Monitoring capabilities of the Earth charged particle environment

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ONERA-DESP, Toulouse, France

CNES-CST, Toulouse, France

First European Space Weather Week

ESTEC, Noordwijk, 30th November 2004

HIGH ENERGY PARTICLES

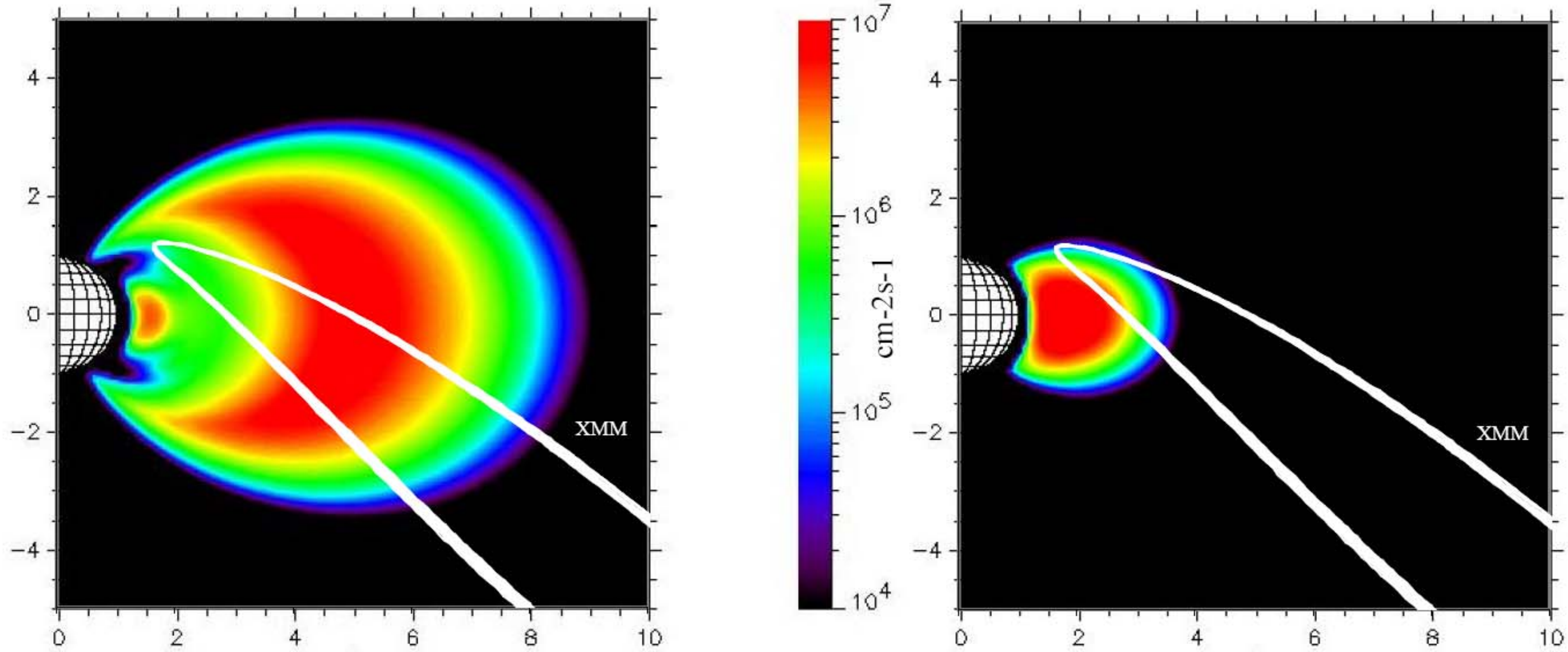
XMM - EPIC Radiation Monitor

SAC-C Icare

DEMETER IDP

ESA X-ray Multi Mirror Mission (XMM)

Launch: December 10, 1999



Orbit: 7000×114,000 km, i= 70°

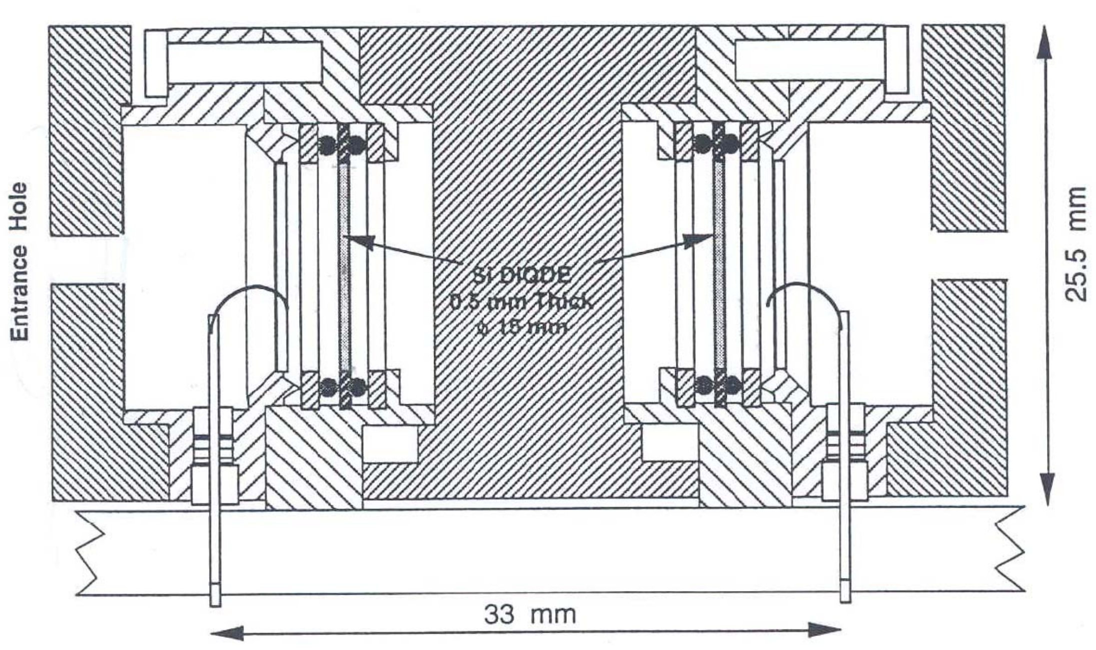
European Photon Imaging Camera, EPIC

EPIC radiation Monitor, ERM

Boer et al.,IEEE Transc. Nucl. Sci., vol.42, n°6, 1995

EPIC Particle Sensors

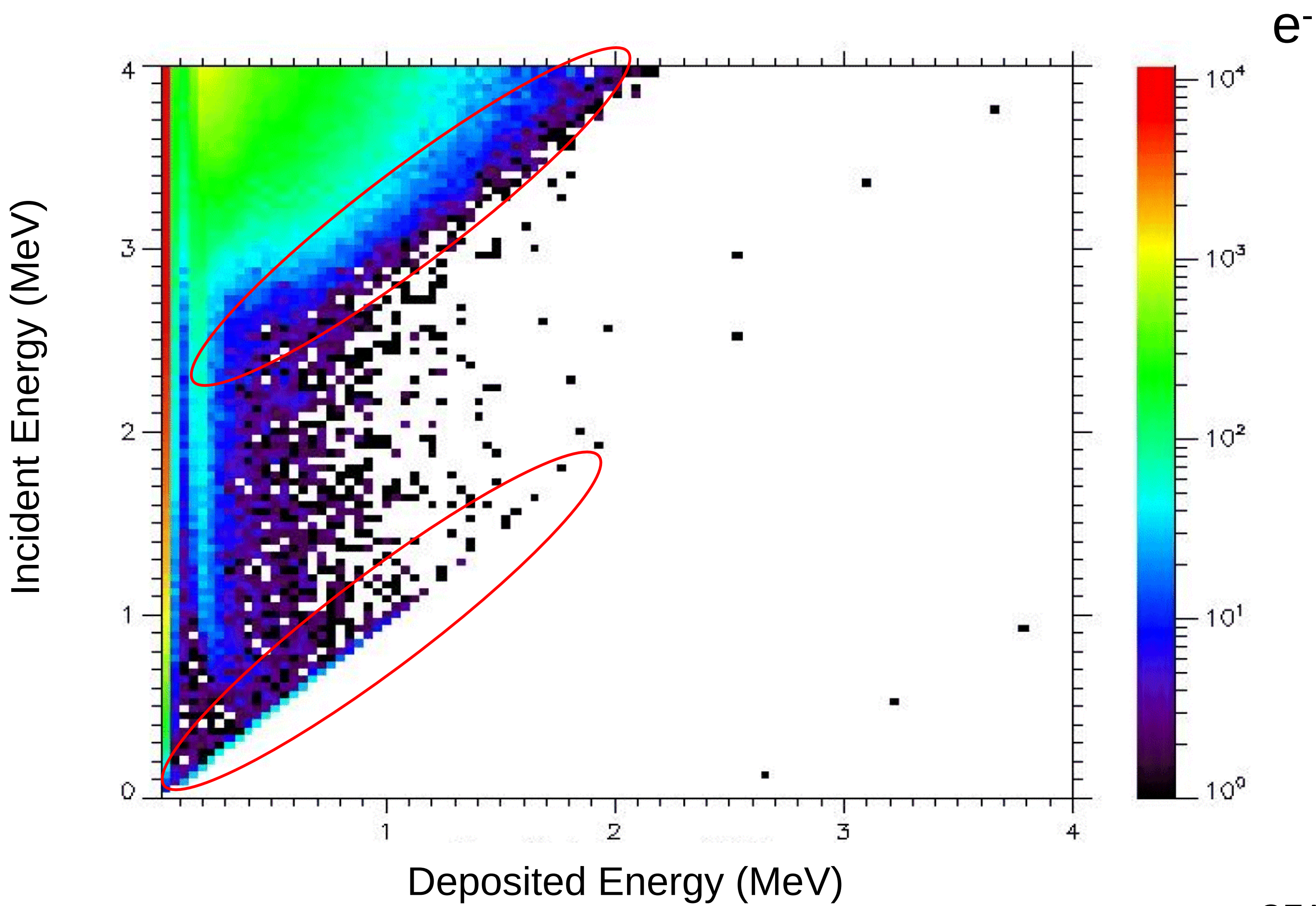
EPIC Low Energy Sensors



Electron energy range: 0.16 – 1.55 MeV

Proton energy range: 1.05 – 2.85 MeV

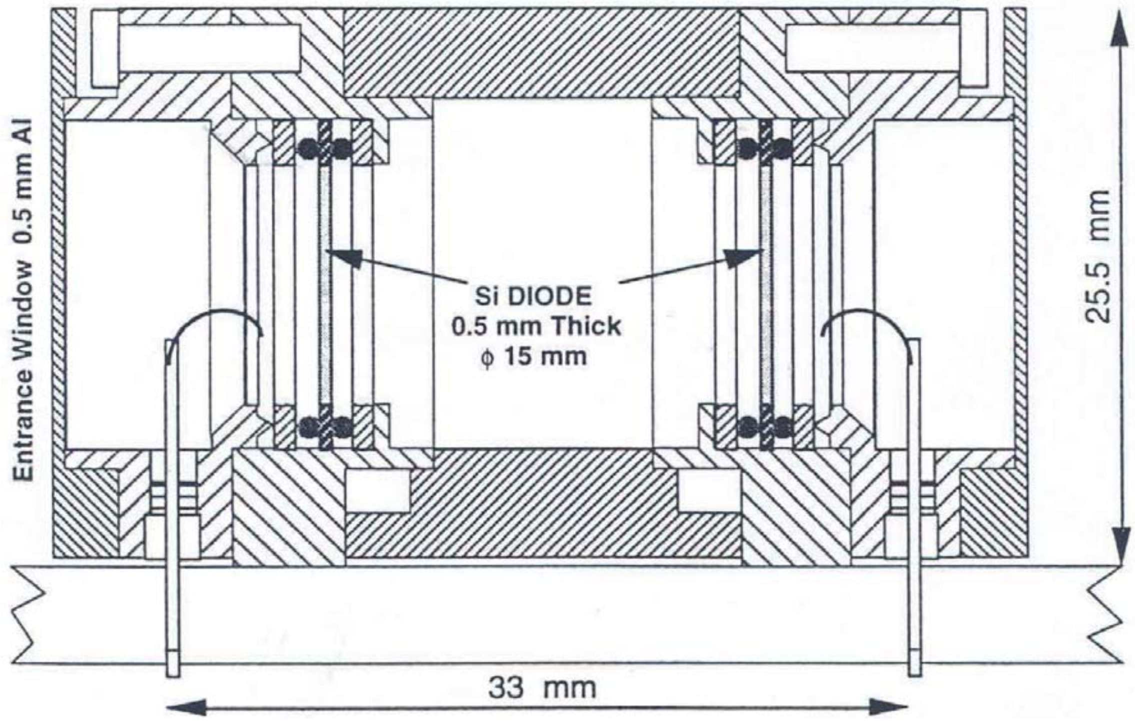
EPIC Low Energy Sensors



GEANT4

		Electrons				Protons			
Reduced channel name	Original channels	Energy (keV)	GEF ($cm^2 sr$)	Delta_e keV)	Flag	Energy (MeV)	GEF ($cm^2 sr$)	Delta_e (MeV)	Flag
LE1	8-11	164	0.0125	63	X	1.053	0.0154	0.030	
LE2	12-15	226	0.0146	63	X	1.079	0.0154	0.030	
LE3	16-19	290	0.0173	63	X	1.106	0.0155	0.030	
LE4	20-23	353	0.0189	63	X	1.140	0.0155	0.032	
LE5	24-27	416	0.0181	63	X	1.175	0.0155	0.034	
LE6	28-31	478	0.0183	63	X	1.211	0.0156	0.036	
LE7	32-35	542	0.0155	63	X	1.250	0.0156	0.038	
LE8	36-39	605	0.0126	63	1	1.289	0.0156	0.040	
LE9	40-47	698	0.0110	126	1	1.350	0.0157	0.086	
LE10	48-55	825	0.0053	126	1	1.438	0.0158	0.091	
LE11	56-67	980	0.0033	190	1	1.554	0.0159	0.142	
LE12	68-83	1200	0.00062	253	1	1.723	0.0160	0.199	
LE13	84-99	1454	0.00048	253		1.926	0.0162	0.208	1
LE14	100-119					2.164	0.0165	0.271	1
LE15	120-203					2.85	0.0172	1.208	X
LE16	204-255					4.5	0.026	1	X

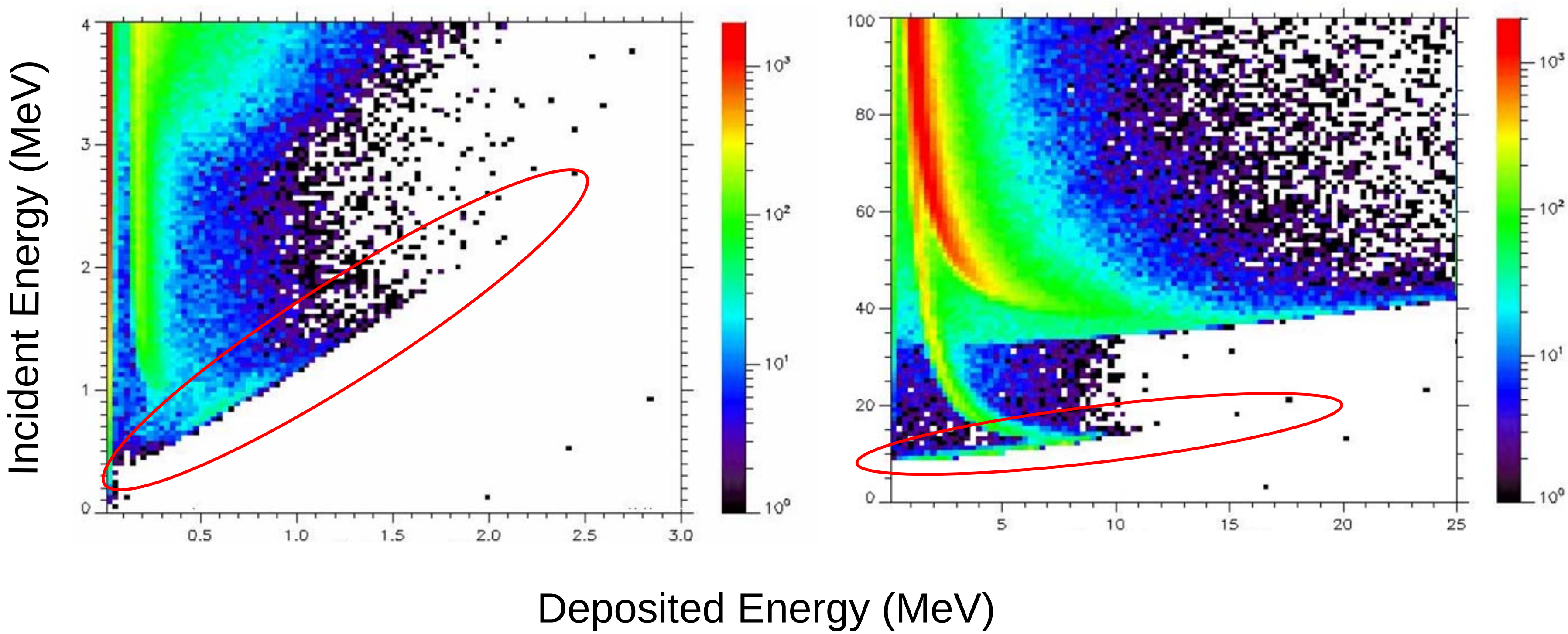
EPIC HIGH ENERGY SENSORS



Electron energy range: 0.95 – 2.54 MeV

Proton energy range: 8.7 – 76 MeV

EPIC HIGH ENERGY SENSORS



GEANT4

HIGH ENERGY TABLES

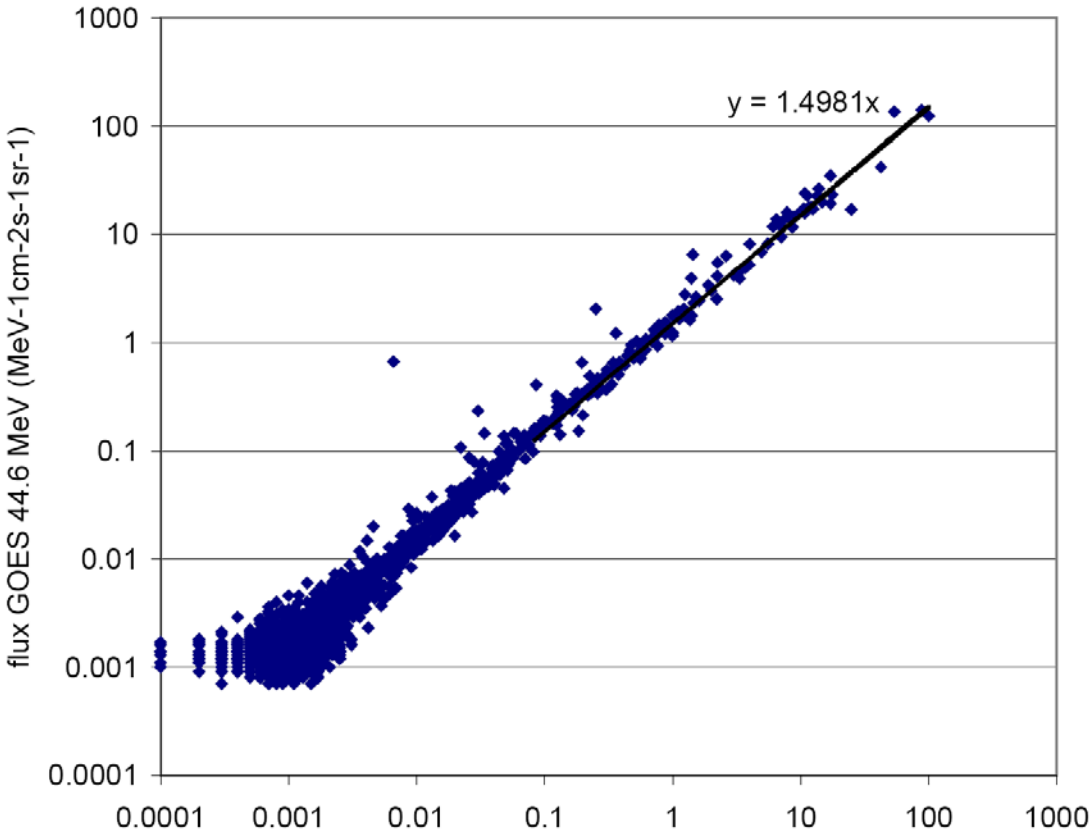
			Electrons				Protons		
Reduced channel name	Original channels	Energy (MeV)	GEF (cm^2sr)	Delta_e (keV)	Flag	Energy (keV)	Gef (cm^2sr)	Delta_e (keV)	Flag
HES1	8-11	0.95	0.166	240	1	8.735	0.013	0.024	
HES2	12-15	0.90	0.198	240	X	8.76	0.019	0.026	
HES3	16-19	1.07	0.122	240	X	8.785	0.026	0.029	
HES4	20-23	1.24	0.057	240	X	8.81	0.033	0.032	
HES5	24-27	1.41	0.027	240	1	8.85	0.042	0.036	
HES6	28-31	1.58	0.011	240	1	8.89	0.054	0.040	
HES7	32-35	1.75	0.0068	240	1	8.93	0.074	0.044	
HES8	120-203					11.8	0.47	2.61	1
HES9	204-255					37.	0.47	7.	1

		Electrons				Protons			
Reduced channel name	Original channels	Energy (MeV)	GEF (cm^2sr)	Delta_e (MeV)	Flag	Energy (MeV)	Gef (cm^2sr)	Delta_e (MeV)	Flag
HEC1	8-11	1.38	0.15	1	1	30	0.0003	1	1
HEC2	12-15	0.94	0.052	1	X	40	0.0003	1	1
HEC3	16-19	1.02	0.035	1	X	40	0.0003	1	1
HEC4	20-23	1.14	0.023	1	X	50	0.005	1	1
HEC5	24-27	1.3	0.013	1	X	49	0.004	1	1
HEC6	28-31	1.44	0.006	1	X	45	0.004	1	1
HEC7	32-35	1.62	0.0031	1	X	40	0.003	1	
HEC8	36-39	1.82	0.0018	1	1	35	0.003	1	
HEC9	40-47	2.02	0.0011	1	1	76	0.443	42	
HEC10	48-55	2.54	0.0005	1	1	65	0.298	41	
HEC11	56-67					44.6	0.085	9.33	1
HEC12	68-83					36.5	0.085	7.01	1
HEC13	84-99					30.9	0.085	4.40	1
HEC14	100-119					27	0.085	3.55	X
HEC15	120-203					22	0.085	6.1	X
HEC16	204-255					17.4	0.085	3.37	X

GOES versus XMM proton fluxes at 44.6 MeV

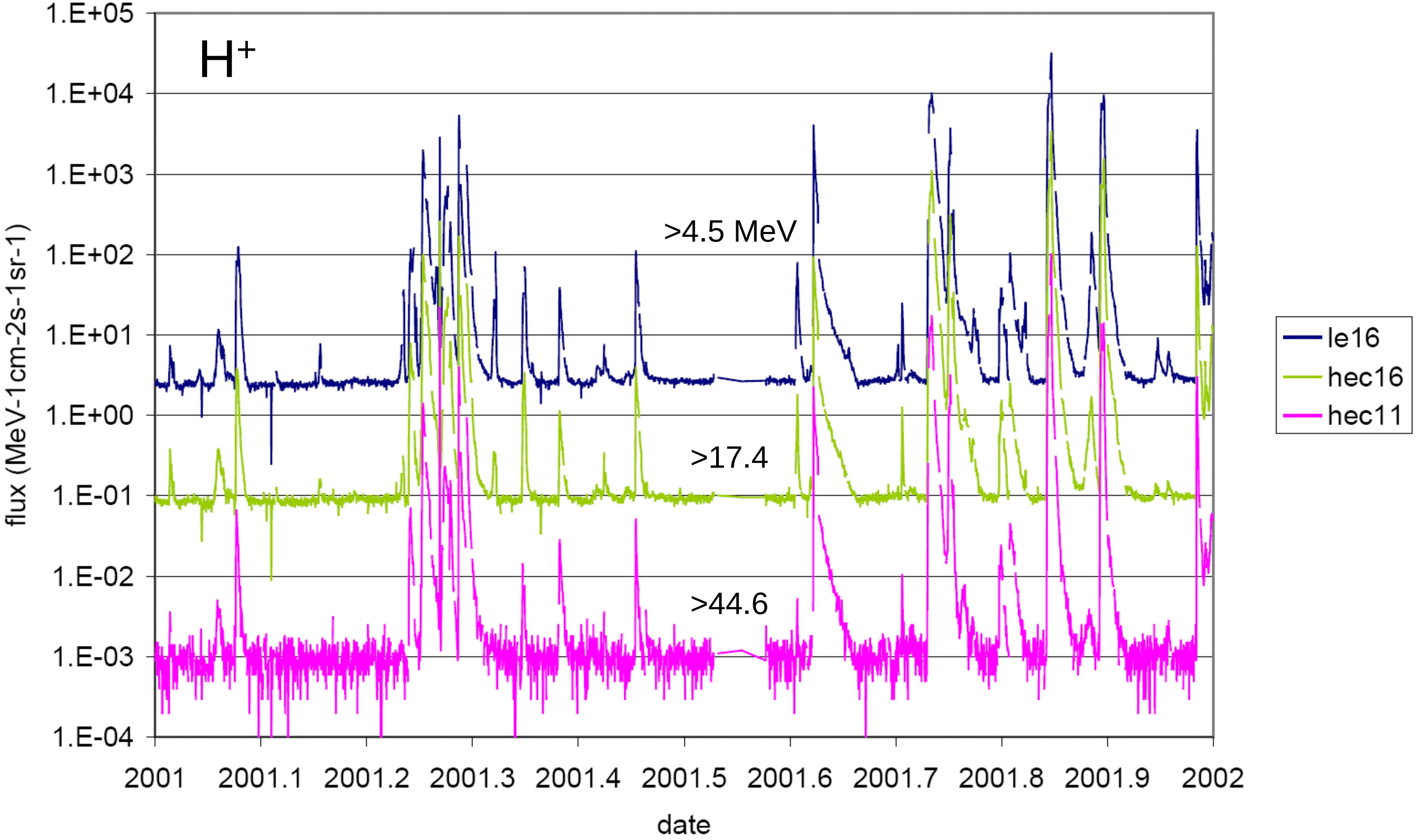
Solar proton event

GOES FLUX

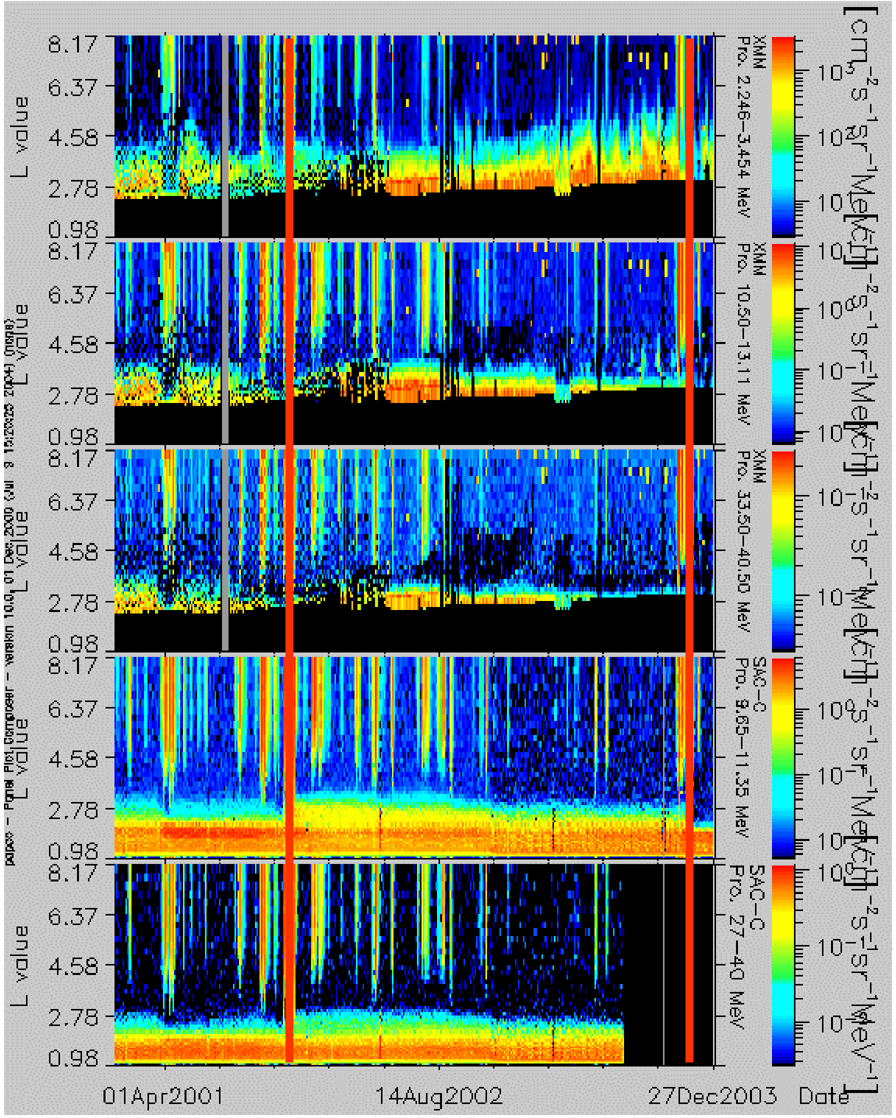


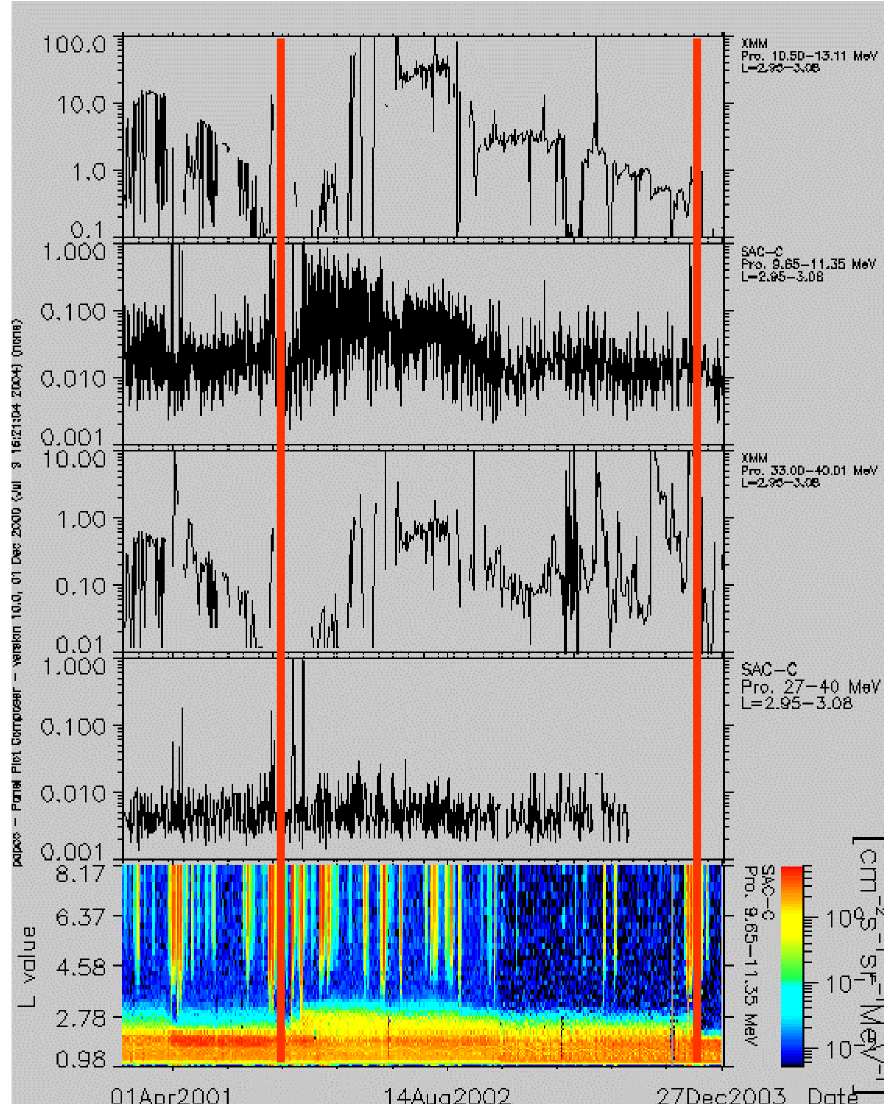
XMM FLUX

XMM-2001



H+
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
1.E-01
1.E-02
1.E-03
1.E-04
flux (MeV-1cm-2s-1sr-1)
>4.5 MeV
>17.4
>44.6
2001
2001.1
2001.2
2001.3
2001.4
2001.5
2001.6
2001.7
2001.8
2001.9
2002
date
le16
hec16
hec11


L value
8.17
6.37
4.58
2.78
0.98
XMM Pro. 2.246–3.454 MeV
XMM Pro. 10.50–13.11 MeV
XMM Pro. 33.50–40.50 MeV
SAC-C Pro. 9.65–11.35 MeV
SAC-C Pro. 27–40 MeV
01Apr2001
14Aug2002
27Dec2003
Date


XMM Pro. 10.50–13.11 MeV L=2.95–3.08
SAC-C Pro. 9.65–11.35 MeV L=2.95–3.08
XMM Pro. 33.00–40.01 MeV L=2.95–3.08
SAC-C Pro. 27–40 MeV L=2.95–3.08
SAC-C Pro. 9.65–11.35 MeV
L value
01Apr2001
14Aug2002
27Dec2003
Date

SAC-C (CONAE, Argentina)

- Orbit:

- 715 x 715km, inclination: 98.2º

- Launch :

- 21 Nov 2000 Delta-2 from VAFB

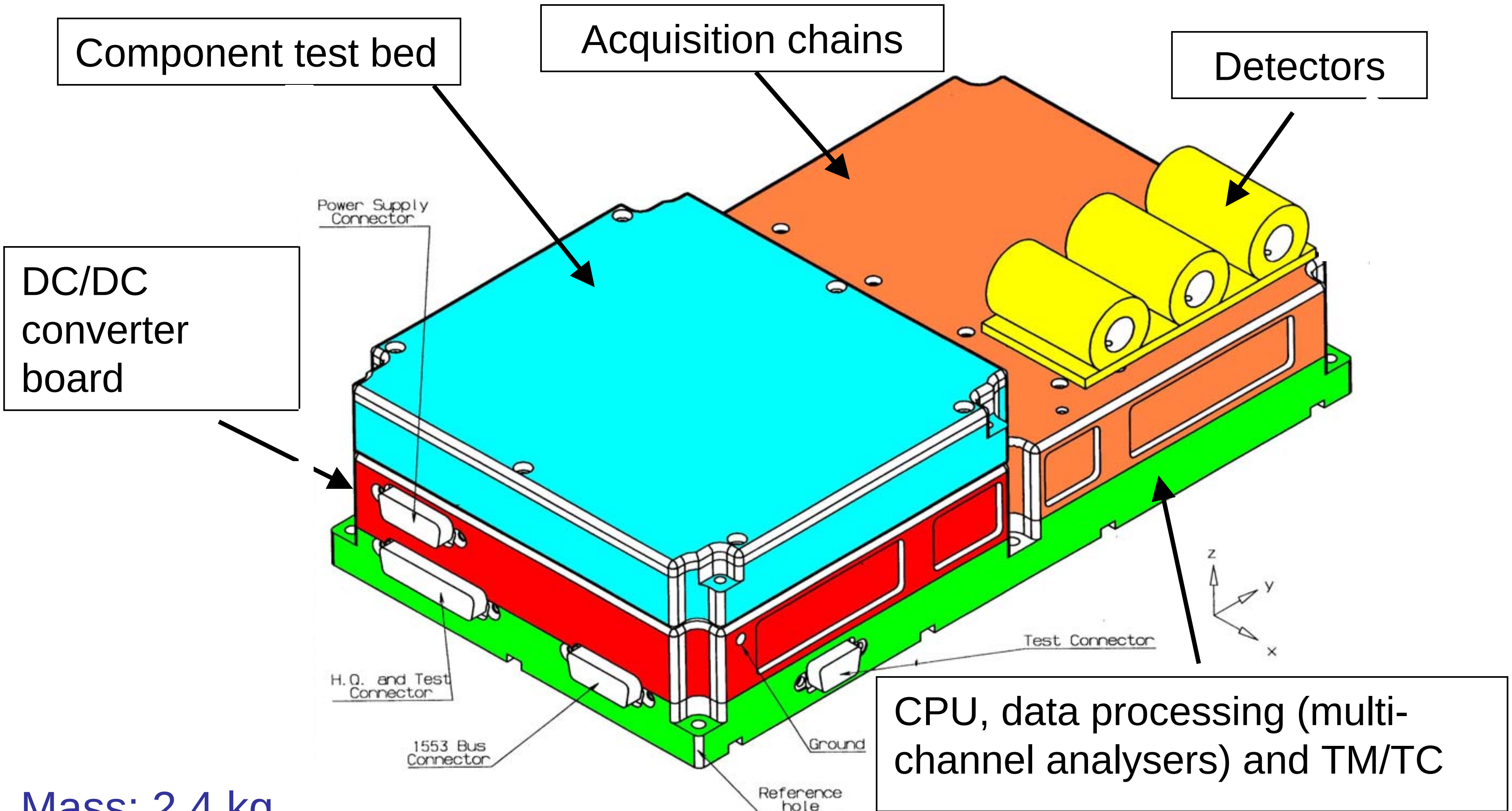
- Instrument : ICARE-CNES

- Detector heads derived from the CESR ERM/XMM instrument
- Development, operations: CNES
- Calibration, science : ONERA
- Investigators : R. Ecoffet (CNES), D. Boscher (ONERA)

- Purpose of the instrument:

- Space environment
- Radiation effects on components (SEE, dose)

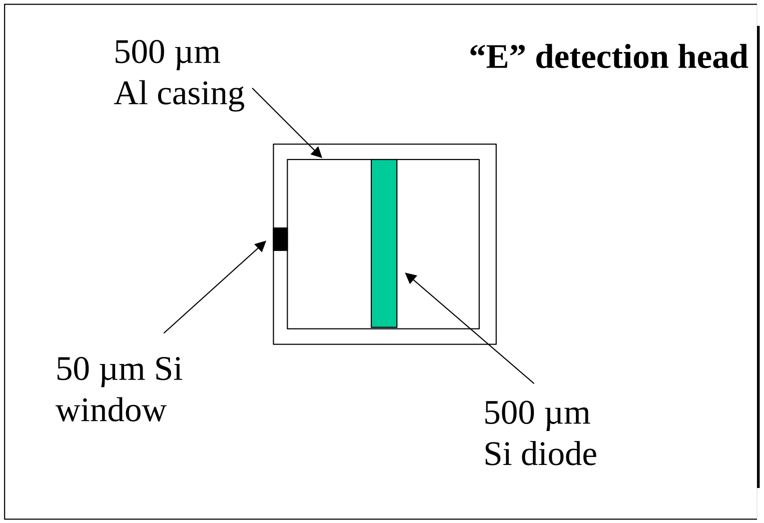
ICARE

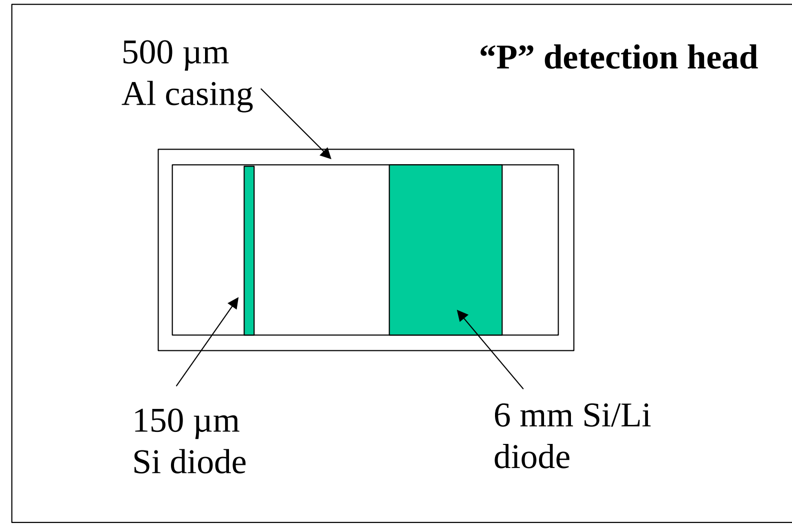


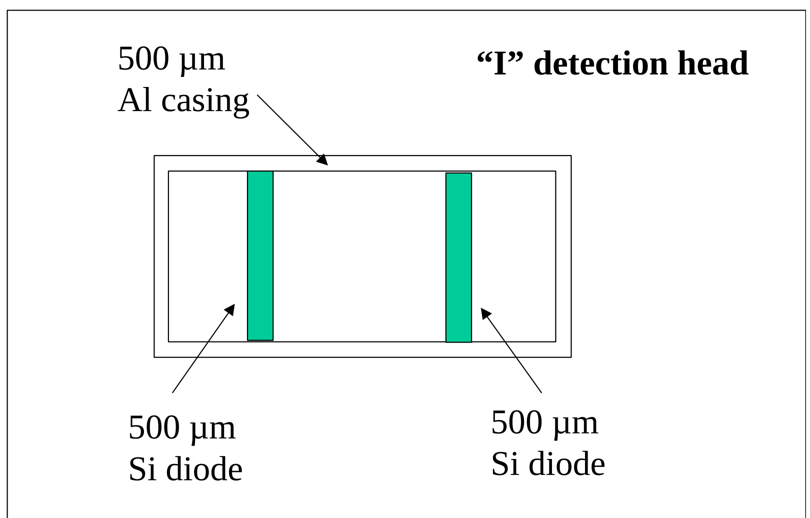
Mass: 2.4 kg
Mean power: 2.5 W
281 x 155 x 71 mm

Sampling rate: 64s

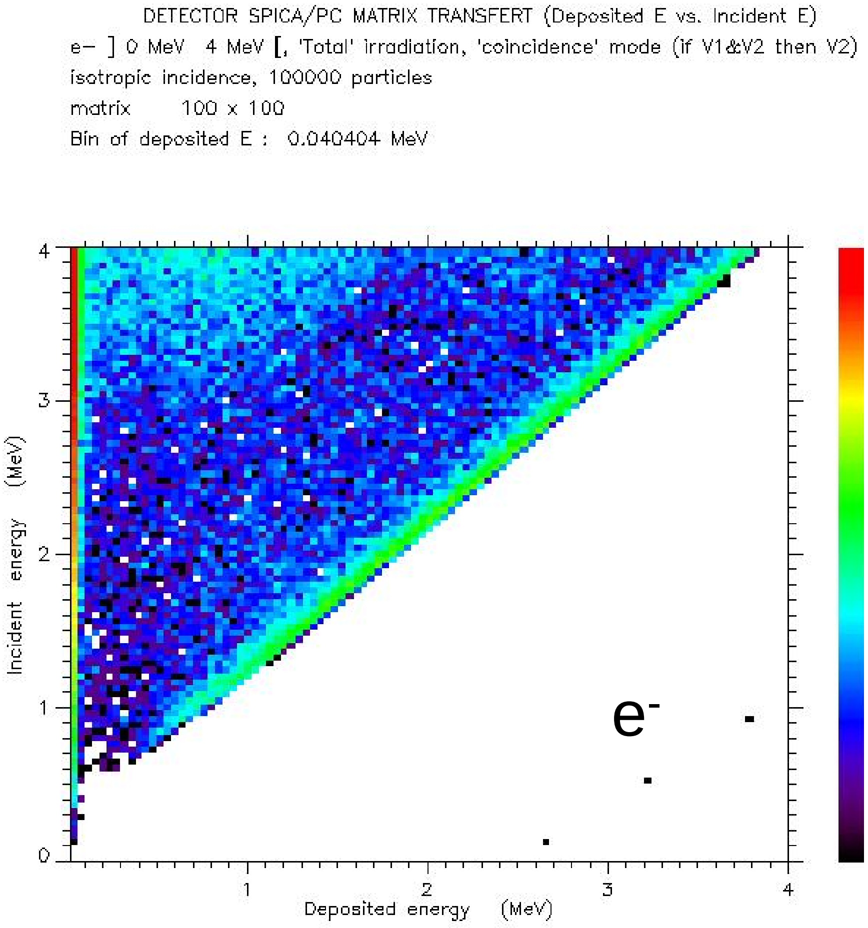
ICARE detectors

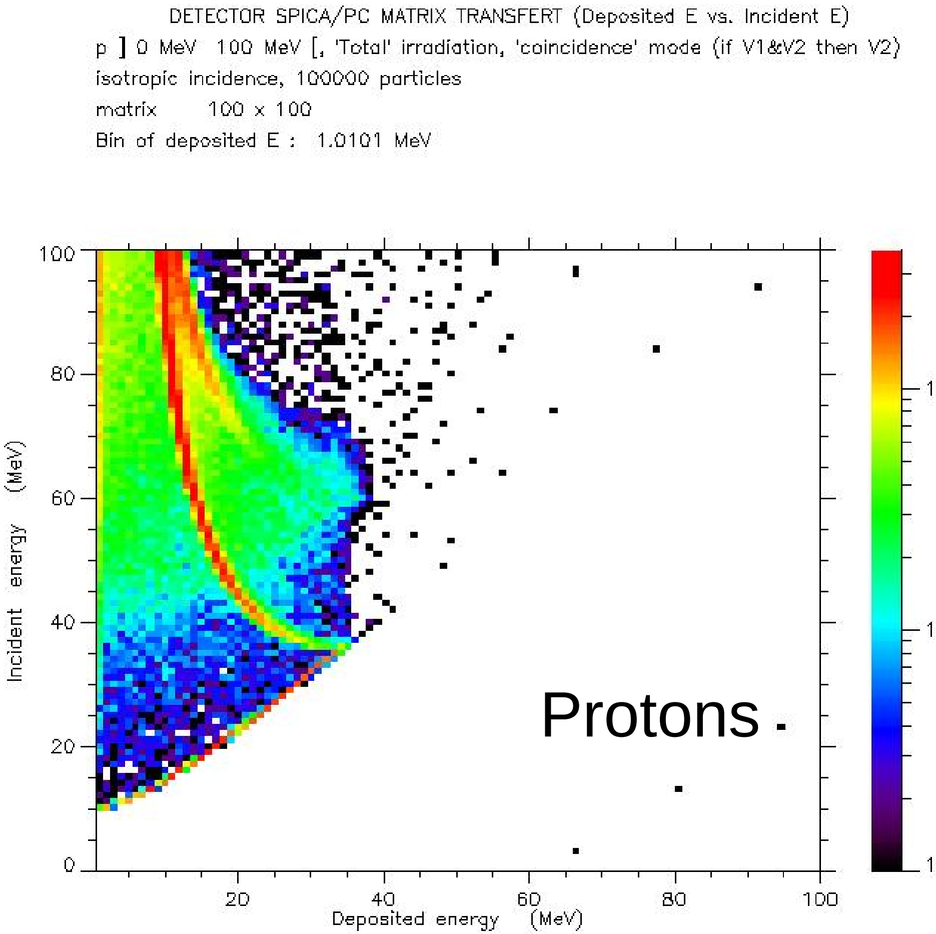




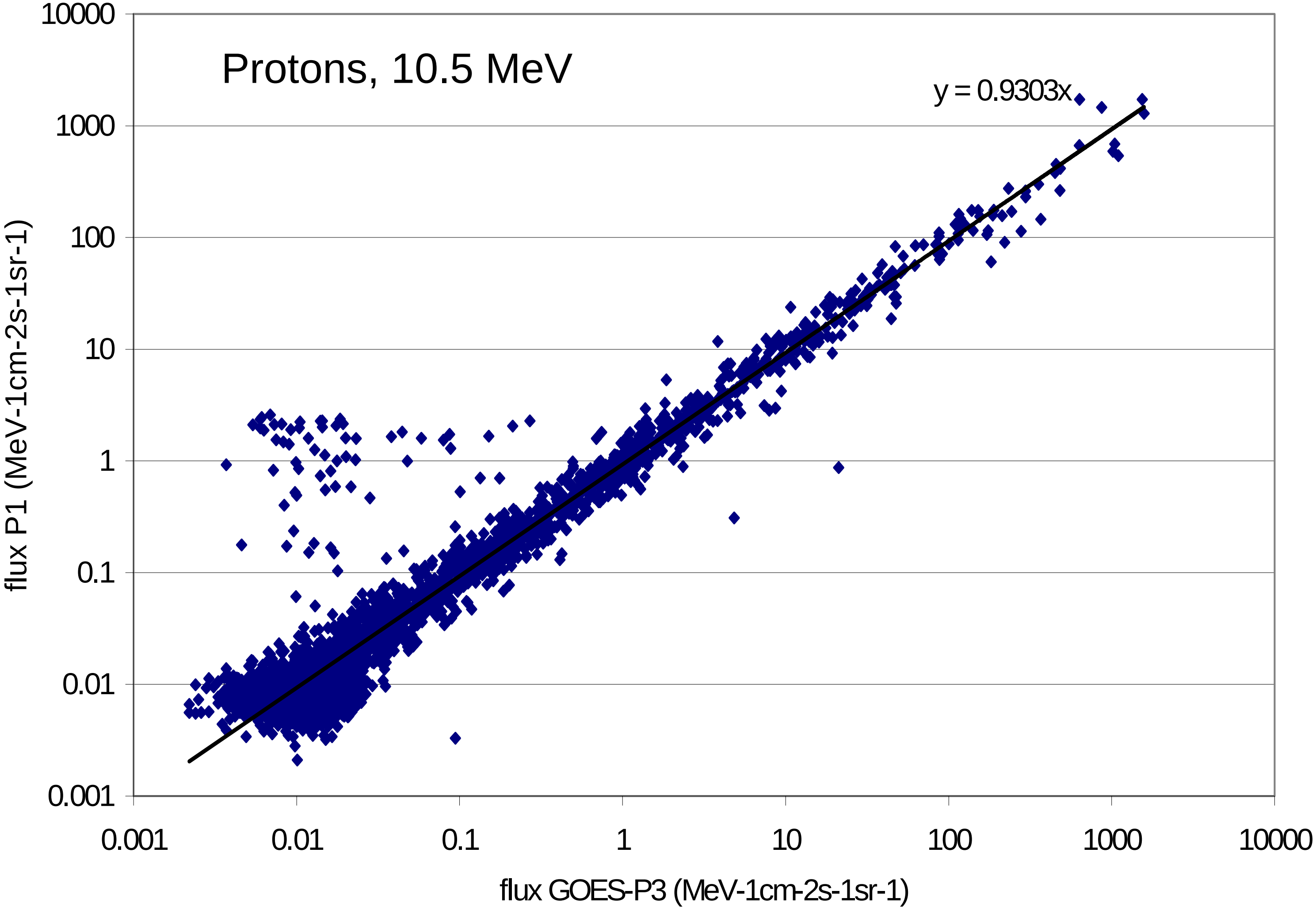


GEANT-4 simulations





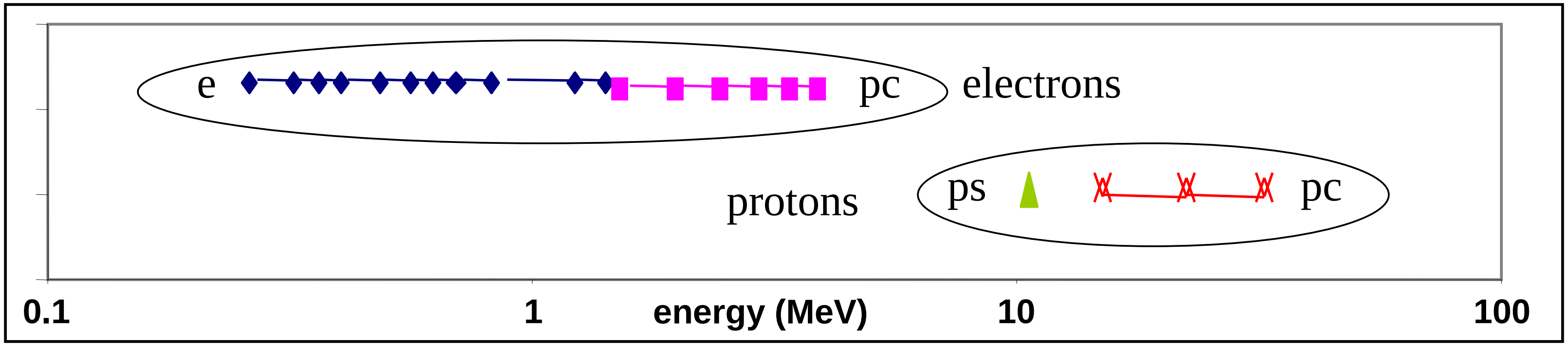
Cross calibration with GOES



Energy channels

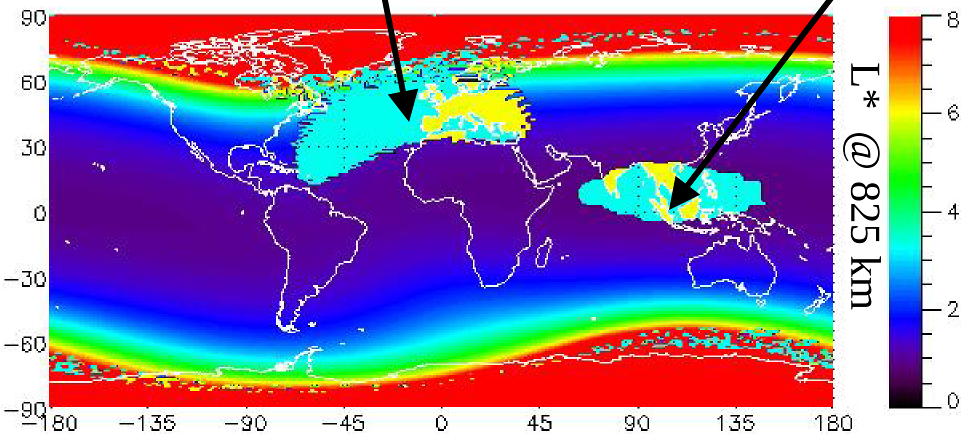
E		P		I	
E1	electrons 260 keV	PE0	electrons > 0.9MeV	I1	ions 54 MeV*
E2	electrons 320 keV	P1	protons 10.5 MeV	I2	ions 65 MeV
E3	electrons 360 keV	PE1	electrons 1.5 MeV*	I3	ions > 100 MeV
E4	electrons 420 keV	PE2	electrons 2. MeV*		
E5	electrons 480 keV	PE3	electrons 2.4 MeV*		
E6	electrons 560 keV	PE4	electrons 2.9 MeV*		
E7	electrons 620 keV	PE5	electrons 3.4 MeV*		
E8	electrons 700 keV	PE6	electrons 3.9 MeV*		
E9	electrons 820 keV	P2	protons 15.5 MeV		
E10	electrons 1200 keV*	P3	protons 23 MeV		
E11	electrons 1400 keV*	P4	protons 33.5 MeV		

* contaminated

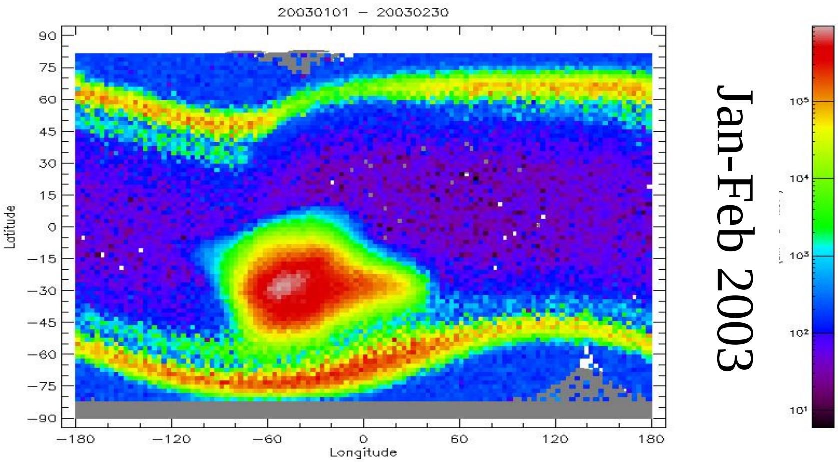


Mirror point in South hemisphere in loss cone

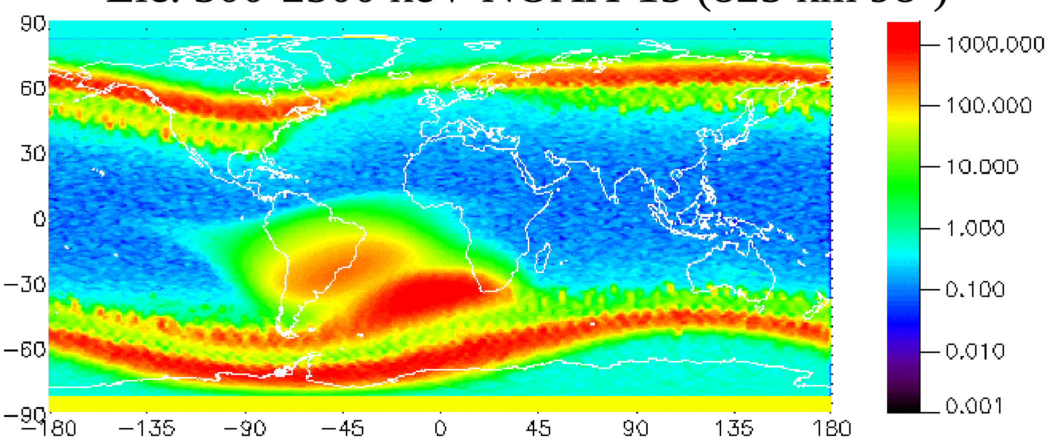
Drift shell inside the Earth in SAA



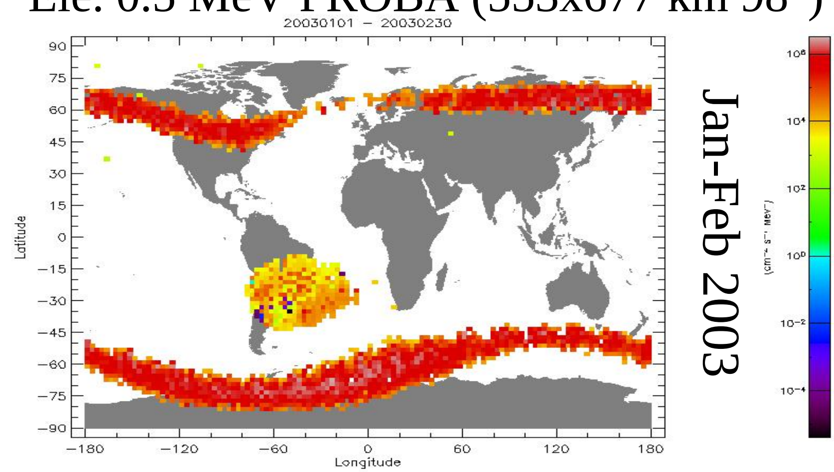
Ele. 0.4 MeV SAC-C (700 km 98°)



Ele. 300-2500 keV NOAA-15 (825 km 98°)



Ele. 0.5 MeV PROBA (553x677 km 98°)



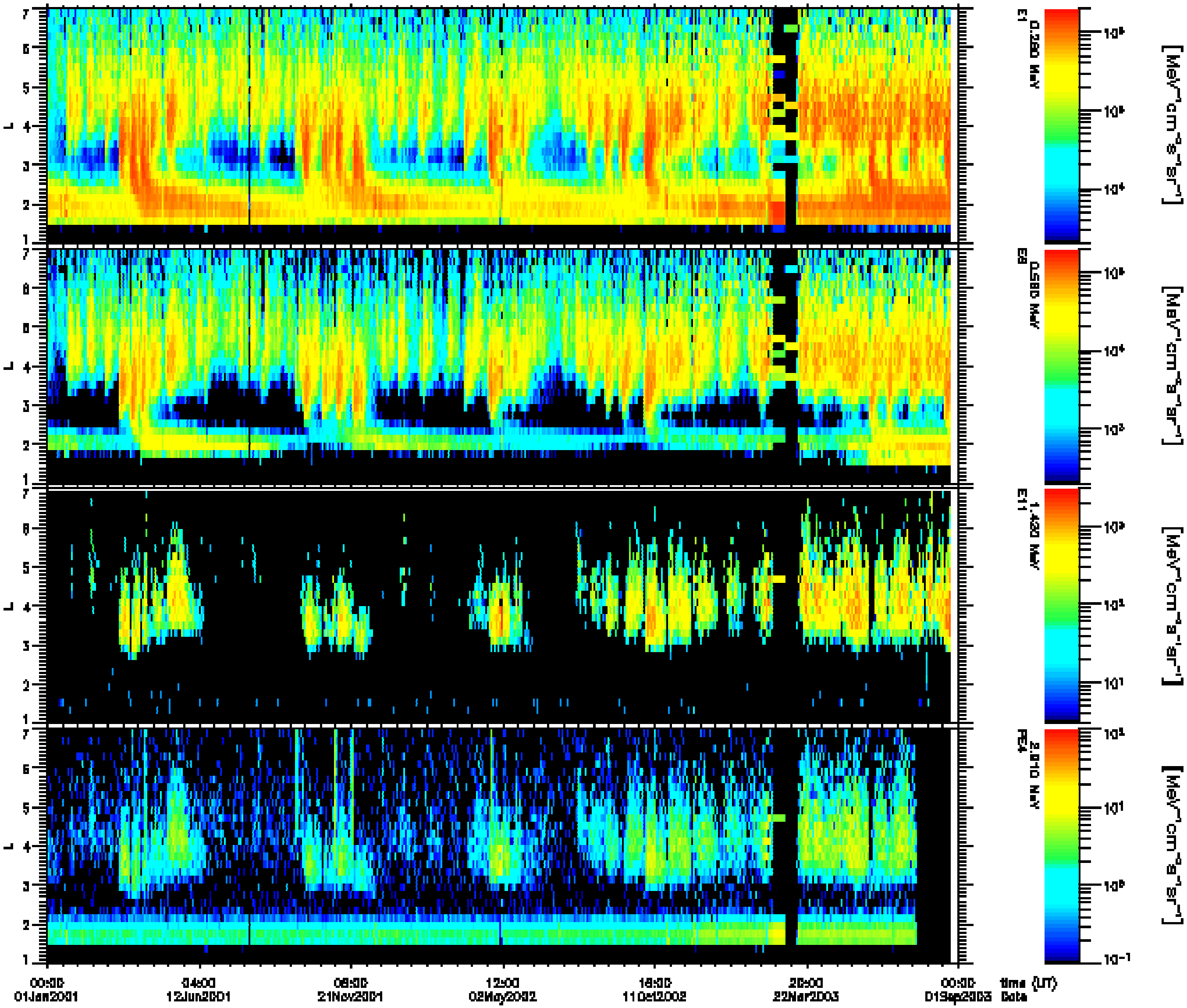
SAC-C electron results: survey plots

e^- 260 keV

e^- 560 keV

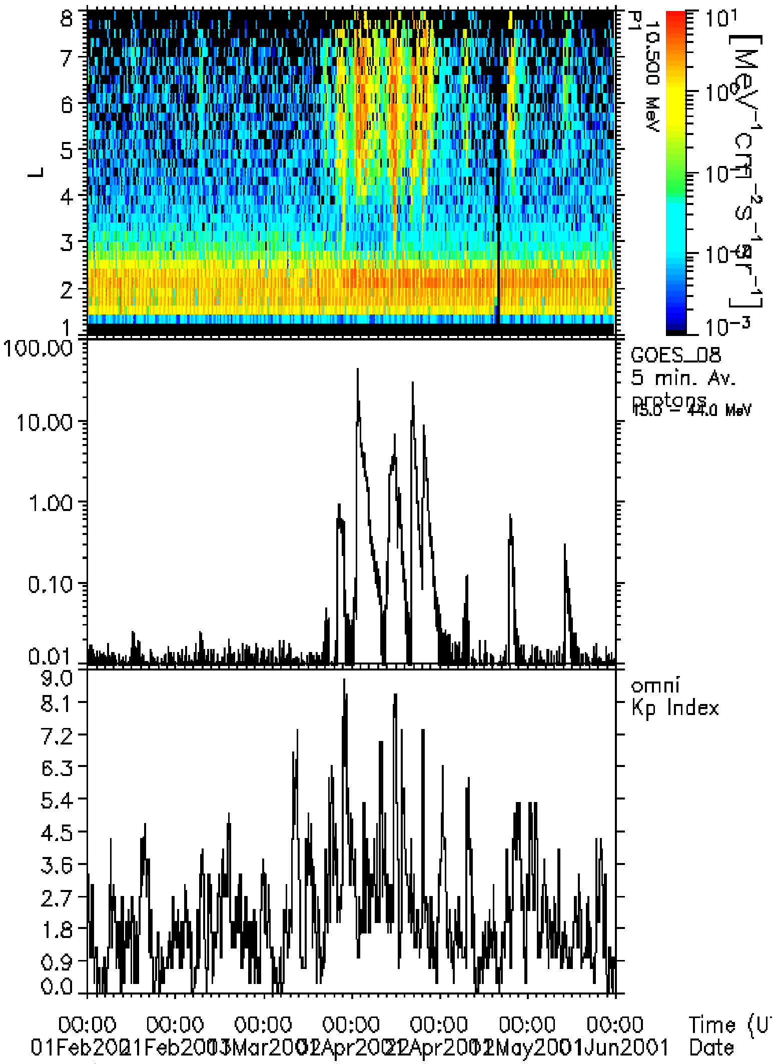
e^- 1.4 MeV

e^- 2.9 MeV

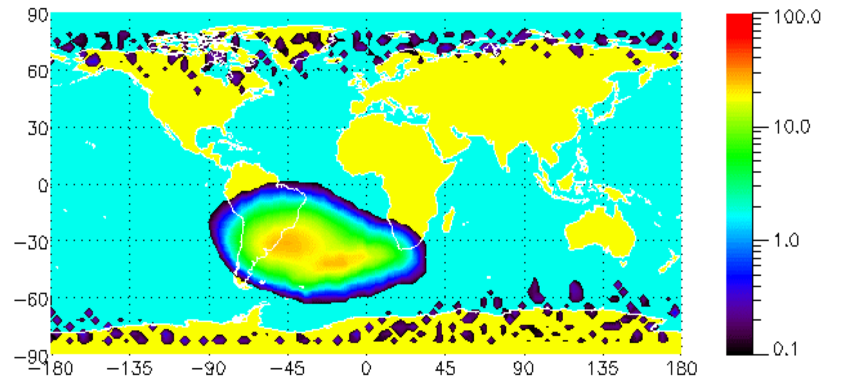


Influence of Solar energetic particles on the proton radiation belt

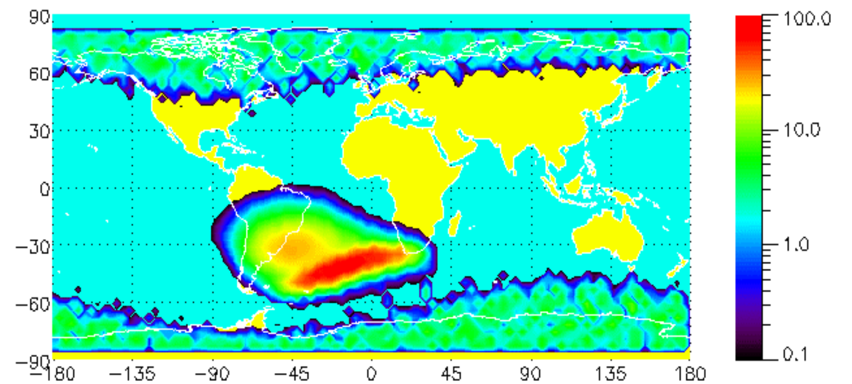
Example of SAC-C measurements E = 10.5 MeV, 31 March 2001 event



4 months



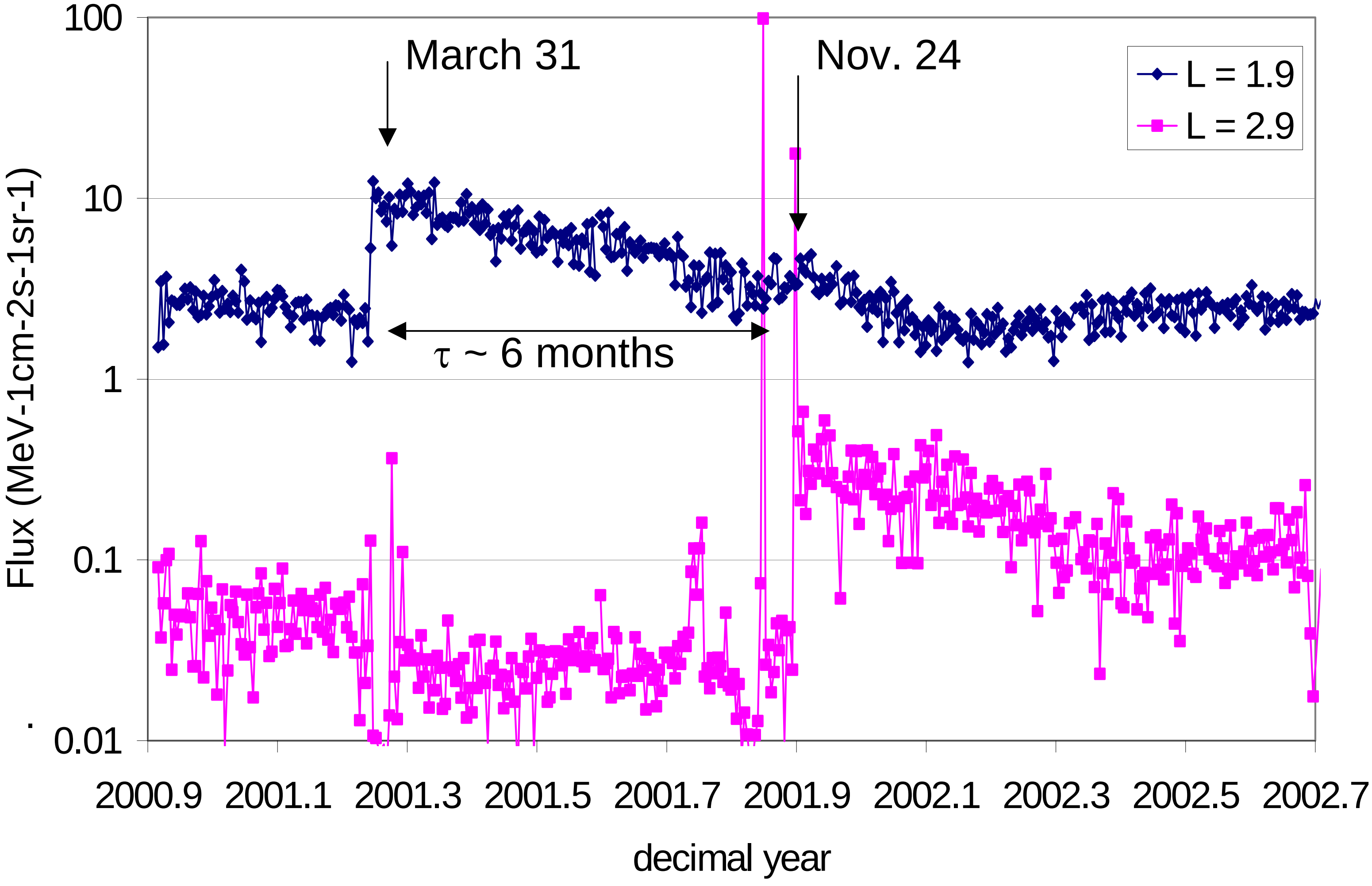
before



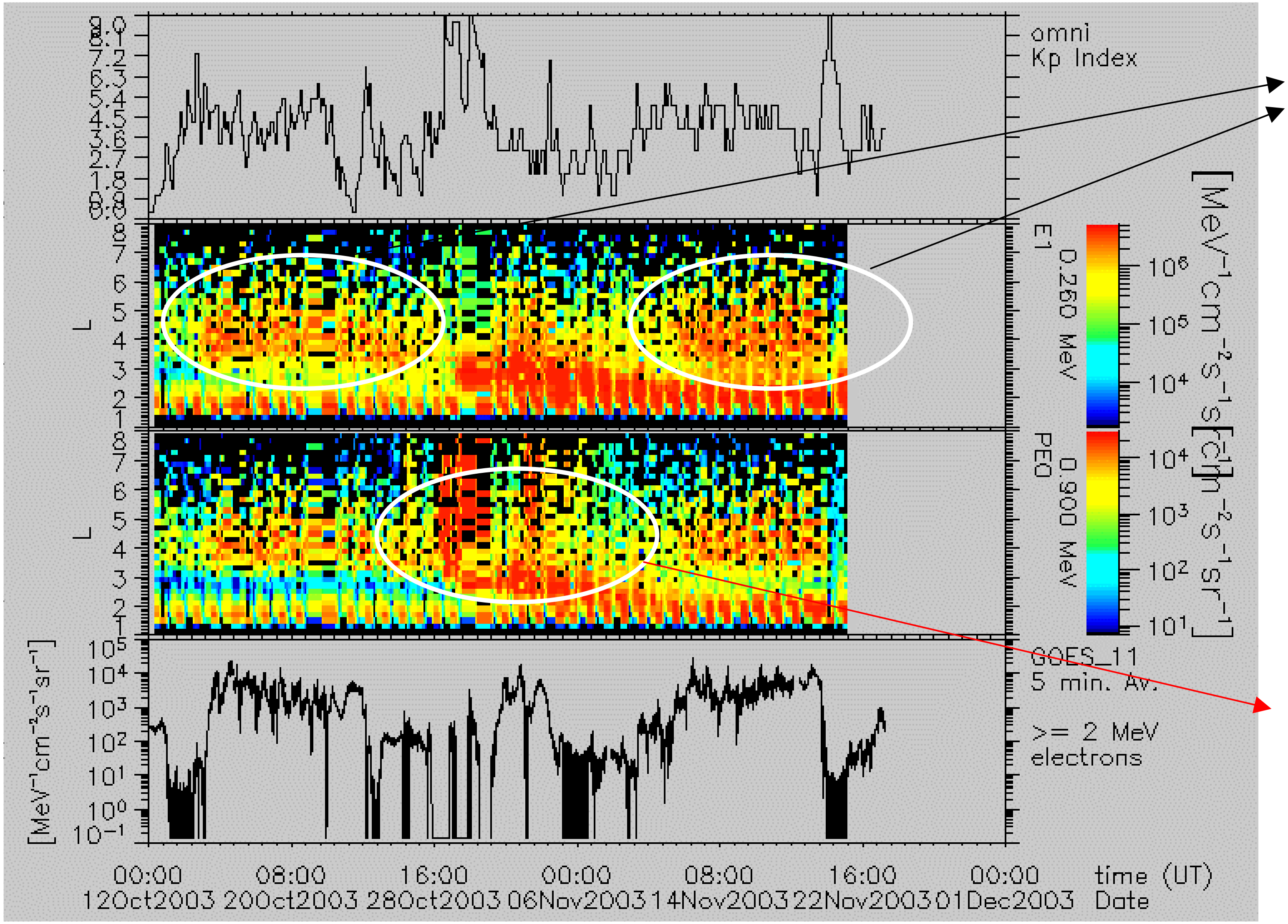
after

Influence of Solar Energetic Particles on the Proton RB

Example of SAC-C measurements E = 10.5 MeV (715km)



Effect of the 29-31 October 2003 event seen by ICARE / SAC-C

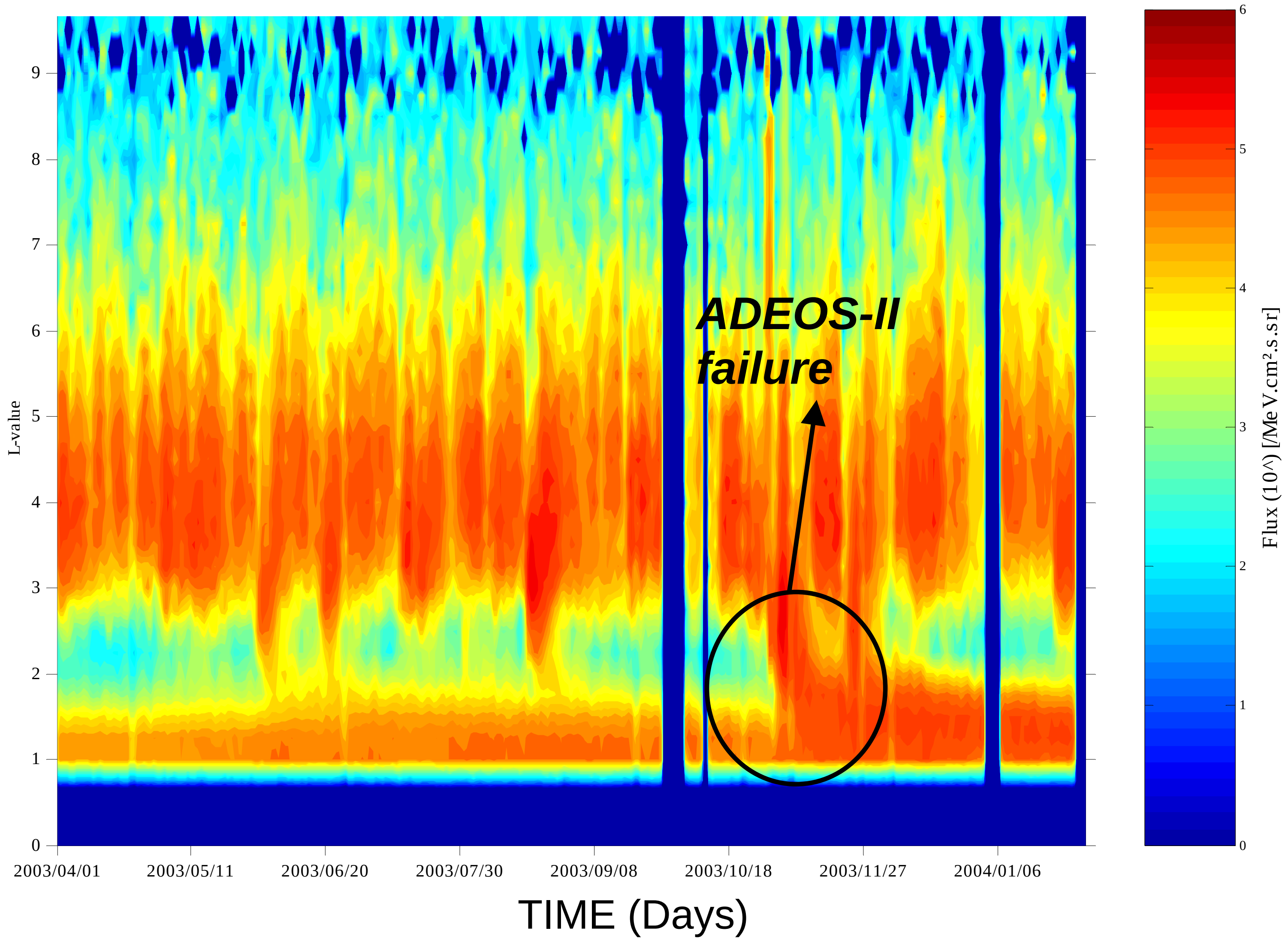


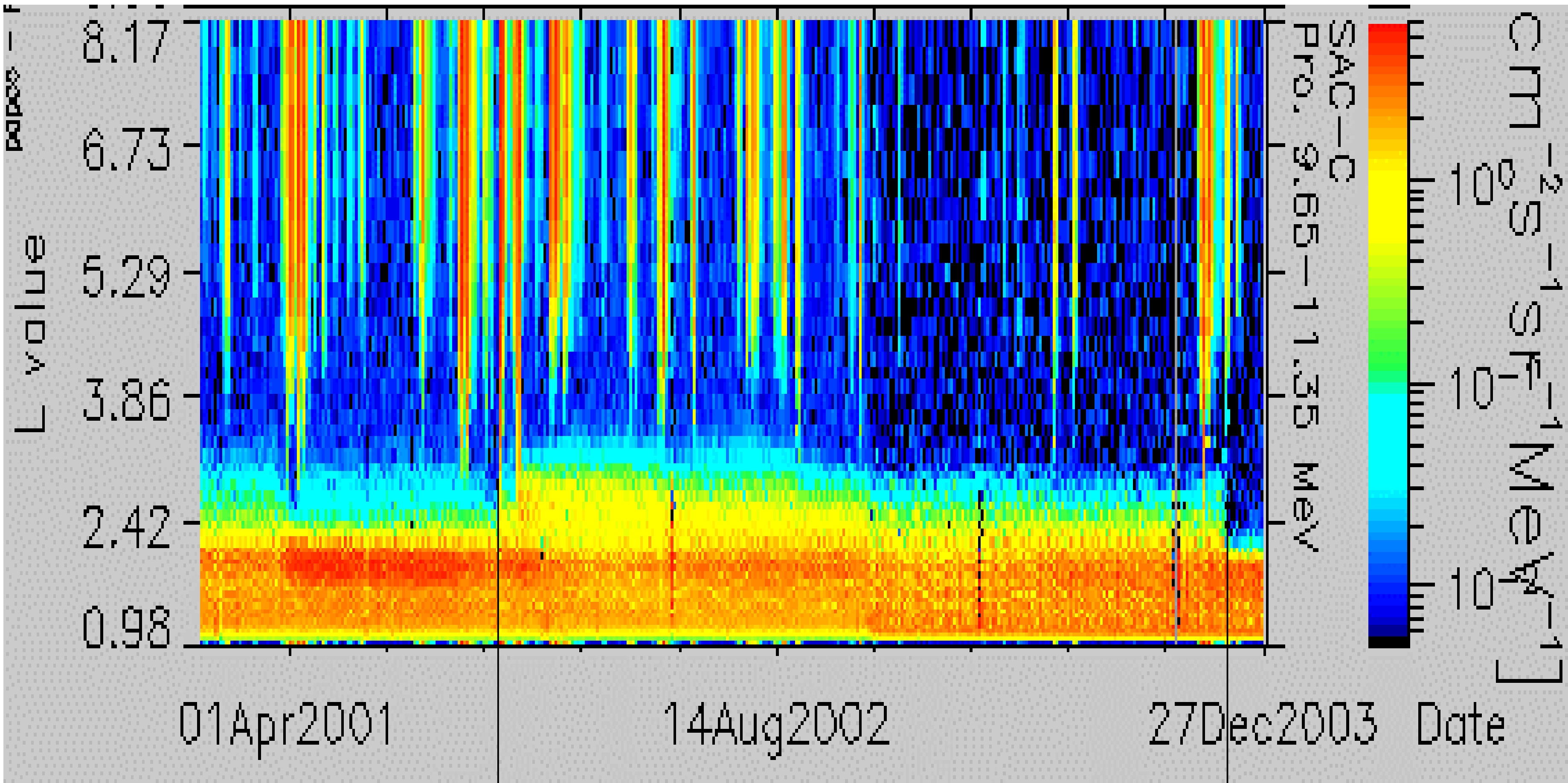
Effect of rotating coronal hole on outer belt

CME and inner belt injection

“SPACECRAFT ANOMALIES”

ICARE SAC-C ELECTRONS 560 keV





Solar events Nov. 2001 (flares = magnetic storms) create conditions for an injection in the proton belt, whose fluxes build up

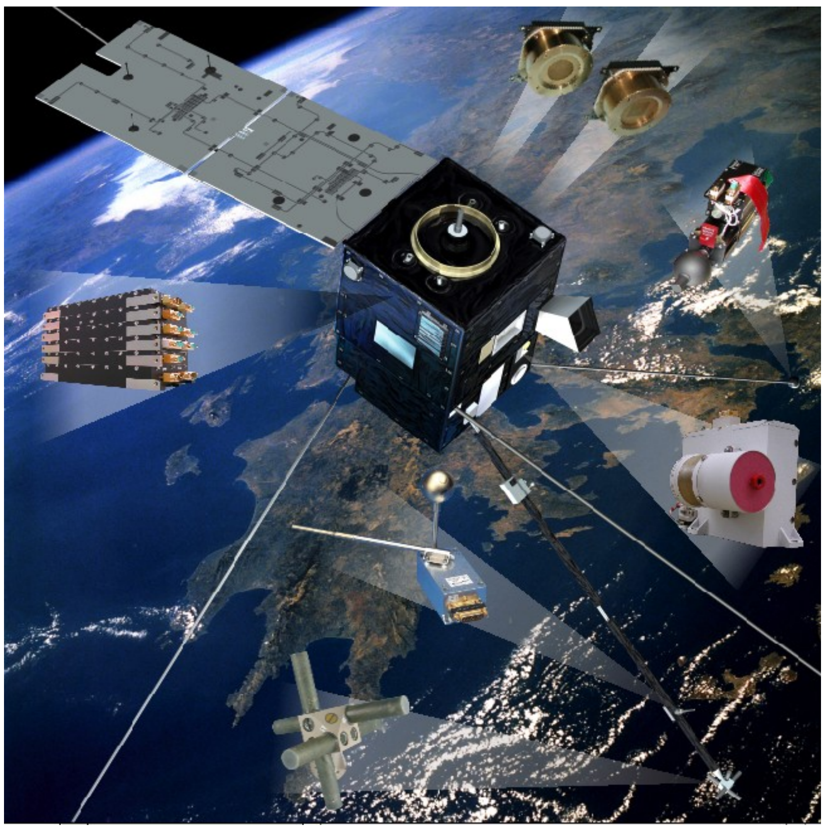
For ~2 years, enhanced fluxes in the proton belt.

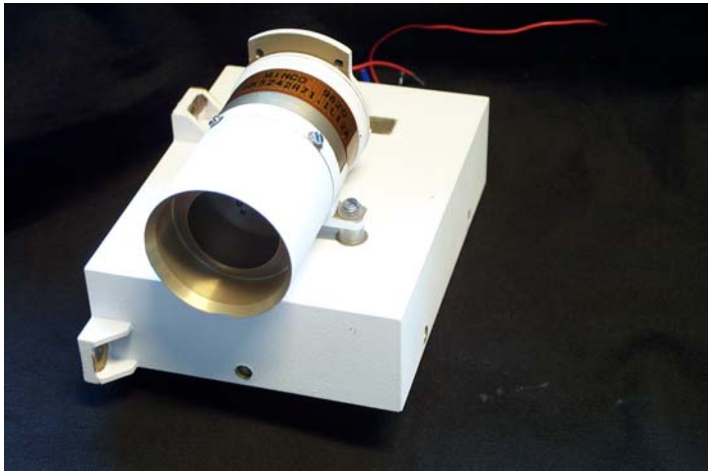
In Oct/Nov. 2003, magnetic storms « sweep out » excess fluxes.

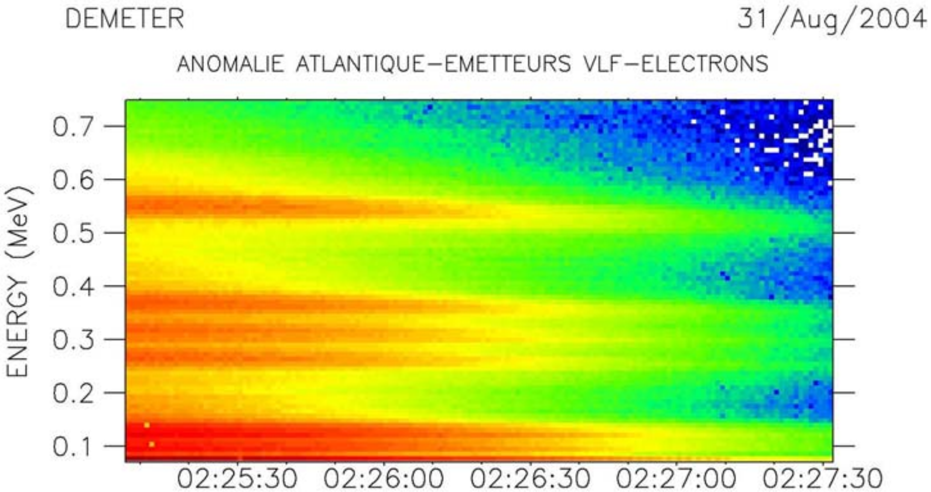
A possible explanation for the decrease of SPOT5 mass memory SEU rates after the solar event of the 29/09/04

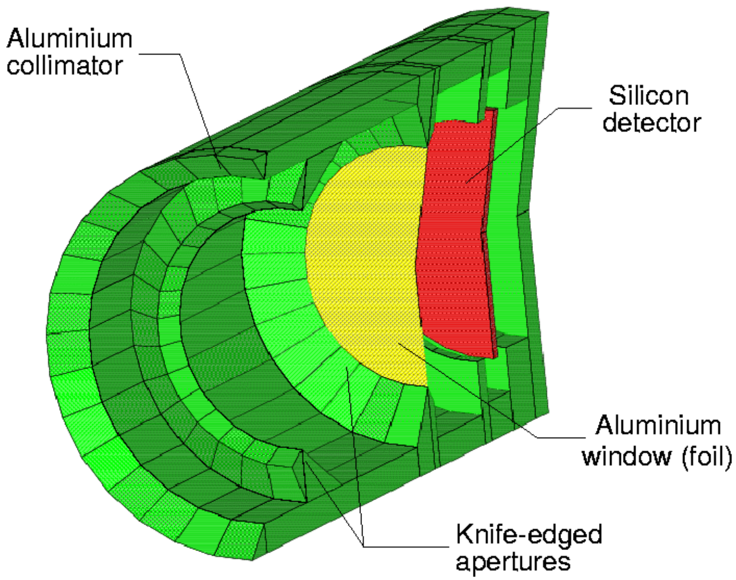
DEMETER: A FRENCH MICRO-SATELLITE ON A LOW POLAR ORBIT

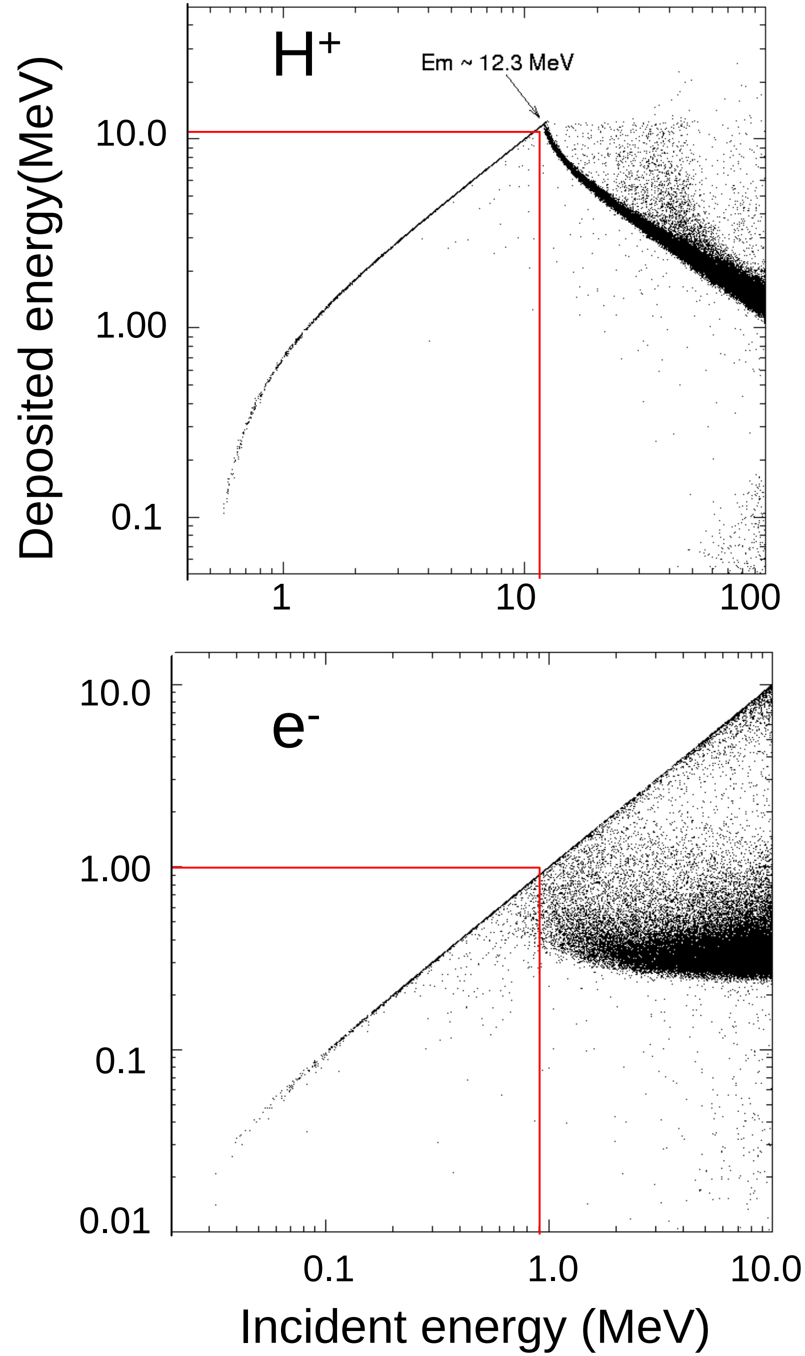
Goals: Study of human electromagnetic emissions, of ionospheric effects of volcanism and earthquakes...











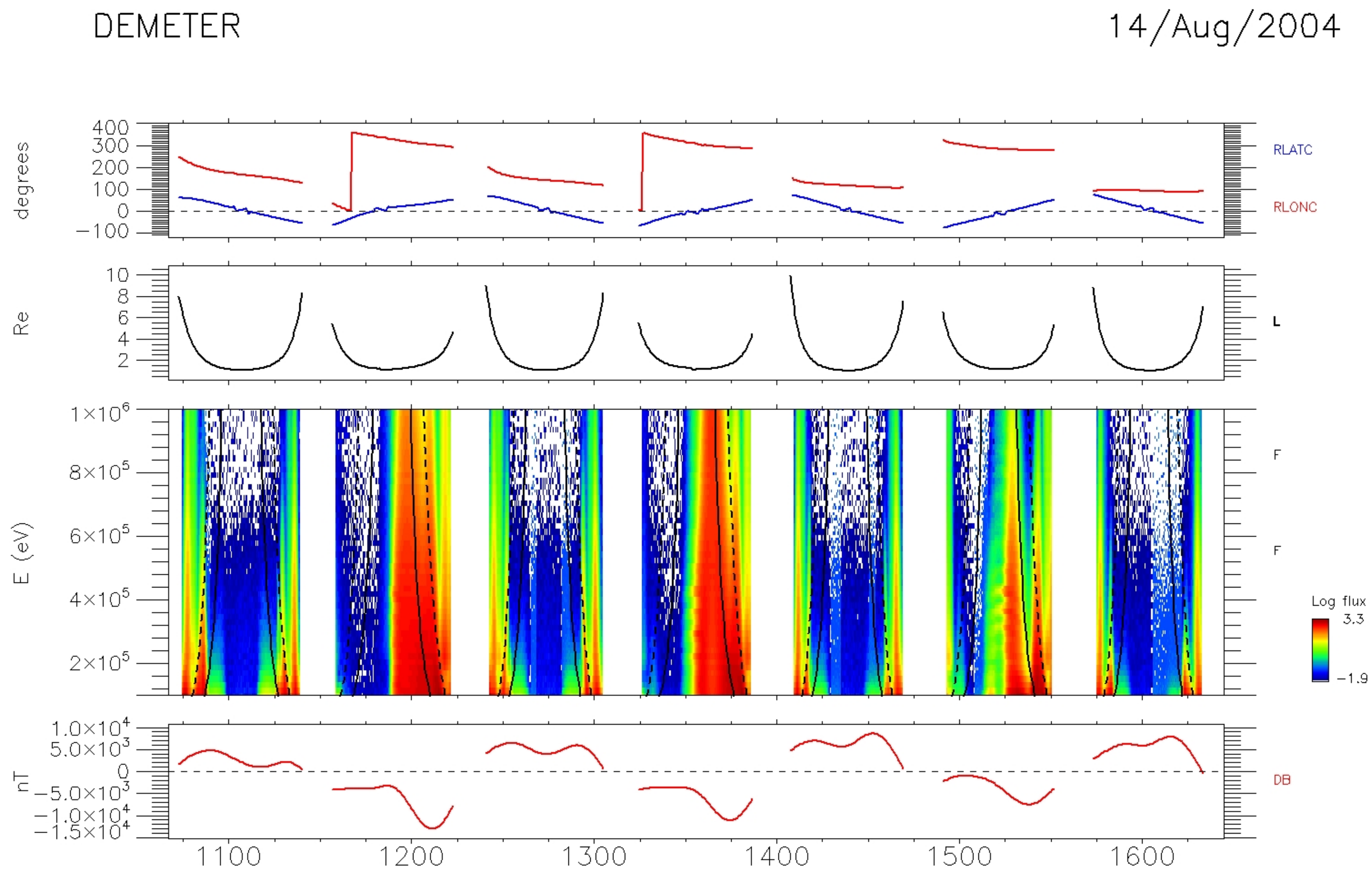
Electrons:

256 channels from 70 keV to 2.5 MeV

Protons:

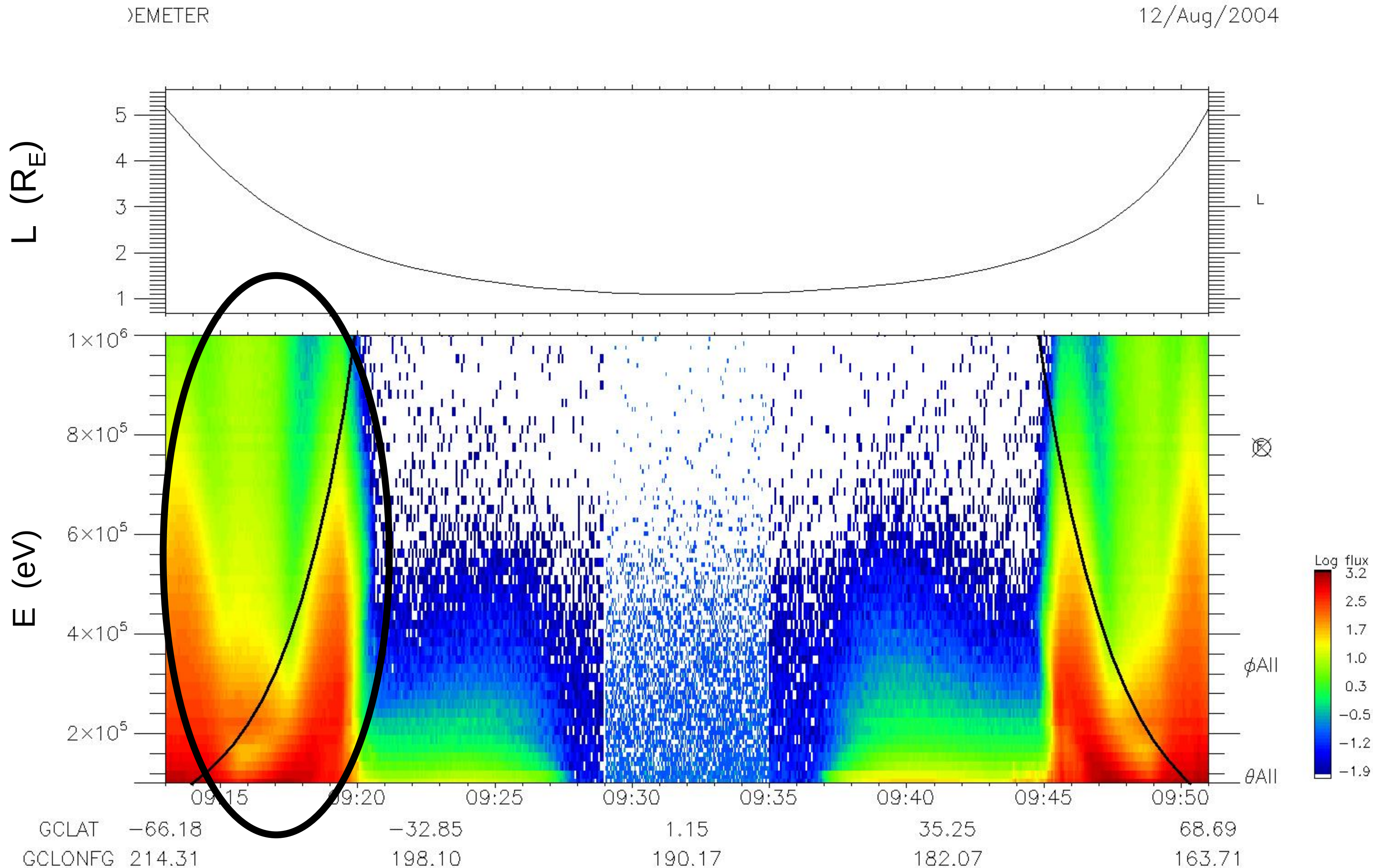
An integral channel E > 2.5 MeV

DEMETER-IDP



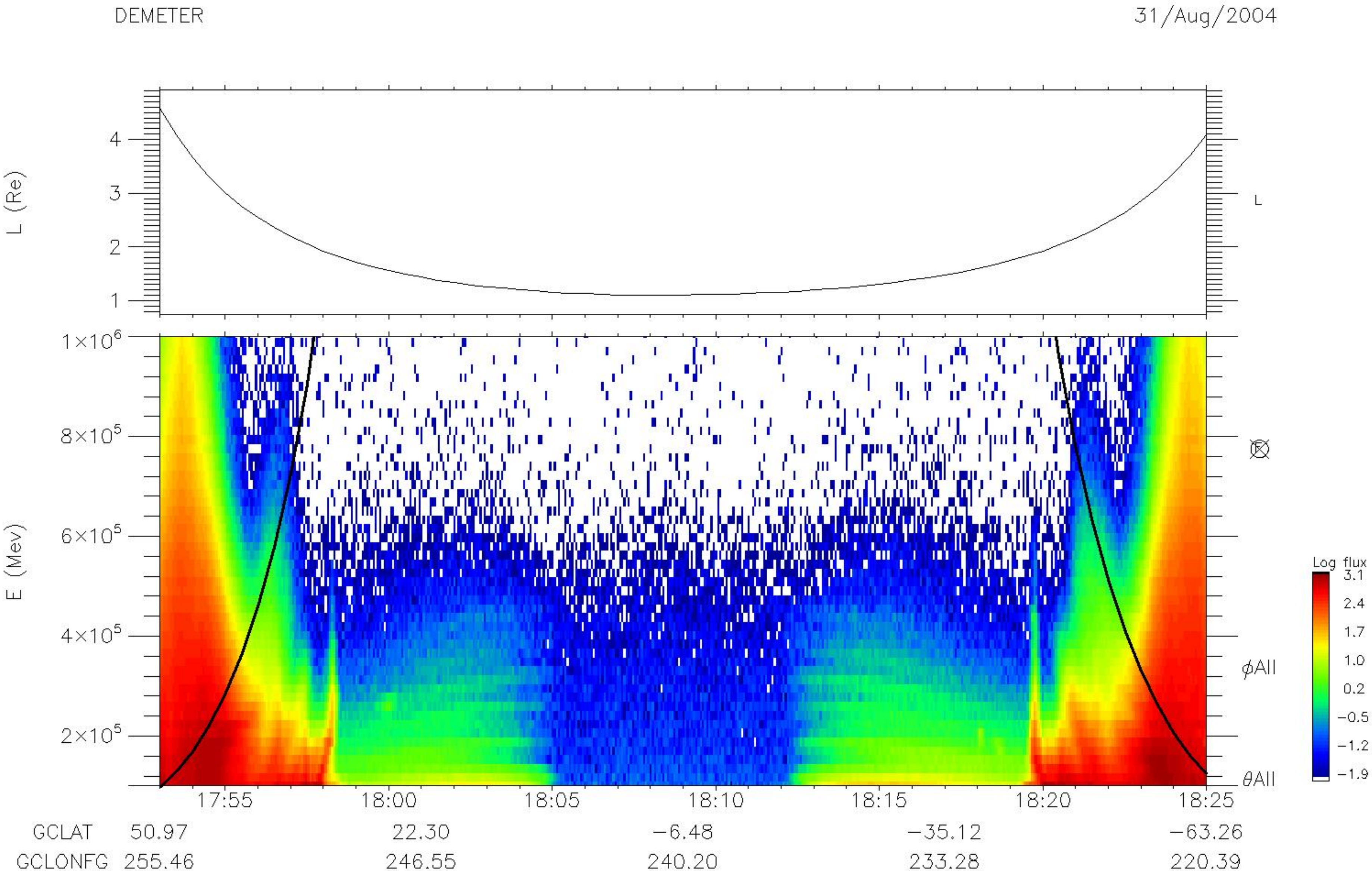
DEMETER
14/Aug/2004
degrees
400
300
200
100
0
−100
RLATC
RLONC
Re
10
8
6
4
2
L
E (eV)
1×10^6
8×10^5
6×10^5
4×10^5
2×10^5
F
F
Log flux
3.3
−1.9
nT
1.0×10^4
5.0×10^3
0
-5.0×10^3
-1.0×10^4
-1.5×10^4
DB
1100
1200
1300
1400
1500
1600

OUTER BELT – SLOT - INNER BELT

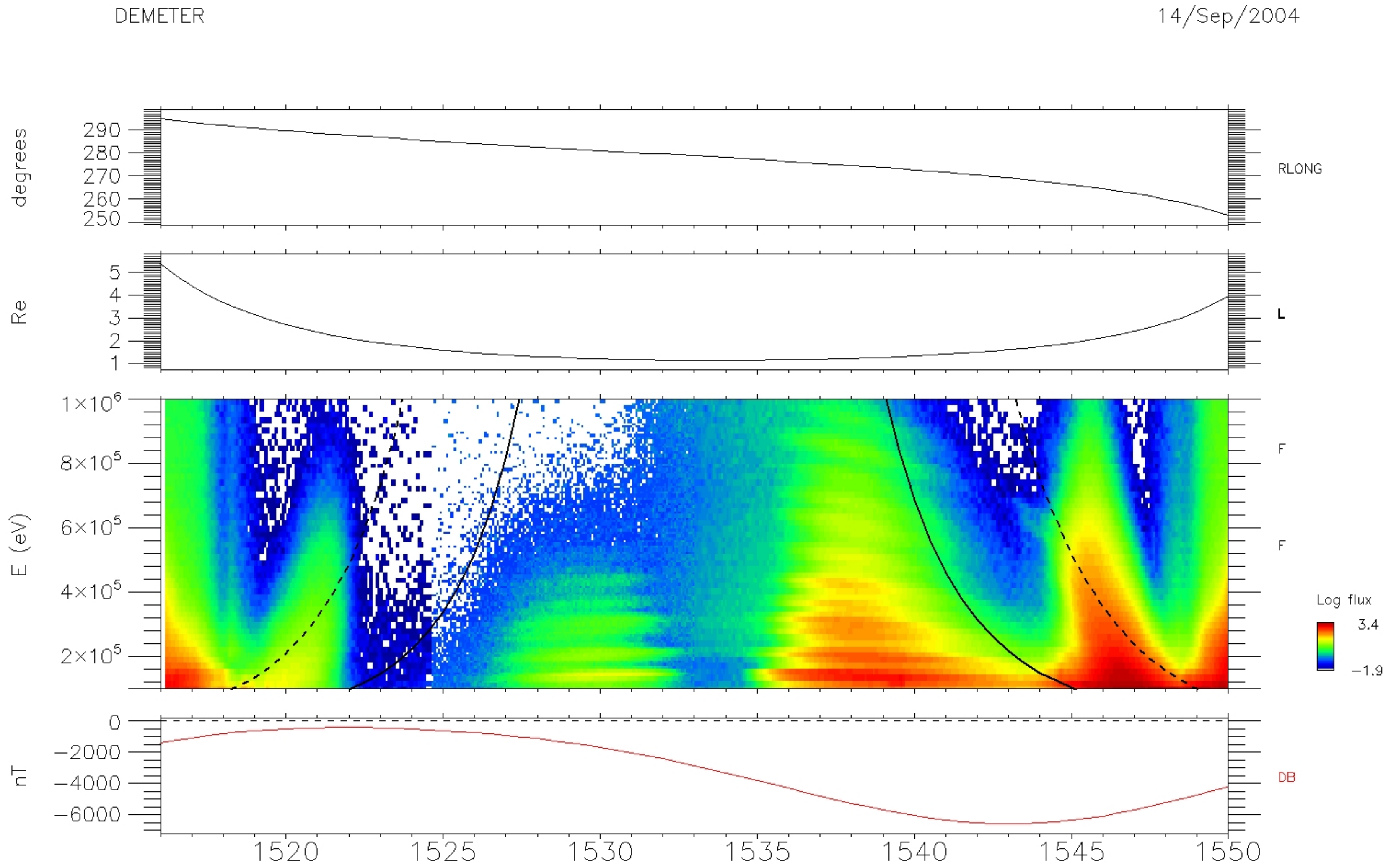


FERMI

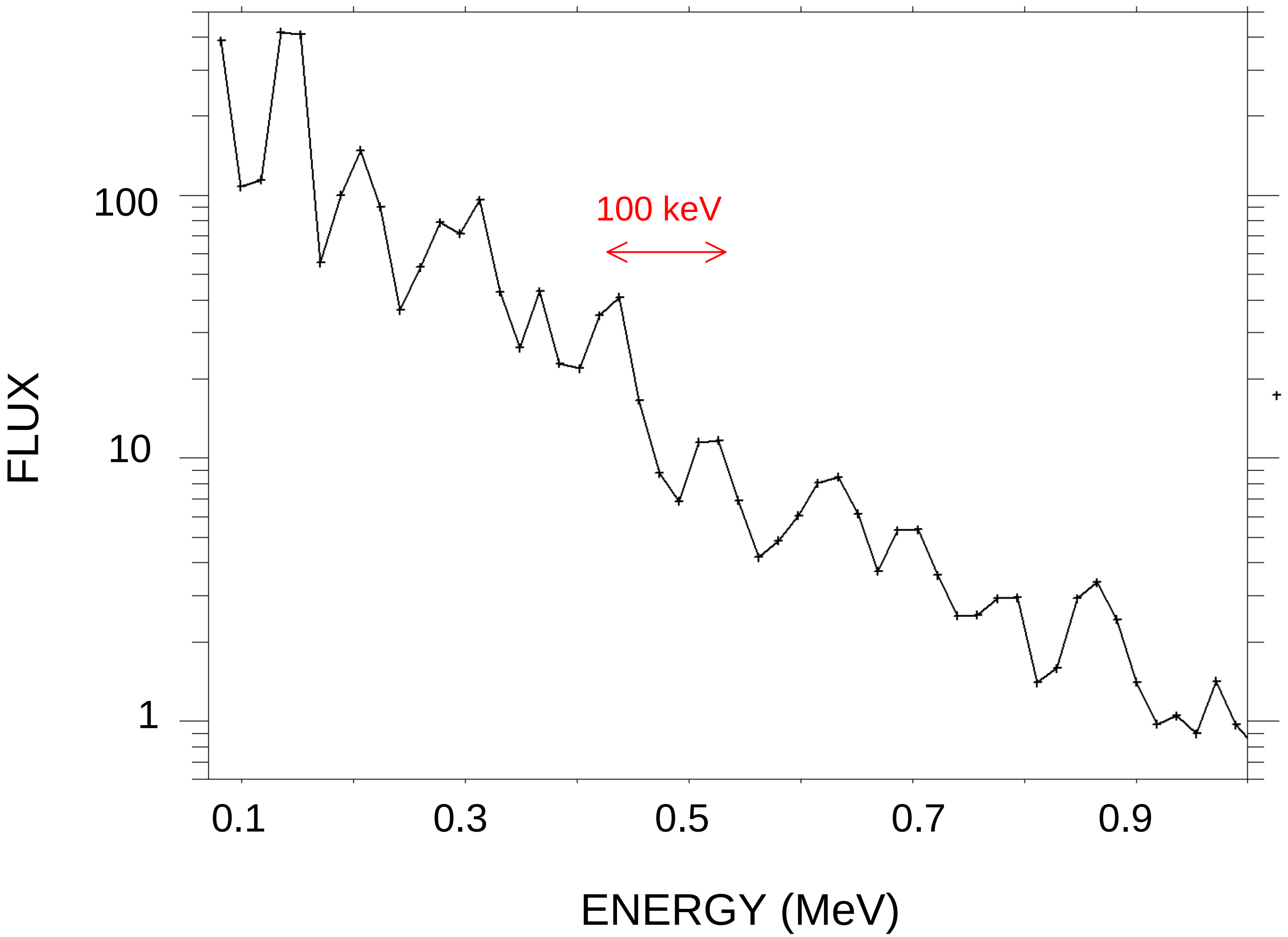
INNER BELT WAVES EFFECT



INNER BELT WAVES EFFECT

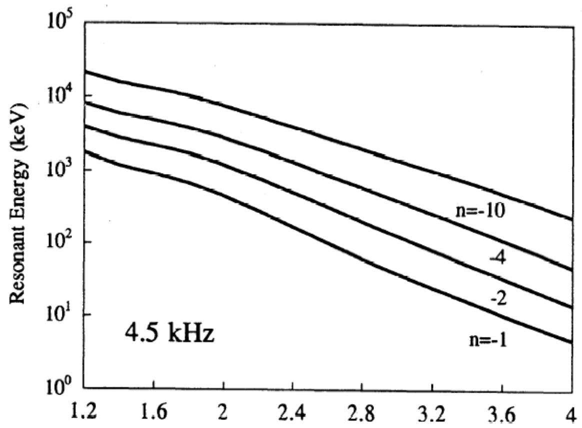


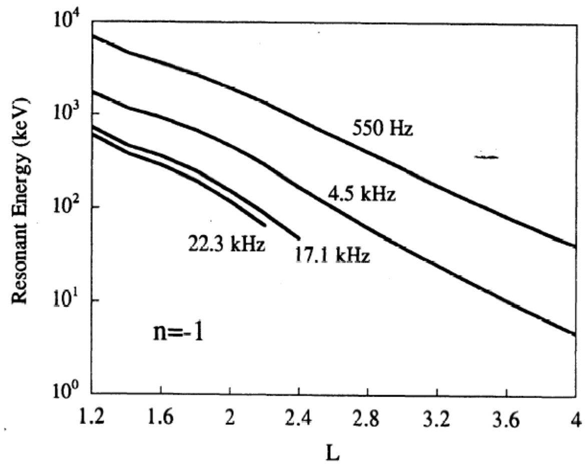
INNER BELT ENERGY SPECTRA



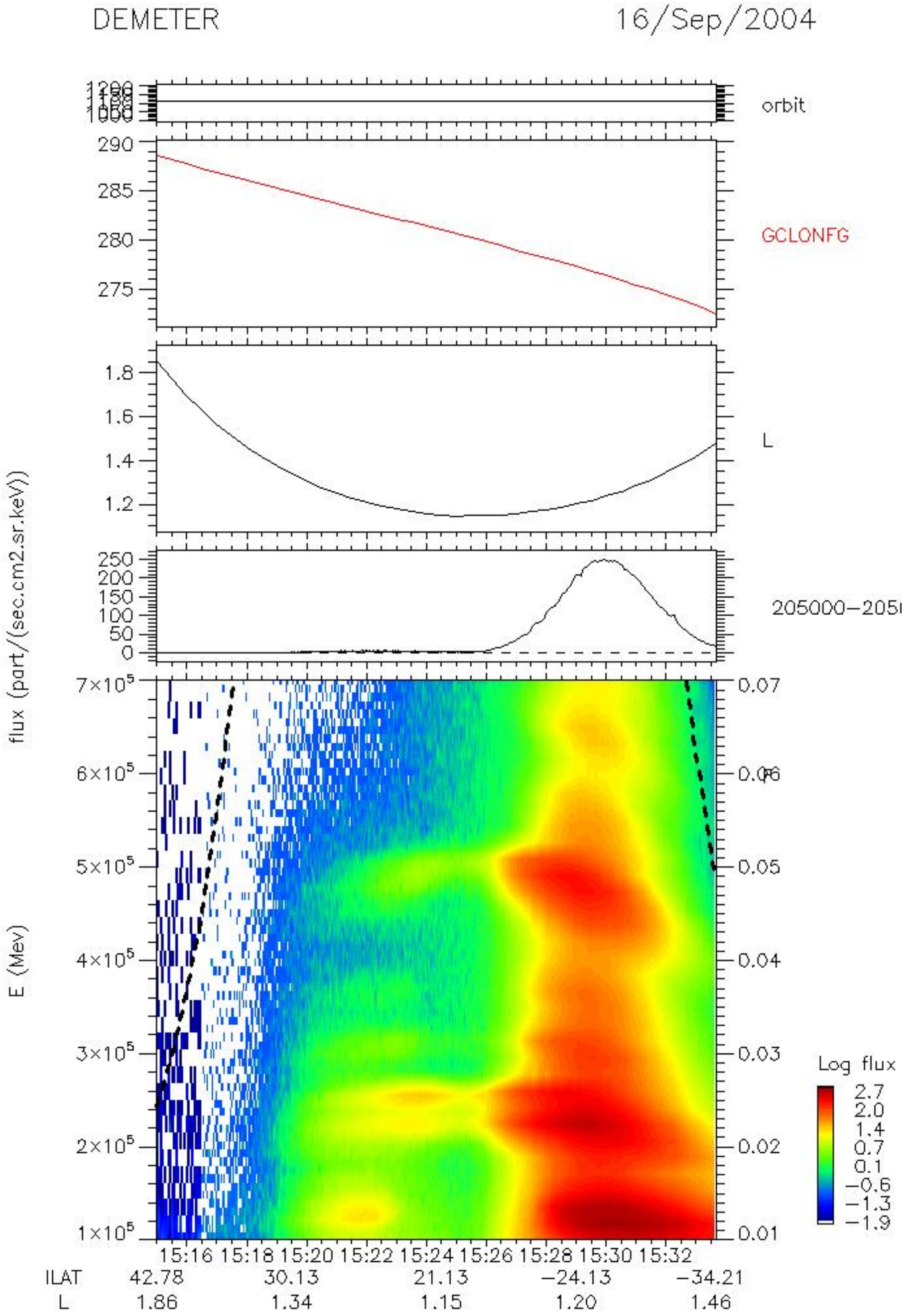
INNER BELT - WAVE

Variation of the resonnant energy with L

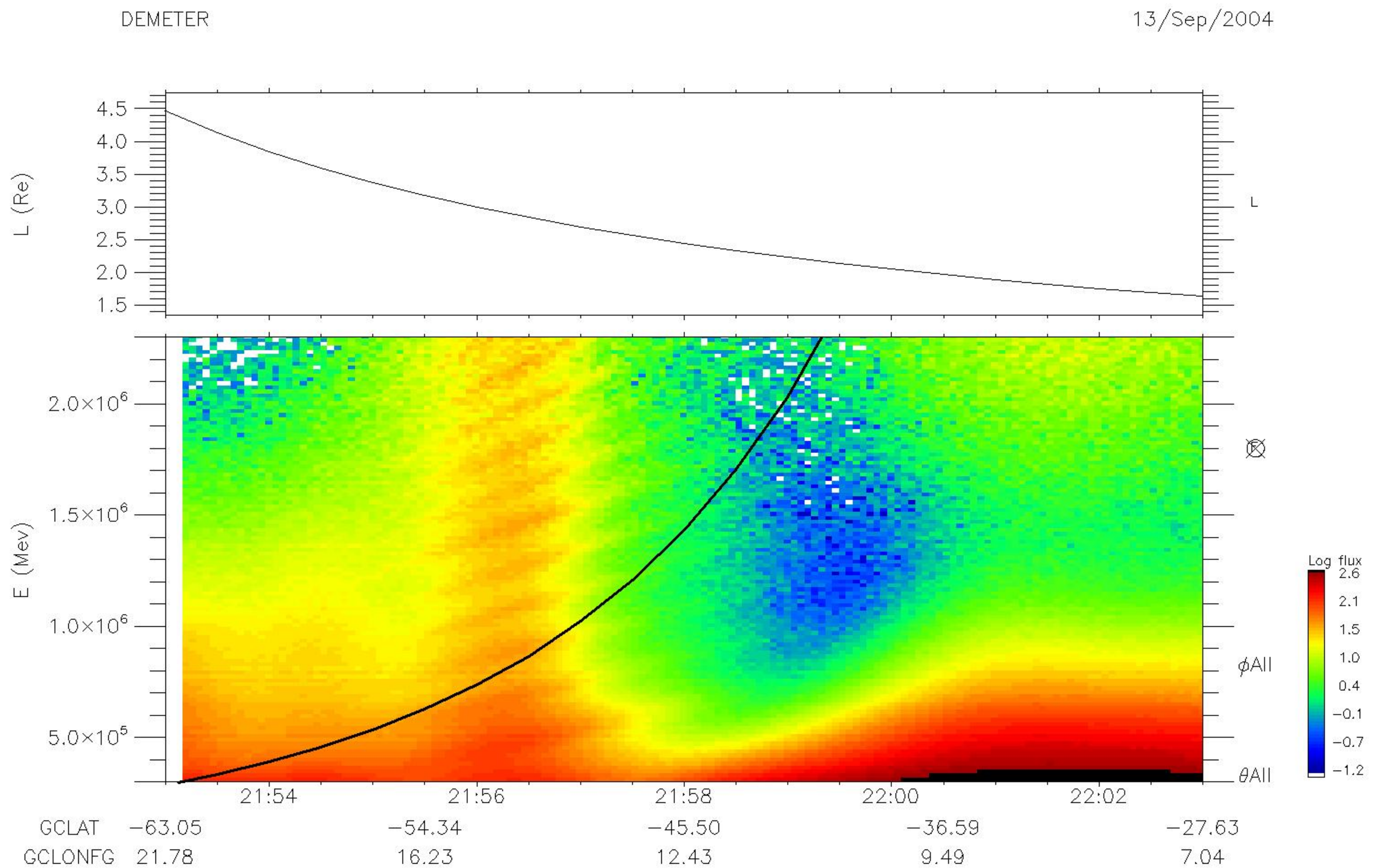




(Abel and Thorne, JGR, 1998)

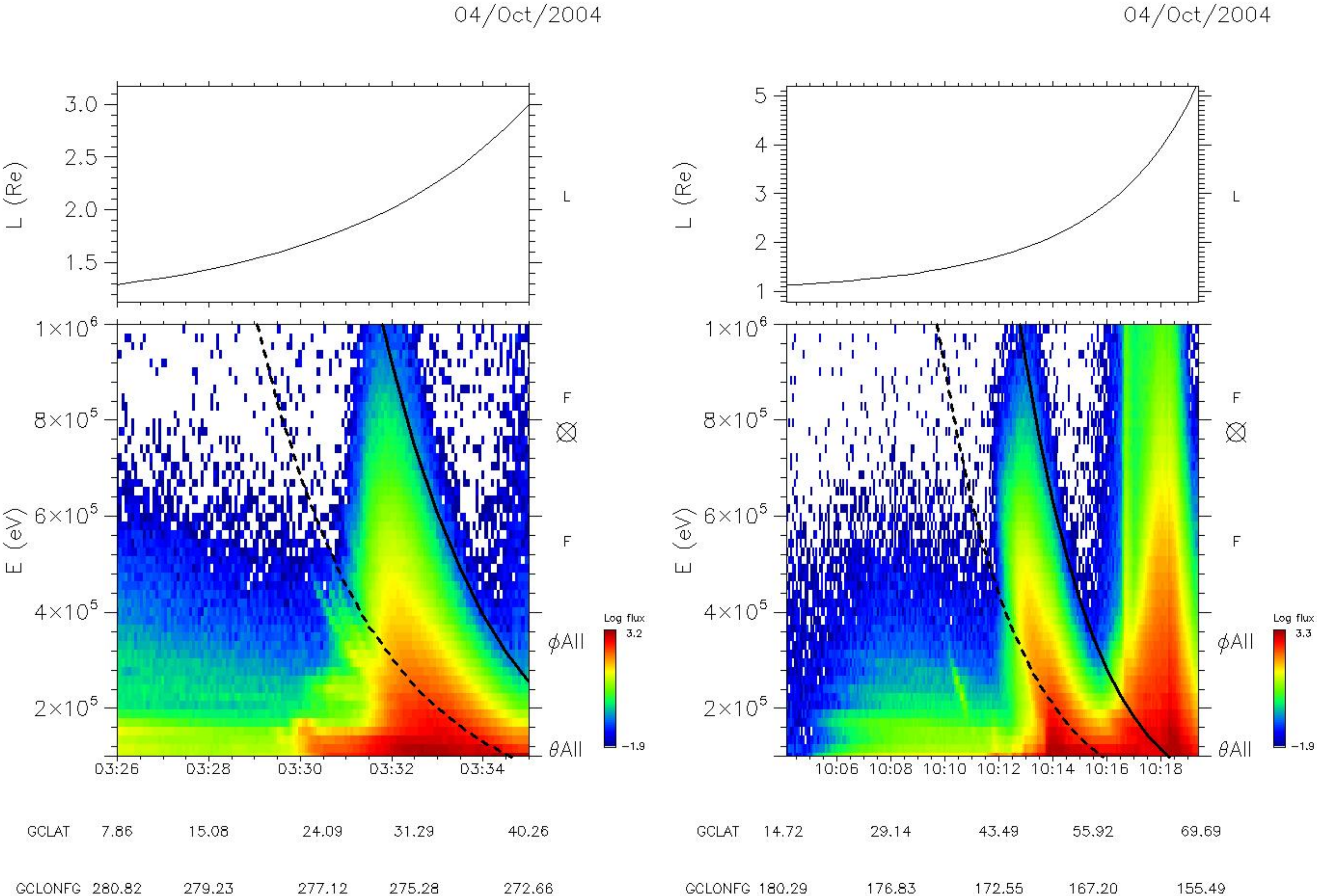


SOUTH OF THE ATLANTIC ANOMALY

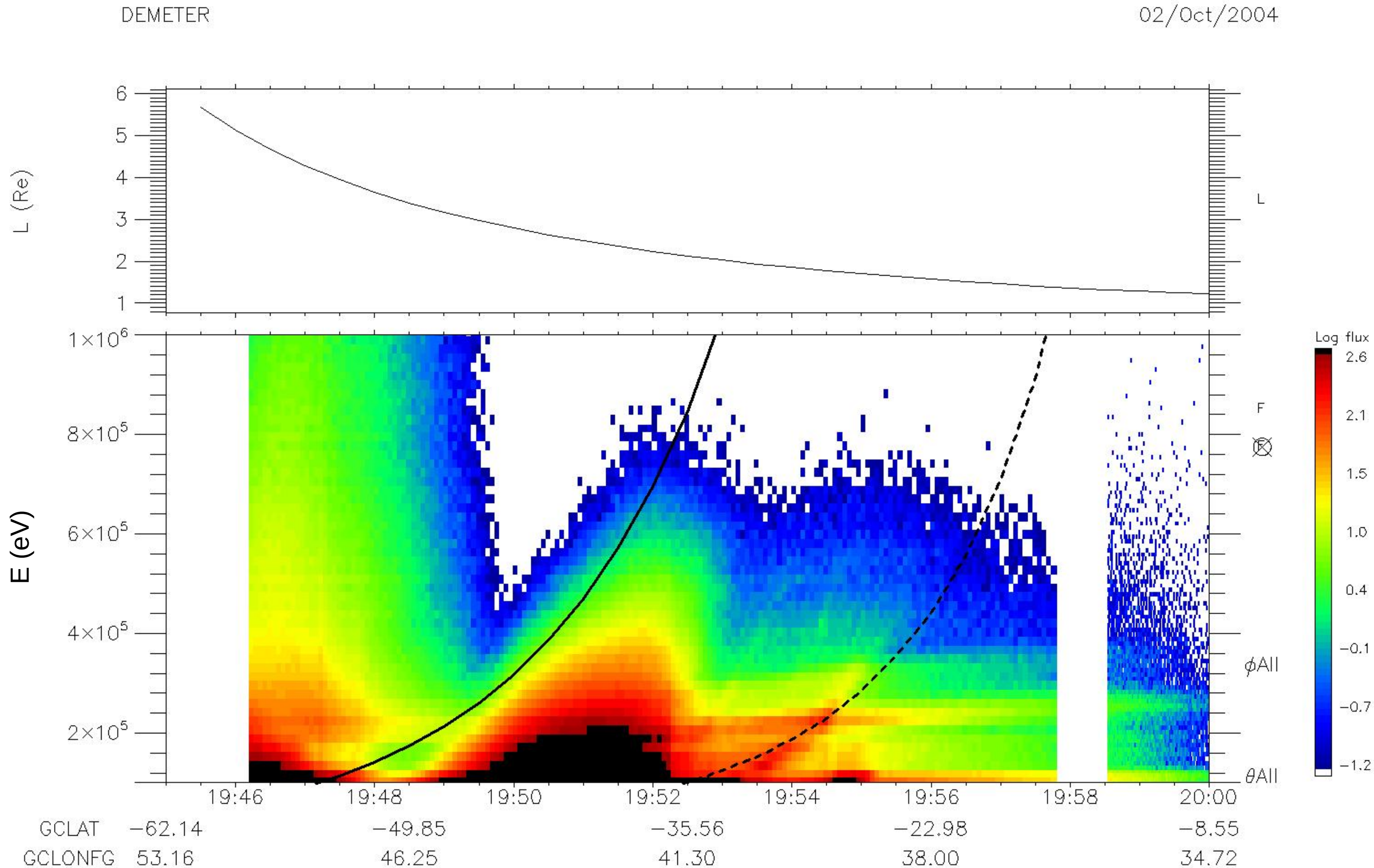


NON HARMONIQUES

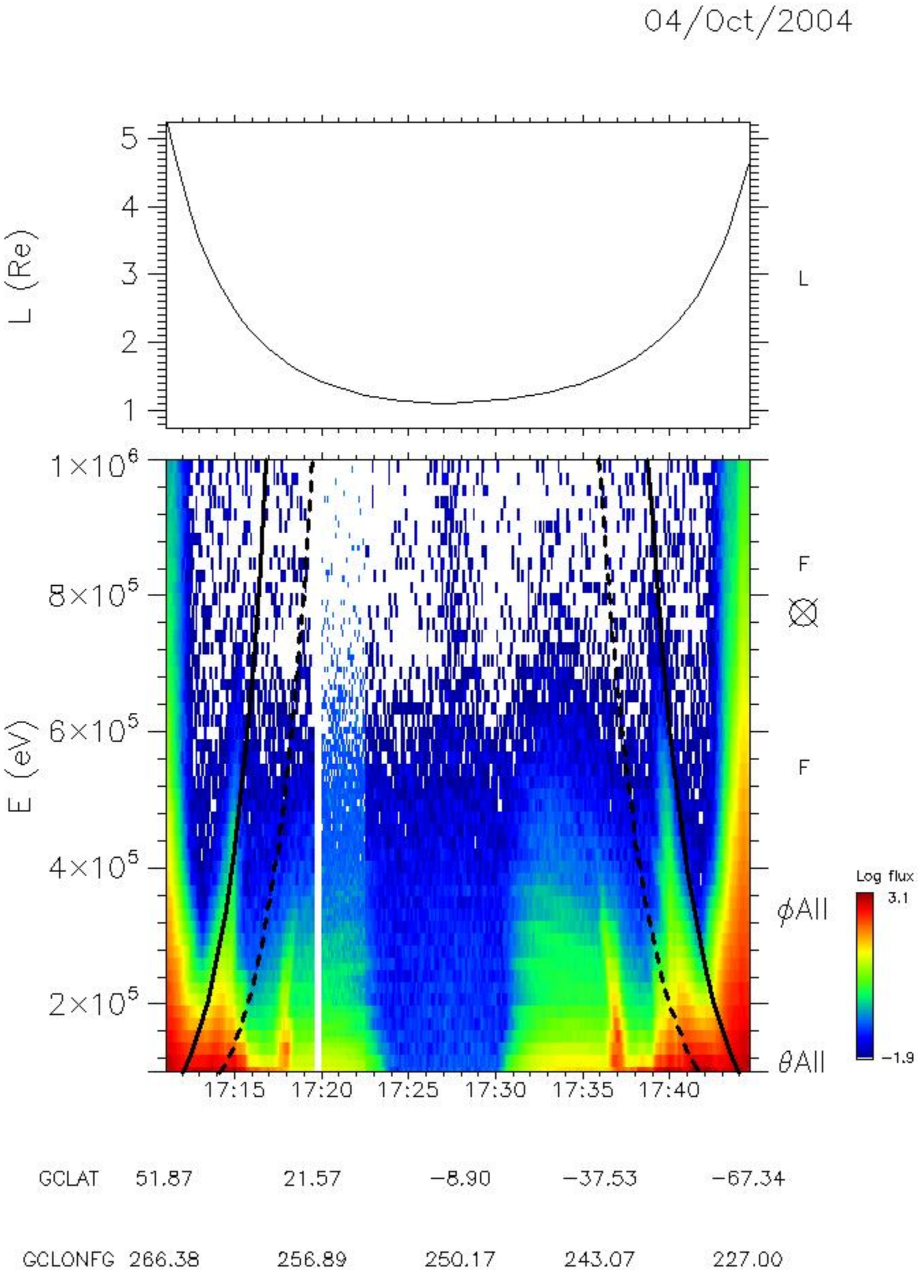
Fréquemment observés au sud de l'Afrique

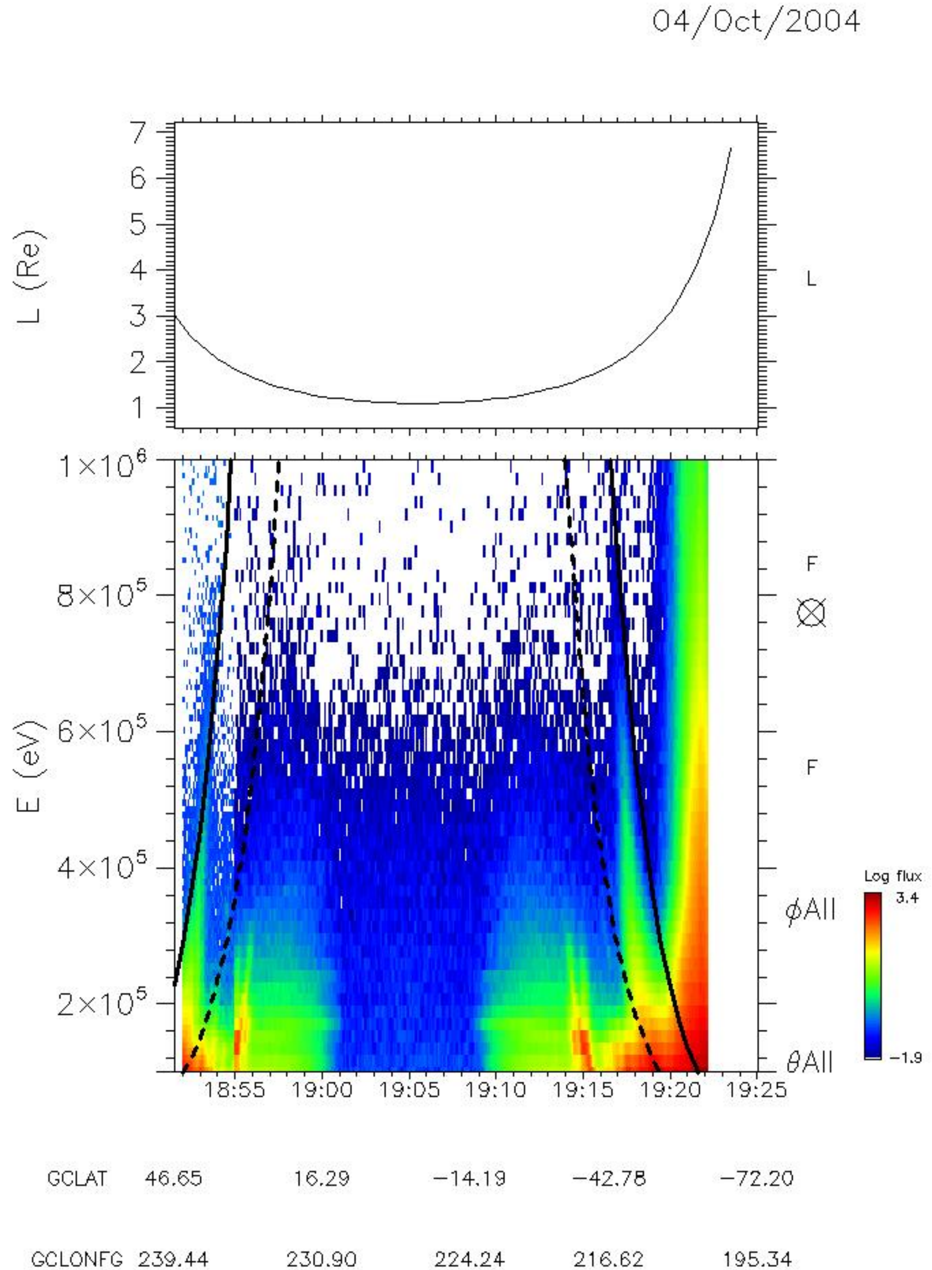


04/Oct/2004
L (Re)
L
E (eV)
F
ϕAll
θAll
Log flux
3.2
−1.9
03:26
03:28
03:30
03:32
03:34
GCLAT 7.86 15.08 24.09 31.29 40.26
GCLONFG 280.82 279.23 277.12 275.28 272.66
04/Oct/2004
L (Re)
L
E (eV)
F
ϕAll
θAll
Log flux
3.3
−1.9
10:06
10:08
10:10
10:12
10:14
10:16
10:18
GCLAT 14.72 29.14 43.49 55.92 69.69
GCLONFG 180.29 176.83 172.55 167.20 155.49

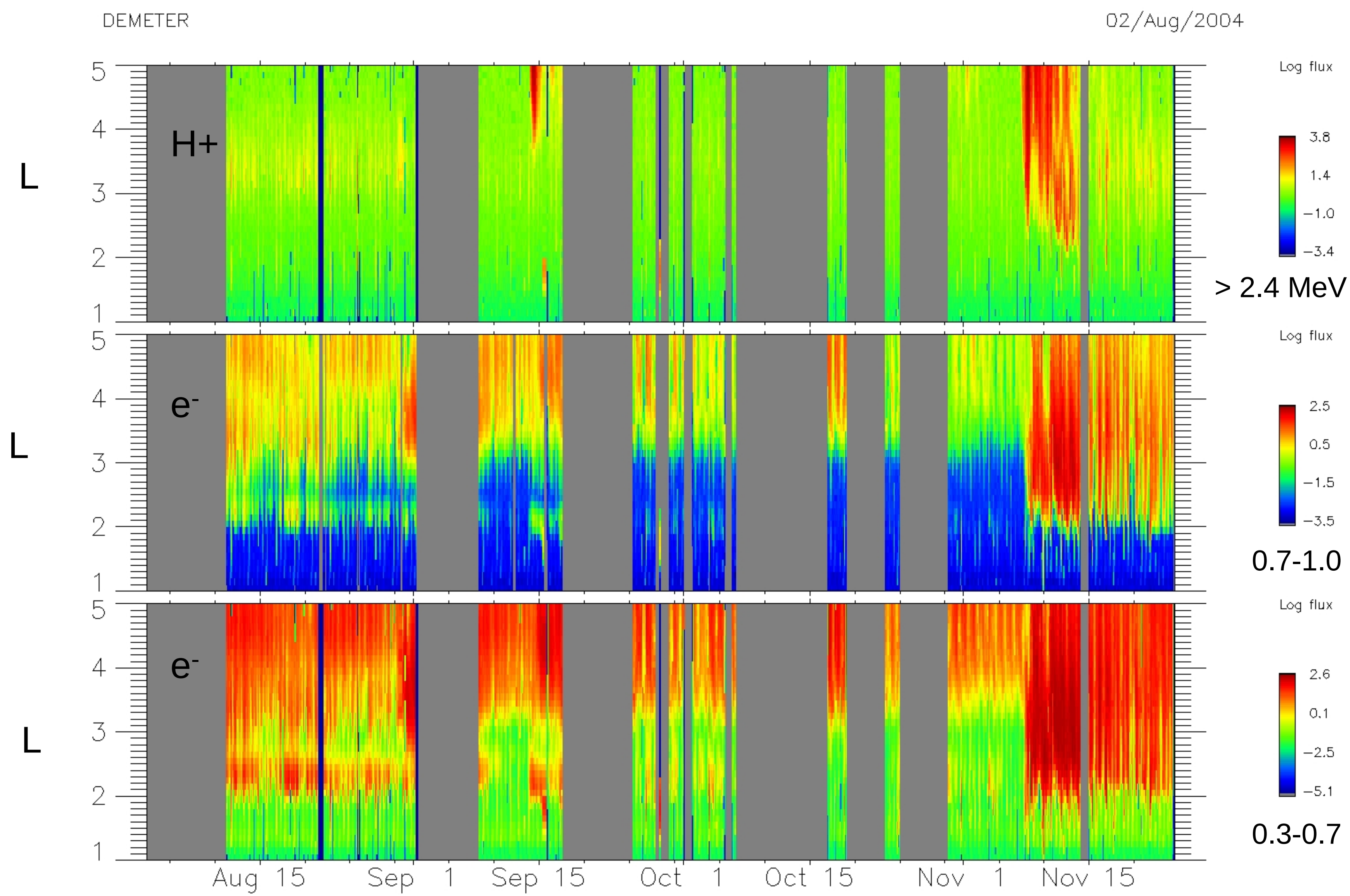


DEMETER
02/Oct/2004
L (Re)
L
E (eV)
Log flux
2.6
2.1
1.5
1.0
0.4
−0.1
−0.7
−1.2
F
ϕAll
θAll
19:46
19:48
19:50
19:52
19:54
19:56
19:58
20:00
GCLAT −62.14 −49.85 −35.56 −22.98 −8.55
GCLONFG 53.16 46.25 41.30 38.00 34.72

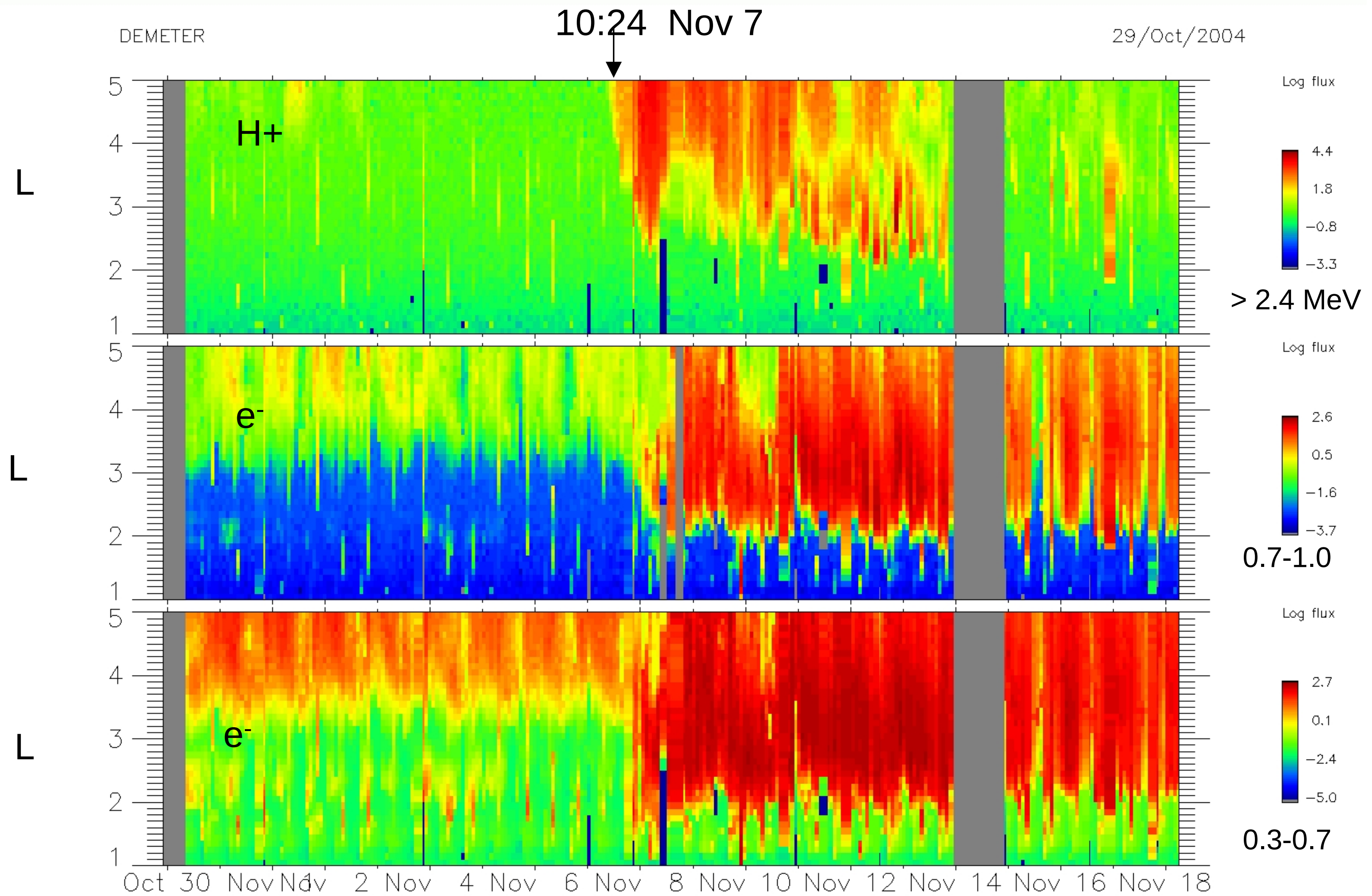

04/Oct/2004
L (Re)
5
4
3
2
1
L
E (eV)
1×10^6
8×10^5
6×10^5
4×10^5
2×10^5
F
F
φAll
θAll
Log flux
3.1
−1.9
17:15
17:20
17:25
17:30
17:35
17:40
GCLAT 51.87 21.57 −8.90 −37.53 −67.34
GCLONFG 266.38 256.89 250.17 243.07 227.00


04/Oct/2004
L (Re)
7
6
5
4
3
2
1
L
E (eV)
1×10^6
8×10^5
6×10^5
4×10^5
2×10^5
F
F
φAll
θAll
Log flux
3.4
−1.9
18:55
19:00
19:05
19:10
19:15
19:20
19:25
GCLAT 46.65 16.29 −14.19 −42.78 −72.20
GCLONFG 239.44 230.90 224.24 216.62 195.34

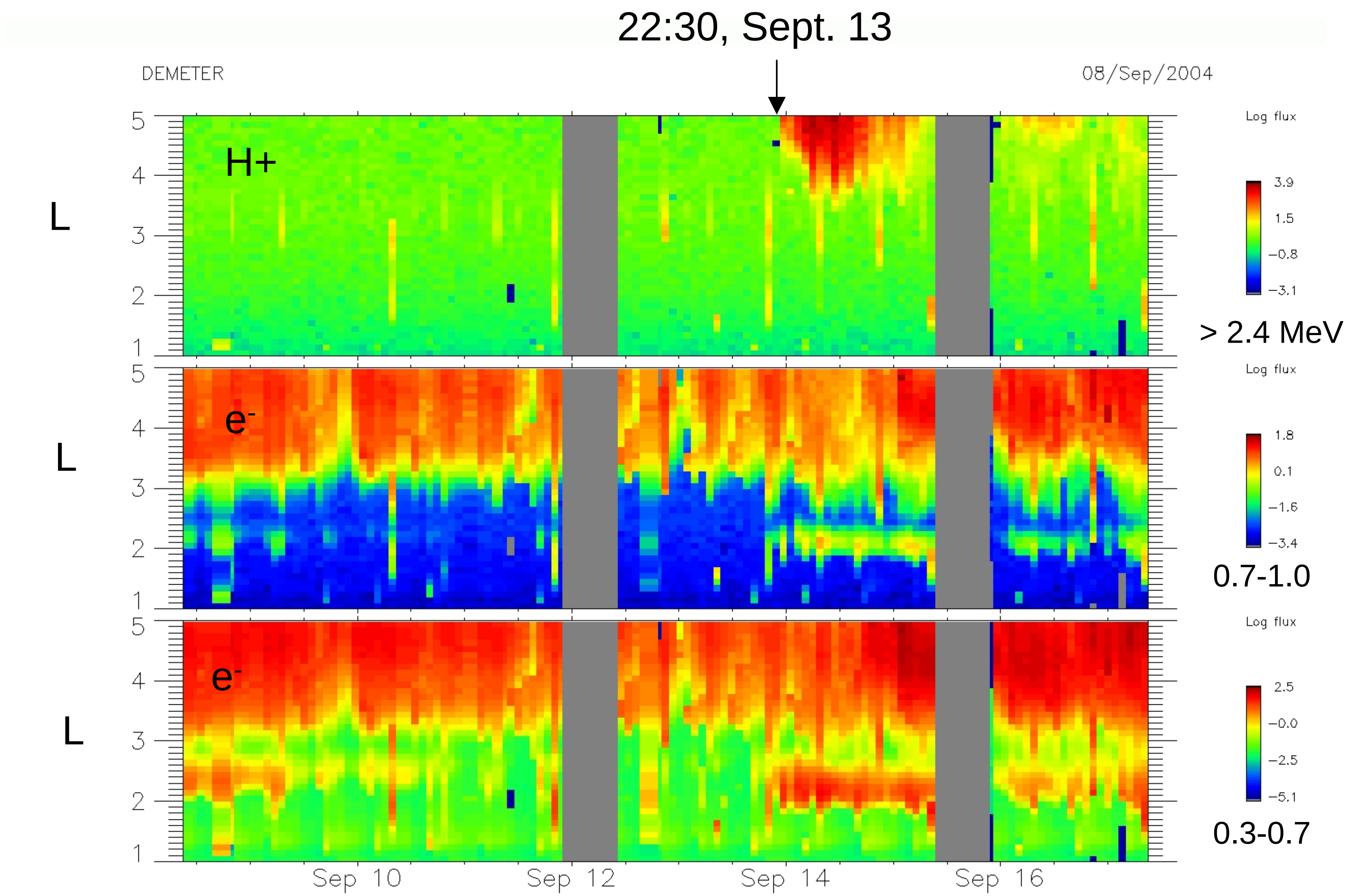
DEMETER - 2004



DEMETER - 2004



DEMETER - 2004



LOW ENERGY PARTICLES

Satellite charging

LOW ENERGY PARTICLES

Earth orbiting spacecraft can encounter plasma of vastly diverse characteristics in the energy range: ~ eV - 60 keV

Versatile and reliable particle experiment are needed.
To meet the objectives, the instrumentation has to satisfy the following criteria:

- Be immune to UV flux
- Be immune to high energy particle background
- Provide uniform coverage over a large pitch-angle range with a good angular resolution
- Have high sensitivity and large dynamic range (~ 10^7)

LOW ENERGY PARTICLES

Rely as much as possible on well-proven designs by basing sensor designs on those successfully flown:

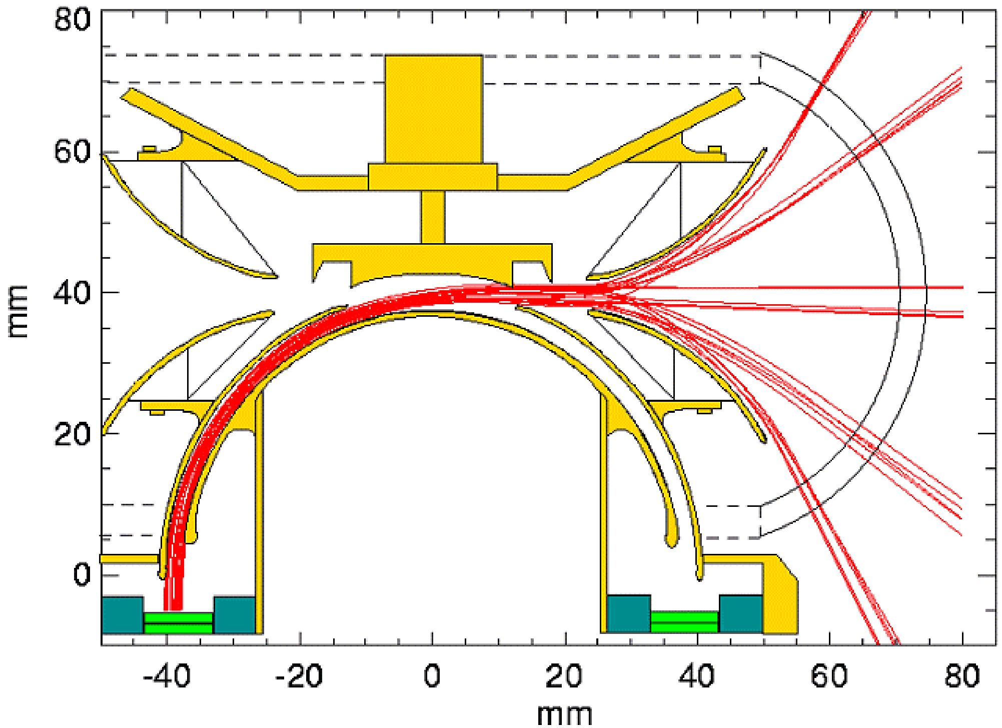
ESRO-1A	CASSINI	ARCAD-1/2/3
GIOTTO	MEX	INTERBALL
AMPTE	STEREO	
VIKING	VEX	
FREJA		
EQUATOR-S		
CLUSTER		

LOW ENERGY PARTICLES

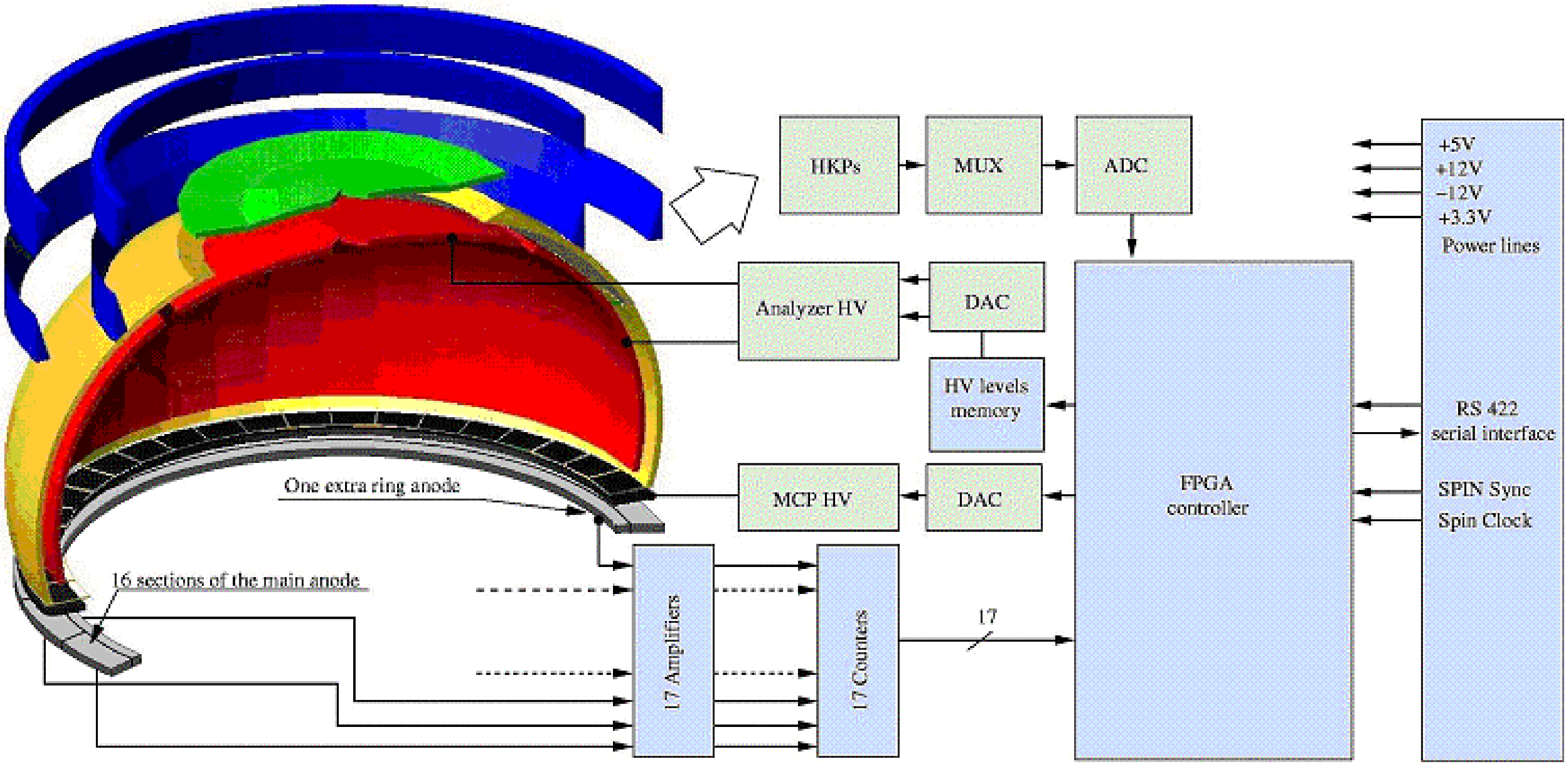
UV: Three reflections, scalloping, coating

High energy particle background: Coincidence or multiplier sample

Uniform coverage: top-hat (Carlson, Paschmann et al., 1982)



LOW ENERGY PARTICLES



SUMMARY

1) We have the necessary tools to measure/model the Earth's radiation belts

   New improvements are needed to measure pitch-angle distributions

2) We need a framework to build common experiments

3) Past and ongoing missions will be used to define simple low energy sensors