The 1, 2, 3 of the Van Allen Radiation Belts: Impacts of Dynamics Driven by Observed ULF Wave Power

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Acknowledgement

The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7–SPACE–2010–1) under grant agreement no. 284520 for the MAARBLE (Monitoring, Analyzing and Assessing Radiation Belt Energization and Loss) collaborative research project.


Image U.S. Geological Survey
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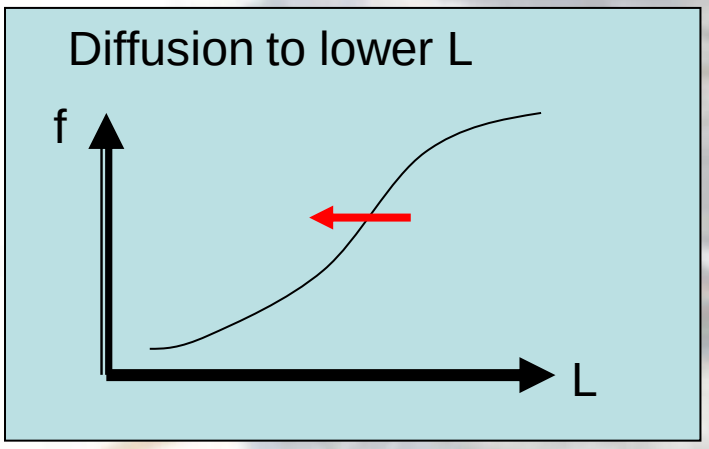
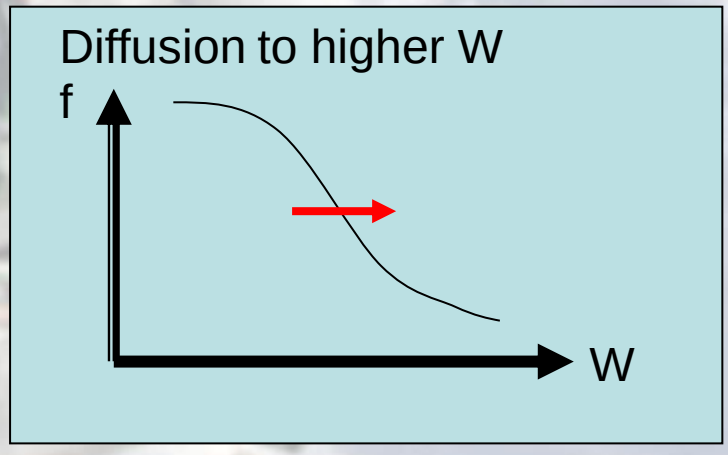
ULF Wave-MeV Electron Diffusion

- Rate of energy change due to ULF interactions:

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

- Effect from electric field and compressional magnetic field; dominated by electric component (Ozeke et al., 2012).
- Can transport particles along phase space density gradients: inwards (energisation) or outwards (e.g., magnetopause loss; Loto'aniu et al., 2010).





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"

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

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

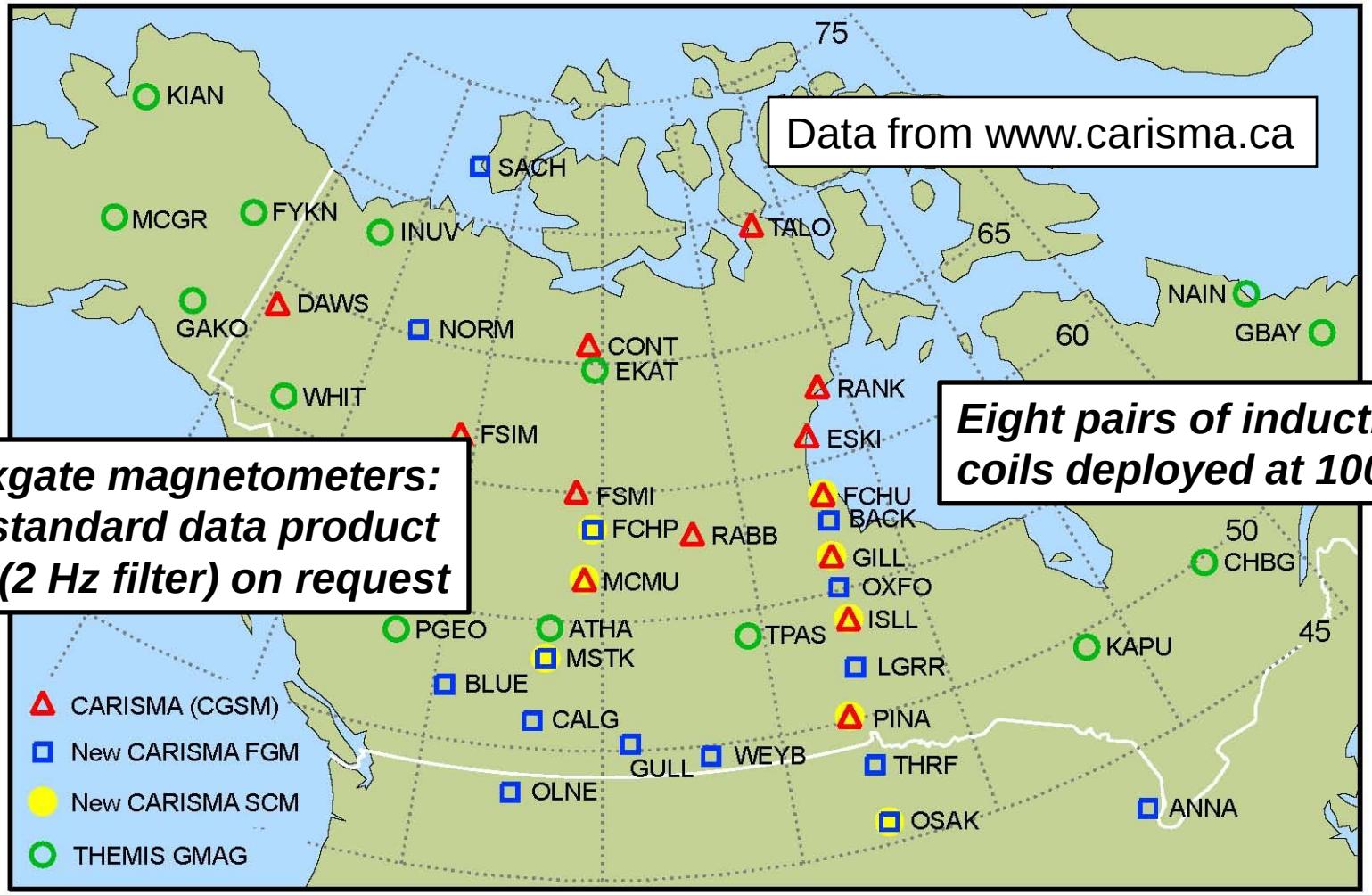
Compressional Magnetic Field Power

Azimuthal Electric Field Power

Energy dependence

These two terms can be derived in space empirically or from the ground. But electric dominates – allows DLL characterization from ground.

Expanded CARISMA Magnetometer Array

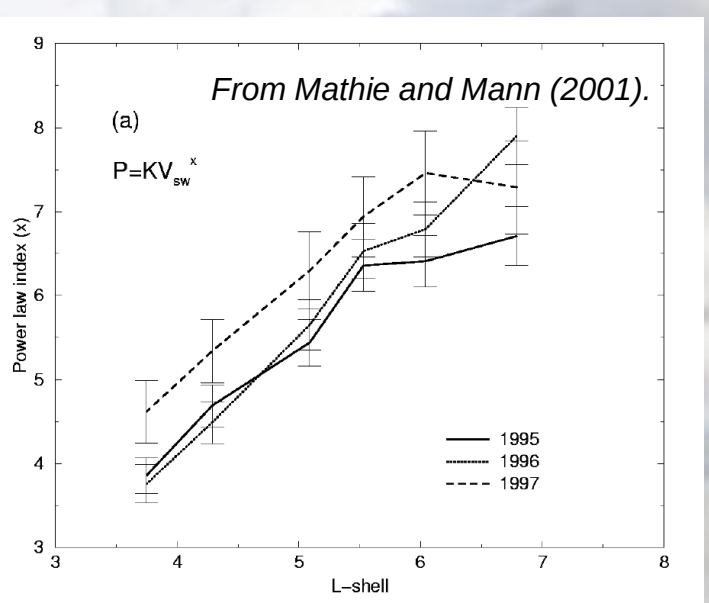


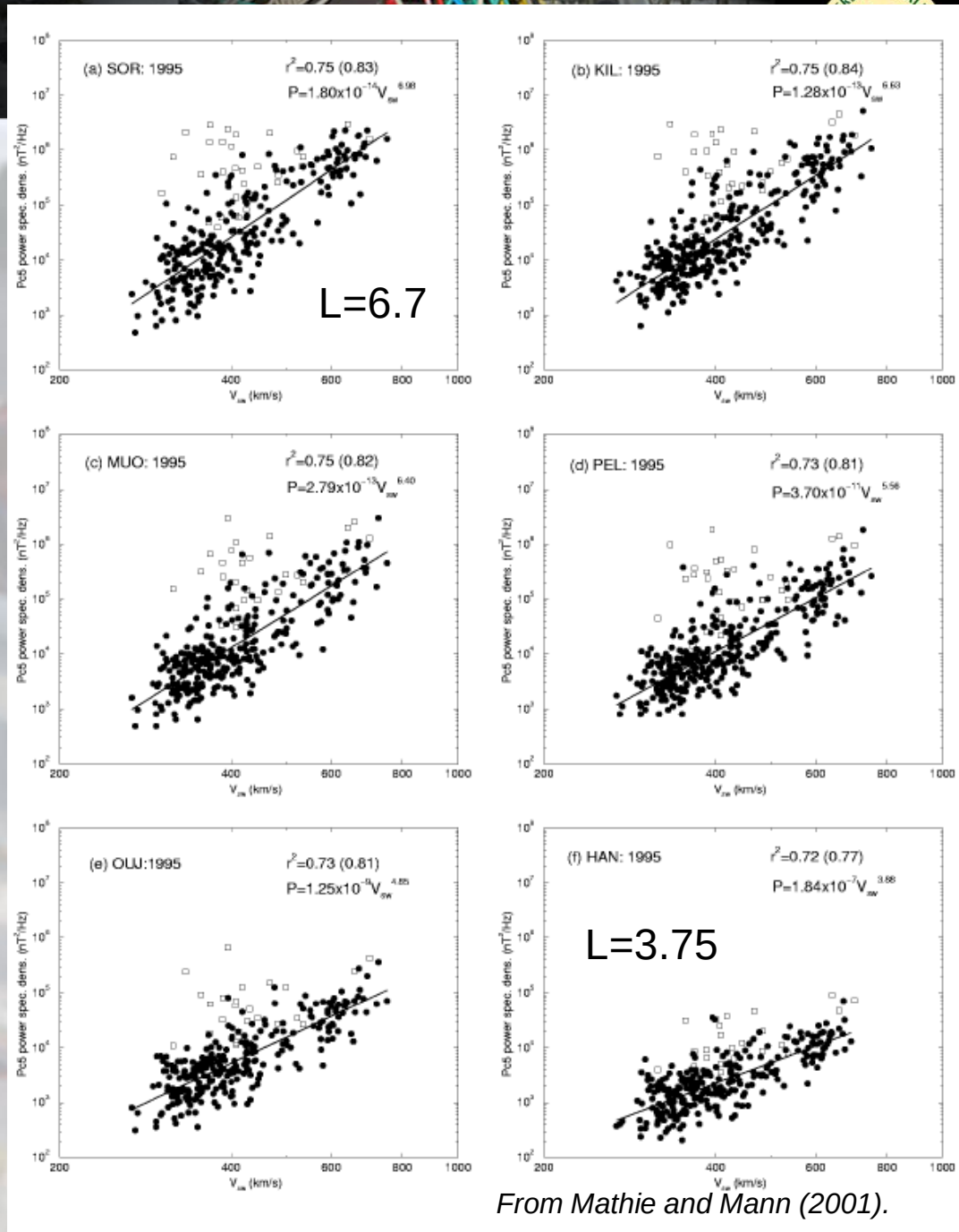
28 fluxgate magnetometers:
- 1Hz standard data product
- 8 Hz (2 Hz filter) on request

Eight pairs of induction coils deployed at 100 Hz.

Solar Wind-ULF Wave Relation

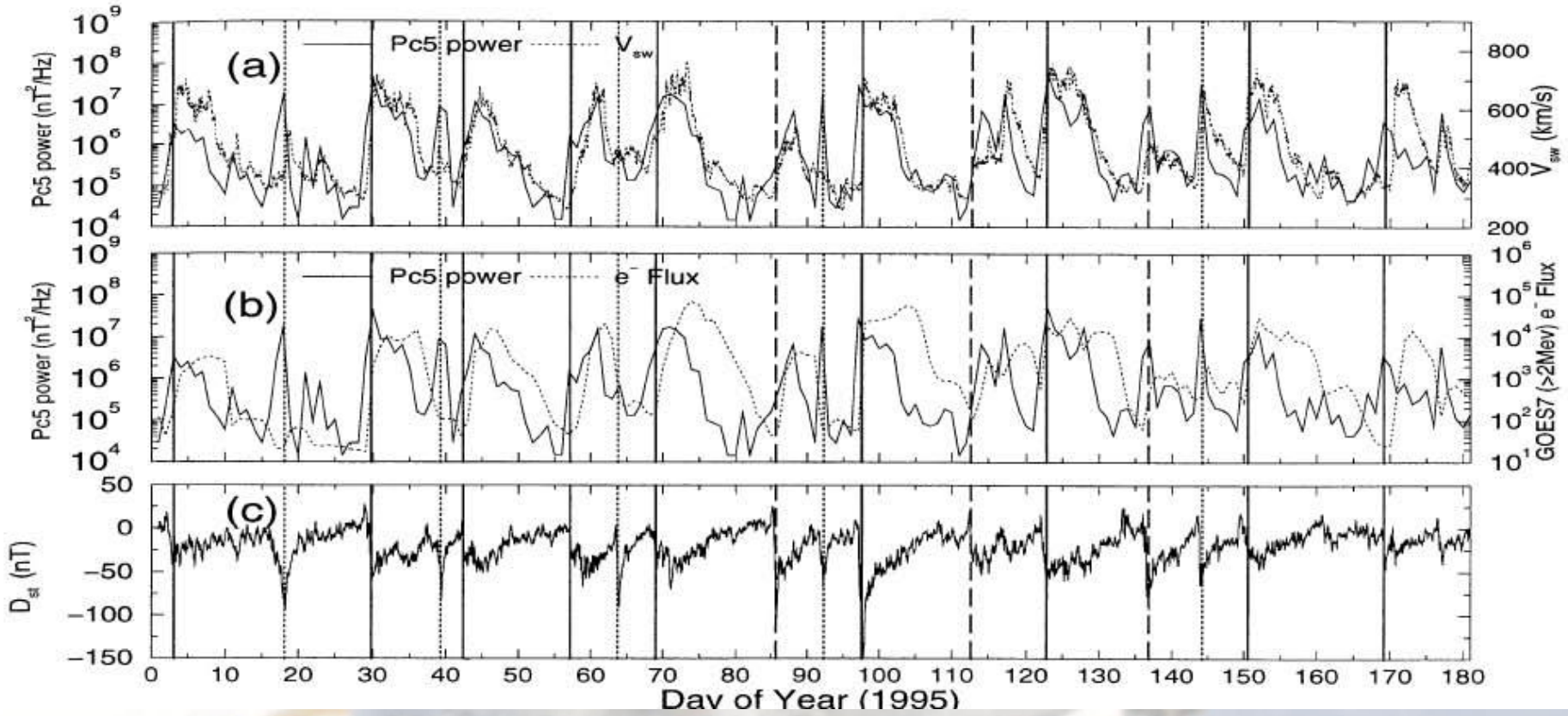
- MeV electron flux correlated with Vsw (e.g., Paulikas and Blake, 1979; Kellerman and Shprits, 2012).
- Can ULF waves provide the physical mechanism for MeV electron acceleration?





From Mathie and Mann (2001).

ULF Waves, Fast Solar Wind Streams and MeV Electrons at GEO

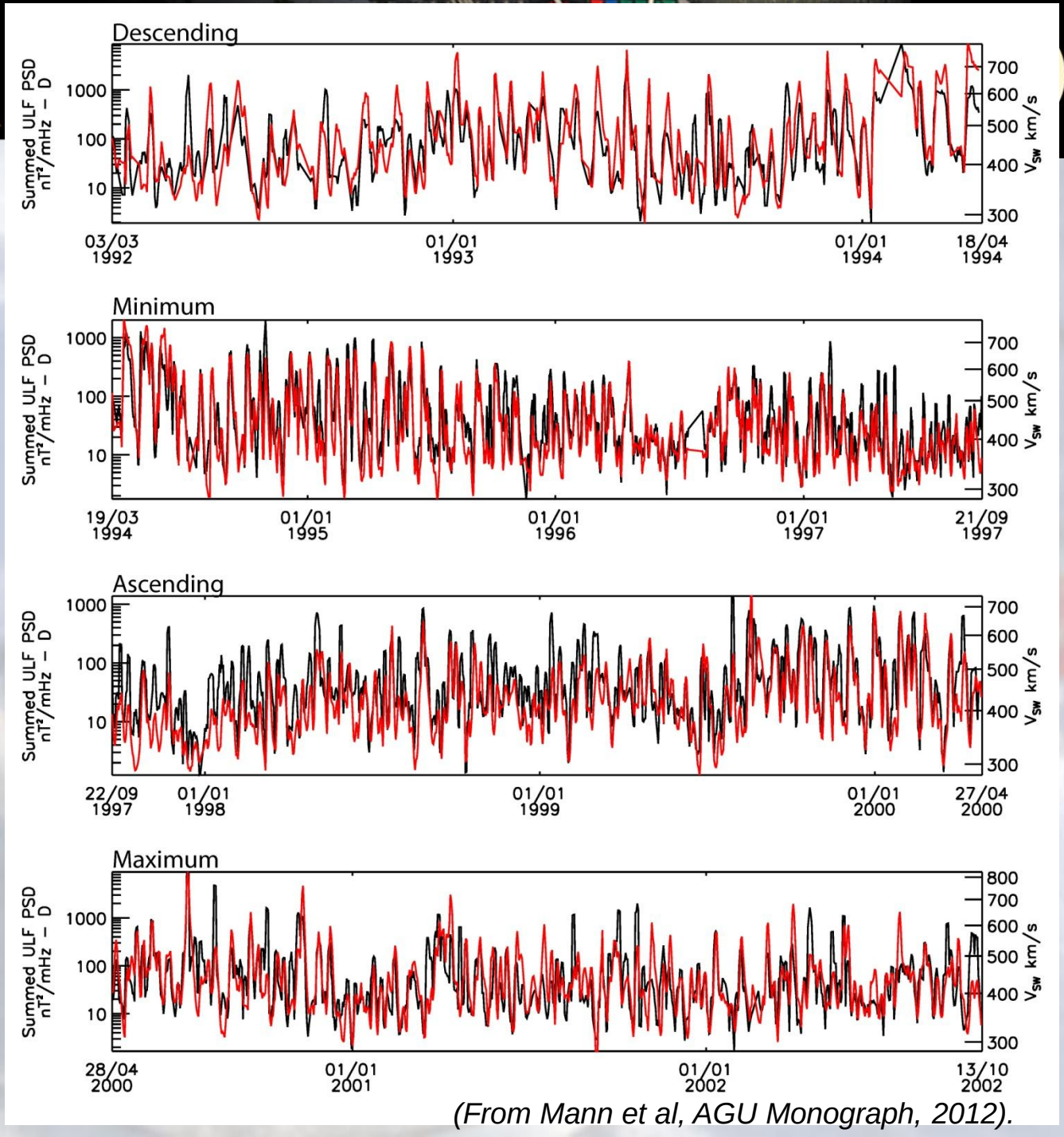


(From Mathie and Mann, GRL, 2000).

CARISMA

How robust is the ULF-Vsw relationship

- All L across outer zone.
- All solar cycle phases!



(From Mann et al, AGU Monograph, 2012).

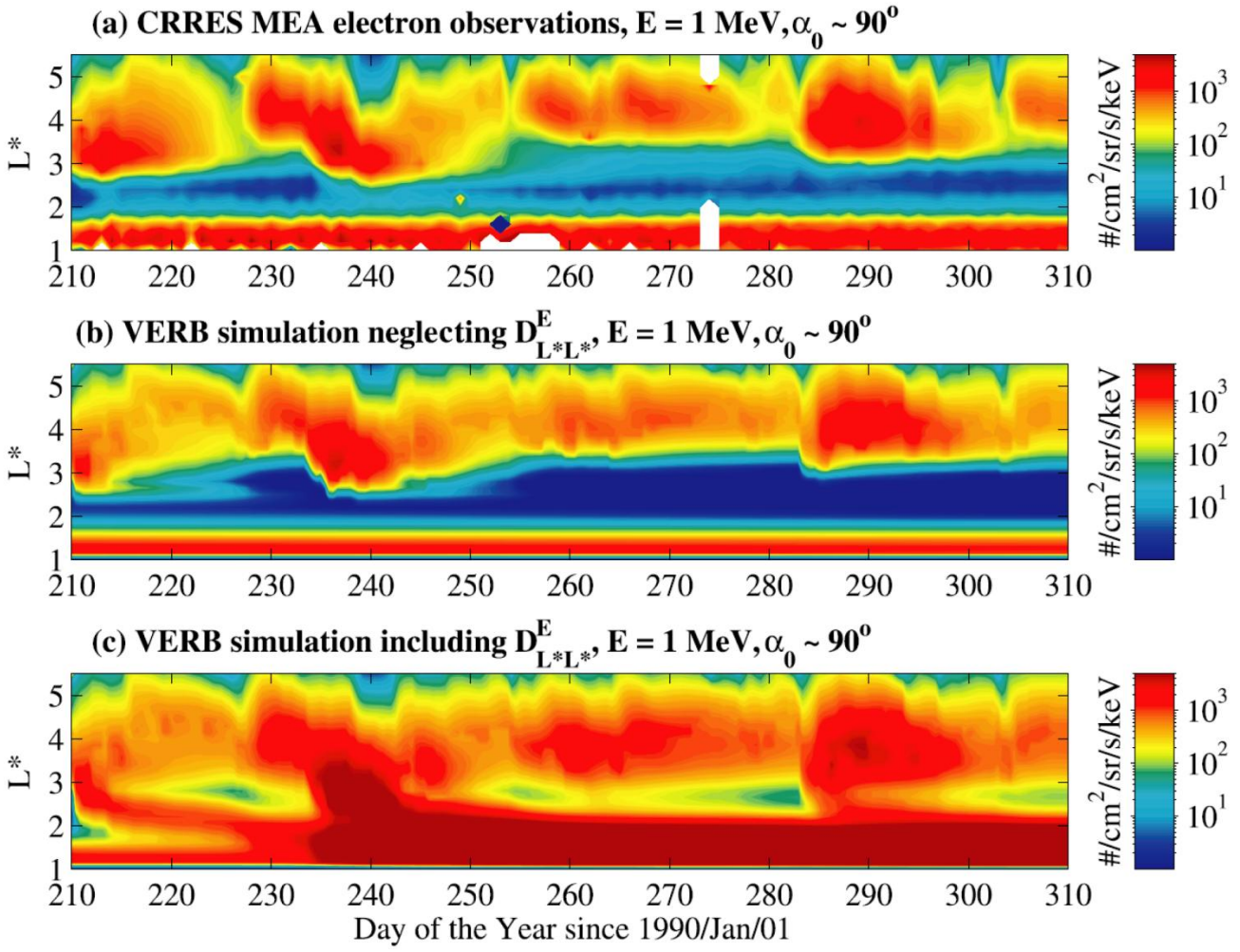
Motivation

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

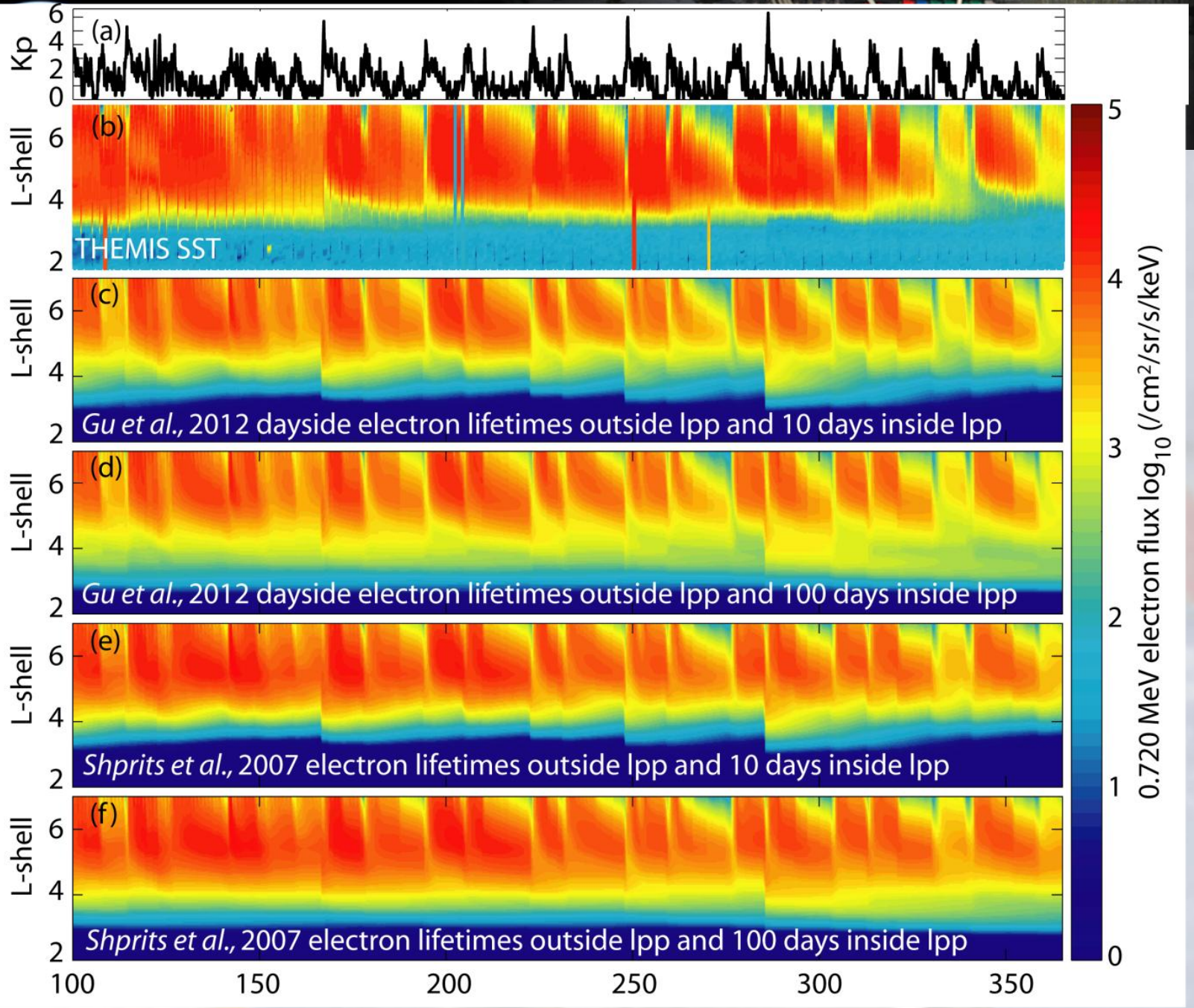
EM ULF waves only →

EM + electrostatic ULF fluctuations →

Shprits et al.



"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 low L-shells."- Kim et al JGR, 2011



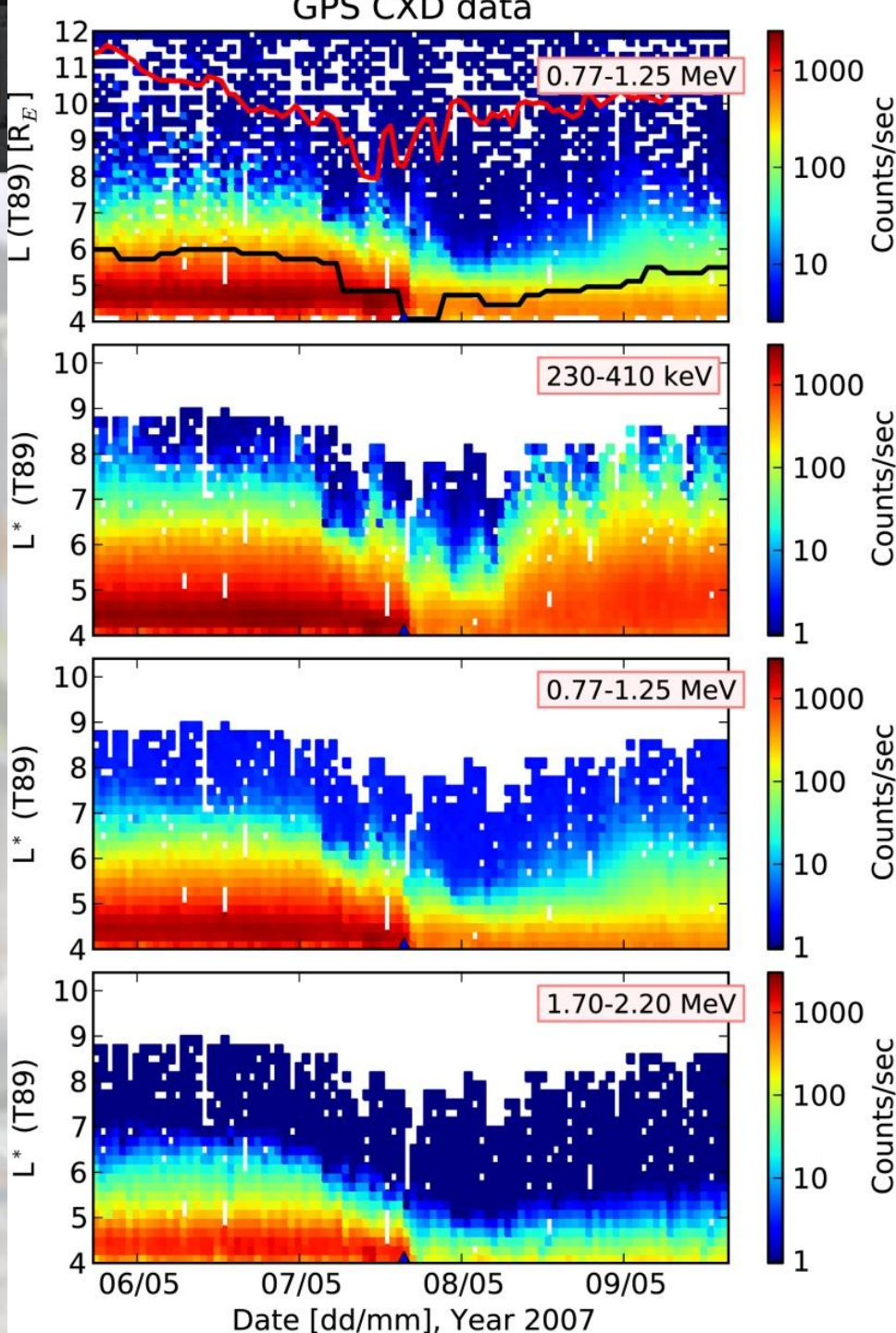
Ozeke et al. GRL 2014.

CARISMA

Role of Pc5 ULF Waves in Loss

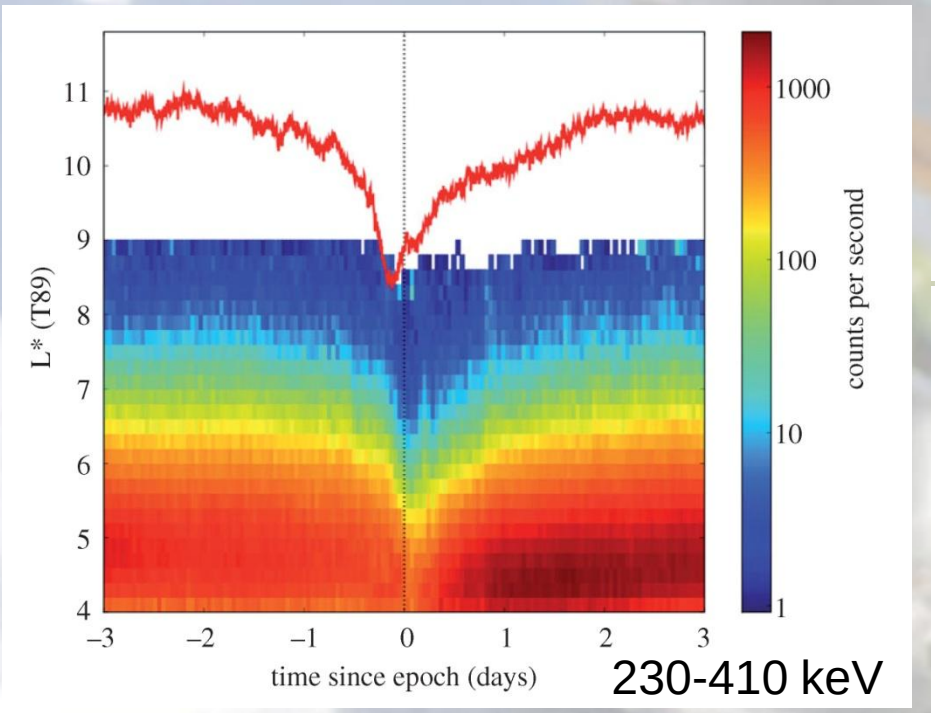
- ULF wave ***outward diffusion*** offers RB loss through transport to MP (e.g., Loto'aniu et al., 2010).
- How far in can this get?

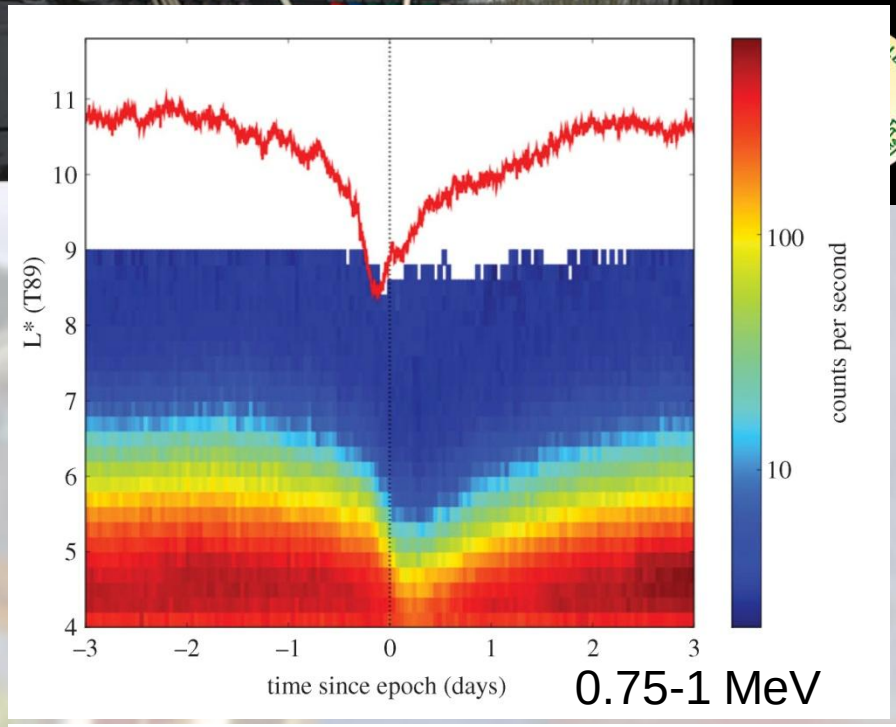
Morley et al., GRL, 2010.

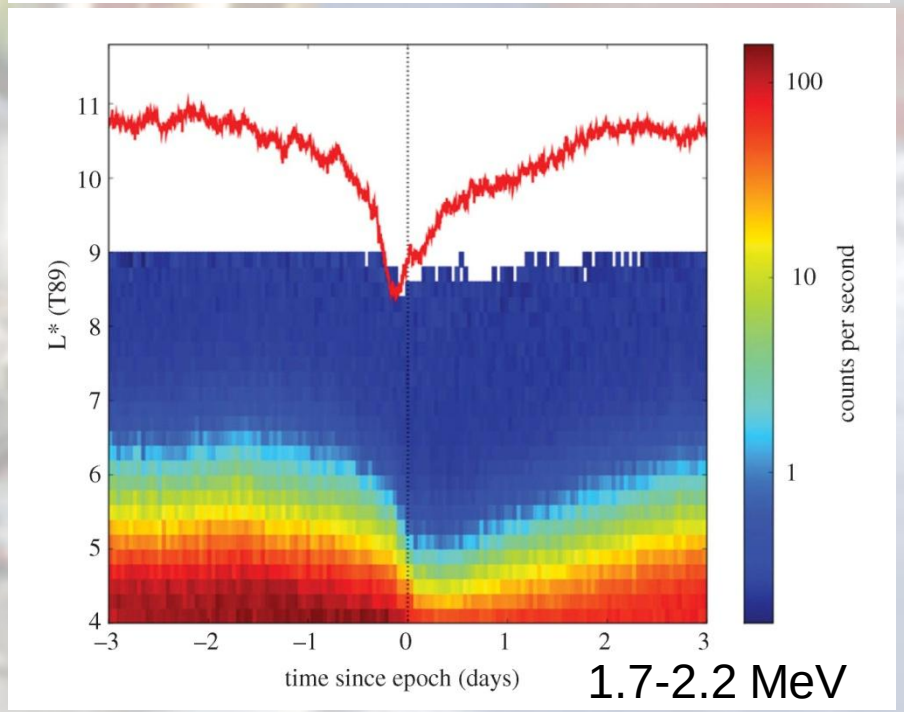


CARISMA

61 Solar wind SIs







Morley et al., Proc. Royal Soc. A, 2010.

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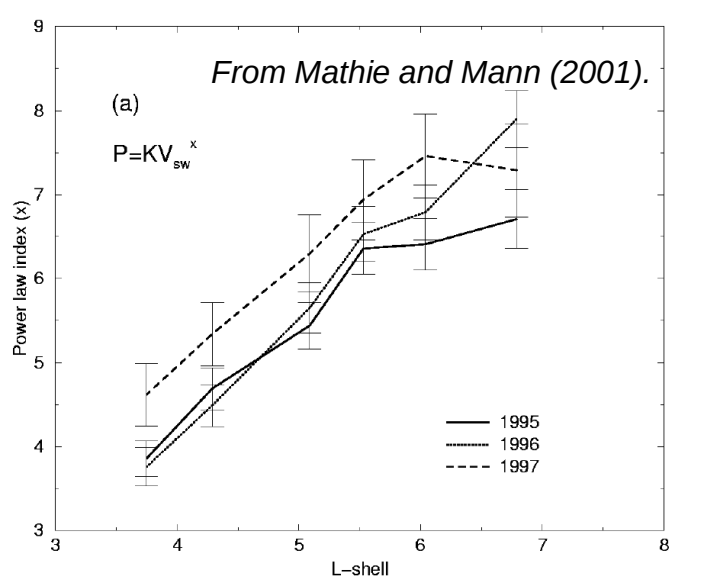
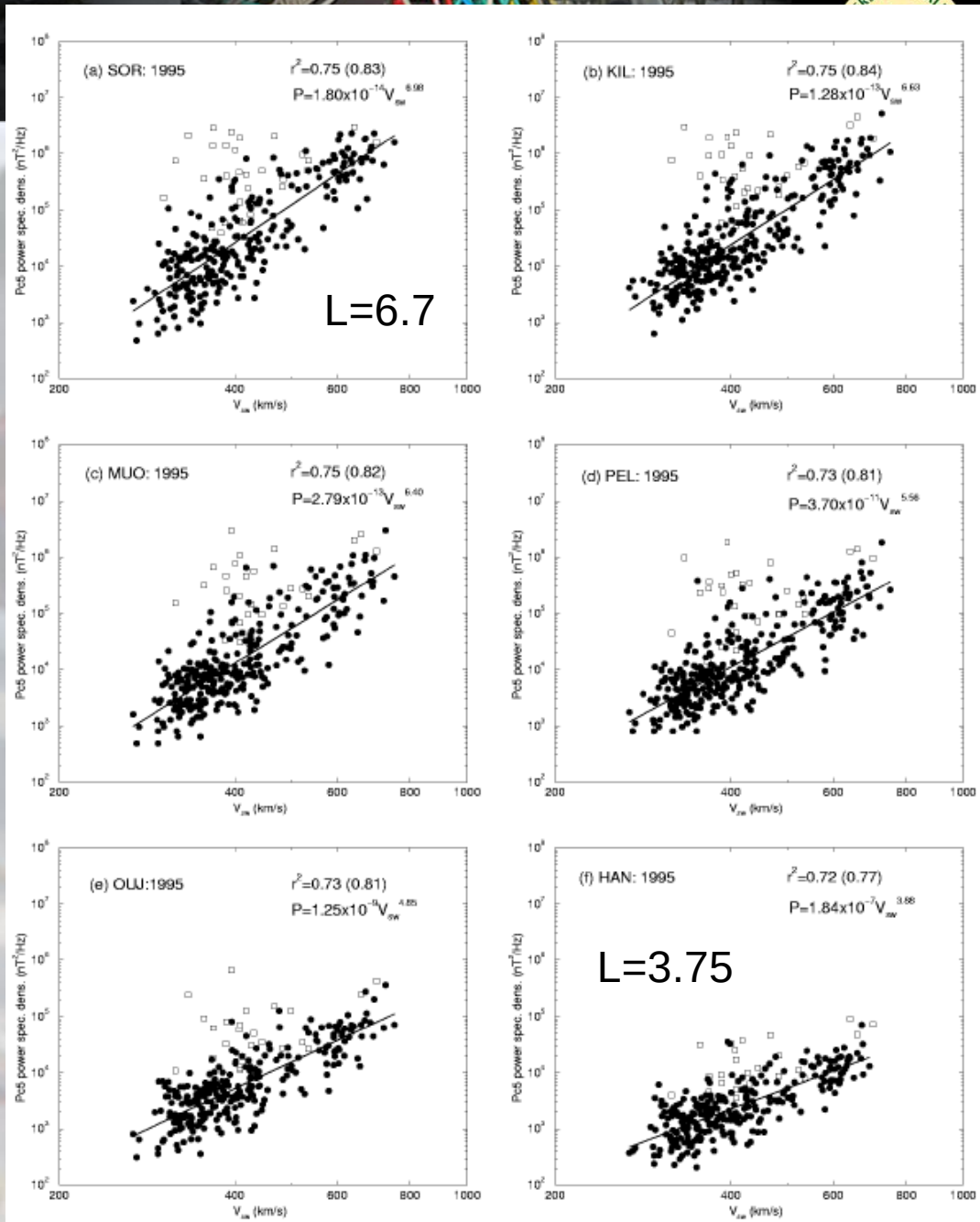
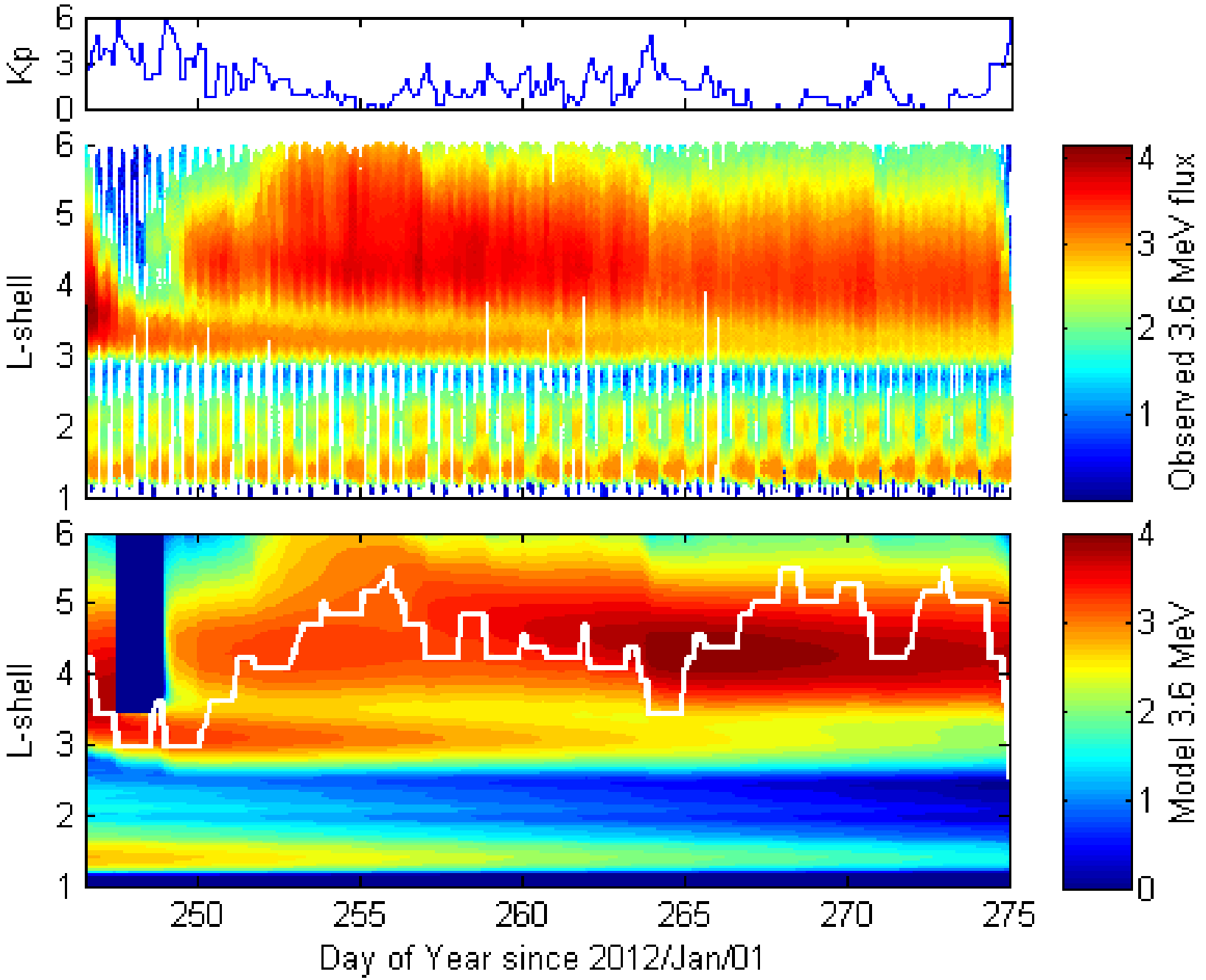
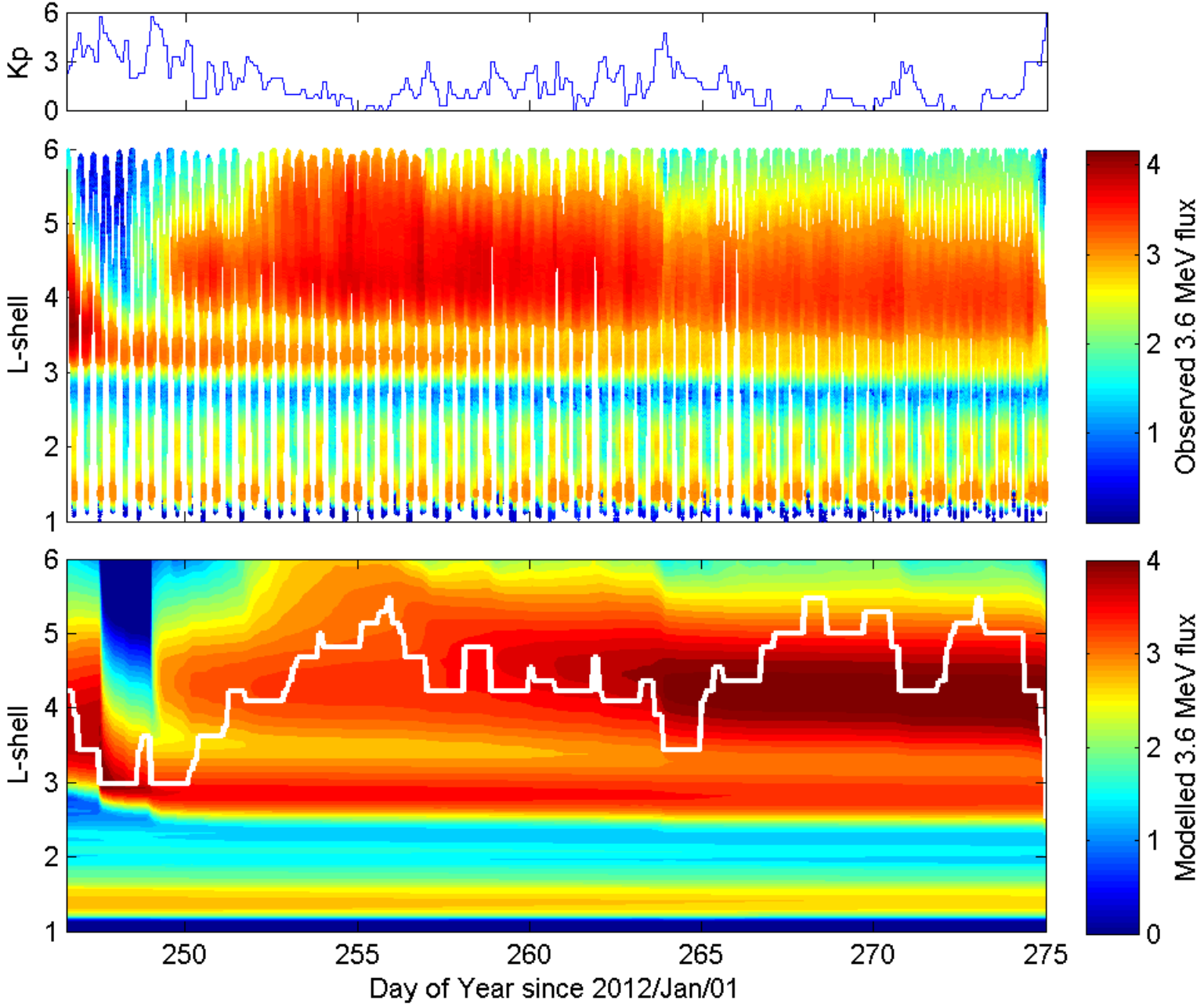




From Mathie and Mann (2001).


Kp
6
3
0
L-shell
6
5
4
3
2
1
Observed 3.6 MeV flux
4
3
2
1
L-shell
6
5
4
3
2
1
Model 3.6 MeV
4
3
2
1
0
250
255
260
265
270
275
Day of Year since 2012/Jan/01


Kp
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1
Modelled 3.6 MeV flux
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2
1
0
250
255
260
265
270
275
Day of Year since 2012/Jan/01

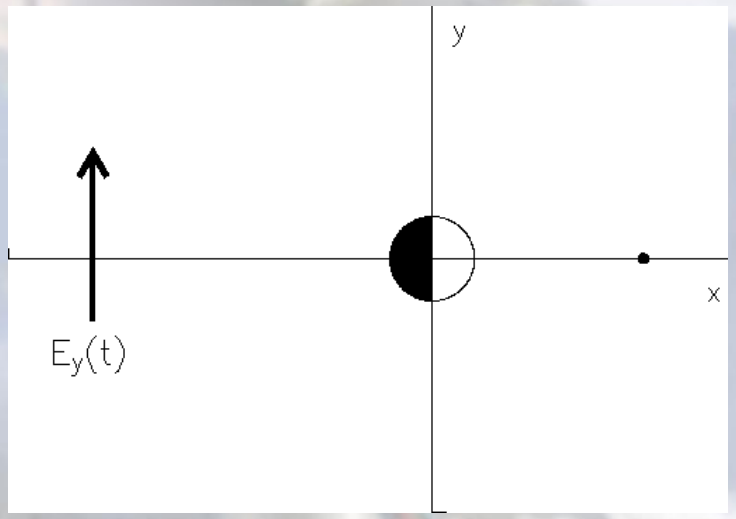
Conclusions

- MeV electron dynamics are strongly linked to Vsw - cf. Paulikas and Blake (1979) – more recently Kellerman and Shprits (2012).
- ULF wave power is similarly strongly dependent on Vsw.
- ULF waves play an important role in radiation belt dynamics, and in our opinion provide an intermediary for the Paulikas and Blake relation.
- Accurate specification of ULF wave power is critical for accurate modelling of the belt – both inward and outward transport.
- In fact ULF power is non-Gaussian with a strong high power tail – preferentially enhanced during high Dst and during storm main phase.
- When ULF wave power is correctly specified, the belt morphology whether in the form on 1, 2 or 3 belts is as easy as 1-2-3.

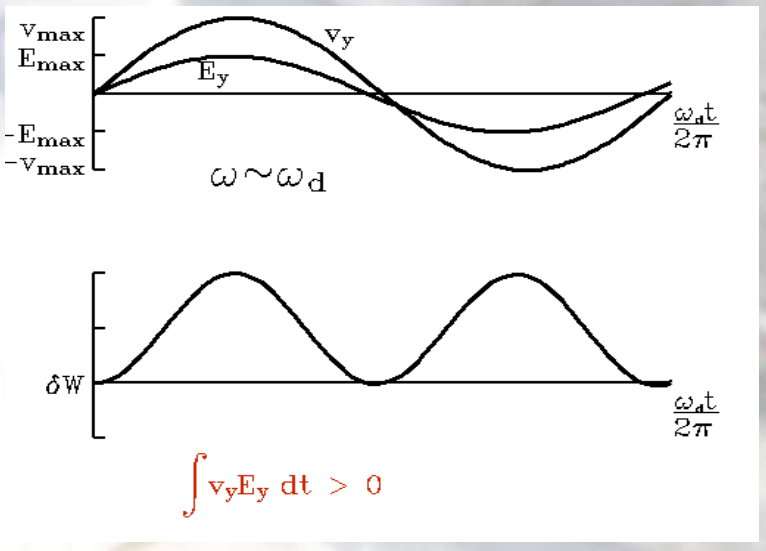
Back up Slides

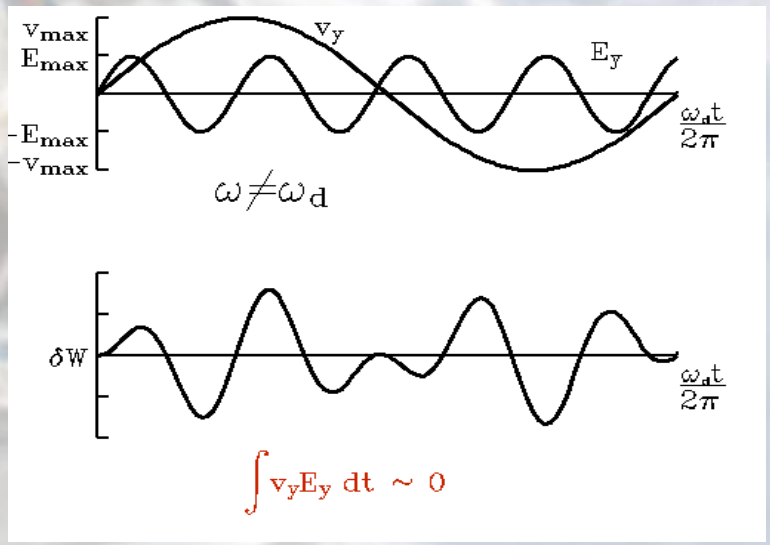
Electrons Influenced All Along Drift Path

Images courtesy of Scot Elkington, LASP.

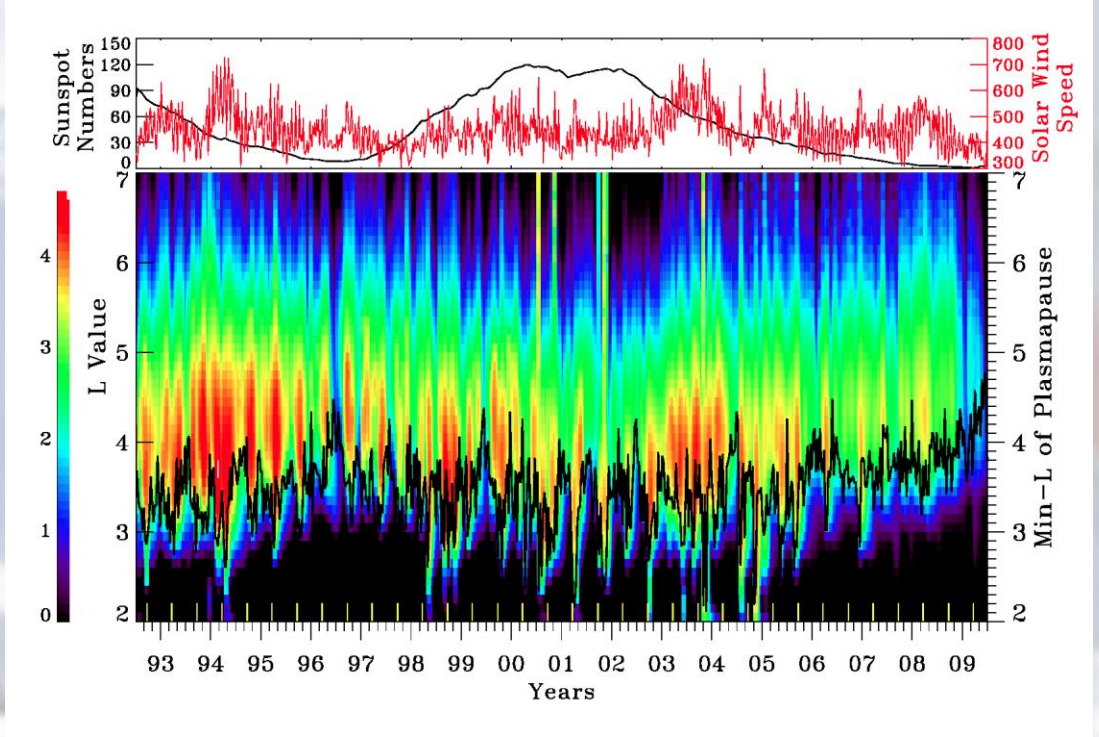


$$\frac{dW}{dt} = q\,\vec{v}_D \cdot \vec{E}$$





From Li et al., (2011).



- Influence of Alfven continuum and cold plasma
- Or …. Influence of ULF wave power penetration (or both)
- Influences the resonance condition as a function of L

$$\omega_A(L) - m\omega_D = N\omega_B$$

What explains MeV electron relationship to Dst…

Comparison: ULF vs BA.