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Title: Particle Acceleration at Parallel Shocks: a fully kinetic simulation

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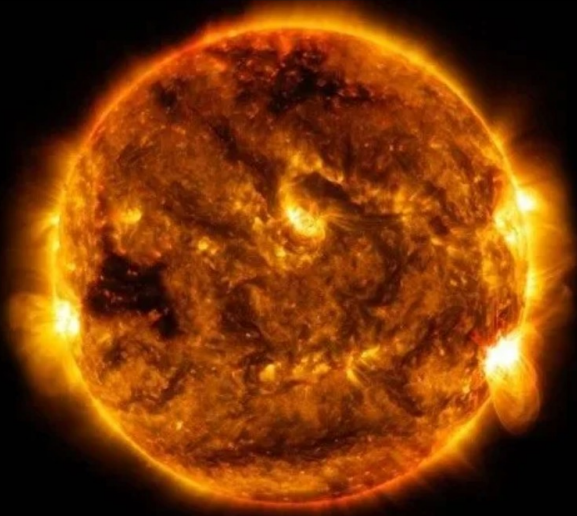


Particle Acceleration at Parallel Shocks: a fully kinetic simulation

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(NASA/SDO)

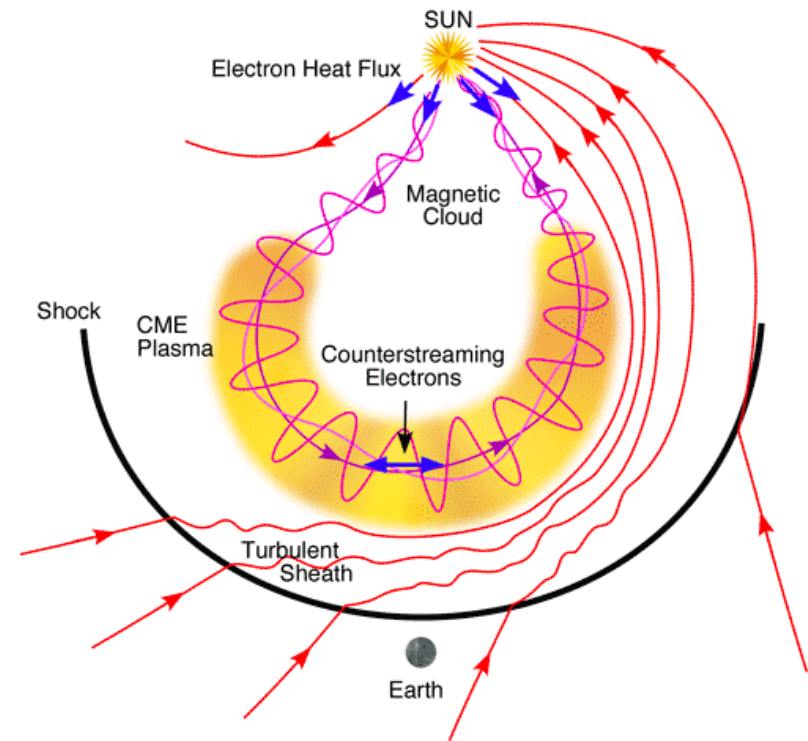
SPACE

Unexpected Solar Wind Stream Hits Earth at 372 Miles Per Second

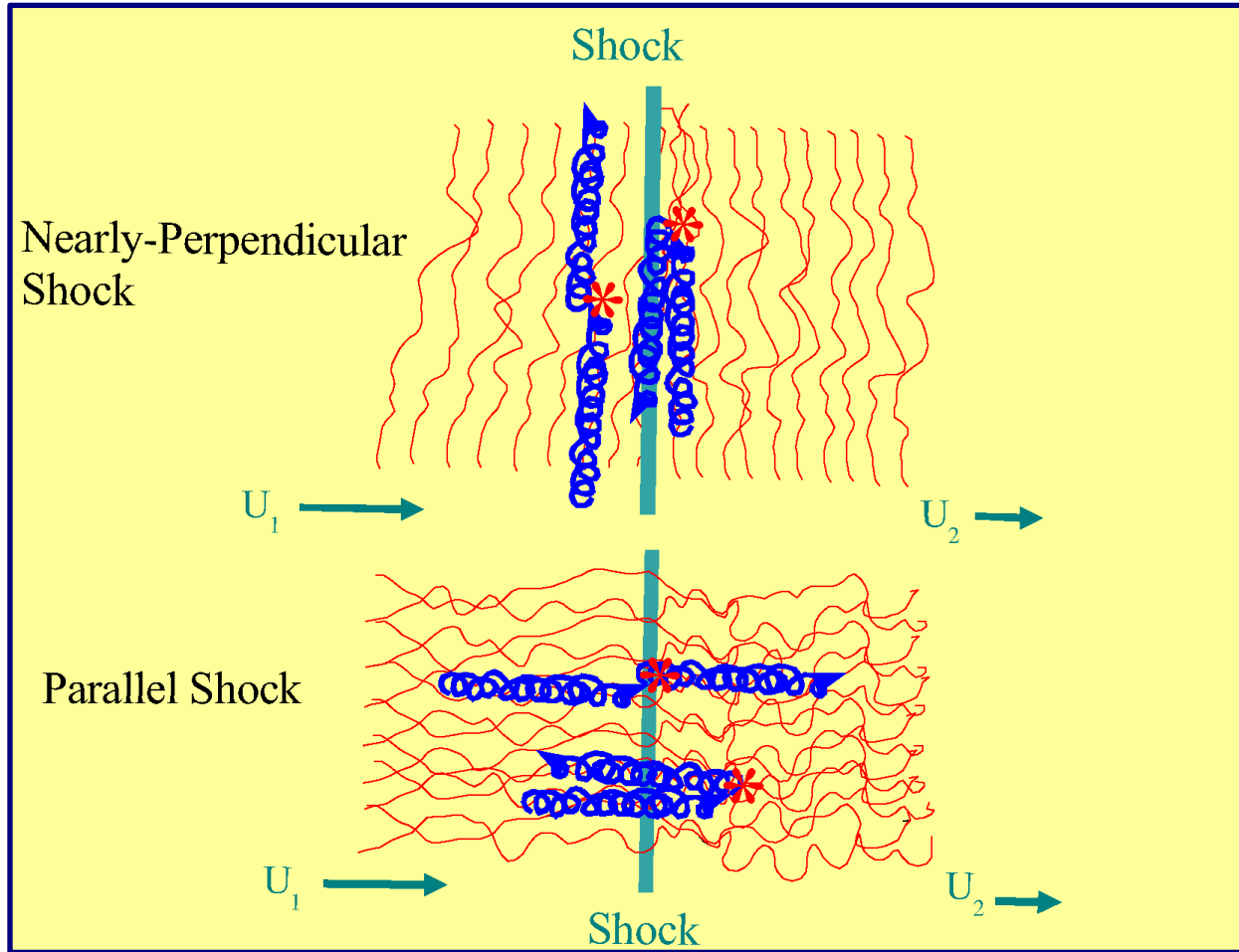
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Solar energetic particles are high-energy charged particles accelerated by solar flares and coronal mass ejections (CMEs).



Diffusive shock acceleration

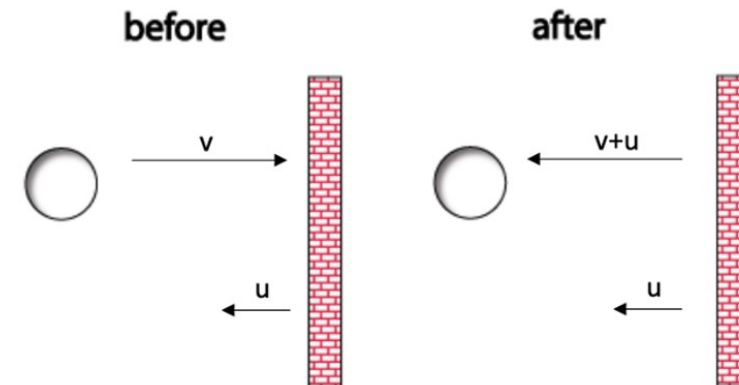


Shock drift acceleration (perpendicular shock)

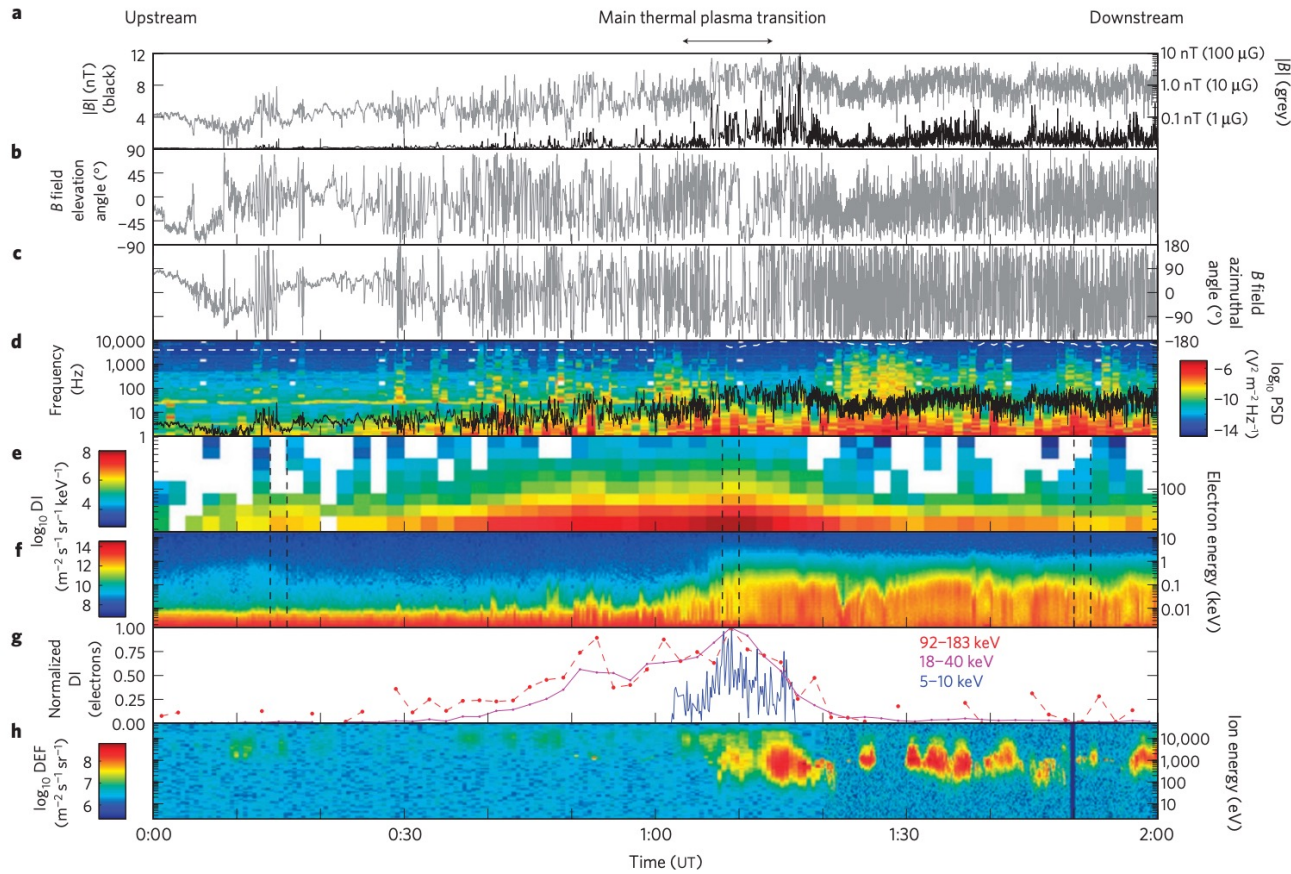
$$\mathbf{v}_{\nabla B} = \frac{K_{\perp}}{qB} \frac{\mathbf{B} \times \nabla B}{B^2} \quad \text{Grad-B drift}$$

$$\mathbf{E} = -\mathbf{U}_i \times \mathbf{B}_i / c \quad \text{Convection electric field}$$

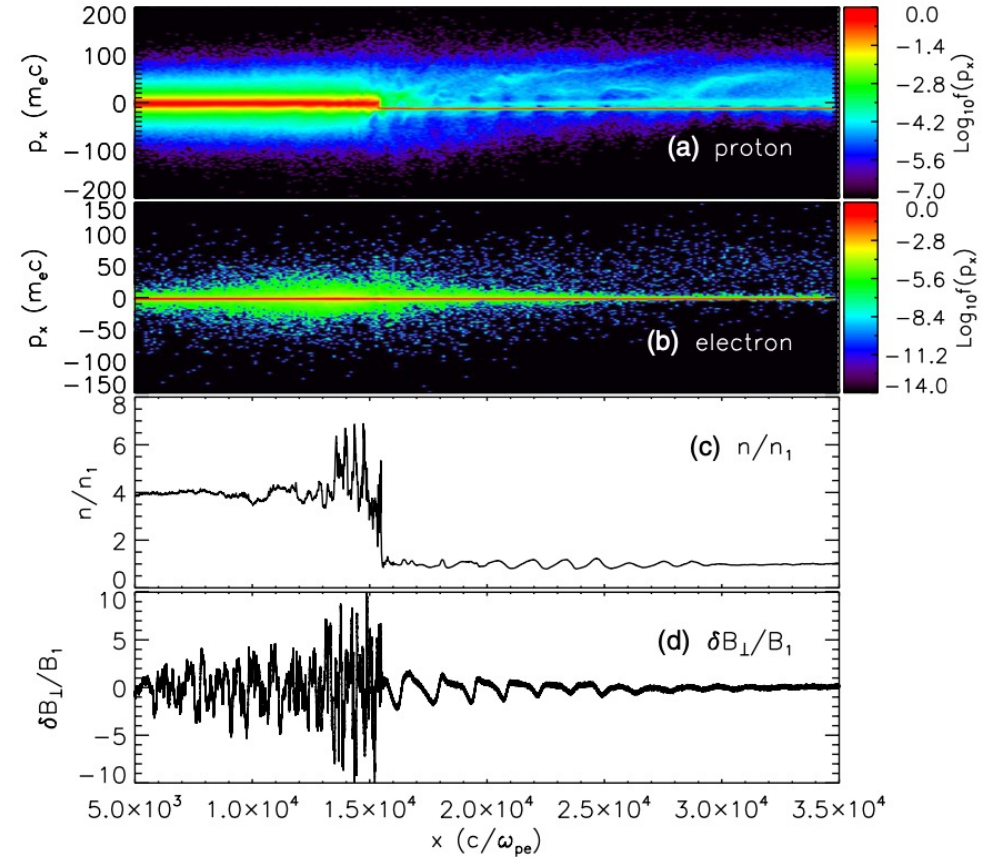
Fermi-like acceleration (parallel shock)



Motivation



Electron acceleration at quasi-parallel shock (Saturn's bow shock) observed by Cassini. (Masters 2013)



1D particle-in-cell simulation (Park 2015)

Simulation setup

- Dimensions:

$$x*y*z = 2400*1*1680 d_e$$

- Normalization

$$e = 1$$

$$m_e = 1$$

$$c = 1$$

$$d_e = 1$$

$$\omega_{pe} = 1$$

$$d_i = 10d_e$$

$$m_i/m_e = 100$$

$$\omega_{pe}/\omega_{ce} = 5$$

$$\theta_{Bn} = 30^\circ$$

$$M_a = 7$$

$$\beta = 0.5$$

$$T_i = T_e = 0.01$$

$$U_1 = 0.14$$

d_e : electron inertial length

d_i : ion inertial length

m_i : ion mass

m_e : electron mass

ω_{pe} : plasma frequency

ω_{ce} : electron gyro-frequency

θ_{Bn} : shock normal angle

M_a : Alfvén Mach number

β : plasma beta

T_i : ion temperature

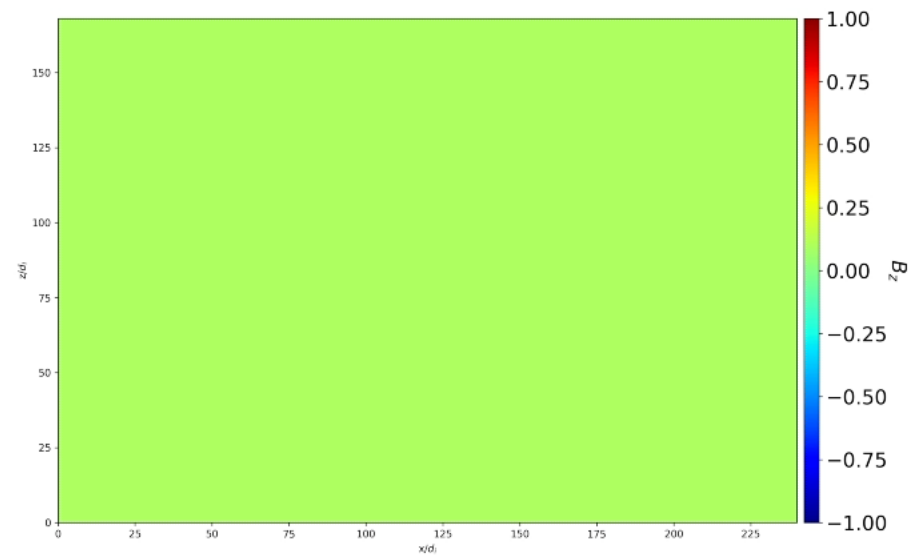
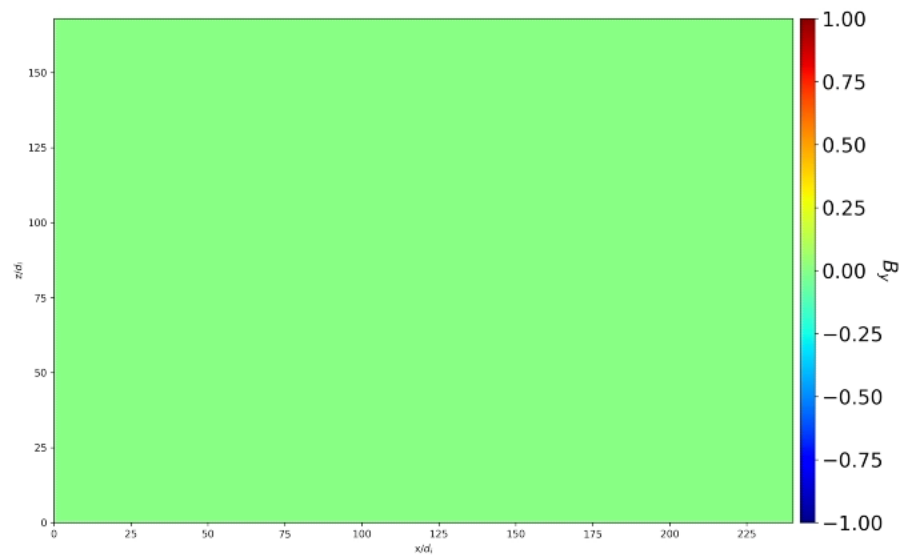
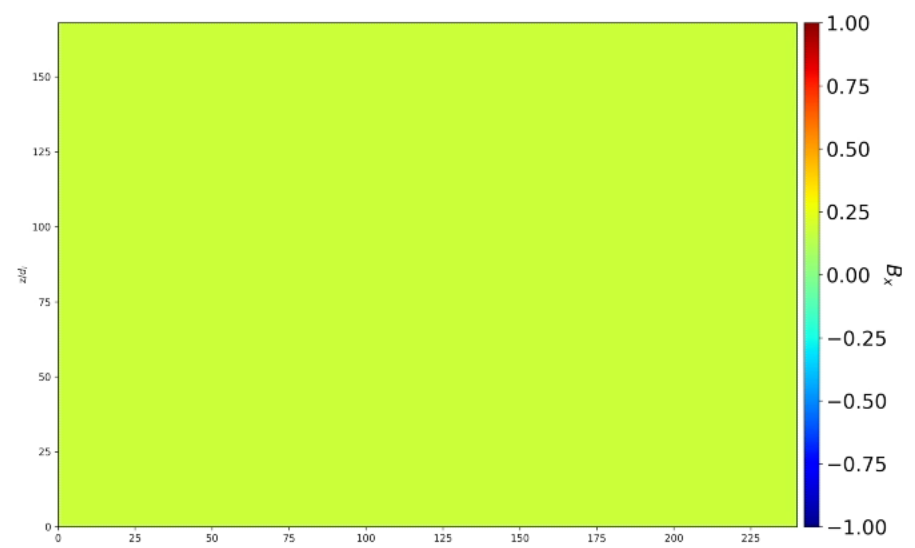
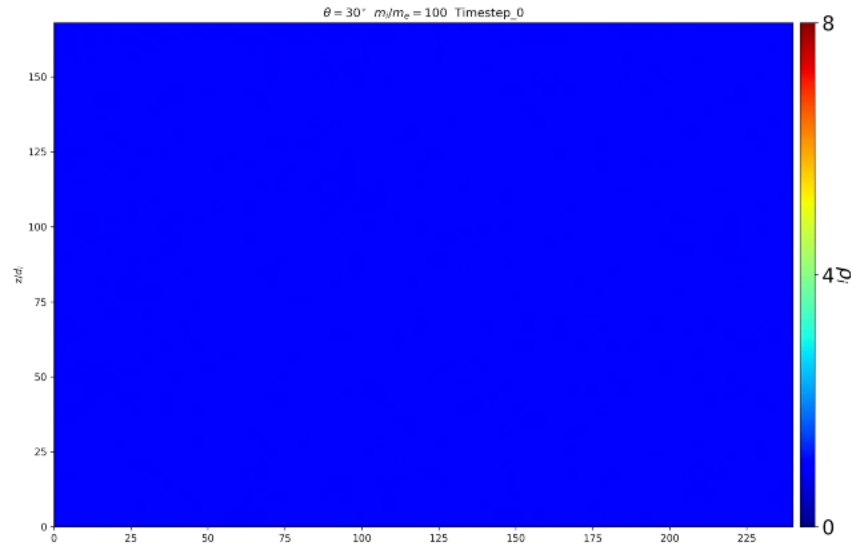
T_e : electron temperature

U_1 : upstream flow speed

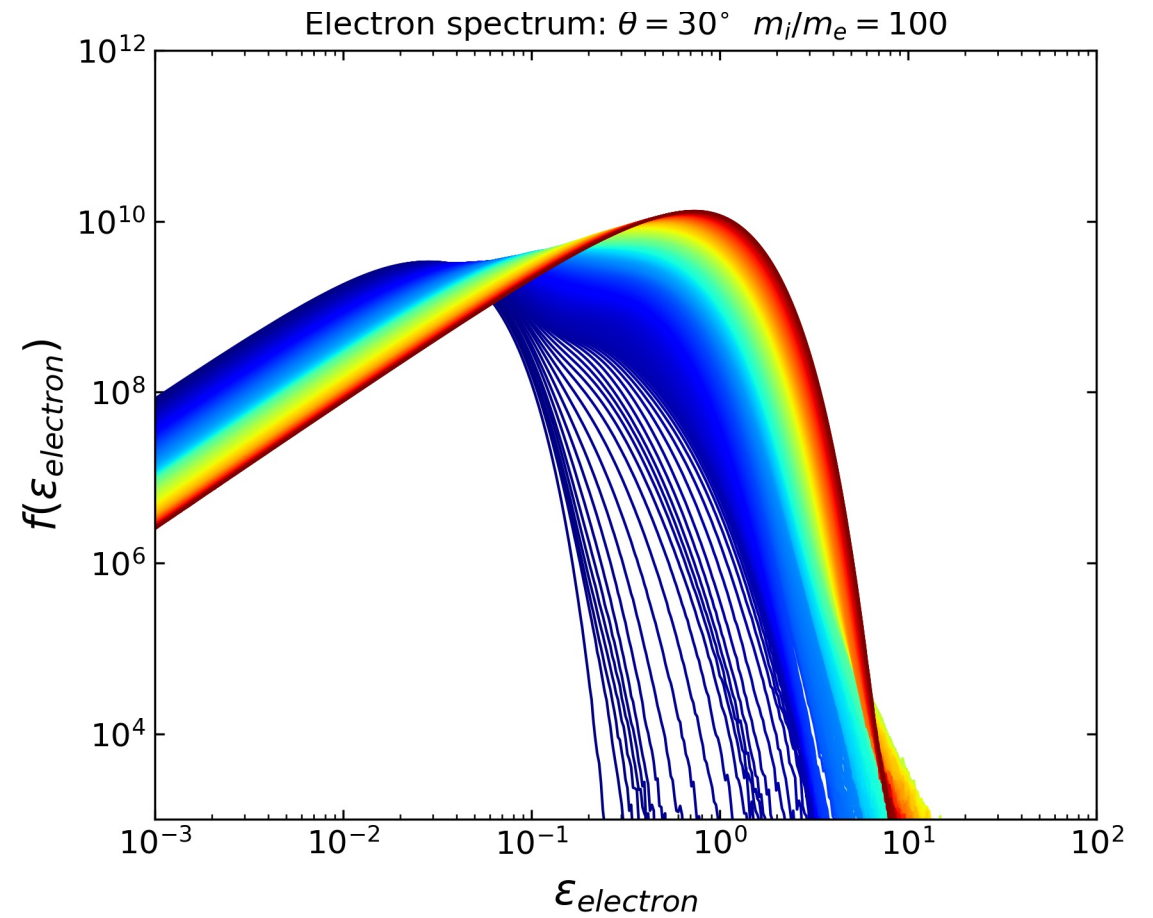
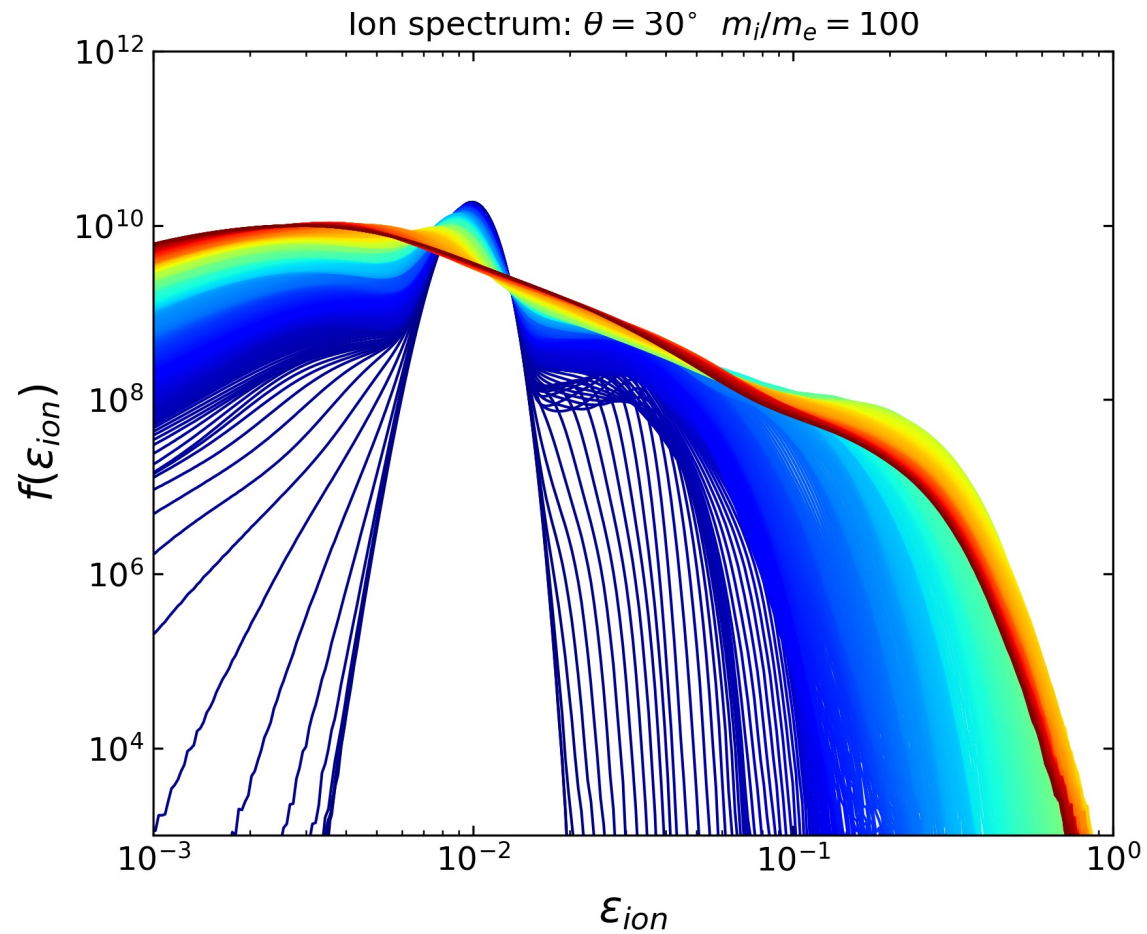
Dimensions:

$x*y*z = 240*0.1*168 d_i$ (d_i : ion inertial length)

~2 billion particles (protons & electrons)



Energy Spectra



Summary

- Both ions and electrons are accelerated (heated) by the parallel shock.
- A power-law spectrum of ions can be reproduced in the model.
- Shock reformations drive strong magnetic turbulence in the downstream.
- More diagnosis need to be done:
 1. Particle trajectory
 2. Magnetic reconnection or wave-particle interaction in the downstream
 3. Extend to 3D