Correlations Between Coherent Waveforms and Particle Distribution Functions Observed in the Near-Earth Magnetotail by the Wind Spacecraft

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Introduction

- Earth's magnetotail is home to a rich collection of plasma waves
- It is a natural laboratory to study wave-particle interactions under a wide variety of physical conditions

Goal:

- To gain a better understanding of the microphysical processes that lead to plasma instabilities and wave generation
  ➔ identify wave modes and associated unstable distributions

Methodology:

- Correlative analysis of waveforms and electron and ion distribution functions using data from Wind/WAVES & 3DP
- Test for instability using WHAMP
- First step, focus on one event

Wind/WAVES

[*Bougeret et al.*, 1995]

Time Domain Sampler (TDS)

- Waveform capture of E_X & E_Y (in eclipitic plane)
- Both sampled simultaneously at 7500, 30000, or 120000 Hz
- One event (2048 points over 270, 70, or 17 msec) every ~ 5 min

Thermal Noise receiver (TNR)

- Spectral receiver measuring **E** power spectra from 4 – 256 kHz

Fast Fourier Transform (FFT)

- Spectral receiver operating in 3 frequency bands:
- FFTL (0.3 – 170 Hz; **E** & **B**), FFTM (7 Hz – 3.5 kHz; **E** & **B**), and FFTH (0.02 – 10 kHz; **E** only)

Radio Receiver Band 1 (RAD1)

- Spectral receiver operating between 20 kHz – 1 MHz; **E** only

(Also **Radio Receiver Band 2 (RAD2)** – not used here)

Wind/3DP

[*Lin et al.*, 1995]

EESA-Low

• Measures electrons from few eV to 1 keV

EESA-High

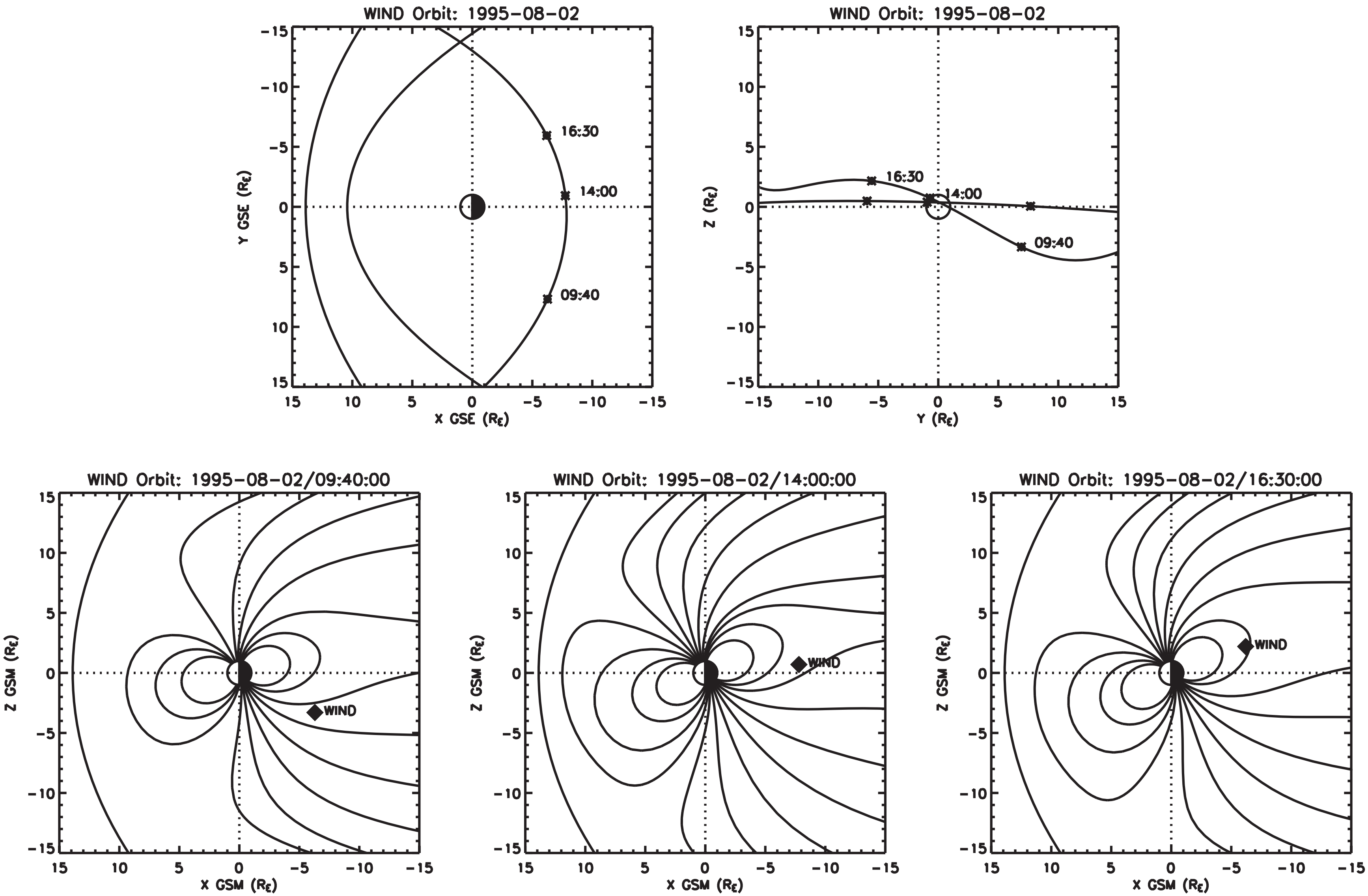
• Measures electrons from 100 eV to 30 keV
• Both cover 4π ster in 3 sec (1 spacecraft spin period)
• Both have 3 sec integration period
• During interval of study, one EL & EH distribution every 96 sec

PESA-High

• Measures ions from 70 eV to 30 keV
• Variable integration period
• During interval of study, 48 sec integration period (16 spins) & one distribution every 48 sec (continuous data collection)

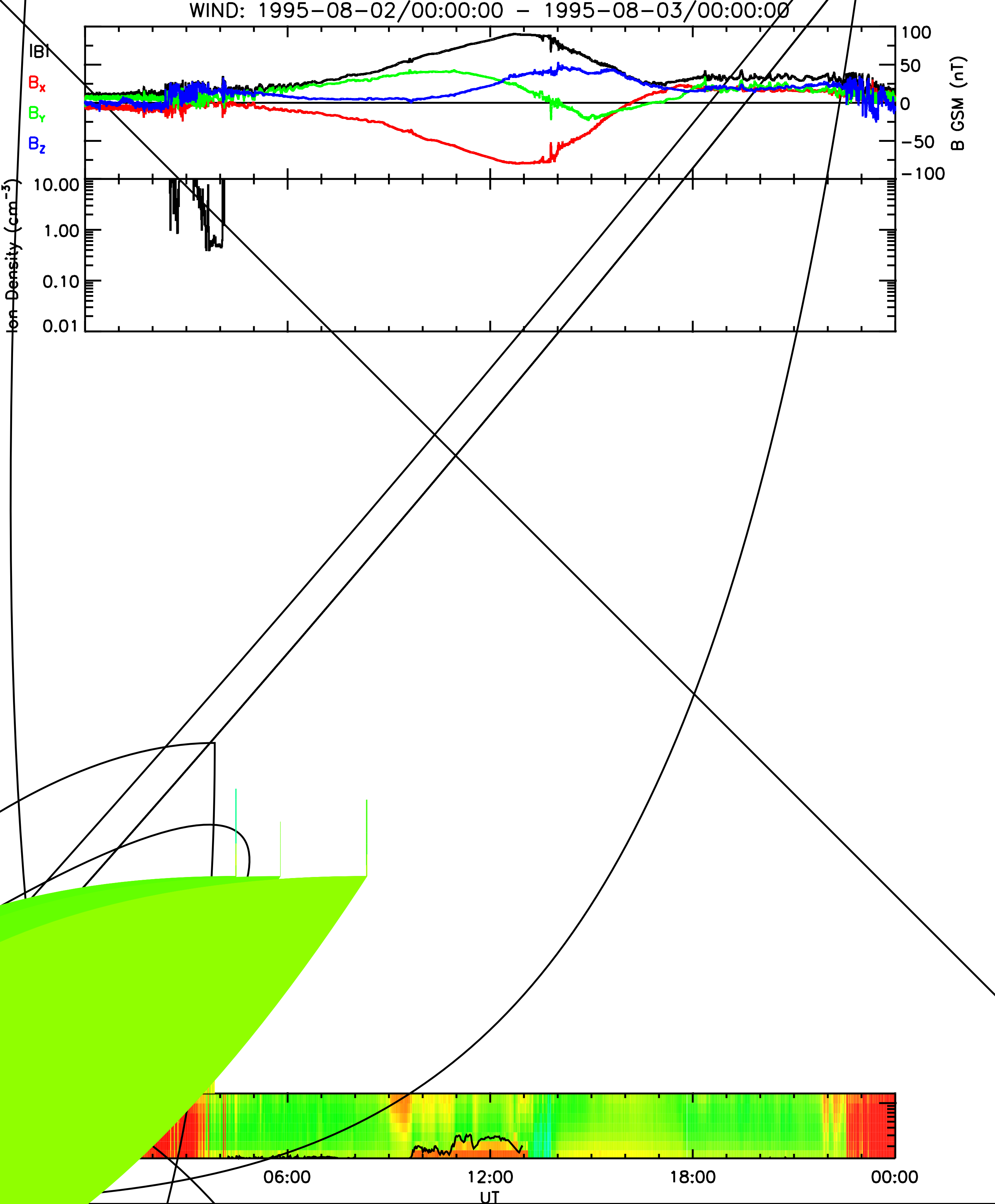
(Also **PESA-Low** – not used here – optimized for solar wind)

Wind Perigee Pass of 1995-08-02



Summary of Plasma Observations

- Wind crosses magnetopause and enters plasma sheet at ~ 3:30 UT
- At 9 UT, encounters cold dense plasma sheet (CDPS)
  ➔ $n > 1\ cm^{-3}$, $T_i < 1$ keV
- Enters plasma sheet boundary layer (PSBL) at 9:36 UT
  ➔ decreased particle fluxes and presence of weak ion beams
- Low energy, tailward ion beams seen from 11 to 12 UT
  ➔ ionospheric outflow?
- Brief (~ 1 min) lobe encounter at 12:42 UT ➔ density minimum
- Energetic Earthward ion beams observed at ~ 13:30 UT in PSBL & again immediately before and after lobe encounter at 13:46 UT
- Enters energized (hotter & denser) plasma sheet at 13:47 UT – energetic Earthward ion beams continue for ~ 1 min
- From 16 to 18 UT, $T_{\perp i,e} > T_{//i,e}$
- Wind exists dawnside magnetosphere at 22:30 UT



WIND: 1995-08-02/00:00:00 - 1995-08-03/00:00:00
|B|
B_X
B_Y
B_Z
B GSM (nT)
100
50
0
-50
-100
Ion Density (cm^{-3})
10.00
1.00
0.10
0.01
06:00
12:00
18:00
00:00
UT

Summary of Wave Observations

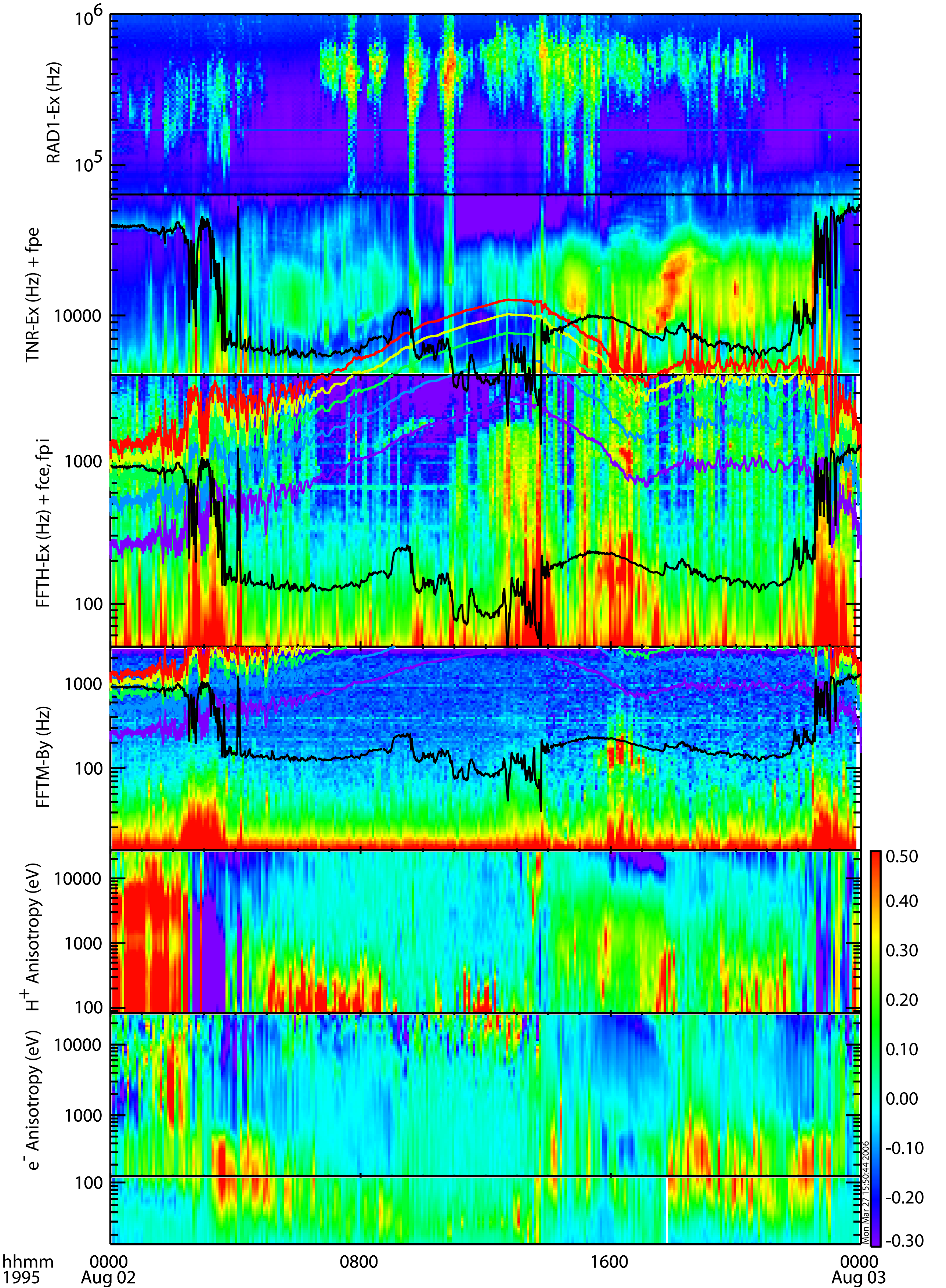
- Waves with $f \geq f_{ce}$ (e.g., 8 – 10 UT): typically monochromatic & elliptically polarized; some examples with harmonic structure
- BEN: observed at magnetopause and in PSBL from 12 – 14 UT; strongest when $f_{pe} < f_{ce}$ (lobe encounters); electrostatic
- VLF wave packets: both electric and magnetic signatures seen (esp. 16 – 17 UT); $f < f_{ce}/2$ (near f_{pi}?); elliptically polarized; probably whistler/chorus emission
- Electron cyclotron harmonics/Bernstein waves ($f \sim (n+½) f_{ce}$): observed from 15 – 17 UT; wave power up to n = 10

Also show electron and ion anisotropy in each energy channel, $A(E)$

For $A(E) > 0$, parallel; < 0, perpendicular; $= 0$, isotropic distribution

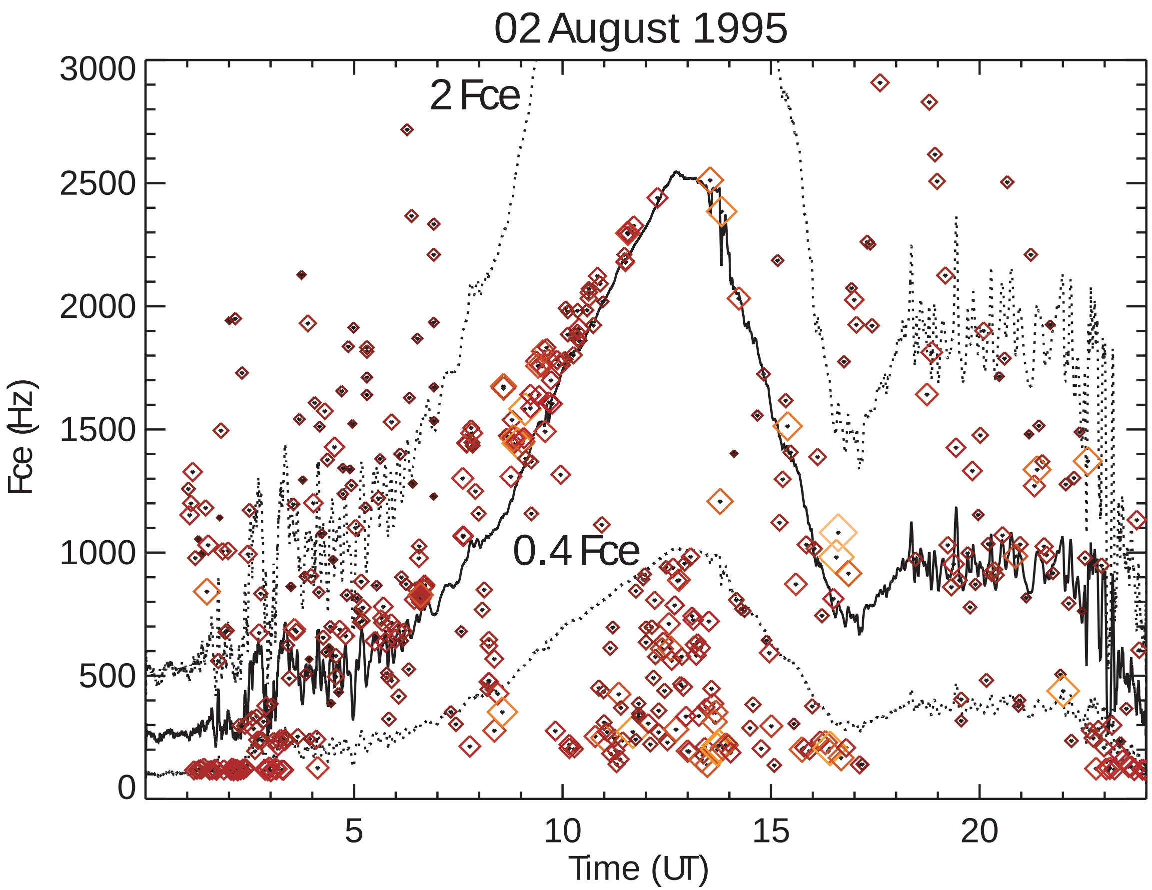
$$A(E) = \frac{\int f(E,\alpha)\ \cos(2\,\alpha)\ d\alpha}{\int f(E,\alpha)\ d\alpha}$$

where α = pitch angle (from *Hada et al.* [1981])


RAD1-Ex (Hz)
TNR-Ex (Hz) + fpe
FFTH-Ex (Hz) + fce, fpi
FFTM-By (Hz)
H+ Anisotropy (eV)
e- Anisotropy (eV)
hhmm
1995
0000
Aug 02
0800
1600
0000
Aug 03
0.50
0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
Mon Mar 27 15:50:44 2006

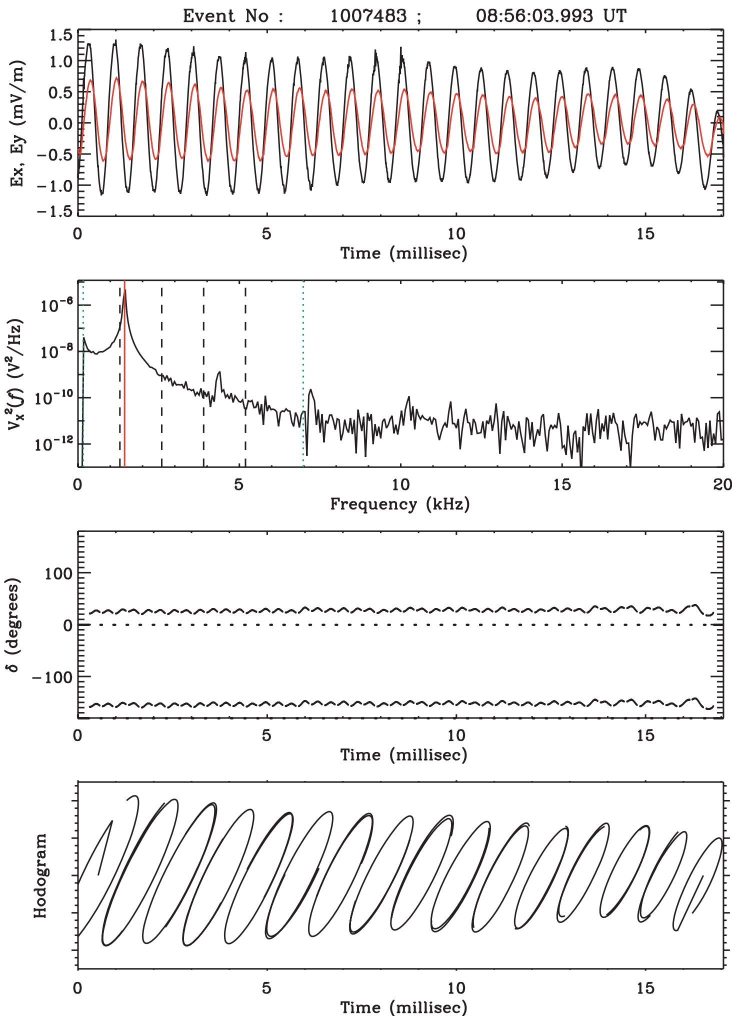
Analysis of TDS Waveforms

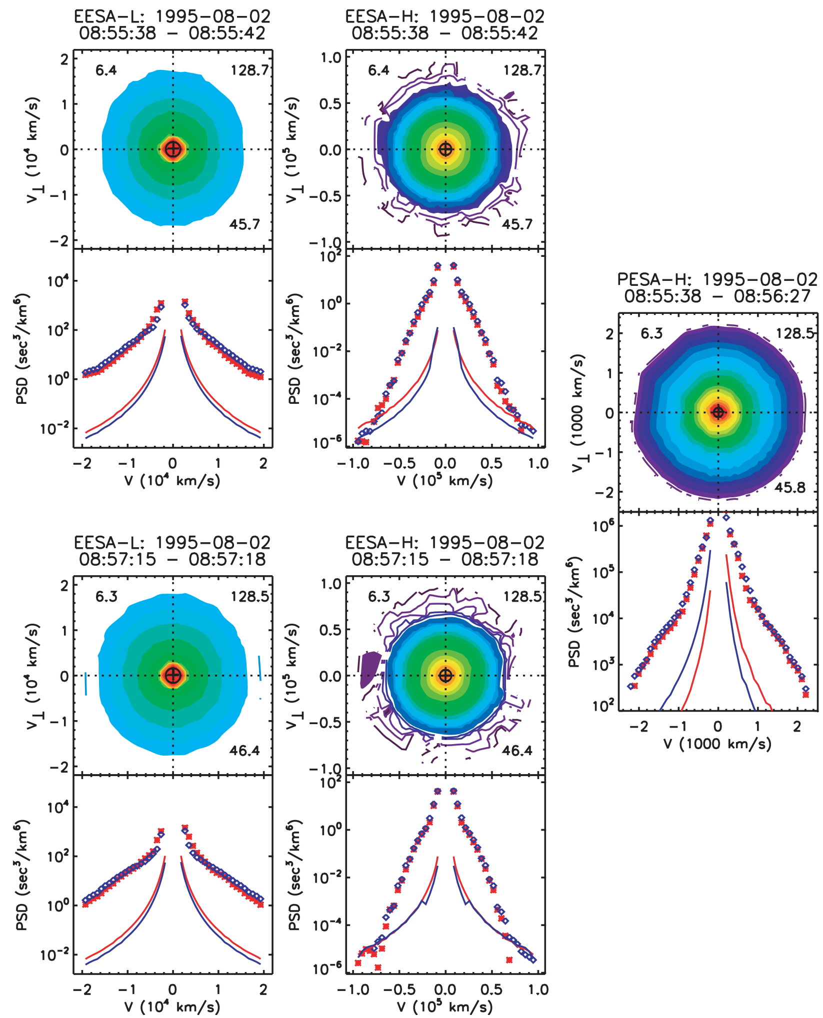
- 500 waveforms sampled by TDS over entire day
- For each event, central frequency (point) and spectral bandwidth (size of diamond) was calculated
- Solid line is electron cyclotron frequency, f_{ce}



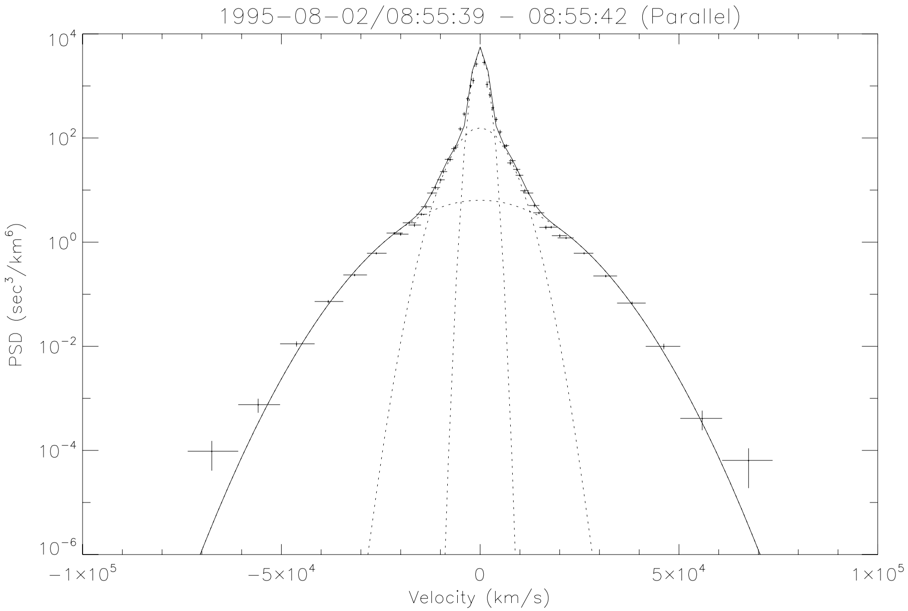
Waveform-Particle Distribution Comparison: $f \sim f_{ce}$

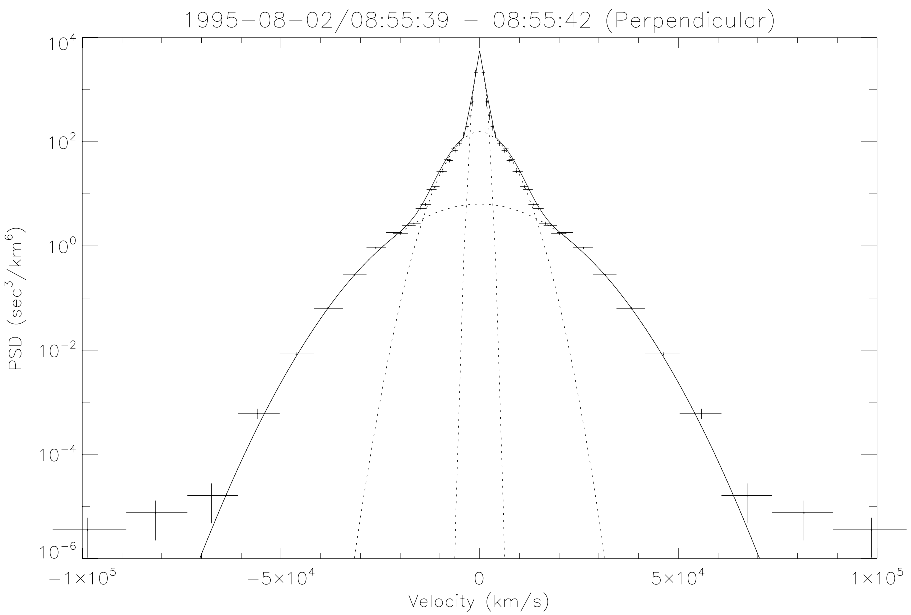
Electrons < 1 keV are slightly perpendicular anisotropic; higher energy electrons and ions are isotropic.



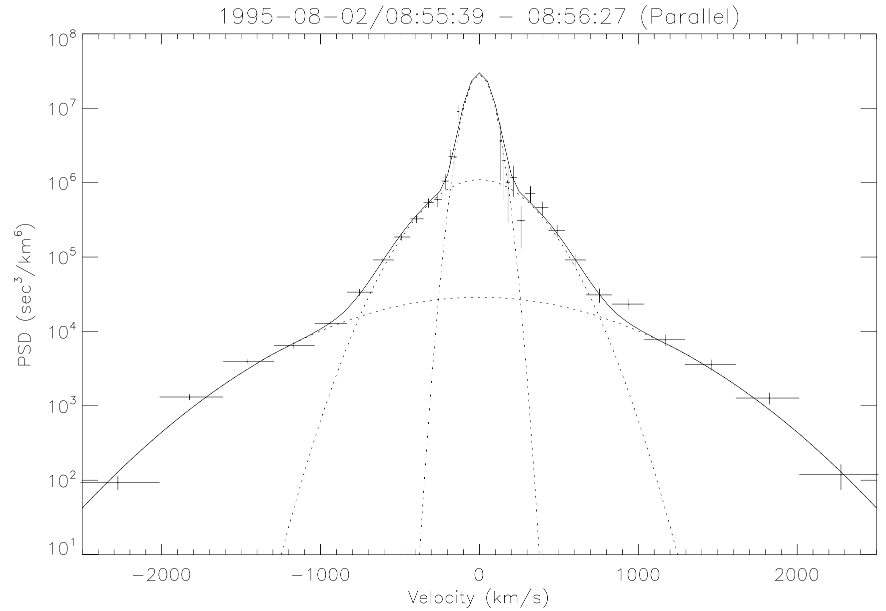


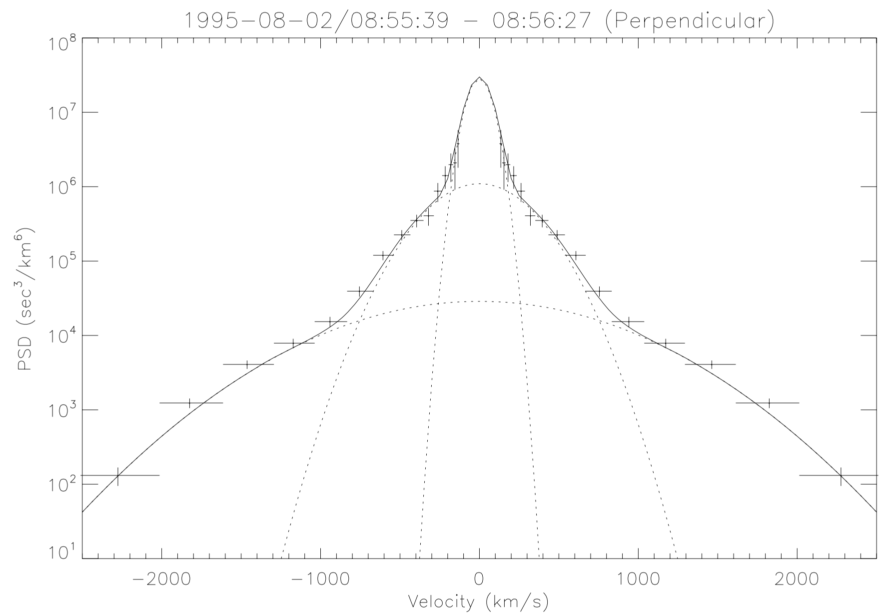
Electrons





Protons





Model Distribution Functions

Both electrons and ions (assumed to be protons) were modeled by three-component distributions

Electrons

Component 1:
- $n = 0.10$ cm^{-3}
- $kT_{//} = 10$ eV
- $kT_{\perp} = 5$ eV

Component 2:
- $n = 0.30$ cm^{-3}
- $kT_{//} = 120$ eV
- $kT_{\perp} = 150$ eV

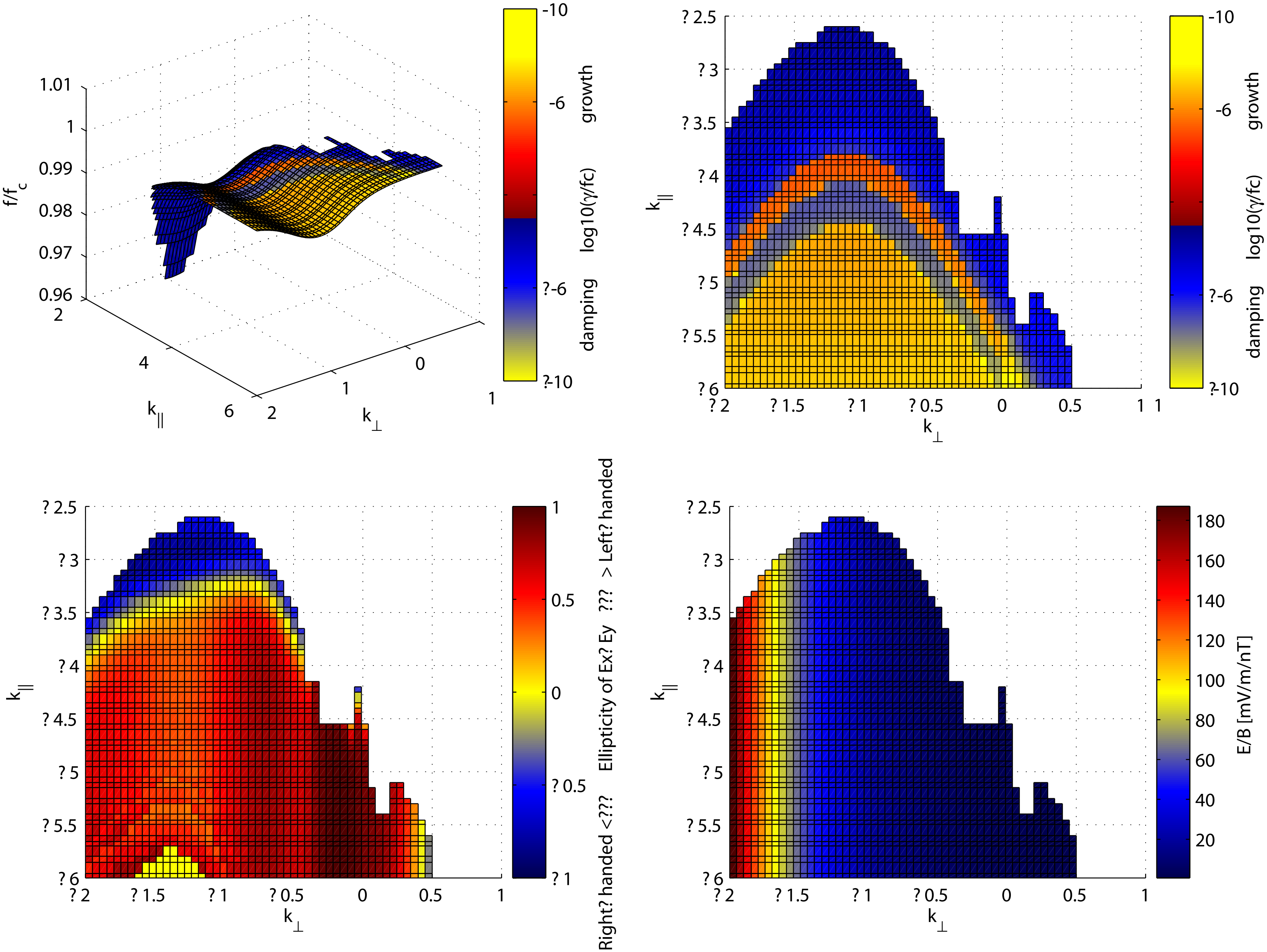
Component 3:
- $n = 0.20$ cm^{-3}
- $kT_{//} = 900$ eV
- $kT_{\perp} = 900$ eV

Protons

Component 1:
- $n = 0.15$ cm^{-3}
- $kT_{//} = 50$ eV
- $kT_{\perp} = 50$ eV

Component 2:
- $n = 0.30$ cm^{-3}
- $kT_{//} = 700$ eV
- $kT_{\perp} = 700$ eV

Component 3:
- $n = 0.15$ cm^{-3}
- $kT_{//} = 5000$ eV
- $kT_{\perp} = 5000$ eV



f/f_c
1.01
1
0.99
0.98
0.97
0.96
2
4
6
k_||
2
1
0
1
k_⊥
-10
-6
?-6
?-10
growth
log10(γ/fc)
damping
? 2.5
? 3
? 3.5
? 4
? 4.5
? 5
? 5.5
? 6
k_||
? 2
? 1.5
? 1
? 0.5
0
0.5
1
k_⊥
-10
-6
?-6
?-10
growth
log10(γ/fc)
damping
? 2.5
? 3
? 3.5
? 4
? 4.5
? 5
? 5.5
? 6
k_||
? 2
? 1.5
? 1
? 0.5
0
0.5
1
k_⊥
1
0.5
0
? 0.5
? 1
Right? handed <??? Ellipticity of Ex? Ey ??? > Left? handed
? 2.5
? 3
? 3.5
? 4
? 4.5
? 5
? 5.5
? 6
k_||
? 2
? 1.5
? 1
? 0.5
0
0.5
1
k_⊥
180
160
140
120
100
80
60
40
20
E/B [mV/m/nT]

Conclusions

- Many types of waves are observed by Wind in the magnetotail
- Our goal was to perform correlative analyses of waveforms and particle distributions to better understand the microphysical processes that generate plasma instabilites and wave emissions
- For this study, focus was placed on one example of a highly monochromatic wave with $f \sim f_{ce}$
- WHAMP modeling using three-component fits of the observed electron and ion distributions as input suggests that wave growth can occur for particular wave numbers
- Unfortunately Wind alone cannot determine the wave number of the observed waveforms to test the results from WHAMP

Possible Source (Hand Waving)

- The waveform analyzed here appears to be co-located with the interval of cold dense plasma sheet (CDPS)

- CDPS regions have been interpreted to be the result of the mixing of plasma sheet and magnetosheath plasmas

- Could the wave-generating instability be related to the mixing of these different plasma populations?

- Much more work to do