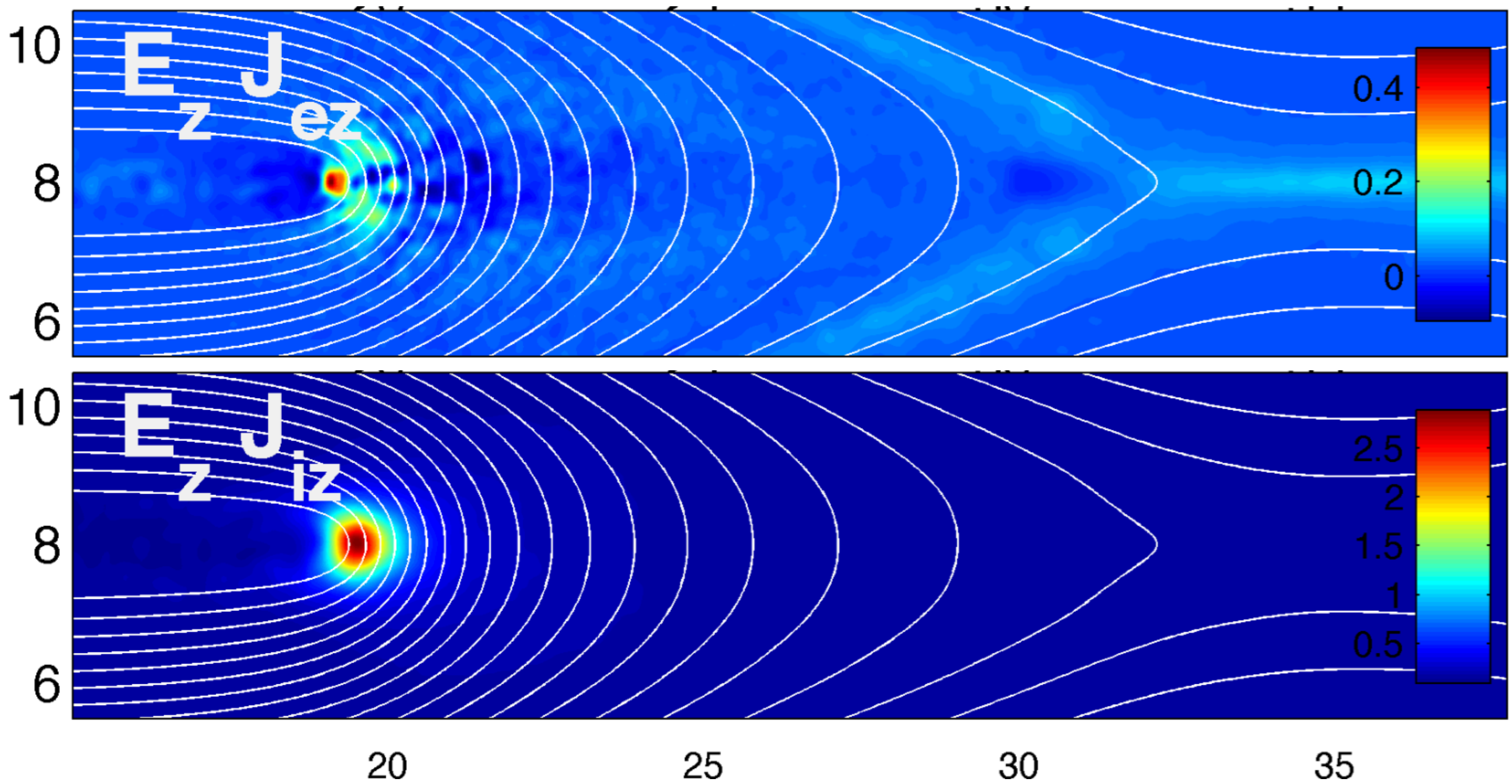
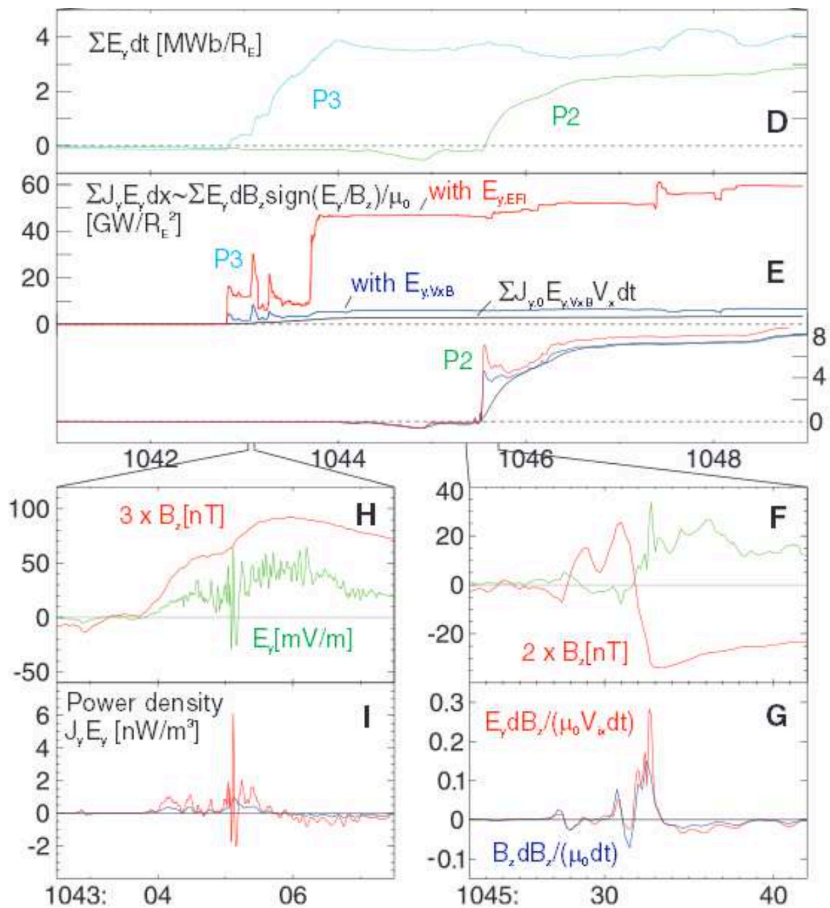
Conversion of Electromagnetic Energy at Plasma Jet Fronts

Yuri Khotyaintsev, Andrey Divin,
Andris Vaivads, Mats André
Swedish Institute of Space Physics, Uppsala
yuri@irfu.se

Energy conversion sites



Observations of energy conversion



Angelopoulos et. al., 2013

- Localized energy conversion sites in the magnetotail are related to BBFs [Hamrin et al, 2011]
- Major dissipation at **scales of the order of electron-inertial length** [Angelopoulos et. al., 2013]

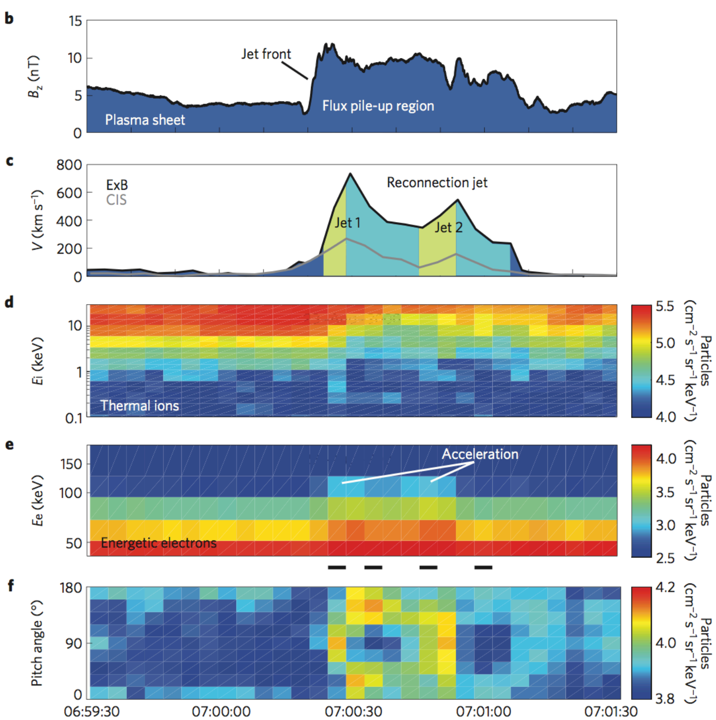
Energy sinks

- Heating/acceleration of thermal ions
- Heating of thermal electrons
- Energetic electrons
- Energetic ions
- Wave/Poynting flux (whistlers, KAW)

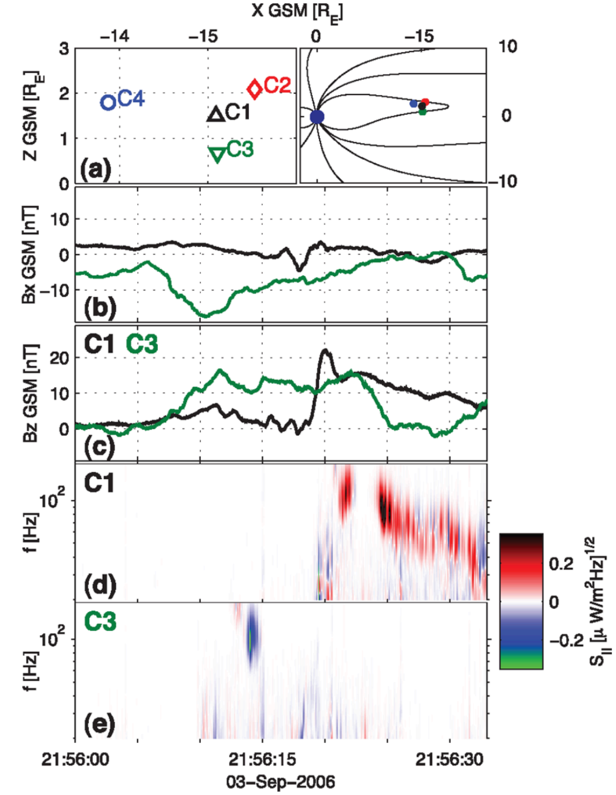
Electric Structure of DFs

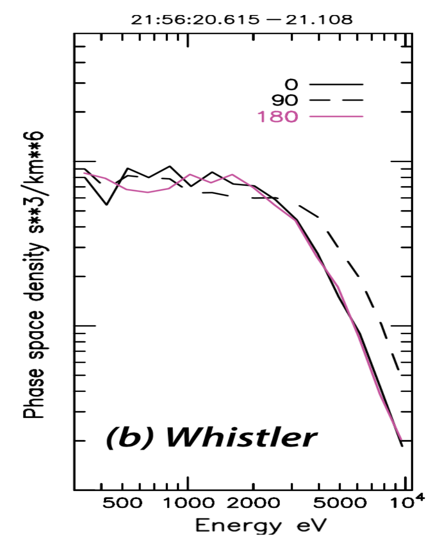
Electrons : FPR

- Adiabatic Fermi and betatron processes in the FPR
- Whistlers cause pitch-angle scattering and carry Poynting Flux



[Fu et al, 2013]

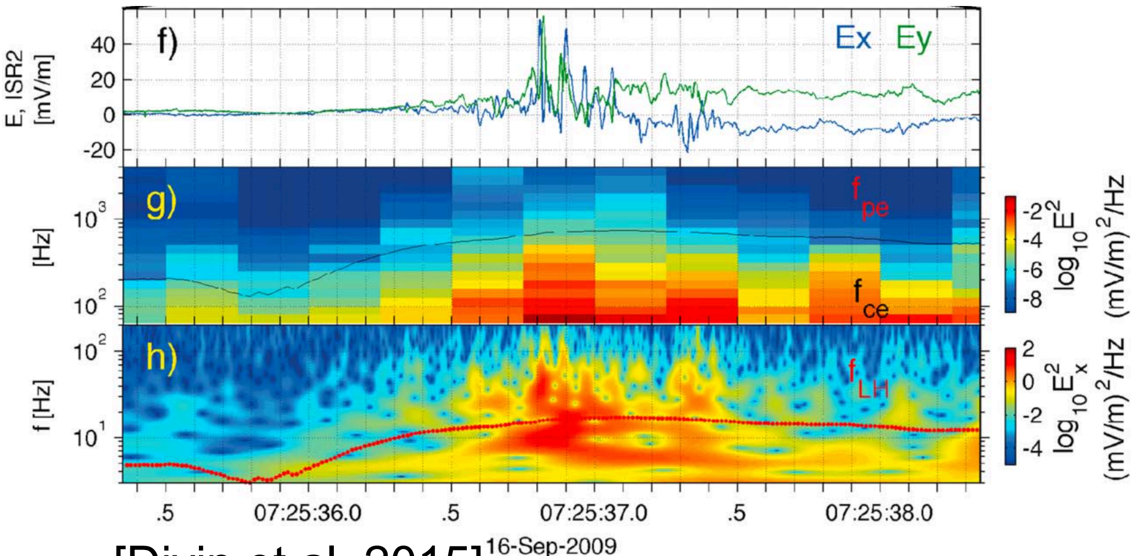




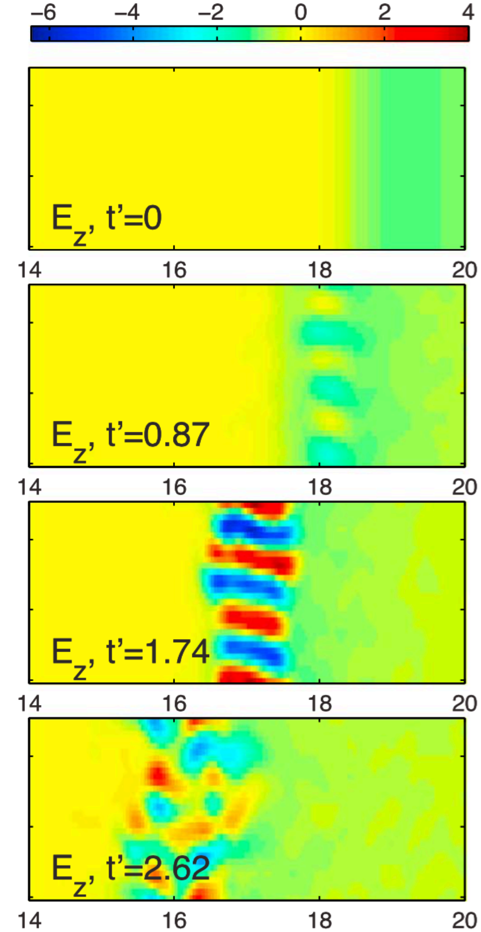
[Khotyaintsev et al, 2011]

Electric Structure of DFs

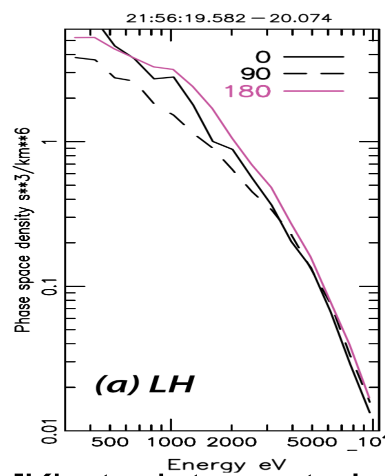
Electrons: Front



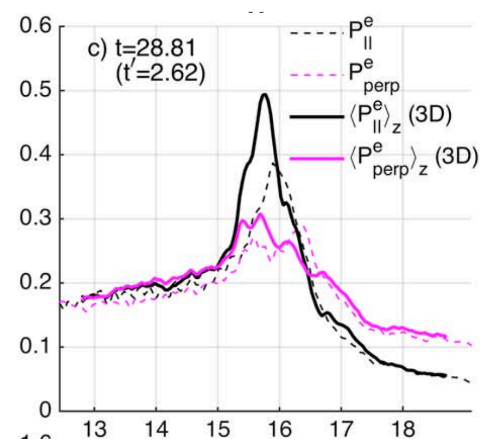
[Divin et al, 2015]



- LHDI at the front, $k_{perp}\rho_e$~1
- Large amplitude LHDI -> Electron heating



[Khotyaintsev et al, 2011]

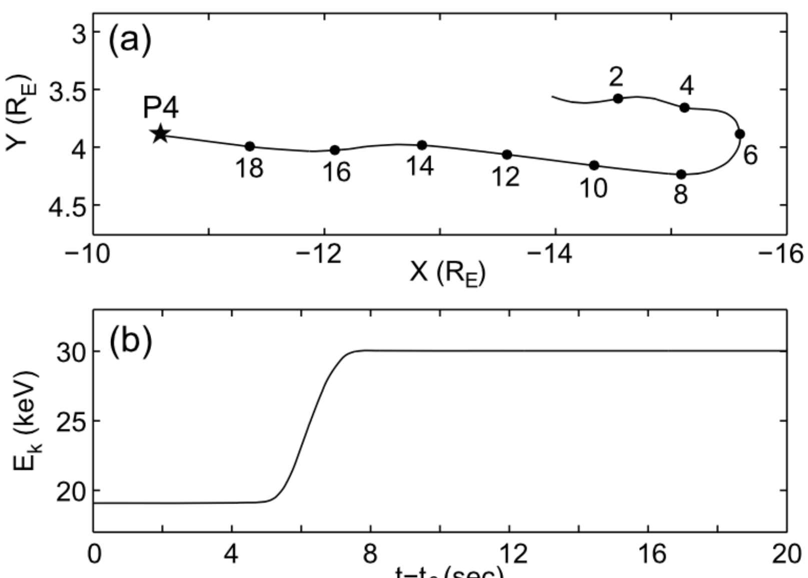


[Divin et al, 2015b]

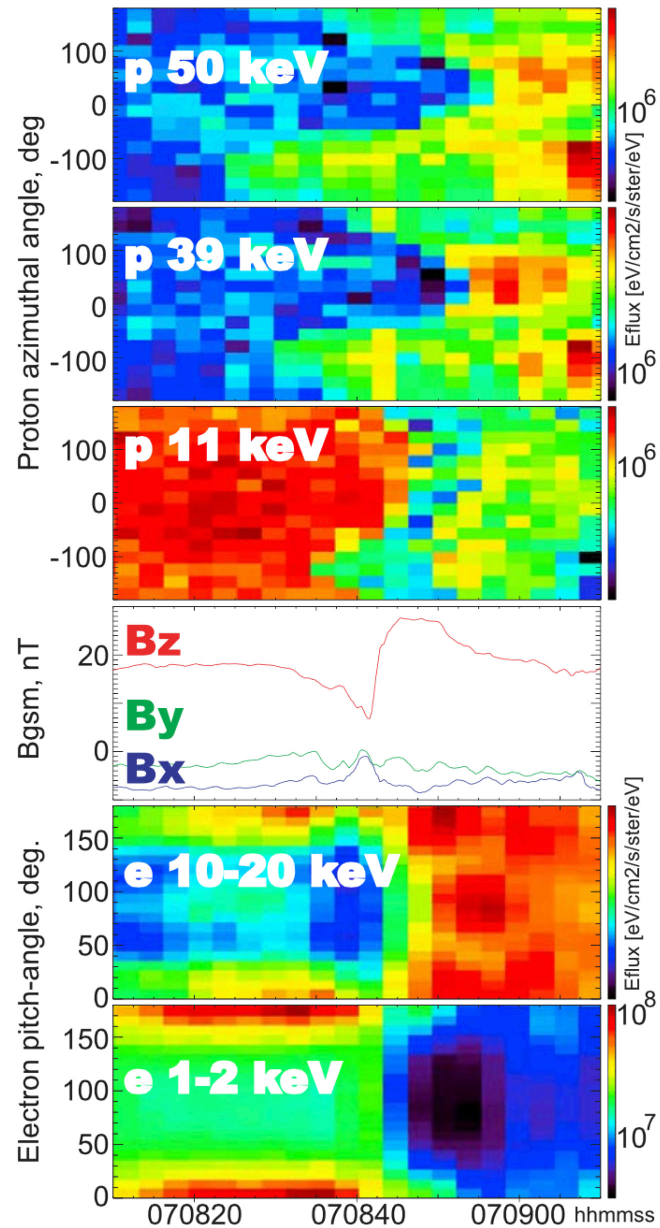
Electric Structure of DFs

Ion acceleration

- Reflection of ions from the fronts, [Sergeev, 2009, Zhou et al, 2010, Wu & Shay, 2012, Birn et al, 2013, Eastwood et al, 2014, Artemyev & Vasiliev, 2015]



[Zhou et al, 2010]



[Sergeev et al, 2009]

Questions

- Where is the energy conversion happening (front or pile-up region) ?
- At which scales (MHD or kinetic electron/ ion)?
- What are the dominant mechanisms?

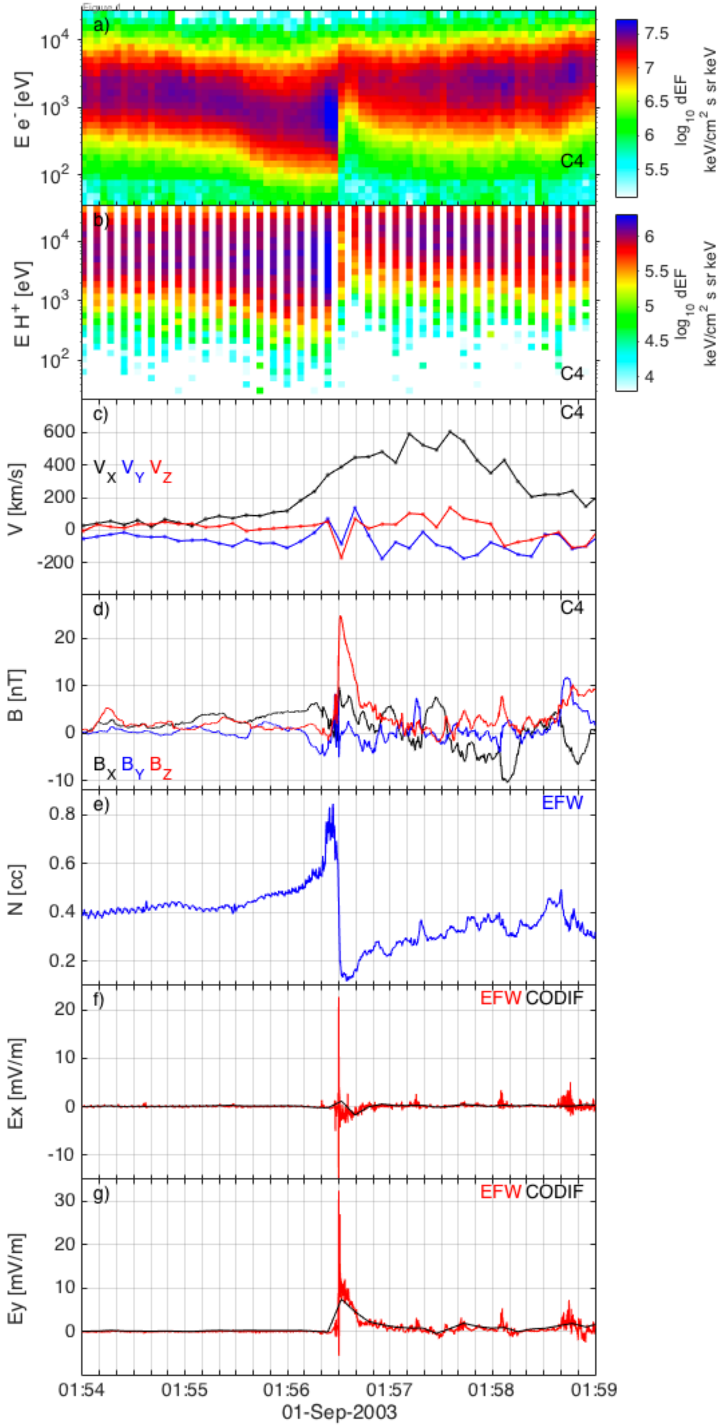
Approach

- DF events observed by Cluster at small separation, ~200 km < λ_i :
  - Good estimate of boundary orientation by multi-spacecraft timing
  - Multi-spacecraft measurement of the electric field
  - “Redundant” ion measurements at several spacecraft (C1-CODIF, C1-HIA, C3-HIA, C4-CODIF)

Electric Structure of DFs

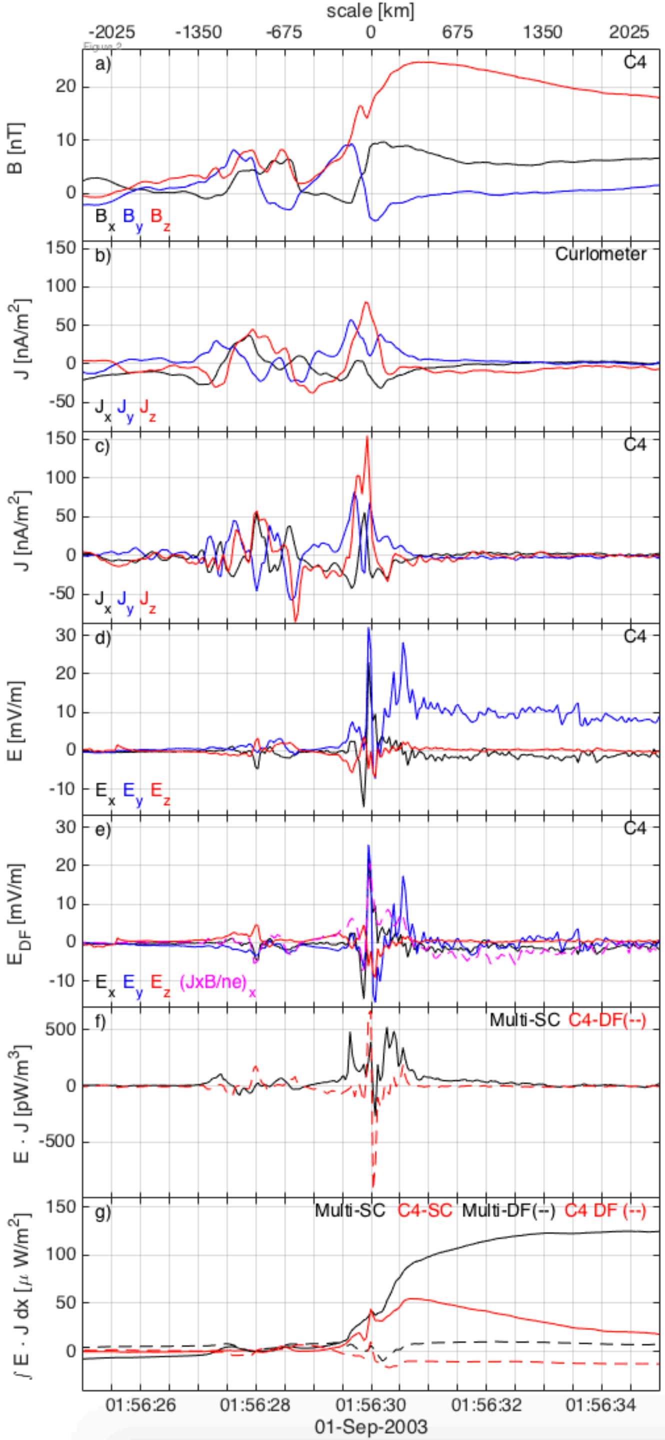
Large E event

R=[-18.6 -1.6 0.0] R_E GSM



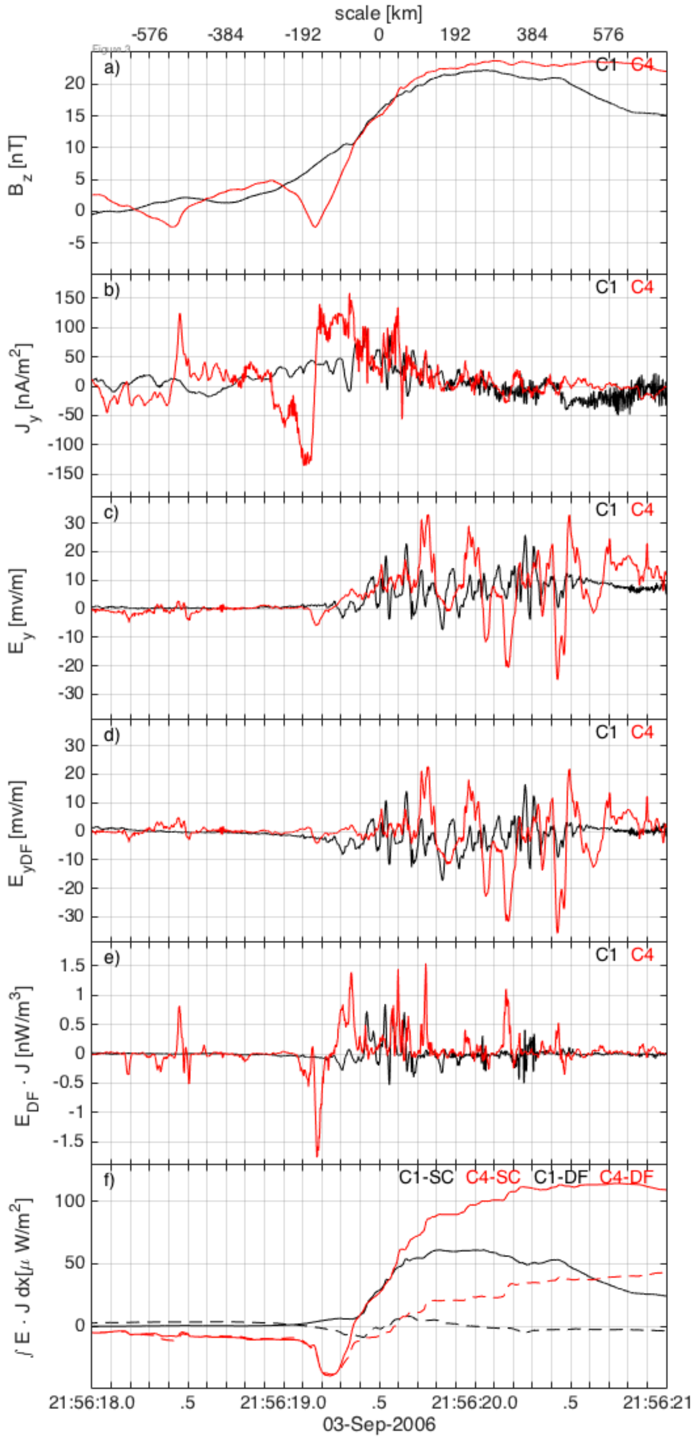
- Cluster separation <d_i
- Fast plasma flow, primarily in X-direction
- Large Bz increase->large Ey
- Multi-SC estimate of DF normal velocity
- V_DF = 450 * [1 0 0] km/s GSM
- V_timing = 410 * [0.77 0.58 -0.26] km/s GSM
- V_CS_DFframe = 293 * [-0.46 0.81 -0.36] km/s GSM
- Indication of small-scale structure of DF

Electric Structure of DFs



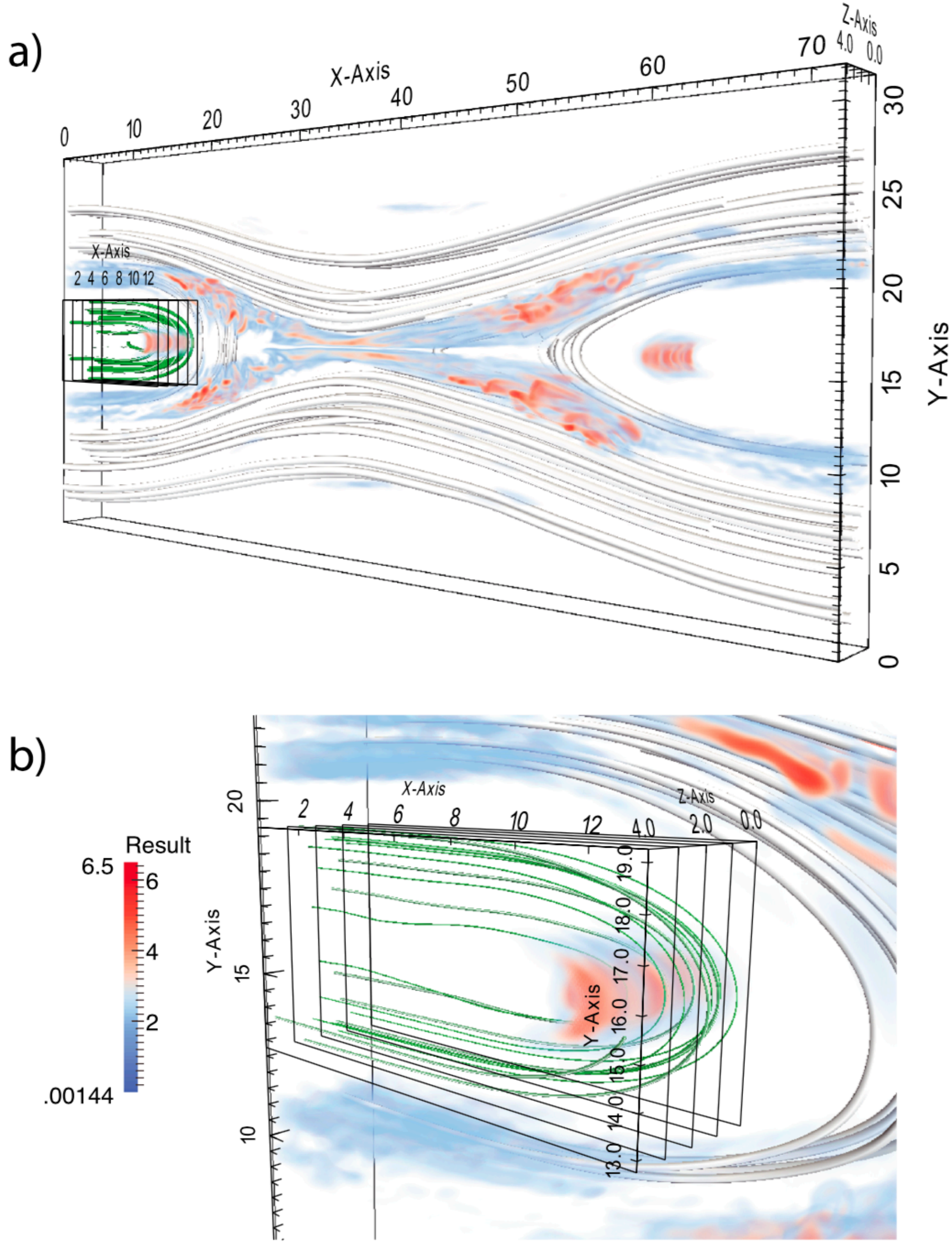
- Cluster separation $<d_i$
- Multi-SC and Single-SC estimate of **J**
- Cluster in NM, E&B sampled at 25 samp/s ~ f_{LH}
- **E*J** non-zero in a ~d_i scale layer in sat/Earth frame
- **E*J** very small in DF frame

Electric Structure of DFs



- Event from Khotyaintsev et al, 2011, Cluster separation ~several d_i
- Single-SC estimate of **J**
- Cluster in BM, E&B sampled at 450 samp/s >> f_{LH}
- C4 sees more complicated DF structure; current estimate is less reliable
- **E*****J** due to LHD waves is small

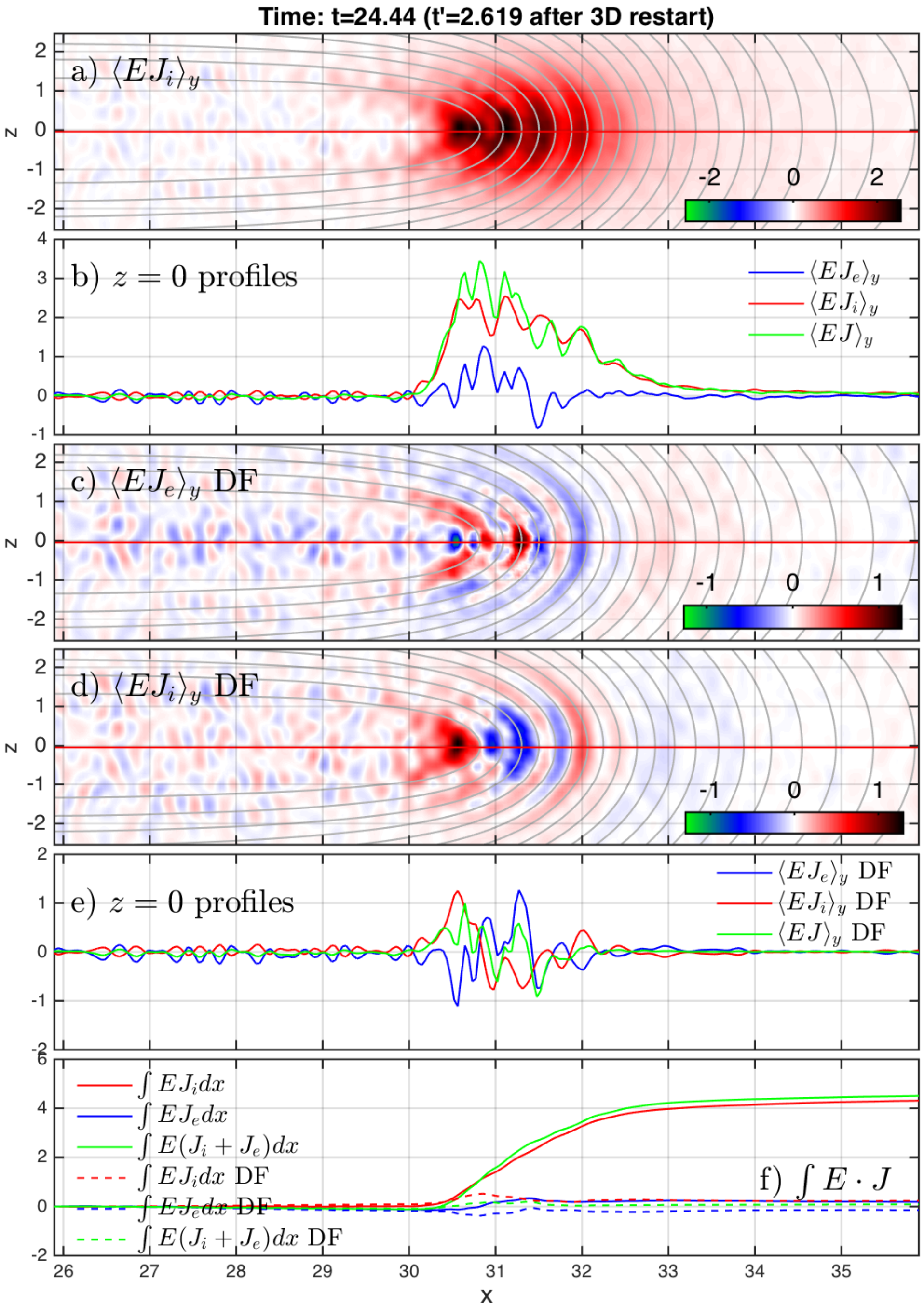
Electric Structure of DFs



3D PIC Simulation of reconnection using iPIC3D [Divin et al, 2015b]

LDHI dynamics is resolved

Electric Structure of DFs



- All quantities are averaged in Y
- In laboratory frame **E*J**$_i$ is dominant
- In DF frame **E*J**$_i$ and **E*J**$_e$ balance each other

Conclusions

- Major dissipation is in sat/Earth frame happening at $d_i=c/\omega_{pi}$ scales, Hall (normal) electric potential reflecting ions, Ey accelerating ions.
- Smaller scale dissipation is very small, and cannot be reliably determined from **E*J**.
- Additional “dissipation” channels: electron heating via LHDI, energetic electrons and ions, generation of whistlers and KAW (energy lost as a Poynting flux).