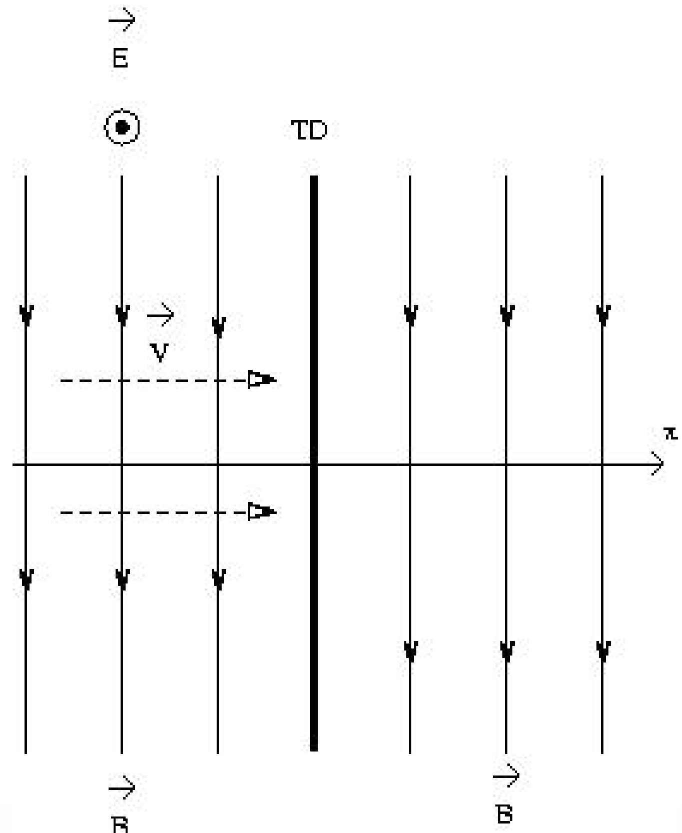
Decoupling of a diamagnetic plasma blob from background magnetic field and plasma

Marius M. Echim

Belgian Institute for Space Aeronomy, Brussels

Institute for Space Sciences, Bucharest



- momentum conservation - one fluid (CGL) approximation :

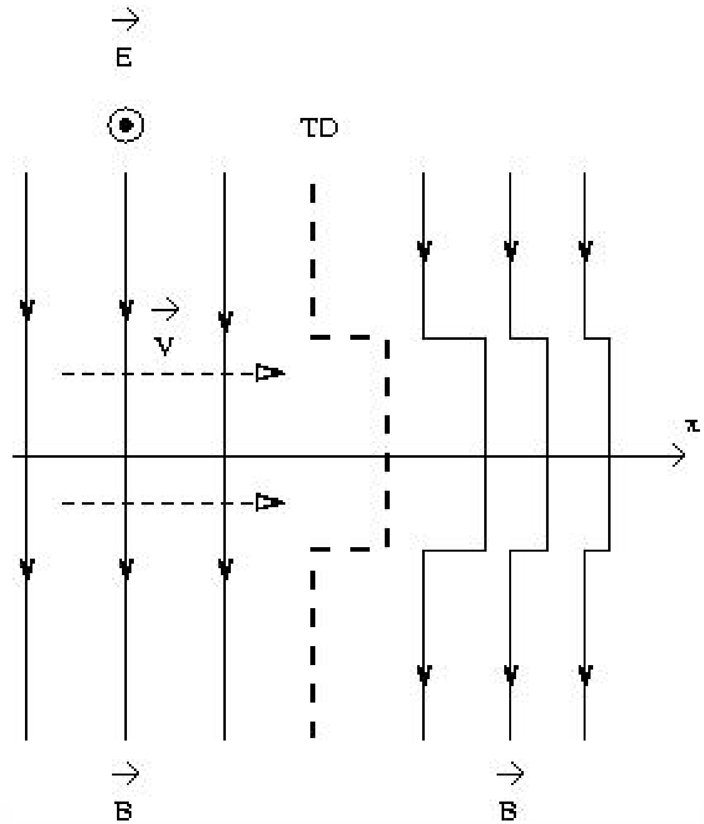
$$\frac{\partial\left(\rho \boldsymbol{U}\right)}{\partial t} = -\boldsymbol{\nabla}\cdot\left[\left(\rho \boldsymbol{U}\boldsymbol{U}\right) + \left(p + \frac{B^2}{2\mu_0}\right)\Im - \frac{1}{\mu_0}\boldsymbol{B}\boldsymbol{B}\right]$$

- "frozen-in" condition :

$$\boldsymbol{E} + \boldsymbol{U}\times\boldsymbol{B} = 0, \qquad E_{parallel} = 0$$

- Faraday law :

$$\frac{\partial \boldsymbol{B}}{\partial t} + \boldsymbol{\nabla}\times\left(\boldsymbol{U}\times\boldsymbol{B}\right) = 0$$



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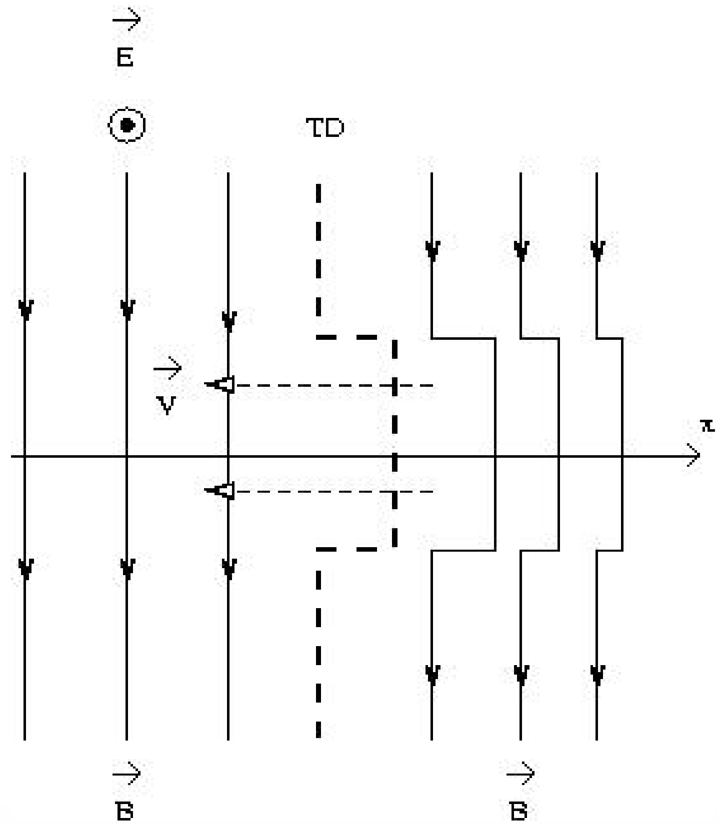

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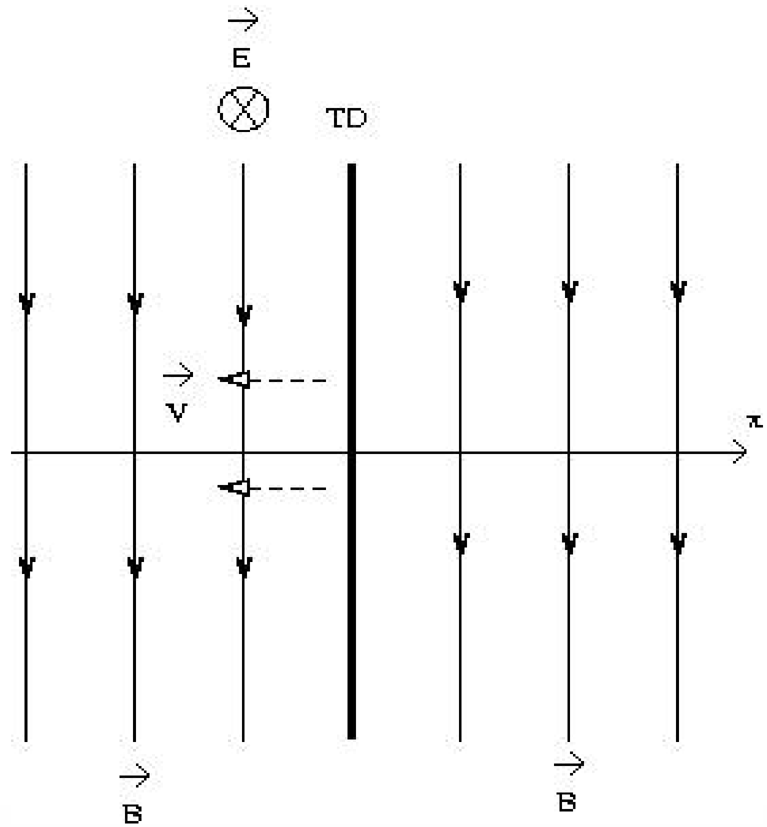

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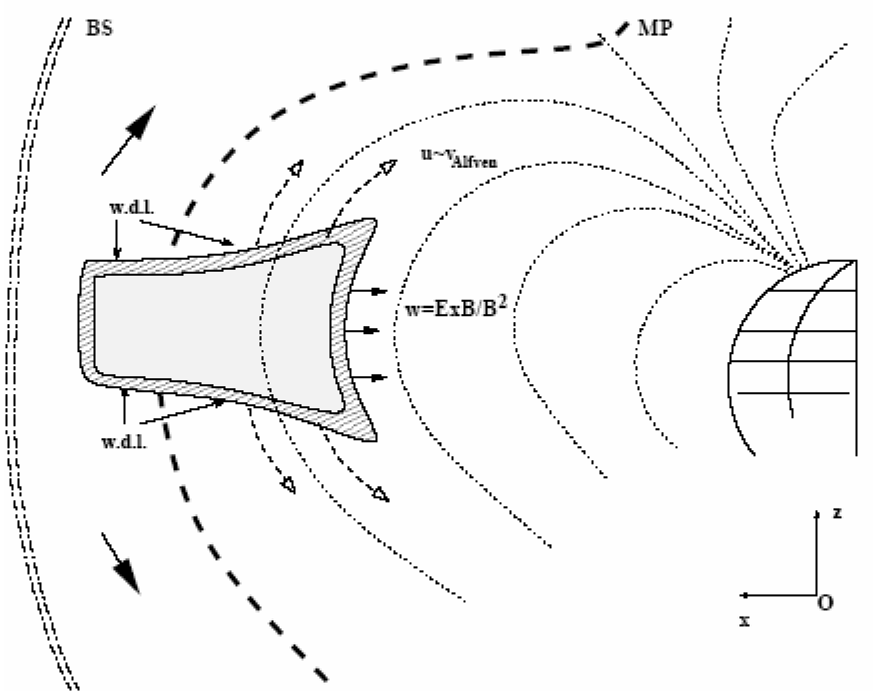
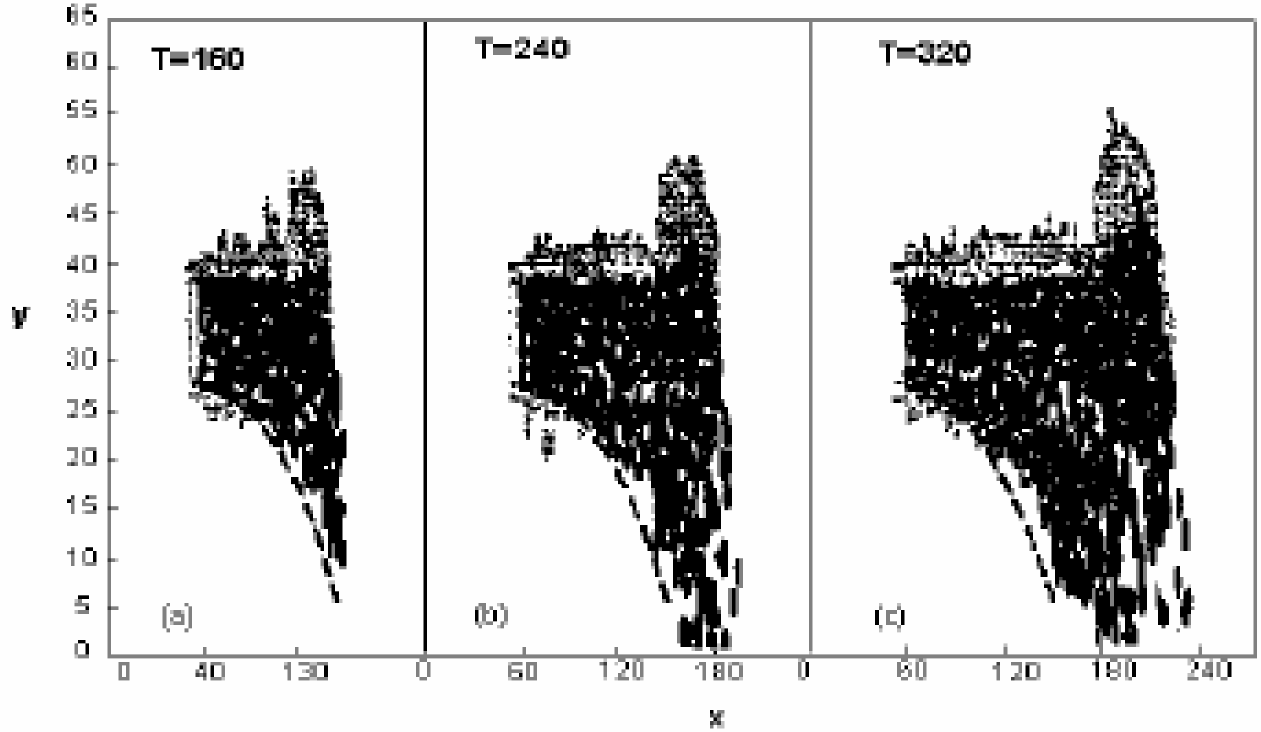


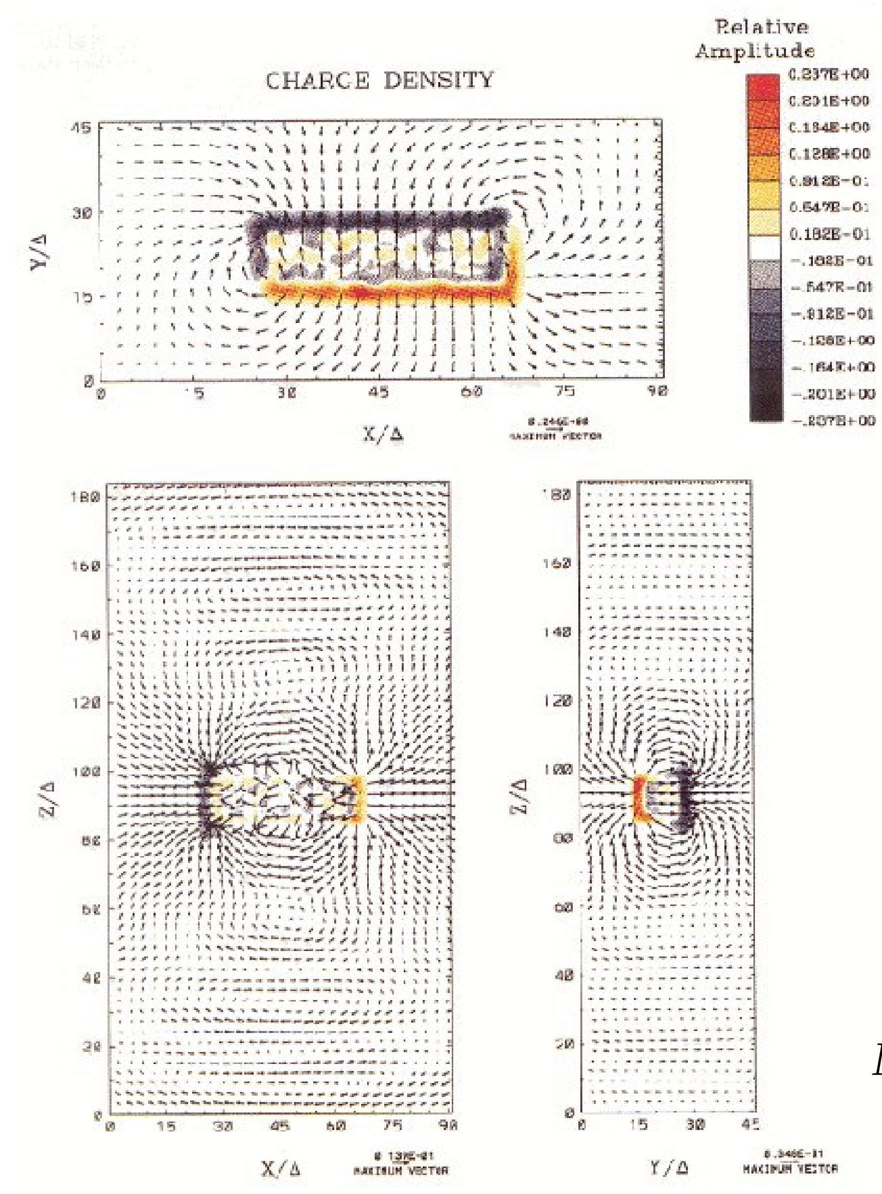
Echim and Lemaire (2002)

- Liouville theorem for f_α
- Maxwell's equations for $\boldsymbol{B}$ and $\boldsymbol{E}$
- localized plasmoid $\longrightarrow$ excess of momentum flux density:

$$\Delta\overline{\overline{P}}_\alpha = m_\alpha \Delta n_\alpha \boldsymbol{V}_\alpha \boldsymbol{V}_\alpha + m_\alpha n_\alpha \Delta\left(\boldsymbol{V}_\alpha \boldsymbol{V}_\alpha\right) + \Delta\overline{\overline{p_\alpha}}$$



Livesey and Pritchett (1989)



Neubert et al., (1992)

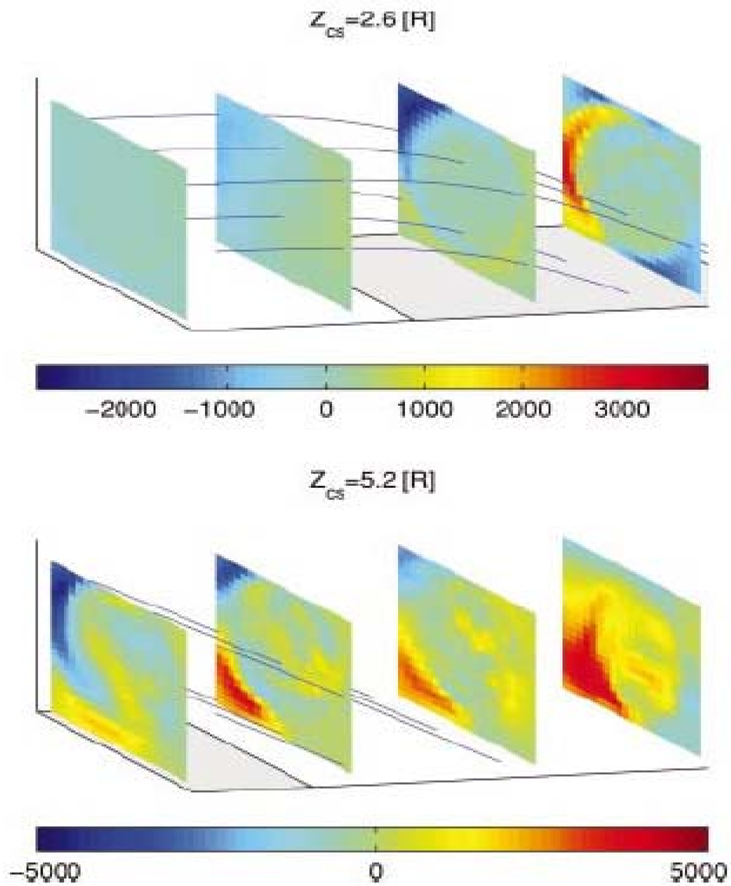


FIG. 12. (Color) Electric field components parallel to the magnetic field, in units V/m. Top panel: the front half of the plasma is inside the transition region. Bottom panel: the whole plasma has passed the transition region. Positive fields are directed to the lower right.

Hurtig, Brenning, Raadu.,(2003)

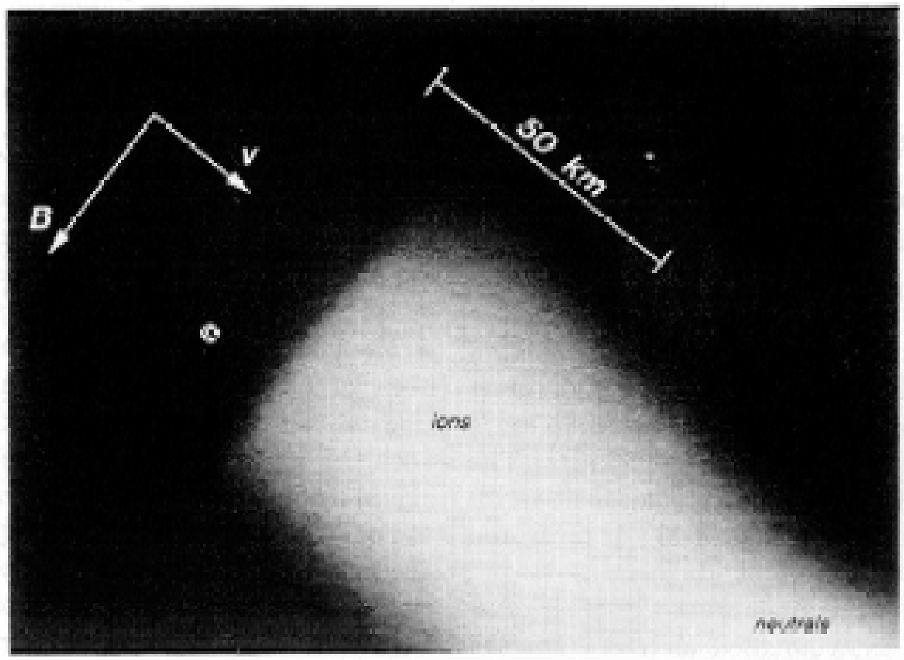


Figure 1. Intensified unfiltered CCD TV image of the G9 release 20 s after the release (aircraft 127). The edge of the ion cloud is not at the release point (marked with cross) but has "skidded" 18 km along the orbit track.

Delamere et al., 1996

Kinetic treatment of 2D sheared flows

- stationary Vlasov equation for plasma state:

$$
\begin{aligned}
v_y \frac{\partial f_\alpha}{\partial y} + v_z \frac{\partial f_\alpha}{\partial z} - \frac{q_\alpha}{m_\alpha}\left[v_y\left(\frac{\partial A_x}{\partial y}\right) + v_z \frac{\partial A_x}{\partial z}\right]\frac{\partial f_\alpha}{\partial v_x} - \\
\frac{q_\alpha}{m_\alpha}\left[\frac{\partial \Phi}{\partial y} - v_x\left(\frac{\partial A_x}{\partial y}\right)\right]\frac{\partial f_\alpha}{\partial v_y} - \\
\frac{q_\alpha}{m_\alpha}\left(\frac{\partial \Phi}{\partial z} - v_x \frac{\partial A_x}{\partial z}\right)\frac{\partial f_\alpha}{\partial v_z} &= 0
\end{aligned}
$$

- Ampere equation for the non-vanishing component of the magnetic potential, $A_x(y,z)$:

$$
\frac{\partial^2 A_x}{\partial y^2} + \frac{\partial^2 A_x}{\partial z^2} = -\mu_0 j_x(y,z)
$$

- quasineutrality equation for the electric potential, $\Phi(y,z)$

$$
\sum_\alpha q_\alpha n_\alpha(\Phi, A_x) = 0
$$

Echim, 2004

Constants of motion and adiabatic invariants

- steady state problem $\longrightarrow$ the total energy, $\mathcal{H}$, is a constant of motion:

$$\mathcal{H} = \frac{1}{2}m_\alpha\left(v_x^2 + v_y^2 + v_z^2\right) + q_\alpha\Phi(y,z)$$

- x ignorable variable $\longrightarrow$ the canonical momentum, p_x is a constant of motion:

$$p_x = m_\alpha v_x + q_\alpha A_x(y,z)$$

- smooth variations with y and z $\longrightarrow$ the magnetic moment, μ, is an adiabatic invariant:

$$\mu = \frac{m_\alpha\left[(v_x - U_{E0})^2 + v_y^2\right]}{2B}$$

Vlasov Solution

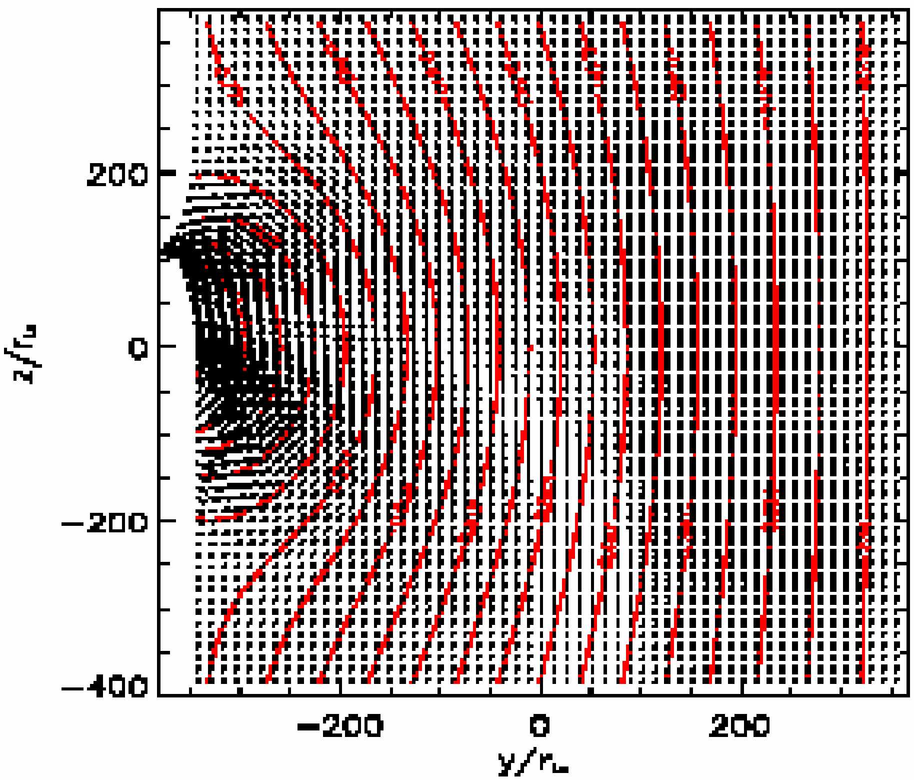
$$f_\alpha(\mathcal{H}, p_x, \mu) = g_{\alpha 1}(p_x) f_{\alpha 1}(\mathcal{H}, p_x) + g_{\alpha 2}(p_x) f_{\alpha 2}(\mathcal{H}, p_x)$$

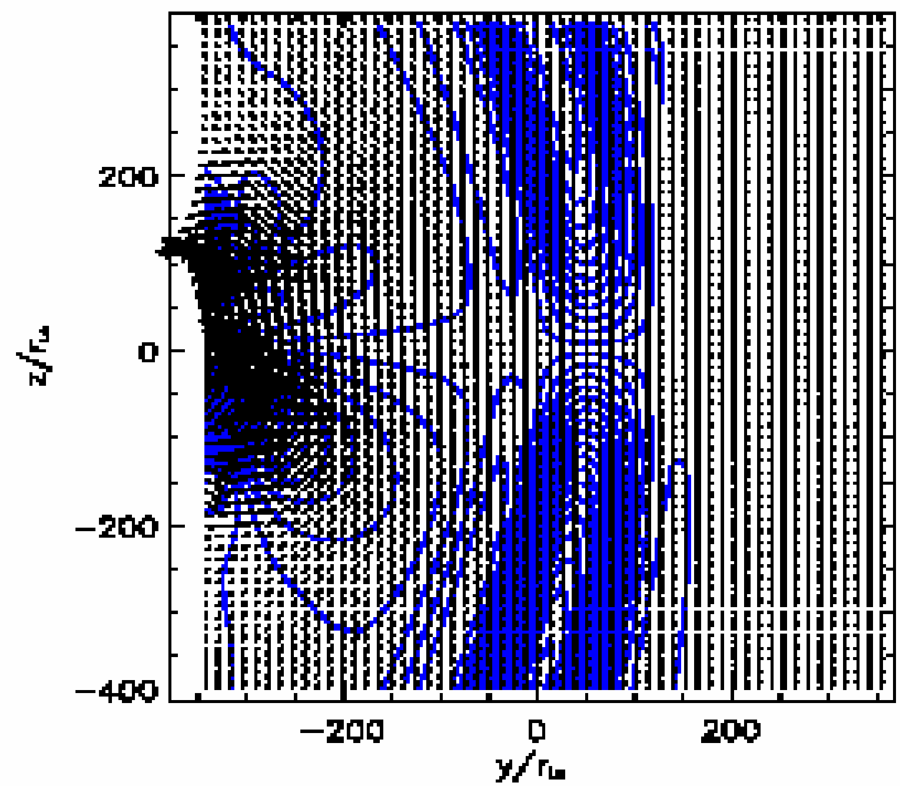
where :

$$f_{\alpha 1}(\mathcal{H}, p_x) = N_{\alpha 1} \left(\frac{m_\alpha}{2\pi \mathcal{K} T_{\alpha 1}} \right)^{\frac{3}{2}} \exp\left(-\frac{\mathcal{H}}{\mathcal{K} T_{\alpha 1}} \right)$$

$$f_{\alpha 2}(\mathcal{H}, p_x) = N_{\alpha 2} \left(\frac{m_\alpha}{2\pi \mathcal{K} T_{\alpha 2}} \right)^{\frac{3}{2}} \exp\left[-\frac{\mathcal{H} - p_x V_0 + \frac{1}{2} m_\alpha {V_0}^2}{k T_{\alpha 2}} \right]$$

Echim & Lemaire (2005)


200
0
−200
−400
z/r
−200
0
200
y/r


200
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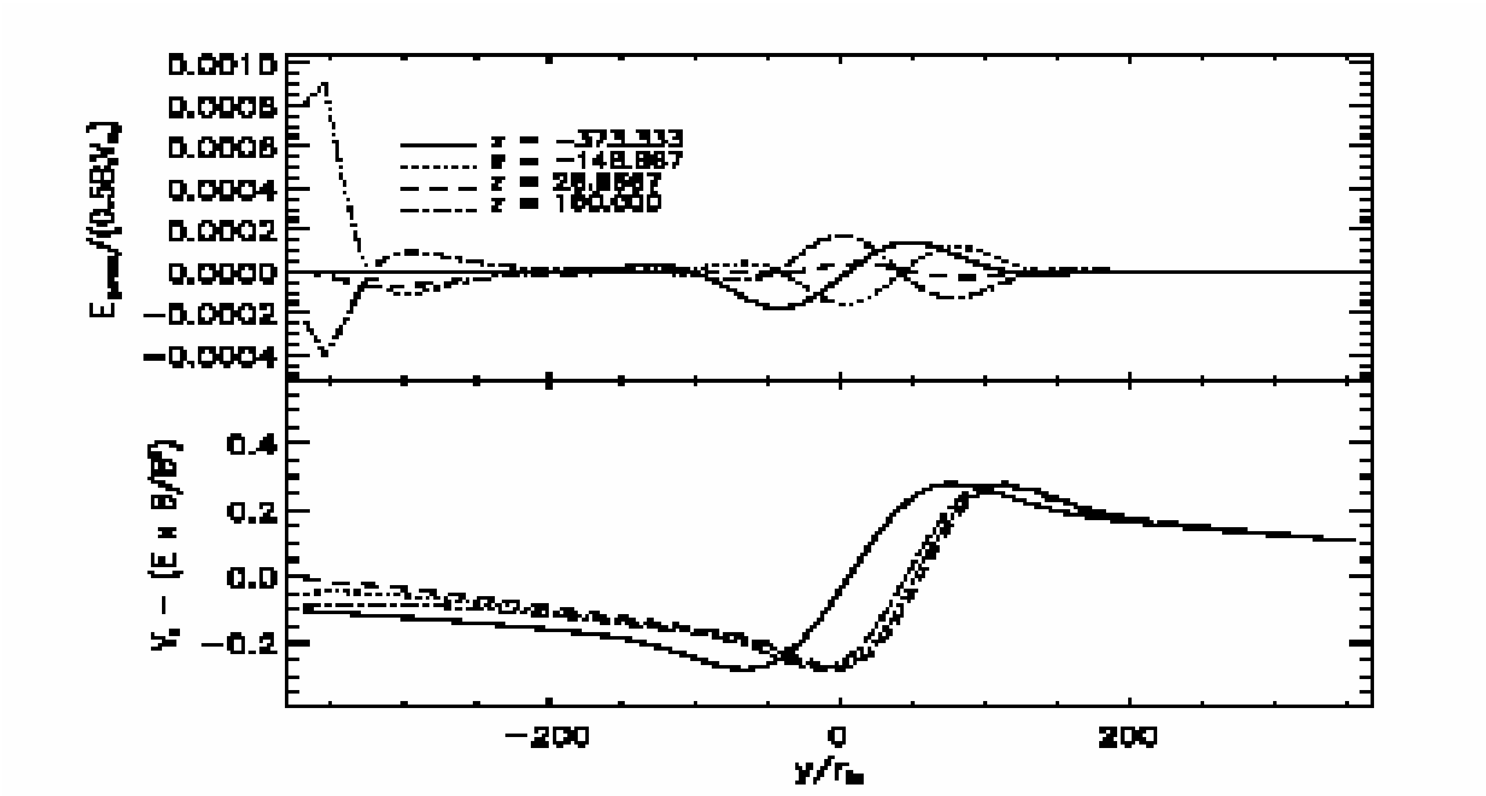
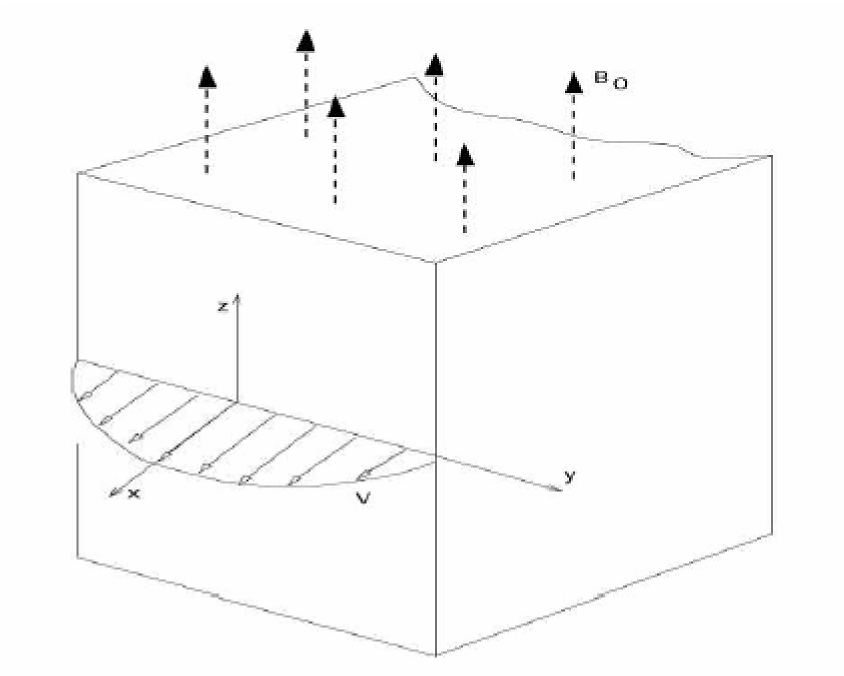
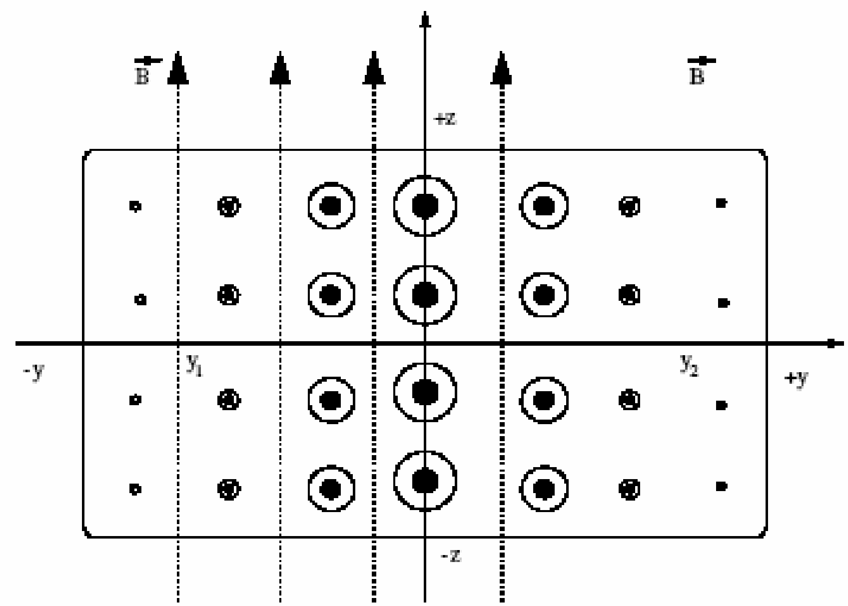
Decoupling of plasma and field in 2D sheared layer







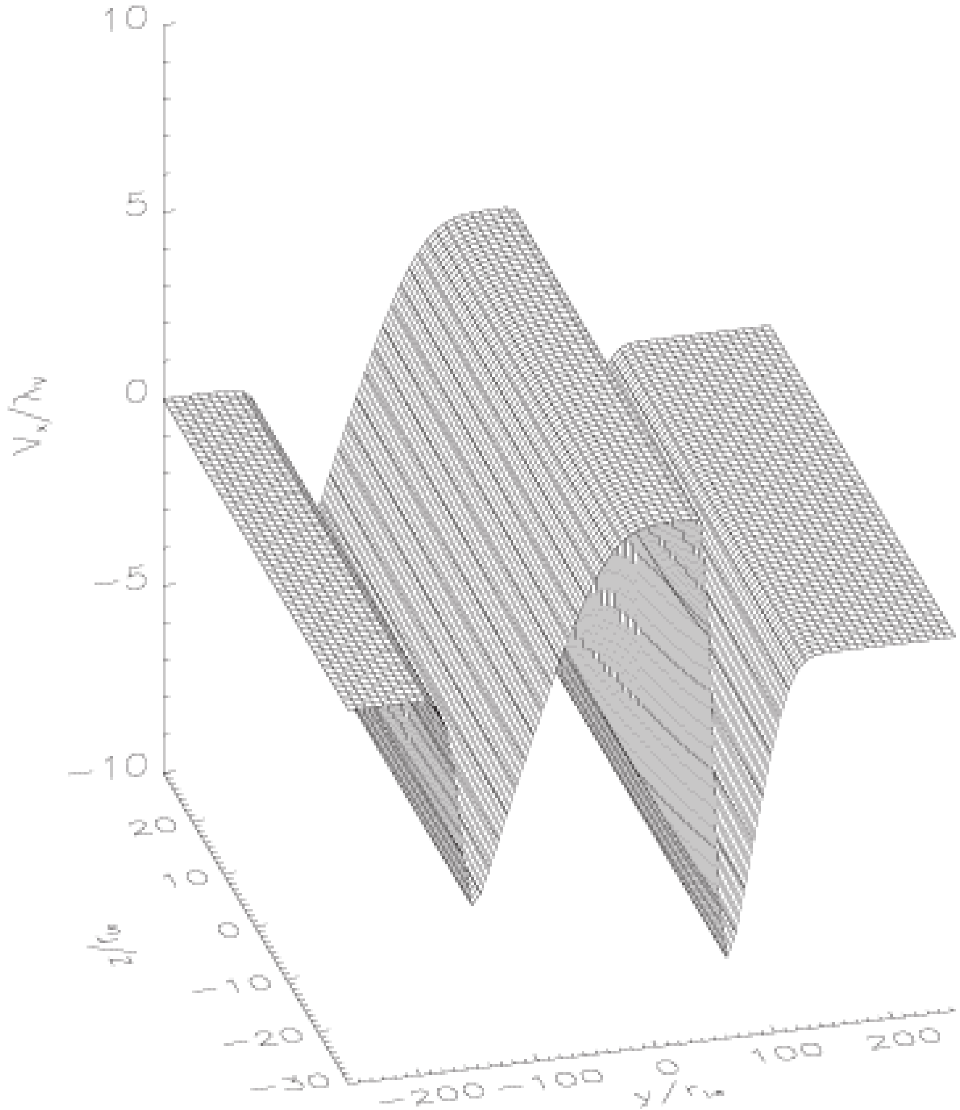
$$f_\alpha(p_x,\mu,H) = g_\alpha(p_x)\, f_{\alpha 1}(p_x,\mu,H) + h_\alpha(p_x)\, f_{\alpha 2}(p_x,\mu,H)$$

where the following functions were defined at $y=0$:

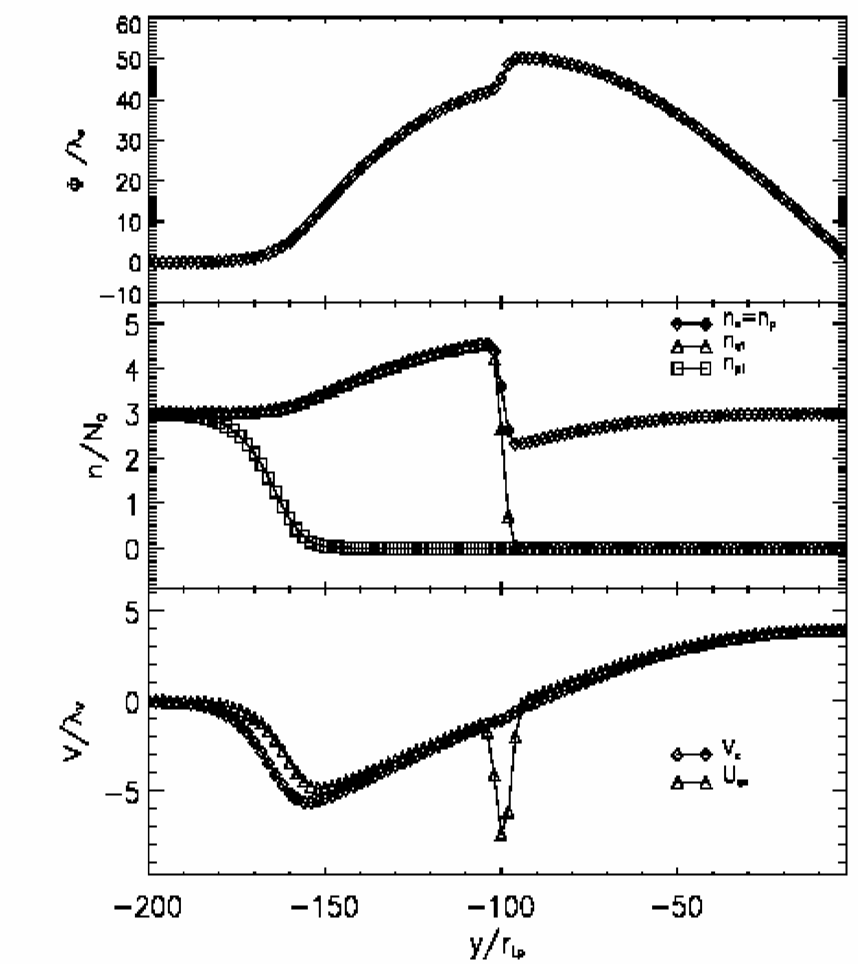
$$\begin{aligned} f_{\alpha 2}(p_x,\mu,H) &= N_{\alpha 2}\left(\frac{m_\alpha}{2\pi K T_{\alpha 2}}\right)^{\frac{3}{2}} e^{-\frac{H - p_x V_0 + \frac{1}{2} m_\alpha V_0^2}{K T_{\alpha 2}}} \\ g_\alpha(p_x) &= \eta\left[sgn(q_\alpha)(p_x - q_\alpha A_{x1})\right] + \eta\left[-sgn(q_\alpha)(p_x - q_\alpha A_{x2})\right] \\ h_\alpha(p_x) &= \eta\left[sgn(q_\alpha)(p_x - q_\alpha A_{x2})\right] - \eta\left[sgn(q_\alpha)(p_x - q_\alpha A_{x1})\right] \end{aligned}$$

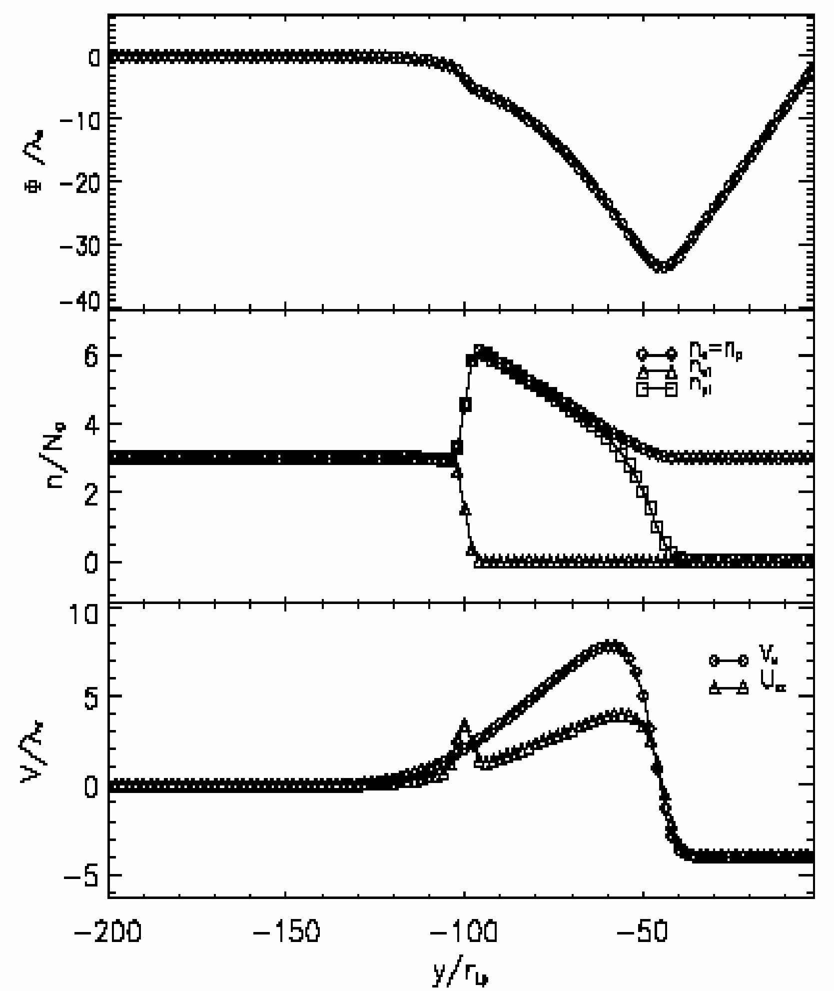
with η the Heaviside step function and sgn the signum function.

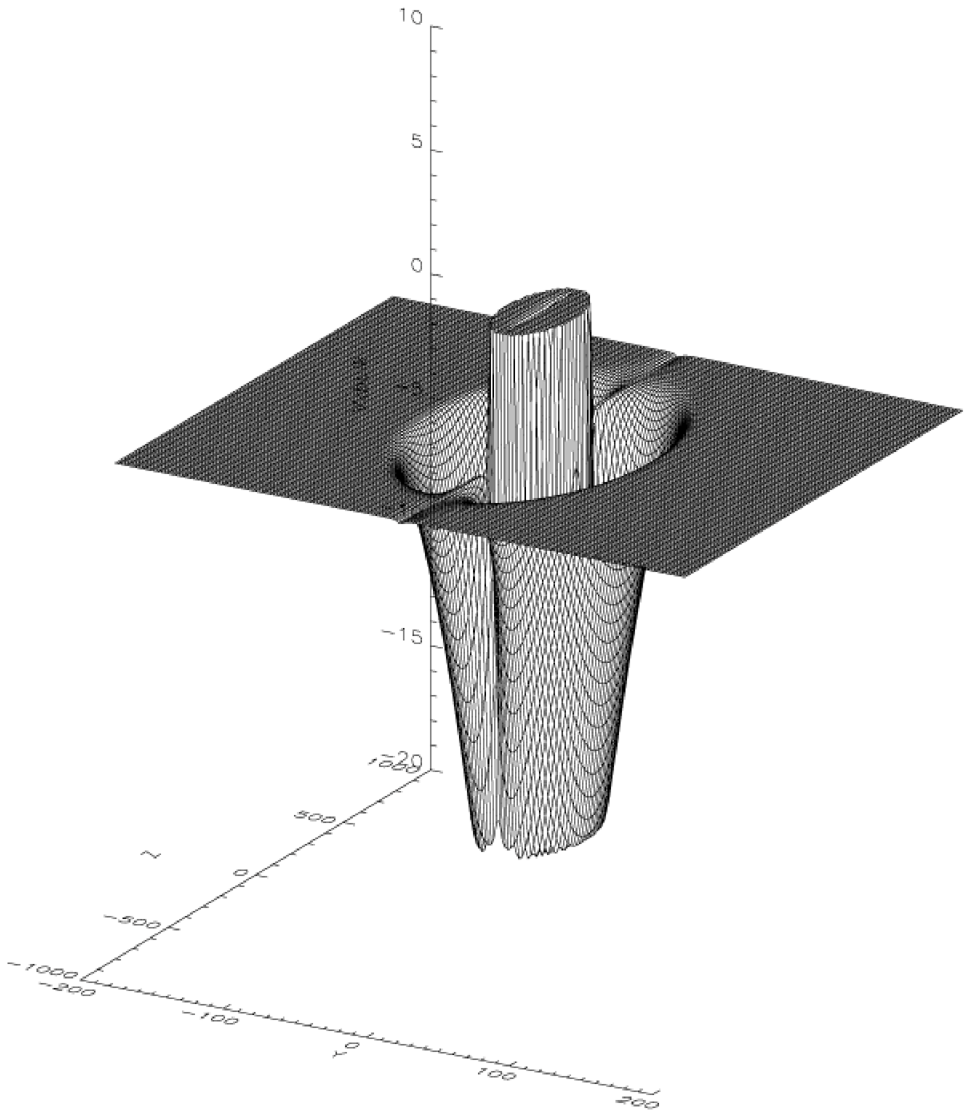
Echim, Lemaire, Roth (2005)



10
5
0
-5
-10
20
10
0
-10
-20
-30
-200
-100
0
100
200


n/N₀
V/λ
−200
−150
−100
−50
y/r


n/N₀
V/λ
−200
−150
−100
−50
y/r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5
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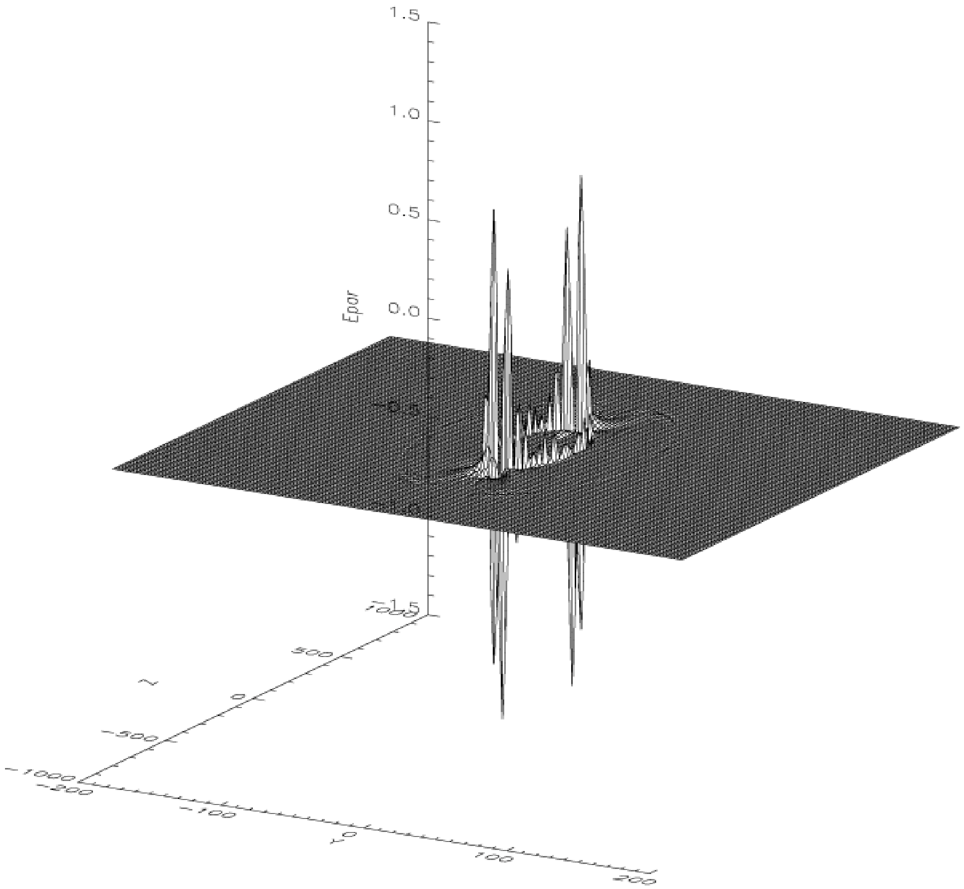
−15
−20
1000
500
0
−500
−1000
Z
−200
−100
0
Y
100
200


Epar
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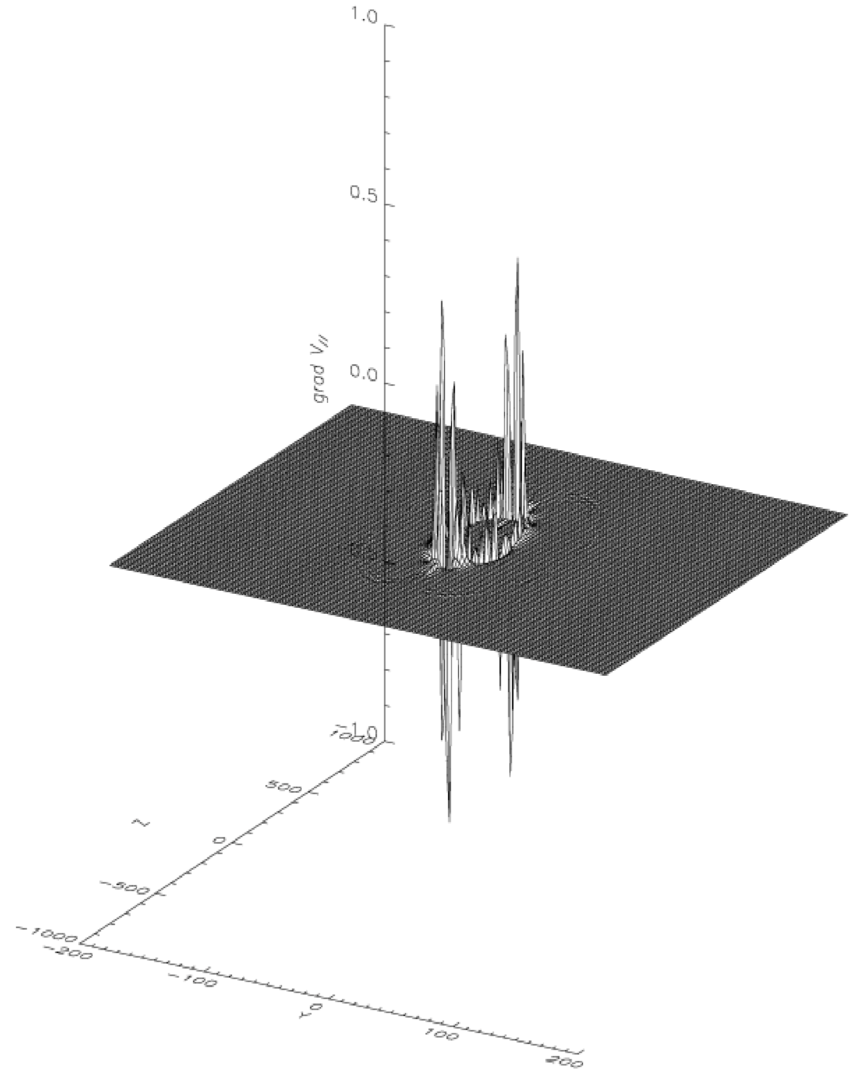
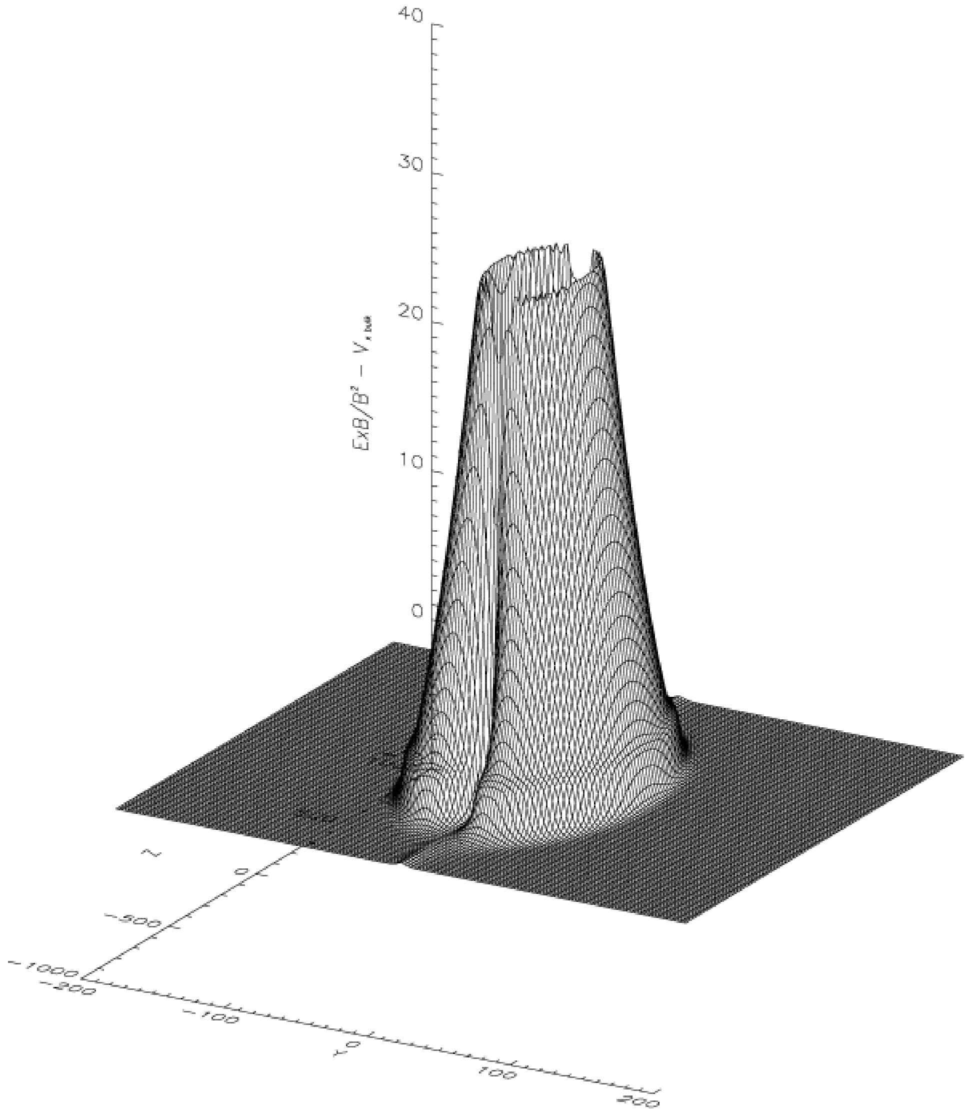
1.0
0.5
0.0
-0.5
-1.0
-1.5
1000
500
0
-500
-1000
Z
-200
-100
0
100
200
Y


grad V//
1.0
0.5
0.0
-0.5
-1.0
1000
500
0
-500
-1000
Z
-200
-100
0
100
200
Y


40
30
20
10
0
$ExB/B^2 - V_{x,bulk}$
Z
0
-500
-1000
-200
-100
Y
0
100
200

Summary

- Experimental and laboratory evidence for "anomalous" transport/skidding/ cross-B motion
- Stationary kinetic solutions found for cross-B transport with shear of perp velocity in the direction of B-field
- Decoupling by a parallel component of the electric field