Experimental analysis of dispersion relations of EMIC triggered emissions

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COOPERATION

MAARBLE

Wave vector (*k*) measurements

- Motivation:
  - *k* is not directly accessible via instrumentation.
  - The wave vector is a key parameter to understand wave particle interaction processes.
  - The dispersion relation *ω (k)* is strongly dependent on the environment: without the full plasma composition parameters, it is not possible to properly estimate the wave vector in the inner magnetosphere (cf. *Silin et al.,* 2011)

- *k* estimations without assumptions about the plasma environment:
  - Multi-spacecraft analysis: k- filtering,…
  - Single-spacecraft analysis: Refractive index, Doppler shift.

k from single-spacecraft analysis: Refractive index (*n*)

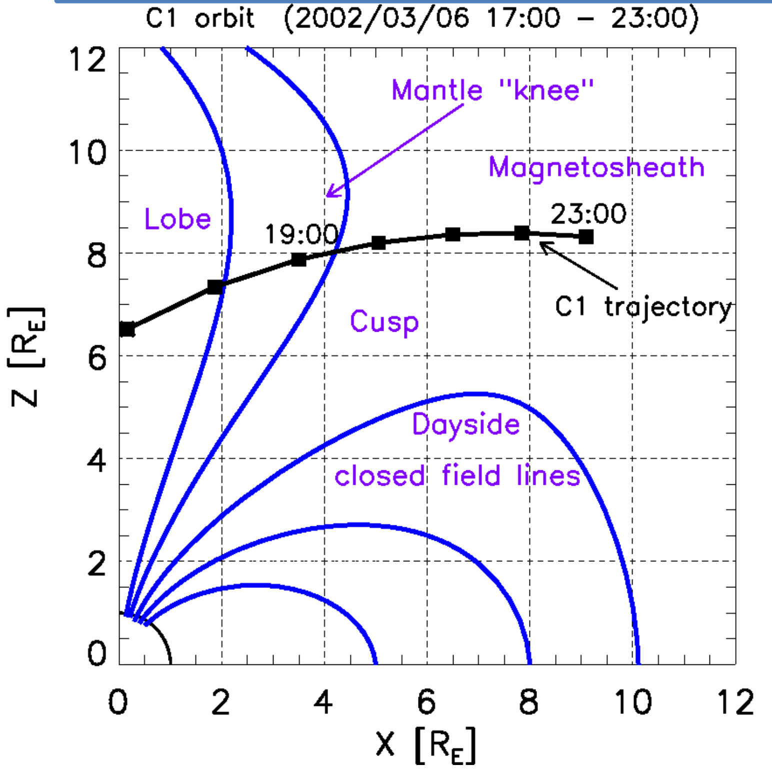
- *n* can be estimated from $\delta \mathbf{B}$ and $\delta \mathbf{E}$: $n (\boldsymbol{\kappa} \times \delta \mathbf{E}) = c\, \delta \mathbf{B}$
  - Assumption: $\mathbf{k} . \delta \mathbf{B} = 0$ to get the wave vector direction $\boldsymbol{\kappa}$
  - $n = kc/\omega$

- For real measurements in space plasmas, **only *n/Z* is accessible**, where *Z* is the impedance of the electric antenna/plasma interface.
  - Problem: *Z* often depends on plasma parameters which may vary.
  - The phase and the amplitude are strongly affected by a short antenna at high frequencies ($f > 32 kHz$) (*Santolík and Parrot*, 2000; *Parrot et al.*, 2001 – table 1):
    - Amplitude: Up to a factor of 10
    - Phase: Up to 70°

- And at low frequencies ? Cluster case studies of EMIC waves (*1Hz*)
  - *k* estimation : we assume $Z=1$
  - We compare these results to : *k* filtering analysis results

    Numerical calculations of wave stability (WHAMP)

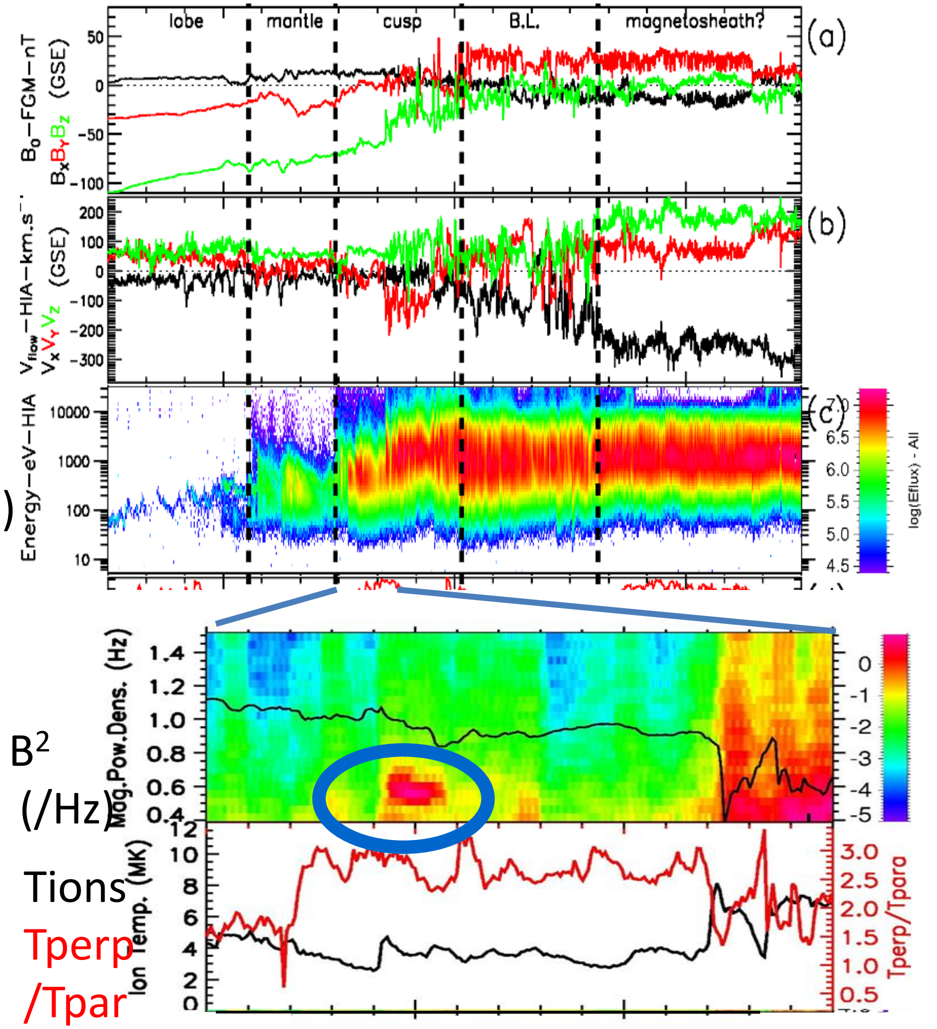
Cluster case study: 6th March, 2002 in the distant cusp region



B0

V flow

E (ions)



B^2 (/Hz)

Tions

Tperp /Tpar

19:30

19:45

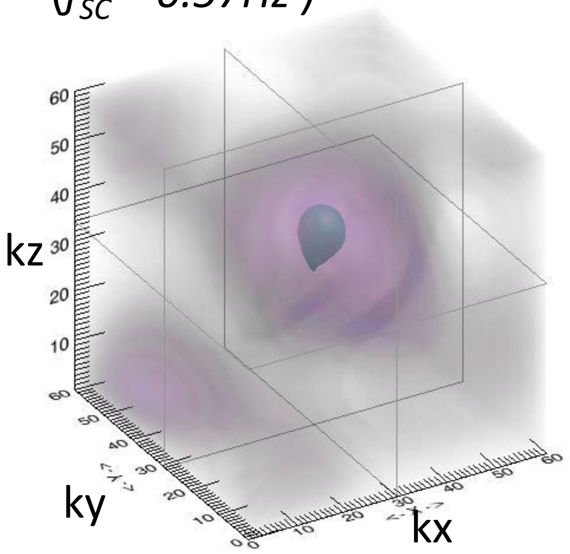
At 19h35: Waves are more intense than their usual levels in the plasma mantle :

What is the wavenumber of these waves?

Wavenumber estimations

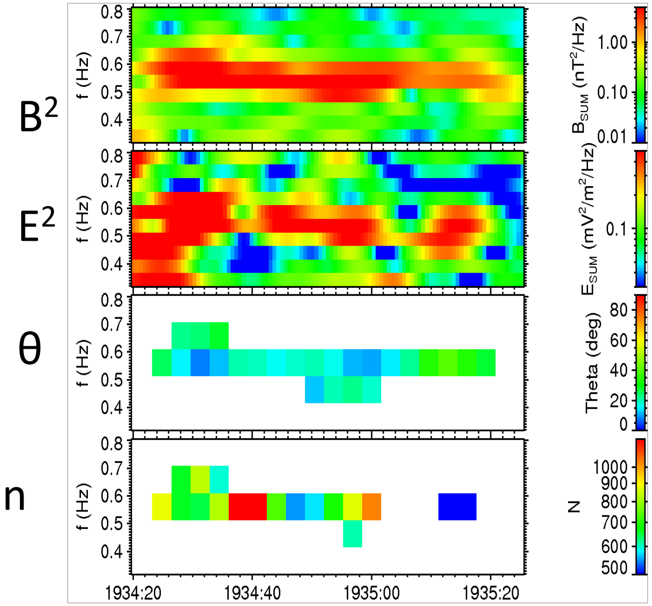
K filtering

Magnetic energy density:
(*f_{SC} = 0.57Hz*)



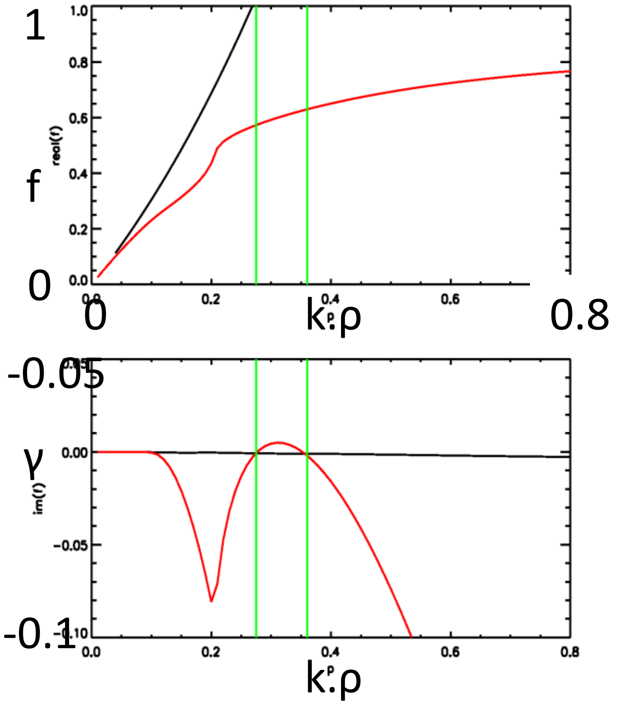
k ≈ 1.2 10^{-2} rad/km
Or
k.ρ ≈ 0.33
(ρ≈27km)

n



for n =775
k= 9.4 10^{-3} rad/km
(+/- 3.5 10^{-3} rad/km)
taking *ω*=2π*0.58 rad/s.

WHAMP



γ>0
for k.ρ in
[0.28,0.35]

Wavenumber estimations

- k.ρ ≈ [0.29 ; 0.33] (k filtering)
- k.ρ ≈ [0.18 ; 0.36] (refractive index)
- k.ρ ≈ [0.28 ; 0.35] (stability analysis)

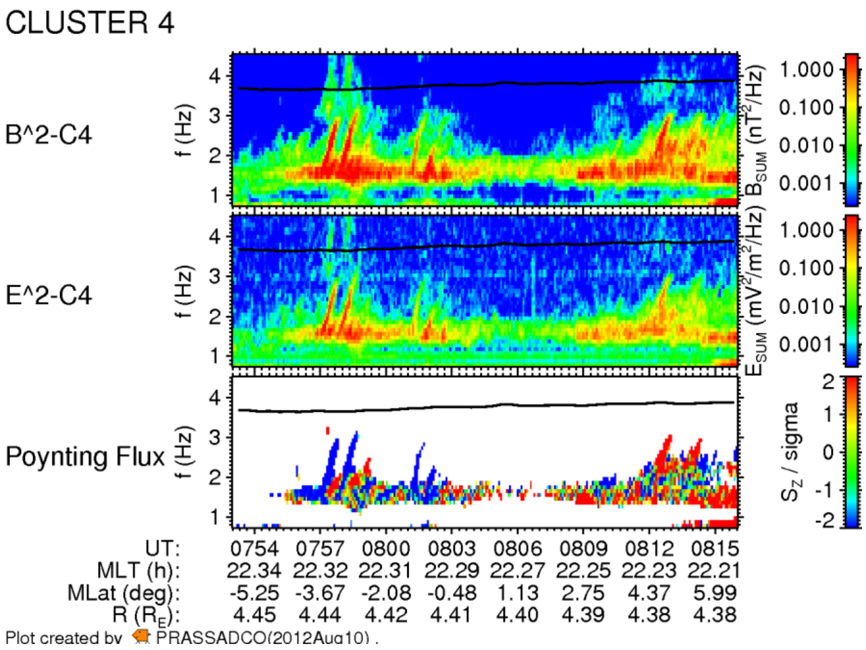
- All these methods provide similar results.

  The assumption *Z* ≈ *1* holds
- The refractive index analysis provides the lowest values: it suggests that *Z* is slightly larger than 1

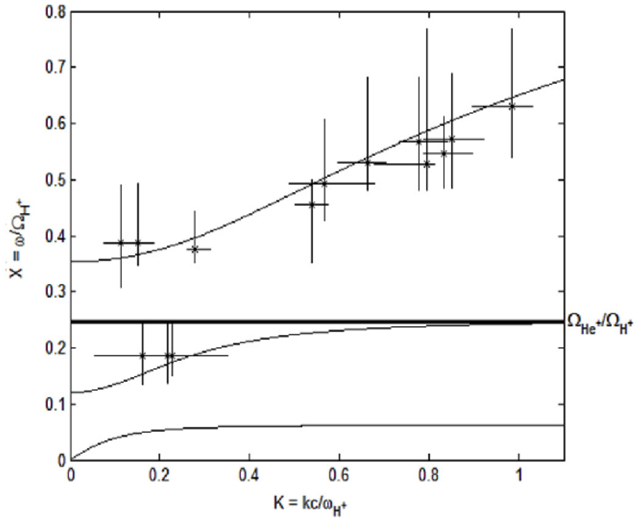
(*Grison et al.*, JGR, accepted)

In the plasmapause region: March 30th, 2002

- Cluster spacecraft crossed the nightside plasmapause in the magnetic equatorial region
- Well studied event (*Pickett et al.*, 2010; *Omura et al.,* 2010; *Shoji et al.*, 2001; *Grison et al.*, 2013; *Pakhotin et al.*, 2013)
- *Z* is sensitive to the plasma environment. Does the dense and cold plasma at the plasmapause affect *Z*?



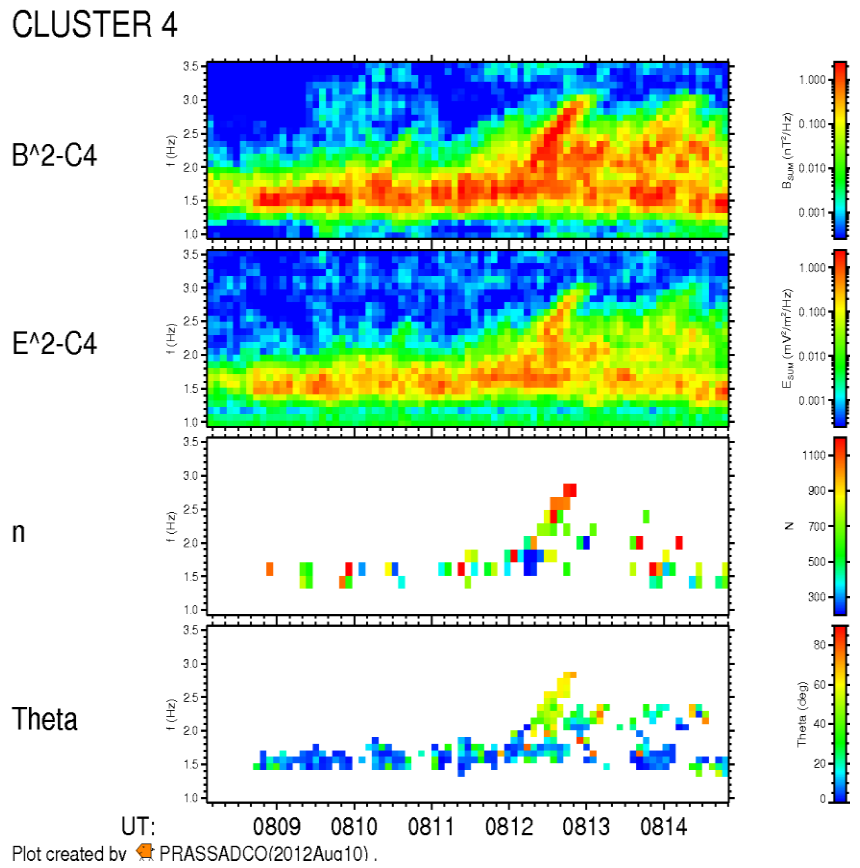
from *Pickett et al.* (2010)



Pakhotin et al., 2013

Observed dispersion relation of EMIC triggered emissions

- EMIC triggered emissions: Coherent emissions that display increasing frequency with time (rising tone)
- We select the widest rising tone among the large ones.



<u>Analysis of the selected rising tone:</u>

Experimental dispersion relation via the refractive index (assuming *Z*=1)

Comparison with the EMIC L-mode in the proton branch (WHAMP numerical calculations)

<u>Local conditions:</u>

Densities (per cc): n_{e-} =200 n_{H+} =156 n_{O+}=19 n_{He+}=19 n_{hotH+}=6

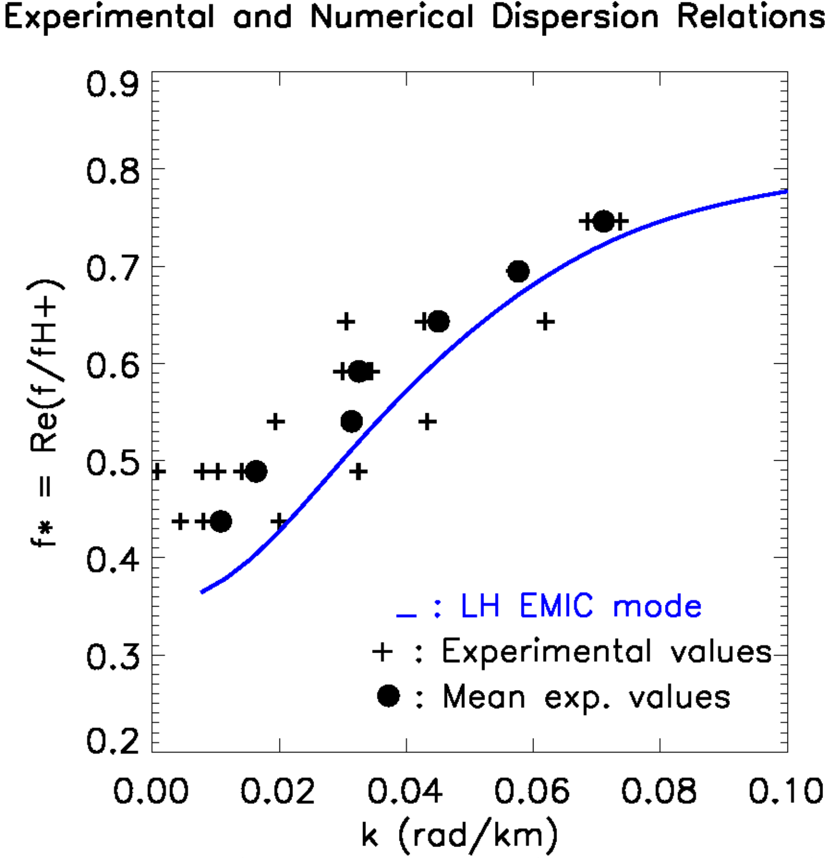
|B|=260nT f_{H+}=3,9Hz

Proton Larmor radius: 8km

<u>We test the influence of the :</u>

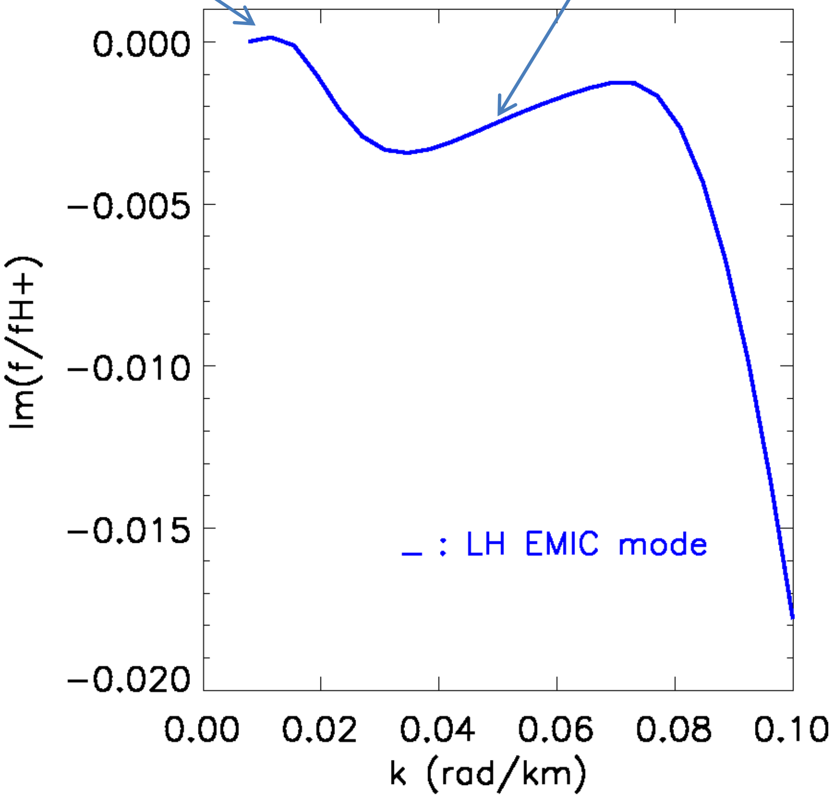
- ○ Cold plasma temperature and composition
- ○ Wave normal angle (theta)
- ○ *Z*

Analysis of a rising tone



Region of classical EMIC wave growth

Triggered emissions reach high frequencies due to non linear processes (*Omura et al.*, 2010)

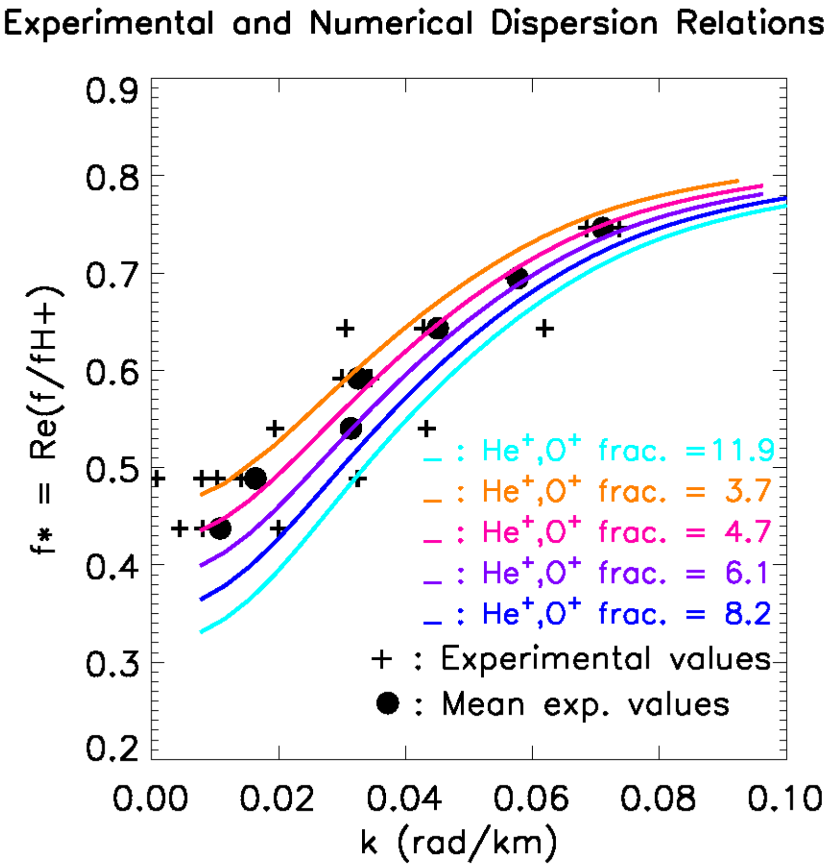


-Experimental and Numerical dispersion relations have a **similar evolution**.

- **The refractive index method works well** in the plasmasphere (to obtain k).

- **Experimental k values are slightly lower** than the numerical ones.

Influence of the plasma composition

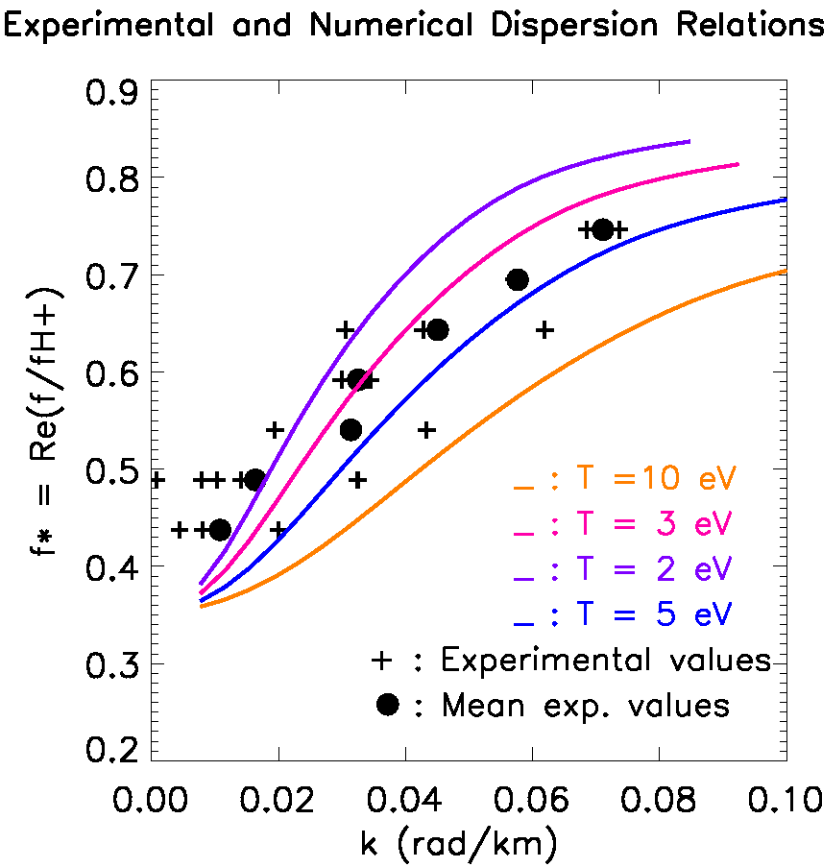


We define the fraction in the following way: n_{H+}/n_{O+} and n_{H+}/n_{He+}

In the present case, observed fractions are estimated via the low frequency cut-off of the EMIC waves (*Pickett et al.*, 2010).

A Higher density of O^+ and He^+ can explain the discrepancy between the observations and WHAMP results (fraction=4.7).

Influence of the core ion temperature

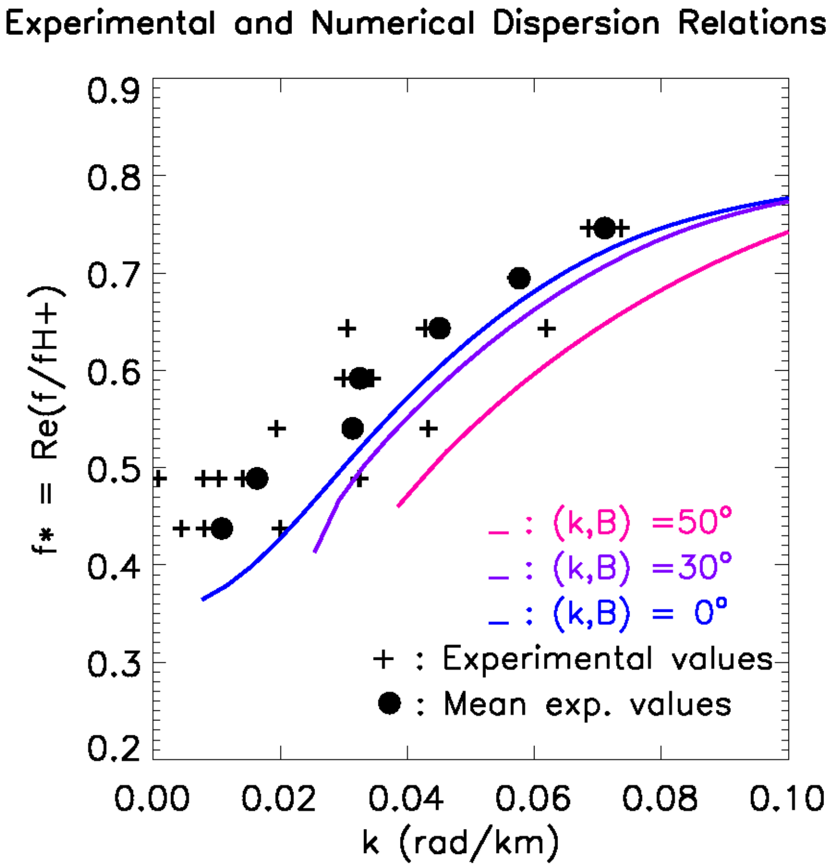


CLUSTER instruments miss a large part of the cold ion population (with a temperature lower than 27eV)

The dispersion relation is very sensitive to the temperature.

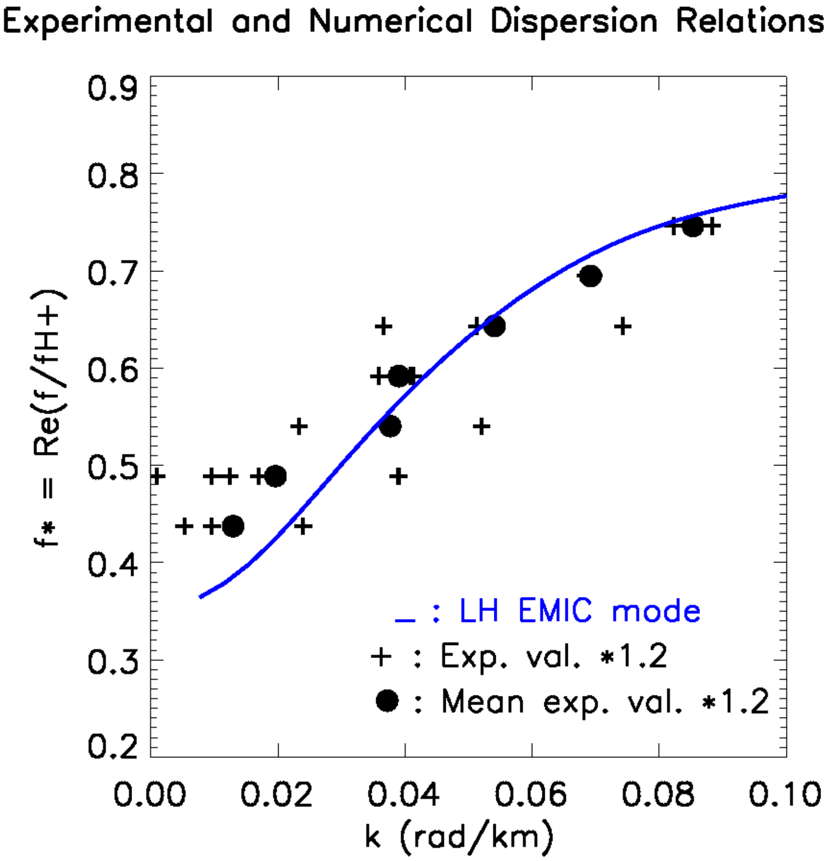
A single temperature model doesn't match the whole experimental dispersion.

Influence of the propagation angle

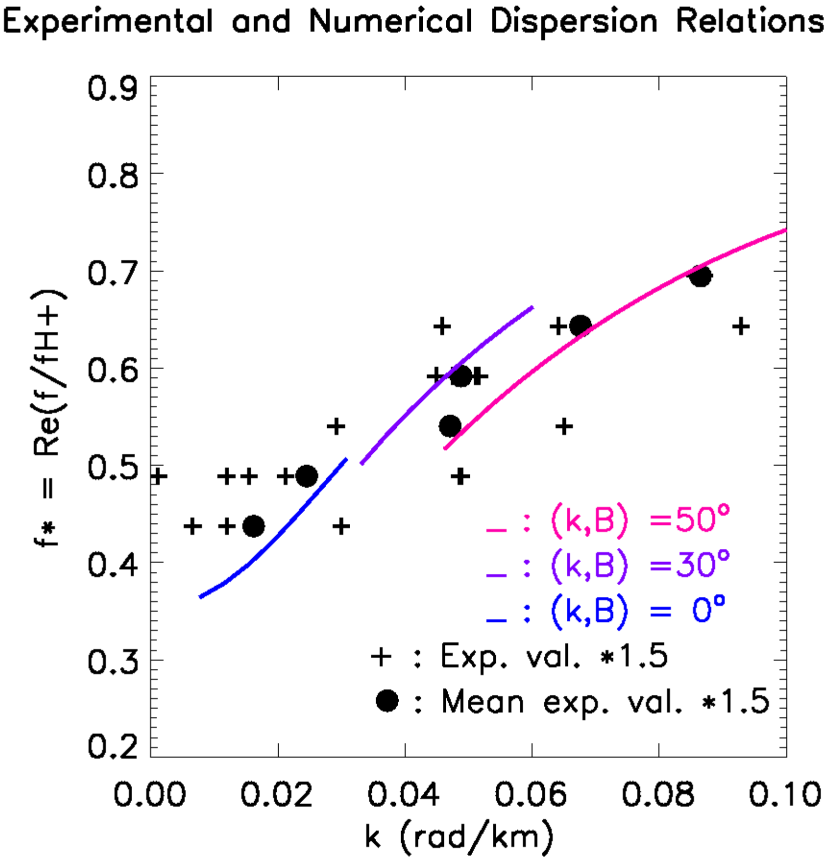


Up to theta = 30°, the (numerical) dispersion relation does not substantially change

Influence of the impedance (Z≠1)



Z=1.2 shows the best match



Taking into consideration the observed propagation angles (*low (high) at low (high) frequencies):*

Z=1.5 shows the best match

Summary and Conclusions

We estimated wavenumbers of EMIC waves via:

- single spacecraft analysis (refractive index) using δ**E** and δ**B** measurements

The comparisons of the observation to the numerical dispersion relation show that the method works well in the plasmasphere region ($Z \approx 1$**).**

- From Cluster observations, we can consider **(**$Z < 1.5$**)**. The impedance *Z* of the electric antenna - plasma interface is low in the ULF range.
- This is similar to the values found in a low density region (*Grison et al.*, accepted)
- The main uncertainty is the core plasma temperature. Need to apply this method to other spacecraft missions.
- The observed propagation angles increase with frequency. A similar effect on the wavenumbers is found in the observations and in the numerical calculations
- This method offers a powerful way to obtain wavenumbers of coherent EMIC emissions.
- Wavenumbers measurements are important to study the wave particle interactions in the radiation belts.