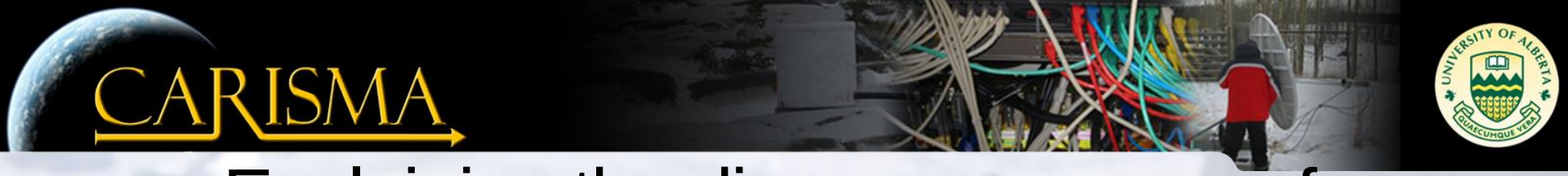



# Explaining the diverse response of ultra-relativistic Van Allen belt electrons to solar wind forcing

Ian R. Mann[1], L.G. Ozeke[1], K.R. Murphy[2], S. Claudepierre[3], L. Olifer[1], S. K. Morley[3], D. Turner[4], I.J. Rae[5], A. Kale[1], D.K. Milling[1], and D.N. Baker[6]

***Email: imann@ualberta.ca***

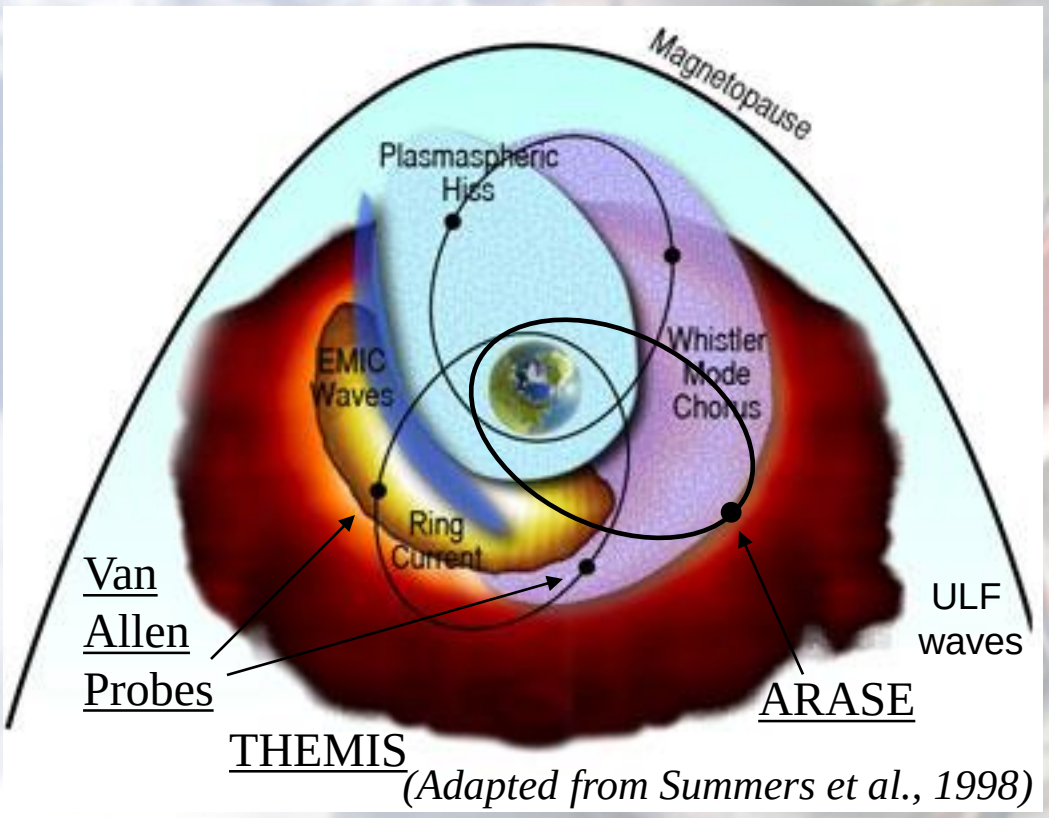
[1]Department of Physics, University of Alberta, Edmonton, Canada;

[2]NASA Goddard Spaceflight Center, MD, USA, [3]The Aerospace Corp., Los Angeles, USA, [4]Los Alamos National Lab., USA, [5]University College London, UK, [6]University of Colorado, CO, USA.

How ULF wave transport coupled to dynamic outer BC can explain the apparently diverse belt response

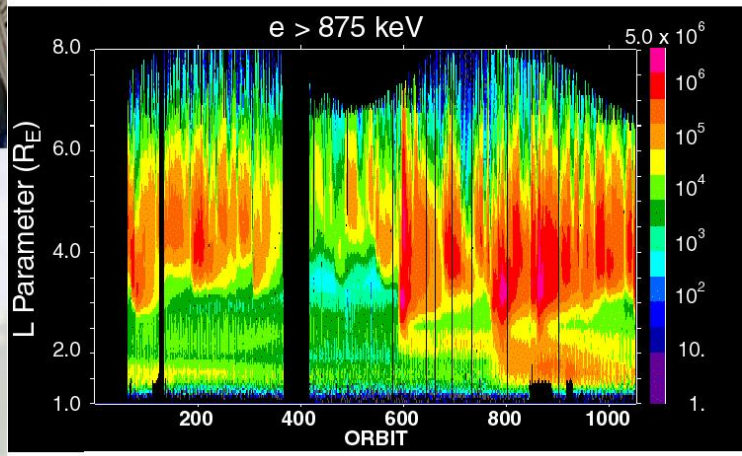
CARISMA

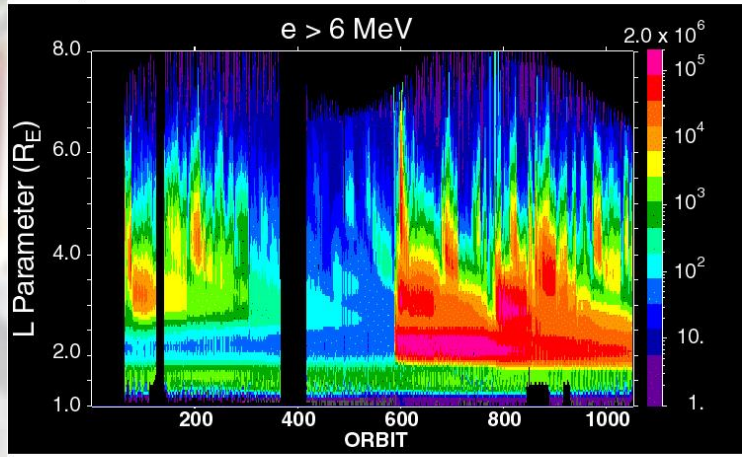
# Radiation Belt Dynamics

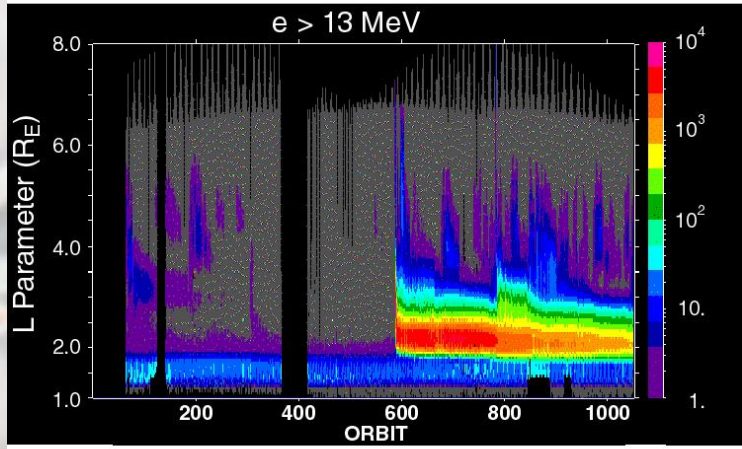



*(Adapted from Summers et al., 1998)*

**Energetic electrons during the CRRES mission**



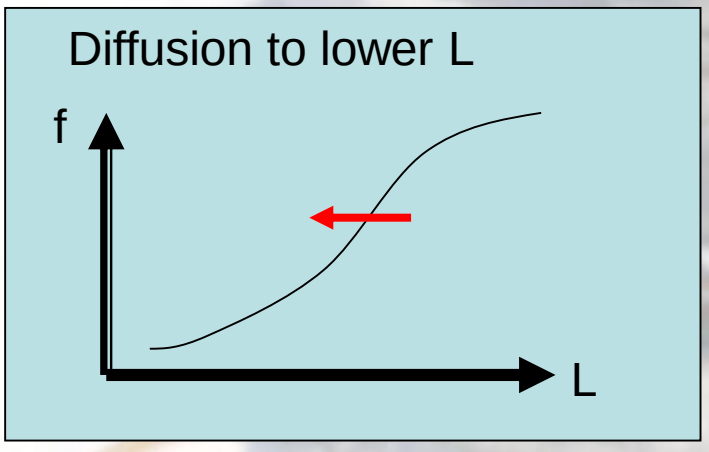

*Which wave-particle interactions? Impact of (outer) boundary condition dynamics?*

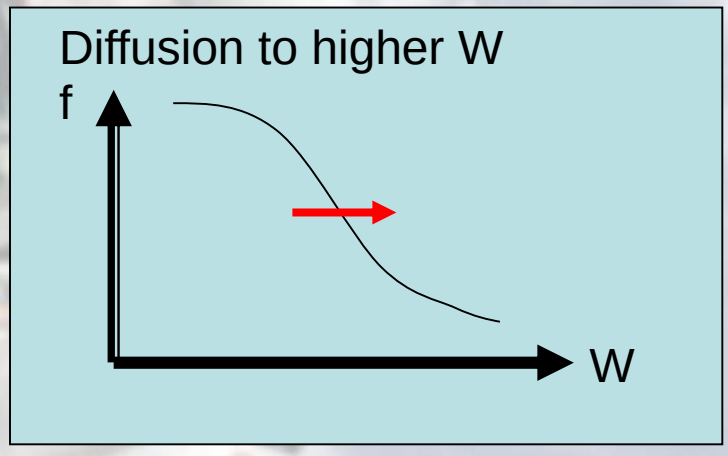
# ULF Wave-MeV Electron Diffusion

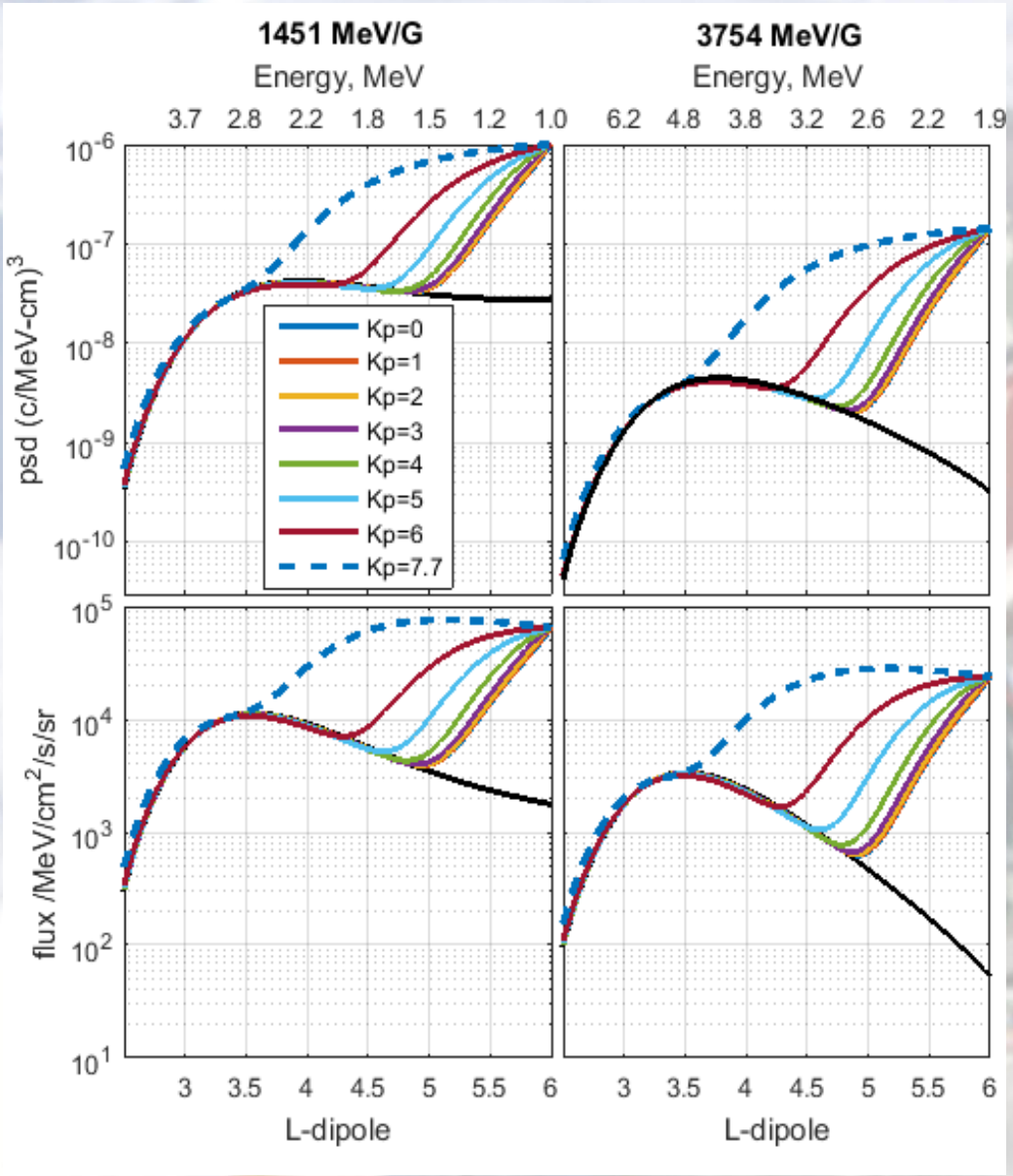
- Rate of energy change due to ULF interactions:

$$\frac{dW}{dt} = q\mathbf{E} \bullet \mathbf{V}_d + \frac{M}{\gamma}\frac{\partial b}{\partial t}$$

- Can transport particles along phase space density gradients: inwards (energisation) or outwards (e.g., magnetopause loss; Loto'aniu et al., 2010; Turner et al., 2012; Mann et al., 2016) explain observed response?






# How Quickly can Outer Boundary Impact the Radiation Belt?

Two hours of Ozeke et al. (2014) Kp dependent ULF wave radial transport (defined by ground ULF waves).

Mann and Ozeke, JGR, 2016.

# ULF Wave Radial Diffusive Transport Model (Brizard & Chan, Phys. Plasmas,2004)

Loss term

$$\frac{df}{dt} = L^2 \frac{\partial}{\partial L}\left(\frac{1}{L^2} D_{LL} \frac{\partial f}{\partial L}\right) - \boxed{\frac{f}{\tau}}$$

"MAGNETIC"

"ELECTRIC"

$$D_{LL}^{m} = \frac{1}{8}\left(\frac{M}{q\gamma B_0 R_E^2}\right)^2 \cdot L^4 \cdot \sum_m m^2 P_m^B(L, m\omega_D)$$

$$D_{LL}^{E} = \frac{1}{8B_0^2 R_E^2} \cdot L^6 \cdot \sum_m P_m^E(L, m\omega_D)$$

Compressional Magnetic Field Power

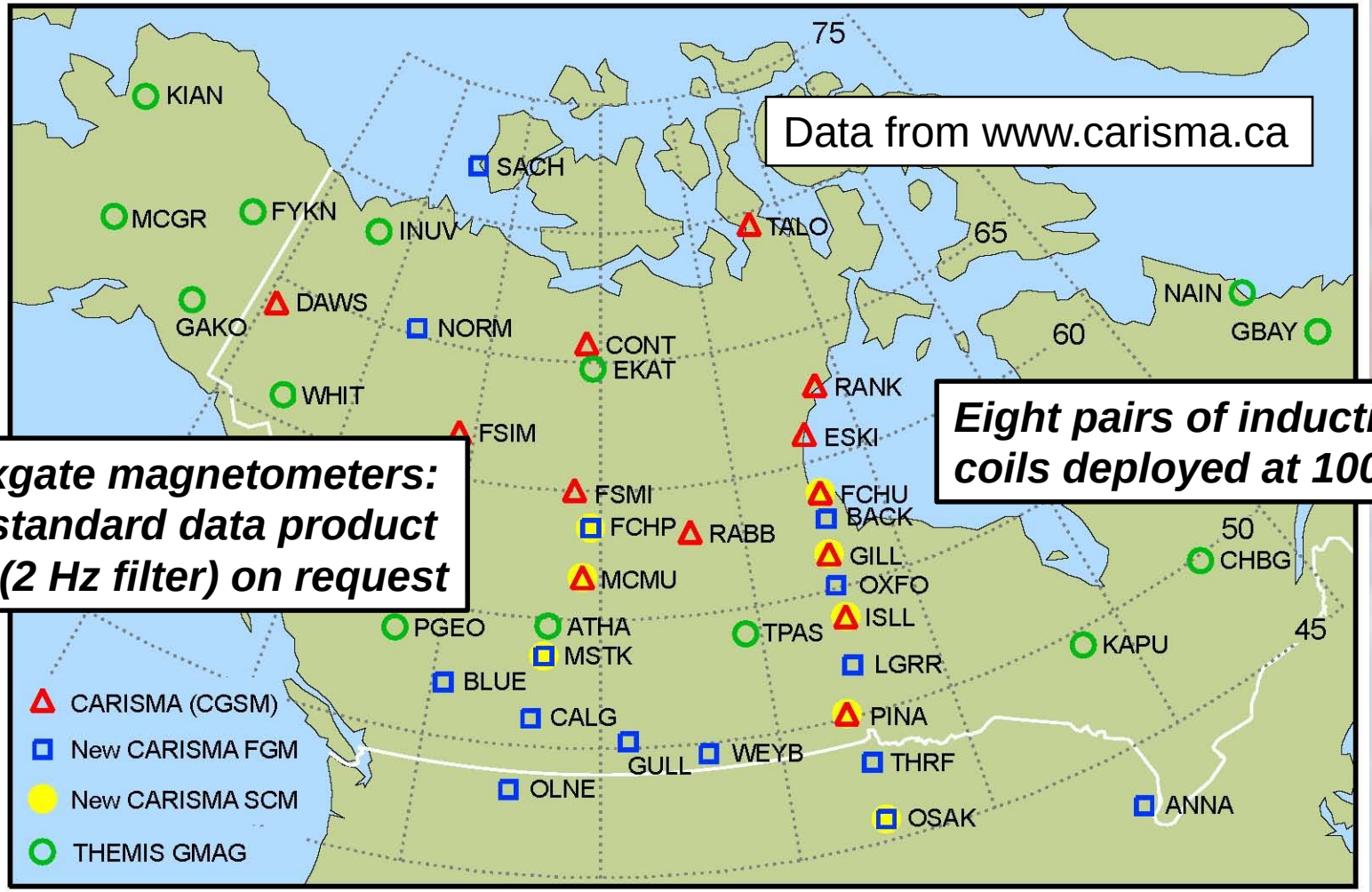
Energy dependence

Azimuthal Electric Field Power

*These two terms can be derived in space empirically.*
*Electric often dominates – allows DLL characterization from ground.*

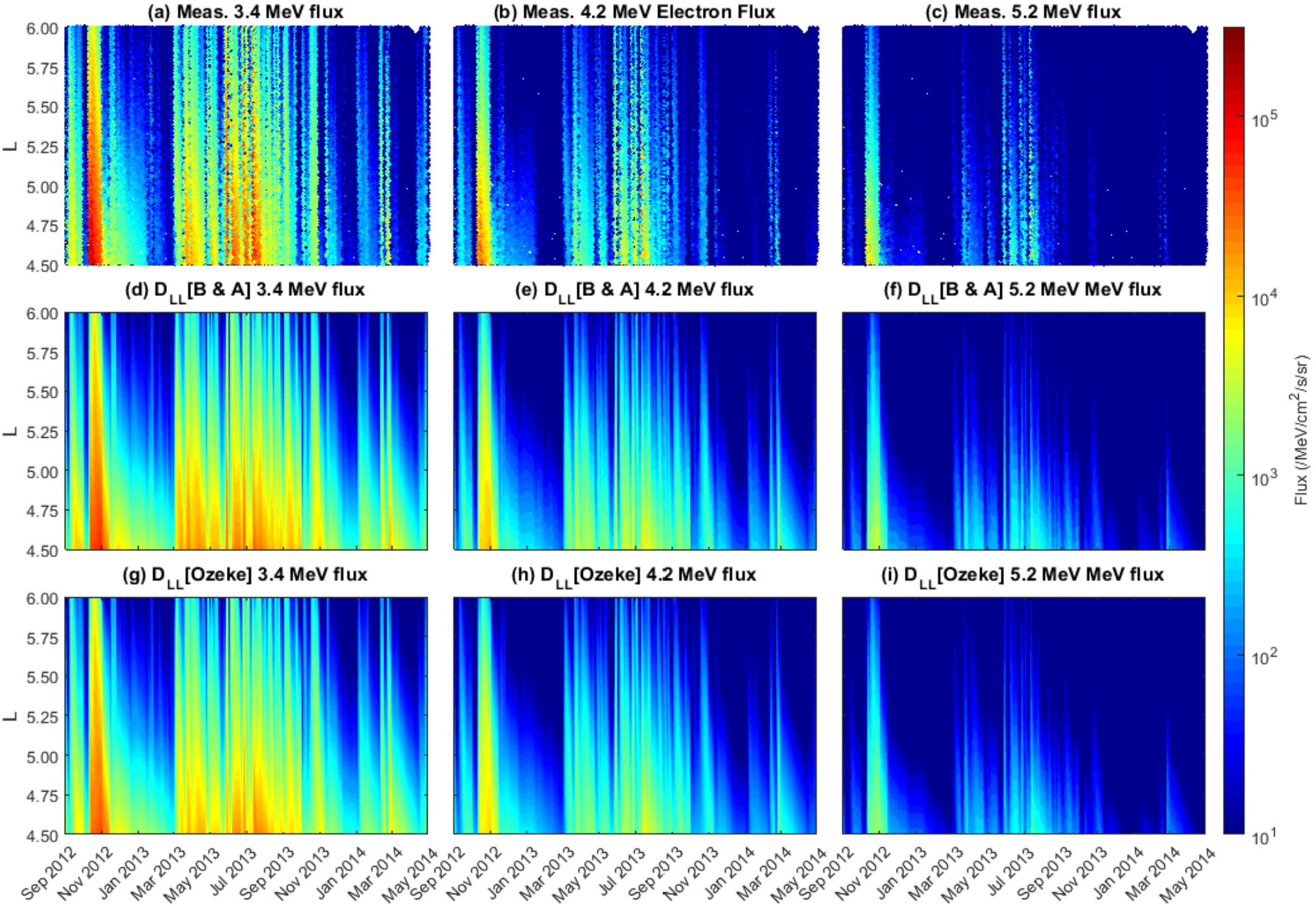
Ozeke et al., 2012, 2013, 2014, 2017

# Expanded CARISMA Magnetometer Array

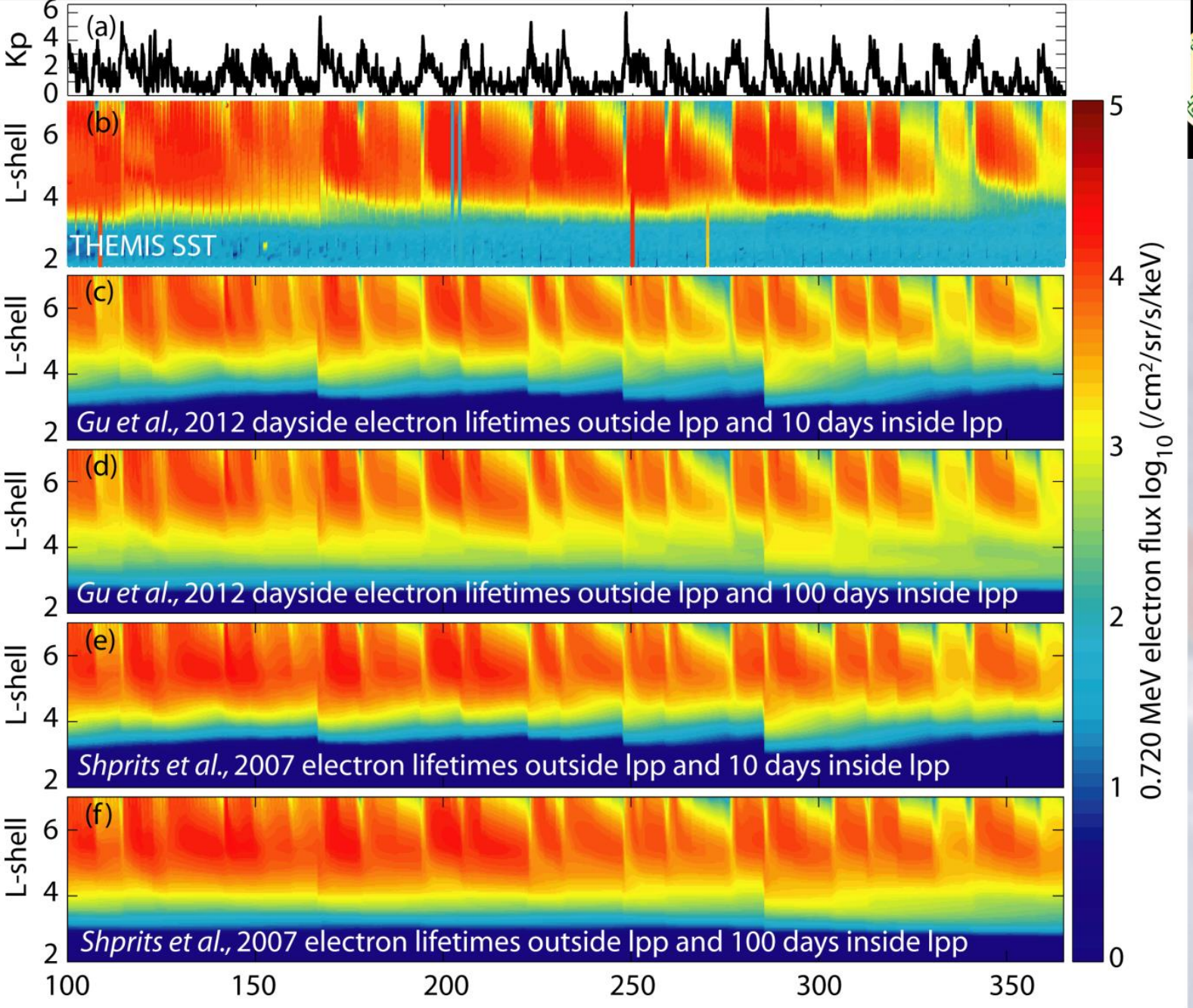



***28 fluxgate magnetometers:***
***- 1Hz standard data product***
***- 8 Hz (2 Hz filter) on request***

***Eight pairs of induction coils deployed at 100 Hz.***

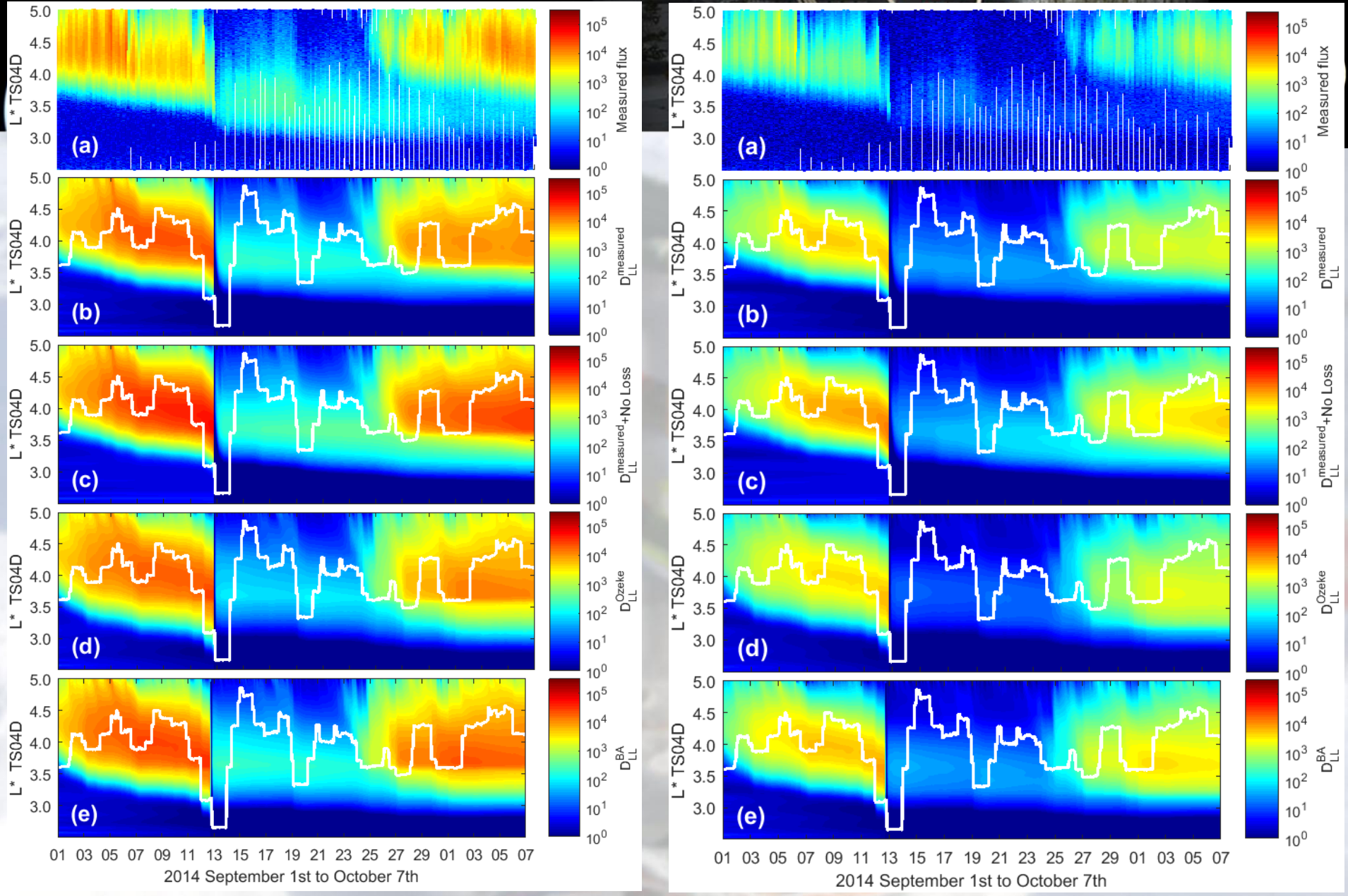



Mann and Ozeke, JGR, 2016.




Driven by Kp ULF statistics.

Ozeke et al. GRL 2014.

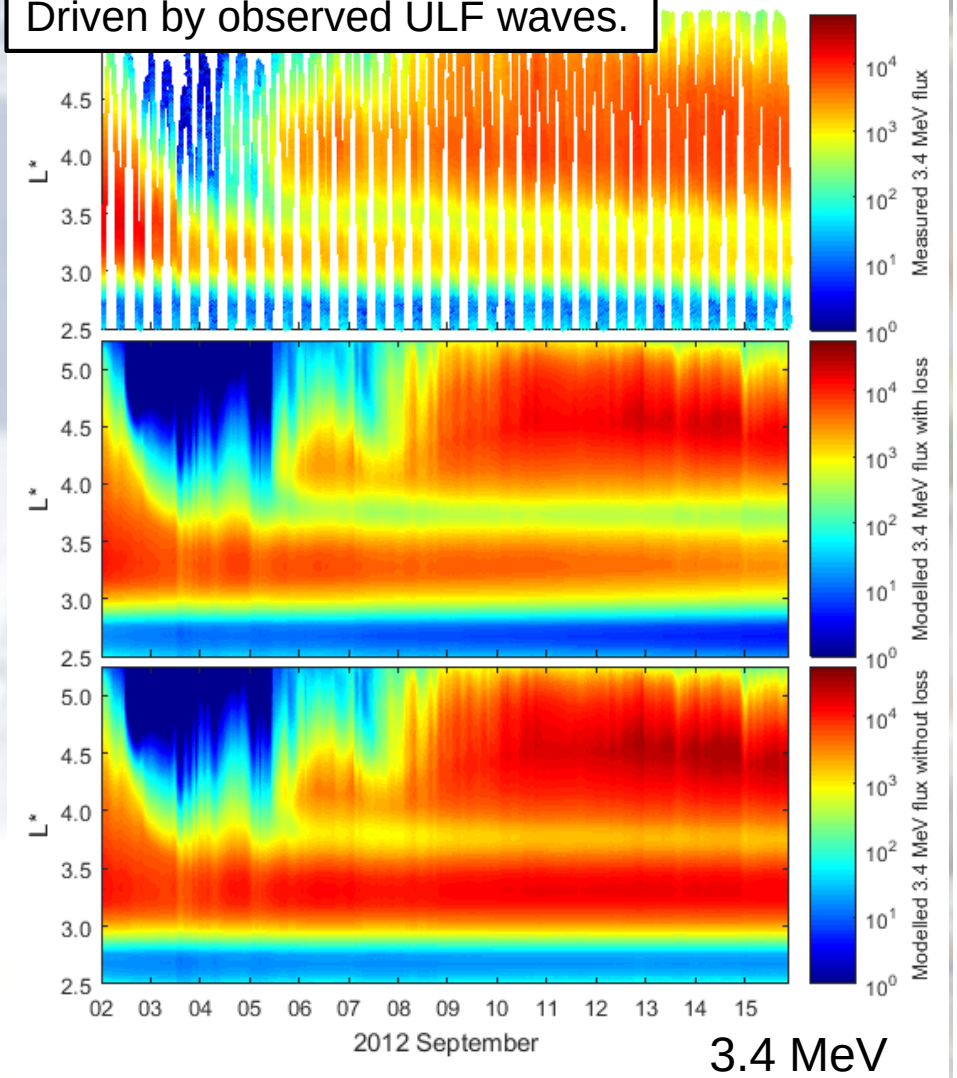



# September 2014 Extended Dropout

Ozeke et al. GRL, 2017

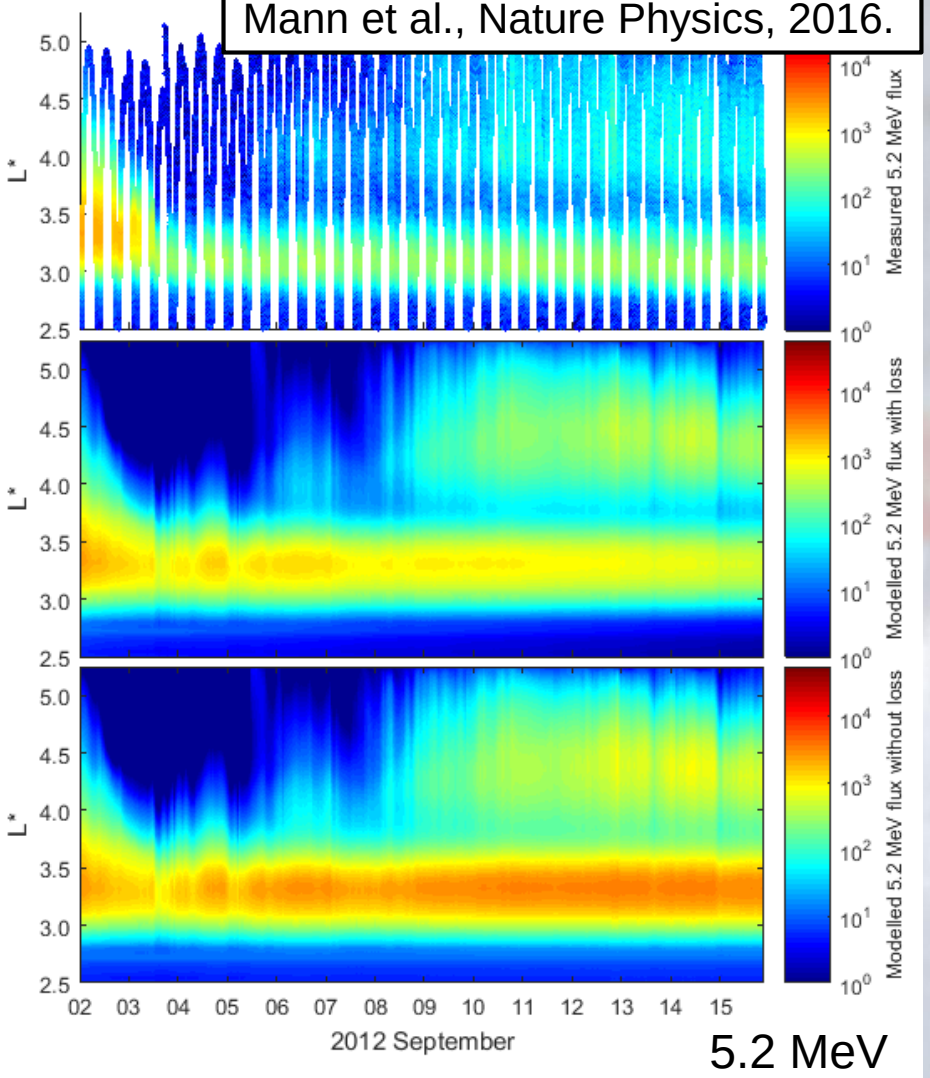
# Third Radiation Belt

Driven by observed ULF waves.



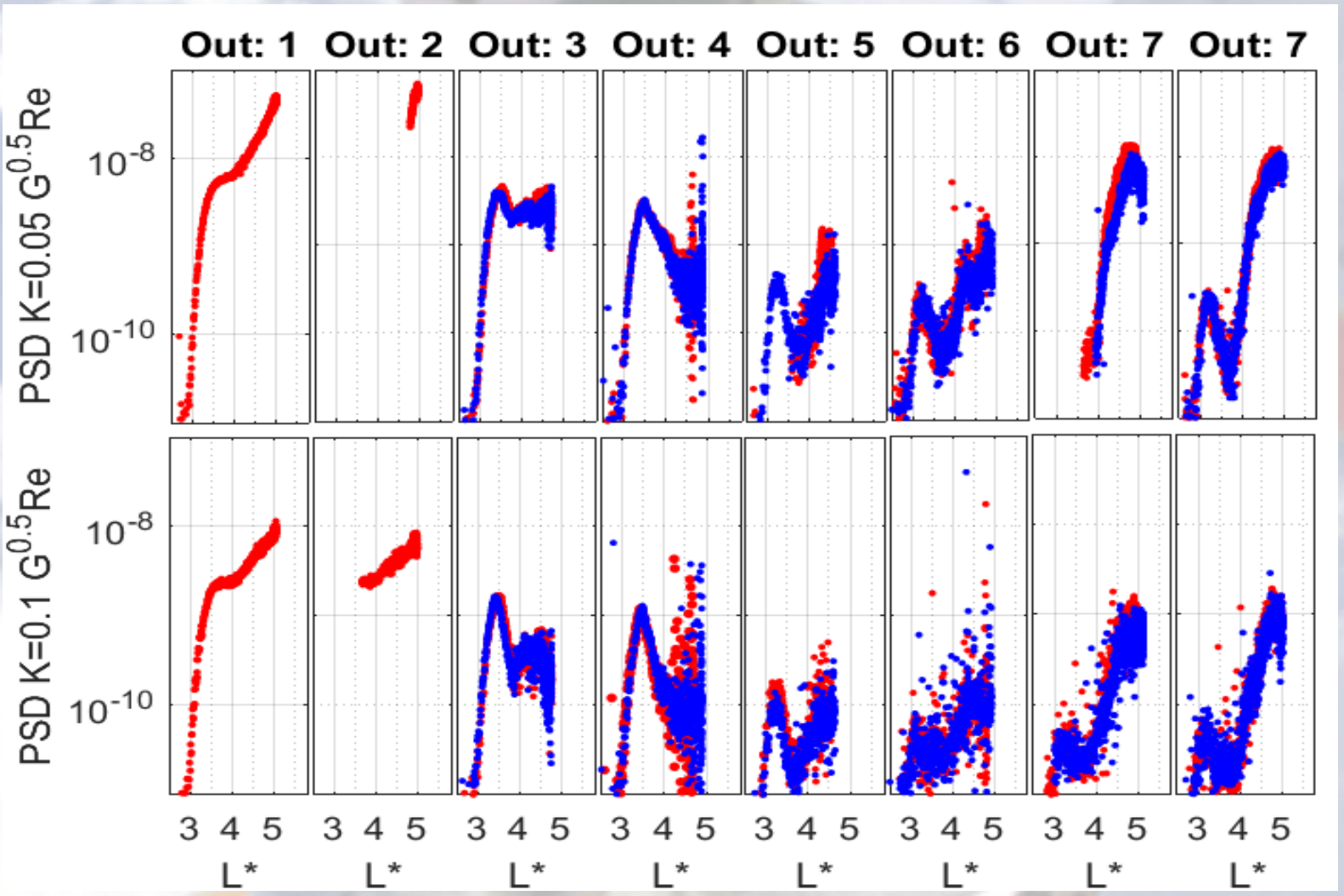

3.4 MeV

Mann et al., Nature Physics, 2016.

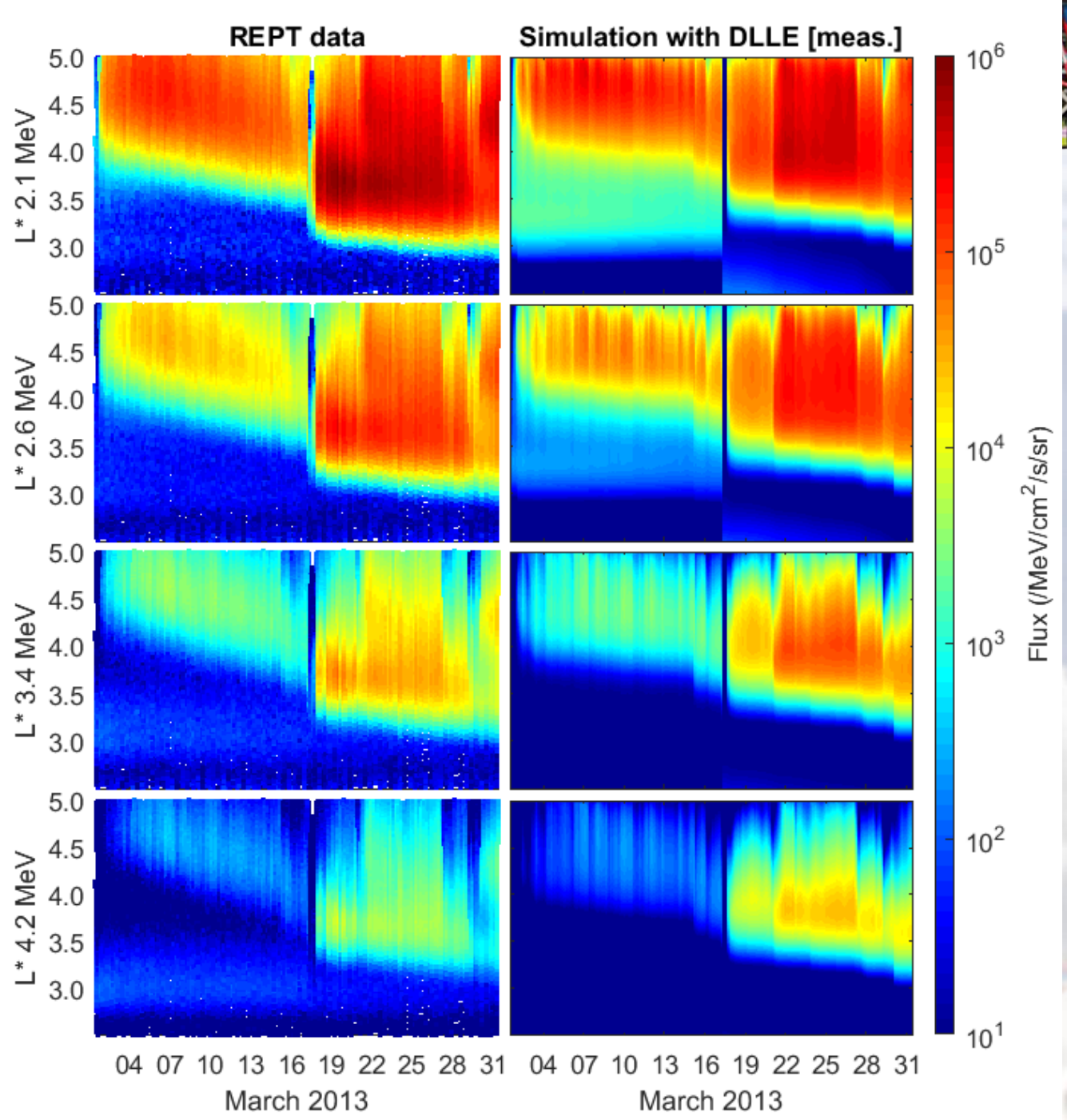



5.2 MeV

# PSD Evolution: Shadowing to low-L

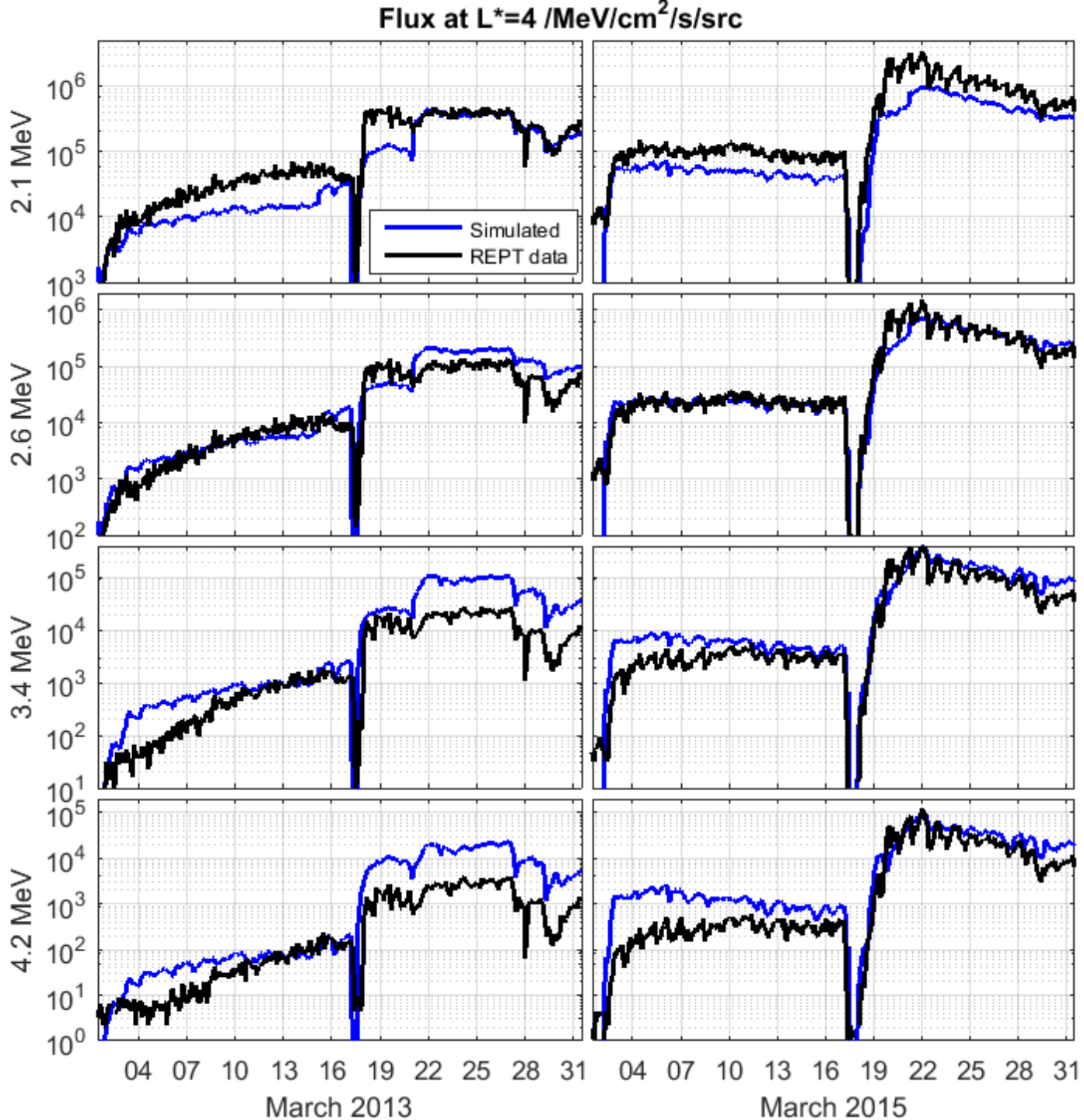



Mann et al., Nature Physics, Feb. (2018).



# March 2013 Storm

Ozeke et al. JGR,
In prep, 2018



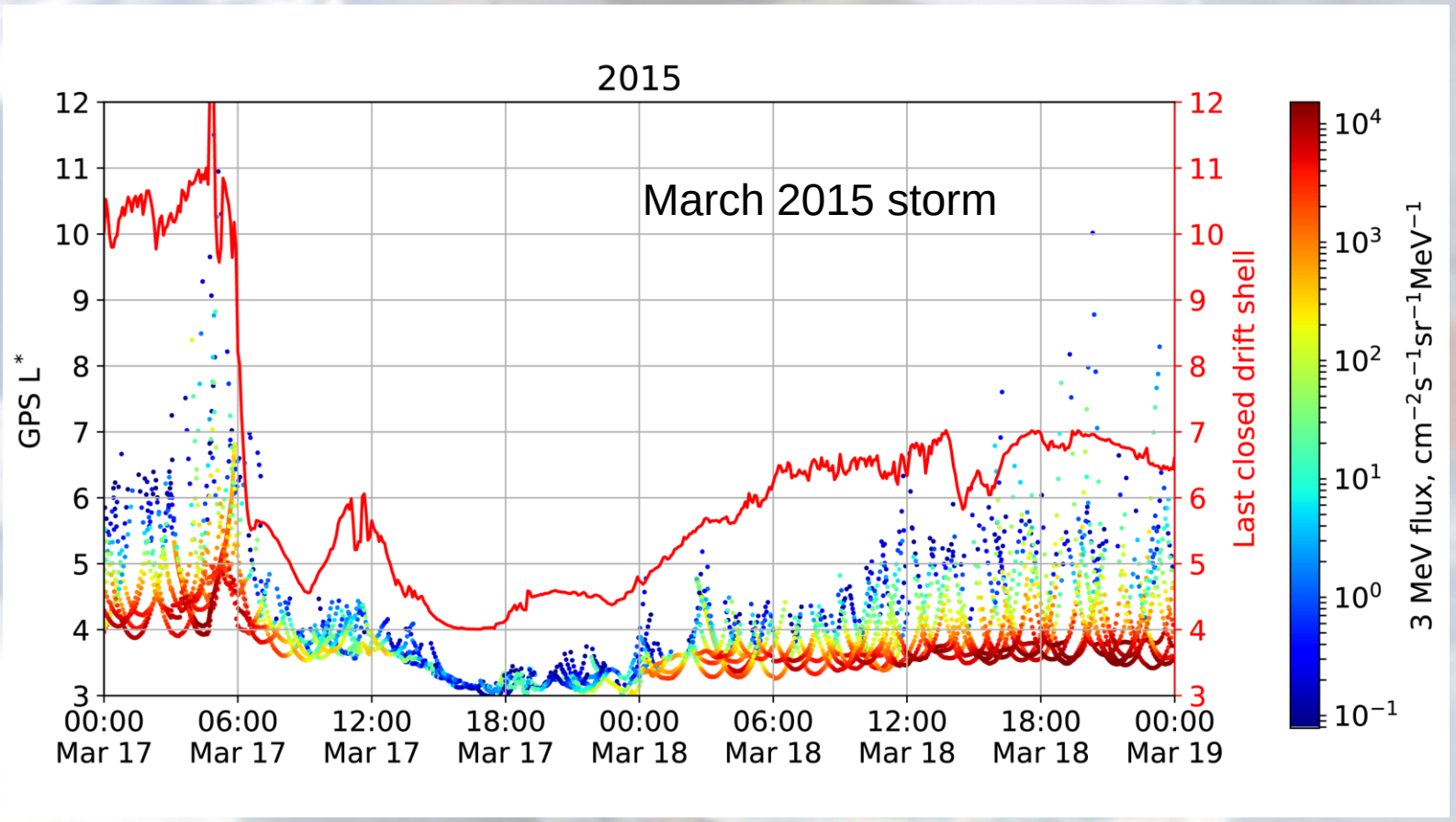
# March 2013 and March 2015 Storms

## L*=4

Ozeke et al. JGR, In prep, 2018.

Ozeke et al. Talk on Friday

# Radiation Belt Extinction

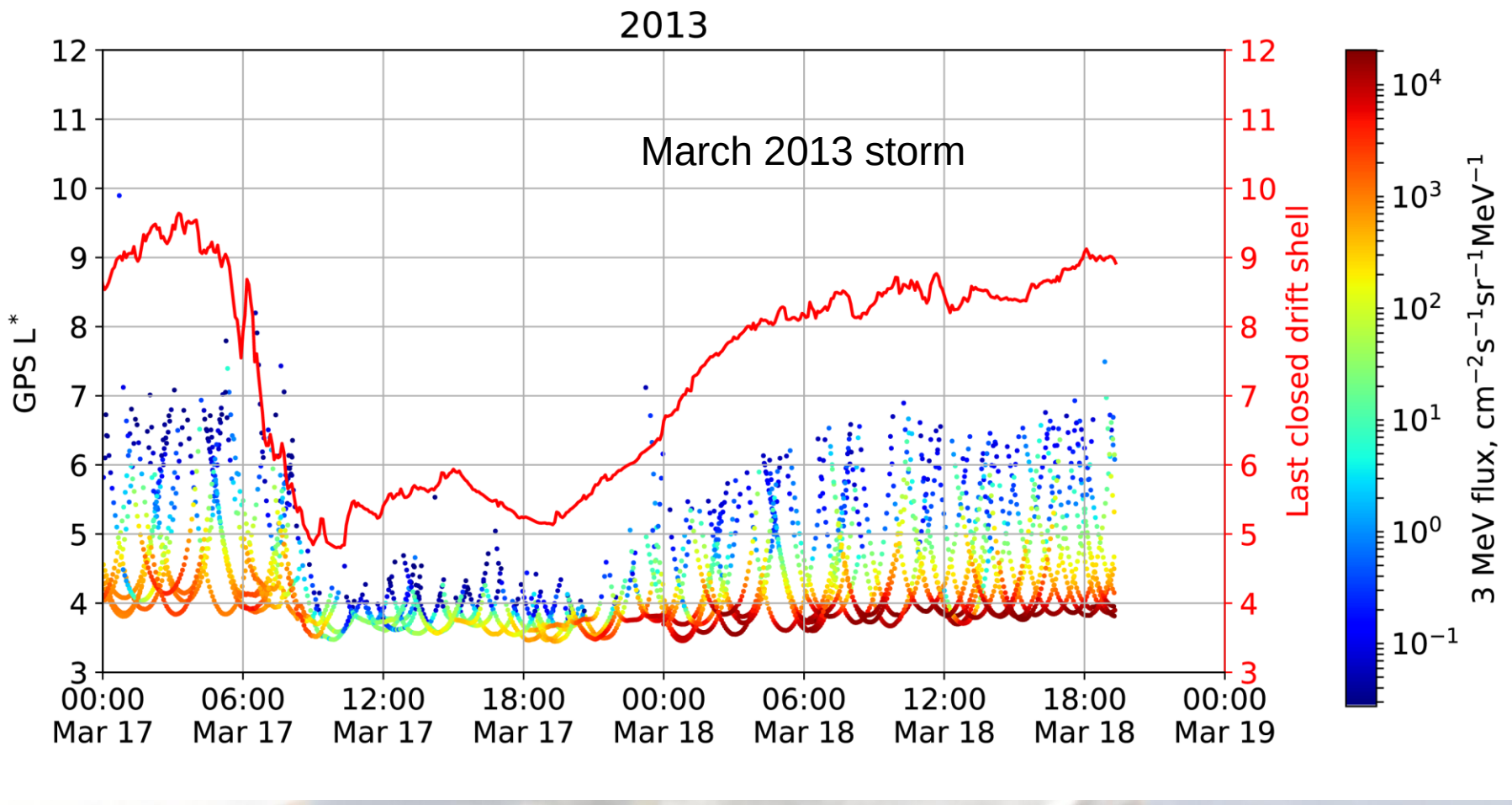



Hour timescale GPS loss; follows LCDS morphology!

Olifer et al., JGR, 2018 Under Review.

Olifer et al. Talk on Thursday.

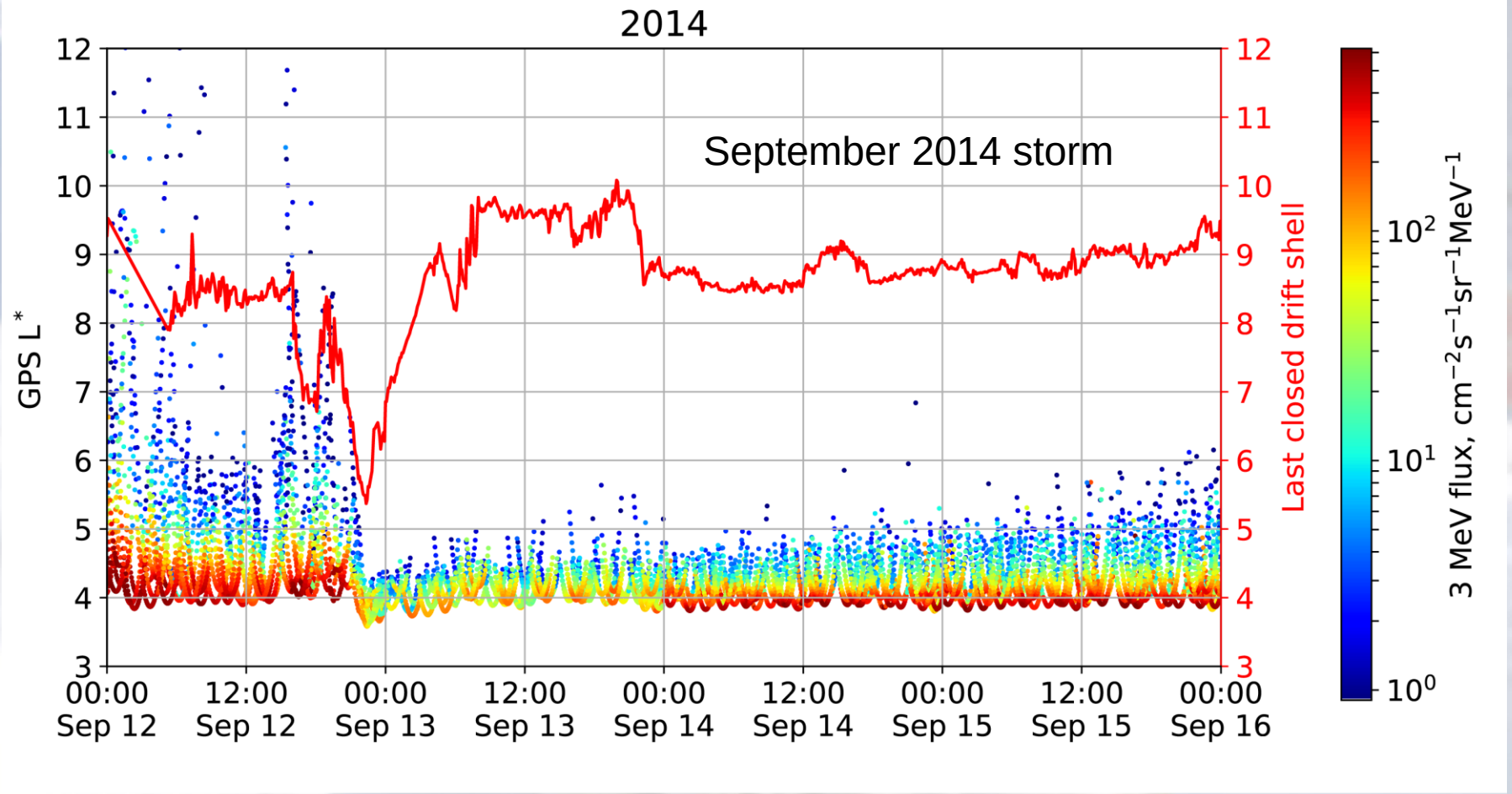
# Radiation Belt Extinction




Olifer et al., JGR, 2018 Under Review.

Olifer et al. Talk on Thursday.

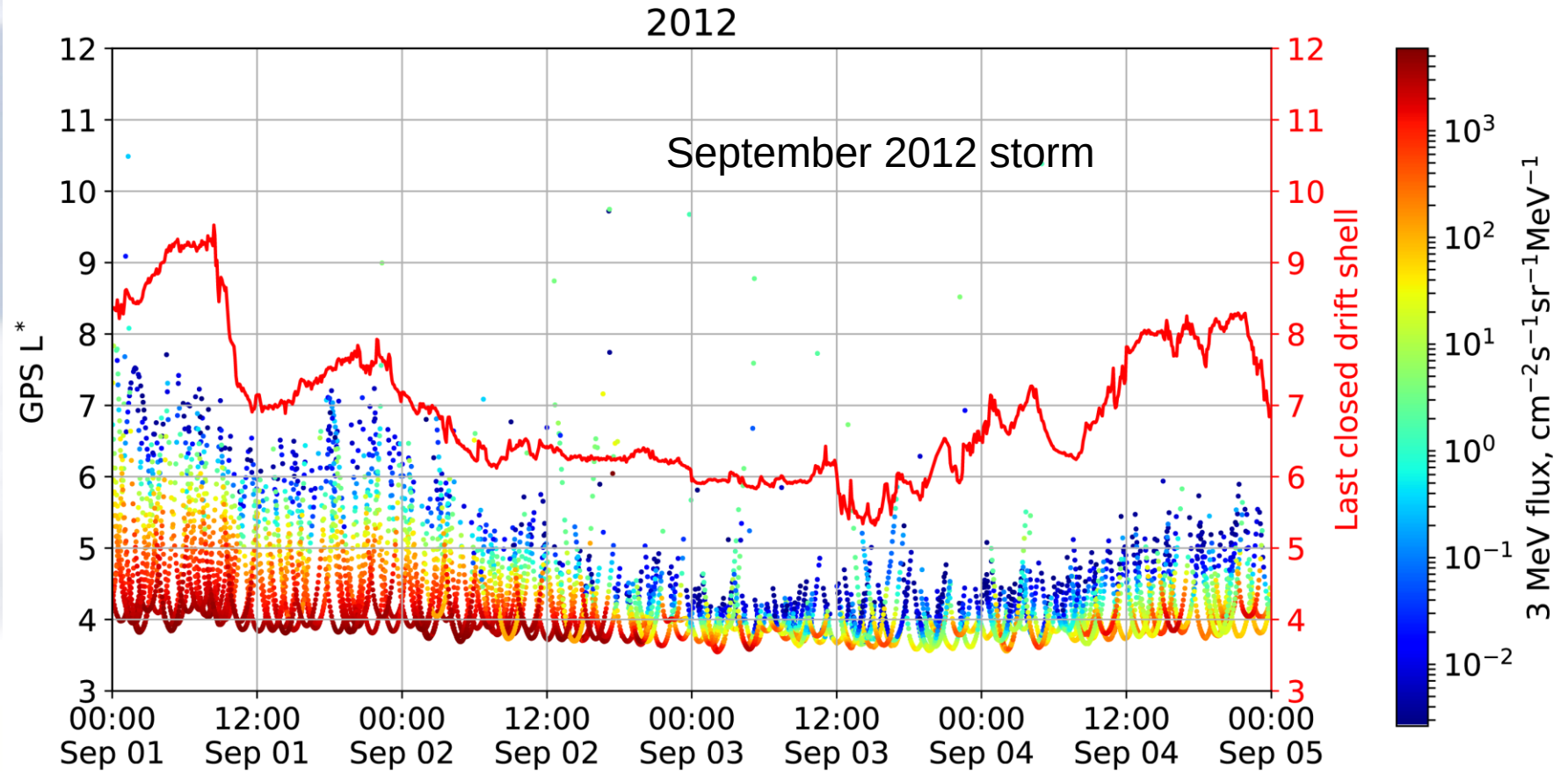
# Radiation Belt Extinction




Olifer et al., JGR, 2018 Under Review.

Olifer et al. Talk on Thursday.

# Third Radiation Belt




Olifer et al., JGR, 2018 Under Review.

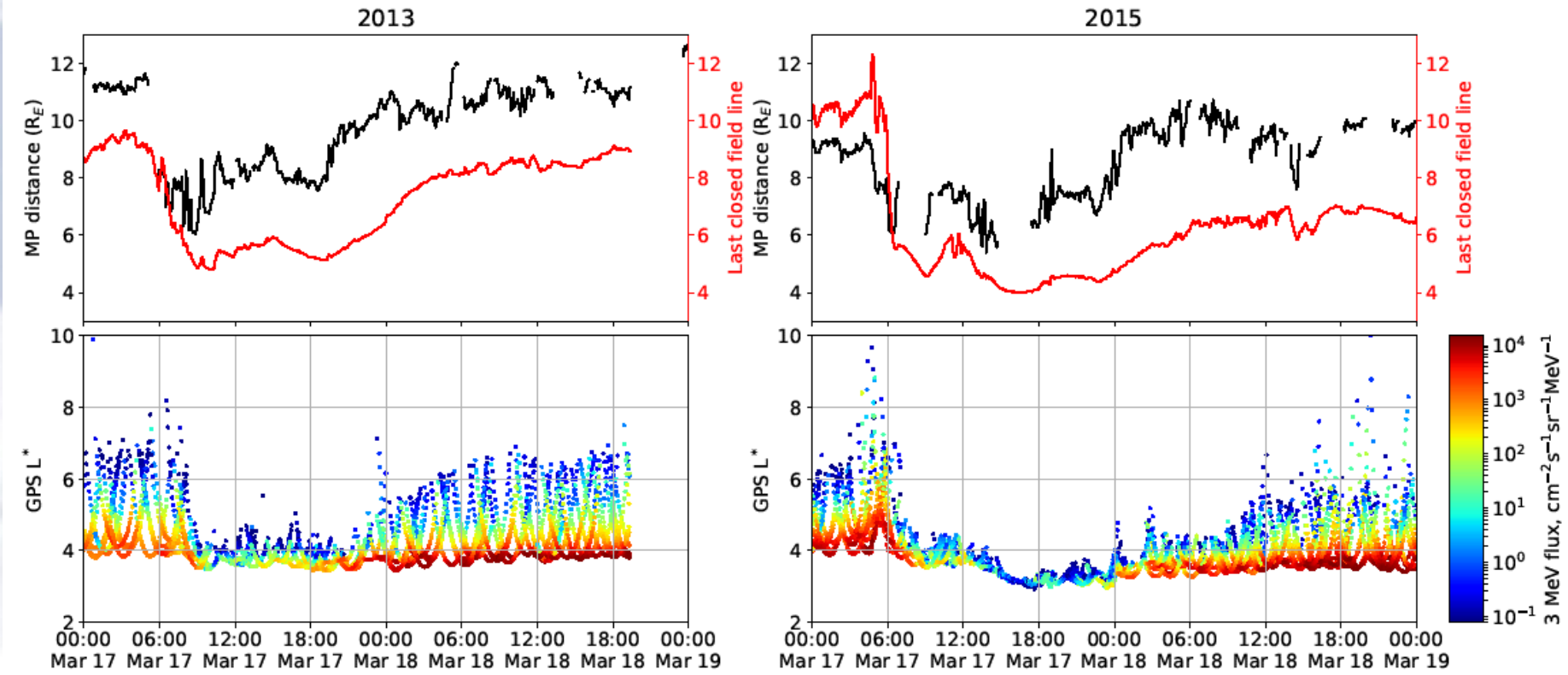
Olifer et al. Talk on Thursday.

# Summary and Conclusions

- ULF wave radial diffusion coupled to dynamic outer boundary condition can reproduce a wide range of observed outer belt morphologies.
- Van Allen Probes can only specify the model outer BC at best on timescales every ~4 hours. At times this may not be sufficient to capture the appropriate internal and indeed BC dynamics.
- GPS can allow the outer boundary source flux to be specified at higher temporal resolution.
- Fast ULF wave coupling, combined with still not fully unexplained fast radiation belt “extinction”, can reproduce ultra-relativistic belt dynamics!
- Has the promise to deliver simple but high fidelity ultra-relativistic radiation belt specification and forecasting!

# Back Up

# Radiation Belt Extinction



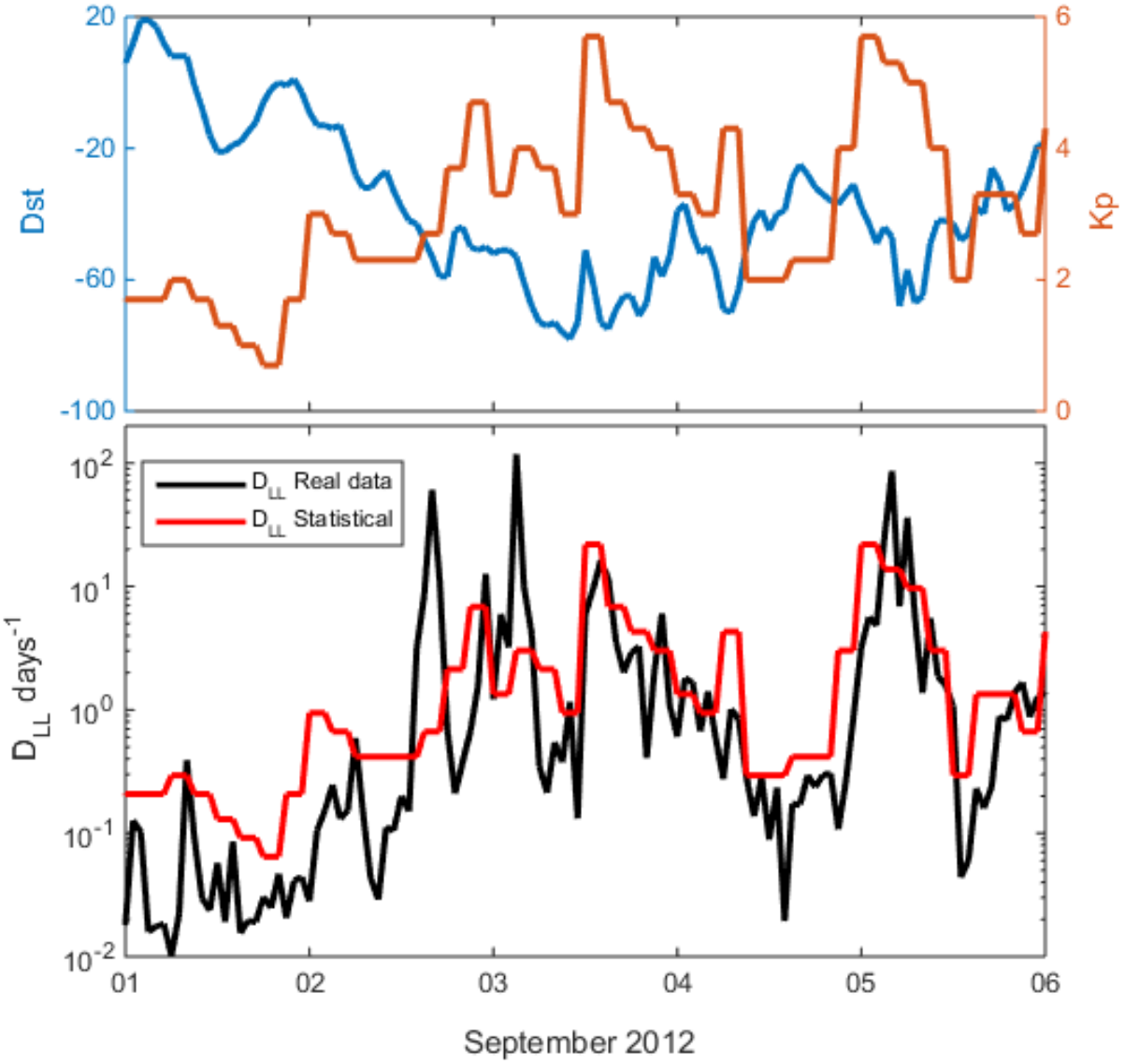

Hour timescale GPS loss; follows LCDS morphology!

Olifer et al., JGR, 2018 Under Review.

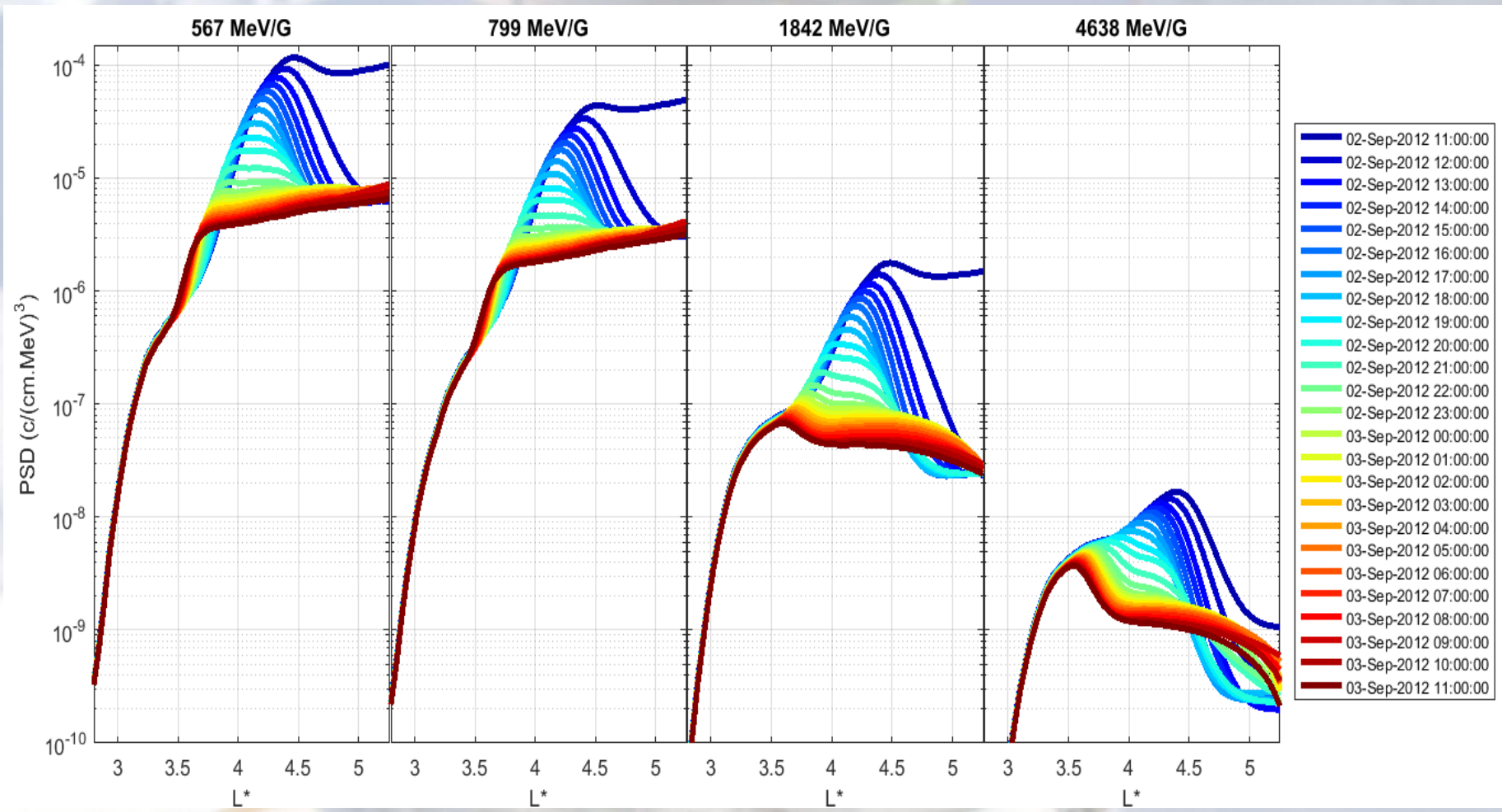
Olifer et al. Talk on Thursday.

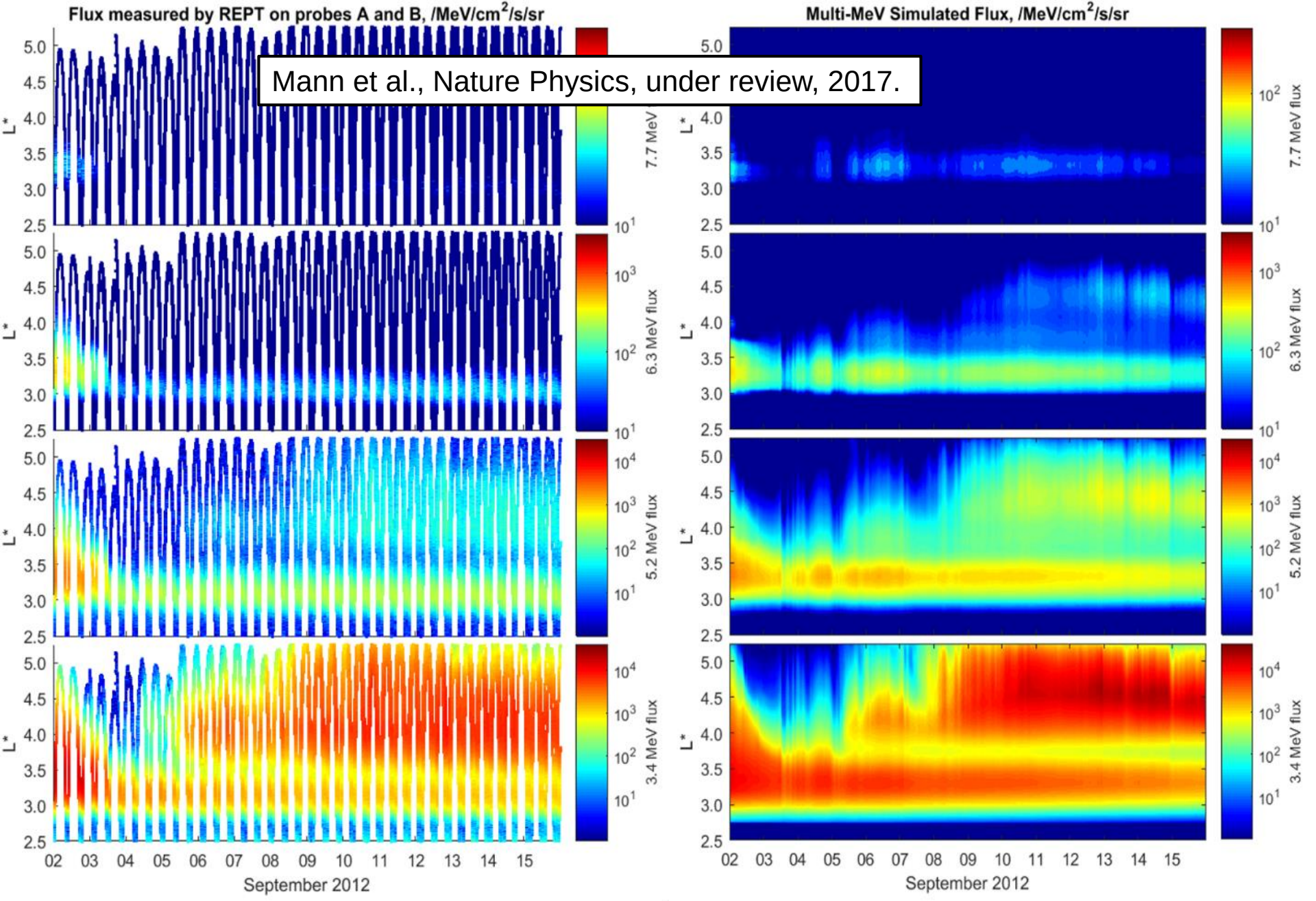
# Measured vs Statistical DLL values

- Statistical DLL model follows Kp (red curves)
- DLLs derived from real data show large spikes around Sept 3rd
- Spikes not seen in the Kp model
- Models solely dependent on Kp are inadequate, especially in main phase.

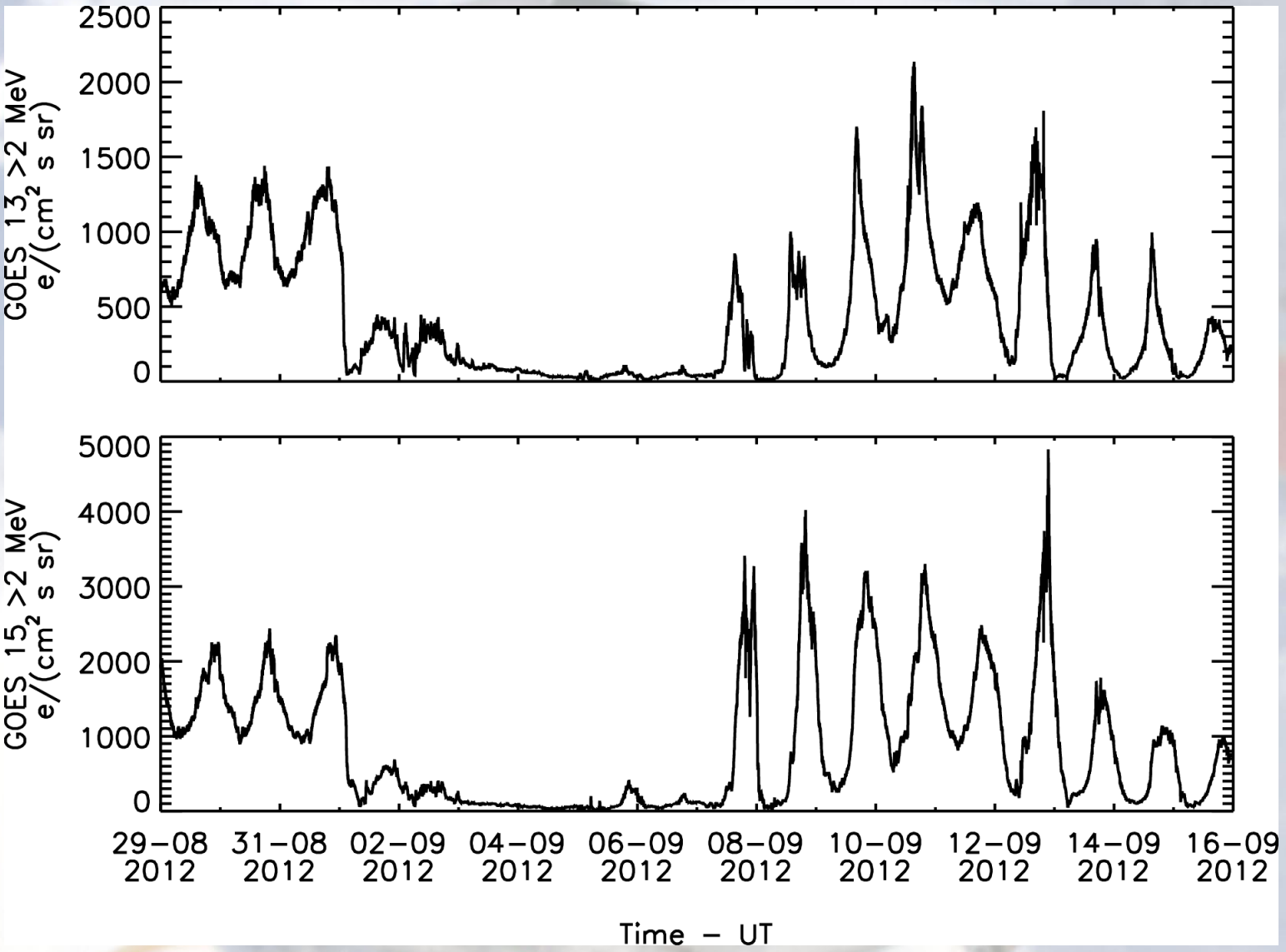


# Energy-Dependent Response






ULF model reproduces observed narrow belt at higher energies > 5 MeV

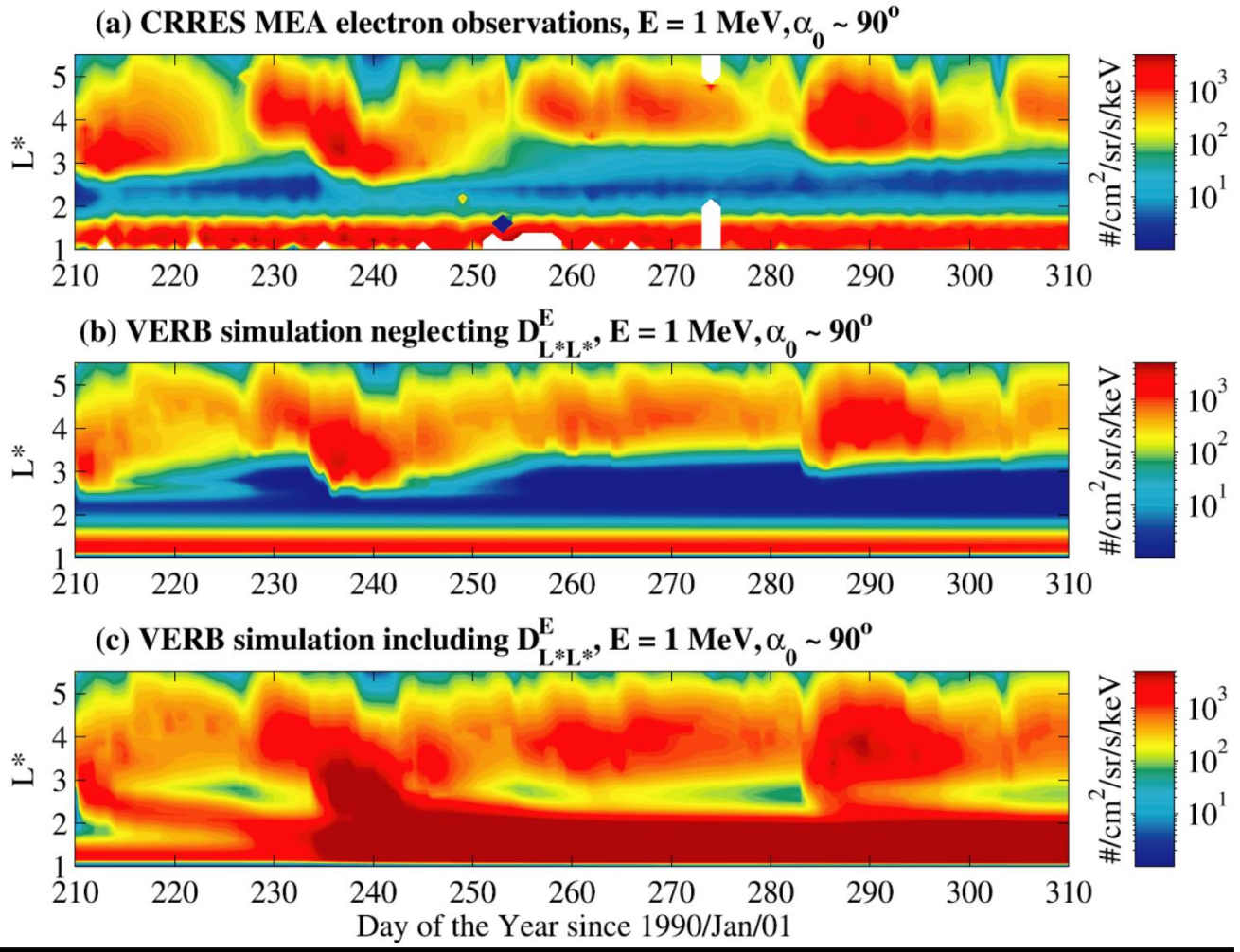

GOES 13 >2 MeV
e/(cm² s sr)
2500
2000
1500
1000
500
0
GOES 15 >2 MeV
e/(cm² s sr)
5000
4000
3000
2000
1000
0
29–08 2012
31–08 2012
02–09 2012
04–09 2012
06–09 2012
08–09 2012
10–09 2012
12–09 2012
14–09 2012
16–09 2012
Time – UT

# Motivation

VERB model runs with Brautigam & Albert, JGR, 2000 diffusion coefficients

EM ULF waves only →

EM + electrostatic ULF fluctuations →




"More accurate models of radial diffusion rates should be determined in future studies and will require more accurate observations of electrostatic and electromagnetic fluctuations at