Kinetic waves and reconnecting current sheets in a quasi-parallel shock

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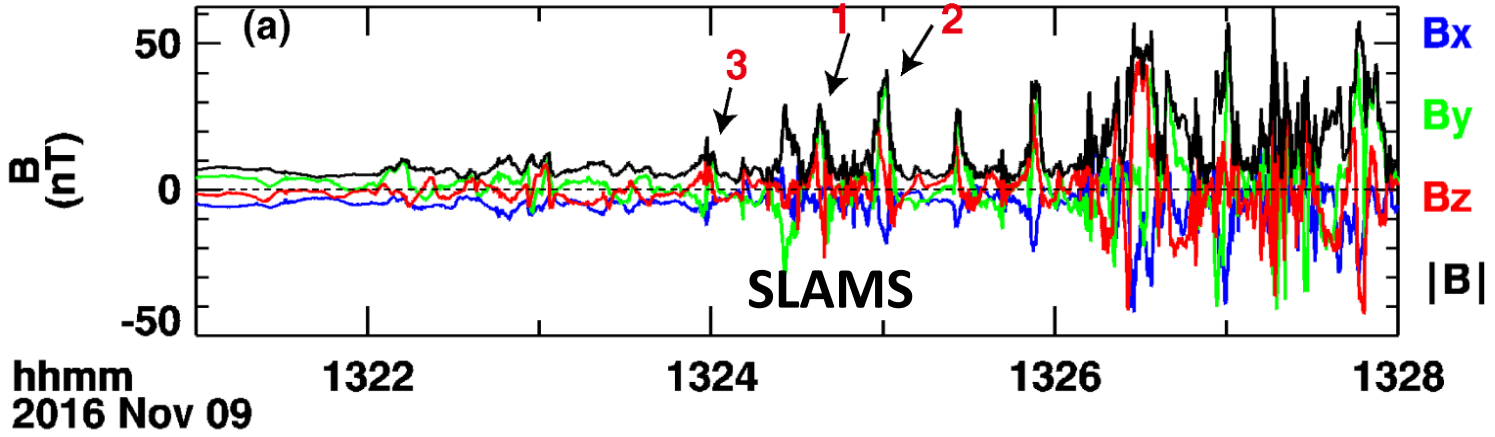
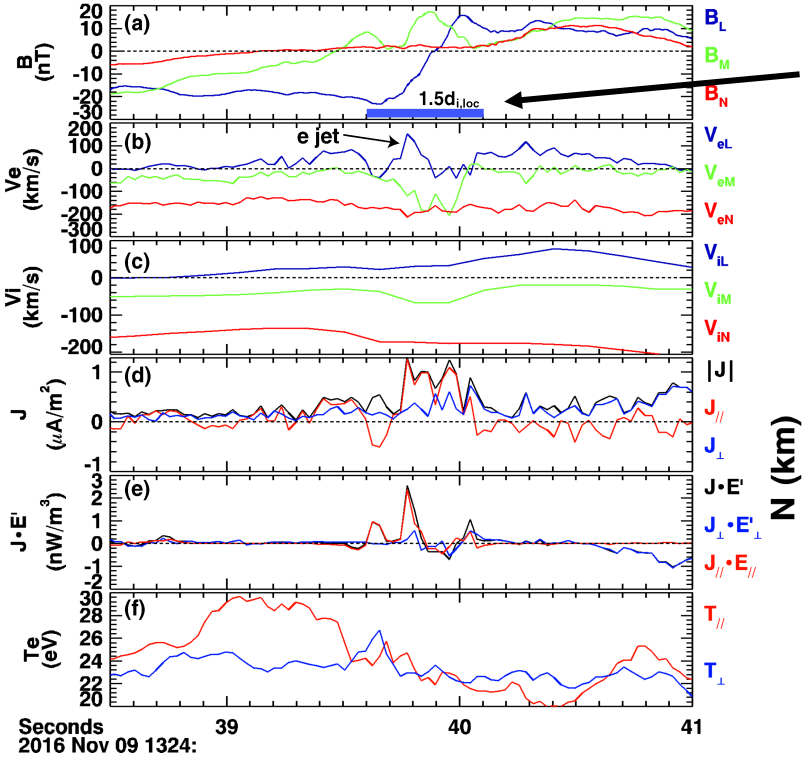
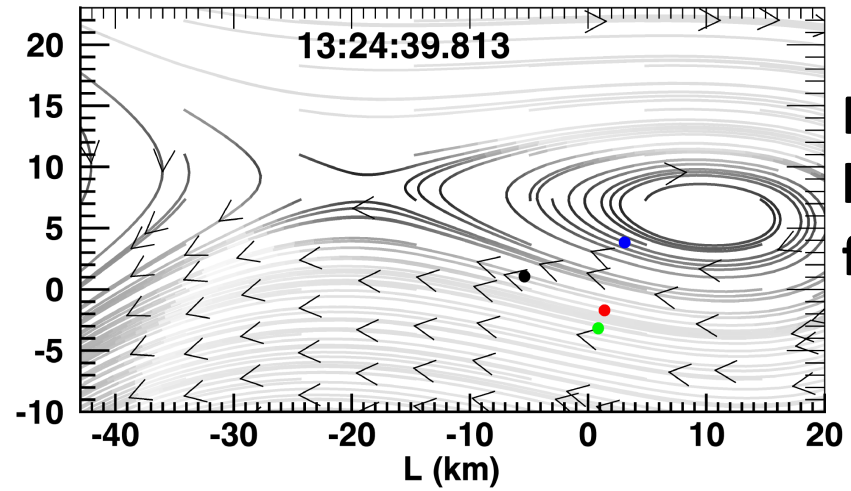
MMS has been observing active reconnecting current sheets in the Earth's bow shock, in magnetosheath (shock downstream) (Yordanova et al. 2016, Vörös et al. 2018, Chasapis et al. 2018, Phan et al. 2018, Wilder et al. 2018) and the foreshock/transition region (Wang et al. 2019, 2020, Gingell et al. 2019, 2020).



[Wang et al., 2020]



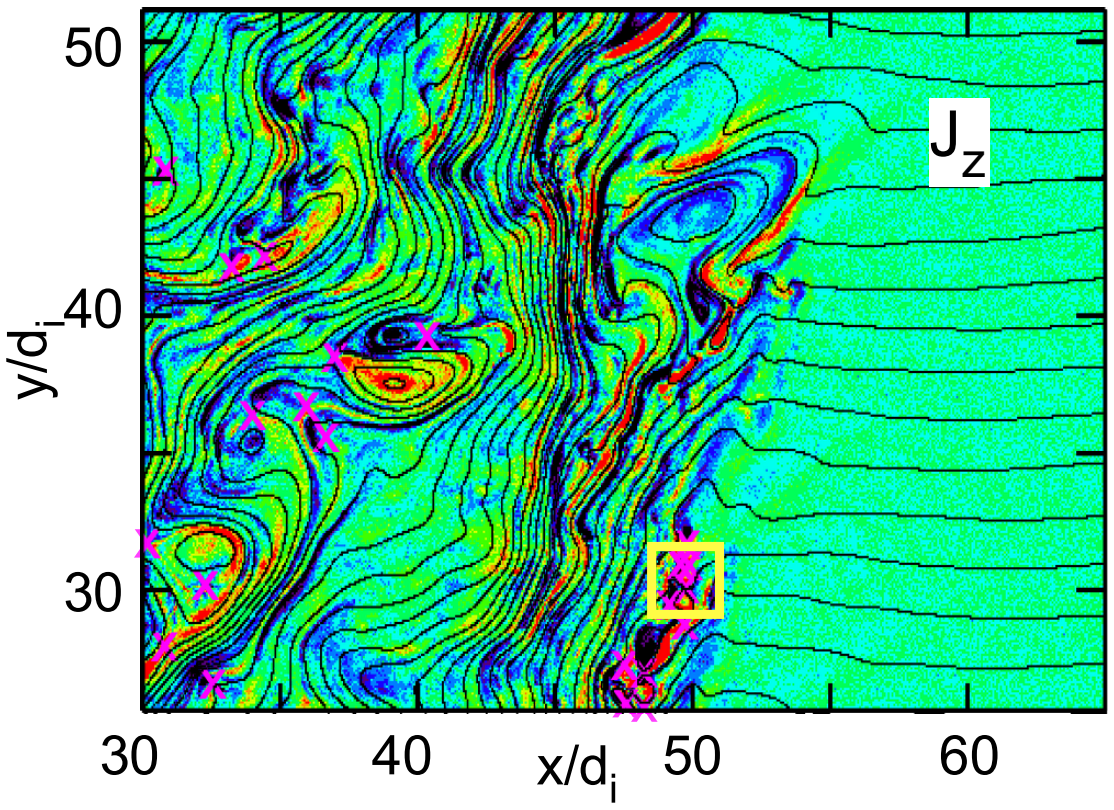
Reconnecting current sheet inside amplified non-resonant mode waves ('SLAMS') with electron outflow jet in the foreshock

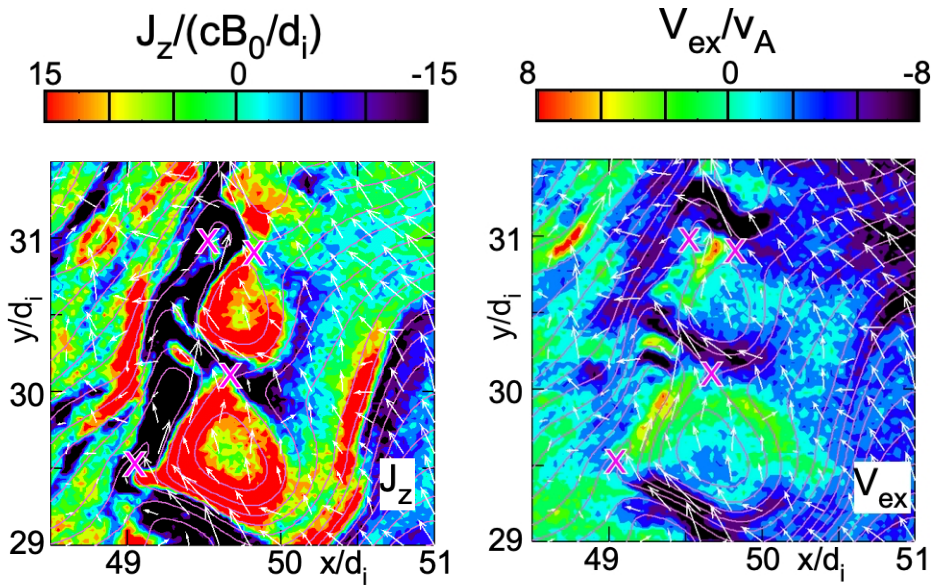


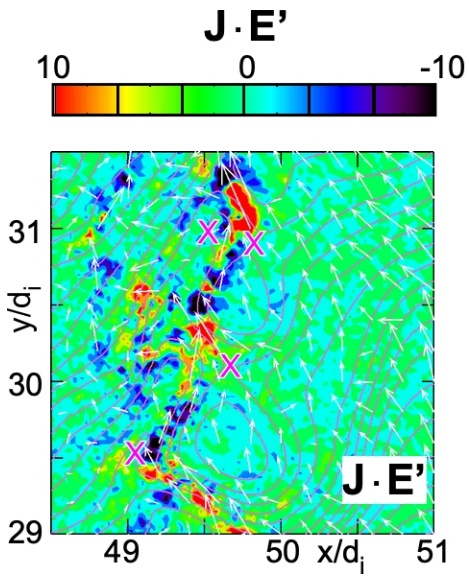
Reconstructed X-line magnetic field topology

2D PIC simulation of a quasi-parallel shock (θ=25 degrees, M_A=11.4)

Bessho et al. 2020, POP







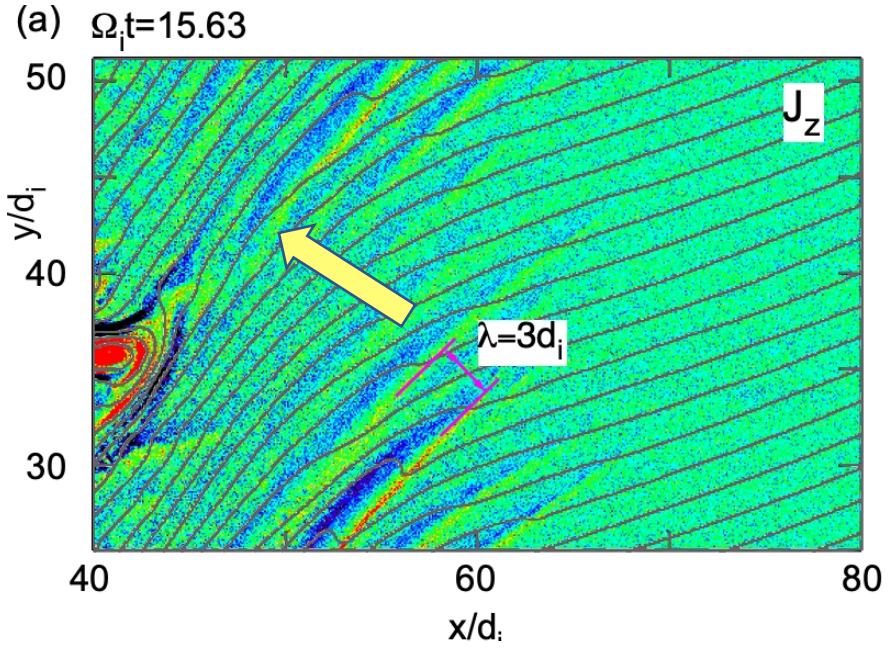
Reconnecting current sheets in the box

Electron-scale current sheets. J_z<0
Strong electron jets V_{ex} <0

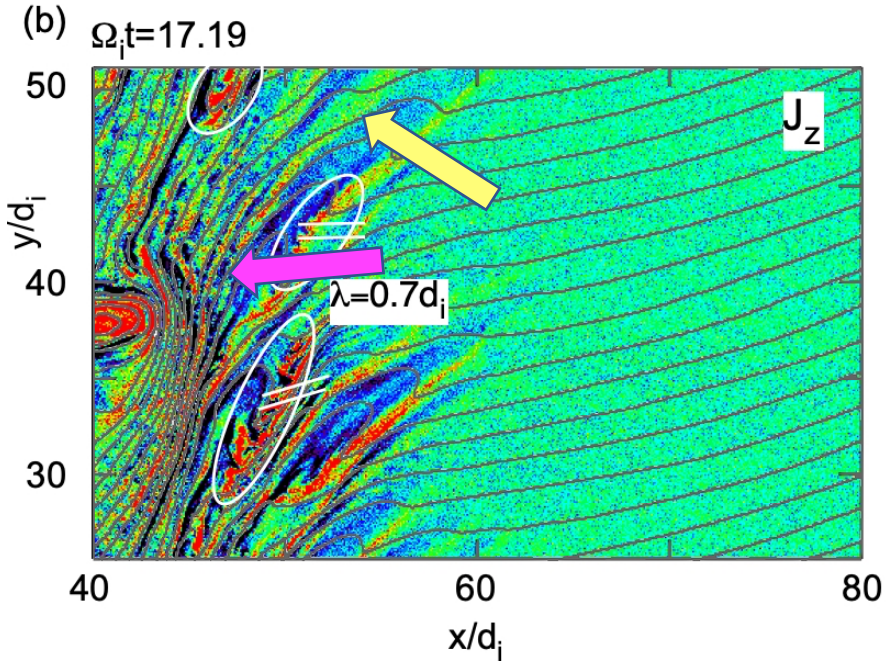
Electron-only reconnection

Energy dissipation rate
$J \cdot E' \sim 30\ cB_0^2/d_i$
in the outflow region

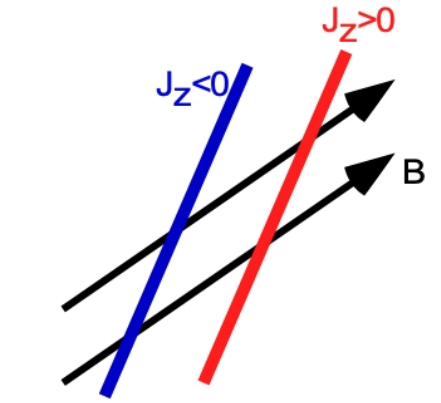
Long-wavelength (LW) mode and short-wavelength (SW) mode



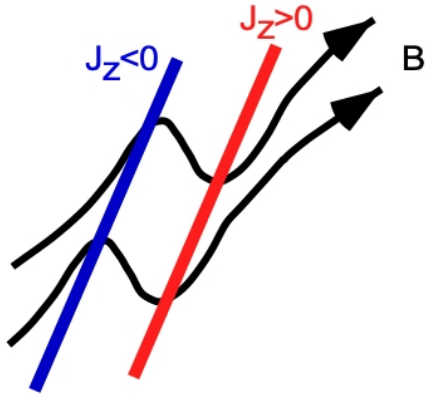
In the early stage, long-wavelength (LW) modes ($\lambda \sim 3d_i$) are generated, propagating downstream.

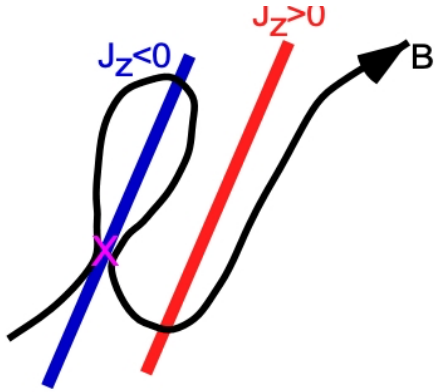


Later, short-wavelength (SW) modes ($\lambda \sim 0.7d_i$) are generated, along the wave planes of the LW modes.



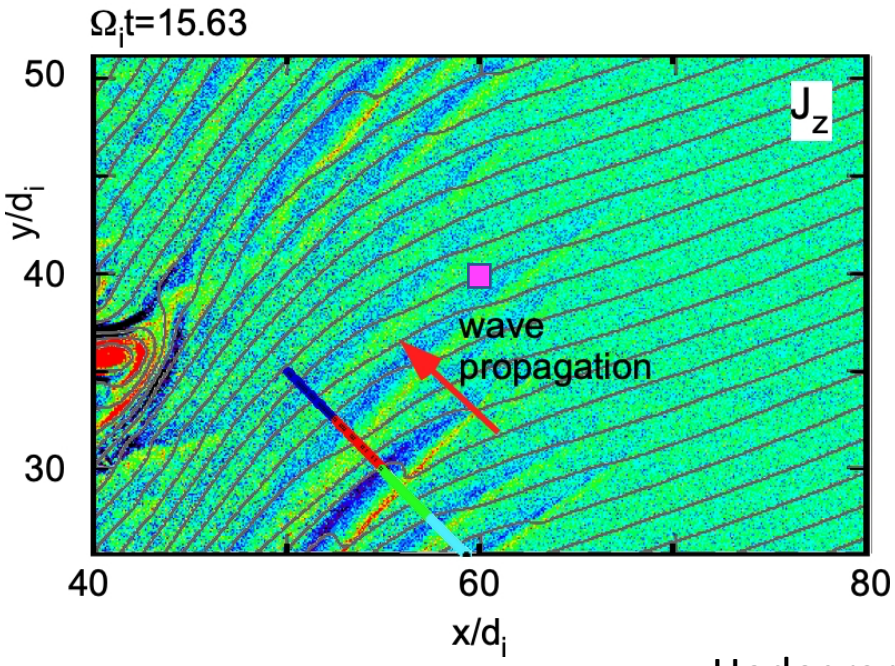
Magnetic field lines are bent due to these generated waves.





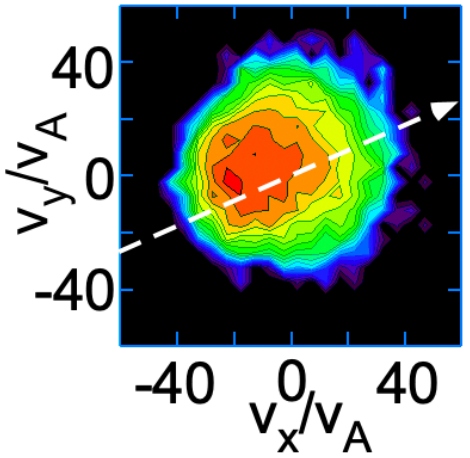
Reconnection occurs where two oppositely-directed field lines come into contact.

LW mode

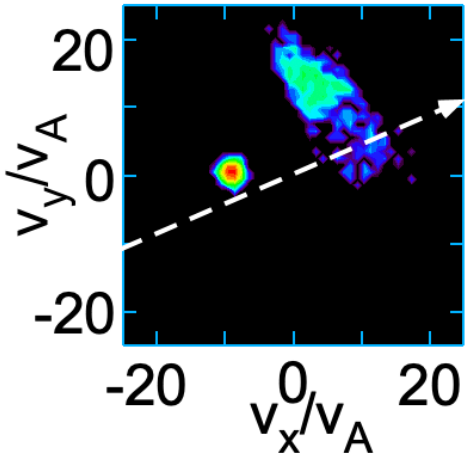


VDF position

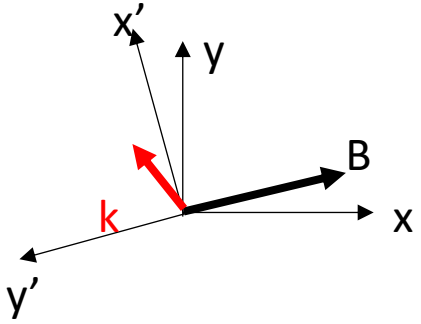
Electron

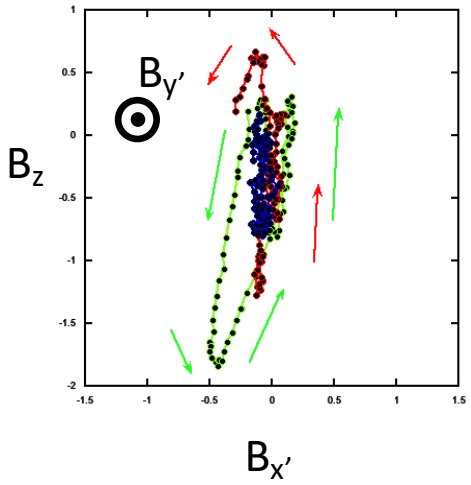


Ion



Hodogram analysis





Waves are propagating in the negative x direction in the plasma rest frame.

Polarization in the plasma rest frame --- right-handed

Non-resonant ion-ion beam instability

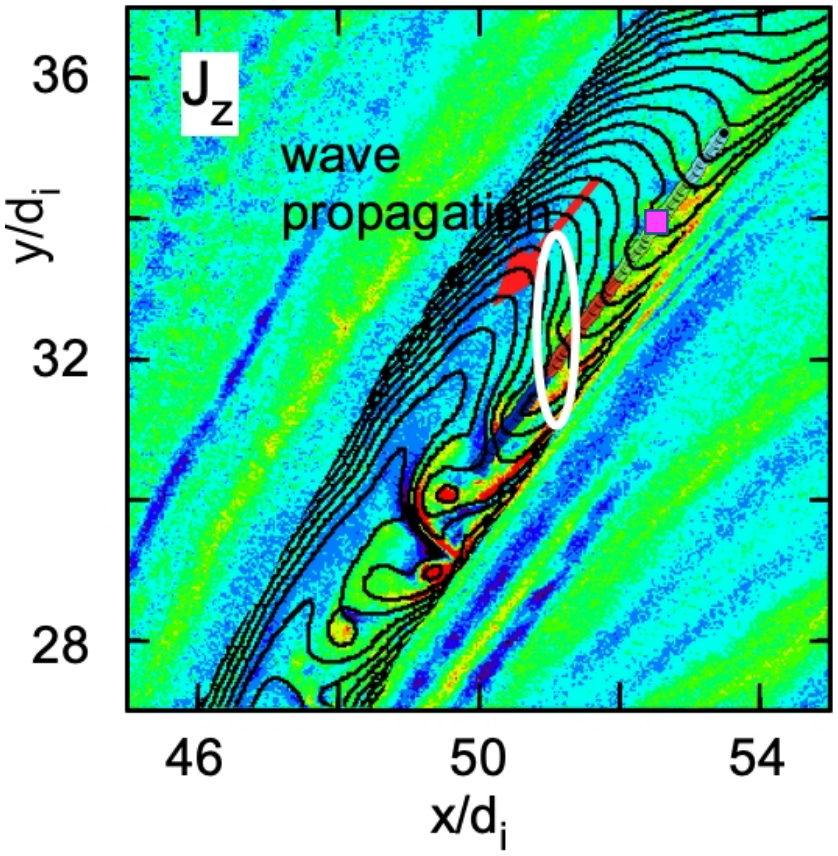
$\lambda \sim$ 2-3 d_i

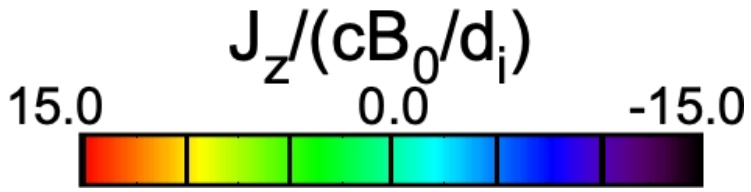
$\omega \sim 13\Omega_i$

$V_{ph} \sim 6\ V_A$

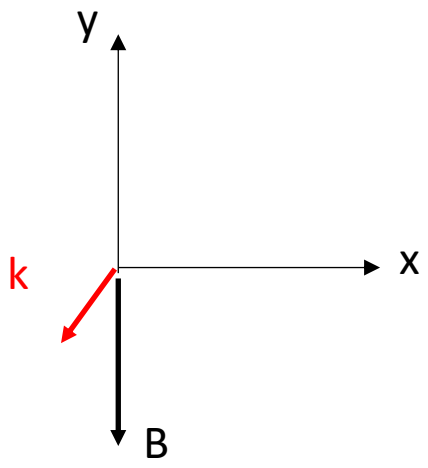
right-handed in the simulation frame

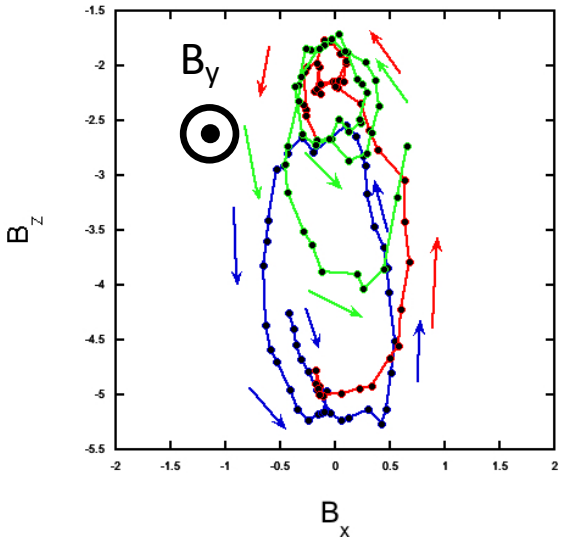
SW mode





Hodogram analysis

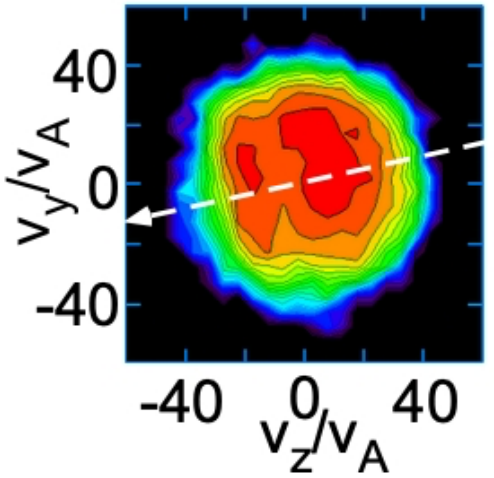


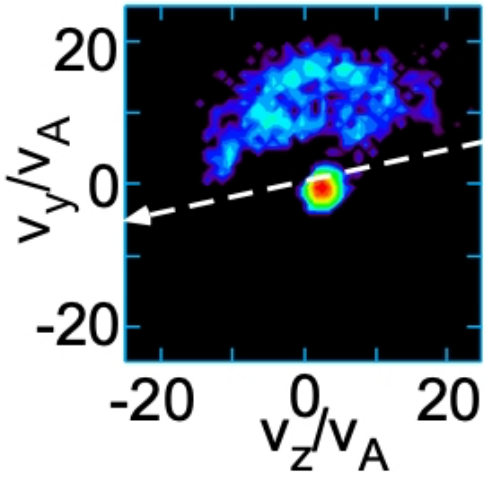


Right-handed

VDF position

Electron beams





SW wave is propagating in the negative y direction in the plasma rest frame

$\lambda < 1 d_i$ $\omega \sim$ 25-40 Ω_i in the plasma rest frame

Whistler wave due to electron beams

Summary

Long-wavelength (LW) waves ($\lambda \sim 3d_i$) and short-wavelength (SW) waves ($\lambda < 1d_i$) are excited in the shock transition region.

Long-wavelength waves are due to a non-resonant ion-ion beam instability.

Short-wavelength waves are in the frequency range of whistler waves, excited due to multiple electron and ion beams.

These two types of waves can bend magnetic field lines, and reconnection can occur.