Electromagnetic energy conversion by various processes in turbulent plasmas observed by MMS

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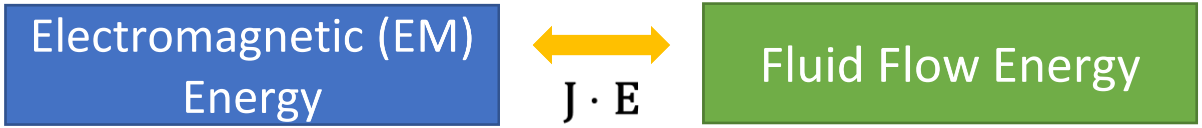
<< See our abstract here

INTRODUCTION

- Energy conversion in turbulent plasmas is central to plasma heating and particle energization.

- We consider the energy conversion from EM to fluid flow via $\boldsymbol{J} \cdot \boldsymbol{E}$.



$\mathrm{J} \cdot \mathrm{E} > 0$ EM Energy → Fluid Flow Energy
$\mathrm{J} \cdot \mathrm{E} < 0$ EM Energy ← Fluid Flow Energy

- To understand what might contribute to $\boldsymbol{J} \cdot \boldsymbol{E}$, we separate it into components for the parallel and perpendicular currents (relative to the magnetic field) and also for different species.

- The perpendicular current can be further separated into various drift motions

- We identify contribution of $\boldsymbol{J}$ and $\boldsymbol{E}$ at various frequencies to the total $\boldsymbol{J} \cdot \boldsymbol{E}$

Methodology

- We analyze burst mode data from Magnetospheric Multiscale (MMS) Mission.

Instruments	Data	Resolution (Burst mode)
Fast Plasma Investigation (FPI)	Ion and Electron (e.g. bulk velocity, number density)	6.67 Hz (150ms) for ion data 33.33 Hz (30ms) for electron data
Fluxgate Magnetometer (FGM)	Magnetic Field, S/C Position	128 Hz
Electric field Double Probe (EDP)	Electric Field	8192 Hz

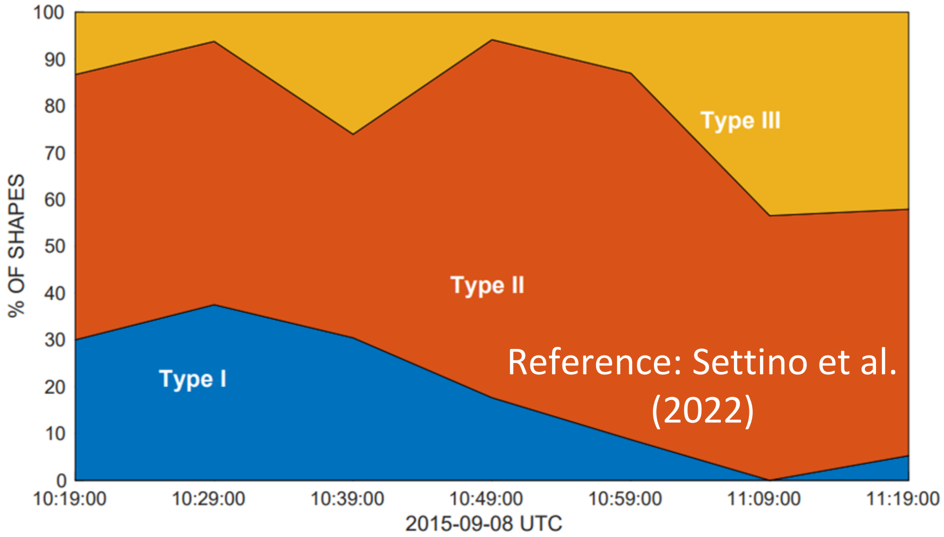
- We averaged all the data to ion data cadence.

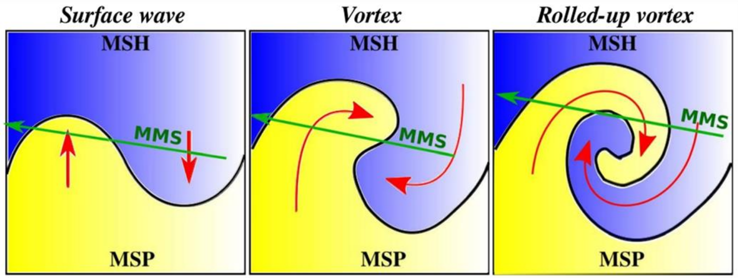
(MMS Data can be downloaded at https://lasp.colorado.edu/mms/sdc/public/)

Kelvin-Helmholtz (KH) waves observed at the Earth's magnetopause by MMS

We analyze the KH event on 8 September 2015, first published by Eriksson et al. (2016).

Settino et al. (2022) has recently characterized the different stages of KH wave development using a mixing parameter.





Type I Type II Type III

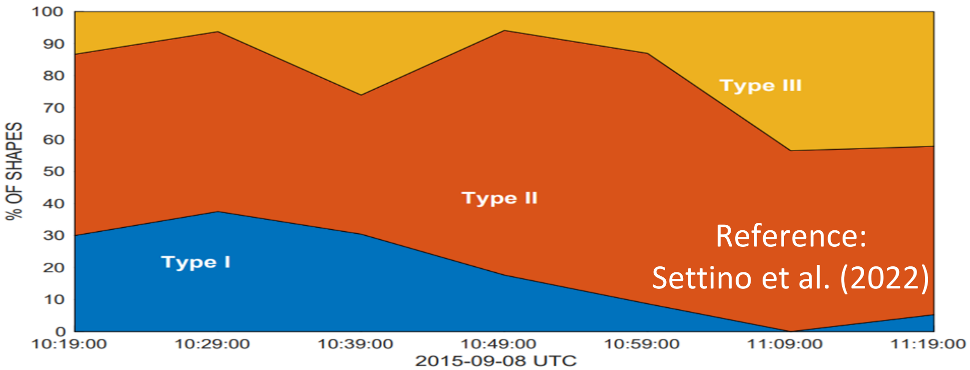
$\mathbf{J} \cdot \mathbf{E}$ in KHI region

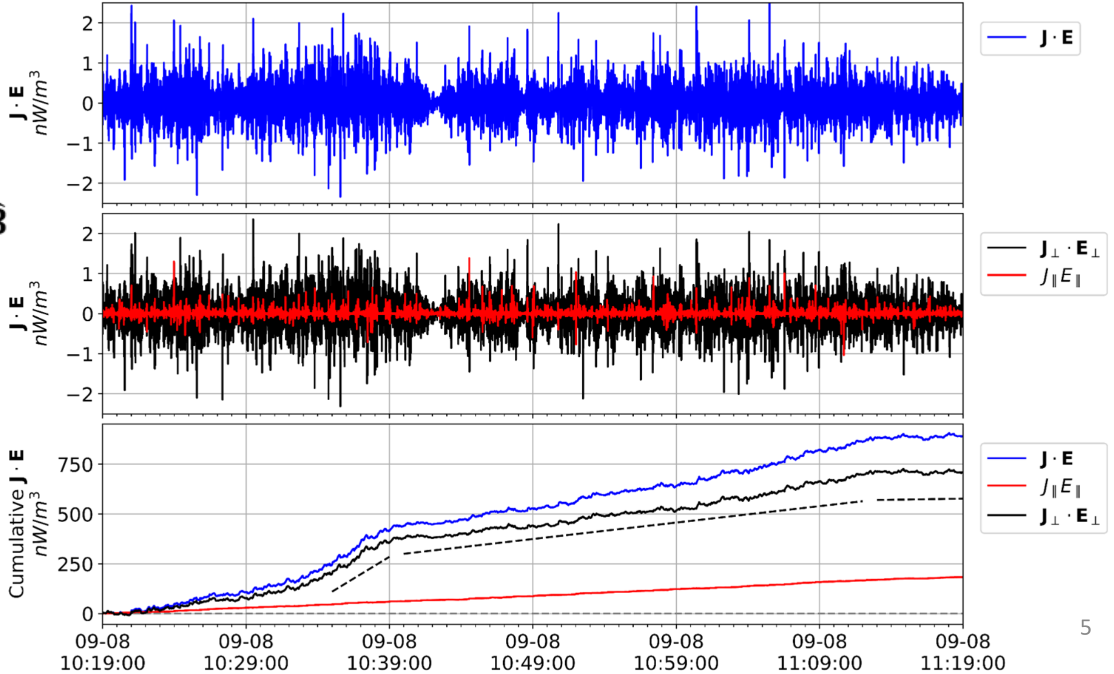
- We decompose the $\boldsymbol{J} \cdot \boldsymbol{E}$ into the parallel and perpendicular components.

$$J_{\parallel} = \mathbf{J} \cdot \hat{\mathbf{B}} \qquad E_{\parallel} = \mathbf{E} \cdot \hat{\mathbf{B}}$$

$$\mathbf{J}_{\perp} = \mathbf{J} - (\mathbf{J} \cdot \hat{\mathbf{B}})\hat{\mathbf{B}} \qquad \mathbf{E}_{\perp} = \mathbf{E} - (\mathbf{E} \cdot \hat{\mathbf{B}})\hat{\mathbf{B}}$$

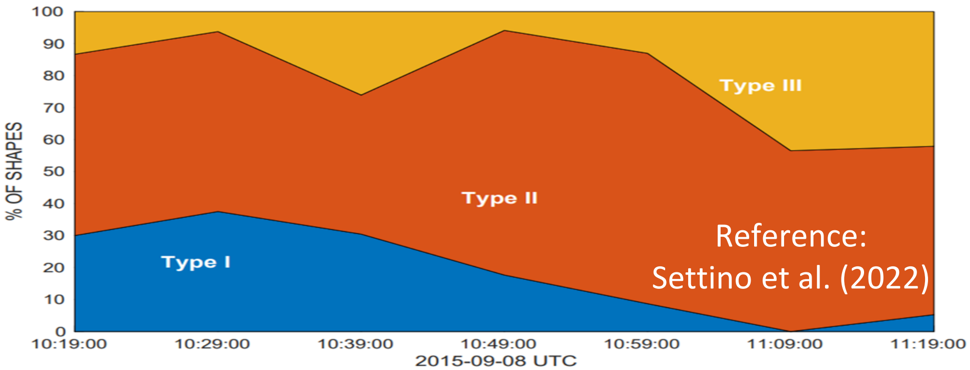
- The perpendicular component has a higher fluctuation compared to the parallel component.

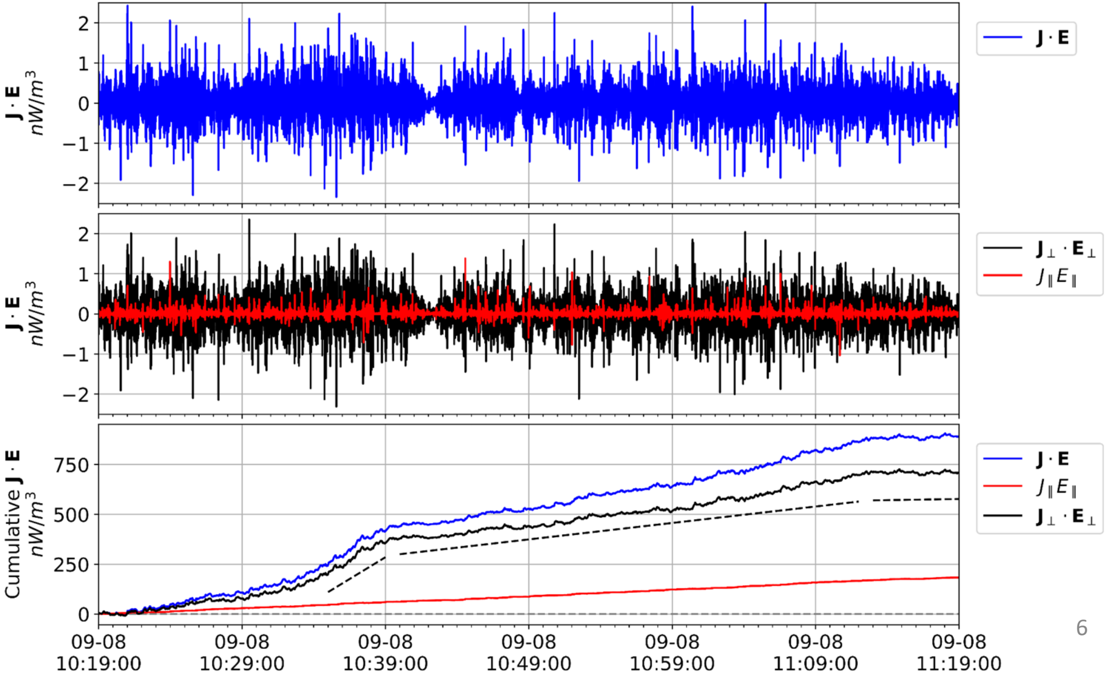




$J \cdot E$ in KHI region

- To assess “net” contribution of $\boldsymbol{J} \cdot \boldsymbol{E}$, we compute a cumulative $\boldsymbol{J} \cdot \boldsymbol{E}$ with time.
- We find that cumulative $\boldsymbol{J} \cdot \boldsymbol{E}$ is positively increasing with time (EM energy is converted into fluid flow energy). This positive increase is mainly contributed by the perpendicular component. The parallel $\boldsymbol{J} \cdot \boldsymbol{E}$ is slowly increasing with time.
- $\boldsymbol{J} \cdot \boldsymbol{E}$ is strong at the end of the 1st stage and $\boldsymbol{J} \cdot \boldsymbol{E}$ is weak at the 3rd stage





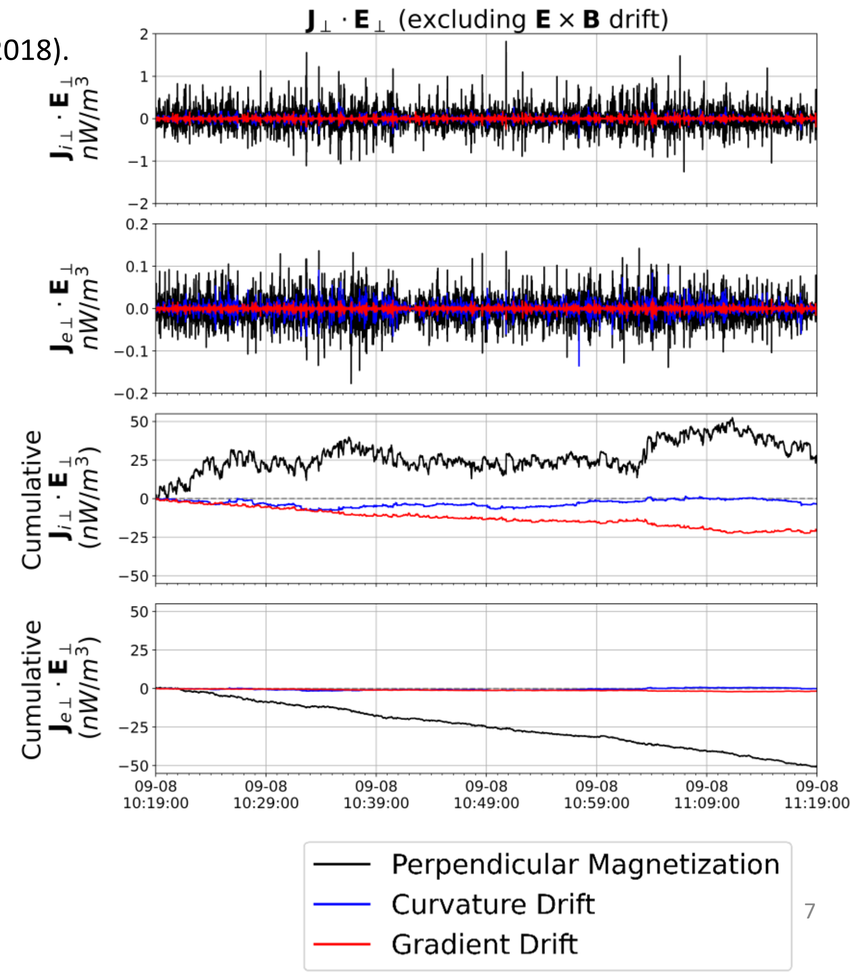
$\mathbf{J}_\perp \cdot \mathbf{E}_\perp$ in terms of drift motions

We separate the perpendicular current into drift motions following Li et al. (2018).

$$\mathrm{J}_{s\perp} = p_{s\parallel}\frac{\boldsymbol{B}\times(\boldsymbol{B}\cdot\nabla)\boldsymbol{B}}{B^4} + p_{s\perp}\frac{\boldsymbol{B}\times\nabla B}{B^3} - \left[\nabla\times\frac{p_{s\perp}\boldsymbol{B}}{B^2}\right]_\perp + \rho_s\frac{\boldsymbol{E}\times\boldsymbol{B}}{B^2} - n_s m_s\frac{d\boldsymbol{u}_s}{dt}\times\frac{\boldsymbol{B}}{B^2}$$

Curvature Drift | Gradient Drift | Perpendicular Magnetization | ExB Drift | Particle Inertia

- **Particle inertia** is incalculable via MMS Data.
- **ExB drift** mostly contributes to the perpendicular current, but it does not take any roles in Energy Conversion via J.E term.
- We consider **Curvature drift**, **Gradient drift**, and **Perpendicular Magnetization** contribution to J.E separately
- **Perpendicular Magnetization** from ions transfers energy to flow, but electrons transfer energy to the EM field.



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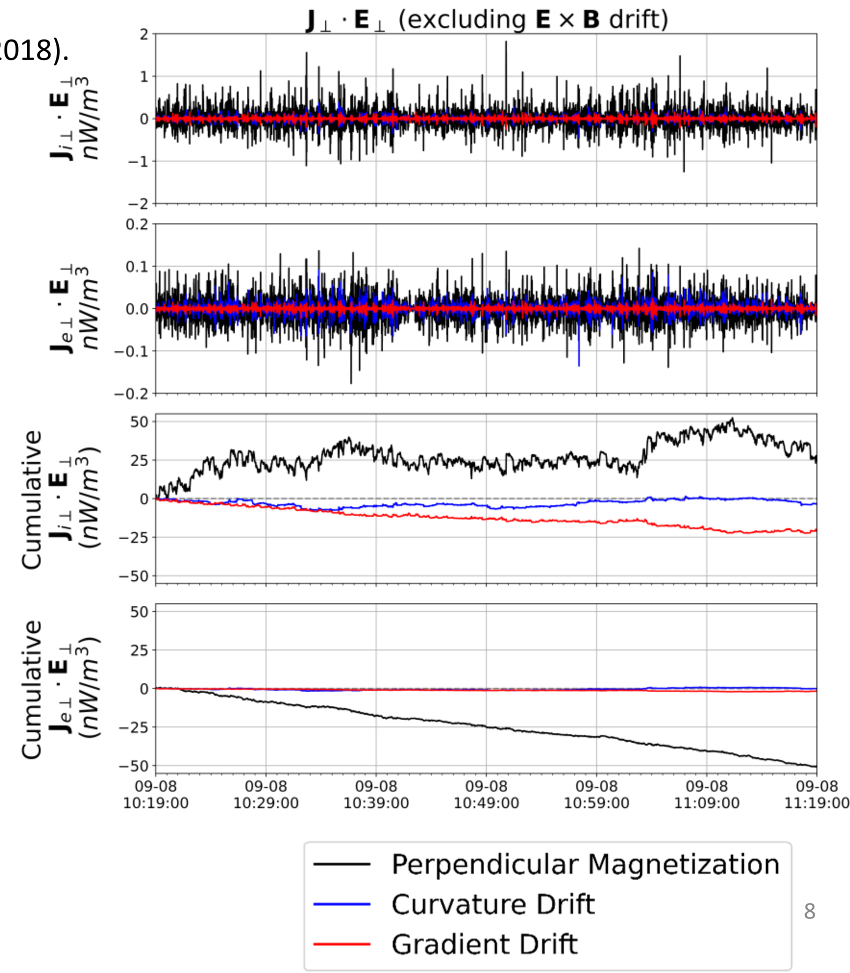
Curvature Drift | **Gradient Drift** | **Perpendicular Magnetization** | **ExB Drift** | **Particle Inertia**

- Net $\boldsymbol{J}\cdot\boldsymbol{E}$ from first three terms is negative.
- By implication, **particle inertia** contribution is positive and dominant.
- Almost all net energy conversion comes from the mode of zero frequency which might be related to the large-scale structure

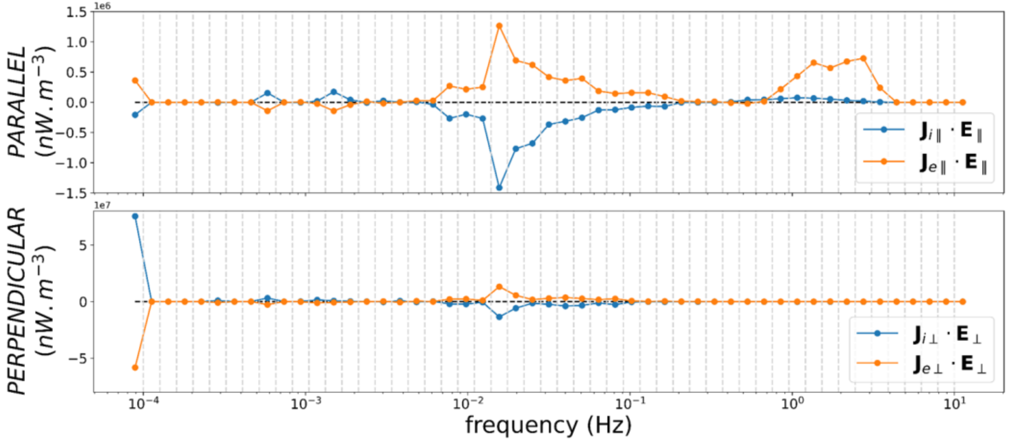


$\mathbf{J} \cdot \mathbf{E}$ in the frequency domain

- We consider J and E separately and find the energy conversion (J.E) through each frequency.

$$\text{Net } \boldsymbol{J} \cdot \boldsymbol{E} = \sum_{f=-f_{max}}^{f=f_{max}} W(f) \qquad \text{where} \quad W(f) = J_f E_{-f} + J_{-f} E_f$$

- The parallel energy conversion via electron peaks at around 0.8 – 4 Hz.
- The perpendicular energy conversion peaks at very low frequency.
- Possible candidates for parallel heating at such frequencies:
  - ➢ Parallel electric field consistent with lower hybrid drift waves (Marshall et al. 2022)



Summary & Discussion

- We investigate the electromagnetic energy conversion via $\boldsymbol{J} \cdot \boldsymbol{E}$ by decomposing it to various terms.
- The net $\boldsymbol{J} \cdot \boldsymbol{E}$ is mainly from the perpendicular term that is dominated by the acceleration term. The strongest drift term involves the perpendicular magnetization current. The reason for strong magnetization current could be the strong density gradient at the magnetopause boundary layer.
- For the net parallel $\boldsymbol{J} \cdot \boldsymbol{E}$, we found that the modes with frequencies ranging from 0.8 to 4 Hz are the main contribution to energy conversion and these modes, consistent with the lower hybrid drift waves.

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