Lower Hybrid Drift Waves in the Magnetotail

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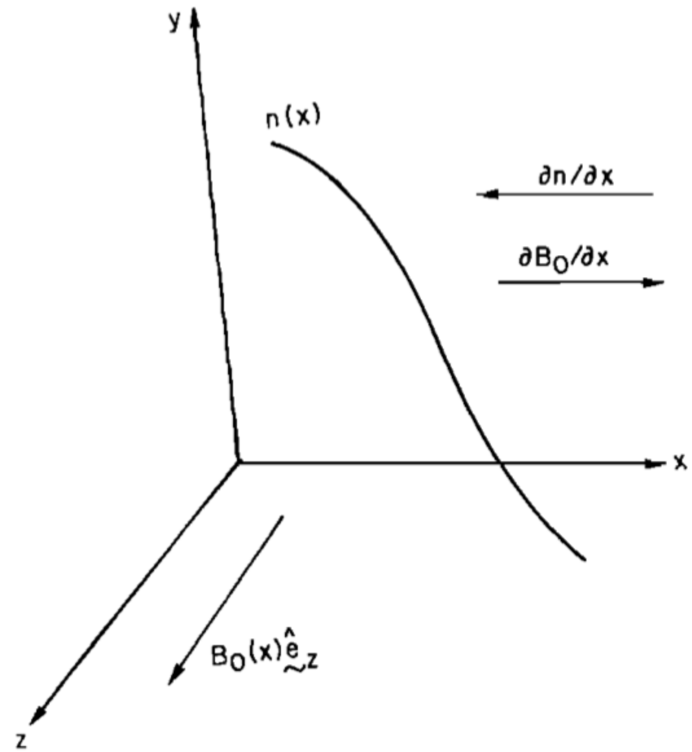
I will talk about…

- 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

$$v_{Di} = T_i / eBL_n$$

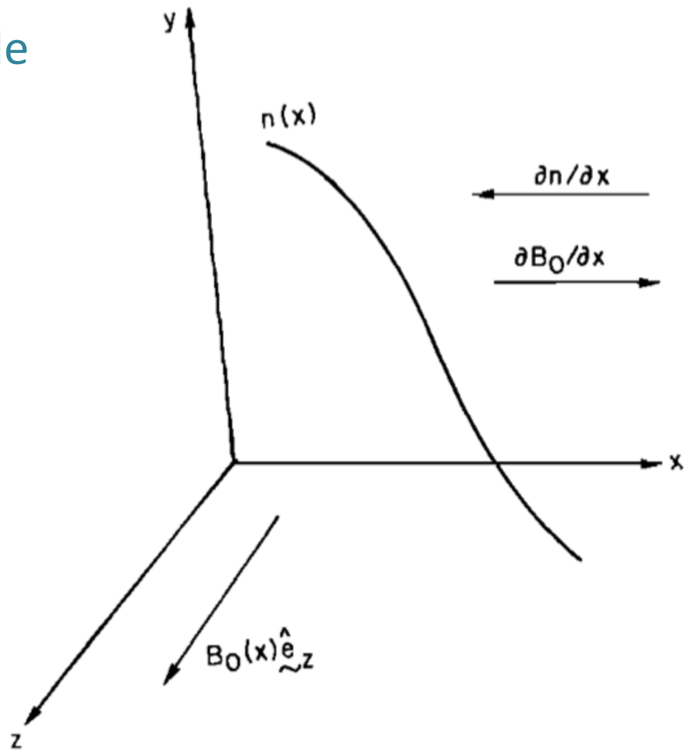
- Ions are unmagnetized
- Electrons are magnetized

$$\omega_{ci} << \omega << \omega_{ce}$$

$$\rho_e << D < \rho_i$$

- Perpendicular waves

$$k_\perp >> k_\parallel$$



Lower Hybrid Drift Waves

- Excitation condition

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

- Wavelength

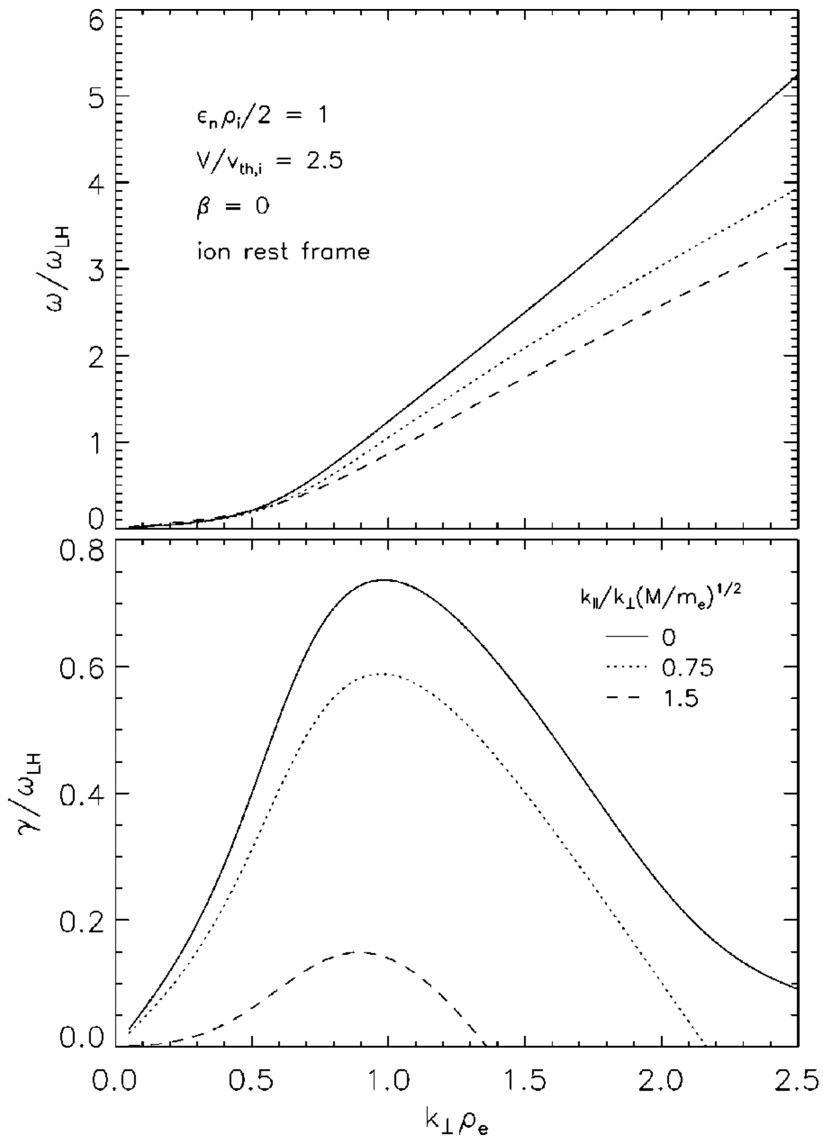
$$k_\perp \rho_e \approx 1 \quad \Rightarrow \quad \lambda_{LH} = 2\pi / k_\perp \approx 2\pi\rho_e$$

- Frequency

$$\omega = \omega_{LH} = \sqrt{\Omega_e \Omega_i}$$

- Large growth rate

  ➢ Nonlinear wave can change rapidly!



Lower Hybrid Drift Waves

- In low β-plasma they are generally electrostatic
- Finite plasma β has a stabilizing effect on the electric wave mode
- As β 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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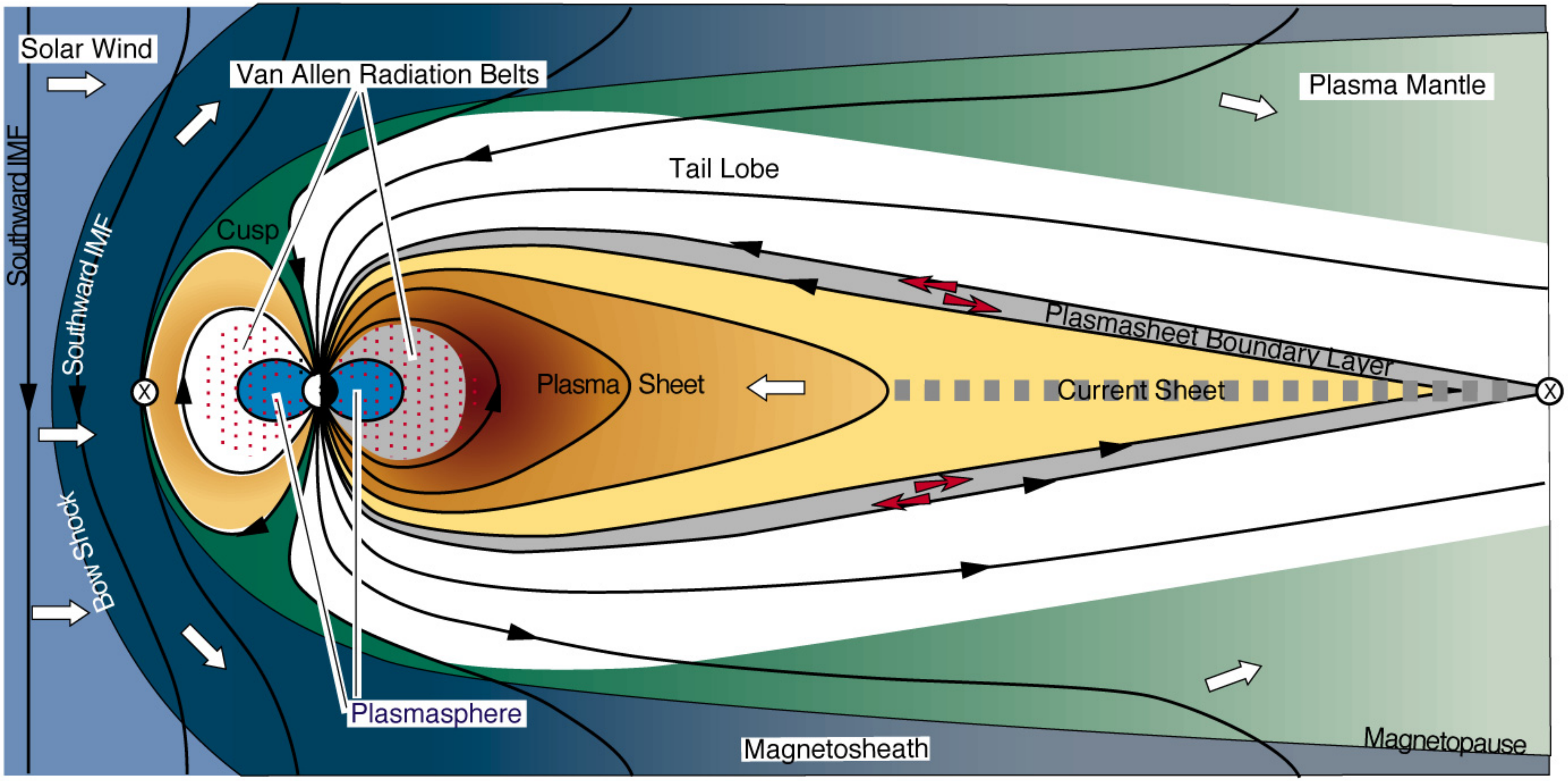
What do we want to measure?

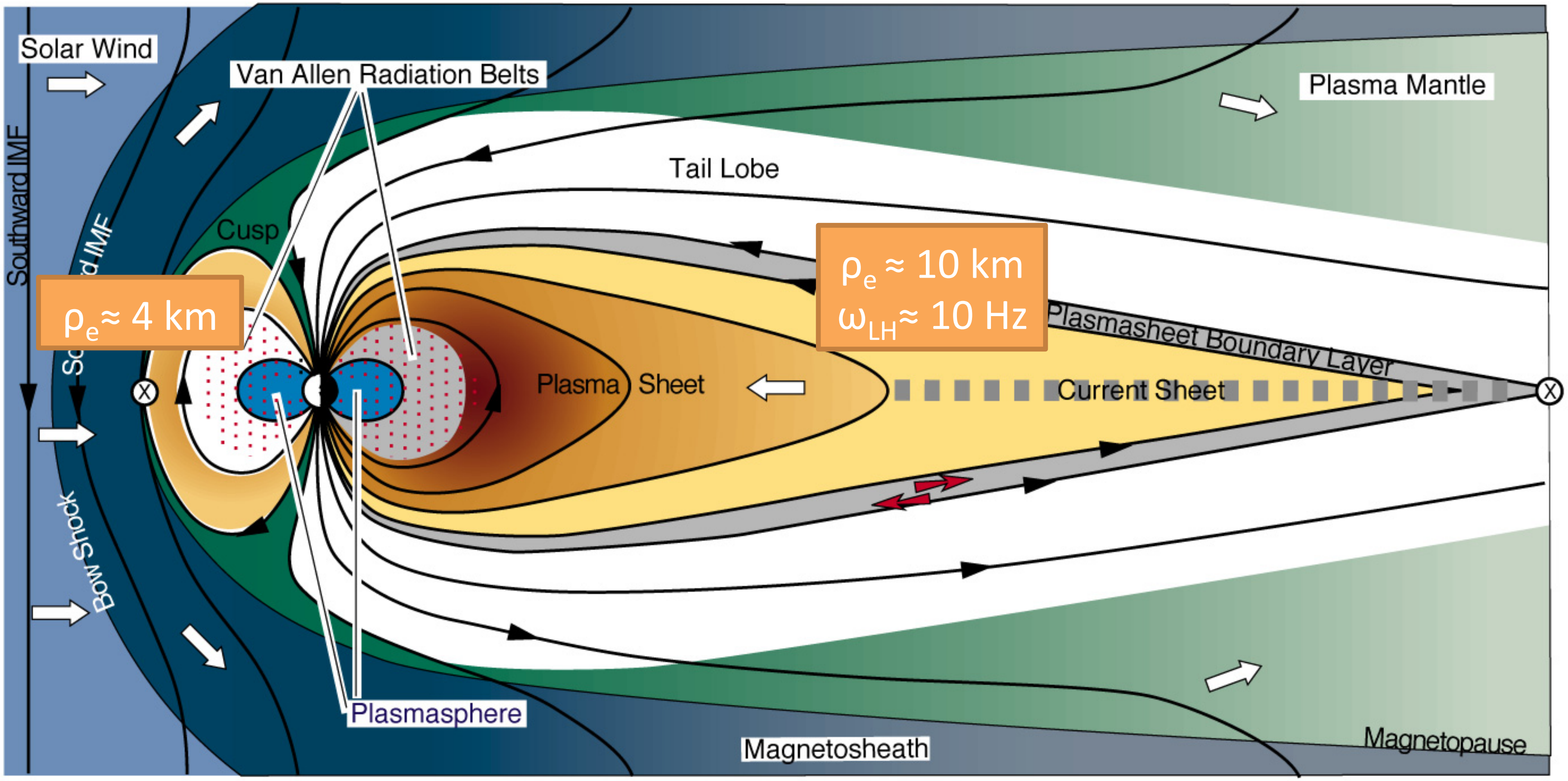
- Velocity
- Wavelength
- Potential
- Instability conditions

The Magnetosphere



The Magnetosphere

- Short separation in the magnetotail + burst mode!



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

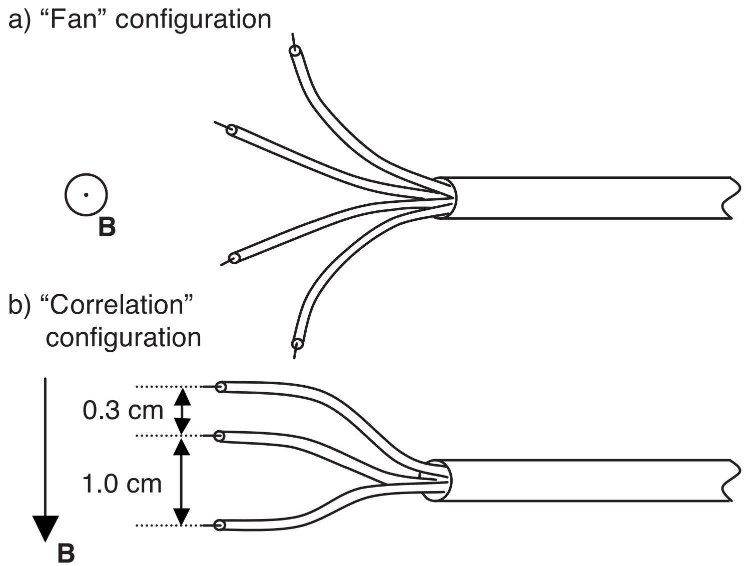
Wouldn't it be easier to just set up a laboratory experiment?

Cluster is so small in the big magnetosphere:

λ_{LH} = 60 km
88 m between probes
separation 10 km

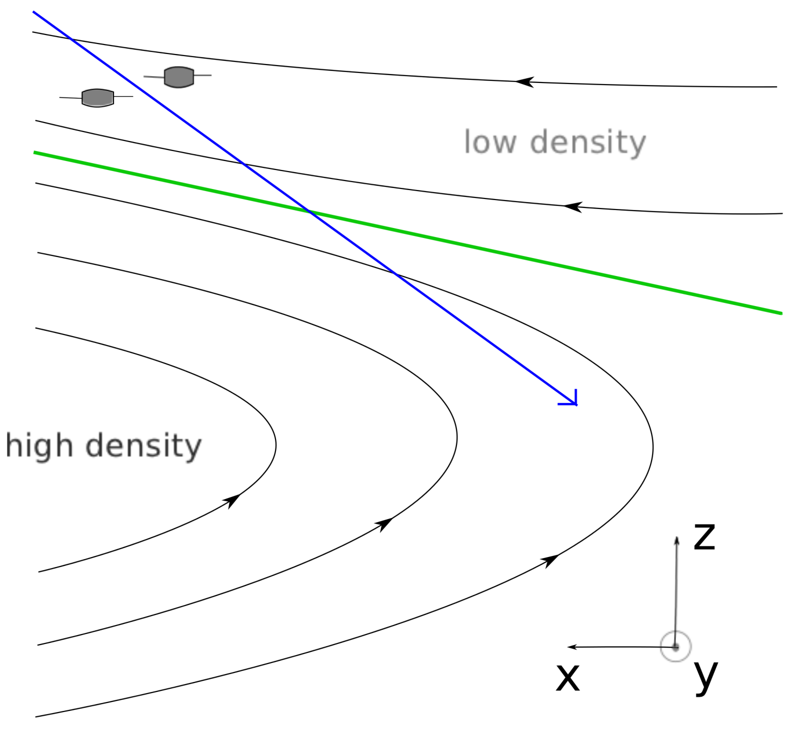
In laboratory (Fox 2010):

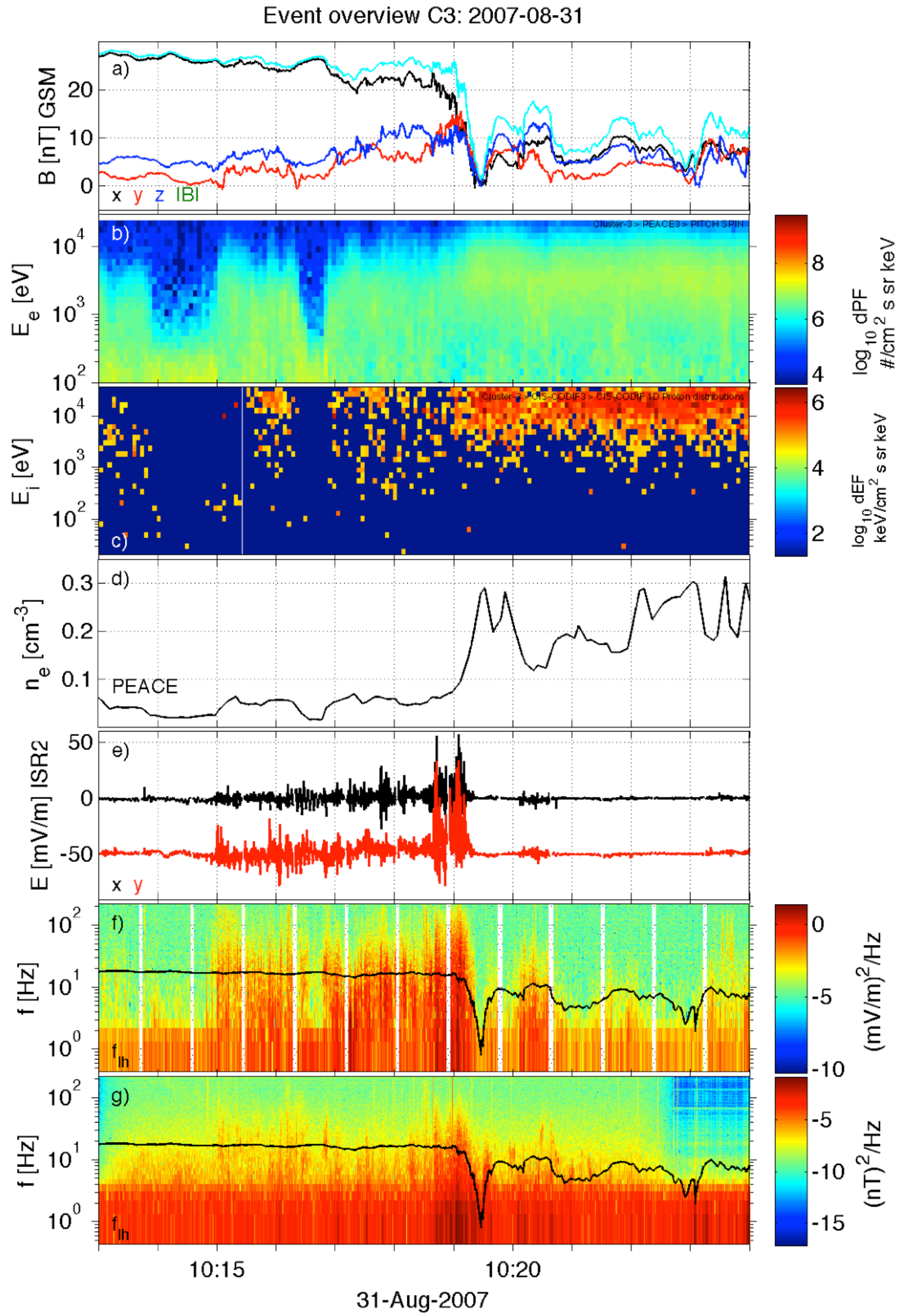
λ_{LH}= 1.2 mm
probe width 0.3 mm
separation 3 mm



August 31, 2007

Tail lobe → Plasma sheet

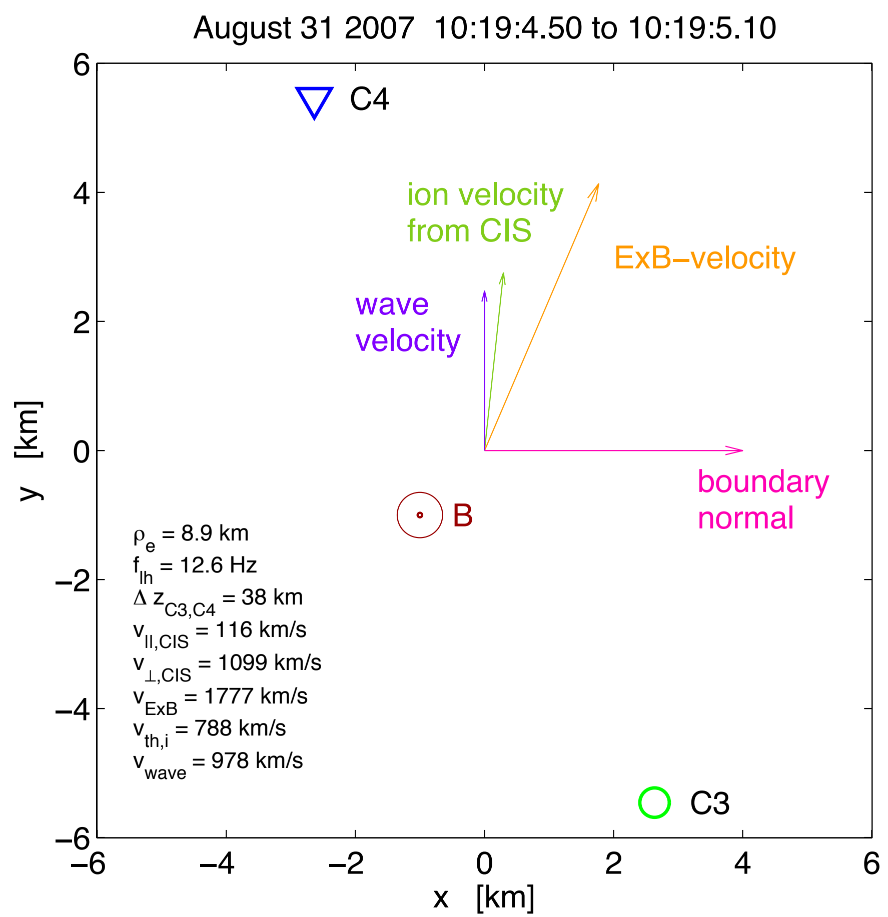




The event set up

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

➢ $\Delta y \approx 11$ km
➢ $\lambda_{LH} \approx 2\pi\rho_e \approx 56$ km

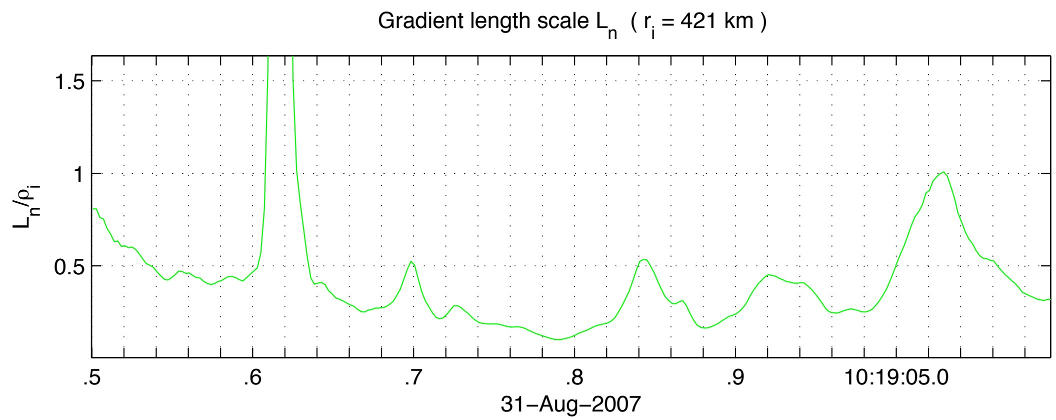


Are the conditions right?

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

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

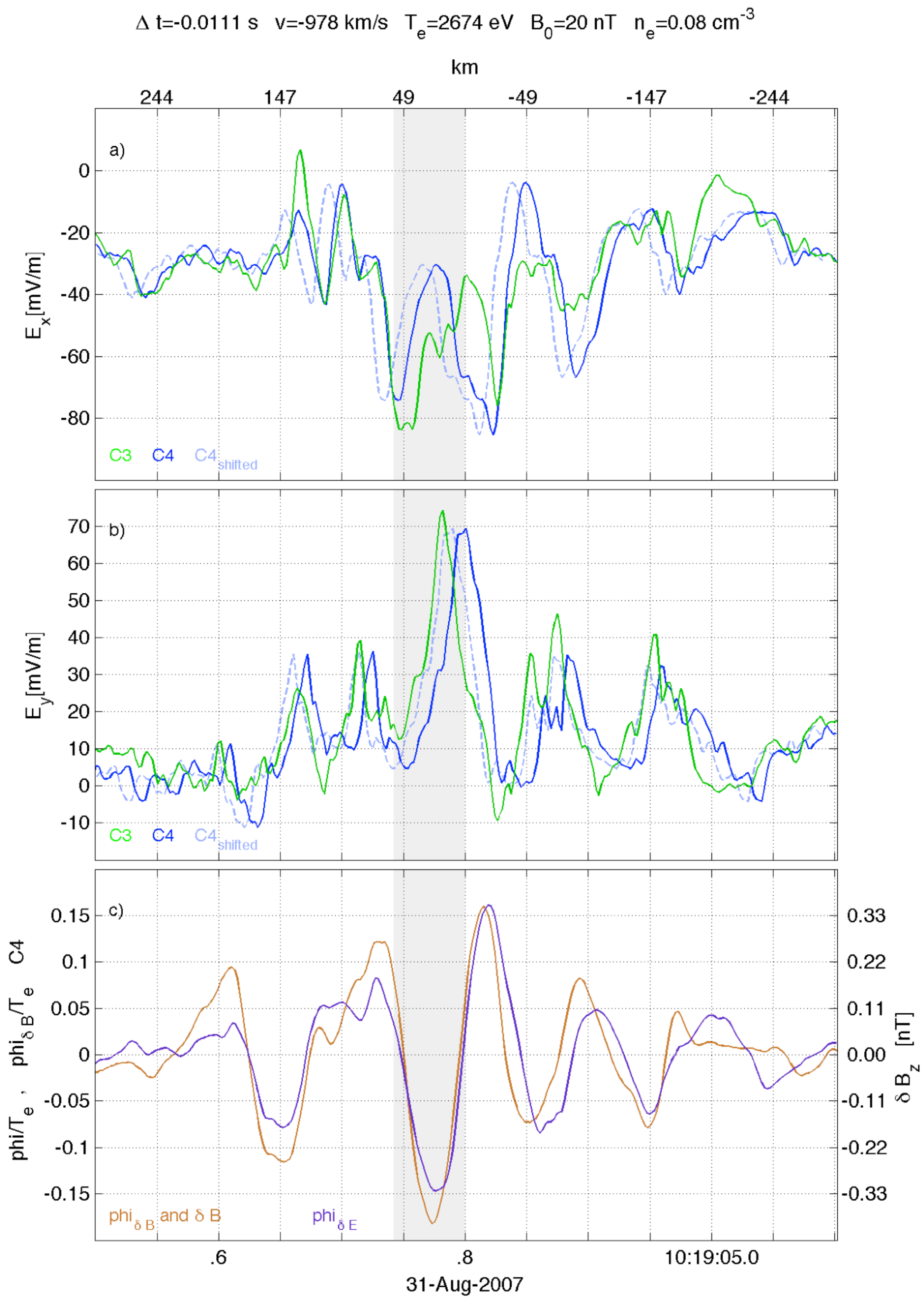
- Assumed total pressure balance



- Integration of ExB normal veloicty 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
  - λ ≈ 80 km



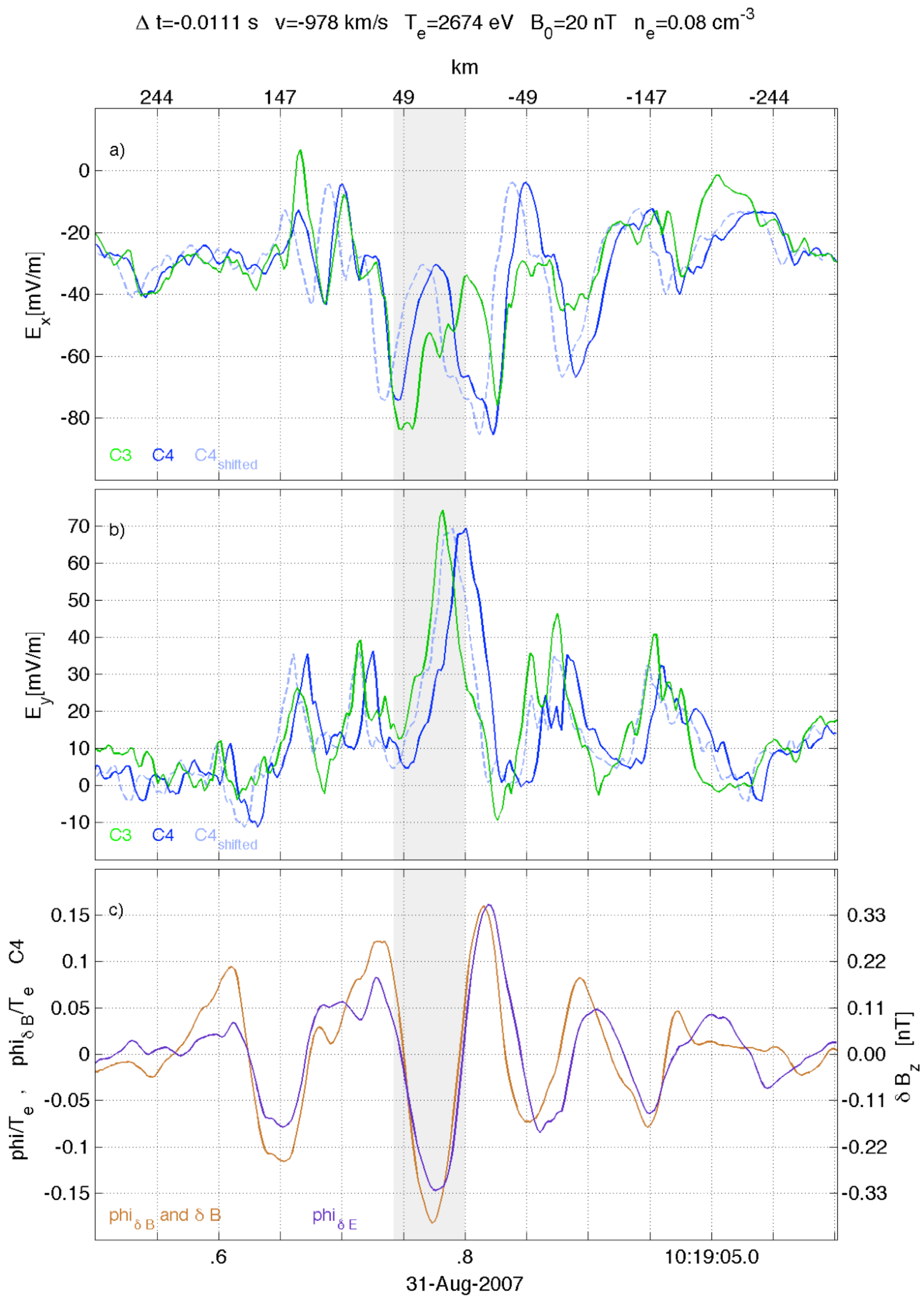
δE and ϕ

- We look how much the electric field is delayed between C3 and C4
  - ➢ v = 978 km/s
  - ➢ λ ≈ 80 km
- The electrostatic potential:

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

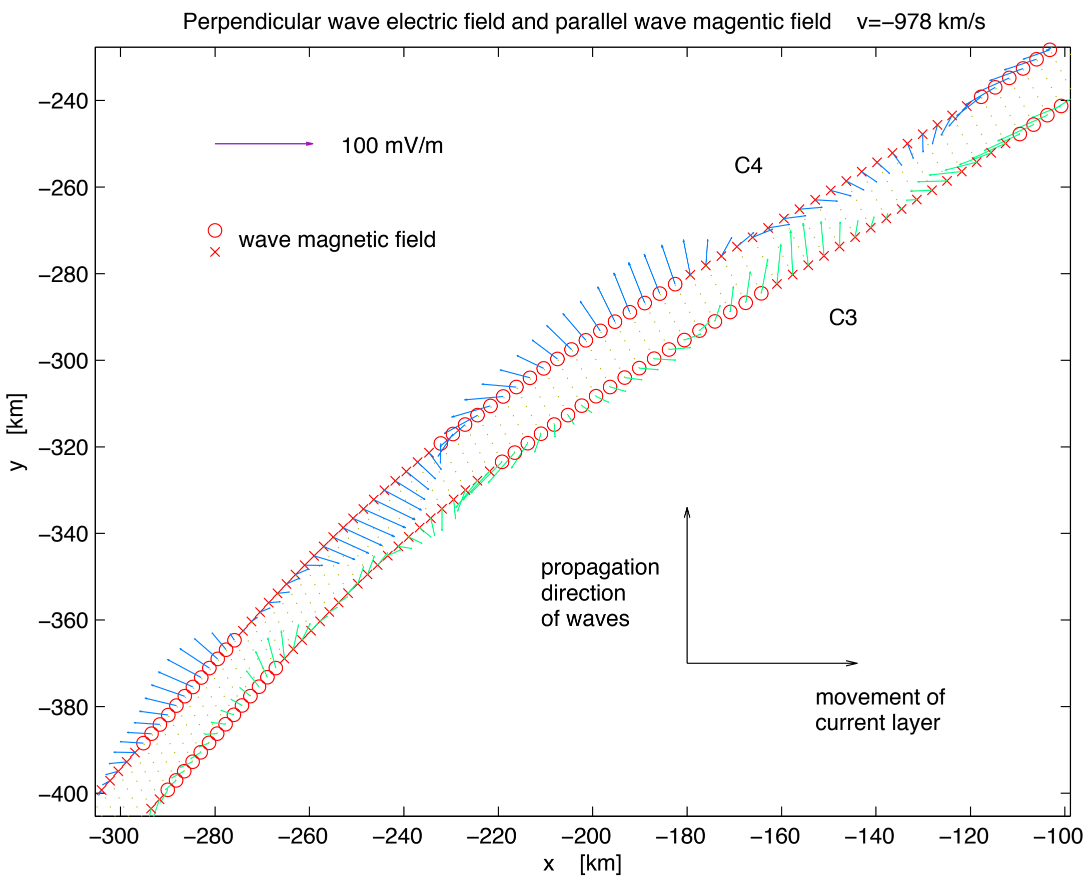
Integrate!

  - ➢ eϕ is 10-30% of $k_B T_e$
    The potential might affect the electrons!



δE in field aligned coordinate system

- ✓ δE_{perp} for each time step
- ✓ $\delta B_{||}$ for each time step
  - ➢ Repetitive pattern!



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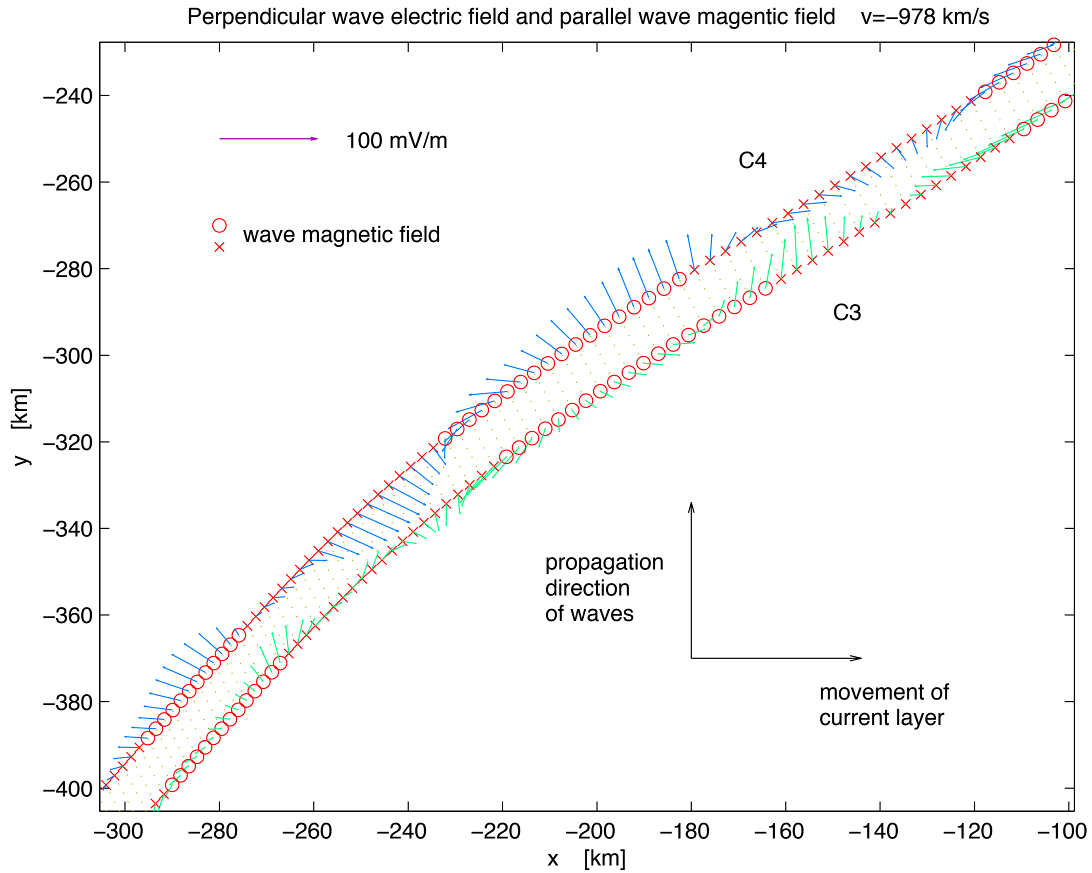
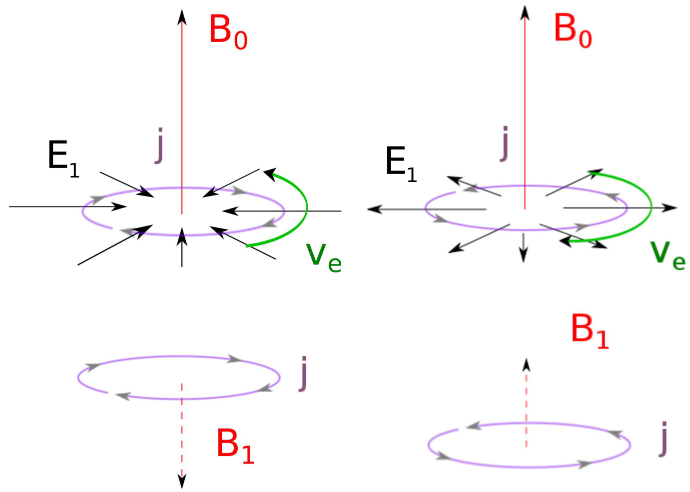


Ions unmagnetized:

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

$$\nabla \times B_1 = \mu_0 j$$

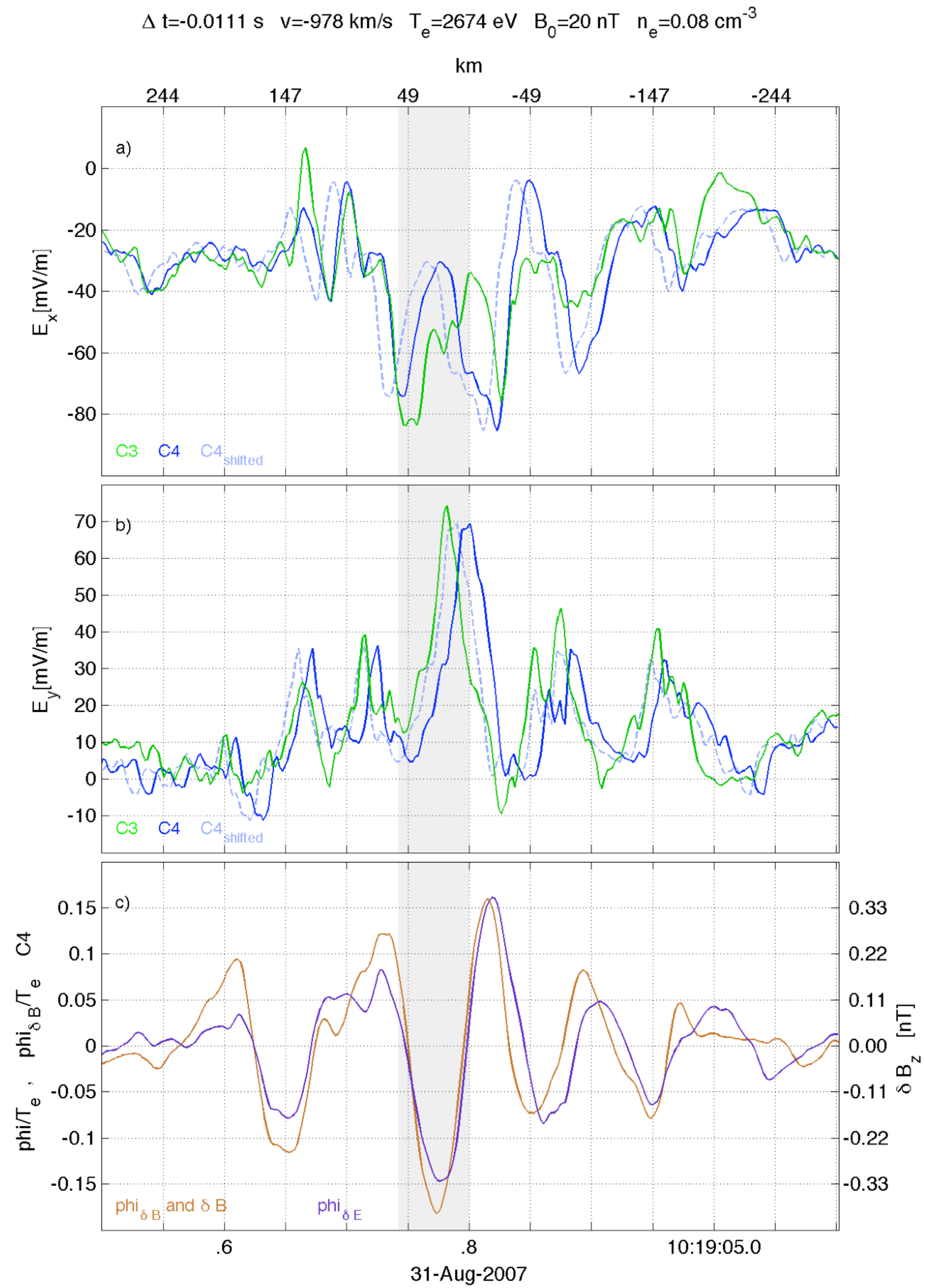


δB and ϕ

- 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

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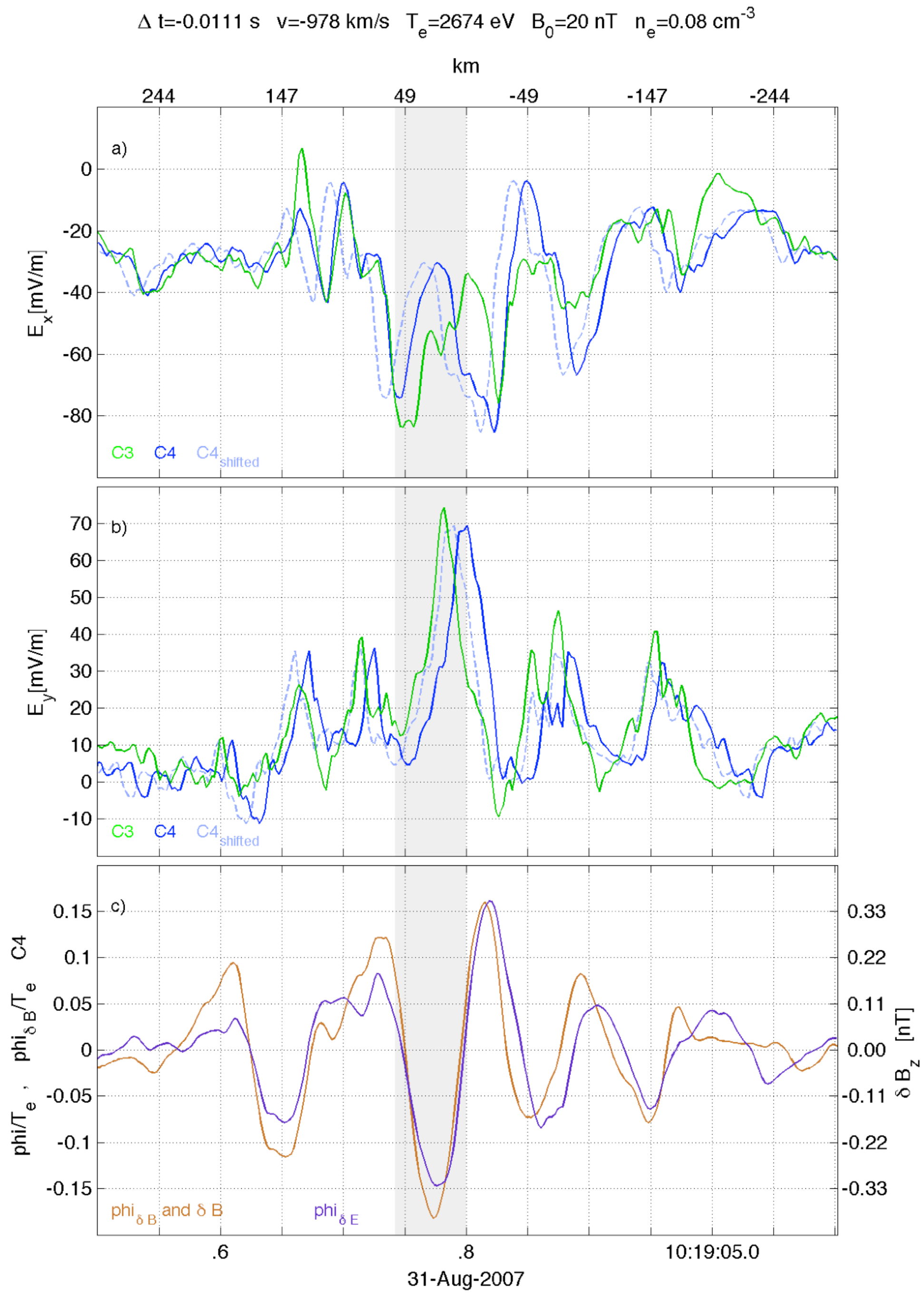
$$\phi_{\delta B} = \frac{B}{\mu_0 ne}\delta B$$

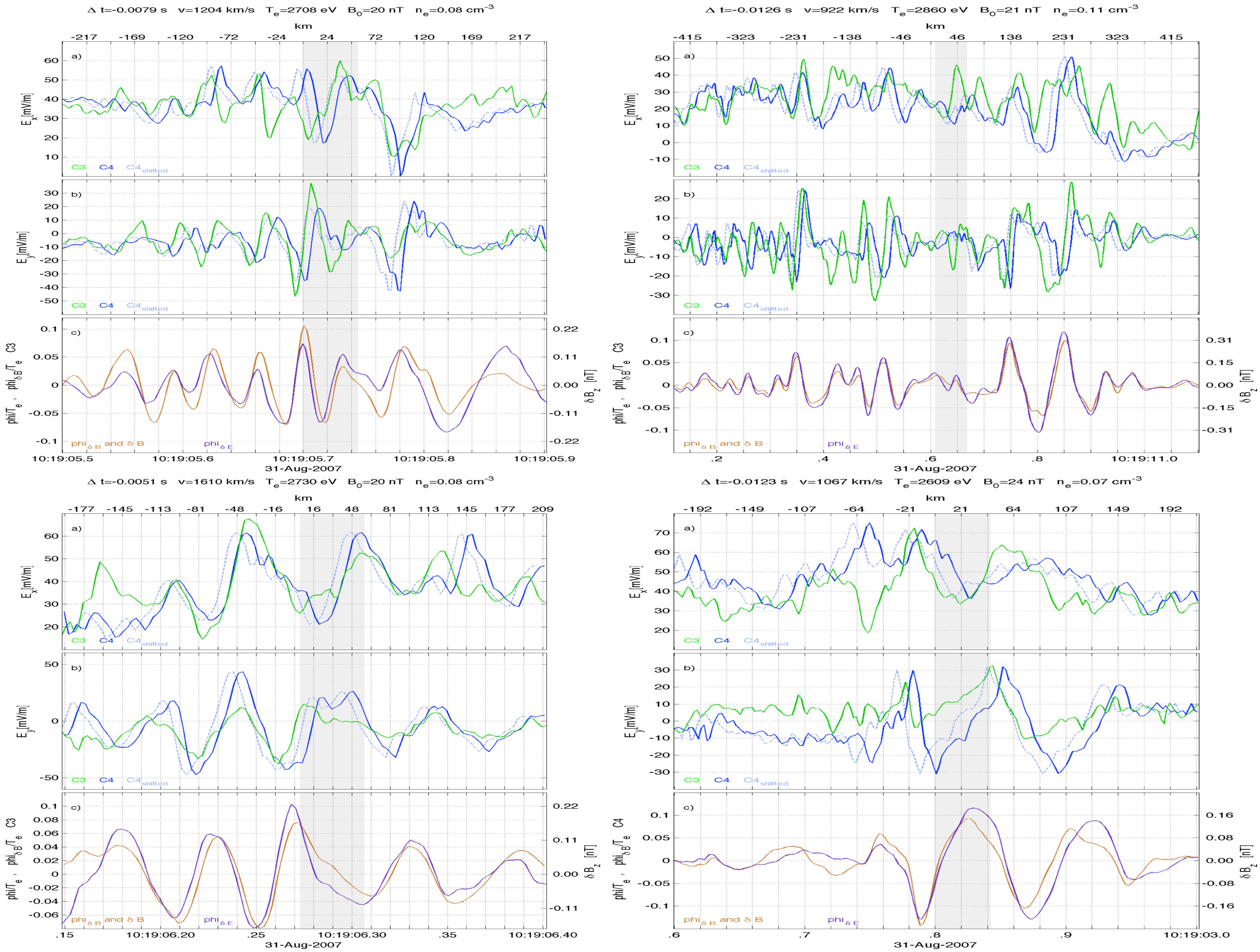
(via the reasoning on the last slide…)

✧ Very good correspondance!

- ✓ Verification
- ✓ Tool

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





Δ t=-0.0079 s v=1204 km/s Te=2708 eV Bo=20 nT ne=0.08 cm-3
km
-217 -169 -120 -72 -24 24 72 120 169 217
a)
Ex [mV/m]
C3 C4 C4shifted
b)
Ey [mV/m]
c)
phi/Te , phiδB/Te C3
δBz [nT]
phiδB and δB
phiδE
10:19:05.5 10:19:05.6 10:19:05.7 10:19:05.8 10:19:05.9
31-Aug-2007
Δ t=-0.0126 s v=922 km/s Te=2860 eV Bo=21 nT ne=0.11 cm-3
km
-415 -323 -231 -138 -46 46 138 231 323 415
.2 .4 .6 .8 10:19:11.0
31-Aug-2007
Δ t=-0.0051 s v=1610 km/s Te=2730 eV Bo=20 nT ne=0.08 cm-3
km
-177 -145 -113 -81 -48 -16 16 48 81 113 145 177 209
.15 10:19:06.20 .25 10:19:06.30 .35 10:19:06.40
31-Aug-2007
Δ t=-0.0123 s v=1067 km/s Te=2609 eV Bo=24 nT ne=0.07 cm-3
km
-192 -149 -107 -64 -21 21 64 107 149 192
phi/Te , phiδB/Te C4
.6 .7 .8 .9 10:19:03.0
31-Aug-2007

δB and δE

Electrostatic wave or not?

Faraday's law

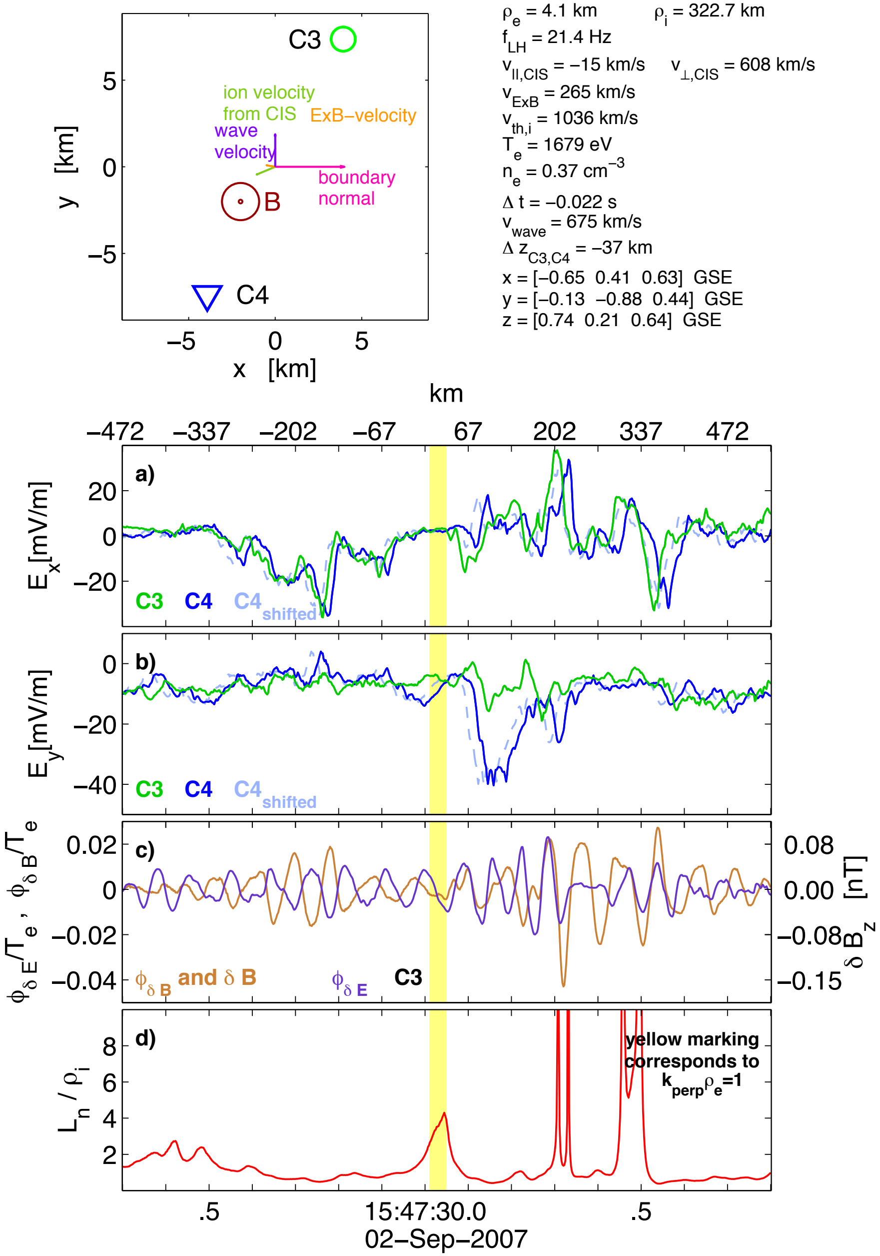
$$\frac{|E_1|}{|B_1|} = \frac{\omega}{k}$$ electromagnetic wave

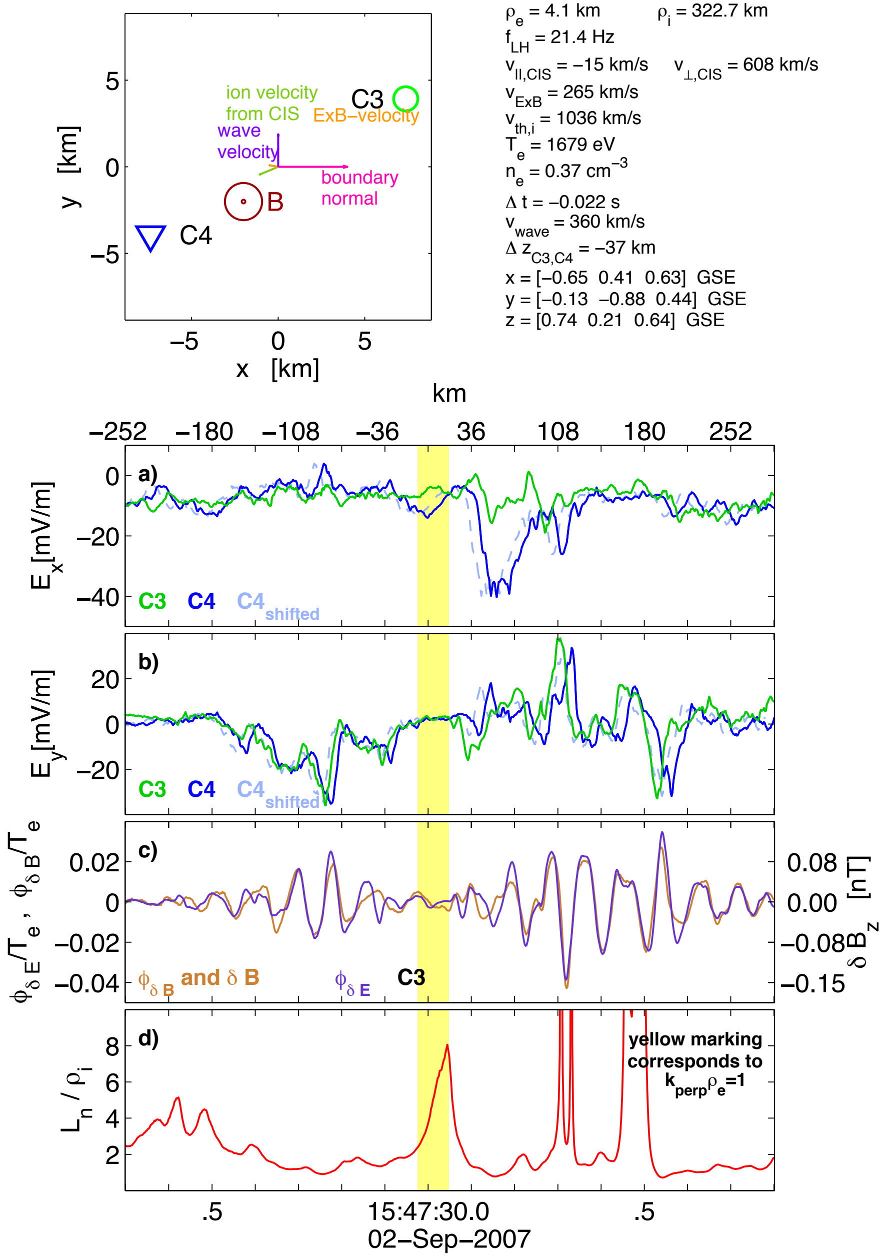
$$\frac{|E_1|}{|B_1|} >> \frac{\omega}{k}$$ electrostatic wave

We have $$\frac{|E_1|}{|B_1|} = \frac{60mV/m}{0.6nT} = 10^5 km/s$$

MVA n

cheating n



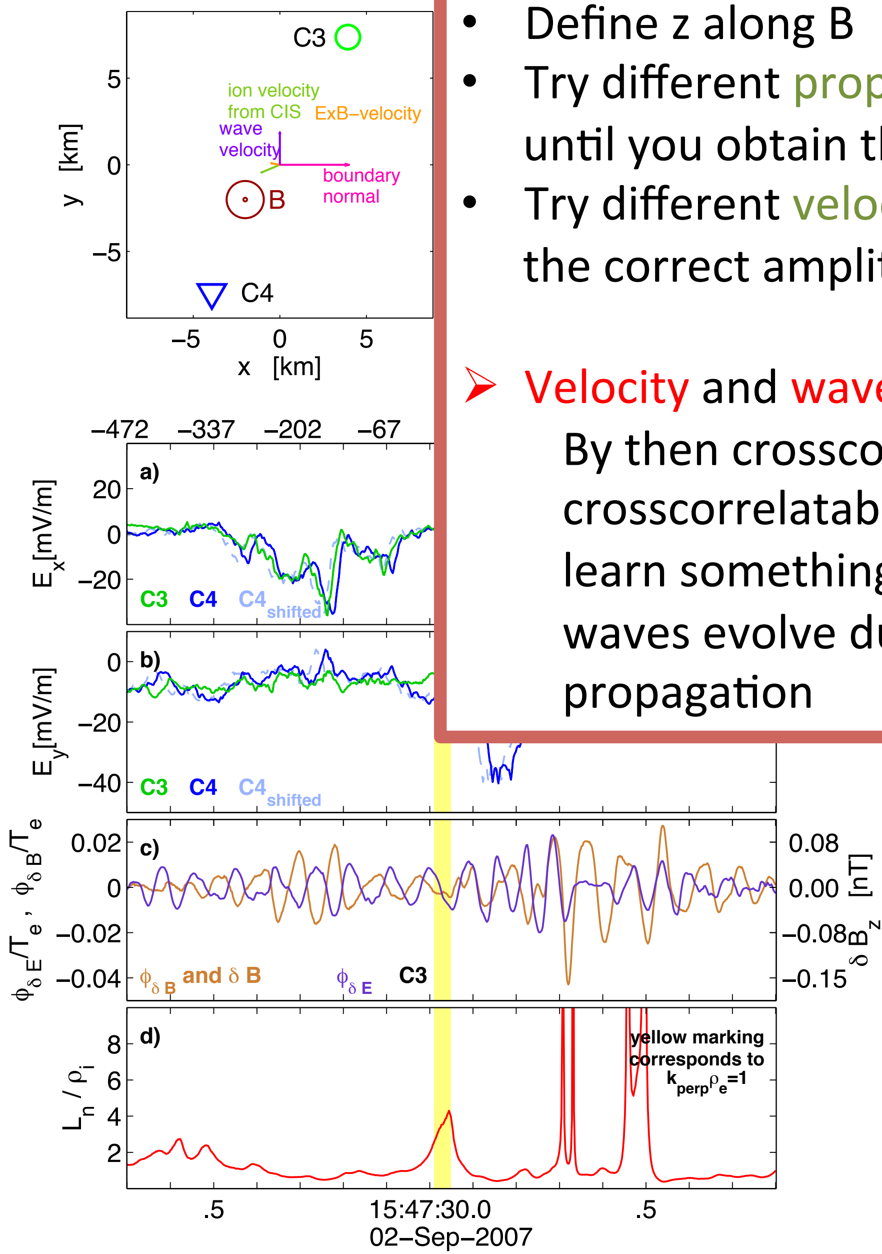


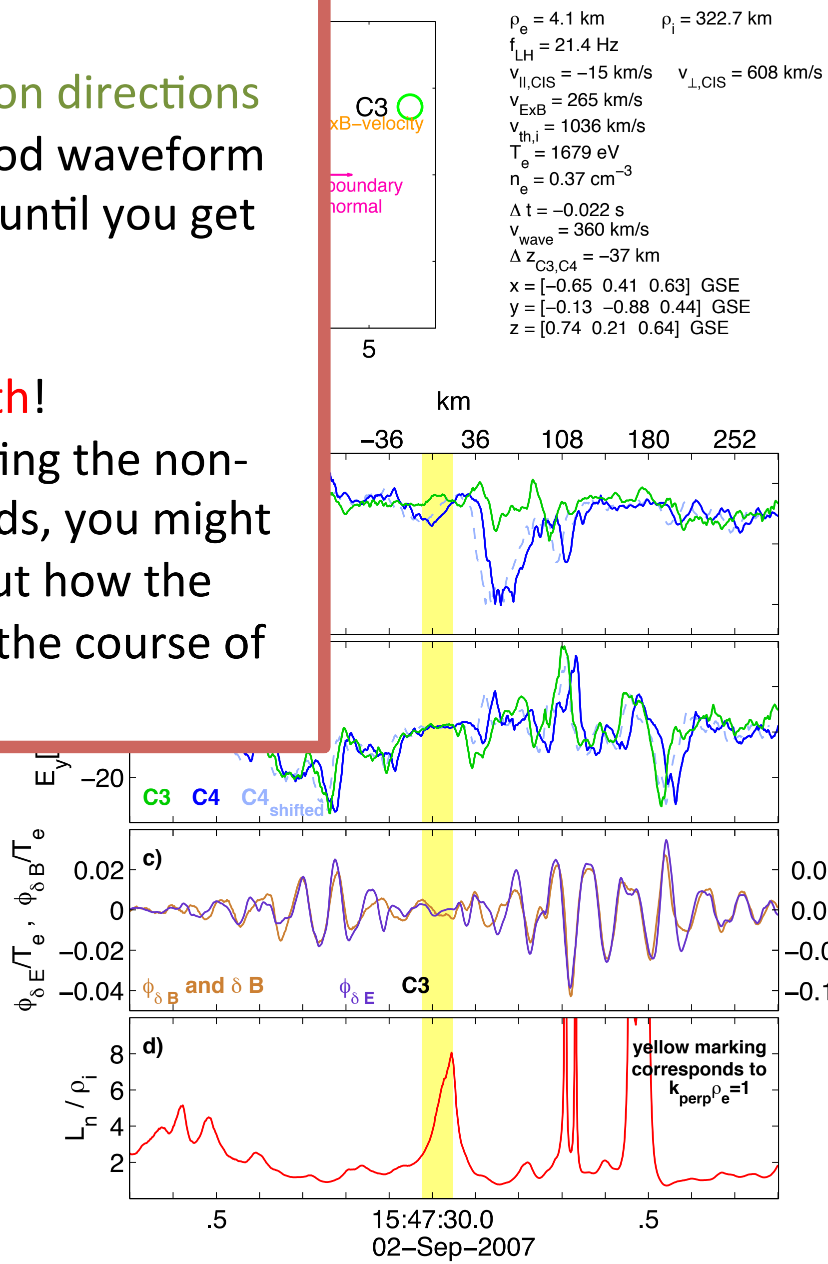
MVA n cheating n

- 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
- ϕ in a wider parameter space using δB

Summary

Short separation between spacecraft + burst mode + boundary layer

- ➢ Three events in all Cluster data!

- Velocity: $v_{wave} \approx 1000$ km/s — $v_{wave} \approx v_{ions}$
- Wavelength: $\lambda_{measured} \approx 50\text{-}100$ km — $\lambda_{measured} \approx \lambda_{theory}$
- Gradient length scale: $L_n/\rho_i \approx 0.5$ — $\%v_{Di}/v_i \approx \rho_i/2L_n \approx 1$
- Electrostatic potential: ϕ is 10-40 % of T_e
- Wave magnetic field: $\phi_{\delta B} \approx \phi_{\delta E}$
- Structure of wave: Vortices!