Electron Dynamics Resolved with MMS

MMS Virtual SWT
October 2020

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The Fast Plasma Investigation (FPI) on MMS

Pollock et al. 2016

16 Dual
Electron Spectrometers (DES)

16 Dual
Ion Spectrometers (DIS)

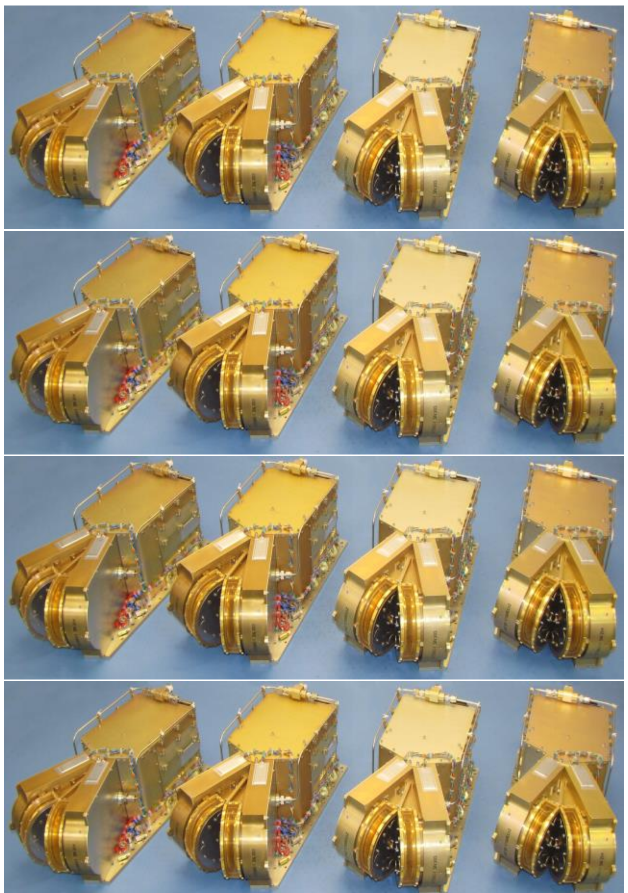
4
IDPUs

Suite 1

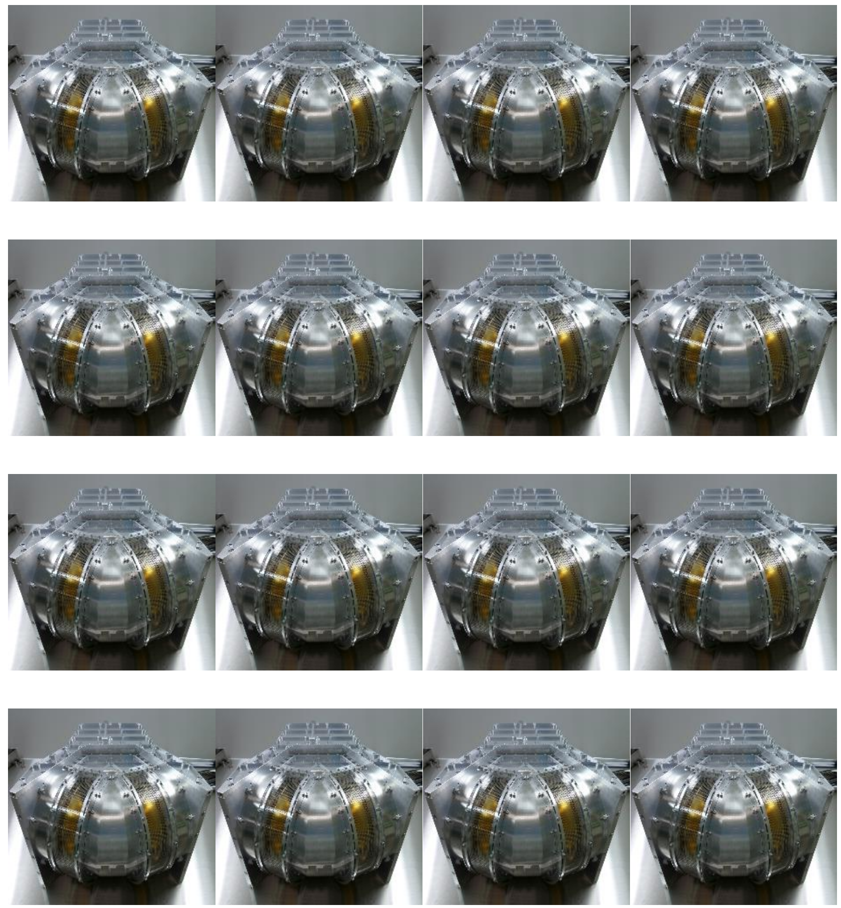
Suite 2

Suite 3

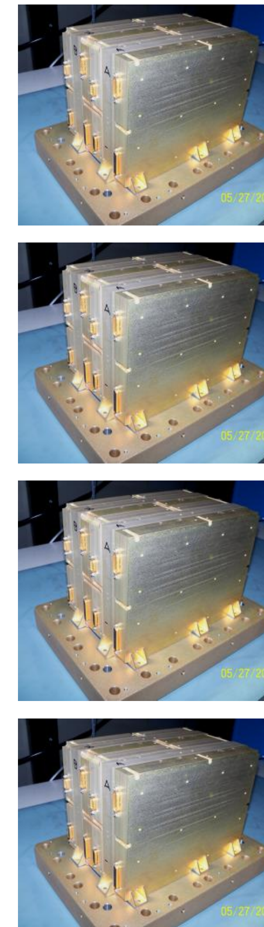
Suite 4



NASA GSFC

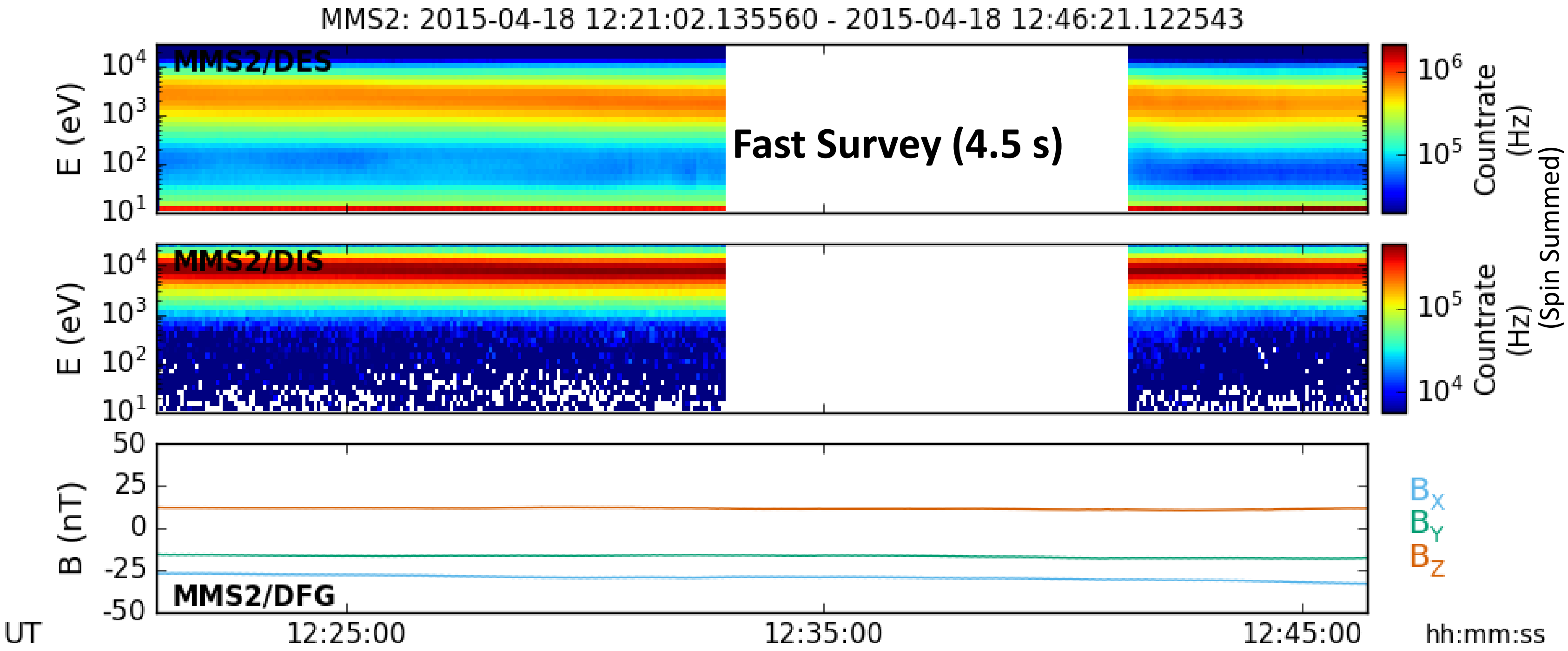


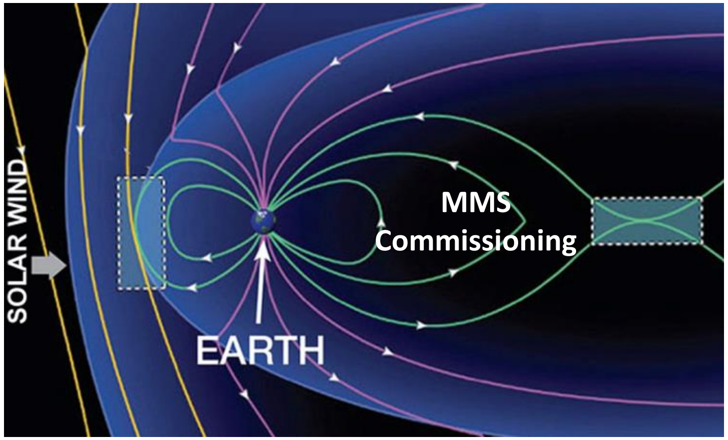
ISAS/Meisei, NASA Marshall



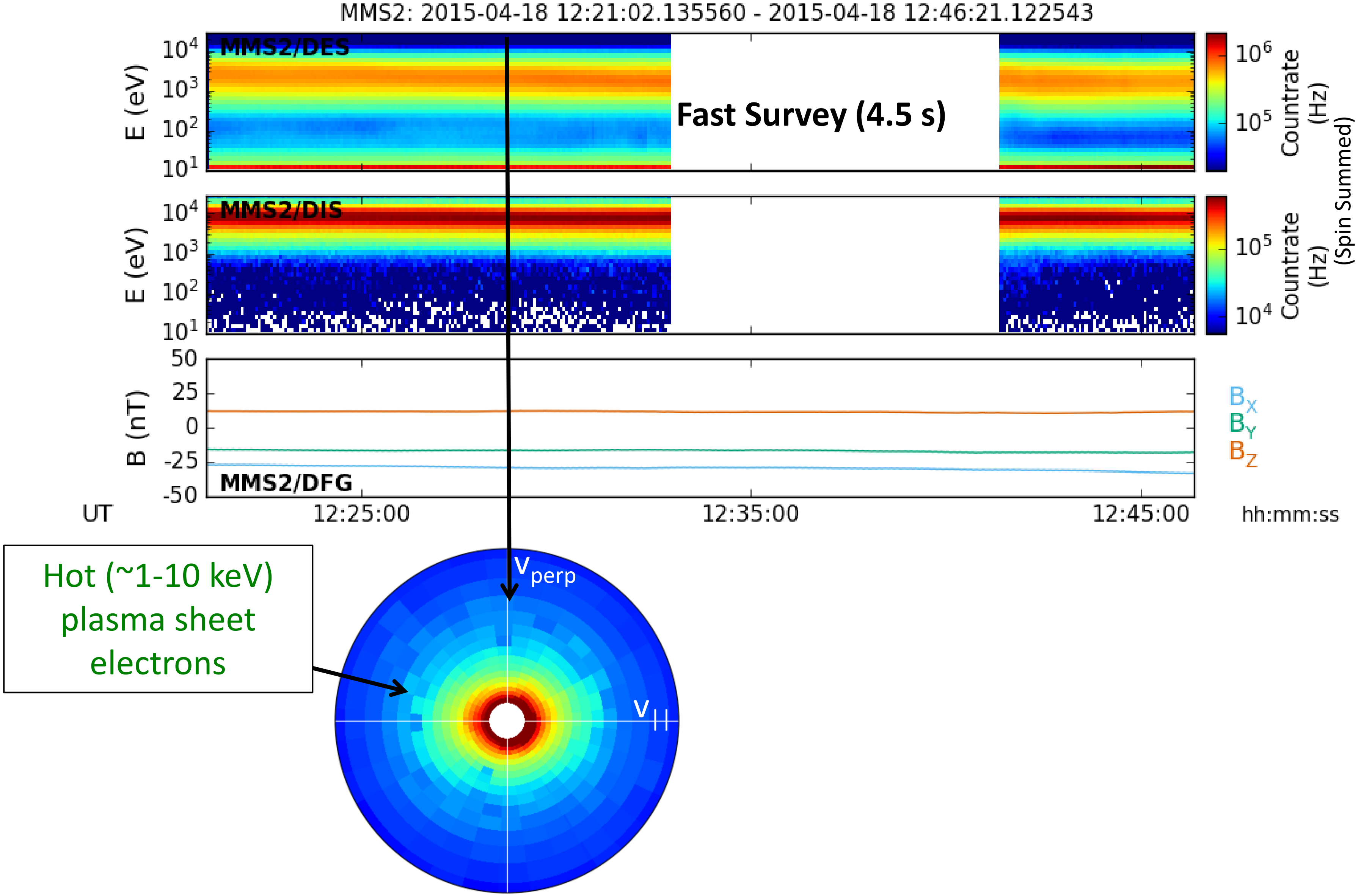
NASA GSFC

FPI First Light

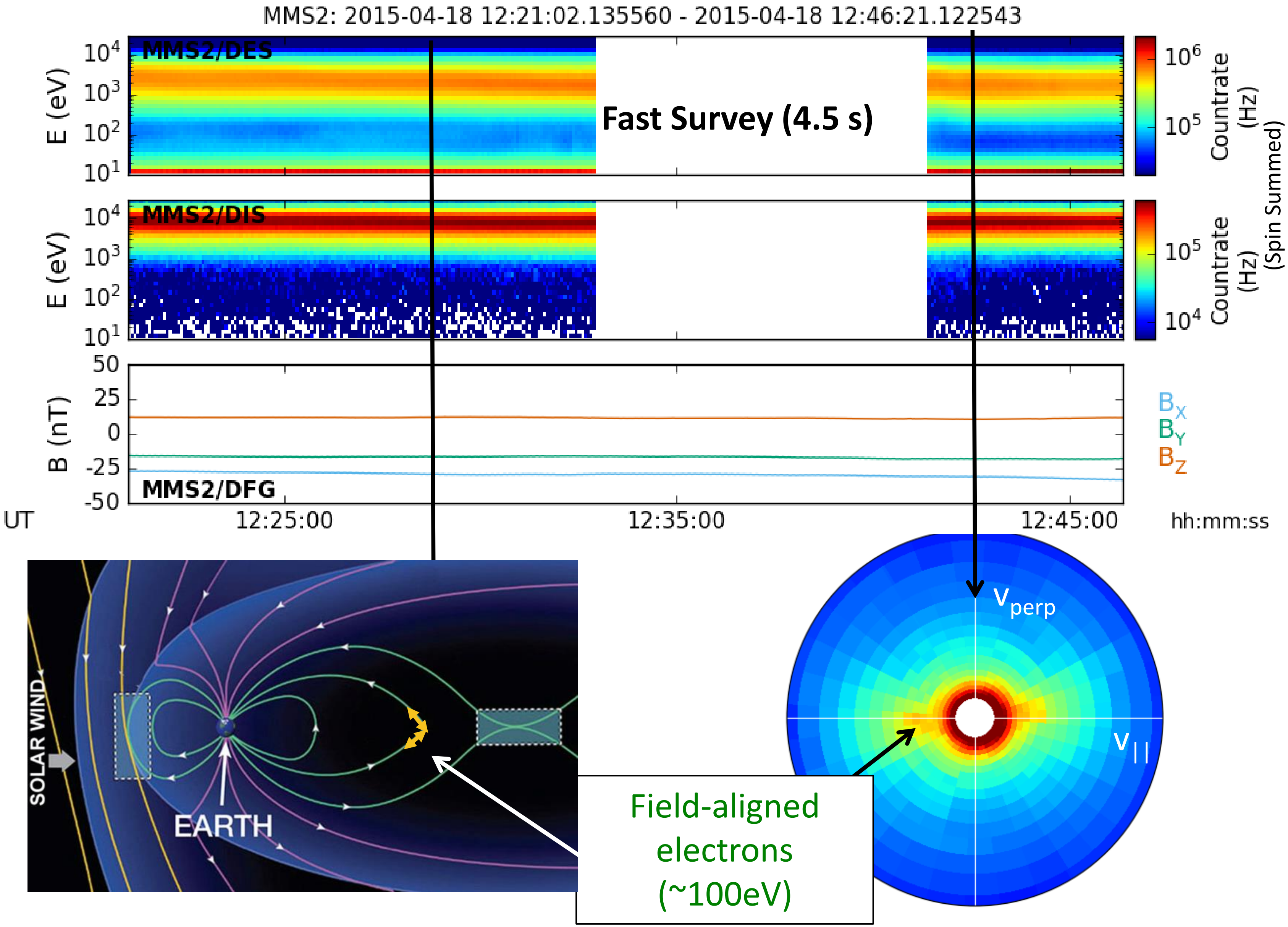


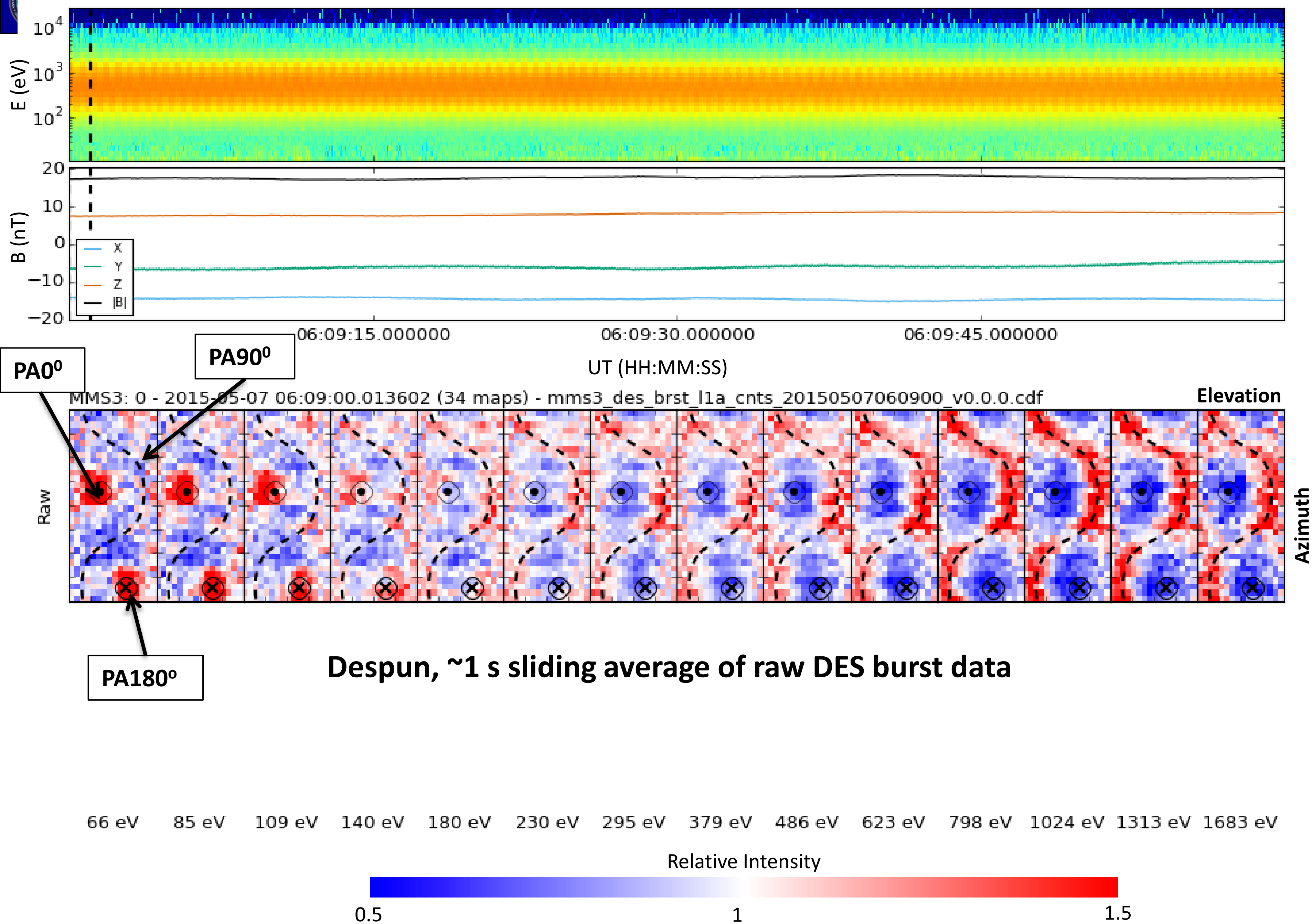


FPI First Light



FPI First Light





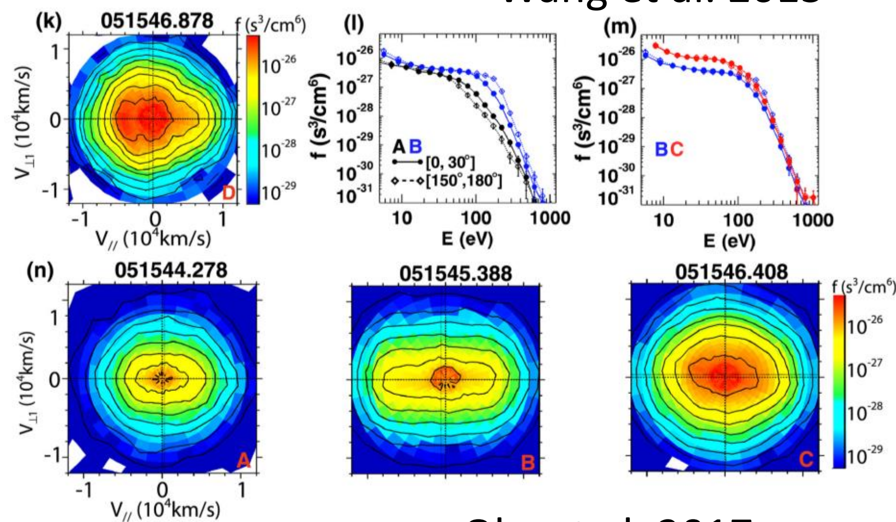
E (eV)
10^4
10^3
10^2
B (nT)
20
10
0
−10
−20
X
Y
Z
|B|
06:09:15.000000
06:09:30.000000
06:09:45.000000
UT (HH:MM:SS)
PA0⁰
PA90⁰
PA180⁰
MMS3: 0 - 2015-05-07 06:09:00.013602 (34 maps) - mms3_des_brst_l1a_cnts_20150507060900_v0.0.0.cdf
Elevation
Raw
Azimuth
Despun, ~1 s sliding average of raw DES burst data
66 eV
85 eV
109 eV
140 eV
180 eV
230 eV
295 eV
379 eV
486 eV
623 eV
798 eV
1024 eV
1313 eV
1683 eV
Relative Intensity
0.5
1
1.5

Gyrotropy

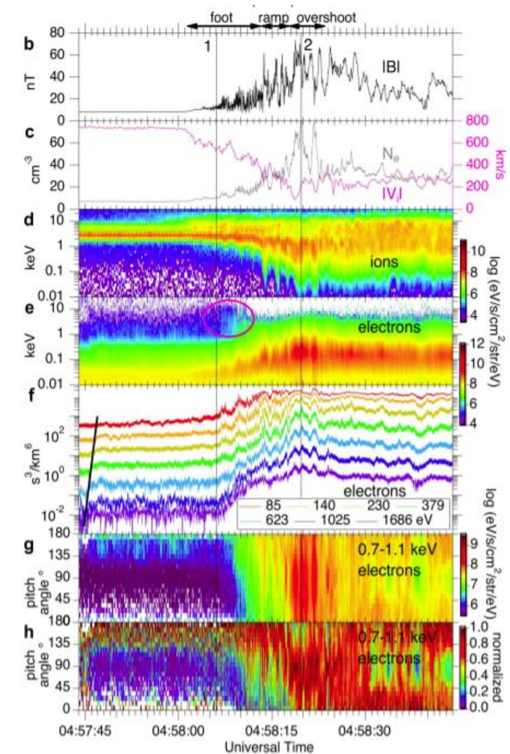
- Investigation of timing signatures and physics distinguishing between parallel and perpendicular dynamics do not require precise (<<10%) calibration.

- Formation of electron beams, parallel crescents, the quantification of parallel and perpendicular heating are robustly resolved using 30 ms electron data

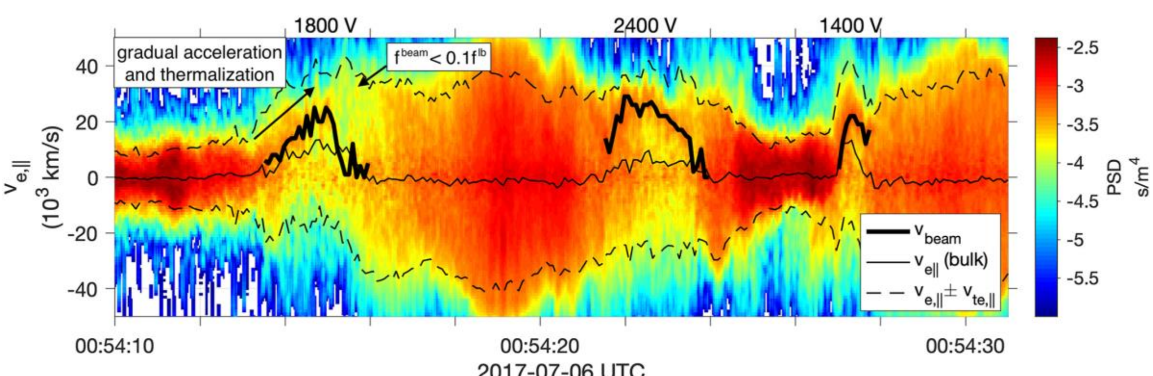
Wang et al. 2015

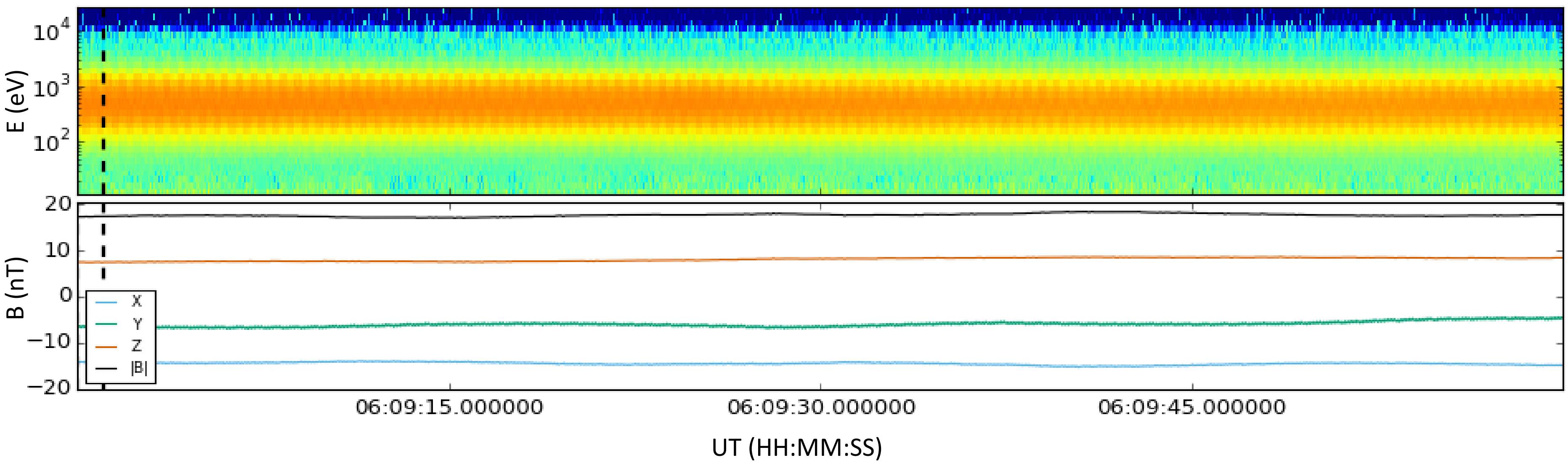


Oka et al. 2017

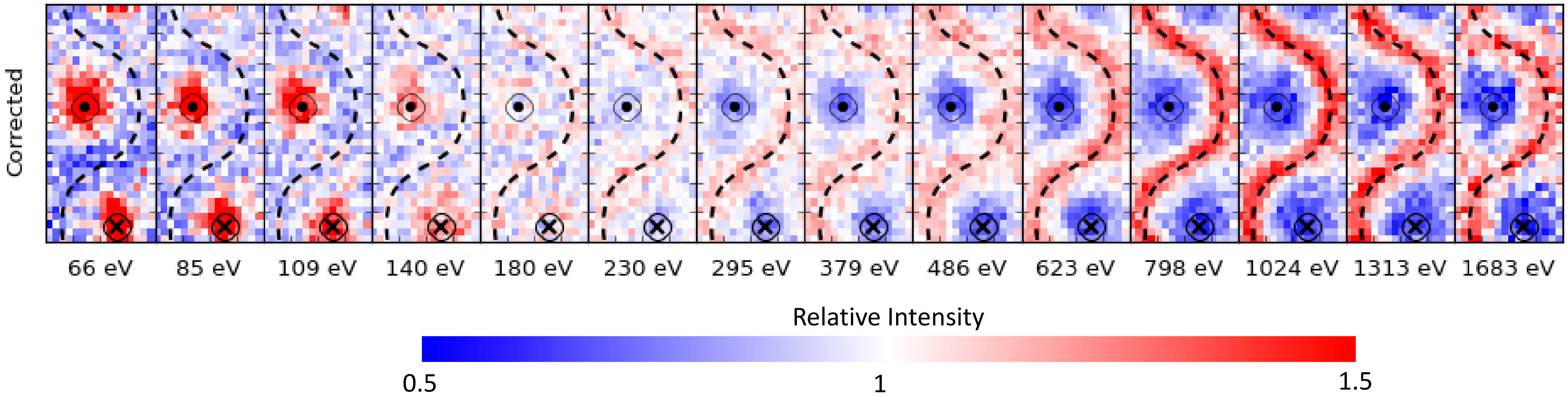


Norgren et al. 2020





Corrected DES burst data

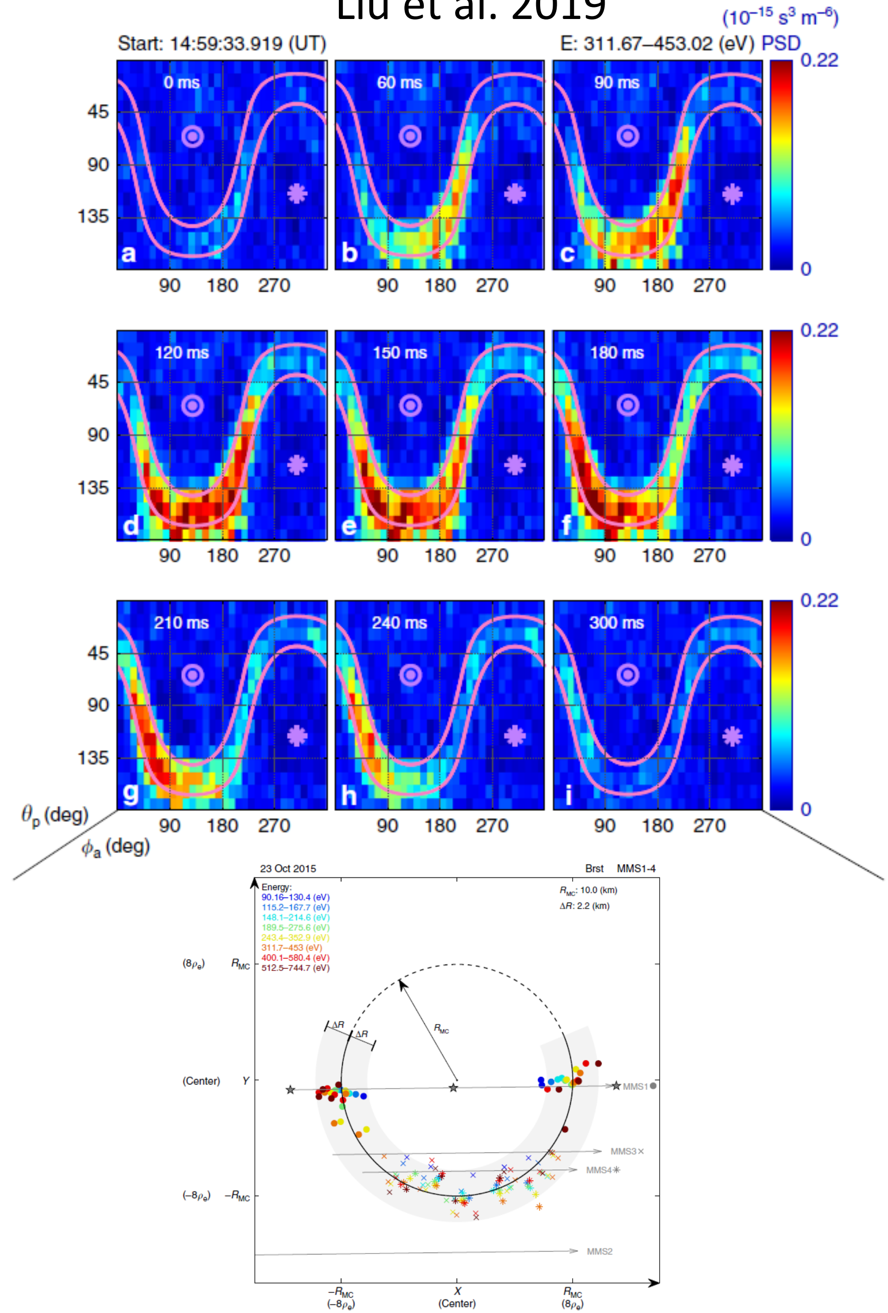


Agyrotropy

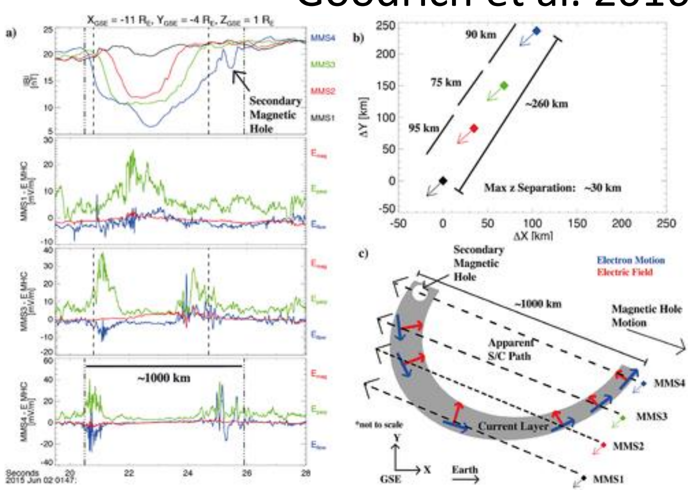
- Instrument-instrument flat-fielding to a few % enabled the identification of agyrotropic features in the distribution functions.

- Electron-scale magnetic holes provided some of the first examples of clear distribution function agyrotropy in magnetized structures.

Liu et al. 2019

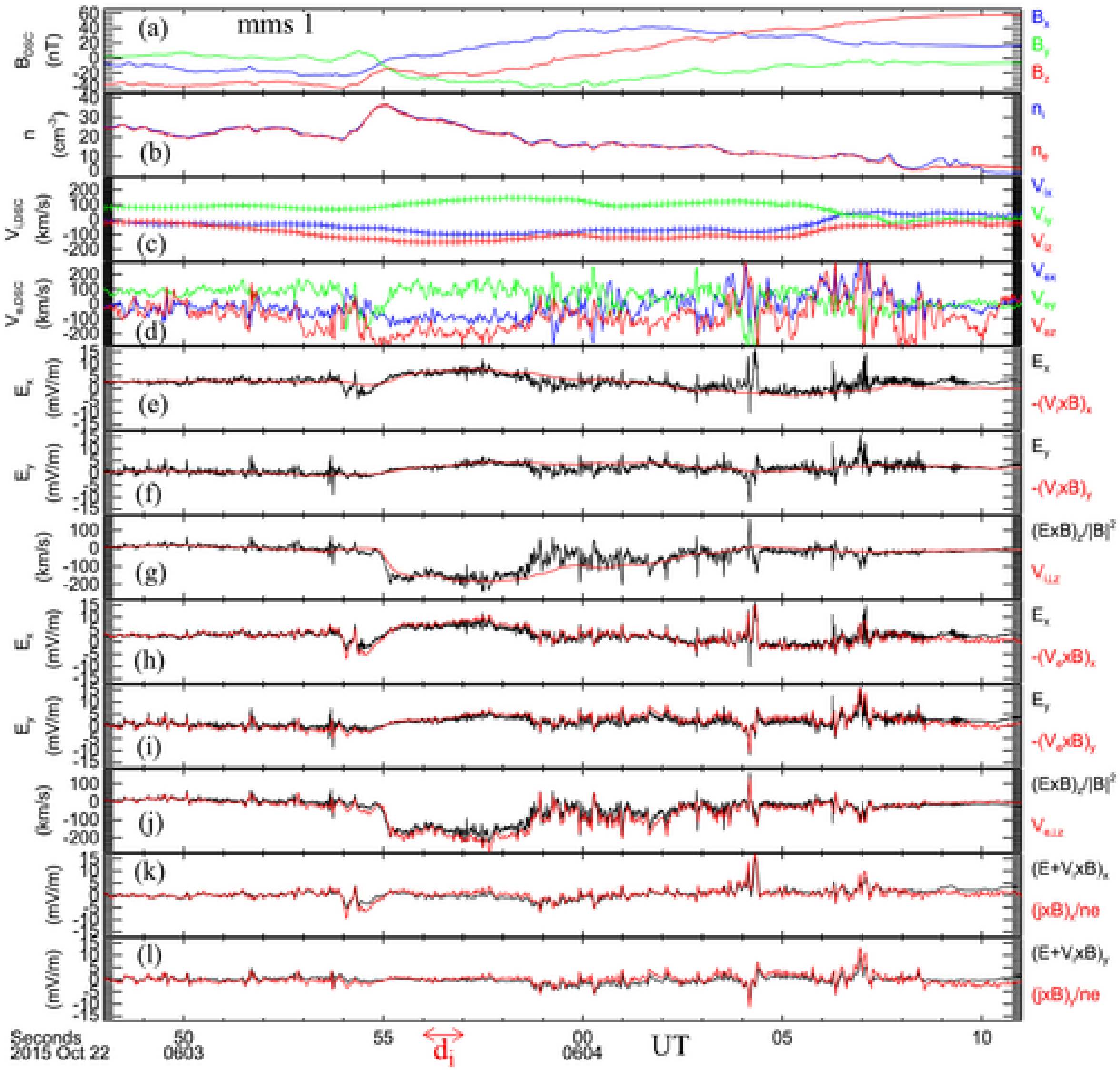


Goodrich et al. 2016



Electron Moments: Bulk Velocity

Phan et al. 2016

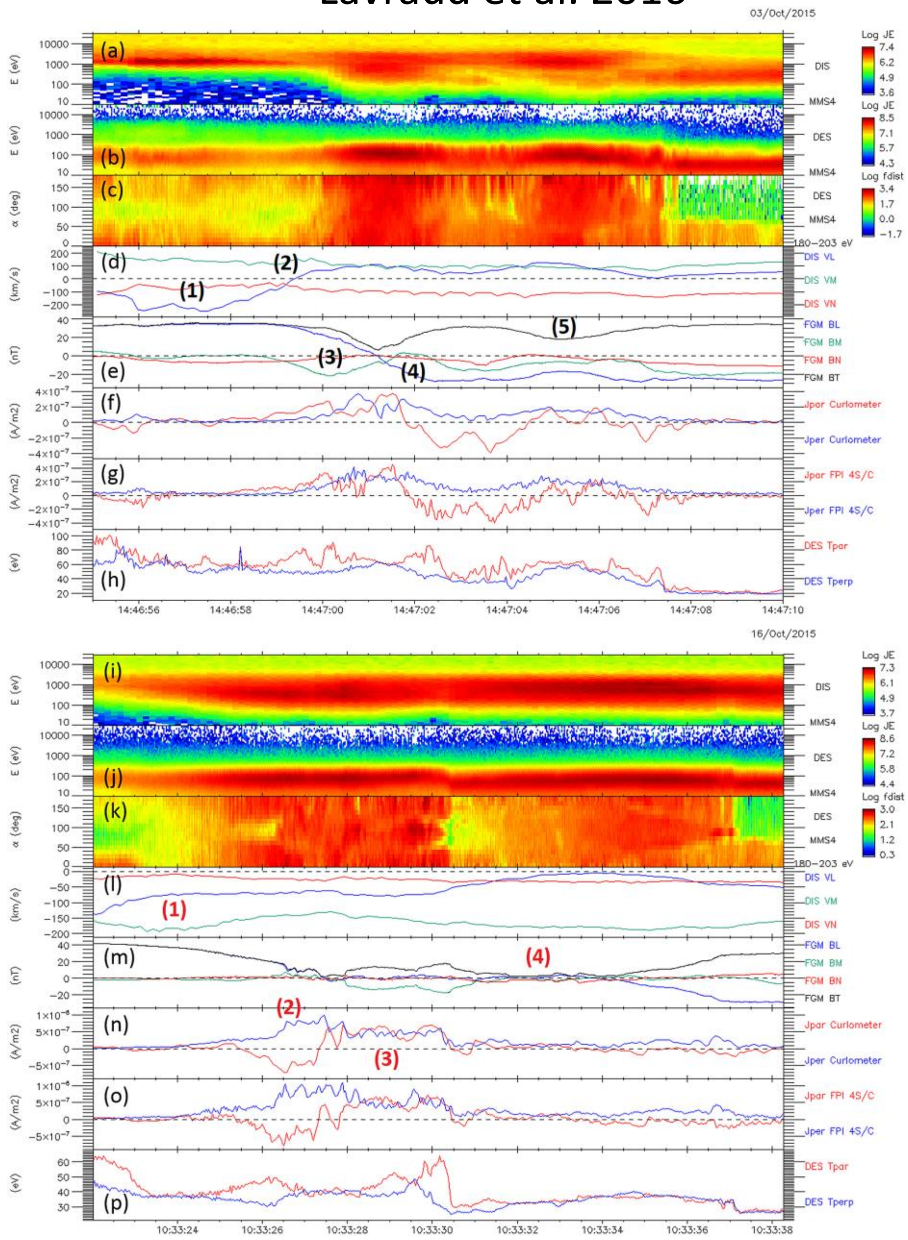


- With accurate spacecraft potential measurements from MMS, electron moments became readily calculable.
- Measurements of DC electric and magnetic fields as well as ion bulk velocities provided a source of validation for electron bulk velocity.

Electron Moments: Bulk Velocity

- With accurate spacecraft potential measurements from MMS, electron moments became readily calculable.
- Electron motion dominates fluctuations at spatial scales below the ion inertial lengths, enabling the curlometer-derived currents to provide yet another validation source for fast electron data
- Filamentary currents observed at only some of the 4 spacecraft enabled electron-scale analysis.

Lavraud et al. 2016



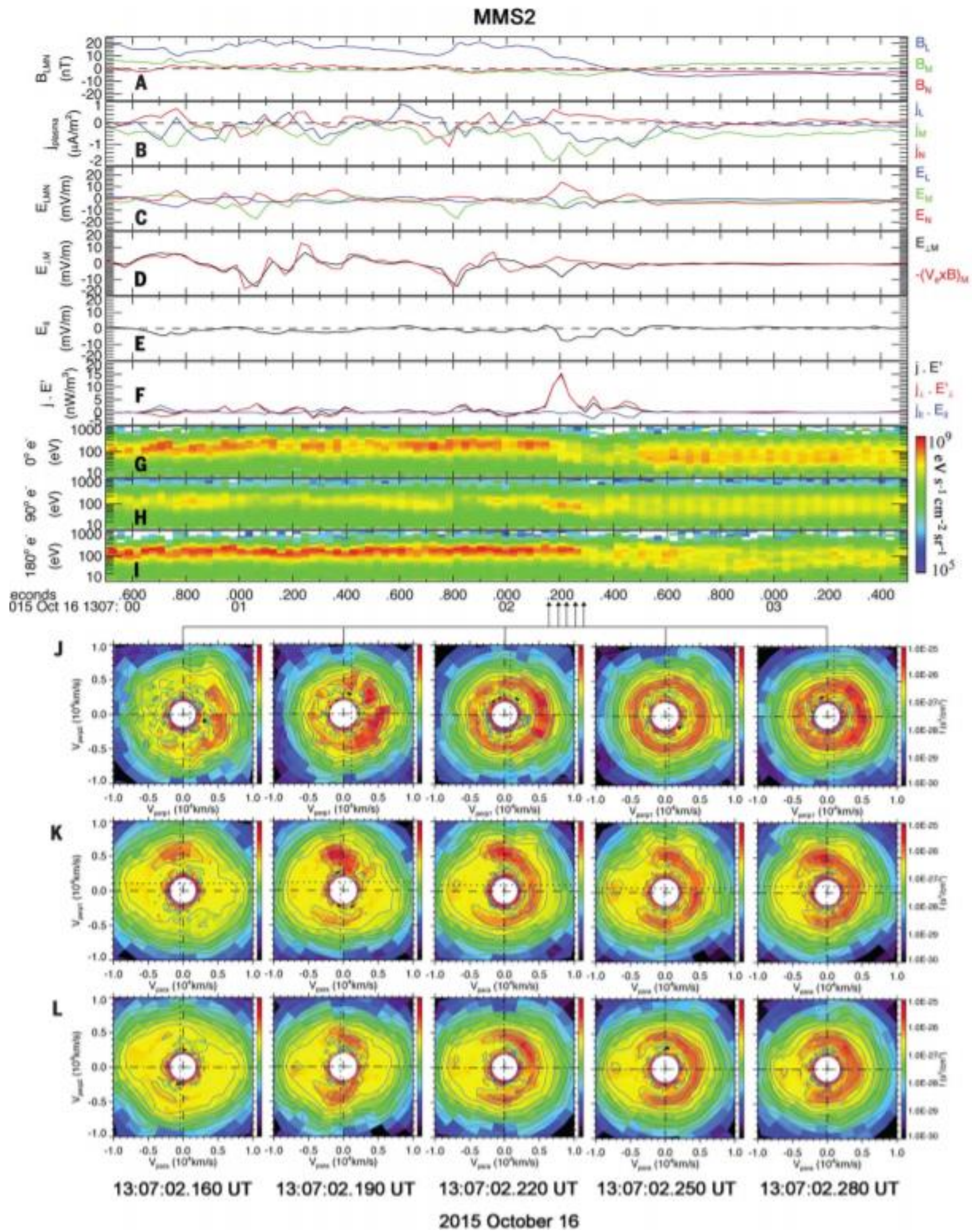
Electron Moments: Dissipation

- Single-spacecraft measurements of J and E provide local measurements of dissipation

- Combined with distribution-function analysis, the relationship between ‘crescents’ and dissipation was resolved.

- Dissipation signatures associated with reconnection have been observed in every environment MMS has visited – rarely in all four spacecraft at once given the small-scale size of observed features.

Burch et al. 2016

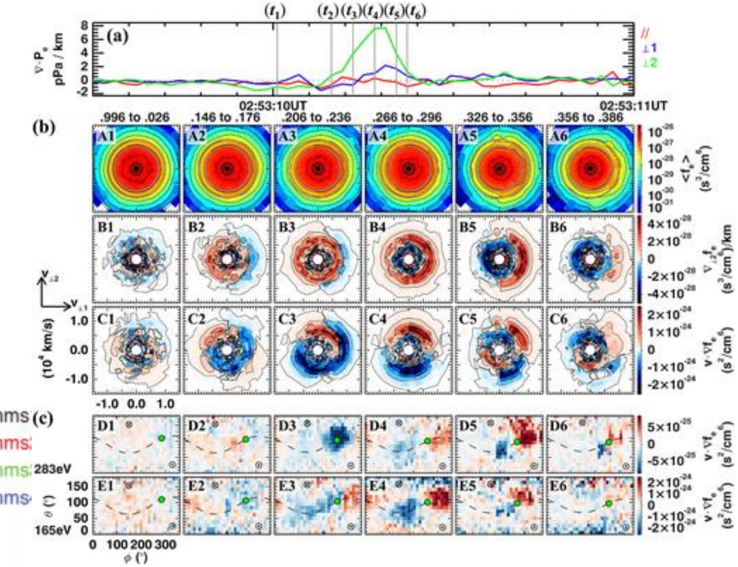


Electron Moments: Divergences

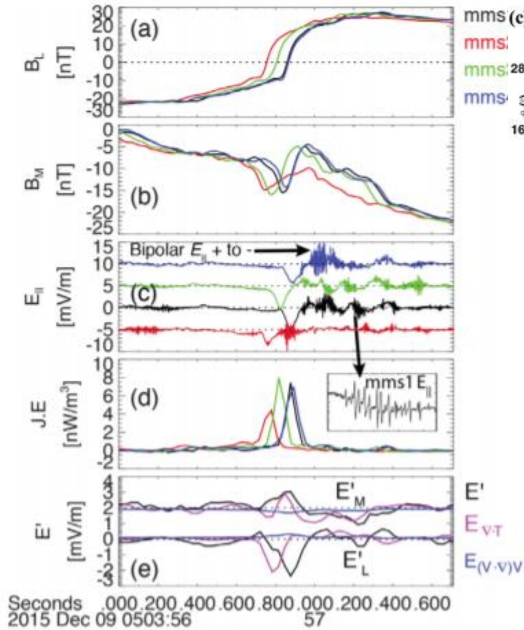
- Analysis of the divergence of the electron pressure tensor became possible in a few events where the spatial scale of interesting structures ‘cooperated’ with the MMS inter-spacecraft spacing.

- Just as phase space density analysis provided insight into the source of bulk velocity (e.g., crescents), analysis of gradients of phase space density provides insights into the source of pressure gradients.

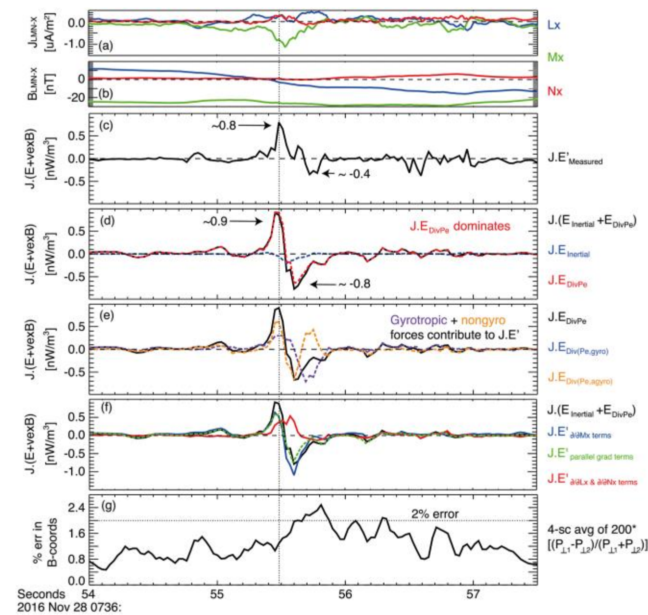
Shuster et al. 2019



Wilder et al. 2017



Genestreti et al. 2018



Electron Moments: Divergences

- Analysis of electron stress tensors and velocity gradients (Pi-D) provides insights into how energy is transferred to electrons at kinetic scales

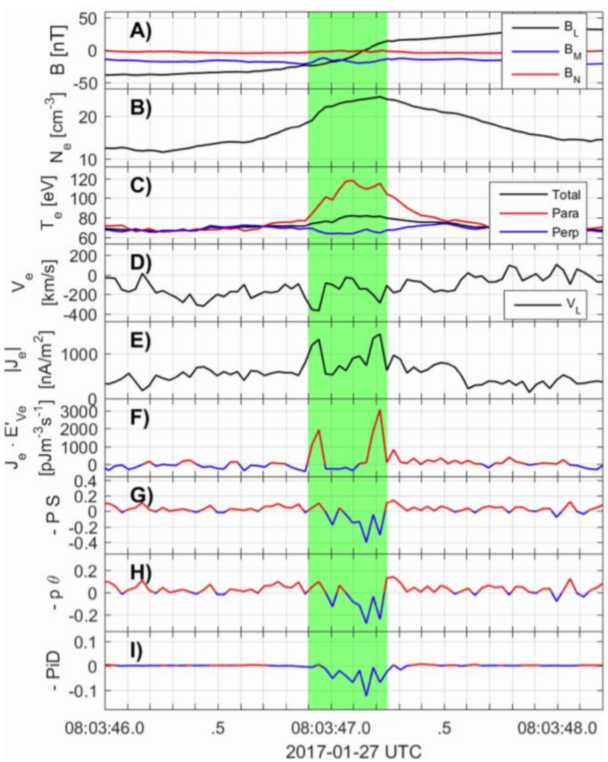
- With limited ability to validate, comparisons with predictions from MHD and PIC simulations become a favored option

$$\mathrm{PS}_\alpha \equiv (\boldsymbol{P}_\alpha \cdot \nabla) \cdot \boldsymbol{u}_\alpha = P_{ij}^{(\alpha)} \nabla_i u_j^{(\alpha)}.$$

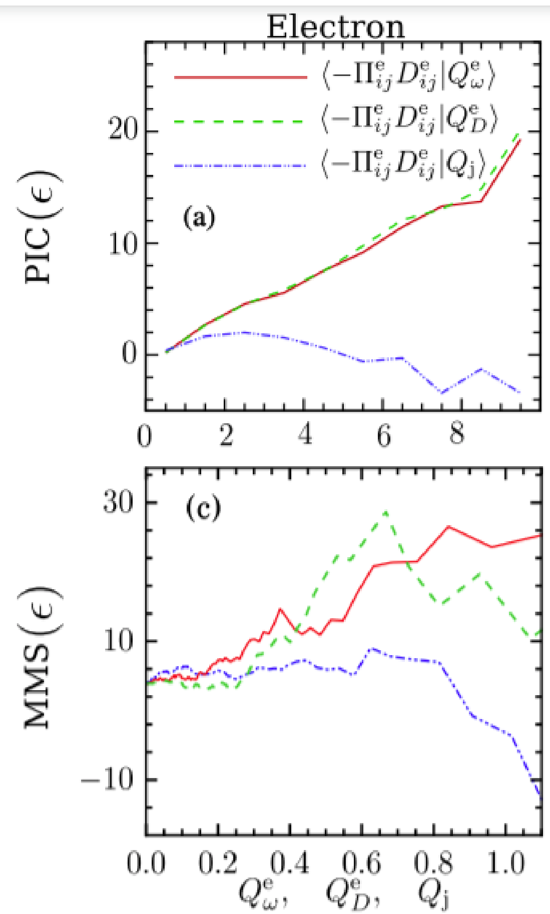
$$P_{ij}^{(\alpha)} = p_\alpha \delta_{ij} + \Pi_{ij}^{(\alpha)}$$

$$D_{ij}^{(\alpha)} = \frac{1}{2}(\nabla_i u_j^{(\alpha)} + \nabla_j u_i^{(\alpha)}) \qquad \mathrm{PiD}_\alpha \equiv \Pi_{ij}^{(\alpha)} D_{ij}^{(\alpha)}$$

Chasapis et al. 2018



Bandyopadhyay et al. 2020

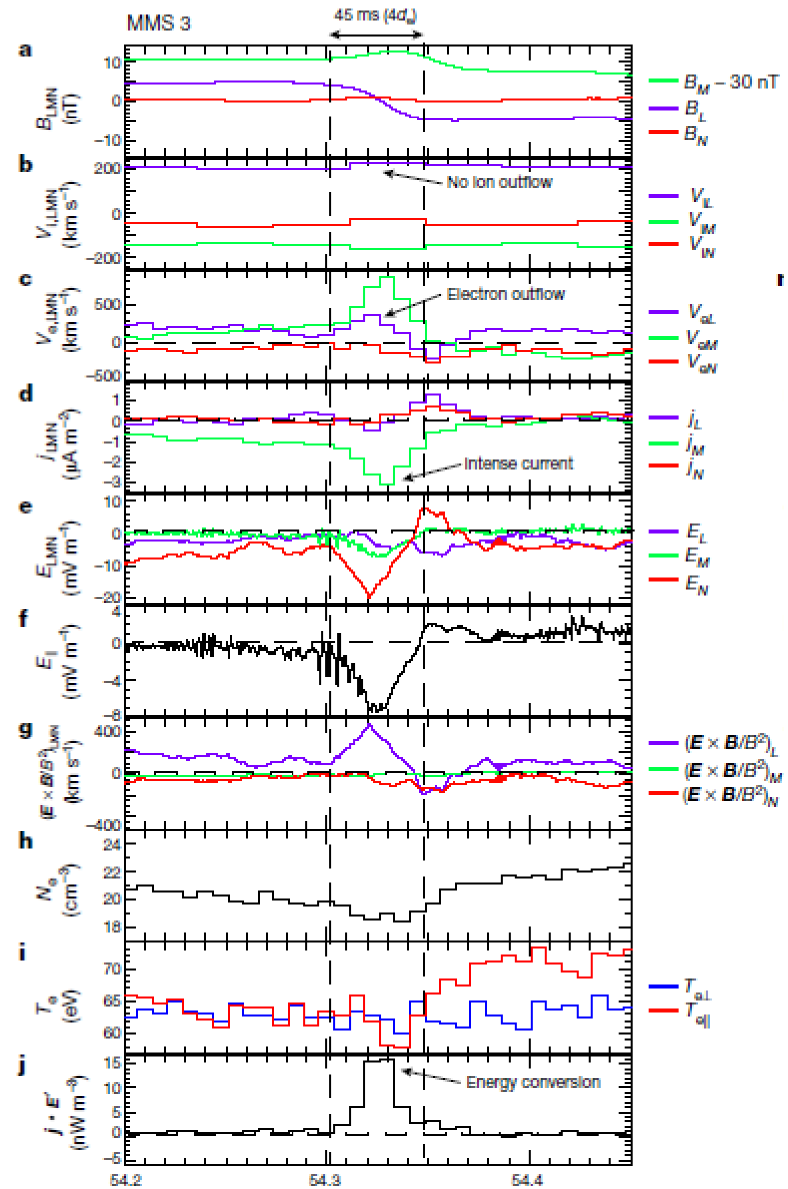


Electron Moments: 7.5ms

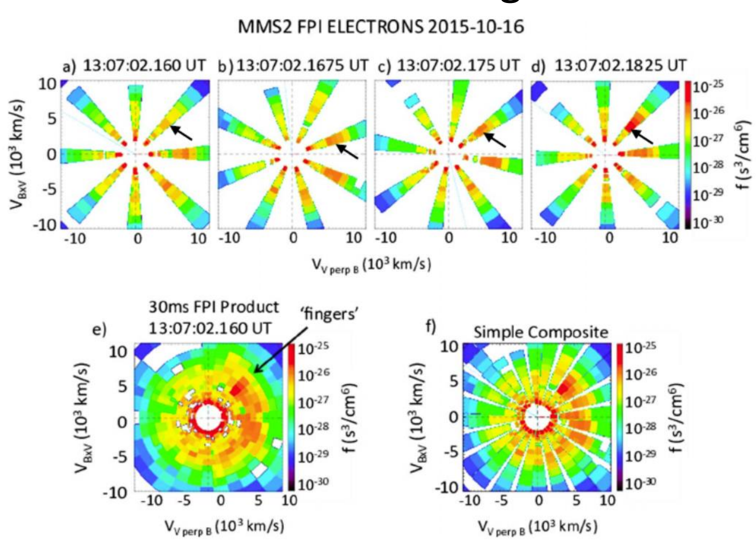
- Synchronized FPI energy-sweeping across different instruments combined with the fact that MMS-measured electron distribution functions are relatively broad in angle provided an opportunity to quadruple the time resolution of DES.

- 7.5ms data has enabled the resolution of jets associated with electron-only reconnection

Phan et al. 2018



Rager et al. 2017



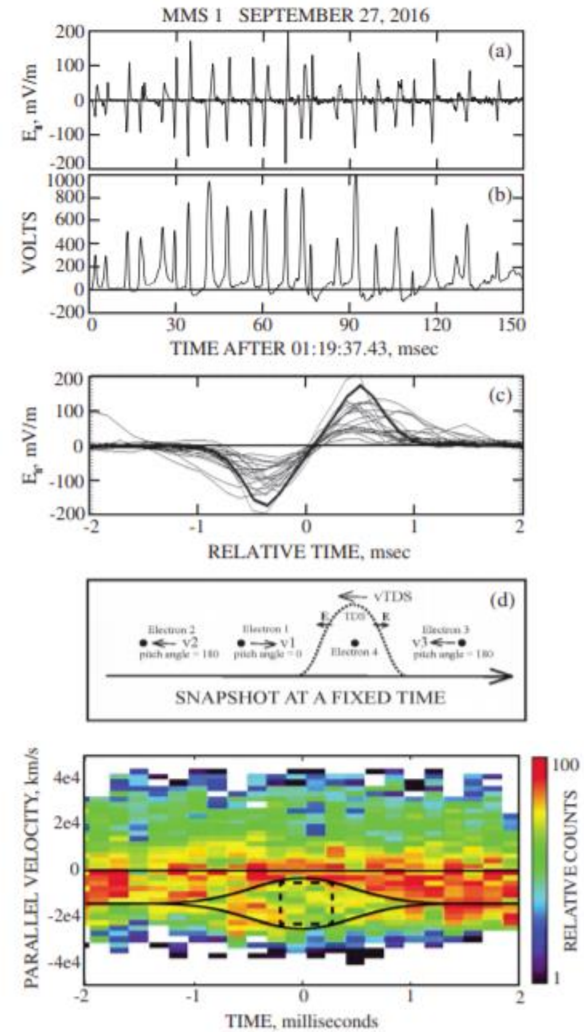
Electron Dynamics with MMS: What's Next?

- The 7.5ms energy sweep can be broken down into 0.2ms synchronized energy steps across 8 instruments.

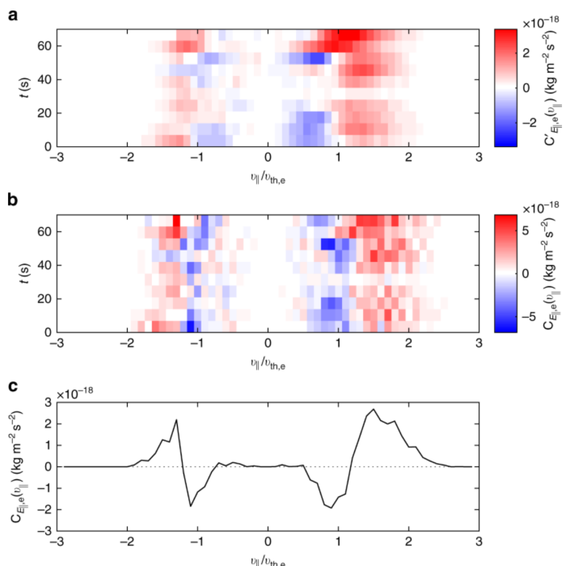
- Superposed epoch analysis of select intervals may provide insights into electron dynamics deep into the kinetic range.

- Can we fully resolve Landau damping with MMS?

Mozer et al. 2018



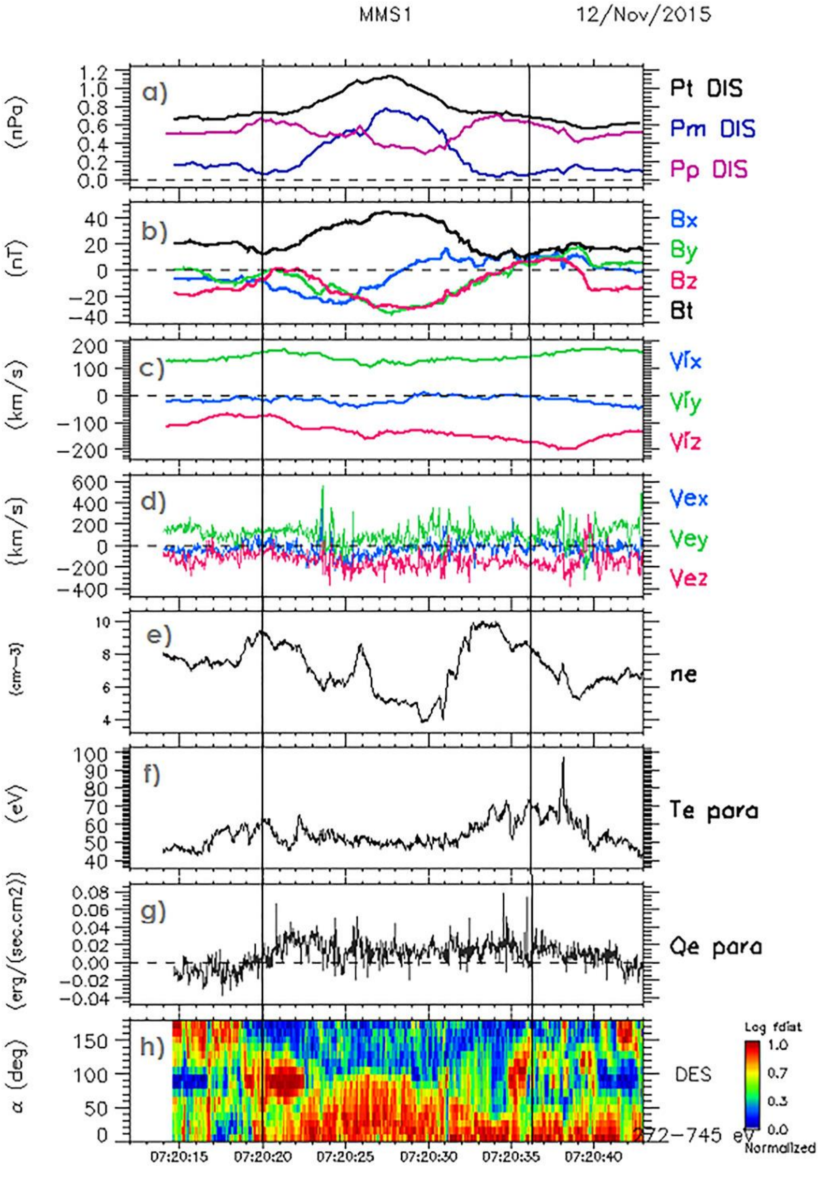
Chen et al. 2019

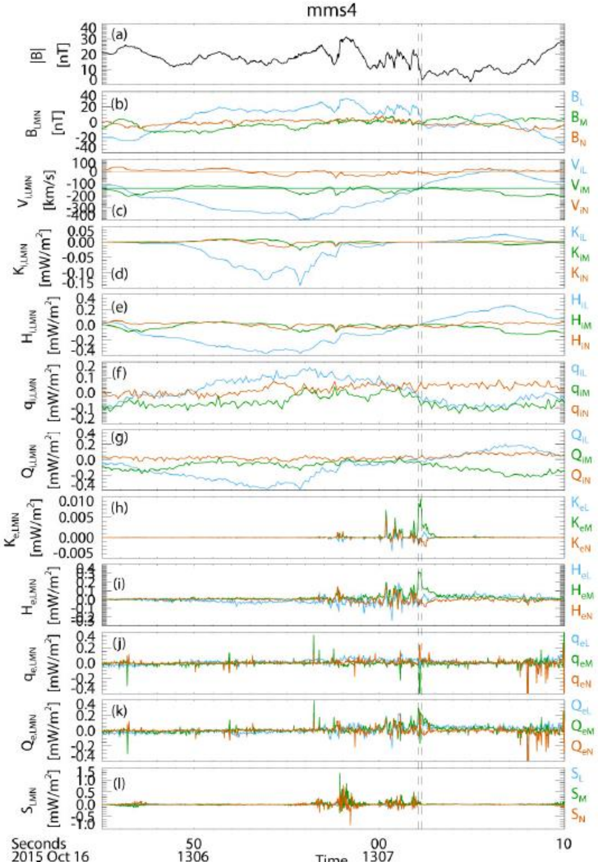


Electron Dynamics with MMS: What's Next?

- Heat flux is even harder to measure than bulk velocity, with validation hard to achieve – yet there are tantalizing hints that there is a lot of information about electron heat conduction and magnetic topology that MMS can provide

Fargette et al. 2020





Eastwood et al. in revision

Summary

- The “**Fast”** in MMS’s Fast Plasma Investigation has unlocked a multitude of new observations of electron dynamics in Earth’s near-space environment

- The extended MMS community has continued to push the envelope to determine what can be done with the collected electron data.

- There are still new frontiers of electron dynamics to investigate with MMS – analysis of 0.2ms energy-angle steps, studies of electron heat flux dynamics, and additional exploration of pressure tensors divergences all provide ample opportunities for breakthrough science.