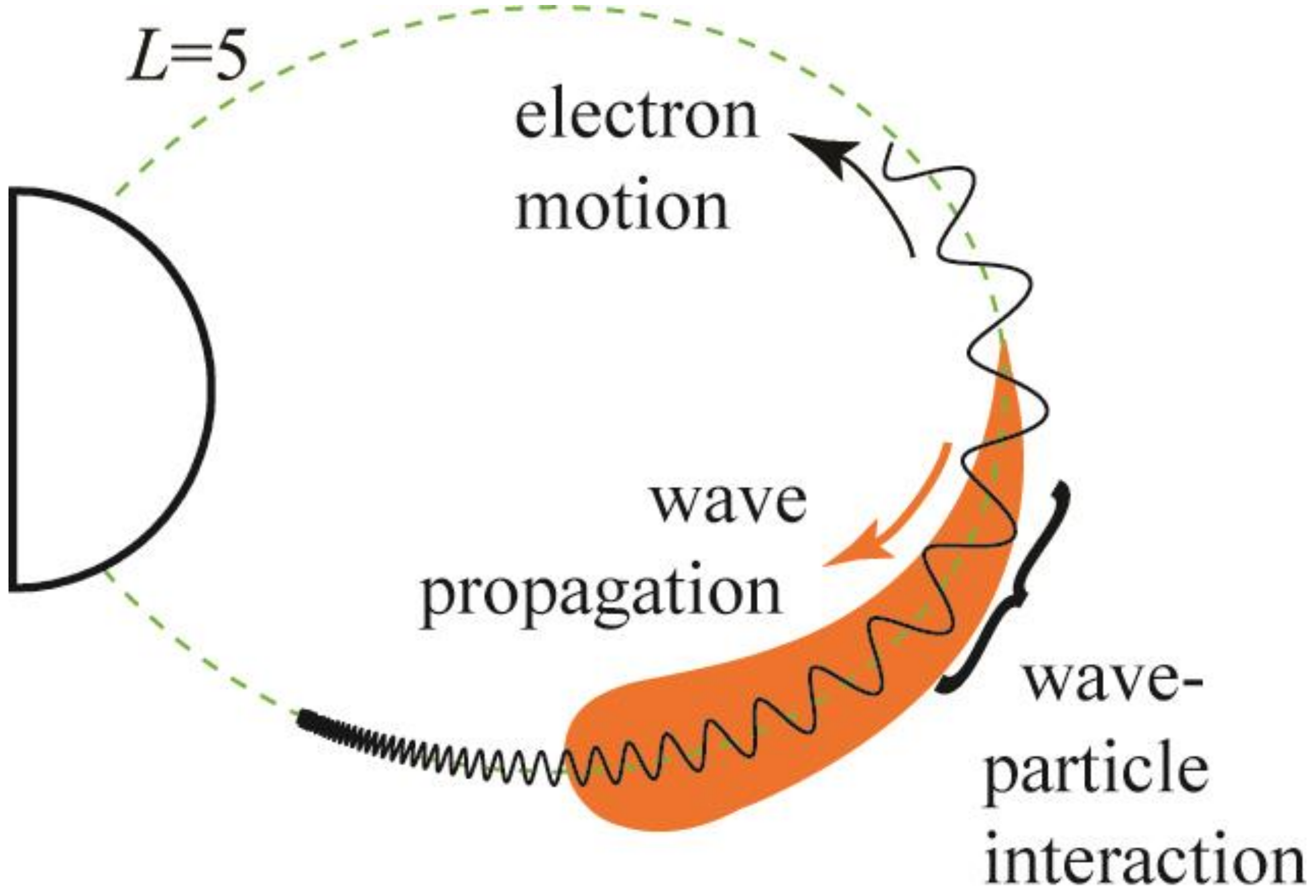
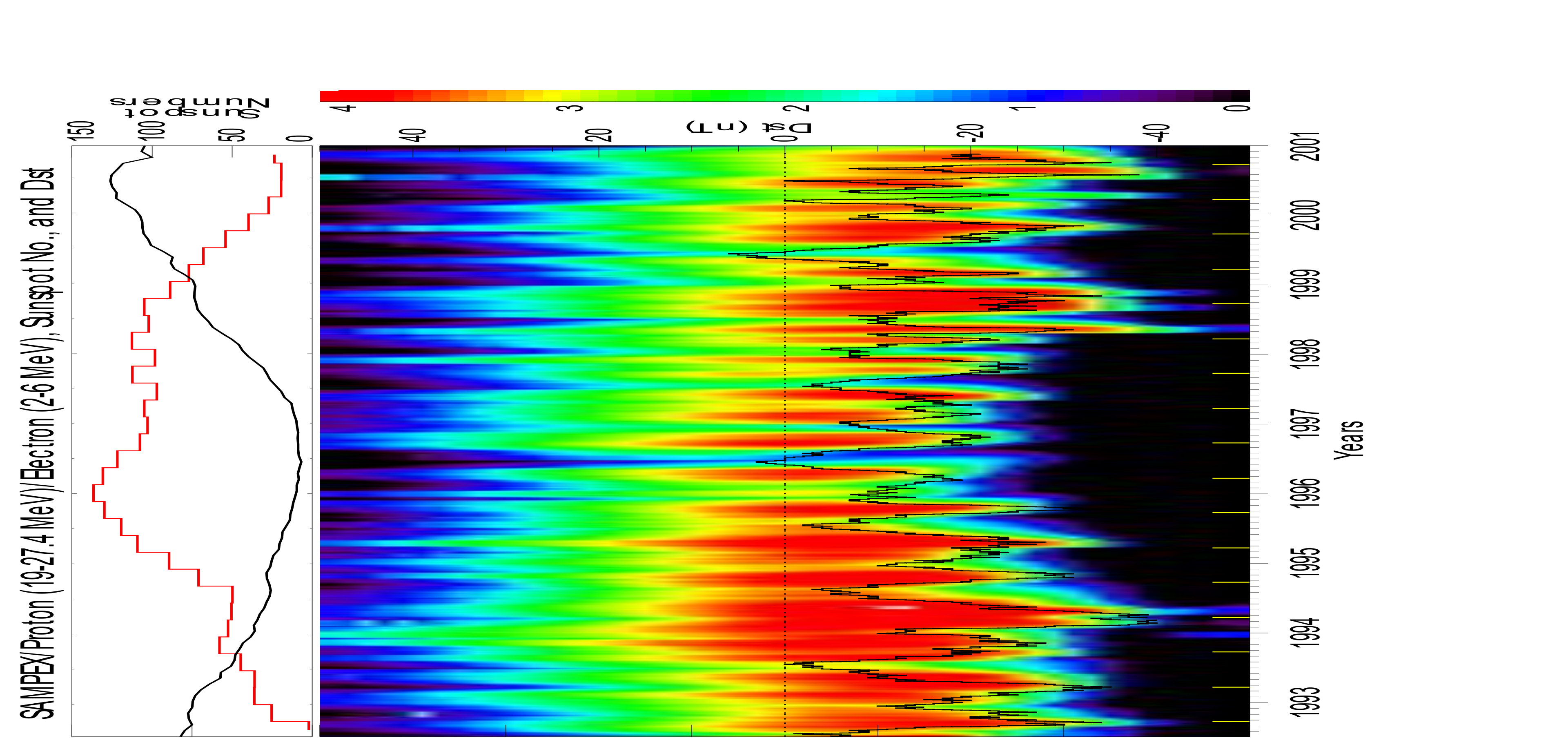
Space Physics Master's Course
Lecture 9
Van Allen Belts Part 2



Flux variability in the radiation belts

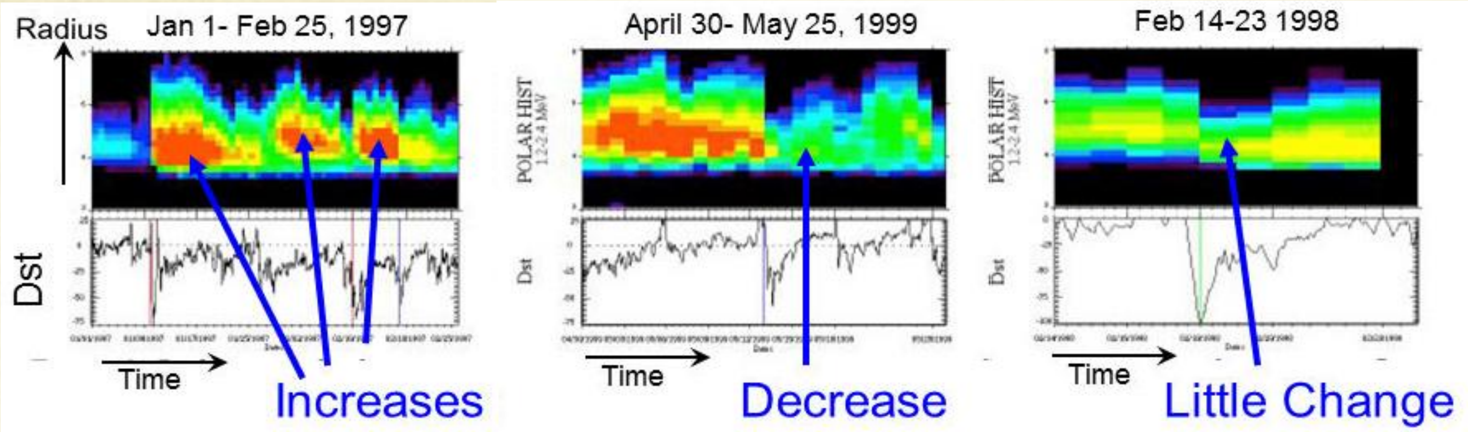
- Solar cycle: years / Solar rotation: 27 days
- Storm recovery: days / Storm main phase: hours
- SSC: minutes



Storms and RBs

Realization that

some storms are "more equal than others"

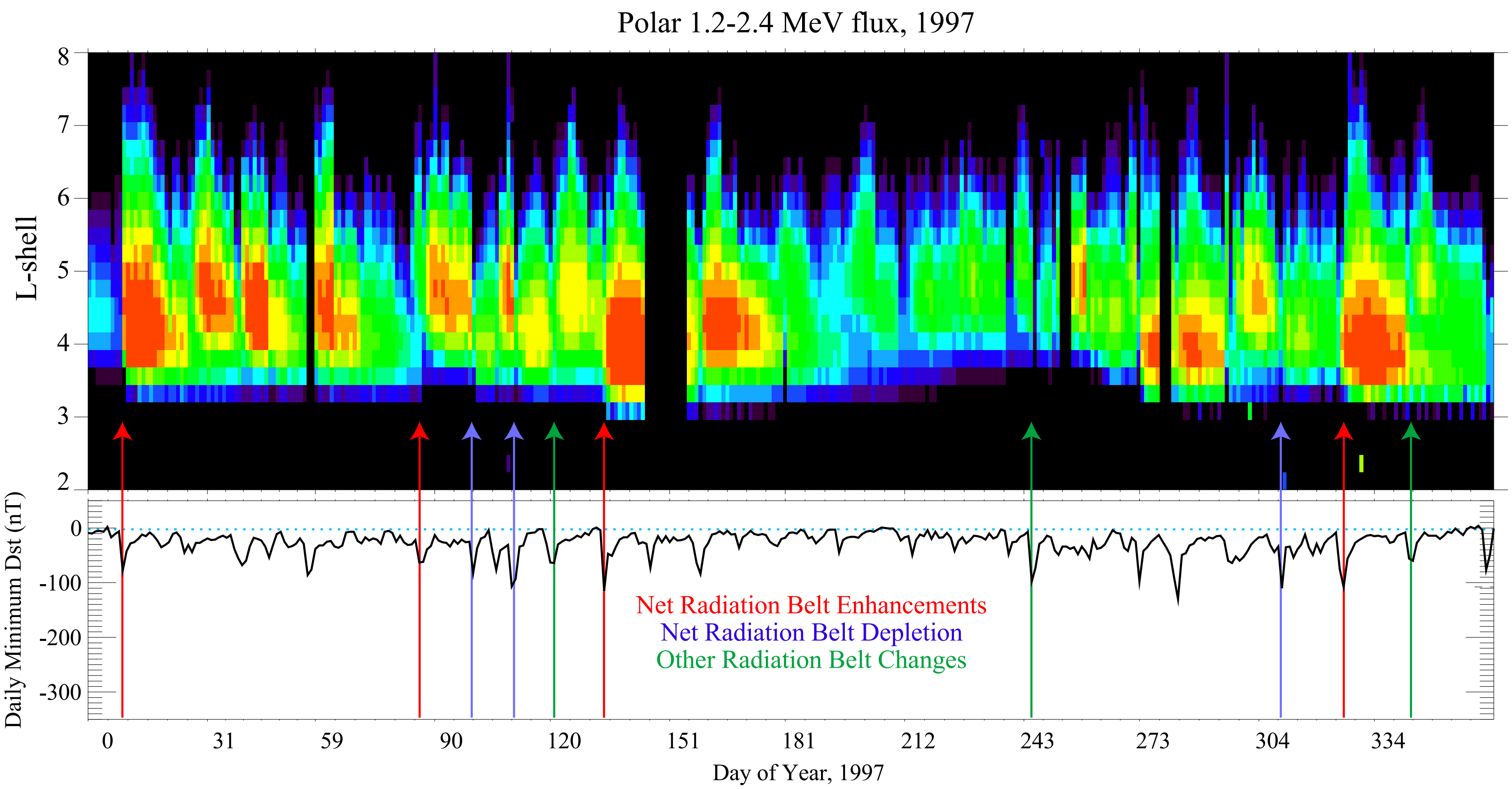


Reeves et al., 2003

G. Orwell, 1945

G. Reeves, 2003: 276 moderate/intense storms, 1989-2000

Geospace Magnetic Storms and Radiation Belts



Reeves, SW2007

Correlation with magnetic storms

Relativistic electron flux

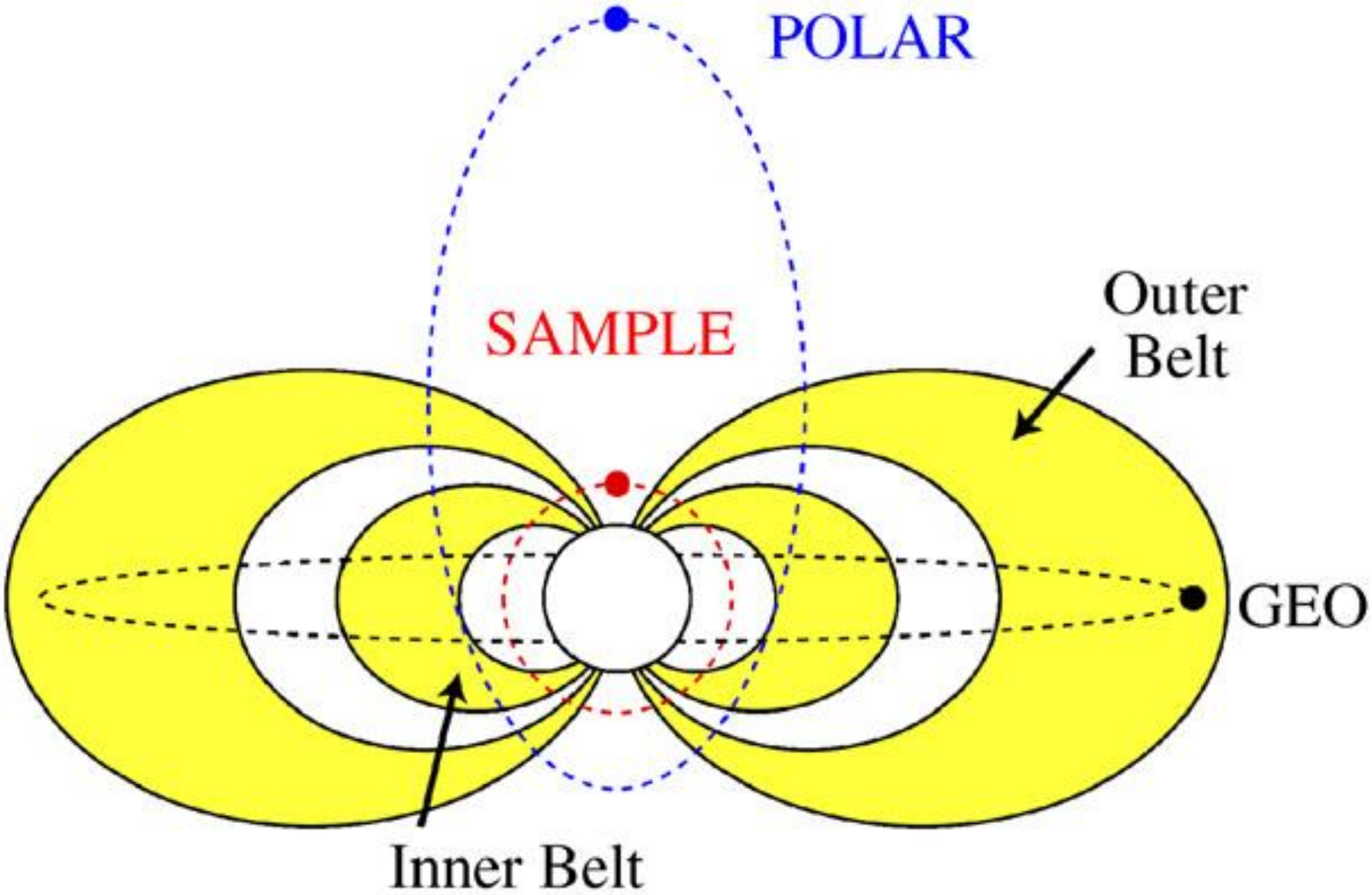
does not always increase

during magnetic storms.

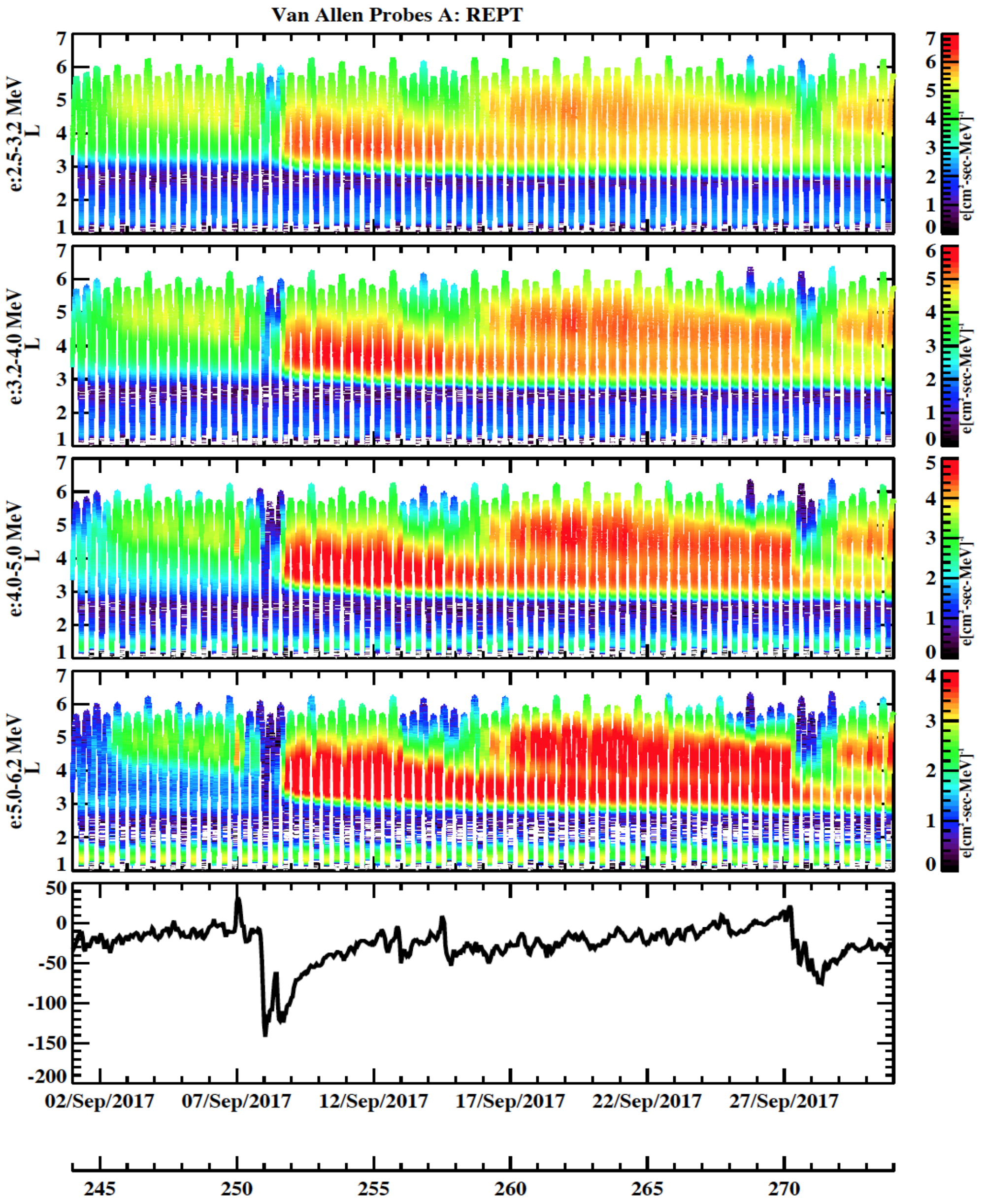
Reeves et al. [2003] showed that:

- 53% cause increase
- 19% cause decrease
- 28% produce no net change

Final flux levels are the balance result between acceleration, transport and losses.


POLAR
SAMPLE
Outer
Belt
GEO
Inner Belt

Long-duration (>20 days) elevated levels of ultra-relativistic (>5 MeV) electrons starting with the September 2017 storm



Kanekal 2019

Radiation belt formation

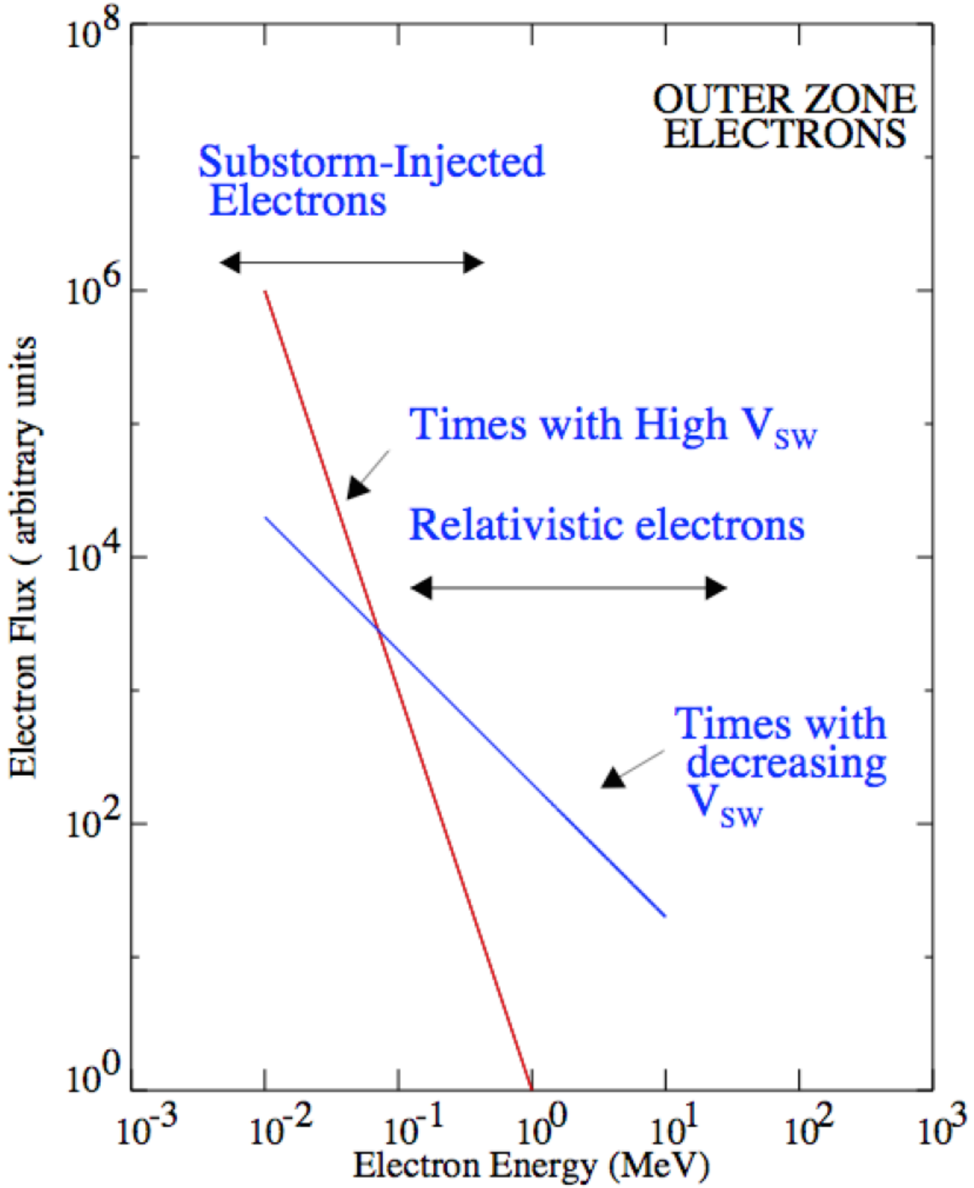
Which mechanism(s) can efficiently accelerate charged particles, leading to enhanced fluxes of MeV radiation belt particles?

Radiation belt formation

The most obvious driver, the magnetospheric substorm, appears to be insufficient.

Typical substorms seldom directly accelerate electrons to energies much above ~300 keV

Relativistic Electrons: Energization



- High solar wind speeds (> 500 km/s) and southward B_z
- Substorm-generated seed population (extending to hundreds of keV)
- Physical processes
  - radial transport
  - in-situ acceleration

Radiation belt formation

Observations have led to the view that an enhancement in magnetospheric activity (e.g., substorms)

- driven by southward IMF -

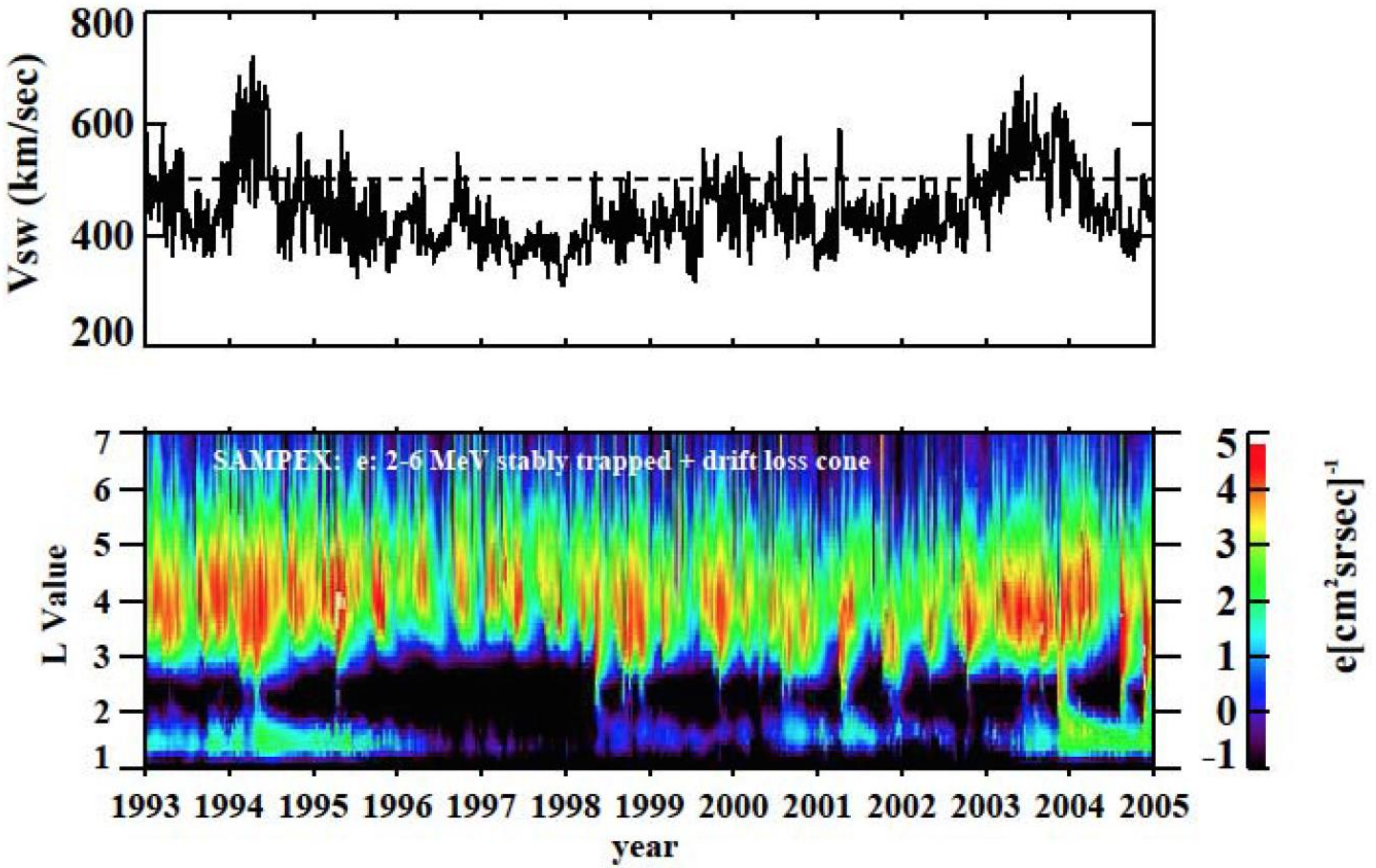
is a key first step

in the acceleration of magnetospheric electrons to high energies.

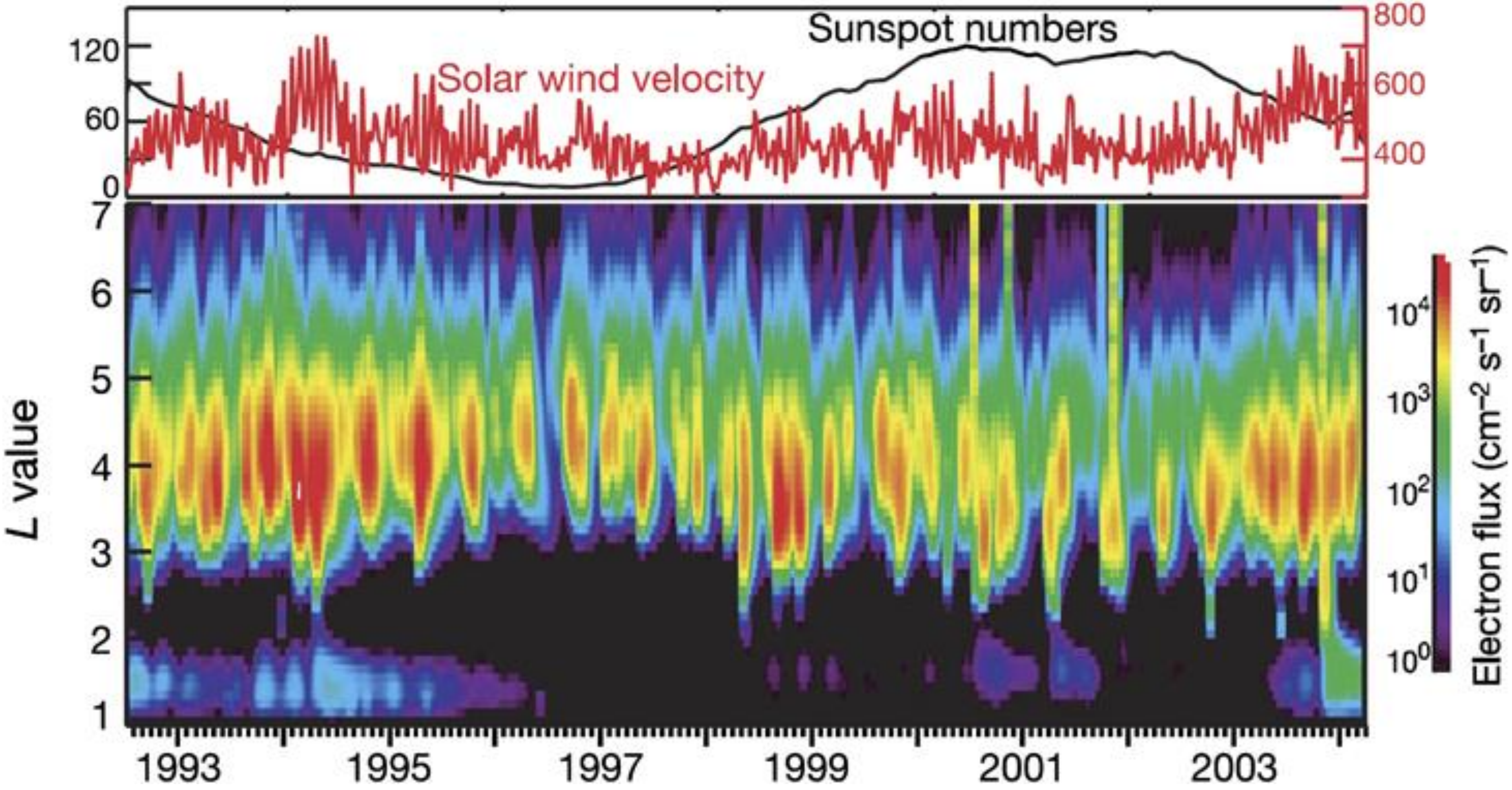
Radiation belt formation

A second step is found to be
a period of intense wave activity
which *often* is closely related
to high values of V_{SW}

Solar Cycle View of Solar Wind Effects

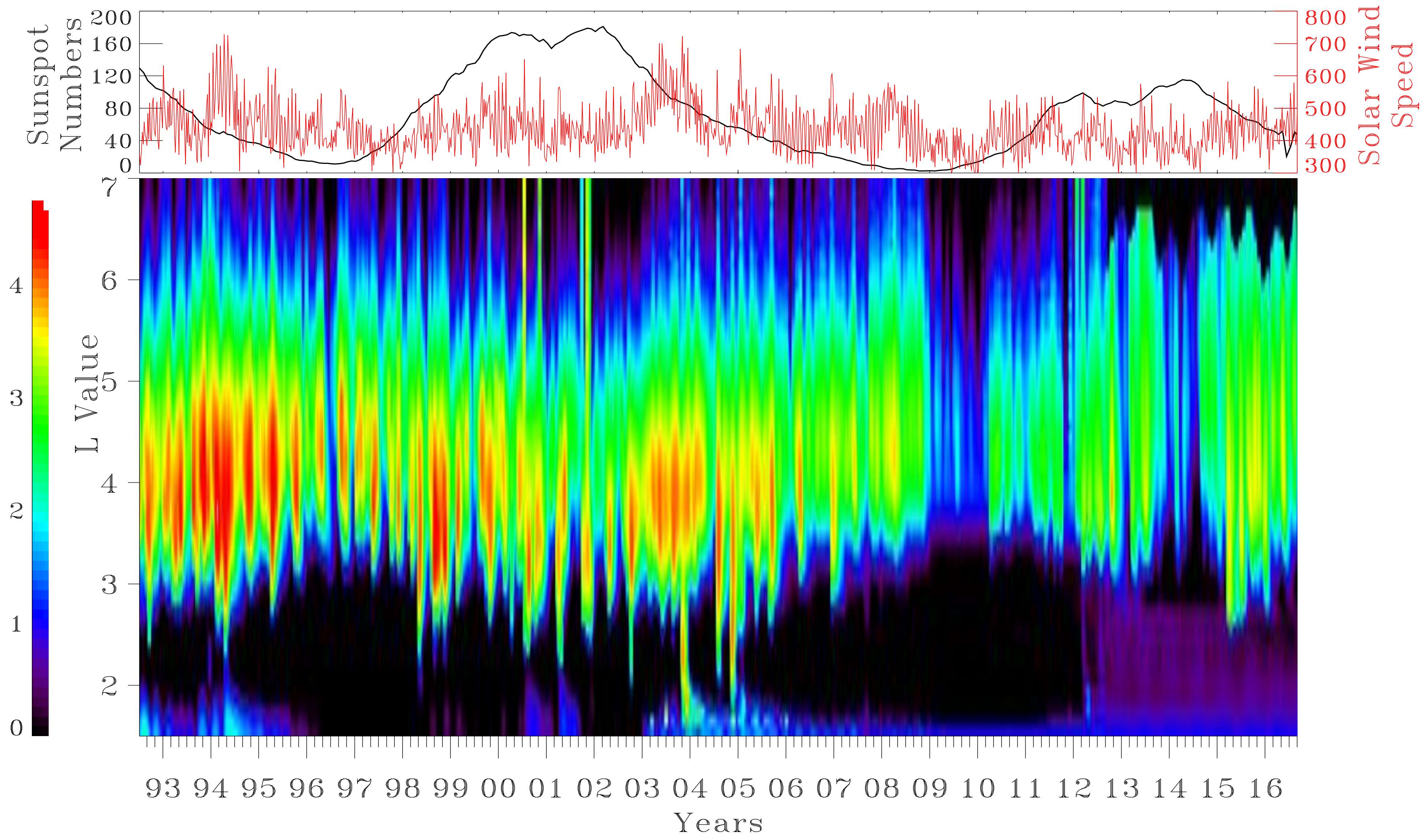


LASP



Sunspot numbers
Solar wind velocity
120
60
0
800
600
400
7
6
5
4
3
2
1
L value
1993
1995
1997
1999
2001
2003
Electron flux (cm^{-2} s^{-1} sr^{-1})
10^4
10^3
10^2
10^1
10^0

SAMPEX and Van Allen Probes – 23+ years!



Radiation belt formation

A pre-requisite of relativistic (MeV) electron enhancement is typically

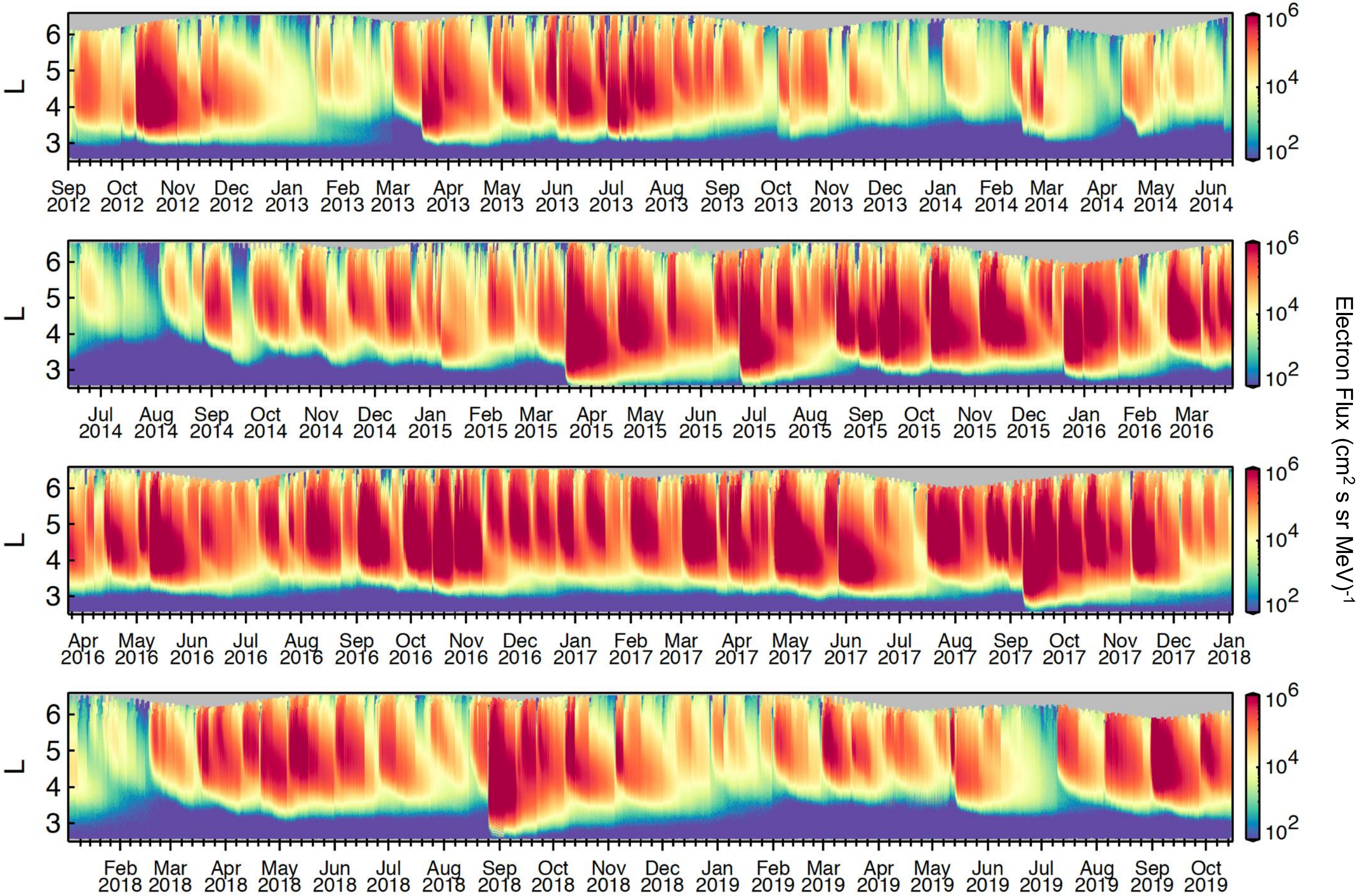
an interval of southward IMF

along with a period of

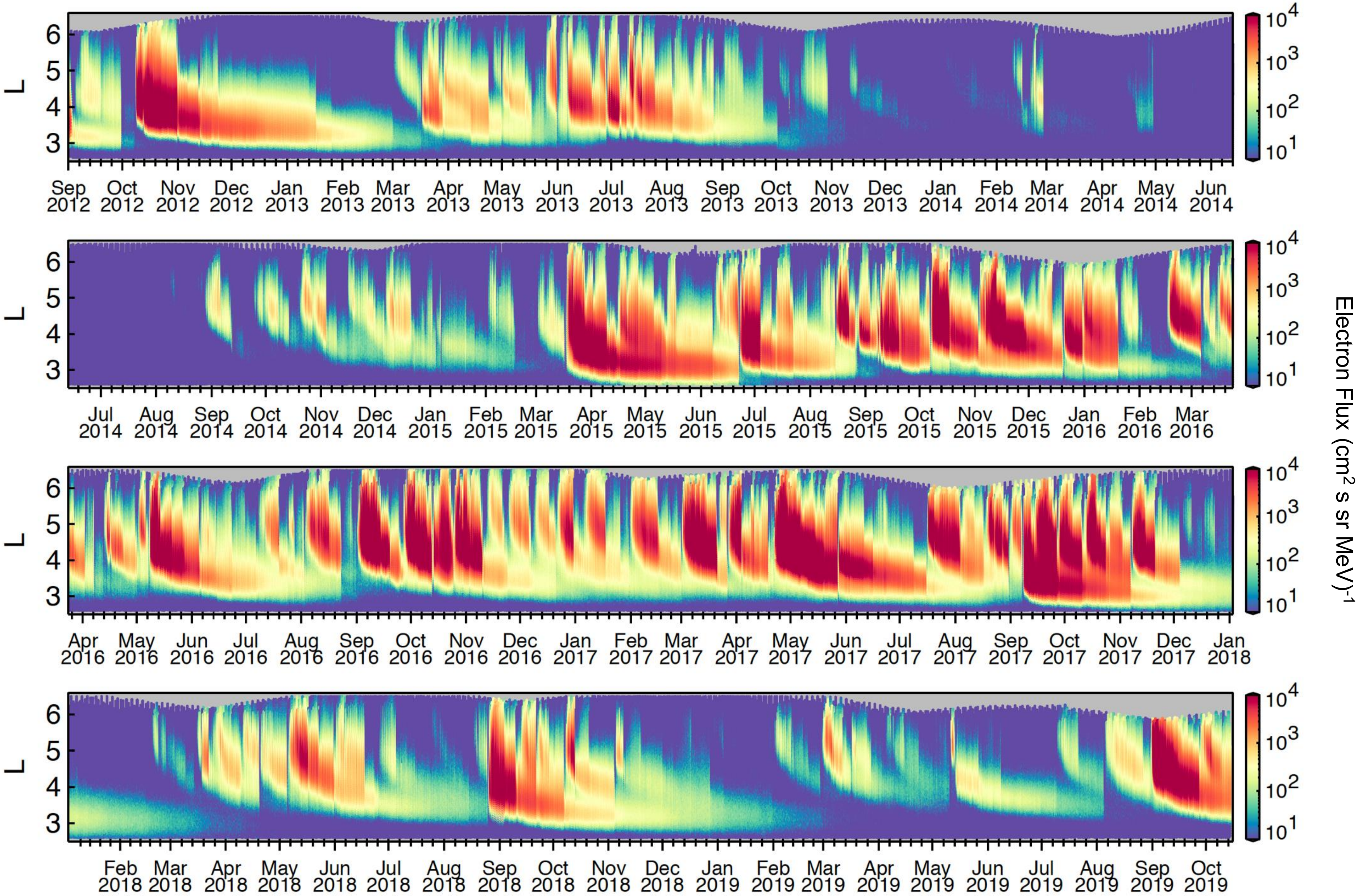
high solar-wind speed

($V_{SW} \geq 500$ km/s).

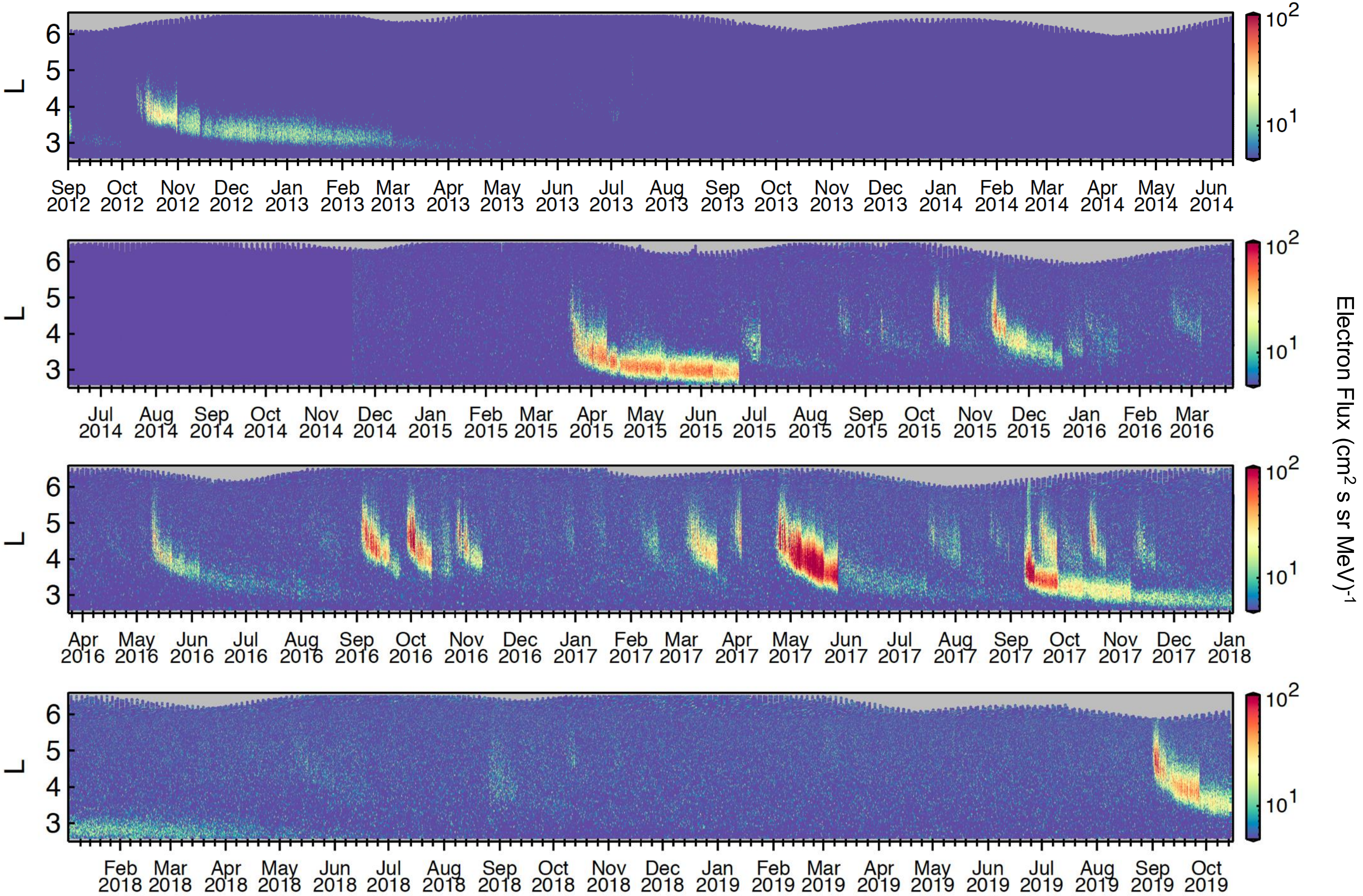
REPT A & B   1.8 MeV Electrons

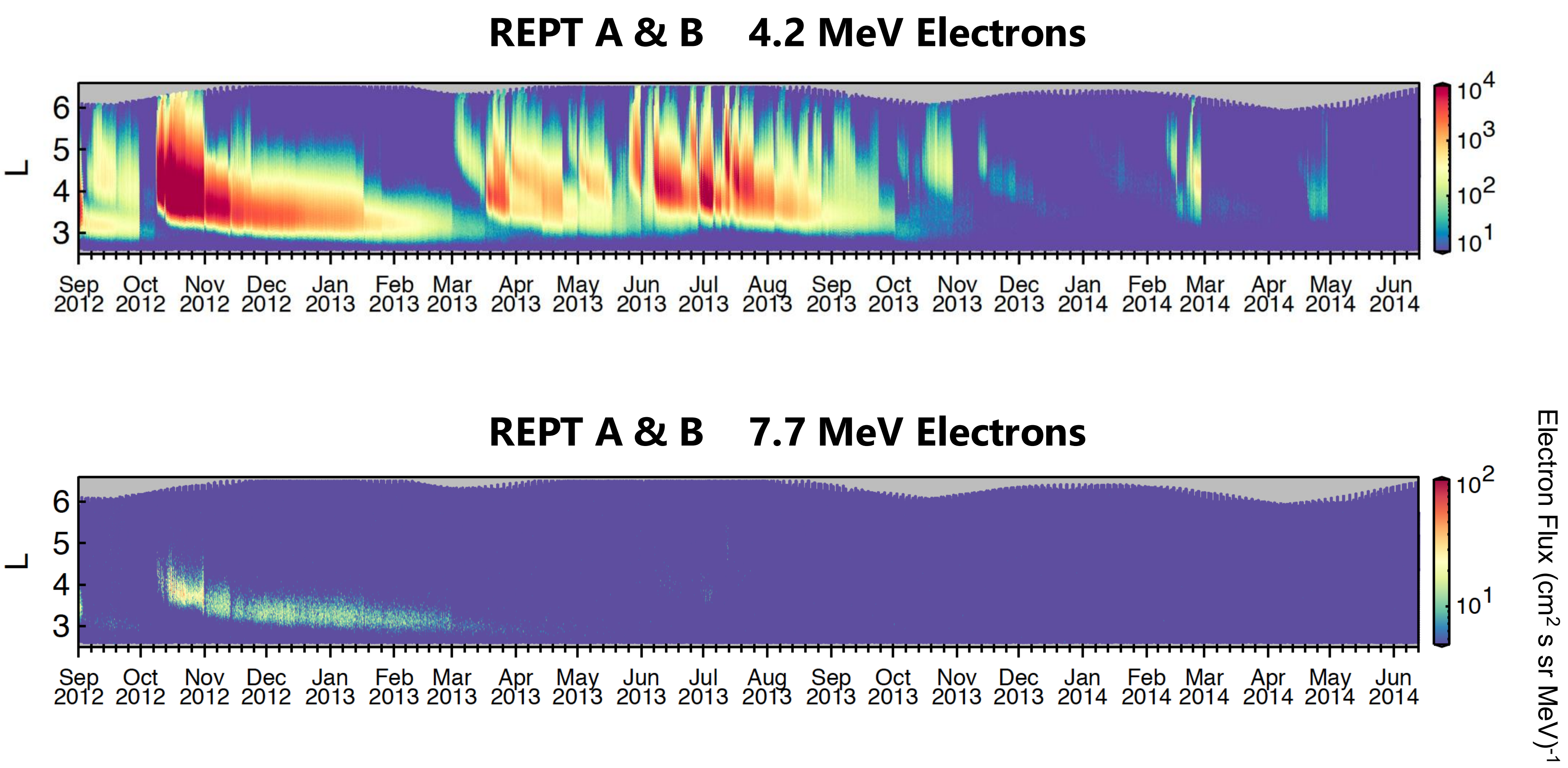


REPT A & B   4.2 MeV Electrons

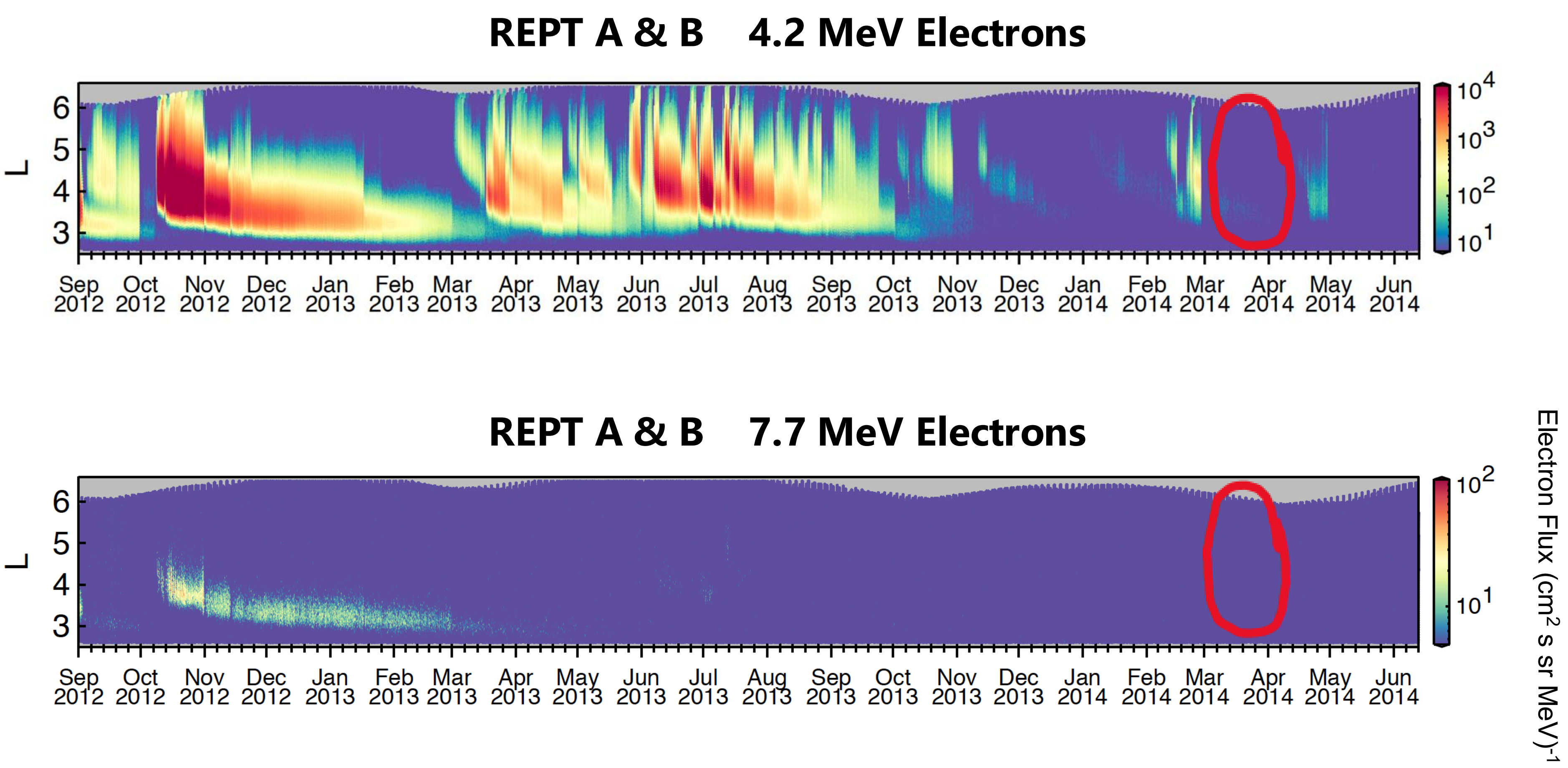


REPT A & B   7.7 MeV Electrons

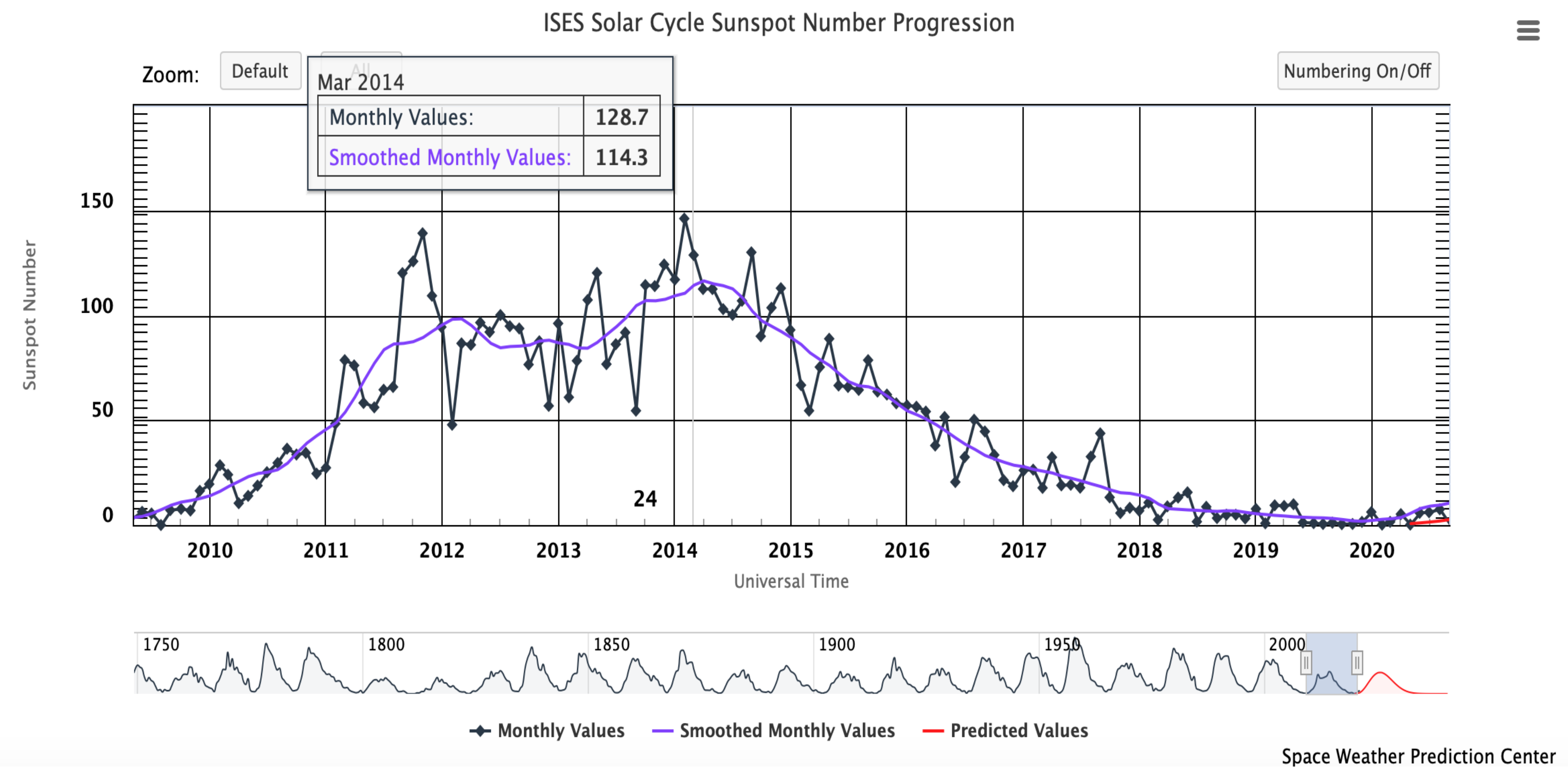




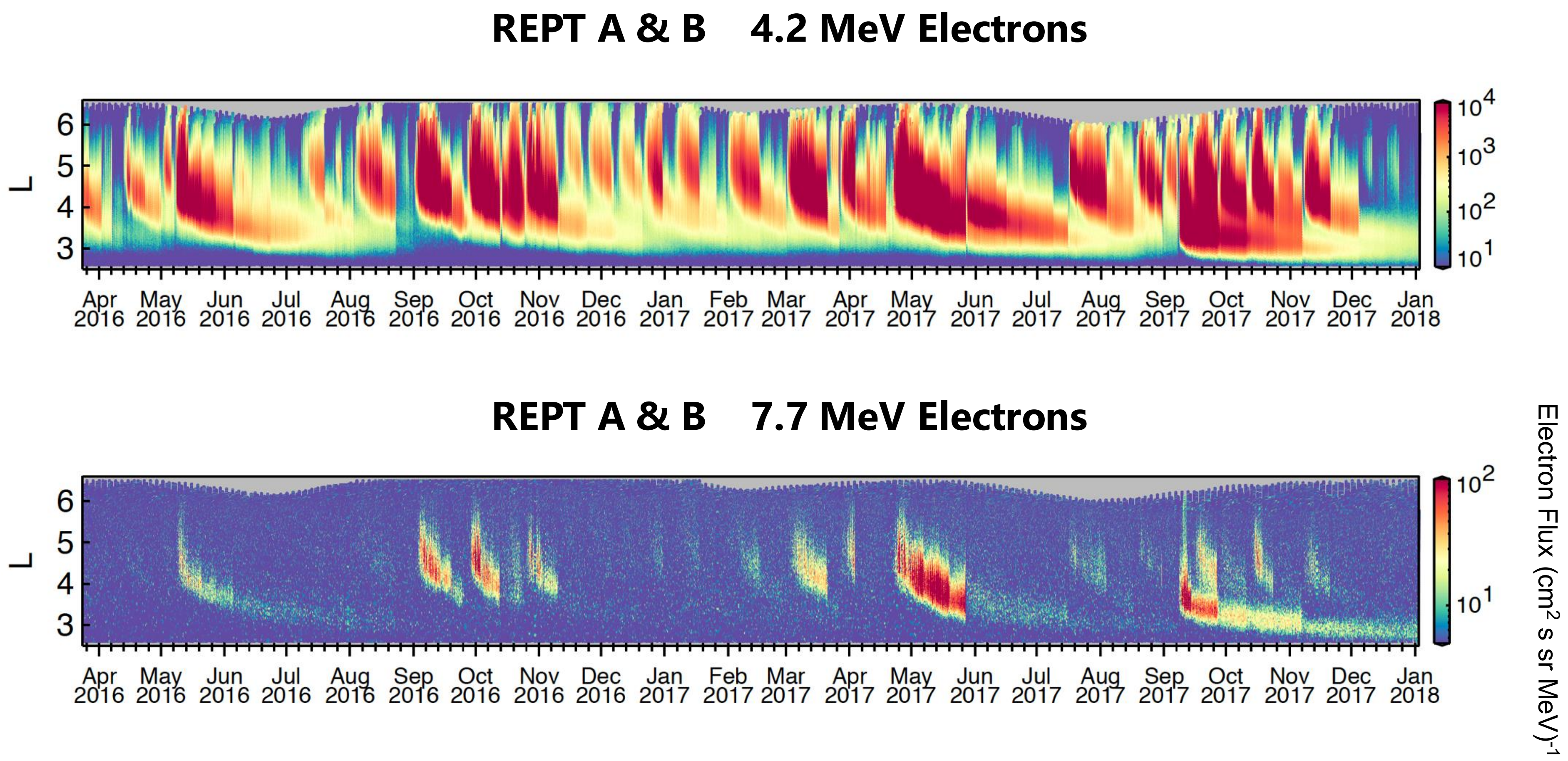
REPT A & B 4.2 MeV Electrons
L
6
5
4
3
Sep 2012 Oct 2012 Nov 2012 Dec 2012 Jan 2013 Feb 2013 Mar 2013 Apr 2013 May 2013 Jun 2013 Jul 2013 Aug 2013 Sep 2013 Oct 2013 Nov 2013 Dec 2013 Jan 2014 Feb 2014 Mar 2014 Apr 2014 May 2014 Jun 2014
10^4
10^3
10^2
10^1
REPT A & B 7.7 MeV Electrons
L
6
5
4
3
Sep 2012 Oct 2012 Nov 2012 Dec 2012 Jan 2013 Feb 2013 Mar 2013 Apr 2013 May 2013 Jun 2013 Jul 2013 Aug 2013 Sep 2013 Oct 2013 Nov 2013 Dec 2013 Jan 2014 Feb 2014 Mar 2014 Apr 2014 May 2014 Jun 2014
10^2
10^1
Electron Flux (cm^2 s sr MeV)^-1



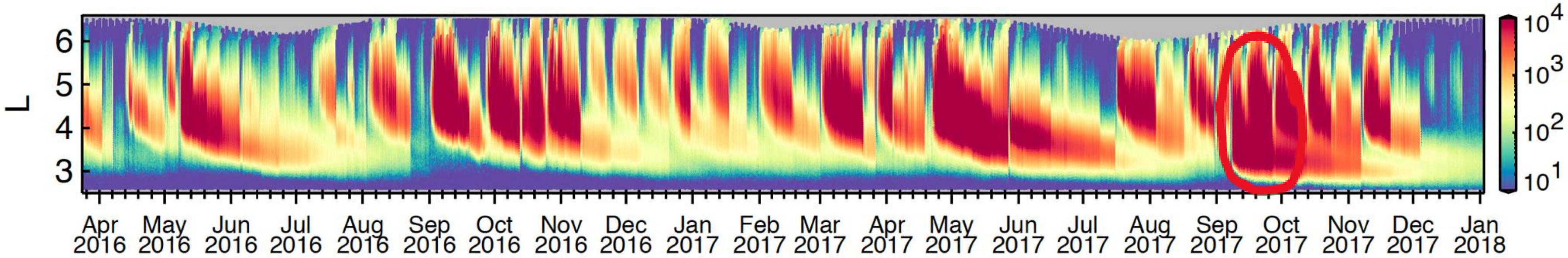
REPT A & B 4.2 MeV Electrons
L
6
5
4
3
Sep 2012
Oct 2012
Nov 2012
Dec 2012
Jan 2013
Feb 2013
Mar 2013
Apr 2013
May 2013
Jun 2013
Jul 2013
Aug 2013
Sep 2013
Oct 2013
Nov 2013
Dec 2013
Jan 2014
Feb 2014
Mar 2014
Apr 2014
May 2014
Jun 2014
10^4
10^3
10^2
10^1
REPT A & B 7.7 MeV Electrons
L
6
5
4
3
Sep 2012
Oct 2012
Nov 2012
Dec 2012
Jan 2013
Feb 2013
Mar 2013
Apr 2013
May 2013
Jun 2013
Jul 2013
Aug 2013
Sep 2013
Oct 2013
Nov 2013
Dec 2013
Jan 2014
Feb 2014
Mar 2014
Apr 2014
May 2014
Jun 2014
10^2
10^1
Electron Flux (cm^2 s sr MeV)$^{-1}$



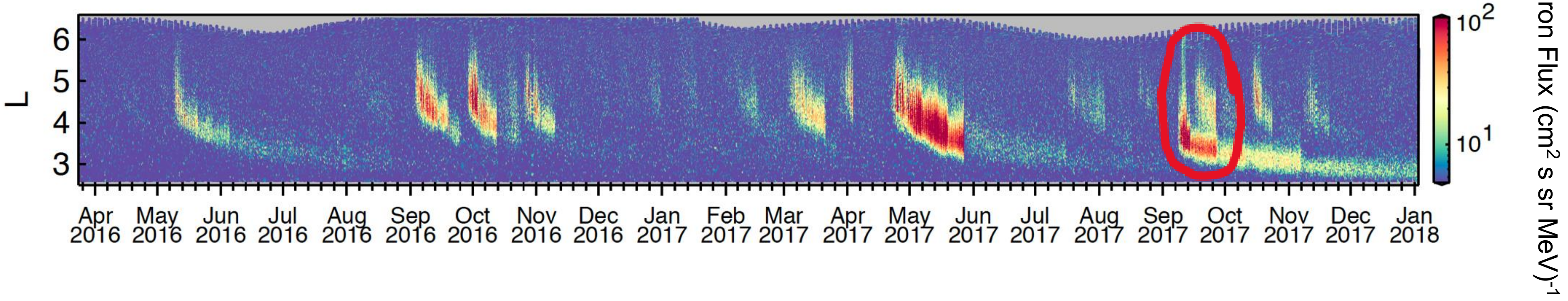
ISES Solar Cycle Sunspot Number Progression
Zoom:
Default
All
Numbering On/Off
Mar 2014
Monthly Values: 128.7
Smoothed Monthly Values: 114.3
Sunspot Number
0
50
100
150
24
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Universal Time
1750
1800
1850
1900
1950
2000
Monthly Values
Smoothed Monthly Values
Predicted Values
Space Weather Prediction Center

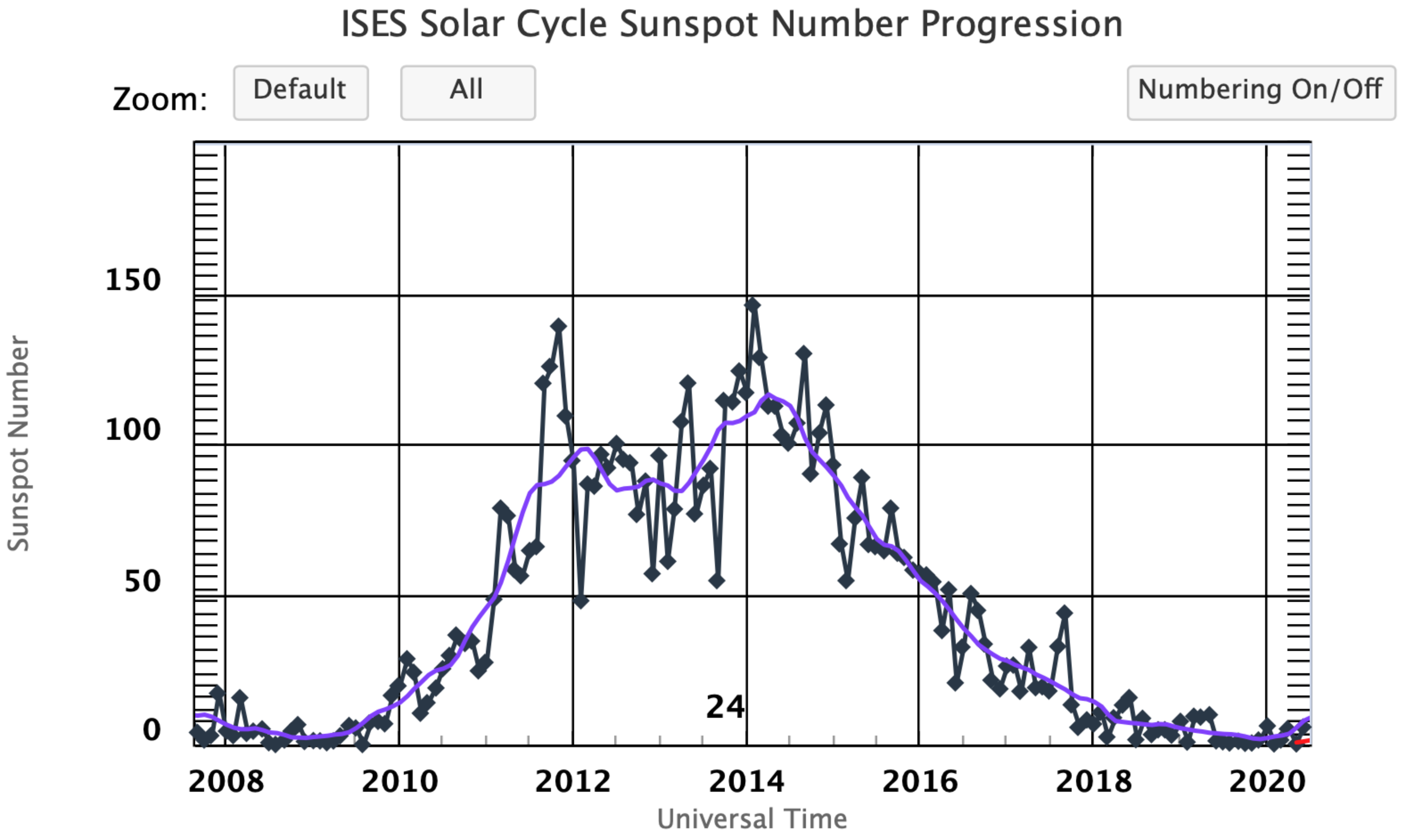

REPT A & B 4.2 MeV Electrons
REPT A & B 7.7 MeV Electrons
L
Electron Flux (cm2 s sr MeV)-1
Apr 2016 May 2016 Jun 2016 Jul 2016 Aug 2016 Sep 2016 Oct 2016 Nov 2016 Dec 2016 Jan 2017 Feb 2017 Mar 2017 Apr 2017 May 2017 Jun 2017 Jul 2017 Aug 2017 Sep 2017 Oct 2017 Nov 2017 Dec 2017 Jan 2018

REPT A & B   4.2 MeV Electrons



REPT A & B   7.7 MeV Electrons

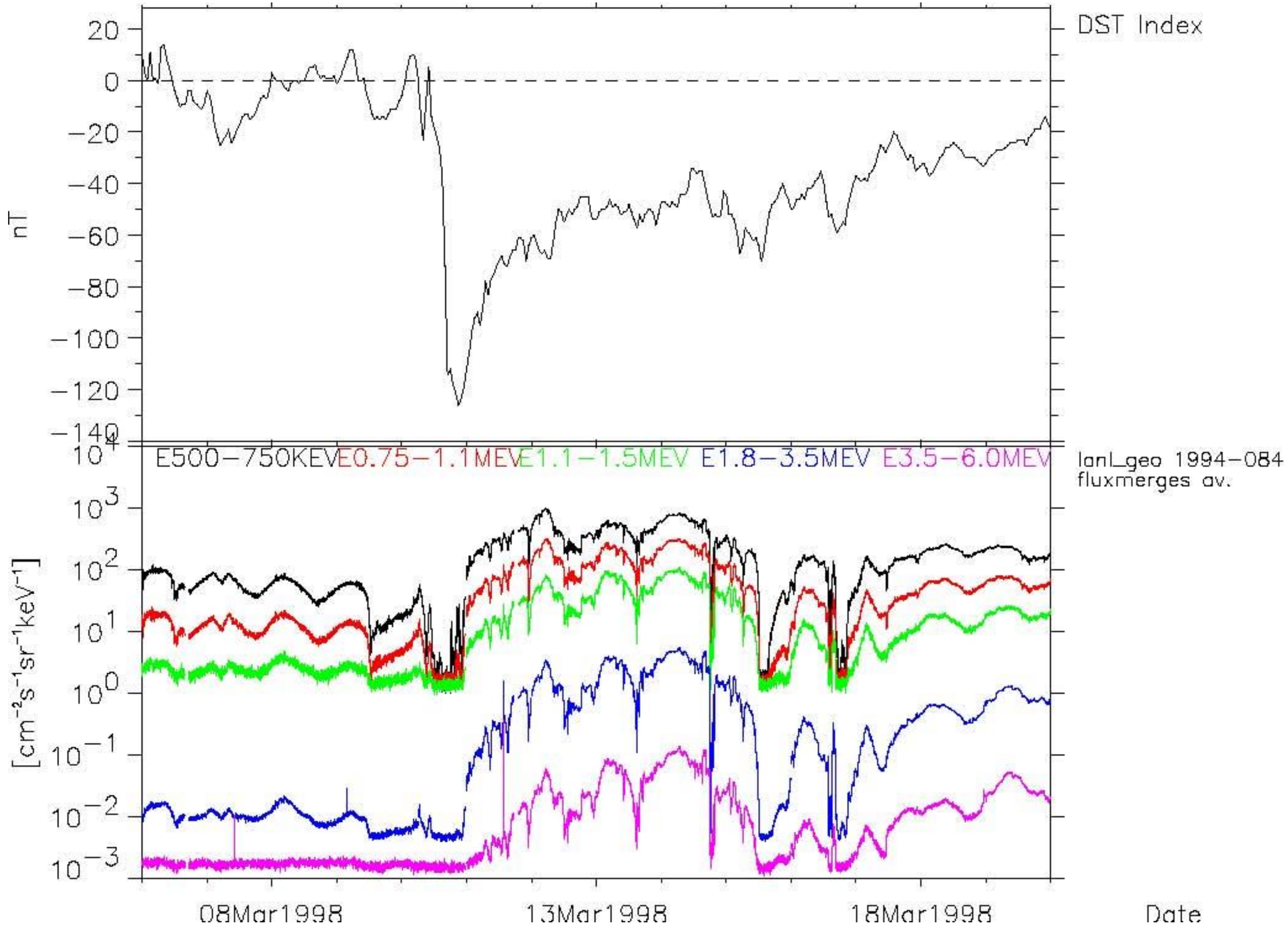




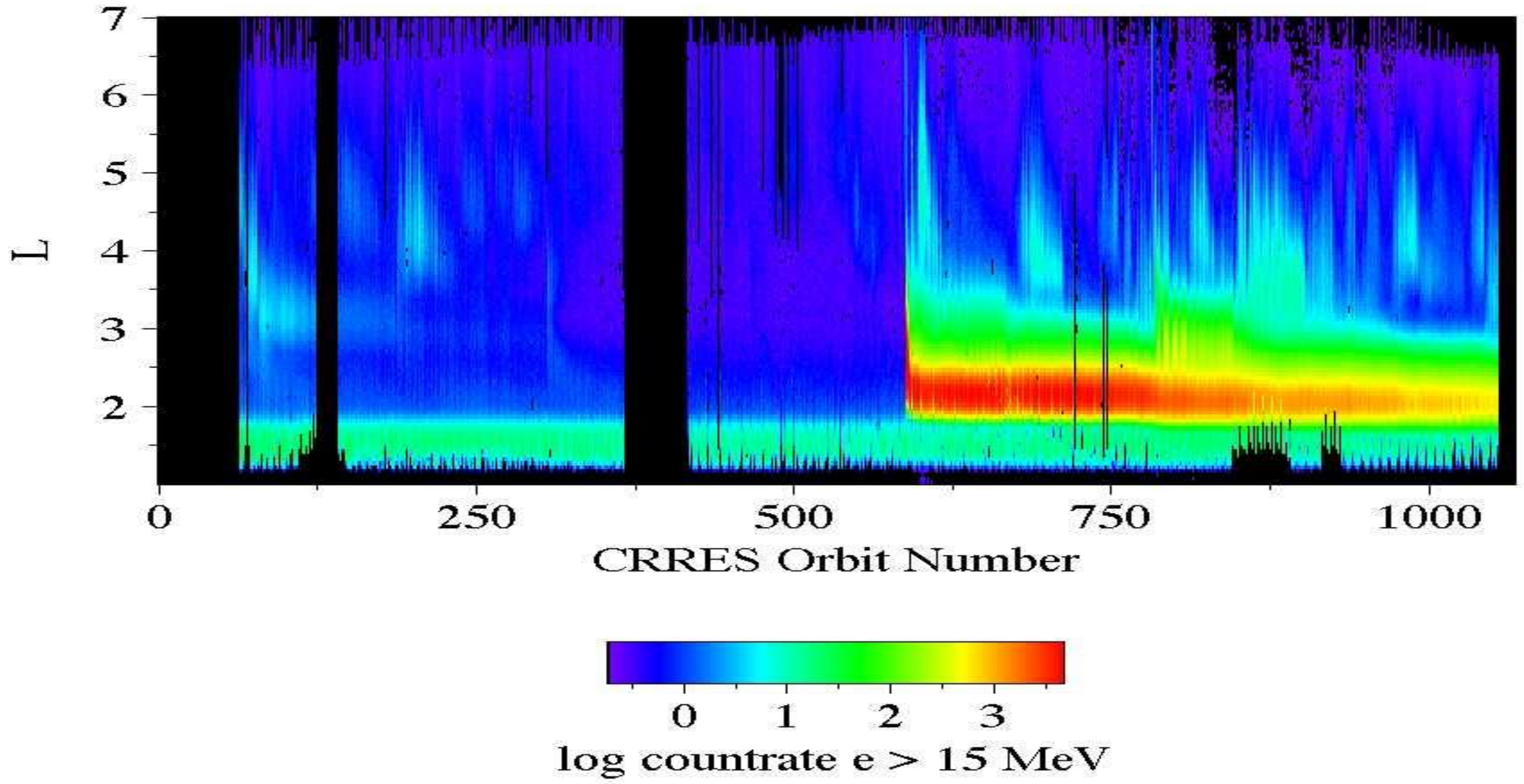
ISES Solar Cycle Sunspot Number Progression
Zoom:
Default
All
Numbering On/Off
Sunspot Number
150
100
50
0
24
2008
2010
2012
2014
2016
2018
2020
Universal Time

Μεταβολές ζωνών Van Allen
κατά τη διάρκεια καταιγίδων

Correlation with magnetic storms

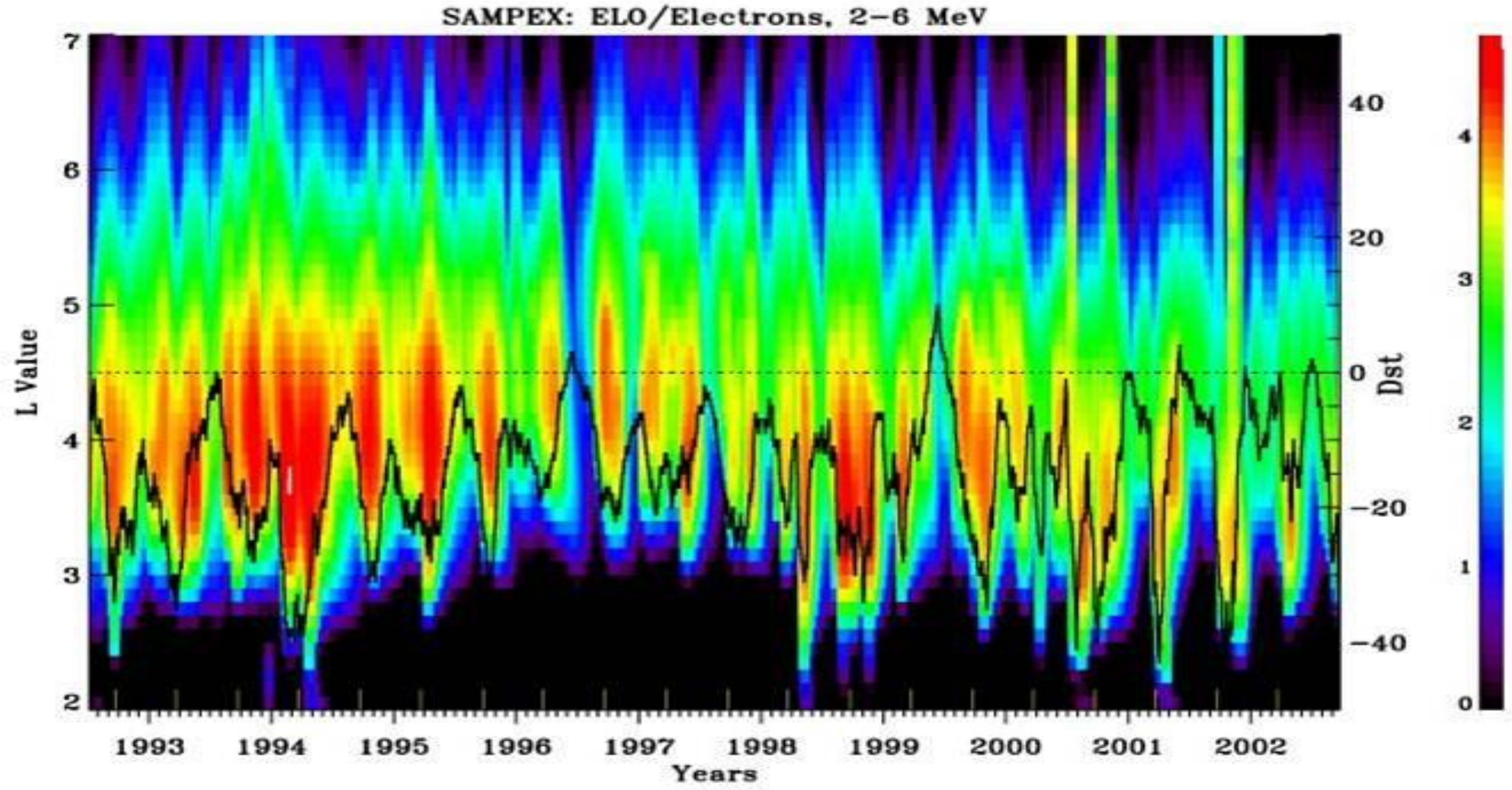


Effects of intense magnetic storms

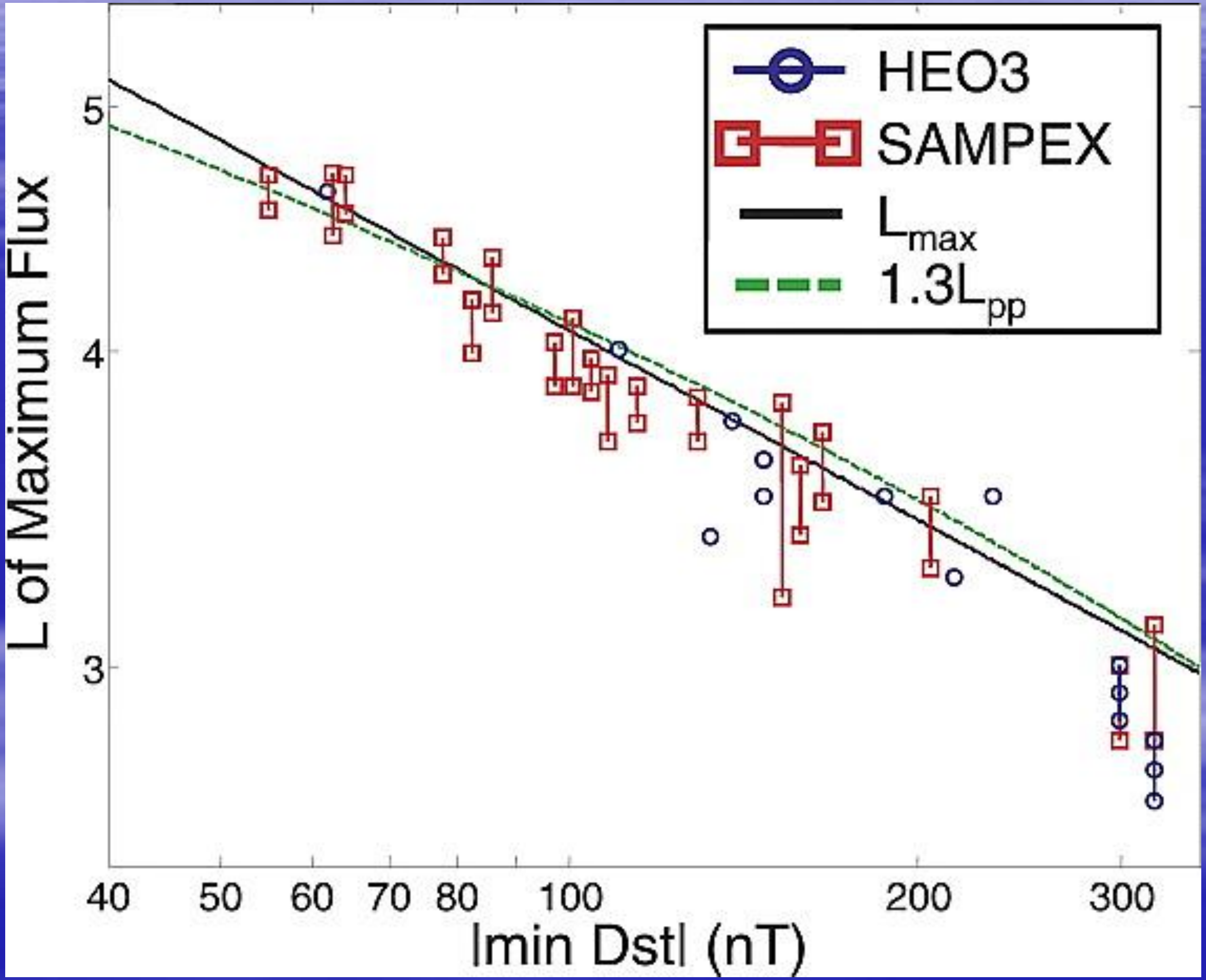


CRRES, Bernie Blake

Correlation with magnetic storms



Correlation with magnetic storms

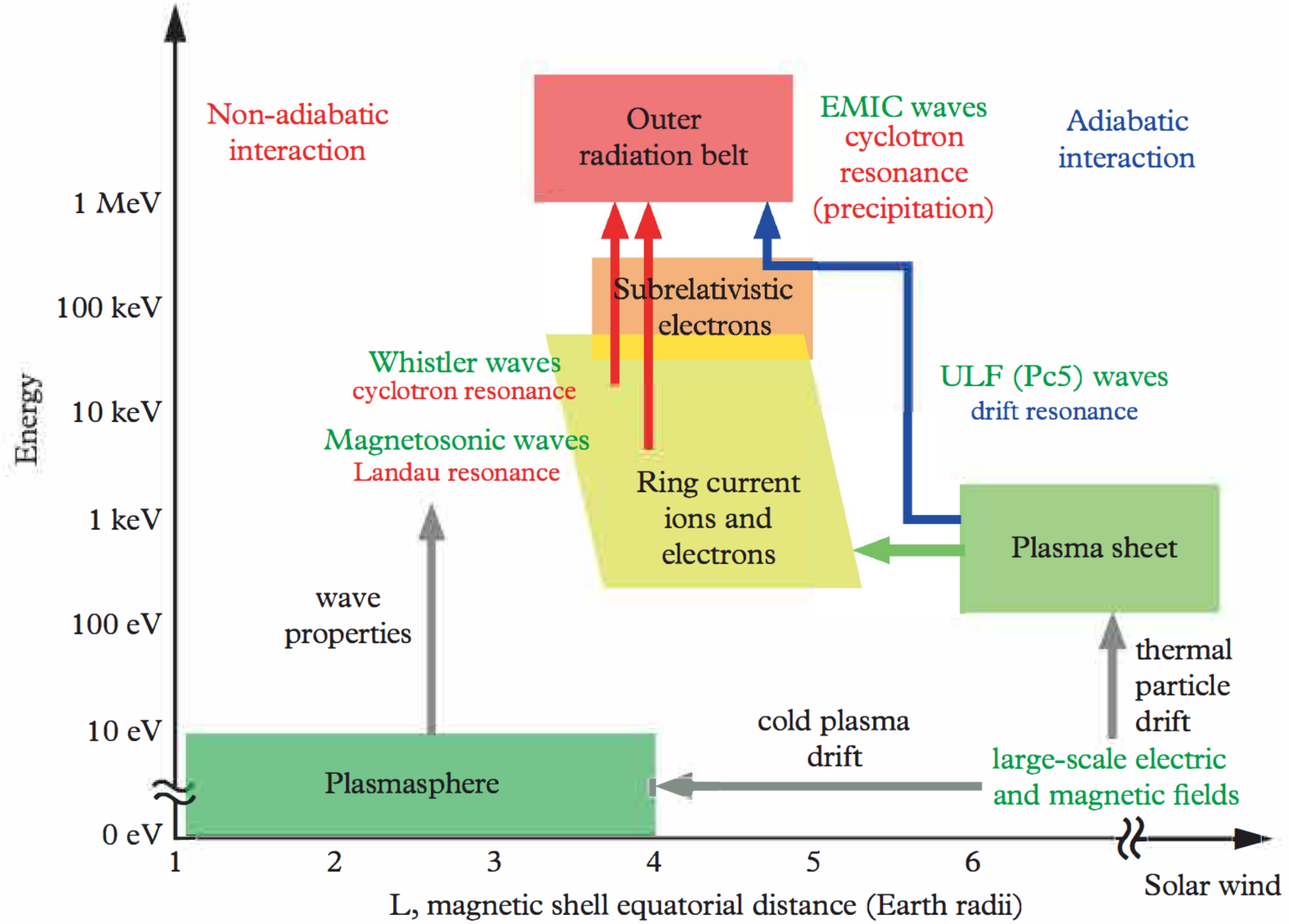


Location of the **peak electron flux** (>1.5 MeV HEO3, >1 MeV SAMPEX) as a function of minimum Dst moves to lower L

O'Brien et al., JGR2003

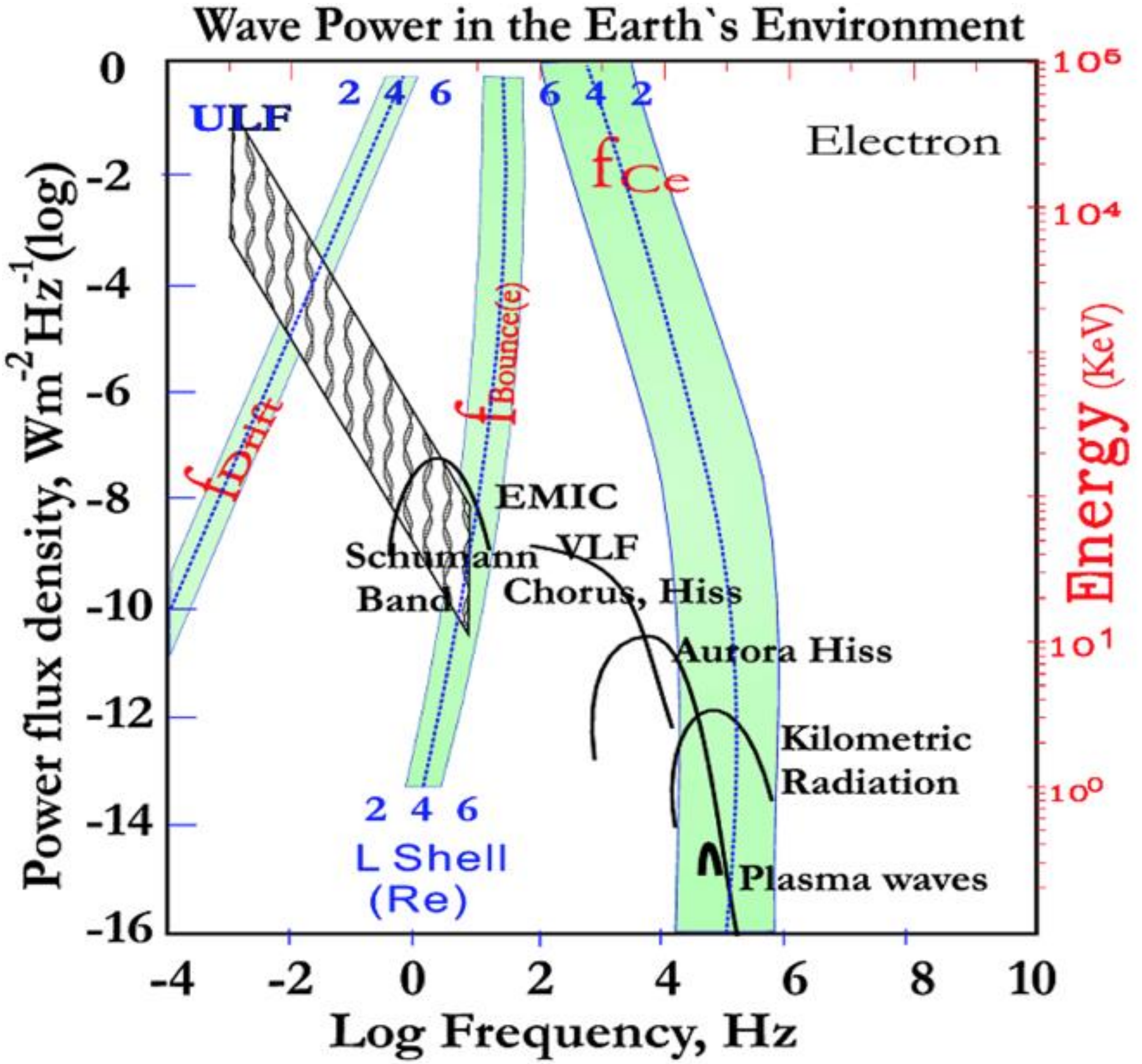
The storms, the substorms and the waves

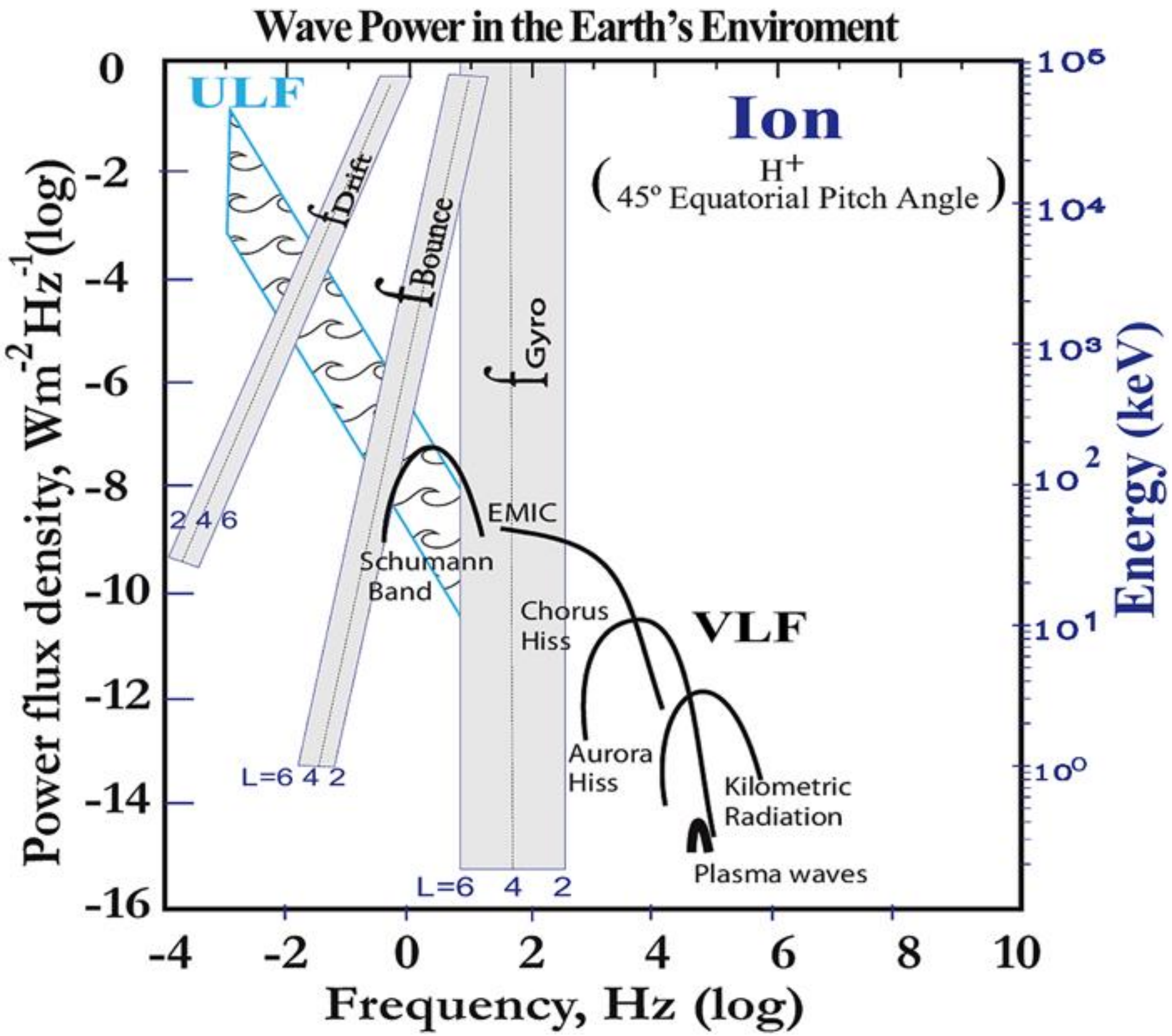
- ULF: Pc5 and EMIC waves
- VLF: Whistler-mode chorus waves



Takahashi and Miyoshi, 2016

Interaction of various waves
(in various ways)
with various particle populations
during storms/substorms


Wave Power in the Earth`s Environment
Electron
ULF
f_{Drift}
$f_{Bounce(e)}$
f_{Ce}
EMIC
VLF
Schumann Band
Chorus, Hiss
Aurora Hiss
Kilometric Radiation
Plasma waves
L Shell (Re)
Power flux density, $Wm^{-2}Hz^{-1}$(log)
Energy (KeV)
Log Frequency, Hz


Wave Power in the Earth's Enviroment
ULF
Ion
H^{+}
(45° Equatorial Pitch Angle)
f_{Drift}
f_{Bounce}
f_{Gyro}
EMIC
Schumann Band
Chorus Hiss
VLF
Aurora Hiss
Kilometric Radiation
Plasma waves
L=6 4 2
Power flux density, $Wm^{-2}Hz^{-1}$(log)
Energy (keV)
Frequency, Hz (log)

ULF Pc5 waves result from:

- *solar wind pressure*
- *magnetopause shear flow instabilities (K-H)*
- *mirror/drift-bounce instabilities*
- *anisotropies in the ring current*

RC O^+ ions, in particular, provide a source of free energy to **drive Pc5 waves**