# Lower hybrid drift instability in coronal loops

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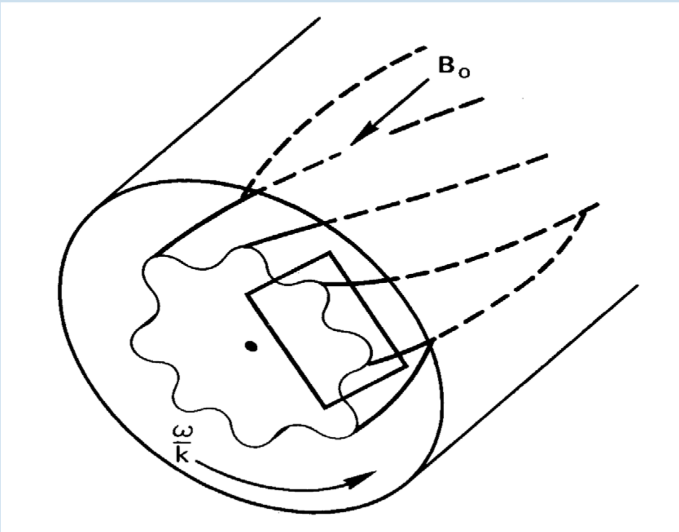
**PROBLEM:** Many heating models have already been proposed for the solar coronal heating problem, and the two theories that currently stick out are the theory of wave heating and the theory of magnetic reconnection. Although a lot of research is still needed on these two theories, it is very unlikely that they will be able to fully explain the problem since they rely on the continuum or fluid approximation (Magnetohydrodynamics, MHD). Hence, these models cannot really explain coronal heating completely because i) it is clear that the actual heating takes place at length scales much smaller than those on which the (macroscopic) MHD model is justified; and ii) it is obvious that the observed discrepancy between ion and electron temperatures in the corona, as well as iii) the observed large temperature anisotropy in the inner corona ($T_\perp > T_\parallel$) and iv) the observed preferential heating of the heavier ions are beyond the (single!) fluid model.

**SOLUTION?:** The alternative that is explored here is ***based on the kinetic theory of drift waves***. Assuming **drift waves** as the cause of the coronal heating implicitly states that the energy source of the heating is located in the corona itself, viz. in the ubiquitous density gradients present there. Though drift waves are studied intensively in the context of nuclear fusion research, not many studies are available on drift waves in solar context. Hence, it is important to look for methods to confirm the presence of drift waves in e.g. the solar corona. Here, the Vlasov theory will be used to study the presence of the lower hybrid drift instability in plasmas with a density gradient perpendicular to the magnetic field. A new approach for this study of Vlasov theory will be used. The main idea consists of expanding the distribution function in a series of Hermite polynomials in velocity space. This approach will facilitate the interpretation of the results obtained, as every expansion term has a specific physical meaning. The study has both numerical and analytical components in an attempt to quantify the presence of drift waves in the solar corona and their contribution to the heating problem.

## Drift waves? Experimentally verified!

- **'drift'** refers to the diamagnetic drifts expected to occur with any density gradients ) → the drift waves considered are related/generated by ***'universal' instabilities***
- Drift waves are *electrostatic* in low-β plasmas, with fluctuations in *n*, $\phi$, and *T* (and not ***B*** or *I*, at least in simplest picture), **unlike MHD waves!**
- Their relatively long wavelength along the magnetic field lines made them excellent candidates for explaining 'anomalous diffusion' across magnetic fields in tokamaks
- Theory showed the **drift wave instability** in inhomogeneous low-β plasmas ('55-'65)
- **Experiments** in linear Q-(quiescent) machines identified various types of drift waves and **compared amazingly well with linear theory** (1965-present)
- **Non-linear drift wave theory was developed and is compared** (in detail!) to explain the observed turbulence and transport in tokamaks (1980 - present)

**Fig. 1. Drift wave geometry:** extremely long wavelengths along the magnetic field lines, but exgtremely short wavelengths in the direction normal to the flux surfaces. The waves run along the flux surfaces perpendicular to **B.**



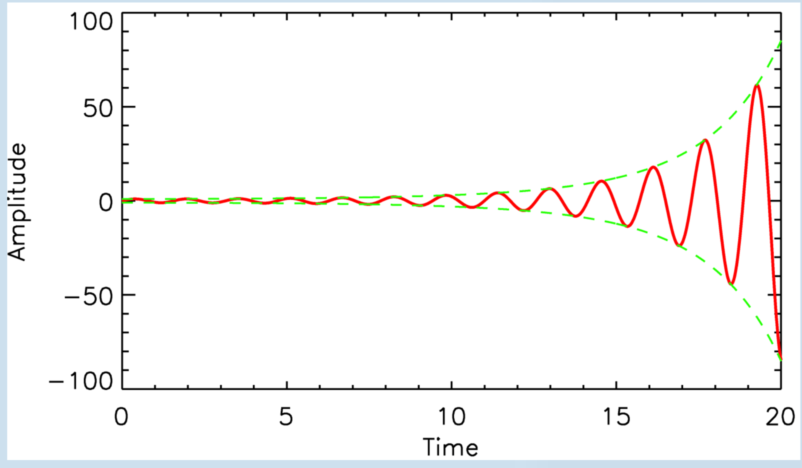




**Fig. 2.** Drift waves are always present in inhomogeneous) plasmas because these waves are intrinsically unstable, i.e. **`overstable'**

## Analytical Linear Stability Analysis

- Common method: Landau approach
- Here: **Hermite polynomial expansion of distribution function**
  - First introduced by Camporeale et al. (2006)
  - Infinite set of equations
  - Truncation by physical closure relation
- Solve the ***linearized Vlasov equation***: together with *Maxwell's equations*

$$\frac{\partial f_{1s}}{\partial t} + \mathbf{v}\cdot\frac{\partial f_{1s}}{\partial \mathbf{x}} + \Omega_{cs}(\mathbf{E}_0 + \mathbf{v}\times\mathbf{B}_0)\cdot\frac{\partial f_{1s}}{\partial \mathbf{v}} = -\Omega_{cs}(\mathbf{E}_1 + \mathbf{v}\times\mathbf{B}_1)\cdot\frac{\partial f_{0s}}{\partial \mathbf{v}}$$

- Assuming the equilibrium only depends on *x* → Fourier analysis in *y* and *z*
- Hermite expanded distribution function:

$$f_{1s}(\mathbf{x},\mathbf{v},t) = \frac{1}{\pi^{3/2}}\sum_{n,m,p} C^s_{n,m,p}(x,t)e^{ik_y y}e^{ik_z z}e^{-(\xi_x^2+\xi_y^2+\xi_z^2)} \times H_n(\xi_x)H_m(\xi_y)H_p(\xi_z)$$

- Normal mode analysis leads to an ***eigenvalue problem***: ω ***X*** = M ***X***
- **Equilibrium:**
  - $f_{0s}(x,\mathbf{v}) = \frac{n(x)}{\pi^{3/2}v^3_{th,s}}\exp\left[\frac{v_x^2+(v_y-V_{ds})^2+v_z^2}{v^2_{th,s}}\right]$
  - $n(x) = \mathrm{sech}^2(x)$
  - $\mathbf{E}_0 = \mathbf{0}$
  - $\mathbf{B}_0 = \tanh(x)\hat{z}$

determined *by 4 parameters*, viz.

$$\frac{T_i}{T_e},\quad \frac{m_i}{m_e},\quad \frac{r_{Li}}{L},\quad \frac{\omega_{pe}}{\Omega_{ce}}$$

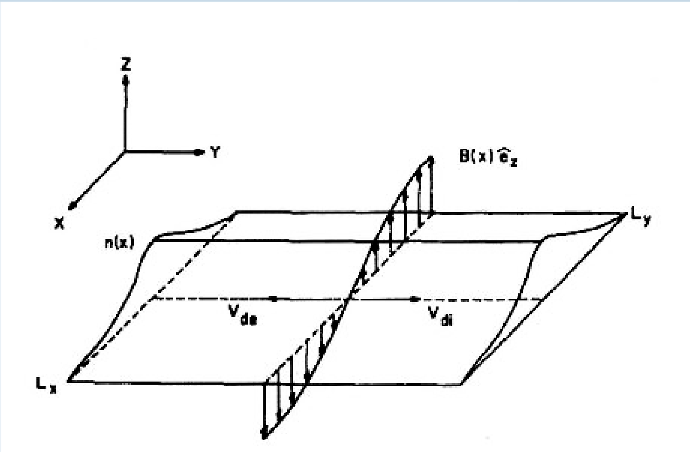



**Fig. 3. Geometry of the Harris equilibrium.**

## Some results of the linear analysis

- **Influence of $\omega_{pe}/\Omega_{ce}$**

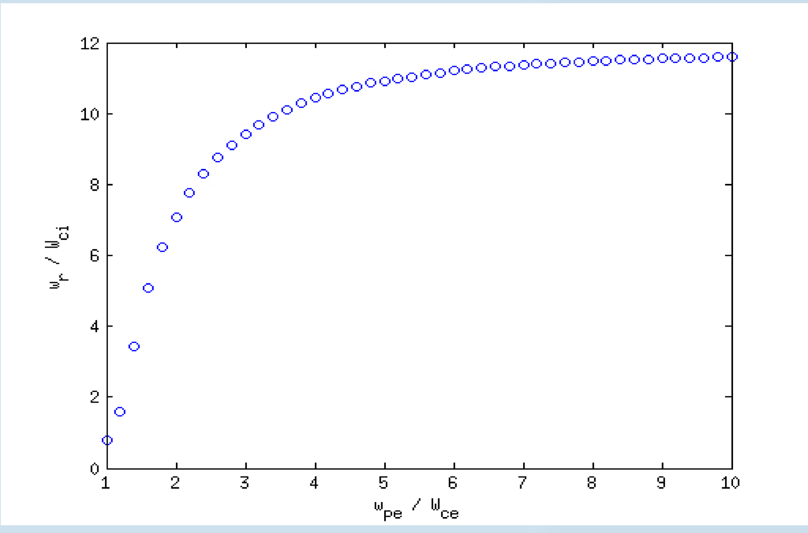



**Fig. 4.** Growth rate of the frequency of the LHDI in function of $\omega_{pe}/\Omega_{ce}$

- **Influence of density length scale**

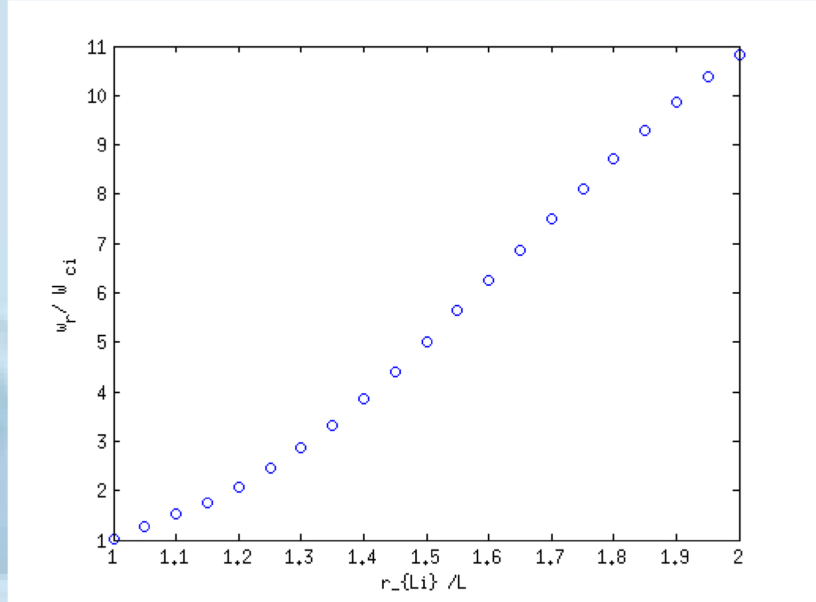



**Fig. 5.** Growth rate of the frequency of the lower hybrid drift instability in function of the length scale.

- **Influence of Influence of $T_i$ / $T_e$**

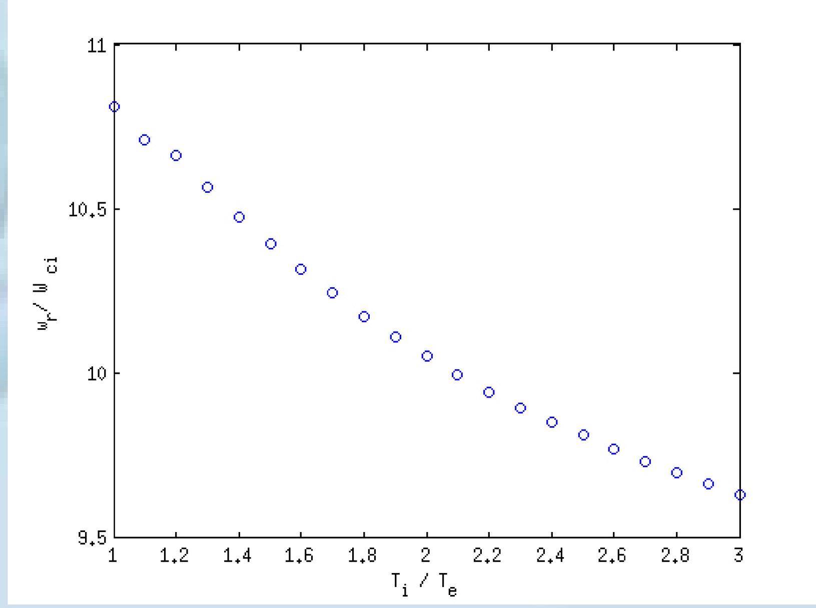



**Fig. 6.** Growth rate of the frequency of the lower hybrid drift instability in function of the temperature ratio.

## Some preliminary conclusions

- The **kinetic model** of drift waves was studied in solar atmospheric plasmas. Drift waves are ***driven by density gradients*** in the direction perpendicular to magnetic flux surfaces and hence should ***occur in all inhomogeneous plasmas***.
- a ***parameter study*** was conducted to analyze the influence of the different equilibrium parameters on the growth rate of the LHDI driving the drift waves.
- The ***presence of lower hybrid drift waves in the solar atmosphere is confirmed by the results***. Due to the nature of these waves however, this result was expected. Quantitatively not much can be concluded yet on the contribution of these waves to the coronal heating.
- The influence of all equilibrium parameters has been determined, and the conclusion is that the growth rate of the LHDI increases when $\omega_{pe}/\Omega_{ce}$ increases and/or the density length scale and the $T_i$ / $T_e$ ratio decreases.
- It is clear that these waves contribute in a certain way, ***but to what extent is still unknown as this requires a more extensive parameter study*** and inclusion of dissipation and nonlinear effects (saturation of the growth, leveling out of the background density inhomogeneity, etc.).
- The conducted parameter study and the considered simulations, however, form a stepping stone to further research on the promising kinetic model of drift waves in the solar atmosphere.

## References

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This work was supported by the projects GOA/2009-009 (KU Leuven), G.0729.11 (FWO-Vlaanderen) and SIDC Data Exploitation (ESA Prodex 9). Financial support by the European Commission through SOLSPANET (project n° 269299, www.solspanet.eu ), SPACECAST (project n° 262468, www.fp7-spacecast.eu), eHeroes (project n° 284461, www.eheroes.eu) and SWIFF (project n° 263340, www.swiff.eu) is gratefully acknowledged as well as support from the European Commission's Seventh Framework Programme (FP7/2007-2013) under the grant agreement nr. 218816.