Electron acceleration at quasi-perpendicular shocks: The effects of surface fluctuations

D. Burgess
Astronomy Unit
Queen Mary, University of London

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Contents

Will not discuss ... electron thermalization, electron foreshock, models relying on “electron-scale” waves, etc.

Bow Shock: Observations

- Anderson et al. [1979]...
  - $>$ 16kEv and 5keV fluxes seen as spikes, with source near tangent point, $\theta_{Bn} > 85^\circ$.
- Gosling et al. [1989] ...
  - field-aligned upstream component "develops" out of distribution at shock and downstream.
  - suprathermal flux appears as power law tail (exponent 3–4) merged onto downstream thermal distribution, "pancake" distribution at ramp
  - argue that mirroring would not produce downstream energetic distributions

Bow Shock: Observations: Anderson 1979

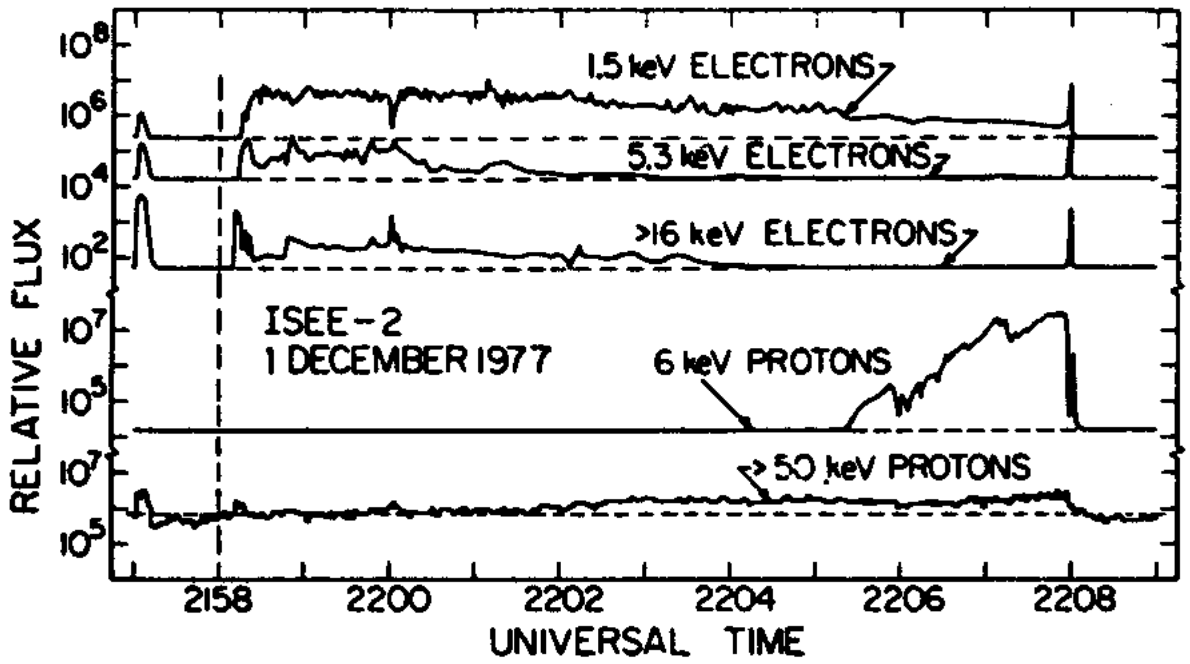
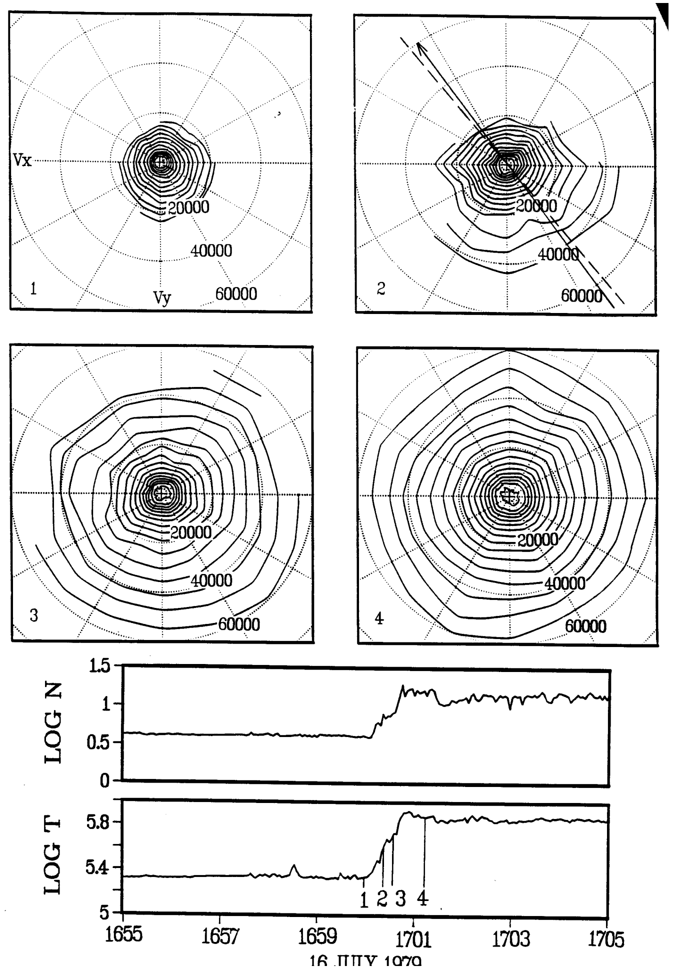
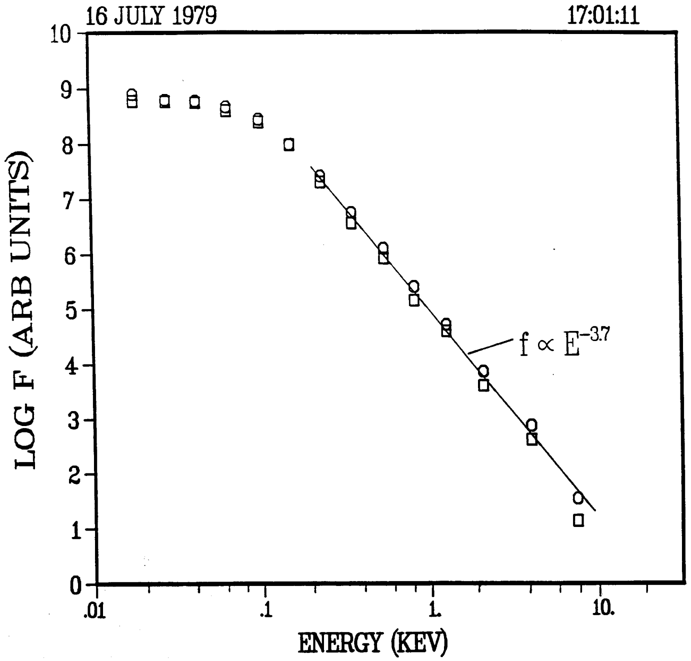


Fig. 4. ISEE-2 observations of upstream particles on 1 December 1977. Note the velocity dispersion in the electrons near onset (~2158). (From Anderson et al. /8/.)

Bow Shock: Observations: Gosling et al. 1989



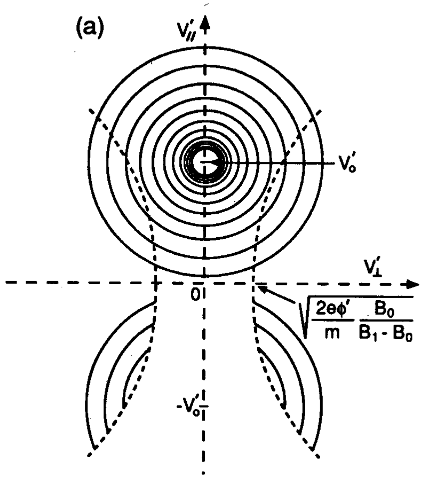


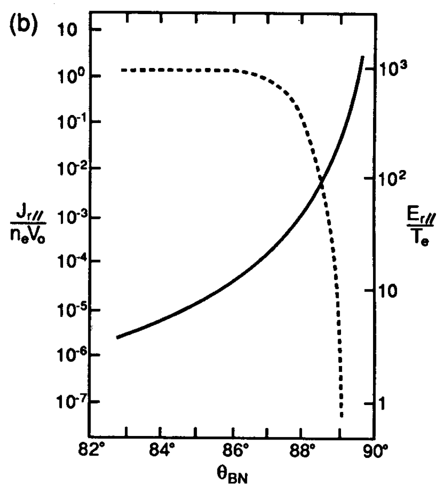
Fast-Fermi Acceleration: Adiabatic Reflection

- Leroy and Mangeney [1984], Wu [1984]
  - Reflection of a small fraction of incident thermal distribution
  - In zero-E, shock (de Hoffman-Teller) frame particles conserve energy and magnetic moment
  - Maximum energization when shock close to perpendicular ($\theta_{Bn} = 90°$)
  - But . . . reflected fraction decreases as θ_{Bn} increases
  - Sensitive to details of wings of distribution function

Modelling Fast-Fermi Electron Acceleration

Analytic results . . .





Initial distributions . . .

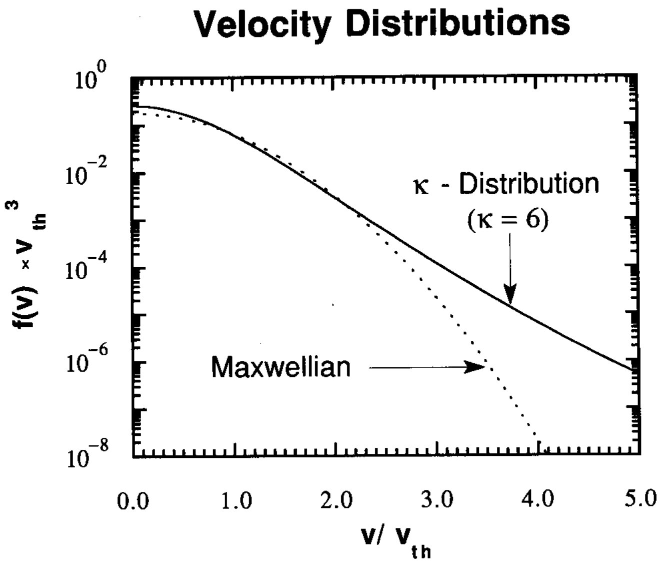
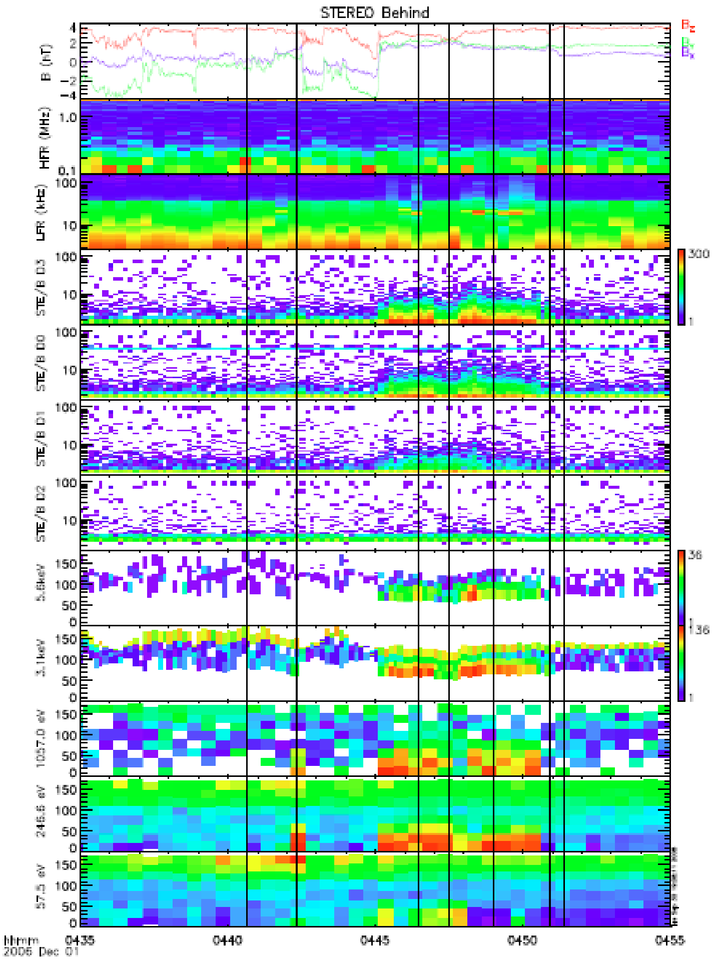


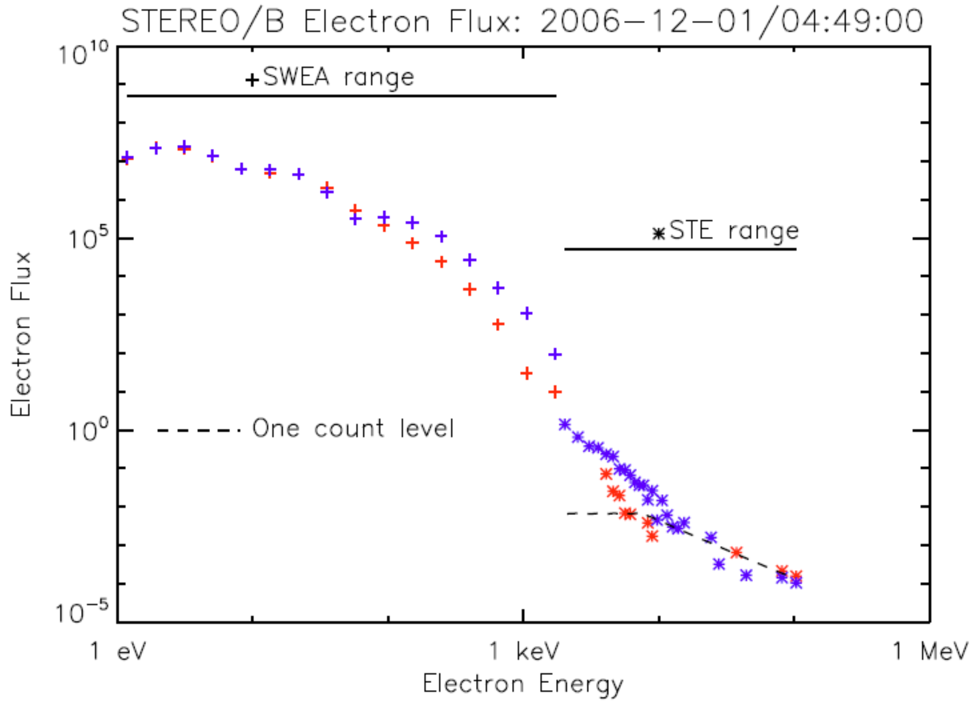
Fig. 2. Comparison of a Maxwellian velocity distribution to a κ distribution with index $\kappa = 6$. Note that there is no significant deviation for velocities v smaller than 2 thermal velocities v_{th}.

STEREO Observations (Pulupa & Bale, 2008)

Overview . . .



Spectra . . .

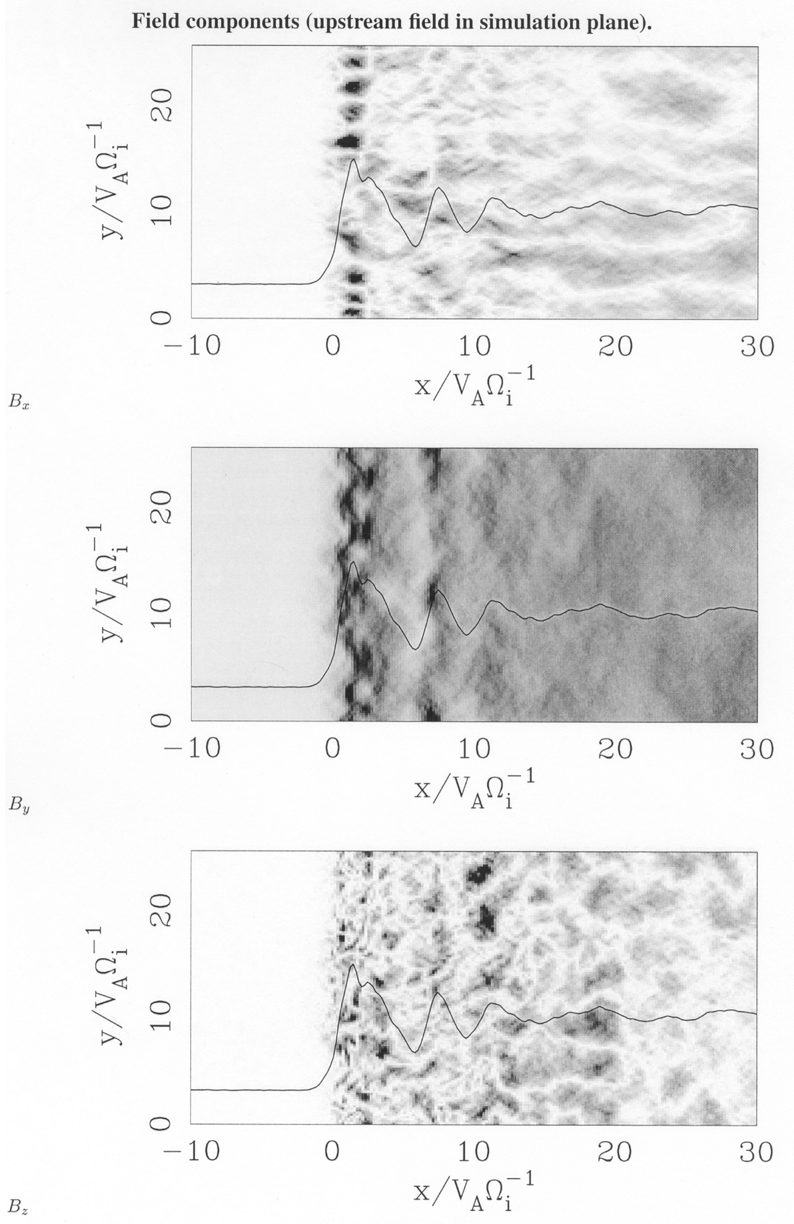


Modelling Electron Acceleration

- Two dimensional hybrid simulations: electron fluid and particle ions
  - Magnetic field *in* simulation plane $\rightarrow$ field aligned perturbations allowed
  - Magnetic field *out of* simulation plane $\rightarrow$ field aligned perturbations *NOT* allowed
- B out of plane $\rightarrow$ looks like 1D
  - and same for electron acceleration ...
  - and not discussed further!

Rippled Shock: Fields

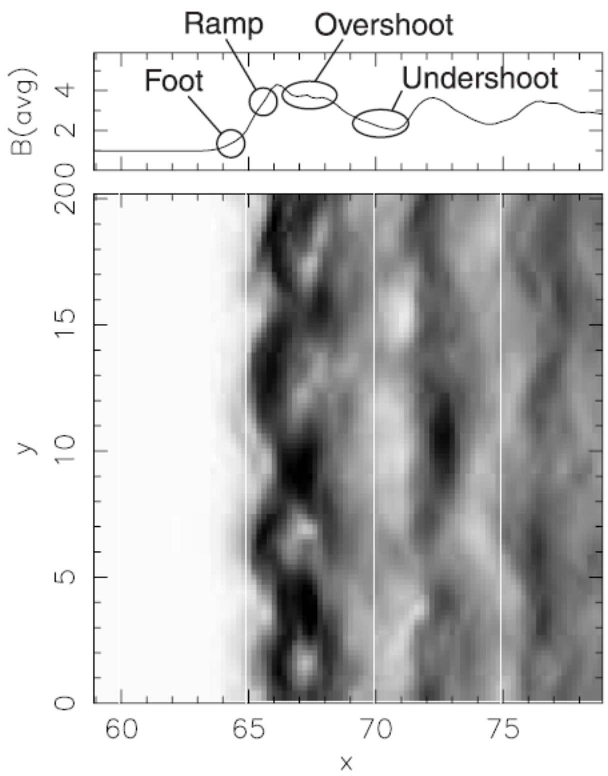
- Magnetic field in simulation plane
  - In B_x ripples propagate along shock surface
  - short-lived wave packets in foot, ie “whistler”
  - Variation of field magnitude along a field line as it convects through shock

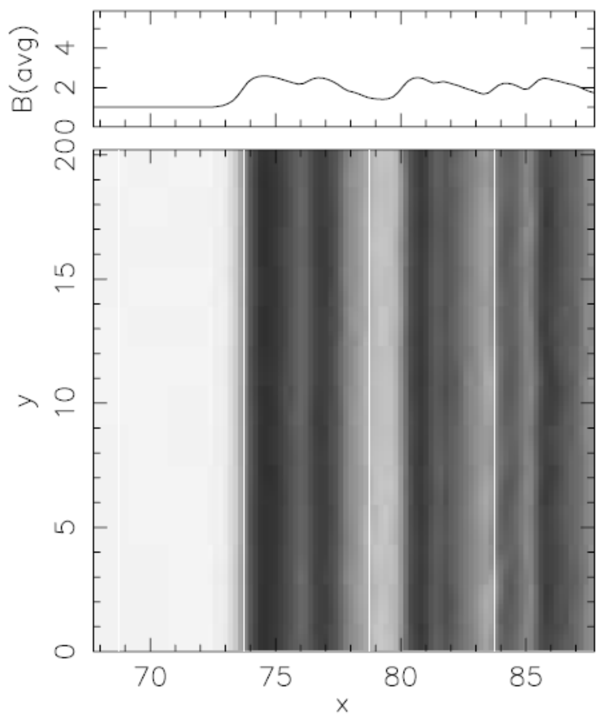


$\theta_{Bn} = 88$, $M_A = 5.7$

Ripple Properties

- Ripples propagate at Alfvén speed of overshoot
- Ripples only seen above certain Mach number
- Presence of ripples depends on reflected ions (ie supercritical Mach number)

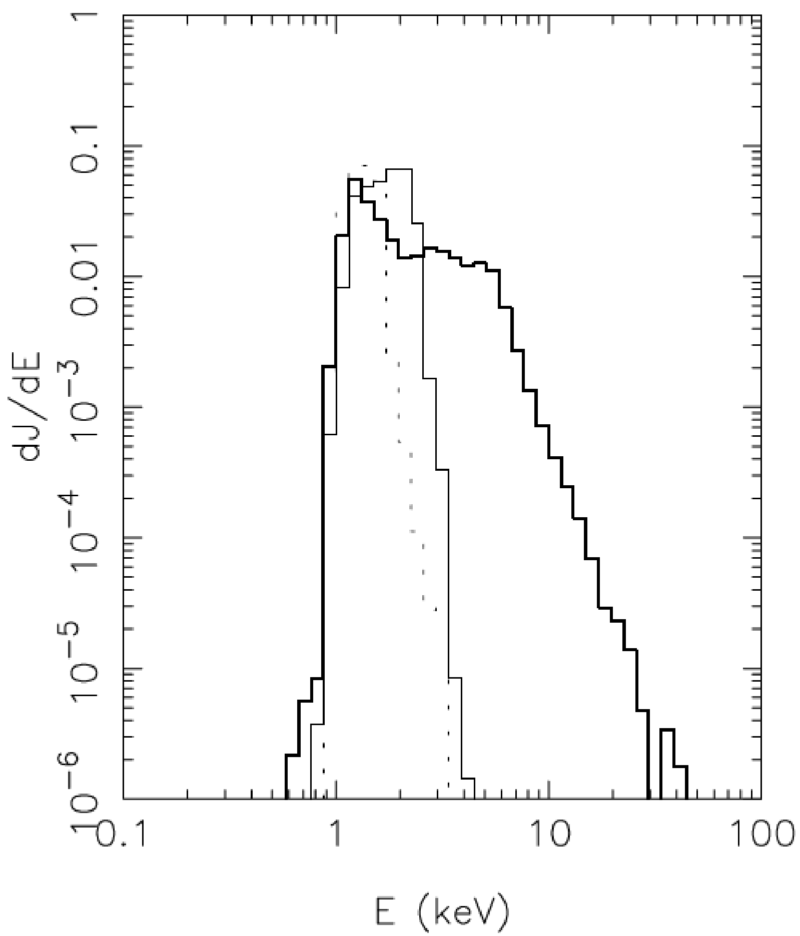


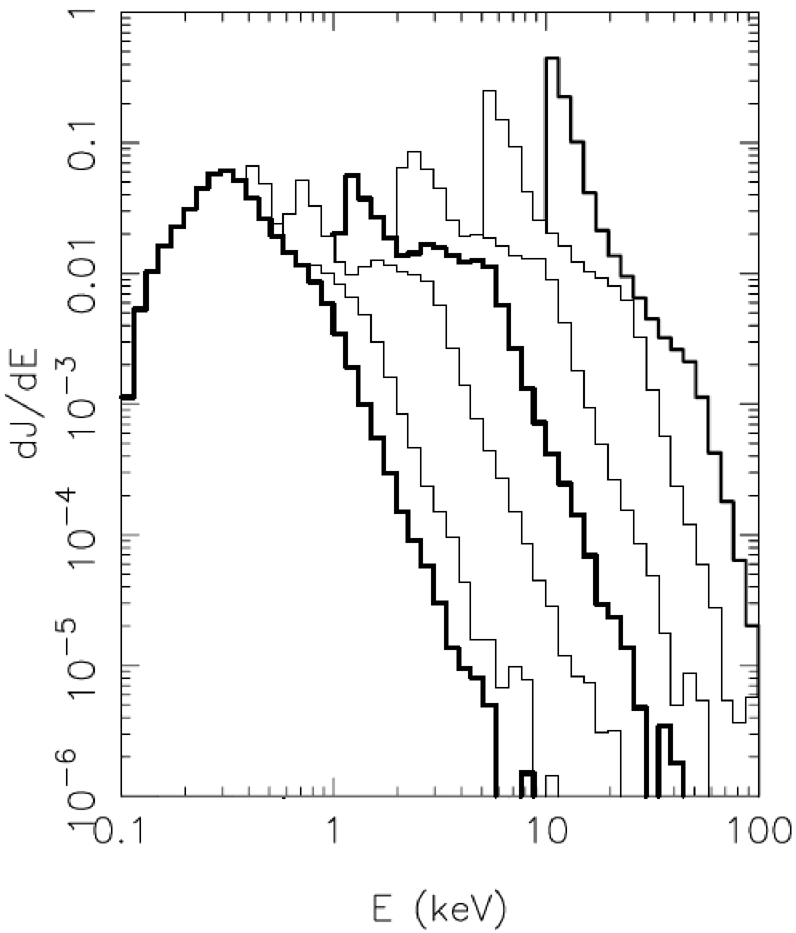


Simulation of Electron Acceleration

- Test particle electrons in fields from 2D hybrid simulation.
- High order integration scheme for high accuracy over long time scales.
- Adaptive time step – electrons motion *along* field line leads to rapid time variations of field sensed by particle.
- Interpolation from hybrid grid linear in time, cubic spline in space.

Monoenergetic injection: $\theta_{Bn} = 87$, Injection Energy 1keV

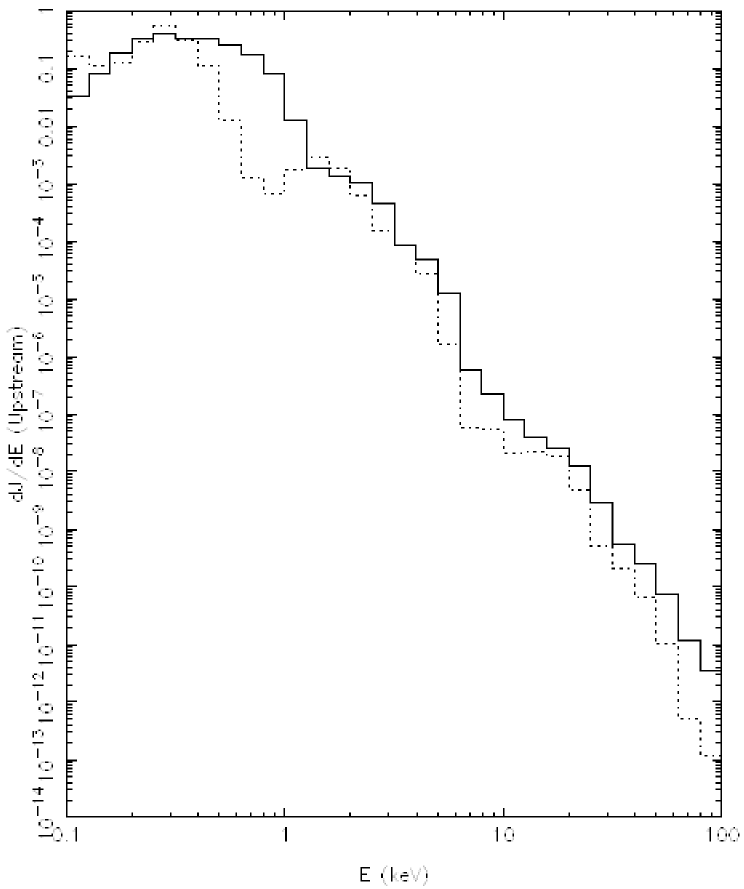




Simulation of Electron Acceleration: Synthetic Energy Spectrum

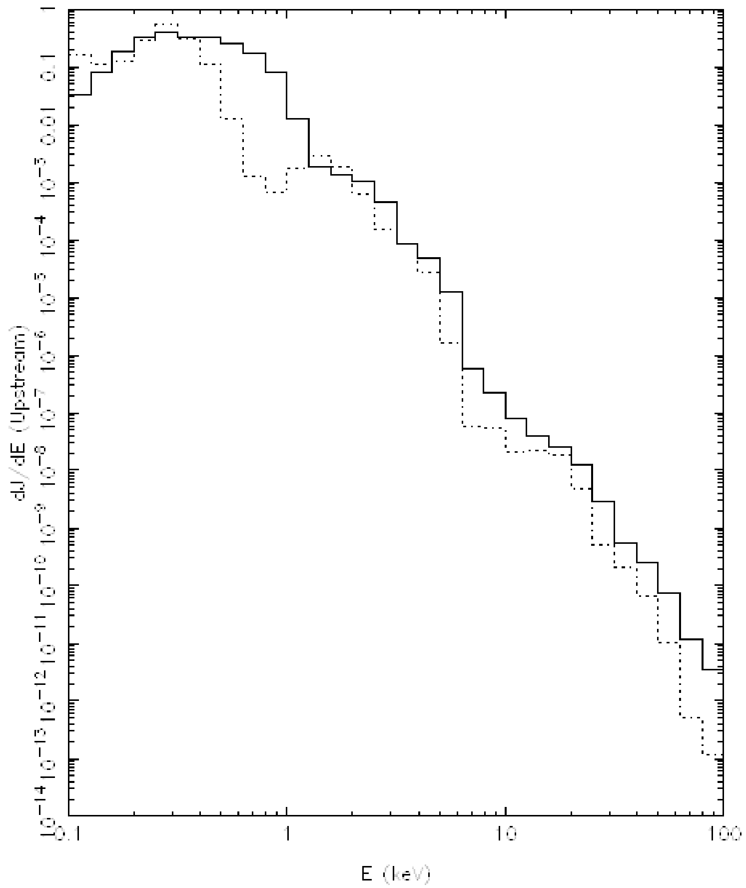
- Different initial energies
- Weight by incident distribution (Kappa or Maxwellian)
- Sum to form final spectum

Initial kappa distribution $\kappa = 4$:

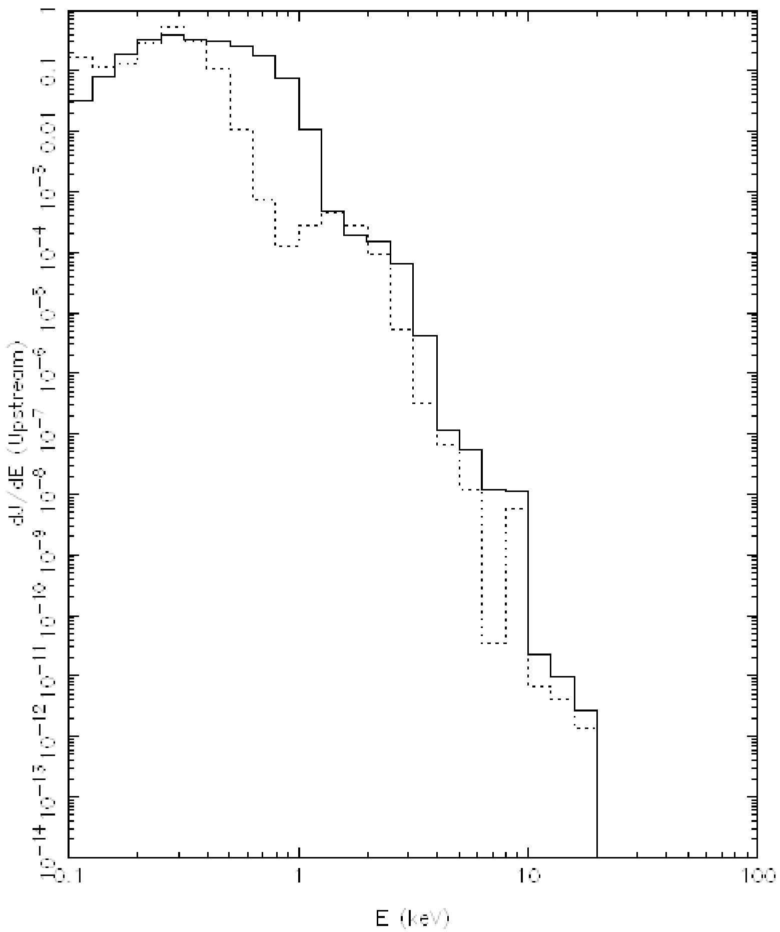


Synthetic Energy Spectrum: Comparison with Maxwellian

Initial kappa distribution $\kappa = 4$:

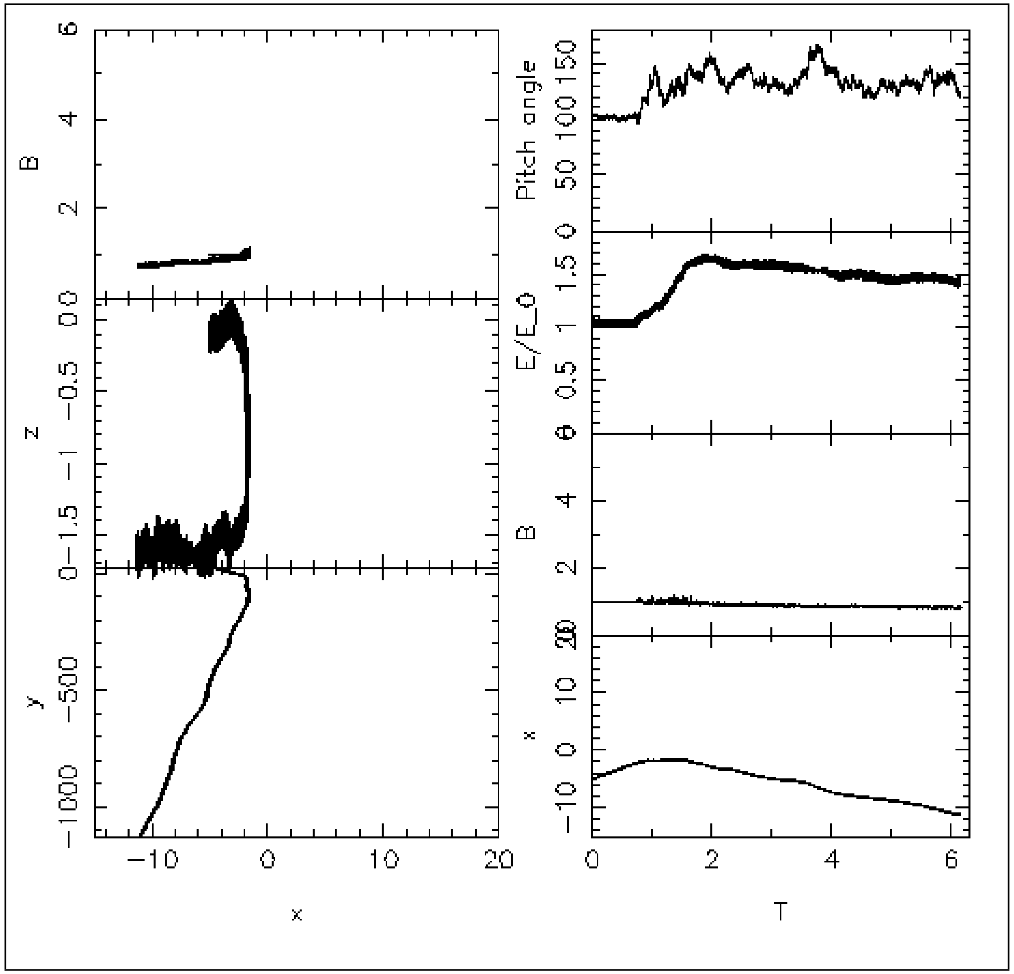


Initial Maxwellian:

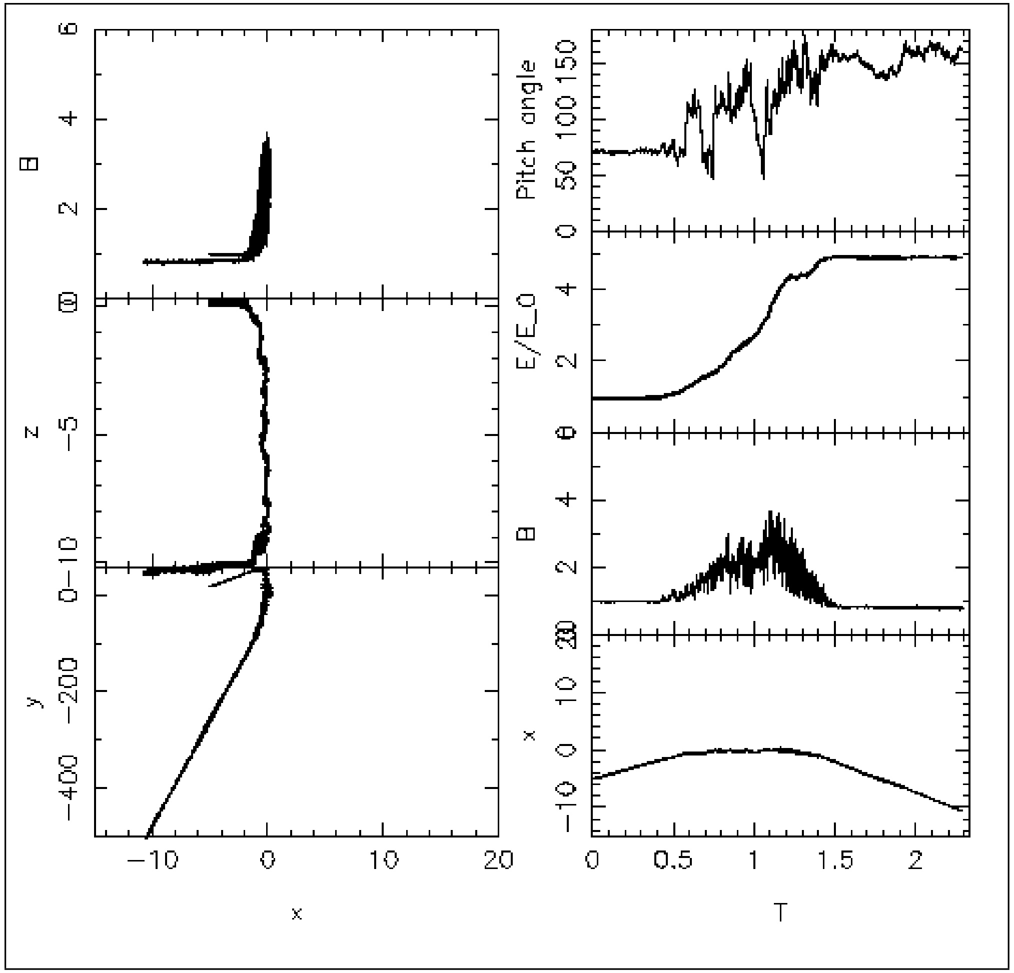


Electron Trajectories: $\theta_{Bn} = 88^{\circ}$, $M_A = 5.7$, $E_0 = 500\text{eV}$

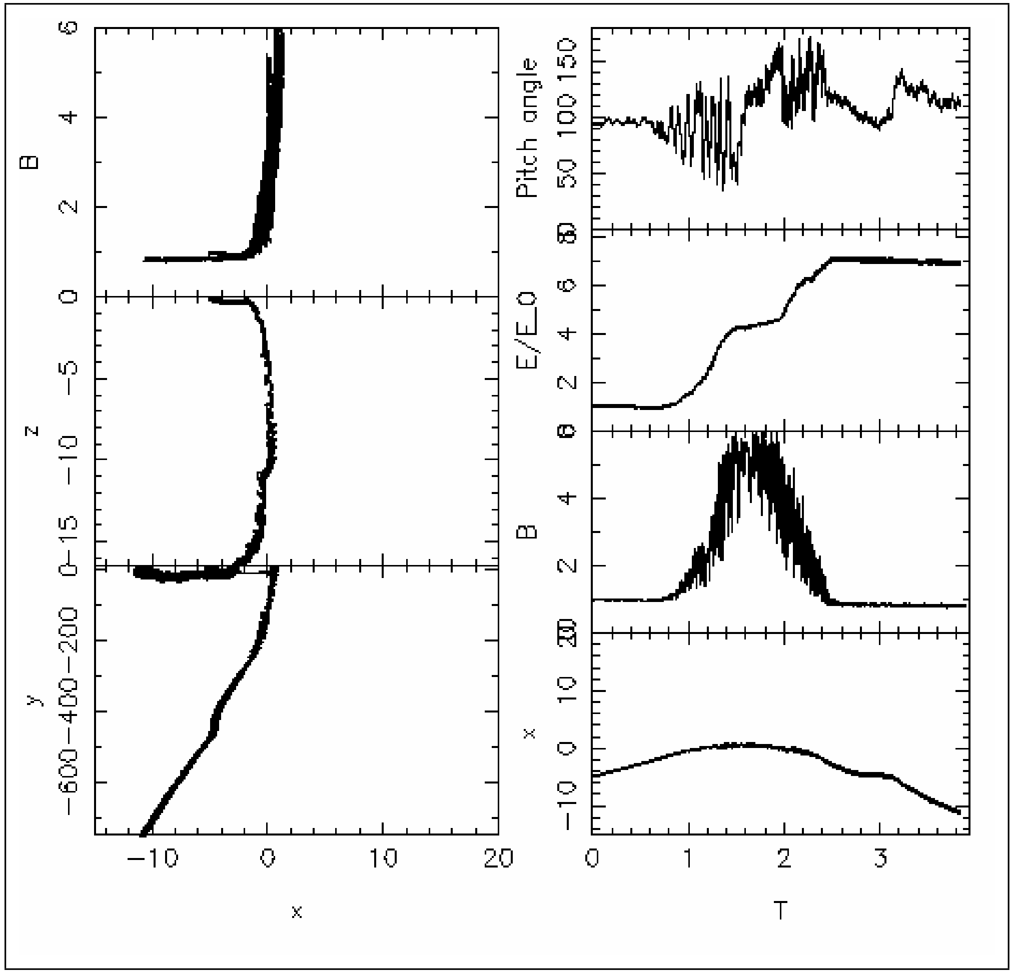
- Benign (boring?) reflection.
- Low energy gain factor.



- Reflected
- Reasonable energy gain factor
- Multiple reflection within foot and ramp, but never reaches peak
- Encounter scales: as before

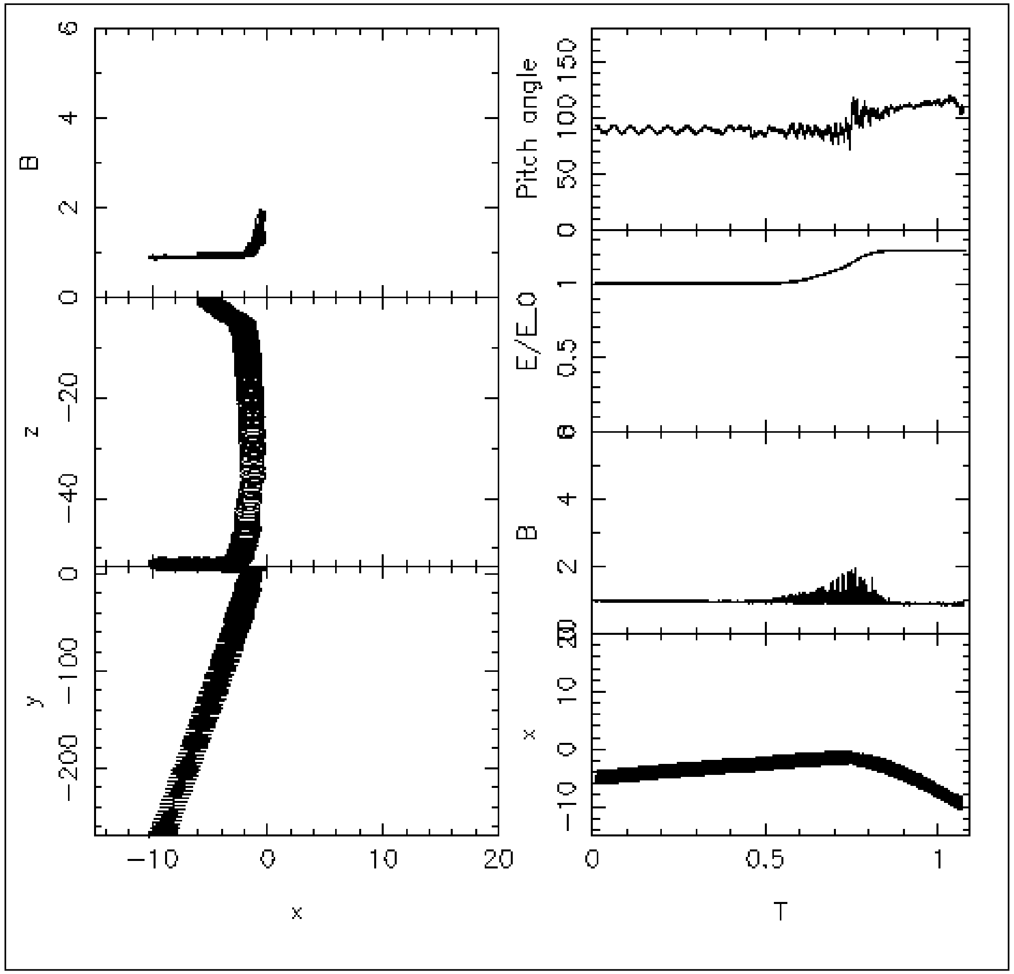


- Reflected.
- “Double” encounter: periods of pitch angle scattering going in and out of foot/ramp to overshoot.



Electron Trajectories: $\theta_{Bn} = 88^\circ$, $M_A = 5.7$, $E_0 = 50$keV

- Reflected
- “Classic” shock drift signature, but only goes little way into ramp.
- Initial pitch angle close to 90°.
- Interaction time $\sim 0.3\Omega_{cp}^{-1}$



Summary: Electron Acceleration

- Pitch angle scattering crucial to explain suprathermal power law.
- Effective reflection over wider range of θ_{Bn} than adiabatic reflection
- Downstream and upstream distributions at similar levels: appearance of leakage?