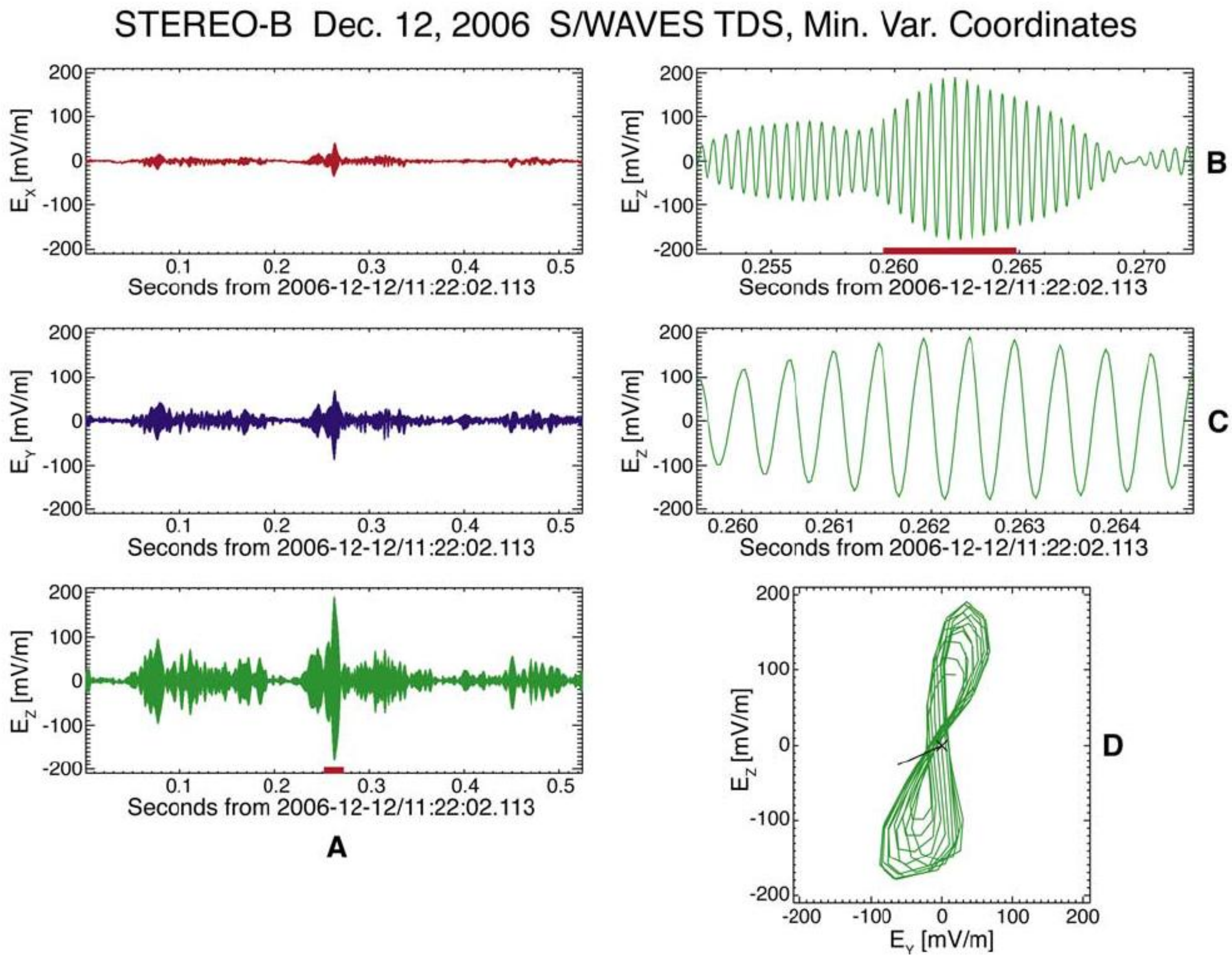
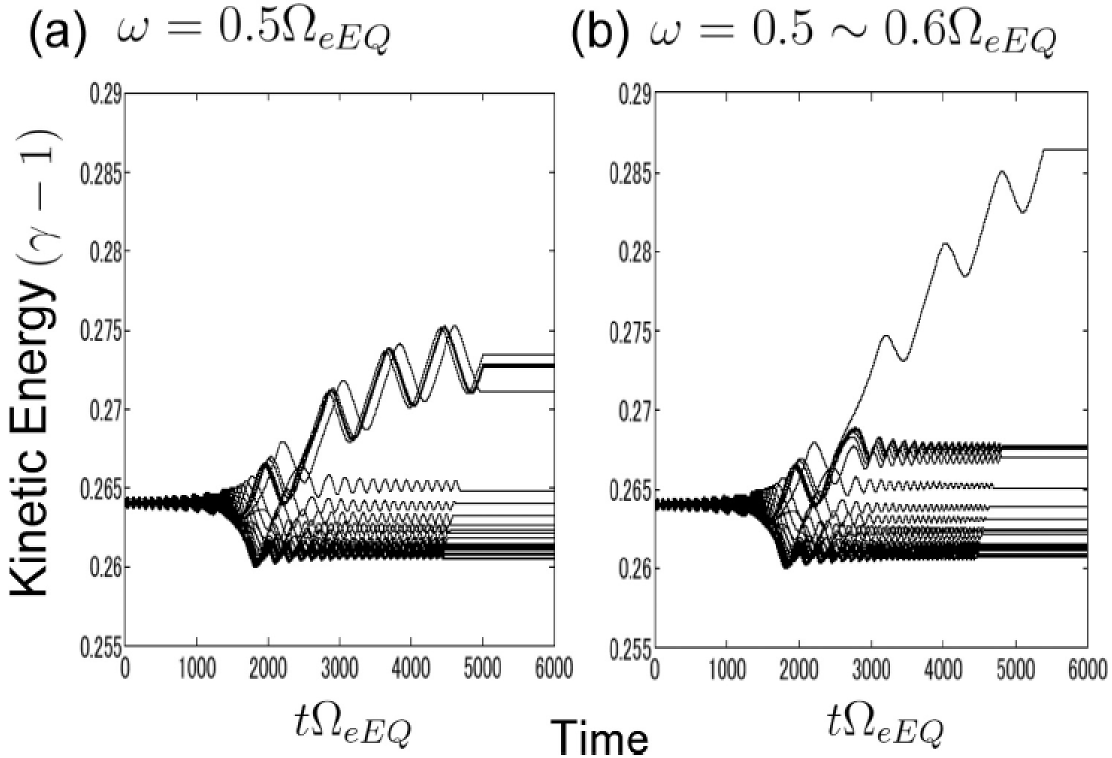
Large-Amplitude Whistler Waves and Relativistic Electron Acceleration

Peter H. Yoon (Kyung HeeUniv&Univ of Maryland)

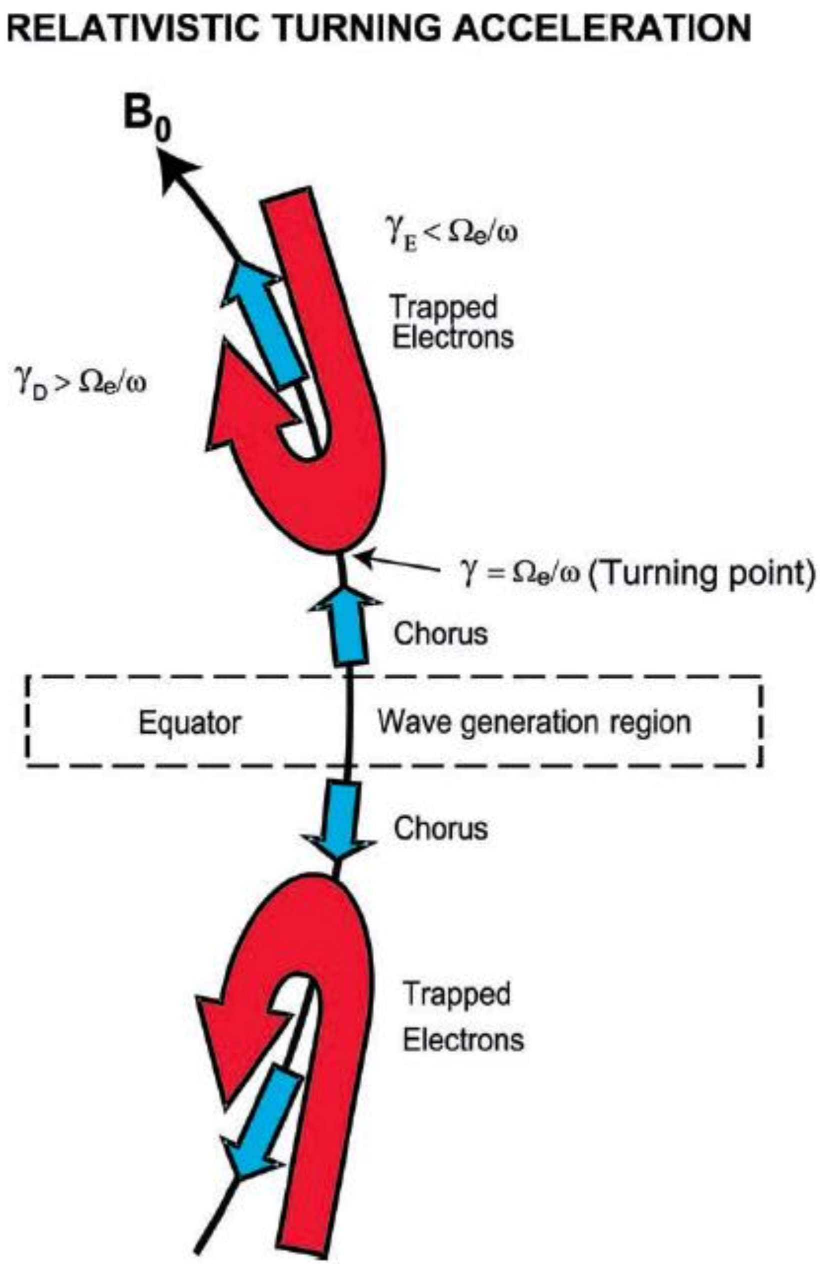


Cattell et al. (2008): Large-amplitude (200 mV/m or $\delta B/B_0$ ~ 0.01) oblique (40°-70°) whistler wave observed at high magnetic latitude (~ 20°).

Theories of Whistler-Acceleration



- Omura and Summers (2006):
  - Inhomogeneous B field. Resonant trapped electrons forming electromagnetic electron hole. Coherent whistler mode. Acceleration of trapped electrons.



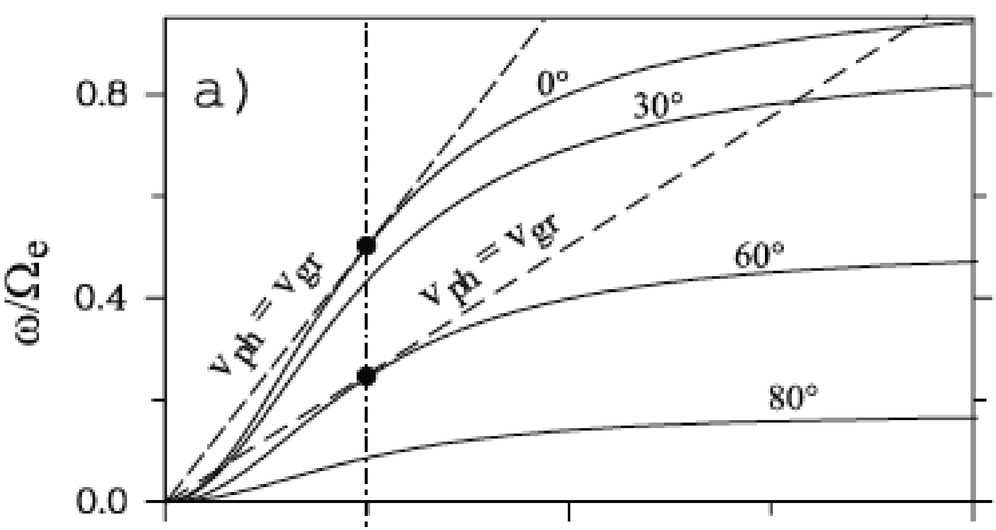
- Omura et al. (2007):
  - Extension of Omura& Summers (2006). Relativistic turning acceleration

- Omura& Summers (2006) and Omura et al. (2007) assume parallel propagation of whistler wave.
- Cattell et al. (2008) STEREO observation is for oblique propagation angle.

Whistler Oscilliton Theory

- Sauer et al. (2002)
- Dubinin et al. (2003, 2007)
- Sauer and Sydora (2010)

- Coherent wave packets for whistler waves satisfying Gendrin condition.



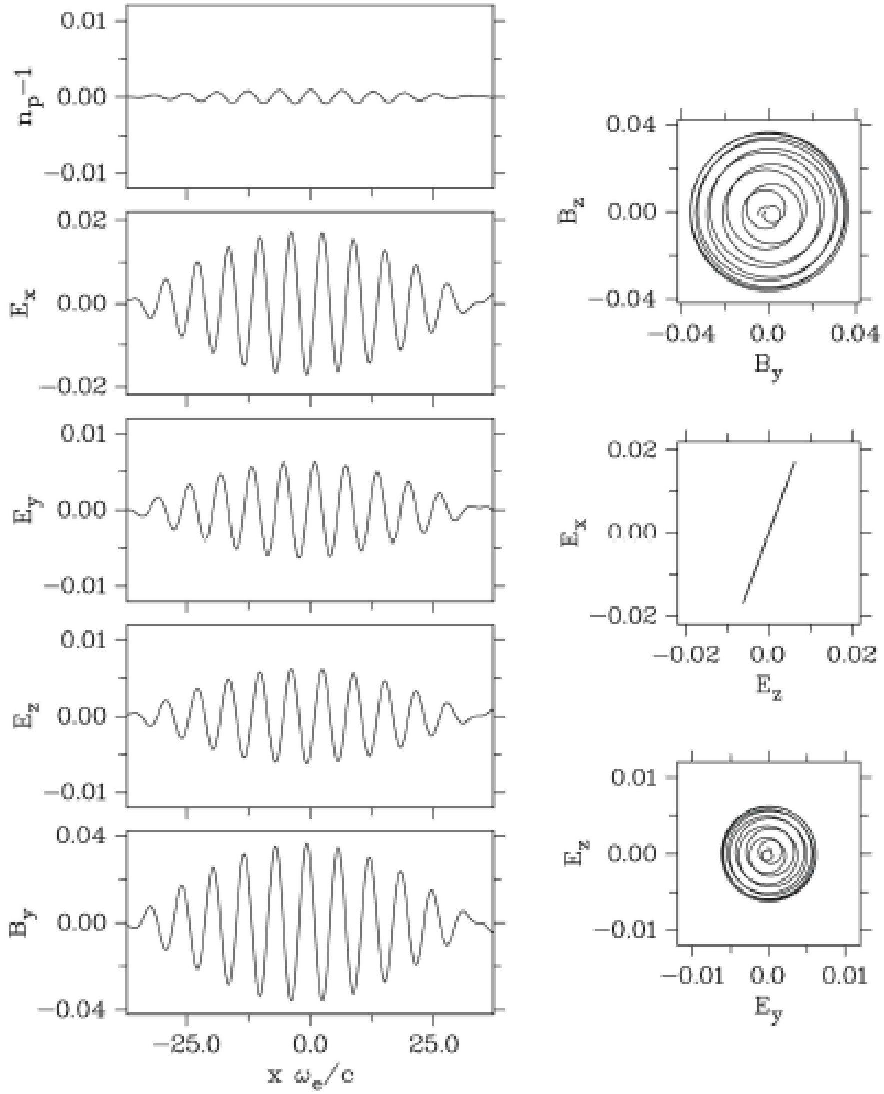


Fig. 8. Spatial profiles of whistler oscillitons for $\theta = 70^\circ$ and $U = 0.172 V_{Ae}$. From top to bottom: proton density $(n_p - n_{po})/n_{po}$, three components of the electric field (in units of $E_o = V_{Ae} B_o$) and the magnetic field component B_y/B_o. The right panels show the hodographs B_z versus B_y, E_x versus E_z, and E_z versus E_y.

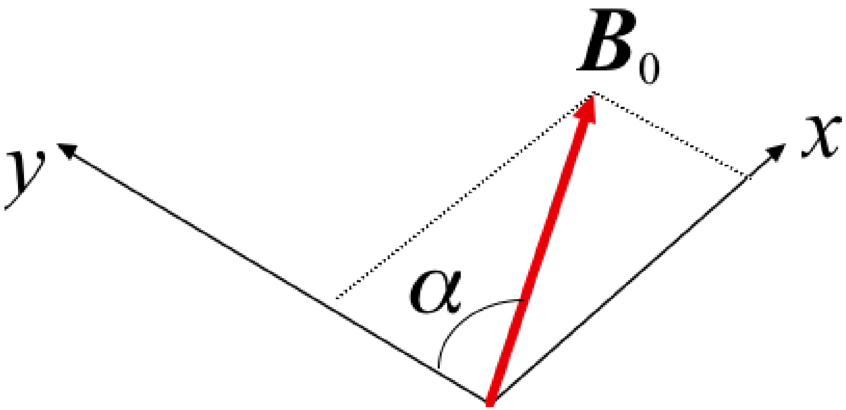
Sauer and Sydora (2010)

Note: The authors do not discuss electron acceleration.

Oblique whistlers

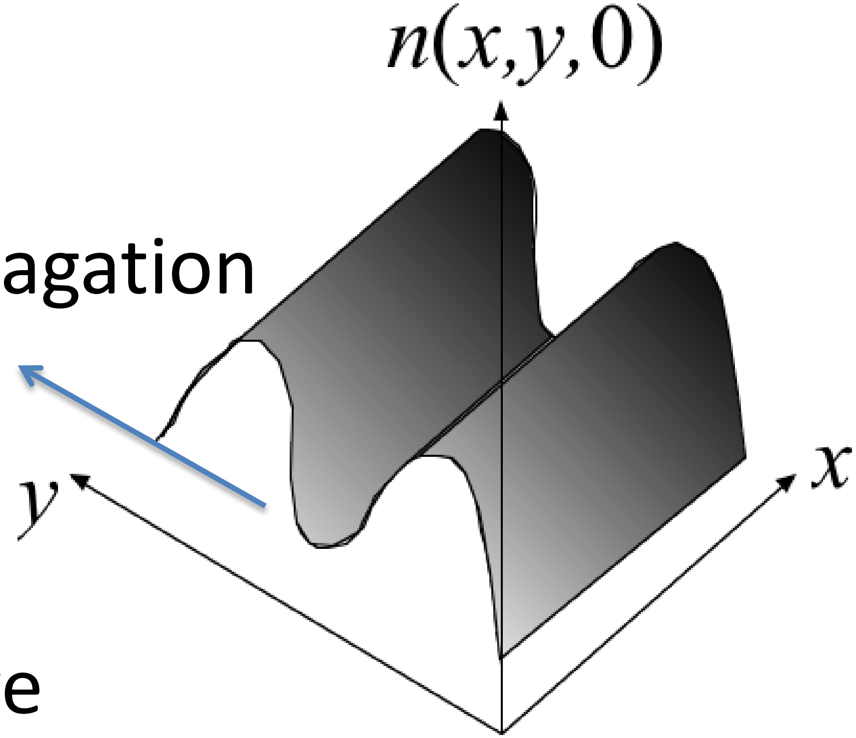
- Tao and Bortnik (2010): Theory of oblique whistler and relativistic electron acceleration — using linear theory of oblique whistler wave.
- Verkhoglyadova et al. (2010): Linear theory of oblique whistler wave — they do not discuss relativistic electron acceleration.

Nonlinear oblique whistlers



2D Geometry

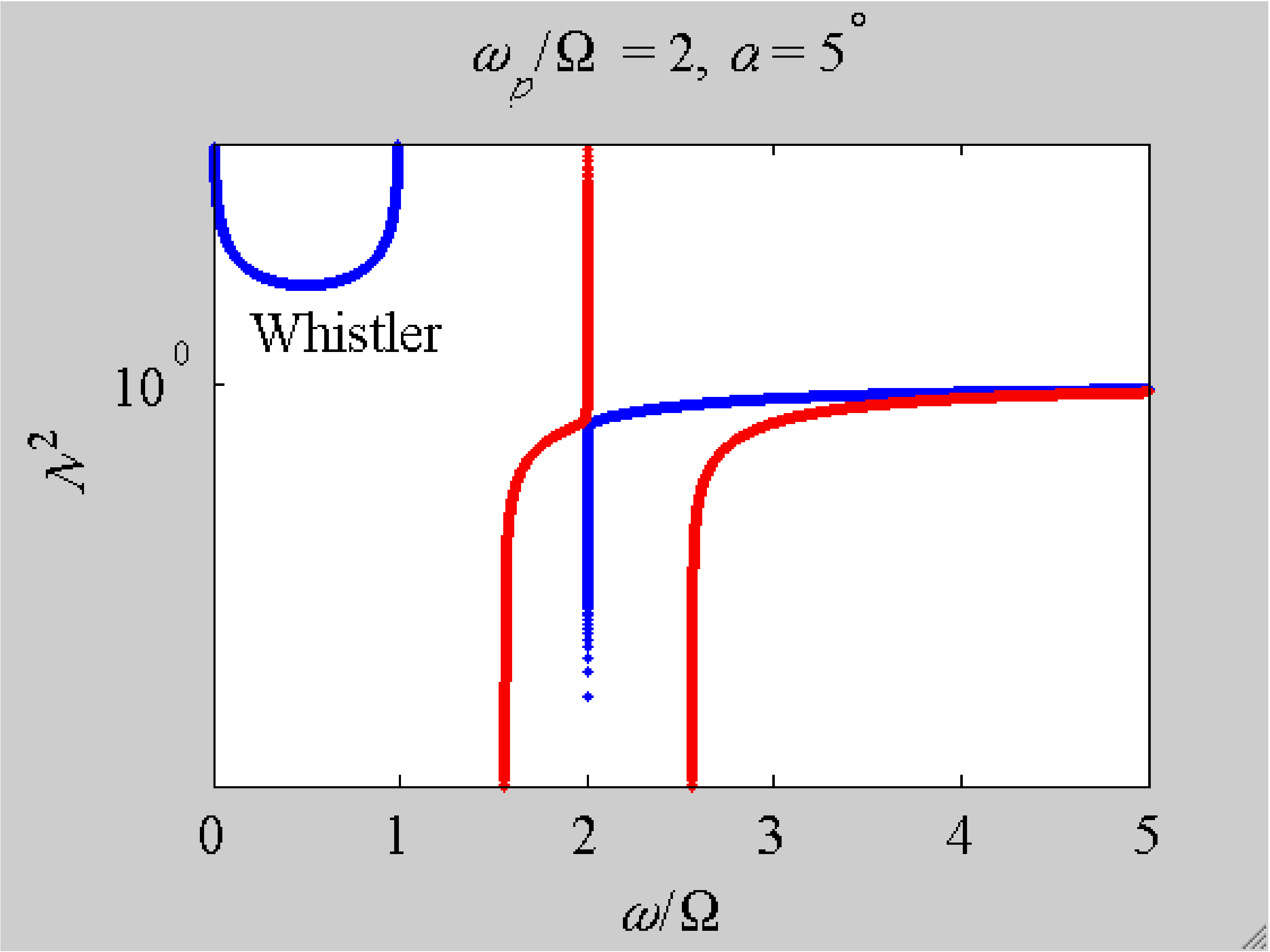
Wave propagation direction



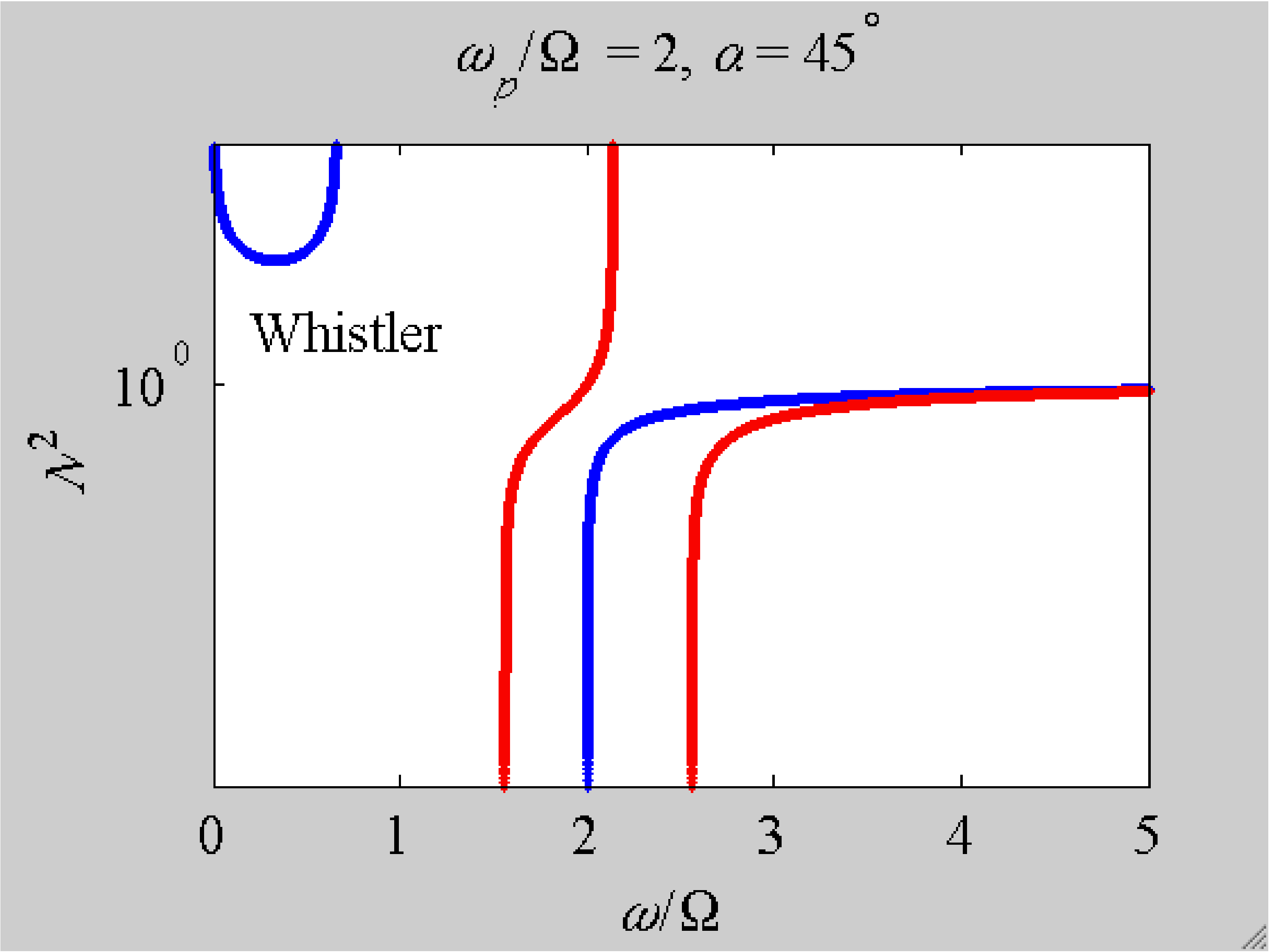
Oblique whistler wave

Initial condition

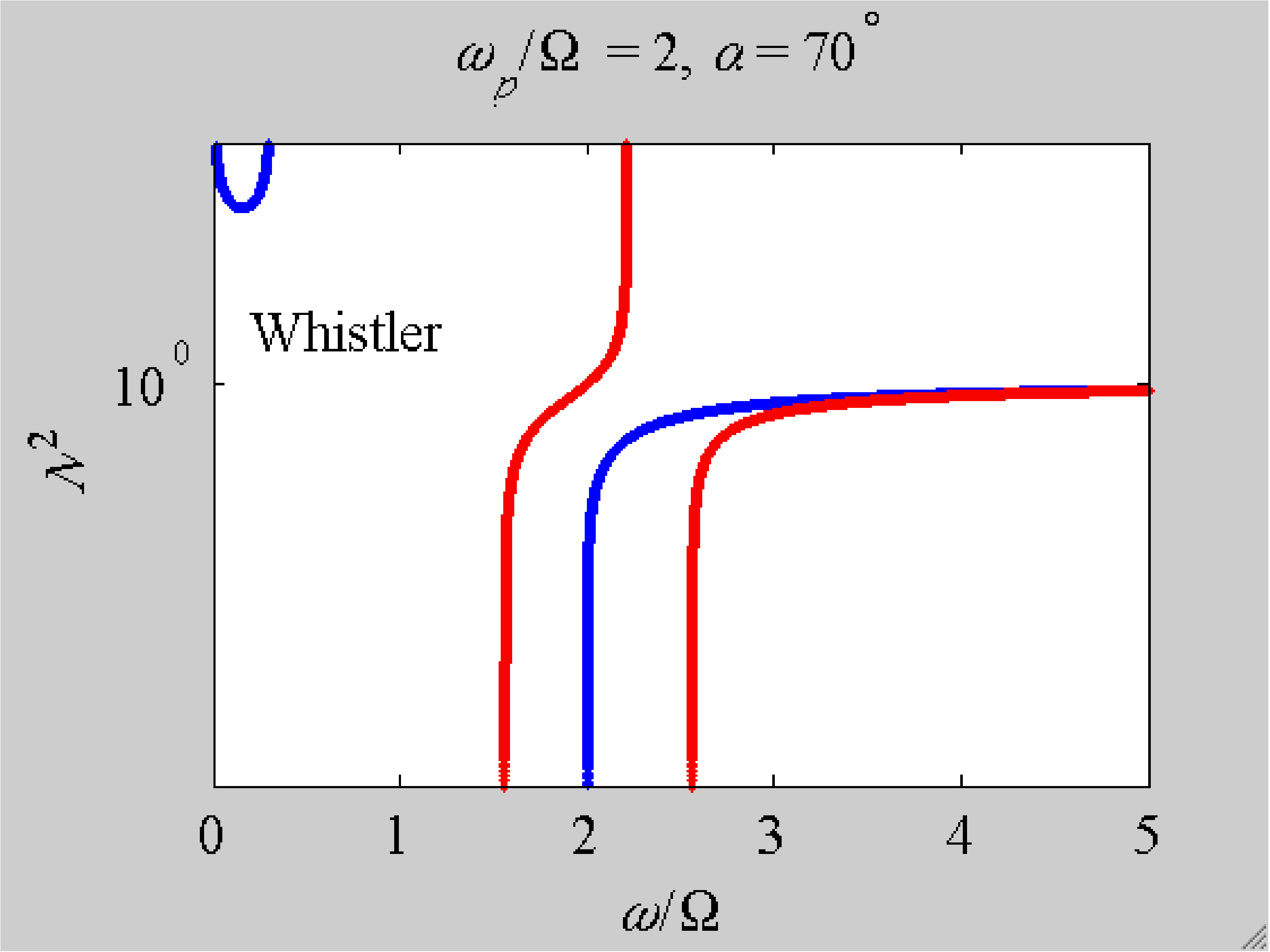
Oblq Whist Wave Dispersion Relation



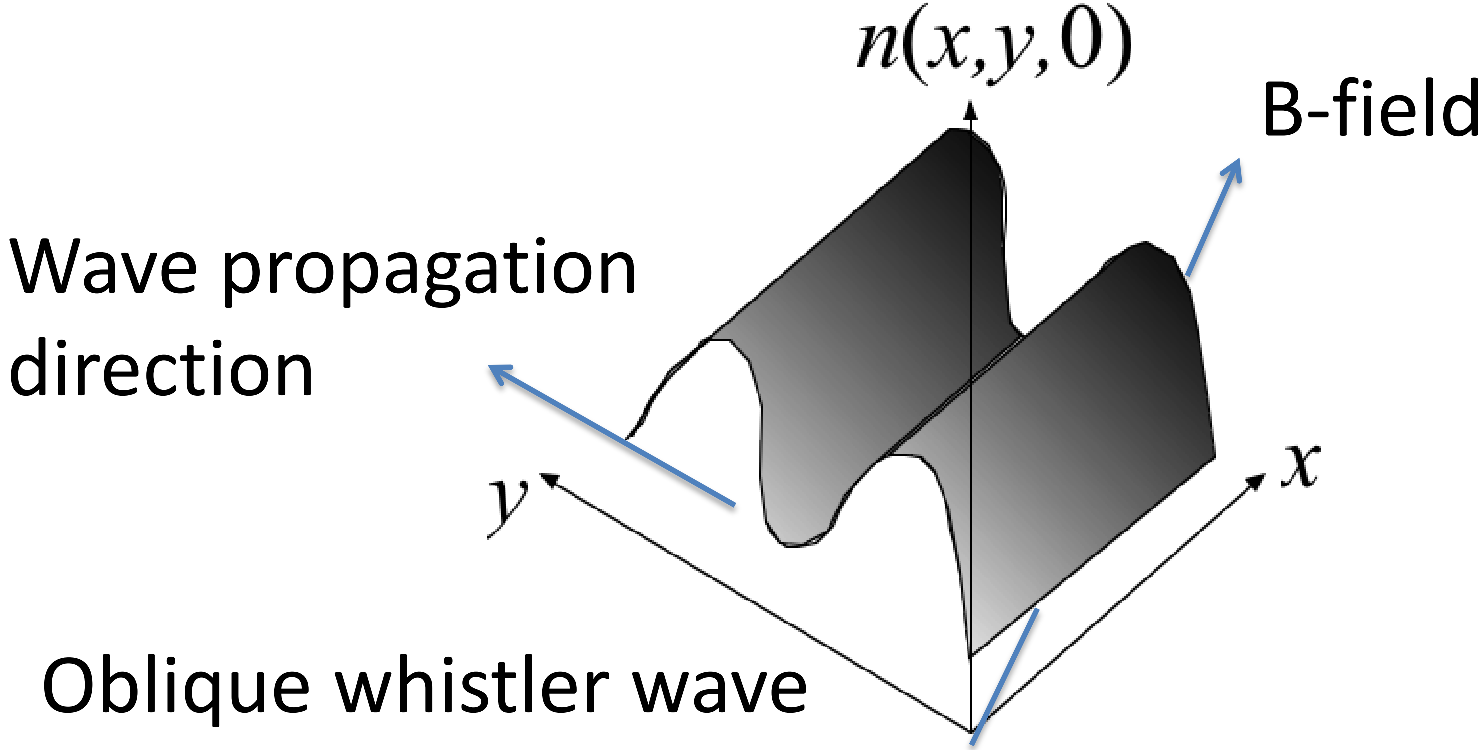
$\omega_p/\Omega = 2,\ \alpha = 5^\circ$
Whistler
10^0
N^2
0
1
2
3
4
5
ω/Ω



$\omega_p/\Omega = 2,\ \alpha = 45^\circ$
Whistler
10^0
N^2
0
1
2
3
4
5
ω/Ω

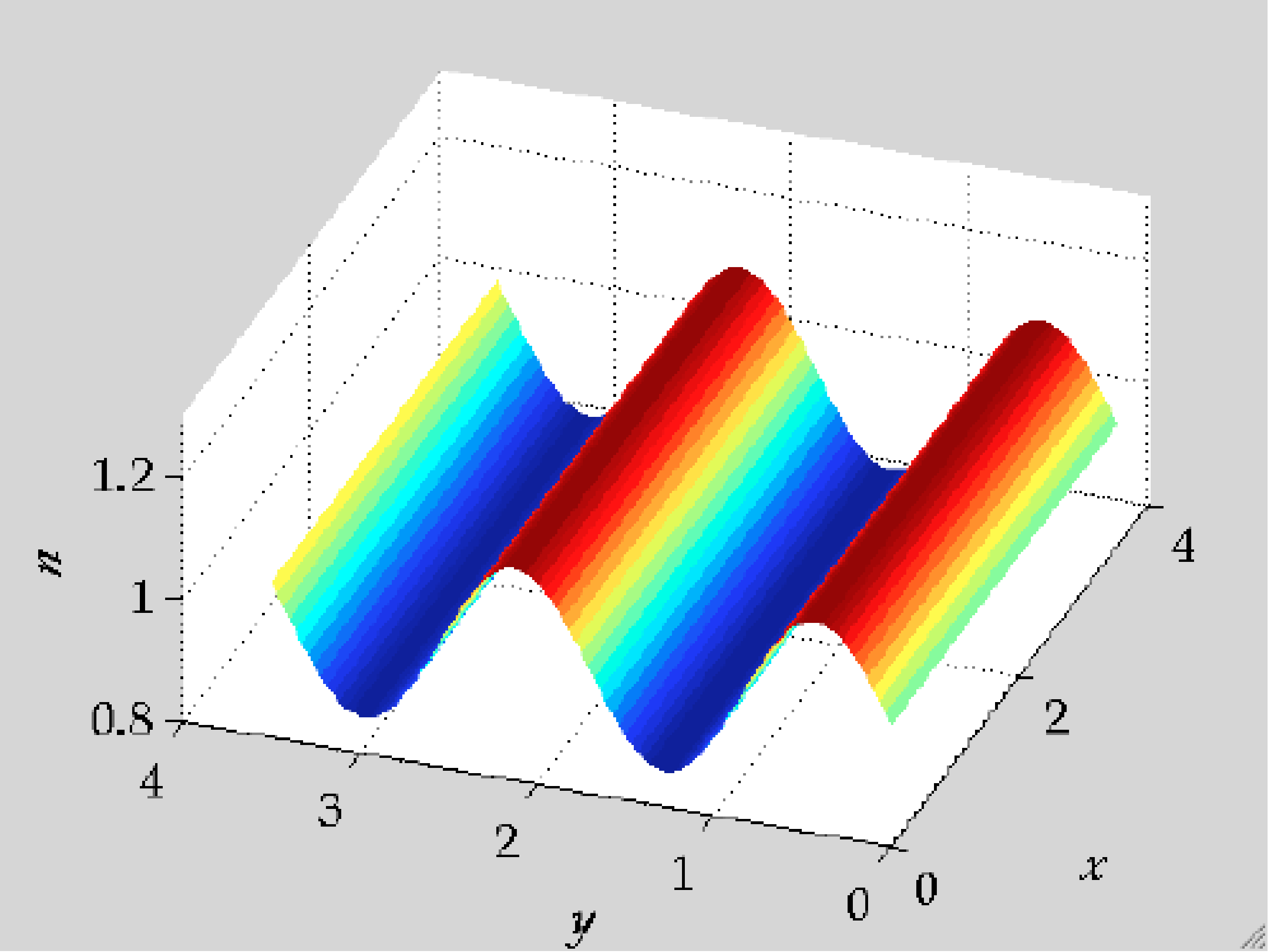


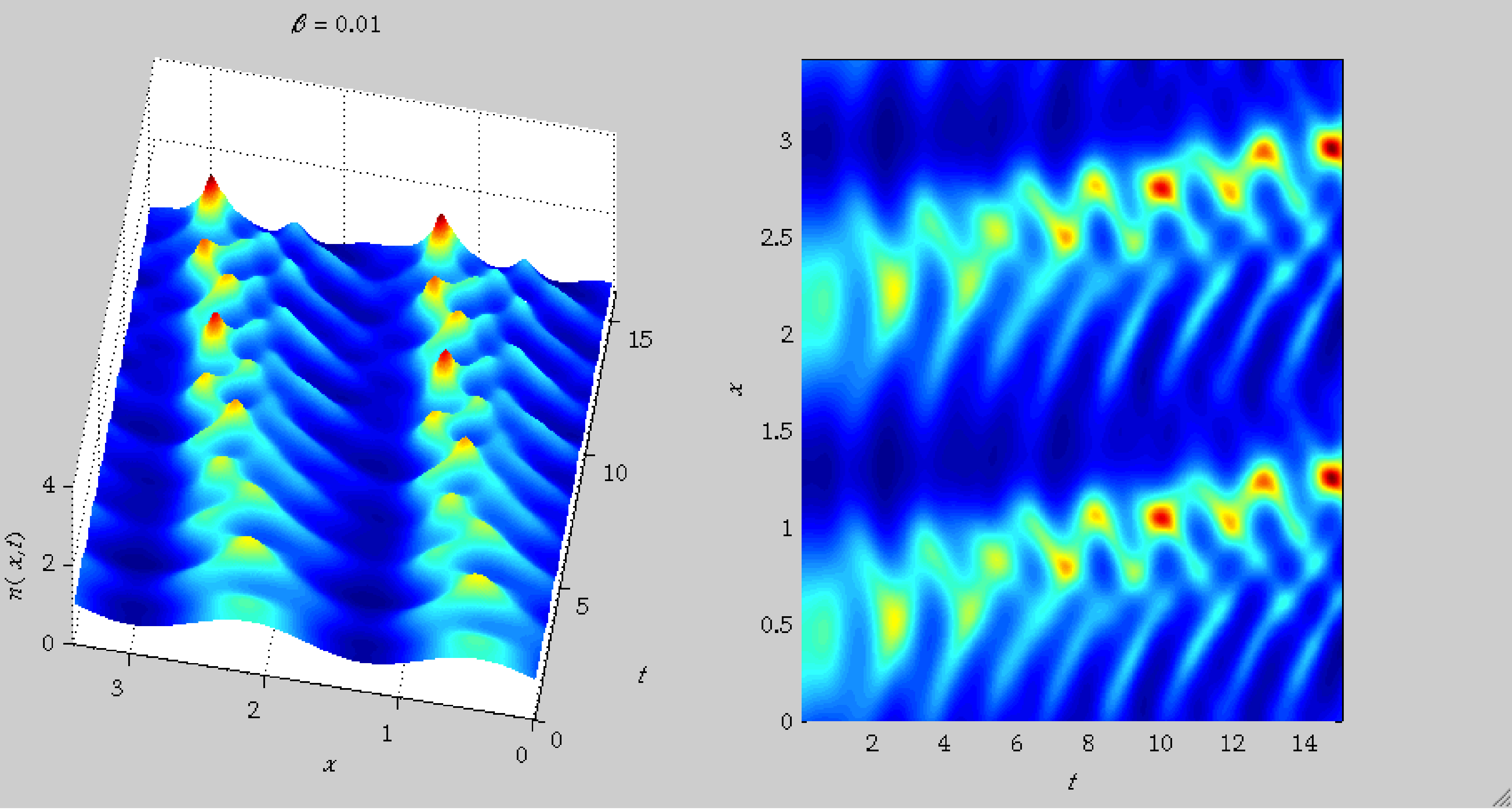
$\omega_p/\Omega = 2,\ \alpha = 70^\circ$
Whistler
10^0
N^2
0
1
2
3
4
5
ω/Ω



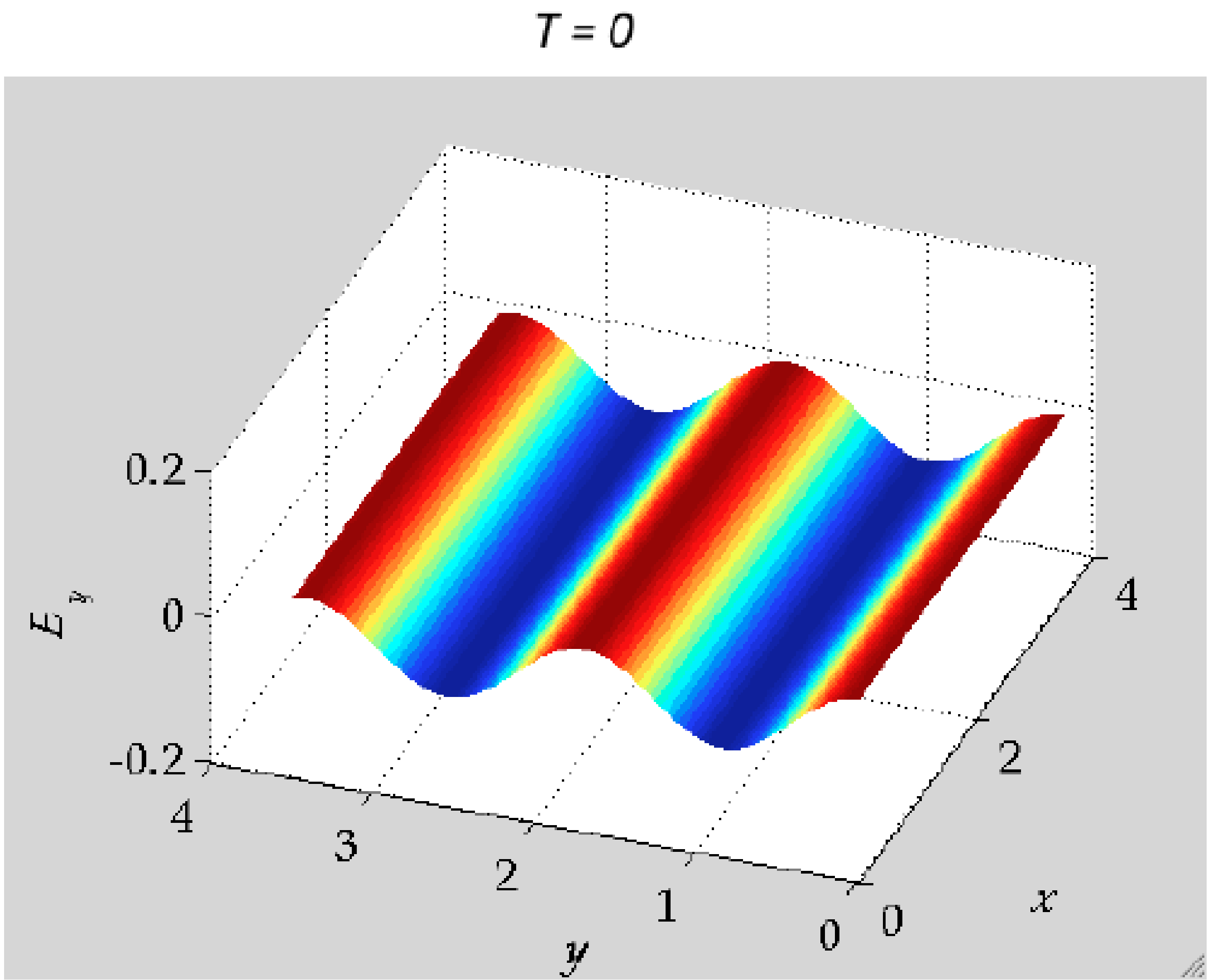
$n(x,y,0)$
B-field
Wave propagation direction
y
x
Oblique whistler wave

T = 0.1

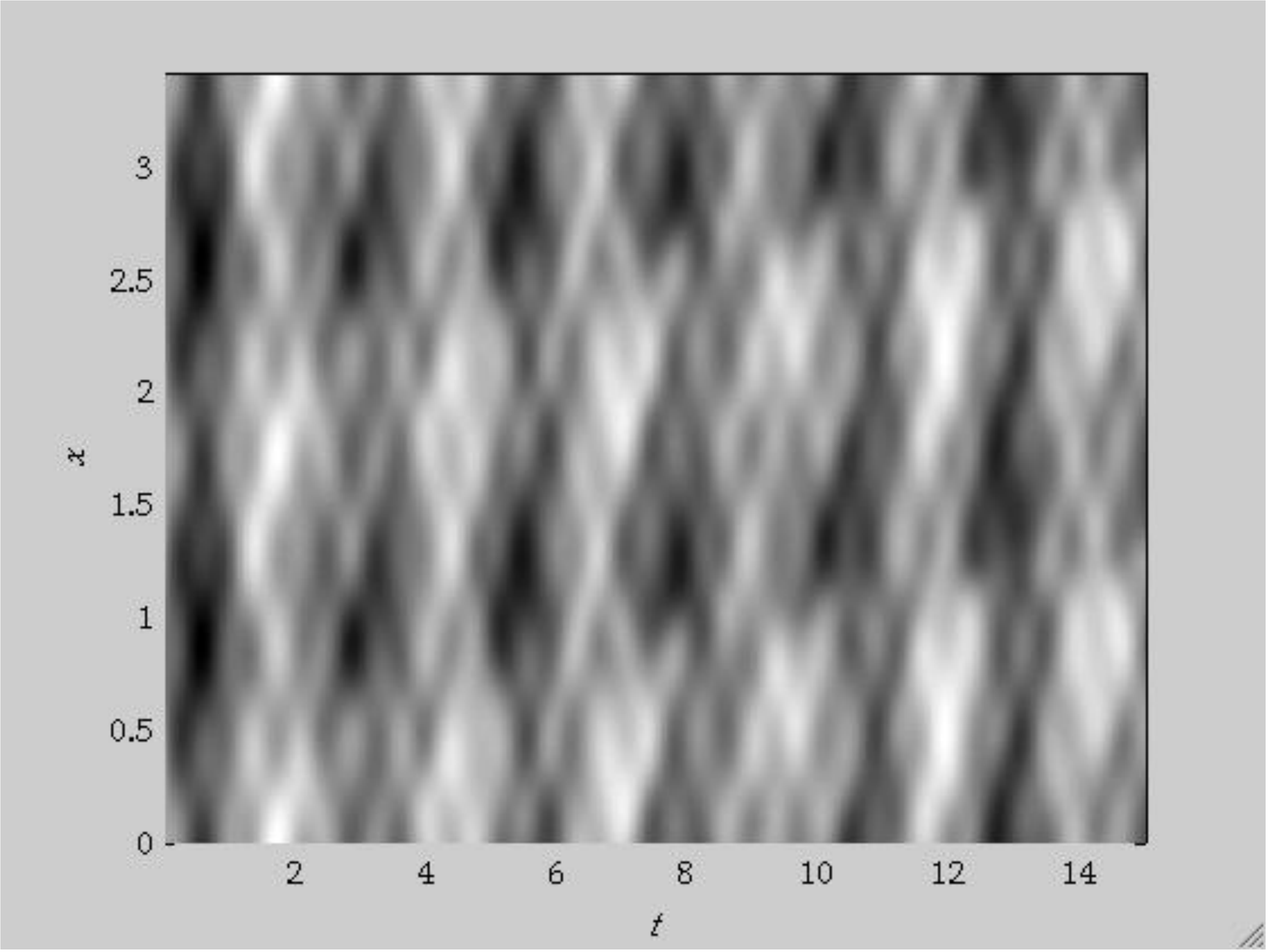




ε = 0.01
$n(x,t)$
0
2
4
3
2
1
0
x
0
5
10
15
t
x
0
0.5
1
1.5
2
2.5
3
2
4
6
8
10
12
14
t



T = 0
0.2
0
-0.2
E
y
4
3
2
1
0
y
0
2
4
x



x
3
2.5
2
1.5
1
0.5
0
2
4
6
8
10
12
14
t

Relativistic e-acceleration

Test-particle simulation over nonlinear whistler wave (cf., Roth et al., 1999)

Resonant enhancement of relativistic electron fluxes during geomagnetically active periods

I. Roth[1], M. Temerin[1], M. K. Hudson[2]

[1] Space Sciences Laboratory, University of California, Berkeley, CA 94720, USA
e-mail: ilan@ssl.berkeley.edu
[2] Physics and Astronomy Department, Dartmouth College, Hanover, NH 03755, USA

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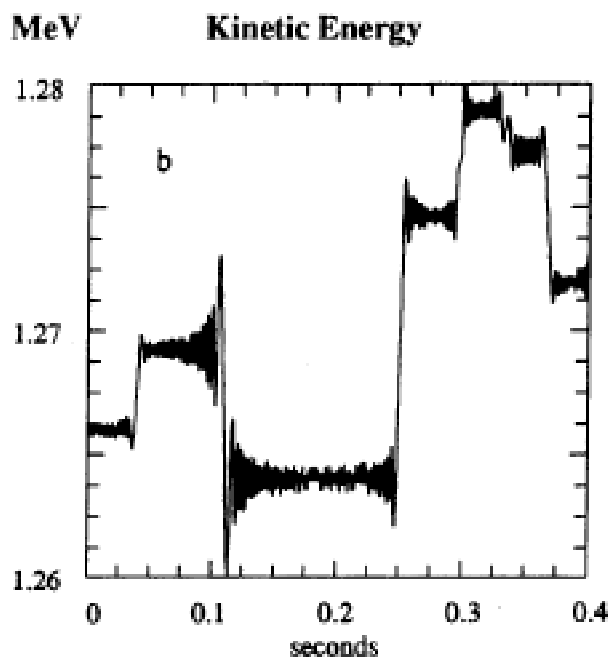
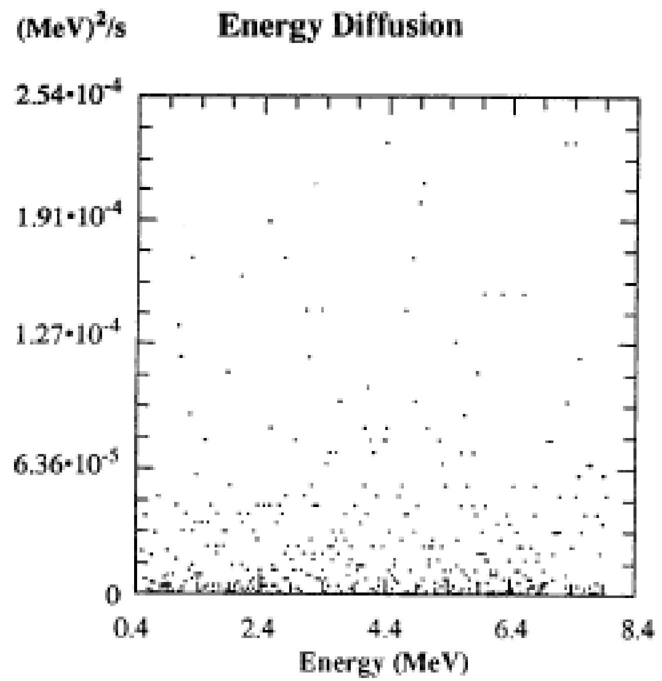
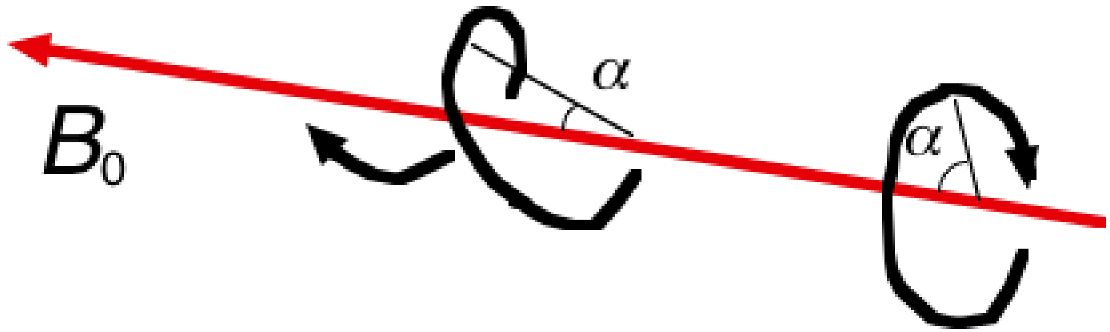
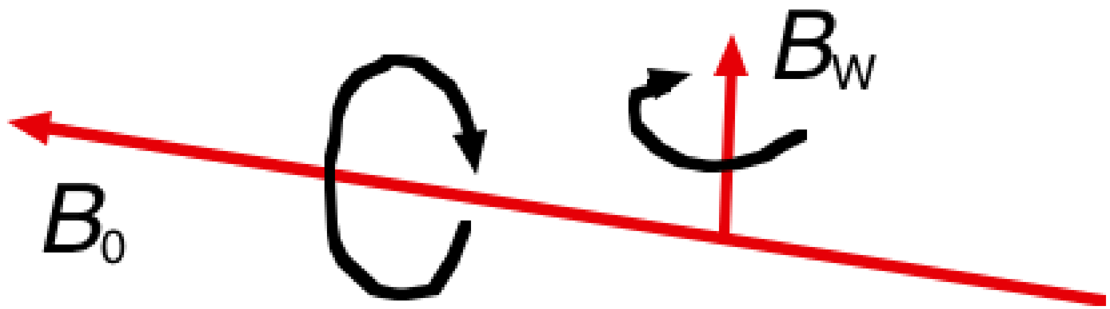




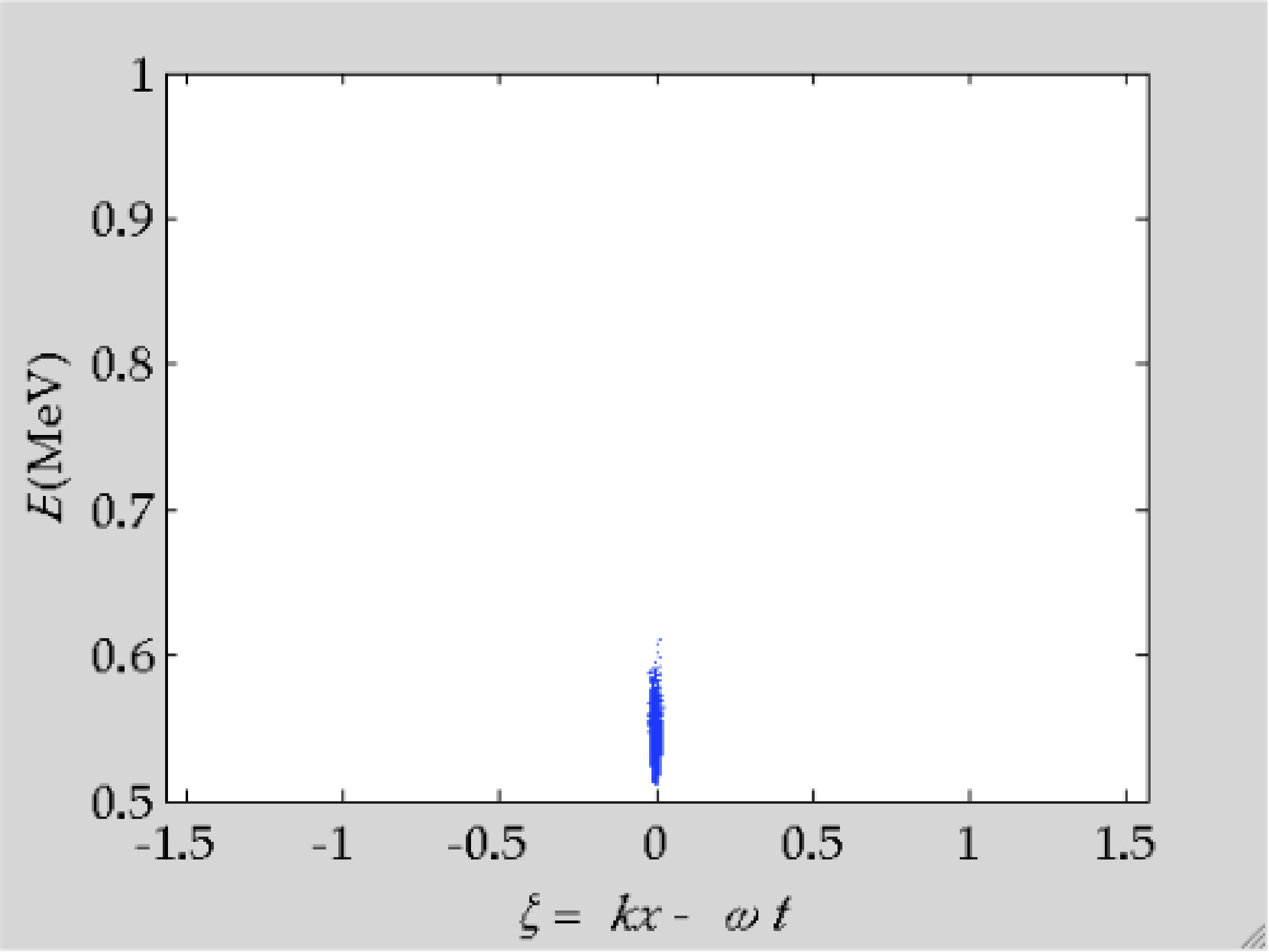
Wave-particle resonance



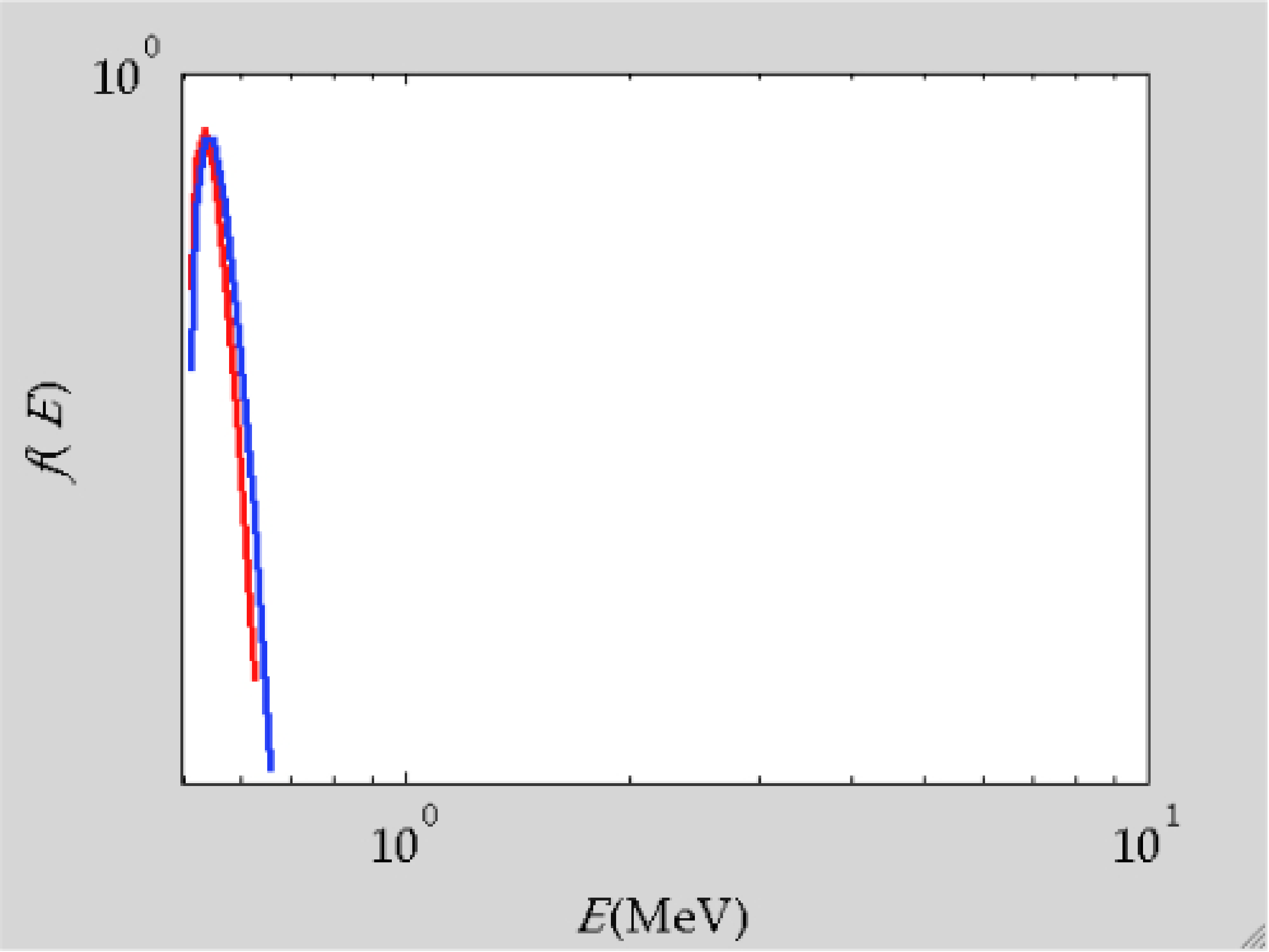
Wave-particle scattering (includes
non-resonant wave-particle interaction)



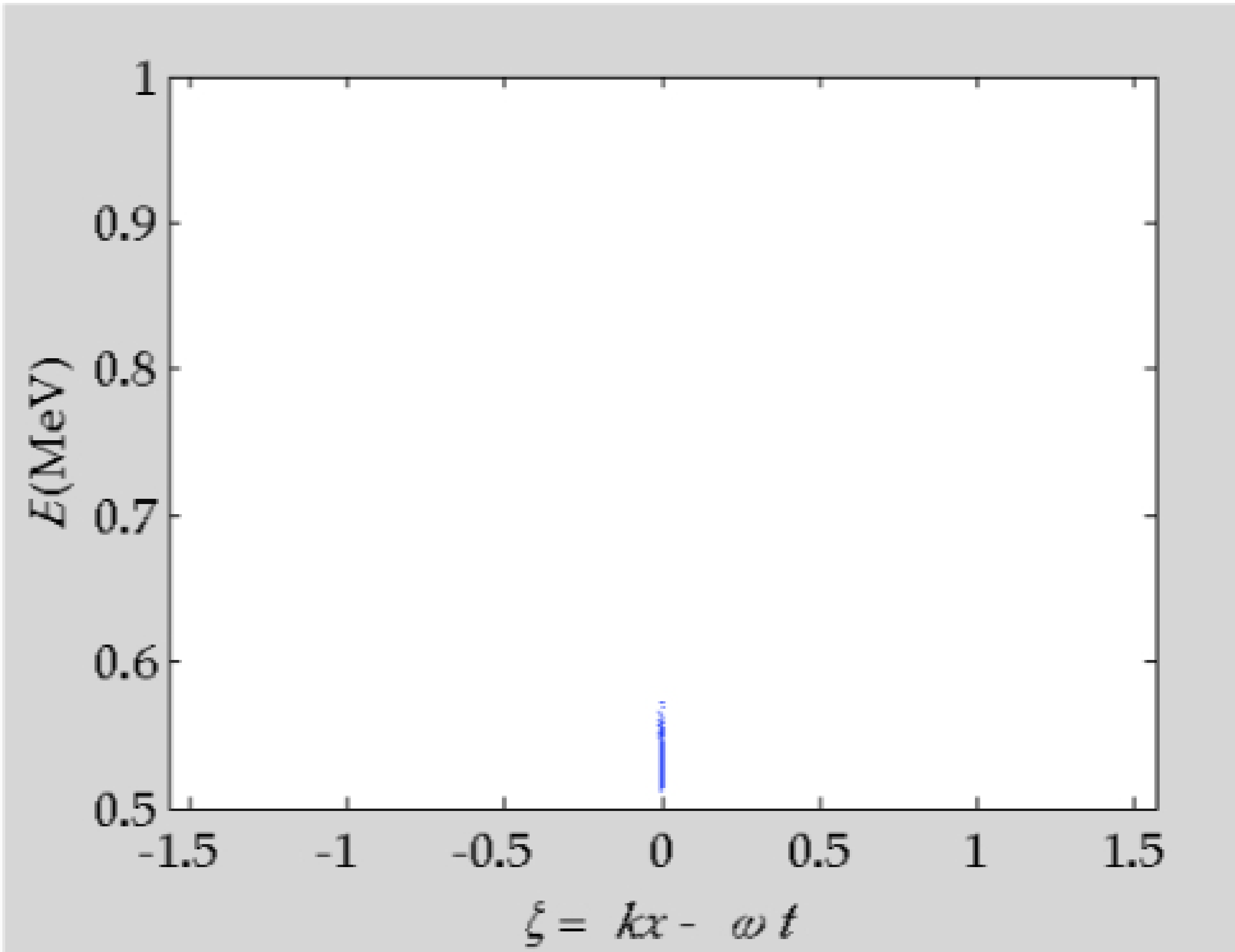
T = 0.01

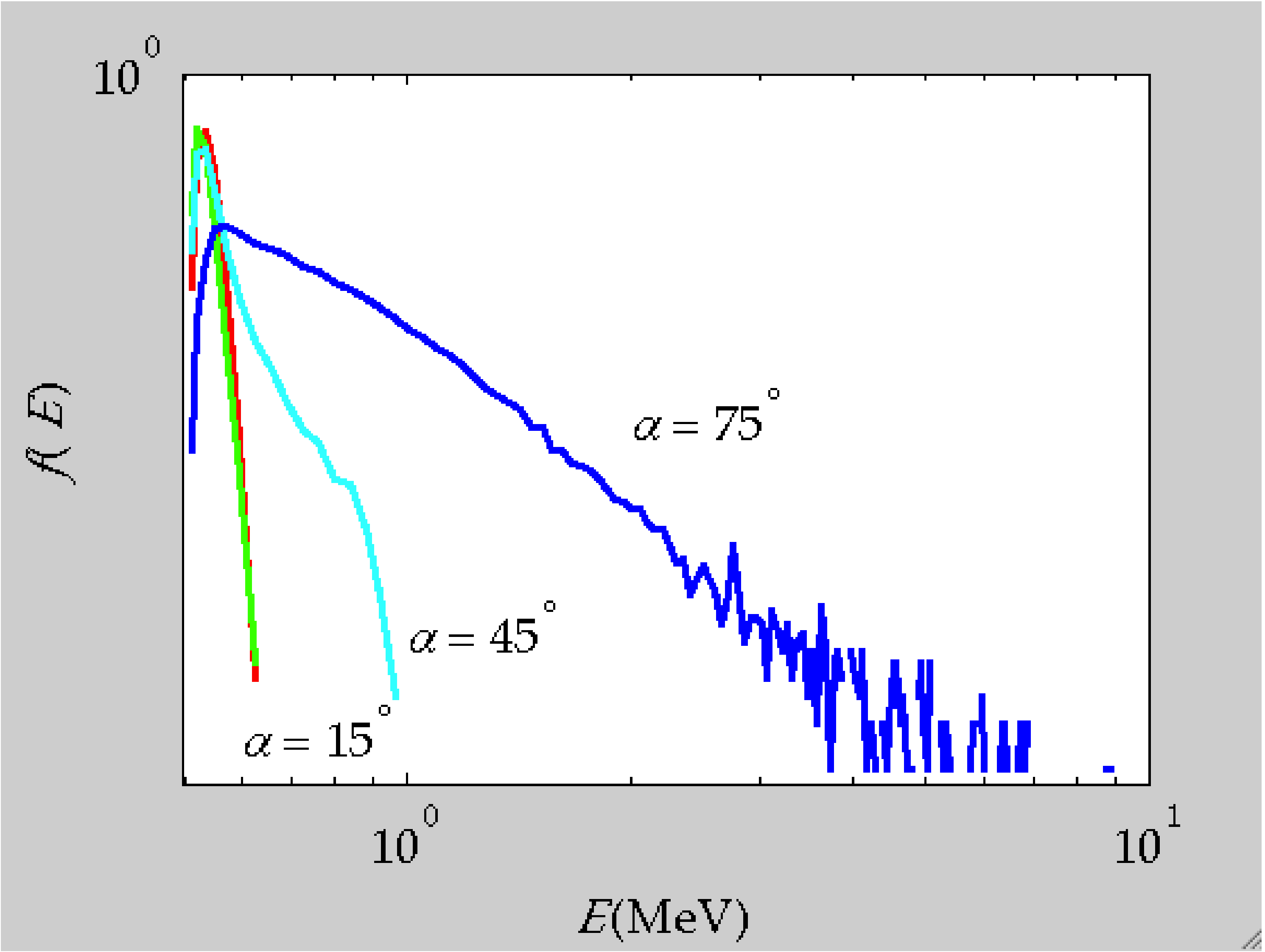


T = 1



T = 0.01





10^0
$f(E)$
$\alpha = 75^\circ$
$\alpha = 45^\circ$
$\alpha = 15^\circ$
10^0
10^1
E(MeV)

Conclusion and Discussions

- Rapid acceleration of relativistic electrons by obliquely-propagating whistler waves.
- The problem of how these waves are created is outstanding.
- Assuming that the source of oblique whistlers are near the equator, the propagation is not understood.