Instabilities in the Earth's bow shock associated with electron nongyrotropy

[1,2]Márcio A. E. de Moraes and [1]Maria V. Alves

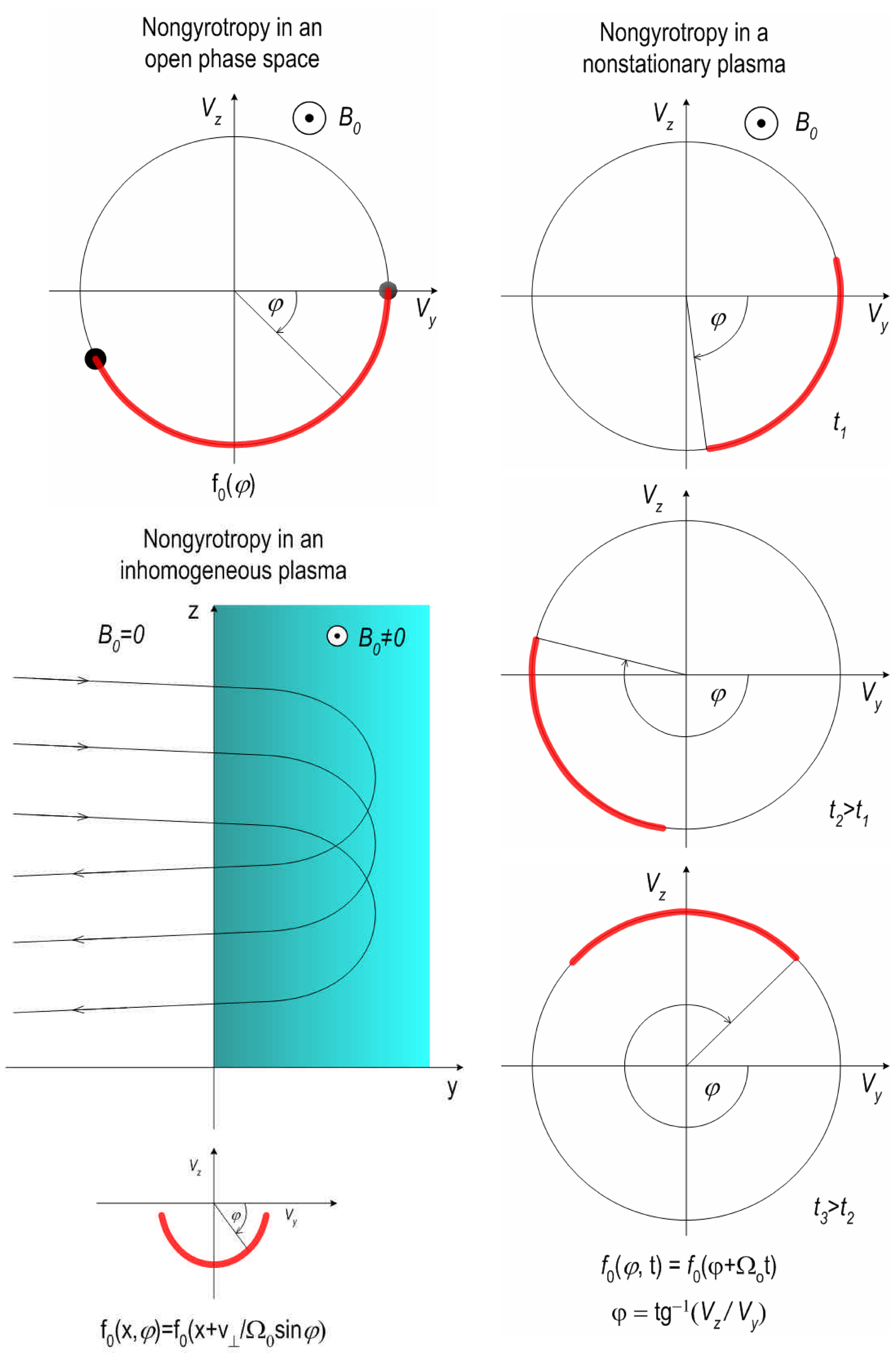
[1]INPE-Instituto Nacional de Pesquisas Espaciais, São José dos Campos-SP, Brasil

[2]UNITAU-Universidade de Taubaté, Taubaté-SP, Brasil

Abstract

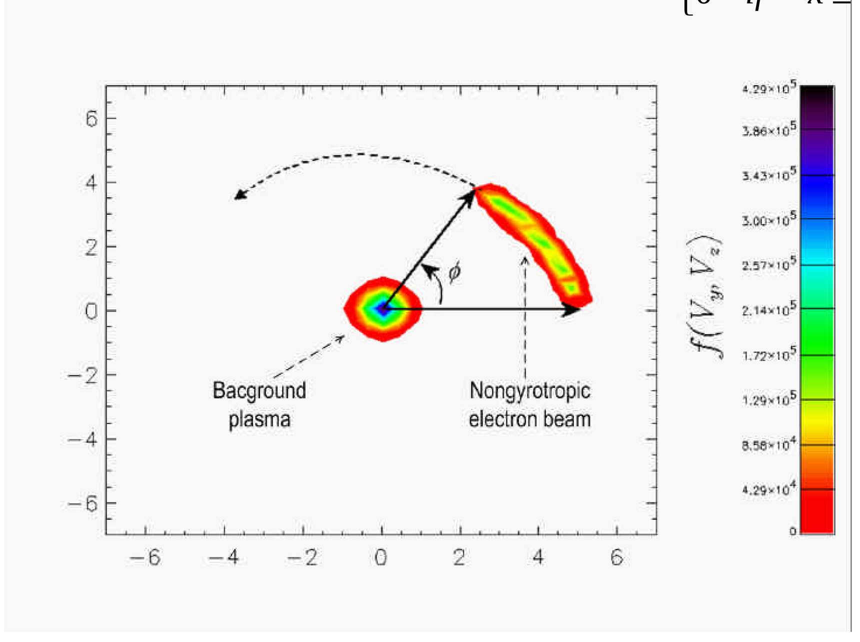
Particle observations in space plasma have shown that high energy particles have some degree of gyrophase organization. Namely, the velocity distributions of the particle populations in the plane perpendicular to the ambient magnetic field depend on the gyrophase angle (Brinca et al., 1992). Several groups have reported the existence of the gyrophase-bunched ions in the Earth's bow shock. This type of event may be explained by the reflection of the incoming solar wind ions by the bow shock, where the displacement of the particle guiding center with respect to the interplanetary electric field can create large perpendicular accelerations which gyrophase bunch the solar wind ions. In contrast, a few observational papers exist in the literature on the electron nongyrotropy from the Earth's bow shock. The importance of nongyrotropy electron distributions in the upstream is not fully understood. It is possible that they may be the source of the upstream ion acoustic wave emissions. Discussions about the processes that generate this type of wave in the upstream of the Earth's bow shock are still open (Gurgiolo et al., 2000). In this paper we solve numerically the nongyrotropic parallel dispersion equation using observational data that show a component of phase-bunched electrons upstream from the Earth's bow shock (Anderson et al., 1985). To anticipate the nongyrotropic behavior, we solve numerically the gyrotropic parallel dispersion equation that shows two potential regions of strong coupling when the electron nongyrotropy is introduced. Solutions of the nongyrotropic parallel dispersion equation show instabilities enhancements and destabilization in the potential regions shown by the gyrotropic dispersion relation.

Types of nongyrotropy distribution functions



Beam-arc distribution

$$\Phi(x)=U(x)-U(x-p/3.67) \qquad U(x-x_0)=\begin{cases}1 & if \quad x\geq x_0\\ 0 & if \quad x\leq x_0\end{cases}$$



Dispersion and coupling

Dispersion equation to Maxwellian distribution function

Gyrotropic $\rightarrow f_{0l}(v_x,v_\perp)=Maxw(v_{tl},V_{dl},A_l)=\dfrac{1}{A_l(\sqrt{p}\,v_{tl})^3}e^{-(v_x-V_{dl})^2/v_{tl}^2}e^{-v_\perp^2/(A_l v_{tl}^2)}$

Nongyrotropic $\rightarrow f_{0b}(v_x,v_\perp)=2p\,Maxw(v_{tl},V_{dl},A_l)\Phi(j+\Omega_b t)$

$$Det\begin{pmatrix} m_{++} & m_{+x} & m_{+-}\\ m_{x+} & m_{xx} & m_{x-}\\ m_{-+} & m_{-x} & m_{--}\end{pmatrix}=0$$

$$m_{++}=k^2c^2-w^2-\sum_j w_{pj}^2\left[\frac{(w-kV_{dj})}{kv_{tj}}Z(x_{j1})-\frac{1}{2}(A_j-1)Z'(x_{j1})\right]$$

$$m_{+x}=\frac{\sqrt{p\,A_b}}{4}ww_{pb}^2\frac{\Phi_1}{kv_{tb}}Z'(x_b) \qquad m_{+-}=\frac{\Phi_2}{2}A_b w_{pb}^2\frac{w}{(w-2\Omega_b)}Z'(x_b)$$

$$m_{x+}=-\frac{\sqrt{p\,A_b}}{2}\frac{w_{pb}^2}{w}\frac{\Phi_{-1}}{kv_{tb}}Z'(x_b) \qquad m_{xx}=1-\sum_j\frac{w_{pj}^2}{kv_{tj}^2}Z'(x_{j2})$$

$$m_{x-}=-\frac{\sqrt{p\,A_b}}{2}\frac{w_{pb}^2}{(w-2\Omega_b)}\frac{\Phi_1}{kv_{tb}}Z'(x_b) \qquad m_{-+}=\frac{\Phi_{-2}}{2}A_b w_{pb}^2\frac{(w-2\Omega_b)}{w}Z'(x_b)$$

$$m_{x-}=\frac{\sqrt{p\,A_b}}{2}(w-2\Omega_b)w_{pb}^2\frac{\Phi_{-1}}{kv_{tb}}Z'(x_b)$$

$$m_{--}=k^2c^2-(w-2\Omega_b)^2-\sum_j w_{pj}^2\left[\frac{(w-2\Omega_b-kV_{dj})}{kv_{tj}}Z(x_{j3})-\frac{1}{2}(A_j-1)Z'(x_{j3})\right]$$

$$x_{j1}=\frac{w-\Omega_j-kV_{dj}}{kv_{tj}} \qquad x_{j2}=\frac{w-kV_{dj}-\Omega_b}{kv_{tj}} \qquad x_{j3}=\frac{w-\Omega_j-kV_{dj}-2\Omega_b}{kv_{tj}}$$

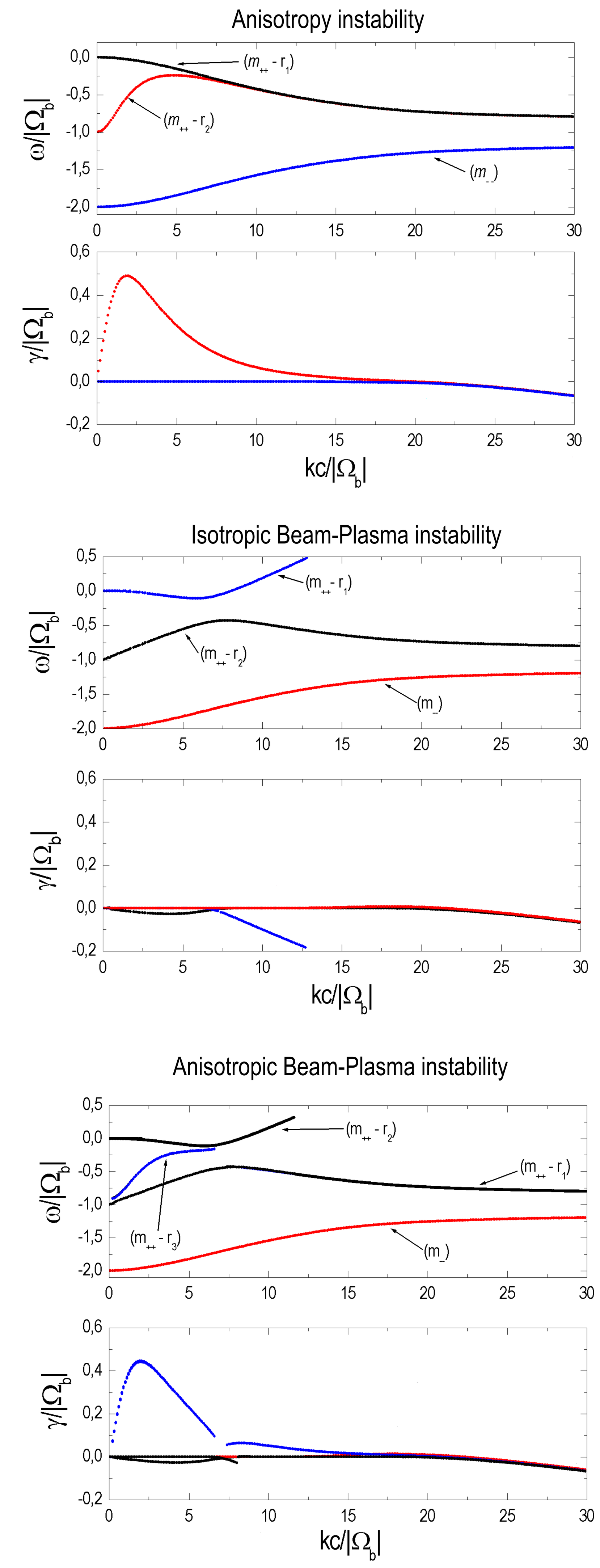
$$Z'(x)=-2[1+x\,Z(x)] \qquad x_b=x_{b1}=x_{b2}=x_{b3}$$

Plasma Parameters

Parameter	Value	Parameter	Value
ω_{pe}	11.35	v_{tb}	0.0146
ω_{pb}	2.54	V_{de}	0.0
ω_{pi}	0.26	V_{di}	0.0
Ω_e	-1.0	V_{db}	0.1066
Ω_b	-1.0	A_e	1.0
Ω_i	0.0005	A_i	1.0
v_{te}	0.0058	A_b	4.0
v_{ti}	0.00013	C	1.0

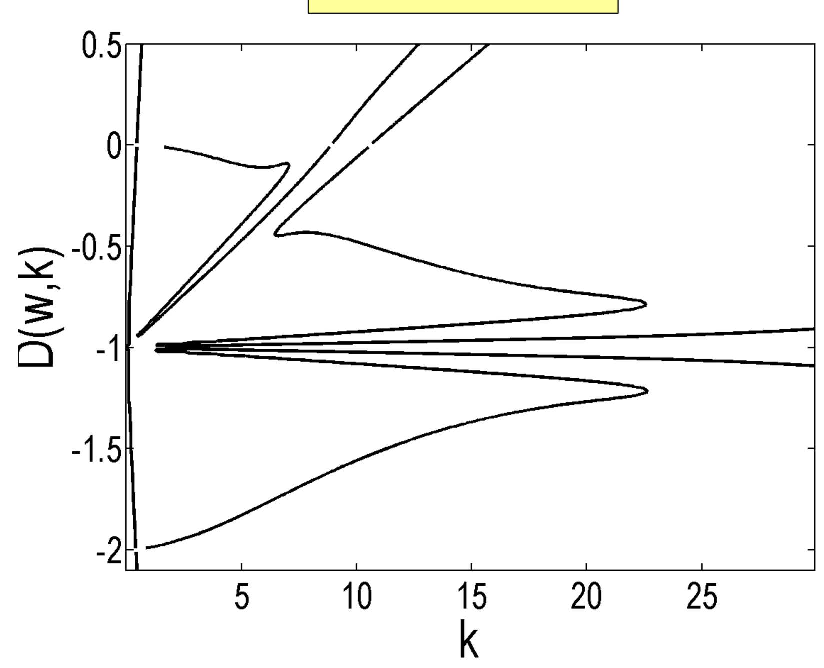
(frequencies normalized by $|\Omega_b|$ and velocities by light speed)

Gyrotropic dispersion



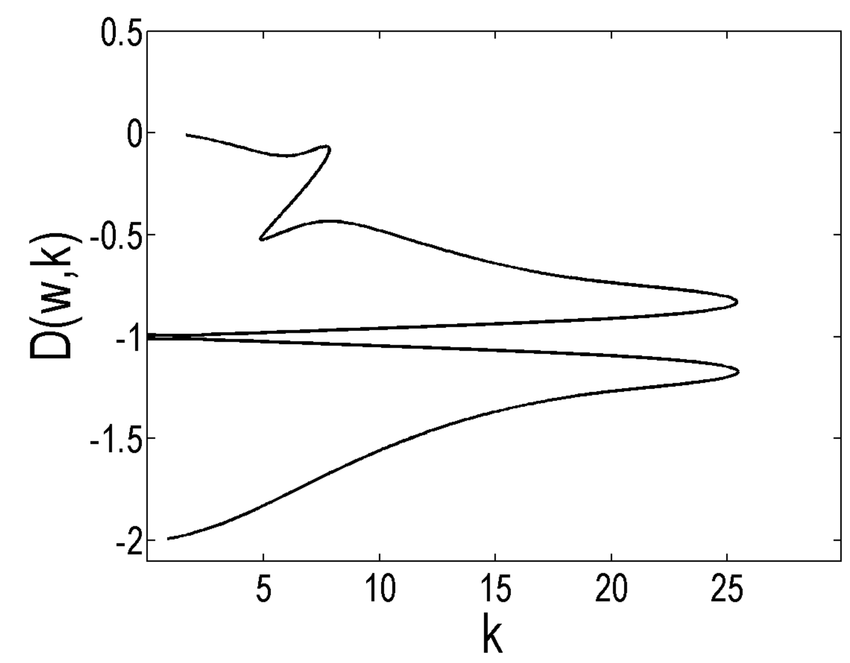
Electrostatic and electromagnetic coupling

$$\Phi(x)=d(x)$$



Electromagnetic coupling

$$\Phi(x)=[d(x)+d(x+p)]/2$$



Acknowledgments

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