Properties of energetic particle injections from orbit tracing in dynamic MHD fields (J. Birn)

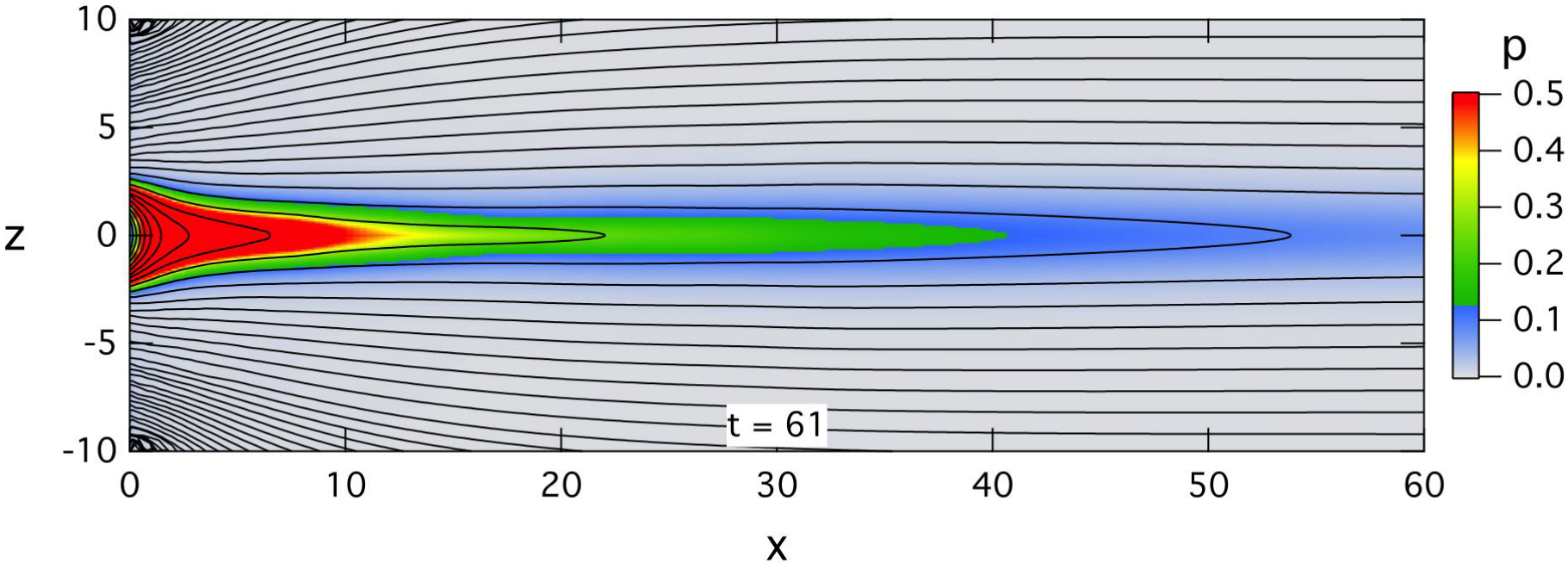
Overview of MHD simulation

Basics of test particle tracing

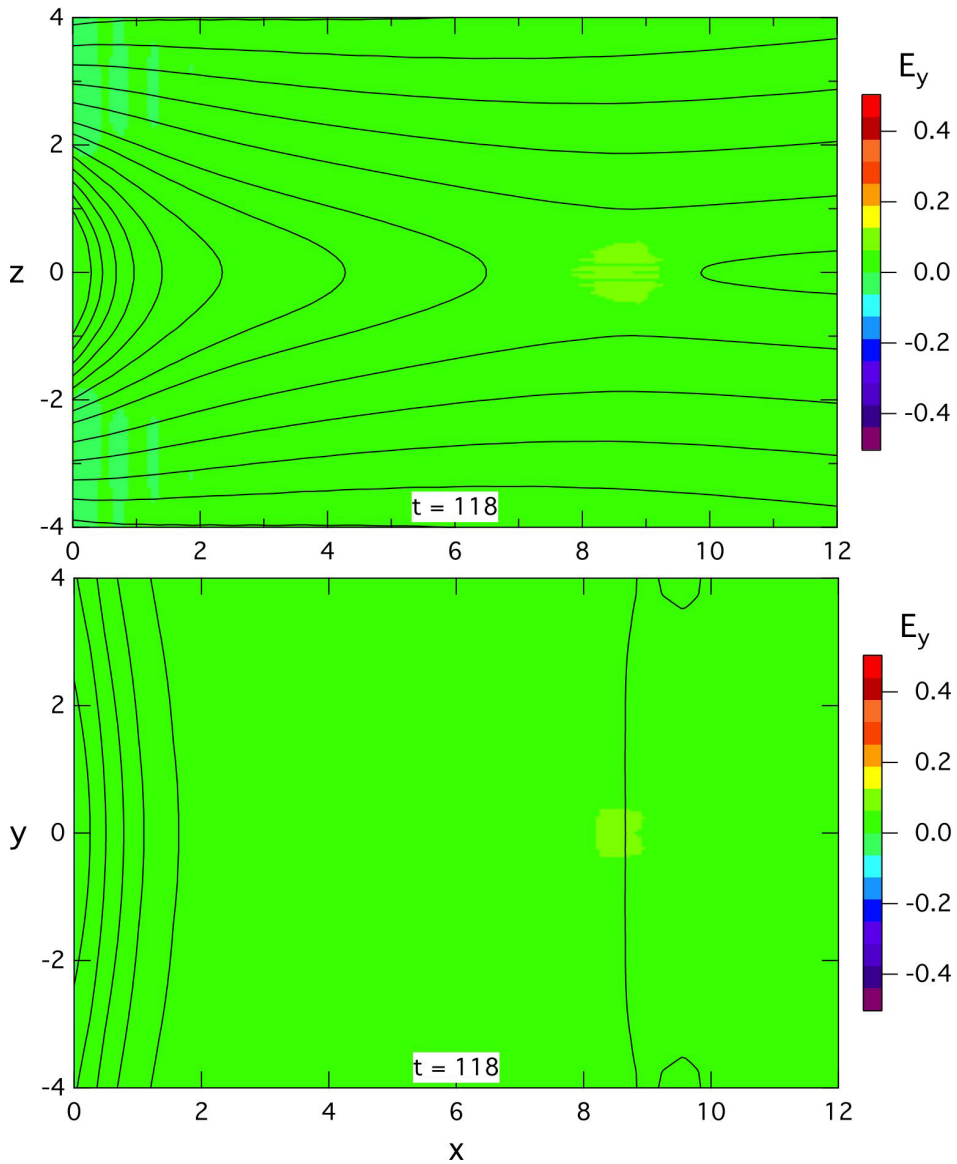
Sample orbits

Spatial, temporal, and energy dependent properties

Reconnection in the Magnetotail



MHD: Electric field at Dipolarization Front



Test particle tracing in MHD fields

Using time-dependent MHD fields, interpolated in space and time (cubic spline in space; monotonicity conserving algorithm)

Backward tracing from final destination to origin at boundary or initial state

Impose f at origin = f at final location (Liouville mapping)

Full equation of motion in strongly varying or weak fields (always for ions)

$$\frac{dm\mathbf{u}}{dt} = q(\mathbf{E} + \mathbf{u} \times \mathbf{B})$$

Gyrocenter drift in weakly varying fields (μ_{rel} conserved)

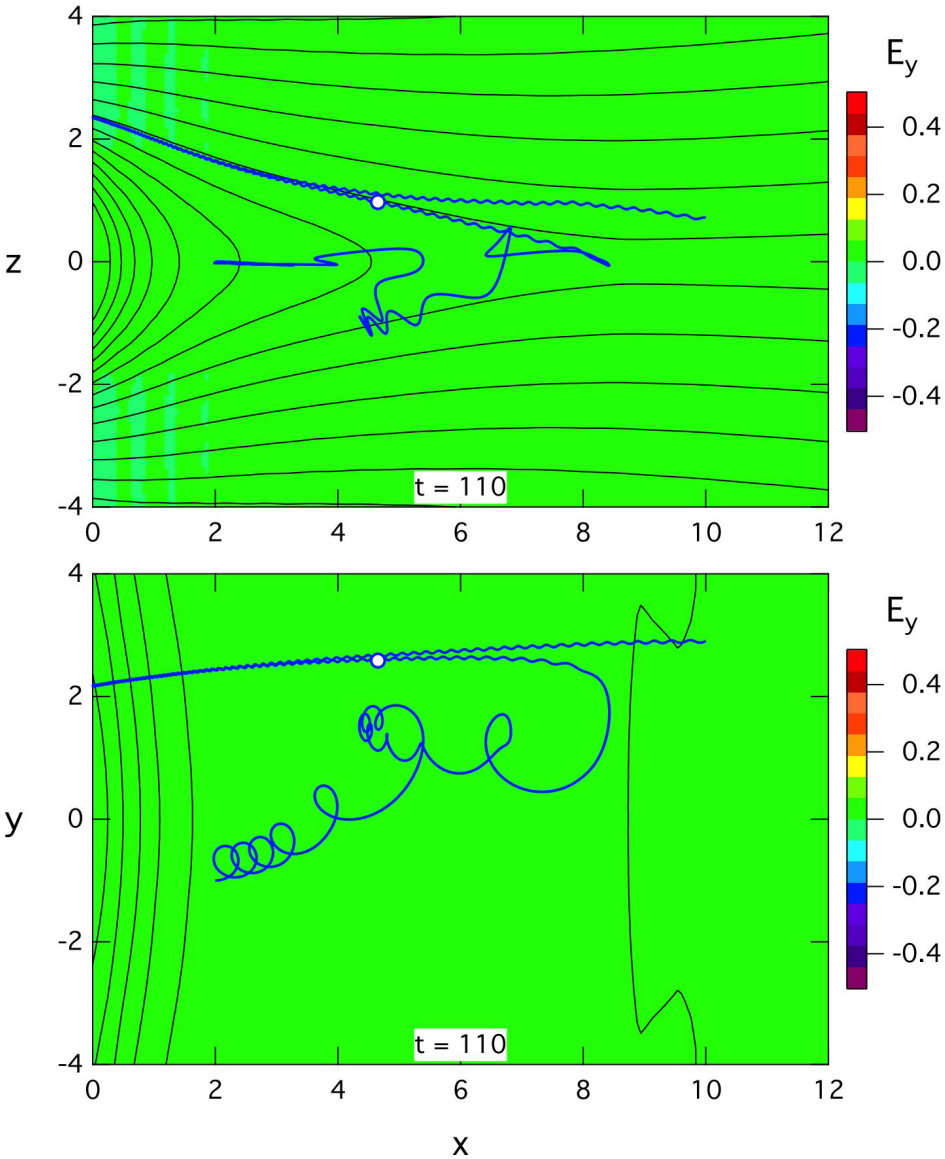
$$\mathbf{v}_\perp = \mathbf{v}_E + \frac{\mu}{q}\frac{\mathbf{B} \times \nabla B}{B^2} + \frac{mv_\parallel^2}{q}\frac{\mathbf{B}}{B^2} \times (\mathbf{b} \bullet \nabla \mathbf{b}) \qquad \mathbf{v}_E = \frac{\mathbf{E} \times \mathbf{B}}{B^2}$$

$$\frac{dmv_\parallel}{dt} = qE_\parallel - \mu \mathbf{b} \bullet \nabla B + mv_\parallel(\mathbf{v}_E + \mathbf{v}_{\nabla B}) \bullet (\mathbf{b} \bullet \nabla \mathbf{b}) \qquad \mathbf{b} = \frac{\mathbf{B}}{B}$$

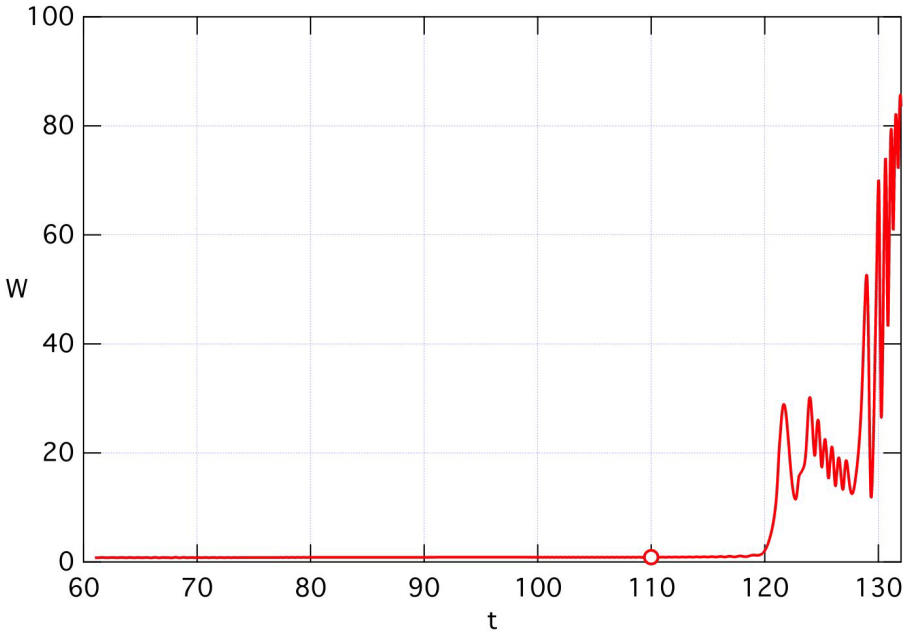
$$m = \gamma m_0 \qquad \mu = \frac{\mu_{rel}}{\gamma} \qquad \mu_{rel} = \frac{p_\perp^2}{2m_0 B} \qquad \gamma = \frac{1}{\sqrt{1-(v/c)^2}}$$

Transition based on adiabaticity parameter ($\kappa^2 = r_{curv}/a_{gyr}$)

Geotail: ion acceleration

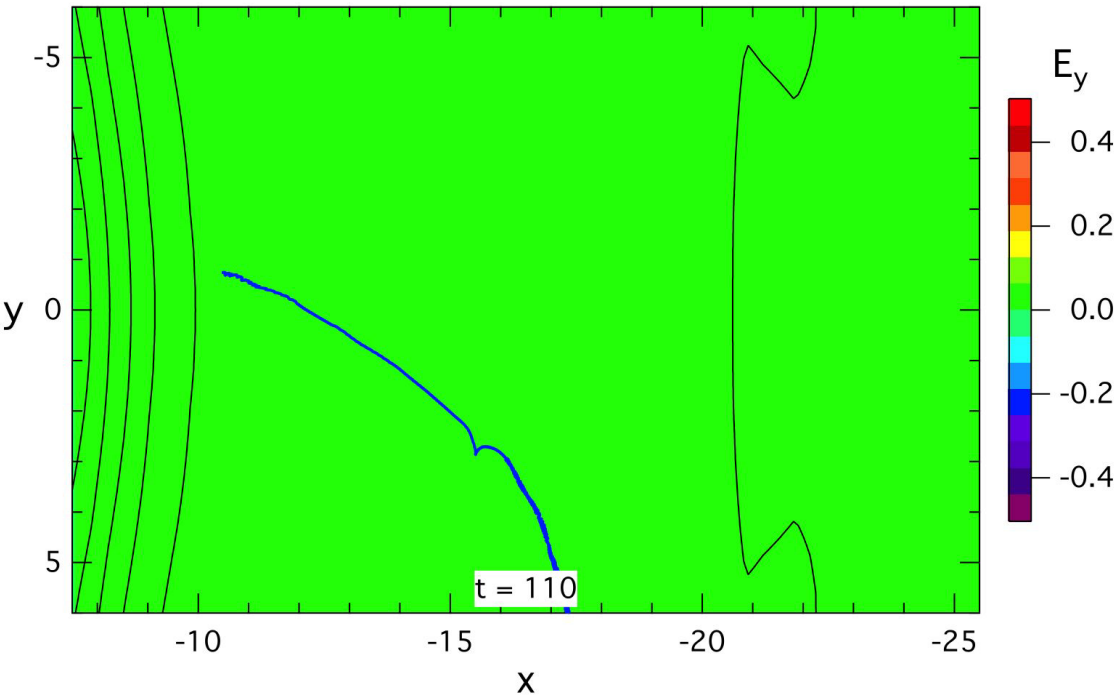


Proton, final energy ≈ 86 keV

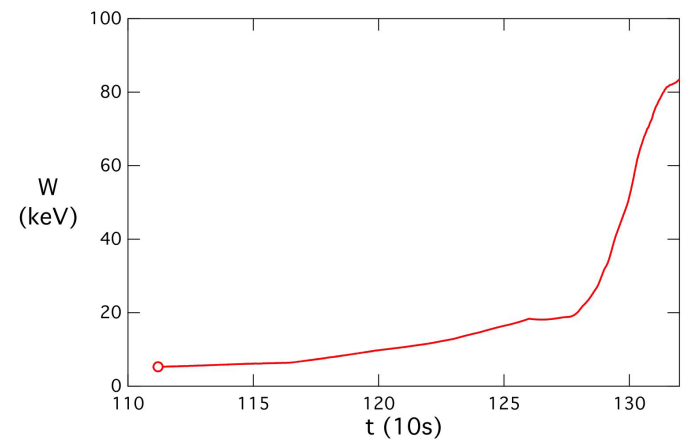


Entry via reconnection

Energetic electron in collapsing field

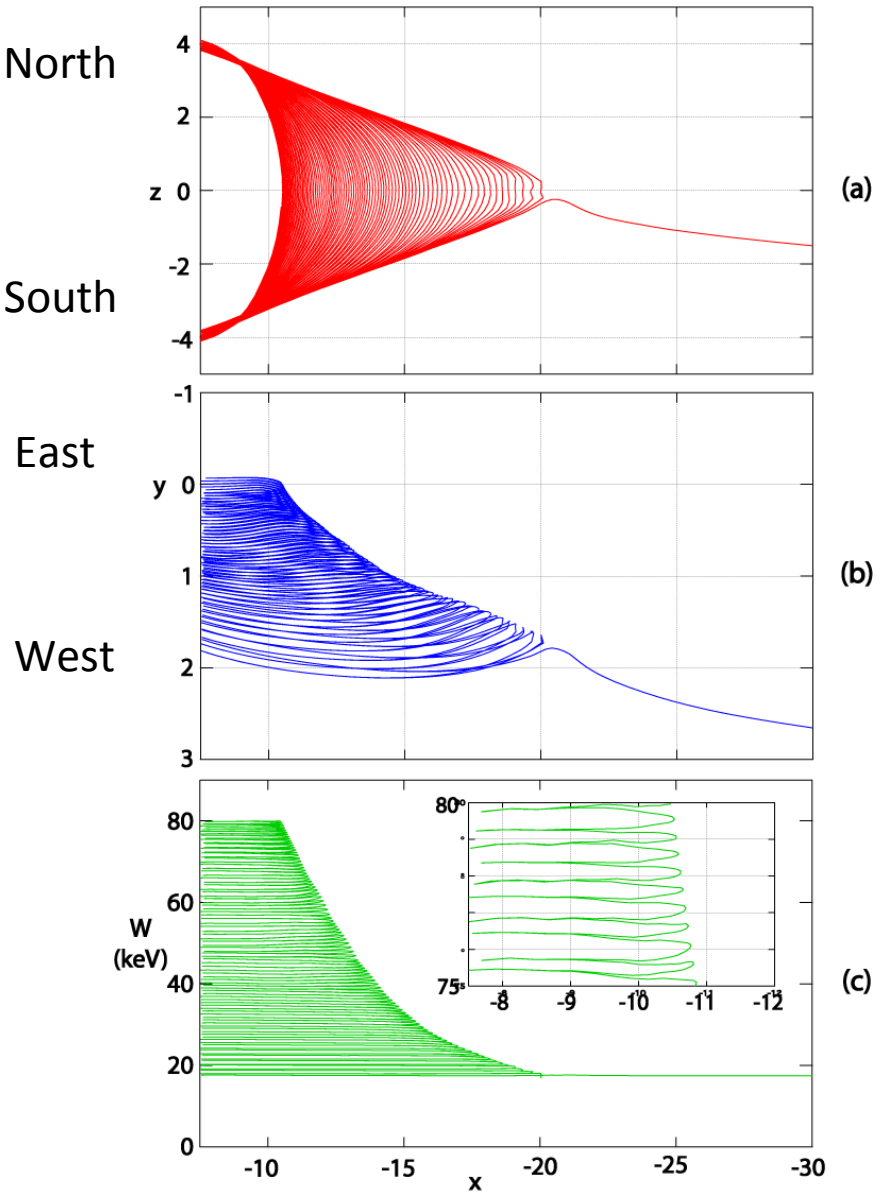


electron, final energy ~80 keV



Drift entry from the flank plasma sheet

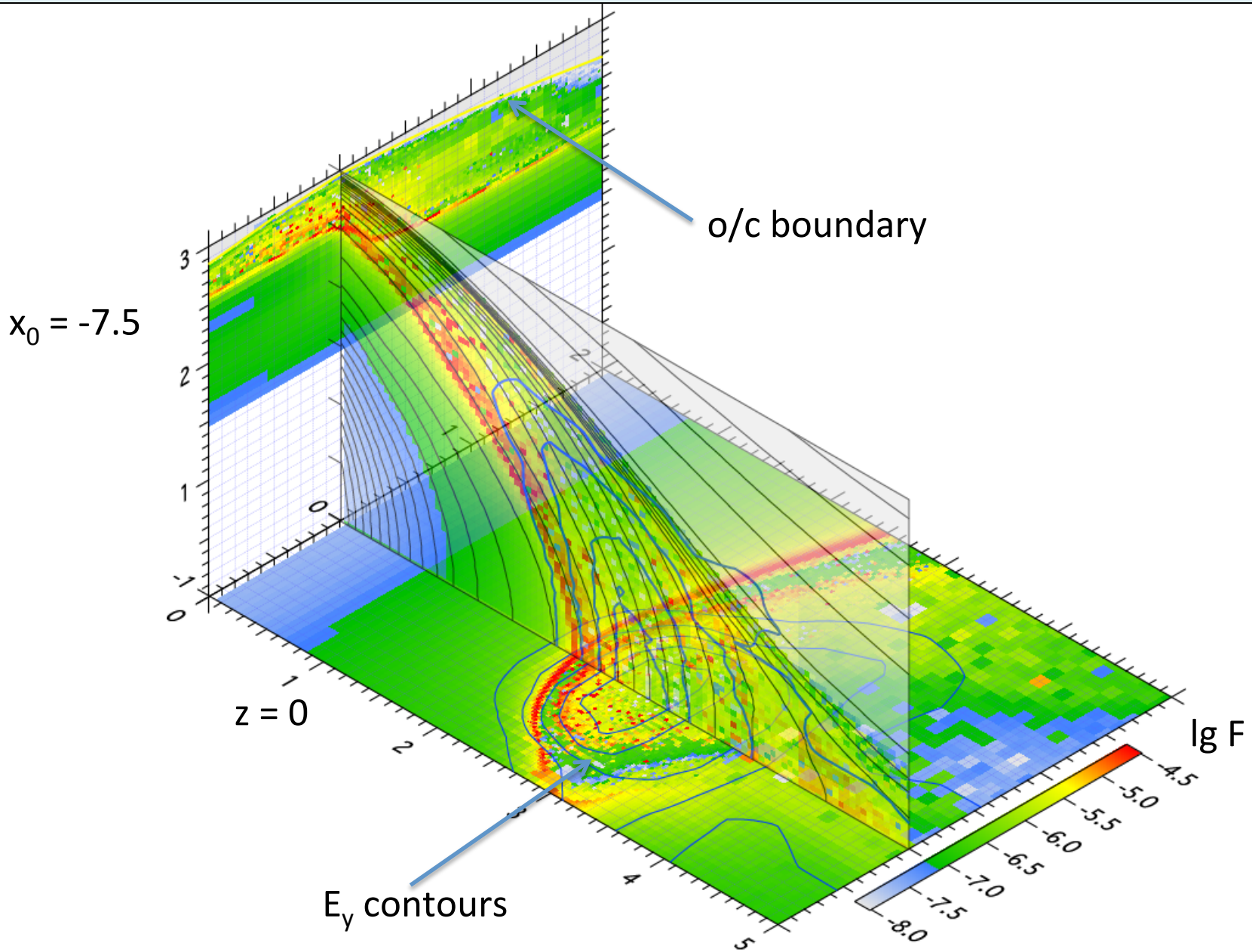
Electron orbit (small pitch angle)



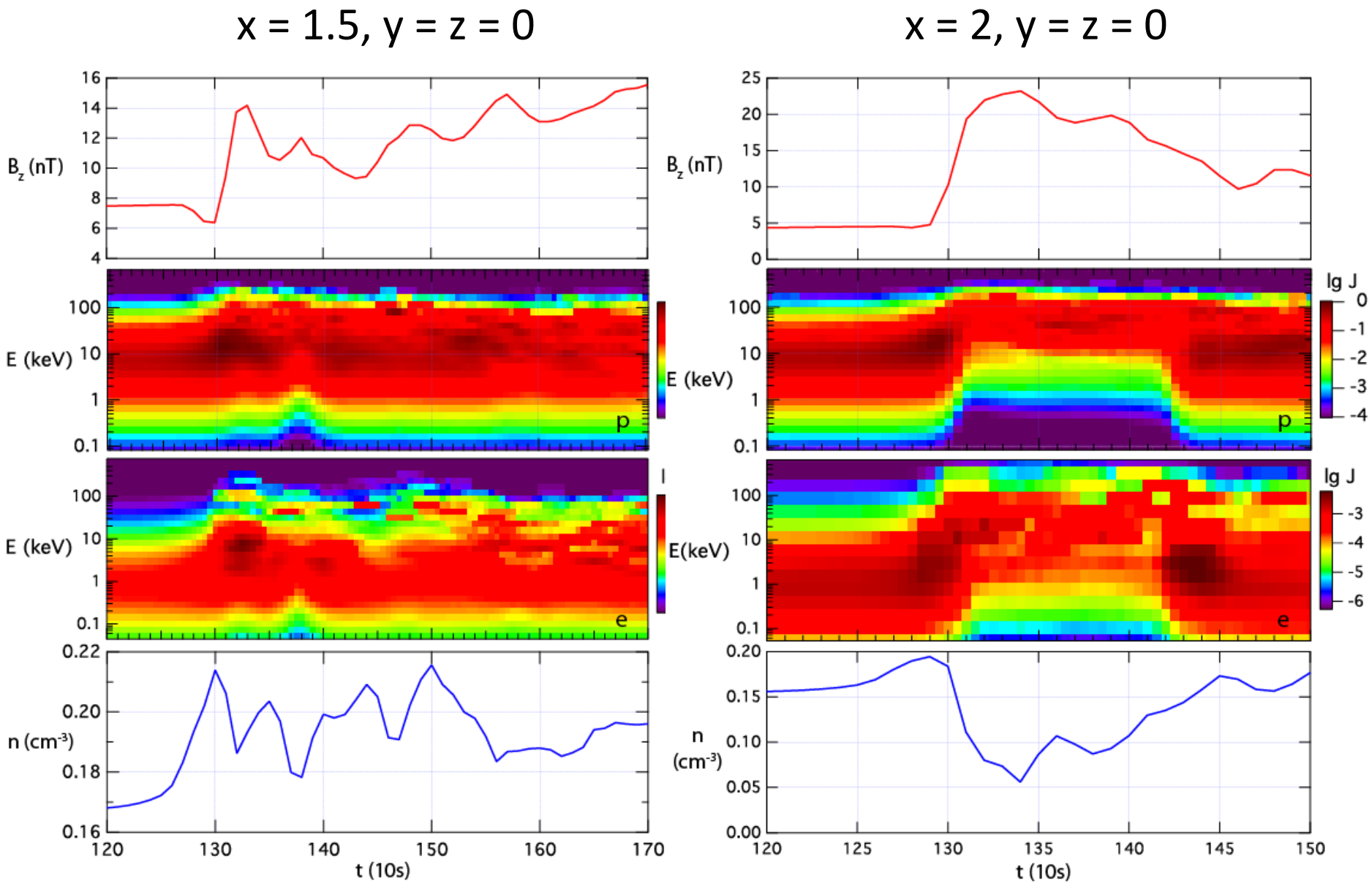
Entry by reconnection
Earthward E×B drift
Cross-tail curvature drift

Repeated energy gain at equatorial crossings between mirroring (current sheet acceleration - 1st order Fermi, type B)

42 keV electron fluxes, α = 5°, t=130

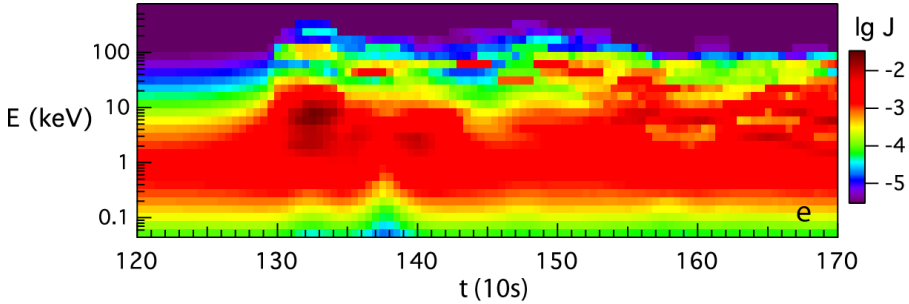


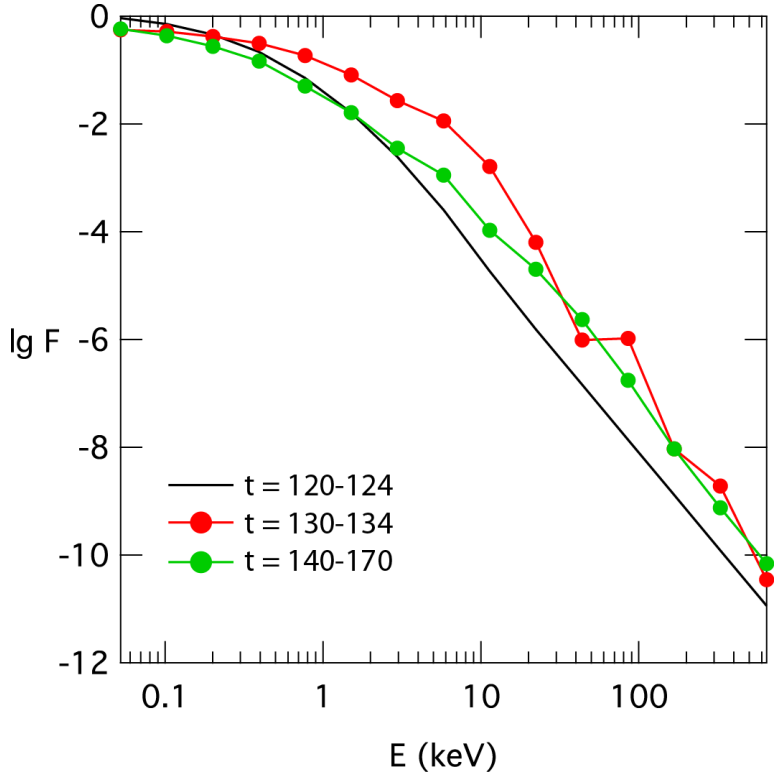
Energy/time spectrogram of protons & electrons



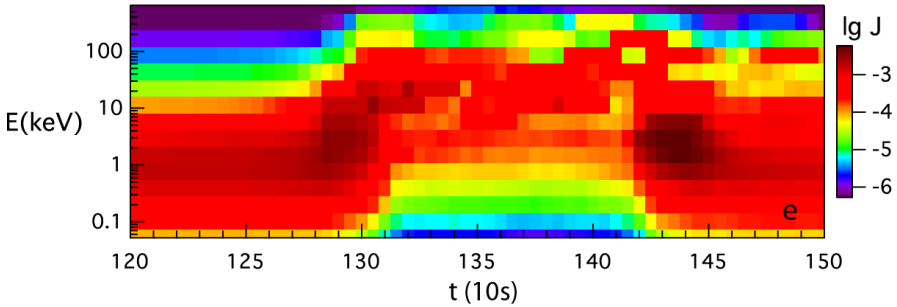
Phase space distributions, electrons

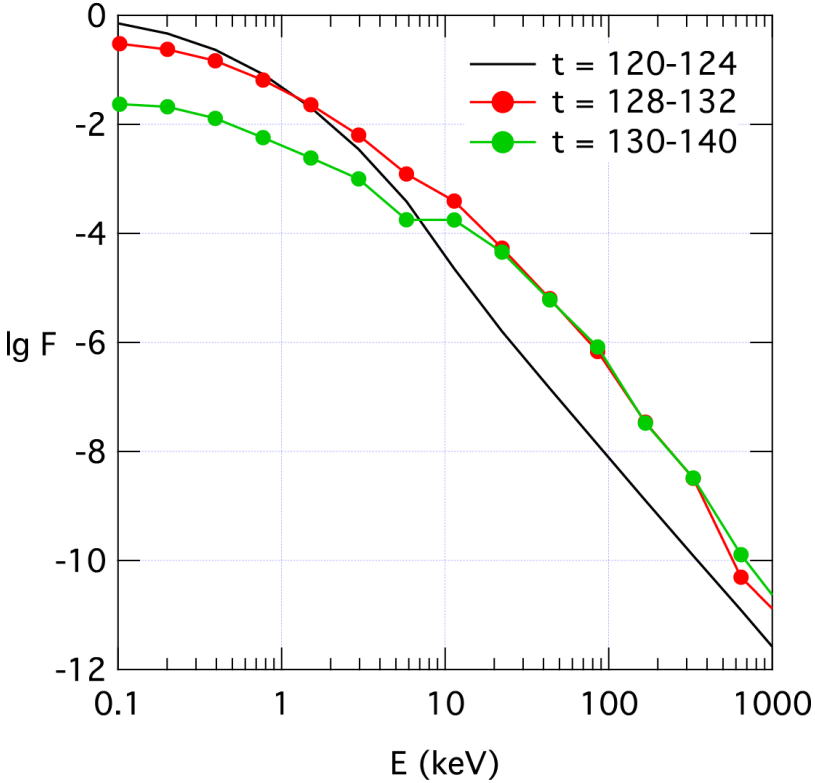
x = 1.5, y = z = 0



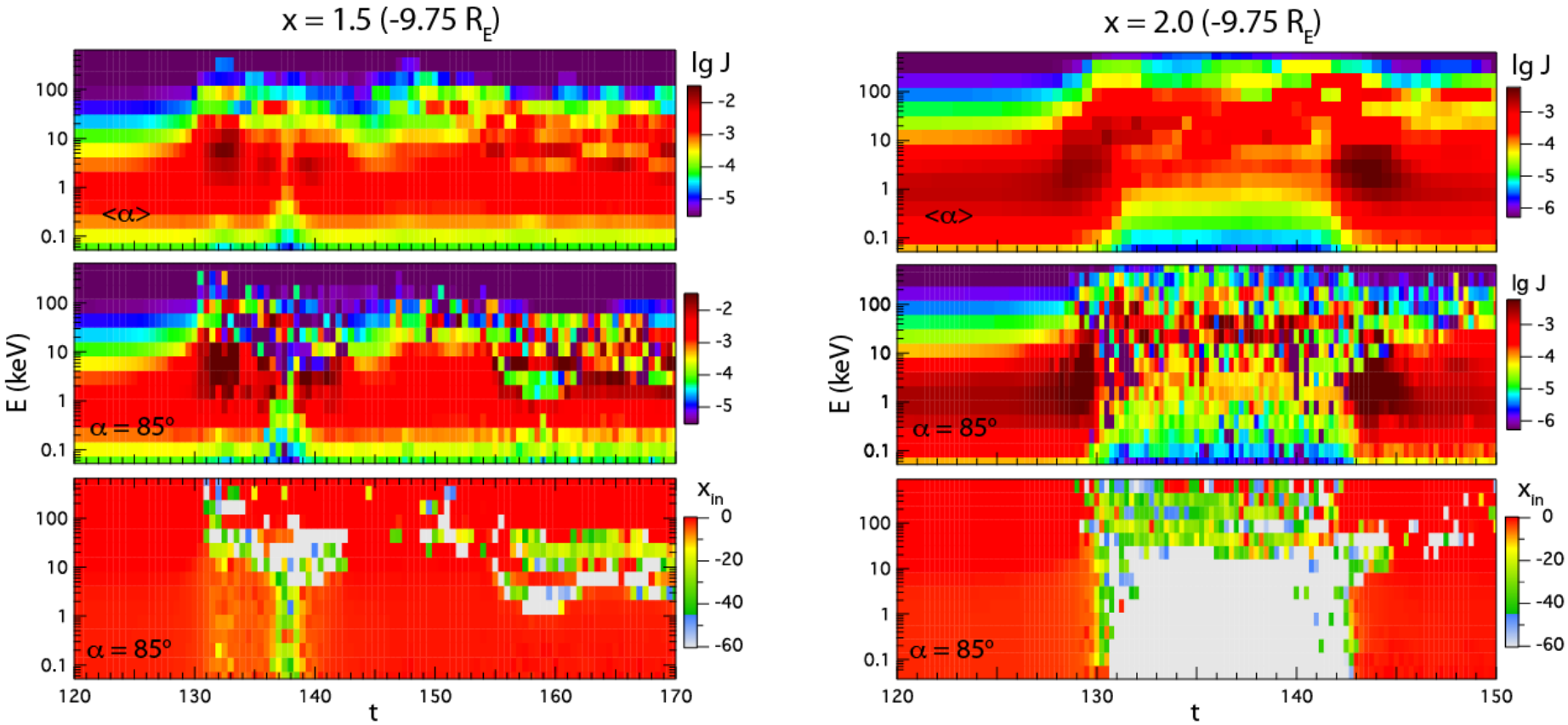


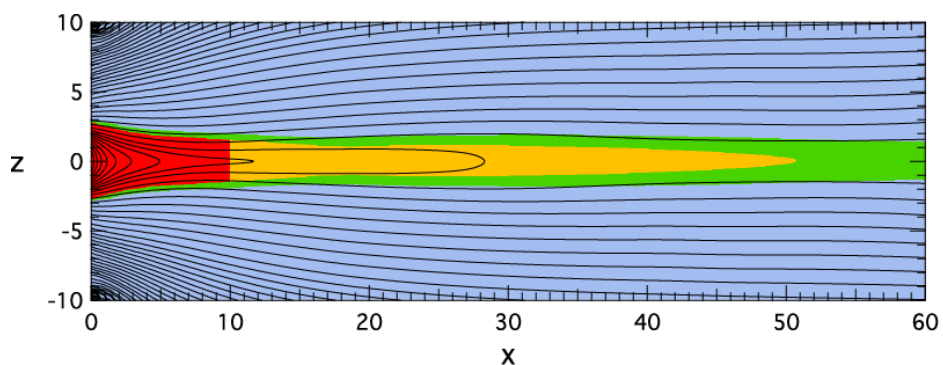
x = 2, y = z = 0



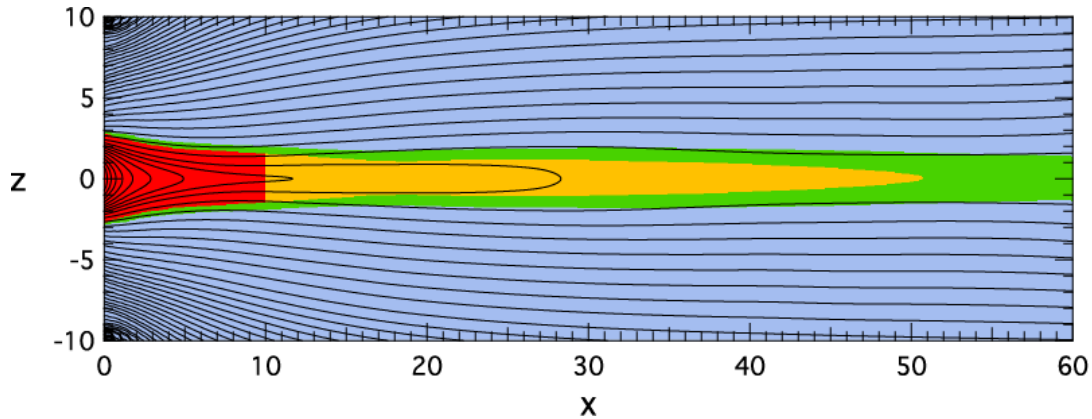


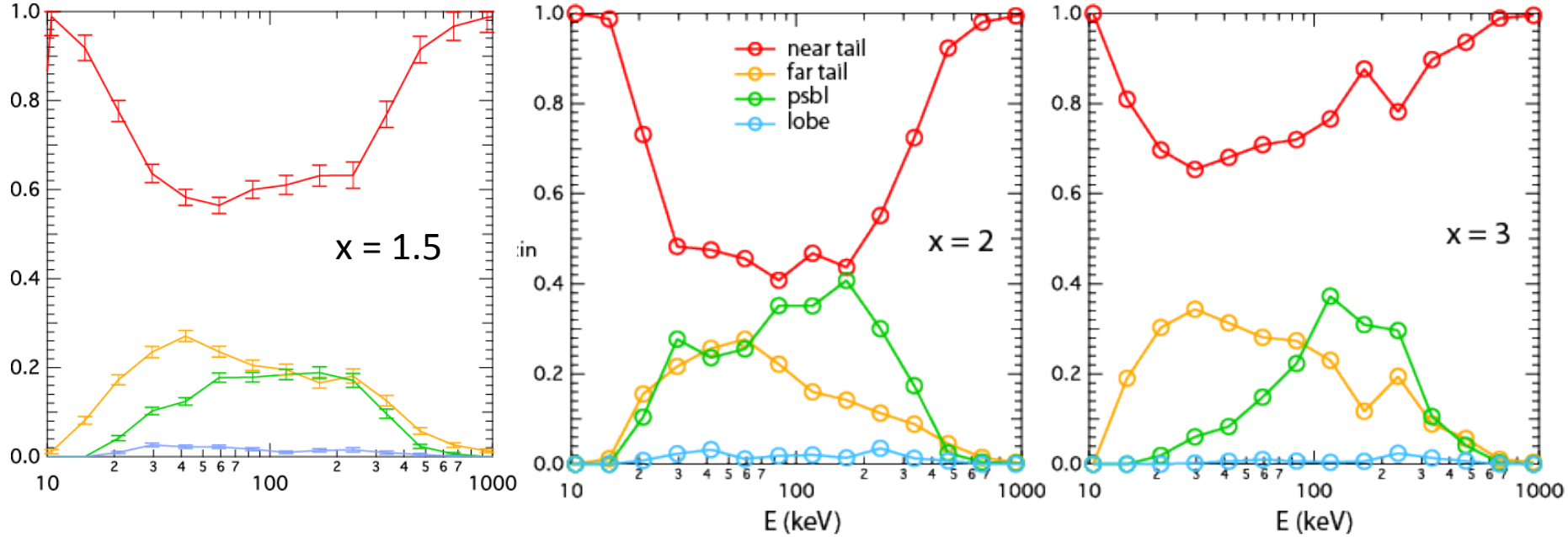
Energy/time spectrograms & sources of electrons



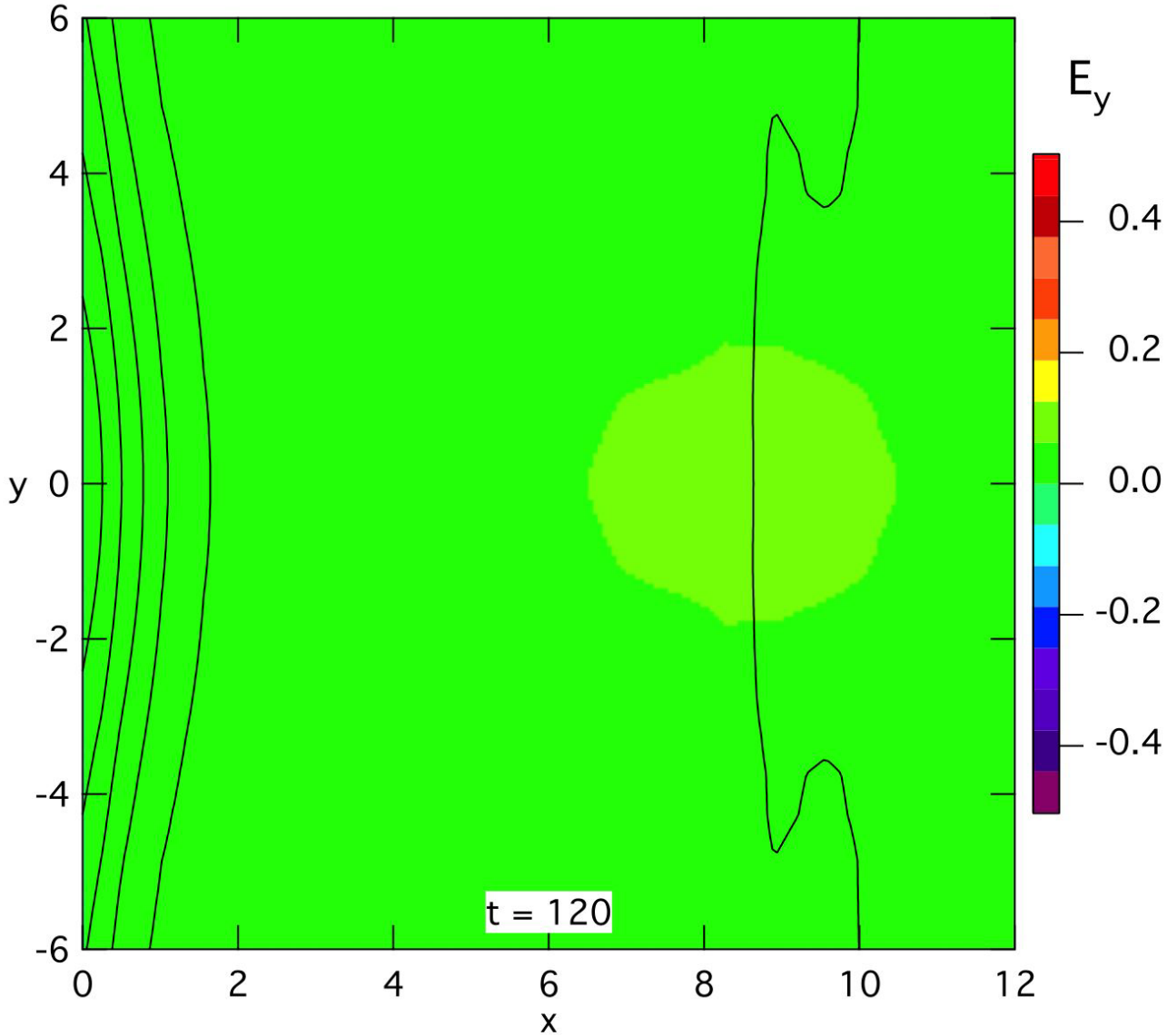


Ion source regions

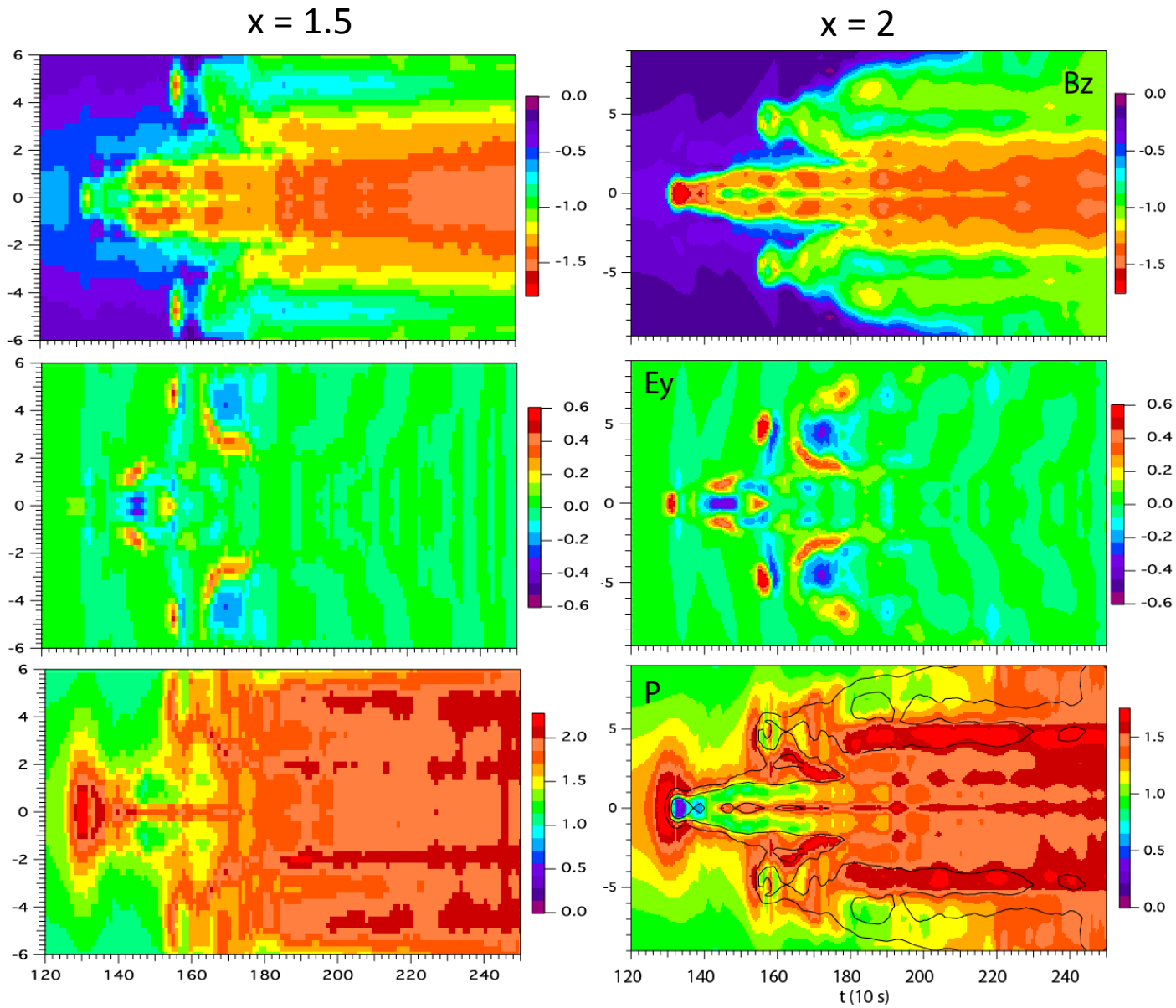




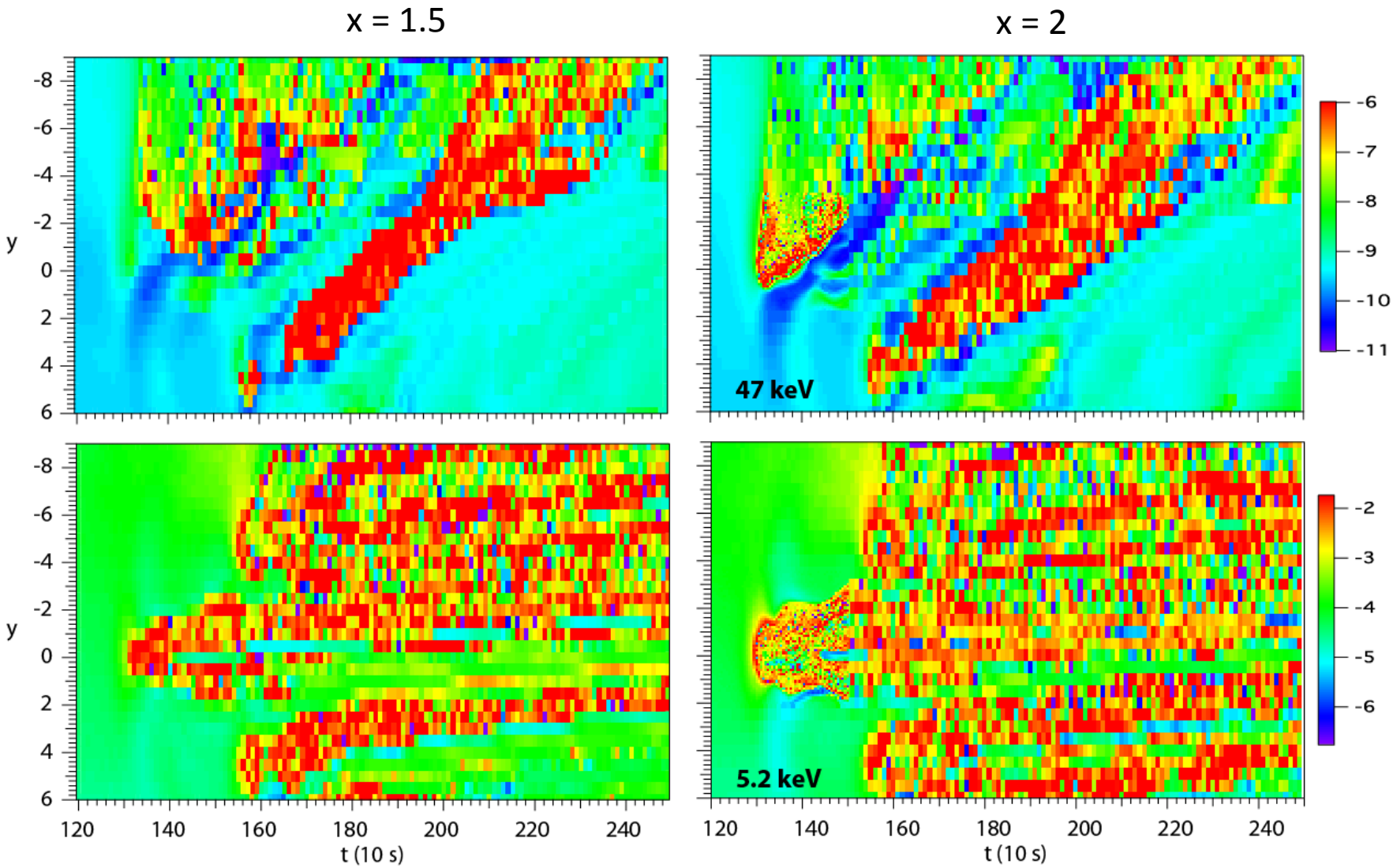
Ey(x,y) in MHD



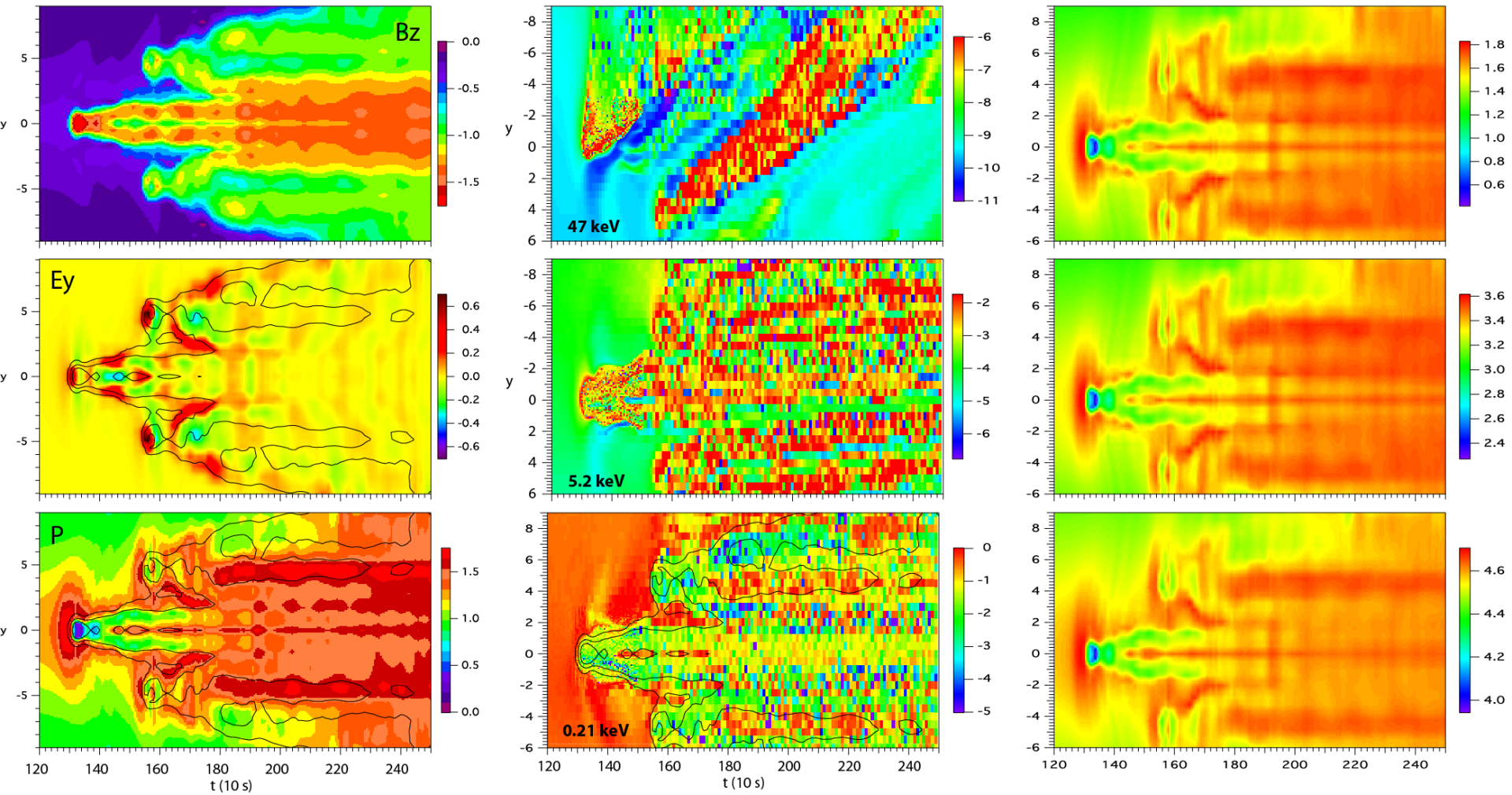
MHD properties as fct (t,y) at x = 1.5, 2



Electron fluxes as fct(t,y) at x = 1.5, 2



Electron fluxes as fct (y,t) at x = 2



Summary

Acceleration mainly from field collapse, governed by $E_y = -v_x \times B_z$

- Importance of localization
- Betatron acceleration (similar if nonadiabatic)
- 1st order Fermi, type B (or A; current sheet acceleration)
- acceleration at x-line ➔ PSBL ion beams

Two source regions (comparable importance in magnetotail):

- flanks, inner tail	- drift entry	- early, higher energy
- outer plasma sheet/psbl	- reconnection entry	- later, lower energy

Both thermal and suprathermal sources important

Energy gain limitedroughly by $\int E_y \, dy$ (few 100 keV)

Comments

Present model does not include background convection (like Volland-Stern), only inductive electric field from dipolarization

Flux patterns include recent acceleration and subsequent drift

Simulated region is limited, f. i., does not include drift echoes