Chandra and ISS SWx Events

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4th NASA Space Weather and Robotic Mission Operations Workshop, NASA/GSFC
27 September 2012

ISS image: 7 March 2012

Overview

- Chandra radiation events ~1.5 Re x 22 Re, 67° inc:
  - Radiation belts, ring currents, solar particle events
  - Science interruptions due to radiation events
  - Aspect Camera Assembly anomaly

- ISS spacecraft charging ~350 km to 420 km, 51.6° inc
  - Low earth orbit, ionospheric plasma
  - ISS anomaly investigations
  - Space weather monitoring for geomagnetic storm studies

CXO and ISS Environments Teams

Chandra X-ray Observatory

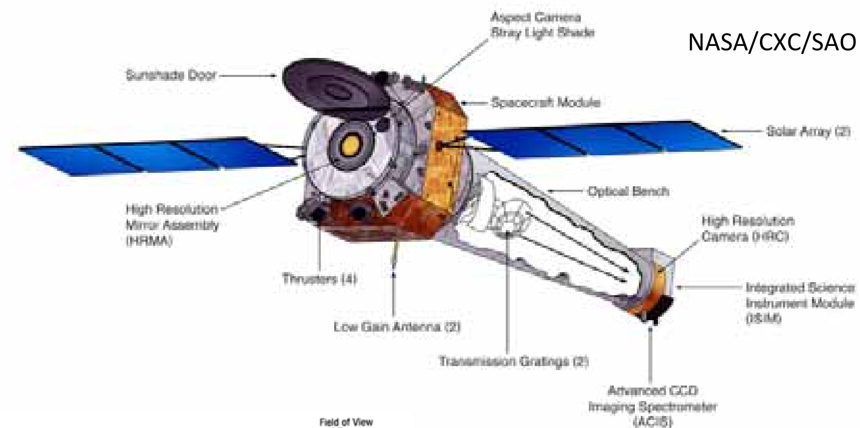
- MSFC: Scott Miller, Joe Minow, Steve O'Dell, Doug Swartz
- SAO Thomas Aldcroft, Eric Martin, Bradley Spitzbart, Scott Wolk

International Space Station

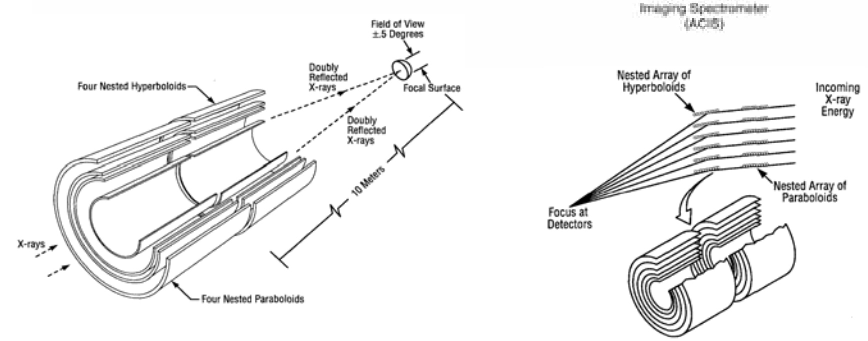
- MSFC Mike Chandler, Paul Craven, Joe Minow, Emily Willis
- JSC John Alred, Jack Bacon, Steve Koontz
- Boeing William Hartman, Ron Mikatarian, Danny Schmidl, Leonard Kramer

Chandra X-Ray Observatory (CXO)

- Launched 23 July 1999 by STS-93
- Current orbit:
  ~1.5 Re x 22 Re x 67°, ~64.5 hour period
- Mission
  - 5-year primary science mission
  - Currently in 2nd 5-year extension
  - Planning for 3rd to 2019

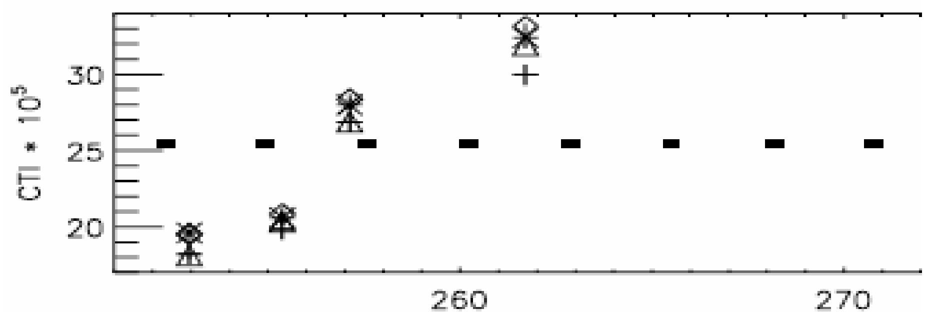


NASA/CXC/SAO



http://chandra.harvard.edu/about/top_ten.html

- Advanced CCD Imaging Spectrometer (ACIS) is CXO's premier science most often requested in observatory proposals
  - Degradation of the 8 front illuminated ACIS CCD detectors was observed to be much worse than expected soon after launch, 2 back illuminated CCD's immune to damage
  - ~5 years worth of degradation in a single perigee passage
  - Damage mechanism identified as soft protons (~100 to 200 keV) depositing energy in CCD substrate



- ACIS can't be operated in high flux, soft proton environment within the magnetosphere and solar particle events

CXO Radiation Environment Monitoring

Radiation mitigation strategy

- Schedule science operations to avoid high flux of soft protons in the Earth's ring currents using Chandra Radiation Model, AP-8/AE-8 (trapped protons)
- Monitor environment real time both in-situ (autonomous) and at operations center (manual), move ACIS to protected position during periods of high flux (solar particle events)

CXO Monitoring and Trends Analysis (MTA) Team utilizes data from a variety of sources for real-time monitoring of CXO radiation environment:

• **EPHIN E1300 rates**	**protons 25 - 41 MeV**	**in-situ**
	electrons 2.6 - 6.2 MeV	
• **HRC rates**	**~10's MeV**	in-situ
• **ACIS rates**	**~10's MeV**	in-situ (in development)
• GOES P1	0.7 – 4 MeV	NOAA SWPC real time (5 min)
P2	**4 – 8 MeV (EPHIN P4GM proxy)**	
P5	**38 – 80 MeV (EPHIN P41GM proxy)**	
• ACE P2'	68 – 115 keV	NOAA SWPC real time (5 min)
P3'	**115 – 195 keV**	
P4'	195 – 321 keV	
• XMM	> 1 MeV	ESA real time (2 to 60 minutes)

CXO Solar Cycle 24 Radiation Interruptions*

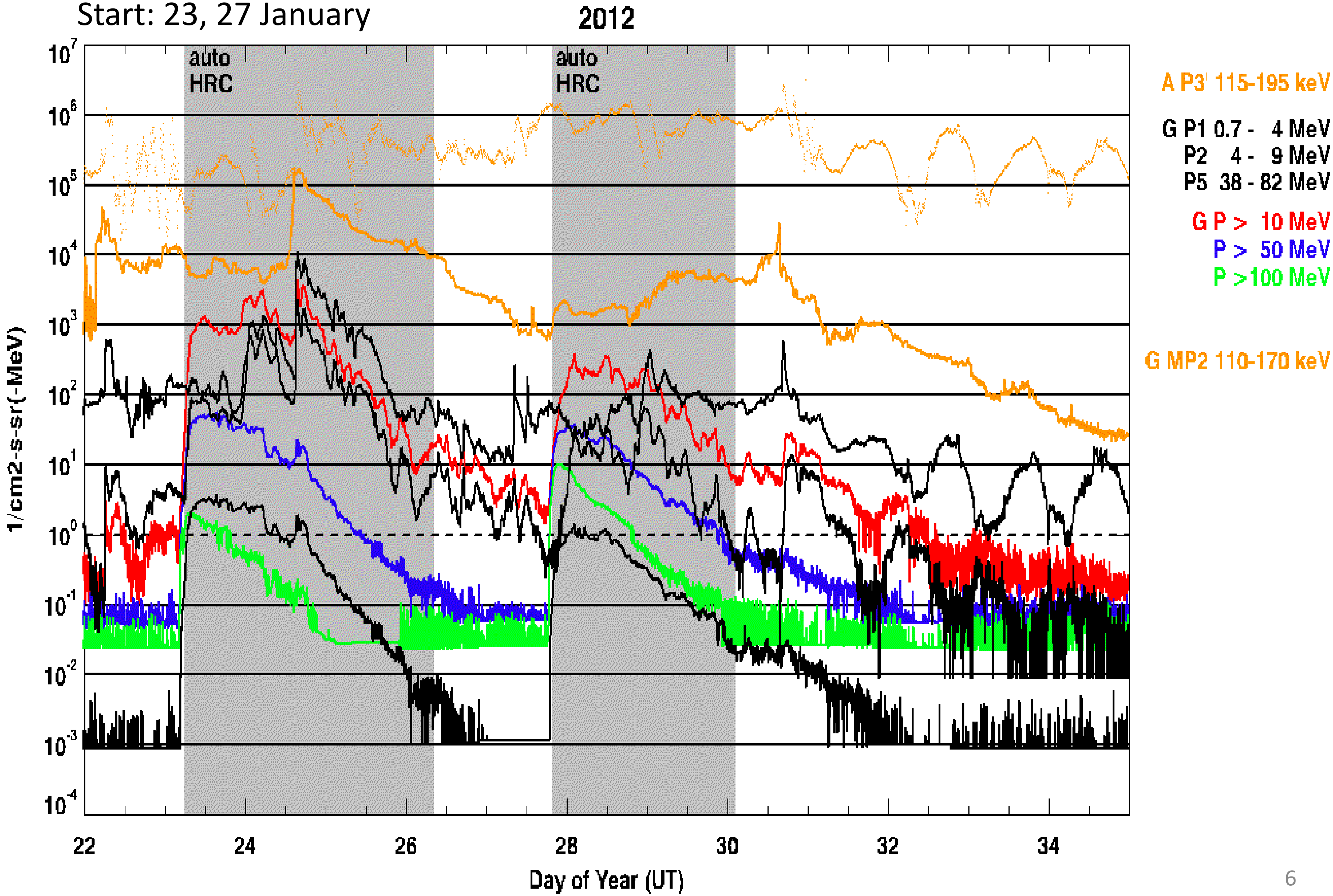
Event	Start	End	Lost time	Man/Auto	Cause
2011					
1**	7 Jun 15:23 UT	8 Jun 12:50 UT	74.9 ks (20.8 hr)	auto	HRC
2	4 Aug 07:03	7 Aug 10:25	270.4 (75)	auto	HRC
3	24 Oct 18:27	25 Oct 22:35	61.1 (17.0)	manual	ACE P3’
4	26 Oct 11:40	28 Oct 12:33	154 (42.8)	auto	SEU, Command Telemetry Unit
2012					
5	23 Jan 06:00	26 Jan 08:27	192.1 (53.4)	auto	HRC
6	27 Jan 19:39	30 Jan 02:20	163.4 (45.4)	auto	HRC
7	27 Feb 03:24	27 Feb 20:23	61 (16.9)	manual	ACE P3’
8	7 Mar 05:30	13 Mar 05:14	440 (122.2)	auto	HRC
9	13 Mar 22:41	14 Mar 13:57	53.3 (14.8)	auto	HRC
10	17 May 02:18	18 May 04:52	93.8 (26.1)	auto	E1300
11	12 Jul 19:59	14 Jul 00:09	61.7 (17.1)	auto	E1300
12	14 Jul 21:08	16 Jul 05:16	80.1 (22.3)	manual	ACE P3’
13	19 Jul 11:44	20 Jul 04:09	56.5 (15.7)	auto	HRC
14	3 Sep 12:57	4 Sep 12:41	44.5 (12.4)	manual	ACE P3’

*Source: Harvard SAO, Radiation Central: http://asc.harvard.edu/mta/RADIATION/

**First radiation interruption since 13 Dec 2006

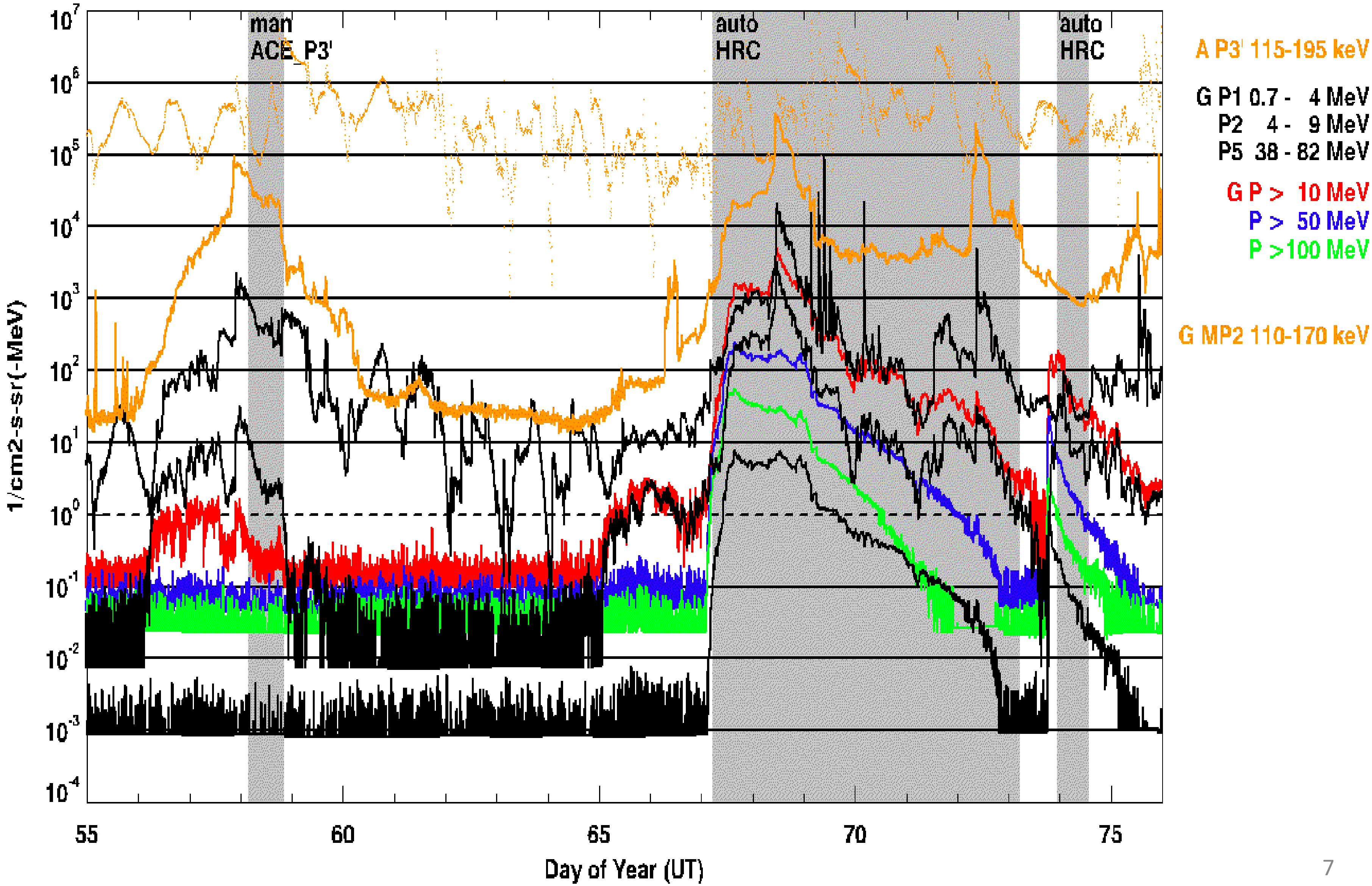
Auto HRC Radiation Interruptions

Start: 23, 27 January



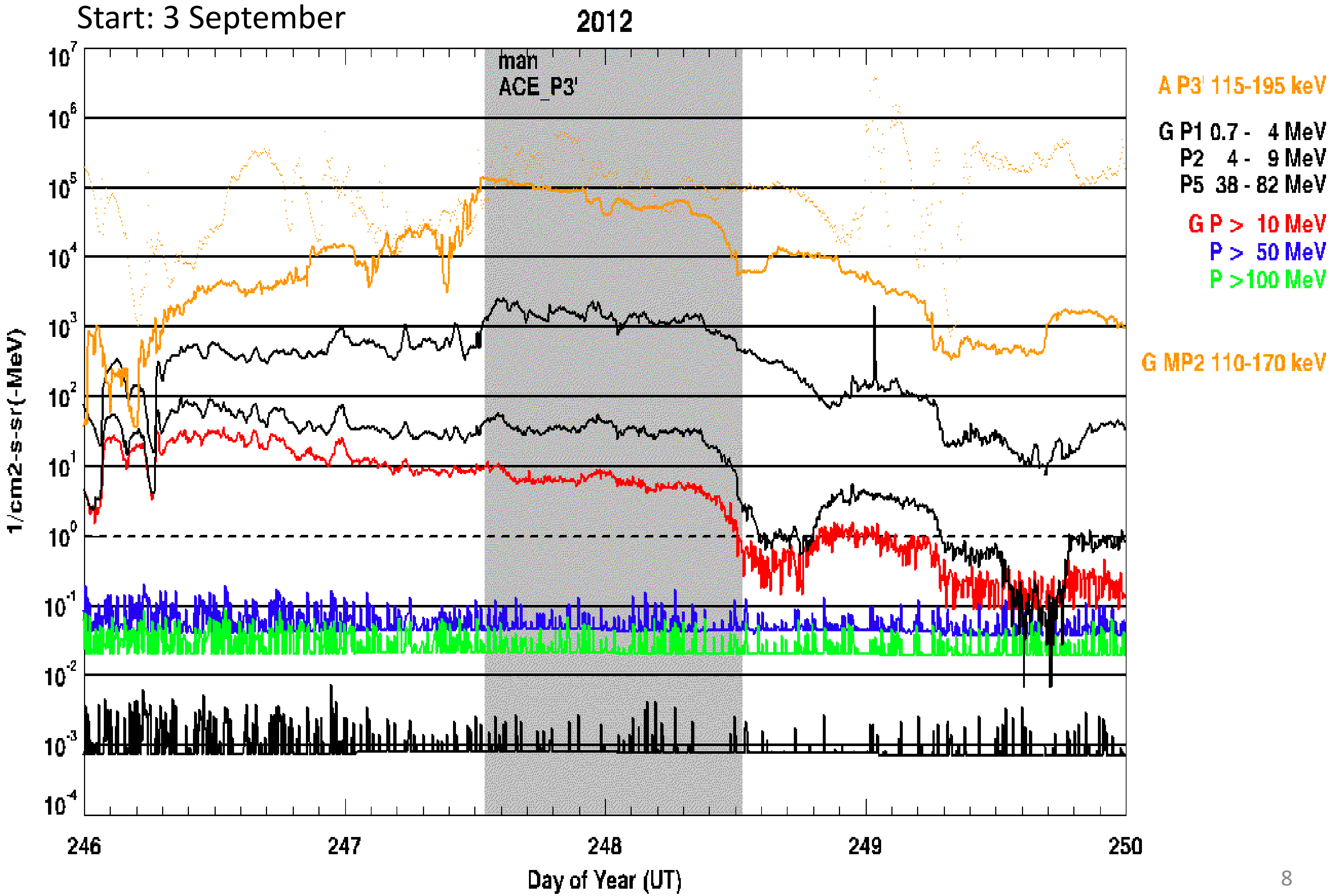
Manual P3', Auto HRC Radiation Interruptions

Start: 27 February, 7, 13 March 2012



Manual ACE P3' Radiation Interruption

Start: 3 September



Future of ACE Real Time Data

- The ACE/EPAM RTSW records are the only real-time data for detecting soft ~100-200 keV proton events in interplanetary space that impact the ACIS instrument

- NOAA plans to replace ACE with Deep Space Climate Observatory (DSCOVR) in late 2014
  - DSCOVR will become the primary NOAA space weather plasma data source
  - ACE RTSW coverage will be discontinued
  - DSCOVR carries a MAG/SWEPAM type cold solar wind plasma and magnetic field instrument
  - No replacement for non-thermal EPAM, SIS energetic particle instruments on DSCOVR

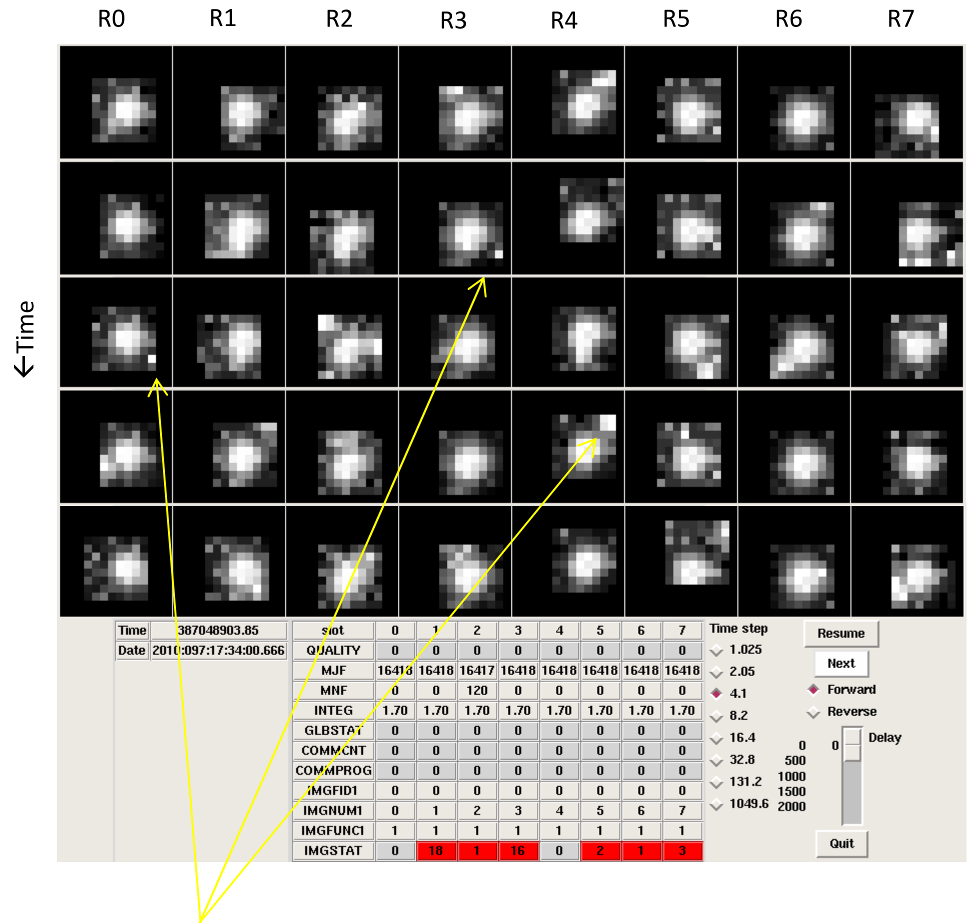
- DSCOVR is planned as an interim solution for an ACE replacement with release of an RFP for a full replacement after DSCOVR is on orbit
  - Full ACE replacement satellite could have a more complete set of cold plasma, energetic particle instruments including an EPAM replacement but there will be a gap in service for a few years for the real-time energetic particle data
  - None of this has been authorized by Congress so it is all uncertain at best
  - The gap could be many years

- Loss of ACE/EPAM soft proton data will impact CXO operations
- Are there other spacecraft or space weather users that require the RTSW ACE/EPAM data for operations that will be similarly impacted? CXO Program would like to know….

Aspect Camera Assembly (ACA) Anomaly

- In early 2010 the CXO ACA star-tracker began to experience loss in star positions used for attitude and alignment control during perigee passes
- Number of 8 alignment stars dropped to 0 or 1 for up to 8 seconds in some cases
- If the star loss extended to 30 seconds a bright star hold or safing action could be triggered (which is bad!)

- Star-tracker uses a CCD based imaging technology that is sensitive to energetic particles
  - Inner radiation belt protons initially suspected due to decreasing perigee altitude from ~2.2 Re in 2010 to 1.5 Re in 2012
  - Analysis demonstrated relativistic electrons were the origin of the radiation events



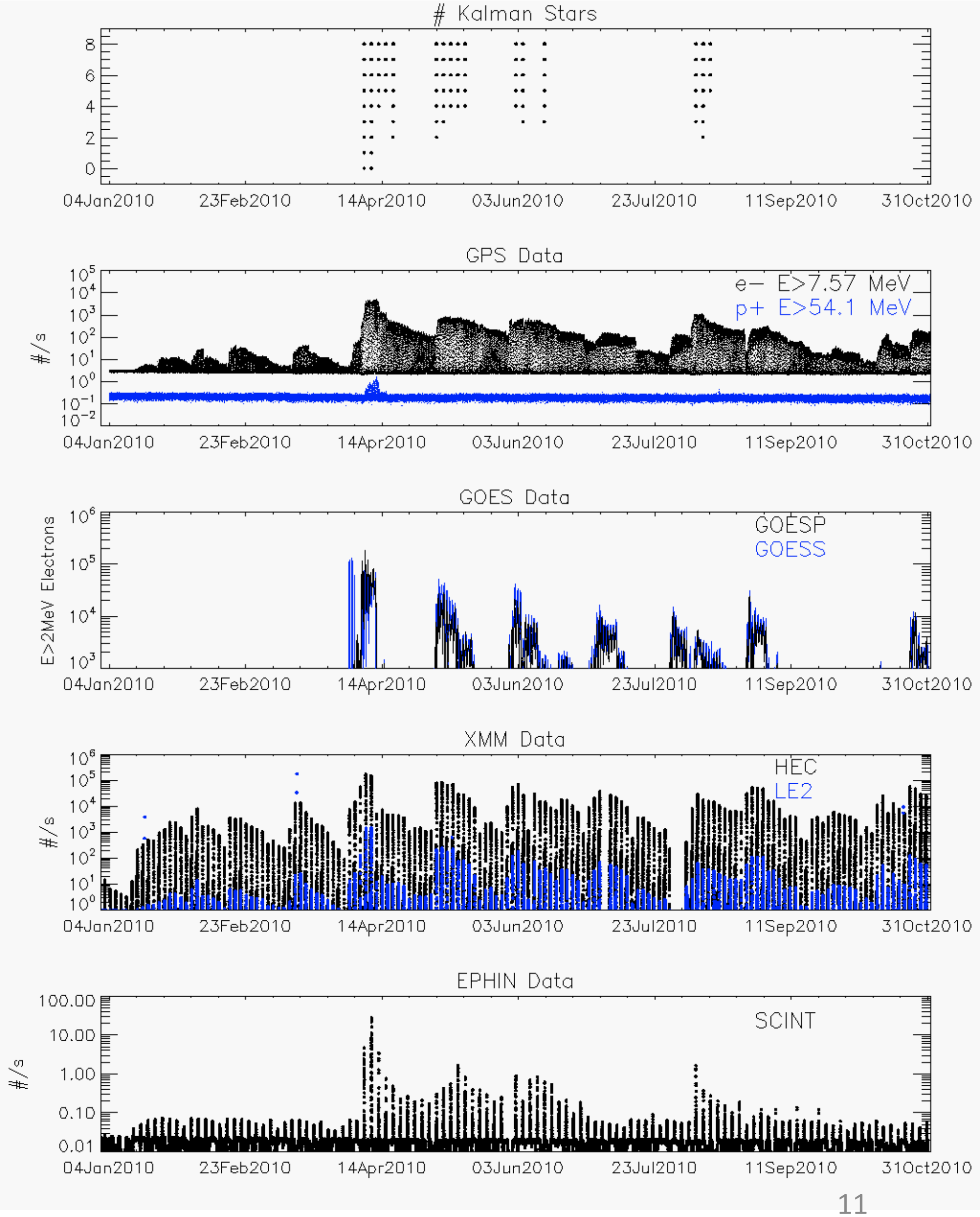
slot	0	1	2	3	4	5	6	7
QUALITY	0	0	0	0	0	0	0	0
MJF	16418	16418	16417	16418	16418	16418	16418	16418
MNF	0	0	120	0	0	0	0	0
INTEG	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70
GLBSTAT	0	0	0	0	0	0	0	0
COMMCNT	0	0	0	0	0	0	0	0
COMMPROG	0	0	0	0	0	0	0	0
IMGFID1	0	0	0	0	0	0	0	0
IMGNUM1	0	1	2	3	4	5	6	7
IMGFUNC1	1	1	1	1	1	1	1	1
IMGSTAT	0	18	1	16	0	2	1	3

‘Hot’ pixels change the centroid and throw off the startracker

Aspect Camera Assembly (ACA) Anomaly

- Enhanced relativistic electrons during solar minimum penetrated ACA housing
  - ~7.91 g/cm2 shielding requires >14 MeV electrons and >87 MeV protons to penetrate to CCD
- Evaluation of radiation environment showed good correlation of loss in tracking stars with increase in relativistic electrons
- Scint >8.7 MeV electrons

  >53 MeV ions
- Identification of radiation belt energetic electrons as cause of anomaly supported development of mitigation strategy
  - Use gyro's for attitude hold during limited periods of perigee passes
  - Identify brighter guide stars



ISS Floating Potential Measurement Unit (FPMU)

- Instrument suite for characterizing ISS plasma environment and charging
  - Floating Potential Probe $\Phi_{s/c}$
  - Narrow Langmuir Probe N_e, T_e, $\Phi_{s/c}$
  - Wide Langmuir Probe N_e, T_e, $\Phi_{s/c}$
  - Plasma Impedance Probe N_e

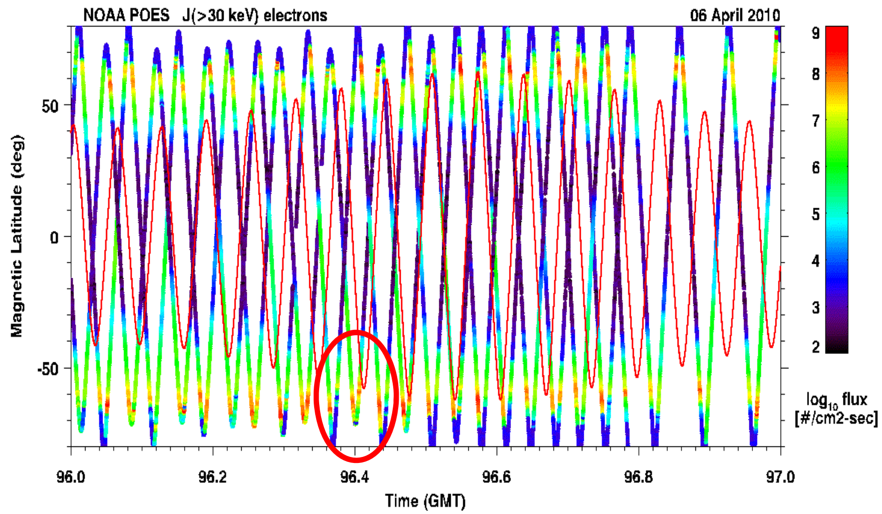
- FPMU is operated on a campaign basis due to restrictions limiting operations to ~30% of a year. Scheduled operations support ISS engineering:
  - ISS charging due to visiting vehicles
  - US and Russian EVA support
  - Science payload support
  - Incoherent Scatter Radar World Day periods

- FPMU is also operated for unscheduled events including:
  - Anomaly investigations
  - Characterizing ionosphere and ISS response to geomagnetic storms
  - Targets of opportunity for collaborating with payloads, independent spacecraft, or ground base science operations

ISS Anomaly Investigations

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

- Russian GNC computer failure (2007)
- Soyuz pyrobolt failure (2008)
- PLEGPay +24 volt safety issue (2008)
- S-band transmission interruptions (2011)
- PVCU MDM card fault required system reset (2011)



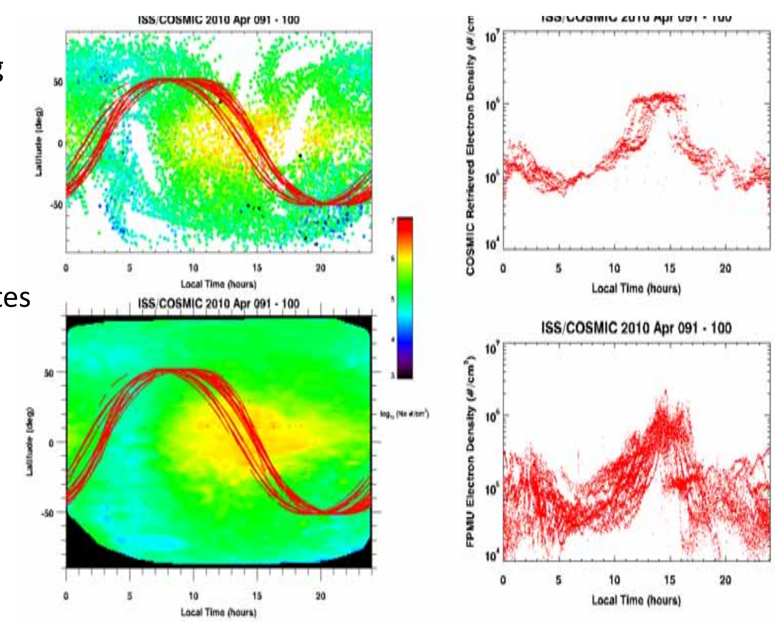
Proposed anomalous ISS 160 volt solar array charging:

- FPMU demonstrates floating potential within program requirements
- Boeing/SAIC ISS charging code demonstrates vehicle 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, auroral electron 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 environments

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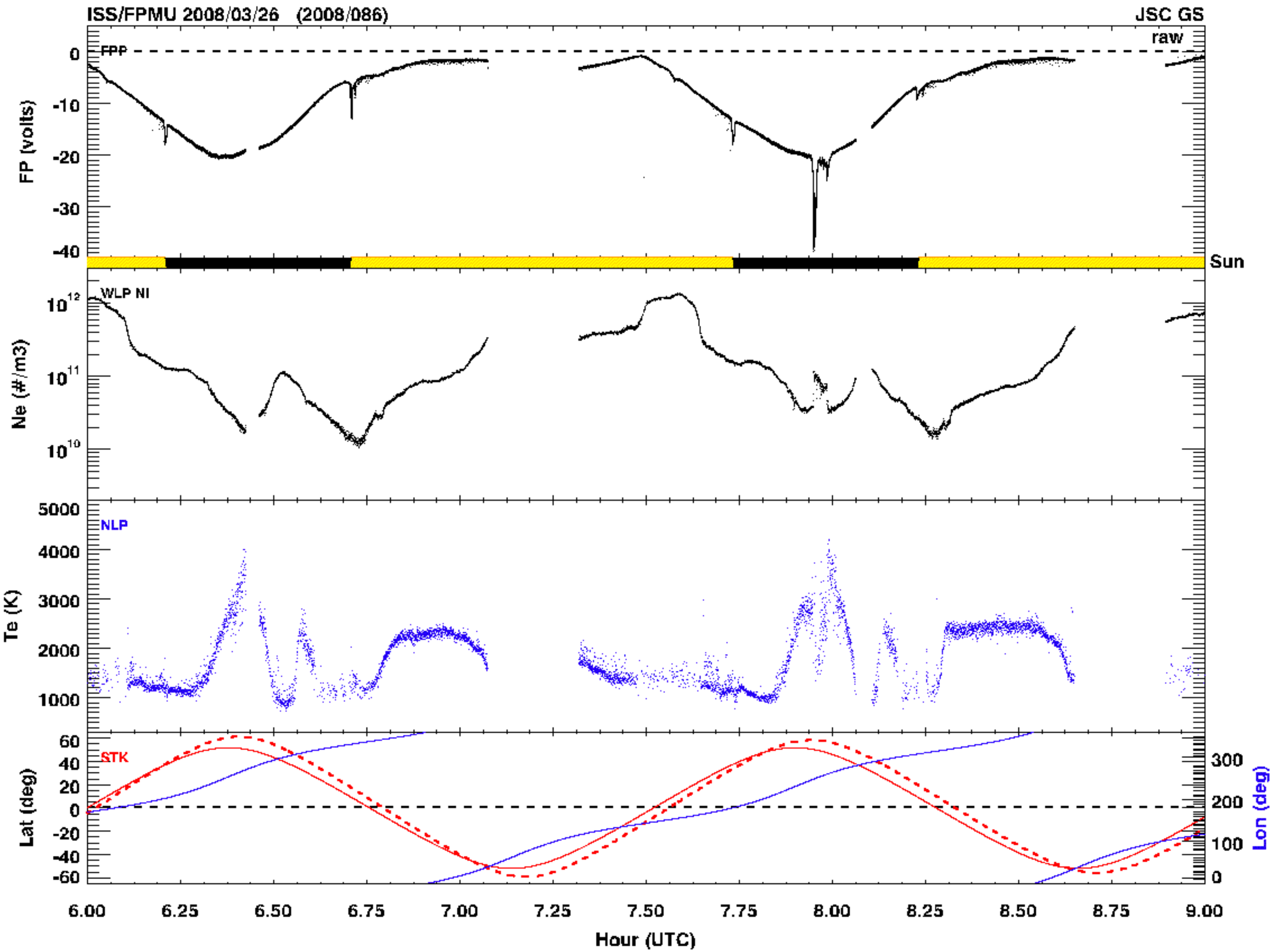
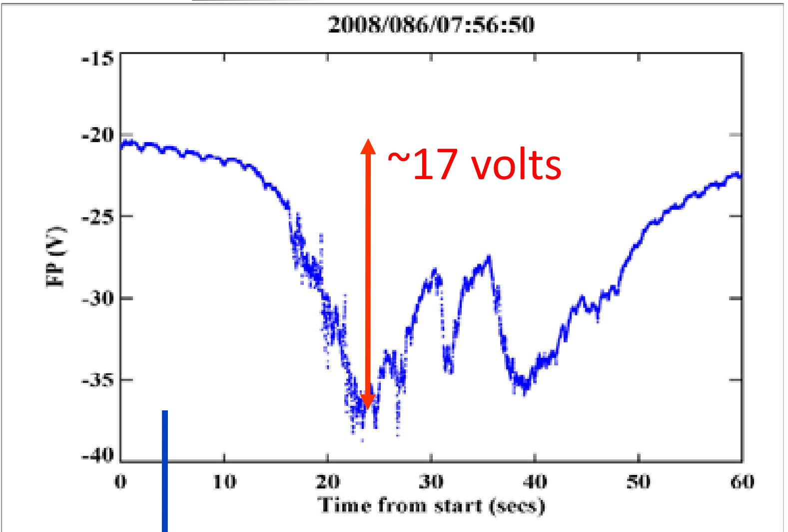
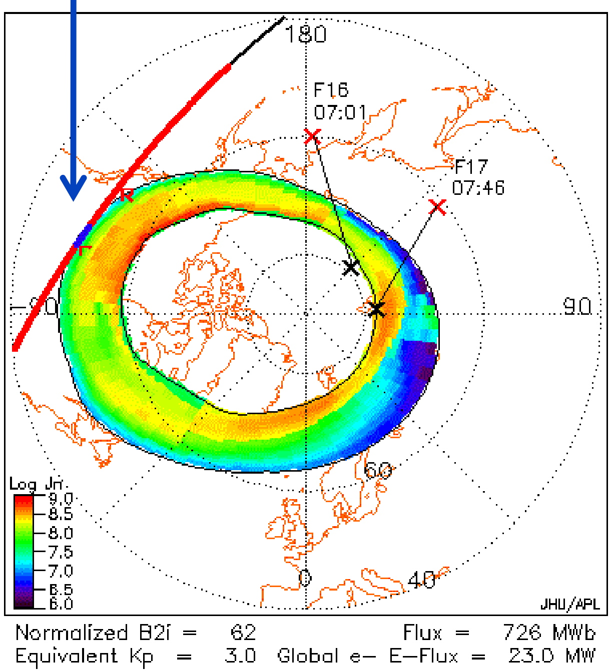
ISS Charging at Night 26 March 2008

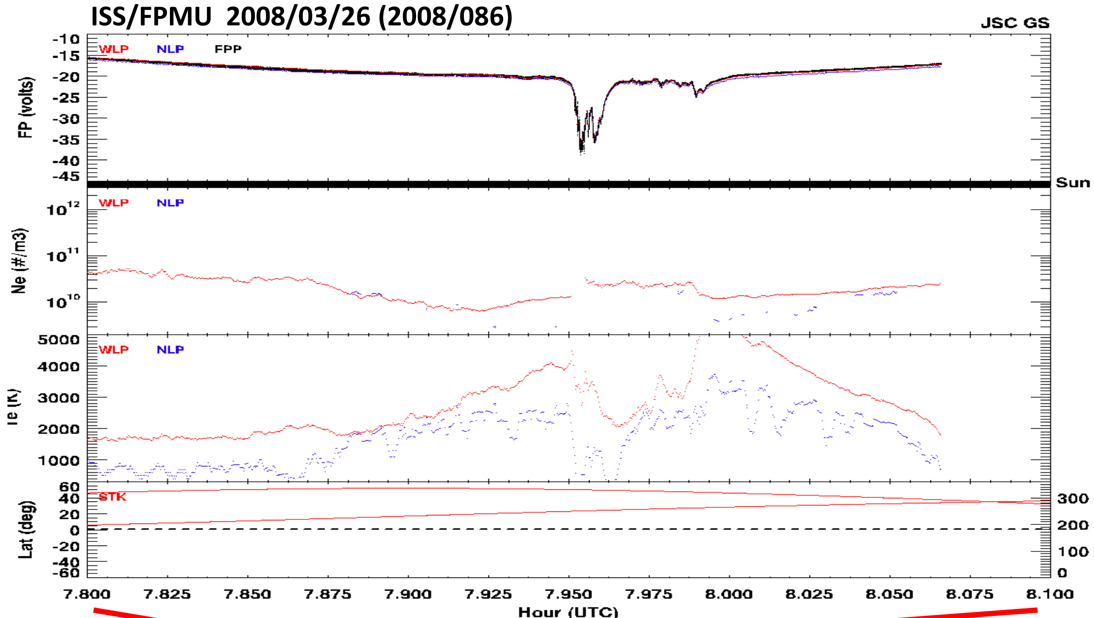


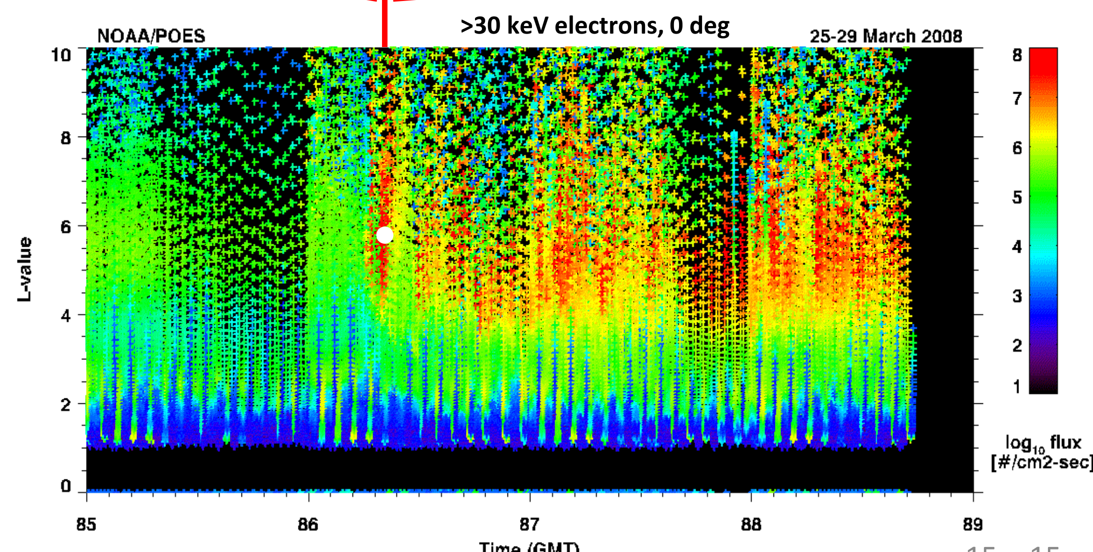
Auroral Charging



26 Mar 2008 07:30 – 08:00 UT







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

ISS Auroral Charging

- Space weather monitoring over past year has helped capture additional examples of ISS auroral charging with FPMU
  - Space weather alerts for earthward directed fast CME's gives us advanced warning for potentially geoeffective solar events
  - Activate FPMU in advance of shock arrival if not already operating

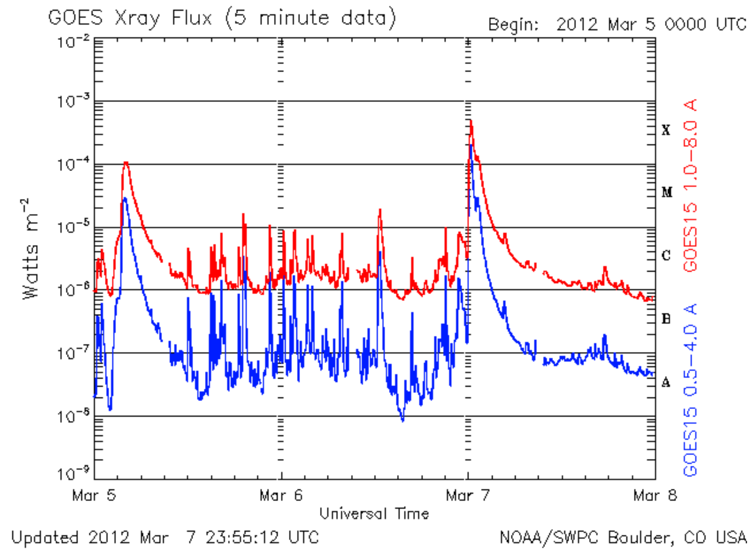
- FPMU observations of ISS auroral charging:

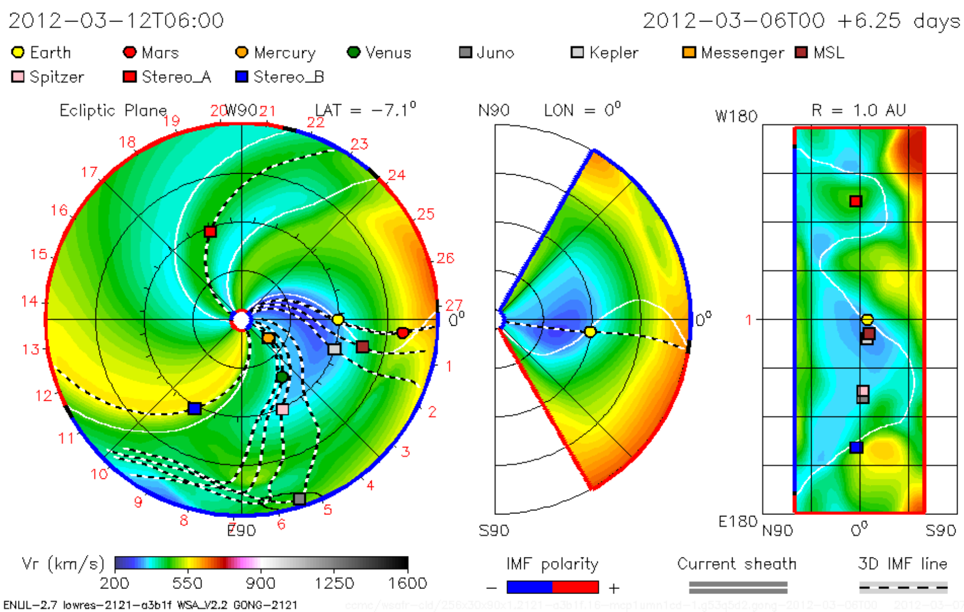
Charging Observations	FPMU Operations
26 March 2008 (GMT 086)	STS-123/ESA ATV-001 docking
5-6 April 2010 (GMT 095-096)	STS-131/19A
22,23,25 January 2012 (GMT 025)	SWx, M8.7 flare, CME ~2211 km/s
9-11 March 2012 (GMT 069-071)	SWx, X5.4 flare, CME ~2200 km/s
	X1.3 flare, CME ~1800 km/s
23 May 2012 (GMT 144)	SpaceX Dragon berth/unberth
15-16 July 2012 (GMT 197-198)	SWx, X1.4 flare, CME ~1400 km/s
3 September 2012 (GMT 247)	US EVA

Space Weather Monitoring

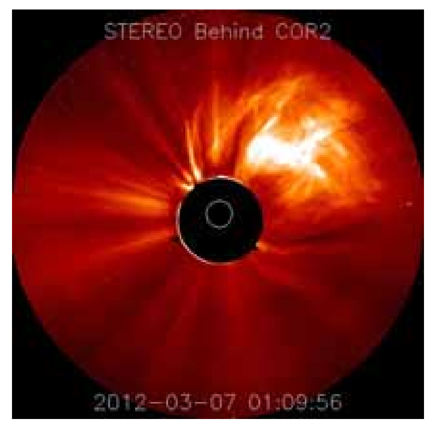
Space Weather Monitoring

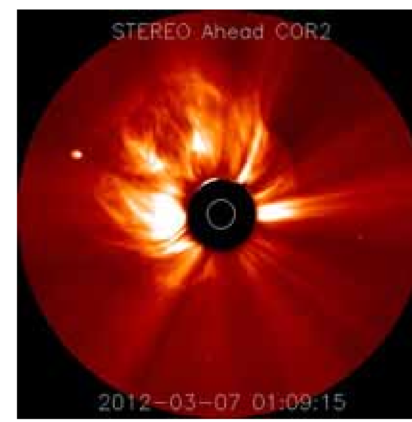
- GOES solar x-rays, SOHO, STEREO images for solar activity
- CCMC SWL, NOAA SWPC, SIDC SWx flare, CME alerts provide advanced warning of potentially geoeffective solar disturbances
- Typically rely on CCMC SWL and NOAA SWPC WSA-Enlil CME propagation models to obtain best estimate of CME arrival times





http://iswa.gsfc.nasa.gov/downloads/20120307_014400_anim.tim-vel.gif





http://stereo-ssc.nascom.nasa.gov/browse/2012/03/07/index.shtml

E-mail SWx Summaries

From: Minow, Joseph I. (MSFC-EV44)
Sent: Tuesday, March 06, 2012 9:16 PM
To: <Geomagnetic Activity Distribution List>
Subject: New x-class flares and CME

Now it's getting interesting, initial data on the X5.4 flare and a new X1.3 flare:

Start Time	Region	Flare	Location	Shock Speed
00:17 UT	AR1429	X5.4	N17E28	2273 km/sec
01:10 UT	AR1430	X1.3	N22E12	1084 to 1329 km/sec

CCMC SWL just issued an alert for the X1.3 flare attributing it to AR1429 (N17E27) so there is some discrepancy here on which region is generating the flares and the speed of the second shock. It does seem more likely that AR1429 is the source although AR1430 has been growing in size and complexity as well so flaring from the new site is not out of the question. The first shock could arrive as early as late 7 March (UT) and the second on late 8 March or early 9 March (UT).

Shock speeds are based on NOAA SWPC Type II radio emission reports, they haven't been checked against STEREO image reconstruction of the shock expansion fronts. I only have access to current STEREO Behind images which show a large CME expanding both above and below the ecliptic plane. We'll have to wait for the updated STEREO Ahead and SOHO imagery to confirm the shock is expanding along the Sun-Earth line. A first look suggests the new events are likely to be geoeffective due to the size of the event and origin so near the Earth-Sun line.

Stay tuned…I'll provide an update later tonight when more quantitative information is available on the direction and size of the CME's.

Summaries distributed to space environments operations, engineering, and science personnel at MSFC, JSC, Boeing, KSC, GSFC, and NASA HQ

From: Minow, Joseph I. (MSFC-EV44)
Sent: Wednesday, March 07, 2012 8:12 PM
Subject: CME update and possible auroral activity

GSFC SWL and NOAA SWPC models for the 7 March CME's are now available. Links to the models and estimated arrival times for the leading edge of the CME at Earth are:

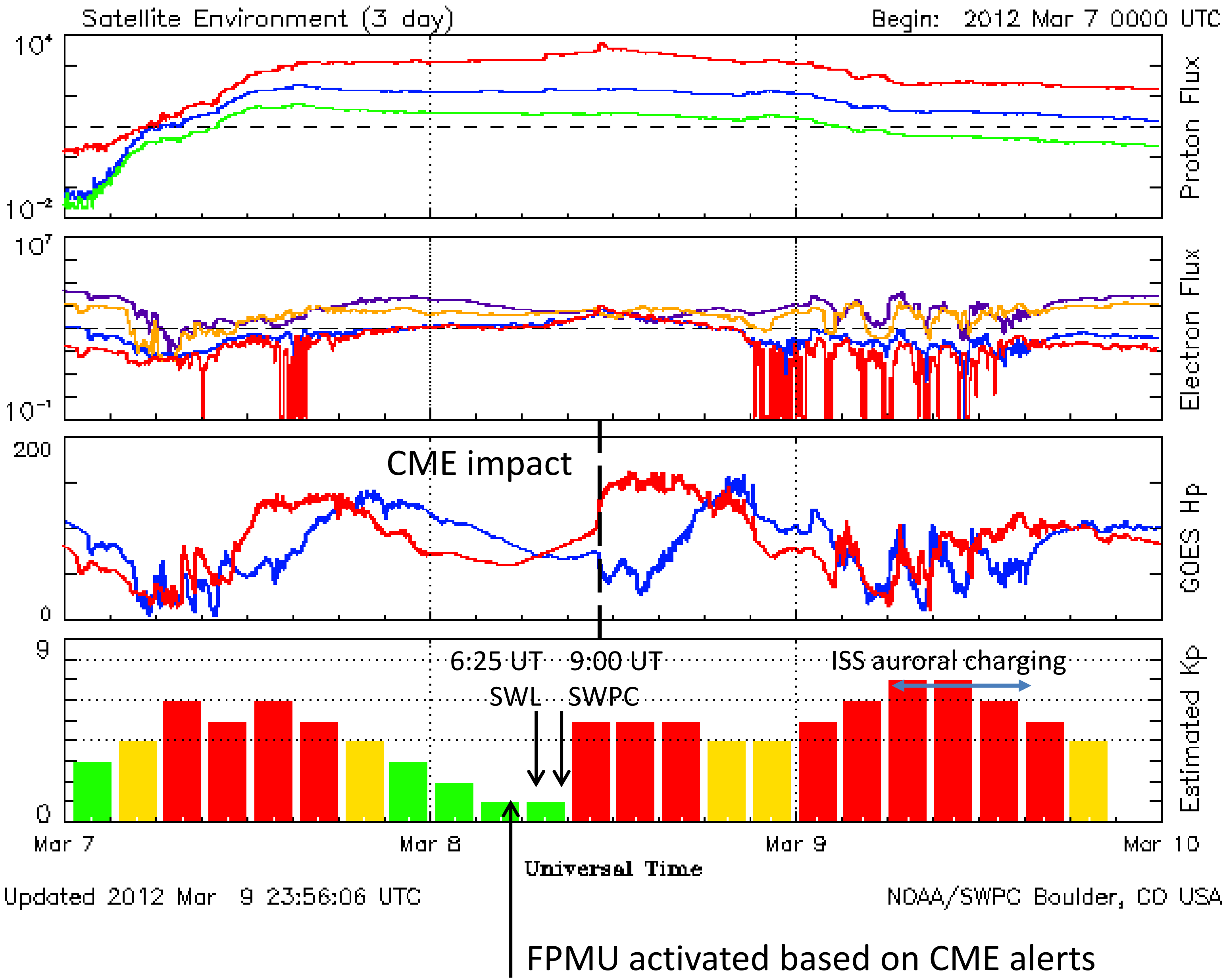
GSFC SWL 8 March 06:25 UT (+/- 7 hours)
http://iswa.gsfc.nasa.gov/downloads/20120307_014400_anim.tim-den.gif
http://iswa.gsfc.nasa.gov/downloads/20120307_014400_anim.tim-vel.gif
NOAA SWPC 8 March 09:00 UT
http://www.swpc.noaa.gov/wsa-enlil/cme-based/

GSFC SWL is estimating a Kp 7 to 9 geomagnetic storm which is at the severe/extreme level. NOAA is predicting G3 (Strong, Kp=7) storm levels.

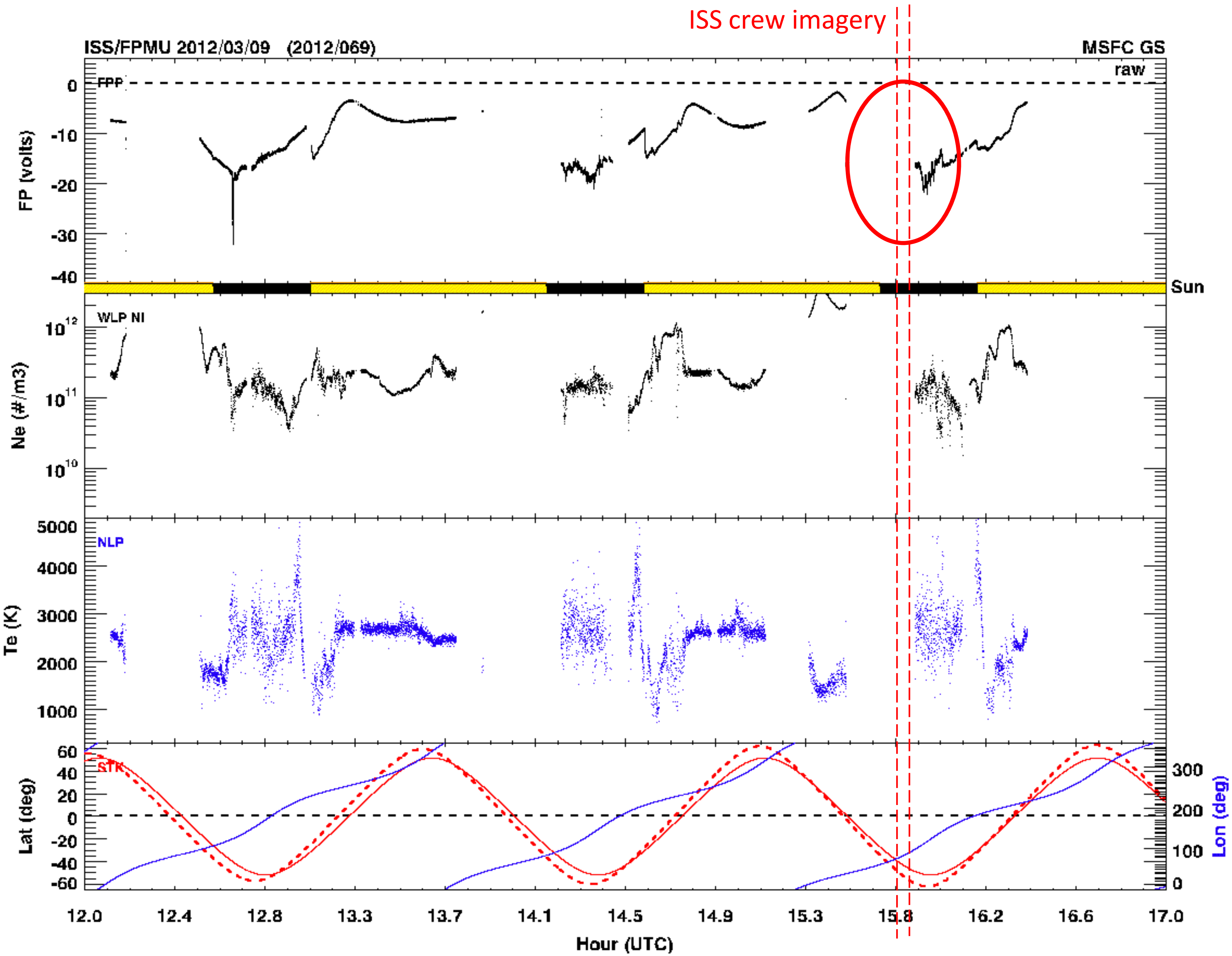
Ground based observers: The local time for the shock arrival is in the early morning hours on 8 march for EST and CST. We have a window of about 5 hours or 6 hours from the predicted arrival time before North America moves into sunlight. The sooner the shock arrives the better for us. If the storm does reach the Kp 7 to 9 levels it could drive the equatorward edge of the aurora oval into Ohio or Kentucky, far enough south for aurora to be visible on the northern horizon in Alabama. Keep in mind these predictions are very rough (=unlikely) and depend on conditions in the shock that are difficult to predict before it arrives.

ISS: The predicted shock arrival time is early in the on-orbit working day so you can fit in observations as time allows. High southern latitudes are now fully in darkness and northern hemisphere portions of the orbit are in full sunlight. ISS is currently (~01:45 UT) passing through -51.6 deg latitude over the south Atlantic and the next few orbits will move westward over the southern edge of South America. This is the region where ISS is the furthest from the auroral zone. The auroral oval will move closer to the ISS orbit over the day so the longer the shock takes to arrive the better your viewing conditions in the southern hemisphere. Your best viewing geometry will be about 12 hours from now when the orbit crosses between Australia and Antarctica and closest to the southern auroral zone. Hopefully the activity will continue until that time.

March 2012 Geomagnetic Storm



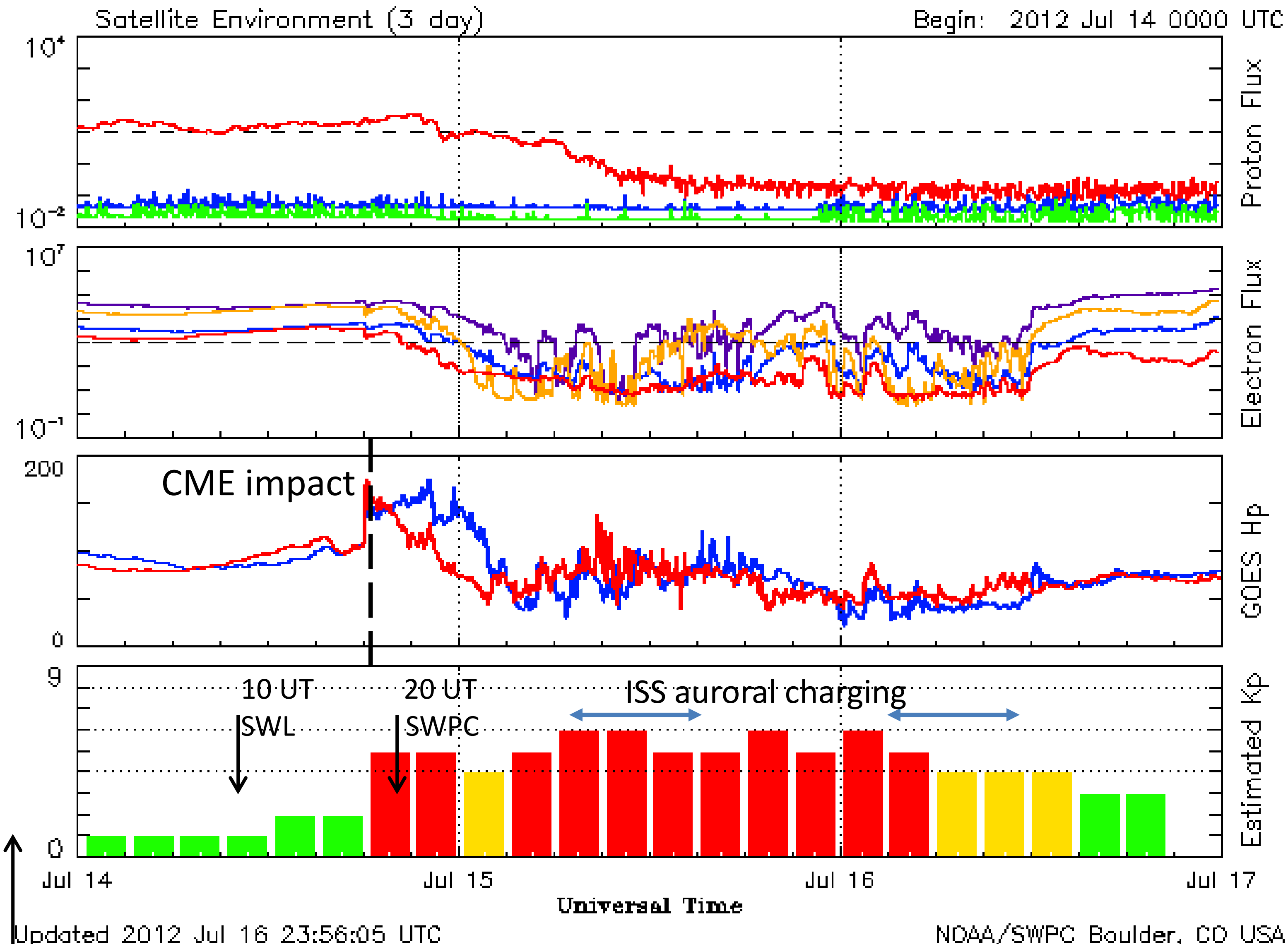
9 March 2012


ISS crew imagery
ISS/FPMU 2012/03/09 (2012/069)
MSFC GS
raw
FPP
FP (volts)
0
-10
-20
-30
-40
Sun
WLP NI
Ne (#/m3)
10^{12}
10^{11}
10^{10}
NLP
Te (K)
5000
4000
3000
2000
1000
STK
Lat (deg)
60
40
20
0
-20
-40
-60
300
200
100
0
Lon (deg)
12.0
12.4
12.8
13.3
13.7
14.1
14.5
14.9
15.3
15.8
16.2
16.6
17.0
Hour (UTC)

Auroral Images

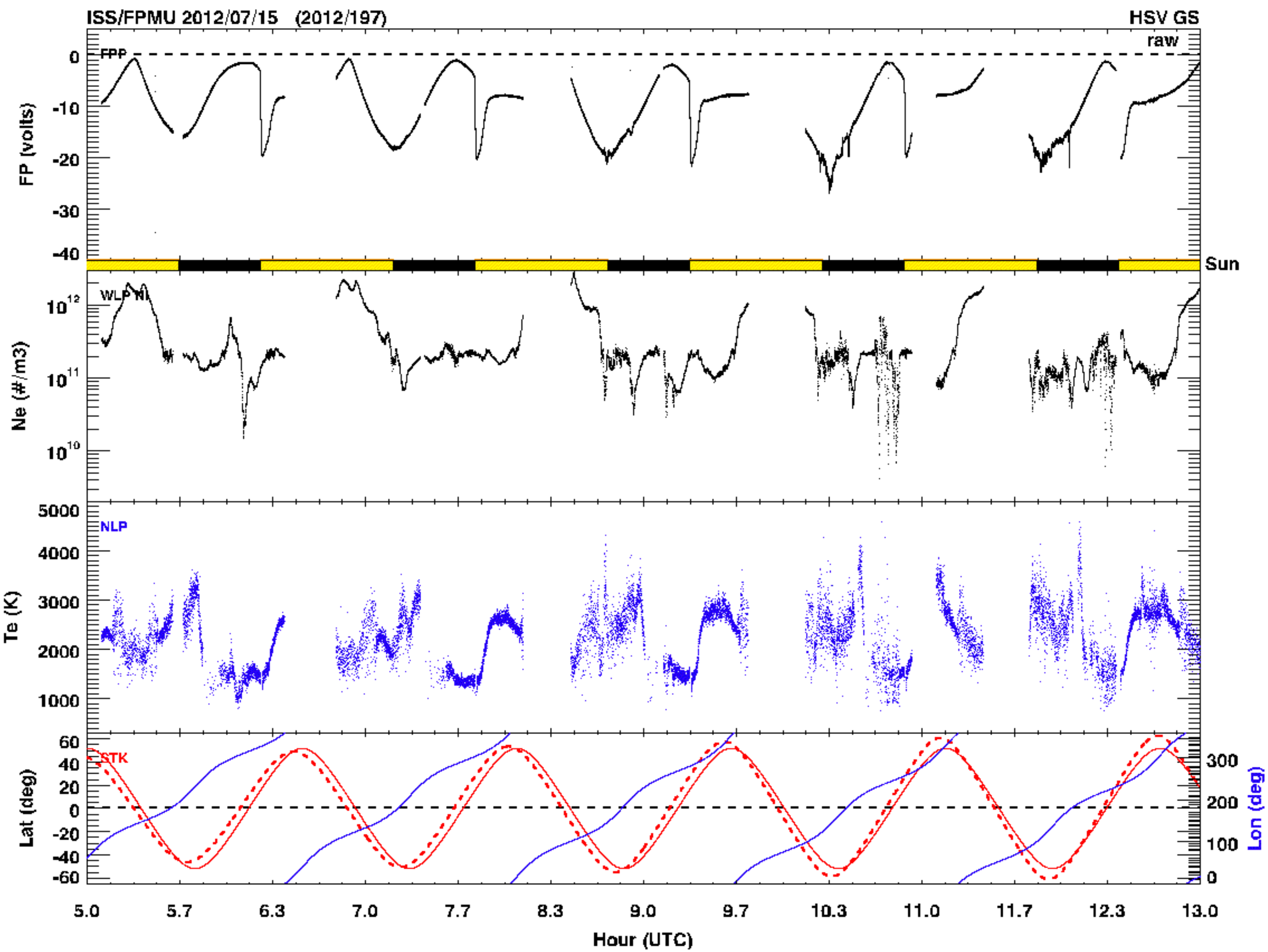
Aurora images using wide angle lens through ISS Cupola (D. Pettit/Exp 30,31) show aurora in nadir immediately before FPMU records auroral charging

July 2012 Geomagnetic Storm



FPMU activated 13 July based on CME alerts

15 July 2012



ISS/FPMU 2012/07/15 (2012/197)
HSV GS
raw
FPP
FP (volts)
0
-10
-20
-30
-40
Sun
WLP Ni
Ne (#/m3)
10^{12}
10^{11}
10^{10}
NLP
Te (K)
5000
4000
3000
2000
1000
STK
Lat (deg)
60
40
20
0
-20
-40
-60
Lon (deg)
300
200
100
0
5.0
5.7
6.3
7.0
7.7
8.3
9.0
9.7
10.3
11.0
11.7
12.3
13.0
Hour (UTC)

ISS image: 11 March 2012