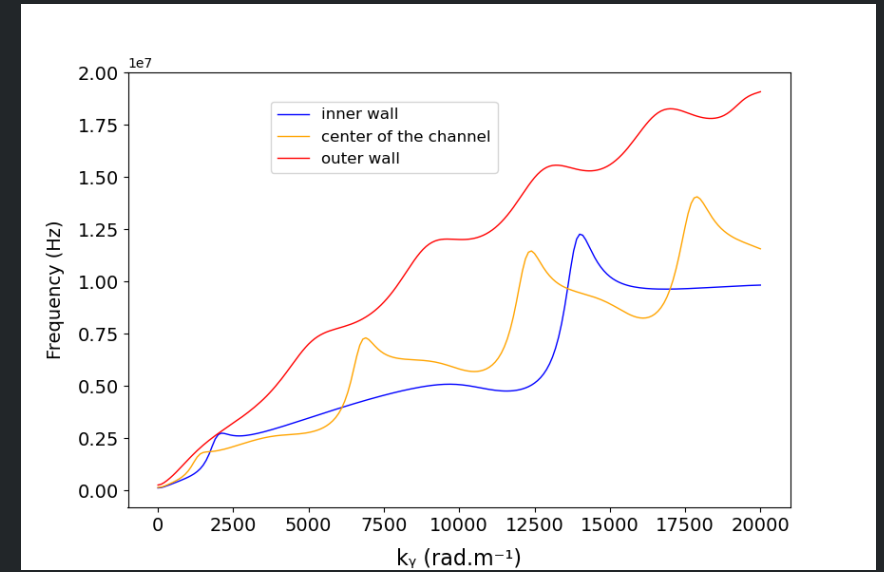


Dispersion relation

- Linear kinetic theory example for varying k_z . Inclusion of k_z reflects the intrinsically 3D nature of the instability²



- Linear kinetic theory solution for **measured** electron property values, fixed k_z
- Clear variation in dispersion relation slope across channel

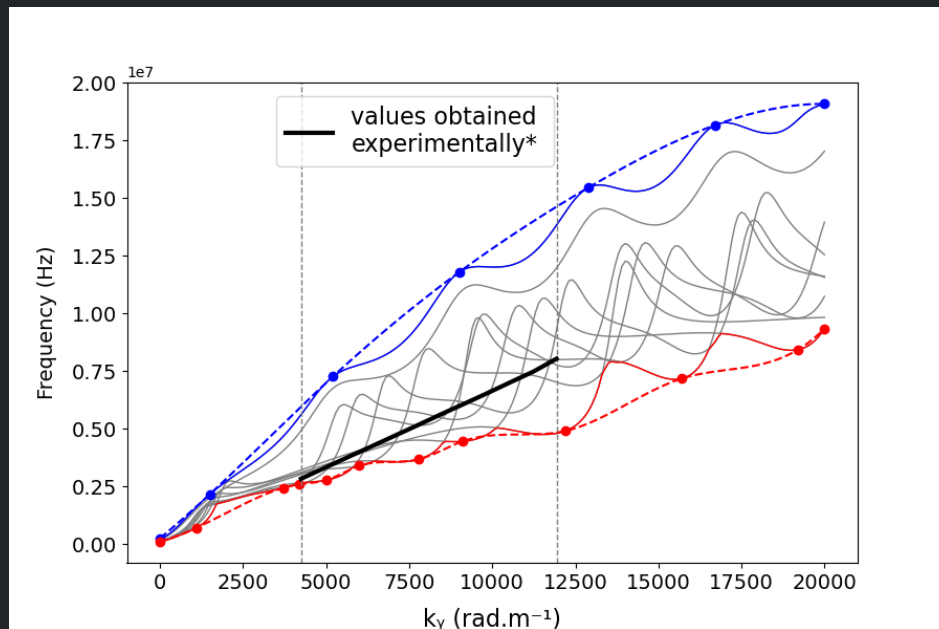


$$1 + \frac{1}{k^2 \lambda_{De}^2} \left[1 + g \left(\frac{\omega - k_y V_d}{\omega_{ce}}, k_{\perp}^2 \rho_{ce}^2, k_z^2 \rho_{ce}^2 \right) \right] - \frac{1}{2k^2 \lambda_{Di}^2} Z' \left(\frac{\omega - k_x v_p}{\sqrt{2} k v_{thi}} \right) = 0$$

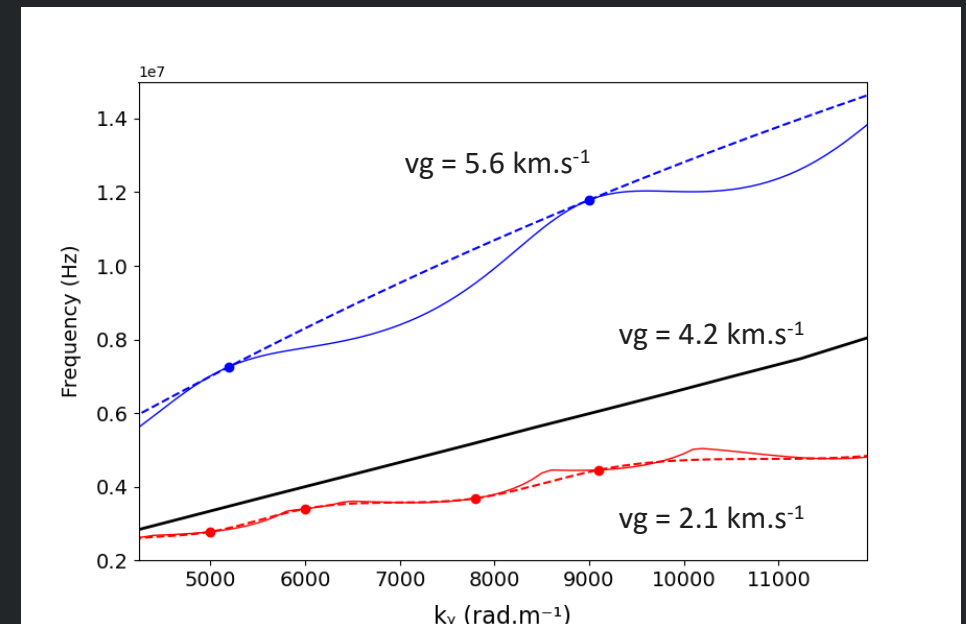
- Cavalier, J., Lemoine, N., Bonhomme, G., Tsikata, S., Honoré, C., & Grésillon, D. (2013) *Phys. Plasmas*, 20(8), 082107.
- Tsikata, S., Honoré, C., Lemoine, N., & Grésillon, D. M. (2010) *Phys. Plasmas*, 17(11), 112110.

Dispersion relation

- The average of the dispersion relations obtained for different plasma parameters at different radial positions gives a continuous dispersion relation



- The envelope of values shows that the measured group velocity will be within a certain window



* The experimental values presented here are given as examples and were obtained for different thruster operating conditions than those used in the ITS.

Conclusion

- Differences between theoretical dispersion relation and experimental dispersion relation can be understood by accounting for the range of electron property values which are scanned in the Thomson coherent scattering (CTS) measurement
- By means of an incoherent Thomson diagnostic (ITS) with high spatial resolution, it is possible to directly observe the plasma properties in the ionization zone of a Hall thruster, and account for these in the dispersion relation
- The combination of two factors:
 - Finite k_z component (verified experimentally using CTS)
 - A spread in n_e and T_e values (verified experimentally using ITS)

drift (km/s)

Allows the continuity of the dispersion relation and value of group velocities measured experimentally to be understood