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

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Context and objectives

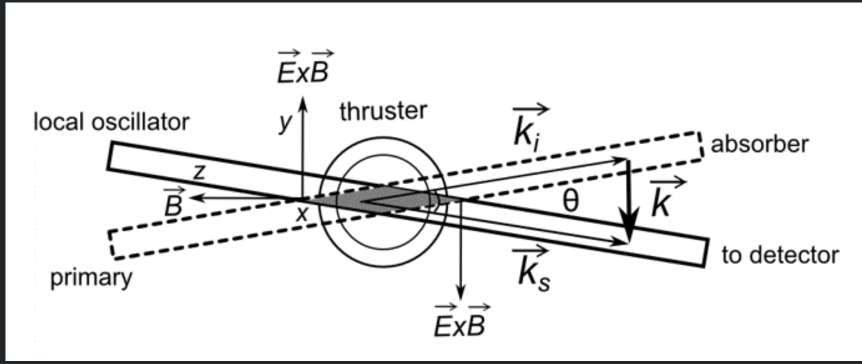
The electron cyclotron drift instability (ECDI) is an important actor in the anomalous transport of electrons in ExB sources :

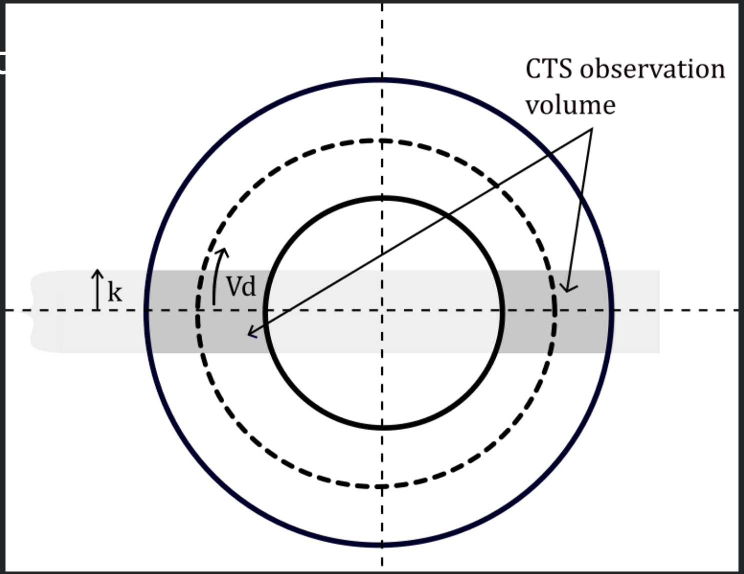
- First evidence for existence and for role in transport in thrusters in 2D PIC simulations in 2004 [1]
- Experimental confirmation in 2009 by coherent Thomson scattering[2]
- Many numerical and theoretical studies conducted since, in several teams, including Refs 3 - 9:

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

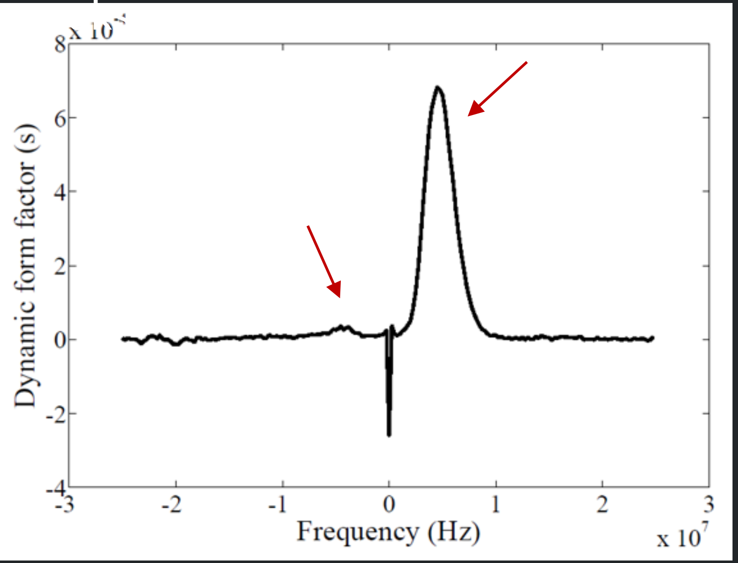
ECDI measurement in experiments

Coherent Thomson scattering (CTS) implementat





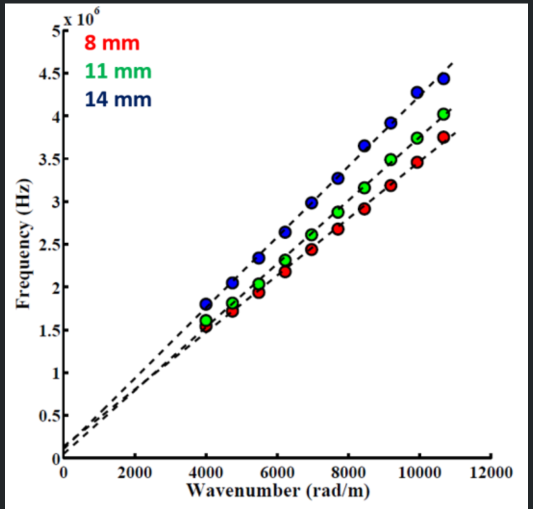
Typical MHz symmetric frequency



- 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 (kz) 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 kz

- 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

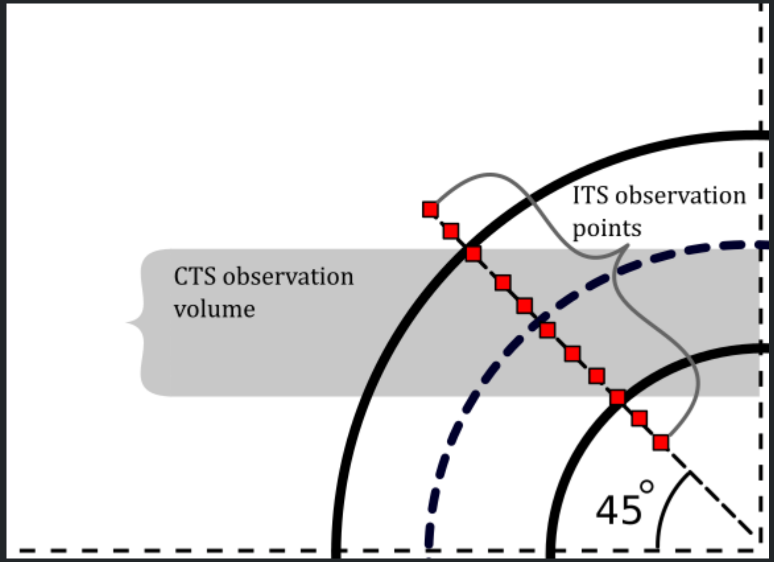
1. Vincent,B., Tsikata, S. et al (2018) Plasma Sources Sci. Technol. 27 055002

Measurement of electron properties using ITS

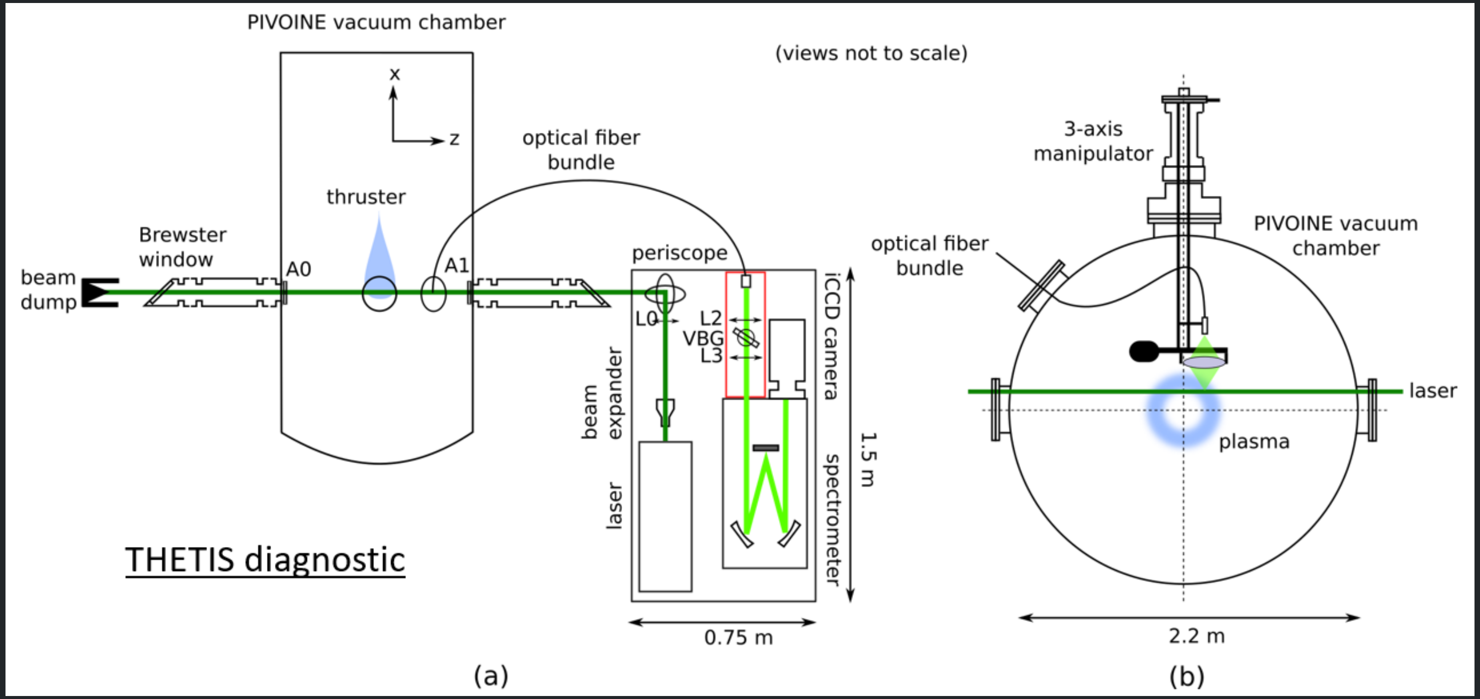
- ITS enables the direct and non-perturbative recovery of the electron properties : ne, Te and drift velocity

- 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



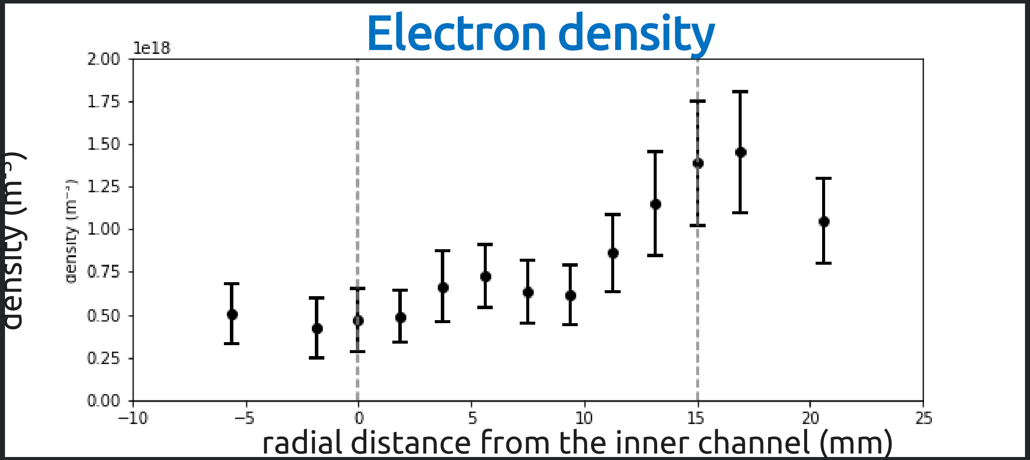
Incoherent Thomson scattering (ITS) implementaion

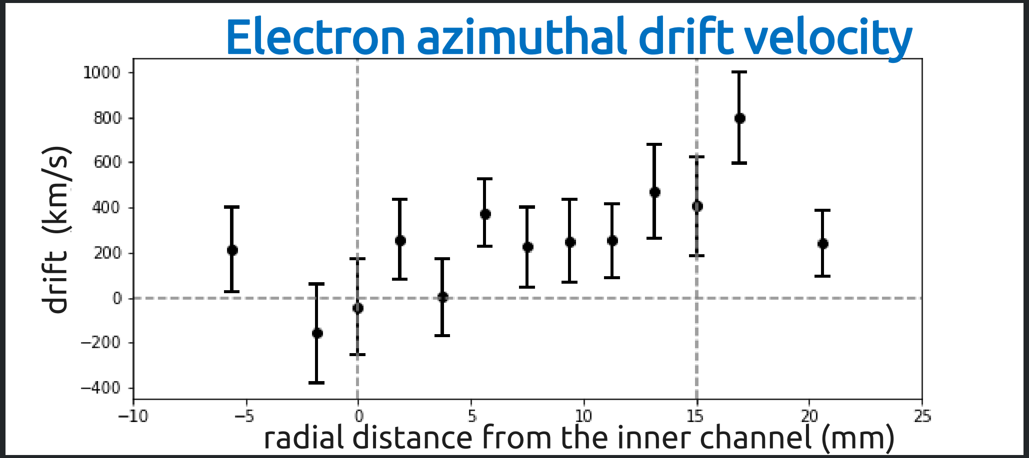


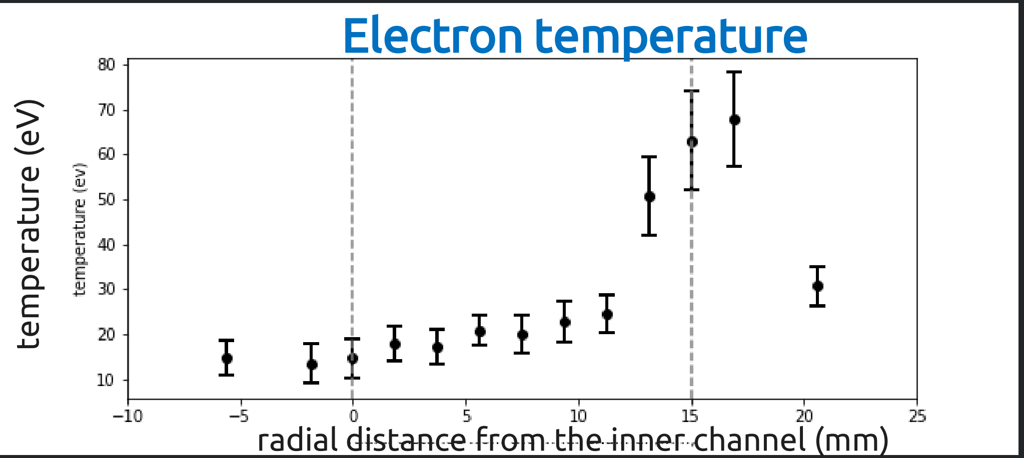
Radial variation in electron properties from ITS

Direct measurement of electron properties

- Large variation of the plasma properties between the inner and outer edge of the channel
- ECDI will develop in an inhomogeneous plasma

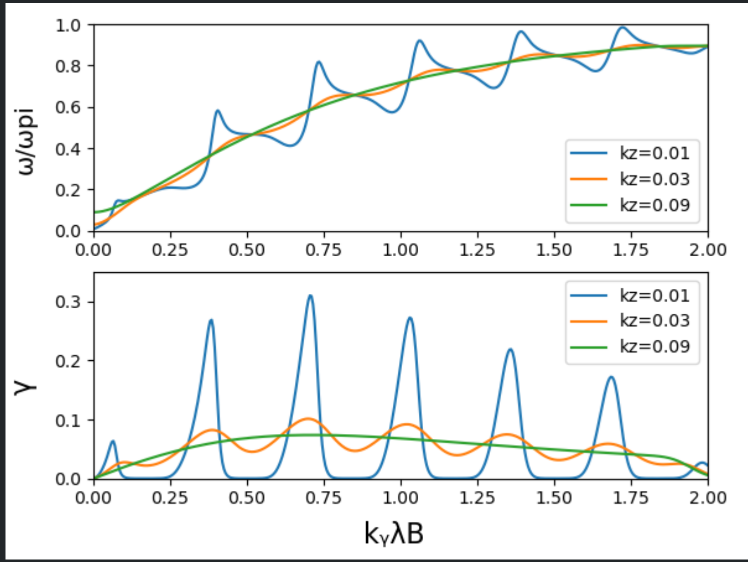






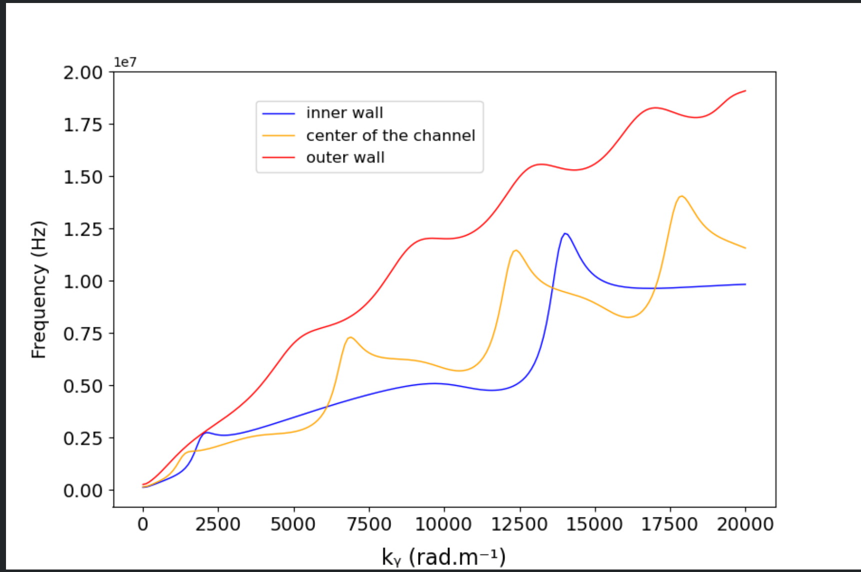
Dispersion relation

- Linear kinetic theory example for varying kz. Inclusion of kz reflects the intrinsically 3D nature of the instability[2]



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

Dispersion relation: we can now use directly measured electron properties

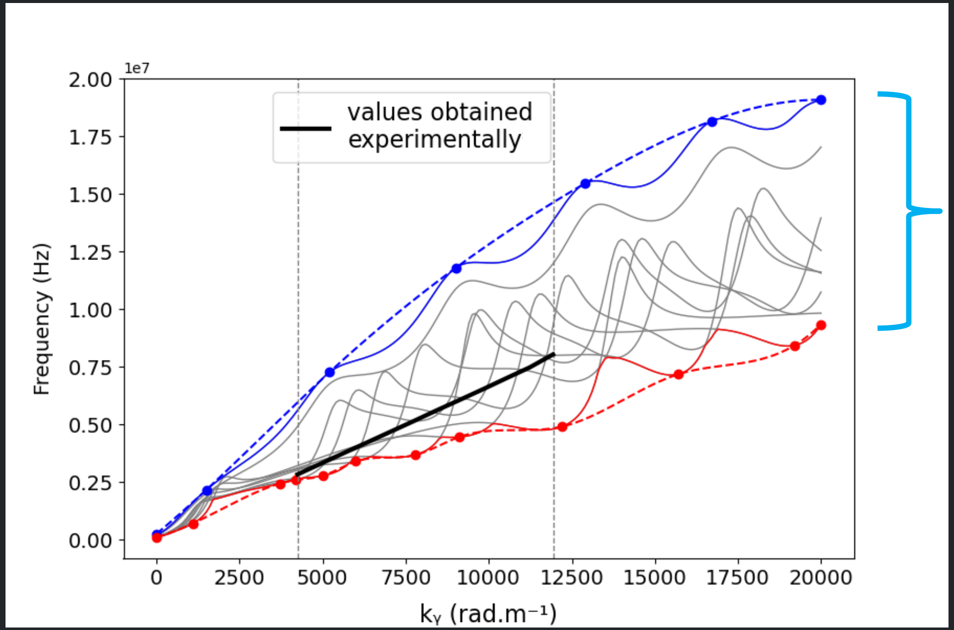


$$1+\frac{1}{k^2\lambda_{De}^2}\left[1+\mathrm{g}\left(\frac{\omega-k_yV_d}{\omega_{ce}},k_\perp^2\rho_{ce}^2,k_z^2\rho_{ce}^2\right)\right]-\frac{1}{2k^2\lambda_{Di}^2}\mathrm{Z}'\left(\frac{\omega-k_xv_p}{\sqrt{2}kv_{thi}}\right)=0$$ [1]

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

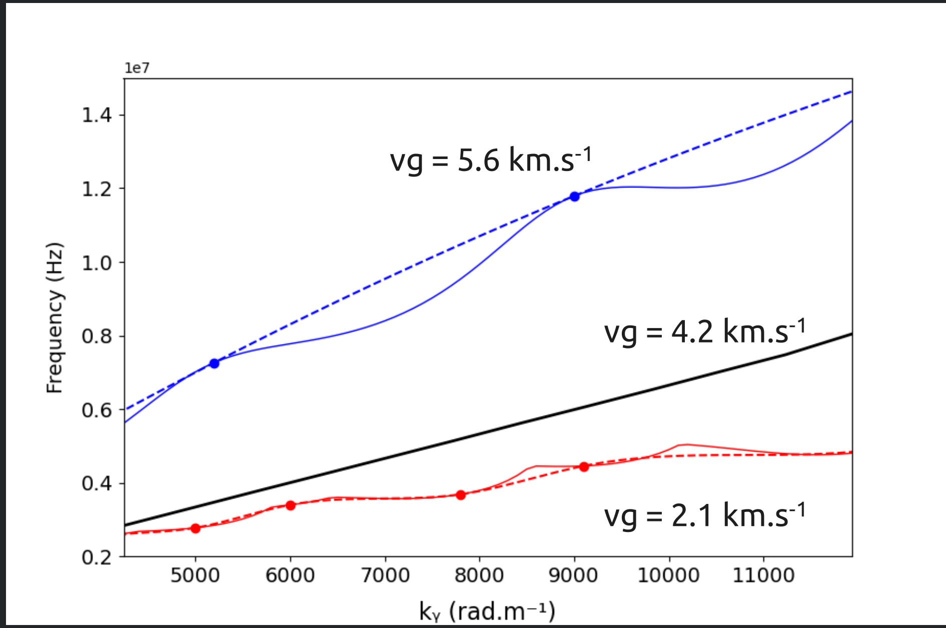
Dispersion relation

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



Linear kinetic theory solution

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



CTS observation volume spans an inhomogeneous plasma

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 <u>incoherent</u> 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 kz component (verified experimentally using CTS)
    - A spread in ne and Te values (verified experimentally using ITS)

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