Developing an improved understanding of Earth's outer radiation belt electrons with combined observations from Van Allen Probes + MMS

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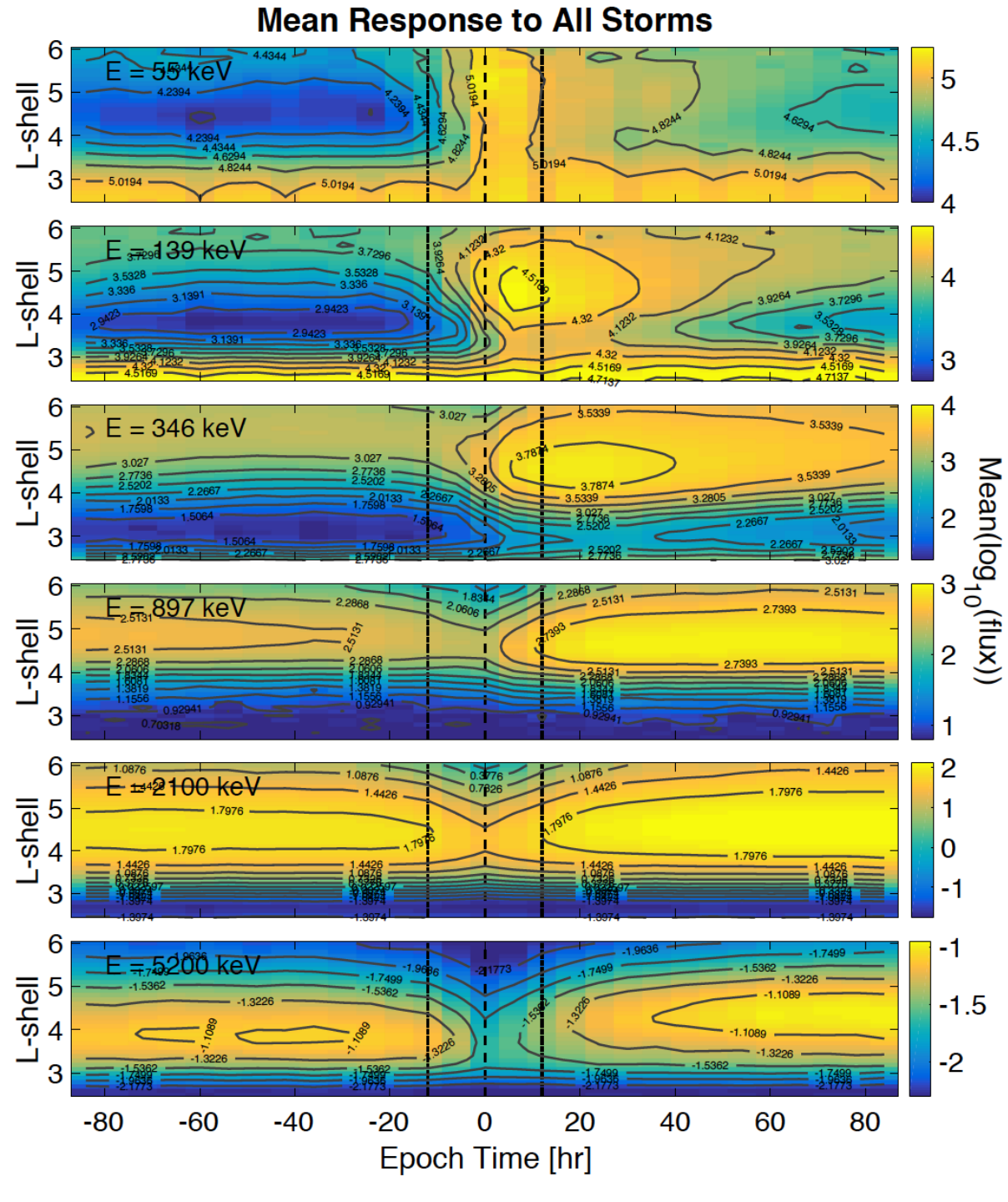
Van Allen Probes SWG
28-31 May 2019

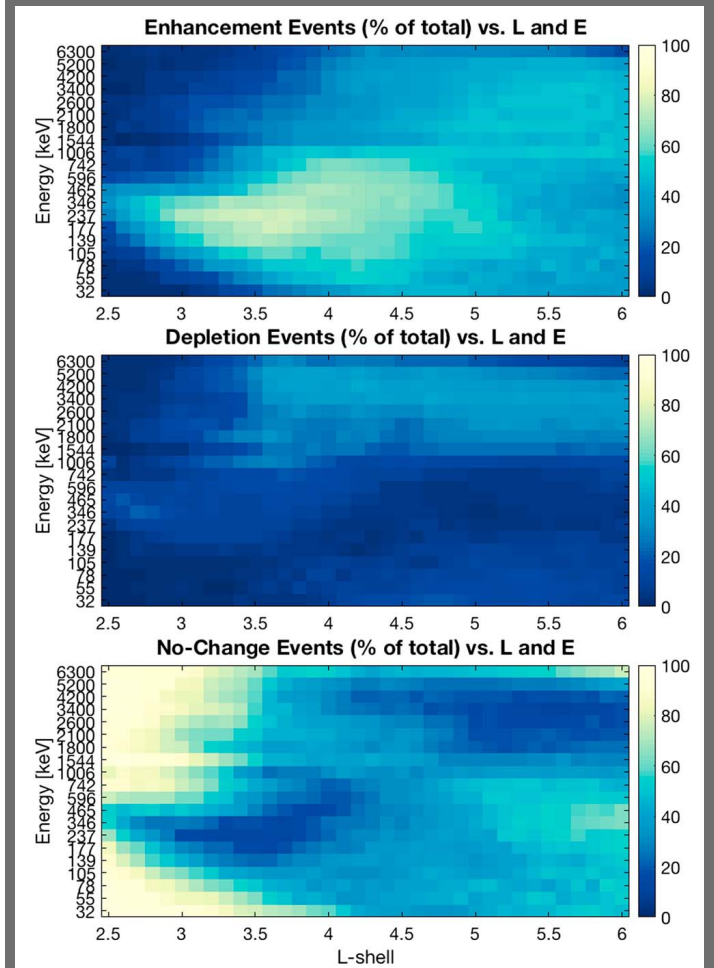


Introduction

Electron radiation belt variability

Earth's radiation belt electrons are highly variable, especially during periods of geomagnetic activity

Figures from Turner et al. [JGR 2019]



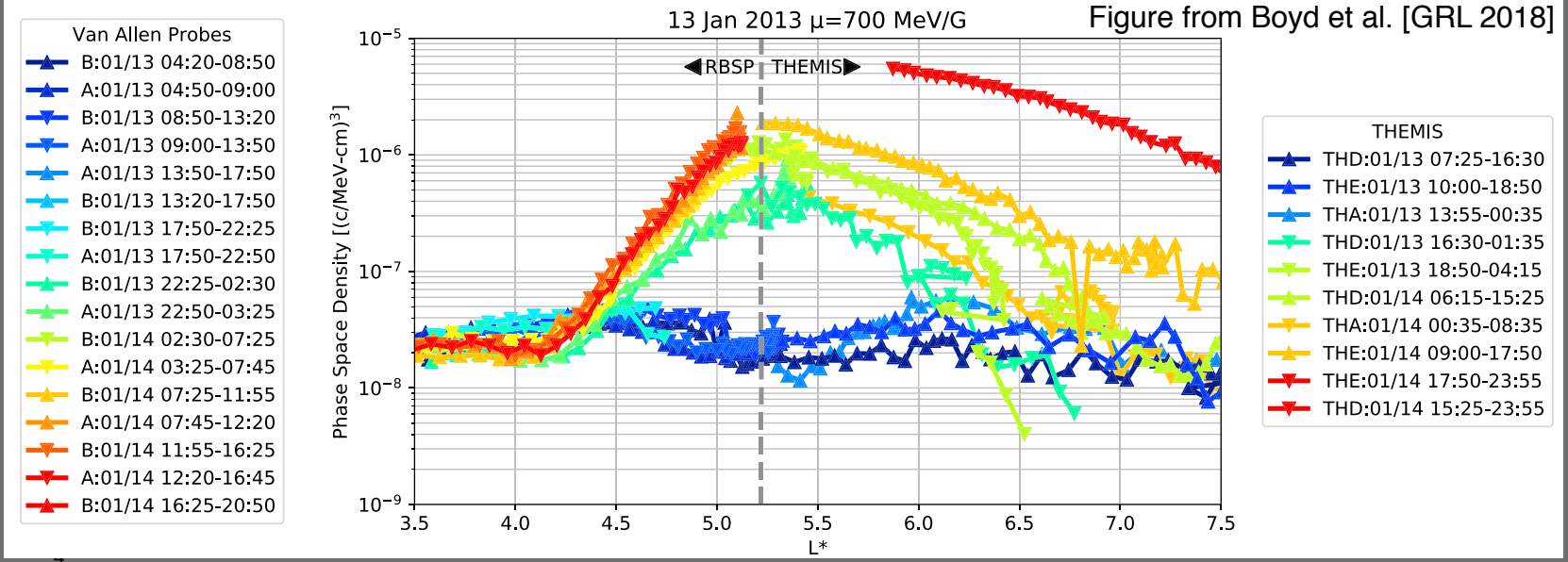
Plots show percentage (in color) of 110 geomagnetic storms that result in outer belt enhancements (top), depletions (middle), or no change (bottom) as a function of electron energy and L-shell

Outer Radiation Belt Enhancements

Electron Radiation Belt Enhancements

Observational considerations

- NASA's Van Allen Probes (RBSP) revolutionized radiation belt science, but…
- RBSP apogees are only ~5.8 R_E
- Key physical processes often occur beyond 5.8 R_E
- Data from missions that observe energetic particles, fields, and waves beyond RBSP apogee can complement RBSP science



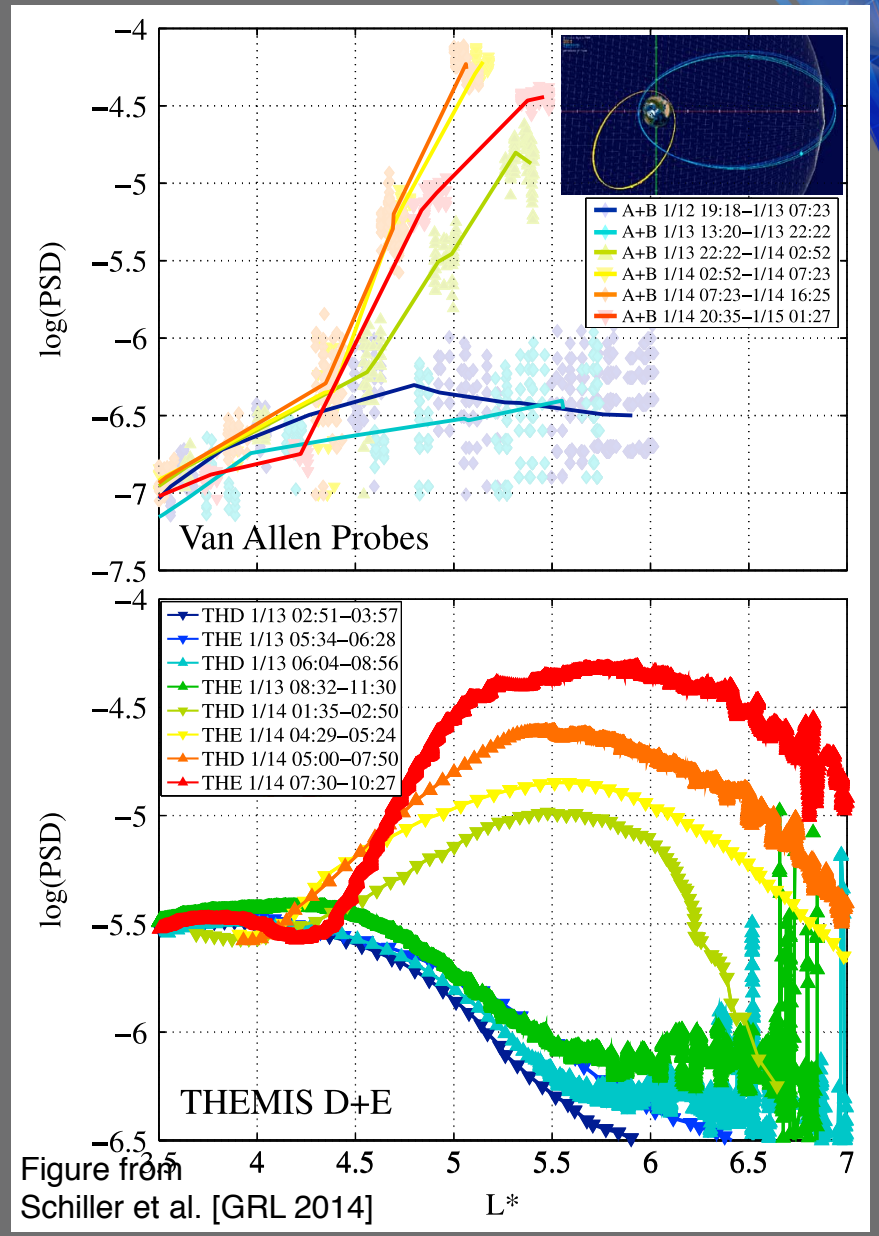
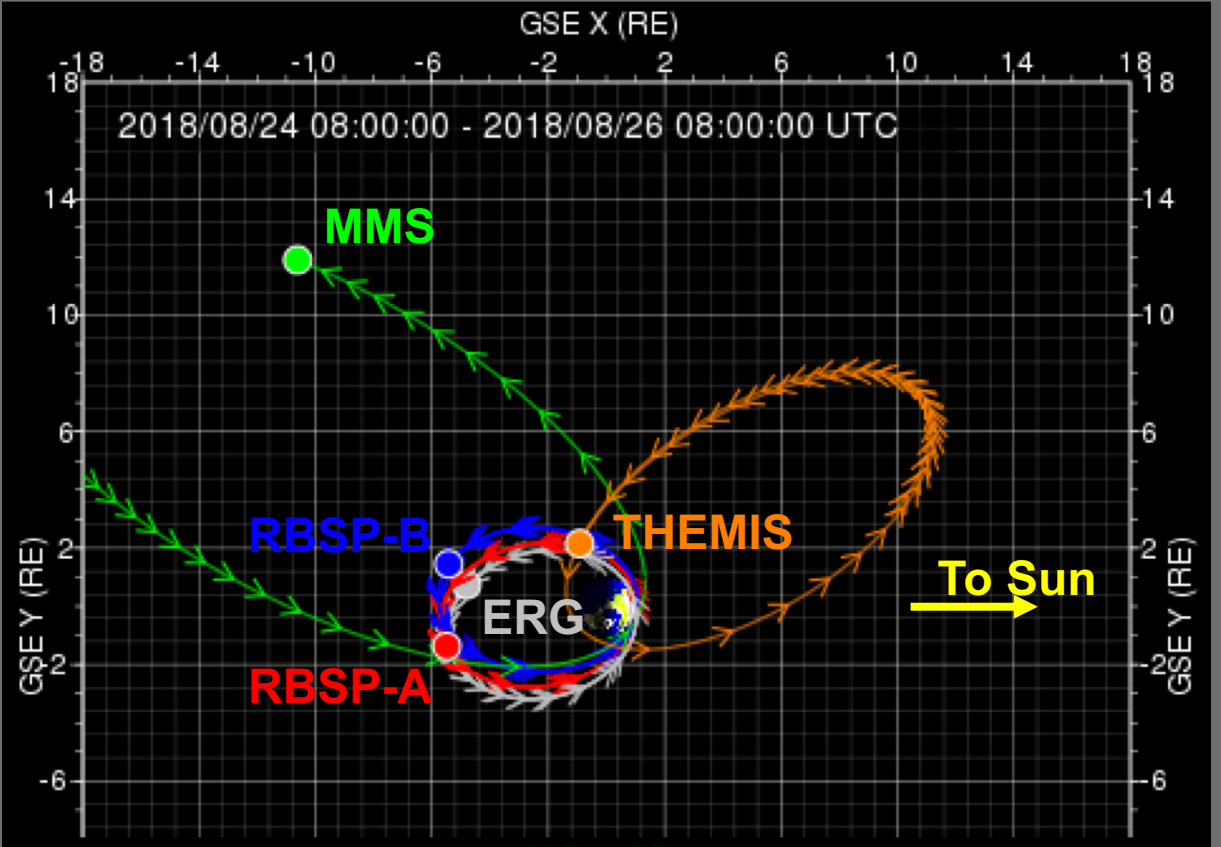
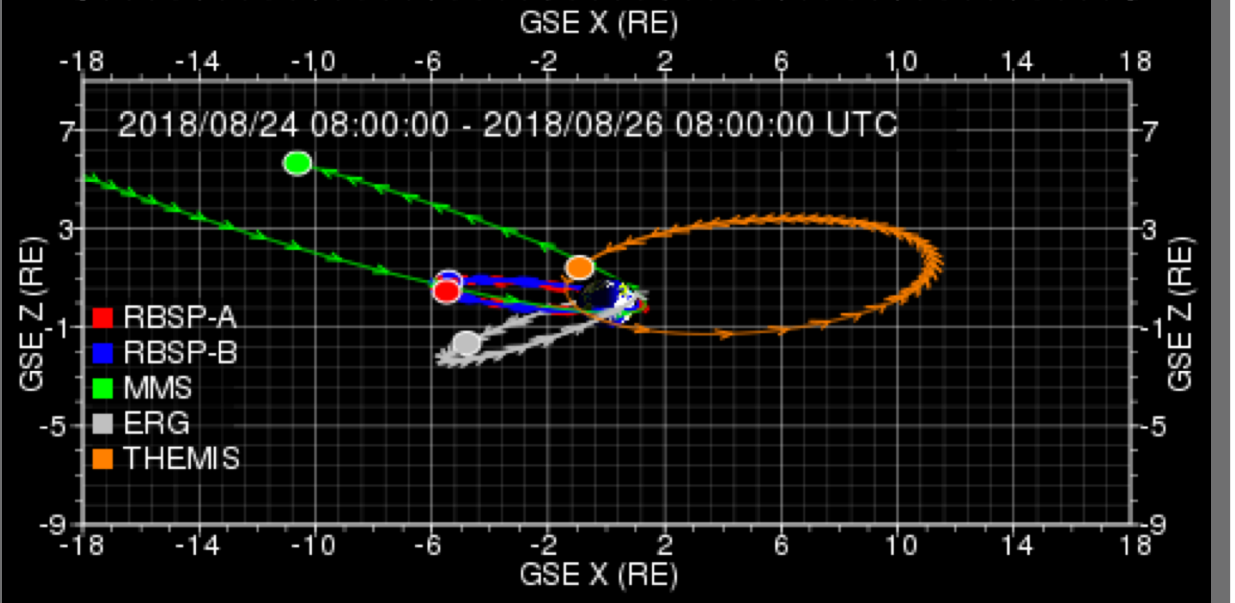


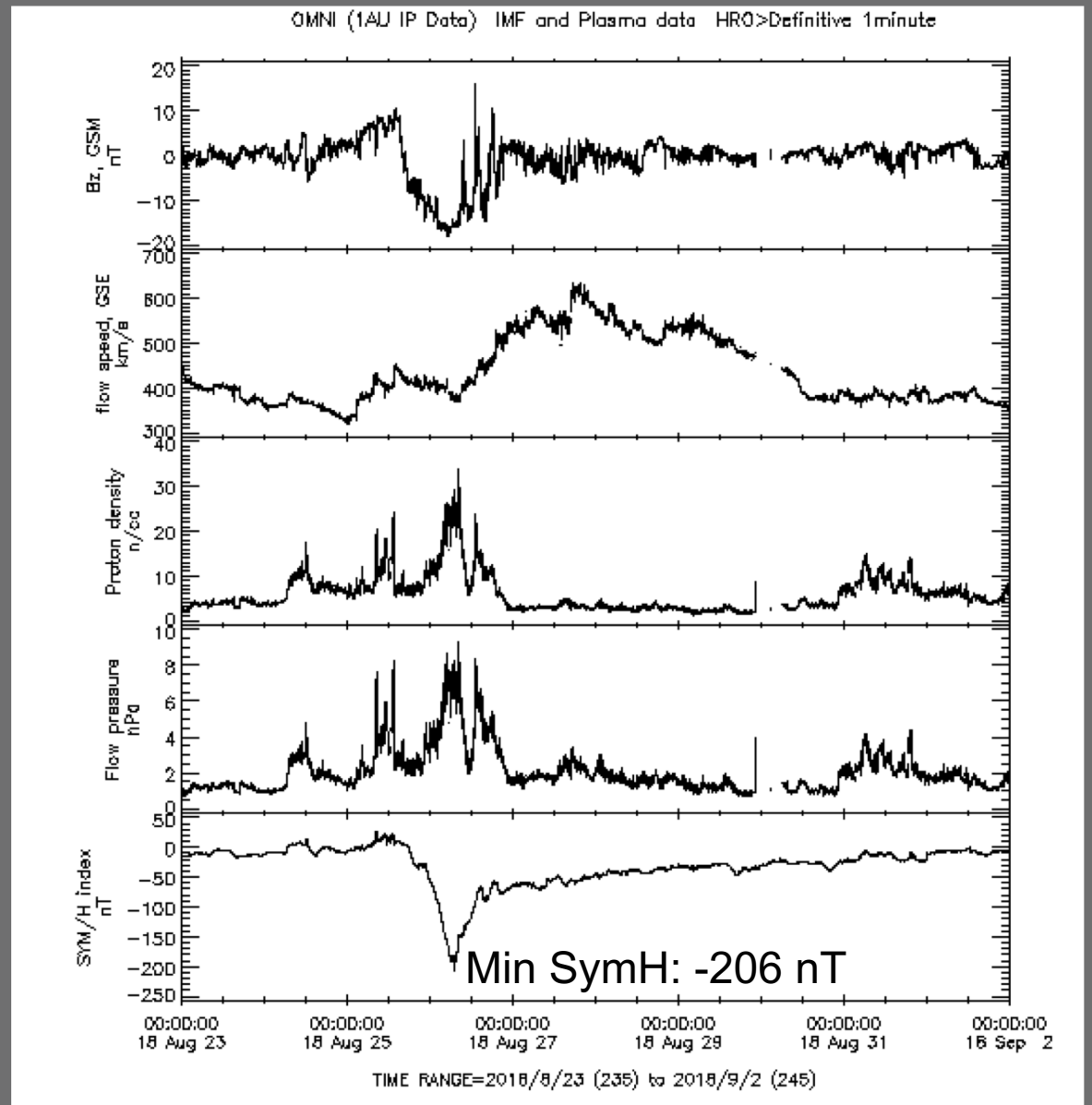
Figure from Schiller et al. [GRL 2014]

Outer Belt Acceleration

Example case: Storm on 26 Aug 2018



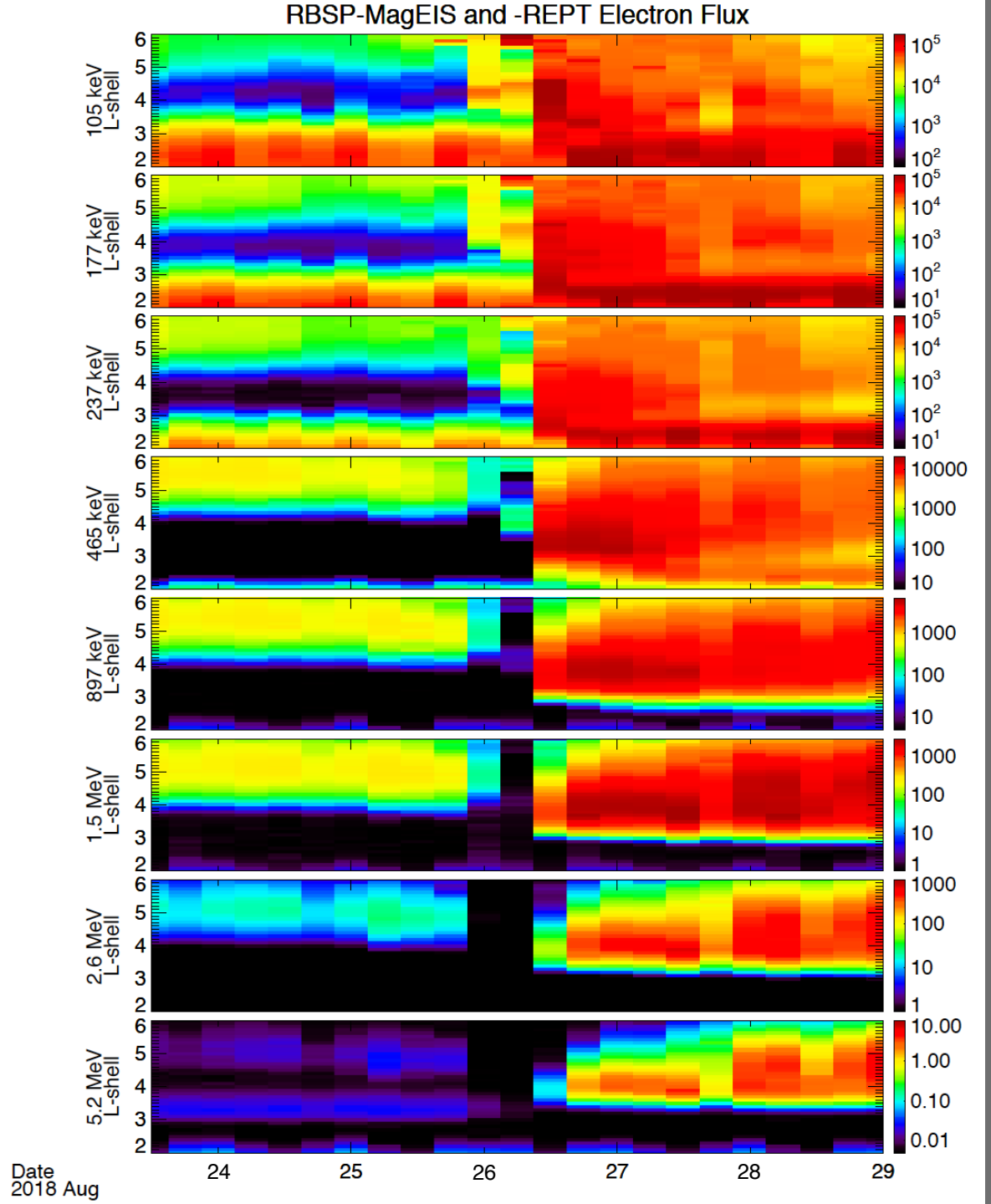


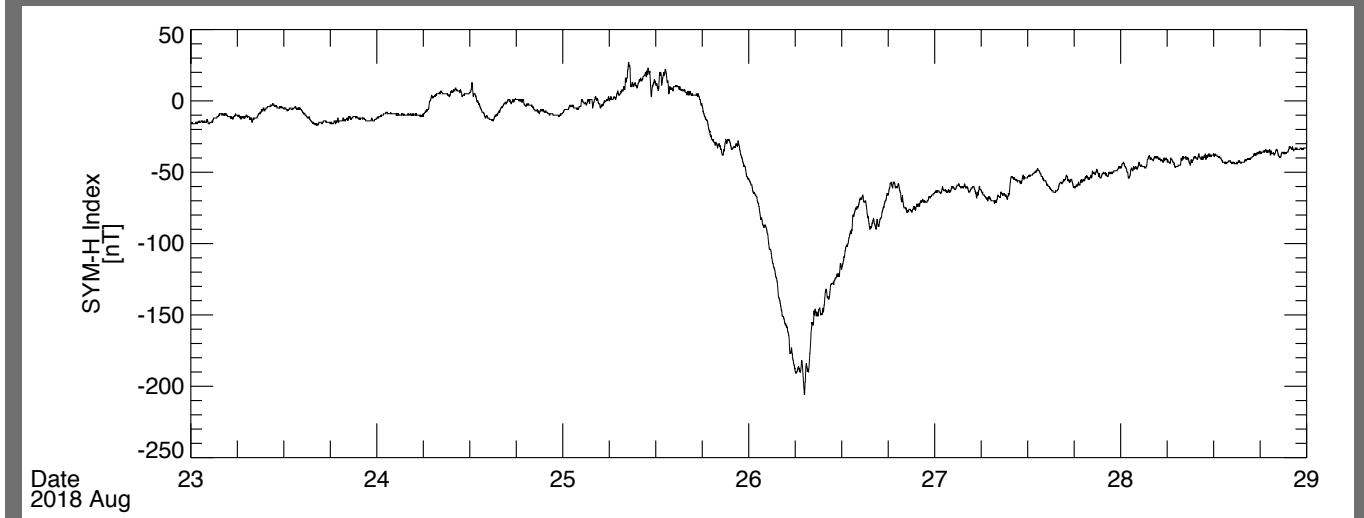


Example Case: Storm 26 Aug 2018

Outer radiation belt response

- Typical outer belt enhancement event; electrons at all energies increase by several orders of magnitude within ~1/2 day of the main phase of the storm

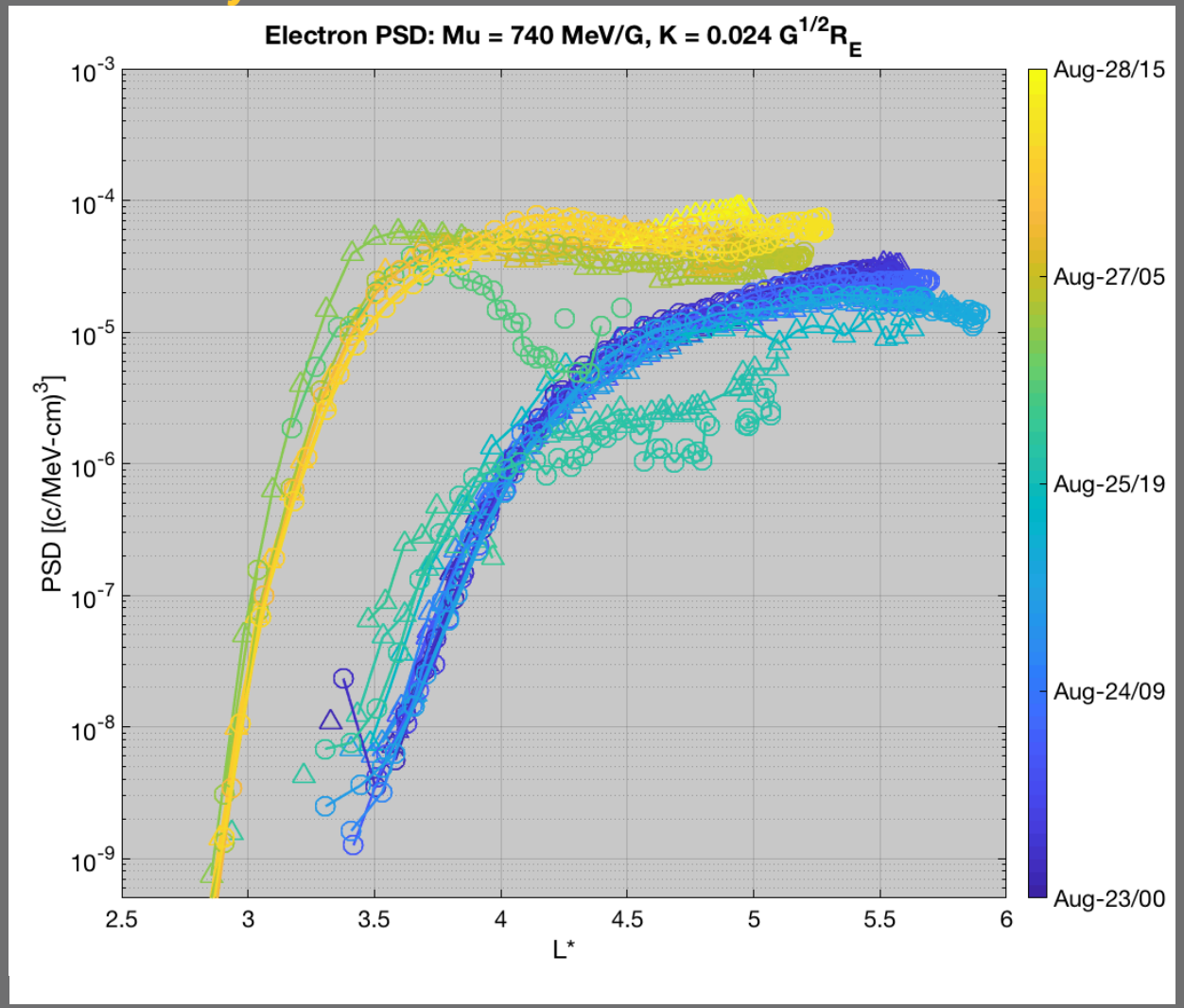




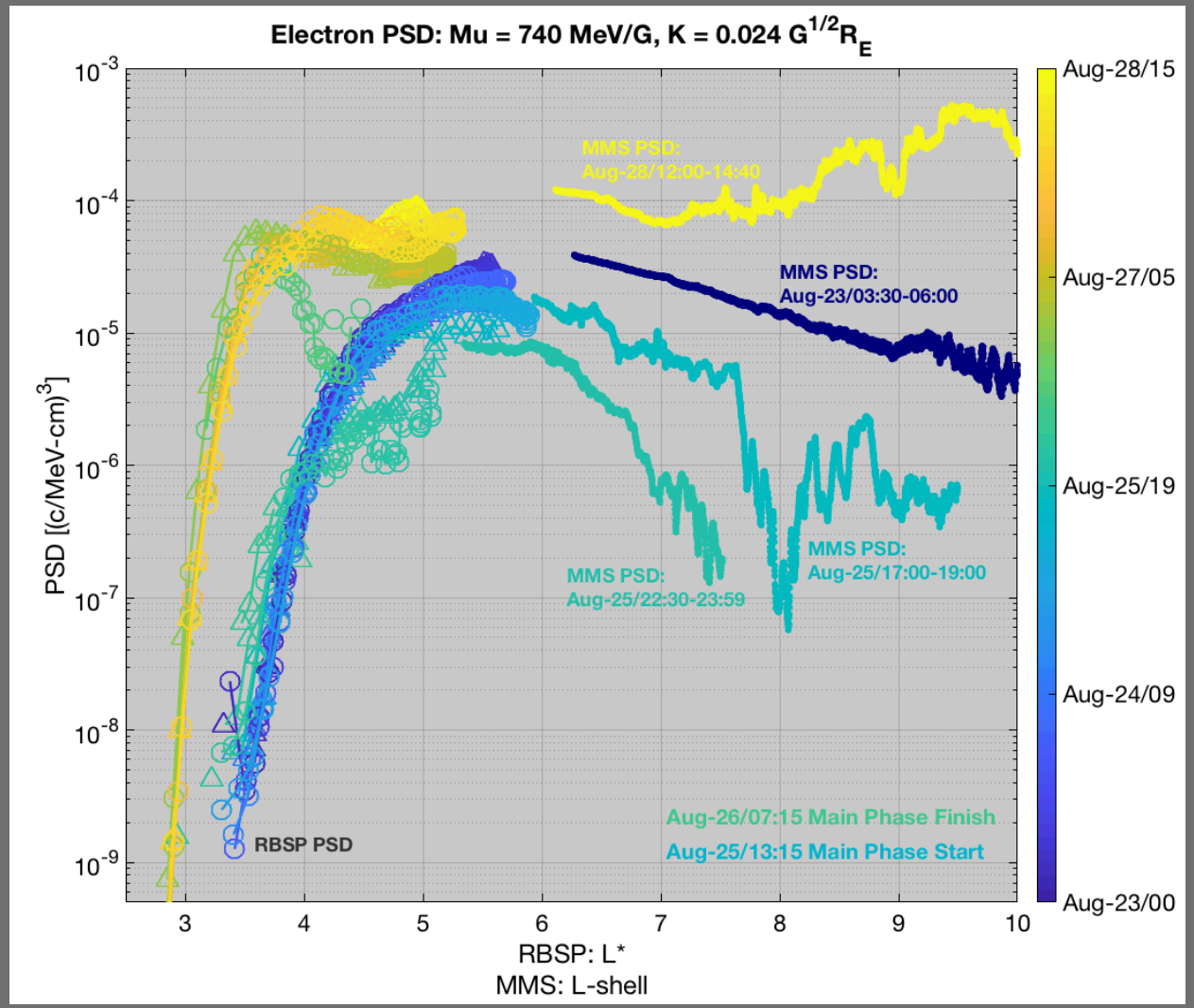
Example Case: Storm 26 Aug 2018

Phase space density analysis

RBSP Only

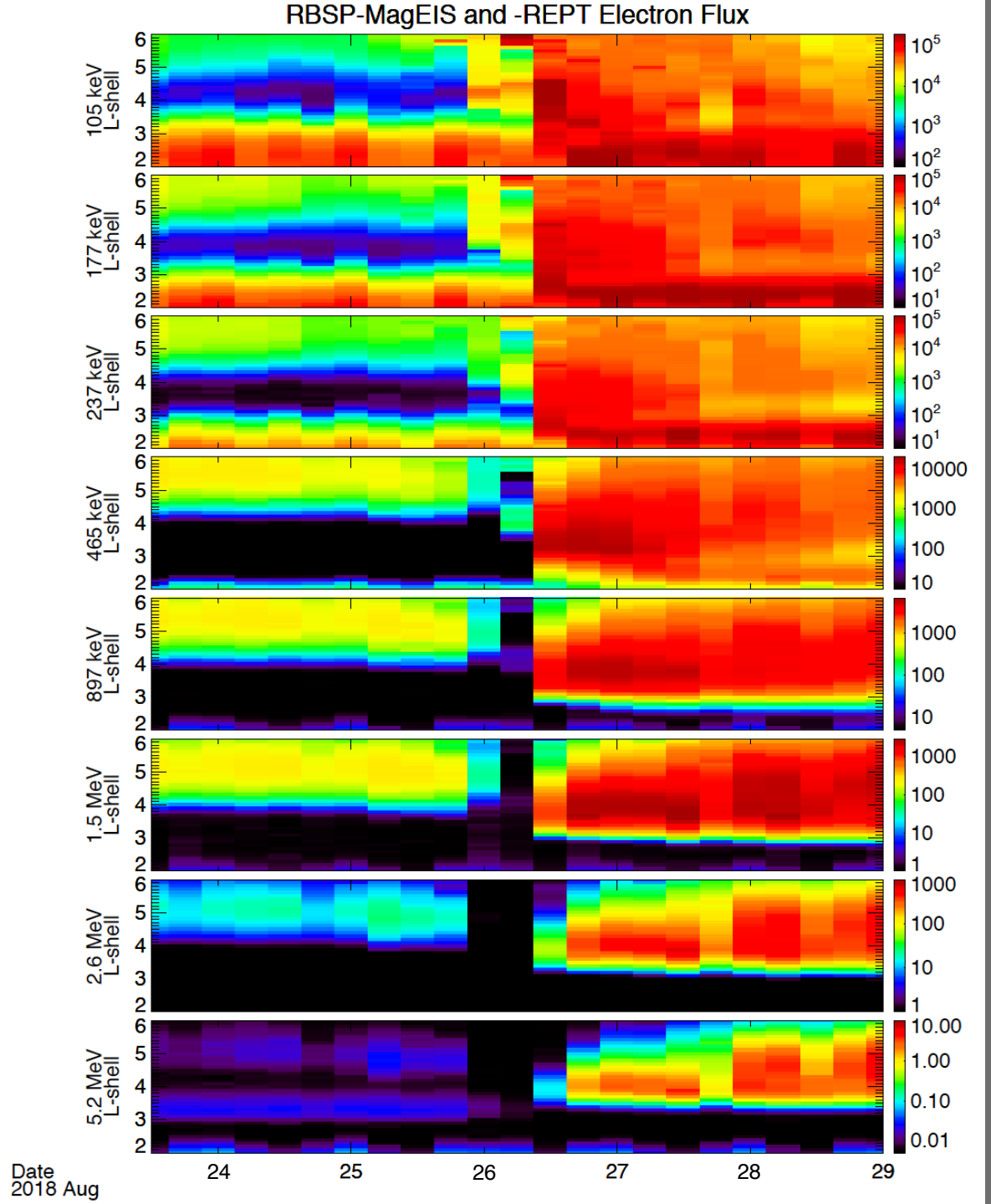


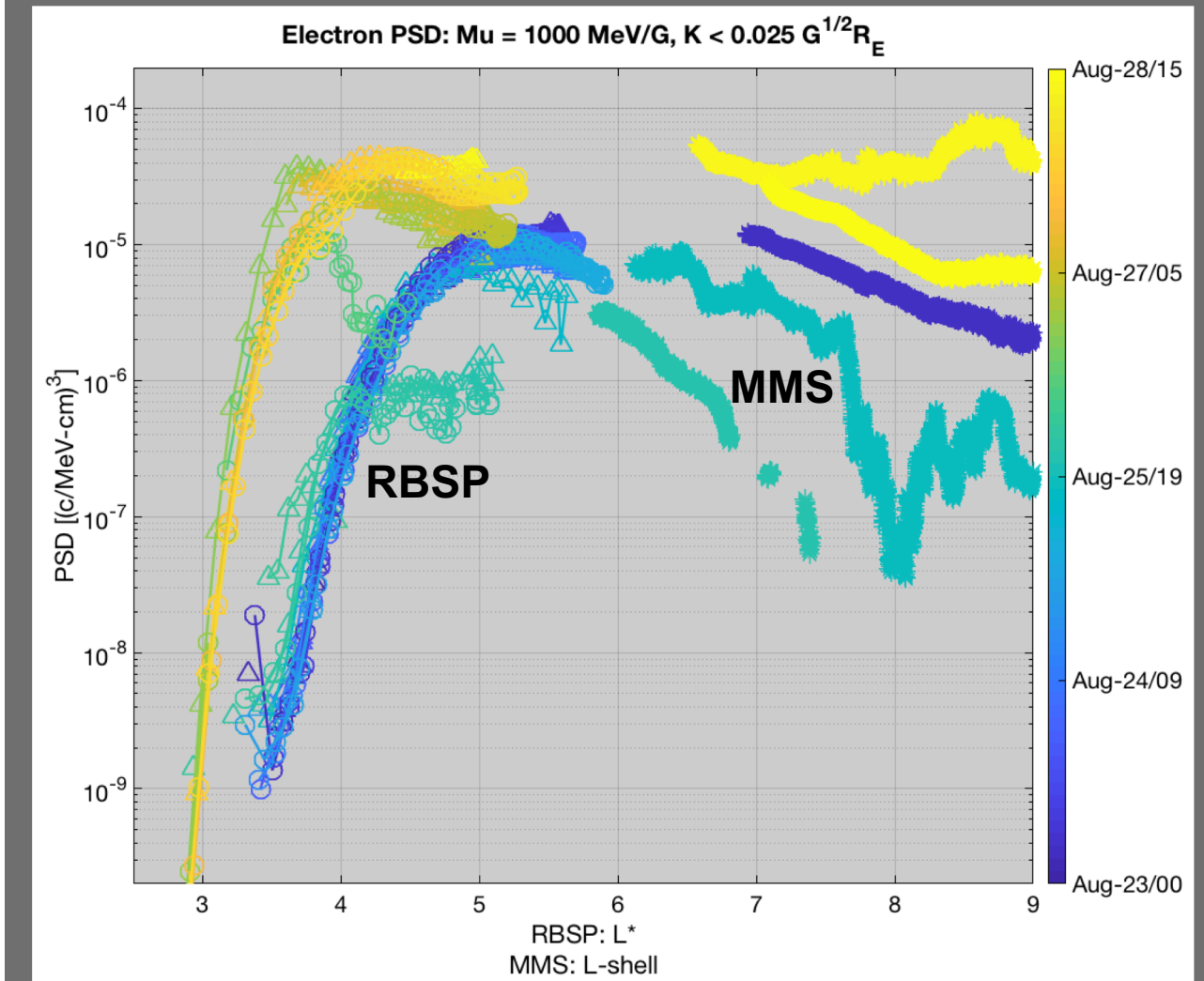
RBSP and MMS



Example Case: Storm 26 Aug 2018

Phase space density analysis





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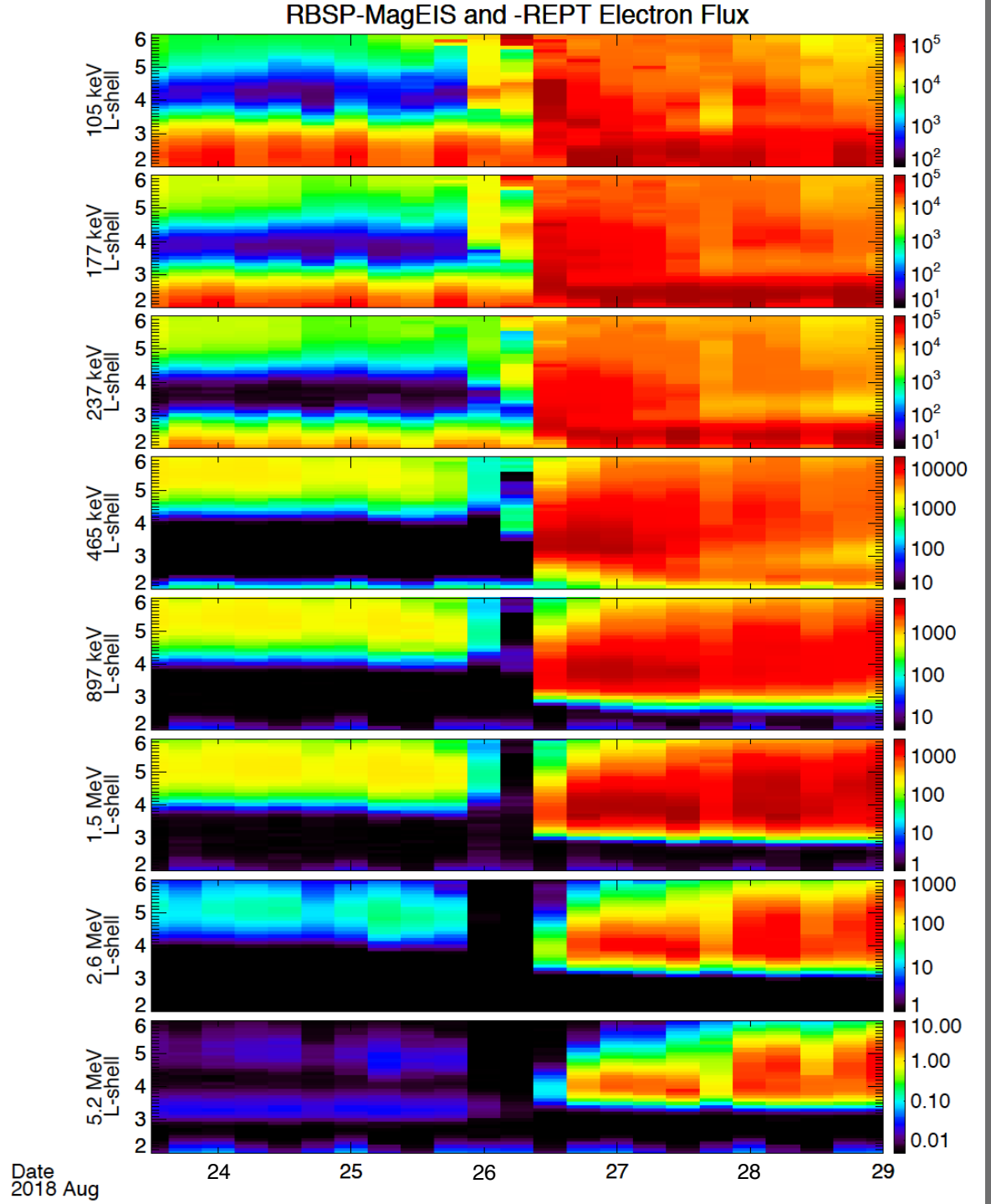

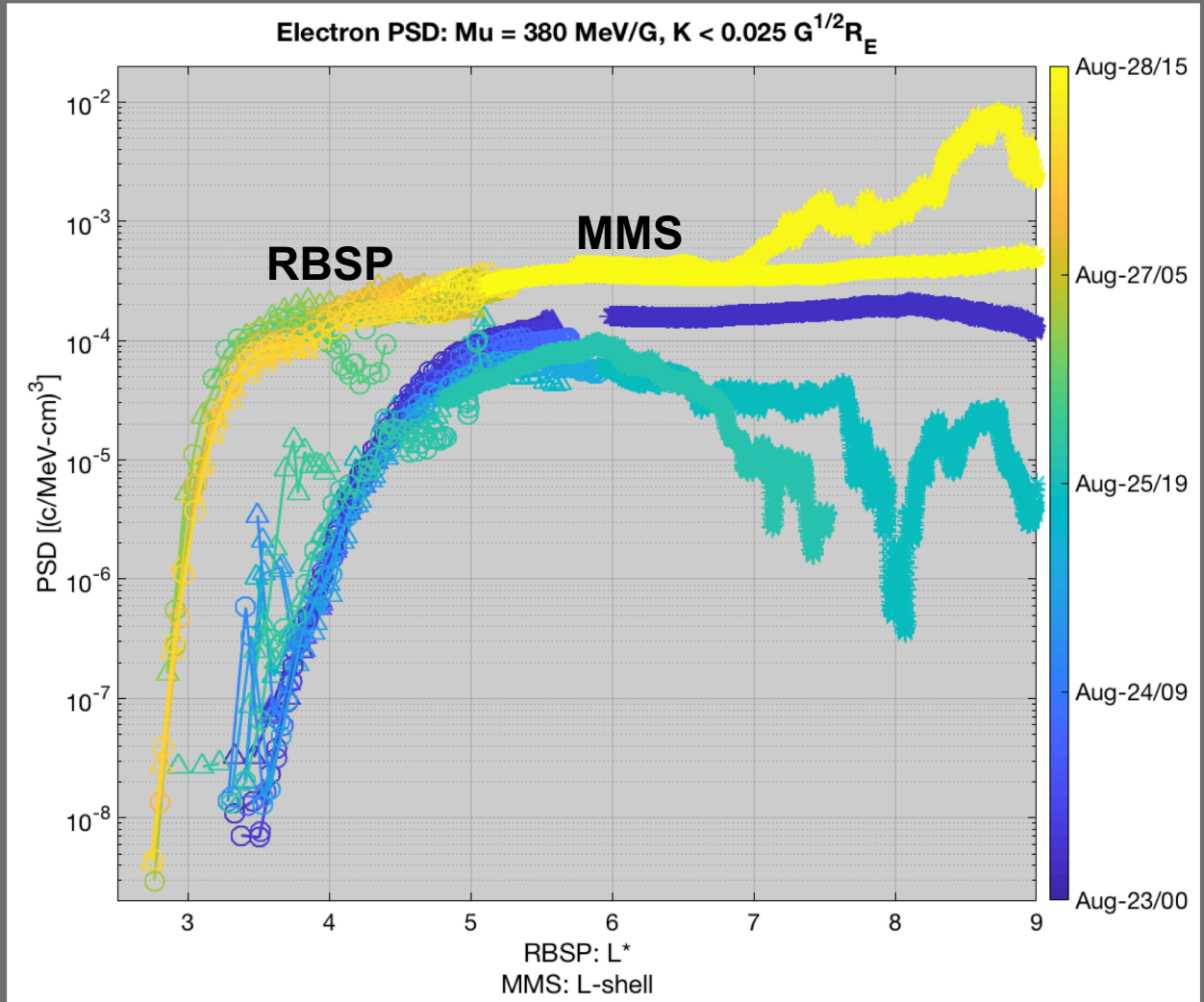

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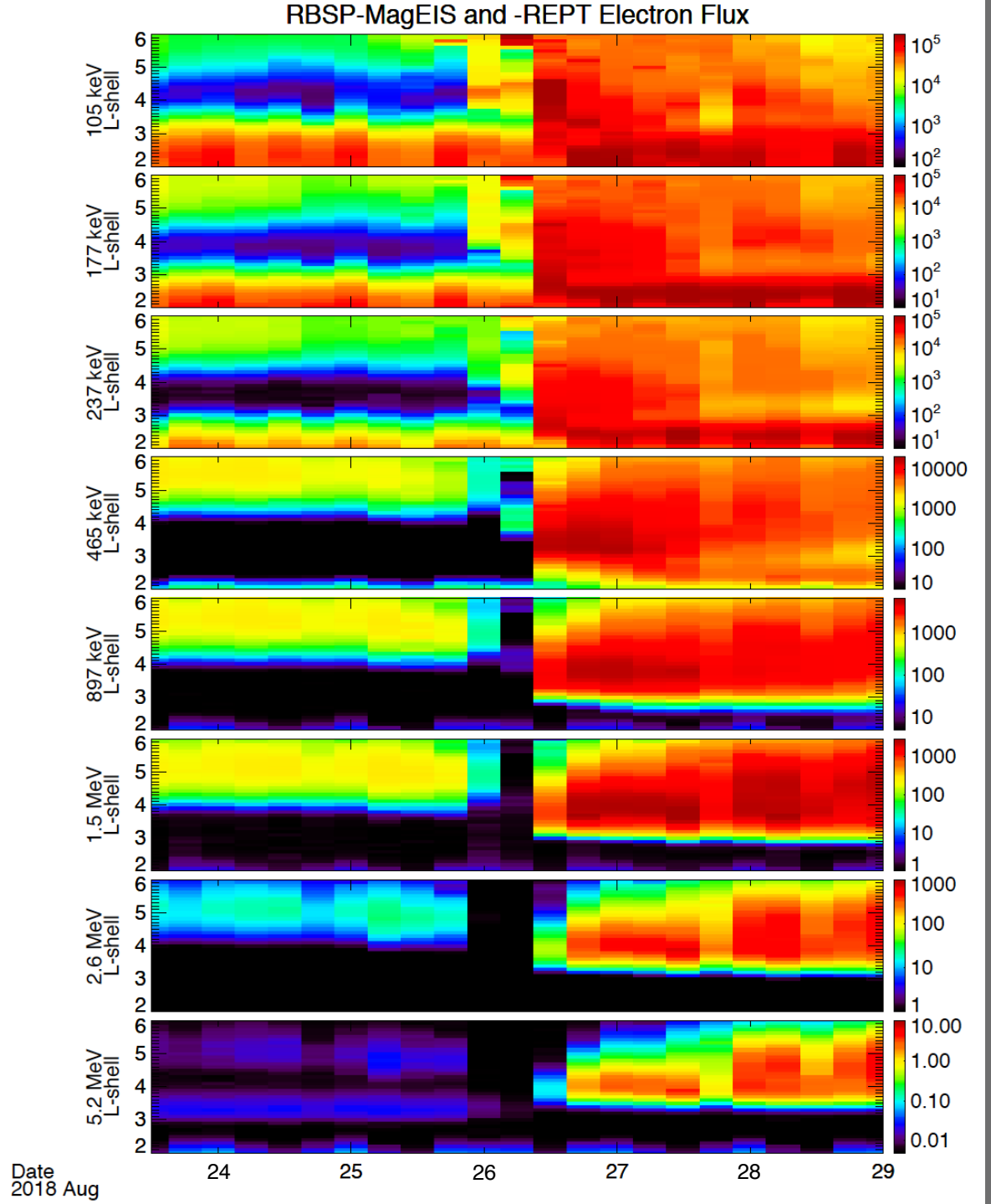
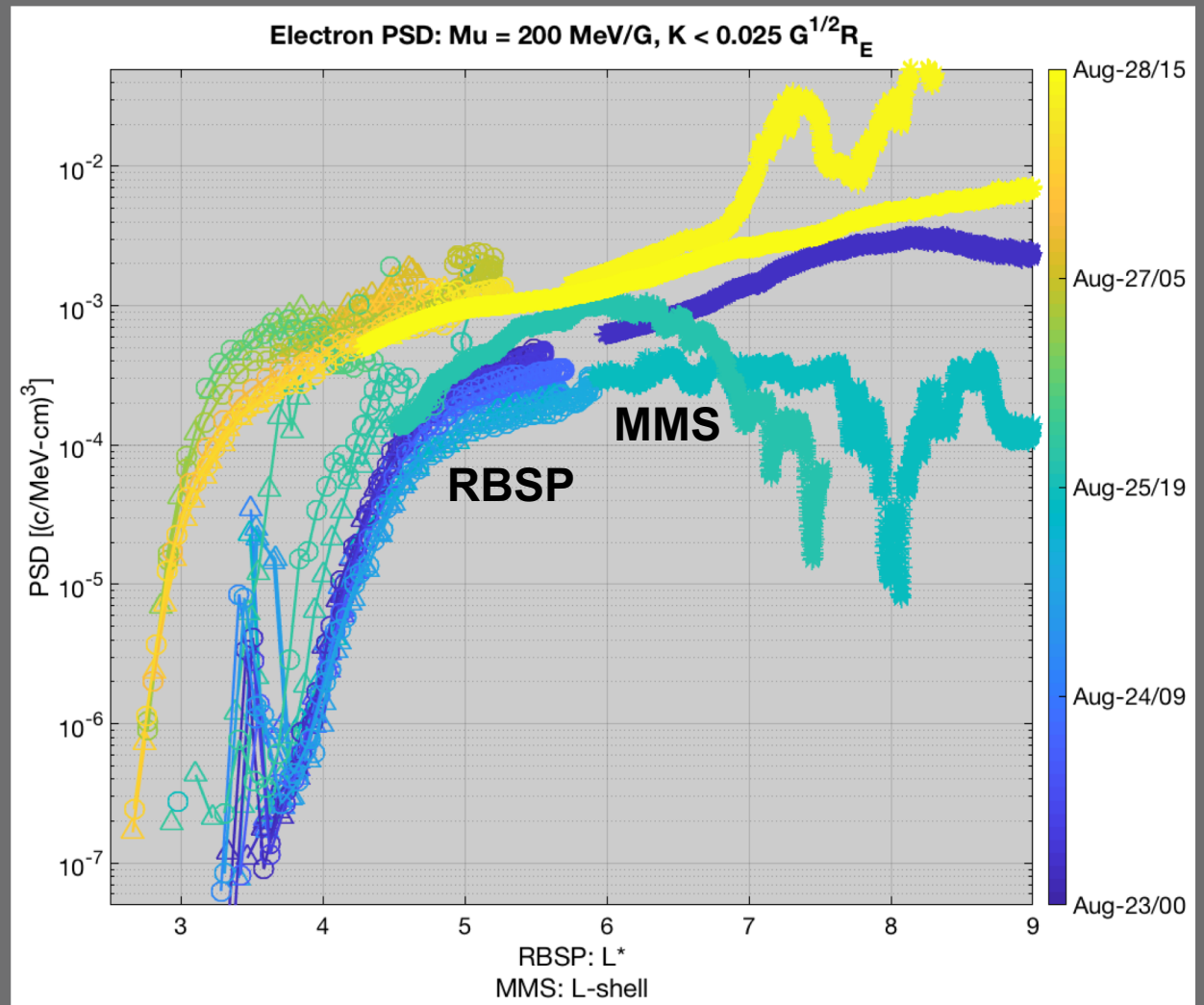
Phase space density analysis





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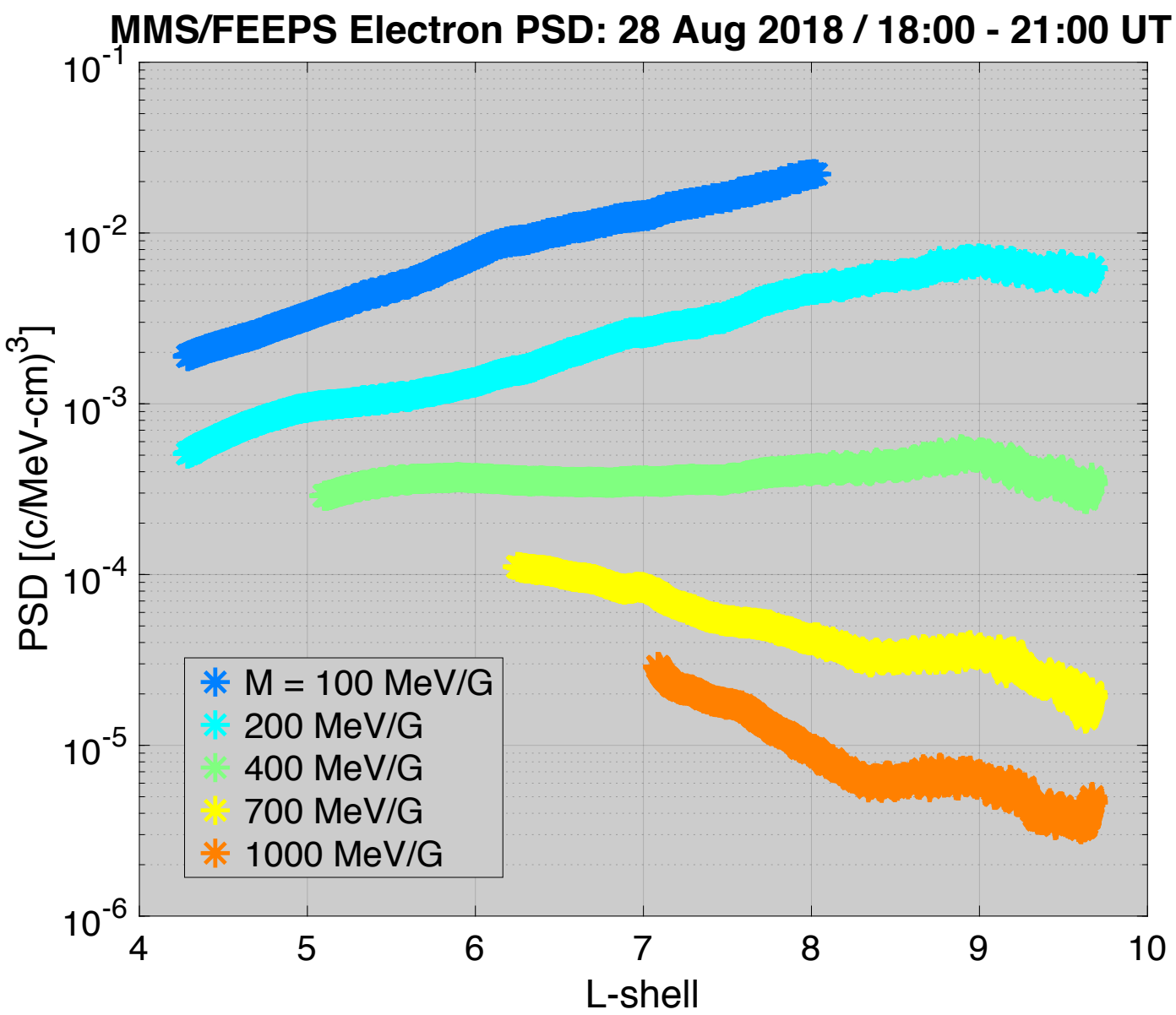
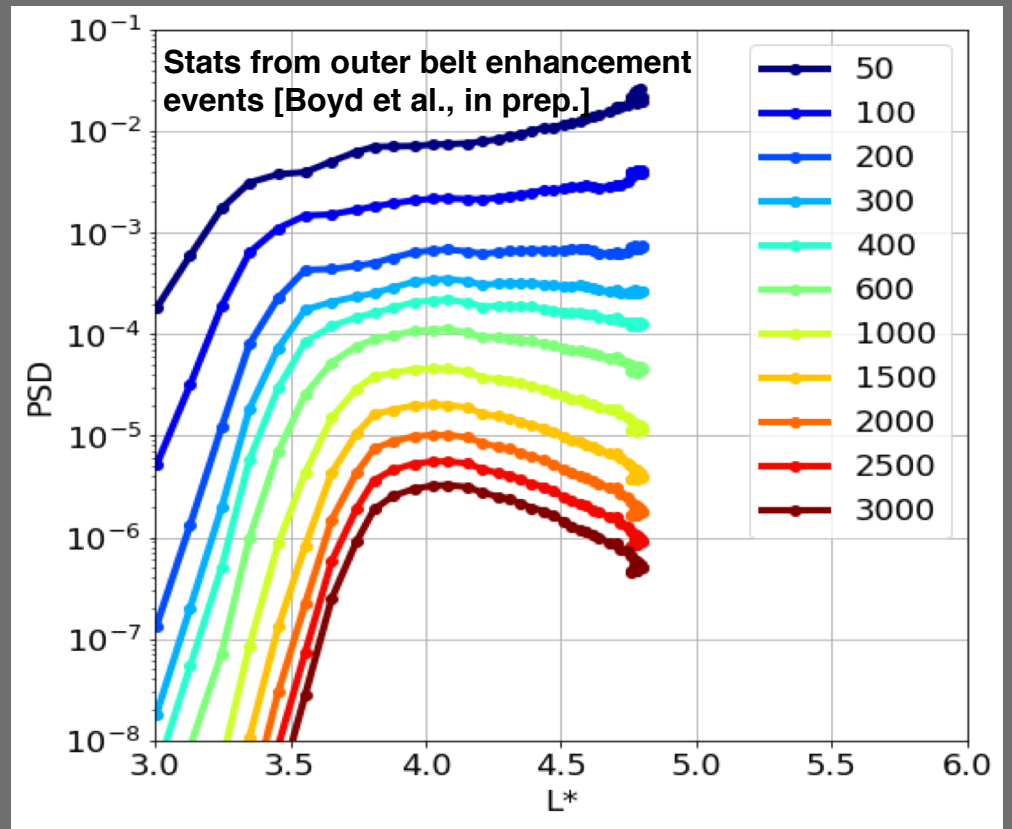


Radial gradients of electron phase space density are Mu-dependent! Indicates internal source for relativistic electrons

MMS results are consistent with:
-Turner and Li [GRL 2008] w/ LANL-GEO
-Turner et al. [GRL 2012] w/ THEMIS
-Boyd et al. [GRL 2014] w/ RBSP
-Boyd et al. [in prep.] w/ RBSP statistics



Acceleration and substorm activity

Chorus waves and injected source/seed electrons

Energy dependent gradients are consistent with chorus acceleration:

- ***Source/seed electrons (10s to a few 100 keV) have positive gradients beyond GEO with peak PSD in the plasma sheet***
- ***Relativistic electrons (>100s keV) have negative gradients beyond GEO with peak PSD within the outer belt***

Several other references:

- *Meredith et al. [JGR 2002; JGR 2003]: stressed the importance of substorms for enhancements of the relativistic electrons in Earth's outer radiation belt*
- *Miyoshi et al. [GRL 2013]: High speed stream storms with Bz-south cause chorus and seed populations from injections → outer belt enhancements*
- *Schiller et al. [GRL 2014] and Su et al. [GRL 2014]: Substorm activity important for non-storm enhancements of the outer belt electrons*
- *Jaynes et al. [JGR 2015]: Key ingredients for MeV electron acceleration are chorus waves and seed electrons from substorm injections!*
- *Turner et al. [JGR 2017]: Direct link between substorm injected source electrons and chorus wave activity at multiple points in MLT around outer belt*

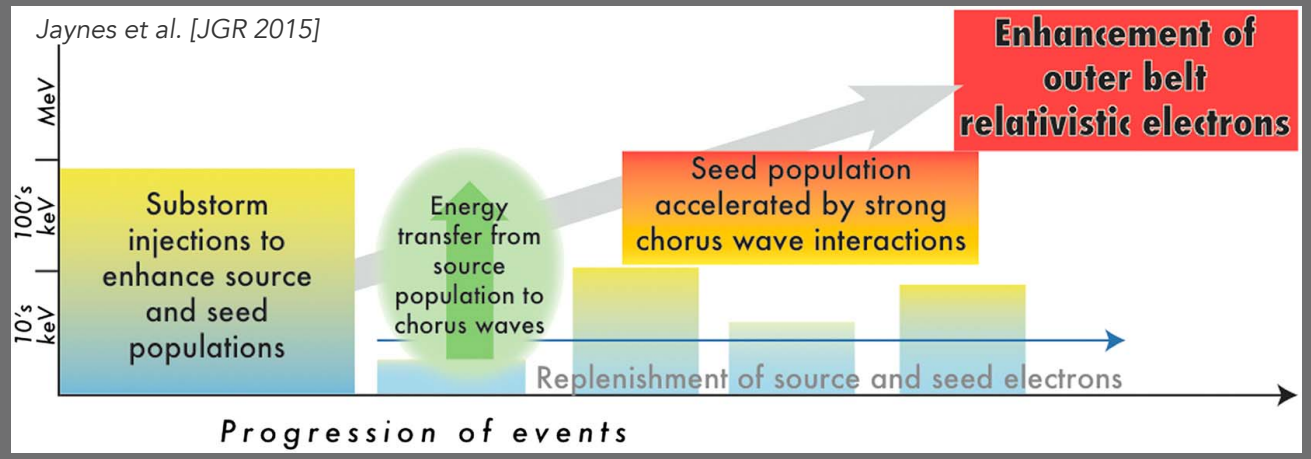
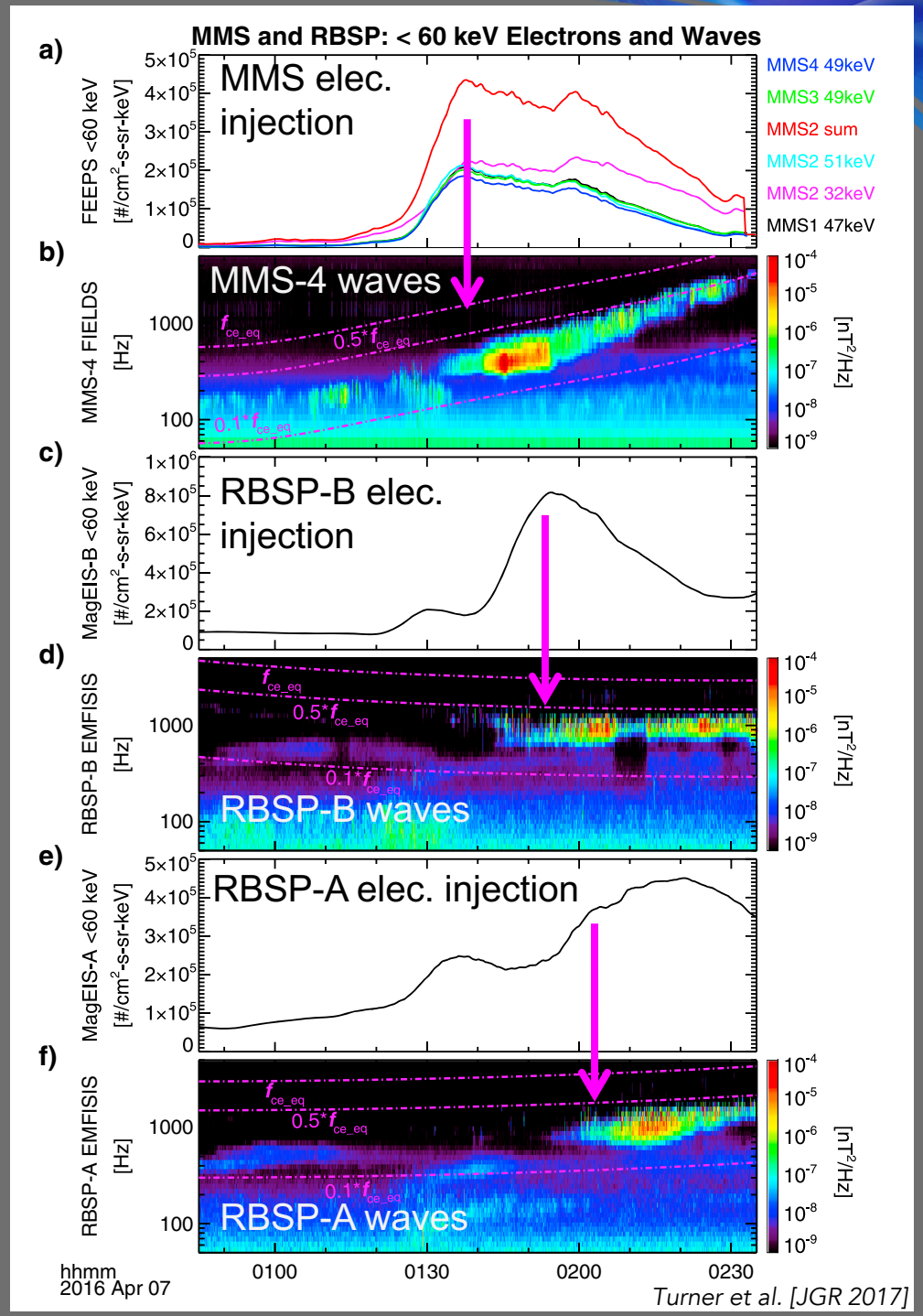


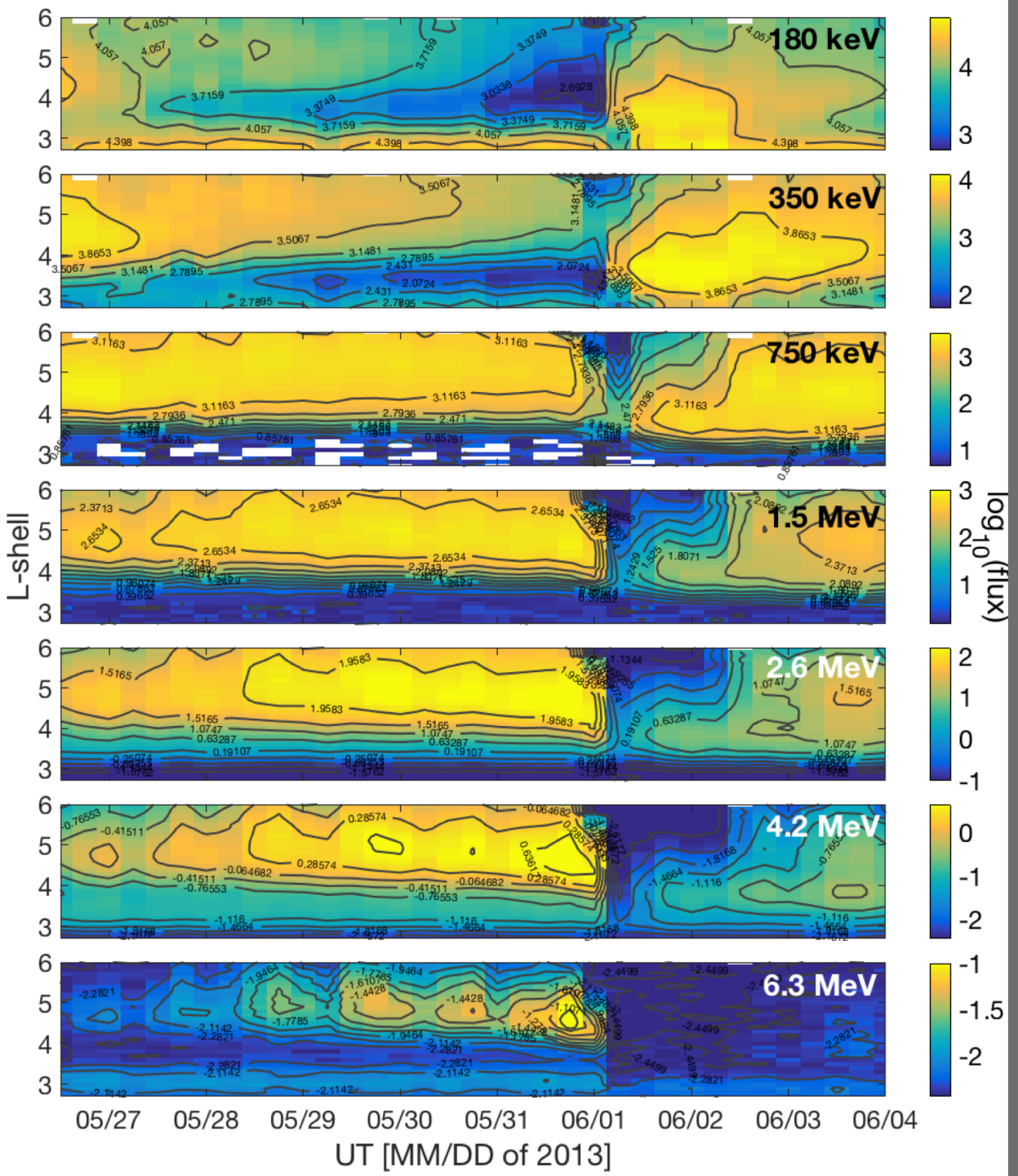
Figure 1. Schematic of the ideal setup and sequence for strong enhancement of outer belt electrons >1 MeV.

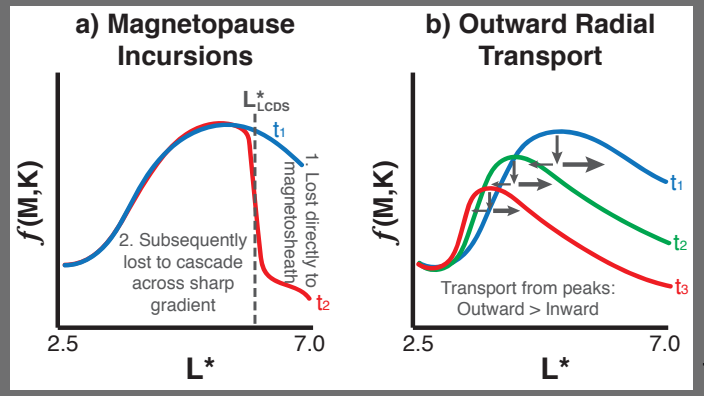


Outer Radiation Belt Losses

Outer Belt Losses

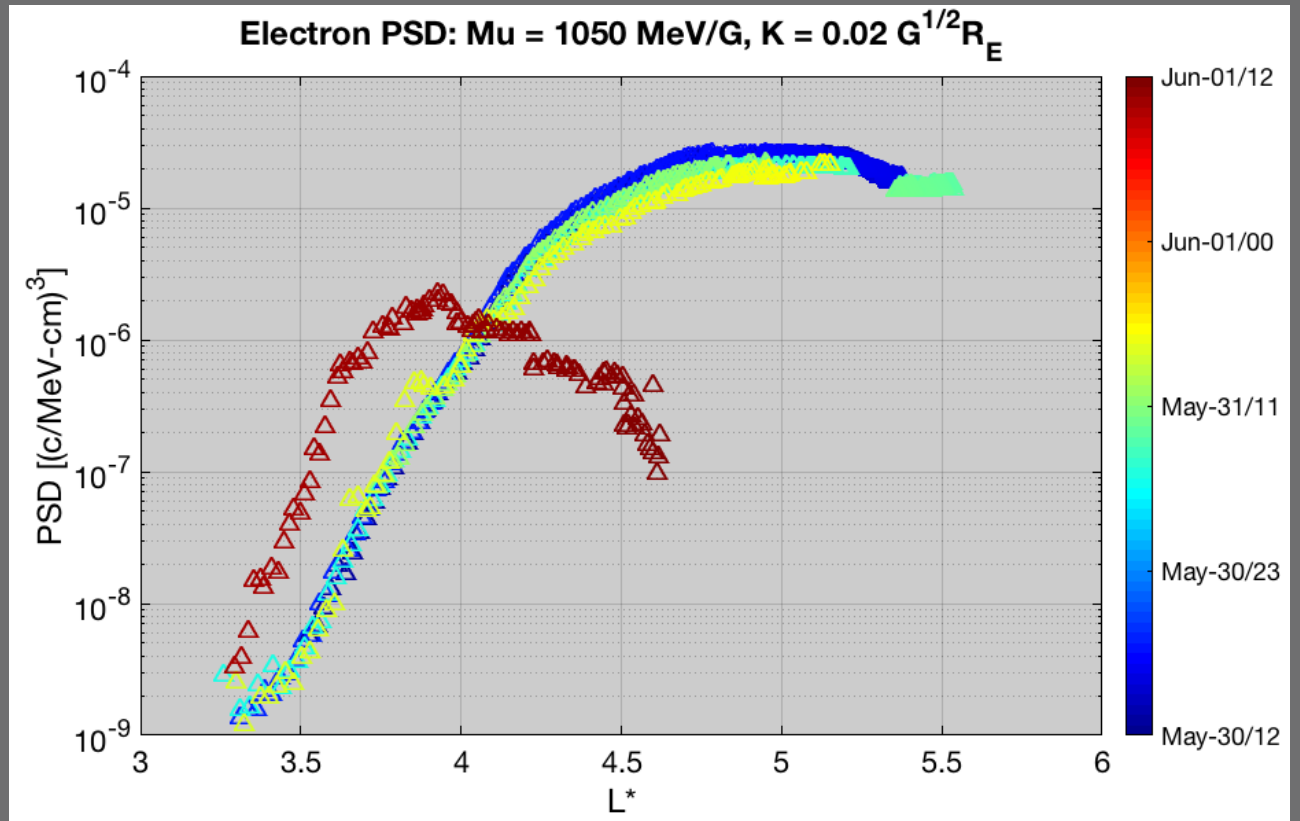
Telltale signatures of loss to outer boundary





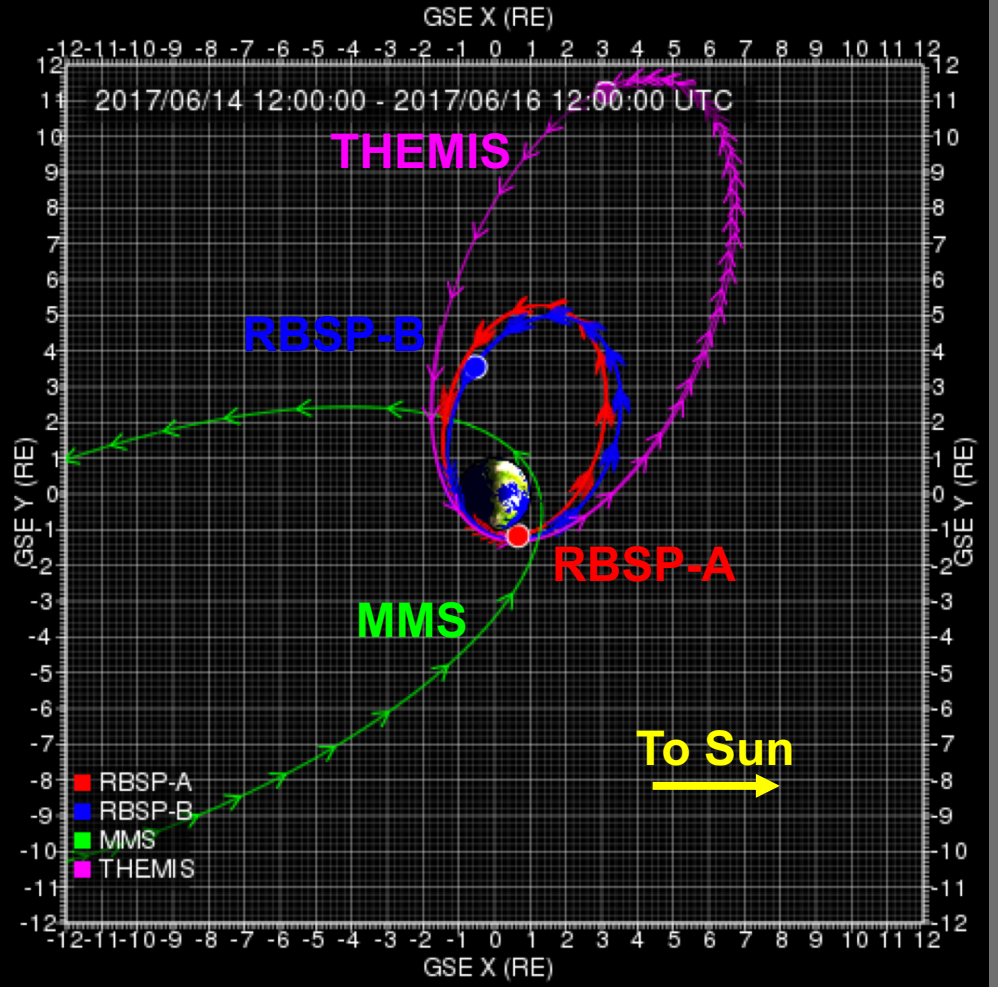
Again, frequent observations at higher L-shells are key

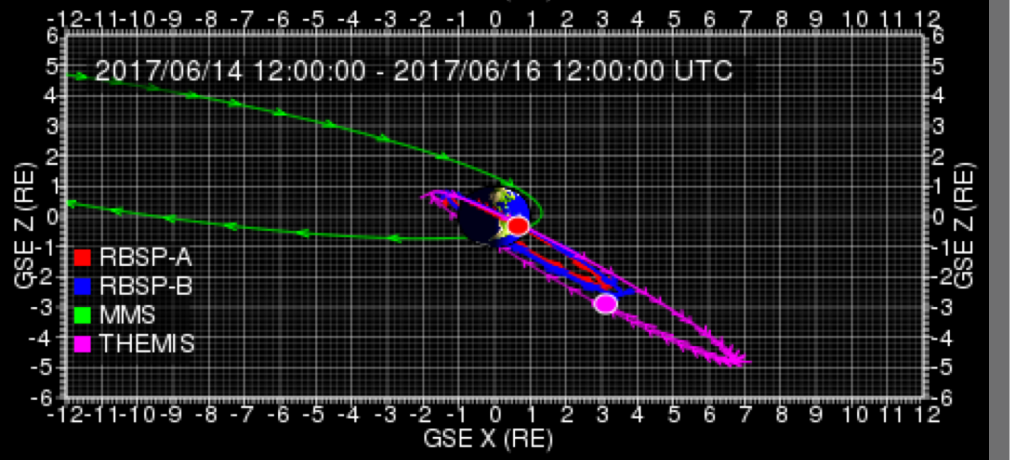
Figures from Turner and Ukhorskiy [in press]

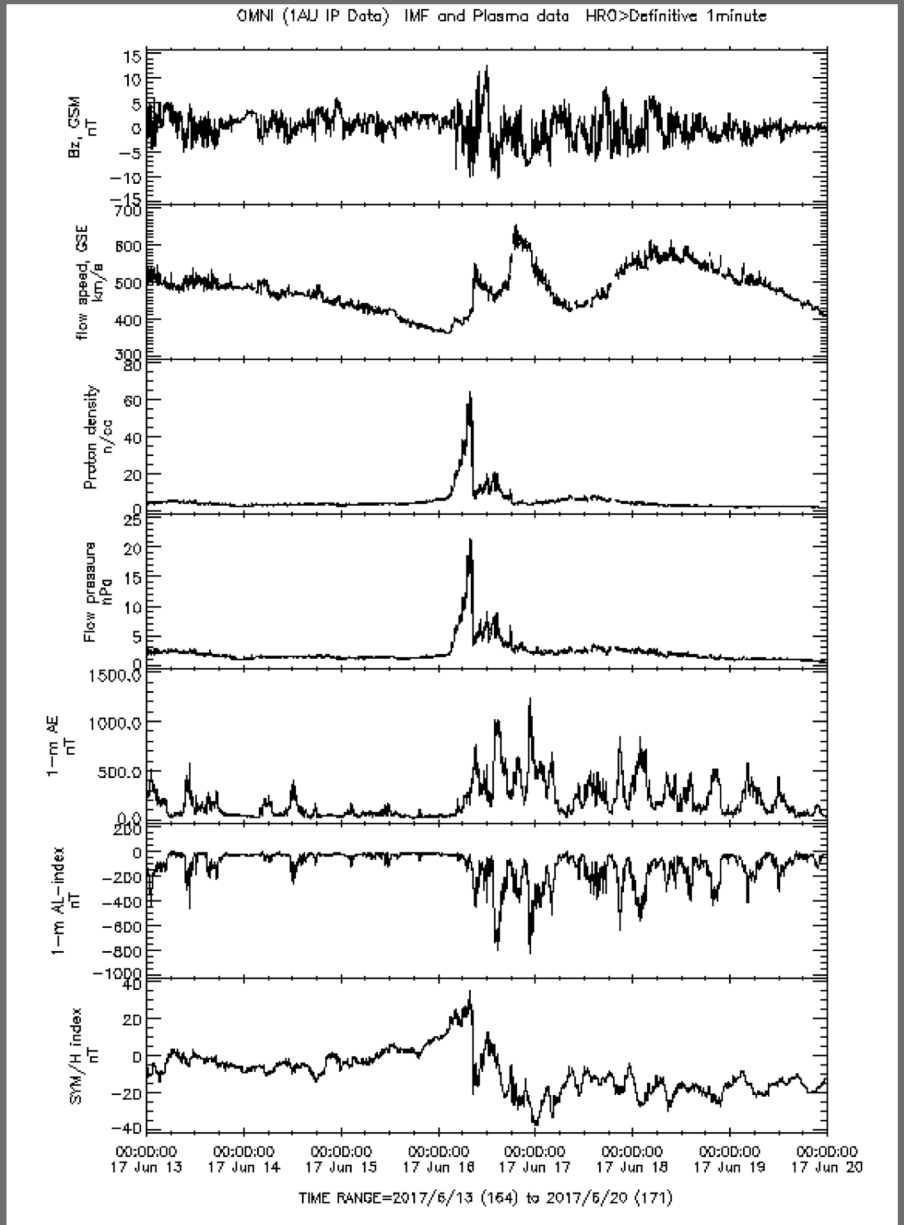


Outer Belt Losses

Example case: Non-storm dropout on 16 Jun 2017







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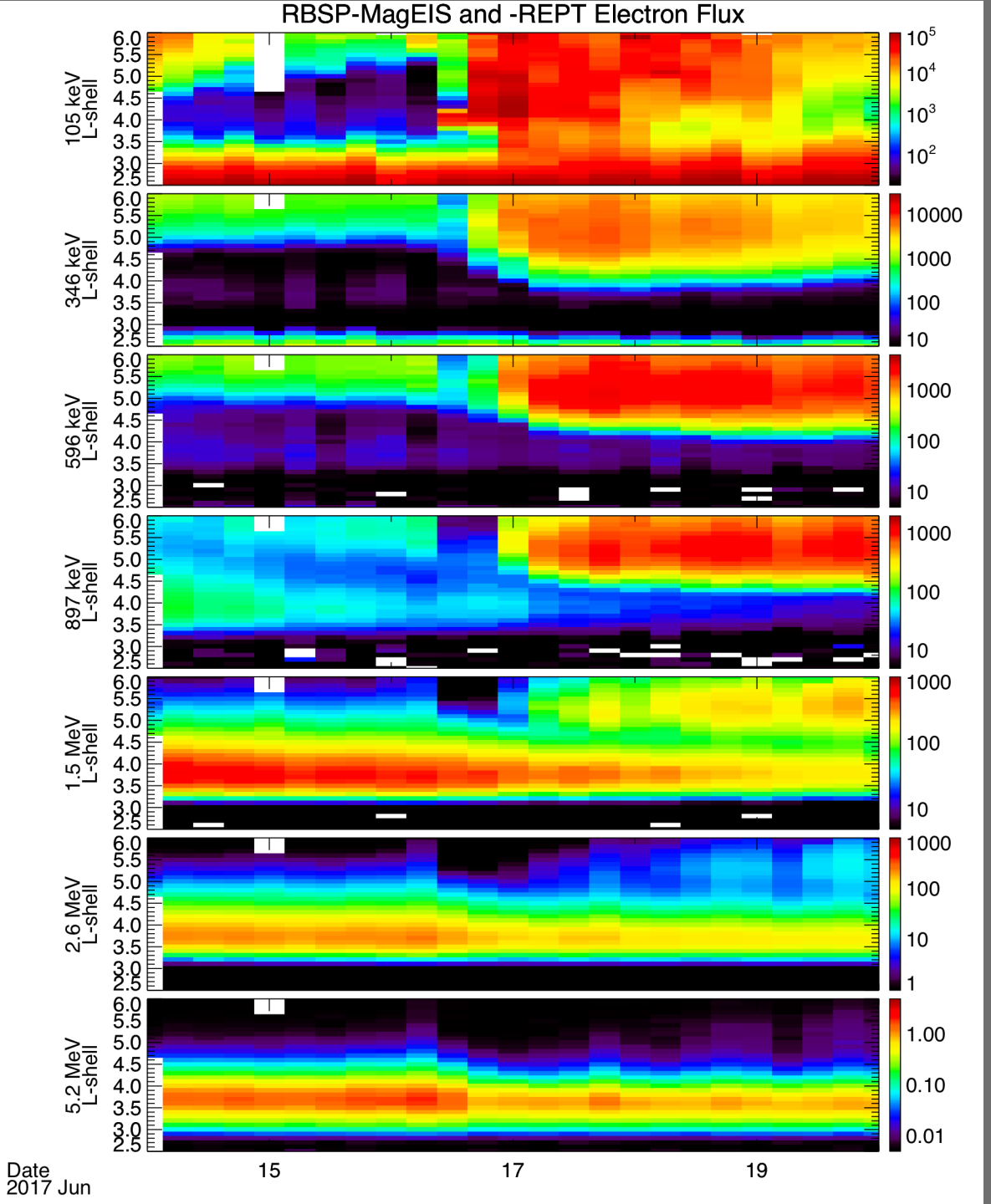

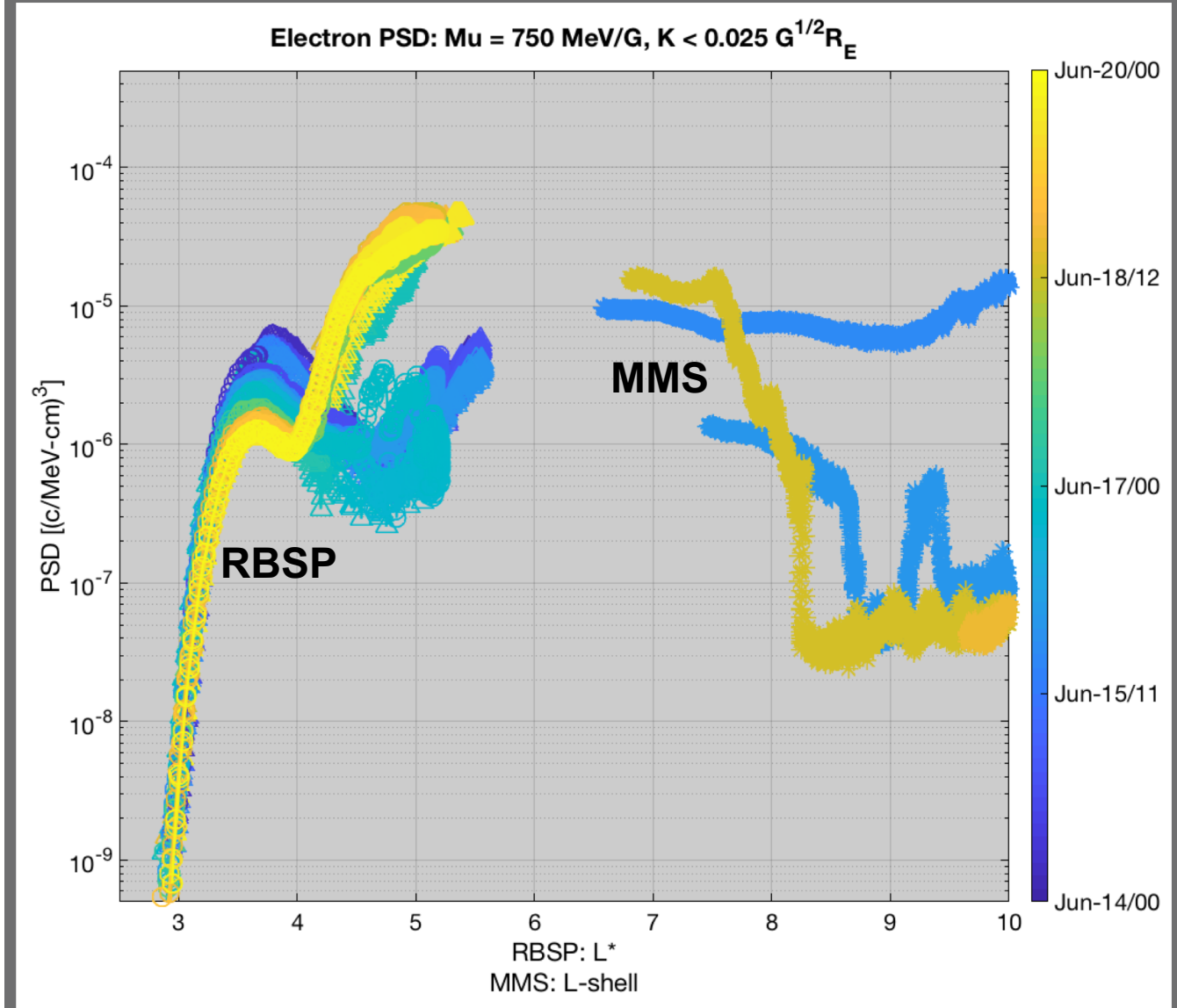

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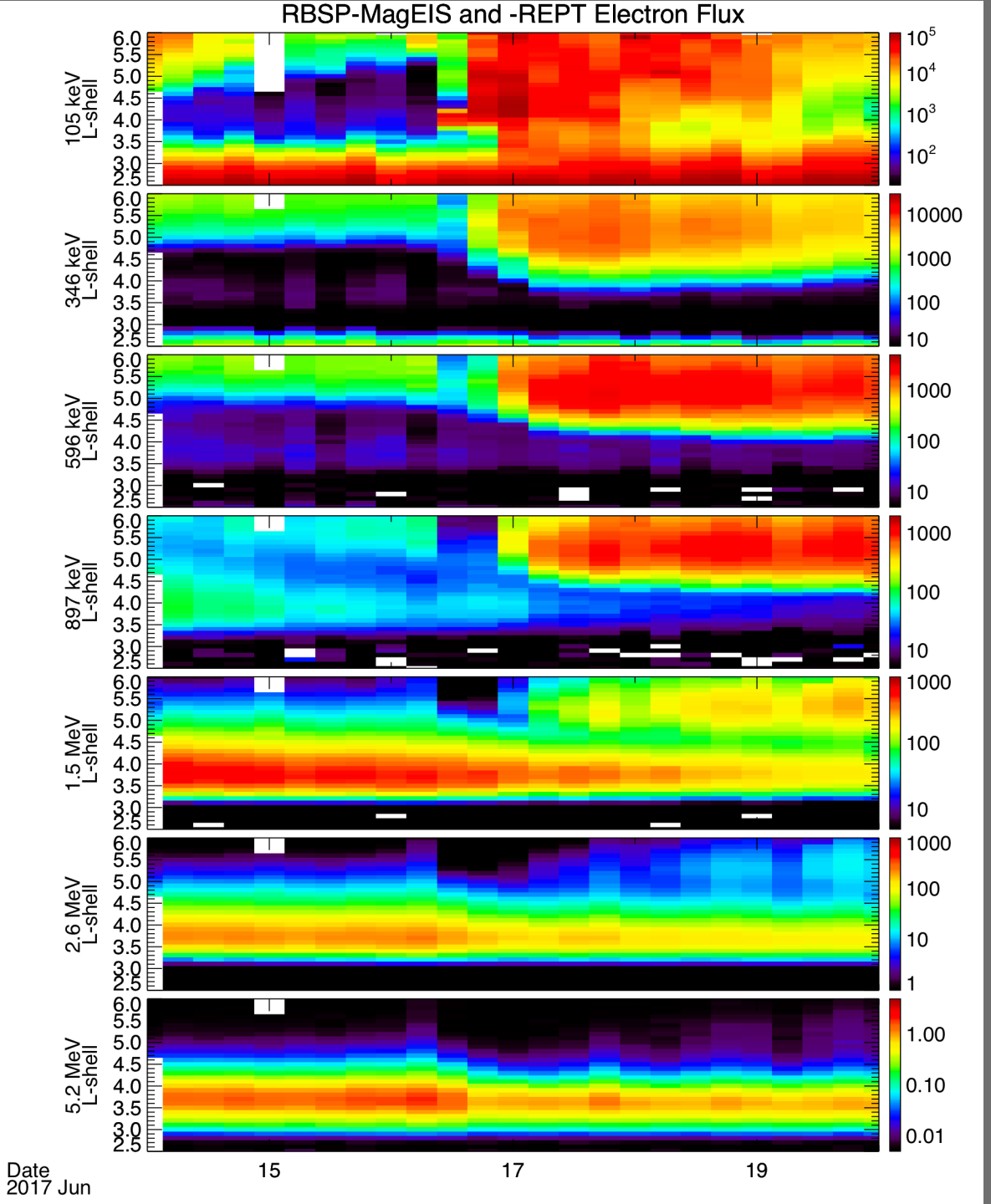
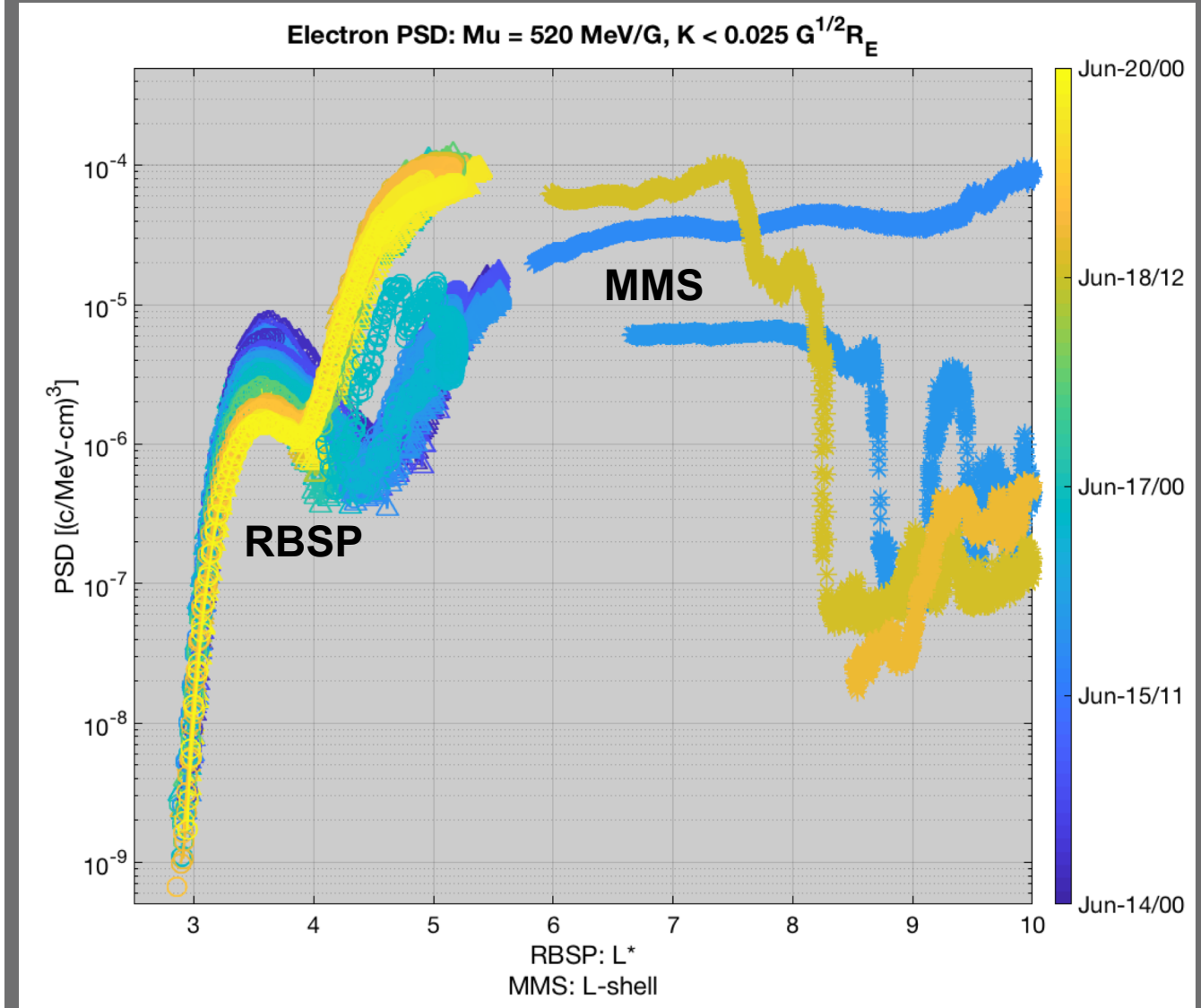
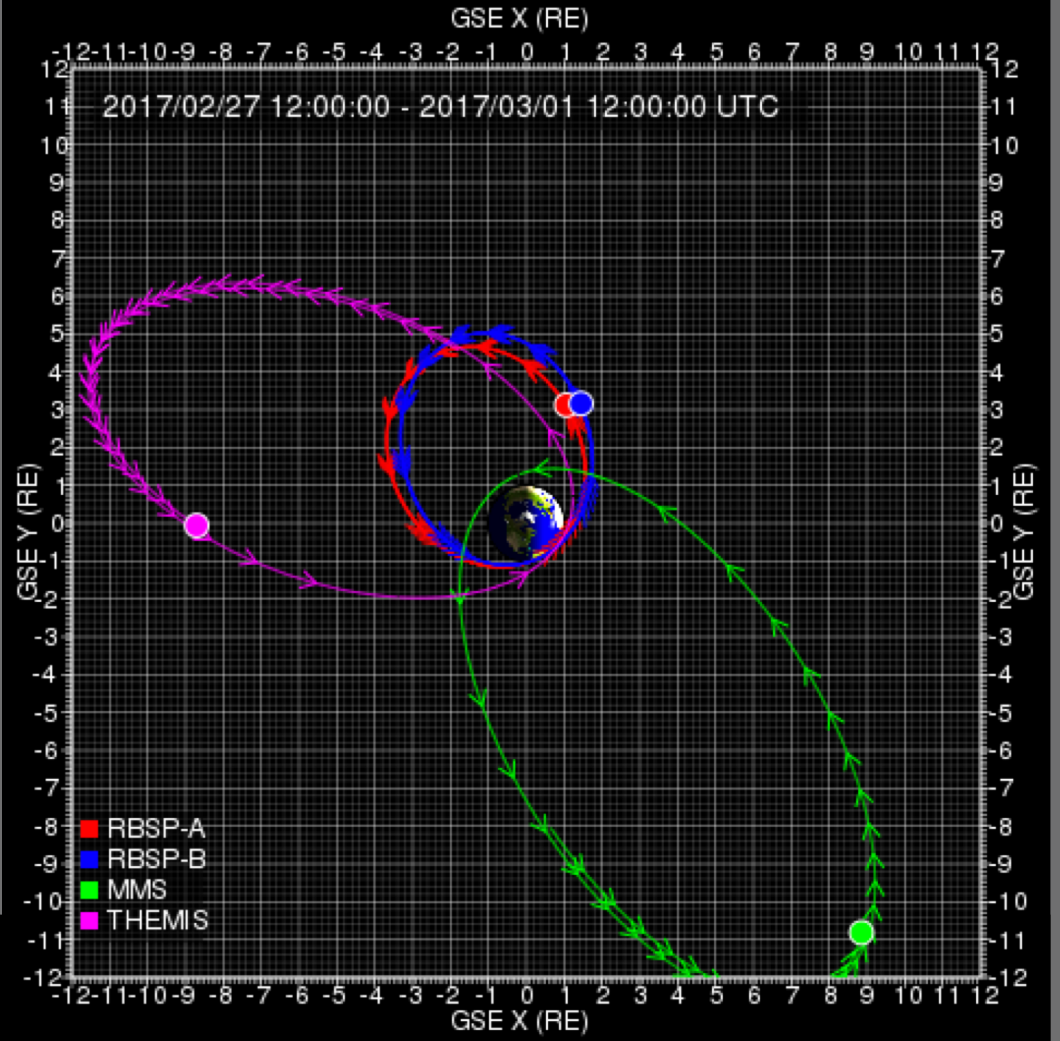


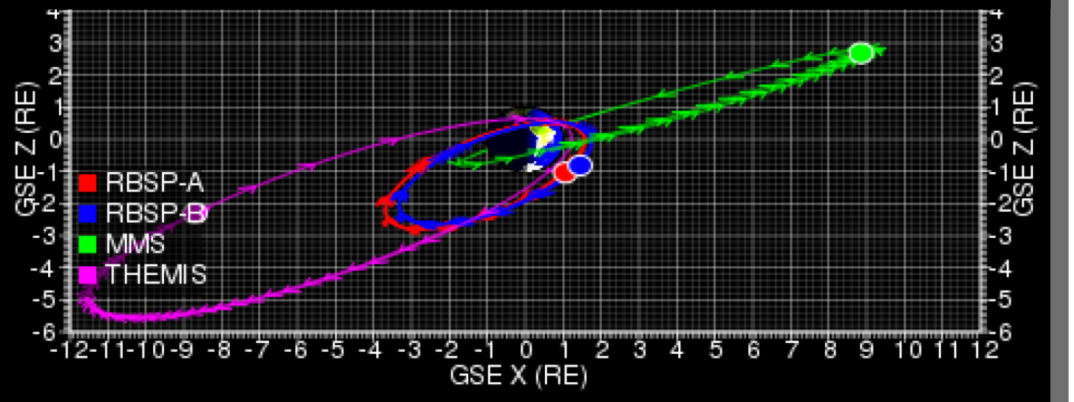


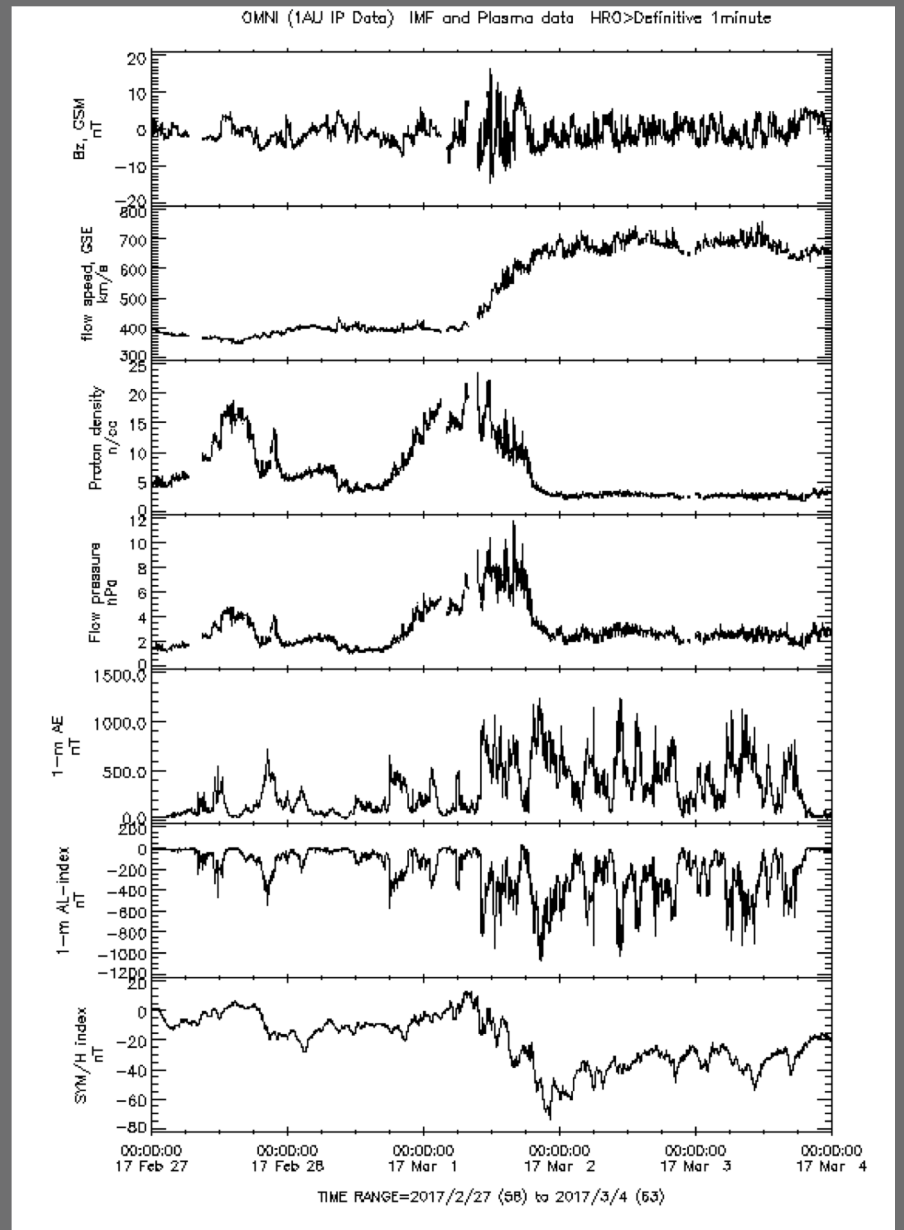
Another Case of Loss and Acceleration

Outer Belt Dynamics

Example Case: Storm 01 Mar 2017







Outer Belt Dynamics

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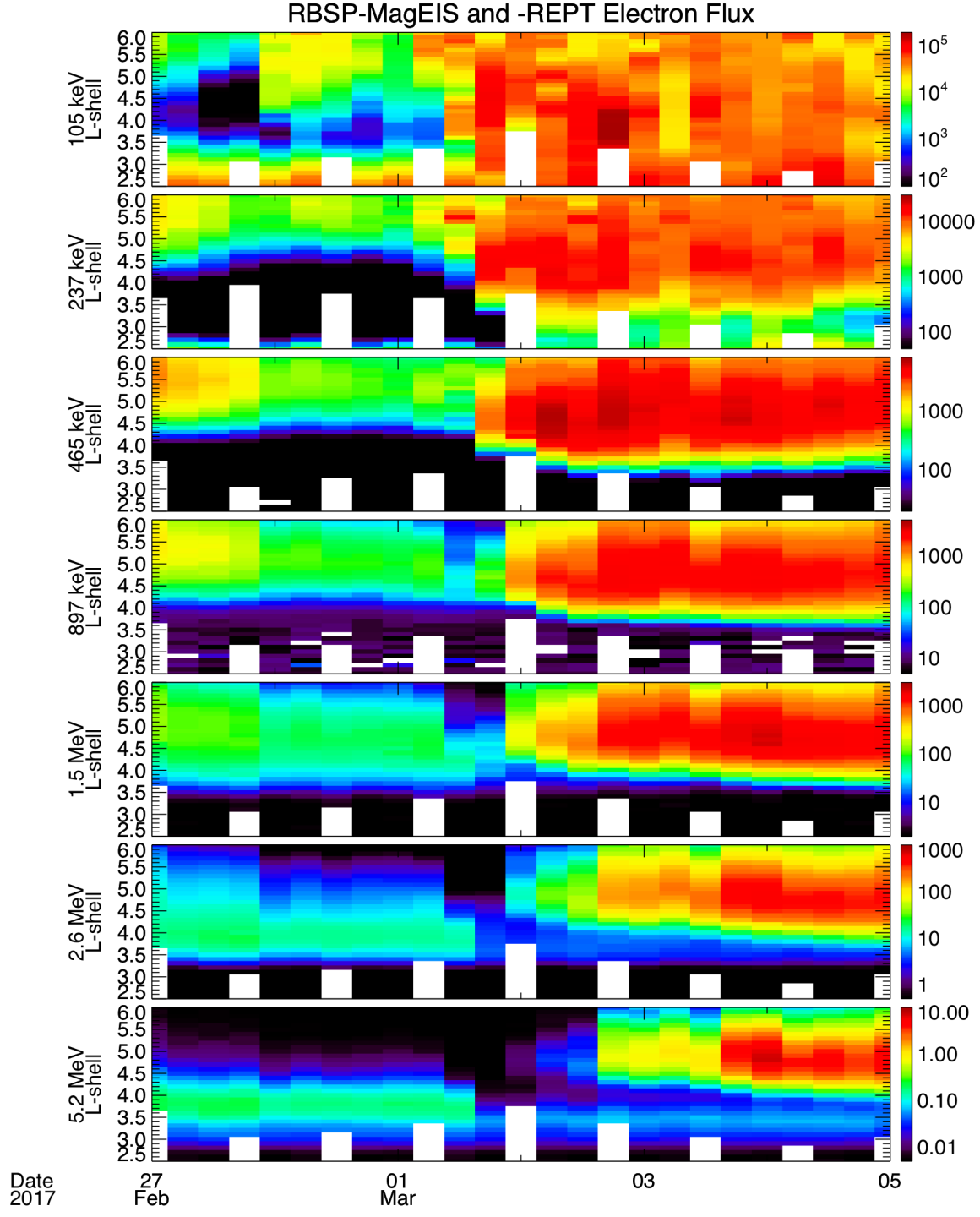

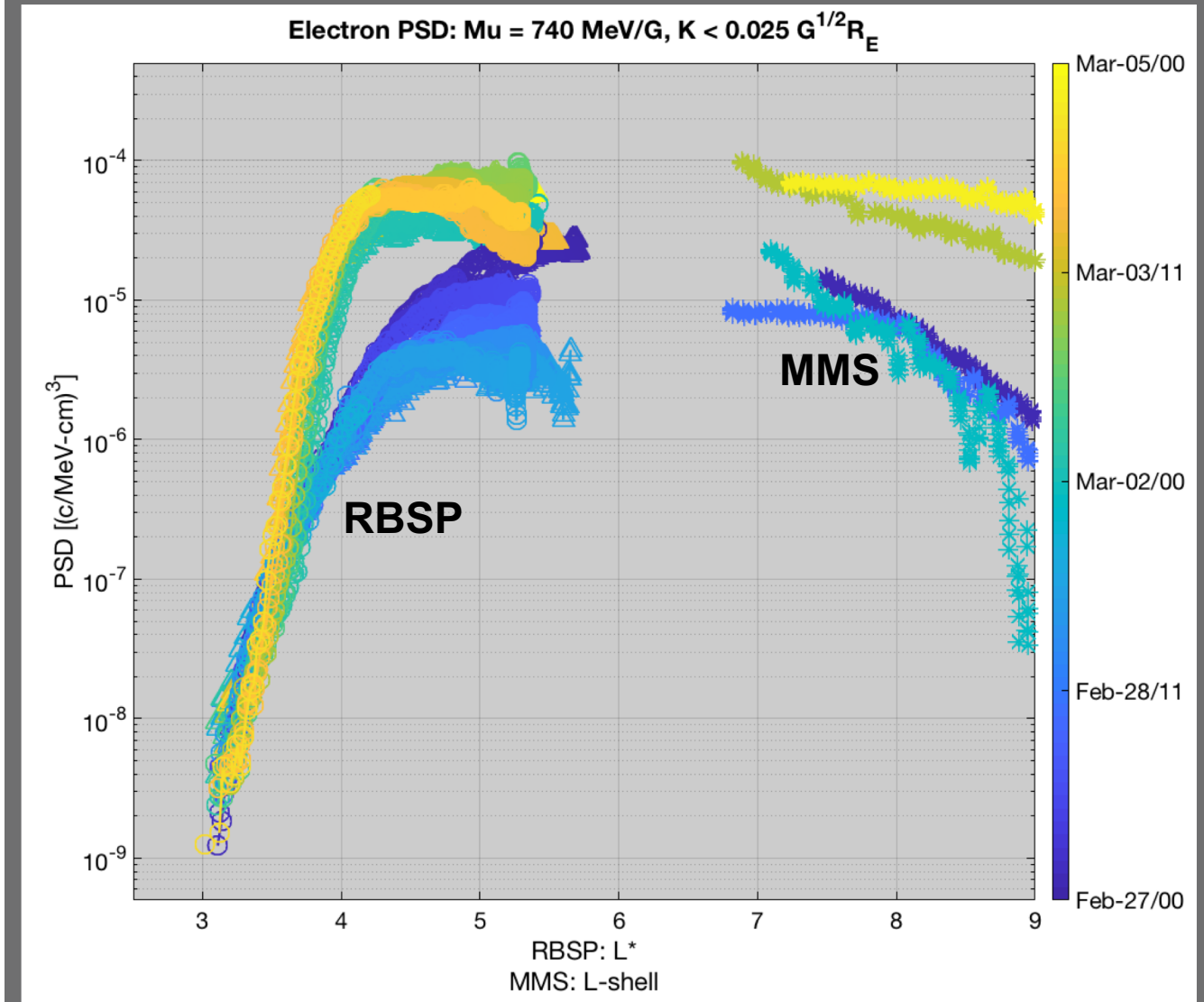

Outer Belt Dynamics

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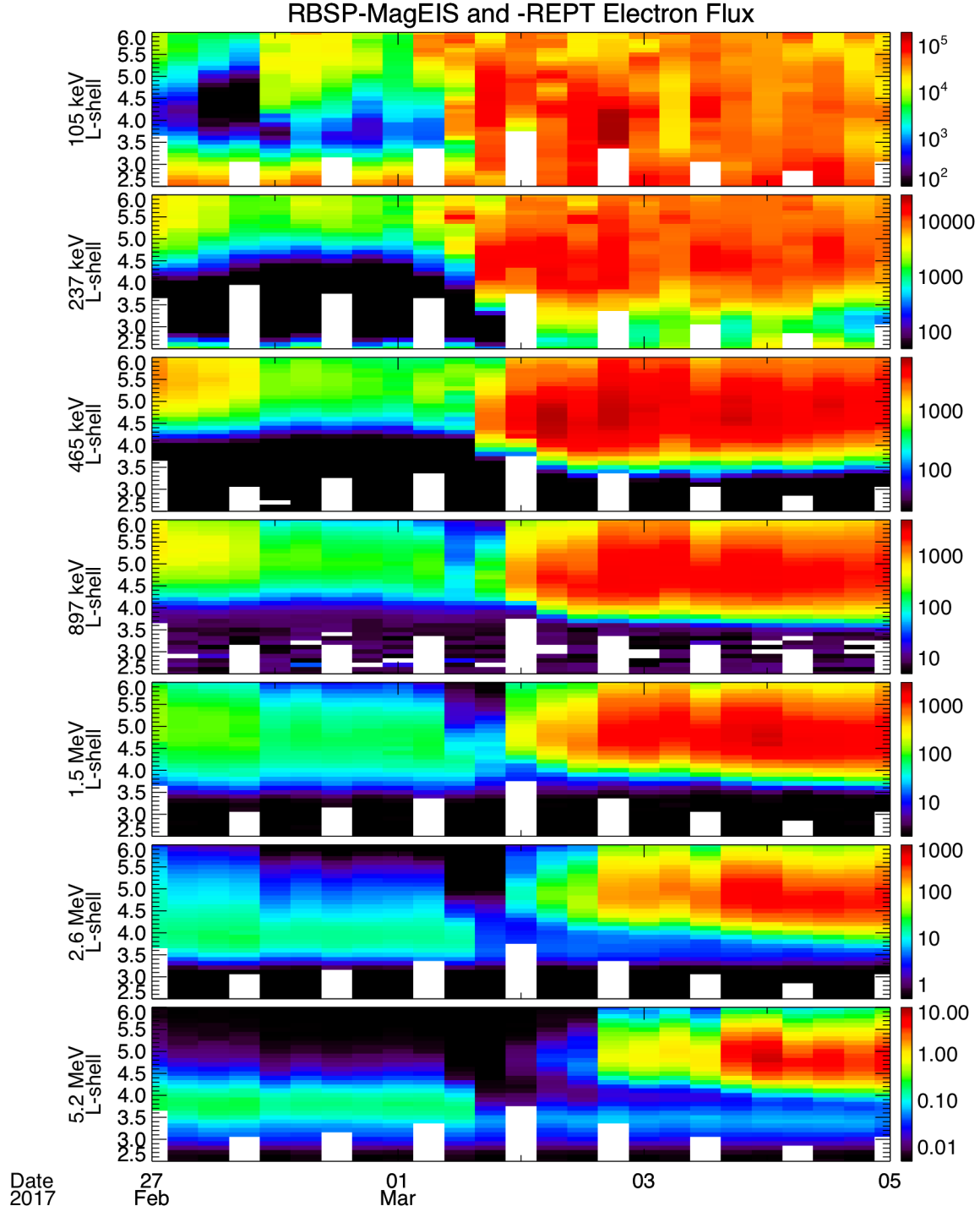

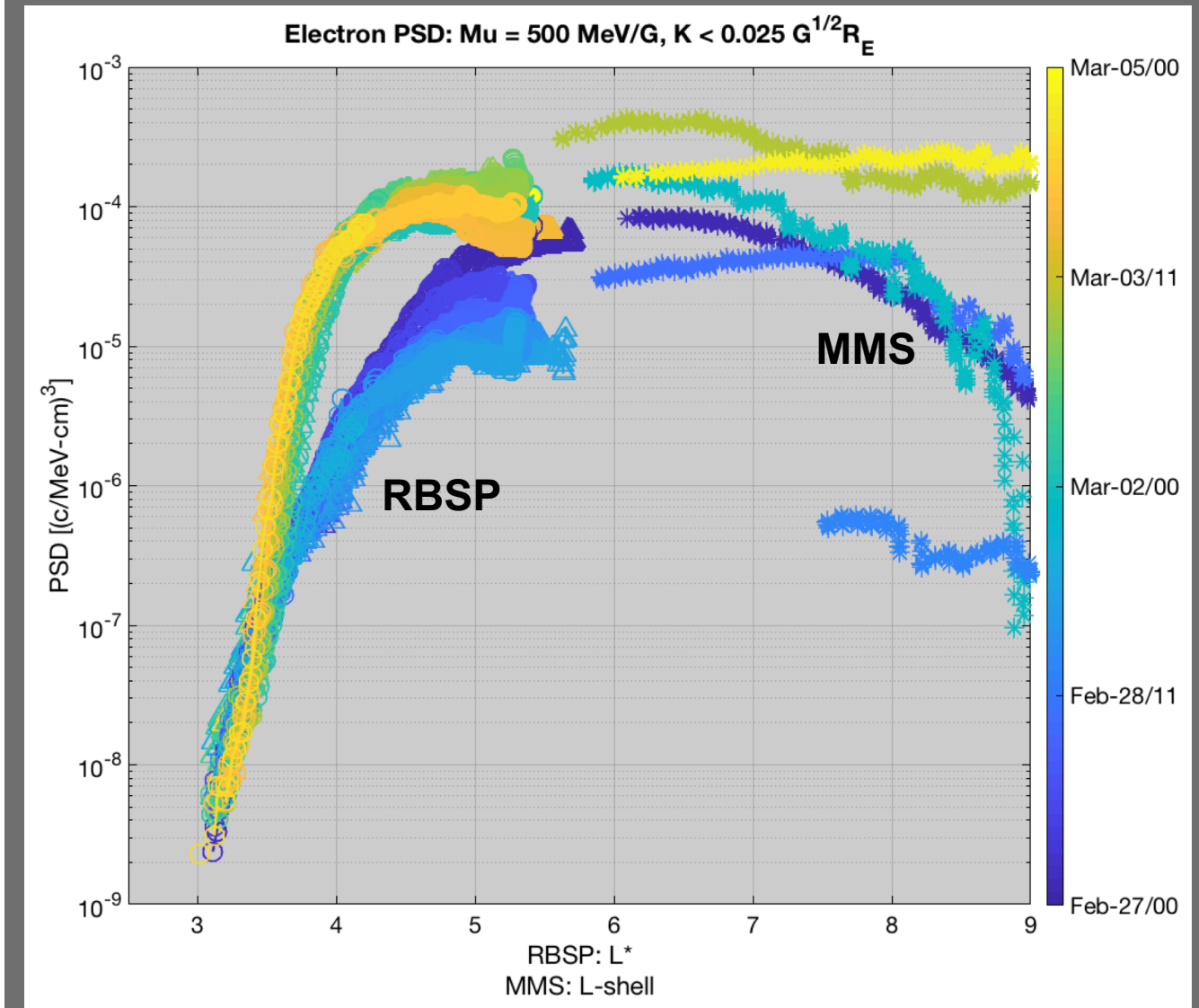

Outer Belt Dynamics

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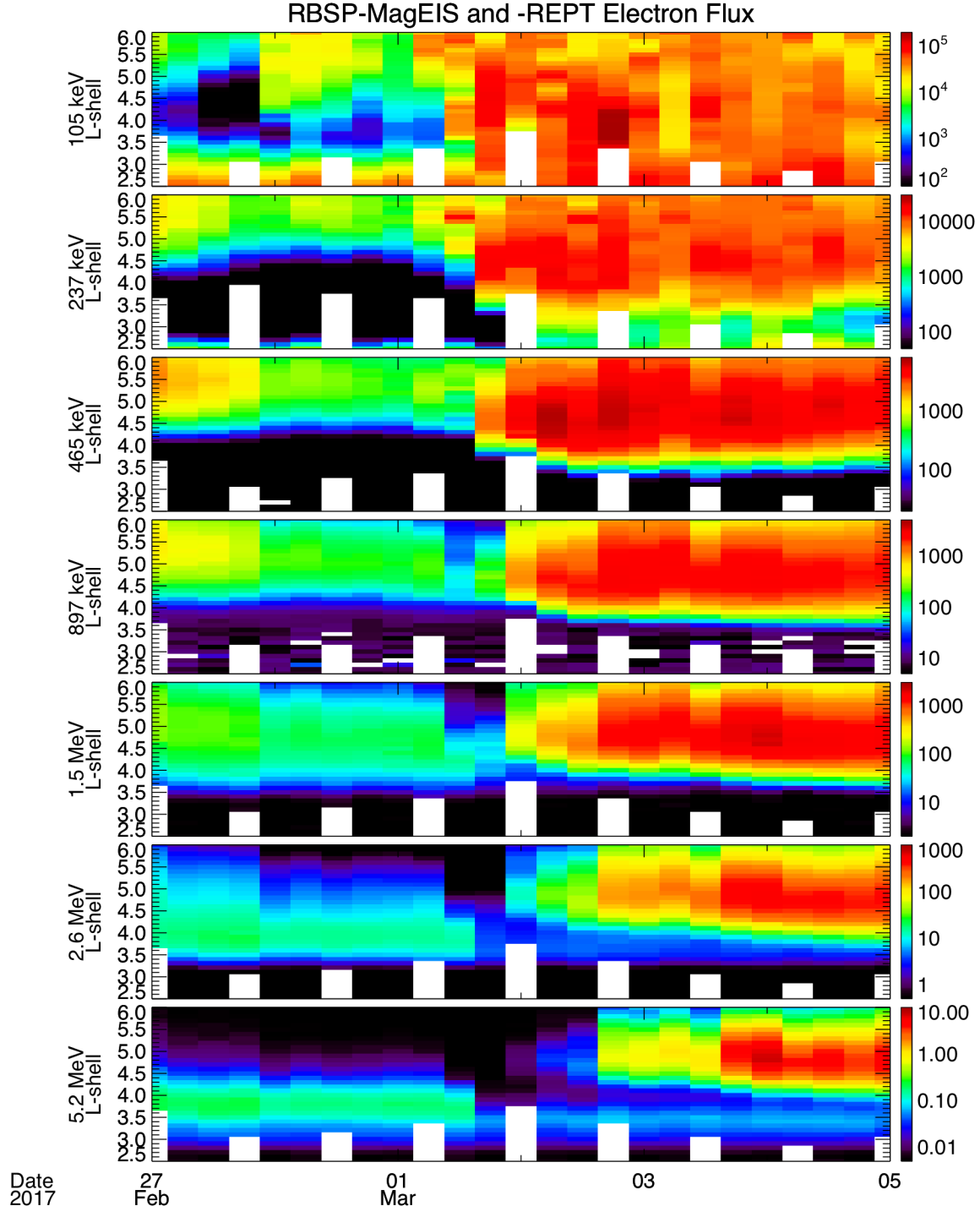
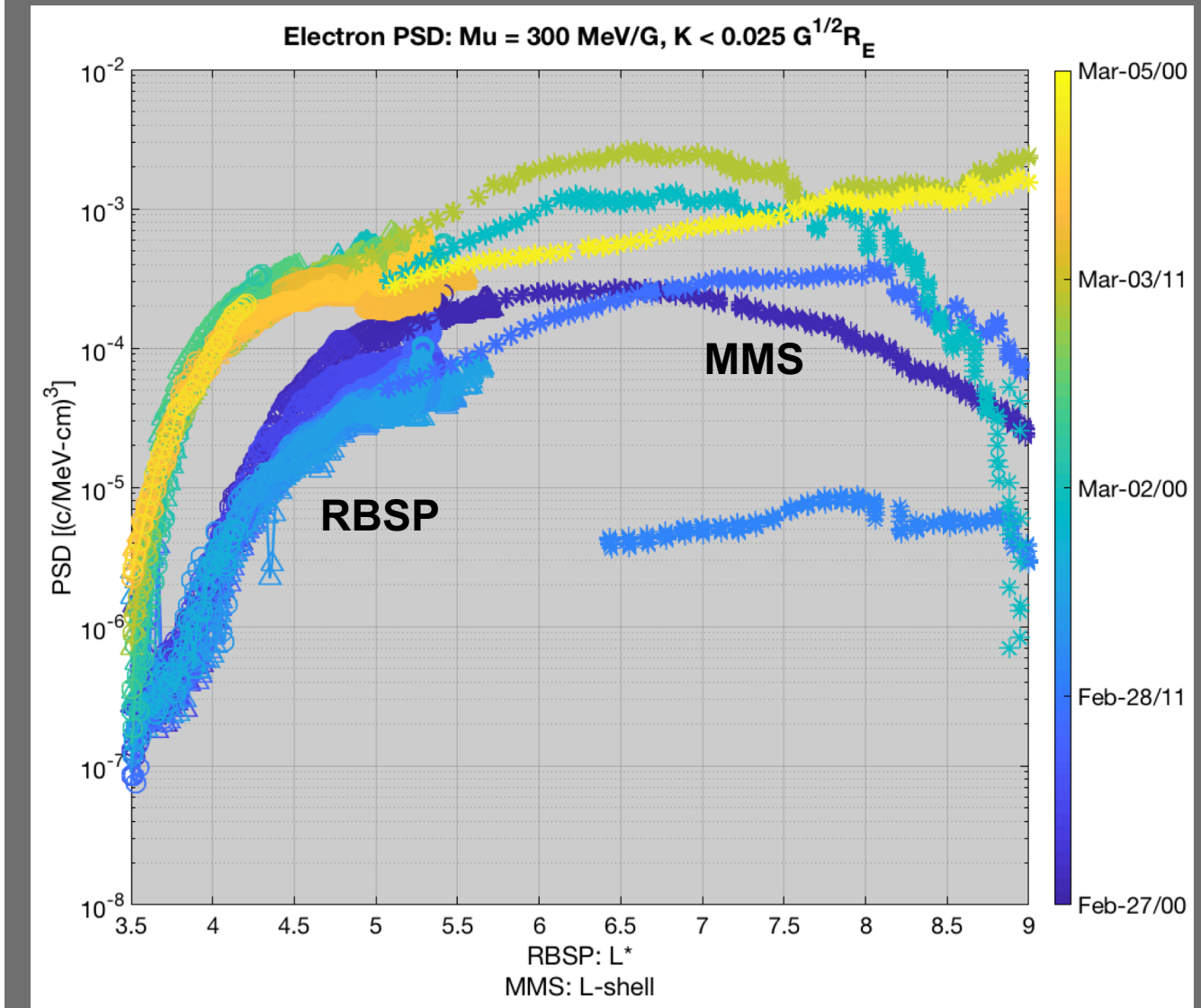




Conclusions

Multipoint perspectives are highly beneficial

- MMS and Arase and THEMIS data all observe L-shells considerably higher than the apogee of Van Allen Probes; these reveal:
  - *Peaks in phase space density are the norm for relativistic electrons (E > ~500 keV), but those peaks are often located at L ≥ 6*
  - *Important signatures of losses due to magnetopause incursions and outward radial transport*

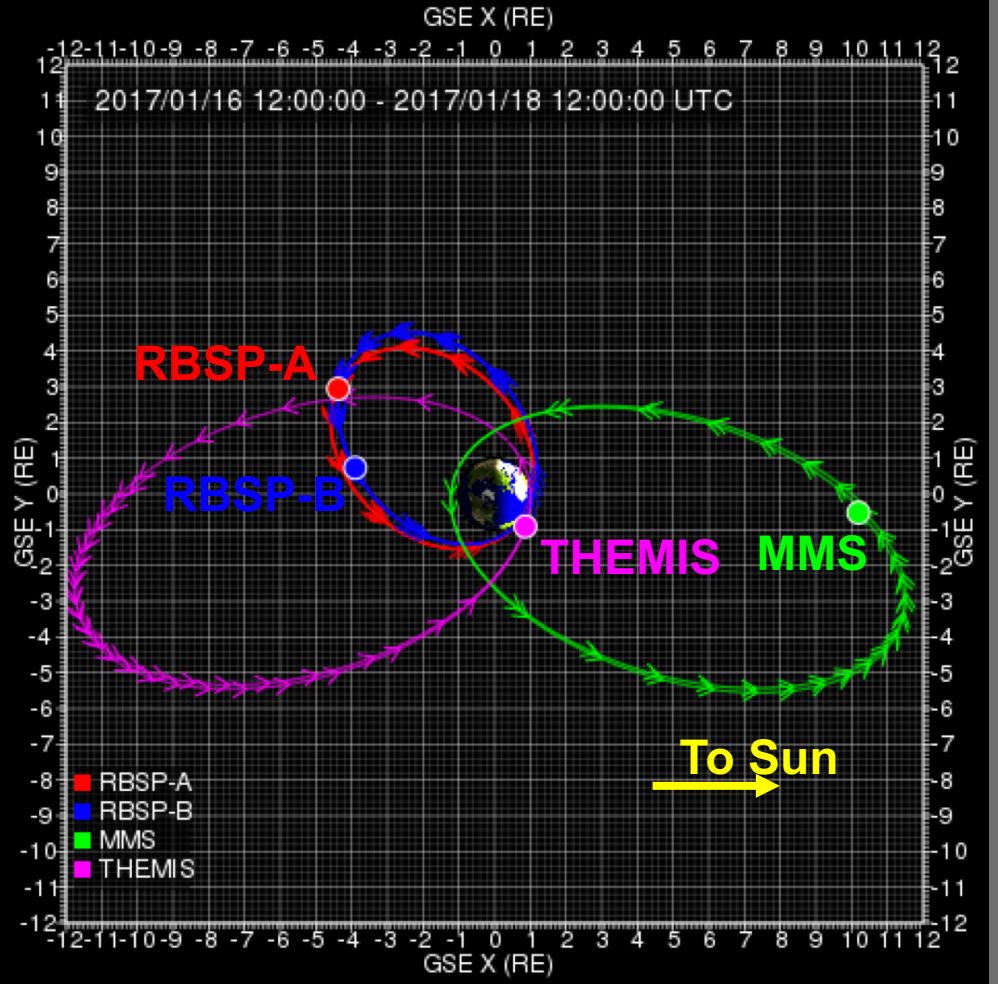
- MMS confirms Mu-dependent radial gradients of electron phase space density, consistent with:
  - *Results from: RBSP [Boyd et al., GRL 2014], THEMIS [Turner et al., GRL 2012], LANL-GEO [Turner et al., GRL 2008]*
  - *Local acceleration of a seed population of 10s to 100s of keV electrons from interactions with whistler-mode chorus waves*
  - *Importance of substorm activity and energetic particle injections*

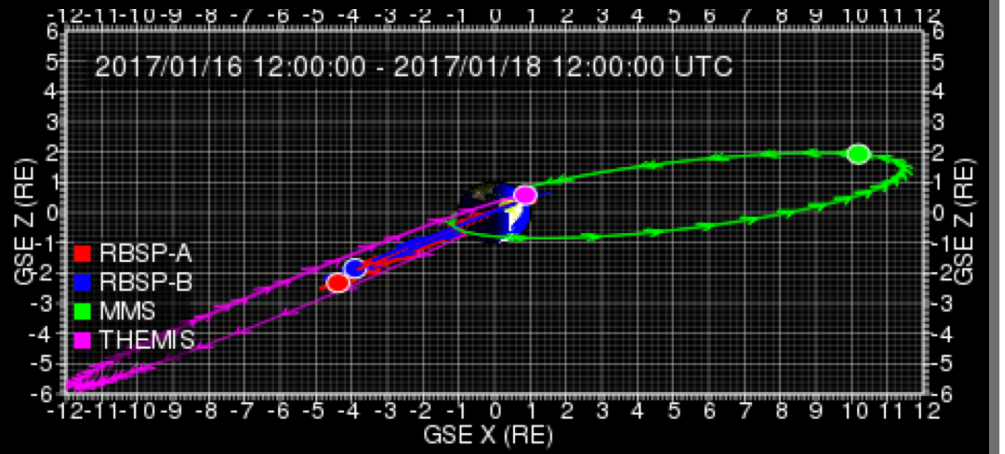
- MMS used to study dropout losses:
  - *Confirms dropout losses at L > 4 are dominated by losses to the outer boundary*
  - *Can be used to estimate losses of outer belt electrons to the magnetopause and outward radial transport*

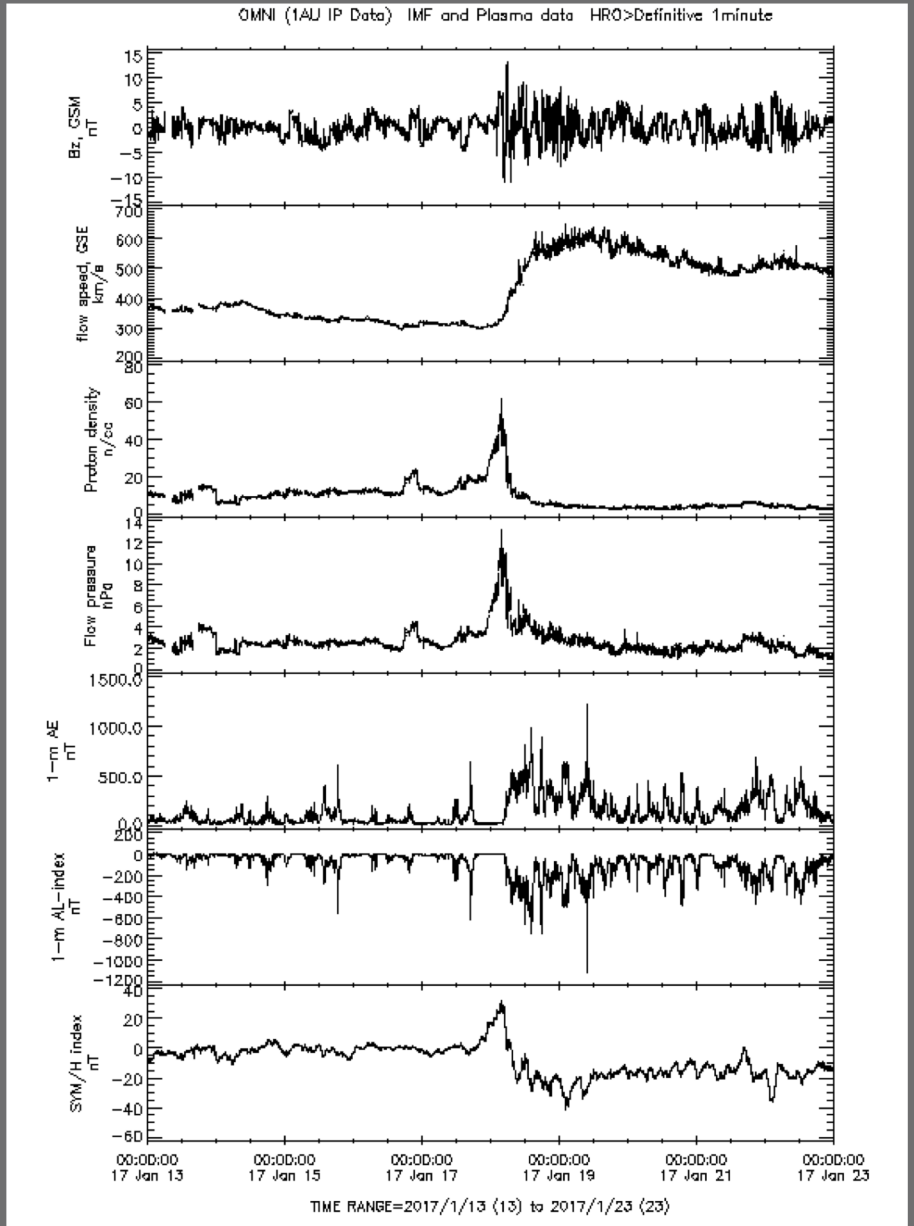
Other Example Cases

Outer Belt Losses

Example case: Dropout on 17 Jan 2017







Outer Belt Losses

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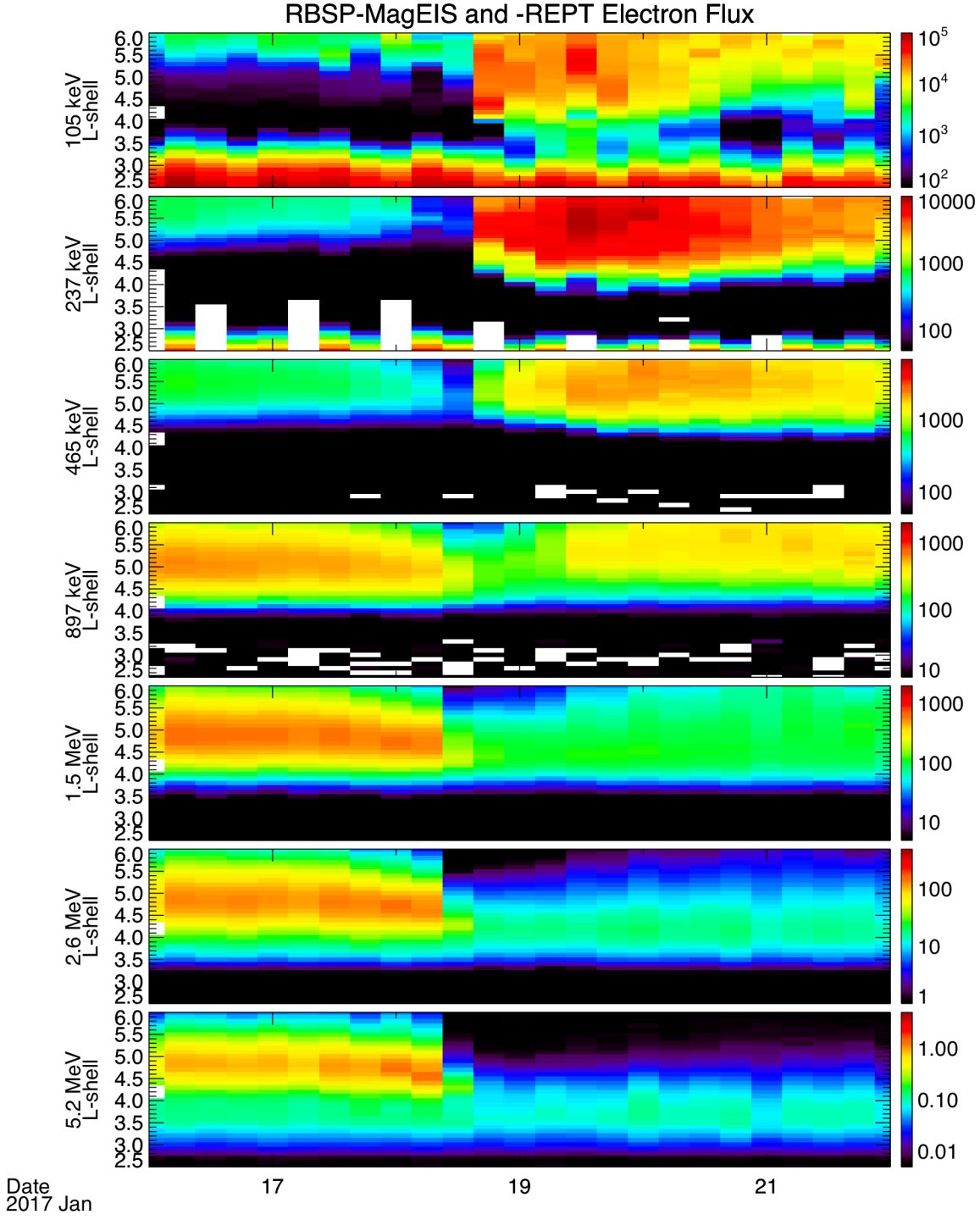
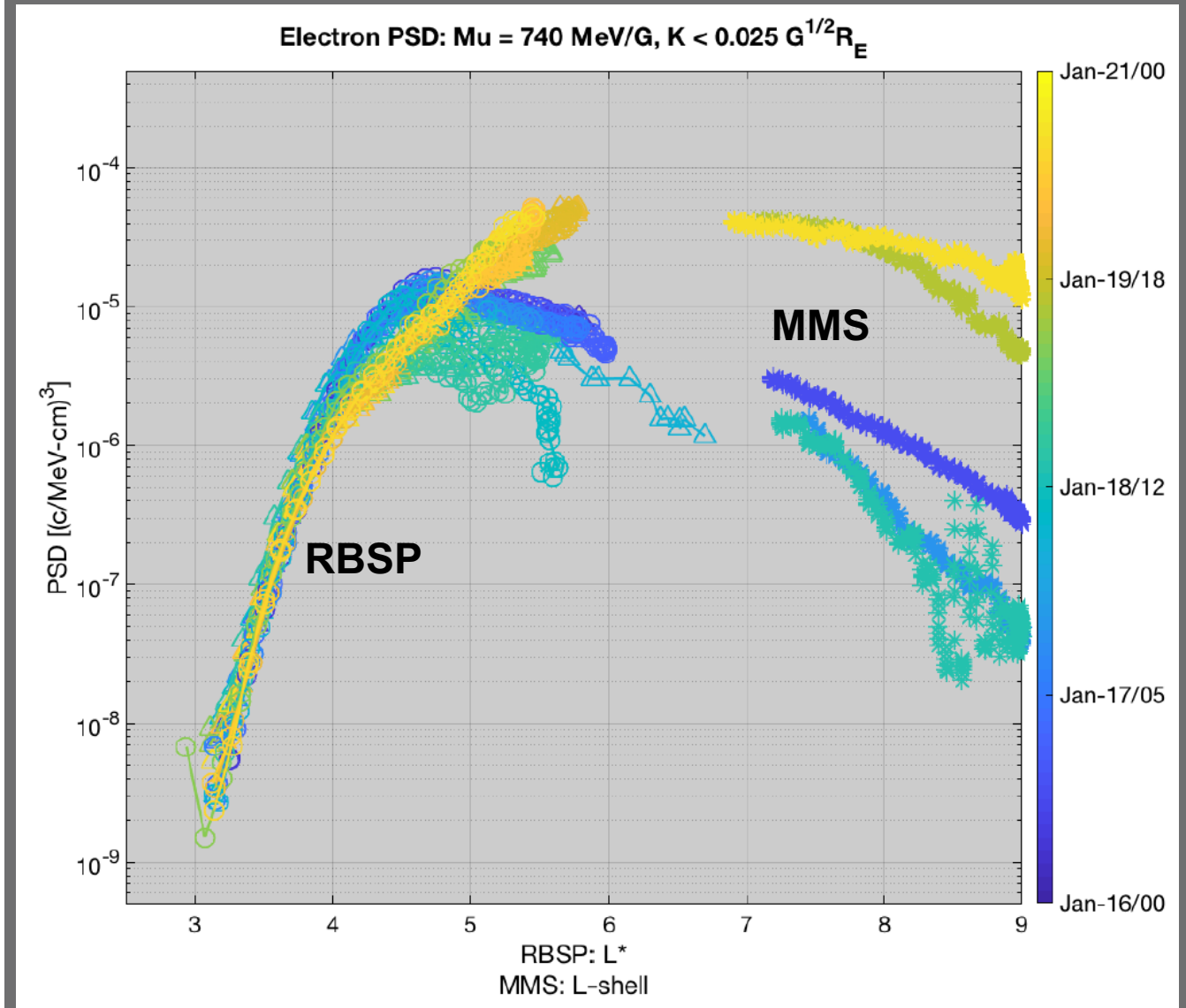
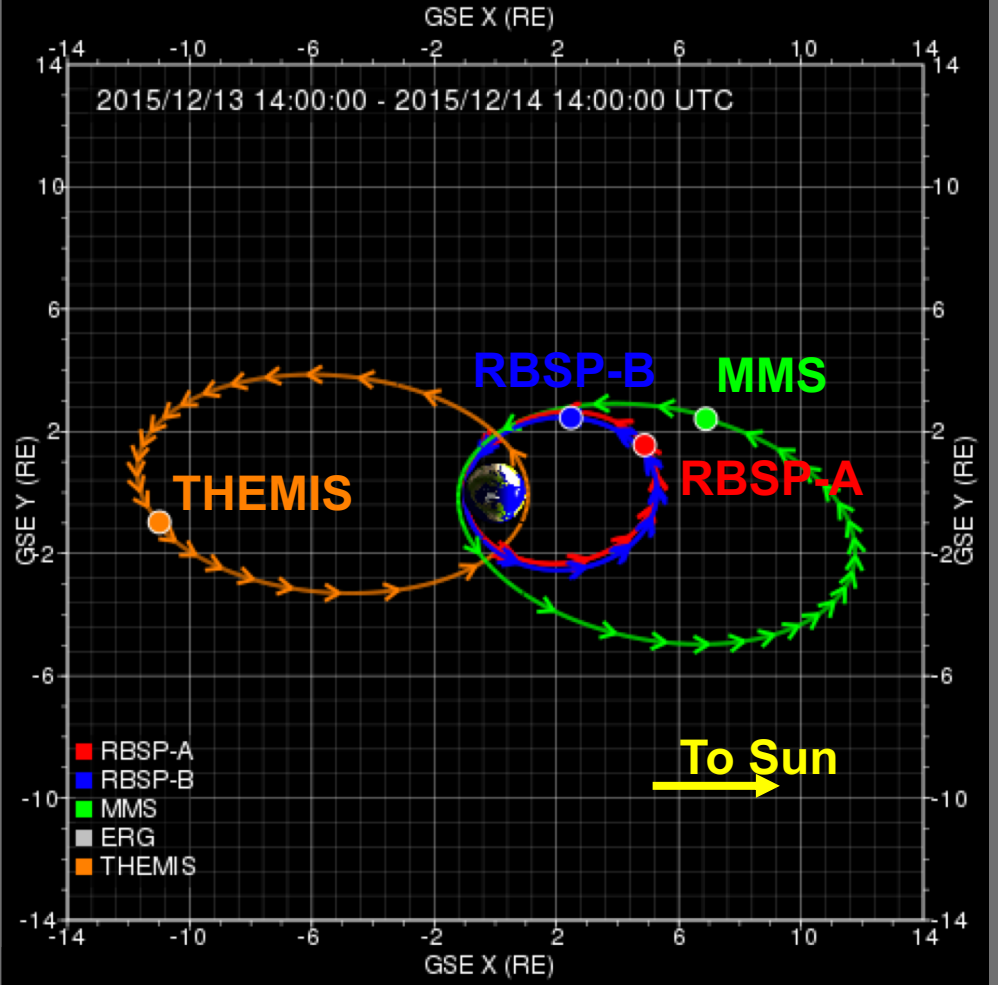
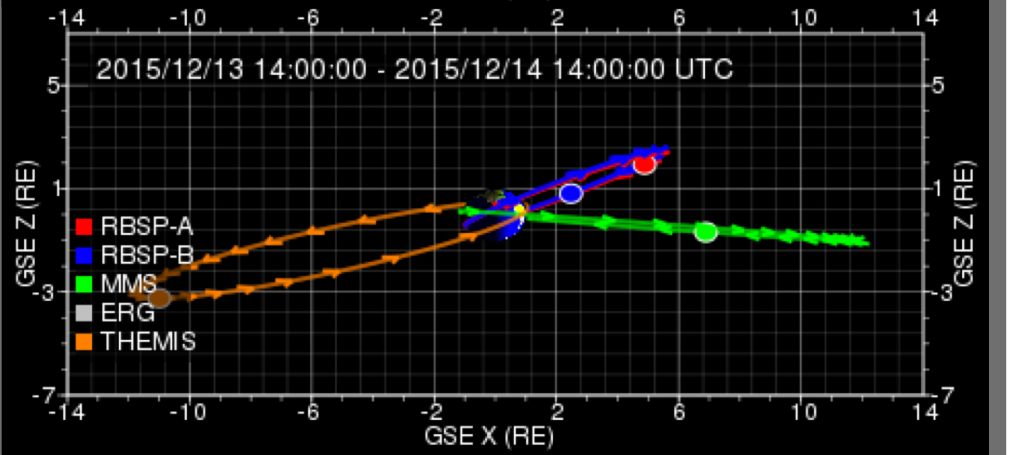


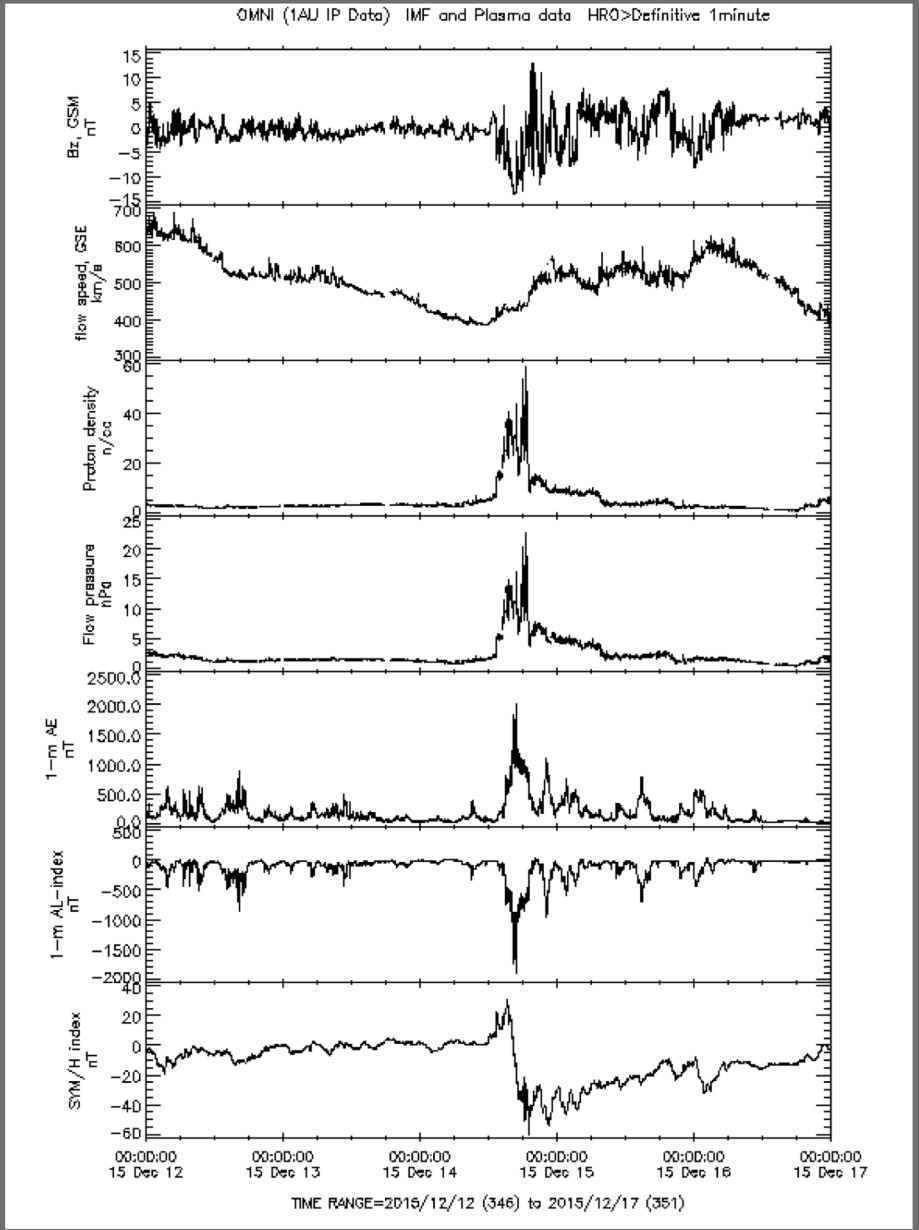


Outer Belt Losses

Example case: Dropout on 14 Dec 2015

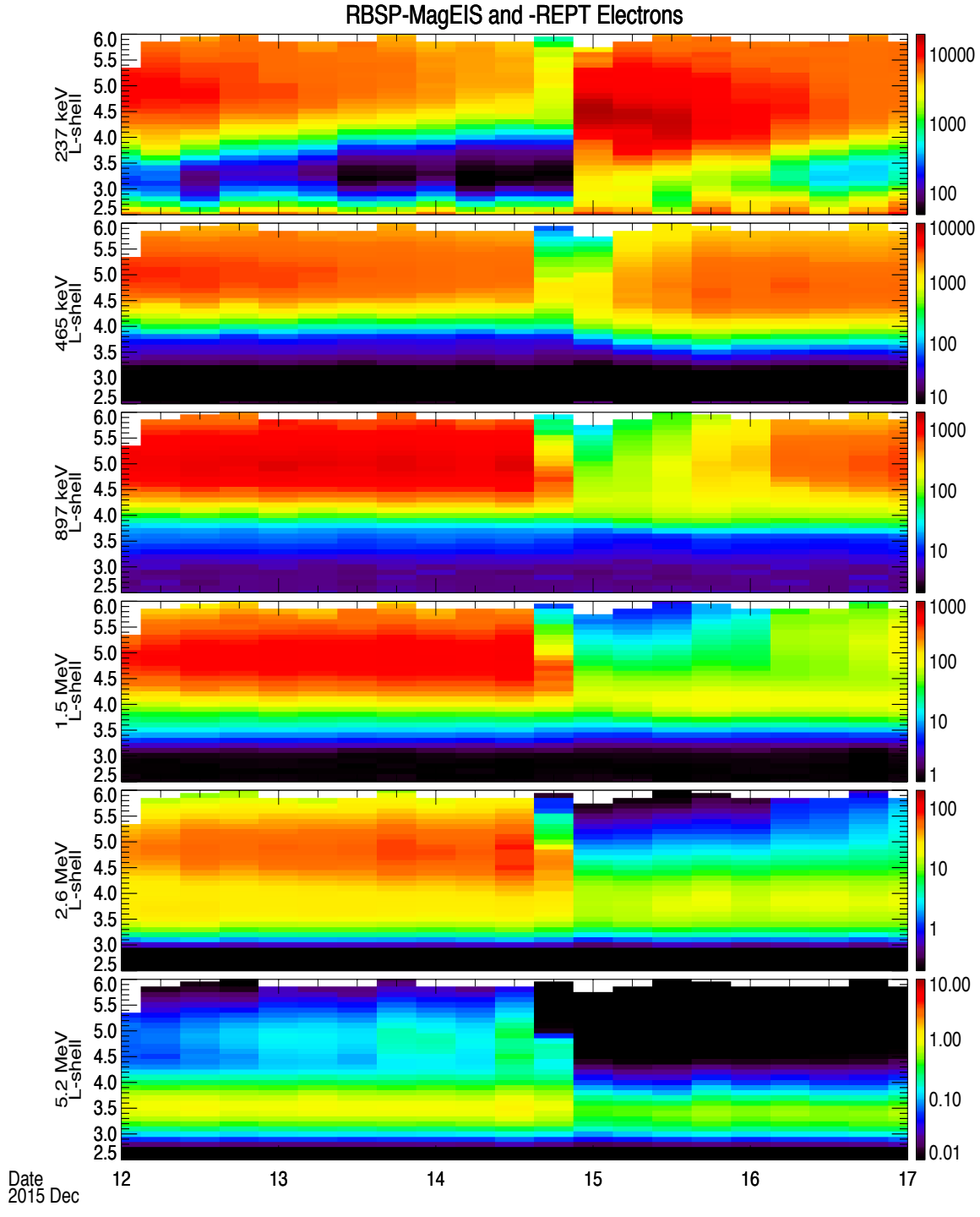






Outer Belt Losses

Example Case: Dropout on 14 Dec 2015



RBSP and MMS