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1. DESY.

Pre-acceleration in the Electron Foreshock by Electron Acoustic Waves

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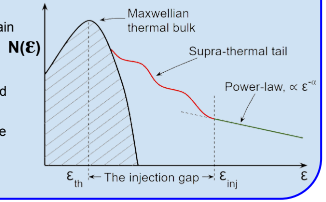
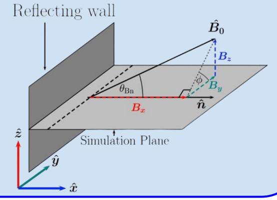
1. Motivation: injection problem, pre-acceleration and the foreshock

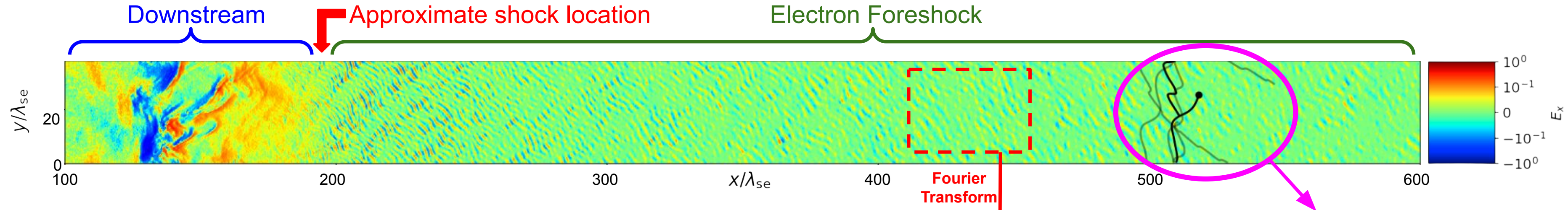
- Observations of astrophysical sources such as supernova remnants imply an underlying power-law particle spectrum, with diffusive shock acceleration (DSA) seemingly able to explain this
- However, DSA only works if the shock width ~ particle gyroradius
- For particles at thermal energies this is only true for ions - to apply to electrons they first need some pre-acceleration
- In oblique shocks, electrons can be reflected back upstream, with the region containing these electrons called the electron foreshock
- Upstream electrons must pass through the foreshock before encountering the shock, so it is important to understand any pre-acceleration here



2. Method: Particle-in-Cell (PIC) Simulations of Oblique Shocks

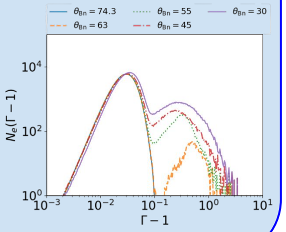
- In Astrophysics we need to understand physical process on a large number of scales, so we choose parameters that allow us to study SNR shocks:
  - Nonrelativistic shocks: $v_{sh} \ll c$
  - Sonic Mach number: $M_S = v_{sh}/c_s > 10$
  - Alfvén Mach number: $M_A = v_{sh}/v_A > 10$
- We **change the magnetic field** configuration to investigate the effect on the electron foreshock
  - simulation plane angle: ϕ=[0 (below image), 90]°
  - and obliquity angle: θ_{Bn} = [30, 45 (below image), 55, 63, 72.4]°





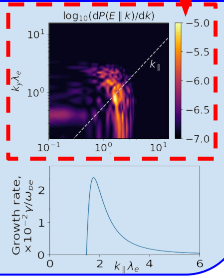
3. Electrons Reflected at the shock

- At early times, electrons are reflected by a combination of shock surfing acceleration and magnetic mirroring (Amano & Hoshino, 2007)
- At smaller θ_{Bn}, electrons need less energy to outrun the shock ($v_e \cos\theta_{Bn} \geq v_{sh}$), so more are reflected and more energy is carried upstream (see also Matsumoto et al. 2017)
- These electrons power electrostatic waves in the electron foreshock region, with these capable of interacting with upstream electrons.



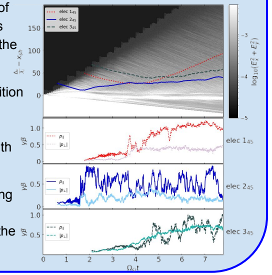
4. Identifying Electron Acoustic Waves (EAWs)

- By taking a discrete fourier transform (DFT) of the electrostatic waves that are generated by the reflected electrons (e.g. in the red dashed region above) we can identify it from the dominant spatial scales
- It the figures, $k_\parallel$ and $k_\perp$ refer to vectors in the direction of the upstream magnetic field
- Analysis by solving the dispersion relation reveals a peak growth rate of EAWs (lower) at approximately the peak spatial scale on which we observe them (upper)
- The calculation uses values calculated from the simulation box regions and was further confirmed using periodic box boundary condition simulations (Bohdan et al. 2022)



5. Upstream Electrons Reflected by EAWs

- The black line in the figure above shows the trajectory of an upstream electron as it approaches the shock and is gradually turned back upstream via an interaction with the EAWs
- The figure to the right (top panel) shows electron *x*-position vs time overplotted on the time-evolved electric field averaged over the transverse position. A horizontal trajectory indicates no relative motion of the electron with respect to the shock
- The lower (colour-coded) panels show the corresponding $p_\parallel$ and $p_\perp$. The increase in $p_\parallel$ shows that the energy changes are due to EAWs as only they have *E*-field in the parallel direction upstream of the shock



References & Acknowledgements

Amano, T., & Hoshino, M. 2007, ApJ, 661, 190; Matsumoto, Y et al. 2017, PhRvL, 119, 105101; Bohdan, A. et al., M. 2022, PhPl, 29, 052301. M.P. acknowledges support by DFG through grant PO 1508/10-1. The numerical simulations were conducted on resources provided by the North-German Supercomputing Alliance (HLRN) under project bbp00033.