Microinstabilities at Quasi-Perpendicular Shocks in High-β ICM

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At collisionless shocks, various microinstabilities are occurred by the temperature anisotropy and/or drift motions of plasmas. Microinstabilities play important roles in both entropy generation and particle acceleration in collisionless shocks. Recent studies have suggested that in the transition region of quasi-perpendicular ($Q_{\perp}$) shocks in the high-beta ($\beta = P_{gas}/P_B$) intracluster medium (ICM), the ion temperature anisotropy due to the reflected-gyrating ions could trigger the Alfv´en ion cyclotron (AIC) instability and the ion-mirror instability, while the electron temperature anisotropy induced by magnetic field compression could excite the whistler instability and the electron-mirror instability.

Adopting the numerical estimates for ion and electron temperature anisotropies found in the particle-in-cell (PIC) simulations of $Q_{\perp}$-shocks with sonic Mach numbers, $M_S = 2 - 3$, we carry out a linear stability analysis for these microinstabilities. The kinetic properties of the microinstabilities and the ensuing plasma waves on both ion and electron scales are described for wide ranges of parameters, including β and the ion-to-electron mass ratio. In addition, the nonlinear evolution of the induced plasma waves is examined by performing 2D PIC simulations with periodic boundary conditions.

We find that for β ≈ 20−100, the AIC instability could induce ion-scale waves and generate shock surface ripples in supercritical shocks above the AIC critical Mach number, $M_{AIC}^{*} \approx 2.3$. Also, electron-scale waves are generated primarily by the whistler instability in these high-β shocks. The resulting multi-scale waves from electron to ion scales are thought to be essential in the electron injection to diffusive shock acceleration in $Q_{\perp}$-shocks in the ICM.

References

[1] Kim, S. et al. ApJ, 892, 85 (2020)
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[3] Ha, J. et al. ApJ 915,18 (2021)

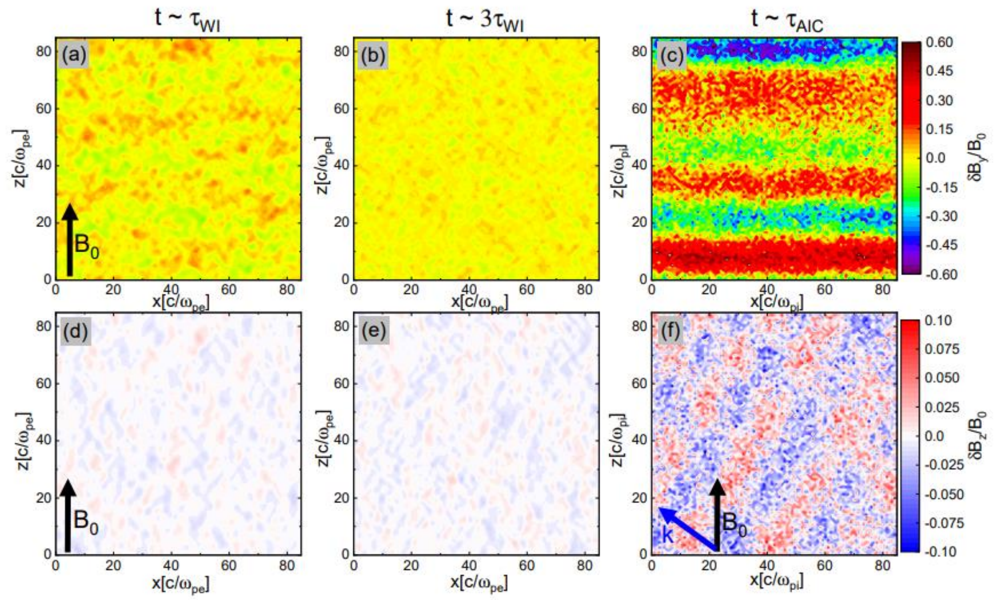

Figure 1. Magnetic field fluctuations in the 2D PIC simulation model, plotted in the x-z plane. At early times, t $\sim (1-3)\tau_{WI}$, shown in panels (a)-(b) and (d)-(e), electron-scale waves are excited by the whistler and e-mirror instabilities, while ion-scale waves are generated by the AIC and i-mirror instabilities at t $\sim \tau_{AIC}$ shown in panels (c) and (f).