MULTISCALE ANALYSIS OF A CURRENT SHEET CROSSING ASSOCIATED WITH A FAST EARTHWARD FLOW DURING A SUBSTORM EVENT DETECTED BY MMS

Laboratoire de Physique des Plasmas

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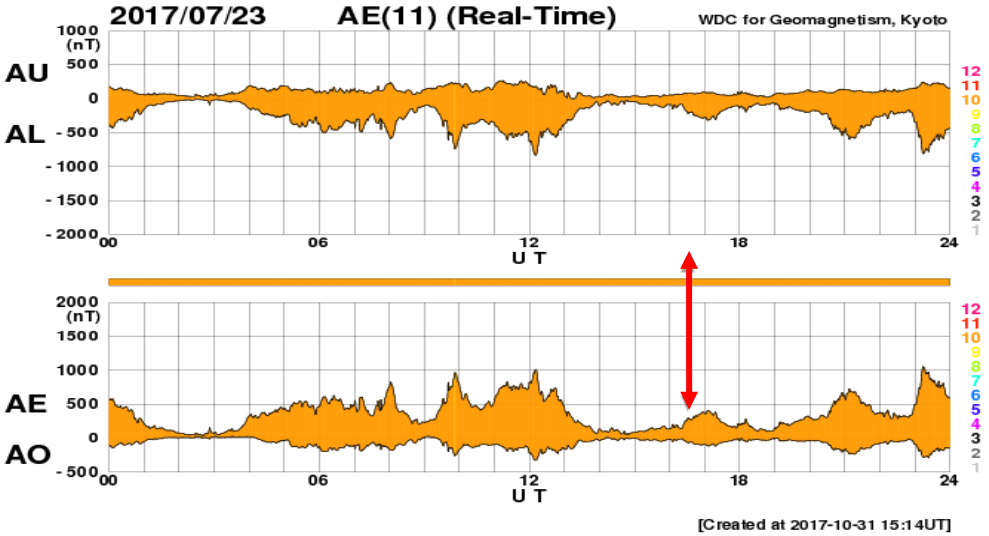
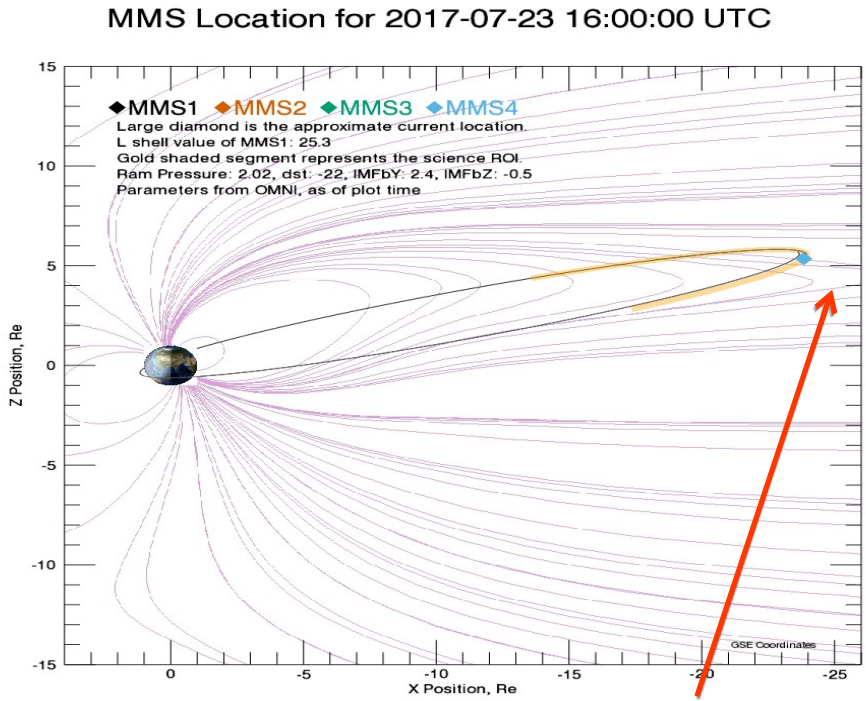
Substorm event on July 23rd , 2017 around 16:19 UT





MMS located in
pre-midnight sector near magnetic equator
X~-23.9RE, Y~5.8RE, Z~ 5.4 RE

Substorm overview 16:05-17:30 UT

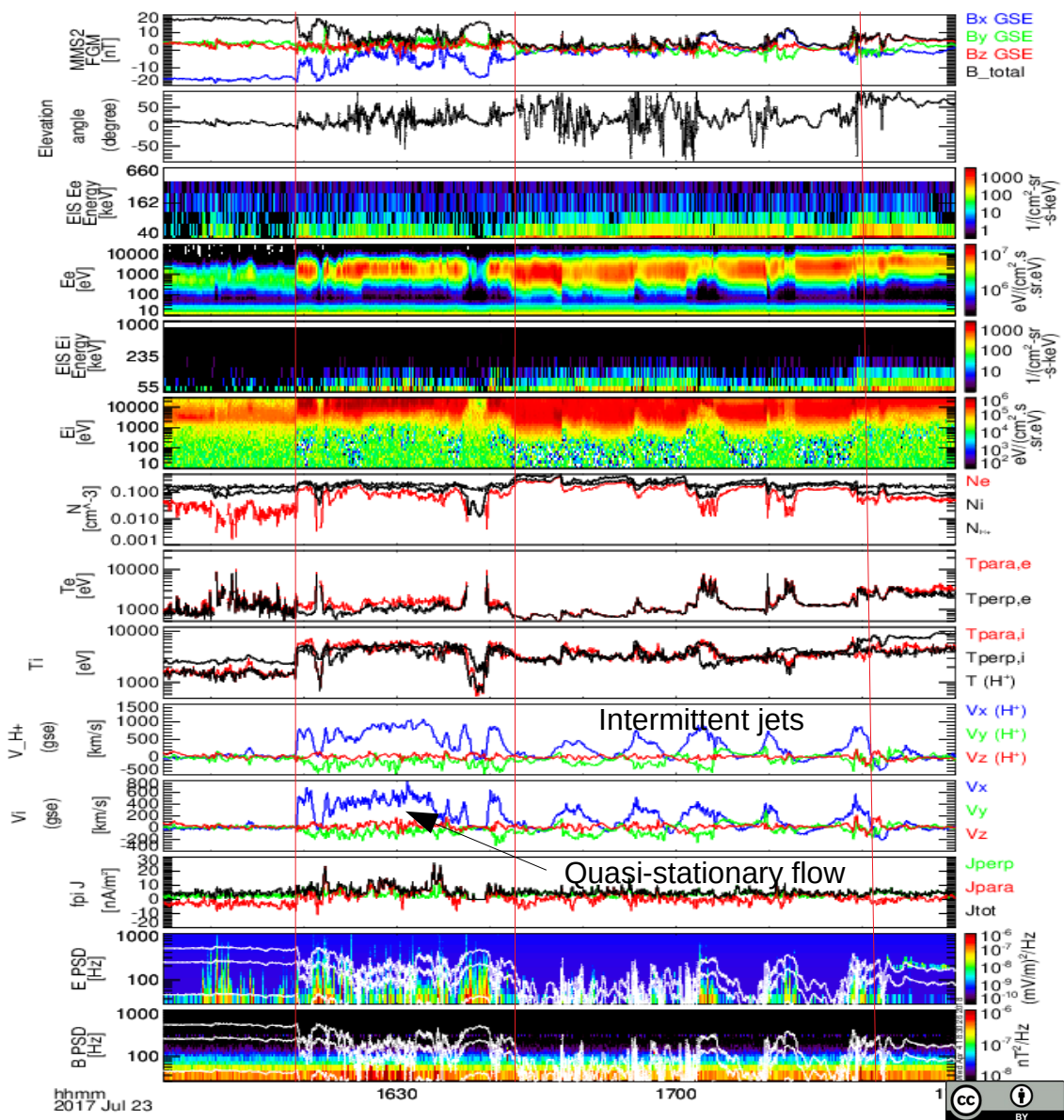
Small substorm AE~ 400 nT
Local onset ~ 1619 UT

- **Quasi-stationary earthward flow**
  Vx(HPCA)~ 800 km/s > Vx(FPI),
  low density~0.1 p/cc and B<15 nT
  with current fluctuations |δj(fpi)|<30nA/m²

- **Intermittent earthward jets** with embedded Dfs (see Alqeeq's presentation)
  0<Vx(HPCA)<800 km/s
  higher density and smaller B<10 nT
  with smaller current fluctuations <15nA/m²
- Electrostatic fluctuations
  up to Fce at the CS edge (Bx>15 nT)
  associated with electron heating

Two regimes of plasma transport?

- Flow reversal at the end of event :
  +800km/s to -400 km/s



Ion scale current sheet & electron scale magnetic hole 1630:05-1630:40 UT

CS detected during a quasi-stationary earthward flow Vx ~ 500 (FPI) ~ 1200 (HPCA) km/s around 1630:15 UT

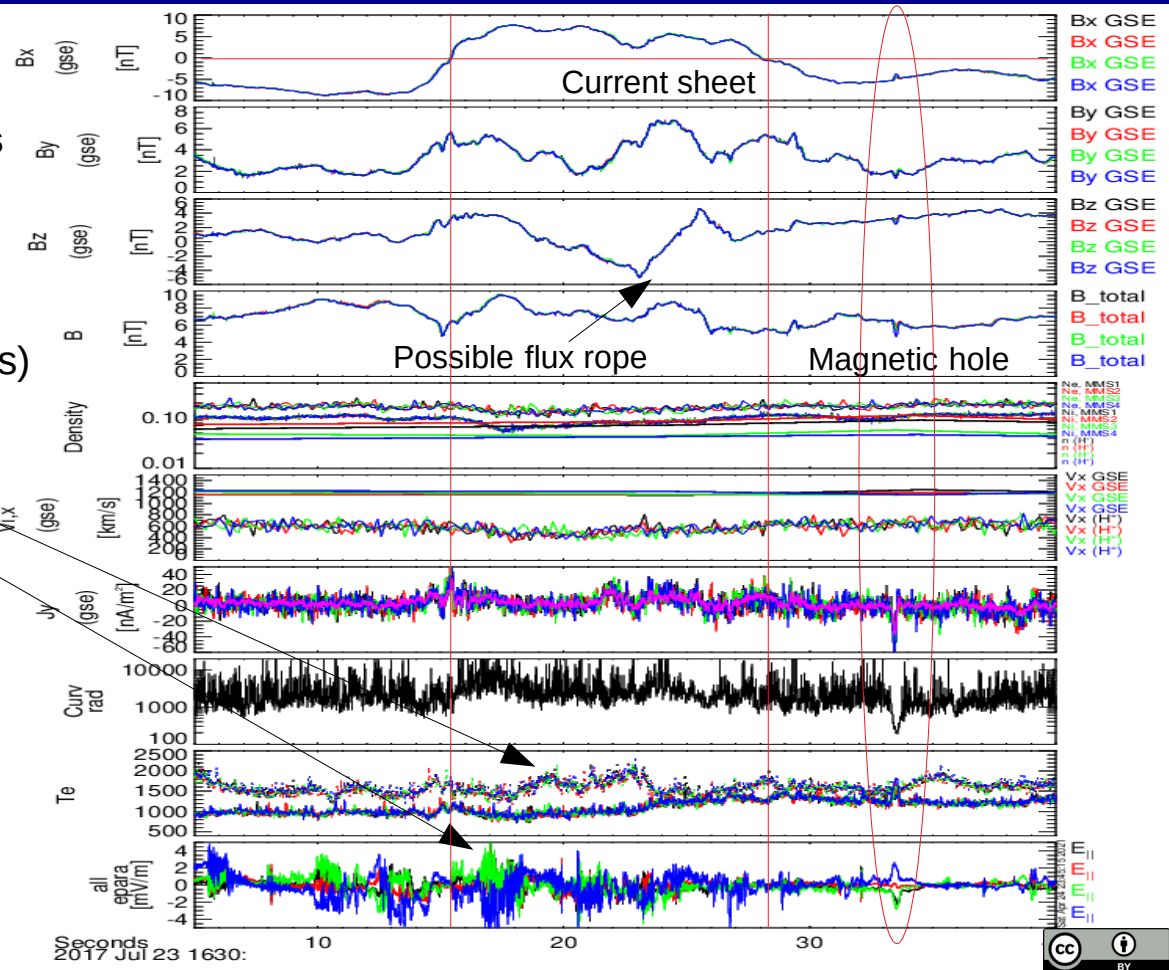
- N ~ 0.1 p/cm^3 (FPI-DES&HPCA)
- Jy~ 50 nA/m^2 (from CurlB or Part.)
- Curvature radius ~ 1000 km ~ ρi (Ion Larmor radius)
- Parallel E fields associated with $T_{\parallel,e} > T_{\perp,e}$

Possible flux rope

- Bipolar Bz with Max By

Electron scale magnetic hole at 1630:32 UT

- Out of equator
- Large Jy up to -60 nA/m^2
- Smaller curvature radius ~ 200 km~ 10ρe
- $T_{\perp,e} > T_{\parallel,e}$ and possible quasi-static parallel E fields

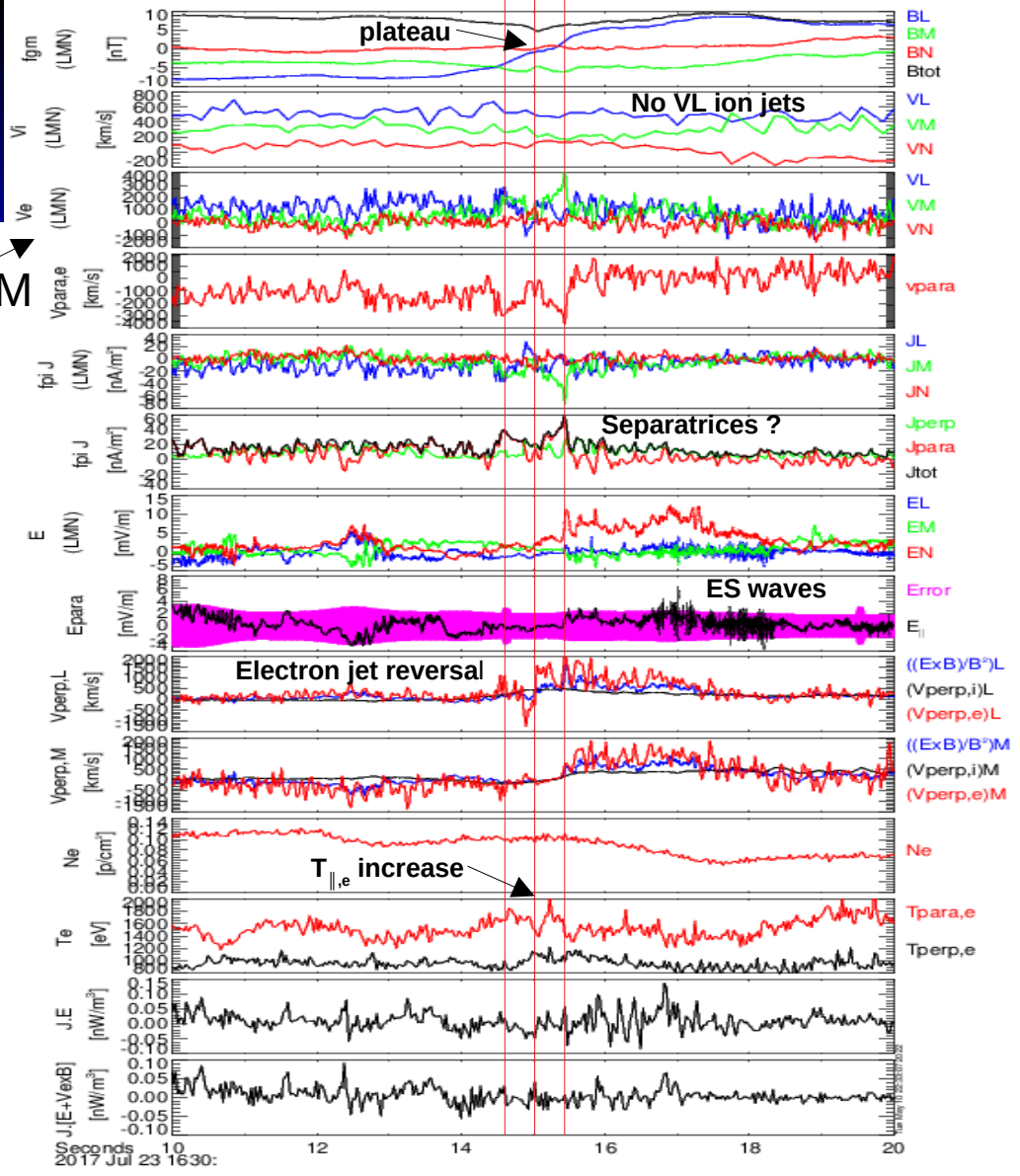


CS analysis from MMS3

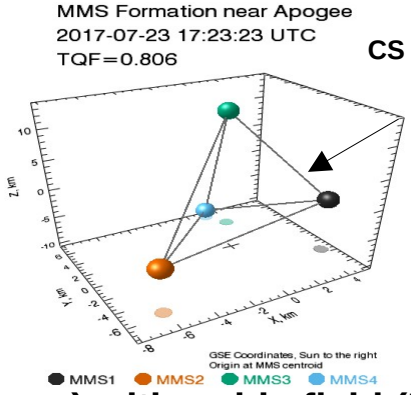
Bifurcated CS (plateau) with guide field (BM/BL~ 0.5)
MVAB between 1630:14-1630:17 UT
L[**0.97**,0.11,0.21], M[0.21,-**0.81,-0.54**], N[0.11,**0.57,-0.81**]
$\lambda_{max}/\lambda_{int}$=90 & $\lambda_{int}/\lambda_{min}$ =3
Timing analysis BL=0 nT
N[0.19,**0.57,-0.79] in agreement with MVAB**
V_CS ~ 344 km/s
Plateau thickness : 344*0.25 ~ 86 km ~ 5de (<dsc ~20km)
CS thickness : 344*3 ~ 1032 km ~ ρi ~ 2di

- Electron jet (Vperp,L) reversal ± 1500 km/s (super-alfvénic ~ 1.7Va,i or 0.05Va,e)
- Increase of $T_{\parallel,e}$
- No VL ion jets
- No large **J**.**E** or **J**.**E'** <0.1nW/m³ at the CS centre
- No whistler or LHD waves yet

Series of electrostatic solitary waves during 2 s at the edge of the CS which suggest electron beams



CS analysis from 4 s/c



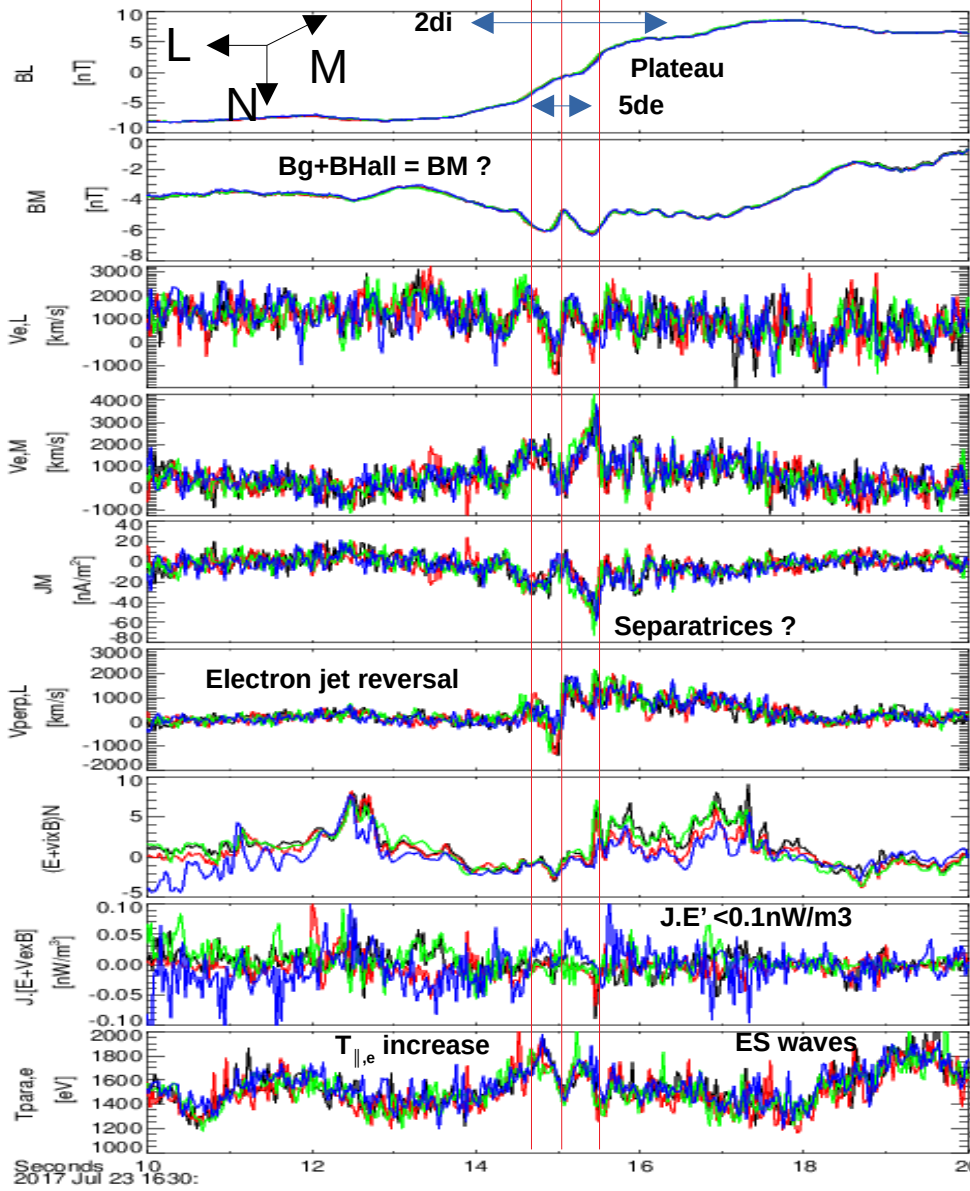
CS motion along N~(+Y,-Z)

MMS3 first
MMS4 last

Bifurcated CS (plateau) with guide field (BM/BL~ 0.5)
Plateau thickness ~ 5de, ion scale CS ~ 2di

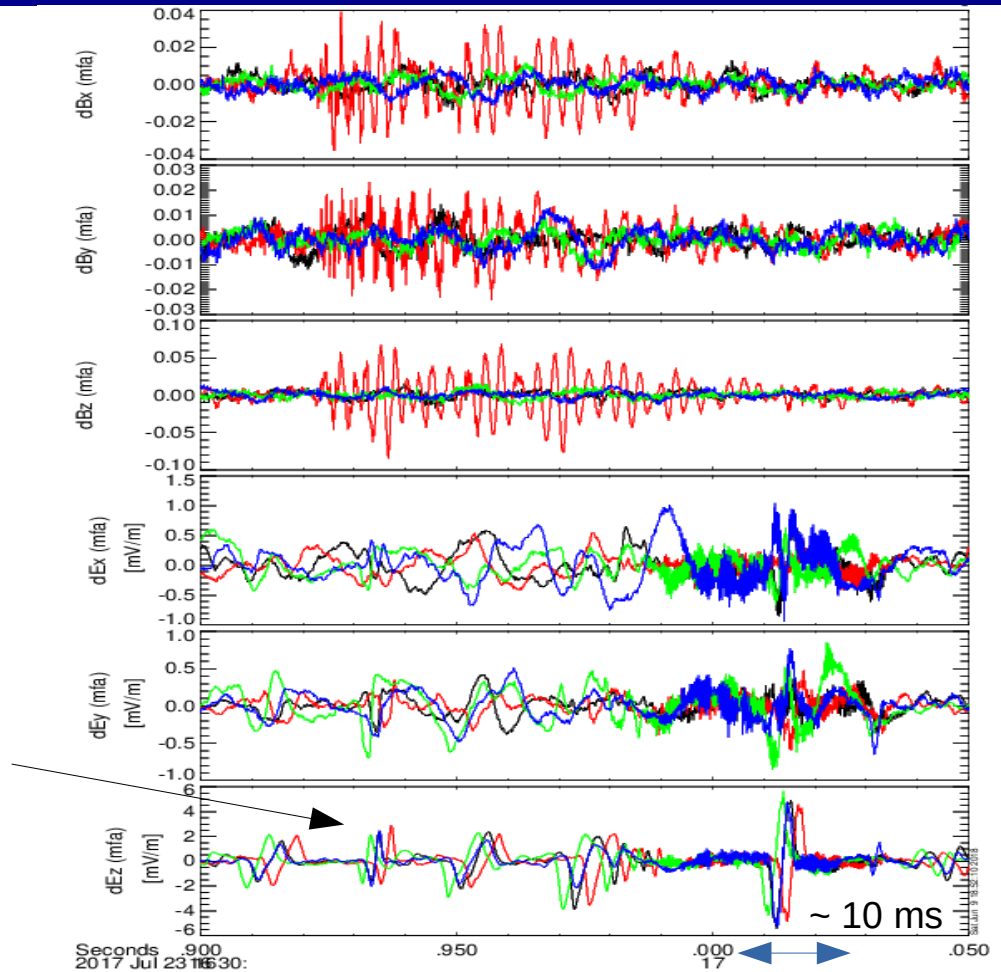
- Electron jet Vperp,L reversal ± 1500 km/s (super-alfvénic ~ 1.7Va,i or 0.05Va,e)
- No ion jets
- Two increases of $T_{\parallel,e}$ **but**
- No large **J.E'** <0.1nW/m³ at the CS centre
- No magnetic waves yet ESW propagating from the CS

Transient electron-only reconnection event (5de) embedded in an ion scale (2di) CS within a turbulent fast earthward flow ? [see Phan et al., 2018, Stawarz 2022 in turbulent magnetosheath]

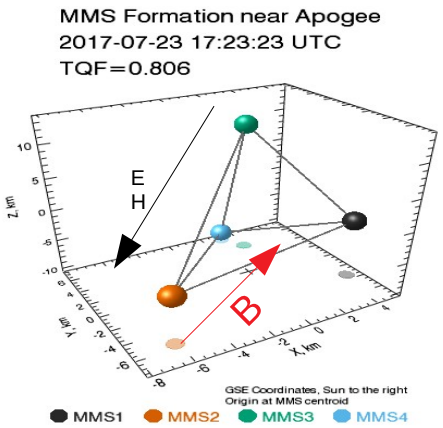


Series of electrostatic solitary waves

Bipolar $E_{\parallel}$ signatures



Electrostatic solitary wave



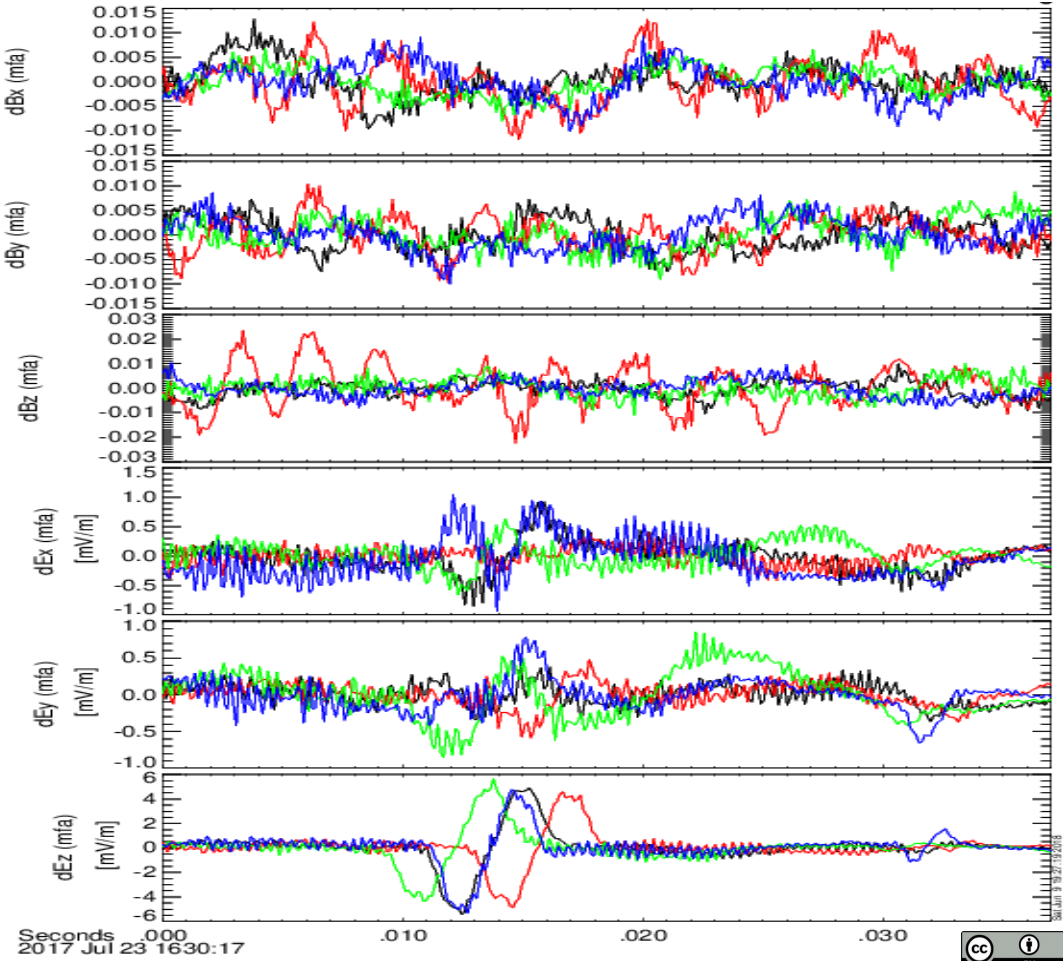
Purely **electrostatic electron phase space hole (EH)** [e.g Matsumoto et al., 1994, Ergun et al., 2008, Norgren et al. 2015] moving tailward/southward

V_{EH} ~ 20/0.004 = 5000 km/s ~ 0.26 Vth,e (slow EH)

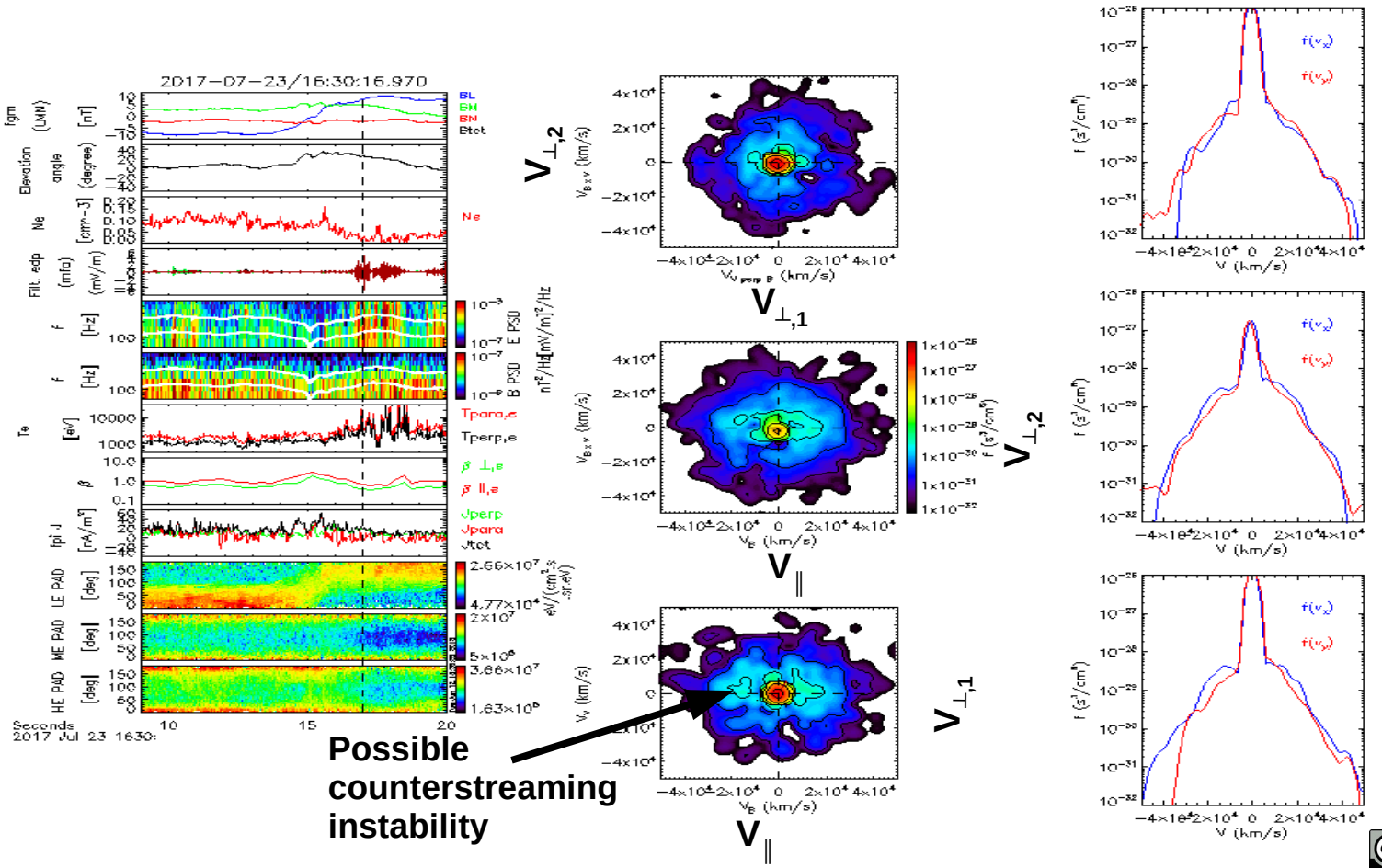
$L_{\parallel}$ ~ 5000x0.005 = 25 km ~ 33 λ_{de}

Φ ~ 100 V

Formation ? Likely by counter streaming instability



DES electron distributions



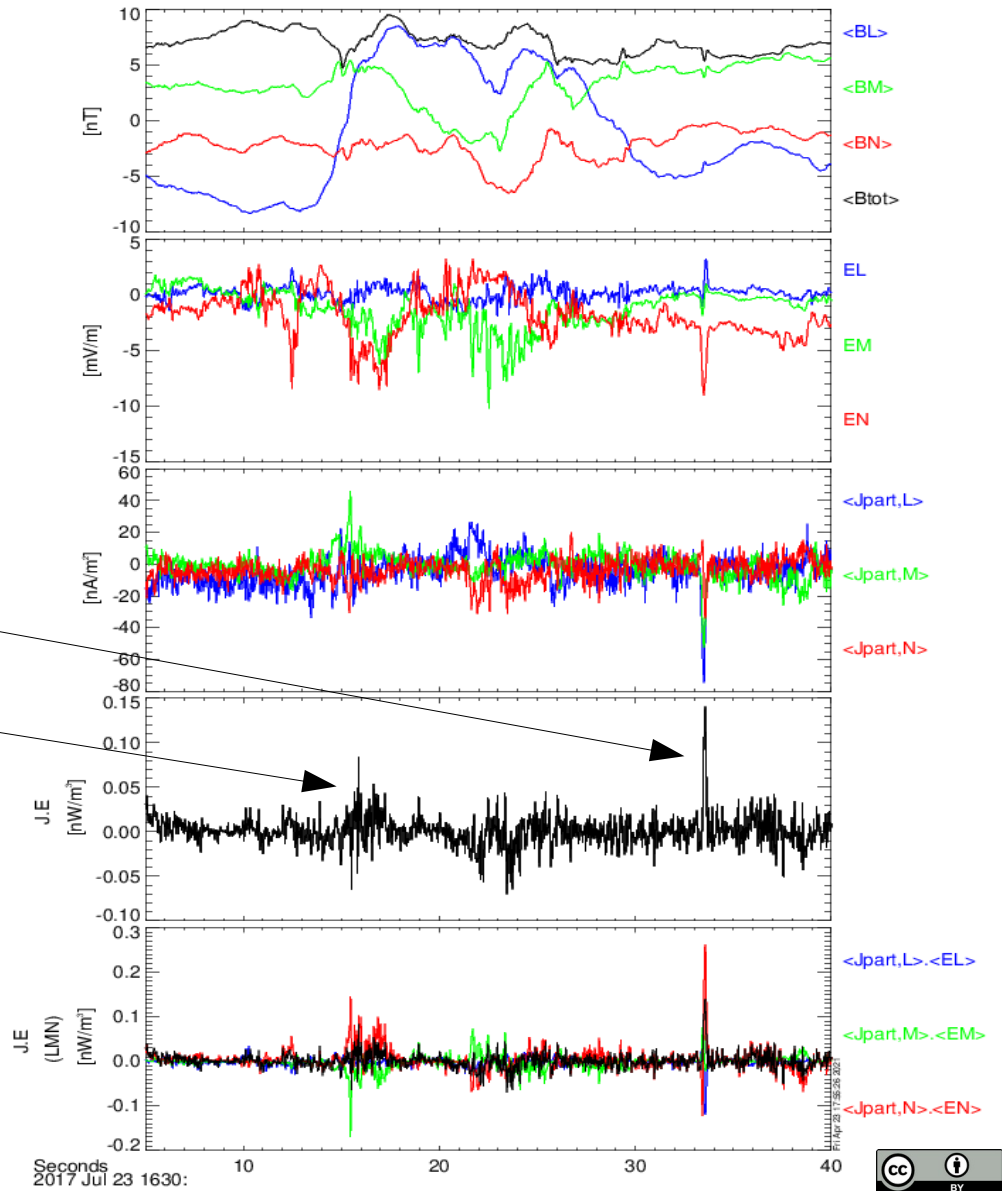
Energy conversion processes 1630:05-1630:40 UT

4 s/c averaged data

Larger energy dissipation in the **electron scale** magnetic hole

J.E ~ + 0.15 nW/m^3

than at the CS crossing **J.E** ~ + 0.05nW/m^3



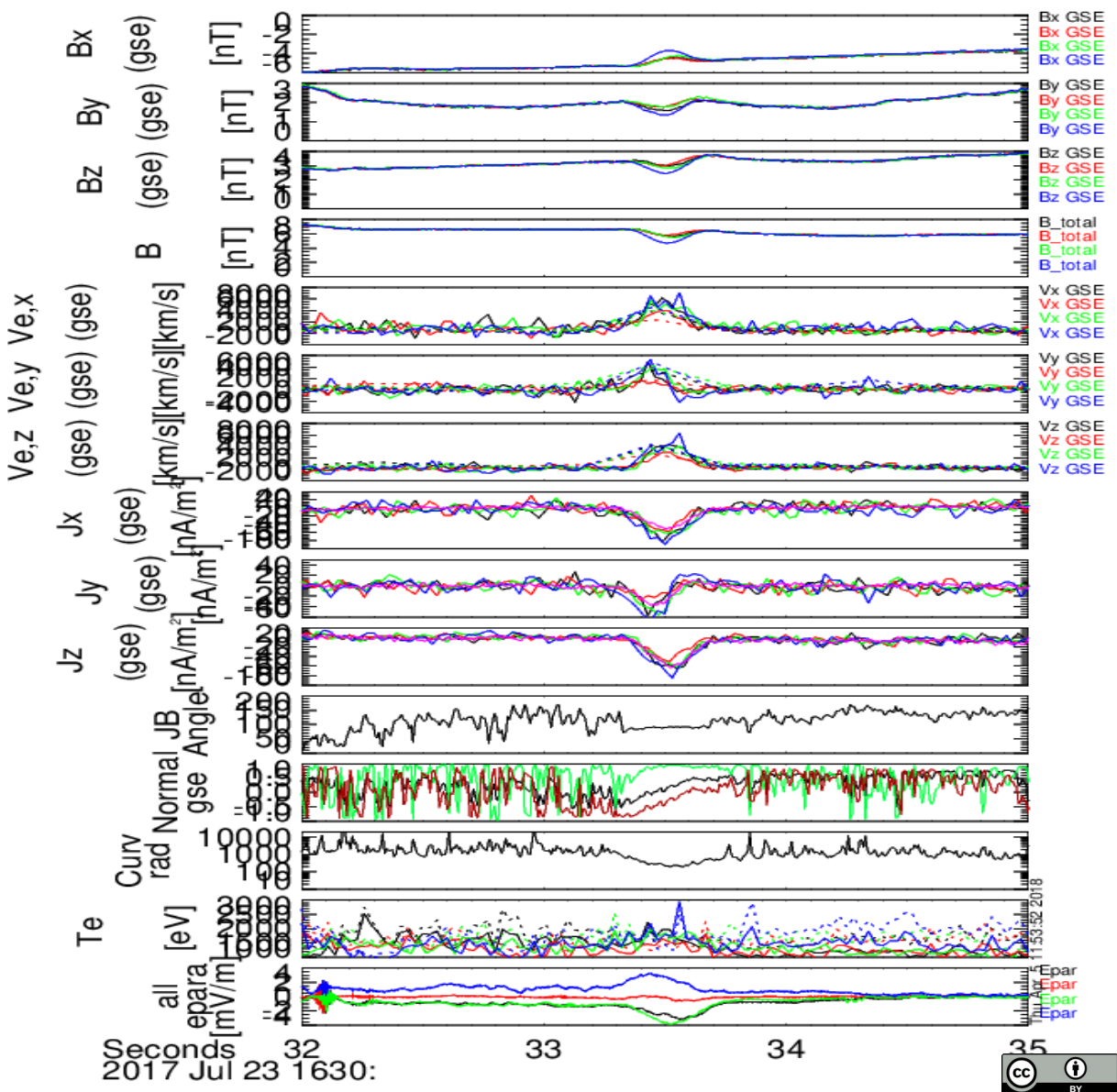
Electron vortex magnetic hole (I) 1630:32-1630:35 UT

- B depression (40%): hole
[Gershman et al., GRL, 2016, Goodrich et al., GRL, 2016, Mtail]
- Bipolar Ve,y : electron vortex
[Huang S. et al., ApJL, 2017, Msheath, Liu H. et al. GRL, 2019, plasma sheet, Li JH, et al, Nature, 2020]
- Perpendicular current signature with ~ 500 ms timescale
- Good agreement between curlB and FPI currents

- Curvature radius ~ 100 km
~ 10de~10pe

- Real parallel E field reversal?

MMS4 ~ 4 mV/m
MMS2 ~ 0 mV/m
MMS1&3 ~ -4 mV/m

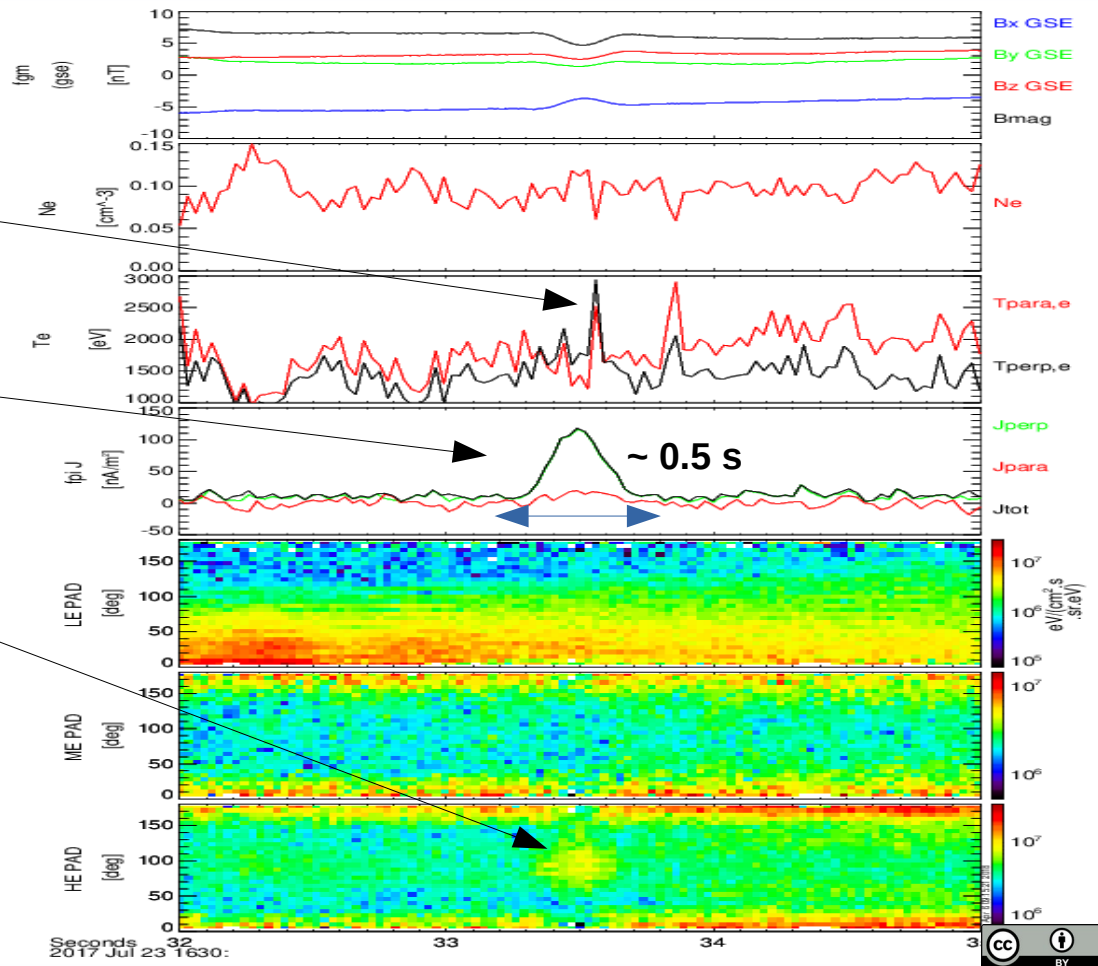


Electron vortex magnetic hole (II)
1630:32-163035 UT

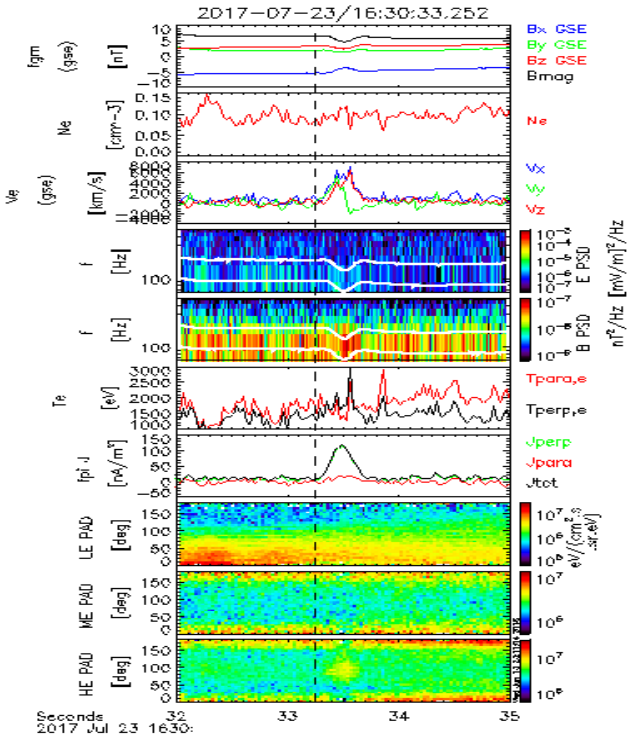
$T_{\perp,e} > T_{\parallel,e}$ inside the hole

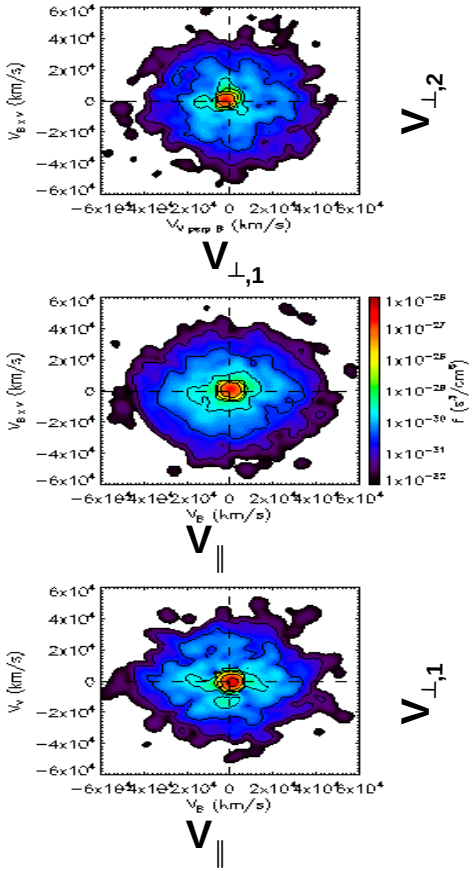
Strong perpendicular current

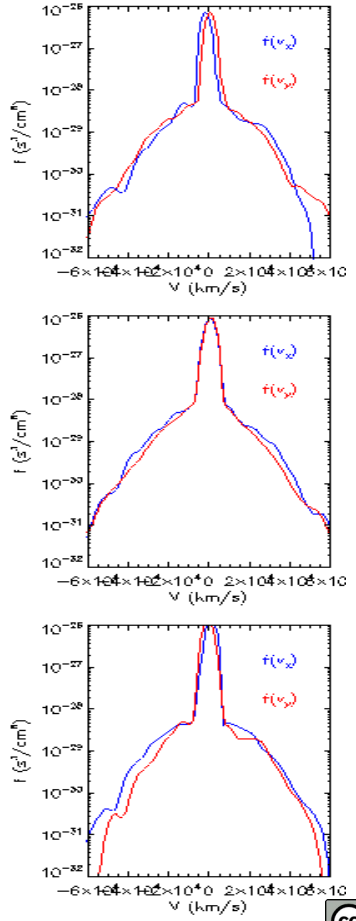
Trapped energetic electrons embedded in a region with $T_{\parallel,e} > T_{\perp,e}$ as in Msheath [Huang et al., 2017]



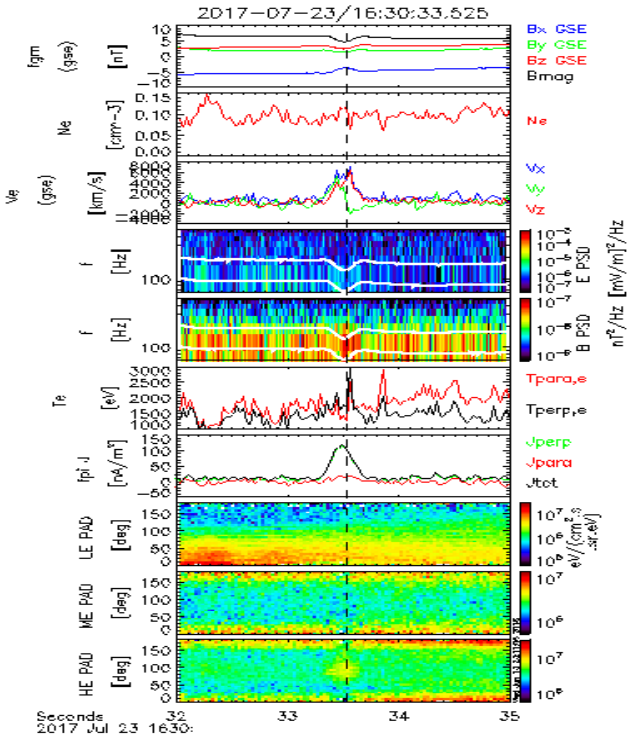
DES electron distributions



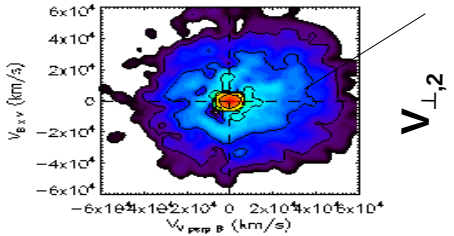


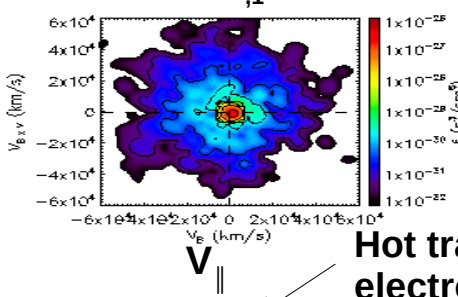


Vortex related DES electron distributions

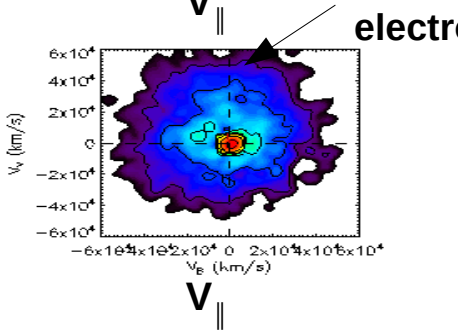


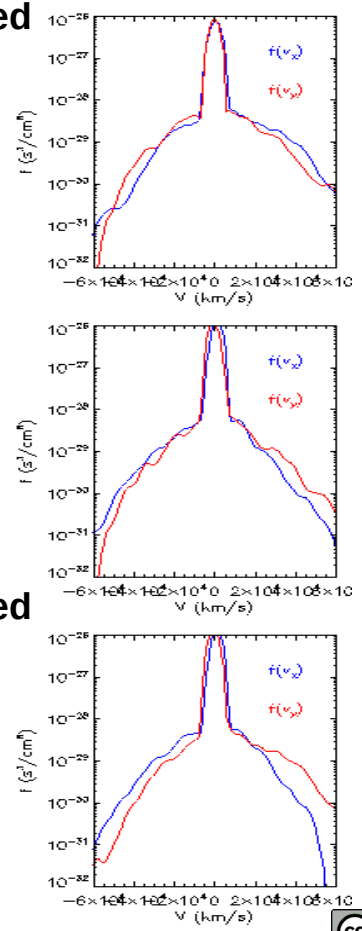
Hot trapped electrons



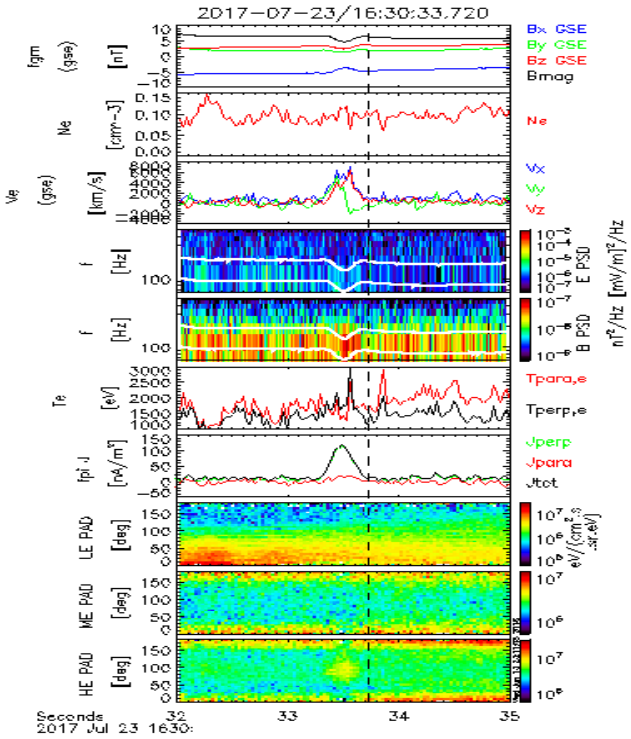


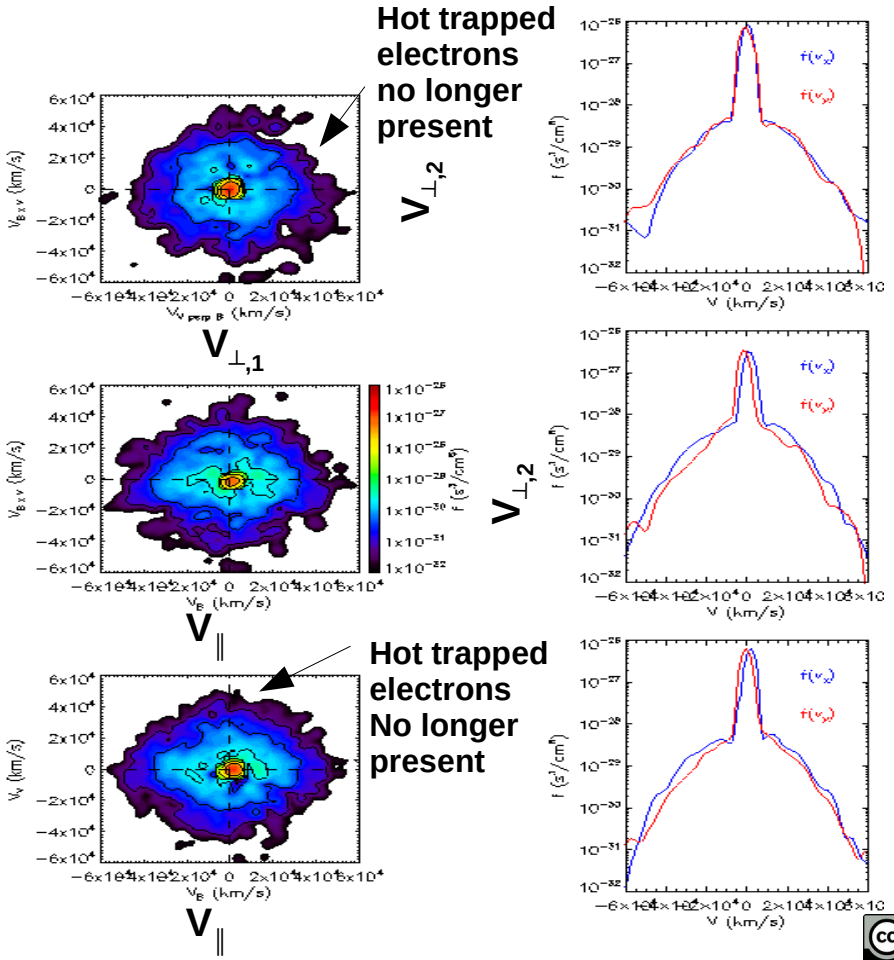
Hot trapped electrons





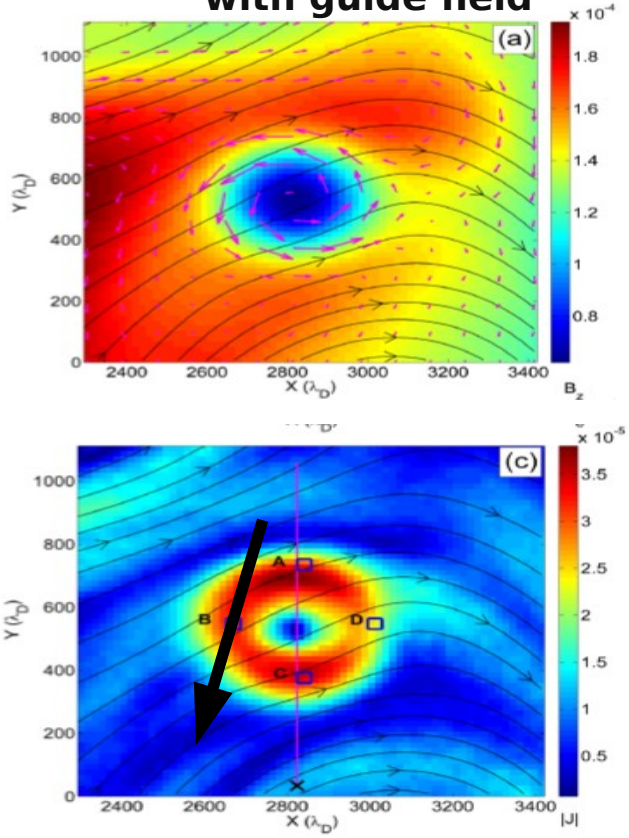
DES electron distributions





Electron vortex magnetic hole (III)

From Haynes etal., PoP, 2015, 2D PIC with guide field



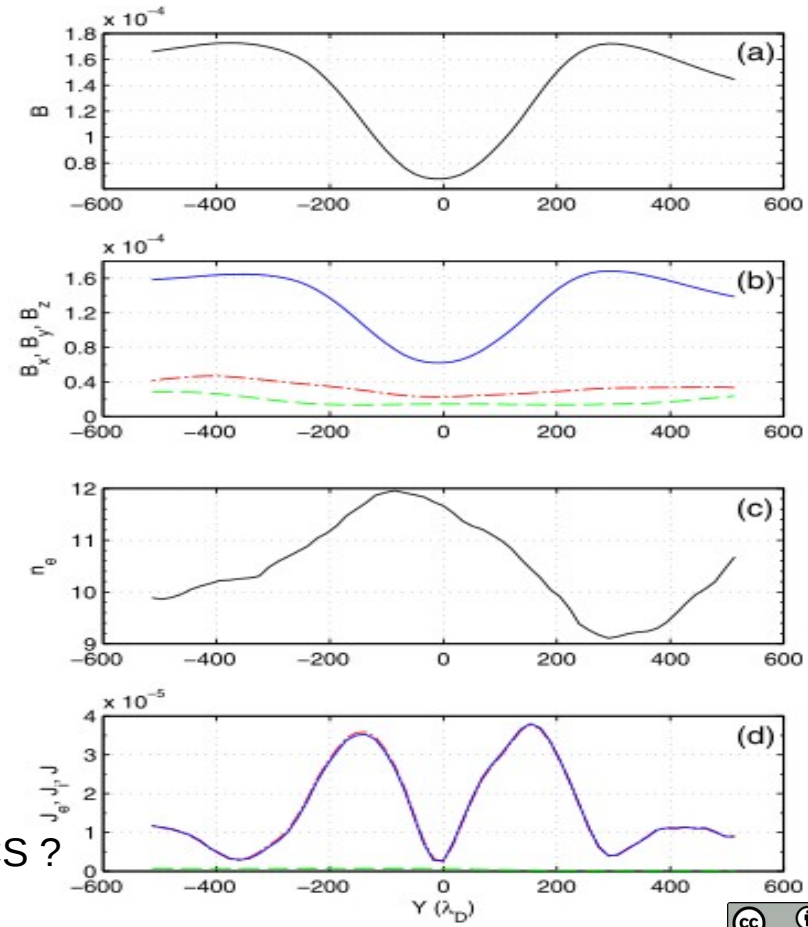
Monopolar vs bipolar current signature could be related to s/c trajectory
Off-central axis crossing

Electron mirror mode
$T_e >> T_i$
$T_{\perp,e}/T_{\parallel,e} > 1$

$T_{\perp,e}/T_{\parallel} > 1$ inside MMS vortex but embedded in $T_{\perp,e}/T_{\parallel,e} < 1$ background plasma

And $T_e < T_i$

Could the vortex formation be linked to the electron scale CS ?



Tentative summary

- Bifurcated **electron scale** (~5de) CS (max $J_{\parallel}$~ 50 nA/m^2) with a guide field (BM/BL~0.5) embedded in a larger ion scale CS (~2di) detected during a fast quasi-stationary earthward flow (substorm context) with small energy dissipation (J.E~0.05nW/m^3) but electron jet reversal, electron heating and ESW => electron-only reconnection as ion scale CS is too short 2di<10di?

- Small amplitude **electrostatic solitary waves identified as electron holes** ($E_{\parallel}$ ~ ± 5 mV/m) moving tailward (V_{EH} ~ 5000 km/s ~ 0.26 Vth,e) from the CS with a parallel size $L_{\parallel}$ ~ 25 km ~ **33 λ_{de}**. Possibly generated by counterstreaming instability at the edge/separatrix of the CS

- **Electron vortex magnetic hole** associated with hot trapped electrons ($T_{\perp,e}/T_{\parallel,e}$ >1) detected at the edge of the ion scale CS embedded in $T_{\perp,e}/T_{\parallel,e}$ <1 plasma and associated with an energy dissipation (**J**.**E**~0.15 nW/m^3) larger than at the CS crossing
  Where and how are these electron vortices generated ?
  Are they linked to the electron scale CS?
  How much (statistically) do they contribute to the flow energy dissipation process?