Lower Hybrid Drift Waves in the Magnetotail

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I will talk about...

- Lower hybrid drift waves
- ... in the magnetosphere
- The Cluster data
- Observations
- Summary
Lower Hybrid Drift Waves

- Energy stored in plasma inhomogeneities
Lower Hybrid Drift Waves

- Energy stored in plasma inhomogeneities

- Ions drift due to density gradients and couple with waves

\[ v_{Di} = \frac{T_i}{eBL_n} \]

- Ions are unmagnetized
- Electrons are magnetized

\[ \omega_{ci} << \omega << \omega_{ce} \]
\[ \rho_e << D < \rho_i \]

- Perpendicular waves

\[ k_\perp >> k_\parallel \]
Lower Hybrid Drift Waves

- Excitation condition
  \[
  \frac{L_n}{\rho_i} < \left( \frac{m_i}{m_e} \right)^{1/4} \approx 7 \quad L_n = \left( \frac{1}{n} \frac{\partial n}{\partial x} \right)^{-1}
  \]

- Wavelength
  \[
  k_\perp \rho_e \approx 1 \quad \Rightarrow \quad \lambda_{LH} = 2\pi / k_\perp \approx 2\pi \rho_e
  \]

- Frequency
  \[
  \omega = \omega_{LH} = \sqrt{\Omega_e \Omega_i}
  \]

- Large growth rate
  - Nonlinear wave can change rapidly!
Lower Hybrid Drift Waves

- In low $\beta$-plasma they are generally electrostatic
- Finite plasma $\beta$ has a stabilizing effect on the electric wave mode
- As $\beta$ increases, a longer wavelength electromagnetic mode becomes prominent

- Role in magnetic reconnection?
Why do we want to measure them?

- We want to know what they look like
- Might provide insight into general electron scale dynamics
- Might play an important role in various plasma processes
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What do we want to measure?

- Velocity
- Wavelength
- Potential
- Instability conditions
The Magnetosphere
The Magnetosphere

- Short separation in the magnetotail + burst mode!

- $r_e \approx 4\, \text{km}$
- $\omega_{\text{LH}} \approx 10\, \text{Hz}$
Cluster

2007

- C3, C4 separated by 40 km in the magnetotail
- 14 planned boundary layer burst modes
  - 3 real plasma sheet boundary layer crossings
Space vs. laboratory

Wouldn’t it be easier to just set up a laboratory experiment?

Cluster is so small in the big magnetosphere:

\[ \lambda_{\text{LH}} = 60 \text{ km} \]
88 m between probes
separation 10 km

In laboratory (Fox 2010):

\[ \lambda_{\text{LH}} = 1.2 \text{ mm} \]
probe width 0.3 mm
separation 3 mm
August 31, 2007

Tail lobe → Plasma sheet

low density

high density
The event set up

- B along z
- Minimum variance analysis gives the normal direction along x
- Only direction left is the wave propagation direction! along y

- $\Delta y \approx 11 \text{ km}$
- $\lambda_{LH} \approx 2\pi\rho_e \approx 56 \text{ km}$
Are the conditions right?

We have a density gradient, but is it sharp enough?

\[ \frac{L_n}{\rho_i} < \left( \frac{m_i}{m_e} \right)^{\frac{1}{4}} \approx 7 \quad L_n = \left( \frac{1}{n \frac{\partial n}{\partial x}} \right)^{-1} \]

- Assumed total pressure balance

- Integration of ExB normal velocity from DC E-field gives \( L_n/\rho_i \approx 5 \)
**δE and φ**

- We look how much the electric field is delayed between C3 and C4
  - $v = 978$ km/s
  - $\lambda \approx 80$ km
$\delta E$ and $\phi$

- We look how much the electric field is delayed between C3 and C4
  
  - $v = 978$ km/s
  - $\lambda \approx 80$ km

- The electrostatic potential:

  $$\phi = \int \vec{E} \, dt \cdot \vec{v}$$
  Integrate!

  - $e\phi$ is 10-30% of $k_B T_e$
  - The potential might affect the electrons!
δE in field aligned coordinate system

- δE_{\text{perp}} for each time step
- δB_{\parallel} for each time step
  - Repetitive pattern!

![Graph showing perpendicular wave electric field and parallel wave magnetic field with v=978 km/s](image)
δE in field aligned coordinate system

- δE\textsubscript{perp} for each time step
- δB\textsubscript{||} for each time step
  ➢ Repetitive pattern!

Ions unmagnetized:

\[ j = ne(v_i - v_e) = -ne \frac{E_1 \times B}{B^2} \]

\[ \nabla \times B_1 = \mu_0 j \]
\( \delta B \) and \( \phi \)

- The wave magnetic field is linearly related to the electrostatic potential

\[
\phi_{\delta B} = \frac{B}{\mu_0 ne} \delta B
\]

(via the reasoning on the last slide...)
δB and φ

- The wave magnetic field is linearly related to the electrostatic potential

\[ \phi_{\delta B} = \frac{B}{\mu_0 n e} \delta B \]

(via the reasoning on the last slide...)

✧ Very good correspondance!

✓ Verification
✓ Tool

Now we can estimate φ even in cases when cross spacecraft correlation is not possible.
δB and δE

Electrostatic wave or not?

Faraday’s law

\[
\frac{|E_1|}{|B_1|} = \frac{\omega}{k}
\]

electromagnetic wave

\[
\frac{|E_1|}{|B_1|} \gg \frac{\omega}{k}
\]

electrostatic wave

We have

\[
\frac{|E_1|}{|B_1|} = \frac{60 \text{mV/m}}{0.6 \text{nT}} = 10^5 \text{km/s}
\]
- Define \( z \) along \( B \)
- Try different propagation directions until you obtain the good waveform
- Try different velocities until you get the correct amplitude

**Velocity and wavelength!**
By then crosscorrelating the non-crosscorrelatable fields, you might learn something about how the waves evolve during the course of propagation.
What have we not done?

- Saturation mechanisms: Why are the waves not more turbulent?
  - Current relaxation
  - Plateau formation
- Wavelength dependance
- $\phi$ in a wider parameter space using $\delta B$
Summary

Short separation between spacecraft + burst mode + boundary layer

- Three events in all Cluster data!

- Velocity: \( v_{\text{wave}} \approx 1000 \, \text{km/s} \)
- Wavelength: \( \lambda_{\text{measured}} \approx 50-100 \, \text{km} \)
- Gradient length scale: \( L_n/\rho_i \approx 0.5 \)
- Electrostatic potential: \( \phi \) is 10-40% of \( T_e \)
- Wave magnetic field: \( \phi_{\delta B} \approx \phi_{\delta E} \)
- Structure of wave: Vortices!