NASA Welcome and
Space Environment Interactions with ISS

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Space System Anomalies and Failures (SCAF) Workshop 2022
11-12 January 2022, virtual

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  - SCAF is the legacy acronym from the Spacecraft Anomalies and Failures Workshop series which is the predecessor to this workshop
  - The name was changed in 2021 from "Spacecraft" to "Space Systems" so anomalies and failures in ground systems and launch vehicles can be included along with spacecraft: consider the complete system required to deploy and operate a space system
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260+ registered for Day 1

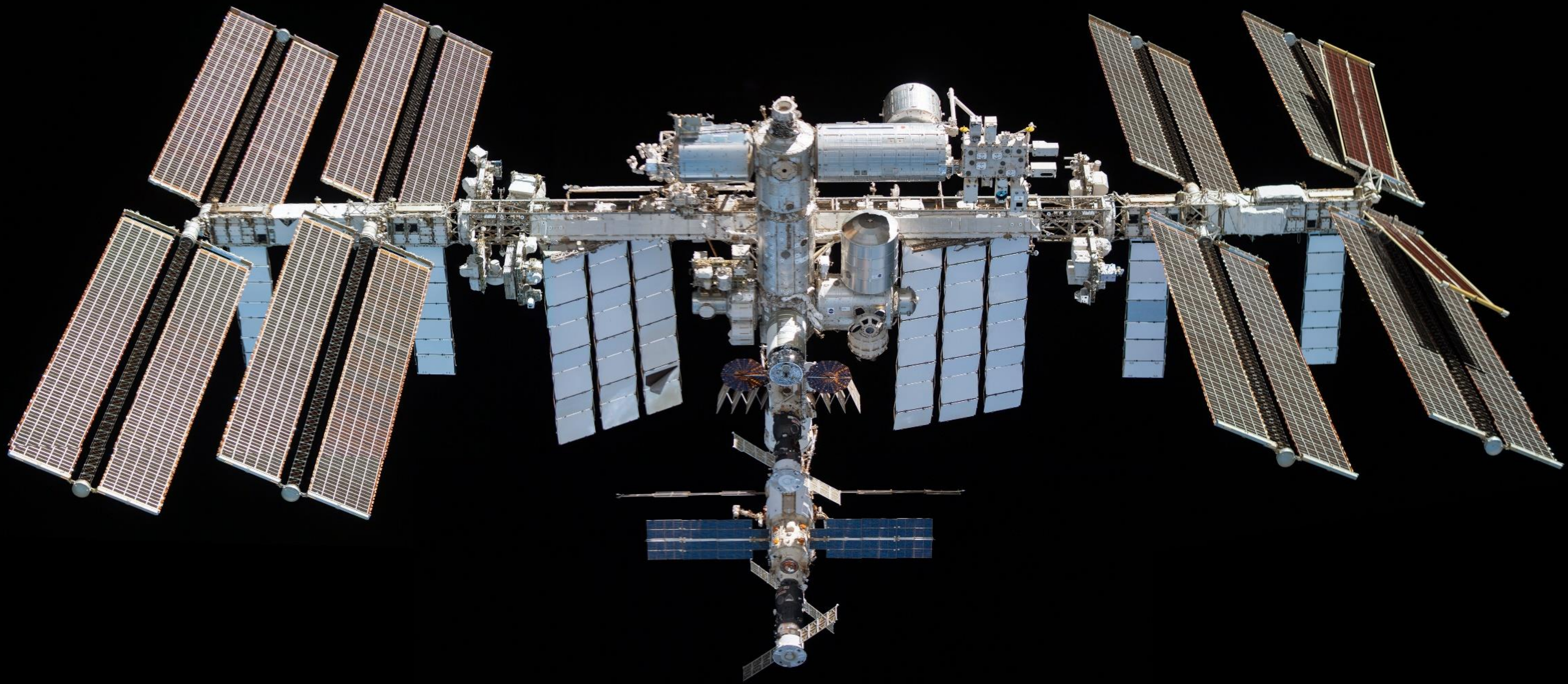
SCAF 2022 Logistics

- Microphones and cameras are disabled to minimize background noise and bandwidth
- Type questions in chat or request we unmute your microphone
- Day 1 presentations will be posted on a NASA website for participant download (pending approval by speakers). Information will be sent out after the workshop.

Impact of Space Environments on Space Systems

Mechanism	Effect	Source
Surface Charging	• Biasing of instrument readings • Power drains • Physical damage	• *Dense, cold plasma* • *Hot plasma*
Deep Dielectric Charging	• Biasing of instrument readings • Electrical discharges causing physical damage	• *High-energy electrons*
Structure Impacts	• Structural damage • Decompression	• *Micrometeoroids* • *Orbital debris*
Drag	• Torques • Orbital decay	• *Neutral thermosphere*
Total Ionizing Dose (TID)	• Degradation of microelectronics	• *Trapped protons* • *Trapped electrons* • *Solar protons*
Displacement Damage Dose (DDD)	• Degradation of optical components and some electronics • Degradation of solar cells	• *Trapped protons & electrons* • *Solar protons* • *Neutrons*
Single-Event Effects (SEE)	• Data corruption • Noise on images • System shutdowns • Electronic component damage	• *GCR heavy ions* • *Solar protons and heavy ions* • *Trapped protons* • *Neutrons*
Surface Erosion	• Degradation of thermal, electrical, optical properties • Degradation of structural integrity	• *Particle radiation* • *Ultraviolet* • *Atomic oxygen* • *Micrometeoroids Contamination*

NASA CCMC



ISS from SpaceX Crew Dragon Endeavour during 8 November 2021 fly around

https://www.nasa.gov/image-feature/the-station-pictured-from-the-spacex-crew-dragon-0

International Space Station (ISS)

- Initial ISS module deployed in 1998 with on orbit assembly over a period of 20+ years
- Many space exposed materials have been on-orbit for 15 to 20 years
- White House directs NASA to extend ISS operations through 2030 (December 2021):
  - By 2030, space exposed materials and hardware currently on orbit will have experienced LEO space environment exposures ranging from 9 to 32 years!
  - Ionizing radiation, UV/EUV, atomic oxygen, MMOD
  - https://blogs.nasa.gov/spacestation/2021/12/31/biden-harris-administration-extends-space-station-operations-through-2030/
- NASA is working life extension planning and refurbishment activities to assure materials and systems exposed to space environment for decades continue to meet program requirements

Module/Component	Partner	Launch Date (mm/yyyy)	Years on Orbit*
Zarya Module (FGB)	Russia	11/1998	23+
Unity Module (Node 1)	US	12/1998	23+
Zvezda Module (Service Module)	Russia	07/2000	21+
Z1 Truss	US	10/2000	21+
P6 Truss – US solar array 1	US	12/2000	20+
Destiny Laboratory Module	US	02/2001	20+
S0 Truss	US	04/2002	19+
P1 Truss, S1 Truss	US	10/2002, 11/2002	19+,19+
P3/P4 – US solar array 2, S3/S4 Truss – US solar array 3	US	09/2006, 06/2007	15+,14+
P5 Truss, S5 Truss	US	12/2006, 08/2007	15+,14+
Harmony Module (Node 2)	US	10/2007	14+
P6 Truss – US solar array 1 (relocation)	US	n/a	20+
Columbus Facility Module	ESA	02/2008	13+
Kibo Japanese Experiment Module	Japan	2008-2009	~13-12
S6 Truss – US solar array 4	US	03/2009	12+
Poisk Mini-Research Module 2	Russia	11/2009	12+
Rassvet Mini-Research Module 1	Russia	05/2010	11+
Bigelow Expandable Activity Module	US	04/2016	5+
Nauka Multipurpose Laboratory Module	Russia	07/2021	<1
Prichal Docking Module	Russia	11/2021	<1
*As of December 2021			

Material Contamination, Degradation, and Atomic Oxygen

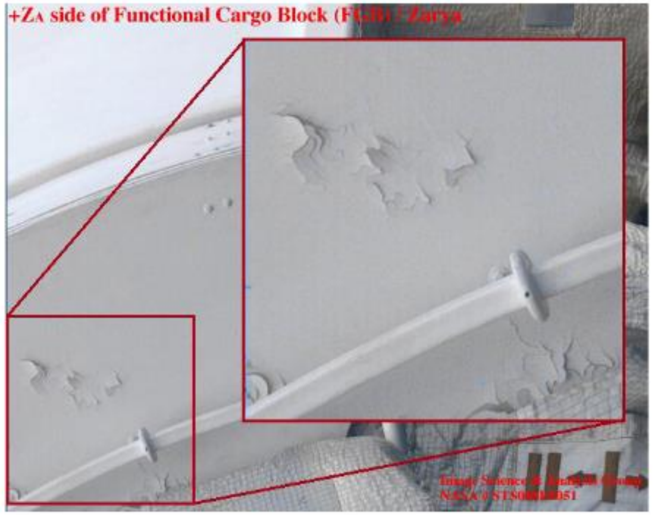


Figure 5: Flaking of the FGB MM/OD shield paint (2A, STS088-E5051)

Figure 6: Flaking of the FGB MM/OD shield paint (4A, STS 97-304-001)

Soares et al., 2002

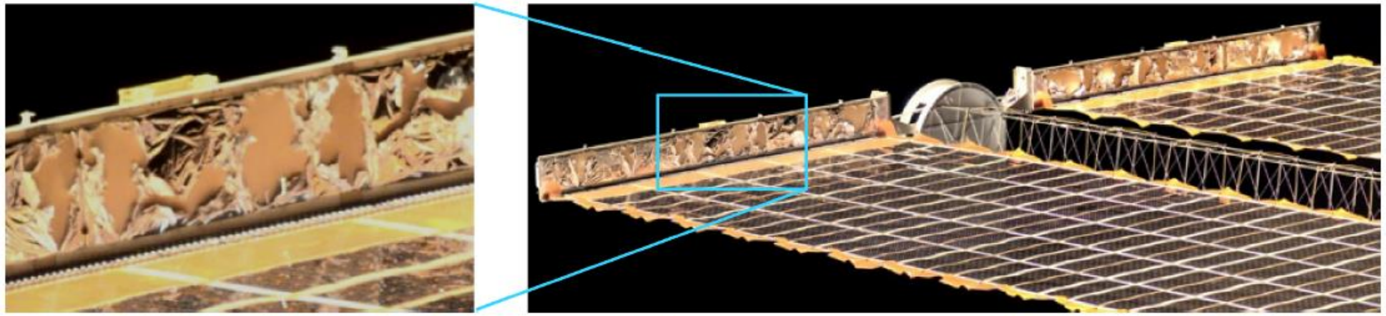


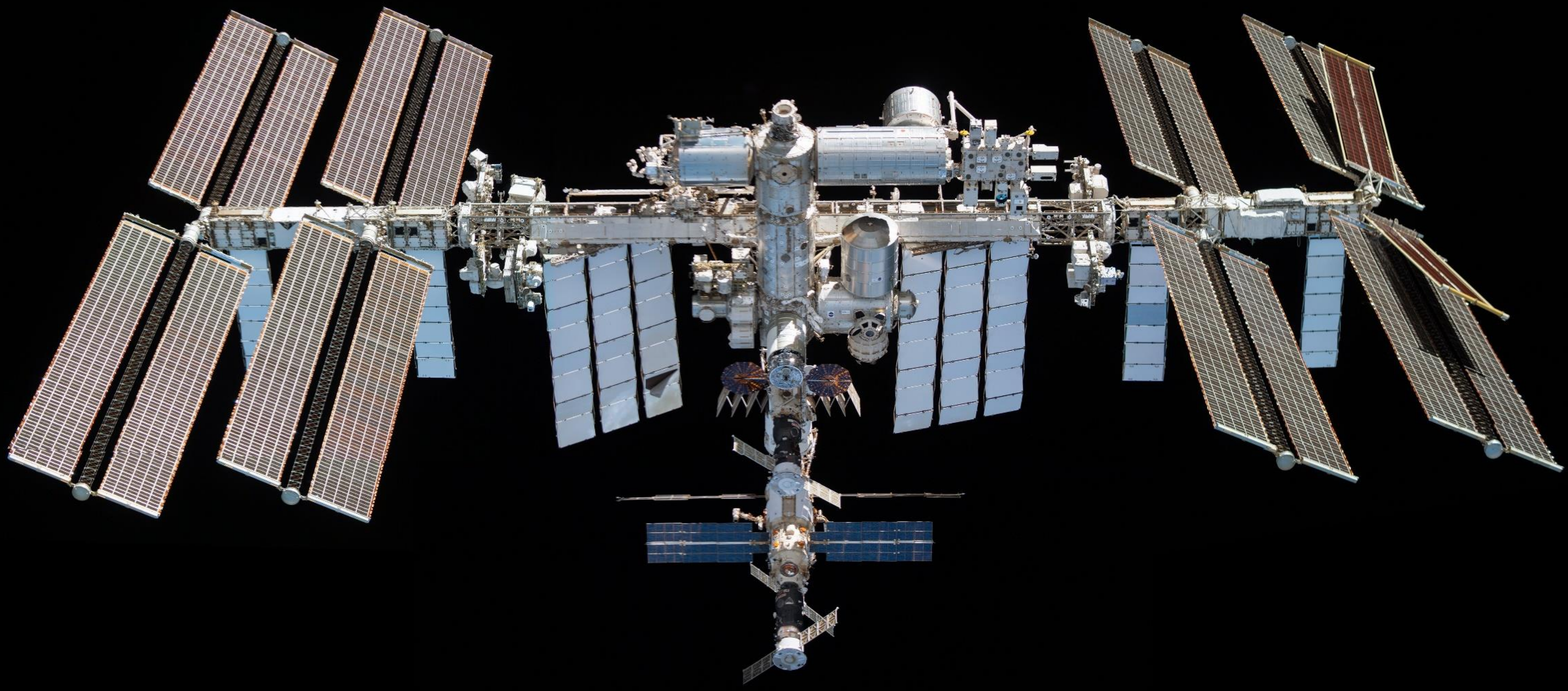
Figure 3.—Atomic oxygen undercutting degradation of the P6 Truss solar array wing blanket box cover on the ISS after only 1 year of space exposure.[10]

de Groh and Banks, 2019

Figure 14: Observed contamination patterns surrounding Service Module zenith side thruster block (5A, STS098-706-011)

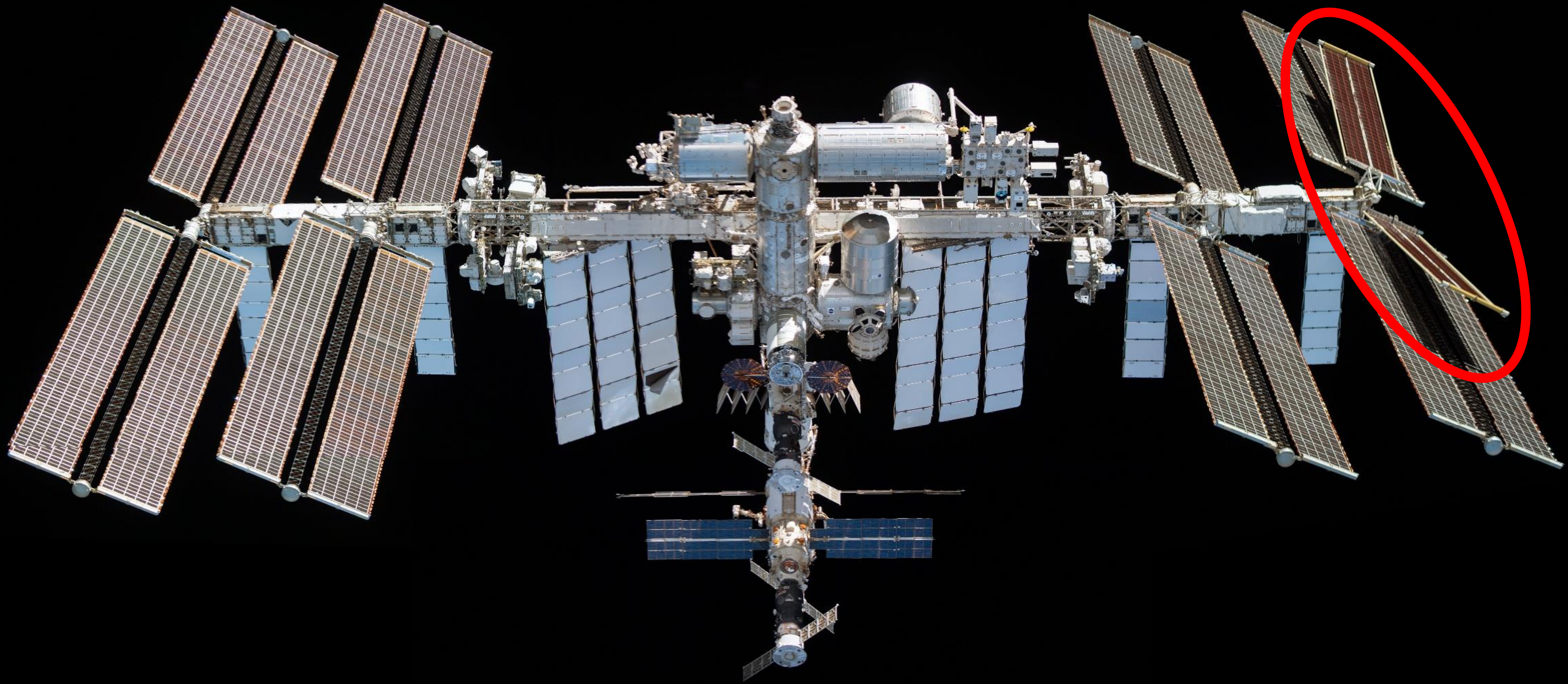
Soares et al., 2002

Soares et al. 2002: https://doi.org/10.1117/12.481654
K. de Groh and B. Banks, 20019: https://ntrs.nasa.gov/api/citations/20190025445/downloads/20190025445.pdf



https://www.nasa.gov/image-feature/the-station-pictured-from-the-spacex-crew-dragon-0

- First pair of ISS solar arrays have been operating on orbit for 20+ years and are showing signs of radiation degradation
- NASA is installing deployable ISS Roll-Out Solar Array (iROSA) to assure adequate power through ISS end of life

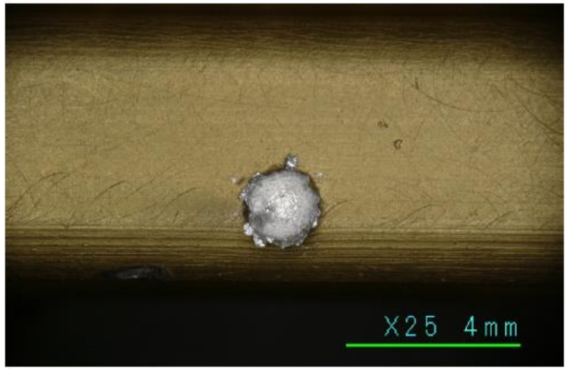


https://www.nasa.gov/feature/new-solar-arrays-to- power-nasa-s-international-space-station-research
https://www.nasa.gov/image-feature/the-new-iss-roll-out-solar-array-irosa-is-deployed

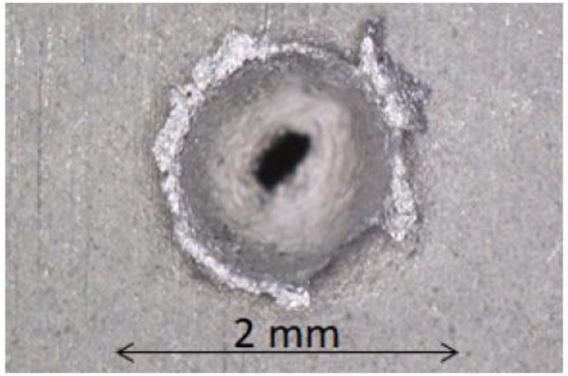
https://www.nasa.gov/image-feature/the-station-pictured-from-the-spacex-crew-dragon-0

ISS MMOD Impacts

- Meteoroid and orbital debris (MMOD) impacts are a continuing issue for spacecraft in LEO including the ISS
- NASA's Hypervelocity Impact Technology (NVIT) group maintains an ISS impact database
  - Current database contains over 1400 records of impact damage
  - Data obtained from ground-based surveys of space-exposed hardware returned to Earth



Impact on ISS handrail

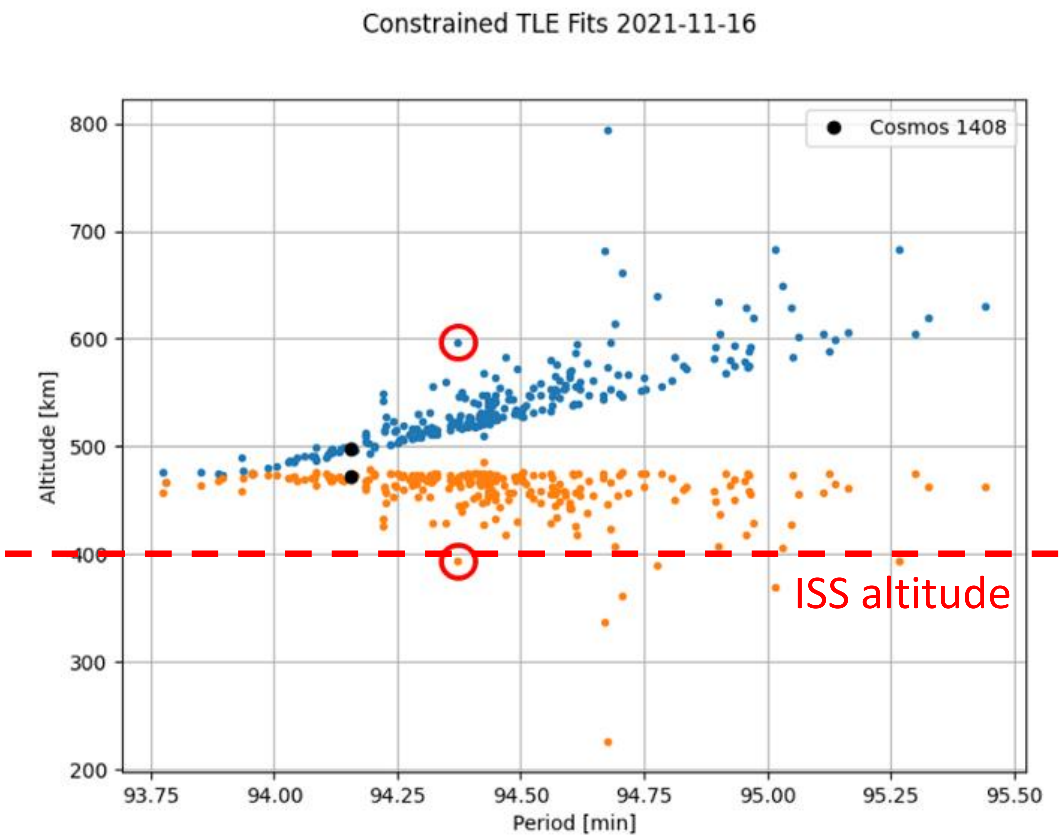


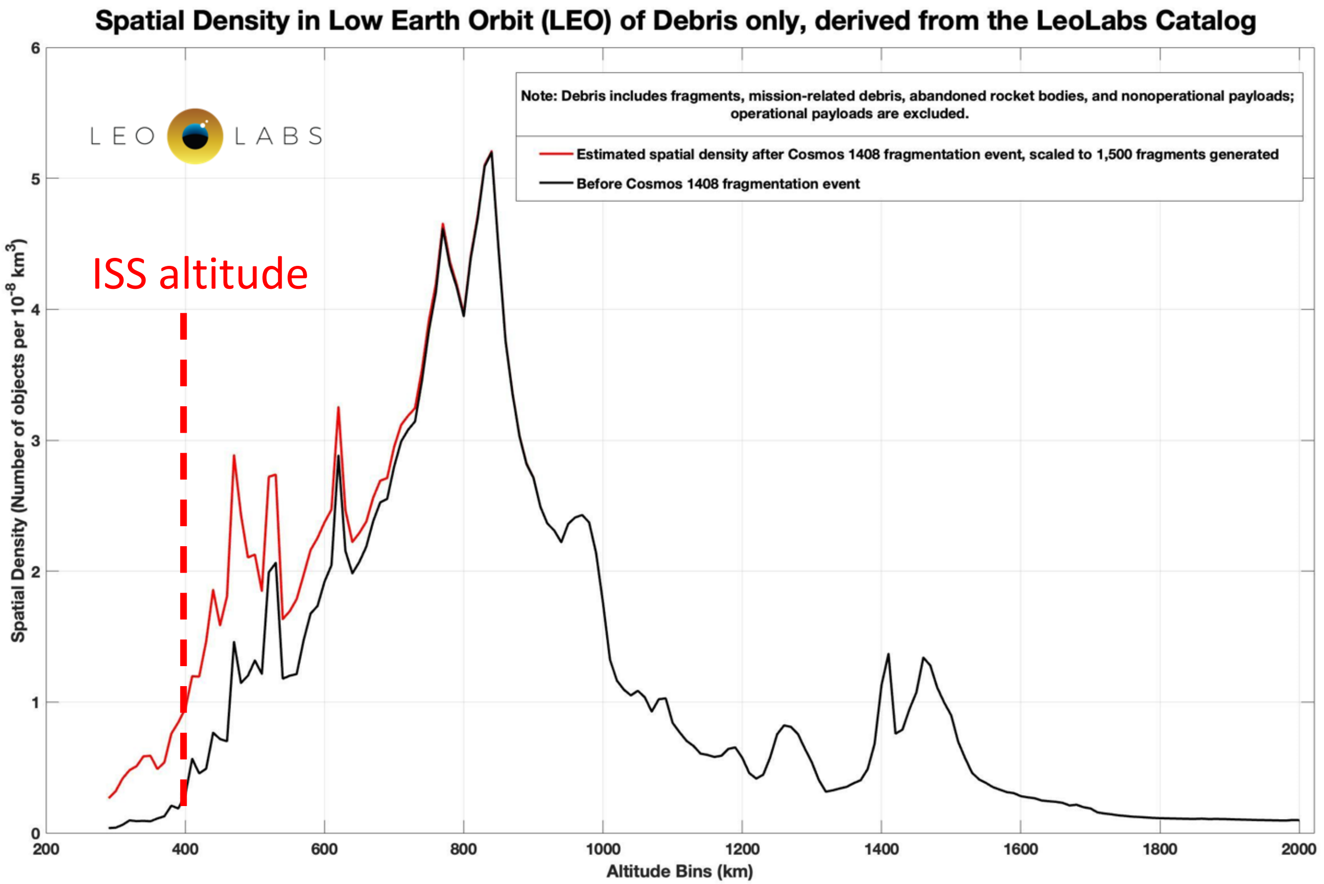
Impact in aluminum MPLM shield

#	Database Table Name	Hardware Class	Exp. Days	Insp. Date	MMOD Impacts	Samples
1	Node 1 port CBM hatch cover	blanket/shield	3,182	Oct-07	16	16
2	PMA 1 MDM Sunshade	blanket/shield	2,984	Mar-08	15	1
3	Airlock shield panel 01-04B	blanket/shield	3,195	Feb-11	24	4
4	Airlock shield panel 02-04B	blanket/shield	3,195	Feb-11	34	6
5	PMA 2 cover	blanket/shield	596	Mar-16	26	6
6	EVA Safety Tether Housing	EVA	733	Feb-01	5	2
7	Node 3 Avionics Bag	EVA	579	Mar-16	30	0
8	MPLM FM1 Flight 1	Logistics	6.06	Apr-01	3	3
9	MPLM FM1 Flight 2	Logistics	6.20	Aug-01	3	1
10	MPLM FM2 Flight 2	Logistics	6.05	Dec-01	8	8
11	MPLM FM1 Flight 3	Logistics	6.08	Jun-02	12	12
12	MPLM FM2 Flight 3	Logistics	7.20	Aug-05	22	2
13	MPLM FM1 Flight 4	Logistics	7.20	Jul-06	24	24
14	MPLM FM1 Flight 5	Logistics	9.28	Dec-08	123	97
15	MPLM FM1 Flight 6	Logistics	7.22	Sep-09	64	25
16	MPLM FM1 Flight 7	Logistics	7.42	Apr-10	75	11
17	MPLM FM2 Flight 4	Logistics	7.03	Jul-11	64	6
18	SpaceX Demo 2	Logistics	5.82	Jun-12	18	18
19	SpaceX CRS-1	Logistics	18.11	Nov-12	18	8
20	SpaceX CRS-2	Logistics	23.02	Apr-13	14	7
21	SpaceX CRS-3	Logistics	28.09	May-14	17	4
22	SpaceX CRS-4	Logistics	32.13	Oct-14	20	0
23	SpaceX CRS-5	Logistics	29.35	Feb-15	13	2
24	SpaceX CRS-6	Logistics	34.01	May-15	25	2
25	SpaceX CRS-8	Logistics	31.08	May-16	20	2
26	SpaceX CRS-9	Logistics	36.97	Sep-16	17	1
27	SpaceX CRS-10	Logistics	23.94	Mar-17	14	6
28	SpaceX CRS-11	Logistics	27.70	Jul-17	15	3
29	SpaceX CRS-12	Logistics	31.88	Sep-17	12	2
30	SpaceX CRS-13	Logistics	26.96	Jan-18	11	3
31	SpaceX CRS-14	Logistics	31.11	May-18	9	3
32	SpaceX CRS-15	Logistics	32.24	Aug-18	18	4
33	SpaceX CRS-16	Logistics	36.47	Jan-19	20	4
34	SpaceX CRS-17	Logistics	27.92	Jun-19	9	1
35	TUS-2 housing and cable	ORU	1,561	Oct-07	13	13
36	S-band Ant. Support Assy (SASA) E-box	ORU	1,842	Jan-08	48	12
37	P1 Nitrogen Tank Assembly (NTA)	ORU	1,906	Mar-08	26	17
38	SASA mast	ORU	1,842	Mar-08	24	18
39	S1 Nitrogen Tank Assembly (NTA)	ORU	2,239	Jan-09	24	13
40	P6 battery	ORU	3,149	Aug-09	92	18
41	P1 Ammonia Tank Assembly (ATA)	ORU	2,474	Oct-09	51	5
42	S1 Ammonia Tank Assembly (ATA)	ORU	2,736	Apr-10	49	4
43	P6 battery	ORU	3,447	Jun-10	34	3
44	P6 battery	ORU	3,447	Jun-10	29	2
45	P6 battery	ORU	3,447	Jun-10	16	0
46	P6 battery	ORU	3,447	Jun-10	21	2
47	P6 battery	ORU	3,447	Jun-10	20	1
48	P6 battery	ORU	3,447	Jul-10	21	2
49	4B guidewire cable	ORU	2,527	Oct-10	1	1
50	Pump Module Assembly	ORU	3,196	Aug-11	37	8
51	Large Adapter Plate Assembly (LAPA)	ORU	3,196	Aug-11	19	2
52	BCDU	ORU	4,631	Jul-19	64	0
		Totals	66,992		1,407	415

Hyde et al., Observations of MMOD Impact Damage to the ISS, 2019
https://www.hou.usra.edu/meetings/orbitaldebris2019/orbital2019paper/pdf/6001.pdf

Russian ASAT Test, 15 November 2021

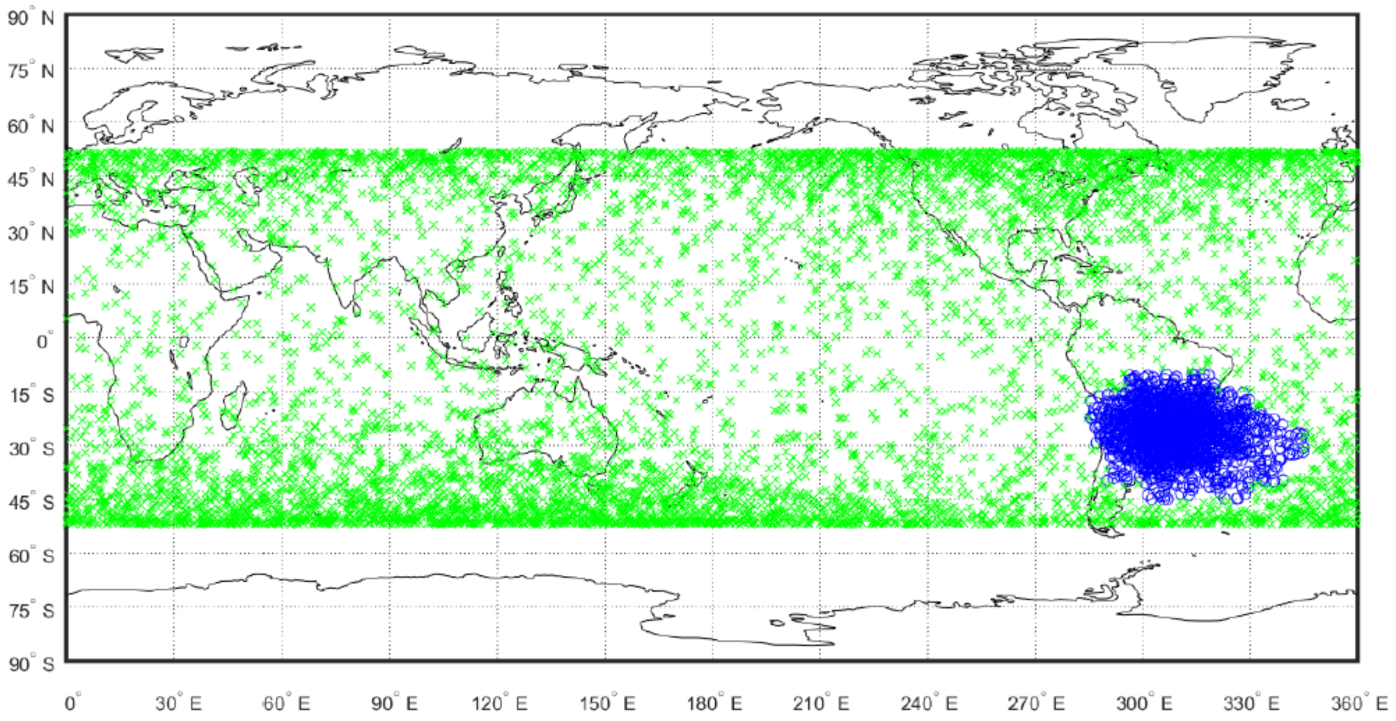




https://leolabs-space.medium.com/analysis-of-the-cosmos-1408-breakup-71b32de5641f

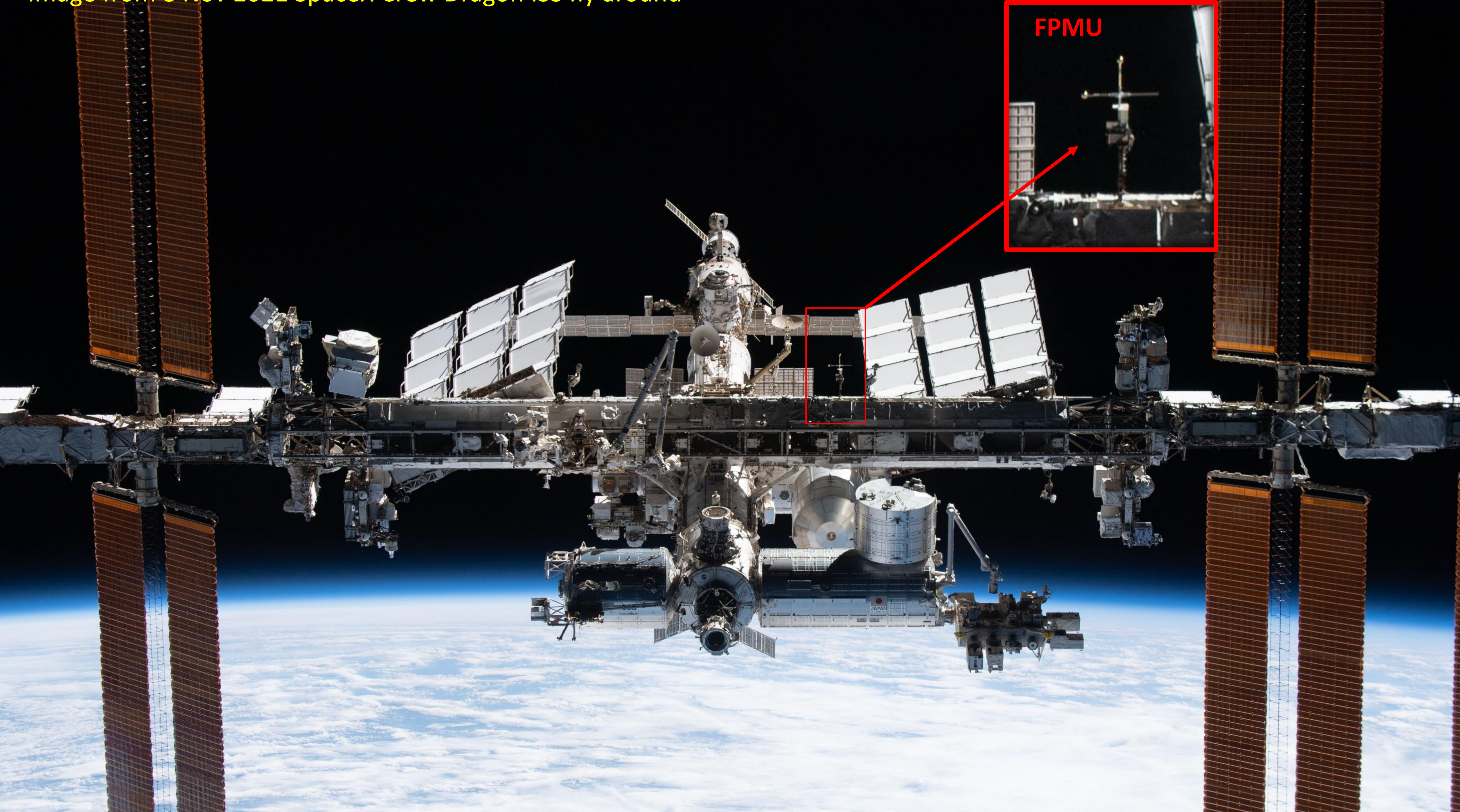
ISS MDM DRAM Single Event Upsets (SEU)

- Geographic distribution of SEUs in ISS Command and Data Handling System Multiplexer de-Multiplexers (MDM).
- ISS operates nearly 50 standard MDMs on the vehicle (as of 2016) that provide system wide, subsystem, and numerous sensor and effector controls
- Events attributed to
  - Galactic cosmic rays
  - Inner radiation belt in South Atlantic Anomaly
- DRAM SEU events with time and location information are reported in ISS telemetry



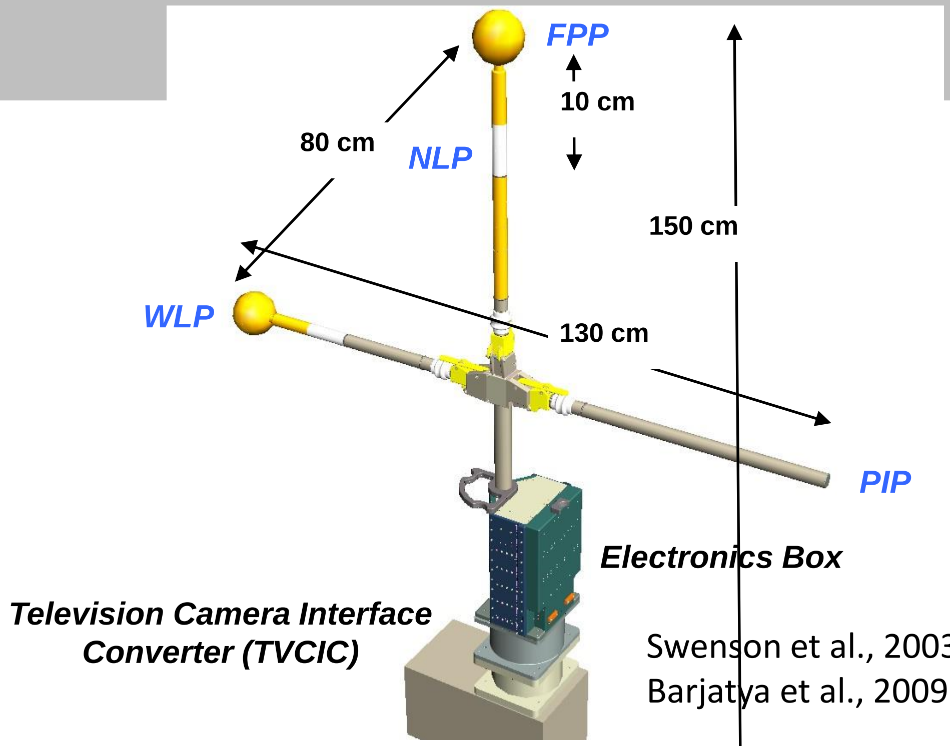
From Koontz et al., 2020
https://ntrs.nasa.gov/api/citations/20200001591/downloads/20200001591.pdf

Image from 8 Nov 2021 SpaceX Crew Dragon ISS fly around

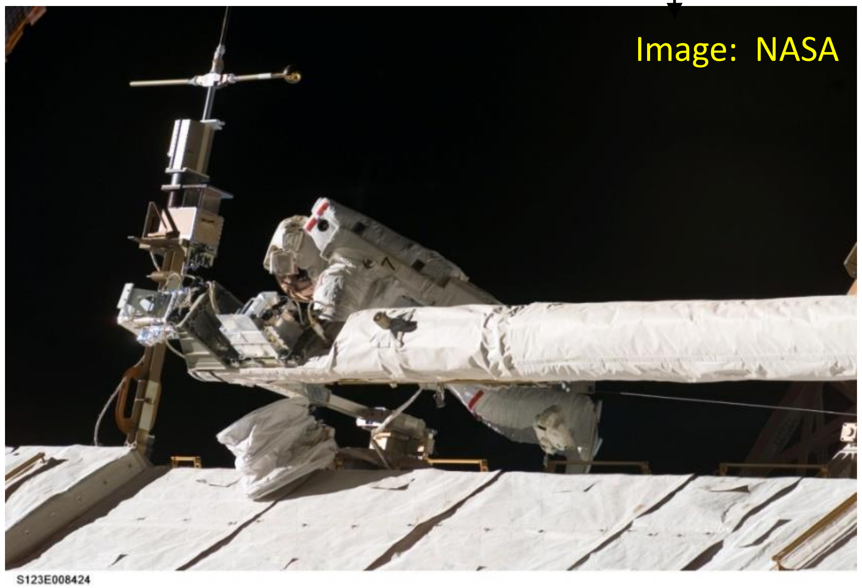


Floating Potential Measurement Unit (FPMU)

- FPMU is a suite of four plasma instruments originally deployed on the ISS in August of 2006, new instrument deployed September 2021
  - Narrow Langmuir Probe (NLP) 1 Hz Ne, Te, Ni, Vf, Vp
  - Wide Langmuir Probe (WLP) 1 Hz Ne, Te, Ni, Vf, Vp
  - Floating Potential Probe (FPP) 128 Hz Vf
  - Plasma Impedance Probe (PIP) 1 Hz Ne
- Primary use: ISS engineering
  - Characterize US high-voltage (160 V) solar array interactions with plasma environment.
  - Evaluate extravehicular activity plasma hazard environments and vehicle charging.
  - Validate the Plasma Interaction Model used to compute ISS frame potentials.
  - Anomaly investigations.
- Secondary use: ionospheric science applications
  - Collaborations with ISS science payloads, other spacecraft, and ground-based ionosphere observations.
  - Support studies of the topside ionosphere near electron density peak.
  - Data provided to science community through Goddard Space Flight Center's (GSFC's) Space Physics Data Facility (SPDF).
  - Auroral charging and ISS space weather interactions.
  - Characterize geophysical events and spacecraft plasma interactions.



Swenson et al., 2003; Barjatya et al., 2009



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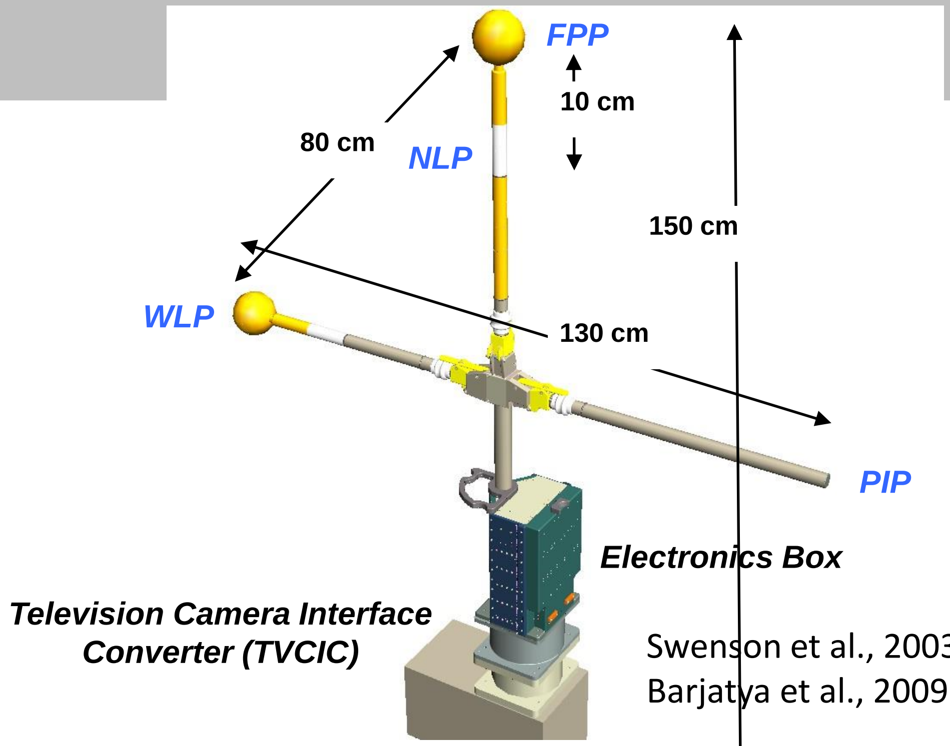

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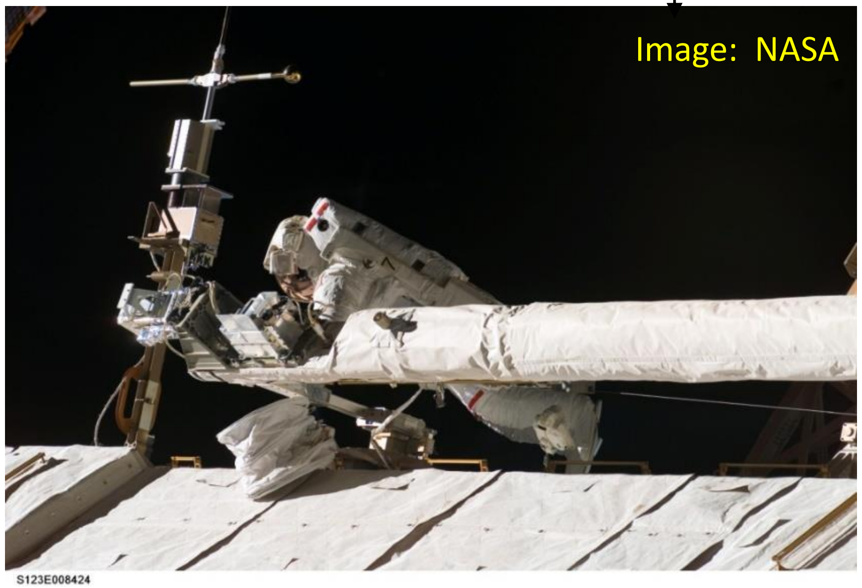
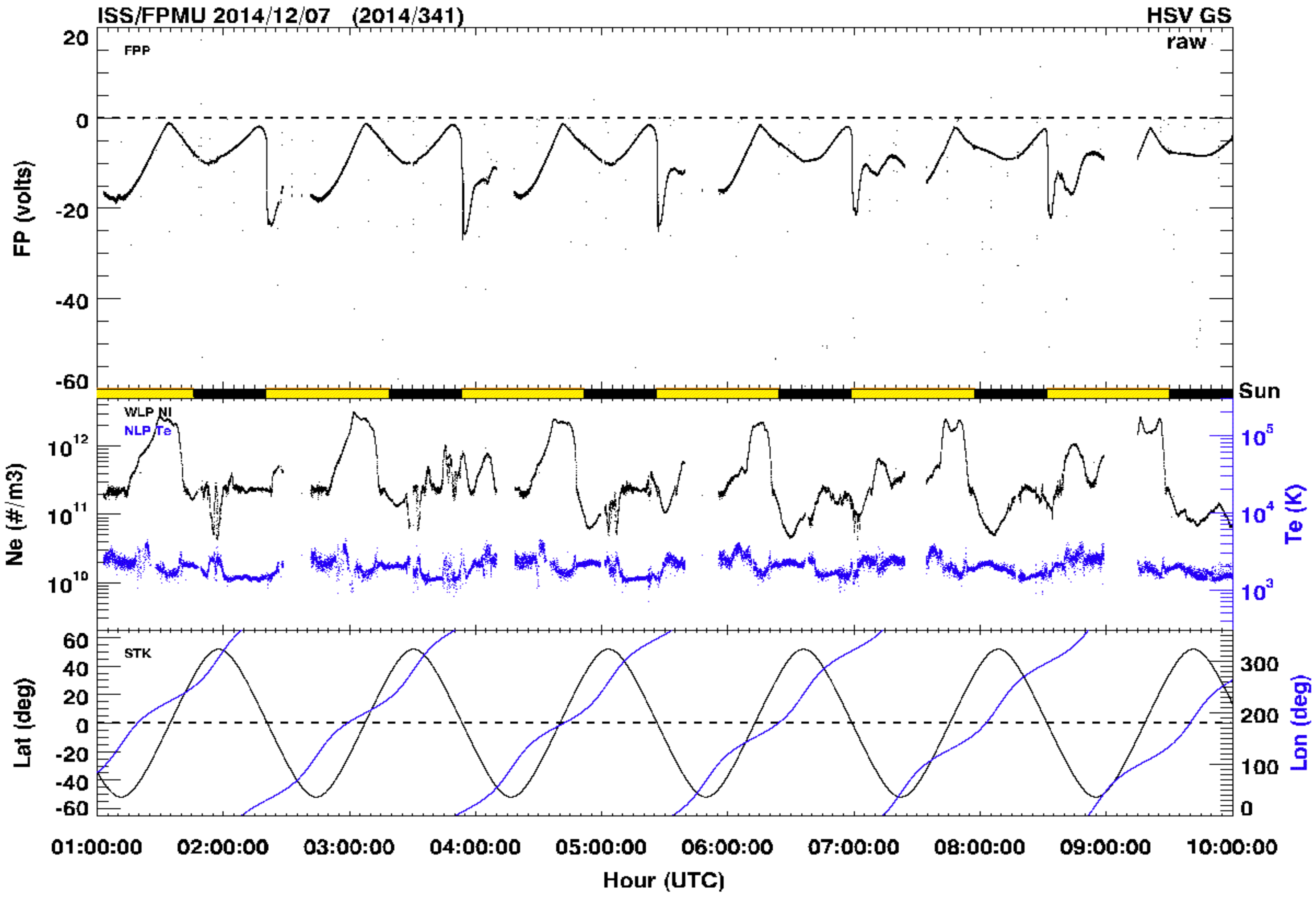


Image: NASA

Example FPMU Records, 7 December 2014

- 5 orbits
- Variation in floating potential (FP) at FPMU location is due to the combined effects of
  - Current collection by US solar arrays (dominates after eclipse exit)
  - Inductive (v x B).L potential (~0.4 V/m)
- Equatorial plasma density peak (equatorial or Appleton “anomaly”)

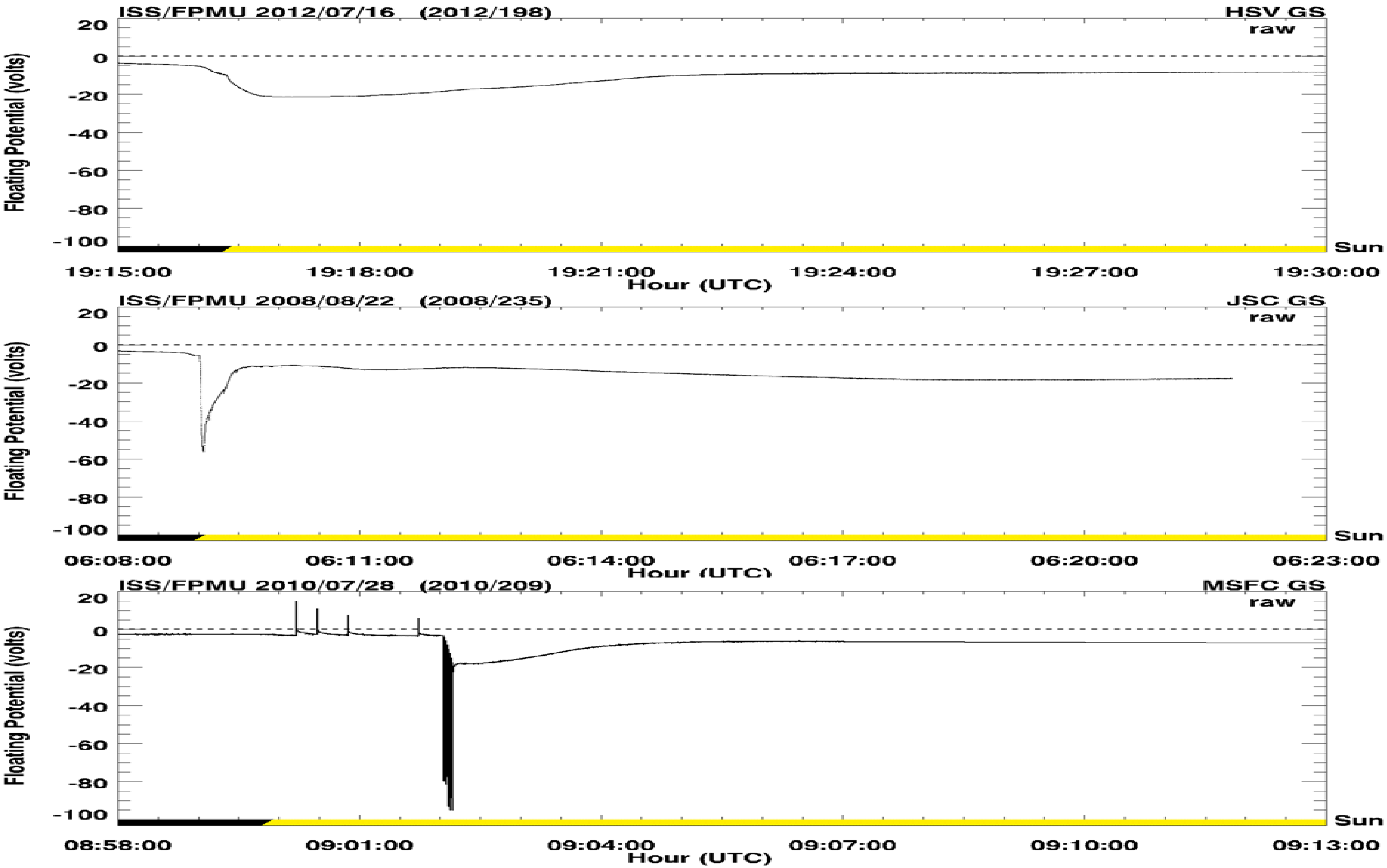


ISS Negative Charging

Normal

Rapid Charging Event (RCE)

Sunlight Unshunt



Minow et al., 2018

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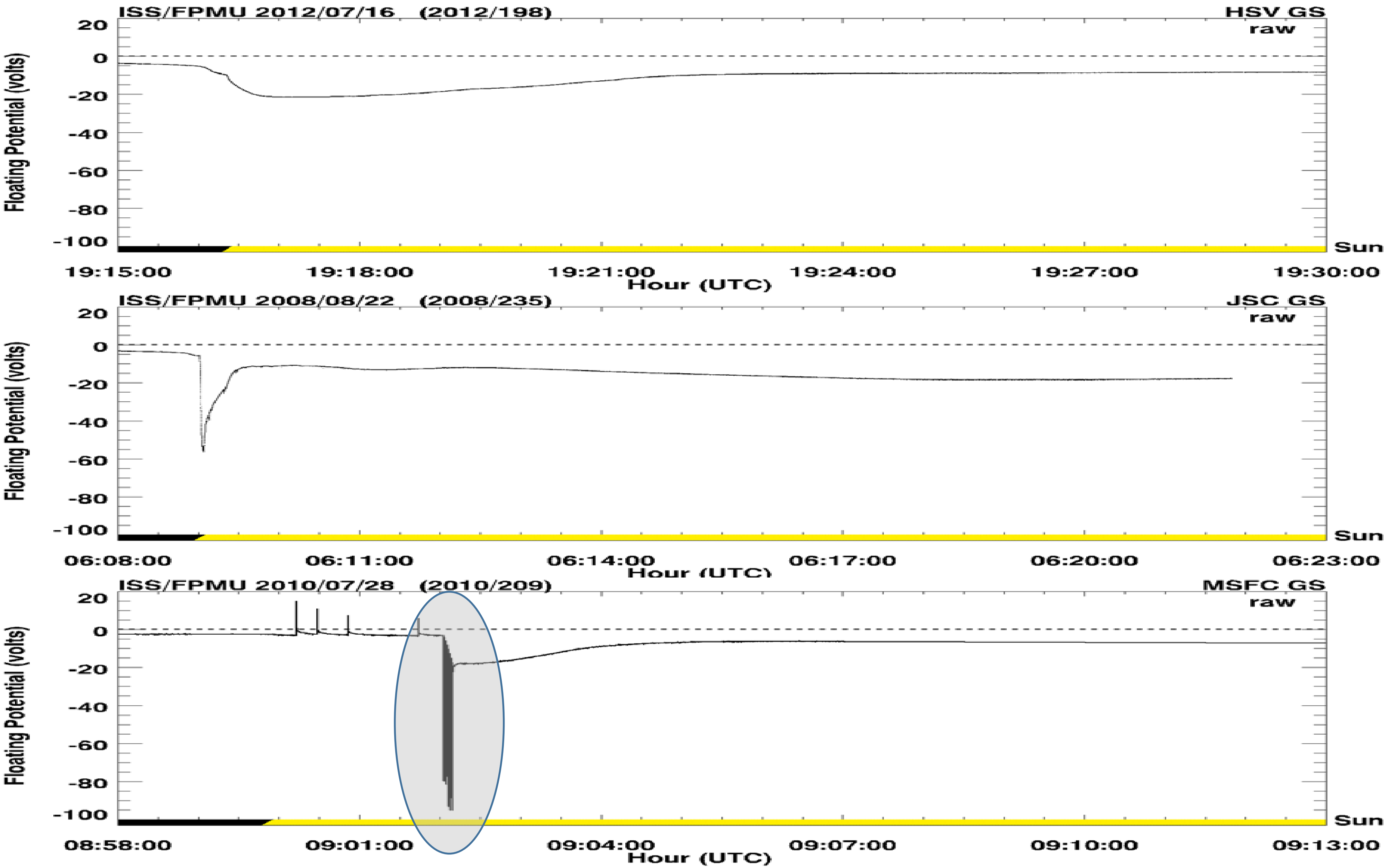

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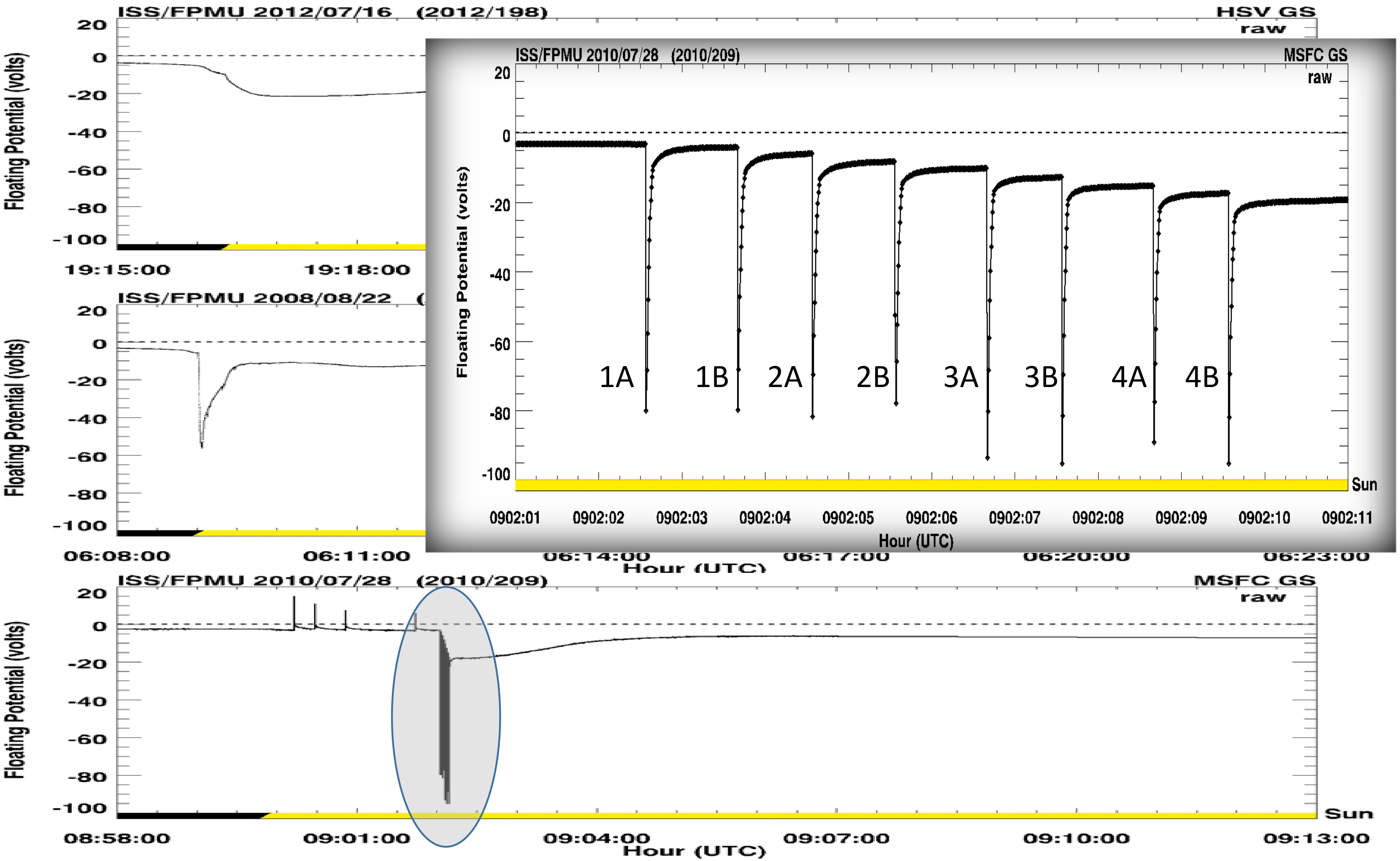
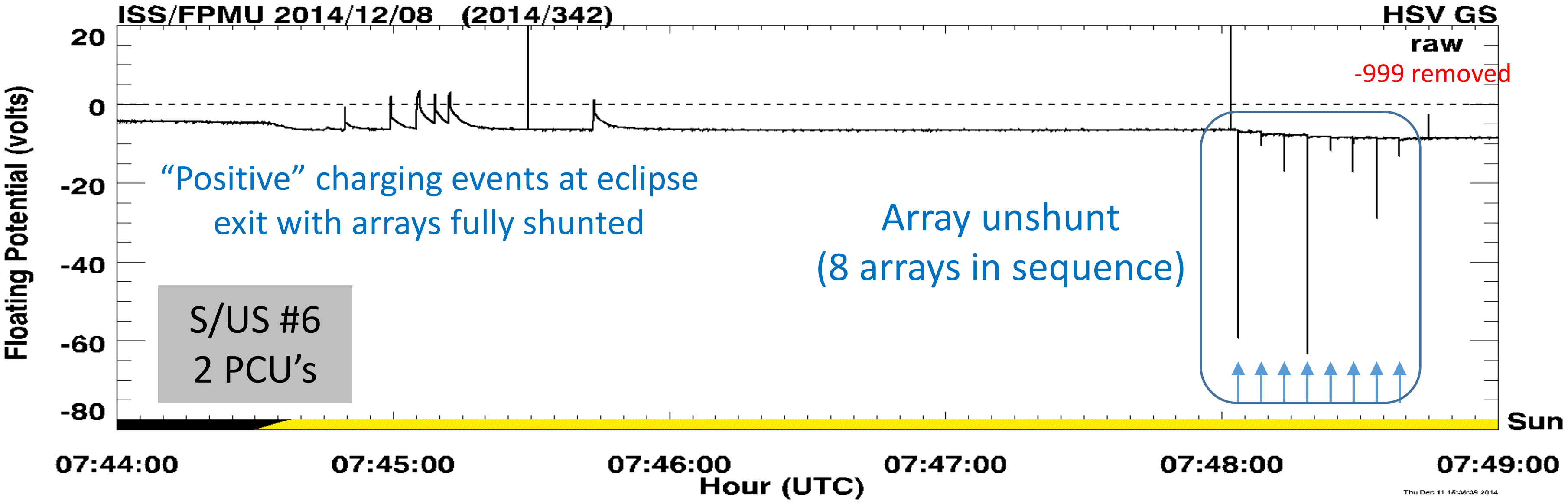
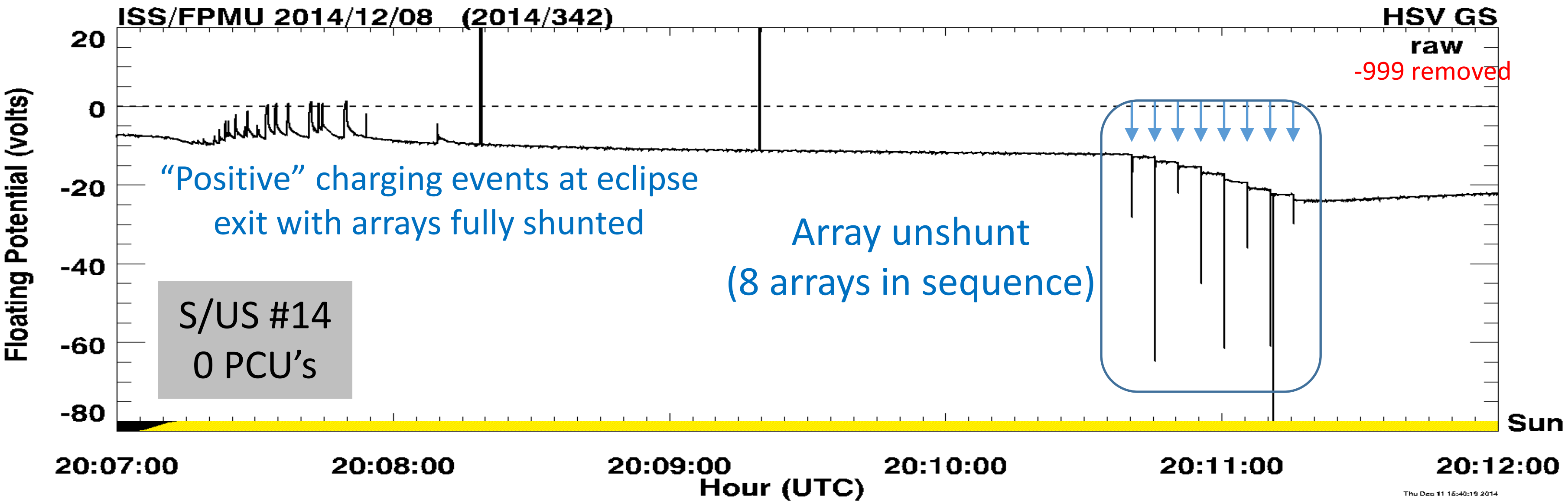


Minow et al., 2018

Sunlight Shunt/Unshunt Experiments

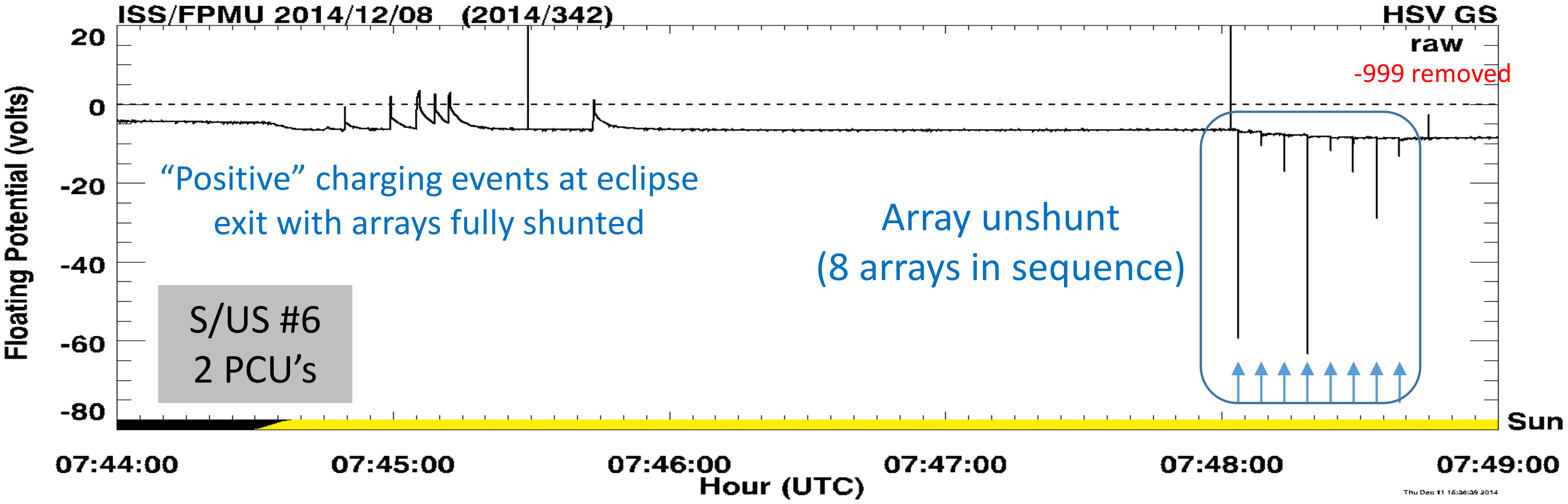


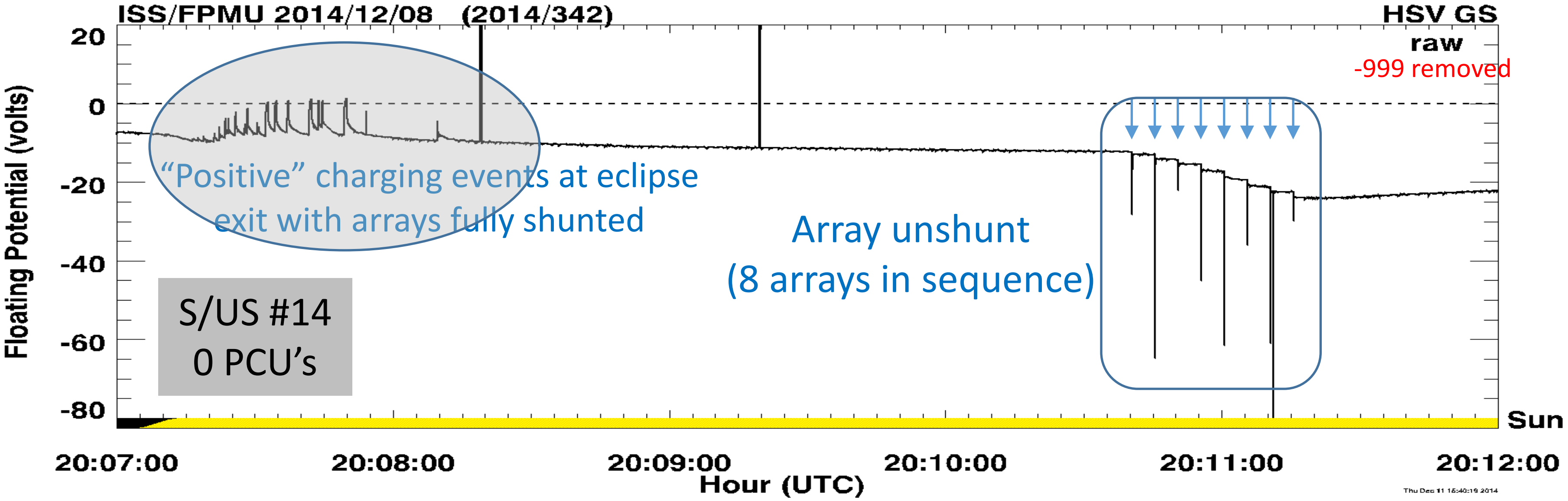


Minow et al., 2018

[*Minow and Willis*, 2014]

Sunlight Shunt/Unshunt Experiments





Minow et al., 2018

[*Minow and Willis*, 2014]

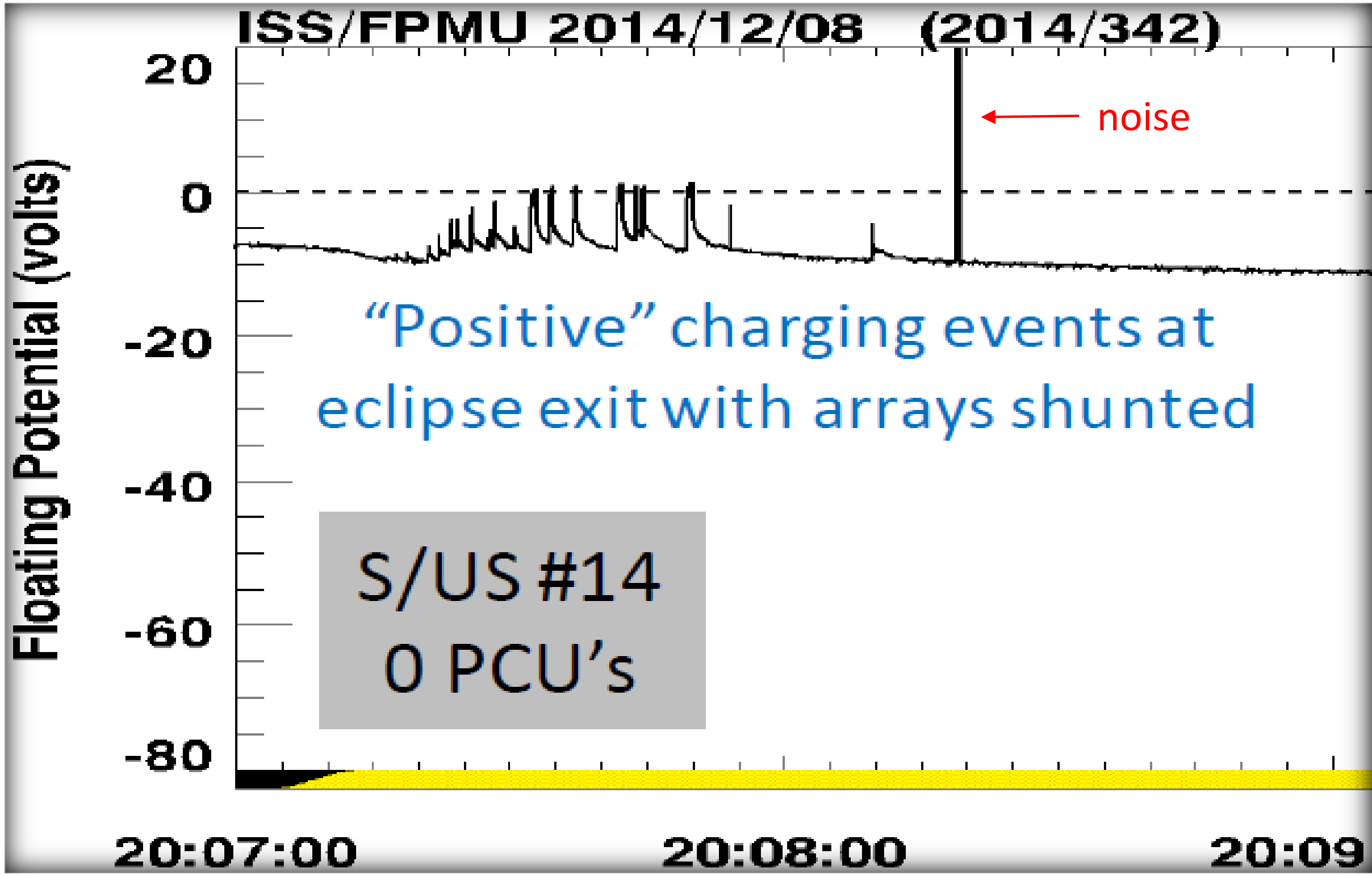
“Positive Charging” Events

- Transient “positive” potential changes at ISS eclipse exit measured by the FPMU during Command Shunt/Unshunt experiments

- All arrays are fully shunted at the time of the “positive” events

- Label:
  - S/US #14: 14th shunt/unshunt operation
  - 0 PCU’s: PCU’s are not operating

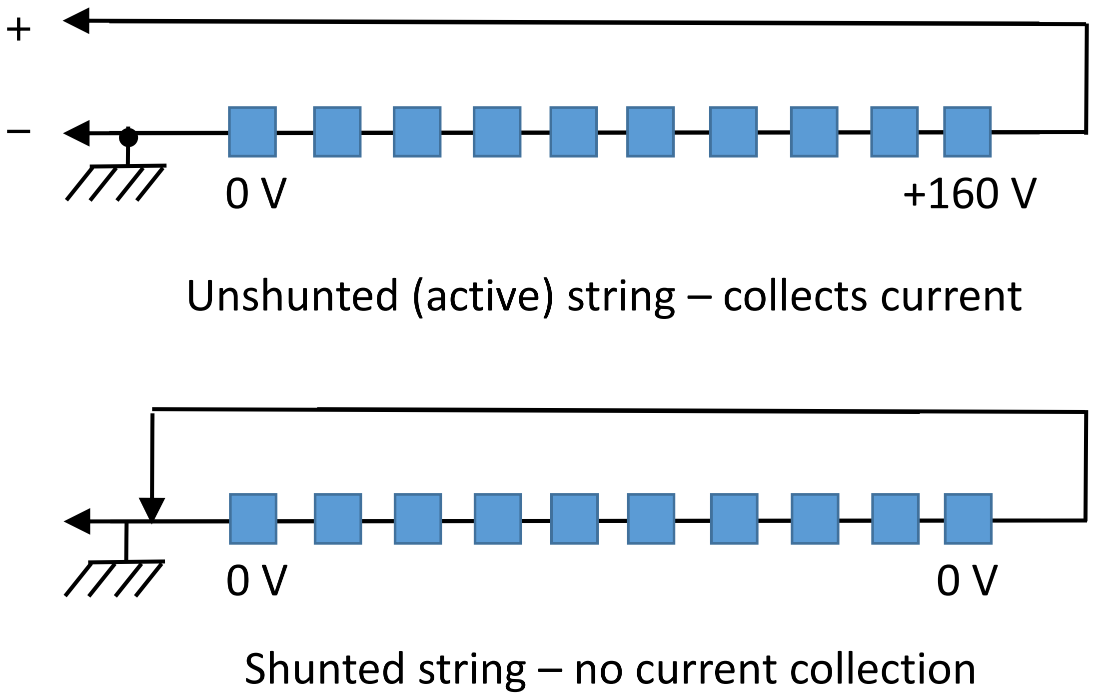
- For many years the origin of these “positive” charging signals were not understood



Minow et al., 2018

Arcing on Damaged, Open-Circuit Strings

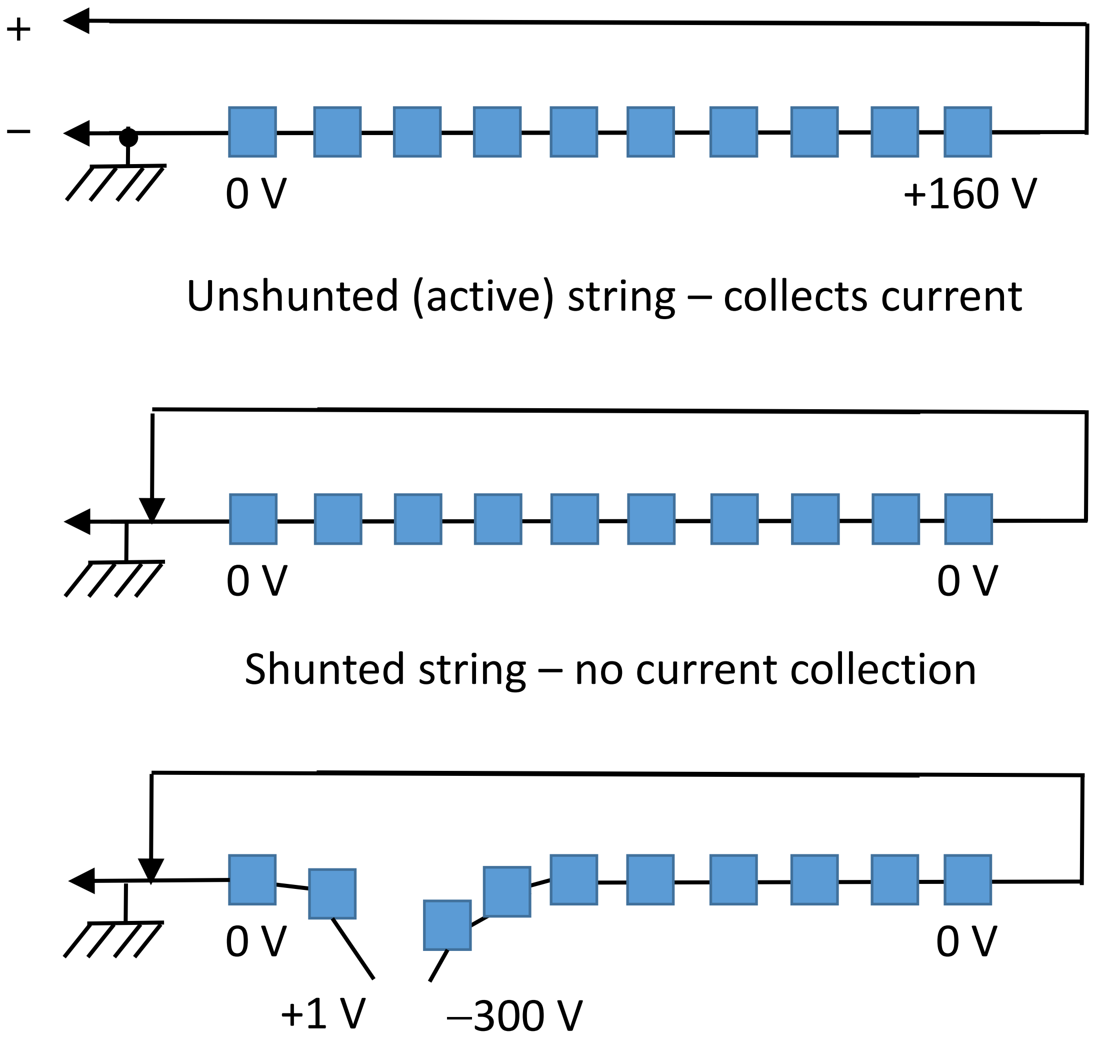
- ISS string potentials are nominally regulated to 160 V



Minow et al., 2018

Arcing on Damaged, Open-Circuit Strings

- ISS string potentials are nominally regulated to 160 V
- However, open circuit string voltages when the arrays are cold coming out of eclipse can run as high as 320 V, twice the nominal operating voltage
    - Voltages on damaged, open-circuit strings can exceed -300 V when the strings are shunted
    - ISS structure is grounded to the positive end of an open-circuit, shunted string



Damaged shunted string – collects current and arcing is possible due to large open circuit voltage

Minow et al., 2018

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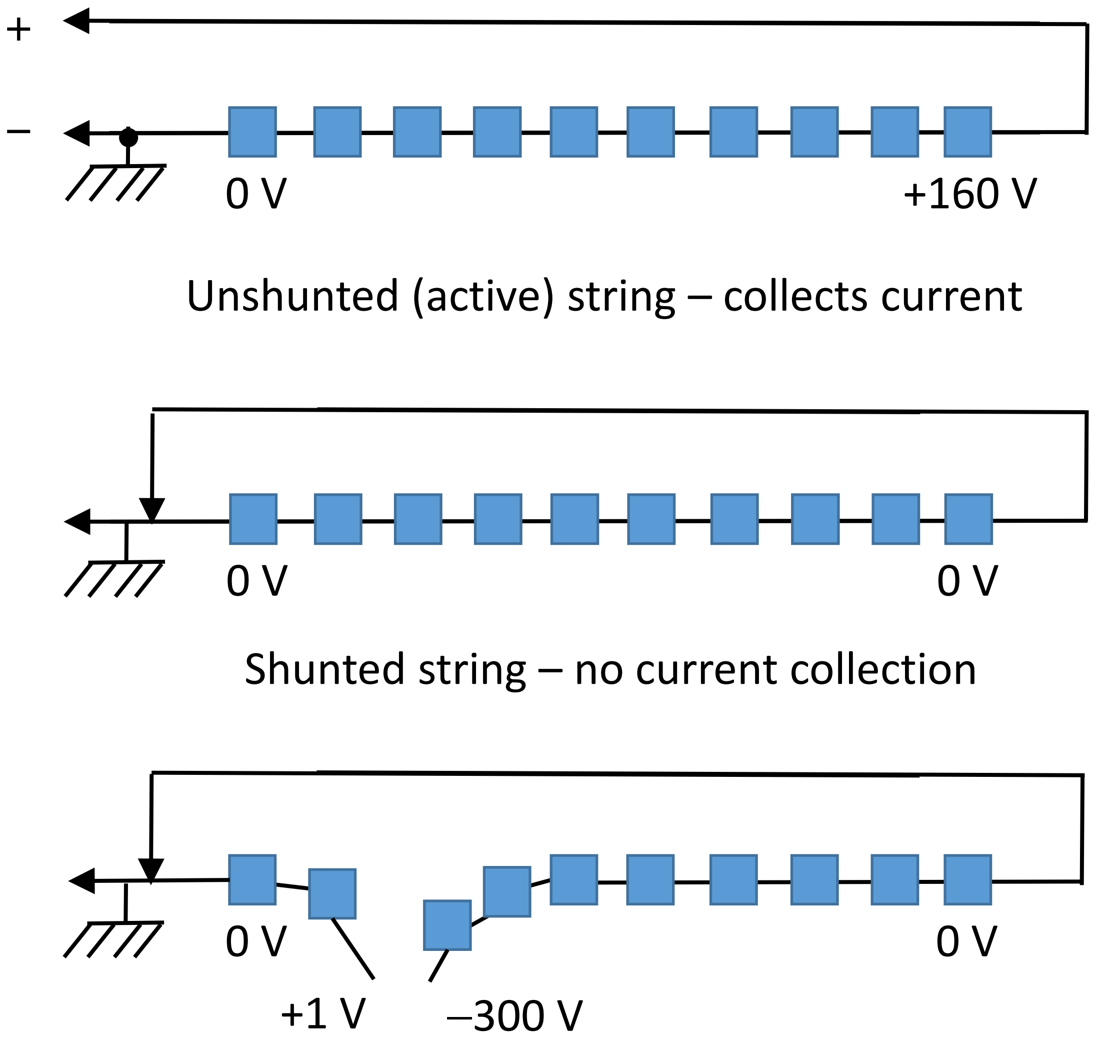
- Arcing thresholds of ISS strings have been measured to range from -210 V to -457 V depending on the plasma density [*Nahra et al*., 1990]

- Under these conditions the local potential on the damaged string can easily exceed arcing thresholds at the low end of the -210 V to -457 V range for ISS PVAs



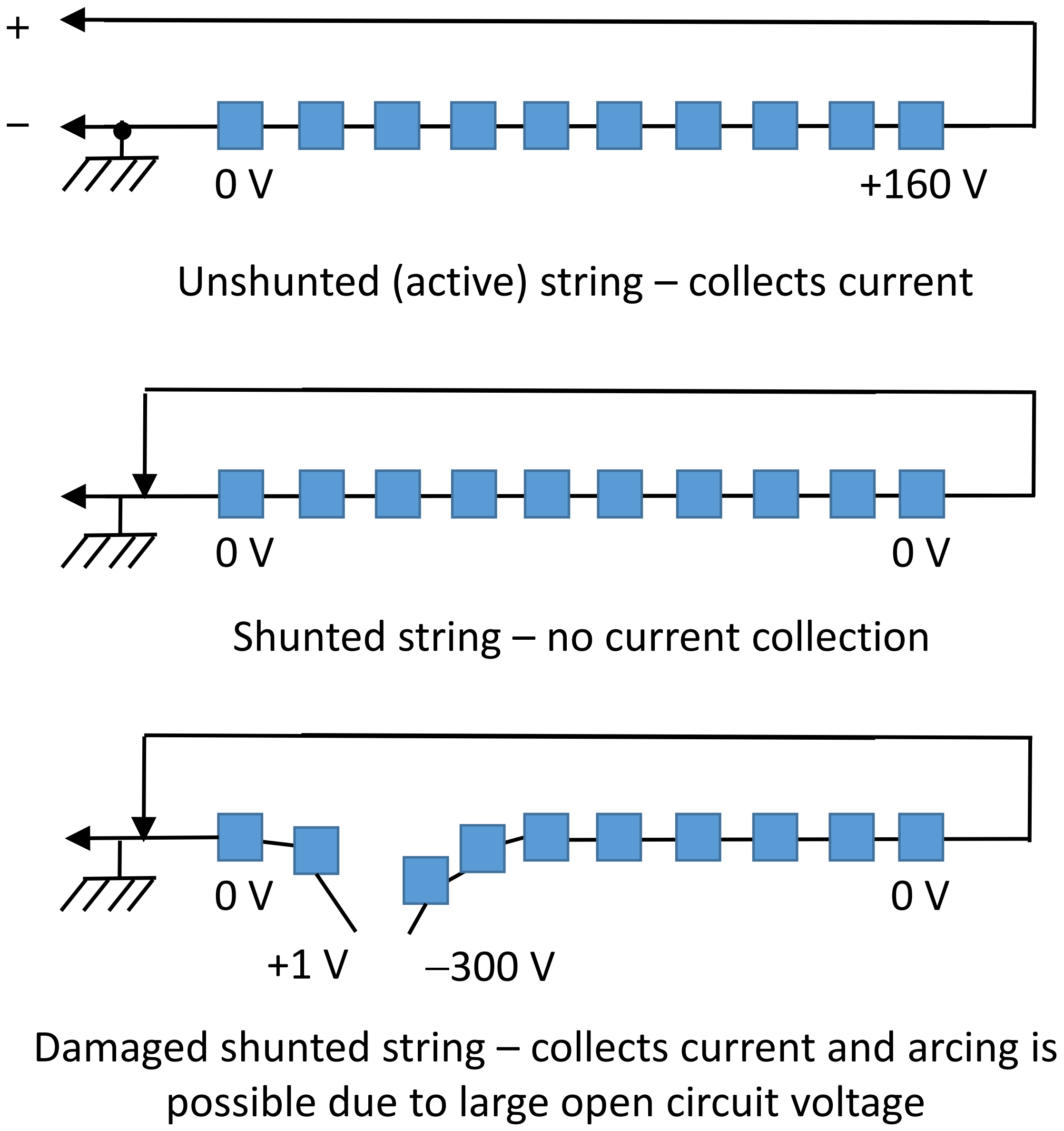
Damaged shunted string – collects current and arcing is possible due to large open circuit voltage

Minow et al., 2018

Arcing on Damaged, Open-Circuit Strings

- ISS string potentials are nominally regulated to 160 V
- However, open circuit string voltages when the arrays are cold coming out of eclipse can run as high as 320 V, twice the nominal voltage
  - Voltages on damaged, open-circuit strings can exceed -300 V when the strings are shunted
  - ISS structure is grounded to the positive end of an open-circuit, shunted string
- Arcing thresholds of ISS strings have been measured to range from -210 V to -457 V depending on the plasma density [*Nahra et al*., 1990]
- Under these conditions the local potential on the damaged string can easily exceed arcing thresholds at the low end of the -210 V to -457 V range for ISS PVAs

Arcing can occur on damaged strings!



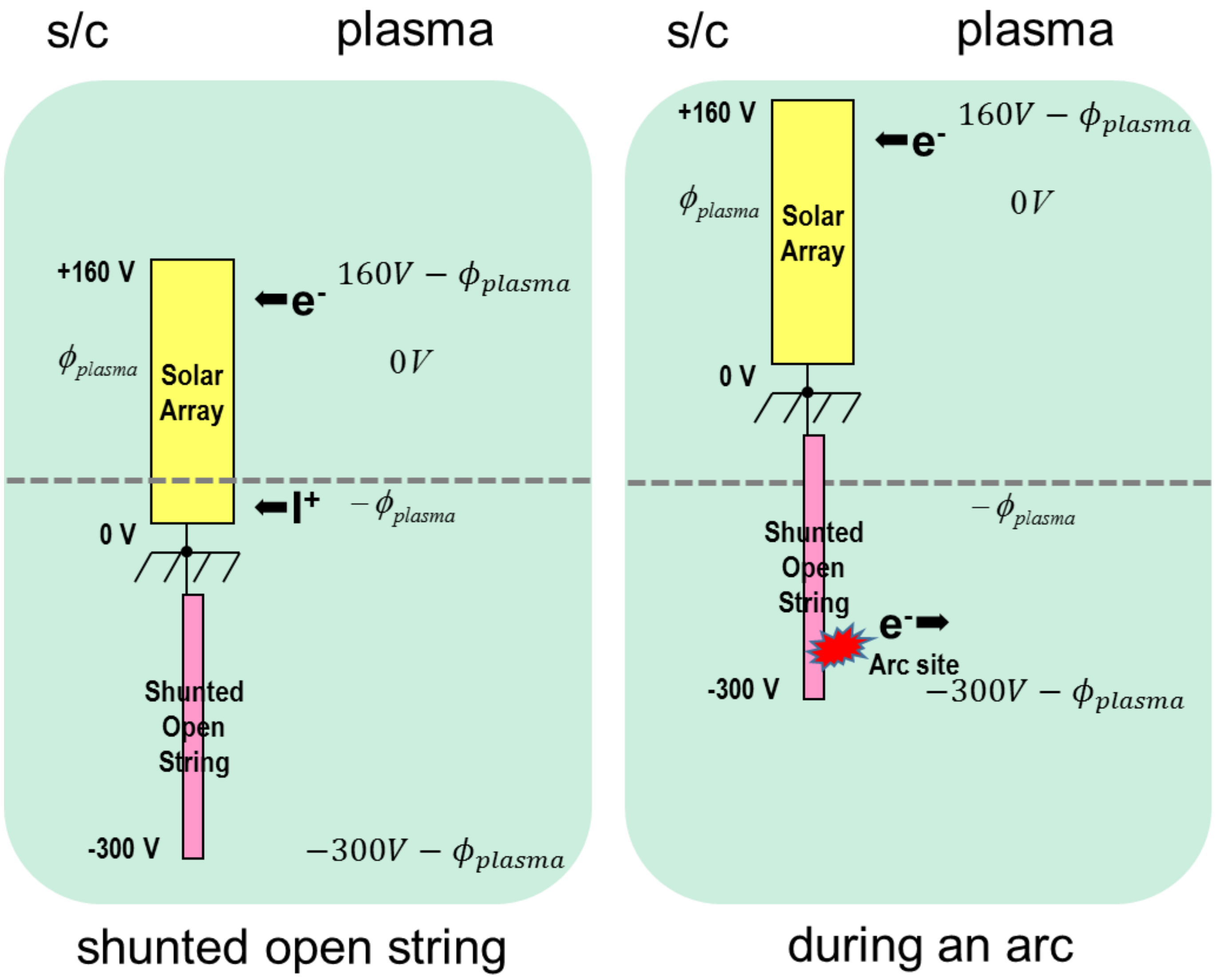
Minow et al., 2018

Arcing on Damaged, Open-Circuit Strings

- Arcing to space on the array will remove some fraction of the net negative charge on the ISS
- Transient variations in the frame potential are expected during the electrostatic discharge events
- ISS potentials for a shunted string with an open-circuit fault near the beginning of the string on eclipse exit

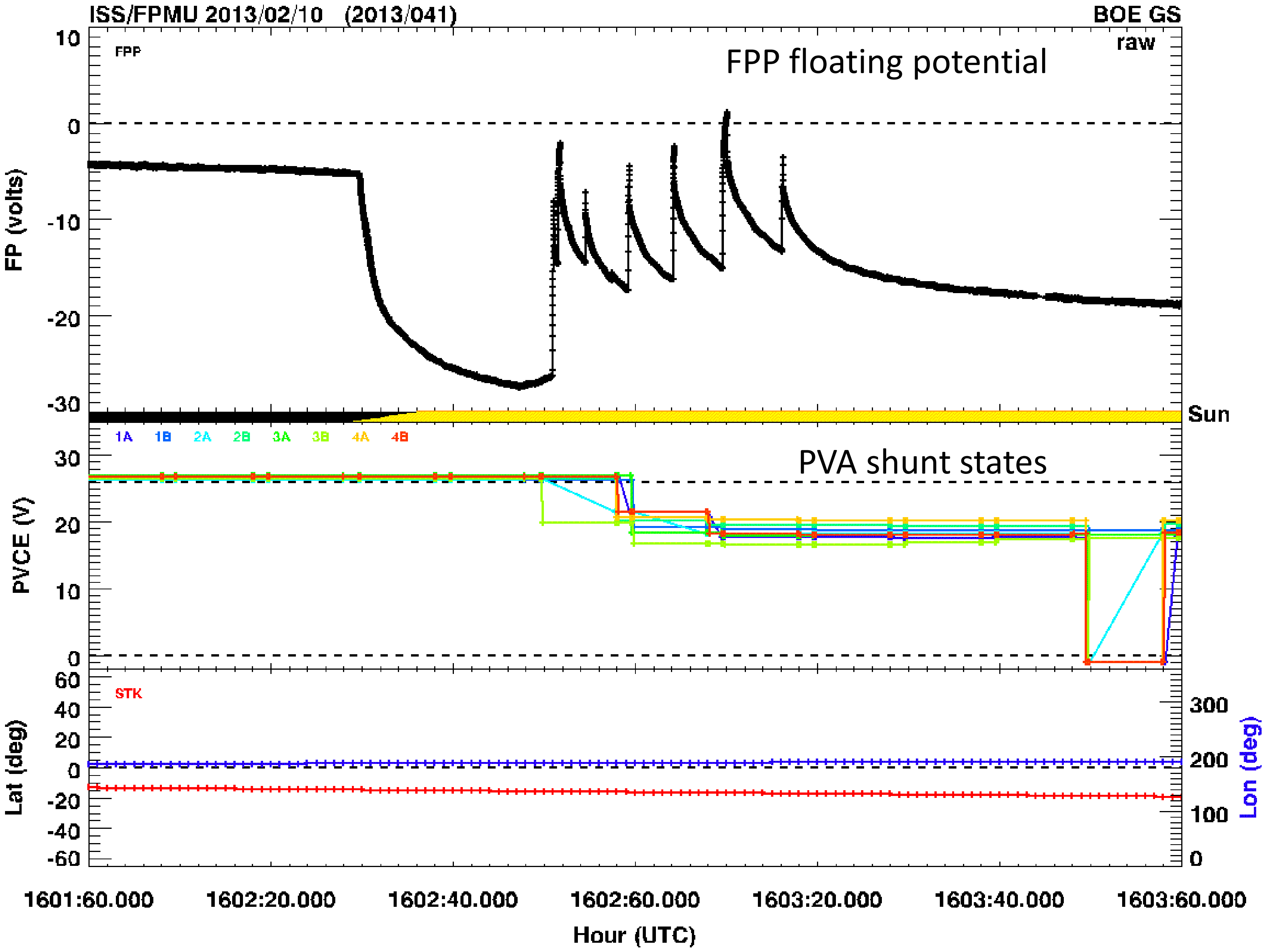
  Left panel: before arc

  Right panel: during arc
- Potential of ISS structure becomes less negative as charge is lost through arc event, and may even become positive



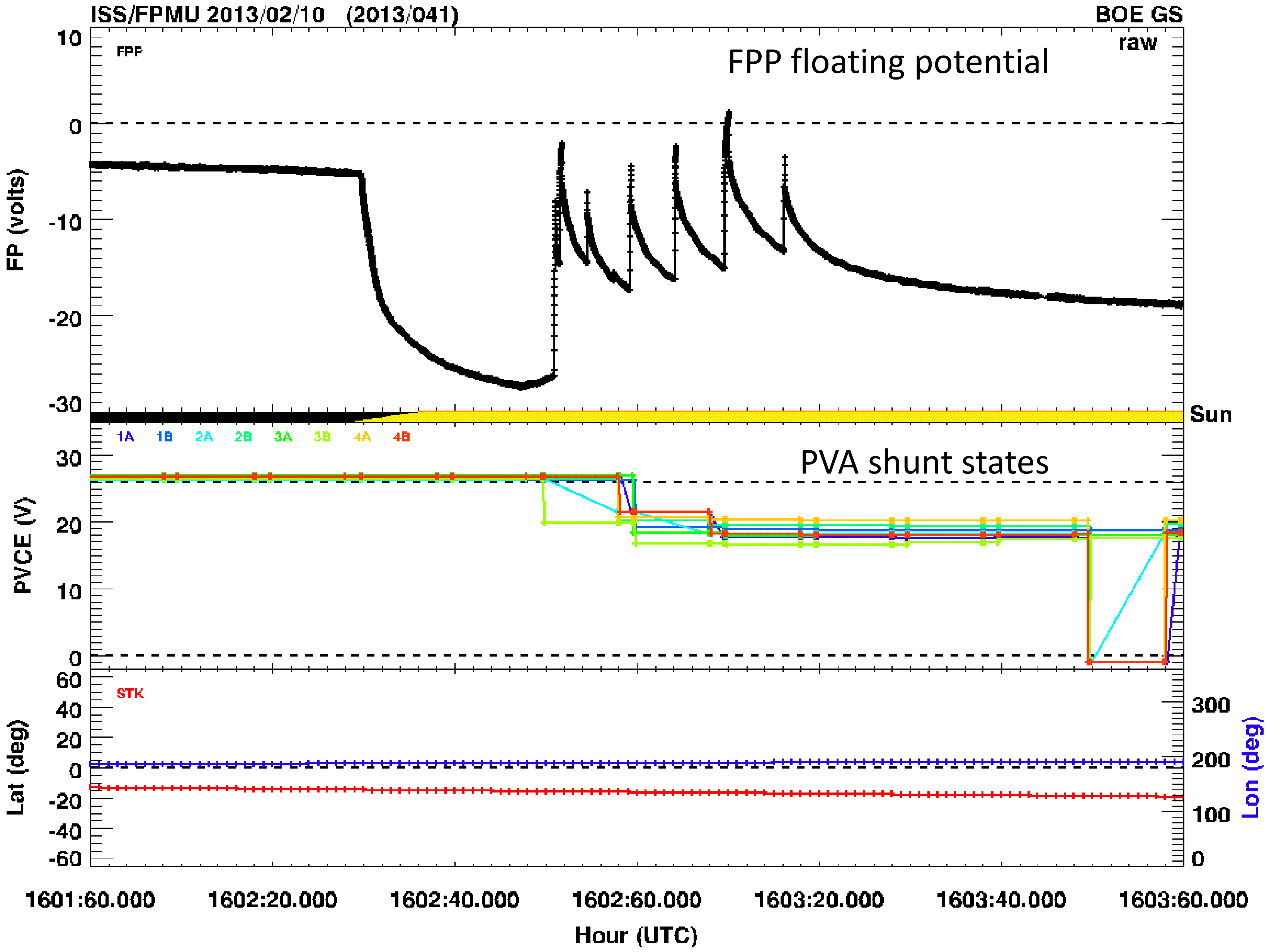
Minow et al., 2018

Example: 10 February 2013



Minow et al., 2018

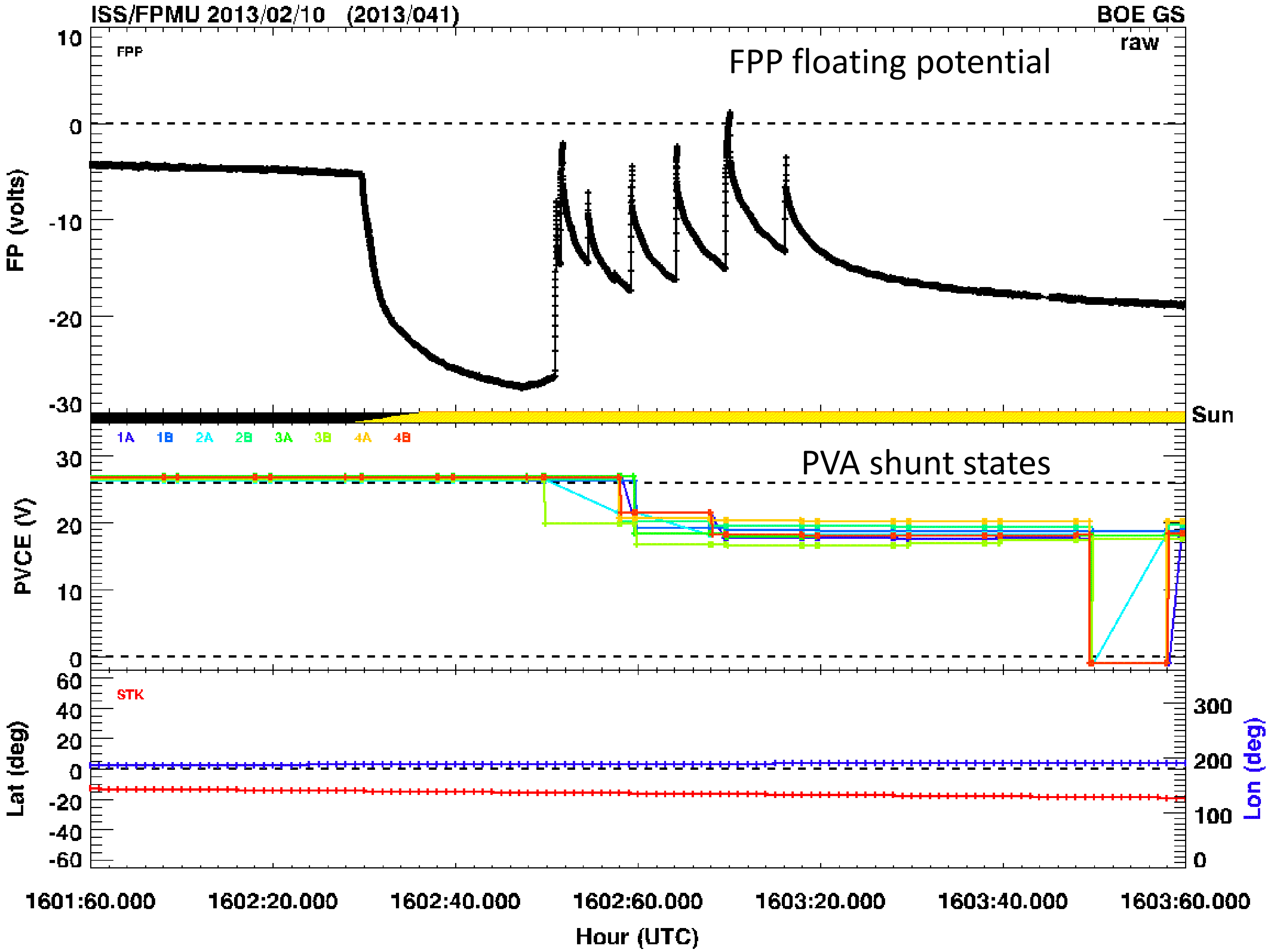
Example: 10 February 2013



Insight into ISS PVA interaction with plasma environment only possible because of high quality FPMU data…

Minow et al., 2018

Example: 10 February 2013



Insight into ISS PVA interaction with plasma environment only possible because of high quality FPMU data…

…in-situ space environment sensors are very useful for diagnosing interaction of space environment with spacecraft

Minow et al., 2018


Questions?