Workshop: Kinetic Physics of Astrophysical Plasmas

Electron–Ion Energy Partition in Supernova Remnant Shocks: A Monte Carlo-Particle-In-Cell Approach

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Background: How are particles energized in perpendicular shocks?

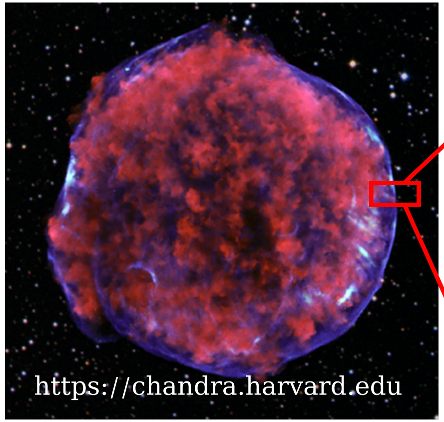
Particle energization in:

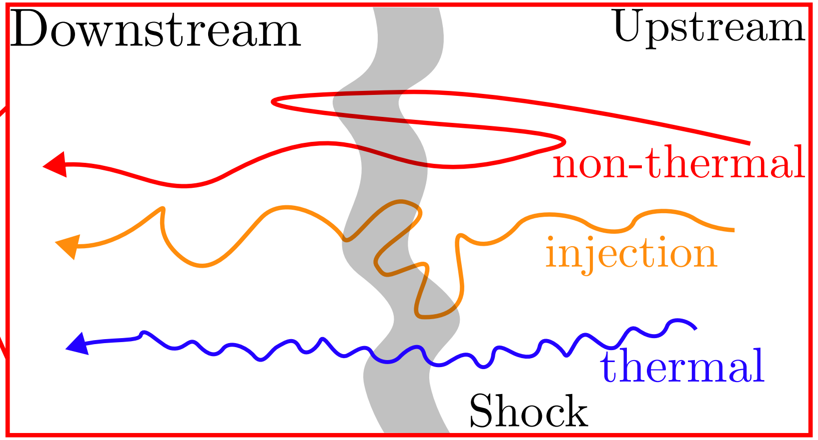
- weakly magnetized
- non-relativistic
- perpendicular shock

$l_{\mathrm{diff}} > L_{\mathrm{sh}}$

$l_{\mathrm{diff}} \sim L_{\mathrm{sh}}$

$l_{\mathrm{diff}} \ll L_{\mathrm{sh}}$

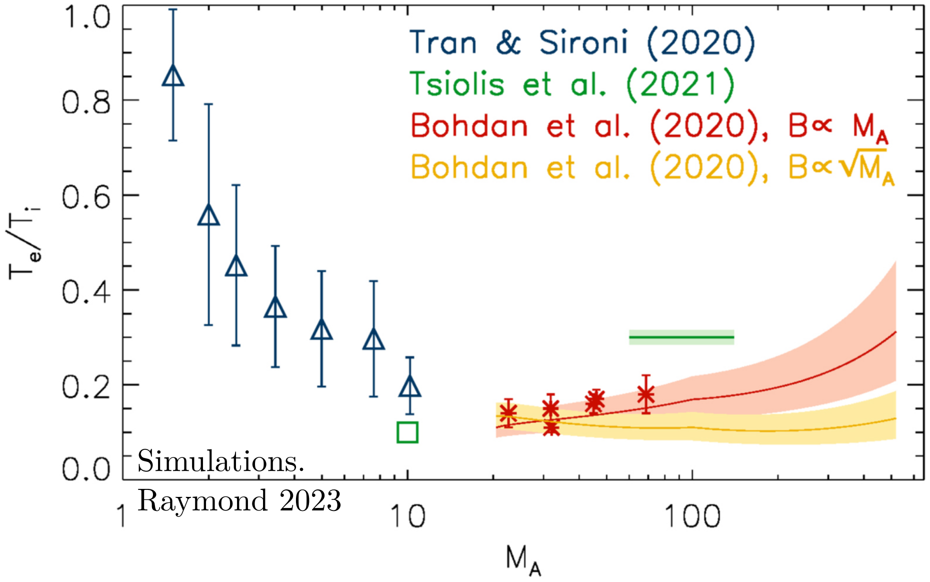




Fermi acceleration
for high-energy particle

Heating through
inter-species interaction

M_{A} dependence of $T_{\mathrm{e}}/T_{\mathrm{i}}$



Scale at r_{L}

Kinetic Scales

→ A reduced method

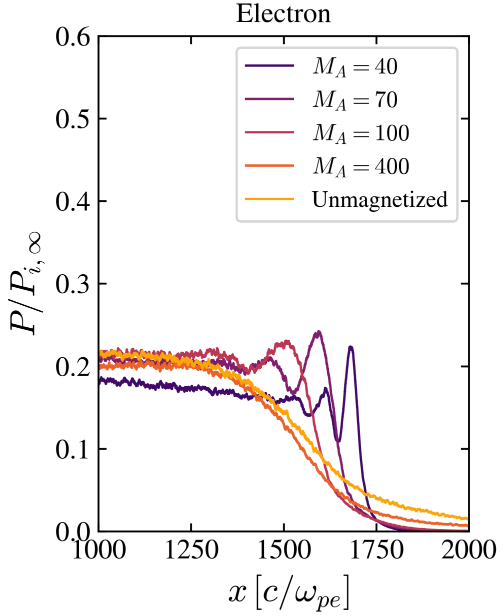
Monte Carlo-Particle-In-Cell Method

Background Field | Kinetic Turbulence

$$\frac{\mathrm{d}p^i}{\mathrm{d}t} = \boxed{qF^b{}_a p^a} + \boxed{q\delta F^b{}_a p^a}$$

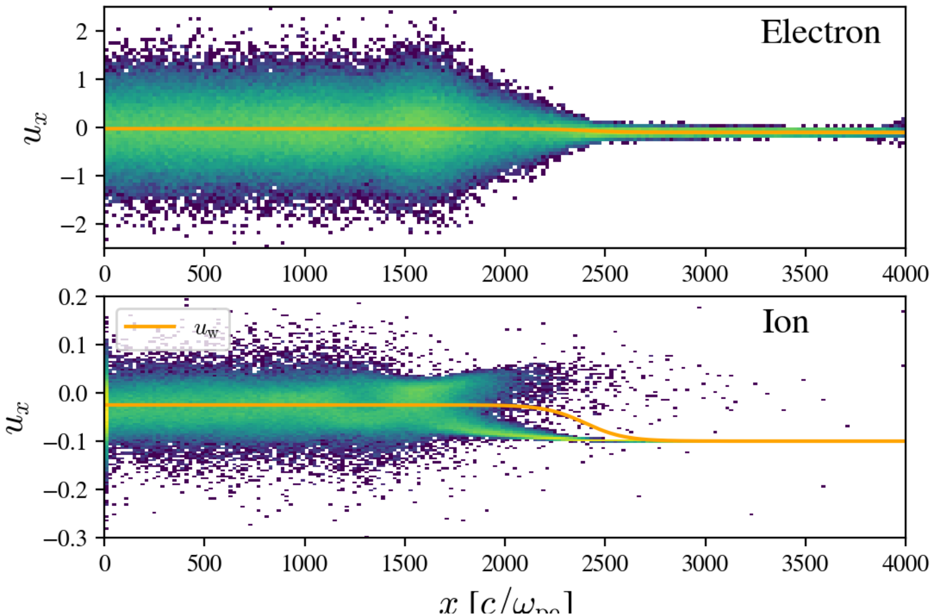
PIC | Monte Carlo

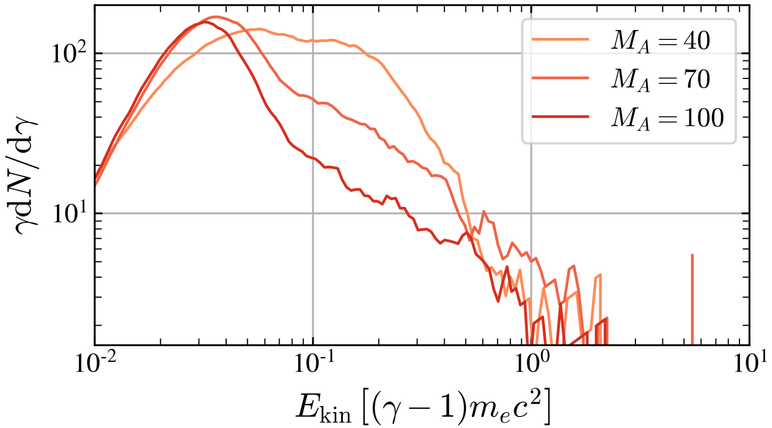
$$\Rightarrow \boxed{qF^b{}_a p^a} + \boxed{\text{Scattering}}$$



← Electron heating

Ion acceleration →
Under the same picture

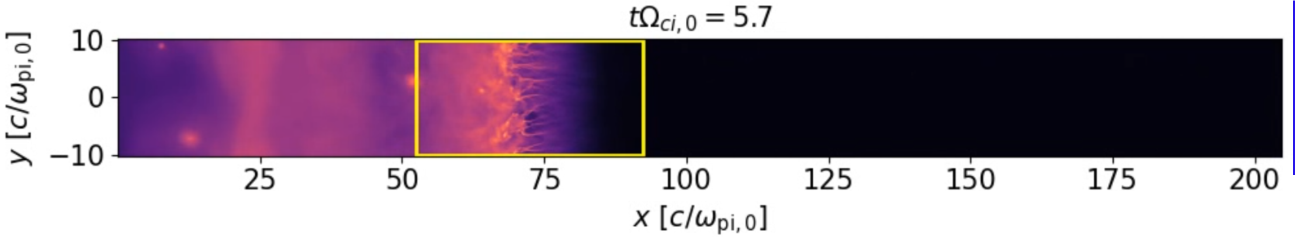


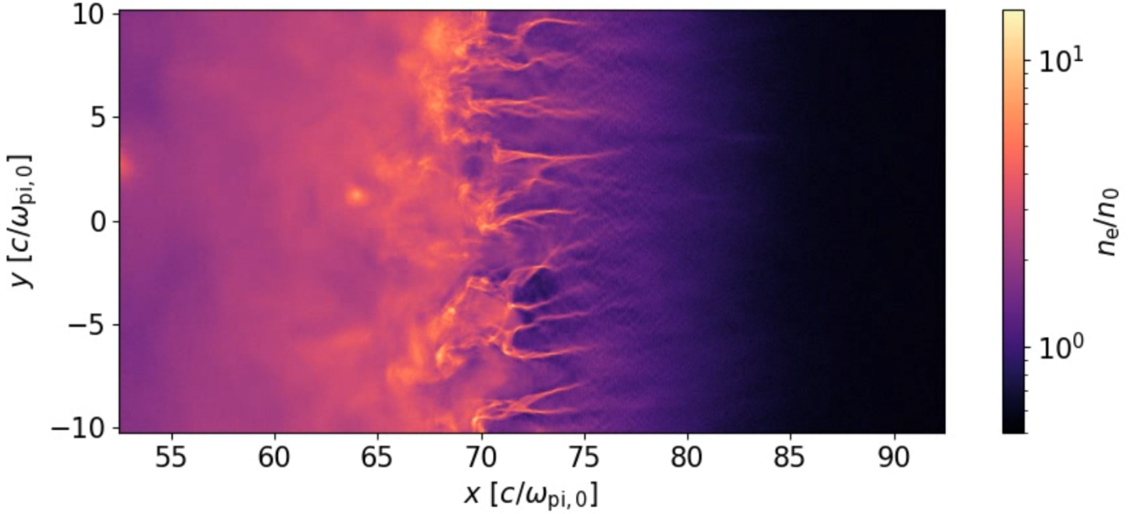


PIC Simulation

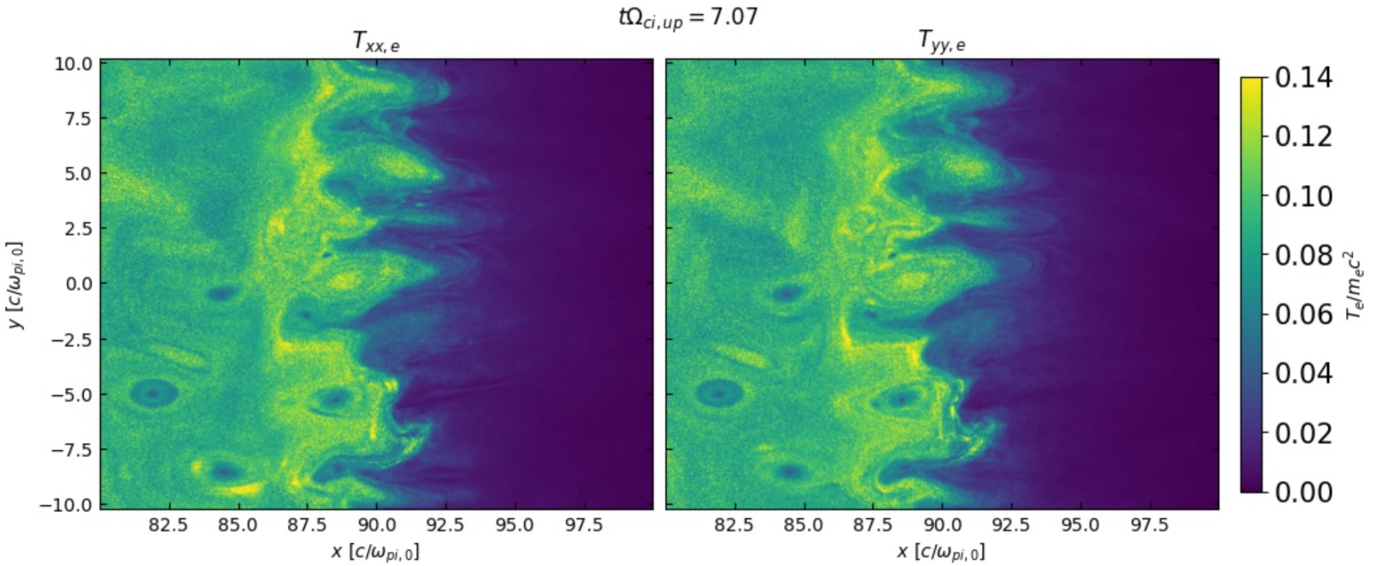
2D3V PIC simulation
perpendicular shock [1]

- $m_\mathrm{i}/m_\mathrm{e} = 400$, $u_\mathrm{sh} = 0.1$, $M_\mathrm{A} \sim 40$, $\beta \sim 0.08$
- 20480×2048 ($x \times y$ in cells), $\Delta x = 0.2\, c/\omega_\mathrm{pe0}$
- $t_\mathrm{sim} = 80000\, \omega_\mathrm{pe0}^{-1}$, $\Delta t = 0.099\, \omega_\mathrm{pe0}^{-1}$
- 2nd order particle shape function[2]





Density plot of electrons



Temperature plots in x and y

With PIC, we can find out:
- electron heating location
- temperature anisotropy
- electron transport

Goal: Understand energy partitioning at the shock

[1] run on 64 AMD Instinct™ MI250X with ENTITY (pusher time 0.6ns/particle/step)
[2] Böss et al. 2026 arxiv.org/abs/2605.15260