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

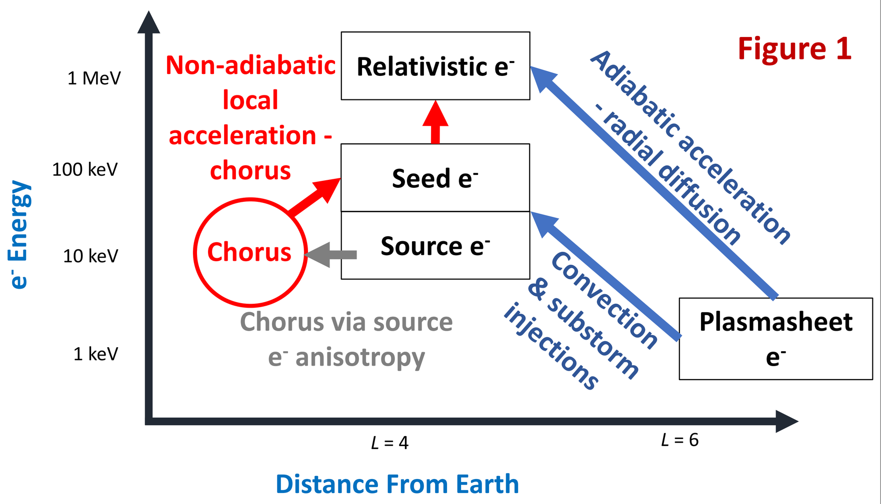
S. Bingham[1], C. G. Mouikis[1], L. M. Kistler[1], K. Paulson[1], A. J. Boyd[2], C. L. Huang[1], C. Farrugia[1], H. E. Spence[1], C. Kletzing[3]

[1]SSC, Eos, Univ. of New Hampshire, Durham, USA, [2]New Mexico Consortium, Los Alamos, New Mexico, USA ,
[3]Department of Physics and Astronomy, University of Iowa, Iowa City, Iowa, USA.

Introduction

- Whistler mode chorus waves can contribute to the outer radiation belt by accelerating seed electrons (100s of keV) to higher energies.
- The temperature anisotropy of source electrons (10s of keV) provides free energy for chorus waves.
- Source & seed electron access to the inner magnetosphere increases during storm times and 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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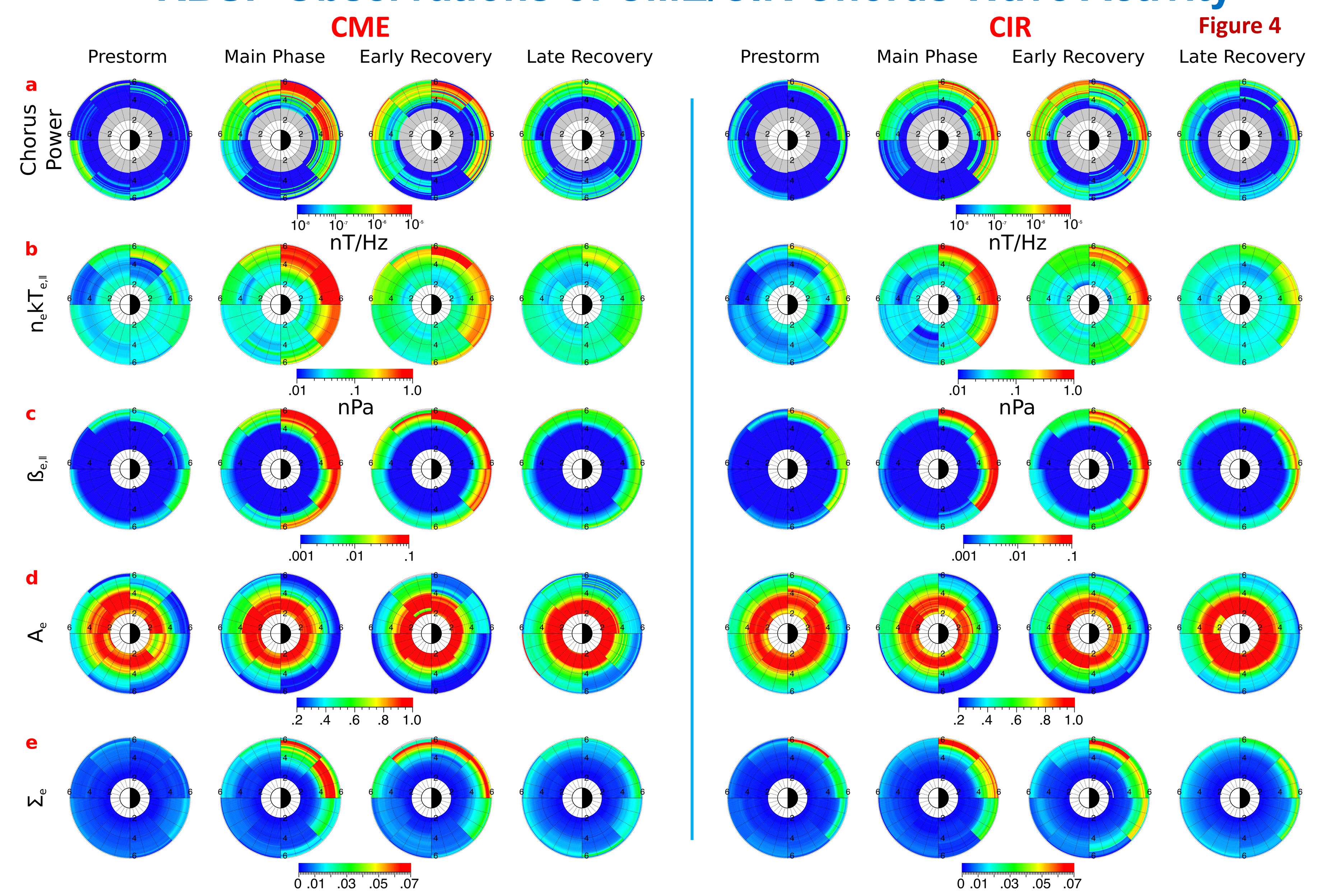
Boyd, A. J. et al., (2016), Statistical properties of the radiation belt seed population, JGR SP, doi:10.1002/2016JA022652.
Gary, S. P. et al., (2005), Electron anisotropy constraint in the magnetosheath: Cluster observations, GRL, doi:10.1029/2005GL023234.
Spasojevic, M. (2014), Statistical analysis 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** $\beta_{e,\|}$:

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

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

- **Chorus power is comparable between CMEs/CIRs – agrees with *Spasojevic* [2014].**
- **Chorus strongest** in **main phase** on **dawn/pre-dawn** sector. In **recovery**, **wave power decreases** but **spreads across dayside**.
- **Location of growth proxy**, Σ_e, **correlates well with measured chorus** power.

- **Chorus activity follows drift path of source electrons**
- **Source electrons** (1-60 keV) **quickly reach dawn** w/ **enhanced convection** of main phase.
- **In recovery periods**, **source electrons drift across the dayside**, however their overall **flux levels drop as** some drift out through the dayside as **open/closed drift boundaries change**.

Data and Storm Selection

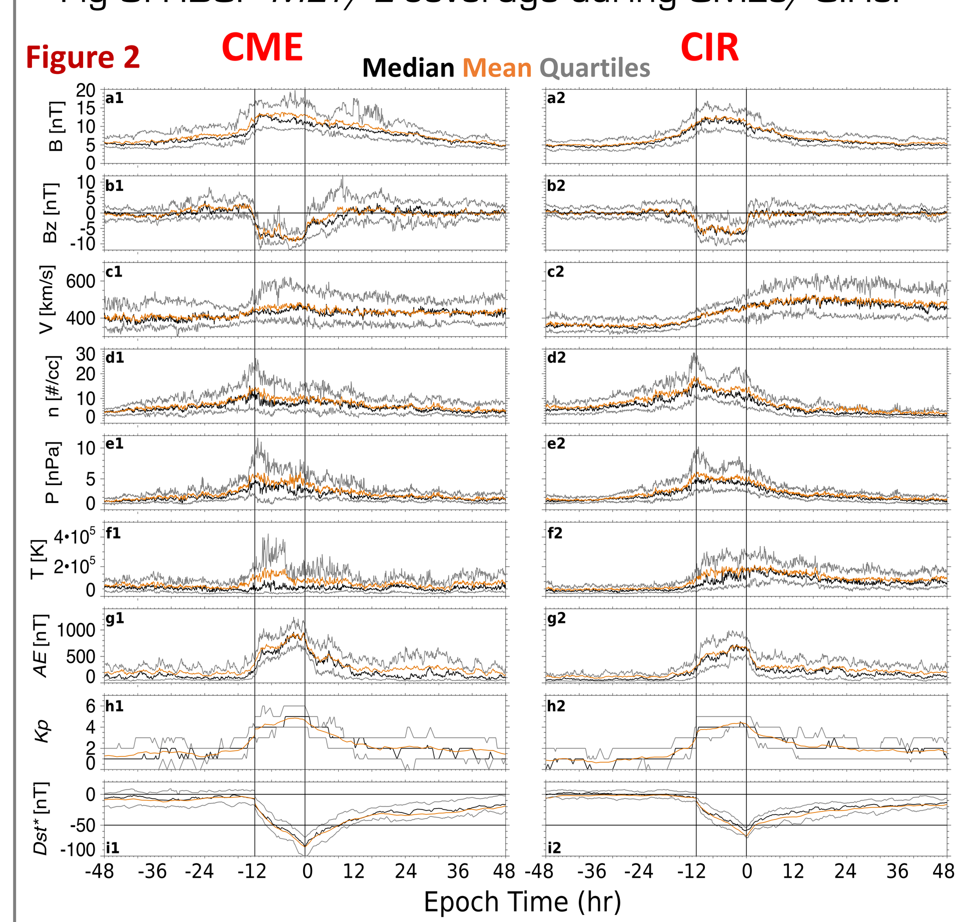
Van Allen Probes

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

Storm Selection

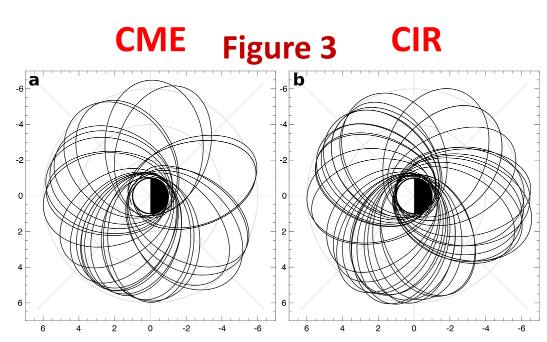
- **25 CME** and **35 SIR/CIR Storms** are **identified between 2013-01-01 and 2016-04-16** with a minimum *Dst** between -50 and -150 nT.
- Storm selection **required a single identifiable driver** (CME/CIR). Periods after the start of a second dip in *Dst* were not used.
- Fig 2: **median**, **mean**,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

Figure 2



- **CMEs** displayed a **lower** n, v_{sw}, **and** T_{sw} than CIRs.
- **CMEs** had **more substorm activity** and **stronger convection**.

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 in 3 different L^* ranges.
- Figure 7: Flux change from prestorm vs L^*.
- Epoch $t = 0$ at min *Dst**, main phase times are normalized to 12 hours.

Figure 5

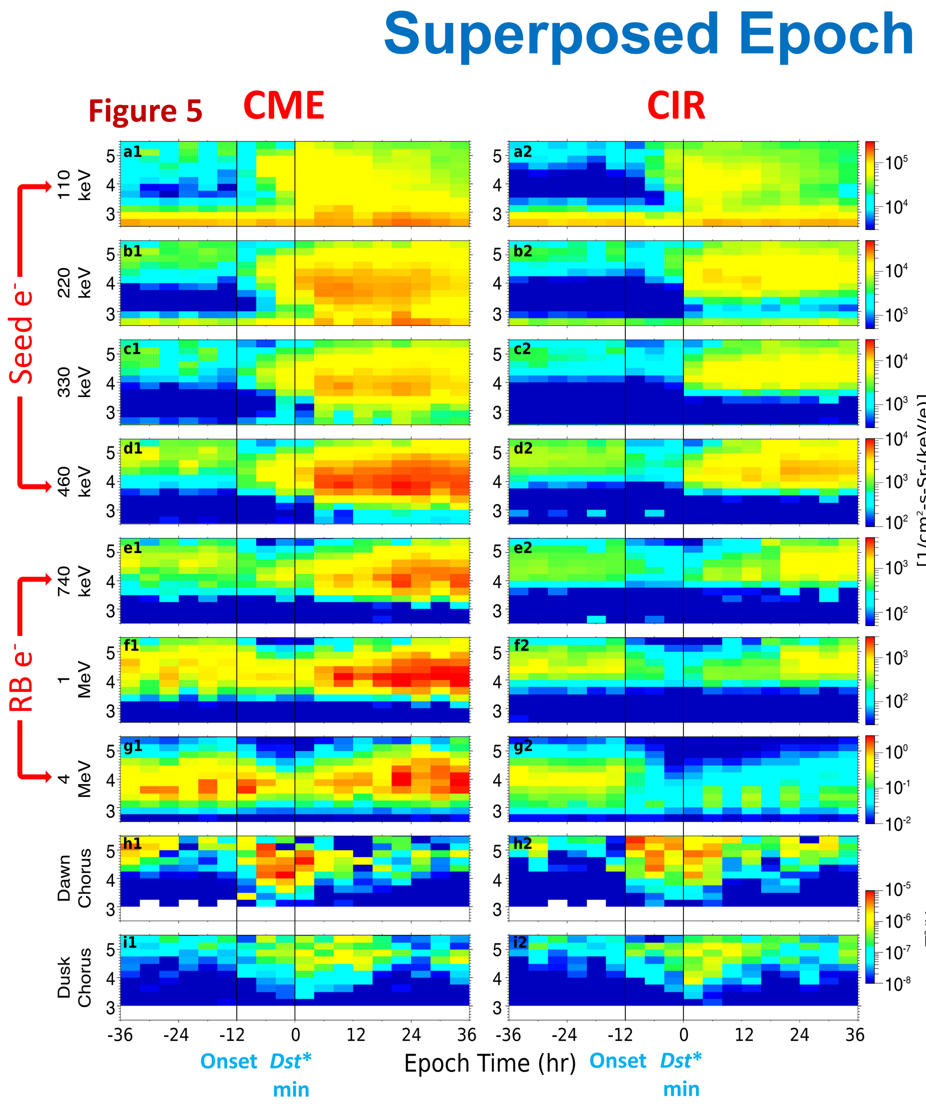
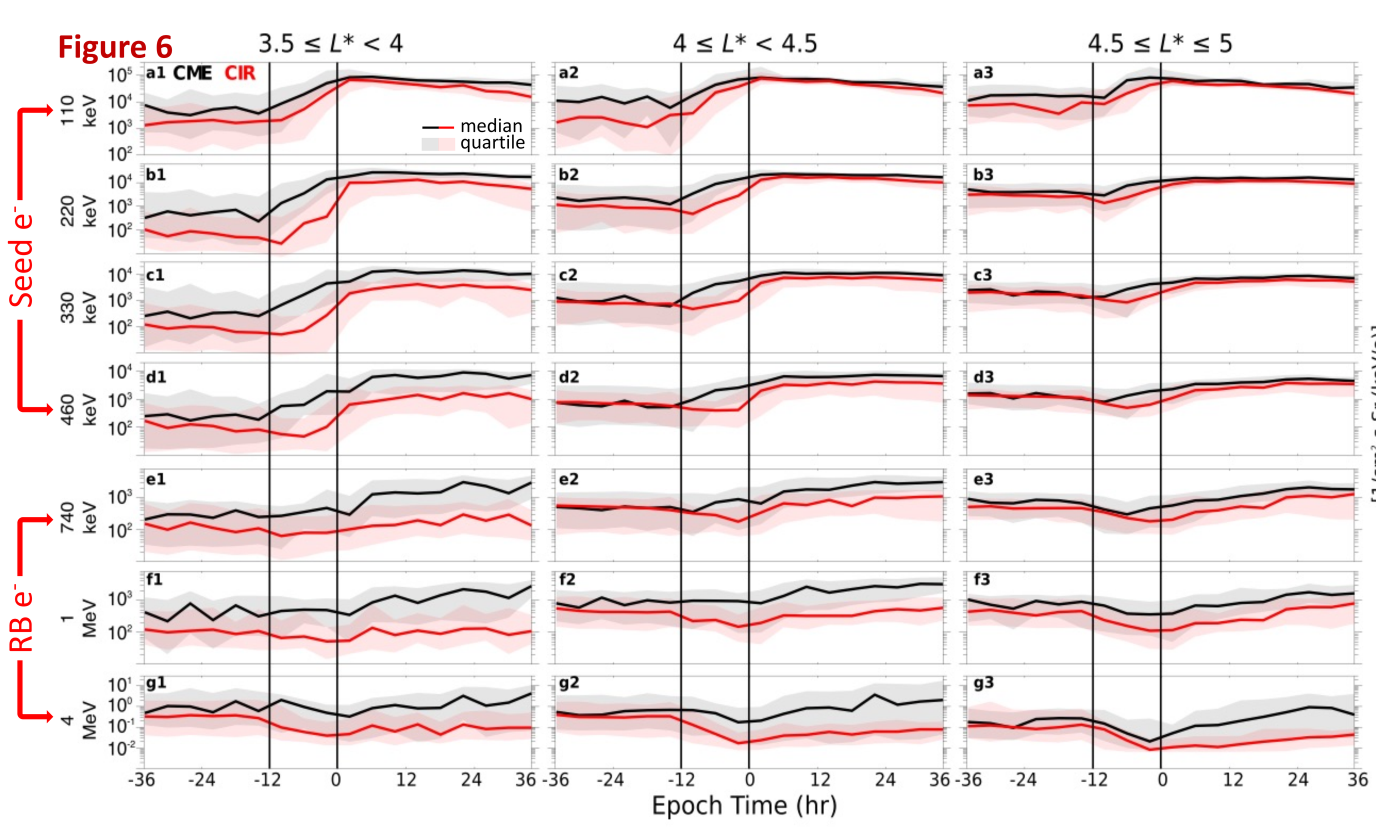
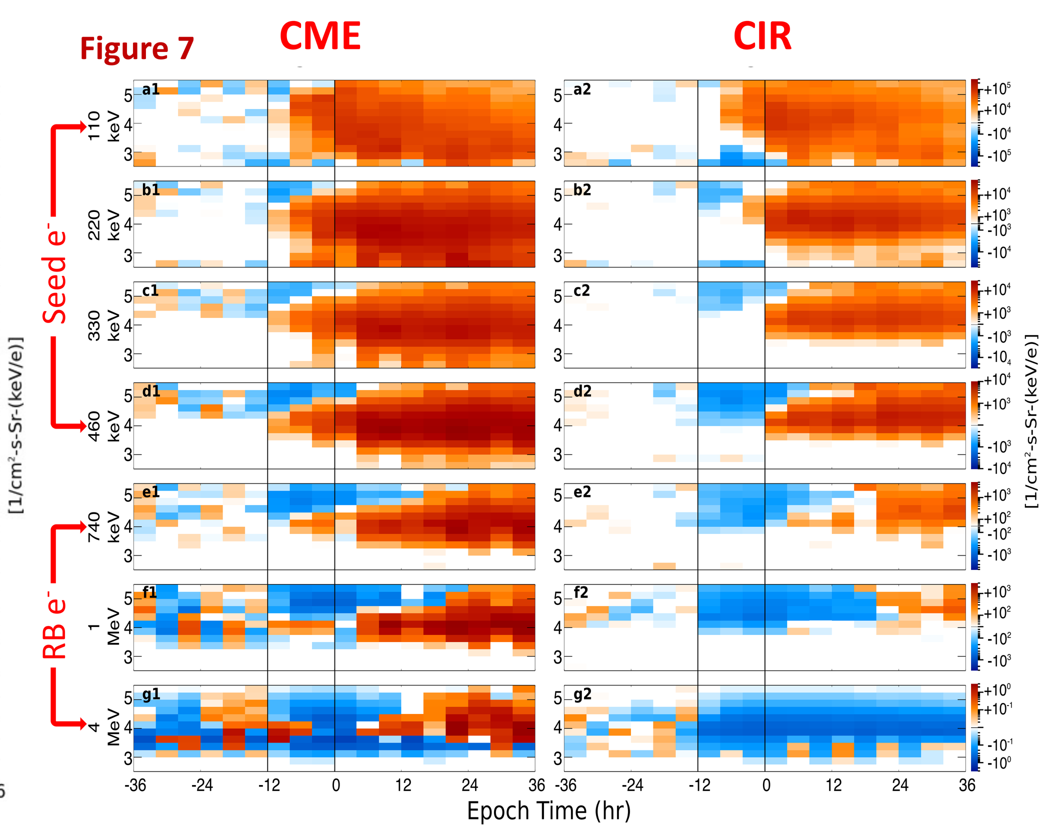


Figure 6



- **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.**

Figure 7



- **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.

Storm Time Phase Space Density

- Gradients of phase space density (PSD) can reveal aspects of the acceleration, transport, and loss of electron populations.
- Figure 8: avg. MagEIS + Rept PSD vs L^* for fixed μ and avg chorus wave power.
- Figure 9: avg. PSD in three different L^* ranges.
- Figure 10: Change in PSD from average prestorm levels vs L^*.

Figure 8

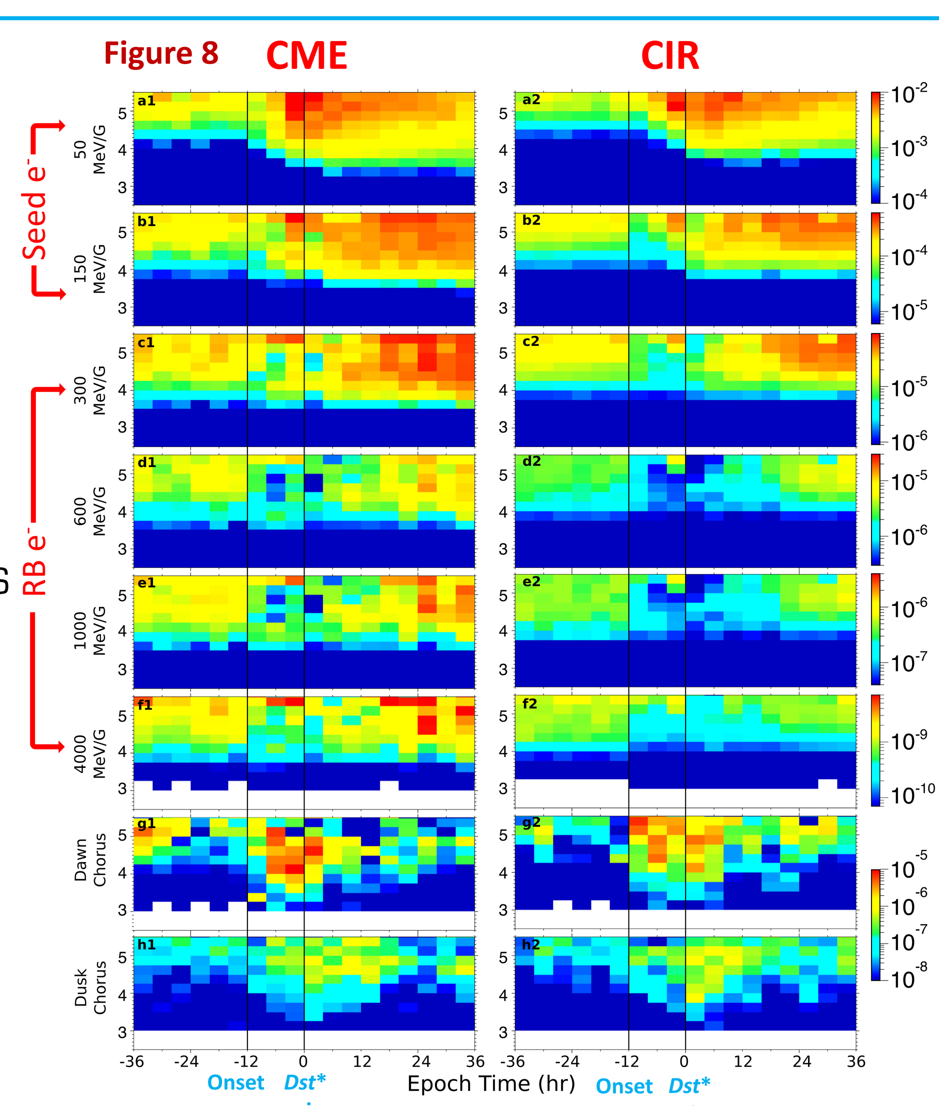
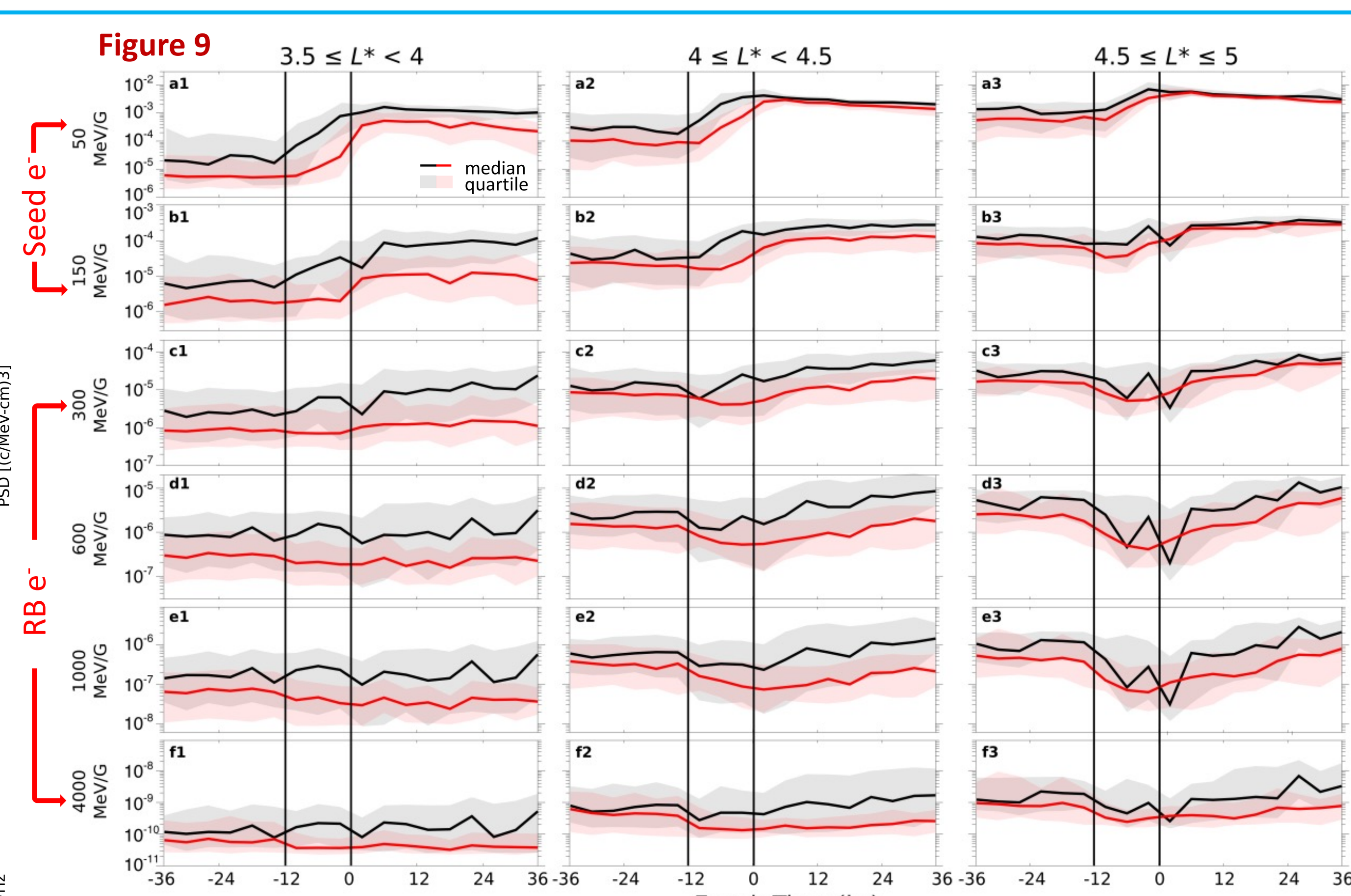
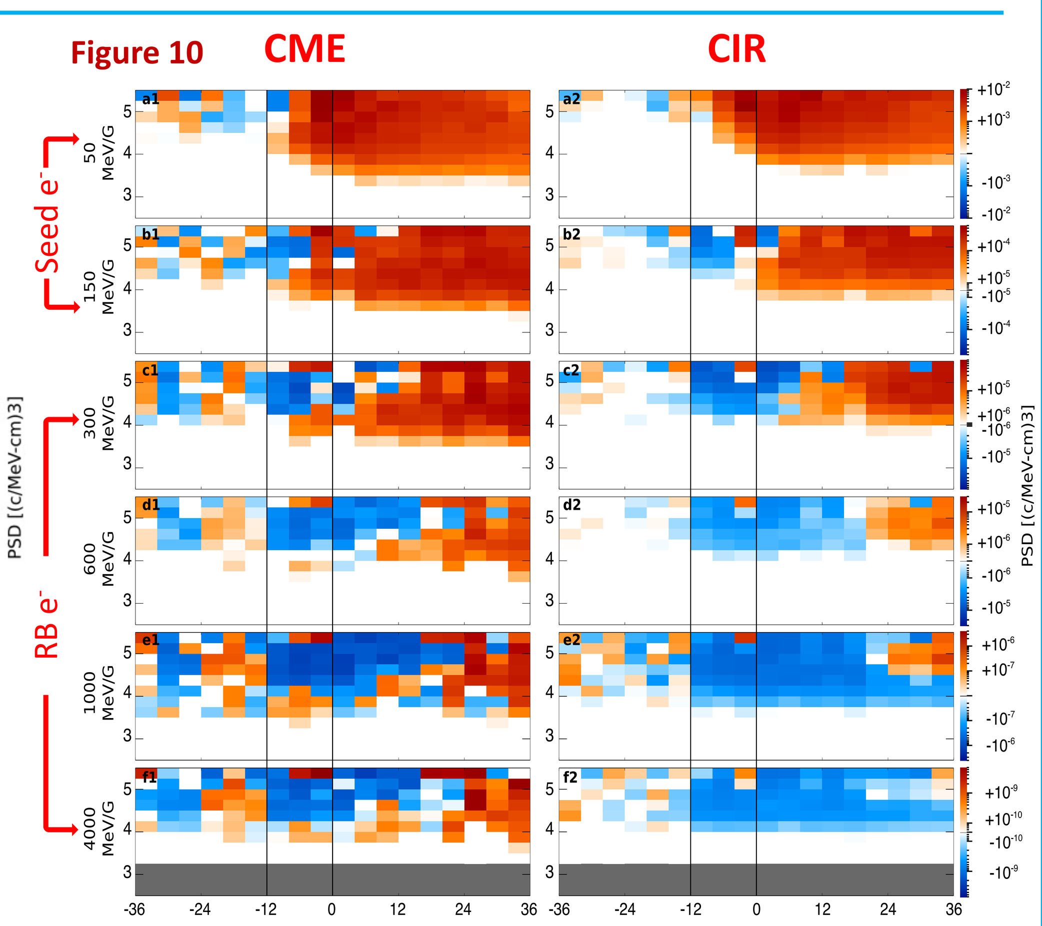


Figure 9



- **Stronger, earlier, deeper seed PSD enhancement in CMEs.**
- **CME 150 MeV/G seed** population **reaches *Boyd et al.* [2015] threshold of 1×10^{-4} (c/MeV-cm)^3 for acceleration earlier and more often.**

Figure 10



- **CME RB population** has a **greater net enhancement,** which **occurs 12-20 hours earlier,** and occurs **at lower L^*. RB enhancement** in **CMEs** is **during time with elevated chorus activity.**
- **PSD profile** of **CME enhancement** shows a bit of a peak at inner L^*.

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 enhancement shows signs of local acceleration**.
- **Larger seed enhancement** is possibly driven by **greater substorm** activity and **convection in CME storms**.