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Suprathermal electron acceleration by an ICME-driven shock on 2000 Feb 11

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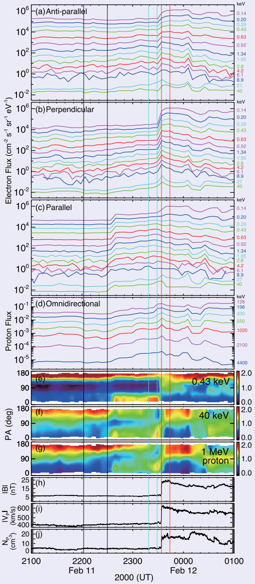
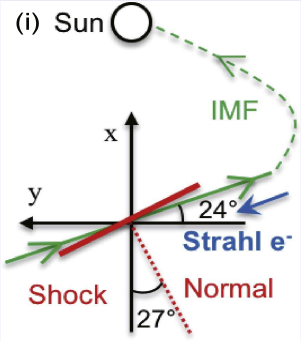
Outline

1. the quasi-perpendicular shock event on 2000 Feb 11
2. Shock acceleration mechanism
3. Numerical simulations
    - Shock acceleration model
    - Simulation results
    - Summary

Observational works



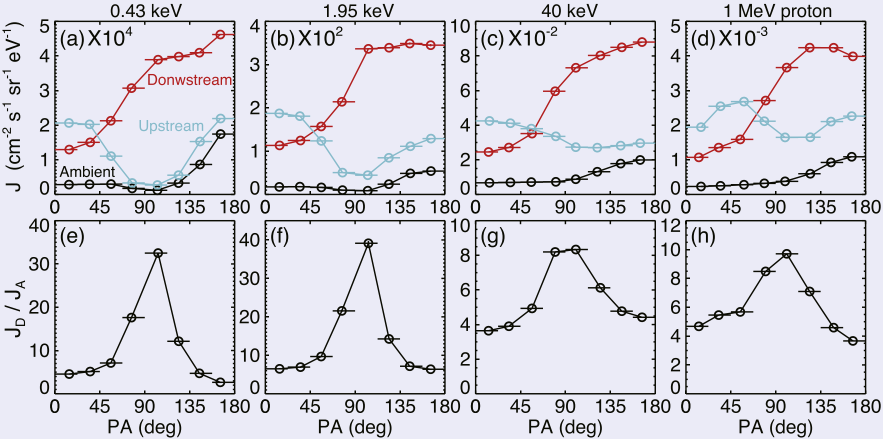
2000 Febrary 11



(Yang et al. 2018, ApJ)

Observational works

average differential flux vs. PA (peak near 90° pitch angles)



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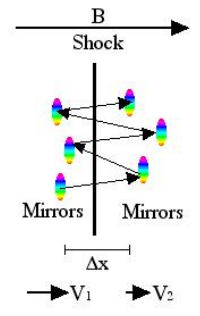
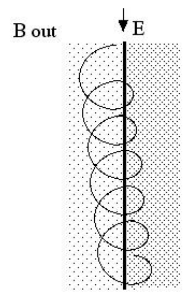
Shock acceleration mechanism

diffusive shock acceleration (DSA) theory explains the power-law cosmic-ray spectrum. first-order Fermi acceleration(FFA，left): caused by the relative motion of scattering centers upstream and downstream of the shock, particles undergo pitch angle scattering due to magnetic turbulence and gain energies by crossing the shock back and forth. shock drift acceleration(SDA，right): due to drift electric field in the shock frame $\boldsymbol{E} = -\boldsymbol{U} \times \boldsymbol{B}$, the non-zero tangential magnetic field component jump across the shock surface, particles drift along the electric field direction.





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Shock acceleration model

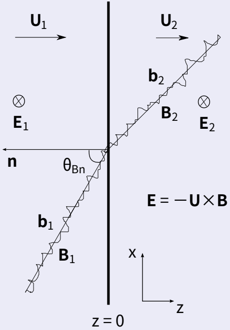
The control equation:

$$\frac{d\boldsymbol{p}}{dt} = q[\boldsymbol{E}(\boldsymbol{r}, t) + \boldsymbol{v} \times \boldsymbol{B}(\boldsymbol{r}, t)], \tag{1}$$

where $\boldsymbol{E} = -\boldsymbol{U} \times \boldsymbol{B}$, and $\boldsymbol{B}(x, y, z) = \boldsymbol{B}_0 + \boldsymbol{b}(x, y, z)$.

The turbulent magnetic field (Matthaeus et al. 1990, Zank & Matthaeus 1992, etc.):

$$\boldsymbol{b}(x, y, z) = \boldsymbol{b}_{\rm slab}(z) + \boldsymbol{b}_{\rm 2D}(x, y) \tag{2}$$



- left: upstream
- right: downstream

Shock acceleration model

backward-in-time method

A total number of 30, 000 electrons (E_i, μ_j) are put into the downstream range $[z_0, z_1]$ at $t = 0$, where $z_0 = L_{th}$ and $z_1 = V_{sh}\Delta t$ with $\Delta t = 10$ min. The trajectory of each electron is followed using an adaptive step fourth-order Runge-Kutta method.

The downstream pitch angle distribution $f_{dn}(E_i, \mu_j)$:

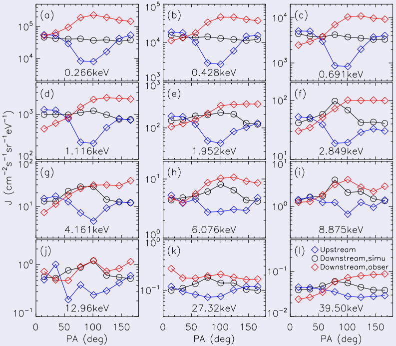
$$f_{dn}(E_i, \mu_j) = \frac{1}{N_{ij}} \sum_{k=1}^{N_{ij}} f_0(E_{ik}, \mu_{jk}) \tag{3}$$

parameters settings

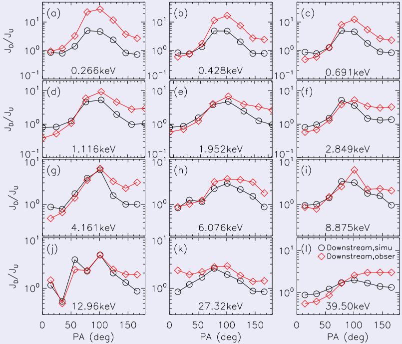
$\theta_{Bn} = 89^\circ$, $V_{\rm sh} = 682$ km/s, $V_{\rm sw} = 434$ km/s, $U_1 = 248$ km/s, $V_{\rm A1} = 67$ km/s, $M_{\rm A1}$=3.70, $B_{01} = 7.0$ nT, r=2.87.

Simulation results

ambient, up- and down-stream flux

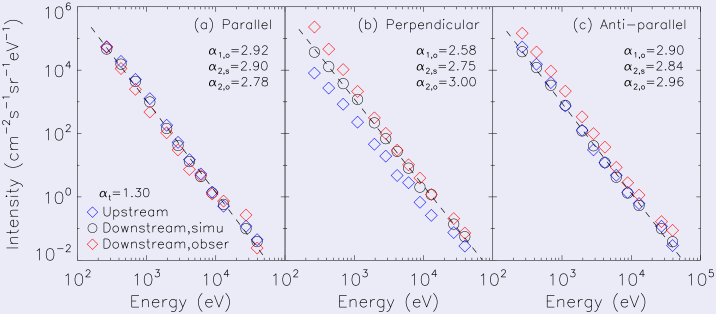


the downstream to upstream flux ratio



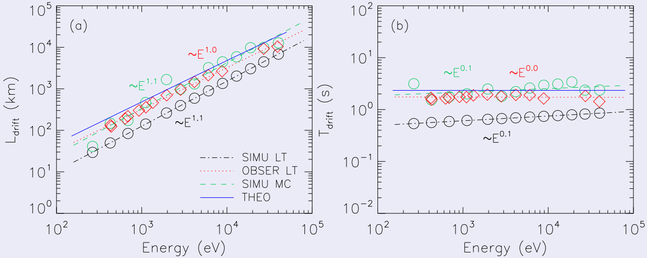
Simulation results

energy spectra in three directions



Simulation results

electron drift length, drift time



LT: $f_2(p_2) = f_1(p_1)$, $L_{\text{drift}} = \frac{\Delta E}{q|\boldsymbol{E}|}$, $T_{\text{drift}} = L_{\text{drift}}/V_{\text{drift}}$ (Yang et al. 2018).
THEO: $T_{\text{drift}} = L_{\text{th}}/2U_1 + L_{\text{th}}/2U_2$,
$L_{\text{drift}} = T_{\text{drift}} V_{\text{drift}} = pv/6q(1/U_1 + 1/U_2)(B_{x1}/B_1^2 - B_{x2}/B_2^2)$.

($\boldsymbol{V}_{\text{drift}} = \hat{\boldsymbol{e}}_y \frac{pcv}{3q}\left(\frac{B_{x1}}{B_1^2} - \frac{B_{x2}}{B_2^2}\right)\delta(z)$, Jokipii 1982, ApJ)

Summary

- In this work, we reveal the reason for 90° pitch angle enhancemants at the ICME-driven quasi-perpendicular shock event on 2000 Feb 11: the dominance of shock drift acceleration.
- We also construct a theoretical model of the electron drift length and drift time, and obtain the drift length and time from the simulations based on the Liouville's theorem or Monte-Carlo method. We find that the electron drift length and time from both our theoretical model and simulations based on Monte-Carlo method or Liouville's theorem agree well with the observations based on Liouville's theorem.

Thank you very much!