The mechanism of efficient electron acceleration at parallel non-relativistic shocks

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Based on: Shalaby+2021 (ApJ 908 206) & Shalaby+2022 (ApJ 932 86)

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Electron-ion magnetized plasma

background B_0

Waves along B_0 :

- Electrostatic
- Electromagnetic Circularly (R & L) polarized waves



electron-ion magnetized plasma



R Alfvén wave: compressional with $v_{\rm ph}\gtrsim v_A$ L Alfvén wave: shear with $v_{\rm ph}\lesssim v_A$

CR driven instability











Impact of the intermeidate-scale instability

• Impact of the new instability on CRs momentum distribution? Electromagnetic wave with v_{ph} + a particle with velocity (v_x, v_y, v_z)

$$\begin{split} \dot{K}_{\parallel} &= \frac{m_s}{2} \frac{dv_x^2}{dt} = q_s \upsilon_x (\upsilon_y B_z - \upsilon_z B_y), \\ \dot{K}_{\perp} &= \frac{m_s}{2} \frac{d\upsilon_{\perp}^2}{dt} = -q_s \left[(\upsilon_x - \upsilon_{\rm ph}) \upsilon_y B_z - (\upsilon_x - \upsilon_{\rm ph}) \upsilon_z B_y \right] \\ & \bullet \ \upsilon_x \approx \upsilon_{\rm ph} \quad \Rightarrow \quad \dot{K}_{\perp} \approx 0, \text{ parallel scattering only} \\ & \bullet \ \upsilon_{\rm ph} \approx 0 \quad \Rightarrow \quad \dot{K}_{\perp} = -\dot{K}_{\parallel}, \text{ energy-conserving scattering} \end{split}$$

Impact of the intermeidate-scale instability

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1. Fast magnetic field amplification at scales < d_i



Impact of the intermeidate-scale instability

Impact of the new instability on CRs momentum distribution?
1. Fast magnetic field amplification at scales < d_i
2. decrease average drift speed



Summary

Found a new instability

- Drives comoving ion-cyclotron waves
- Growth only if $v_{\mathrm{dr}}/v_{\mathcal{A}} < \sqrt{m_i/m_e}/2$
- Typically much faster growth compared to gyro-scale growth

$$\Gamma/\Omega_i = \alpha^{3/4} + \left(\frac{\alpha}{3}\right)^{1/3} \left(\frac{\upsilon_{\rm dr}\upsilon_{\perp}}{\upsilon_{\rm A}^2}\right)^{2/3} \tag{1}$$

- Impacts
 - Fast magnetic field amplification on scales $< d_i$.
 - 2 Decrease average drift speed

Implications

Potential implications:

- Impacts on CR injection and propagation models @ ISM sims & galaxy sims ⇒ on distribution of gas, magnetic field amplification ect.)
- Since $v_{\rm dr}$ decreases: impact the confinement near sources and thus the expected emission
- Coupling of CRs in partially ionized medium (clouds); impact also emission from partially ionized clouds

Today's talk/application

Role of the new instability in the e-acceleration at non-relativistic shocks

arXiv:2202.05288 & ApJ 932 86

Shalaby+2022; ApJ 932 86

Today's talk/application

Role of the new instability in the acceleration of electrons at non-relativistic shocks

electron injection Problem:

- electrons: $r_e = (m_e/m_i)r_i$.
- electrons can not scatter at shock front
- Intermediate-scale instability provide large-amplitude magnetic perturbation at sub ion-gyroscale
 ⇒ a solution? let's check with PIC

Shalaby+2022; ApJ 932 86

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Acceleration of electrons at parallel non-relativistic shocks

Shalaby+2022; ApJ 932 86

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Magnetic field amplification



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The mechanism of electron acceleration at || e-p shocks

Impacts of Intermediate-scale instability



Impacts of Intermediate-scale instability



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Where/how e-acceleration



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Talk summary

Conclusions:

- new CR-driven dominant instabilities at scales $< c/\omega_i$
- potential impacts are not just solving the electron injection problem (at parallel e-p shocks) so stay tuned for more papers to come!
- the new wavemodes provide a new mechanism to accelerated/pre-accelerated electrons at shocks (not just at the shock fronts but also at shock downstream)

Thank you for your attention