Dissipation in Electron-only Reconnection Events: Insights from Pressure-Strain Interaction

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Pressure-Strain and Dissipation

$$\partial_t f_\alpha + \boldsymbol{v} \cdot \nabla f_\alpha + \frac{\mathbf{F}}{m_\alpha} \cdot \nabla_{\boldsymbol{v}} f_\alpha = 0$$

Assume Vlasov

Distribution function

α = proton, electron, ...

$$\partial_t \mathcal{E}^f_\alpha + \nabla \cdot (\mathcal{E}^f_\alpha \mathbf{u}_\alpha + \mathbf{P}_\alpha \cdot \mathbf{u}_\alpha) = (\mathbf{P}_\alpha \cdot \nabla) \cdot \mathbf{u}_\alpha + n_\alpha q_\alpha \mathbf{E} \cdot \mathbf{u}_\alpha . \quad (1)$$

$$\partial_t \mathcal{E}^{th}_\alpha + \nabla \cdot (\mathcal{E}^{th}_\alpha \mathbf{u}_\alpha + \mathbf{h}_\alpha) = -(\mathbf{P}_\alpha \cdot \nabla) \cdot \mathbf{u}_\alpha . \quad (2)$$

$$\partial_t \mathcal{E}^m + \frac{c}{4\pi} \nabla \cdot (\mathbf{E} \times \mathbf{B}) = -\mathbf{E} \cdot \mathbf{J} \quad (3)$$

Add internal energy: dissipation

Why Pi-D?

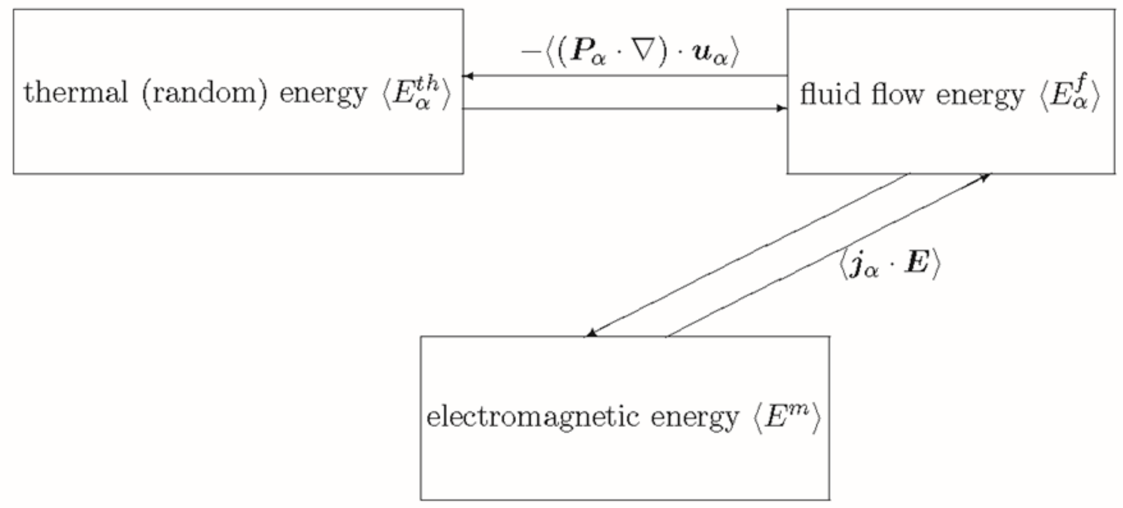
$$\partial_t \langle E_\alpha^f \rangle = \langle (\boldsymbol{P}_\alpha \cdot \nabla) \cdot \boldsymbol{u}_\alpha \rangle + \langle n_\alpha q_\alpha \boldsymbol{E} \cdot \boldsymbol{u}_\alpha \rangle,$$

$$\partial_t \langle E_\alpha^{th} \rangle = -\langle (\boldsymbol{P}_\alpha \cdot \nabla) \cdot \boldsymbol{u}_\alpha \rangle,$$

$$\partial_t \langle E^m \rangle = -\langle \boldsymbol{E} \cdot \boldsymbol{j} \rangle.$$

- Pi-D distinguishes ion/electron heating.
- Triangle diagram describes energy conversion.

j.E and Pi-D measure somewhat different stages of energy conversion (dissipation)



Pi-D & pθ Decomposition

$$
\begin{aligned}
-(\boldsymbol{P}\cdot\nabla)\cdot\boldsymbol{u} &= -p\delta_{ij}\partial_j u_i - (P_{ij} - p\delta_{ij})\partial_j u_i \\
&= -p\theta - \Pi_{ij} D_{ij},
\end{aligned}
$$

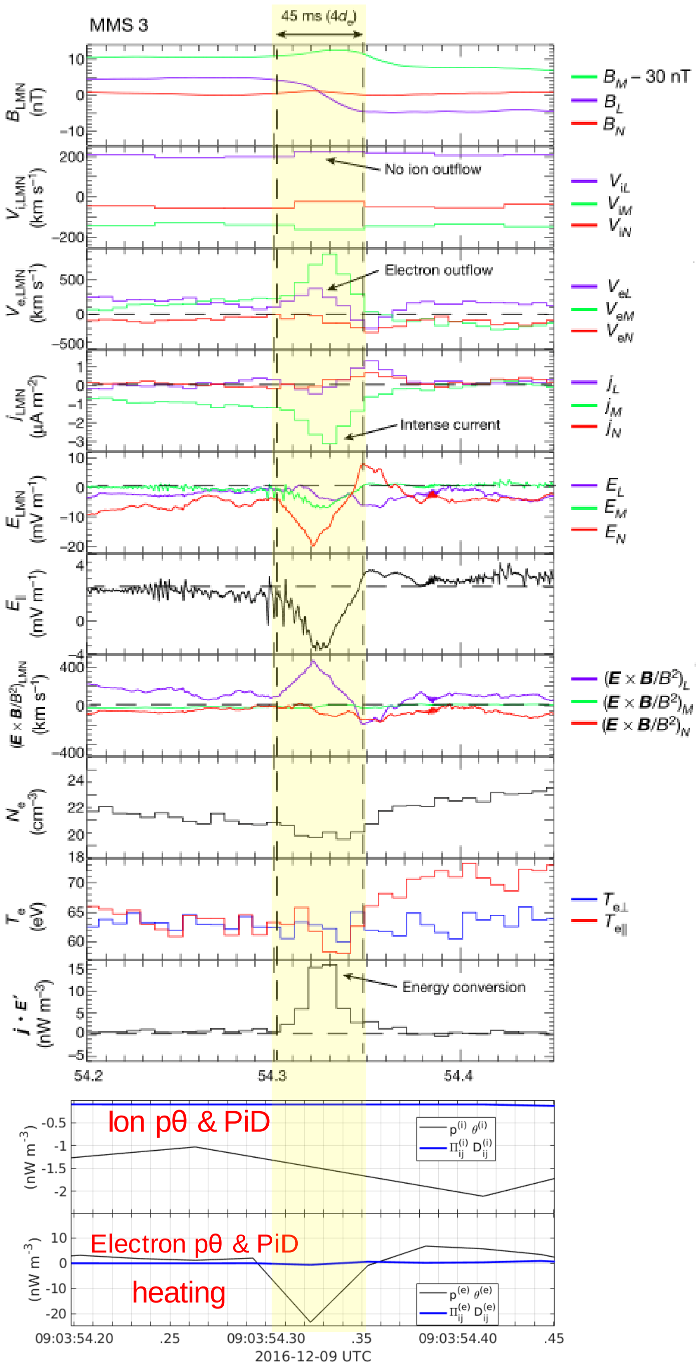
Compressive heating

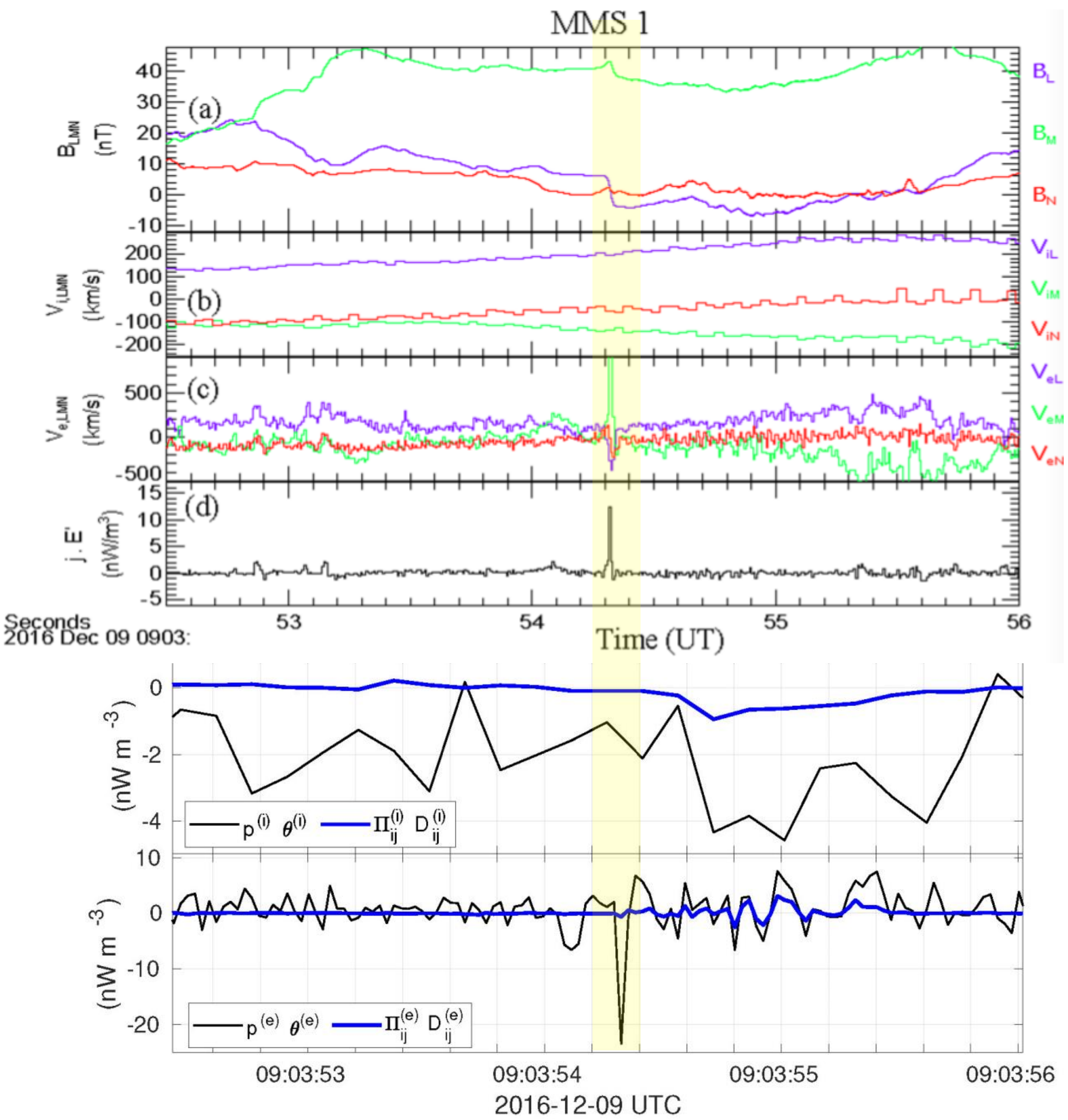
Incompressive heating: “Pi-D”

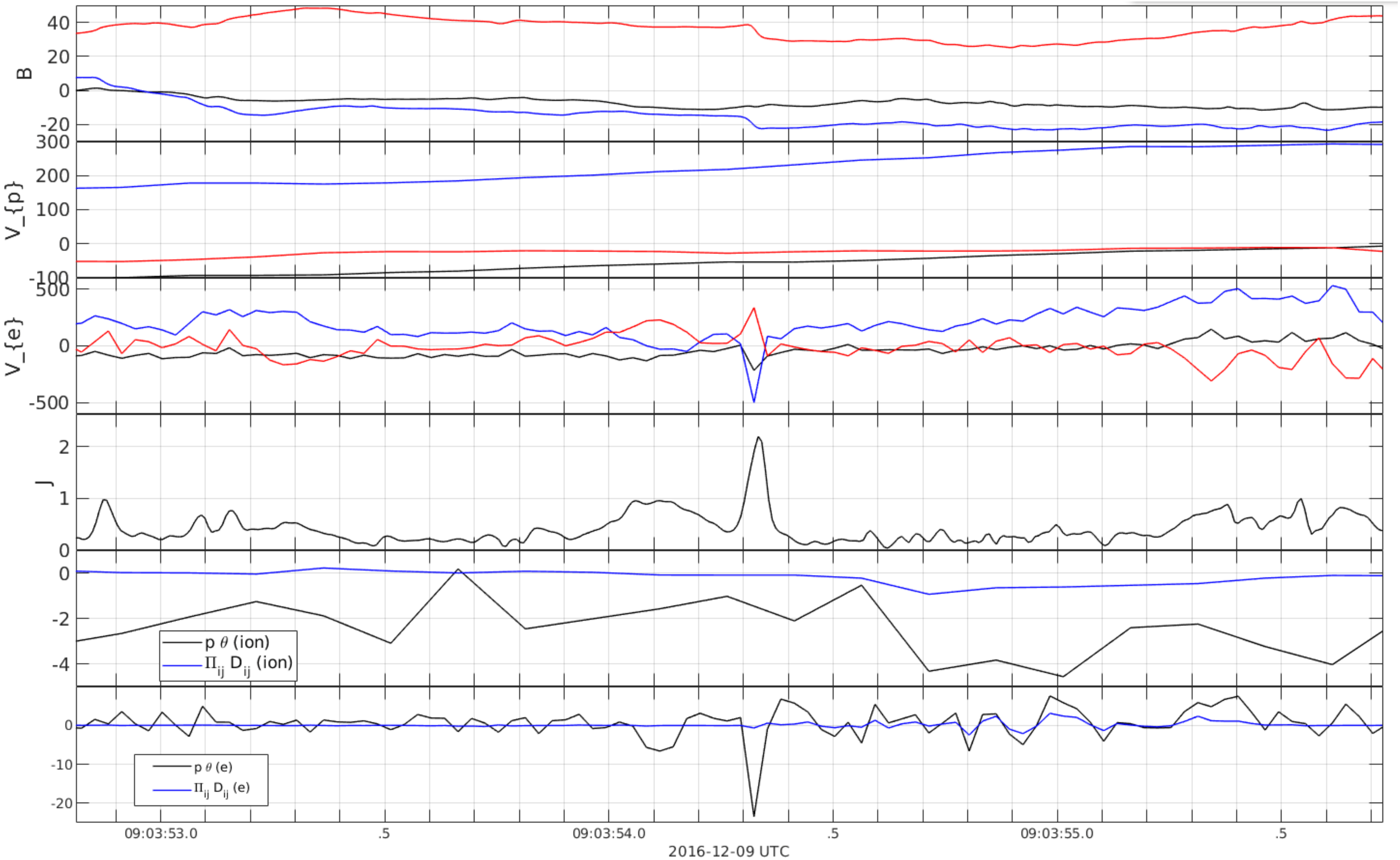
$$p = \tfrac{1}{3} P_{ii} \qquad \theta = \nabla\cdot\boldsymbol{u}$$

$$\Pi_{ij} = P_{ij} - p\delta_{ij} \qquad D_{ij} = \tfrac{1}{2}(\partial_i u_j + \partial_j u_i) - \tfrac{1}{3}\theta\delta_{ij}$$

Phan et al. (Nature 557, 202 (2018))







B
V_{p}
V_{e}
J
p θ (ion)
Π_ij D_ij (ion)
p θ (e)
Π_ij D_ij (e)
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.5
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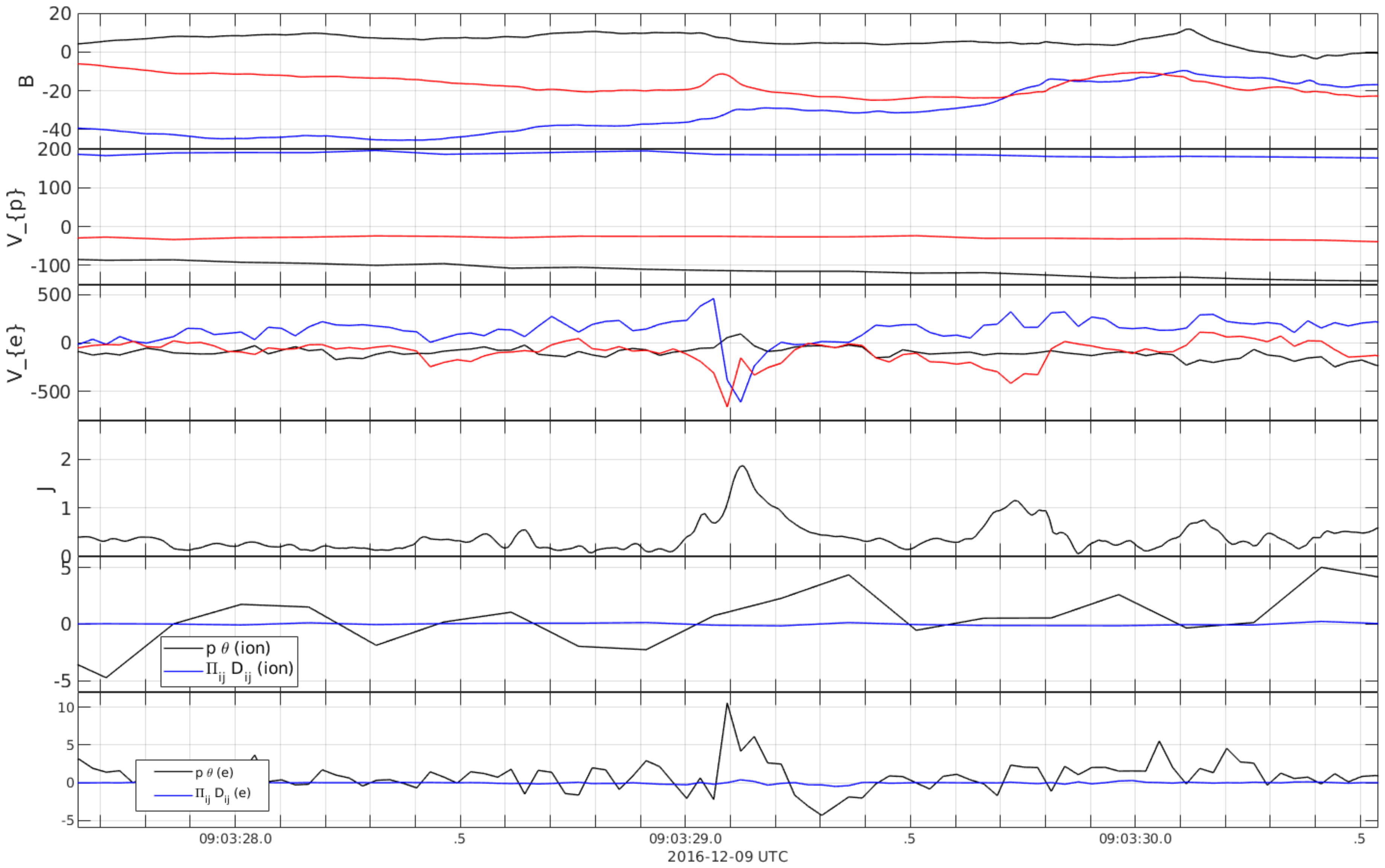

B
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Summary

- Preliminary analysis shows dominant electron heating.
- Heating via compressive channel.