Quantifying the Effect of Strong Subpacket Structure in VLF Chorus Rising Tones on Radiation Belt Acceleration

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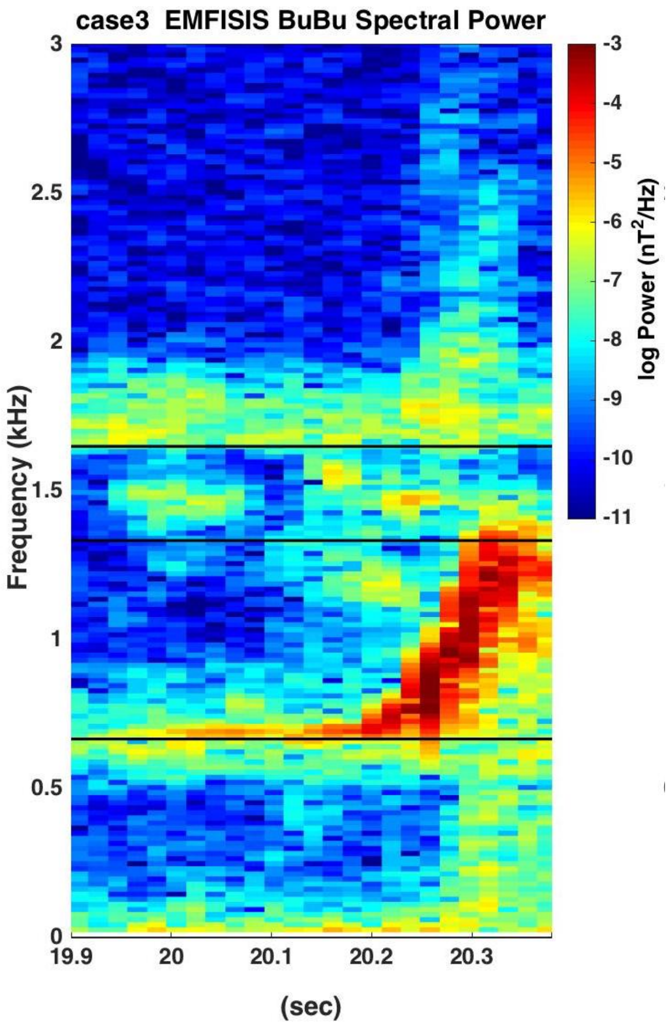
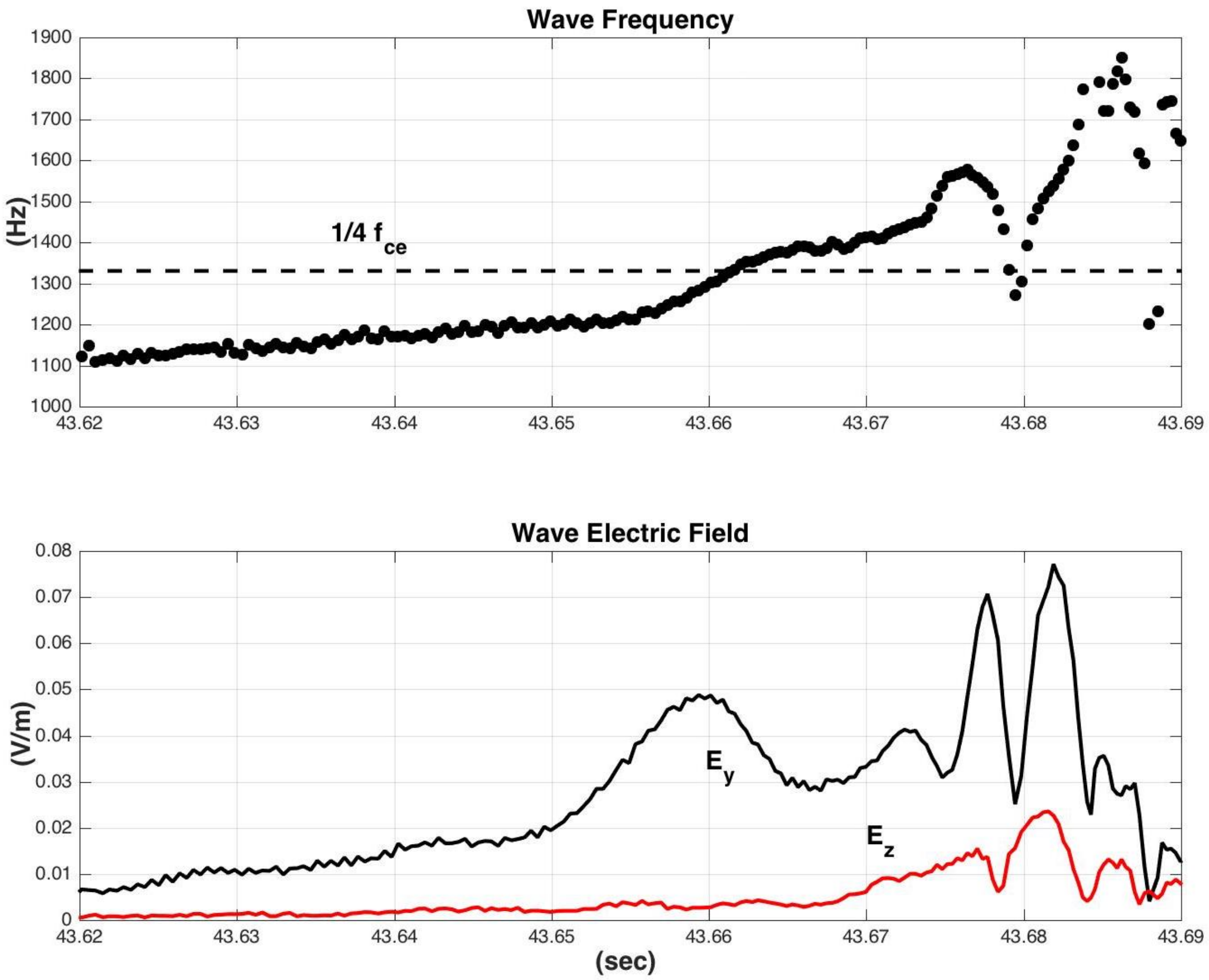
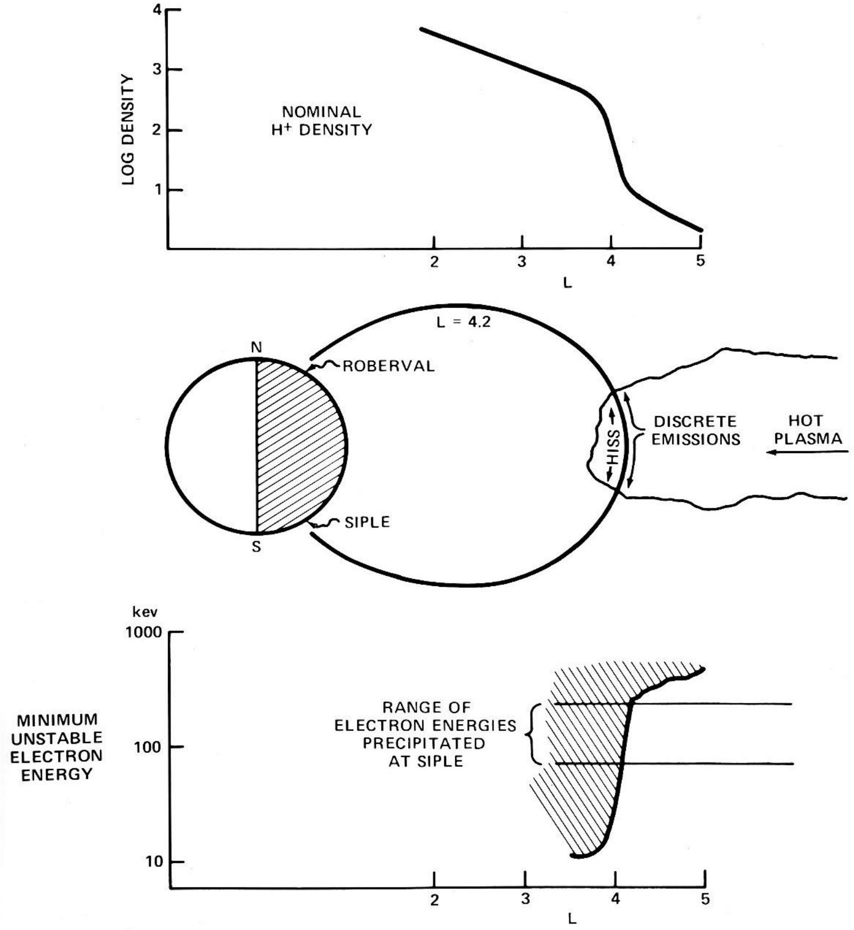
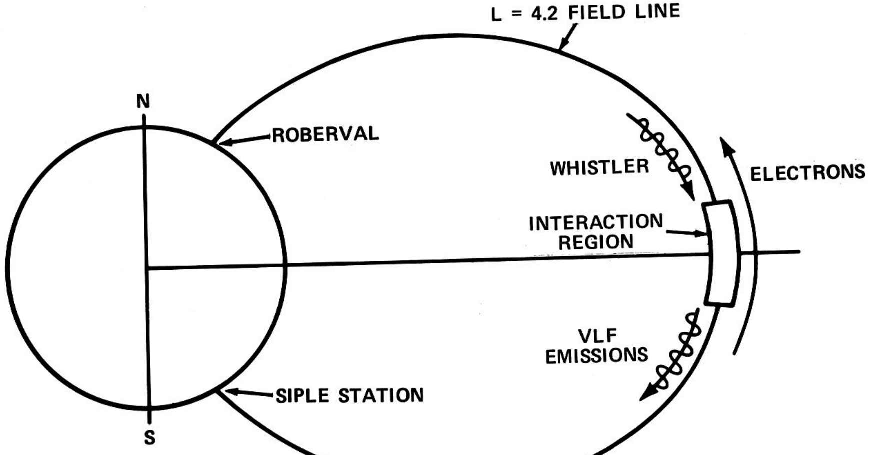
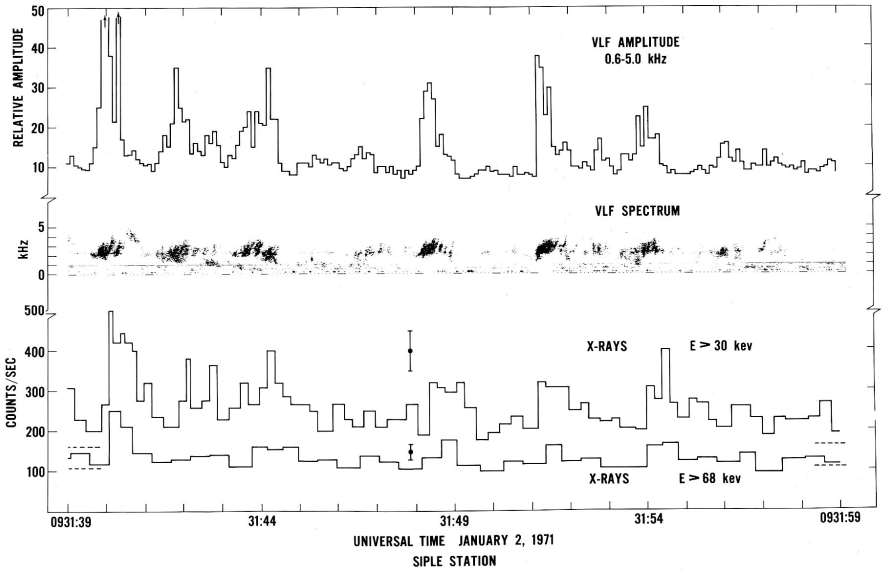




VLF Chorus: Cyclotron Resonance Wave Growth leads to Microburst Electron Precipitation







[Foster & Rosenberg, 1976]

Characteristics of Strong Riser Subpackets

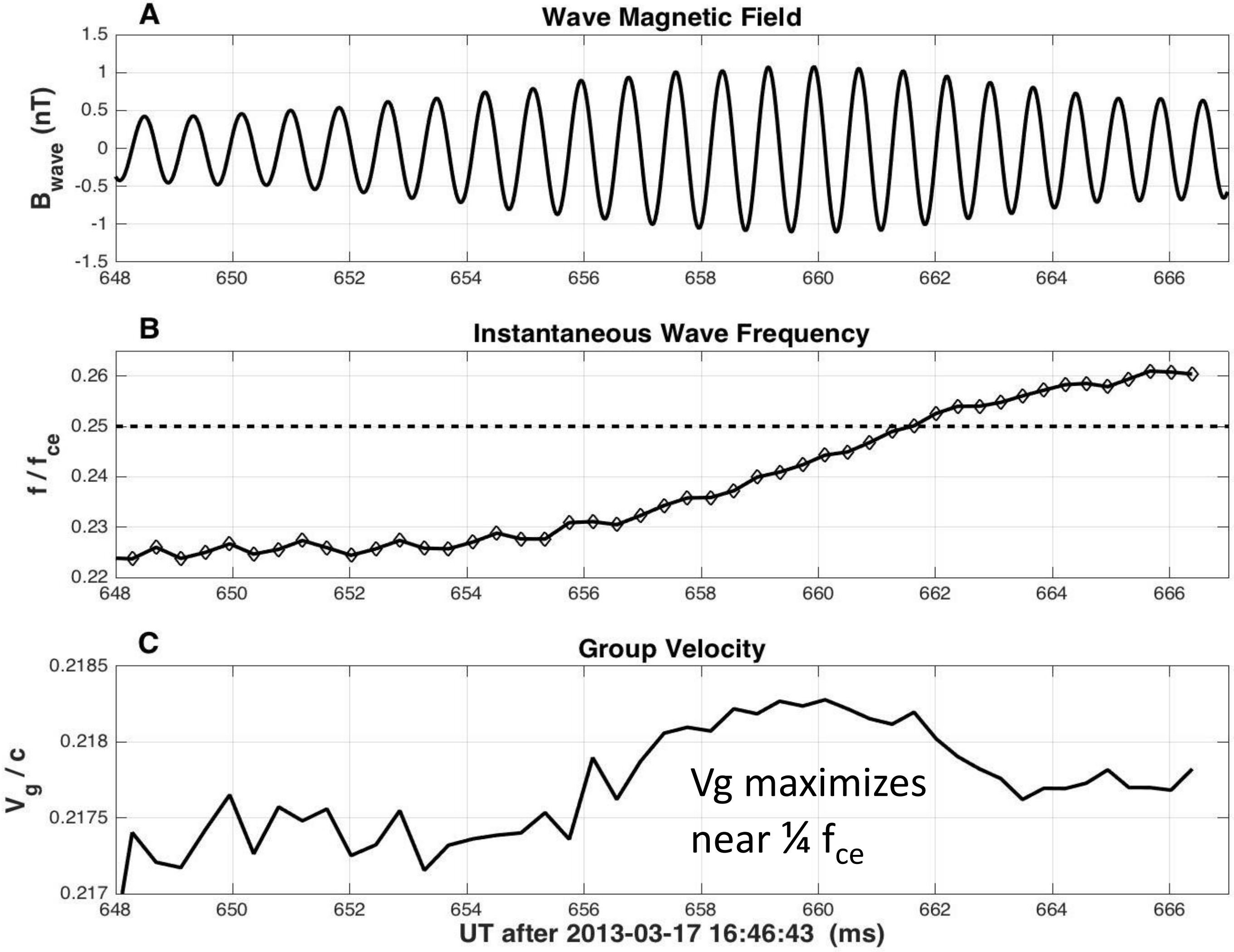
- Strong (|Bw| ~ 1nT; |Ew| ~ 0.03 V/m), long duration (~10 ms) subpacket structure often is seen **immediately following the transition from linear to nonlinear wave growth**.
- These strong subpackets exhibit **envelope solition characteristics** and often are observed at wave frequencies very near ¼ f_{ce} (the local electron gyrofrequency).
- **Subpackets at ¼ f_{ce}** are associated with a pronounced **steepening of df/dt** and **small wave normal angle** (<10^{o}).
- Observed off the equator, **riser frequencies span ¼ f_{ce}EQ to ½ f_{ce}EQ**. Whistler mode waves are **strongly absorbed at ½ f_{ce}**.

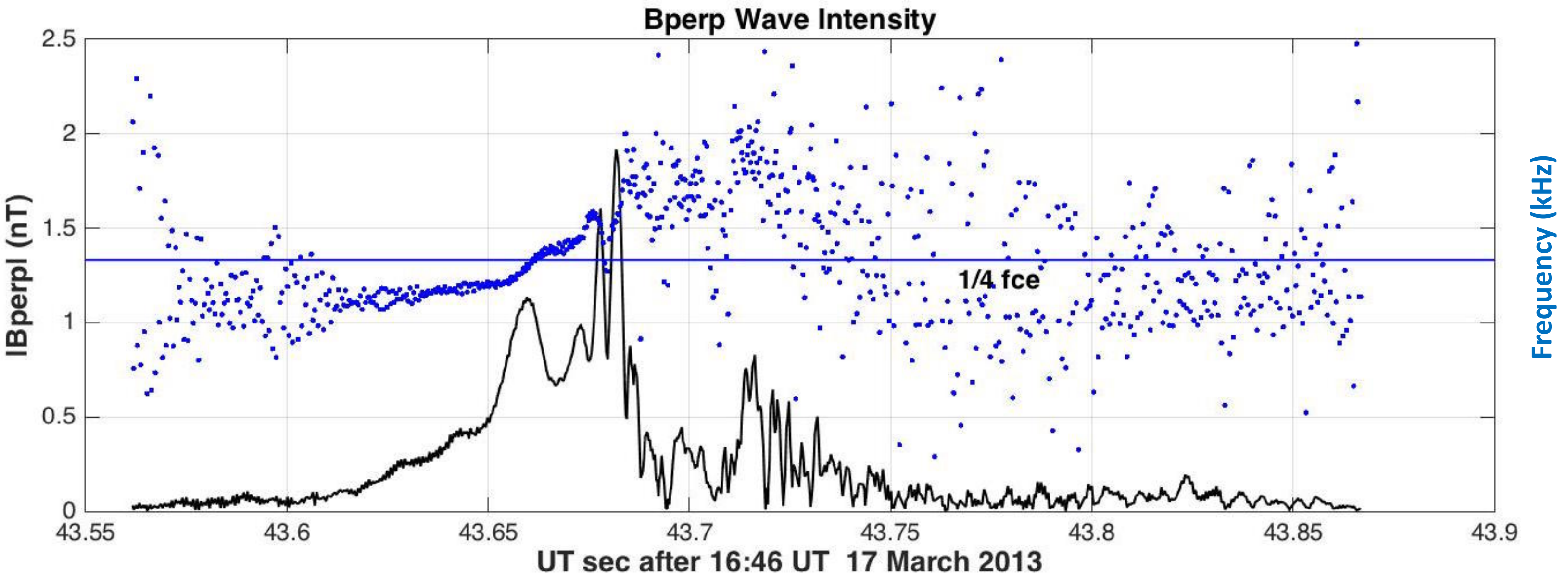
Radiation Belt Energization by Strong Subpackets

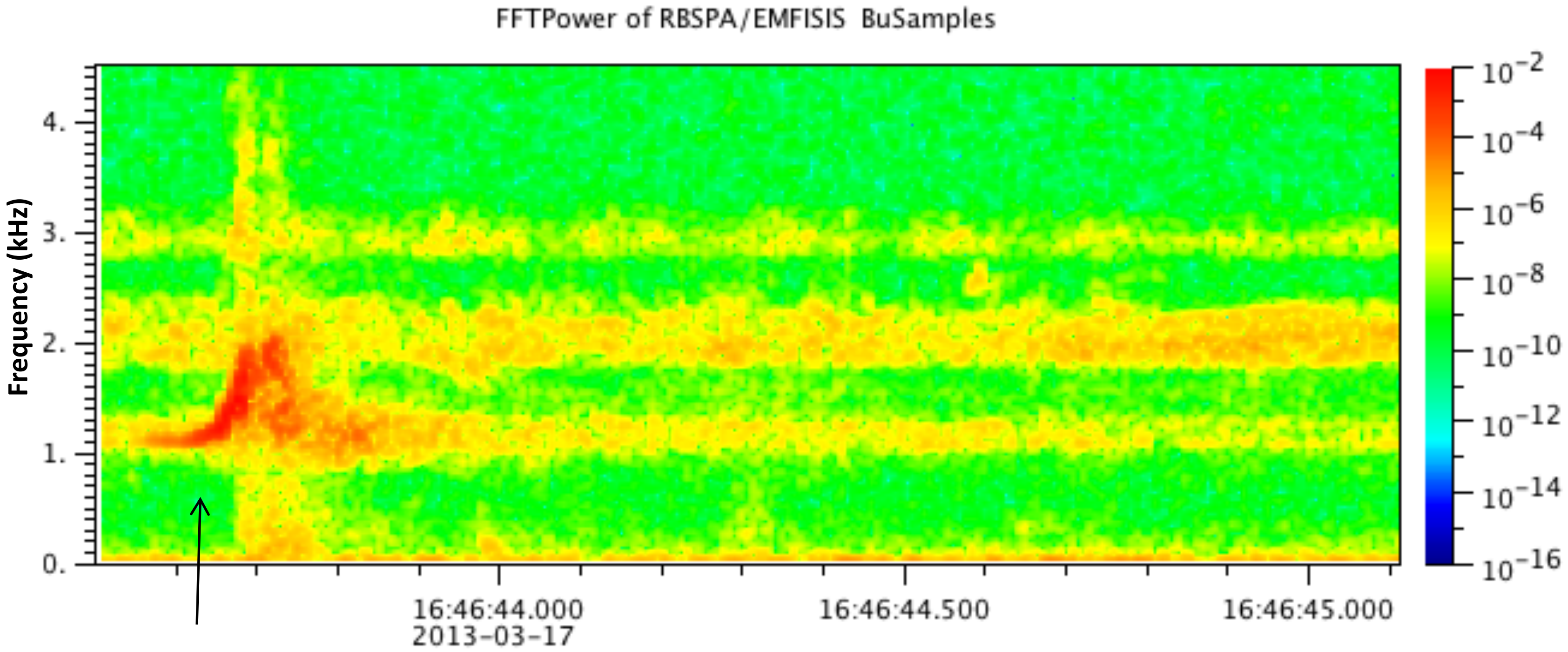
- Maximum energy gain of 5-10 keV/wave cycle occurs for electrons with 1-3 MeV initial energy.
- For electrons resonant with the waves throughout a single subpacket (~10 ms), total energy increase >100 keV is possible.

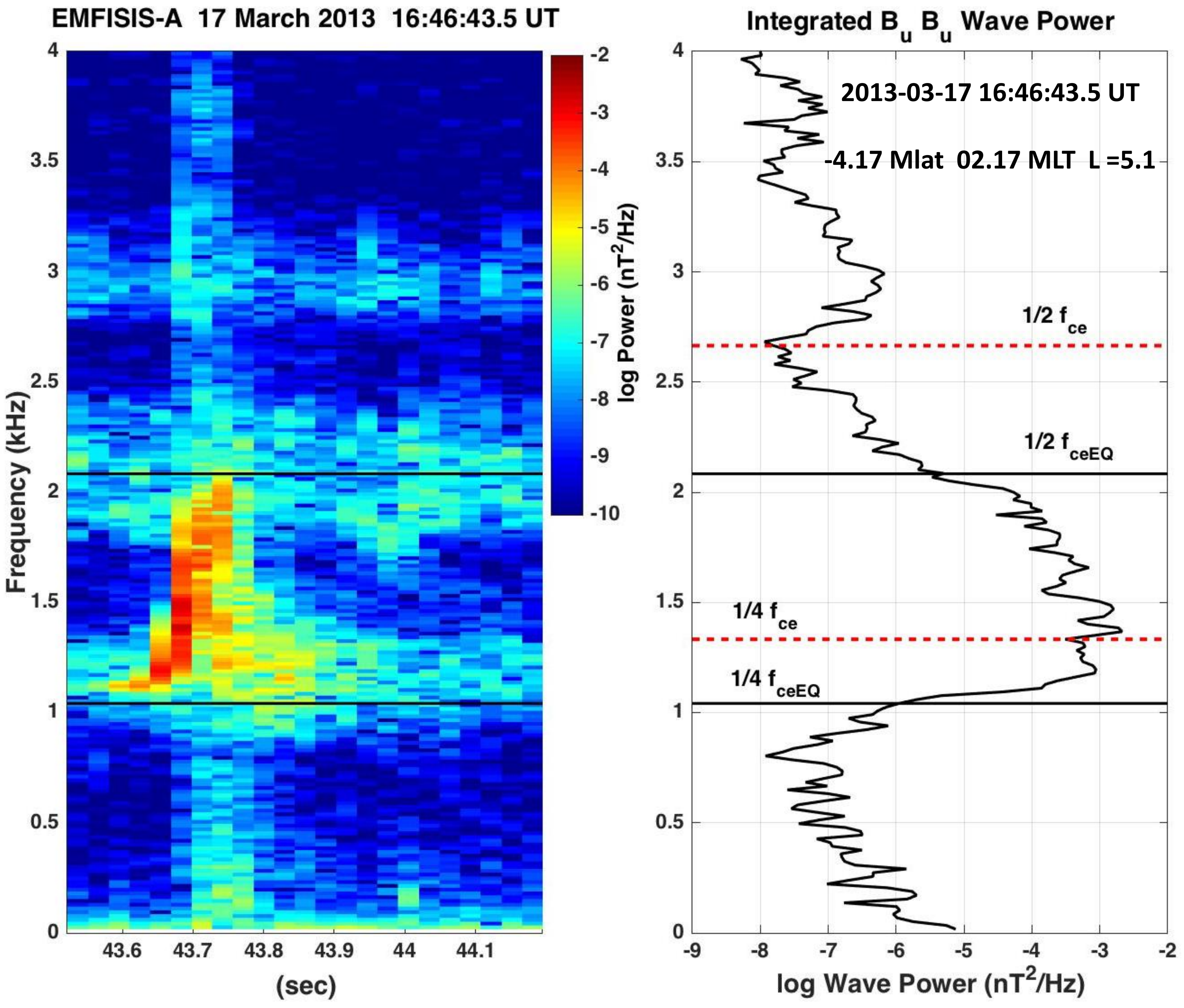
The strongest subpackets exhibit **envelope solition characteristics** and are centered at wave frequencies very near ¼ f_{ce} (the local electron gyrofrequency).

A soliton is a self-reinforcing solitary wave packet that maintains its shape while it propagates at a constant velocity.




Bperp Wave Intensity
lBperpl (nT)
Frequency (kHz)
1/4 fce
UT sec after 16:46 UT 17 March 2013
2.5
2
1.5
1
0.5
0
43.55
43.6
43.65
43.7
43.75
43.8
43.85
43.9


FFTPower of RBSPA/EMFISIS BuSamples
Frequency (kHz)
4.
3.
2.
1.
0.
16:46:44.000
2013-03-17
16:46:44.500
16:46:45.000
10^{-2}
10^{-4}
10^{-6}
10^{-8}
10^{-10}
10^{-12}
10^{-14}
10^{-16}



Damping at ½ f_{ce} as wave propagates from equator to satellite

Oblique Propagation

Variation of Kinetic Energy

Kinetic Energy *K*

$$\frac{\mathrm{d}K}{\mathrm{d}t} = e \sum_{n=-\infty}^{\infty} \left[v_{\parallel} E_{\parallel}^{w} J_n(\beta) + v_{\perp} E_R^{w} J_{n-1}(\beta) - v_{\perp} E_L^{w} J_{n+1}(\beta) \right] \sin \zeta_n$$

where $\beta = \frac{\gamma V_{\perp} k_x}{\Omega_e}$ $\zeta_n = n\phi - \psi_B$ $V_R^{(n)} = \frac{1}{k_z}\left(\omega - \frac{n\Omega_e}{\gamma}\right)$

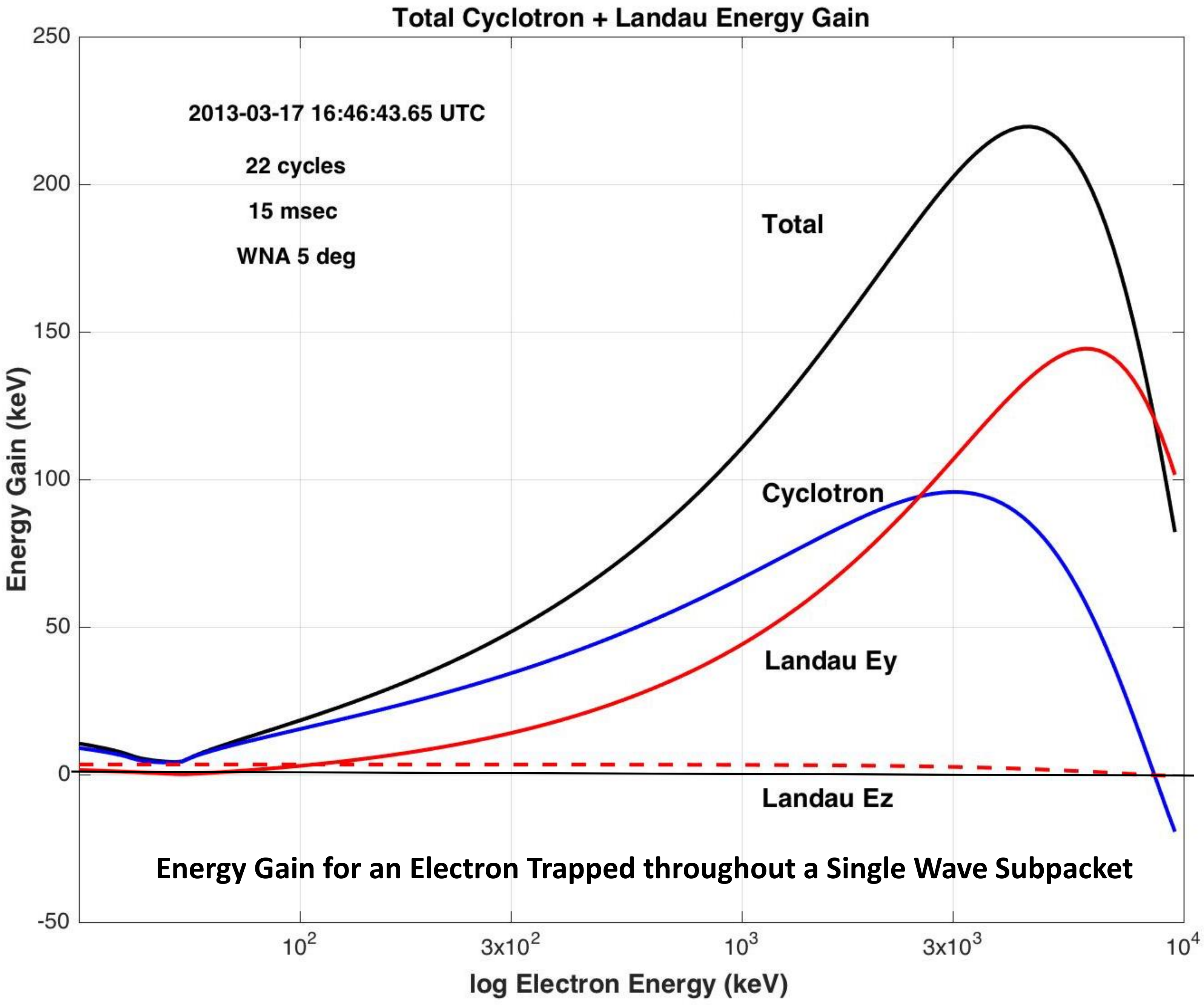
Landau Resonance (*n* = 0)

$$V_{p\parallel} = \omega / k_z, \quad V_{\perp} = \sqrt{c^2(1-\gamma^{-2}) - V_{p\parallel}^2}$$

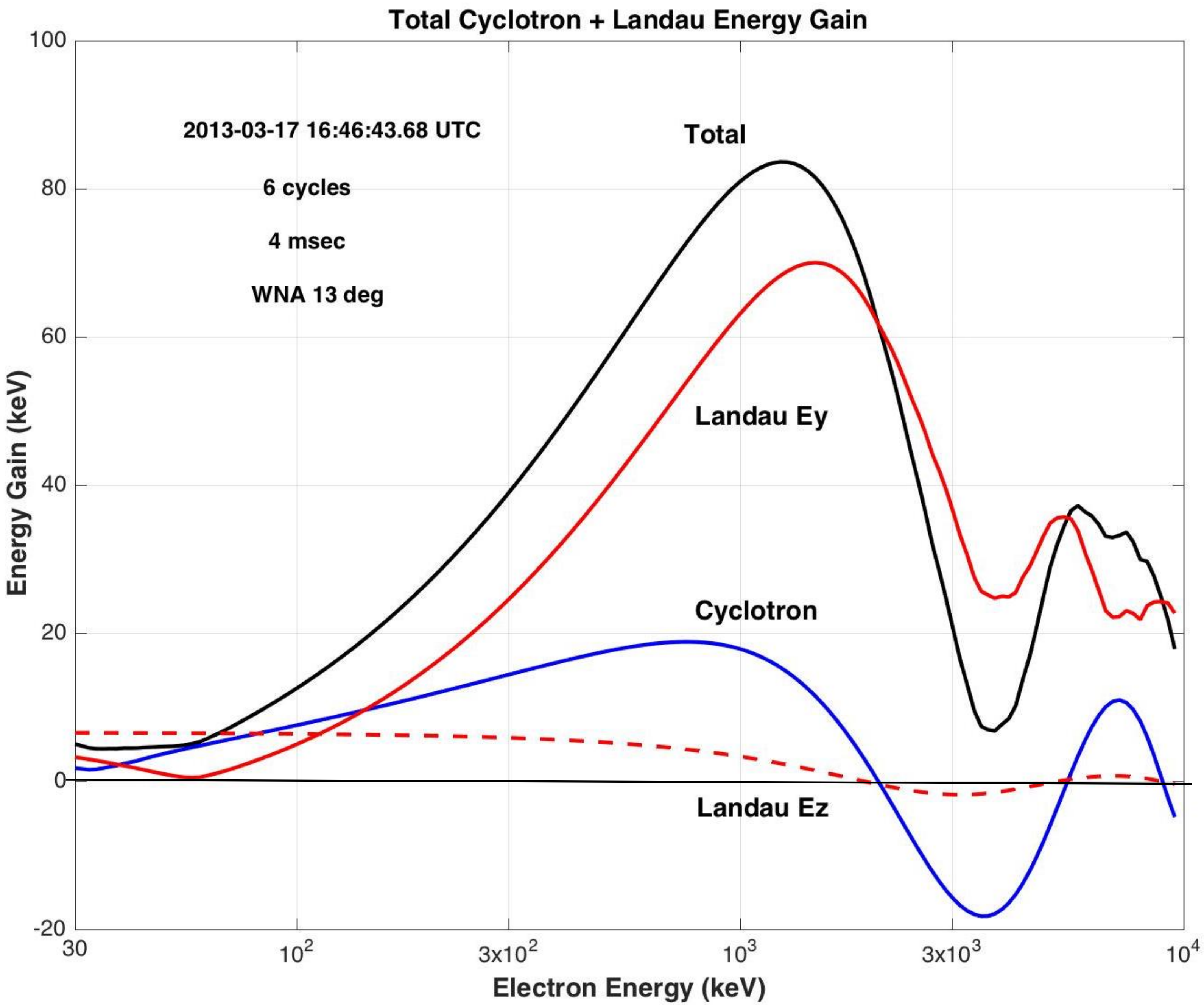
$$\frac{\mathrm{d}K^0}{\mathrm{d}t} = e \left[V_{p\parallel} E_z^{w} J_0(\beta) - V_{\perp} E_y^{w} J_1(\beta) \right] \sin \zeta_0$$

Interaction Time

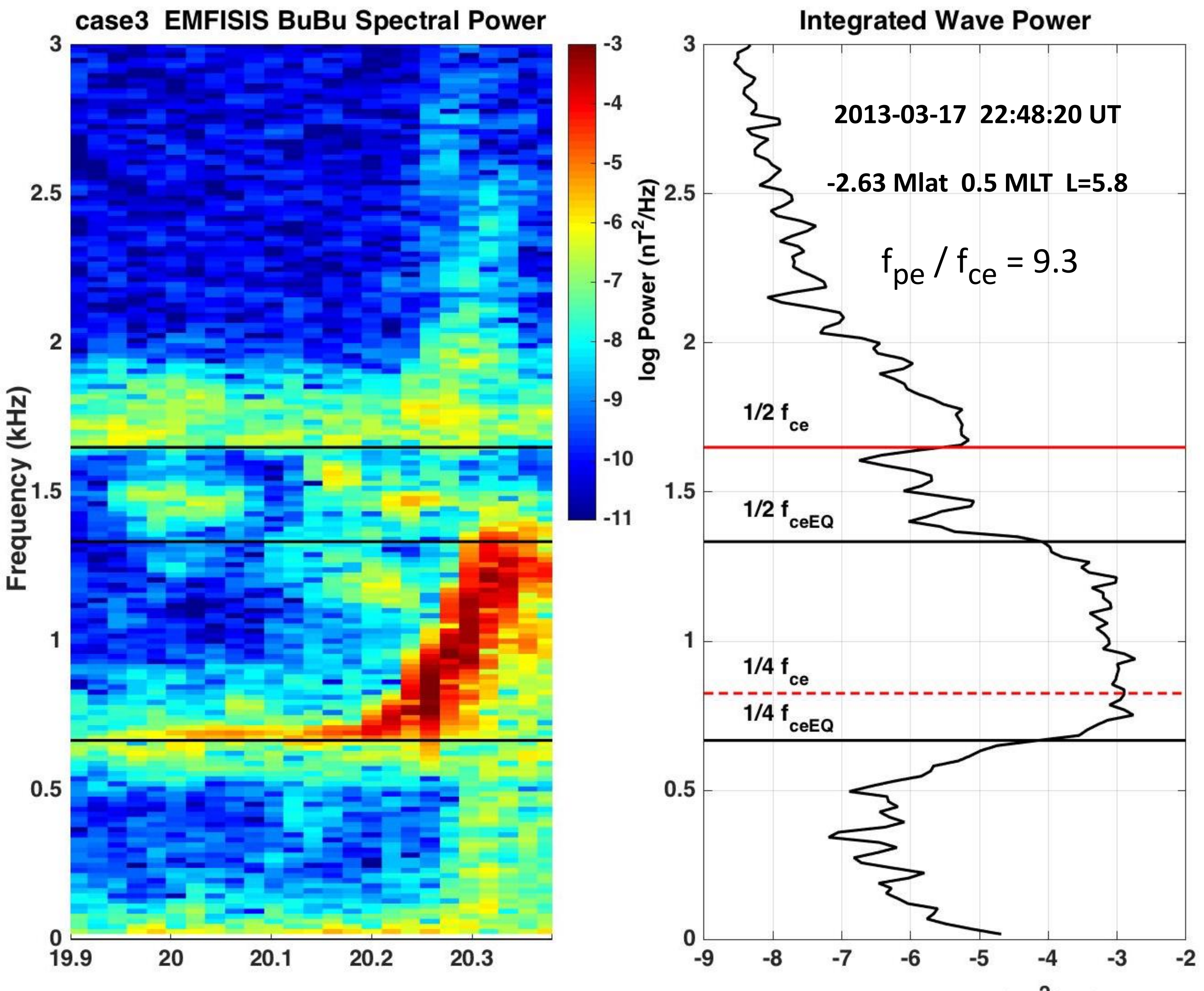
$$\Delta K^0 = \sum_{\delta t} \frac{\mathrm{d}K^0}{\mathrm{d}t} \cdot \frac{V_{g\parallel}\delta t}{V_{g\parallel} - V_{p\parallel}} \left(1 - \frac{V_{g\parallel} V_{p\parallel}}{c^2}\right)$$



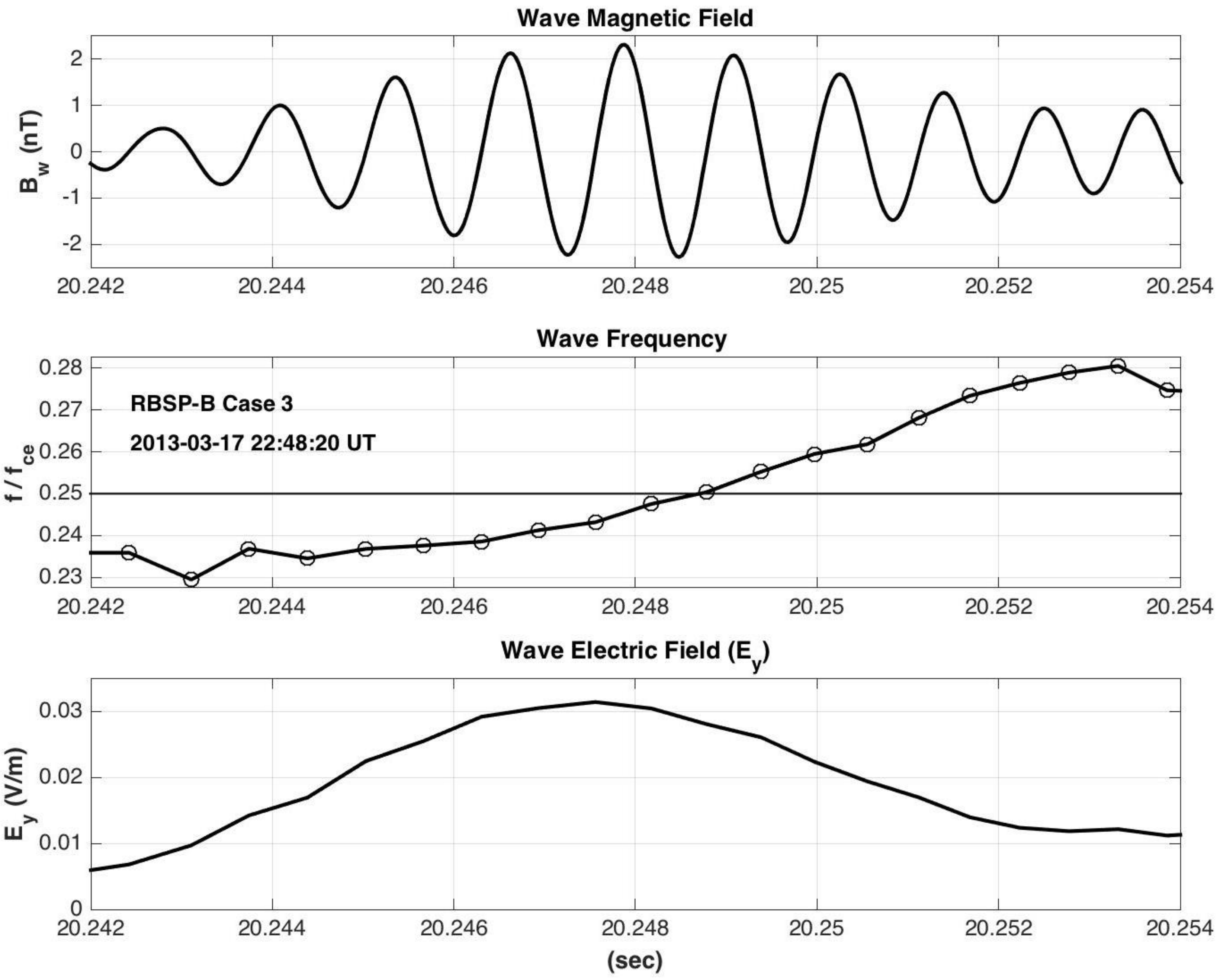
Energy Gain for an Electron Trapped throughout a Single Wave Subpacket

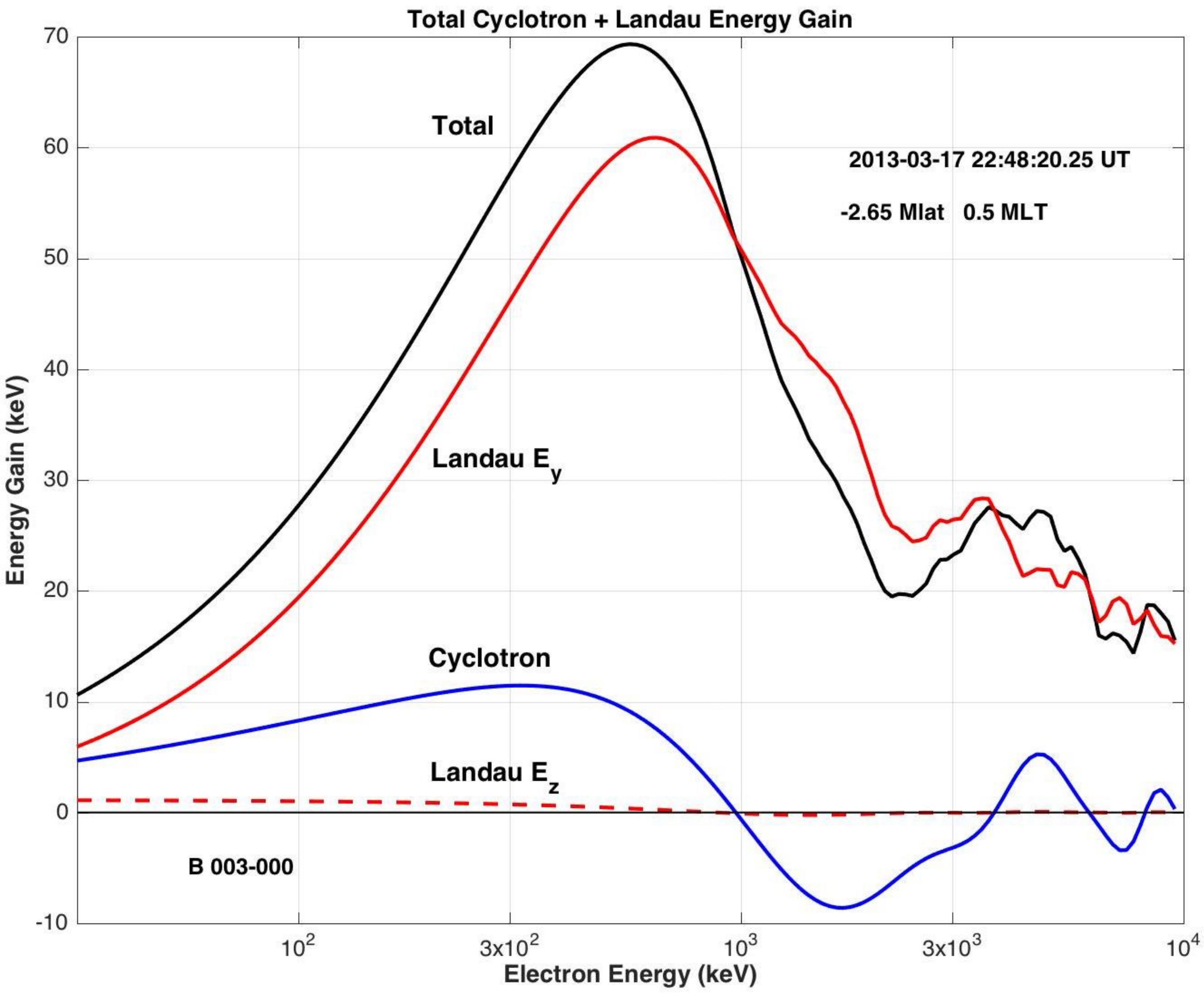


Total Cyclotron + Landau Energy Gain
2013-03-17 16:46:43.68 UTC
6 cycles
4 msec
WNA 13 deg
Total
Landau Ey
Cyclotron
Landau Ez
Energy Gain (keV)
Electron Energy (keV)
100
80
60
40
20
0
-20
30
10^2
$3x10^2$
10^3
$3x10^3$
10^4

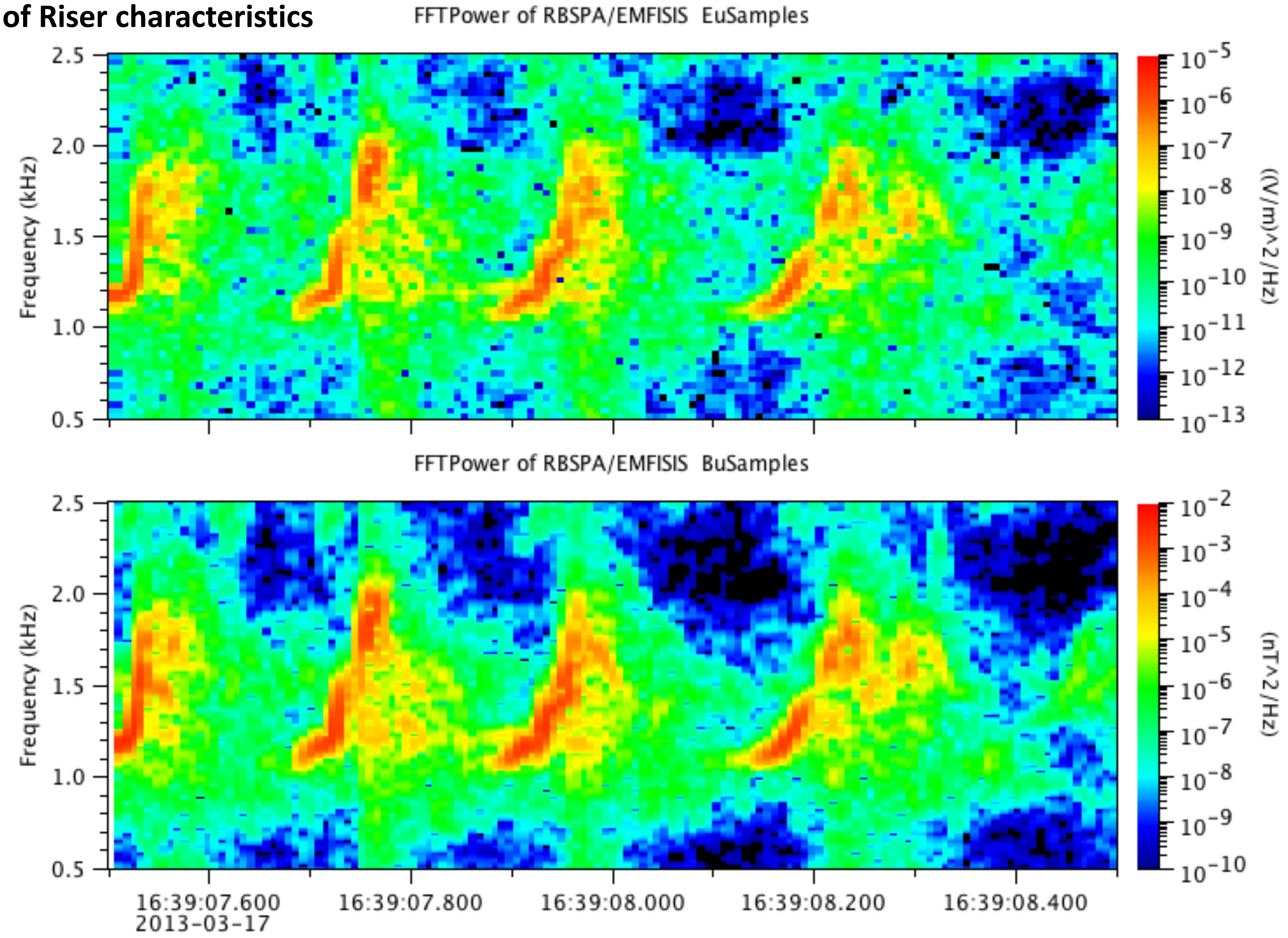


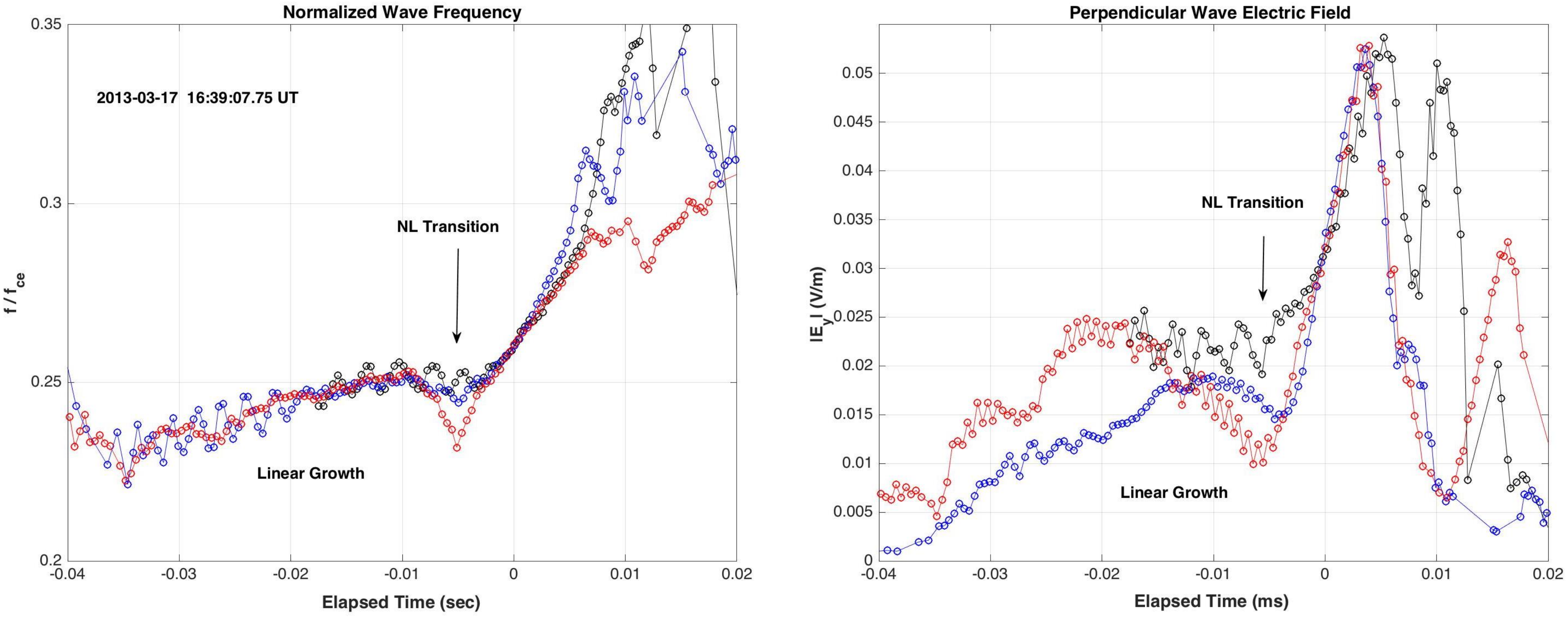
case3 EMFISIS BuBu Spectral Power
Frequency (kHz)
log Power (nT^2/Hz)
Integrated Wave Power
2013-03-17 22:48:20 UT
-2.63 Mlat 0.5 MLT L=5.8
f_pe / f_ce = 9.3
1/2 f_ce
1/2 f_ceEQ
1/4 f_ce
1/4 f_ceEQ


Wave Magnetic Field
B_w (nT)
Wave Frequency
f / f_ce
RBSP-B Case 3
2013-03-17 22:48:20 UT
Wave Electric Field (E_y)
E_y (V/m)
(sec)
20.242
20.244
20.246
20.248
20.25
20.252
20.254


Total Cyclotron + Landau Energy Gain
Total
Landau E_y
Cyclotron
Landau E_z
2013-03-17 22:48:20.25 UT
-2.65 Mlat 0.5 MLT
B 003-000
Energy Gain (keV)
Electron Energy (keV)
70
60
50
40
30
20
10
0
-10
10^2
$3x10^2$
10^3
$3x10^3$
10^4

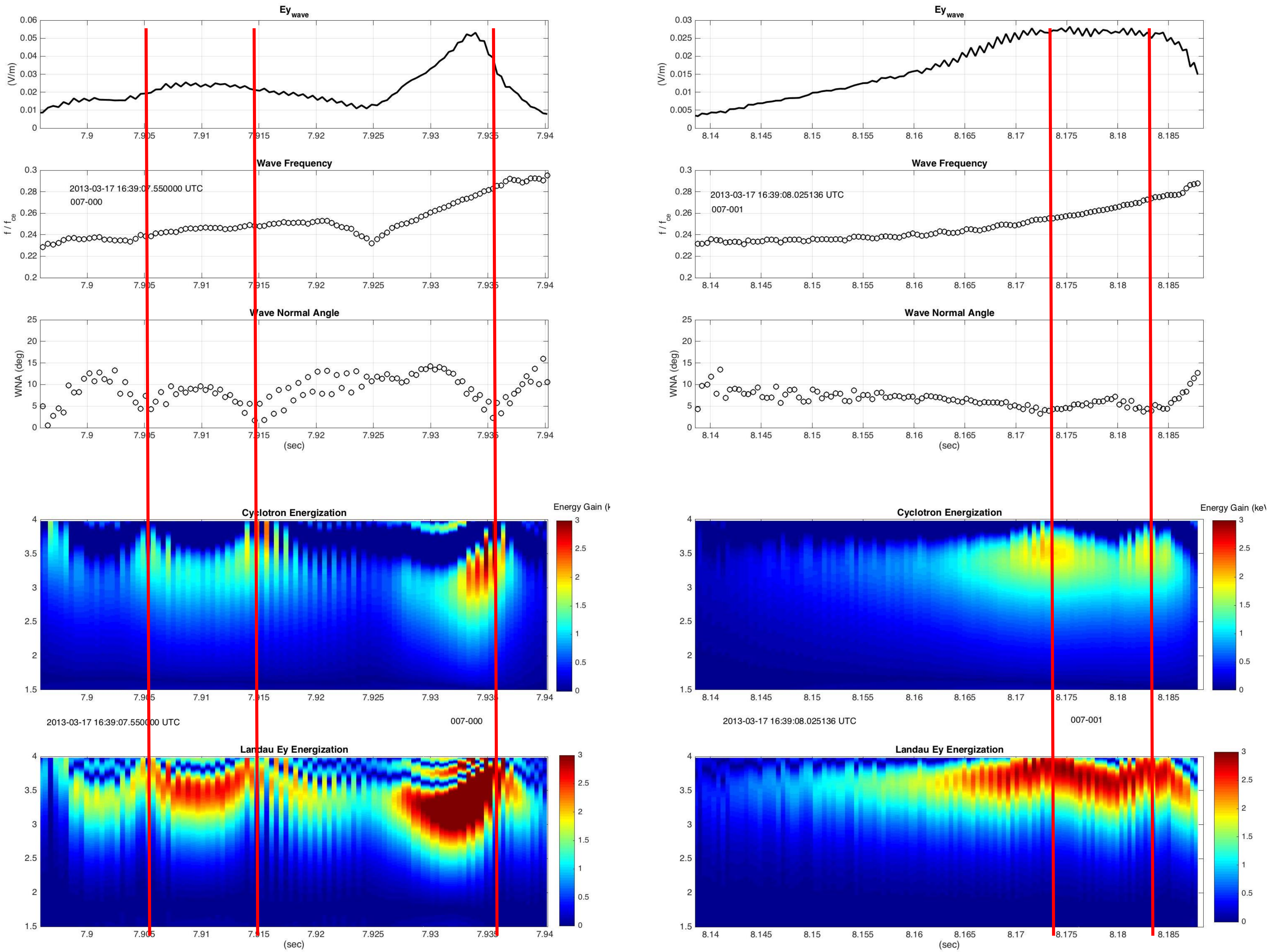
Repeatability of Riser characteristics

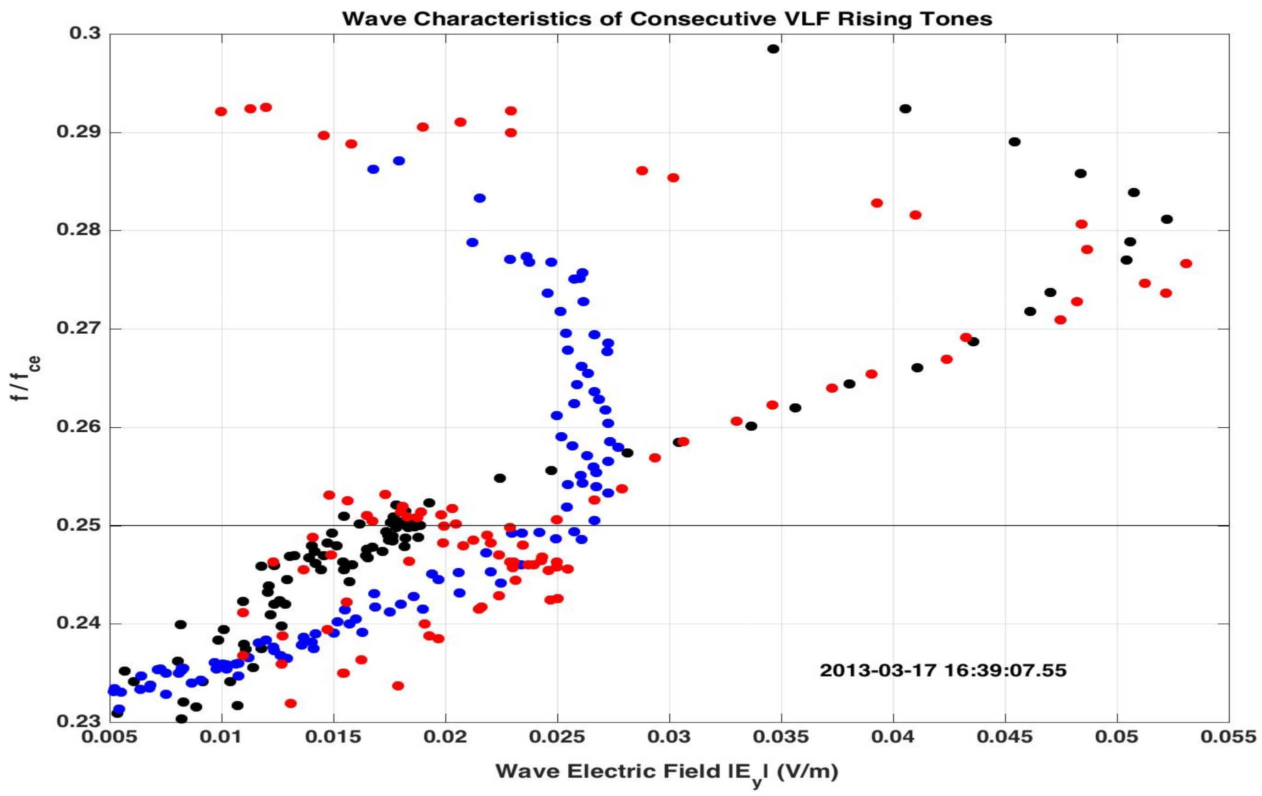


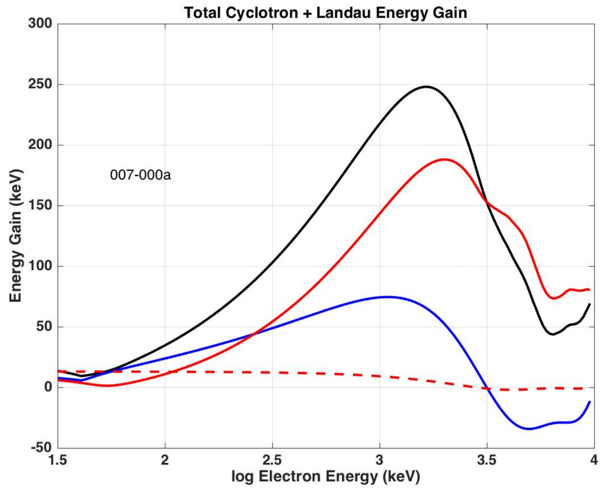


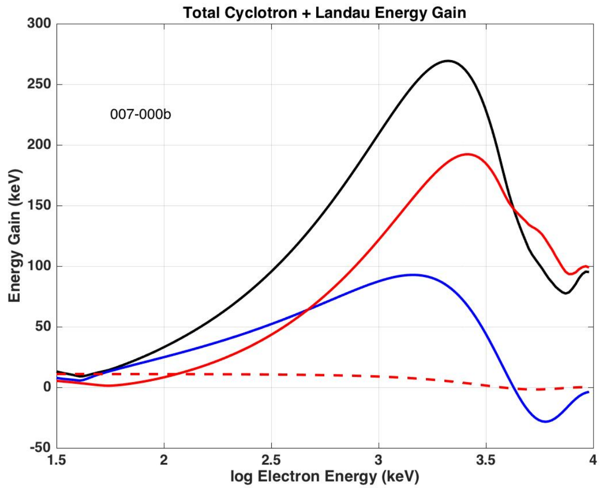
Normalized Wave Frequency
2013-03-17 16:39:07.75 UT
NL Transition
Linear Growth
f / f_ce
Elapsed Time (sec)
Perpendicular Wave Electric Field
NL Transition
Linear Growth
|E_y| (V/m)
Elapsed Time (ms)

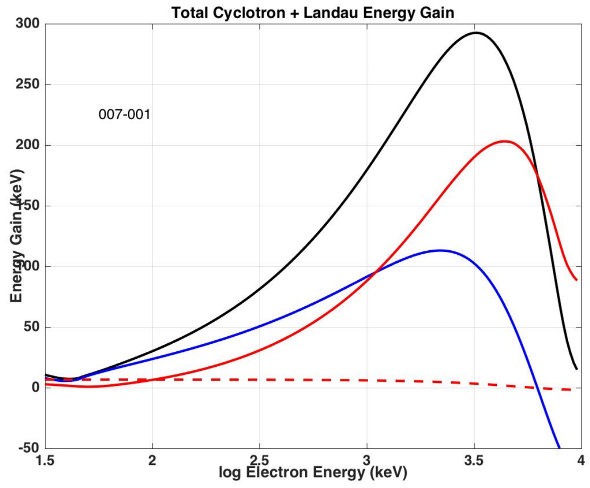
Importance of Wave Normal Angle for RB Acceleration

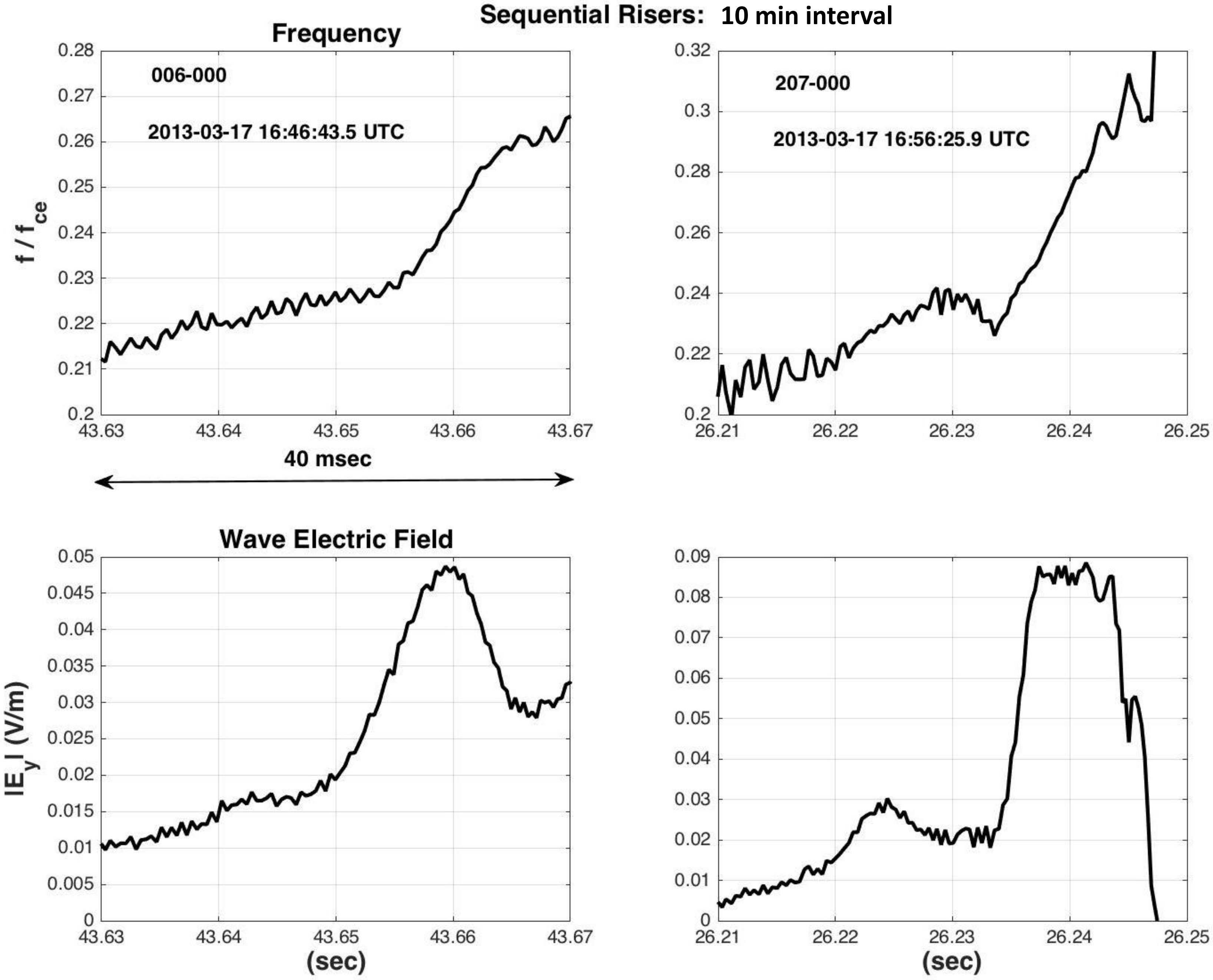



Wave Characteristics of Consecutive VLF Rising Tones
f / f$_{ce}$
Wave Electric Field |E$_y$| (V/m)
2013-03-17 16:39:07.55
0.3
0.29
0.28
0.27
0.26
0.25
0.24
0.23
0.005
0.01
0.015
0.02
0.025
0.03
0.035
0.04
0.045
0.05
0.055


Total Cyclotron + Landau Energy Gain
007-000a
Energy Gain (keV)
log Electron Energy (keV)


Total Cyclotron + Landau Energy Gain
007-000b
Energy Gain (keV)
log Electron Energy (keV)


Total Cyclotron + Landau Energy Gain
007-001
Energy Gain (keV)
log Electron Energy (keV)


Sequential Risers: 10 min interval
Frequency
006-000
2013-03-17 16:46:43.5 UTC
f / f_ce
40 msec
207-000
2013-03-17 16:56:25.9 UTC
Wave Electric Field
|E_y| (V/m)
(sec)
(sec)

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