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Title: Summary of 2006 to 2010 FPMU Measurements of International Space Station Frame Potential Variations

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Topic Area: Plasma and E Field Probes, Surface and Internal Charging, Photo-voltaic Interactions

Abstract: Electric potential variations on the International Space Station (ISS) structure in low Earth orbit are dominated by contributions from interactions of the United States (US) 160 volt solar arrays with the relatively high density, low temperature plasma environment and inductive potentials generated by motion of the large vehicle across the Earth's magnetic field. The Floating Potential Measurement Unit (FPMU) instrument suite comprising two Langmuir probes, a plasma impedance probe, and a floating potential probe was deployed in August 2006 for use in characterizing variations in ISS potential, the state of the ionosphere along the ISS orbit and its effect on ISS charging, evaluating effects of payloads and visiting vehicles, and for supporting ISS plasma hazard assessments. This presentation summarizes observations of ISS frame potential variations obtained from the FPMU from deployment in 2006 through the current time. We first describe ISS potential variations due to current collection by solar arrays in the day time sector of the orbit including eclipse exit and entry charging events, potential variations due to plasma environment variations in the equatorial anomaly, and visiting vehicles docked to the ISS structure. Next, we discuss potential variations due to inductive electric fields generated by motion of the vehicle across the geomagnetic field and the effects of external electric fields in the ionosphere. Examples of night time potential variations at high latitudes and their possible relationship to auroral charging are described and, finally, we demonstrate effects on the ISS potential due to European Space Agency and US plasma contactor devices.

Summary of 2006 to 2010 FPMU Measurements of International Space Station Frame Potential Variations

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STS-128

Introduction

Wright et al. presented initial FPMU results at 10th SCTC

This talk presents a variety of interesting examples of ISS charging observations from FPMU data set over the period 2006 through 2010

Overview of Presentation

- FPMU instrumentation
- Charging by visiting vehicles
- Payload interactions (ESA PLEGPAY)
- Auroral charging
- $\Delta\varphi = E \cdot L$ potential variations in equatorial holes
- Solar array current collection
  - Eclipse exit normal charging
  - Eclipse exit rapid charging
  - Array unshunt in sunlight
- Summary

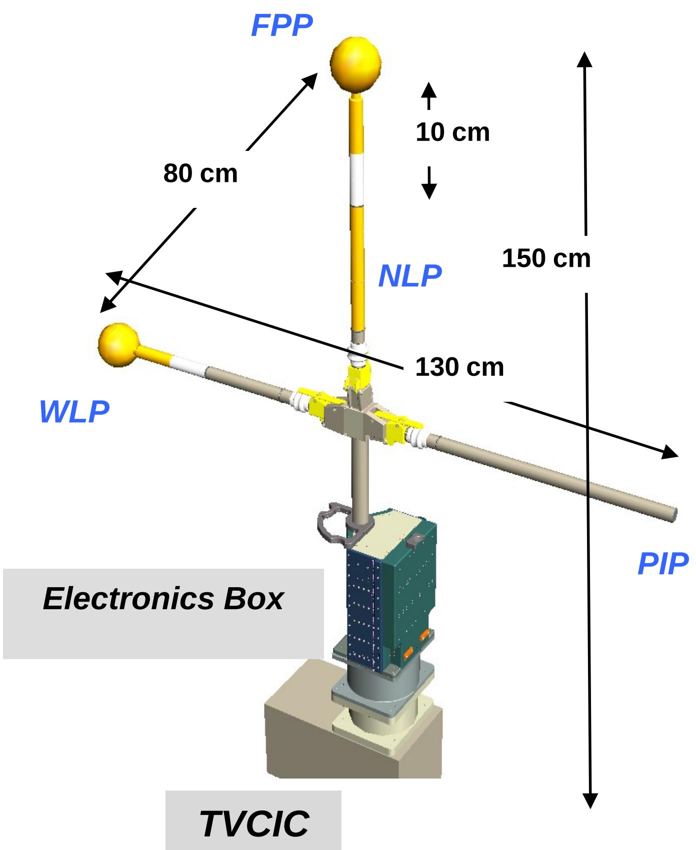
Floating Potential Measurement Unit (FPMU)

FPP: Floating Potential Probe

WLP: Wide-sweep Langmuir Probe

NLP: Narrow-sweep Langmuir Probe

PIP: Plasma Impedance Probe



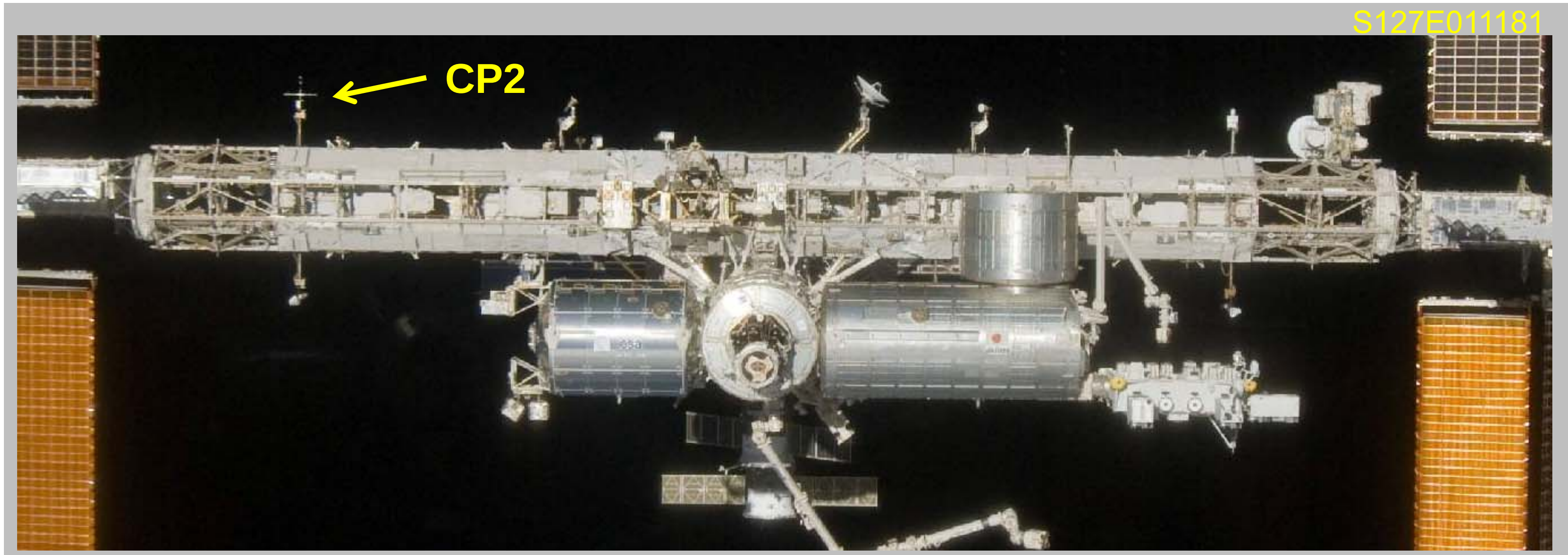
FPMU Instrument Characteristics

Sensor	Measured Parameter	Rate (Hz)	Effective Range
FPP	V_F	128	-180 V to +180 V
WLP	N T_e V_F	1	10^9 m^{-3} to $5{\cdot}10^{12}$ m^{-3} 500 K to ~10,000 K -20 V to 80 V
NLP	N T_e V_F	1	10^9 m^{-3} to $5{\cdot}10^{12}$ m^{-3} 500 K to ~10,000 K -180V to +180 V
PIP	N	512	$1.1{\cdot}10^{10}$ m^{-3} to $4{\cdot}10^{12}$ m^{-3}

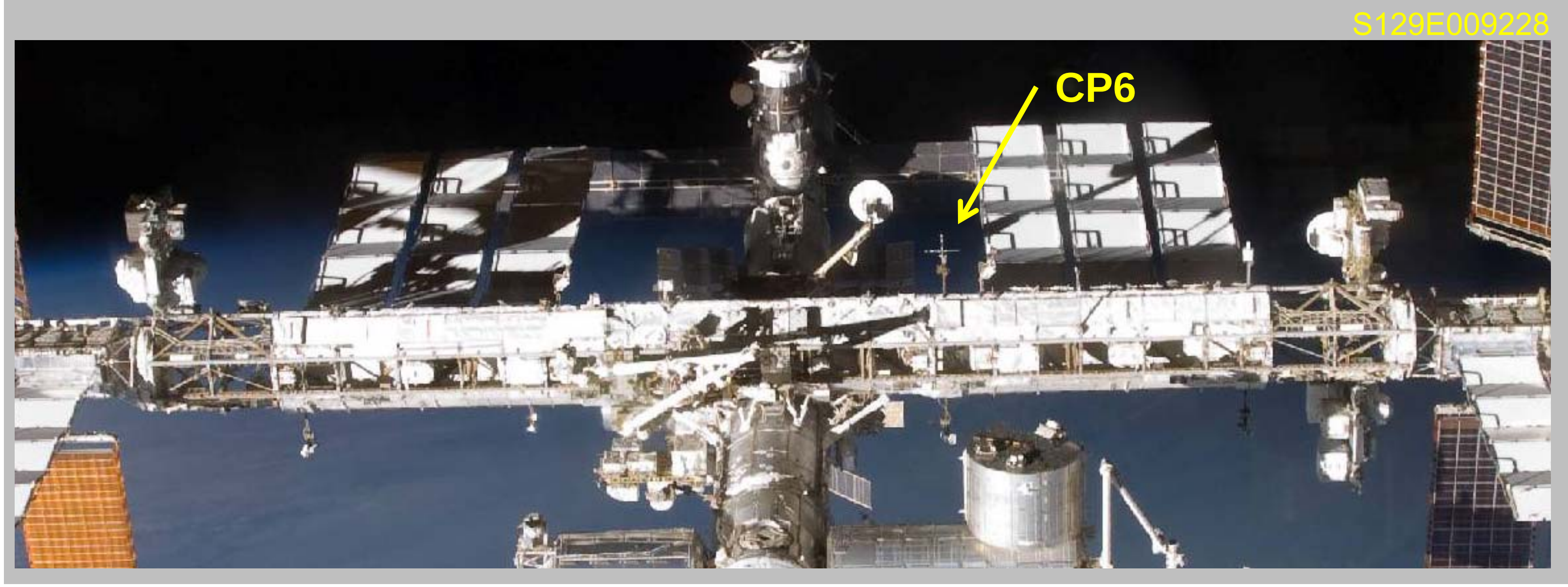
[*Wright et al*., 2008; *Barjatya et al*., 2009]

FPMU Deployment Locations

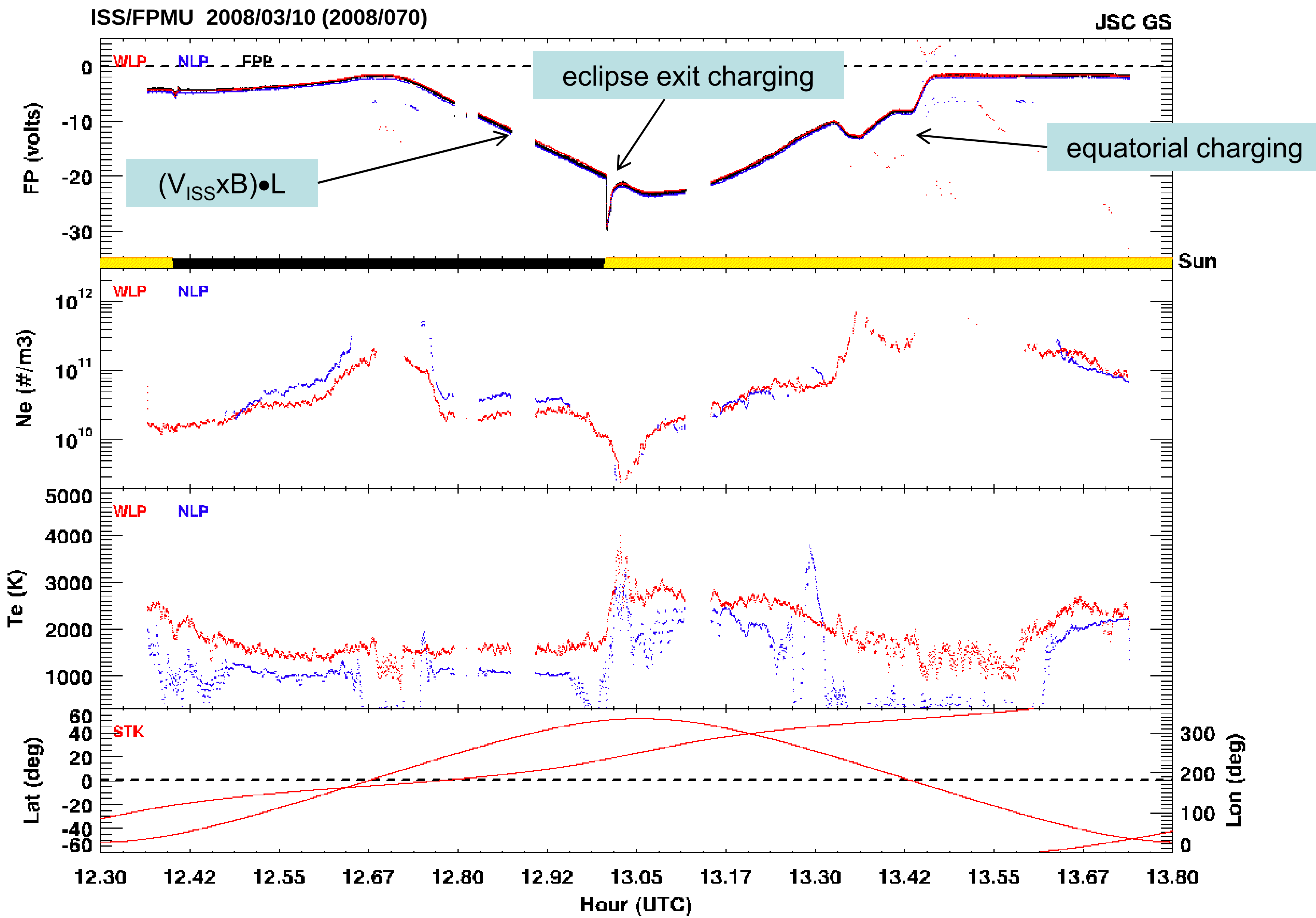
Aug 2006 – 21 Nov 2009



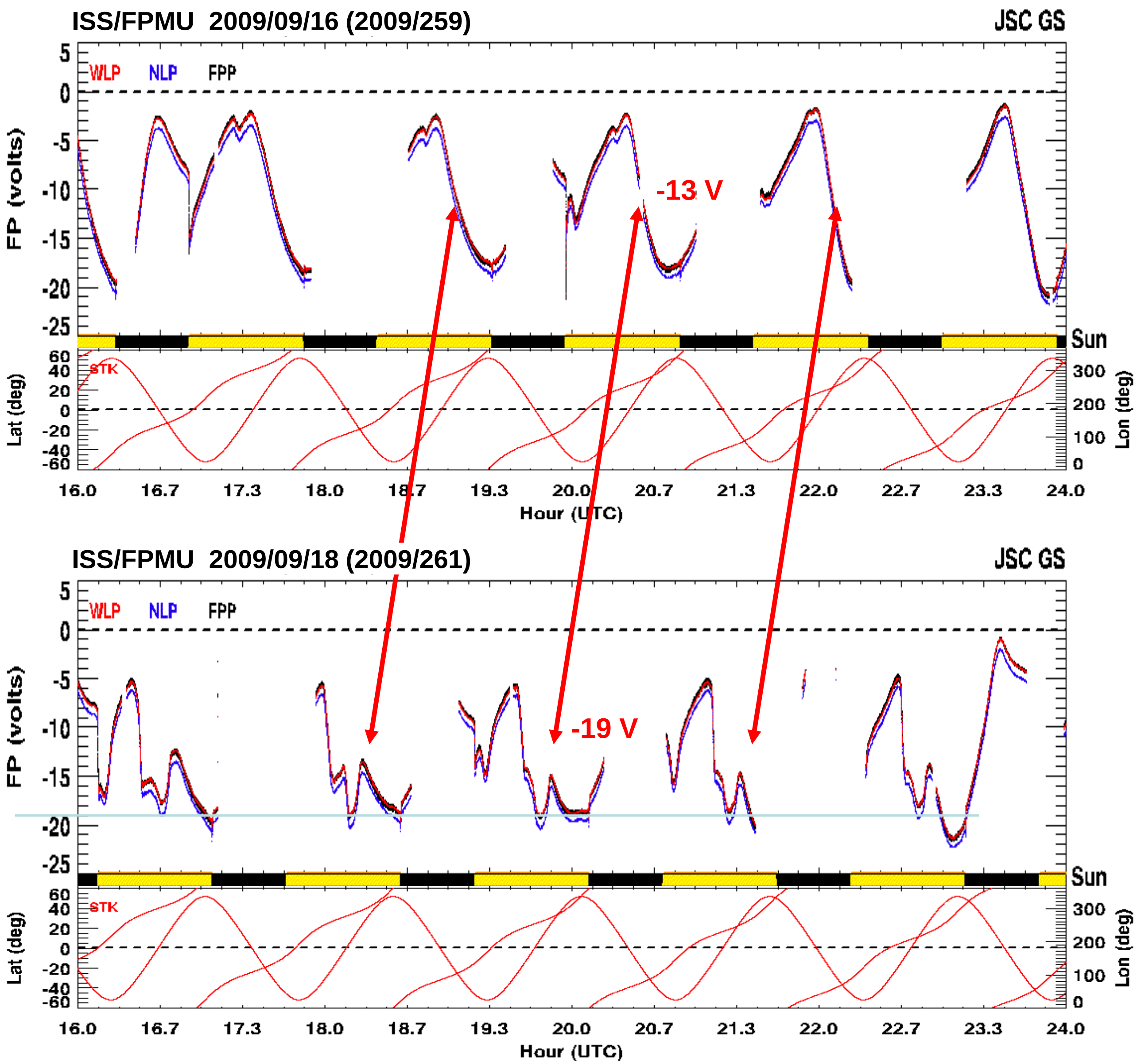
21 Nov 2009 – present



Characterizing ISS Environments, Charging

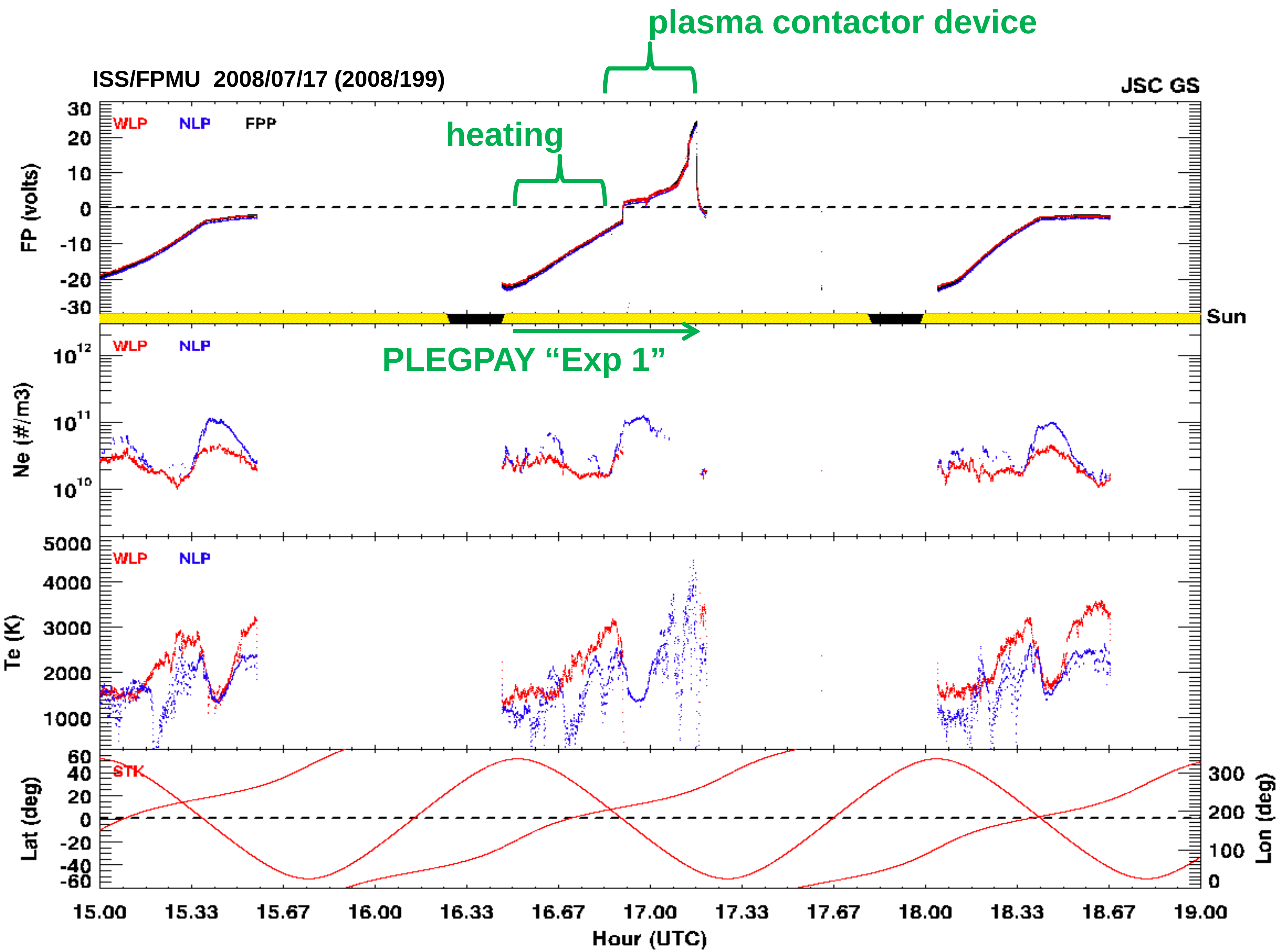


ISS Charging by Visiting Vehicle: JAXA HTV

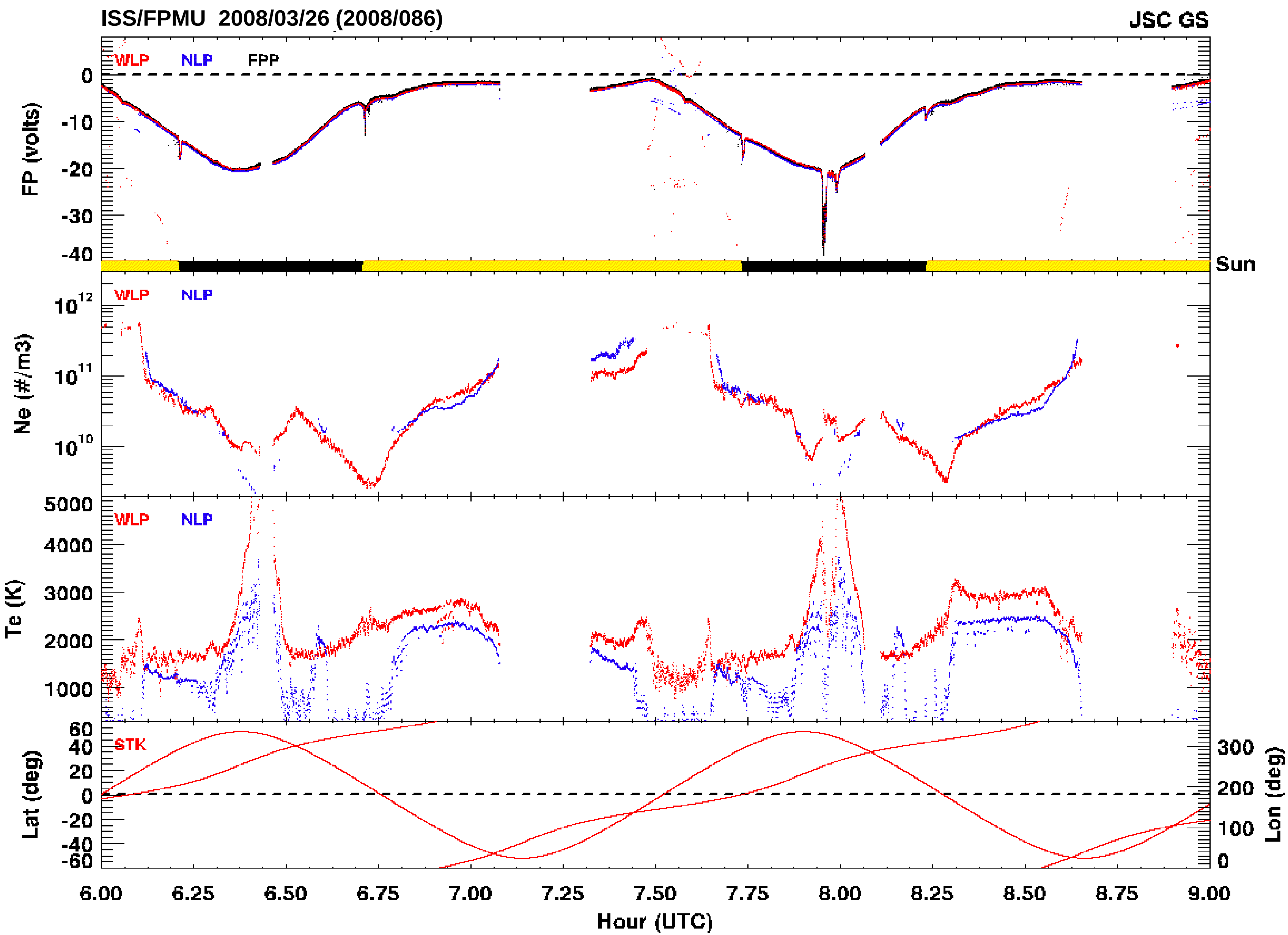


HII Transfer Vehicle (HTV)
~117 volt solar arrays
Dock: 17 Sept 2009
22:26 UT

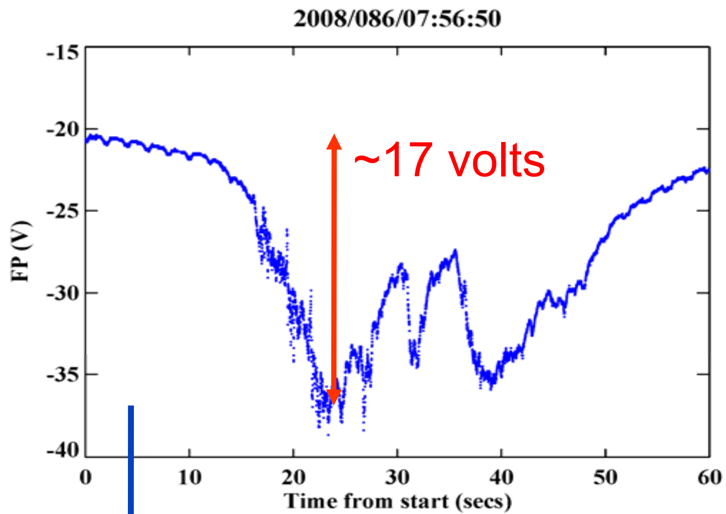
ESA Plasma Electron Gun Payload (PLEGPAY)



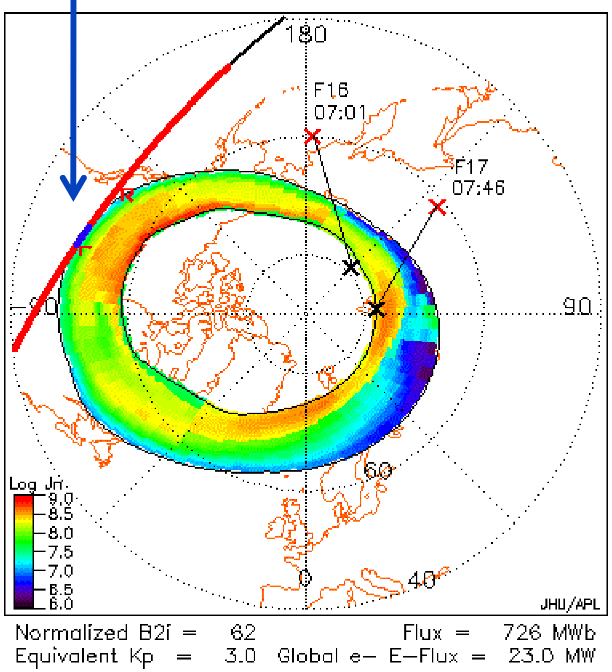
ISS Charging at Night

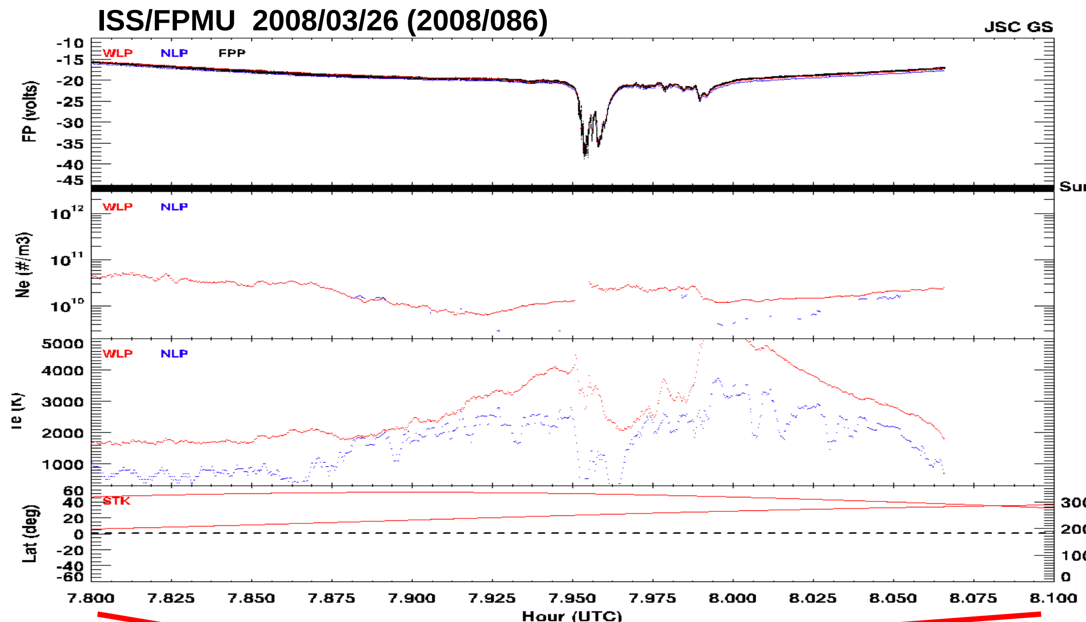


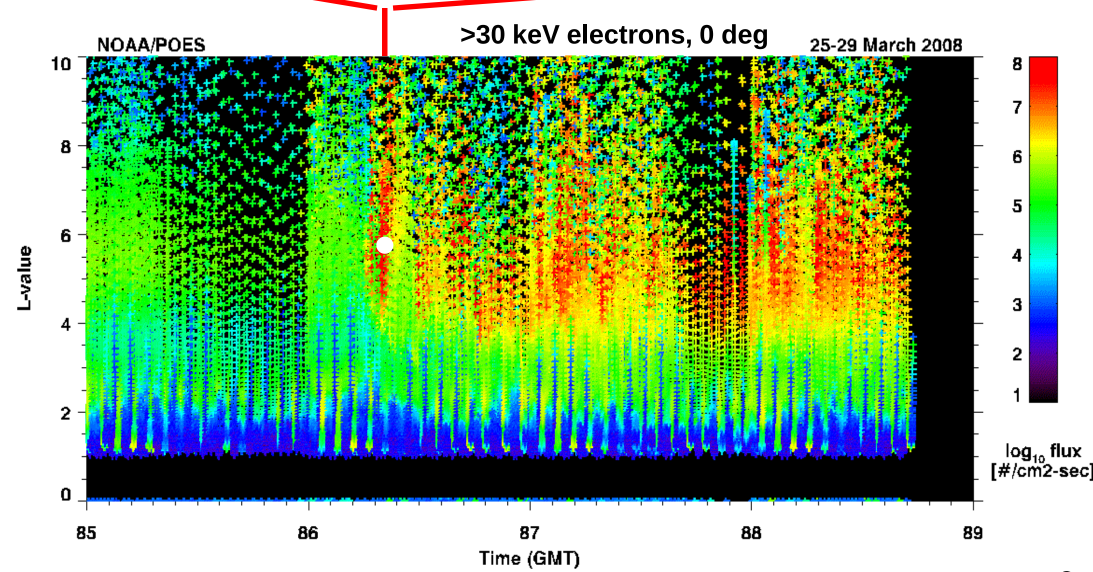
Auroral Charging (?)



26 Mar 2008 07:30 – 08:00 UT

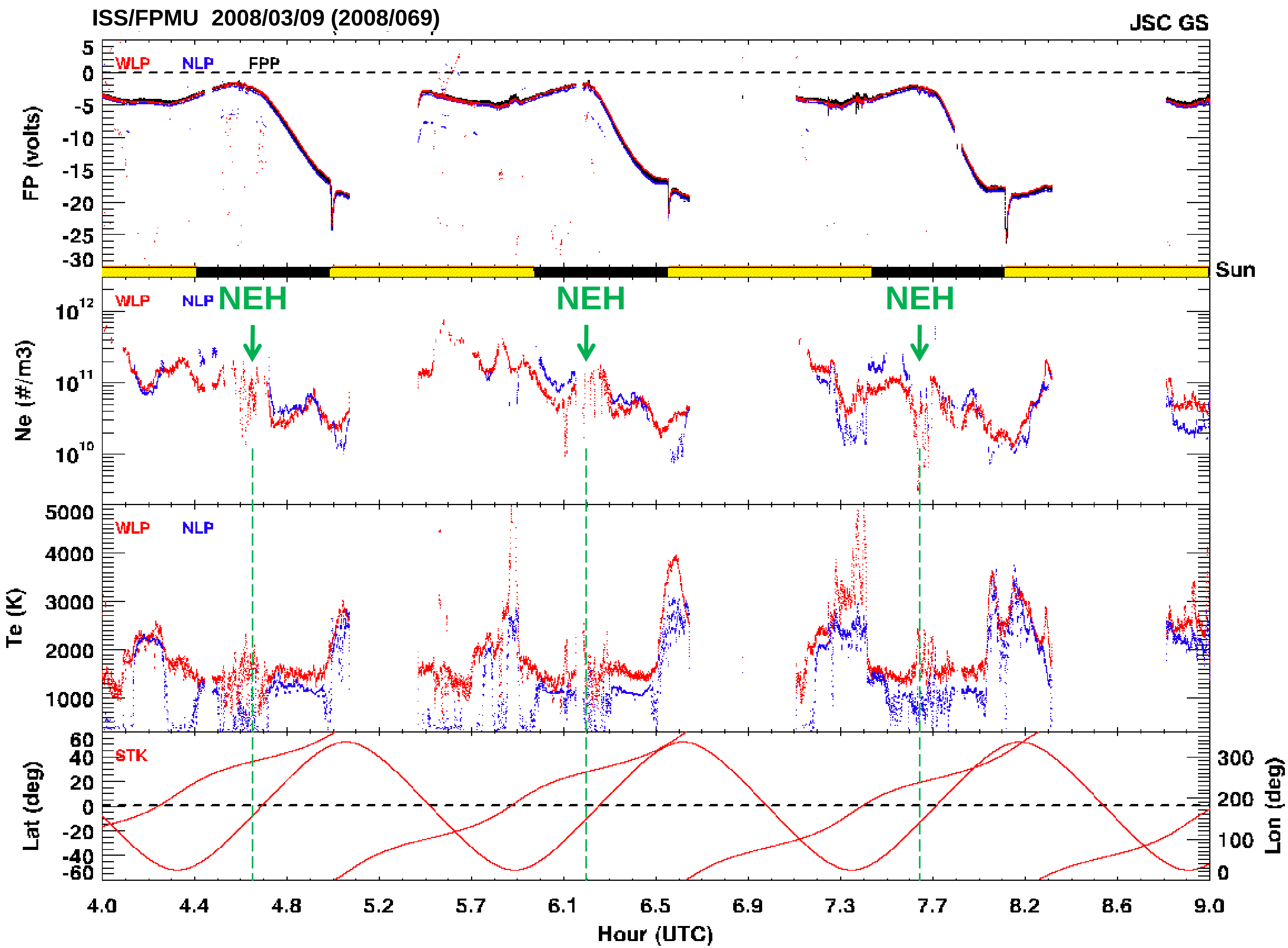




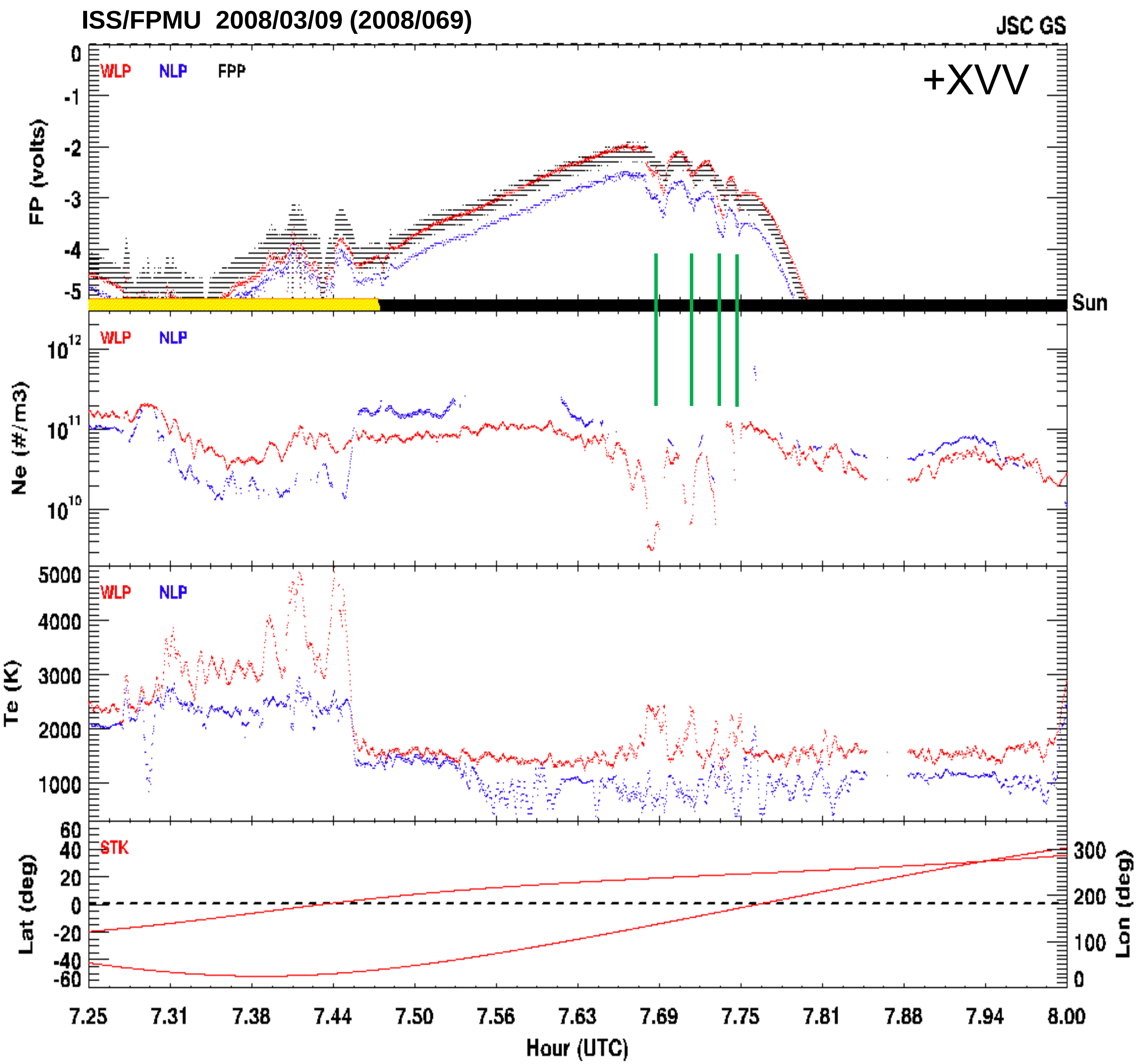


[adapted from *Craven et al.*, 2009]

Equatorial Plasma Depletions (Ne "Holes")



Equatorial Plasma Depletions (Ne “Holes”)

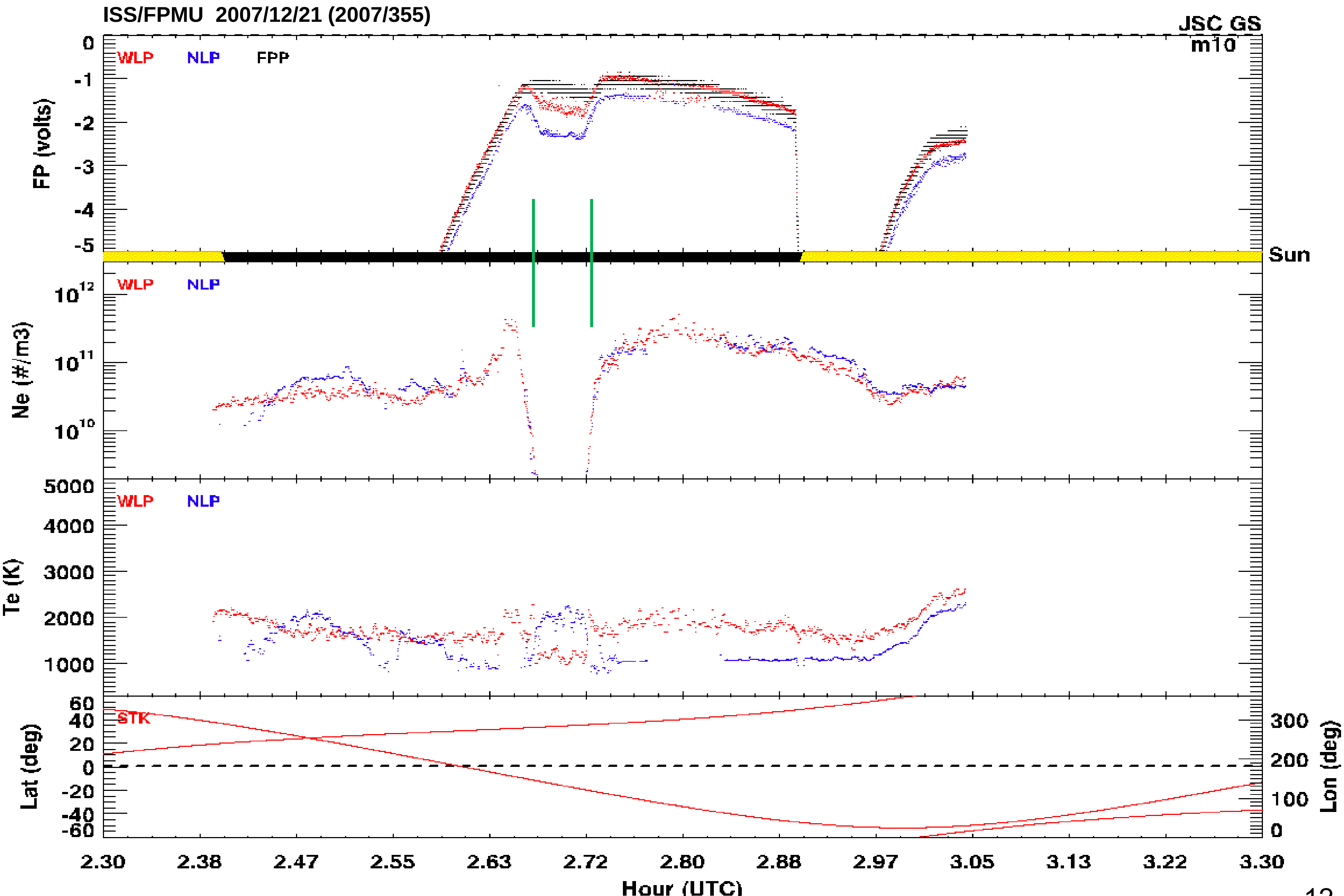


ISS potential ~0.5 to 1 volt more negative at FPMU location as vehicle passes through the Ne depletions

Solar array charging not involved in process: event in darkness

Potential variations due to ionospheric electric fields associated with the plasma depletions

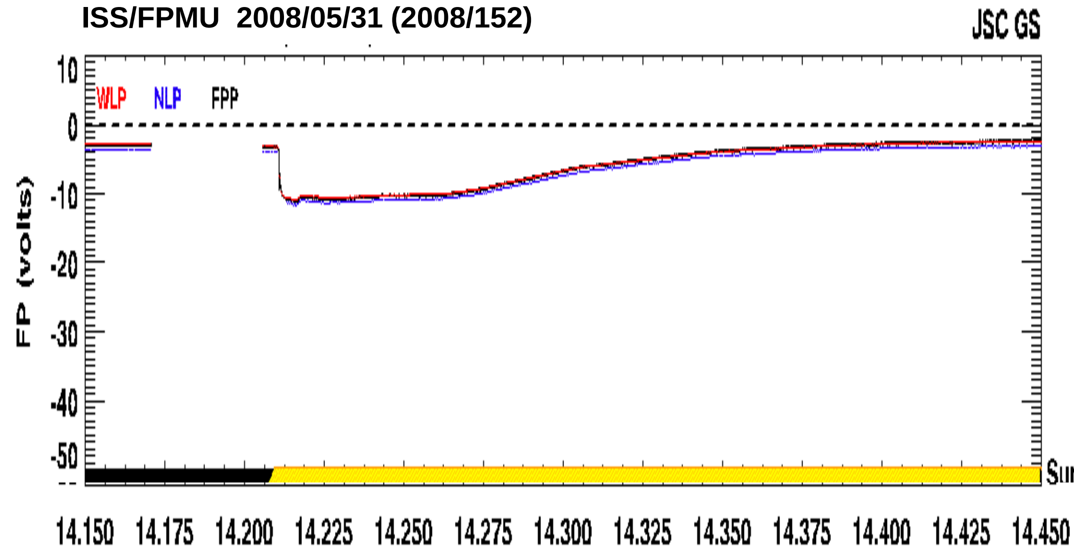
Equatorial Plasma Depletions (Ne “Holes”)



Eclipse Exit Solar Array Charging Peaks

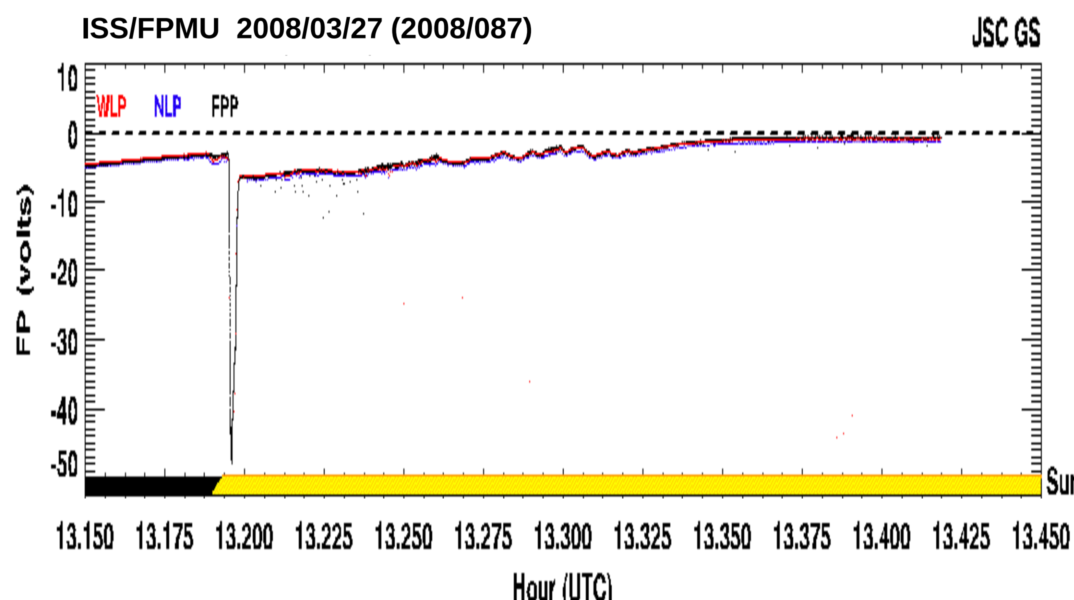
Normal charging

- Rise time ~10's sec
  Decay ~minutes
- Potential variations in charging peak due to combined effects of array shunt operations, plasma environment along orbit, solar array orientation
- Always form on sunlit side of terminator



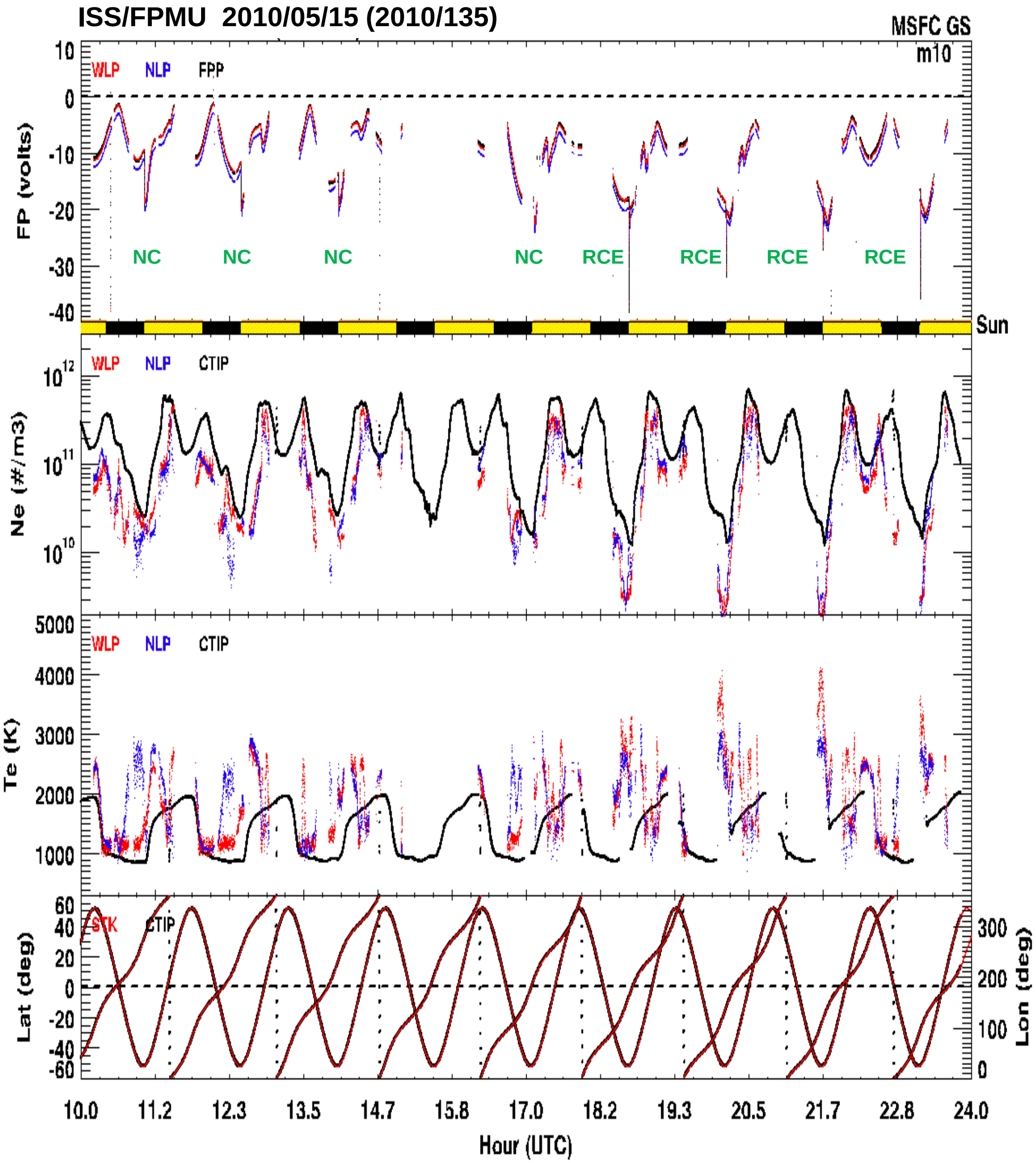
Rapid charging event (RCE)*

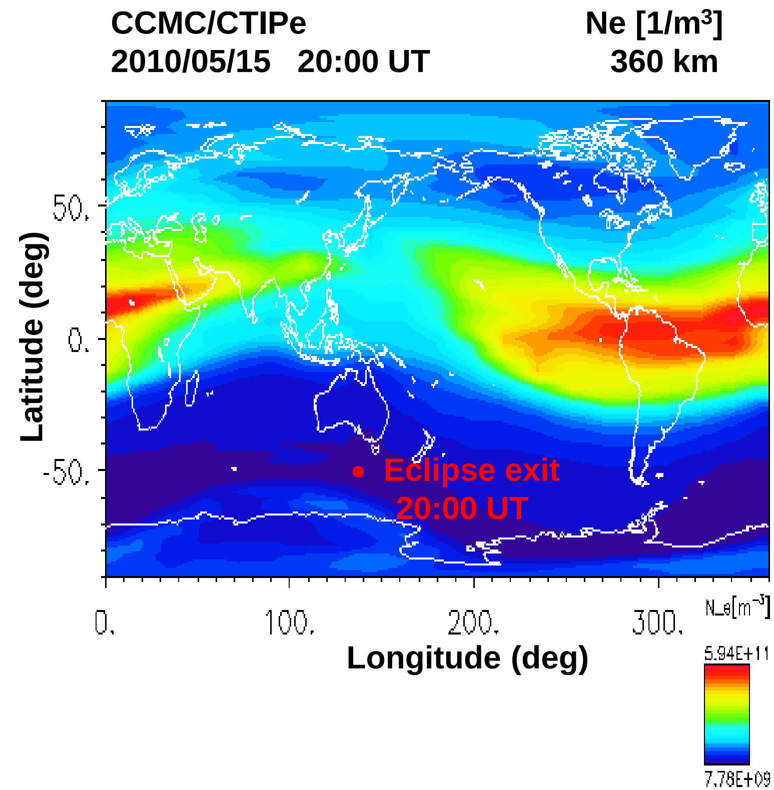
- Rise time ~2-5 sec
  Decay ~10's sec
- Occur without array shunt operation
- Time scale too short for significant changes in plasma environment or solar array orientation
- Always form on sunlit side of terminator



*Craven et al., 2009; Ferguson et al., 2009

RCE in High Latitude Ion Trough

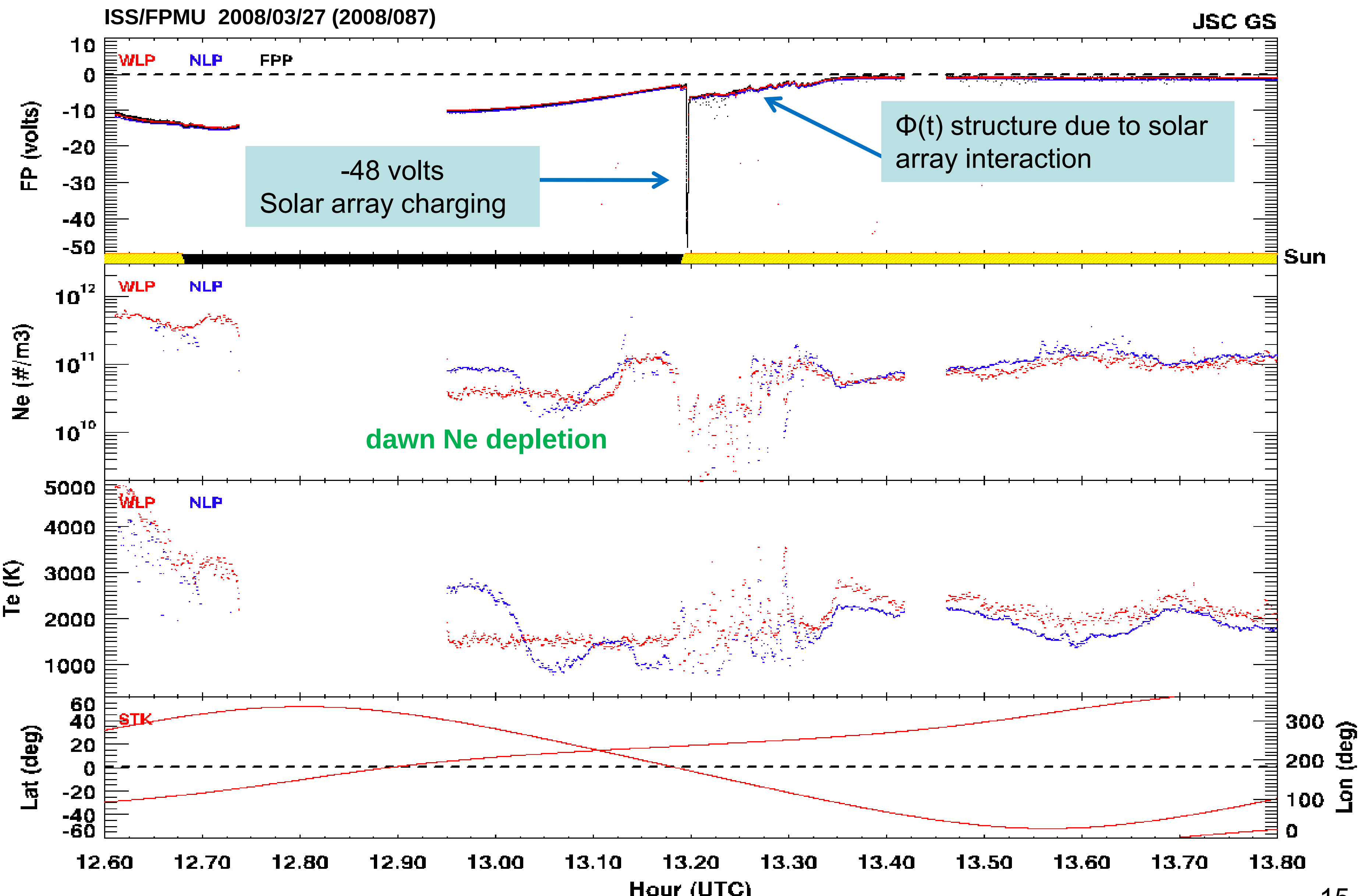




Eclipse exits occur in southern hemisphere, winter conditions for this example

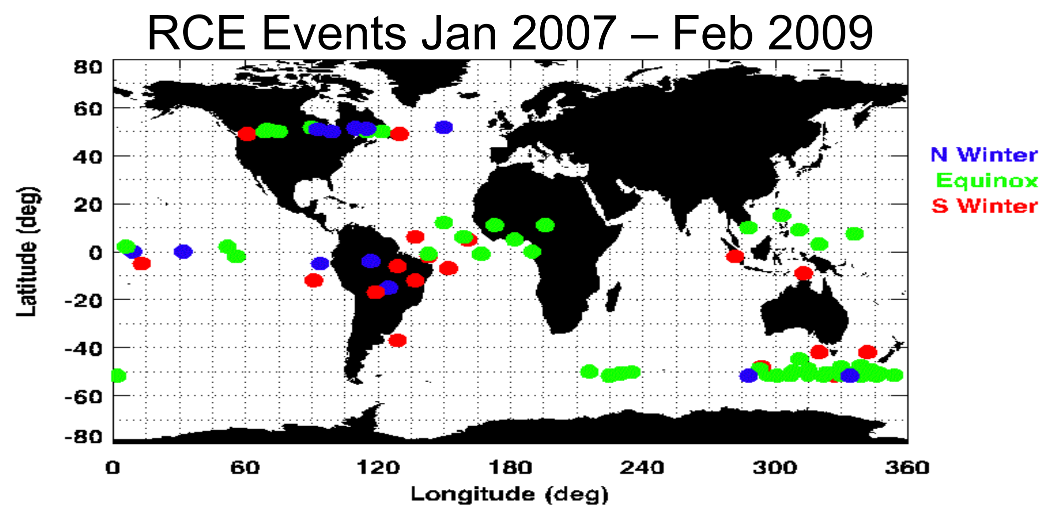
Normal charging events until ISS encounters Ne depletions in high latitude plasma trough

RCE in Dawn N_e Depletions

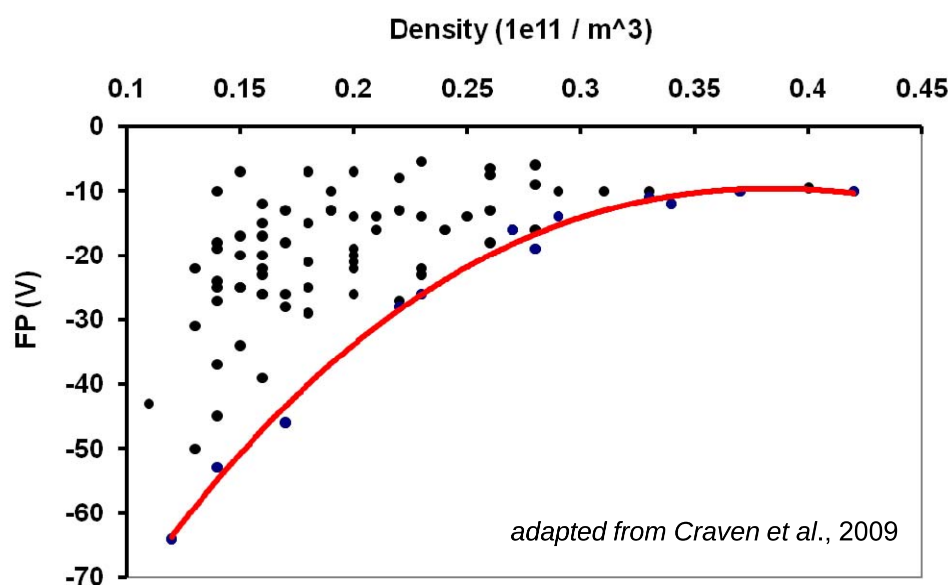


Conditions for RCE Formation

- RCE's are observed in relatively low density plasma environments
- The low density environments occur in two distinct geographic regions
  - plasma troughs at high latitude
  - dawn plasma density depletion in the dawn equatorial ionosphere*

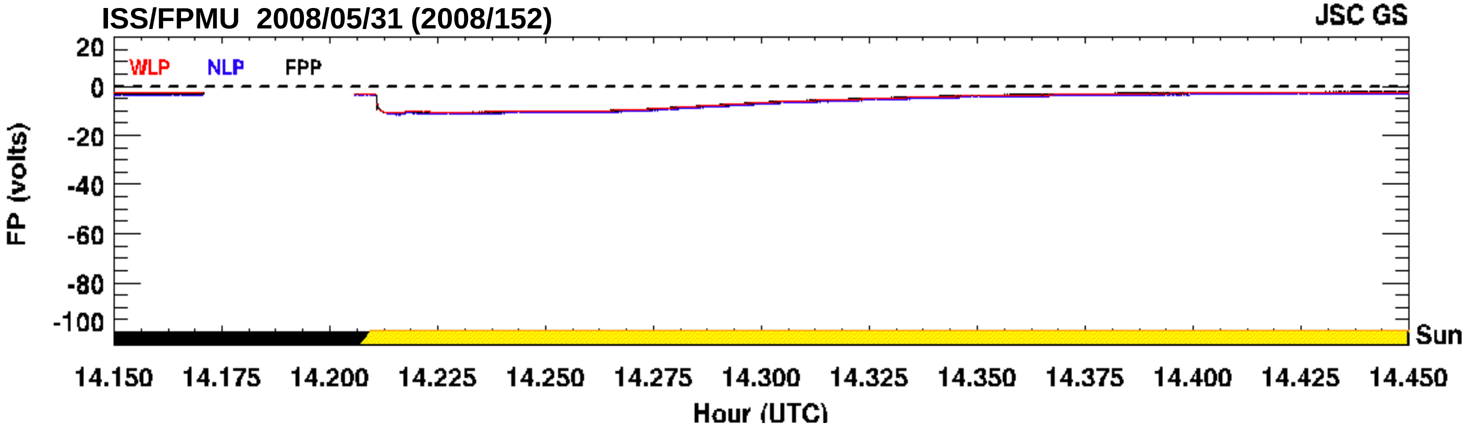


- The magnitude of the potential minimum is inversely related to density
- Scatter is due to umbra duration, solar array attitude, and other variables

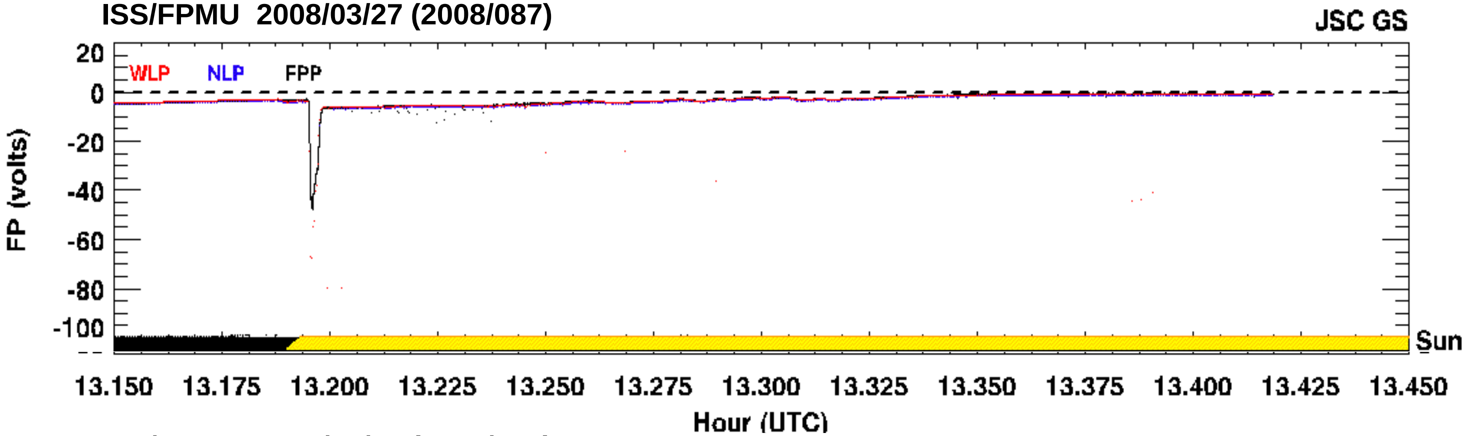


* c.f., *Burke et al.*, 1979; *Aggson et al.*, 1995; *de la Beaujardiere et al.*, 2009

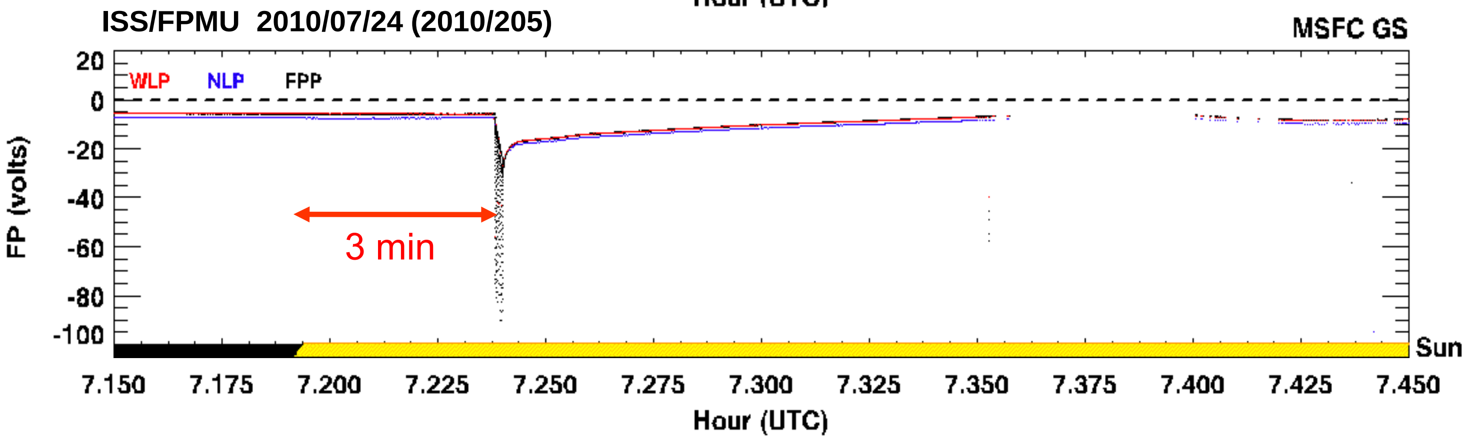
Array Charging Events



Normal eclipse exit charging



Rapid eclipse exit charging

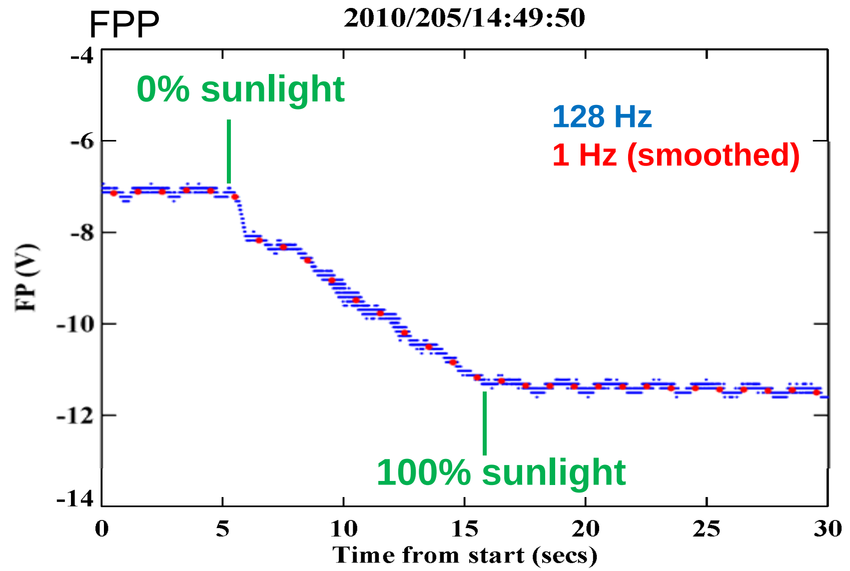


Commanded unshunt

Unshunt in Sunlight

Normal charging

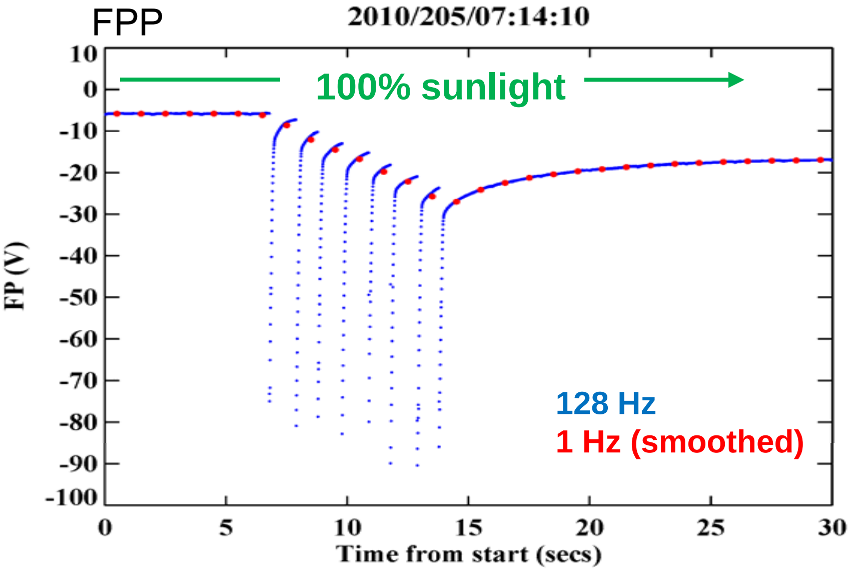
- Normal array operation:
  - Unshunted before and through eclipse exit
  - Shunting of some array strings to match loads as ISS moves further into daylight
- Decrease in vehicle potential over ~10 sec umbra passage as array bias increases from exposure to sunlight



Commanded unshunt

- Fully shunted at eclipse exit and for three minutes into sunlight
- Unshunt in full sunlight
- Rapid charging as array string voltage increases from ~22 volts (full shunt) to ~160 volts (unshunt)
- 4 solar arrays with 2 wings each on ISS

  8 peaks due to sequential unshunt of each wing
- Maximum negative potential could be lower because the FPP 128 Hz sample rate is too low to resolve all of the data in the unshunting sequence!



Summary

- FPMU has monitored ISS charging from August 2006 to the present
- Measurements of ISS floating potential and ionospheric Ne, Te along ISS orbit from FPMU provides:
  - Data for characterizing plasma hazards to vehicle and crew (EVA)
  - Tool for investigating interactions of negatively grounded, high voltage solar arrays with the ionospheric plasma environment (including the US 160 V arrays and visiting vehicles)
  - Opportunities for collaborative ionospheric studies with ground and space based ionospheric sensors

- Extreme charging events observed to date (above background):
  - Auroral charging -17 to -20 volts [*still under review*]
  - Eclipse exit rapid charging -40 to -65 volts
  - Unshunt operations -65 to -85 volts (or lower!)
  - Payload (PLEGPAY) + 26 volts

- Future of FPMU operations:
  - ISS Program Office approved ongoing FPMU operations for use in short term plasma hazard forecasting for EVA support, characterizing effects of ISS payloads and hardware changes, and other operational support to ISS program
  - Spare FPMU unit manifested on STS-134 for flight to ISS to be used as a pre-positioned on-orbit spare