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

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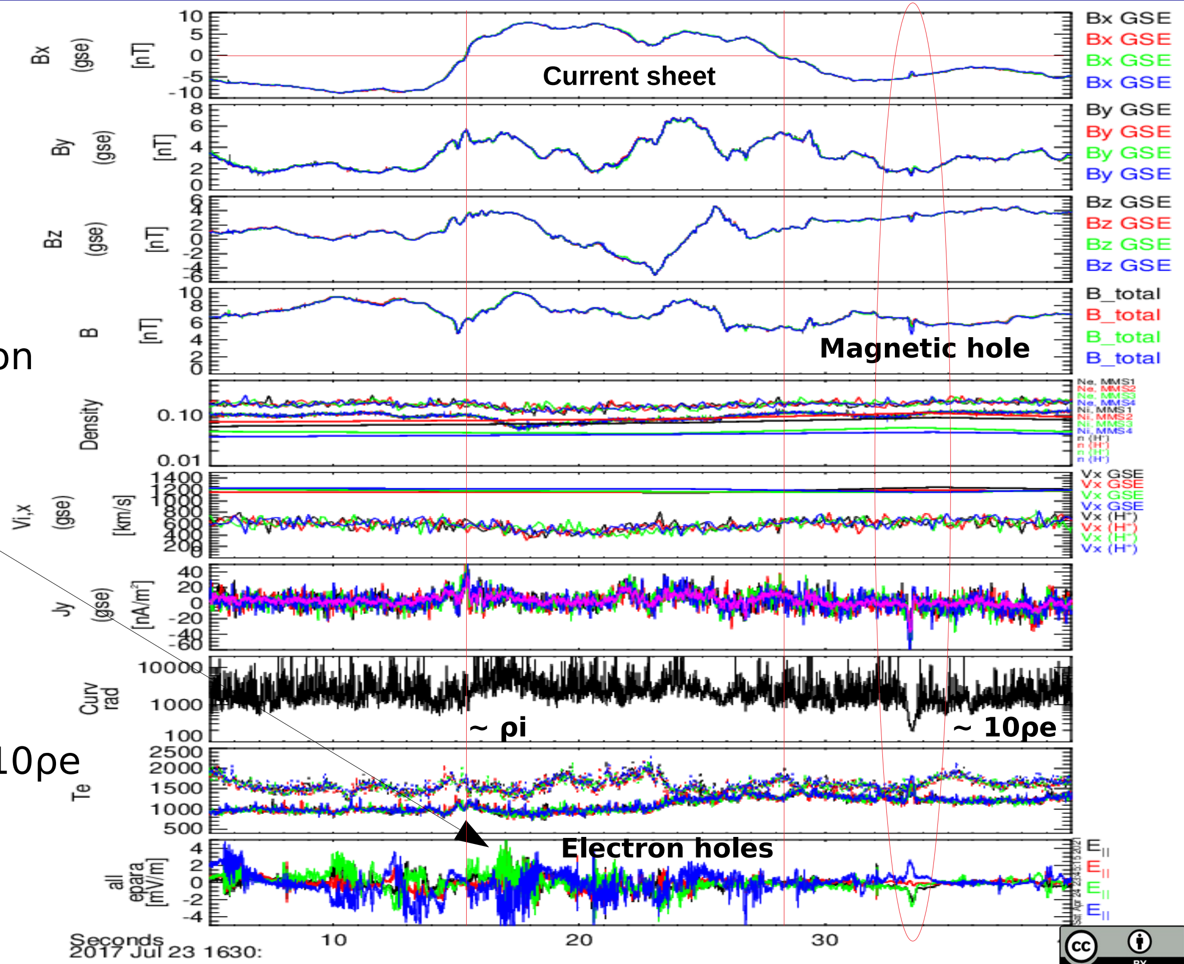
Motivation: multiscale kinetic structures

Current Sheet detected during a quasi-stationary earthward flow Vx ~ 1000 km/s after a substorm onset

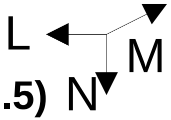
- N ~ 0.1 p/cm³
- Jy~ 50 nA/m² (from CurlB or Part.)
- **Ion scale** curvature radius ~ 1000 km ~ ρi (Ion Larmor radius)
- Parallel E fields associated with $T_{\parallel,e} > T_{\perp,e}$
  => Electron holes ~ **few Debye lengths**

Magnetic hole

- Out of equator
- Large Jy up to -60 nA/m²
- **Electron scale** curvature radius ~ 200 km~ 10ρe
- $T_{\perp,e} > T_{\parallel,e}$ and possible quasi-static parallel E fields



CS analysis from MMS3



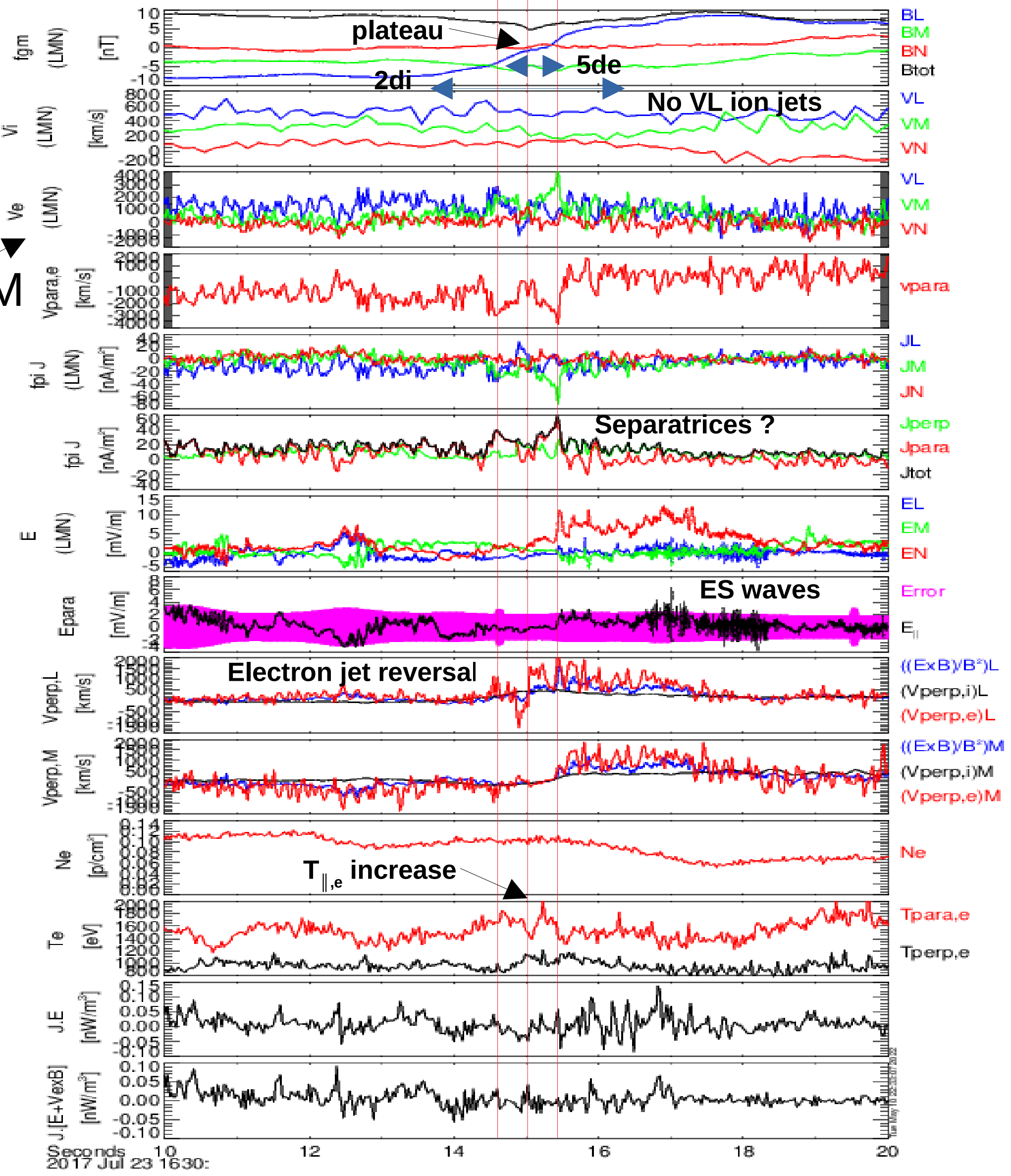
Bifurcated CS (plateau) with guide field (BM/BL~ 0.5)

MVAB
L[**0.97**,0.11,0.21], M[0.21,-**0.81,-0.54**], N[0.11,**0.57,-0.81**]
Timing analysis
N[0.19,**0.57,-0.79] in agreement with MVAB**
V_CS ~ 344 km/s along N

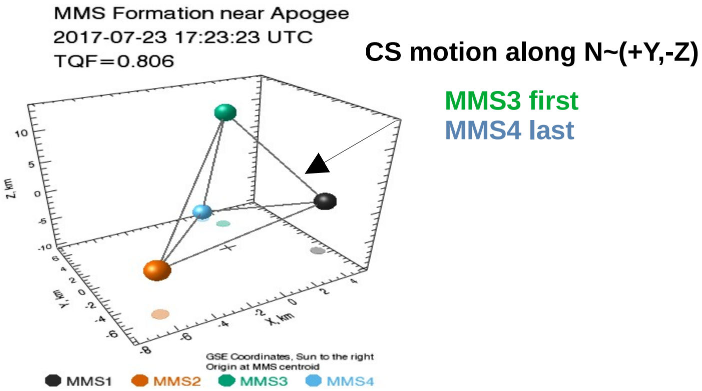
Plateau thickness : 344*0.25 ~ 86 km ~ 5de (dsc ~20km)
CS thickness : 344*3 ~ 1032 km ~ ρi ~ 2di

- 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



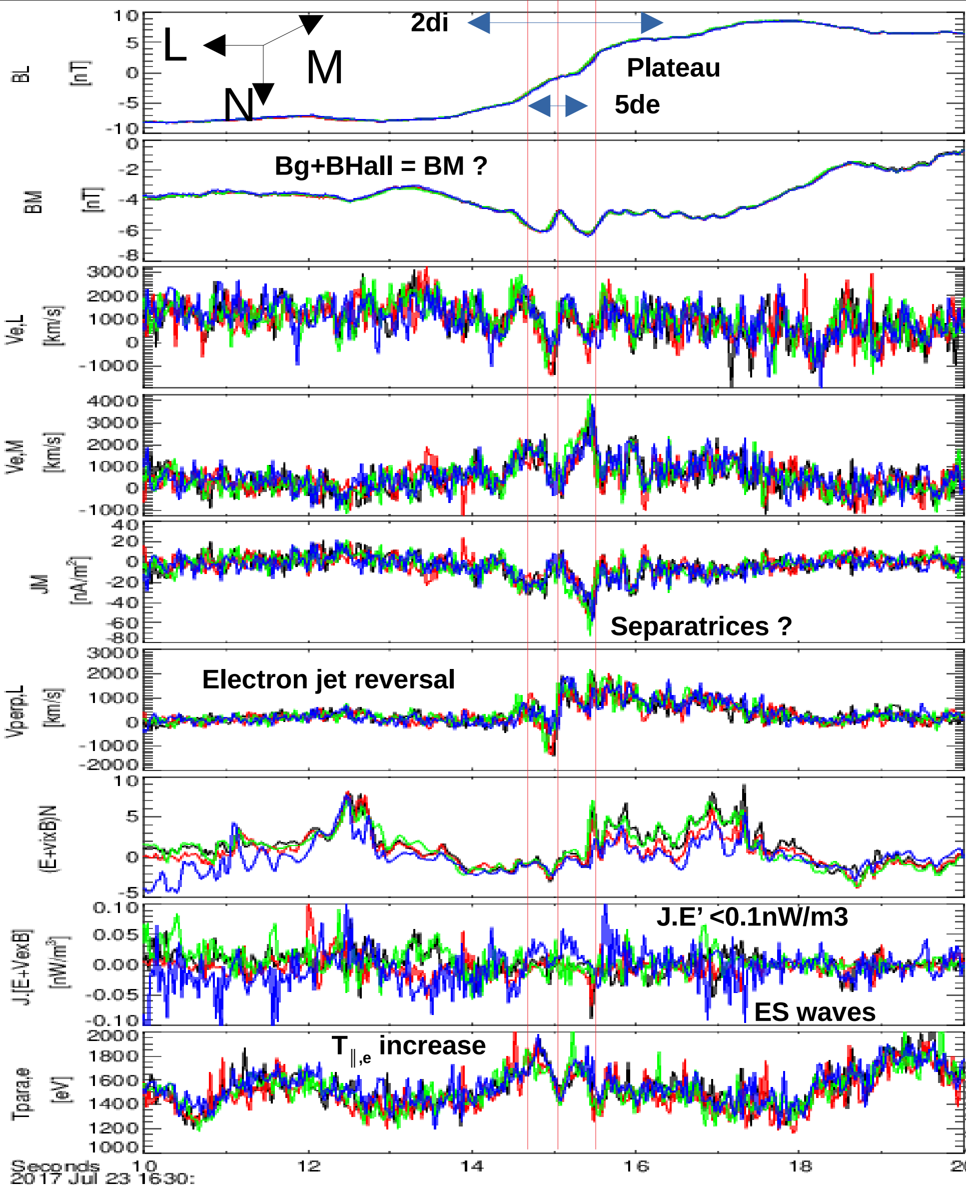
CS analysis from 4 s/c



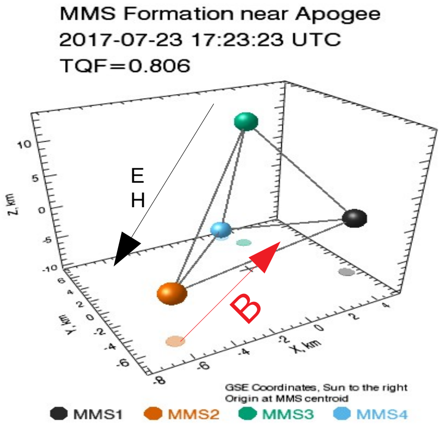
- Bg + BHall ?
- Electron jet (Vperp,L) reversal ± 1500 km/s (super-alfvénic ~ 1.7Va,i or 0.05Va,e)
- Two increases of $T_{\parallel,e}$
- But still no large **J.E’** <0.1 nW/m³ at the CS centre
- No magnetic waves yet ESW propagating from the CS

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]



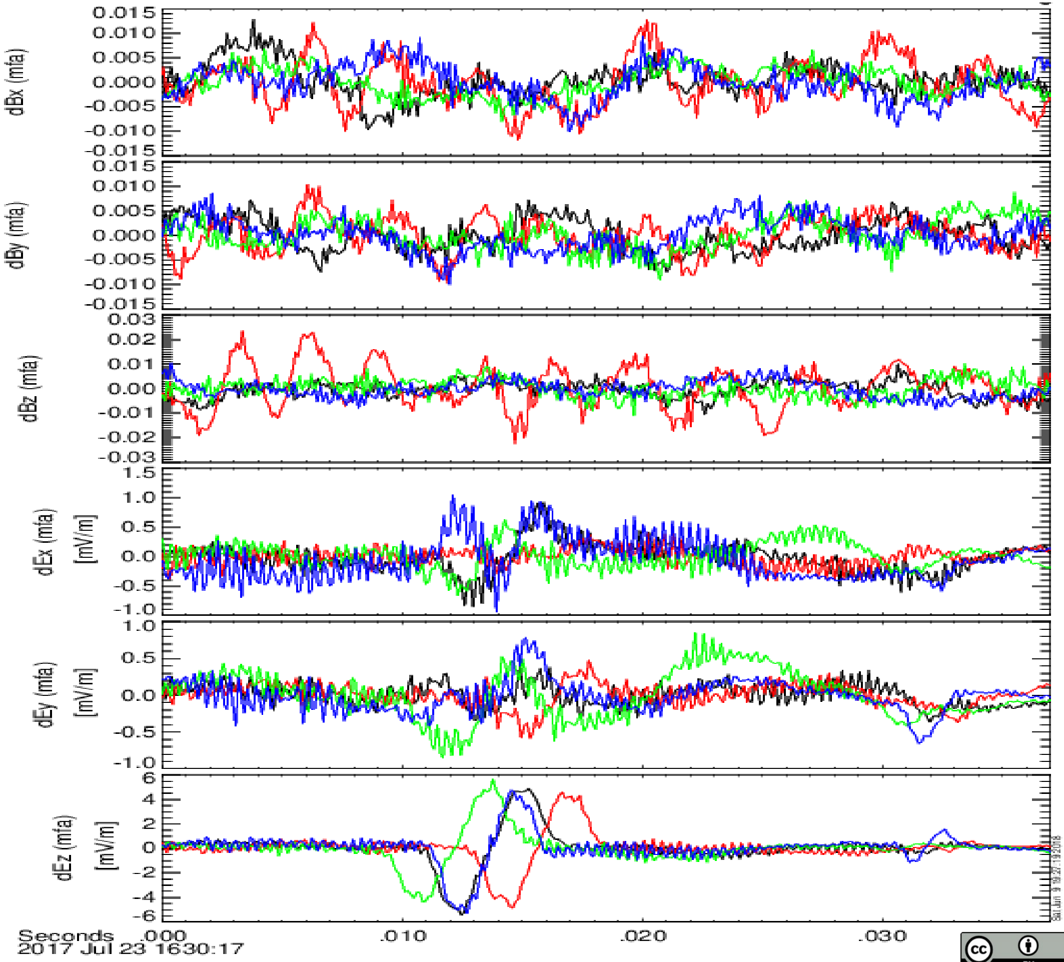
Electrostatic solitary wave



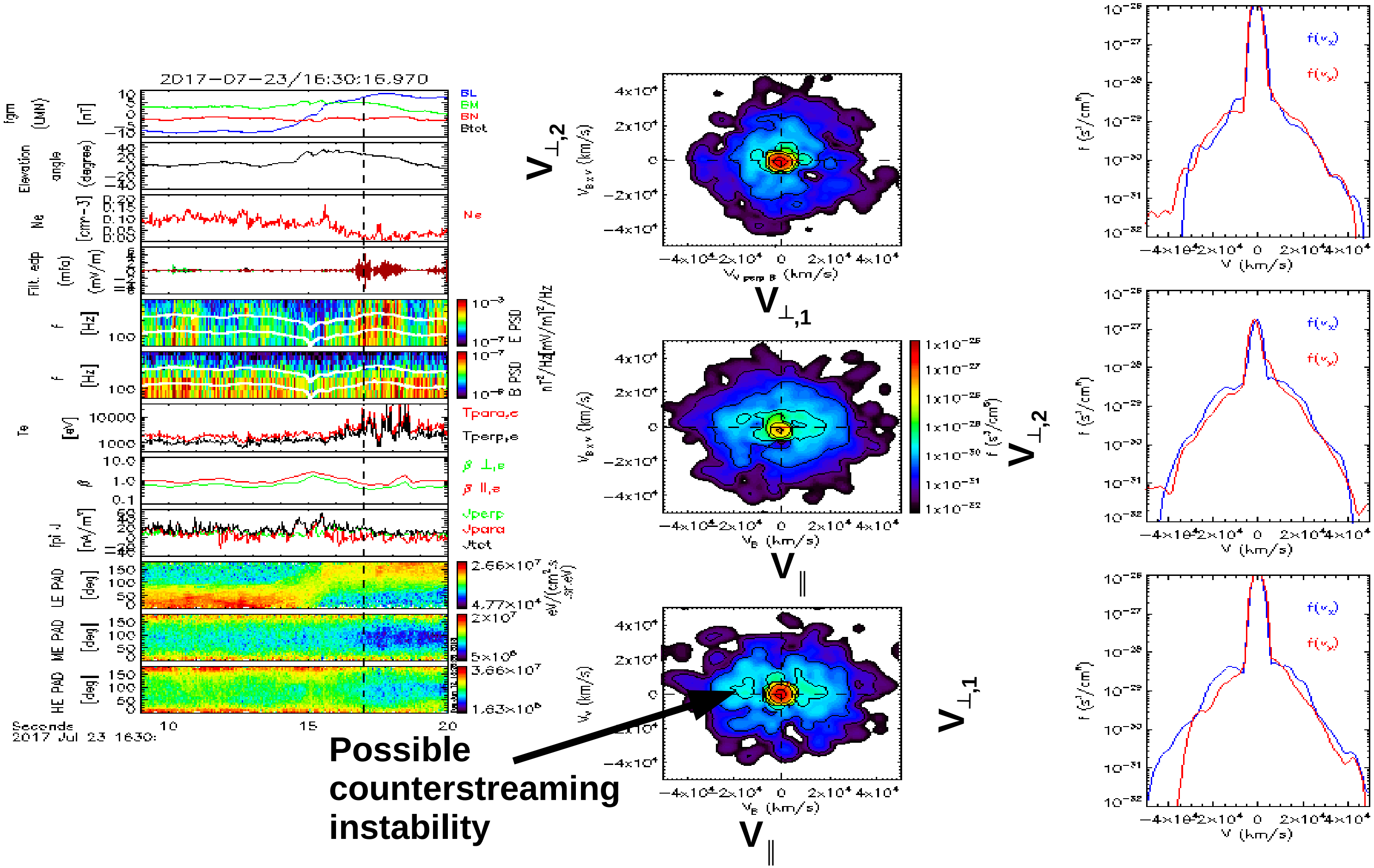
Purely **electrostatic electron phase space hole (EH)** [e.g Matsumoto et al., 1994, Ergun et al., 2008, Norgren et al. 2015] moving tailward/southward

V_{EH} ~ 20/0.004 = 5000 km/s ~ 0.26 Vth,e (slow EH)
$L_{\parallel}$ ~ 5000x0.005 = 25 km ~ 33 λ_{de}

Likely formed by counter streaming instability



DES electron distributions



Possible counterstreaming instability

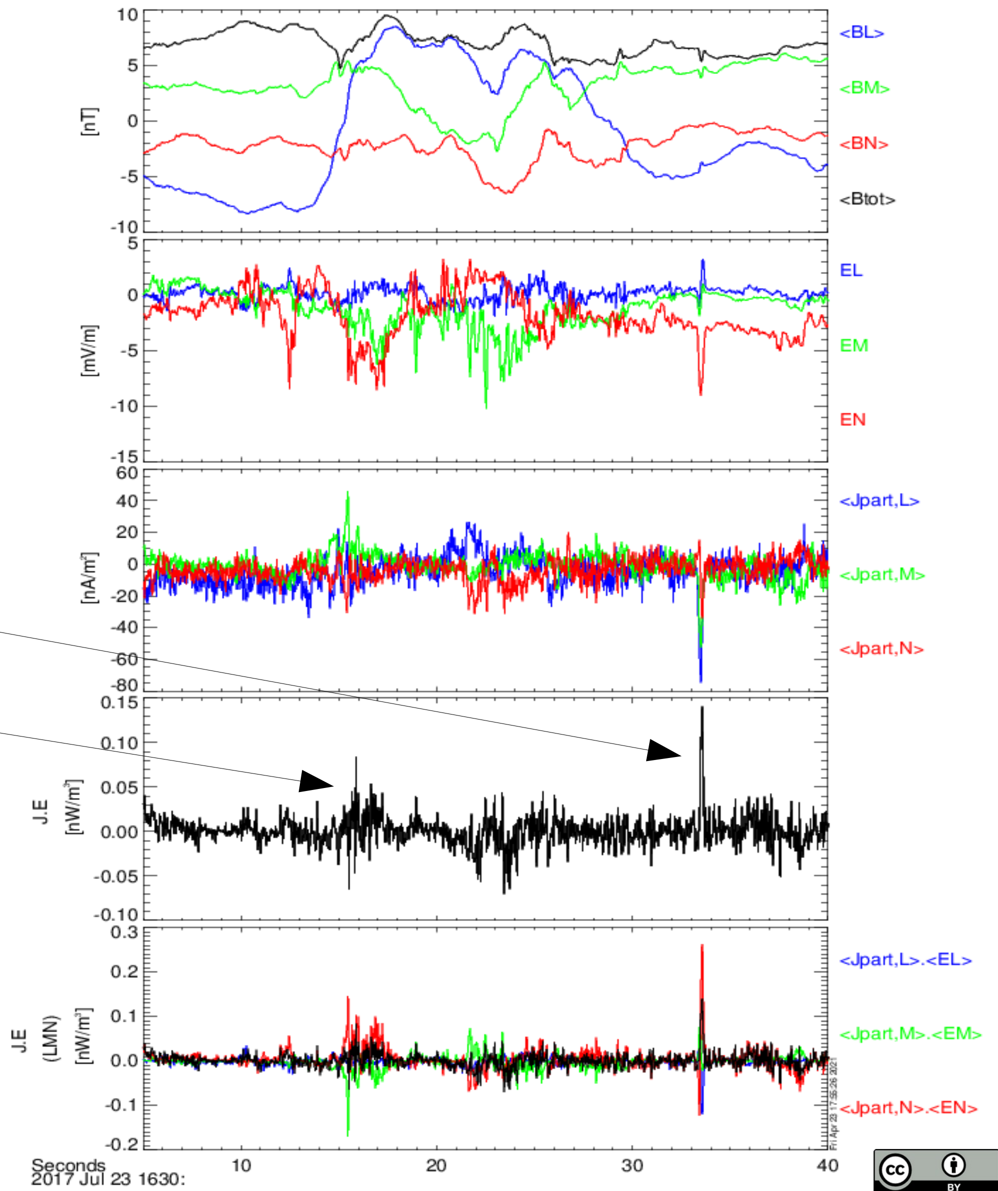
Energy conversion processes

4 s/c averaged data

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

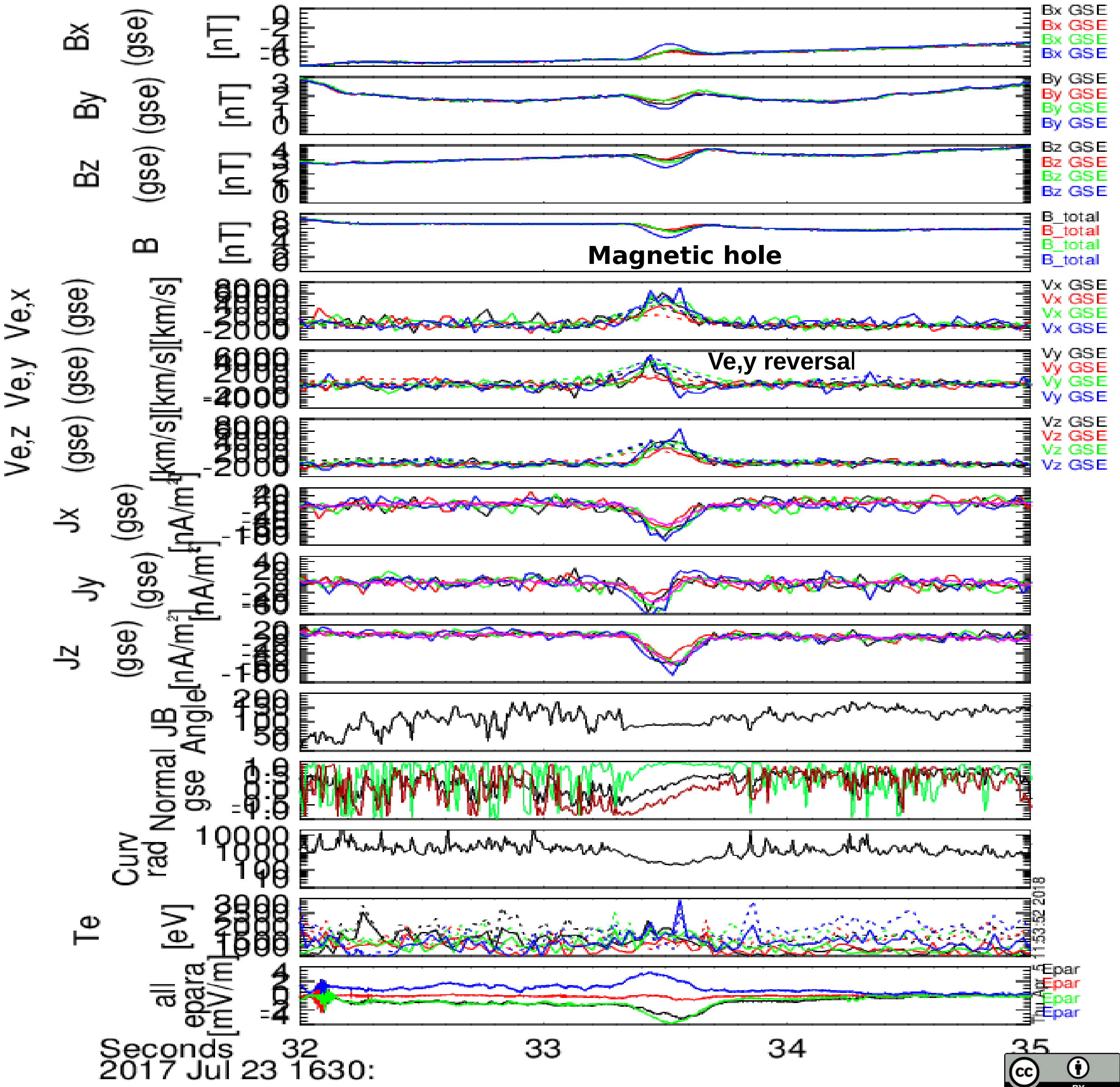
J.E ~ + 0.15 nW/m^3

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 ~ 200 km ~ 10de~10ρe

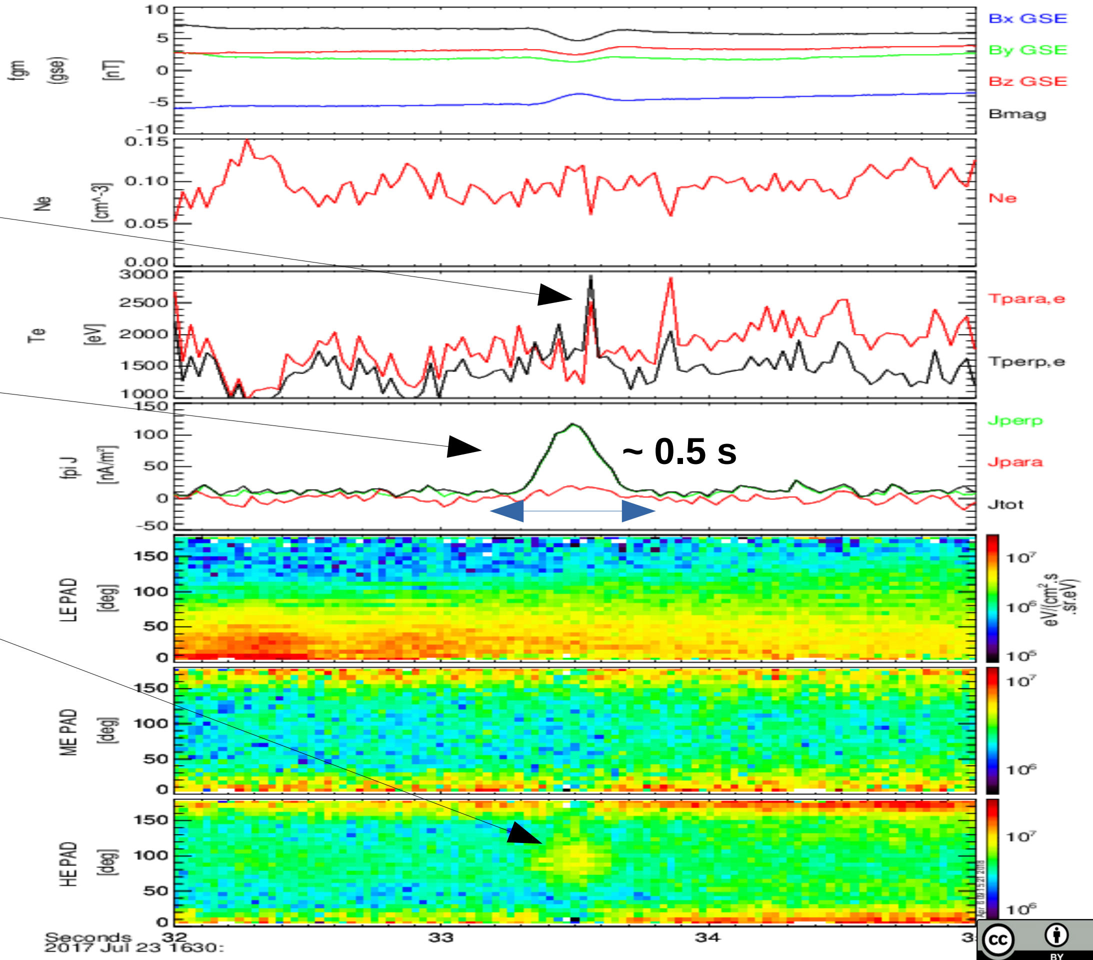


Electron vortex magnetic hole (II) 1630:32-163035 UT

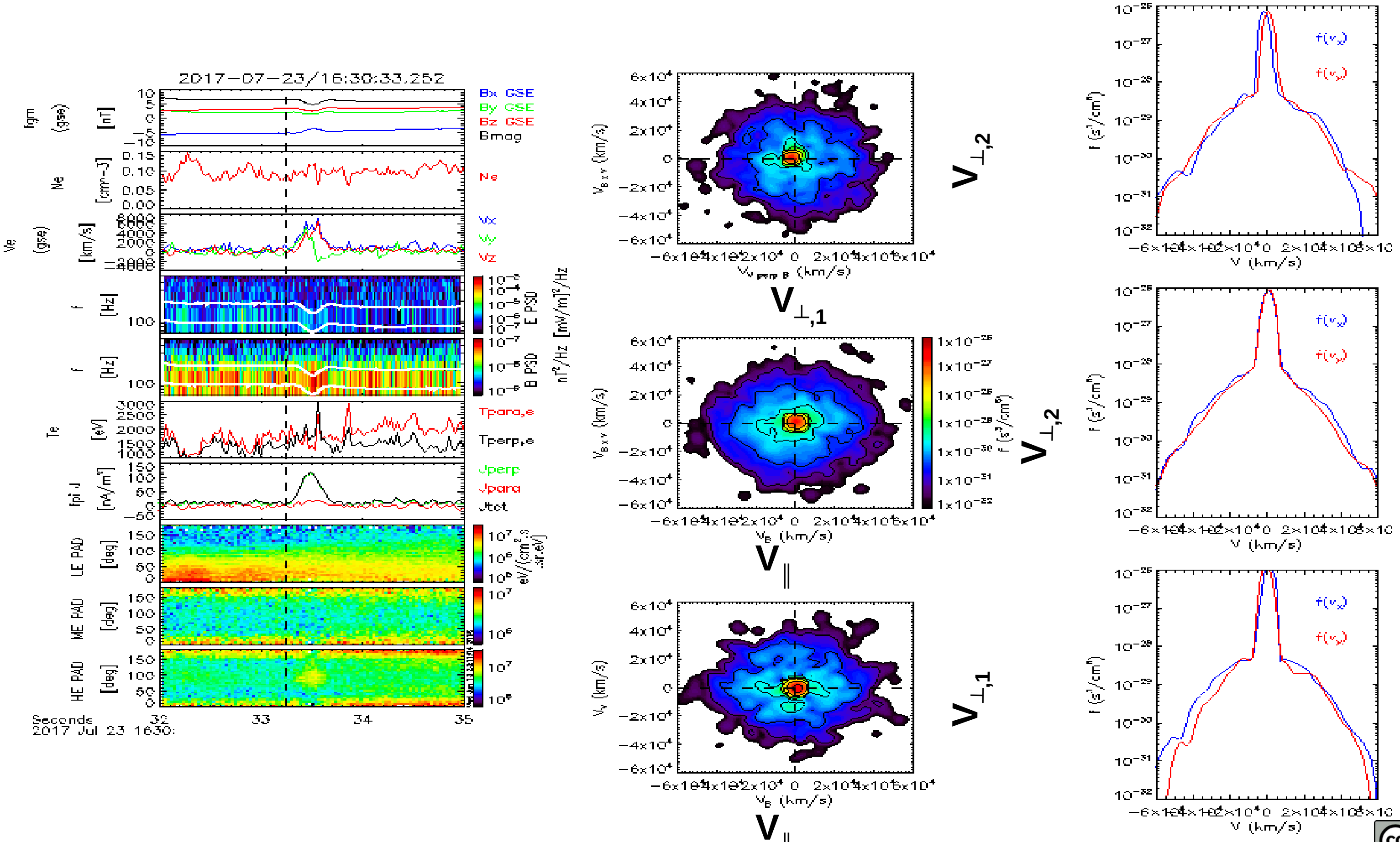
$T_{\perp,e} > T_{\parallel,e}$ inside the hole

Strong perpendicular current

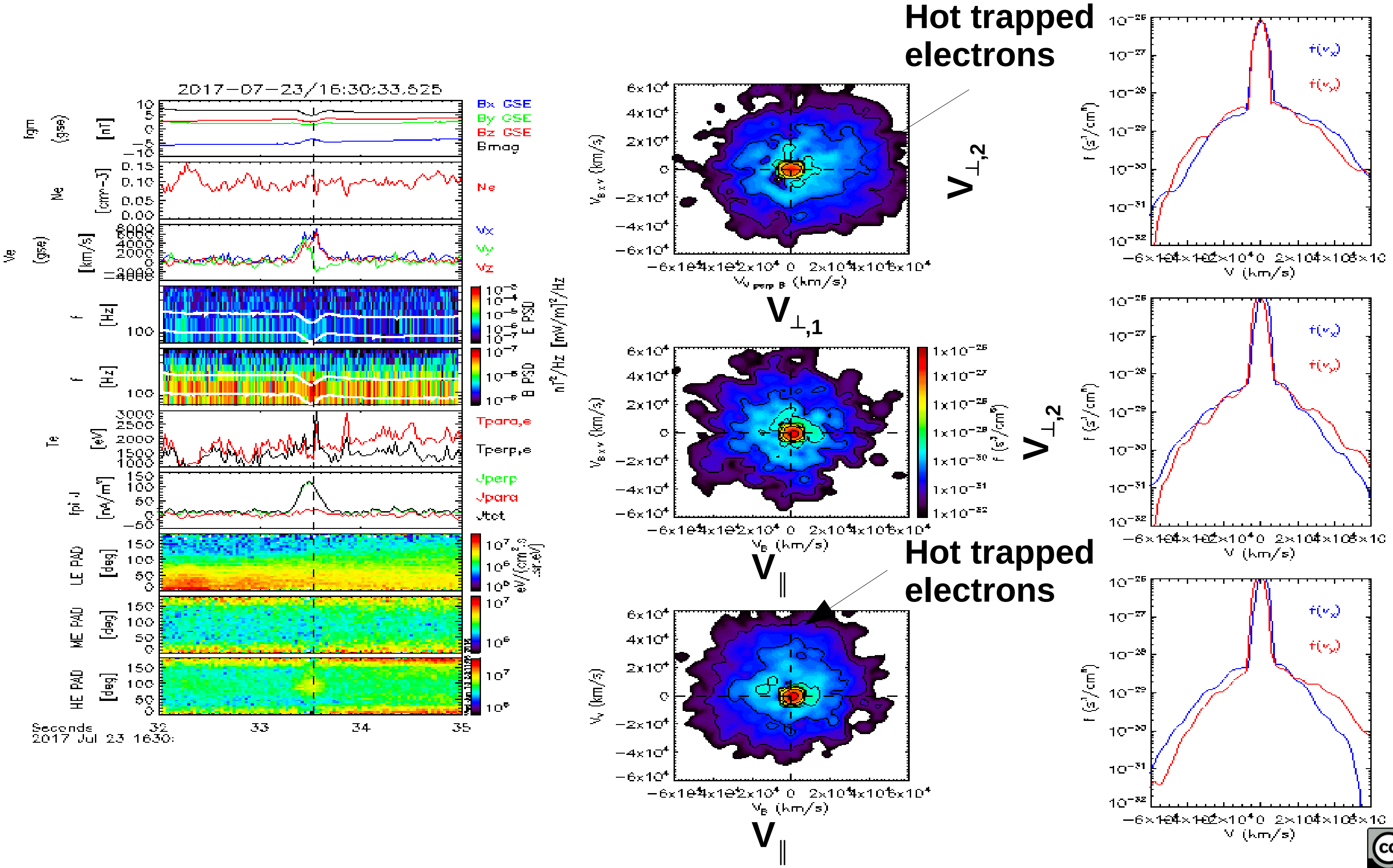
Trapped energetic electrons embedded in a region with $T_{\parallel,e} > T_{\perp,e}$ as in Msheath [Huang et al., 2017]



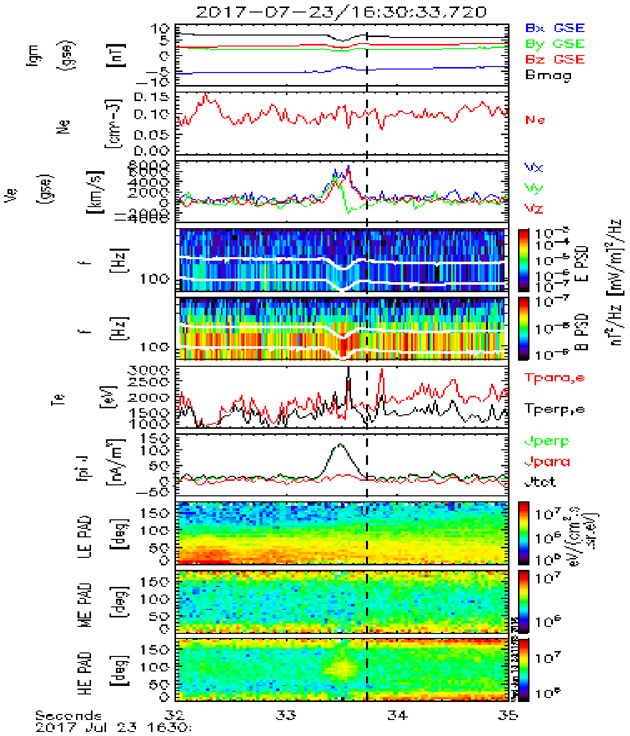
DES electron distributions

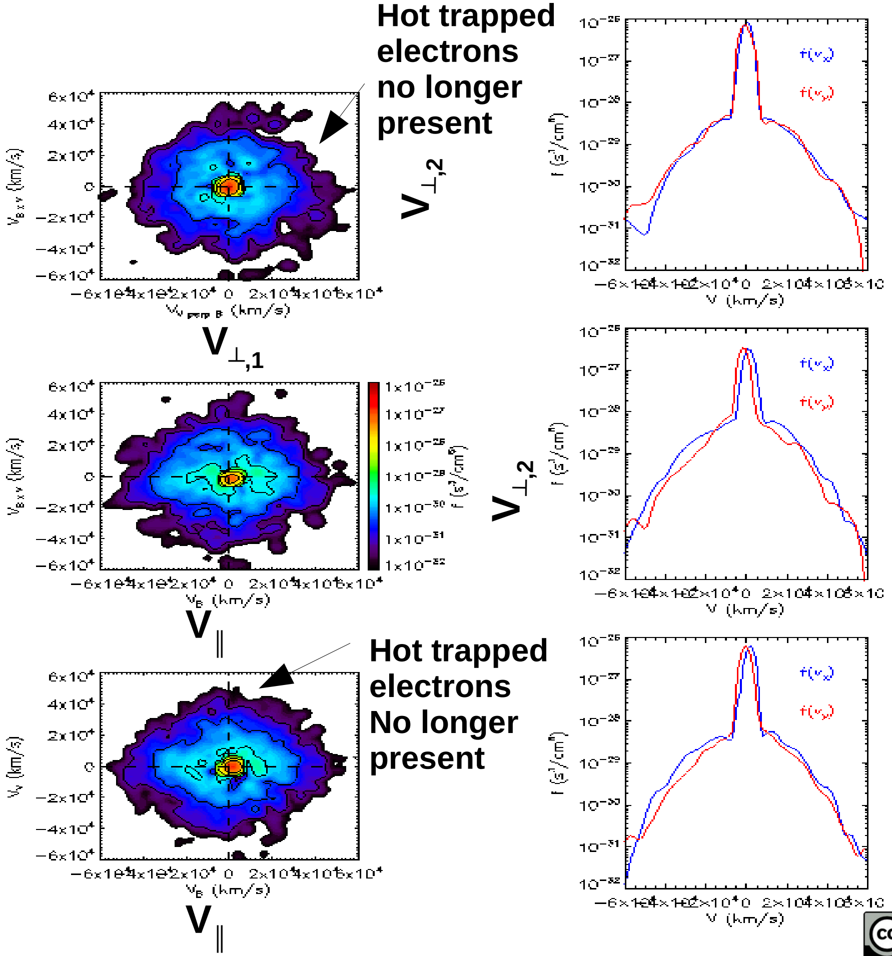


Vortex related DES electron distributions



DES electron distributions





Tentative summary

- Bifurcated **electron scale** (~5de) CS (max $J_{\parallel}$~ 50 nA/m²) 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/m³) 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 $\boldsymbol{\lambda_{de}}$**. 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/m³) 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?