

New Radiation Belts and Other Effects of Cycle 23 SEP Events

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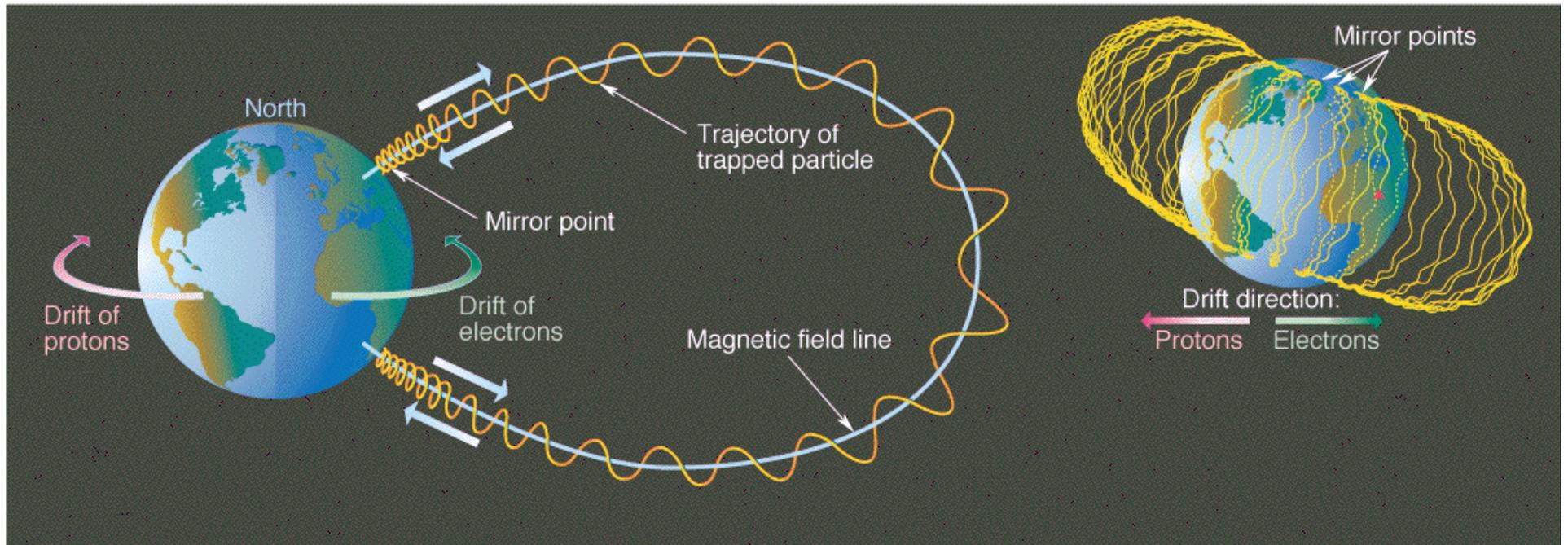
University of Maryland

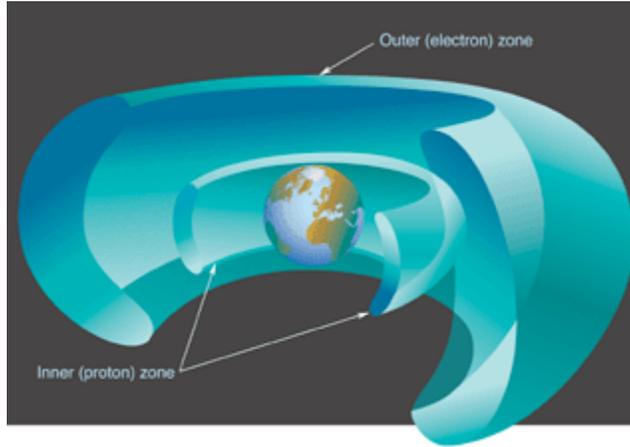
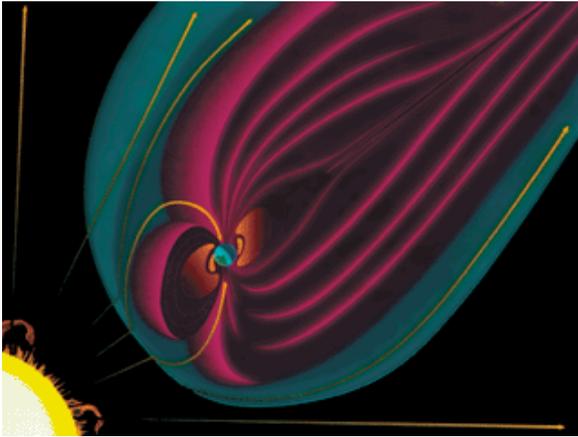
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Outline

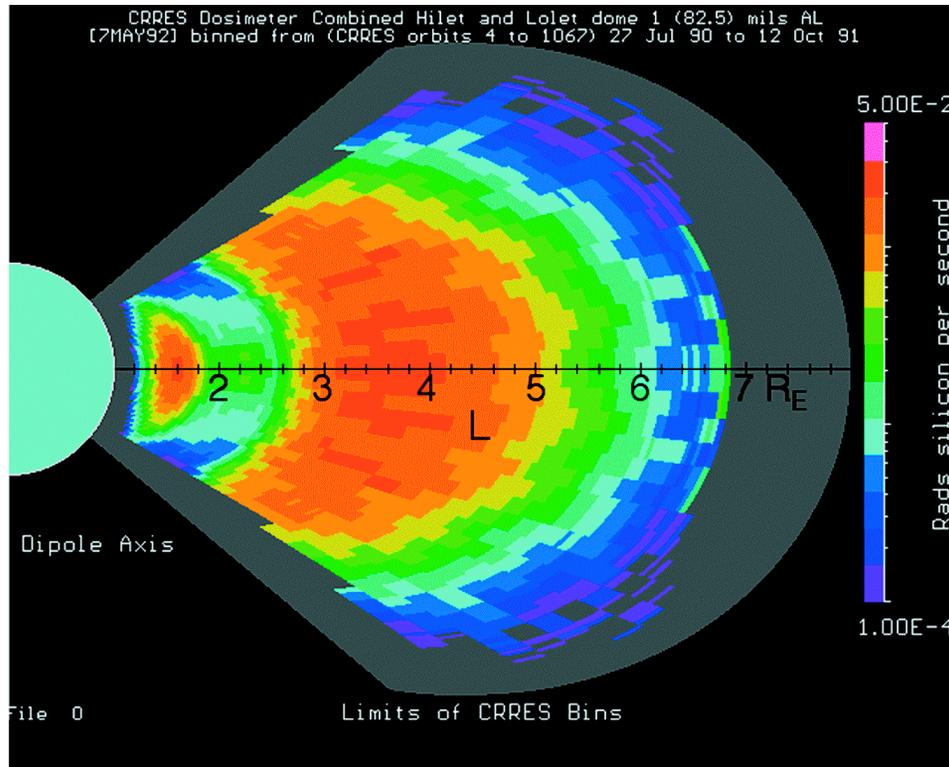
- Brief review of observational facts of new radiation belts that form in the inner magnetosphere during intense SEP events and CME-related shocks
- Late 2003 events and SHINE campaign events

Charged particle motion

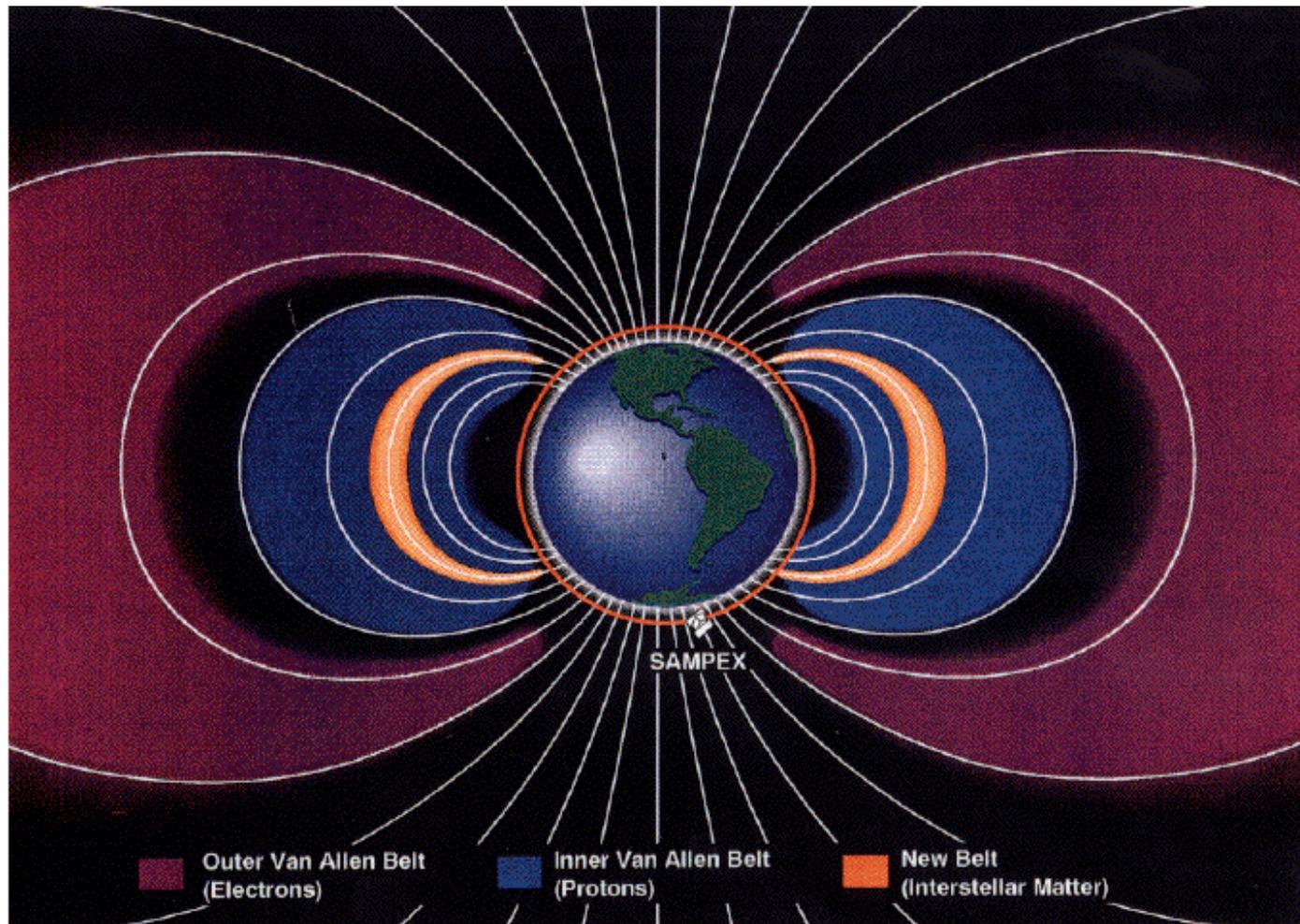




Cartoons of the inner magnetosphere



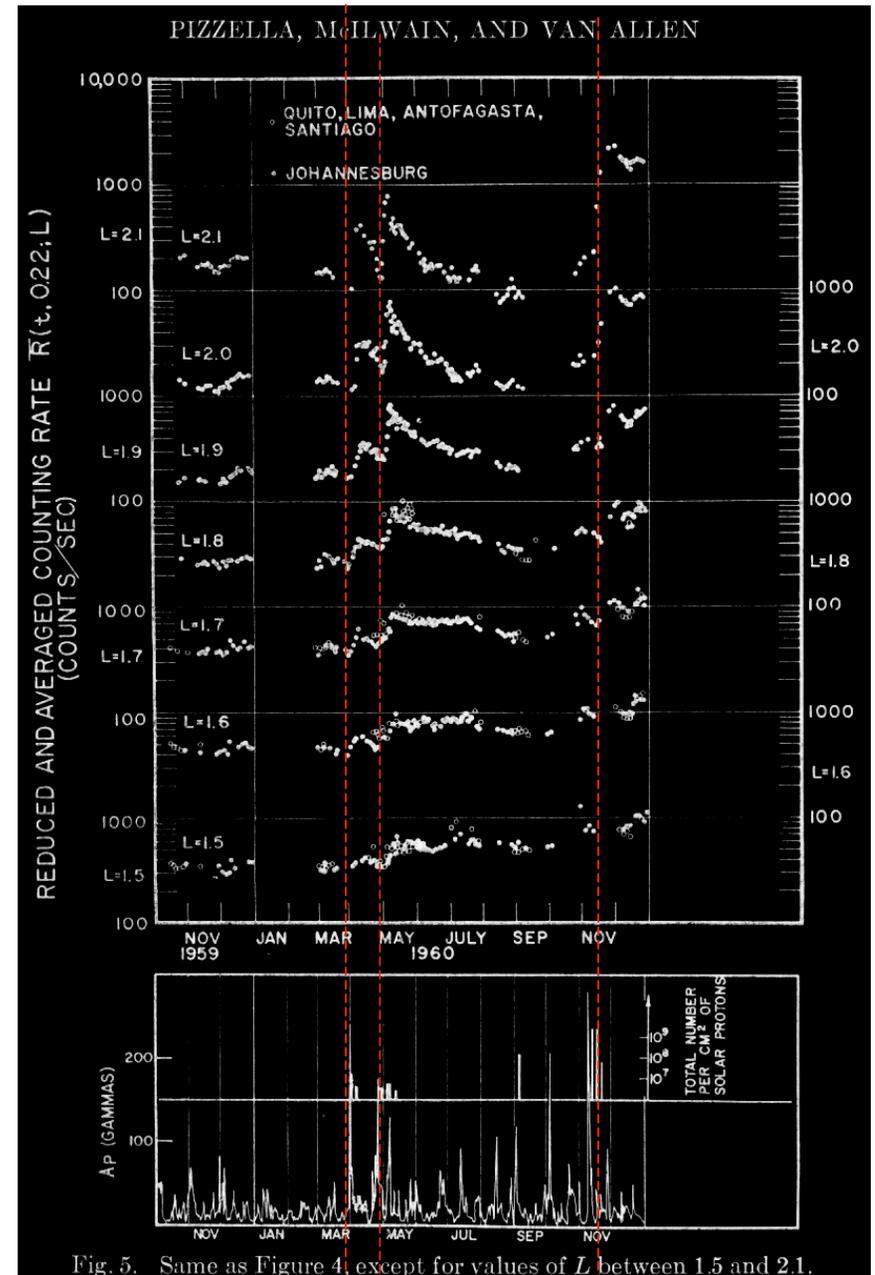
Reality as viewed with a 15-month average



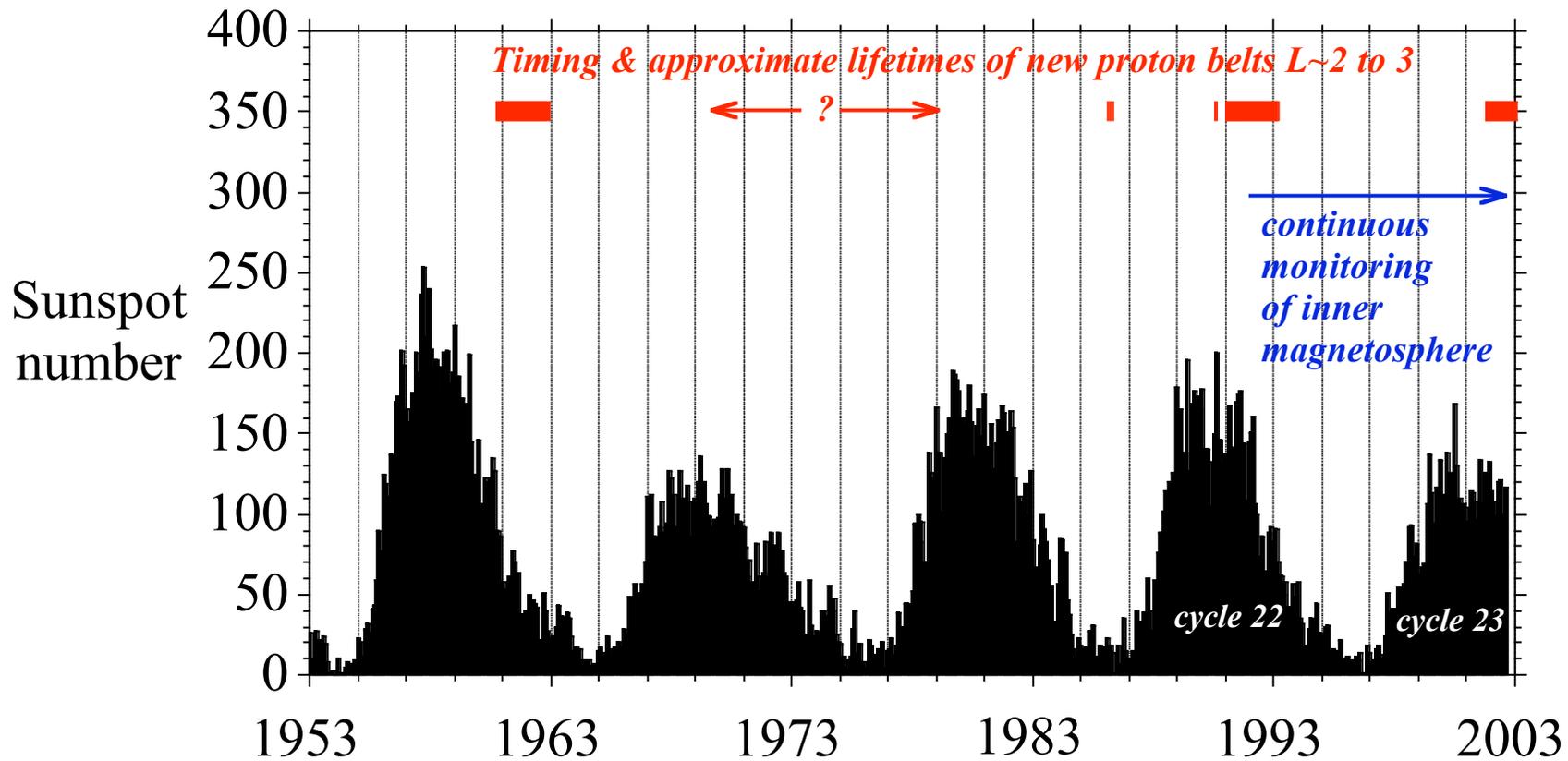
The inner magnetosphere is host to a variety of time-dependent trapped populations and is not static.

Observations of large changes near L=2: 1960

- Explorer 7:1959-1960
- GM tube: >18 MeV protons, >1.1 MeV electrons
- Pizzella, McIlwain, & Van Allen JGR 1961

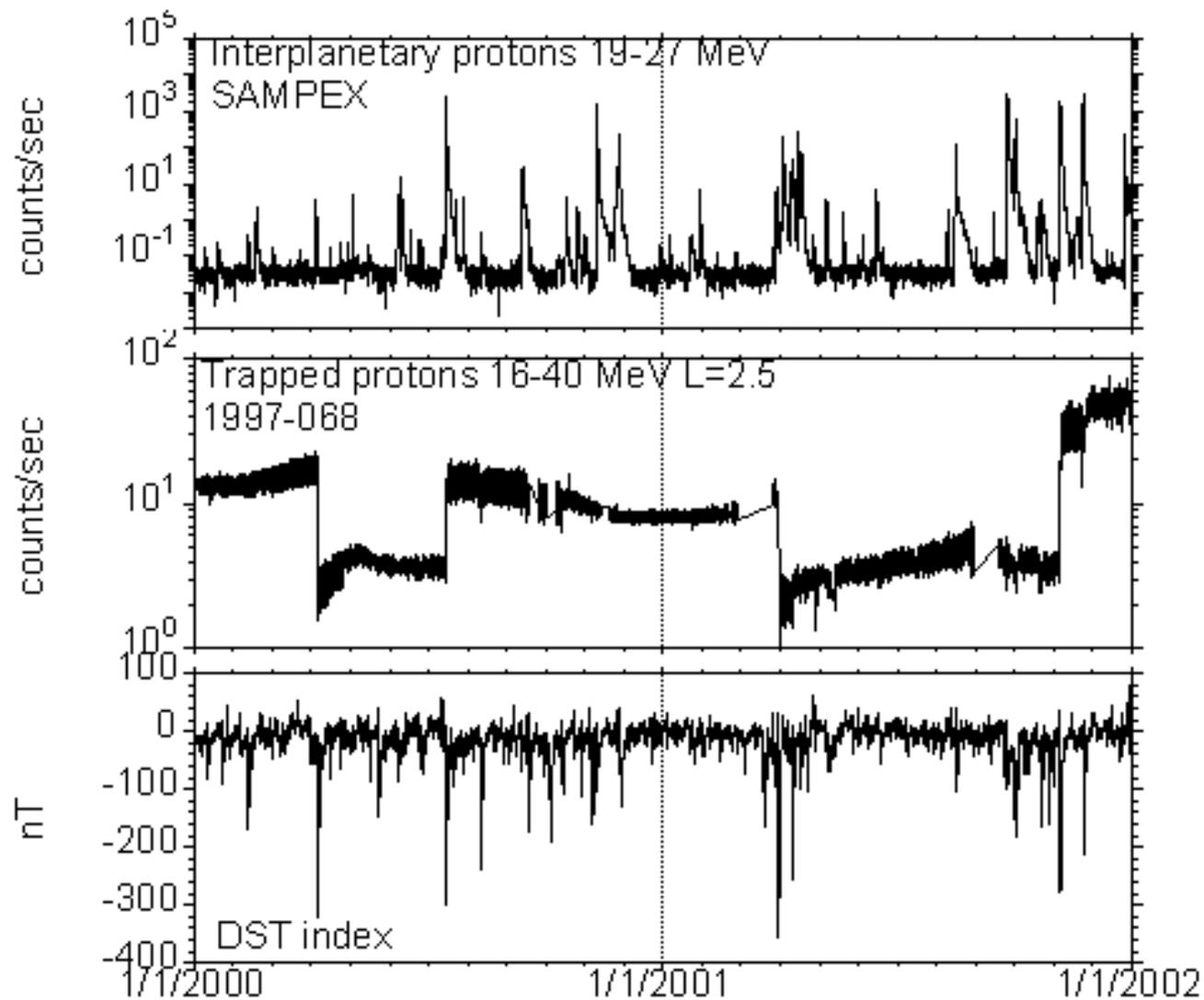


Other glimpses of new belts



ftp://ftp.ngdc.noaa.gov/STP/SOLAR_DATA/SUNSPOT_NUMBERS/MONTHLY

Radiation belt duration from *Lorentzen et al. JGR 107(A9), 1231, doi:10.1029/2001JA000276, 2002*

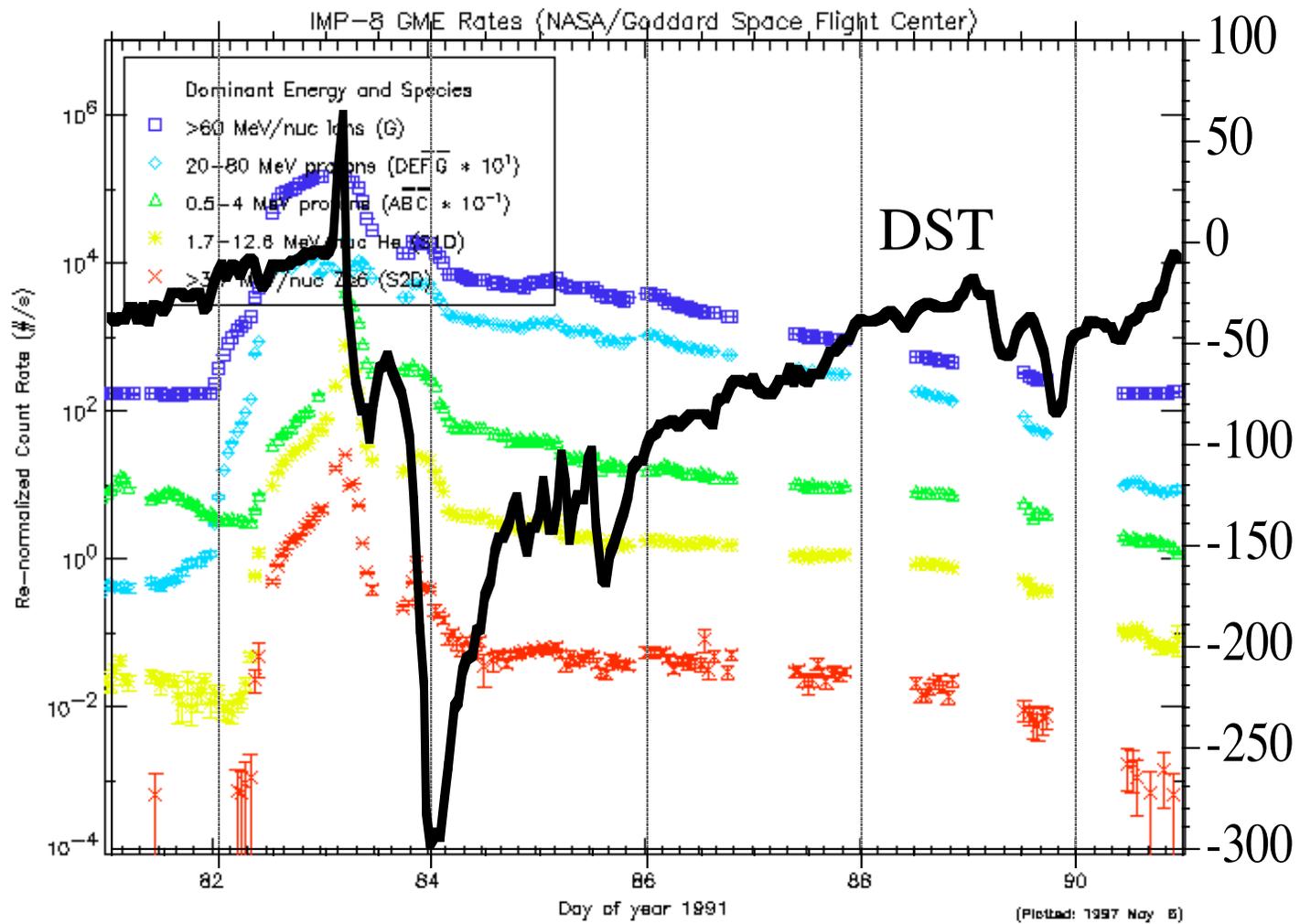


There were discontinuous changes to the outer edge of the inner proton belt in 2000 & 2001.

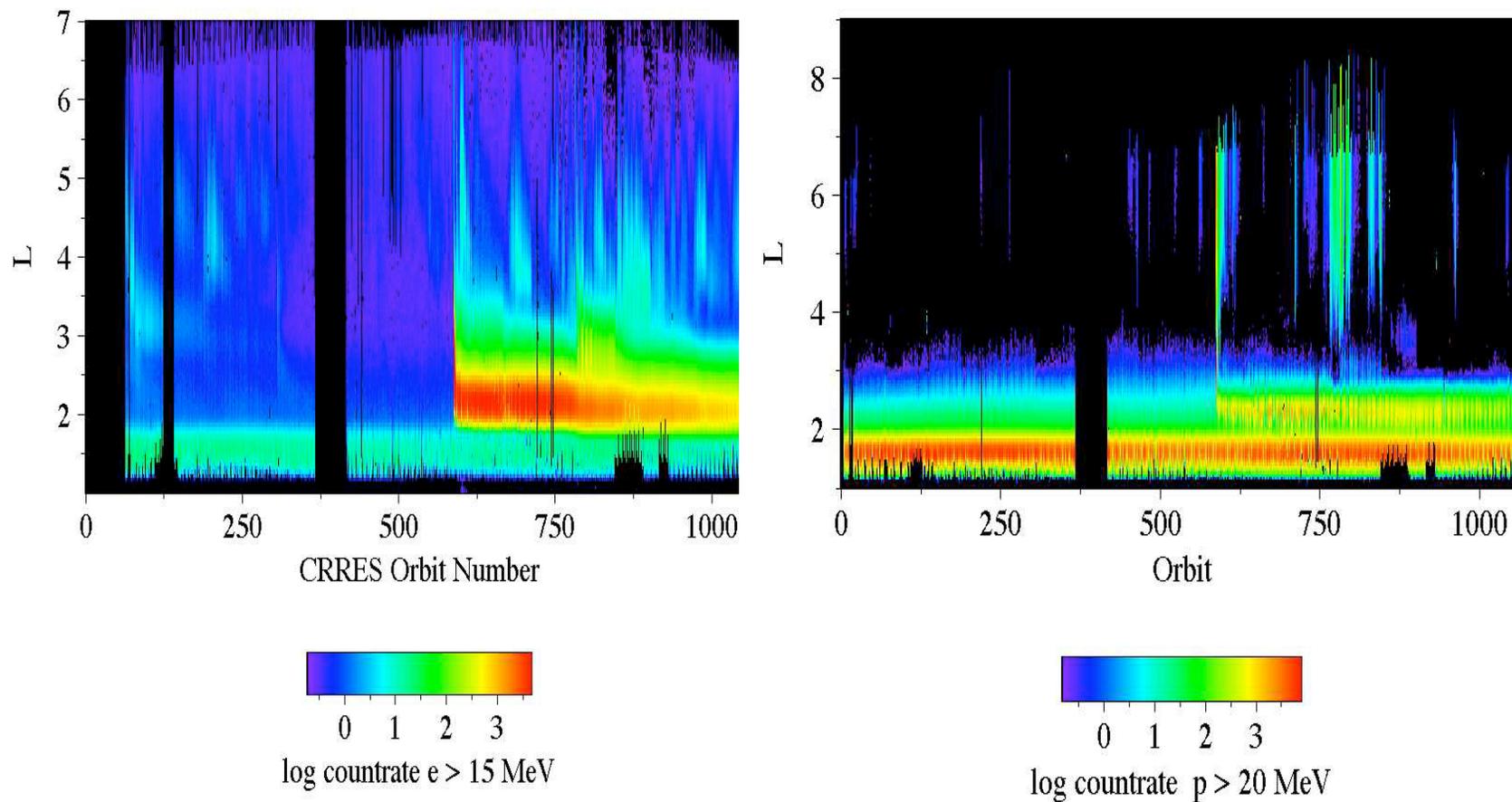
24 March 1991

Creation of >15 MeV electron and
 >50 MeV proton belts

*- A lone spacecraft at the right
place at the right time -*



24 March 1991 shock injection as seen by CRRES

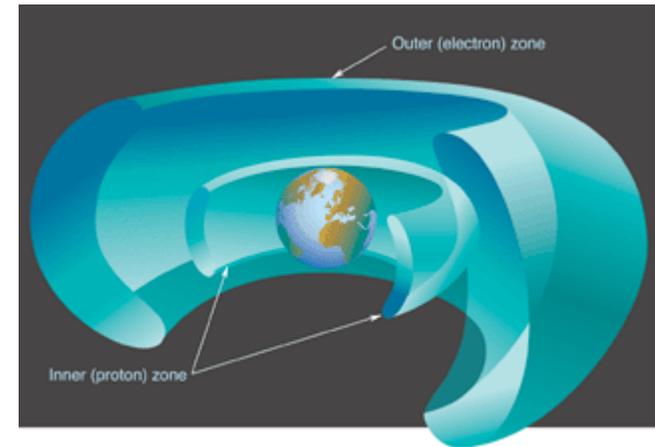


The new belts lasted more than 2 years.

Summary of 24 March 1991 event

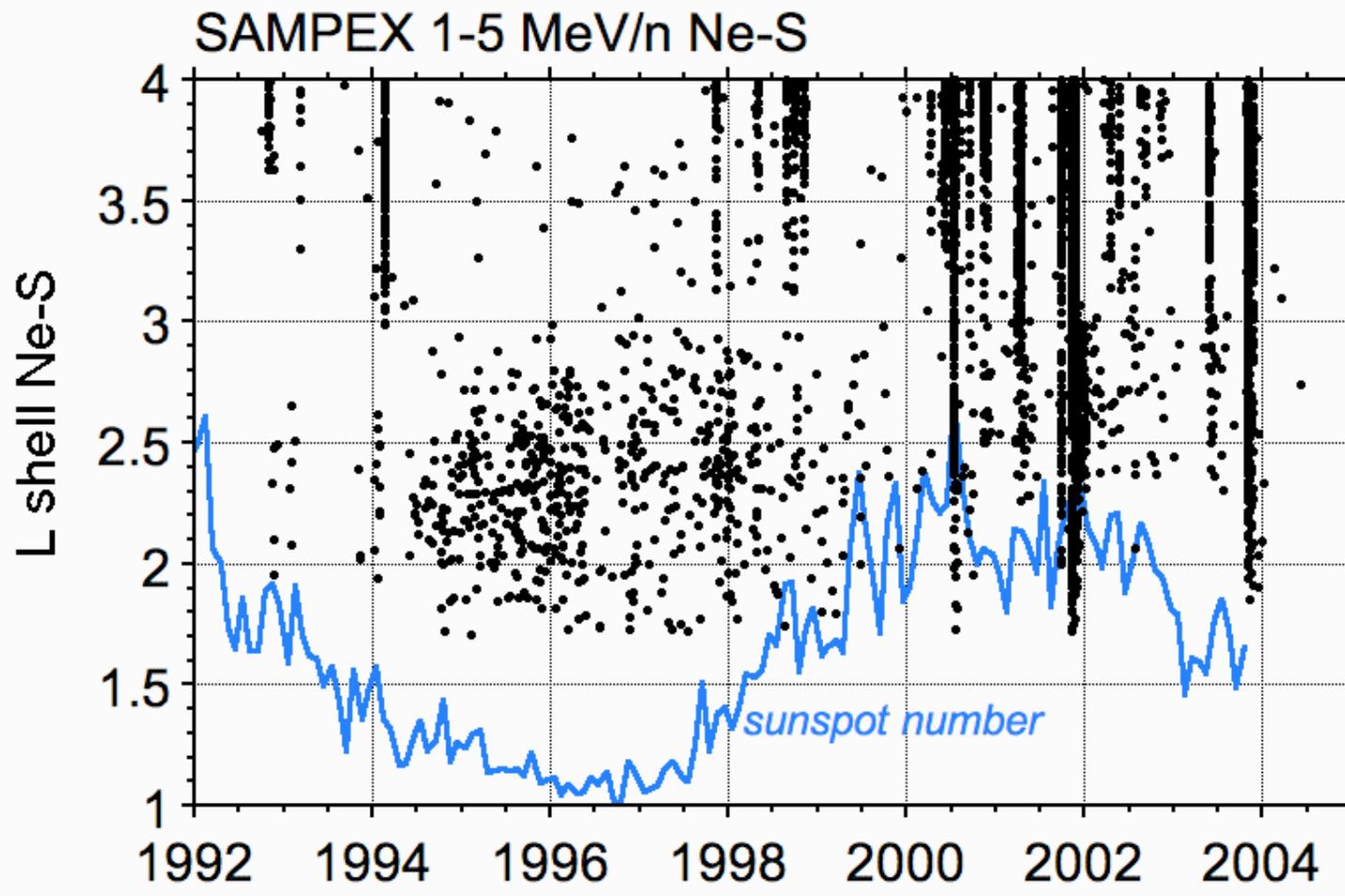
- Particle injection immediate
 - Injected particles strongly peaked in pitch angle
 - Successfully modeled by Li *et al.* GRL 20, 2423-2426, 1993
 - Radial transport of outer zone electrons (energy gain $L^{-1.5}$) & SEP protons (energy gain L^{-3})
- Both protons and electrons clearly visible in new belt
 - Very high electron energies for Earth's magnetosphere
- Long lifetime: >2 years

Search for new belts in cycle 23

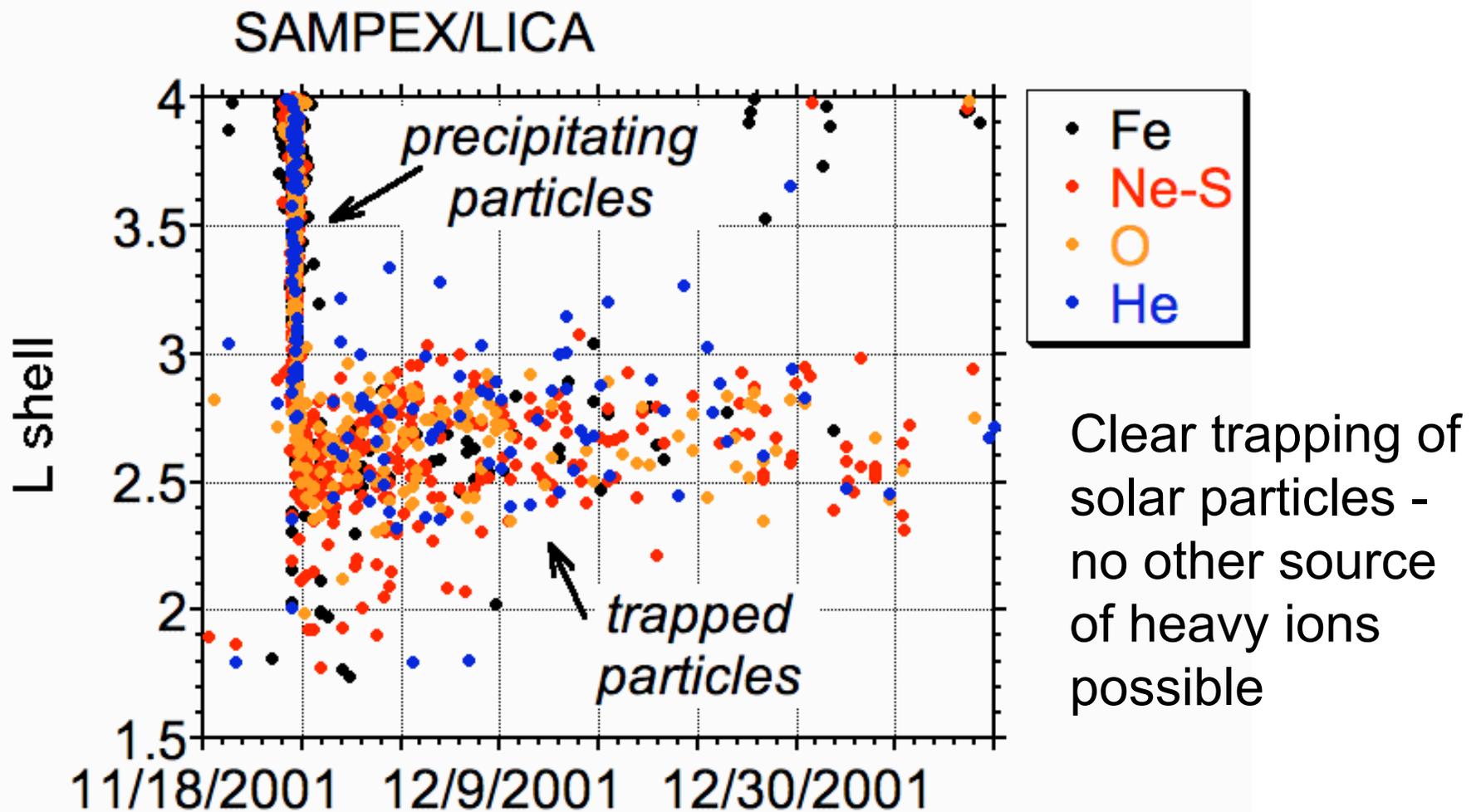


- Potential ambiguity: protons and electrons are present throughout the magnetosphere
 - Is the presence of a new belt a result of a redistribution of previously trapped particles or due to some other process?
- Use SAMPEX ion composition to search for heavy ions below $L=4$
 - $Z>2$ ions rare in the magnetosphere above 1 MeV/n (except for trapped ACR)
 - Long monitor of inner magnetosphere with well-calibrated instruments

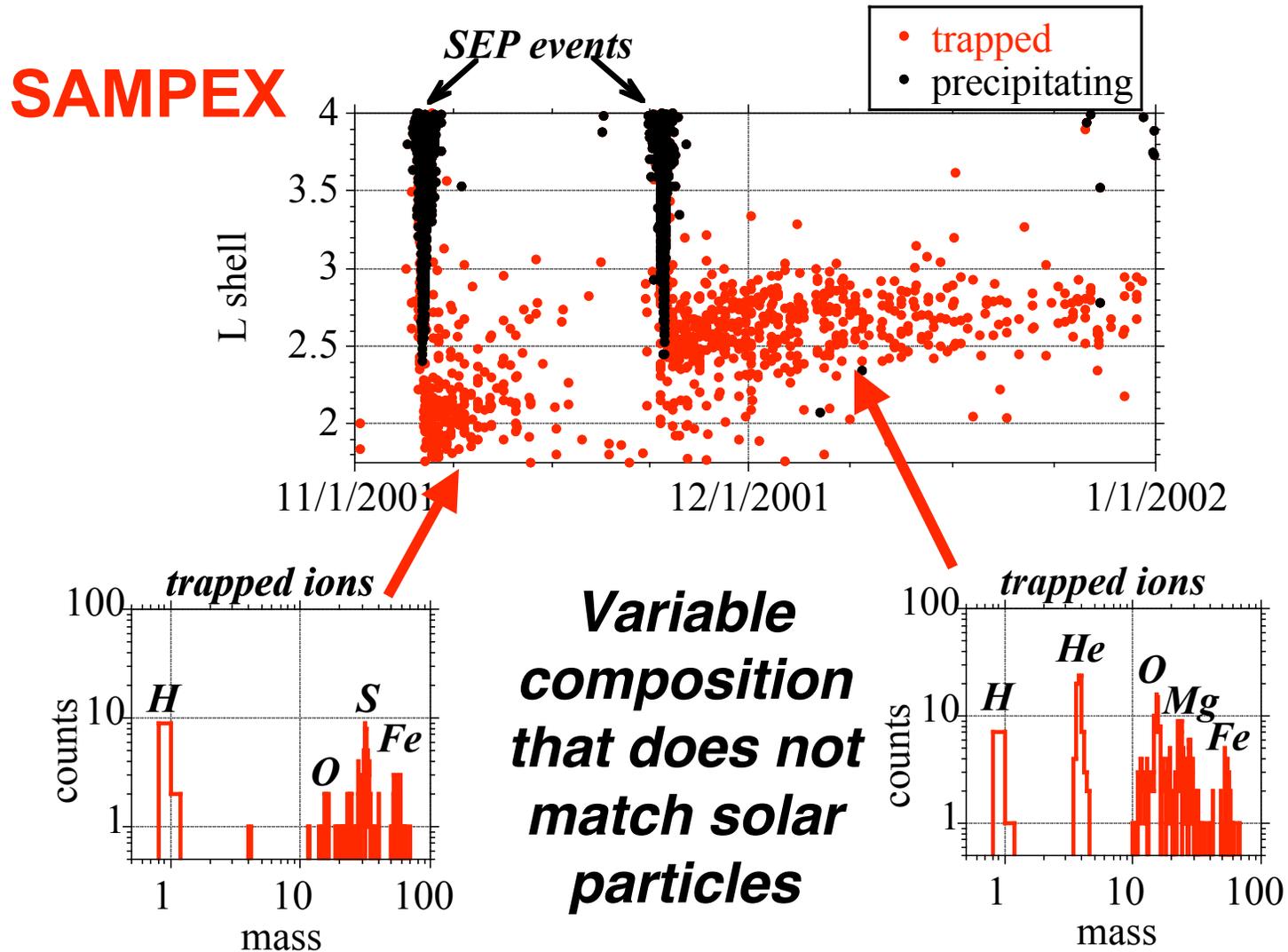
SAMPEX mission history



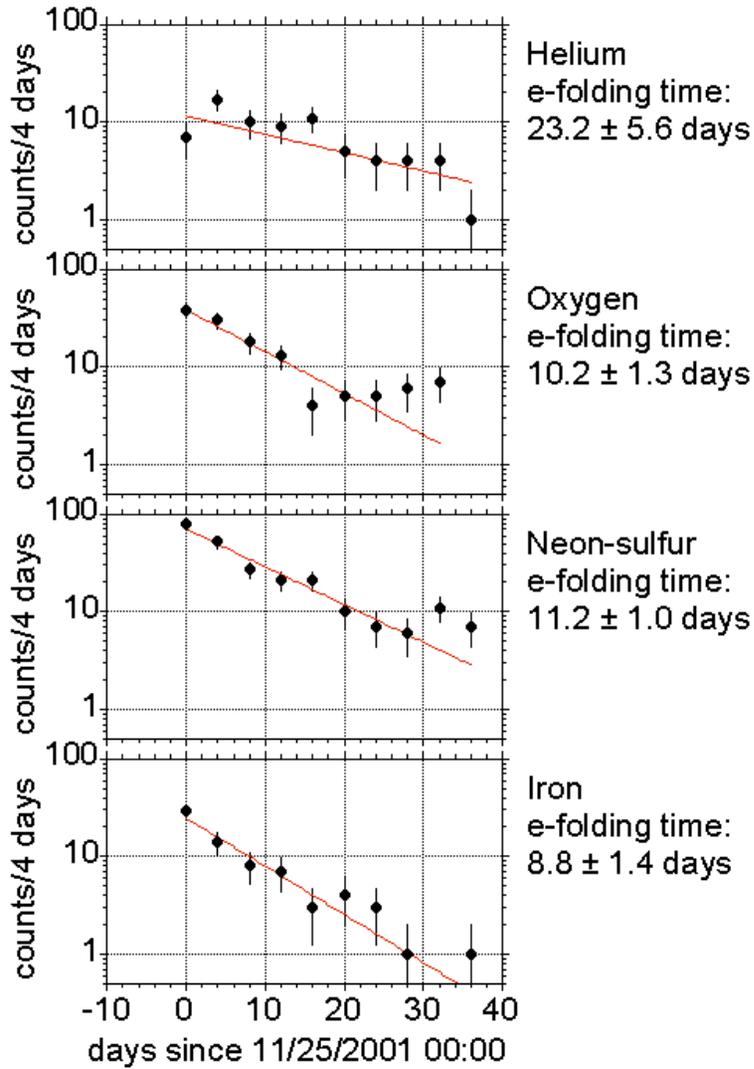
New belt example: 24 Nov 2001



Species-dependent injection?

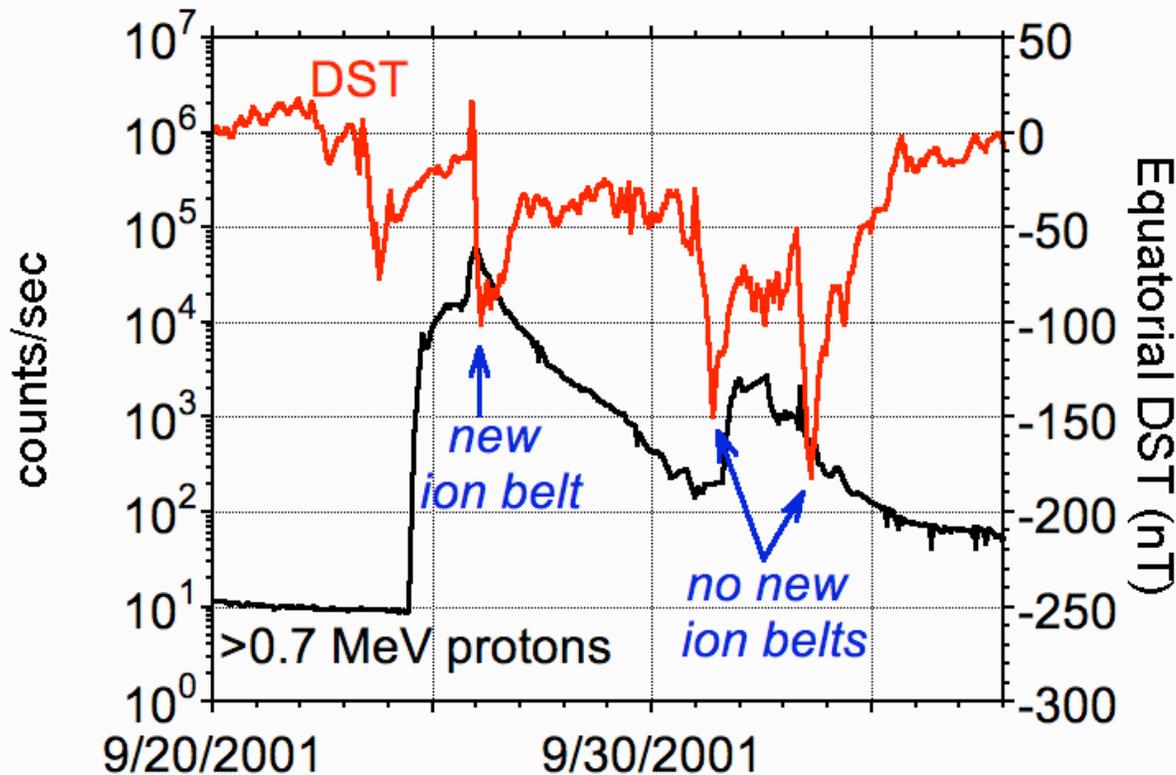


Lifetimes of new belts



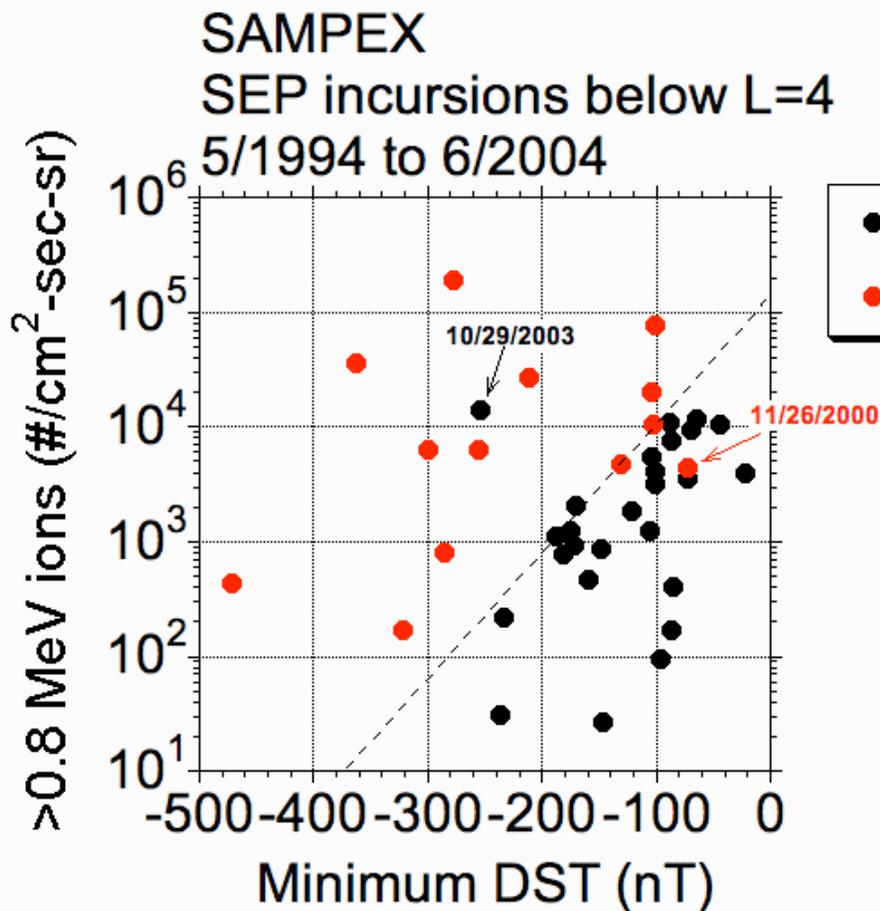
- 24 Nov 2001 case
- Decay rate was faster for increasing Z
- Expected trend if energy loss in residual atmosphere was the dominant loss process

New belts & SEP intensity



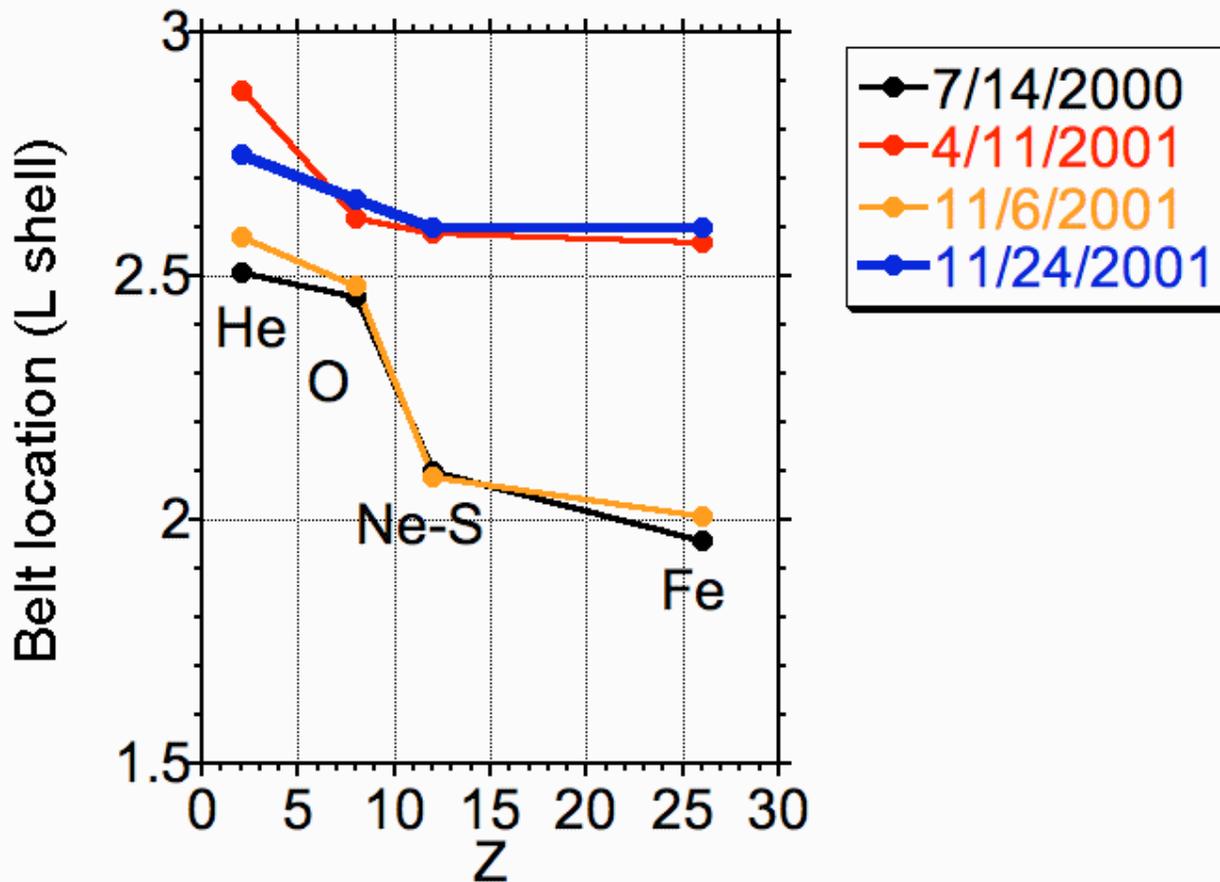
- What is required for creation of a new ion belt?
- SEP access to $L < 4$ during main phase of geomagnetic storm
- Sufficient intensity of SEPs

Statistics of new ion belts



- 39 SEP incursions below L=4 in 10 years
- All occurred during geomagnetic storms
- 13 of these incursions resulted in detectable new ion belts (33%)
- Creation depends upon SEP intensity *and* magnitude of storm
- DST related to SEP access, but high-latitude currents may also be important

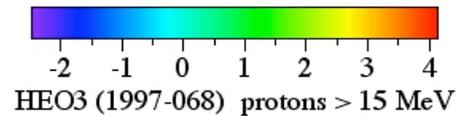
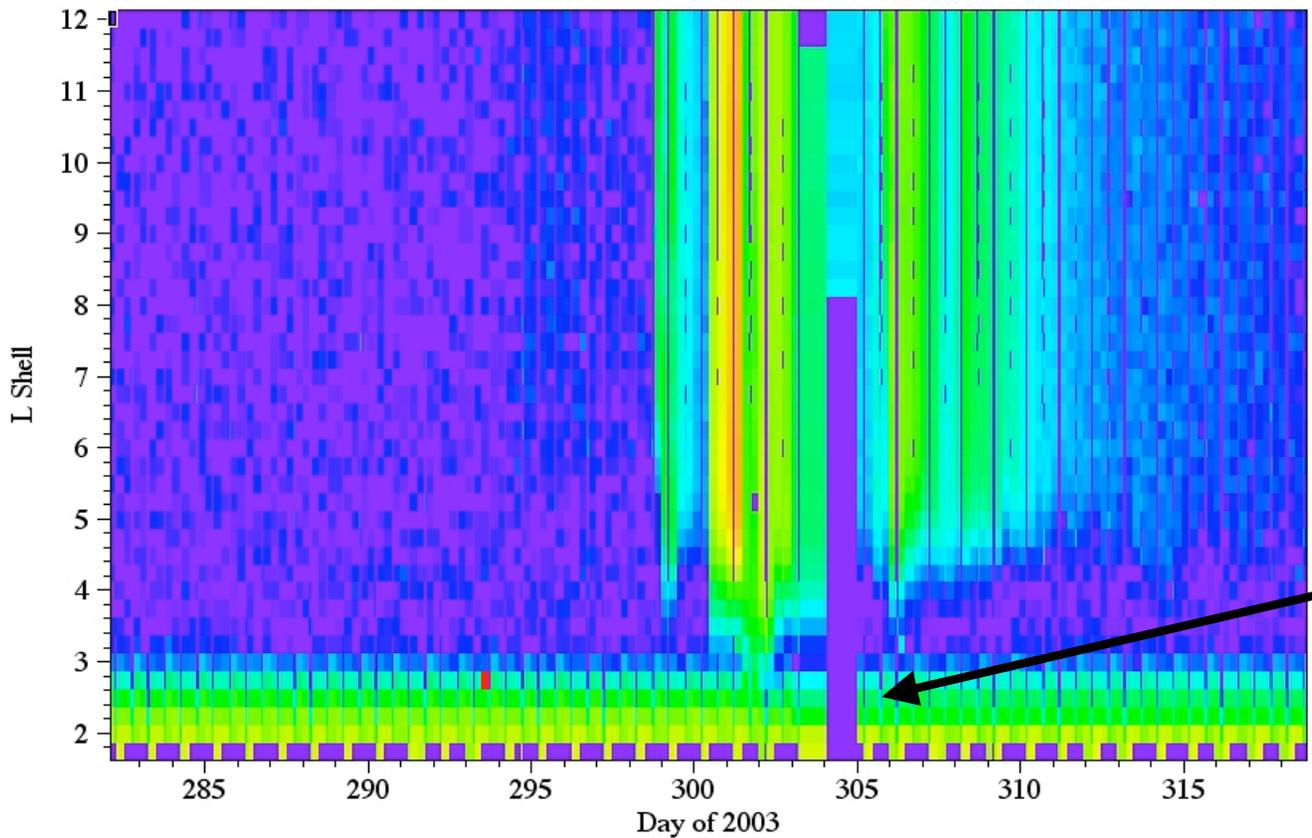
Statistics of new ion belts



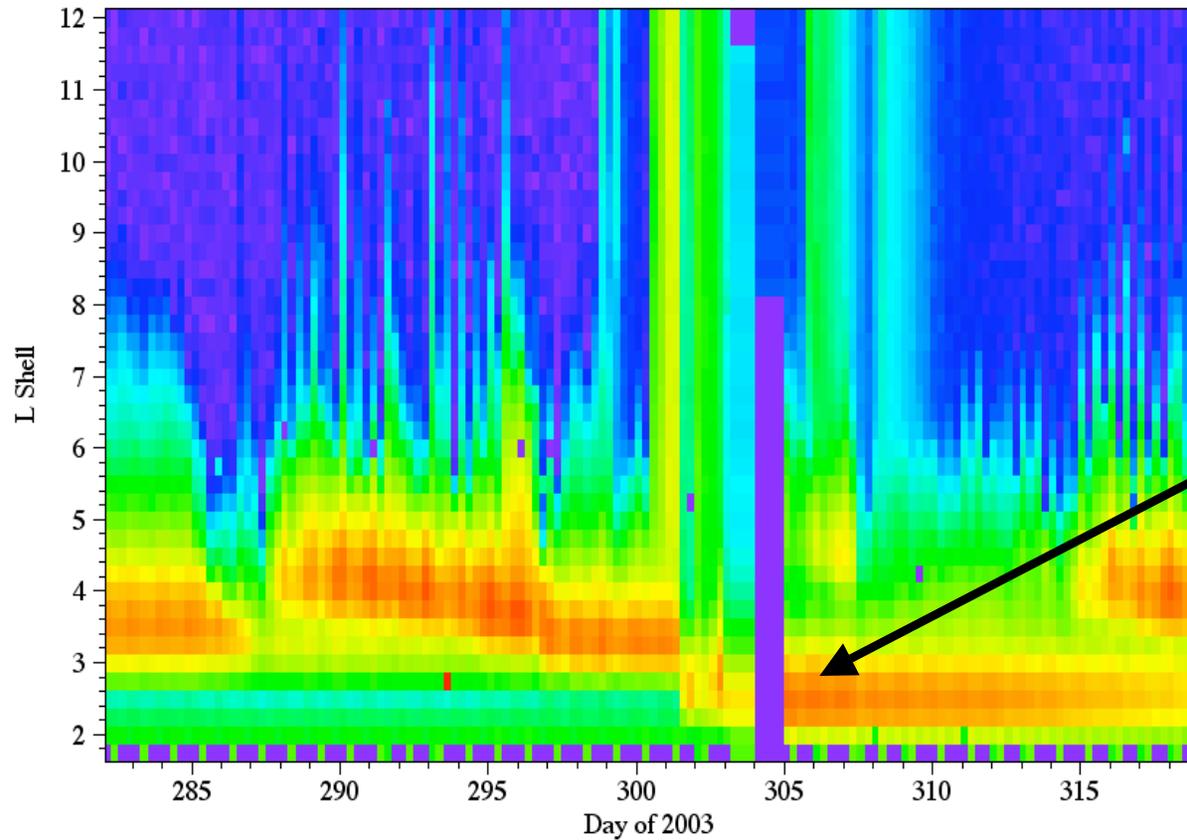
- Locations of new belts ordered by particle Z even for differences in mean L-shells as small as 0.2 L
- Indicates rigidity-dependent access and trapping

October-November 2003

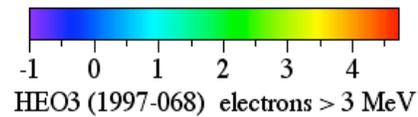
Protons > 15 MeV

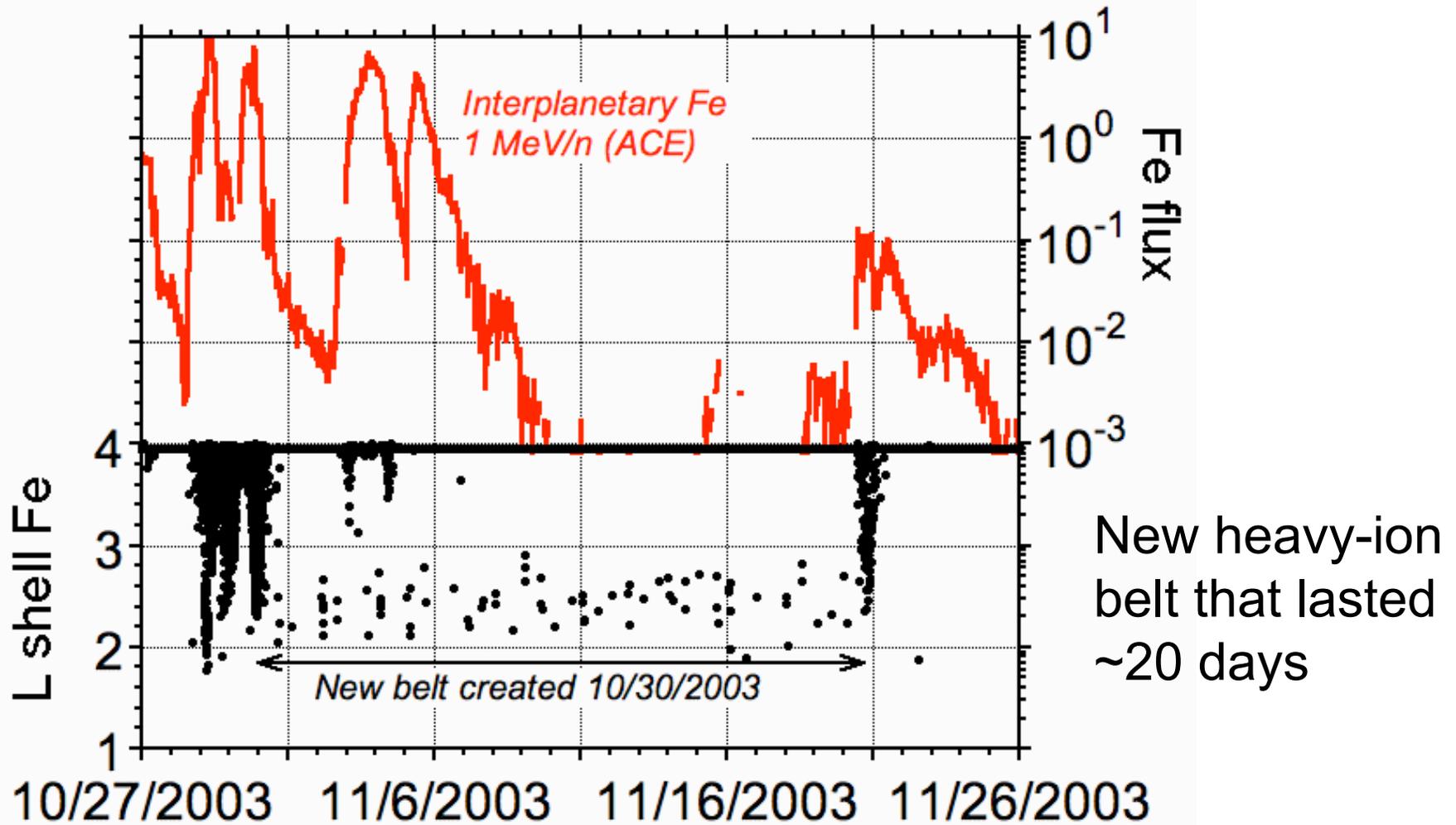


Electrons >3 MeV

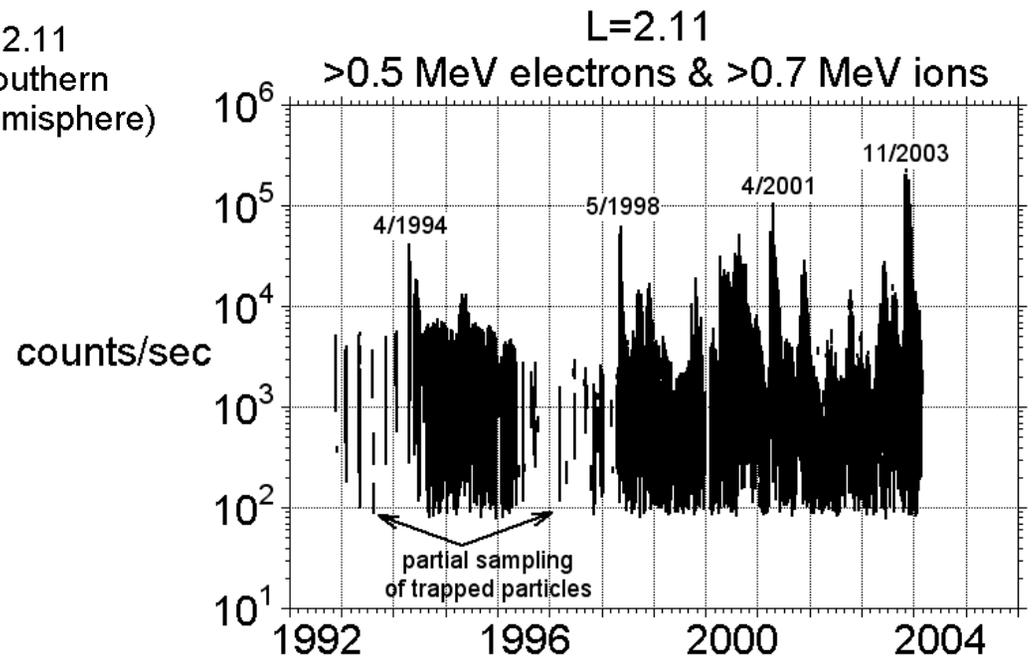
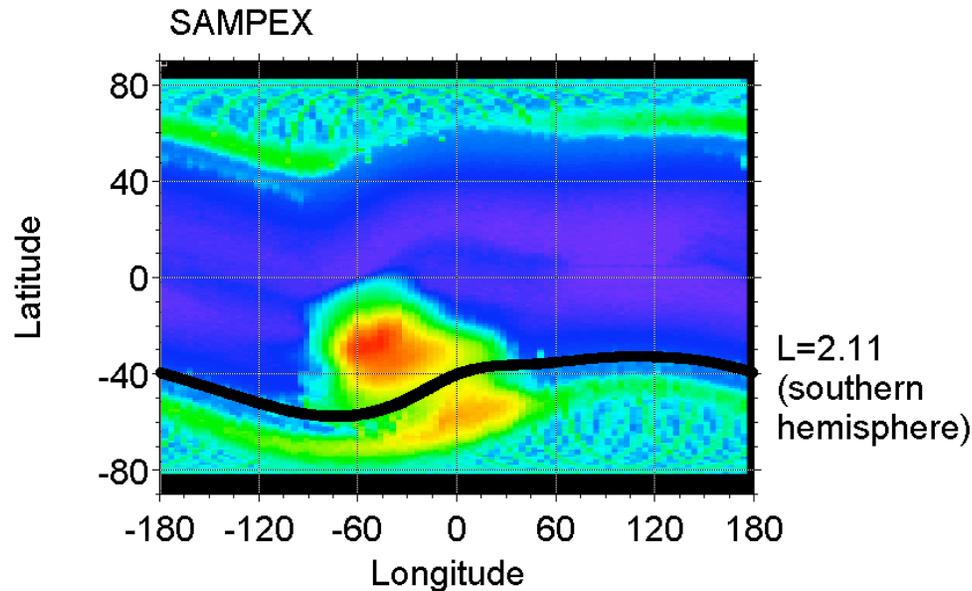


Multi-MeV electrons
at L~2.5

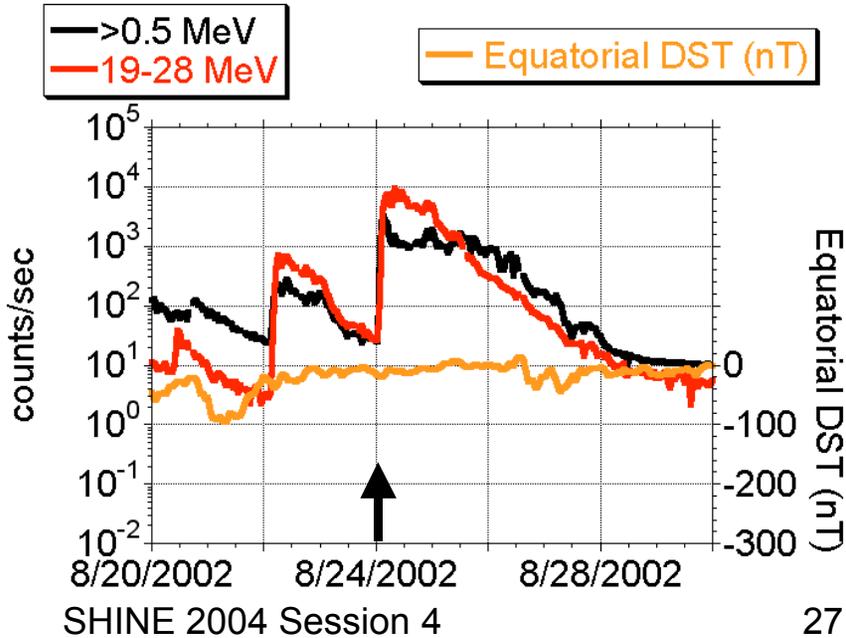
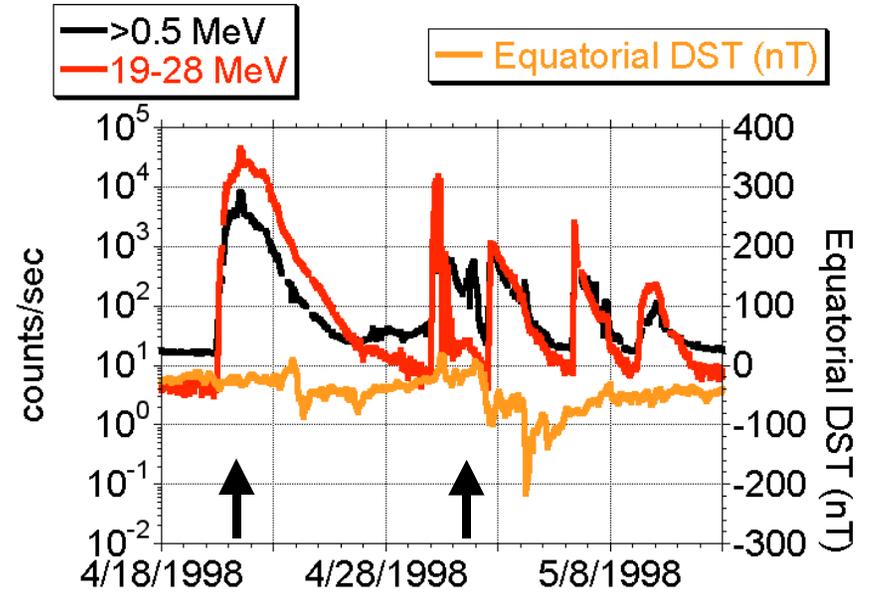
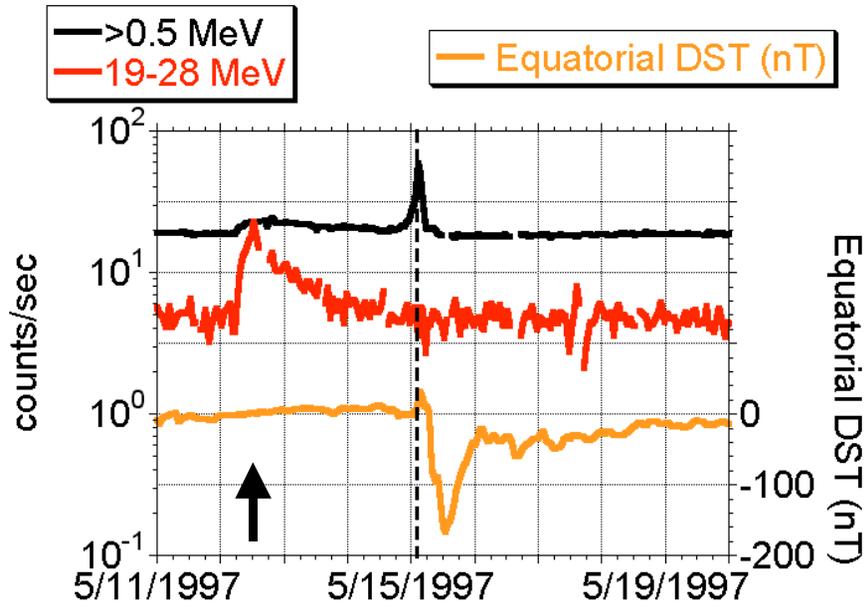




Highest intensity of trapped ~ 0.5 MeV particles at L=2 in 11.5 years



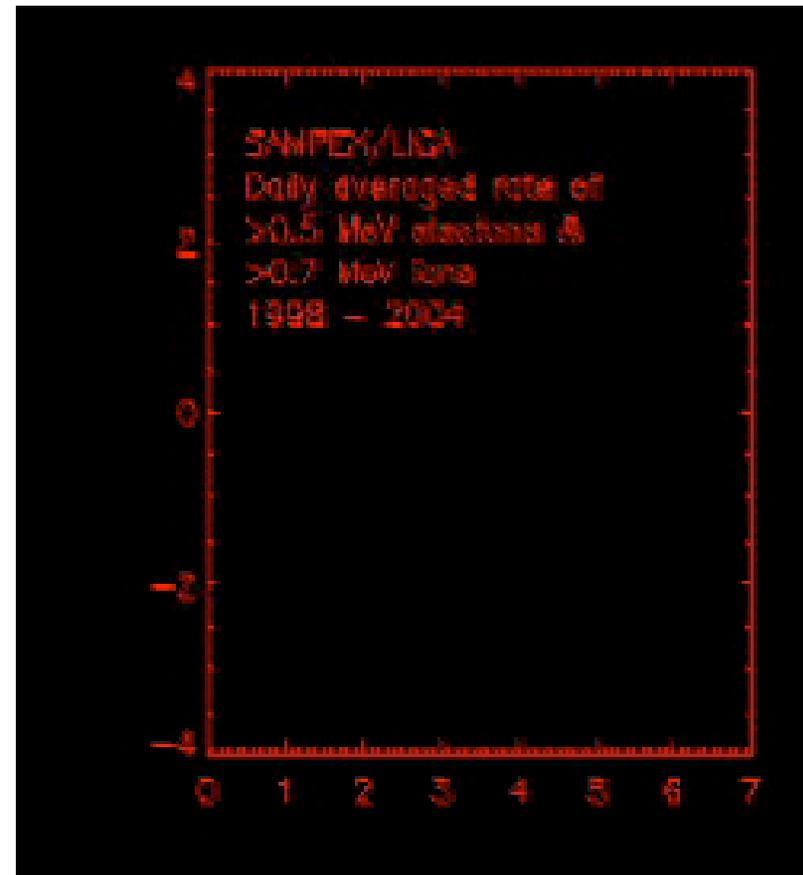
SHINE campaign events



SHINE campaign events:
no new ion belts

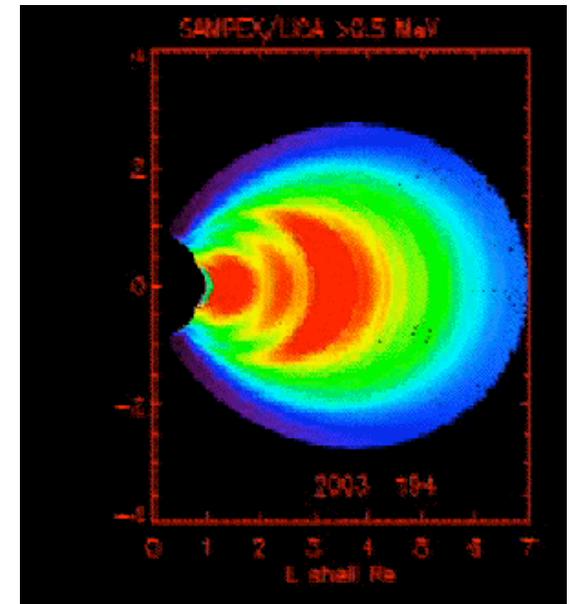
Recent History of the Radiation Belts

- SAMPEX daily averaged data mapped to a dipole
- >0.5 MeV electrons
- >0.7 MeV protons
- 1998 to 2004



Summary

- Inner magnetosphere is a dynamic place and a reservoir of interplanetary and interstellar material
- Previous best example of SEP-related new belts: March 1991
- This survey used heavy-ions as tracers of solar particle material that becomes trapped in the inner magnetosphere during intense SEP events with geomagnetic storms
 - One-third of the SEP incursions below L=4 resulted in new belts
 - Belt creation dependent on SEP intensity and size of storm
 - Not clear what determines belt location
- Heavy-ion belt decay consistent with energy loss

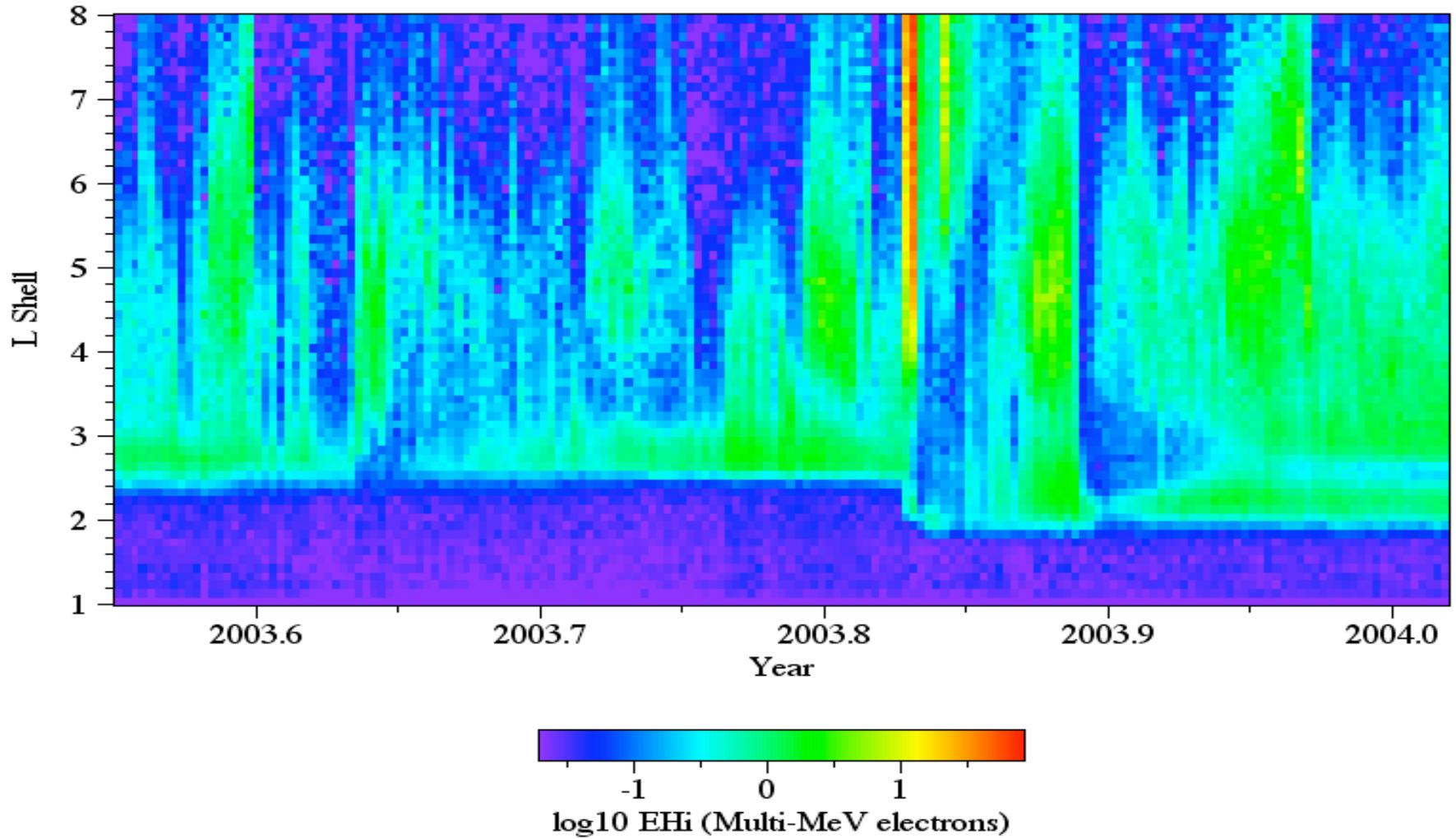


The way ahead

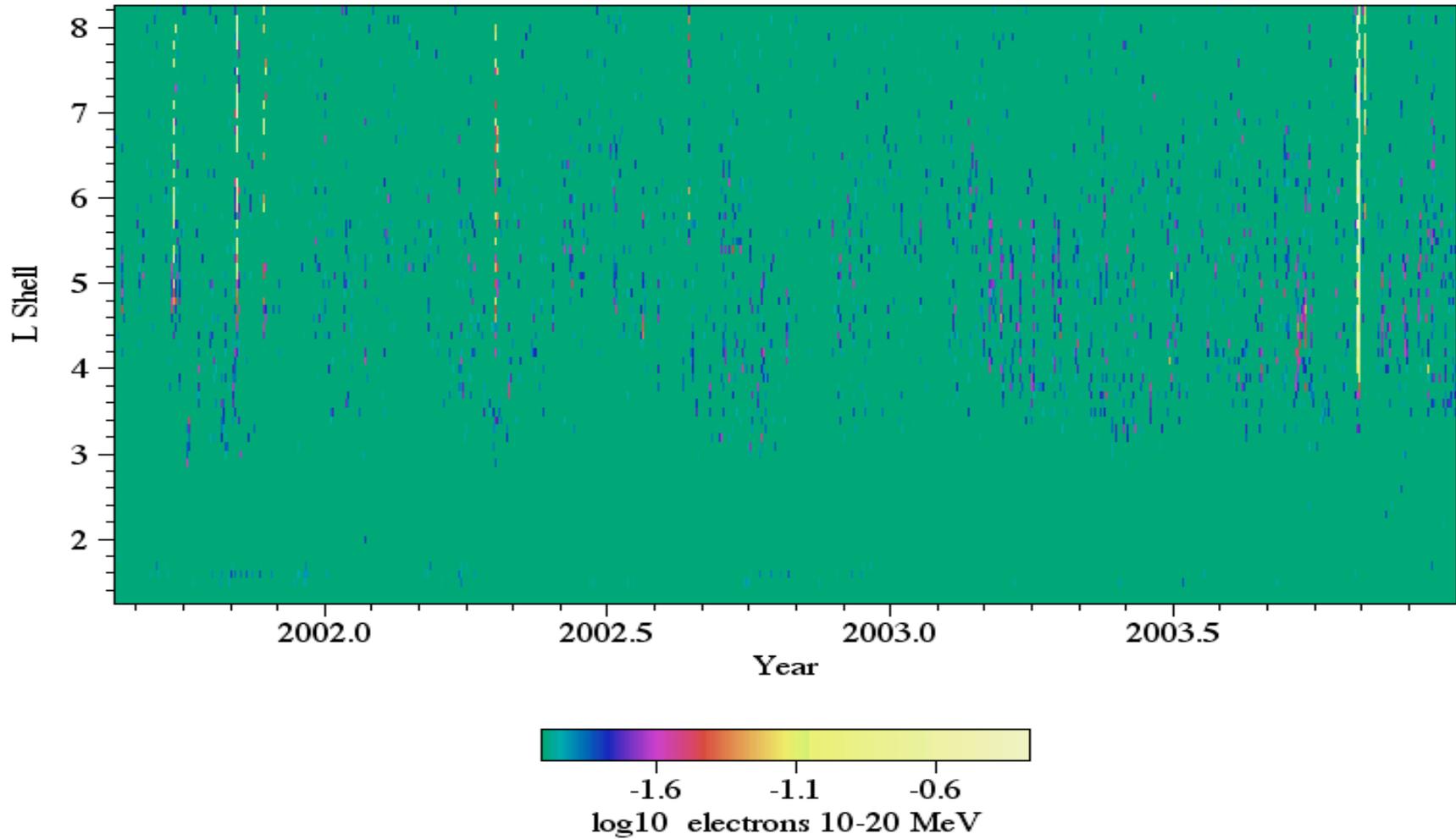
- Modeling of shock events
 - what solar wind characteristics lead to the fast risetime in ground-based magnetometer observations of storm commencements?
 - what is the temporal cadence of solar wind measurements needed for modeling ssc risetimes of a minute or less?
- High-duty cycle measurements in the slot region:
 - ion composition sensors
 - electron sensors with good energy resolution and dynamic range to more than 10 MeV
 - comprehensive field investigations

Backup charts

SAMPEX



SAMPEX

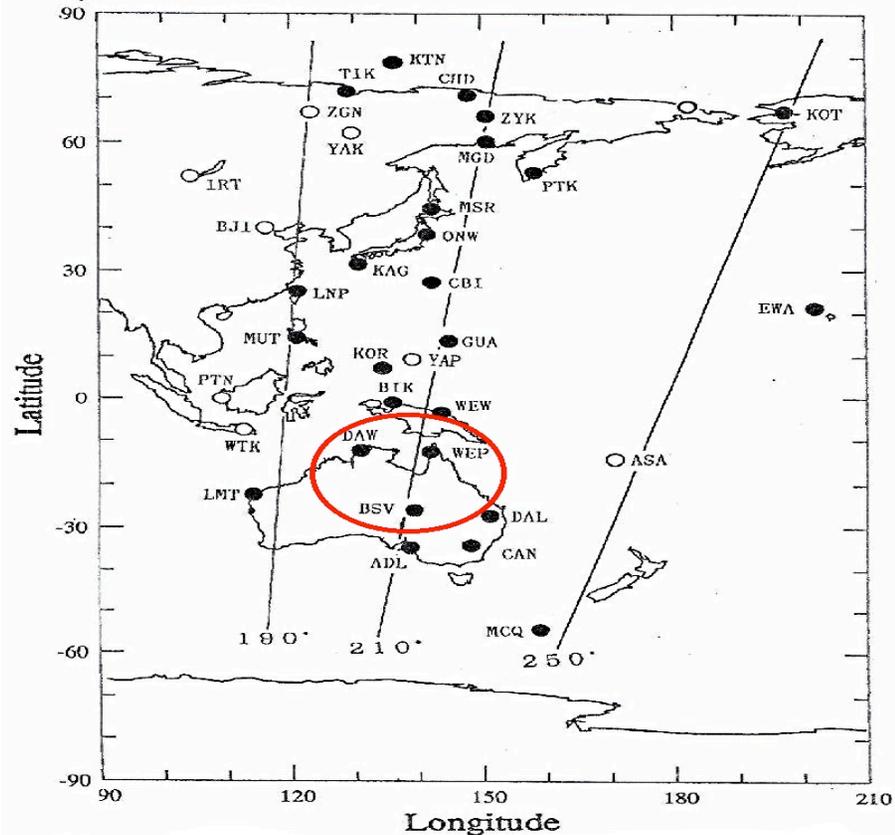


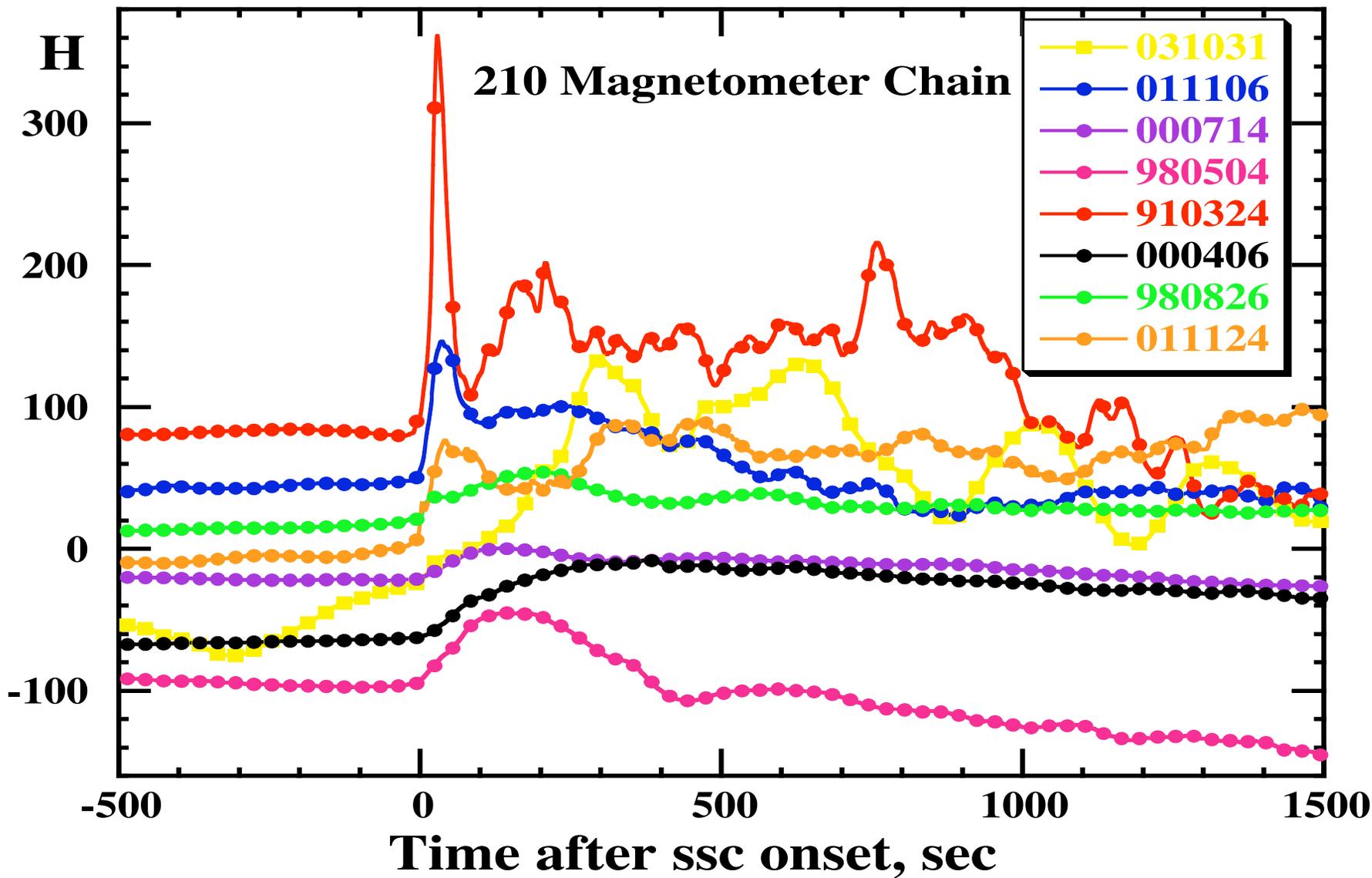
31 October 2003

- No energetic protons injected
- Multi-MeV electrons appear at $L = 2.5$
 - direct shock association unclear
- 10-20 MeV electrons among solar population
 - First time seen by SAMPEX (launch July 1992)

210 Magnetometer Chain

- Timing of the SSCs associated with energetic particle injection events determined using the 210 Magnetometer chain.
- Allows comparisons of the state of the Earth's magnetic field at high time resolution.

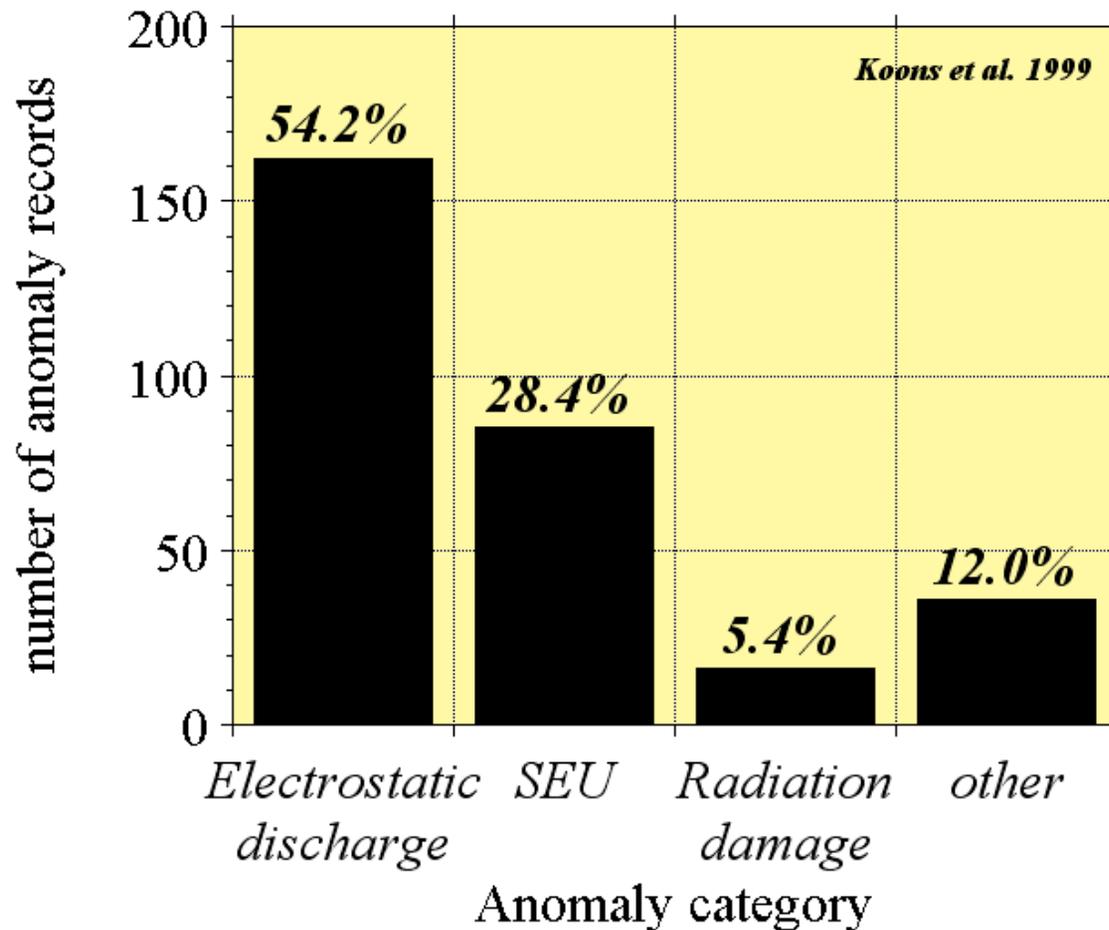




Upsets and Anomalies Caused by the Space Environment

- Loss of data
- Spurious signals
 - False alarms, noise strobes, erroneous telemetry values
- Phantom commands
 - For example gain changes and attitude sensor errors
- Mission or sensor degradation
- Solar array degradation
- Safeholds
- Latchups
- Subsystem failure
 - Loss of a redundant system
- Mission Loss

How can one assess the impact of the environment?
Examples from one or two missions are not sufficient.



- Survey of spacecraft anomaly databases (Space Architect Study: Koons et al. 1999)

- This study quantified the impact of the space environment by looking at how long it took to solve the problem

- Difficulties: many spacecraft operators do not want their troubles to be known

- Few radiation damage records probably due to conservative limits in the models & conservative designs

Space Environment Hazards

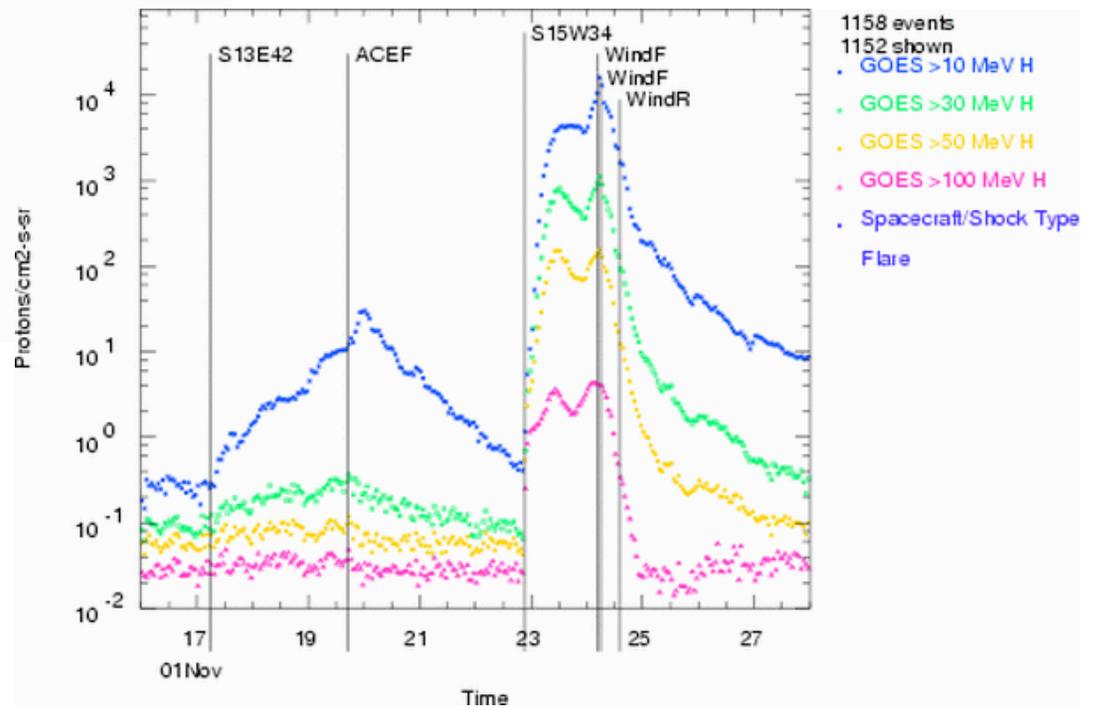
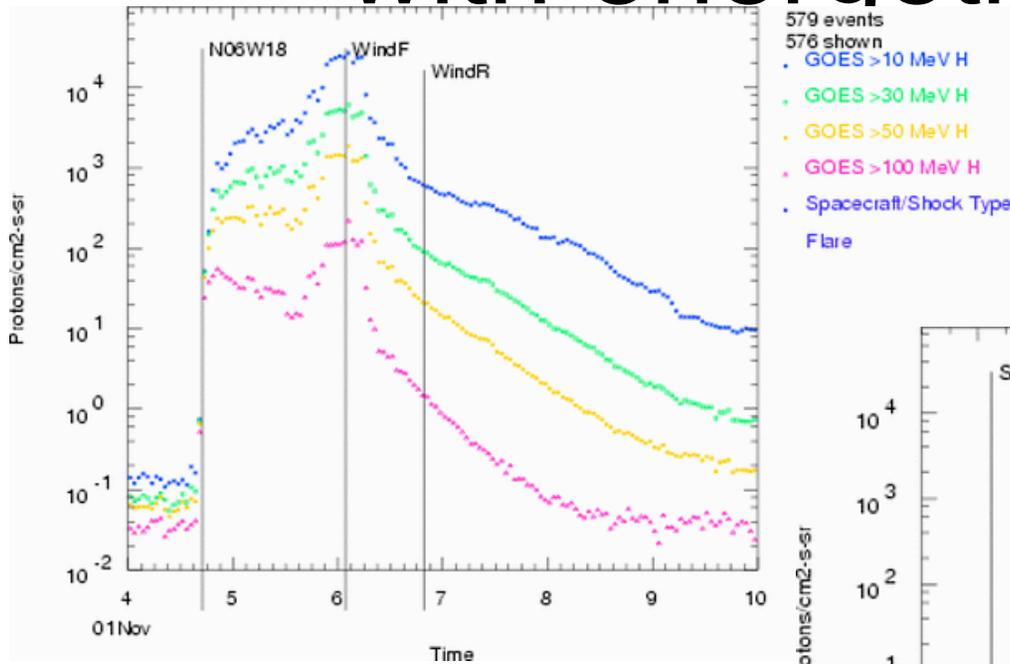
	space hazard	spacecraft charging:		single event effects			total radiation dose		surface degradation		plasma interference with spacecraft communication	
	specific cause	surface	internal	galactic cosmic rays	trapped radiation	solar particle	trapped radiation	solar particle	ion sputtering	O+ erosion	scintillation	wave refraction
orbit	LEO i<60	1	1	not applicable	2	not applicable	2	1	1	2	2	2
	LEO i>60	1	1	2	2	2	2	1	1	2	2	2
	MEO	2	2	2	2	2	2	2	1	2	2	2
	GPS i~55	2	2	2	not applicable	2	2	2	1	2	2	2
	GTO	2	2	2	2	2	2	2	1	1	2	2
	GEO	2	2	2	not applicable	2	2	2	1	1	2	2
	HEO	2	2	2	2	2	2	2	1	1	2	2
	Interplanetary	not applicable	not applicable	2	not applicable	2	not applicable	2	1	not applicable	1	1

Table key:

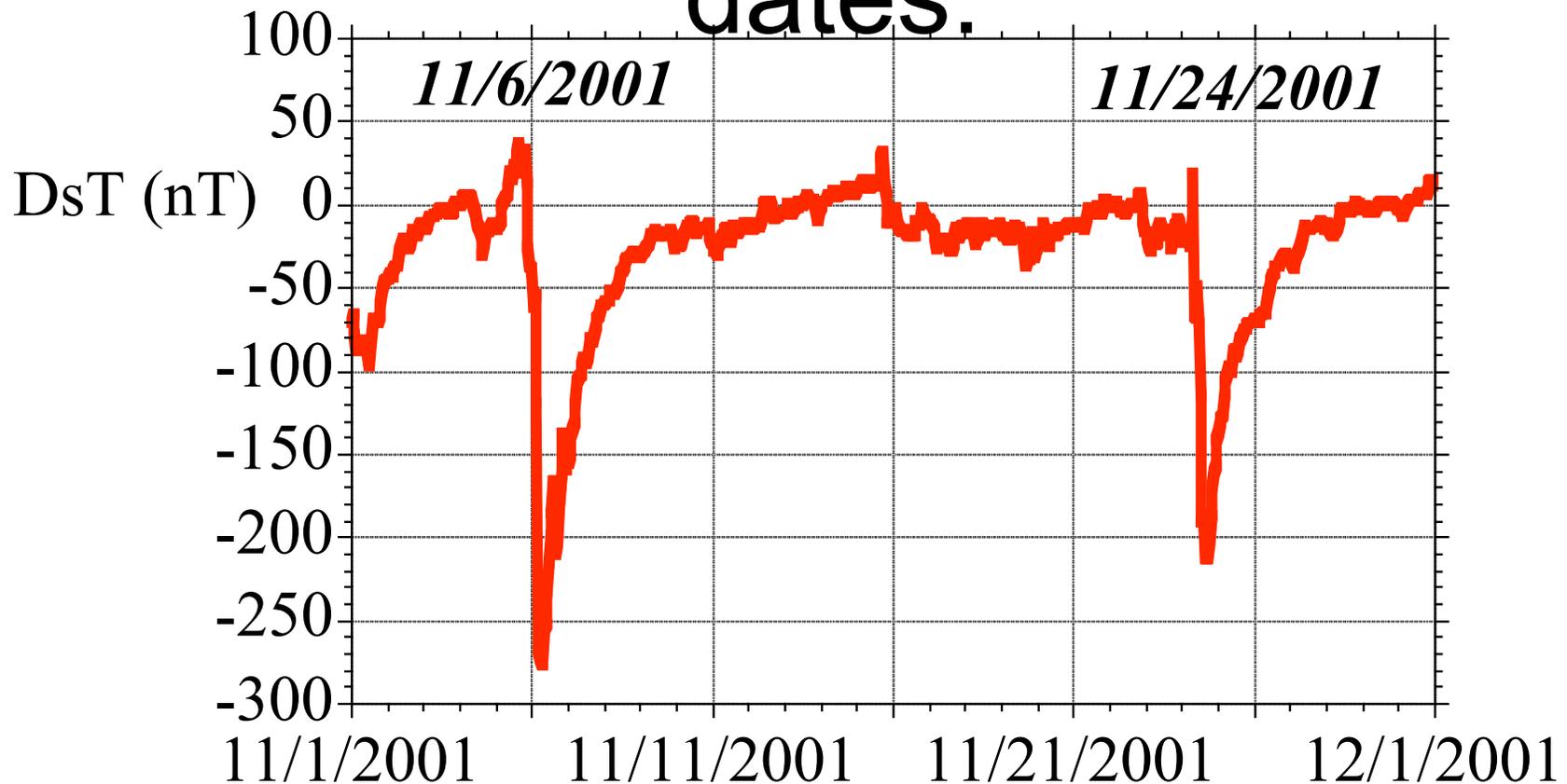
2 important
1 relevant

6 & 24 November 2001

The inner heliosphere filled with energetic particles

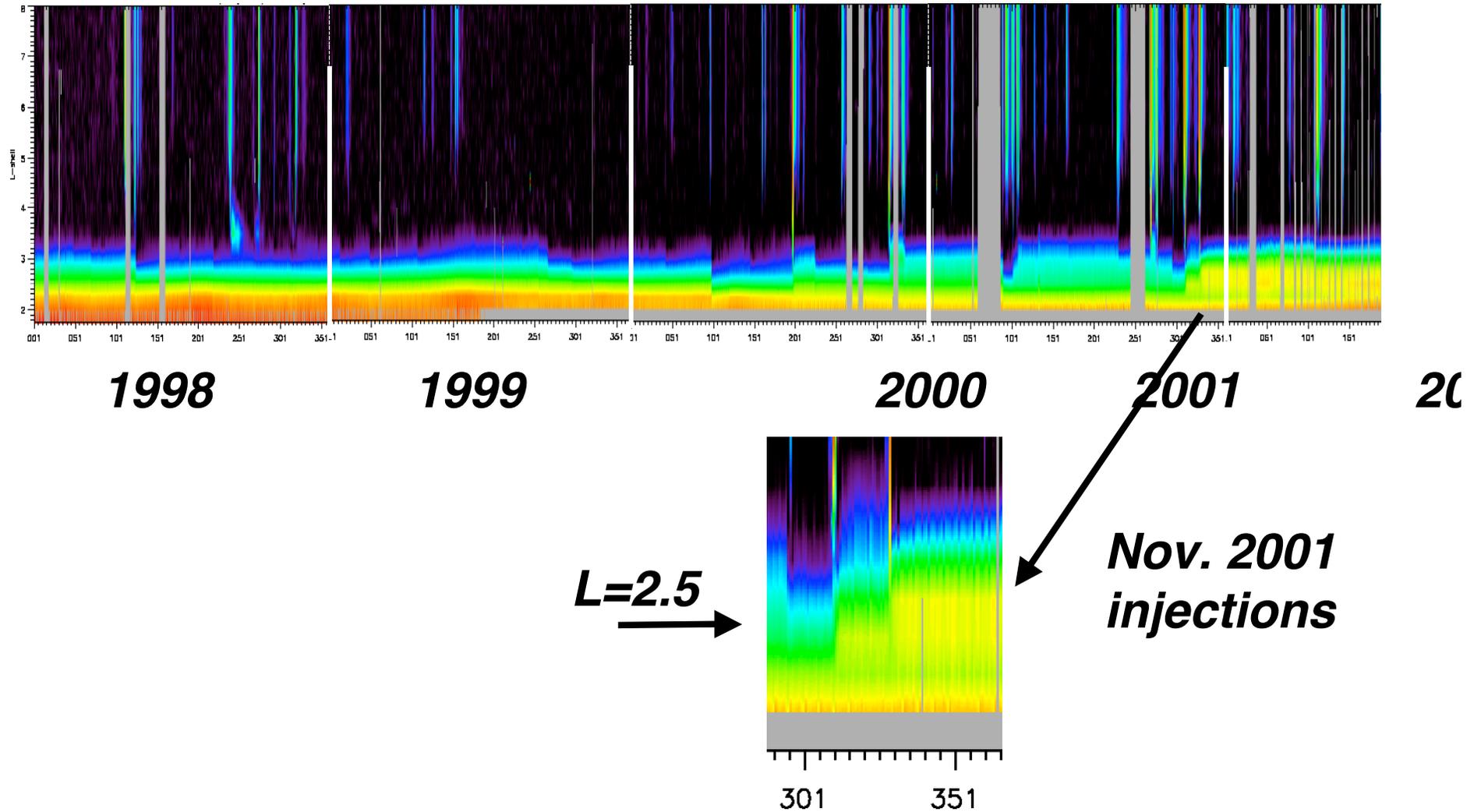


The CME-related shocks caused geomagnetic storms on these dates:

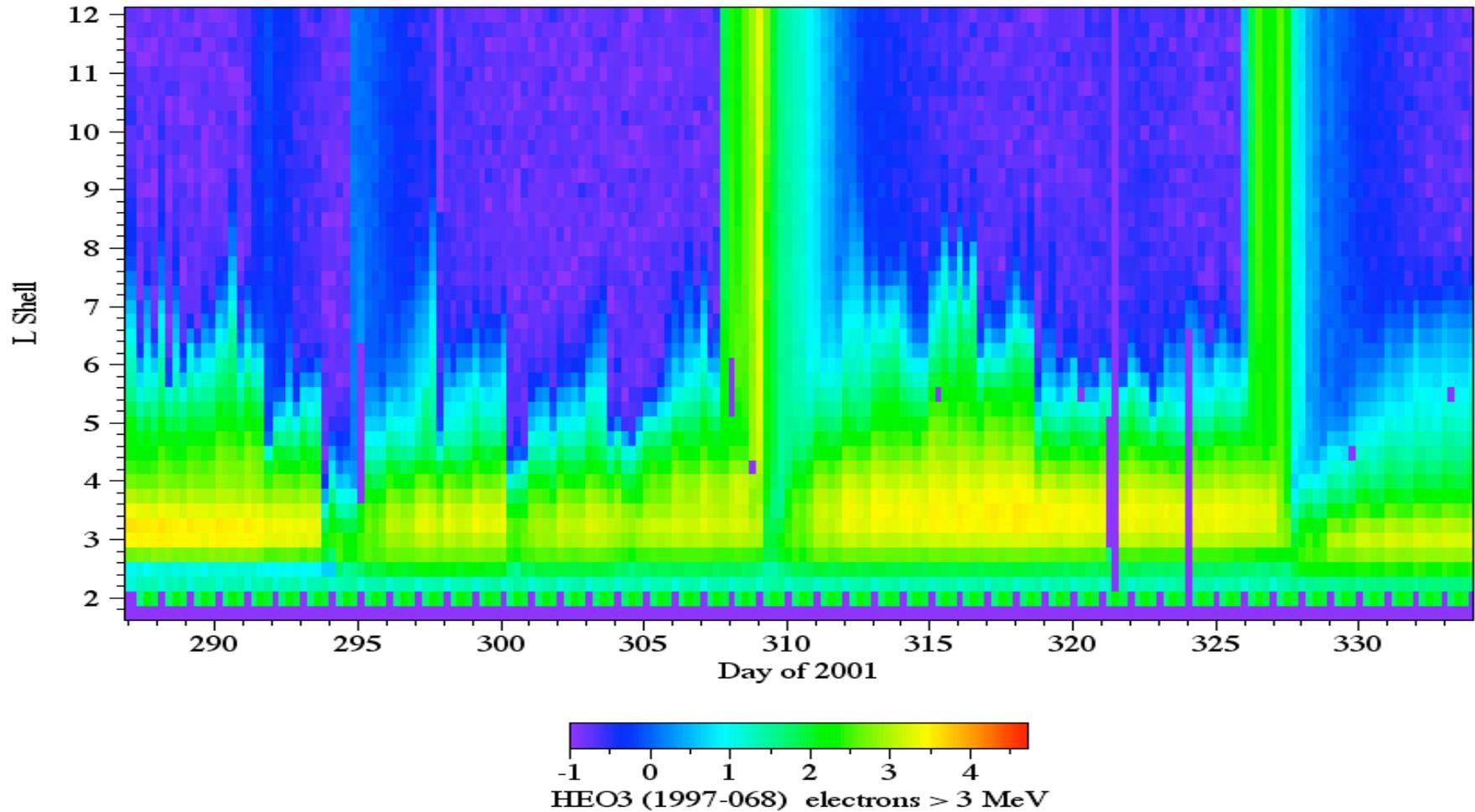


DST data from <http://swdcwww.kugi.kyoto-u.ac.jp/wdc/Sec3.html>

Radial Profile of 15 MeV Protons



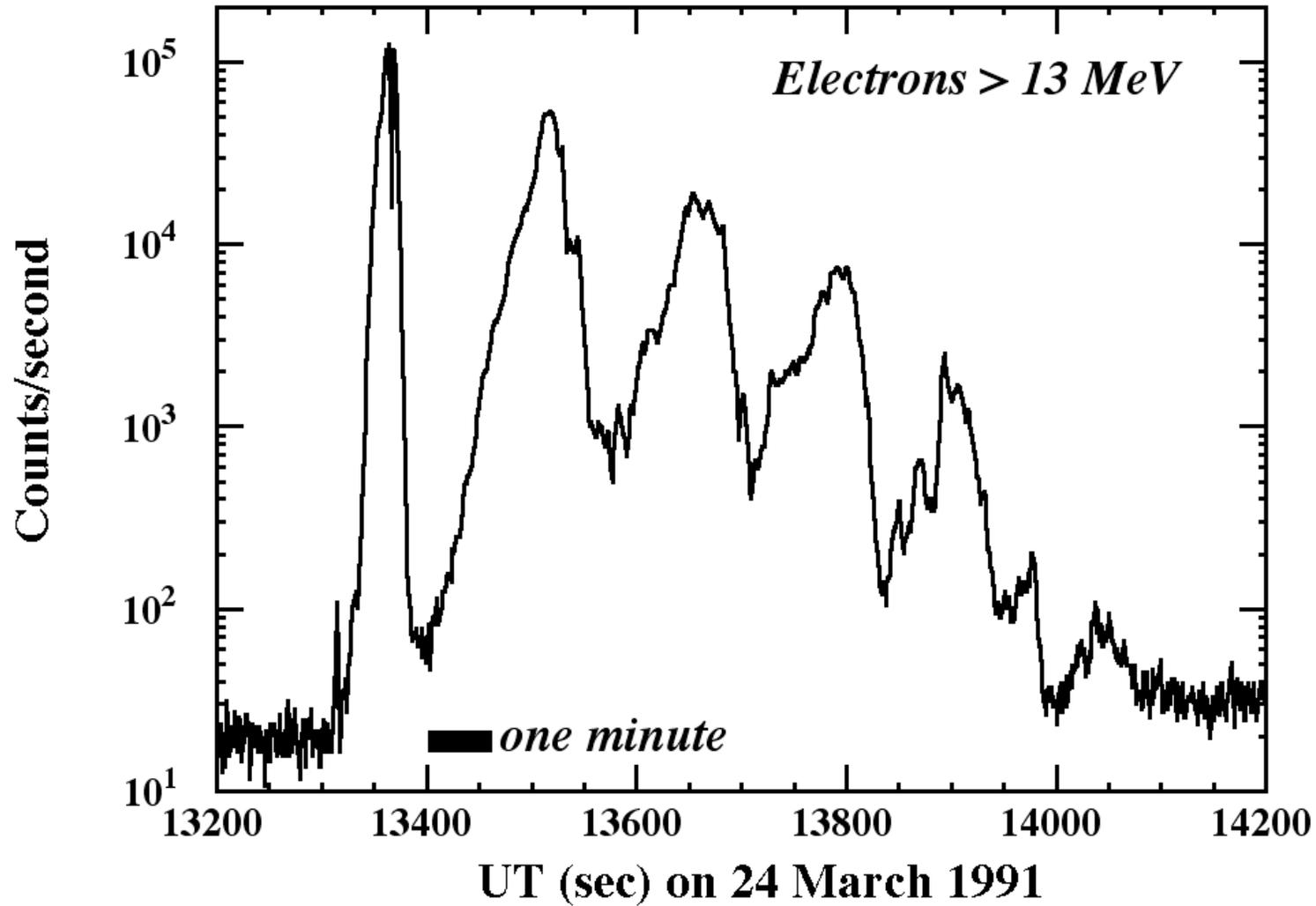
NOVEMBER 2001



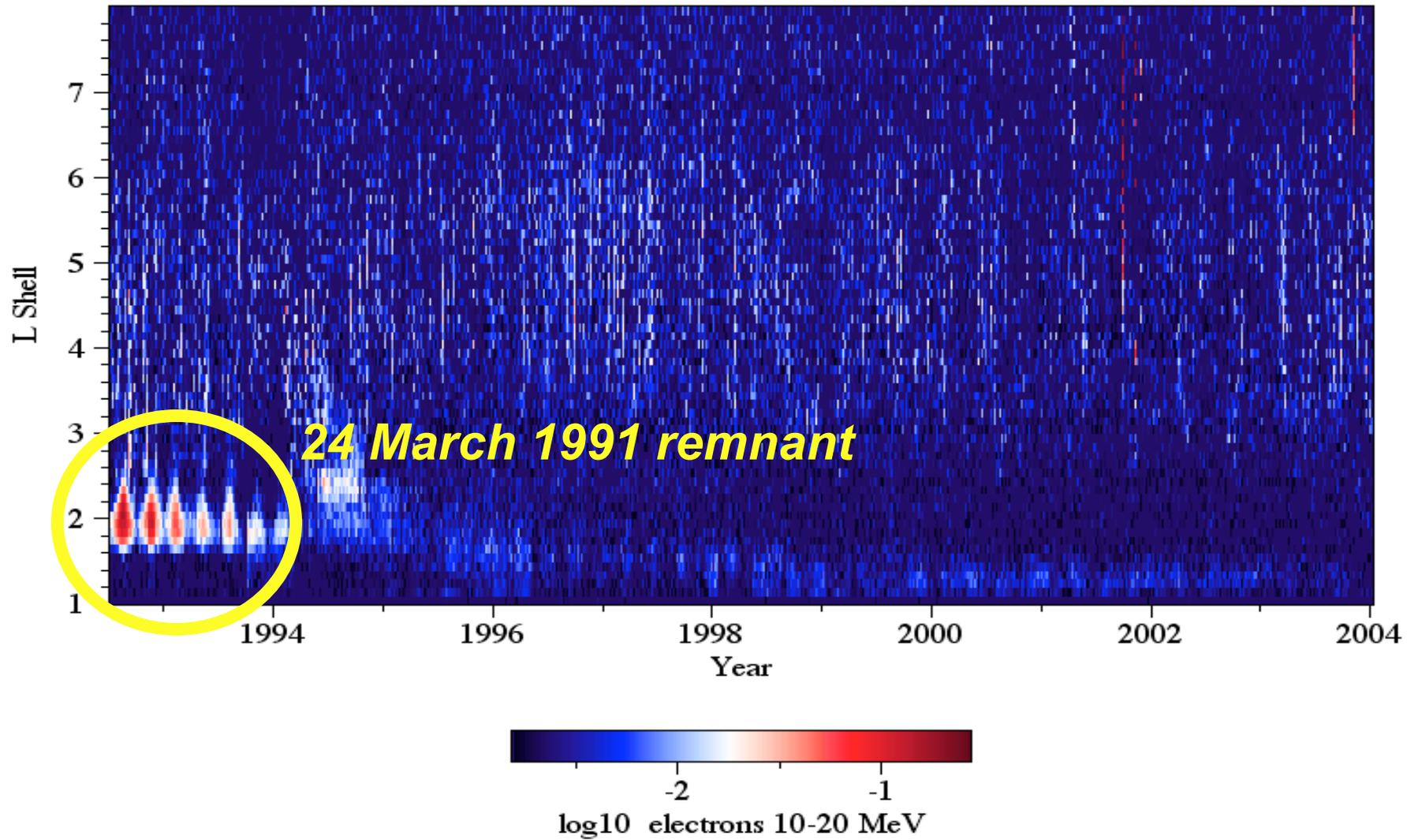
6 and 24 November 2001 Events

- 6 Nov injection may have been prompt, certainly occurred within few hours
- 24 Nov injection partially obscured by 6 Nov, also may have been prompt
- Injection of heavy ions, including Fe observed
- No electrons clearly associated with ion injections

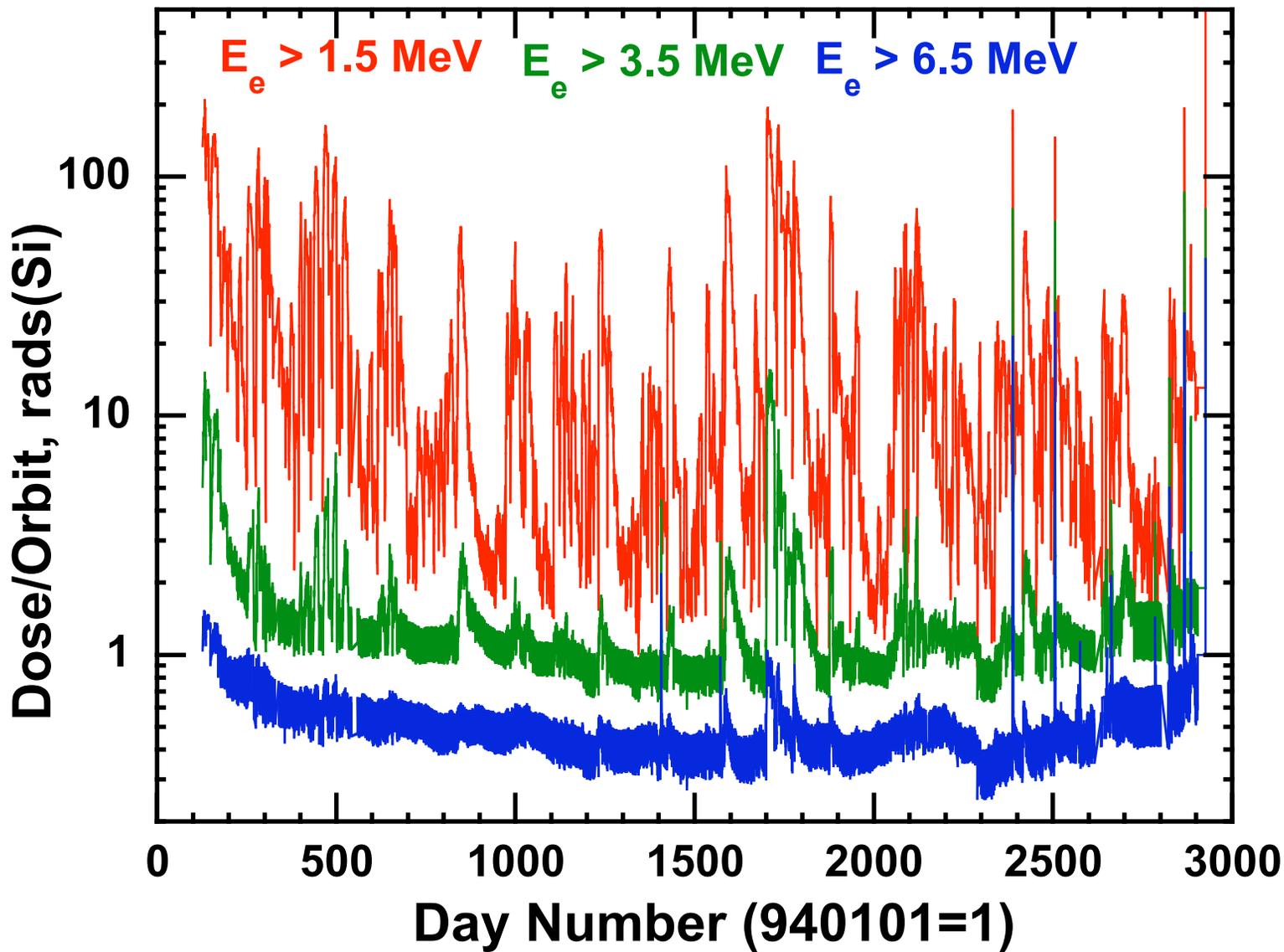
CRRES: >13 MeV electrons



SAMPEX



HEO1 (1994-026)



Particle Lifetimes in New Belts

- Proton lifetimes in inner zone determined by energy loss in residual atmosphere and inelastic nuclear collisions
- At 50 MeV, lifetime is ~ 3 years