Vlasov simulation of auroral processes

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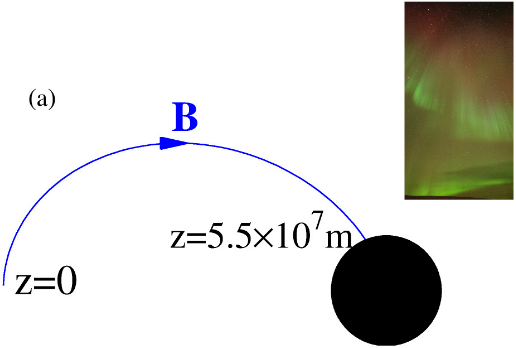
Simulation model

The distribution function is $f_s(z, v_z, \mu)$ and the Vlasov equation

$$\frac{\partial f_s}{\partial t} + v_z \frac{\partial f_s}{\partial z} + \frac{1}{m_s}\left(q_s E - \mu \frac{\partial B}{\partial z} + m_s a_g \right) \frac{\partial f_s}{\partial v_z} = 0$$



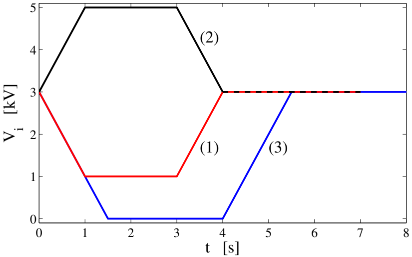
$$\mu = \frac{m_s v_\perp^2}{2B}$$

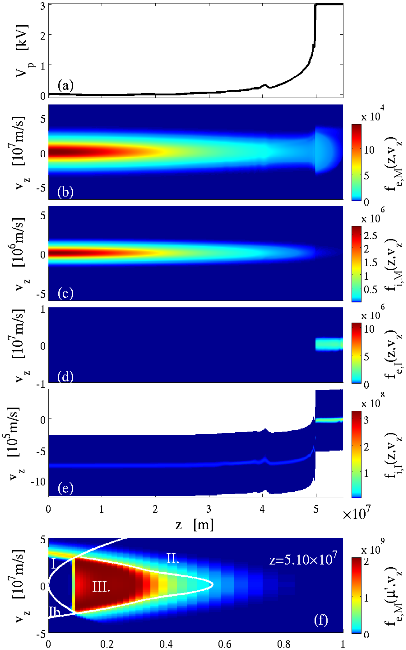
is a constant of motion. The electric field is given by

$$\frac{d}{dz}\left(\frac{B_{\mathrm{S}}}{B} E\right) = \frac{\rho_I}{S\epsilon}$$

Computer code published by Gunell et al. (2013a)

Changing the acceleration voltage during the simulation

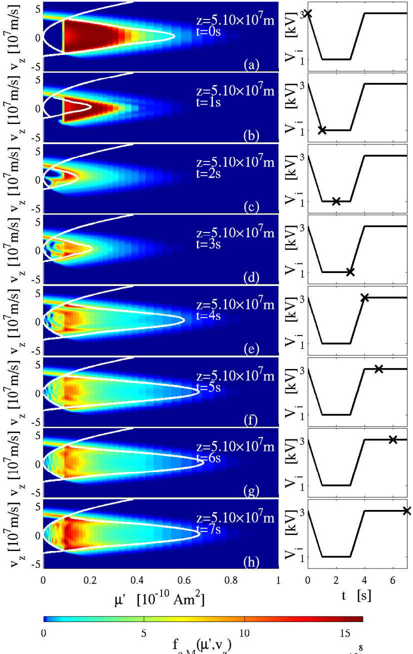




<u>Above:</u> Prescribed total voltage as a function of time.

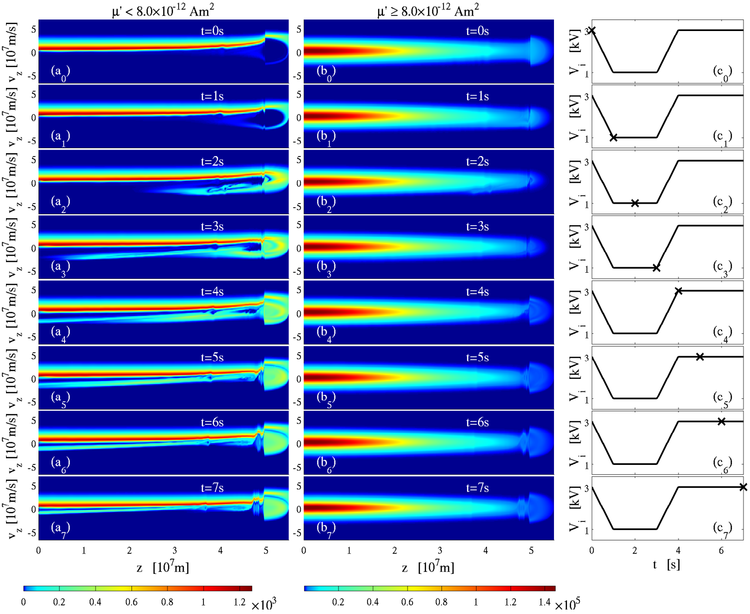
<u>Right:</u> Initial state, common to all three experiments.

Experiment 1: $f(\mu, v_z)$ at $z = 5.1 \times 10^7$ m

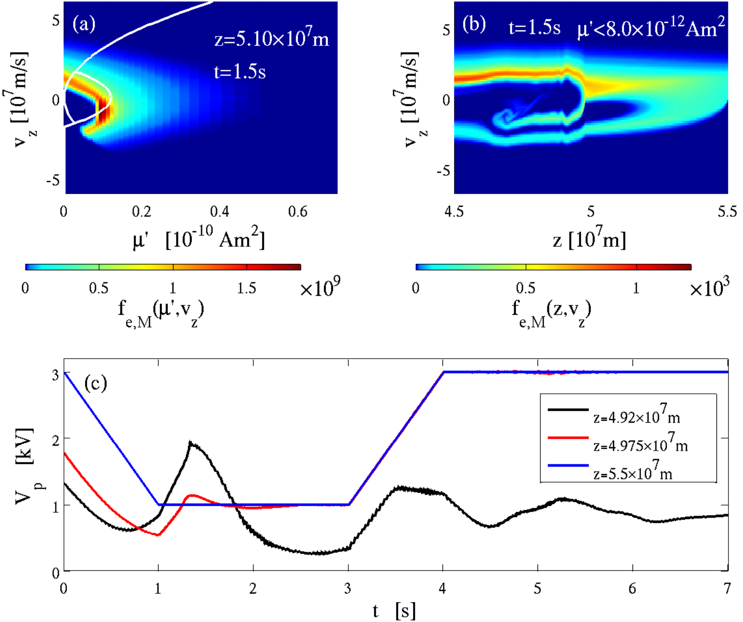


- Trapped electrons are released.
- New electrons get trapped.
- The distribution in the μ direction changes.

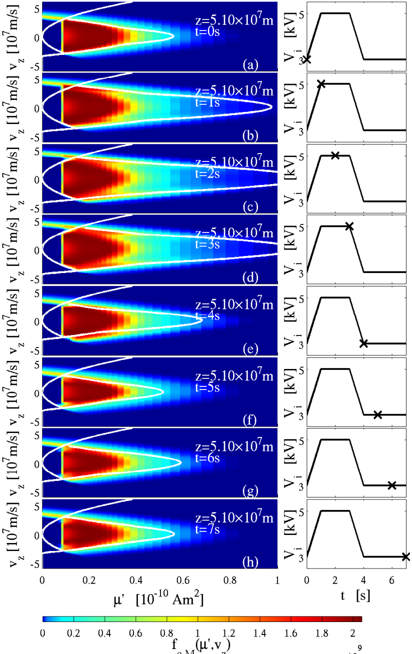
Experiment 1: $f(z, v_z)$



Experiment 1: fluctuations

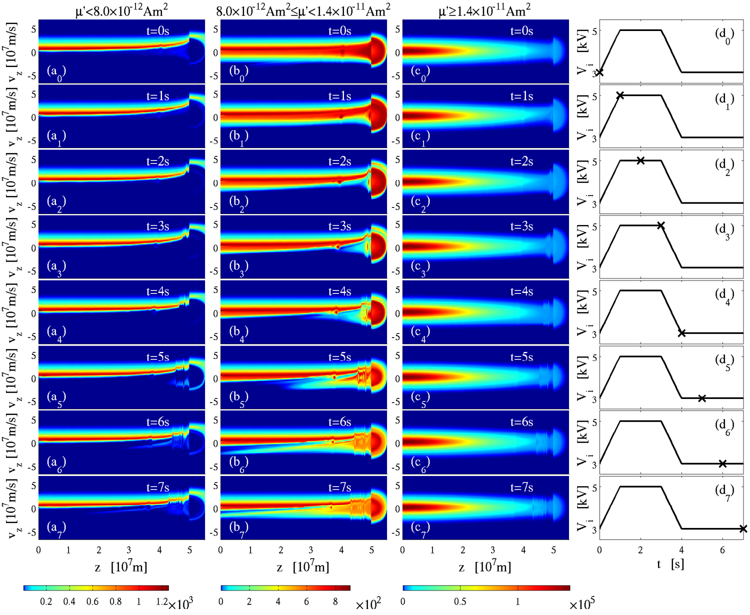


Experiment 2: $f(\mu, v_z)$ at $z = 5.1 \times 10^7$ m

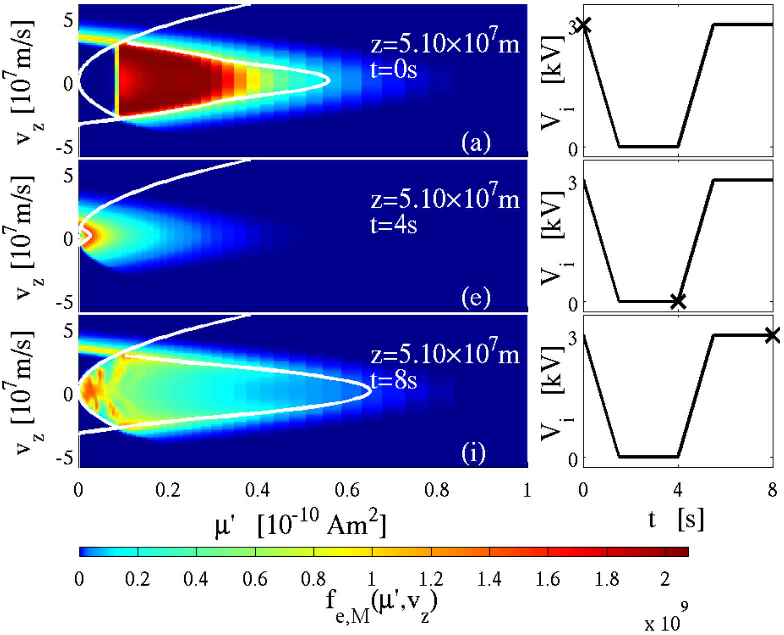


- New electrons are trapped at large μ values.
- Then these are lost again.
- The final state resembles the initial, although there is new structure at intermediate μ values.

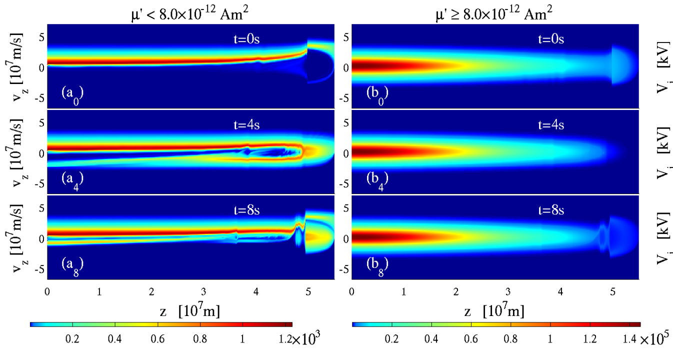
Experiment 2: $f(z, v_z)$

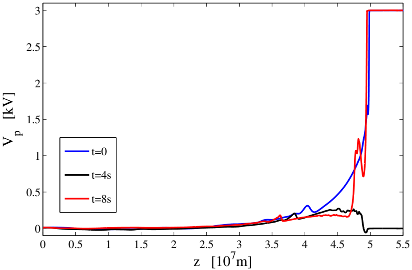


Experiment 3: $f(\mu, v_z)$ at $z = 5.1 \times 10^7$ m



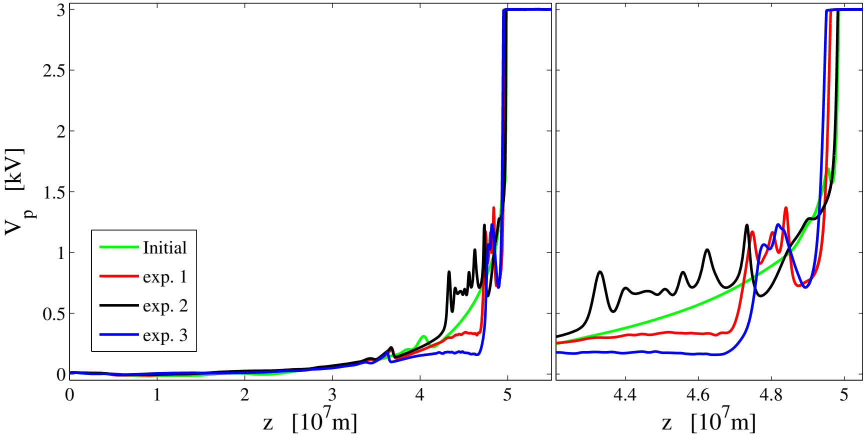
Experiment 3: $f(z, v_z)$

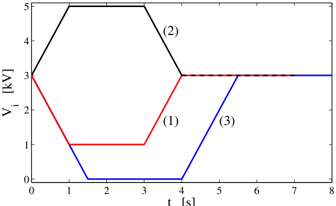




- The double layer changes polarity when the voltage is low.
- At $t = 8\,\mathrm{s}$, a new potential peak traps some electrons.

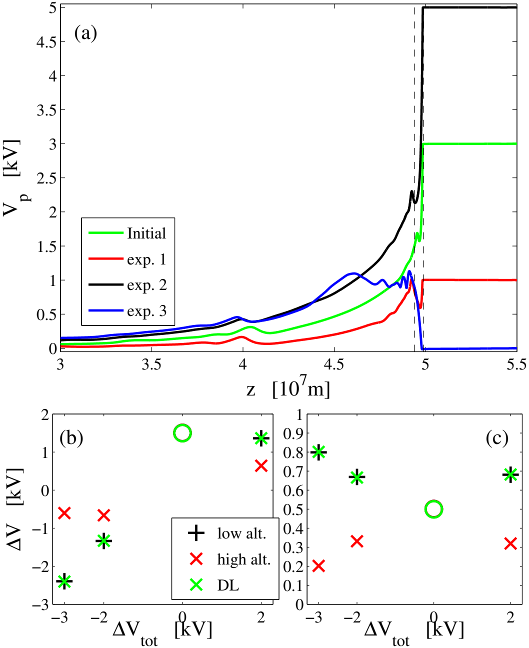
Final state



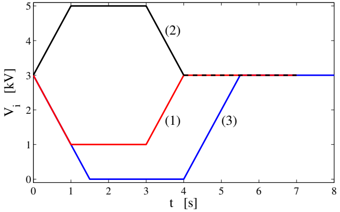


- The potential structure changes on the low potential side of the double layer.
- The double layer moved for $\Delta V < 0$.

Where does ΔV go?

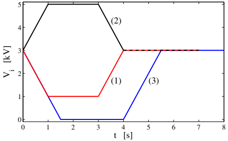


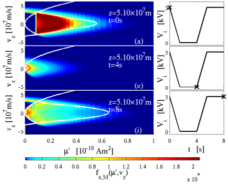
Most of ΔV is assumed by the double layer, c.f. observations by Forsyth et al. (2012).

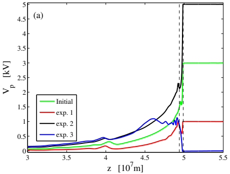


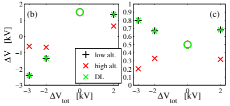
Summary

- Trapping and release processes can be followed in simulations.
- The history of the acceleration voltage affects the distribution function of the trapped electrons.
- Most of the change in the acceleration voltage is assumed by the double layer.
- For a quickly decreasing voltage the double layer changes polarity.
- Phase space holes are created in these numerical experiments.
- The double layer position exhibits hysteresis phenomena.









Bibliography

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Vlasov simulations – technical details – ϵ_r

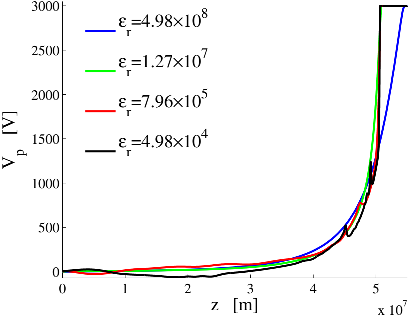
Computational advantages

$\omega_p \sim 1/\sqrt{\epsilon_r}$ $\Rightarrow$ lets us use a longer time step

$\lambda_D \sim \sqrt{\epsilon_r}$ $\Rightarrow$ lets us use a coarser grid

Disadvantage

Suppression of small scale and high frequency phenomena



	Magneto-sphere	Iono-sphere
z	0	$5.5 \cdot 10^7$m
B	0.086 μT	56 μT
$k_\mathrm{B} T_\mathrm{e}$	500 eV	1 eV
$k_\mathrm{B} T_{\mathrm{H}^+}$	2500 eV	1 eV
n	$3 \cdot 10^5\mathrm{m}^{-3}$	$1 \cdot 10^9\mathrm{m}^{-3}$