

Megavolt Parallel Potentials Associated With Double Layer Streams In The Earth's Outer Radiation Belt

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Double layers are regions of charge separation along B that produce parallel E and parallel potential drops
They were proposed by Alfvén 55 years ago to be the mechanism for accelerating electrons in astrophysics
Until now, they have not been observed with sufficient total potentials to matter

VAP have seen huge numbers of double layers (7000 in one minute of data) that produced a total parallel potential crossing the spacecraft of 1,000,000 volts in six minutes during a spacecraft charging event

You may not believe this (but you will eventually) because you may think that such potentials will accelerate away all the plasma.

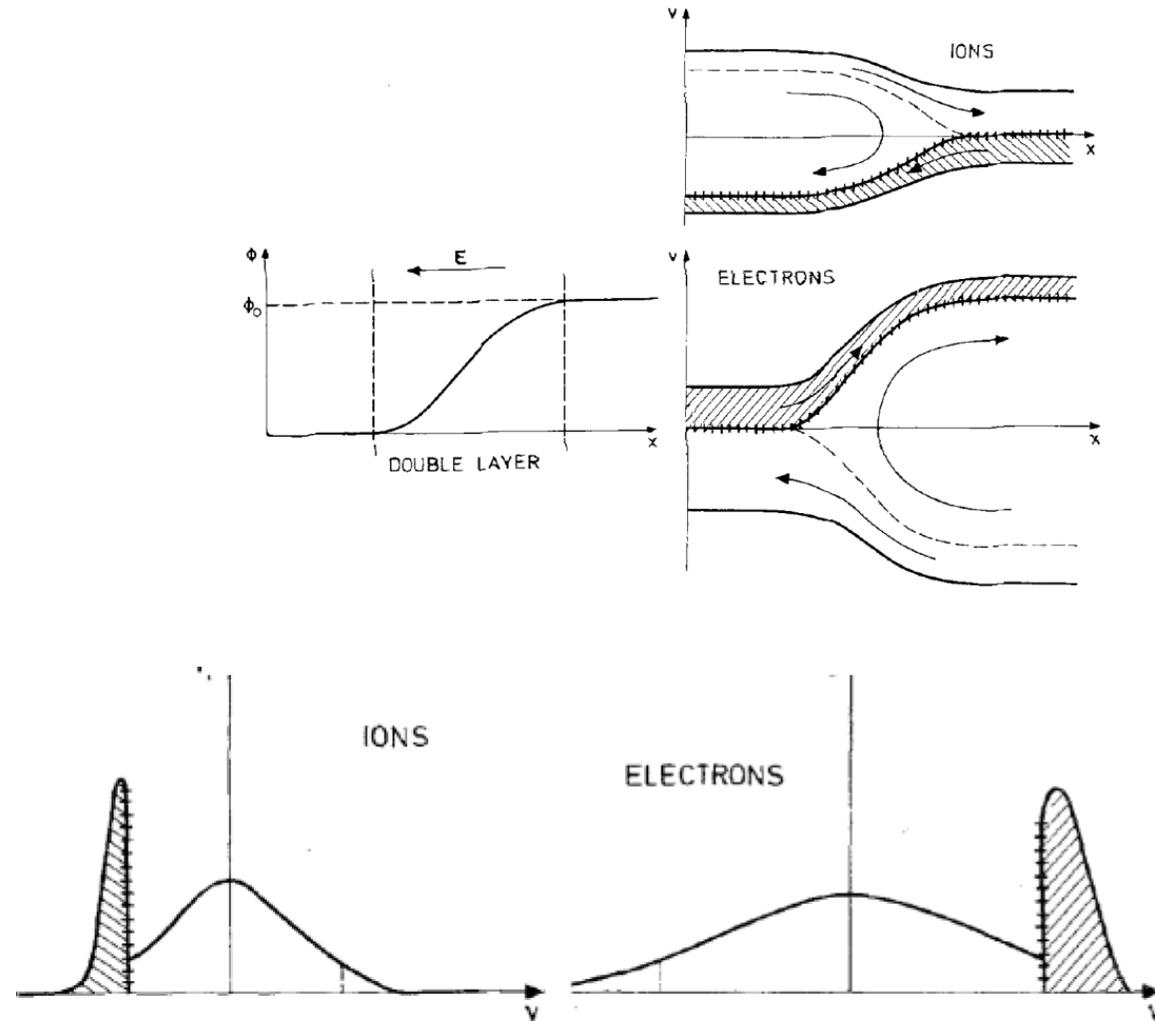
This is wrong because the double layers exist in a self-consistent interaction with the plasma, so there would be no double layers if all the plasma was accelerated away.

In fact double layers have been shown via simulations to do almost the opposite in some situations such as stopping the transport of electrons in the solar corona.

The important issues are to understand the plasma distributions, and the interactions of the plasma with the double layers.

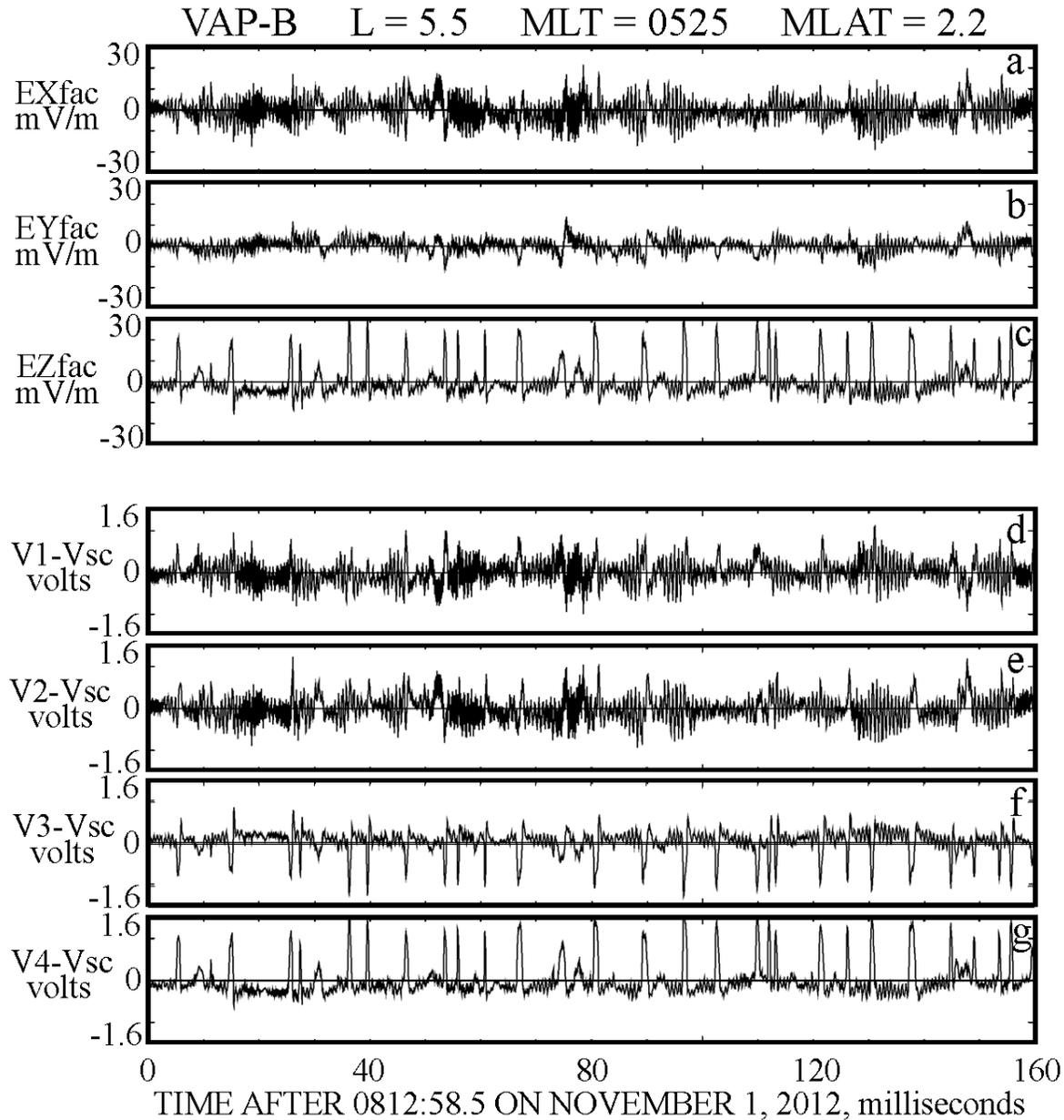
Double layers may be the drivers for microburst electron precipitation, providers of the seed ~100 keV electrons required for whistler wave efficient accelerate of electrons to relativistic energies, etc.

PLASMA DISTRIBUTIONS IN AN ION ACOUSTIC DOUBLE LAYER



Raadu and Rasmussen
Astrophysics and Space Science 144 (1988) 43-71.
© 1988 by Kluwer Academic Publishers.

Analyze the fortunate occurrence of one minute of double layer collection by the burst memory

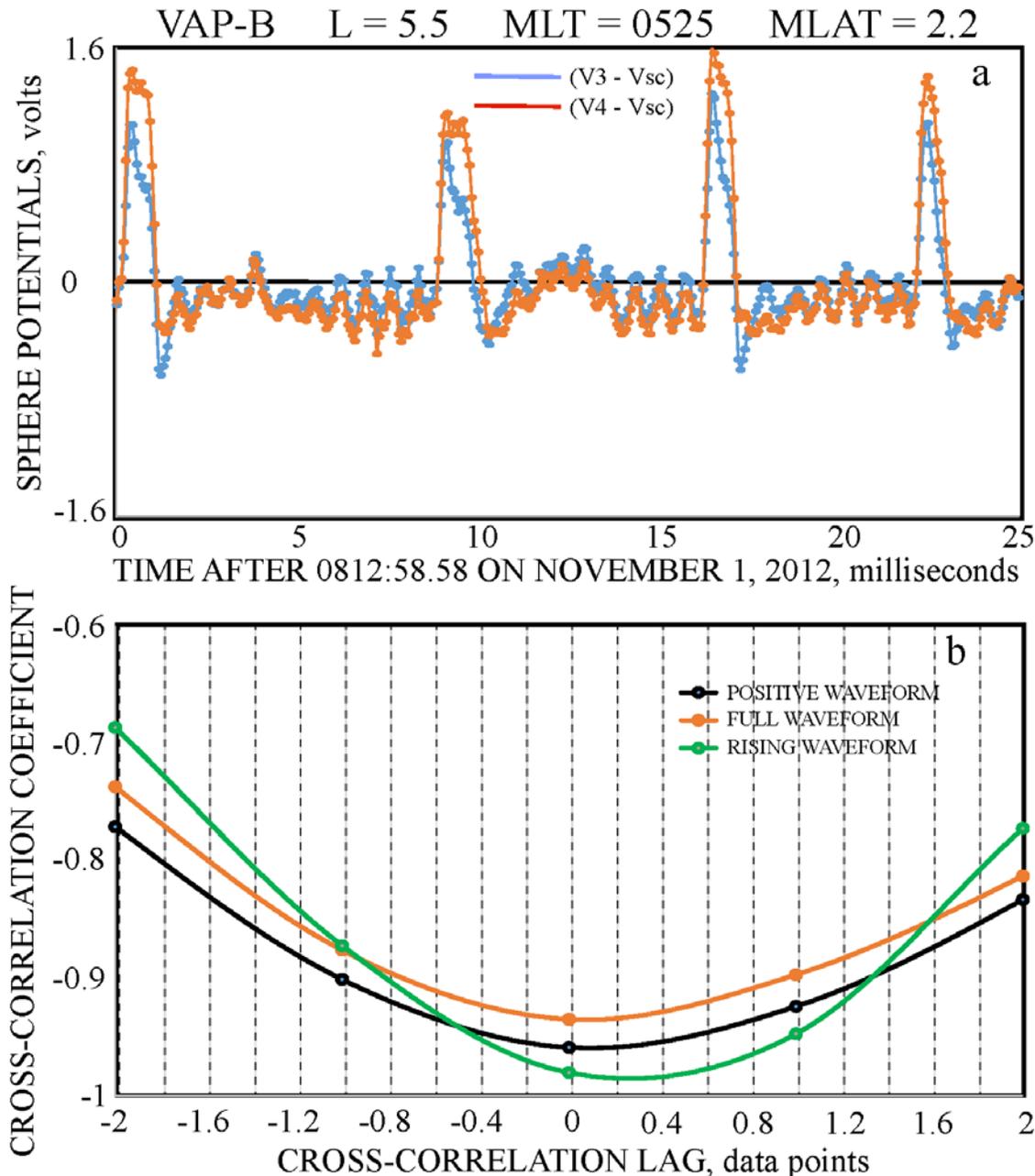


150 msec of data when spheres 3 and 4 were aligned along B to within 2 degrees

Top three panels give components of E in field-aligned coordinates with Z being parallel to B

See low amplitude whistlers in X and double layers in Z

Bottom four panels are the individual sphere potentials. See the double layer signatures in spheres 3 and 4.



Four double layer voltages from the 150 msec interval, with sphere 3 voltage inverted for easy comparison.

For all the double layers in the 150 msec interval, cross-correlation lag is 0.2 ± 0.1 data points

At 16,384 points/second, 0.2 points = 12 microsec

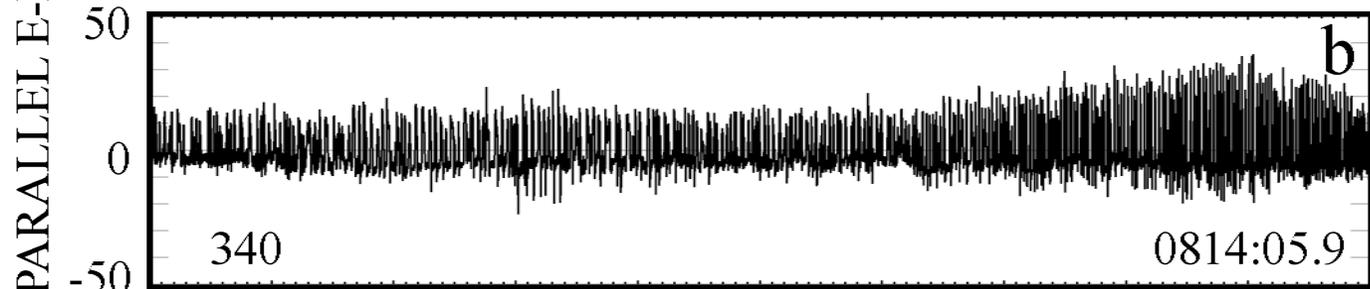
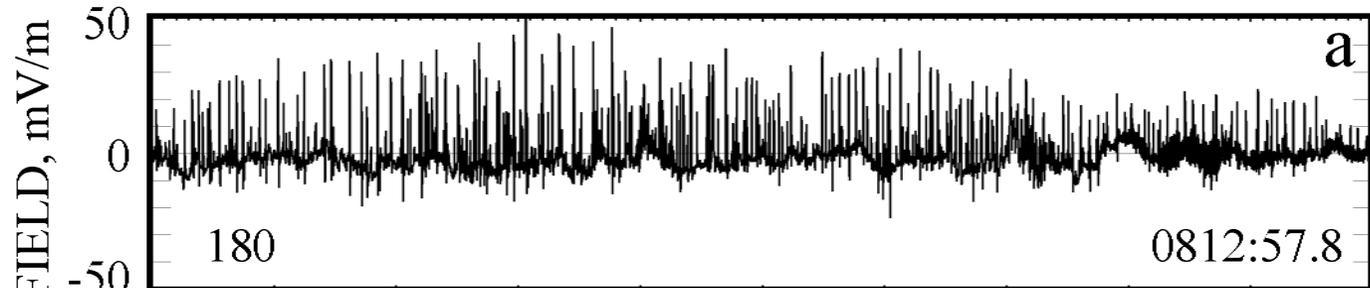
$50 \text{ m} / 12 \text{ microsec} = 4000 \text{ km/sec}$

Average width is 0.45 msec which is 1.8 km

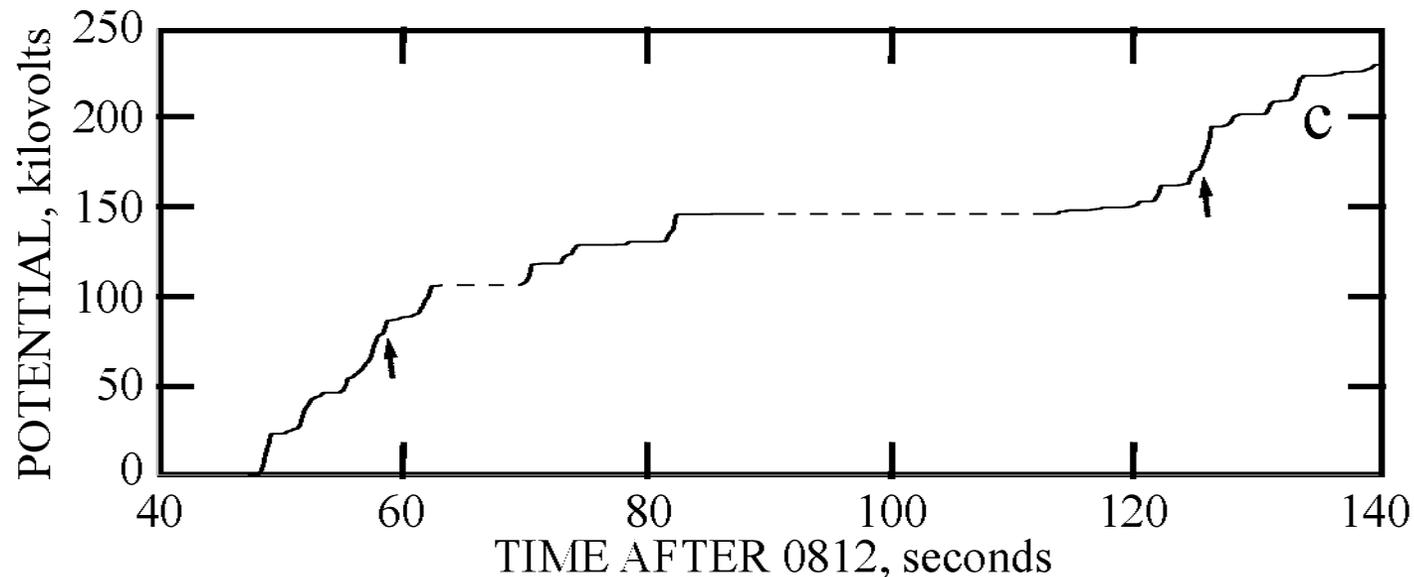
Average $E = 20 \text{ mV/m}$

Single double layer potential = 35 volts

VAP-B 11/01/2012 MLT = 0530 L = 5.6



ONE SECOND OF PARALLEL E-FIELD AT INDICATED TIMES



Two one second examples of double layers in a one minute interval of high (16384 Hz) rate observations.

See 520 double layers in these 2 seconds of data.

See 7000 double layers in the one minute of data

Summed potential of these double layers in bottom figure, where steps are the brief double layer streams

TOTAL POTENTIAL IN ONE MINUTE IS 230 KILOVOLTS

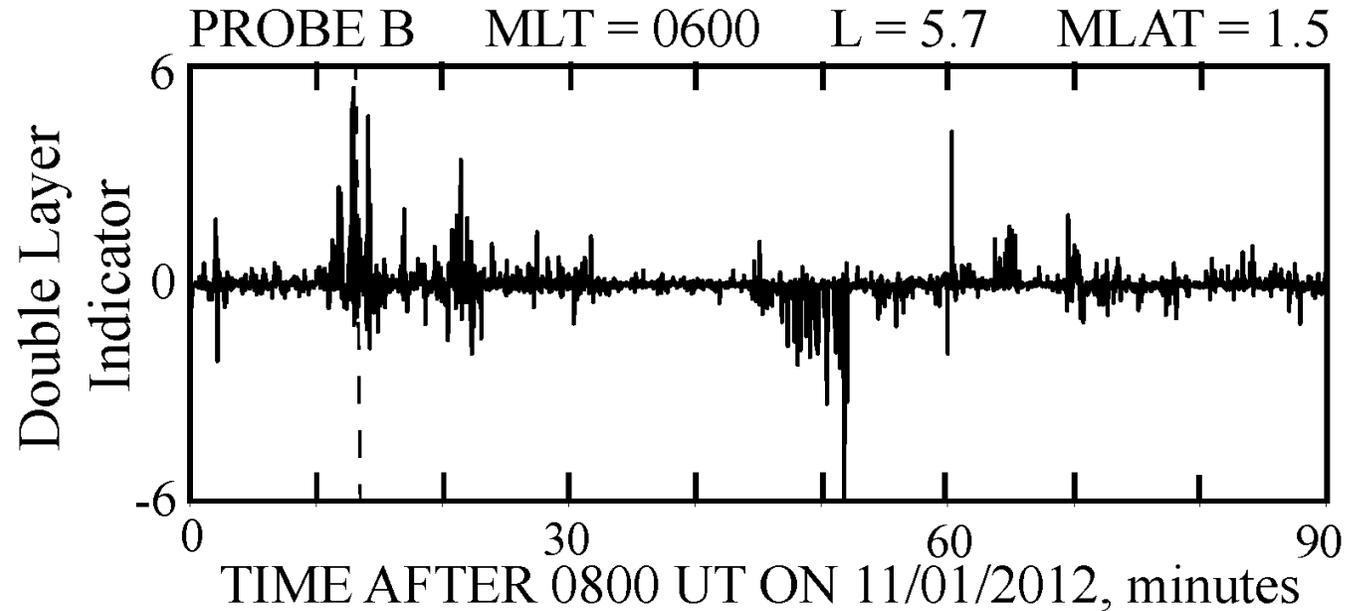
Use 512 Hz data to examine larger time interval

Plot is data after:

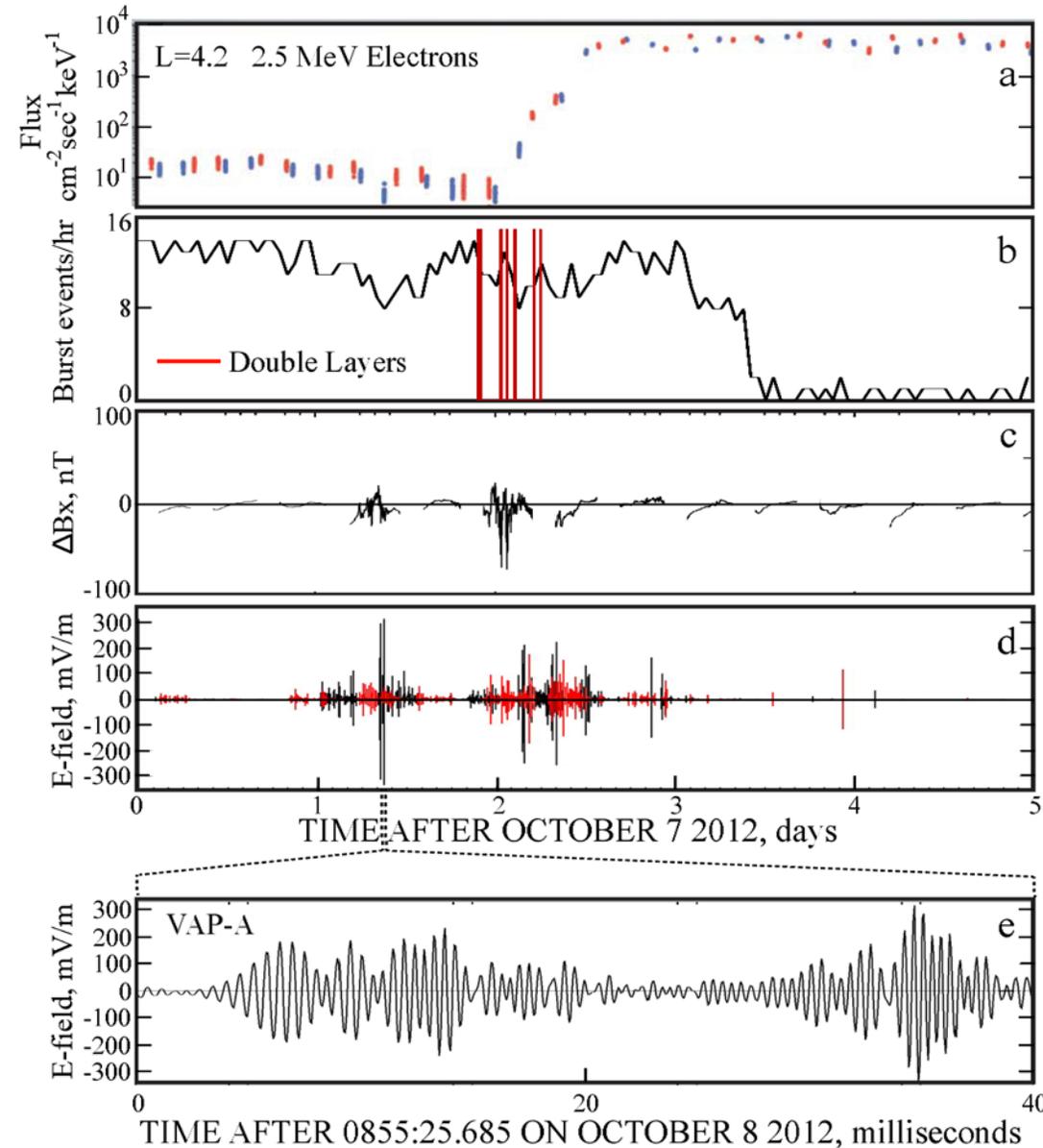
- high pass 512 Hz data at 20 Hz
- compute (max+min) in each second
- low pass filter at 0.25 Hz

Plot shows double layers lasted for 6 minutes

230,000 volts in one minute suggests 1,000,000 volts during the 6 minutes



EXAMPLE ILLUSTRATING RELATIONSHIP OF DOUBLE LAYERS AND RELATIVISTIC ELECTRON ACCELERATION



ION ACOUSTIC AND ELECTRON ACOUSTIC DOUBLE LAYERS

Double layers that have been seen previously are ion acoustic signatures produced by single temperature ions and single temperature electrons. They travel at the ion acoustic speed.

The VAP double layers travel at the electron acoustic speed, not the ion acoustic speed. Such double layers have not been seen before and they have been little studied theoretically

The double layers may be associated with a dual temperature electron plasma of cold and hot electrons, where the cold electrons play the role of the ions in the case of ion acoustic double layers.

To understand these double layers we need:

- measurements of the electron distribution function
- simulations or theories of the electron acoustic mode.

Because the double layer observations are new and exceptional, it is necessary to consider alternative explanations for the data that do not involve extremely large parallel potentials:

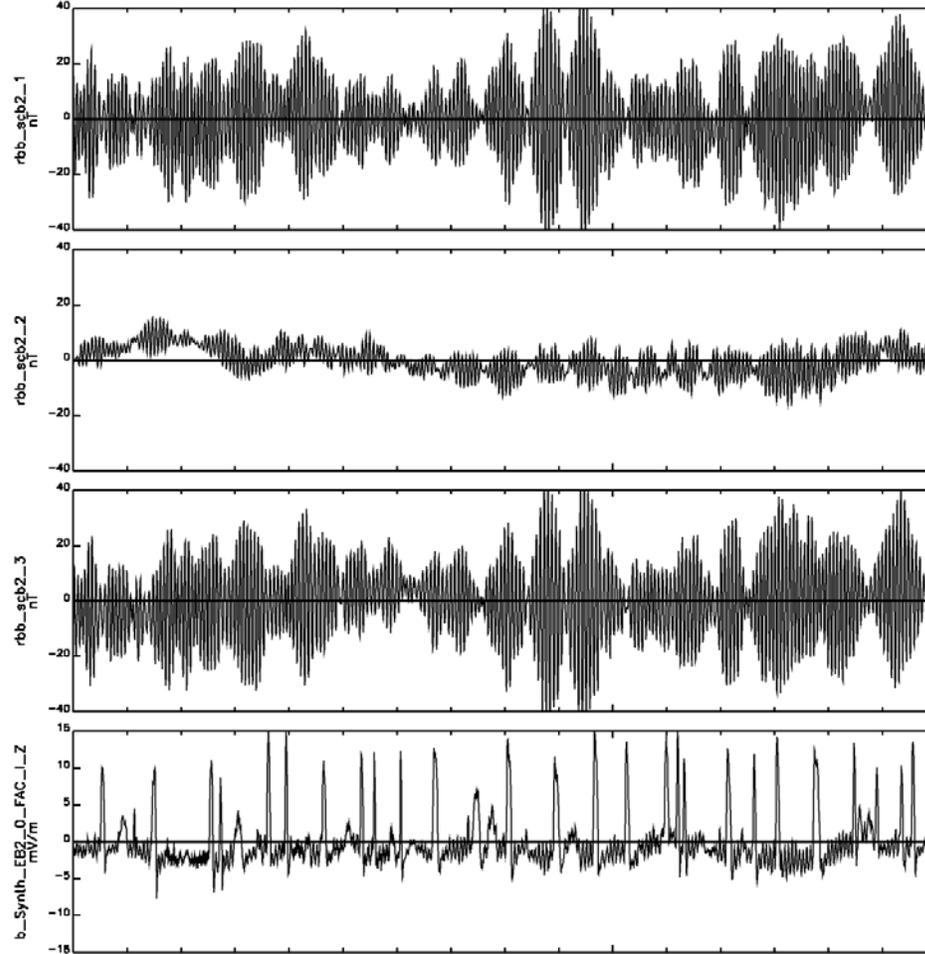
1. Observations are due to currents, not voltages.
No magnetic field signals are observed in the search coil. So the observed structures are electrostatic.
2. Walls of increased plasma density move along B and cross the spacecraft.
To balance the pressure gradient across the front of the wall, a parallel electric field is required. So this becomes a self-consistent description of a double layer.
3. Cross talk between spheres.
From in-flight calibrations, there is no cross-talk.
4. Fluctuations of the spacecraft potential.
Not a possible explanation because such fluctuations produce the same signal on all four spheres.
5. Malfunction of sphere electronics.
Not possible because signals are seen in all four spheres equally and in the pairs expected from the B-field orientation.
6. Increase of V_4 causes a decrease of V_{sc} so $(V_4 - V_{sc})$ is overestimated.
The effect on V_{sc} of an increase of V_4 can only be through current balance. V_{sc} cannot respond to a current change in a fraction of a millisecond because of the charging time of its capacitance.
7. Increase of V_4 causes increase of V_{sc} (due to grounded wire boom near the sphere).
If this happens, it produces an underestimate of $(V_4 - V_{sc})$, so the potential is larger than measured.
8. Particle distribution functions are modified near the spacecraft by the -200 volt potential so double-layer-like structures are formed in this potential.
The spheres are 50 meters from this potential so their potentials are altered by only a few volts. Thus, the spheres would see only a few percent of the structures formed while the spacecraft would see it all. So this produces case 4 above.

REMAINING QUESTIONS

1. Are there parallel accelerated electrons?
2. What is the pitch angle distribution as a function of energy?
3. Is there parallel flow?
4. What is the geometry of the field-aligned current?
5. How are parallel electrons pitch angle scattered enough to avoid being lost?
6. Spectra? In theories, what must one assume for the distributions? Single temperature species is probably inaccurate.
7. Physics of double layer formation and maintenance? Electron acceleration in these double layers?
8. Is a new electron acoustic double layer theory needed?

EXTRA SLIDES

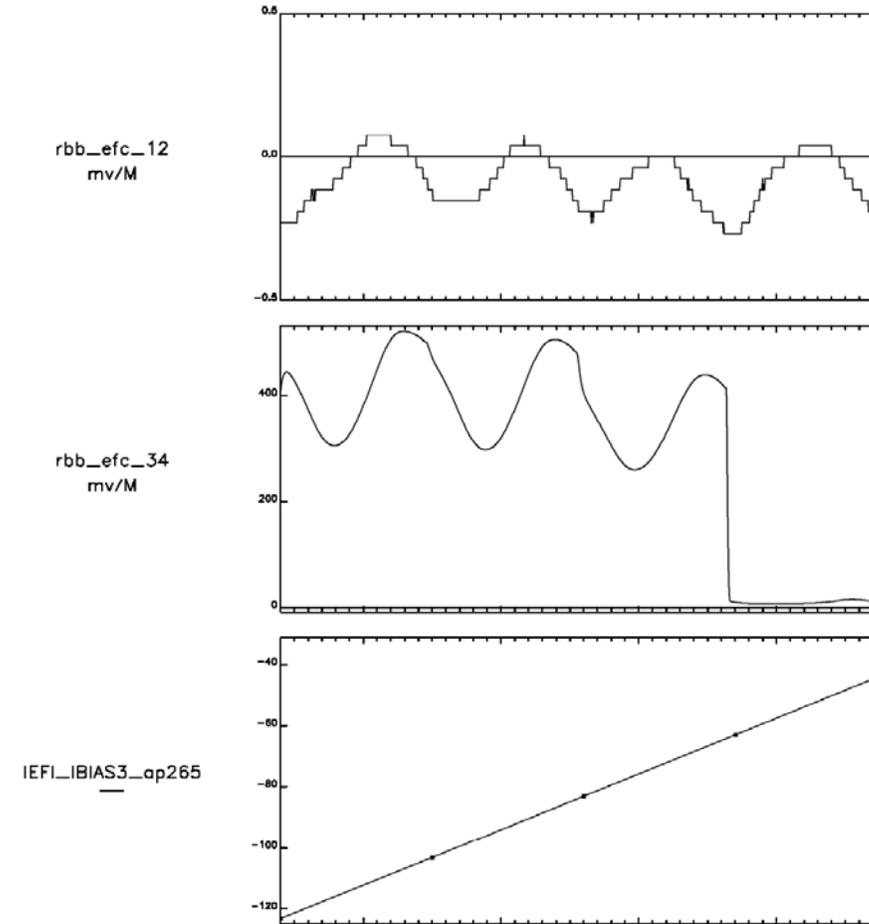
RBSP 2012/11/01 (Day 306), 08:12:58.500 - 08:12:58.660



Time: 08:12:58.6
A-Hgt(Re) 3.78
A-MLat 4.63
A-MLT 4.58
A_LShell 4.81
B-Hgt(Re) 4.52
B-MLat 2.25
B-MLT 5.43
B_LShell 5.52
P:<SDT>, V:<5.0> T:<Sat Aug 10 12:18:39 2013>

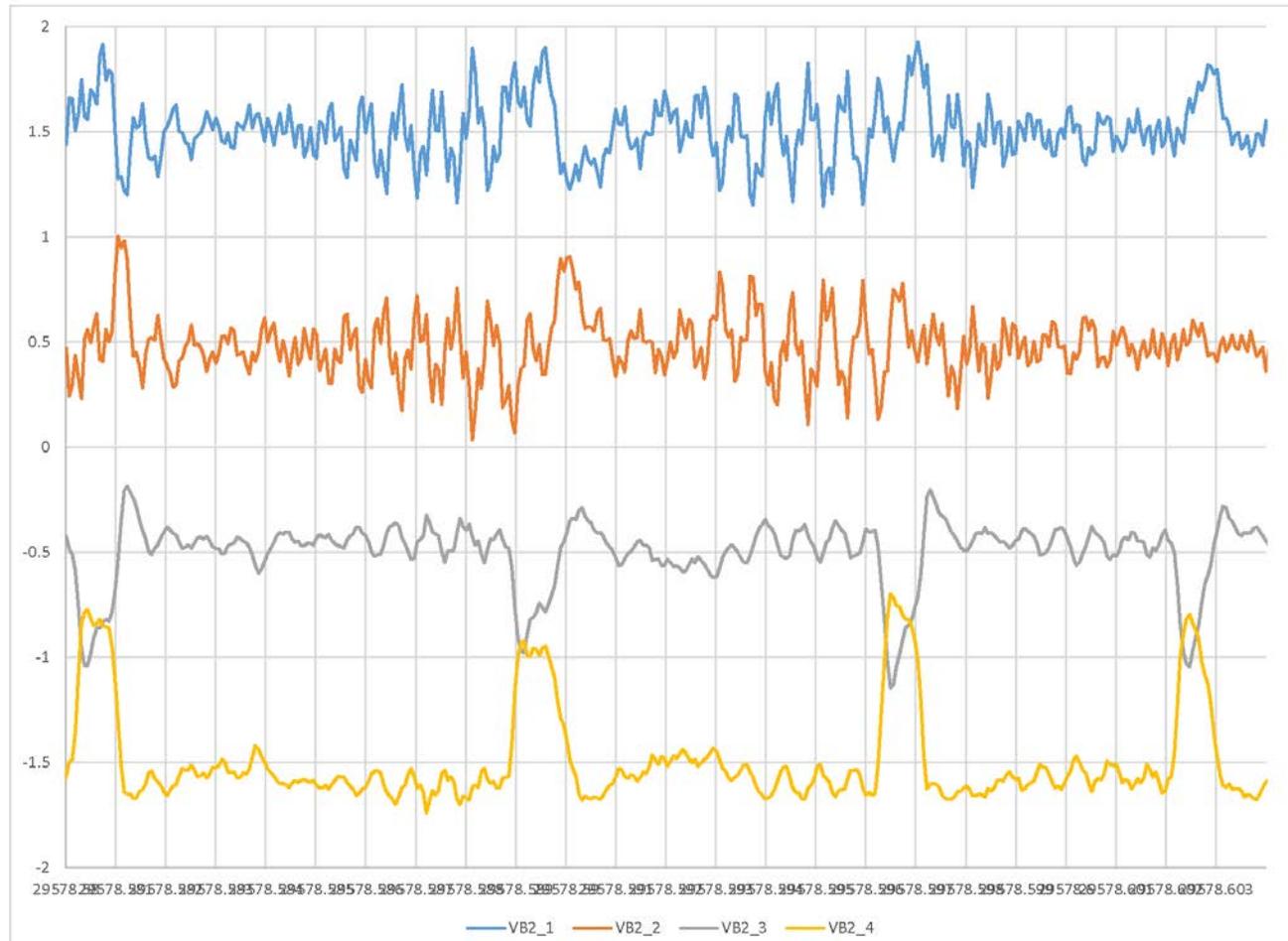
Bias current on 34 decreasing (bottom panel). V34 comes out of saturation when the current is -60 namps. When this happens there is no change in V12 (whose amplitude is ~ 0.1 mV/m). So there is no cross-talk between spheres, etc.

RBSP 2013/07/03 (Day 184), 03:15:03.999 - 03:15:48.105

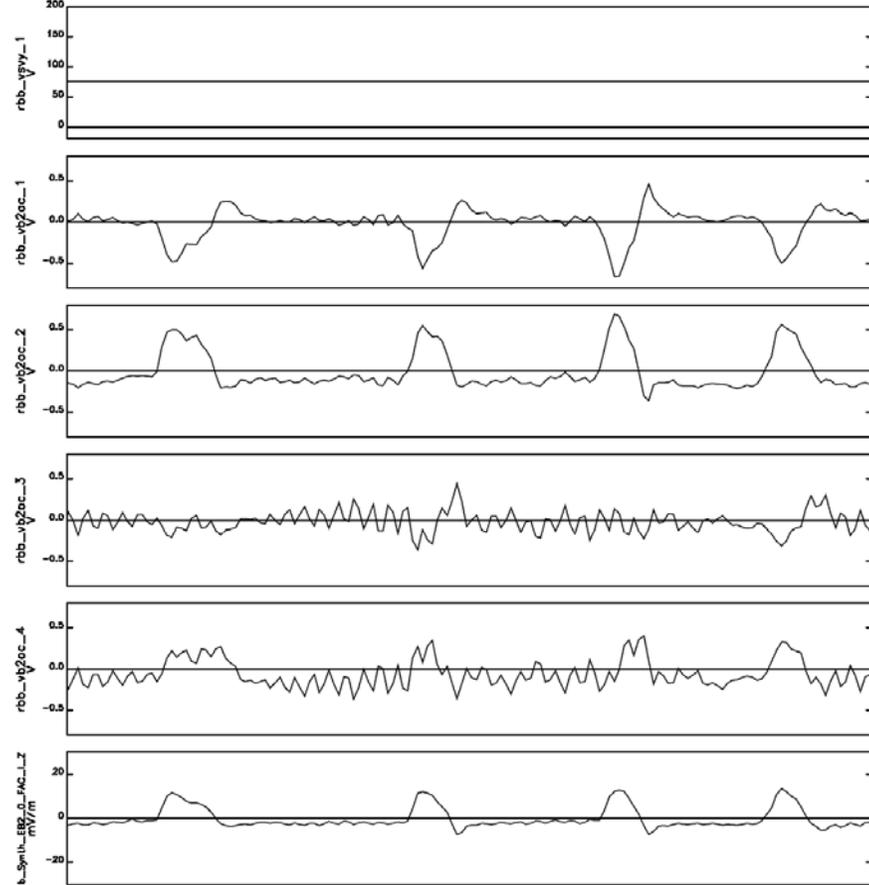


Time:	03:15:10	03:15:20	03:15:30	03:15:40
A-Hgt(Re)	1.56	1.55	1.54	1.54
A-MLot	9.70	9.67	9.63	9.59
A-MLT	1.44	1.45	1.46	1.47
A_LShell	2.59	2.58	2.57	2.57
B-Hat(Re)				

Data when V3 V4 along B to within 2 degrees. Shows that rise times of V3 and V4 have no signals in V1 or V2. Later, during fall of V3 and V4, there are signals in V1 and V2 that result from perturbation of the DL by the spacecraft.

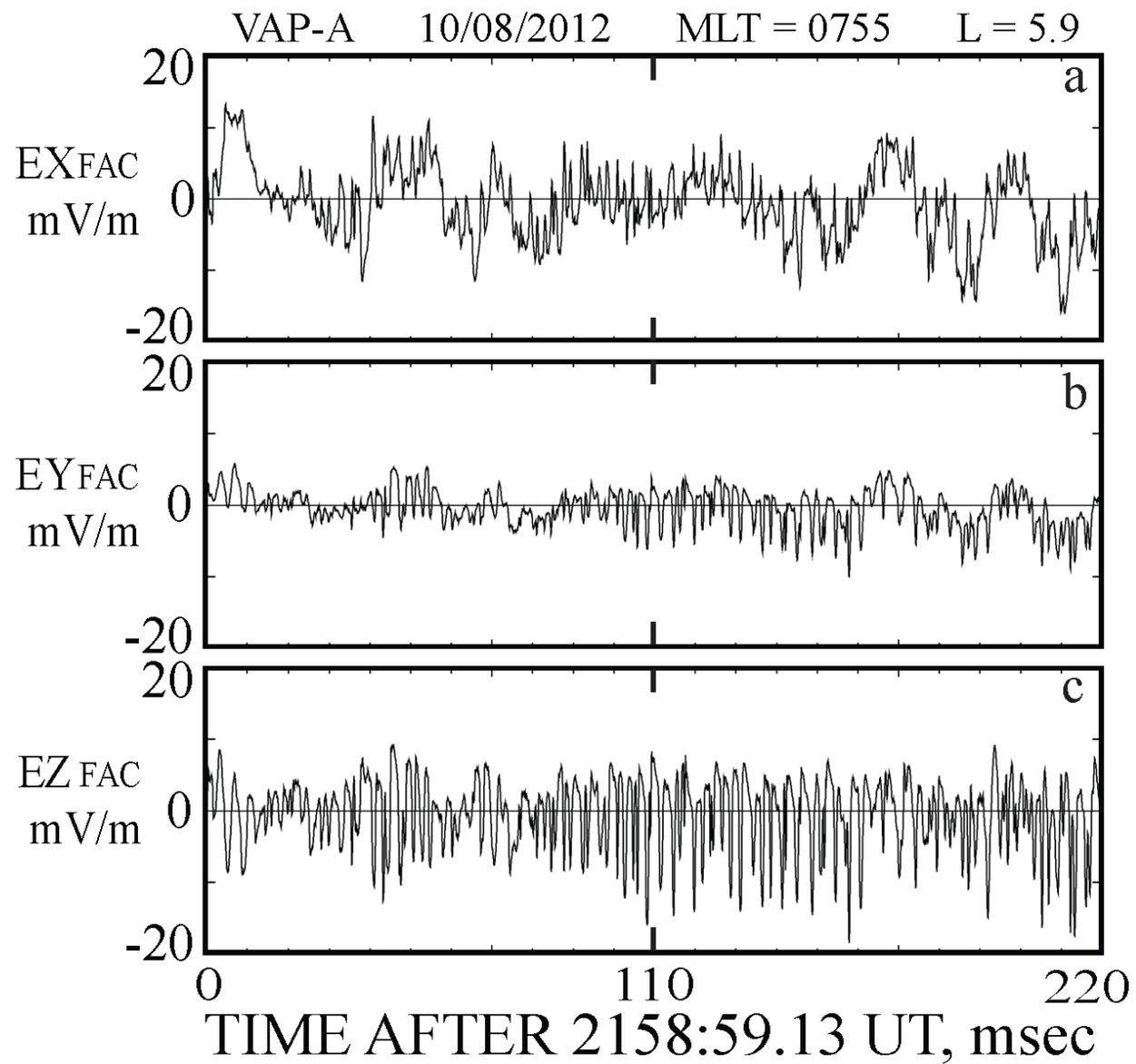


RBSP 2012/11/01 (Day 306), 08:14:06.210 - 08:14:06.220

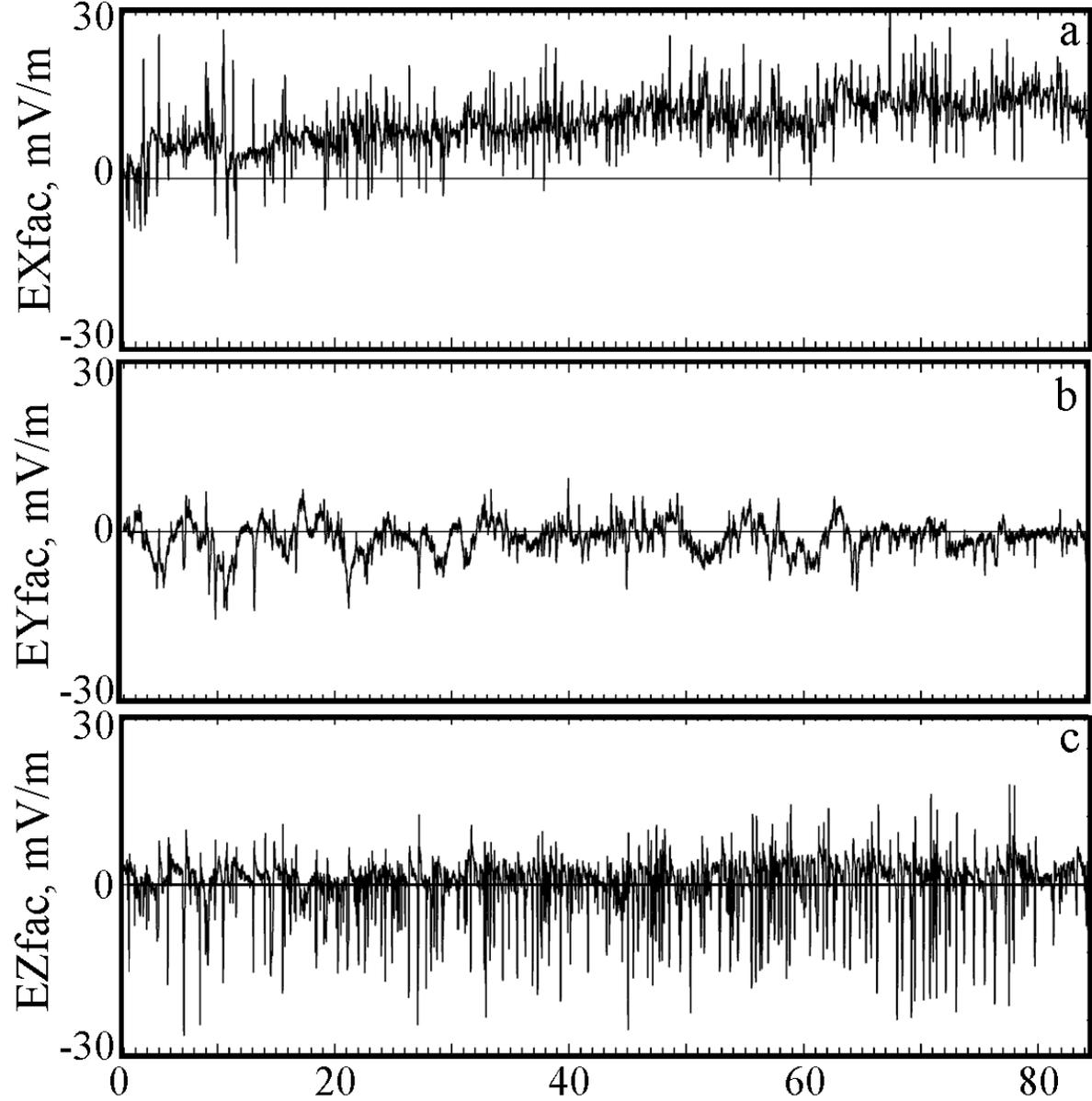


Time: 08:14:06.2
A-Hgt(Re) 3.80
A-MLot 4.59
A-MLT 4.60
A_LShell 4.82
B-Hgt(Re) 4.53
B-MLot 2.23
B-MLT 5.44
B_LShell 5.53

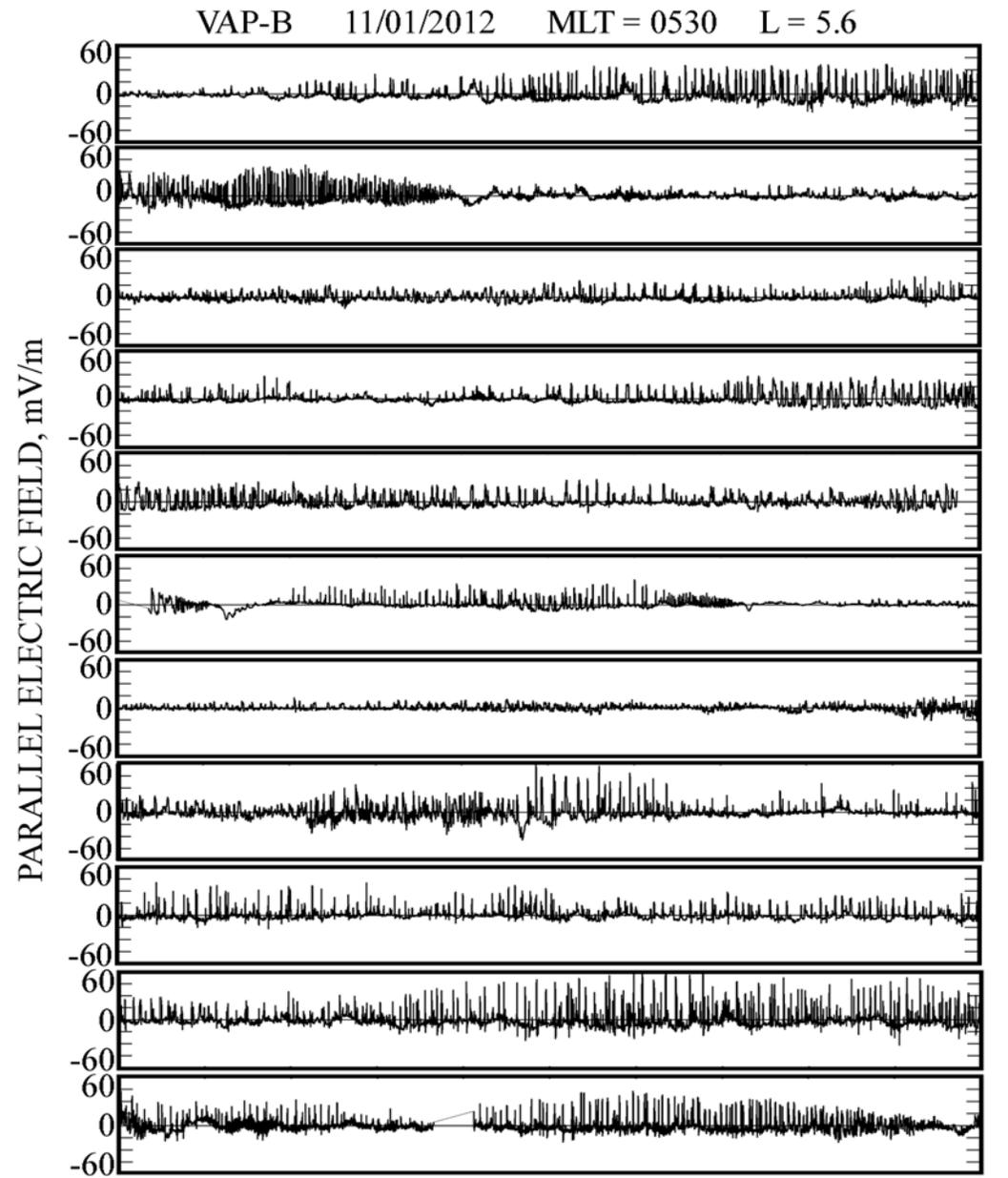
P:<SDT>, V:<5.0> T:<Sat Aug 10 12:44:37 2013>



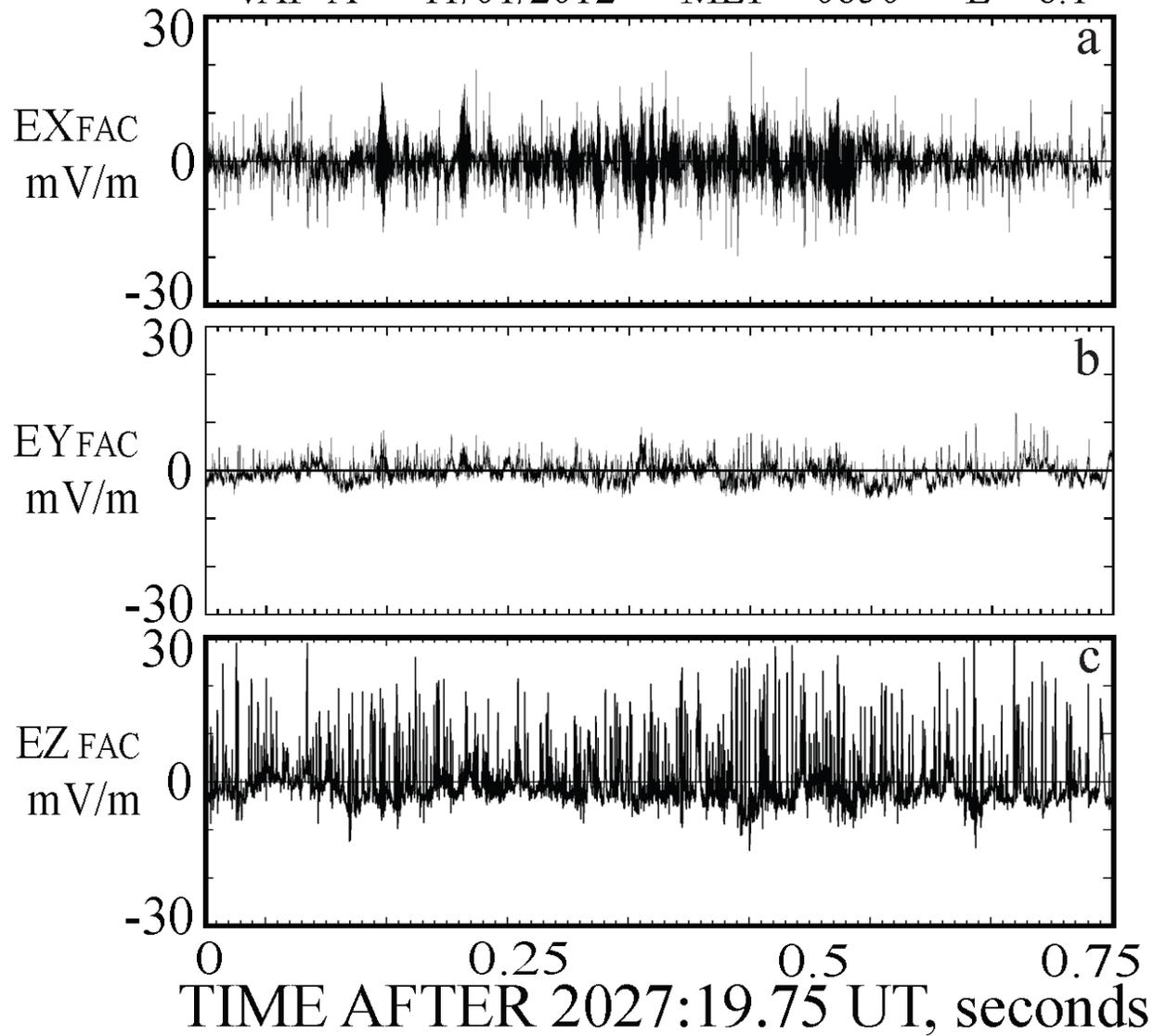
VAP-B L = 6.4 MLT = 0657 MLAT = -14.3

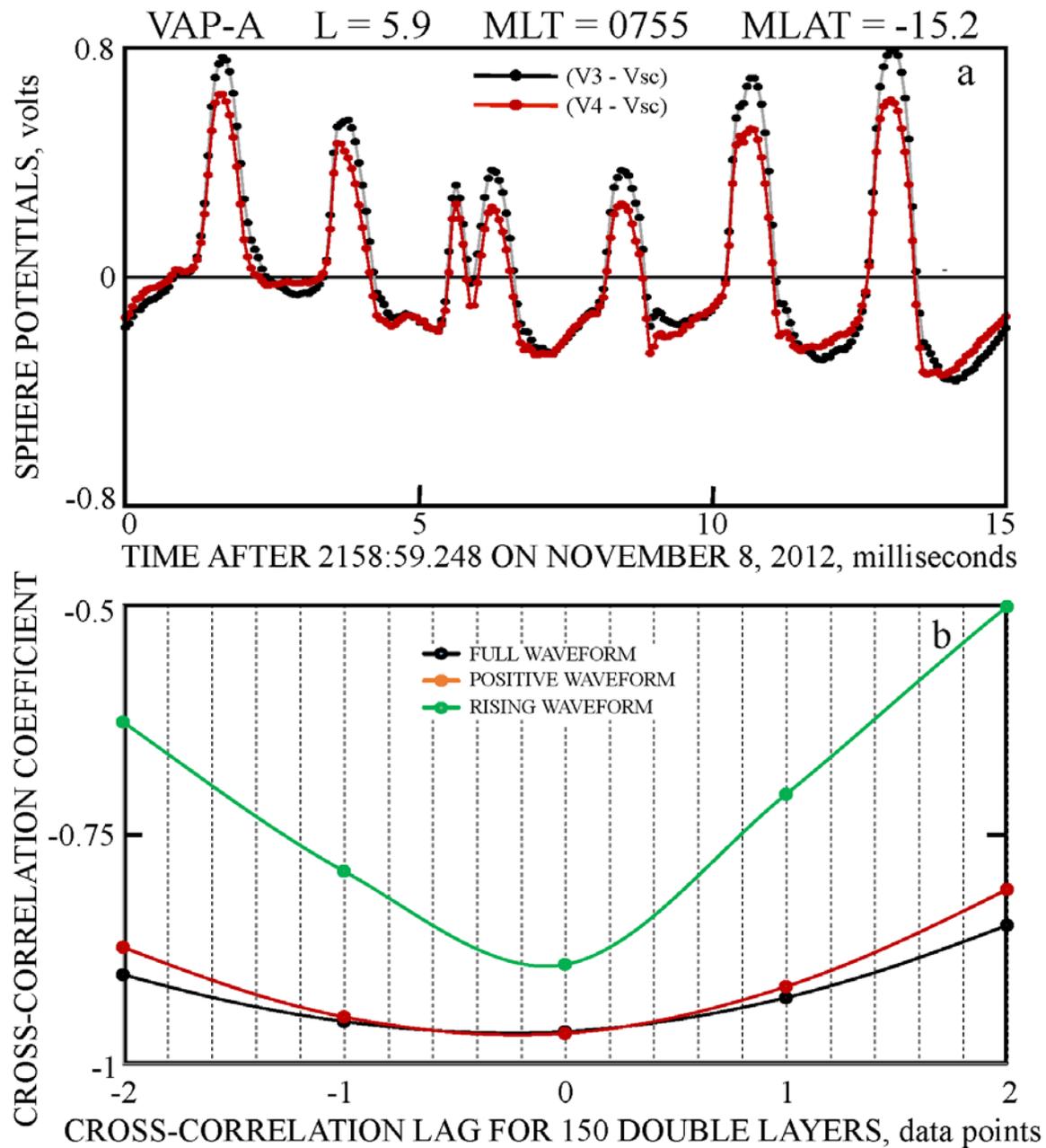


TIME AFTER 0155:30.6 ON OCTOBER 9, 2012, msec

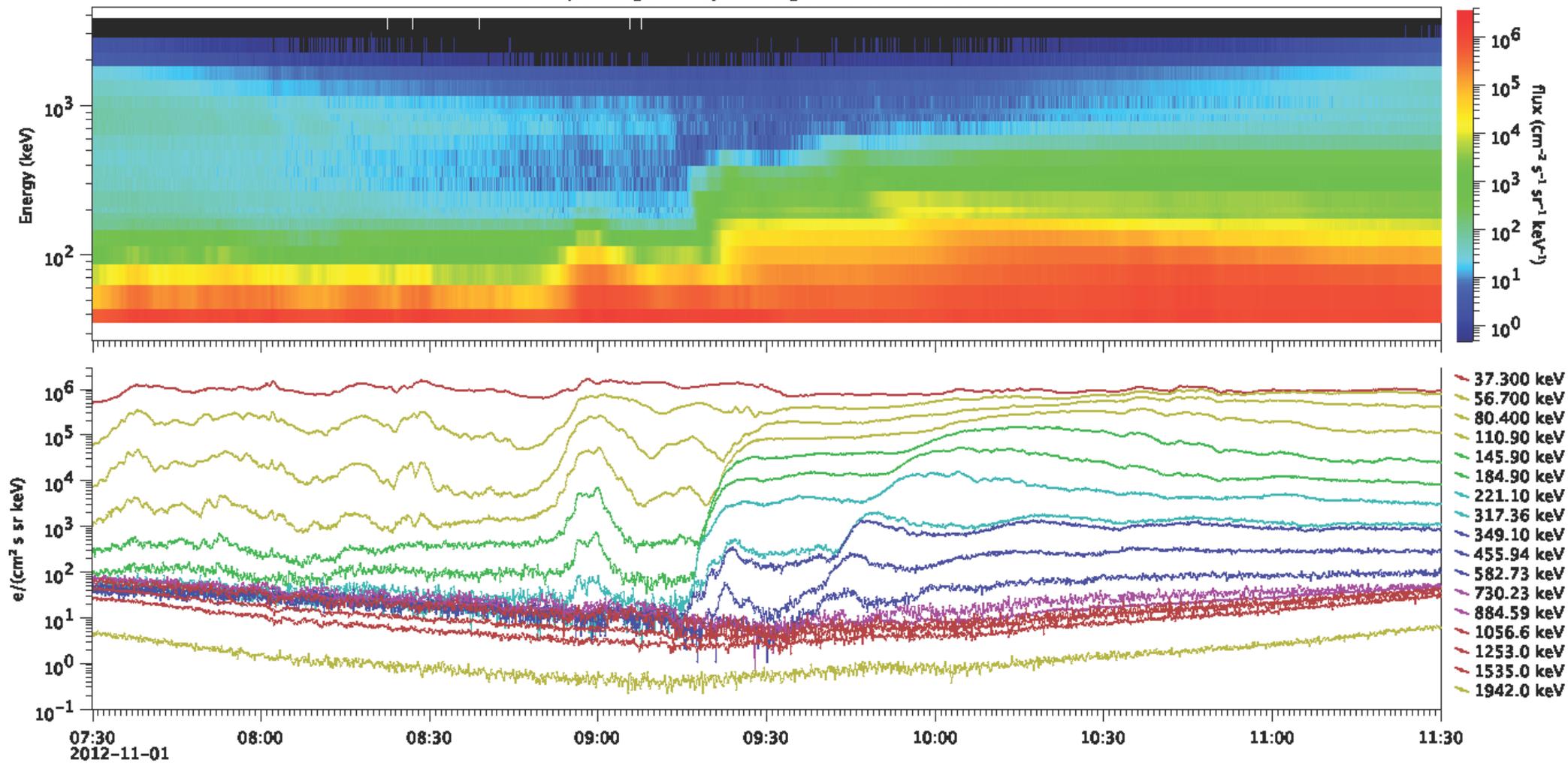


VAP-A 11/01/2012 MLT = 0650 L = 6.1

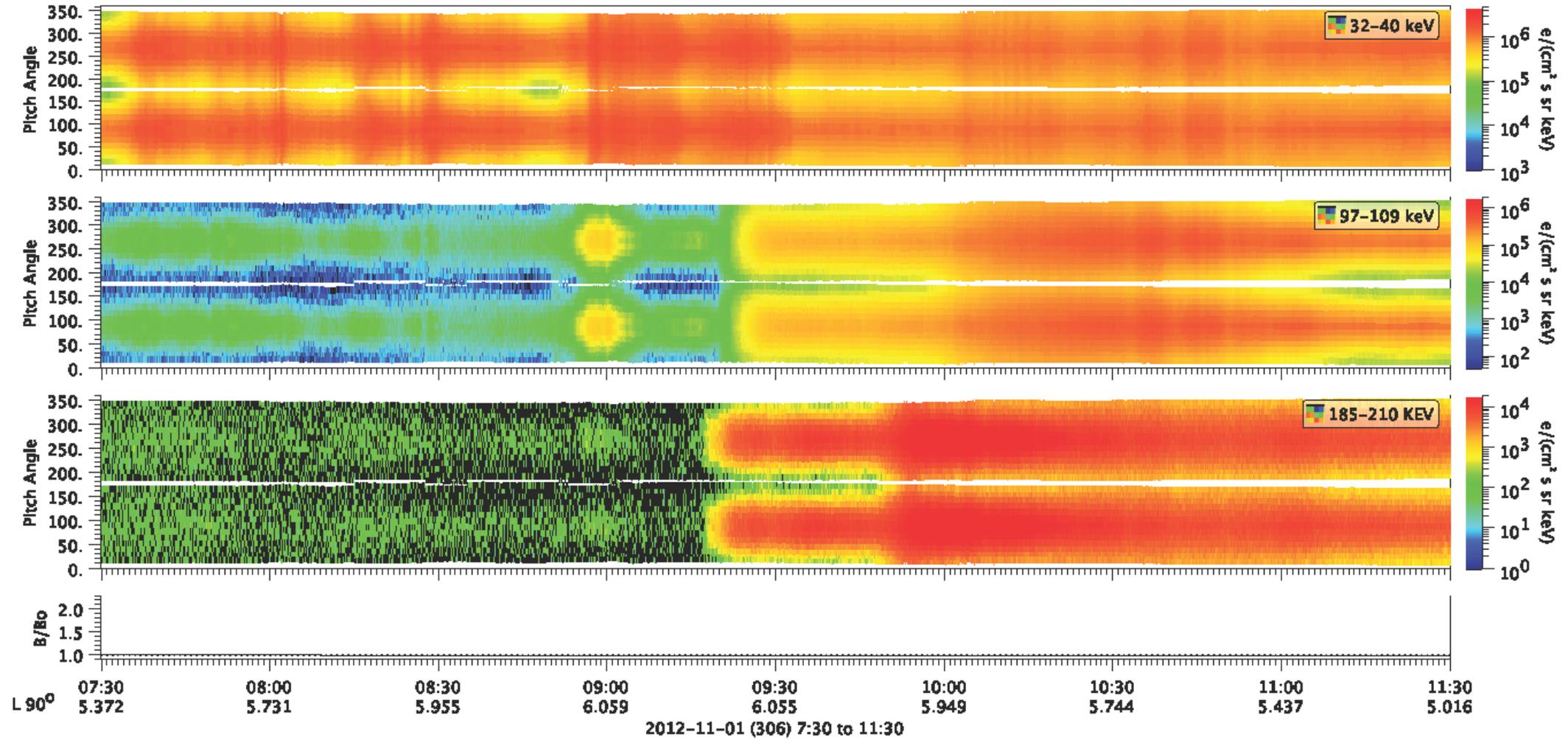




RBSP-B/ect-magels-L2 Spin-Averaged Differential Electron Flux



rbspb/ect-magelslow-L3 FEDU_Unblinned_0to360 - Unidirectional Differential Electron Flux (raw sector data).



WOW, WE SEE A LOT OF DOUBLE LAYERS
IN ONE EVENT, ~20,000 DOUBLE LAYERS CROSS THE
SPACECRAFT IN SIX MINUTES

THESE DOUBLE LAYERS CARRY A NET POTENTIAL OF
~1,000,000 VOLTS

THIS IS A RELATIVELY FREQUENT PHENOMENON

MAYBE THESE DOUBLE LAYERS ACCELERATE THE
~100 KEV SEED ELECTRONS THAT ARE NEEDED FOR
COHERENT WHISTLER ACCELERATION OF
RELATIVISTIC ELECTRONS.

OR MAYBE THEY IMPEDE ELECTRON TRANSPORT

OR MAYBE THEY CREATE THE X-RAY MICROBURSTS
SEEN ON BALLOONS

PLASMA DATA AND THEORY ARE NEEDED

COME TO THE DOUBLE LAYER WORKSHOP WITH
YOUR THEORY AND PLASMA DATA

WHAT IS A DOUBLE LAYER?

A DOUBLE LAYER IS

1. A local region of charge separation along the magnetic field that produces an electric field parallel to the magnetic field direction.
2. Two adjacent layers with equal and opposite net charge (think parallel plate capacitor).
3. Determined in a self-consistent manner by the particle dynamics in the electric field set up by the charge separation.