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UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION
INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
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H4-SMR 393/14

SPRING COLLEGE ON PLASMA PHYSICS

15 May - 9 June 1989

AURORAL ELECTRON ACCELERATION (II)

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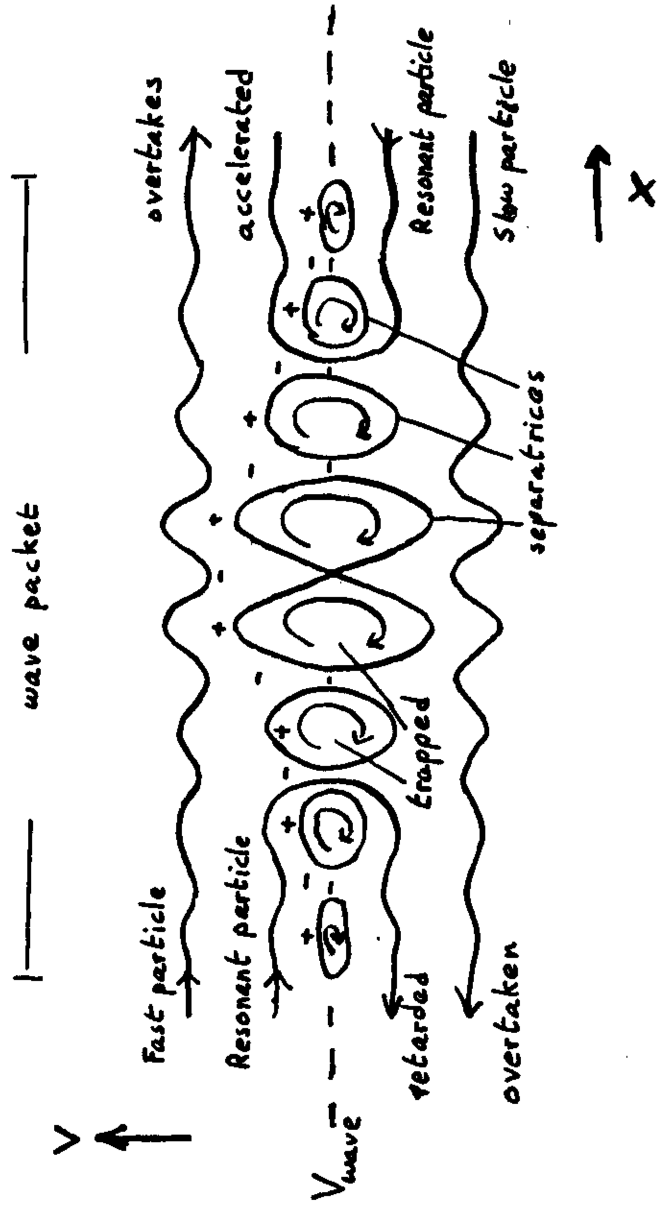
U. K.

Auroral Electron Acceleration

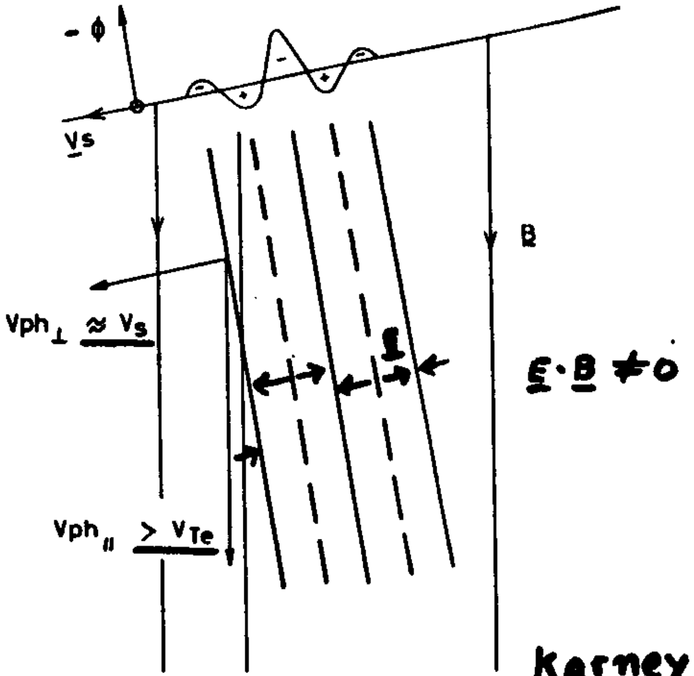
D A Bryant

Part 2

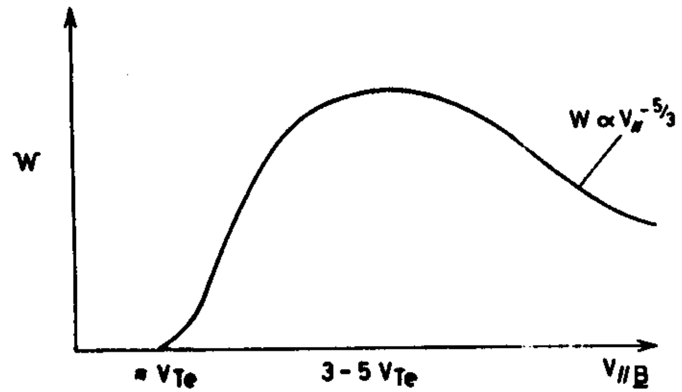
Stochastic acceleration by turbulent electric fields



Basic Interaction Between negatively-charged particle and electrostatic wave packet



Karney and Fisch (1979)



(Mc Bride 1972)

Lower-hybrid waves

$k_\perp \gg k_\parallel$

$$\omega^2 = \omega_{LH}^2 \left(1 + \frac{k_\parallel^2}{k_\perp^2}\frac{m_i}{m_e}\right) \geq \omega_{LH}^2 \equiv \frac{\omega_{pi}^2}{\left(1 + \frac{\omega_{pe}^2}{\omega_{ce}^2}\right)}$$

$$V_{ph\perp} \left(= \frac{\omega}{k_\perp}\right) = C_s = \left(V_{Ti}^2 + \frac{m_e}{m_i} V_{Te}^2\right)^{\frac{1}{2}} \ll V_{Te}$$

$$V_{ph\parallel} \left(= \frac{\omega}{k_\parallel}\right) = V_{Te} \frac{\sqrt{1 + \frac{m_i}{m_e}\frac{V_{Ti}^2}{V_{Te}^2}}}{\sqrt{\frac{\omega^2}{\omega_{LH}^2} - 1}}$$

$$\sim V_{Te} \qquad , \omega \not\approx \omega_{LH}$$

$$V_{g\parallel} \left(= \frac{\partial\omega}{\partial k_\parallel}\right) = \left(1 - \frac{\omega_{LH}^2}{\omega^2}\right) V_{ph\parallel}$$

$$\sim V_{ph\parallel} \qquad ; \omega \not\approx \omega_{LH}$$

$$V_{g\perp} \left(= \frac{\partial\omega}{\partial k_\perp}\right) = \frac{k_\parallel}{k_\perp} V_{g\parallel}$$

$$\ll V_{g\parallel}$$

$k_\perp$ wave no. perpendicular to $\underline{B}$
$k_\parallel$ " " parallel " "

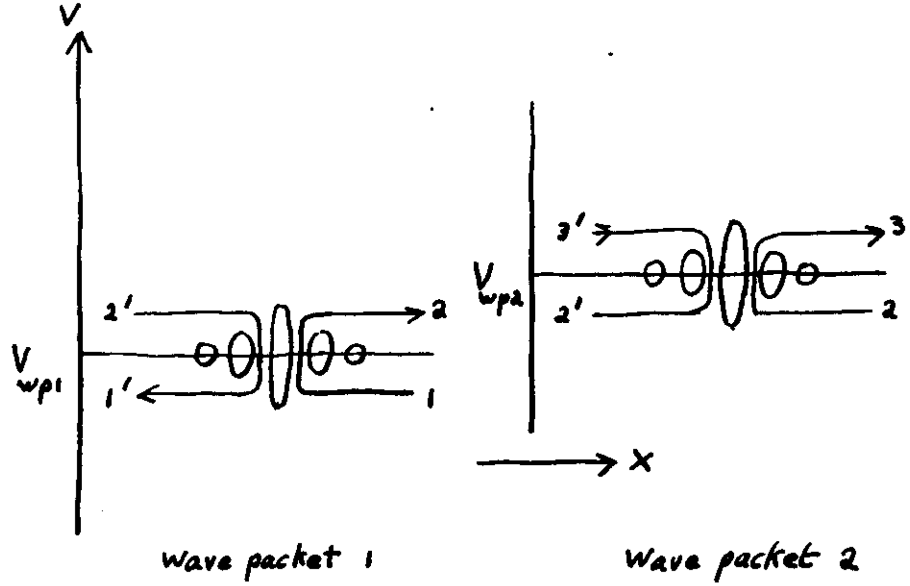
m_i ion mass
m_e electron mass

ω_{LH} lower-hybrid angular frequency
ω_{pi} ion plasma " "
ω_{pe} electron " " "

V_{Ti} ion thermal speed
V_{Te} electron " "
V_{ph} phase velocity
V_g group "

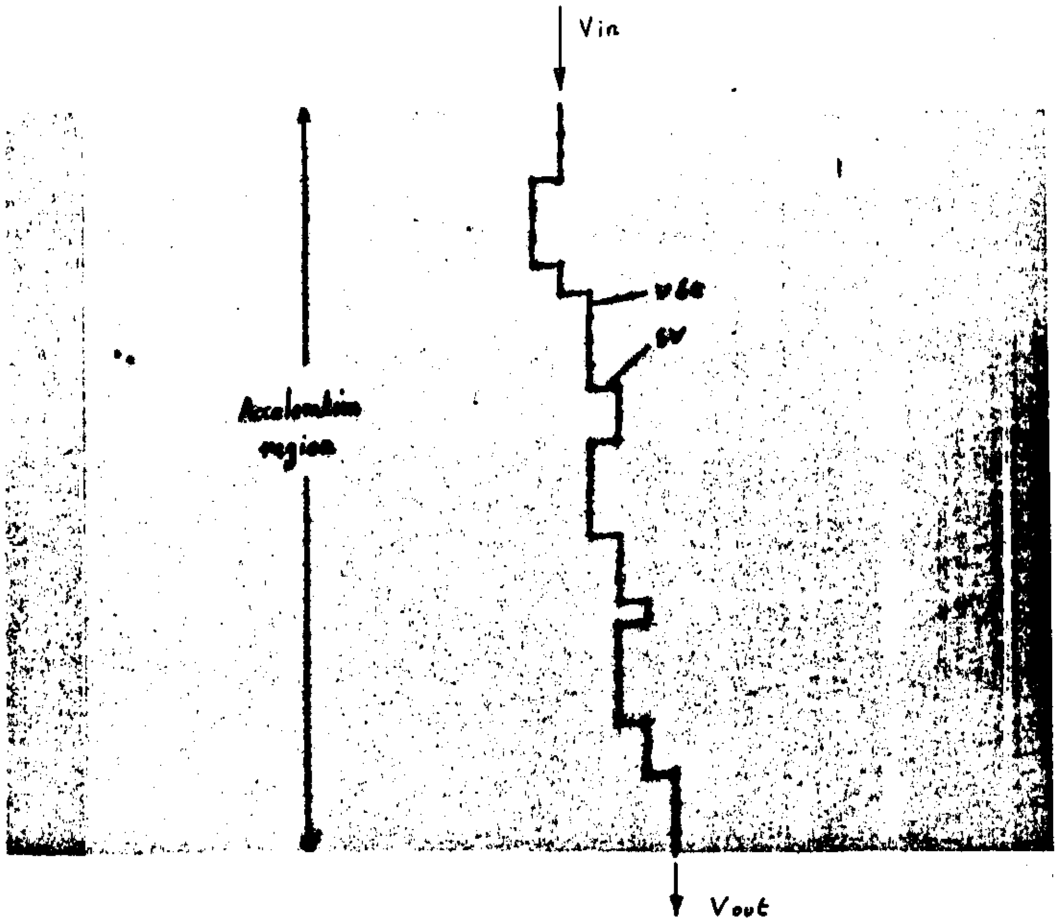
Kintner 1983

Observed lower-hybrid waves

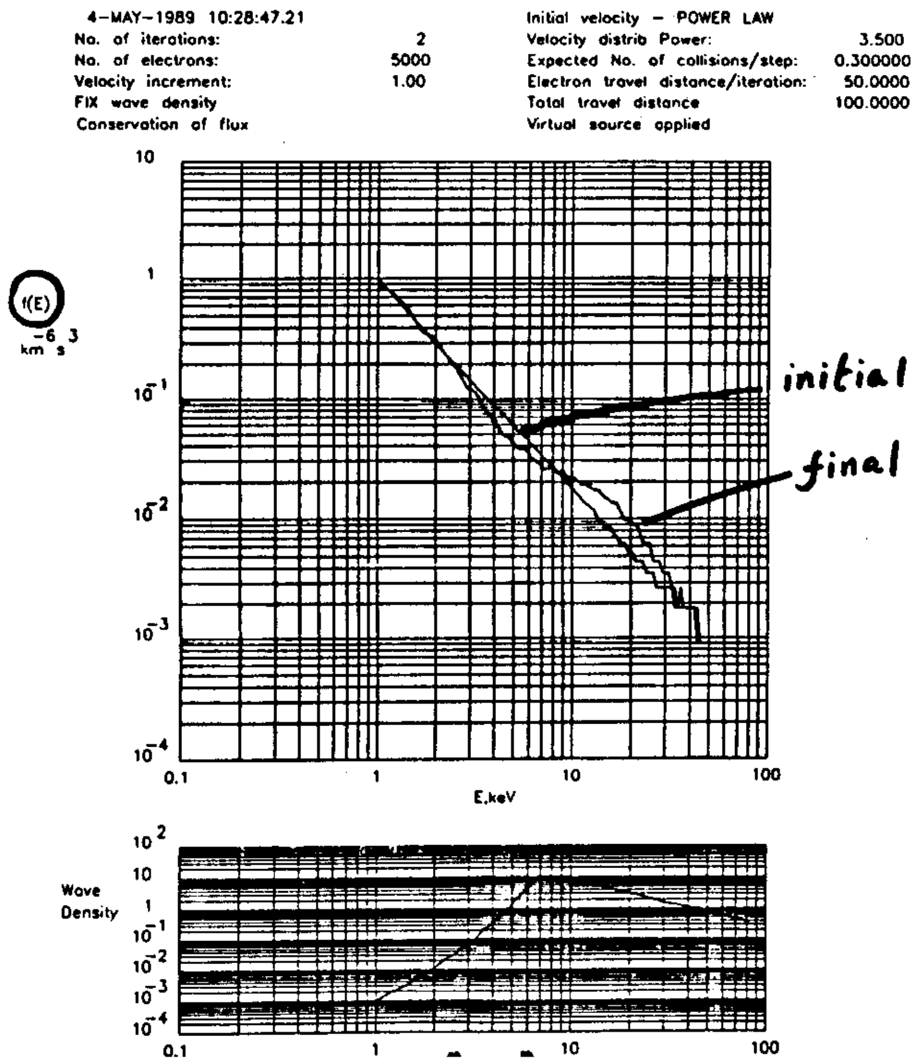


Stochastic acceleration (eg 2 → 3)

and retardation (eg 2' → 1')

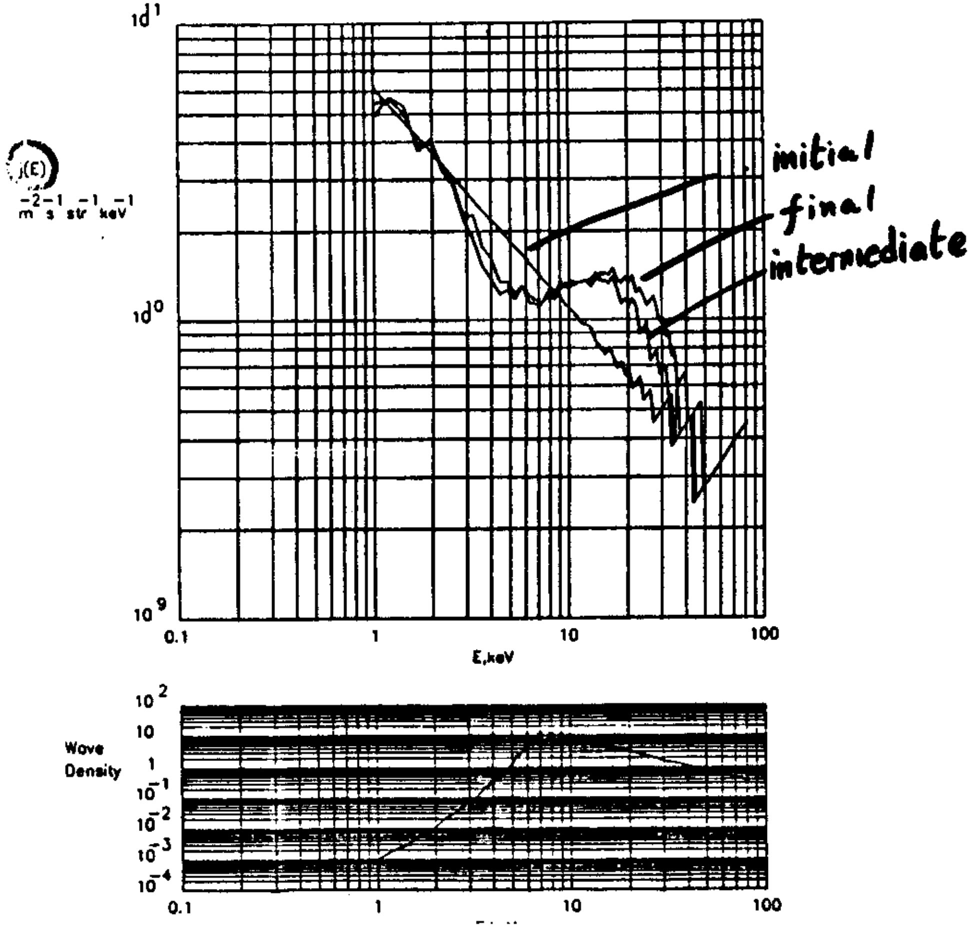


random walk in velocity space



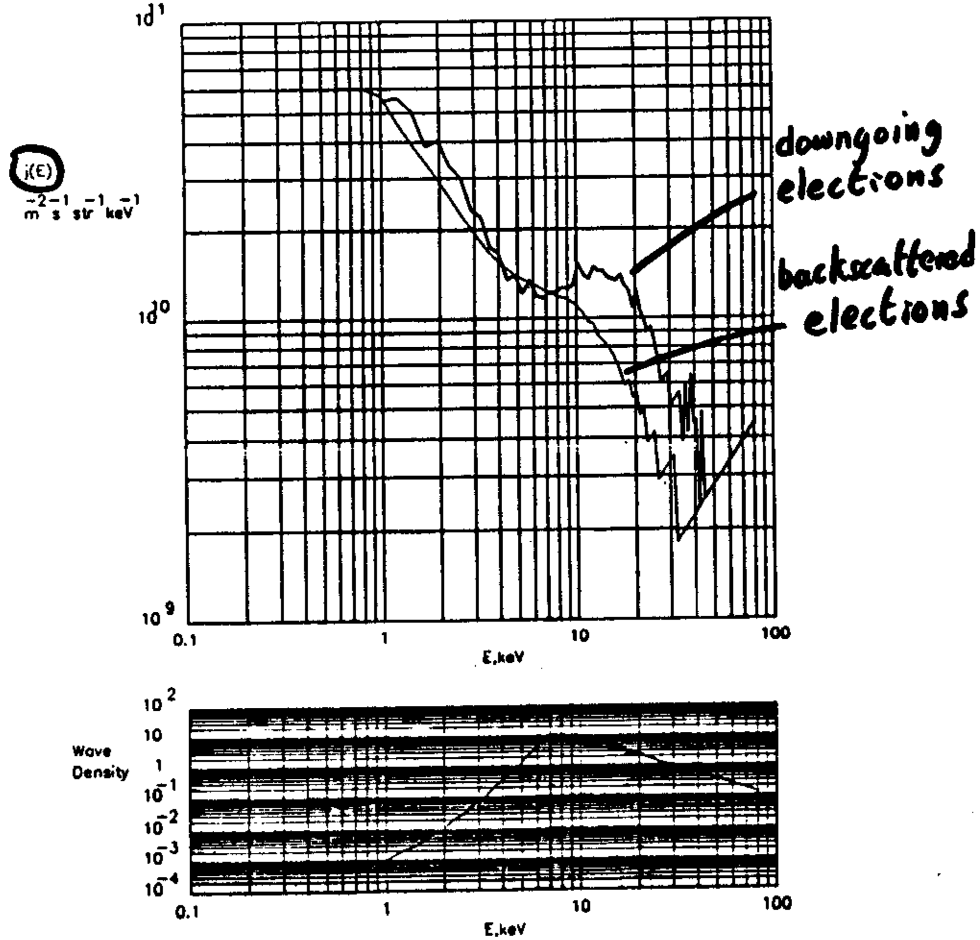
4-MAY-1989 10:28:47.21
No. of iterations: 2
No. of electrons: 5000
Velocity increment: 1.00
FIX wave density
Conservation of flux

Initial velocity – POWER LAW
Velocity distrib Power: 3.500
Expected No. of collisions/step: 0.300000
Electron travel distance/iteration: 50.0000
Total travel distance 100.0000
Virtual source applied



4-MAY-1989 14:37:12.92
No. of iterations: 1
No. of electrons: 5000
Velocity increment: 1.00
FIX wave density
Conservation of flux

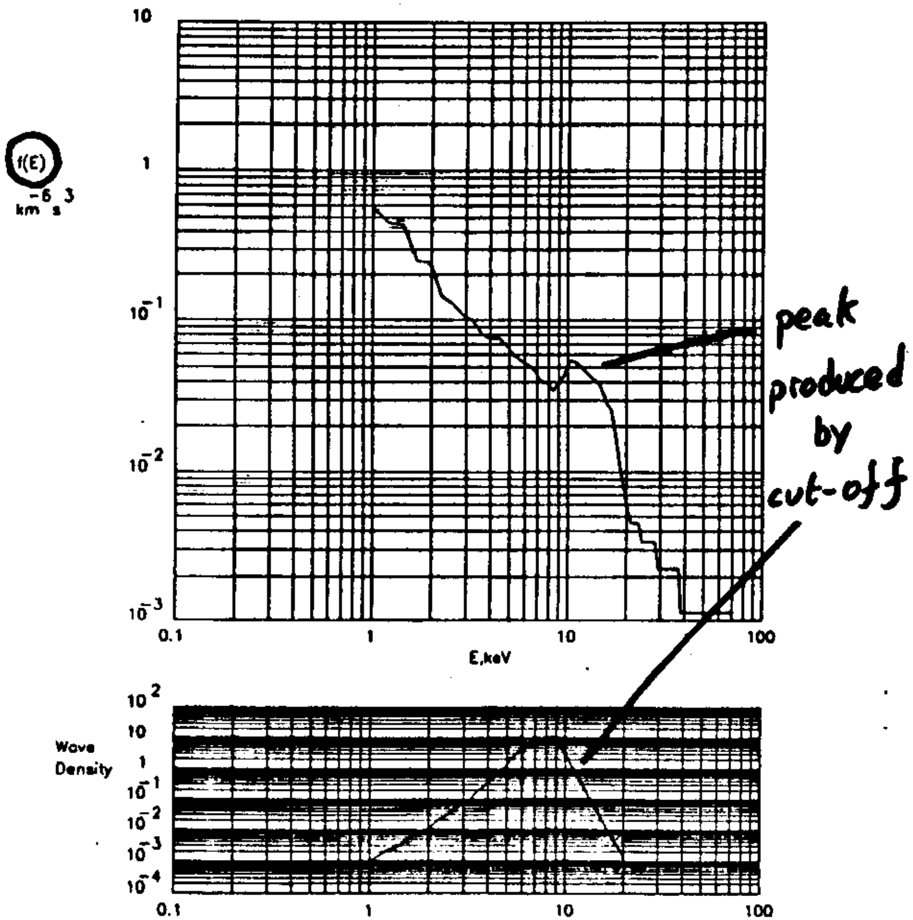
Initial velocity – POWER LAW
Velocity distrib Power: 3.500
Expected No. of collisions/step: 0.300000
Electron travel distance/iteration: 50.0000
Total travel distance 50.00000
Virtual source applied



8-MAY-1989 19:34:54.60

No. of iterations: 4
No. of electrons: 4000
Velocity increment: 2.00
FIX wave density
Conservation of flux

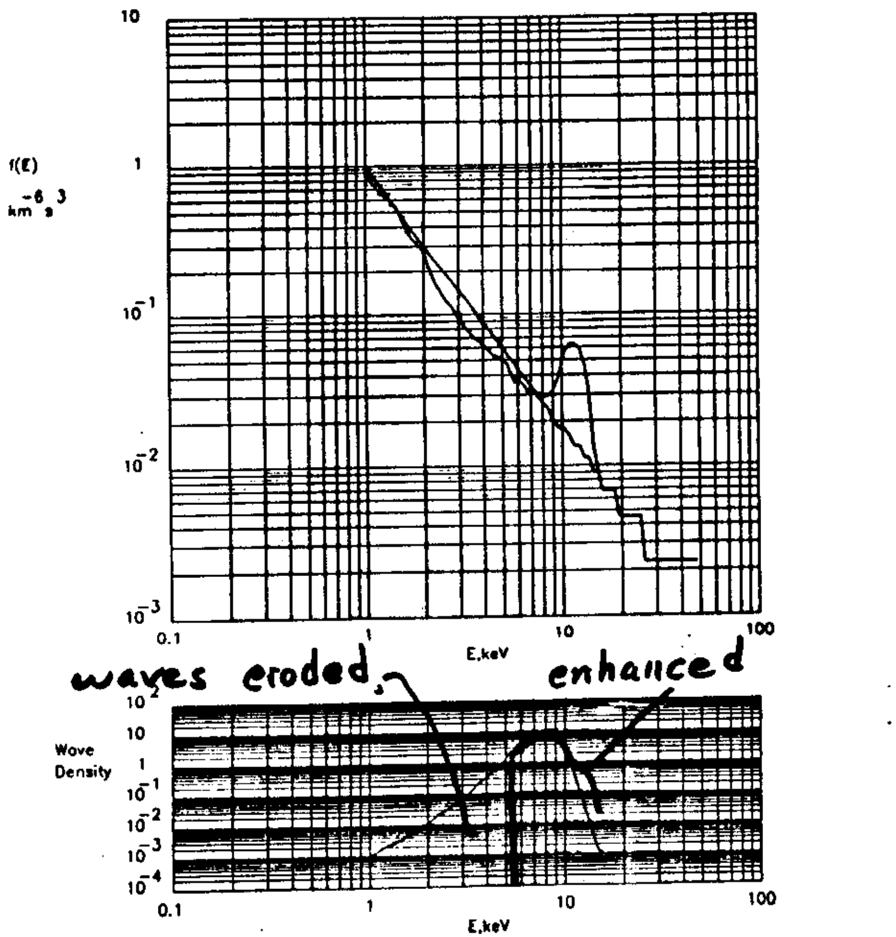
Initial velocity - POWER LAW
Velocity distrib Power: 3.500
Expected No. of collisions/step: 0.300000
Electron travel distance/iteration: 150.0000
Total travel distance 600.0000
Virtual source applied



8-MAY-1989 13:44:41.13

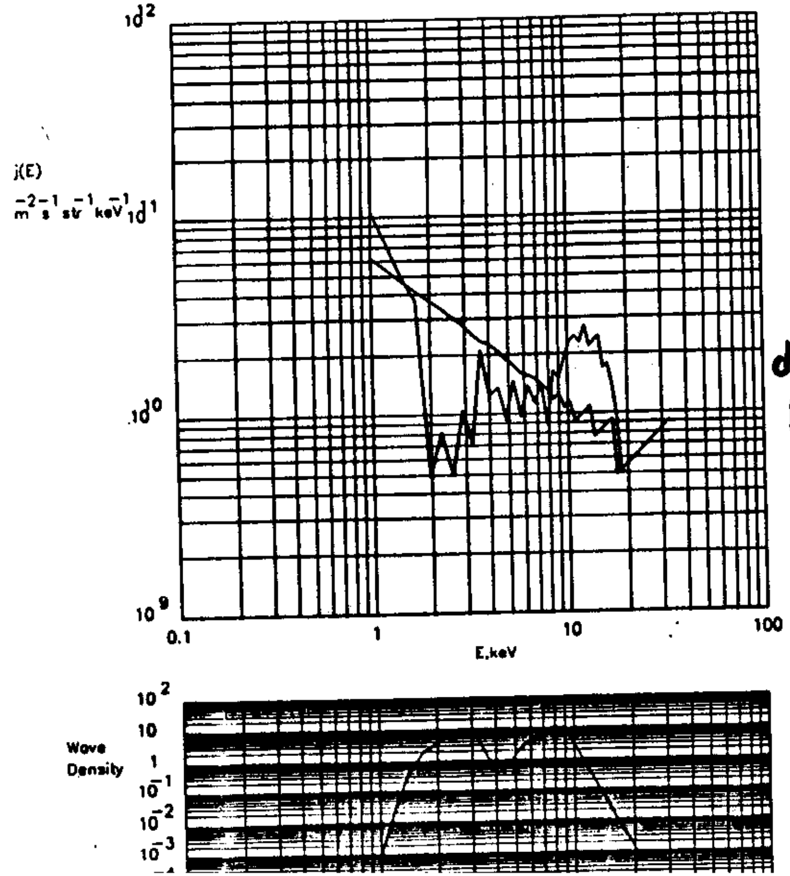
No. of iterations: 1
No. of electrons: 2000
Velocity increment: 2.00
VARY wave density, inc/dec ratio: 0.1000
Conservation of flux

Initial velocity - POWER LAW
Velocity distrib Power: 3.500
Expected No. of collisions/step: 0.300000
Electron travel distance/iteration: 150.0000
Total travel distance 150.0000
Virtual source applied

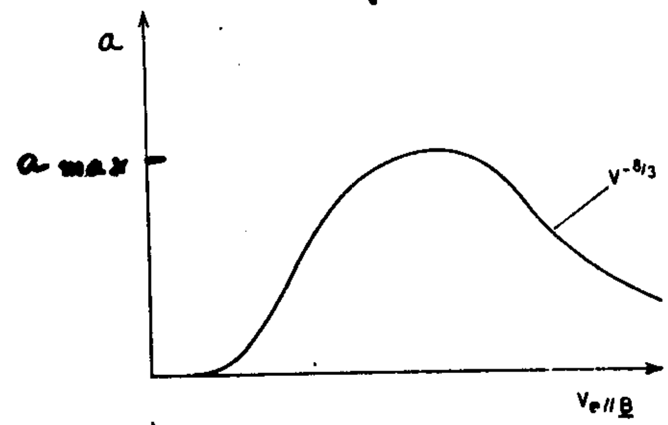


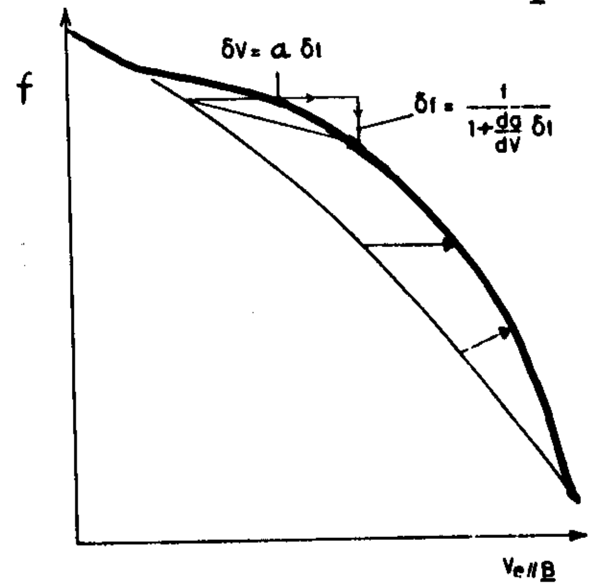
9-MAY-1989 11:49:28.77

No. of iterations:	1	Initial velocity – POWER LAW	
No. of electrons:	1000	Velocity distrib Power:	3.500
Velocity increment:	2.00	Expected No. of collisions/step:	0.300000
FIX wave density		Electron travel distance/iteration:	150.0000
Conservation of flux		Total travel distance	150.0000
		Virtual source applied	

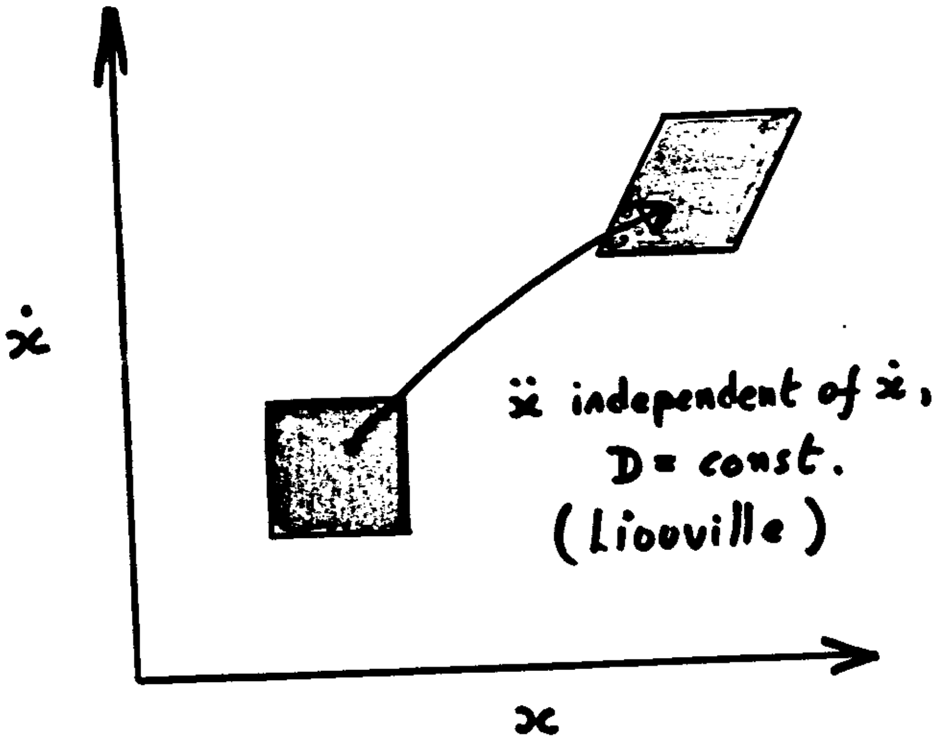


double peak

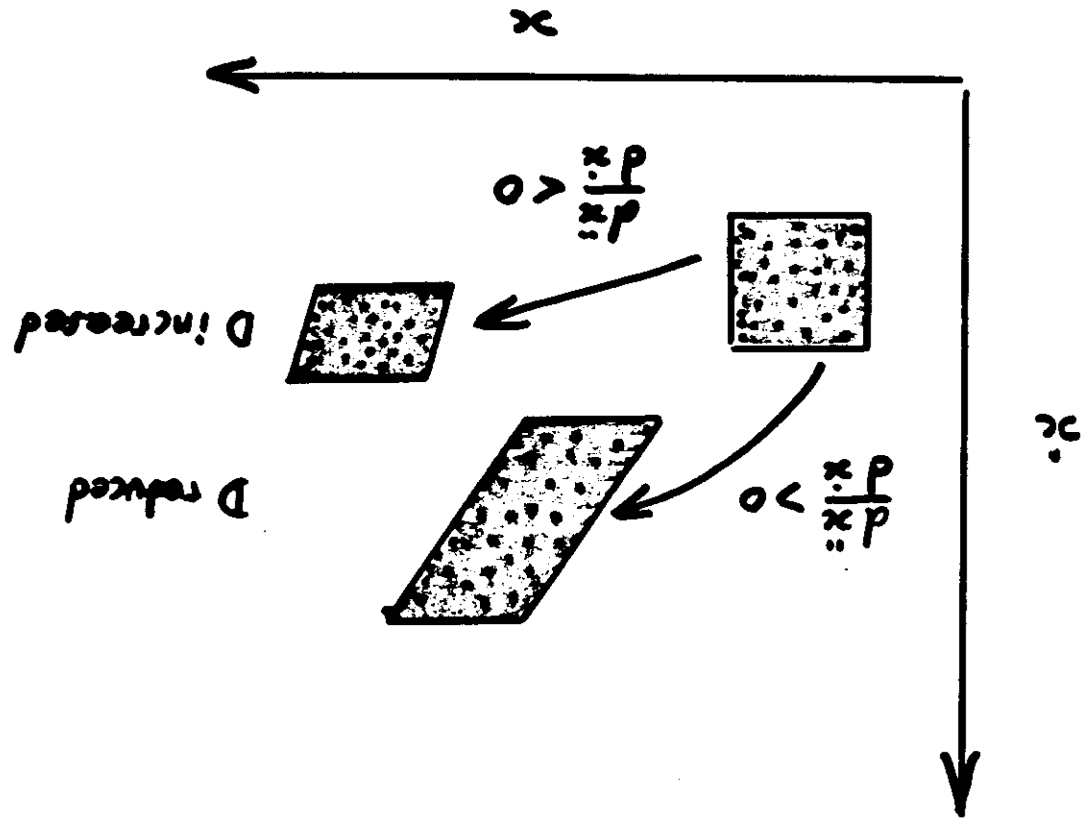




see Bryant, Hall and Bingham in "Auroral Physics" Cambridge University Press 1989 (in press.



ẋ
x
ẍ independent of ẋ,
D = const.
(Liouville)



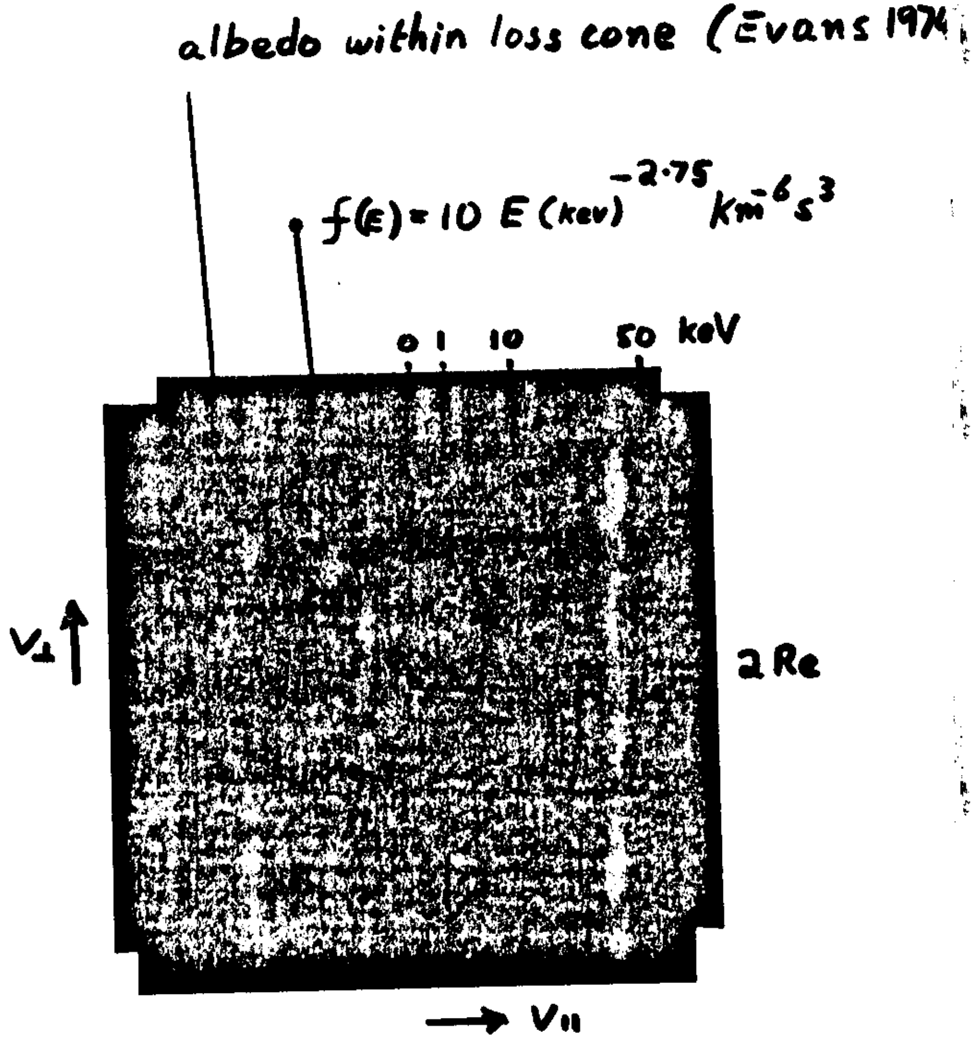
x
ẋ
dẍ/dẋ < 0
dẍ/dẋ > 0
D increased
D reduced

$$\frac{d\rho}{dt} + \rho \, \mathrm{div}_c \, v + \rho \, \mathrm{div}_v \, a = 0$$

$$\frac{d\rho}{dt} + \rho\left(\frac{\partial a}{\partial v}\right) = 0$$

$$\rho = \rho_0 \exp\left(-\left(\frac{\partial a}{\partial v}\right)\delta t\right)$$

$$\rho = \rho_0\left[1 - \left(\frac{\partial a}{\partial v}\right)\delta t\right]$$

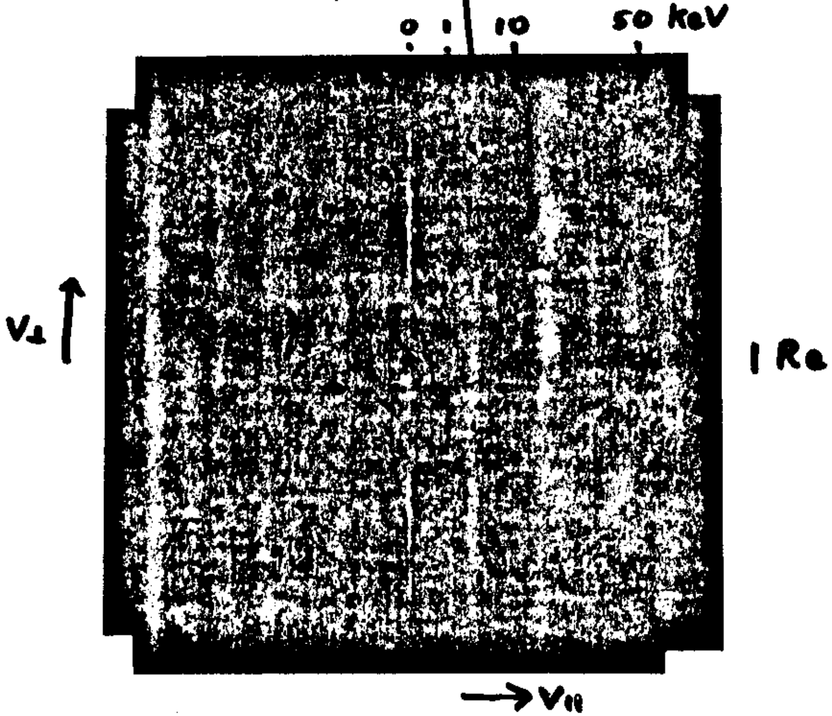


<u>control : no accel.</u>

at 1 Re: $j_{\parallel}$ $-2\,\mu A/m^2$

$\varepsilon_{\parallel}$ $3\ mW/m^2$

- Field alignment at peak and below



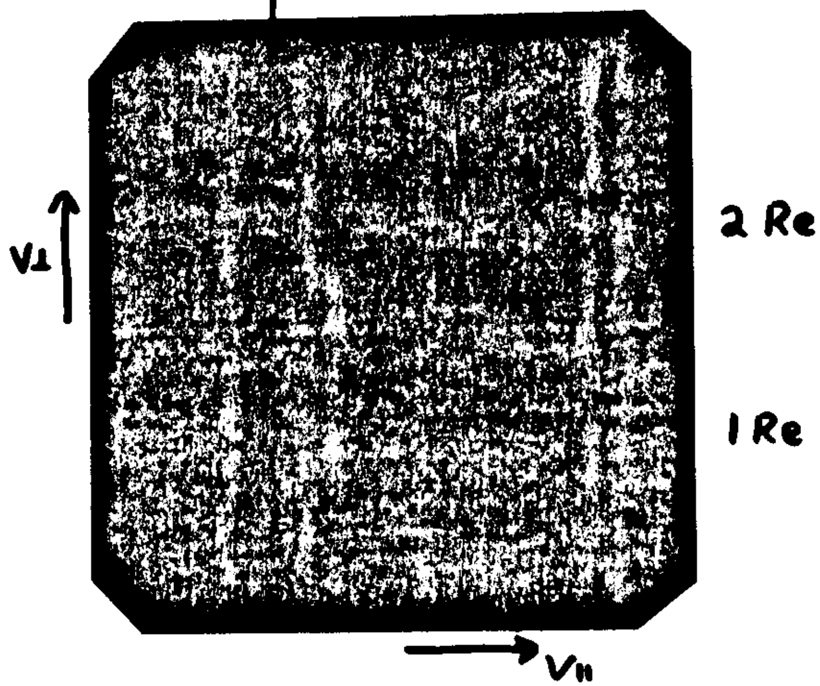
Accel: 15 keV 1·2 → 1·0 Re

at 1 Re : $j_{\parallel}$ −1·5 μA/m²

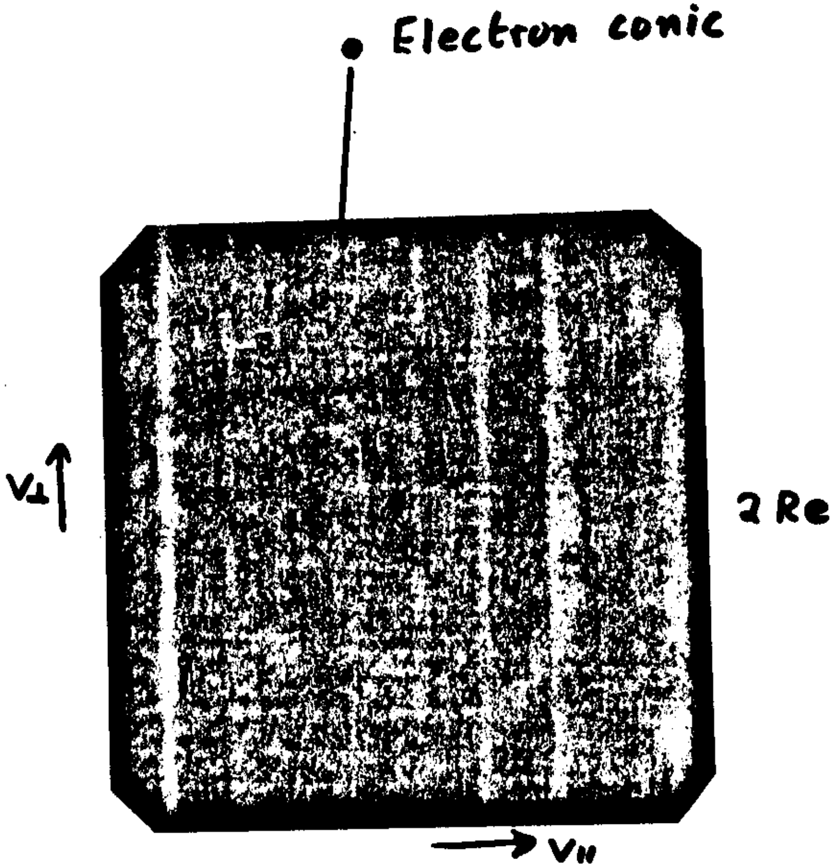
$\mathcal{E}_{\parallel}$ 6·5 mW/m²

- modifies field-aligned current −2·8 μA/m² } for high-altitude

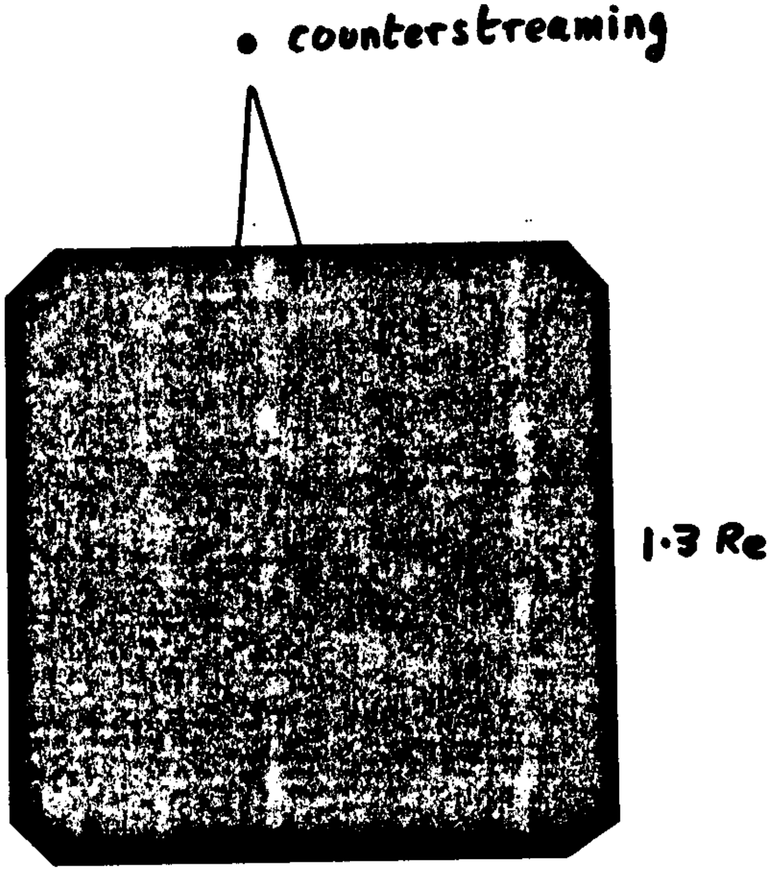
- Valley adjacent to loss cone (widened loss cone ?)



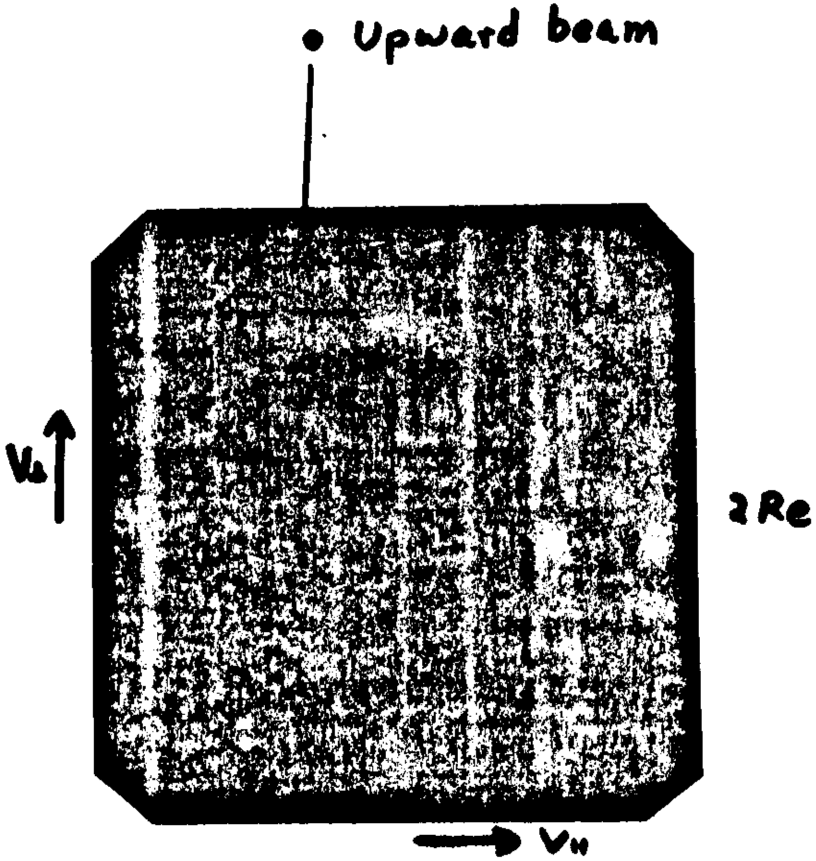
Accel. 6·3 keV 1·4 → 1·0 Re



Accel: 2.4 keV 1.95→1.87 Re



Accel: 8.25 keV 1.53↔1.1 Re



Accel: 8·25 keV 1·5 ⟷ 1·1 Re

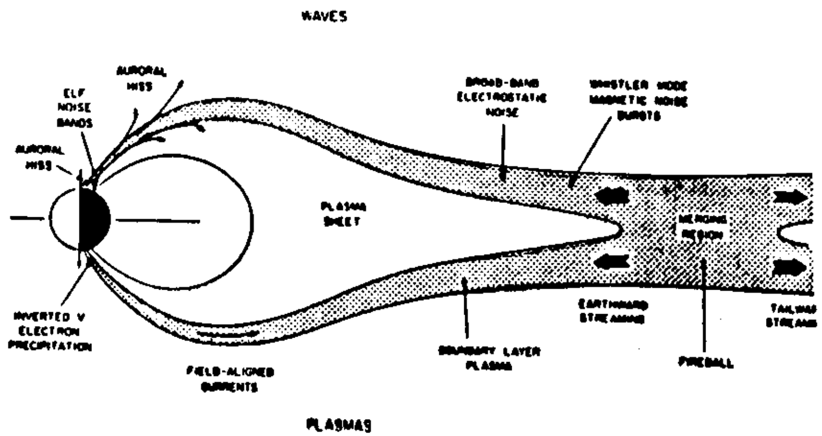
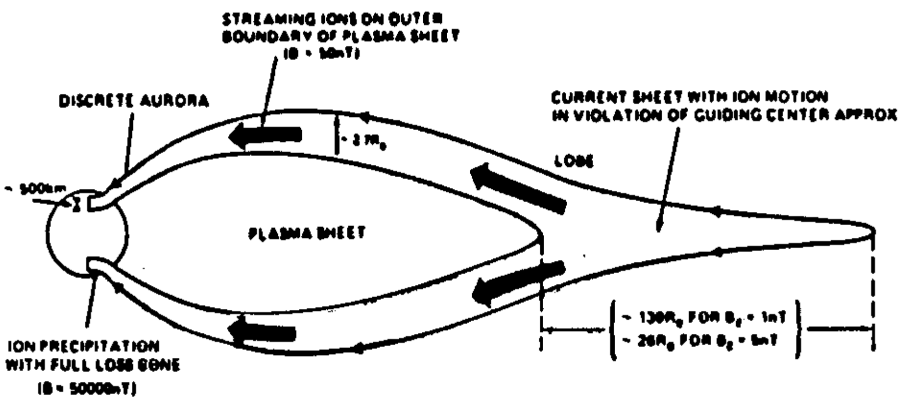


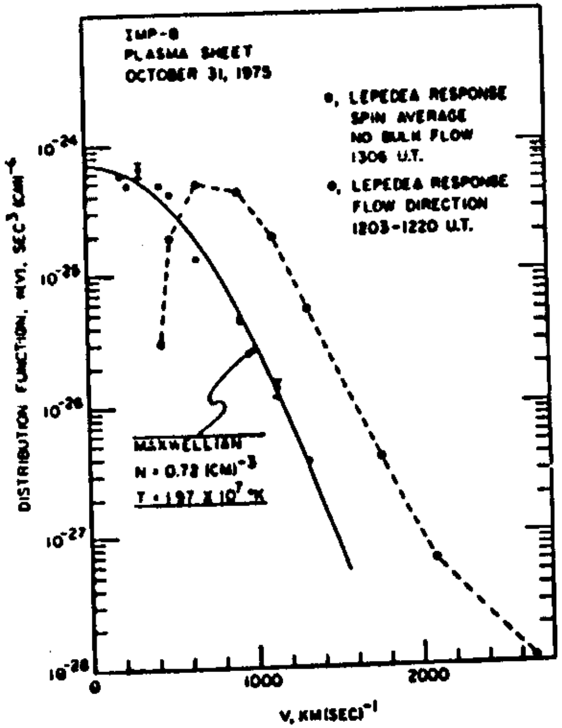
Fig. 17. The spatial relationships between the broad-band electrostatic noise, field-aligned currents, low-altitude inverte V electron precipitation, and earthward streaming protons in the distant magnetotail suggested by this study.

SCHEMATIC MAPPING FOR THOSE DISCRETE AURORA ASSOCIATED WITH OUTER BOUNDARY OF PLASMA SHEET



Hoffman & Evans 1984

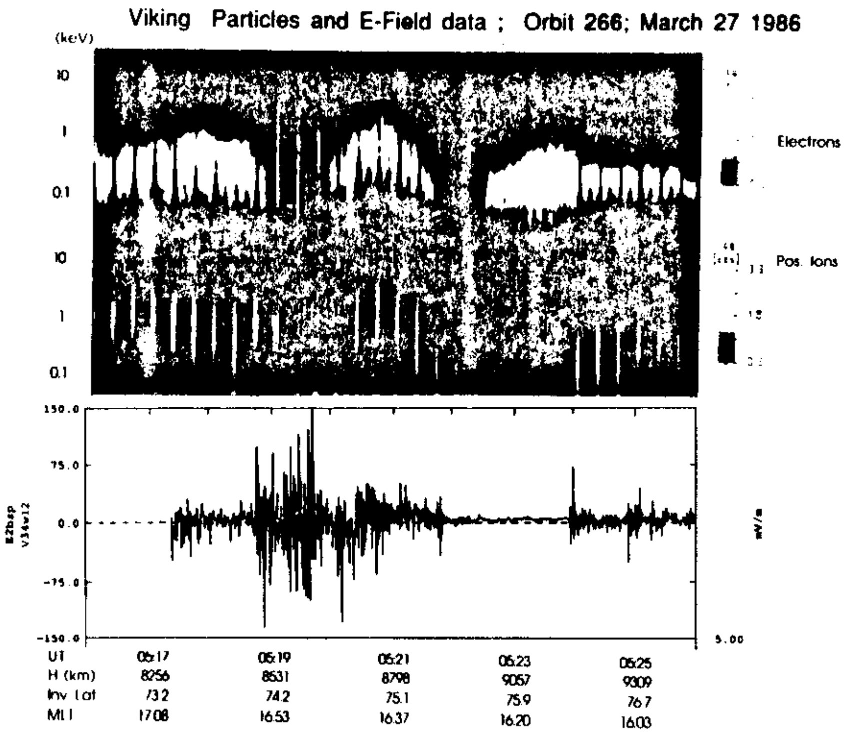
also Bryant et al 1972



DeCoster & Frank 1979

1 mW m^{-2} at 10 Re ≡ 1000 mW m^{-2} at 1Re

1 mW m^{-2} at 3 Re ≡ 27 mW m^{-2} at 1Re



Viking Science Team 1988

Quasi - linear diffusion coefficient

$$D \left(= \frac{\overline{\Delta v^2}}{\Delta t} \right) = 4 \times 10^{19} \frac{\overline{E^2}}{\sqrt{n}}$$

(from Bhadra et al 1983, Liu et al 1982)

Acceleration length

$$L \left(= \bar{v} \Delta t \right) = 2.5 \times 10^{-20} \frac{\sqrt{n}}{\overline{E^2}} \bar{v} \, \overline{\Delta v^2}$$

with $n = 10^7 \ m^{-3}$

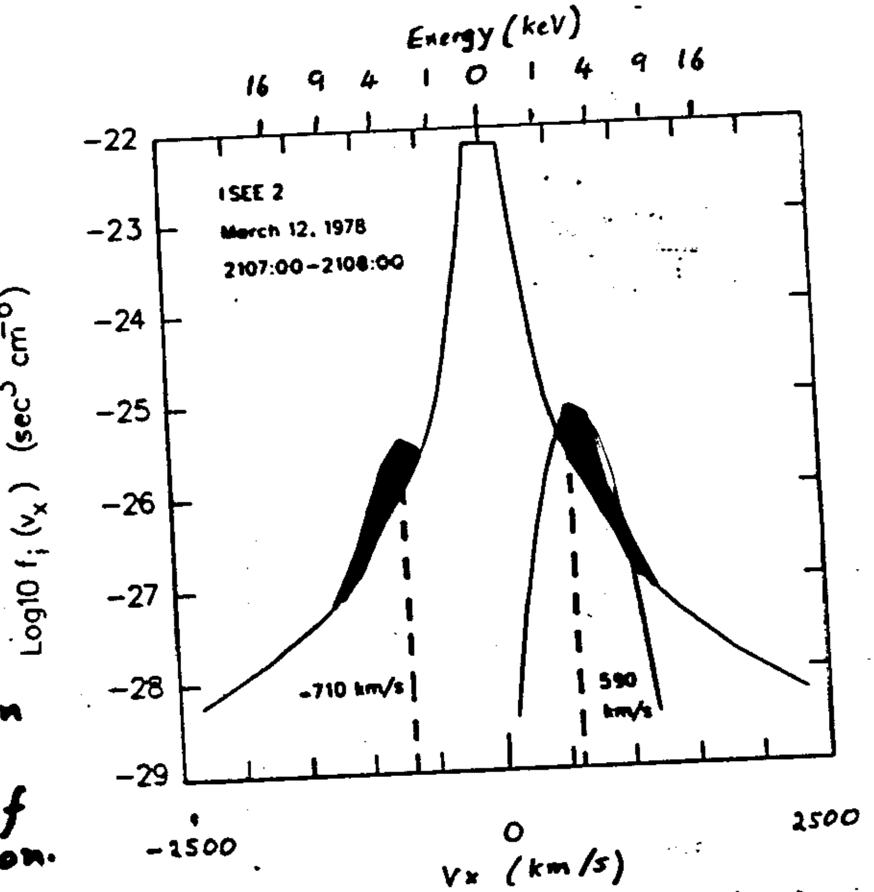
$E = 0.5 \ V m^{-1}$

$$L \, (1 \text{ keV}, 4 \text{ keV}) = 3{,}600 \text{ km} \approx \tfrac{1}{2} R_e$$

$$L \, (2.5 \text{ keV}, 10 \text{ keV}) = 10{,}000 \text{ km} \approx 2 \, R_e$$

.....showing that observed wave amplitude is adequate to account for observed degree of acceleration.

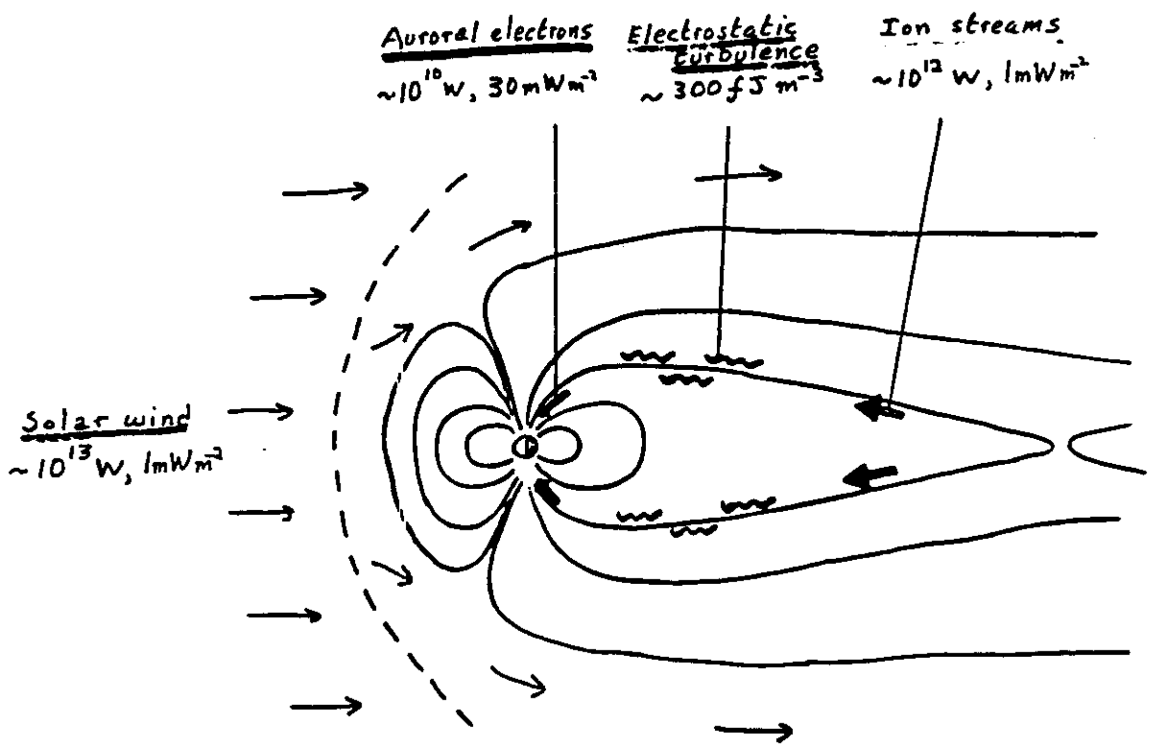
(Takahashi & Hones 1986)



← Tailward Earthward →

(Takahashi & Hones 1986)

.... suggesting ion acceleration Earthward of merging region.



Outline of stochastic acceleration model

Applications

Ion ⟶ Wave ⟶ Electron interactions.

phenomenon	electron energy affected
Alfvén critical ionization	~ 1eV
energization at Bow Shock, AMPTE releases and comets.	~ 10eV
energization at magnetopause boundary layer.	~ 100eV
energization in aurora, solar flares, and tokamaks.	~ keV
etc.	?

WDC C2 Tokyo 198'