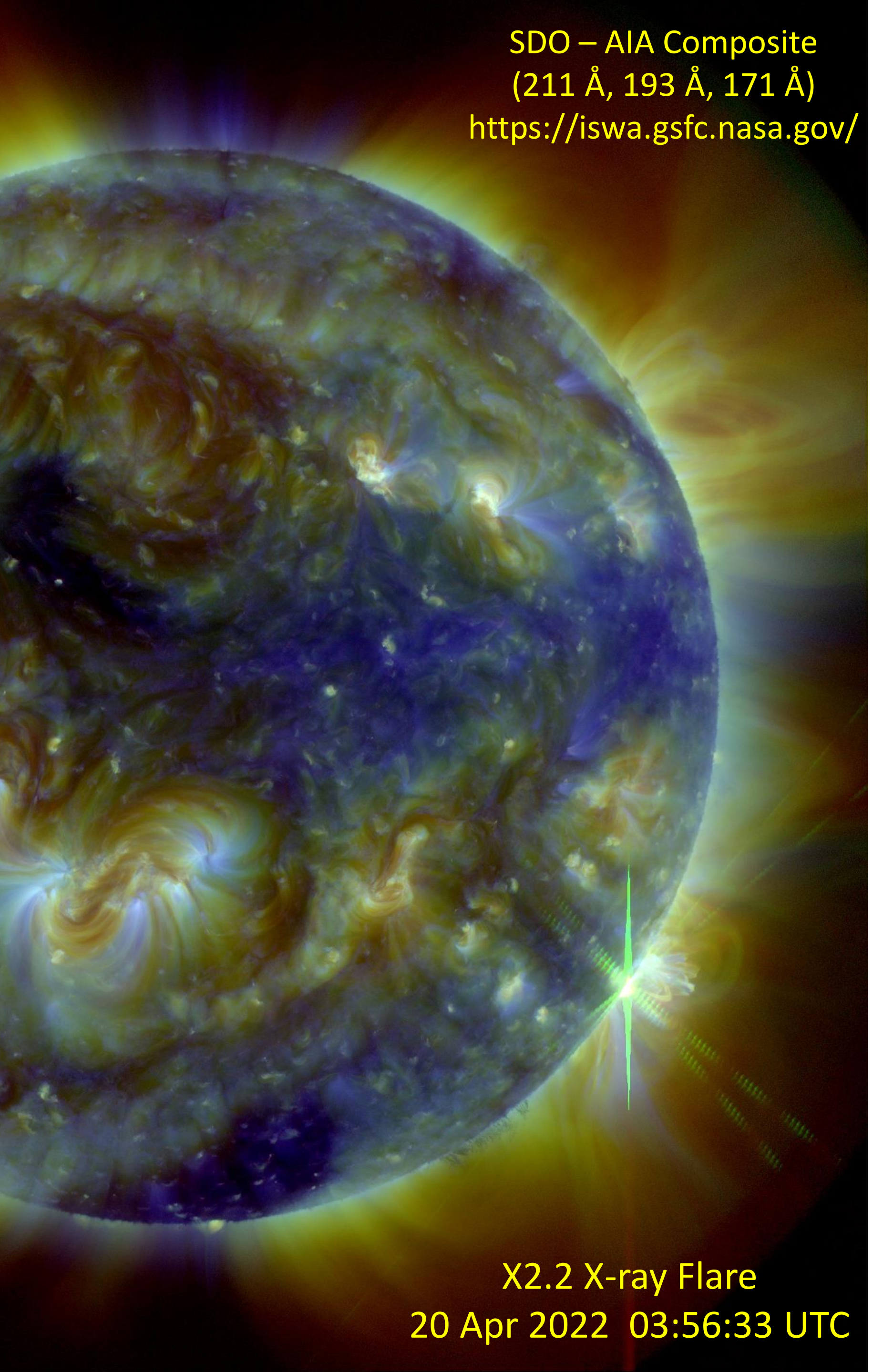


NESC Space Environments Activities

Joseph Minow
NASA Engineering and Safety Center (NESC)
Langley Research Center

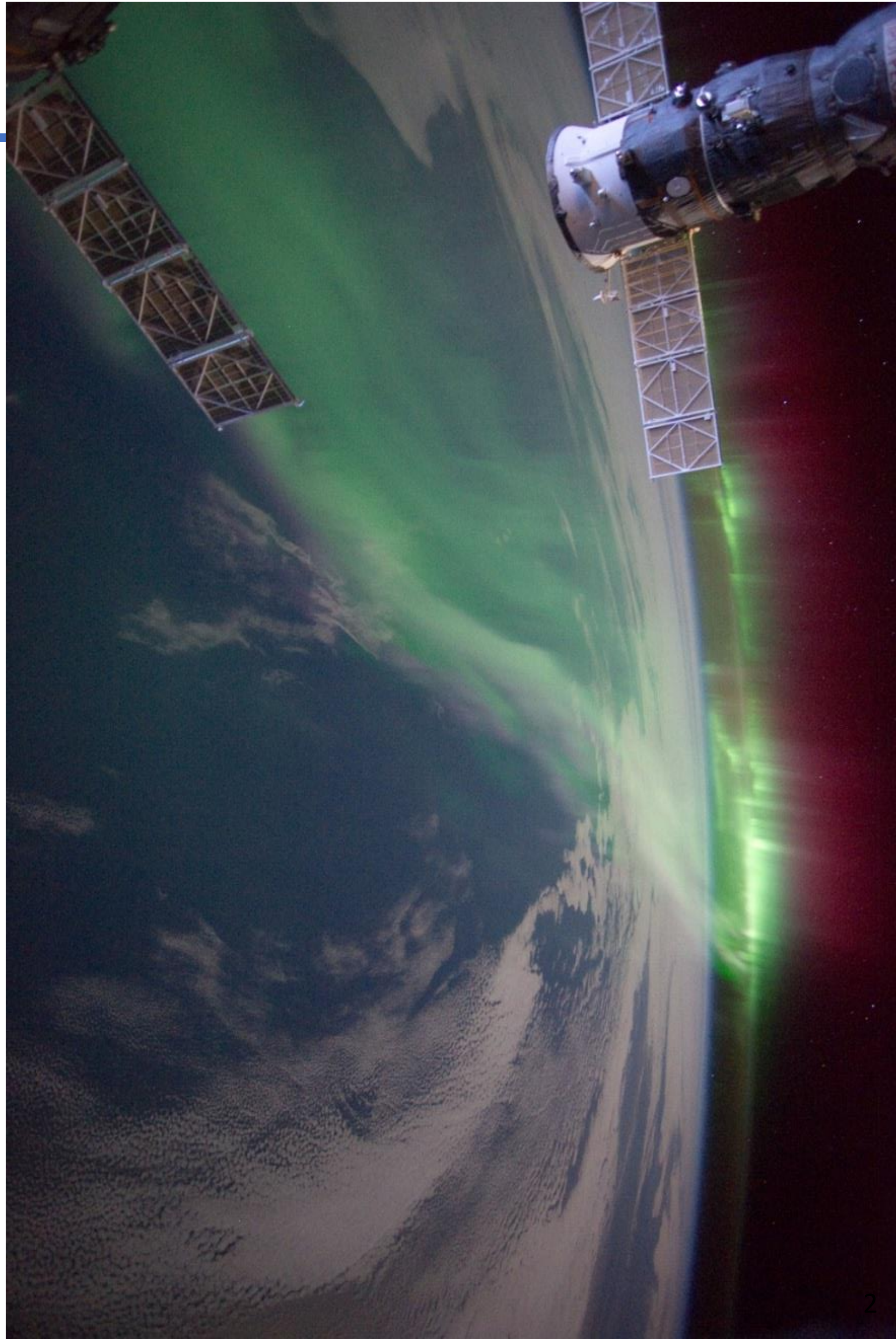
Space Environmental Effects and Science Applications Workshop
JHU/APL, Laurel, MD
12 – 16 September 2022

joseph.minow@nasa.gov

NESC Space Environments Discipline Scope

Space environments and their effects that impact the design, construction, and operation of NASA's human and robotic space systems and health of the crew

- Ionizing radiation, neutral energetic particles
- Meteoroids and orbital debris, hypervelocity impact
- Gravitational fields, microgravity
- Magnetic, electric fields and currents
- Space plasma, spacecraft charging
- Neutral atmosphere, vacuum, atomic oxygen
- Photons (IR, visible, UV/EUV, x-ray, gamma-ray)
- Applied space climate and space weather
- Planetary and interplanetary dust



Space Environments Assessment, Support Activities (since last SEESAW)

ID	Title	Discipline	Type	NESC Lead	Tech Lead	ECD
TI-17-01215	Space Weather Architecture	Radiation	**A**	**Minow**	**Parker**	**Complete**
TI-17-01257	NOVICE Support to LSP and CCP Radiation Assessment	Radiation	**S**	**Minow**		**Complete**
TI-18-01404	**PAMELA Radiation Data Recovery Technical Support**	**Radiation**	**S**	**Minow**	**Minow**	**Complete**
TI-19-01433	**Badhwar-O'Neill Galactic Cosmic Ray Model Improvements**	**Radiation**	**A**	**Minow**	**Jun**	**08/04/2022**
TI-19-01468	**CCP Post-flight Reference Radiation Environments**	**Radiation**	**A**	**Minow**	**Jun**	**08/31/2022**
TI-20-01520	***Independent Assessment Study for the GSFC LISA Laser***	***Radiation***	***A***	***Singh****	***Horan***	***Complete***
TI-21-01718	***Space-Shielding Radiation Dosage Code Evaluation and Identification***	***Radiation***	***A***	***Gentz****	***Jun***	***08/31/2022***
TI-20-01589	***Safe Human Expeditions Beyond LEO***	***Radiation, Microgravity***	***A***	***Valinia****	***Minow***	***Complete***
TI-22-01792	**Roman Space Telescope Radiation and Charging Support**	**Radiation, Plasma/Charging**	**S**	**Minow**	**Minow**	**09/30/2022**
TI-17-01281	**Europa Lander Radiation Test Technical Support**	**Radiation, Plasma/Charging**	**S**	**Minow**		**Complete**
TI-18-01407	**Technical Support for Revising NASA-HDBK-4002A**	**Plasma/Charging**	**S**	**Minow**	**Minow**	**Complete**
TI-19-01428	**NASCAP Integrated Spacecraft Charging Analysis Support**	**Plasma/Charging**	**S**	**Minow**		**Complete**
TI-19-01434	**FPMU Data Processing Algorithm Development and Analysis Assessment**	**Plasma/Charging**	**A**	**Minow**	**Parker**	**12/31/2022**
TI-19-01435	**Orion, NDSB2, and Gateway Material Electrical Properties Support**	**Plasma/Charging**	**S**	**Minow**	**Minow**	**10/31/2022**
TI-20-01562	**Space Charging of Ocean Color Instrument (OCI) Rotating Mechanism**	**Plasma/Charging**	**S**	**Minow**		**Complete**
TI-21-01648	***Spacesuit Electrical Model Review***	***Plasma/Charging***	***S***	***Abney****		***Complete***
TI-22-01793	**Mars Sample Return CCRS-OS Charging Support**	**Plasma/Charging**	**S**	**Minow**	**Minow**	**09/30/2022**
TI-22-01794	**Auroral Charging Environments and Effects Assessment**	**Plasma/Charging**	**A**	**Minow**	**Parker**	**pending plan**
TI-22-01733	***Lessons Learned on Possible Incompatibility DART with its NEXT-C Ion Engine***	***Plasma/Charging, electric propulsion***	***A***	***Iannello****		***09/01/2022***
TI-17-01204	**Southern Hemisphere Meteoroid Environment Measurements**	**M/OD**	**A**	**Minow**	**Matney**	**09/30/2022**
TI-20-01576	**Lunar Meteoroid Ejecta Model Review**	**M/OD**	**A**	**Minow**	**Matney**	**Complete**
TI-21-01711	***Materials Expertise Support for Lucy Project ART Kevlar Lanyard Testing***	***UV/EUV, materials***	***S***	***Conaty****		***03/31/2022***
TI-22-01747	**Lunar Ground Testing Guidebook Support**	**Multiple Environments**	**S**	**Minow**		**05/31/2023**

**Space Environments contributing, activity led by other NESC personnel*

Type: (A) assessment (S) support

Space Environments Assessment, Support Activities (since last SEESAW)

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TI-19-01428	NASCAP Integrated Spacecraft Charging Analysis Support	Plasma/Charging	S	Minow		Complete
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TI-22-01747	Lunar Ground Testing Guidebook Support	Multiple Environments	S	Minow		05/31/2023

*Space Environments contributing, activity led by other NESC personnel

Type: (A) assessment (S) support

PAMELA Support Activity

- **NASA, ESA, and US Air Force collaboration to process PAMELA data for use in future 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)

- 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

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

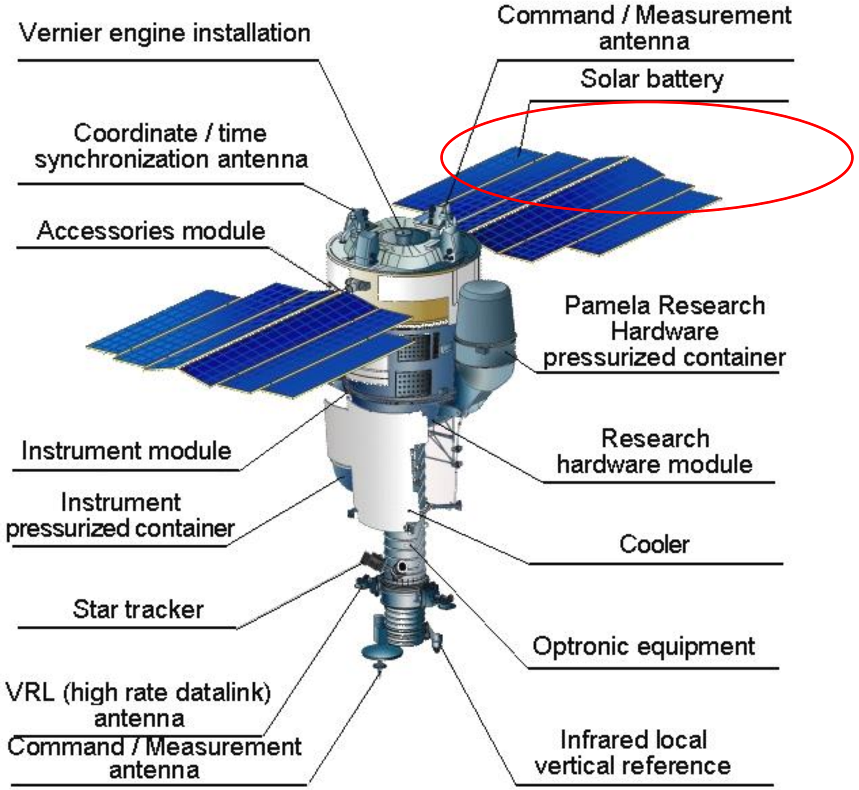


Image: Roscosmos

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

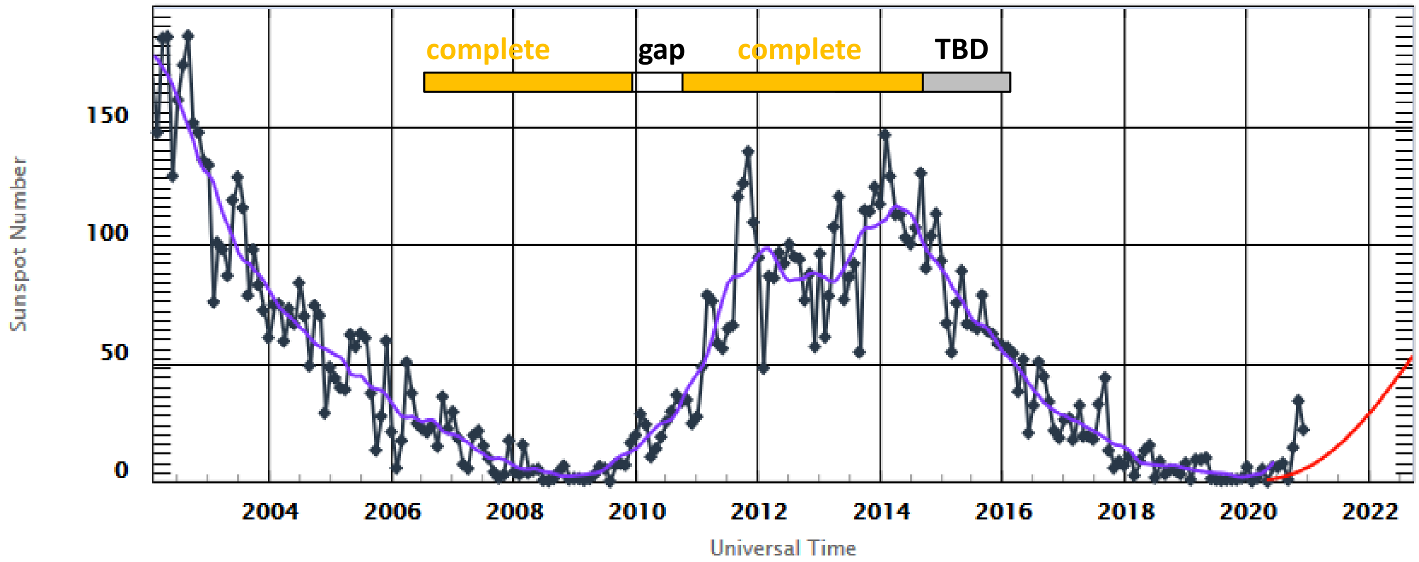
PAMELA Data Processing

- 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.

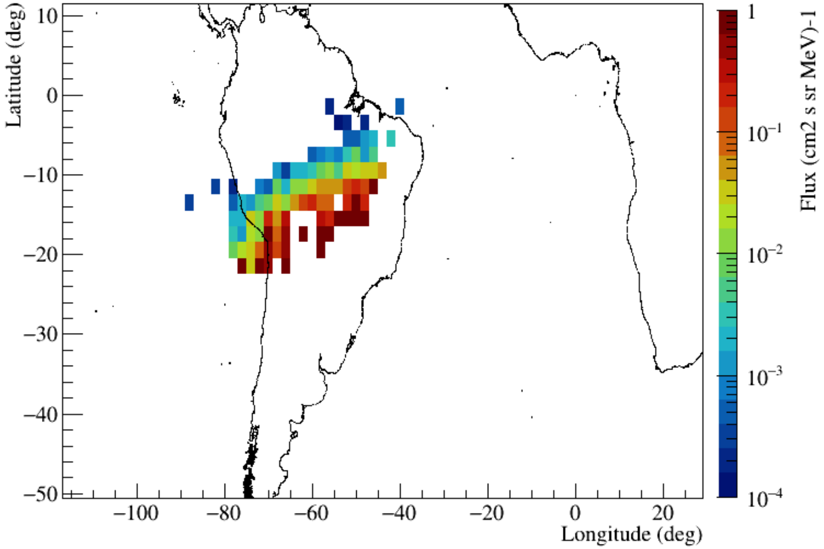
- Proton intensity records processed into 5-D intensity bins for each time file:
  - Local pitch angle: 3-deg bins, range 0 to 180 degrees
  - Energy: 20 logarithmic bins, range 80 MeV to 4 GeV
  - Longitude: 2-deg bins, range -120 deg to 0 deg Latitude: 2-deg bins, range -50 deg to +10 deg
  - Altitude: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

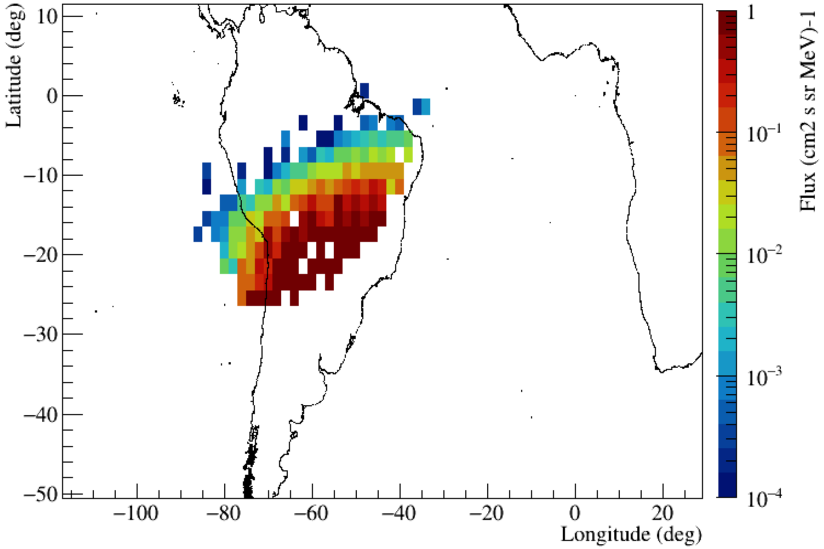
- Data processed covers periods of both solar minimum (highest proton flux in SAA) and solar maximum (lowest proton flux in SAA).



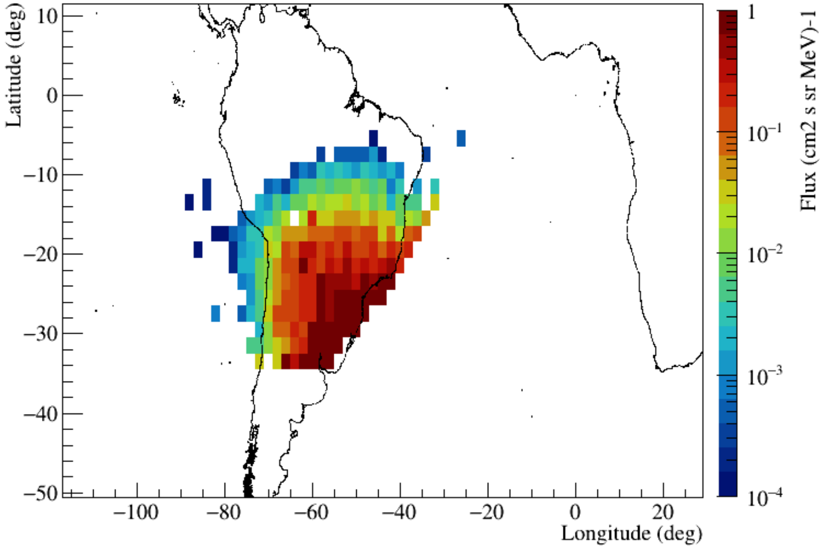
https://www.swpc.noaa.gov/products/solar-cycle-progression

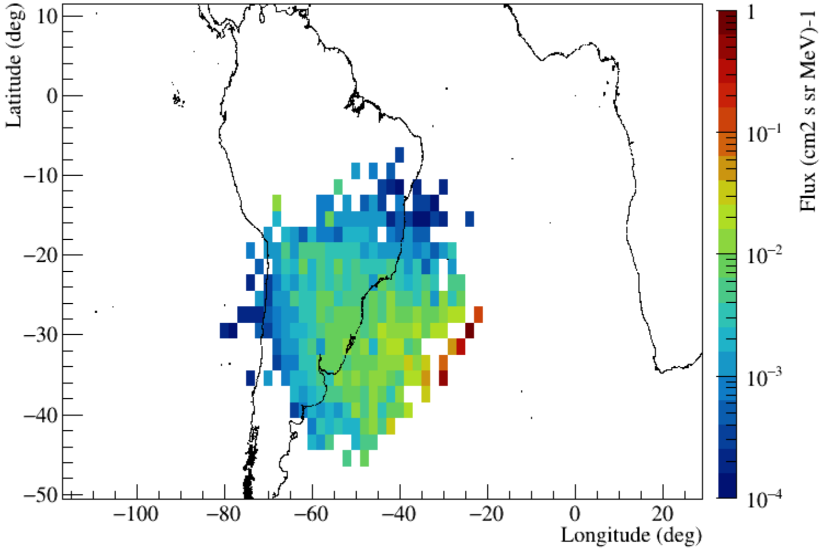
Example Proton Flux Maps





M. Matteo et al., November 2020



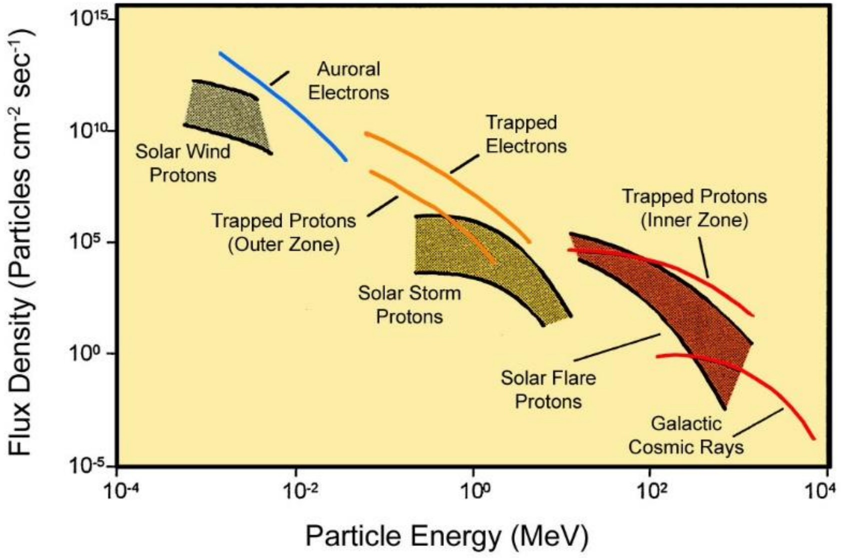


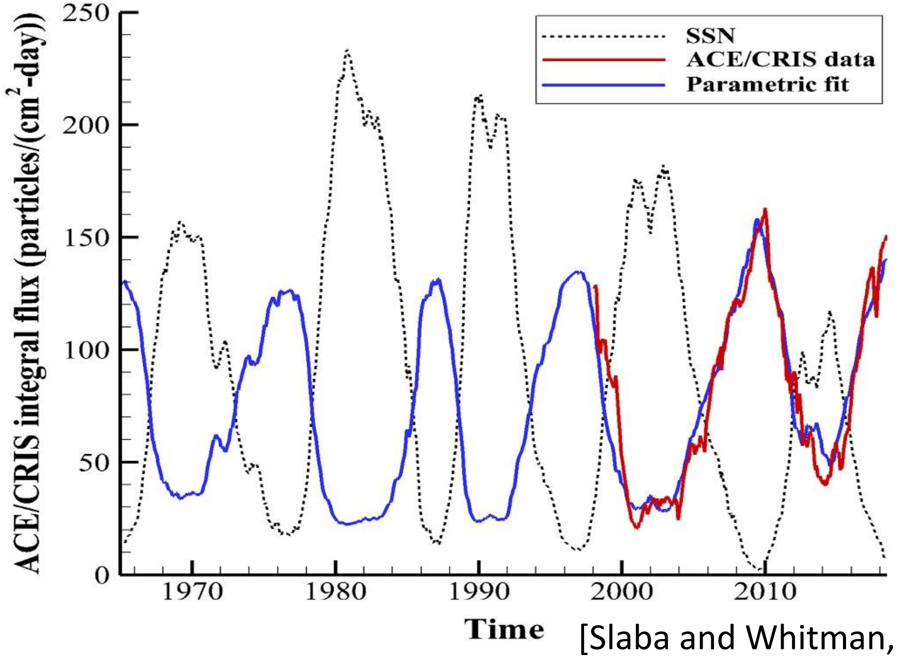
Badhwar-O'Neil (BON) Galactic Cosmic Ray (GCR) Model Improvements

- NESC support activity
  - ~21 month project 05/2021 – 03/2023
  - NESC Tech Lead: Insoo Jun/JPL
  - JSC modeling team: Kathryn Whitman, Claudio Corti

- Improve the BON2020 GCR model including
  - Use BON2020 as a starting point for development work
  - Calibrate extension to environments >1 AU
  - Improve local interstellar spectrum (LIS) for multiple ions using AMS and Voyager (and other) data
  - Updates to modulation potential algorithms
  - Estimates of model uncertainty

- Improved BON2020 GCR model functionality will provide
  - Better GCR dose estimates for designing human missions to Moon and Mars
  - Improvements in GCR environments of importance to single event effects in electronics

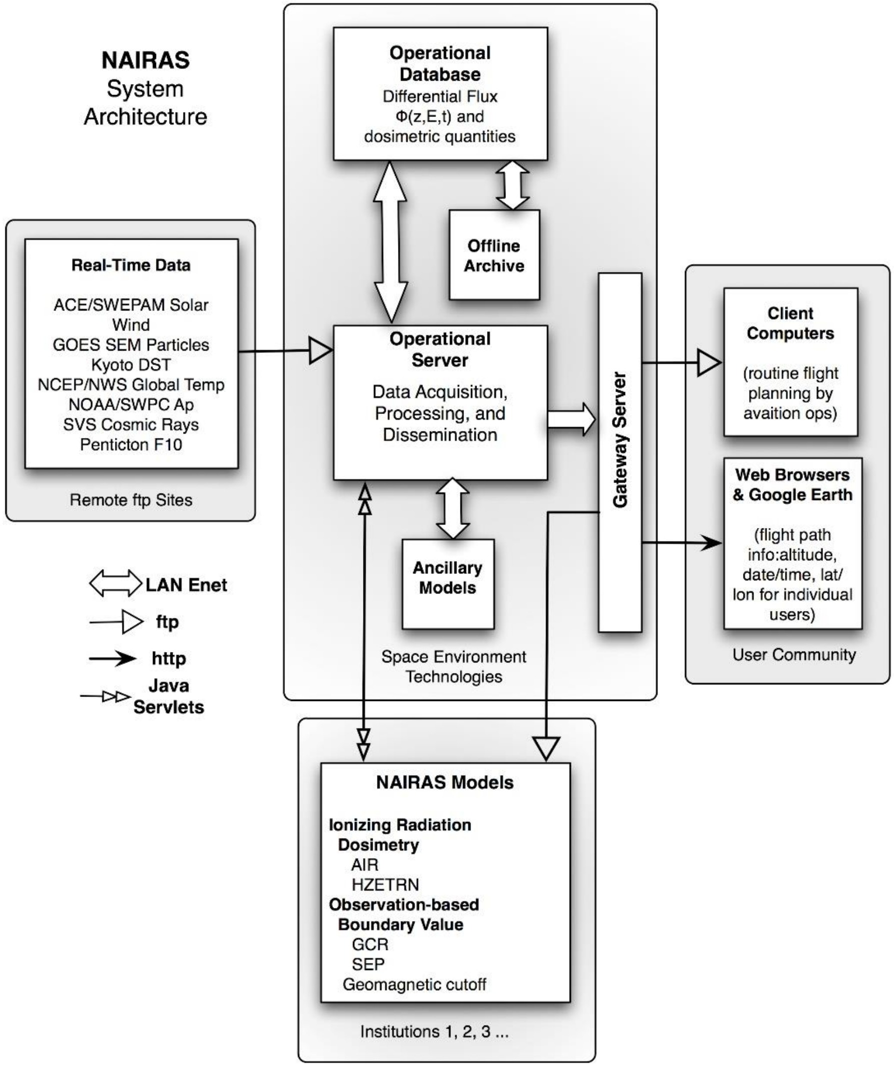




[Slaba and Whitman, 2020]

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



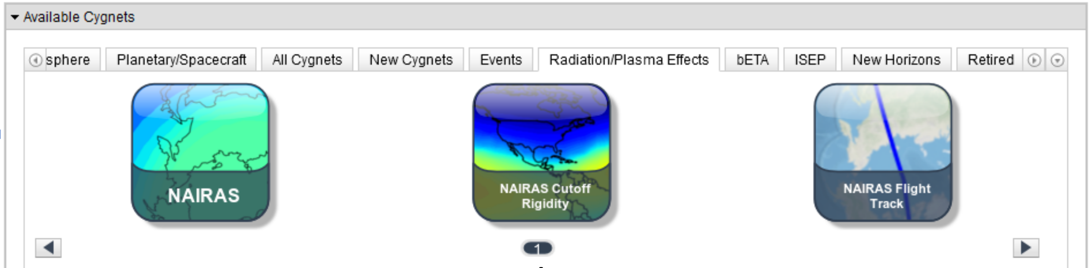
https://sol.spacenvironment.net/nairas/

NAIRAS Real-Time Model

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

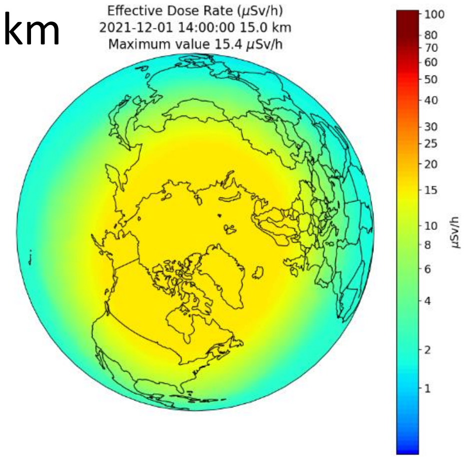
  URL: https://ccmc.gsfc.nasa.gov/iswa/

- 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

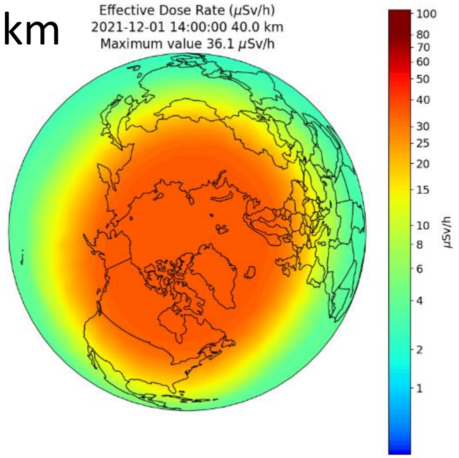


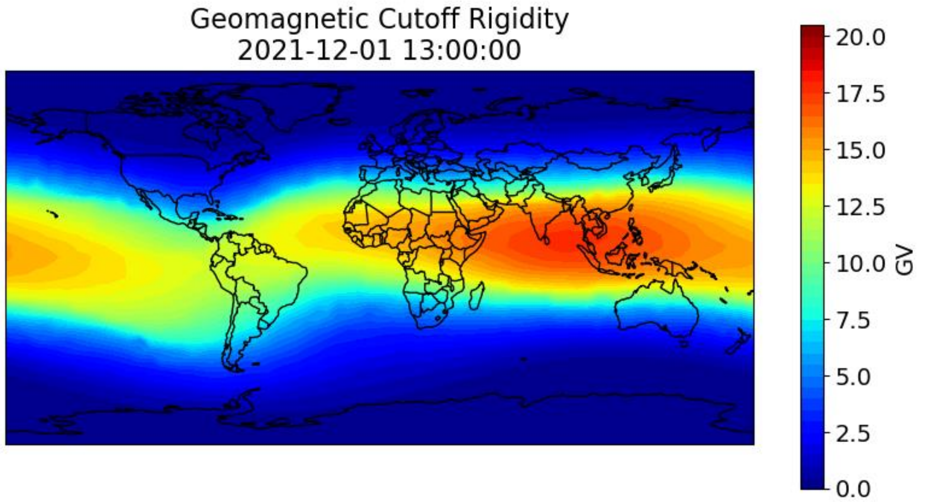
iSWA Radiation/Plasma Effects Tab

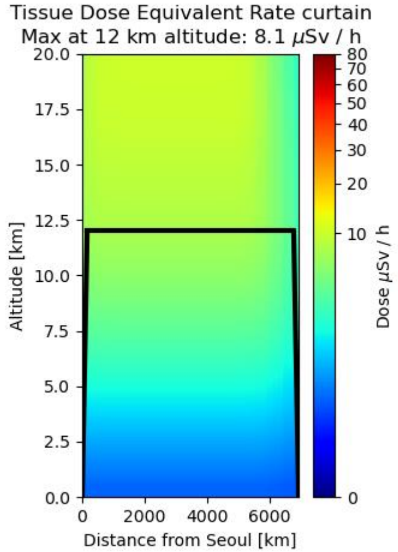
15 km



40 km







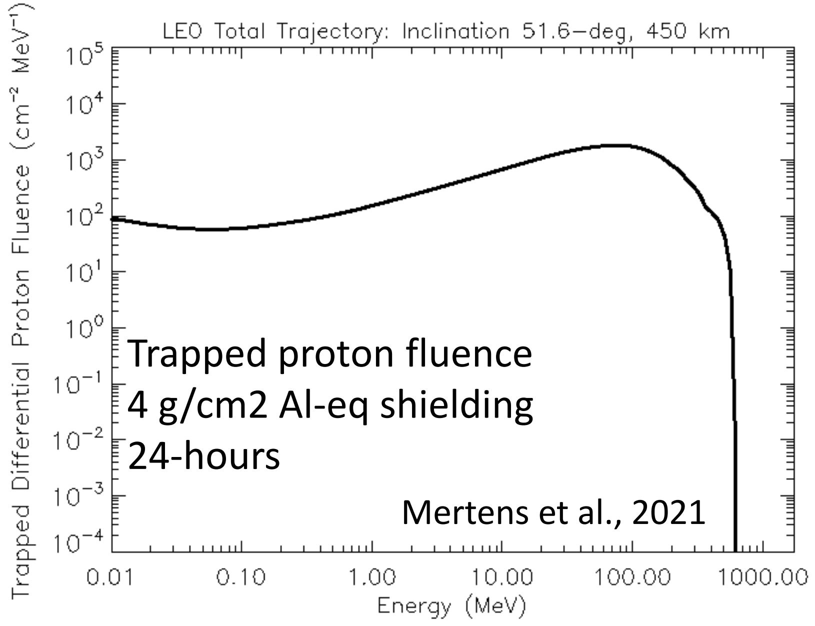
NAIRAS Runs-on-Request

- 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



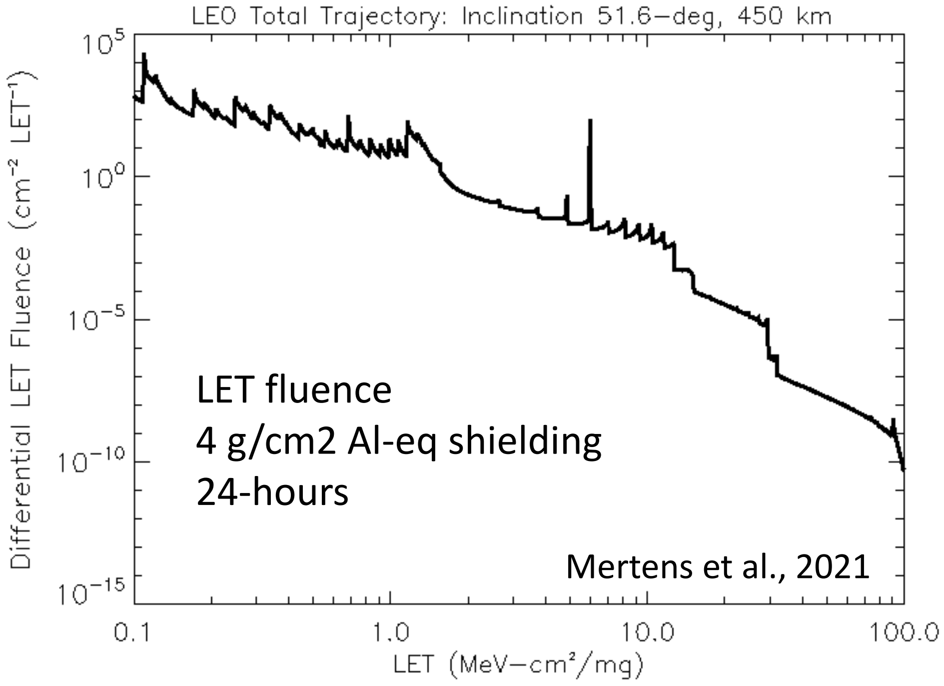


Image from SpaceX Crew Dragon flyaround of ISS on November 8, 2021

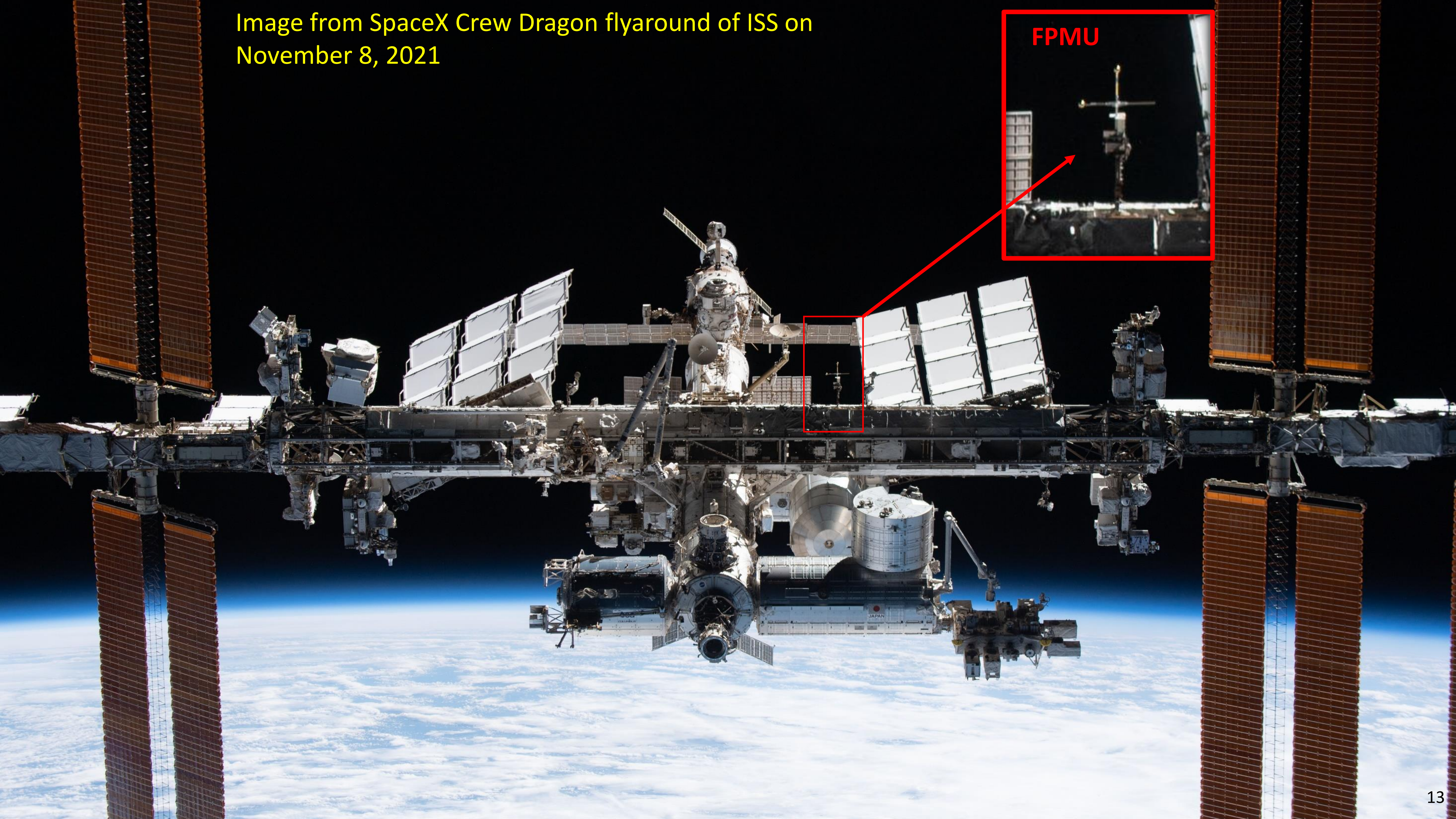


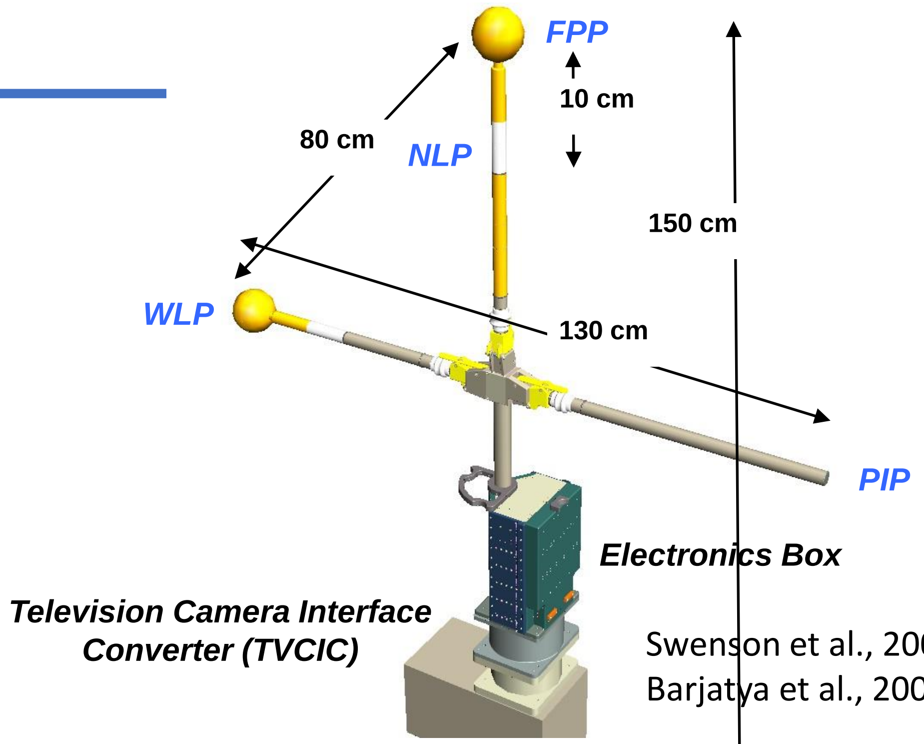
Image from SpaceX Crew Dragon flyaround of ISS on
November 8, 2021
FPMU

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.



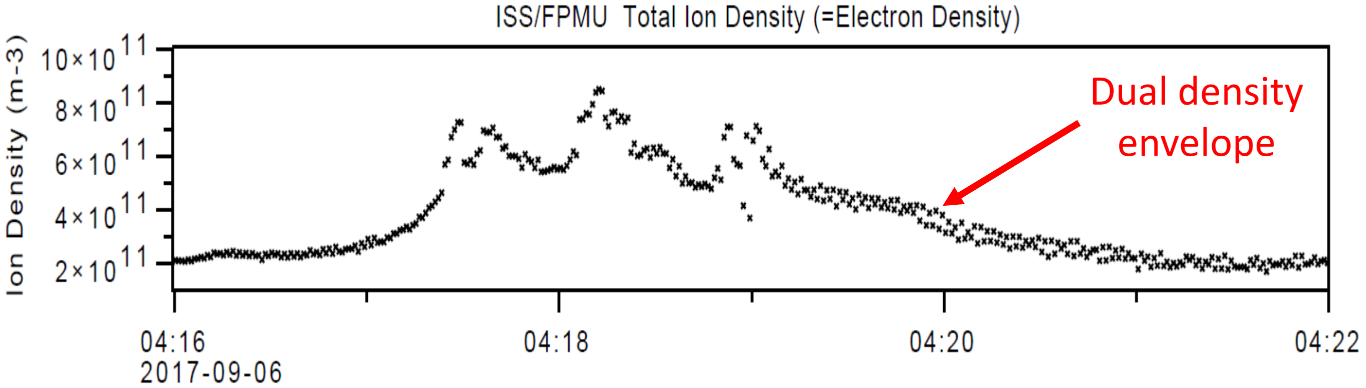
Swenson et al., 2003; Barjatya et al., 2009

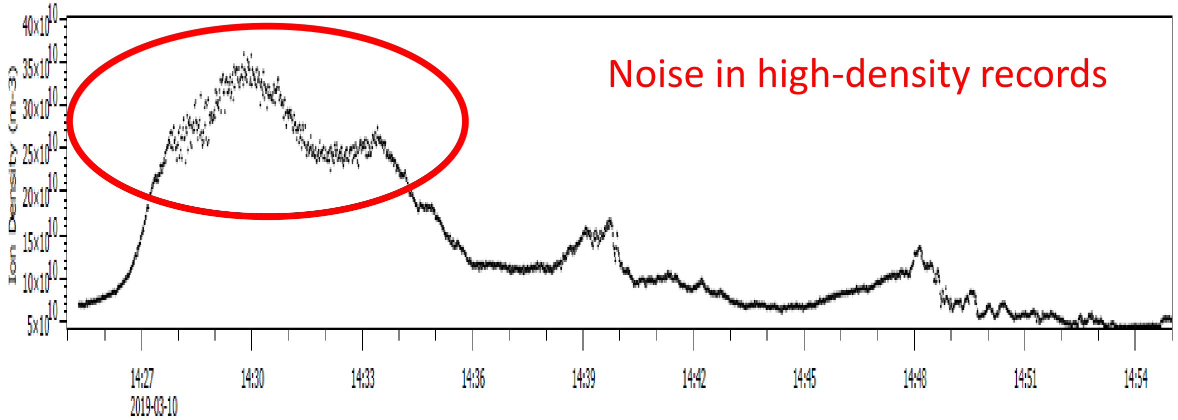
S123E008424

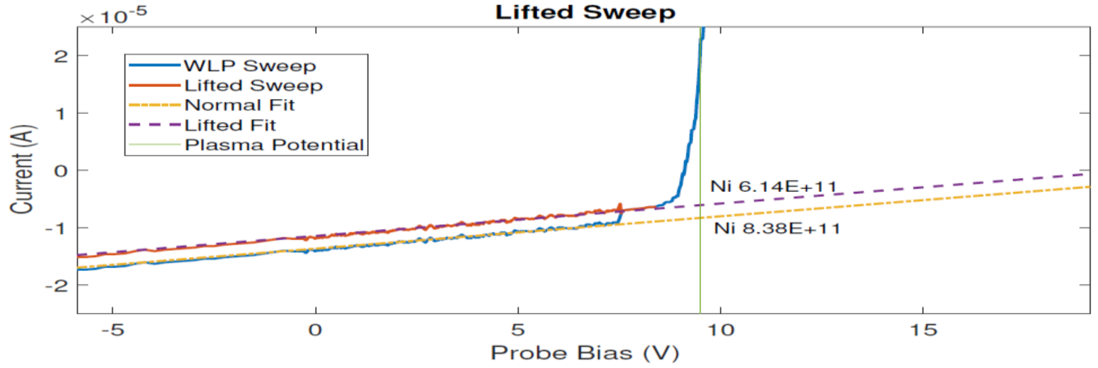
FPMU Data Processing Algorithm Development

- NESC assessment team:
  - Tech Lead: Linda Parker
  - Team: 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

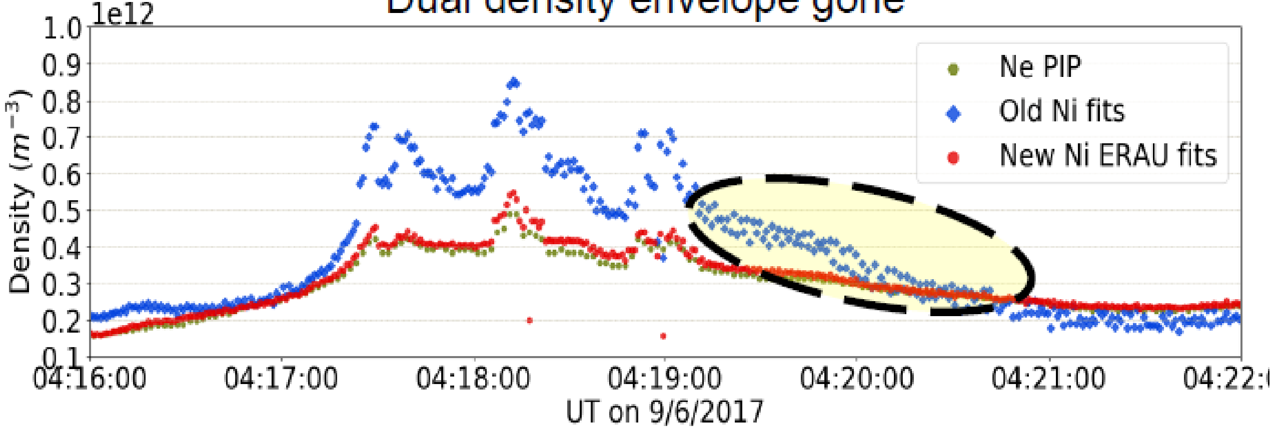


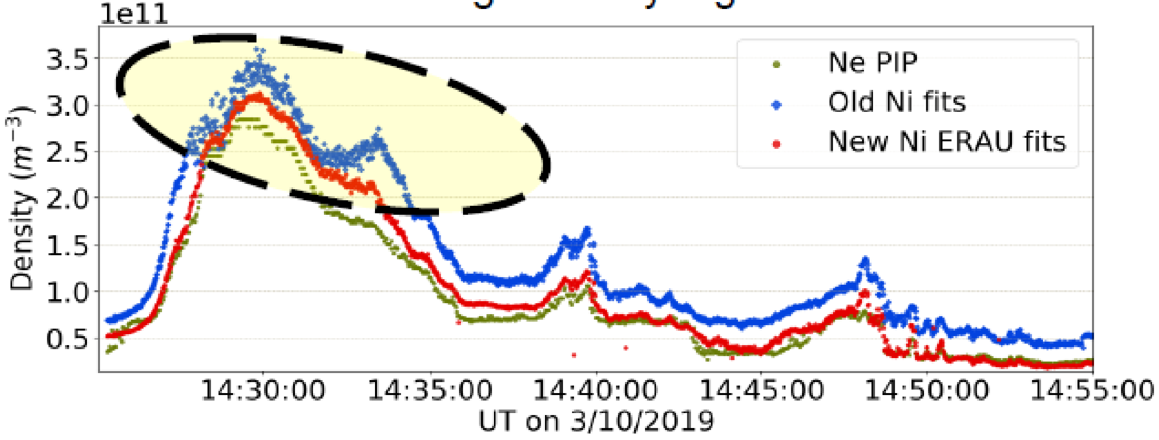




Debchoudhury and Barjatya, 2020

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

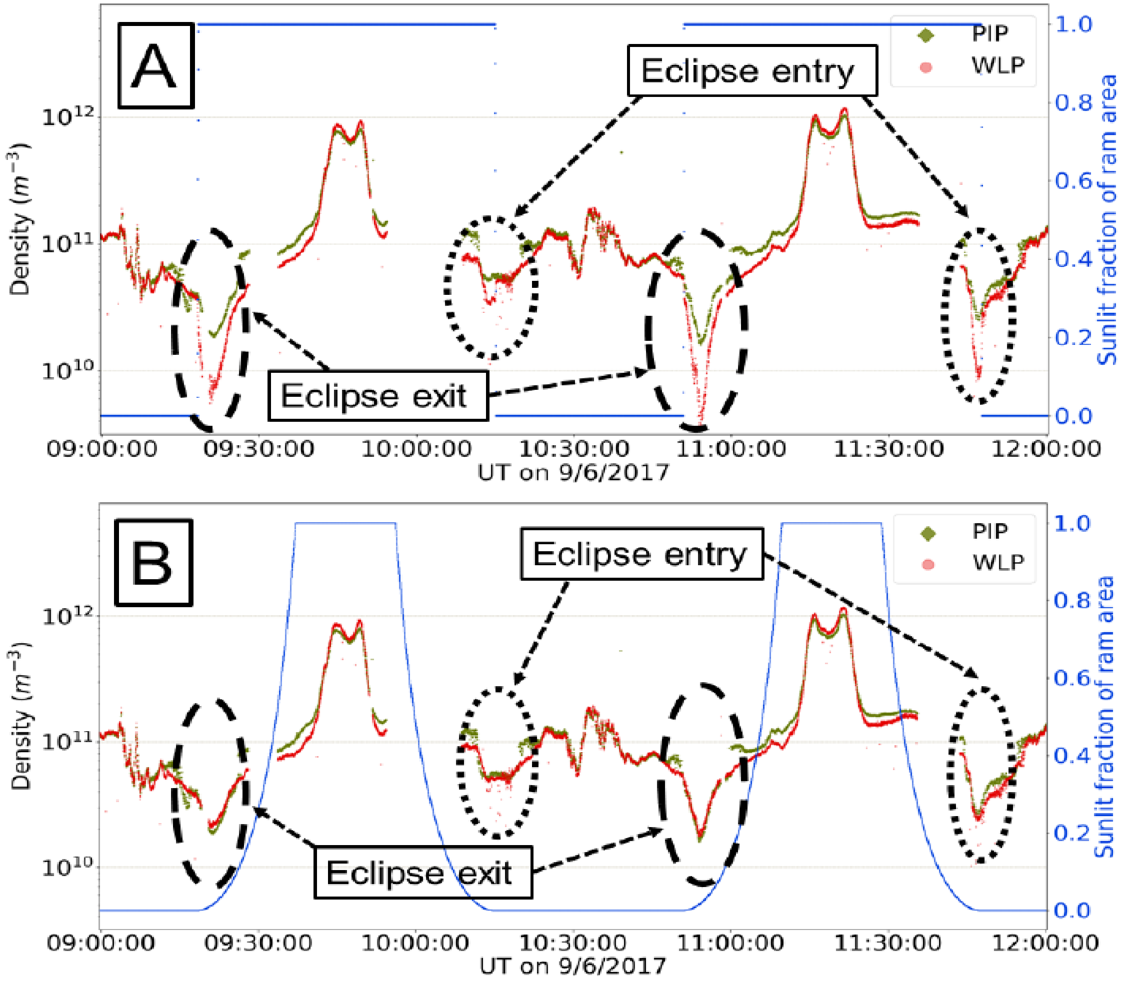
- Average inter-sweep error using old fits = 15%
- Average inter-sweep error using the new ERAU fits = 2%

Debchoudhury and Barjatya, 2020

FPMU Photoemission Correction

Debchoudhury and Barjatya, 2020

- 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)*

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

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

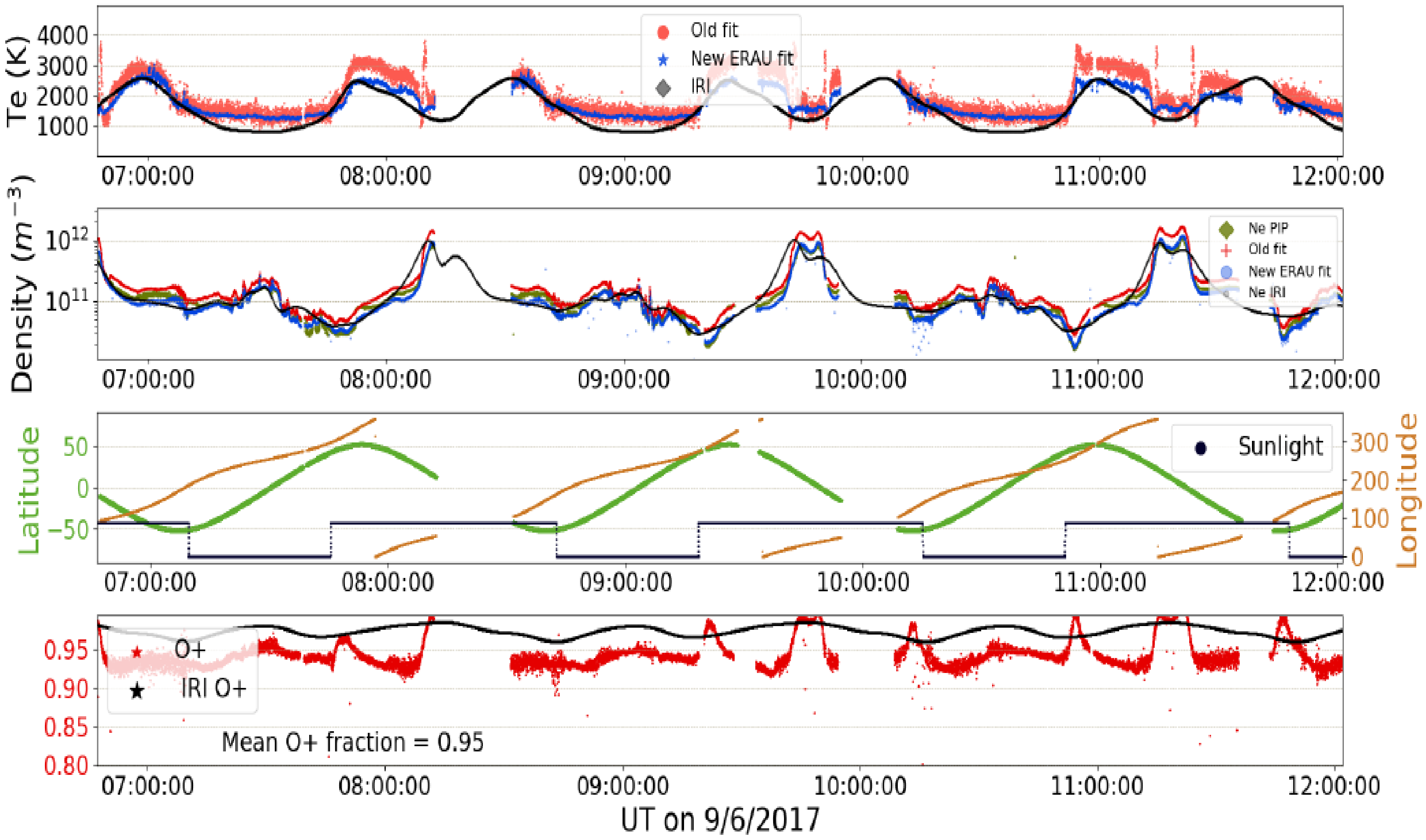
where, $r_j = \frac{u_o}{\sqrt{\frac{2kT_i}{m_j}}}$, $\eta = \frac{-e(V - V_p)}{kT_i}$, and *j* can be O+ or H+

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

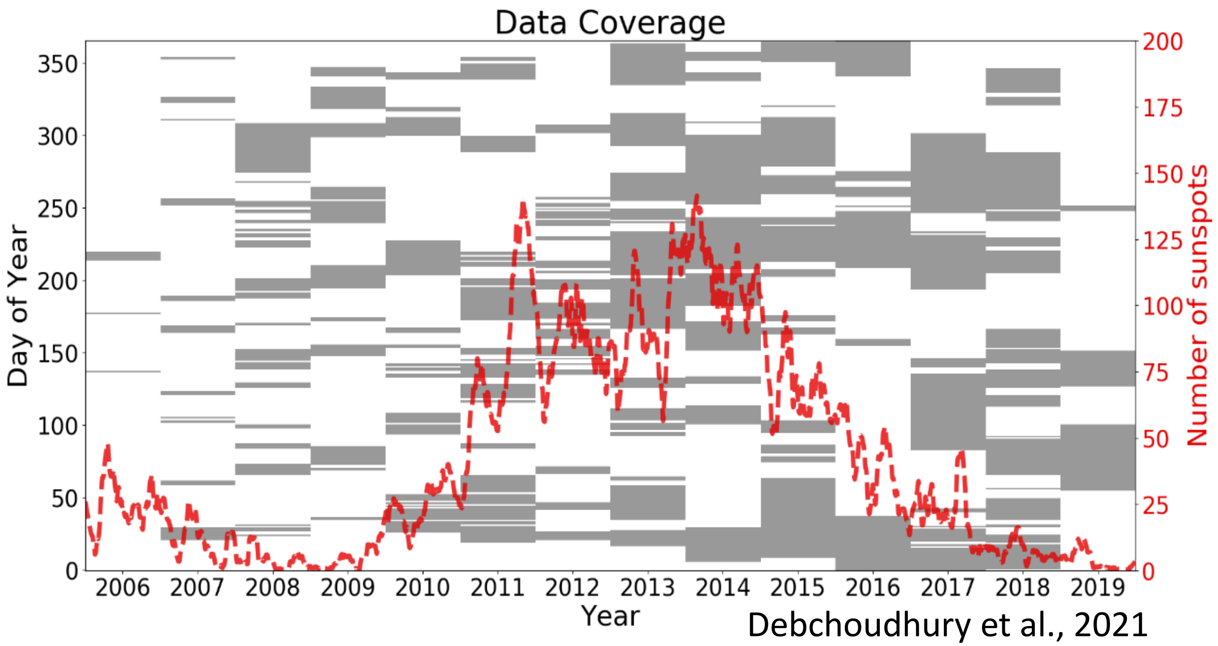
CDAWeb Data Archives

- 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

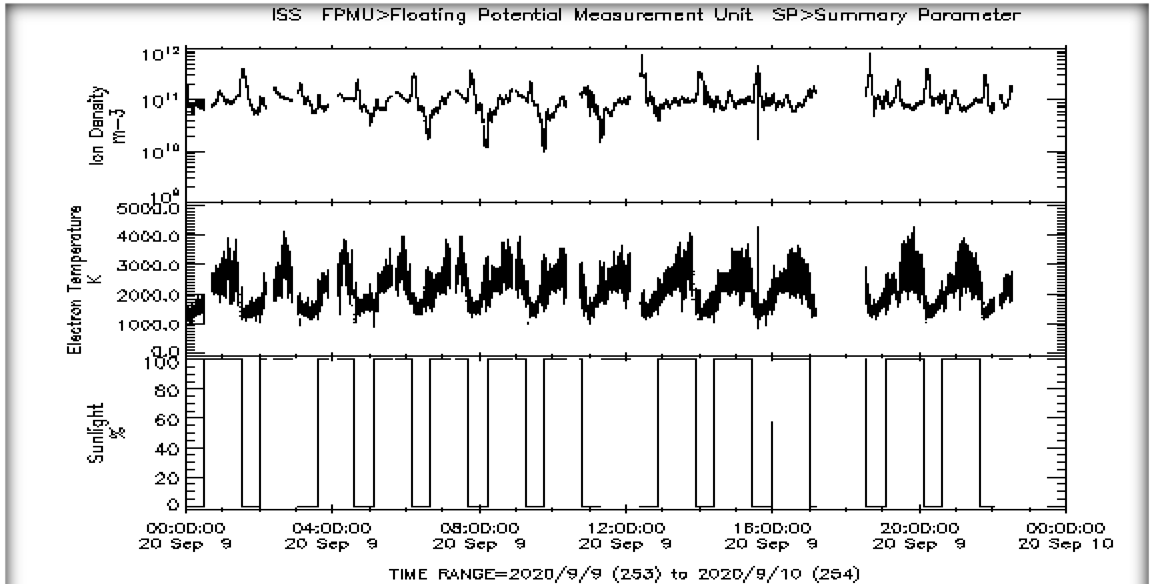
- Current CDAWeb FPMU holdings include the 2006/08/03 to 2020/09/14 (~full data set from original FPMU)

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

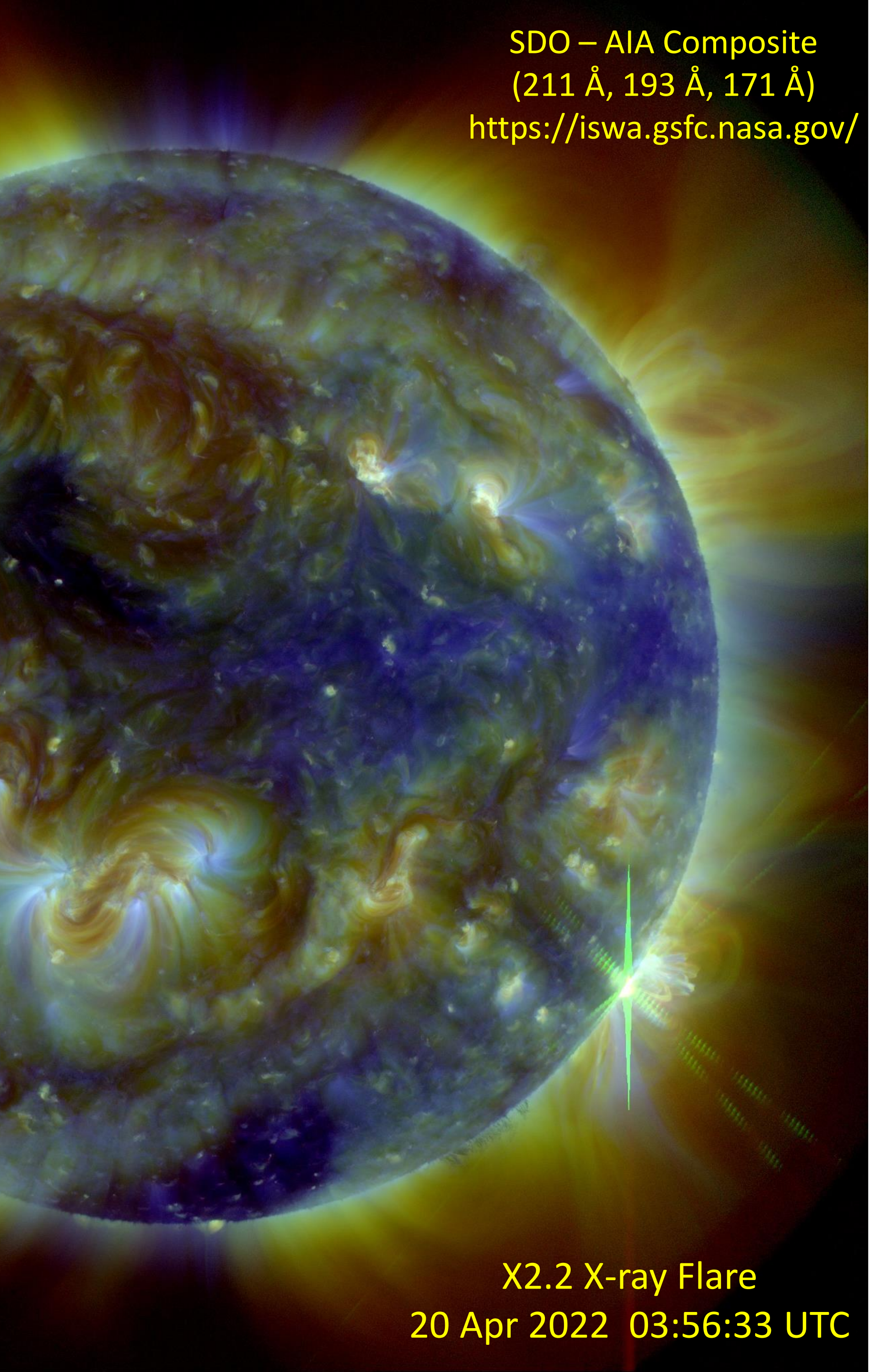
- CDAWeb holdings will be updated periodically as records from the new FPMU become available



Debchoudhury et al., 2021



NASA CDAWeb


SDO – AIA Composite
(211 Å, 193 Å, 171 Å)
https://iswa.gsfc.nasa.gov/
X2.2 X-ray Flare
20 Apr 2022 03:56:33 UTC

Questions?