Electron Acceleration in Non-relativistic Quasi-perpendicular Shocks

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The Injection Problem

Injection Problem

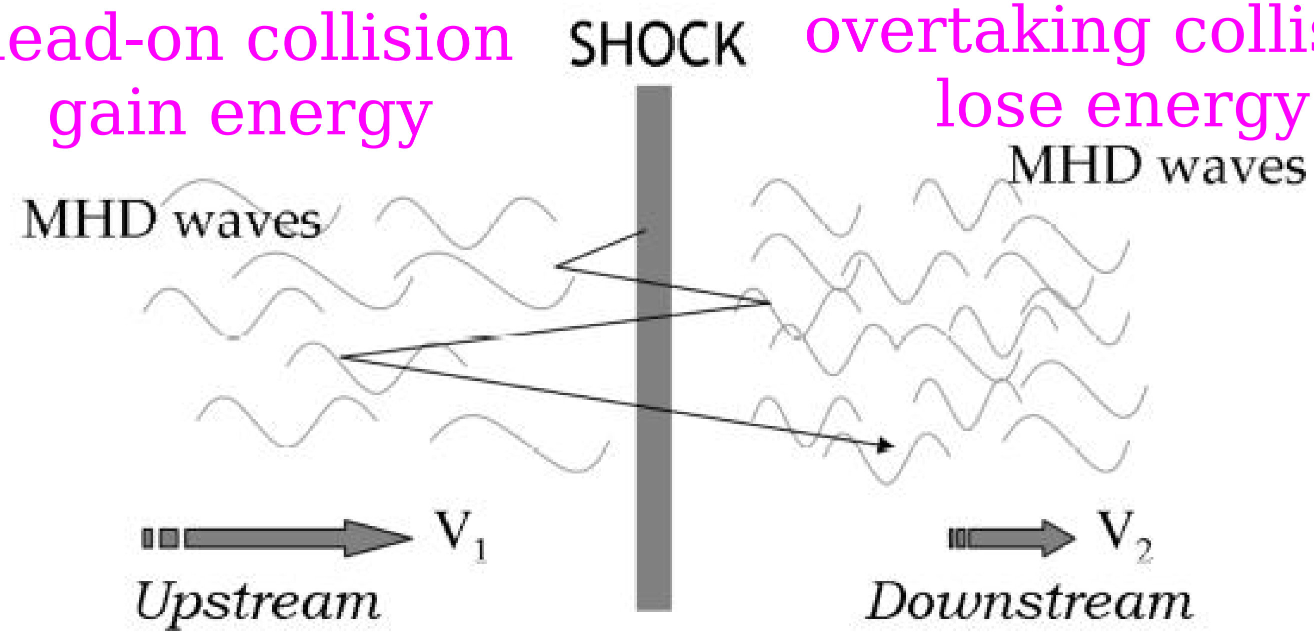
escape condition : escape from downstream to upstream

resonance condition : resonantly scattered by MHD waves

these conditions should be satisfied for effici

head-on collision
gain energy

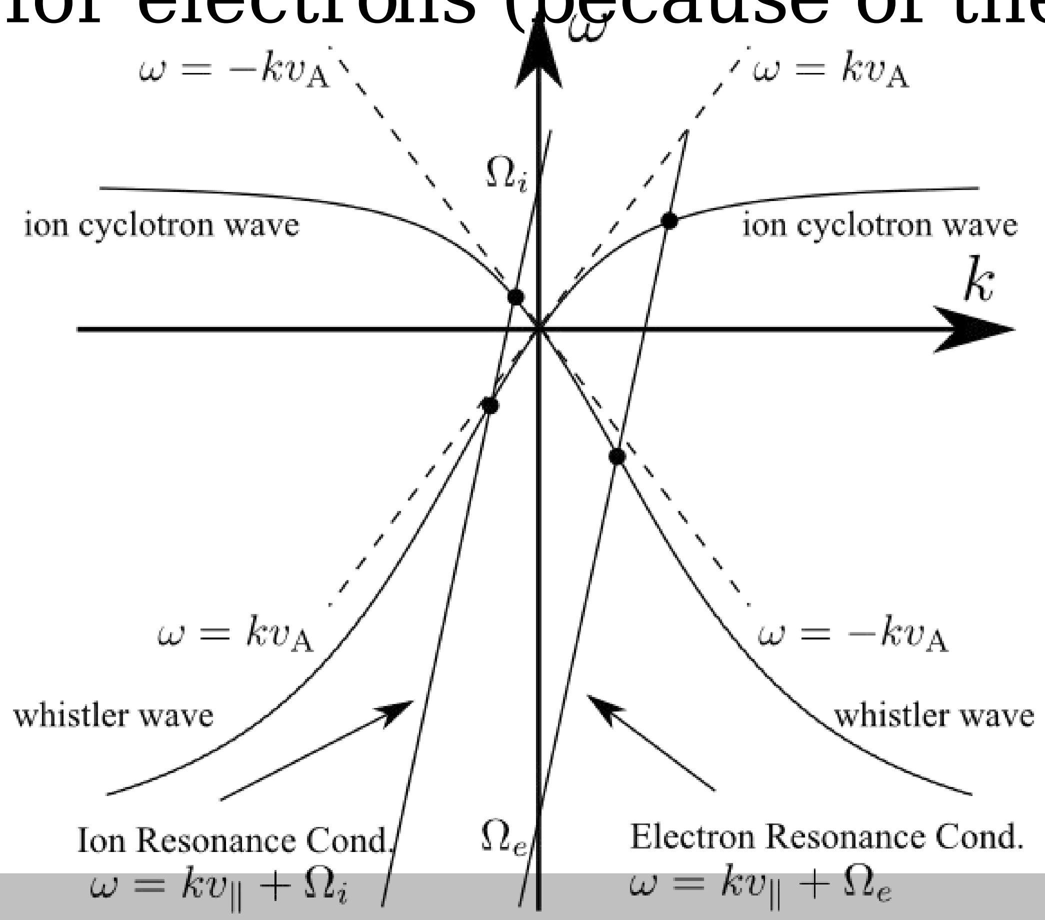
overtaking collision
lose energy



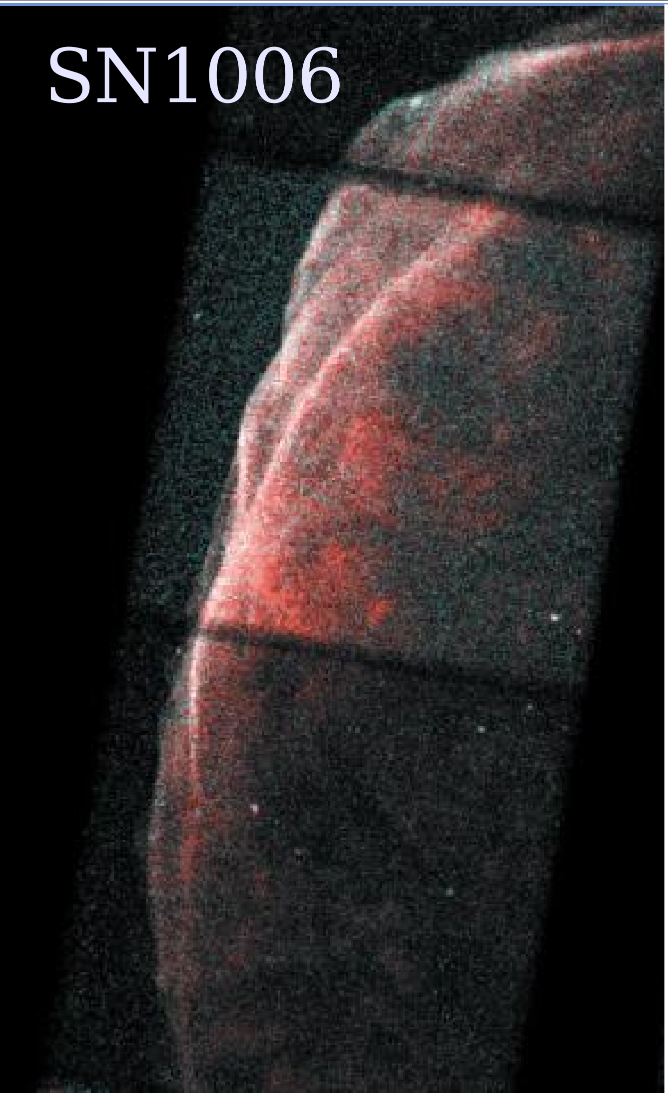
Electron and Proton Injection

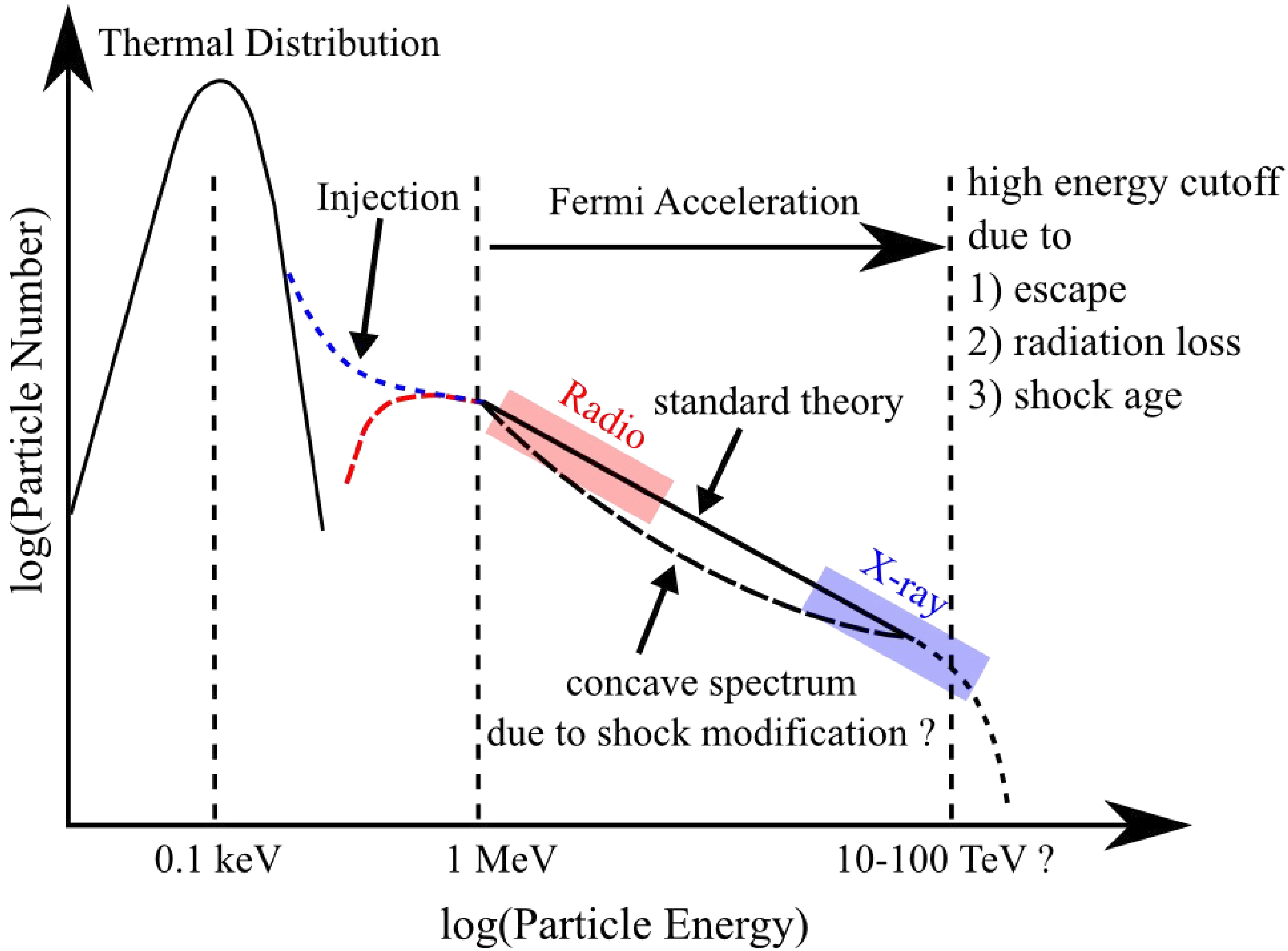
scattering by MHD turbulence requires cyclotron resonance

- easy for protons
- but not for electrons (because of their light mass)



Evidence for Ultra-relativistic Electrons at SNR Shocks





Electron acceleration is typically efficient at SNR
while it is not at shocks in the heliosphere probab
of the difference in Mach numbers

Quasi-perpendicular Shock (θ_{Bn}=80)

[Amano & Hoshino, 2007]

Shock Surfing Acceleration (SSA)

Energetic electrons are generated at the leading edge of the foot

[e.g., Hoshino & Shimada 2002]

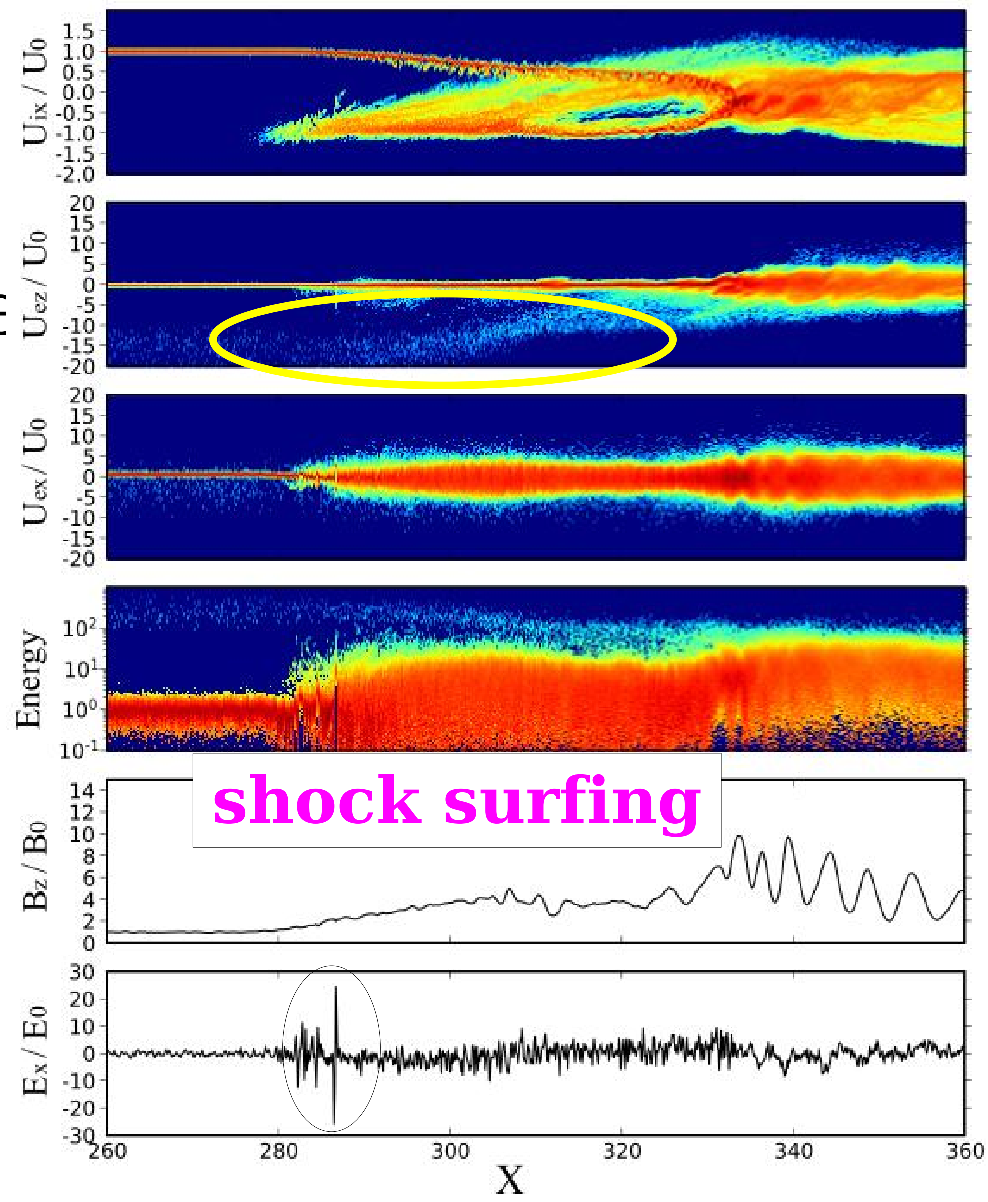
Shock Drift Acceleration (SDA)

further accelerated by the magnetic mirror reflection

[Wu et al., 1984; Leroy & Mangeney 1984]

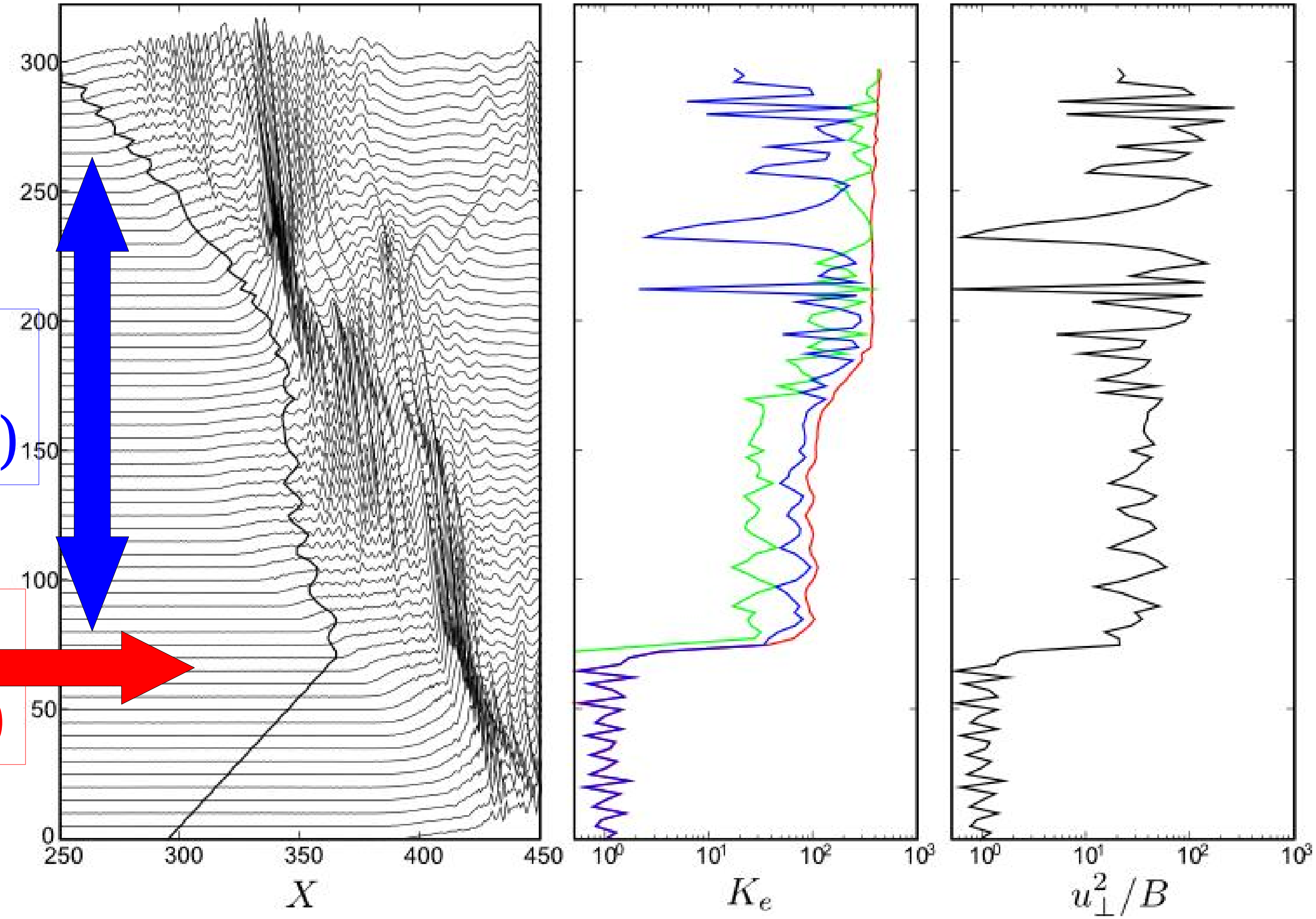
Shock Parameter

m_i/m_e	= 100
ω_{pe}/Ω_{ce}	= 20
$\beta_i = \beta_e$	= 0.08
M_A	~ 15



Trajectory of Energetic Electron

total,perp,para energy history

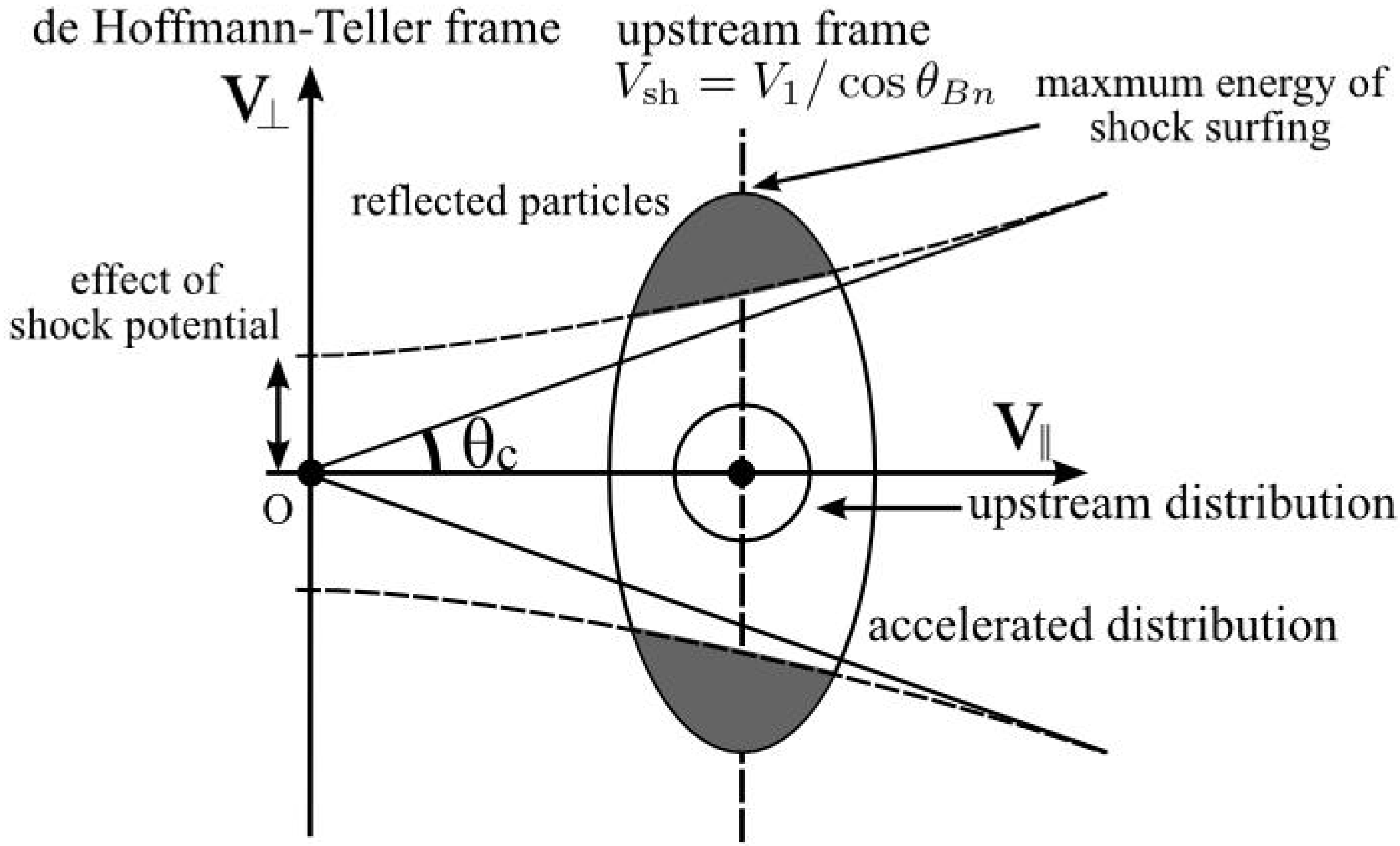


Shock Drift
(para. and slow ~ Ω_{ci}^{-1})

Shock Surfing
(perp. and fast ~ Ω_{ce}^{-1})

The energy of reflected electrons is large enough f
when the Ma > 100 (depends on shock angle)

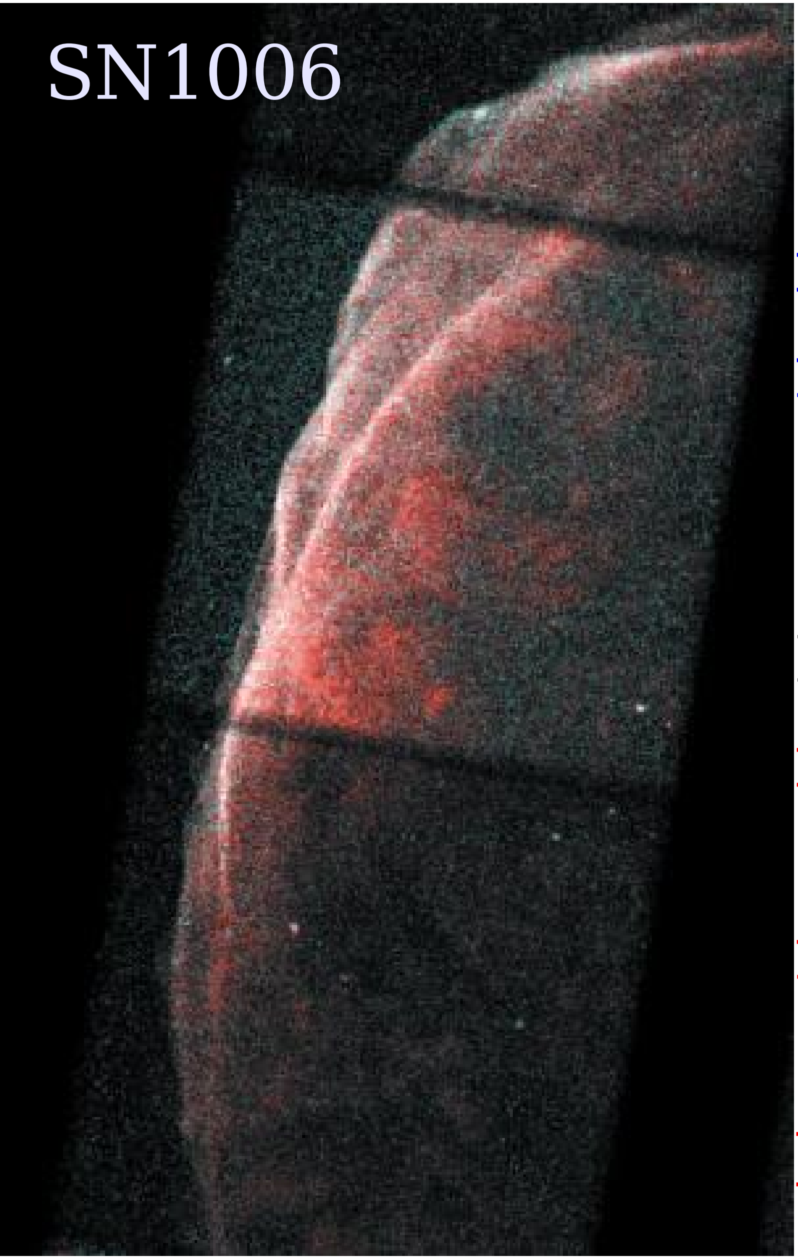
Interpretation: Surfing and Drift Acceleration



non-adiabatic acceleration by SSA initiates SDA

assuming the pre-accelerated distribution function, we can estimate the fraction of

Application to SNR Shocks
comparison between model and observation



Observation [e.g., Bamba et al. 2003]

injection efficiency ~ 10^{-4}-10^{-3}

non-thermal / thermal energy ~ 30%

Injection Model [Amano & Hoshino 2007]

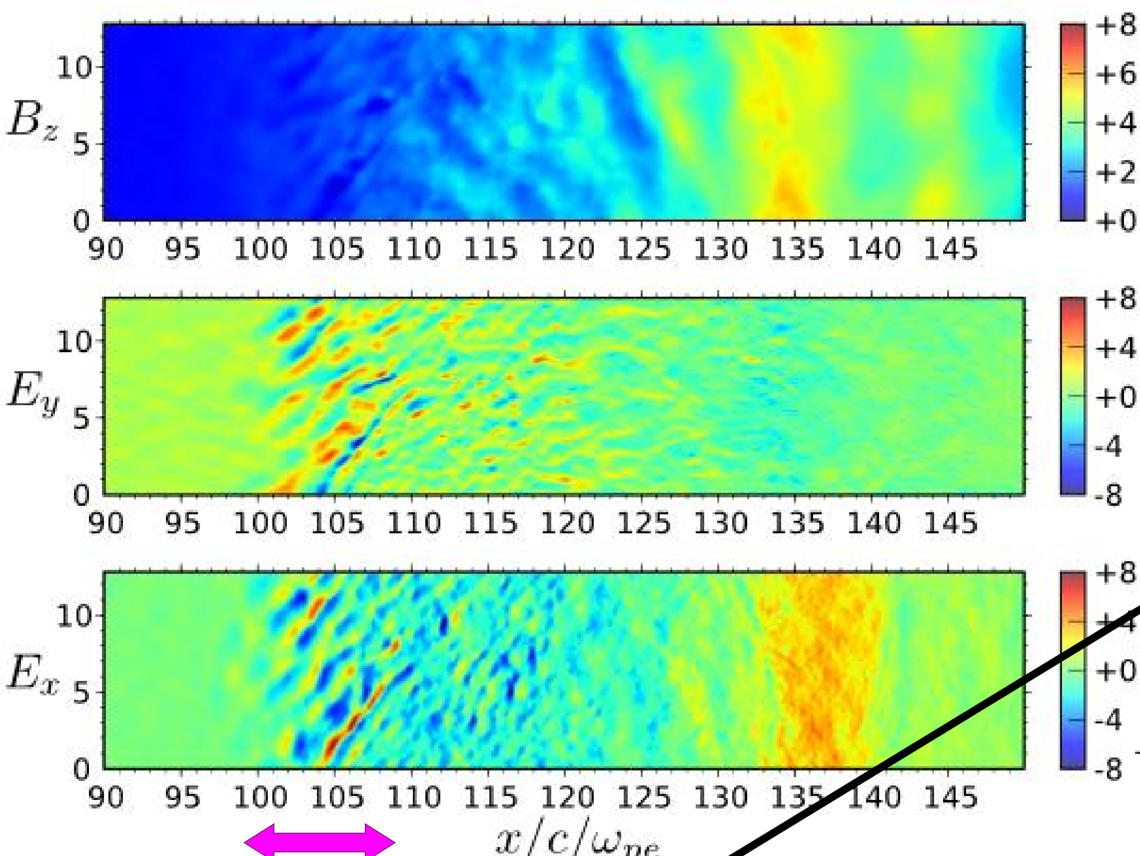
injection efficiency ~ 2×10^{-4} (peak)

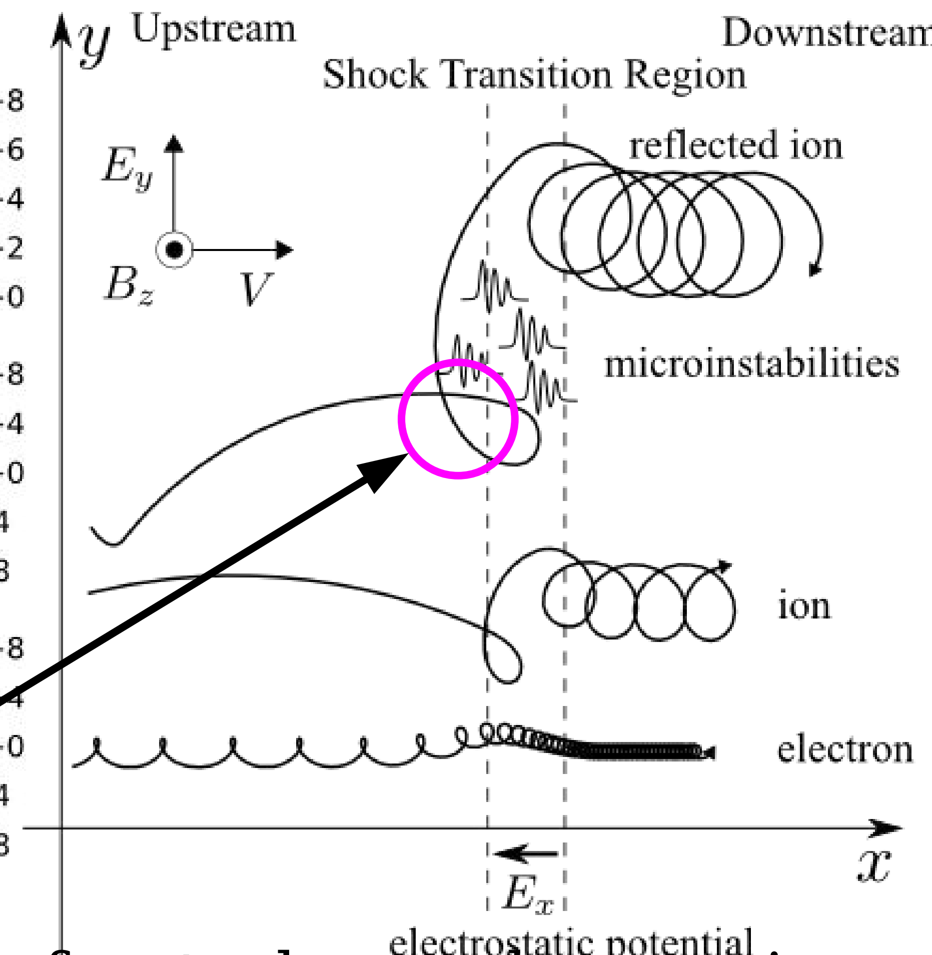
non-thermal / thermal energy ~ 10%

peak appears at $75 \leq \theta_{Bn} \leq 80$

2D Shock Structure

consider purely perpendicular shock with out-of-plane B-field => electron acceleration should occur in-plane



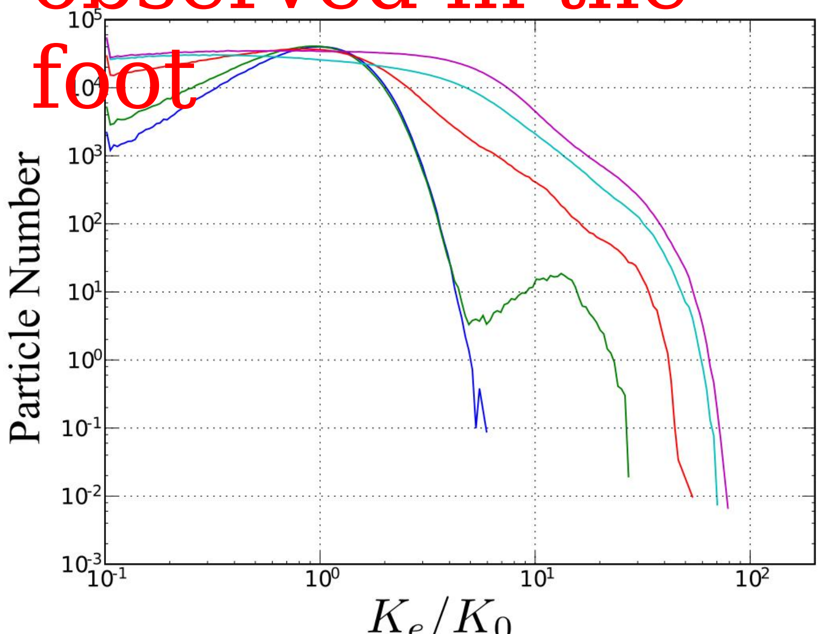


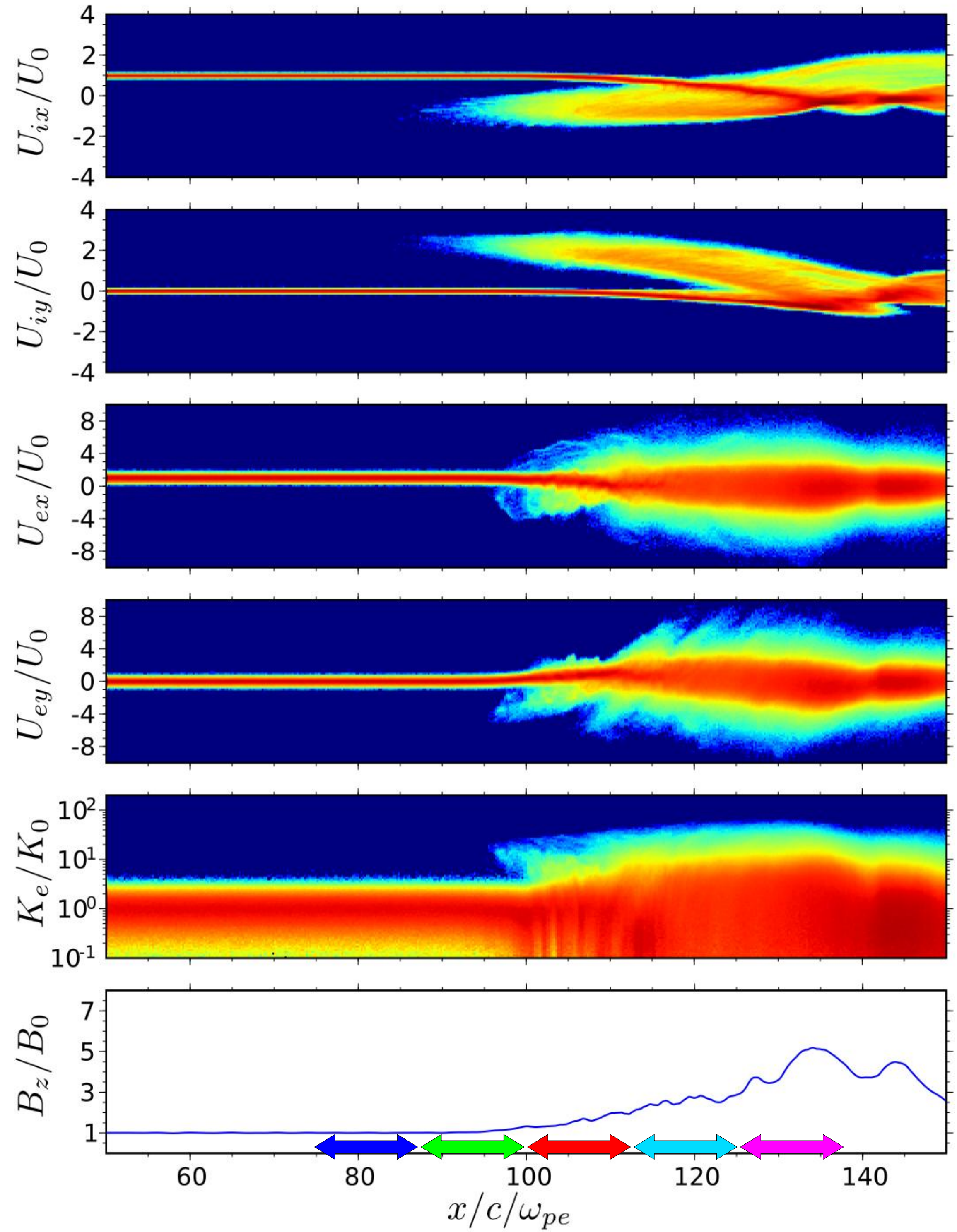
Buneman Instability

oblique wavefronts due to the rotation of the reflected ion beam

Electron Acceleration

strong electron acceleration is observed in the foot





Shock Parameter

m_i/m_e = 25

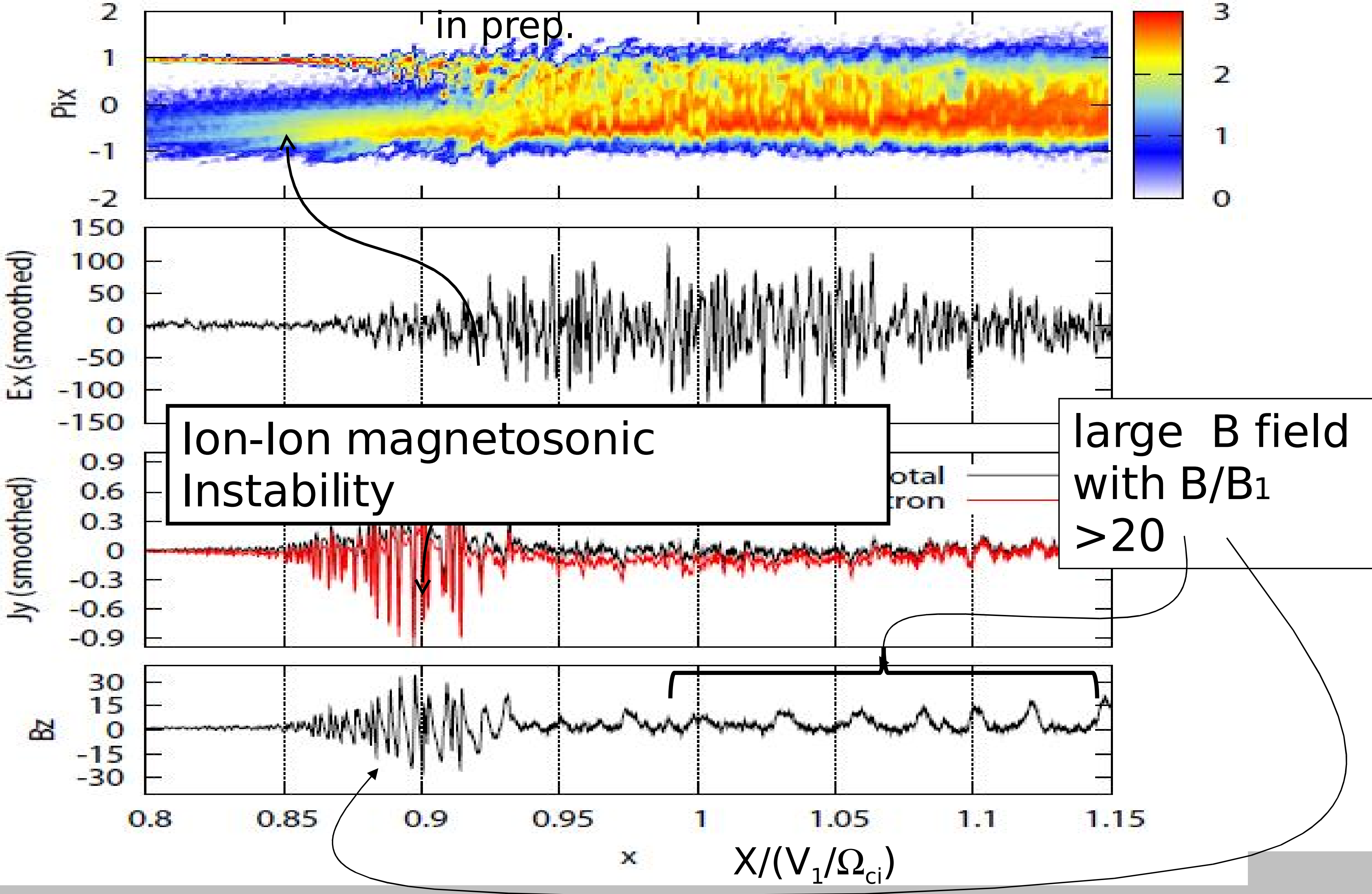
ω_{pe}/Ω_{ce} = 10

$\beta_i = \beta_e$ = 0.5

M_A ~ 14

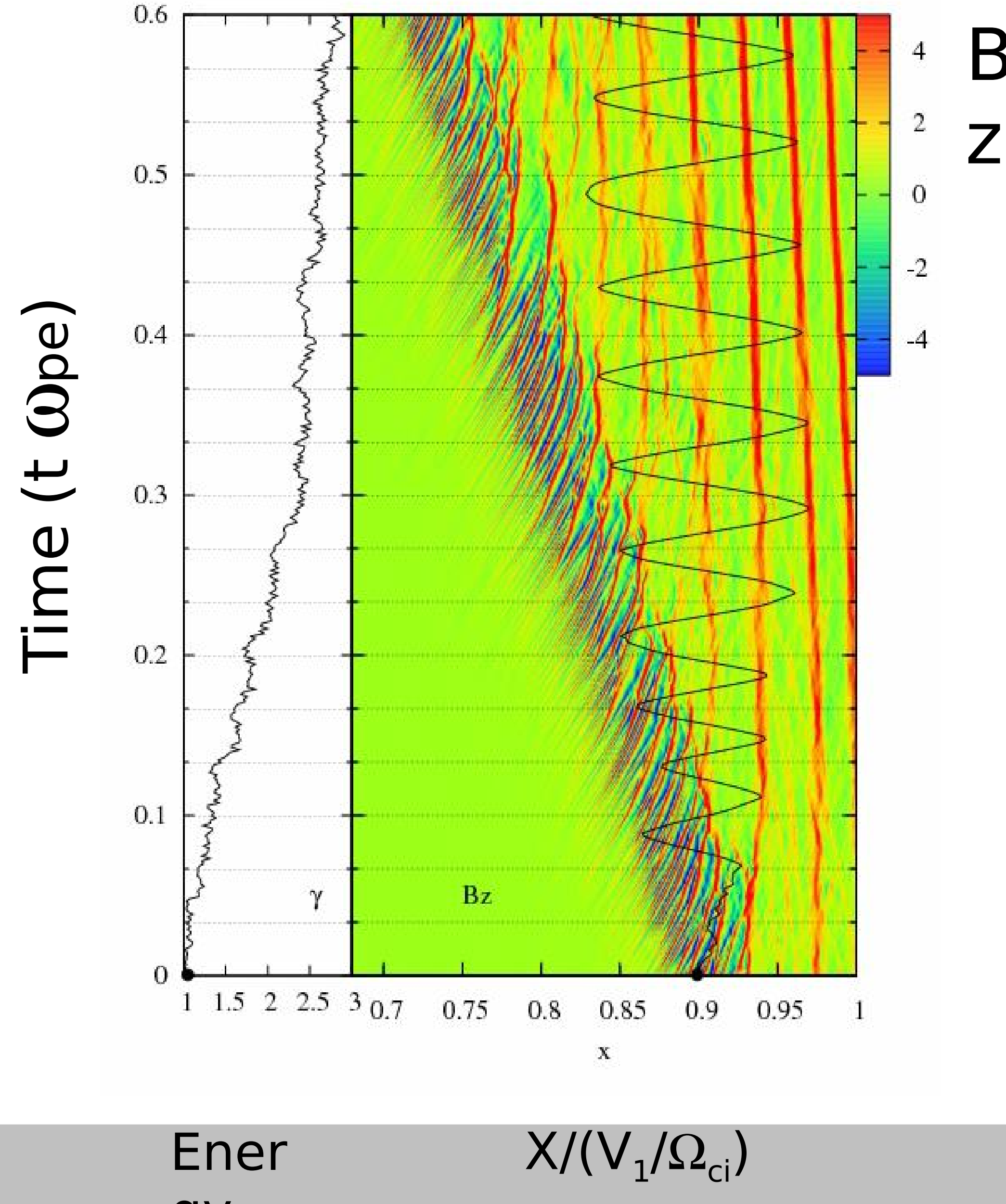
Very High Mach Number Shock (1D)

M_a =174, ω_{pe}/ω_{ce}=120, mi/me=100, in prep.   Shimada+



Fermi-like energy gain

- electrons confined in a thin shock layer are energized by a mechanism similar to Fermi acceleration
- large amplitude magnetosonic waves/solitons play a role
- caveat: 1D perp. shock, additional



Summary

the electron injection is difficult in general, but may be possible at high Mach number, Q-perp shocks

we still do not understand the physics of electron acceleration in Q-para shocks (inefficient, at least in-situ observations at relatively low Mach number shocks)

injection of protons are unlikely to occur in Q-perp shocks, but the self-generated turbulence may change the situation