Cluster observations of magnetosonic waves in the inner magnetosphere

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Outline

- Characteristics of EMW
- Cluster observations of banded emissions
- Dispersion
- Rising tone EMW
- Non time-continuous EMW
- Applicability of quasi-linear theory

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Magnetosonic waves

Various names

- Equatorial noise – original OGO-3 observations
- Magnetosonic – from dispersion – low frequency merges with fast magnetosonic branch
- Ion Bernstein mode – emission at discrete frequencies

Characteristics

- Frequency range $\Omega_p < \omega < \omega_{LH}$
- Discrete frequency spectrum – $n\Omega_p$
- *k-vector* almost perpendicular to B_0
- ΔB, wave magnetic field, parallel to B_0 , high compressibility
- Highly elliptical polarisation

Source

- Ring or shell proton distributions with positive df/dv_{perp}

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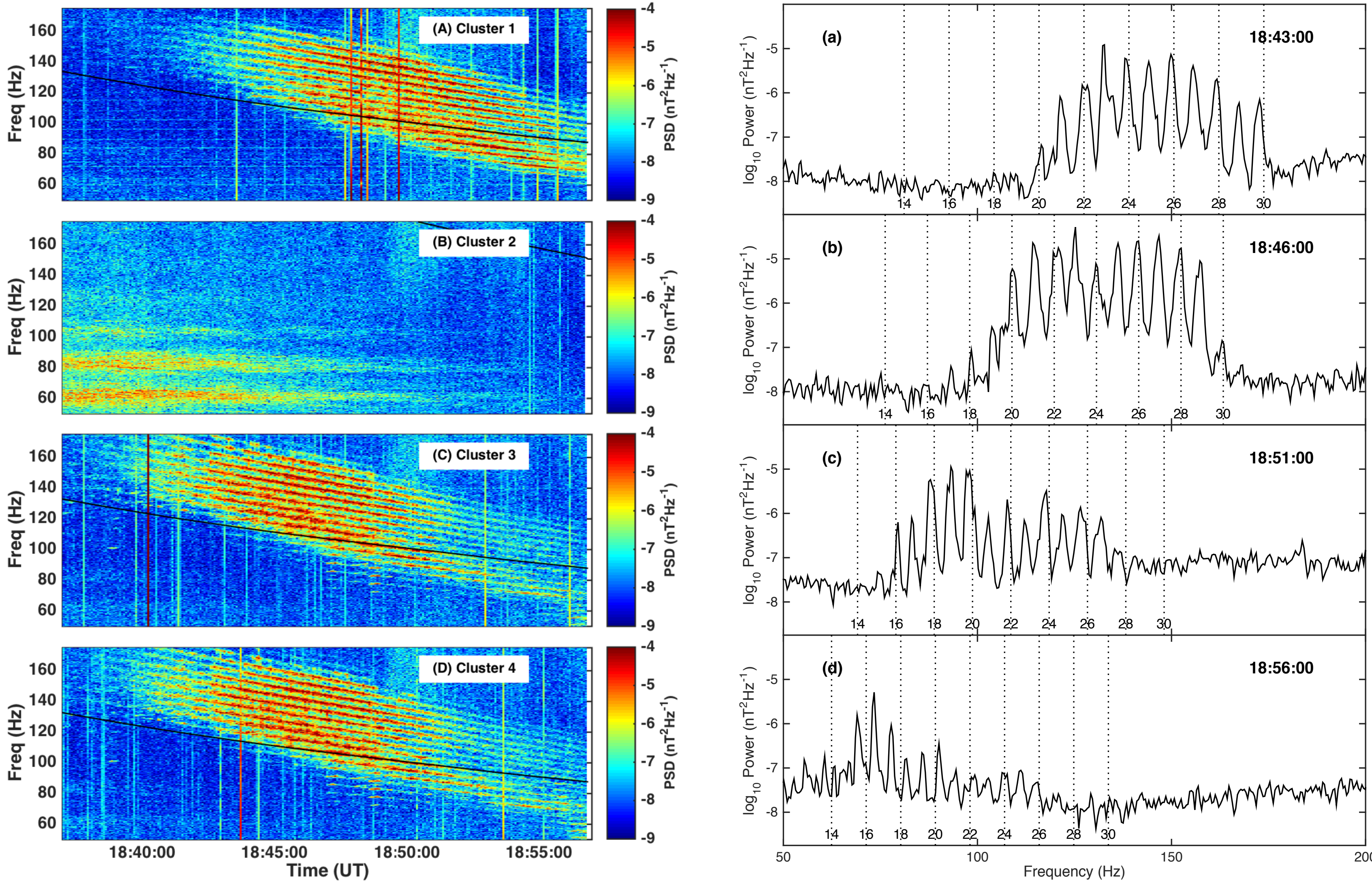
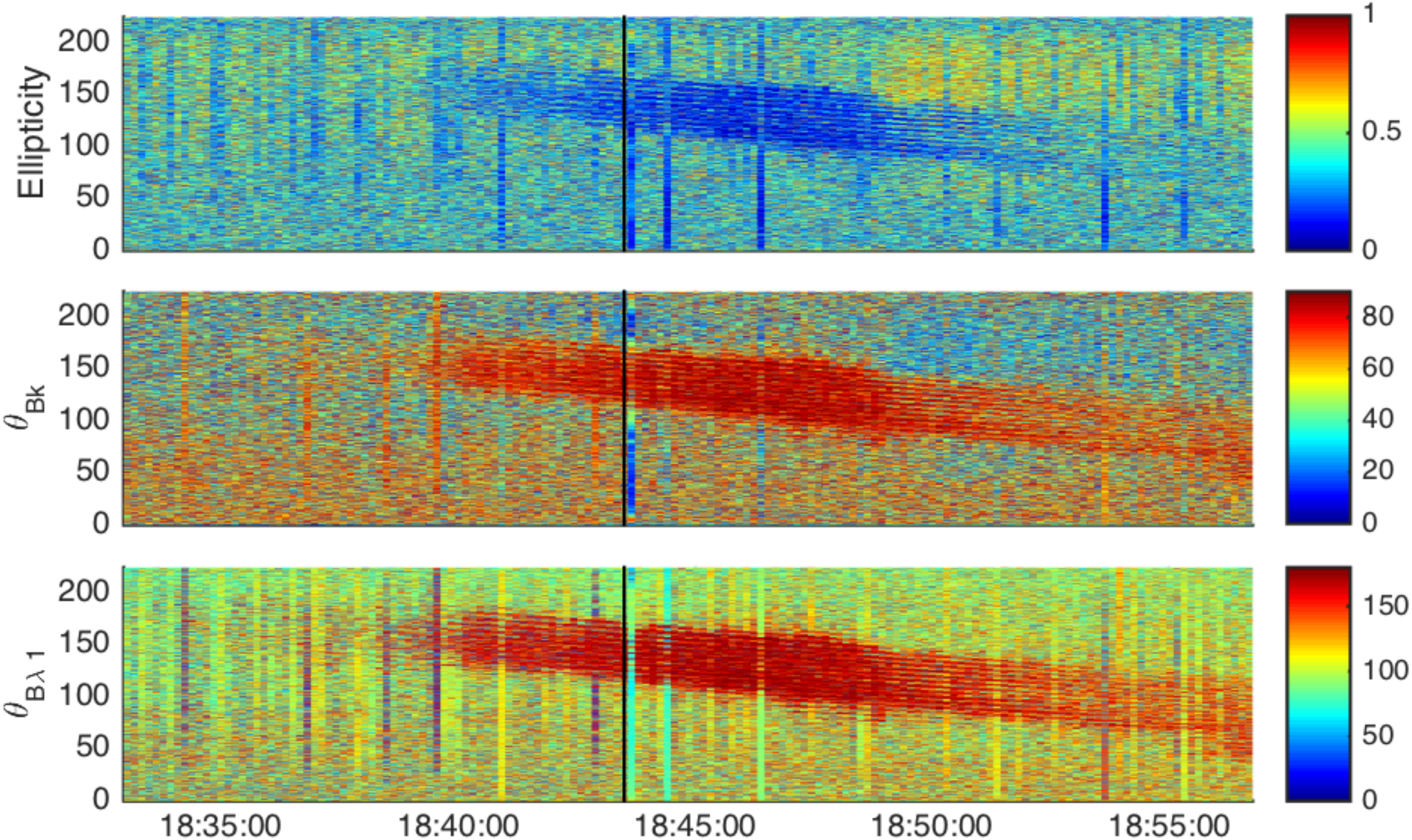
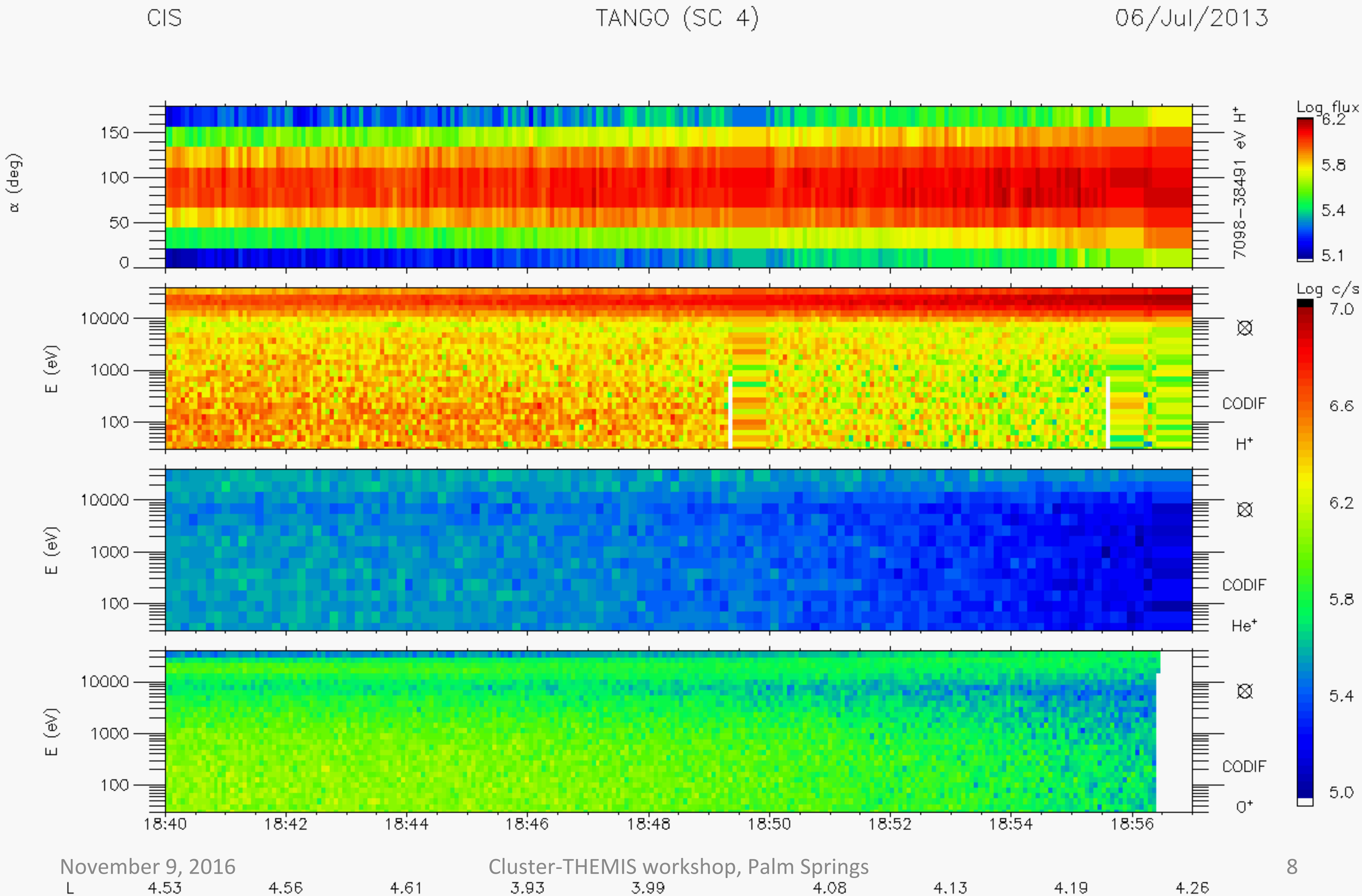
Cluster observations



Wave properties



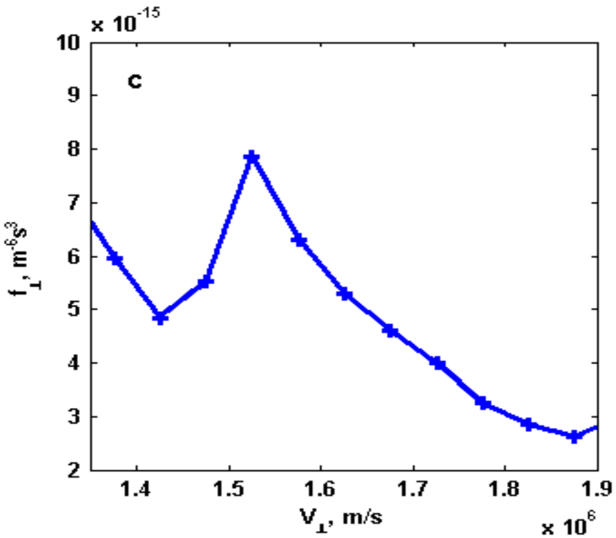
CODIF Ions

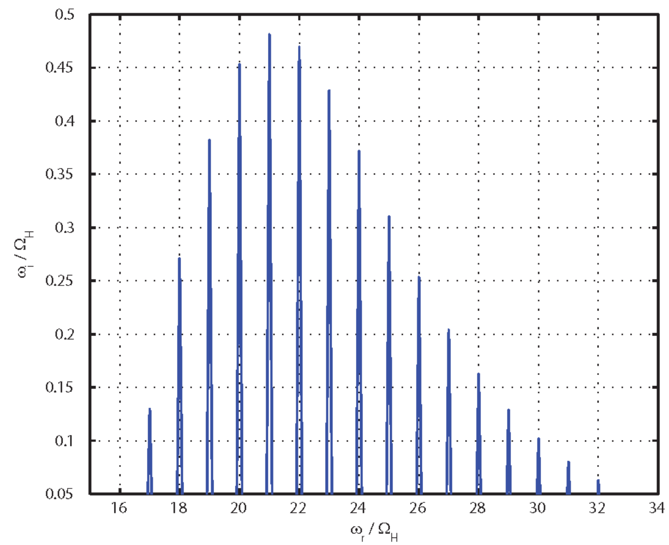


CIS
TANGO (SC 4)
06/Jul/2013
α (deg)
150
100
50
0
7098–38491 eV H+
Log flux
6.2
5.8
5.4
5.1
E (eV)
10000
1000
100
CODIF
H+
He+
O+
Log c/s
7.0
6.6
6.2
5.8
5.4
5.0
18:40
18:42
18:44
18:46
18:48
18:50
18:52
18:54
18:56
L
4.53
4.56
4.61
3.93
3.99
4.08
4.13
4.19
4.26

Liner growth rate

- Express as sum of different harmonics of an integral over perpendicular velocity that depends on the gradients of ion phase space density in the velocity space





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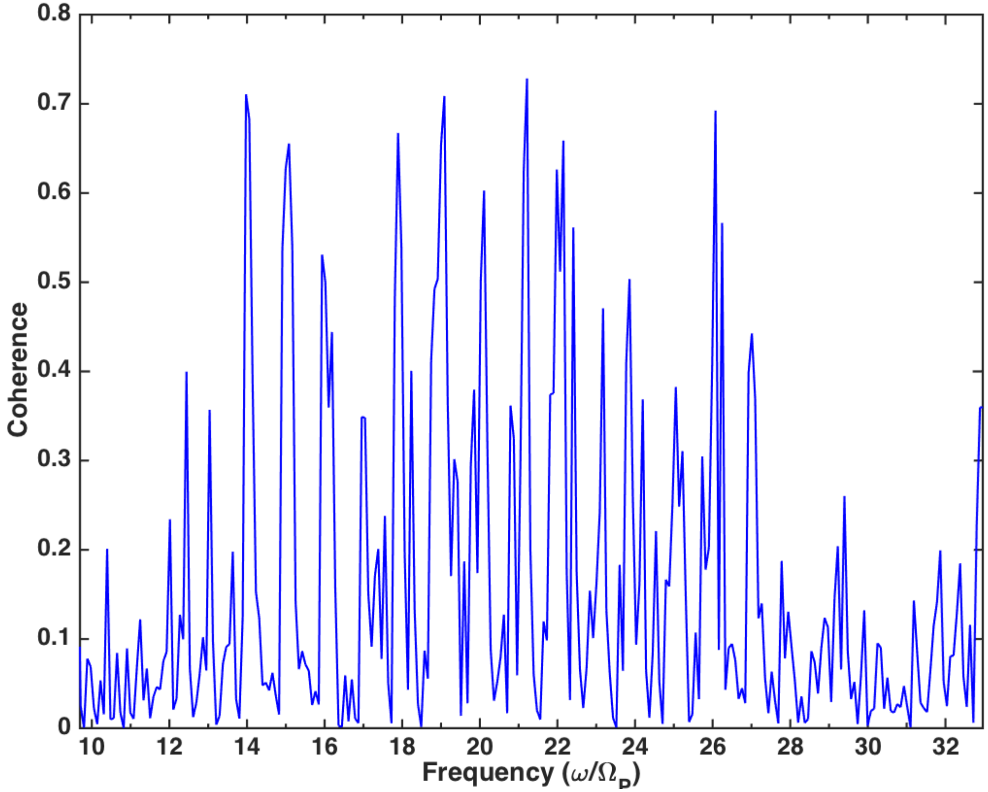
Coherence



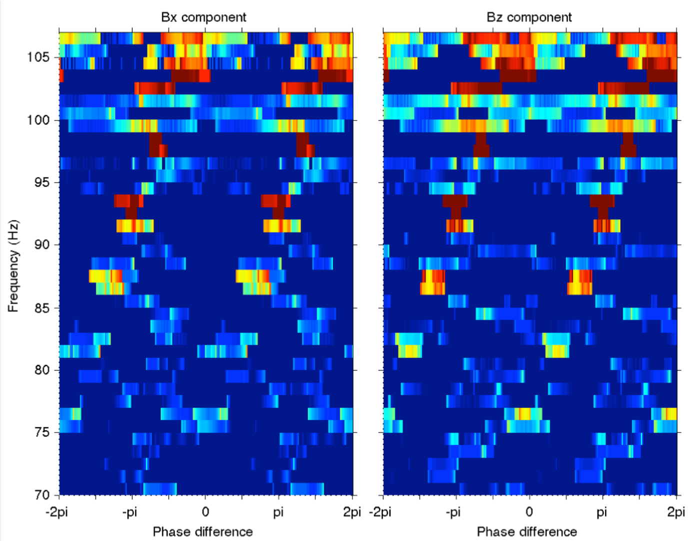
Coherence of measurements between satellites 3 and 4

Separation C3-C4 60 km

At harmonics of proton gyrofrequency coherence is high, typically ~0.7

High coherence suggests that satellite separation distance is less than the coherence length of waves

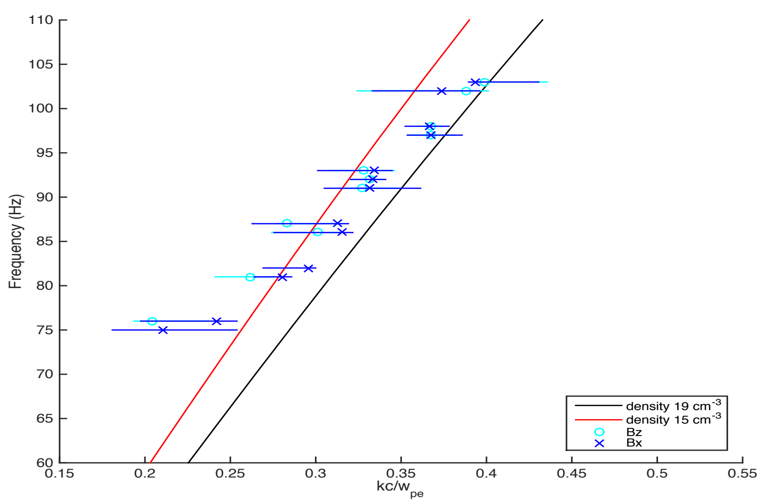
Dispersion



Dispersion estimated using phase differencing method in which phase shift between two measurements is proportional to the wave *k-vector* along the measurement separation vector

$\Delta\psi(\omega)=|k||r|\cos(\theta_{kr}) + 2n\pi$

k-vector direction determined using MVA



Comparison of experimental dispersion with theoretical cold plasma dispersion.

Lines indicate limits of density from WHISPER observations

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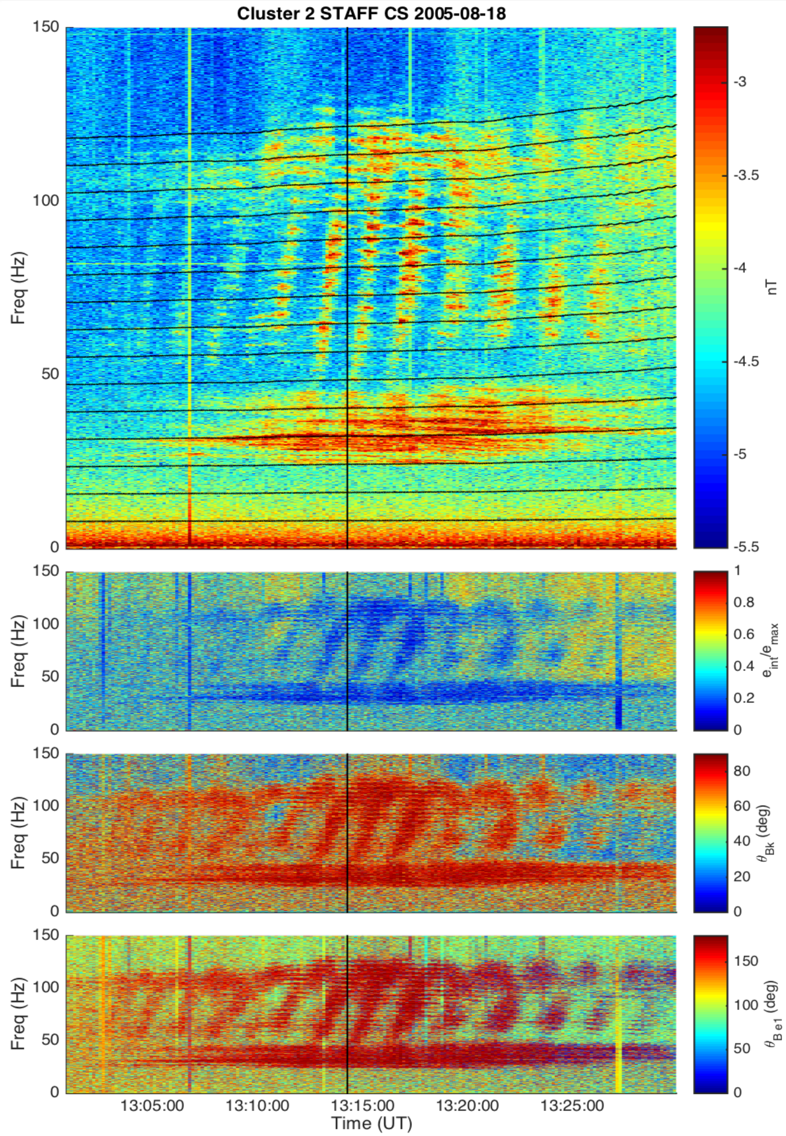
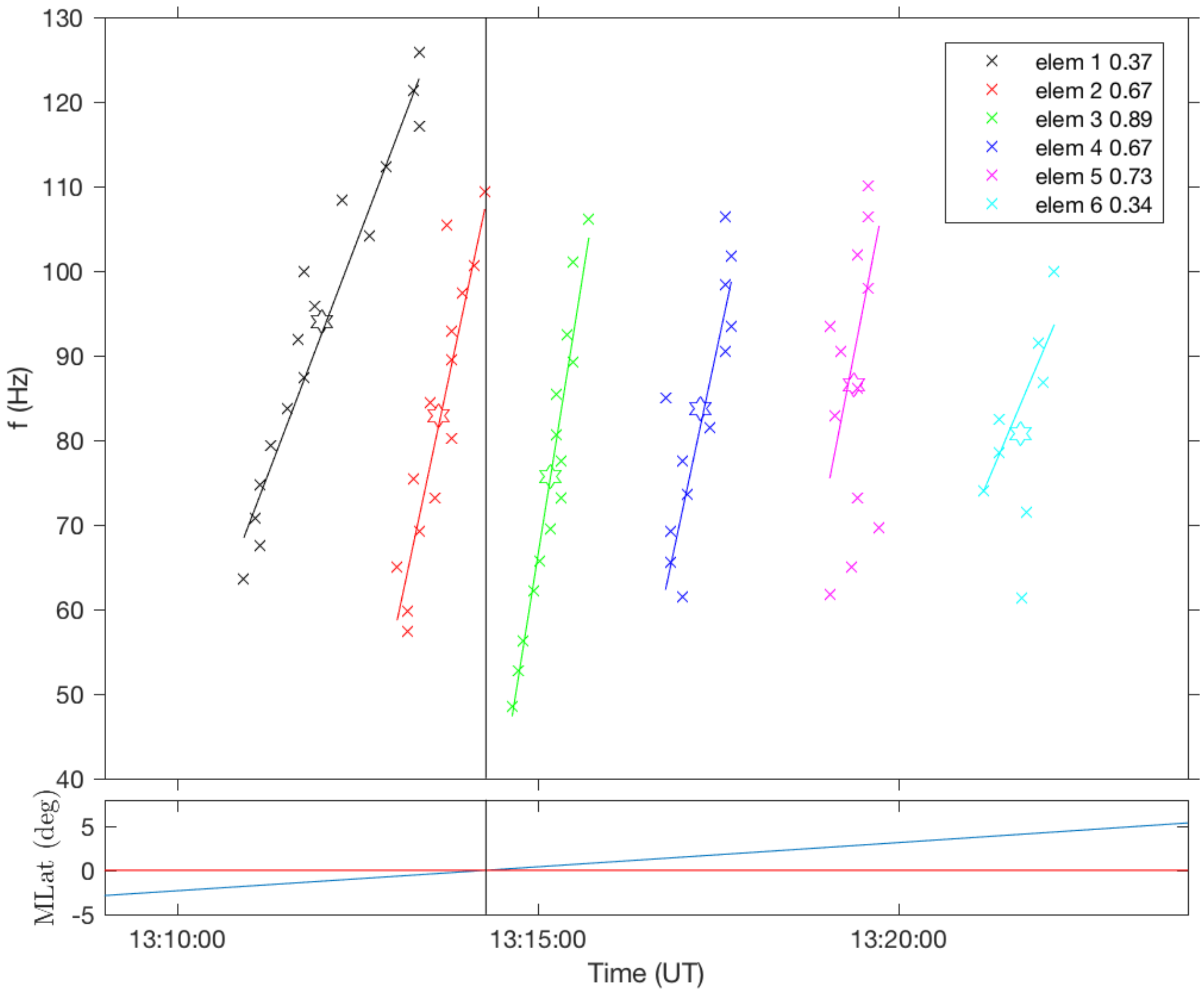
Rising tone emissions



- First reported Fu 2014 (VAP), Boardsen, 2014 (THEMIS), Nemec 2015 (Cluster)
- Periodic occurrence, 1-2 minutes
- Emission frequencies coincident with gyroharmonic frequencies
- Usually accompanied by other magnetosonic emissions above or below periodic emissions
- Cluster's polar orbit allows us to study their variation with latitude.

Sweep rates



Van Allen Probes/ THEMIS show sweep rates ~1Hz/s

Cluster results show that sweep rate changes with observed latitude Stepper sweep rages observed in the vicinity of the geomagnetic equator

The University Of Sheffield.

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space systems laboratory

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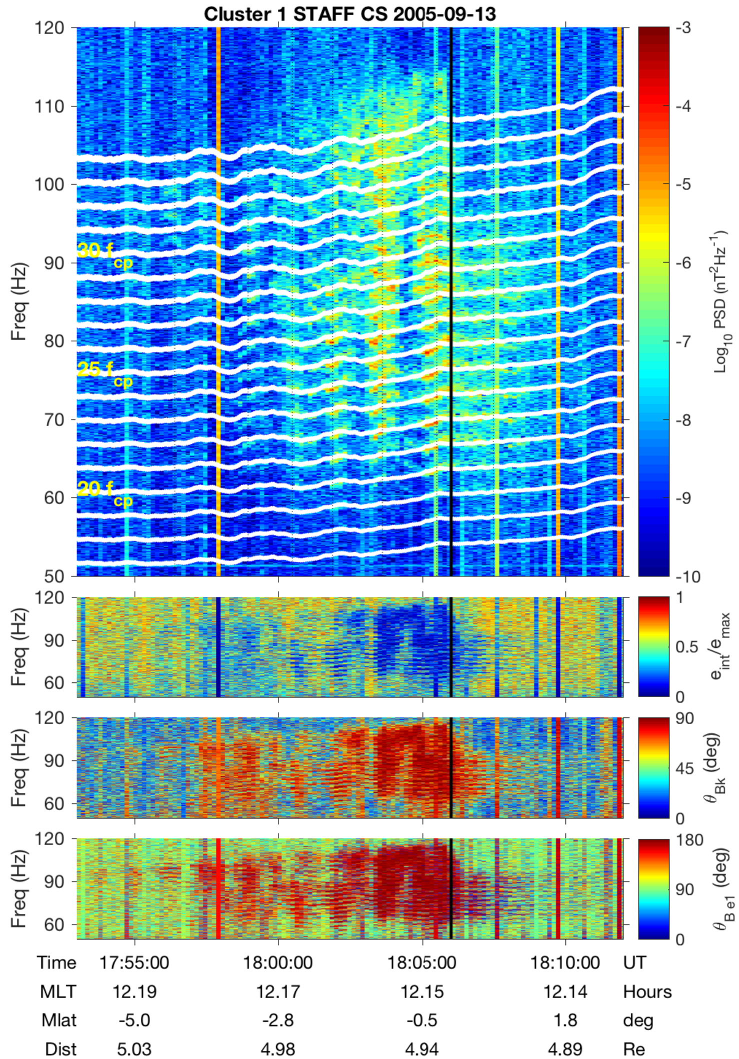
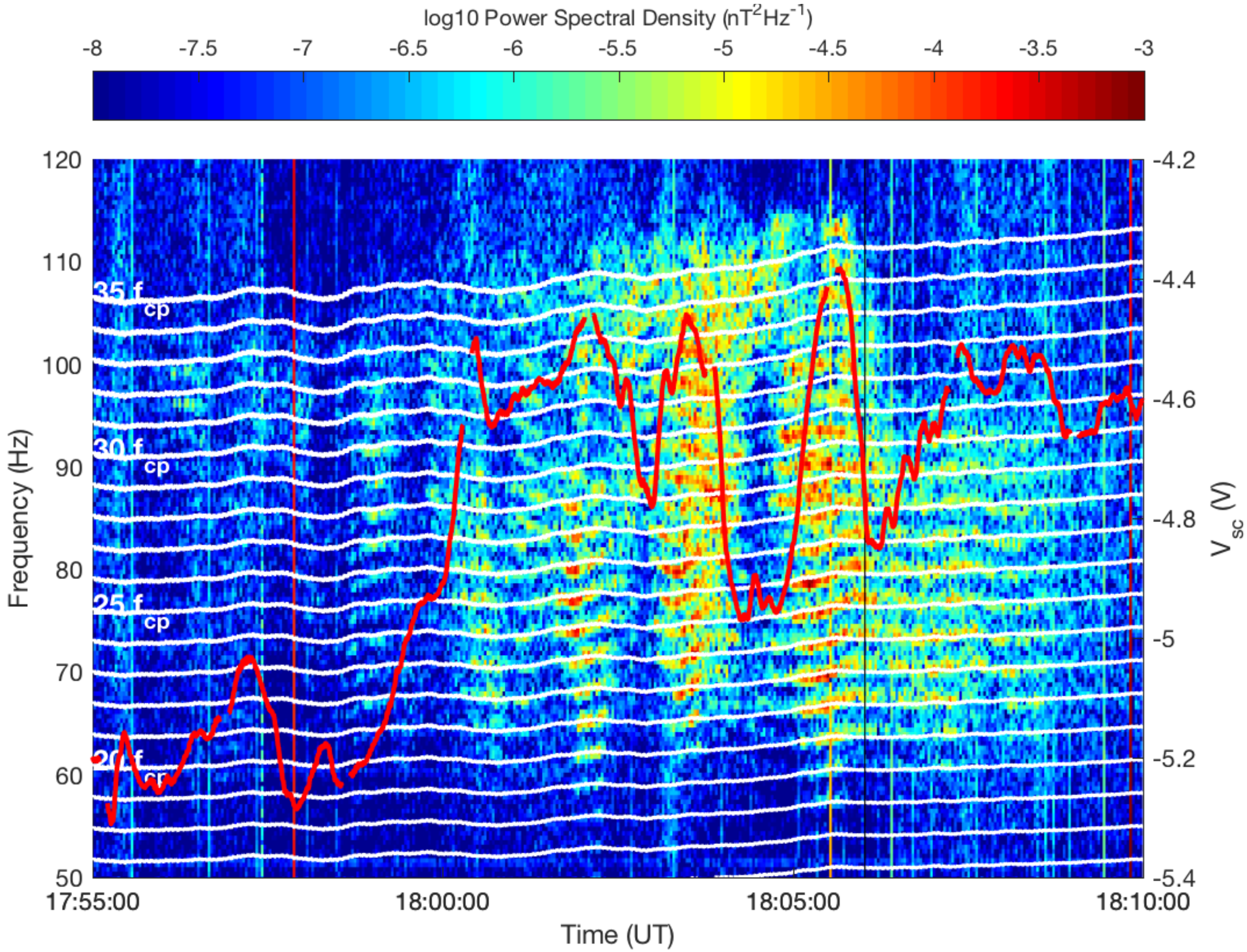
Non time continuous



Non time continuous



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Applicability of QLT

- EMW modify local electron distributions
- Numerical models use diffusion tensors to describe this process
- Wave models are based on quasi-linear theory which assumes a continuous spectrum

- Is this applicable to discrete EMW spectrum ?

Chirikov criterion

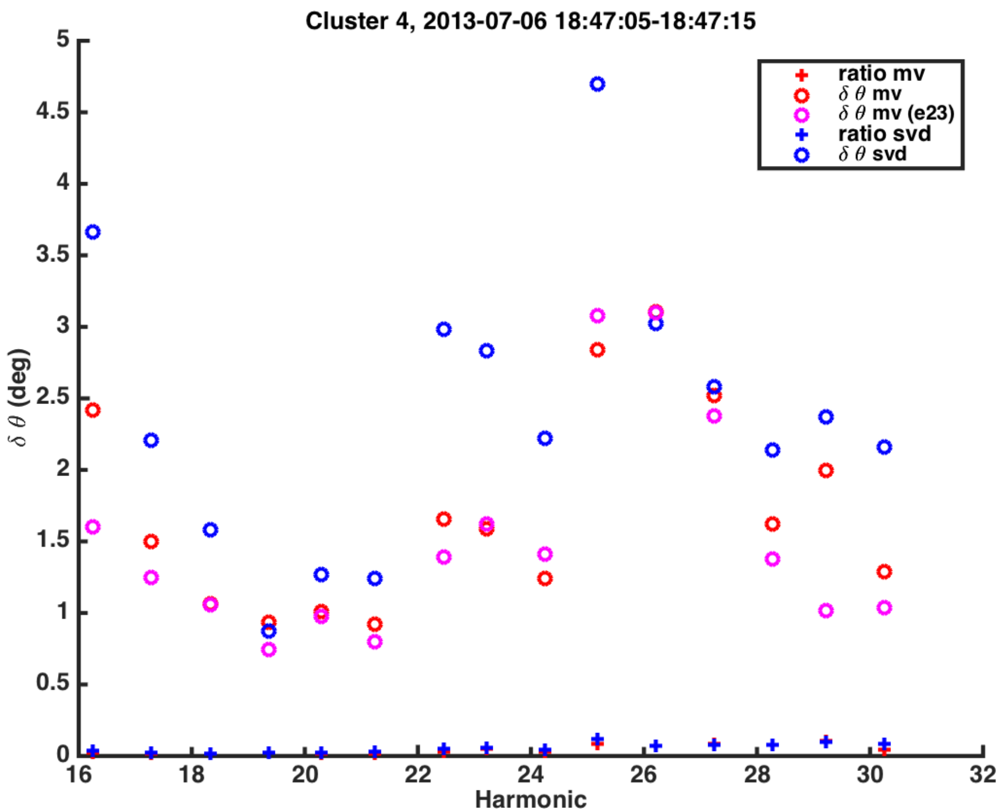
- Justify assumption of continuous spectrum provided that the harmonic elements satisfy the Chirikov resonance overlap criterion
- Particle trajectory will begin to move between two nonlinear resonances in a chaotic manner as soon as the resonances overlap

$$\delta\theta > \frac{\nu l / \tan(\theta_m)}{1 - \omega^2 / \nu\Omega_{ce}^2}$$

(Artemyev et al, 2015)

Where θ_m is mean angle between propagation direction and external magnetic field, $\delta\theta$ is the standard deviation of θ_m, l is the harmonic number, ν is the electron to proton mass ratio, Ω_{ce} is the electron gyrofrequency.

Using data from 6 July, 2013 18:47:05-18:47:15



Since RHS << LHS, Chirikov criterion is fulfilled and quasi-linear theory is applicable

Summary

Presented Cluster observations of EMW

- Demonstrated link between ring distribution and occurrence of waves
- Sweep rate of rising tone emissions
- Experimental dispersion closely matches cold plasma approximation
- Chirikov criterion shows that quasi-linear theory is valid for the numerical treatment of the discrete emissions

Thank you

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Data used in this analysis are available from the Cluster Science Archive