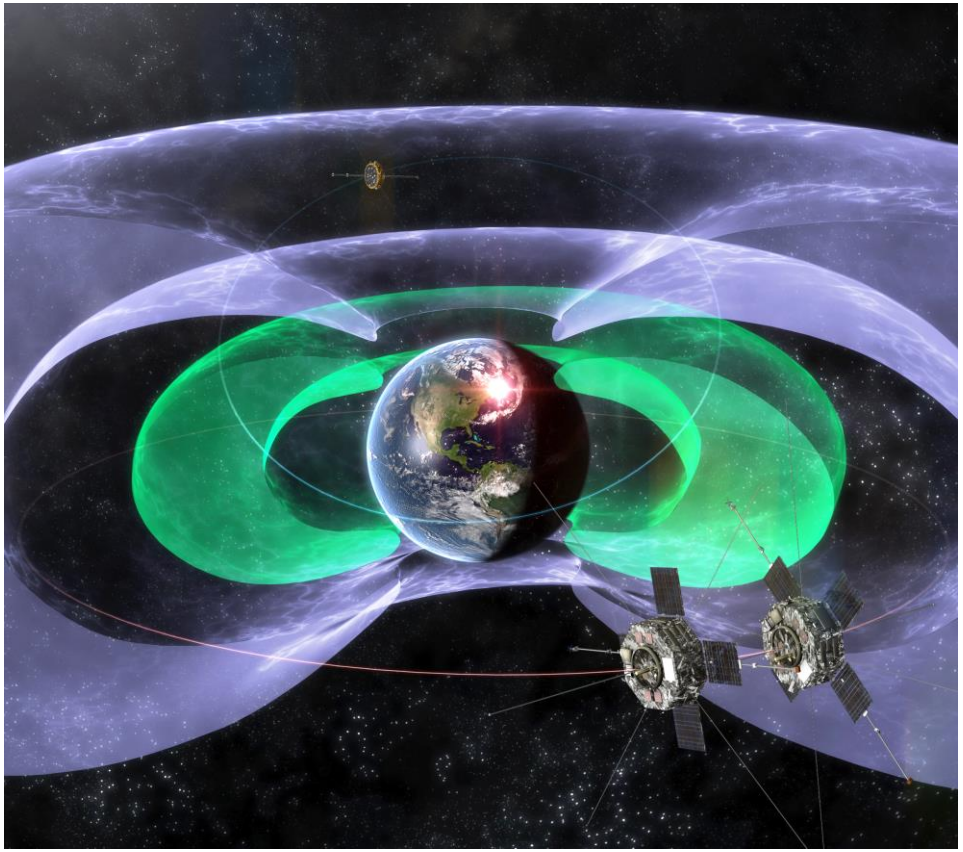
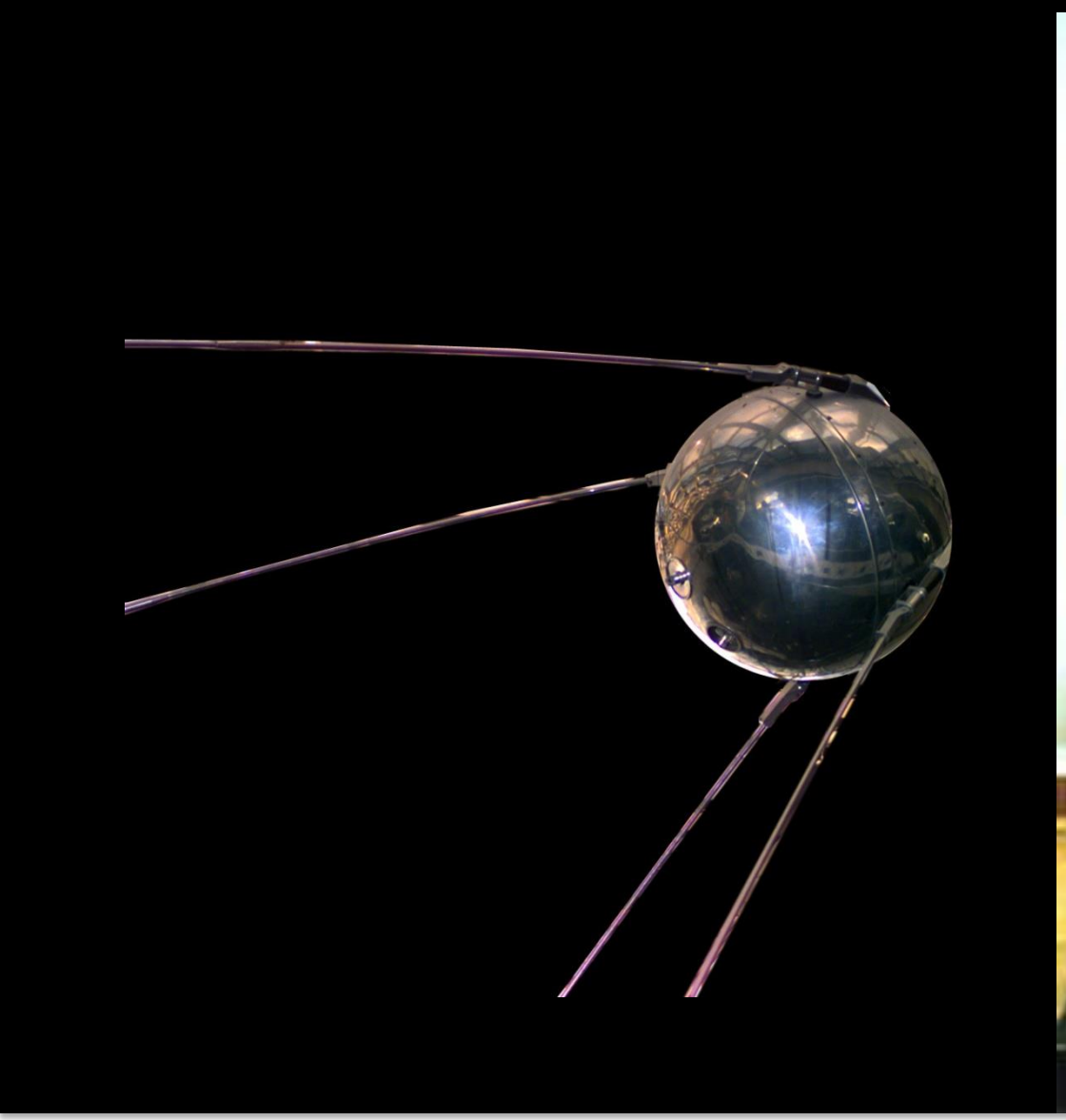


The Role of Solar and Solar Wind Forcing of the Radiation Belts

Daniel N. Baker
Laboratory for Atmospheric and Space Physics
Astrophysical and Planetary Sciences Department
Department of Physics
University of Colorado - Boulder

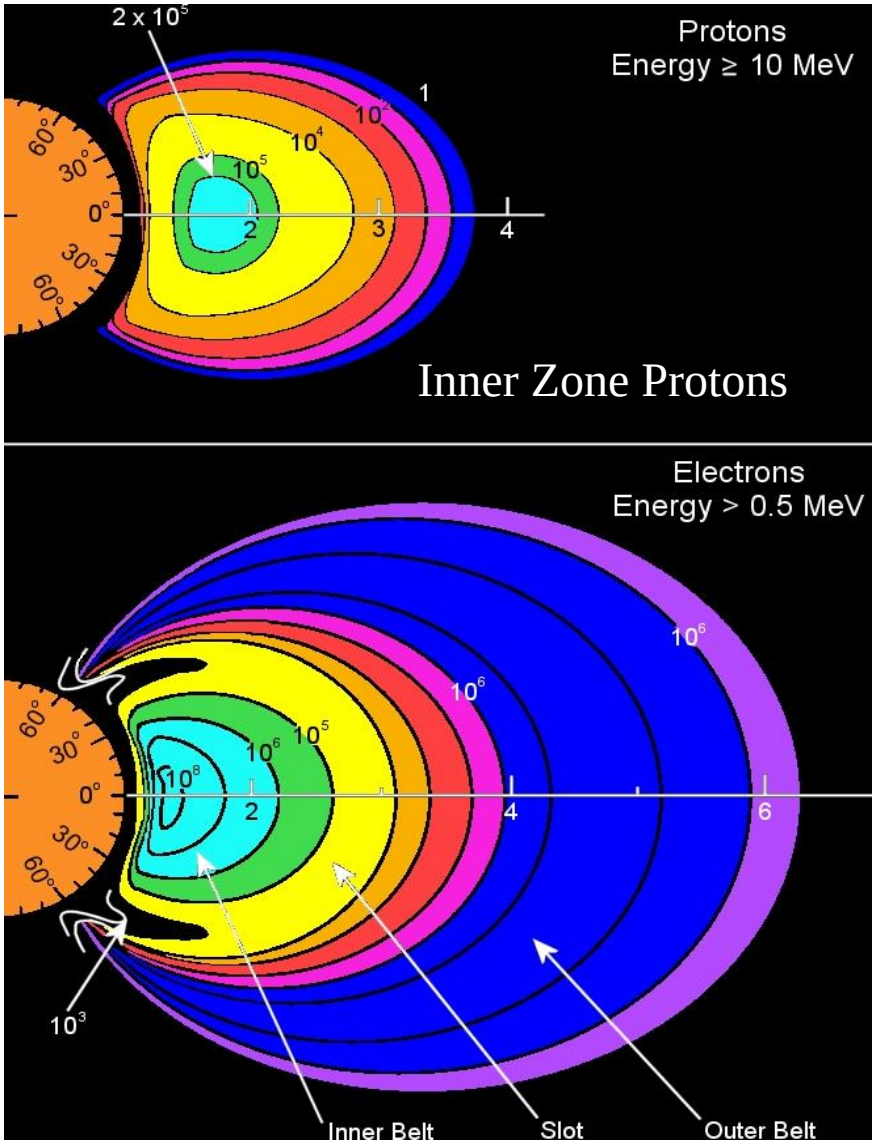


4 October 1957:
Sputnik 1

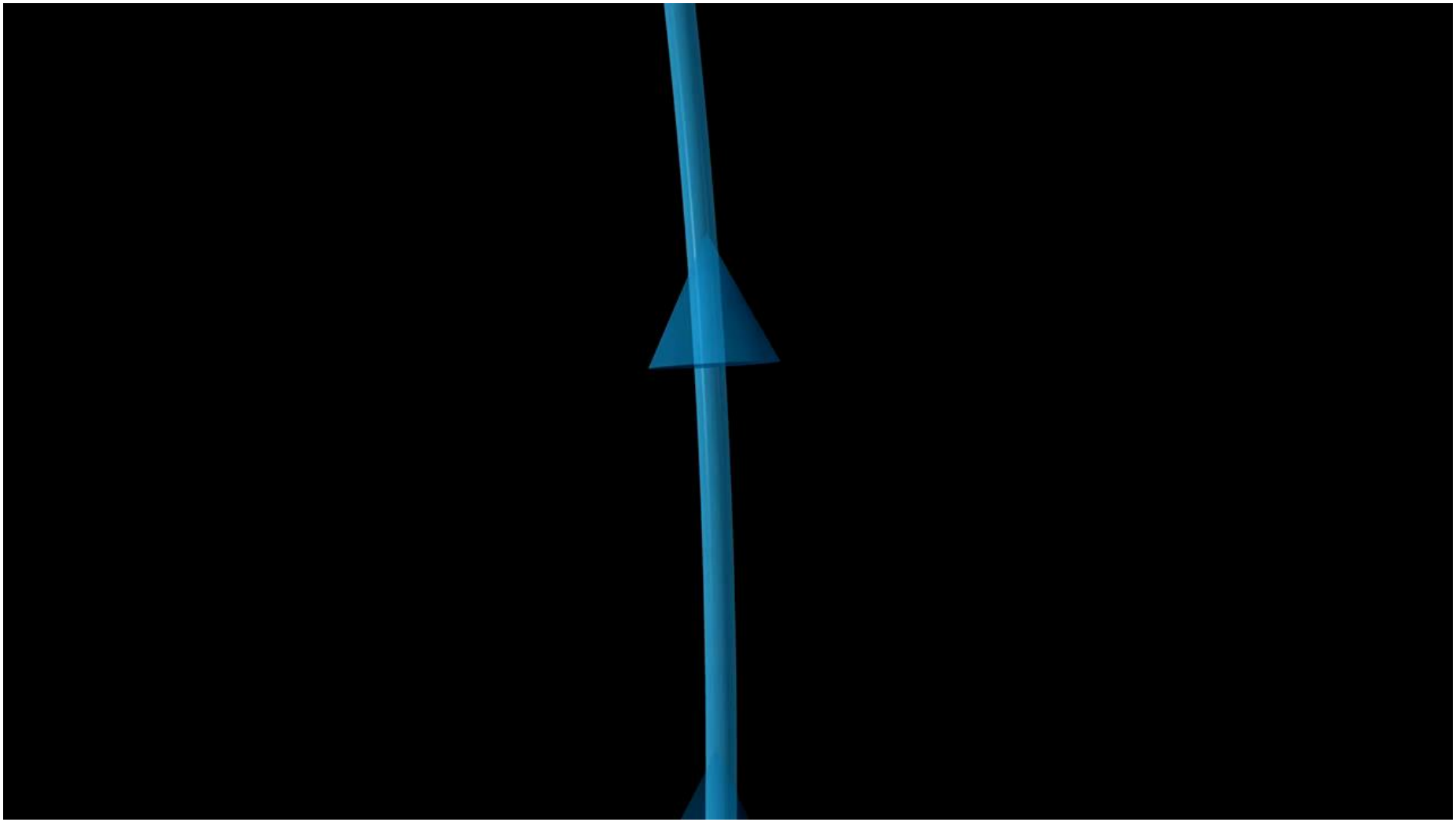
7 November 1957
Sputnik 2


TWENTY-FIVE CENTS
MAY 4, 1959
TIME
E WEEKLY NEWSMAGAZINE
SPACE and the RADIATION BELT
PHYSICIST
JAMES VAN ALLEN
$7.00 A YEAR
VOL. LXXIII NO. 18

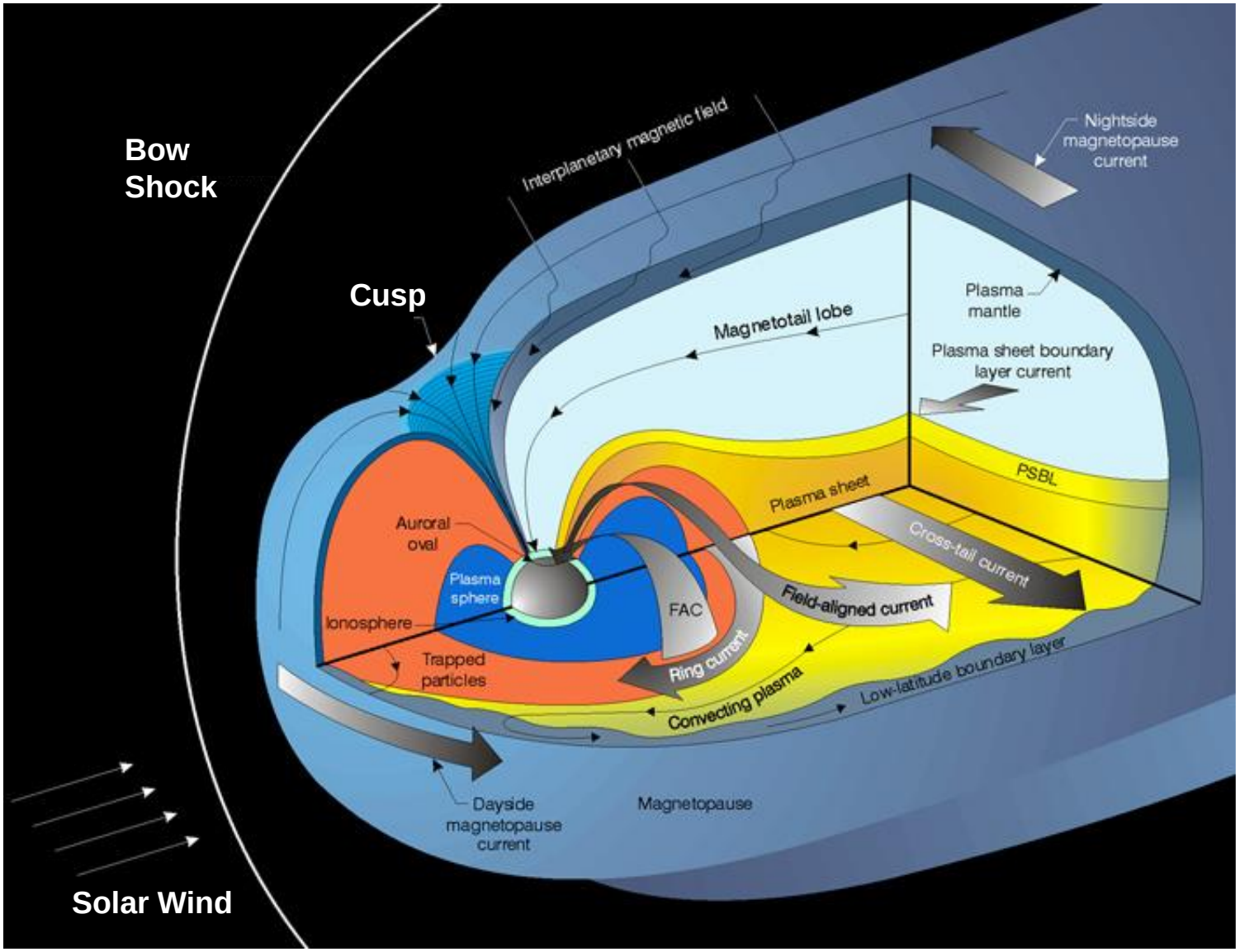
The Van Allen Radiation Belts



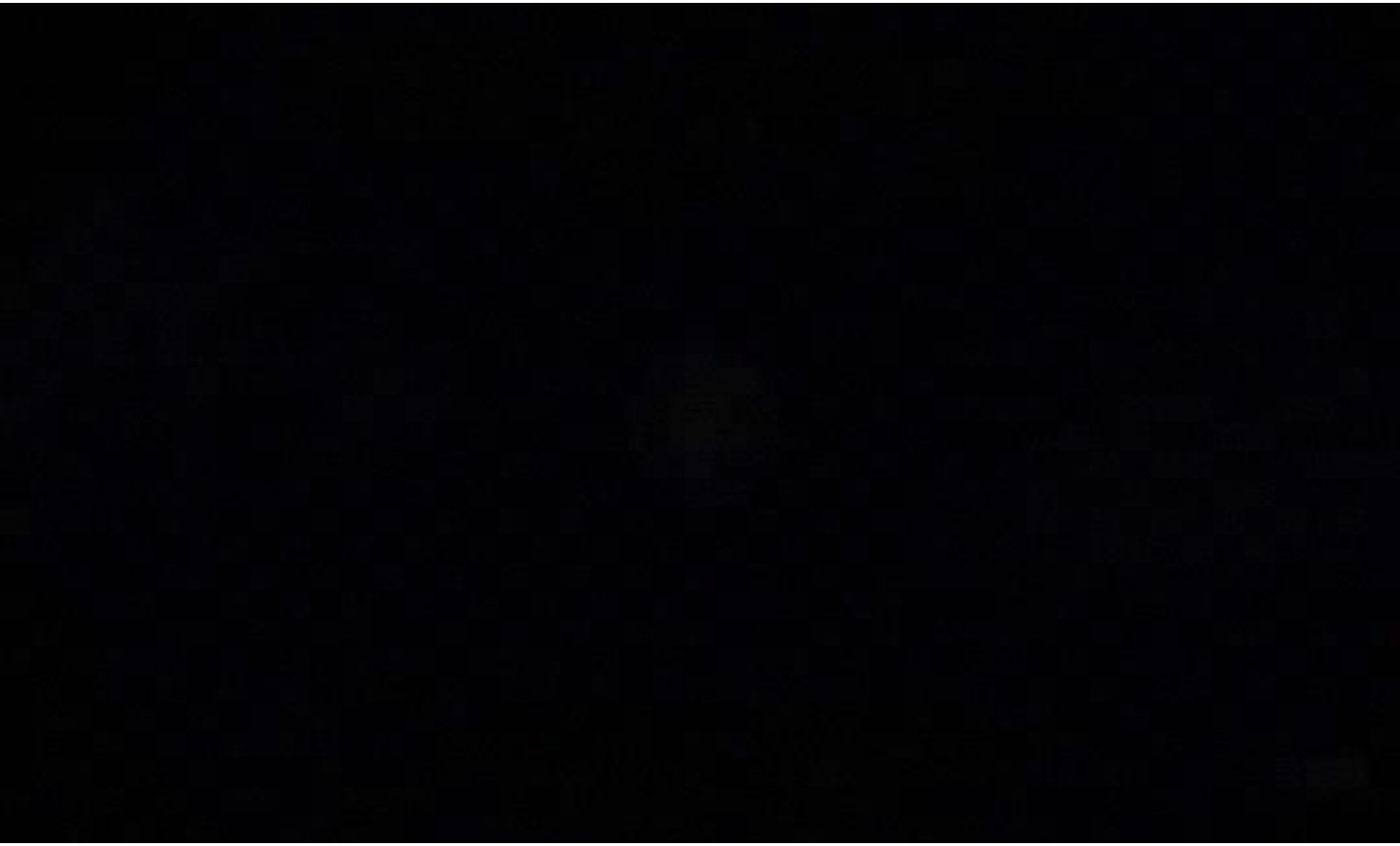
Radiation Belt Particle Motion



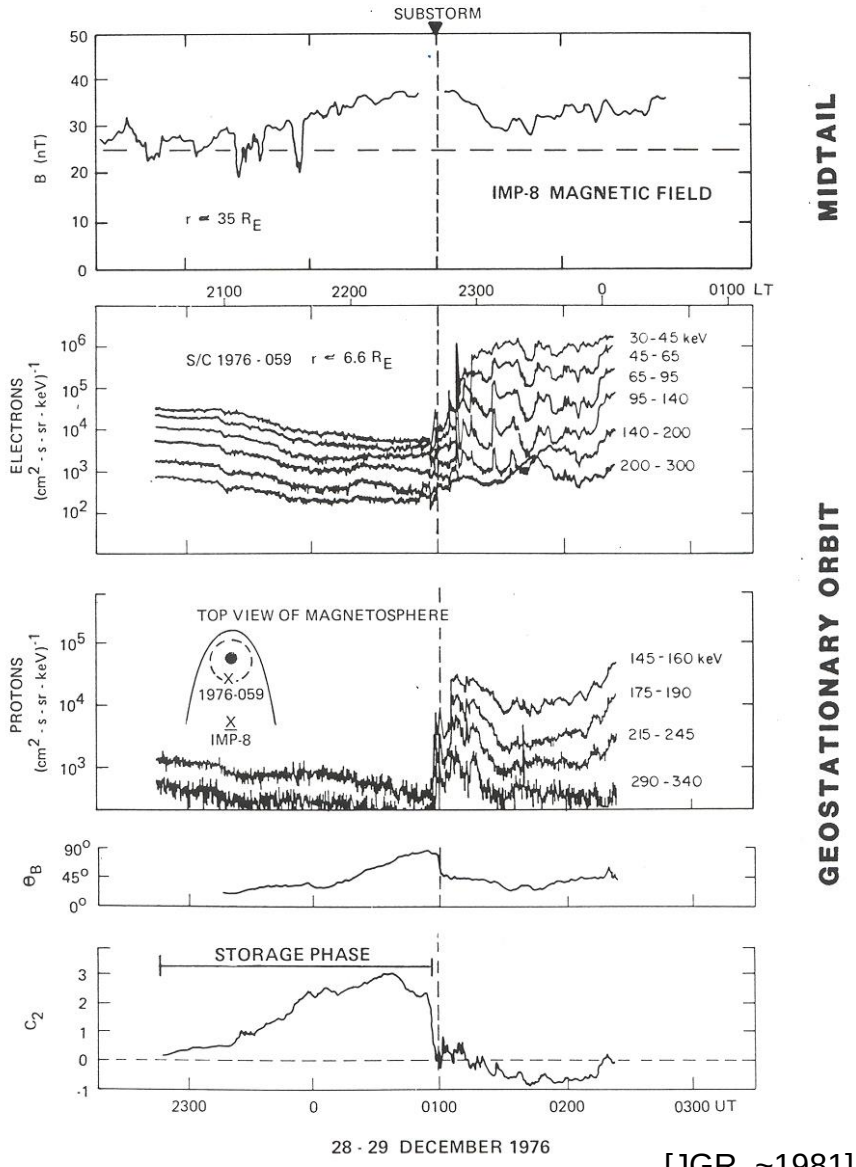
Magnetospheric Regions and Currents



Earth’s Magnetosphere-Ionosphere System



Substorm Particle Injection



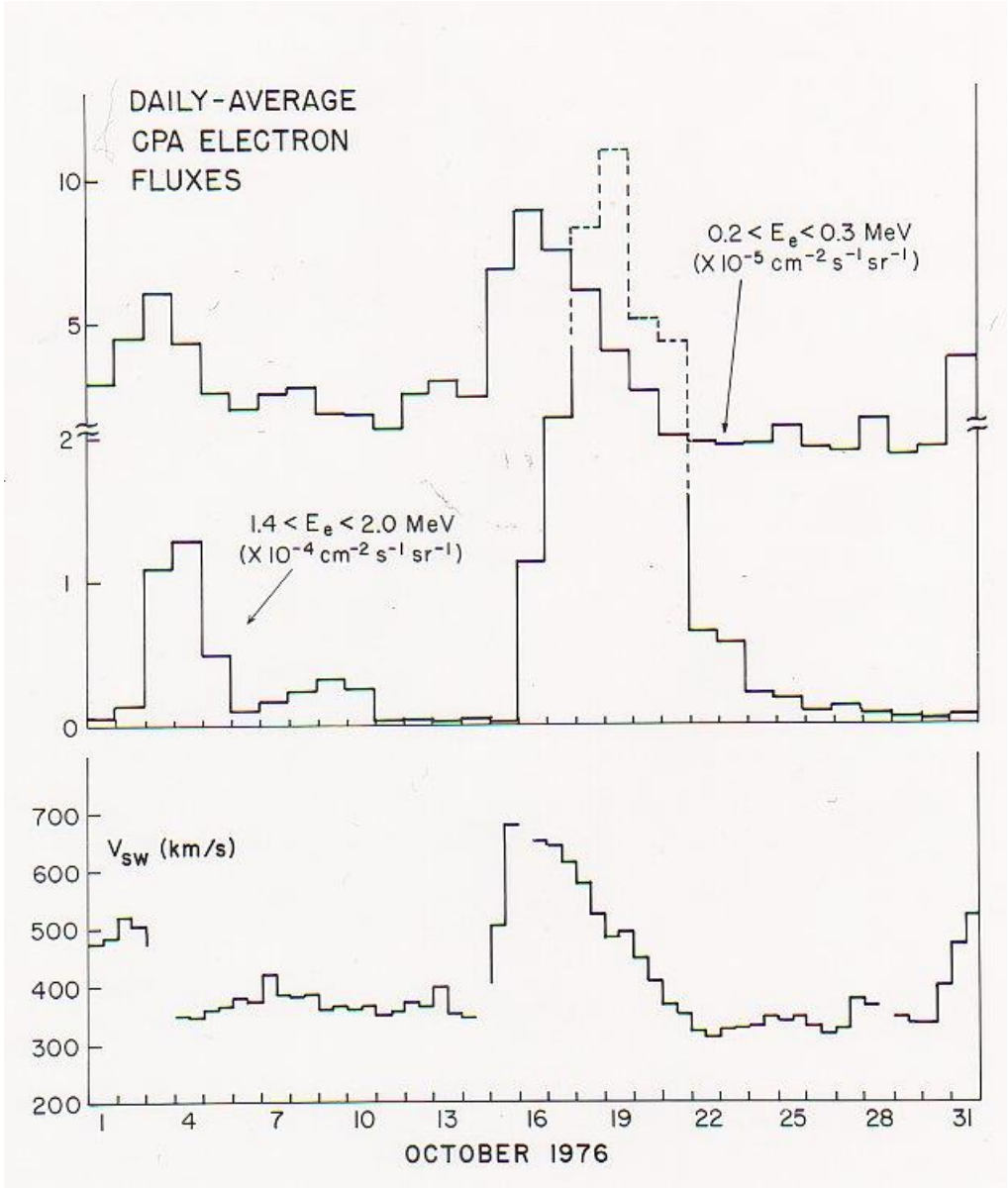
[JGR, ~1981]

Magnetic energy increase in magnetotail (IMP-8)

30 - 300 keV particle enhancements near geostationary orbit (LANL)

Magnetic field "dipolarization" near GEO (plus DAPP/DMSP images!)

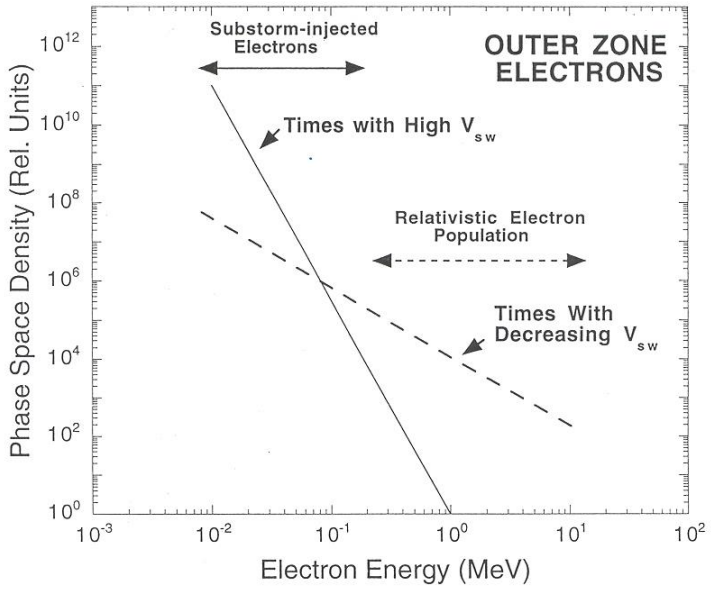
Low- vs. High-Energy Electron Responses



It was found that electrons from E ~ 30 keV to E ~ 300 keV (at geostationary orbit) were closely related to solar wind speed variations.

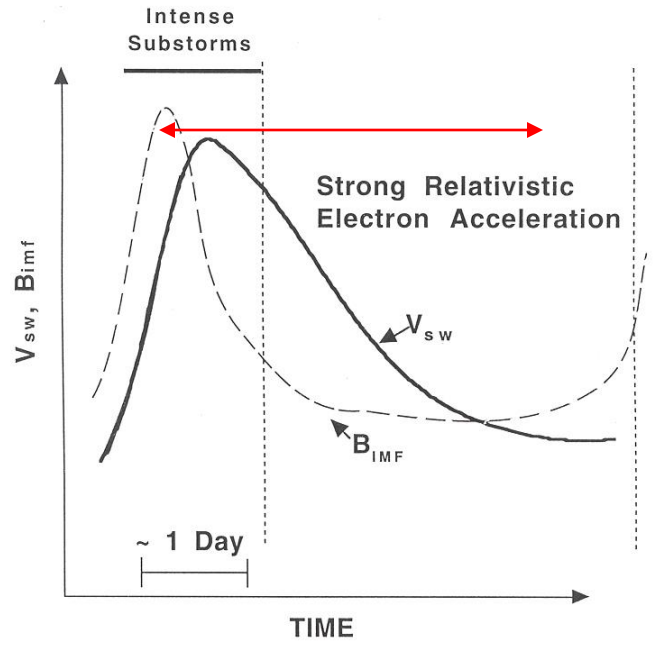
On the other hand, electrons with E > 1 MeV were found to be delayed in relation to solar wind stream profiles.

Baker et al. (JGR)



The Role of High-Speed Solar Wind Streams

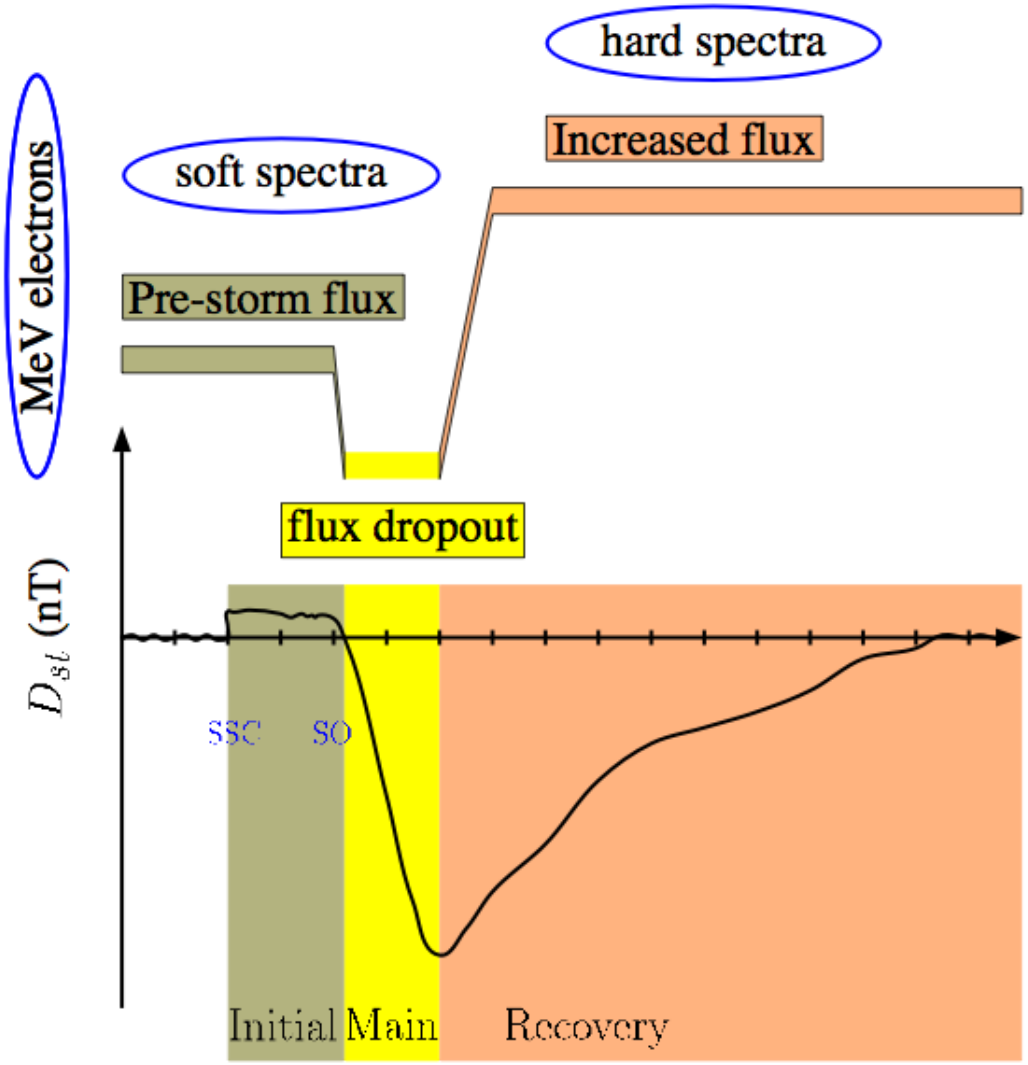
- Prompt substorm acceleration of electrons < 300 keV
- Delayed relativistic electron acceleration (2-3 days)



(GEO)

[Baker et al, 1986;1997]

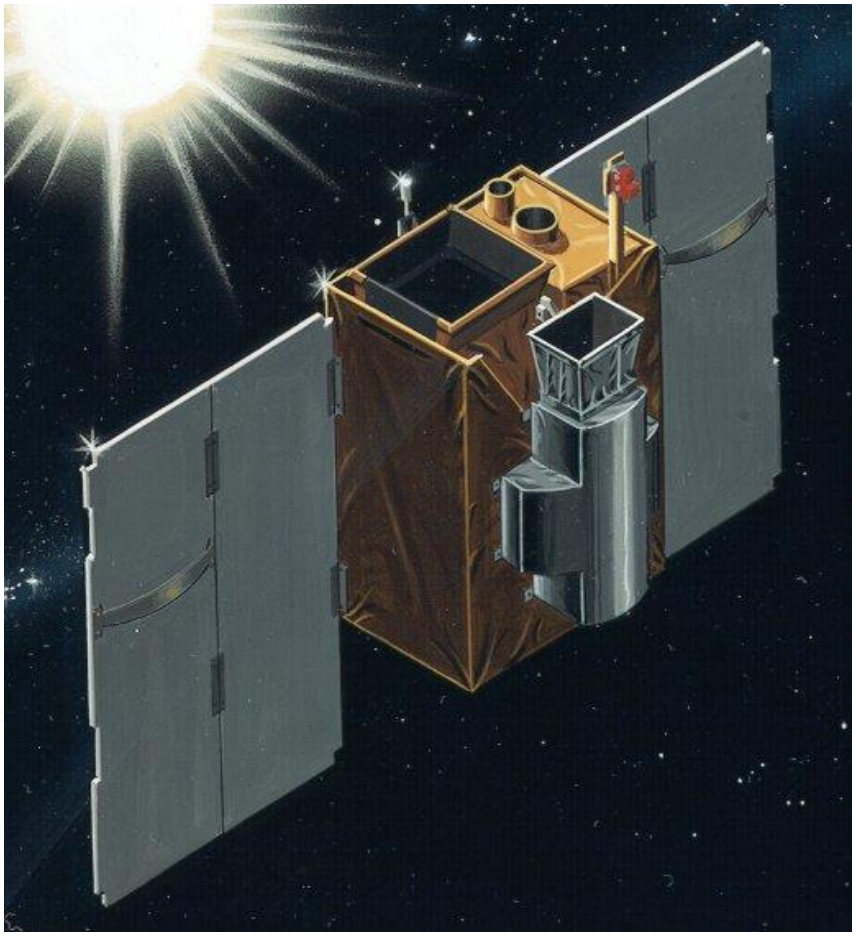
Rad Belt Electrons, Storms and Substorms

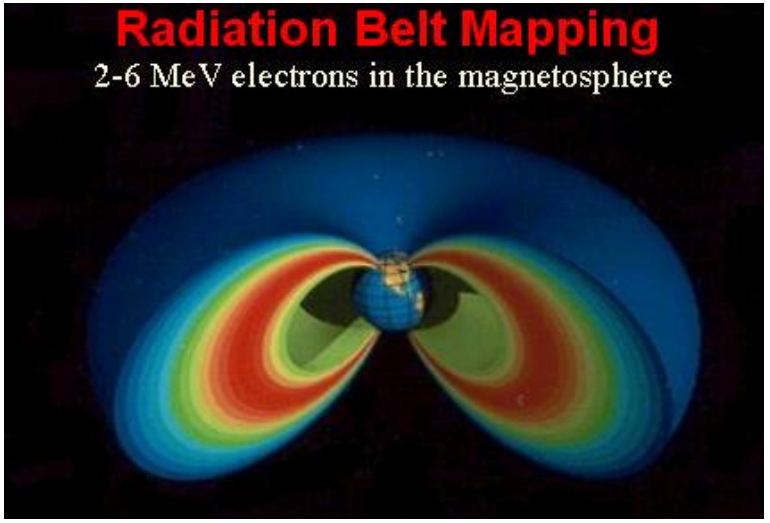


- Recovery phase
  - Increased PSD
  - Broad L range
- Main phase
  - Flux dropout
  - Adiabatic field changes and particle loss
- Flux changes
  - Decrease or no change in about 50% of storms - GEO data

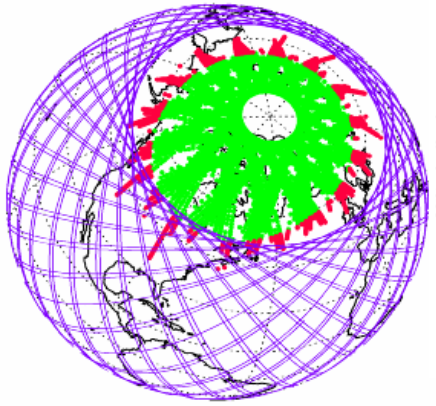
[See Kanekal et al., 2004; Reeves et al., 2003]

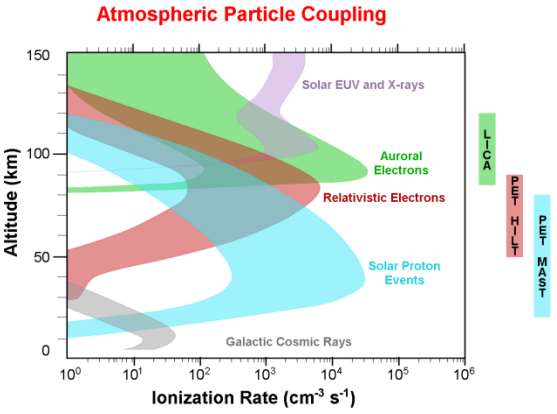
The Solar, Anomalous, and Magnetospheric Particle Explorer: SAMPEX



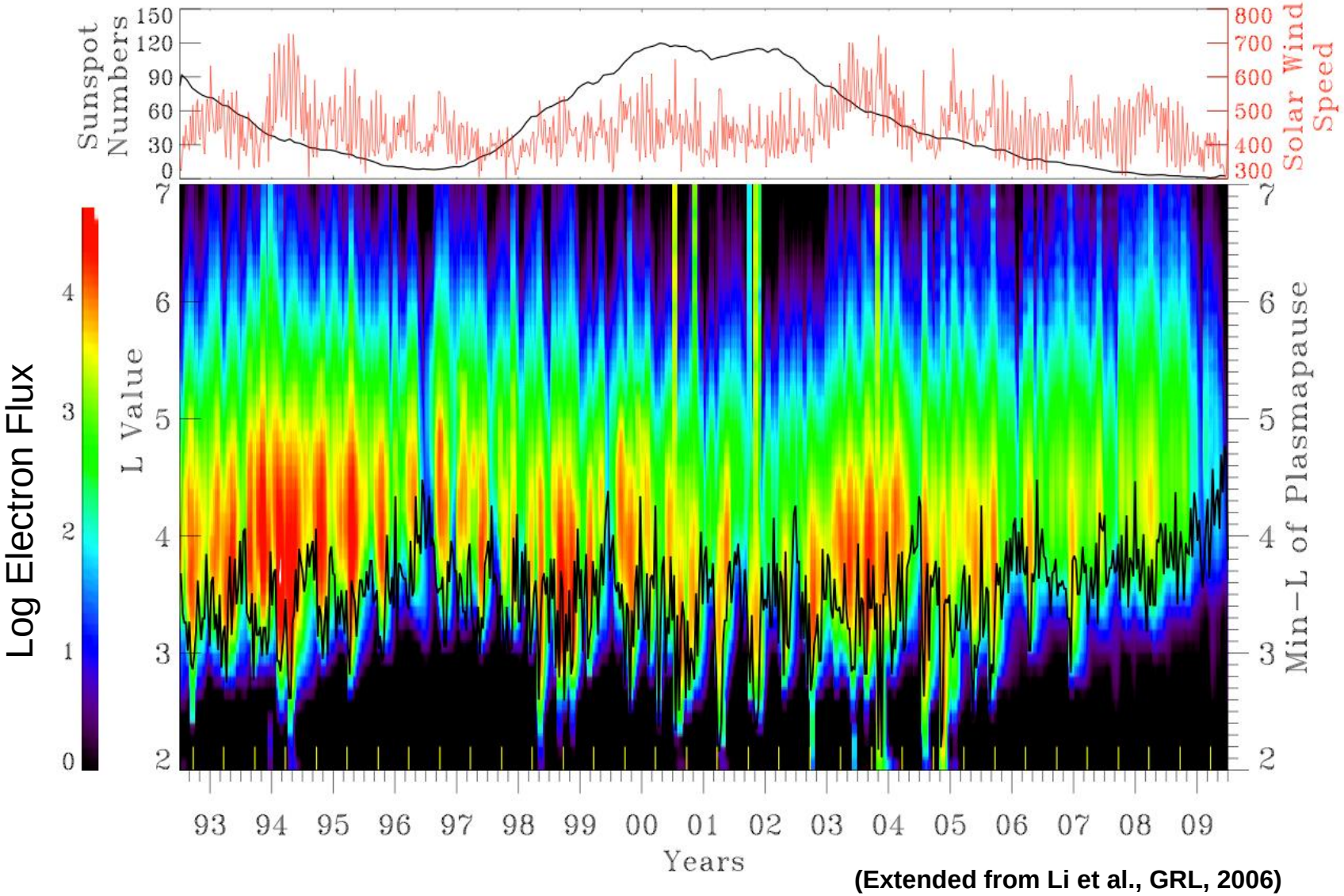


Solar Energetic Particles



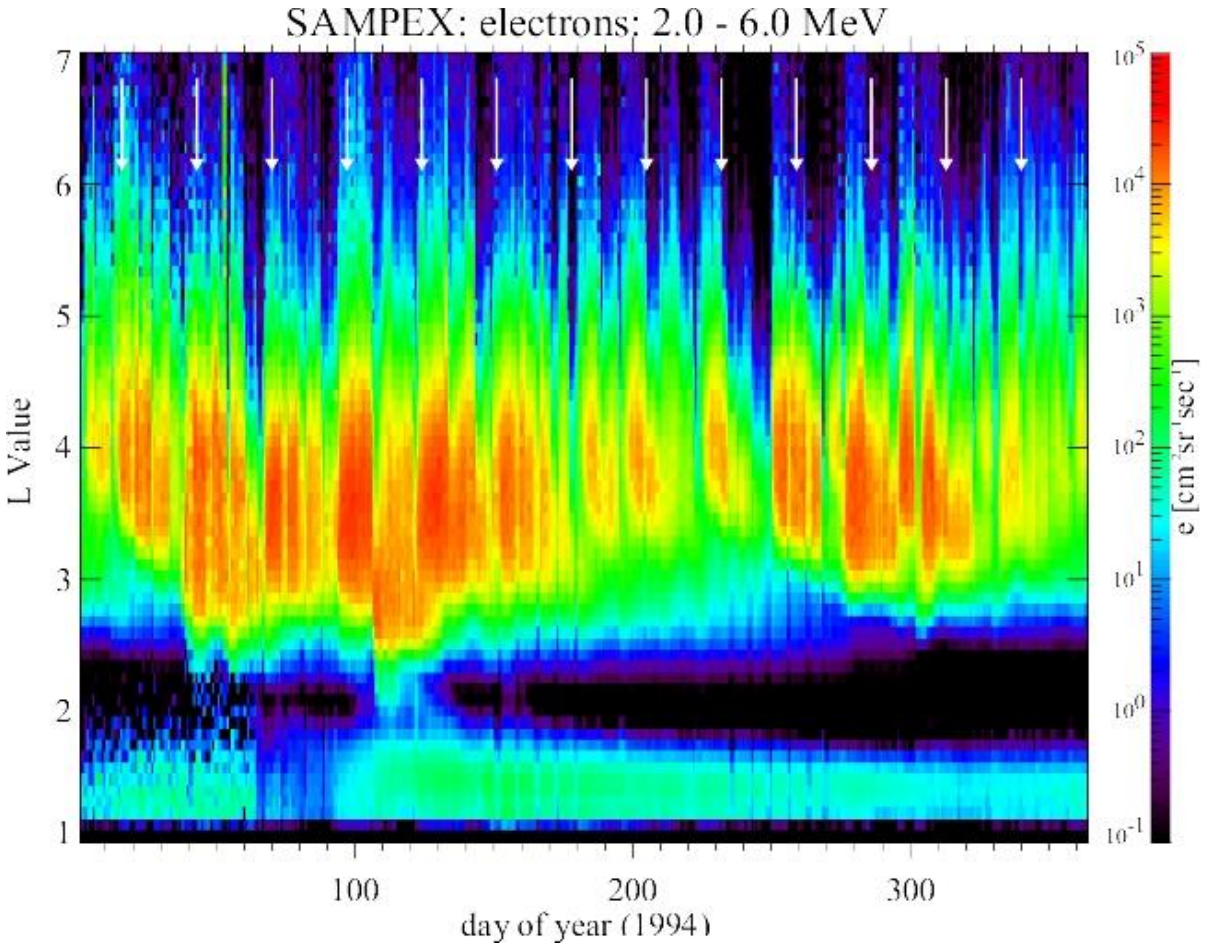


SAMPEX: Nearly Two Solar Cycles



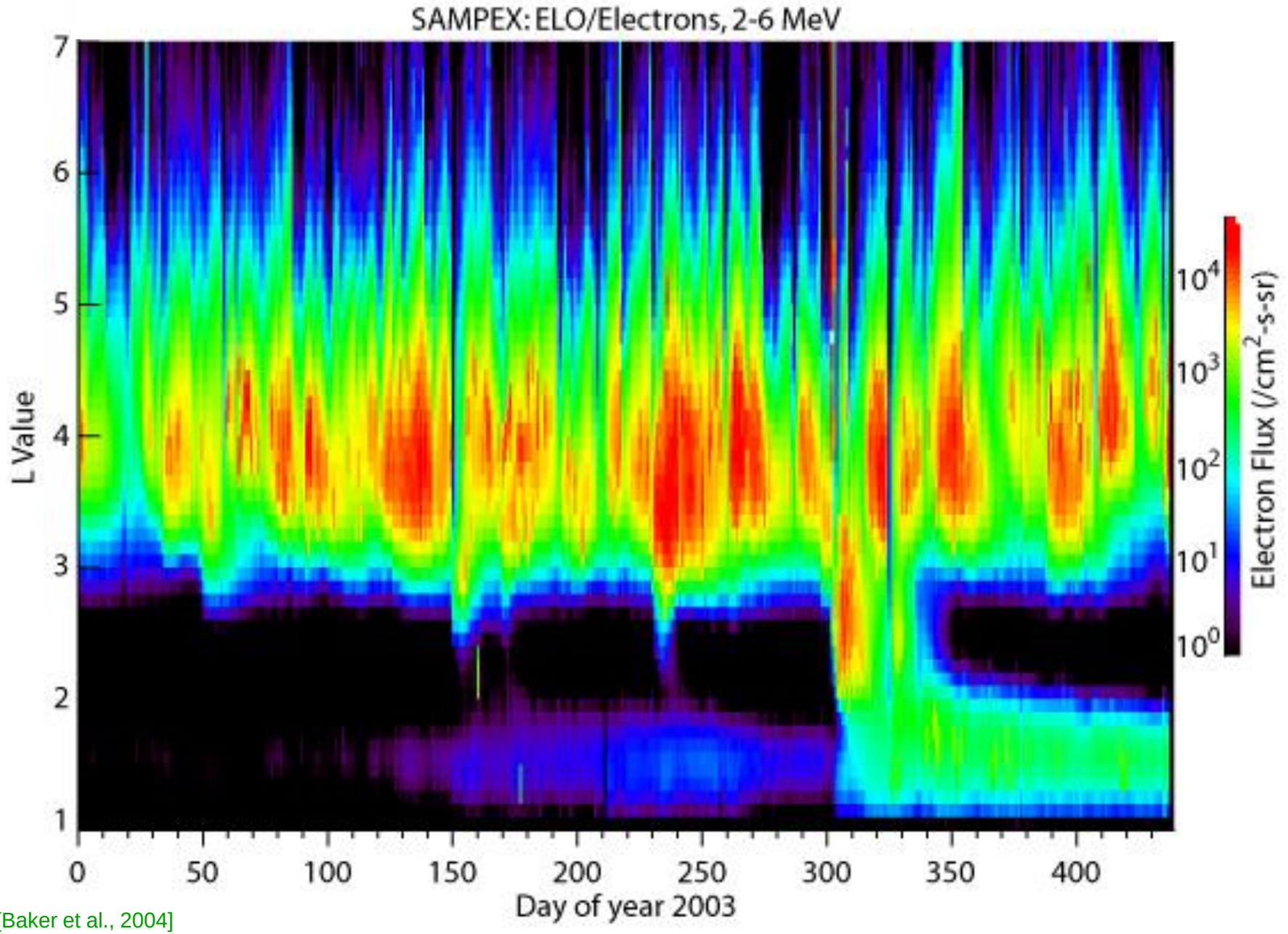
(Extended from Li et al., GRL, 2006)

1994 – High Speed Stream Control



Strong electron acceleration in the approach to sunspot minimum

White arrows indicate 27-day recurrent events: High-speed solar wind streams

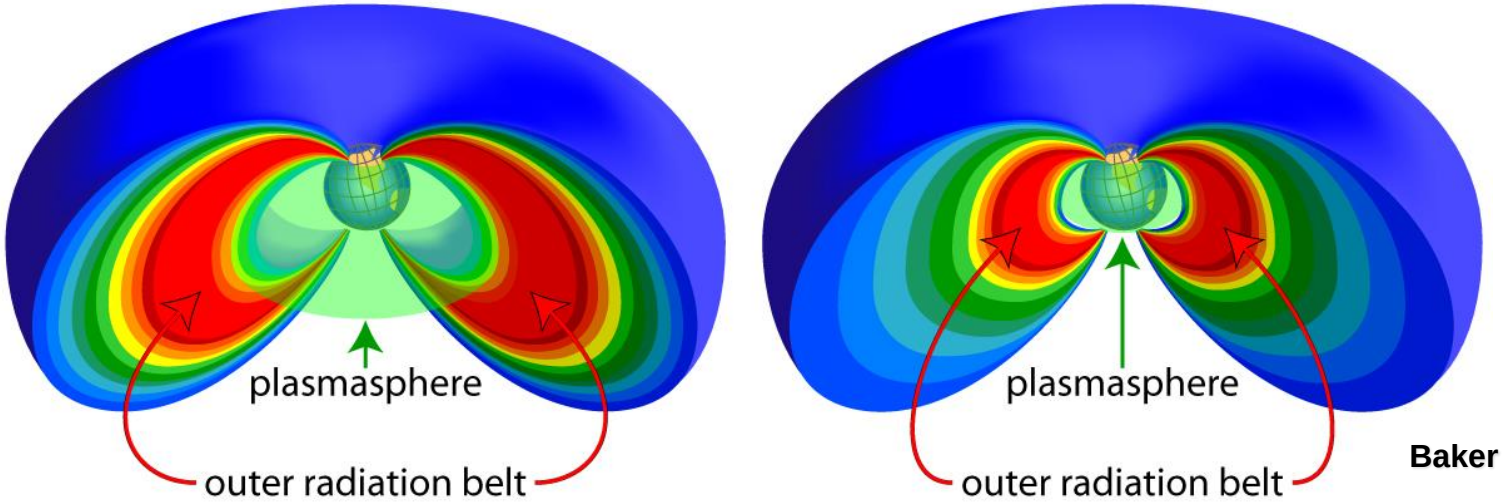


[Baker et al., 2004]

“Halloween” Storms

a. Normal plasmasphere/radiation belt location under typical conditions

b. Distorted plasmasphere/radiation belt during October/November 2003 storm



SAMPEX Particle Mapping

Baker et al.,[Nature, 2004]

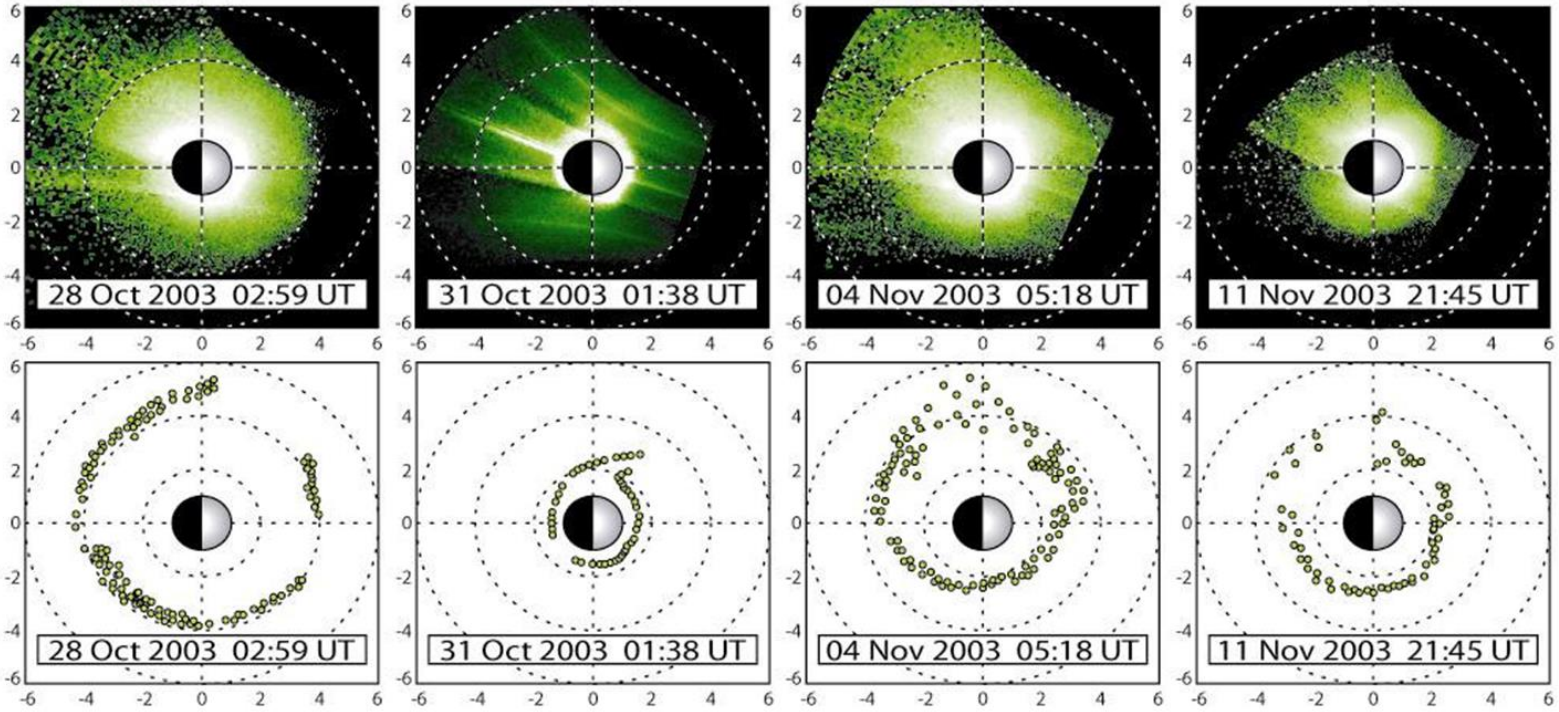
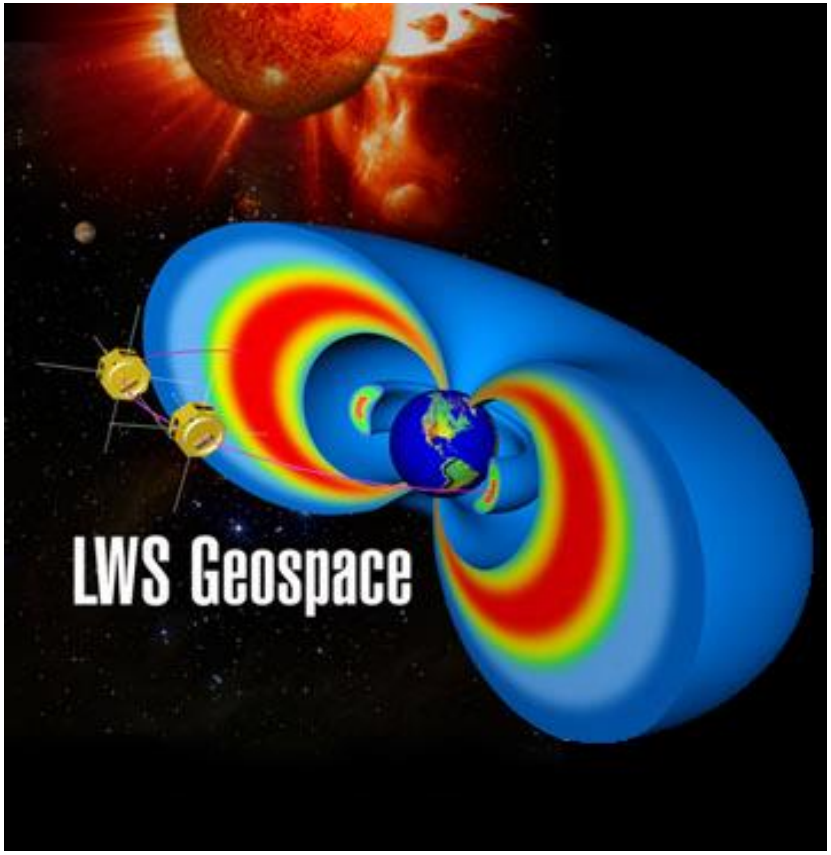


IMAGE EUV Data

RBSP Science Definition Report



Radiation Belt Storm Probes (RBSP) constellation

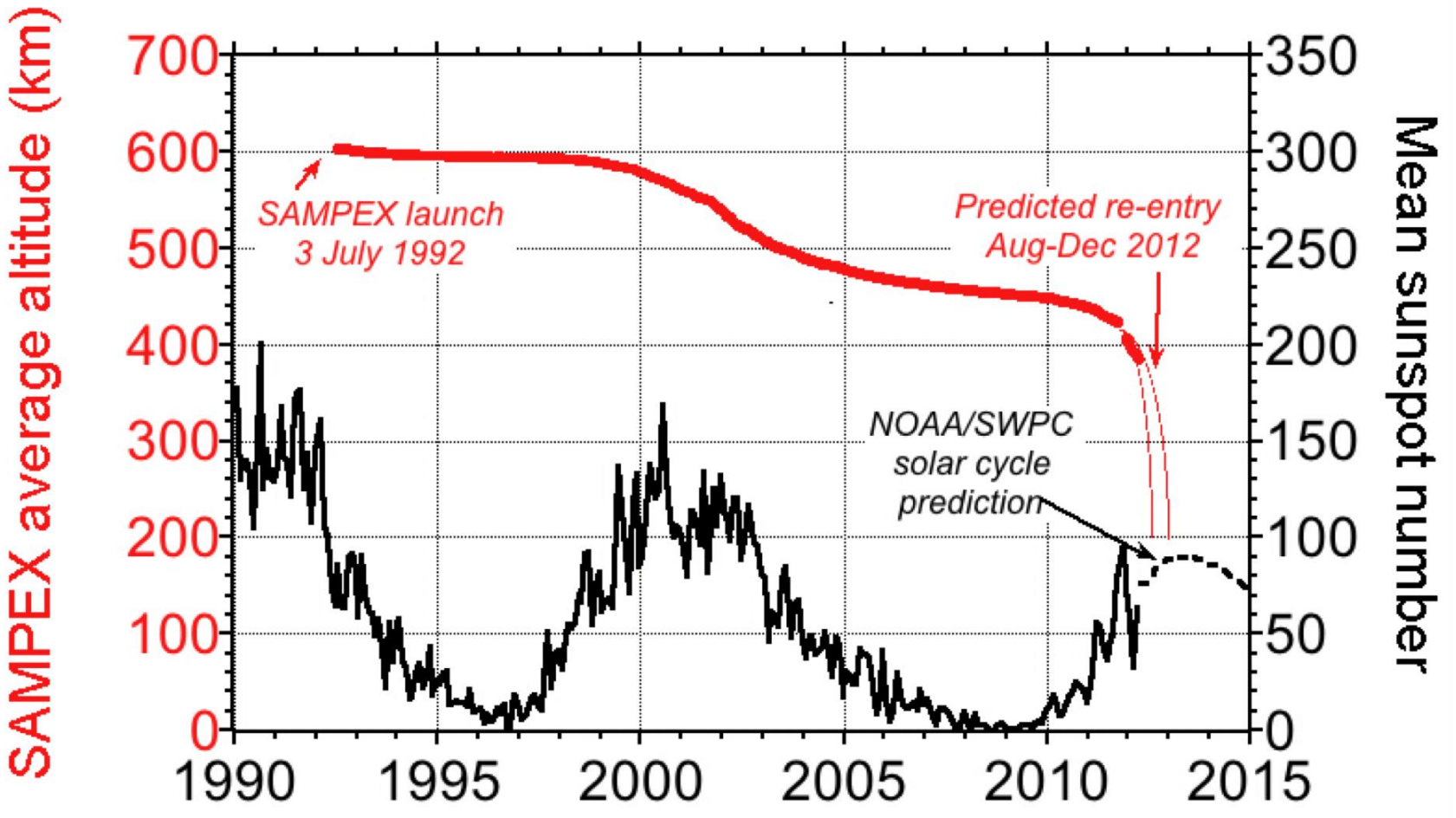
Mission Objectives:

1. Differentiate among competing processes affecting the acceleration and loss of radiation belt electrons;
2. Understand the creation and decay of new radiation belts;
3. Quantify the relative contribution of adiabatic and nonadiabatic processes;
4. Understand the role of “seed” or source populations; and
5. Develop and validate specification models of the radiation belts.

RBSP addresses the scientific and programmatic goals of the NASA Living With a Star program.

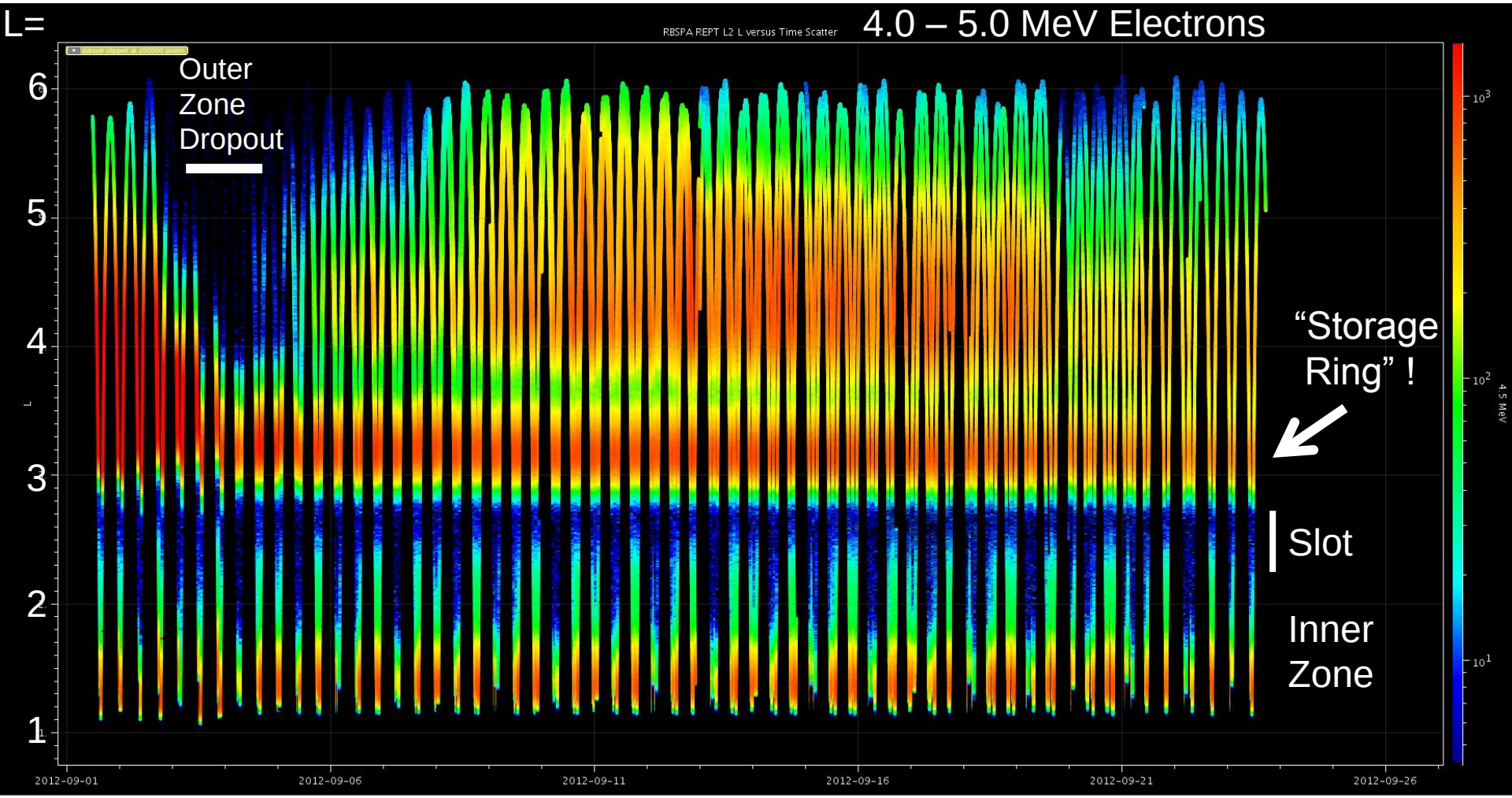
RBSP Launch—30 August 2012

Demise of SAMPEX



Re-entry on 13 November 2012

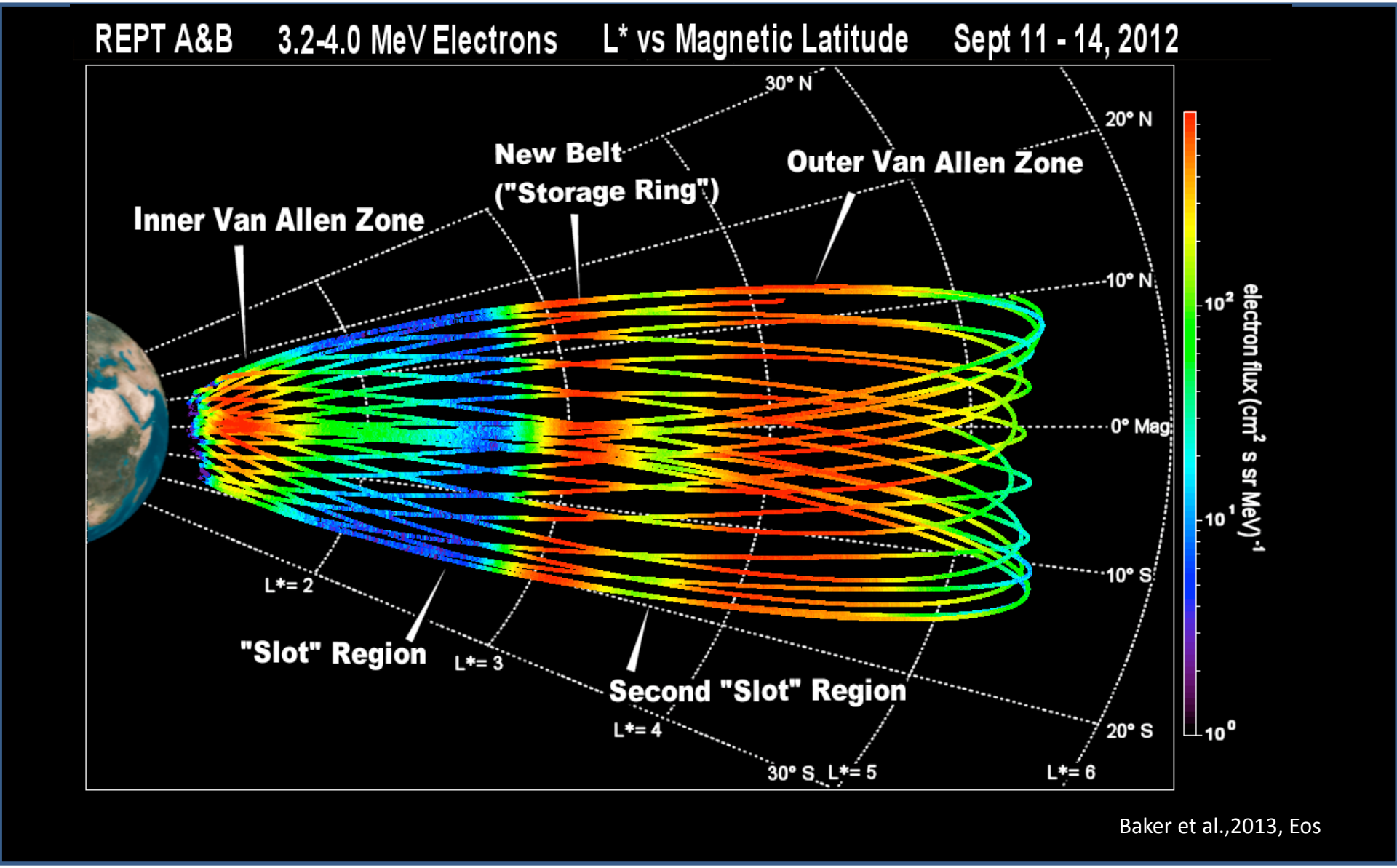
Radiation Belt Storm Probes—REPT A & REPT B



1 Sept. 6 Sept 11 Sept 16 Sept 21 Sept 26 Sept

2012

REPT Observations of “Storage Ring”



Baker et al.,2013, Eos

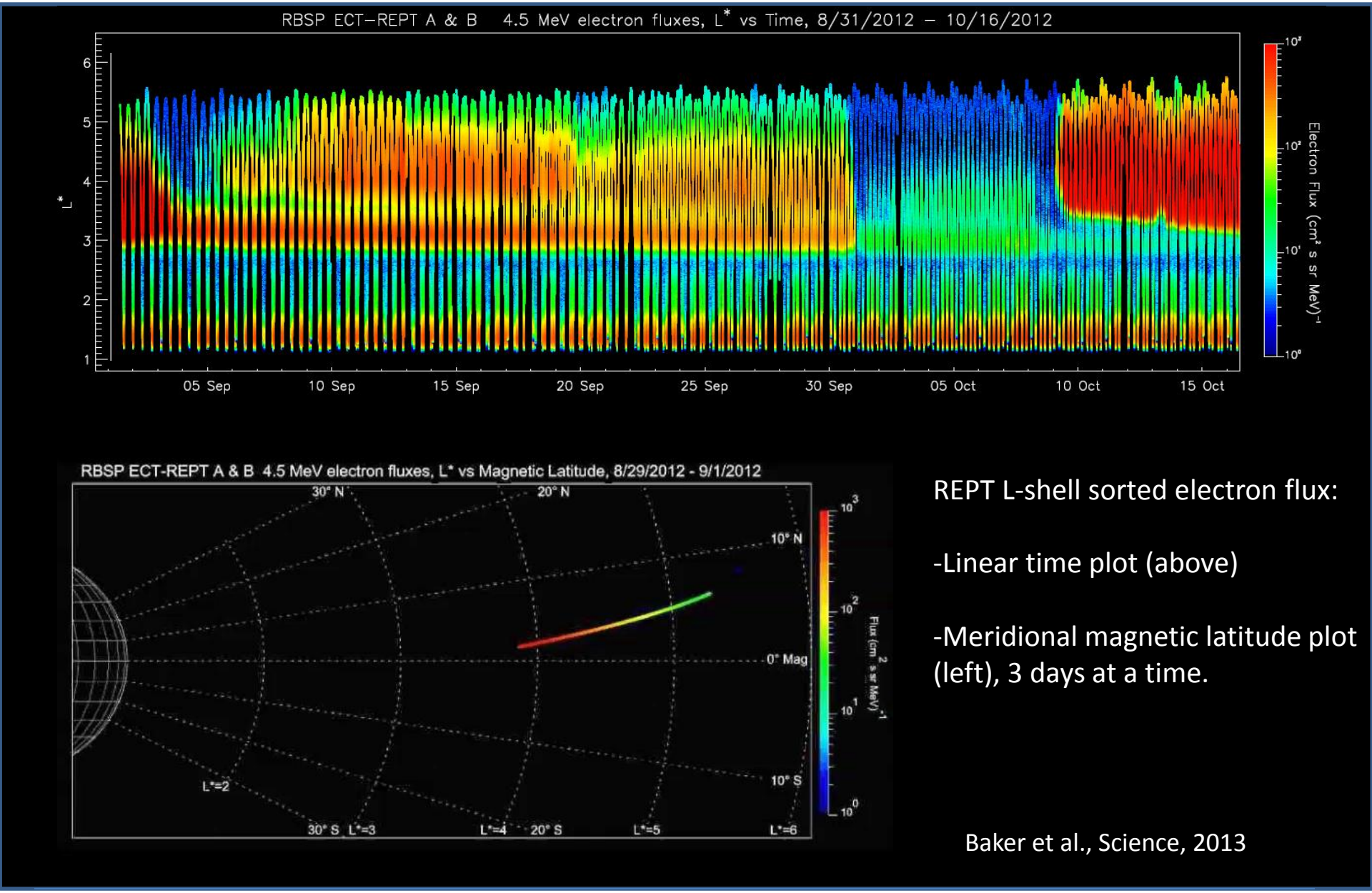
Unexpected Radiation Belt Results

Science Express Online
28 February 2013

Science *Issue*
12 April 2013

Baker et al., 2013

Radiation Belt Evolution



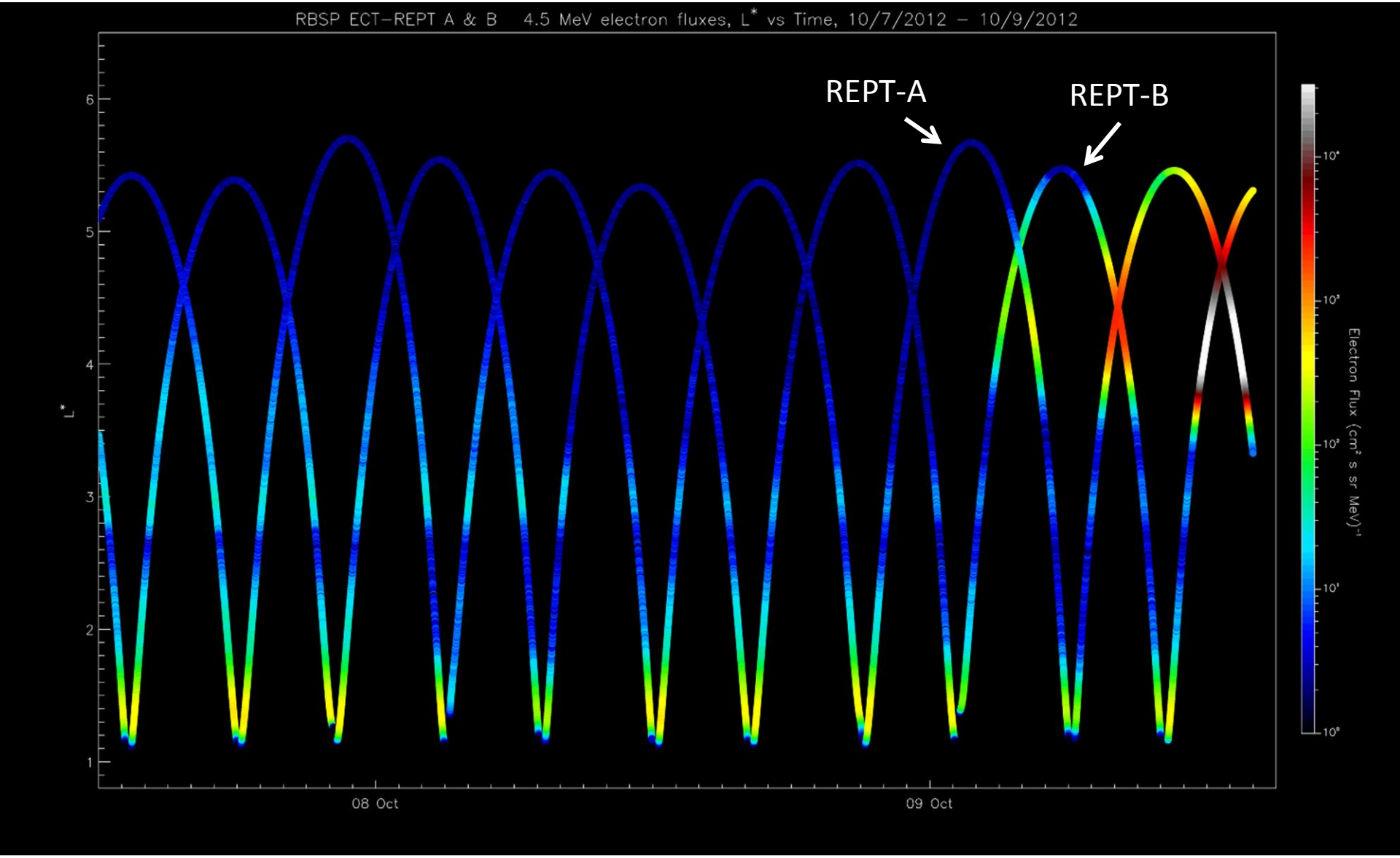
REPT L-shell sorted electron flux:

-Linear time plot (above)

-Meridional magnetic latitude plot (left), 3 days at a time.

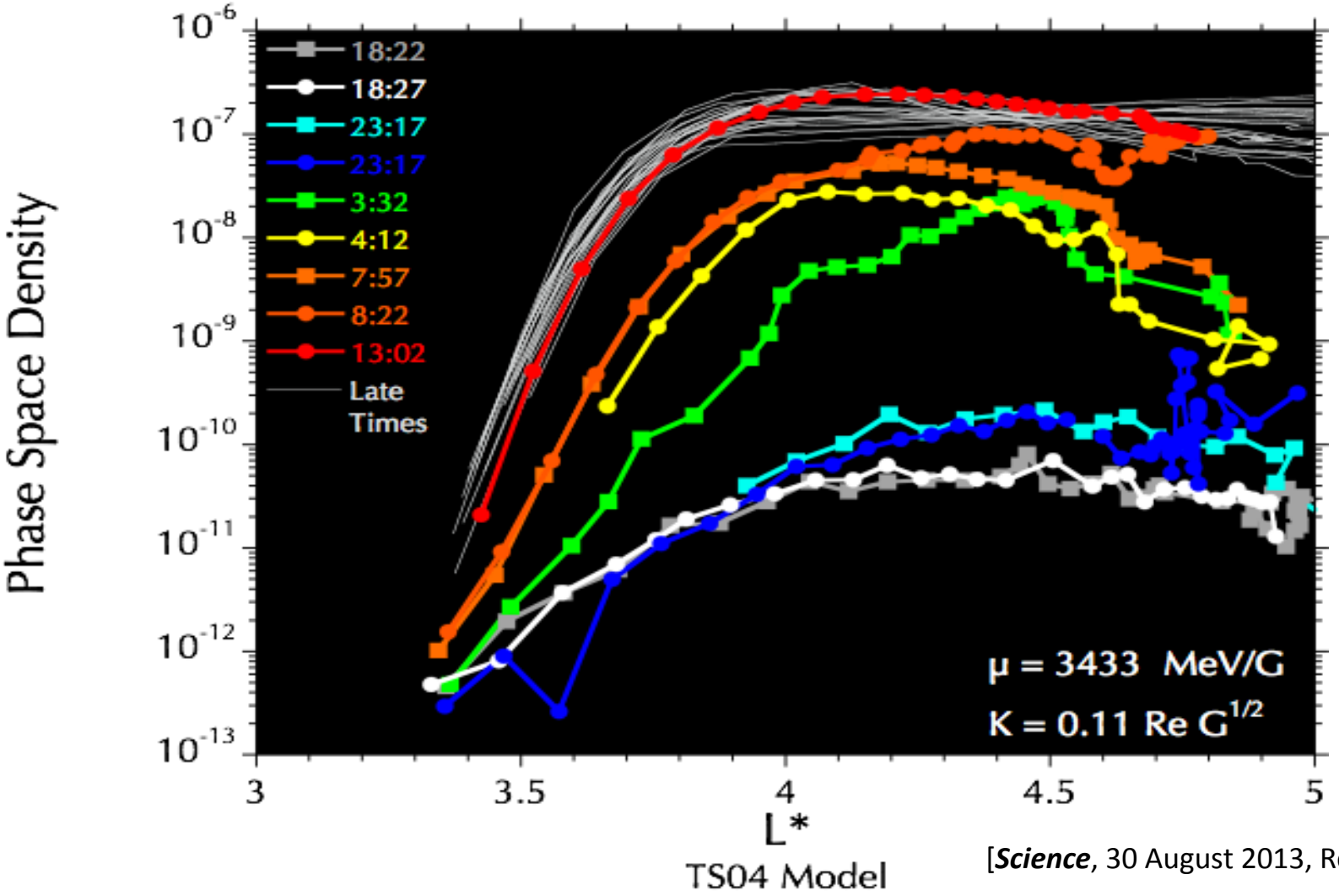
Baker et al., Science, 2013

October 2012: Anatomy of a Storm Onset

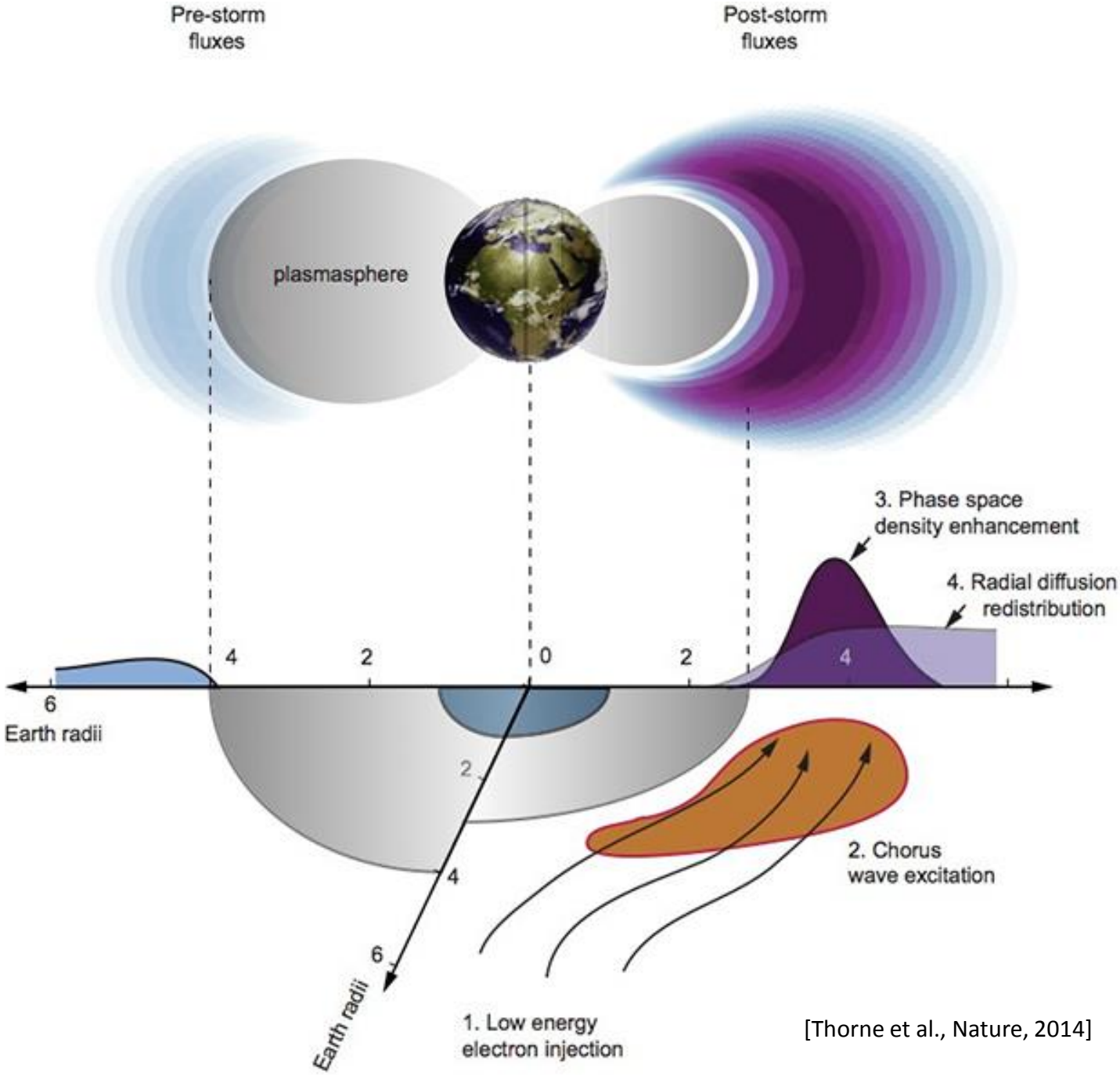


REPT-based Phase Space Density (PSD)

8-9 October 2012



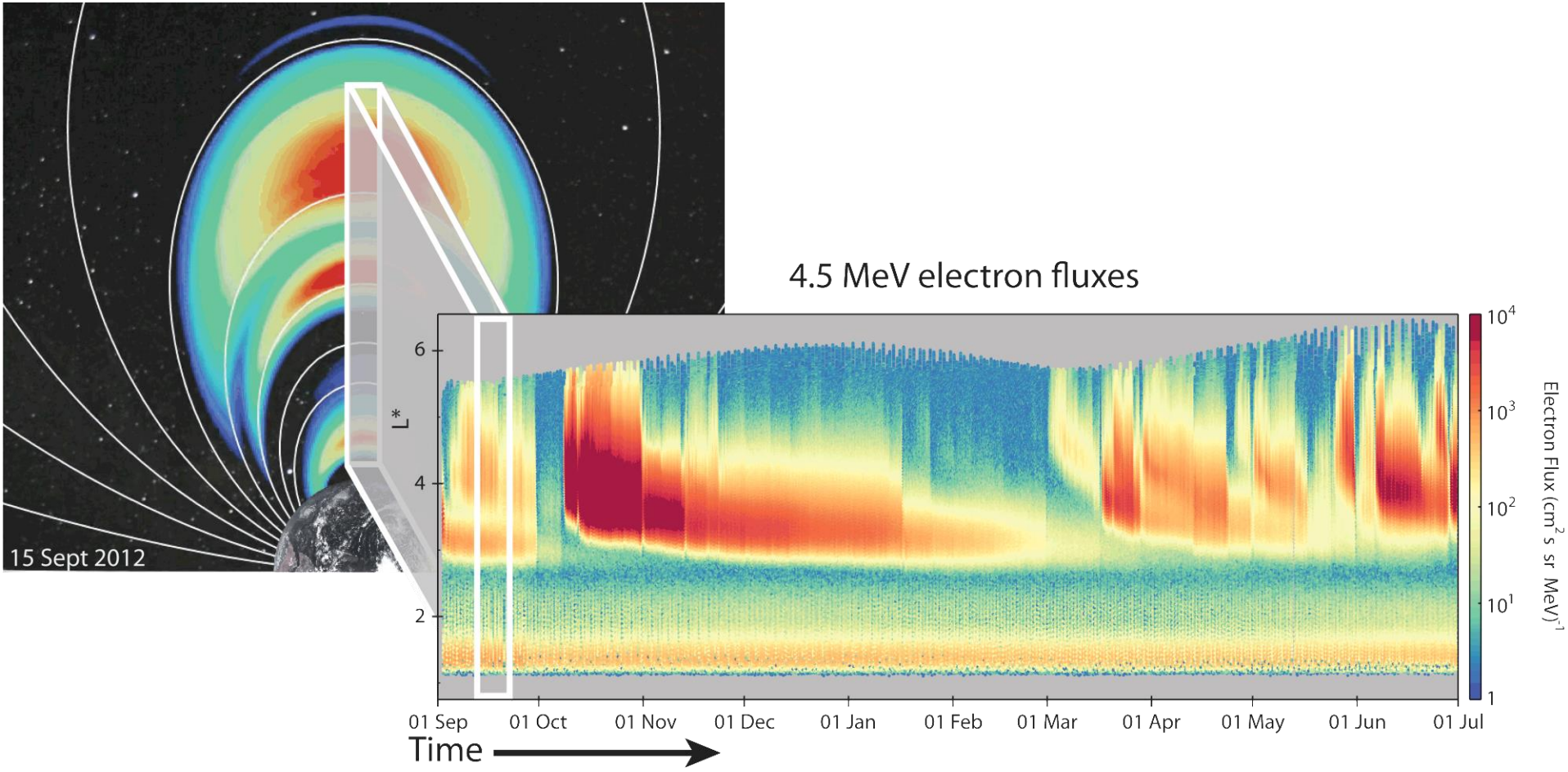
[***Science***, 30 August 2013, Reeves et al.]



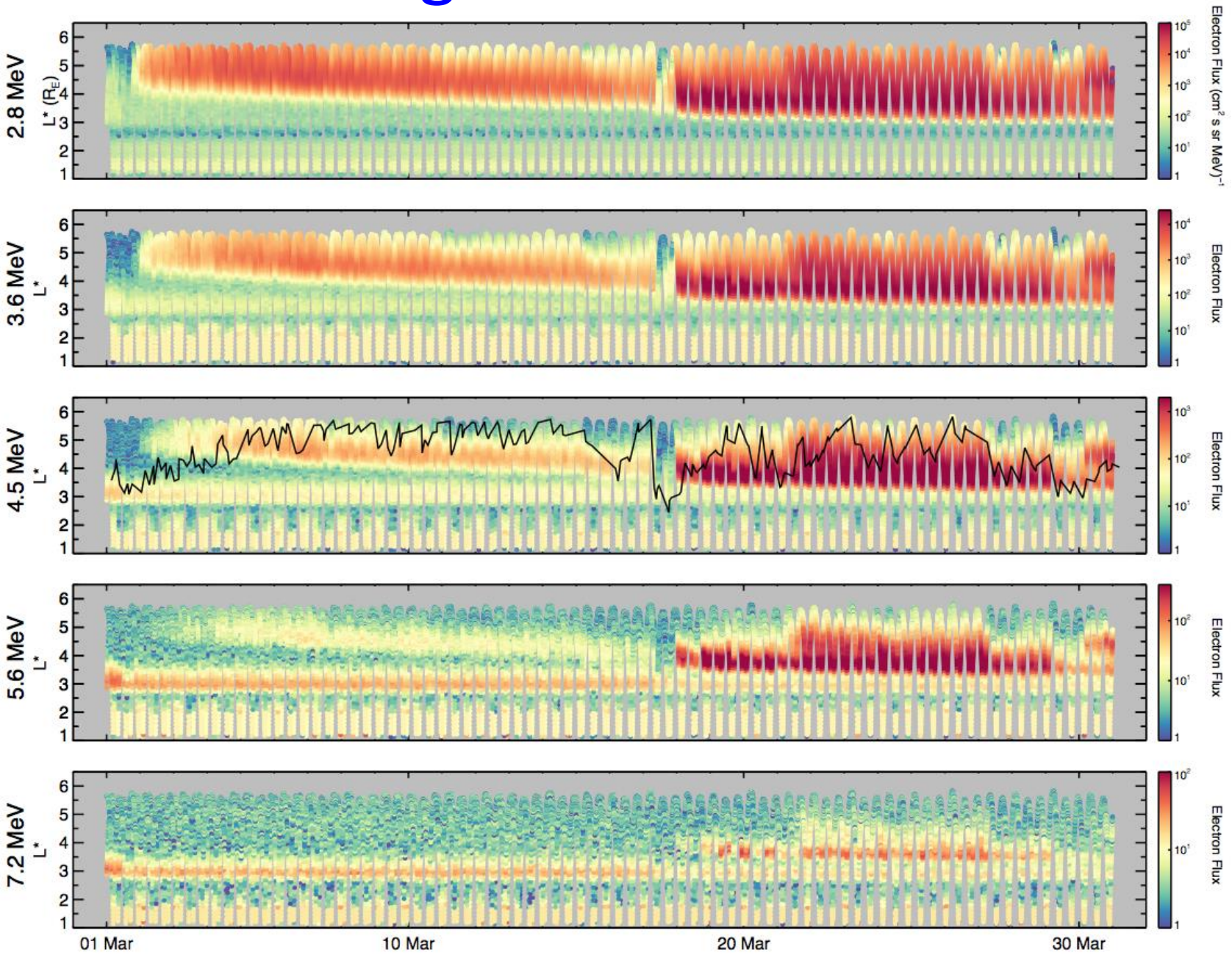
[Thorne et al., Nature, 2014]

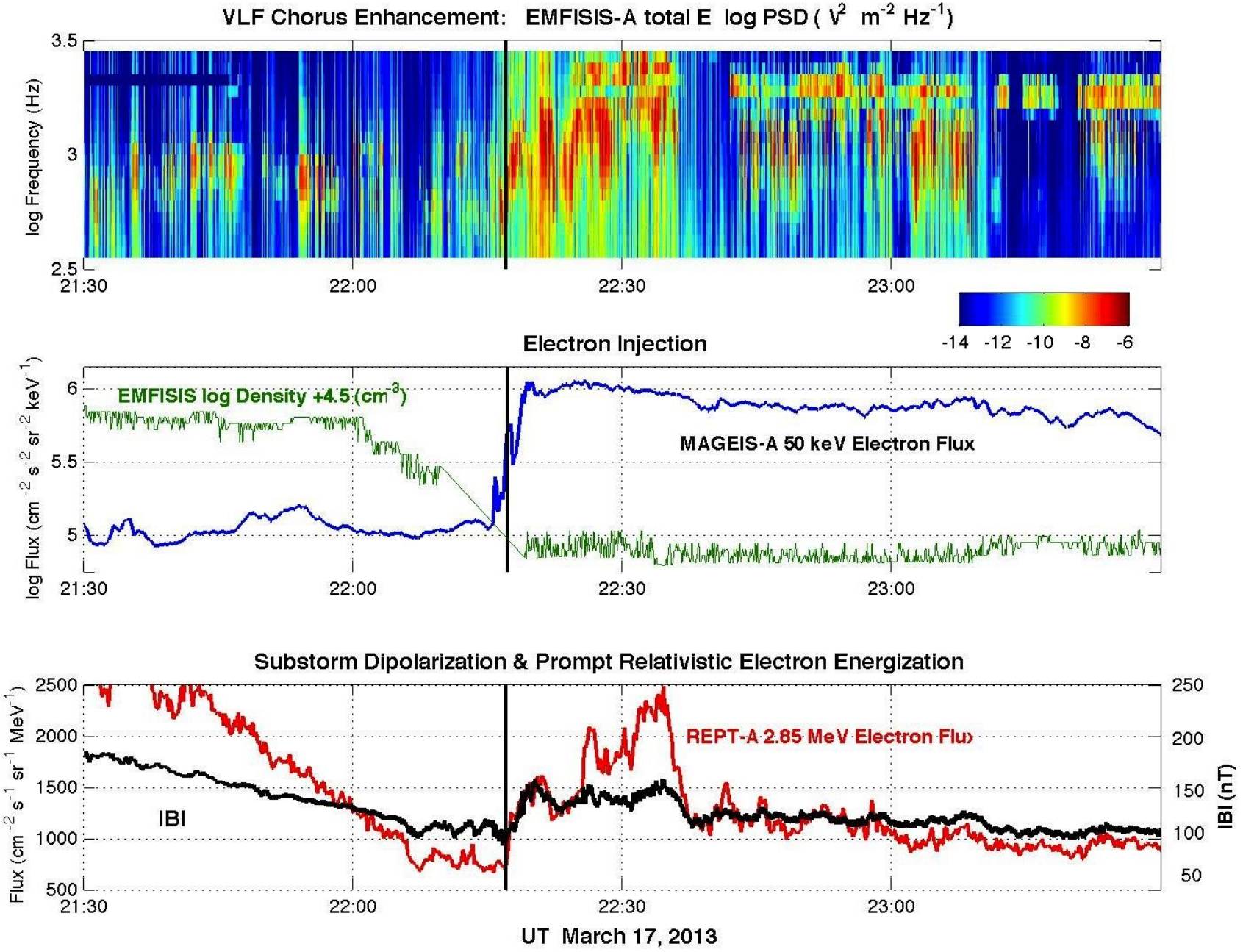
Ultra-Relativistic Electron Observations:

Acceleration, Remanence, and Sudden Loss

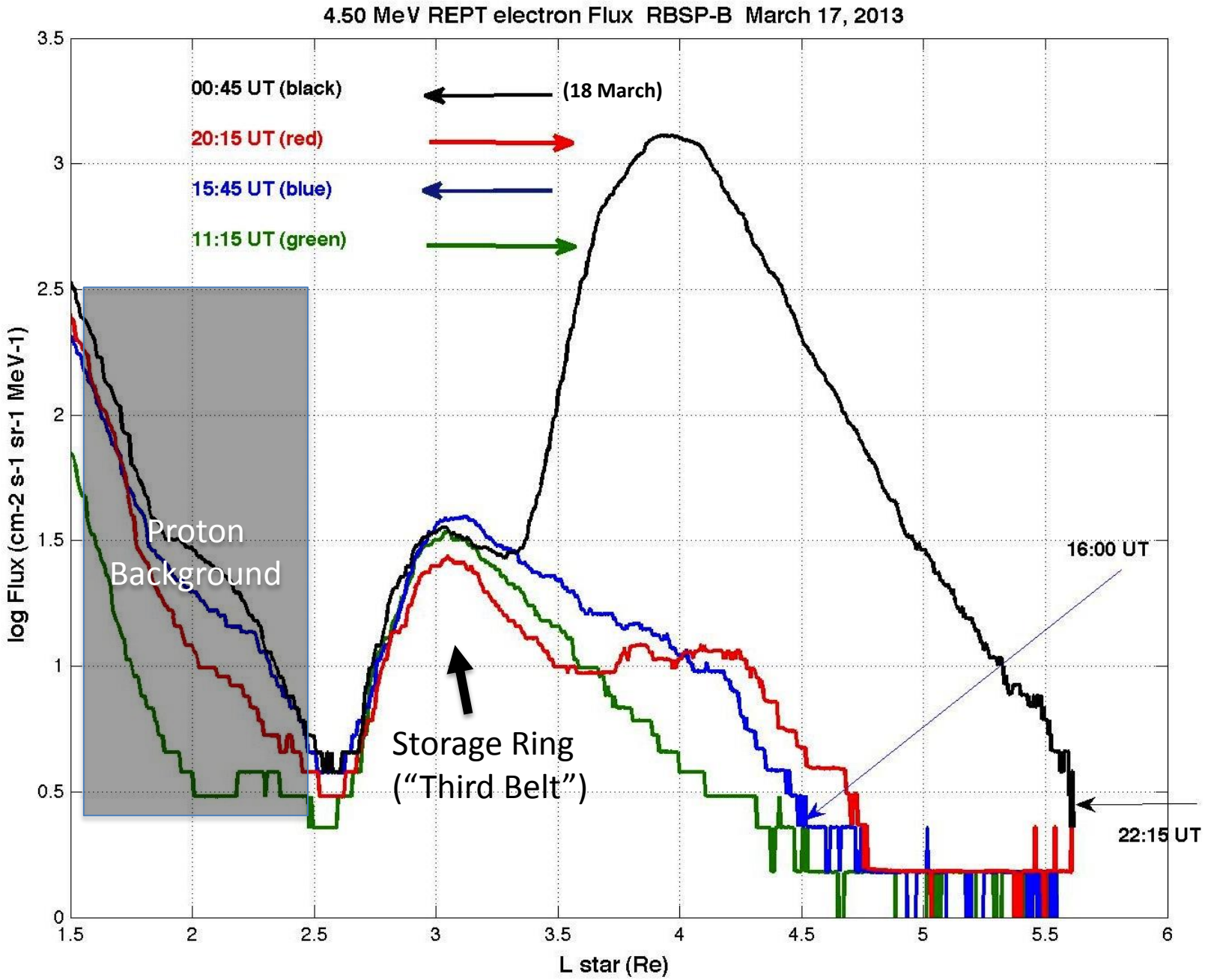


Fascinating Period: March 2013

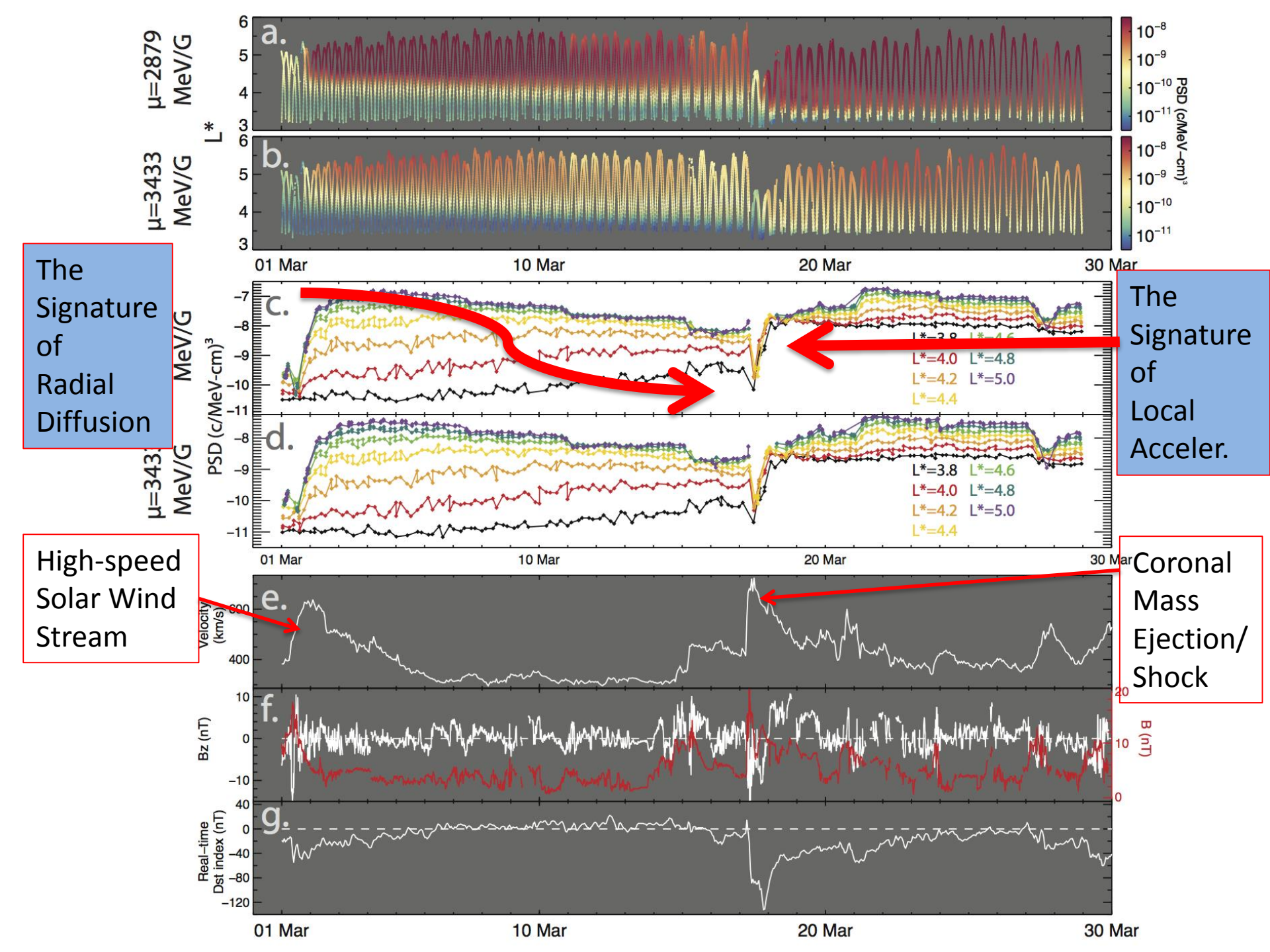




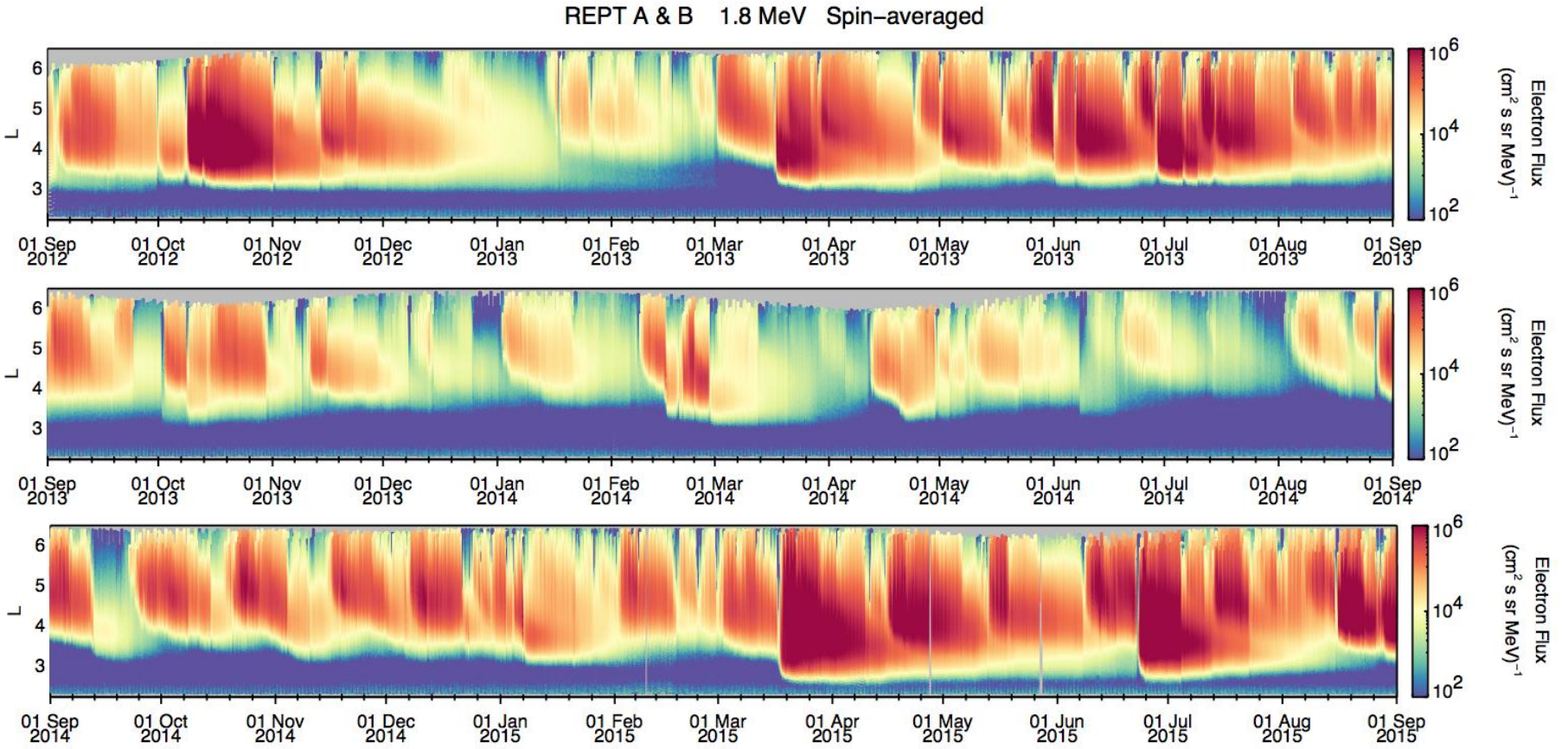
[Foster et al., GRL, 2014]



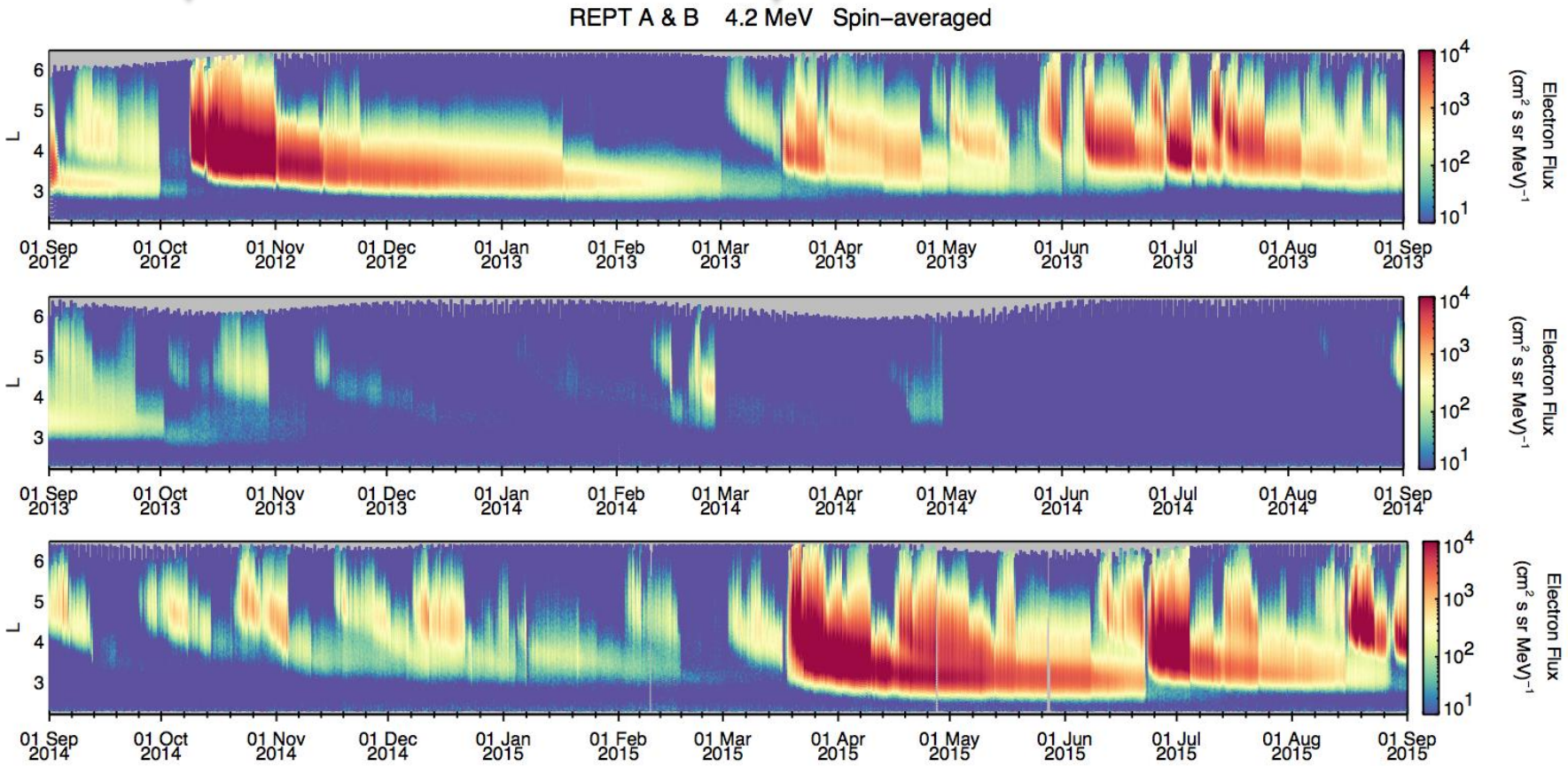
Foster et al. [2014]


The Signature of Radial Diffusion
The Signature of Local Acceler.
High-speed Solar Wind Stream
Coronal Mass Ejection/ Shock
a.
b.
c.
d.
e.
f.
g.
μ=2879 MeV/G
μ=3433 MeV/G
L*
PSD (c/MeV-cm)³
Velocity (km/s)
Bz (nT)
B (nT)
Real-time Dst index (nT)
L*=3.8
L*=4.0
L*=4.2
L*=4.4
L*=4.6
L*=4.8
L*=5.0
01 Mar
10 Mar
20 Mar
30 Mar

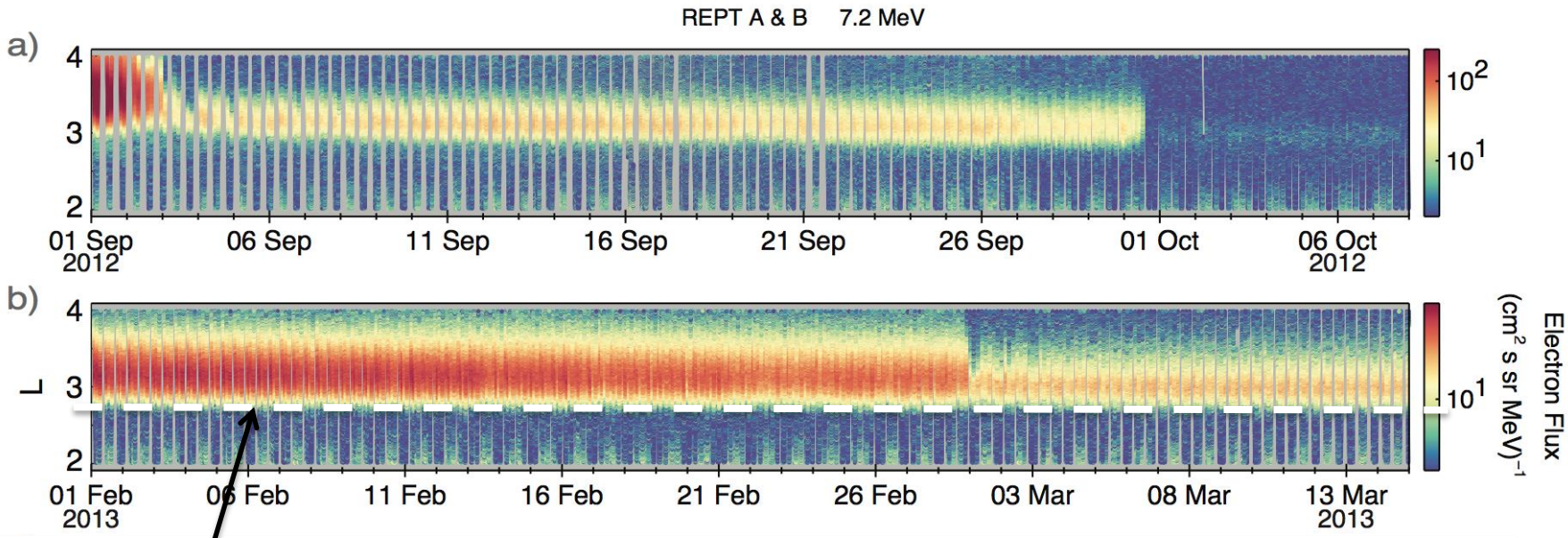
Van Allen Probes – 3 Years



Van Allen Probes – 3 Years

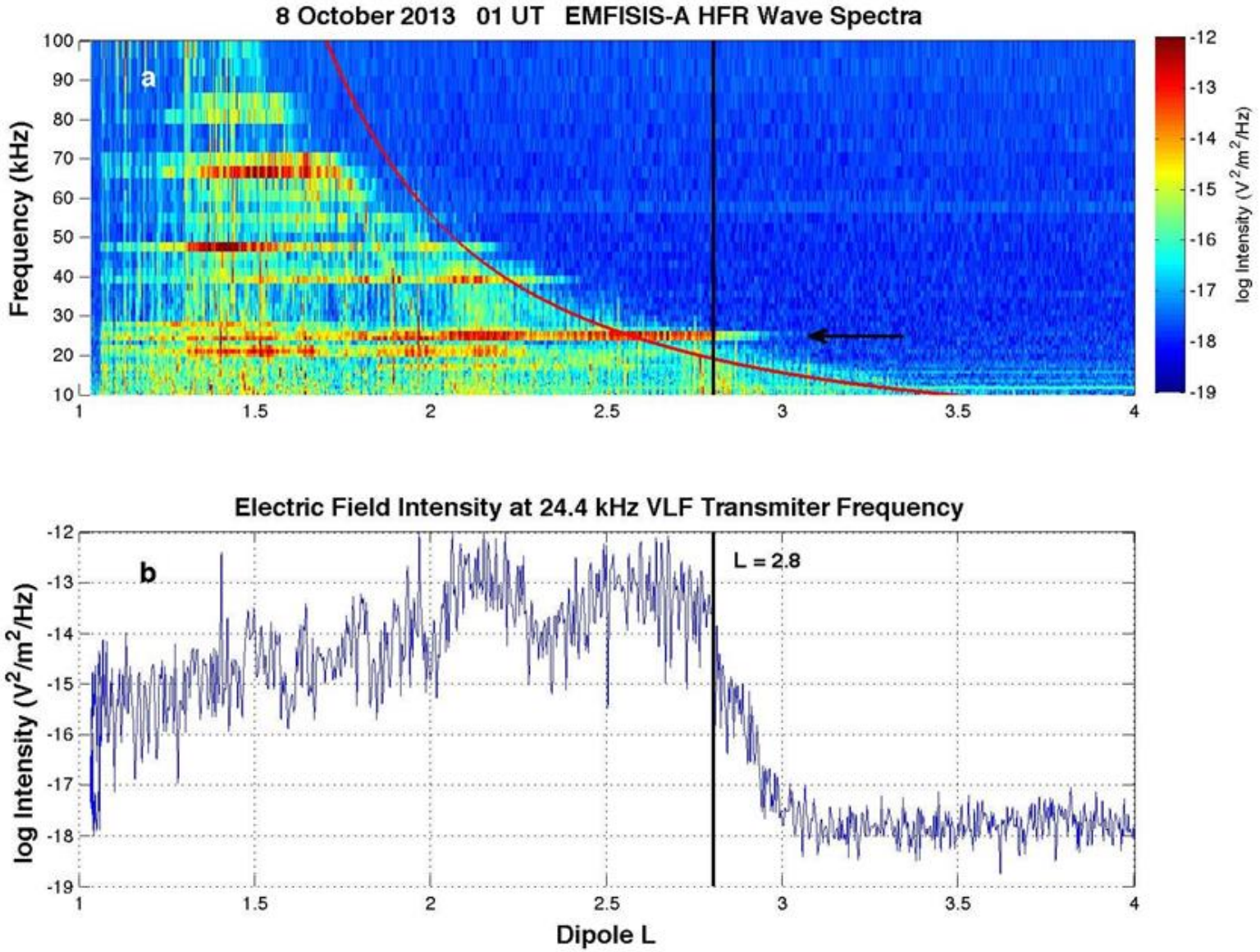


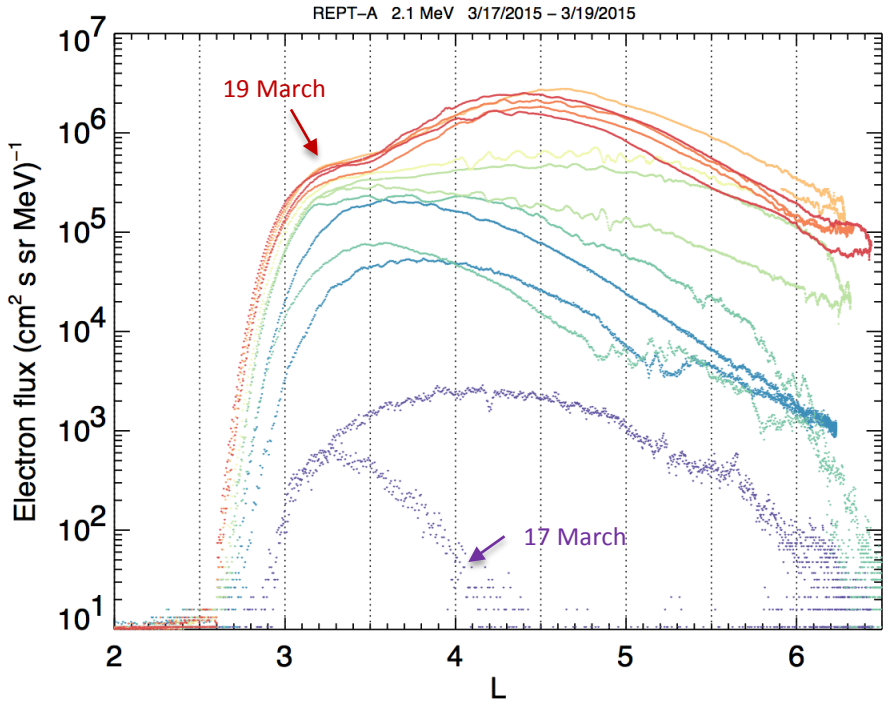
An Impenetrable Barrier?

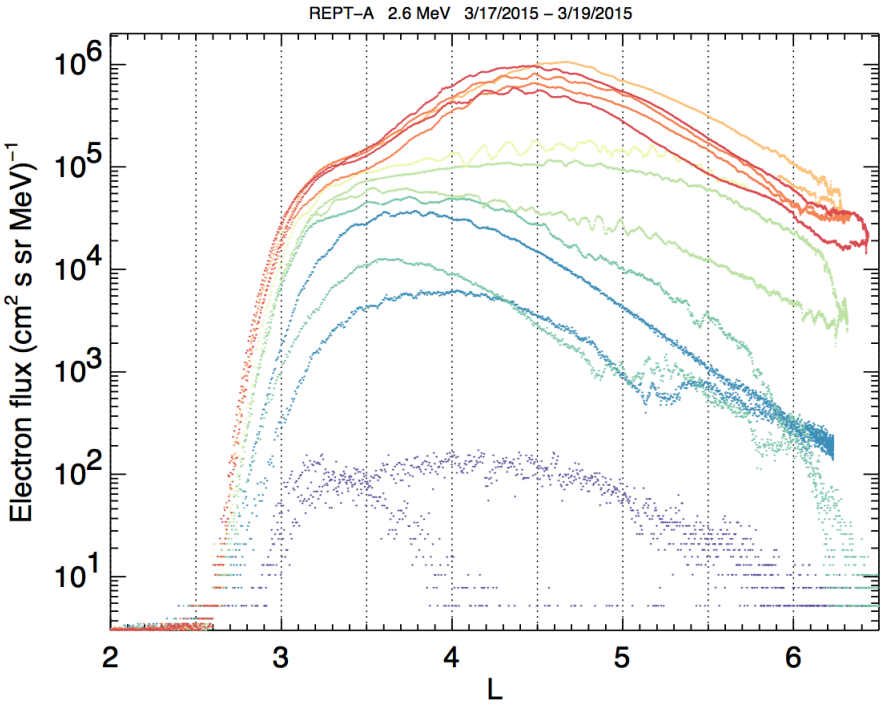


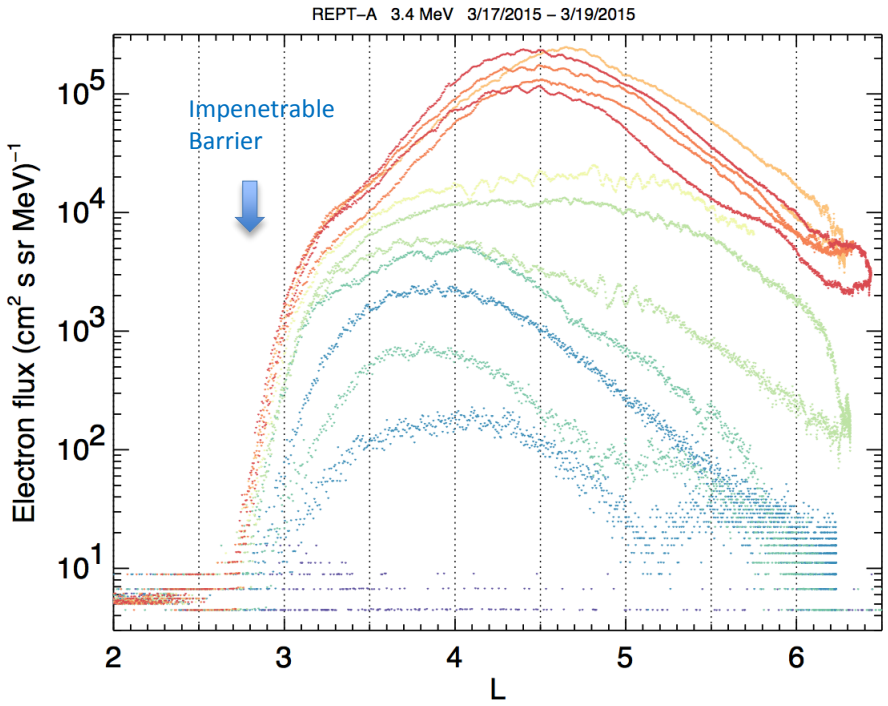
Ultrarelativistic electrons seem never to penetrate inward of L~2.8

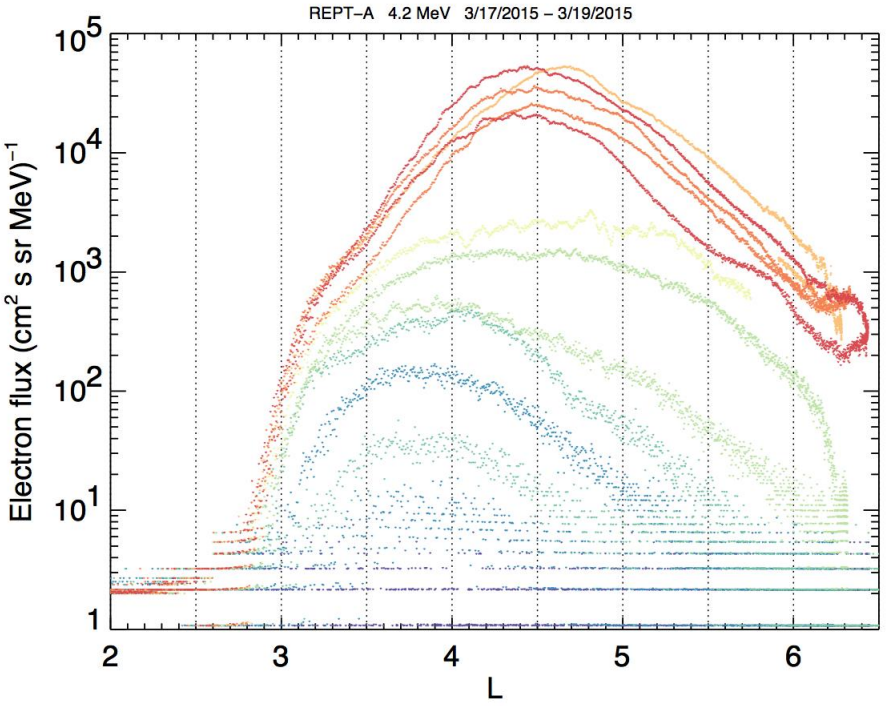
Baker et al., Nature, 2014

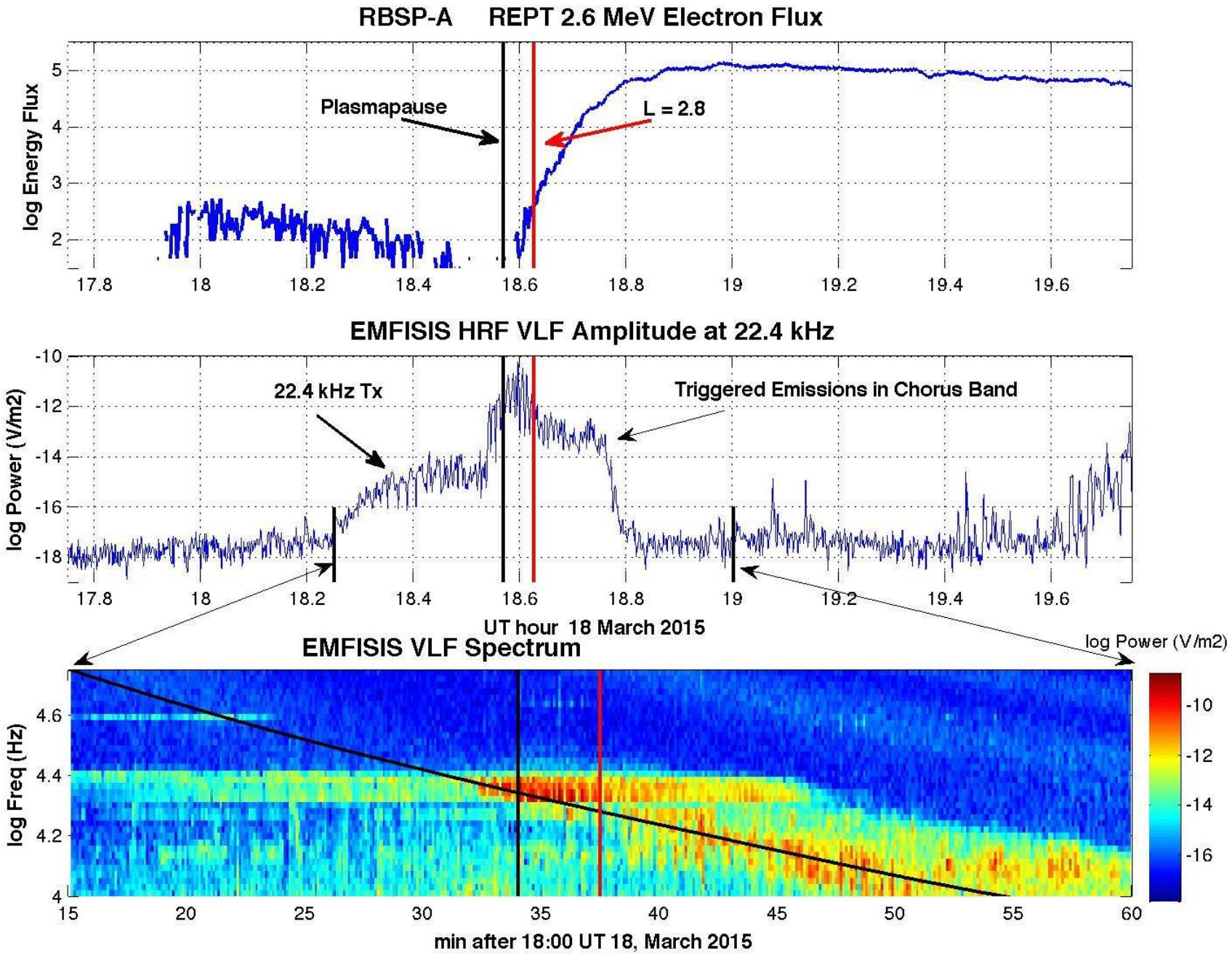

8 October 2013 01 UT EMFISIS-A HFR Wave Spectra
a
Frequency (kHz)
log Intensity (V²/m²/Hz)
Electric Field Intensity at 24.4 kHz VLF Transmiter Frequency
b
L = 2.8
log Intensity (V²/m²/Hz)
Dipole L


REPT–A 2.1 MeV 3/17/2015 – 3/19/2015
19 March
17 March
Electron flux (cm² s sr MeV)⁻¹
L


REPT–A 2.6 MeV 3/17/2015 – 3/19/2015
Electron flux (cm² s sr MeV)⁻¹
L

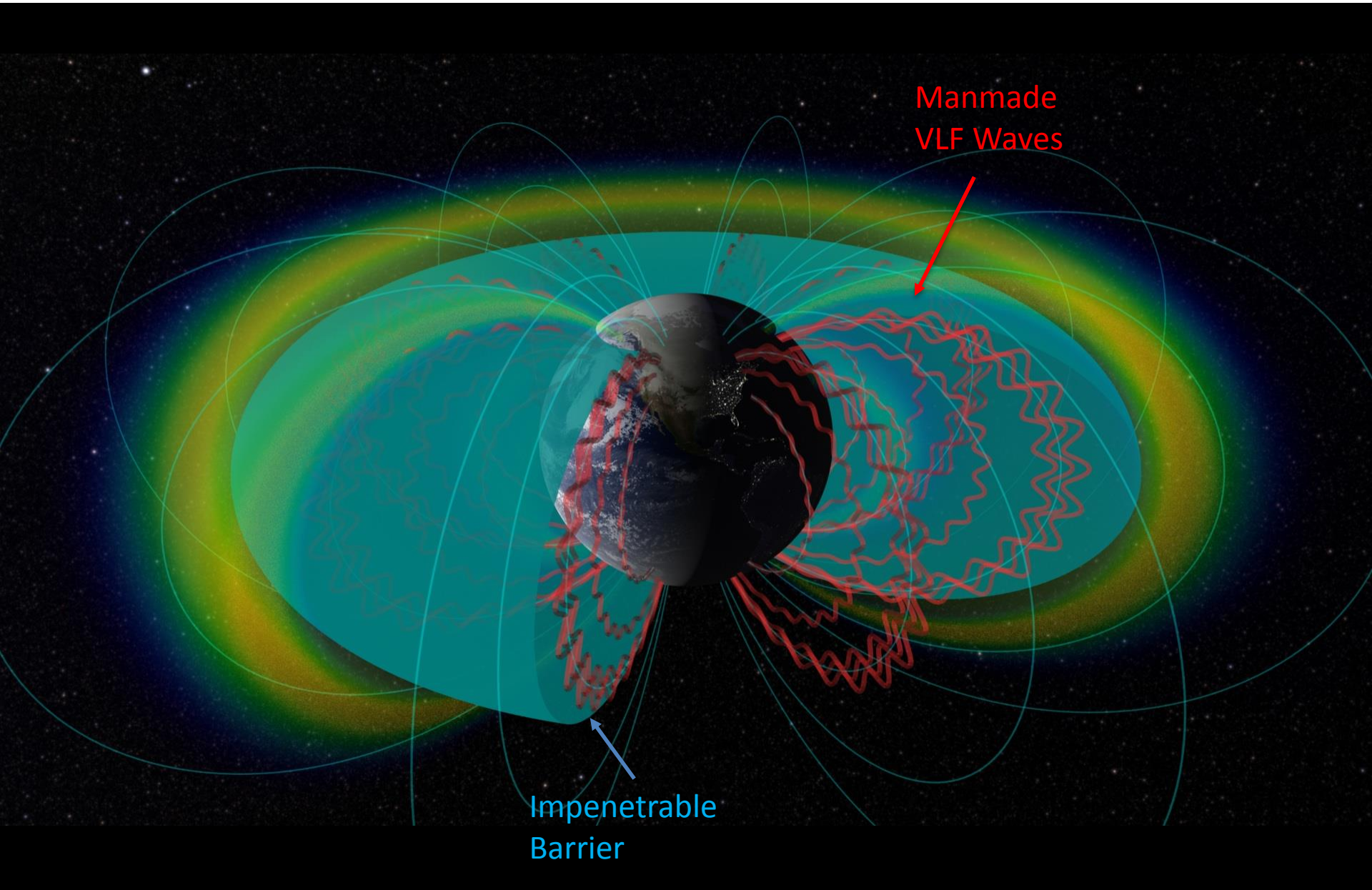

REPT–A 3.4 MeV 3/17/2015 – 3/19/2015
Impenetrable
Barrier
Electron flux (cm² s sr MeV)⁻¹
L


REPT–A 4.2 MeV 3/17/2015 – 3/19/2015
Electron flux (cm² s sr MeV)⁻¹
L

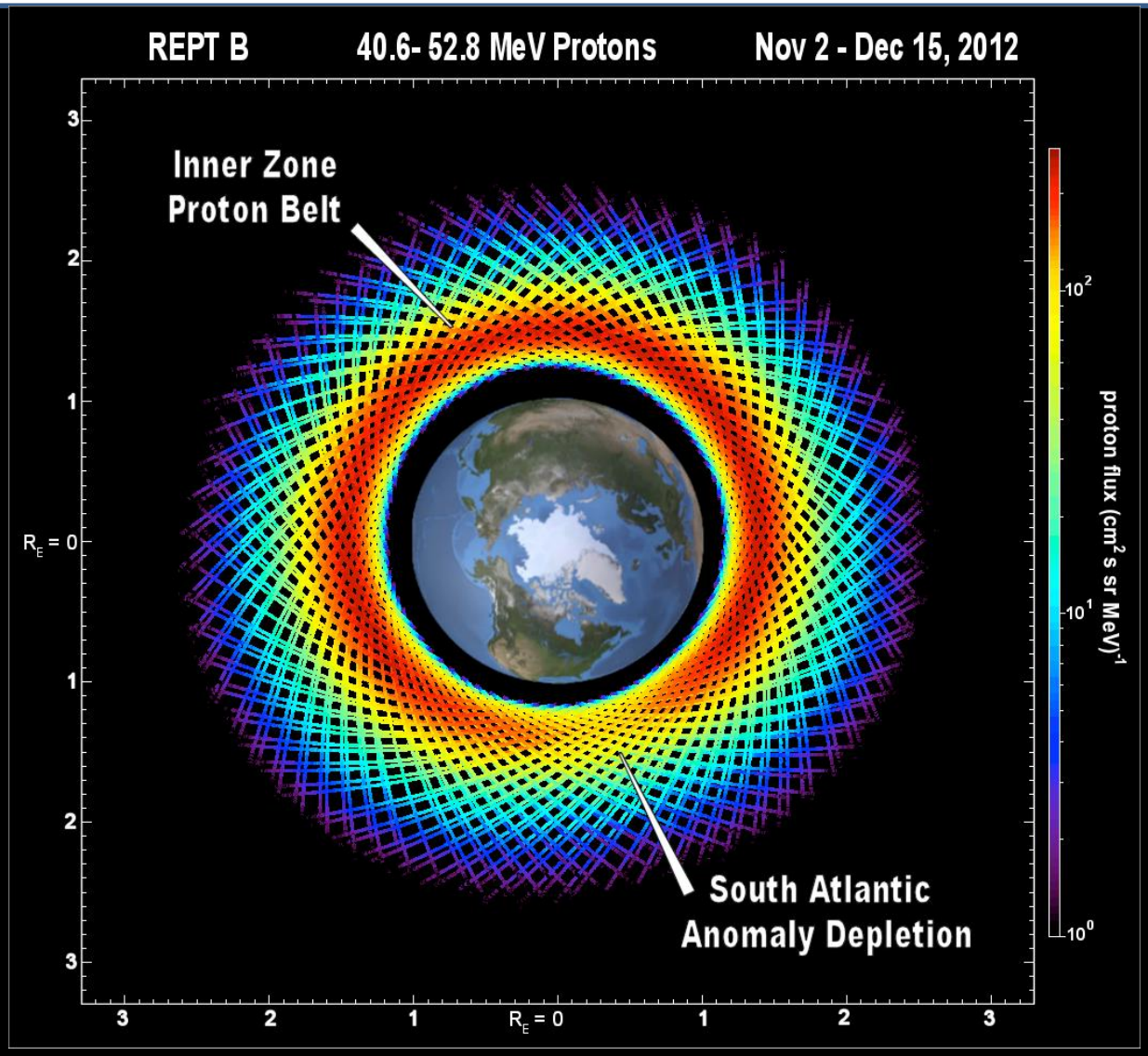


Foster, Baker, Erickson,…(2015)

Electron Barrier and VLF Bubble

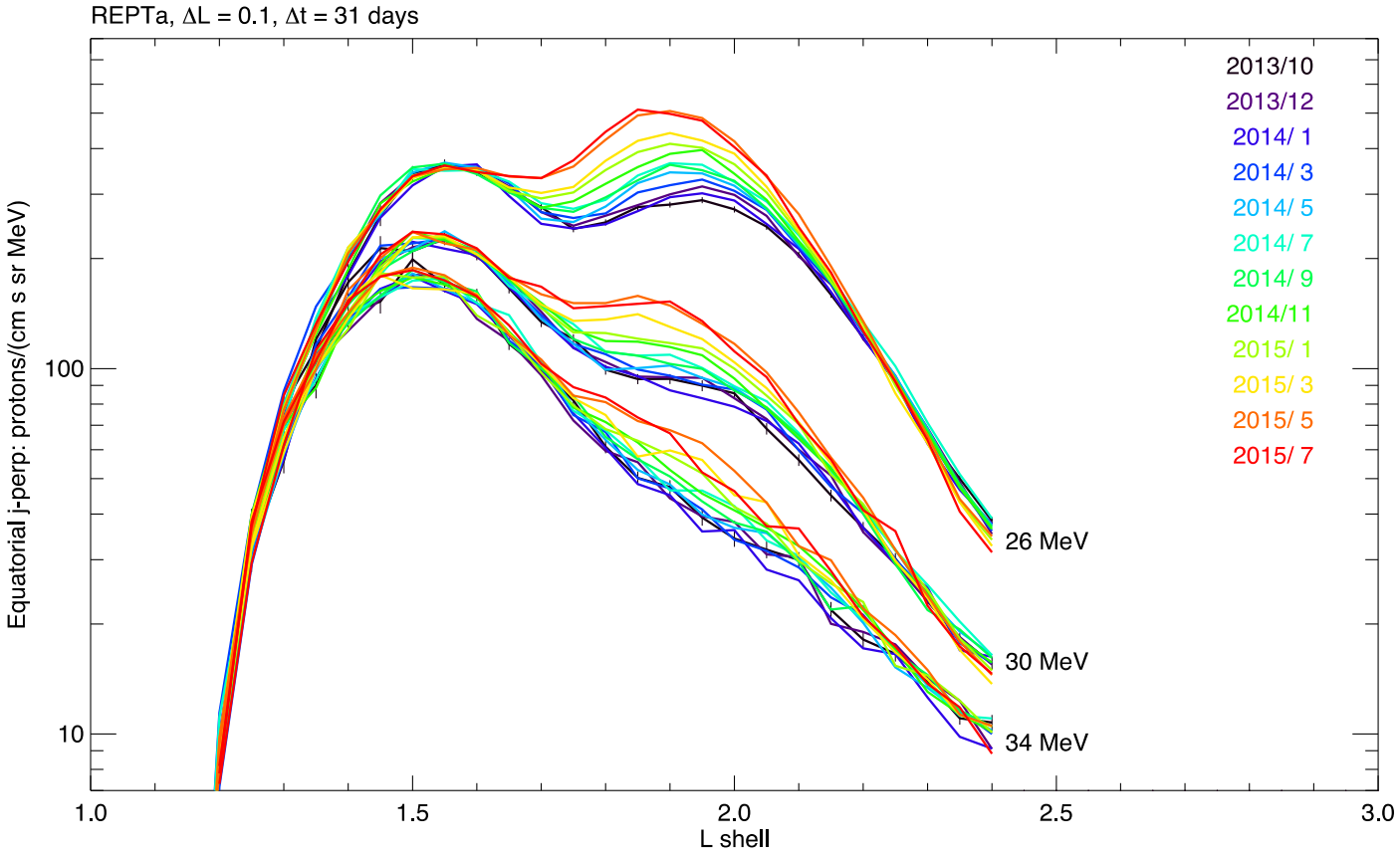


The Geographic View: Inner Zone



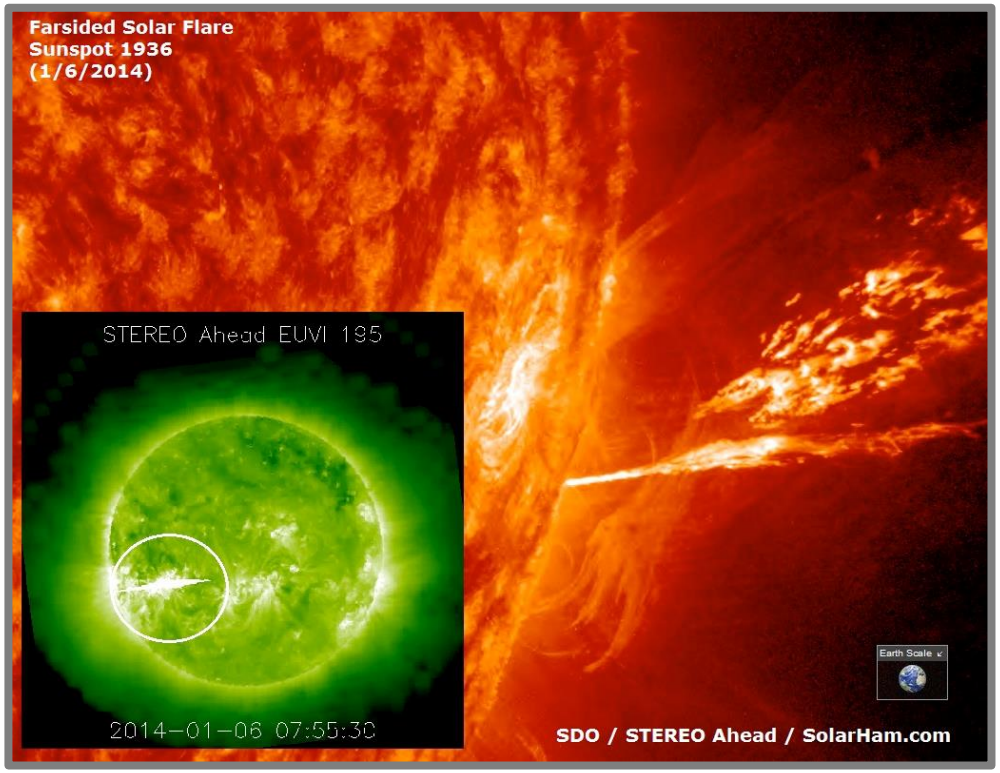
REPT-A equatorial perpendicular intensity vs. L

- Color coded by Year/Month
- $\alpha_0 = 90 \pm 20^\circ$, 3 energies
- Peak near $L = 1.5$ is not changing
- Peak near $L = 2$ is increasing (by inward diffusion of trapped solar protons?)



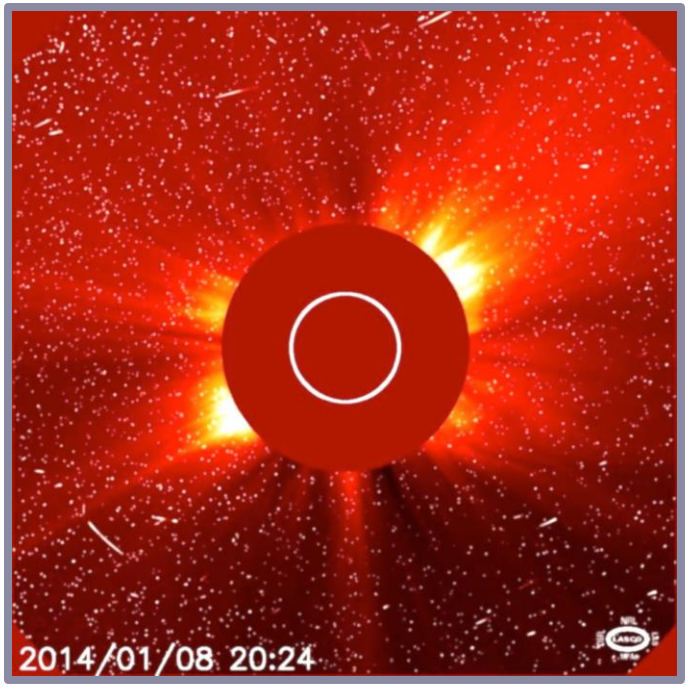
January 2014 SEP Events

- Flare eruption on 06 Jan 2014
- Caused the smaller SEP that lasted for a short time



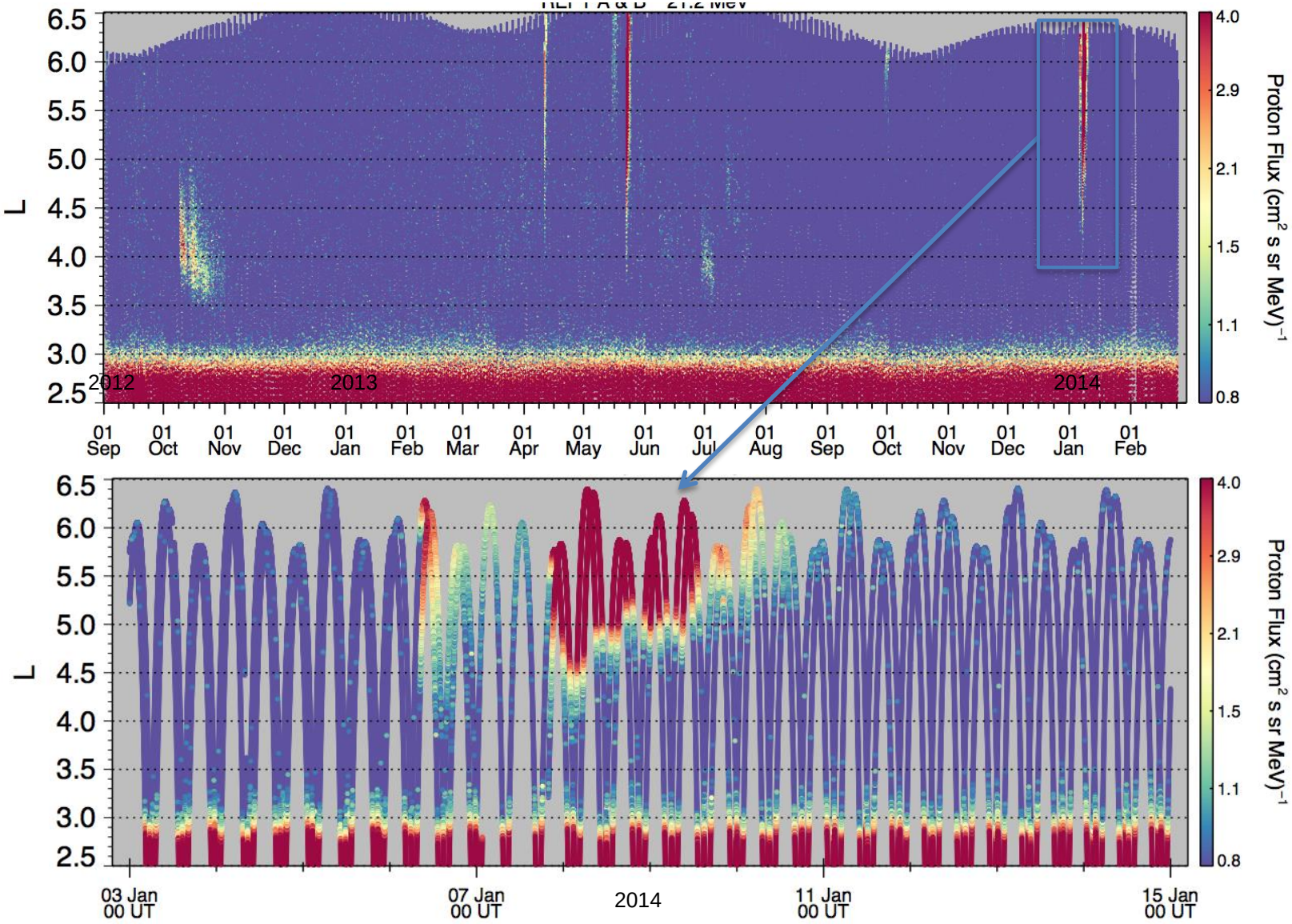
SDO STEREO – 06 Jan 2014 SEP

- X1-class flare erupted on 07 Jan from “giant sunspot” – along with associated coronal mass ejection (the CME that wasn’t)
- Larger SEP event that persisted for several days
- More intense and harder spectrum

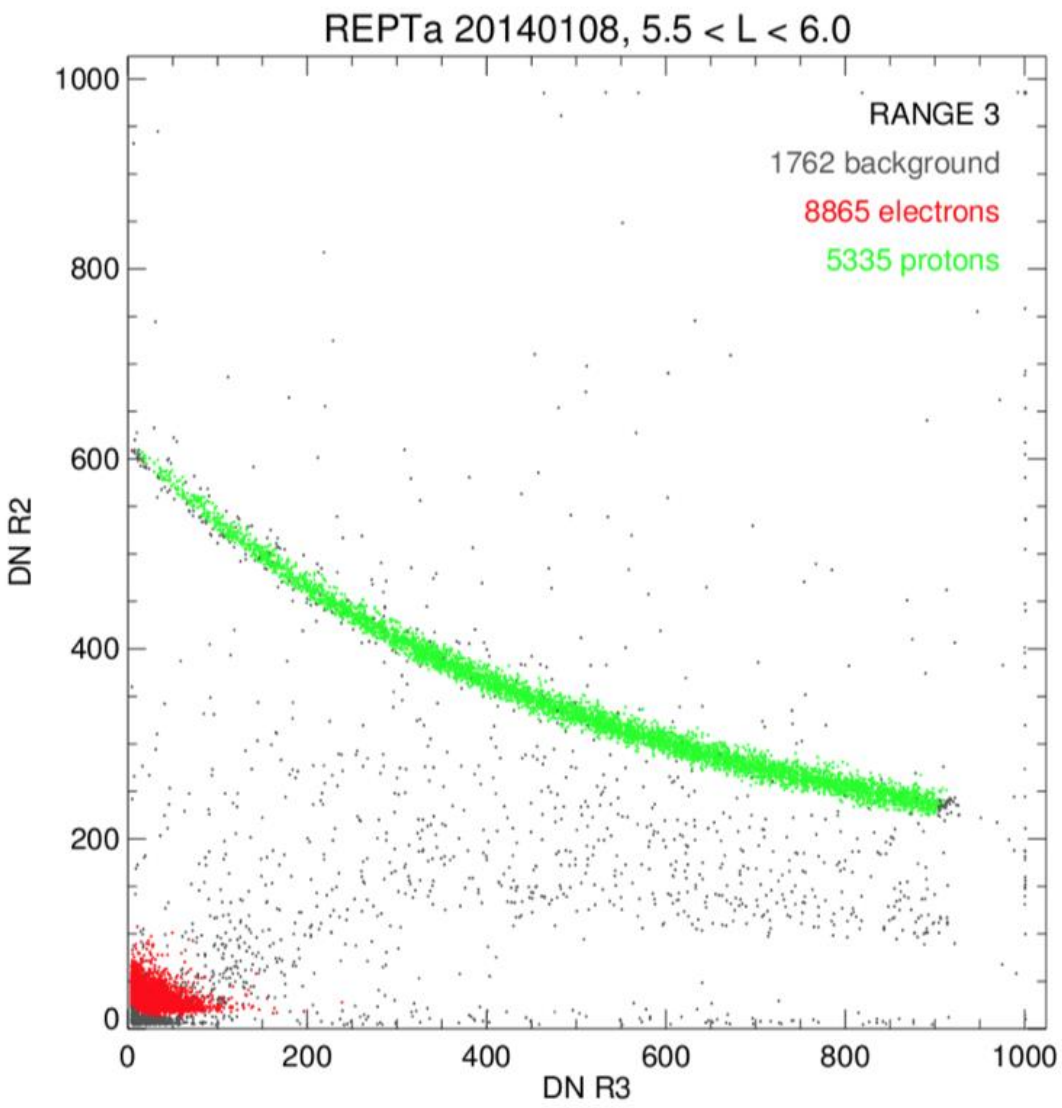


SOHO LASCO – 08 Jan 2014 SEP

REPT A & B Ep > 18.5 MeV



PHA analysis: 08 Jan 2014 SEP event



Ratio plot of energy deposits in detector 2 vs. detector 3, for high L between 5.5 and 6.0

Green shows valid proton events based on theoretical energy deposited

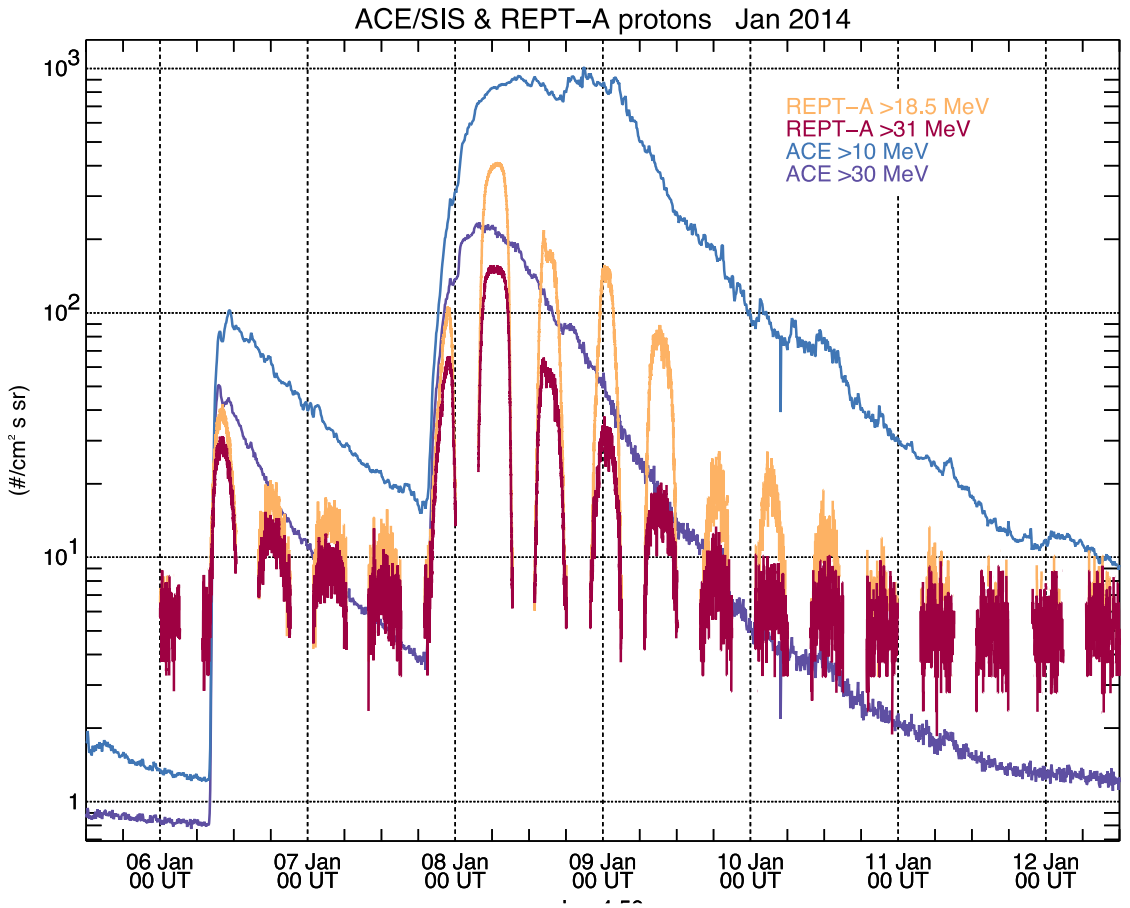
Red shows valid outer belt electrons

Gray is background from high-energy protons that penetrate shielding from the sides or behind

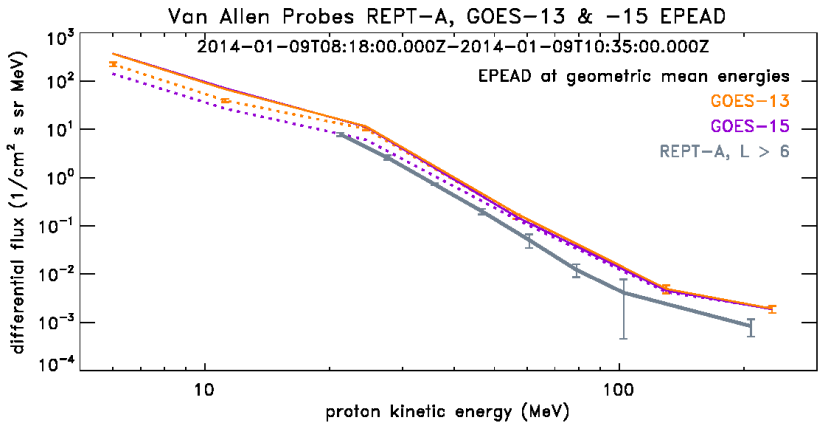
REPT-A & ACE Comparison

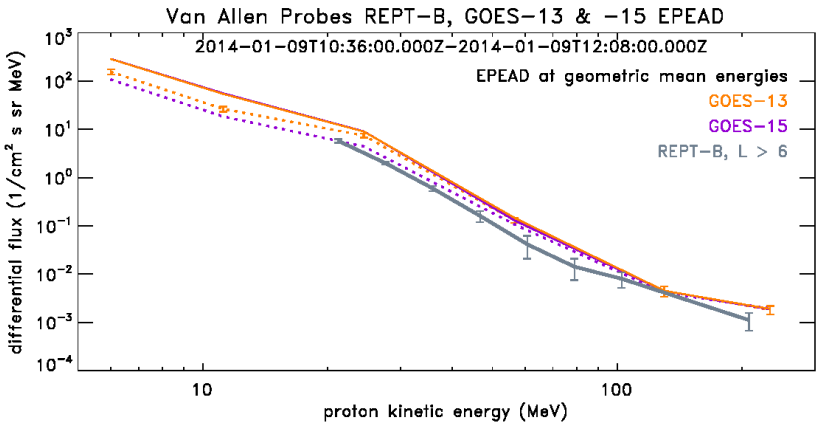
- ACE Solar Isotope Spectrometer (SIS) measures protons for E > 10 MeV and E > 30 MeV
- False integral channels for REPT to create analogous energy range
- ACE located at L1 point (~230 R_E)
- Expect higher counts at L1 than at RBSP within the magnetosphere

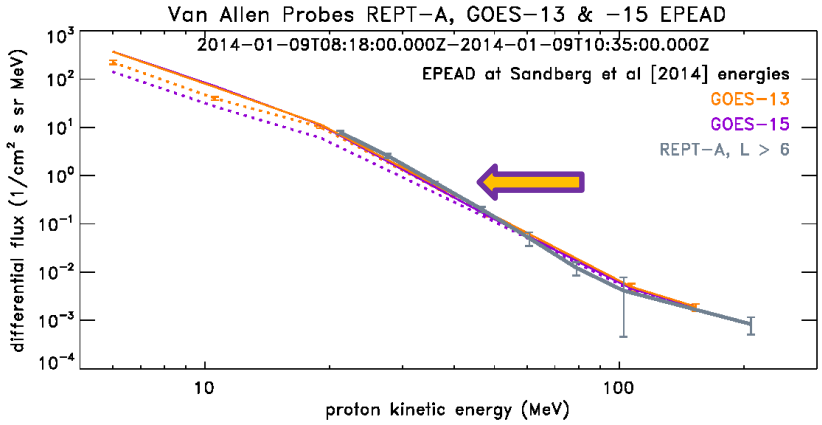
- REPT measurements are indeed lower at apogee (L~6.3) than at ACE (L1)
- GCR 'background' can easily be seen in REPT data (more later)
- (B s/c looks the same)

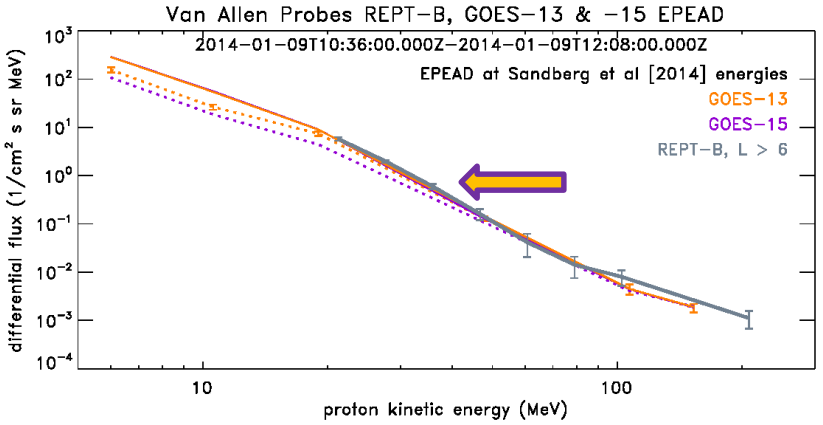


GOES/EPEAD-REPT cross-comparison 09 Jan 2014









REPT spectra constructed from 20-min- and spin-averaged PHA fluxes

Conclusions

- Results from the Van Allen Probes mission have been rewriting the textbooks about radiation belt structure, acceleration, transport, and loss.
- Excellent energy and pitch angle data reveal distinctive behavior in several electron energy regimes: Highly; Super; and Ultra (> 5 MeV) relativistic.
- REPT data often show three belt structure and show there is an impenetrable barrier to inward penetration of ultra-relativistic electrons at L ~2.8 [Baker et al., Nature, 2014; Foster et al., Science, 2015].
- The Van Allen Probe data clearly demonstrate the crucial role played by SEP and solar wind forcing in allowing radiation belt flux enhancements: Seed populations.
- **A new window has been opened on understanding acceleration, injections, and strong plasma physical gradients in Earth's magnetosphere: This has crucial significance for remote cosmic systems.**

Thank you.

Questions?