Magnetic reconnection as a mechanism to produce multiple near-thermal proton populations and beams locally in the solar wind

B. Lavraud, R. Kieokaew, N. Fargette, P. Louarn, A. Fedorov, N. André, G. Fruit, V. Génot, V. Réville, A. P. Rouillard, I. Plotnikov, E. Penou, A. Barthe, L. Prech, C. J. Owen, R. Bruno, F. Allegrini, M. Berthomier, D. Kataria, S. Livi, J. M. Raines, R. D'Amicis, J. P. Eastwood, C. Froment, R. Laker, M. Maksimovic, S. Perri, D. Perrone, T. D. Phan, D. Stansby, J. Stawarz, S. Toledo-Redondo, A. Vaivads, D. Verscharen, I. Zouganelis, V. Angelini, V. Evans, T. S. Horbury, and H. O'Brien

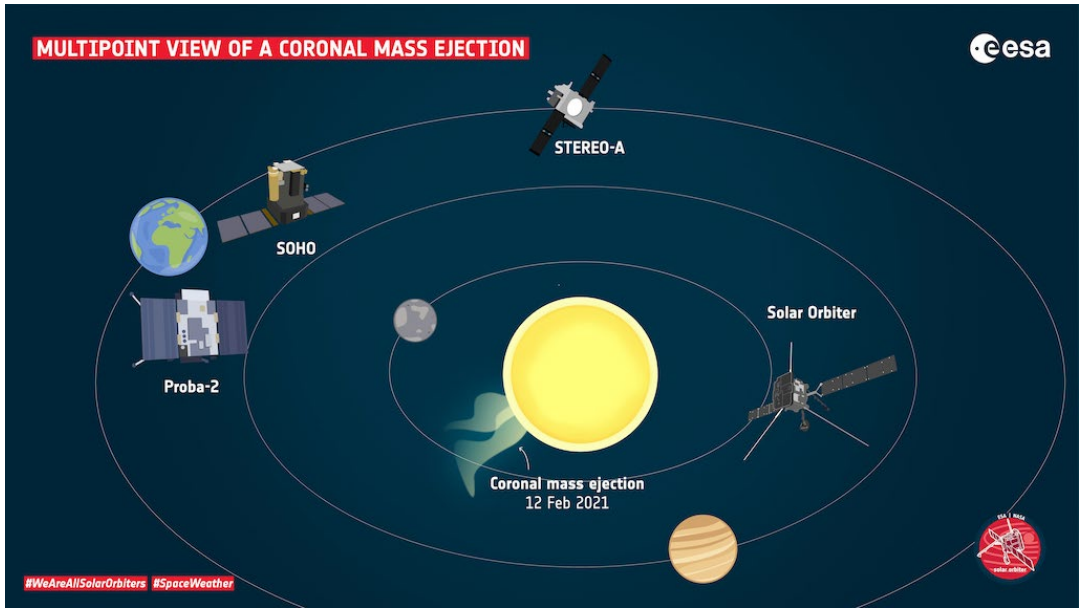
RPW-SWA workshop, Meudon, Dec. 2021

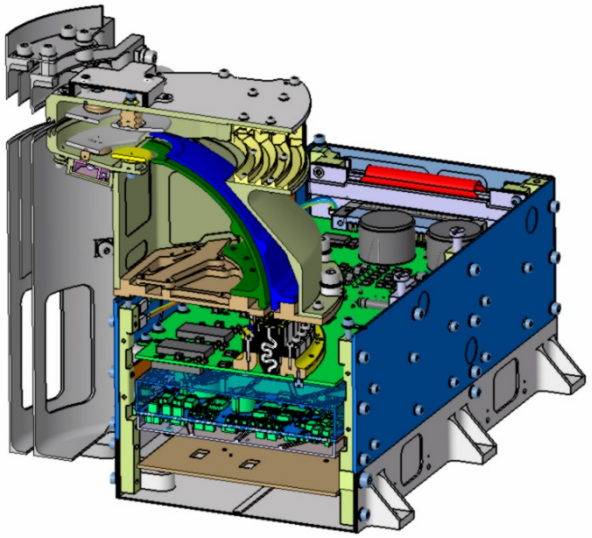
Outline

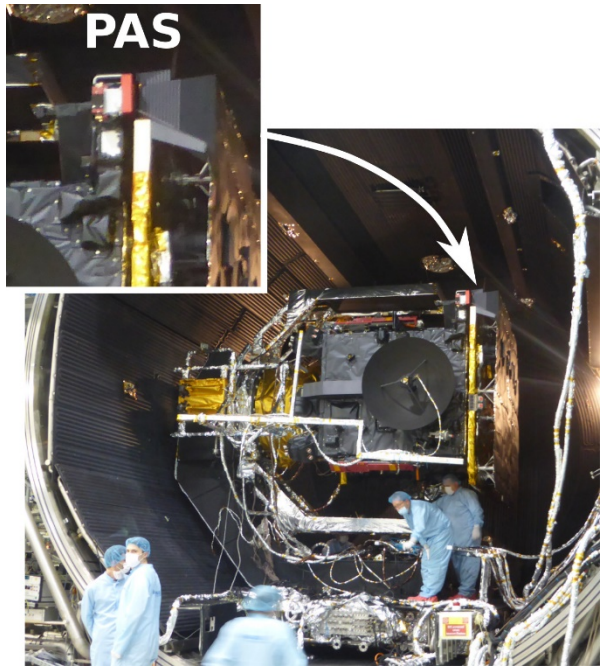
- Solar Orbiter and the Proton Alpha Sensor (PAS)
- Proposed origins of proton beams in the solar wind
- Counter-streaming proton beams and reconnection
- Solar Orbiter observation of multiple proton beams
- Conclusions

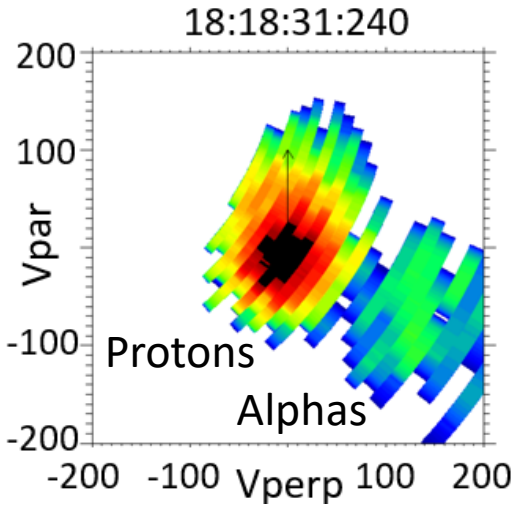
Solar Orbiter and the Proton Alpha Sensor (PAS)

- Solar Orbiter
  Sun-inner heliosphere connection
- Proton and Alpha Sensor
  designed & built at IRAP, Toulouse
  (with Prague and UCL)









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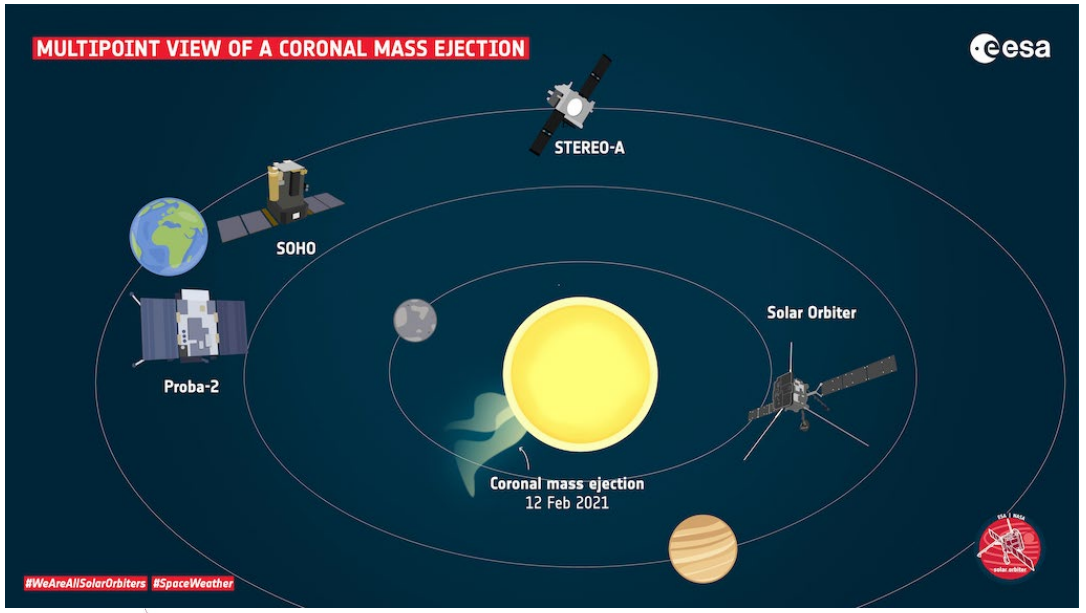
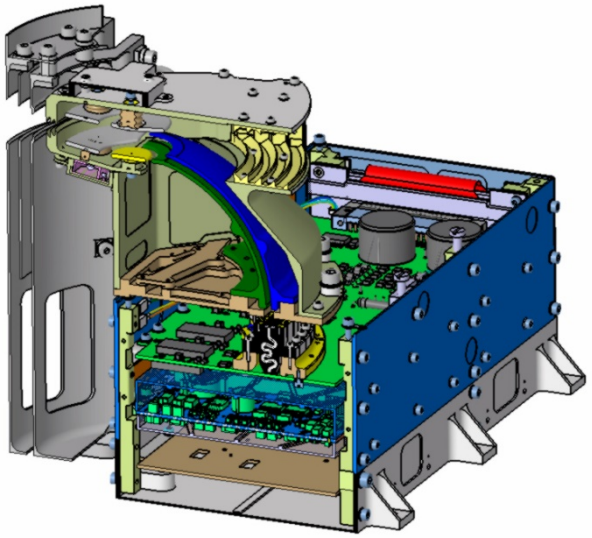
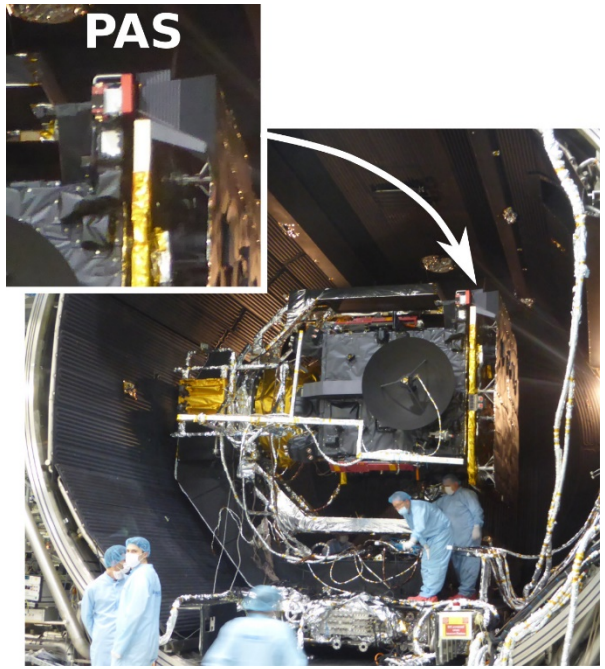
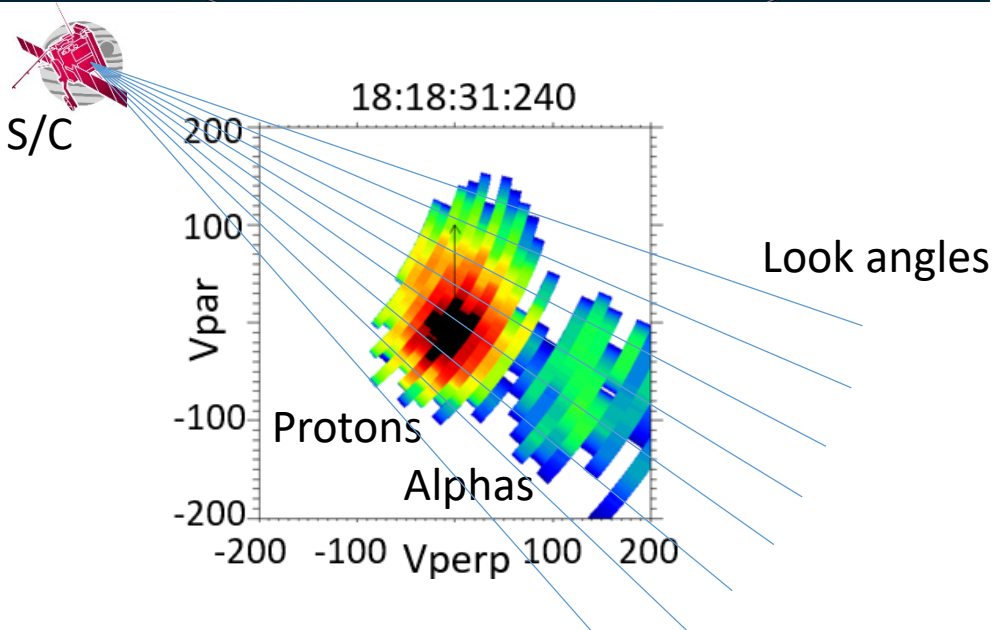


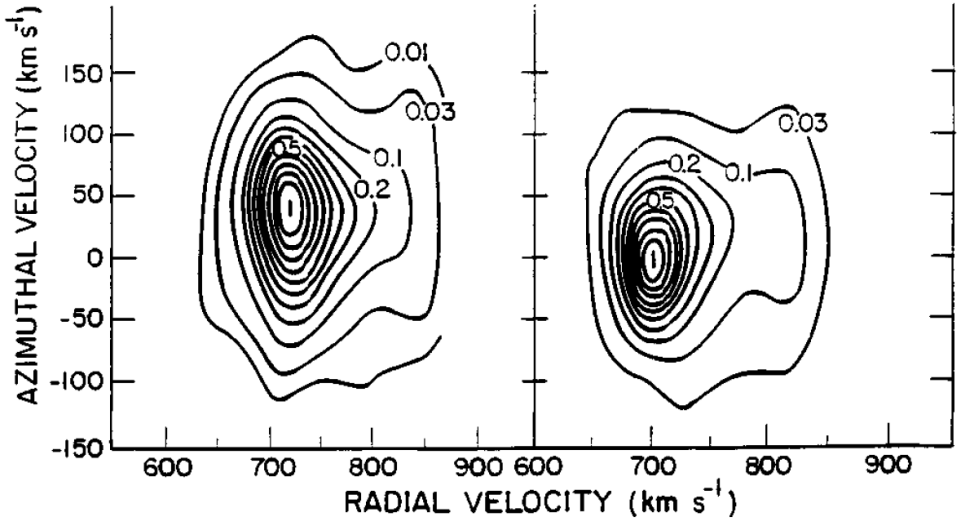




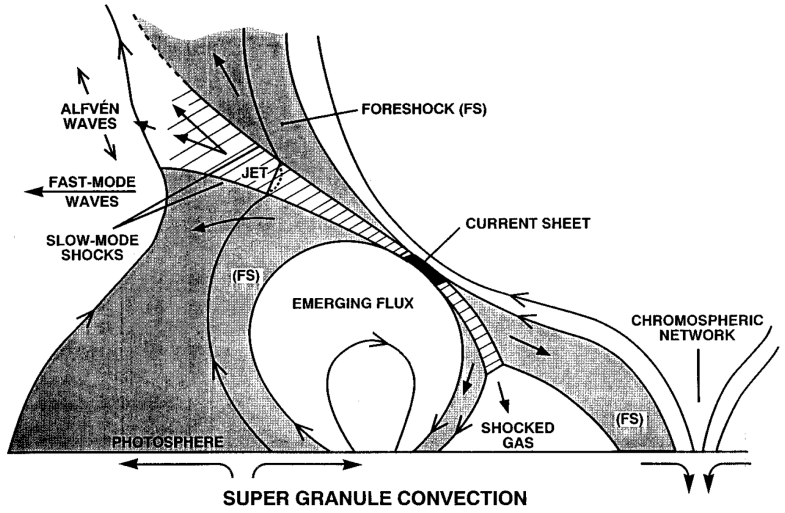


Early observation of near-thermal proton beams in solar wind

- Beams observed nearly 70% of the time (*Alterman*, 2019)
- Mechanism initially proposed as interchange reconnection in low corona (*Feldman et al*. 1974, 1976, 1996)



(*Feldman et al*. 1976 & 1996)



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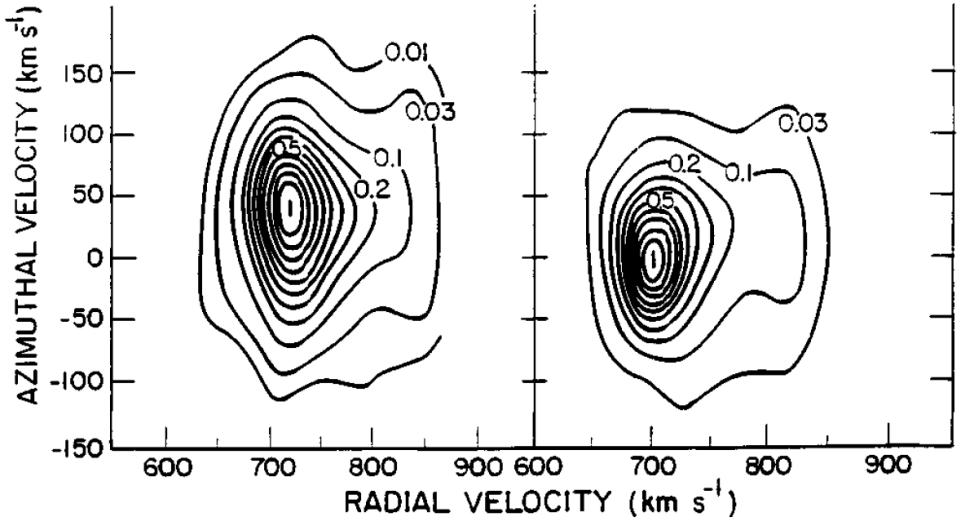

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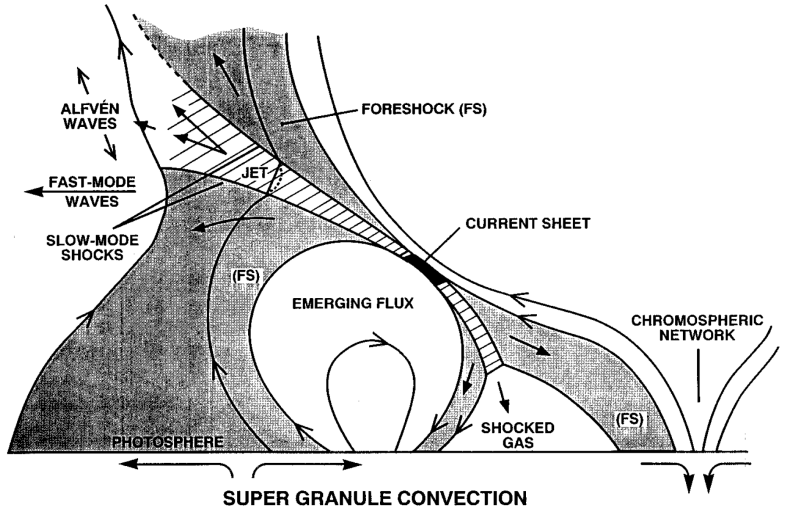

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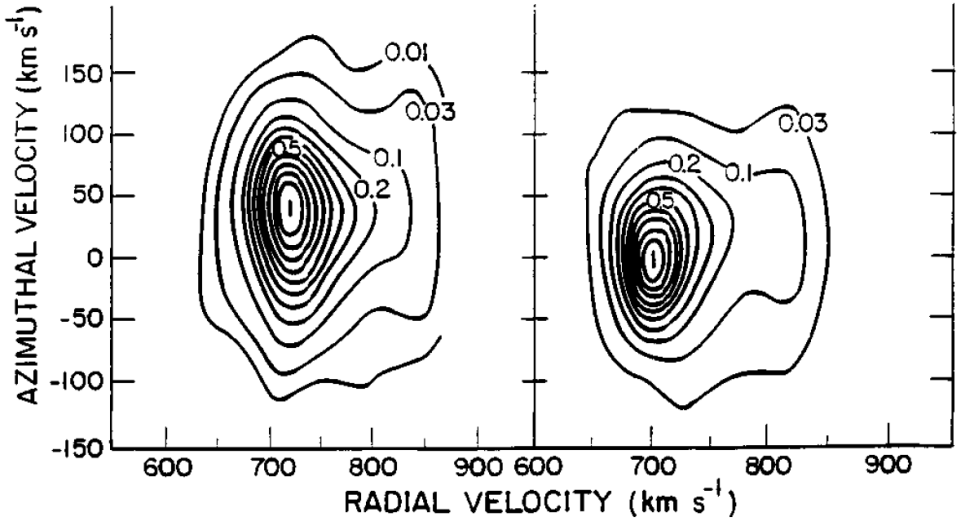
- But reconnection in solar wind not considered (only *Chen et al.* (2016) mentions it)



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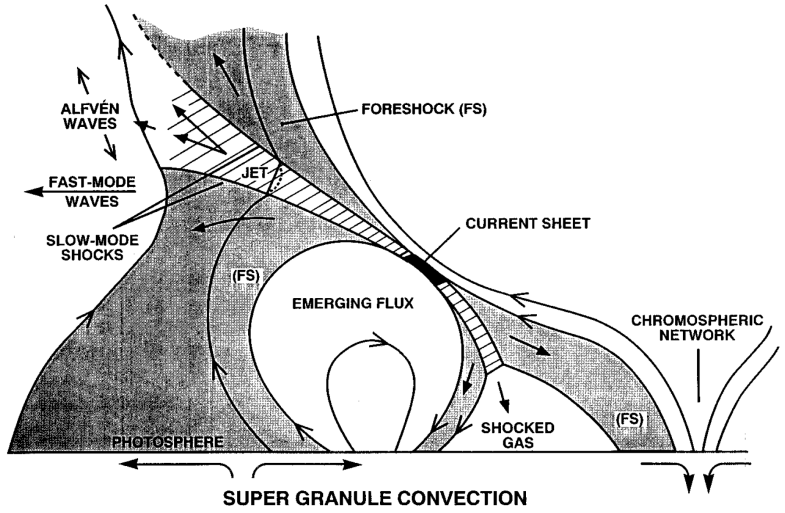
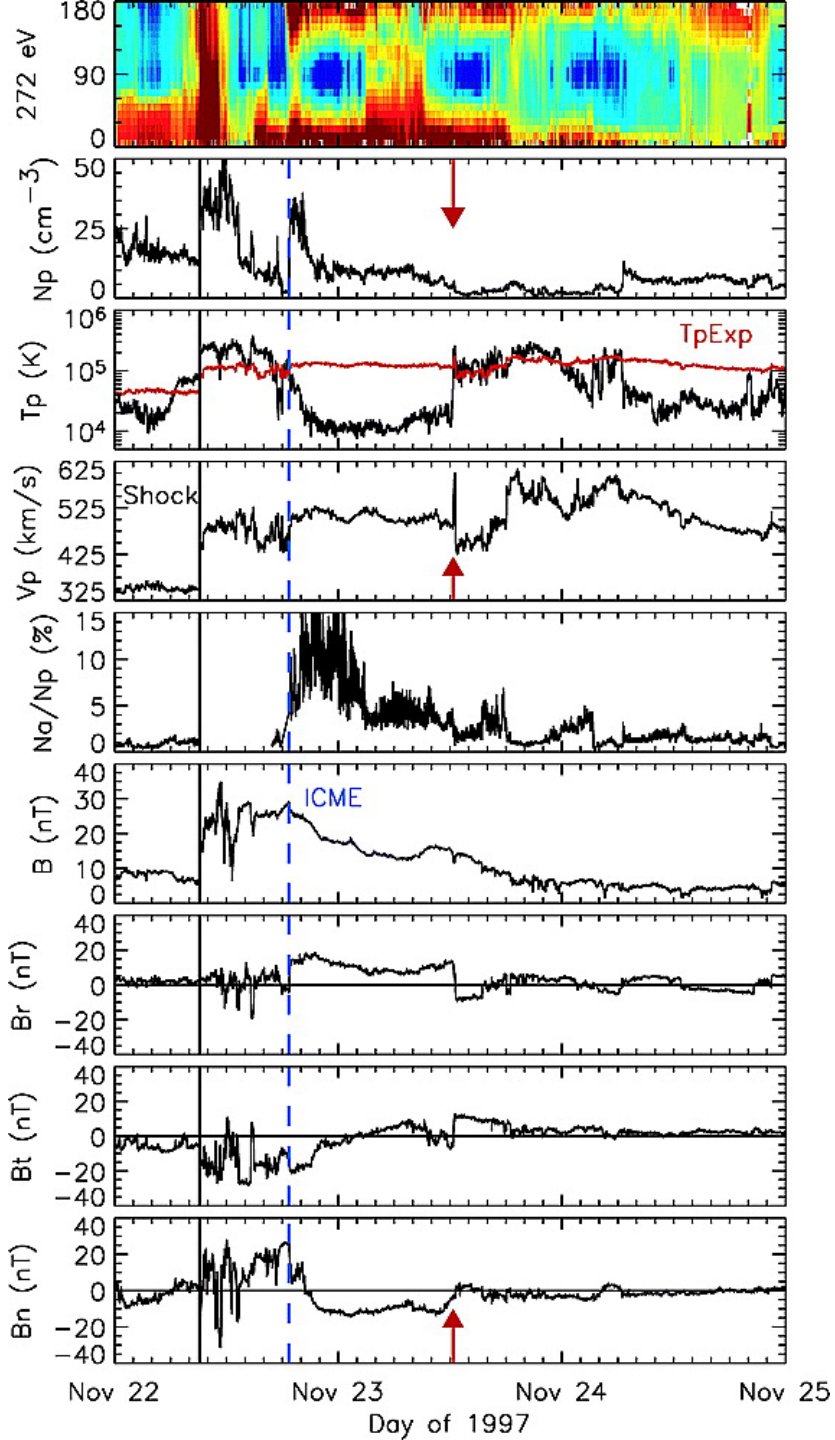


Early observation of magnetic reconnection in solar wind

First reconnection observed inside a CME

- High Alfvén speed → large jet

Gosling et al. (2005)



Early observation of magnetic reconnection in solar wind

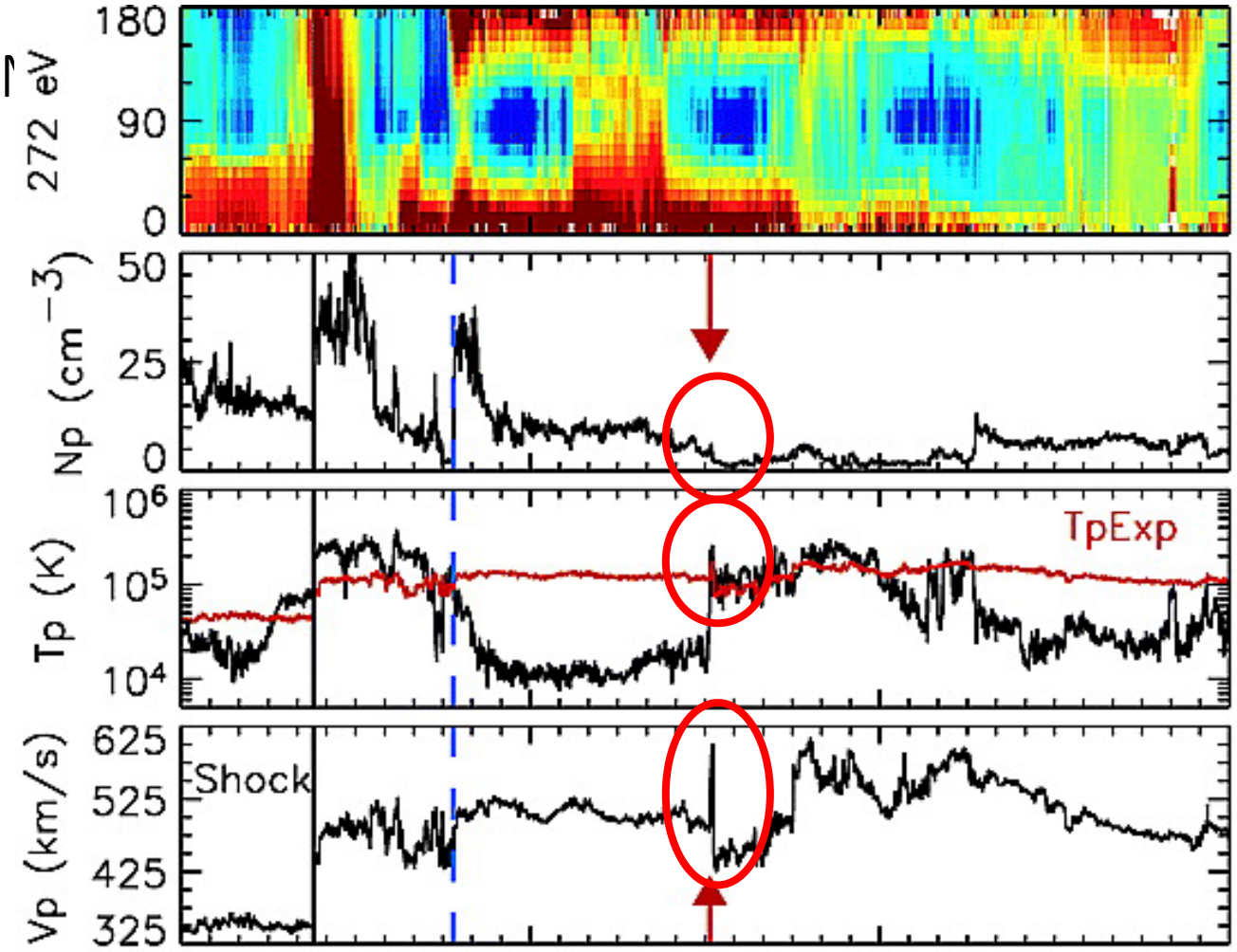
First reconnection observed inside a CI

- High Alfvén speed → large jet

Typical signatures:

- Density increase
- Temperature increase
- Velocity increase OR decrease

Gosling et al. (2005)



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Signatures **specific** to reconnection:

- Bifurcated current sheets
- Alfvénic plasma flows with opposite correlation at each current sheet

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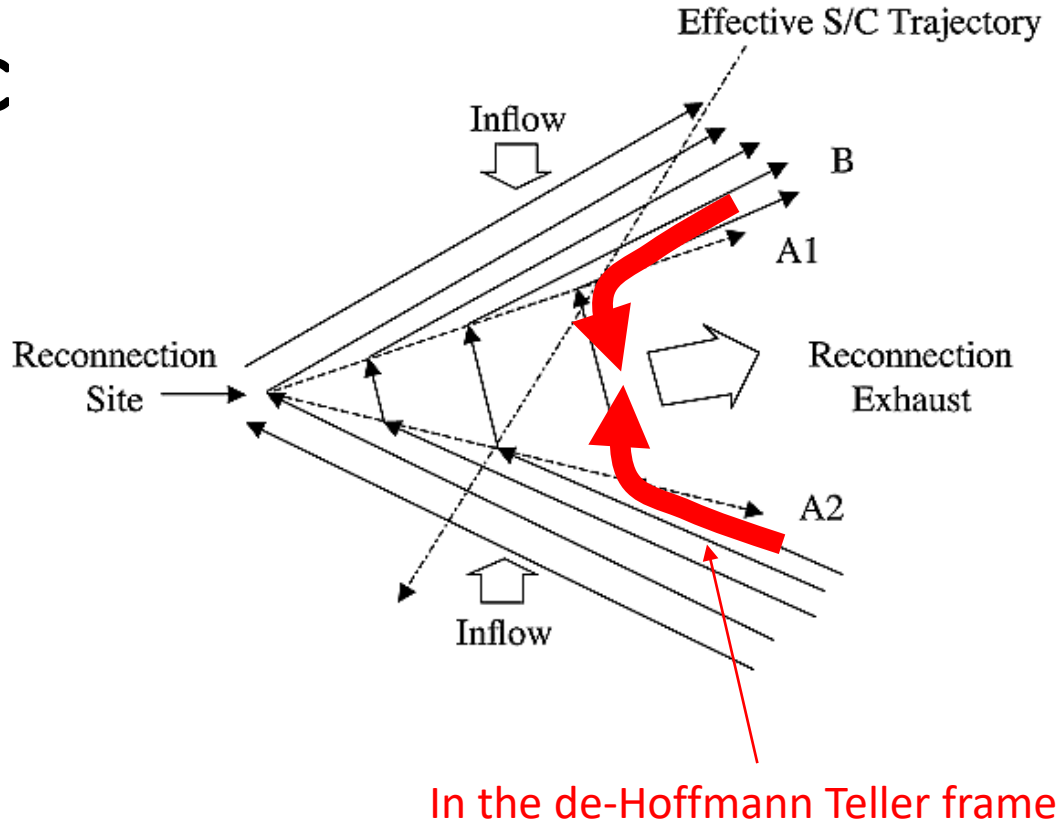

Early observation of magnetic reconnection in solar wind

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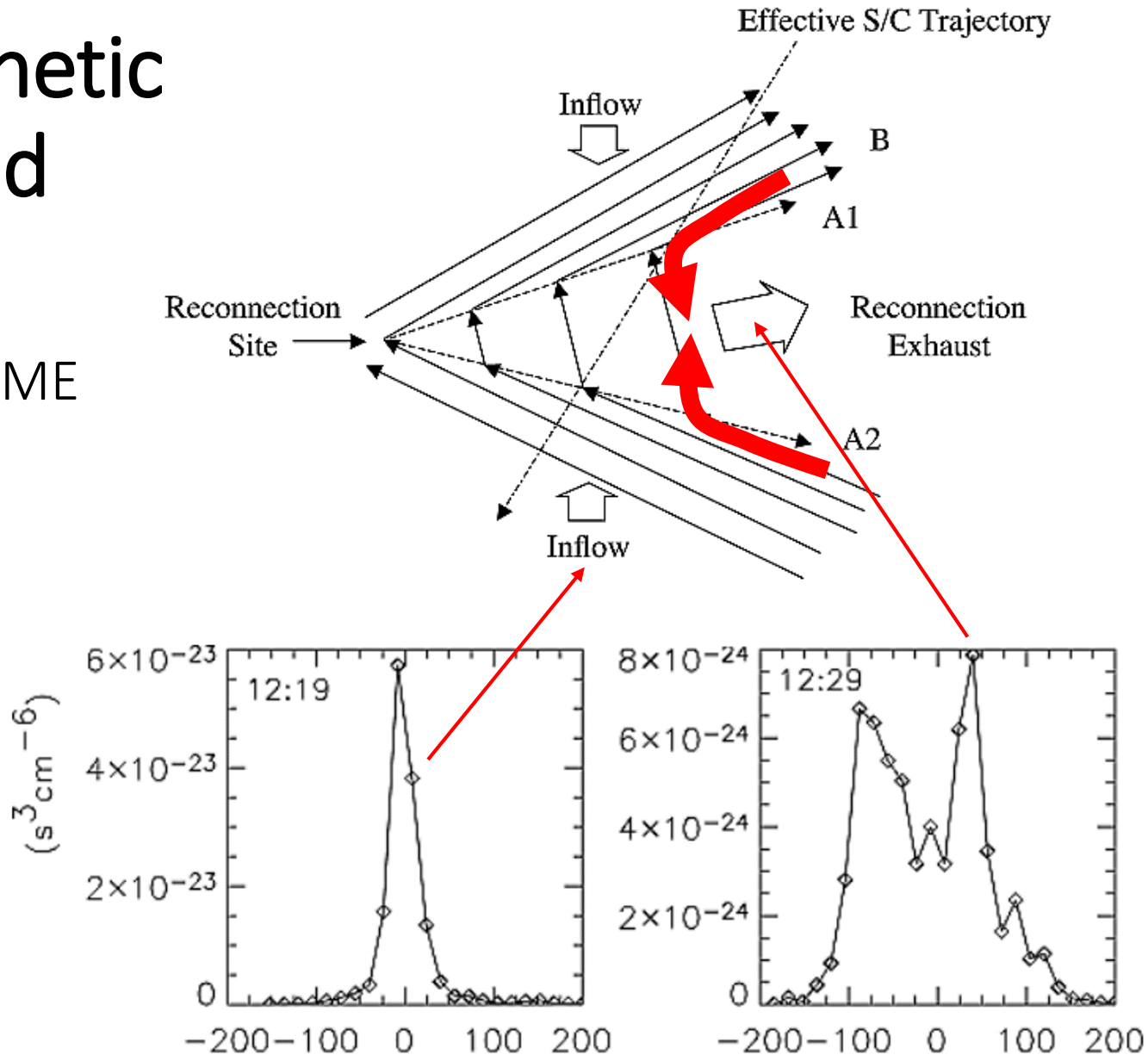
Signatures **specific** to reconnection:

- Bifurcated current sheets
- Alfvénic plasma flows with opposite correlation at each current sheet
- Interpenetrating proton beam

Gosling et al. (2005)

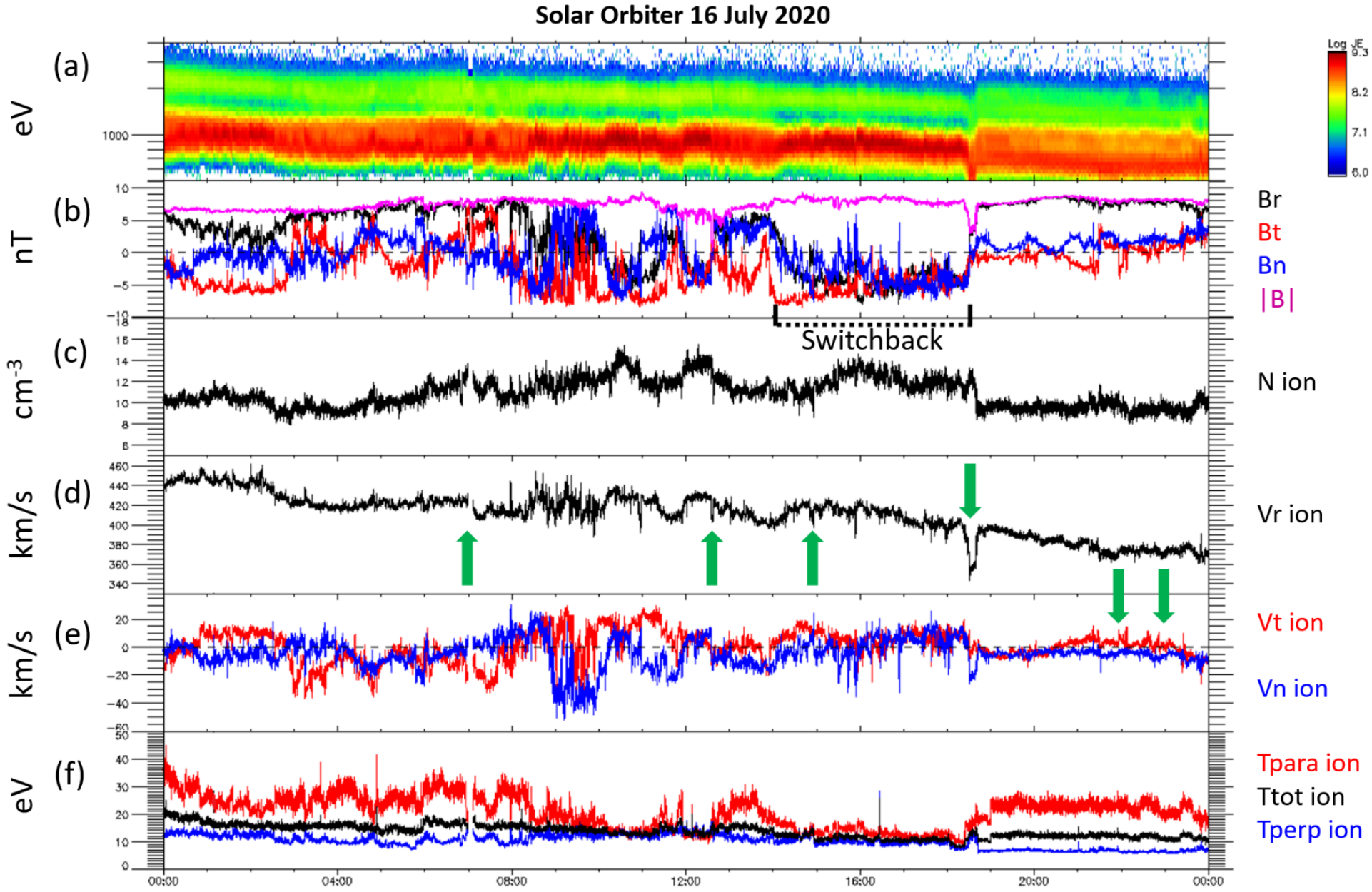


1 day of Solar Orbiter solar wind studied

- Slow Alfvénic wind

D'Amicis et al. (2021)

- Several switchbacks
- 6 reconnection jets



Example reconnection in slow Alfvénic wind

- Reconnection exhausts confirmed by:

→ Deep in magnetic field

→ Bifurcated current sheet (CS)

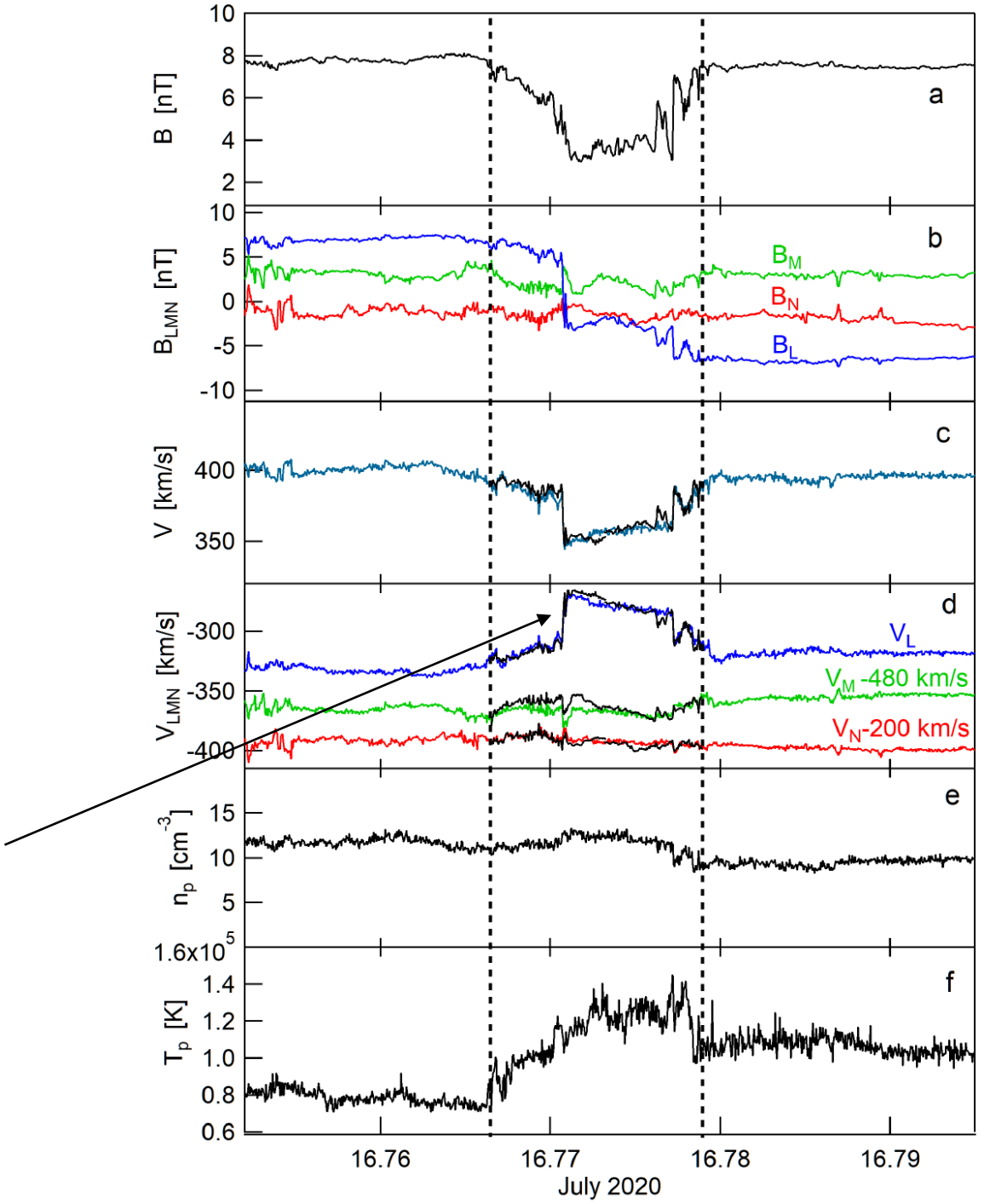
→ Slight density enhancement

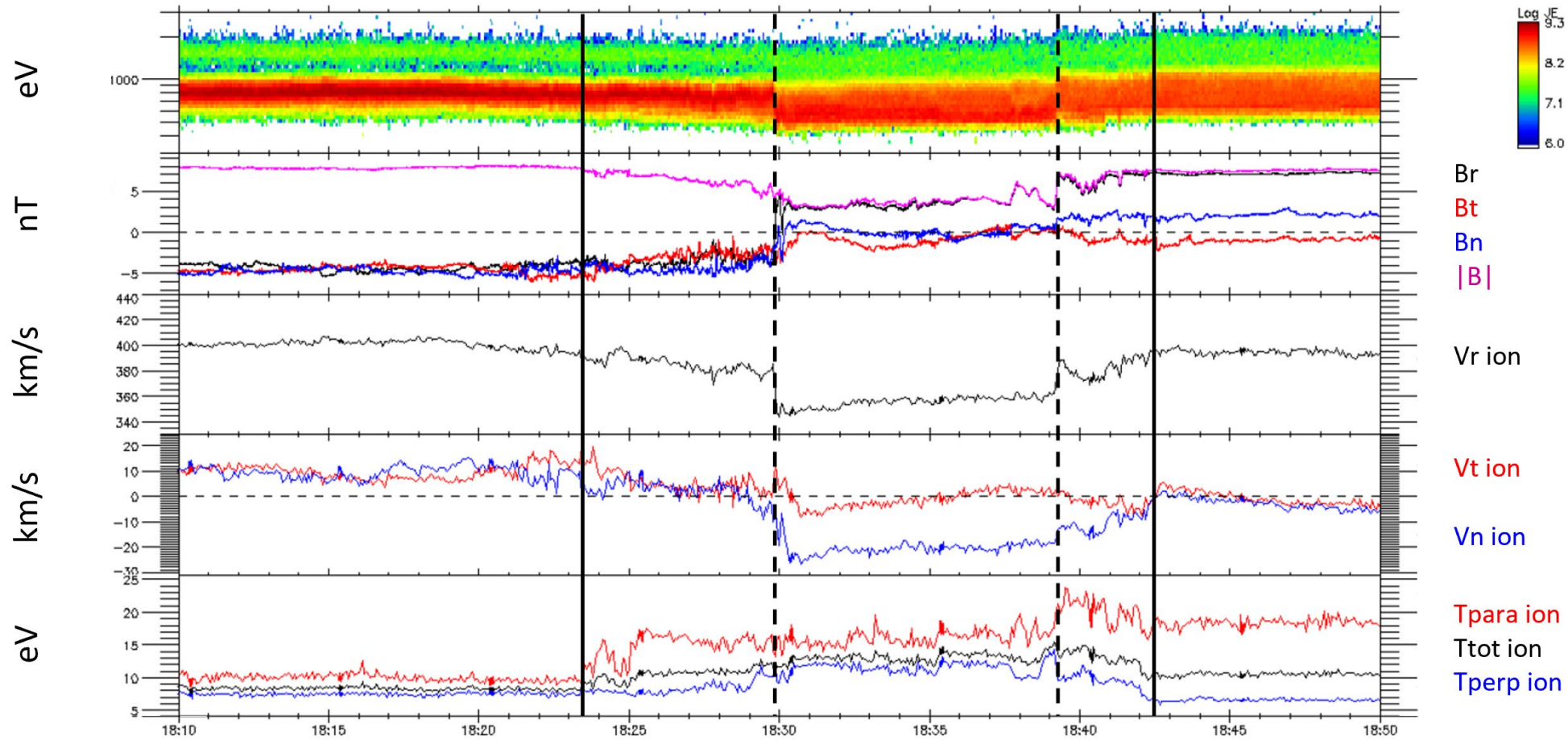
→ Temperature enhancement

→ Walén relation (Alfvénic at both CS)

D'Amicis et al. (2021)

Lavraud et al. (2021)

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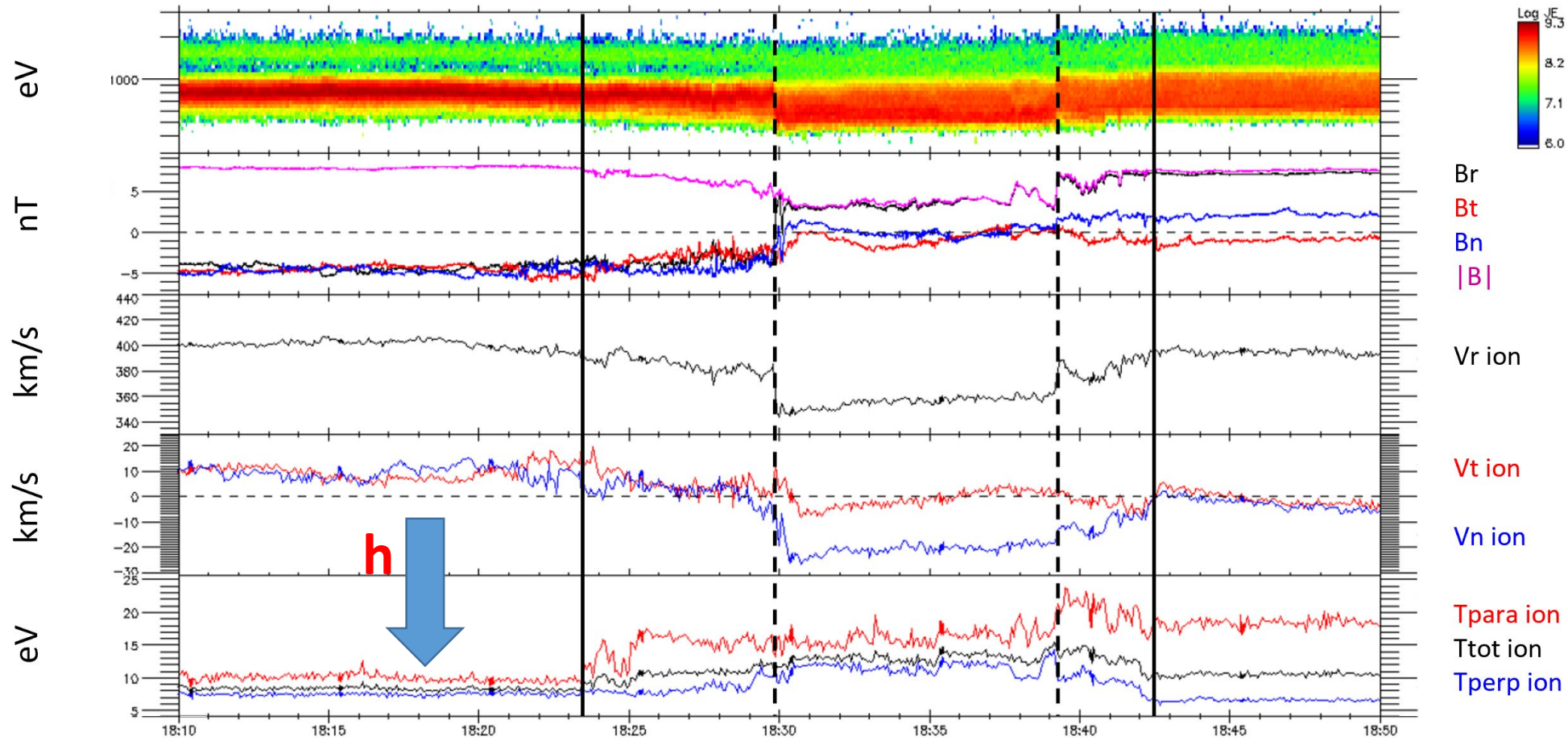
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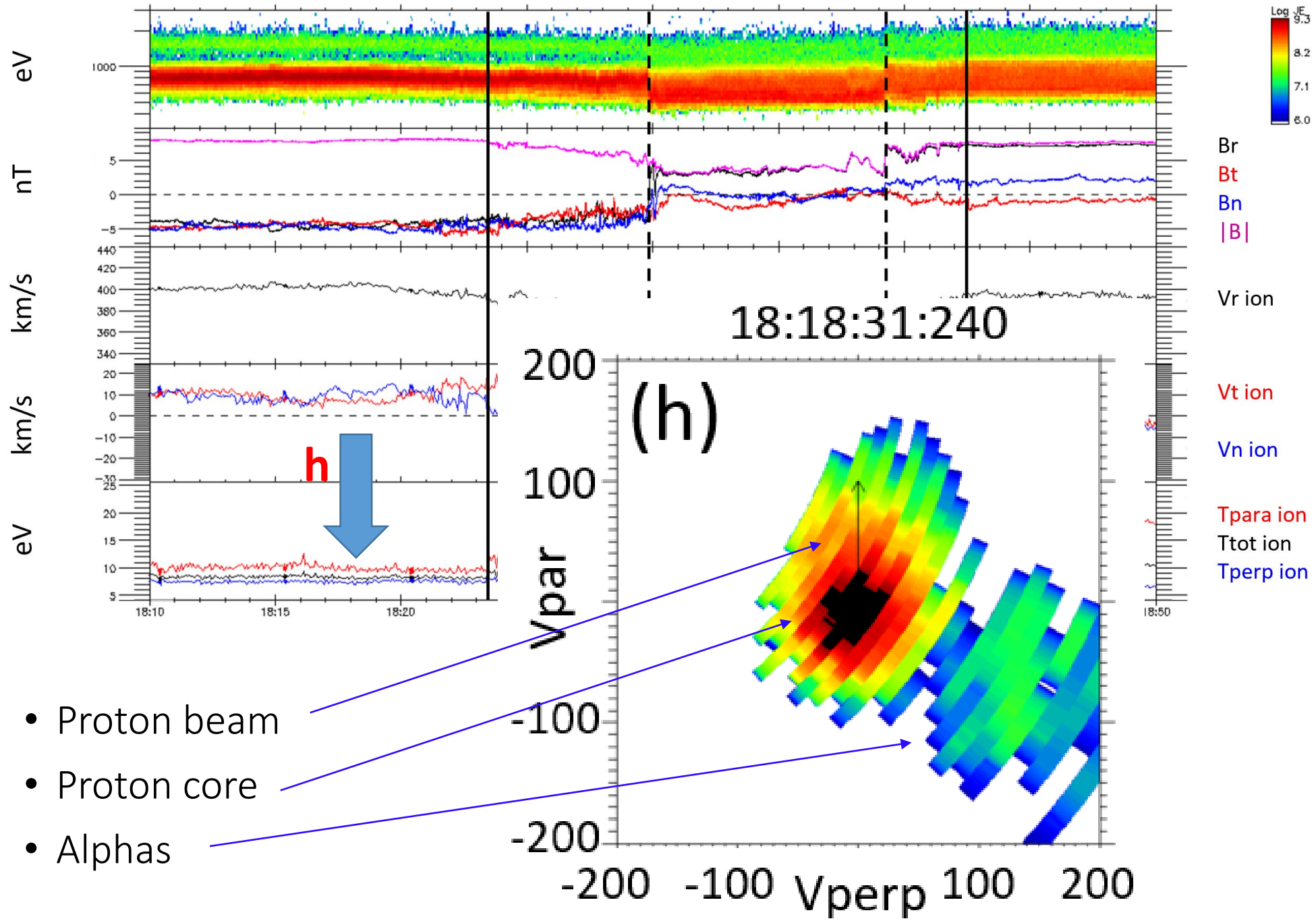
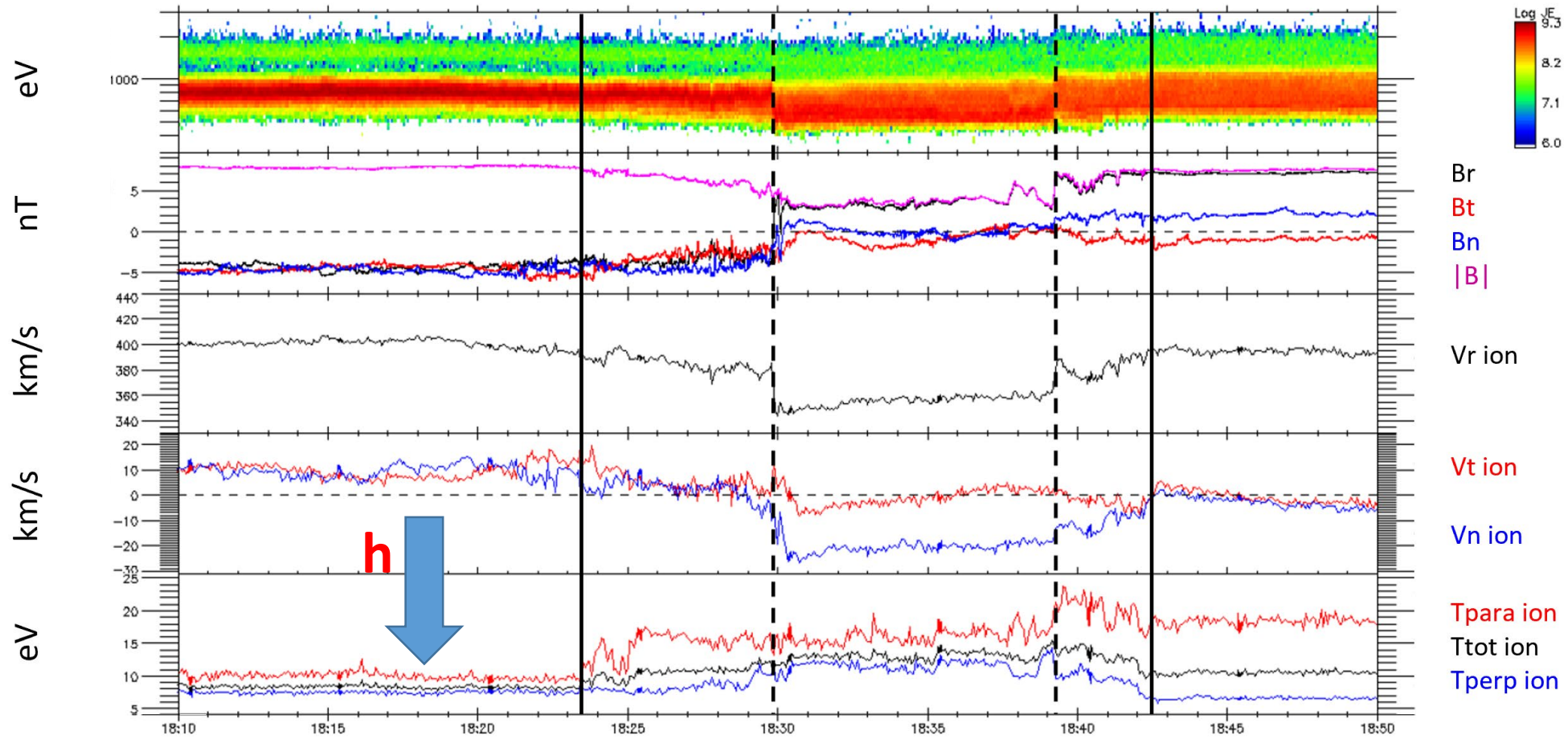


- Proton beam
- Proton core
- Alphas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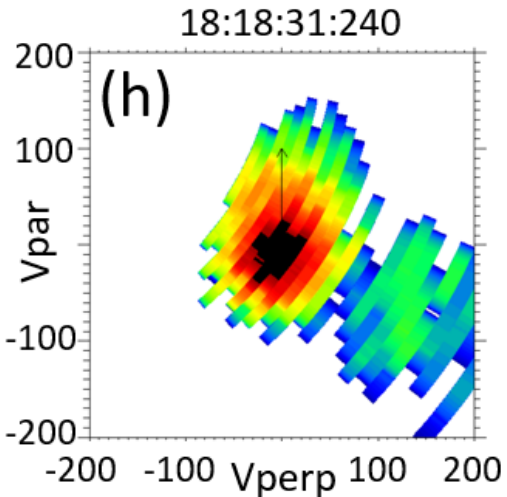
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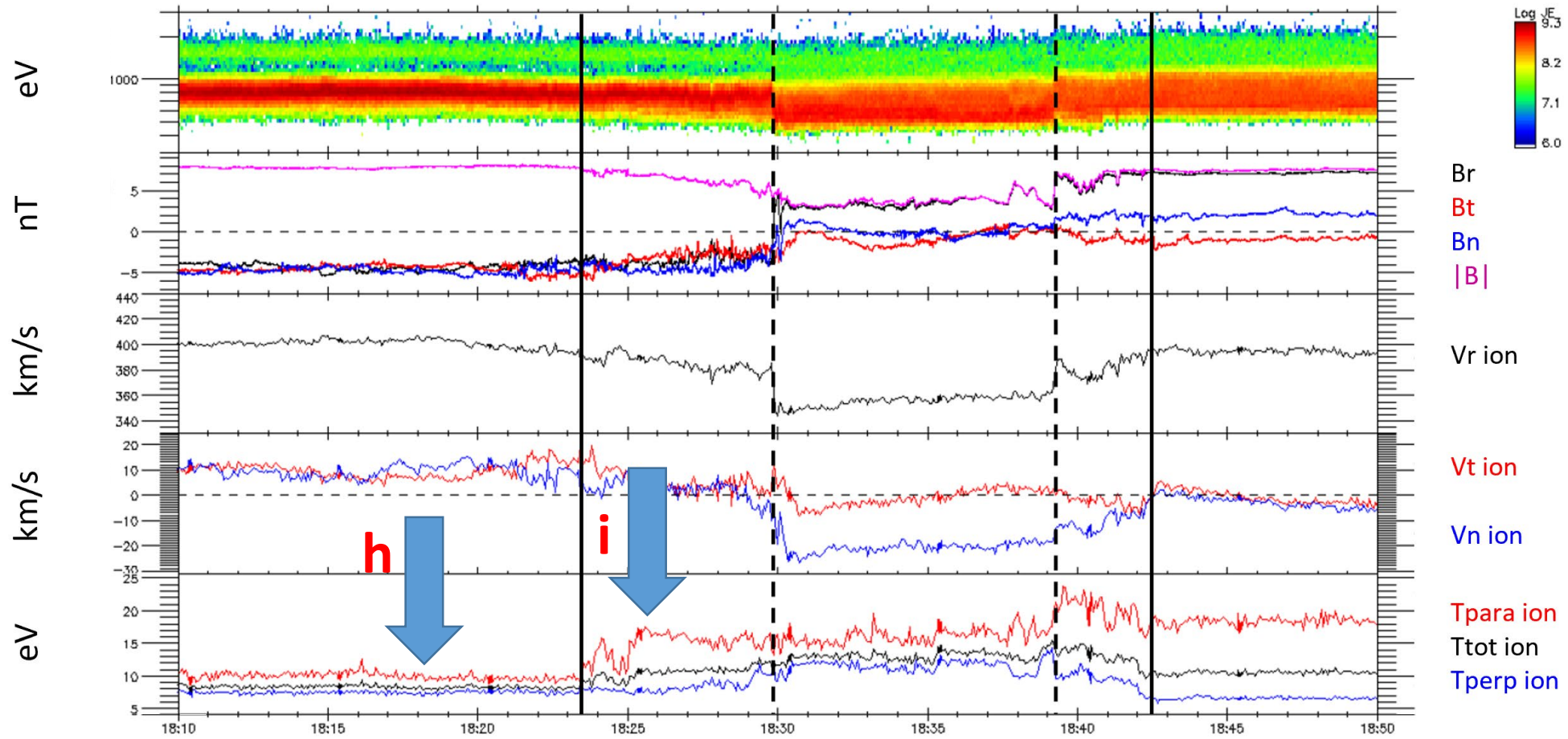
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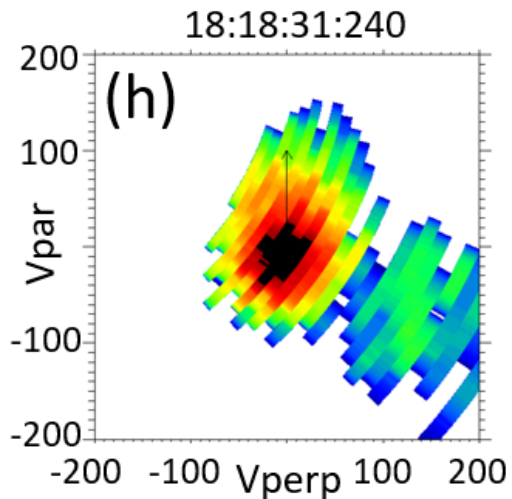
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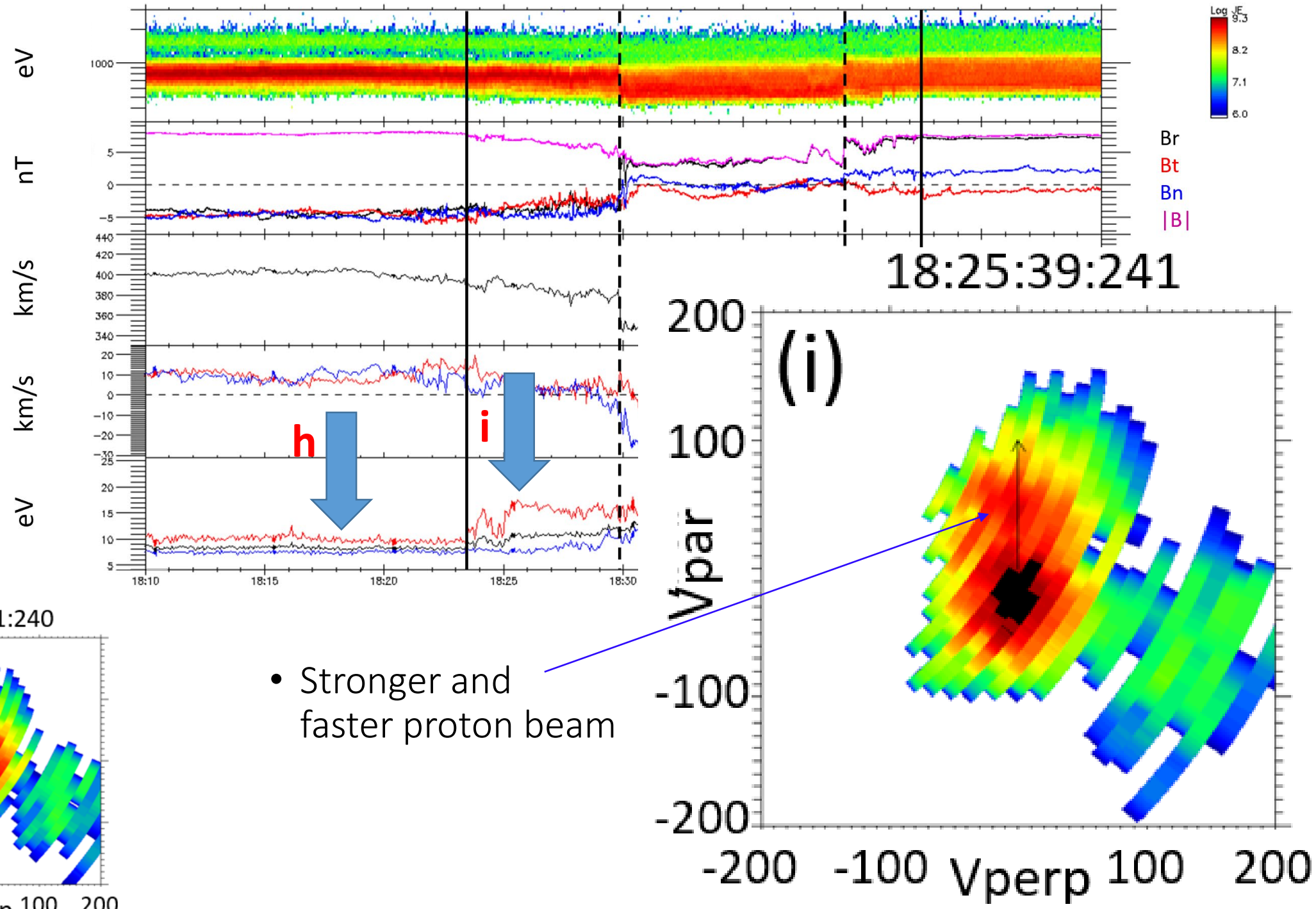
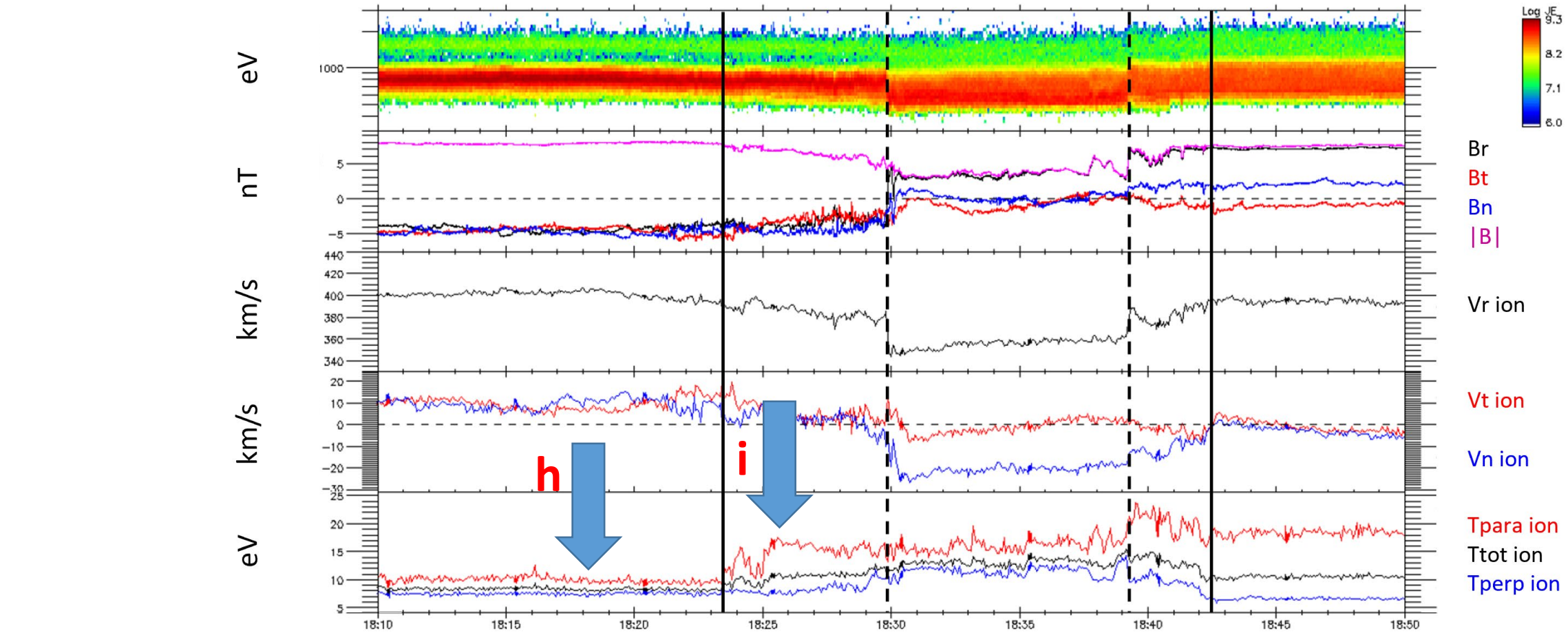


- Stronger and faster proton beam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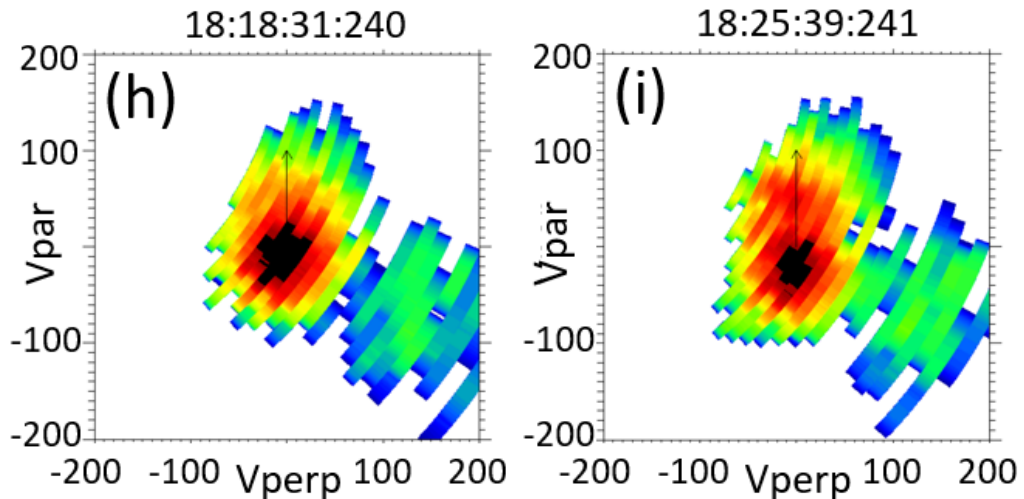
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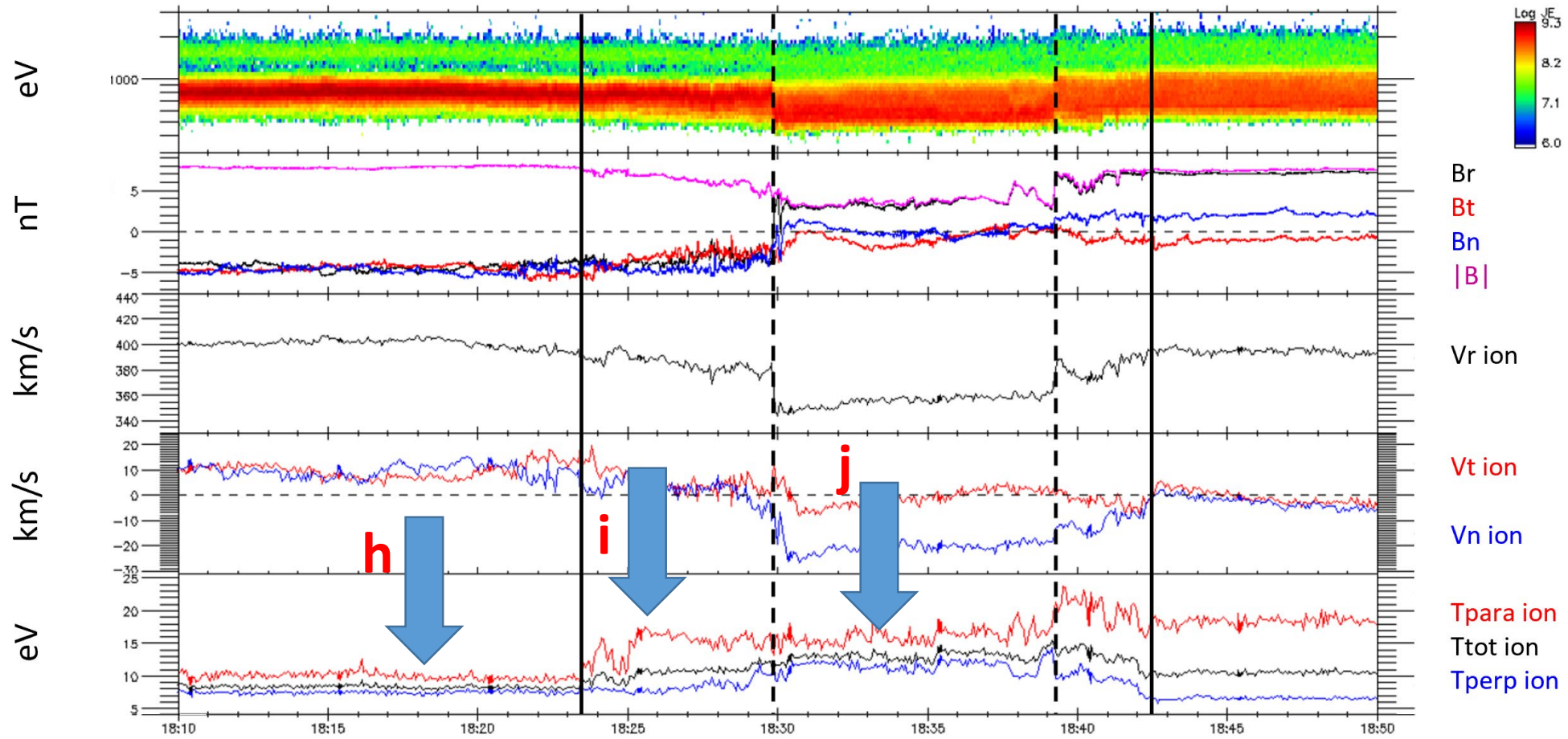
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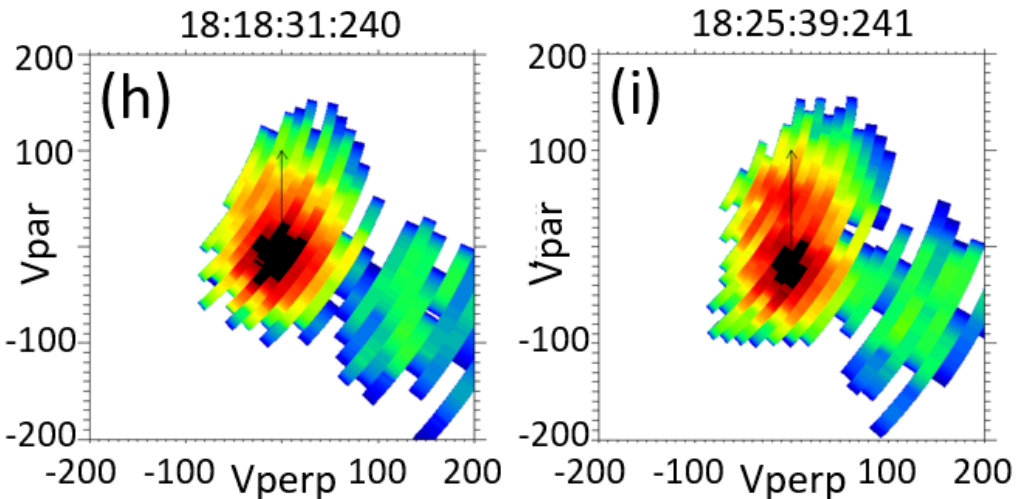
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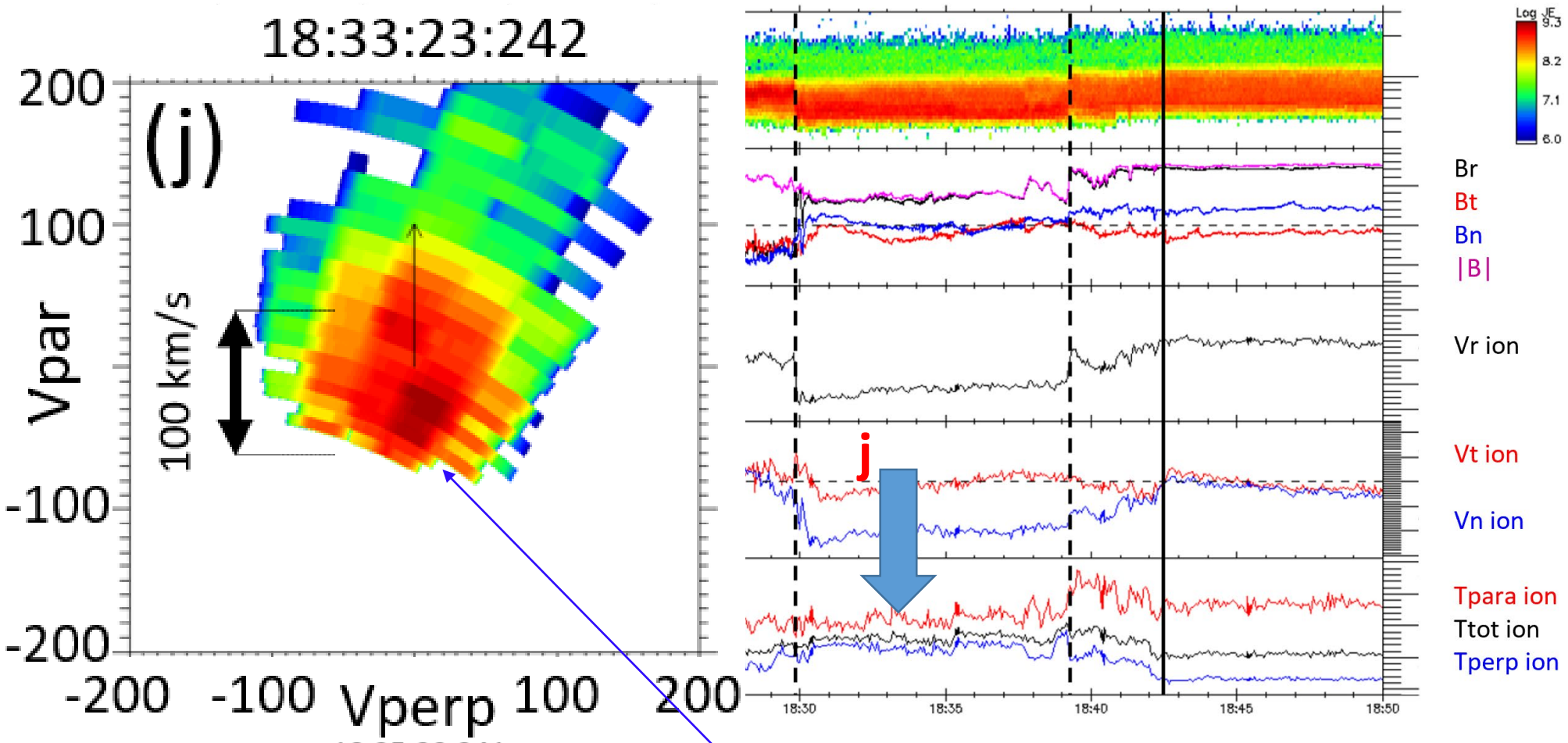
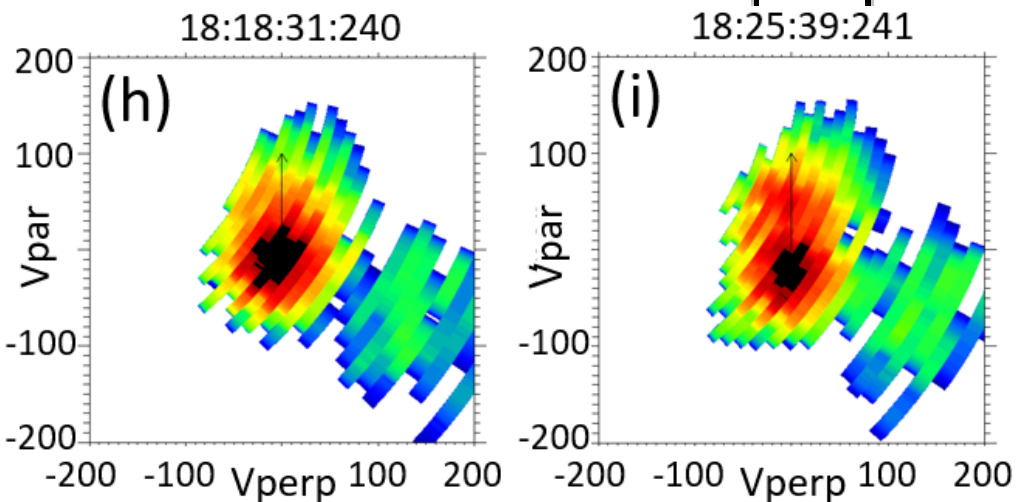
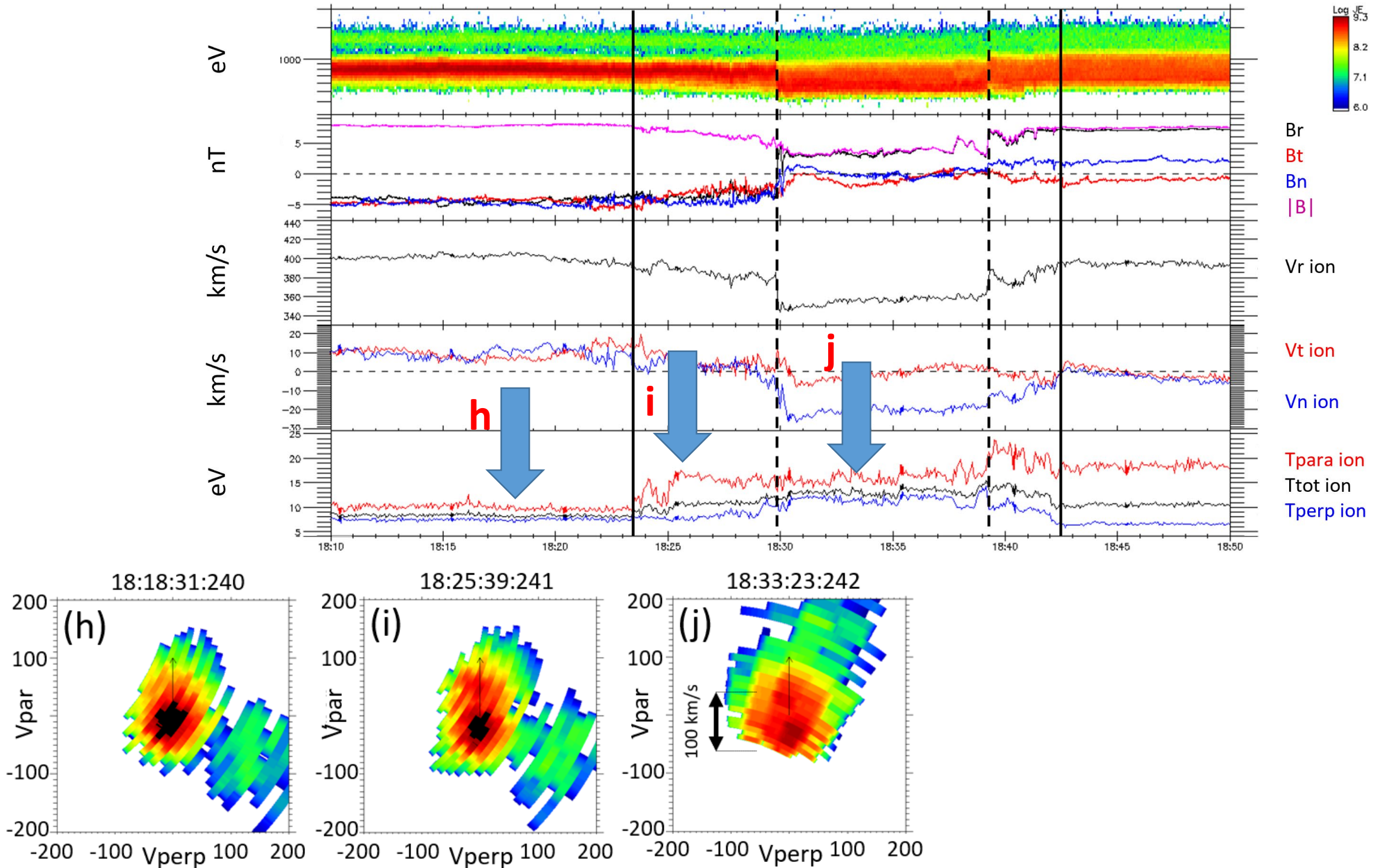




- Two cores of similar intensity
- Field-aligned ‘a la Gosling’
- Separated by 2x the Alfvén speed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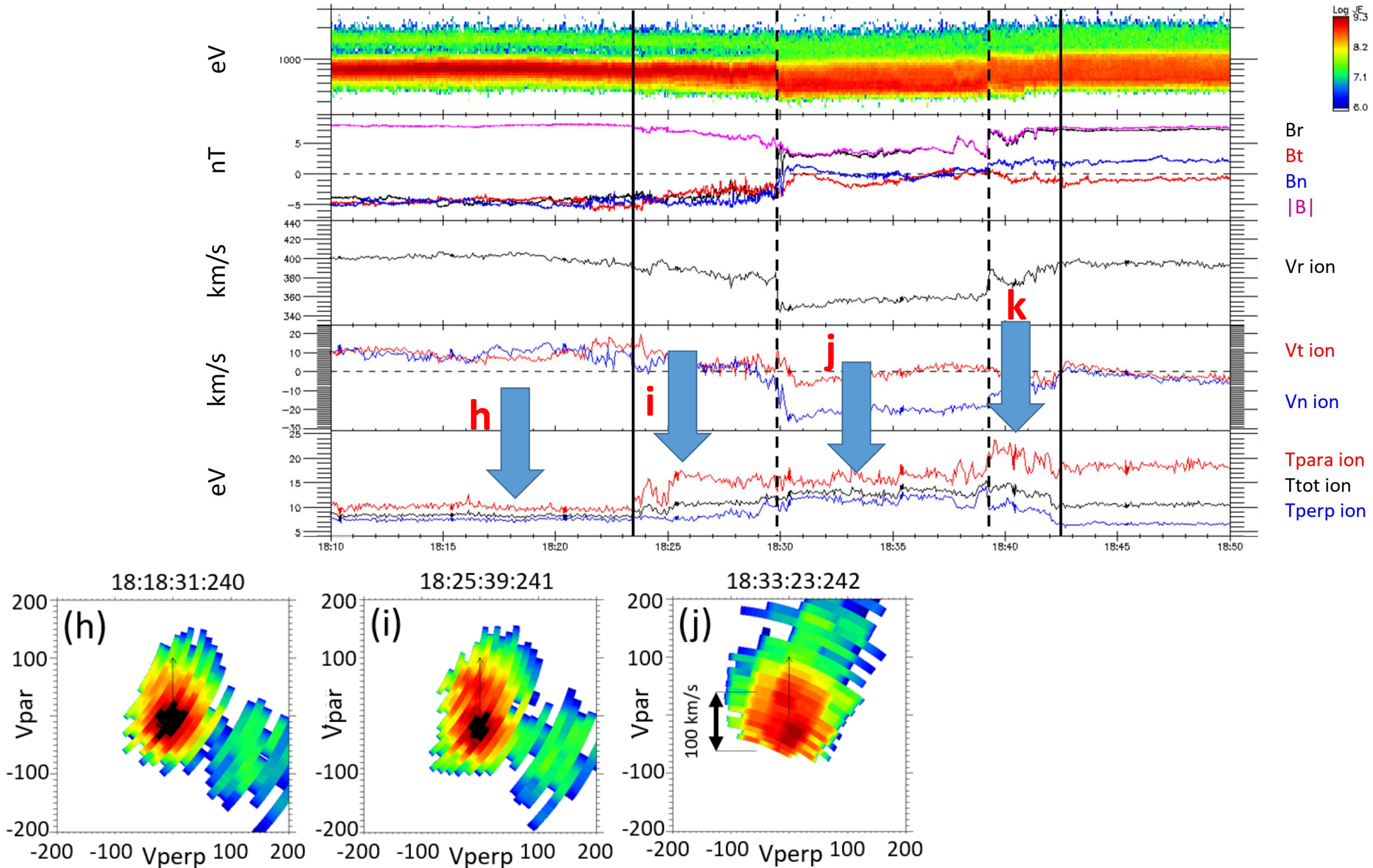
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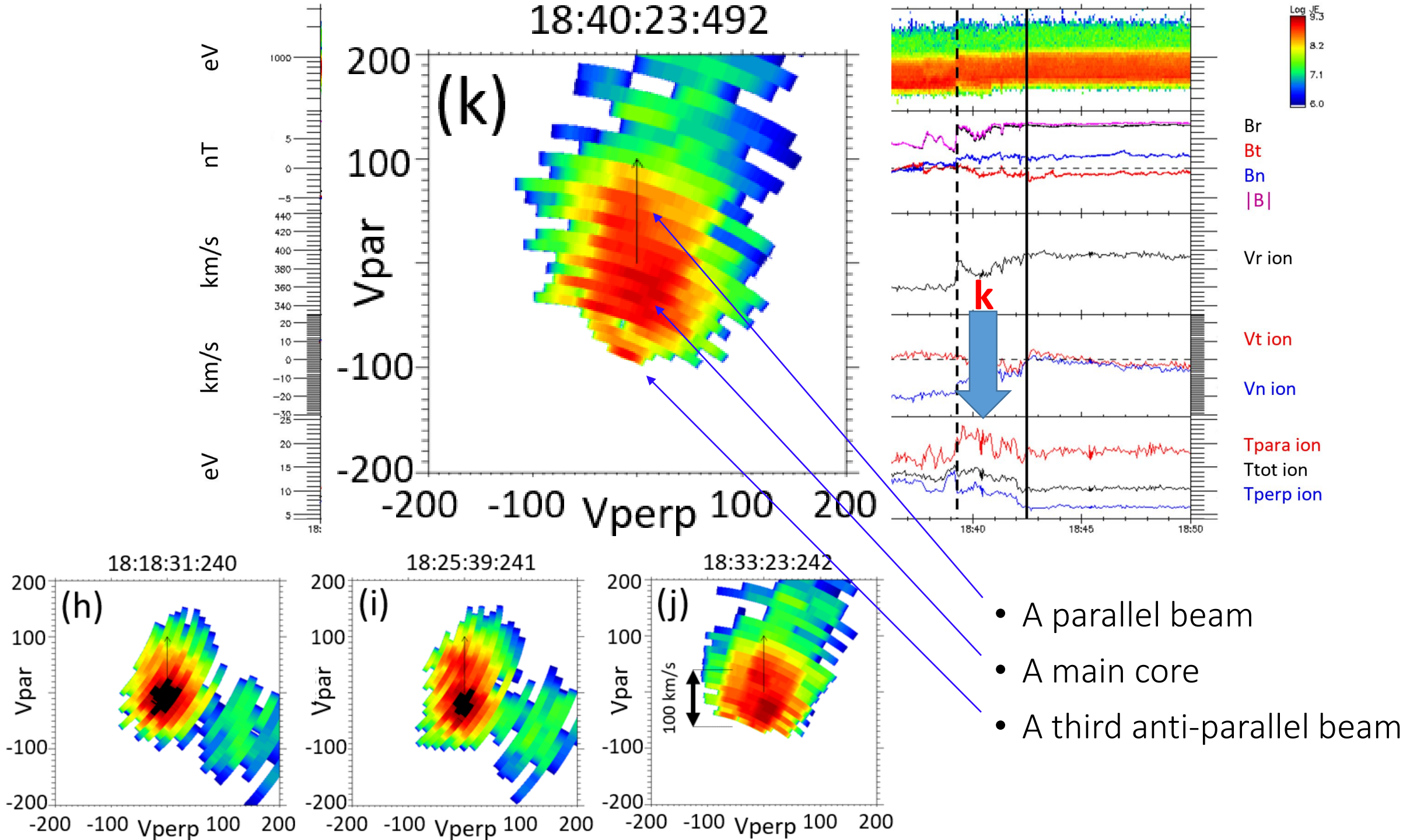
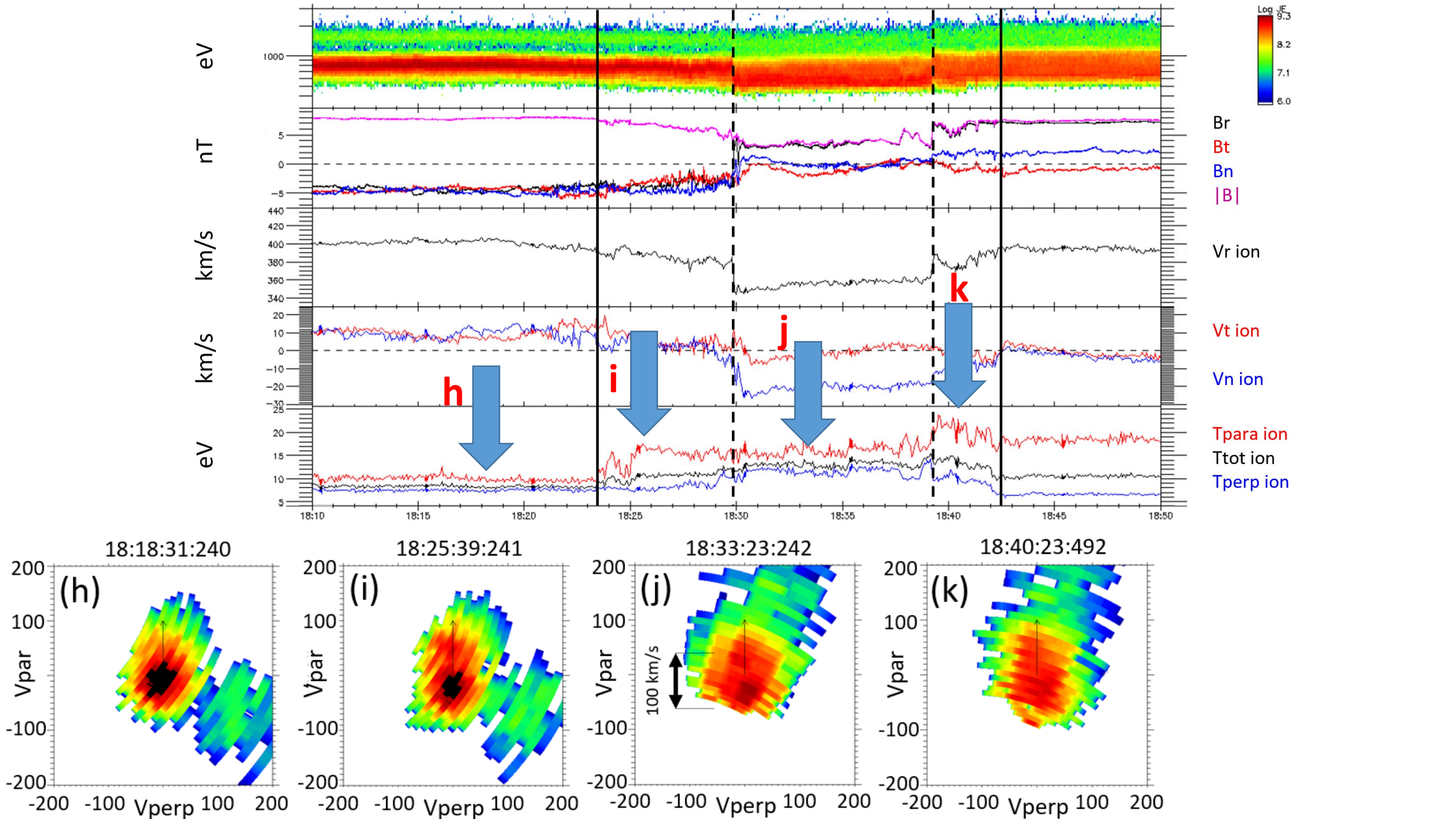


- A parallel beam
- A main core
- A third anti-parallel beam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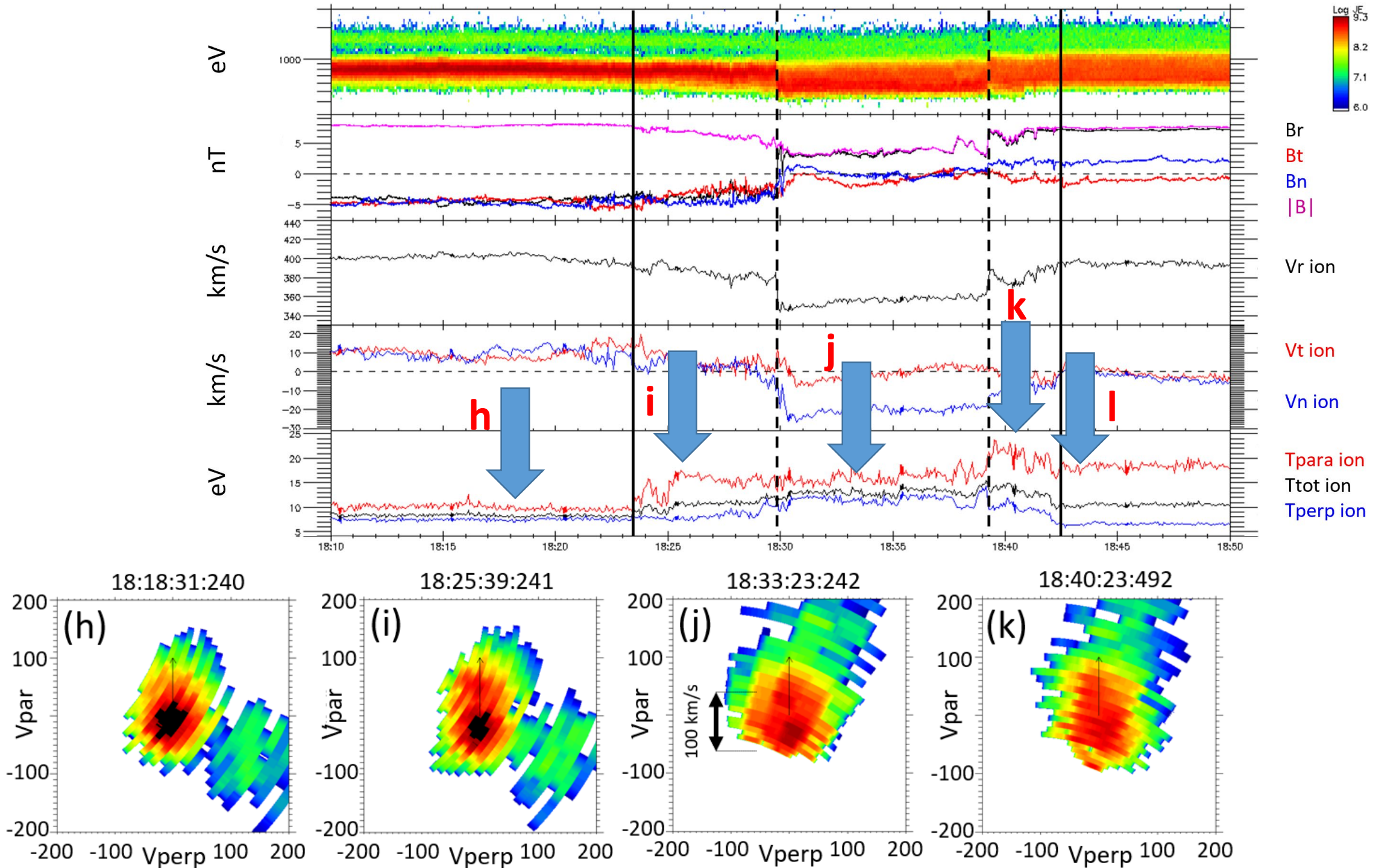
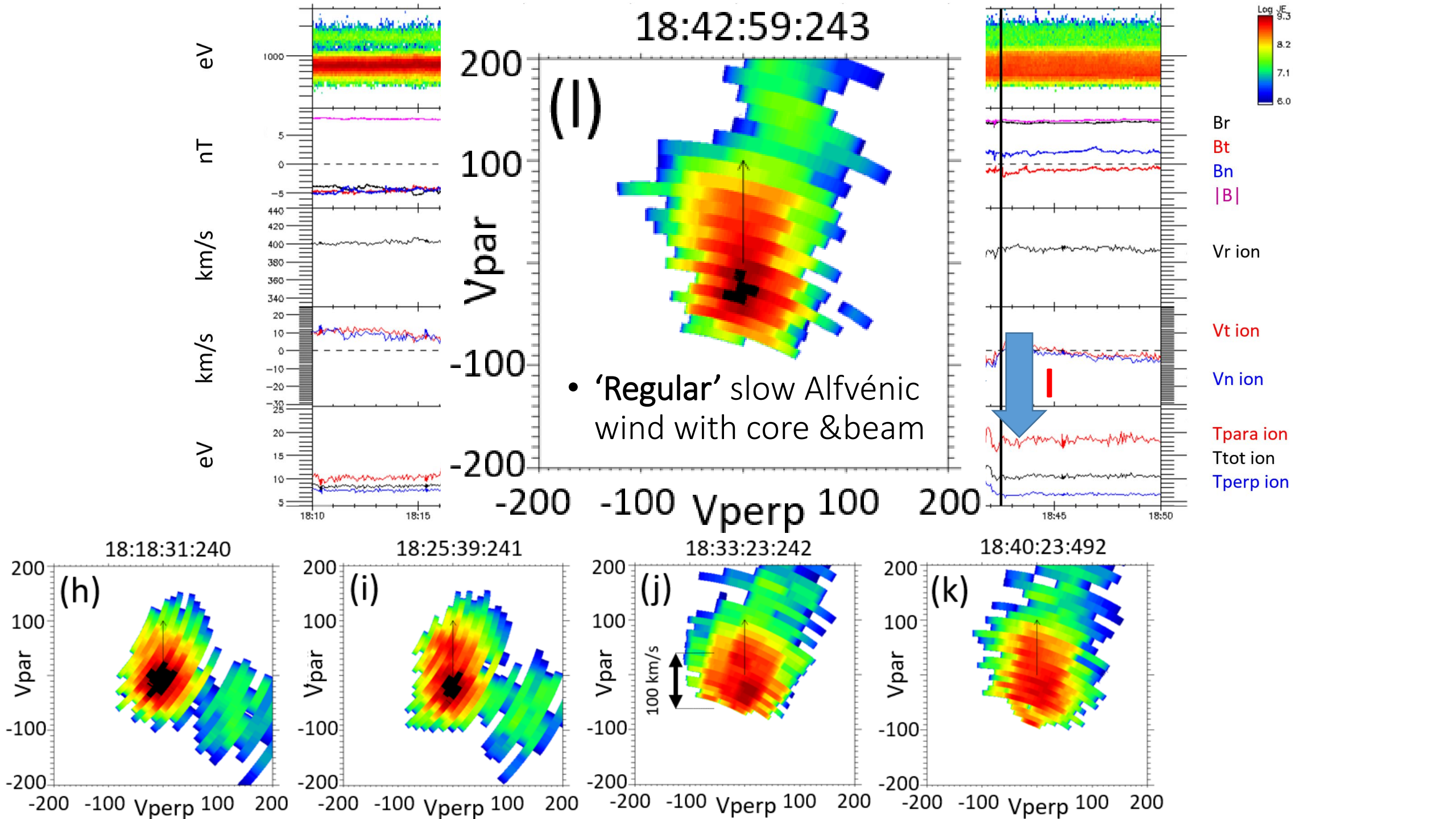
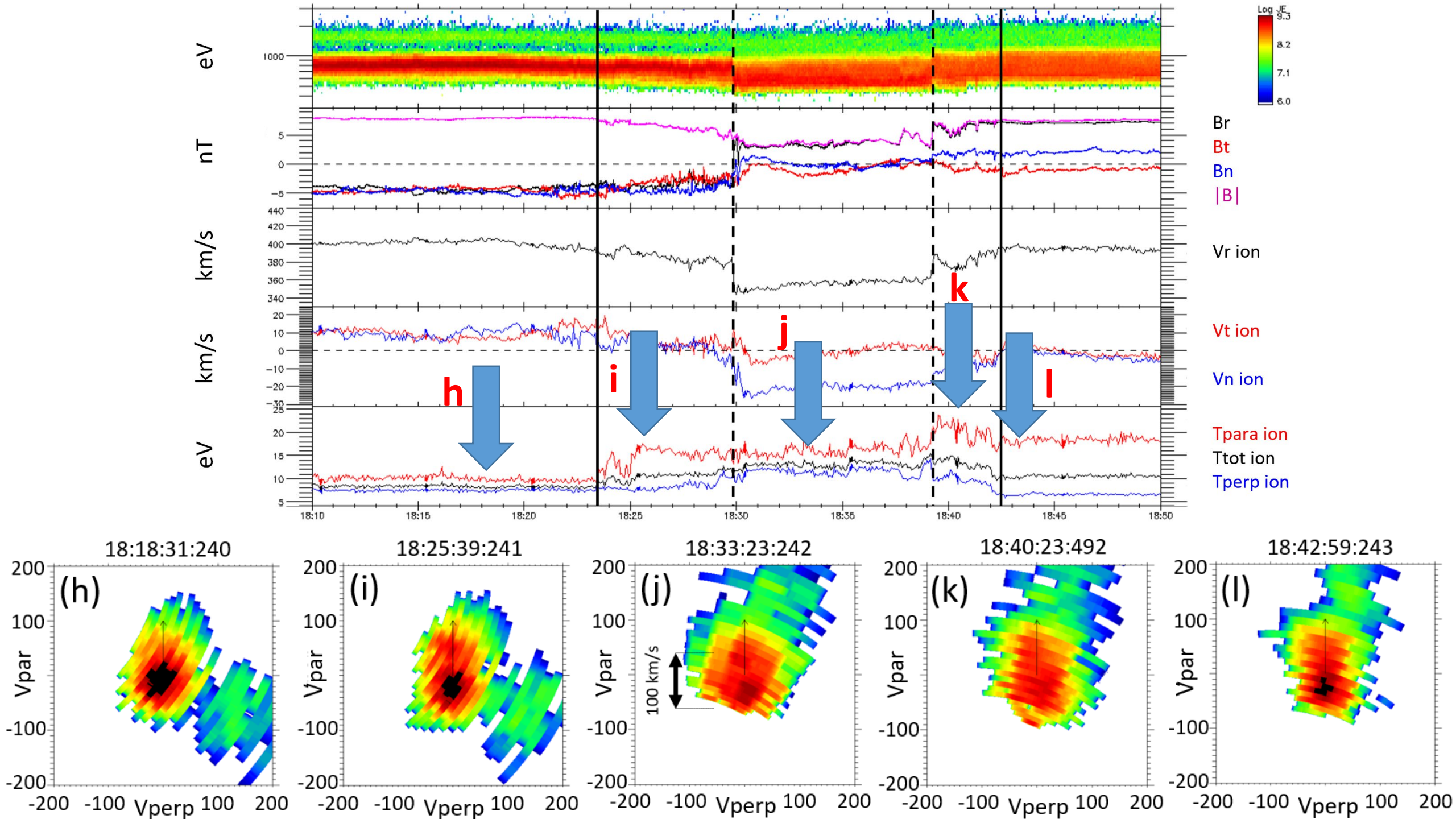
(k)
Vpar
Vperp
100 km/s


eV
nT
km/s
km/s
eV
Log JE
9.3
8.2
7.1
6.0
Br
Bt
Bn
|B|
Vr ion
Vt ion
Vn ion
Tpara ion
Ttot ion
Tperp ion
h
i
j
k
l
18:10
18:15
18:20
18:25
18:30
18:35
18:40
18:45
18:50
18:18:31:240
18:25:39:241
18:33:23:242
18:40:23:492
(h)
(i)
(j)
(k)
Vpar
Vperp
100 km/s


18:42:59:243
(l)
• 'Regular' slow Alfvénic wind with core &beam
Vpar
Vperp
eV
nT
km/s
km/s
eV
Br
Bt
Bn
|B|
Vr ion
Vt ion
Vn ion
Tpara ion
Ttot ion
Tperp ion
Log JE
18:18:31:240
(h)
18:25:39:241
(i)
18:33:23:242
(j)
100 km/s
18:40:23:492
(k)


eV
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km/s
km/s
eV
Log JE
9.3
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18:45
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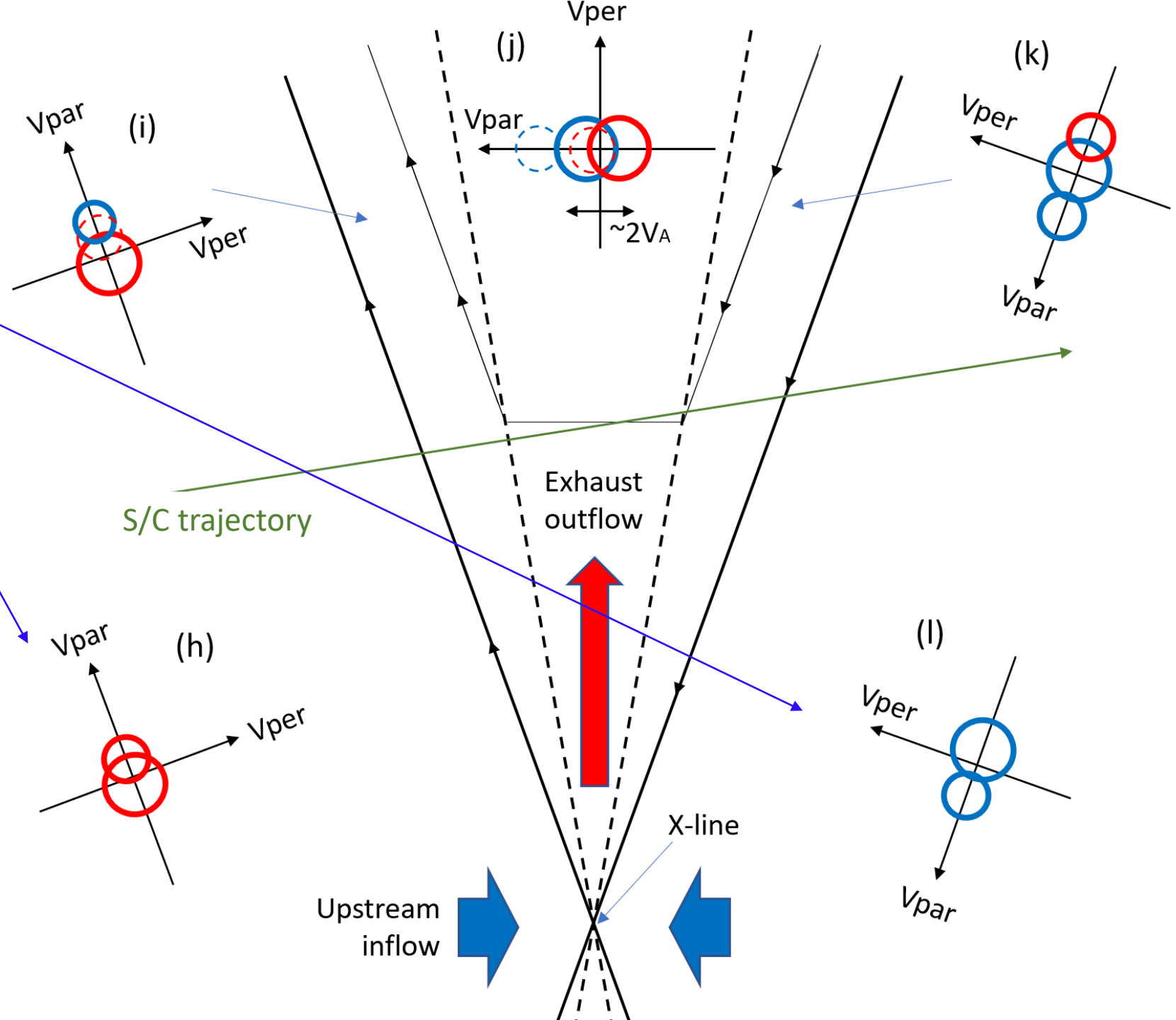
18:18:31:240
18:25:39:241
18:33:23:242
18:40:23:492
18:42:59:243
(h)
(i)
(j)
(k)
(l)
Vpar
Vperp
100 km/s

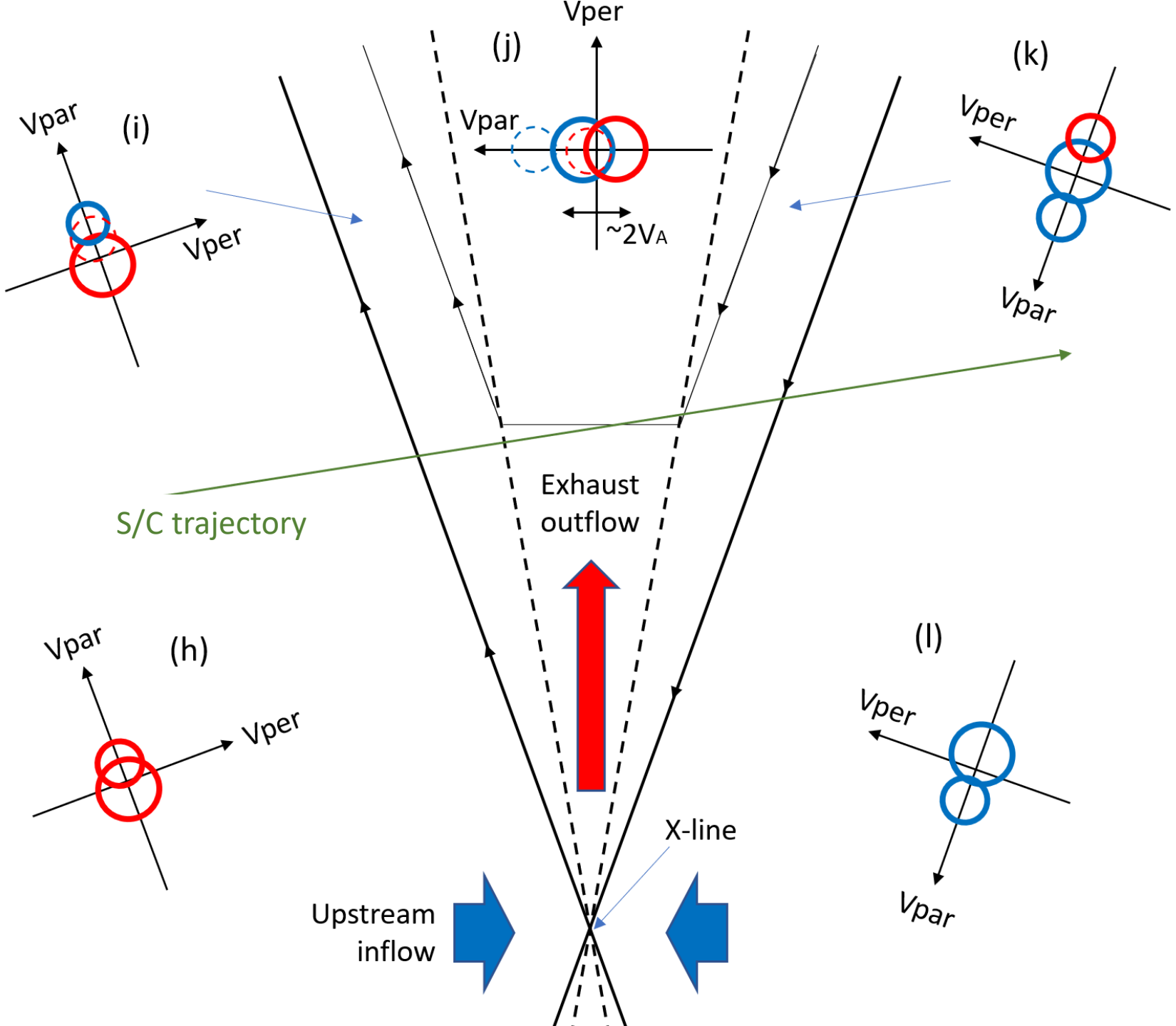
Interpretation

- Boundary conditions with preexisting beams



Interpretation

- Boundary conditions with preexisting beams
- Intermixing of multiple proton populations
- Some populations may overlap or hide weaker ones



Interpretation

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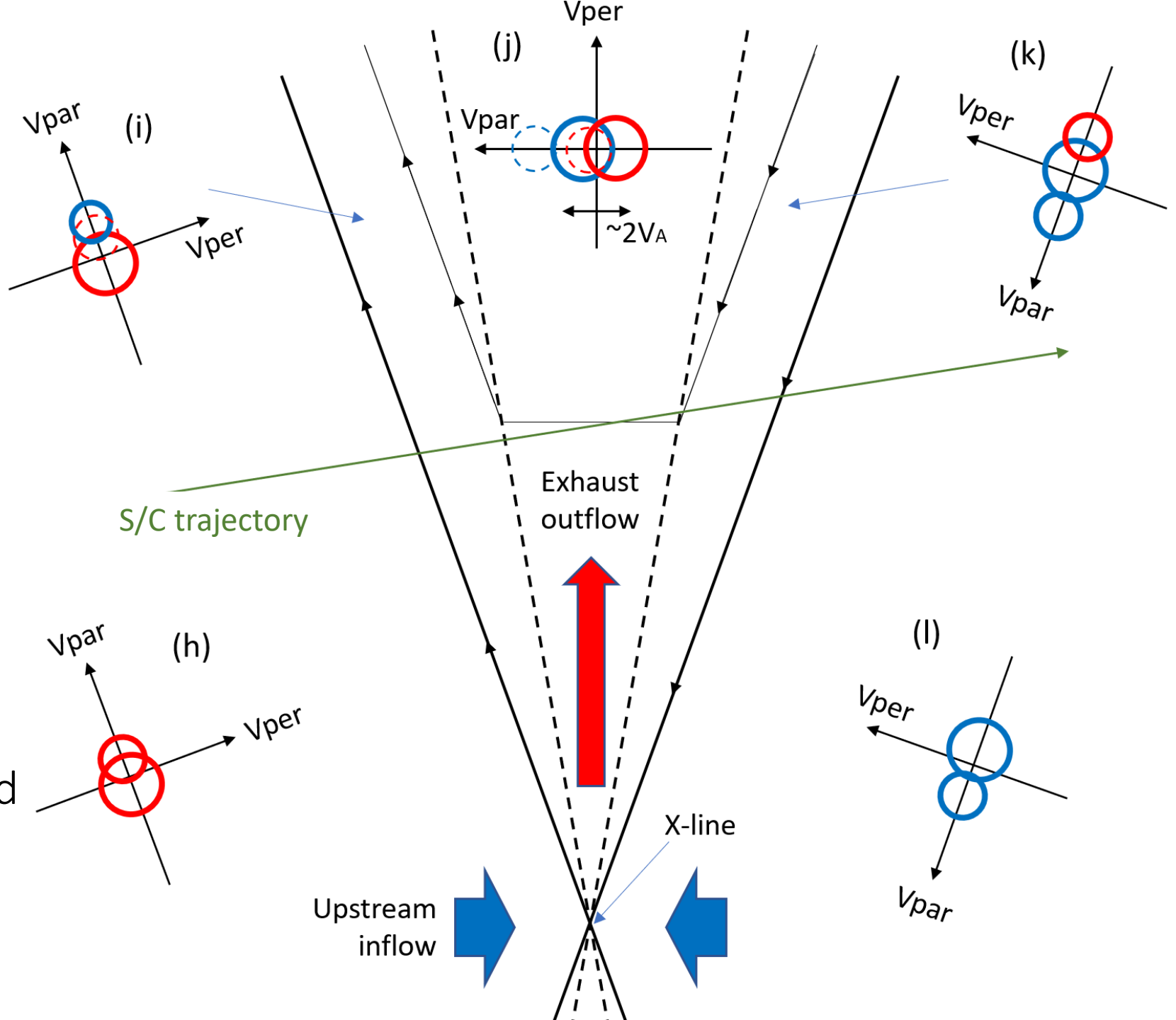

Interesting implications:

- Origin of beams in solar wind
- Impact of preexisting beams on reconnection dynamics

Conclusions

→ Solar Orb. shows reconnection is a frequent source of multiple near-thermal proton populations and beams in the solar wind

Conclusions

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We also note that:

- ✓ For the present slow Alfvénic solar wind interval, while beams are present throughout the wind, 2% are associated to reconnection
- ✓ The beams are often multiple, owing to the specifics of reconnection (separatrix regions, interpenetration with pre-existing inflow beams…)
- ✓ The event confirms reconnection can occur at switchback boundaries
- ✓ Impact of preexisting beams on reconnection dynamics to study