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NASA Engineering and Safety Center (NESC) Space Environments Activities

Joseph I. Minow

NASA, Marshall Space Flight Center

12th Space Exploration and Space Weather Workshop

3 December 2021, virtual

Joseph.minow@nasa.gov

ID/Type*	Title	Discipline	NESC Lead	ECD
15-01079/A	JWST Space Environment Launch Constraints	Radiation, Charging	Minow	Complete
17-01215/A	Space Weather Architecture	Radiation	Minow	Complete
17-01257/S	NOVICE Support to LSP and CCP Radiation Assessment	Radiation	Minow	Complete
18-01404/S	PAMELA Radiation Data Recovery Technical Support	Radiation	Minow	Complete
19-01423/A	**Solar Wind Radiation Damage of Metallic Coatings**	**Radiation**	**Minow**	**TBD**
19-01433/A	**Badhwar-O'Neill Galactic Cosmic Ray Model Improvements**	**Radiation**	**Minow**	**08/04/2022**
19-01468/A	**Commercial Crew Program Post-flight Reference Radiation Environments**	**Radiation**	**Minow**	**04/30/2022**
20-01520/A	*Independent Assessment Study for the GSFC LISA Laser*	*Radiation*	*Singh*	*Complete*
20-01589/A	***Safe Human Expeditions Beyond LEO***	***Radiation, Microgravity***	***Valinia***	***12/31/2021***
17-01281/S	Europa Lander Radiation Test Technical Support	Plasma/Charging	Minow	Complete
18-01322/A	**Auroral Charging Threat Assessment**	**Plasma/Charging**	**Minow**	**TBD**
18-01407/S	**Technical Support for Revising NASA-HDBK-4002A**	**Plasma/Charging**	**Minow**	**10/31/2021**
19-01428/S	NASCAP Integrated Spacecraft Charging Analysis Support	Plasma/Charging	Minow	Complete
19-01434/A	**FPMU Data Processing Algorithm Development and Analysis Assessment**	**Plasma/Charging**	**Minow**	**12/31/2022**
19-01435/S	**Orion, NDSB2, and Gateway Material Electrical Properties Support**	**Plasma/Charging**	**Minow**	**09/30/2021**
20-01562/S	**Space Charging of Ocean Color Instrument (OCI) Rotating Mechanism**	**Plasma/Charging**	**Minow**	**09/30/2021**
17-01204/A	**Southern Hemisphere Meteoroid Environment Measurements**	**M/OD**	**Minow**	**04/30/2021**
18-01367/A	*Assessment of Spacecraft Passivation Techniques*	*M/OD*	*Squire*	*Complete*
18-01409/A	*Review of ORDEM3.1*	*M/OD*	*Squire*	*Complete*
20-01576/A	**Lunar Meteoroid Ejecta Model Review**	**M/OD**	**Minow**	**08/31/2021**
21-01633/A	***Mars Sample Return MMOD Protection Review***	***M/OD***	***Squire***	***TBD***

*(A) Assessment Activity, (S) Support Activity **In Development or Active,** Complete Space Environments TDT, *Other NESC Group*

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PAMELA Radiation Data

A. Bruno, April 2020

- **PAMELA energetic proton data can be used to improve the AE9/AP9/IRENE model proton environments at ISS altitudes**
  - ~10-years PAMELA proton data are available covering an altitude range from 360 km to 604 km, relevant to the ISS altitude at ~400 km.
  - There was a plan to incorporate PAMELA data into IRENE to update LEO environments, but the data archive in Italy was lost in a flood.
  - The data is recoverable from the original Russian data archive but required processing into format that can be used for ingesting into the IRENE model.

- **A NASA, ESA, and US Air Force collaboration is implementing the PAMELA data processing and IRENE development work:**
  - Dr. Alessandro Bruno/GSFC/Catholic University of America (CUA) processed PAMELA data (supported by NESC)
  - National Institute of Nuclear Physics (INFN) personnel in Italy processed PAMELA data (supported by ESA)
  - Aerospace Corporation is the IRENE developer and will implement the updates with PAMELA data (supported by the Air Force)

PAMELA Processing Steps

1) Calculate proton fluxes in the South Atlantic Anomaly
- Proton count as a function of (lon, lat, alt, θ_B, ϕ_B)
- Effective area as counts as a function of (lon, lat, alt, E, α)
- Live-time a function of (E, α, θ_B, ϕ_B)
- Quaternions as a function of (lon, lat, alt, θ_B, ϕ_B)
- Fluxes as a function of (lon, lat, alt, E, α) with uncertainties

2) Calculate proton flux at guiding center (East-West effect)
- Proton counts as a function of (cglon, cglat, cgalt, E, α)
- Live-time as a function of (cglon, cglat, cgalt, E, θ_B, ϕ_B)
- Effective area as a function of (E, α, θ_B, ϕ_B)
- Quaternions as a function of (cglon, cglat, cgalt, θ_B, ϕ_B)
- Fluxes as a function of (cglon, cglat, cgalt, E, α) with uncertainties

3) Calculate temporal variations
- Bin into time ranges between July 2006 and Sept 2014, each including 244 days (or longer if required)
- Fluxes as a function of (cglon, cglat, cgalt, E, α, t) with uncertainties

E is energy; α is pitch angle; θ_B, ϕ_B are angles of the geomagnetic field in the instrument frame; lat/lon/alt are the geographic coordinates; cglat/cglon/cgalt are the geomagnetic coordinates

PAMELA Instrument

- The Payload for Antimatter Matter Exploration and Light-nuclei Astrophysics (PAMELA) instrument was an international (Italy, Russia, Sweden, Germany) cosmic ray payload on the Russian Resurs- DK1 satellite

- Resurs DK1
  - Commercial Earth observation satellite, built in Russia by TsSKB-Progress for Roskosmos
  - Operational from 2006 to 2016
  - Initial orbit: 360 km x 604 km x 70° inclination
  - Orbit ~circularized to 567 km by 573 km x 70° in September 2010

Particle	Energy Range
Antiproton	80 MeV – 190 GeV
Positron	50 MeV – 270 GeV
Electron	up to 400 GeV
Proton	up to 700 GeV*
Electron/positron	up to 2 TeV
Light nuclei (≤Z = 6)	up to 200 GeV/n
Light isotopes (D, 3He)	up to 1 GeV/n

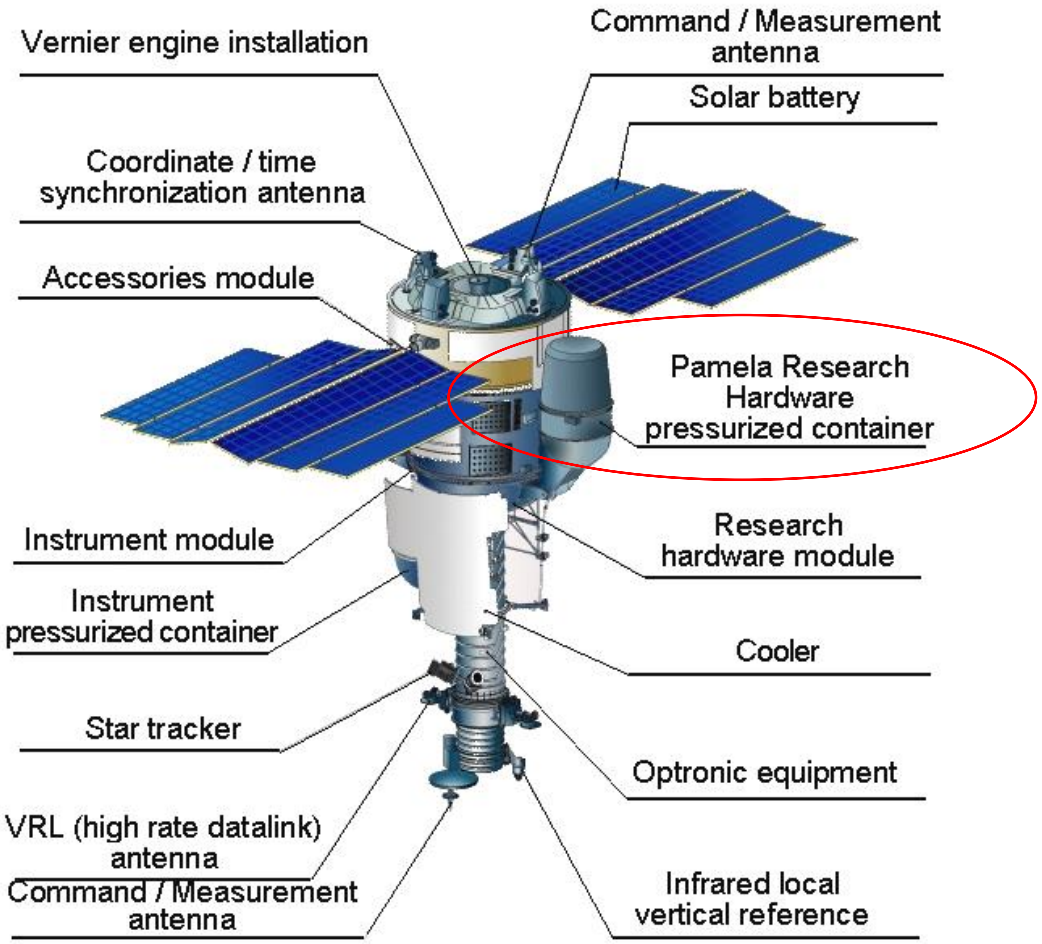


Image: Roscosmos

*Proton energy range is 80 MeV – 4 GeV for this work

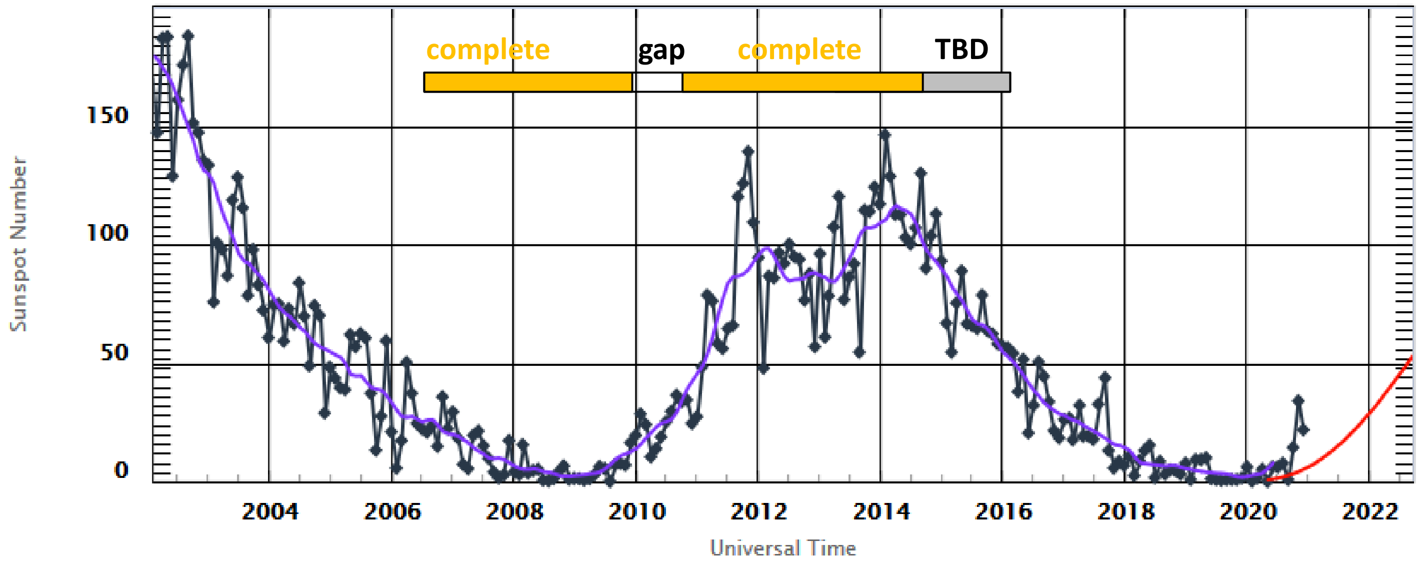
PAMELA Data Processing

- Data from July 2016 through January 2016 processed into temporal files for two orbit configurations:
  - Elliptical 350 km x 600 km orbit — Jul 2006 – Dec 2009 — 6 files of ~244 day intervals
  - Near circular ~570 km orbit — Sep 2010 – Sep 2014 — 6 files of ~240 day intervals

- ~8 month data gap starting in December 2009 into September 2010, due to the temporary loss of contact with the spacecraft.

- Proton intensity records processed into 5-D intensity bins for each time file:
  - Local pitch angle: 3-deg bins, range 0 to 180 degrees
  - Energy: 20 logarithmic bins, range 80 MeV to 4 GeV
  - Longitude: 2-deg bins, range -120 deg to 0 deg
    Latitude: 2-deg bins, range -50 deg to +10 deg
  - Altitude: 4 65-km bins, range 350 km to 610 km)
  - Orientation: 1 deg for both azimuth and zenith

- Data processed covers periods of both solar minimum (highest proton flux in SAA) and solar maximum (lowest proton flux in SAA).

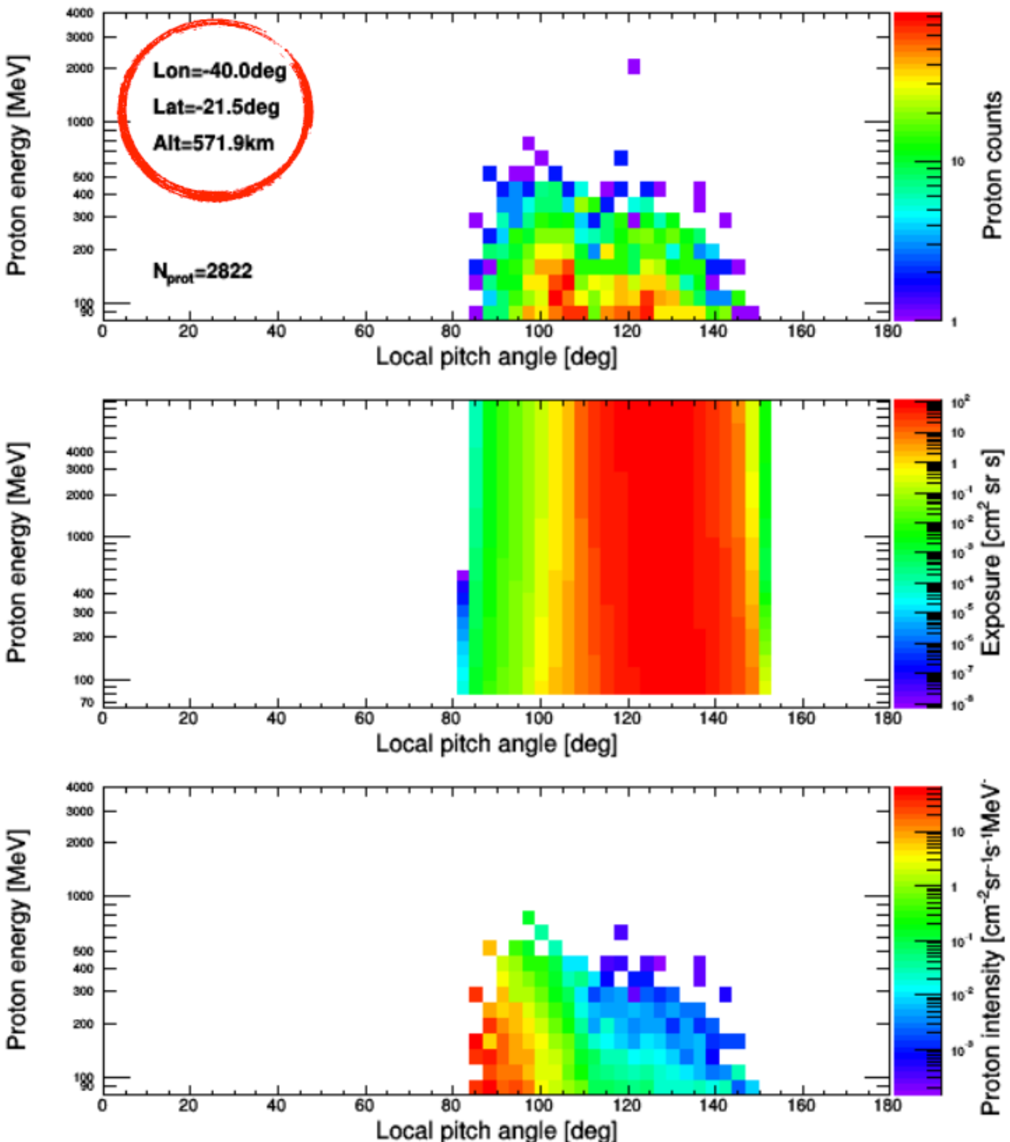


https://www.swpc.noaa.gov/products/solar-cycle-progression

Proton Intensity Processing

Proton intensities at sample location 1

as a function of local pitch angle and energy



Proton counts

Exposure

(effective area integrated over solid angle and time)

Proton intensities

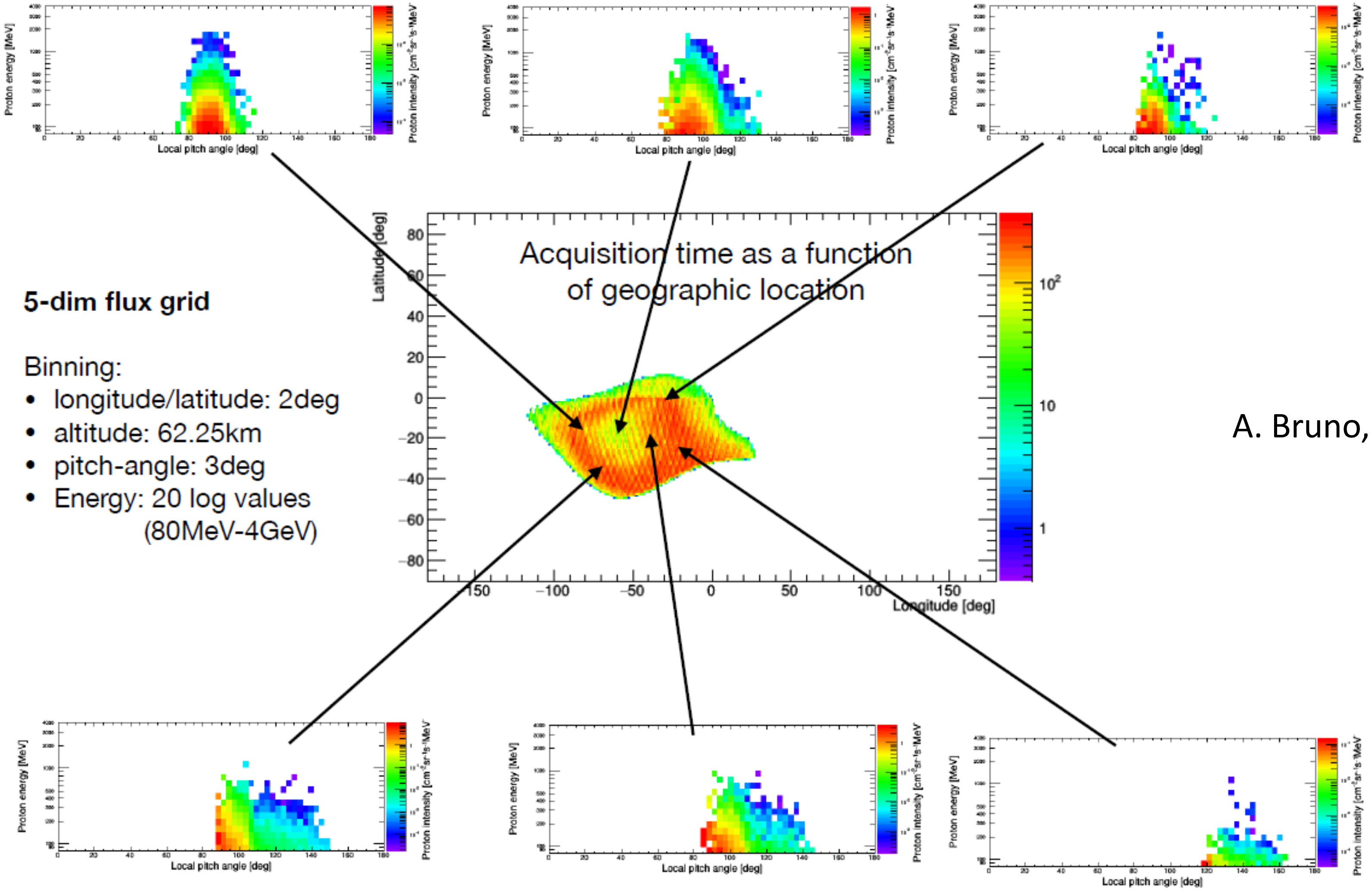
A. Bruno, September 2020

Proton Intensity Processing

Proton intensities at sample locations

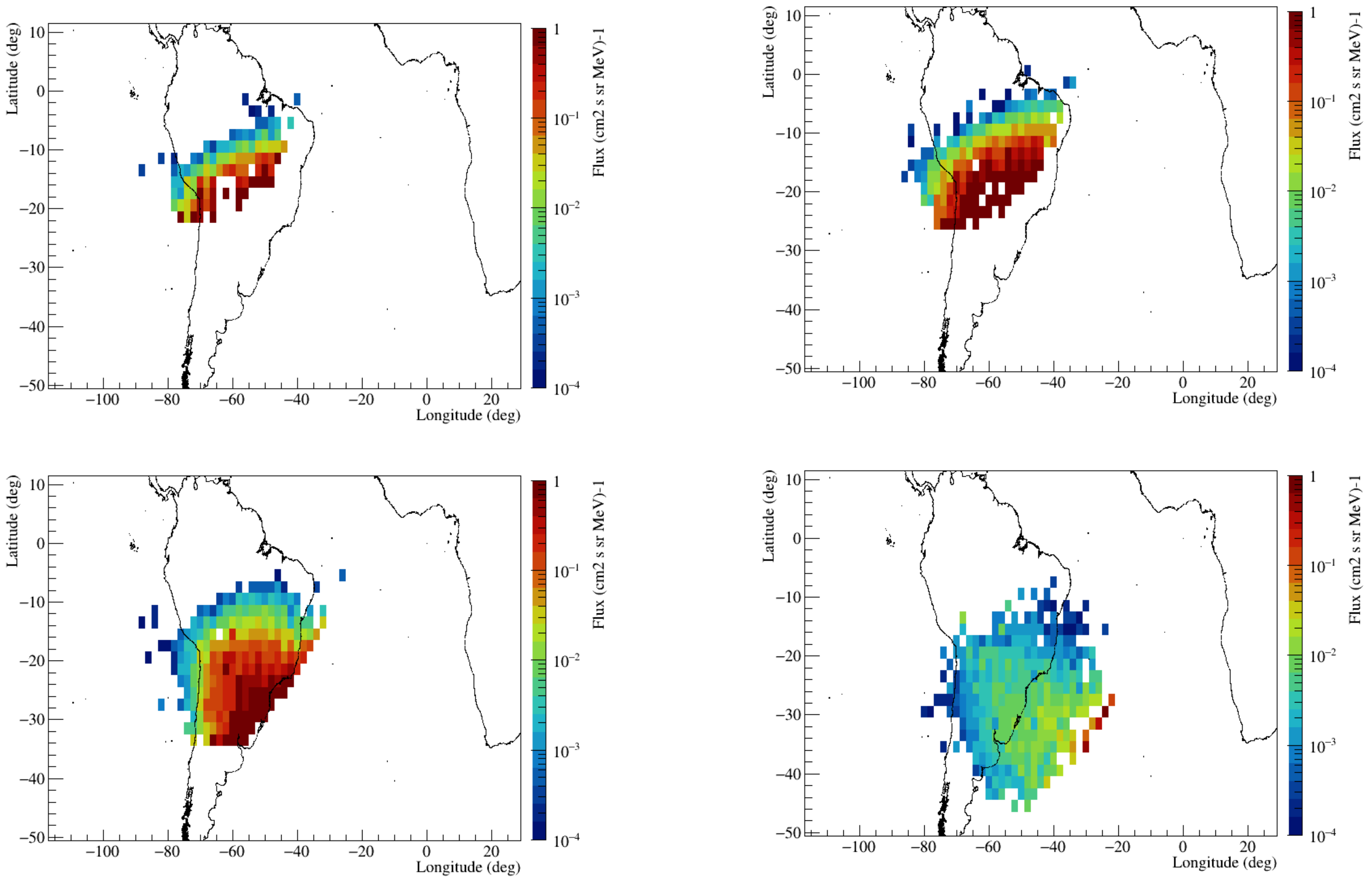
5-dim flux grid

Binning:
- longitude/latitude: 2deg
- altitude: 62.25km
- pitch-angle: 3deg
- Energy: 20 log values (80MeV-4GeV)



A. Bruno, September 2020

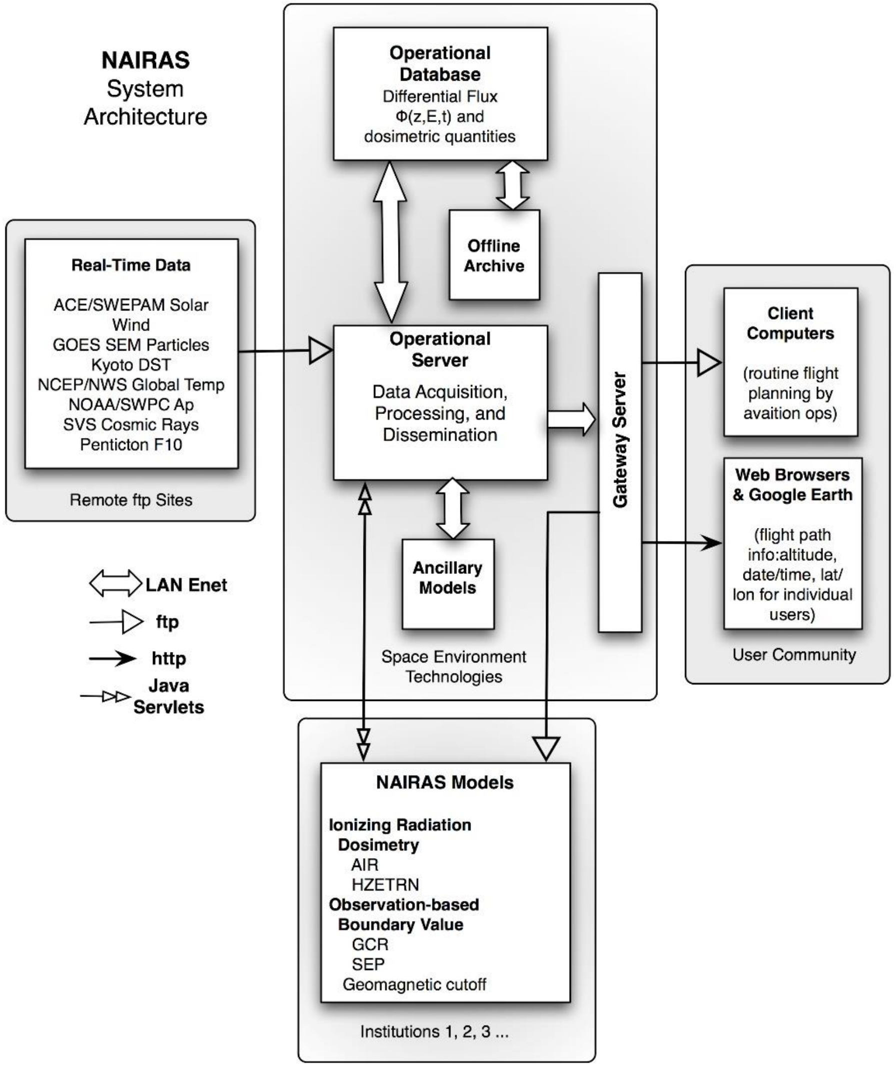
Example Proton Flux Maps



M. Matteo et al.,
November 2020

CCP Post-Flight Reference Radiation Environments

- **NASA uses conservative ionizing radiation design environments to predict single event effects (SEE) and total ionizing dose (TID) in design of launch vehicle and spacecraft avionics**
  - The goal of using conservative radiation design environments is to assure SEE rates and TID during flight operations are within avionics design margins
- **Flight programs are often interested evaluating how their avionics perform in the flight radiation environment with respect to SEE and TID and compare these results to the preflight assessments**
  - Requires an estimate of the radiation environment during flight, often for launch vehicles or spacecraft without charged particle sensors or dosimeters to measure the flight radiation environment
- **NESC team is developing an operational version of the Nowcast of Aerospace Ionizing Radiation System (NAIRAS) software as a solution to generating the required flight radiation environments**
  - Technical Lead: Insoo Jun/JPL
  - Team: GSFC, JPL, KSC, LaRC, MSFC, NESC
- **NAIRAS provides only the radiation environment, upset rates are computed using the environments as inputs to other tools**
  - Examples include the CRÈME-MC (CREME96) and SIRE2 software packages as well as other contractor proprietary radiation effects tools



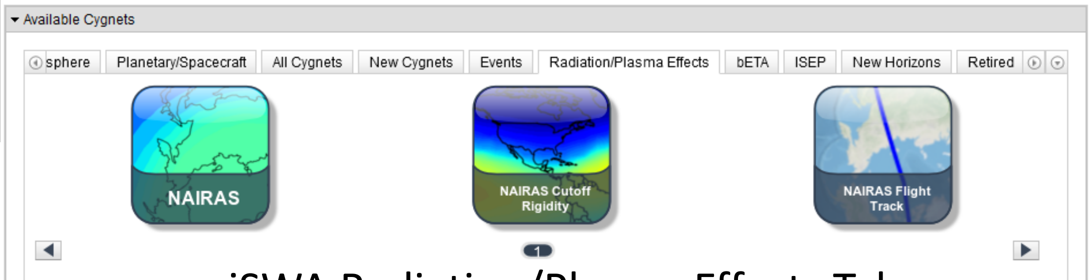
https://sol.spacenvironment.net/nairas/

NAIRAS Real-Time Model

- NAIRAS Real-Time Global model dosimetric quantities available through CCMC Integrated Space Weather Analysis System (iSWA):

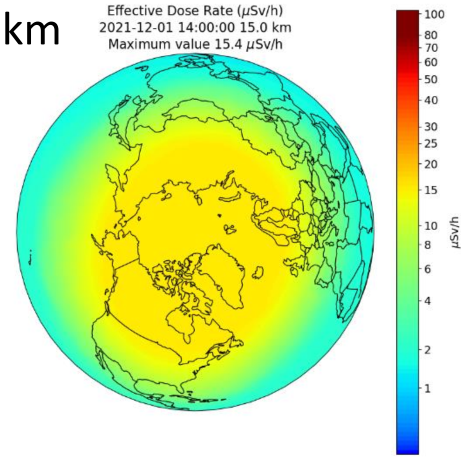
  URL: https://ccmc.gsfc.nasa.gov/iswa/

- NAIRAS products:
  - Dose maps (effective dose, Si absorbed dose, tissue absorbed dose, ambient dose equivalent, tissue dose equivalent) at 5, 11, 15, and 40 km altitude
  - Cutoff rigidity map
  - Tissue dose equiv. along Seoul/New York flight path

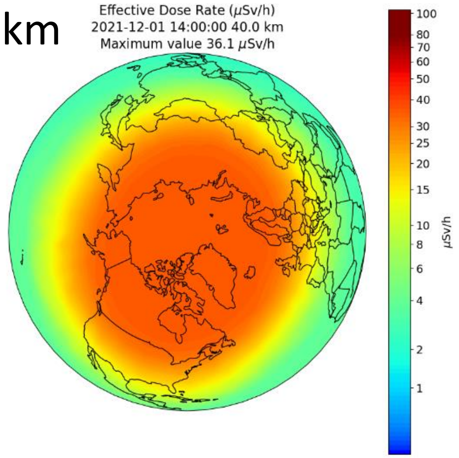


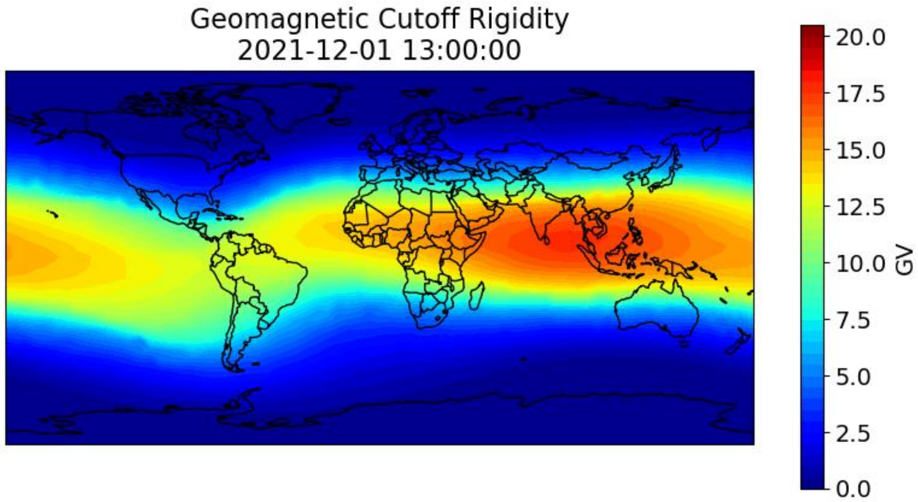
iSWA Radiation/Plasma Effects Tab

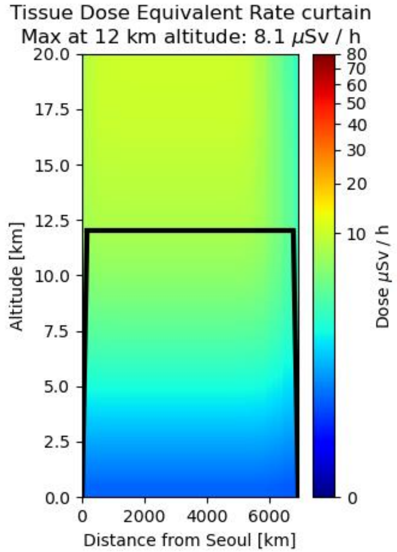
15 km



40 km







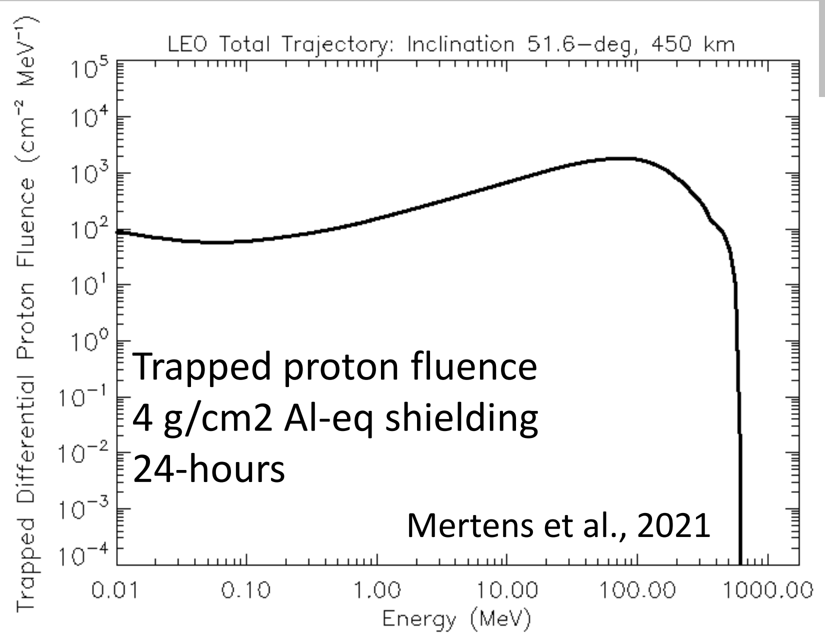
NAIRAS Runs-on-Request

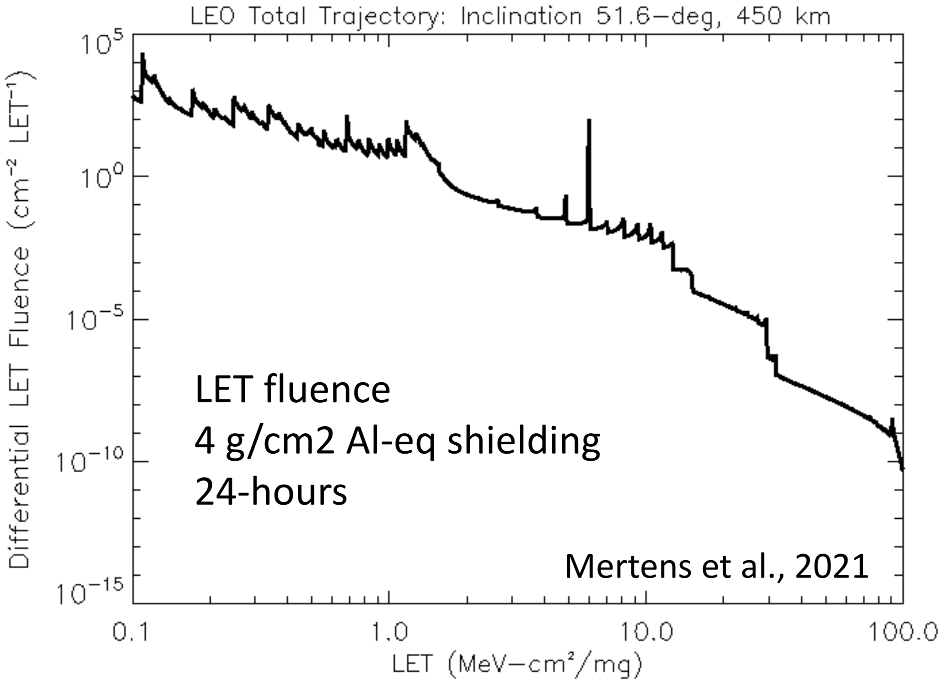
- A NAIRAS run-on-request version will be deployed on CCMC servers providing users with an interactive capability for obtaining NAIRAS results for specific mission profiles including user provided flight trajectories

- Global dosimetric quantities
  - Same dosimetric quantities as real-time model
  - Cutoff rigidity maps
  - Dose quantities along flight path

- Trajectory quantities
  - Dosimetric quantities
  - GCR integral, differential LET flux and fluence
  - Trapped proton integral, differential flux and fluence
  - SEP proton integral, differential flux and fluence

- User uploads a trajectory file, defines shielding depths of interest to define the mission that can include aeronautical flight paths, suborbital and orbital launch trajectories, balloon flights, and LEO orbits





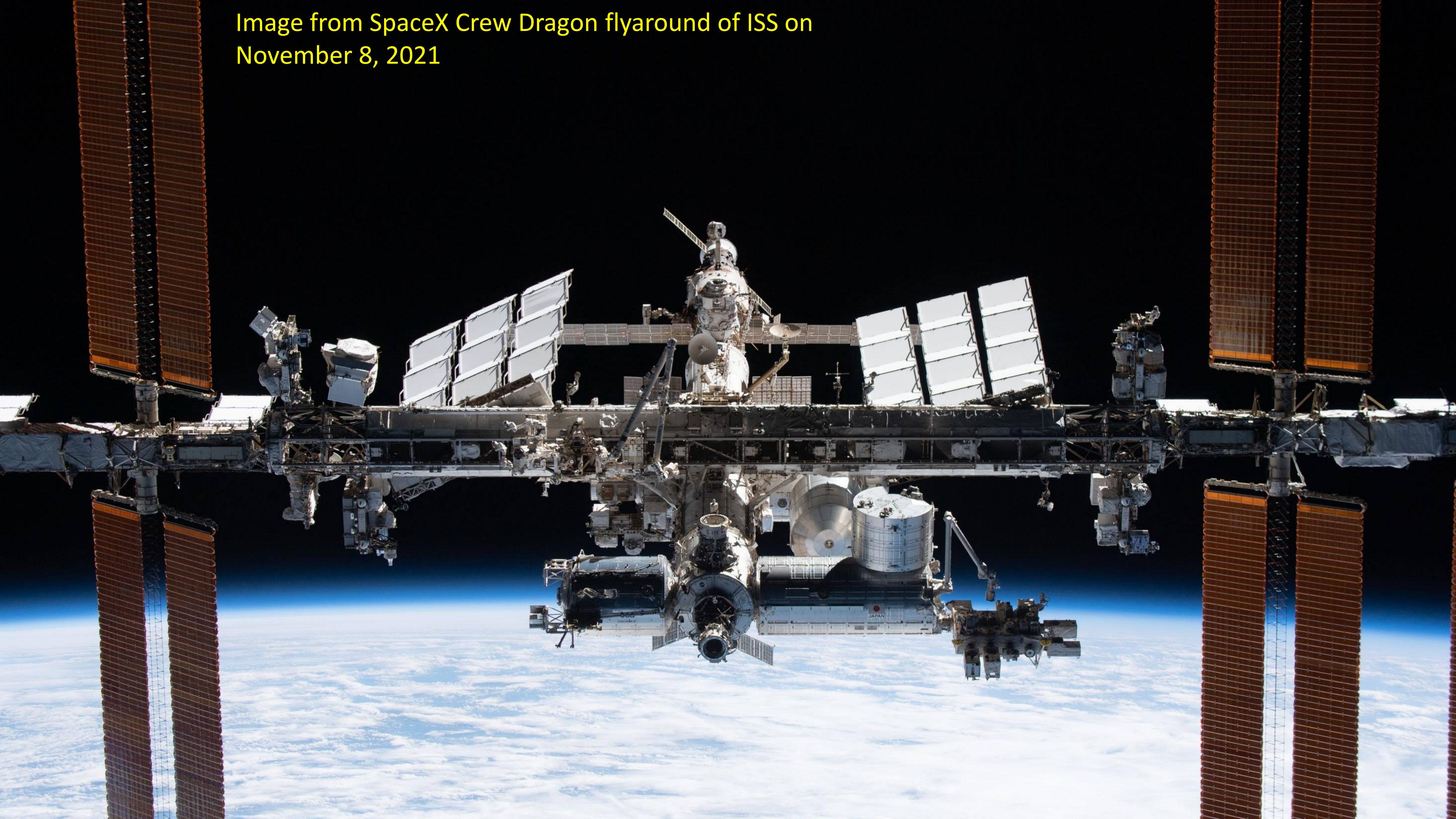


Image from SpaceX Crew Dragon flyaround of ISS on November 8, 2021

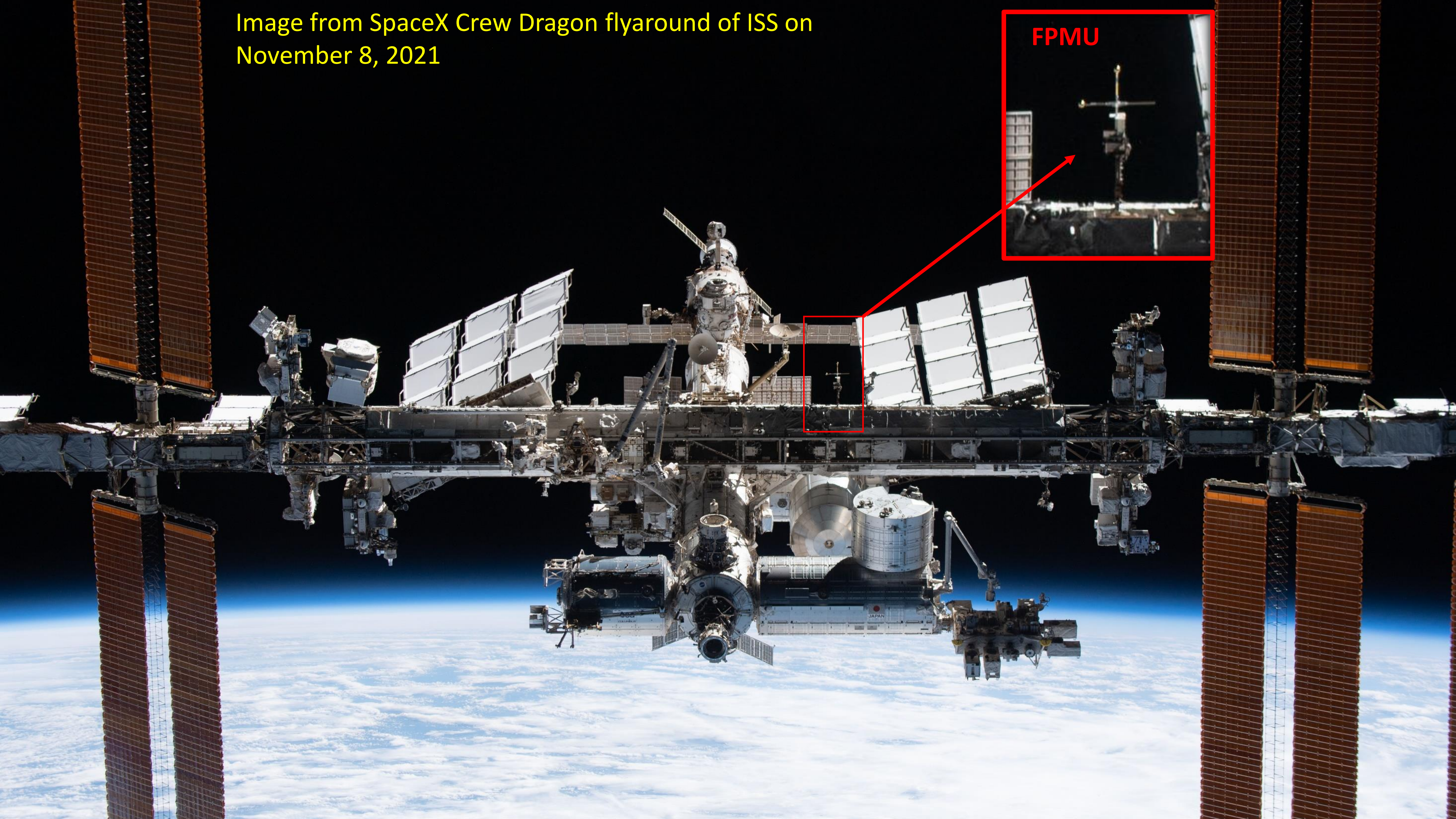


Image from SpaceX Crew Dragon flyaround of ISS on November 8, 2021
FPMU

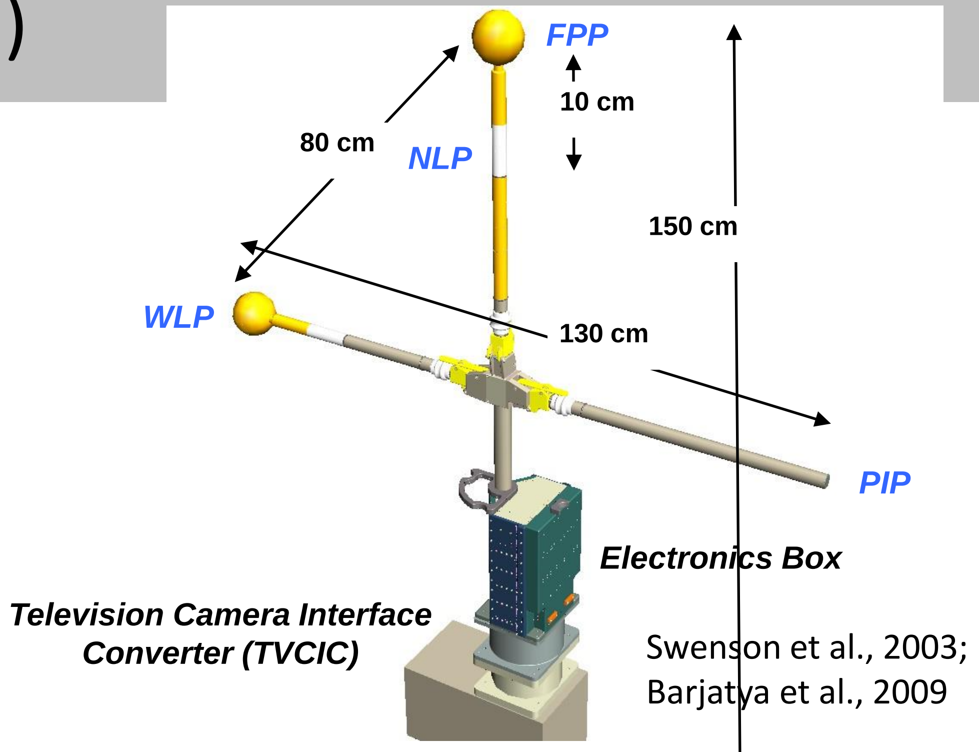
Floating Potential Measurement Unit (FPMU)

- FPMU is a suite of four plasma instruments originally deployed on the ISS in August of 2006, new instrument deployed September 2021

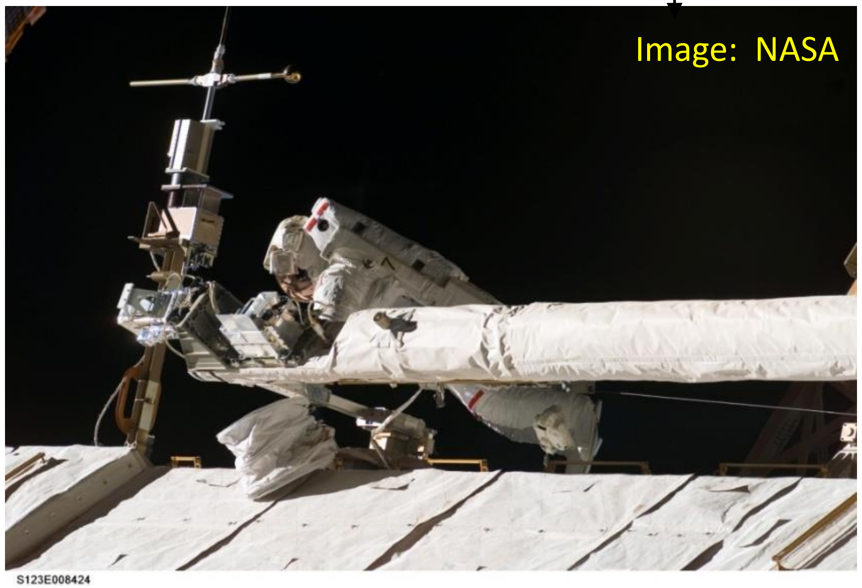
Narrow Langmuir Probe (NLP)	1 Hz	Ne, Te, Ni, Vf, Vp
Wide Langmuir Probe (WLP)	1 Hz	Ne, Te, Ni, Vf, Vp
Floating Potential Probe (FPP)	128 Hz	Vf
Plasma Impedance Probe (PIP)	1 Hz	Ne

- Primary use is 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 is 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.



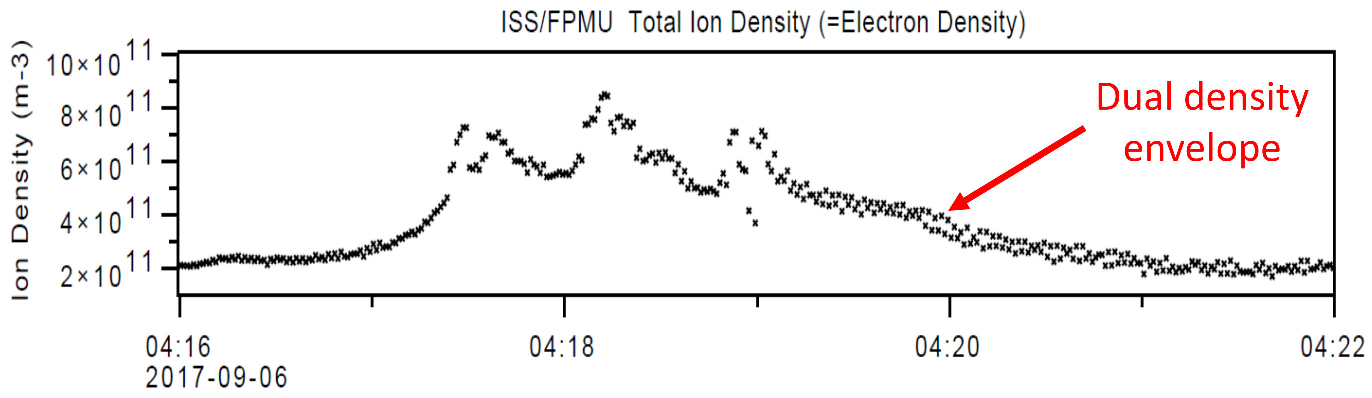
Swenson et al., 2003; Barjatya et al., 2009

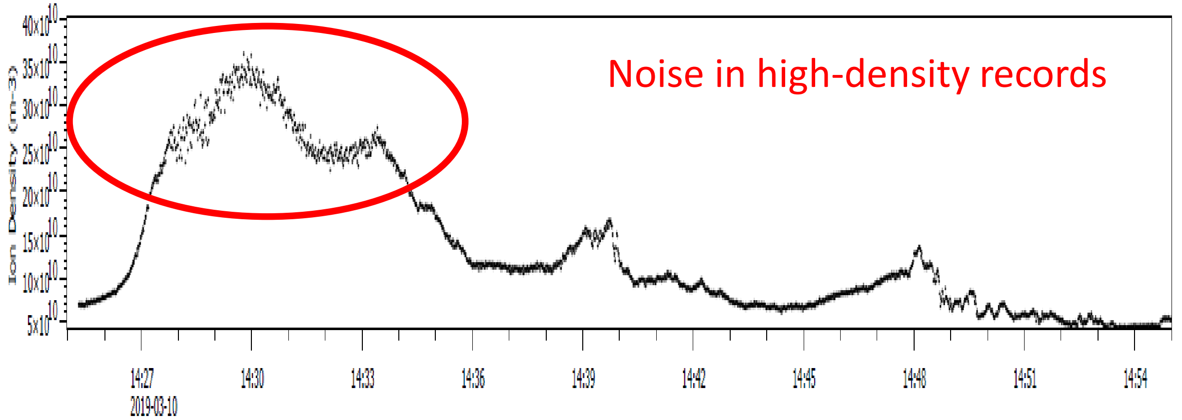


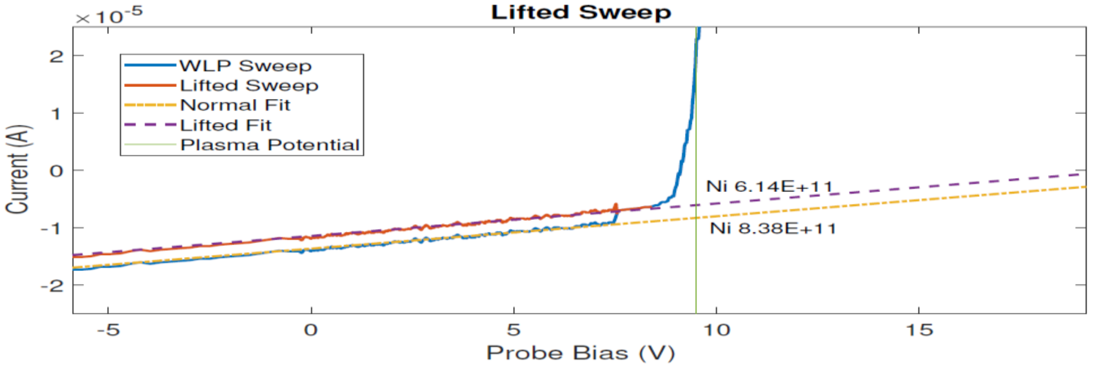
FPMU Data Processing Algorithm Development

- NESC assessment team:
  - Tech Lead: Linda Parker
  - Team: Embry-Riddle Aeronautical University (ERAU), MSFC, NESC

- ERAU identified and developed corrections for a number of data issues, including:
  - Hysteresis
  - Dip in ion-saturation region
  - Dual density envelope feature
  - Noise in high-density records
  - Electron temperature noise spikes
  - Anomalously high electron temperatures
  - WLP low-gain/high-gain channel offset
  - Photoemission currents
  - H+/O+ ratio

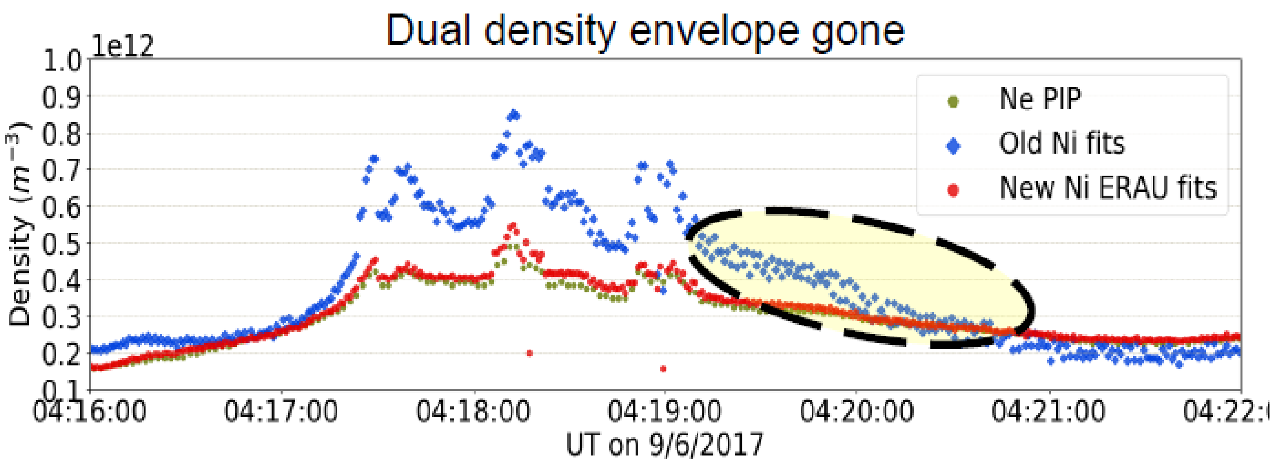


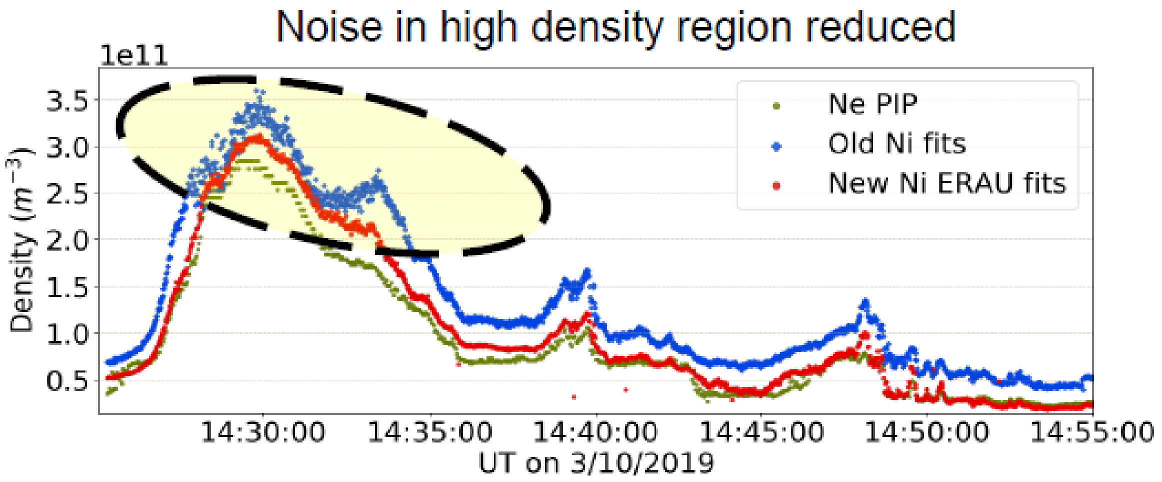




Debchoudhury and Barjatya, 2020

FPMU Corrected Density Data





Sweep Time	Sweep Type	Old Ni (m^{-3})	New Ni (m^{-3})	Old fits (% difference from previous sweep)	New fits (% difference from previous sweep)
04:19:59	Up	3.81e11	3.12e11	13.65	3.66
04:20:00	Down	3.15e11	2.97e11	20.95	4.77
04:20:01	Up	3.55e11	3.00e11	11.27	0.85
04:20:02	Down	3.13e11	2.96e11	13.42	1.44
04:20:03	Up	3.35e11	2.98e11	6.57	0.61
04:20:04	Down	2.89e11	2.89e11	15.92	2.92
04:20:05	Up	3.52e11	2.94e11	17.90	1.70
04:20:06	Down	2.93e11	2.86e11	20.14	2.72

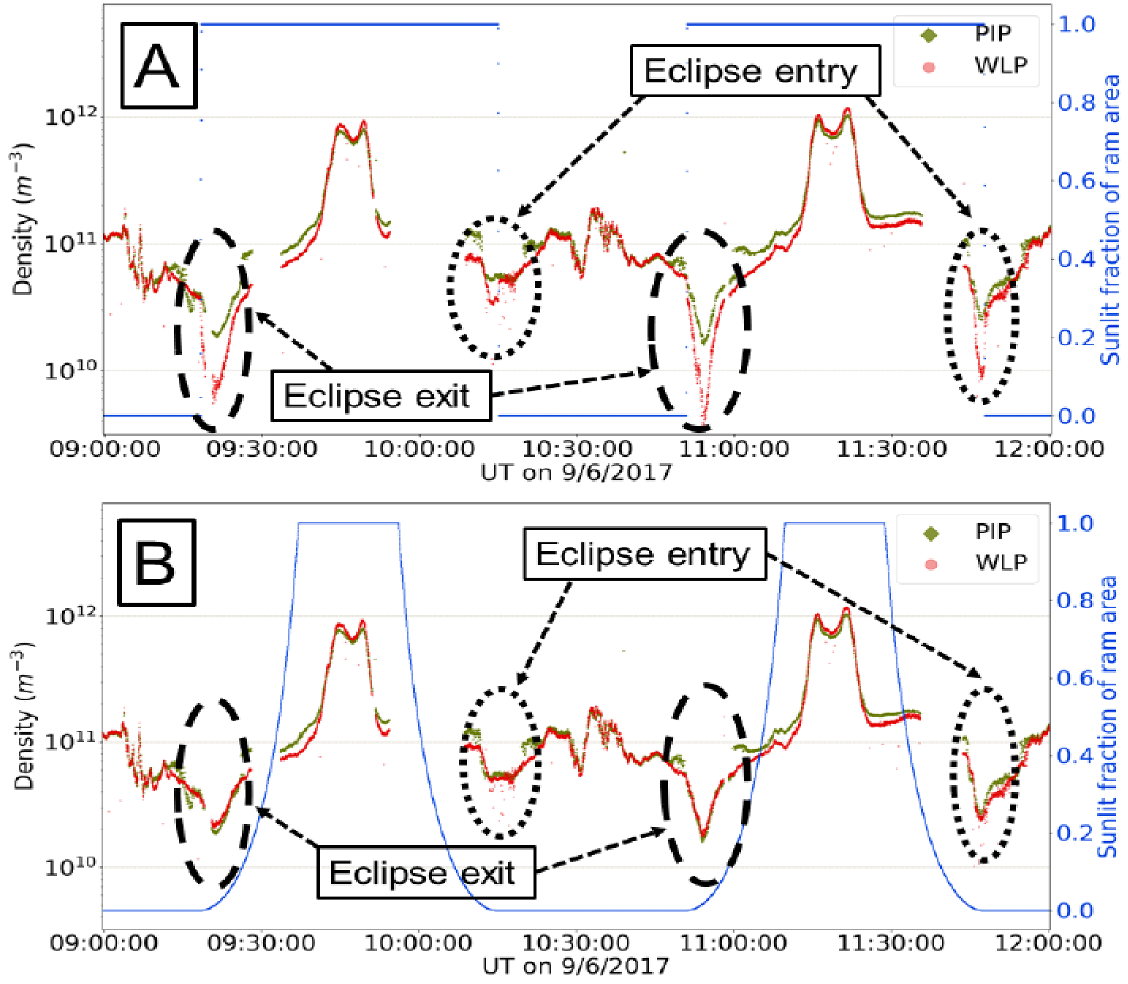
- Average inter-sweep error using old fits = 15%
- Average inter-sweep error using the new ERAU fits = 2%

Debchoudhury and Barjatya, 2020

Debchoudhury and Barjatya, 2020

FPMU Photoemission Correction

- Photoelectron emission currents were not included in the original NASA data reduction algorithms (expected to only be significant at very low densities).
- Initial attempt to correct for photoemission used a flat profile for solar illumination:
  - 100% illumination in sunlight
  - 0% illumination in darkness
  - Photoelectron saturation current for Au
- Latest ERAU photoemission correction is based on varying illumination through orbit:
  - Angle to the Sun (θ)
  - Angle to the orbit (β)
- Ni values derived using the new algorithm provides geophysical results.
- New Ni matches PIP profile:
  - PIP provides Ne values from radiofrequency (RF) method, independent of photoemission.



A) Constant photoelectron profile:
- 100% illumination in daylight
- 0% illumination in darkness
- WLP Ni and PIP Ne difference:
  - 27% in sunlight
  - 16% overall

B) Adjusted photoelectron profile:
- θ, β angle dependence through orbit
- WLP Ni and PIP Ne difference:
  - 11% in sunlight
  - 14% overall

H+/O+ Fits

- Original NASA data processing algorithms assumed ionosphere at ISS orbital altitude is 100% O+ ions:
  - H+ ions can contribute to ion composition at ISS altitudes during solar minimum conditions
  - H+ has a higher thermal speed compared with that of O+, resulting in a significant difference in ion current at attractive potentials
  - ERAU modified the processing algorithms to include ion mass and an O+/H+ ratio fit when V < Vp.

Stage I: (gives accurate fits for N,Te,Vp)

Fitting region: V from [-20,Vf+0.1V]
Fit parameters: $N, T_e, V_p, \beta, m_i, T_i$
Fit equations:

$$I_{total} = I_i + I_e == I_{ram} + I_{OML} + I_e$$

$$I_{OML} = NeA\sqrt{\frac{KT_i}{2\pi m_i}}\left(1 - \frac{e(V - V_p)}{kT_i}\right)^{\beta}$$

$$I_e = NeA\sqrt{\frac{KT_e}{2\pi m_e}}\exp\left(\frac{e(V - V_p)}{kT_e}\right)$$

$$I_{ram} = NeA_{proj}v_{sat}$$

Stage II: (fix accurate N,Te and Vp from Stage I to better resolve O+/H+ ratio and Ti)

Fitting region: V from [-20, Vf - 0.5V]
Fit parameters: pO, T_i
Fit equations: *(Hoegy and Brace, Rev. Sci Instrum.1999)*

$$I_{total} = I_i + I_e == I_{ram} + I_O + I_H + I_e$$

$$I_j = p_j NeA\sqrt{\frac{KT_i}{2\pi m_i}}\left[\frac{1}{2}\exp(-r_j^2) + \frac{(\eta + r_j^2 + \frac{1}{2})}{r_j}\frac{\sqrt{\pi}}{2}\mathrm{erf}(r_j)\right]$$

where, $r_j = \frac{u_o}{\sqrt{\frac{2kT_i}{m_j}}}$, $\eta = \frac{-e(V-V_p)}{kT_i}$, and *j* can be O+ or H+

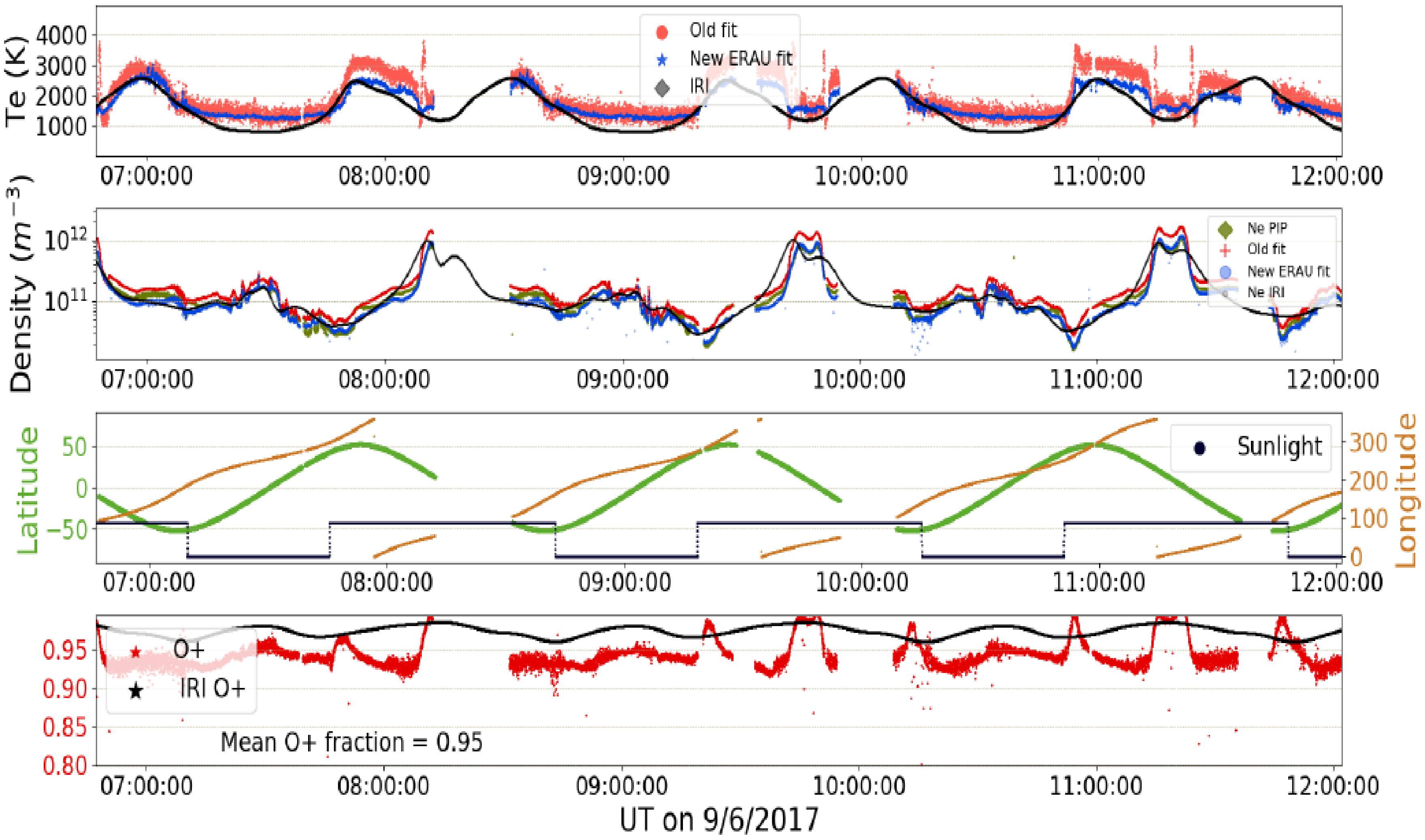
Bulk ion velocity $u_o \sim v_{sat}$ in the satellite reference frame and fraction p_j is constrained to fit $p_O + p_H = 1$.

Debchoudhury et al., 2021

H+/O+ Fits

- ERAU Ni matches closely with PIP Ne (11% for new fits versus 24% for old fits).

- All physical parameters match reasonably well with the International Reference Ionosphere (IRI) climatology model



Debchoudhury and Barjatya, 2021

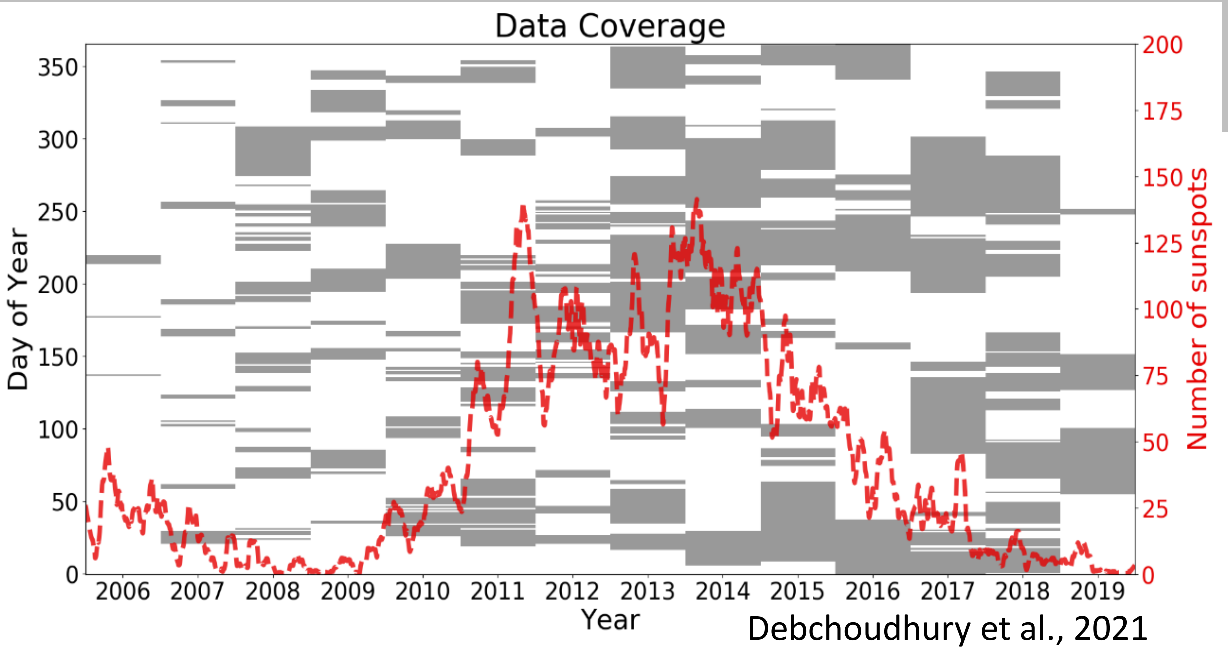
CDAWeb Data Archives

- MSFC/EV44 is providing the FPMU plasma environment records to the science community through the CDAWeb archive at GSFC's Space Physics Data Facility
  - URL: https://cdaweb.gsfc.nasa.gov/index.html/
  - Source: ISS Instrument Type: Plasma and Solar Wind
  - Select: ISS_SP_FPMU

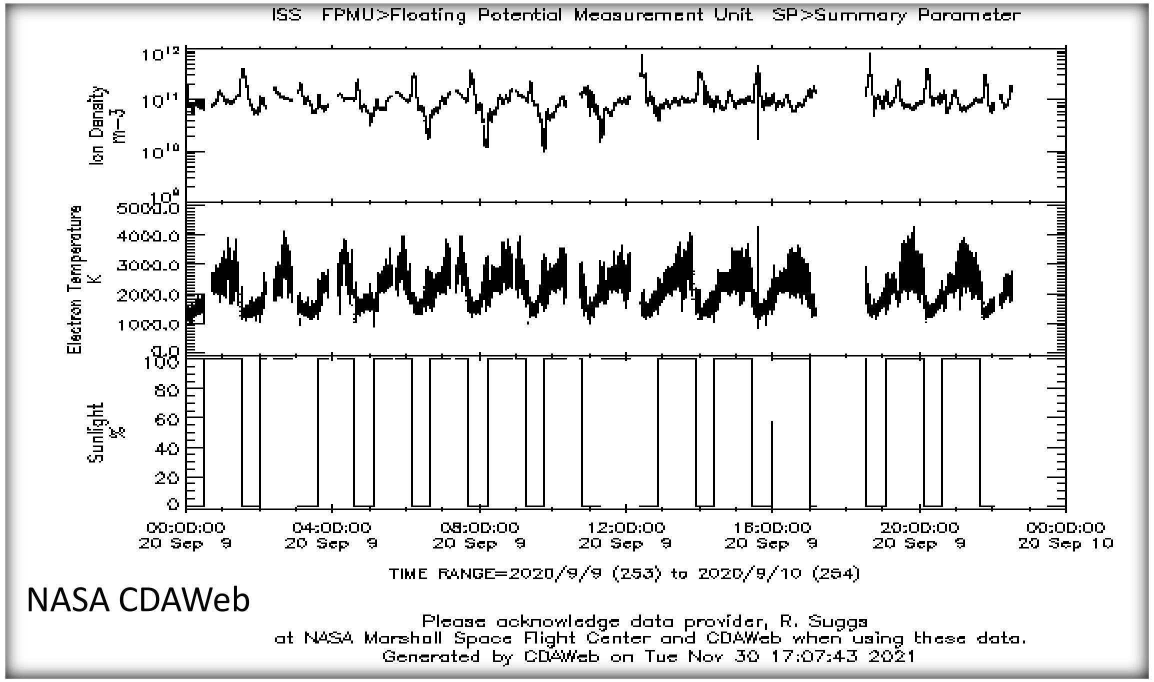
- Current CDAWeb FPMU holdings include the 2006/08/03 to 2020/09/14 (~full data set from original FPMU)

- ERAU is reprocessing the full data set using the updated processing algorithms, an updated set of plasma density and temperature, spacecraft floating potential, and light ion ratio will be provided to CDAWeb in the near future

- CDAWeb holdings will be updated periodically as records from the new FPMU become available



Debchoudhury et al., 2021



NASA CDAWeb

Gateway/NESC Electrical Properties of Materials

- Gateway Program and NESC collaboration to obtain electrical properties of materials used in spacecraft charging analyses for Orion, Gateway, and other NASA programs.

- Technical support activity obtains expertise from Utah State University (USU) solid state physics group with extensive experience in testing of material electrical properties relevant to spacecraft charging (led by Dr. JR Dennison/USU)

- Electrical properties included in work are:
  - Dielectric constant
  - Volume and surface conductivity (=1/resistivity)
  - Secondary electron yield due to incident electrons, protons
  - Backscattered electron yield
  - Photoemission yield
  - Dielectric breakdown strength
  - Radiation induced conductivity parameters
  - Other material properties (density, effective atomic number, etc)

- Data formatted for the 19 Nascap-2k surface charging code material parameters, also applicable to internal charging analysis

Technical 316 Stainless Steel (Clean, Smooth)

Parameters for NASCAP Materials Properties

Parameter	Value
[1] Relative dielectric constant; ε_r (Input as 1 for conductors)	1, NA
[2] Dielectric film thickness; d	0 m, NA
[3] Bulk conductivity; σ_o (Input as -1 for conductors)	-1; $(1.4\pm0.1)\cdot10^{6}$ $ohm^{-1}\cdot m^{-1}$
[4] Effective mean atomic number $\langle Z_{eff}\rangle$	28.6± 0.05
[5] Maximum SE yield for electron impact; δ_{max}	1.17 ± 0.03
[6] Primary electron energy for δ_{max}; E_{max}	(0.311 ± 0.002) keV
[7] First coefficient for bi-exponential range law, b_1	1 Å, NA
[8] First power for bi-exponential range law, n_1	1.51 ± 0.02
[9] Second coefficient for bi-exponential range law, b_2	0 Å
[10] Second power for bi-exponential range law, n_2	0
[11] SE yield due to proton impact δ^H (1keV)	0.357 ± 0.001
[12] Incident proton energy for δ^H_{max}; E^H_{max}	(600 ± 200) keV
[13] Photoelectron yield, normally incident sunlight, j_{pho}	$(2.86 \pm 0.1) \cdot 10^{-6}$ $A\cdot m^{-2}$
[14] Surface resistivity; ρ_s (Input as -1 for conductors)	-1 $ohms\cdot square^{-1}$, NA
[15] Maximum potential before discharge to space; V_{max}	10000 V, NA
[16] Maximum surface potential difference before dielectric breakdown discharge; V_{punch}	2000 V, NA
[17] Coefficient of radiation-induced conductivity, σ_r; k	0 $ohms^{-1}\cdot m^{-1}$, NA
[18] Power of radiation-induced conductivity, σ_r; Δ	0, NA
[19] Density; ρ	$(8.03 \pm 0.02) \cdot 10^{3}$ $kg\cdot m^{-3}$

NA -- Not applicable or approximated for bulk conductors

Values measured at USU in blue.

Dennison, 2021

Gateway/NESC Electrical Properties of Materials

- Materials chosen on basis of applicability to charging of
  - Task 1: Gateway, Orion, and NDSB2 hardware
  - Task 2: NESC materials of general interest to NASA programs

- Preliminary materials analysis uses existing USU data, science and engineering literature, and USU expertise.

- Materials of interest fall into 5 categories
  - Basic Materials – Conductors
  - Basic Materials – Insulators
  - Basic Materials – Coated Materials
  - Lubricants
  - New Untested Materials

- Surface state (e.g., clean or oxidized, smooth or rough) that can impact charging included when relevant

- Data generated by the activity (which materials is TBD) will be incorporated into the Spacecraft Charging Materials Database (SCMD) where it will be available to NASA and external personnel

Basic Materials

Conductors

- √ **Copper**
  - Technical, Moderately rough, Moderately oxidize
  - Clean Cu (Low Oxidization, Low Roughness)
  - Oxidized Cu (Heavy Oxidization, Low Roughness)
- √ **Aluminum**
  - Technical, Moderately rough, Moderately oxidized (Al alloys 6061-T651 and 7075-T7351)
  - Smooth, Clean High Purity Elemental Al
  - Oxidized Al
- √ **Stainless Steel**
  - Technical 316 Stainless Steel (Clean, Smooth)
  - Technical 304 Stainless Steel (Clean, Smooth)
  - Technical Stainless Steel (Contaminated, Rough)
- √ **Ti**
  - Technical Ti Alloy 6Al4V
  - Smooth, Clean High Purity Elemental Ti
  - Rough, Contaminated Elemental Ti
- √ **Cr**
  - Technical Cr
  - Smooth, Clean High Purity Elemental Cr
- √ **Ni**
  - Technical Ni
  - Smooth, Clean High Purity Elemental Ni
- √ **Inconel**
  - Technical Inconel
- √**Mo**
  - Rough, Contaminated High Purity Elemental Mo
  - Technical Mo
- √**W**
  - Technical W
  - Smooth, Uncontaminated High Purity Elemental W

Dennison, 2021

Gateway/NESC Electrical Properties of Materials

Basic Materials

Insulators

- √ **Kapton HN (Bulk Technical Polyimide)**
- √ **Black Kapton (Kapton® XC Black Conductive Polyimide Film)**
- √ **Teflon**
  - Teflon PTFE (polytetraflouroethylene)
  - Teflon PFA (perfluoroalkyoxy)
  - Teflon FEP (tetrafluoroethylene hexafluoropropylene-copolymer)
  - Tefzel ETFE (ethylene tetrafluoroethylene)
- √ **Silicone Rubber (PVMQ)**
- √ **RTV-Silicone Adhesives**
  - Dow DC-93-500
  - NuSil Technology CV-2510
- √ **Epoxy (Insulating potting material?)**

Lubricants

- **Diffusion Pump Oil**
  - √ Silicone Diffusion Pump Oil DC 704-705
  - √ Hydrocarbon Diffusion Pump Oil Octoil-S
- **Grease**
  - √ Silicone Grease
  - √ Perfluoropolyether (PFPE) Grease
  - √ Silahydrocarbon (SiHC, Mineral Oil) Grease
- √ **Braycote 815Z lubricant (polymer grease)**
- √ **Braycote 601EF lubricant (MoS_2-based polymer grease)**
- √ **NPI-1220C Lubricant (graphite/MoS_2/ceramic comp. lube)**
- √ **NPI 425 Lubricant (MoS_2/polyimide composite lubricant)**
- √ **Everlube 620C Molybdenum Disulfide Lubricant (MoS_2 in phenolic binder)**
- √ **Molybdenum Disulfide (MoS_2) Dry Lubricant**
- √ **Tungsten Disulfide (WS_2) Dry Lubricant**

Basic Materials

Coated Materials

- √ **Sulfuric (Hard) Anodize Aluminum**
- √ **Chromic Anodize Aluminum**
- √ **Tiodize Type II coating**
- √ ***Chem Film Chromate Coating***
- √ ***Graphitic Amorphous Carbon***
- √ ***Aquadag Graphite Lubricant***

New Untested Materials

- **MLI (Teflon-coated glass fiber Beta cloth)**
- √ Teflon-coated glass fiber Beta cloth—Teflon limiting case
- √ Teflon-coated glass fiber Beta cloth—SiO_2 limiting case
- √ Aluminum-coated glass fiber Beta cloth—technical Al limiting case
- **Umbilicals**
- √ Cable electrical insulation (PTFE)
- √ Sleeving (PFA)
- **Carbon Fiber Epoxy Resin Composite**
- √ Carbon Fiber Epoxy Resin Composite
- √ Carbon Fiber
- √ Epoxy Resin

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Gateway/NESC Electrical Properties of Materials

(black) Space Environments and Effects (SEE) Charging Database enhanced material reports
(red) New materials

Key for Status of Work on Materials

1 Materials Report in new format. New information partially added. Materials Reports not fully finalized
2 Added to USU Range Tool
3 Added to USU SEY Materials Database
4 Fit with NASCAP and ERPL SEY Models

USU SEE Spacecraft Charging Materials Database

1234 Aluminum (oxidized)
1234 Aluminum 6061-T6 (technical)
1234 Beryllium
1234 Carbon-Aquadag
1234 Carbon-Amorphous (g-C)
1234 Carbon-HOPG graphite
1234 Copper
1234 Gold
1234 Silver

1234 Black Kapton
1234 Carbon-Filled Polyester

1234 Al on 2 µm PI
1234 Al on 8 µm PI
1234 Al on PET
1234 Al on PI on ITO
1234 Ag/Inconel on FEP

Additional Materials for NSEC Database

1234 Kapton
234 PEEK
234 PTFE
234 LDPE

1234 SiO_2 (fused quartz)
1234 Al_2O_3 (microcrystalline ceramic)
1234 Al_2O_3 (sapphire)

1234 Mo
1234 Stainless Steel

1234 Ge-PI
1234 ITO on PI on Al
1 34 L'Garde Solar Sail

Dennison, 2021

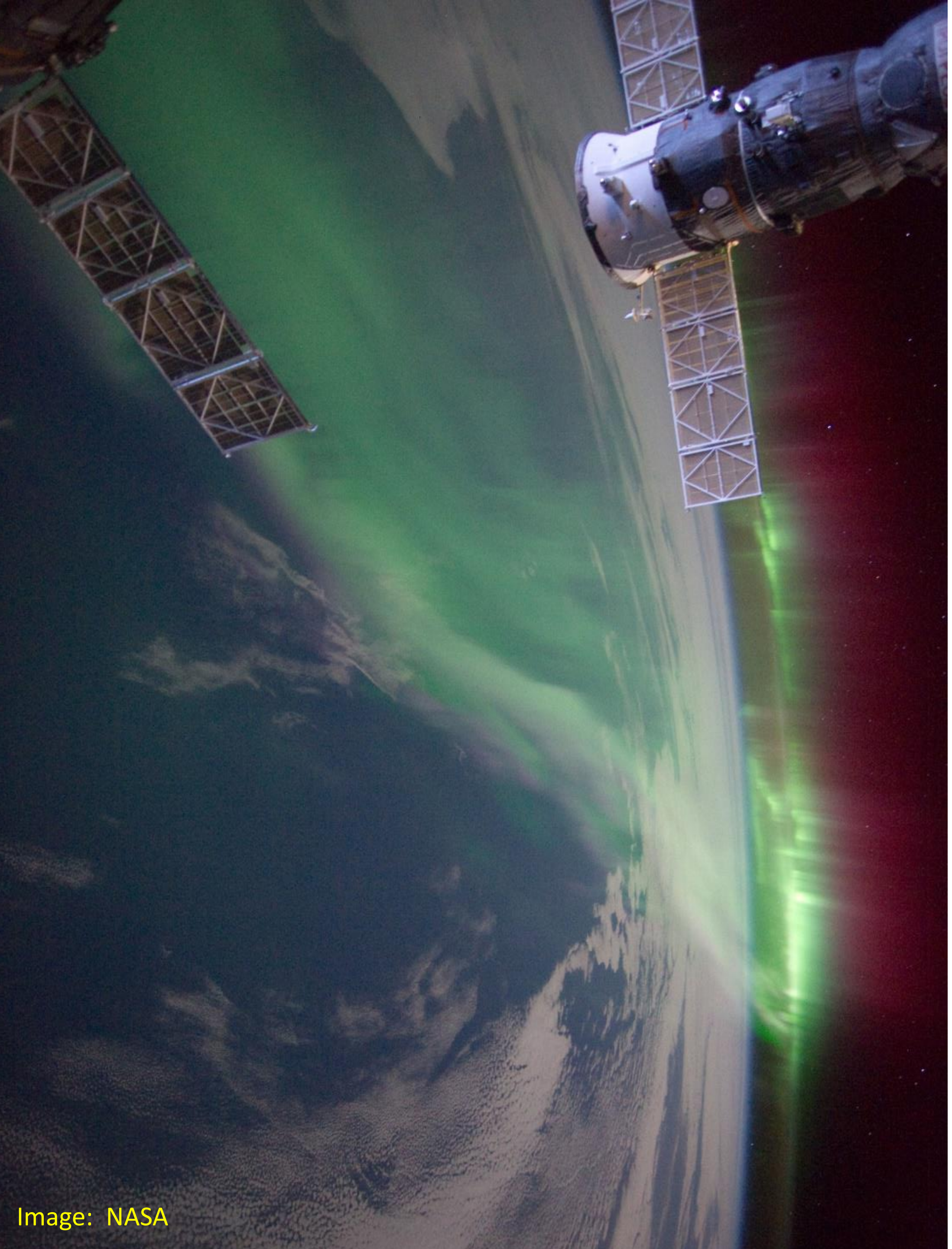
Image: NASA

Questions?