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SMR 1331/12

AUTUMN COLLEGE ON PLASMA PHYSICS

8 October - 2 November 2001

Alfvénic Wave Packets - I & II

B. Buti

California Institute of Technology
Pasadena, U.S.A.

These are preliminary lecture notes, intended only for distribution to participants.

strada costiera, 11 - 34014 trieste italy - tel. +39 0402240111 fax +39 040224163 - sci_info@ictp.trieste.it - www.ictp.trieste.it

Alfvénic Wave Packets

* SMALL AMPLITUDE (LINEAR) AW ALWAYS STABLE

$$\omega^2 = k^2 V_A^2 \qquad \text{MHD}$$

$$\omega \sim k V_A \left(1 + \frac{k^2 V_A^2}{4 \Omega_i^2}\right)^{1/2} \pm k^2 V_A^2 / 2\Omega_i$$

DISPERSIVE MHD

$$V_A = (B_0^2 / 4\pi\rho)^{1/2} = \text{ALFVÉN SPEED}$$

FOR $k > 0$

$+$ RHP

$-$ LHP

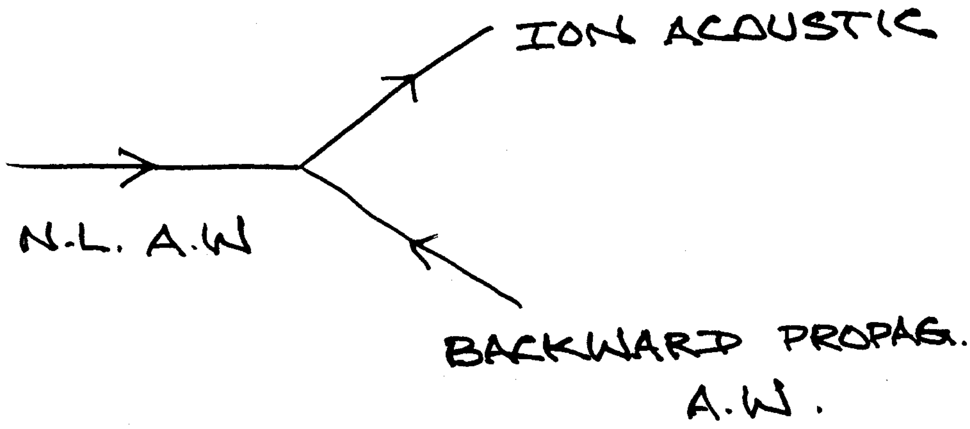
NOTE :

NO DENSITY FLUCTUATIONS ASSOCIATED WITH LINEAR AW

* LARGE AMPLITUDE (NONLINEAR) AW CAN BE UNSTABLE

N.L. EVOLUTION :

* DECAY INSTABILITY



* MODULATIONAL INSTABILITY ⇒
* SOLITARY A.W.

CHARACTERISTIC EVOLUTION EQN.

DNLS / MODIFIED DNLS

* DRIVEN ALFVÉN WAVES

⇒ CHAOS

FURTHER REMARKS

RHP ($\beta < 1$) $\Longrightarrow$ NO MOD. INST.

DECAY INST. — yes

NOTE

* DECAY INST. only QUASI-LINEAR
* GROWTH RATE of DECAY INST. MUCH SMALLER FOR LARGER β.
*
* GROWTH RATES FURTHER REDUCED BY KINETIC EFFECT (FINITE ION PRESSURE)
FOR SOLAR WIND,

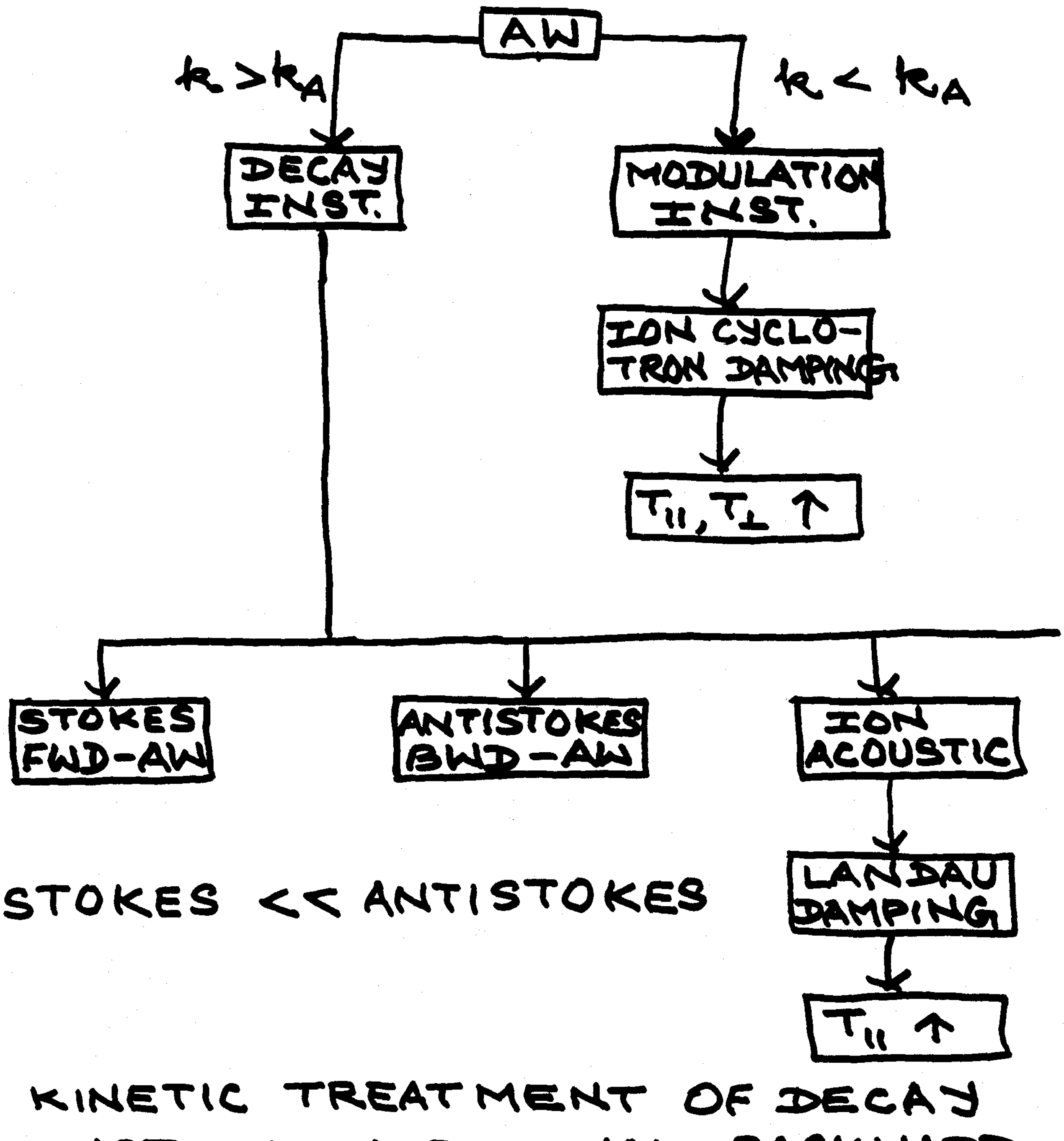
$$\frac{\gamma_{max}(\beta_i \gtrsim \beta_e)}{\gamma_{max}(\beta_i = 0)} \approx 30\%$$

↓ MHD CASE

TWO MODES OF SOLAR WIND FLOW

PROPERTY (1 AU)	LOW SPEED	HIGH SPEED
Speed (V)	< 400 km/sec	700 - 900 km/sec
Density (n)	~ 10 /cm^3	~ 3 /cm^3
Flux (nV)	$\sim 3 \times 10^8$/cm^2 sec	$\sim 2 \times 10^8$ /cm^2 sec
Magnetic Field(B_r)	~ 2.8nT	~ 2.8 nT
Temperatures	$T_p \sim 4 \times 10^4$ K	$T_p \sim 2 \times 10^5$ K
	$T_e \sim 1.3 \times 10^5 \text{K} > T_p$	$T_e \sim 10^5 \text{K} < T_p$
Coulomb collisions	Important	Negligible
Anistropies	T_p isotropic	$T_p(\perp) > T_p(\parallel)$
Beams	None	Fast ion beams
		+ electron "strahl"
Structure	Filamentary, highly variable	Uniform, slow changes
Composition	$He/H \sim 1 - 30\%$	$He/H \sim 5\%$
Waves	Both directions	Outwards propagating
Minor species	n_i/n_p variable	$n_i/n_p \sim$ constant
	$T_i \sim T_p$	$T_i \sim AT_p$
	$V_i \sim V_p$	$V_i \sim V_p + V_A$
Associated with	Streamers,	Coronal holes
	transiently open field	
Sunspot minimum	±15 deg from "equator"	> 30 deg
Sunspot maximum	Dominant at most latitudes	Less frequent

EVOLUTION OF NONLINEAR LHP ($\beta < 1$) ALFVÉN WAVE



STOKES << ANTISTOKES

* KINETIC TREATMENT OF DECAY INST. ⟹ ADDITIONAL BACKWARD PROPAGATING IAW.

OBSERVATIONS:

Large amplitude Alfvén waves observed in a variety of plasmas:

* solar wind
* solar corona
* environment of comets
* planetary bow shocks
* interplanetary shocks etc.

Some Chaotic Features of Solar Wind:

* Intermittent Turbulence
* Fractal / Multifractal Nature (Dimension)

Solar Wind Spectral Characteristics:

* Power Law Spectra
* Increase in Spectral Index with heliocentric distance
* Break in Power Spectra; Break-point moves towards lower frequencies with increasing heliocentric distances

COSMIC PLASMAS:

Implications of the existence of large-amplitude Alfvén waves in many cosmic plasmas have been investigated to model :

* turbulent heating of the solar corona
* interstellar scintillations of radio sources
* coherent radio emissions
* generation of stellar winds and extragalactic jets etc

DIFFERENT APPROACHES

1. EVOLUTION EQUATION

For finite but not very large fluctuations,

$\delta B / B \not\ll 1$

Singular Perturbation $\Rightarrow$ DNLS / MDNLS Equation

2. MHD (DISPERSIVE) SIMULATIONS

* DNLS not valid for $\beta \sim 1$
* For $\beta \sim 1$, coupling of δn and δB significant
* Kinetic Effects negligible

3 HYBRID SIMULATIONS

to incorporate

* Finite Larmor Radius Effects,
* Nonlinear LANDAU Damping

. . . . . .

SOLITARY ALFVÉN WAVES

DISPERSIVE MHD

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathrm{v}) = 0$$

$$\rho \frac{d\mathrm{v}}{dt} = -\nabla p + \mathrm{J} \times \mathrm{B}$$

$$\frac{\partial \mathrm{B}}{\partial t} = \nabla \times \left[(\mathrm{v} \times \mathrm{B}) - \frac{1}{\rho} (\nabla \times \mathrm{B}) \times \mathrm{B} \right]$$

B is normalized to B_0, ρ to ρ_0,
v to $V_A = B_0/(4\pi\rho_0)^{1/2}$,
t to Ω_i^{-1}, the ion cyclotron frequency
and l to V_A/Ω_i.
Subscript '0' refers to equilibrium quantities.

Nonlinear Evolution Equations

$\Longrightarrow$ Integrable Systems

* KdV (Ion Acoustic Waves)

$$\frac{\partial \phi}{\partial t} + \phi \frac{\partial \phi}{\partial x} + \frac{\partial^3 \phi}{\partial x^3} = 0$$

* NLS (Langmuir Waves)

$$i \frac{\partial \phi}{\partial t} + \frac{\partial^2 \phi}{\partial x^2} + |\phi|^2 \phi = 0$$

* DNLS (Polarized Alfvén Waves)

$$\frac{\partial \phi}{\partial t} \pm i \frac{\partial^2 \phi}{\partial x^2} + \frac{\partial}{\partial x}\left(|\phi|^2 \phi\right) = 0$$

+ LH Polarization

− RH "

Evolution Eqs. $\Longrightarrow$ Solitary Waves

DNLS :

$$\frac{\partial B_\pm}{\partial t} + \frac{1}{4(1-\beta)} \frac{\partial}{\partial x}\left(B_\pm |B_\pm|^2\right) \pm \frac{i V_A}{2\Omega_i} \frac{\partial^2 B_\pm}{\partial x^2} = 0$$

$+$ LHP

$-$ RHP

$$B_+ = B_y + i B_z$$

$$B_- = B_y - i B_z$$

$$\vec{k} \parallel \vec{B}_0 \equiv B_0 \hat{e}_x$$

DNLS $\Longrightarrow$ SOLITONS

$$B_\pm = \frac{(\sqrt{2}-1)^{1/2} B_{max}\, e^{\pm i\theta(X)}}{\left[\sqrt{2}\cosh(2V_s X) - 1\right]^{1/2}}$$

$$\theta(X) = -V_s X + 3\tan^{-1}\left[(\sqrt{2}+1)\tanh(2V_s X)\right]$$

$$V_s = \frac{(\sqrt{2}-1) B_{max}^2}{8(1-\beta)} = \text{SOLITON SPEED}$$

$$X = (x-t)$$

B_{max} = AMPLITUDE OF SOLITON

SOLITARY AW in INHOMOGENEOUS STREAMING PLASMAS

$$\frac{\partial \rho}{\partial t} + \frac{1}{r^2}\frac{\partial}{\partial r}(r^2 \rho v_r) = 0$$

$$\rho \frac{dv_r}{dt} = -\frac{\partial p}{\partial r} - \frac{\partial}{\partial r}\frac{B_\perp^2}{2} - \frac{B_\perp^2}{2}$$

$$\rho \frac{d\mathbf{v}_\perp}{dt} = \frac{B_r}{r}\frac{\partial}{\partial r}(r\mathbf{B}_\perp)$$

and

$$\frac{\partial \mathbf{B}_\perp}{\partial t} = \frac{1}{r}\frac{\partial}{\partial r}(B_r v_\perp - v_r B_\perp) + \frac{1}{r}\frac{\partial}{\partial r}\left[\frac{B\hat{\mathbf{e}}_r}{r\rho} \times \frac{\partial(\mathbf{B}_\perp r)}{\partial r}\right]$$

$\mathbf{B}_\perp = (B_\theta, B_\phi), \mathbf{v}_\perp = (v_\theta, v_\phi)$, and $B_\perp^2 = (B_\theta^2 + B_\phi^2)$

$$p\rho^{-\gamma} = const.$$

$$B_0(r)\, r^2 = const$$

$$\rho_0(r)\, U(r)\, r^2 = const.$$

$$\frac{\partial B}{\partial \eta} + \frac{3\,U}{2\,V\,\eta}\,B + \frac{B}{4\,V\,(V-U)}\,\frac{\partial}{\partial \eta}\left(V^2 - U^2\right)$$
$$+\frac{(V-U)}{4\,B_0^2(\eta)\,V^2\,(1-\beta(\eta))}\frac{\partial}{\partial \xi}\left(B \mid B \mid^2\right) + \frac{i\,(V-U)^2}{2\,V^3\,B_0(\eta)}\frac{\partial^2 B}{\partial \xi^2} = 0$$

MDNLS

$$\eta = \epsilon^2 r; \qquad \xi = \epsilon\left[\int \frac{dr}{V(r)} - t\right]$$

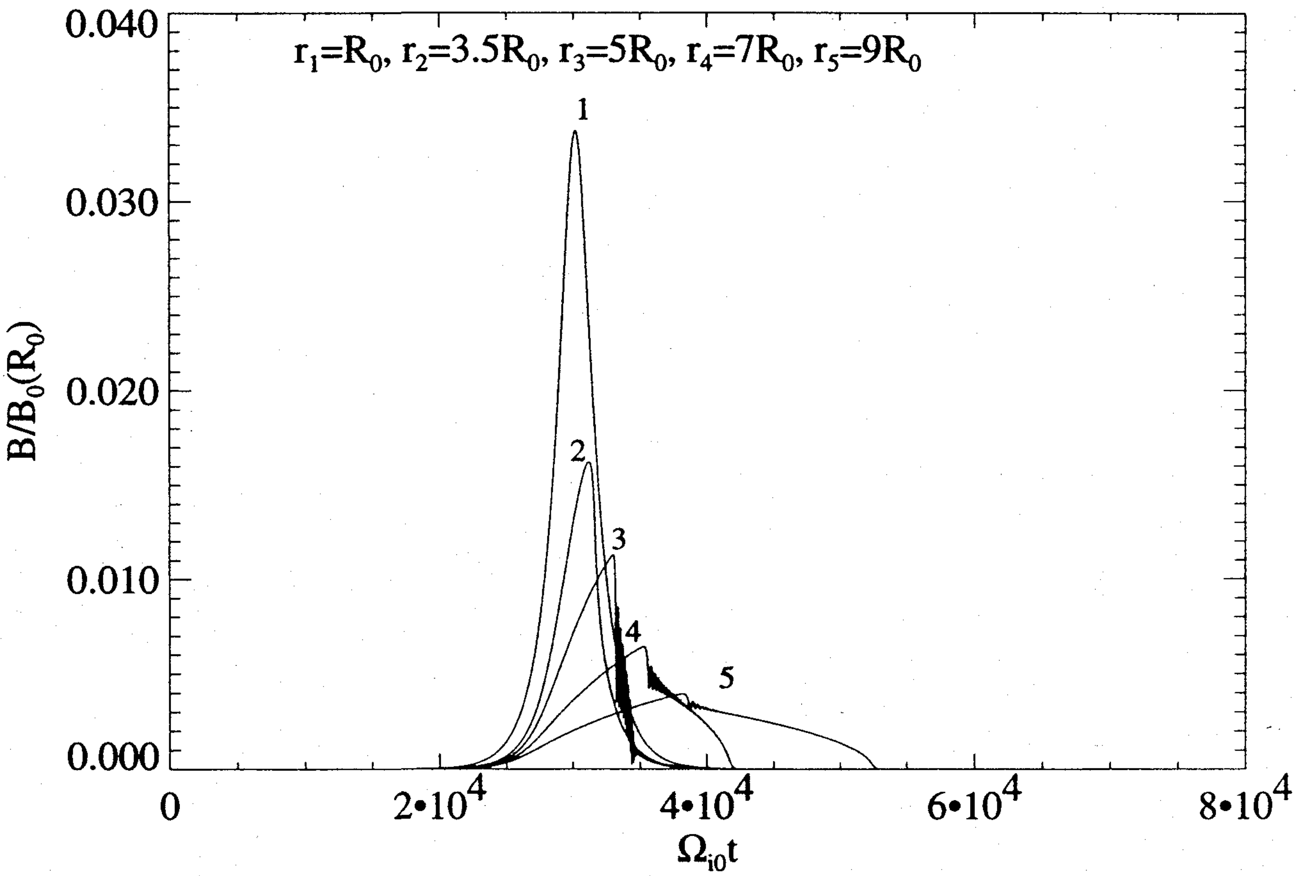
ϵ is the stretching parameter and $V(r)$ is the phase velocity of the Alfvén

$$V(r) = U(r) + \frac{B_0(r)}{\rho_0^{1/2}(r)}$$

U is the equilibrium streaming plasma velocity.

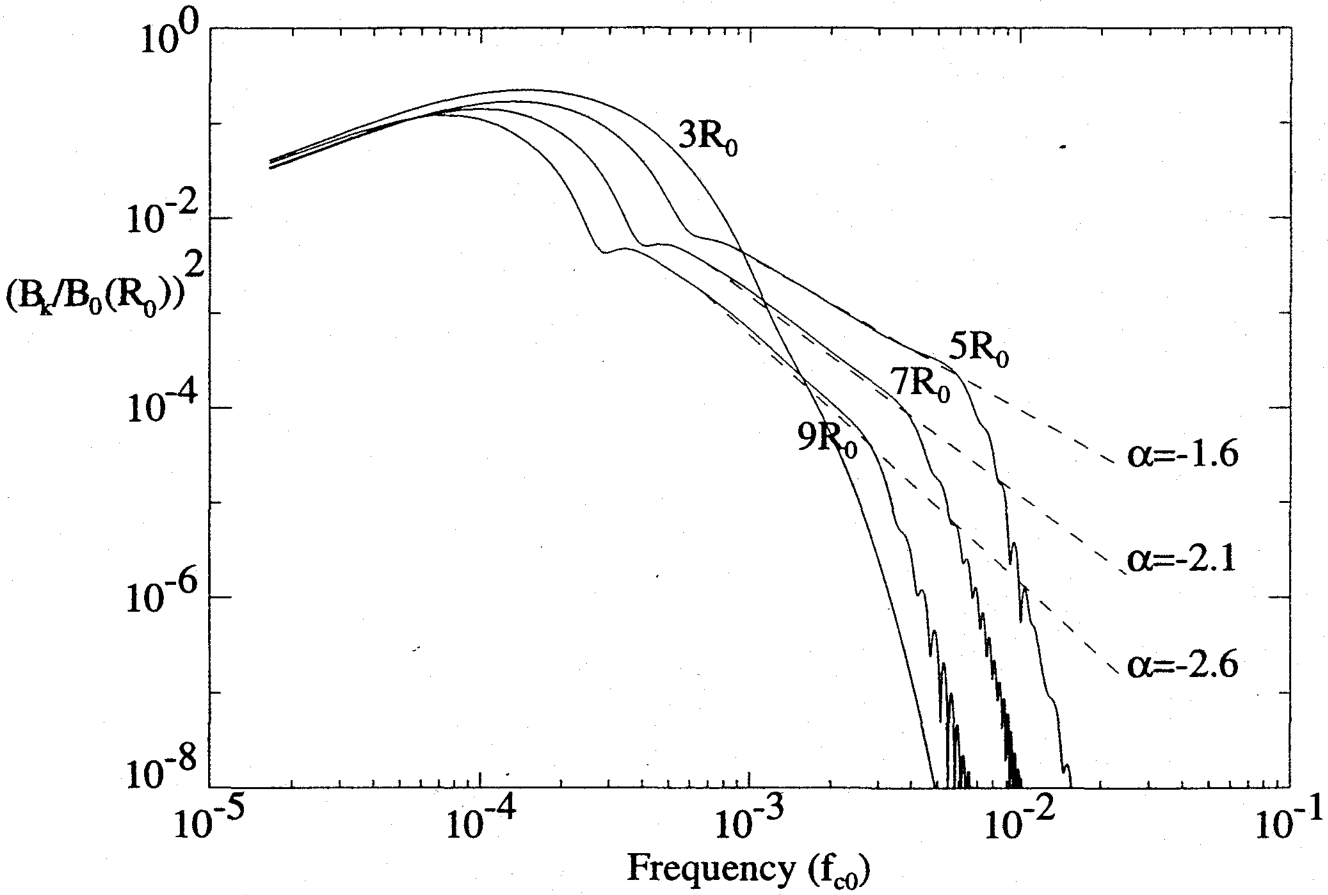
FOR $\rho_0(r) = 1$, $B_0(r) = 1$, $U = 0$

$$B\,(\xi,\, r_0) \;=\; \frac{B_{max}\, e^{i\theta\,(\xi)}}{cosh^{1/2}\,\psi},$$



0.040
0.030
0.020
0.010
0.000
B/B0(R0)
r1=R0, r2=3.5R0, r3=5R0, r4=7R0, r5=9R0
1
2
3
4
5
0
2•10^4
4•10^4
6•10^4
8•10^4
Ωi0t

Fig. 2a



10^0
10^{-2}
10^{-4}
10^{-6}
10^{-8}
$(B_k/B_0(R_0))^2$
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
Frequency (f_{c0})
$3R_0$
$5R_0$
$7R_0$
$9R_0$
α=-1.6
α=-2.1
α=-2.6

OBSERVATIONS
TURBULENCE
POWER SPECTRA
etc.

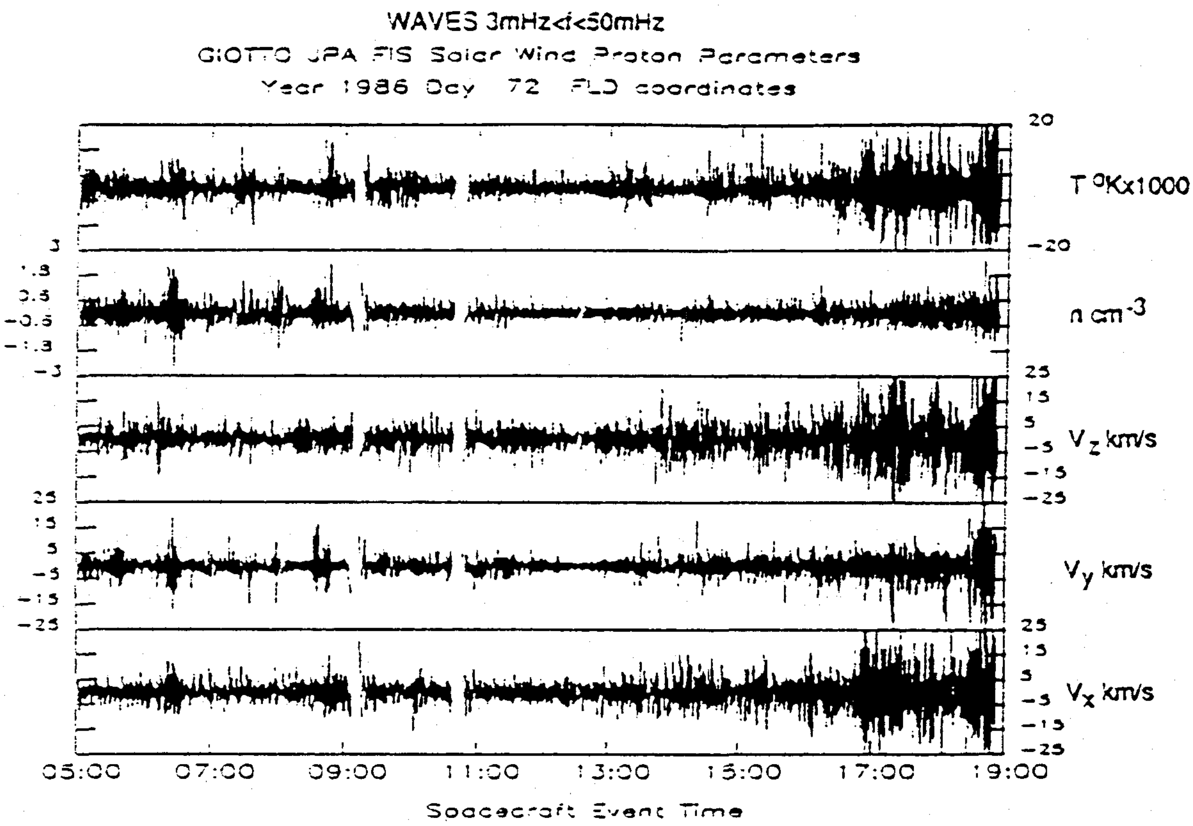


Figure 6. The turbulence in the solar wind proton parameters over the period from 0500 SET to 1900 SET on March 13th 1986 when the spacecraft was travelling from 4.5 million km to 1.2 million km from the nucleus. The FLD coordinate system has the y axis magnetic field aligned, the z axis in the -v x B direction and the x axis forming a right handed set. The mean value of the parameters has been subtracted. The frequency range indicated is set at the low frequency end by the digital filter and at the high end by the sample rate of the instrument.

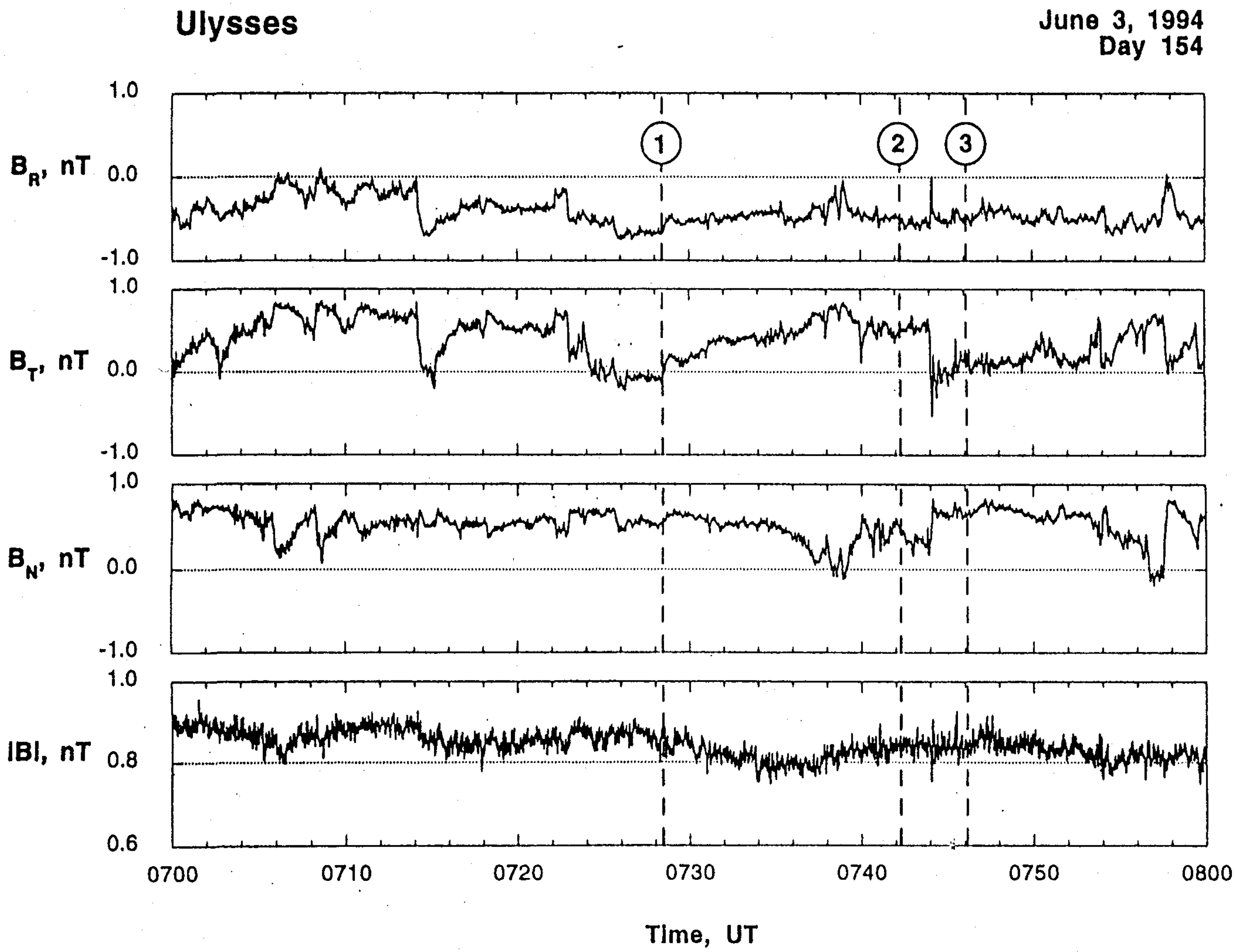


Figure 10. An example of an Alfvén wave with a phase-steepened edge (rotational discontinuity [RD]). From left to right, dashed vertical lines give the start and stop times of intervals of analyses.

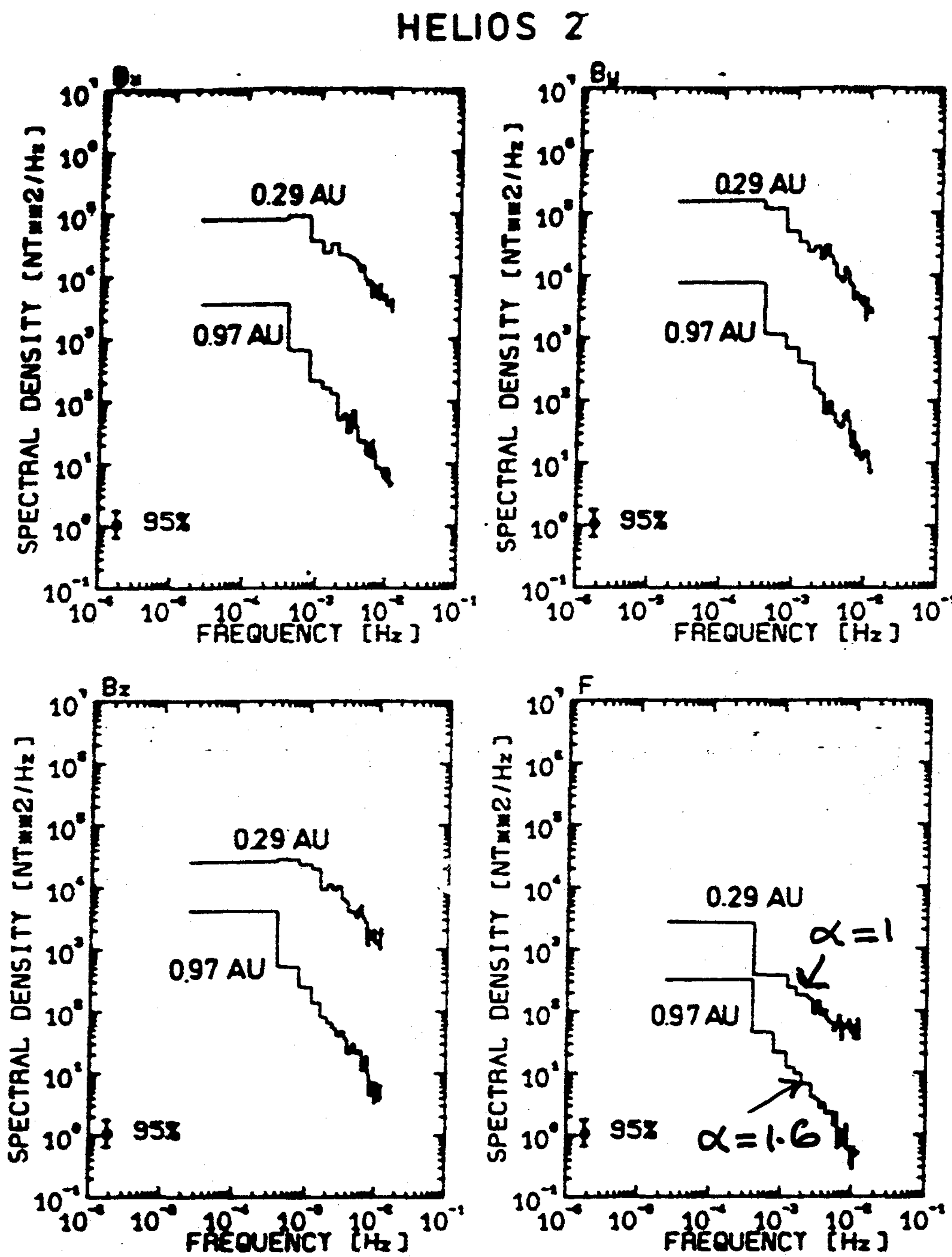
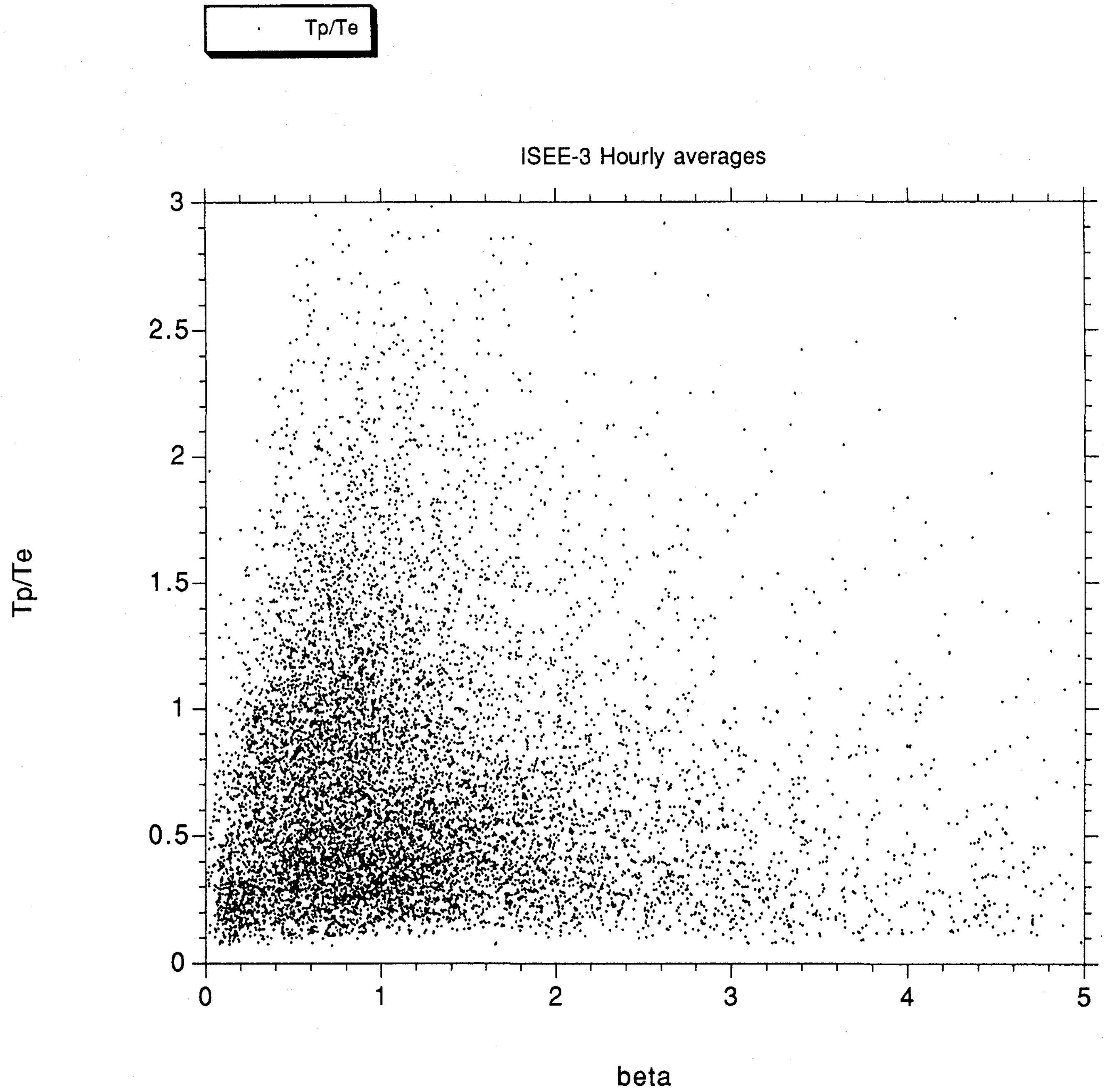


Fig. 2. Magnetic field (vector components and magnitude) power spectral densities at different heliographic distances. The 'mean field' coordinate system (Z axis parallel to the average direction of the vector magnetic field) was used throughout the paper. The spectra were computed from 40-s averages of the magnetic field over 11 1/2 hours on January 24, 1900 UT to January 25, 0623 UT, 1976 (0.97 AU) and on April 14, 2300 UT to April 15, 1023 UT, 1976 (0.29 AU). Also given are the 95% confidence limits for the spectral density computed from an equivalent of 32 degrees of freedom.

From JGR, 87, 1982.



Tp/Te
ISEE-3 Hourly averages
3
2.5
2
1.5
1
0.5
0
0
1
2
3
4
5
Tp/Te
beta

CHAOTIC ALFVÉN WAVES

DRIVEN DNLS EQUATION:

$$\frac{\partial B}{\partial t}+\frac{1}{4\,(1-\beta)}\frac{\partial}{\partial x}\left(B \mid B \mid^2\right)+\frac{i}{2}\frac{\partial^2 B}{\partial x^2} = A\ e^{i(\kappa x-\Omega t)}$$

NUMERICAL SOLUTION

Spectral-collocation method with periodic boundary conditions used

Initial condition:

$$B\ (x,\ t=0)\ =\ \frac{(2^{1/2}-1)^{1/2}\ B_{max}\ e^{i\theta\ (x)}}{[2^{1/2}\ \cosh\ (2\ V_s\ x)\ -\ 1]^{1/2}}$$

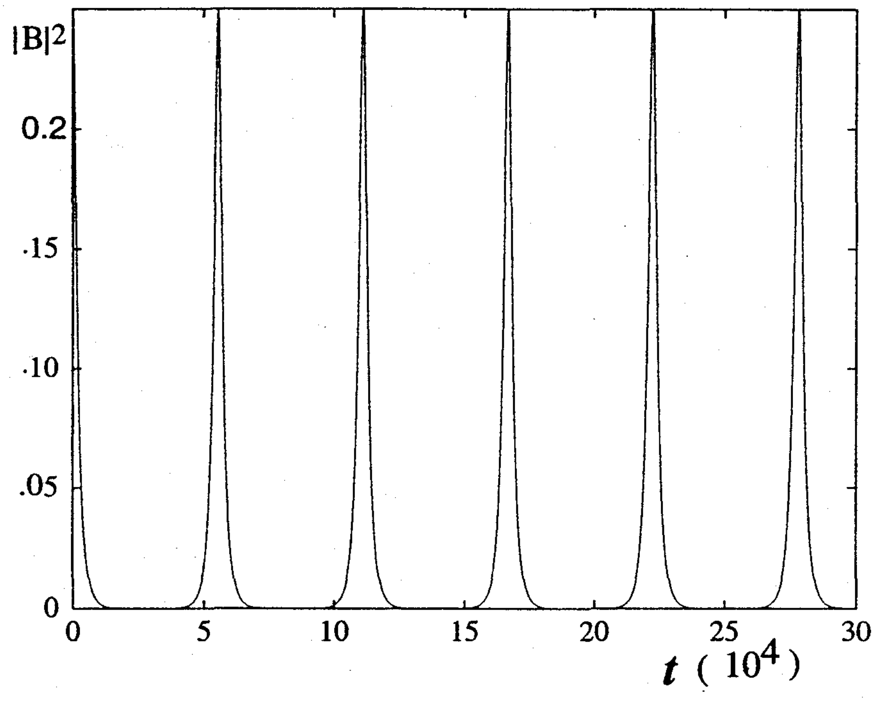
B_{max} is the amplitude of the soliton

$$\theta\ (x, t=0)\ =\ -\ V_s\ x + 3\ \tan^{-1}\ [(2^{1/2}+1)\ \tanh(2V_s\ x)]$$

V_s is the soliton speed defined by,

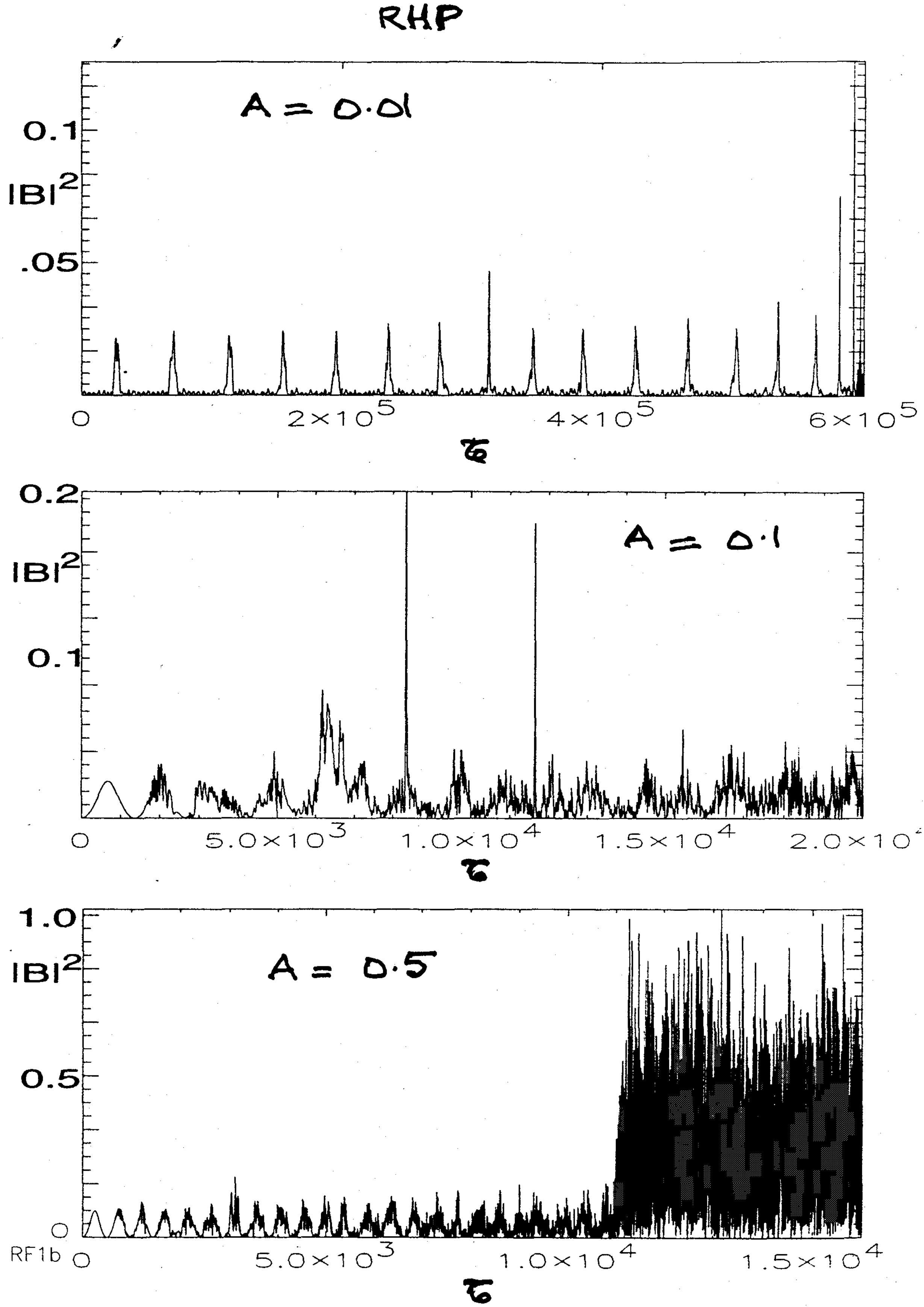
$$V_s\ =\ \frac{(2^{1/2}-1)\ B^2_{max}}{8\ (1\ -\ \beta)}$$

A = 0

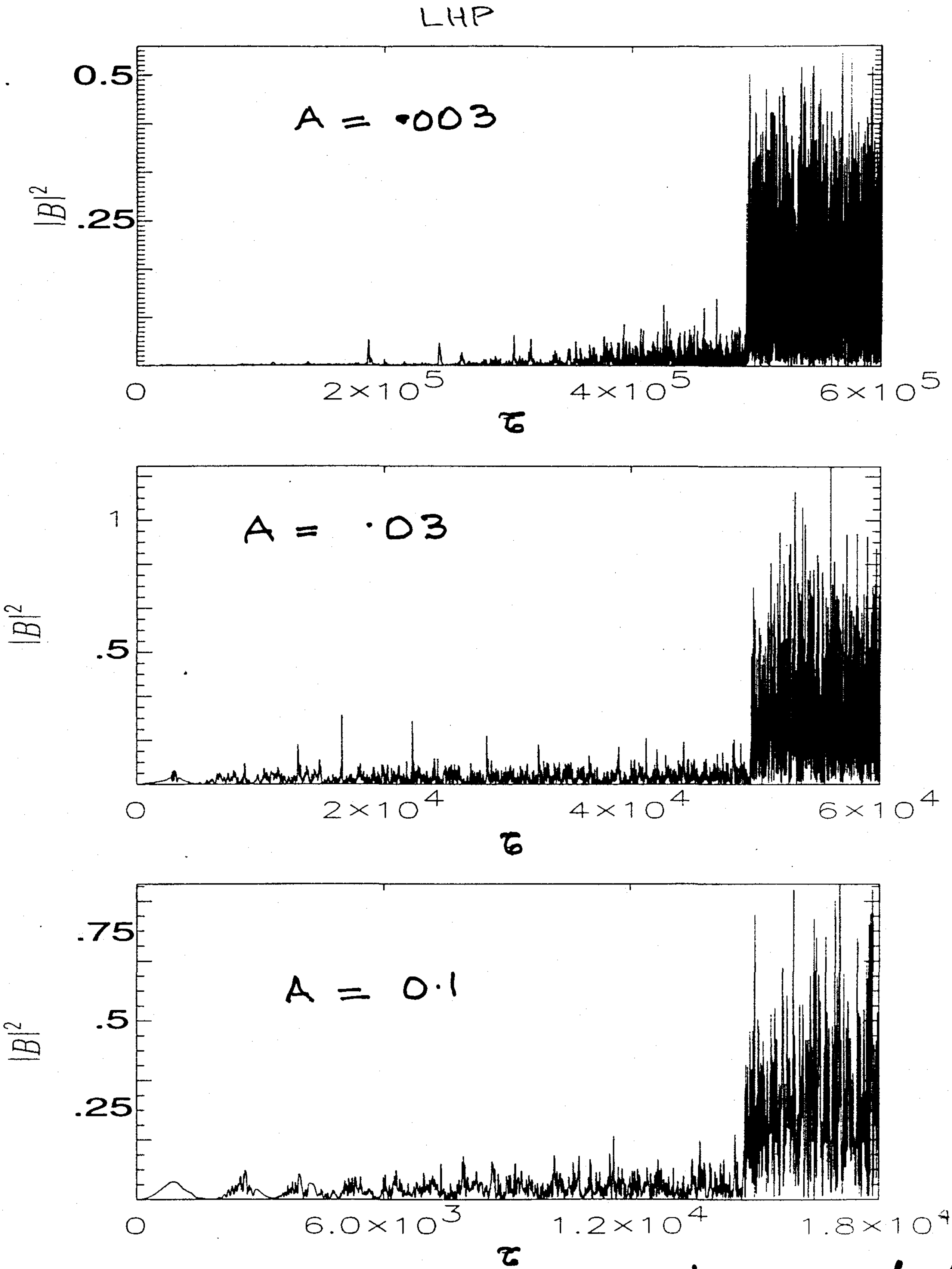


B = 0.1

CHAOTIC AW



Fig



CHAOS ONSET TIME $\propto A^{-1}$

$t = 144\tau$

Fig.

POWER SPECTRA

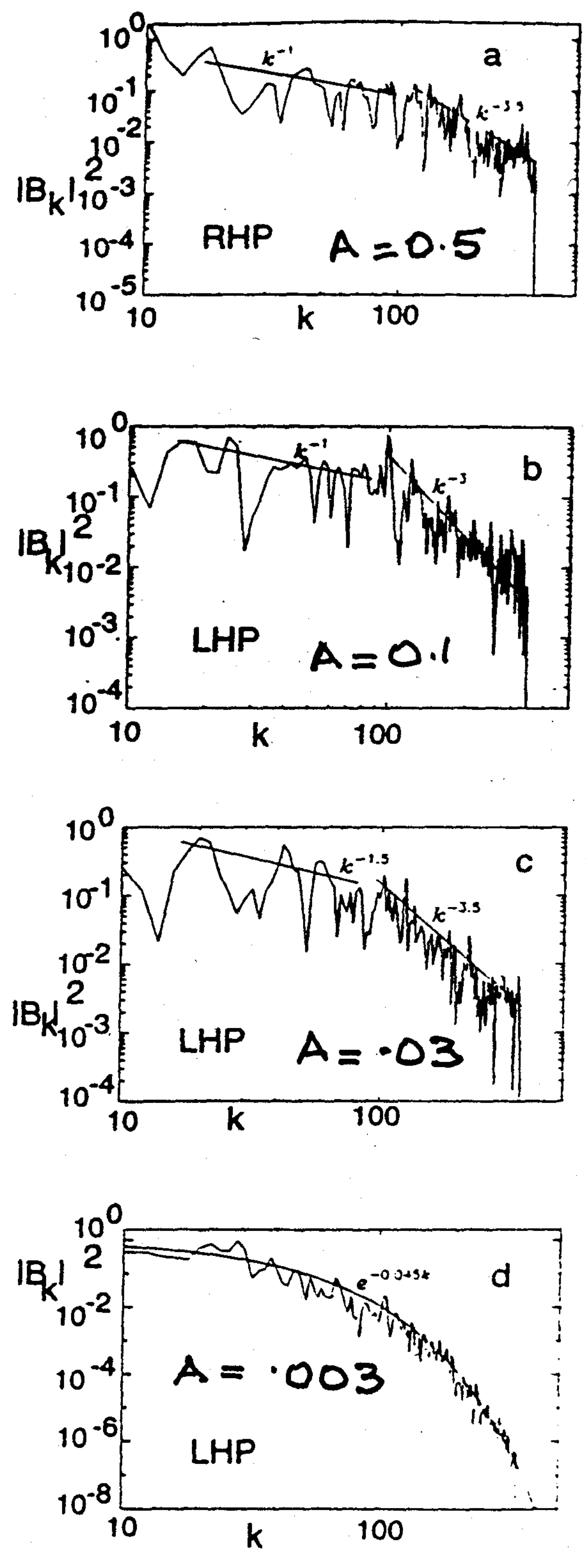


FIGURE Shows Spectra for magnetic field turbulence generated through chaos for a) RHP with A = 0.5, b) LHP with A = 0.1, c) LHP with A = .03 and d) LHP with A = .003.

SLOW SOLAR WIND (~ 1 AU)

β large ; $\beta \sim 1$

$T_i < T_e$

FAST SOLAR WIND :

β large

$T_i > T_e$

SIMILAR FEATURES IN VICINITY OF SHOCKS

LARGE AMPLITUDE AW

$\delta B / B_0 \gtrsim 1$

* MODELS BASED ON

DNLS / MDNLS / KNLS

NOT ADEQUATE

* $\delta N - \delta B$ COUPLING SIGNIFICANT
* KINETIC EFFECTS CRUCIAL
* FOR L-F WAVES ($\omega^2 << \Omega_e^2$)

HYBRID SIMULATIONS

ADEQUATE

HIGH RESOLUTION SIMULATIONS

$\Longrightarrow$

NEW FEATURES

* COLLAPSE $\Rightarrow$ TRANSPORT OF ENERGY

* ION HOLES

SIMULATIONS of AMPLITUDE-MODULATED ⊙ POLARIZED AW
(MACHIDA et al., JGR, 1987)

* SB FINITE BUT NOT LARGE
* β FINITE BUT $\not\sim 1$
* RESOLUTION NOT VERY HIGH
* DISCUSSED DECAY INST. and MODULATIONAL INST. FOR LHP and RHP AW

HALL MHD SIMULATIONS OF ALFVÉNIC WAVE PACKETS
(BUTI et al., GRL, 1998 ;
VELLI, BUTI, GOLDSTEIN, SOLAR WIND 9, 1999)

* DISCUSSED DISRUPTION of WAVE PACKETS (SB, β not very large)
* SIMULATIONS RESOLUTION NOT VERY HIGH

MHD SIMULATIONS

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x}(\rho v_x) = 0$$

$$\frac{\partial}{\partial t}(\rho v_x) + \frac{\partial}{\partial x}(\rho {v_x}^2) + \frac{\partial \beta}{\partial x} + \frac{\partial}{\partial x}\left(\frac{B^2}{2}\right) = 0$$

$$\frac{\partial}{\partial t}(\rho \tilde{v}) + \frac{\partial}{\partial x}(\rho v_x \tilde{v}) - \frac{\partial B}{\partial x} = 0$$

$$\frac{\partial B}{\partial t} + \frac{\partial}{\partial x}(v_x B - \tilde{v}) = -i\frac{\partial}{\partial x}\left(\frac{1}{\rho}\frac{\partial B}{\partial x}\right)$$

$$\frac{\partial \beta}{\partial t} + \frac{\partial}{\partial x}(\beta v_x) + (\gamma - 1)\beta\frac{\partial v_x}{\partial x} = 0$$

v_x is flow velocity along direction of propagation, $B = (B_y + i\ B_z)$ and $\tilde{v} = (v_y + i\ v_z)$. Adiabatic equation of state: $p\rho^{-\gamma} = \text{const.}$. γ is ratio of specific heats.

Initial condition:

$$B\ (x,\ t=0)\ =\ \frac{(2^{1/2}-1)^{1/2}\ B_{max}\ e^{i\theta\ (x)}}{[2^{1/2}\ \cosh\ (2\ V_s\ x)\ -\ 1]^{1/2}}$$

B_{max} **is the amplitude of the soliton**

$$\theta\ (x, t=0)\ =\ -\ V_s\ x + 3\ \tan^{-1}\ [(2^{1/2}+1)\ \tanh(2V_s\ x)]$$

V_s **is the soliton speed defined by,**

$$V_s\ =\ \frac{(2^{1/2}-1)\ B_{max}^2}{8\ (1\ -\ \beta)}$$

$$SN\ (x, t=0)\ =\ \frac{1}{2}\ \frac{1}{(1-\beta)}\ |B(x, t=0)|^2$$

$$\vec{B}_0\ =\ B_0\ \hat{e}_x$$

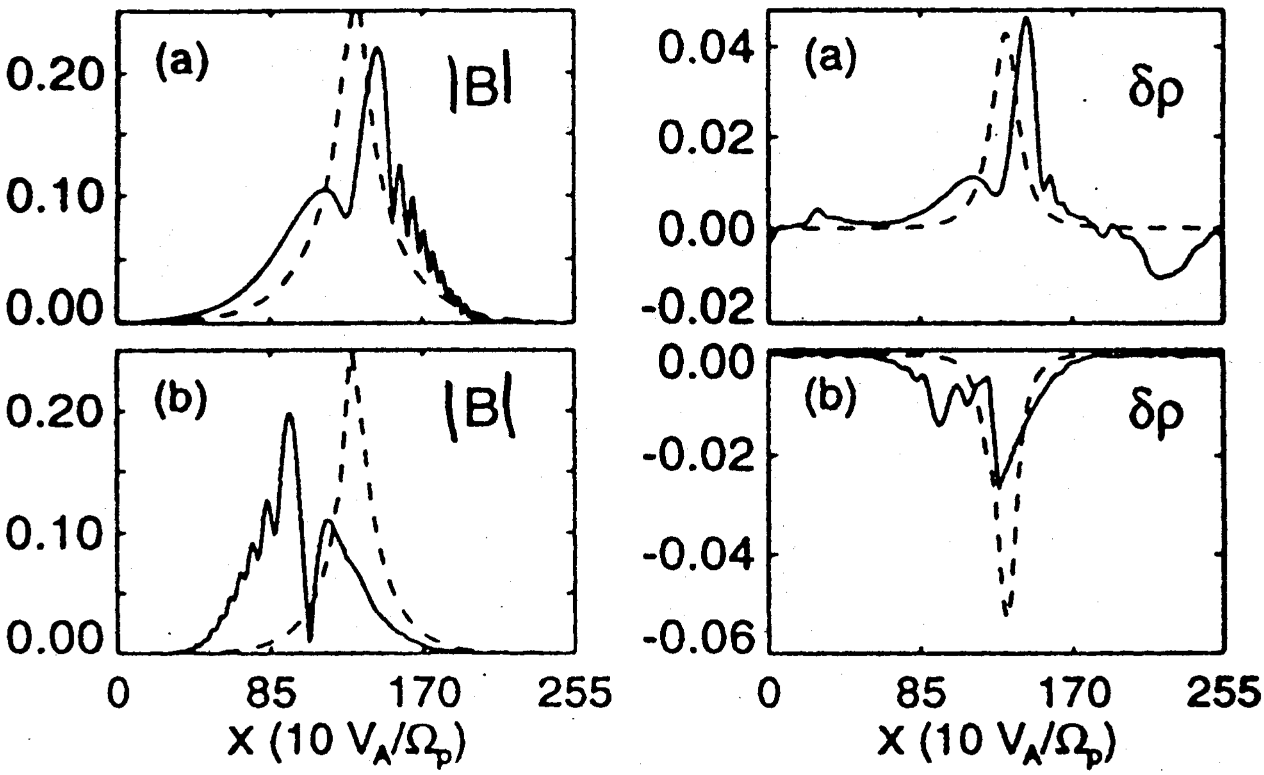


Figure 1. (a) The evolution of the magnetic and density fluctuations, B and $\delta\rho$, respectively, for a RHP soliton for $\beta = 0.3$ at $t \approx 40\Omega_p^{-1}$ (dashed line) and at 5000 Ω_p^{-1} (solid line). (b) Same as (a) but for $\beta = 1.5$.

$$\delta\rho = \frac{1}{2(1-\beta)} |B|^2$$

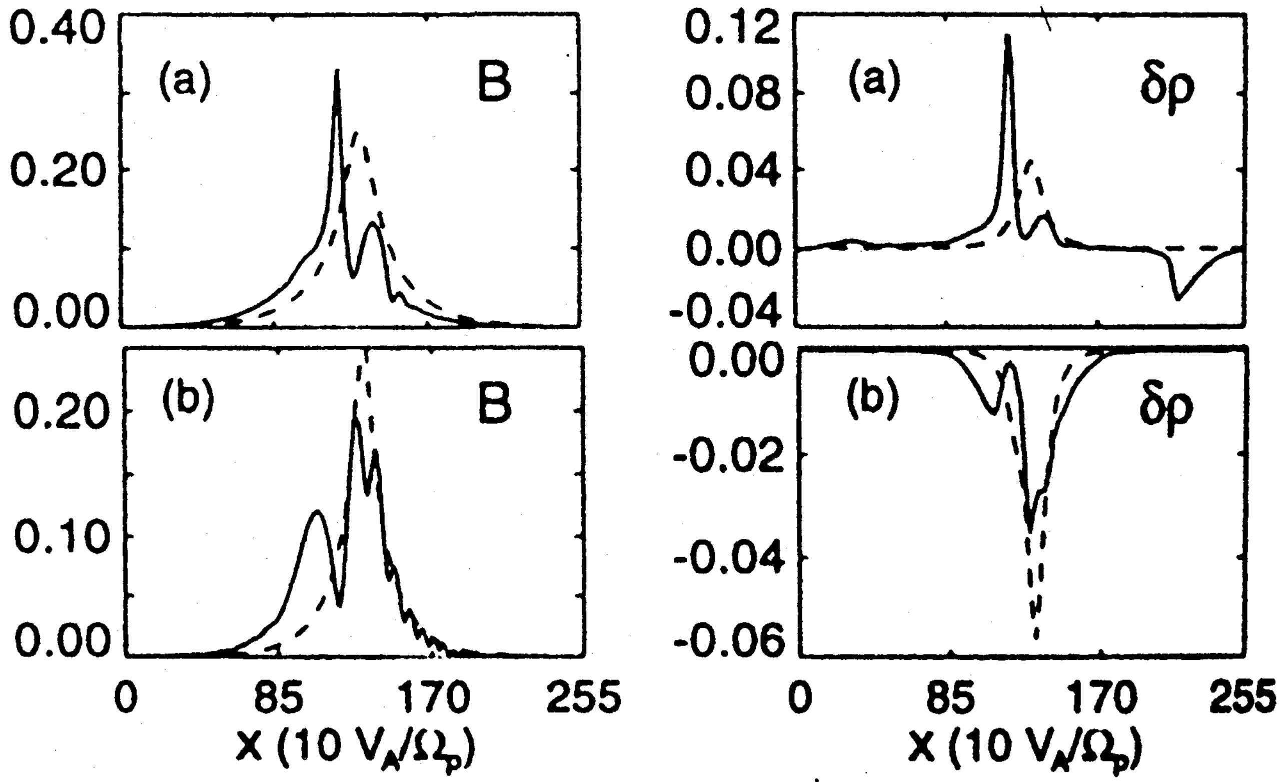
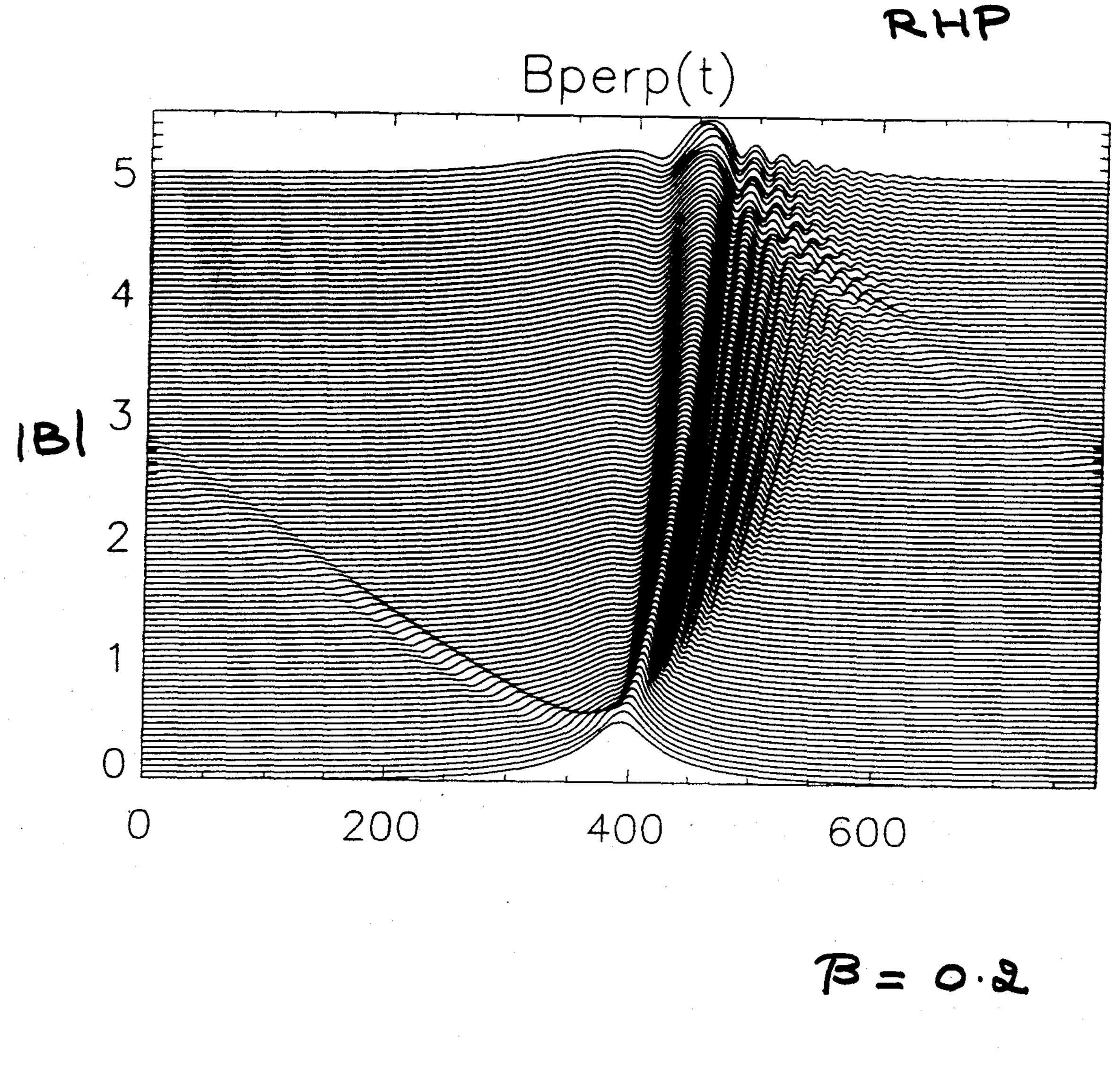
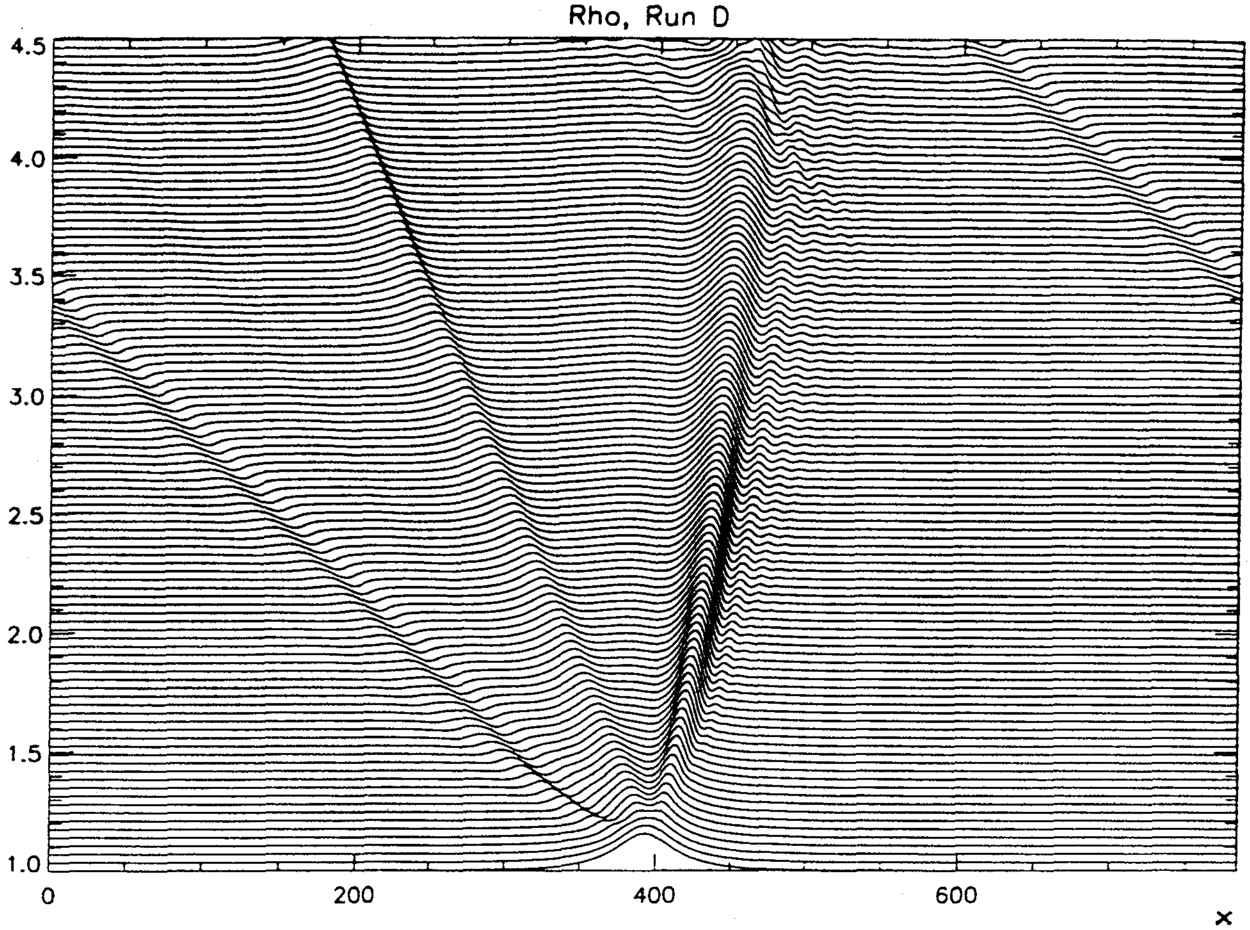


Figure 2. (a) Same as Fig. 1a but for LHP soliton. (b) Same as Fig. 1b but for LHP soliton.

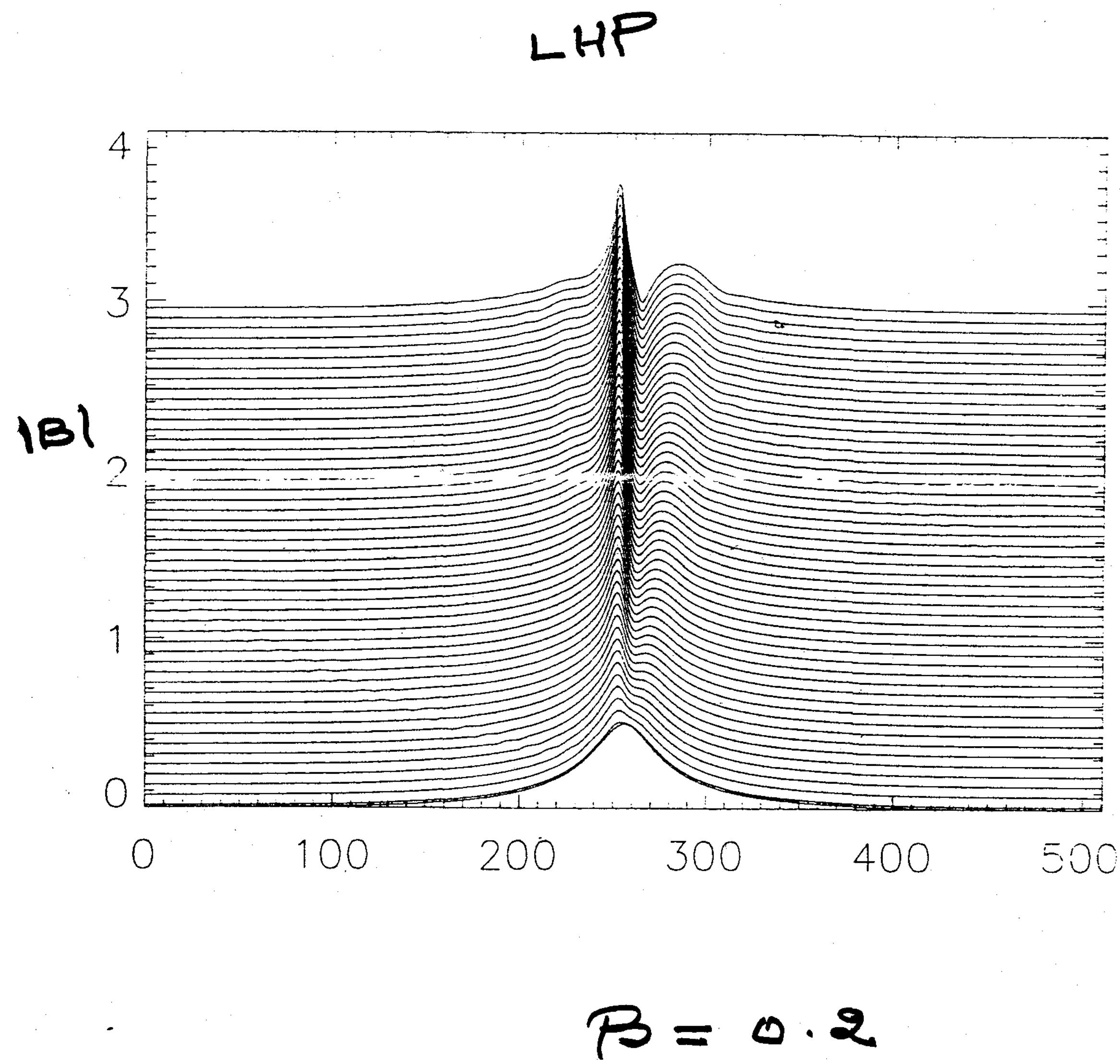

RHP
Bperp(t)
|B|
5
4
3
2
1
0
0
200
400
600
β = 0.2

time (rescaled)

RHP



B = 0.2



LHP
|B|
4
3
2
1
0
0
100
200
300
400
500
B = 0.2

HYBRID SIMULATIONS

COLLAPSE OF ALFVÉNIC WAVE PACKETS

DYNAMICAL TURNING POINT
→ CHANGE OF POLARIZATION

RADIATIONS

Simulation Model

* One - Dimensional Hybrid Code
* Electrons as Isothermal Fluid
* Protons as Particles -------- Maxwellian , BIMAXWELLIAN etc.
* HIGH RESOLUTION:

Simulation Box Length ------ 860 Ion Inertial Lengths (V_A/Ω_i)

Number of Cells ------- 2048

number of Particles / Cell ----- 200

Simulation Time ------- 1000 Ion Gyro-Periods (Ω_i^{-1})

Time resolution ------- 0.01

$\Omega_i = 10^4 B$

Initial condition:

$$B\,(x,\ t=0)\ =\ \frac{(2^{1/2}-1)^{1/2}\ B_{max}\ e^{i\theta\,(x)}}{[2^{1/2}\ \cosh\,(2\ V_s\ x)\ -\ 1]^{1/2}}$$

B_{max} is the amplitude of the soliton

$$\theta\,(x,t=0)\ =\ -\ V_s\ x+3\ \tan^{-1}\left[(2^{1/2}+1)\ \tanh(2V_s\ x)\right]$$

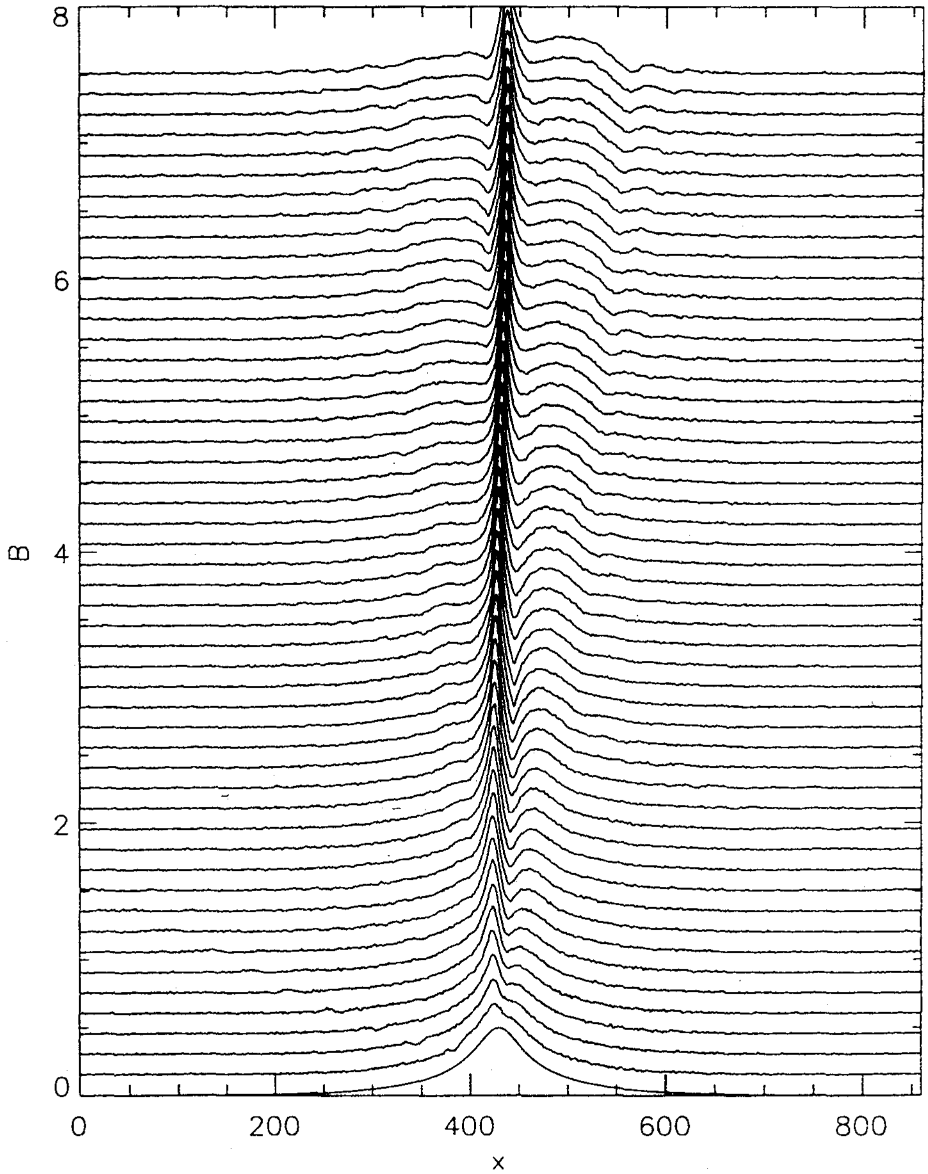
V_s is the soliton speed defined by,

$$V_s\ =\ \frac{(2^{1/2}-1)\ B_{max}^2}{8\ (1\ -\ \beta)}$$

$$\delta N\ (x,t=0)\ =\ \frac{1}{2}\ \frac{1}{(1-\beta)}\ |B\ (x,t=0)|^2$$

(DRIVEN by PONDERMOTIVE FORCE)

COLLAPSE



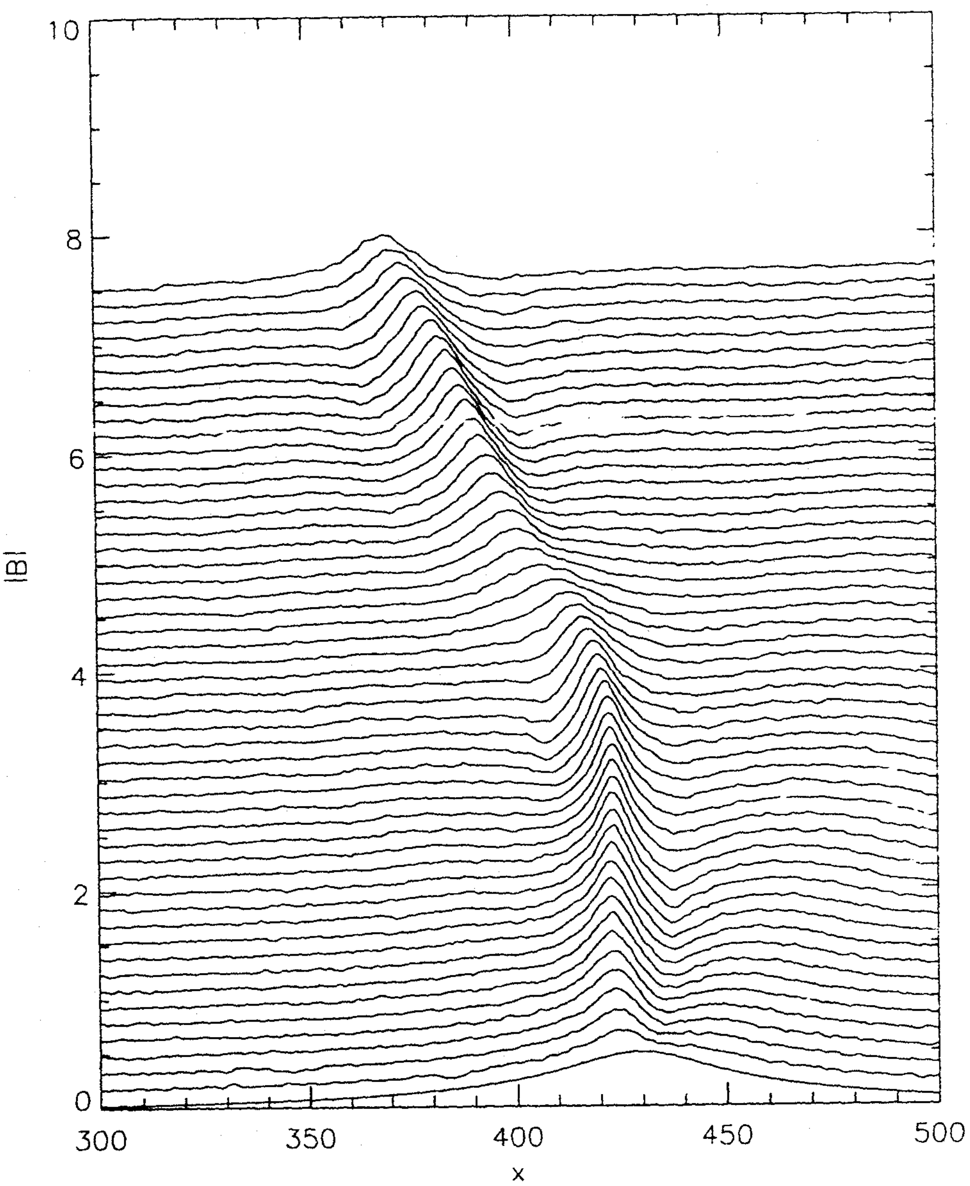
P10b

$\beta = .2$

LHP

$T_e = T_i$

⇒ ENERGY TRANSPORT
TO LARGER K



$\beta = 0.4$

$T = 1$

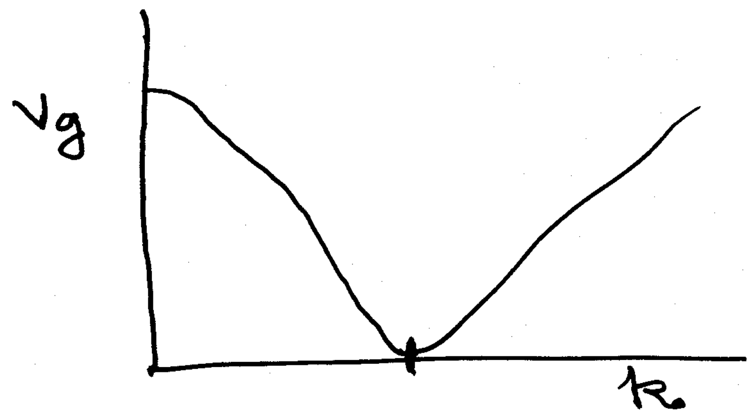
DYNAMICAL TURNING POINT

NONLINEAR DISPERSION RELATION IN WAVE FRAME OF REFERENCE

$$\omega \simeq k|B|^2/(1-\beta) \pm \mu k^2$$

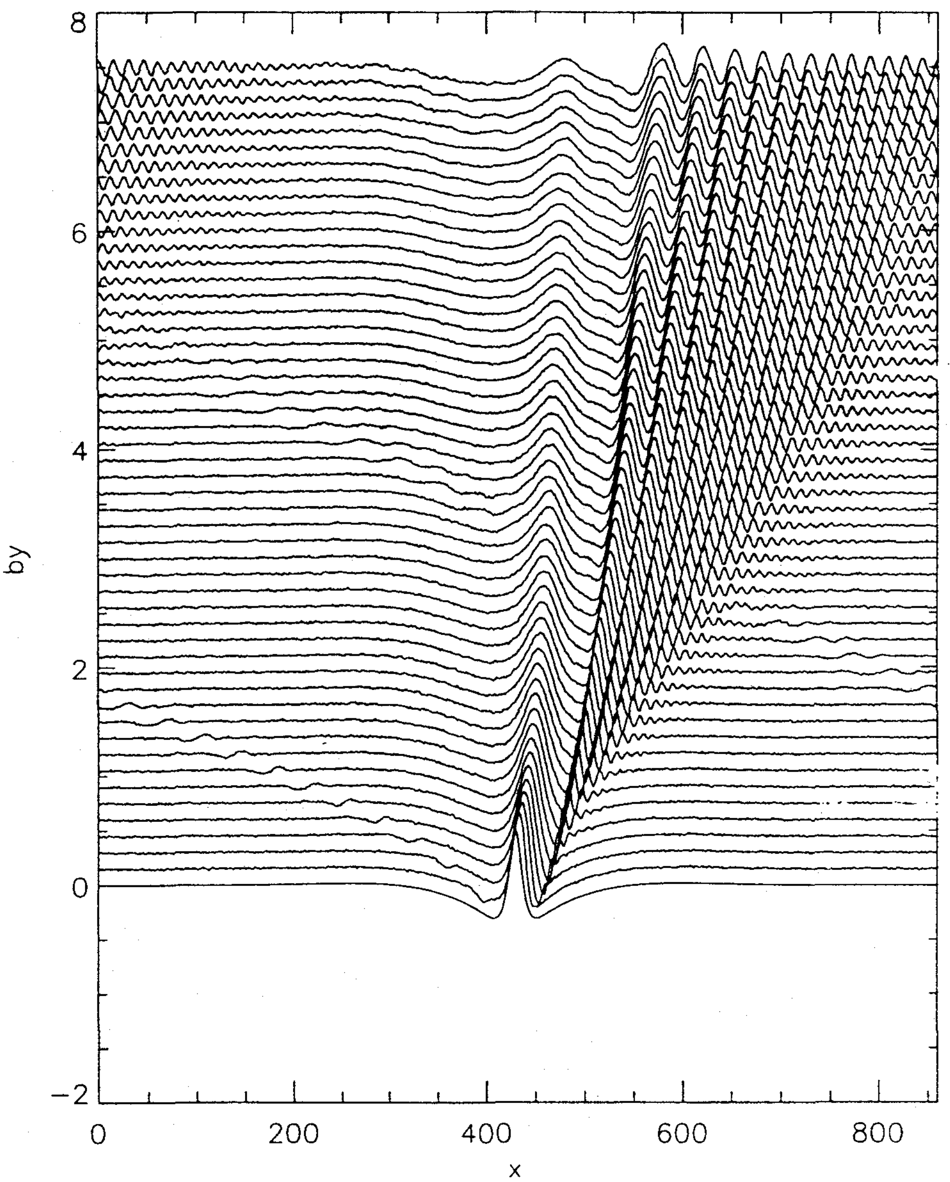
$+$ RHP

$-$ LHP

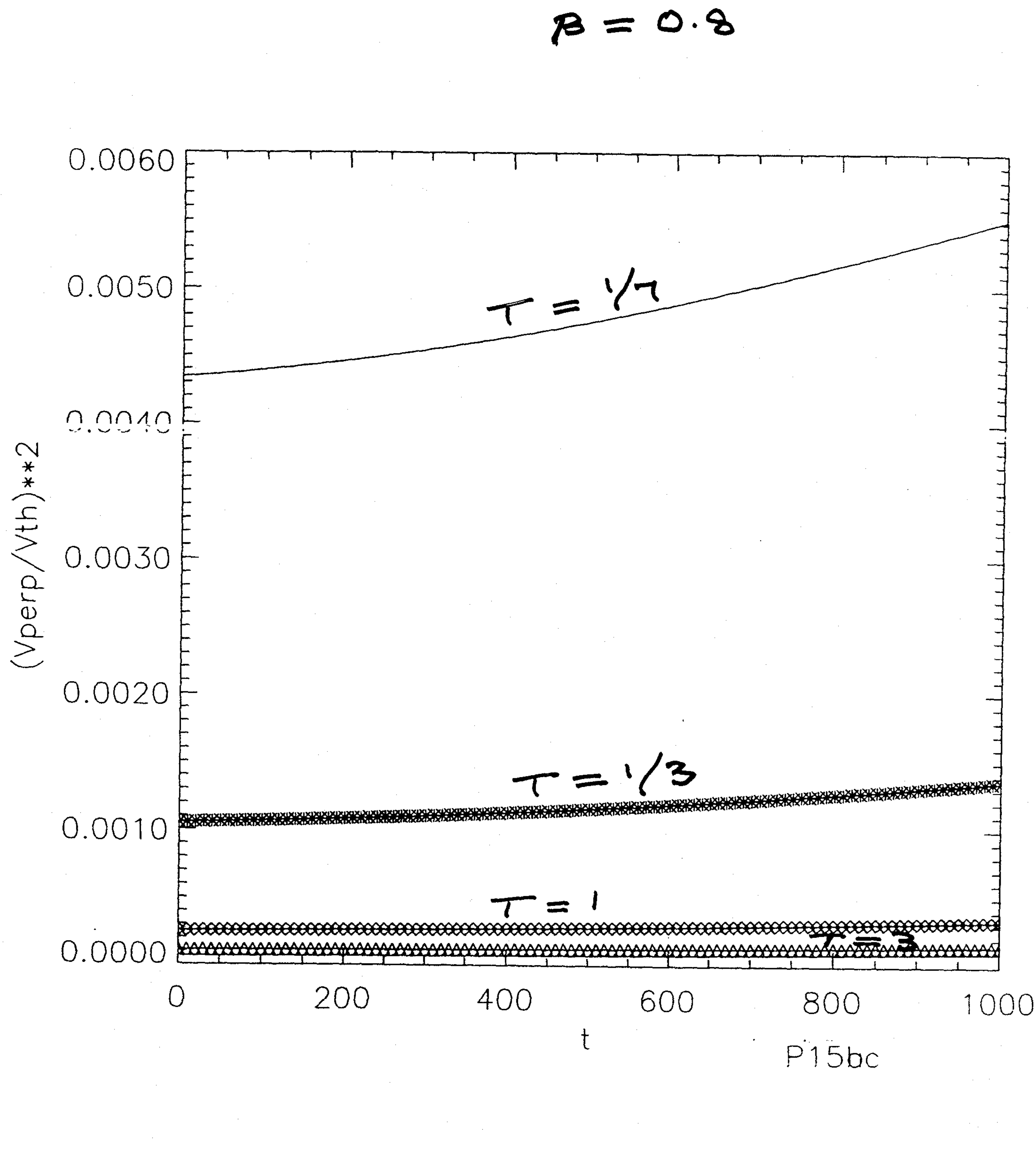


$$v_g = \partial\omega/\partial k$$

RHP



R10b

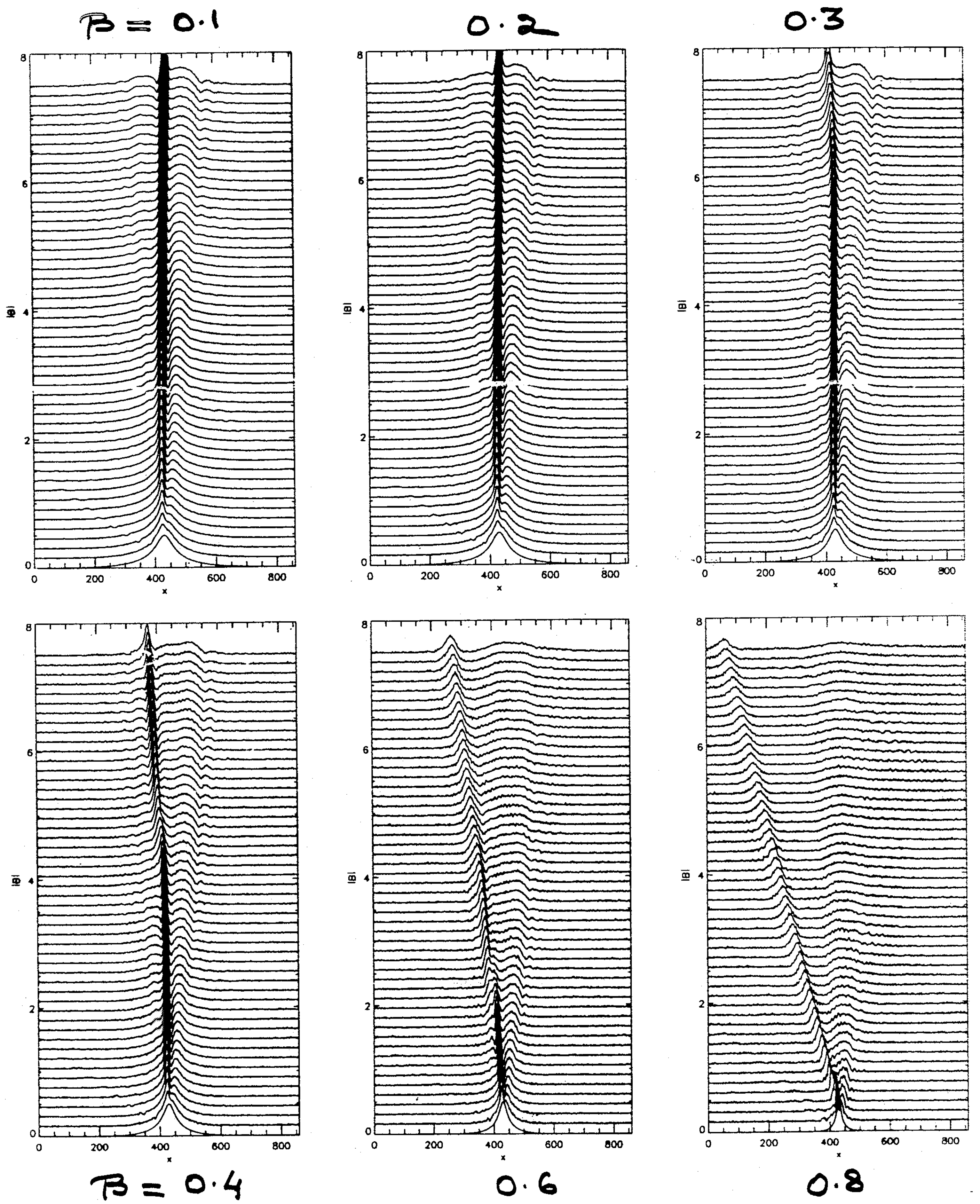


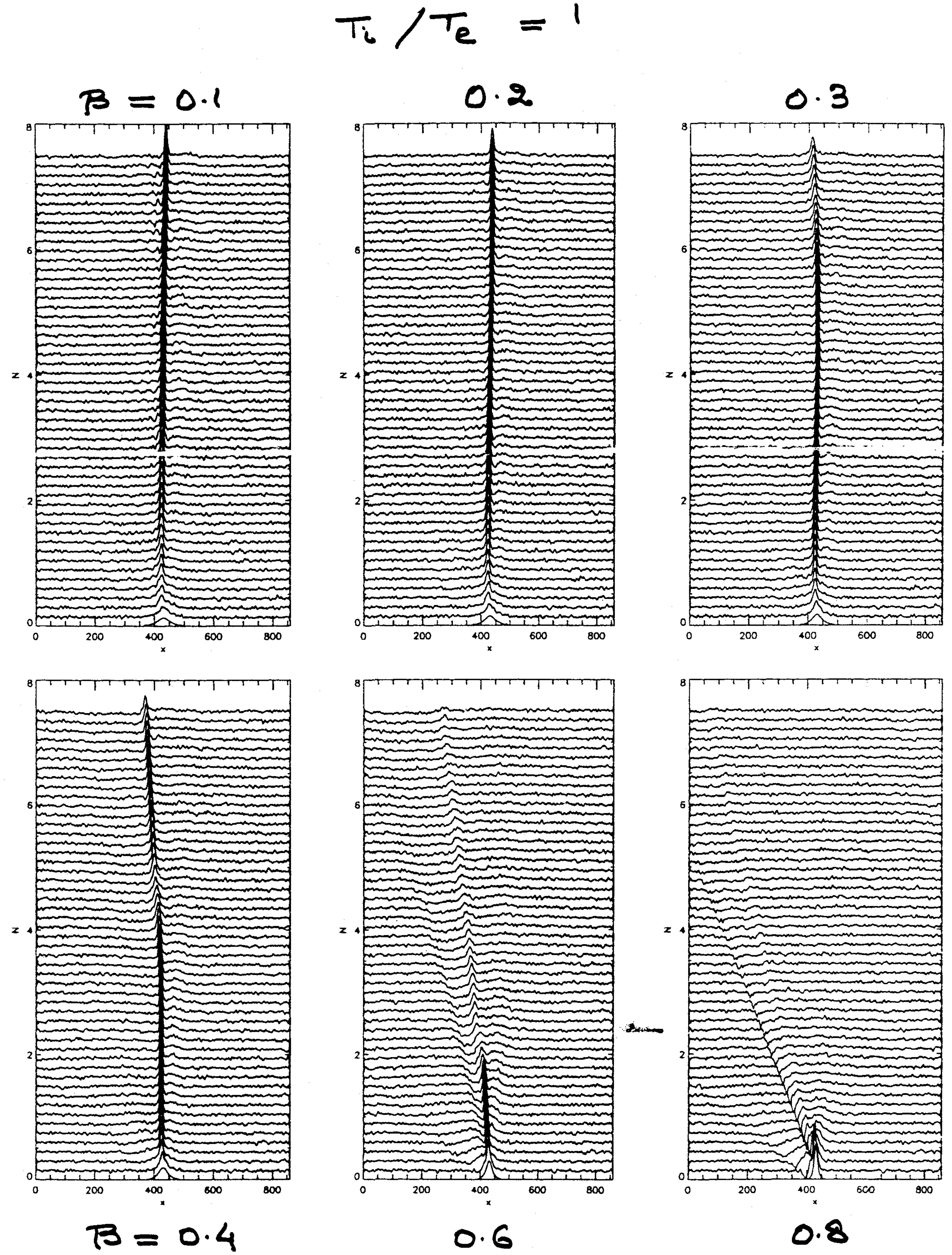
β = 0.8
0.0060
0.0050
0.0040
0.0030
0.0020
0.0010
0.0000
(Vperp/Vth)**2
T = 1/7
T = 1/3
T = 1
T = 3
0
200
400
600
800
1000
t
P15bc

ION HOLES

NONLINEAR LANDAU DAMPING

$T = T_i / T_e = 1$




$T_i / T_e = 1$
$\beta = 0.1$
0.2
0.3
$\beta = 0.4$
0.6
0.8
z
x

LOW FREQ. WAVES

ION DYNAMICS CRUCIAL

ION ACOUSTIC WAVES (IAW)

ALFVÉN WAVES (AW)

EVOLUTION OF IAW:

SMALL AMPLITUDE LINEAR WAVES

$$\omega^2 = k_o^2 V_A^2 \left[\beta_i + \frac{\beta_e}{(1 + k^2 \lambda_D^2)} \right]$$

$$\approx k^2 C_s^2$$

LARGE AMPLITUDE $\Rightarrow$

GOVERNING EQN. — NLS $\Rightarrow$

COMPRESSIVE SOLITARY WAVES

$$\delta N > 0$$

OBSERVATIONS

* DENSITY CAVITIES in AURORAL PLASMA

* SCALE LENGTH for THE CAVITIES VERY SMALL

  (~ a few ELECTON INERTIAL LENGTH)

* PLASMA $\beta << 1$

---

* DENSITY CAVITIES in INTER-PLANETARY MEDIUM ?

* ION DENSITY HOLES WITH SCALE LENGTH ~ a few ION INERTIAL LENGTH

  ||

  ION INERTIAL LENGTH $= V_A / \Omega_i$

* β LARGE

ARE ION HOLES ($\delta N < 0$) FEASIBLE ?

UNDER WHAT CONDITIONS ?

YES

1. IN MULTISPECIES PLASMAS

MODEL : (BUTI, PHYS. LETT., 76A 251, 1980)

a) COLD IONS

b) HOT and COLD ELECTRONS

c) VERY LARGE δN

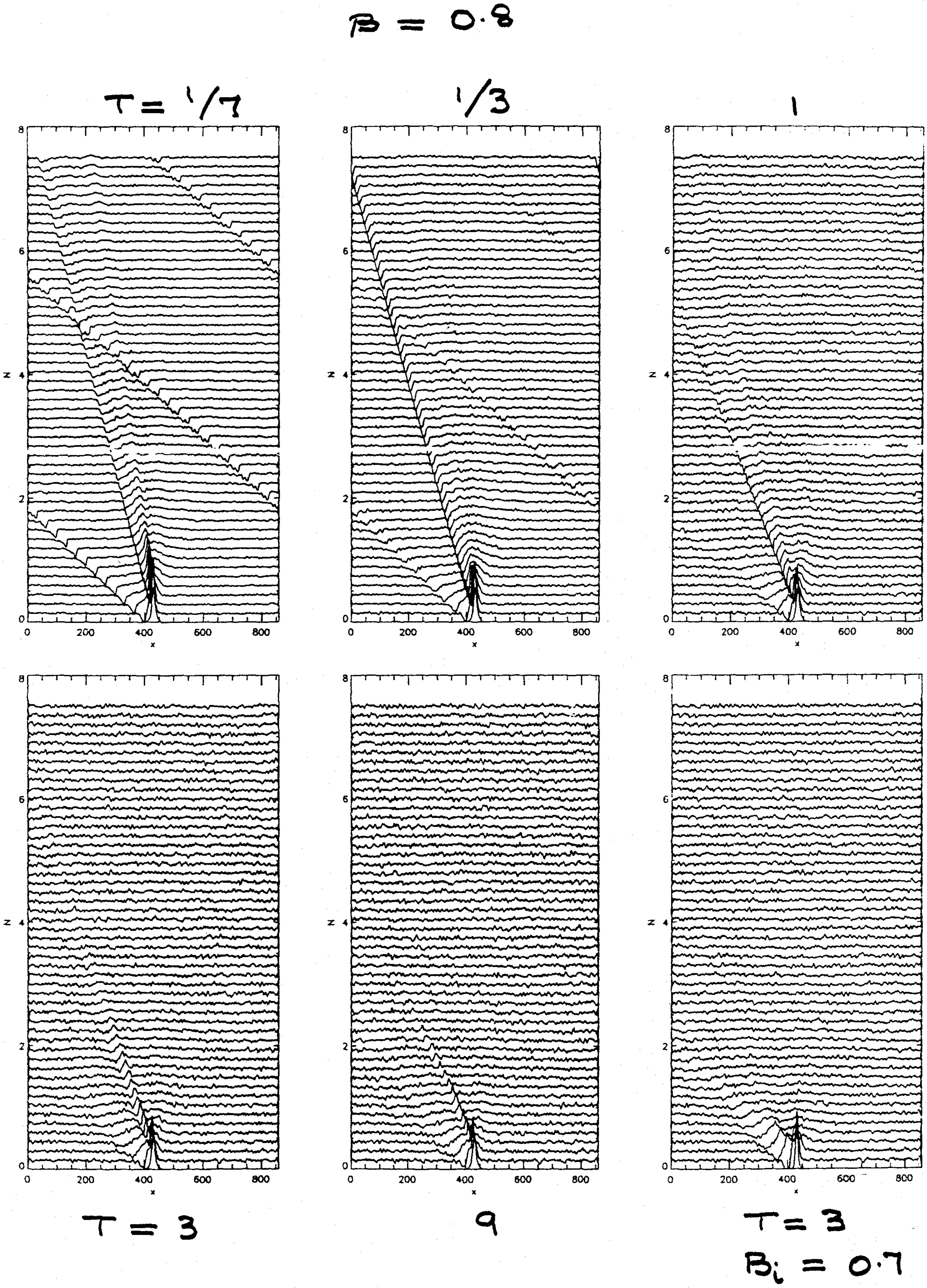
d) $$\left[\frac{N_H T_c^2 + N_c T_H^2}{(N_H T_c + N_c T_H)^2}\right] > 3$$

$$\| $$

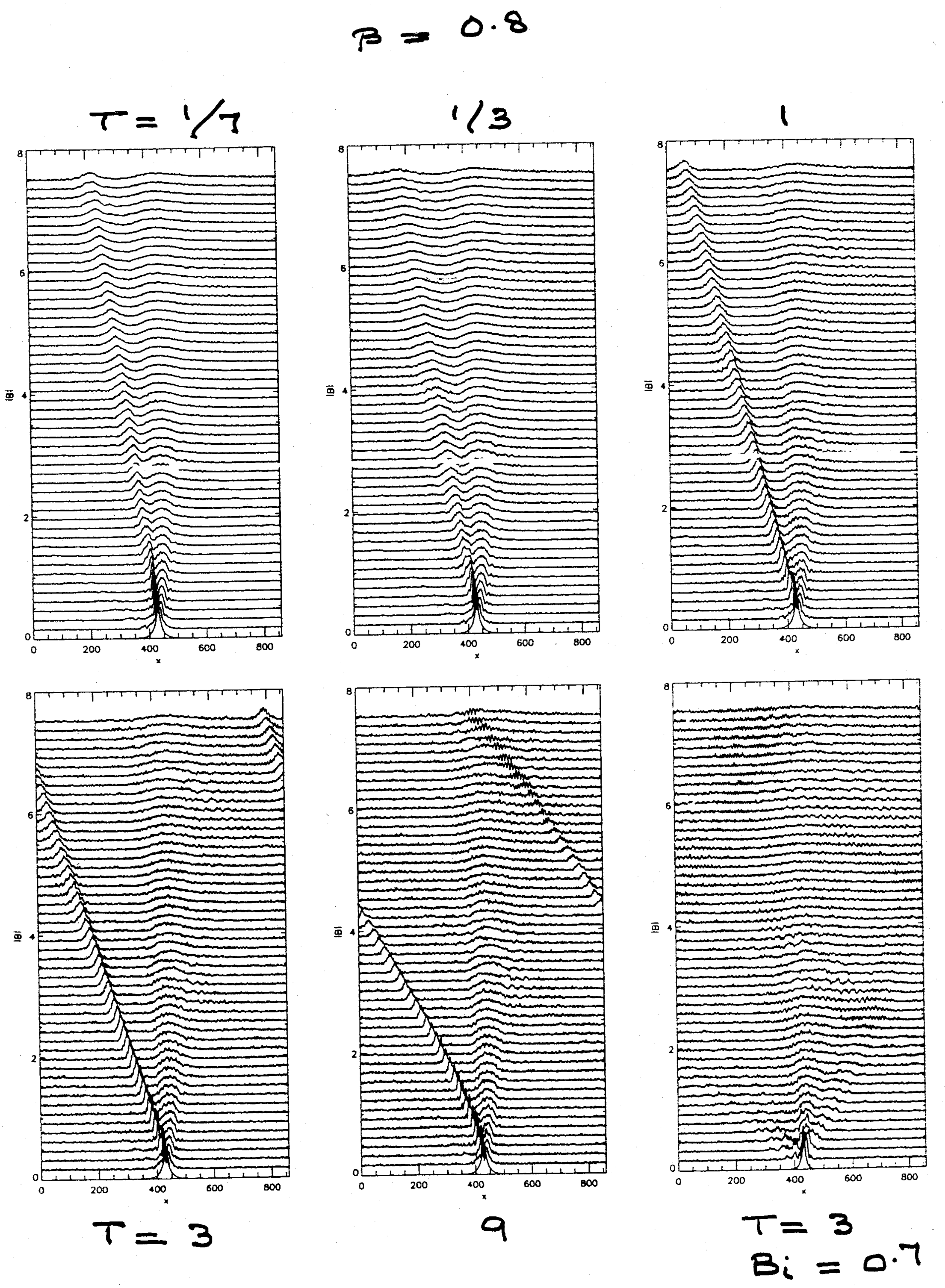
1 for $T_H = T_c$

F8cc30 $N_{H,c} = n_{H,c}/n_0$

$N_H + N_c = 1$



β = 0.8
T = 1/7
1/3
1
T = 3
9
T = 3
B_i = 0.7
z
x
0
200
400
600
800
2
4
6
8



β = 0.8
T = 1/7
1/3
1
|B|
x
T = 3
9
T = 3
B_i = 0.7

Bs	Ti / Te	BP IA HOLES Speed	FP IA HOLES Speed
0.5	1/7	0.61 Va	0.65 Va
0.5	1/3	0.6 Va	0.63 Va
0.5	1	A	0.46 Va
0.5	3	A	A
0.5	9	A	A

Bs	Ti / Te	B Speed (Va)	N Speed (Va)
0.5	1/7	0.83	0.81
0.5	1/3	0.75	A
0.5	1	0.66	A
0.5	3	0.56	0.54
0.5	9	0.32	0.34

0.7	1/3	0.3	A
0.7	9	A	A

CONCLUSIONS

* Governing Evolution Equation for Nonlinear ALFVEN Waves is DNLS / MDNLS

* DNLS $\Rightarrow$ Stable Solitary Waves

* Inhomogeneities destroy the coherent structures

* Driven DNLS can $\Rightarrow$ Chaos

* Chaotic Route to Turbulence with k^{-1} spectra

* For $\beta \approx 1$ and $\delta B / B \approx 1$ Simulations needed

MHD SIMULATIONS :

* δN and δB coupling very significant

* Evolution of RHP Alfvenic Wave Packet very different than LHP Wave Packet

* LHP $\Rightarrow$ Blow - up
  RHP $\Rightarrow$ Steepening and High Frequency Radiations

HYBRID SIMULATIONS :

* For Large β, δN - δB coupling as well as Wave - Particle interactions very crucial

1. LHP EVOLUTION:

* Blow - up observed in LHP case in MHD Simulations arrested by Kinetic Effects

* COLLAPSE $\Rightarrow$ Transport of Energy to larger k

* Appearance of Turning Point due to Structural Instability in the evolution of LHP

* Turning Point function of β and the initial amplitude of the Wave Packet

* At the Turning Point LHP $\Rightarrow$ RHP

* Ion Acoustic Waves (Coherent Ion Holes) generated for $T_e > T_i$

* For $T_e >> T_i$, forward and backward (in inertial frame) propagating Ion Holes

* Nonlinear Landau damping for $T_e \leq T_i$

* Forward propagating Magnetosonic waves in some cases

2. RHP EVOLUTION :

* High - Frequency Radiations for relatively lower β
* Only Backward Propagating Ion Holes
* No Magnetosonic waves generated
* More robust compared to LHP

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