Phase space density analysis of outer radiation belt electron energization and loss during geoeffective and non-geoeffective sheath regions

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EGU 2021

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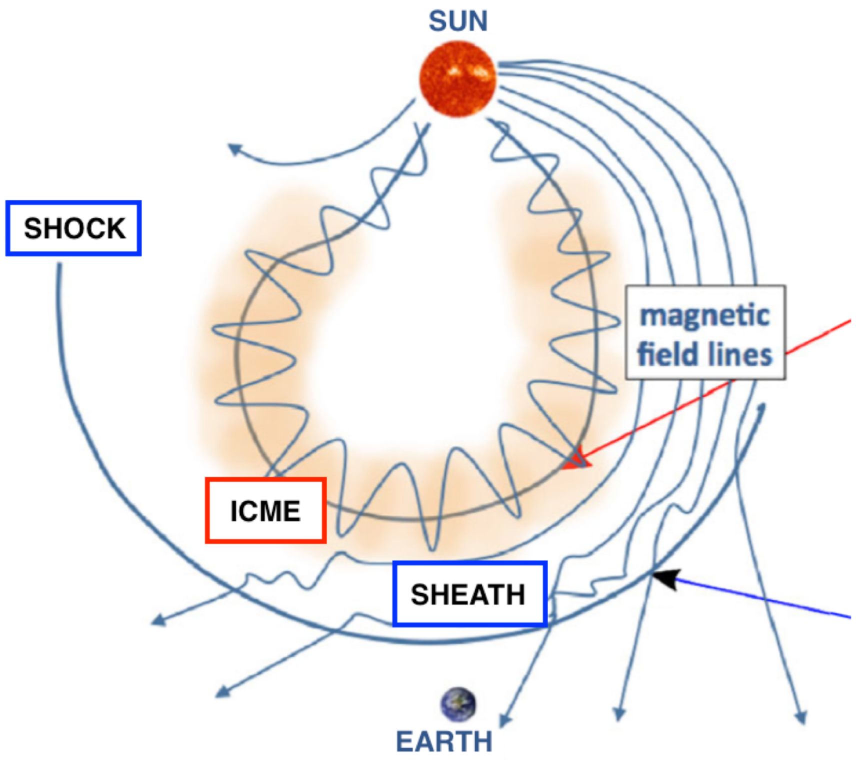
Introduction

- Turbulent sheath region forms between the shock and ejecta of an interplanetary coronal mass ejection (ICME)
- We study outer radiation belt response to sheath regions
  - Using Van Allen Probes data
- Statistical study of 37 sheath events in 2012–2018

Kalliokoski et al. (2020), https://doi.org/10.5194/angeo-38-683-2020

- More detailed study using Phase Space Density (PSD) for one geoeffective and one non-geoeffective sheath

Kalliokoski et al., *in prep.*



Adapted from Kilpua et al. (2017)

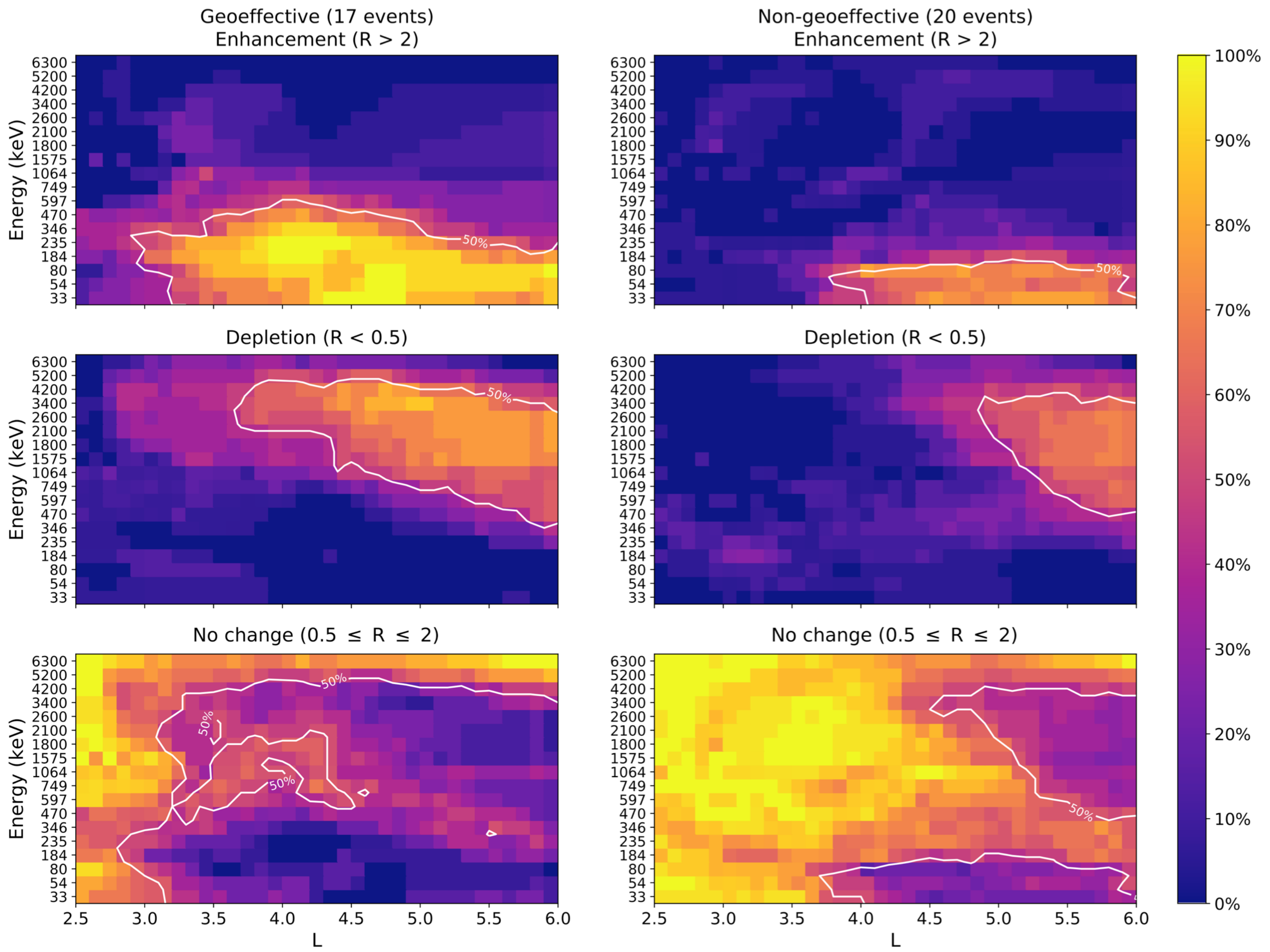
Immediate outer belt response

Geoeffective sheaths (17 events): min. *SYM-H* ≤ -30 nT
Non-geoeffective sheaths (20 events): min. *SYM-H* > -30 nT

- Outer belt response R: ratio of electron fluxes averaged over a 6 h interval before and after the sheath

$$R = \frac{\langle flux \rangle_{after}}{\langle flux \rangle_{before}}$$

- Response categories: enhancement (R > 2), depletion (R < 0.5) & no change (0.5 ≤ R ≤ 2)
- Enhancement & depletion more common throughout the outer belt during geoeffective sheaths
- But significant changes, both enhancement & depletion, occur also during non-geoeffective sheaths



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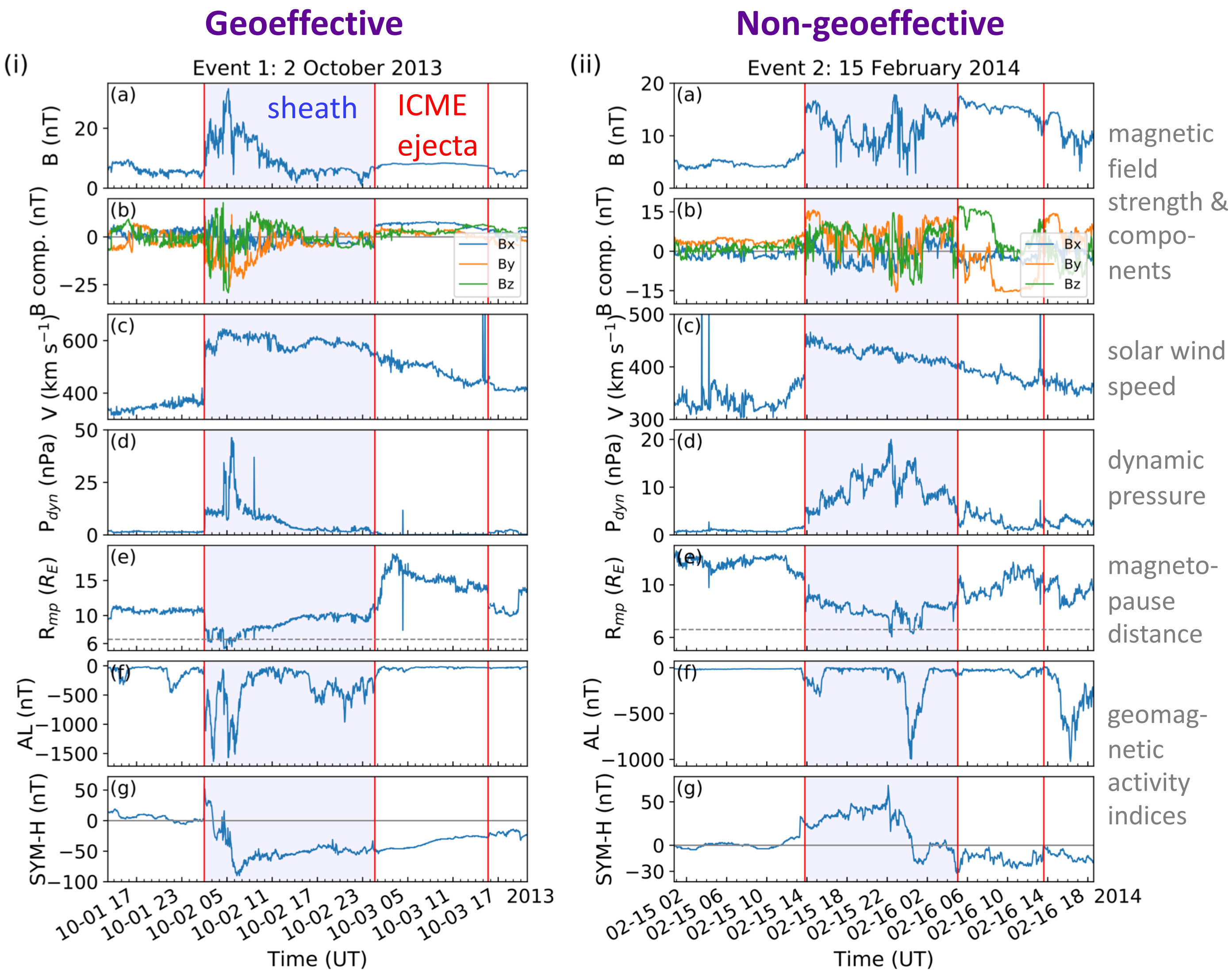
Phase Space Density (PSD) analysis: sheath events

- Calculating electron PSD profiles grants insight into the energization and loss processes during sheaths

- We compare these processes during a geoeffective sheath
    - Event 1: 2 October 2013 (left)

  and a non-geoeffective sheath
    - Event 2: 15 February 2014 (right)

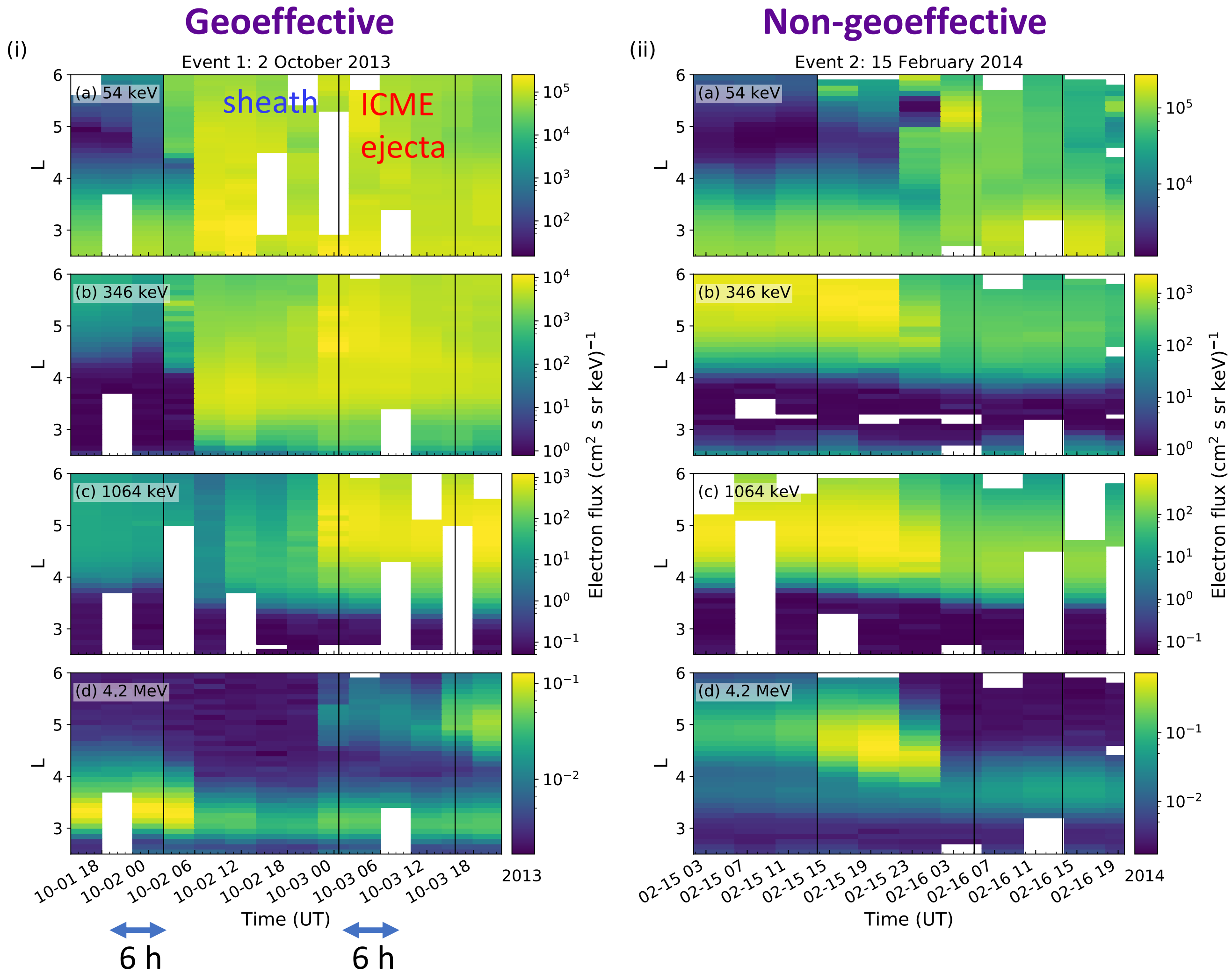
- Solar wind parameters, magnetopause location and geomagnetic activity indices during these events shown here
    - Note different timing of solar wind dynamic pressure enhancement and substorm activity

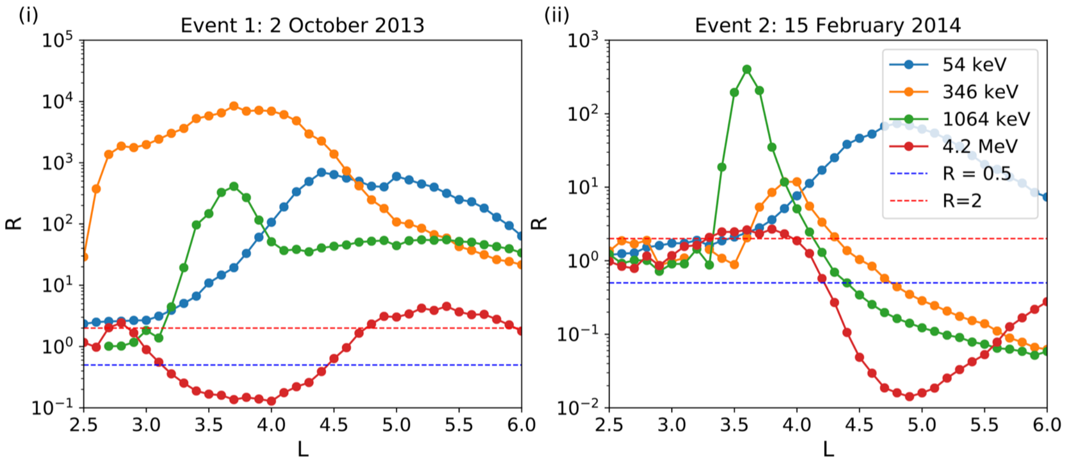


Electron flux from Van Allen Probes A & B, MagEIS & REPT instruments

PSD analysis: electron fluxes

- Opposite trends in response:
- Geoeffective sheath causes mainly strong enhancement
- Non-geoeffective sheath causes depletion at $L > 4$ at 100s keV & MeV energies
    - Note also strong enhancement during the non-geoeffective sheath at 4.2 MeV





← Outer belt response R from 6 h flux averages

$$R = \frac{\langle flux \rangle_{after}}{\langle flux \rangle_{before}}$$

PSD analysis: adiabatic invariants μ & K

- We investigated near-equatorial electrons ($K \leq 0.05\ R_E \mathrm{G}^{1/2}$) in two energy ranges:
  - $\mu = (300 \pm 10)$ MeV/G
    - ~900 keV at $L^* = 4$
  - $\mu = (3000 \pm 100)$ MeV/G
    - ~3.7 MeV at $L^* = 4$

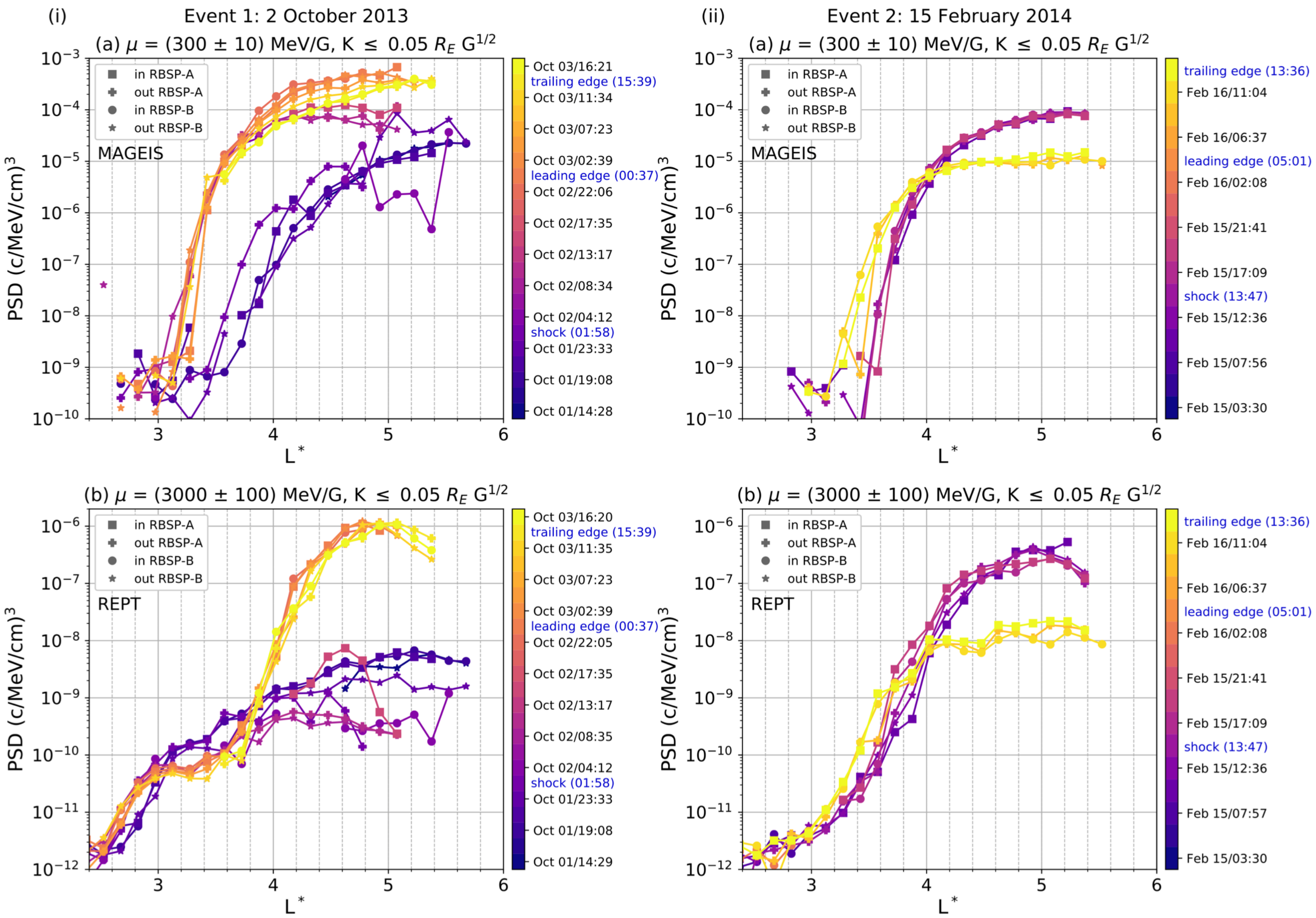
- These ranges allow for sufficient resolution of PSD as a function of L*
- We employed Tsyganenko & Sitnov (2005) geomagnetic field model available in Van Allen Probes ephemeris data files to calculate *K* and L*
- PSD vs L* on next slide is separated to profiles for each inbound & outbound pass of the orbits of Van Allen Probes A & B, color coding from purple to yellow indicating increasing time

PSD analysis: results

- Geoeffective sheath mainly caused enhancement
  - μ = 300 MeV/G: Substorm injections + fast ULF wave driven inward radial diffusion
  - μ = 3000 MeV/G: Likely local acceleration by chorus waves

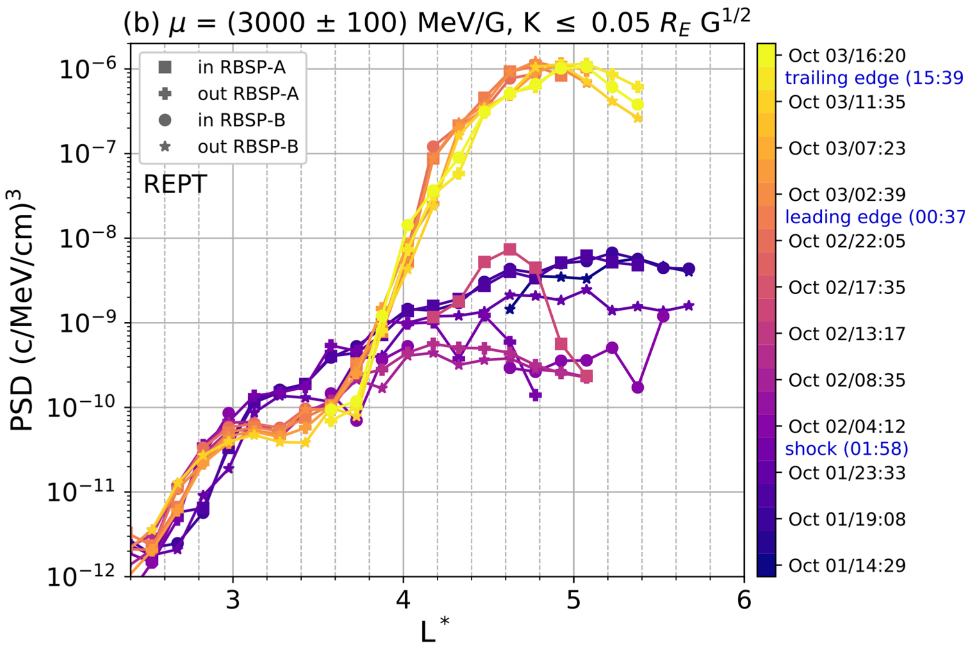
- Non-geoeffective sheath lead to magnetopause shadowing losses
  - Combined effect of magnetopause compression & ULF wave driven radial diffusion

Geoeffective **Non-geoeffective**



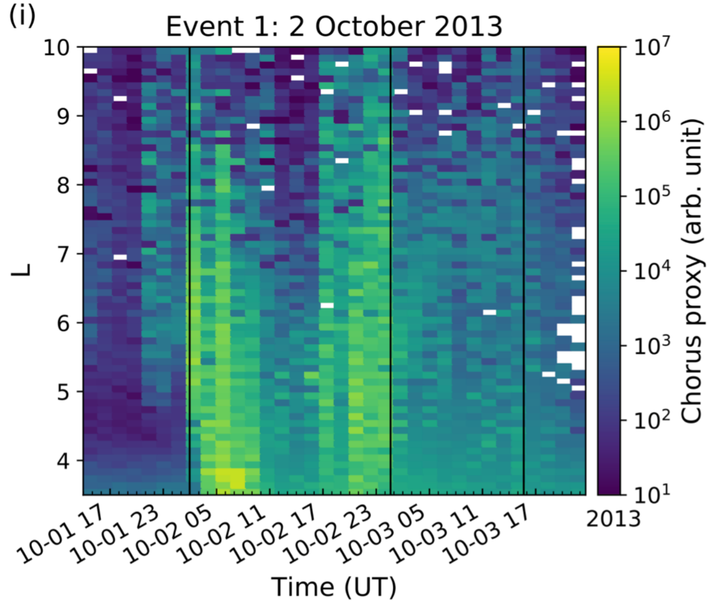
PSD analysis: local acceleration

Geoeffective sheath



- Van Allen Probe A observed a peak in PSD during the geoeffective sheath at ultrarelativistic energies
  - The peak grew about three orders of magnitude in 12 h (from magenta pluses to oranges squares)
  - Van Allen Probe B unfortunately has no PSD observations at these μ & K during the time of peak formation

- Local peak likely generated via local acceleration by chorus waves
  - Chorus proxy, using POES electron precipitation (Chen et al., 2014), indicates strong chorus activity during peak growth
  - Chorus proxy used since in this event Van Allen Probes miss the dawn sector where chorus predominantly occurs



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Summary

- Sheaths cause significant changes in outer belt electron fluxes, including non-geoeffective sheaths
- Case study of electron phase space density shows that
  - Geoeffective sheath mainly caused outer radiation belt electron energization
  - Non-geoeffective sheath mainly caused losses
- Opposite responses are related to different level of substorm activity and different timing of solar wind dynamic pressure enhancements causing magnetopause compression and ULF wave activity to peak in different parts of the sheaths
- Results highlight key role of ULF wave driven inward and outward radial transport governing electron dynamics
- Key regions during sheaths: major variation in radiation belt system seem to occur in two parts of the sheath, close to the shock and close to the ejecta leading edge