GOES-19 MPS-HI Calibration: The Newest GOES Radiation Belt Instrument

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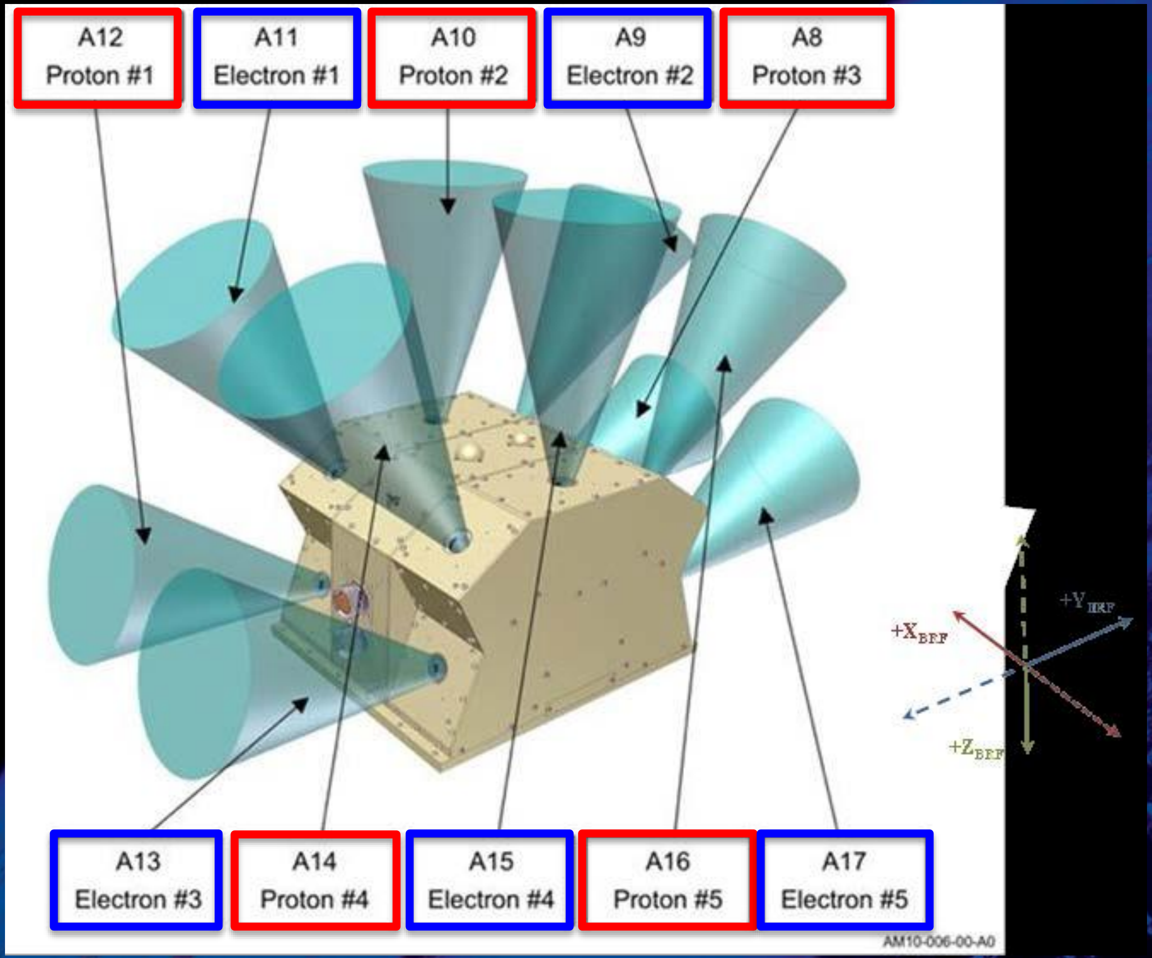
GOES-R Program

- **Satellites launched to date:**
  - **GOES-16 (R): launched 19 November 2016**
    - **GOES-East (75.2ºW) since 18 December 2017**
  - **GOES-17 (S): launched 01 March 2018**
    - **In storage (104.7ºW) since 14 March 2023**
    - **Was GOES-West (137.2ºW) from 12 February 2019 to 4 January 2023**
  - **GOES-18 (T): launched 01 March 2022**
    - **GOES-West (137ºW) since 4 January 2023**
  - **GOES-19 (U): launched 25 June 2024**
    - **Currently undergoing post-launch tests (89.5ºW)**
    - **Will replace GOES-16 as GOES-East on April 4, 2025 (75.2ºW)**
- **Each GOES-R-series observatory carries a Space Environment In-Situ Suite (SEISS)**
  - **GOES-19 SEISS was turned on on 22 August 2024**

Magnetospheric Particle Sensor – High Energy (MPS-HI)

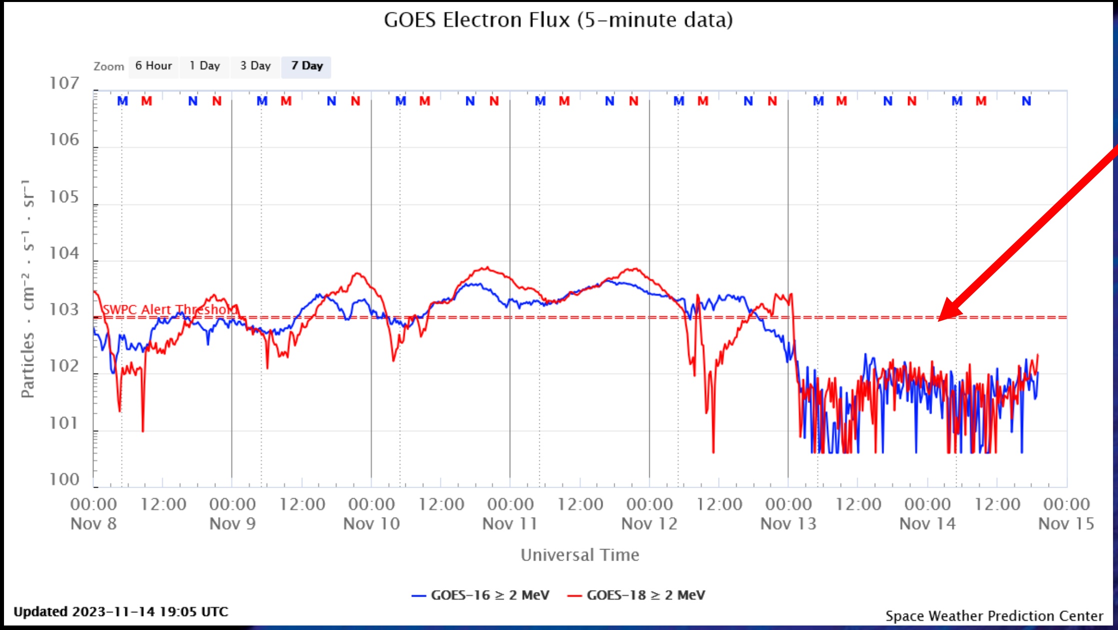
MRD 3.3.6.1.3 Magnetospheric Electrons and Protons: Medium and High Energy



Credit: SEISS-TR-MH074-2 Rev C, Figure 3-1

- Primary purpose: measure radiation belt particle fluxes in the energy range responsible for internal charging
- 5 electron telescopes and 5 proton telescopes
  - 30 deg full-width conical FOVs, centers separated by 35 deg
- Each electron telescope:
  - 10 differential channels, 50 keV – 4 MeV
  - 2 integral channels, >2 MeV and >4 MeV (latter not part of L1b)
- Each proton telescope:
  - 11 differential channels
  - 7 channels, 80 keV – 1 MeV (trapped)
  - 4 channels, 1-12 MeV (solar protons)
- Two dosimeters (250 and 100 mil Al)
  - Distinguish particles depositing < 1 MeV and >1 MeV

ALERT: Electron 2 MeV Integral Flux Exceeded 1000 pfu



Space Weather Message Code: ALTEF3
Serial Number: 3381
Issue Time: 2023 Nov 07 1624 UTC
ALERT: Electron 2MeV Integral Flux exceeded 1000pfu
Threshold Reached: 2023 Nov 07 1600 UTC
Station: GOES16
Potential Impacts: Satellite systems may experience significant charging resulting in increased risk to satellite systems.

Space Weather Message Code: ALTEF3
Serial Number: 3386
Issue Time: 2023 Nov 12 0500 UTC
CONTINUED ALERT: Electron 2MeV Integral Flux exceeded 1000pfu
Continuation of Serial Number: 3385
Begin Time: 2023 Nov 07 1600 UTC
Yesterday Maximum 2MeV Flux: 4373 pfu

- **Space Weather Prediction Center (SWPC) alert at 1000 electrons/(cm^2 sr s) [pfu] was developed in consultation with the satellite industry**
- **Based always on GOES-East observations**
  - **Fluxes systematically lower than at GOES-West by factor of 2.5 [Meredith et al., 2015]**
- **First alert was issued on 18 May 1995**
- **MeV electron fluxes have been very elevated starting in 2015**
  - **Primarily owing to the action of stream interaction regions (interface between solar wind of coronal hole and quiet sun origins) on the magnetosphere**

Steps of Radiation Belt Electron and Proton Calibration

- **Initial Data Calibration**
  - Dead time correction
  - Bowtie Analysis (electrons only)
  - Background removal for electron channels E9-E11
- **MPS-HI Telescope Cross-Comparison**
  - Statistical comparison between telescopes observing the same pitch angles
- **Solar Energetic Particle Cross-Comparison**
  - Comparison between MPS-HI and Solar and Galactic Proton Sensor (SGPS, also onboard GOES-R satellites) during an SEP event under high solar wind dynamic pressure
- **Cross-Satellite Comparison of Trapped Particles**
  - Comparison between GOES-R satellites

Inverse Model: Bowtie Method

Differential Channels

$$G\delta E = \frac{\int_0^\infty j(E)G(E)dE}{j(E_{eff})}$$

Bowtie analysis, differential: cm² sr keV

$$j(E_{eff}) = \frac{R}{G\delta E}$$

L1b processing (diagonalized)

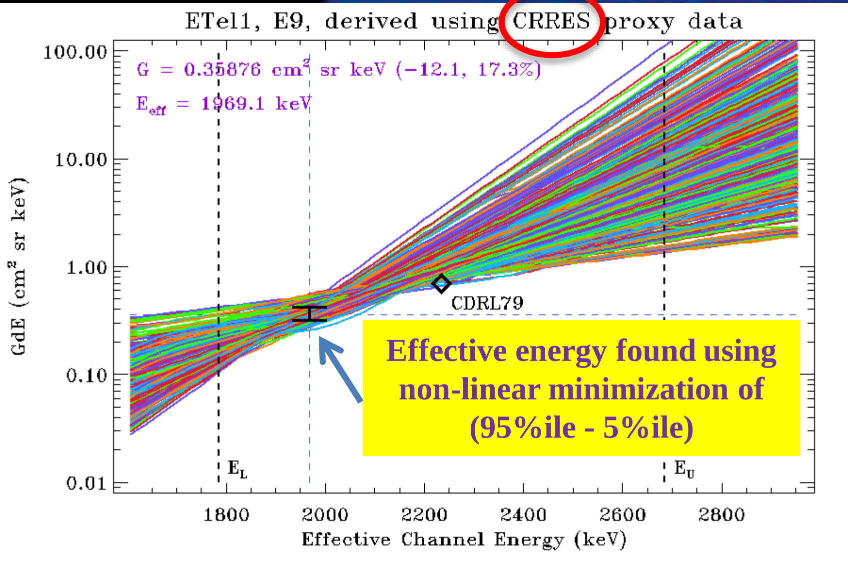
Integral Channel

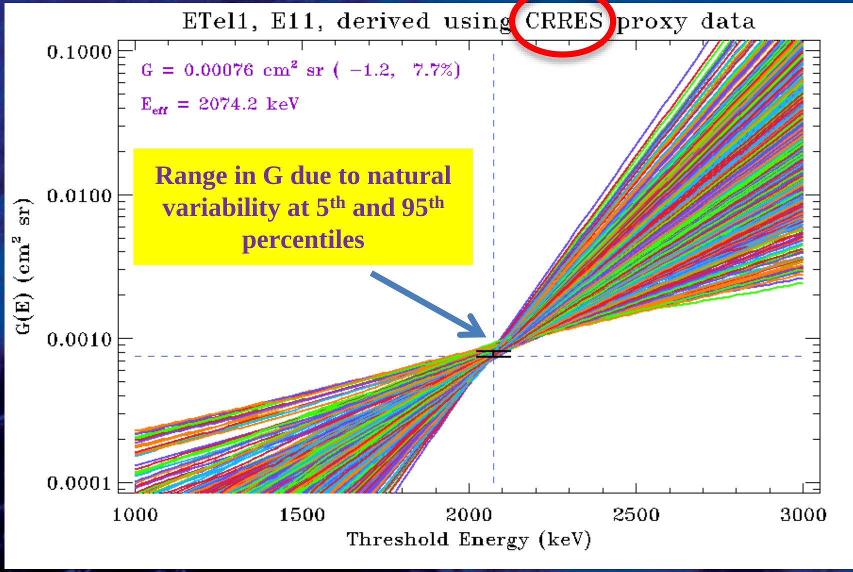
$$G_I(E_L) = \frac{\int_0^\infty j(E)G(E)dE}{\int_{E_L}^\infty j(E)dE}$$

Bowtie analysis, integral: cm² sr

$$J(E > E_L) = \frac{R}{G_I}$$

L1b processing





Boudouridis, A., Rodriguez, J. V., Kress, B. T., Dichter, B. K., & Onsager, T. G. (2020). Development of a bowtie inversion technique for real-time processing of the GOES-16/-17 SEISS MPS-HI electron channels. Space Weather, 18, e2019SW002403. https://doi.org/10.1029/2019SW002403

Backgrounds Trending: Methodology

GOES-19 MPS-HI E9-E11 Revised Background Removal

The baseline algorithm is inadequate to correct for the observed slowly-varying background due presumably to Galactic Cosmic Ray (GCR) protons. The background removal coefficients were corrected so as to better account for the GCR proton contamination. This involves a number of observations and assumptions (demonstrated for MPS-HI E11 (> 2 MeV) channel):

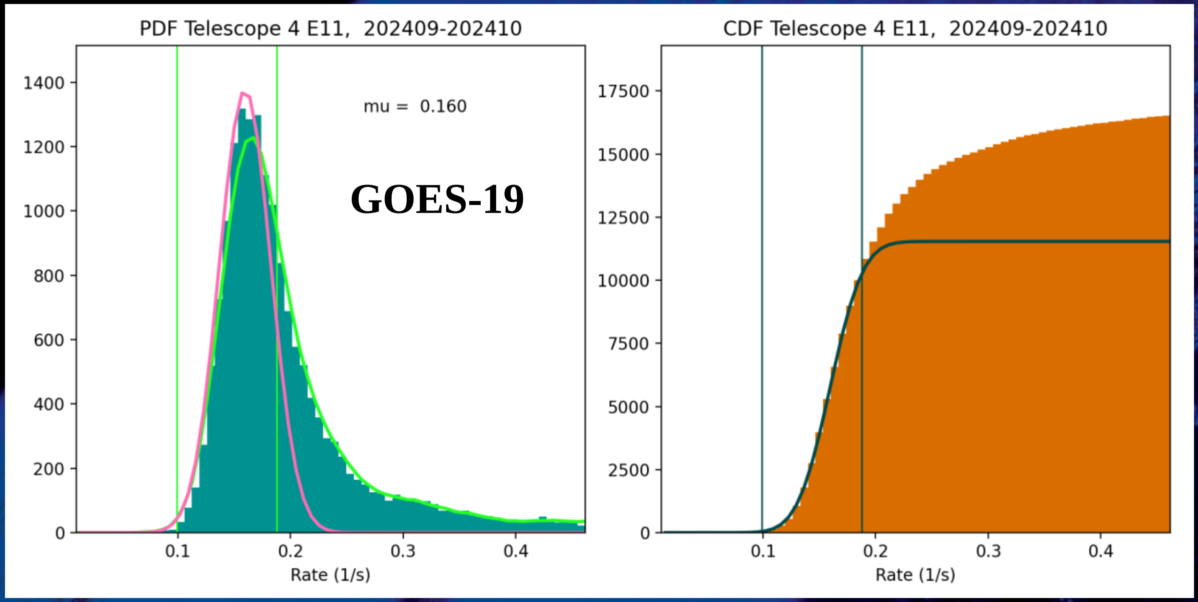
- **The first assumption is that the MPS-HI backgrounds are due to the GCRs.**
- **Solar and Galactic Proton Sensor (SGPS) P11 channel is the best single measure of GCR fluxes. Use the −X sensor (looking east)**
- $M_{ELE}(i,E11) = N_{ELE}^{true}(i,E11) - C_{ELE}^{obc}(i,E11) = N_{ELE}^{true}(i,E11) - \gamma(i,E11)F_{SGPS-X_{P11}}$
- **The coefficient γ is calculated separately for each telescope.**
- **Assuming that SGPS-X P11 can track the GCR background well, we can average the SGPS-X P11 fluxes and the background fluxes in E11 due to the GCRs, yielding**

$$\gamma(i,E11) = \overline{C_{ELE}^{obc}(i,E11)} \Big/ \overline{F_{SGPS-X_{P11}}} = G_{P11}\,\overline{C_{ELE}^{obc}(i,E11)} \Big/ \overline{C_{P11}}$$

Backgrounds Trending: Methodology

Modeling the GCR background

- Assume that the peak and the part of the PDF below the peak are dominated by the rates due to GCRs, model as Gaussians.
- Gaussian PDF: $f(x) = a\, exp\left[-\frac{(x-\mu)^2}{2\sigma^2}\right]$
- Gaussian CDF: $F(x) = a\sigma\sqrt{\frac{\pi}{2}}\left[1 + erf\left(\frac{x-\mu}{\sigma\sqrt{2}}\right)\right]$



- Conduct the analysis using 5-min averages for **09/01/2024-10/31/2024.**
- Fit the CDF that is varying smoothly, instead of PDF.
- $\overline{C_{ELE}^{obc}(i, E11)} = \mu_{E11}$ (fitted E11 mean).
- Do the same for SGPS-X P11 counts, $\overline{C_{P11}} = \mu_{P11}$
- Repeat for E9, E10, E10A.
- Estimate gammas.
- **Apply to the 1s L1b data.**

Application of the revised background removal to GOES-19 MPS-HI E11 data

T3

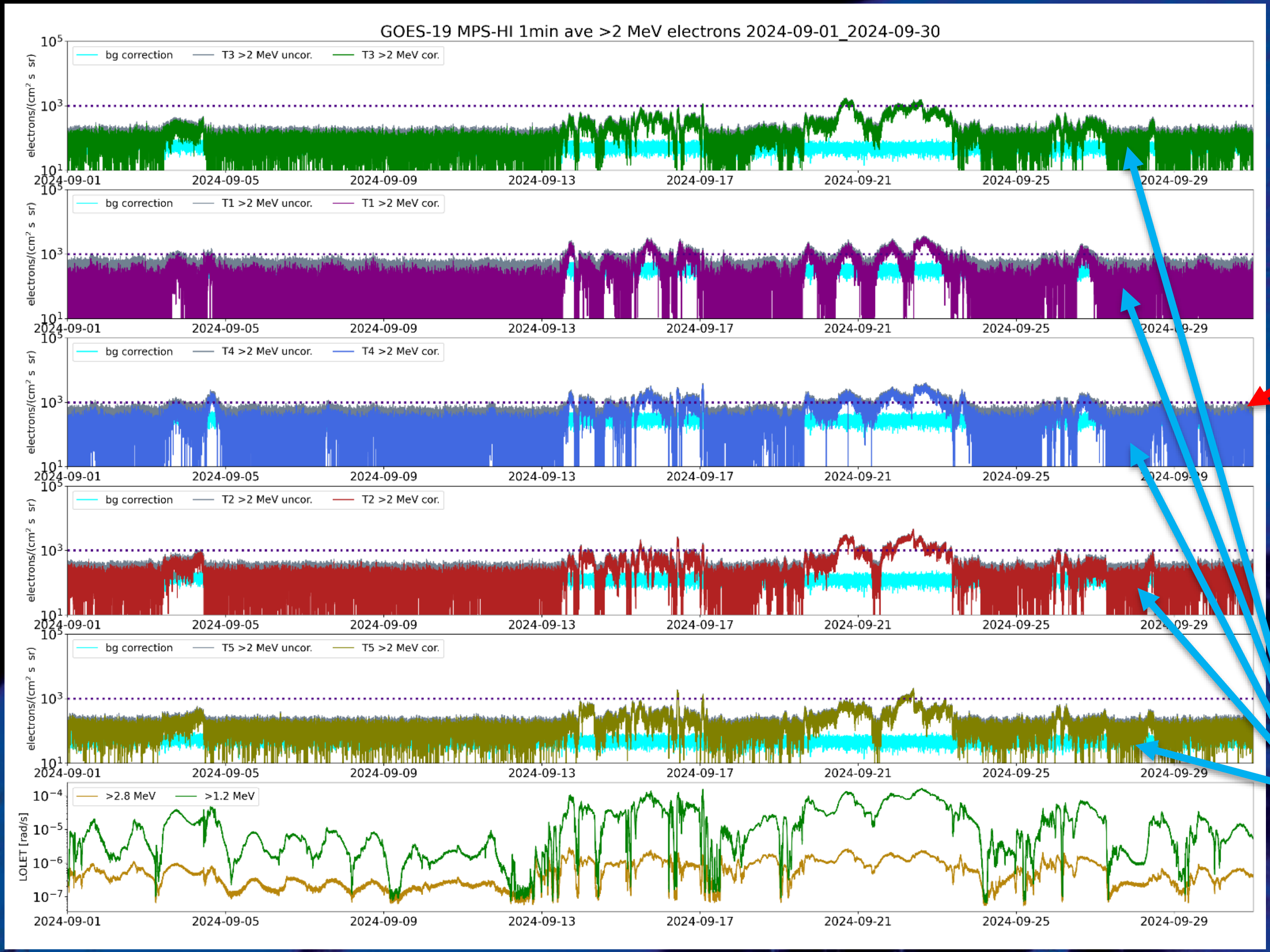
T1

T4

T2

T5

DOS



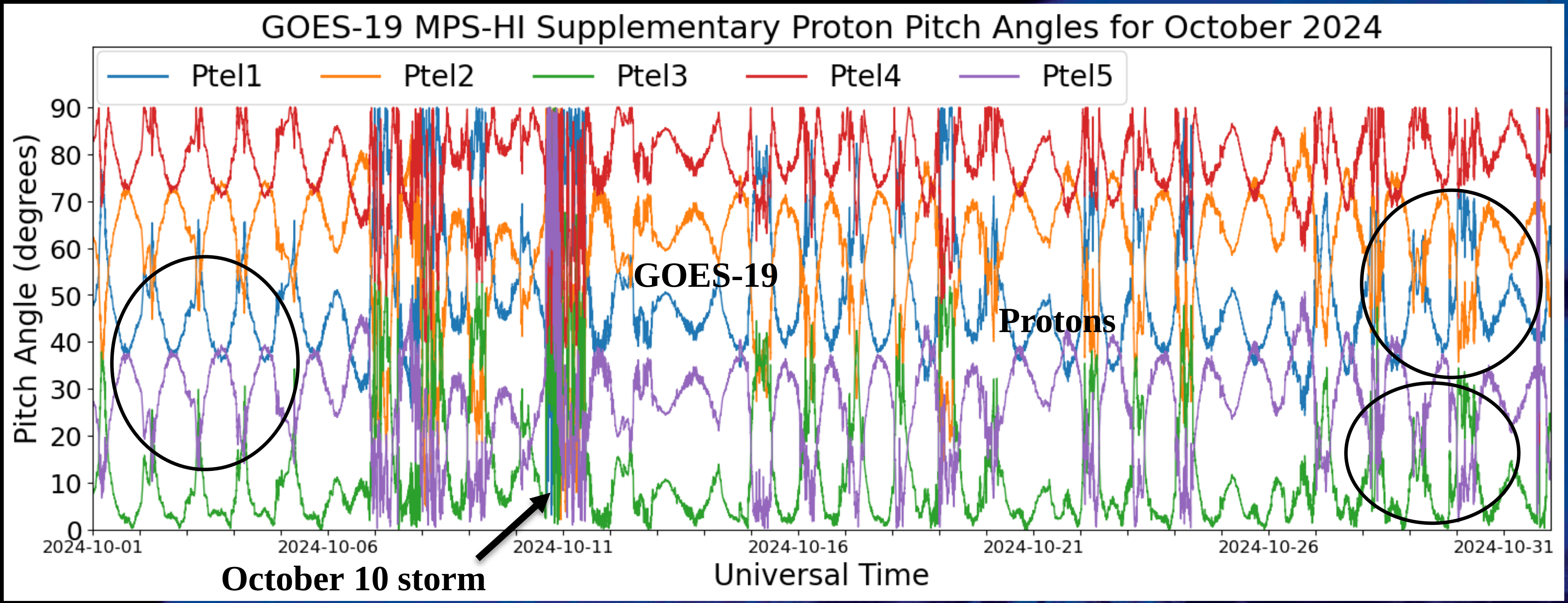
GOES-19 channel E11 (> 2 MeV)

1000 electrons per (cm^2 sr s)

SWPC alert level very close to uncorrected backgrounds

Corrected backgrounds more representative of the GCR spectrum

GOES-19 MPS-HI Telescope Cross-Comparison: Method



- Comparison of responses of MPS-HI telescopes when central pitch angle is the same
- Under such conditions, telescopes should be measuring the same flux for the same effective energy
- Use Nelder-Mead method to minimize the objective function: sum of squares of the following difference term

$$R(m) = \frac{SF_i(m)J_i(m) - SF_j(m)J_j(m)}{SF_i(m)J_i(m) + SF_j(m)J_j(m)}$$

Rowland, W., and R. S. Weigel (2012), Intra-calibration of particle detectors on a three-axis stabilized geostationary platform, *Space Weather, 10*, S11002, doi:10.1029/2012SW000816.

- Use supplementary pitch angles (fold pitch angles > 90 degrees) to increase the number of matches
- To reduce effect of statistical noise, use only matches where both fluxes correspond to at least 1000/100 counts/min
- Because Scale Factors are only valid in a relative sense, they must be normalized to a reference telescope

GOES-19 MPS-HI Telescope Cross-Comparison: Results

Electron Scale Factors
September 1-October 31, 2024

Energy band	Count threshold	T1	T2	T3	T4	T5
E1	1000/min	1.104	0.851	1.037	1.000	0.969
E2	1000/min	1.069	0.882	1.018	1.000	1.122
E3	1000/min	0.883	0.773	0.751	1.000	0.967
E4	1000/min	0.996	0.877	1.022	1.000	0.977
E5	1000/min	1.026	0.963	1.037	1.000	0.940
E6	1000/min	1.082	0.823	0.988	1.000	1.175
E7	1000/min	1.047	0.989	0.960	1.000	0.841
E8	100/min	0.968	1.064	1.011	1.000	0.955
E9	100/min	1.058	1.043	1.136	1.000	0.960
E10	100/min					
E11	100/min	0.957	0.603	1.157	1.000	

Blue: <10%, Green: 10-25%, Red: >25%
Pink: <100 PA matches
Orange: <1000 PA matches

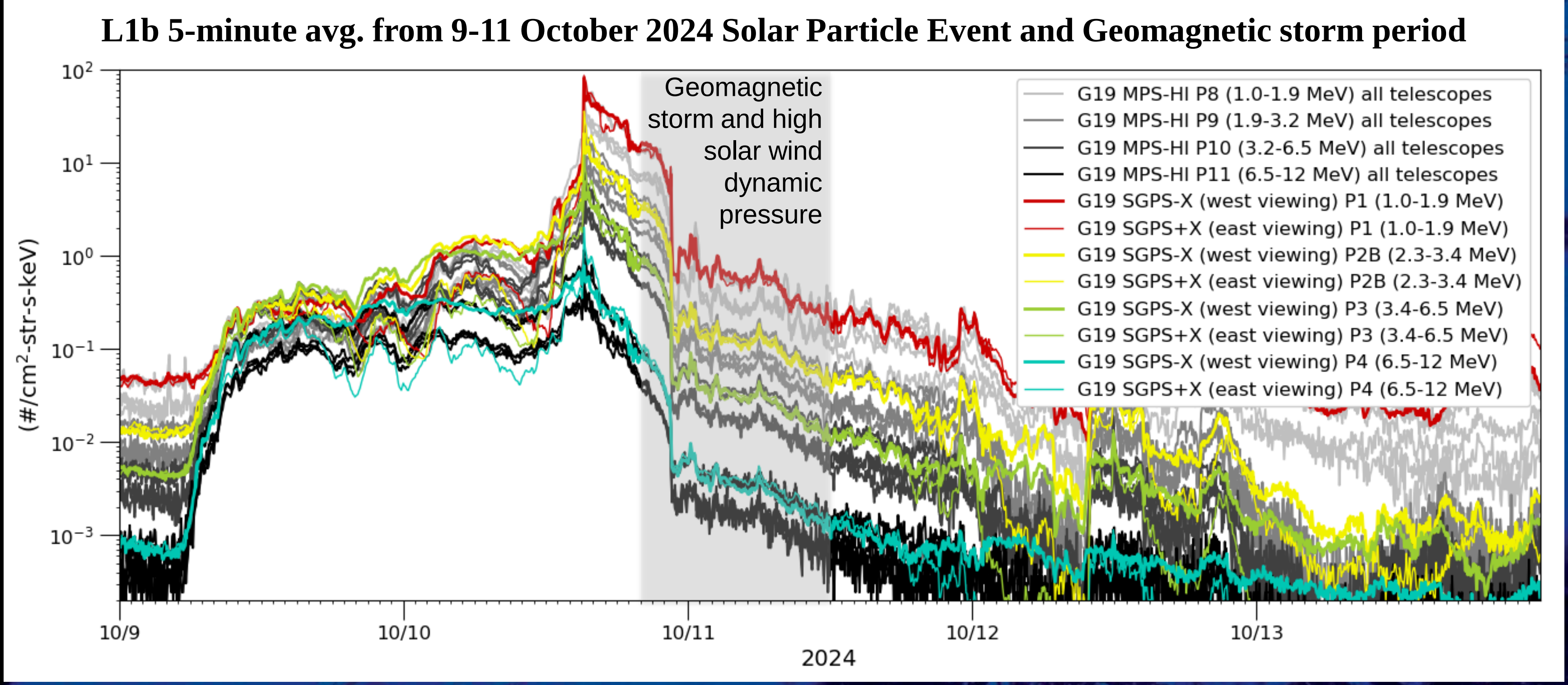
Proton Scale Factors
September 1-October 31, 2024

Energy band	Count threshold	T1	T2	T3	T4	T5
P1	1000/min	0.784	1.000	2.962	1.535	1.336
P2	1000/min	1.121	1.000	1.788	1.701	1.838
P3	1000/min	1.091	1.000	1.791	1.611	1.486
P4	1000/min	1.189	1.000	1.850	1.937	1.678
P5	100/min	1.239	1.000	1.968	1.909	1.835
P6	100/min	0.992	1.000	1.502	1.865	1.791
P7	100/min	1.011	1.000	1.877	1.974	1.991

Technique not applicable to solar proton channels P8-P11

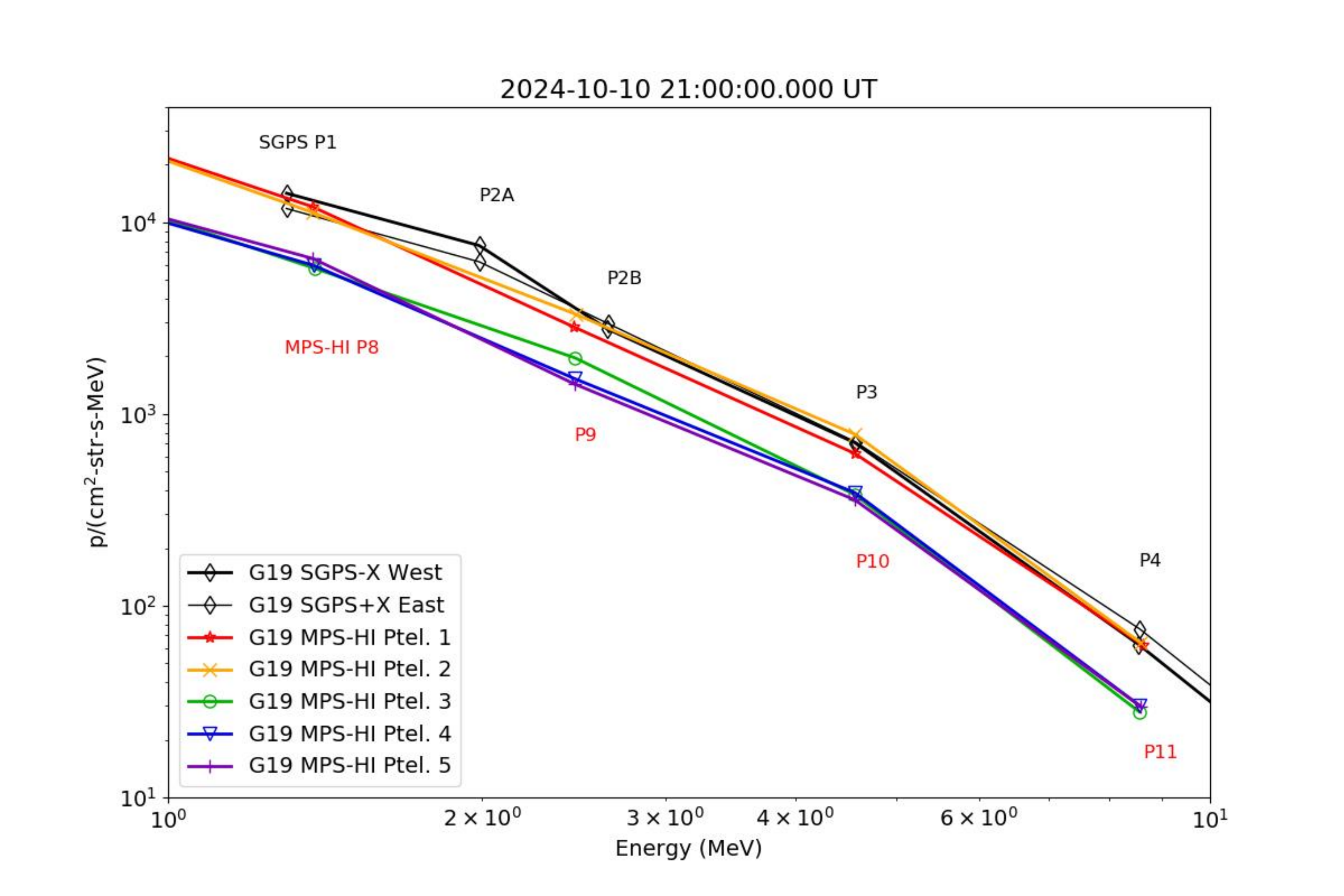
- **Electron scale factors are mostly within the 25% requirement. No pitch angle matches for E10 and very few for E11, due to lack of high fluxes.**
- **Proton scale factors are within the 25% requirement for PTel1, but quite high for PTels 3-5. Two distinct telescope families.**

Solar Energetic Particle (SEP) Channels Cross-Comparison: G19 MPS-HI and SGPS Time series



- Fluxes from the GOES-19 MPS-HI Solar Energetic Particle (SEP) channels (P8-P11) are shown by the gray traces (all 5 proton telescopes), and SGPS P1-P4 channels with colored traces.
- MPS-HI P8-P11 have energy bands similar to SGPS P1, P2B, P3 and P4.
- In all four MPS-HI channels shown (P8-P11), two MPS-HI proton telescopes (PTels) are in close agreement with SGPS and three are reporting low.
- The period indicated by the gray shaded region is used for the SEP channel cross comparisons.

SEP Channels Cross-Comparison: Example Spectra

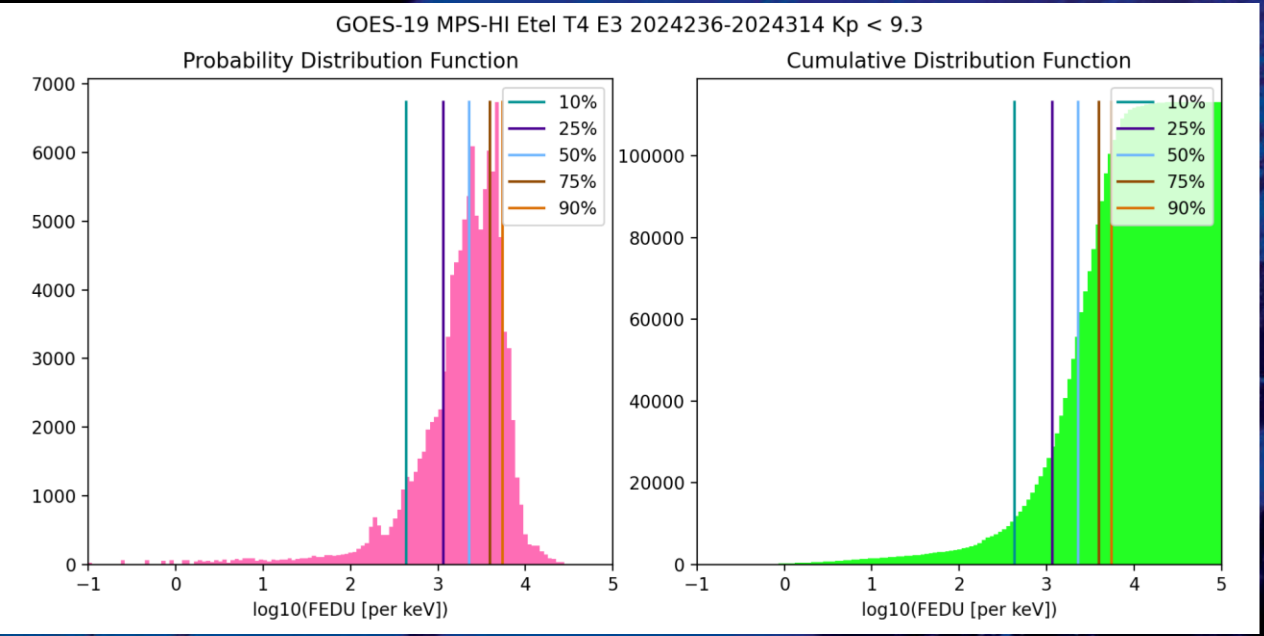


- MPS-HI P8-P11 and SGPS P1-P4 5-minute averaged L1b spectra at 21 UT on 2024-10-10.
- MPS-HI PTel-1 and -2 are in close agreement with SGPS. MPS-HI PTels 3-5 are reporting low.
- The north-to-south order of MPS-HI proton telescopes is PTel-1, -4, -2, -5, -3.

Cross-Satellite Comparison of Trapped Particles: Technique

Compare statistical differential flux spectra from GOES-16 and GOES-19, separated by ~1 hour in Magnetic Local Time (MLT):

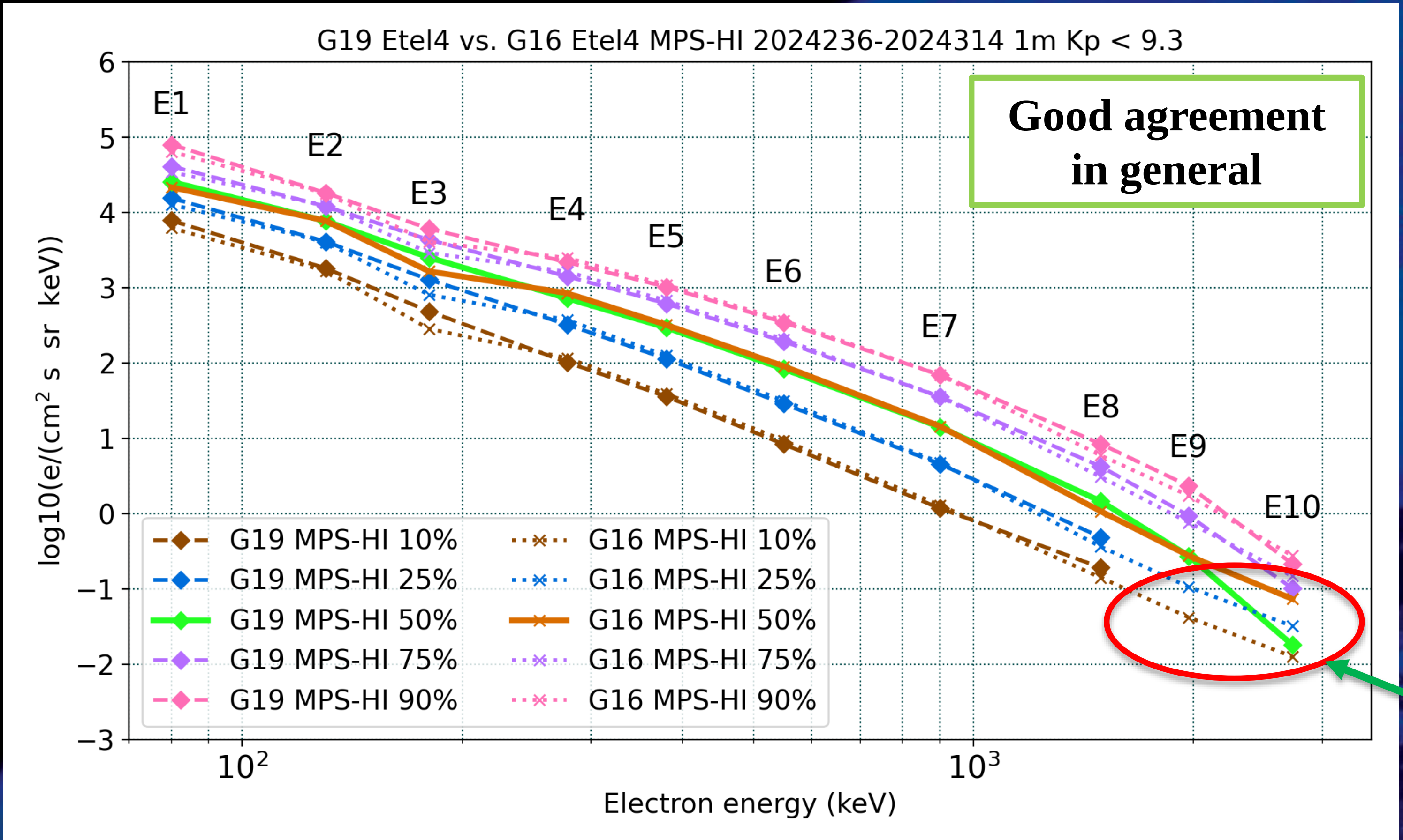
- **GOES-16 (75.2W) to GOES-19 (89.5W), 08/23/2024-11/09/2024 (~2.5 months)**
- **Calculate the particle distributions for all channels and telescopes**
- **Compare flux percentile spectra for telescopes of the same orientation**
  - **0, ±35, ±70 deg from zenith (radially outward)**



- **PDF: Number of fluxes in each flux bin**
- **CDF: Number of fluxes up to a flux bin**
- **Percentile fluxes: Flux at which number of fluxes < percentile**
- **50% is the median of the distribution**

Cross-Satellite Comparison of Trapped Particles: Electron Results

GOES-19 vs GOES-16 Electrons , 08/23/2024-11/09/2024



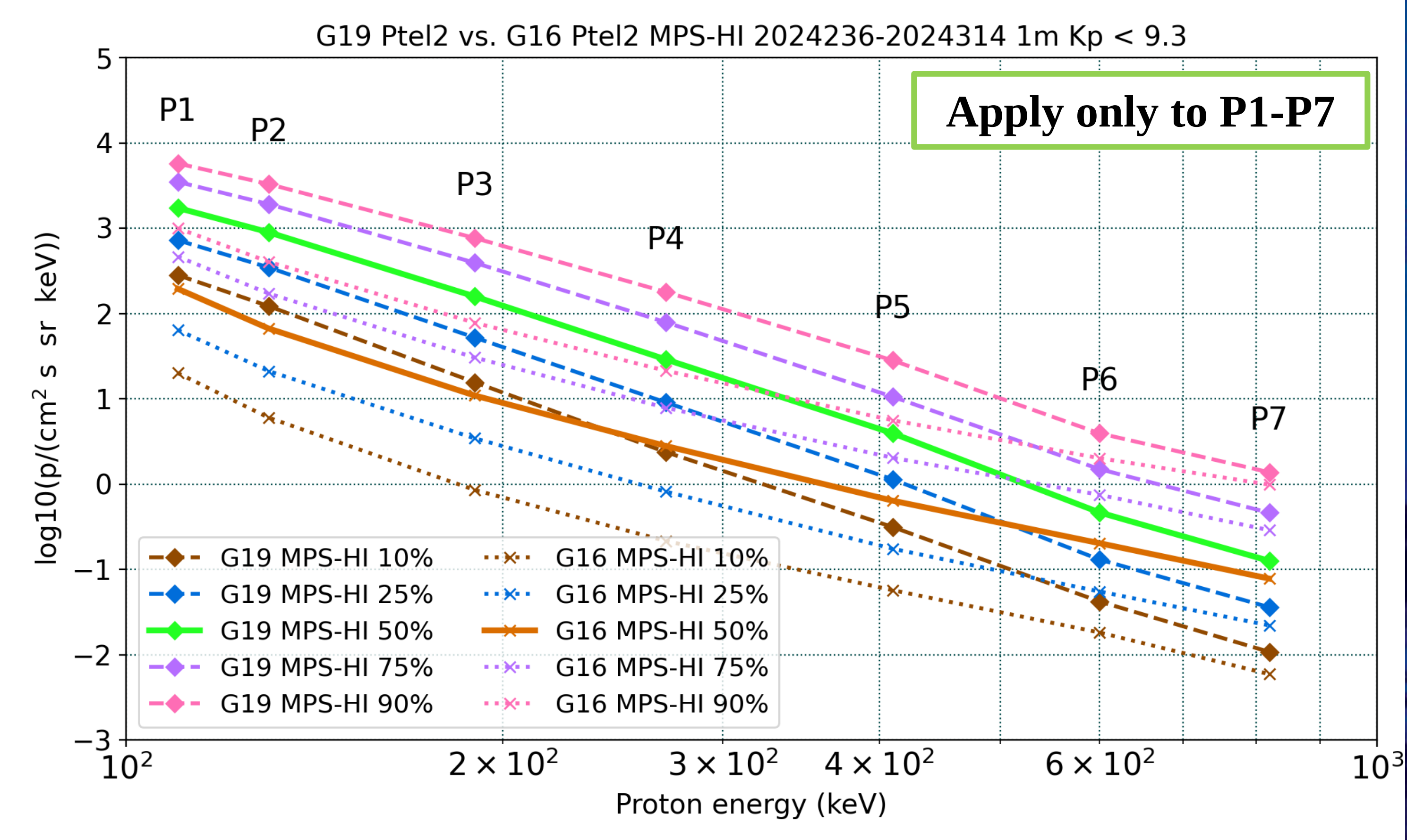
- **GOES-16 E3 fluxes are appreciably lower**
- **E9-E10 fluxes are affected by the applied background correction**

Missing or significantly lower fluxes are at residual background levels

Boudouridis, A., Rodriguez, J. V., Kress, B. T., Dichter, B. K., & Onsager, T. G. (2020). Development of a bowtie inversion technique for real-time processing of the GOES-16/-17 SEISS MPS-HI electron channels. Space Weather, 18, e2019SW002403. https://doi.org/10.1029/2019SW002403

Cross-Satellite Comparison of Trapped Particles: Proton Results

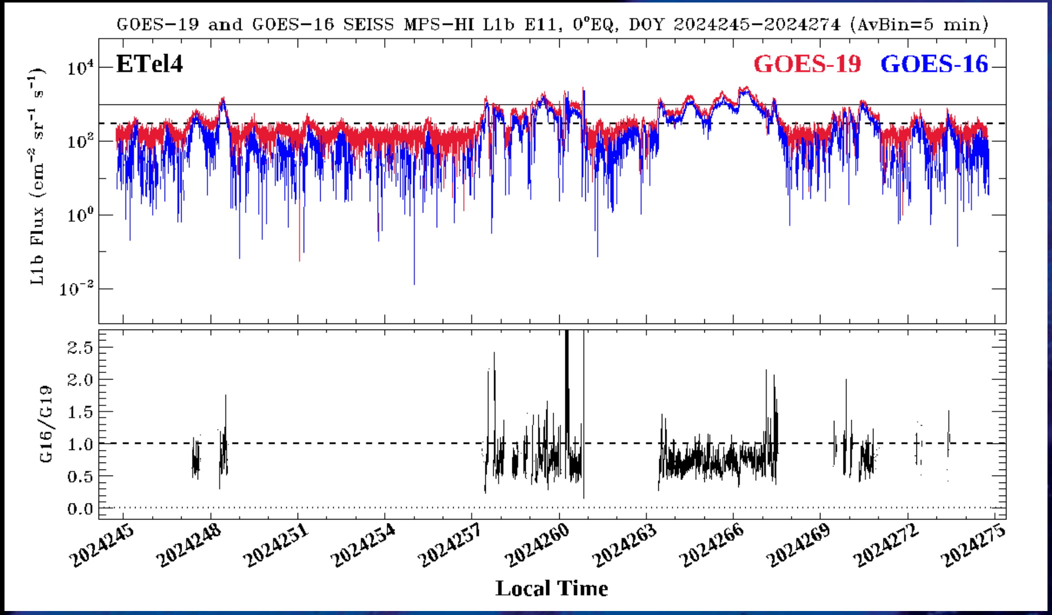
GOES-19 vs GOES-16 Protons , 08/23/2024-11/09/2024



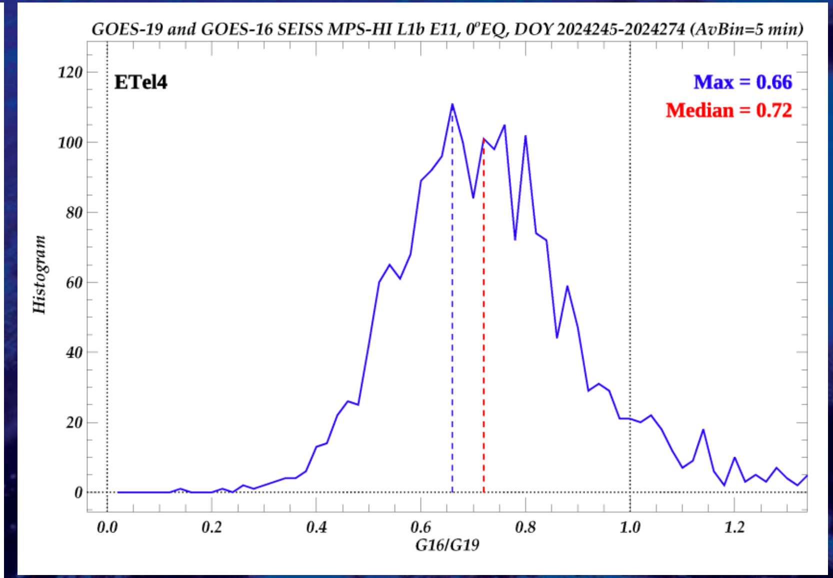
- **GOES-16 fluxes are significantly lower than GOES-19 in channels P1-P5 and all telescopes)**
- **This observation has been documented extensively**
- **A degradation of the proton detectors is actively being investigated**
- **The proton spectrum is flattening for channels P6 and P7: effect of Solar Energetic Particle (SEP) events**

Cross-Satellite Comparison of Trapped Particles (E11): Technique and Results

- Plot GOES-19 and GOES-16 MPS-HI channel E11 (> 2 MeV) Electron Telescope 4 (ETel4) 5-min averaged fluxes for September 2024.
- ETel4 is the central electron telescope looking along the equator.
- Take the ratio GOES-16/GOES-19 of E11 ETel4 5-min average fluxes.
- Make the histogram of the ratio GOES-16/-19 MPS-HI E11 ETel4 5-min average fluxes > 300 pfu.



The G16/G19 flux ratios are in general below 1. Lack of high fluxes affects the results.



The median of the GOES-16 to GOES-19 T4 >2 MeV flux ratio distribution is 0.72.

Concluding notes

- **Steps taken to ensure accurate flux determination**
  - **Dead time correction**
  - **Bowtie Analysis for accurate conversion from electron counts to fluxes**
  - **Background removal for channels E9-E11 for accurate GCR backgrounds specification and removal**
- **Steps taken to ensure accurate calibration**
  - **Cross-telescope comparison: Statistical comparison between telescopes observing the same pitch angles**
  - **SEP Cross-Comparison: Comparison between MPS-HI and SGPS during an SEP event under high dynamic pressure**
  - **Cross-satellite: Comparison between GOES-R satellites**