NASA Robotic Missions:
Feedback and Future Needs - ISS

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Space Environment Model, Data Needs

- **MSFC's Environments Branch is an applied science organization utilizing space environment data, models for NASA program support:**
  - Characterizing space environments and effects for space system design
  - Launch vehicle space weather constraints
  - On-orbit vehicle operations, science payload support
  - Development of laboratory test protocols for qualifying materials for use in space environments
  - Anomaly investigations

- **Today's presentation gives examples of ISS space weather support activities**
  - Introduction to data and model needs for NASA program support
  - ISS plasma instrumentation
  - Examples of data, model use for
    - EVA plasma hazard assessments (PVA charging)
    - ISS plasma interactions, payload science support
    - Anomaly investigations
  - Summary

Applied Space Environment Model, Data Needs

- Characterizing space environments for space system design
  - Historical data, environment models (empirical, physics based)
  - Effects models including surface and internal charging codes, radiation transport codes, single event upset rate calculations

- Launch vehicle space weather constraints
  - Requires data to verify current environment within launch constraint
  - Primarily used by NASA for solar proton launch constraints to protect launch vehicles
  - Evaluating options for establishing constraints for auroral, geostationary orbit charging environments (data? models?)

- On-orbit environments support for vehicle operations, science payloads
  - In-situ data preferred
  - Appropriate independent data (other satellites or ground based sensors) acceptable
  - Data constrained environment models
  - Unconstrained first principle physics models
  - Empirical models

- Anomaly investigations
  - In-situ measurements preferred
  - Measurements from independent spacecraft, ground based sensors acceptable if in-situ not available
  - Data constrained environment models

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ISS Structure Potential, Charging Hazards

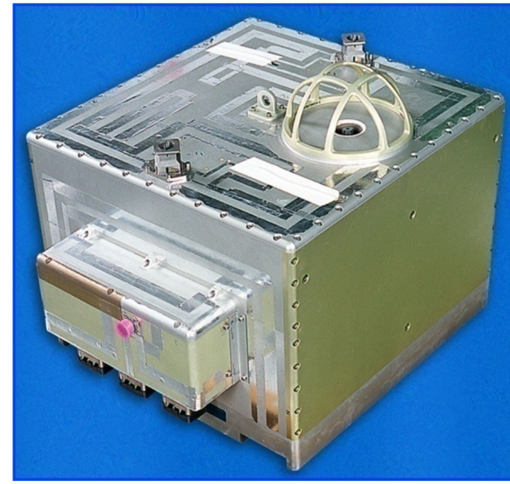
- ISS frame potential varies in low Earth orbit environment due to:

Current collection	**Voltage Range (Observed to Date)**
– Current collection from ambient plasma	-0.1 to -0.5 volts
– 160 V US solar array	- 20 to -90 volts
– Visiting vehicle (high voltage) solar arrays	-10 volts
– Operation of payloads that emit current sources	+10 to +25 volts
– Auroral electrons	-20 volts
Inductive potentials	
– (vxB) • L due to motion across geomagnetic field	+/-40 volts
– E.• L due to ionospheric electric fields	few volts

- Hazards to vehicle and crew
  - ISS-EVA-305: long term degradation of thin dielectric surface thermal control coatings due to arcing …EVA touch temp violations (eventually)
    - Hazard marginalized by test and analysis - no controls needed
  - ISS-EVA-312: EVA electric shock
    - Hazard 1 - Catastrophic at floating potentials more negative than -40V
    - Hazard 2 - Critical to catastrophic at positive floating potentials (> 0V)
    - Hazard 3 – critical to catastrophic ISS electrical power short through EVA crew to ground
      - Plasma is a secondary cause – one circuit closure pathway

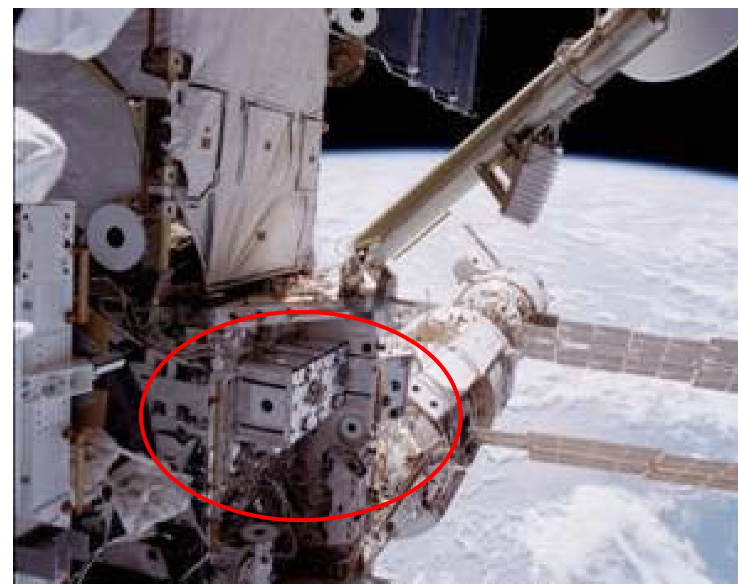
ISS Plasma Hazard Management

ISS Program controls plasma hazards through a process of active potential control, operational mitigation strategies, environment monitoring and characterization, and probabilistic risk assessment



- **Plasma Contactor Units (PCUs)**
  - Provides active ISS “ground” by dissipating excess charge to space
  - Two redundant PCU units provides single fault failure tolerance, two required for EVA

- **Operational control using ISS flight attitude, solar array wing angle, and solar array shunt state**
  - Manages solar array and magnetic induction charging
  - Provides two fault tolerance



- **Floating Potential Measurement Unit (FPMU)**
  - Provides validated measurements of ISS floating potential and ionospheric Ne, Te along ISS orbit
  - Predict EVA charging hazards based on measurements before EVA

- **Boeing/SAIC Plasma Interaction Model (PIM)**
  - ISS charging model validated with FPMU data
  - Predicts charging hazard severity and frequency of occurrence

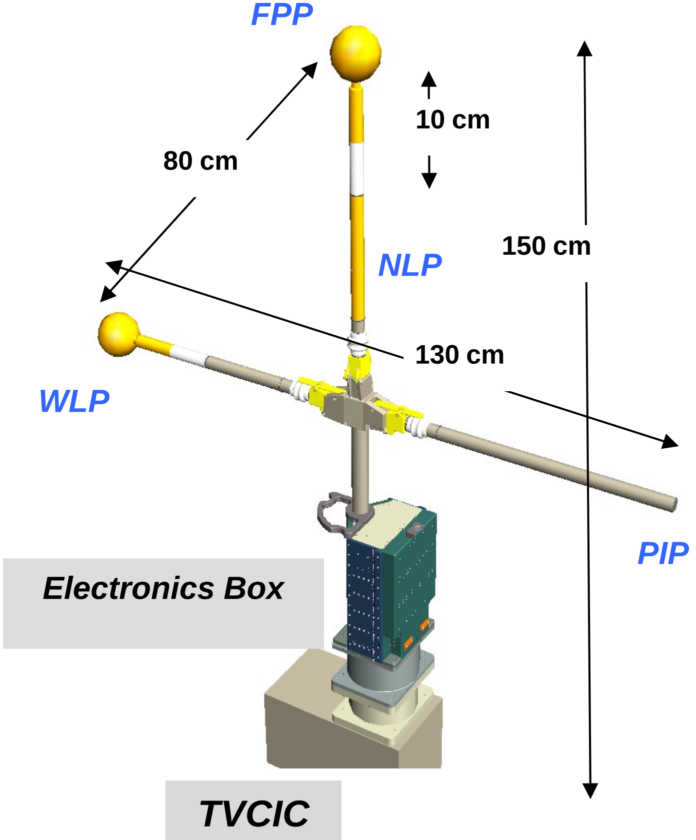
Floating Potential Measurement Unit (FPMU)

FPP: Floating Potential Probe

WLP: Wide-sweep Langmuir Probe

NLP: Narrow-sweep Langmuir Probe

PIP: Plasma Impedance Probe



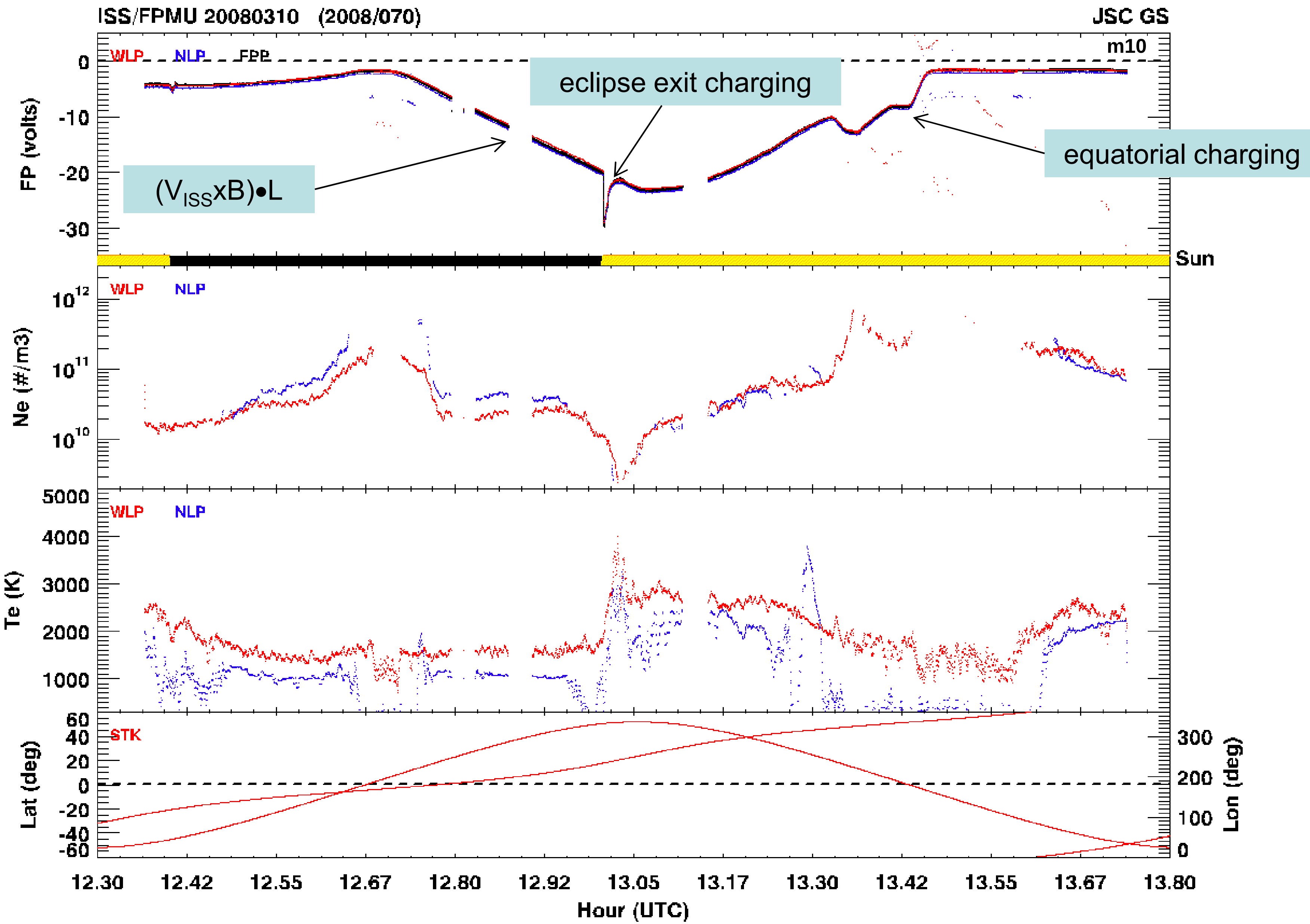
Role:

- ***Validation of PIM***
- ***Assess PV array variability***
- ***Interpreting IRI predictions***
- ***Characterize ISS charging***

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 $5\cdot10^{12}$ m^{-3} 500 K to ~10000 K -20 V to 80 V
NLP	N T_e V_F	1	10^9 m^{-3} to $5\cdot10^{12}$ m^{-3} 500 K to ~10000 K -180V to +180 V
PIP	N	512	$1.1\cdot10^{10}$ m^{-3} to $4\cdot10^{12}$ m^{-3}

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

Characterizing ISS Environments, Charging



Alternative Ne, Te Data and/or Model Sources

We have in-situ FPMU Ne, Te measurements along ISS orbit that we use for

- Assessing plasma hazards for charging before EVA's
- Characterizing ISS plasma environment for payloads, other science collaborations

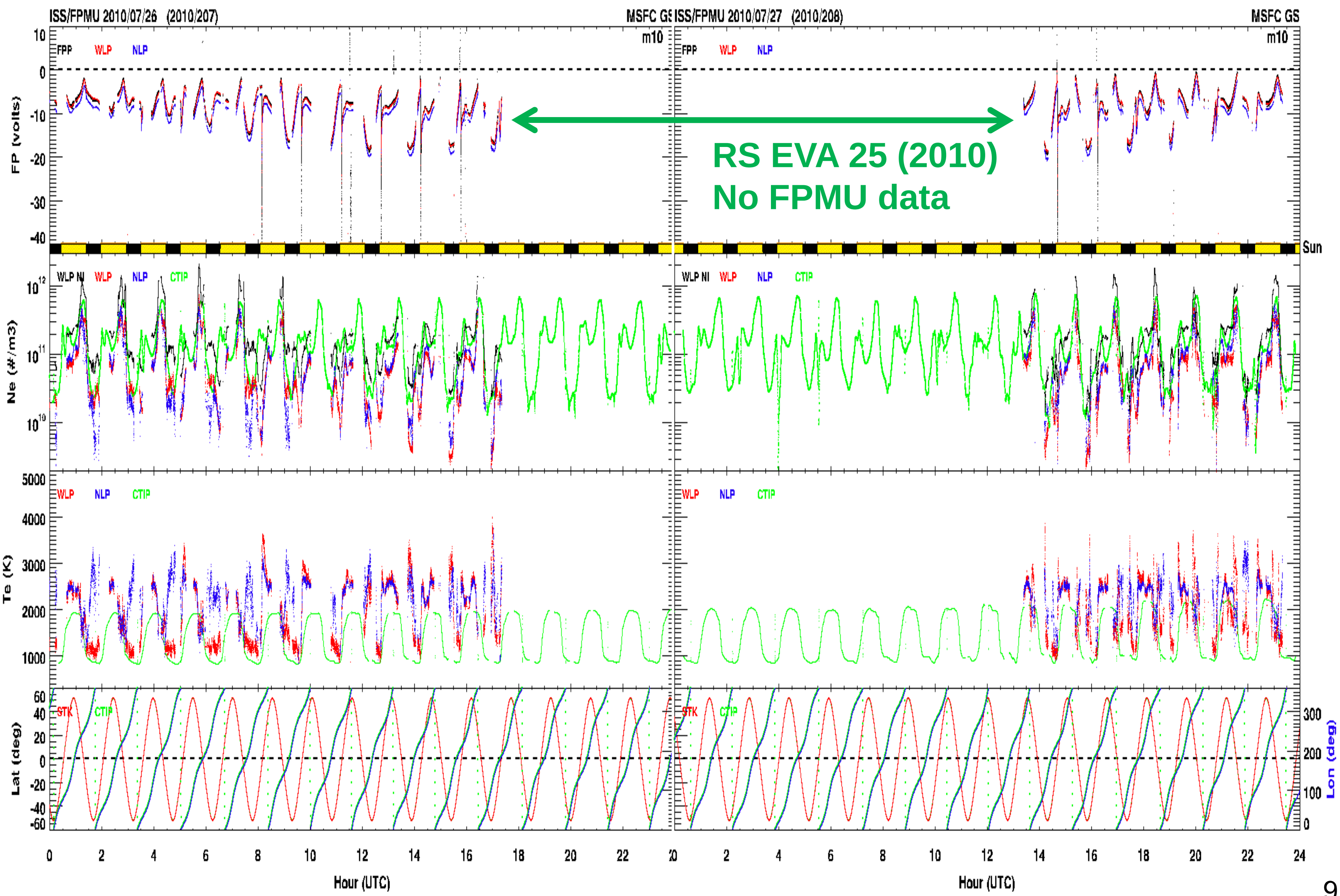
…but we are interested in identifying independent Ne, Te data sources from both measurements and models appropriate for ISS altitudes

- FPMU data unavailable during EVA, docking, and other operations with higher Ku band video downlink priority
- Ku band downlink is real time so we lose data during gaps in ISS to TDRS downlink
  - Real time data, models may be useful to provide coverage during these periods

- FPMU operated on campaign basis (~25 to 30% of year)
  - Well validated models or alternate data sources can provide environment characterization data between FPMU runs

- Contingency planning in case of FPMU failure
  - Default to current "worst case" analysis for EVA planning…but that impacts ISS power availability
  - Alternative data, validated models could provide operations relief to power constraint

FPMU Data Unavailable During EVA

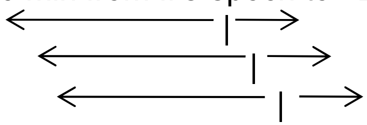


CCMC Real-time Ionosphere Ne, Te for ISS

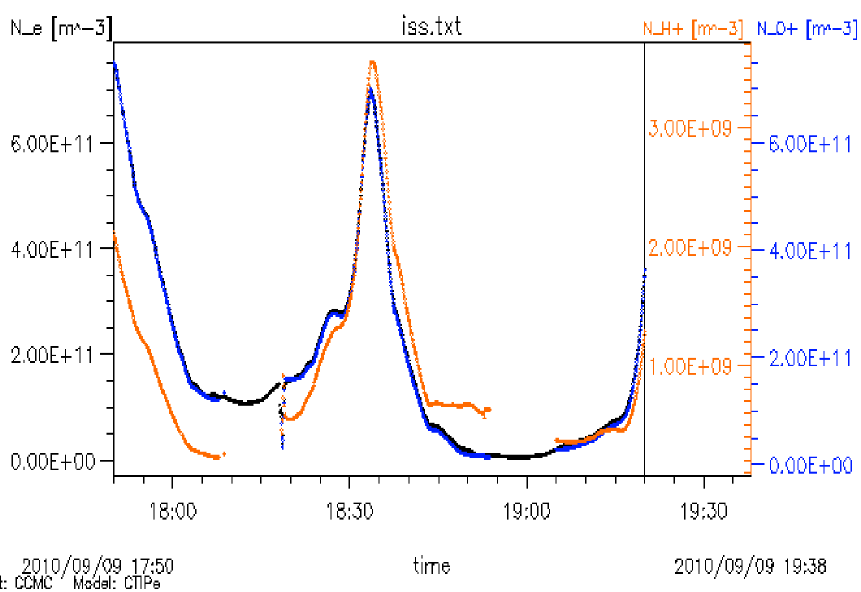
Coupled Thermosphere Ionosphere Plasmasphere Electrodynamics (CTIPe) Model

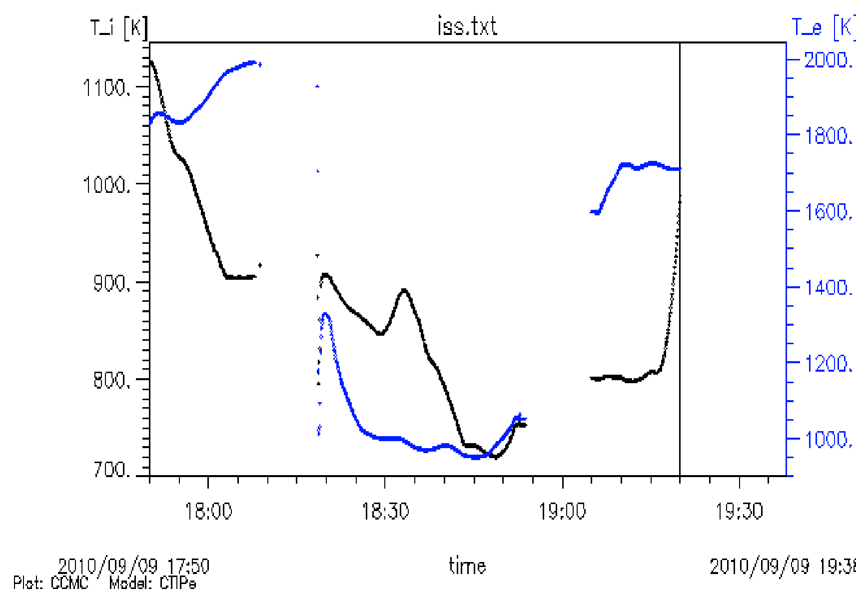
– CCMC implemented real time CTIPe model in spring 2010 (CTIPe_RT) with output specific for ISS orbit
– ISS ephemeris from GSFC/SSCWeb
– New record every 10 minutes gives 90 minutes of data at 5 sec time steps

-70 min from file epoch to +20 min



```
CTIPe_at_ISS_20100909_192000.txt                        09/09/2010   07:01PM
# Data printout from CCMC-simulation: version 1.1
# Data type:  CTIP  ionosphere/thermosphere
# Run name:   2010-09 Missing data:   -1.100E+12
# Coordinate System: GEO
# fixed dipole tilt angles used: SM-GSM:       0.00000 GSM-GSE:       0.00000
# Satellite Track: iss
# Output data: field with 1x1081=1081 elements
#YYYYMM DD HH MM   Sec     lon     lat     IP        N_e         N_O+        N_H+      T_i   T_e
# year month day  h m s  [deg]  [deg]   [km]      [m^-3]      [m^-3]      [m^-3]     [K]   [K]
2010 09 09 17 50  0.000  254.4 -9.250  351.5  7.522E+11  7.501E+11  2.108E+09  1125. 1828.
2010 09 09 17 50  5.000  254.6 -8.994  351.5  7.494E+11  7.473E+11  2.089E+09  1125. 1831.
2010 09 09 17 50 10.000  254.8 -8.738  351.4  7.465E+11  7.444E+11  2.069E+09  1125. 1834.
2010 09 09 17 50 15.000  254.9 -8.483  351.4  7.434E+11  7.414E+11  2.050E+09  1125. 1837.
2010 09 09 17 50 20.000  255.1 -8.227  351.3  7.402E+11  7.382E+11  2.030E+09  1124. 1840.
2010 09 09 17 50 25.000  255.3 -7.971  351.3  7.366E+11  7.346E+11  2.010E+09  1124. 1843.
2010 09 09 17 50 30.000  255.5 -7.715  351.2  7.312E+11  7.292E+11  1.989E+09  1123. 1844.
2010 09 09 17 50 35.000  255.7 -7.459  351.1  7.259E+11  7.239E+11  1.968E+09  1122. 1846.
2010 09 09 17 50 40.000  255.9 -7.203  351.1  7.205E+11  7.186E+11  1.947E+09  1120. 1848.
2010 09 09 17 50 45.000  256.1 -6.947  351.0  7.151E+11  7.132E+11  1.927E+09  1119. 1850.
                   ---------------- (records deleted)  -----------------------
2010 09 09 19 20  0.000  227.5 -14.02  352.8  3.634E+11  3.621E+11  1.289E+09  989.1 1710.
```





Example CTIPe_RT Daily Output

CTIPe_RT output at CCMC:

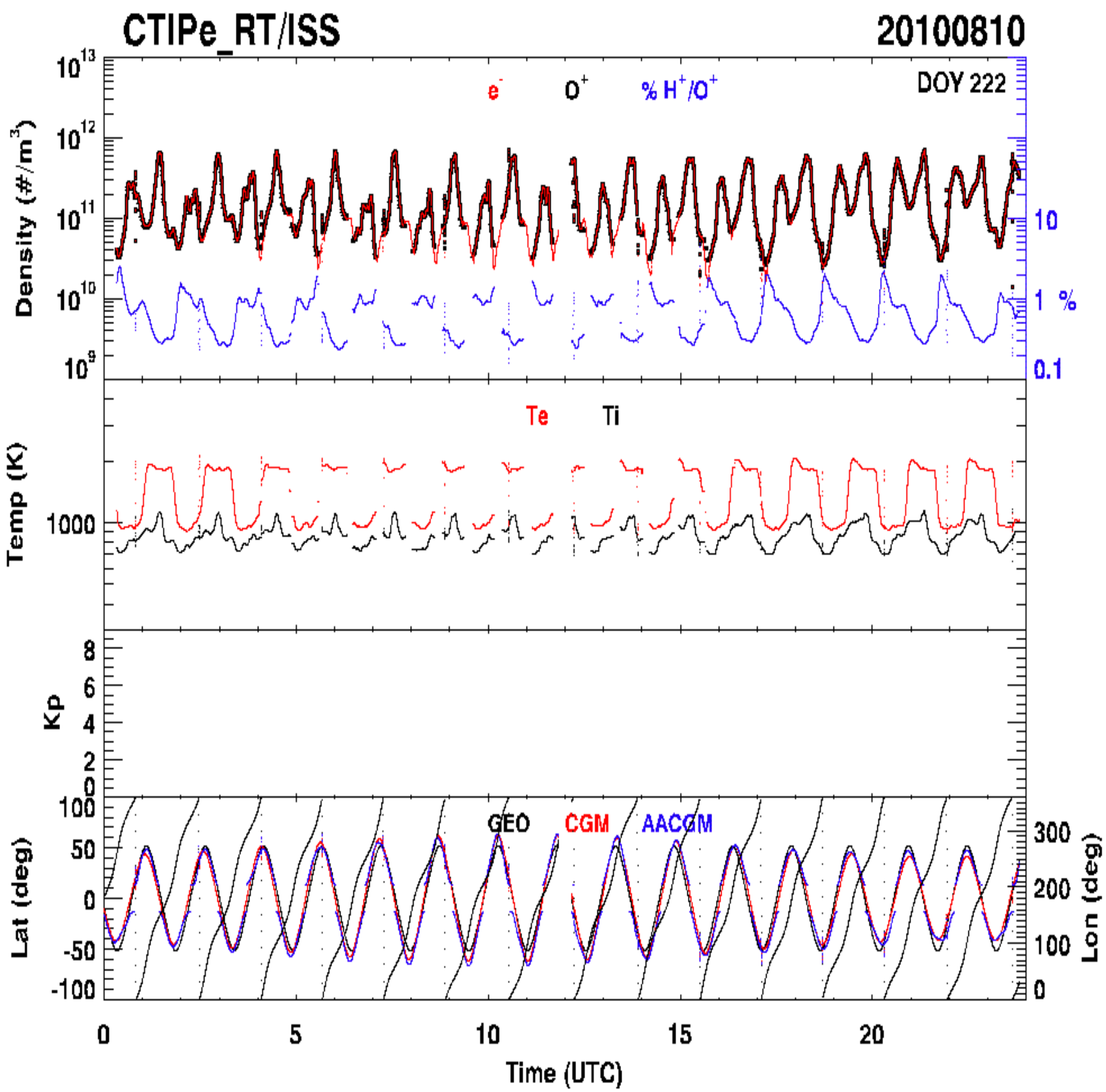
Integrated Space Weather Analysis System (iSWA)
http://iswa.gsfc.nasa.gov/iswa/iSWA.html

Anonymous ftp
ftp://hanna.ccmc.gsfc.nasa.gov/

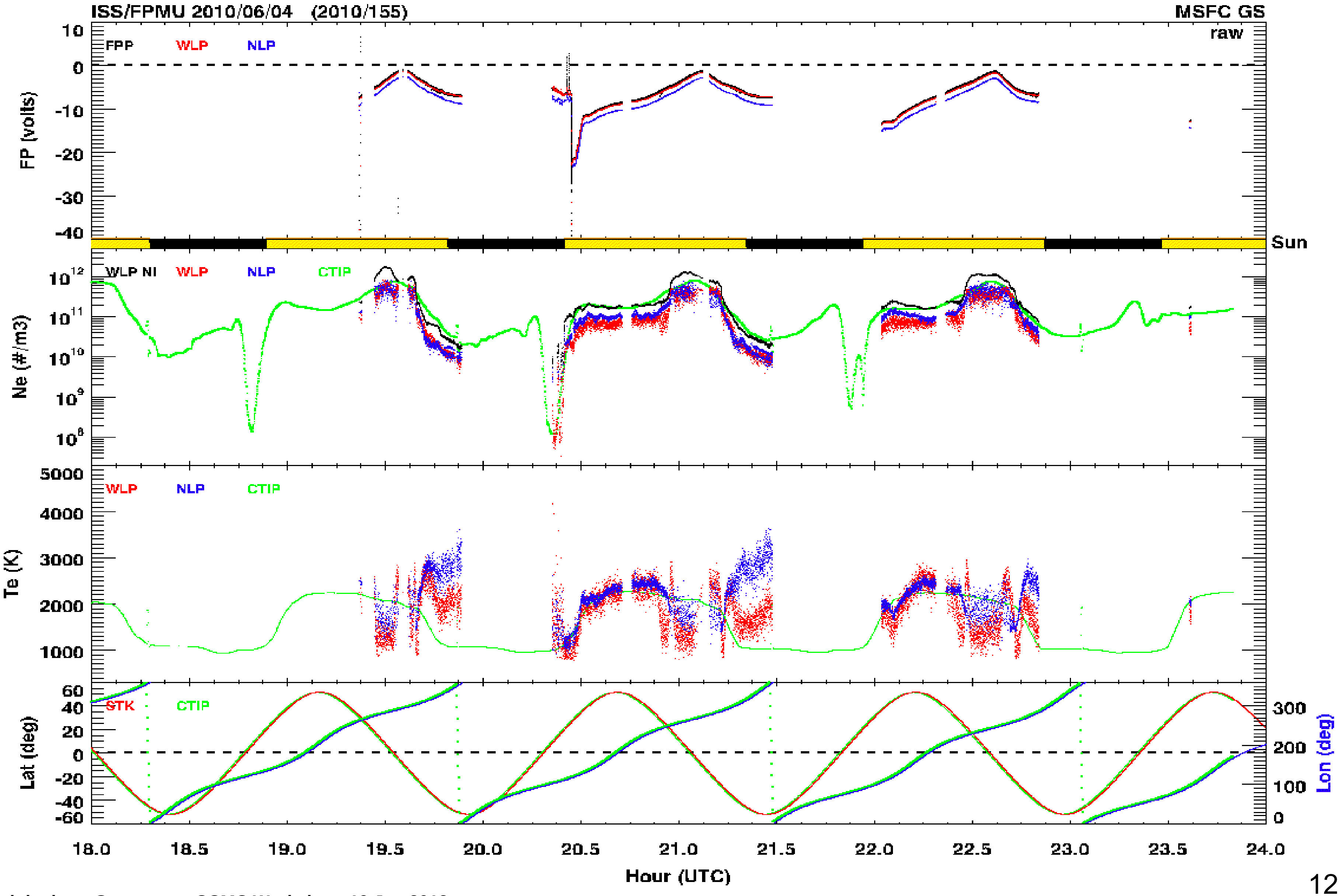
CTIPe Model Description:
http://ccmc.gsfc.nasa.gov/models/modelinfo.php?model=CTIPe

MSFC is evaluating CTIPe_RT for possible ISS ops use:

- Periodically download text output files and process into daily data sets retaining the unique records
- Compare CTIPe_RT Ne, Te with measurements from FPMU



Good CTIPe_RT/FPMU Comparison



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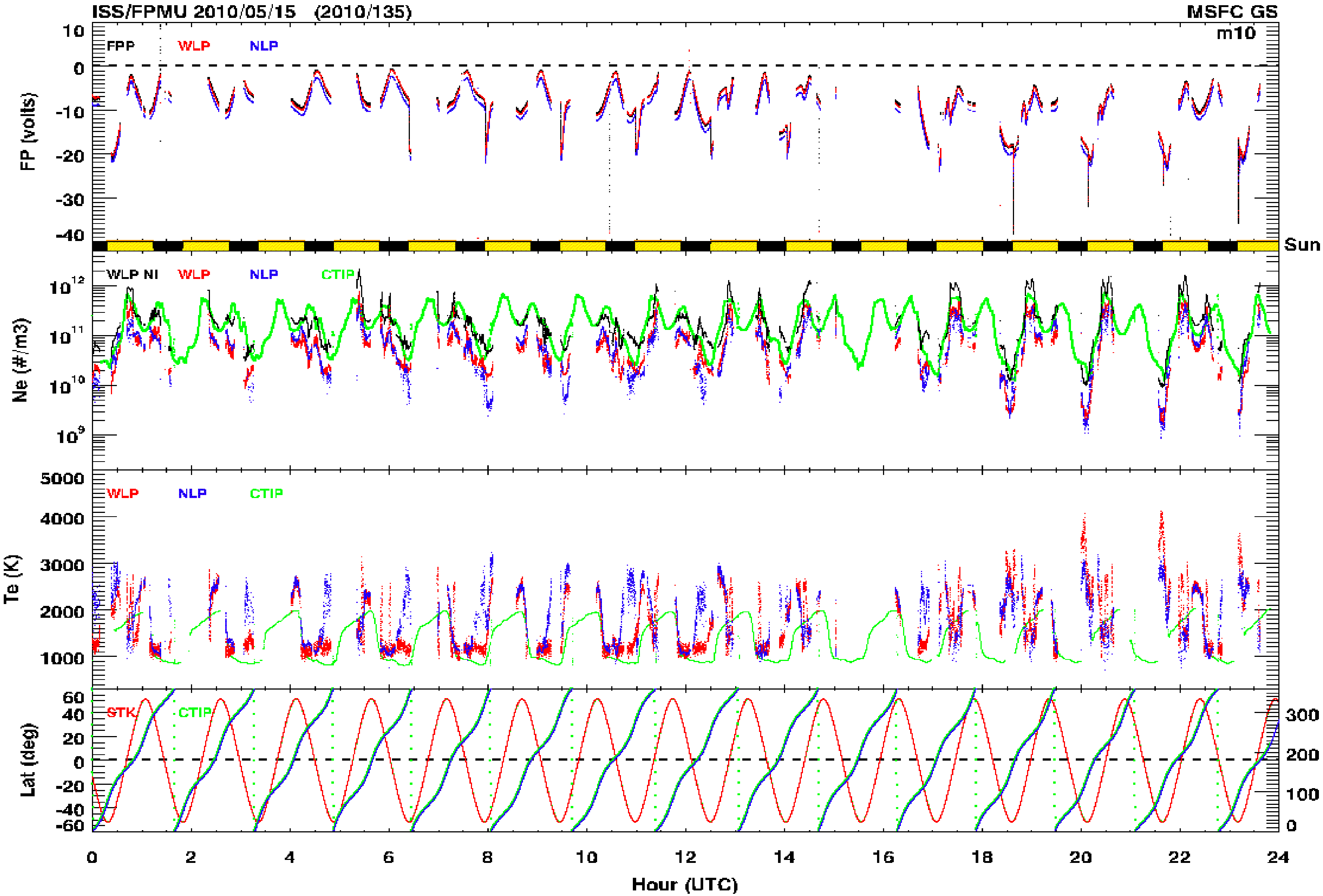
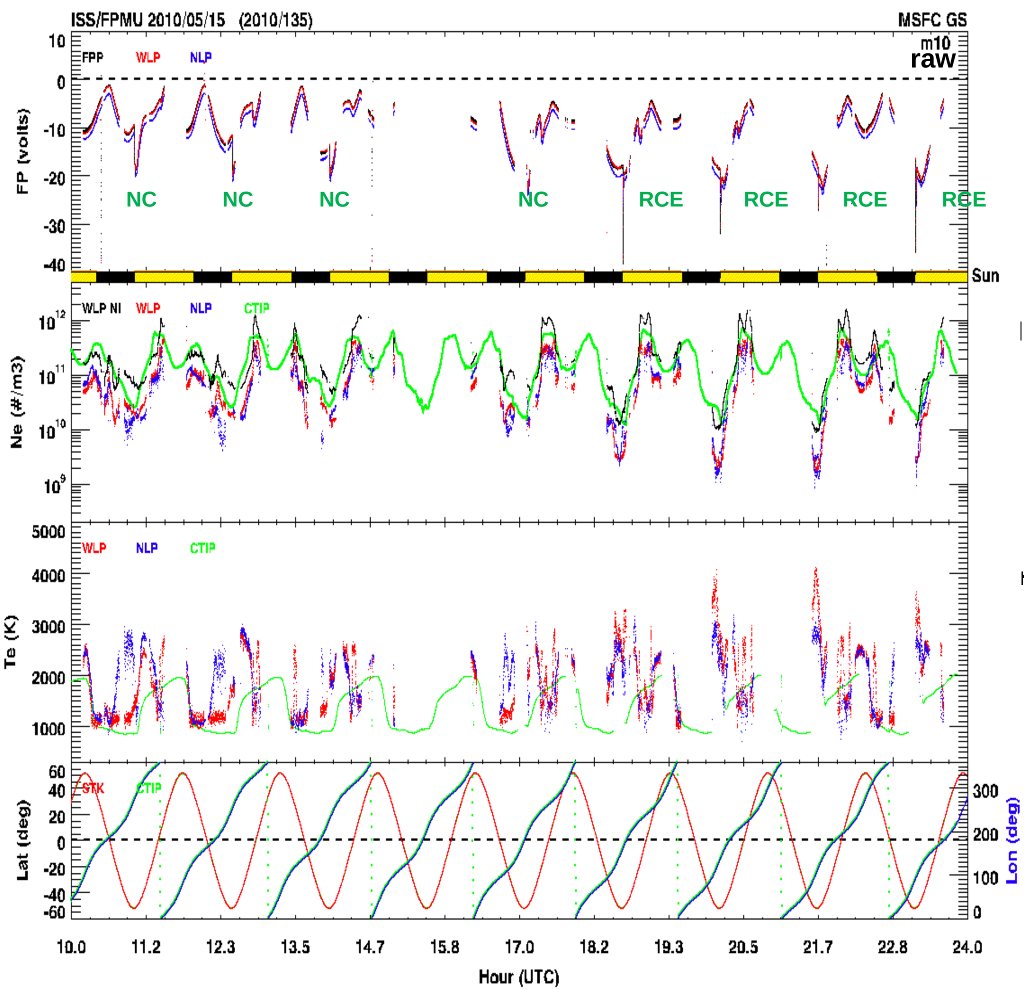
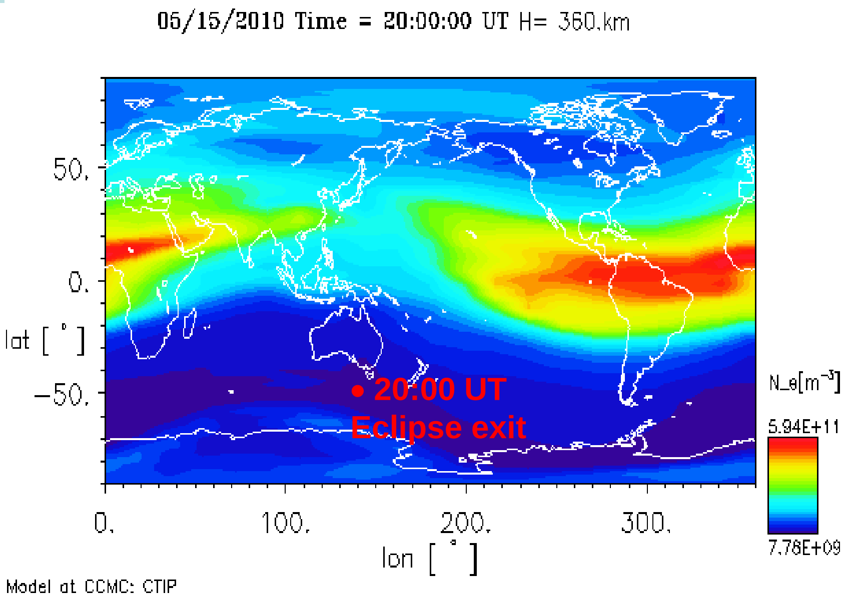
Less Good CTIPe_RT/FPMU Comparison



Characterizing High Latitude Charging Environment

- ISS environments teams are investigating variations in physics of eclipse exit charging
- CTIPe_RT model confirmed physical origin of the plasma depletions for charging events observed at high latitudes, allows us to predict periods for studying charging phenomenon





10-17 UT Eclipse Exit
Normal charging (NC) events observed at eclipse exit

17 – 24 UT Eclipse Exit
Rapid charging (RC) events observed when eclipse exit occurs in low density plasma troughs

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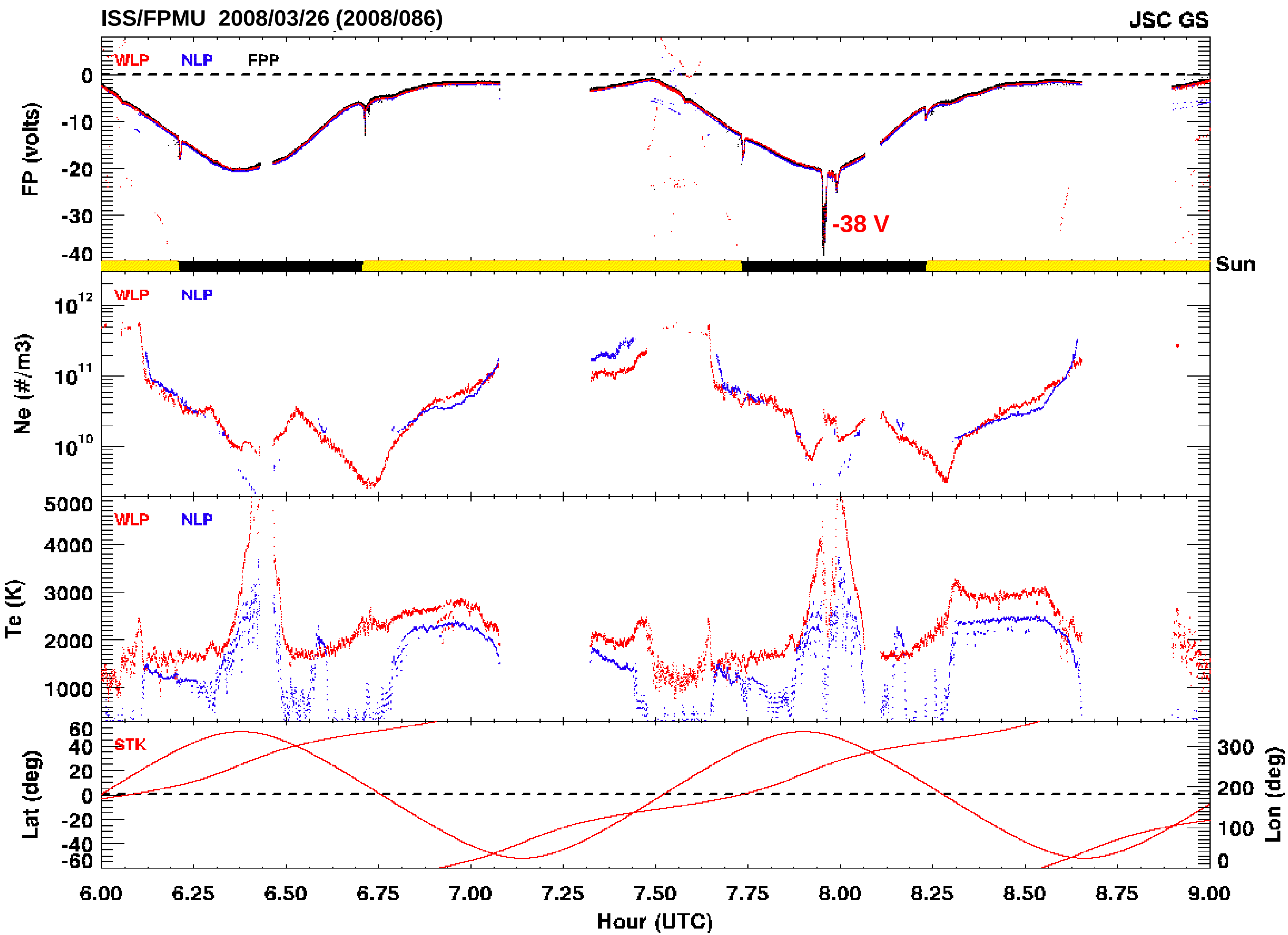
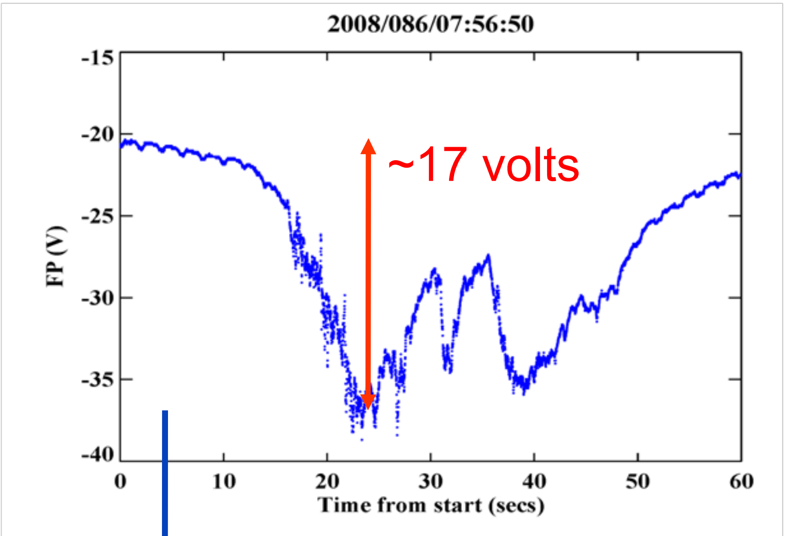
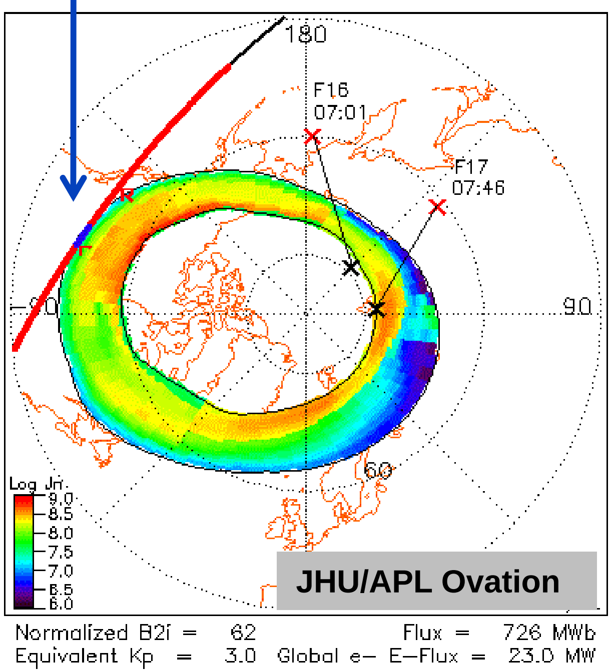
Auroral Charging

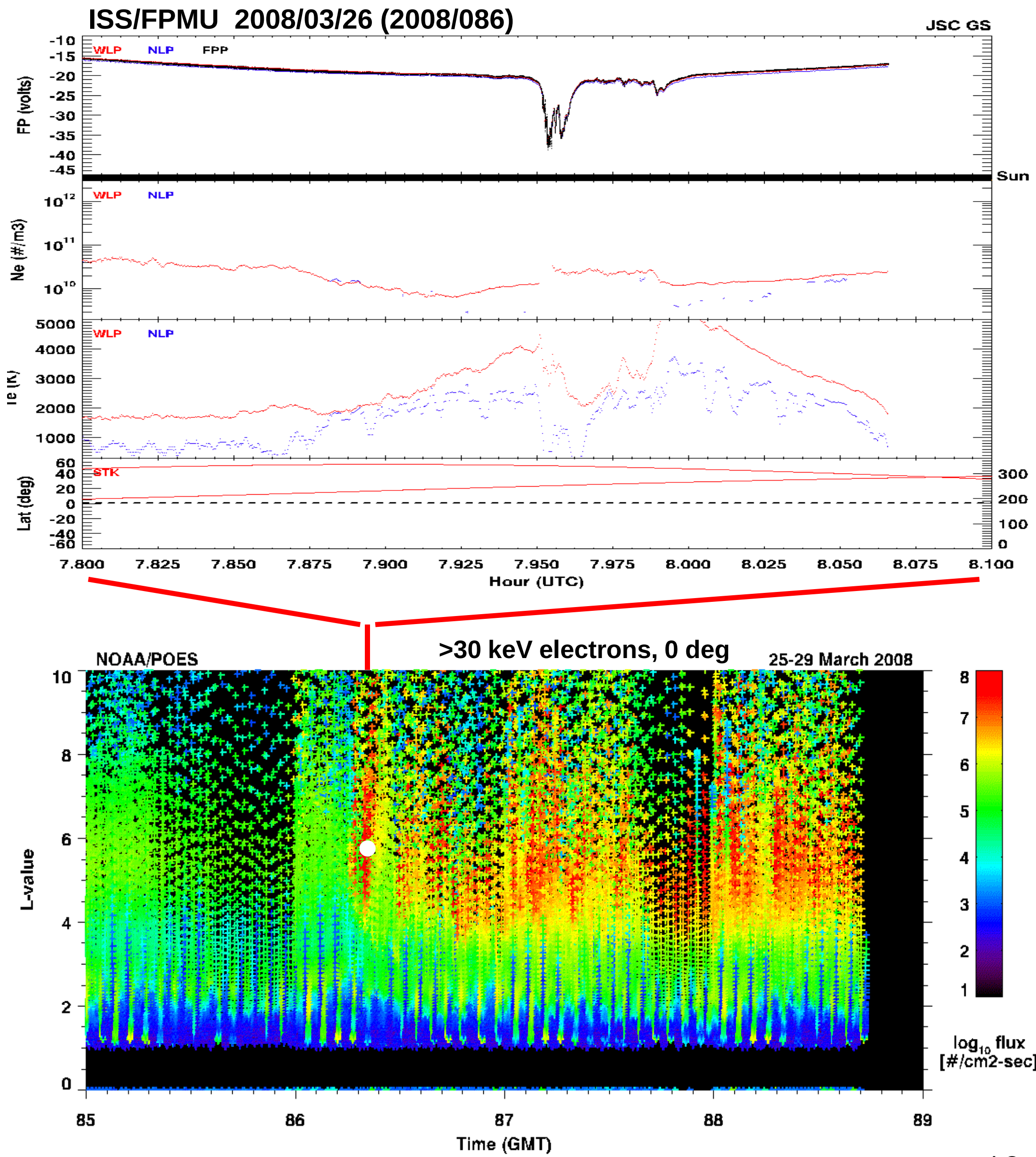


Auroral Charging



26 Mar 2008 07:30 – 08:00 UT





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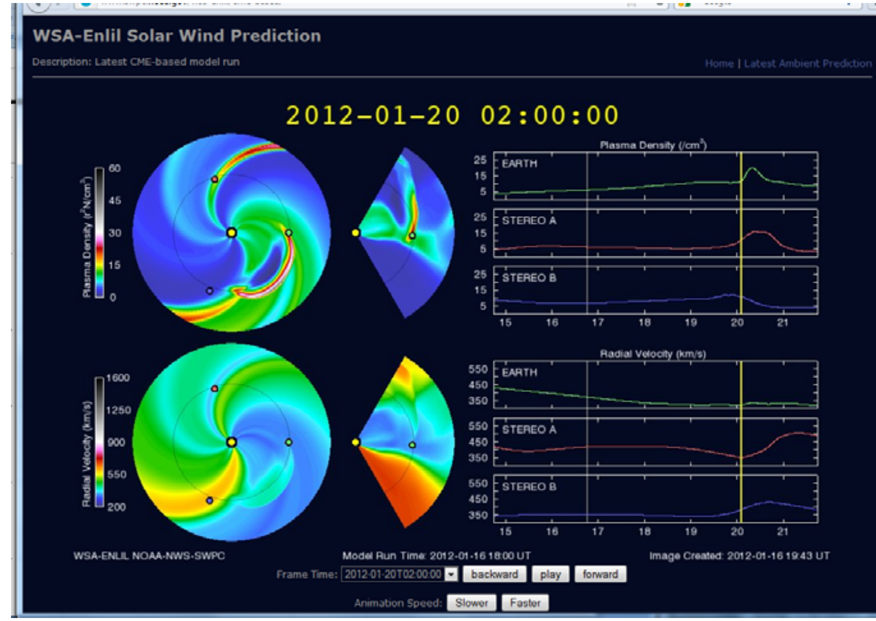
[*Craven et al*., 2009; Minow et al., 2011]

Solar Activity and CME Monitoring

X-ray flare, type II radio emission, halo CME alerts
- NOAA/SWPC, CCMC, SIDC

Models used to estimate shock arrival time
- NOAA/WSWPC, CCMC WSA-Enlil solar wind models
- CME transit time empirical models

ISS applications:
- Supports scheduling FPMU campaigns to investigate auroral charging of vehicle
- Alert ISS crew (D. Pettit/Expedition 30/31) for auroral observation opportunities
- Space situational awareness for storm driven changes in solar array charging environments
  - EVA support
  - Anomaly investigations



December 2011

Shock Time (UTC)	Shock Speed (km/s)	Arrival Time (UTC) No Drag	Zhang	Gopalswamy	Wang
024/00:54	520.	027/08:49	027/00:08	027/14:20	026/21:27
024/09:18	600.	027/06:34	027/04:44	027/15:02	027/00:27
024/14:30	500.	028/01:37	027/14:41	028/05:59	027/12:41
025/01:24	480.	028/15:58	028/02:33	028/19:00	028/01:20
025/20:54	770.	028/02:52	028/08:14	028/12:50	028/04:17
026/12:09	721.	028/21:47	029/01:49	029/07:44	028/21:24
027/04:54	728.	029/13:59	029/18:14	029/23:57	029/13:52

Gopalswamy et al. 2000; Wang et al. 2002; Zhang et al. 2003

21 Dec 2011 18:44:56 UTC

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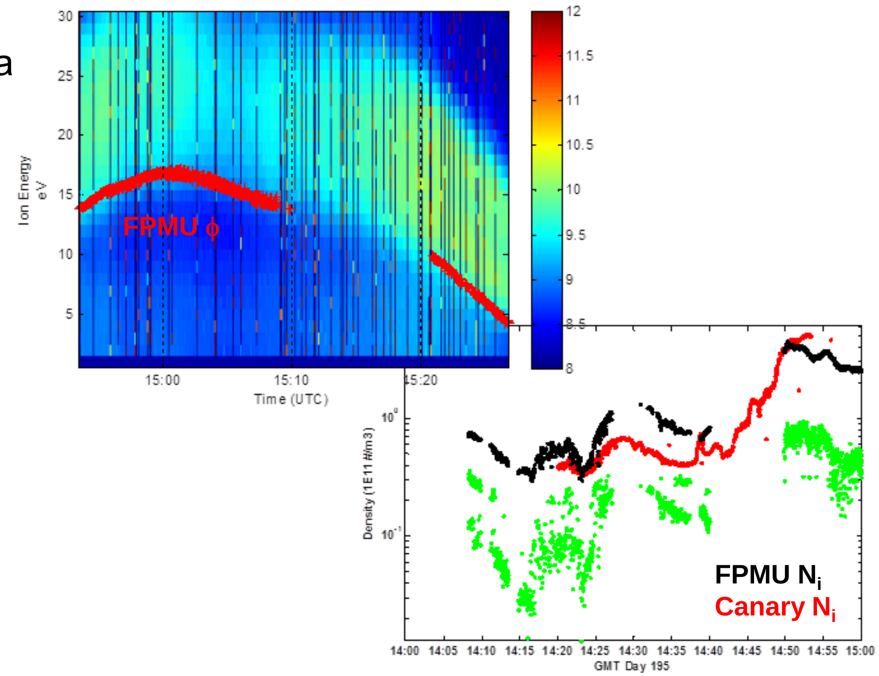
DoD Space Test Program Payload Support

[adapted from Balthazor et al. 2011]



Canary: USAF Academy (G. McHarg), JHU/APL

- Investigate ion interactions with ISS background plasma environment
- Target of opportunity to sample ram ions provided by ISS flight attitude when STS docked
- Correlate shifts in Canary energy spectrum, ion density with FPMU measured floating potential, ion density

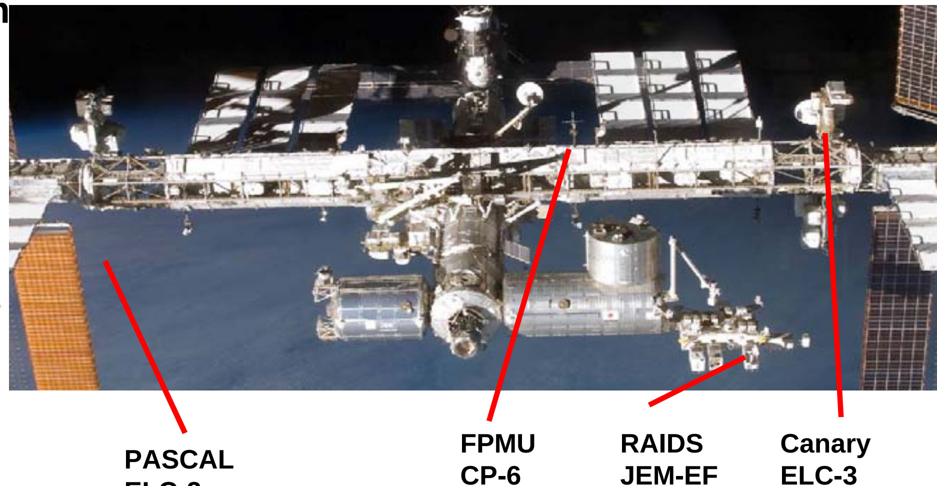
Primary Arcing of Solar Cells at LEO (PASCAL) :

Lockheed Martin (J. Likar), Kyushu Inst Tech, JAXA

- Solar array arcing experiment
- Plasma diagnostics not included in package for evaluating current collection
- FPMU provides Ne, Te data for computing charging currents to solar cells biased to $\leq$ 300 volts

Remote Atmopshere and Ionospheric DetectionSystem (RAIDS): NRL (S. Budzien), Aerospace Corp., ONR

- UV/VIS remote sensing of airglow
- Compare RAIDS Ne(z) profiles retrieved from limb radiances with FPMU Ne(s) records at ISS altitude



FPMU data only available for limited campaign periods

- **Alternative Ne, Te data source is desirable for full environment coverage for payload support when FPMU data not available**

ISS Anomaly Investigations

Examples where anomaly investigations included anlaysis of charging, plasma environments:

- Russian GNC computer failure (2007)
- Soyuz pyrobolt failure (2008)
- S-band transmission interruptions (2011)
- PVCU MDM card fault required system reset (2011)

Proposed anomalous ISS 160 volt solar array charging:

- FPMU measurements demonstrate floating potential within program requirements
- Boeing/SAIC ISS charging code demonstrated charging within acceptable levels
- Ne(s) along ISS orbit reconstructed from COSMIC Ne(z) profiles demonstrated environment within nominal levels for typical PVA charging

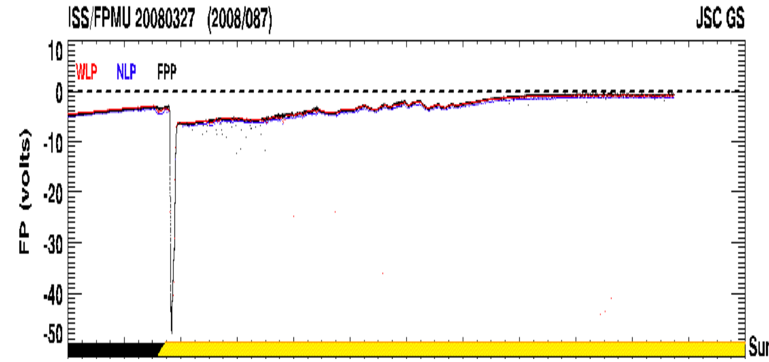
Result: data, modeling demonstrate no charging effects

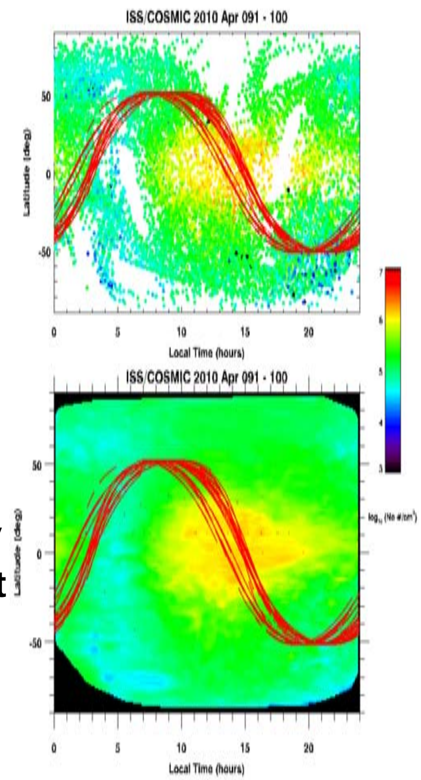
Anomalous plasma environment

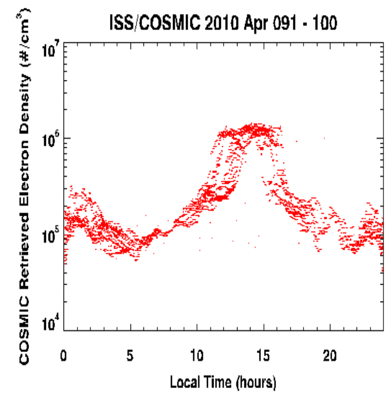
- FPMU measured Ne, Te within nominal range
- Ne(s) reconstructed from COSMIC constellation Ne(z) profiles demonstrates environment within flight history
- NOAA SWPC, NGDC records demonstrate low geomagnetic activity

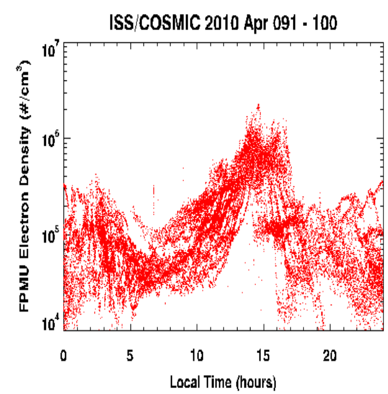
Result: data, modeling show nominal plasma environment

ISS would benefit from additional ionospheric data sources or data constrained models providing Ne, Te along ISS orbit (e.g., GAIM, CTIPe update?)









Summary and Future Needs

- **ISS Program currently using FPMU Ne, Te in-situ measurements to support operations and anomaly investigations**
  - Working to acquire alternative data sources if FPMU is not available

- **Work is progressing on CCMC tools for low Earth orbit ionosphere characterization**
  - Validation against FPMU data required before model output can be used for ISS operational support
  - Continue comparing CTIP output during FPMU campaigns
  - Results to date have been useful in identifying ionospheric origins of high latitude charging environments
  - WSA-Enlil model very useful for predicting arrival times of CME shocks

- **Future needs:**
  - Incorporate environment constraints (F107, HPI, etc) used in model in CTIPe_RT output files
  - Implement CTIPe_RT output for ISR, ionosonde sites
    - Provide additional data for validating CTIP output
    - Support validation of real time data to supplement FPMU output
  - Implement assimilative ionosphere models (e.g., GAIM)
    - Models constrained by Ne, Te data better for operations support, anomaly investigations

ISS Space Weather Needs

- Solar activity/thermosphere density prediction and satellite torque/drag predictions for:
  - Mission planning and controllability/real-time operations
  - MM/OD environment evolution
- Meteor storm severity predictions for potential impact to vehicle, operations
- Role of solar/geomagnetic activity/thermosphere in managing ISS crew ionizing radiation dose exposure
- Monitor for changes in the south Atlantic anomaly altitude structure and geographic extent for crew IR dose management
- Ionospheric Ne, Te values along ISS orbit for characterizing ISS charging hazards, payload science support, and anomaly investigations:
  - Near real time Ne, Te data
  - Well validated real time model Ne, Te output
- ISS interaction with auroral particle precipitation
  - characterize magnitude of charging
  - determine if auroral forecasting is required to support EVA