高マッハ数衝撃波における磁気リコネクション誘発と電子加速

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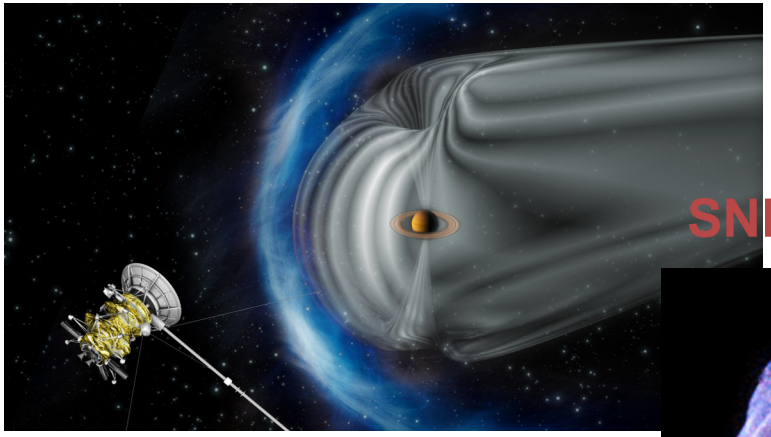
Collisionless shocks as particle accelerators

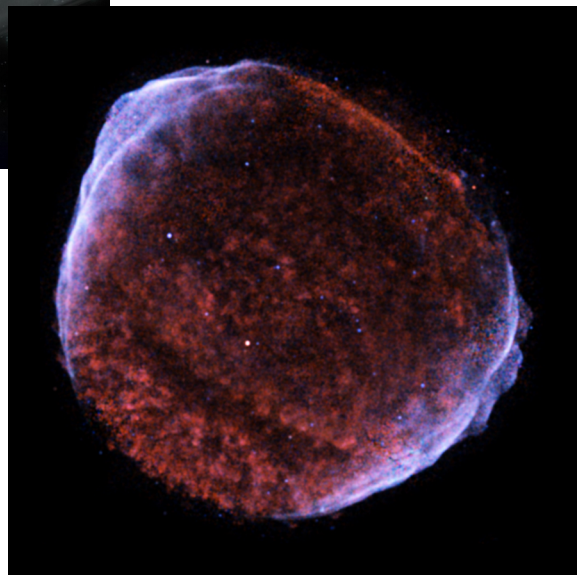
Planetary bow shocks



e.g., Masters+ '13

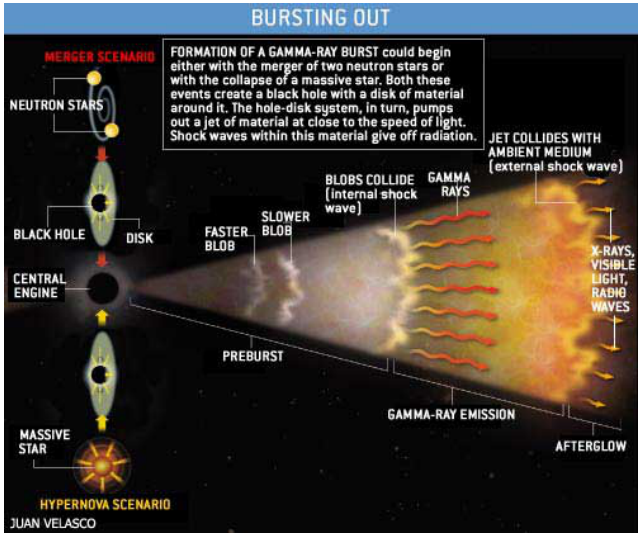
v_{sh}/c

SNR shocks (M_A>100)



e.g., Bamba+ 03

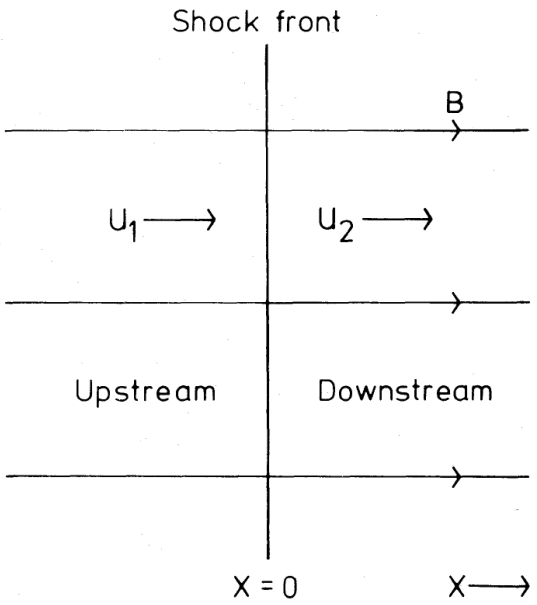
GRBs, AGN jets (v_{sh} ~ c)



e.g., Meszaros '01

Theoretical issues

- Injection
  - Shock scale $L \sim \alpha\lambda_i >> r_{ge}$
  - Thermal electrons are strongly magnetized
  - $\gamma_e > \sim 10$ can be injected
  - Pre-acclerations for electrons are necessary

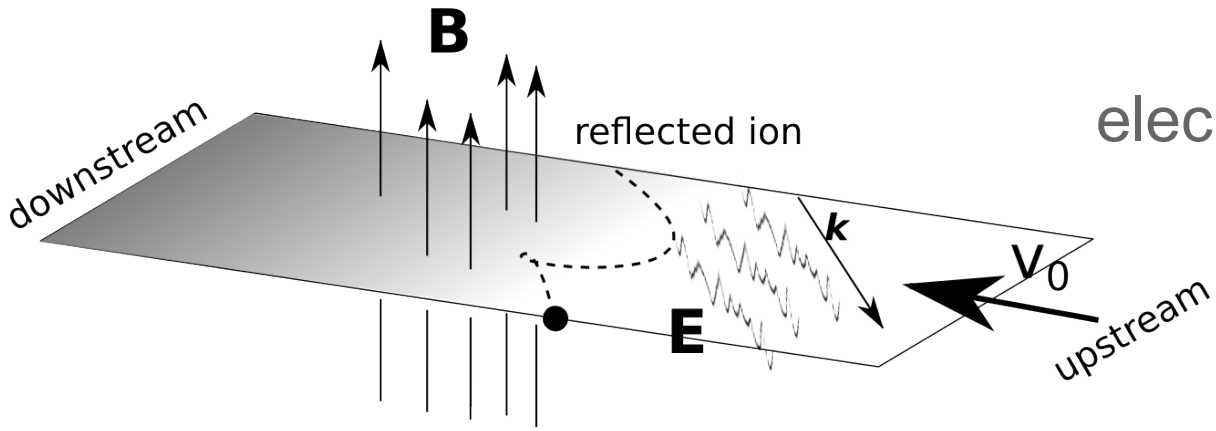


Bell, 1974

- Scattering bodies
  - Alfven waves – preferential in paralllel shocks
  - magnetic clouds – found in perpendicular shocks (this work)
  - magnetic field amplification (x ~100)

Physics in high M_A shocks

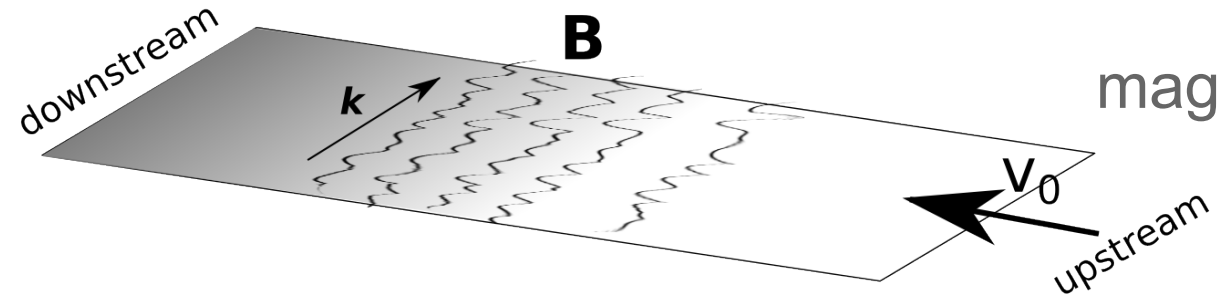
out-of-plane field



$\boldsymbol{k} \perp \mathbf{B}_0$

elecron pre-acceleration

in-plane field

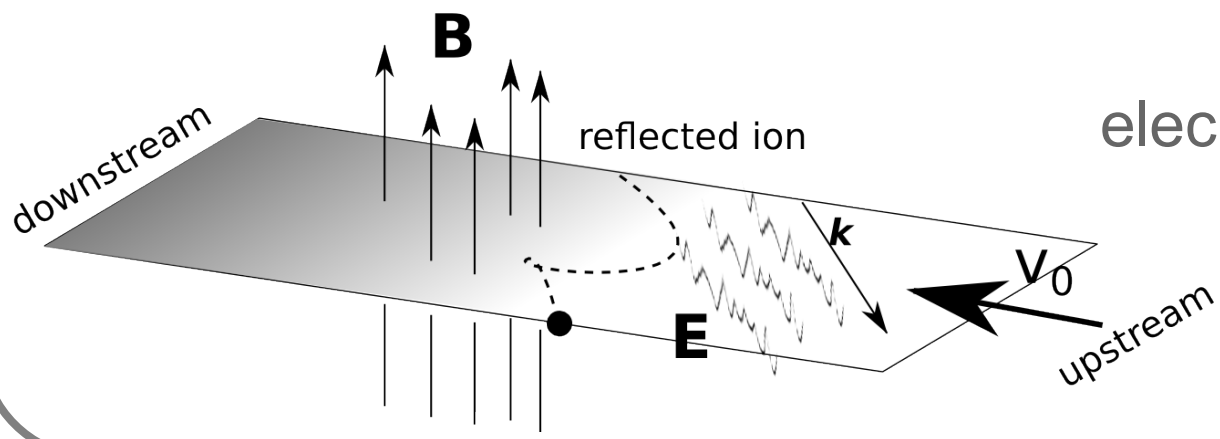


$\boldsymbol{k} \parallel \mathbf{B}_0$

magnetic field turbulence

Physics in high M_A shocks

out-of-plane field



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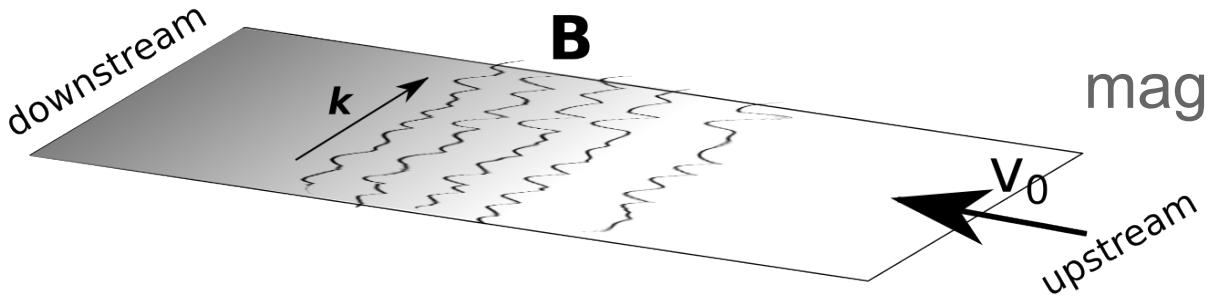
elecron pre-acceleration

in-plane field



$\boldsymbol{k} \parallel \mathbf{B}_0$

magnetic field turbulence

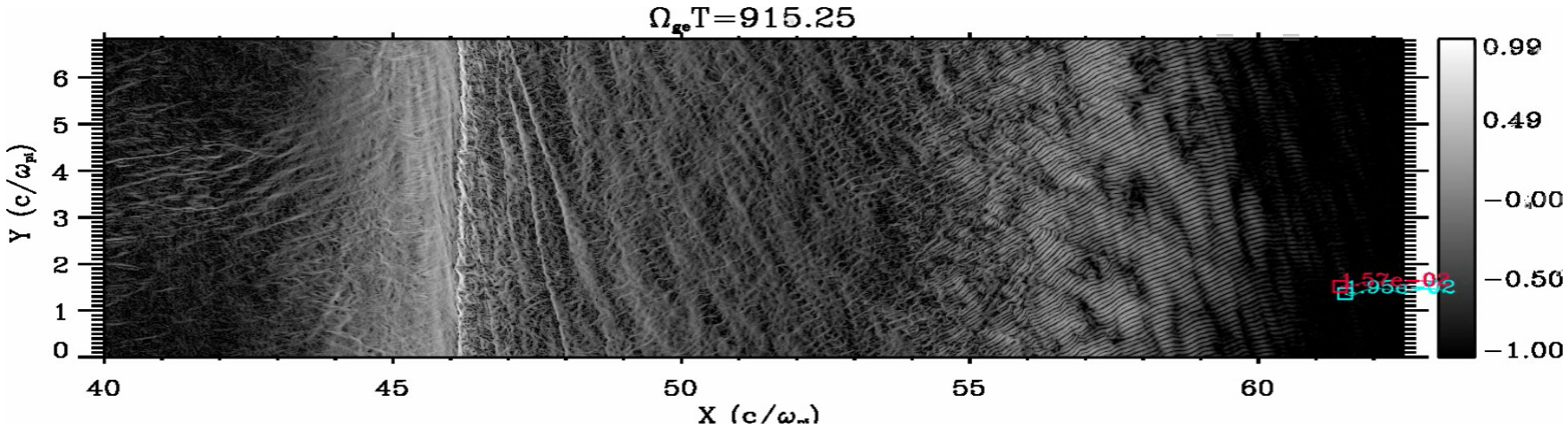
M/m=225, M_A~45 shock

Electron shock surfing acceleration

downstream

$|E_{es}|/B_0$

upstream



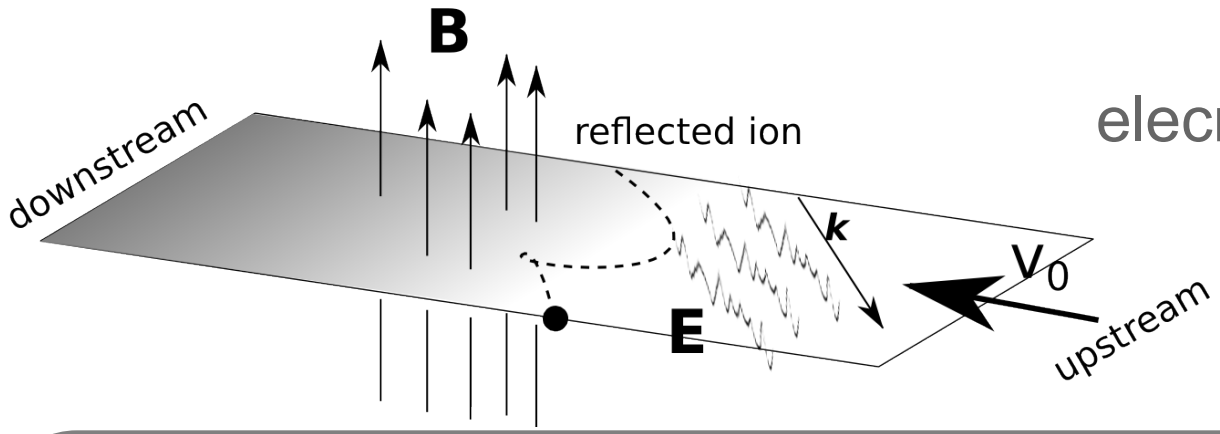
Matsumoto+ '13 *PRL*

:accelerated

:thermal

Physics in high M_A shocks

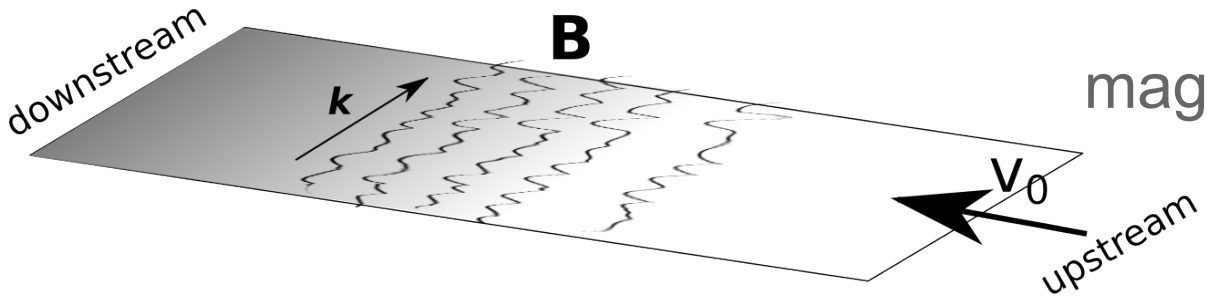
out-of-plane field



$\boldsymbol{k} \perp \mathbf{B}_0$

elecron pre-acceleration

in-plane field

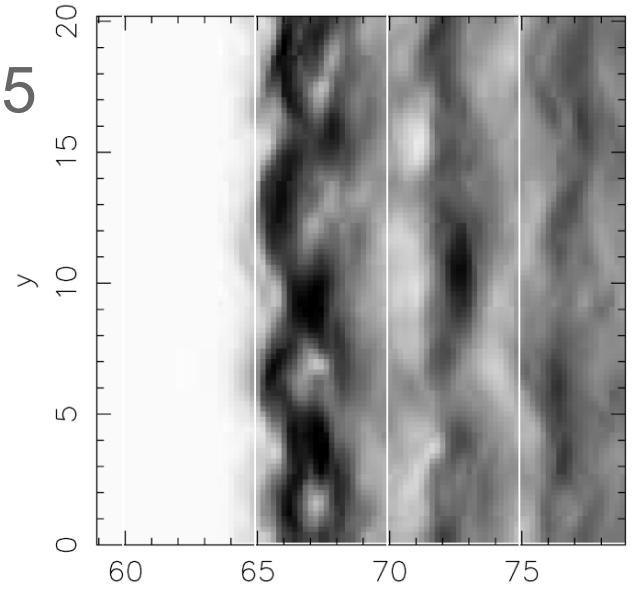


$\boldsymbol{k} \parallel \mathbf{B}_0$

magnetic field turbulence

In-plane **B** field case

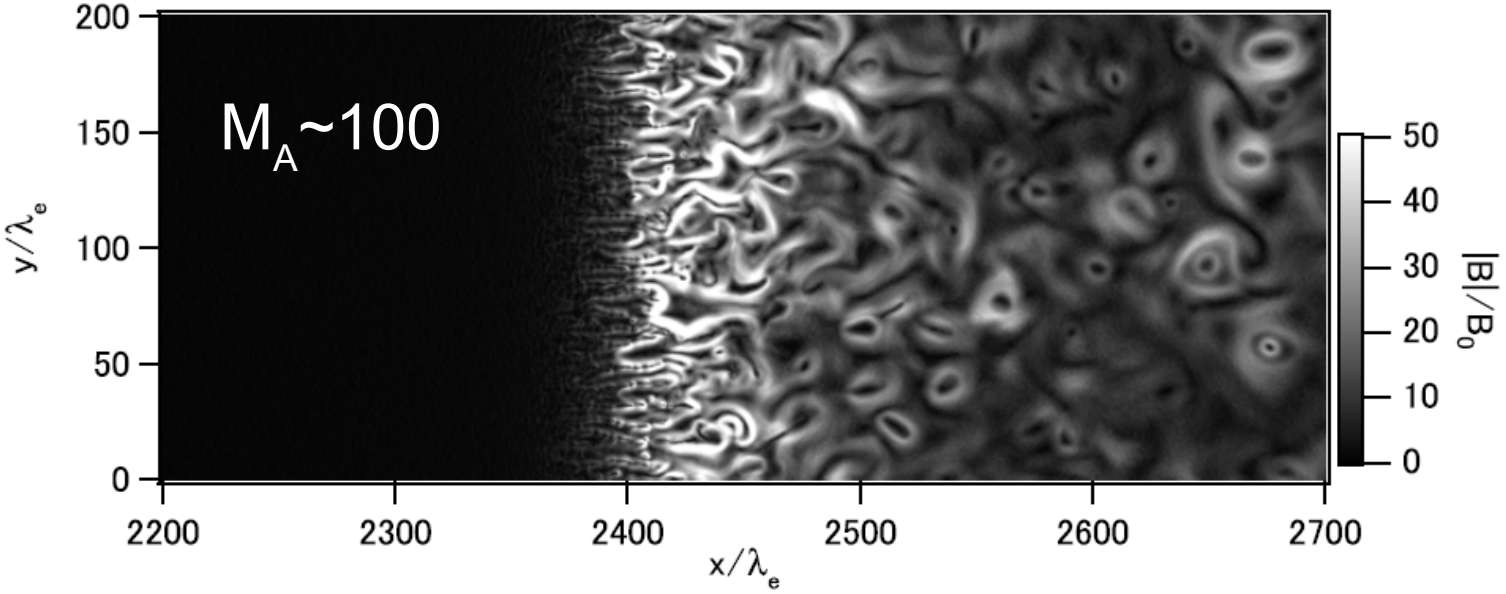
M_A~5



- Ion-scale ripples along the shock surface
- Ion cycrotron-instability
- Ion-beam Weibel instability
- Origin of ion-scale magnetic field turbulence

Burgess, '06

Kato & Takabe, '11

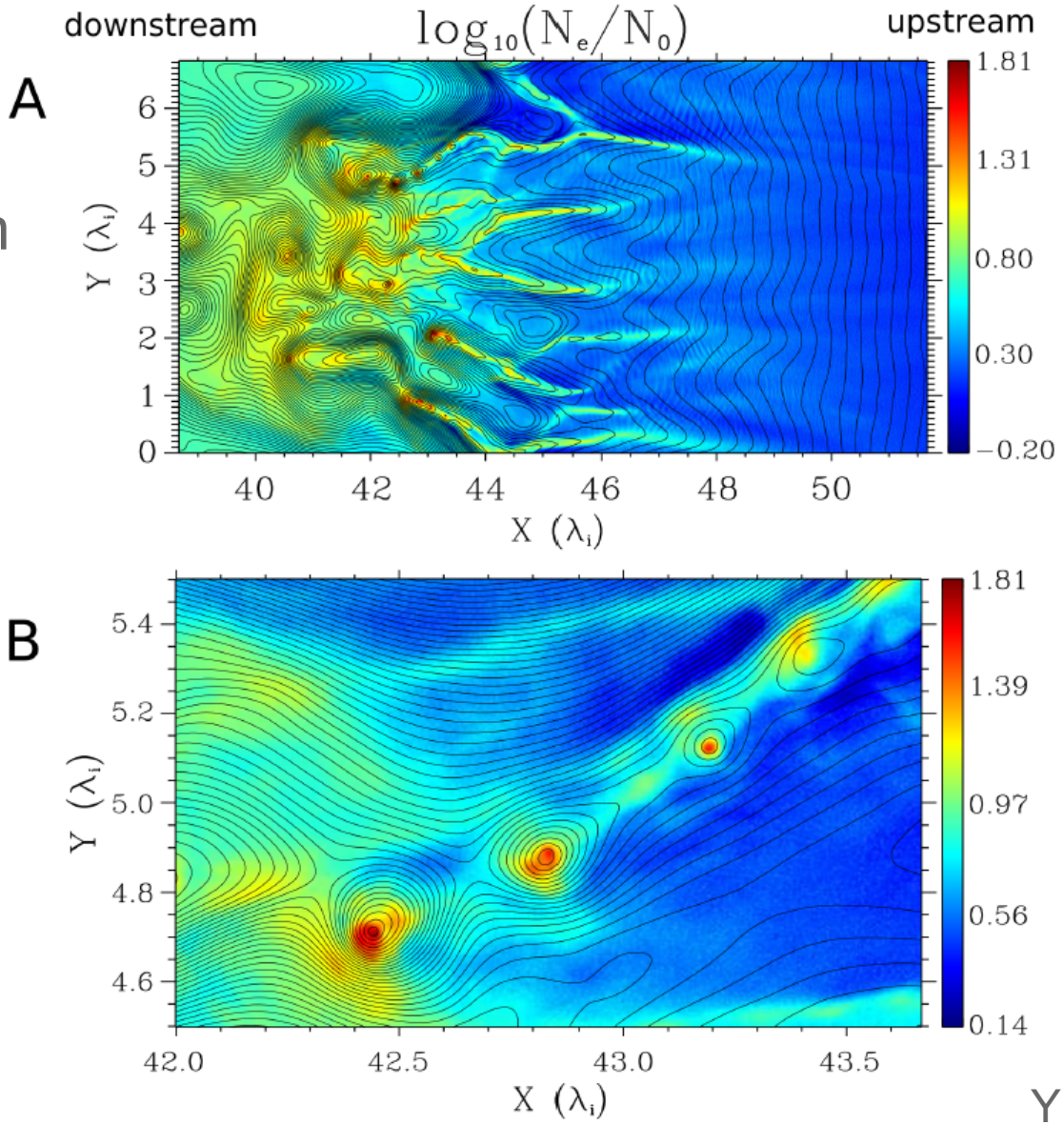


Shock experiments on supercomputer systems

- SIMD-optimized 2D PIC code
- Injection method for shock creation
- Moving injector (Riquelme & Spitkovsky '11)
- M/m = 225
- M_A~41.7, M_s~45.7 (v_{sh}/c ~ 0.28)
- N_p ~ up to 10^{10} particles (24000 x 2048 cells)
- 256 nodes (x 8 cores)

Overview around the shock front

downstream

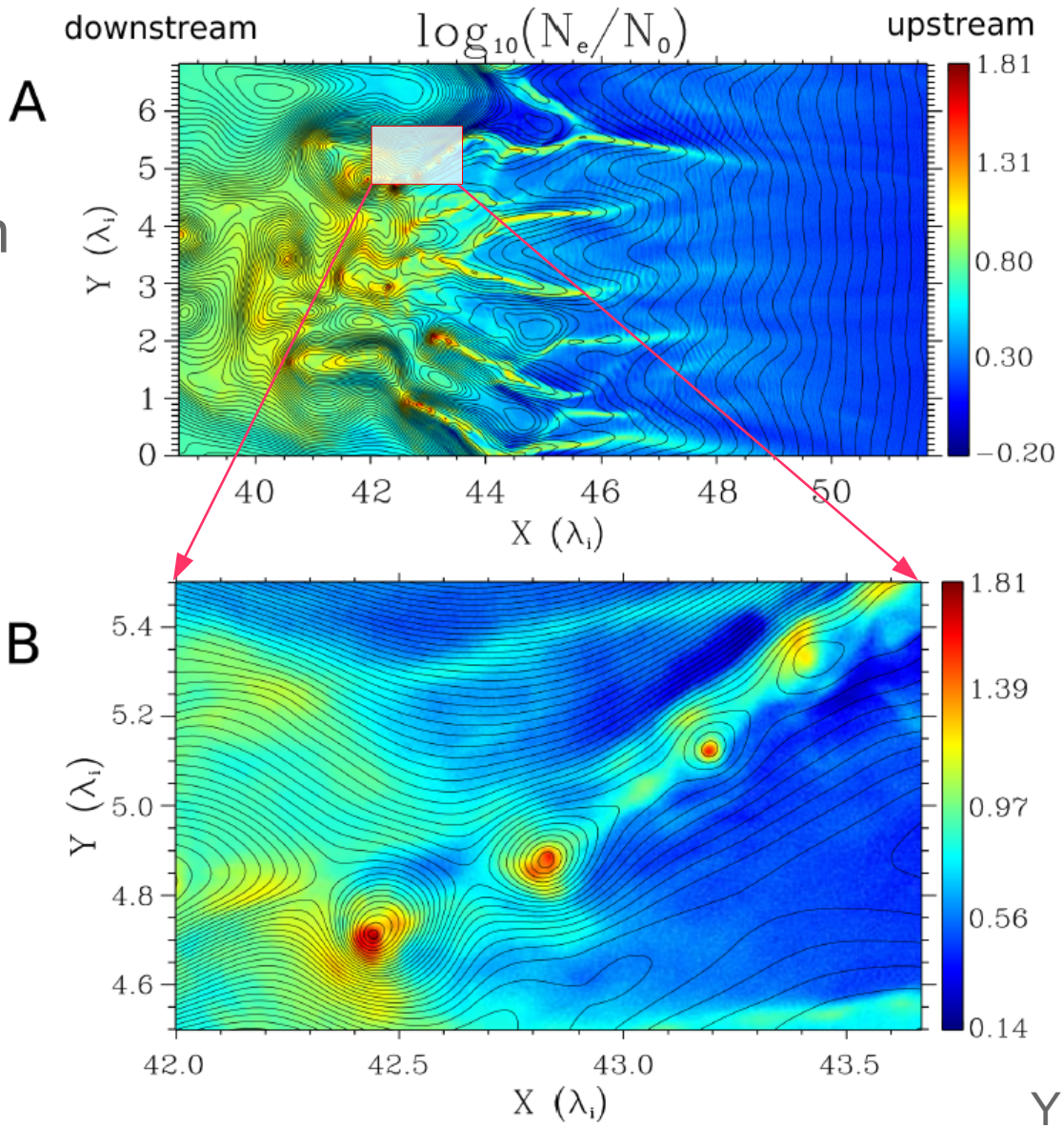


upstream

YM+ submitted

Overview around the shock front

downstream

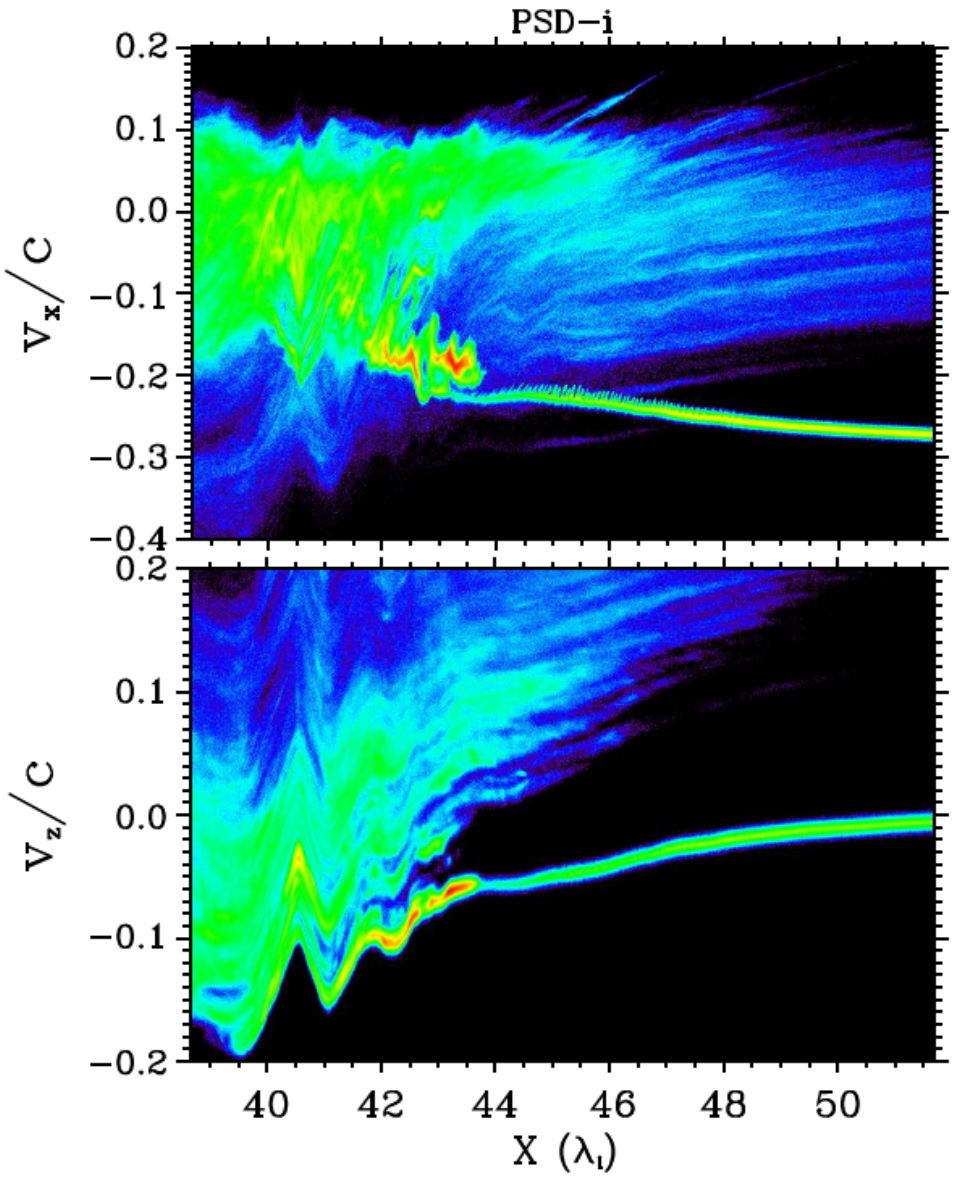


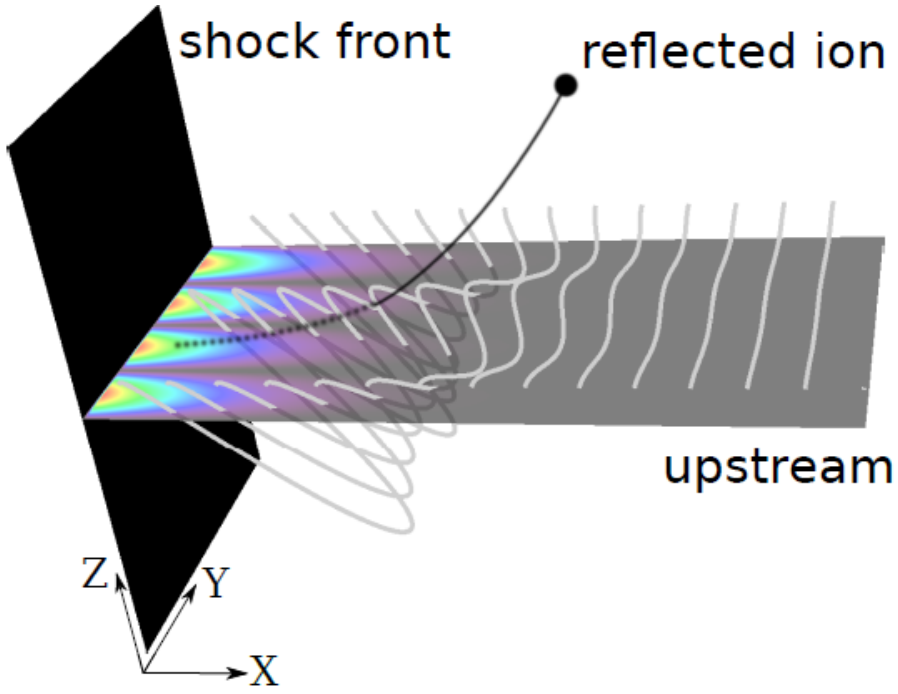
upstream

YM+ submitted

Current sheet formation via ion Weibel instability

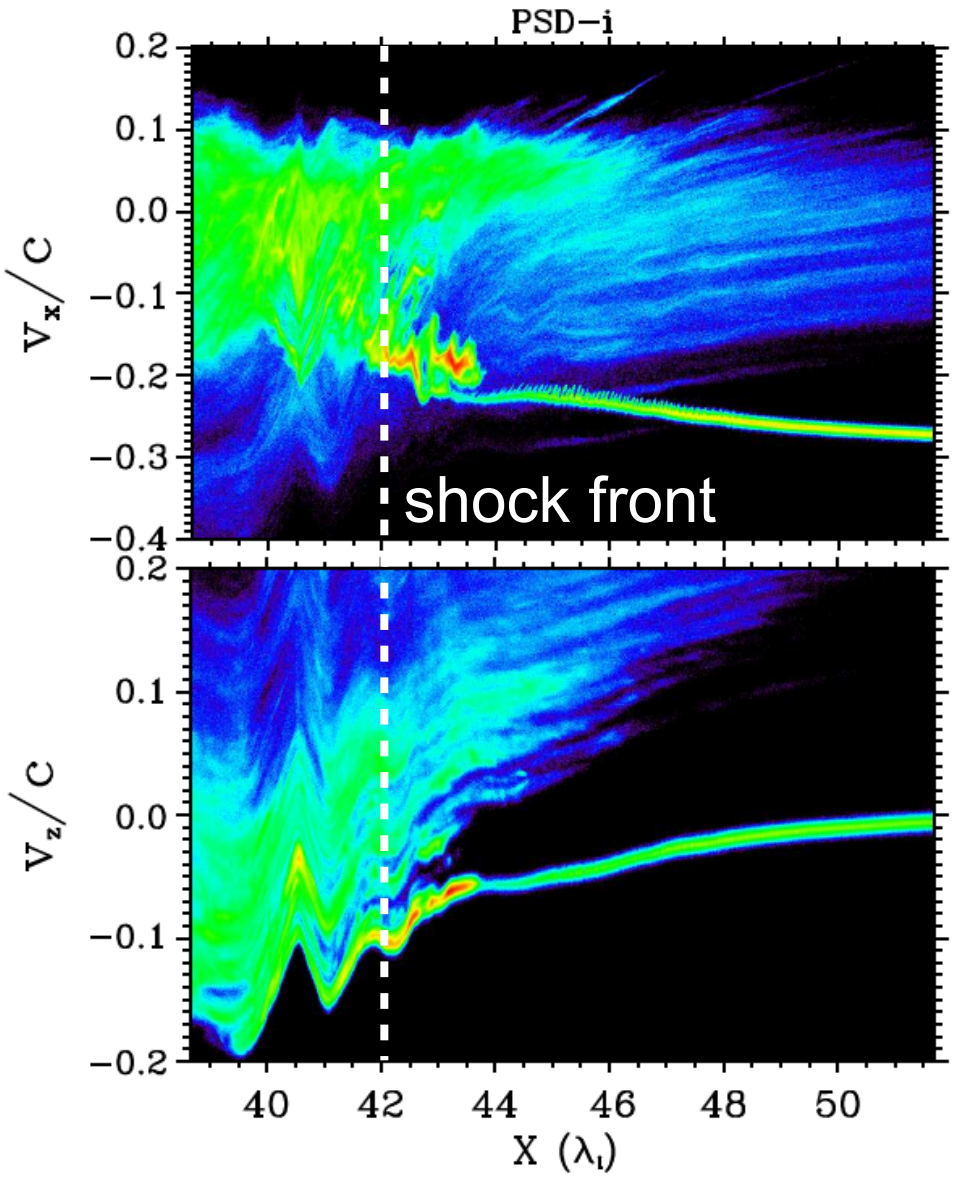
cf. Kato & Takabe 08,10

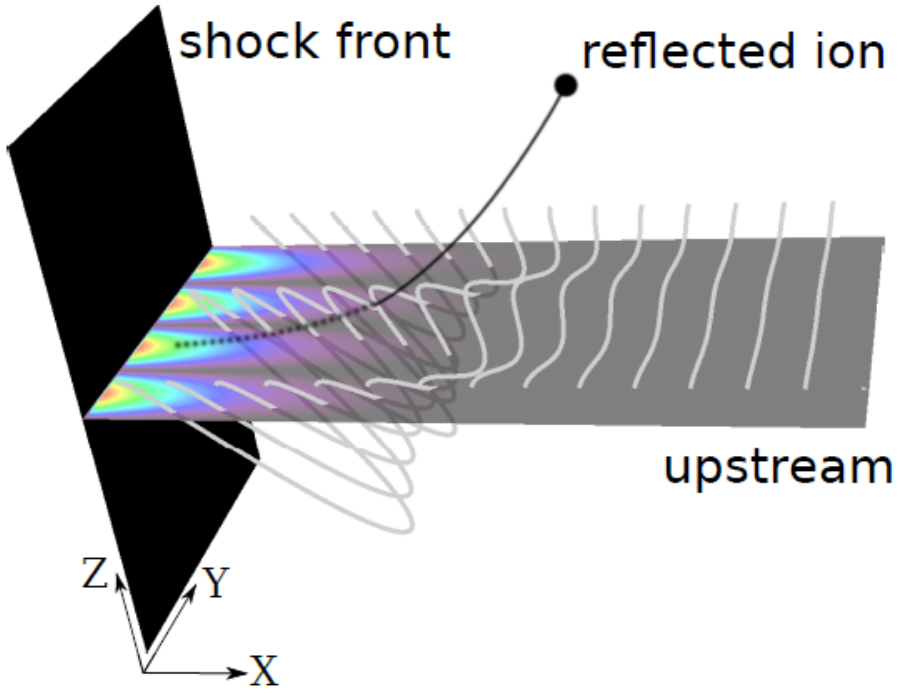




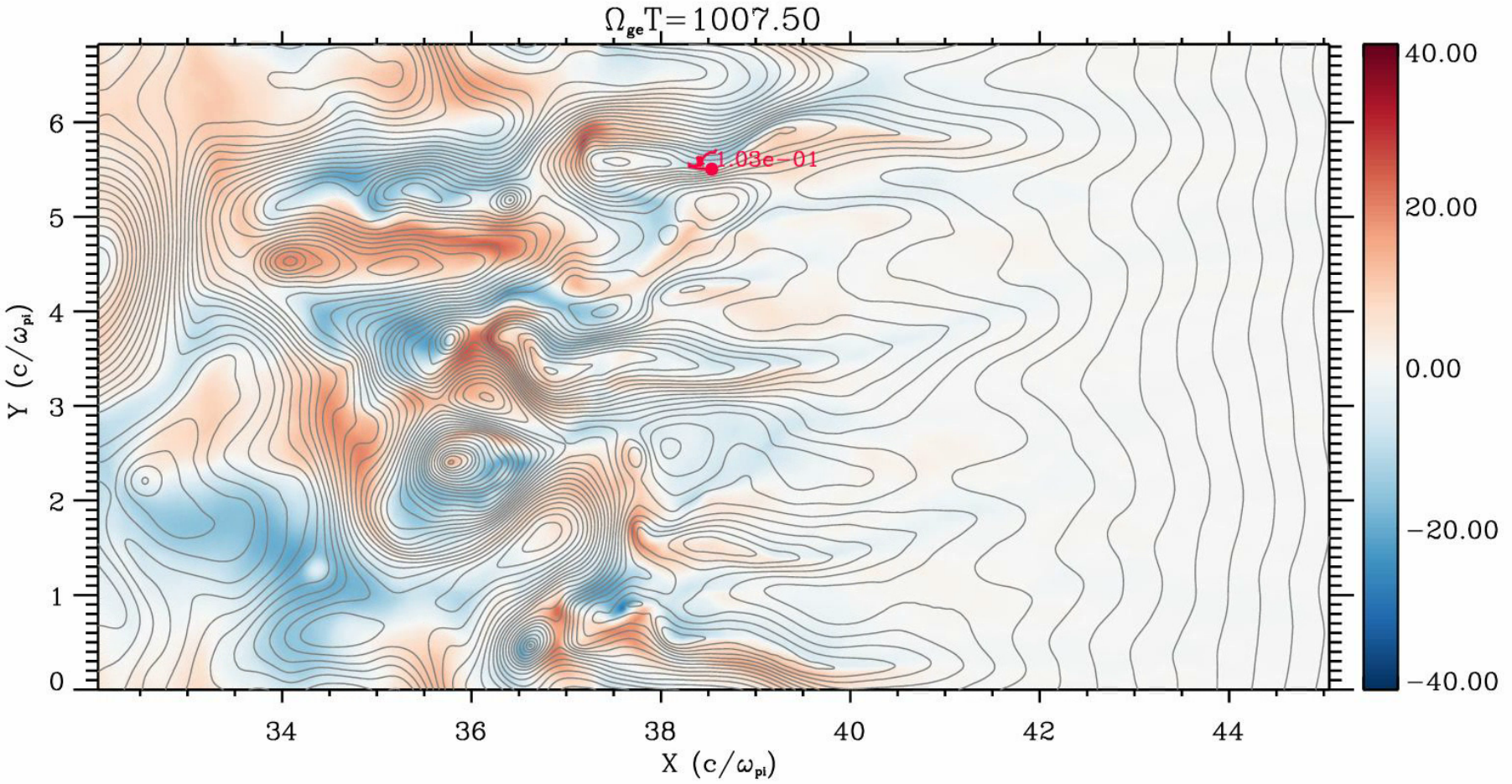
Current sheet formation via ion Weibel instability

cf. Kato & Takabe 08,10



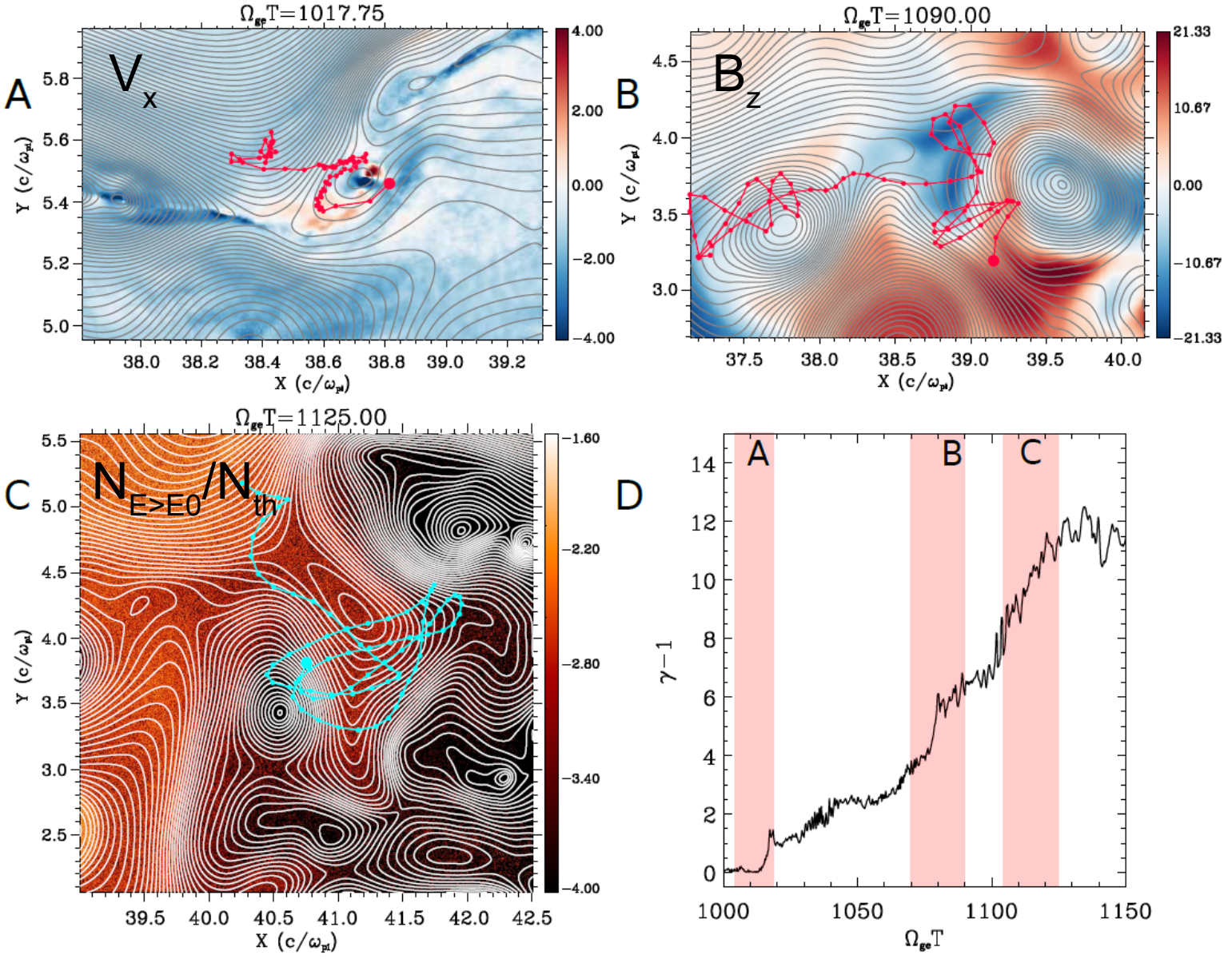


Stochastic electron acceleration

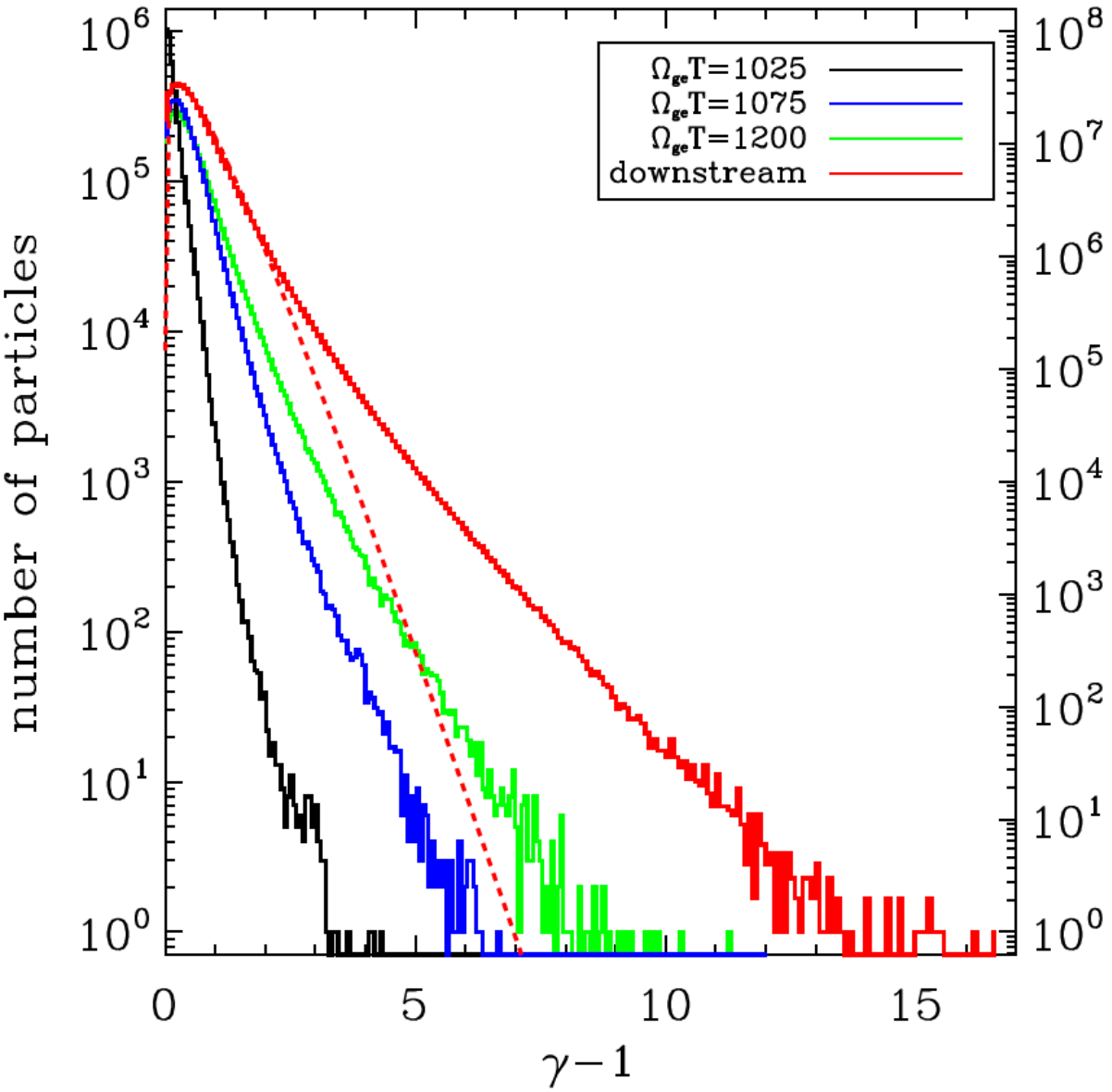


blue: B_z component, gray: in-plane **B** field lines, red: electron orbit

Stochastic electron acceleration (contd.)

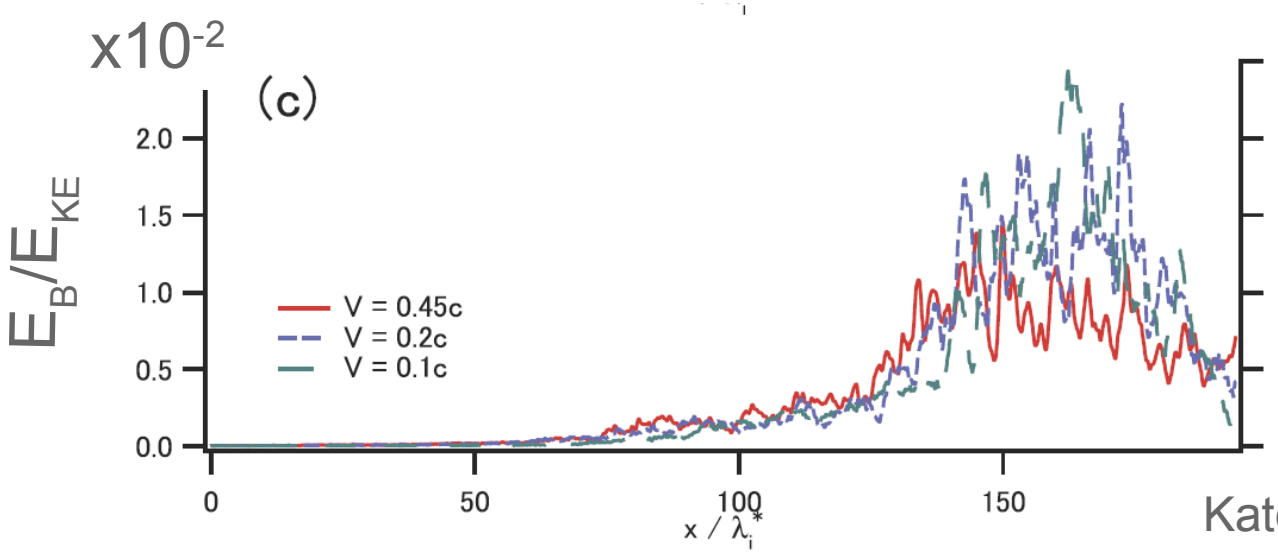


Time evolution of energy distribution



Condition for turbulent reconnection

- イオンワイベル不安定の飽和磁場強度B_{iw} >> 上流磁場B_0
- 不安定の飽和磁場エネルギーはビームの運動エネルギーの1-2%（ここでは１%）



Kato & Takabe '08

$$B_{iw} \sim 0.1\sqrt{4\pi\rho_0 V_0^2} \gg B_0$$

$$M_A \gg 10$$

Summary

- 無衝突衝撃波の中規模２次元PICシミュレーション（M/m=225, $M_{A,s}$>40）
- 強い衝撃波（M_A>>10）ではイオンワイベル不安定を介した乱流リコネクションでエネルギー散逸
- 上流電子の一部はリコネクションジェット・磁気島と弾性衝突を何度も繰り返すことによりエネルギーを獲得（cf. Hoshino '12 PRL)
- 磁気リコネクションが介在した電子加速過程を世界で初めて解明
- XC30を用いて、衝撃波角依存性の調査
- それを元に「京」で大規模3次元PIC計算中