Ion Acceleration at Magnetotail Turbulent Plasma Jet Fronts

L. Richard, Yu. V. Khotyaintsev, D. B. Graham, A. Vaivads, R. Nikoukar, I. J. Cohen, D. L. Turner, S. A. Fuselier, C. T. Russell

louisr@irfu.se

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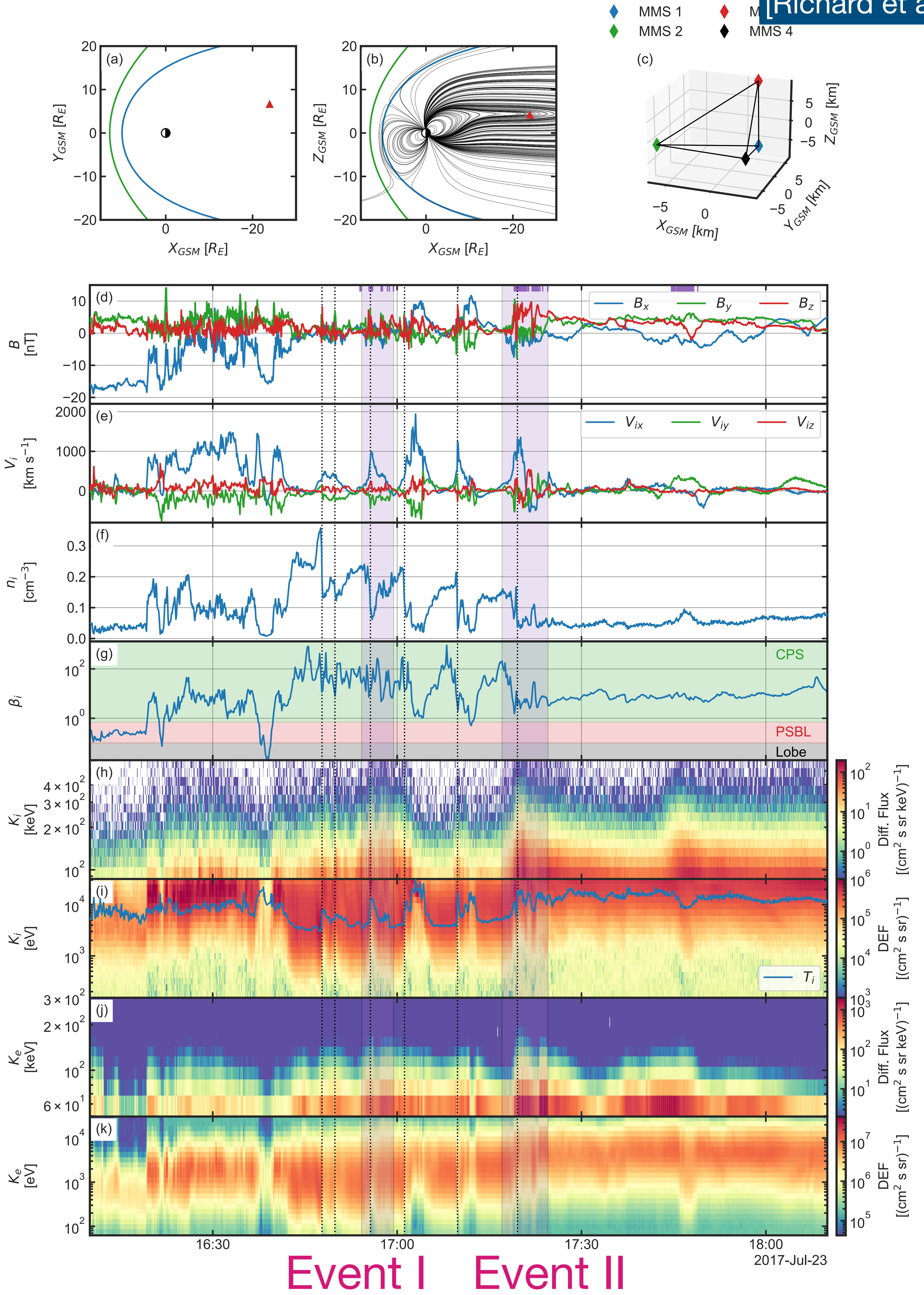
Overview

- Quasi-stationary jet followed by 5 bursty bulk flows (BBFs) during moderate substorm activity AE reaching 400 nT.
- MMS located in the plasma sheet with some excursions in the lobe (with possible signature of global North-South motion of the plasma sheet.)
- Multiple signatures of ion/electron energisation associated with dipolarization fronts (DFs) at the leading edge of the BBFs.
- Focus on two intervals with ion (FEEPS) flux at 200 keV above the 95%ile or

$$J^{200} > \bar{J}^{200} + 2\sigma_{J^{200}} = \bar{J}^{200} + 2\sqrt{\frac{\sum_{i=1}^{n}\left(J_i^{200} - \bar{J}^{200}\right)}{n-1}}$$

[Richard et al., submitted]



Questions

What is behind the ion energy enhancements?

- What is the ion composition?

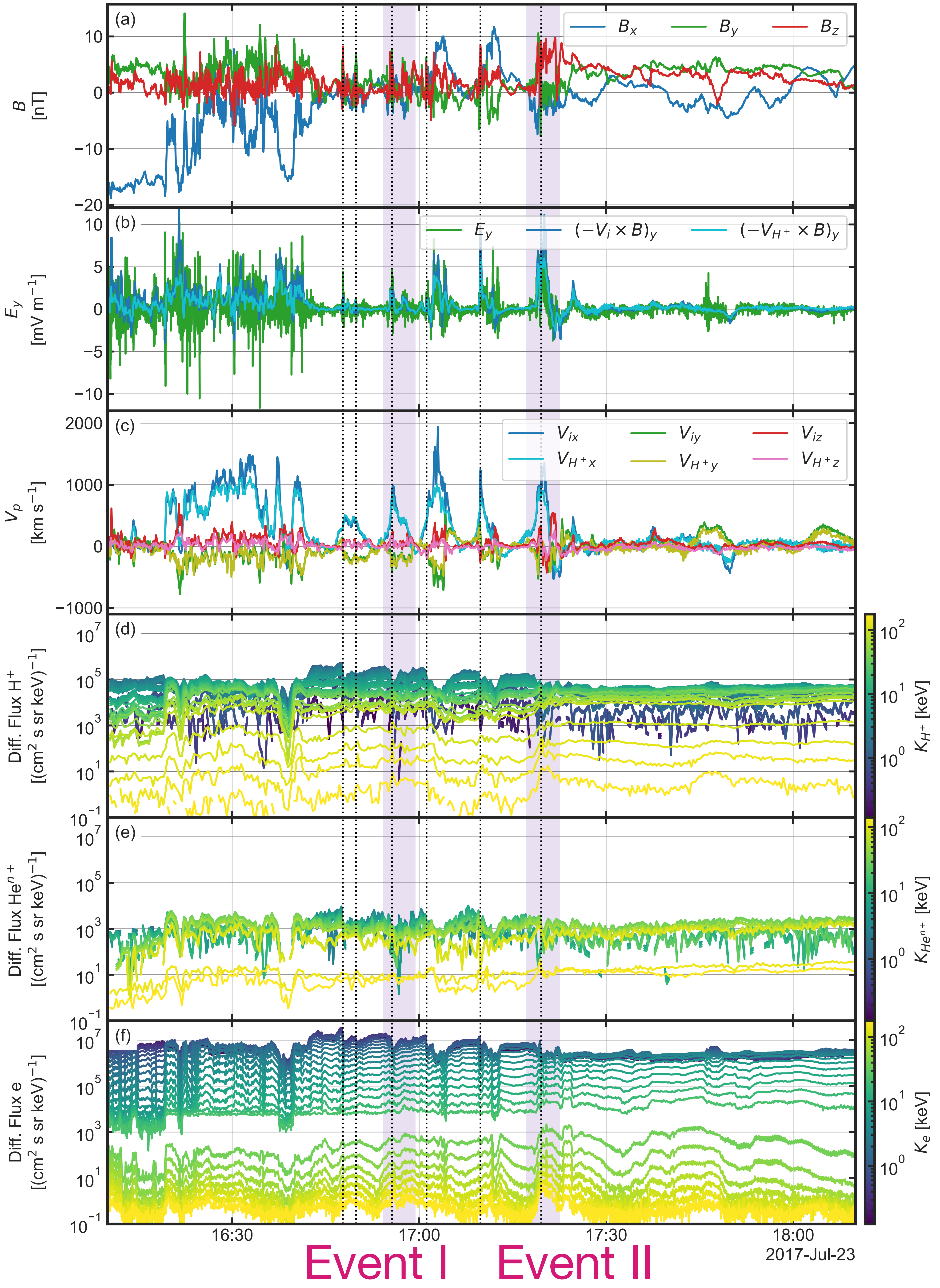
- How does the acceleration differ for different ion species?

- What is the acceleration mechanism? What is the scale of the acceleration region with respect to the ion?

- What are the differences/similarities between the acceleration in the small scale structure and that of the large scale?

Ion Composition

- H^+, He^{n+} and e^- fluxes are well correlated.
- No He^+ observed at thermal energies (HPCA) thermal helium flux dominated by He^{2+} flux.
- **Flux dominated by:**
  - **Electrons at energies < 10 keV (Runov+2015)**
  - **Protons at energies 10 keV < K < 150 keV**
  - **Helium ions at energies > 150 keV (Cohen+2017)**
- **The correlation technique indicates that the helium is in the He^{2+} charge state (i.e. of solar wind origin).**

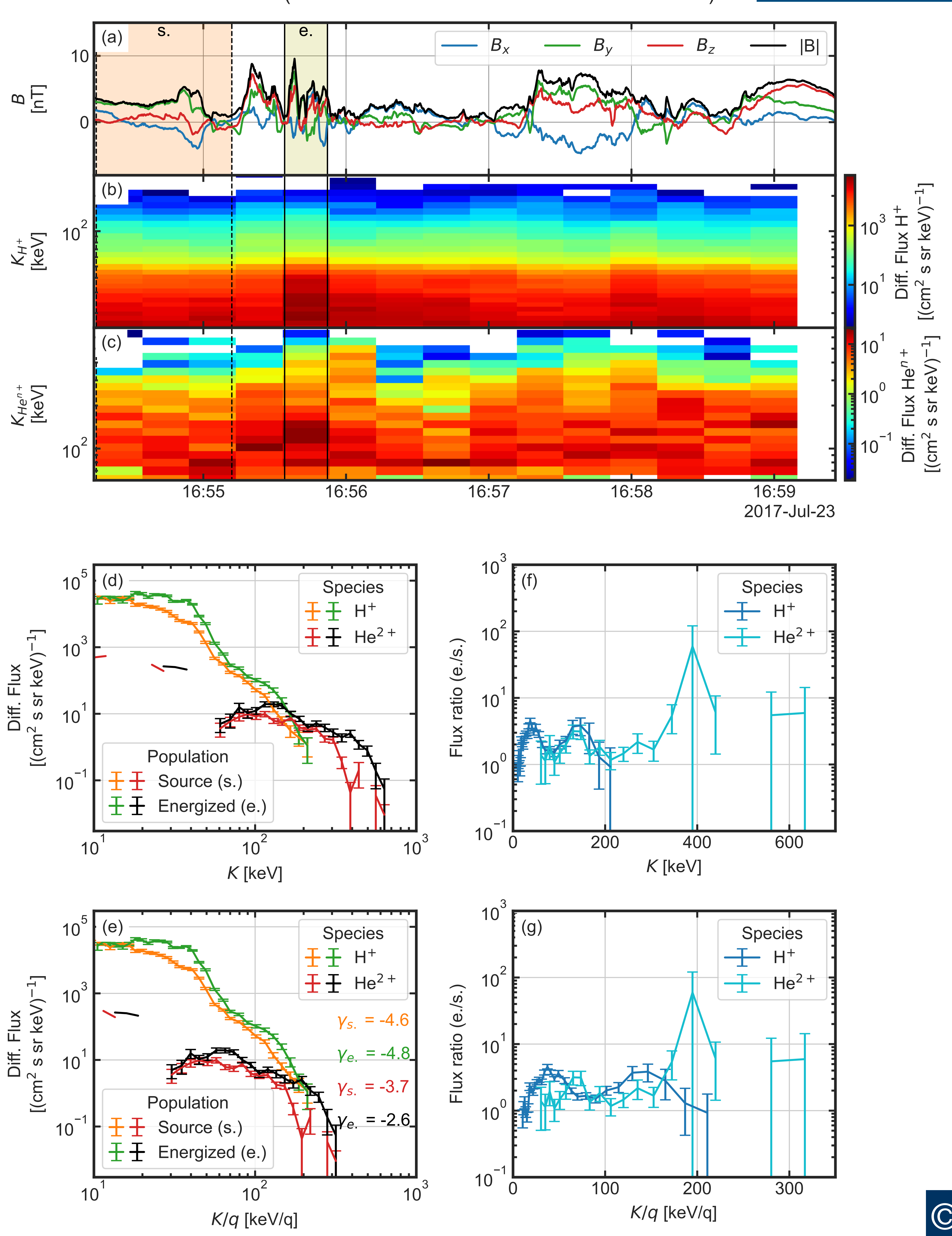


Event I

Ion Composition

- Alpha particles (He^{2+}) flux dominates at energies > 150 keV (Cohen+2017).
- Verification of the assumption:
  - Flux ratio is not well ordered by K/q (i.e different species with the same energy per charge will be energised differently.)
  - On local scales the assumption of q-dependent energisation is not valid.
- **Non q-dependent energisation indicates non-adiabatic energisation consistent with electromagnetic fluctuations on ion time scales.**

[Richard et al., submitted]

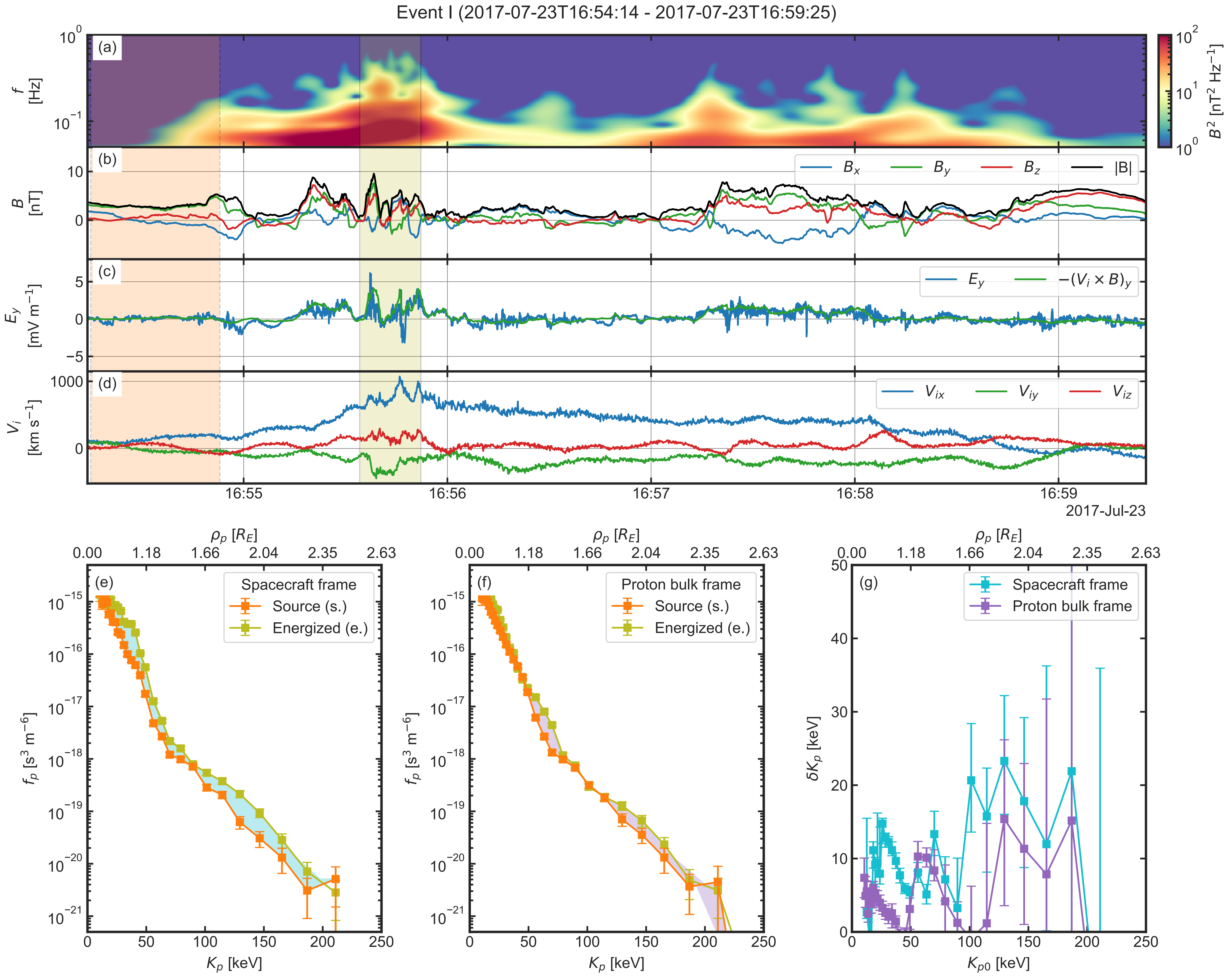


[Richard et al., submitted]

Event I

Acceleration Mechanism

- Two different behaviour above and below $K_p = 50$ keV $\Leftrightarrow \rho_p \sim 1.18\ R_E$
- Low energy:
  - **Energy enhancement $\sim K_{bulk}$ indicates contribution of the bulk flow to the supra thermal ~10 keV protons.**
- High energy (50 keV < K < 100 keV):
  - **Localized energy enhancement of protons with gyro radiii of the order of the Earth-tail scale of the structure (~1.18-1.66 RE), suggesting acceleration by resonant interaction of the protons with the DF (Artemyev+2012, Ukhorskiy+2013).**
  - Estimated “hidden” dawn-dusk scale of the electric field region ~2 RE consistent with the azimuthal scale of the DFB (Sergeev+1996, Liu+2015).
- High energy (> 100 keV):
  - No conclusions because of the low counts (i.e large error $\delta f/f = 1/\sqrt{n}$).

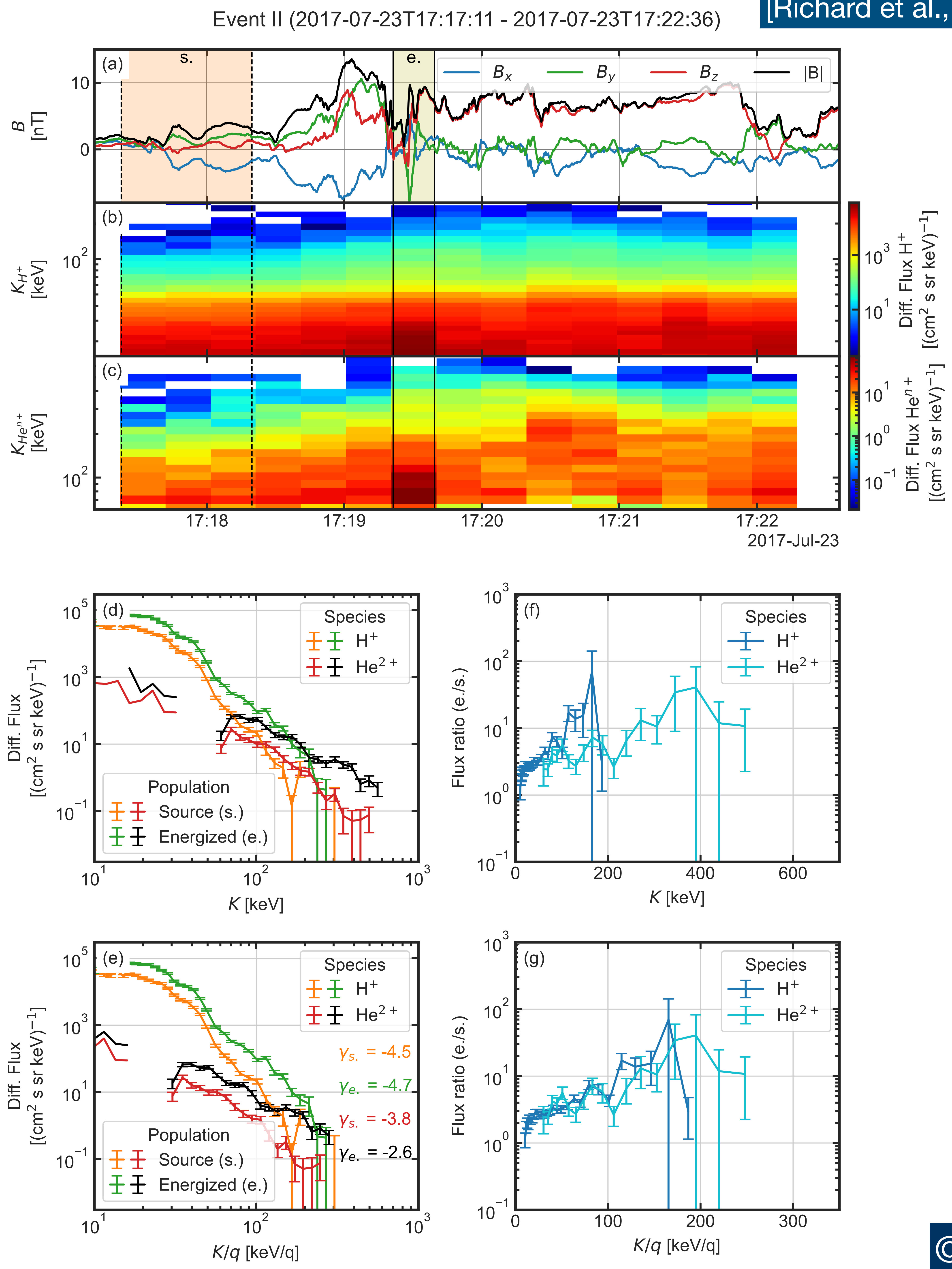


Event II

Ion Composition

- Alpha particles (He^{2+}) flux dominates at energies > 150 keV (Cohen+2017).
- Verification of the assumption:
    - Flux ratio is well ordered by K/q (i.e different species with the same energy per charge will be energised similarly.)
    - On scales larger than the ion (temporal) scales the q-dependent energisation assumption is valid.
- **q-dependent energisation does not indicates adiabatic energisation (Catapano+2015, Ukhorskiy+2017).**

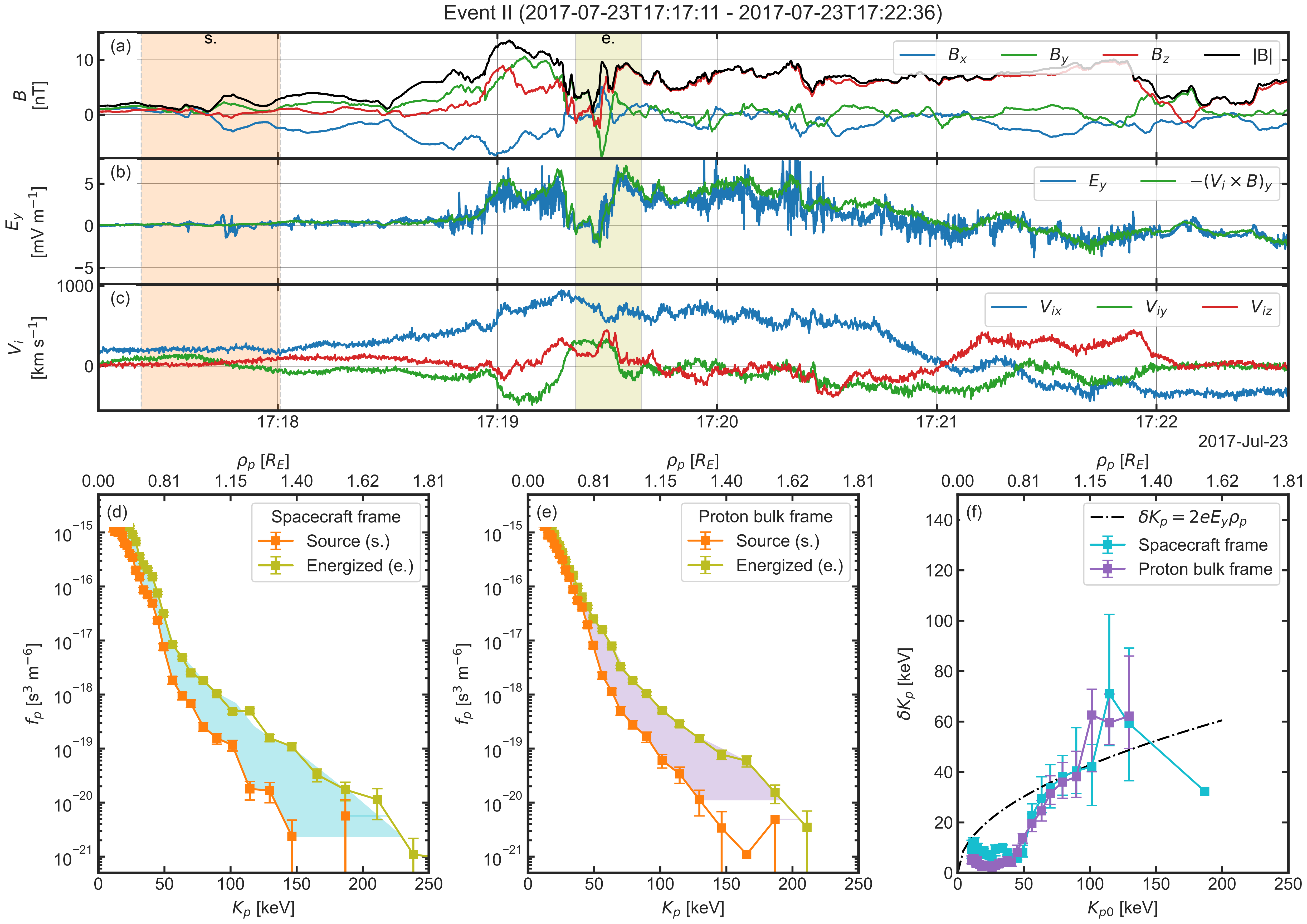
[Richard et al., submitted]



Event II

Acceleration Mechanism

- Two different behaviour above and below $K_p = 50$ keV $\Leftrightarrow \rho_p = 0.81\ R_E$
- Low energy:
  - **Energy enhancement $\sim K_{bulk}$ indicates contribution of the bulk flow to the supra thermal < 50 keV protons.**
- High energy:
  - **Energy gain increasing with initial gyroradii consistent with acceleration by the electric field in a spatially limited electric field structure (Artemyev+2015).**
  - Disagreement at energies 50 keV < K < 70 keV due to more complicated orbits (e.g. part of the downward orbit in the electric field region.)
  - **Energy increase of the order of the initial energy i.e. non-adiabatic energization.**

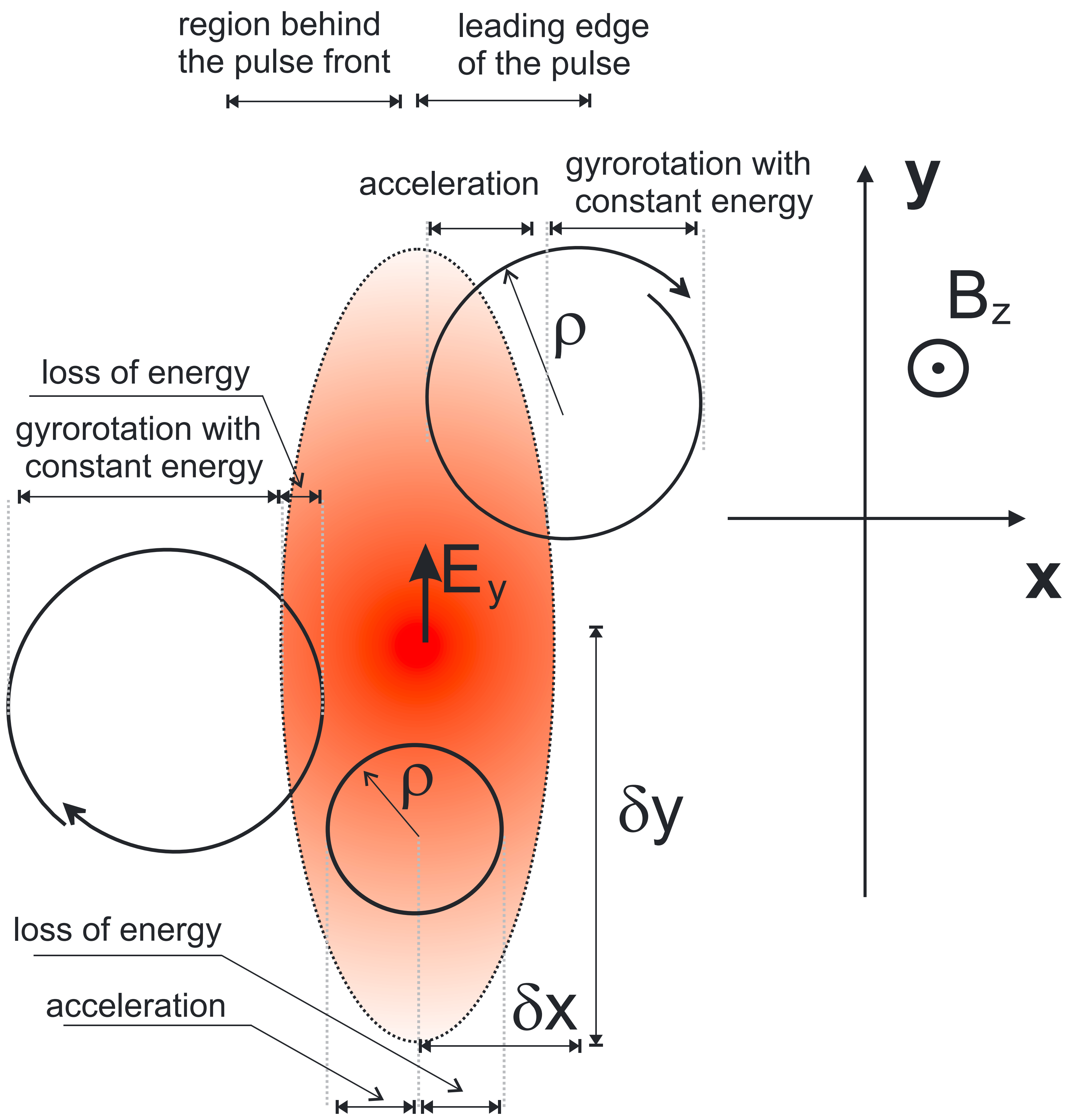


Acceleration by Localised Spatially Limited Electric Field Pulses

Artemyev et al. 2015

- Particles with $\rho < \min(\delta x, \delta y)$ have no net energy gain.
- Particles with $\rho > \min(\delta x, \delta y)$ gain/loose energy if they interact with the localised spatially limited electric field pulse during the dawnward/duskward part of the orbit.
- **The acceleration results from a finite gyroradius effect.**
- For particle with $\rho \sim \min(\delta x, \delta y)$ the energy gain for one gyro period is $\delta K \sim 2qE_y\rho$ and for particles with $\rho \gg \delta y$ the energy gain is $\delta K \sim \delta y E_y$

[Artemyev+2015]



Conclusions

- What is the ion composition?
  - **Protons & heavier ions of solar wind origin (He2+).**
- How the acceleration differs for different ion species?
  - **On scales with changes in the electromagnetic fields shorter than the ion scales, not (only?) q-dependent.**
- What is the acceleration mechanism? What is the scale of the acceleration region with respect to the ion?
  - **Protons with gyroradii smaller than the scale of the magnetic field structures are ExB drifting.**
  - **For electromagnetic fluctuations on the proton time scale, protons with energy of the order of the structure scale are accelerated by non-adiabatic resonant interaction with the DF.**
  - **For electromagnetic fluctuation on time scales larger than the proton scales, proton are accelerated in the localised spatially limited electric field structure.**
- What are the differences/similarities between the acceleration in the small scale structure and that of the large scale?
  - **In both cases the protons with energy of the order of the scale of the structure are non-adiabatically energised.**