Deepening Minimums in PSD as an Evidence of the Localied Loss of Electrons by EMIC waves

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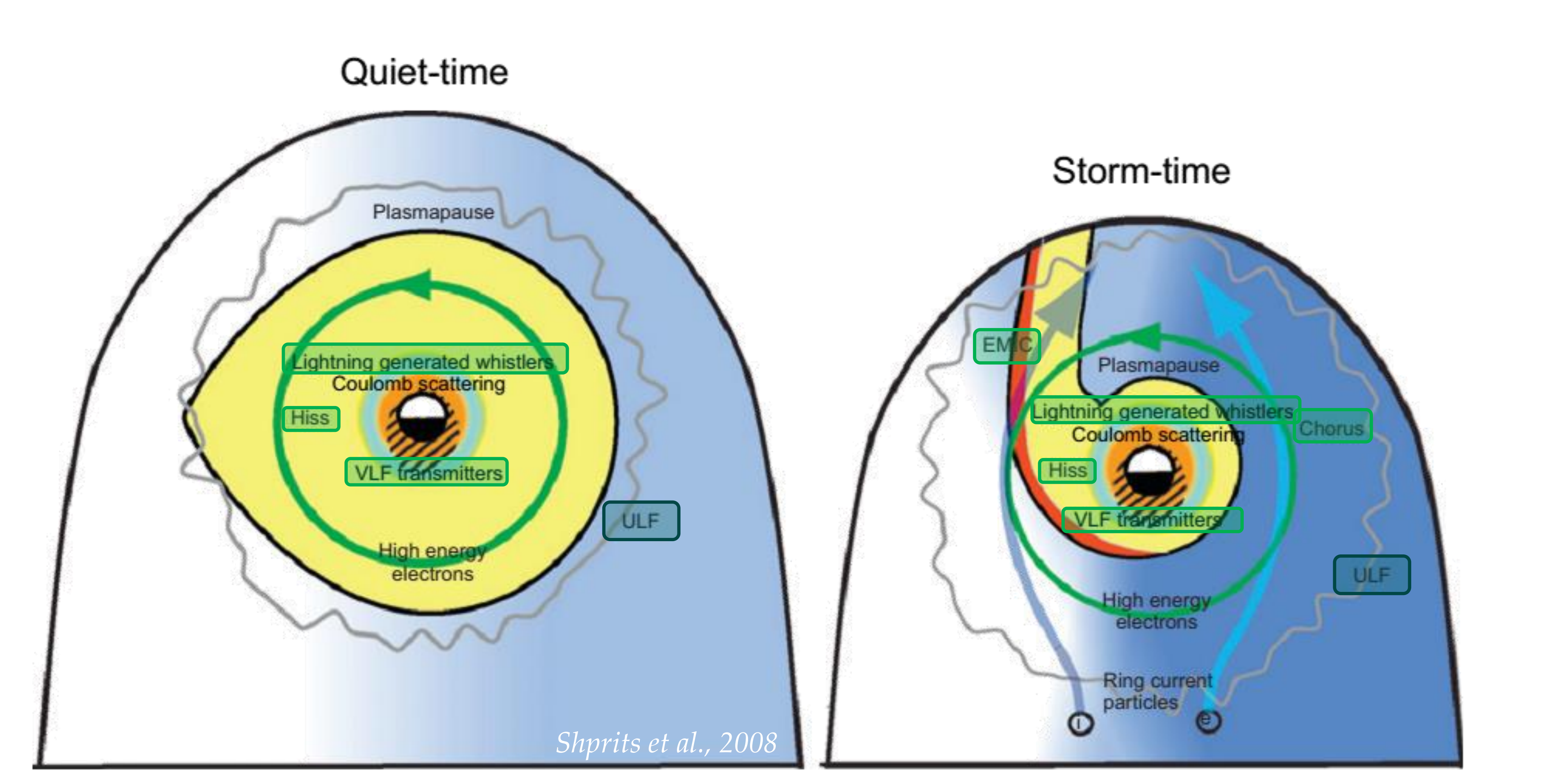
GFZ
Helmholtz Centre
POTSDAM

Fokker-Planck equation and the VERB code



$$\frac{\partial f}{\partial t} = \frac{1}{G}\frac{\partial}{\partial L^*} G D_{L^*L^*} \frac{\partial f}{\partial L^*}$$
$$+ \frac{1}{G}\frac{\partial}{\partial V} G \left(D_{VV}\frac{\partial}{\partial V} f + D_{VK}\frac{\partial}{\partial K} f \right) + \frac{1}{G}\frac{\partial}{\partial K} G \left(D_{KK}\frac{\partial}{\partial K} f + D_{VK}\frac{\partial}{\partial V} f \right) - \frac{f}{\tau}$$

- VERB code
- Radial diffusion
- Local diffusion
  - Pitch-angle
  - Energy
  - Mixed-terms
- Loss into atmosphere or magnetopause

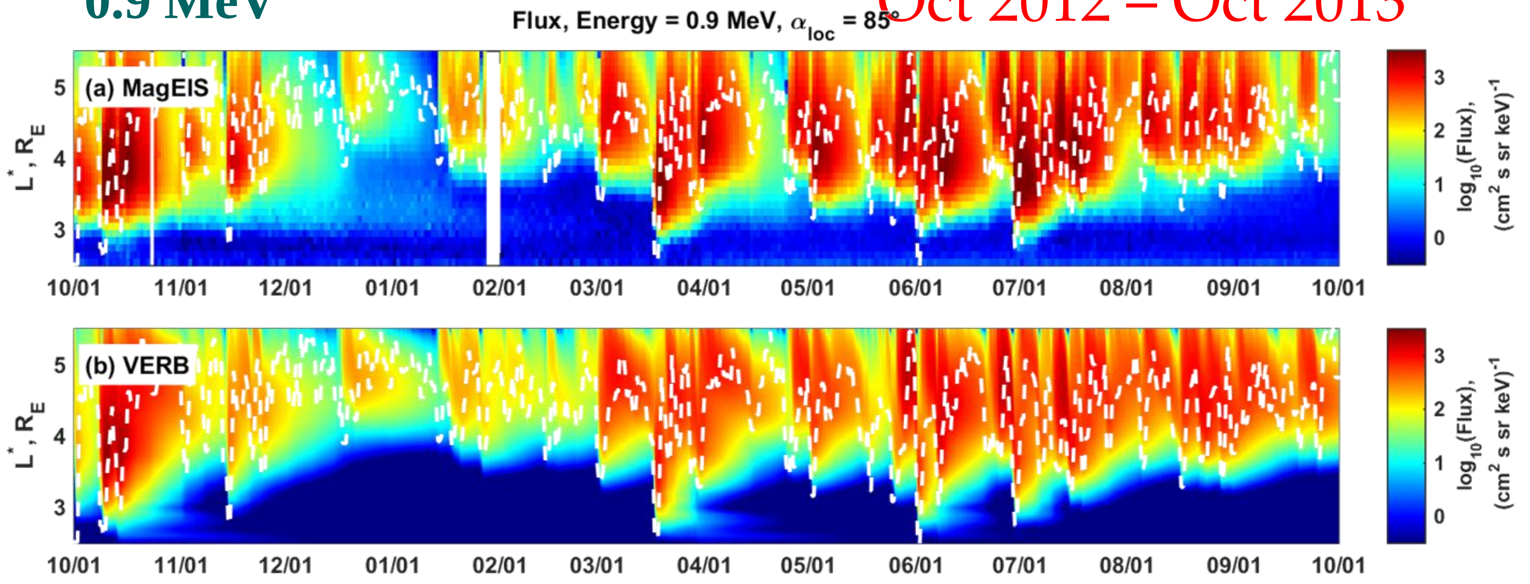
Waves:

- ULF

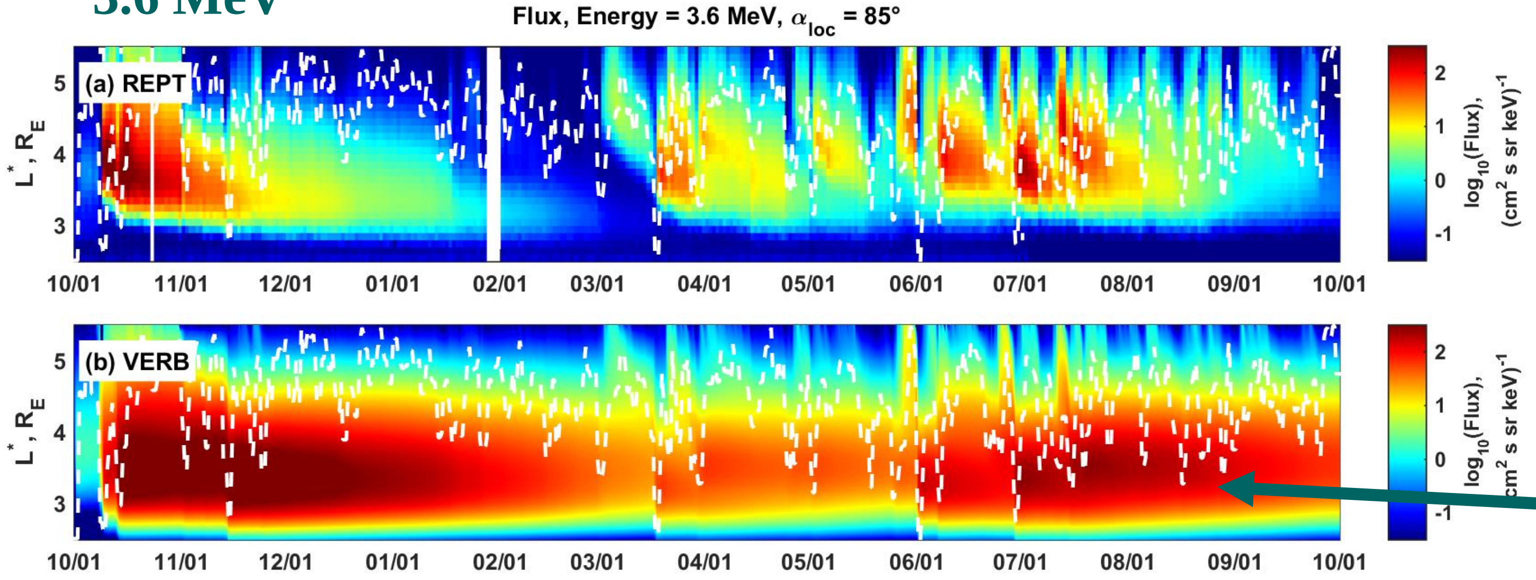
- Hiss
- Chorus
- VLF transmitters
- Lightning whistlers
- EMIC

Long-term VERB code simulation
Oct 2012 – Oct 2013

0.9 MeV



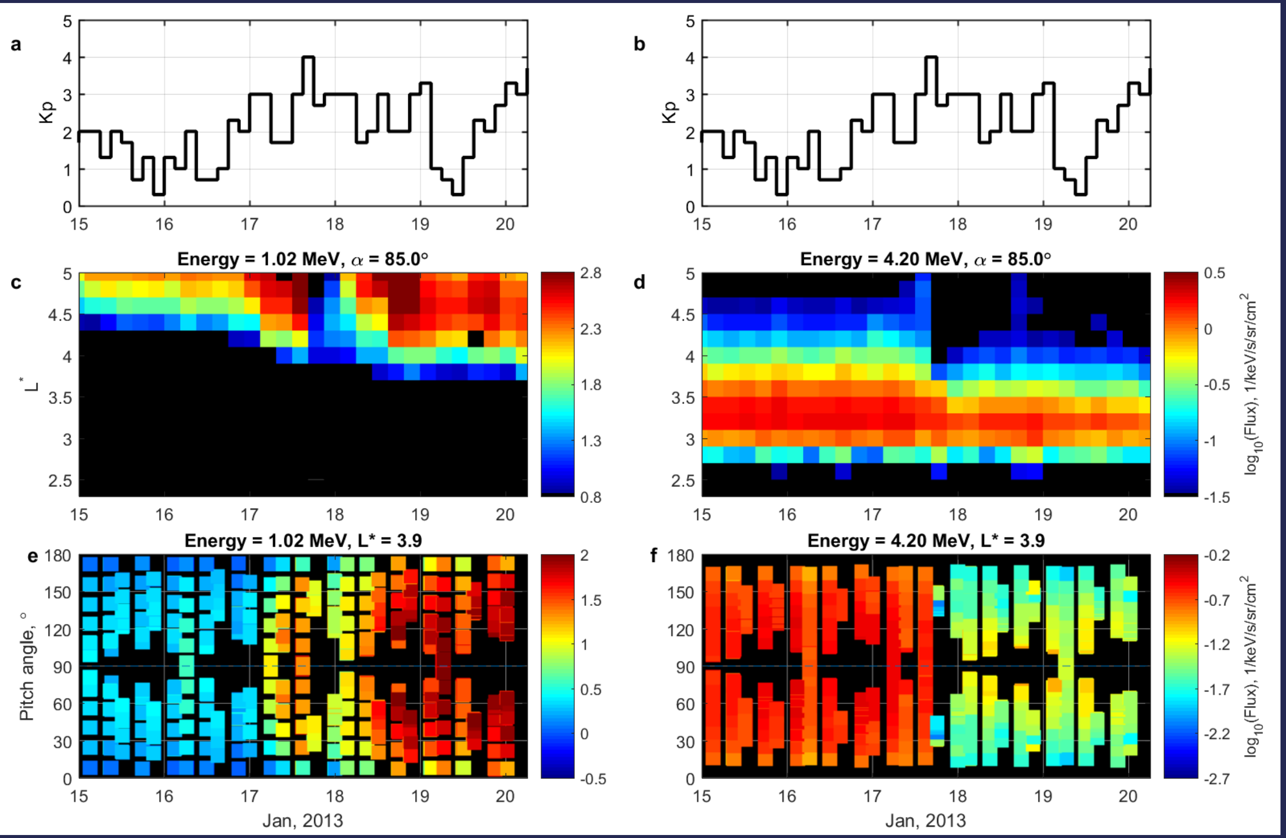
3.6 MeV



We reproduce the dynamics of relativistic electrons, but not for the ultrarelativistic energies

No EMIC waves

Evolution of the Pitch Angle Distribution during the January 17, 2013 Storm



[Shprits et al., 2016, *Nature Comms*.]

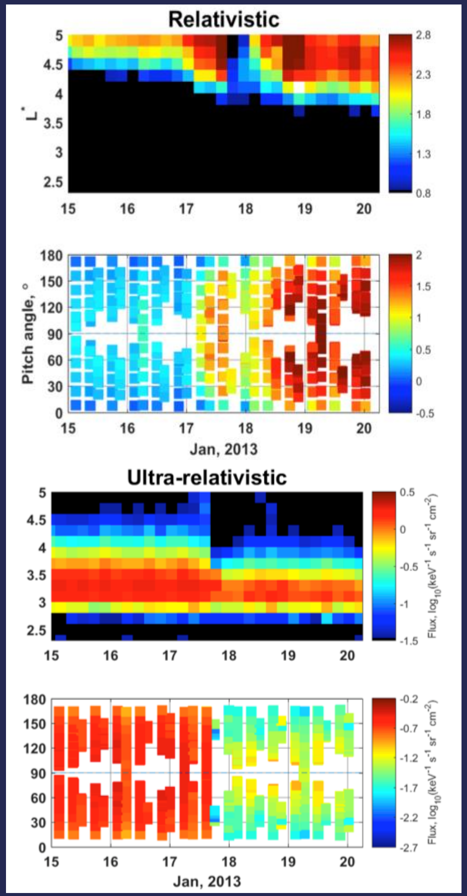
Unique conditions during the January 17, 2013 storm:

1) Pre-storm peak fluxes of relativistic and ultra-relativistic electrons were separated.
2) Magnetopause was not compressed inside GEO.
3) The previous October storm created an abundance of ultra-relativistic electrons which allowed us to measure pitch-angle distributions on REPT.

Comparison of Model and Observations at Multiple Energies

- At MeV energies model can reproduce acceleration and widening of the belts.
- At Multi-MeV the model reproduces the dropout and narrowing of the pitch angle distribution.

Data



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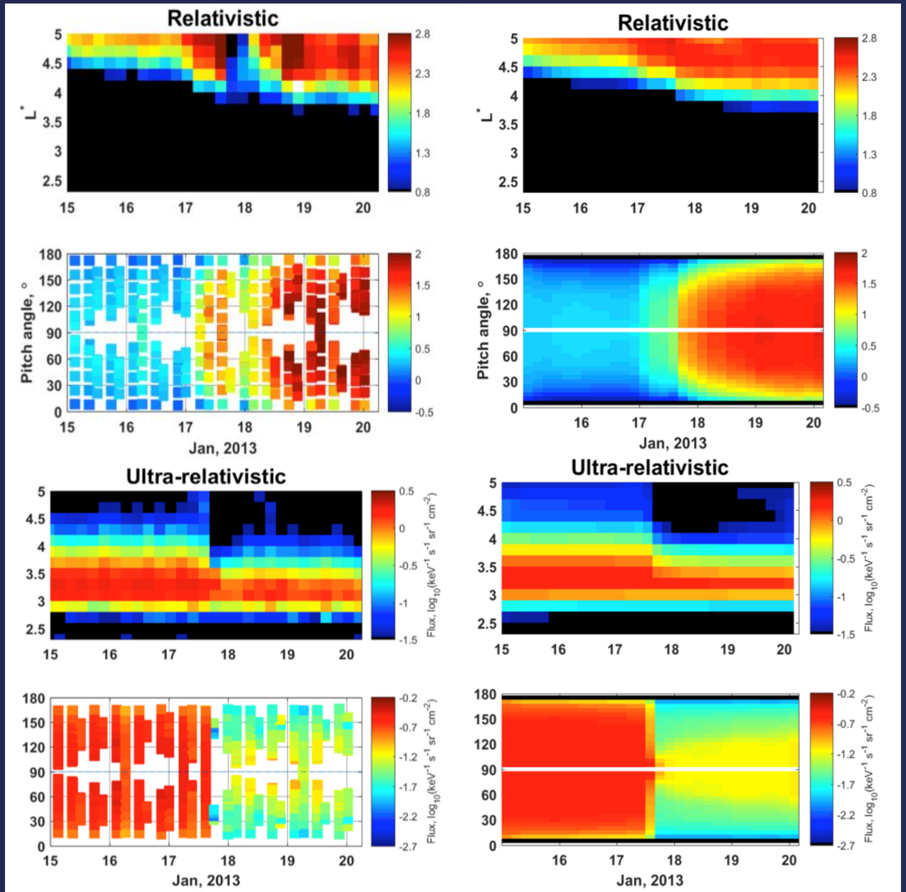
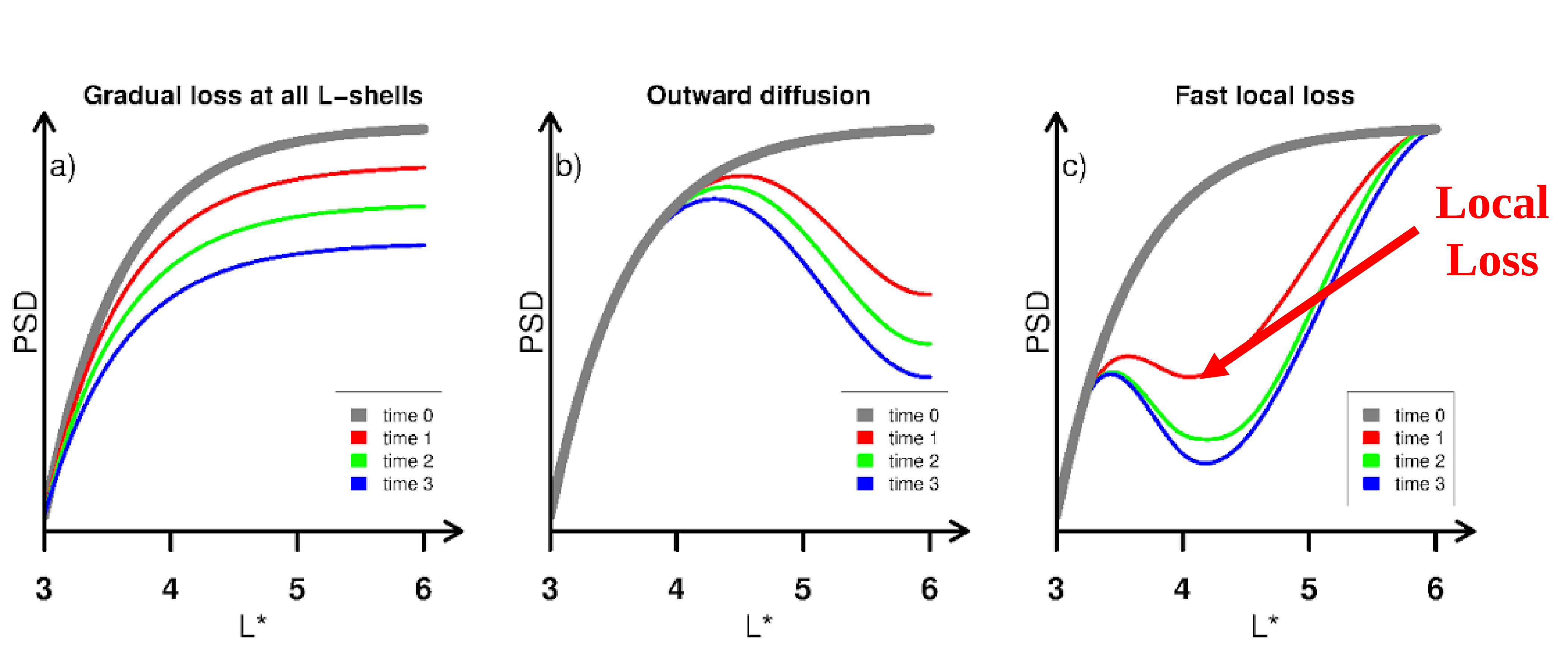
Data **Model**



[Shprits et al., 2016, *Nature Comms.*]

Three Scenarios of the Evolution of the PSD Profiles



[Shprits et al., 2017, *GRL*]

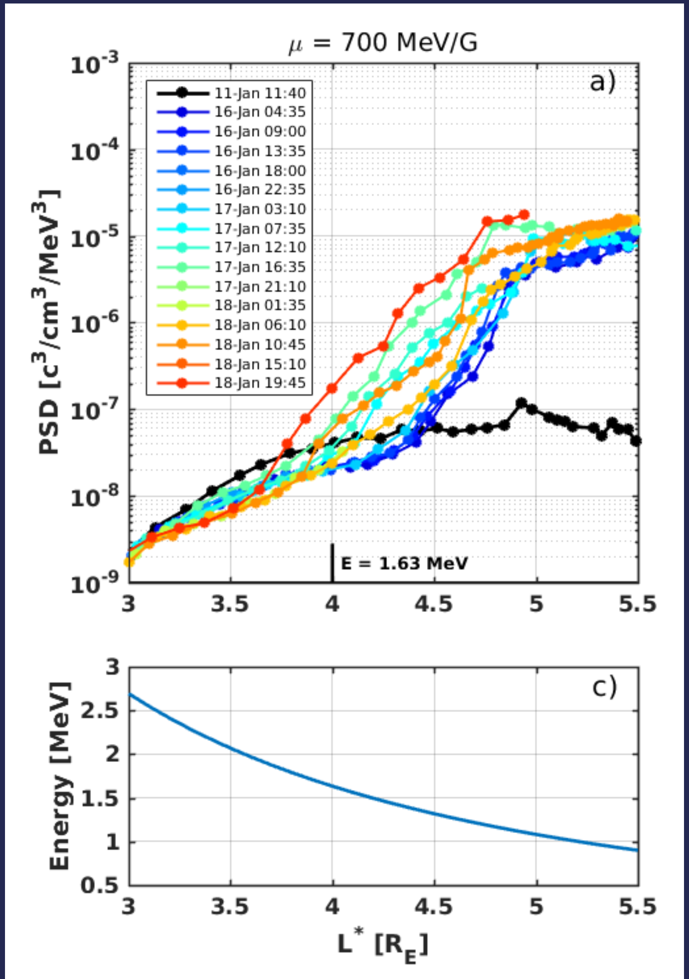
A similar methodology has been used by Green and Kivelson [2004] and Reeves et al. [2014] to identify the local acceleration.

Deepening Minimums in PSD at Ultra-relativistic Energies

During the January 17, 2013 Profiles of PSD are monotonic at MeV energies.

Profiles of PSD show deepening local minimum for all considered magnetic fields models.

Such evolution of PSD is consistent with EMIC-induced scattering of ultra-relativistic electrons into the loss cone.



[Shprits et al., 2017, *GRL*]

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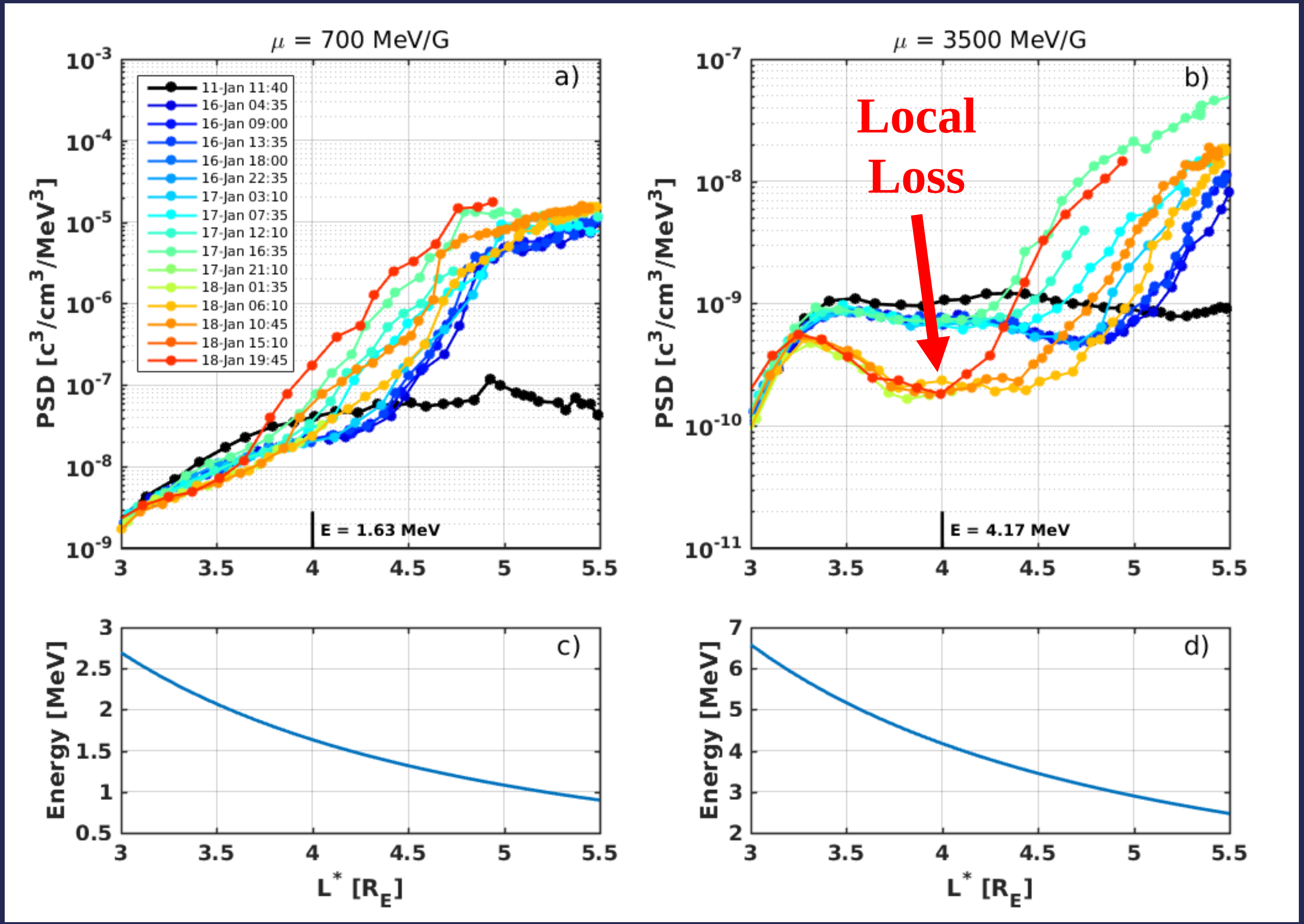


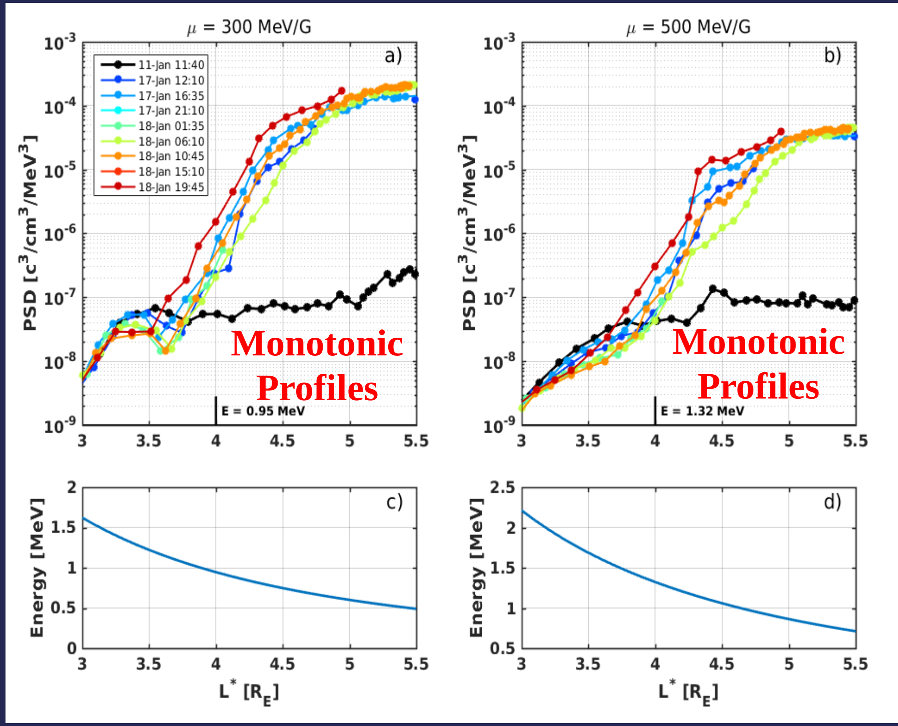
[Shprits et al., 2017, *GRL*]

Profiles of PSD for Different Values of the First Invariant

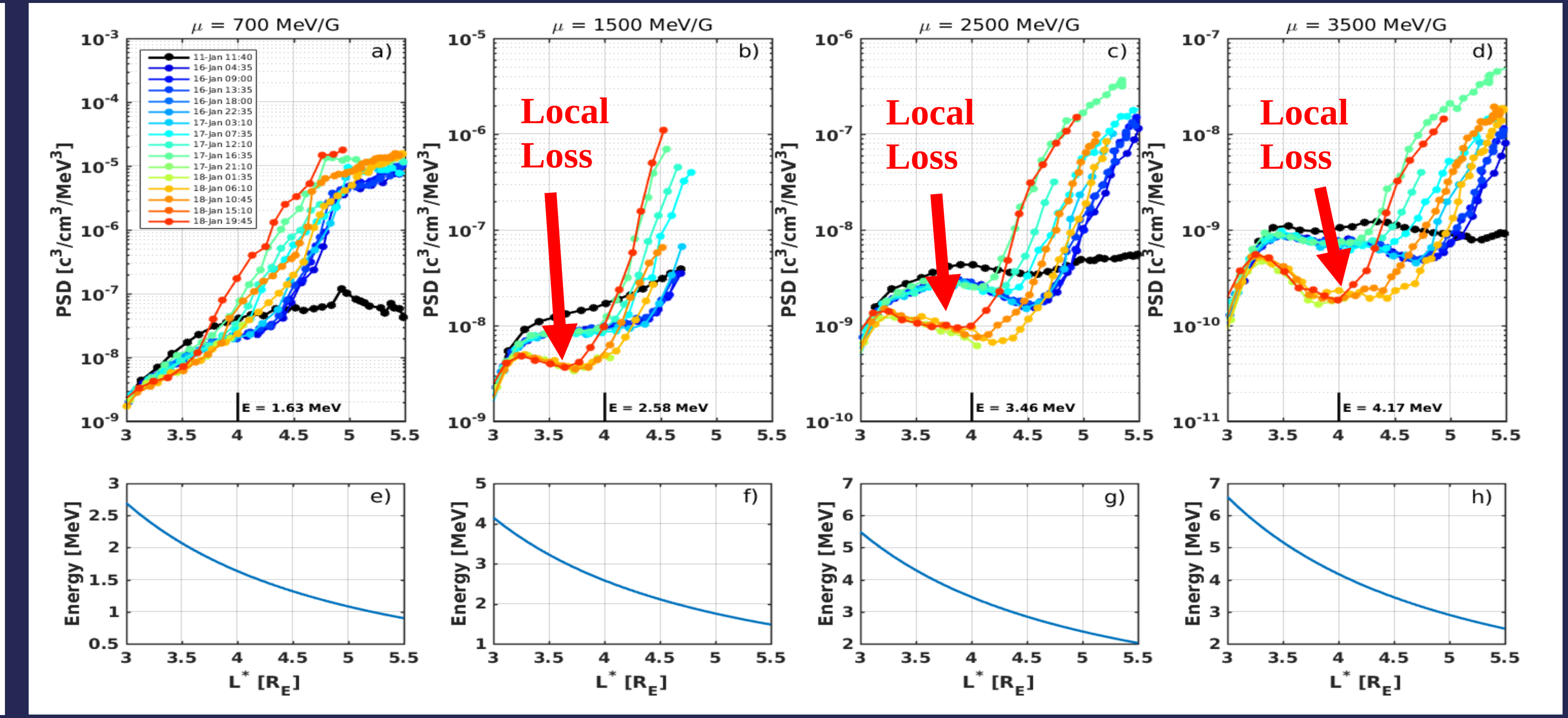
At lower energies, profiles are monotonic.

Deeps in PSD are observed at E>~2MeV and deepen with increasing energy.

m=300MeV/G *m*=500MeV/G

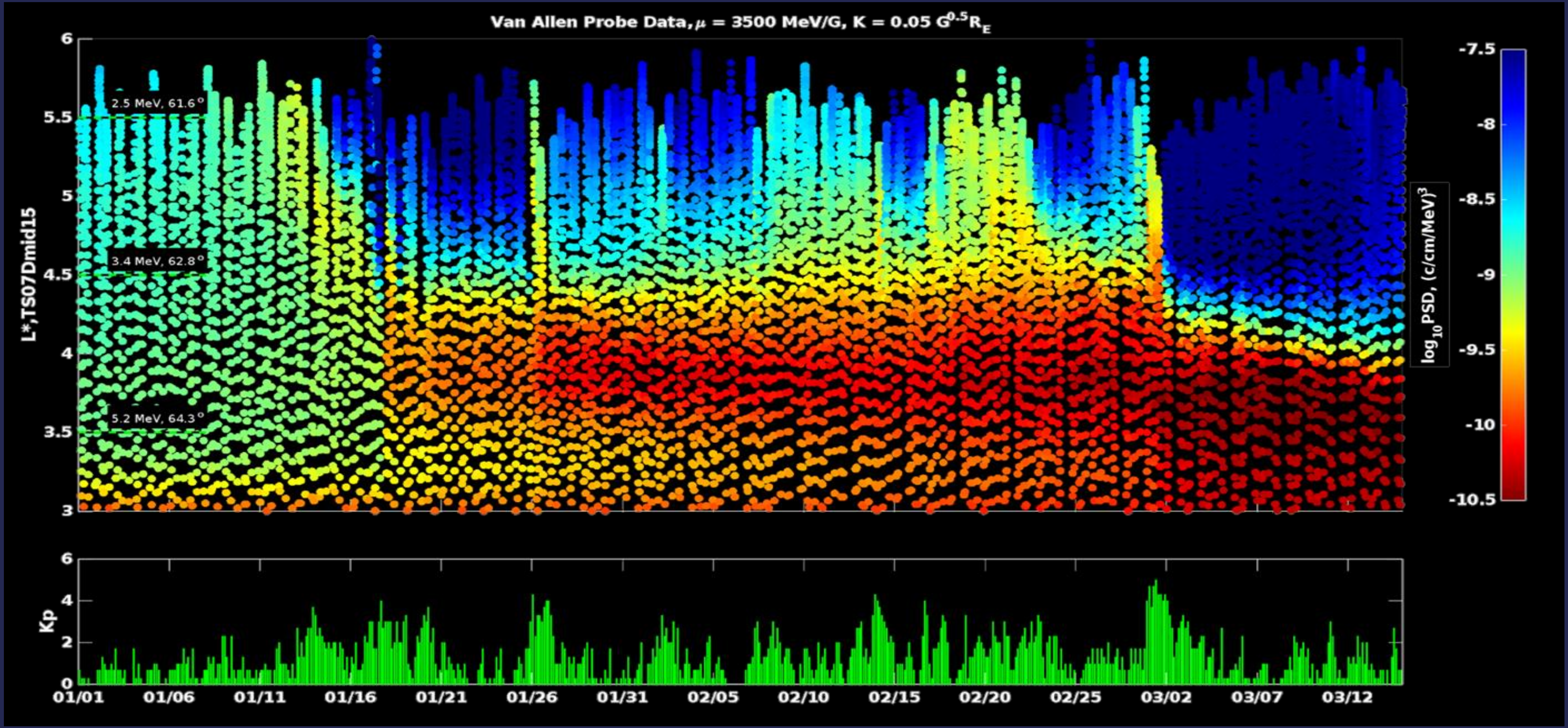


m=700MeV/G *m*=1500MeV/G *m*=2500MeV/G *m*=3500MeV/G



[Shprits et al., 2017, *GRL*]

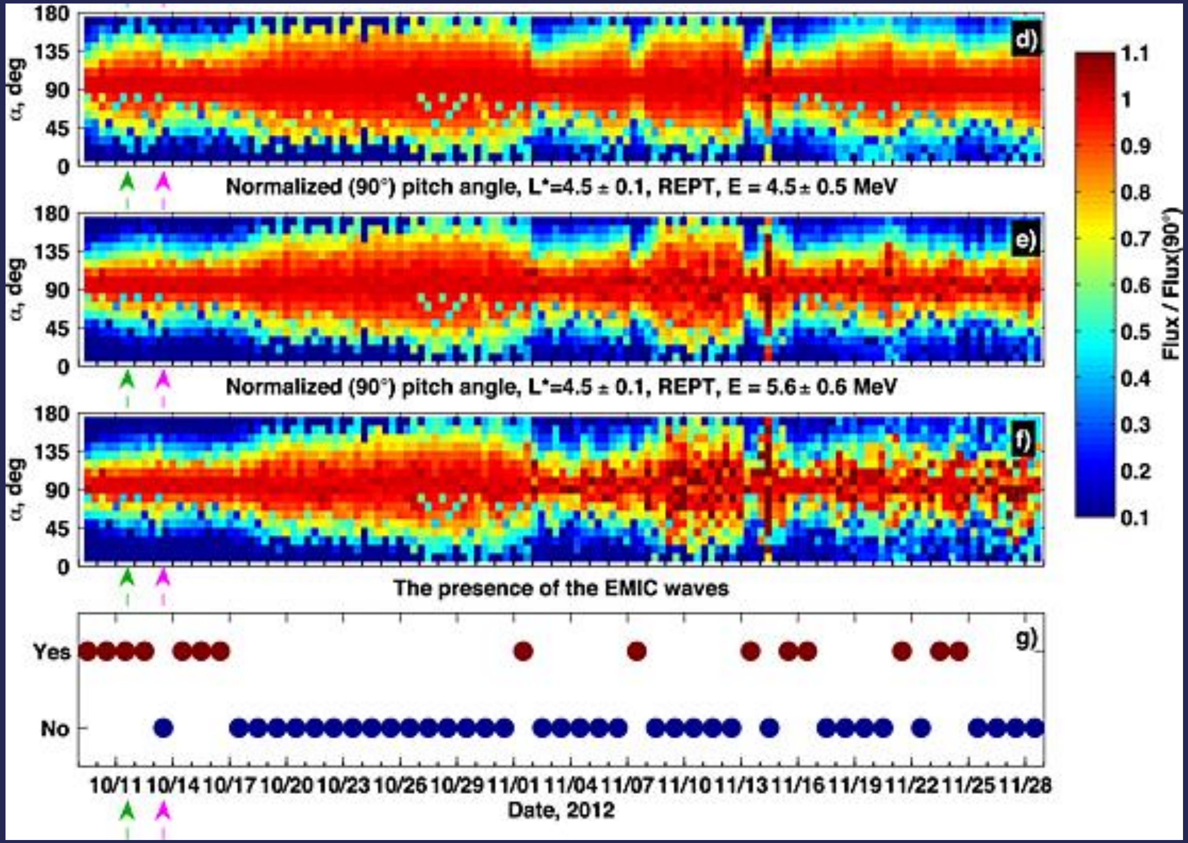
Dynamic Evolution of Deeps in PSD



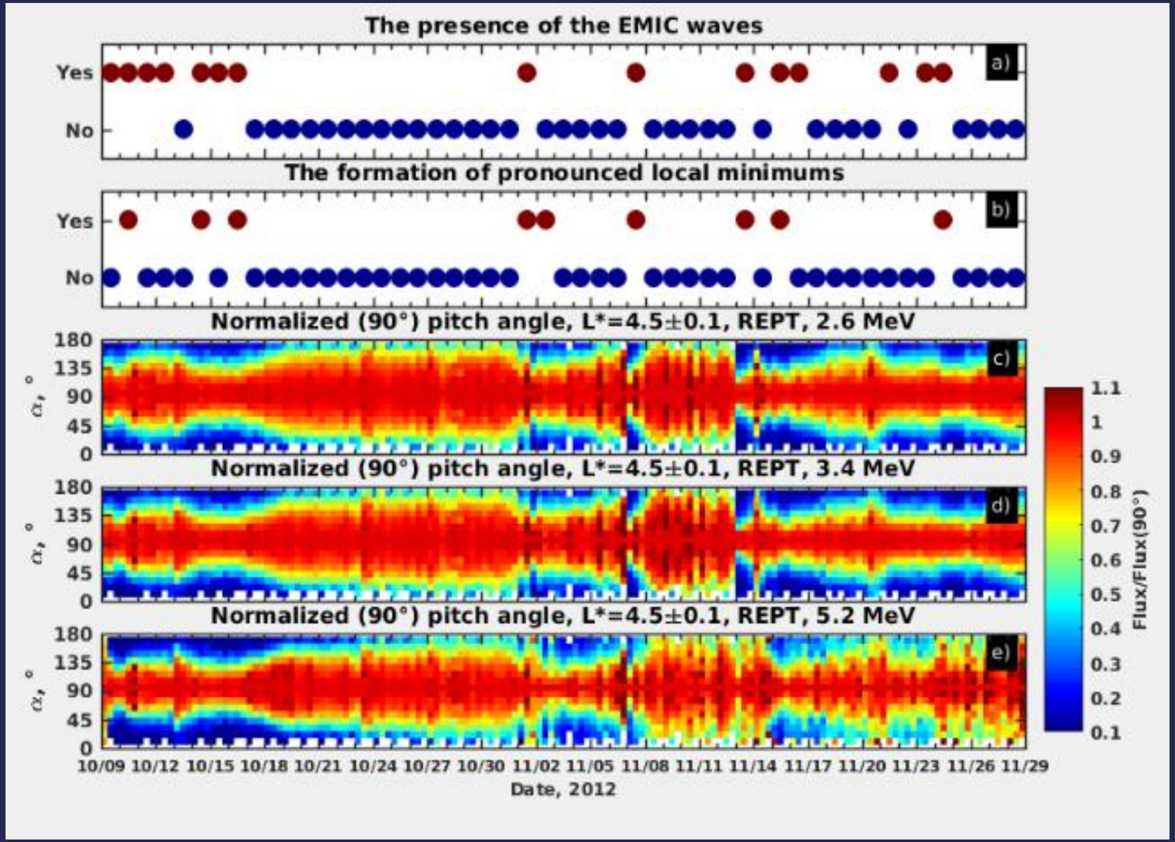
[Shprits et al., 2017, *GRL*]

Evidence for EMIC Scattering

Deeps in PSD correlate with Wave Observations and narrowing of pitch angle distributions



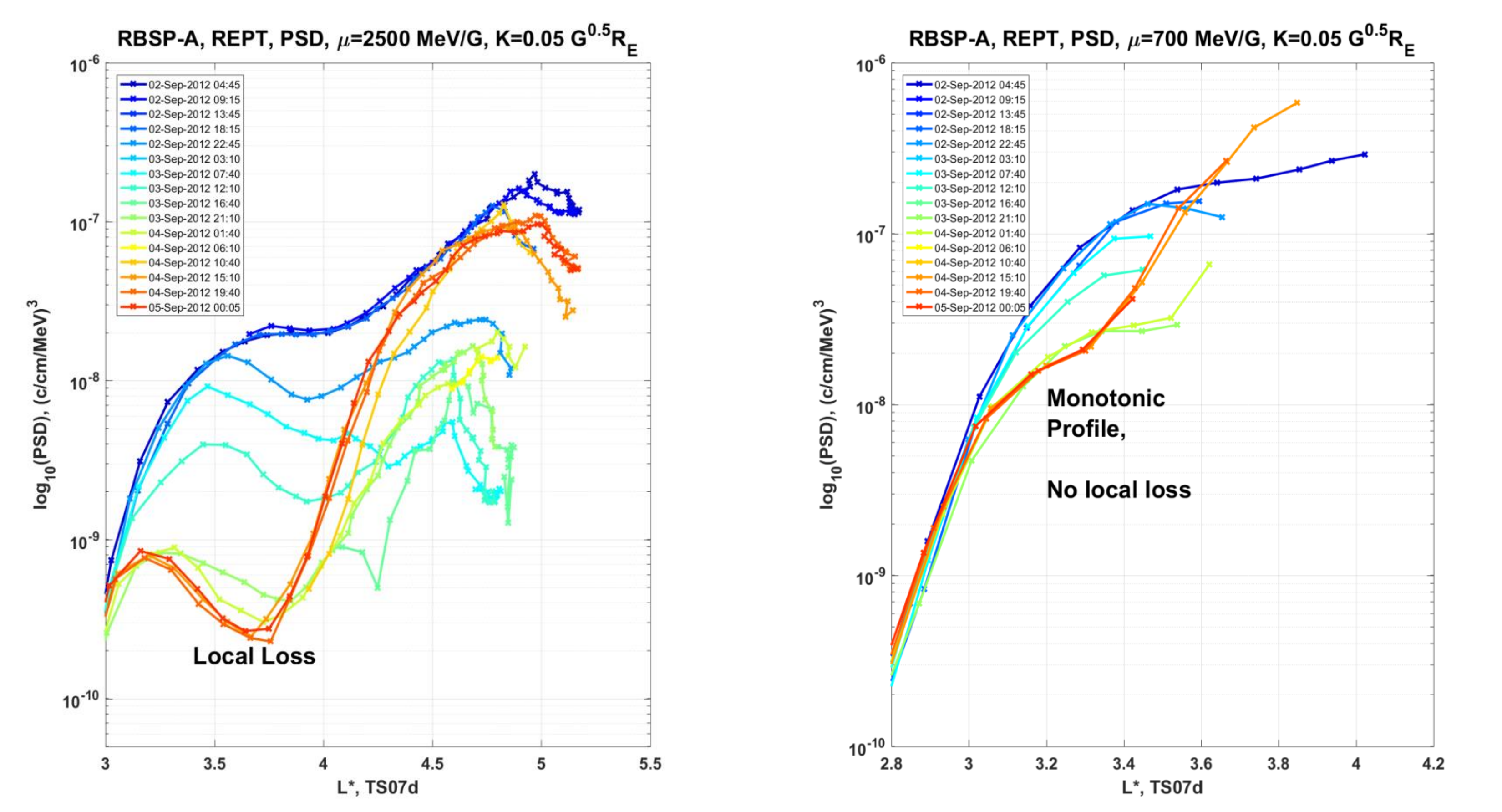
[Usanova et al., 2014, *GRL*]



[Aseev et al., 2017, *JGR*]

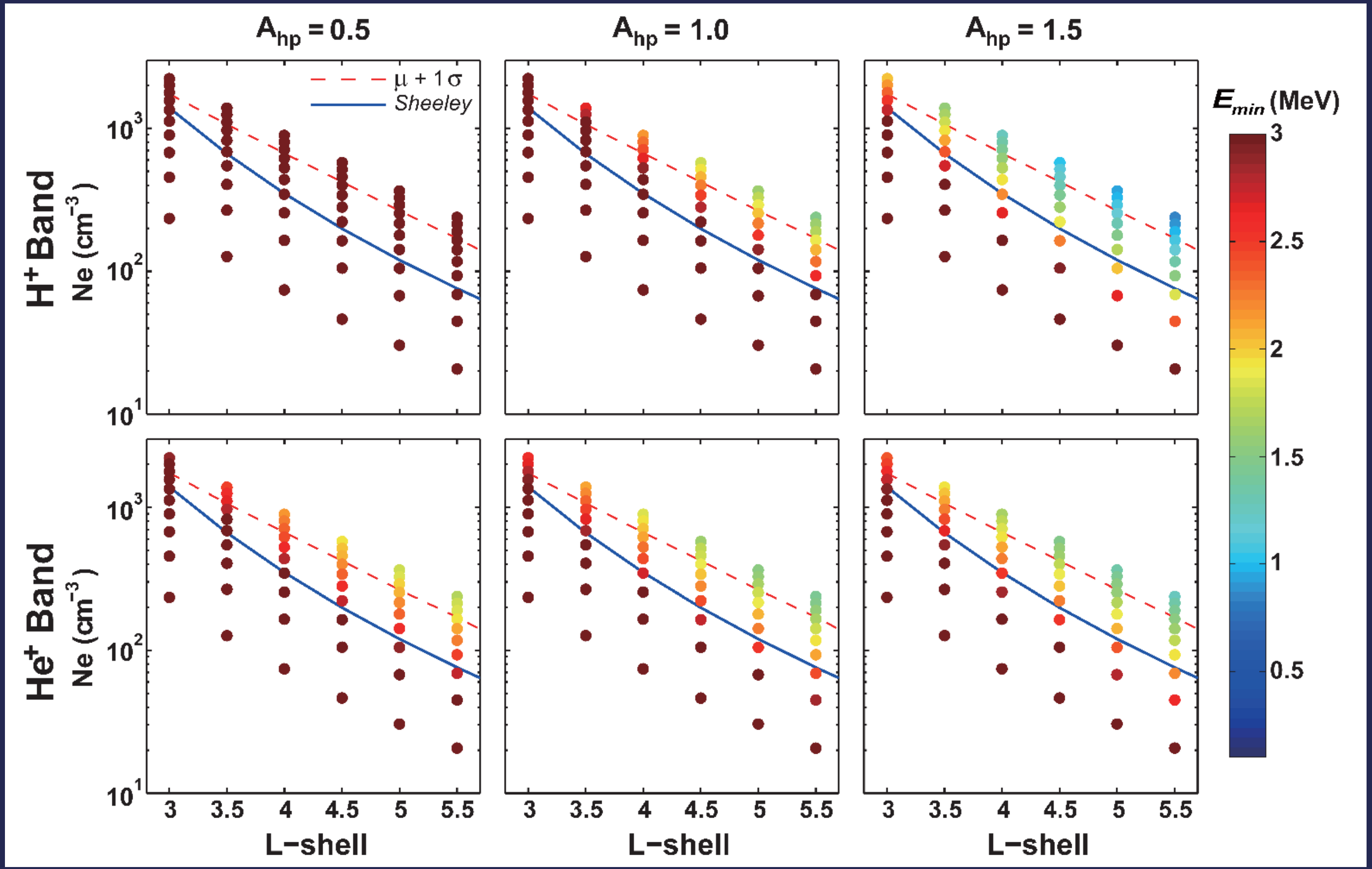
PSD Profiles During September 2012 Storm

Deeps in PSD confirm conclusions of modeling by Shprits et al. [2015]



[Shprits et al., 2017, Accepted *Nature Physics*]

Theoretic Estimates of the Minimum Resonance Energies

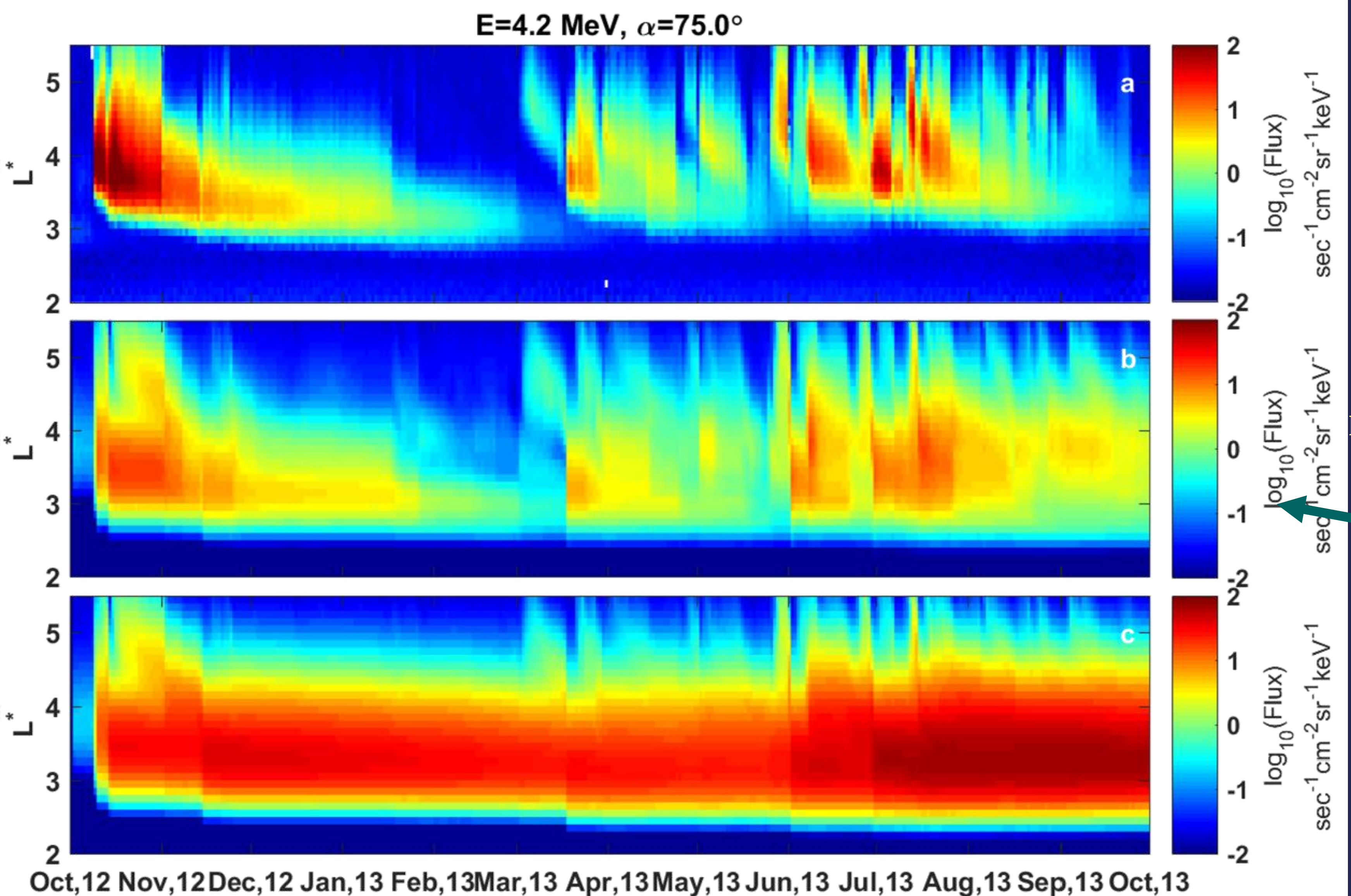


For realistic values of anisotropy, density and various combinations of ion composition calculations including hot plasma effects result in resonance energies above ~2 MeV .

[Shprits*, Zhu *, et al., 2017, *Scientific Reports*
Authors contributed equally]

Simluation with and without EMIC waves

Oct. 2012 – Oct. 2013



Observations
REPT 4.2 MeV

Model
with 0.4 nT² EMIC
parameterized with
$P_{dyn} \geq 3$ nPa

We reproduce the dynamics of ultrarelativistic electrons

Model
without EMICs

Drozdov et al. 2017 JGR

Summary

- While EMIC waves do not substantially change the dynamics of the relativistic electrons, at ultra-relativistic energies, scattering by EMIC waves start to play a crucial role.
- Knife-edge dropout at ultra-relativistic energies, pitch angle distributions with bite-outs at small pitch angles and clear differences between relativistic and ultra-relativistic dynamics all show that EMIC waves play a dominant role in scattering ultra-relativistic electrons.[Shprits et al., 2016, Nature Communications]
- Scattering by EMIC waves explains the formation of a narrow belt that lasted for approximately 1 month in September 2012.
- Deepening minimums in PSD provide additional evidence for the loss at ultra-relativistic energies and regions where EMIC-induced loss depletes ultra-relativistic electrons.[Shprits et al., 2016, GRL; Shprits et al., 2017 Nature Physics, Aseev et al., 2017 JGR]
- Estimates of MRE that account for realistic plasma density, composition, anisotropy, and density show that resonances below 2 MeV are unlikely. [Shprits et al., 2017, Scientific Reports.]
- Ultra-relativistic electrons form a new population of the belts that is driven by different physical processes [Shprits et al., 2013, *Nature Physics*].