Van Allen Probe Observations of Chorus Wave Activity, Source and Seed Electrons, and the Radiation Belt Response During CME and CIR Storms

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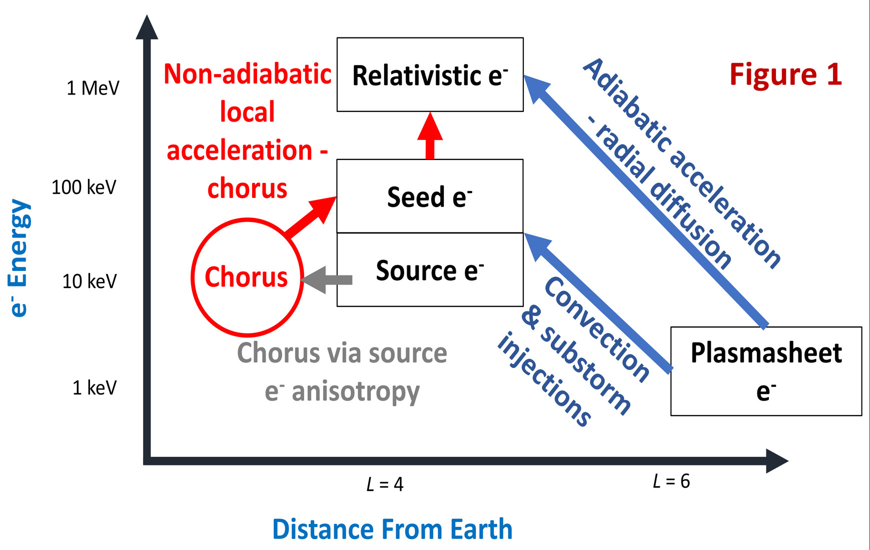
Introduction

- Gyroresonant wave-particle interactions between chorus and 100s of keV seed electrons can lead to radiation belt enhancements.
- Temperature anisotropy of 10s of keV source electrons 10s of keV gives free energy for chorus.
- Source & seed electron access to the inner magnetosphere is dependent on convection, sub-storm activity, and conditioning in the plasmasheet.
- CMEs and CIRs create differences in the energy spectrum and composition of the plasmasheet, convection, and substorm activity.

Figure 1



- **Van Allen Probes** (RBSP) used to create **storm phased epoch analysis** of **chorus wave power** and **plasma conditions driving chorus activity** - via a linear theory proxy - **during CME/CIR storms**.
- Used **RBSP** to create a **superposed epoch analysis** of the growth of the **seed** and **radiation belt** electrons vs L^* **during CME/CIR storms**.

Acknowledgements and References

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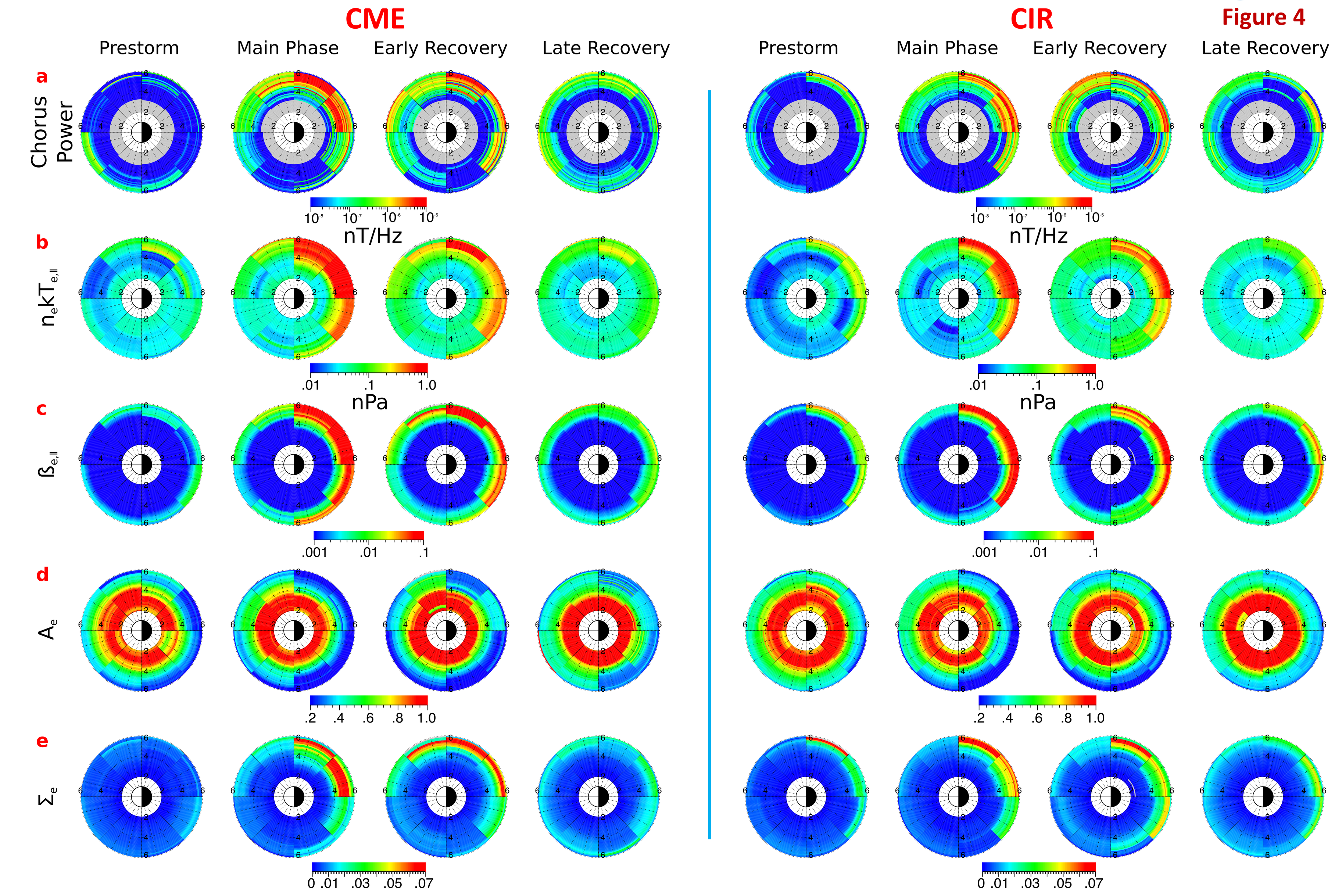
Boyd, A. J. et al., (2016), Statistical properties of the radiation belt seed population, JGR SP, doi:10.1002/2016JA022652.
Gary, S. P. et al., (2005), Electron anisotropy constraint in the magnetosheath: Cluster observations, GRL, doi:10.1029/2005GL023234.
Spasojevic, M. (2014), Statistical analysis of ground-based cho- rus observations during geomagnetic storms, JGR SP, doi:10.1002/2014JA019975.

RBSP Observations of CME/CIR Chorus Wave Activity

Figure 4



- Gary et al. [2005] developed a **linear theory proxy inferring chorus growth from plasma parameters.**
- **Proxy for chorus growth, Σ_e, is a product of hot** (1-60 keV) **electron anisotropy, A_e,** and **hot electron** $\beta_{e,\parallel}$:

$$\Sigma_e = \left(\frac{T_{e,\perp}}{T_{e,\parallel}} - 1\right)\beta_{e\parallel}^{\alpha} \qquad \beta_{e,\parallel} = \frac{n_e k T_{e,\parallel}}{B^2/2\mu_0}$$

- RBSP used to measure average CME/CIR chorus power and proxy components: (a) observed chorus wave power, (b) hot e⁻ pressure, (c) hot e⁻ $\beta_{e,\parallel}$, (d) hot electron anisotropy: $A = T_{e\perp}/T_{e\parallel} - 1$, and (e) proxy growth.

- **Chorus power is comparable between CMEs/CIRs**
- **Strongest** in **main phase** on **dawn/pre-dawn** sector. **Decreases** but **spreads across dayside** in recovery phases.
- **Source electrons** (1-60 keV) **quickly reach dawn** w/ **enhanced convection** of main phase.

- **Chorus activity follows drift path of source electrons**
- **During recovery phases, source electrons drift across the dayside**, however their overall **flux levels** drop as **open/closed drift boundaries change**.
- **Location of growth proxy**, Σ_e, **correlates well with measured chorus** power.

Data and Storm Selection

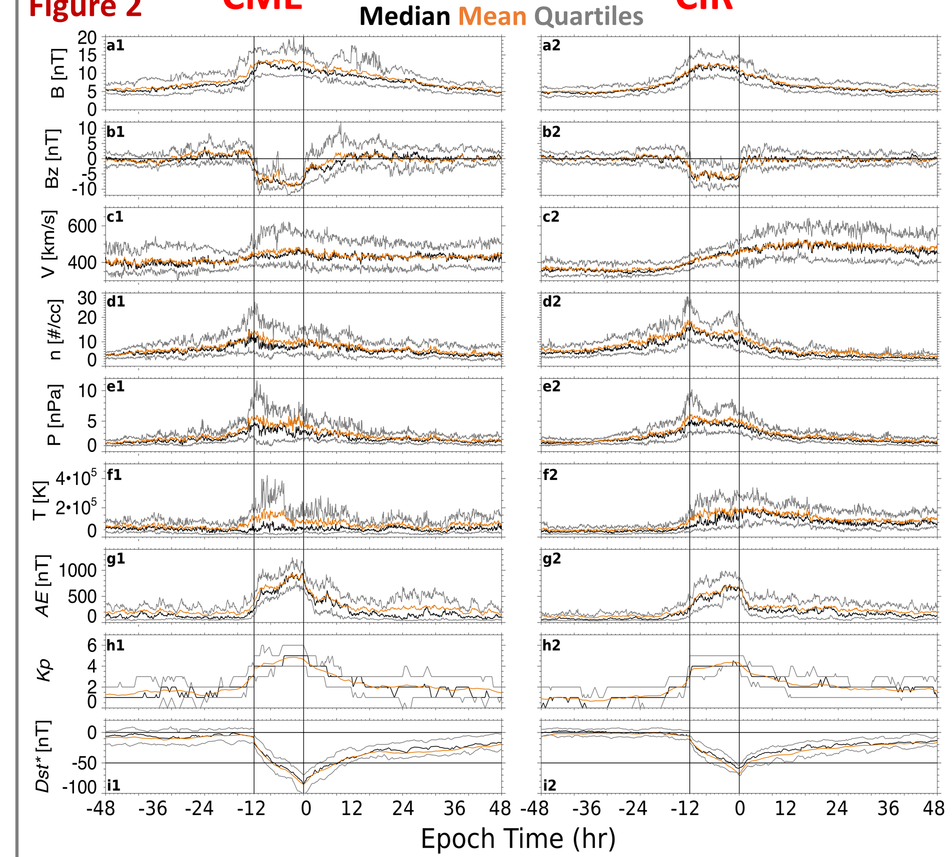
Van Allen Probes

- **HOPE** – e⁻ < 60 keV. **MagEIS** – e⁻ 30 keV – 3 MeV.
- **REPT**– e⁻ 1 MeV – 20 MeV. **EMFISIS** – magnetometer and waves instrument.

Storm Selection

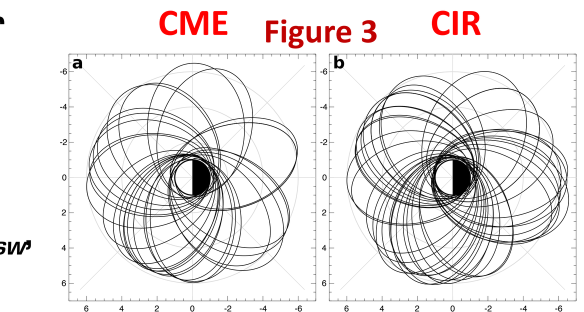
- **25 CME** and **35 SIR/CIR Storms** are **identified between 2013-01-01 and 2016-04-16** with a minimum *Dst** between -50 and -150 nT.
- Storm selection **required a single identifiable driver** (CME/CIR). Periods after the start of a second dip in *Dst* were not used.
- Fig 2: **median**, **mean**, and **quartile** superposed epoch sw for CMEs/CIRs. Main phase normalized to 12 hrs.
- Fig 3: RBSP *MLT*/*L* coverage during CMEs/CIRs.

Figure 2



- **CMEs** – **greater substorm activity** and **stronger convection**.
- **CIRs** – **higher n_{sw}, v_{sw}, and T_{sw}.**

Figure 3

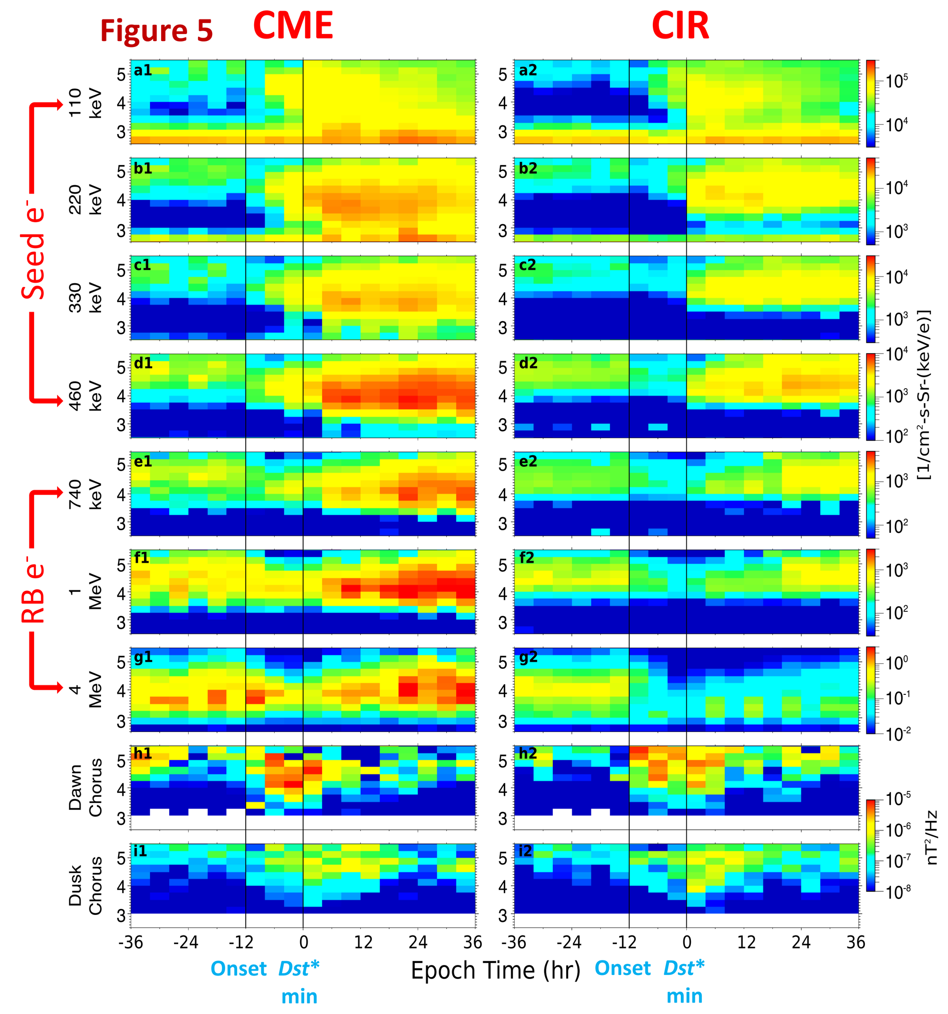


Superposed Epoch Analysis of CME/CIR Seed and Radiation Belt Electrons

Storm Time Flux

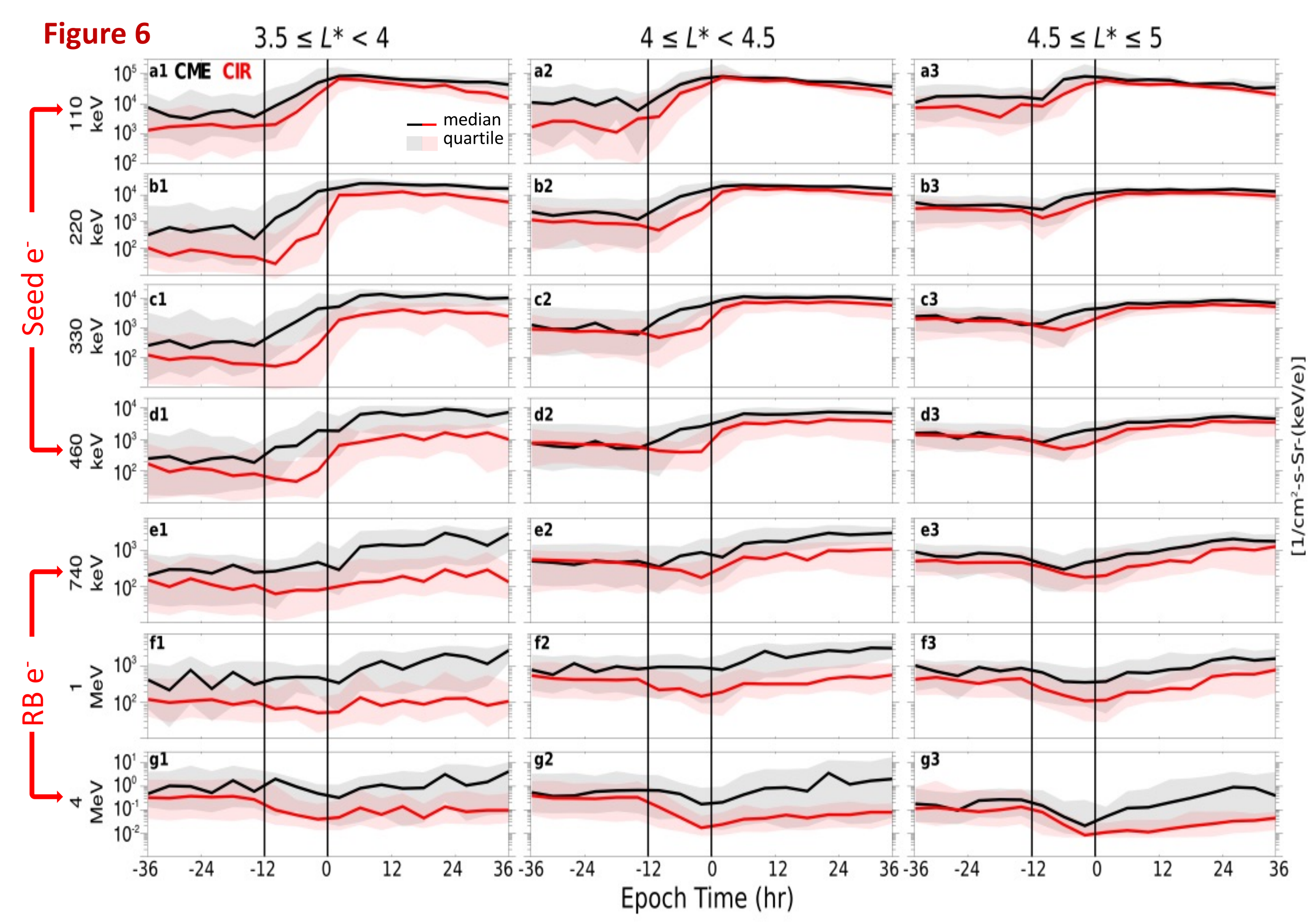
- Using RBSP map average seed & radiation belt (RB) electron response to CMEs/CIRs vs L^*.
- Figure 5: avg. flux and chorus power for fixed energies vs L^*.
- Figure 6: avg. flux between L^* = 3.5-4, 4-4.5, 4.5-5.
- Epoch $t = 0$ at min *Dst**, main phase times are normalized to 12 hours.

Figure 5



- **Stronger seed enhancement**, that **occurs earlier**, and **penetrates deeper** in **CME** storms over CIR storms.
- **Stronger radiation belt enhancement in CME storms on average compared to CIR storms.**
- **Earlier seed enhancement provides greater opportunity for local acceleration; more overlap of chorus with strong seed population.**
- **Biggest CME/CIR seed differences are at higher energies/lower L**, **Stronger convection** and more **substorm** activity **gives higher energies more access** to **lower *L*** in the inner magnetosphere.

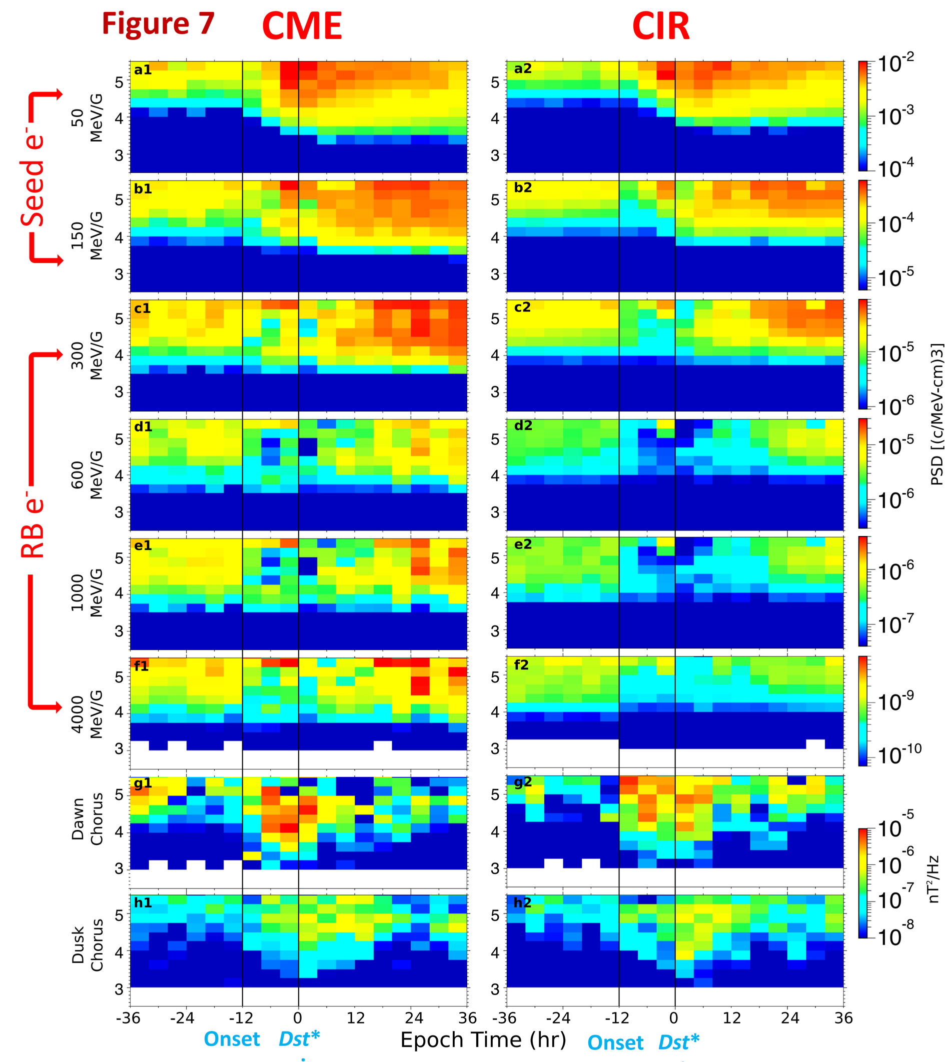
Figure 6



Storm Time Phase Space Density

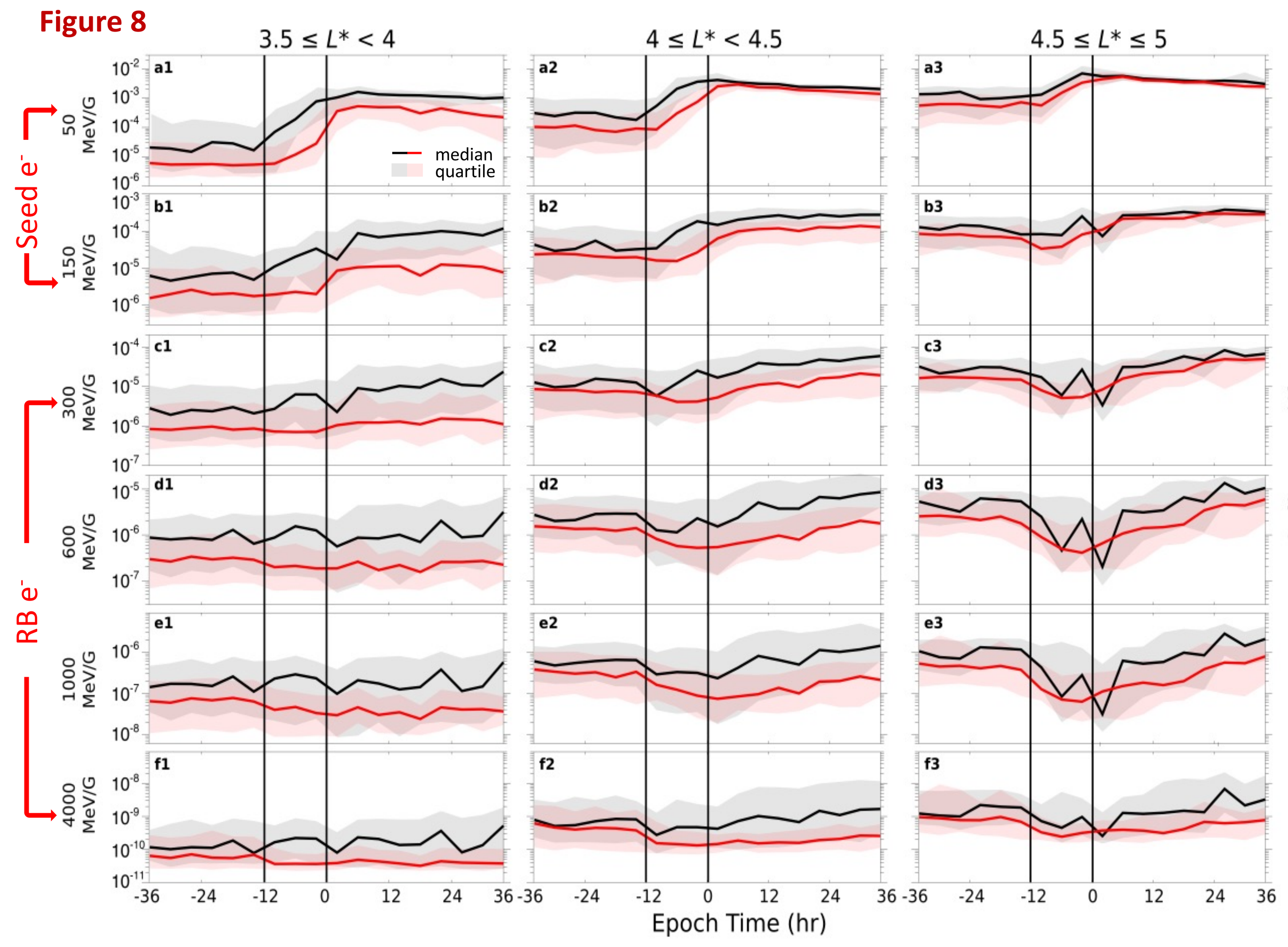
- Gradients of phase space density (PSD) can reveal aspects of the acceleration, transport, and loss of electron populations.
- Figure 7: avg. MagEIS + Rept PSD vs L^* for fixed μ and avg chorus wave power.
- Figure 8: avg. PSD between L^* = 3.5-4, 4-4.5, 4.5-5.

Figure 7



- **Seed population enhancement primarily adiabatic, as PSD is peaked at highest L^*.**
- **CME** 150 MeV/G **seed** population **reaches *Boyd et al.* [2015] threshold of** $1{\times}10^{-4}$ (c/MeV-cm)^3 **for acceleration earlier and more often.**
- **RB enhancement** during **CME** storms occurs **during overlap of chorus activity and seed population well over threshold.**
- **PSD profile** of **RB CME enhancement** has a **peak around L^* = 4-4.5** for 300-1000 MeV/G electrons – **suggests non-adiabatic acceleration.**
- **PSD profile of RB during CIR** storms is peaked at highest L*, **RB restoration is adiabatic below L^*=5.5**

Figure 8



Summary

- **Similar** levels of **chorus activity during CMEs/CIRs**.
- Observe **MLT/storm phase dependence** of **chorus wave power.**
- **Wave power follows changing open/closed drift paths of** 10s of keV **source electrons** during storm times.
- **Stronger, earlier, and deeper** penetrating **seed e⁻ enhancements** during **CME storms**.
- **Greater likelihood** of **overlap** between **seed** enhancement and **chorus during CME storms**.
- **Radiation belt enhancement** occurs **more often during CME** storms and reaches **lower L^*.**
- **PSD profile of CME RB enhancement** has **signs of local acceleration.**
- **Larger seed enhancement** is possibly driven by **greater substorm activity** and **convection in CME storms**.