The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific
and Cultural Organization

International Atomic
Energy Agency

SMR 1673/22

AUTUMN COLLEGE ON PLASMA PHYSICS

5 - 30 September 2005

Collisionless shocks : new results from Cluster mission

Vladimir Krasnoselskikh
LPCE / CNRS-University of Orleans
France

Strada Costiera 11, 34014 Trieste, Italy - Tel. +39 040 2240 111; Fax +39 040 224 163 - sci_info@ictp.it, www.ictp.it

"High frequency waves in electron foreshock region: Cluster results".

(Part I)

V. Krasnoselskikh

(LPCE/CNRS-University of Orleans, France)

with the assistance of

V. Lobzin, B. Lefebvre, S. Schwartz, I. H. Cairns,

P. Décréau, J. Soucek, T. Dudok de Wit, J. Pickett

Plan

- Part 1. Downshifted waves
- Historical background
- Cluster observations of high frequency waves and particles in electron foreshock region
- Analysis of linear instabilities
- Part II. Parametric instabilities.
- Wide-band data and their characteristics
- Basic theoretical notions about parametric instabilities.
- Statistical analysis of parametric instabilities
- Interpretation (a little ennoying theoretical part)
- and (finally)
- Conclusions

GEOPHYSICAL RESEARCH LETTERS, VOL. 32, L18101, doi:10.1029/2005GL023563, 2005

Generation of downshifted oscillations in the electron foreshock: A loss-cone instability

V. V. Lobzin,[1] V. V. Krasnoselskikh,[1] S. J. Schwartz,[2] Iver Cairns,[3] B. Lefebvre,[2]
P. Décréau,[1] and A. Fazakerley[4]

[1] Measurements performed aboard Cluster spacecraft near Earth's bow shock on 24 January 2001 provide convincing evidence of a loss-cone feature within the electron foreshock region. This feature is formed by suprathermal electrons with energies 15–45 eV and pitch angles 130°–150° and is always accompanied by electrostatic waves with frequencies well below the local plasma frequency. An instability analysis shows that these downshifted oscillations can result from a loss-cone instability of electron cyclotron modes rather than from the beam instability as previously suggested.

Citation: Lobzin, V. V., V. V. Krasnoselskikh, S. J. Schwartz, I. Cairns, B. Lefebvre, P. Decreau, and A. Fazakerley (2005), Generation of downshifted oscillations in the electron foreshock: A loss-cone instability, *Geophys. Res. Lett.*, *32*, L18101, doi:10.1029/2005GL023563.

Historical background – 1

- First observations of fluctuating electric fields near the Earth's bow shock near f_{pe} [Fredricks et al., Phys. Rev. Lett., 21, 1761, 1968].
- These wave are associated with energetic electron fluxes moving from the bow shock [Scarf et al., J.Geophys. Res., 76, 5162, 1971].
- Time-of-flight mechanism of bump-on-tail formation, a beam instability of plasma waves [Filbert and Kellogg, J. Geophys. Res., 84, 1369, 1979]

Historical background – 2

- Observations of field-aligned beams in the reduced distributions at the foreshock boundary [Feldman et al., J. Geophys. Res., 88, 96, 1983; Fitzenreiter et al., Geophys. Res. Lett., 11, 496, 1984].
- Statistical studies of electrostatic waves upstream of the Earth's bow shock [Etcheto and Faucheux, J. Geophys. Res., 89, 6631, 1984; Lacombe et al., J. Geophys. Res., 90, 73, 1985].

Historical background – 3

- Observations of downshifted oscillations with large frequency shifts [Fuselier et al., J. Geophys. Res., 90, 3935, 1985].
- Wide-band waves are beam modes [Lacombe et al., 1985; Fuselier et al., 1985; Cairns and Fung, J.Geophys. Res., 93, 7307, 1988; Dum, J.Geophys. Res., 95, 8123, 1990].

The generation of downshifted oscillations . . .

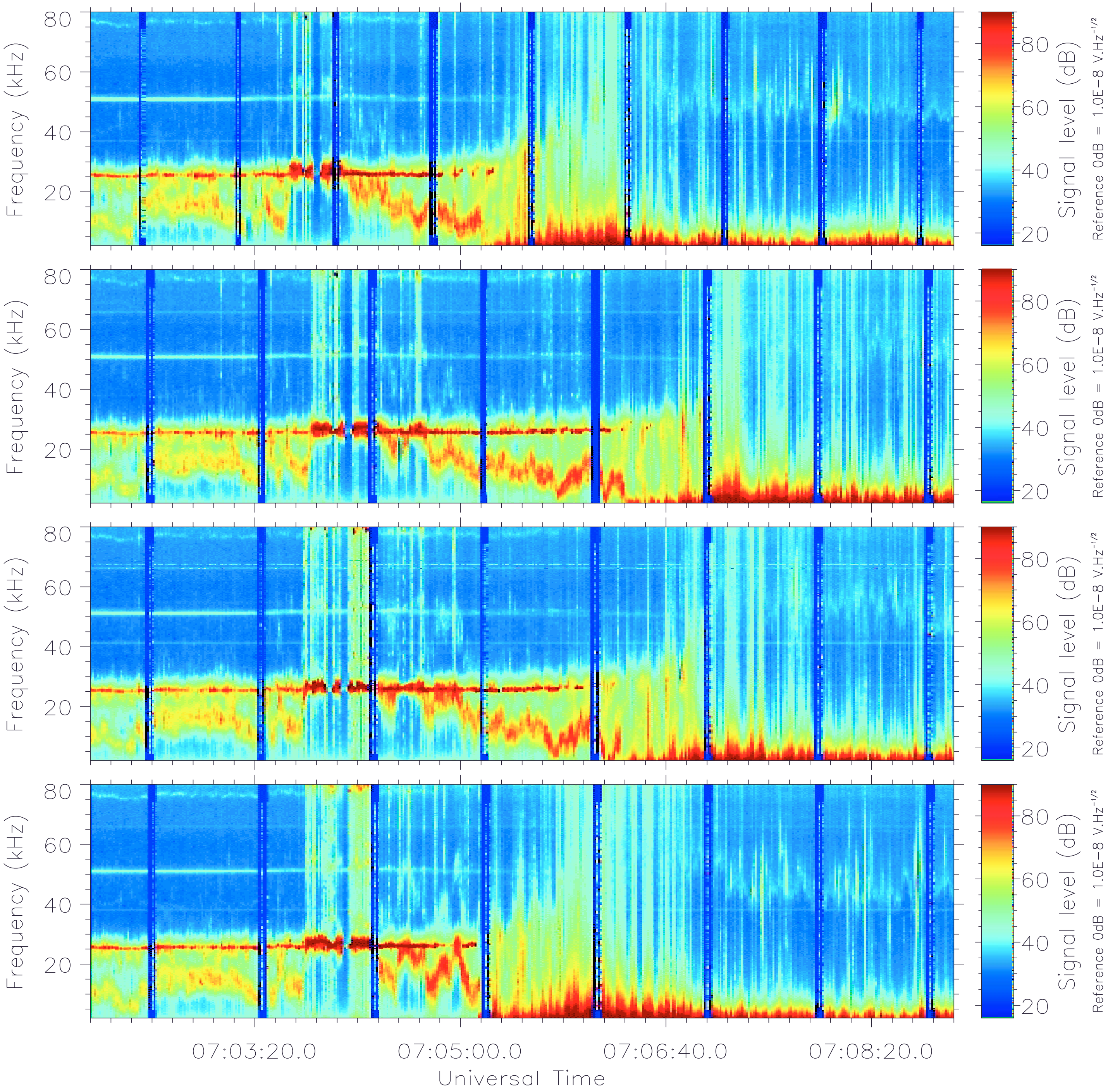
IAGA 2005

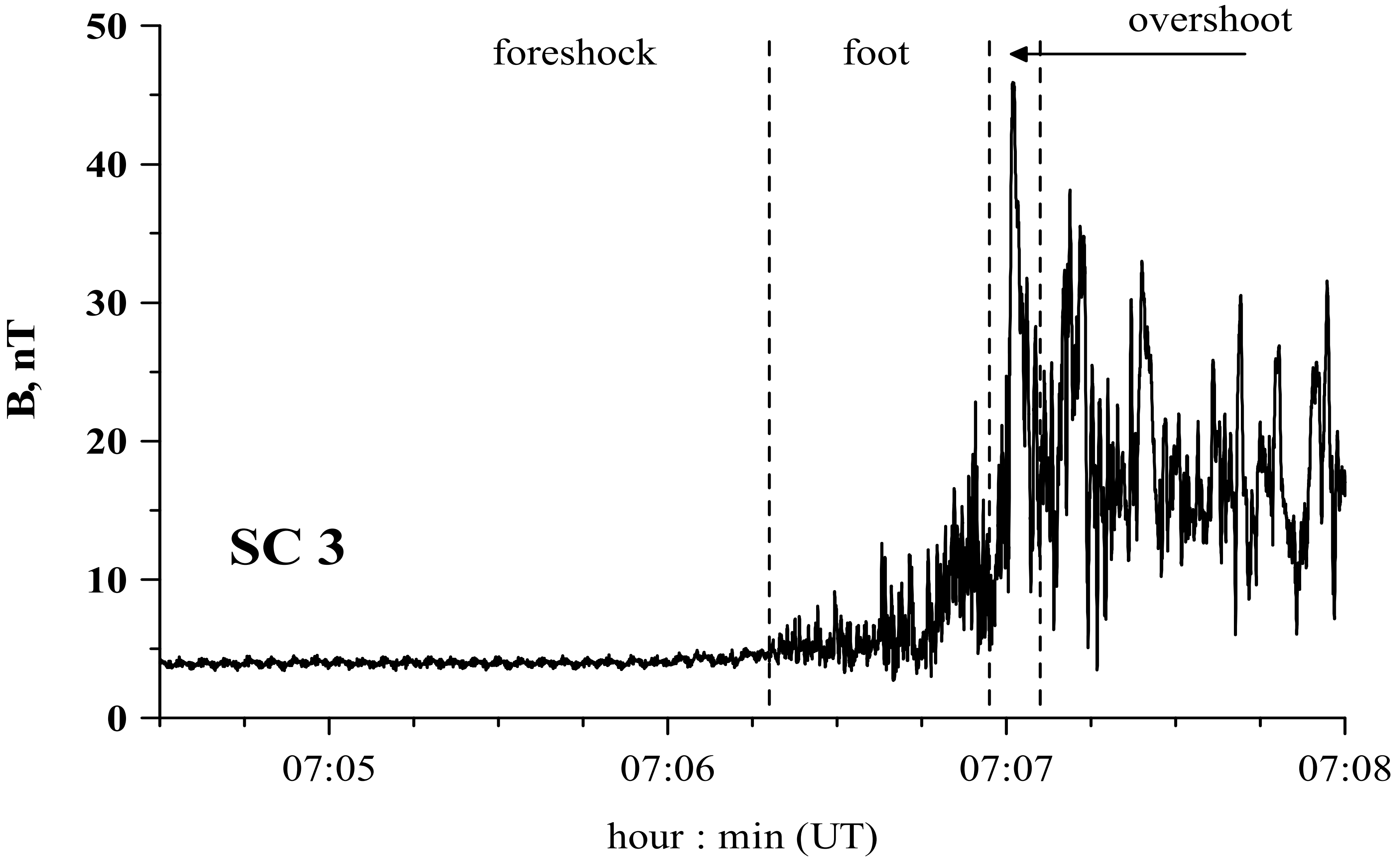
- Plasma oscillations at the plasma frequency have wavelengths much greater than a Debye length. Plasma oscillations at frequencies well below the plasma frequency have wavelengths of the order of a few Debye lengths.

- As the plasma oscillations shift below the plasma frequency, their bandwidth increases from a few hundred Hertz near the plasma frequency to ±2kHz well below the plasma frequency.

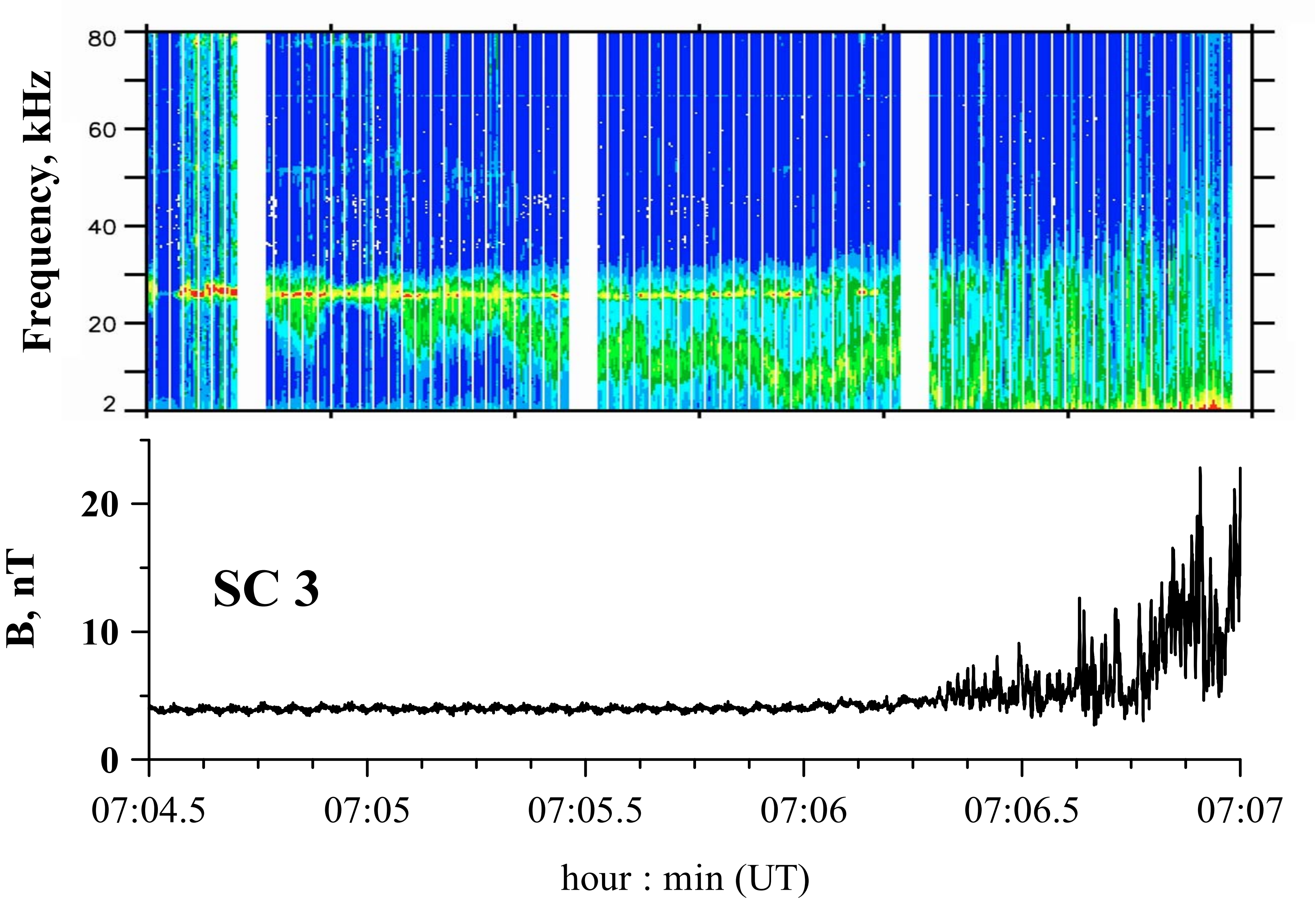
- Plasma oscillations much below the plasma frequency are correlated with times when ISEE 1 is located deep in the foreshock region, far downstream of the foreshock boundary.

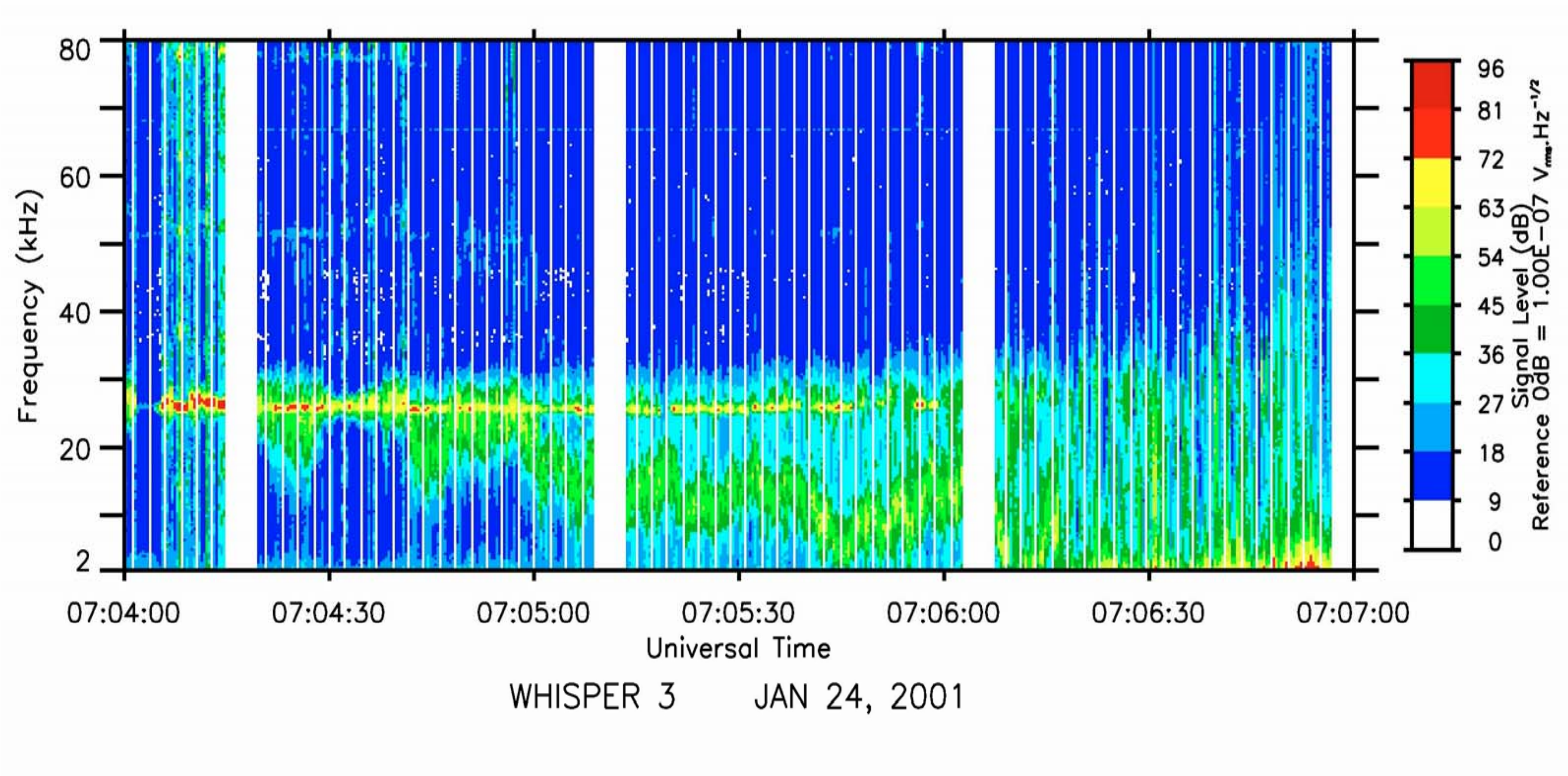
- As the plasma oscillations shift below the plasma frequency, the flux of energetic electrons streaming from the bow shock increases at successively lower velocities.


80
60
40
20
Frequency (kHz)
Signal level (dB)
Reference 0dB = 1.0E−8 V.Hz$^{-1/2}$
80
60
40
20
07:03:20.0
07:05:00.0
07:06:40.0
07:08:20.0
Universal Time



Profile of the magnetic field

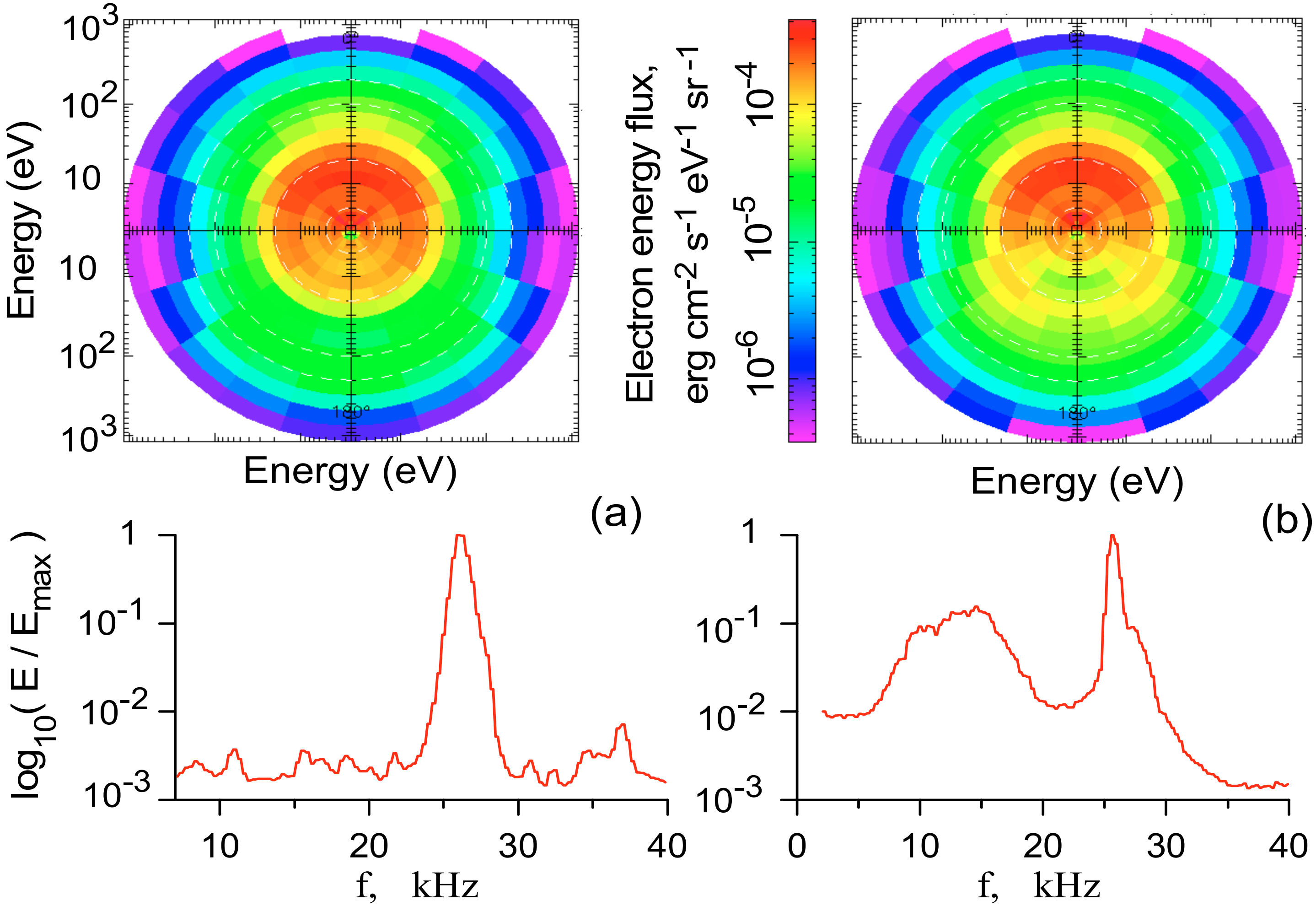

Frequency, kHz
80
60
40
20
2
B, nT
20
10
0
SC 3
07:04.5
07:05
07:05.5
07:06
07:06.5
07:07
hour : min (UT)



The frequency-time spectrogram for the Earth's bow shock crossing on January 24, 2001.

Parameters of the Shock Wave

Upstream magnetic intensity	4.21 ± 0.09 nT	**Speeds, Frequencies, and Characteristic Lengths**	
Upstream electron density	9.0 ± 0.2 cm^{-3}	Alfvén speed V_A	31 km/s
Upstream electron temperature	8.2 ± 0.3 eV	Upstream electron thermal speed V_{Te}	1700 km/s
Main Dimensionless Parameters		Upstream electron plasma frequency f_{pe}	27.0 ± 0.3 kHz
Upstream θ_{Bn}	$81^{\circ} \pm 4$	Upstream electron gyrofrequency f_{Be}	118 ± 3 Hz
Upstream β_e	1.7	Upstream thermal electron gyroradius ρ_e	2.3 km
Alfvén Mach number M_A	10	Upstream electron Debye length λ_{De}	5 m



Electron differential energy flux versus energy and pitch angle and the corresponding electric field spectra (a) near the forward edge of the electron foreshock, at 07:04:29-07:04:33 UT, and (b) deeper, at 07:05:13-07:05:17 UT.

Instability analysis – 1

Electron distributions:

$$f_{c,h}(\mathrm{v}) = \frac{n_{c,h}}{(2\pi)^{3/2}\mathrm{V}_{Tc,h}^{3}}\exp\left(-\frac{\mathrm{v}^2}{2\mathrm{V}_{Tc,h}^{2}}\right),$$

$$f_r(\mathrm{v}) = \frac{n_r\, g\left(\upsilon_\perp/\mathrm{V}_{\mathrm{Tc}}\right)}{(2\pi)^{3/2}\mathrm{V}_{\mathrm{Tr}}\mathrm{V}_{\mathrm{Tc}}^{2}}\exp\left[-\frac{\left(\upsilon_\parallel - \mathrm{V}_0\right)^2}{2\mathrm{V}_{\mathrm{Tr}}^{2}}\right]$$

Instability analysis –2

Dielectric response function:

$$\varepsilon = 1 + \delta\varepsilon_c(\omega, \mathrm{k}) + \delta\varepsilon_h(\omega, \mathrm{k}) + \delta\varepsilon_r(\omega, \mathrm{k})$$

Growth rate:

$$\gamma = \operatorname{Im} \varepsilon(\omega, \mathrm{k}) \Big/ \frac{\partial \operatorname{Re} \varepsilon(\omega, \mathrm{k})}{\partial \omega}$$

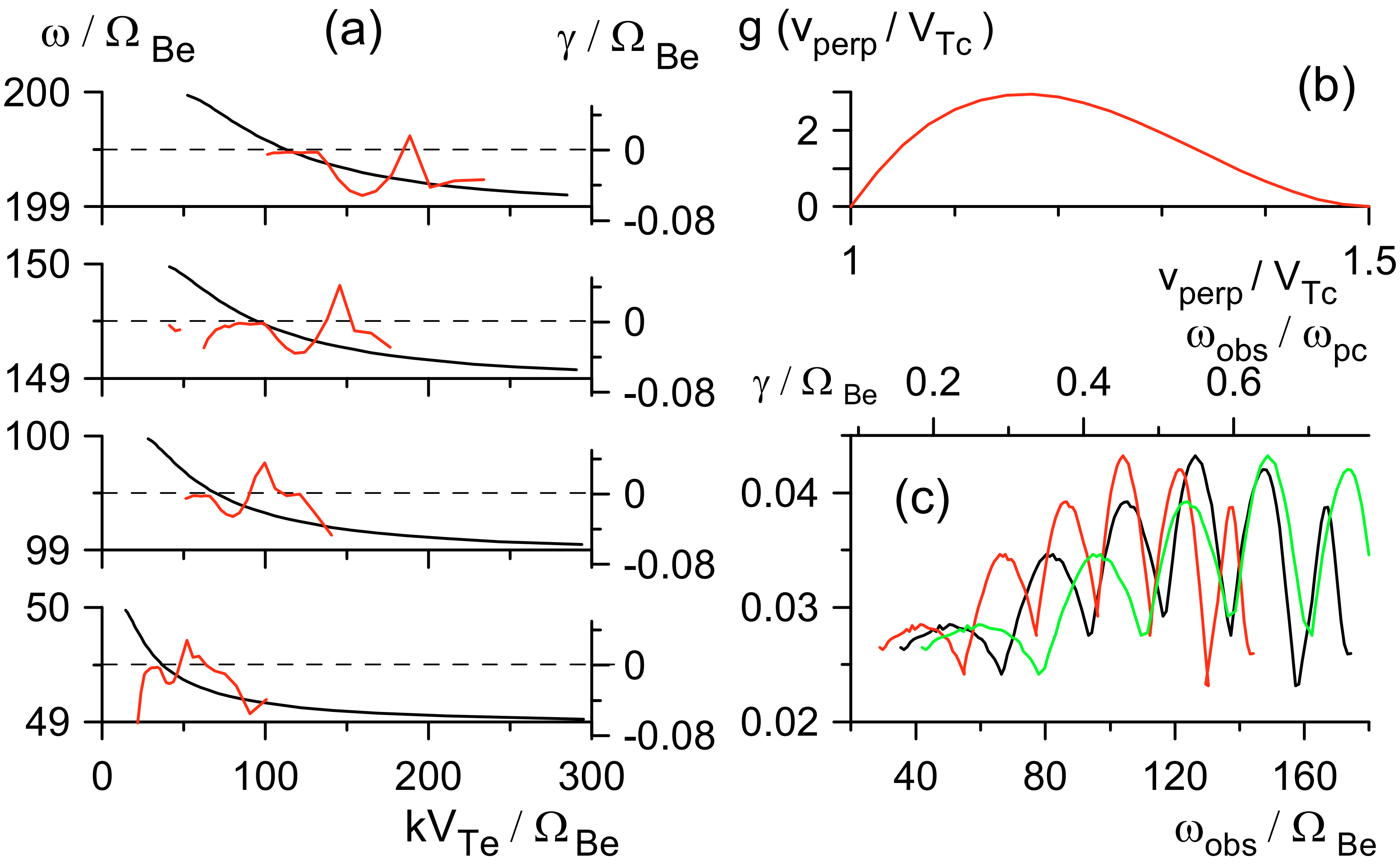
Instability analysis –3

$$\mathrm{Re}\left(\partial\varepsilon_c\right) = -\frac{\omega_{pc}^2\Omega_{Be}^2}{k_\perp^2 \mathrm{V}_{\mathrm{Tc}}^2}\sum_{n=-\infty}^{\infty}\frac{n^2\Lambda_n\left(k_\perp^2\mathrm{V}_{\mathrm{Tc}}^2/\Omega_{Be}^2\right)}{\omega\left(\omega - n\Omega_{Be}\right)}$$

$$\mathrm{Im}\left(\delta\varepsilon_\alpha\right) = -\sqrt{\frac{\pi}{2}}\,\frac{\omega_{p\alpha}^2}{k^2\mathrm{V}_{\mathrm{Tc}}^2}\,\frac{1}{\Delta n_\alpha}\sum_{n=-\infty}^{+\infty}\exp\left[-\frac{1}{2}\left(\frac{n-n_{0\alpha}}{\Delta n_\alpha}\right)^2\right]$$

$$\times\left\{\int_0^\infty J_n^2(\kappa x)\left[\frac{(n-n_{0\alpha})x g_\alpha(x)}{\left(\mathrm{V}_{\mathrm{T}\alpha}/\mathrm{V}_{\mathrm{T}c}\right)^2} + n g_\alpha^{/}(x)\right]dx\right\},$$

where $n_{0\alpha} = (\omega - k_\parallel V_{0\alpha})/\Omega_{Be},\ \Delta n_{0\alpha} = |k_\parallel| V_{T\alpha}/\Omega_{Be},\ \kappa = k_\perp V_{Tc}/\Omega_{Be}$



Instability of electron cyclotron waves due to loss-cone distribution of reflected/accelerated electrons.

Parameters

$N_h / N_c = 0.10$

$T_h / T_c = 8$

$N_r / N_c = 0.03$

$T_r / T_c = 5$

$\omega_{pe} / \Omega_{Be} = 230.5$

$V_{SW\perp} / V_{Tc} = 0.18$

Another possibility: electron sound mode generation

red line	growth rate due to core population of cold electrons
green line	growth rate due to hot isotropic halo
blue line	growth rate due to electron population with anisotropic distribution
black line	the total growth rate

Parameters of the electron distribution

	panel I	panel II
$N_{\mathrm{halo}} / N_{\mathrm{core}}$	0.1	0.1
$T_{\mathrm{halo}} / T_{\mathrm{core}}$	10	10
$T_{\mathrm{reflected}} / T_{\mathrm{halo}}$	1	1
$N_{\mathrm{reflected}} / N_e$	0.02	0.02
$V_0 / V_{Te\ \mathrm{core}}$	0	1.5

$\theta = 10$□ for both panels

$T_{\parallel} / T_{\perp} = 1$ for reflected electrons

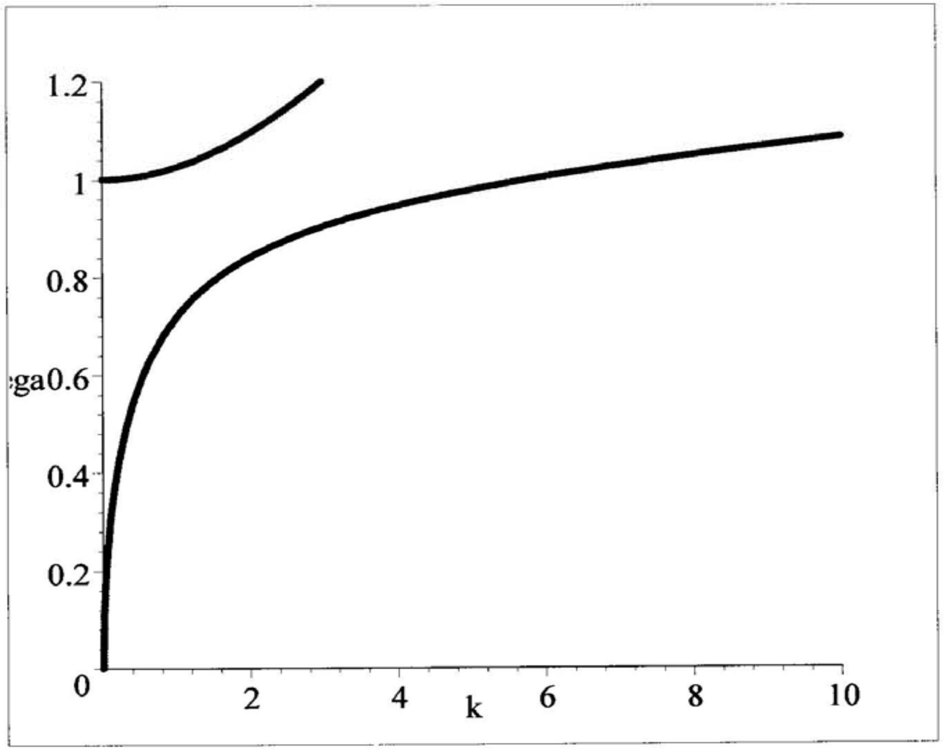
Electron-sound and Langmuir waves

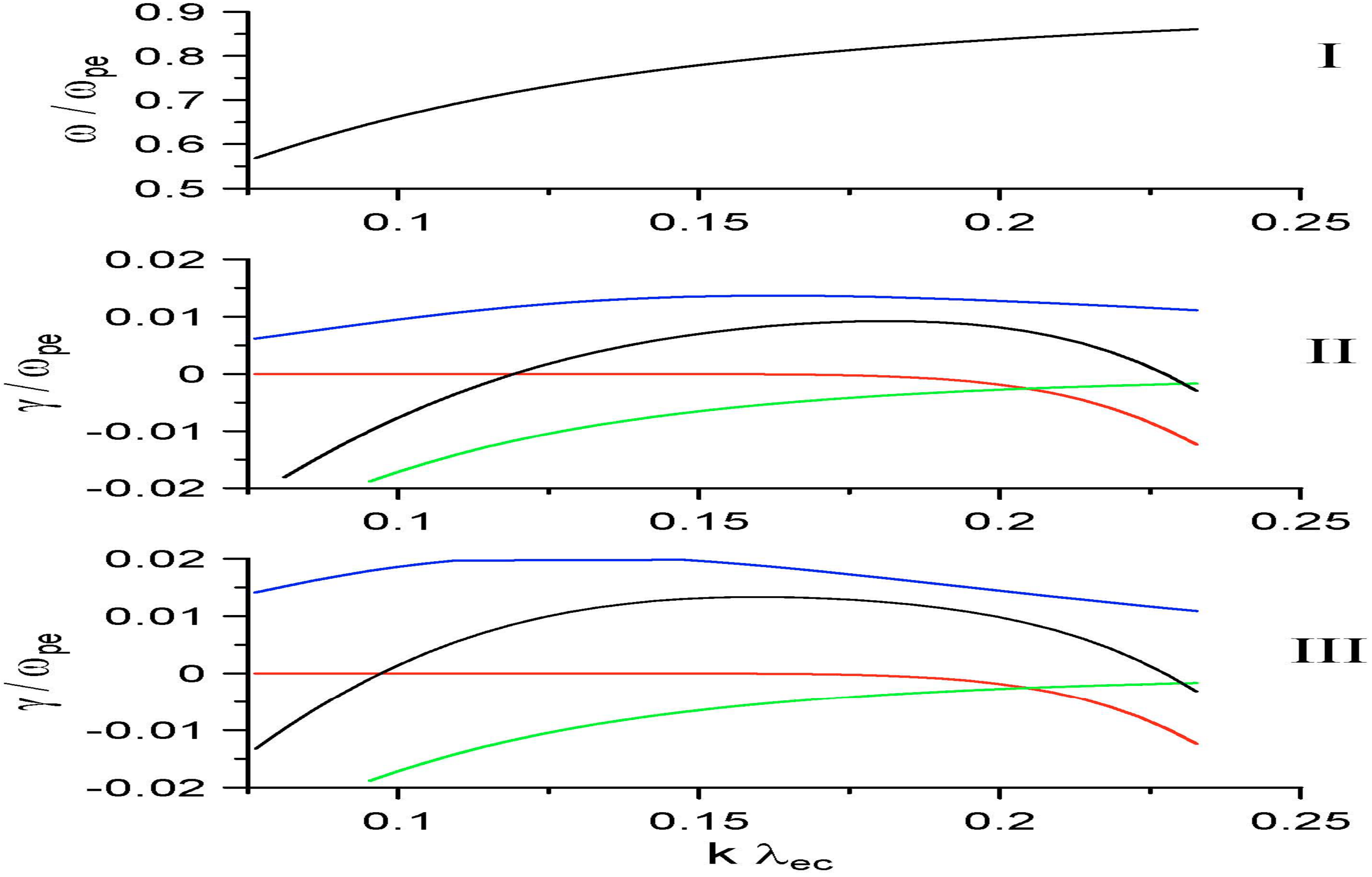
$$\frac{\partial^2}{\partial t^2}\left(\Delta\phi - \frac{4\pi n_{h0}e^2}{T_h}\phi\right) +$$

$$+\,\omega_{pc}^2\left(1+\frac{3T_e}{T_h}\frac{n_{h0}}{n_0}\right)div\left[\frac{n_S}{n_0}\nabla\phi\right]+$$

$$+\,\omega_{pc}^2\left(1+\frac{3T_e}{T_h}\frac{n_{h0}}{n_0}\right)\Delta\phi - 3\omega_{pc}^2\lambda_{Dc}^2\Delta^2\phi = 0$$

$$\omega^2 = \frac{k^2\lambda_{Dh}^2}{(k^2\lambda_{Dh}^2+1)}\left[\omega_{ph}^2\left(1+\frac{3T_e}{T_h}\frac{n_{h0}}{n_0}\right)+3\lambda_{Dc}^2k^2\right]$$

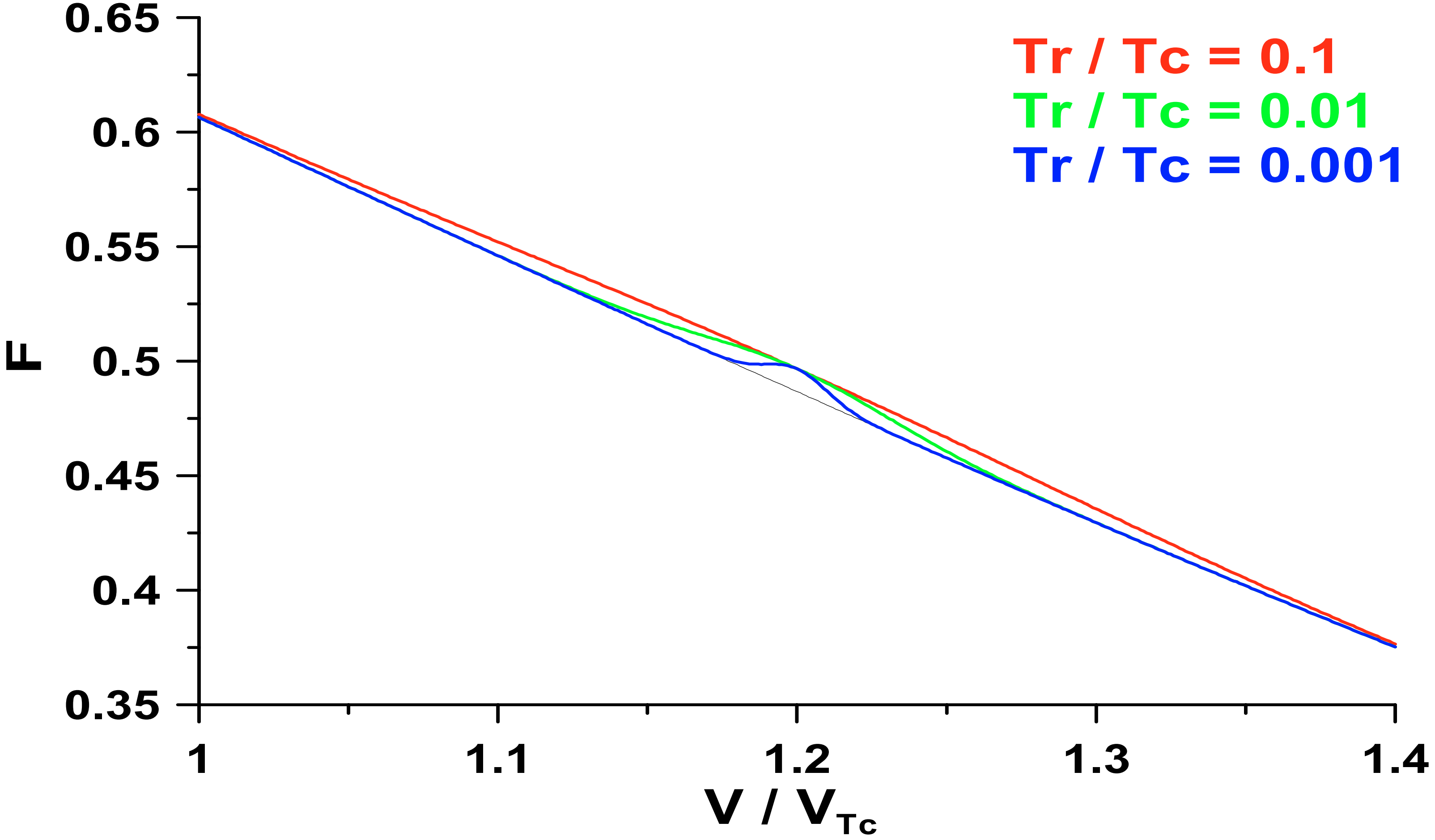




ω/ω_{pe}
0.9
0.8
0.7
0.6
0.5
I
0.1
0.15
0.2
0.25
γ/ω_{pe}
0.02
0.01
0
-0.01
-0.02
II
0.1
0.15
0.2
0.25
γ/ω_{pe}
0.02
0.01
0
-0.01
-0.02
III
0.1
0.15
0.2
0.25
$k\,\lambda_{ec}$

Reduced distribution functions

for N_r/N_c = 0.03 and different beam temperatures



Conclusions

- The observed loss-cone feature is always accompanied by electrostatic waves with frequencies well below the local plasma frequency.
- The downshifted oscillations can result from a loss-cone instability of electron cyclotron or electron-sound modes rather than a beam instability of the Langmuir and/or beam modes.